The Interstellar Medium in the Nearby Universe: SOFIA Science Vision Ideas

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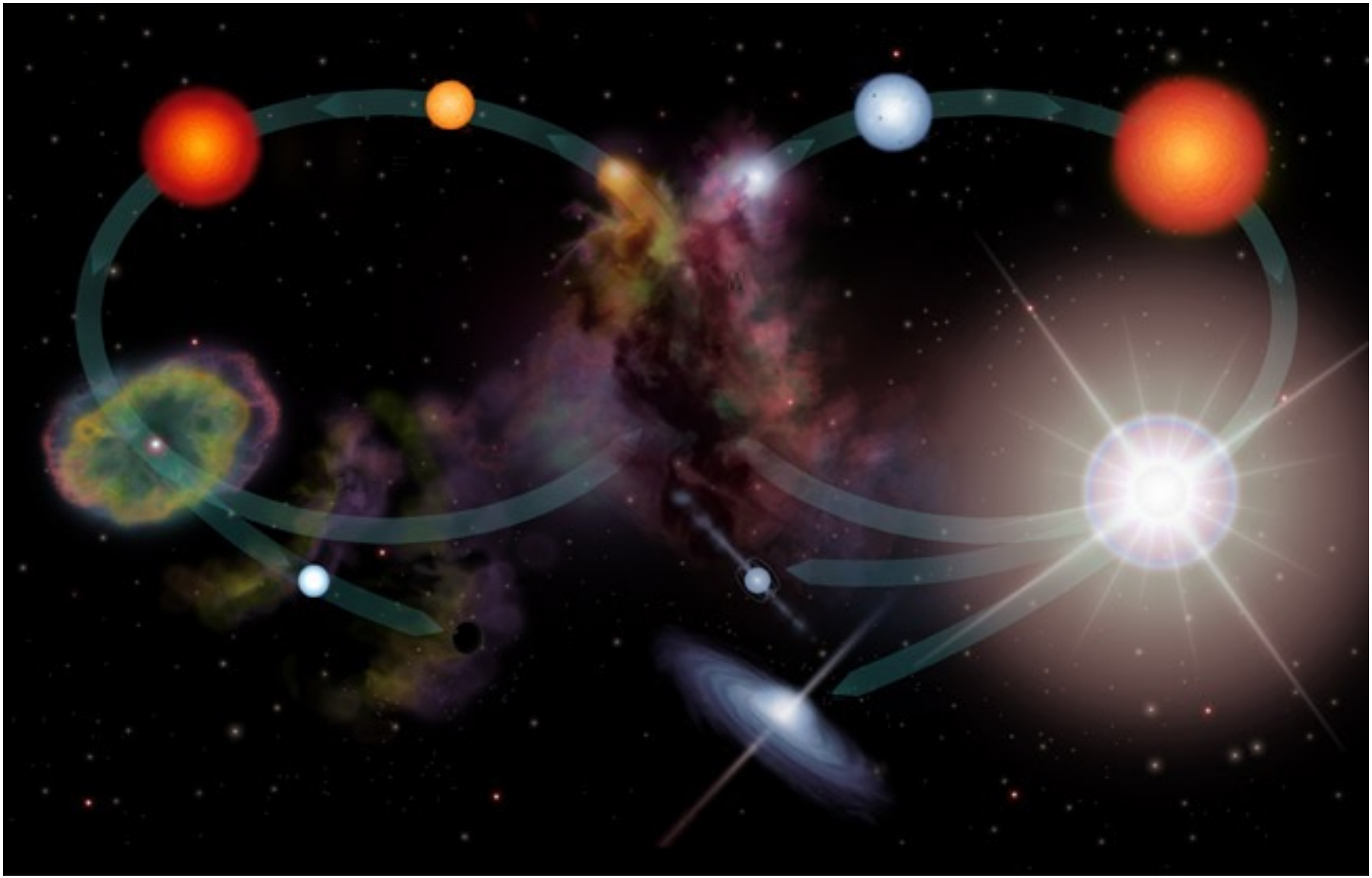
Outline of talk

- Scientific context for SOFIA in the post-Spitzer, post-ISO and Herschel era:
  - Spitzer SAGE surveys of the Magellanic Clouds
  - Herschel HERITAGE survey of MCs
- SOFIA's special contribution to this area
- Questions that could be addressed by SOFIA
  - Calculations necessary

SAGE: Tracing the Lifecycle of Baryonic Matter:

Intermediate mass stars High mass stars

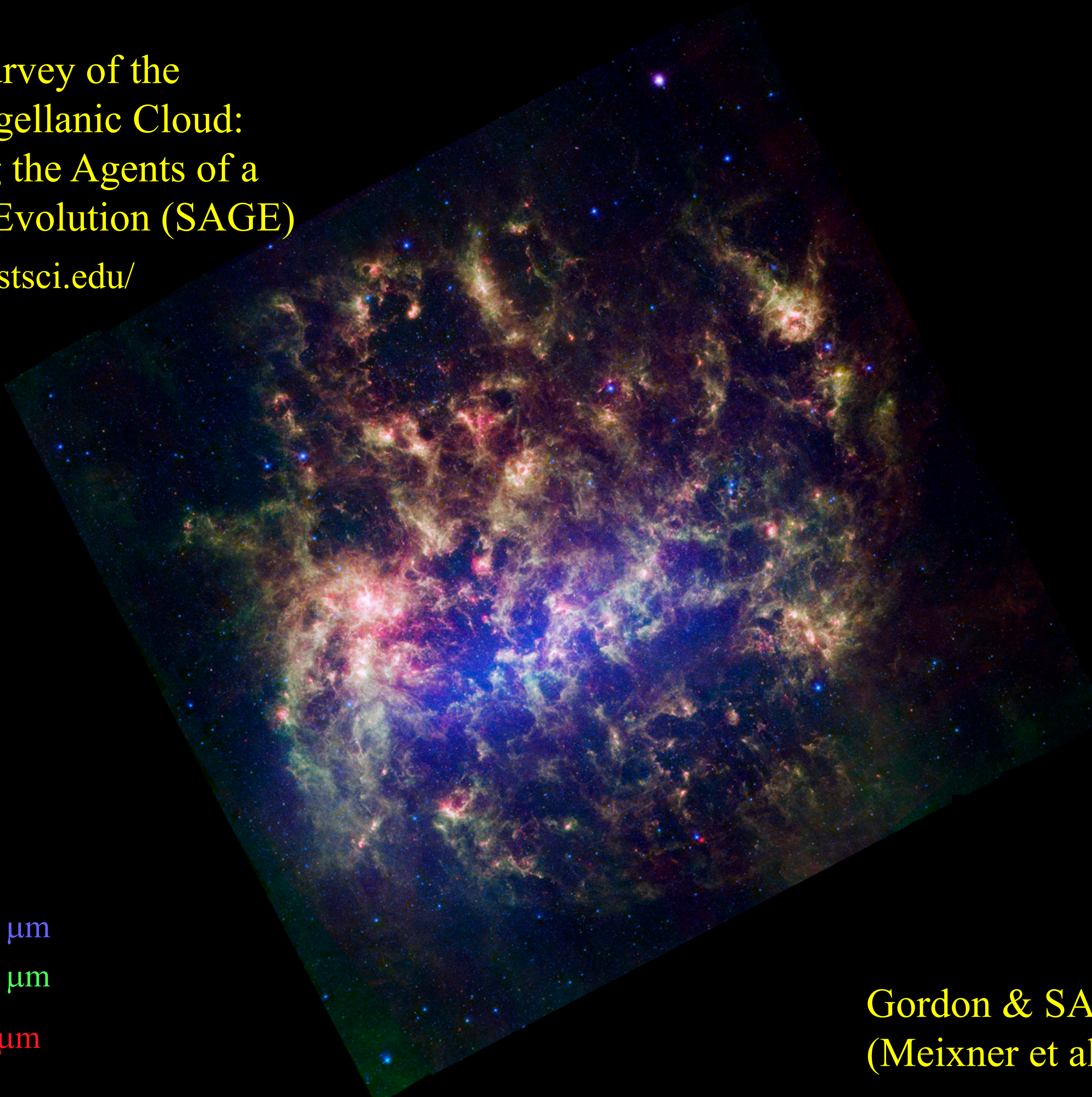


3 September 2008 M. Meixner/ HERITAGE- SOFIA

credit: http://hea-www.cfa.harvard.edu/CHAMP/EDUCATION/PUBLIC/ICONS/

Spitzer Survey of the
Large Magellanic Cloud:
Surveying the Agents of a
Galaxy’s Evolution (SAGE)

http://sage.stsci.edu/

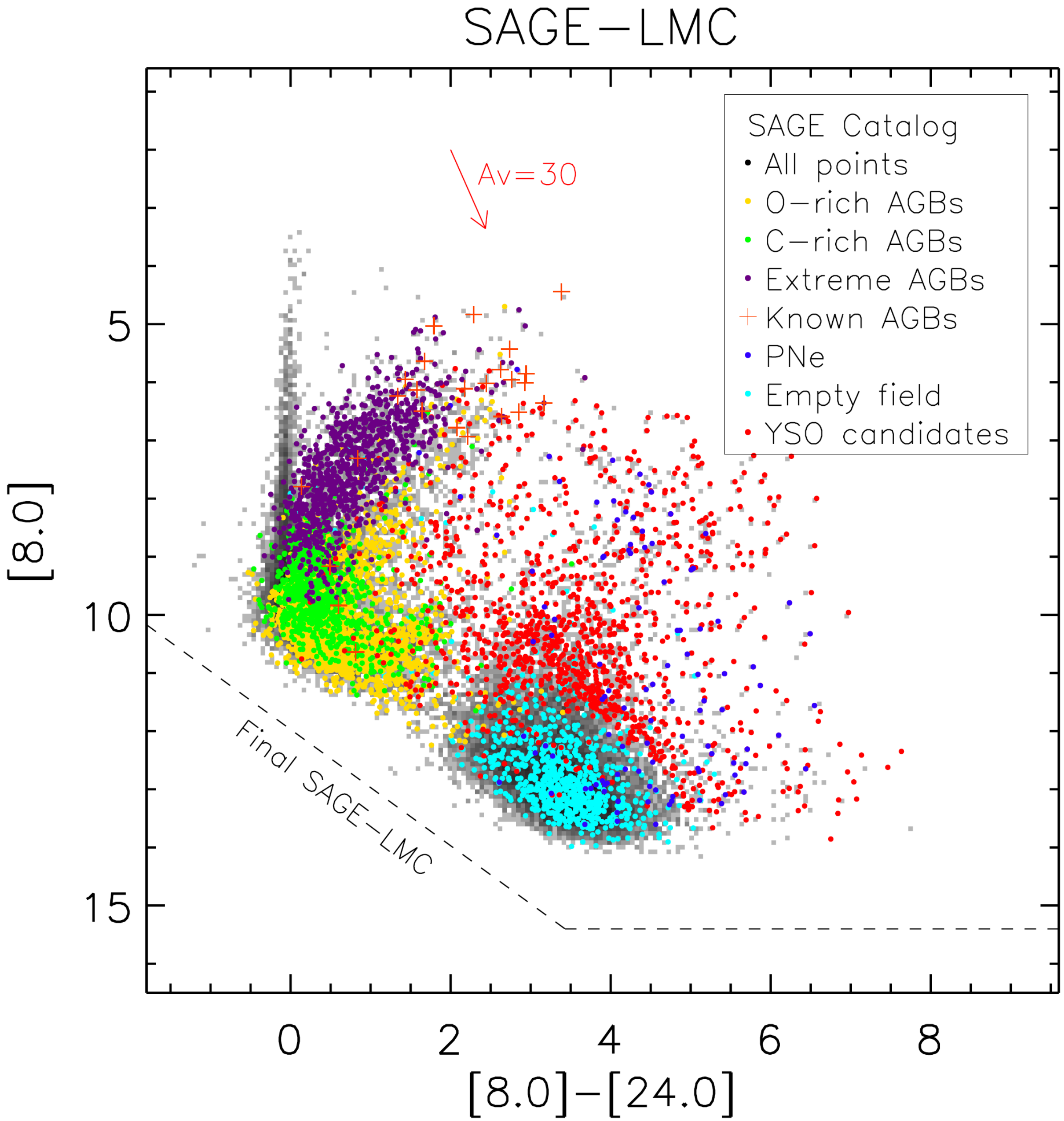


IRAC 3.6 μm

IRAC 8.0 μm

MIPS 24 μm

Gordon & SAGE team
(Meixner et al. 2006)



SAGE Point Source Populations:

AGB stars: Blum et al. (2006)
YSO candidates: Whitney et al.
PNe: Hora et al. (in prep.)
Empty field = background galaxies: Whitney, Sewilo et al.

Sewilo & SAGE Team (2006)

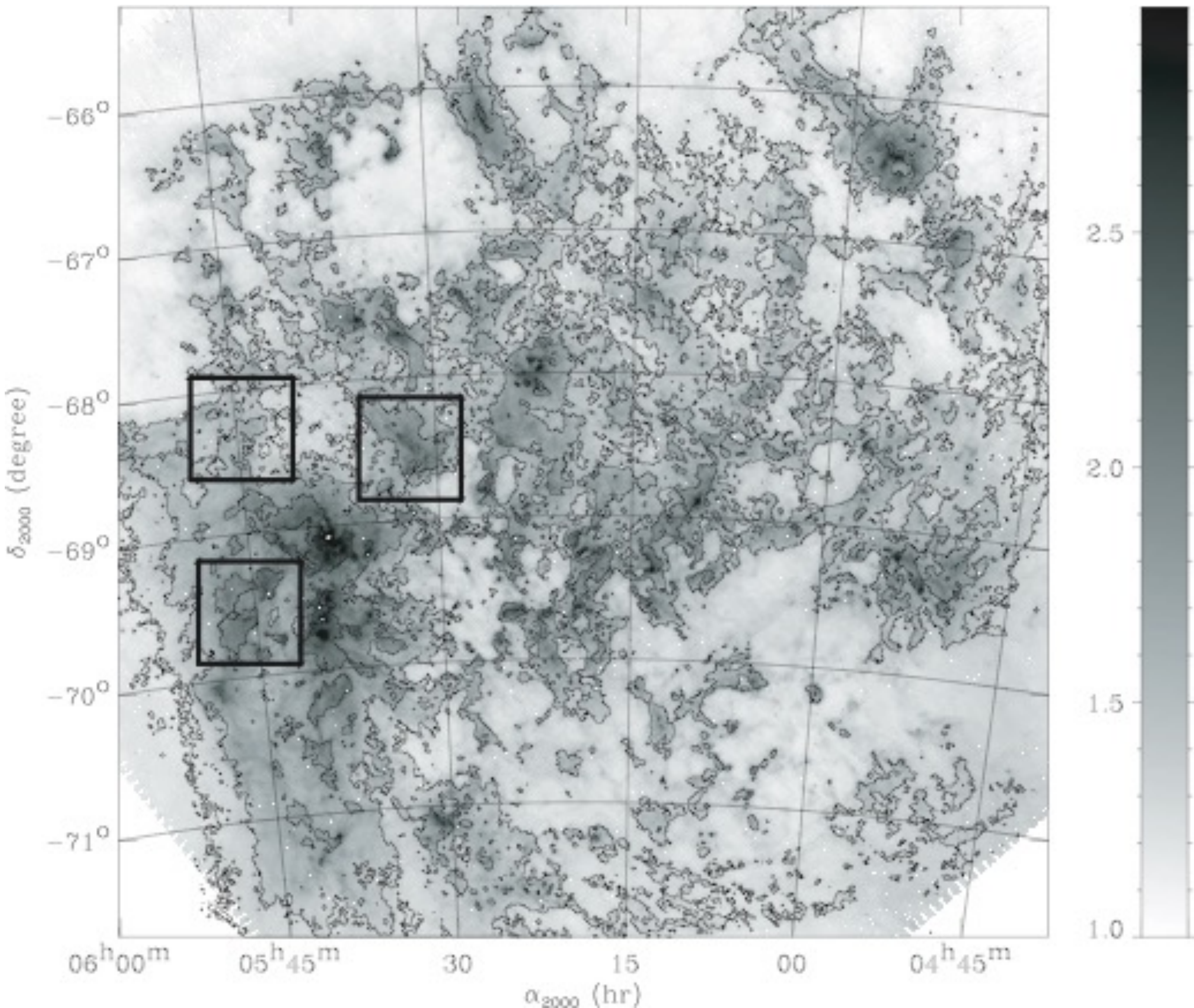
MIRI/JWST [8.0]~17.5

SAGE key questions:

– ISM: What are the properties and abundance of dust in different parts of the ISM in the LMC?
– Star Formation: What is the galaxy-wide star formation rate of the LMC and how do the details vary on a scale of a few pc?
– Evolved Stars: What is the mass budget of material injected into the ISM by evolved stellar winds?

