The Local Truth: Star Formation and Feedback in the SOFIA Era

Celebrating 50 Years of Airborne Astronomy

Asilomar Conference Grounds
Pacific Grove, California
October 17–20, 2016

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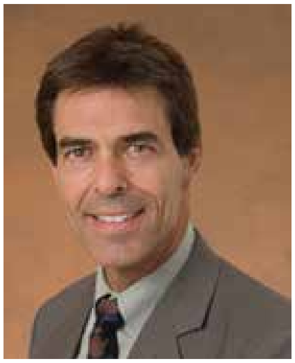
Welcome

Young



Yorke

Dear attendees of "The Local Truth: Star Formation and Feedback in the SOFIA Era,"

Welcome to the Asilomar conference grounds and the 2016 SOFIA conference. We're excited to have all of you come to Northern California for this important meeting, focusing on a central area of astronomical research — Star Formation — and, at the same time, celebrating fifty years of the unique capabilities and advances in airborne observation.

SOFIA is now in routine operations offering its full suite of First Generation instruments covering imaging and spectroscopy from the visible to far infrared. SOFIA's Second Generation instrument, HAWC+, is in commissioning, and the Third Generation instrument, HIRMES, has just been selected and is on track for a 2019 commissioning. Plans for a Call for Proposals for a Fourth Generation instrument are currently underway.

At this meeting we'll hear about the progress made with SOFIA and other facilities in star formation research and of the promises and challenges of the future. The high spatial resolution and wide area mapping, complemented by high spectral resolution and polarimetry of the local universe enabled by SOFIA's current and future instruments, will help us form a more complete picture of star formation over time and in different environments.

Almost by chance, this meeting also marks the transition of SOFIA's Science Mission Operations leadership from the past director, Erick Young, to SOFIA's new SMO director, Harold Yorke.

Again, welcome, and we look forward to an exciting and productive conference.

Erick Young and Harold Yorke
SOC co-Chairs

Committee & Information

SOC/LOC

B-G Andersson, *USRA*
John Bally, *University of Colorado Boulder*
Eric Becklin, *USRA*
Edwin Bergin, *University of Michigan*
Adwin Boogert, *USRA*
Crystal Brogan, *NRAO*
Andrew Helton, *USRA*
Suzanne Madden, *CEA Saclay*
Margaret Meixner, *STSci*
Ravi Sankrit, *SOFIA Science Center/USRA*
Michael Werner, *JPL*
Friedrich Wyrowski, *Max Planck Institute for Radio Astronomy*
Harold Yorke (co-Chair), *USRA*
Erick Young (co-Chair), *USRA*
Hans Zinnecker, *Deutsches SOFIA Institut (DSI)*

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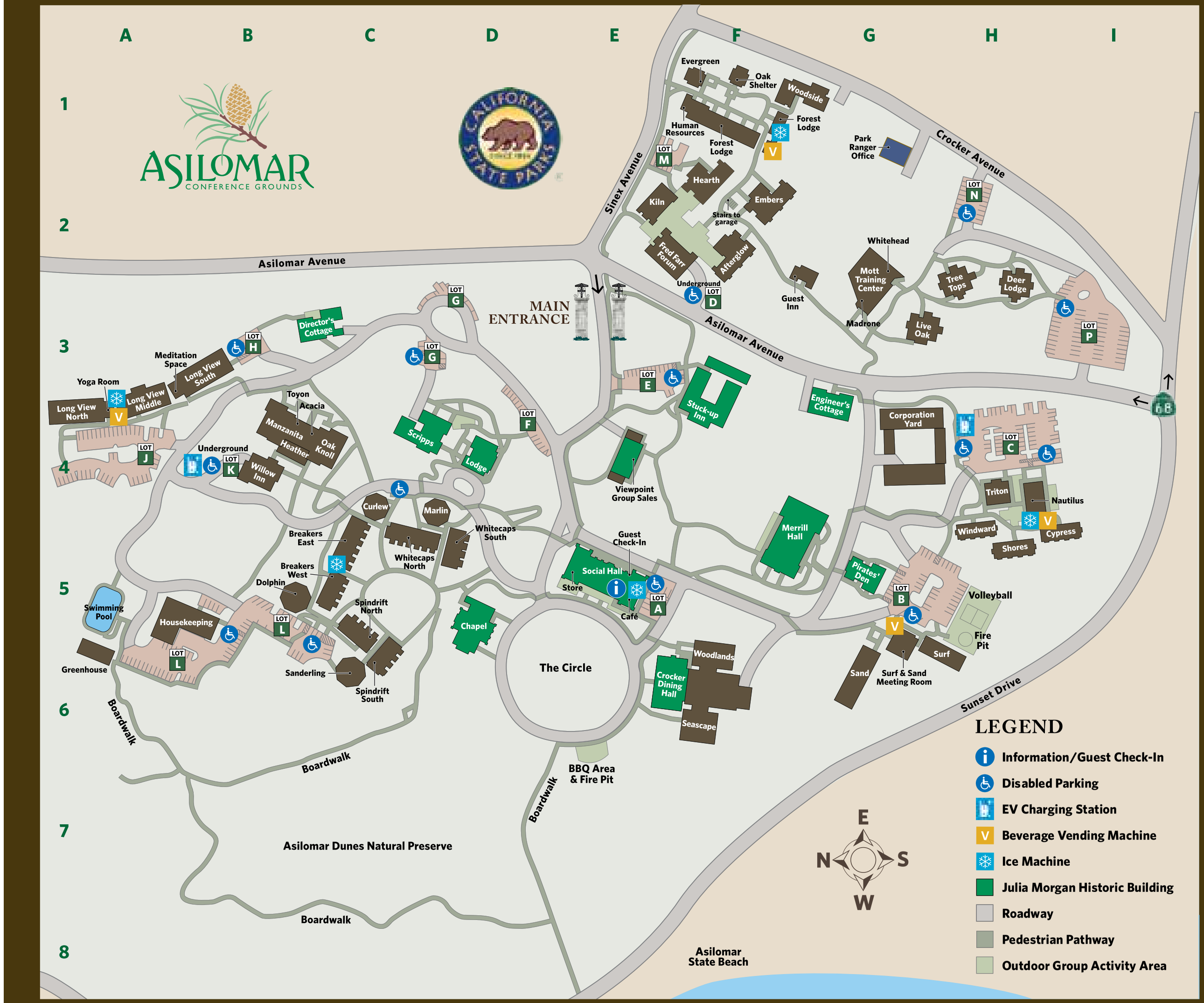
Follow SOFIA on Facebook, Instagram, and Twitter: @SOFIATelescope

Conference hashtag: #SOFIAscience16

Crocker Dining Hall Hours of Operation
Breakfast
7:30 am–9:00 am
Lunch
12:00 pm–1:00 pm
Dinner
6:00 pm–7:00 pm

Asilomar Conference Grounds Map



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Participants

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Eddie Zavala, *NASA*
Monika Anna Ziebart, *University of Cologne*
Hans Zinnecker, *Deutsches SOFIA Institut (DSI)*

Monday, October 17, 2016

Start Time	Duration (minutes)	Topic	Presenter
8:30	15	Welcome & Introduction	Hal Yorke, Erick Young, Pam Marcum, Kartik Sheth
8:45	45	Theoretical Perspectives	Ralf Klessen
9:30	20	What FIREs Up Star Formation: the Emergence of the Kennicutt-Schmidt Law from Feedback	Matthew Orr
9:50	20	The Role of Cosmic Rays in Tracing Molecular Gas in Galaxies	Thomas Bisbas
10:10	20	Break	
10:30	45	Observational Basis	Charlie Lada
11:15	30	Low Mass Star Formation in the Diverse Environments of Orion: Result from the Herschel Orion Protostar Survey	Tom Megeath
11:45	20	What Does Polarization Really Measure?	B-G Andersson
12:05	120	Lunch	
14:05	45	ISM Phases: Heating and Cooling	Xander Tielens
14:50	30	Far-infrared Fine Structure Cooling in Dark Molecular Clouds	Sarah Ragan
15:20	20	[CII] 158 µm Self-absorption and Optical Depth Effects: M17SW	Cristian Guevara
15:40	30	Break	
16:10	30	What are We Learning from Galactic Fine Structure Lines?	Paul Goldsmith
16:40	30	Tracing CO-dark Gas in Galaxies	Diane Cormier
17:10	30	SOFIA Capabilities	Erick Young
18:00	60	Dinner	
19:00	120	Reception	

Daily Schedule

Tuesday, October 18, 2016

Start Time	Duration (minutes)	Topic	Presenter
8:30	45	Chemistry of the Interstellar Medium	David Neufeld
9:15	20	EXES Observations of CH4 and SO2 toward Massive Young Stellar Objects	Adwin Boogert
9:35	20	The Cold Interstellar Medium Traced by the Largest Bound Atoms in Space	Pedro Salas
9:55	20	Break	
10:15	45	Cloud and Filament Support	Edith Falgarone
11:00	30	SOFIA Follow-ups of Massive Clumps from the ATLASGAL Galactic Plane Survey	Friedrich Wyrowski
11:30	30	HAWC+ and Magnetic Fields	Darren Dowell
12:00	120	Lunch	
14:00	45	Disks	Uma Gorti
14:45	30	A Far-IR Determination of Gas Mass and Carbon Depletion in Protoplanetaery Disks	Melissa McClure
15:15	30	Velocity Resolved [OI] 63 micron Line Emission in Proto-planetary Disks	Göran Sandell
15:45	30	Break	
16:15	30	Variable Accretion in Protostars	Klaus Hodapp
16:45	30	Investigating Accretion Variability Onto Deeply Embedded Protostars: A Tool for Measuring Accretion Processes Within Protostellar Disks	Doug Johnstone
17:15	30	The Unique Outburst from S255IR-NIRS3 — Clues for High-mass Star Formation	Bringfried Stecklum
18:00	90	Dinner	
19:30	45	Historical Review of Airborne Astronomy	Ed Erickson, Eric Becklin

Wednesday, October 19, 2016

Start Time	Duration (minutes)	Topic	Presenter
8:30	45	High Mass Star Formation	Jonathan Tan
9:15	20	The Location, Clustering, and Propagation of Massive Star Formation in Giant Molecular Clouds	Bram Ochsendorf
9:35	30	FORCAST Studies of High-Mass Star Formation on Small and Large Scales	Jim De Buizer
10:05	20	Break	
10:25	45	Feedback	John Bally
11:10	20	Feedback and Accretion Toward Proto-O-stars	Adam Ginsburg
11:30	30	Chemical Feedback	Helmut Wiesemeyer
12:00	120	Lunch	
14:00	45	Galactic Center	Mark Morris
14:45	30	The Circumnuclear Disk around Sgr A* — Observations with FIFI-LS	Alfred Krabbe
15:15	30	Investigating Dust Production and Survival with SOFIA and Beyond	Ryan Lau
15:45	30	Break	
16:15	30	FIR-line Spectroscopy of S106 with GREAT/SOFIA as a Versatile Diagnostic Tool for the Evolution of Massive Stars	Nicola Schneider
16:45	30	Turbulence and Reconnection Diffusion	Alex Lazarian
17:15	30	SPICA and its Instruments in the ESA Cosmic Vision M5 Competition	Frank Helmich
18:00	90	Dinner	
19:30	45	Synergies	Karl Menten

Daily Schedule

Thursday, October 20, 2016

Start Time	Duration (minutes)	Topic	Presenter
8:30	45	Exploring ISM and Star Formation Physics in the LMC and SMC in the SOFIA Era	Julia Roman-Duval
9:15	20	Multi-Wavelength Analysis of the Most Luminous Young Stellar Object in the Large Magellanic Cloud	Omnarayani Nayak
9:35	20	SOFIA/GREAT Observation of LMC-N11: Does [CII] Trace Regions with a Large Molecular Gas Fraction?	Vianney Lebouteiller
9:55	20	Break	
10:15	30	Probing the Large-Scale Multiphase ISM in an Extreme Star Forming Low-metallicity Environment: 30 Doradus in the LMC	Sue Madden
10:45	45	External Galaxies	Gordon Stacey
11:30	20	FIFI-LS Observations of M82	Christian Fischer
12:00	120	Lunch	
14:00	30	Unraveling the Evolution of the Interstellar Medium and Star formation in the M51 Grand-design Spiral Galaxy with SOFIA	Jorge Pineda
14:30	20	The Origin of Cold Gas in Giant Elliptical Galaxies and Its Role in Fueling Radio-mode AGN Feedback	Norbert Werner
14:50	30	The High-Resolution Mid-infrared Spectrometer (HIRMES): a Third Generation Instrument for SOFIA	David Neufeld
15:20	30	Break	
15:50	45	Synthesis	Mike Werner, Hal Yorke
16:35	30	Open Discussion Session: SOFIA 4th Generation Instrument	Kartik Sheth
17:05	30		
18:00	90	Dinner	

Short Talk Abstracts
(listed in order of appearance in schedule)

Short Talk Abstracts • Monday, October 17, 2016

Time: Monday 8:45–9:30

Topic: Theory of Star Formation

7051 ISM Dynamics and Star Formation: A Theoretical Perspective

Ralf S. Klessen, *Heidelberg University*

Stars and star clusters form by gravitational collapse in regions of high density in the multi-phase ISM. Turbulence plays a key role. On global scales it provides support, while promoting collapse on local scales. This process is modified by the thermodynamic response of the gas and its chemical make-up. I will discuss examples of recent progress and controversy, and I will report about current attempts to bring numerical simulations and theoretical models closer to the observations.

Time: Monday 9:30–9:50

Topic: Theory of Star Formation

7002 What FIREs Up Star Formation: the Emergence of the Kennicutt-Schmidt Law from Feedback

Matthew E. Orr, *California Institute of Technology*

C. Hayward, P. F. Hopkins, D. Keres, C. A. Faucher-Giguere,
E. Quataert, N. Murray, T. K. Chan, R. Feldmann

We present an analysis of the Kennicutt-Schmidt star formation relation in the FIRE (Feedback In Realistic Environments) suite of cosmological simulations. We show that due to the effects of feedback on local scales, the Kennicutt-Schimdt relation emerges robustly, independent of the particular local star formation physics. We also find that gas disk instability to fragmentation and collapse, leading to self-shielding, is the trigger for star formation in regions larger than individual GMCs.

Time: Monday 9:50–10:10

Topic: Interstellar Medium & Cloud

7017 The Role of Cosmic Rays in Tracing Molecular Gas in Galaxies

Thomas Bisbas, *University of Florida & Max Planck Institute*

P. P. Papadopoulos, E. F. van Dishoeck, L. Szűcs, Z-Y. Zhang, S. Bialy

We present three-dimensional astrochemical simulations of a fractal cloud embedded in different cosmic ray (CR) energy densities. We examine how CO(1-0), [CI](1-0) and [CII] 158um emission maps change as we increase the CR ionization rate. We find that although the cloud remains H_2-rich at all times, all aforementioned lines change severely implying that the commonly used techniques to estimate the H_2 column densities require significant adjustments.

Time: Monday 11:15–11:45

Topic: Star Formation Regions

7021 Low Mass Star Formation in the Diverse Environments of Orion: Result from the Herschel Orion Protostar Survey

Samuel Thomas Megeath, *University of Toledo*

The HOPS team

Comparative studies of protostars in different regions are needed to assess how both the external environment (gas density, turbulence, kinetic temperature, density of stars) and internal processes affect the formation of stars and disks. I will overview a survey of protostars in the Orion A & B molecular clouds with the Spitzer, Herschel, Hubble and APEX telescopes, spanning 1.6 to 870 μm, as well as follow-up observations with SOFIA and ALMA.

Time: Monday 11:45–12:05

Topic: Interstellar Medium & Cloud

7001 What Does the FIR Polarization Really Measure?

B-G Andersson, *USRA*

J. E. Vaillancourt

Magnetic fields may regulate star formation, by supplying pressure and large-scale structure in molecular clouds. One of the prime methods for tracing and characterizing ISM magnetic fields is through dust induced polarization — whether as dichroic extinction at short wavelengths, or dichroic emission in the FIR/sub-mm range. The interpretation of such polarization, however, requires a detailed knowledge of the dust grain alignment. We will review the current understanding of grain alignment.

Time: Monday 14:05–14:50

Topic: Interstellar Medium & Cloud

7048 Physics of the Interstellar Medium

Alexander Tielens, *Leiden University*

The interstellar medium (ISM) plays a central role in the evolution of galaxies. On the one hand, the ISM is the repository of stellar ejecta; e.g., in the form of gentle winds from asymptotic giant branch stars and by violent supernova explosions. On the other hand, the ISM is the birthplace of future generation of stars. In this way, material is cycled from stars to gas and back again and in each cycle it is enriched in heavy elements forged through nucleosynthetic processes in the fiery cauldrons of stellar cores. Stars also control the radiative energy budget of the ISM and its emission characteristics. The complex feedback between stars and their environment drives the evolution of the interstellar medium and of galaxies — and hence their observational characteristics — over cosmic time. Our understanding of what observations tell us about what really happens at those epochs will depend very much on our understanding of the microscopic physical and chemical processes and their dependence on the local conditions.

Time: Monday 14:50–15:20

Topic: Interstellar Medium & Cloud

7035 Far-Infrared Fine Structure Cooling in Dark Molecular Clouds

Sarah Elizabeth Ragan, *Cardiff University*
H. Linz, T. Henning, H. Beuther

Stars are born in the densest regions of molecular clouds, but the processes of cloud assembly and dispersal are poorly understood. We use fine structure lines, [CII] and [OI] to trace molecular clouds and their environments. I present the results of two studies: (1) A velocity-resolved survey of [CII], [CI] and CO to acquire complete dynamical profiles of young clouds, and (2) a FIFI-LS study of [CII] and [OI] in dark clouds to relate the cooling properties to embedded star formation.

Time: Monday 15:20–15:40

Topic: Interstellar Medium & Cloud

7007 [CII] 158 µm Self-Absorption and Optical Depth Effects: M17SW

Cristian Guevara, *University of Cologne*
J. Stutzki, R. Simon

[CII] optical depth has been one of the big unknowns and had been assumed in general as unity. Recently, it has been possible to detect the three hyperfine components of [13CII] together with [CII] at high velocity resolution and signal to noise and directly determine the optical depth of the [CII] line. Current observations using SOFIA/upGREAT have shown for M17SW and other sources that the [CII] line has an opacity significantly larger than unity and is heavily affected by self-absorption.

Time: Monday 16:10–16:40

Topic: Interstellar Medium & Cloud

7006 What Are We Learning from Galactic Fine Structure Line Observations?

Paul F. Goldsmith, *Jet Propulsion Laboratory*
W. D. Langer, J. L. Pineda

We discuss surveys of the Milky Way in [CII] and [NII], and what they are telling us about the structure of the neutral and ionized phases of the interstellar medium. Observations with Herschel and SOFIA are revealing new information including non-neglibie optical depth in the [CII] line and the electron density in regions producing [NII] emission.

Time: Monday 16:40–17:10

Topic: Interstellar Medium & Cloud

7032 Tracing the CO-dark Gas in Galaxies — Where SOFIA Shines

Diane Cormier, *CEA Saclay*
Suzanne C. Madden

We are studying the effects of density, Go, Av and metallicity on the quantity of CO-dark gas to understand the dearth of CO emission in low metallicity dwarf galaxies which are bright in [CII] and vigorously forming stars. We show from our models that L[CII]/L(CO), which constrains Av, can be used to quantify the CO-dark gas to CO-bright gas fraction which can be up to 100% in some cases. CO-dark gas can be studied in a wide range of galaxies with SOFIA with sensitive observation of [CII].

Time: Tuesday 8:30–9:15

Topic: Chemistry of the ISM

7009 Chemistry of the Interstellar Medium

David A. Neufeld, *Johns Hopkins University*

Observations at far- and mid-infrared wavelengths provide a wealth of information about the molecular inventory of interstellar gas clouds. Because of the different chemical pathways responsible for their formation and destruction, different molecules probe specific aspects of the interstellar environment. Carefully interpreted, they provide unique information about the cosmic ray density, the molecular fraction, the UV radiation field, and the dissipation of energy within the turbulent ISM.

Time: Tuesday 9:15–9:35

Topic: Chemistry of the ISM

7030 EXES Observations of CH_4 and SO_2 toward Massive Young Stellar Objects

Adwin Boogert, *USRA*

M. Richter, C. DeWitt, N. Indriolo, D. Neufeld, A. Karska, E. Bergin, R. Smith

We present high resolution (6-12 km/s) infrared (7-8 µm) spectra of massive YSOs observed with the Echelon-Cross-Echelle Spectrograph (EXES) on SOFIA. Absorption lines of gas phase methane (CH_4) are detected. Abundances are derived in the different dynamical regions towards the central star by comparing the line profiles to those of CO and other species observed at ground based facilities (TEXES). A search is also conducted for sulfur-dioxide, using data from our ongoing Cycle 4 program.

Time: Tuesday 9:35–9:55

Topic: Interstellar Medium & Cloud

7038 The Cold Interstellar Medium Traced by the Largest Bound Atoms in Space

Pedro Salas, *Leiden Observatory*

J. B. R. Oonk, A. G. G. M. Tielens, H. J. A. Röttgering, K. Emig,
M. C. Toribio, R. J. van Weeren, F. Salgado, L. K. Morabito

Low frequency (<1 GHz) carbon radio recombination lines (CRRLs) are a powerful probe of cold diffuse gas, whose role in the Galactic life cycle is not completely understood. What is the relation relation between the gas traced by CRRLs and other phases of the interstellar medium? To answer this, we analyzed the line of sight towards Cassiopeia A in detail. Based on the derived physical conditions and the spatial distribution of CRRLs we were able to place this gas into the broader context.

Time: Tuesday 10:15–11:00

Topic: Theory of Star Formation

7098 Interstellar Filaments, Turbulence and Magnetic Fields

Edith Falgarone, *Ecole Normale Supérieure and Observatoire de Paris*

The dynamic properties of interstellar filaments broaden our perspectives on interstellar turbulence, its multi-phase facets, its dissipation processes, the topology of the magnetic fields. Among recent observational results, I will present those that are particularly challenging.

Time: Tuesday 11:00–11:30

Topic: Star Formation Regions

7022 SOFIA Follow-Ups Of Massive Clumps from the ATLASGAL Galactic Plane Survey

Friedrich Wyrowski, *Max Planck Institute for Radio Astronomy*

With GREAT we started a concerted observing effort towards a well selected sample of clumps with high masses covering a range of evolutionary stages. The goal is threefold: (i) SOFIA/GREAT allows to study the cooling budget of the clumps. (ii) With SOFIA/GREAT high-J CO lines. (iii) Using rotational transitions of ammonia kinemtics of the clumps can be probed to search for infall. Here we will describe these efforts with focus on the ammonia infall results.

