Ultra-luminous IR Galaxies: their nature and evolution and what next?*

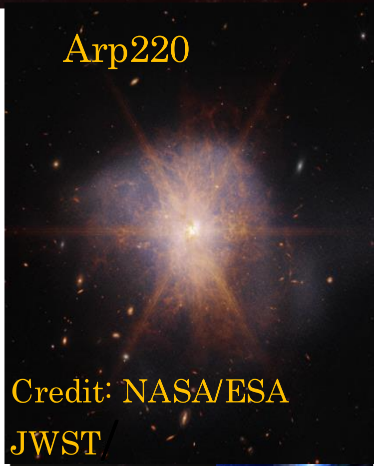
Dimitra Rigopoulou

* : introducing LETO and the LETO Consortium

LIRGs and ULIRGs – dusty luminous galaxies

Luminous and Ultra-luminous IR Galaxies (U/LIRGs) are **dusty galaxies with** $L_{IR} > 10^{11} L_\odot$ and $L_{IR} > 10^{12} L_\odot$

- invariably **interacting**
- **fundamental** to galaxy mass assembly/ galaxy evolution (e.g. Sanders & Mirabel+96, Elbaz & Cesarsky+03)
- some harbour a **highly obscured nuclei** which is either a very active evolutionary stage of AGN and/or a massive Starburst.
- Nuclear activity will often drive **mechanical feedback** in the form of molecular winds, jets and outflows (e.g. Fabian+99, Gonzalez-Alfonso+12, Veilleux+13, Sturm+13)



LIRGs and ULIRGs – why study them?

Peak of the cosmic star formation rate (SFR) density and AGN activity at z≈ 1 – 3 ("cosmic noon").

• Similar redshift trend seen in molecular gas density

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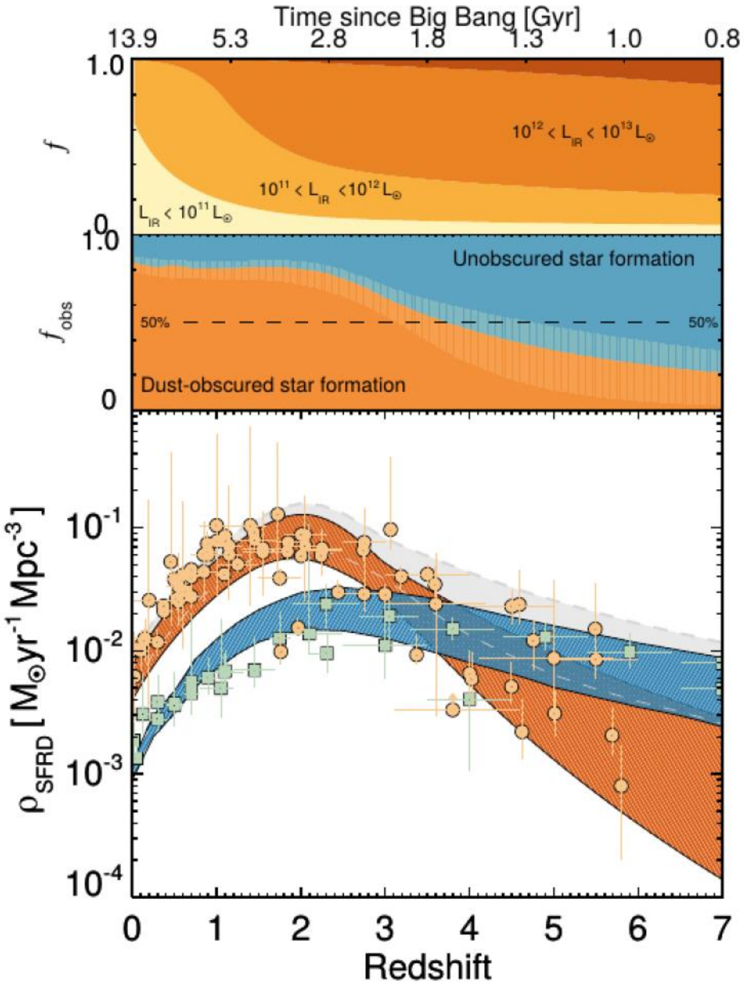
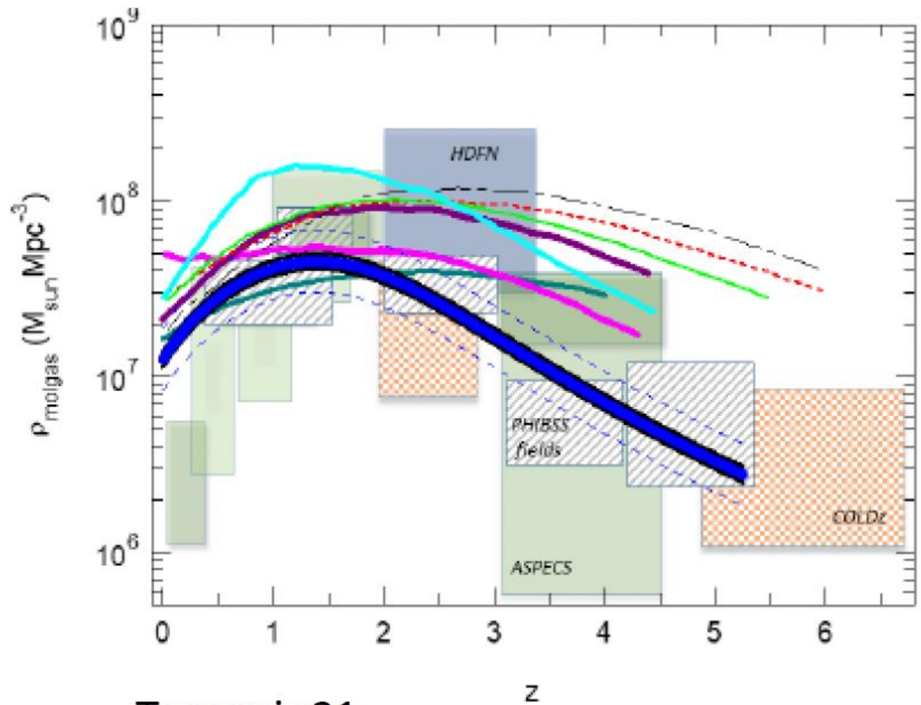
• ‘Obscured’ SFR dominates ‘unobscured’ SFR up unt



