Asilomar 2010

Conference Summary

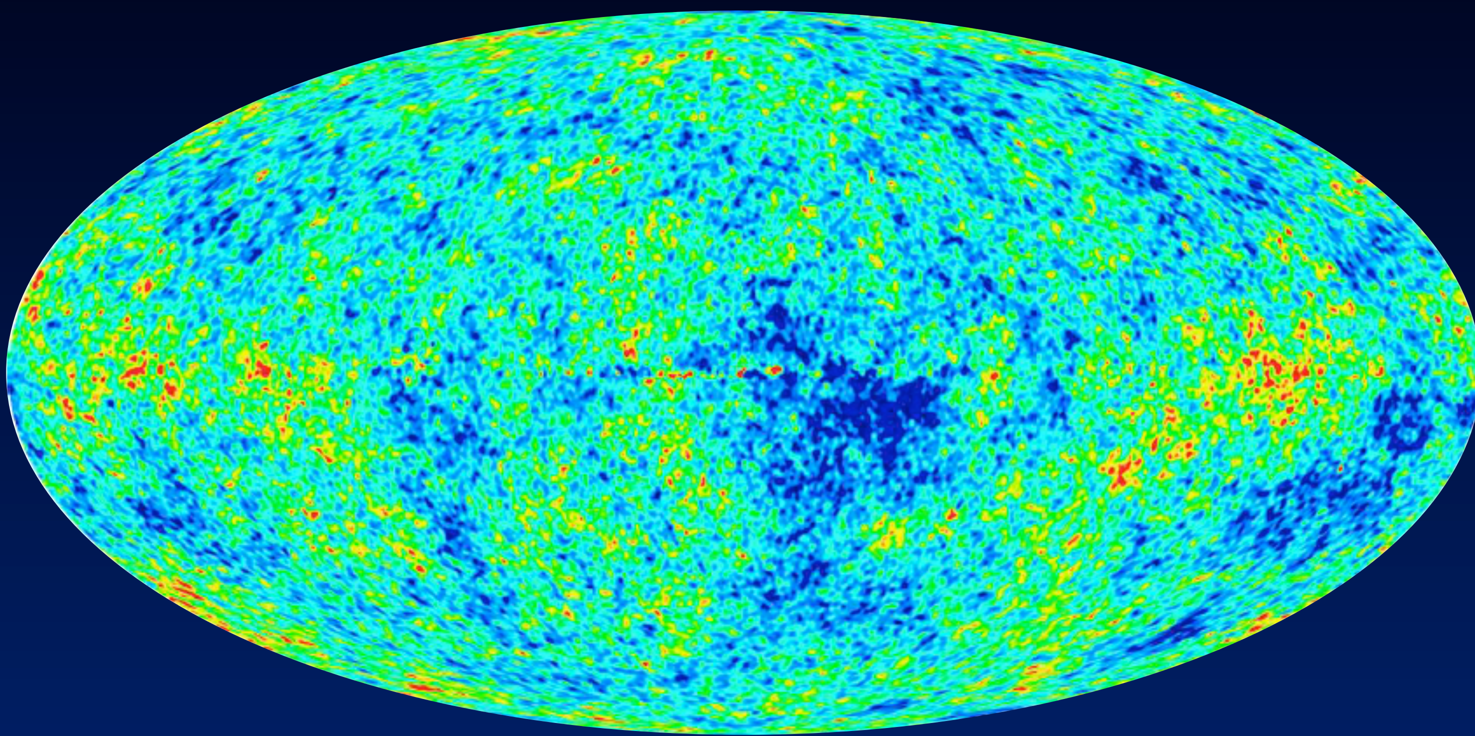
Steven Beckwith

University of California

