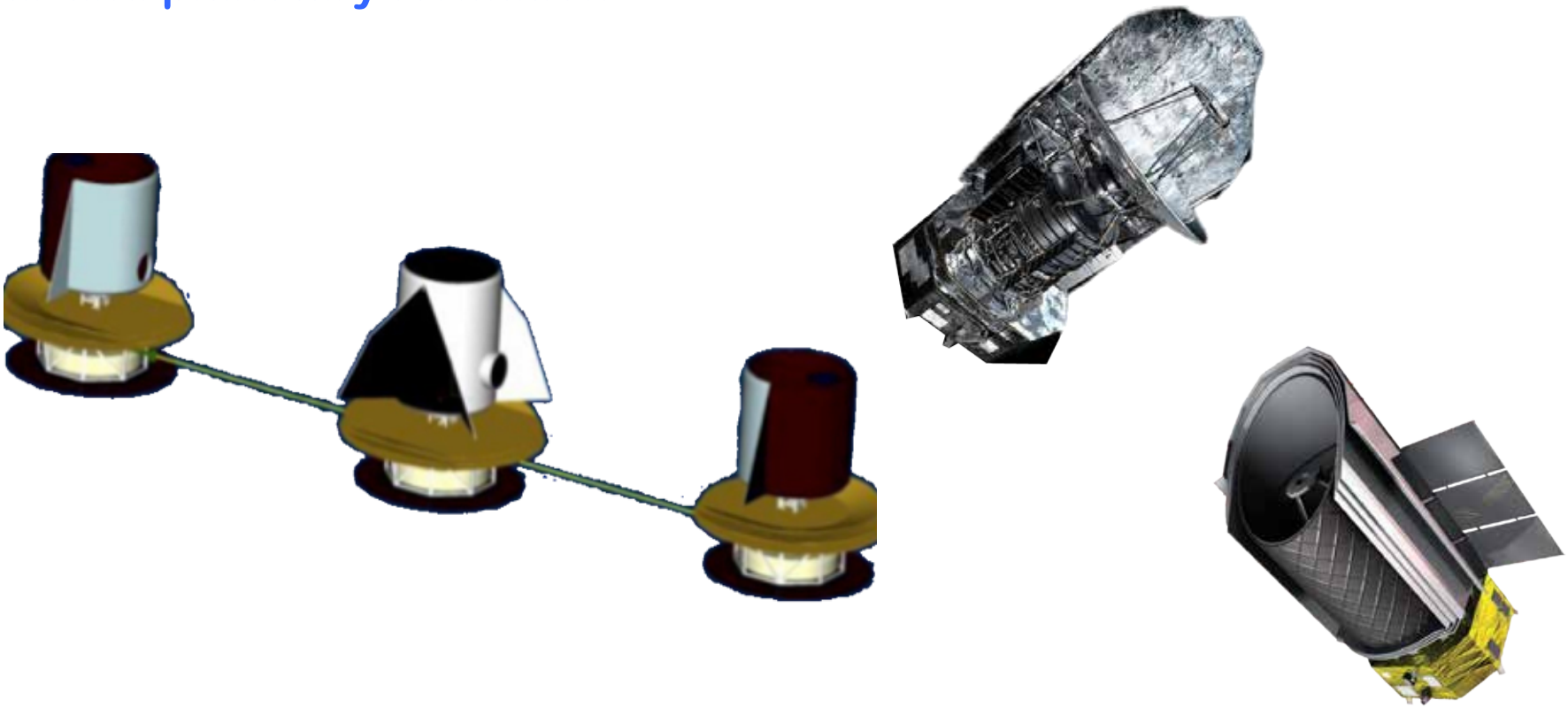
The need of high spatial resolution and The limits of single dish telescopes in space

Chris Pearson: RAL Space

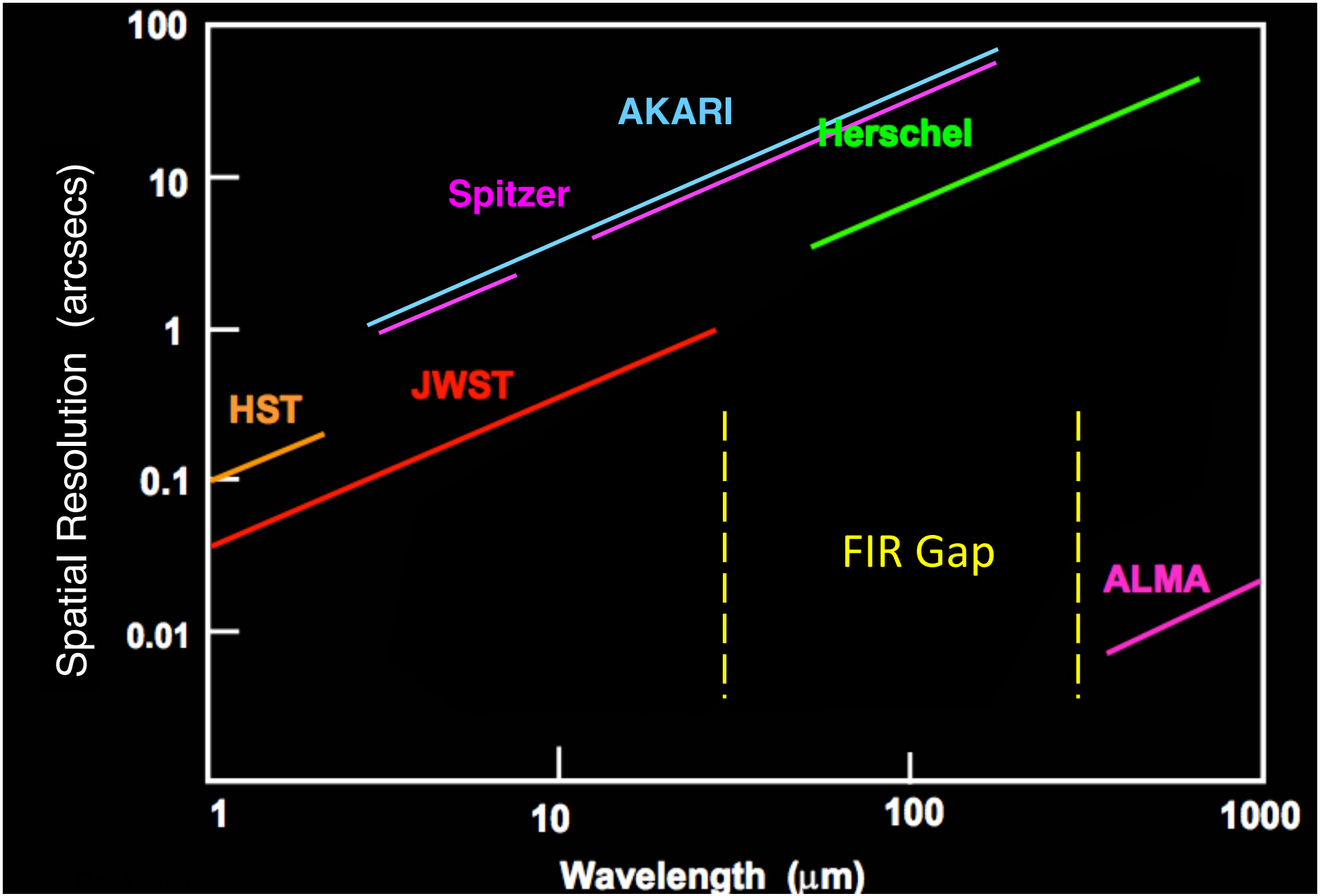
Angular Resolution and the Single Dish Limit

- Need for high angular resolution in the FIR to investigate key science / astronomy / astrophysics questions

- Poor FIR angular resolution is now the main limitation in the study of star and planetary formation



Angular Resolution and the Single Dish Limit



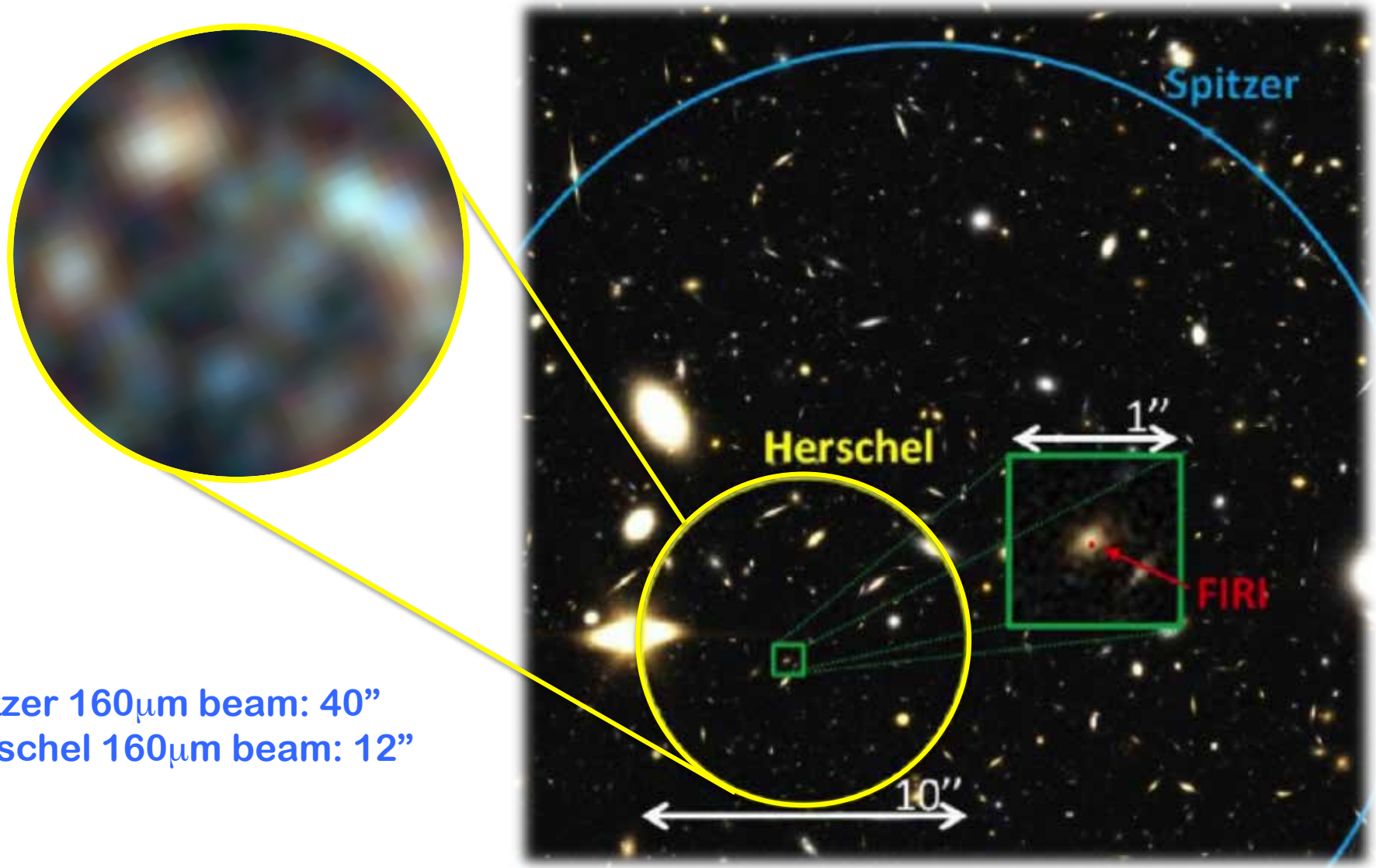
Far Infrared Astrophysics

- **Galaxies and Cosmic Evolution**
  - Star Formation History
  - Gas Cooling from FIR bands
  - AGN / host relation, black hole accretion and growth
  - CIRB
  - Molecular Hydrogen at high redshift
- **Star Formation and The Interstellar Medium**
  - ISM structure
  - High mass star formation, filament dynamics
  - molecular tracers (H2O, CO, …),
  - pre-stellar cores
  - Galaxy dust
  - dust heating and cooling
  - formation of Massive stars
- **Proto-Planetary discs and planet formation**
  - Resolving snow line (liquid/ice regions)
  - water dynamics
  - dust structure / dynamics