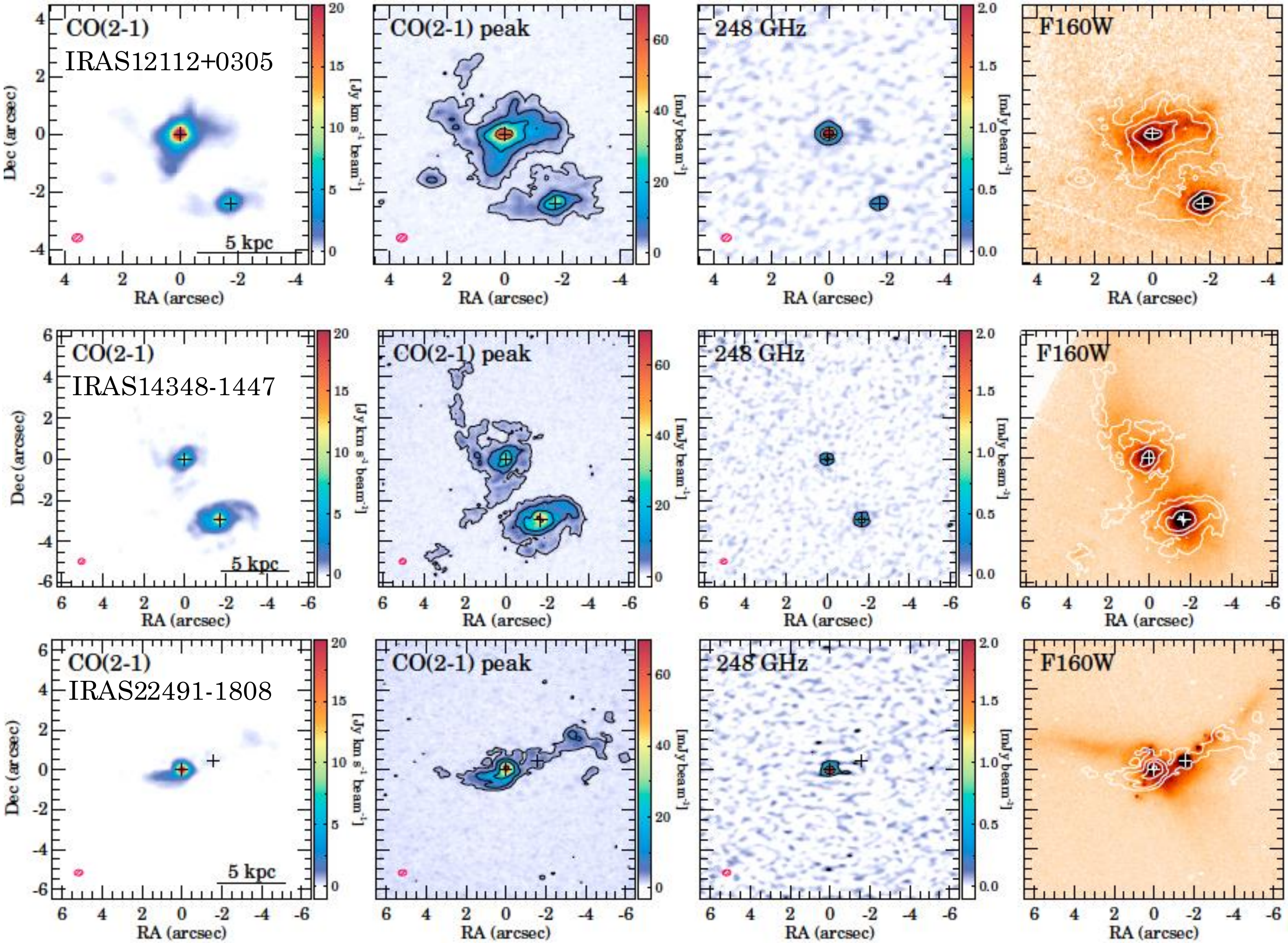
Zavala+21



Tacconi+21

The molecular gas content of ULIRGs

ALMA B6
CO(2-1), 0."3-0."4
~400-500 pc
at the distance of these ULIRGs



Pereira Santaella+18

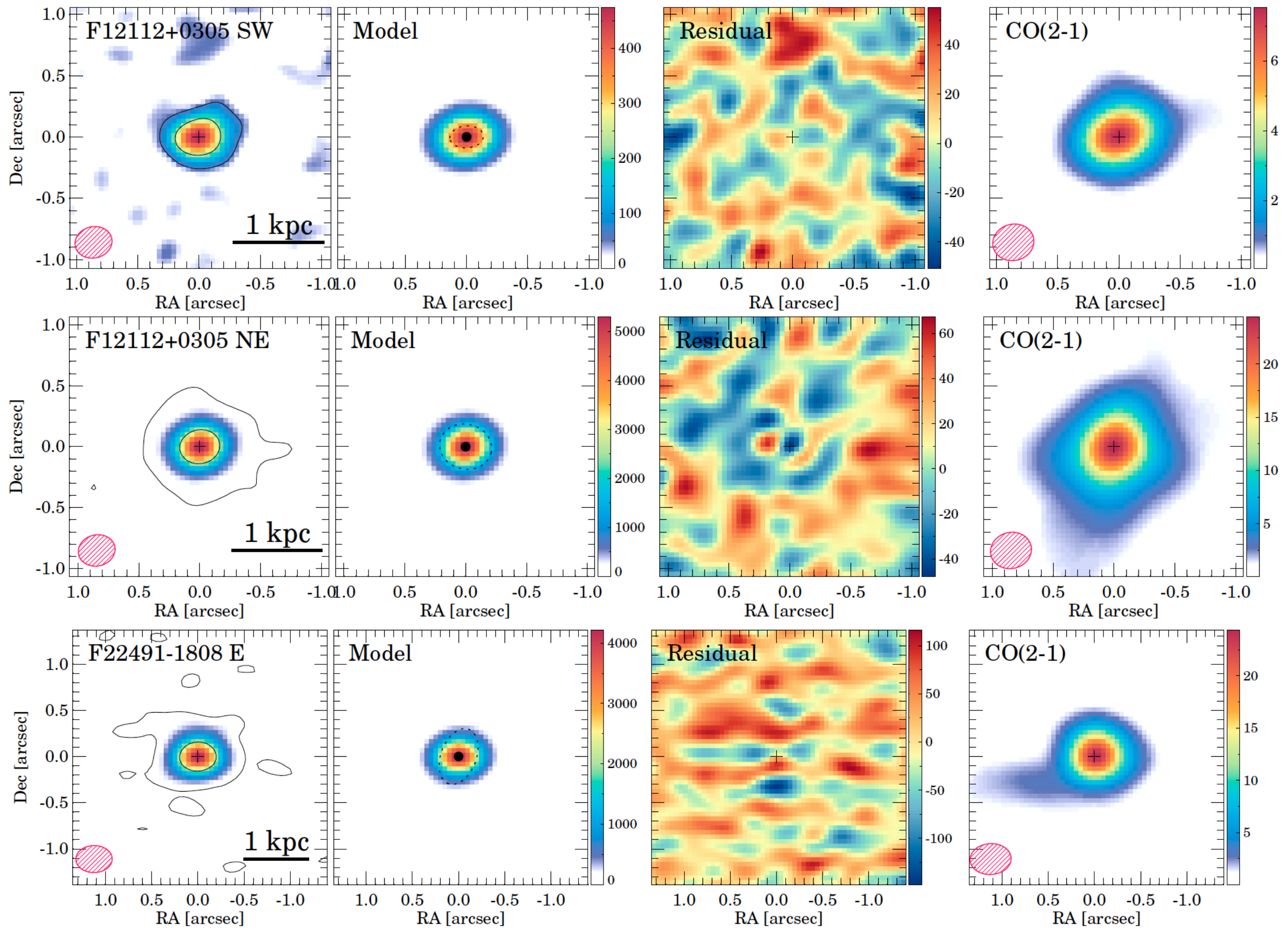
The molecular gas content of ULIRGs

ALMA 220 GHz continuum, 0.”3-0.”4
~400-500 pc
at the distance of
these ULIRGs

Used to measure sizes:

r_cont: <60 -350 pc

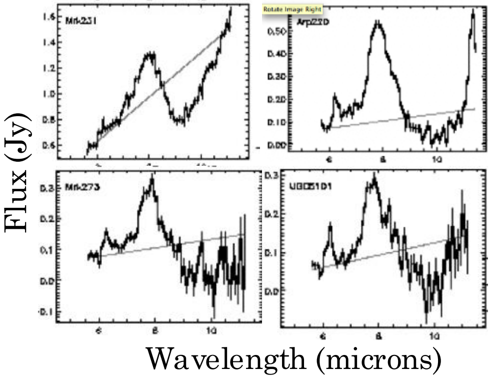
incompatible with an SF origin (small t_{depl})