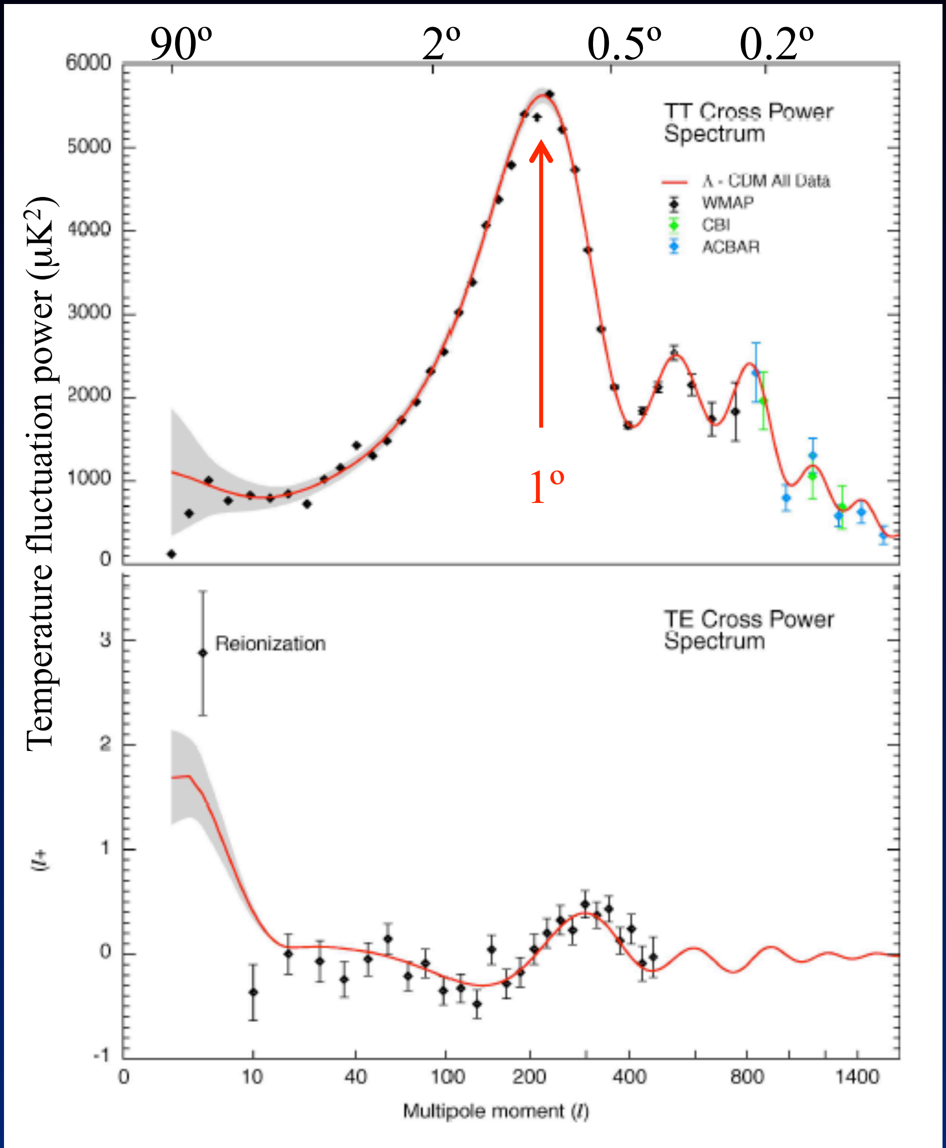
Eierlegende Wollmilchsau
(="egg-laying wool-milk-sow")