All require much better spatial resolution at moderate spectral resolution

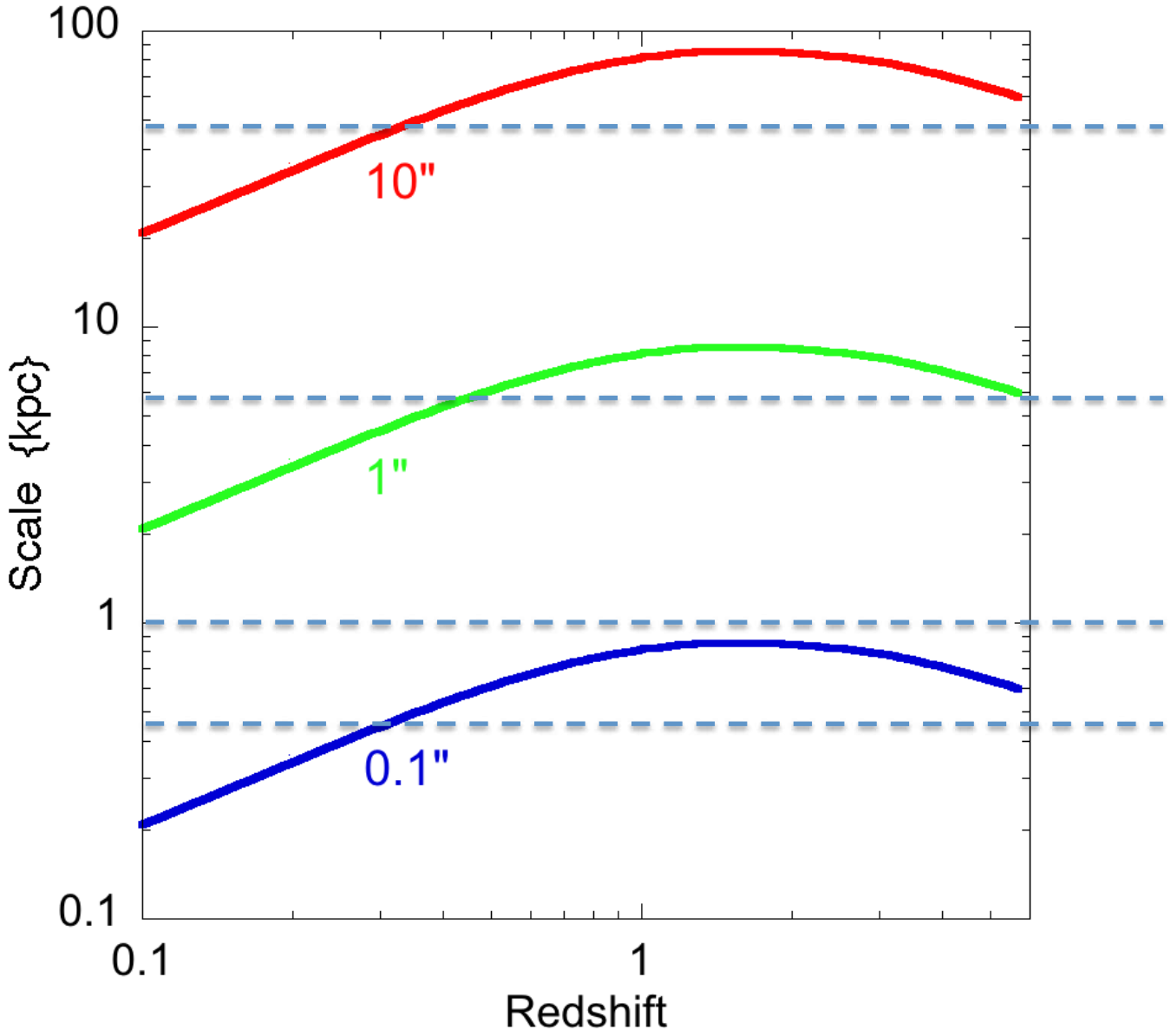
Galaxies and Cosmic Evolution

Distant Galaxies



Spitzer 160μm beam: 40”
Herschel 160μm beam: 12”