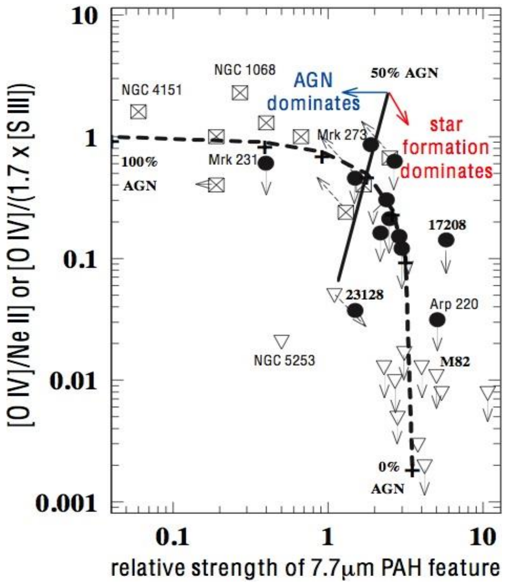


Pereira Santaella+21

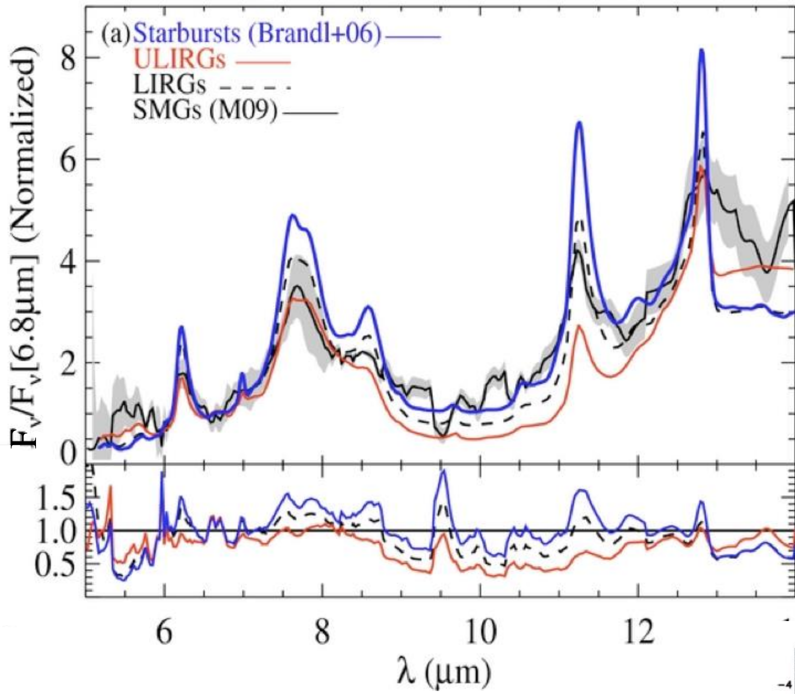
The nature of ULIRGs: insights from the mid-IR

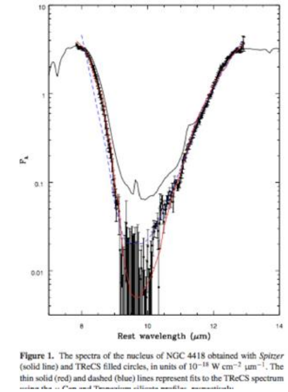
Insights into the powering source from ISO spectra





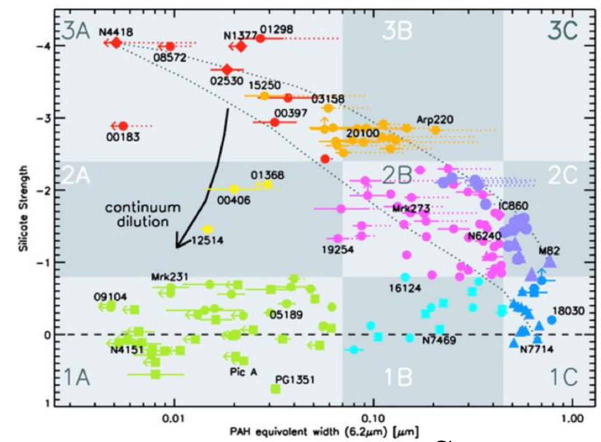
Genzel+98, Lutz+98, Rigopoulou+99
Sturm+00, Tan+01, ea





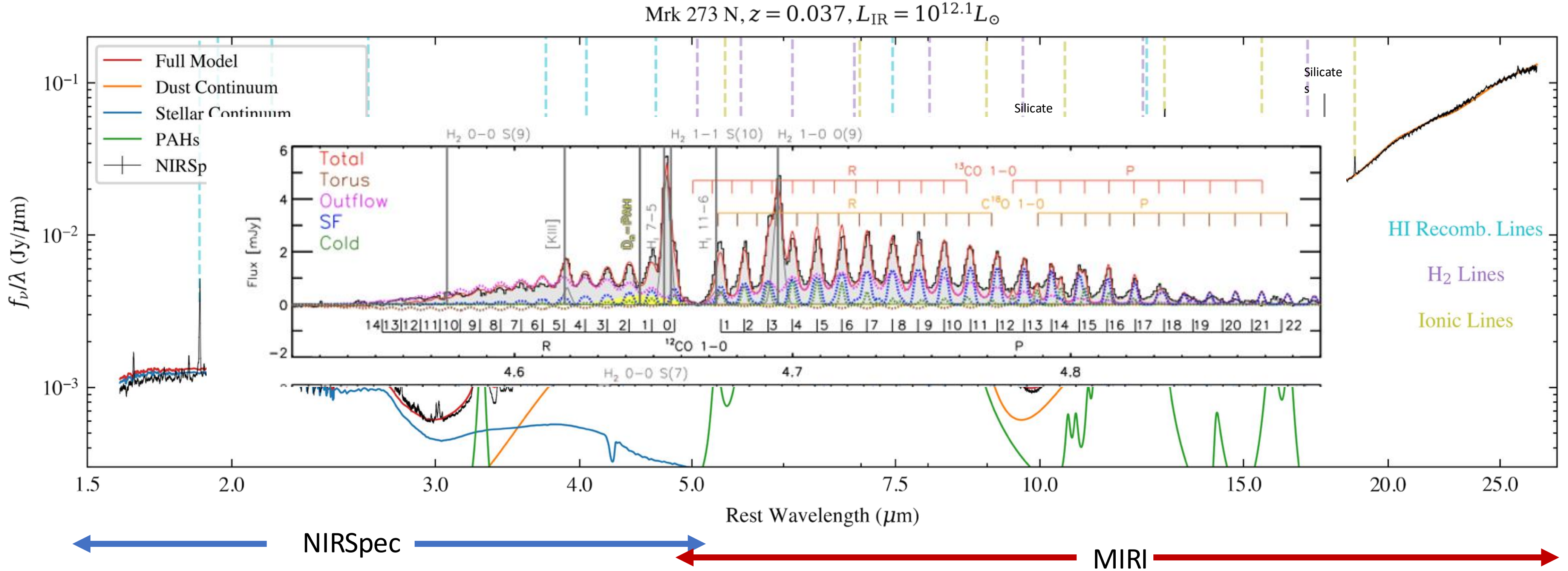
Silicate profile of LIRG NGC4418 (Roche+15)

Large range in PAH EQW, silicate absorption, mir-IR slope
Evolution with merger stage
Grain size, compactness and temperature
PAHs: trace global SF and more...