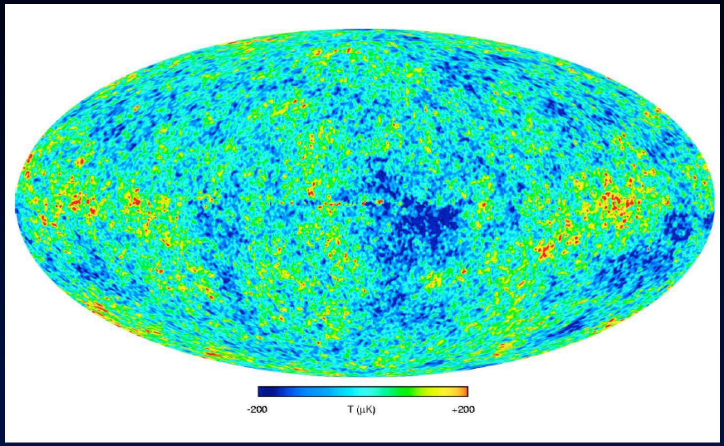
Expansion of the universe

Fluctuations in the early universe



Size scale of fluctuations

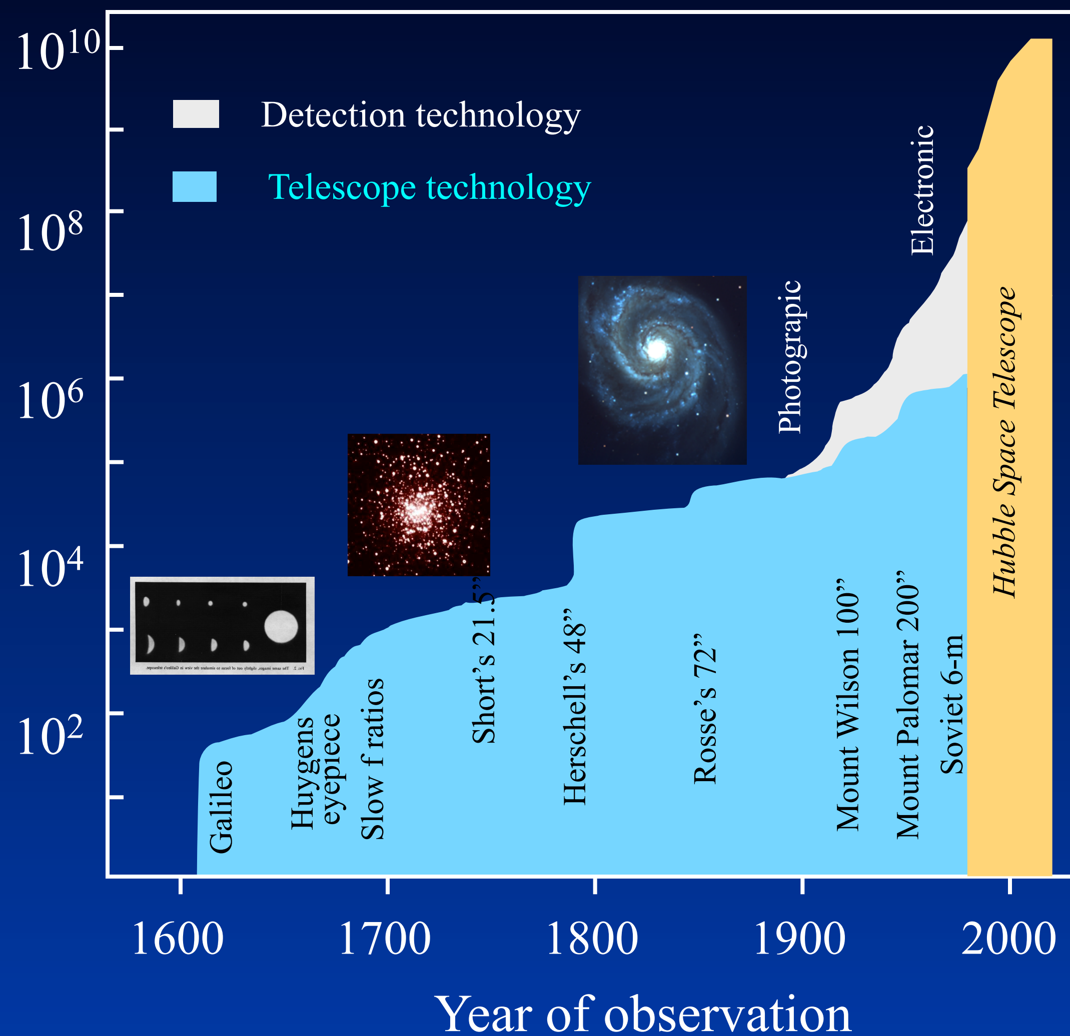


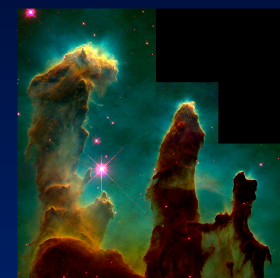


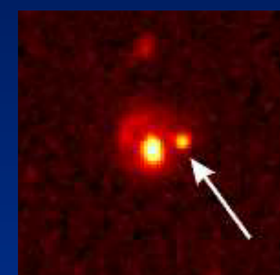
Discovering New Phenomena

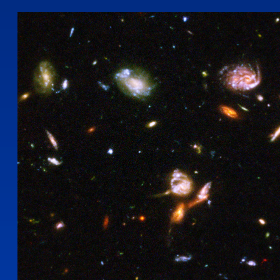
After Fig. 3.10 in *Cosmic Discovery*, M. Harwit