Distant Galaxies



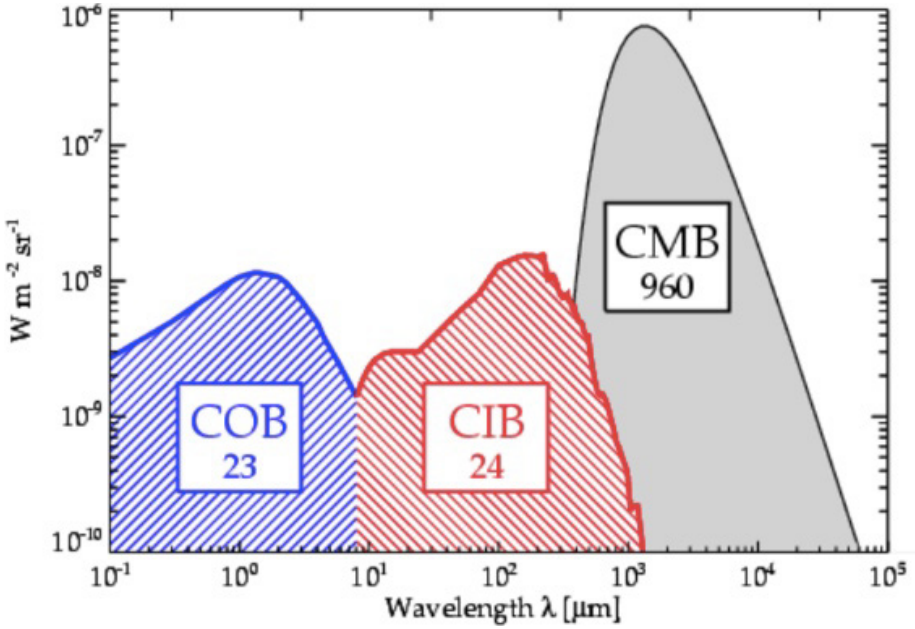
Galaxy Scale

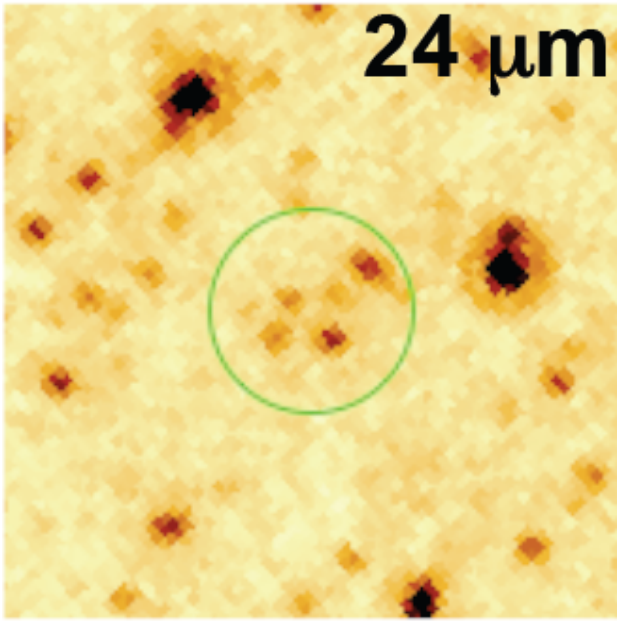
Galaxy Structure

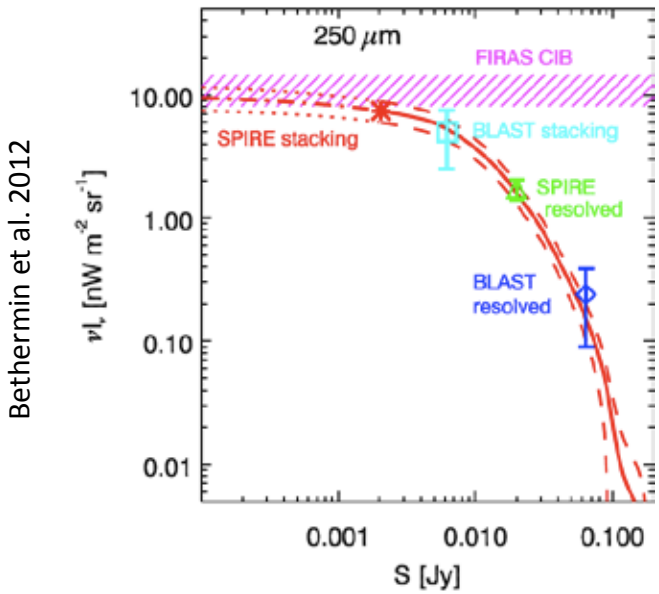
ULIG core

AGN Dust Torus

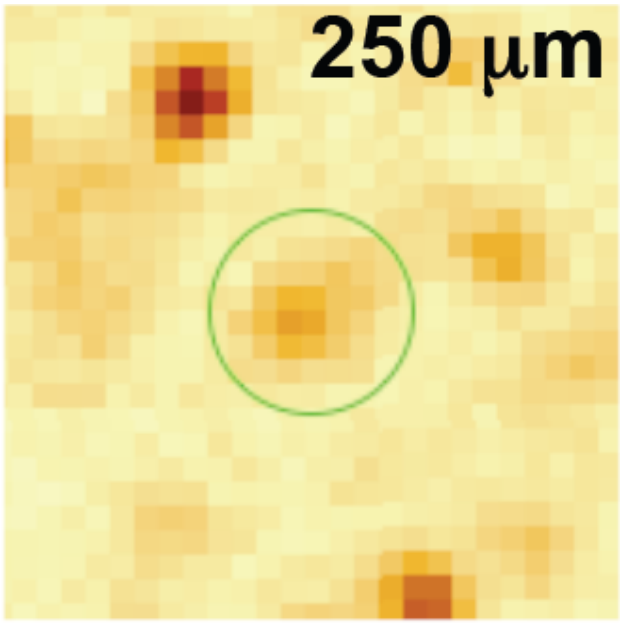
Resolving the CIRB



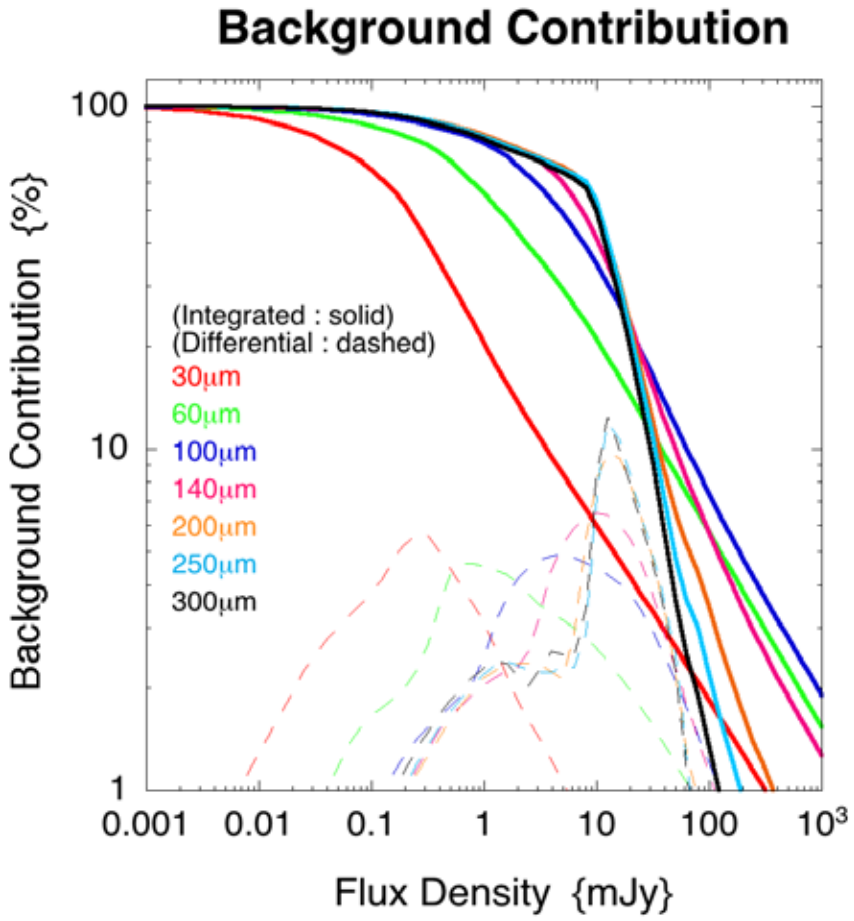


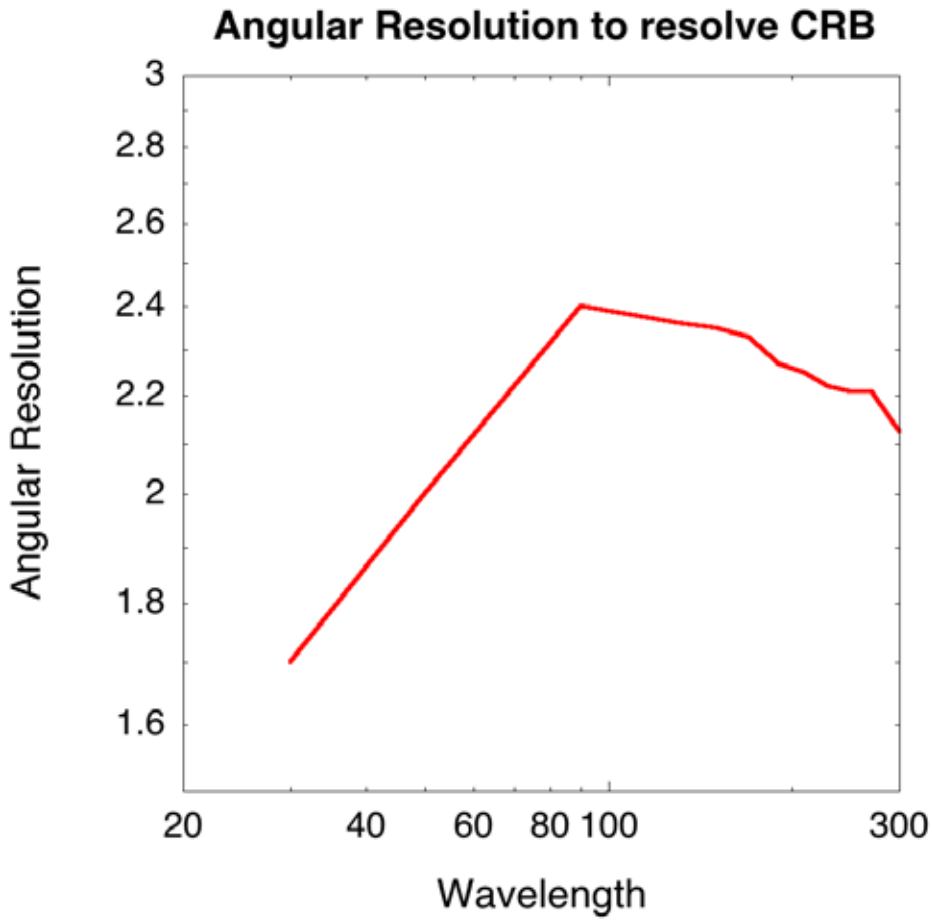


Bethermin et al. 2012



Resolving the CIRB

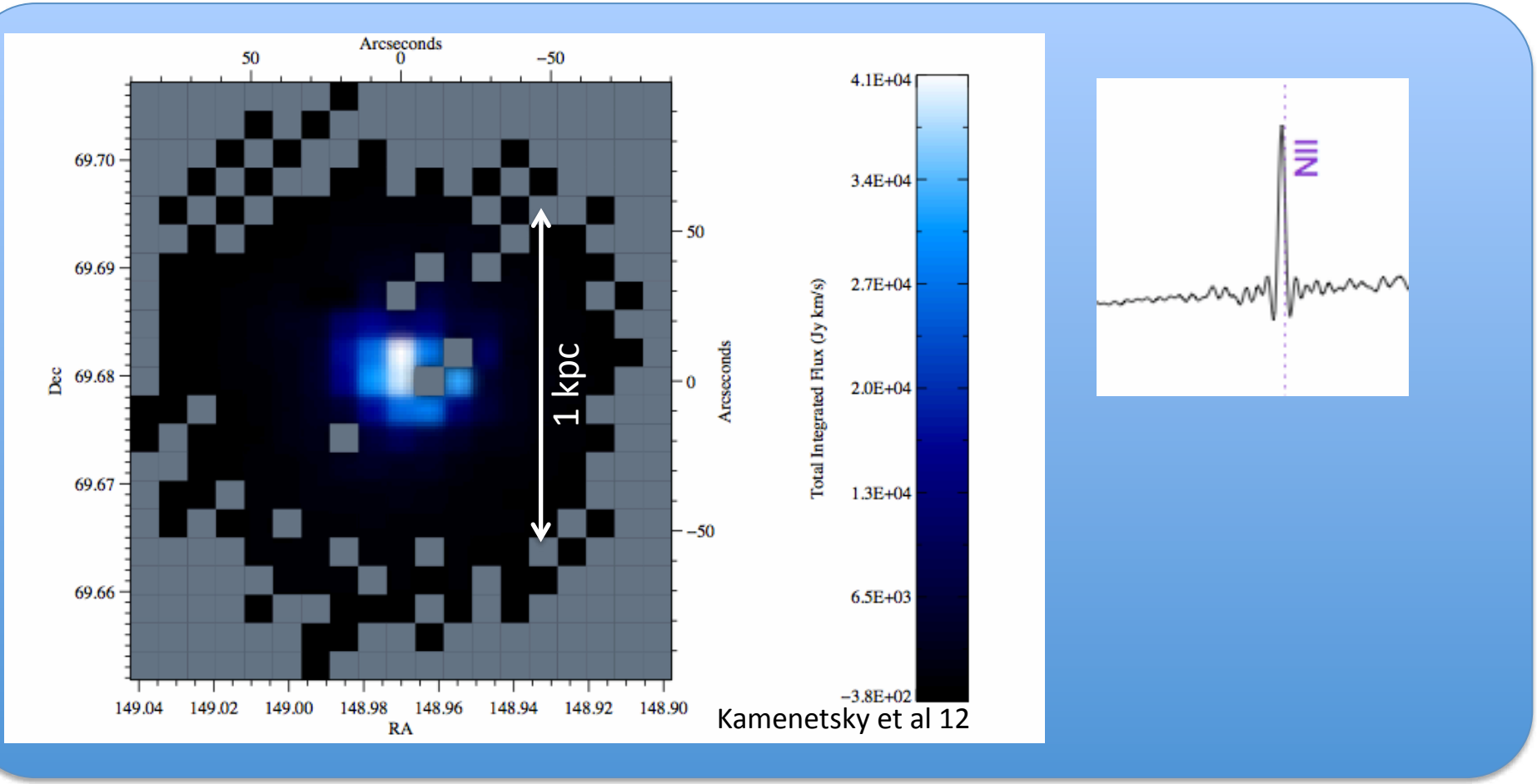




- CIRB ~100% resolved even at ~1'' resolution at 30-300μm
- 0.1'' resolution is not required to resolve the CIRB

Galaxies and AGN

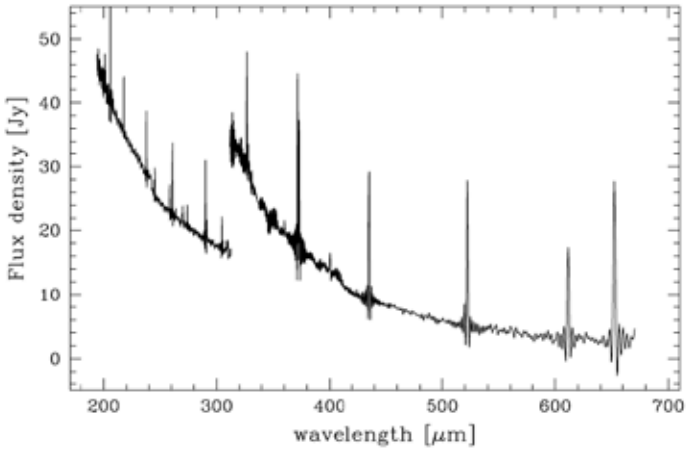
SPIRE-FTS Spectral Map of [NII] from M82

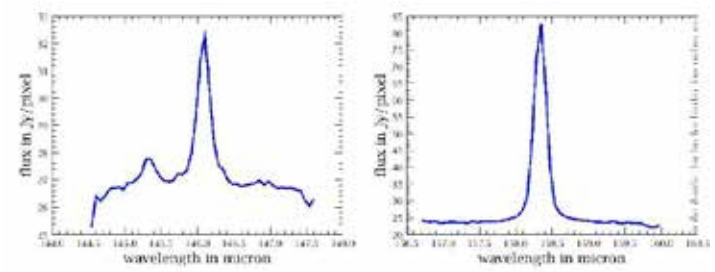


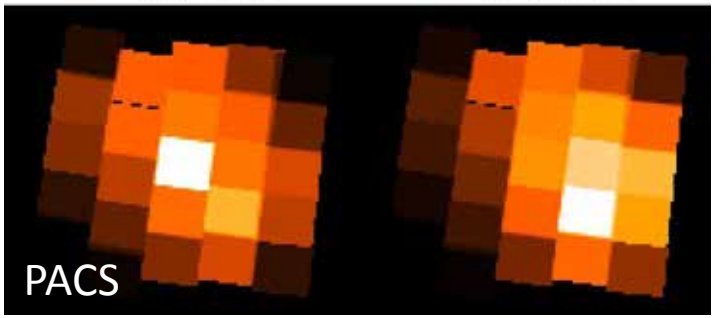
- central starburst area <1kpc
- Combining FIR FS lines and CO ladder we can probe the atomic, ionic and molecular ISM but urgently need resolution!

