Evolved Stars and their Circumstellar Environments

Dust Formation and Properties: Tuesday, December 14, 2021

Chairs: Kathleen Kraemer (Boston College), Arielle Moullet (USRA/SOFIA)

Click on a presentation title to see the abstract.

Time (Pacific)	Speaker (Affiliation)	Presentation Title
7:00–7:10am		Welcome
7:10–7:40am	Ciska Kemper (ASIAA/ESO)	Infrared and Submillimeter Observations of the Circumstellar Environments of Evolved Stars: the Formation and Properties of Astrophysical Dust
7:40–8:00am	Raghvendra Sahai (JPL/NASA)	Using the Far-IR to Study a New Evolutionary Class of Evolved Stars — Dusty Post-RGB Objects
8:00–8:10am	10 minute break	
8:10–8:30am	B-G Andersson (SOFIA/USRA)	Polarization in the Envelopes of IRC+ 10216 and IK Tau — From Optical to sub-mm.
8:30–8:40am	Terry Jay Jones (University of Minnesota)	Magnetic Fields in Red Supergiant Winds
8:40–8:50am	Enrique Omar Serrano Bernal (INAOE, México)	The Near-Infrared Polarization of the pre-Planetary Nebula Frosty Leo
8:50–9:20am	30 minute break	
9:20–9:50am	Maria Lugaro (Konkoly Observatory Budapest)	Dust from Asymptotic Giant Branch Stars
9:50–10:00am	Flavia Dell'Agli (INAF)	A New Perspective for the Extremely Red Asymptotic Giant Branch Stars: Are They Hiding a Close Companion?
10:00–10:10am	Toshiya Ueta (University of Denver)	Views from Spitzer, AKARI, and Herschel: Far-IR Probing of the Extended Circumstellar Shells of Evolved Stars
10:10–10:20am	10 minute break	
10:20–10:30am	Ryan Arneson (SOFIA/USRA)	SOFIA/FORCAST Imaging and Grism Observations of the Red Supergiant W26 in Westerlund 1
10:30–11:00am	Moderated by Angela Speck (University of Texas at San Antonio)	Day-End Discussion

Evolved Stars and their Circumstellar Environments

Gas Chemistry of Evolved Stars and Envelopes: Wednesday, December 15, 2021

Chairs: B-G Andersson (USRA/SOFIA), Nimesh Patel (SMA/CfA)

Click on a presentation title to see the abstract.

Time (Pacific)	Speaker (Affiliation)	Presentation Title
7:00–7:05am		Welcome
7:05–7:35am	Jose Cernicharo (CSIC)	The Molecular Composition of IRC+10216: from the Photosphere to the External Layers of the Envelope
7:35–7:55am	Jose Pablo Fonfría (IFF-CSIC)	Dissecting the Circumstellar Envelopes of Evolved Stars with Infrared Observations
7:55–8:05am	10 minute break	
8:05–8:25am	Deborah Schmidt (Franklin & Marshall College)	A Cornucopia of Molecules: New Detections in Planetary Nebulae
8:25–8:35am	Ashkbiz Danehkar (University of Michigan)	Chemical Compositions of [WR] Planetary Nebulae based on IFU Observations
8:35–8:45am	Cristobal Bordiu (Osservatorio astrofisico di Catania)	Molecular Gas: the Forgotten Ingredient of Luminous Blue Variable Ejecta
8:45–9:15am	30 minute break	
9:15–9:45am	Lucy Ziurys (University of Arizona)	Chemical Trends in Evolved Stellar Objects: From Red Giants to Planetary Nebulae
9:45–9:55am	Ambesh Pratik Singh (University of Arizona)	A 1 mm Spectral Survey of the Hypergiant NML Cyg: Insights into Chemistry and Dynamics
9:55–10:05am	William Reach (SOFIA/USRA)	Ionized Carbon around IRC+10216
10:05–10:15am	10 minute break	
10:15–10:35am	Megan Lewis (Polish Academy of Sciences)	SiO Masers as a Probe of Ten Thousand Galactic Evolved Stars
10:35–11:05am	Moderated by Christine Joblin (IRAP Toulouse)	Day-End Discussion

Evolved Stars and their Circumstellar Environments

Evolution in Time and Space: Thursday, December 16, 2021

Chairs: B-G Andersson (USRA/SOFIA), Edward Montiel (USRA/SOFIA)

Click on a presentation title to see the abstract.

Time (Pacific)	Speaker (Affiliation)	Presentation Title
7:00–7:05am		Welcome
7:05–7:35am	Greg Sloan (STScI/UNC)	Dust, Pulsation, and Metallicity in Evolved Stars
7:35–7:55am	Harriet Dinerstein (University of Texas at Austin)	Observed Outcomes of AGB S-Process Nucleosynthesis in Planetary Nebulae
7:55–8:05am	10 minute break	
8:05–8:25am	Roberta Humphreys (University of Minnesota)	Gaseous Outflows and Mass Loss from Red Supergiants
8:25–8:35am	Evgenia Koumpia (University of Leeds/ESO)	Multiple Mass Loss Events on Timescales of Hundreds of Years of the Post-Red Supergiant the Fried Egg Nebula
8:35–8:45am	Olivia Jones (UK Astronomy Technology Center)	Infrared Variable Stars in the Compact Elliptical Galaxy M32
8:45–9:15am	30 minute break	
9:15–9:45am	Albert Zijlstra (University of Manchester)	Mass Loss on the AGB
9:45–9:55am	Tomasz Kamiński (Polish Academy of Sciences)	Cool and Dusty Remnants of Stellar Mergers
9:55–10:05am	Sundar Srinivasan (IRyA-UNAM)	The Nearby Evolved Stars Survey: The Dust and Gas Return to the Galactic Interstellar Medium
10:05–10:15am	10 minute break	
10:15–10:35am	Mikako Matsuura (Cardiff University)	Circumstellar Material Developed during the Red-Supergiant Phase from the Progenitor of Supernova 1987A
10:35–11:05am	Moderated by Joel Kastner (Rochester Institute of Technology)	Session Discussion

Evolved Stars and their Circumstellar Environments

Laboratory Studies, Modeling and Future Directions: Friday, December 17, 2021

Chairs: Guido Fuchs (Kassel University), Pepe Cernicharo (CSIC)

Click on a presentation title to see the abstract.