Time: Tuesday 14:45–15:15

Topic: Chemistry of the ISM

7024 A Far-infrared Determination of Gas Mass and Carbon Depletion in Protoplanetary Disks

Melissa K. McClure, *European Southern Observatory*

E. A. Bergin, L. I. Cleeves, E. F. van Dishoeck, G. A. Blake,
N. J. Evans II, J. D. Green, Th. Henning, K. I. Oberg,
K. M. Pontoppidan, C. Salyk

A new technique (Bergin et al. 2013) has been demonstrated to assess directly the bulk molecular gas reservoir of molecular hydrogen using the HD J=1-0 line at 112 microns. We present a small survey of T Tauri disk observations of the HD line. Line emission is detected in two cases at >3 sigma significance. Using detailed disk structure models we determine the amount of gas required to fit the HD line and the amount of dust required to fit the observed disk spectral energy distributions.

Time: Tuesday 15:15–15:45

Topic: Star Formation Regions

7028 Velocity Resolved [OI] 63 micron Line Emission in Proto-planetary Disks

Göran Sandell, *USRA*

R. Güsten, K. Menten, F. Wyrowski

Here we present preliminary results of [OI] observations with GREAT of two disk sources, HL Tau and AB Aur. HL Tau is a deeply embedded Class I object of spectral type K7. We are still assessing whether the emission is dominated by the disk or whether we have a contribution from the jet, which is very prominent in H alpha and [SII].The disk of AB Aur, an A0 Herbig Ae/Be star, is more face-on and it does not drive an outflow. Here the GREAT [OI] emission is clearly from the inner part of the disk.

Time: Tuesday 16:15–16:45

Topic: Star Formation Regions

7034 Variable Accretion in Protostars

Klaus Werner Hodapp, *University of Hawaii*

This paper will discuss some of the deeply embedded accretion outburst objects discovered in recent years, some with periodic variability and some showing sporadic outbursts. For our understanding of the role that these outburst events play in the overall mass accretion history of stars, it is important to distinguish changes in bolometric accretion luminosity from possible changes in the local disk extinction as a possible side effect of an outburst.

Time: Tuesday 16:45–17:15

Topic: Theory of Star Formation

7013 Investigating Accretion Variability Onto Deeply Embedded Protostars: A Tool for Measuring Accretion Processes Within Protostellar Disks

Doug Johnstone, *National Research Council Canada*

Low-mass stars form via gravitational collapse. The evolution of the mass accretion depends on the rate at which the interior of the core collapses, the significance of a circumstellar disk as a temporary mass reservoir, and the physics of how the gas is transported through the disk. We investigate the manner in which the protostar's enshrouding envelope responds to change in the accretion luminosity and use this to devise a collection of long-term episodic accretion monitoring campaigns.

Time: Tuesday 17:15–18:00

Topic: Star Formation Regions

7036 The Unique Outburst from S255IR-NIRS3 — Clues for High-Mass Star Formation

Bringfried G.W. Stecklum, *Thueringer Landessternwarte Tautenburg*

A. Caratti o Garatti, J. Eislöffel, Ch. Fischer, A. Krabbe, R. Klein, A. Sanna, L. Moscadelli, R. Cesaroni

Signaled by the flare of its methanol masers, S255IR-NIRS3, a ~20Msun HMYSO, recently experienced a disk-mediated accretion burst — the first ever observed for a HMYSO. This unique event provides evidence for high-mass star formation via circumstellar disks, and indicates that the latter are prone to disk instability as well. The burst SED, based on NIR and SOFIA data, shows a five-fold gain in luminosity, and features an FIR peak possibly caused by a heat wave propagating outward in the disk.

Time: Tuesday 19:30–20:15

Topic: History of Airborne Astronomy

7044B Historical Review of Airborne Astronomy: the Evolution of SOFIA

Edwin F. Erickson, *NASA Ames Research Center (retired)*

The unique program of airborne astronomy at NASA Ames Research Center which began in the late 1960s, provided the needed technical understanding, scientific motivation, and cadre of advocates for promoting and building SOFIA. The talk will describe some salient features of (a) the precursor facilities — a Convair 990, Learjet, and Kuiper Airborne Observatory, (b) the process by which SOFIA achieved approval for construction, and (c) the technical details of its development. Along the way, we'll highlight a few of the very many people who deserve credit for giving the world this incredible flying machine.

Time: Tuesday 19:30–20:15

Topic: History of Airborne Astronomy

7044A Historical Review of Airborne Astronomy: Science Highlights from the 990, Learjet, KAO and SOFIA

Eric Becklin, *SOFIA Chief Scientific Advisor*

A review will be given of the NASA airborne astronomical highlights over the last 50 years, beginning with the Convair 990 (Galileo) and ending with SOFIA. Emphasis will be placed on those observations that advanced because of the improved facilities, better instrumentation and better understanding of the science. A few highlights of the SOFIA science with personal involvement will be included.

Time: Wednesday 9:15–9:35

Topic: Star Formation Regions

7019 The Location, Clustering, and Propagation of Massive Star Formation in Giant Molecular Clouds

Bram B. Ochsendorf, *Johns Hopkins University*

M. Meixner, J. Chastenet, J. Roman-Duval, X. Tielens

We have employed several galaxy-wide data sets to study the location and clustering of massive star formation and its relation to the internal structure of GMCs in the LMC. We find that (1) massive stars do not typically form at column density peaks of GMCs (2) massive star formation is more active in clouds close to young stellar clusters. These results may provide important clues to the collapse of molecular clouds and the initial conditions that lead to the formation of massive stars.

Time: Wednesday 9:35–10:05

Topic: Star Formation Regions

7010 FORCAST Studies of High-Mass Star Formation on Small and Large Scales

James De Buizer, *USRA*

M. Liu, J. Tan, Y. Zhang, G. Sandell, M. Beltran, R. Shuping, J. Staff, T. Tanaka, B. Whitney

FORCAST has been used over the last several cycles for two long-term projects; one aimed at understanding the arcsecond-scale circumstellar environment of individual (or small multiple) high-mass star systems in the earliest stages of forming within these cores, and the other aimed at understanding the arcminute-scale environments of the giant molecular clouds that clusters of such high-mass stellar systems form in. I will present preliminary results from both of these ongoing studies.

Time: Wednesday 11:10–11:30

Topic: Star Formation Regions

7029 Feedback and Accretion toward Proto-O-stars

Adam G. Ginsburg

I will discuss observations of the high-mass star-forming region W51, examining the effects of forming massive stars on the dense, prestellar gas around them. The forming stars have a greater effect than the already-formed, main-sequence stars. However, the main sequence stars heat the lower density surrounding material and regulate cluster formation. SOFIA will detect feedback from these main sequence stars on larger scales.

Time: Wednesday 11:30–12:00

Topic: Chemistry of the ISM

7041 Chemical Feedback: The Link between Diffuse Clouds and Late Stages of Stellar Evolution.

Helmut W. Wiesemeyer, *Max Planck Institute for Radio Astronomy*

R. Güsten, S. Heyminck, H. W. Hübers, K. M. Menten, D. A. Neufeld, H. Richter, R. Simon, J. Stutzki, B. Winkel, F. Wyrowski

In the recent past novel instrumentation for far-infrared spectroscopy has deepened our understanding of diffuse cloud chemistry and its agents, such as interstellar hydrides. Their ground-state transitions, along with atomic fine structure lines, emerged as important tools for a truly quantitative analytical chemistry. In two case studies we determine abundances of oxygen-bearing species in diffuse clouds, and attempt to characterize the chemical feedback provided by various planetary nebulae.

Time: Wednesday 14:45–15:15

Topic: Galactic Center

7037 The Circumnuclear Disk around Sgr A* — Observations with FIFI-LS

Alfred Krabbe, *University of Stuttgart*

C. Iserlohe, A. Bryant, C. Fischer, S. Beckmann, S. Colditz, F. Fumi, N. Geis, H. Linz, R. Hönle, R. Klein, L. Looney, A. Poglitsch, W. Raab, F. Rebell, W. Vacca

The central region of our galaxy has been the site of reoccurring episodes of star formation. The mechanism leading to such repeating events requires accretion of matter towards the nuclear region in particular towards the circum nuclear disk. We will present FIFI-LS spectroscopic maps of the central region in several FIR emission lines and will discuss implications on mass infall, excitation and star formation.

Time: Wednesday 15:15–15:45

Topic: Interstellar Medium & Cloud

7011 Investigating Dust Production and Survival with SOFIA and Beyond

Ryan M. Lau, *Caltech/JPL*

M. J. Hankins, T. L. Herter, M. R. Morris, J. D. Adams, Z. Li, M. E. Ressler

Dust formation in the ejecta of supernovae is currently the leading theory for dust production in galaxies in the early Universe. However, the contribution from Wolf-Rayet (WR) stars with close O/B-star companions has been largely neglected. The details of how dust forms and survives in such hostile environments are still uncertain. SOFIA and future missions such as the upcoming James Webb Space Telescope will be crucial for addressing these questions of dust production and survival.

Time: Wednesday 16:15–16:45

Topic: Star Formation Regions

7008 FIR-line Spectroscopy of S106 with GREAT/SOFIA as a Versatile Diagnostic Tool for the Evolution of Massive Stars

Nicola Maria Schneider, *University of Cologne*

R. Simon, R. Güsten, J. Stutzki, S. Bontemps, M. Roellig, S. Anderl, J. D. Adams

The bipolar HII region S106 was observed in the CII 158 μm, the OI 63 μm, and the CO 16-15, 11-10 lines using upGREAT on SOFIA. We possibly detect an atomic jet collimated by a small disk-like structure around the star, driving an associated molecular outflow. PDR surfaces on the cavity walls are the main source of emission, SiO as a shock tracer was not detected. We conclude that S106 is a massive object on the main sequence but still in a late accretion phase with a disk-like structure.

Time: Wednesday 16:45–17:15

Topic: Theory of Star Formation

7039 Turbulence and Reconnection Diffusion

Alex Lazarian, *University of Wisconsin-Madison*

I shall discuss how advances in our understanding of theory of reconnection entail the conclusion that magnetic fields are not frozen in turbulent regions. This entails the process termed “reconnection diffusion” that allows the efficient removal of magnetic fields from star formatin clouds and disks. I shall discuss numerical simulations supporting the theory.

Time: Wednesday 17:15–18:00

Topic: Facilities and Instrumentation

7016 SPICA and its Instruments in the ESA Cosmic Vision M5 Competition

Frank Paul Helmich, *SRON Netherlands Institute for Space Research*

SPICA is a candidate mission for the 5th medium size slot of ESA’s Cosmic Vision. If successful in the competition with probably 30-40 other candidate missions it will enter Phase A/B1 after June 2017 as an ESA-led mission with JAXA as junior partner. The SPICA concept is created in a complex interaction between scientists, engineers and space agencies. This has led in the past to very different concepts. In this talk I will describe the current mission with emphasis on the instruments.

Time: Thursday 8:30–9:15

Topic: Interstellar Medium & Cloud

7020 Exploring ISM and Star Formation Physics in the LMC and SMC in the SOFIA Era

Julia C. Roman-Duval, *Space Telescope Science Institute*

Thanks to the proximity and face-on geometry of the Magellanic Clouds, we can resolve the ISM processes at the level of individual star-forming regions and molecular clouds, while also getting the broad spatial coverage needed to understand the ISM on global scales. In this talk, I will review how SOFIA can complement existing multi-wavelength data sets in the Magellanic Clouds, and address outstanding questions related to ISM and star formation physics using the LMC and SMC as laboratories.

Time: Thursday 9:15–9:35

Topic: Star Formation Regions

7015 Multi-Wavelength Analysis of the Most Luminous Young Stellar Object in the Large Magellanic Cloud

Omnarayani Nayak, *Johns Hopkins University*

M. Meixner, Y. Fukui, T. Onishi, Y. Okada, M. Reiter,
R. Indebetouw, J. Stutzki, M. Sewilo, A. Bolatto, M. Chevance,
A. Kawamura, M. Y. Lee

We present a comprehensive analysis of the most luminosity young stellar object located in the N79 region of the LMC. We analyze multiple different data: spectrum from Spitzer infrared spectrometer, Spitzer IRAC and MIPS photometry, Herschel PACS and SPIRE photometry, ALMA CO and HCN images, SOFIA GREAT [CII] and high-J CO transitions, and high resolution spectrum from the Magellan FIRE Spectrometer. We probe the physical and chemical conditions under which massive star formation takes place.

Time: Thursday 9:35–9:55

Topic: Interstellar Medium & Cloud

7033 SOFIA/GREAT Observation of LMC-N11: Does [CII] Trace Regions with a Large Molecular Gas Fraction?

Vianney Lebouteiller, *CEA Saclay*

We present GREAT [CII] observations of LMC-N11. The spectral profile is compared to CO and HI to identify the origin of [CII] either in the warm diffuse gas (associated or not with PDRs) or in the diffuse ionized gas. Along with ALMA and Herschel observations, we find that most [CII] can be associated with CO, but a significant fraction of [CII] individual components trace a purely atomic medium. One component seems to be a direct evidence of [CII] emission arising in the so-called CO-dark gas.

Time: Thursday 10:15–10:45

Topic: Interstellar Medium & Cloud

7014 Probing the Large-Scale Multiphase ISM in an Extreme Star Forming Low-Metallicity Environment: 30 Doradus in the LMC

Suzanne Madden, *CEA/SAp/AIM*

M. Chevance, V. Lebouteiller, D. Cormier, B. Godard, F. Galliano,
S. Hony, R. Indebetouw, M.-Y. Lee, F. Le Petit, E. Roueff, W. Vacca,
C. Fisher, H. Zinnecker

30 Doradus offers the best laboratory to examine the interplay between stellar activity and metal-poor ISM over large scales. Herschel and Spitzer spectroscopic maps are used to constrain the physical conditions and ISM structure in the PDR. We build a 3D view of the region and bring constraints to the fraction of CO-dark gas. Our SOFIA/FIFI-LS observations of [CII], [OI] and [OIII] of the full region allow us to study the evolution of the gas conditions and structure with the proximity of R136.

Time: Thursday 11:30–12:00

Topic: External Galaxies

7046 Observations of M82 with FIFI-LS on SOFIA — A First Look at the Results and How We Got Them

Christian Fischer, *Deutsches SOFIA Institut*

W. Vacca, A. Krabbe, A. Bryant, S. Beckmann, S. Colditz, F. Fumi,
N. Geis, T. Henning, R. Höhnle, C. Iserlohe, R. Klein, L. Looney,
A. Poglitsch, W. Raab, F. Rebell

One of the very first science targets observed with FIFI-LS on SOFIA is the star bursting galaxy M82. An extensive guarantied time program resulted in maps for the transition of [CII] at 157.741 μm and [OIII] at 51.815 μm. The maps cover the central area as well as the two outflows.

Time: Thursday 14:00–14:30

Topic: External Galaxies

7004 Unraveling the Evolution of the Interstellar Medium and Star Formation in the M51 Grand-design Spiral Galaxy with SOFIA.

Jorge Pineda, *Jet Propulsion Laboratory*

J. Stutzki, P. F. Goldsmith, C. Buchbender, M. Ziebart, M. Kapala,
SOFIA M51 team

We present preliminary results on a joint impact project to map the entire extent of the M51 spiral galaxy in the [CII] 158μm line with the upGREAT and FIFI-LS instruments on SOFIA. We will describe the goals of the project and we will present preliminary results on the distribution of [CII] across M51 and on the relationship between the different constituents of the ISM traced by FUV, Halpha, CO, HI, and [CII] emission both spatially and spectrally in the arms and interarm regions of M51.

Time: Thursday 14:30–14:50

Topic: External Galaxies

7018 The Origin of Cold Gas in Giant Elliptical Galaxies and its Role in Fueling Radio-mode AGN Feedback

Norbert Werner, *Eotvos University*

R .E. A. Canning, J. B. R. Oonk, M. Sun, P. E. J. Nulsen, S. W. Allen, A. Simionescu

We will present far-infrared spectral imaging of the ISM in nearby giant elliptical galaxies with Herschel PACS and SOFIA FIFI-LS. We find that all systems with extended Hα emission in our sample display [CII] line emission. The atmospheres of the cold-gas-rich systems are prone to cooling instabilities, indicating that the cold gas is produced by cooling from the hot phase. We will also discuss models of cold gas excitation by collisions and mixing with the surrounding hot phase.

Time: Thursday 14:50–15:10

Topic: Third Generation Instrumentation

7099 The High-resolution Mid-Infrared Spectrometer (HIRMES): a Third Generation Instrument for SOFIA

David A. Neufeld, *Johns Hopkins University*

The High-Resolution Mid-Infrared Spectrometer (HIRMES) is a versatile facility instrument for the Stratospheric Observatory for Infrared Astronomy (SOFIA) that directly observes key ingredients of habitable worlds, answering questions such as: How does the disk mass evolve during planetary formation? What is the distribution of oxygen, water ice, and water vapor in different phases of planet formation? HIRMES provides low (R ~ 600) to very high (R ~ 100,000) spectral resolving power over the critical spectral range 25–122 μm, combining grating dispersive spectroscopy and Fabry-Perot tunable narrow-band filters with high efficiency background-limited direct detectors.

Time: Thursday 15:50–16:35

Conference Synthesis

Michael Werner, *Jet Propulsion Laboratory,* ***Harold Yorke****, USRA SOFIA Science Center*

Short Poster Abstracts
(listed by abstract number)

Short Poster Abstracts

Topic: Interstellar Medium & Cloud

7003 Discovery of Millimeter Shocked Molecular Gas and Molecular Hydrogen from the Supernova Remnant G357.7+0.3: HHSMT, APEX, Spitzer and SOFIA Observations

Jeonghee Rho, *SETI Institute and NASA Ames Research Center*

J. W. Hewitt, J. Bieging, W. T. Reach, M. Andersen, R. Güsten

We report a discovery of shocked gas from the supernova remnant G357.7+0.3 using millimeter and infrared observations. Broad molecular lines of CO(2-1), CO(3-2), CO(4-3), 13CO (2-1) and 13CO (3-2), HCO+ and HCN with widths of 15-30 km/s are detected and show that G357.7+0.3 is interacting with clouds. The SOFIA/GREAT spectrum of [C II] in 3 sigma detection shows a broad line profile that is similar to those of broad CO lines. We will discuss physical conditions of shocked gas.

Topic: Interstellar Medium & Cloud

7005 Characterizing the Formation and Evolution of Molecular Clouds in the Magellanic Clouds with [CII], [CI] and CO

Jorge Pineda, *Jet Propulsion Laboratory*

P. F. Goldsmith, W. D. Langer

We present an analysis of deep Herschel/HIFI observations of the [CII] 158μm, [CI] 609μm, and [CI] 370μm lines towards 54 lines-of-sight (LOS) in the Large and Small Magellanic clouds. These observations are used to determine the physical conditions of the line-emitting gas, which we use to study the transition from atomic to molecular gas and from C+ to C to CO in the low metallicity environments of the LMC and SMC.

Topic: Galactic Center

7025 Characterizing the Circumnuclear Disk Around Sgr A* with Far Infrared FIFI-LS Observations

Aaron Bryant, *University of Stuttgart*

A. Krabbe, C. Iserlohe, C. Fischer, S. Beckmann, S. Colditz, F. Fumi, N. Geis, T. Henning, R. Höhnle, R. Klein, L. Looney, A. Poglitsch, W. Raab, F. Rebell

The Circumnuclear Ring, a clumpy, uneven ring of gas and dust of uncertain mass and temperature, exists between 1.5 and 5 pc from the central point of Sgr A*. We present high resolution FIFI-LS maps of the entire ring and surrounding region at eight FIR wavelengths, and discuss the astrophysical implications of these observations, including the gas cooling efficiency, transport processes, and heating mechanisms of the matter in the ring, and its role in the general galactic core.

Topic: Star Formation Regions

7027 The Ionized Jet and Molecular Outflow from NGC7538 IRS1

Göran Sandell, *USRA*

B. Mookerjea, M. Wright

The young heavily accreting ultra-compact HII region NGC 7538 IRS1 is known to drive a well collimated bipolar ionized jet approximately N-S. Yet most studies have reported that it drives a bipolar molecular outflow oriented from SE to NW. New [CII] and CO(11-10) maps with GREAT on SOFIA combined with ground based mm-data as well as IRAC images show that all the observed characteristics of NGC7538 IRS1 can be explained by a large (parsec scale)north-south outflow, possible rotating.

Topic: Galactic Center

7031 Infrared Observations of the Arched Filaments in the Galactic Center using SOFIA/FORCAST

Matthew J. Hankins, *Cornell University*

R. M. Lau, M. R. Morris, T. L. Herter

We present 19.7, 25.2, 31.5, and 37.1 μm maps of the Arched Filaments region in the Galactic center taken with the Faint Object InfraRed CAMera for the SOFIA Telescope (FORCAST). Color-Temperature maps of the region created with the 25.2 and 37.1 μm data reveal a remarkable level of temperature uniformity (~70-100 K) over the extent of the filaments. Heating analysis of the region along with the modeled properties of the filaments were used to study the nature of the dust in the region.

Topic: History of Airborne Astronomy

7040 Airborne Infrared Astronomical Telescopes

Edwin F. Erickson, *NASA Ames Research Center (retired)*

This poster is a slightly updated version of one presented at a meeting celebrating the 400th anniversary of the invention of the telescope, held 28 September–2 October 2008 at Noordwijk, The Netherlands. It describes primarily the airborne observational facilities developed at NASA Ames Research Center, and some of the scientific highlights they produced leading up to SOFIA.

Topic: Chemistry of the ISM

7042 SOFIA/EXES 13 Micron High Spectral Resolution Observations of Orion IRc2

Naseem Rangwala

X. Huang, T. J. Lee, S. Colgan

We present high spectral resolution (~5 km/s) observations in the 12.96–13.33 micron range toward Orion IRc2 taken by the EXES instrument on SOFIA.

Topic: Interstellar Medium & Cloud

7043 SOFIA Large Impact Proposal [CII] Mapping of M51: Observing Strategy, Data Analysis & First Results

Monika Ziebart

J. Pineda, J. Stutzki, P. Goldsmith, C. Buchbender, C. Fischer, on behalf of the M51 GREAT-Team

The M51 large Joint Impact Proposal will obtain the complete velocity resolved (with upGREAT) & deep map (with FIFI-LS) of M51 in [CII]. Here we present the observing strategy, the calibration and data analysis with up-GREAT and the first [CII] maps obtained with upGREAT and FIFI-LS. A first comparison of the [CII] spectra with CO and HI emission line of the norther spiral arm of M51 shows a small shifts in velocity and the velocity channel map, reveal the velocity gradients in the spiral arms.