Spoon+07

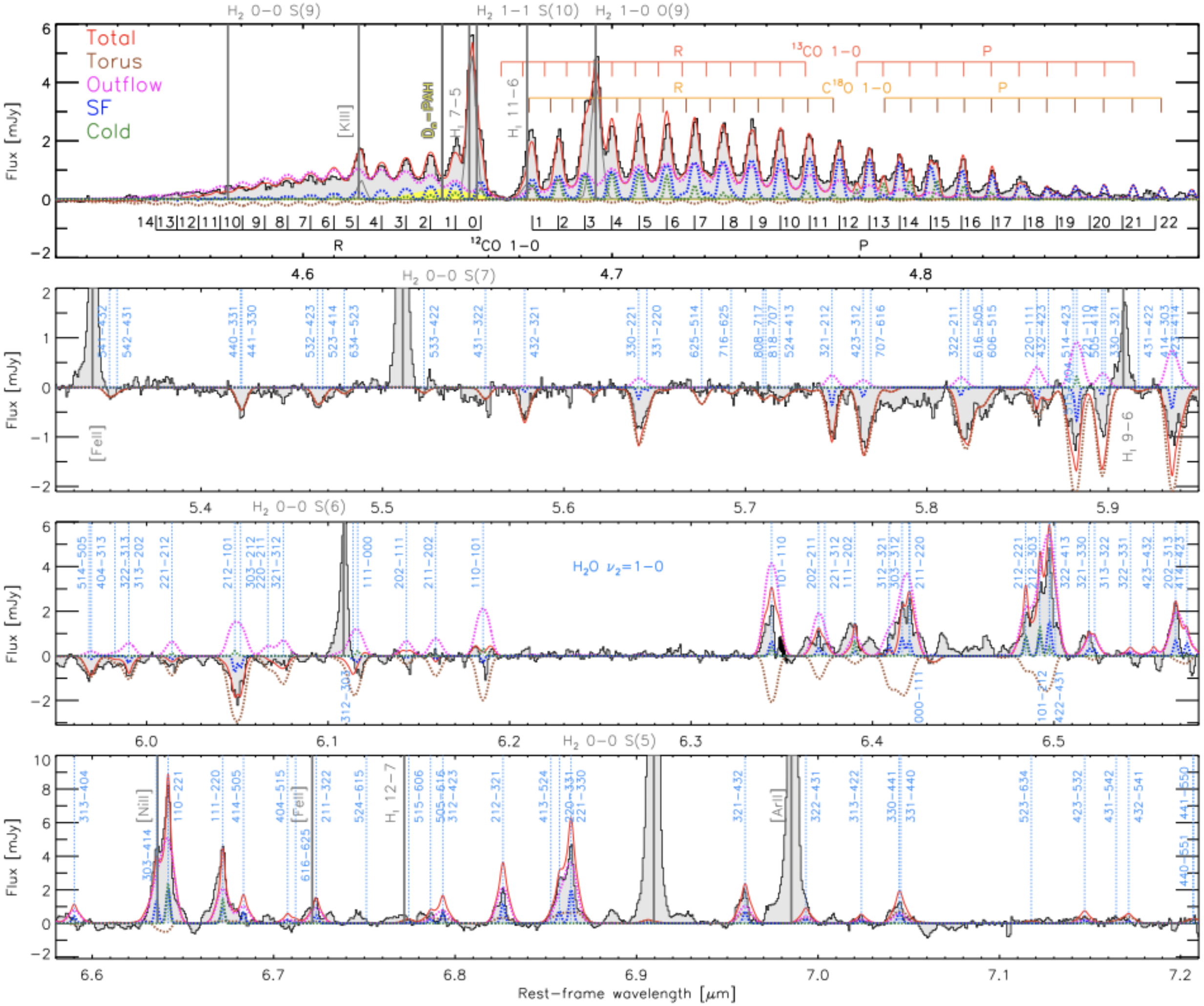
Mid-infrared Spectroscopy



see also: **Mrk 231:** Alonso-Herrero+24, **Arp220:** Buiten+25, **NGC 6240**: Ceci+24, Hermosa-Munoz+25

Donnan, Rigopoulou+24, Donnan, Rigopoulou+25, in prep

New ways to probe the nature of U/LIRGs: CO absorption spectroscopy



CO ro-vibrational transition

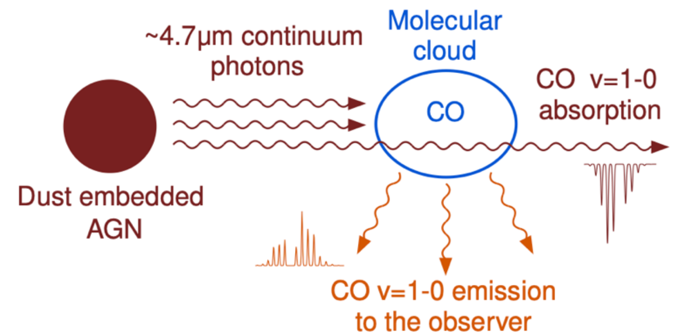
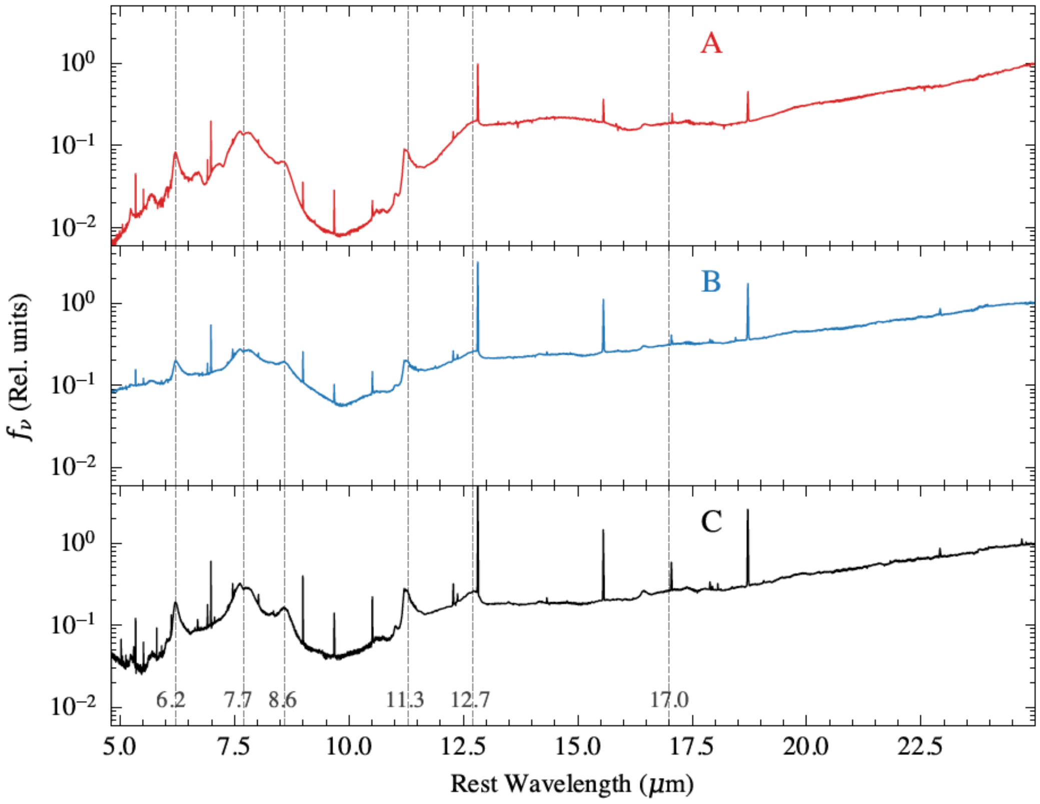