Time (Pacific)	Speaker (Affiliation)	Presentation Title
7:00–7:05am		Welcome
7:05–7:35am	Harold Linnartz (Leiden)	DIBS, PAHs and Fullerenes — the Chemical Heritage of Evolved Stars?
7:35–7:55am	Marie Van de Sande (University of Leeds)	The Impact of UV Photons of a Stellar Companion on the Chemistry of AGB Outflows
7:55–8:05am	Anna Ciurlo (UCLA)	Can Molecular Gas Form in the Wind of a Wolf-Rayet Star?
8:05–8:15am	10 minute break	
8:15–8:45am	Christine Joblin (IRAP Toulouse)	What IR Emission from PAHs and Fullerenes Can Tell Us? The View of Laboratory Astrophysics
8:45–8:55am	Le Ngoc Tram (Max Planck Institute for Radio Astronomy)	Radiative Feedback from Evolved Stars
8:55–9:05am	Milan Sil (Indian Centre for Space Physics)	Exploring Noble Gas Species in the Radiation-Dominated Region
9:05–9:25am	20 minute break	
9:25–9:35am	Lisa Shepard (University of Texas at San Antonio)	Using MiraFitter to Identify Circumstellar Dust Around Optically-Thin Oxygen-Rich Mira Variables
9:35–9:45am	Bao Truong (Vietnam National University)	Modeling Extinction and Reddening Effects by Circumstellar Dust in the Betelgeuse Envelope
9:45–10:15am	Moderated by Susanna Widicus Weaver (U. Wisconsin Madison)	Session Discussion
10:15–10:25am	10 minute break	
10:25–10:35am	Alec Hirschauer (Space Telescope Science Institute)	Our First Glimpse of Dust Production and Star Formation in Metal-Poor, Early-Universe Analog Environments with JWST
10:35–10:45am	Edward J. Montiel (SOFIA/USRA)	High Resolution Spectral Observations of Evolved Stars with EXES
10:45–10:55am	Arielle Moullet (SOFIA/USRA)	SOFIA Opportunities in 2022
10:55–11:25am	Moderated by Nimesh Patel (Harvard)	Observations Synergies Panel

Abstracts

B-G Andersson (USRA/SOFIA)

Title: Polarization in the Envelopes of IRC+10216 and IK Tau — From Optical to sub-mm

Abstract: The envelopes of AGB stars can serve as unique laboratories for the mineralogy effects of dust grain alignment, because of their "clean" chemical composition. Because the stability of the CO molecule, either all the carbon, or all the oxygen is tied up in it and the remaining gas and dust are either (almost) fully carbonaceous of composed of silicates and metal oxides. Most grain alignment theories require the dust grain to be (at least) paramagnetic to produce polarization. While silicate are paramagnetic, carbon solids are not and would produce, at most, very weak polarization. In the chemically mixed ISM any such contribution would be difficult to separate from the silicate dust aligned grains. We have observed IRC+12 216 and IK Tau, as type examples of carbon and oxygen-rich AGB stars, in polarimetry - from the optical (Lick/Kast) to FIR (SOFIA/HAWC+) and sub-mm wavelengths (JCMT/SCUBA2-POL2). We will present and contrast these observations and discuss the results in terms of carbon and silicate dust grain alignment. We show that for small-to-medium sized carbon grains a second-order direct radiative alignment dominates while for large carbon grains and for silicate grains radiatively driven magnetic alignment (as in most of the ISM) explains the polarization.

Ryan Arneson (SOFIA/USRA)

Title: SOFIA/FORCAST Imaging and Grism Observations of the red supergiant W26 in Westerlund 1

Abstract: We present SOFIA/FORCAST mid-infrared imaging and spectroscopic observations of the dust shell surrounding the M2-5Ia red supergiant (RSG) W26 in the massive star cluster Westerlund 1 (Wd1). The grism spectrum exhibits several notable features, including a very broad 10 micron emission bump with an extremely sharp onset to the blue and a slow decline to the red, a very broad 20 micron emission bump, and a shallow slope for the long wavelength spectrum. The spectrum was modeled with the radiative transfer code DUSTY. We find that the spectral shape is particularly sensitive to the dust properties of the source. Based on the fit we estimate a mass-loss rate of 2.45 x10^-5 solar masses per year. Using the FORCAST images in 4 passbands, we estimate the average intra-cluster dust temperature surrounding W26 to be 250 K. Our results are consistent with those of Mackey et al. 2015 who suggest that the dust surrounding W26 is confined by the cluster into a dense shell. The SOFIA/FORCAST observations allow for a better understanding of the dust morphology and evolution of massive stars in the cluster environment. These results help to determine the physical properties of the circumstellar environment and the mass-loss history of cluster stars, and to constrain supernovae models.

Cristobal Bordiu (Osservatorio astrofisico di Catania)

Title: Molecular gas: the forgotten ingredient of Luminous Blue Variable ejecta

Abstract: When talking about molecular envelopes, one immediately thinks of low and intermediate-mass stars, objects with hospitable conditions that allow for the formation of dust and molecules. By contrast, the search for a molecular component associated with evolved hot massive stars has been long overlooked due to their extremely high temperatures, strong UV fields, and shocks, that would allegedly sterilize their outskirts. However, the study of luminous blue variables at (sub) millimeter wavelengths has recently unearthed a missing mass component in the form of conspicuous amounts of molecular gas. In some occasions this gas, arranged into slowly expanding circumstellar structures, bears unmistakable traces of stellar ejecta, such as nitrogenated species and low 12C/13C isotopic ratios. This talk will explore how these detections, integrated into a broader multiwavelength context, represent a crucial step to understand and better constrain the evolution and mass-loss record of the parent stars. In particular, we will be focusing on the outstanding examples of AG Car and Eta Car, sources where the mix of dust, ionized gas and molecular gas conform a strikingly complex circumstellar scenario. From the lessons learned in these two cases, we will discuss the view of evolved massive stars as molecule factories, and the implications for stellar evolution and the chemical enrichment of the Galaxy.

Anna Ciurlo (University of California Los Angeles)

Title: Can molecular gas form in the wind of a Wolf-Rayet star?