Topic: Star Formation Regions

7047 [CII], [NII], and [OI] Emission from an Evolving HII Region/PDR

Mark Wolfire

D. J. Hollenbach

The HII Region/PDR is a strong source of [CII], [NII], and [OI] line emission. We are developing a code which combines HII region models and PDR models along with a 1-D treatment of the dynamics to trace the emission from the evolving HII region and PDR. Most previous results have coupled the HII region to the PDR without accounting for the dynamical processes which modify both the HII region and PDR. We present line intensities for a parameter study and preliminary dynamical calculations.

Topic: Star Formation Regions

7049 LkHα101, an Extreme Emission Line Star with a Disk and illuminating an HII Region

Göran Sandell, *SOFIA Science Center, NASA-Ames/USRA*

W. Vacca, S. Corder

We present new results on LkHα101 based on imaging with FORCAST on SOFIA, CARMA 3 mm imaging, IRTF SpeX medium resolution spectra, and Herschel/PACS archive data. These observations, combined with published VLA data reveal that LkHα101 is surrounded by a photo-evaporating accretion disk and illuminating an HII region. The accretion disk is hot $T > 1000$ K and mostly ionized. The FORCAST, PACS and CARMA CO(1-0) and ^{13}CO(1-0) images show strong interaction with the molecular cloud to the north.

Topic: Galactic Center

7050 Feeding the Milky Way's Supermassive Black Hole

Elisabeth A.C. Mills, *San Jose State University*

S. Martin, H. B. Liu, M. R. Morris, J. Rodriguez, M. A. Requena Torres, V. Rosero, J.-H. Zhao, D. Riquelme, L. Moser, N. Harada, A. Ginsburg

The circumnuclear disk that surrounds our Galaxy's supermassive black hole is the closest reservoir of molecular gas for black hole growth and star formation in the central parsecs of the Milky Way. I will present new observations of the physical conditions and kinematics of gas in the circumnuclear disk from ALMA and the Very Large Array. I will discuss prospects for more accurate density measurements in this gas and what they tell us about the prospects for star formation in this gas.

Topic: Facilities and Instrumentation

7059 ALMA-SOFIA Synergies

Hans Zinnecker, *SOFIA Science Center, NASA-Ames/DSI*

Göran Sandell, SOFIA Science Center, NASA-Ames/USRA

ALMA is a high-altitude interferometric observatory which provides extreme sensitivity and high spatial resolution in the mm/submm wavelength regime. SOFIA is an airborne observatory which has broad wavelength coverage (most importantly in the 30-300 micron range), albeit with more moderate spatial resolution and sensitivity (2.5m telescope in a B747SP plane). There are many synergies between the two observatories, which will be discussed in our poster, particularly in terms of continuum observations, spectroscopy, and polarimetry.

Long Talk Abstracts
(listed alphabetically by last name)

What Does the FIR Polarization Really Measure?

7001

B-G Andersson et al. (SOFIA Science Center/USRA)

Magnetic fields are thought to provide important constraints on the regulation of star formation, by supplying pressure terms and large-scale structure in molecular clouds. One of the prime methods for tracing and characterizing interstellar medium (ISM) magnetic fields is through dust induced polarization – whether as dichroic extinction in the UV - NIR or dichroic emission in the FIR - sub-mm wave regime.

That such polarization is due to asymmetric dust aligned with the magnetic field is well established, but the details of the mechanism, and hence limitations of the probe, have only recently been clarified in quantitative detail. The leading candidate for explaining ISM polarization is the Radiative Alignment Torque (RAT) theory, which predicts that paramagnetic dust grains will be aligned with the magnetic field if exposed to an anisotropic radiation field with wavelengths less than the grain diameter. These theoretical requirements lead to a number of observational predictions, many of which have already been tested and – so far – confirmed. These include that the alignment depends on the angle between the magnetic- and radiation- fields, and that the alignment is lost at large depths into star-less clouds (Andersson et al., 2015, ARA&A, 53, 501). We discuss the consequences of RAT theory on the use of dust-induced polarization for understanding ISM magnetic fields and star formation.

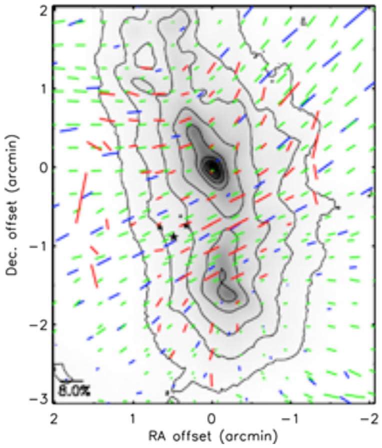

***Figure 1**. FIR polarimetry in the Orion molecular cloud. (B: 100μm, G: 350μm, R: 850 μm) The 350μm total intensity is shown in grayscale with contours. The Trapezium cluster is indicated east of the submillimeter intensity ridge.*

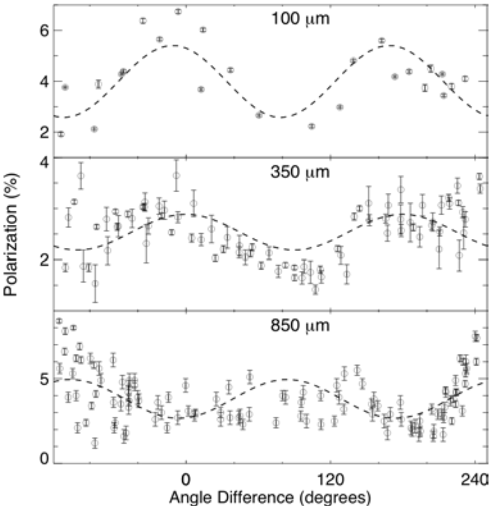

***Figure 2.** Polarization vs. angle. The polarization signals for OMC-1 is shown as a function of the angle difference between the magnetic field orientation and radiation direction. Fits to 180° sinusoids are shown as dotted curves. The good fits (for 100 and 350μm) support the prediction of RAT theory. (Vaillancourt & Andersson, 2015, ApJ, 812, L7)*

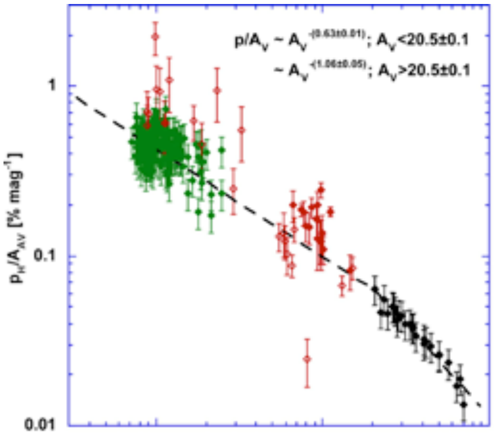

Figure 3.** The fractional polarization in the Ldn 183 star-less cloud is shown, observed from the visual (green), through the NIR (red) to the sub-mm wave (black). RAT alignment predicts that when reddening has excluded all light with wavelengths less than the largest grain diameters, no further polarization is generated. The break in p/A_V at A_V=20.5, supports this prediction. This means that, **for star-less cores, dust induced polarization does not trace the magnetic field at large extinctions.

Historical Review of Airborne Astronomy: Science Highlights from the 990, Learjet, KAO and SOFIA

7044A

Eric Becklin, SOFIA Chief Scientific Advisor

A review will be given of the NASA airborne astronomical highlishts over the last 50 years, beginning with the Convair 990 (Galileo) and ending with SOFIA. Emphasis will be placed on those observations that advanced because of the improved facilities, better instrumentation and better understanding of the science. A few highlights of the SOFIA science with personal involvement will be included.

The role of cosmic rays in tracing molecular gas in galaxies

7017

T. G. Bisbas, P. P. Papadopoulos, E. F. van Dishoeck, L. Szücs, Z-Y. Zhang and S. Bialy

About 70% of the total bayonic non-stellar mass of the Universe consists of hydrogen. In its molecular form (H_2) it plays the dominant role in the star-formation process of all galaxies. However, owing to its quantum mechanical properties, H_2 is not readily observable by radiotelescopes and because of this, the CO molecule is widely used as a tracer. During the last 5 years, however, there is growing evidence that this tracer may not always be accurate or even applicable to extragalactic studies. We report here on the effects of cosmic rays on the abundance distribution of CO in H_2-rich clouds under conditions typical for star forming galaxies and the Galactic Centre (Bisbas, Papadopoulos & Viti, 2015, ApJ, 803, 37). We perform three-dimensional photodissociation (PDR) and cosmic-ray (CRDR) dominated region simulations of a fractal cloud embedded in different cosmic ray energy densities and we find that CO is very effectively destroyed in ISM environments with cosmic ray energy densities of the order of 50-1000 × the typical Milky Way value. Using simulated observations we show how the emission maps of CO(1-0), [CI] (1-0) and [CII] 158 μm change as the cosmic-ray ionization rate increases (see Fig. 1). We conclude that [CI](1-0) and possibly [CII] 158 μm can be considered as best alternative proxies for detecting molecular gas in systems permeated by high cosmic-ray energy densities. We further find that at higher temperatures, charge transfer reactions increase OH which results in a CO increase in the high density parts of the fractal cloud. OH plays therefore an important role in regulating the CO-formation and the [CO]/[H2] abundance ratio in CRDRs (Bisbas et al., *in preparation*).

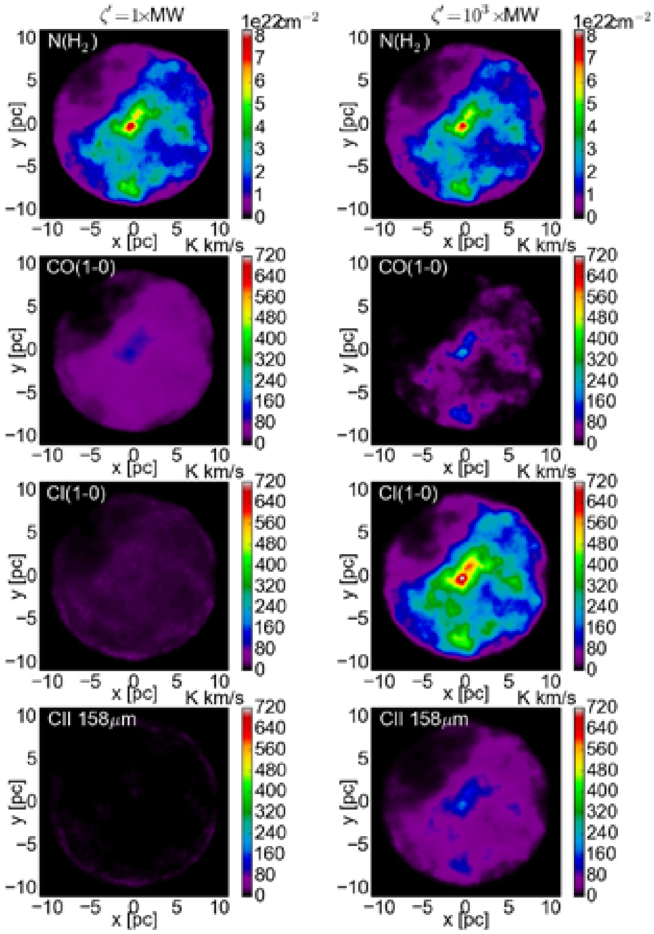

Figure 1 *This figure shows 3D-PDR (Bisbas et al., 2012, MNRAS, 427, 2100) simulations of a fractal cloud interacting with cosmic-ray ionization rates of* 1xMW *(left) and* 10^3 x MW, *where* MW=10^{-17} s^{-1} *the average cosmic-ray ionization rate of Milky Way. Although the* H_2 *column density (top) remains unaffected, the emission of* CO (1-0) *(second row) overall decreases whereas the denser parts brighten. However, both emissions of* [CI] (1-0) *(third row) and* [CII] 158μm *(bottom row) increase with the first one to remarkably surpass the brightness of* CO (1-0) *in the* 10^3 x MW *case, being on average 3 to 4 times brighter. This makes it a much better tracer for molecular gas.*

EXES Observations of CH_4 and SO_2 toward Massive Young Stellar Objects

7030

Adwin Boogert (USRA-Stratospheric Observatory for Infrared Astronomy, NASA Ames Research Center), Matt Richter (UC Davis), Curtis DeWitt (UC Davis), Nick Indriolo (STScI), David Neufeld (Johns Hopkins University), Agata Karska (Adam Mickiewics University), Ted Bergin (University of Michigan), Rachel Smith (Appalachian State University)

The ro-vibrational transitions of molecules in the near to mid-infrared are excellent tracers of the composition, dynamics, and excitation of the inner regions of Young Stellar Objects (YSOs). They trace a wide range of excitations in a short wavelength range, they can be seen in absorption against strong hot dust continuum sources, and they trace molecules without permanent dipole moment not observable at radio wavelengths. In particular, at high infrared spectral resolution, spatial scales smaller than those imaged by millimeter wave interferometers can be traced dynamically.

In this poster, we present high resolution ($R=\lambda/\Delta\lambda\sim50,000-100,000$; 6-12 km/s) infrared (7-8 μm) spectra of massive YSOs observed with the Echelon-Cross-Echelle Spectrograph (EXES) on SOFIA. Absorption lines of gas phase methane (CH_4) are detected in our Cycle 2 observations. CH_4 is thought to be a starting point of the formation of carbon chain molecules. Abundances are derived in the different dynamical regions along the sight-line towards the central star by comparing the line profiles to those of CO and other species observed at ground based facilities such as EXES' sister instrument TEXES at IRTF and Gemini. A search is also conducted for sulfur-dioxide, using data from our ongoing Cycle 4 program. SO_2 was previously detected towards these massive YSOs with the space-based ISO/SWS instrument (Keane et al. 2001, A&A 376, L5) at much lower spectral resolution (R~2,000). At high spectral resolution we should be able to pin-point the dynamical location of this SO_2 gas. Up to 98% of the sulfur in dense clouds and protostellar envelopes is presently missing, and we intend to search for that with the EXES/SOFIA observations.

Tracing the CO-dark gas in galaxies- where SOFIA shines

7032

Diane.Cormier,.Suzanne.Madden.(CEA,.Saclay,.France)

Star Formation is one of the most widely sought-after properties in galaxies at any epoch, with the presence of H_2 being a requisite. The use of CO as a proxy for the mass of H_2 is practically universal, despite the issues related to the CO-to-H_2 calibration. A potentially non-negligible reservoir of H_2 can, in principle, be residing outside of the CO-emitting region, due to the self-shielding capability of H_2, while CO succumbs more readily to the photdissociating UV radiation. We have use CLOUDY and the MIR (Spitzer/IRS) and FIR (Herschel/PACS) fine structure lines to model the multiphase ISM of low metallicity star-forming dwarf galaxies (Cormier et al 2015; Cormier et al in prep). We are now studying the effects of density, Go, Av and metallicity on the quantity of CO-dark gas to understand the dearth of CO emission, yet relatively bright [CII] emission in these galaxies which are vigorously forming stars. L[CII]/L(CO) in dwarf galaxies is at least an order of magnitude higher than metal-rich star burst galaxies, for example (Figure 1). We show from our models that the observed L[CII]/L(CO), which constrains Av, can be used to quantify the CO-dark gas to CO-bright gas fraction (Madden et al. in prep). We find the CO-dark gas can be a significant H_2 reservoir in these galaxies, and up to 100% in some cases. It is becoming clear that CO does not trace much of the molecular gas in dwarf galaxies.

SOFIA is the only telescope that can probe the CO dark gas now in local universe galaxies, using the [CII] emission. Our study so far has been conducted on low-metallicity dwarf galaxies, and now the CO-dark gas can now be studied in a wide range of galaxies with SOFIA with sensitive observation of [CII] as well as tracers of the ionized phase from which [CII] may also originate, such as [NII] for example. Refinement of this calibration is necessary to determine if any of the [CII] emission is arising from outside of the PDR, for example. SOFIA can zoom into galaxies and determine the effect of size scale on this relationship. This will help to understand the scatter in the calibration of [CII]/CO as a CO-dark gas tracer. Quantifying this elusive component of H_2, which may make up much of the total H_2 reservoir in some galaxies, and determining the conditions favorable for its presence, will alter the way we account for the total gas reservoir and the scaling relations associated with star formation. Beyond SOFIA, SPICA, a new sensitive MIR to FIR telescope proposed for the call for ESA's M5 mission, will refine this topic even further, quantifying the molecular gas and PDR properties of the lower surface brightness environments and the extremely low metallicity galaxies, beyond what Herschel could do.

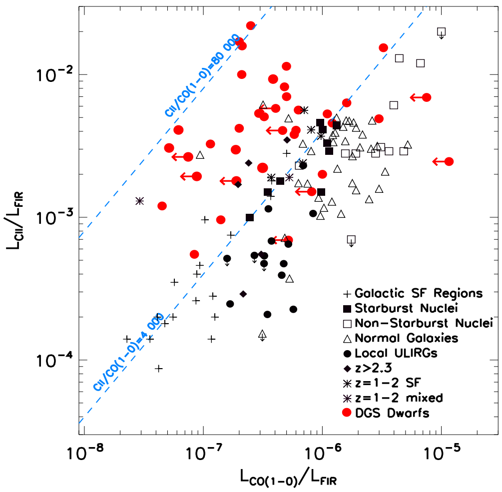

Figure 1. L(CO)/LFIR vs. L[CII]/LFIR is observed in galaxies of widely-varying metallicities and star formation properties (Madden et al. in prep). Figure modified from Stacey et al.(1991; 2010) and Hailey-Dunsheath et al.(2010). Blue dashed lines are lines of constant L[CII]/L(CO) ratios. The red dots are low metallicity galaxies from the Herschel Dwarf Galaxy Survey (Madden et al. 2013; Cormier et al 2015). The dwarf galaxies have a significantly higher

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The low-metallicity multi-phase ISM: the dwarf irregular NGC 4214

7012

Diane Cormier (ITA/ZAH, University of Heidelberg, Germany)

Star formation is a strongly self-regulated process in normal galaxies, with the star-formation rate and the amount of cold molecular gas being well correlated. However, in low-metallicity galaxies, active star formation is often observed while CO is exceedingly faint due to photo-dissociation. Does this point to a time effect with all the cold gas consumed by the recent burst, or to the presence a massive reservoir of gas hidden from CO? This puzzle is showcased by the dwarf irregular galaxy NGC 4214. With metallicity ∼1/3 solar and three main star-forming regions at different stages of their evolution, we investigate how the presence of a super star cluster and different time evolution affect the physical properties of those star-forming regions.

I will present results from two recent studies based on GREAT velocity-resolved [C II] data (Fahrion et al. submitted) and multi-phase modeling of the star-forming regions in NGC 4214 (Dimaratos et al. 2015). These studies are part of our larger systematic effort to study physical properties under low-metallicity conditions (Cormier et al. in prep). We use the spectral synthesis code CLOUDY to determine densities and radiation fields in the H II region and PDR. Our models of the H II region agree with different evolutionary stages found in previous studies of NGC 4214, with a more evolved, diffuse central region, and a younger, more compact southern region. However, the local PDR conditions are found similar for both regions. The increased porosity of the PDRs stands out as an intrinsic characteristic of the low-metallicity ISM, while the PDR covering factor is the only parameter tracing the evolution of the regions. We find that the GREAT [C II] spectra resemble closely those of CO, indicating that [C II] arises mostly from PDRs (Fig. 1). Combining our models and the GREAT spectra, we estimate that 70-90% of the molecular gas mass is CO-dark.

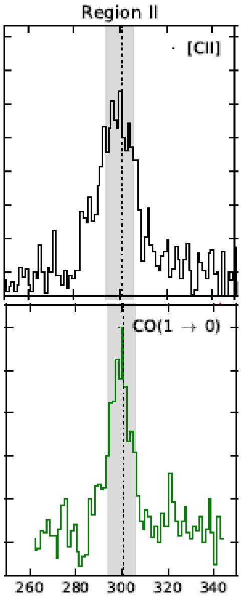

Figure 1: *Spectra of GREAT [C II]and CO(1-0) in one of the main star-forming region of NGC 4214.*

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FORCAST Studies of High-Mass Star Formation on Small and Large Scales

7010

James De Buizer (USRA-SOFIA)

We know less about how high-mass stars form than low-mass stars like our Sun. This is due in large part to the fact that the highest-mass stars form in regions of extremely high extinction, hidden from study at a large range of wavelengths. Individual high-mass stars form at the centers of the densest and dustiest molecular cores which are in turn embedded within larger obscuring molecular clouds. Thermal infrared wavelengths, however, allow one to both observe the star formation occurring within these small-scale molecular cores as well as the larger-scale environment of the surrounding molecular cloud. FORCAST has been used over the last several cycles for two long-term projects; one aimed at understanding the arcsecond-scale circumstellar environment of individual (or small multiple) high-mass star systems in the earliest stages of forming within these cores, and the other aimed at understanding the arcminute-scale environments of the giant molecular clouds that clusters of such high-mass stellar systems form in. I will present preliminary results from both of these ongoing studies.

Historical Review of Airborne Astronomy: the Evolution of SOFIA

Edwin F. Erickson, NASA Ames Research Center (retired)

Infrared observations of the Sun were made from a Canberra jet in 1957 by John Houghton. By the late 1960s, the potential of this discipline had been convincingly demonstrated by Gerard Kuiper on a Convair 990 and Frank Low on a Learjet, both operated by NASA Ames. Plans for the KAO were drafted at Ames beginning in 1967, and development begun in 1969. Concurrently, efforts to include endorsement of studies for a 3-m class stratospheric infrared telescope in the 1970 Decadal "Greenstein" Report were successful. Impressive scientific results from the KAO, which started operations in 1974, accumulated, as did a growing cadre of supportive KAO investigators .

By the late 1970s, enthusiasm for a Large Airborne Telescope (LAT) – based largely on KAO results – was heating up. Ames sponsored a 1977 study by Boeing, which recommended a 2.5 m telescope installed aft of the wing in a Boeing 747. Ames management and scientists began promoting the LAT idea at NASA Headquarters. German astronomer Peter Mezger spearheaded the concept of a collaborative project. However the 1980 decadal survey "Field" committee was convinced by the infrared community to endorse construction of a "Large Deployable Reflector" (LDR), a 10-m space borne infrared telescope. Studies in the mid-1980s showed LDR to be infeasible with near-term technology.