Meixner & SAGE Team
http://sage.stsci.edu/

160 um and the HI contours

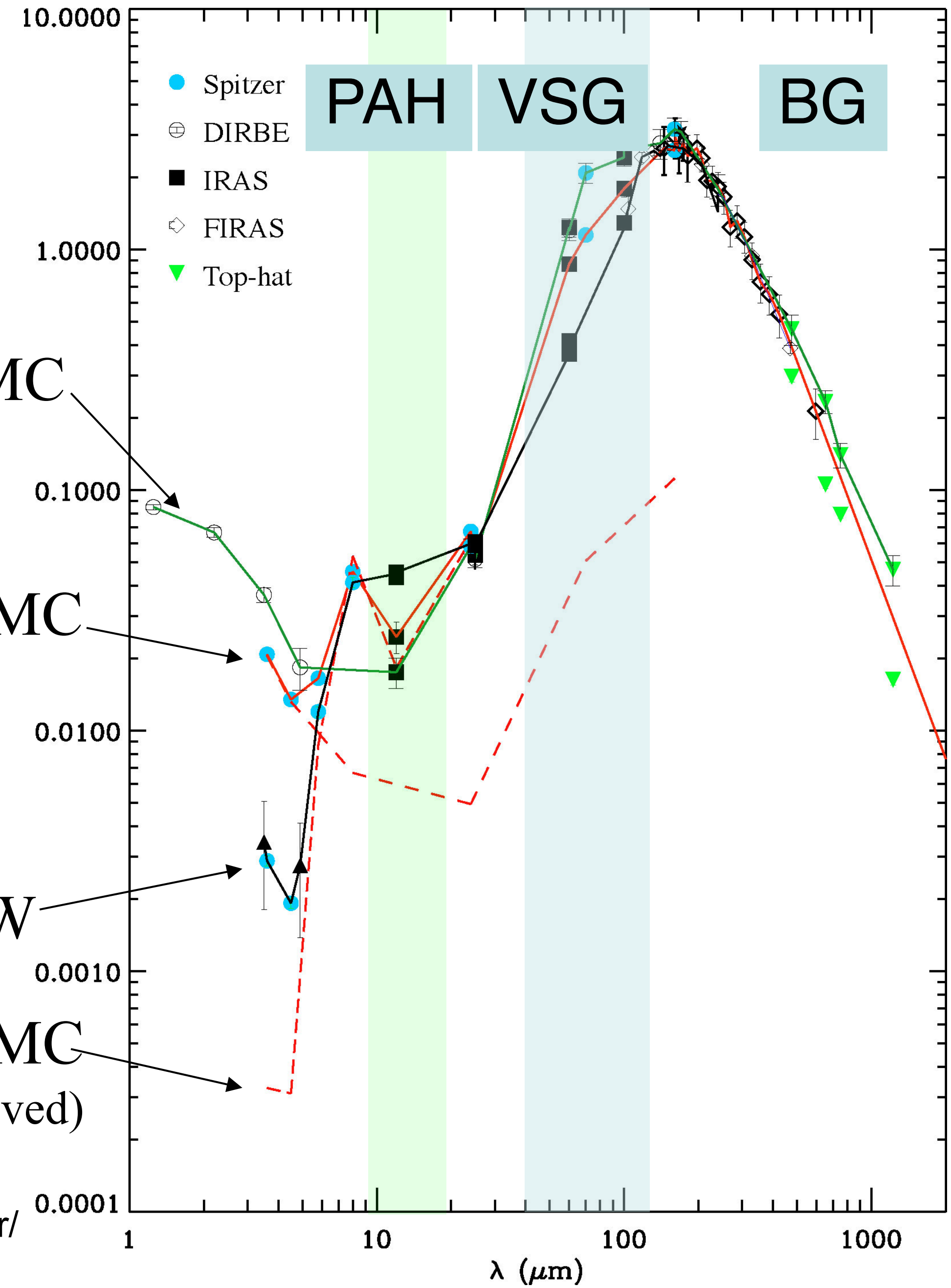


Bernard et al. (2008) in press

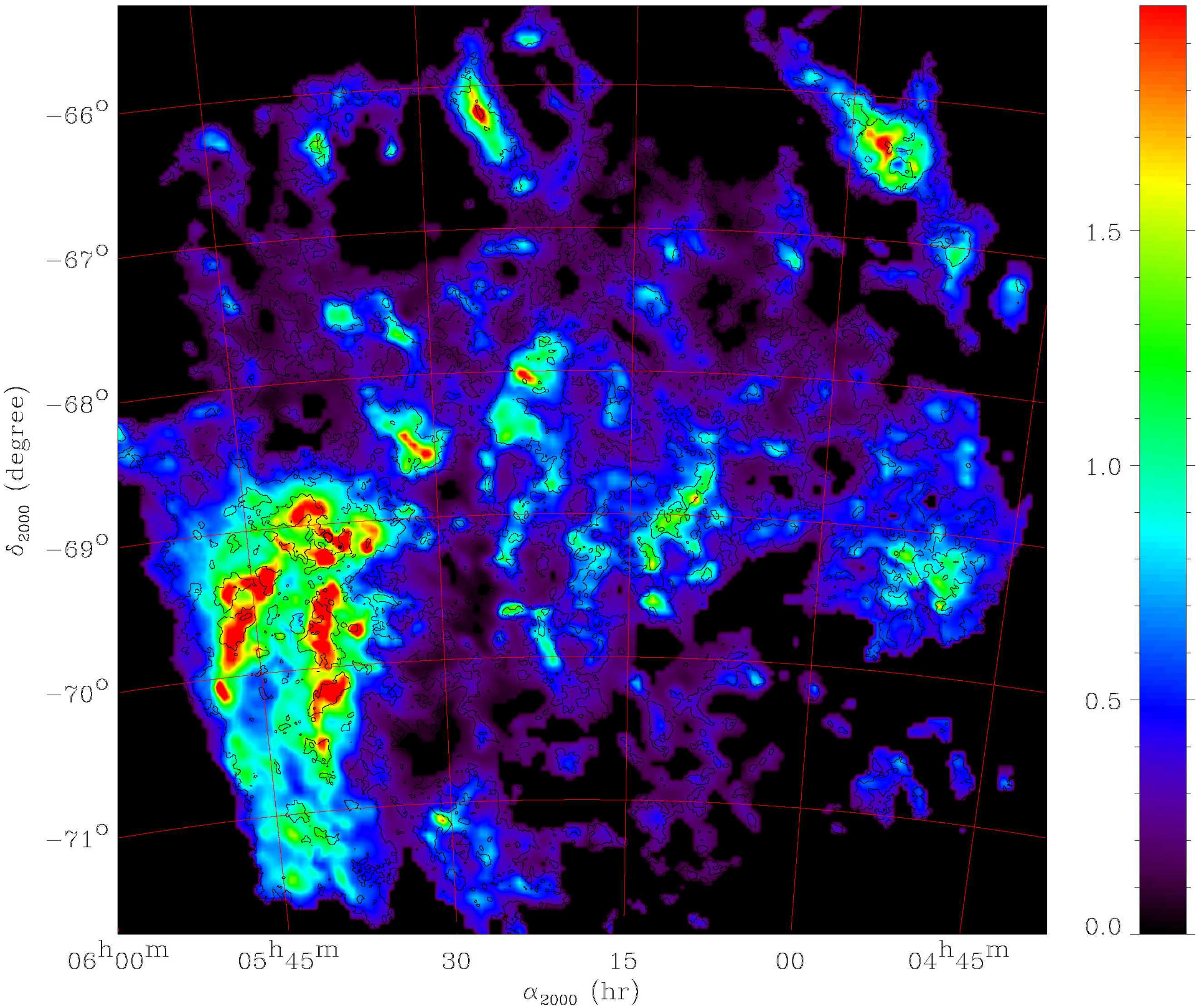
Integrated SED includes DIRBE, IRAS, Spitzer, FIRAS, Top-hat Bernard et al. 2008 (in press)

SMC SED from Leroy et al. 2007

Large excess observed at 70 μm
Excess rising from MW to SMC
(rising with decreasing metalicity)



LMC FIR excess map & ISM mass



Color: N_H^x

Units: 10^{22} H/cm^2

Contours H_I

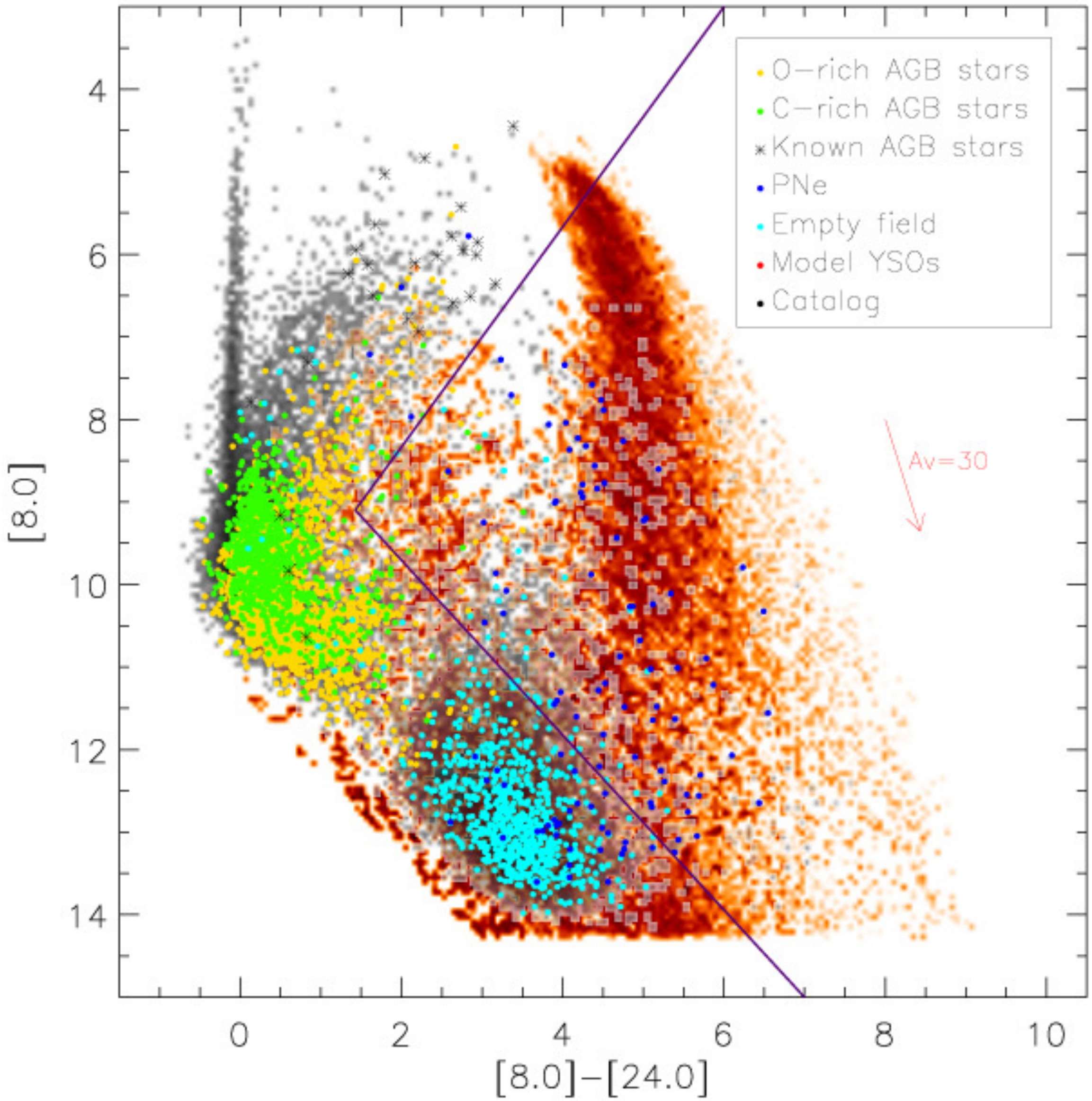
Total mass of excess component = HI mass = 5.6×10^8 Msun