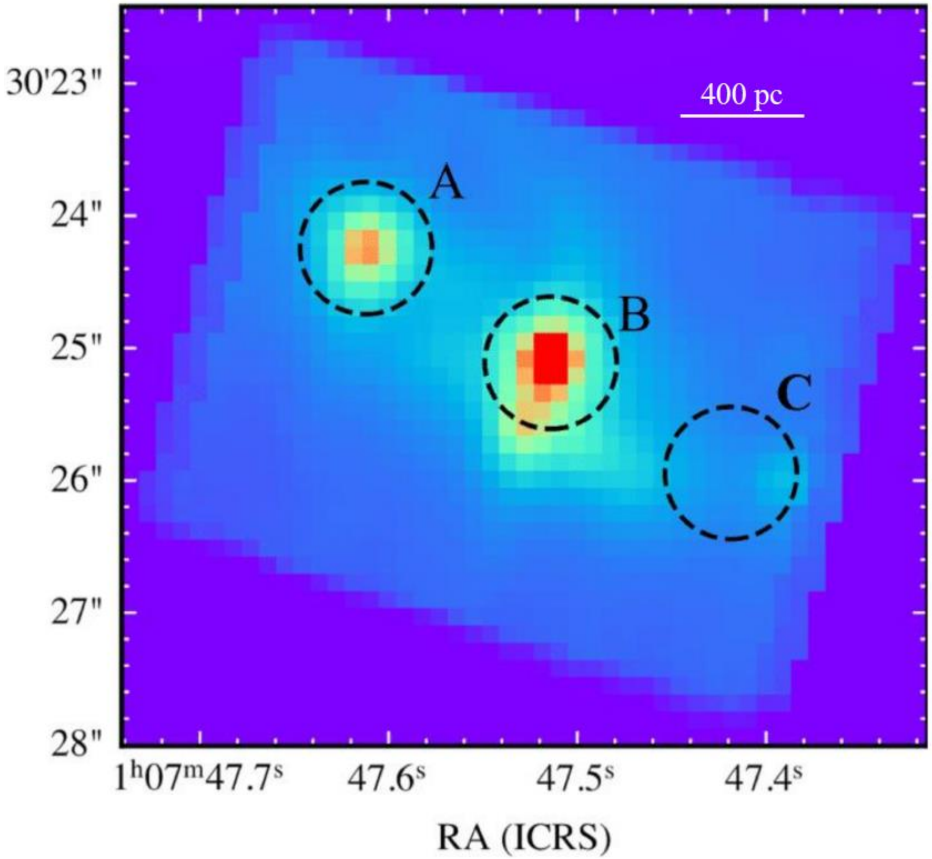
Fig. 5: Sketch showing how the CO v=1–0 band emission is produced in the outflow region of NGC 3256 S. The ~4.7 μm photons from the dust around the AGN (brown lines) illuminate the molecular clouds (blue ellipse). These photons are absorbed by CO molecules which are excited to the v=1 levels and decay through the P- and R-branches (orange lines). The CO v=1–0 absorption is only observed in lines of sight that intersect both the ~4.7 μm continuum source and the molecular clouds.

Pereira-Santaella+24
Garcia-Bernete+24

PAH studies in the JWST era: VV114

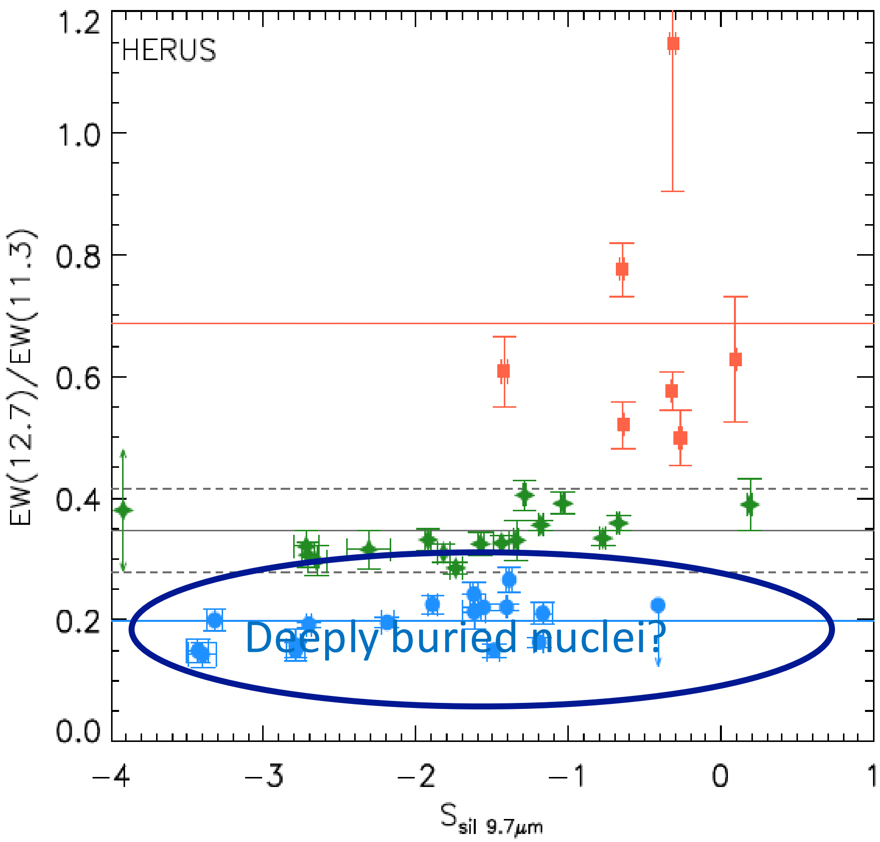
What does PAH emission from obscured nuclei looks like?

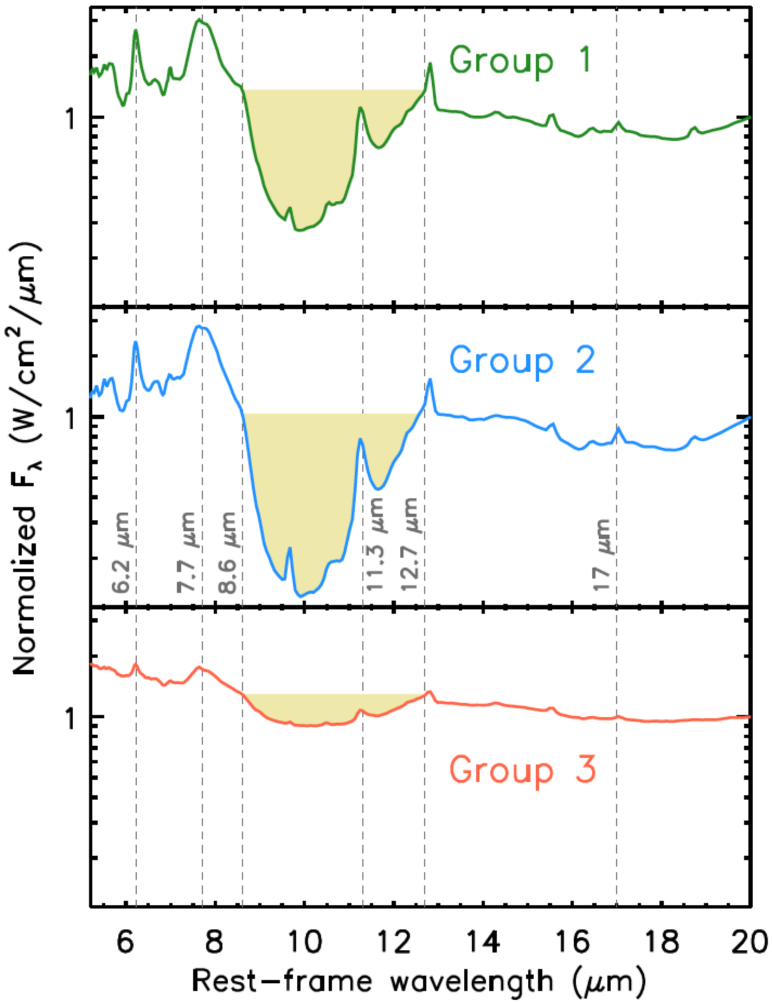




Donnan, Garcia-Bernete, Rigopoulou+23

Can PAHs uncover deeply embedded sources ?