The 1984 Airborne Astronomy Symposium at Ames fanned the flames of enthusiasm. The name SOFIA was coined by senior KAO staff member Carl Gillespie in 1985. In 1986 a SOFIA Technology Workshop was held at Ames with interested contractors, both U.S. and German, as well as representatives of what is now the German Aerospace Center (DLR). KAO users drafted requirements and organized science advocacy efforts. Detailed collaborative technical studies for the aircraft and mission systems in the U.S. and for the telescope in Germany were undertaken, led by engineers Nans Kunz for the aircraft and Hans Kärcher for the telescope. These studies and numerous reviews led to requests by NASA to begin SOFIA development in both FY1989 and FY1990; these were rejected by the Office of Management and Budget, based on NASA budget constraints.

In November 1989, the wall between East and West Germany came down, resulting in a hiatus of official German participation. U.S. studies including a U.S.-built telescope were implemented, with the caveat that NASA's cost would not increase, prompting moving the telescope to behind the wing (previous designs had it in front of the wing). Promotions by the science community (read KAO users) convinced the 1990 Decadal Survey (Bahcall) Committee to recommend development of SOFIA.

Wind tunnel tests begun at Ames in 1990 evolved a configuration for the critical shear-layer control and cavity door. Interest by the Germans remained high and they officially rejoined the effort, their studies leading to a telescope design incorporating a large hydraulic spherical bearing for stabilization. A plethora of technical and administrative details were worked out in close collaboration. A second Airborne Astronomy Symposium in 1994 stirred further enthusiasm for SOFIA. Promotional efforts and the Bahcall endorsement resulted in the project's inclusion in the President's FY1996 budget request. Shortly following a SOFIA soirée at the German Embassy in Washington DC organized by Hans Peter Röser, Congress approved starting the project. Development contracts were signed in both Germany and the U.S. in December 1996, so development began in earnest in January 1997.

Technical development proceeded largely according to the pre-development designs. The aircraft modification was undertaken at the L3 Communications facility in Waco Texas. The Germans delivered the telescope there in September 2002. Installed in the aircraft, it saw first light from the ground there in September 2004. When the aircraft modification was completed, the beautiful SOFIA first took flight in April 2007. After extensive flight testing and commissioning of some science instruments, full operational capability was declared in June 2014.

The talk will highlight features of SOFIA's forerunners that were based at NASA Ames, some of the technology that makes SOFIA work, and some of the people who helped it become a reality.

Interstellar filaments, turbulence and magnetic fields

7098

Edith Falgarone (Ecole Normale Supérieure and Observatoire de Paris)

The dynamic properties of interstellar filaments broaden our perspectives on interstellar turbulence, its multi-phase facets, its dissipation processes, the topology of the magnetic fields. Among recent observational results, I will present those that are particularly challenging.

Observations of M82 with FIFI-LS on SOFIA – A First Look at the Results and how we got them

7046

Christian Fischer et al. (Deutsches SOFIA Institut, Stuttgart, Germany)

The Field-Imaging Far-Infrared Line-Spectrometer (FIFI-LS) entered service on SOFIA in March 2014. Up to July 2016 it has completed 40 commissioning and science observing flights. The instrument features two parallel spectral channels with wavelength ranges of ~51µm to ~120µm and ~115µm to ~203µm respectively. Each channel has a field of view of 5 by 5 spatial pixels with a size of 6"/pixel in the short wavelength channel and 12"/pixel in the long wavelength channel. The spectral resolution of the instrument is in the range of R=~1000 to ~2000. With its combination of wavelength range, resolution and imaging capabilities FIFI-LS is designed specifically for the investigation of the interstellar medium in our own and other galaxies.

One of the very first science targets observed with FIFI-LS is the star bursting galaxy M82. An extensive guarantied time program resulted in maps for the transition of [CII] at 157.741 µm and [OIII] at 51.815 µm. Data was taken during 3 flight series in 2014, 2015 and 2016 in about 7 hours of telescope time. The maps cover the central area as well as the two outflows.

We will present the maps and show how they complement the data available from PACS. Also we will lay out how the observing process works with FIFI-LS, using this data set as an example. We will show the preparation of the observations concerning chops, mapping and strategy. Also we will present some features of the FIFI-LS reduction pipeline that are relevant for this kind of observation.

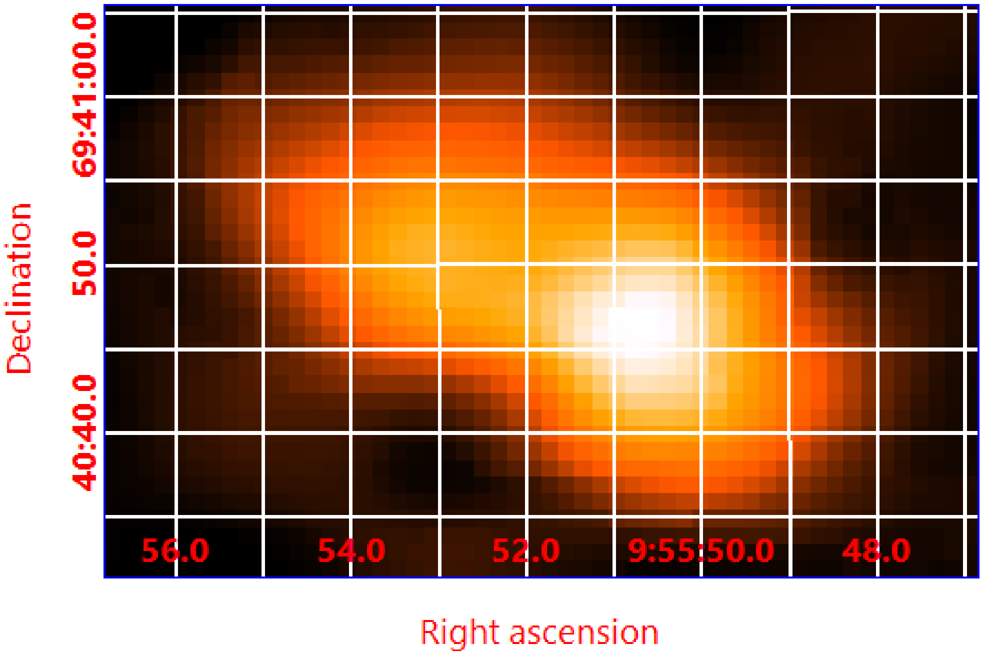

Figure 1Integrated line emission of the [OIII] at 51.815 µm

Feedback and accretion toward proto-O-stars

A. Ginsburg

I will present observations of the high-mass star-forming complex W51 in which dozens of O-stars have already formed and many more OB stars are vigorously accreting. We have used ALMA to probe scales from 200 AU to 0.5 pc both toward the known proto-O-stars and in the surrounding protocluster cloud. These data have allowed us to compare the impact of different feedback mechanisms on the formation of both low- and high-mass stars. We detect dozens of collimated outflows with lengths 0.03-0.5 pc, many of which originate in barely resolved or even unresolved sources at 200 AU resolution, which identify the accreting massive stars. Where the central source is resolved in the dust continuum, it is elongated orthogonal to the outflow. Observations of temperature probes reveal that regions within about 0.1 parsecs of these high-mass protostars are significantly warmer than their surroundings, reaching temperatures of 100-200 K. The enhanced temperature only occurs around the accreting proto-massive-stars, not around their main sequence colleagues or nearby compact HII regions. These high-mass stars are able to maintain their food source by heating their surroundings, suppressing the fragmentation of infalling and orbiting gas, thereby keeping it available for future accretion

What are we learning from Galactic fine structure line observations?

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Jet Propulsion Laboratory, California Institute of Technology
Pasadena CA 91109

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Atomic and ionic fine structure lines are powerful probes of conditions in various phases of the interstellar medium. With the advent of suborbital and space observatories, astronomers have been able to measure their emission and absorption spectra. Herschel enabled large-scale surveys of the Milky Way and imaging of nearby galaxies. This talk focuses on recent Herschel surveys of the Milky. Carbon is ionized in a wide range of conditions and thus its emission is widespread, but determining the actual source of the emission is a challenge. In the GOT C+ survey, we used comparisons of [CII] with HI and CO surveys to determine that a significant fraction of the 158 μm line emission arises from gas in which hydrogen is molecular but carbon is ionized rather than being in molecular form. This "CO Dark Molecular Gas" adds approximately 30% to the molecular mass of the Milky Way, and is particularly prevalent in the outer portions of our galaxy. A survey of [NII] emission, which arises from ionized gas, used its two FS transitions to determine a mean electron density of ~30 cm^{-3} in this gas that seems widespread in the inner portion of the Milky Way. SOFIA has enabled observations of FS lines of both of these species, and we will discuss some recent results that highlight the synergy between them, and indicate the contribution that observations of FS lines with suborbital and space instruments will make to our understanding of the evolution of the ISM and star formation.

[CII] 158 μm self-absorption and optical depth effects: M17SW

7007

C. Guevara[1], *J. Stutzki*[1], *R. Simon*[1]
[1]*I. Physikalisches Institut, Universität zu Köln*

The [CII] 158 μm fine structure line, being one of the dominant cooling lines of the warm interstellar medium (ISM), is ubiquitously used to study the physical conditions of the ISM, both in the Milky Way and in nearby and high-z galaxies. [CII] optical depth has been one of the big unknowns and had been assumed from simple models of Photon Dominated Regions (PDRs) to be unity or lower. But, with the recent advances in Heterodyne receivers, we are able to detect the hyperfine line emission of the three components of [^{13}CII] together with the [^{12}CII] emission at high velocity resolution and signal to noise. Assuming an isotopic abundance ratio for [^{12}CII] vs [^{13}CII](in the range of 25 to 80), we can thus directly determine the optical depth of the [CII] line.
We have a running observational program to study several Galactic sources in [CII] and [^{13}CII] using the heterodyne array upGREAT on SOFIA. All of the so far three observed sources show that the [CII] line is heavily self-absorbed with an opacity significantly larger than unity in all positions observed. Under these conditions, line ratios of fine structure lines derived from line-integrated, spectrally unresolved observations, when blindly used to derive physical source properties such as UV-intensity and density, give questionable results. Here, we focus on one of the sources, M17SW. M17SW is a giant molecular cloud located at 1.98 kpc, and it is illuminated by a cluster of OB stars at 1 pc to the east. It is one of the best studied prototype galactic PDRs. The cloud structure is highly clumpy. We discuss the implications of the complex self absorbed [^{12}CII]-spectra, the physical characteristics of the emitting gas and the nature of the discrete foreground absorption features.

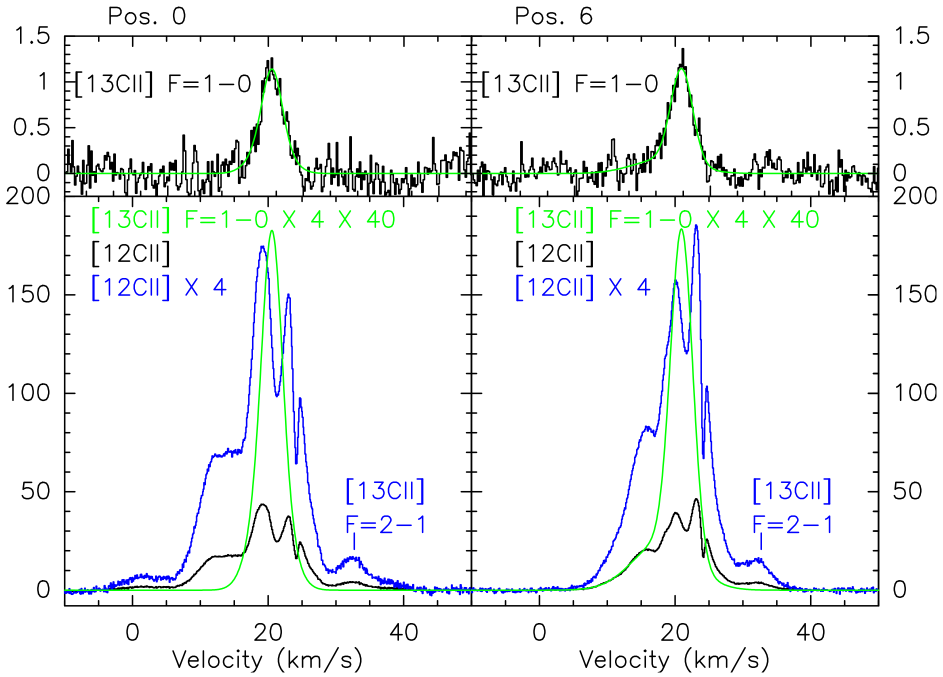

Figure 1: *[CII] M17SW composite image for two positions.* ***Top:*** *[^{13}CII] F=1-0 and best-fit gaussian profile.* ***Bottom*** *[^{13}CII] emission scaled up using a [CII]/[^{13}CII] abundance ratio of 40 for M17SW. Note that the scaled-up [^{13}CII] profile nicely envelops the [CII] line in the line wing, in particular at show a scaled-up [^{12}CII] spectrum to demonstrate the difference between the line profile for both isotopes. The [^{12}CII] spectrum is heavily self-absorbed at the core with a rich absorption profile originating from different foreground velocities.*

7016

SPICA and its instruments in the ESA Cosmic Vision M5 competition

Frank Helmich (SRON Netherlands Institute for Space Research & University of Groningen)

SPICA is a candidate mission for the 5th medium size slot of ESA's Cosmic Vision. If successful in the competition with probably 30-40 other candidate missions it will enter Phase A/B1 after June 2017 as an ESA-led mission with JAXA as junior partner.

The SPICA concept is created in a complex interaction between scientists, engineers and space agencies. This has led in the past to very different concepts. In this talk I will describe the current mission with emphasis on the instruments.

Variable Accretion in Protostars

Klaus W. Hodapp, Institute for Astronomy, University of Hawaii

Young stars accumulate their mass from the surrounding molecular cloud by accretion via a disk. There is now growing evidence that in many individual stars, this process is not steady, but subject to outbursts of accretion activity, as recently reviewed by Audard et al. (2014, PPVI). It is currently an open question whether a typical low-mass star accretes most of its final mass during the longer quiescent accretion phases, or during the shorter, but much more intense accretion outbursts. The earliest discoveries of such outburst were done at optical wavelengths on relatively well developed young stars, and have been classified as FUor or EXor outbursts (Herbig, 1977, ApJ 217, 693). While optical outbursts of these two classes are being discovered with increased efficiency, infrared monitoring is now also reveiling new outburst phenomena in younger, still more embedded protostars that do not fit well into the two classical classes.

This paper will discuss some of the deeply embedded accretion outburst objects discovered in recent years, some with periodic variability and some showing sporadic outbursts. The class I outflow source SVS 13 experienced an outburst in 1990 and the lower mass source OO Ser was discovered undergoing an outburst in 1995. Neither of the two has yet returned to the pre-outburst brightness (Hodapp et al. 2014, ApJ 794, 169 and Hodapp et al. 2012, ApJ 744, 56, respectively). On the other hand V371 Ser and L1634 IRS7 (Hodapp et al. 2015, ApJ 813, 107) show periodic increases in brightness, possibly triggered by binary interaction. A number of other objects in the class 0 and I outflow phases show similar brightness variations, but have not yet been studied in detail.

For our understanding of the role that these outburst events play in the overall mass accretion history of stars, it is important to distinguish changes in bolometric accretion luminosity from possible changes in the local disk extinction as a possible side effect of an outburst. The distinction can be made with repeated FIR SED measurements, a task particularly suited for a long-term project with SOFIA.

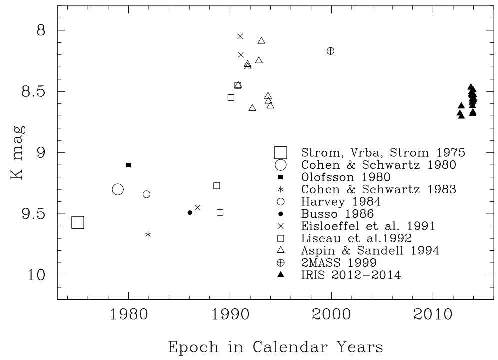

Figure 1: *NGC1333 SVS13 K-band light curve. After 25 years, the eruptive YSO has not yet returned to the pre-outburst brightness.*

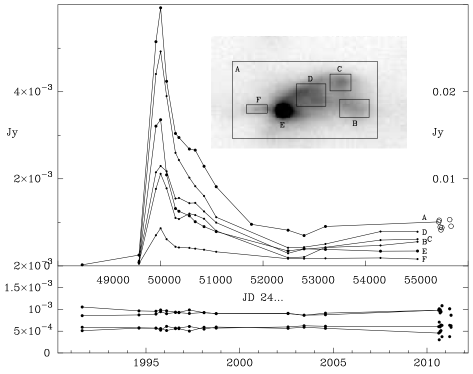

Figure 2: *OO Ser K-band light curve of the central star and areas in the reflection nebula. The object has not yet returned to its pre-outburst brightness and at the present time, has stable elevated brightness.*

Investigating Accretion Variability Onto Deeply Embedded Protostars: A Tool for Measuring Accretion Processes Within Protostellar Disks

7013

Doug Johnstone, National Research Council, Herzberg Astronomy and Astrophysics

Low-mass stars form via gravitational collapse of molecular cloud cores. The evolution of the mass accretion onto a forming protostar depends on the rate at which the interior of the core collapses, the significance of a circumstellar disk as a temporary mass reservoir, and the physics of how the gas is transported through the disk and accretes onto the central star. Despite a clear requirement for time dependency in the accretion rate and a large number of theoretical mechanisms for powering accretion variability within the protostellar disk, our understanding of both the timescale and amplitude of these variations is almost entirely unconstrained.

The bolometric luminosity of deeply embedded protostars is a direct proxy for the accretion luminosity, modified only by the addition of the stellar luminosity itself. Thus, monitoring the brightness of these sources provides a robust measure of both the timescale and amount of accretion variability taking place. For deeply embedded protostars, the spectral energy distribution peaks in the far infrared, near 100 microns, making this an ideal wavelength for a long-term survey of accretion variability.

We investigate the manner in which the protostar's enshrouding envelope responds to any change in the accretion luminosity (Johnstone et al. 2013) and use this information to devise a collection of long-term episodic accretion monitoring campaigns. We conclude that SOFIA will be an extremely important telescope for both uncovering variability and analysing such discoveries.

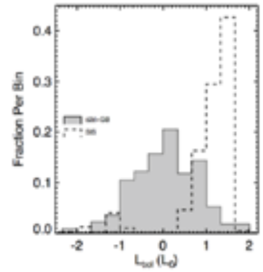

Figure 1: *Histogram showing observations (filled) and model predictions for singular isothermal spheres (dashed) with a range of masses (0.3-3 $M_\odot$) collapsing according to the predictions of Shu inside-out collapse. Figure adapted from Young & Evans (2005) and Dunham et al. (2010).*

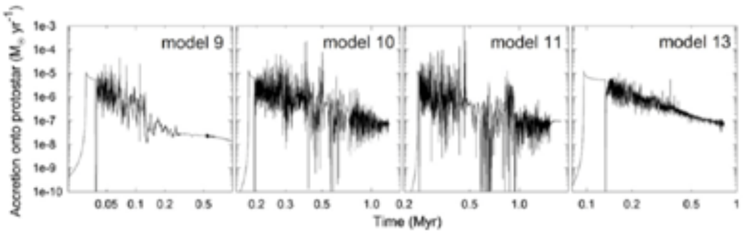

Figure 2: *Examples of the time evolution of the mass accretion rate onto a protostar for four simulations by Vorobyov & Basu (2010). Variability is found over a large range of timescales with a variety of amplitudes. Figure adapted from Dunham & Vorobyov (2012).*

ISM dynamics and star formation: A theoretical perspective

7051

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Stars and star clusters form by gravitational collapse in regions of high density in the dynamically evolving multi-phase interstellar medium. The process of stellar birth is controlled by the intricate interplay between the self-gravity of the star-forming gas and various opposing agents, such as supersonic turbulence, magnetic fields, radiative feedback, cosmic rays pressure, and gas pressure. Turbulence plays a dual role. On global scales it provides support, while at the same time it can promote local collapse. This process is modified by the thermodynamic response of the gas, which is determined by the balance between various heating and cooling processes, which in turn depend on the chemical composition of the material. I will discuss examples of recent progress and controversy, and I will report about current attempts to bring numerical simulations and theoretical models closer to the observational domain.

Klessen, R. S., Glover, S. C. O.: Physical Processes in the Interstellar Medium. in Star Formation in Galaxy Evolution: Connecting Numerical Models to Reality (eds. Y. Revaz, Yves, P. Jablonka, R. Teyssier, L. Mayer), Saas Fee Advanced Lecture, 43, 85 (2016), also available as arXiv:1412.5182

The Circumnuclear Disk around Sgr A* – Observations with FIFI-LS

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The Field Imaging Far-Infrared Line Spectrometer (FIFI-LS) is a German-built Facility Science Instrument for SOFIA. As part of its initial commissioning campaign, FIFI-LS observed several Far-Infrared emission lines and their associated continua in the Circumnuclear Disk around the Sagittarius A* region of the Galactic Center. This data was complemented by additional observations taken throughout 2016. Here, some results of these observations are presented.

The Circumnuclear Disk is a clumpy and warped structure of gas and dust of uncertain mass and temperature. It has been traced between roughly 1.5 and 5 pc from the central position of Sgr A*. The role of this disk in the general dynamics of the ISM and for star formation events that have taken place at the core of the galaxy is still under debate. Past studies have demonstrated that the disk is fed by infalling gas from dense molecular clouds in outer regions, and seems to be actively feeding material into the central cavity via streamers.

We present high resolution maps of the entire disk and surrounding region at several FIR wavelengths, and discuss the astrophysical implications of these observations for the dynamics of the disk and for matter transport into the core of the Galaxy.

Investigating Dust Production and Survival with SOFIA and Beyond

R. M. Lau *et al.* (Caltech/JPL)

Dust is ubiquitous in the interstellar medium (ISM) and an important component in the lifecycle cycle of stars. However, there are prevailing questions on the origin of large quantities of dust observed in galaxies in the early and local Universe. Condensation in supernova (SN) ejecta is currently the leading theory to explain the presence of dust in early Universe galaxies. Recent SOFIA/FORCAST imaging observations of SN-condensed dust in the ejecta of the ~10,000 yr-old Sgr A East SN remnant near the Galactic center reinforce this explanation. Quantifying the contribution of additional dust-production mechanisms is still of great importance since SNe may also destroy significant quantities of dust in the ISM. Notably, the contribution from Wolf-Rayet stars with close O/B-star companions to galactic dust budgets has been largely neglected. Carbon-rich WR (WC) stars, identified by broad C emission lines, with binary companions are observed to produce up to 10^-6 M_Sun yr^-1 in dust. SOFIA/FORCAST observations of the presumed dusty WC stars in the Quintuplet Cluster reveal that one system contains at least a factor of 10 more mass in dust than other known dusty WC systems. This may have profound implications on the dust production yield from WC binaries; however, the details of how dust forms and survives in such hostile environments are still uncertain. Utilizing the unique mid- to far-IR capabilities of SOFIA in conjunction with future missions such as the upcoming James Webb Space Telescope will be crucial for addressing the questions of dust production and survival in dusty WC systems.