Total mass of ISM (MIPS 160 um): $\sim 10^9$ Msun

Total mass of LMC: $\sim 9 \times 10^9$ Msun

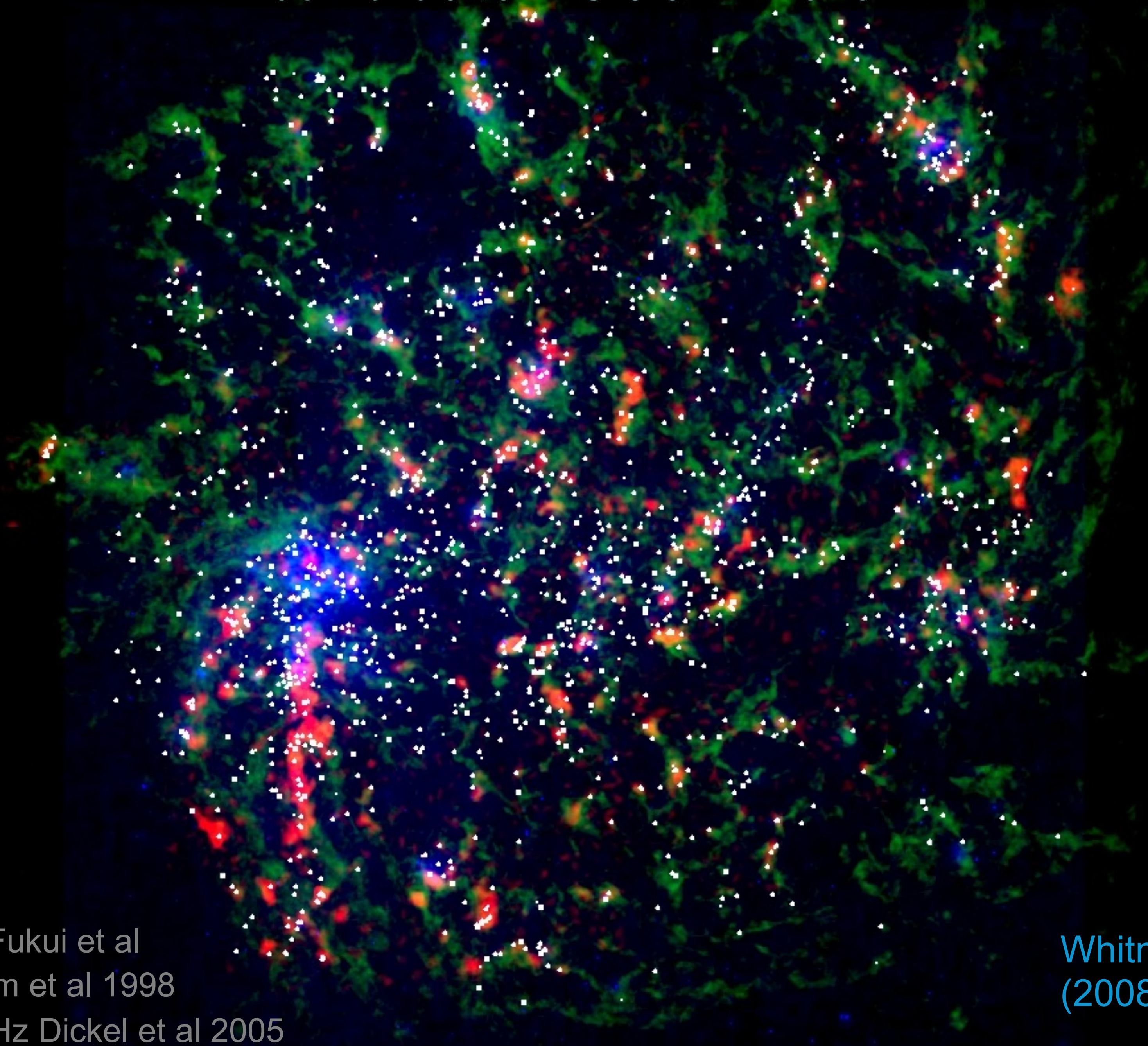
Bernard et al. (2008; in press)

point sources ~ candidate YSOs/protoclusters



Whitney, Sewilo et al. 2008, in press

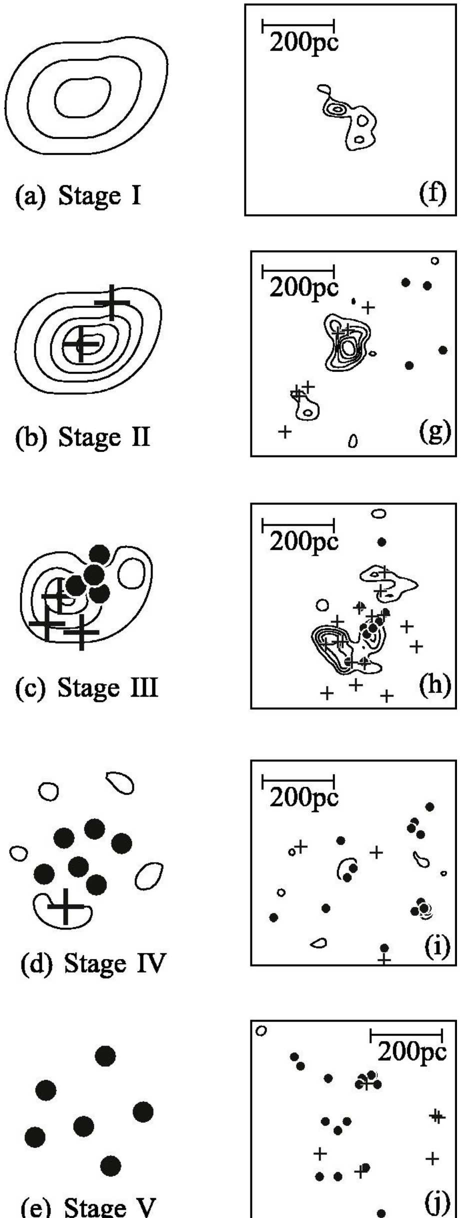
candidate YSOs: where?



R: CO Fukui et al
G:HI Kim et al 1998
B:4.8GHz Dickel et al 2005

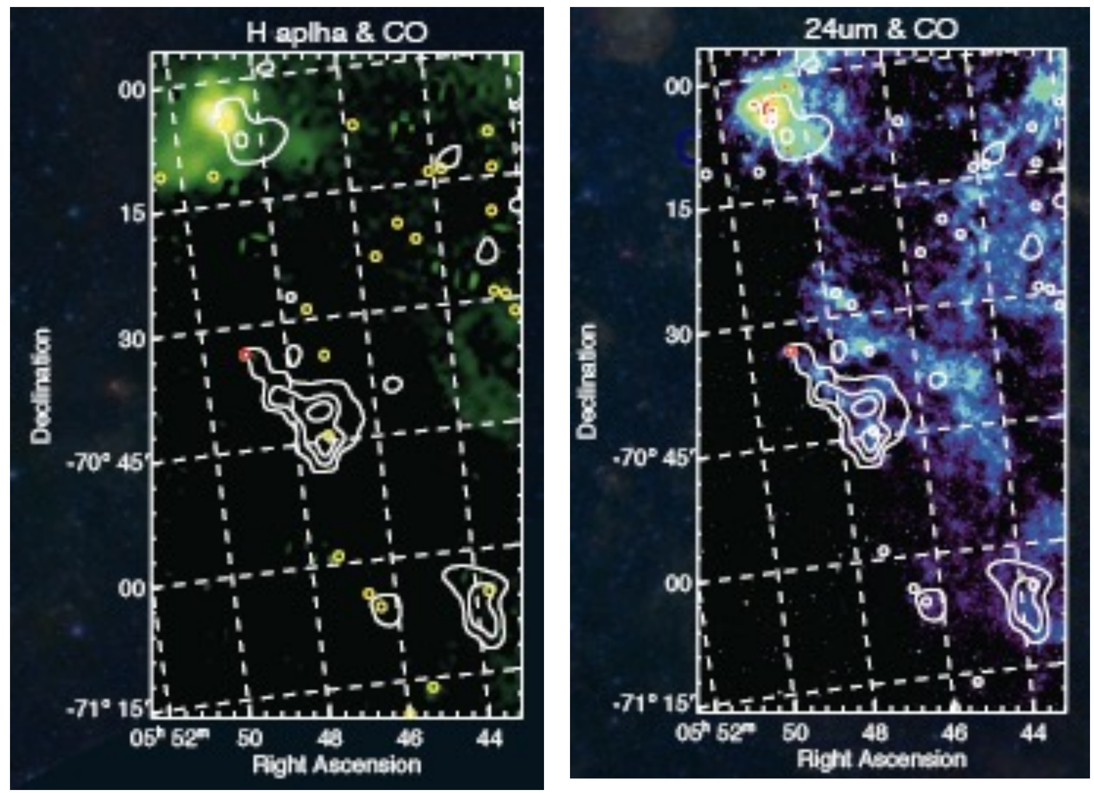
Whitney, et al.
(2008 in press)

timescales and “starless” clouds



← Yamaguchi et al. 2001

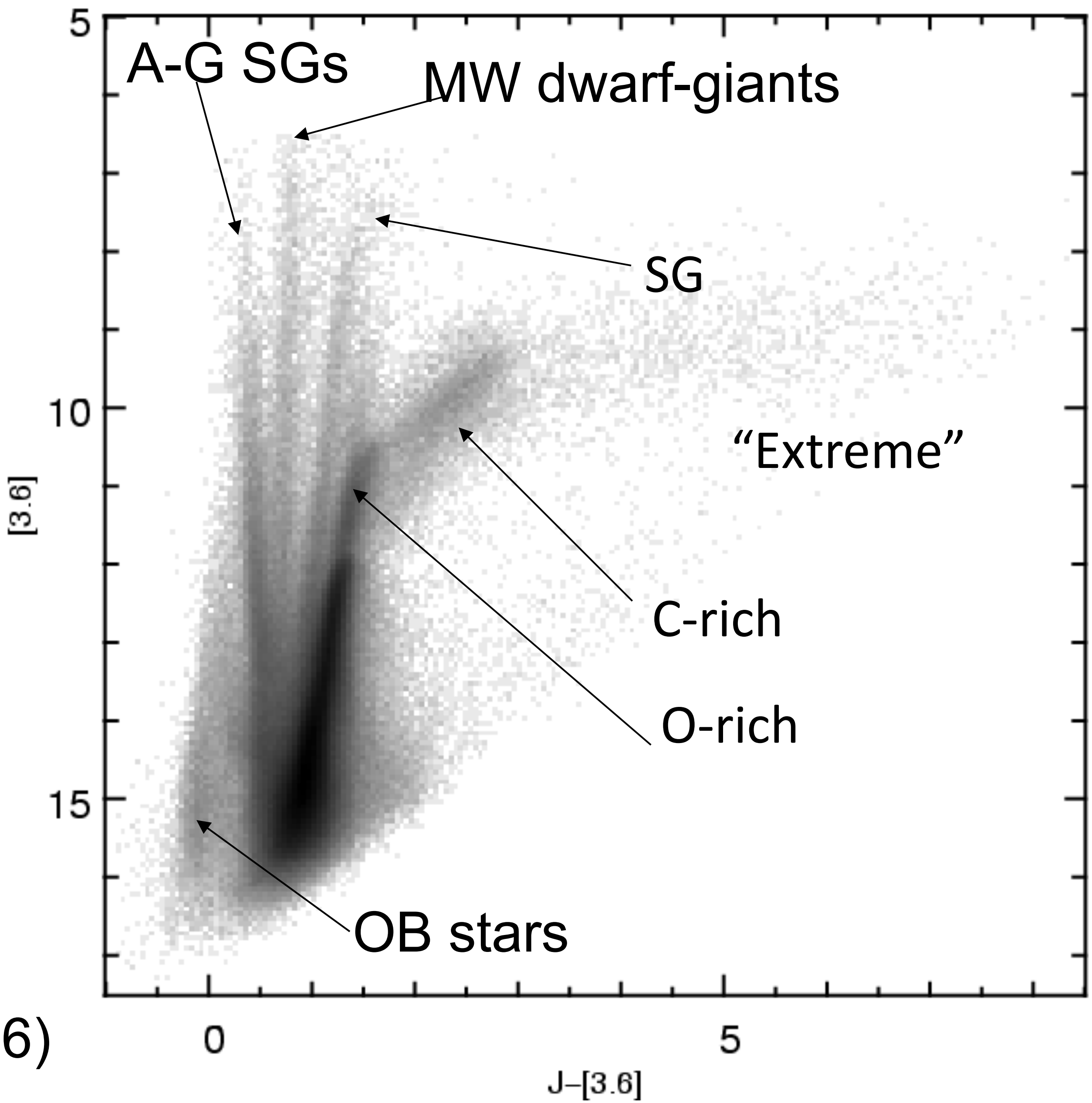
timescales of clouds and clusters



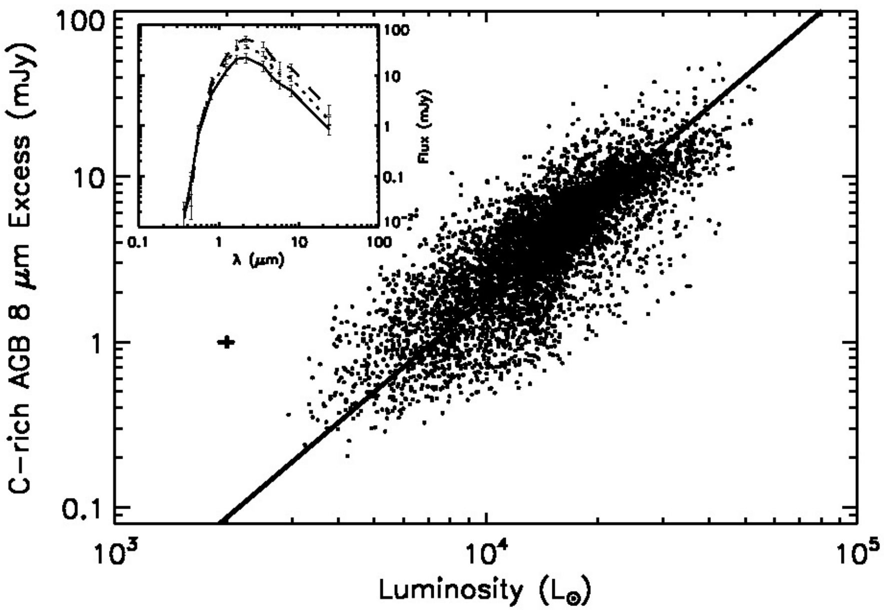
some optically starless molecular clouds (Type I) have some IR star formation, but not as much as Type II and III