Sensitivity Improvement over the Eye



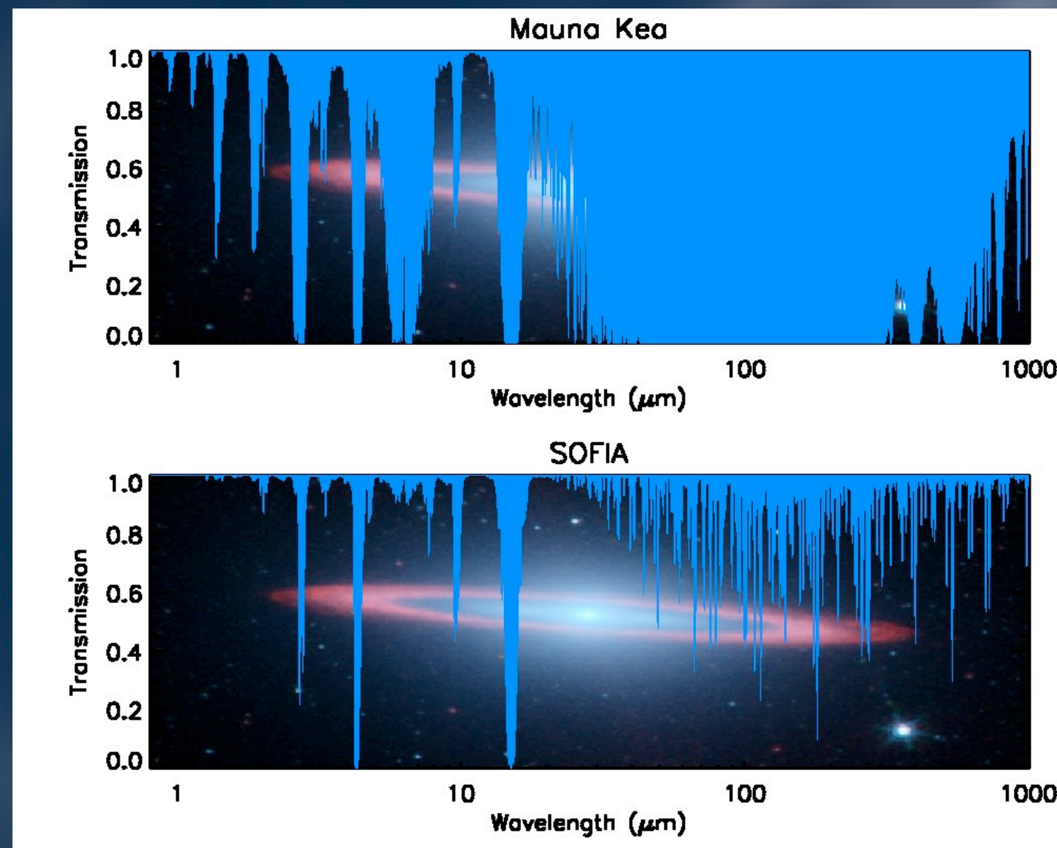