Turbulence and Reconnection Diffusion

Alex Lazarian (University of Wisconsin-Madison)

The theory of star formation was developed assuming magnetic flux conservation in highly conductive fluids (Alfven theorem). Thus it usually assumed that to form a star either collecting of matter along magnetic field lines or non-ideal effects of ambipolar diffusion are necessary. However, the above assumption is not true. I shall show that magnetic flux freezing is violated in the perfectly conducting turbulent fluid. My conclusion is based on our analytical model of magnetic reconnection in the presence of weak turbulence. The predictions of this model have been successfully tested numerically and, in a separate development, the deep relation of our reconnection model with the recent developments in the Lagrangian theory of MHD turbulence has been established. On the basis of this I shall show the existence of a new process termed "reconnection diffusion". In my talk I shall show how reconnection diffusion induces flux loss in molecular clouds and accretion disks and provide a comparison of the observational data and the theoretical predictions. In particular, I shall show that the reconnection diffusion can solve the so - called the problem of "magnetic braking catastrophe" for the circumstellar accretion disk

GREAT observation of LMC-N 11: does [C II] trace regions with a large molecular gas fraction? 7033

Vianney LEBOUTEILLER - Laboratoire AIM - CEA, Saclay, France

The [C II] 157 μm line is the dominant coolant in the warm neutral atomic gas, either in the form of low extinction (A_V) sheets or filaments or at the interface with molecular clouds (photodissociation regions; PDRs). The ubiquity of [C II] makes it difficult to derive physically meaningful quantities such as the star-formation rate or the amount of molecular gas. The latter is subject to much debate, as [C II] has been proposed to trace a significant fraction of molecular gas unseen with the traditional tracer CO(1-0), the so-called CO-dark gas (e.g., Poglitsch et al. 1996, Madden et al. 1997). The fraction of CO-dark gas is expected to increase in low-metallicity environments, as the low dust-to-gas ratio enhances the penetration of far-UV photons deeper into clouds where H_2 is self-shielded but CO is photodestroyed (e.g., Wolfire et al. 2010).

Observations with the KAO and with the *Herschel* Space Telescope toward several H II regions in the Large Magellanic Cloud (≈ 1/2 solar metallicity) show that [C II] seems to trace photodissociation regions, with negligible contribution from the warm diffuse ionized gas (e.g., Israel & Maloney 2011, Lebouteiller et al. 2012). The evidence is however only circumstancial, based on spatial comparisons, and usually biased toward the CO-bright regions. Furthermore, the fraction of CO-dark gas so far has to rely on PDR modeling (e.g., Chevance et al. 2016).

The combination of spatial and spectral information is key to understand the origin of [C II]. We present here velocity-resolved observations of [C II] with SOFIA/GREAT toward 12 pointings in the second largest H II region in the Large Magellanic Cloud, N 11 (Fig. 1). The [C II] line was observed toward CO-dominated (identified with the MAGMA survey), [C II]-dominated (identified with *Herschel*/PACS), and ionized gas dominated regions. In addition, we use the deep CO spectral profiles of our Cycle 1 ALMA map of N 11B. We compare the [C II], CO, and H I profiles at 1.6 km s^{-1} resolution.

In general, [C II] seems to correspond to CO, but a detailed analysis shows important differences. We examine in detail the individual components by decomposing the [C II], CO, and H I profiles and by assuming that *each component contributes to the* 3 *tracers*. Thanks to this simultaneous fit, we find that all CO components are associated with a [C II] component of similar velocity and at least as large spectral width, implying that [C II] traces the PDR around the molecular cloud in these cases. For many other [C II] components, there is no CO associated but there is most often H I emission, implying that [C II] traces a mostly atomic medium not necessarily associated to any PDR. One notable exception is a component seen in [C II] but not in CO and extremely weak in H I. Such a component is our best candidate for a direct detection of a CO-dark gas dominated region.

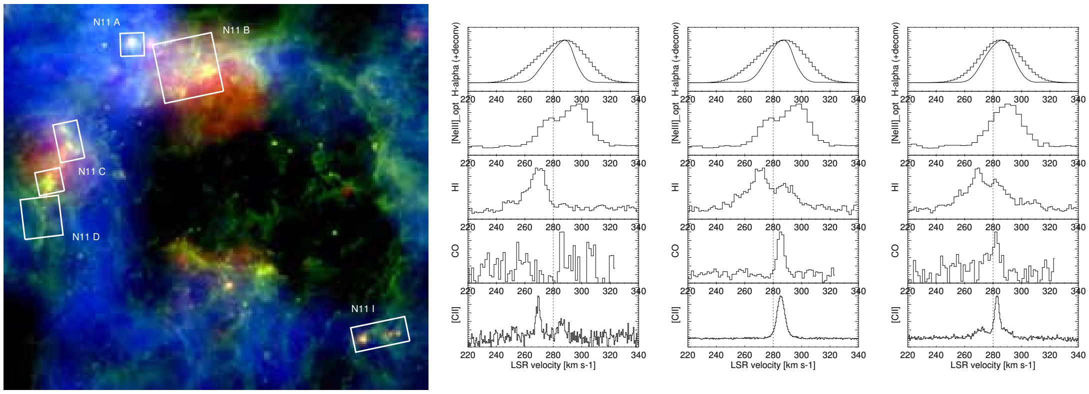


Figure 1 *Left – N 11 (R: 24 μm, G: PAH, B: H I). Boxes show the Herschel/PACS maps. Right – Example of spectral profiles toward* 3 *pointings. From top to bottom, Hα and [Ne III] (VLT/GIRAFFE), H I (ATCA+Parkes), CO (MOPRA), and [C II].*

Probing the Large-Scale Multiphase ISM in an Extreme Star Forming Low-Metallicity Environment: 30 Doradus in the LMC

Suzanne.Madden,.Mélanie.Chevance.et.al..(CEA/Sap/AIM)

The 30 Doradus region in the Large Magellanic Cloud (LMC) offers the best laboratory to examine in detail the interplay between stellar activity and a metal-poor interstellar medium (ISM). The main stellar source of radiation, provided by the closest example of a super star cluster, R136, shapes the surrounding half-solar metallicity ISM. The proximity of 30 Doradus (50kpc) makes it possible to study gas and dust over large scales in this dramatic environment. I will present a far-infrared (FIR) view of this extreme star-forming region.

The *Herschel*/PACS and SPIRE/FTS observations of FIR fine structure lines, combined with *Spitzer*/IRS spectroscopic maps, have been used to constrain the physical conditions in the photo-dissociation regions (PDR) with the Meudon PDR code (Le Petit et al., 2006, ApJS, 164, 32). This allows us to construct a comprehensive, self-consistent picture of the density, radiation field, and ISM structure (Chevance et al., 2016, A&A, 590, A36). We quantify the effect of intense radiation field on this low metallicity ISM. In particular, we build a 3-dimensionnal view of the region (Figure 1). We bring constraints to the fraction of molecular dark gas not traced by CO, the so-called "CO-dark gas" and find that a large reservoir of H_2 is not traced by CO in this extreme environment.

Our follow-up observations of [CII] 158 μm, [OI] 145 μm, [OIII] 88 μm and [OIII] 52 μm of the full 90pc*75pc region with SOFIA/FIFI-LS reveal a more complete picture (Figure 2) and allow us to study the evolution of the gas conditions and structure with the proximity of R136.

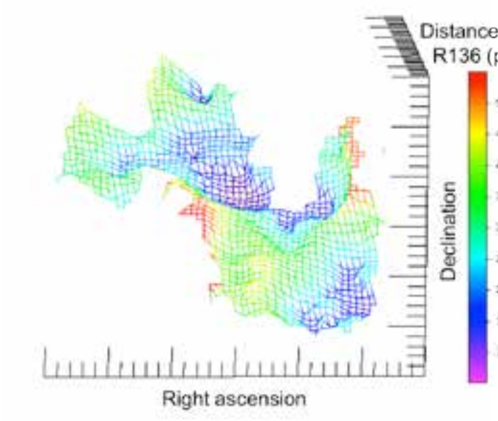


***Figure 1**: Modeled 3D reconstruction of the structure of the PDR clouds around R136, limited by the PACS [OI] 145μm coverage. Color and surface show the distance of each pixel to R136.*

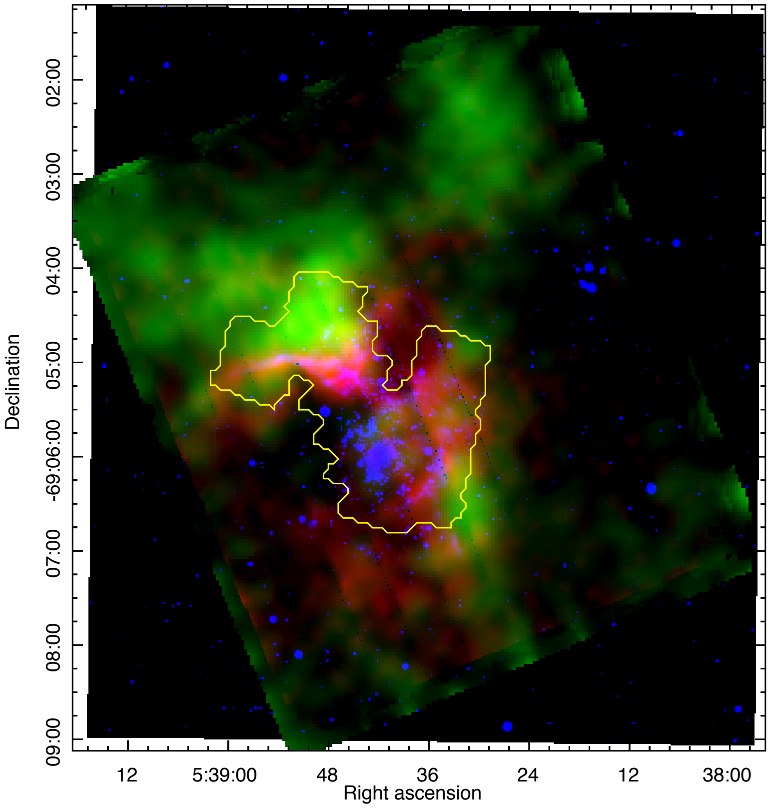


***Figure 2**: SOFIA/FIFI-LS [OIII] 88μm (red) and [CII] 158μm (green) and VISTA J band (blue). The yellow contour outlines the PACS [OI] 145μm coverage.*

A Far-infrared Determination of Gas Mass and Carbon Depletion in Protoplanetary Disks

M. K. McClure et al. (2016)

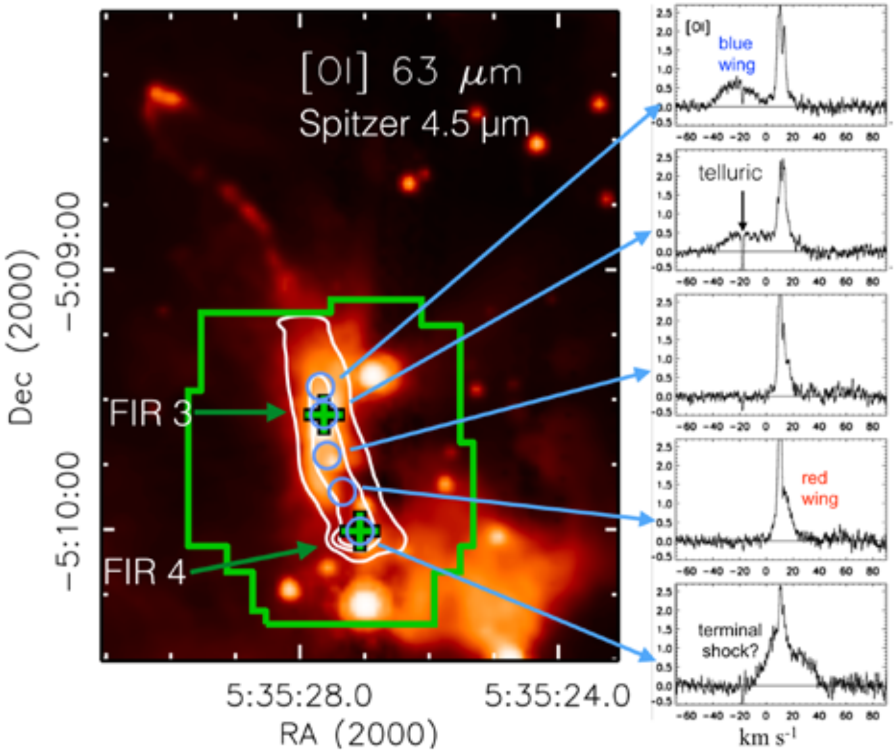
The total gas mass of a protoplanetary disk is a fundamental, but poorly determined, quantity. A new technique (Bergin et al. 2013) has been demonstrated to assess directly the bulk molecular gas reservoir of molecular hydrogen using the HD J=1-0 line at 112 microns. We present a small survey of T Tauri disk observations of the HD line. Line emission is detected in two cases at >3 sigma significance. Using detailed disk structure models we determine the amount of gas required to fit the HD line and the amount of dust required to fit the observed disk spectral energy distributions. For both disks, the amount of gas required is more than the MMSN value and a factor of 5 to 100 greater than gas masses derived from CO. This comparison suggests that the results of Schwarz et al. 2016, who use resolved ALMA CO imaging to find a carbon depletion factor of 100 in TW Hya, apply to younger disks as well.

7021

Low Mass Star Formation in the Diverse Environments of Orion: Result from the Herschel Orion Protostar Survey

Tom Megeath: University of Toledo

Low mass stars from in a diverse range of environments, from isolated dark clouds to dense clusters in close proximity to massive stars. How the low mass star formation process differs between these environments is not well understood. We know that within this range of environments, the densities of young low mass stars varies by orders of magnitude, yet the initial mass function remains relatively invariant. Comparative studies of protostars in different regions are needed to assess how both the external environment (gas density, turbulence, kinetic temperature, density of stars) and internal processes affect the formation of stars and disks. I will overview a survey of protostars in the Orion A & B molecular clouds with the Spitzer, Herschel, Hubble and Apex telescopes, spanning 1.6 to 870 um, as well as follow-up observations with SOFIA and ALMA. The goals of these observations are to audit infall, accretion and outflow of mass in the diverse regions found in the Orion clouds. I will discuss how these observations are leading to a better understanding of how envelopes, disks, feedback and environment control the rate of mass accretion onto low mass stars and ultimately determine their multiplicity and masses.



Left panel: Herschel PACS map of the [OI] jet from the protostar OMC2 FIR3 (contours) overlaid on the Spitzer 4.5 µm image showing the full extent of the northern jet. The protostars FIR3 (HOPS 370) and FIR4 (HOPS 108) are marked by the crosses and the green box shows the extent of the PACS field (from Gonzales-Garcia et al. 2016). **Right panels:** [OI] spectra taken at five positions with the GREAT instrument showing the velocity structure of the [OI].

7015

Multi-Wavelength Analysis of the Most Luminous Young Stellar Object in the Large Magellanic Cloud

O. Nayak (JHU), M. Meixner, Y. Fukui, T. Onishi, Y. Okada, M. Reiter, R. Indebetouw, J. Stutzki, M. Sewilo, A. Bolatto, M. Chevance, A. Kawamura, M. Y. Lee

The Large Magellanic Cloud has been the subject of star formation studies for decades due to its proximity to the Milky Way (50 kpc), a nearly face-on orientation, and a low metallicity (0.5 solar) similar to that of galaxies at the peak of star formation in the universe (z~2). The most luminous young stellar object (J72.971176-69.391112) is located in the N79 region of the Large Magellanic Cloud and has a luminosity of $1.5 \times 10^6 \, L_{\odot}$. It is surprising that this massive and luminous object is on the opposite side of the Large Magellanic Cloud from 30 Doradus, one of the most active and most massive giant molecular clouds in the Local Group. How do massive stars form? What is the impact of outflows on the local environment? How can a massive star like J72.971176-69.391112 form in a relatively quiescent environment far away from an active star formation region like 30 Doradus? We will present a comprehensive multi-wavelength analysis of J72.971176-69.391112: SED fits to Spitzer and Herschel photometry, near-IR and mid-IR spectroscopy from Magellan/FIRE and Spitzer/IRS, low-J CO data from ALMA, high-J CO data and a [CII] map from SOFIA/GREAT. SED fits show this object is a O5V star, H_2 and other IR lines seen in the spectrum show the existence of shocks, ALMA images indicate that J72.971176-69.391112 could be at the center of colliding filaments, and results from SOFIA allow us to probe the PDR region

Chemistry of the Interstellar Medium

7009

David A. Neufeld (Johns Hopkins University)

Observations at far- and mid-infrared wavelengths provide a wealth of information about the molecular inventory of interstellar gas clouds. Because of the different chemical pathways responsible for their formation and destruction, different molecules probe specific aspects of the interstellar environment. Carefully interpreted, they provide unique information about the cosmic ray density, the molecular fraction, the ultraviolet radiation field, and the dissipation of energy within the turbulent interstellar medium. Because their formation and destruction pathways are relatively simple, small hydride molecules have proven to be particularly valuable chemical probes. In the past decade, with the use of *Herschel* and SOFIA, high-resolution absorption line spectroscopy has led to the discovery of several new interstellar hydrides - including SH, OD, OH^+, H_2O^+, H_2Cl^+, HCl^+, and ArH^+ (the first known astrophysical molecule containing a noble gas atom) – along with a wealth of new information about previously-known species such as CH, CH^+, OH and H_2O. Such observations have enabled astrochemical studies in which the abundances of multiple species are measured and modeled simultaneously to derive key information about the interstellar environment. Future spectroscopic observations with ALMA and SOFIA promise to extend further our understanding of fundamental physical and chemical processes in the molecular ISM.

The High-resolution Mid-Infrared Spectrometer (HIRMES): a Third Generation Instrument for SOFIA

David A. Neufeld, Johns Hopkins University

The High-Resolution Mid-Infrared Spectrometer (HIRMES), recently selected as a third generation instrument for SOFIA, will address fundamental questions about the evolution of planetary systems. HIRMES is a versatile facility instrument for the Stratospheric Observatory for Infrared Astronomy (SOFIA) that directly observes key ingredients of habitable worlds, answering questions such as: How does the disk mass evolve during planetary formation? What is the distribution of oxygen, water ice, and water vapor in different phases of planet formation? What are the kinematics of water vapor and oxygen in protoplanetary disks? In answering these questions, HIRMES will discover where and in what form the raw materials for life reside, and how planetary systems like our own evolve. HIRMES answers these questions definitively by providing low (R ~ 600) to very high (R ~ 100,000) spectral resolving power over the critical spectral range 25–122 µm. HIRMES combines grating dispersive spectroscopy and Fabry-Perot tunable narrow-band filters with high efficiency background-limited direct detectors. The instrument spectral resolution is designed to match the width of the spectral lines, significantly reducing the background and noise, to achieve the maximum possible sensitivity for far-IR spectroscopy with SOFIA. With this design, the observing speed is 100 times greater than what has previously been possible.

7019

The location, clustering, and propagation of massive star formation in giant molecular clouds

Bram Ochsendorf (JHU), M. Meixner (STScI/JHU), J. Chastenet, J. Roman-Duval (STScI), X. Tielens (Leiden)

Massive stars are key players in the evolution of galaxies, yet their formation pathway remains unclear. In this talk, I will present results from a project utilizing data from several galaxy-wide surveys to build an unbiased dataset of ~700 massive young stellar objects (MYSOs), ~200 giant molecular clouds (GMCs), and ~100 young (< 10 Myr) optical stellar clusters (SCs) in the Large Magellanic Cloud. We have employed this data to quantitatively study the location and clustering of massive star formation and its relation to the internal structure of GMCs. Surprisingly, massive stars do not typically form at the highest column densities nor centers of their parent GMCs. Massive star formation clusters over multiple generations and on size scales much smaller than the size of the parent GMC. We find that massive star formation is significantly boosted in clouds near SCs. Yet, comparison of molecular clouds associated with SCs with those that are not reveals no significant difference in their global properties. These results reveal a connection between different generations of massive stars on timescales up to 10 Myr.

I will compare these results with Galactic studies, and illustrate how we can extend these studies by using SOFIA's *unique* capabilities, allowing us to trace massive star feedback (e.g., photodissociation regions and shocks) that may hold key information to GMC collapse, triggered star formation, and a potential dichotomy between low- and high-mass star formation.