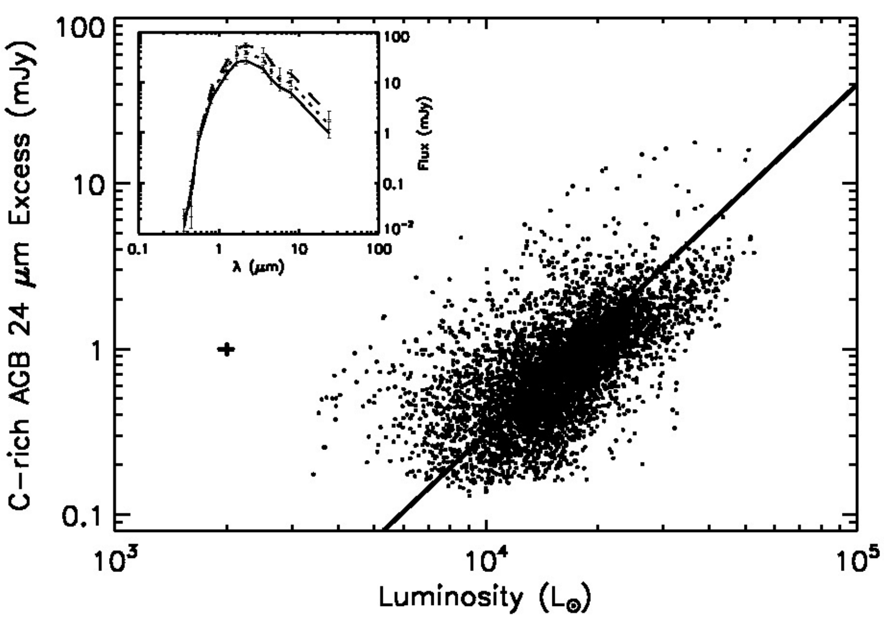
Onishi, Kawamura et al. 2008 in prep

- AGB, SG
- AGB->O-rich become C-stars during dredge up
- Lower Z, easier to get C/O > 1
- Extreme stars mostly C-rich, but need spectra to decide



Blum et al. (2006)





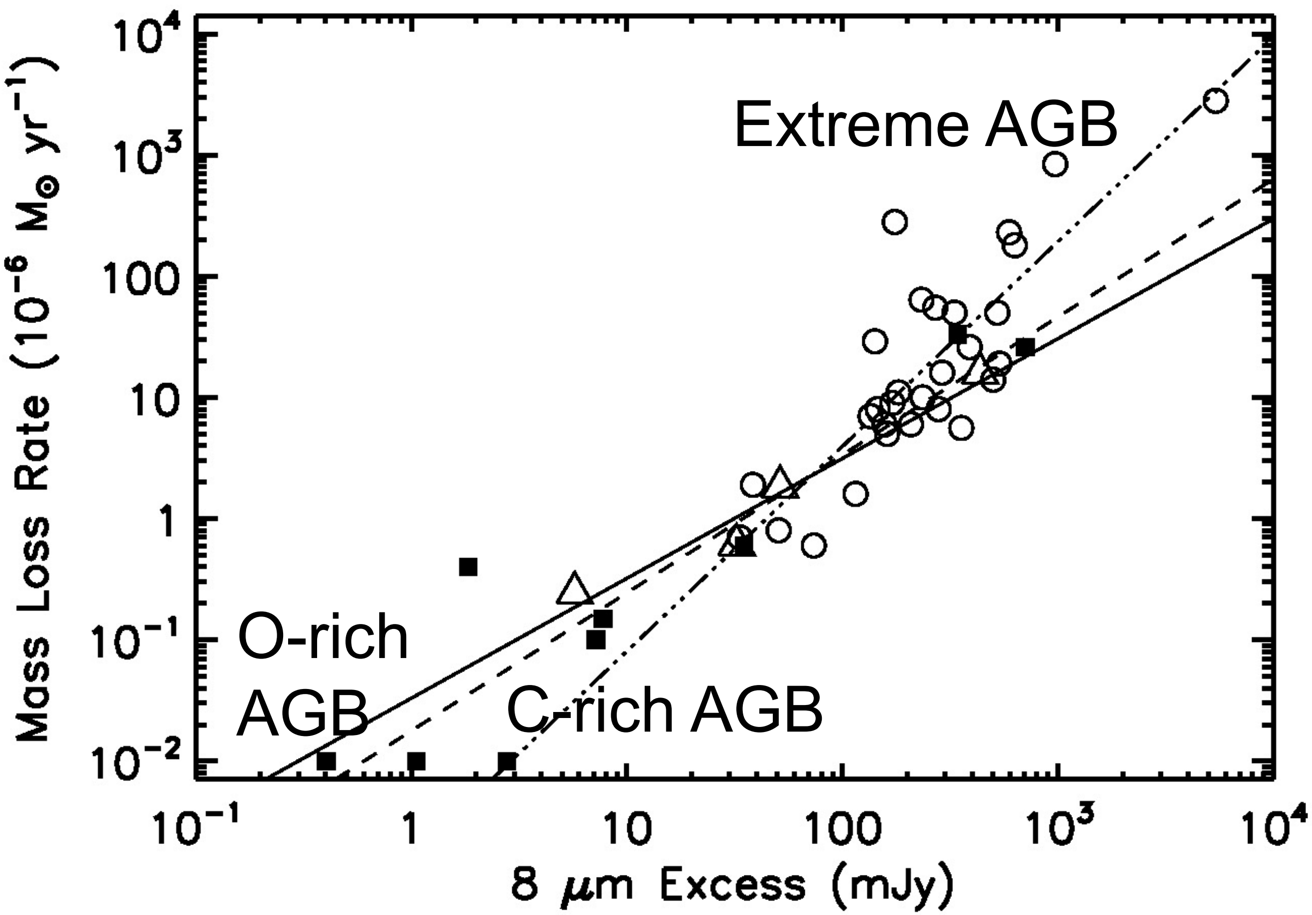
Empirical Shell Properties

- C-rich AGB stars

Srinivasan et al. (2008) submitted

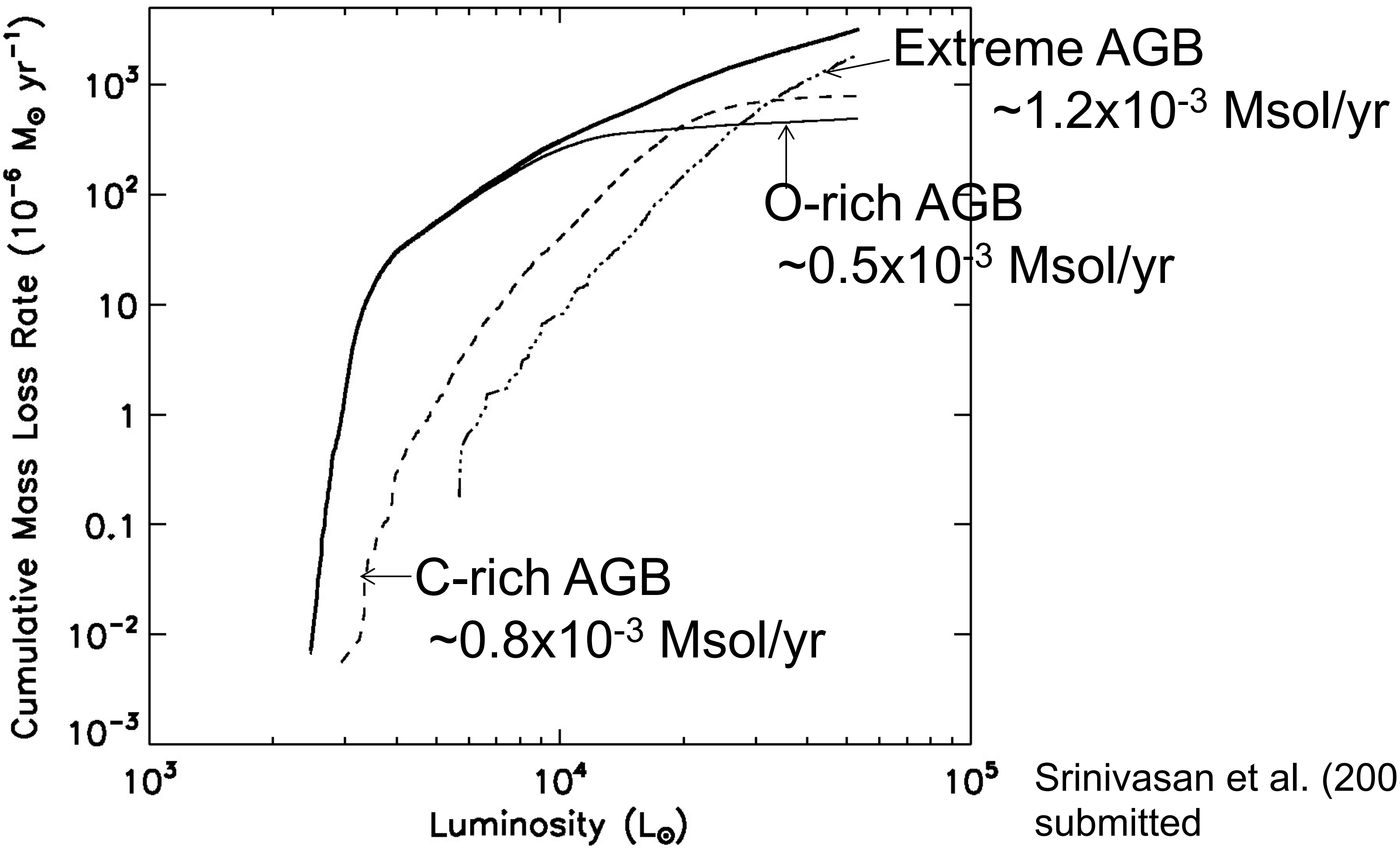
GE- SOFIA

Mass Loss Rate vs. 8 um excess



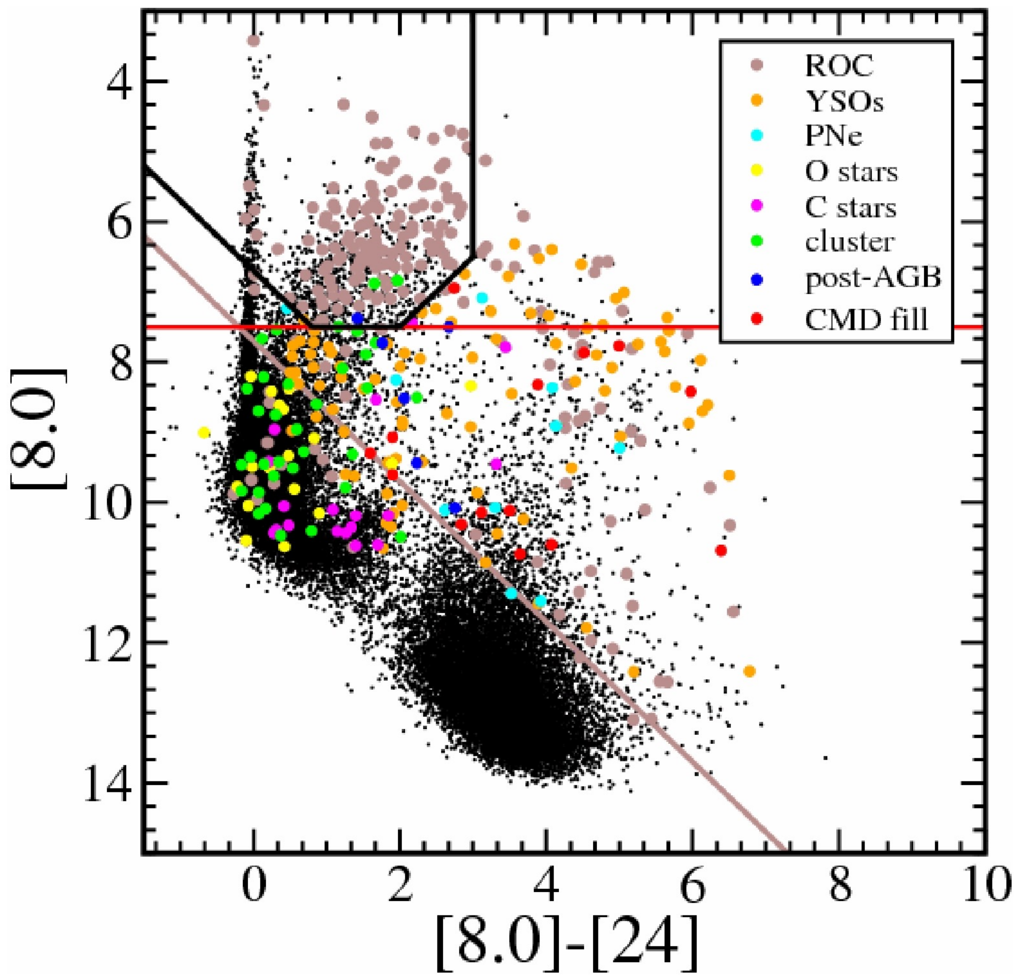
Srinivasan et al. (2008) submitted

AGB star mass loss return: $2.5x10^{-3}$ Msol/yr



Srinivasan et al. (2008) submitted

SAGE Legacy continues:

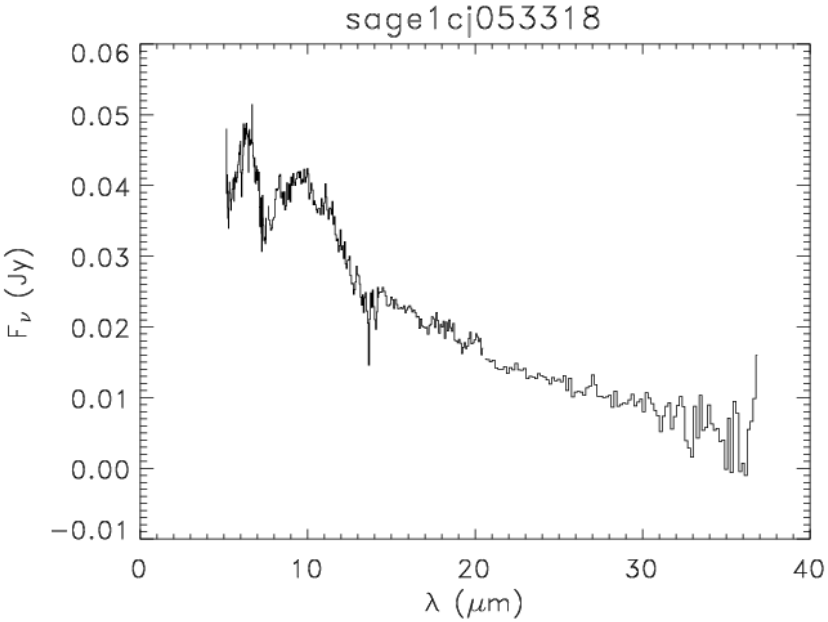


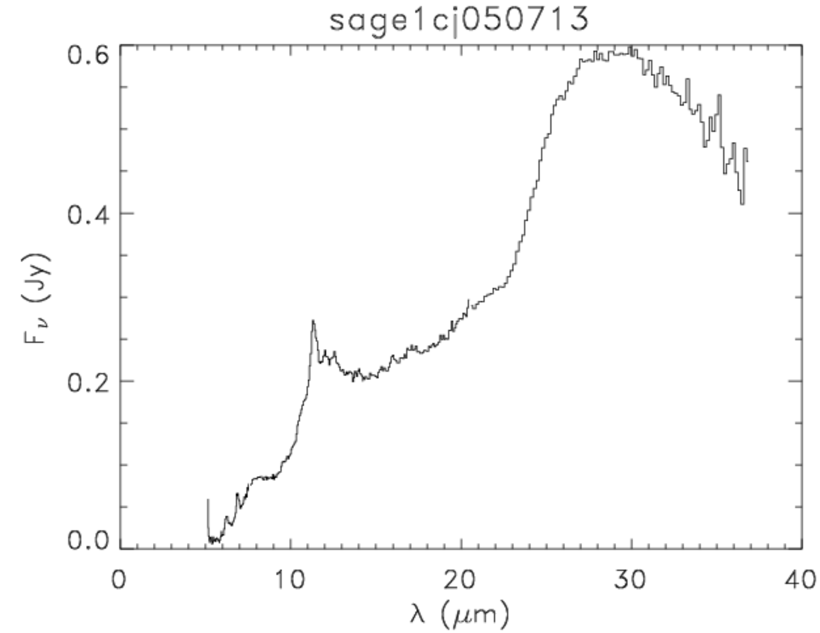
SAGE-Spec:
PI: Ciska Markwick-Kemper
(U Manchester) &
Xander Tielens
(NASA/Ames)