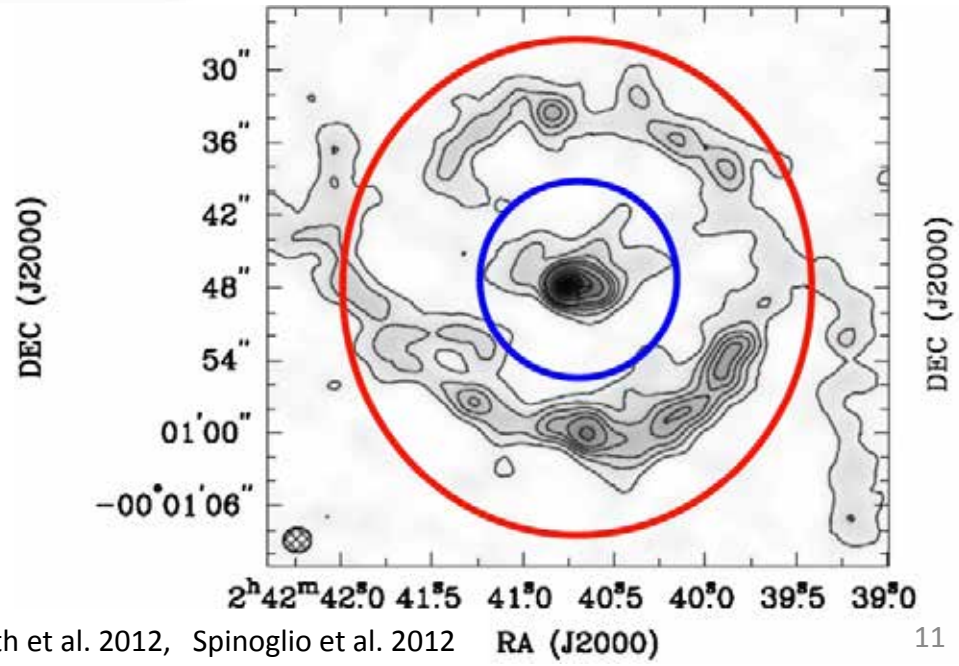
Galaxies and AGN

- NGC1068: Strongest nearby Seyfert 2 galaxy 47 Mly: template AGN / SF
- Central Compact Circumnuclear Disk, associated with AGN 4” 0.3kpc
- Extended Star Formation ring, with a radius of the order of 10 –20” 1-1.5 kpc





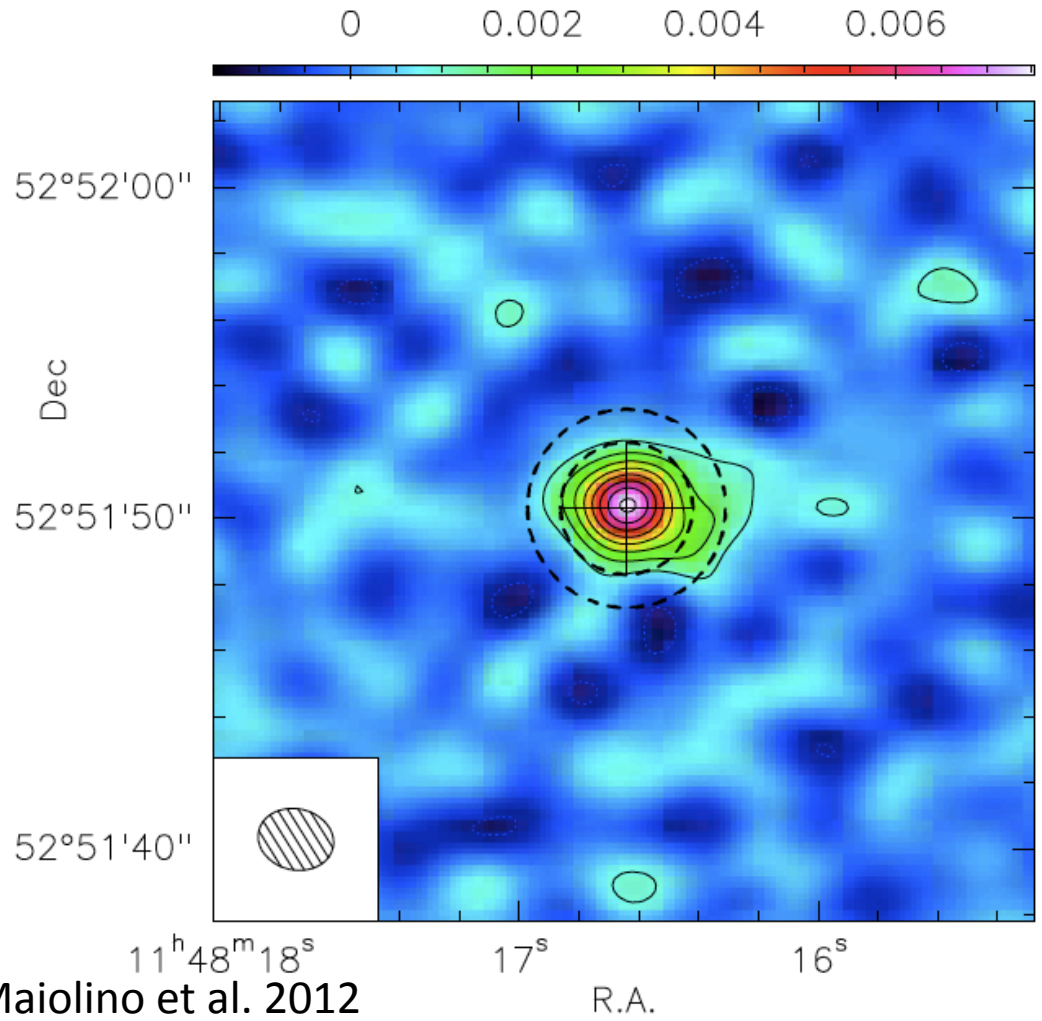


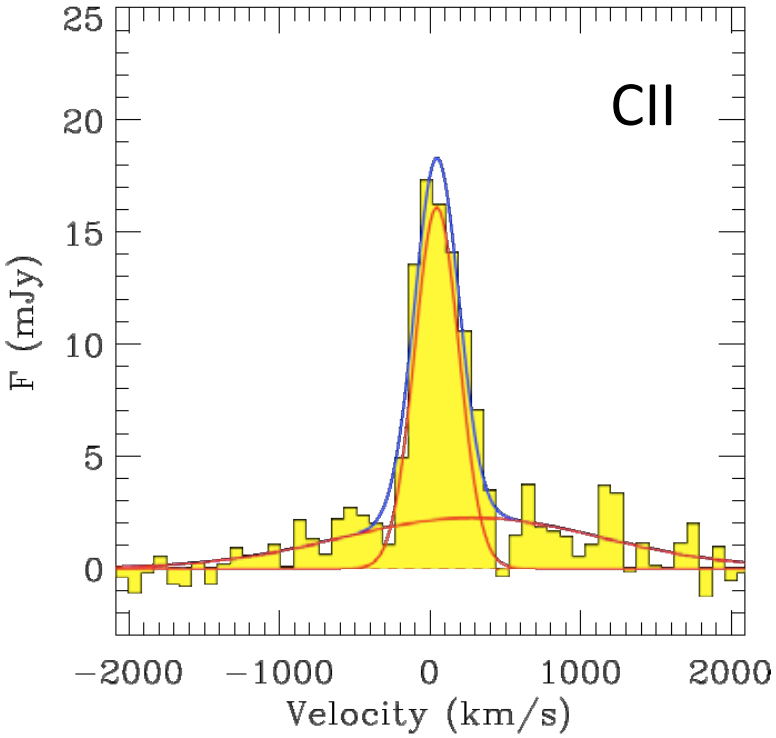


Hailey-Dunsheath et al. 2012, Spinoglio et al. 2012

Gas at High Redshift

- 1.1 mm Observations of CII (158μm) emission in z = 6.4 QSO
- Evidence for massive outflows at high redshift
- At z = 6.4: 1 arcsec corresponds to ~ 5.5 kpc





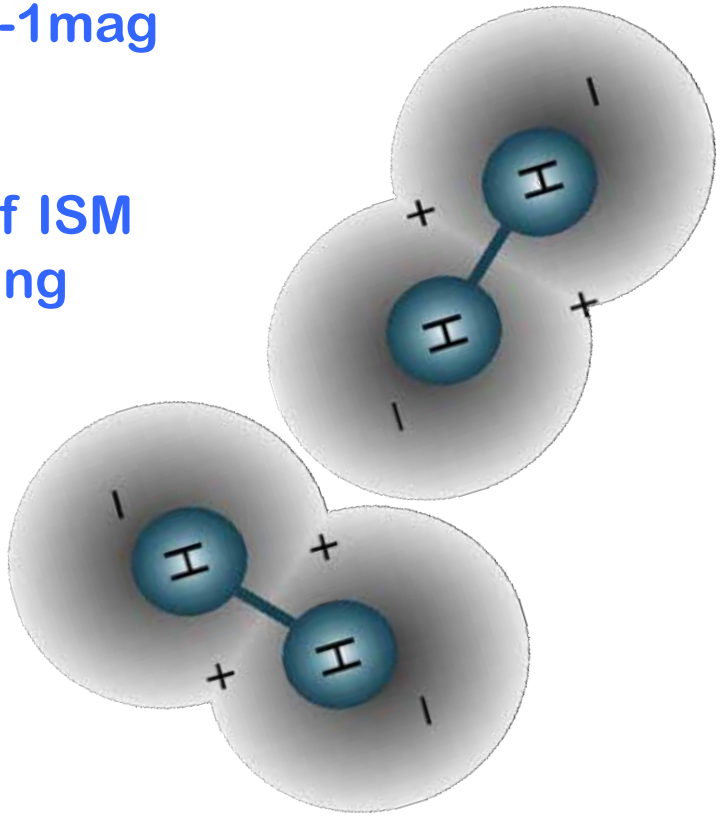
Maiolino et al. 2012

Gas at High Redshift

Probe pristine gas in proto-galaxies through detection of the pure rotational H_2 28 μm and 17 μm lines

- H_2 most abundant molecule in the Universe
- found in regions where shielding from UV photons (responsible for its dissociation) is sufficiently large Av >=0.5-1mag

Key role:
- H_2 formation on grains initiates chemistry of ISM
- Major contributor to the astrophysical cooling



- z~ 5 H_2 moves into 100-200μm band

- Spatial resolution < 1 arsec to map distribution at high redshift

Galaxies and Cosmic Evolution

High Spatial Resolution needed for:

- **Resolving crowded fields**
  compare like for like at shorter ancillary wavelengths
  FIRI type resolution NOT required to resolve the FIR background

- **Mapping spatial distribution of spectral lines in central regions of Star forming galaxies ~ <kpc scales**

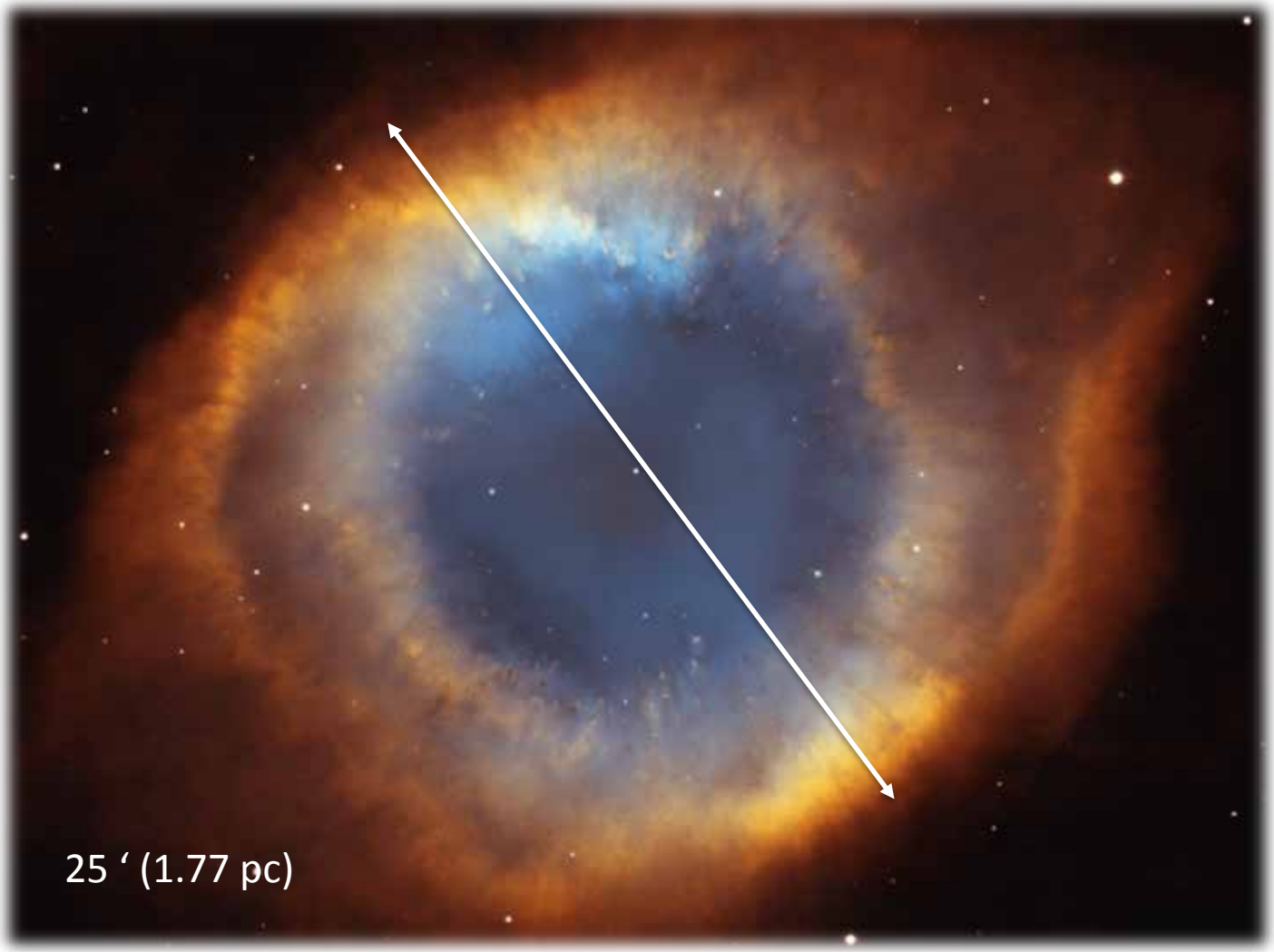
- **Disentangling AGN torus / starburst phenomena**