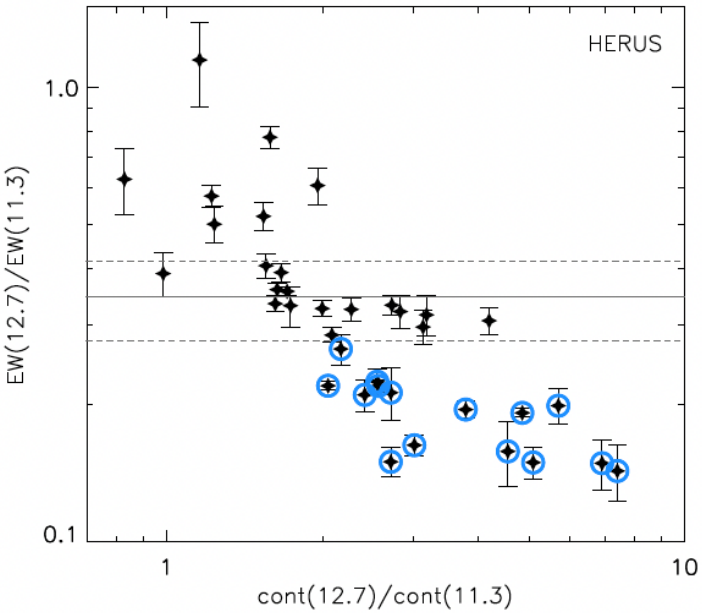


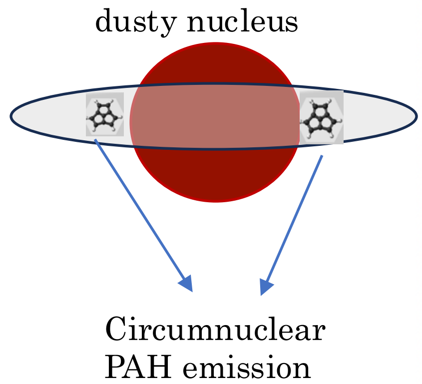
(data from the HERUS sample, Farrah+13)

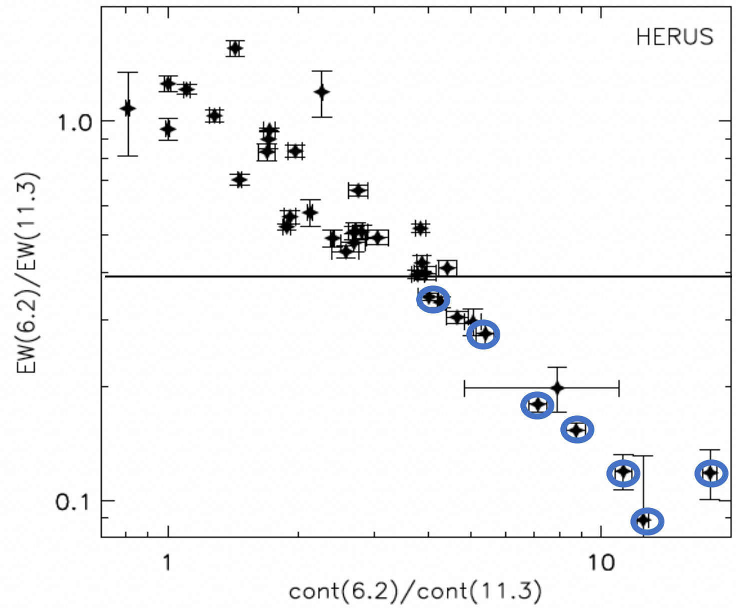
Garcia-Bernete+22

Obscuration and PAH emission

- In deeply embedded sources the dusty nucleus and the main source of the circumnuclear PAH emission **are spatially separated and subject to different levels of extinction.**
- Assuming circumnuclear PAH emission is near universal (Xie+18) then differences in PAH EW **must reflect differences in the underlying continuum**



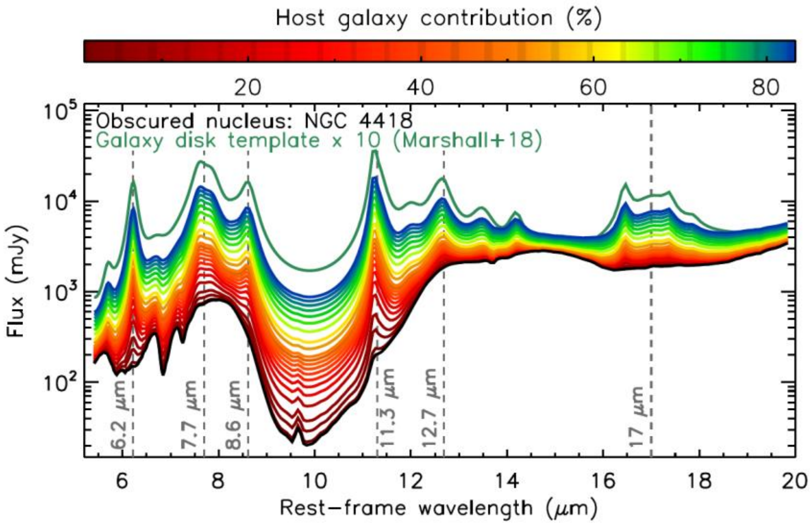


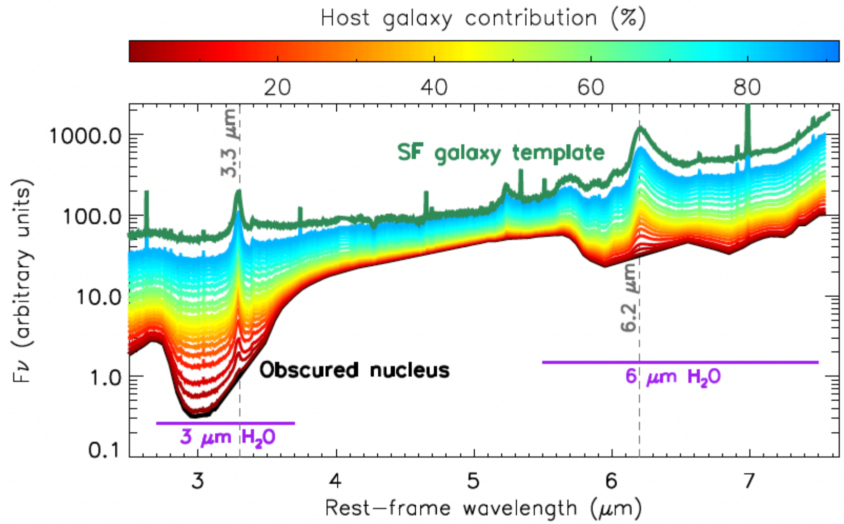


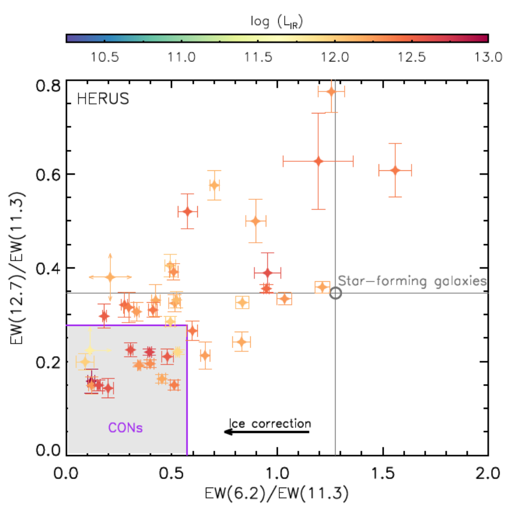
- ➢ We find an anti-correlation indicating that the PAH EW ratio is tracing the continuum emission.
- ➢ The intrinsic shape of the MIR continuum should be driving the difference