Abstract: The central parsec of the Galaxy, where the ionization coming from the young stars would nominally destroy it. The presence of molecular gas (H2) in this extreme environment therefore remains unexplained. H2 could form in the circumstellar envelope of young, windy stars. For example, the central parsec contains ~30 Wolf-Rayet stars with large mass loss rates. However, any newly formed molecules in the stellar outflows of such stars would be ionized by the UV radiation field of the numerous massive young stars in this region, so detection of H2 would require that the formation rate be competitive with the photo-dissociation rate. Here, we present observations of resolved layers of molecular and ionized gas around the massive young Wolf-Rayet star GCIRS 16C, obtained with the integral field unit OSIRIS at the Keck Observatory. This is an exemplary case to test the hypothesis that molecular hydrogen can form and survive in the cooling, outflowing winds of evolved stars and then be injected in the surrounding interstellar medium.

Ashkbiz Danehkar (University of Michigan)

Title: Chemical Compositions of [WR] Planetary Nebulae based on IFU Observations

Abstract: We have determined temperatures, density, and chemical elements of a sample of planetary nebulae (PNe) around Wolf-Rayet ([WR]) central stars using collisionally excited lines (CELs) and optical recombination lines (ORLs) measured in IFU observations with the ANU 2.3-m telescope. We found that densities and temperatures derived from CELs are closely related to nebular surface brightness and excitation class, respectively, whereas physical properties based on ORLs could correspond to some cool, dense filamentary structures in some PNe. Moreover, we notice a correlation among CEL-ORL temperature dichotomies and ORL/CEL abundance discrepancies, which could be an indication of a tiny proportion of cool, H-deficient knots within warm, H-rich nebulae. There could be a possible evolutionary link between ORL/CEL abundance discrepancies and H-deficient [WR] cores in these objects, which need further studies.

Flavia Dell'Agli (INAF)

Title: A new perspective for the extremely red asymptotic giant branch stars: are they hiding a close companion?

Abstract: Asymptotic giant branch stars are main sources of carbon dust in galaxies. The analysis of these objects in the Large Magellanic Cloud unearthed a group of stars, called "Extremely Red Objects" (ERO). The analysis of EROs spectral energy distribution suggests the presence of large quantities of dust in their surroundings, which demands gas densities in the outflow significantly higher than expected from theoretical modeling of single stars. In this talk I will discuss the possibility that EROs are part of an interacting binary system where the presence of a common envelope would favor a conspicuous dust formation.

Harriet Dinerstein (University of Texas at Austin)

Title: Observed Outcomes of AGB s-Process Nucleosynthesis in Planetary Nebulae

Abstract: Many evolved lower-mass stars synthesize nuclei beyond the Fe peak during the Asymptotic Giant Branch (AGB) stage, through captures of free neutrons by Fe nuclei. Products of this slow neutron-capture or "s-process," together with C from triple-alpha reactions, are mixed into the star's envelope when convective zones periodically dip into the deep interior. The star eventually transforms into a C star with enhanced surface abundances of s-process products. When the envelope is expelled as a planetary nebula, the enriched gas flows into the ISM. Infrared emission line spectroscopy of planetary nebulae has proven to be a powerful tool for studying the products of AGB nucleosynthesis. I discuss results from three high-spectral resolution infrared instruments: (1) IGRINS, the Infrared Grating Spectrometer, which covers the H and K bands; (2) iSHELL on NASA's IRTF, which operates from J to M; and (3) HPF, the Habitable-zone Planet Finder on the 10m Hobby-Eberly Telescope, which observes in the z, Y, and J bands. These spectrometers have discovered and measured emission lines from ions of trans-iron species from Se and Kr (Z = 34 and 36) to Te and Xe (52 and 54). Some planetary nebulae show abundance enhancements as large as factors of 10 or more in certain elements. The results can be compared with theoretical predictions of AGB evolution and nucleosynthesis, and provide crucial inputs to models of galactic chemical evolution in the form of empirically determined AGB star yields.

Jose Pablo Fonfría (IFF-CSIC)

Title: Dissecting the circumstellar envelopes of evolved stars with infrared observations

Abstract: Circumstellar envelopes (CSEs) of evolved stars are warm to cold, dense environments where molecules with different degrees of complexity can form. Dust grains, which result from the condensation of refratory molecules, enrich the interstellar medium with processed matter. It is thus crucial to understand the gas phase chemistry and dust formation processes in CSEs along with the gas and dust kinematics to describe how evolved stars impact the chemical evolution of the Galaxy. Interferometer and single-dish observations in the millimeter and infrared spectral ranges have been carried out so far in order to shed some light on these topics. All these techniques are powerful tools to understand the matter ejection process from evolved stars. However, single-dish high spectral resolution infrared observations are especially suitable to describe the gas kinematics and the physical and chemical conditions in the inner and intermediate layers of CSEs. Furthermore, molecules without a permanent dipole moment can be observed with this technique, covering a gap of Millimeter Astronomy. In this talk, we will present a summary of relevant works based on infrared observations during the last decades and the progress of our more recent projects based on data taken with SOFIA/EXES, in particular the first detection of the H2 S(1) line toward an AGB star and its use to simultaneously estimate the mass-loss rate and the CO abundance of IRC+10216.

Alec Hirschauer (Space Telescope Science Institute)

Title: Our First Glimpse of Dust Production and Star Formation in Metal-Poor, Early-Universe Analog Environments with JWST