- **Detection and mapping of H2 at high redshift**

Stellar Evolution and the Interstellar Medium

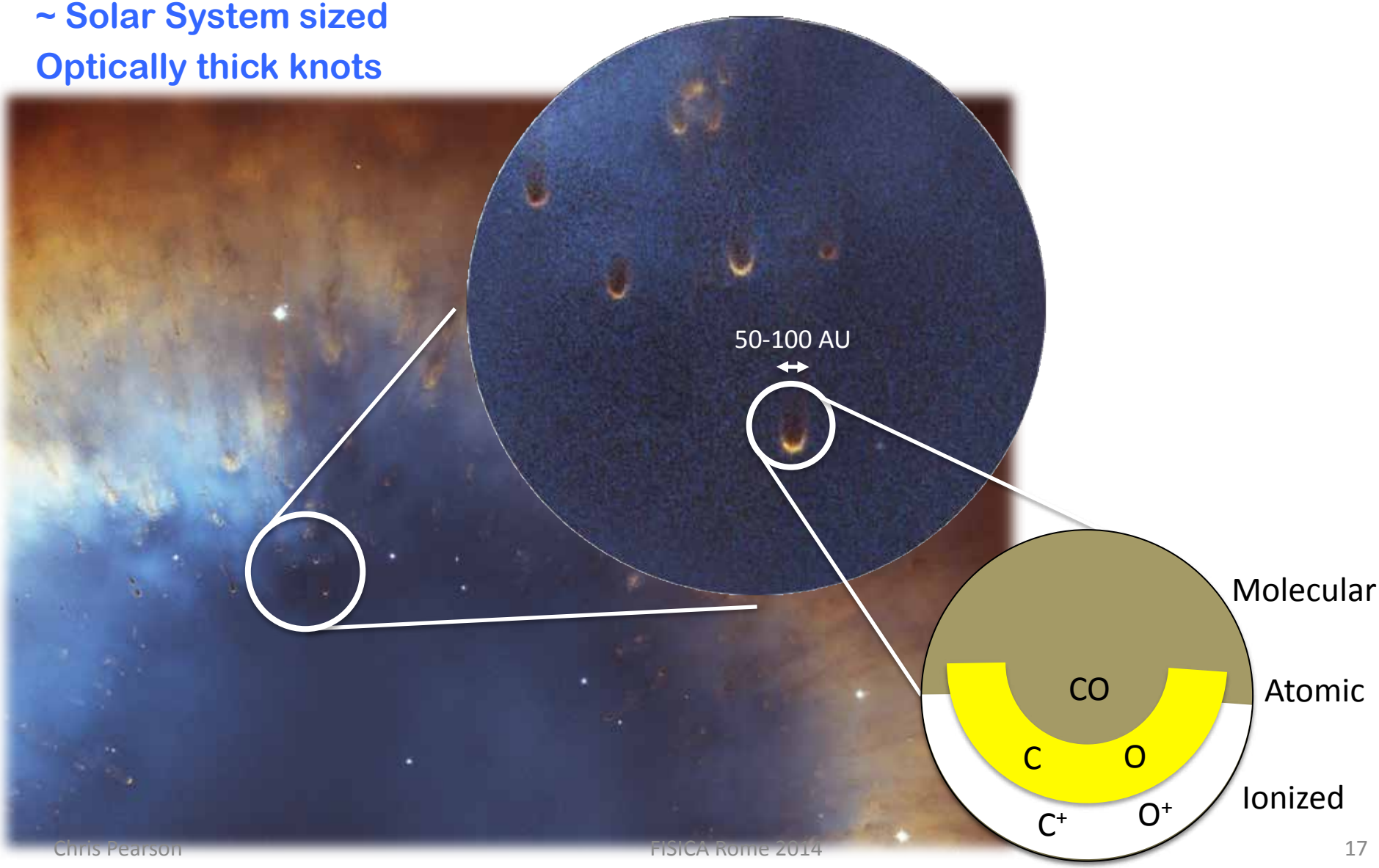
Star Formation and the Interstellar Medium

- Helix Planetary Nebula
- Photochemical studies at small spatial scales, PDR regions
- Distribution of atomic and molecular gas



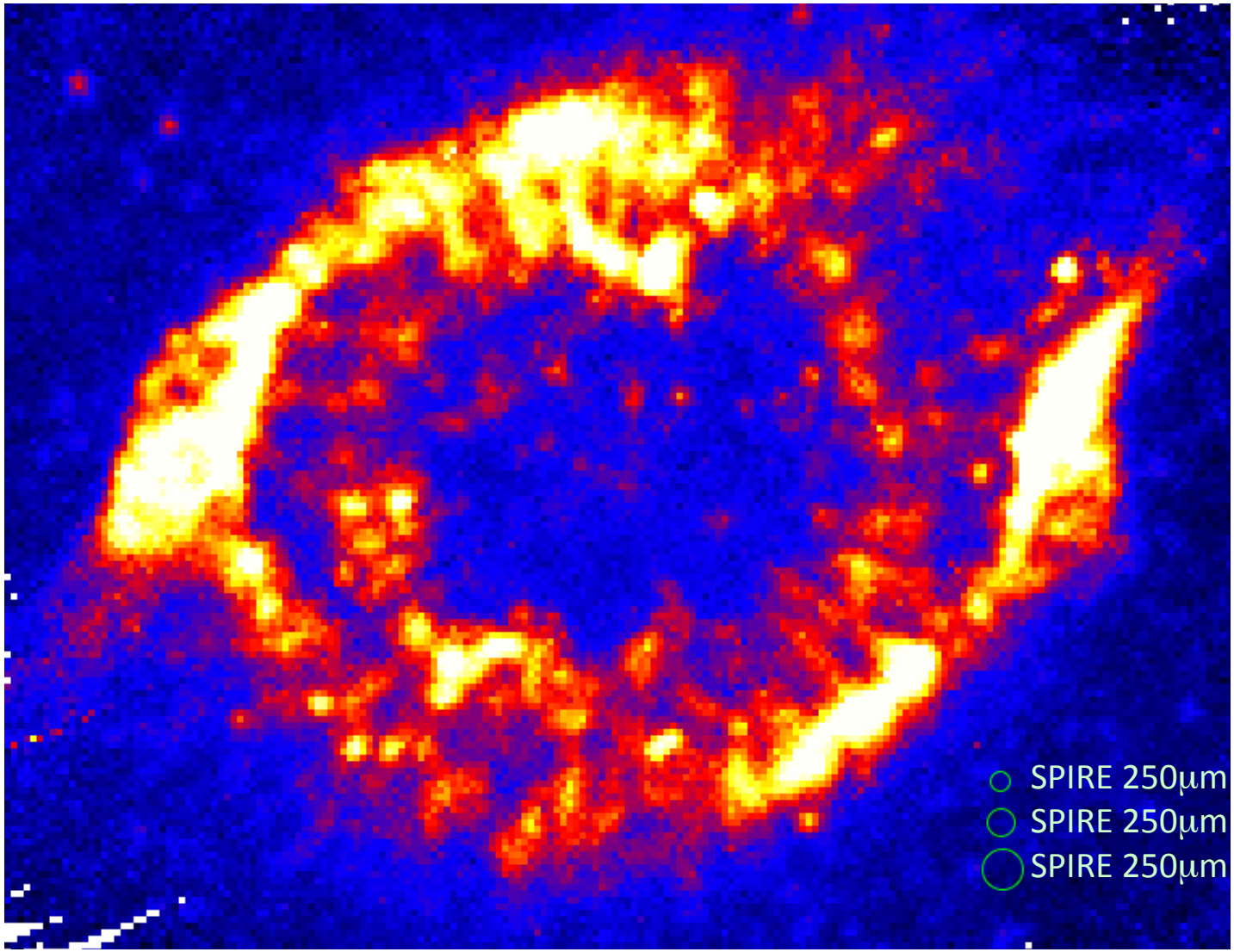
Star Formation and the Interstellar Medium

- Cometary Knots: radially Symmetric bright cusps (local photoionization fronts) and tails
- ~ Solar System sized
- Optically thick knots



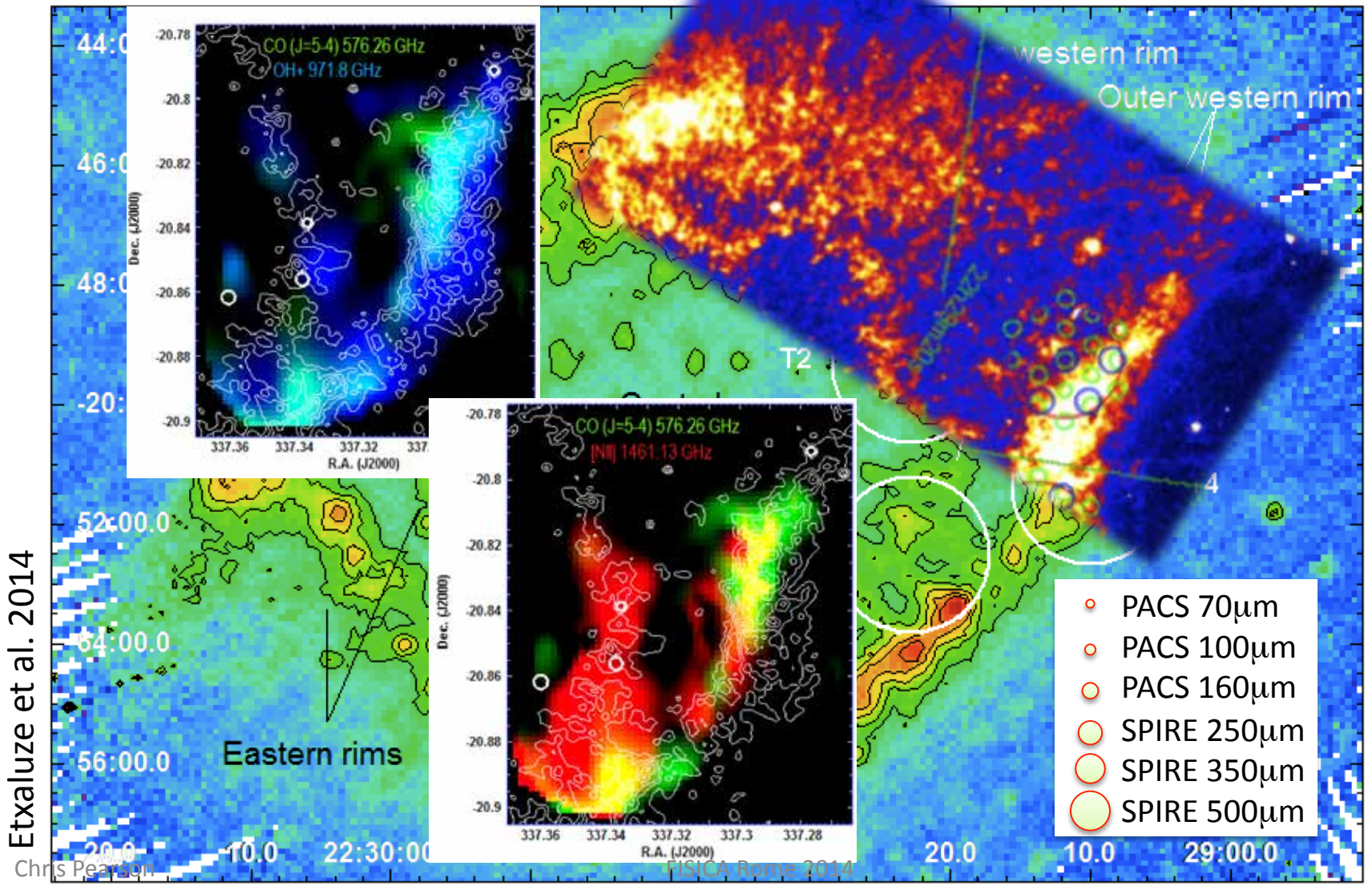
Star Formation and the Interstellar Medium