PAHs as a tool to unveil extremely dust-embedded nuclei

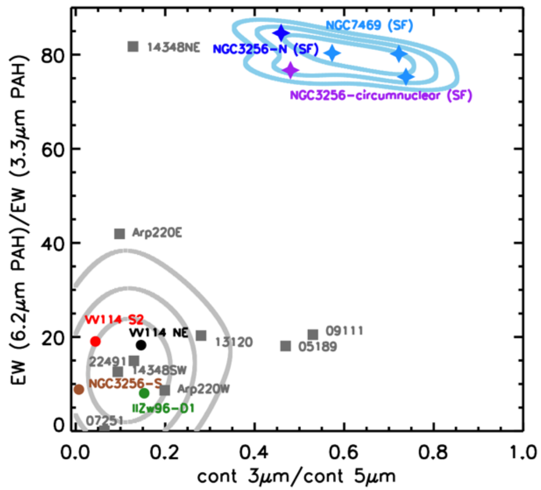
By exploiting the impact of the silicate (9.8 μm) and H_2O (3 and 6 μm absorption features) on the PAH bands we can identify deeply obscured galaxies.





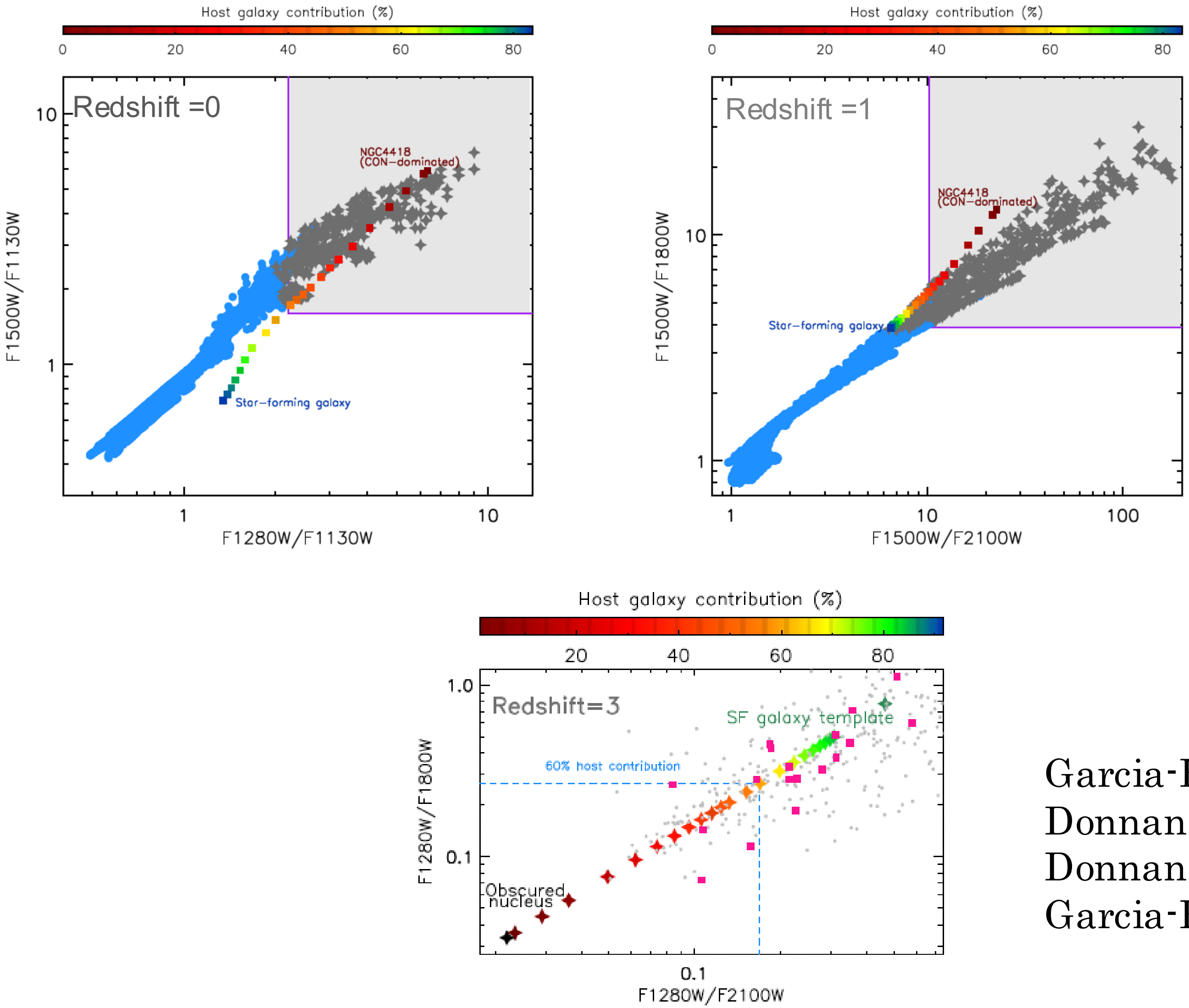


Garcia-Bernete, Rigopoulou+23, Donnan, Rigopoulou+23, Donnan, Garcia-Bernete +24 Garcia-Bernete, Rigopoulou+25



PAHs as a tool to unveil extremely dust-embedded nuclei

Applied to data from JWST deep surveys to identify dust-obscured nuclei at 1<z<3



Garcia-Bernete, Rigopoulou+23,
Donnan, Rigopoulou+23
Donnan, Garcia-Bernete +24
Garcia-Bernete, Rigopoulou+25

ULIRGs so far....

Local ULIRGs essential for understanding deeply obscured nuclei at cosmic noon and beyond

- ALMA probes the molecular gas reservoir (raw material for SF/ feeding the central AGN)
- Mid-IR (ISO/Spitzer/JWST) : properties of the central source, small grains, PAHs
- Herschel : first inroads into the cold ISM but we need more....

Access to the 60-400 microns important → probe the SF part

Dissect the ISM → probe feedback
→ probe the obscuring nucleus
Gas coolants : FIR FS lines
Other ISM lines, high-J CO, H_2O, OH, OH+
to probe:
Dynamics: infall / outfall gas
Molecular gas excitation and chemistry

Line Emission Terahertz Observatory

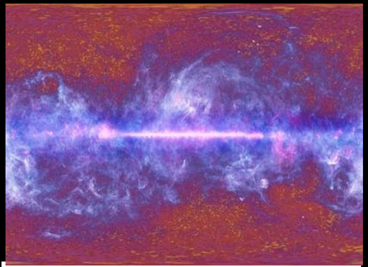
What is LETO ?

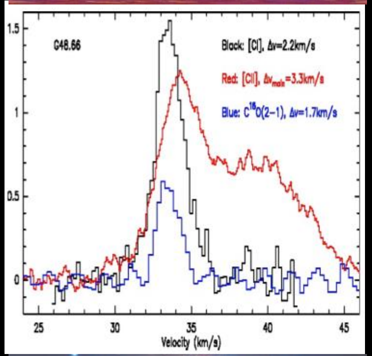
- LETO will focus on the ISM ecosystems:

Radiative and mechanical feedback drives the flow of gas from stars through the ISM and in and out of galaxies, disrupting clouds, ***initiating Star Formation*** and generating turbulence.

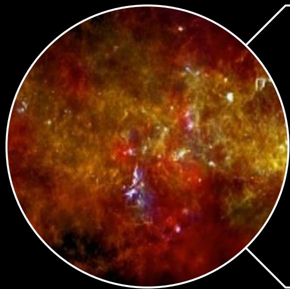
- Builds on rich European/US heritage in Space technology.