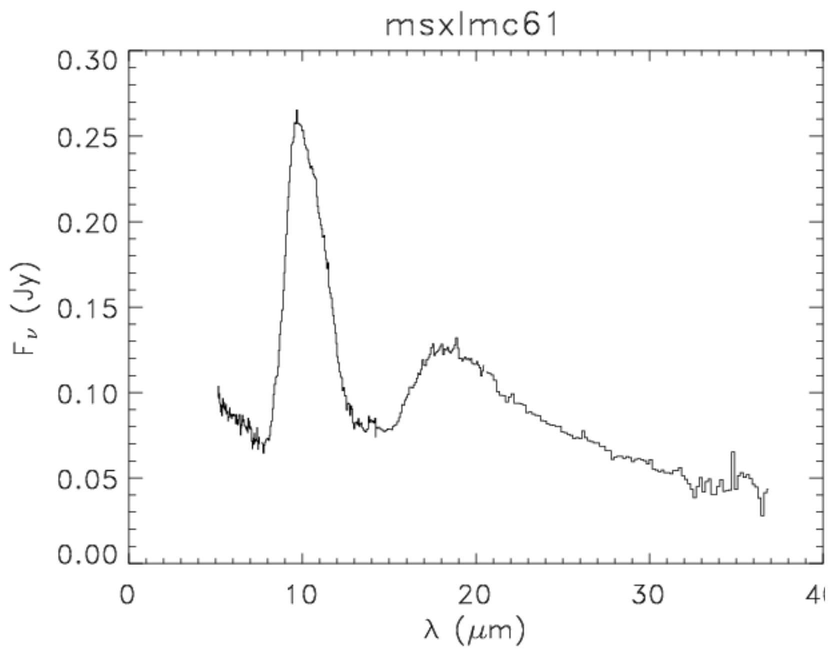
Spitzer IRS & MIPS SED Followup to SAGE-LMC

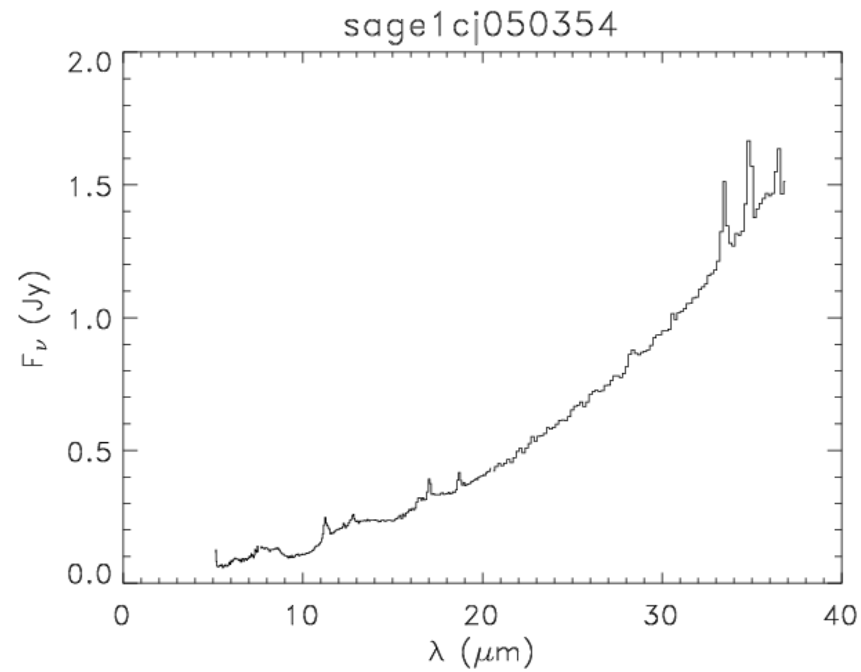
Goal to sample CMD Space.

SAGE-IRS spectra



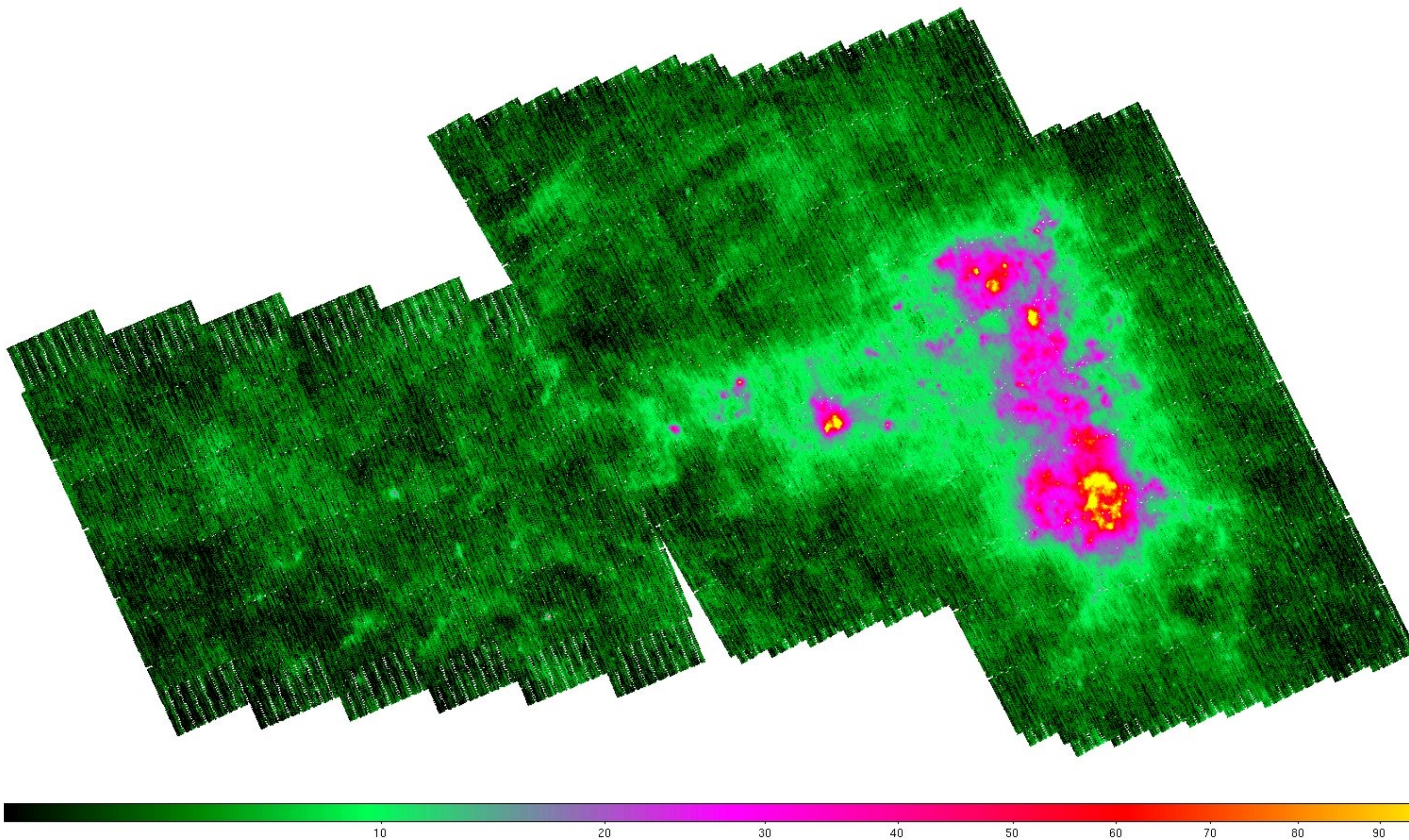




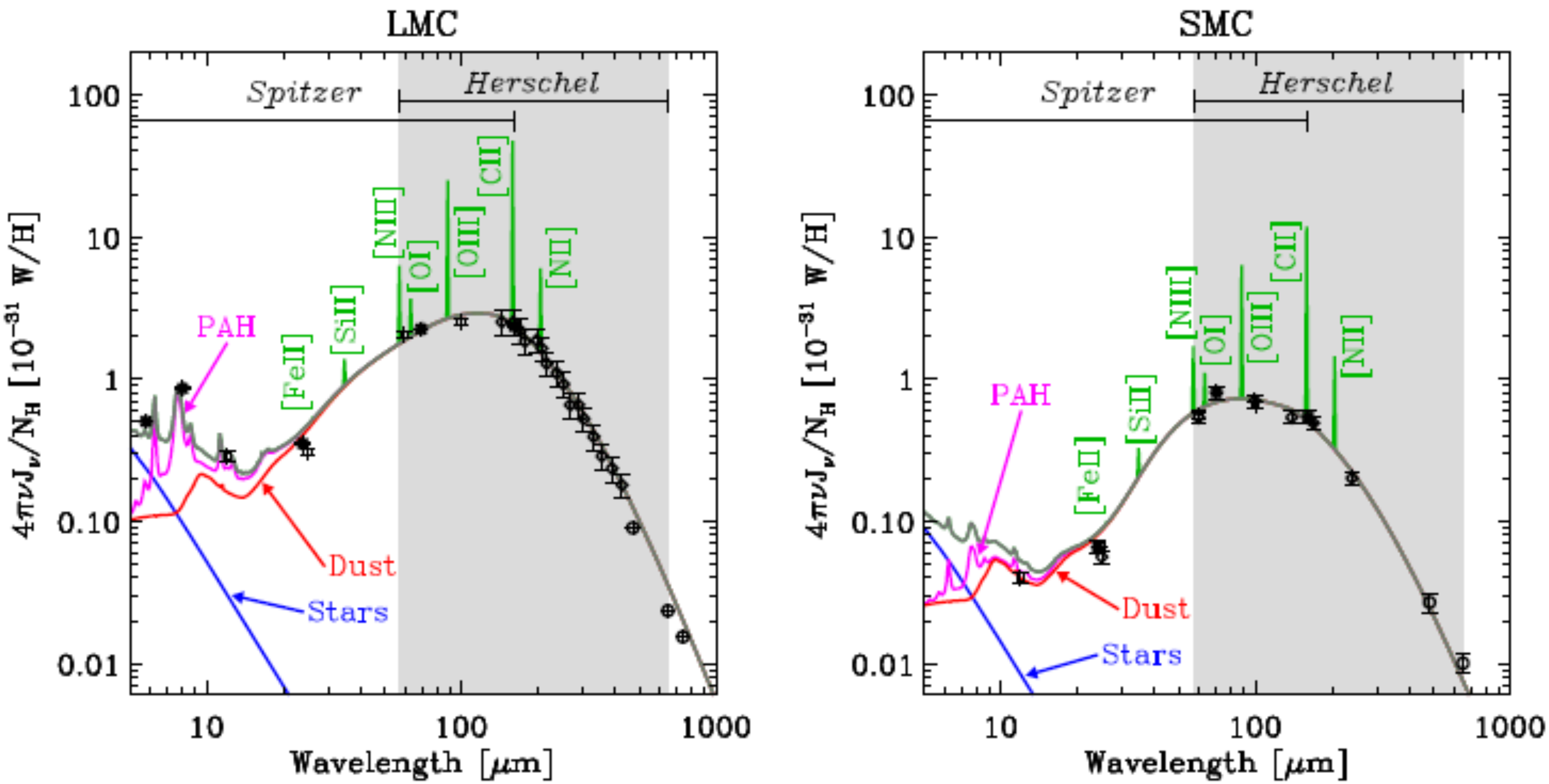


SAGE Legacy continues:

SAGE-SMC: PI Karl Gordon (STScI)
Spitzer IRAC & MIPS Imaging of Small Magellanic Cloud