Abstract: The James Webb Space Telescope (JWST) will soon offer an

unparalleled glimpse into the infrared (IR) Universe, sensitive to the dustiest young and evolved stars within the nearby cosmic neighborhood. We present the parameters of two Guaranteed Time Observation (GTO) programs designed to take advantage of this unique capability in order to study the star formation and dust production properties of early-Universe analog metal-poor systems. Program 1233 examines the extremely metal-poor (XMP) blue compact dwarf (BCD) galaxy I Zw 18, with an oxygen abundance of roughly ~3% solar, a level of chemical enrichment equivalent to the very early Universe. Program 1234 investigates the isolated dwarf NGC 6822 (Barnard's Galaxy), home to some of the largest star-forming regions in the local Universe, including the recently-identified proto super star cluster (SSC) candidate Spitzer I. At ~30% solar metallicity, NGC 6822 is similar in structure and composition to the Small Magellanic Cloud (SMC), and possibly represents a later stage of galaxy evolution than I Zw 18. Imaging data with the Mid-Infrared Instrument (MIRI) and Near-Infrared Camera (NIRCam), utilizing a variety of filter combinations selected for sensitivity to dusty objects and stellar populations, will allow for study of objects not detected by the Hubble Space Telescope (HST). With these data, among the first that will be acquired with JWST, we will address questions such as: How is substantial dust produced in high-redshift systems where insubstantial time has passed for low- to intermediate-mass stars to evolve to the asymptotic giant branch (AGB) phase, where considerable mass loss takes place? How are massive stars formed at low metallicity? Do star-formation mechanisms for these massive stars evolve in parallel with the evolution of their metal-poor host galaxies? JWST will be a crucial and powerful tool for better understanding dust production, evolution, and star formation mechanisms in early-Universe systems that are otherwise inaccessible to observation. This JWST work builds on past Spitzer analysis of the infrared stellar populations in NGC 6822 in which Spitzer I was discovered and the Spitzer SAGE surveys of the LMC and SMC.

Roberta Humphreys (University of Minnesota)

Title: Gaseous Outflows and Mass Loss from Red Supergiants

Abstract: Mass loss from red supergiants has been well known for decades, but the mechanism is not understood. The red hypergiant VY CMa and the more typical red supergiant Betelgeuse provide clear observational evidence for discrete, directed gaseous outflows in their optical and infrared imaging, spectra, and light curves. In the very luminous VY CMa, mass loss estimates from the infrared bright knots and clumps, not only dominate its measured overall mass loss, but explain it. In the lower luminosity Betelgeuse, similar mass estimates of its circumstellar condensations show that they contribute significantly to its measured mass loss rate. We present new measurements for both stars and discuss additional evidence for gaseous ejections in other red supergiants. We conclude that gaseous outflows, related to magnetic fields and surface activity, comparable to coronal mass ejections, are a major contributor to mass loss from red supergiants and the missing component in discussions of their mass loss mechanism and their mass loss rate - luminosity relation.

Christine Joblin (IRAP Toulouse)

Title: What IR emission from PAHs and fullerenes can tell us? The view of laboratory astrophysics

Abstract: The aromatic infrared bands (AIBs) are major emission features usually attributed to polycyclic aromatic hydrocarbons (PAHs) that are heated by the absorption of ultraviolet (UV) photons. The AIBs present significant spectral difference in evolved stars (post-AGB and planetary nebulae) compared to star forming regions [1]. This can be attributed to emission from freshly irradiated matter that is rich in aliphatics [2,3,4], together with emission from a PAH population that is strongly processed by UV photons [5]. The latter process might also explain the detection of C60 emission [6] in some of these objects. An additional complication to chemical processing is that, in heated molecules, vibrational coupling (anharmonicity) plays a major role, by affecting the band positions and widths [7] and by leading to a number of new bands such as combination/difference bands and overtones. Disentangling temperature effects from chemical complexity requires then a detailed comparison of the observed spectra with synthetic spectra that model the emission of a given PAH molecule in a given UV-visible astrophysical radiation field [8]. In this presentation I will summarize recent results from activities in laboratory astrophysics. These include the preferred formation of aliphatics compared to aromatics in the simulation of carbon dust formation in AGB [9], and the UV photoprocessing of PAHs showing the impact of size [10] and aliphatic bonds [11] on stability. Empirical anharmonic parameters were also derived to describe the evolution of band positions and widths with temperature [12,13]. These studies extend to C60 and PAHs of different sizes. I will illustrate how these data combined with an emission code can provide perspectives for the analysis of the coming James Webb Space Telescope observations.

Olivia Jones (UK Astronomy Technology Center)

Title: Infrared variable stars in the compact elliptical galaxy M32

Abstract: Using three epochs of photometry from the Spitzer Space Telescope at 3.6 and 4.5 μm, separated by 32 to 381 days we identified 83 candidate large-amplitude, long-period variables in the compact elliptical galaxy M32. The luminous AGB stars observed in M32 are likely the progeny of an intermediate-age population with lifetimes between 0.2 - 5 Gyr. To unambiguously identify the chemical type of these stars we have obtained follow-up Hubble Space Telescope observations of M32 using medium-band WFC3/IR filters which are sensitive to molecular absorption features in the atmosphere of dust-producing AGB stars. Here we will present the first results of this HST programme.

Terry Jay Jones (University of Minnesota)

Title: Magnetic Fields in Red Supergiant Winds

Abstract: Mass-loss in evolved luminous stars has a major effect on their evolution, has a strong effect on the surrounding ISM, and creates the surrounding environment within which the star may go supernova. Unlike the relatively gentle, radiation driven winds of red giants, many of the cool supergiants have much faster winds and show dense, massive clumps in in their ejecta. The physics underlying this mass-loss mechanism is largely unknown, but the presence of magnetic fields in the winds of dusty red supergiants would provide a possible energy source for a very scaled up mechanism similar to Coronal Mass Ejections in the Sun. Here I review the current status of observations of the mass-loss winds in red supergiants. Evidence for magnetic fields in these stars is problematic, but a global magnetic field geometry that aligns dust grains in the mass-loss wind should be detectable at Far Infrared wavelengths.

Tomasz Kamiński (Polish Academy of Sciences)

Title: Cool and dusty remnants of stellar mergers We know of five Galactic objects that are classified as red novae

Abstract: Their eruption were observed in real time and are thought to be manifestations of stellar mergers between non-compact stars (main-sequence, subgiants, giants). The products of the collisions look like red supergiants and have circumstellar environments rich in dust and molecules. The properties of the collision product and the complex circumstellar envelopes allow us to study the physics of stellar mergers. I am going to review what we have leaned about those rare objects through observations of dust and molecular gas in the remnants. I am going to focus on some exotic characteristics (e.g., isotopic composition, molecular composition, shock interactions) that have an impact on our understanding of circumstellar media of evolved stars in general.