- LETO consists of a warm ~3.5m telescope with a cryogenic coherent SIS/HEB receivers (63-370 microns) operating in L2.

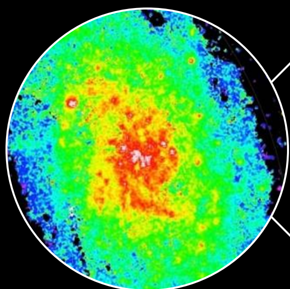




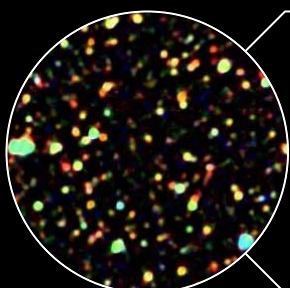
How will LETO achieve its objective:



The ISM in our Galaxy: large area survey of the Galactic Plane



Nearby Galaxies: large scale mapping of a number of nearby Starburst/Normal Galaxies and AGN, probing feeding and feedback mechanisms

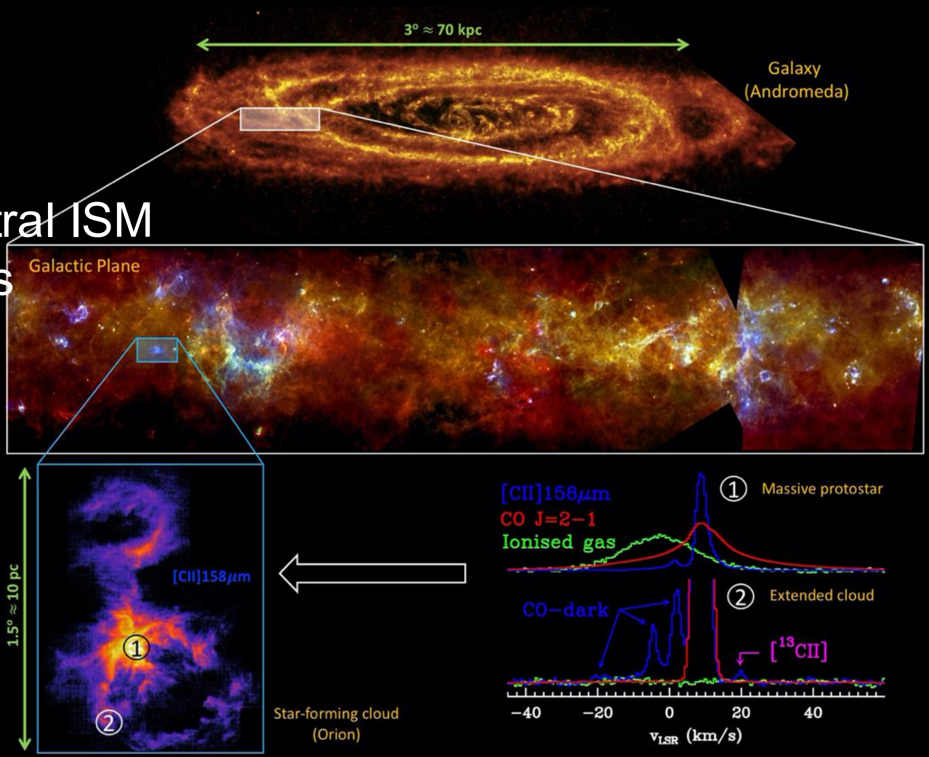


Blind deep survey of extragalactic fields, FIR FS Lines number counts and ISM in high redshift Galaxies

LETO will link scales and give a full dynamic picture of the ISM

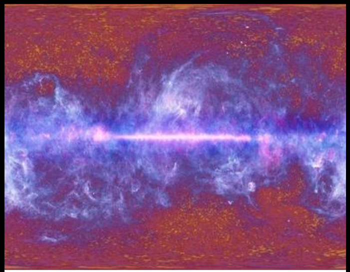
Key FIR cooling lines:

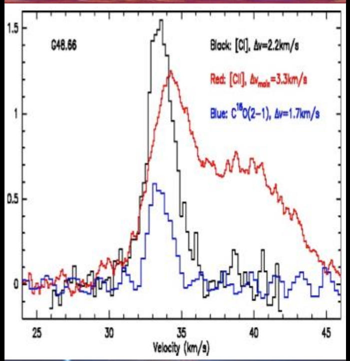
[CII]158μm: traces all phases of the ISM
[OI]63μm: traces the thermal properties of the neutral ISM
[NII]122 & 205μm: tracers of the diffuse ionized gas
[CI] (2-1) 370μm probe of molecular gas



In addition, the LETO receiver channels will cover the CO(7-6) 368μm and OH119μm lines.

Technical requirements





CI [370], NII [205] , CII [158], OI [145,63] , OH [119] & NII [122] → 0.8 to 4.7 THz → space

- Spectral Resolution: 0.3 to 100km/s
  → heterodyne instruments

- Sensitivity: 0.1 K in 1h → cooled receivers, i.e.

  SIS and HEB mixers

- Spatial Scale: large surveys (degrees to MW)
  → medium -sized telescope ~3.5 m

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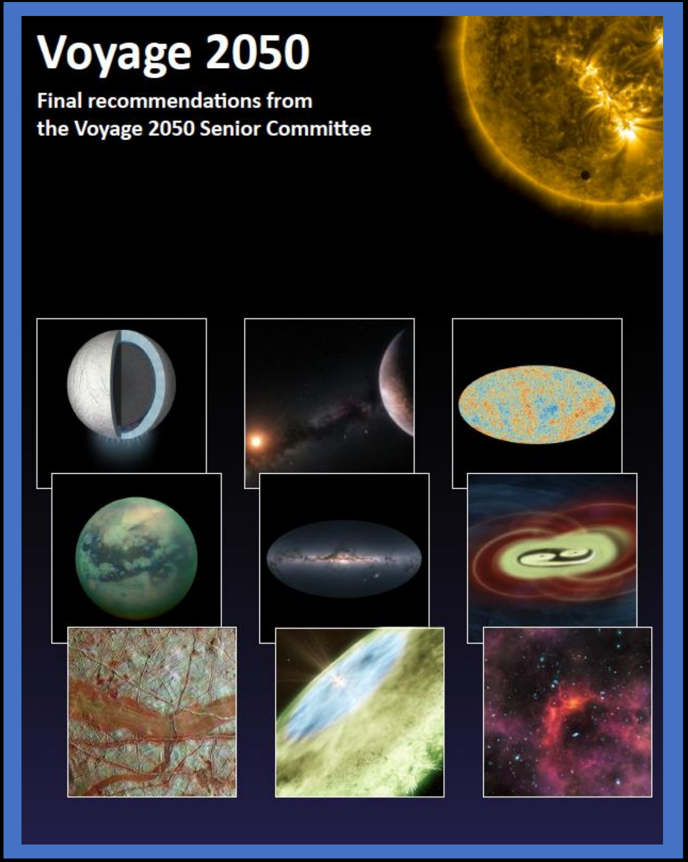
LETO in a nutshell

Observations of major far-IR ISM lines are key to unlocking the physics behind the process that regulates star formation in galaxies.

Understanding how gas clouds collapse to form stars is a crucial piece in the puzzle of galaxy evolution.

Studying the multiphase structure of the ISM and its evolution will reveal the underlying physical phenomena that set star formation rates and efficiencies.



Through a medium-sized (~3.5m) telescope, sensitive receivers, broad spectral coverage, LETO will unlock the process that converts gas into stars the most fundamental of processes behind galaxy formation and evolution.