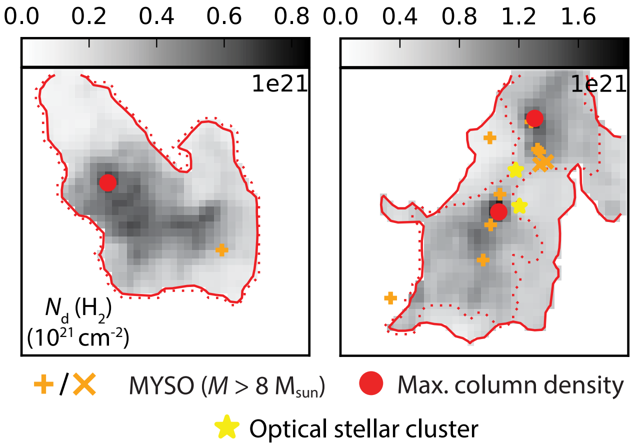


Figure 1: *Examples of column density maps of GMCs (grayscale) with different levels of massive star forming activity. Overplotted are locations of MYSOs (orange plus symbols), stellar clusters (yellow asterisks), and local column density maxima (red dots). The two main results from this project are:* ***(1) massive stars do not typically form at column density peaks of GMCs. (2) massive star formation is more active in clouds close to young SCs.*** *These results provide important clues to the collapse of molecular clouds and the initial conditions that lead to the formation of massive stars.*

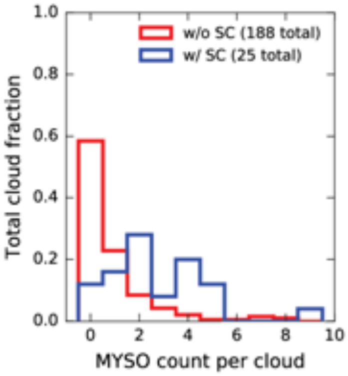


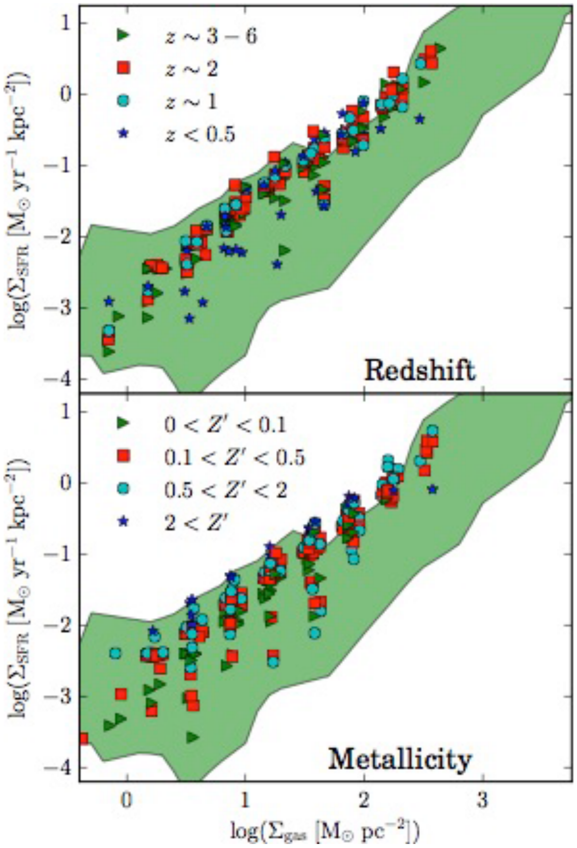
Figure 2: *the massive star formation activity for clouds within 10 pc of a stellar cluster (w/ SC; blue histogram), versus GMCs outside 10 pc of a stellar cluster (w/o SC; red histogram). There is a clear dichotomy in the MYSO count, i.e.,* ***massive star formation is more active in clouds close to young SCs.*** *This result reveals a connection between different generations of massive stars on timescales up to 10 Myr, and may illustrate the importance of triggered star formation on galactic scales.*

7002

What FIREs Up Star Formation: the Emergence of the Kennicutt-Schmidt Law from Feedback

M.E. Orr et al. (California Institute of Technology)

We present an analysis of the Kennicutt-Schmidt star formation relation in the FIRE (Feedback In Realistic Environments) suite of cosmological simulations, including halos with $z \approx 0$ masses ranging from $10^{10} – 10^{13}$ $M_\odot$, and redshifts in the range of 6 - 0. We show that due to the effects of feedback on local scales, where star formation is near-instantaneous compared to galactic dynamical times, the Kennicutt-Schimdt power-law relation emerges robustly at length scales observable in extragalactic systems (>500 pc) independent of the particular prescription of the local star formation physics. We demonstrate that the time-averaged relation is relatively insensitive to redshift, and pixel size above 500 pc (c.f. observational resolution), and depends nearly linearly on metallicity across several orders of magnitude in gas surface density and star formation rates. As well, scatter in the relation, like star formation itself, appears to be predominately stochastic in nature. Finally, we find that gas disk instability to fragmentation and collapse, which leads to self-shielding, is the prime criterion for star formation in regions on scales larger than individual giant molecular clouds.



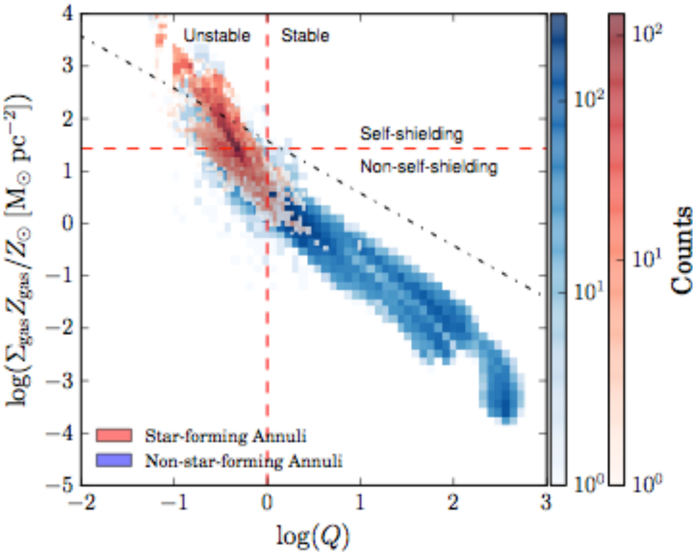


Figure 2: *Demonstrating the relative primacy of the stability criterion (Toomre-Q) as compared to opacity as the trigger for what FIREs up star formation. Annuli in the simulations appear to cross the instability threshold (Q<1) ~dex before the self-shielding threshold, and immediately begin forming stars.*

Figure 1: *The Kennicutt-Schmidt relation in the FIRE simulations, at 1 kpc resolution, for 10 Myr average star formation rate and molecular gas surface density, binned by redshift and metallicity. No apparent dependence on redshift is seen, and a positive correlation with metallicity at low gas surface densities. Observations from Boquien et al. (2011), Bothwell et al. (2010), Kennicutt, Jr. et al. (2007), Lisenfeld et al. (2011), Onodera et al. (2010), Shi et al. (2011), and Verley et al. (2010) are included in the green shaded region.*

Unraveling the evolution of the interstellar medium and star formation in the M51 grand-design spiral galaxy with SOFIA.

Jorge L. Pineda[1], Juergen Stutzki[2], Christof Buchbender[2], Christian Fischer[3], Paul F. Goldsmith[1], Maria Kapala[4], Monika Ziebart[2], and the SOFIA M51 team.

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[4]*Department of Astronomy, University of Cape Town, Private Bag X3, Rondebosch, 7701, South Africa*

We present preliminary results on a joint impact project to map the entire extent of the M51 grand-design spiral galaxy in the [C II] 158μm line with the upGREAT and FIFI-LS instruments on SOFIA. Spiral density waves play a fundamental role in the conversion of atomic gas to molecular gas, which is followed by gravitational contraction leading to star formation. Understanding the impact of spiral density waves on the life cycle of the interstellar medium (ISM) and on star formation is a critical step for understanding galaxy evolution, and requires having a complete picture of all constituents of the ISM in galaxies. The [C II] 158m line is an important tool to diagnose the physical state of the ISM as it can reveal the distribution of the gas that is in the transition between atomic and molecular phases, including the CO–dark H_2 gas (hydrogen is molecular, but carbon is not, resulting in this gas being traced neither by CO nor by H I).

In this talk we will describe the goals of the project and we will present preliminary results on the distribution of [C II] across M51 and on the relationship between the different constituents of the ISM traced by FUV, Hα, CO, H I, and [C II] emission both spatially and spectrally in the arms and interarm regions of M51.

Far-infrared fine structure cooling in dark molecular clouds

7035

S. E. Ragan, Cardiff University

Stars are born in the densest regions of molecular clouds, but the processes of cloud assembly and dispersal are poorly understood. Traditional cloud tracers like CO do not trace the formation and destruction of clouds, but fine structure lines of ionised carbon ([CII]) and atomic oxygen ([OI]) reliably trace clouds and their environments in these stages throughout the Galaxy.

Using observations from *Herschel*-HIFI and SOFIA-GREAT, we have conducted a velocity-resolved study of infrared-dark molecular clouds, representing the initial phases of star formation. With these instruments, we have the sub-parsec resolution that is essential to disentangling different sources of [CII] emission within the cloud substructure. With complementary, resolution-matched observations of CO and [CI], we have a complete profile of the cloud structure and kinematics in all gas phases.

The formation of high-mass stars and the feedback they produce in their early lives is of fundamental importance to understand the cycle of star formation in galaxies, yet it has been difficult to constrain these processes observationally because the nearest sites are distant and heavily-obscured by dust. Observations of fine-structure cooling lines such as [CII] and [OI] in young molecular clouds help characterise the global cooling properties.

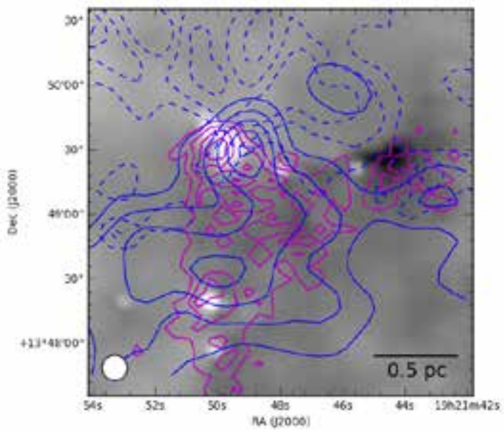

Figure 1: Herschel 70μm image of IRDC G48.66 (*Beuther et al. 2014).* Magenta contours show the $C^{18}O$ emission, and blue contours show Herschel/HIFI [CII] (solid contours show the velocity component matching that of the $C^{18}O$, and the dashed contours are a second high-velocity component).

In order to investigate this further, we have observed a sample of clouds representing the earliest phases of high-mass star formation, known as infrared-dark clouds (IRDCs), in the terahertz fine-structure cooling lines [CII] and [OI] with FIFI-LS aboard SOFIA. Extended emission is detected in all lines, peaking at sites of embedded protostellar activity that we have studied with *Herschel* continuum observations. We connect the emission properties of the fine-structure lines to the local radiation field (G_o, estimated from *Herschel*-determined T_{dust}) in a sample of clouds to determine the effects of environment.

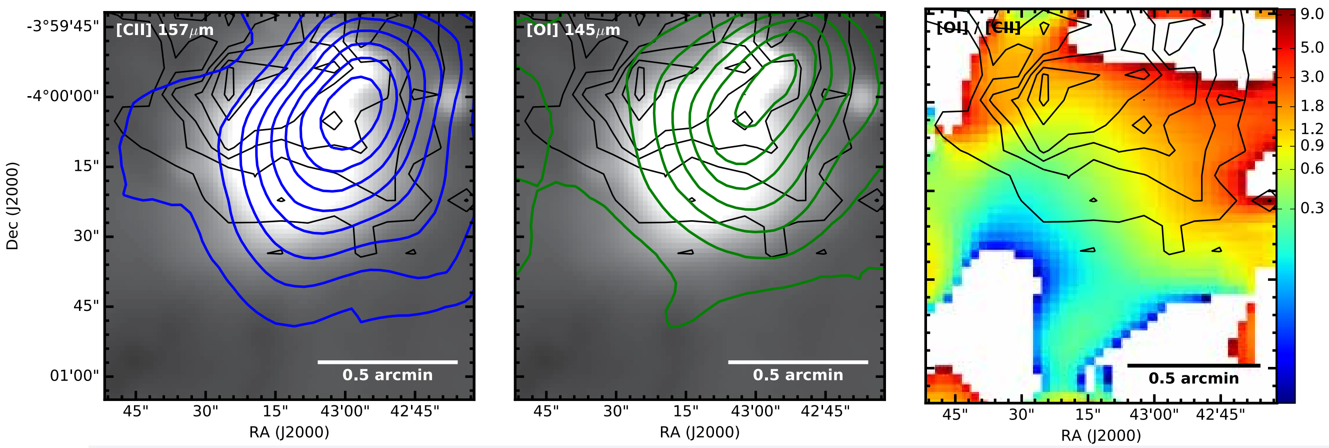

Figure 2: *Left panels:* Herschel 70μm image of IRDC G28.34 (*Ragan et al. 2012)* with $C^{18}O$ contours in black. The left panel also shows (blue) contours of integrated [CII] emission and the centre panel shows (green) contours of integrated [OI] emission at 145μm, both measured with FIFI-LS. The [OI]-to-[CII] ratio is shown in the rightmost panel.

Exploring ISM and Star Formation Physics in the LMC and SMC in the SOFIA Era

Julia Roman-Duval
STScI

Far-infrared imaging and spectroscopy of star forming regions in the Milky Way with SOFIA (and Herschel) have revealed details about the physical processes that govern the structure, chemistry, and thermal balance of the ISM, and how they relate to star formation and feedback. While a substantial amount of results have accumulated in the Milky Way thanks to SOFIA, we have yet to reveal the effects of metallicity and other environmental parameters on ISM phases and star formation. Thanks to the proximity and relatively face-on geometry of the Magellanic Clouds (LMC and SMC, 50 kpc and 62 kpc respectively), we can resolve the ISM processes of interest at the level of individual star-forming regions and molecular clouds, while also getting the broad spatial coverage needed to understand the ISM on global scales. In this talk, I will review how SOFIA can complement the wealth of existing multi-wavelength data sets in the Magellanic Clouds, and address outstanding questions related to ISM and star formation physics using the LMC and SMC as laboratories.

The cold interstellar medium traced by the largest bound atoms in space

7038

P. Salas et al. (Leiden Observatory)

The interstellar medium (ISM) is central to the evolution of galaxies. New stars are formed from interstellar gas, and these in turn enrich the gas with the products of nucleosynthesis. This gives rise to a recycling of matter in the ISM. One interesting aspect of this cycle is the relation between the cold neutral medium, which comprises most of the ISM mass, and other phases of the ISM, such as molecular clouds. Our understanding of the ISM has increased notoriously over the last decades, in part thanks to the opening of the radio and submillimeter windows. In these windows systematic surveys of atomic and molecular gas through surveys of the 21 cm-HI line and from CO line transitions are possible. These have revealed a complex and dynamic ISM in which the different phases are related, but the relative importance of the mechanisms that drive one phase into the other has not been established. Low frequency (< 1 GHz) radio recombination lines (RRLs) offer a complementary way of studying the ISM. Carbon, having a lower ionization potential than hydrogen, is ionized throughout the ISM, which makes carbon RRL (CRRL) emission ubiquitous in our Galaxy. Given the physics of low frequency CRRL emission, the lines are good tracers of cold diffuse gas and sensitive probes of its physical conditions.

Here we will present observations of low frequency CRRLs towards Cassiopeia A. These are being used to understand the relation between the gas traced by CRRLs and other phases of the ISM.

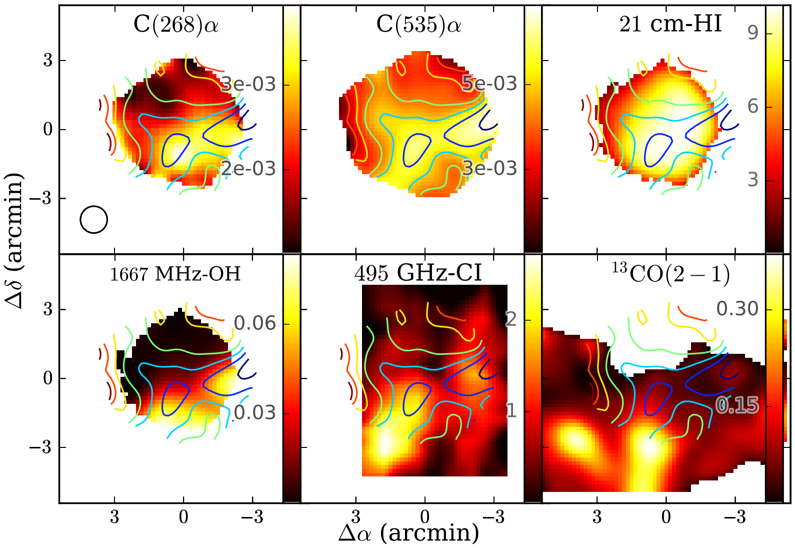

Figure 1: Spatial distribution of different ISM tracers towards Cassiopeia A. The color contours mark the emission from C(535)α in all panels.

Velocity resolved [OI] 63 µm Emission in Proto-planetary Disks

G. Sandell et al. (SOFIA Science Center/USRA)

Results from Herschel surveys show that PDR emission of the [OI] 63 µm fine structure line is by far the strongest emission line in protoplanetary disks and often the only line detected, especially in fainter sources. It is even detected in several debris disks. What is still debated is whether the [OI] emission originates in the warm surface layers in the inner part of the disk, as suggested by the strong correlation with 63 micron continuum emission, or whether the emission comes from the whole disk, in which case the colder outer part of the disk would dominate. Another complication is that the [OI] line is also strong in shocks, which can dominate over PDR emission in disks sources powering jets/outflows.

Here we present preliminary results of observations with GREAT of two disk sources, HL Tau and AB Aur. HL Tau is a deeply embedded Class I object of spectral type K7. ALMA observations beautifully resolve the disk, which has an inclination of 46 degrees. We obtained a high S/N spectrum of HL Tau with the GREAT H-channel, which shows a broad, roughly symmetric [OI] line profile with a narrow self-absorption from cold foreground gas. We are still assessing whether the emission is dominated by the disk or whether we have a contribution from the jet, which is very prominent in H alpha and [SII]. The disk of AB Aur, an A0 Herbig Ae/Be star, is more face-on, ~21.5 degree, and it does not drive an outflow. Here the GREAT [OI] emission is clearly from the disk, because the line profile is much broader than the [CII] 158 micron line, observed simultaneously, which originates from PDR emission in the surrounding reflection nebula. The emission is also broader than the emission from CO(1-0), confirming that it is dominated by emission from the inner part of the disk. We also have some short observations of [OI] towards DG Tau, where the [OI] emission is shock dominated (J-shock). Here the emission is extended with relatively modest outflow velocities.

FIR-line spectroscopy of S106 with GREAT/SOFIA as a versatile diagnostic tool for the evolution of massive stars

7008

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Observations are critically needed to better understand the physical processes, such as mass accretion and ejection, and feedback (thermal heating, ionization, radiation pressure, stellar winds) involved in the formation and evolution of *massive stars*. For that, we observed the well-known bipolar H II region *S106*, powered by the O-star S106 IR in the [C II] 158 μm (Simon et al. 2012) and [O I] 63 μm (Schneider et al., 2016, in prep.) finestructure lines, and the CO 16→15, 11→10 transitions with the upGREAT instrument on SOFIA. The spatial and spectral emission distribution of these tracers was compared to the one of molecular lines and continuum (radio, near/mid/far-infrared, optical). Figure 1 shows average spectra across S106, displayed in Figure 2 as an overlay of [O I] emission on mid-IR emission (FORCAST/SOFIA observations, Adams et al. 2015). We attribute broad, very high blue- and redshifted [O I] emission to a possible atomic jet arising from S106 IR, collimated by a small disk-like structure around the star. The associated molecular outflow is seen in low-J CO lines but is more dispersed. At lower velocities broad line wings seen in most of the lines ([O I], [C II], CO) indicate outflowing gas, outlining the cavity walls and matching perfectly the emission distribution of heated dust, arising from PDR surfaces on the cavity walls. To which extend high- and low-velocity shocks can be the driving sources for excitation is currently under investigation. SiO as a typical shock tracer was not detected. The velocity range –4 to 0.5 km/s is dominated by emission from the clumpy molecular cloud and [O I], [C II], and high-J CO lines are excited in the PDRs on the clump surfaces.

We conclude that S106 IR is a massive object on the main sequence but still in a late accretion phase with a disk-like structure. The jets and outflows are not well organized so that the spatial and kinematic distributions of the molecular lines and FIR finestructure lines are more consistent with the competitive accretion star formation model than with the core model.

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Adams, J.D., Herter, T.L., Hora, J.L., Schneider, N., et al., 2015; ApJ, 814, 54; McKee, C.F., Tan, J.C., 2002, Nature, 416, 59; Bate, M.R., 2012, MNRAS, 419, 3115; Bonnell, I., 2007, KITP Conference: Star Formation Then and Now, Santa Barbara, 25; Simon, R., Schneider, N., Stutzki, J., Güsten, R., et al., 2012, A&A, 542, L12

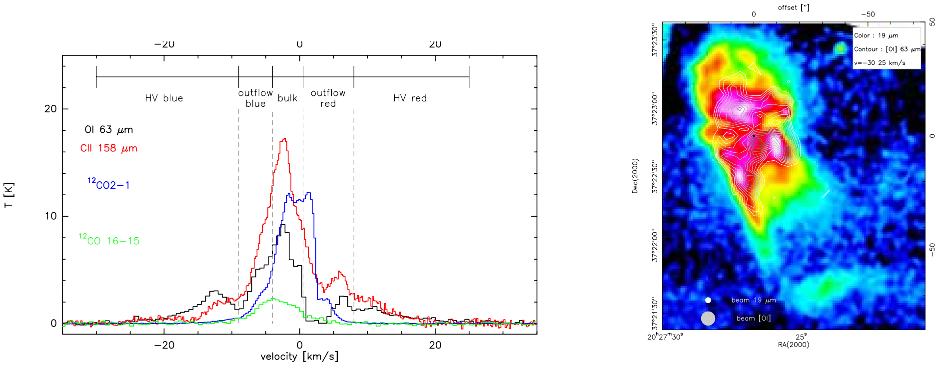

Figure 1: Left: Average spectrum of various molecular and atomic lines in the central 100″×100″ area around S106 IR. Based upon the different spectral features, we define 5 major velocity ranges. Right: [O I] emission for v= –30 to 25 km/s in contours overlaid on a map of 19 μm emission (FORCAST/SOFIA, Adams et al. 2015)

The unique outburst from S255IR-NIRS3 - clues for high-mass star formation

B. Stecklum et al. (Thüringer Landessternwarte Tautenburg, Tautenburg, Germany)

Signaled by the flare of its 6.7GHz methanol masers, S255IR-NIRS3, a ~20$M_\odot$ HMYSO, recently experienced a disk-mediated accretion burst - the first ever observed for a HMYSO. This unique event provides evidence for high-mass star formation via circumstellar disks, and indicates that the latter are prone to disk instability as well. The following observational facts prove that the observed brightening of the source and its associated bipolar outflow cavities (Fig. 1) cannot be due to reduced extinction but point to a disk-mediated accretion burst instead.