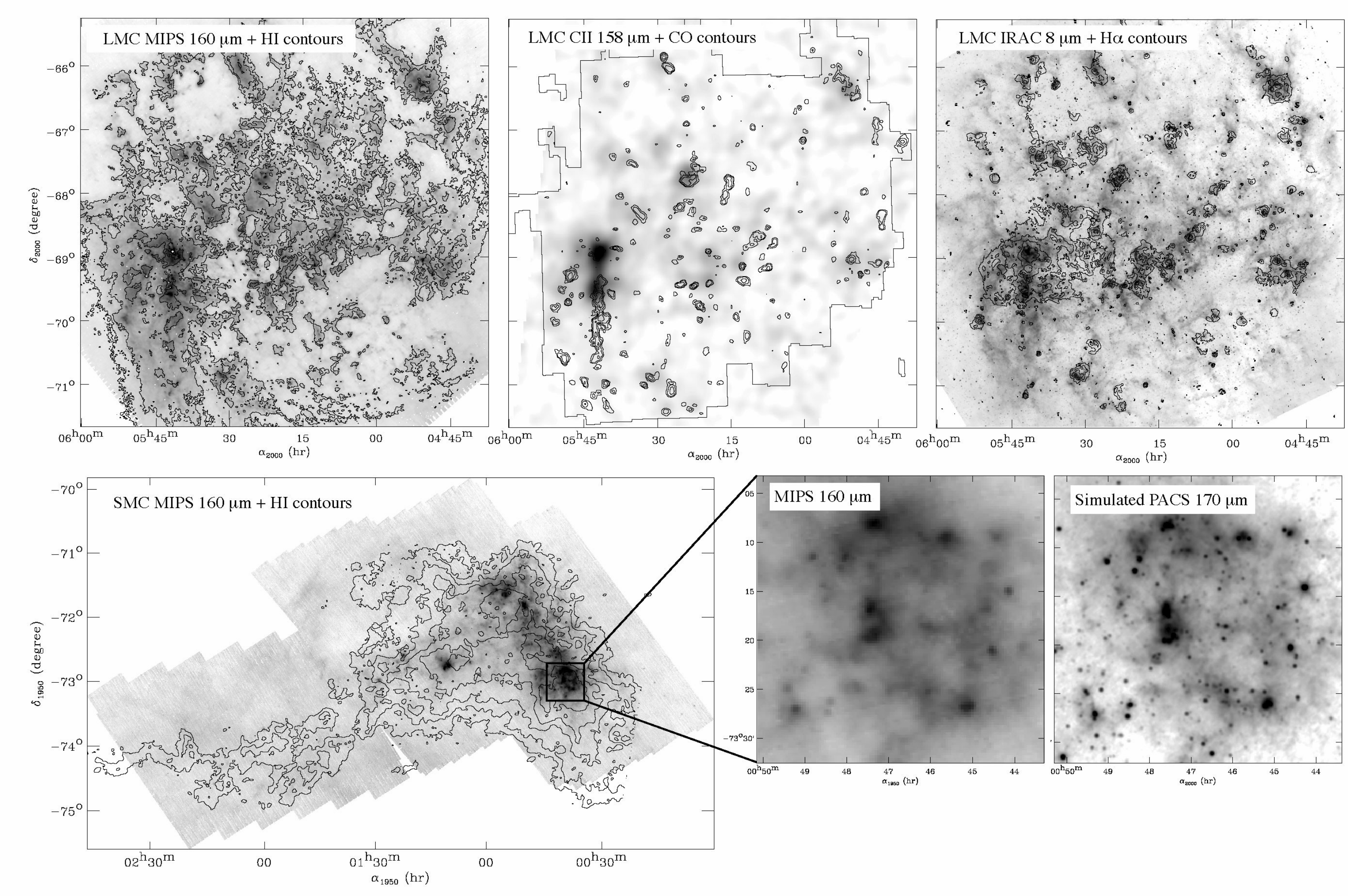


HERschel Inventory of The Agents of Galaxy Evolution: HERITAGE

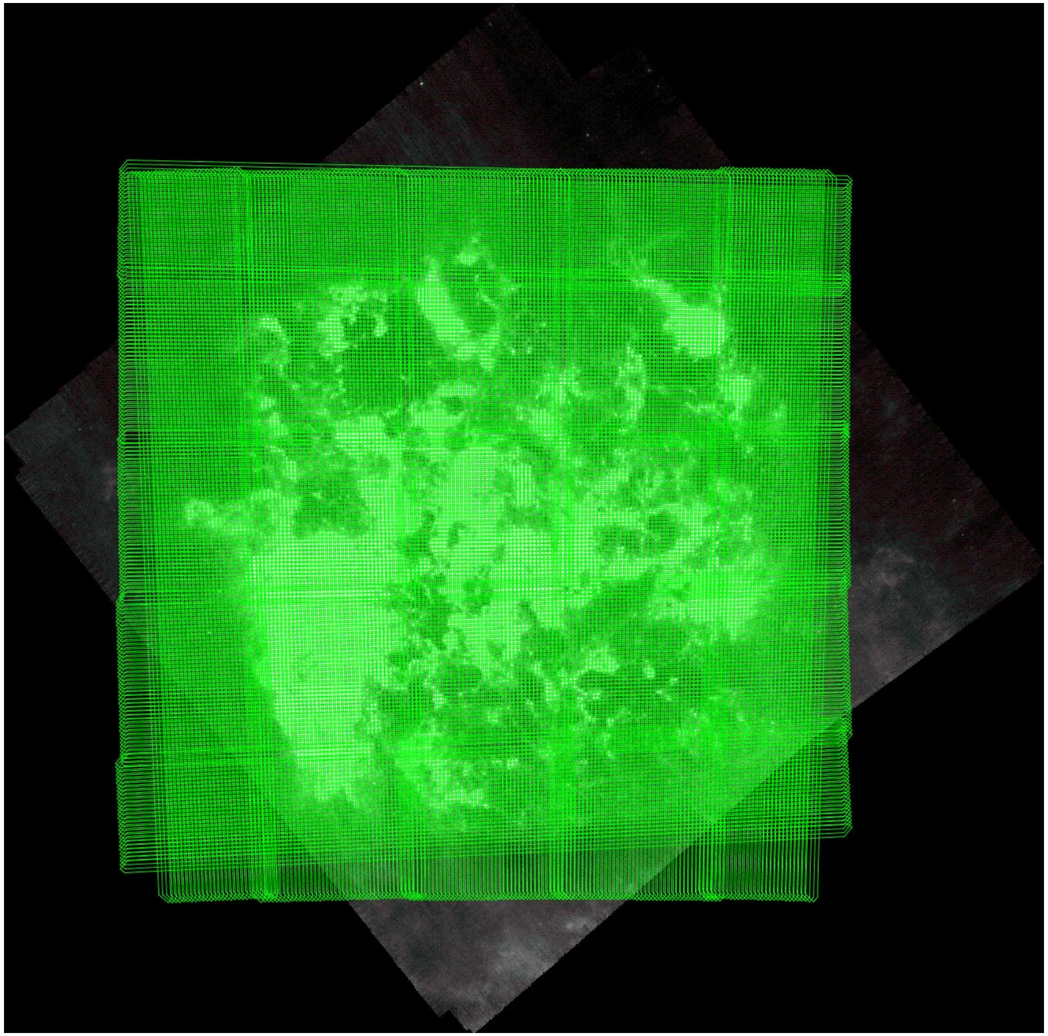


Meixner & HERITAGE team

Context for HERITAGE



SPIRE coverage on SAGE-LMC 160 micron image



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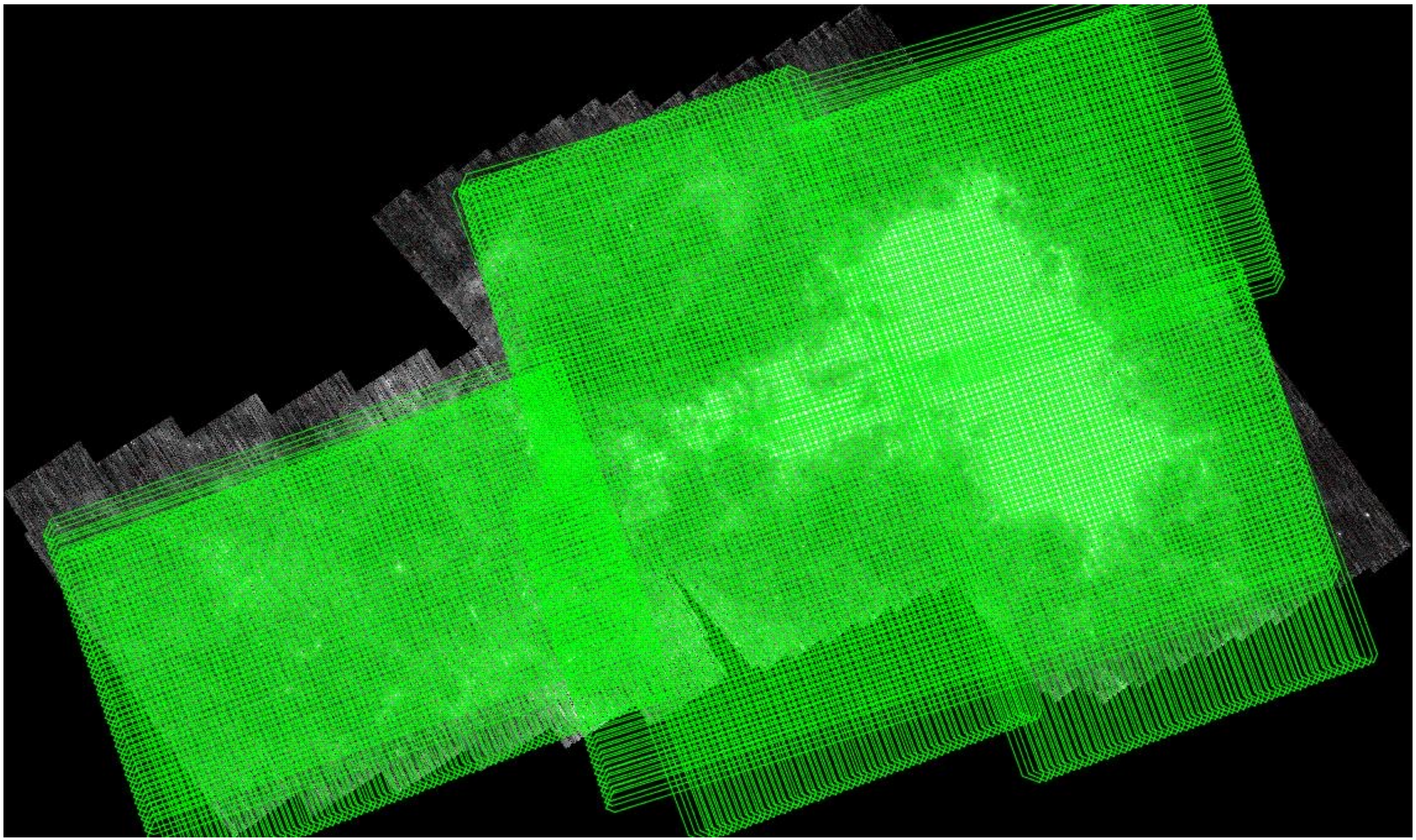
SPIRE coverage on SAGE-SMC 160 micron image



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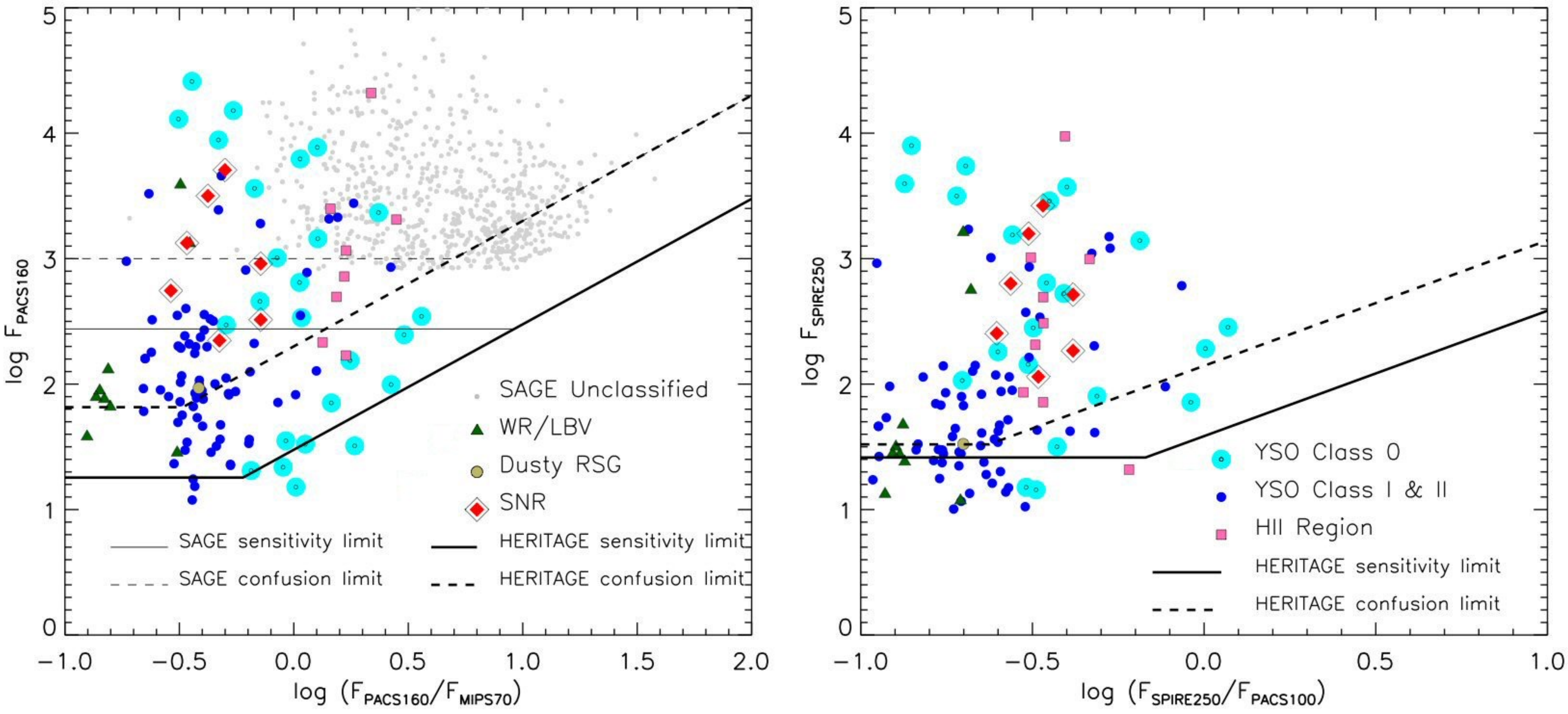
HERITAGE will detect the circumstellar dust from the most massive stars at all stages of their evolution.