- Helix Nebula



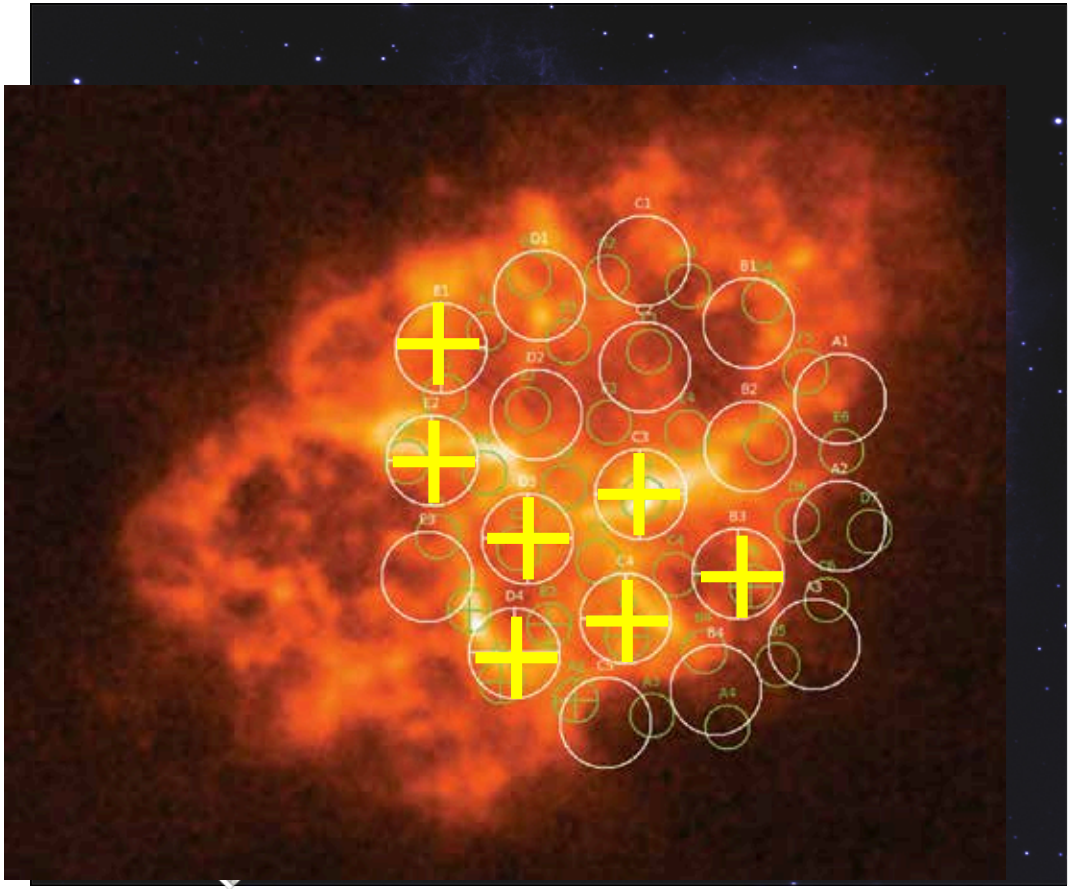
Star Formation and the Interstellar Medium

- CO from dense shielded clumps
- CI and OH+ traces extended CO photo-dissociation regions along the rims
- [N II] traces the diffuse ionized gas in the clump medium.



Star Formation and the Interstellar Medium

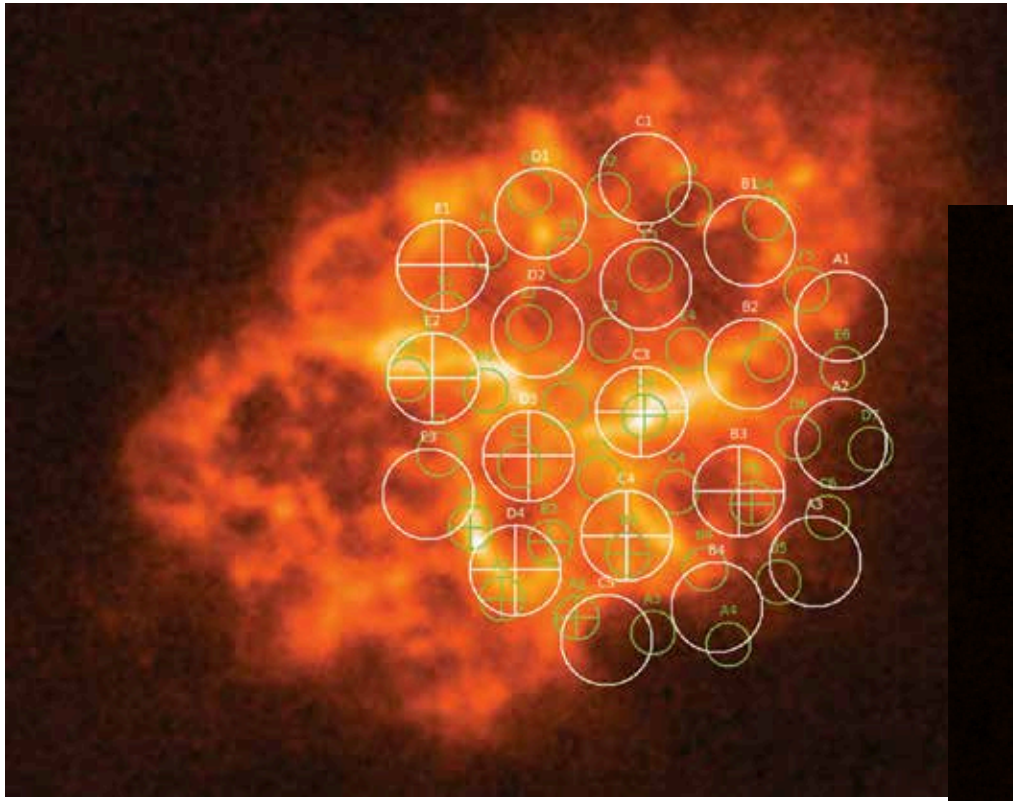
- Crab Nebula Supernova Remnant – Heavy element factory
  Chains of knots and filaments of scales < 1arcsec
- Observed with PACS 70μm imaging
- Observed with SPIRE FTS

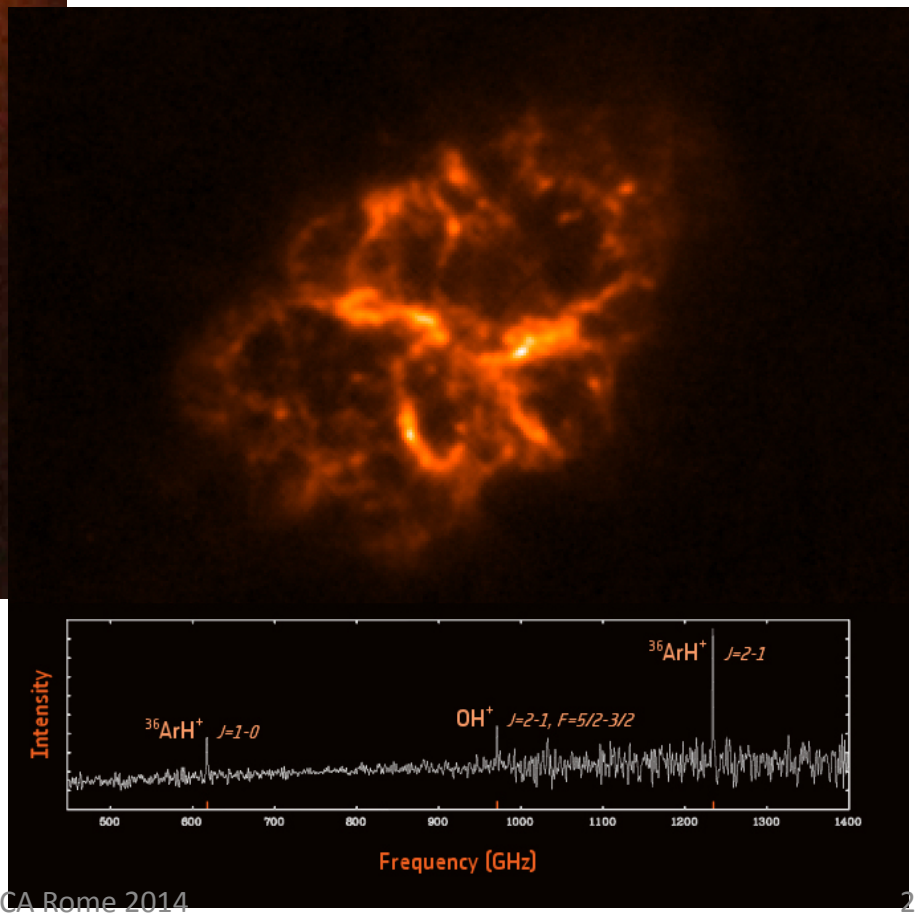


Barlow et al 2014

Star Formation and the Interstellar Medium

- Crab Nebula Supernova Remnant – Heavy element factory
- First detection of Noble Gas molecule ArH^+ in the knotty filaments





Stellar Evolution and The Interstellar Medium

High Spatial Resolution needed for:

- **Obtaining resolution on the scales probed at shorter wavelengths (Hubble) in planetary nebula, e.g. Cometary Tails**