- A brightness increase of the central source without "blueing"
- The detection of a light echo from the burst which propagates along the outflow lobes
- The spectroscopy of the light echo reveals emission lines typical for outbursts
- The discovery of new 6.7GHz methanol maser spots
- The drastic change of the SED due to enhanced thermal emission from warmed-up dust

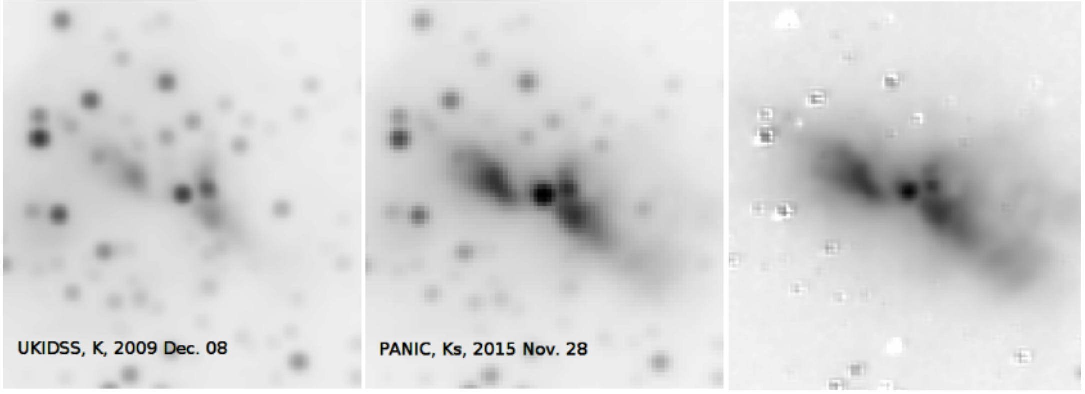

Figure 1. *Archival UKIDSS K-band image (left), Ks-band image taken with PANIC (center), and difference image (right)*

The burst SED, based on NIR and SOFIA data, shows a five-fold increase in luminosity, and features an FIR peak possibly caused by a heat wave propagating outward in the disk. Follow-up FORCAST and FIFI-LS observations were proposed to monitor the SED change over time. This "thermal screening", i.e. the analysis of the thermal response to the burst over time by means of time-dependend radiative transfer modeling, will allow us to infer major disk properties.

Moreover, the detection of new maser spots in connection with the burst suggests that the 6.7GHz methanol masers are likely pumped by thermal IR radiation from warm dust. Thus, this finding suggests that the frequent and even periodic variability of these masers may serve as a proxy for accretion variability of the exciting YSOs.

Physics of the interstellar medium

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The interstellar medium (ISM) plays a central role in the evolution of galaxies. On the one hand, the ISM is the repository of stellar ejecta; e.g., in the form of gentle winds from asymptotic giant branch stars and by violent supernova explosions. On the other hand, the ISM is the birthplace of future generation of stars. In this way, material is cycled from stars to gas and back again and in each cycle it is enriched in heavy elements forged through nucleosynthetic processes in the fiery cauldrons of stellar cores. Stars also control the radiative energy budget of the ISM and its emission characteristics. Photons from massive stars with energies above 13.6 eV ionize hydrogen, creating HII regions. Less energetic photons couple to the gas through photoelectrons from large molecules and clusters of large molecules that heat atomic gas in PhotoDissociation regions (PDRs) surrounding HII regions and on a much larger scale in the diffuse ISM. Through their winds and explosions, stars also stir up the ISM dynamically, sweeping up gas and forming large bubbles. This injection of mechanical energy into the ISM is a source of turbulent pressure, supporting the gas disk and the clouds therein against galactic- and self-gravity. This complex feedback between stars and their environment drives the evolution of the interstellar medium and of galaxies – and hence their observational characteristics– over cosmic time. Our understanding of what observations tell us about what really happens at those epochs will depend very much on our understanding of the microscopic physical and chemical processes and their dependence on the local conditions. This review describes our understanding of the synergetic interaction of these micro and macro processes and their observational consequences.

The origin of cold gas in giant elliptical galaxies and its role in fueling radio-mode AGN feedback

7018

N. Werner (MTA Lendület Hot Universe Research Group at Eötvos University, Budapest)

The nature and origin of the cold interstellar medium (ISM) in early-type galaxies are still a matter of debate, and understanding the role of this component in galaxy evolution and in fueling the central supermassive black holes requires more observational constraints. Here, we present a multi-wavelength study of the ISM in nearby, X-ray and optically bright, giant elliptical galaxies, all central dominant members of relatively low-mass groups. Using far-infrared spectral imaging with the *Herschel* PACS and *SOFIA* FIFI-LS we mapped the emission of cold gas in the cooling lines of [C II]λ157 µm, [O I]λ63 µm and [O Ib]λ145 µm. Additionally, we present Hα+[N II] imaging of warm ionized gas with the Southern Astrophysical Research (SOAR) telescope, and a study of the thermodynamic structure of the hot X-ray emitting plasma with *Chandra*.

All systems with extended Hα emission in our sample display significant [C II] line emission indicating the presence of reservoirs of cold gas. This emission is cospatial with the optical Hα+[N II] emitting nebulae and the lowest entropy soft X-ray emitting plasma. These systems have similar [C II]/(Hα+[N II]) ratios of 0.4–0.8, indicating that the [C II] and Hα+[N II] emission are powered by the same energy source. The likely dominant source of energy is the hot X-ray emitting plasma penetrating into the cold gas. We will discuss models of cold gas excitation by collisions with the surrounding hot phase.

The entropy profiles of the hot galactic atmospheres show a clear dichotomy, with the systems displaying extended emission-line nebulae having lower entropies beyond $r \sim 1$ kpc than the cold-gas-poor systems. We show that while the hot atmospheres of the cold-gas-poor galaxies are thermally stable outside of their innermost cores, the atmospheres of the cold-gas-rich systems are prone to cooling instabilities. This provides considerable weight to the argument that cold gas in giant ellipticals is produced chiefly by cooling from the hot phase. The hot atmospheres of cold-gas-rich galaxies display disturbed morphologies indicating that the accretion of clumpy multiphase gas in these systems may result in variable power output of the AGN jets, potentially triggering sporadic, larger outbursts.

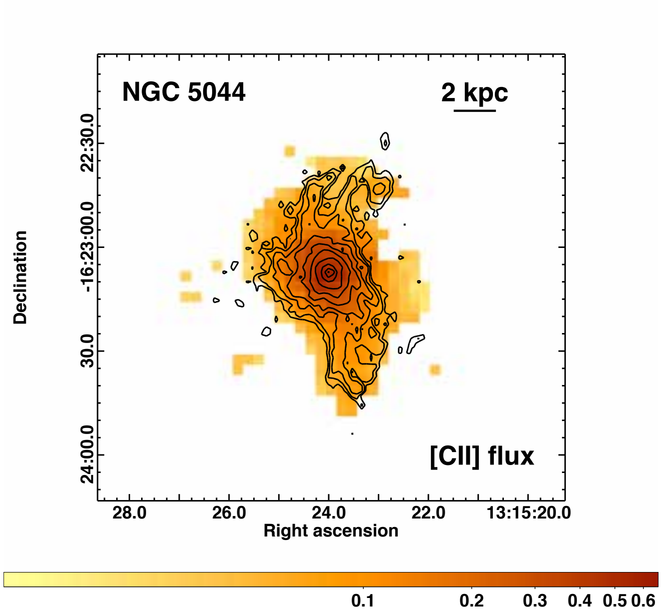

Figure 1. *Herschel PACS map of the integrated [CII] line flux in units of 10^{-14} erg s^{-1} cm^{-2} per 6” × 6” spaxel obtained with Herschel PACS for the giant elliptical galaxy NGC 5044. Contours of the Hα+[NII] emission are overlaid.*

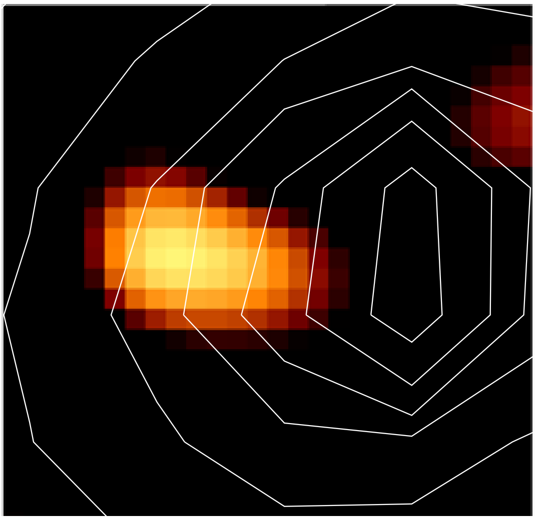

Figure 2. *SOFIA FIFI-LS map of the [CII] line flux in the central 1’x1’ region of the giant elliptical galaxy M86. Contours of the R-band SDSS image are overlaid. The [CII] emitting gas is displaced from the center of the galaxy and is co-spatial with bright Hα+[NII] emitting filaments. M86 is being tidally stripped of its gas as it is in-falling into the Virgo cluster of galaxies.*

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Chemical Feedback: The Link between Diffuse Clouds and Late Stages of Stellar Evolution

7041

Helmut Wiesemeyer et al. (Max-Planck-Institute for Radioastronomy, Bonn)

Thanks to HIFI and GREAT, far-infrared absorption spectroscopy towards Galactic hot cores has become a testing bench for the chemistry of diffuse, neutral clouds located on the sightlines. This has two reasons: (1) The upper levels of the rotational lines of light hydrides and of fine-structure lines of carbon and oxygen are difficult to populate in the diffuse gas, (2) the continuum brightness of the background sources peaks in the far-infrared. Abundances can thus be determined from first principles and compared to models.

In a case study toward nine hot cores (Wiesemeyer et al., 2016, A&A 585, A76), we show that the OI ground state line at 63.2μm traces the ensemble of atomic and molecular hydrogen: The correlation between the column density of OI and that of molecular and atomic hydrogen is statistically significant (false-alarm probabilities < 5%). We derive oxygen abundances of 310-350 ppm. These values are remarkably close to determinations using UV lines forming in low-density diffuse gas (e.g., Meyer et al. 1998, Cartledge et al. 2004, Jensen et al. 2005). For the diffuse gas this result precludes a substantial depletion of OI into unidentified carriers of oxygen (cf. Jenkins 2009, Whittet 2010). Interstellar OH (Fig. 1) and H_2O form subsequently from a series of hydrogen abstraction reactions: OH^+ (H_2, H) H_2O^+ (H_2, H) H_3O^+. On two out of three sightlines we indeed find a significant correlation between the fraction of OH^+ forming OH and the the molecular hydrogen fraction. Dissociative recombination of H_3O^+ forms OH and H_2O, with an experimentally determined branching ratio of 74-83% (Jensen et al., Neau et al., 2000), adjacent to our estimate of 84-91%. While these findings agree with predictions of chemical networks involving ion-neutral reactions, our abundances do not exclude a contribution from endothermic reaction pathways, e.g., in turbulence dissipation regions (e.g., Godard et al. 2009).

The continuation of this study on sightlines including the outer Galaxy aims at the determination of a Galactocentric oxygen abundance gradient, which is linked to the enrichment of the diffuse gas in late stages of stellar evolution. We therefore started another case study concerned with the chemistry of planetary nebulae. The [OI] fine structure triplet traces PDRs and atomic jets as well as molecular envelopes (e.g. in NGC6302, Fig. 2) in a single, homogeneous data set. Together with the [CII] fine structure doublet, we can determine the temperature and density of these components.

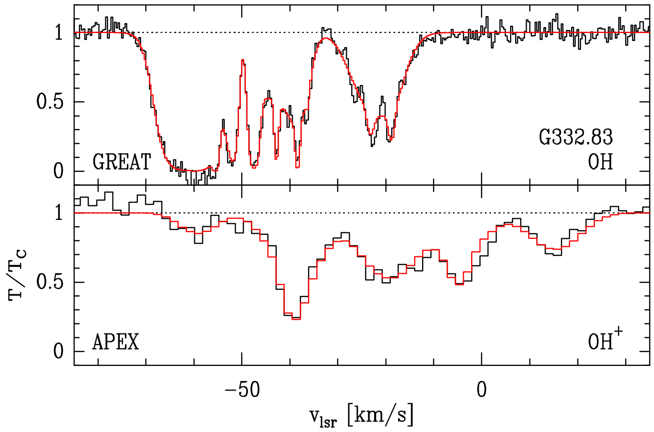

Figure 1. *Absorption spectra of the ground-state transitions of OH (top, GREAT, M-channel) and OH^+ (bottom, APEX THz) towards hot core G332.83. While the OH absorption is saturated in the environment of the hot core, it displays multiple, in OH narrow components from diffuse clouds in the crossings of the Norma and Crux spiral arms.*

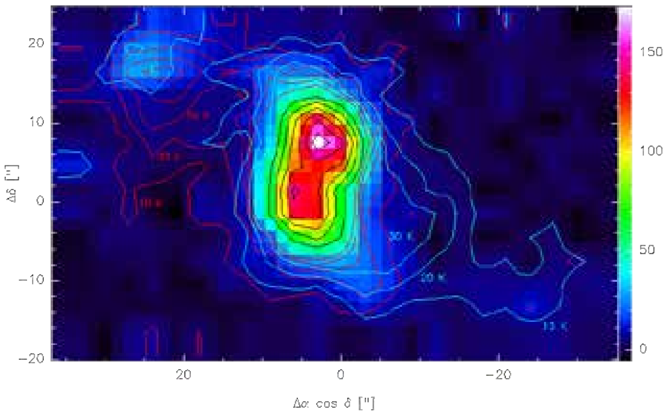

Figure 2. *[OI] 63μm emission from the oxygen-rich planetary nebula NGC6302 as observed with GREAT's H channel. The false-color scale shows the molecular torus, (-36 to -26 km/s). the red and blue contours the outflow lobes (-30 to -12 km/s, respectively -50 to -30 km/s). The north-eastern lobe displays both velocity components, signpost of a wide opening angle.*

SOFIA follow-ups of massive clumps from the ATLASGAL galactic plane survey

F. Wyrowski et al. (MPIfR Bonn)

With the GREAT receiver at the Stratospheric Observatory for Infrared Astronomy (SOFIA) we started a concerted effort towards a well selected sample of clumps with high masses covering a range of evolutionary stages based on their infrared properties. The sources were selected from the ATLASGAL sub-millimeter dust continuum survey of our Galaxy. The goal is threefold: (i) SOFIA/GREAT allows to study the cooling budget of the clumps, in particular with observations of the CII and OI cooling lines. (ii) With SOFIA/GREAT high-J CO lines can be observed to measure in combination with ground based data the CO SEDs of the sources. (iii) Using rotational transitions of ammonia at THz frequencies the kinemtics of the clumps can be probed with absorption spectroscopy to search for infall.

Here we will describe these efforts and in particular report new results from the ammonia $3_{2+} - 2_{2-}$ (1.8 THz) observing program. The ammonia line was detected in all observed sources, leading to five new detections of red-shifted absorption. These detections include two clumps embedded in infrared-dark clouds. The measured velocity shifts of the absorptions compared to optically thin $C^{17}O$ (3–2) emission are 0.3–2.8 km/s, corresponding to 3 to 30% fractions of the free-fall velocities of the clumps. The ammonia infall signature is compared with complementary data of high density tracers. The best agreement with the ammonia results is found for the HCO^+ (4–3) transitions but the latter is still strongly blended with emission from associated outflows. This outflow signature is far less prominent in the THz ammonia lines confirming it as a powerful probe of infall in molecular clumps. Infall rates in the range from 0.3 to 16 $10^{-3}\,M_\odot$/yr have been derived with a tentative correlation with the virial parameters of the clumps. The new observations show that infall on clump scales is ubiquitous through a wide range of evolutionary stages, from L/M covering about ten to several hundreds.

Long Poster Abstracts
(listed by abstract number)

Discovery of Shocked Gas and Molecular Hydrogen from the Supernova Remnant G357.7+0.3: HHSMT, APEX, Spitzer and SOFIA Observations

7003

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We report a discovery of shocked gas from the supernova remnant (SNR) G357.7+0.3 using millimeter and infrared observations. Our millimeter observations reveal broad molecular lines of CO(2-1), CO(3-2), CO(4-3), 13CO (2-1) and 13CO (3-2), HCO+ and HCN using Arizona HHSMT and 12-Meter, APEX and MOPRA Telescopes. The widths of the broad lines are 15-30 km/s, caused by strong supernova (SN) shocks passing through dense molecular clouds. The detection of such broad lines is the first, dynamic evidence showing that G357.7+0.3 is the SNR interacting with molecular clouds. We also present detection of H_2 lines in mid-infrared using the Spitzer Infrared Spectrograph (IRS) observations to map a few arcmin area. The rotational H2 lines of S(0)-S(5), and S(7) are detected with the IRS. G357.7+0.3 lacks ionic lines compared with other H2 emitting SNRs. The H_2 excitation diagram shows a best-fit with a two-temperature LTE model. We observed [C II] at 158um and high-J CO(11-10) with GERAT on SOFIA. The CO(11-10) line is not detected. The GREAT spectrum of [C II] in 3 sigma detection shows a broad line profile with a width of 15.7 km/s that is similar to those of broad CO lines. The line width of [C II] implies that ionic lines can come from a low-velocity C-shock. Comparison of H_2 emission with shock models shows that a combination of two C-shock models is favored over a combination of C- and J-shocks or a single shock. We estimate the CO density, column density, and temperature using a RADEX model. The best-fit model with $n(H_2) = 1.7\text{x } 10^4 \text{ cm}^{-3}$, $N(CO) = 5.6\text{x}10^{16} \text{ cm}^{-2}$, and T = 75 K can reproduce the observed CO brightness of G357.7+0.3.

7005

Characterizing the formation and evolution of molecular clouds in the Magellanic clouds with [C II], [C I] and CO

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We present an analysis of deep *Herschel*/HIFI observations of the [C II] 158 μm, [C I] 609 μm, and [C I] 370 μm lines towards 54 lines-of-sight (LOS) in the Large and Small Magellanic clouds. These LOSs represent different stages of interstellar cloud evolution and have been chosen to study the formation and evolution of molecular clouds in metal poor galaxies. These observations are used to determine the physical conditions of the line–emitting gas, which we use to study the transition from atomic to molecular gas and from C^+ to C^0 to CO in the low metallicity environments of the LMC and SMC. We show that the CO–dark H_2 gas represents an intermediate stage in cloud evolution. This stage has molecular fractions in the range $0.1 < f(H_2) < 1$, between those in the diffuse H_2 gas detected by UV absorption ($f(H_2) < 0.2$) and well shielded regions in which hydrogen is essentially completely molecular. The [C I] and/or CO are only detected in regions with molecular fractions $f(H_2) > 0.5$. Ionized carbon is the dominant gas–phase form of this element that is associated with molecular gas, with C^0 and CO representing a small fraction, implying that most (92% in the LMC and 81% in the SMC) of the molecular gas in our sample is CO–dark H_2. The observed [C II] intensity in our sample represents about 1% of the total far–infrared intensity from the LOSs observed in both Magellanic Clouds.

Characterizing the Circumnuclear Disk around Sgr A* with Far Infrared FIFI-LS Observations

7025

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F. Fumi[1], N. Geis[3], R. Hönle[1], R. Klein[4], H. Linz[5],
L. Looney[6], A. Poglitsch[3], W. Raab[3], F. Rebell[1], W. Vacca[4]

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The Field Imaging Far-Infrared Line Spectrometer (FIFI-LS) is a German-built science instrument that has been commissioned for use on the Stratospheric Observatory for Infrared Astronomy (SOFIA). As part of its initial commissioning campaign, FIFI-LS observed several far-infrared emission lines and their associated continuums in the Circumnuclear Disk around the Sagittarius A* region of the galactic centre. This data was complemented by additional observations taken throughout 2016.

The Circumnuclear Disk[1], a warped ring of gas and dust of uncertain mass and temperature, exists between roughly 1.5 and 5 pc from the central position of Sgr A*. Its nature is a subject of debate, with past studies attributing its various clumps with both low[2] and high[3] densities, creating a dichotomy as to the disk's stability against tidal forces and suitability for star formation. The clear presence of fine structure line emission demonstrates that these clumps are part of a strong excitation mechanism, which may originate from the central massive black hole, although possible embedded star formation may also play an important role in illuminating this material[4].

We present high resolution maps of the entire disk and surrounding region in the far-infrared, with line and continuum emission, compare them to existing results, and discuss the astrophysical implications, including:

- The distribution and nature of the clumpy material within the disk
- The role of localized star formation in exciting the disk
- The stability of the disk to tidal forces and its transience

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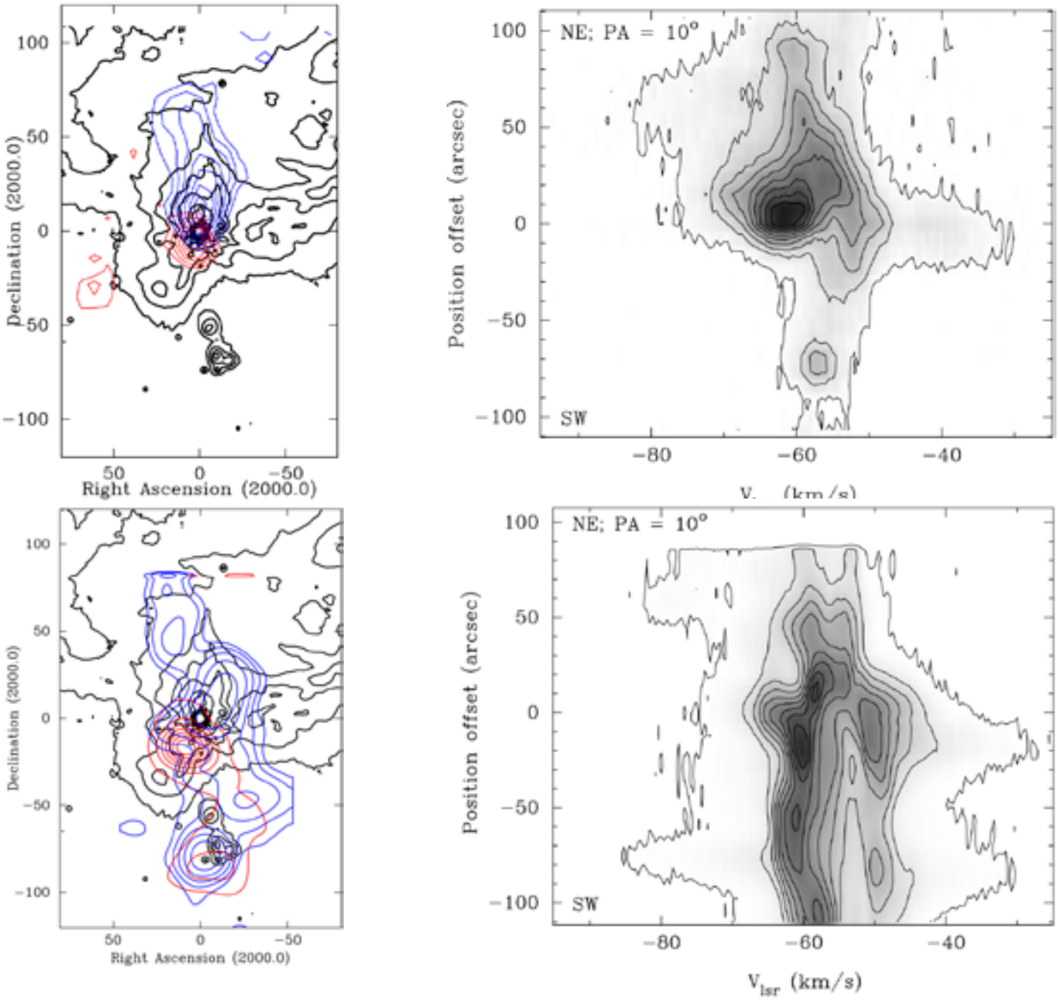
The ionized Jet and Molecular Outflow from NGC7538 IRS1

7027

G. Sandell et al. (SOFIA Science Center/USRA) 7027

The young heavily accreting (~ 10^{-4} M_{Sun}/yr) ultra-compact HII region NGC 7538 IRS1 (d = 2.65 kpc) is known to drive a well collimated bipolar ionized jet approximately north south. Yet most studies have reported that it drives a bipolar molecular outflow oriented from south east (red-shifted) to north west (blue-shifted). Precession has been suggested as an explanation of why the ionized and molecular outflows are misaligned. New [CII] 158 micron and CO(11-10) maps obtained with GREAT on SOFIA combined with mm-data from OSO, FCRAO, JCMT, BIMA, and CARMA as well as mid-IR images from SPITZER show that all the observed characteristics of NGC7538 IRS1 can be explained by a large (parsec scale)north-south outflow, possibly rotating.