Ciska Kemper (ESO/ASIAA)

Title: Infrared and submillimeter observations of the circumstellar environments of evolved stars: the formation and properties of astrophysical dust

Abstract: The presence of dust in the interstellar medium regulates the interstellar radiation field, chemical processes, cooling rates and star formation rates, and thus drives galaxy evolution. Although evolved stars were previously thought to be the main producers of dust in the Galaxy, it has, in recent years, become clear that dust formation in the interstellar medium may represent the dominant source of interstellar dust. However, regardless of location, dust formation processes in astrophysical environments are not yet well understood, and the circumstellar environments of evolved stars remain important, as they provide convenient laboratories to study these processes. In this talk I will review our current understanding of dust formation in the circumstellar environments of evolved stars, based on observations from infrared and submillimeter observatories, including SOFIA and ALMA. I will also look forward to future observational capabilities that have the potential of further revealing the process of dust formation in these environments.

Evgenia Koumpia (Universiy of Leeds/ESO)

Title: Multiple mass loss events on timescales of hundreds of years of the post-Red Supergiant the Fried Egg Nebula

Abstract: The fate of a massive star during the latest stages of its evolution is highly dependent on its mass-loss rate and geometry. The geometry of the mass-loss process can be inferred from the shape of the circumstellar material, having a significant influence on the evolution of massive stars (25 and 40 Msun), i.e., type II SN progenitors. In this context, yellow hypergiants (YHGs) offer an excellent opportunity to study mass-loss events. I will present the analysis of a large set of optical and near-infrared data in spectroscopic, photometric, spectropolarimetric, and interferometric (GRAVITY/VLTI) modes, towards the IRAS 17163-3907 and its associated Fried Egg Nebula. This talk will cover the first reconstructed images of IRAS 17163−3907 around the 2-micron emission tracing milli-arcsecond scales, but also how our 2D radiative transfer modelling led to the discovery of a third hot inner shell with a maximum dynamical age of only 30 yr. We find three observed distinct mass-loss episodes which are characterised by different mass-loss rates and can inform theories of mass-loss mechanisms, which is a topic still under debate both in theory and observations. These will be discussed in the context of photospheric pulsations and wind bi-stability mechanisms.

Le Ngoc Tram (Max-Planck-Institute for Radio Astronomy)

Title: Radiative feedback from evolved stars

Abstract: Material ejected from AGB/RSG stars allows dust to form (aka stardust) in the dust formation zone. Because the AGB/RSG temperature is low, causing a lack of UV photons available that can trigger the mid-IR emission of PAHs. The spinning dust emission from rapidly spinning nanoparticles at frequencies below 100 GHz is believed to help to understand the formation of dust in AGB envelopes. Intense radiation from the central stars can change the properties of stardust due to rotational disruption by radiative torques. Furthermore, the polarimetric observations at optical/NIR and FIR wavelengths from AGB envelopes open the possibility to study the grain growth in these media. In this talk, we present our project linking the mass-loss mechanism, grain formation, and evolution in AGB/RSG envelopes.

Megan Lewis (Polish Academy of Sciences)

Title: SiO masers as a probe of ten thousand Galactic evolved stars

Abstract: With an unprecedentedly large sample of uniformly selected asymptotic giant branch (AGB) stars, we present results focused on understanding the intermediate-age stellar populations in the Milky Way. Via radio and mm observations, the Bulge Asymmetries and Dynamical Evolution (BAaDE) survey has detected SiO maser emission in about 10,000 AGB stars, effectively probing the AGB stellar kinematics via their velocities, and providing the largest database of SiO maser data with which to address the connections between maser emission and AGB properties. Relying on radio spectra as a guide (primarily SiO masers), we show how to best separate C-rich from O-rich stars in this set of thin-shelled AGBs using multiple IR colors. These data imply the possible existence of a much larger sample of C-rich stars in the bulge than previously has been reported, although distances are needed for confirmation. The data have also provided exceptionally detailed statistical information about SiO lines and their line ratios, including isotopologue transitions. Findings include situations where the 29SiO isotopologue lines can become stronger than the main 28SiO isotopologue lines despite the fact that 28SiO is 15 times more abundant. Follow-up observations suggest a possible dependence on stellar cycle, further complicating our understanding of the origin of these unusually bright maser lines and illustrating the need for extensive modeling.

Harold Linnartz (University of the Netherlands)

Title: DIBS, PAHs and Fullerenes — the chemical heritage of evolved stars?

Abstract: Dedicated laboratory studies, finally, have lifted a small piece of the veil on the origin of the diffuse interstellar bands, DIBs. In a number of studies, the fullerene cation, C60+, has been identified as the carrier of four bands arond 930-950 nm. Up to then, the largest molecule, identified in the diffuse interstellar medium was C3. So what is the origin of this chemical complexity, are other species at play? Can we learn more about the carriers of the other DIBs, linking back to species formed in the outflow of evolved stars, e.g. by studying the photo-dynamics of large PAHs? This talk will provide a short overview of lab based DIB research, focusing on fullerenes and PAHs.

Maria Lugaro (Konkoly Observatory Budapest)

Title: Dust from asymptotic giant branch stars

Abstract: Asymptotic giant branch (AGB) stars are one of the dustiest objects in the Universe and their dust production is intimately linked to the nuclear processes that occur in their deepest layers. This is because these nuclear reactions, together with the mixing processes that take their products to the stellar surface, determine the relative availability of carbon and oxygen (the C/O ratio) in the external dust-forming regions. Due to the strong bound of the carbon monoxide (CO) molecule, the C/O ratio controls the chemistry of these two major chemical elements, which, in turn, determines the bulk and the properties of the dust. In the deep, hot layers of AGB stars, carbon is destroyed by the burning of hydrogen (via proton capture reactions) and produced by the burning of helium (via the triple-alpha reaction). Therefore, ultimately it is the temperature of the nuclear burning and the mixing that carries its products to the stellar surface that control the dust formation. In this talk, I will discuss how such temperatures and mixing processes, and therefore the subsequent variability of the dust, are strongly mass and metallicity dependent. I will also demonstrate how can we directly constrain the process of dust formation in AGB stars of different masses and metallicities using stardust grains found in meteorites, and how this AGB stardust contributed to determine the composition of different planetary bodies in the Solar System.