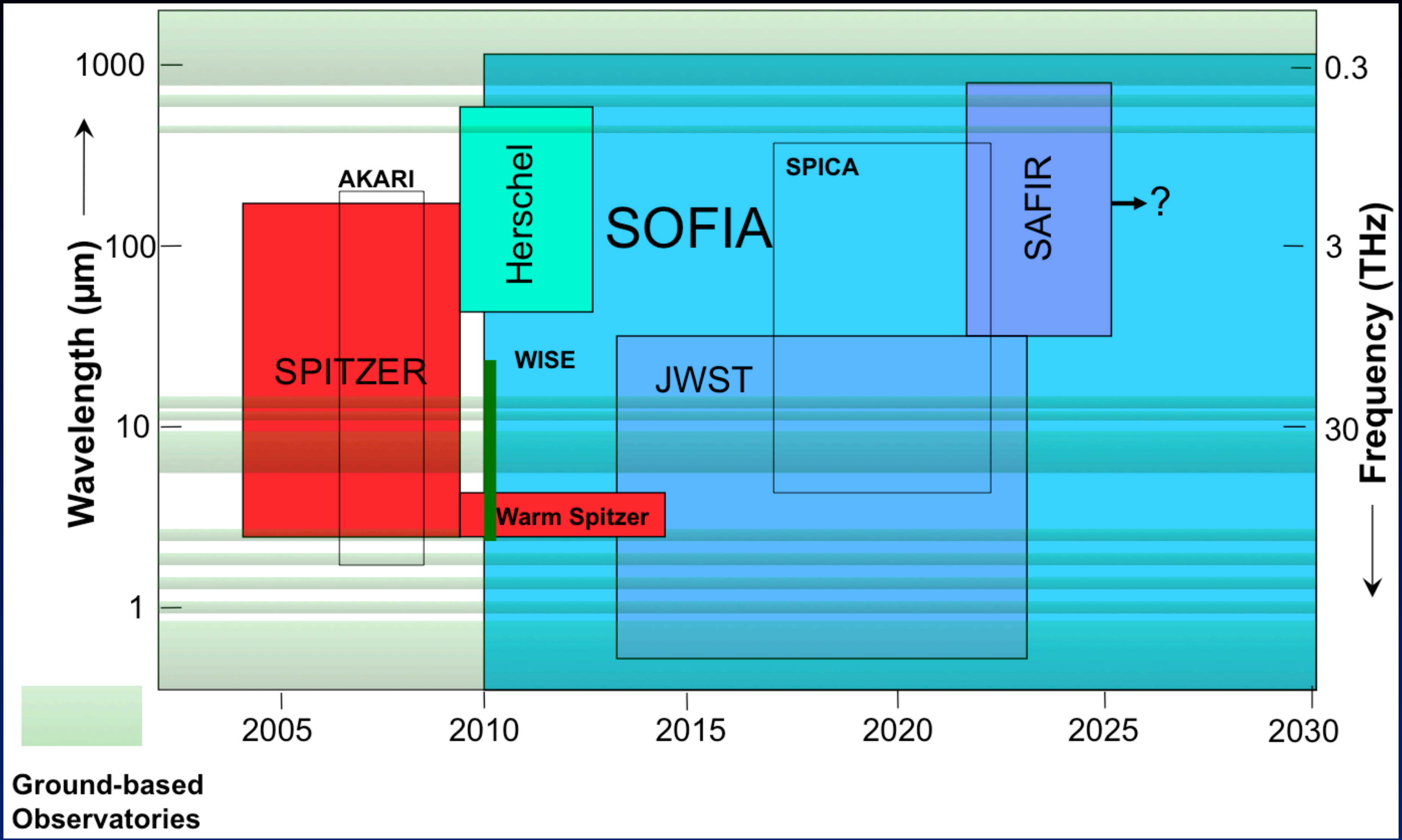


Why Instruments on SOFIA (Becklin)