Left panel: [CII] high velocity emission (blue: -80 to -65 km/s, red: -40 to -32 km/s) overlaid on *Spitzer/IRAC* 8 µm image. *Lower left*: JCMT CO32 high velocity emission (same velocity intervals) with same spatial resolution as [CII]; *Right*: Position velocity cuts through IRS1 (0,0) at a PA of 10 deg. The northern outflow lobe looks very similar in both. The outflow seen at ~ -80" is from S, another high-mass star.

Infrared Observations of the Arched Filaments in the Galactic Center using SOFIA/FORCAST

7031

M. J. Hankins et al. (Cornell University)

Large stellar clusters inject a significant amount of energy into the interstellar medium (ISM), which has a profound impact on star formation and feedback. Radiation and winds produced by clusters act to process and shape their surroundings. In this work, thermal dust emission from the Arched filaments HII region was studied to characterize the emission and search for signs of interactions between the Arches cluster. The Arched filaments were observed with the Faint Object InfraRed CAMera for the SOFIA Telescope (FORCAST) at 19.7, 25.2, 31.5, and 37.1 µm. Color-Temperature maps of the region created with the 25.2 and 37.1 um data reveal a remarkable level of temperature uniformity (70-100 K) over the extent of the filaments. Global properties of the filaments were modeled to determine the infrared luminosity ($L_{IR}=8.2\pm2.5\times10^{6}$ $L_{\odot}$) and observed dust mass ($M_{d}=6.7\pm2.3$ $M_{\odot}$). The dust covering fraction implied by the infrared luminosity of the filaments suggests that the Arches cluster ($L_{cluster}=6.3\times10^{7}$ $L_{\odot}$) is the primary source of heating for the filaments. However, there is a discrepancy between the observed distances separating the Arches cluster and filaments and the distances predicted by the equilibrium heating of 0.1 µm dust grains. This inconsistency can be explained by the heating of smaller (0.01 µm) silicate grains. The smaller grain size is consistent with sputtering of the grains due to interactions with cluster winds. DustEM models of the filaments are used to study the relative abundances of grain species in the region. Models indicate polycyclic aromatic hydrocarbons (PAHs) appear to be depleted by factors of ~2-5 in mass compared to the diffuse ISM. Such evidence for both PAH depletion and grain sputtering indicates that the Arches Cluster has had a strong effect of grain materials in the Arched Filaments.

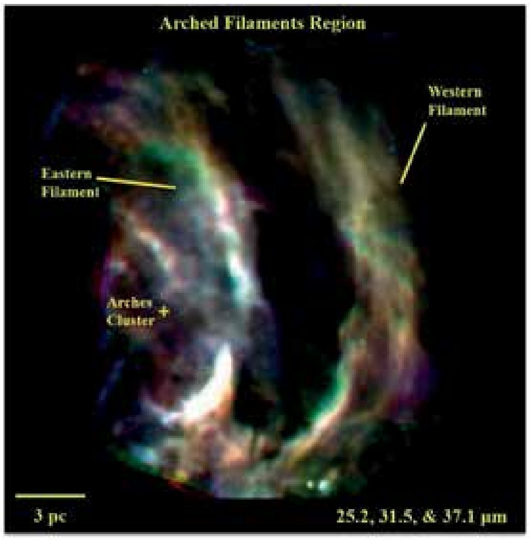


Figure 1. *FORCAST false-color maps of the Arched Filaments with 25.2 (blue), 31.5 (green), and 37.1 µm (red) emission.*

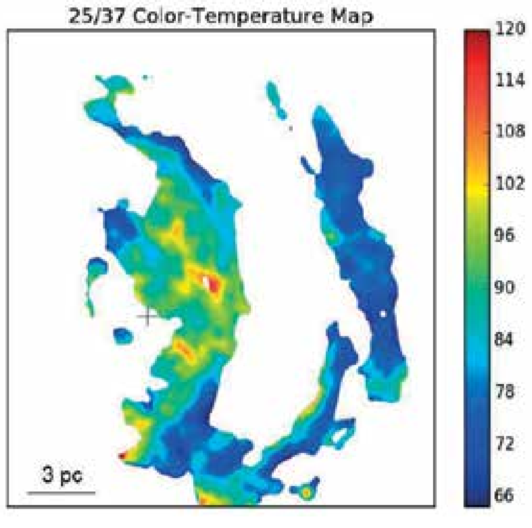


Figure 2. *Color-temperature map of the filaments using the 25.2 and 37.1 µm data of the region. The location of the Arches cluster is marked with a cross.*

7040

Airborne Infrared Astronomical Telescopes

Edwin F. Erickson, NASA Ames (retired)

This poster is a slightly updated version of one presented at a meeting celebrating the 400th anniversary of the invention of the telescope, held 28 September – 2 October 2008 at Noordwijk, The Netherlands. It describes primarily the airborne observational facilities developed at NASA Ames Research Center, and some of the scientific highlights they produced leading up to SOFIA.

TITLE: SOFIA/EXES 13 micron high spectral resolution observations of Orion IRc2 7042

AUTHORS: Naseem Rangwala, Xinchuan Huang, Sean Colgan, Timothy Lee

ABSTRACT: We present high spectral resolution (~5 km/s) observations in the 12.96 - 13.33 micron range toward Orion IRc2 taken by the EXES instrument on SOFIA. Ten absorption lines of Ortho and Para C2H2, three 12C13CH2, and eight HCN transitions were detected with high-S/N. The Ortho C2H2 transitions may be optically thick with a covering fraction of roughly 0.5. However, this covering fraction does not affect the estimated total column density of C2H2 and the Ortho to Para ratio. The Ortho to Para ratio is unusually low, ~0.6, compared to the standard ratio of 3.0, suggesting a different formation path for C2H2 in this source.

This project began as a search for c-C3H3+, the most important precursor in the formation of c-C3H2 - an interstellar organic ring molecule widespread in the ISM. There has been interest in detecting c-C3H3+ in astrophysical environments for more than 25 years. Using these EXES observations along with ab-initio calculations from the Ames quantum chemistry group, we report a robust upper limit for c-C3H3+ for the first time. Additionally, we report the 12C/13C isotopic ratio and an analysis of the HCN lines.

7043

SOFIA Large Impact Proposal [CII] Mapping of M51: Observing Strategy, Data Analysis & First Results

M. Ziebart[1]*, J. Pineda*[2]*, J. Stutzki*[1]*, P. Goldsmith*[2]*, C. Buchbender*[1]*, C. Fischer*[3]*, on behalf of M51 GREAT-Team (*[1]*I.Physikalisches Institut, Universität zu Köln,* [2]*NASA Jet Propulsion Laboratory (JPL),* [3]*Deutsches SOFIA Institut, Stuttgart)*

The M51 large Joint Impact Proposal of the SOFIA Observatory (the first large Impact Proposal of the SOFIA Observatory together with the large proposal for the large scale map of Orion [A.Tielens et. al]) with 62 h (upGREAT) and 13 h (FIFI-LS) total observing time over two years (cycle 4 & 5) will obtain the complete velocity resolved (with upGREAT) and deep maps (with FIFI-LS) of M51 grand design spiral galaxy in [CII] down to 0.07 K (upGREAT) and 10^{-17} $\mathrm{Wm^{-2}Pixel^{-1}}$ (FIFI-LS). The first observation were completed in February/March 2016 for FIFI-LS with 6 h and in May 2016 for upGREAT with 8 h (scheduled 11 h) observing time. The main goal of the project is to understand the impact of spiral density waves on the life cycle of the interstellar medium and the star formation in galaxies. Spiral density waves play a fundamental role in the conversion of atomic to molecular gas, leading to gravitational contraction and thus to star formation. The [CII] line (in combination with the low-J CO lines and HI 21cm) is an important tool to diagnose the physical state of the ISM. It reveals the distribution of the gas that is making a transition between atomic and molecular phases, including the CO-dark H_2 gas in the spiral arms and interarm regions of M51. We use the high spectral resolution [CII] observation of the upGREAT instrument to resolve spiral arms in velocity, allowing us to study the flow of the gas through spiral arms, measure line widths, and determine the dynamical state of prominent clouds relative to HI and CO gas. The FIFI-LS map, significantly more sensitive for the integrated intensity, will be used to detect extended faint [CII] emission in the interarm regions and outskirts of the galaxy, including the gas connection to the companion galaxy. Here we present the observing strategy, the calibration and data analysis with upGREAT and the very first [CII] maps obtained with upGREAT and FIFI-LS instruments. A first comparison of the [CII] spectra with CO (2-1) and HI 21cm emission line of the prominent norther spiral arm of M51 shows a small shifts in velocity and the velocity channel map, reveal the velocity gradients in the spiral arms.

7047

[CII], [NII], and [OI] Emission From An Evolving HII Region/PDR

M. G. Wolfire (UMD), and D. J. Hollenbach (SETI Inst.)

The HII Region/PDR is a strong source of [CII], [NII], and [OI] fine-structure line emission. We are developing a code which combines detailed HII region models and PDR models along with a 1-D treatment of the dynamics to trace the line emission from the evolving HII region and PDR. Most previous results have coupled the HII region to the PDR without accounting for the dynamical processes which modify both the HII region structure and PDR structure. Here we account for several processes which affect the HII region including the thermal expansion of the HII region, the OB association wind, the radiation pressure, the rocket effect of the champagne flow on the cloud, and the mass evaporation of the HII gas. For the PDR we include the swept up neutral gas layer, the ambient cloud, the loss of PDR mass due to evaporation, and the evolving incident far-ultraviolet radiation. We insure that the HII region and swept up PDR shell are in thermal pressure balance. We also include the evolution of the wind and of the ionizing and far-ultraviolet radiation emitted by the stellar association. In order to gain physical insight into the effects of various (evolving) parameters we have carried out a study over a limited range of parameters while holding others fixed in time. We present line intensities for our parameter study and preliminary dynamical calculations. The results will be useful for interpreting SOFIA observations of Galactic and extragalactic HII regions and PDRs.

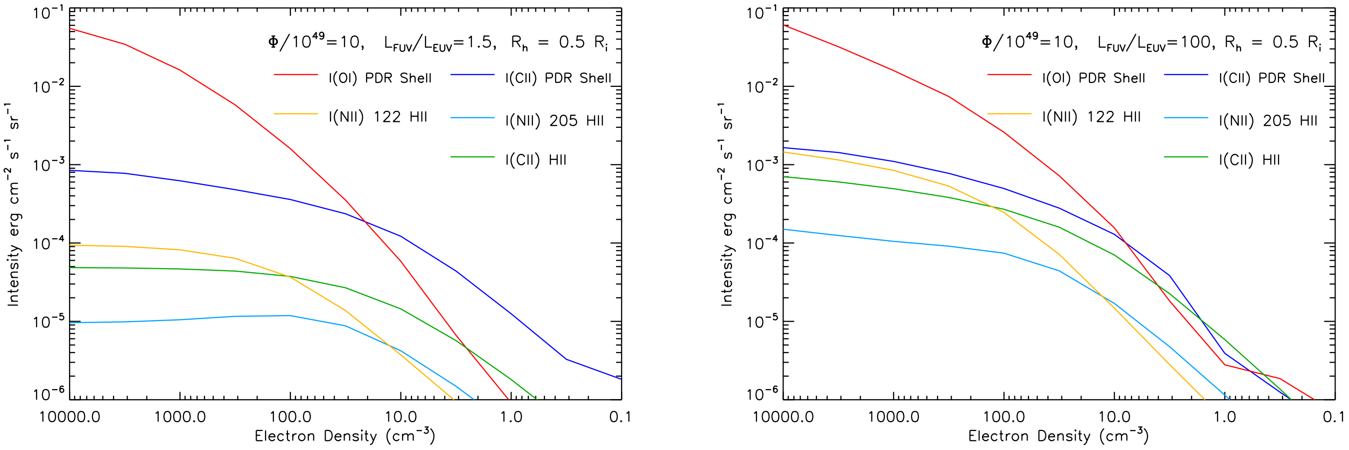


Fig. 1.— Line intensities versus electron density for a combined H II region/PDR model. Curves are shown for C II 158 μm and O I 63 μm emitted by the swept-up PDR shell, and N II 122, 205 μm and C II 158 μm emitted by the H II region. The models are calculated at fixed ionizing luminosity $\Phi/10^{49} = 10$, and H II region hole size $R_h = 0.5R_i$, and with an evolving stellar association ($L_{\rm FUV}/L_{\rm EUV} = 1.5, 100$)

7049

LkHα 101, an extreme Emission Line Star with a Disk and Illuminating an HII region

G. Sandell et al. (SOFIA Science Center/USRA)

We present new results on LkHα 101 based on mid-infrared imaging with FORCAST on SOFIA, CARMA 3 mm imaging, IRTF SpeX medium resolution spectra from 0.8 – 5 μm, and *Herschel* PACS archive data. These observations, combined with published VLA data reveal that LkHα 101 is still surrounded by a face-on photo-evaporating accretion disk and is illuminating an HII region. The accretion disk is hot T > 1000 K and mostly ionized. The FORCAST, PACS and CARMA CO(1-0) and ^{13}CO(1-0) images show a strong interaction between the dense molecular cloud north of LkHα 101 and the expanding HII region, but no interaction with the cold foreground cloud providing most of the extinction toward the star.

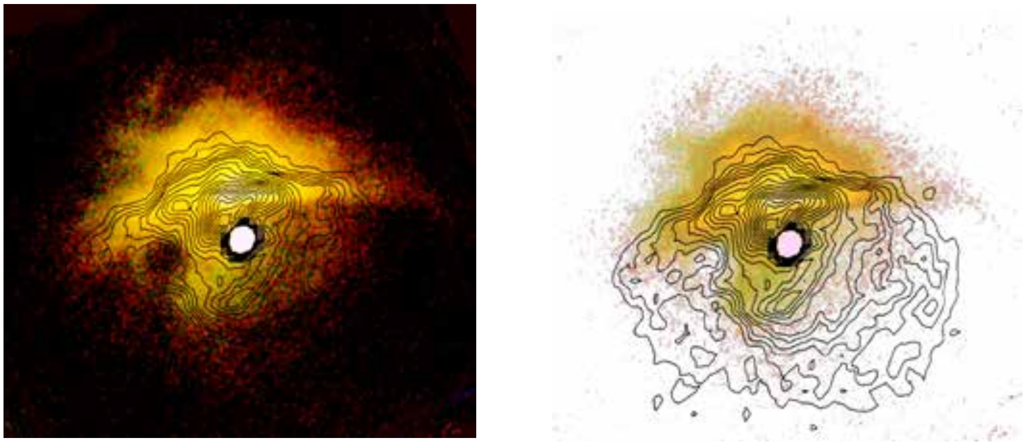


Figure 1. VLA 5 GHz image (contours) overlaid on a SOFIA FORCAST color image (20/31/37 μm) plotted with both black and white background. To the north the expansion of the HII region is blocked by the dense molecular cloud (at -2.6 km/s) north of the star, while the HII region expands more freely to the south where the cloud densities are low. Note the absence of mid-IR emission (hole) to the east of LkHa 101, noticeable even in the free-free image. This hole, presumably a dense cold globule, is not seen in the CARMA CO and ^{13}CO images. The size of the FORCAST image is ~ 2 x 2 arcmin.

7050

Feeding the Milky Way's Supermassive Black Hole

E.A.C. Mills (San Jose State University)

The circumnuclear disk that surrounds our Galaxy's central supermassive black hole is the closest reservoir of molecular gas for black hole growth and star formation in the central parsecs of the Milky Way. However the future role that this gas will play in increasing the activity in our galaxy's nucleus remains unclear, as estimates of the density and mass of this gas still vary by orders of magnitude. The origin of the circumnuclear disk is also debated, as its location relative to nearby clouds and the connections between it and Galactic center gas on larger scales remain elusive. I will present new observations of the physical conditions and kinematics of gas in the circumnuclear disk from ALMA and the Very Large Array. I will discuss prospects for more accurate density measurements in this gas and what they tell us about the prospects for star formation in this gas. I will also present the detection of several new kinematic features that may help determine the relative placement of gas in the central parsecs of the Milky Way and shed light on the origin of the circumnuclear disk. Finally, I will discuss current observations of gas inside the cavity of the circumnuclear disk and the accretion of this gas toward the central supermassive black hole.

ALMA-SOFIA Synergies

Hans Zinnecker, SOFIA Science Center, NASA-Ames/DSI
Göran Sandell, SOFIA Science Center, NASA-Ames/USRA

ALMA is a high-altitude interferometric observatory which provides extreme sensitivity and high spatial resolution in the mm/submm wavelength regime. SOFIA is an airborne observatory which has broad wavelength coverage (most importantly in the 30-300 micron range), albeit with more moderate spatial resolution and sensitivity (2.5m telescope in a B747SP plane). There are many synergies between the two observatories, which will be discussed in our poster, particularly in terms of continuum observations, spectroscopy, and polarimetry. One particular example focuses on the C+ fine structure line at 158 microns, which has been and is being detected with ALMA in high-redshift galaxies but its interpretation (eg. as a high-z star formation tracer) hinges on local C+ measurements (maps) in our Galaxy and other nearby galaxies. SOFIA upGREAT and FIFI-LS data can provide the "local truth" in terms of the multiple origins and optical depths of galactic C+ emission and can inform the interpretation of the C+ detections in very distant young galaxies.

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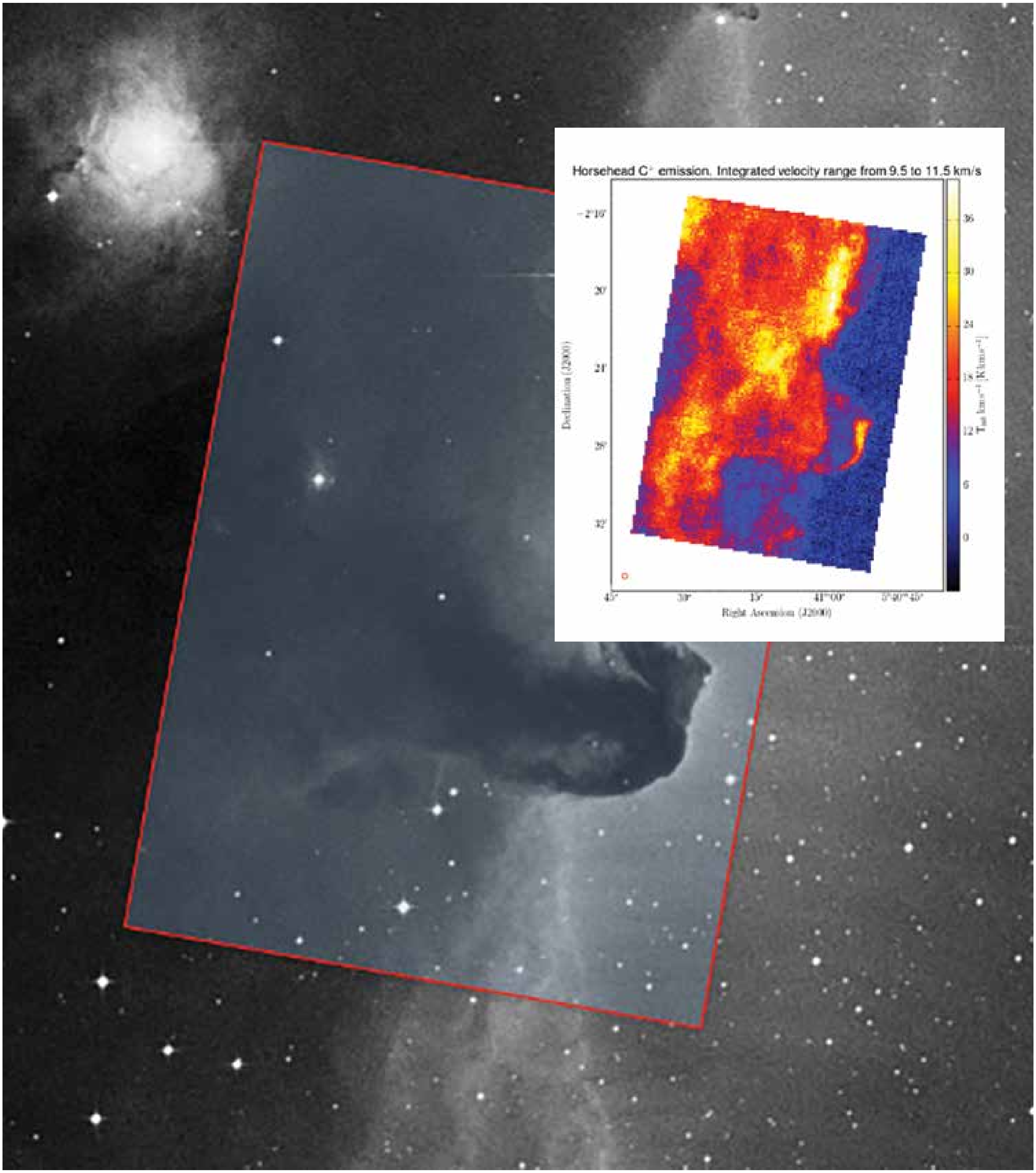

Mapped region of the Horsehead Nebula overlaid on a POSS-red Sky Survey image.
Inset: Integrated [C II] line intensity over velocity range 9.5 – 11.5 km/s.

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