Mikako Matsuura (Cardiff University)

Title: Circumstellar material developed during the red-supergiant phase from the progenitor of Supernova 1987A

Abstract: The progenitor of Supernova 1987A was red-supergiant about 40,000 years ago, and it had experienced extensive mass loss, forming what we seen as an equatorial ring. The blast wave from the supernova caused shocks against the equatorial ring, brightening it up since 1990's. The Hubble Space Telescope (HST) continued to monitor, and its images showed that the brightness of the ring started fading about 2010, and at the same time, circumstellar material beyond the ring started being illuminating. The blast wave has exited the equatorial ring. The time evolution of Supernova 1987A was also monitored at infrared wavelengths, which traces dust emission in the equatorial ring. The dust emission is considered to be heated by the collisional shocks by the blast waves, which would eventually destroy the dust grains. It seems the mid-infrared brightness follows the HST brightness very well, but the time scale of dust destruction might be longer than it was anticipated. Monitoring Supernova

1987A development traces mass-loss history during the red-supergiant, and also indicate the dust destruction efficiency by blast waves from the subsequent supernova explosion, with a potential of showing final dust input from the red-supergiant to the interstellar medium.

Edward J. Montiel (SOFIA/USRA)

Title: High Resolution Spectral Observations of Evolved Stars with EXES

Abstract: The Echelon Cross Echelle Spectrograph (EXES), as of October 2021, is a Facility class instrument on SOFIA. It is optimized for high spectral resolution (R = 50,000 — 100,000) between 4.5 and 28.3 microns. It is also able to operate in medium (R = 15,000 — 25,000) and low (R = 4,000 — 6,000), although with some limitations. A brief introduction into observing with EXES and highlights of observations of evolved stars from previous flight series will be presented.

William Reach (USRA/SOFIA)

Title: Ionized carbon around IRC +10216

Abstract: Asymptotic giant branch stars create a rich inventory of molecules in their envelopes as they lose mass during later stages of their evolution. These molecules cannot survive the conditions in interstellar space, where they are exposed to ultraviolet photons of the interstellar radiation field. As a result, daughter molecules are the ones injected into space, and a halo of those molecules is predicted to exist around cool evolved stars. The most abundant molecule in the envelopes other than H2 is CO, which dissociates into C that is rapidly ionized into C+ in a halo around the star. We develop the specific predictions of the C+ halo size and column density for the well-studied, nearby star IRC+10216. We compare those models to observations of the [C II] 157.7 micron far-infrared fine-structure line using SOFIA and Herschel. The combination of bright emission toward the star and upper limits to extended [C II] is inconsistent with any standard model. The presence of [C II] toward the star requires some dissociation and ionization in the inner part of the outflow, possibly due to a hot companion star. The lack of extended [C II] emission requires that daughter products from CO photodissociation in the outer envelope remain cold.

Raghvendra Sahai (Jet Propulsion Laboratory NASA)

Title: Using the Far-IR to Study a New Evolutionary Class of Evolved Stars - dusty post-RGB objects

Abstract: Dusty post-RGB (pRGB) stars represent a newly identified evolutionary class, resulting from a strong binary interaction (e.g., common envelope ejection) while the primaries are still red giant stars. Although the spectral-energy-distributions (SEDS) of these objects — found in the Magellanic Clouds — look very similar to the more common class of post-AGB (pAGB) stars, their low luminosities (<~2000 Lsun) clearly separate them from the latter. The only known object of this class in our Galaxy is the Boomerang Nebula (also the coldest object in the Universe). In a first study, we have investigated the warm circumstellar ejecta in these objects by modeling the optical to 24 micron SEDs of eight pRGBs (and eight pAGBS for comparison) in the LMC. We find the presence of geometrically thick disks with substantial opening angle in some pRGBs, in addition to warm surrounding shells. We find that the masses of these ejecta is small compared to the total mass that needs to be ejected in order for the RGB to post-RGB transition to occur. We hypothesize that this “missing” ejecta mass in pRGB stars lies in a cool extended shell, and we find far-IR emission in some of these objects that supports our hypothesis. We show that HAWC+ photometry in the ~50-200 micron can potentially lead to the discovery of the missing mass in many more pRGB objects.

Deborah Schmidt (Franklin & Marshall College)

Title: A Cornucopia of Molecules: New Detections in Planetary Nebulae

Abstract: The low temperatures and densities in the extended outer envelopes of asymptotic giant branch (AGB) stars foster the synthesis of a variety of molecular species. As these stars evolve toward planetary nebulae (PNe), their remnant cores grow hotter and emit increasing amounts of high-energy radiation. Chemical models predict that molecules from the AGB stage should be photodissociated shortly after the onset of the PN phase. In contrast, recent observations have identified numerous species, including HCN, HCO+, HNC, CCH, and c-C3H2, in approximately 30 nebulae. In particular, a new survey of HCN and HCO+ in a sample of 13 PNe has detected HCN in 10 new sources and HCO+ in 11. Abundances for these species, estimated with radiative transfer modeling, fall within 1-2 orders of magnitude of each other across the sample. As these nebulae span the projected PN lifespan of ~10,000 years, these findings confirm that molecules can survive well beyond the photodissociation timescales predicted by models. The catalog of molecules detected in PNe has continued to grow with ongoing molecular studies of PNe. Of special interest is the identification of H2S in two nebulae, NGC 6537 and M2-48, the first detection of this molecule in PNe. The detections of these and other sulfur-bearing species may provide a means of addressing the anomalous paucity of sulfur in PNe. The results of these works will be discussed, along with their implications for the cosmic recycling of molecular material.

Enrique Omar Serrano Bernal (INAOE, México)

Title: The Near-Infrared Polarization of the pre-Planetary Nebula Frosty Leo

Abstract: We present a near-infrared imaging polarimetric study of the pre-planetary nebula: Frosty Leo. The observations were carried out in J, H and K bands using the new polarimeter POLICAN mounted on the 2.1m telescope at the Guillermo Haro Astrophysical Observatory, Sonora, Mexico. The most prominent result observed in the polarization maps is a large and well-defined dusty envelope (35" diameter in H-band). The polarization position angles in the envelope are particularly well ordered and nearly parallel to the equator of the nebula (seen in J and H bands). Within the bipolar lobes, we find high polarization levels (up to 90% in the K band), and the polarization angles trace a centrosymmetric pattern. Using the near-infrared polarization, we found the remnants of superwind shells at the edges of the bipolar lobes. Additionally, we estimated that the superwind phase has lasted around 600 yrs. The origin of polarization features in the nebula is most likely due to a combination of single and multiple scattering. Our results clearly demonstrate new structures that provide new hints on the evolution of Frosty Leo from its previous asymptotic giant branch phase.