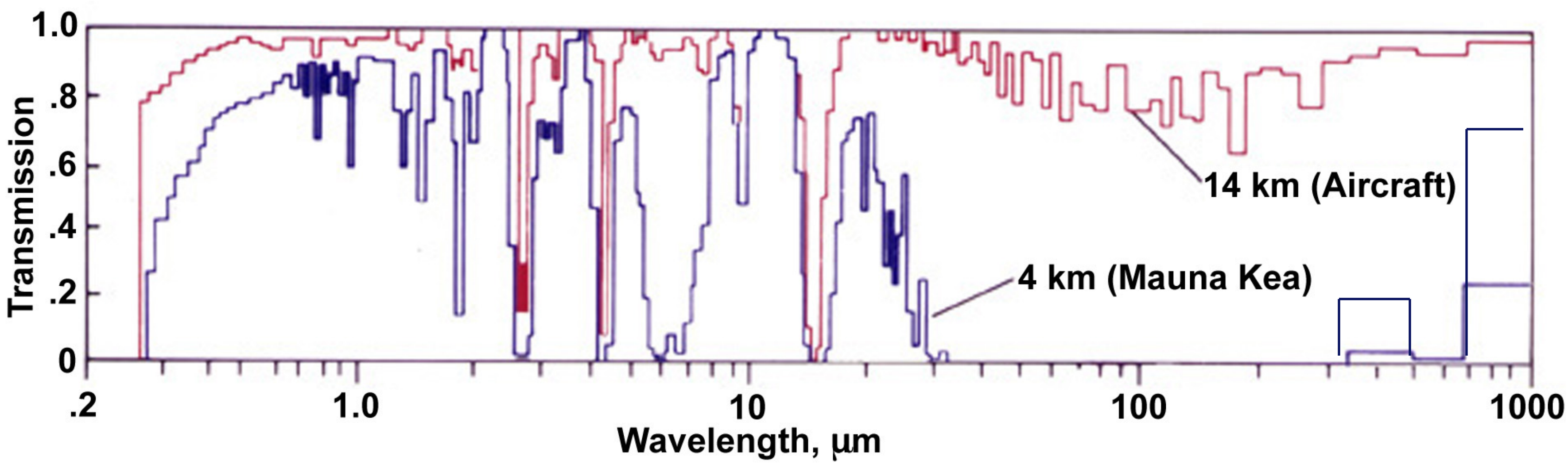


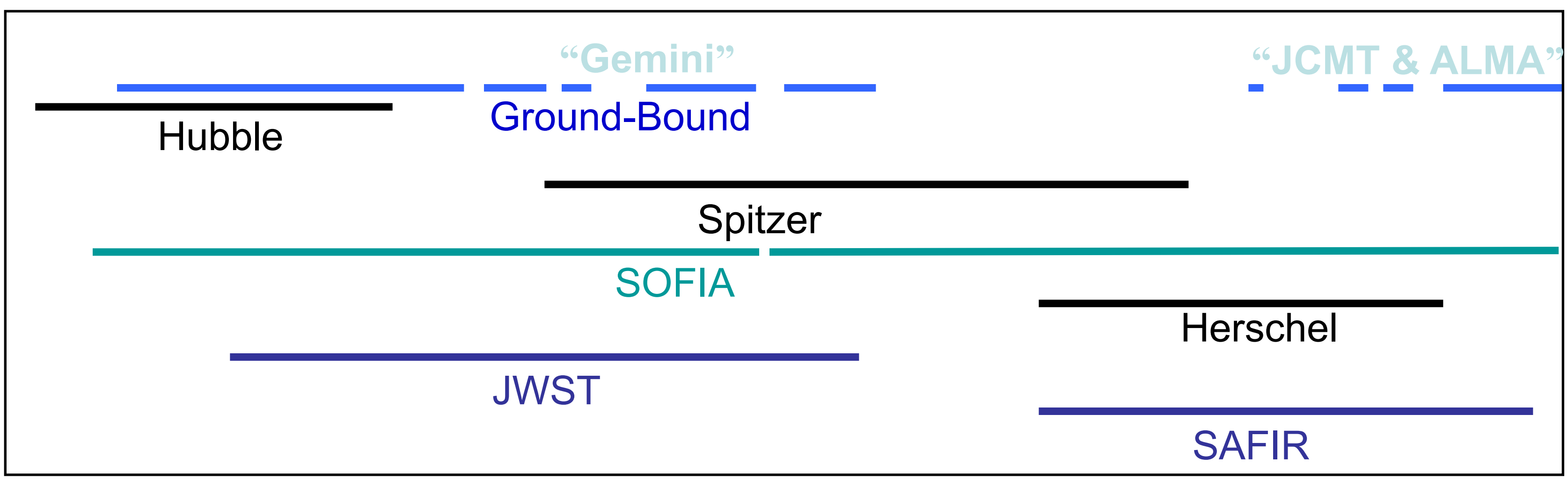
Meixner & HERITAGE team

Nearby Universe: Missions

- Current: Spitzer & Akari
  - Dominated by imaging and photometry
  - What are these newly discovered sources? Need spectroscopy….
- Missions Happening in next Decade:
  - Herschel, SOFIA, JWST, ALMA
  - important to capitalize on the synergy of these missions

Atmospheric Transmission and Observatory Wavelength Ranges

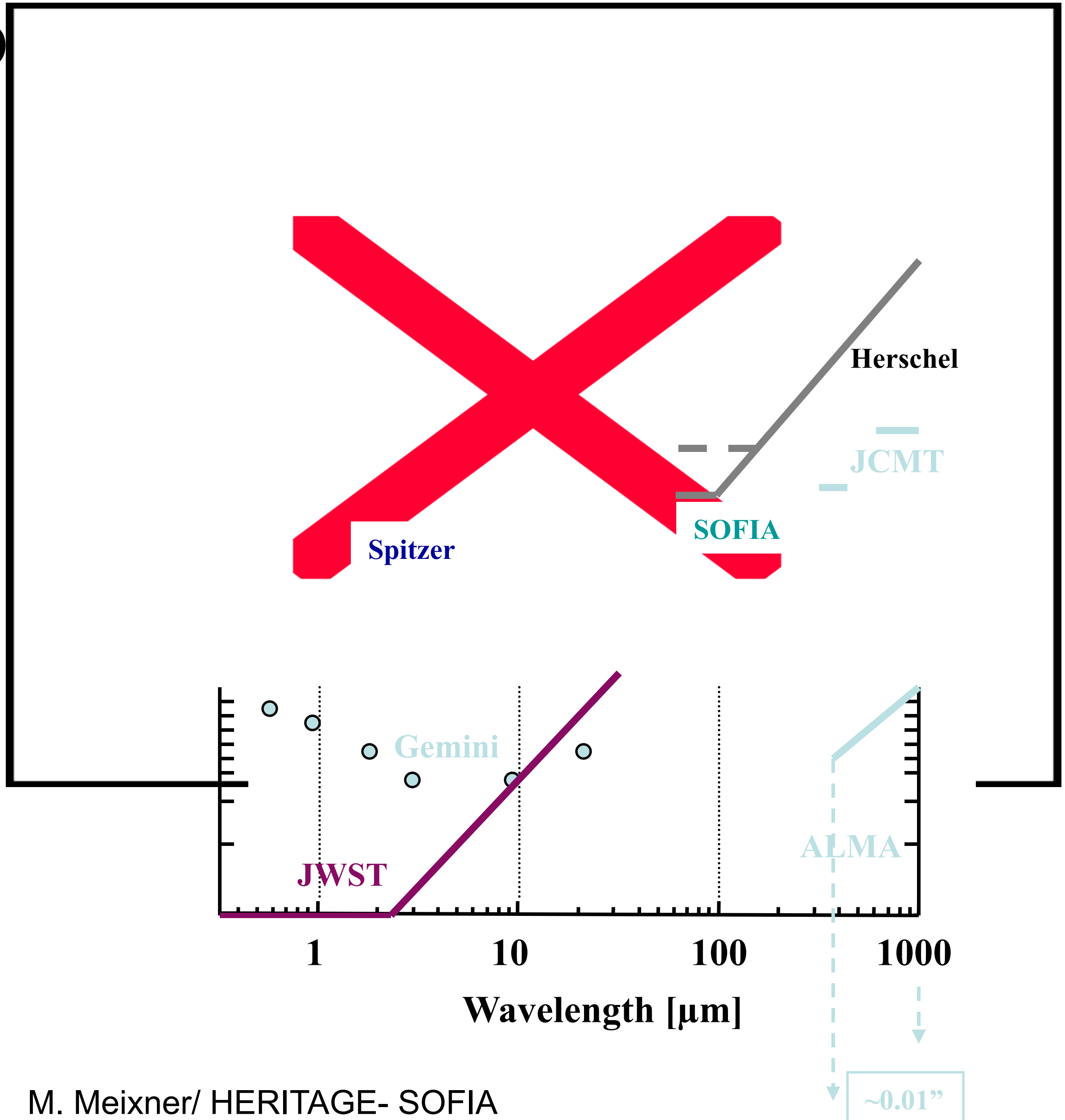




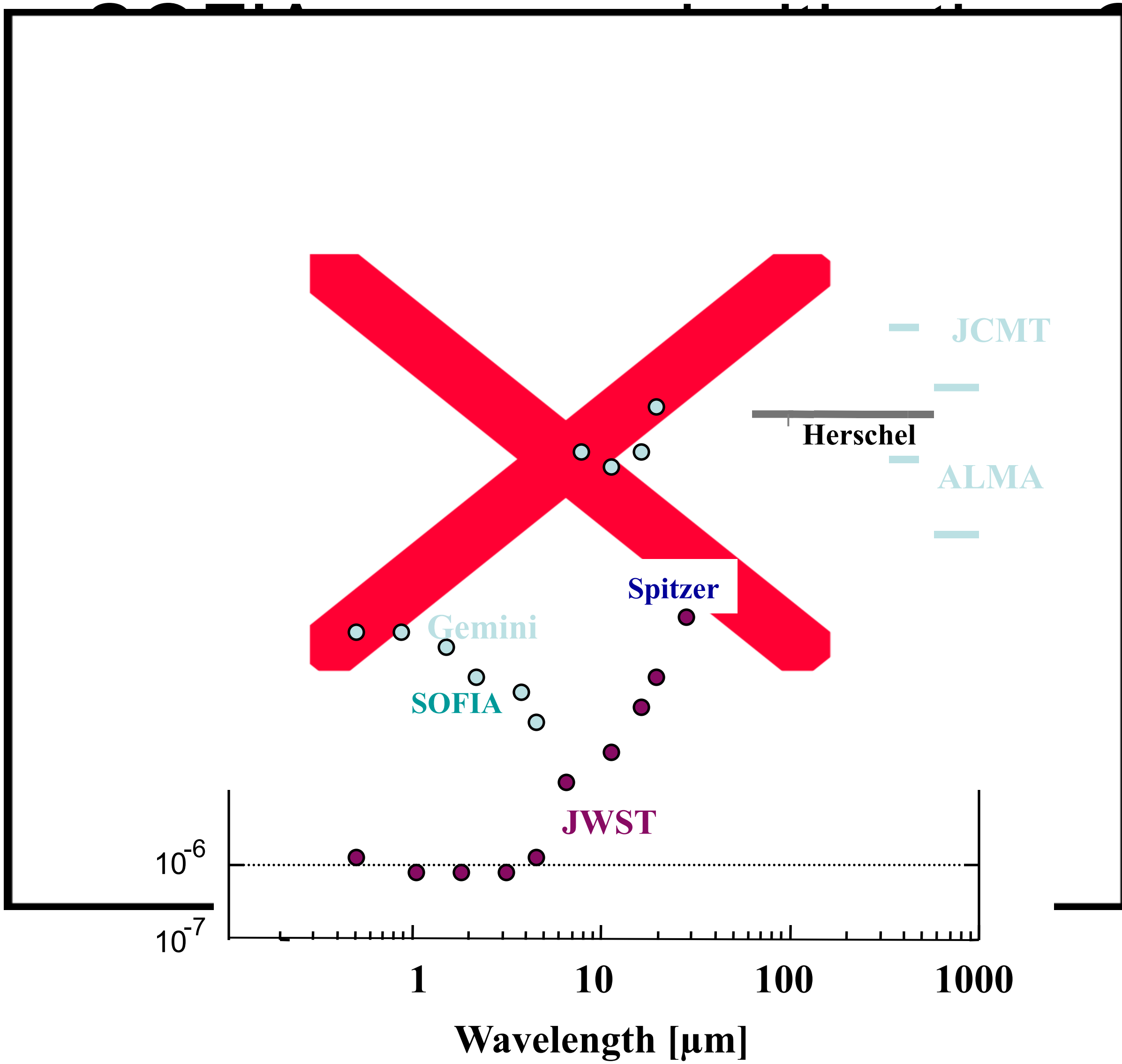
Infrared/Sub-MM Observatories

SOFIA comp

SOFIA and Herschel will provide images of the Far-IR Universe with at least three times the spatial resolution ever achieved before.