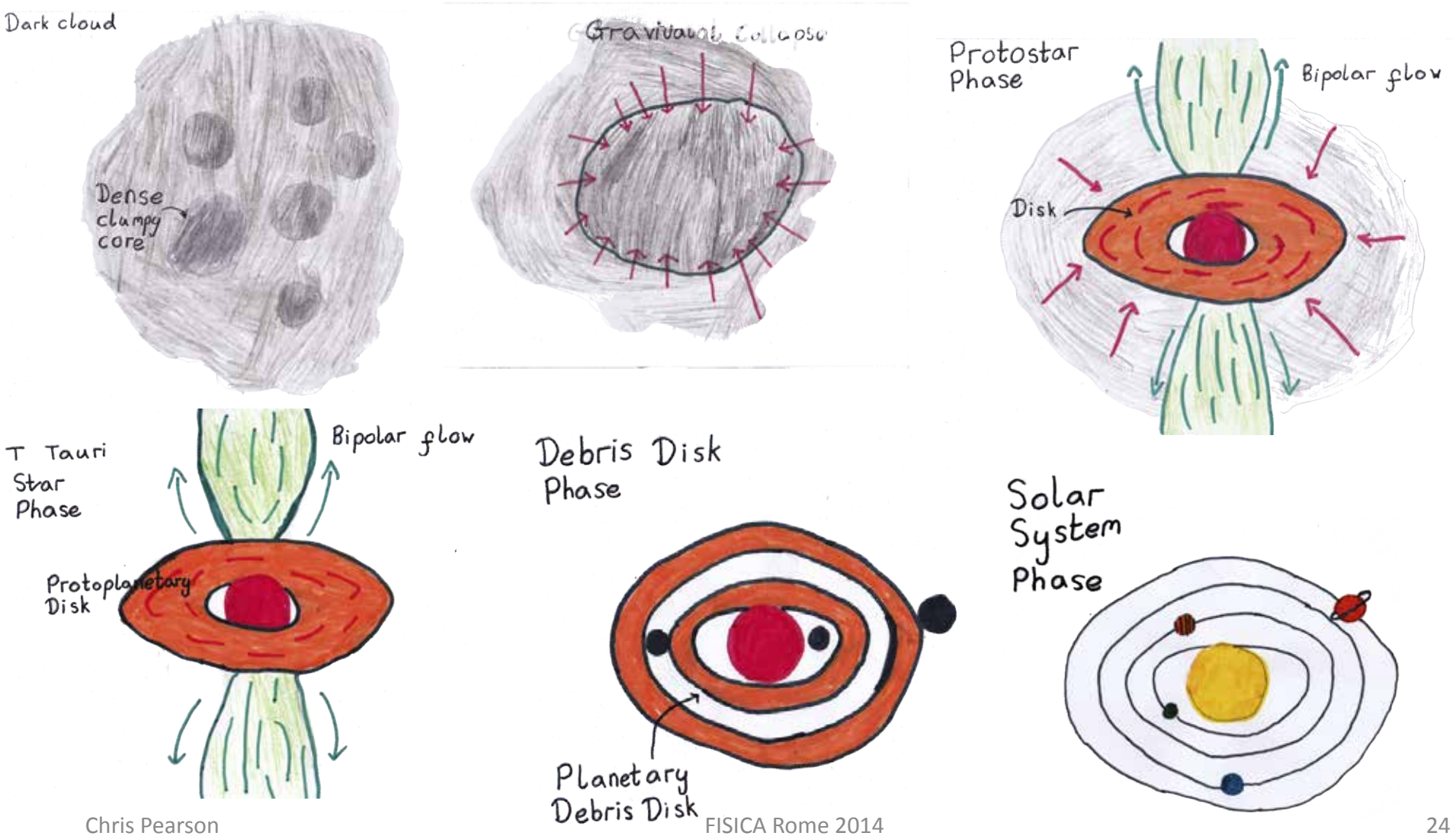
- **Mapping PDR regions and radial ionizing gradients**

- **Distribution of bright filaments and knots in ISM**

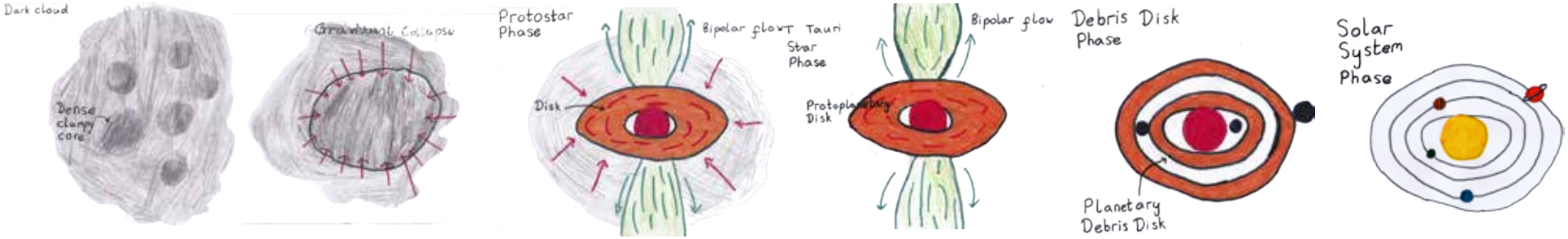
Proto-Planetary Disks and Planet Formation

Star and Planetary Formation

- Fundamental Goal: Understanding formation of stars and planets
- Evolution from cloud collapse, debris disc to planet formation
- Requires angular scales of ~degrees to 1/100 arcsec



Star and Planetary Formation



	Scale	Angular size @ 100pc
Dark globules / cloud cores / overdensities	~ few parsec	~ degree
Cloud Collapse	~ few 10,000 AU	200 arcsec
Protostar + disk + Outflow	~10,000 AU	100 arcsec
T Tauri + Outflow	~few 100AU	2 arcsec
PMS + Debris Disk	~ 200AU	2 arcsec
Main Sequence Star + Solar System	~100 AU	1 arcsec
Rocky Habitable bodies	~ 1 AU	0.01 arcsec

PACS/SPIRE	70 μm	100 μm	160 μm	250 μm	350 μm	500 μm
Beam	6 “	8 “	12 “	18 “	25 “	36 “

Protoplanetary Disks

Resolving, dust structure / dynamics in Proto-Planetary Discs

Source

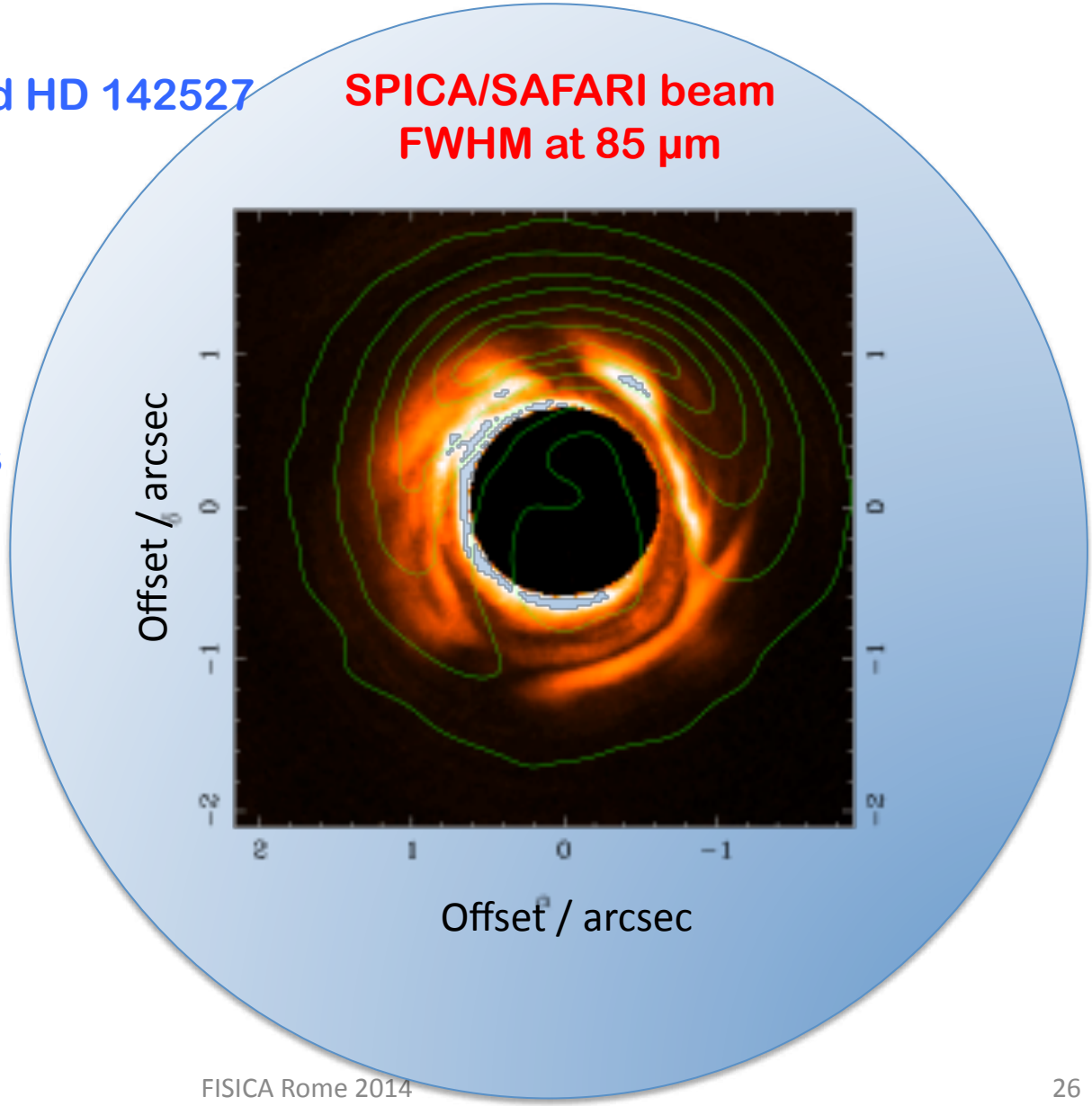
- Protoplanetary disc around HD 142527 (Casassus et al. 2013).
- Distance of ~140 pc
- Inner radius of ~10 AU.
- perturbing planetary-mass at 90 AU ?

Image:

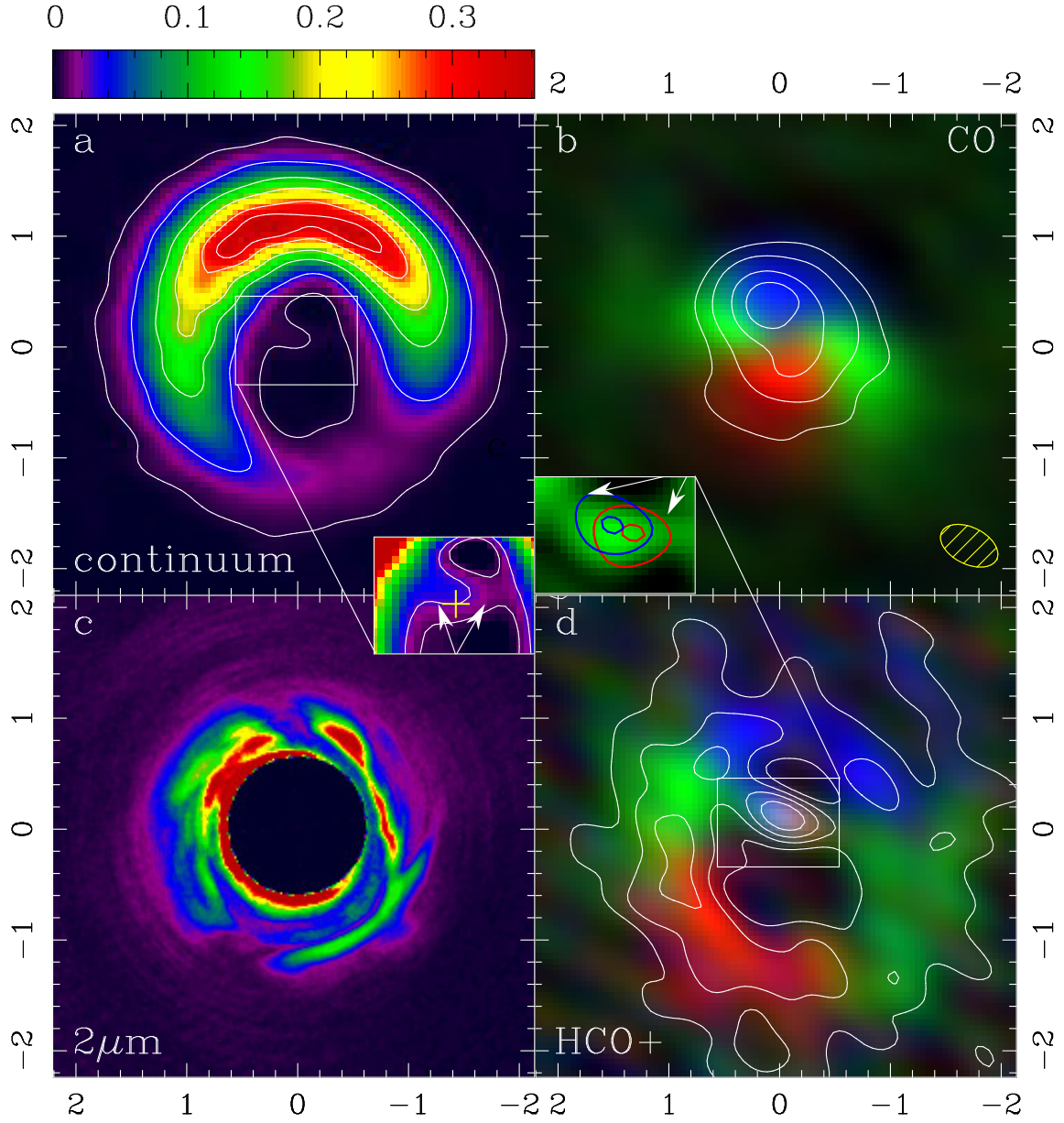
- GEMINI 2 μm NIR

Contours:

- ALMA 870 μm continuum



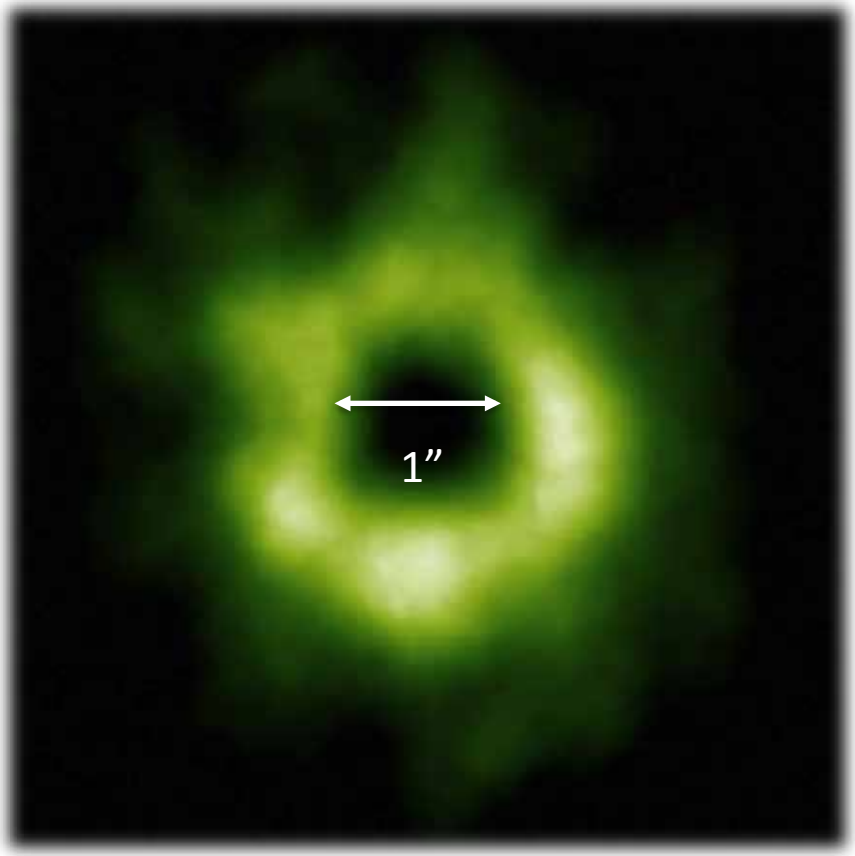
Protoplanetary Disks

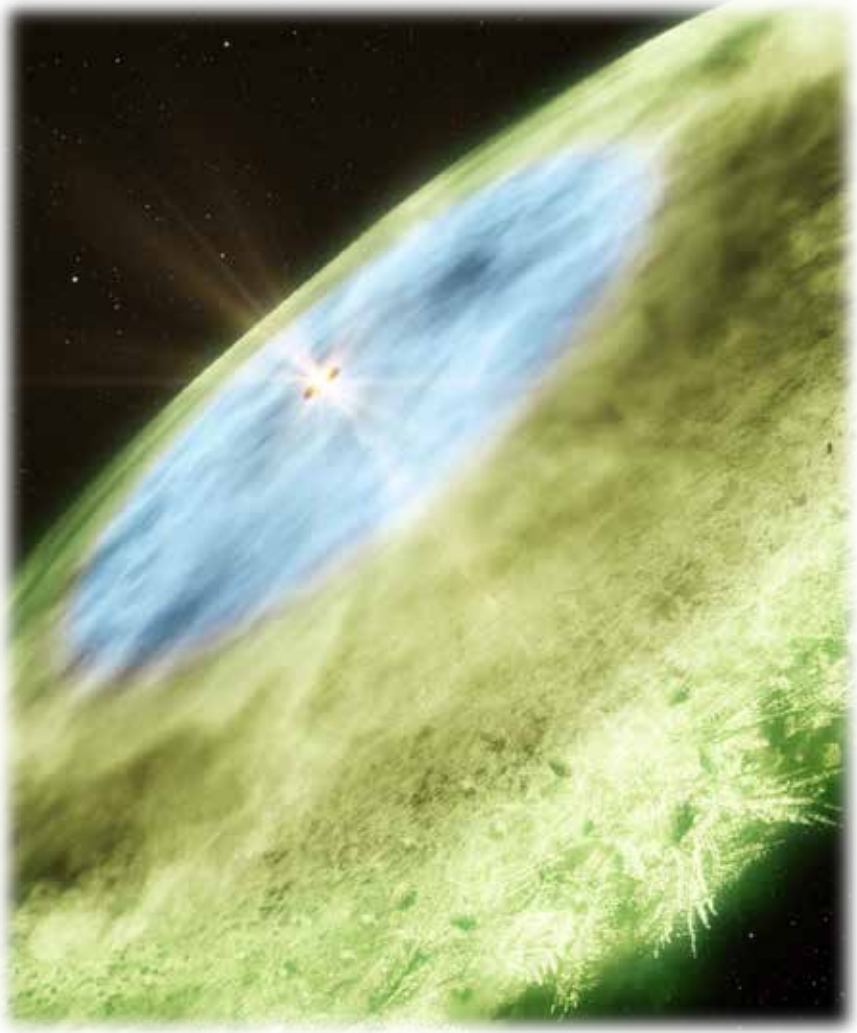


(Casassus et al. 2013)

Planet Formation

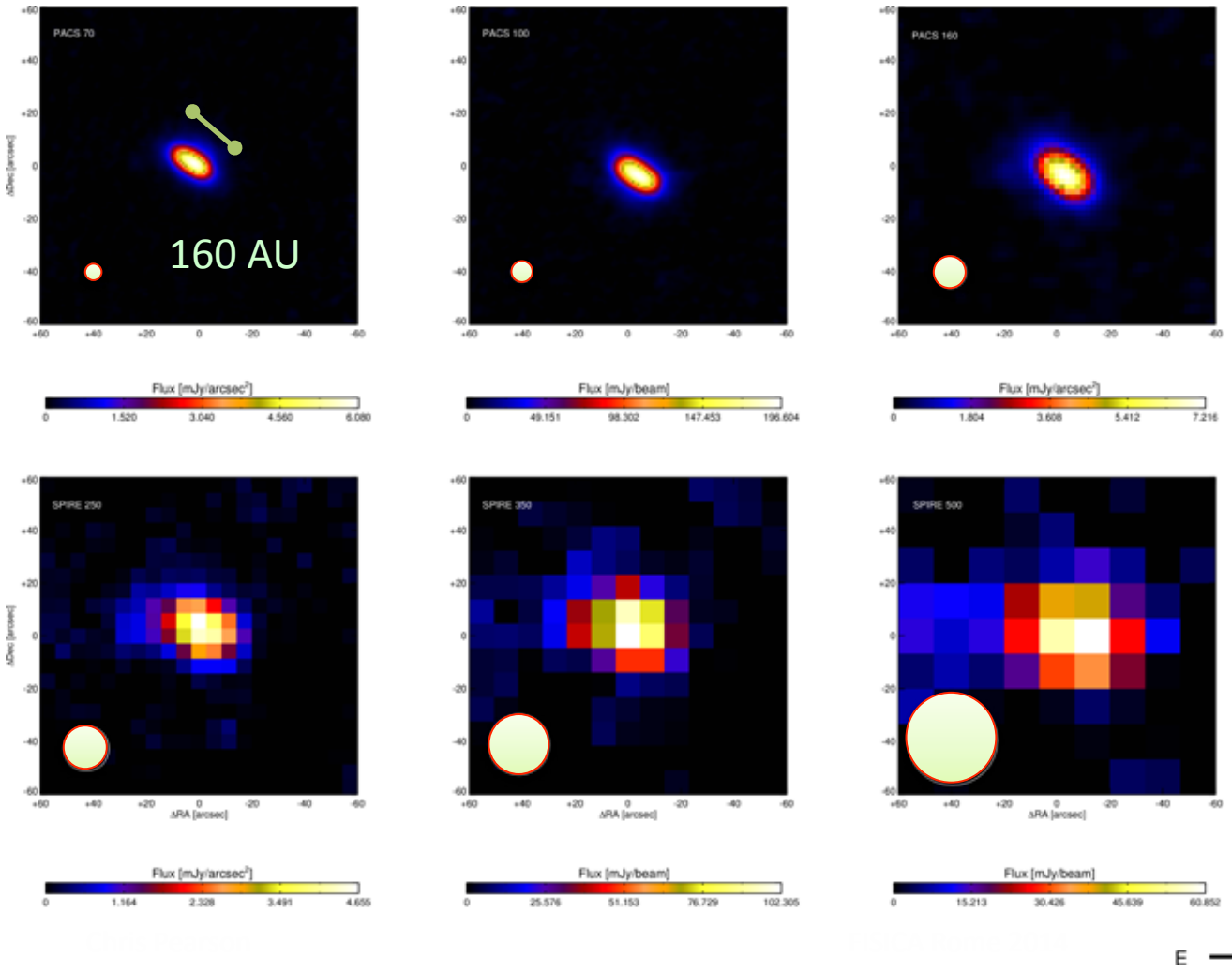
- TW Hydrae young star 176 light-years distant
- ALMA image shows carbon monoxide 30 AU snow line around star.

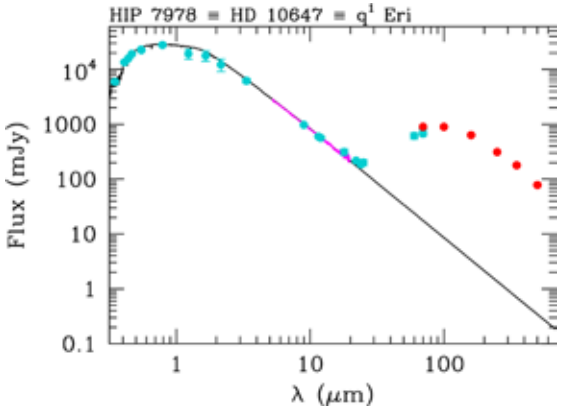




Debris Disks

- Herschel DUNES has revealed excess IR emission from debris disks around nearby stars
- Angular scale at ~60 light years ~10”





Liseau et al. 2010

Proto-Planetary Disks and Planet Formation

High Spatial Resolution needed for:

- **Probing extended Gas and Dust structure in Planetary disks**
- **Mapping the snow lines in young systems**
- **Decomposing Debris Disks**

Conclusions

Single Dish Observations:

- Adequate for nearby objects and local Universe
- But limited sample sizes
- Relatively 'coarse' physics for distant objects

Space Interferometry:

- Required to bring the quality of far-infrared observations to the level of shorter and longer wavelength studies
- Decompose objects into distinct regimes of physical processes
- Extend local studies to greater distances and greater sample sizes
- Examine the structure (physics) of objects at high redshift