Lisa Shepard (University of Texas at San Antonio)

Title: Using MiraFitter to Identify Circumstellar Dust Around Optically-Thin Oxygen-Rich Mira Variables

Abstract: There are various studies of dusty environments with the FORCAST instrument on SOFIA that focus on the shape and strength of silicate features near 10μm and 18μm. The study we will present may impact how people interpret silicate dust in their SOFIA observations. Radiative Transfer (RT) modeling has often been used to analyze spectra and obtain a match to the overall spectral energy distribution with certain parameters. While RT modeling should allow us to build a spectrum that includes all contributions to the observed spectra, we are hampered by a lack of detailed or appropriate laboratory data for such modeling. This limits the application of RT modeling if we want to determine the detailed mineralogy of the dust. In some cases (usually very optically-thin scenarios), we can simply eliminate a continuous contribution to the observed spectrum to isolate any observed features and measure their basic spectral parameters. We created a program called MiraFitter to investigate several methods of continuum elimination using spectroscopy data for the archetypal dusty AGB star, Mira. We have investigated the ~10μm and ~18μm spectral features in the continuum-eliminated spectrum including peak position, barycenter, and full width half maxima (FWHM). The positions and widths of observed spectral features were compared with those seen in laboratory spectra. The results show that the method of continuum elimination matters for correct identification of dust minerals, while varying the temperature and precise continuum shapes do not have a major effect on the positions of spectral features.

Milan Sil (Indian Centre for Space Physics)

Title: Exploring Noble Gas Species in the Radiation-Dominated Region

Abstract: Two noble gas molecular cations, argonium (ArH+) and hydro-helium or helenium (HeH+), are discovered toward the two radiation-dominated environments in space: the Crab nebula supernova remnant and the planetary nebula (NGC 7027), respectively. The elemental abundance of neon is lower than helium but higher than that of the argon. However, the neonium cation (NeH+) is yet to be identified in space. In the Crab nebula supernova remnant, the hydroxyl radical and hydroxyl ion are abundant. But the hydroxyl cations of these noble gases (i.e., ArOH+, NeOH+, and HeOH+) are yet to be detected in space. Here, we attempt to model the noble gas chemistry containing hydride and hydroxyl cations of noble gases (ArH+, NeH+, HeH+, ArOH+, NeOH+, and HeOH+). We also consider various isotopologs of these hydride and hydroxide cations (36Ar, 38Ar, 40Ar, 20Ne, and 22Ne). The chemical evolution of these species under the diffuse and exotic environment (the Crab nebula filamentary r egion) is studied (Das et al., 2020). The intrinsic line surface brightness is calculated to find a favorable parameter space that can explain the observational features for the condition suitable in the Crab filamentary region. The possibility of detecting some hydride and hydroxyl cations in the Crab nebula environment is also highlighted.

Ambesh Pratik Singh (University of Arizona)

Title: A 1 mm Spectral Survey of the Hypergiant NML Cyg: Insights into of Chemistry and Dynamics

Abstract: A 1 mm spectral-line survey (214.5-285.5 GHz) of the hypergiant star NML Cygni (NML Cyg) has been conducted using the Submillimeter Telescope (SMT) of the Arizona Radio Observatory (ARO). The survey has now been completely analyzed and offers further insight into the properties of hypergiant stars. The envelope of NML Cyg was found to contain a variety of molecules, including the carbon-bearing species CO, HCN, HCO+, CN and HNC, sulfur and silicon-containing compounds H2S, SO, SO2, SiO and SiS, and more exotic NaCl and AlO.. The spectral-line data have been modeled with the non-LTE code ESCAPADE and abundance and spatial distributions determined. The survey has revealed that spectra of certain molecules such as SO2 and SO, as well as CO, have asymmetric line profiles suggesting at least two non-isotropic outflows: a highly-collimated blue-shifted wind near VLSR ~ -21 km s-1 and

a more diffuse red-shifted flow at 15 km s-1, as well as a spherical component near VLSR = 1 km s-1. The LSR velocities of these components align closely with those of 22 GHz water masers. The red and blue velocity components are positioned ~34° and ~12°, respectively, from the line of sight, and are clearly not bipolar. NML Cyg appears to be another example of rare, massive stars with collimated, episodic ejections, analogous to Betelgeuse and VY CMa.

Greg Sloan (STScI)

Title: Dust, pulsation, and metallicity in evolved stars

Abstract: Evolved stars, both supergiants and on the asymptotic giant branch, contribute much of the interstellar dust in their host galaxies. Spectroscopy from infrared space telescopes reveals how that dust depends on the metallicity and pulsation properties of the star. In carbon stars, weakly pulsating variables form limited amounts of SiC dust, but stronger pulsators generate much more dust dominated by amorphous carbon. The metallicity of carbon stars has little impact on their dust. In oxygen-rich stars, the situation is reversed, with a clearer trend of less dust in stars with lower metallicities. The dust forming around oxygen-rich AGB stars includes various mixtures of amorphous alumina and silicates, with crystalline alumina often appearing around semi-regular variables. Supergiants produce mostly amorphous silicates. All of these results provide clues about how the dust condenses in the atmospheres of evolved stars and will help solve the puzzle of how they eject most of their mass as they die.

Sundar Srinivasan (IRyA-UNAM)

Title: The Nearby Evolved Stars Survey: The dust and gas return to the Galactic interstellar medium

Abstract: Evolved stars are key to enriching galaxies with dust, gas, and fusion products through mass loss. For low-mass stars, a large part of this mass loss occurs on the AGB in a dusty wind. Recently, great progress has been made in dust, thanks to e.g. Spitzer, but Galactic studies are impeded by confusion from e.g. extinction or distances. Gas, however, is difficult to observe statistically beyond the Solar neighbourhood for sensitivity reasons. Galactic AGB stars have been studied in molecular lines, but a lack of large, unbiased samples of homogeneous observations makes it difficult to draw statistical conclusions. The Nearby Evolved Stars Survey is observing a volume-limited, representative sample of ~850 sources within 3 kpc in (sub-)mm tracers, to infer mass-loss rates, dust-to-gas ratios and mass-loss histories. I will present our objectives, methodology and some early results. We find a significant difference between observed and predicted sub-mm emission, suggesting large reservoirs of cold dust or changes in dust properties. CO(1-0) maps from the NRO 45m find extended 12CO and 13CO, indicating abundant cold gas, while CO(3-2) maps from the JCMT reveal diverse extended emission at higher excitations. The large sizes highlight the need for deep single-dish data to study the outer envelopes. Preliminary mass-loss rates, expansion velocities, and dust-to-gas ratios for the ~300 sources observed and analysed so far will be presented, and compared with models.