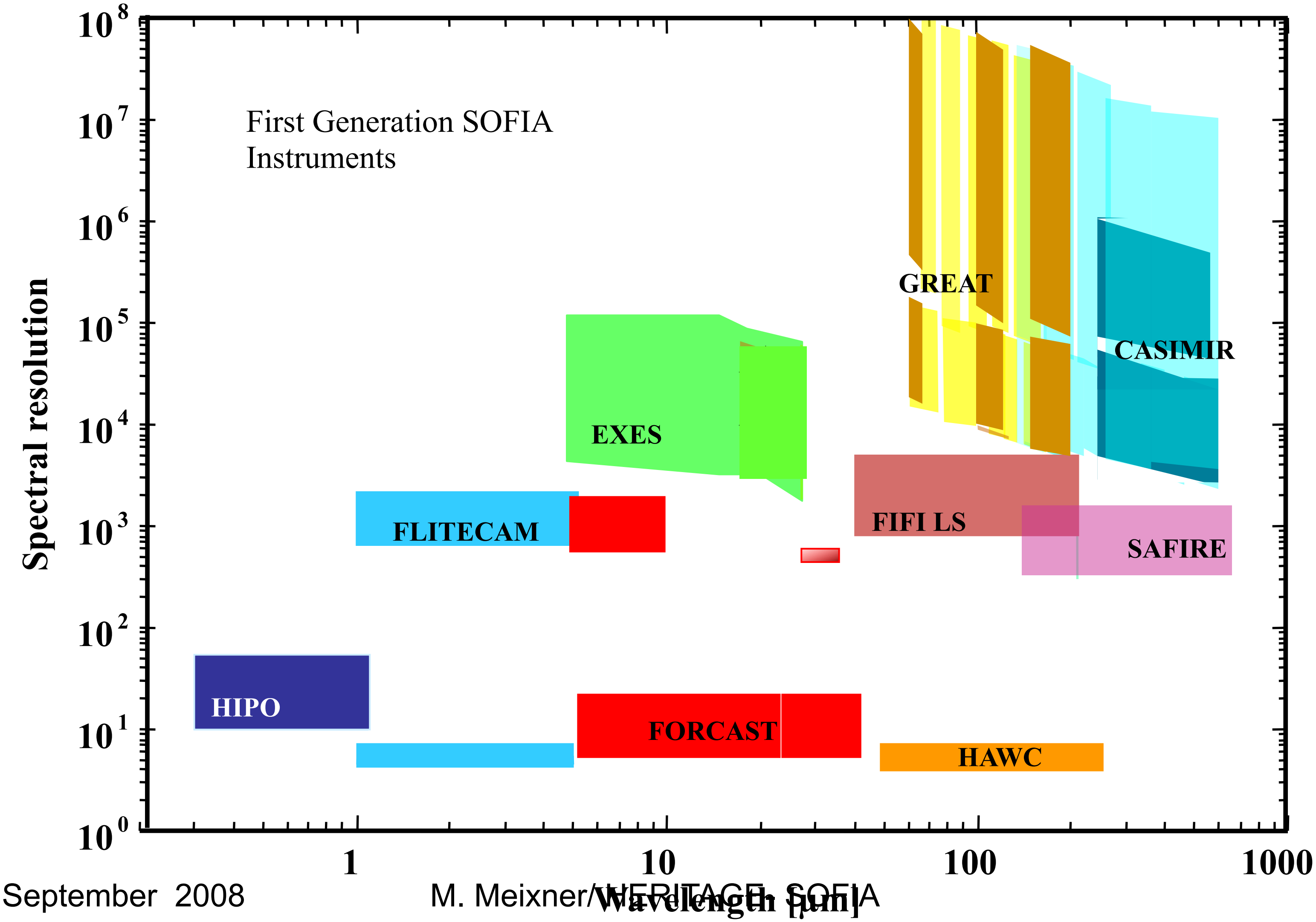
Observatories



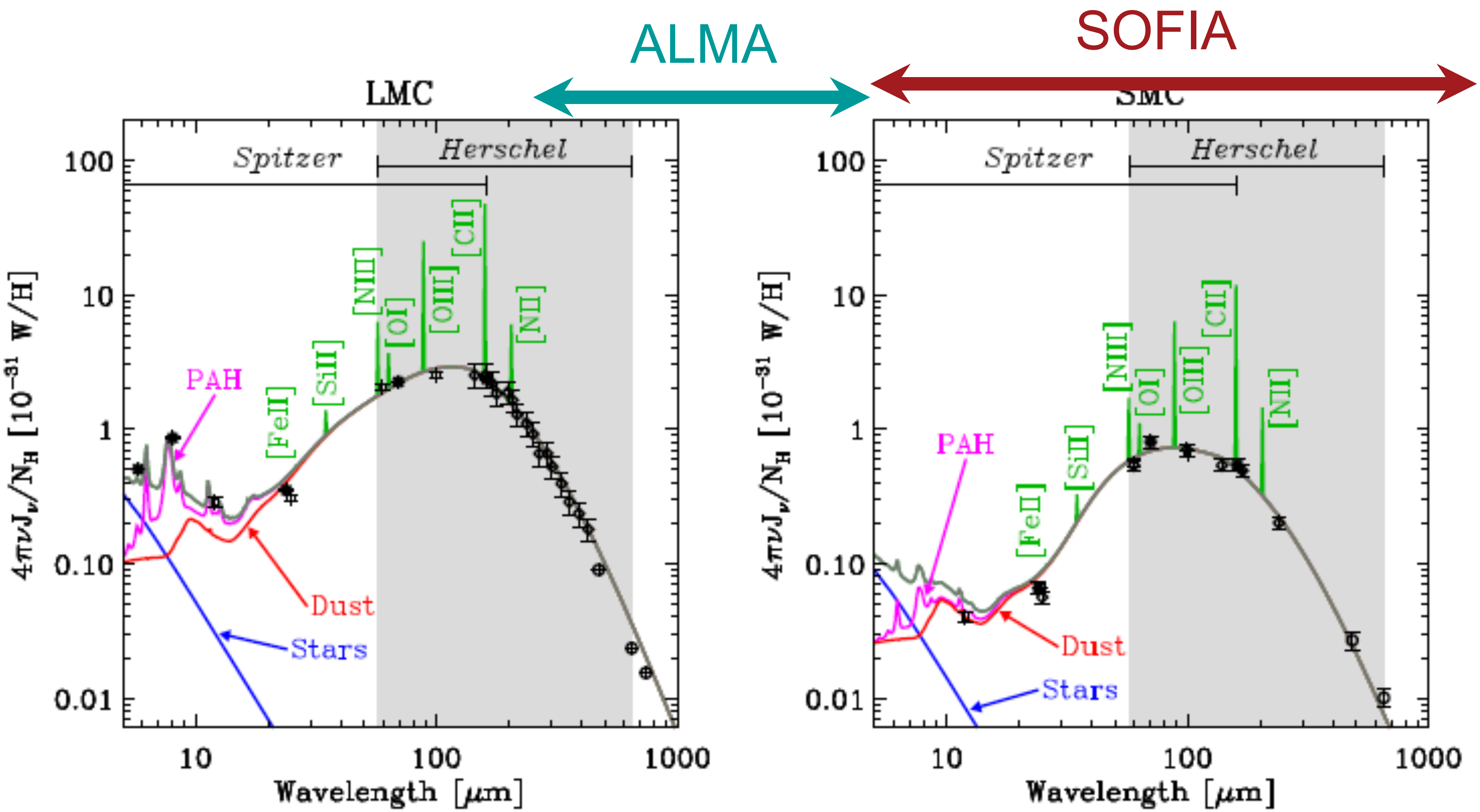
Spitzer and Herschel will provide best sensitivity in the Far-IR so far achieved

SOFIA will provide the best spectral coverage and spectral resolutions

SOFIA's first generation of Science Instruments….



Followup on SAGE and HERITAGE with SOFIA and ALMA: Spectroscopy, spectroscopy, spectroscopy



Questions to be addressed with SOFIA

- Spitzer and Herschel will provide photometry catalogs and a census of the diffuse ISM, but what is the nature of these objects?
- Spectroscopic observations with SOFIA are key to answering this question.

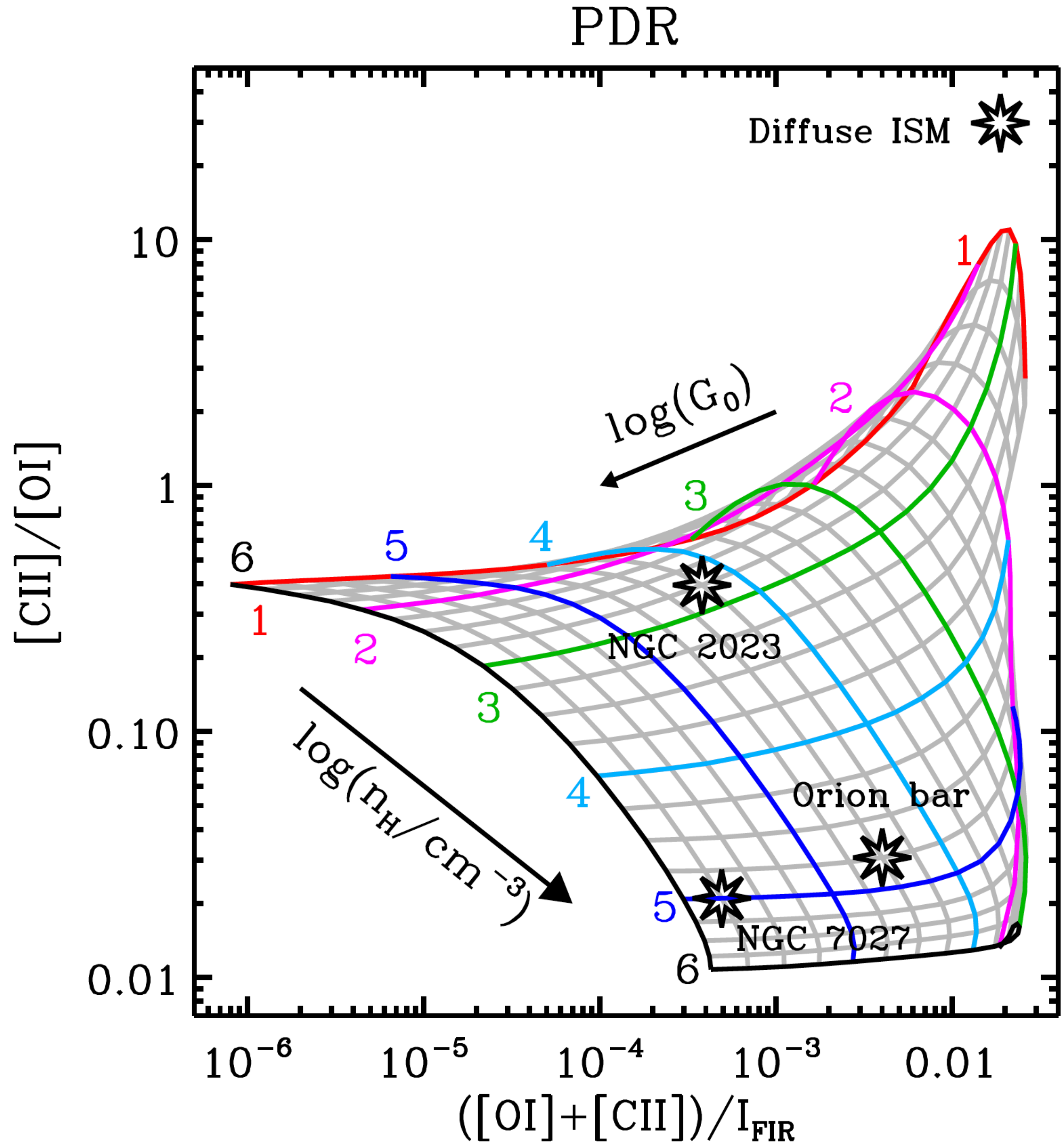
Questions to be addressed with SOFIA

- What is the dust composition of the evolved star population in the Milky Way and nearby galaxies?
  - Spectra are important constraints on the composition of the dust returned to galaxies.
  - FORCast spectroscopy of dust mineralogy in evolved stars, YSOs, ISM, SNRs, supernovae
  - EXES spectroscopy of ices and molecular absorption bands

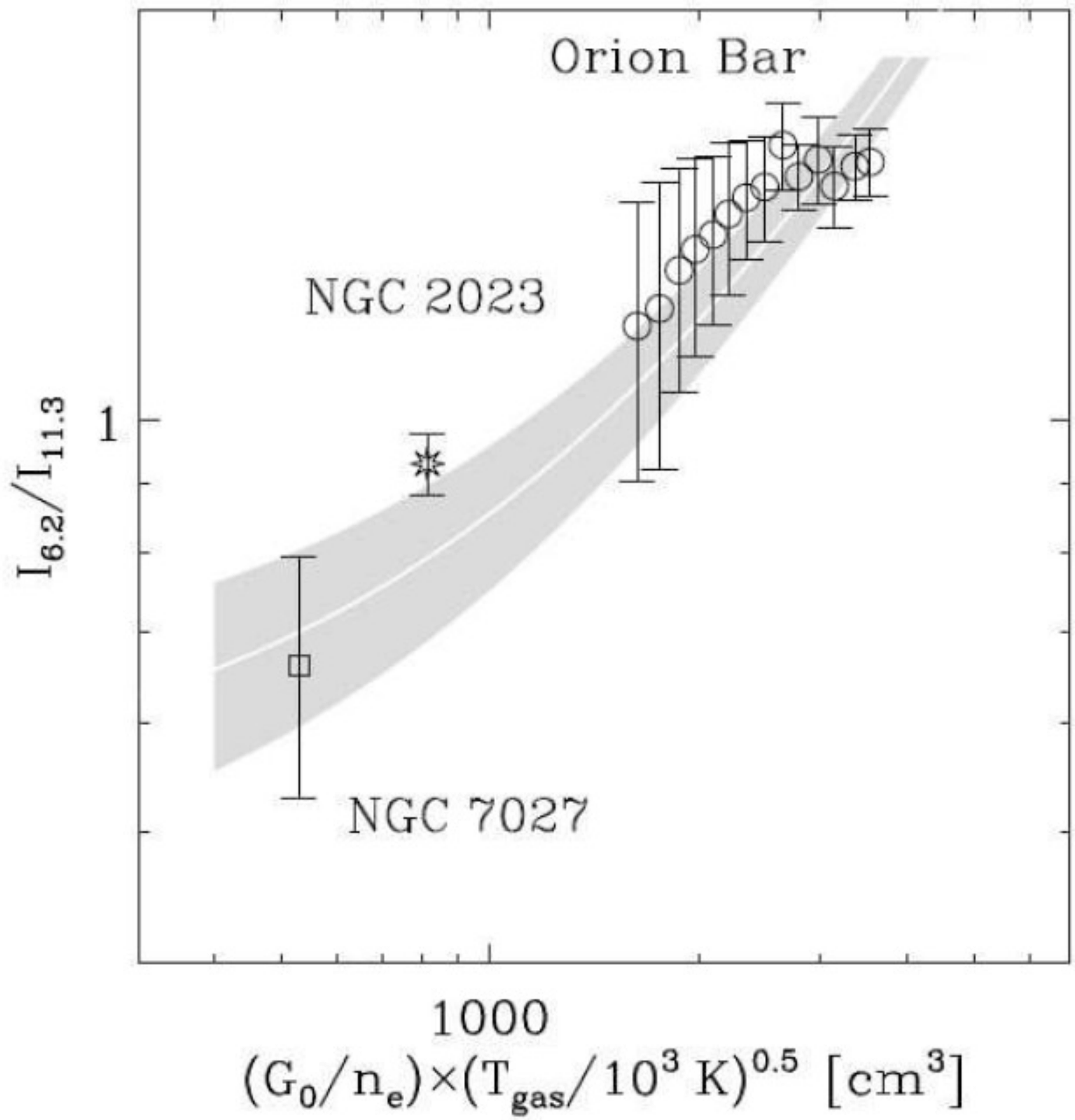
Questions to be addressed with SOFIA

- Herschel and Spitzer give us the inventory of the ISM via the dust emission.
  - What are the physical conditions of the gas associated with the dust in these galaxies?
  - How do gas clouds condense to form the GMCs from which stars are formed?

Spectroscopy is key for physical constraints for the ISM energetics



SOFIA can test these theoretical relations of PAH emission bands and the energetics of the ISM.



Galliano et al. 2008

Questions to be addressed with SOFIA

- SOFIA spectroscopic programs:
  - FORCast spectroscopy of ionized gas lines, PAHs, H_2 pure rotational lines of ISM regions
  - GREAT spectroscopy kinematics of [OI] 63 & 145 um, [CII] 158 um, [NII] 122 um, high CO transitions lines
    - Dynamics of ISM in PDRs: is the ISM really hydrostatic? Do shocks contribute, how much?
    - Key to understanding how gas condenses into GMCs
  - FIFI-LS spectroscopy of same lines, larger fainter regions
    - What are the physical conditions in these different galactic environments

Questions needing help from URSA

- Impact of any SOFIA program will depend on its ability to deliver quality and quantity of data
  – What types of sources can SOFIA really detect (sensitivity wise)?
    - Galactic center evolved stars?
    - Magellanic Clouds Evolved stars?
    - M31?
    - Local volume of galaxies?
  – How many sources are practical to observe with SOFIA? i.e. what is the observing efficiency for spectroscopic programs
  – Mapping strategies: how efficient are these? how easy are these to reduce?

Nearby Universe: Questions Emerging from current studies

- Nearby galaxies
  - How do stars, gas, dust cycle in galaxies?
  - How does the star formation rate change from the global galaxy view we have down to the size of a YSO (10 pc) and how does it vary in different galaxy environments?
  - How does cycling occur at the interface between galaxies and the intergalactic medium?

Nearby Universe: Questions Emerging from current studies

- ISM
  - How do molecular clouds form?
  - What is the full extent of interstellar chemistry?
  - What is the inventory of dust/ISM in the galaxy?
  - How important are magnetic fields in molecular cloud and star formation?

Nearby Universe: Questions Emerging from current studies

- Star Formation
  - How do massive stars form: Competitive accretion? Fragmentation?
  - What is the timescale for the process?
  - How does galaxy/ISM environment change the process?

Nearby Universe: Questions Emerging from current studies

- How much dust is generated and produced by the evolved star population and supernovae?
- How does this metal/dust rich material mix with the ISM?
- How far out does the dust emission from galaxies extend? Can we use this as a tracer of metal enrichment of the intergalactic medium?