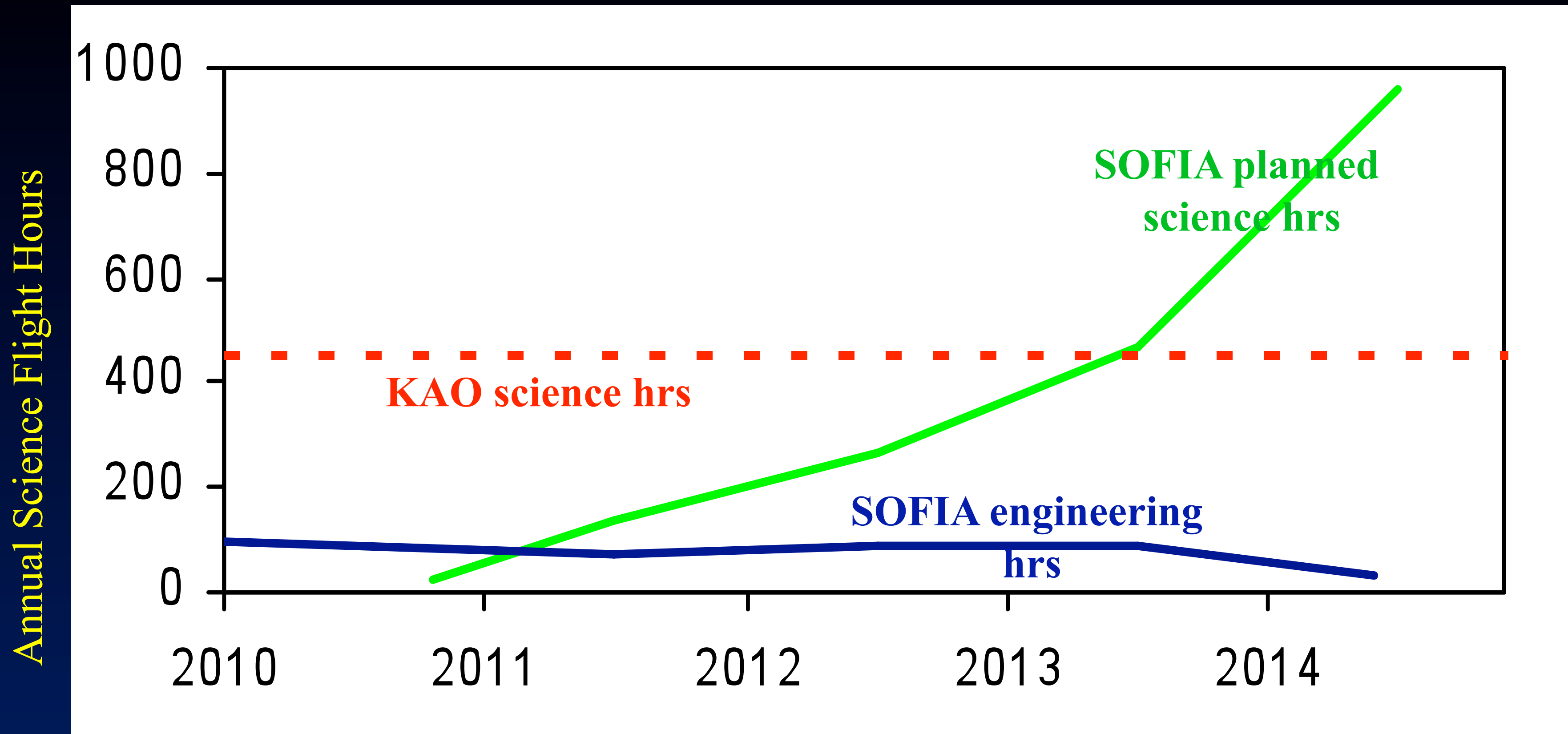
- Infrared transmission in the Stratosphere very good: >80% from 1 to 1000 microns
- Instrumentation: wide complement, rapidly interchangeable, state-of-the art
- Long lifetime
- Outstanding platform to train future Instrumentalists
- Near Space Observatory that comes home after every flight



SOFIA in Observational Phase Space (Marcum)