Bao Truong (Vietnam National University)

Title: Modeling extinction and reddening effects by circumstellar dust in the Betelgeuse envelope

Abstract: Dust is believed to form in the circumstellar envelope around the Asymptotic Giant Branch (AGB) and Red Supergiant (RSG) stars. The formation and evolution of circumstellar dust could be affected by radiative and mechanical feedback. In this talk, we present how intense radiation from evolved stars could modify the grain-size distribution through the RAdiative Torque Disruption (RATD) mechanism. Due to the RATD effects, large grains presumably formed in the dust formation zone are disrupted into smaller species of a < 0.5 um. Then we modeled the extinction curve of the Betelgeuse envelope as a case study. Our model showed that the extinction decreases at near-UV, optical, and infrared wavelengths while increasing at far-UV wavelengths due to the abundance of small grains. The consequent flux well reproduced the observations from the near-UV to the near-IR range, which suggested the scenario of driving stellar winds by smaller grains a < 0.1 um. Our model can be used to explain dust extinction and reddening in other RSG/AGB spectra.

Toshiya Ueta (University of Denver)

Title: Views from Spitzer, AKARI, and Herschel: Far-IR Probing of the Extended Circumstellar Shells of Evolve Stars

Abstract: Stellar mass loss is a critical process by which stars enrich the Universe with nucleosynthesized materials material while they self-regulate their own evolution, yet remains poorly understood. Extended circumstellar shells of evolved stars are the Holy Grail to understand this mass loss process as they record pristine histories of mass loss over a long time in their density distributions of cold thermal dust emission in the far-IR. The fact that density distributions permit time variations of mass loss to be traced directly gives a clear advantage over more traditional methods of estimating the rate of mass loss from, for example, photometry. By this contribution, accomplishments made with the latest trio of far-IR satellites, Spitzer, AKARI, and Herschel, are briefly reviewed and forthcoming prospects are summarized.

Marie Van de Sande (University of Leeds)

Title: The impact of UV photons of a stellar companion on the chemistry of AGB outflows

Abstract: Binary interaction with a (sub)stellar companion has been proposed to be the driving mechanism behind large-scale asymmetries observed within AGB outflows, such as spirals and disks. Additional evidence comes from observations of UV emission, which could be intrinsic to the AGB star or could arise from an external source, such as an accretion disk or a stellar companion. A stellar companion's UV radiation can impact the chemistry of the outflow. We developed the first chemical kinetics model that takes the effect of the UV radiation field of a stellar companion into account. We present a first analysis on any effect a stellar companion might have on the chemistry using our one-dimensional gas-phase chemical model. We vary over a red dwarf, a solar-type star, and a white dwarf companion within different O-rich and C-rich outflows. We find that the presence of a close-by stellar companion can initiate a rich photochemistry in the dense inner wind. This type of chemistry is otherwise restricted to the tenuous outer regions of the outflow, where it is initiated by interstellar UV photons. The chemistry throughout the entire outflow can be affected, the resulting composition depends on the extinction within the outflow and the companion's radiation field. Observations of the outflow's molecular content, especially when combined with abundance profiles, could indicate the presence of a stellar companion.

Albert Zijlstra (University of Manchester)

Title: Mass loss on the AGB

Abstract: AGB stars lose mass in extreme stelar winds. The mechanism which drives the wind, and its limits, has long been controversial but is now becoming clearer. The winds appear symmetric at large scales. However, in later phases of the evolution, post-AGB stars and planetary nebulae, the morphologies are very different. This talk will review our current knowledge on AGB winds and on their shaping.

Lucy Ziurys (U. of Arizona)

Title: Chemical Trends in Evolved Stellar Objects: From Red Giants to Planetary Nebulae

Abstract: The chemistry of the carbon-rich circumstellar envelopes of asymptotic giant branch (AGB) stars has been studied for decades, mostly through observations of IRC+10216. Such measurements have shown that this object has a rich chemical content, with long carbon chain species, a wide range of silicon-bearing molecules, and exotic compounds with metals (Al, Mg, Na, K, Fe) and phosphorus. Studies of other evolved stellar sources has not been nearly as thorough. Recently, however, the envelopes of oxygen-rich stars have gained attention. Sensitive molecular line surveys have been caried out for red supergiant stars (RSGs), including VY Canis Majoris (VY CMa), NML Cygnus (NML Cyg) and Betelgeuse (Alpha Ori). Surprisingly, the envelopes of VY CMa and NML Cyg are chemically complex, with their own examples of unusual molecules such as PO, VO and AlO. In contrast, the circumstellar shell of Betelgeuse appears to have very few chemical species. The envelopes of O-rich AGB stars, objects that have not yet exhibited thermal pulses and third dredge-up (E-AGB vs. TP-AGB), are not particularly molecule-rich either, although they do contain PO and PN. The envelopes of extreme hypergiants therefore appear to foster the most complex chemistry of O-rich stars, perhaps because of their energetic and asymmetric mass loss histories. The molecular content of planetary nebulae (PNe) has additionally been probed by more recent observations. Over thirty PNe have now been found to contain polyatomic molecules, including HCN, HCO+, CCH, c-C3H2 and HNC, and building towards greater chemical complexity with detections of CH3CN, CH3CCH and CH2NH. Sulfur-bearing molecules (SO, SO2, and H2S) have also been identified in various nebulae. In analogy to AGB envelopes, the C-rich PNe seem to be more chemically complex, as those with bipolar morphologies. Perhaps the most interesting finding is that molecular abundances remain relatively constant with age of the nebulae, even beyond 10,000 years of PNe evolution. The molecular abundances in PNe do vary from the AGB phase, for example, those of HCO+ and HNC drastically increase while HCN abundances decreases. Molecular abundances appear to be altered in the protoplanetary (PPNe) stage, and the "freeze-out" in PNe. A significant decrease in the 12C/13C ratio is also found in PNe relative to C-rich AGB envelopes, providing clues to the nature of the PPNe phase.