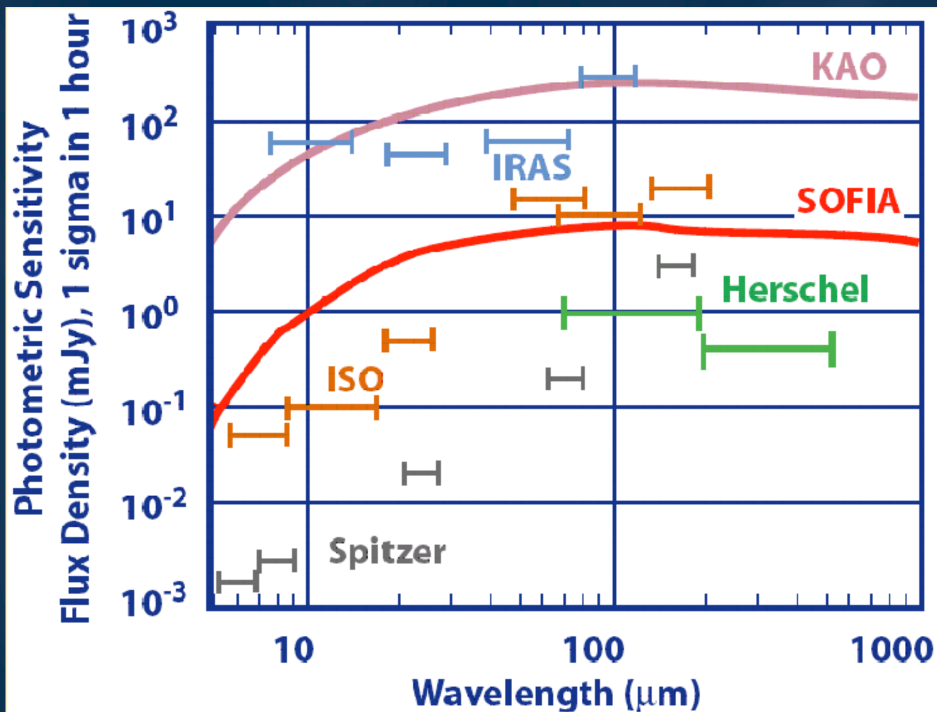


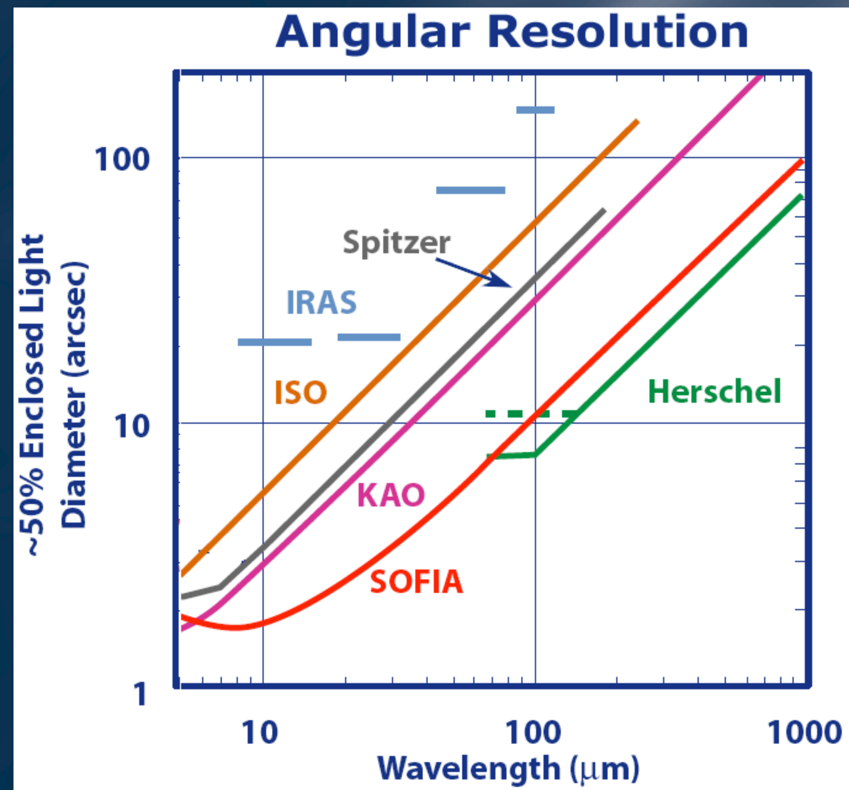
Science Flight Hours Ramp Up



With the onset of science flights in 2010, science hours available using SOFIA will steadily increase as all of the 8 first-generation instruments are commissioned, envelop expansion flights conclude, and aircraft system development is completed.

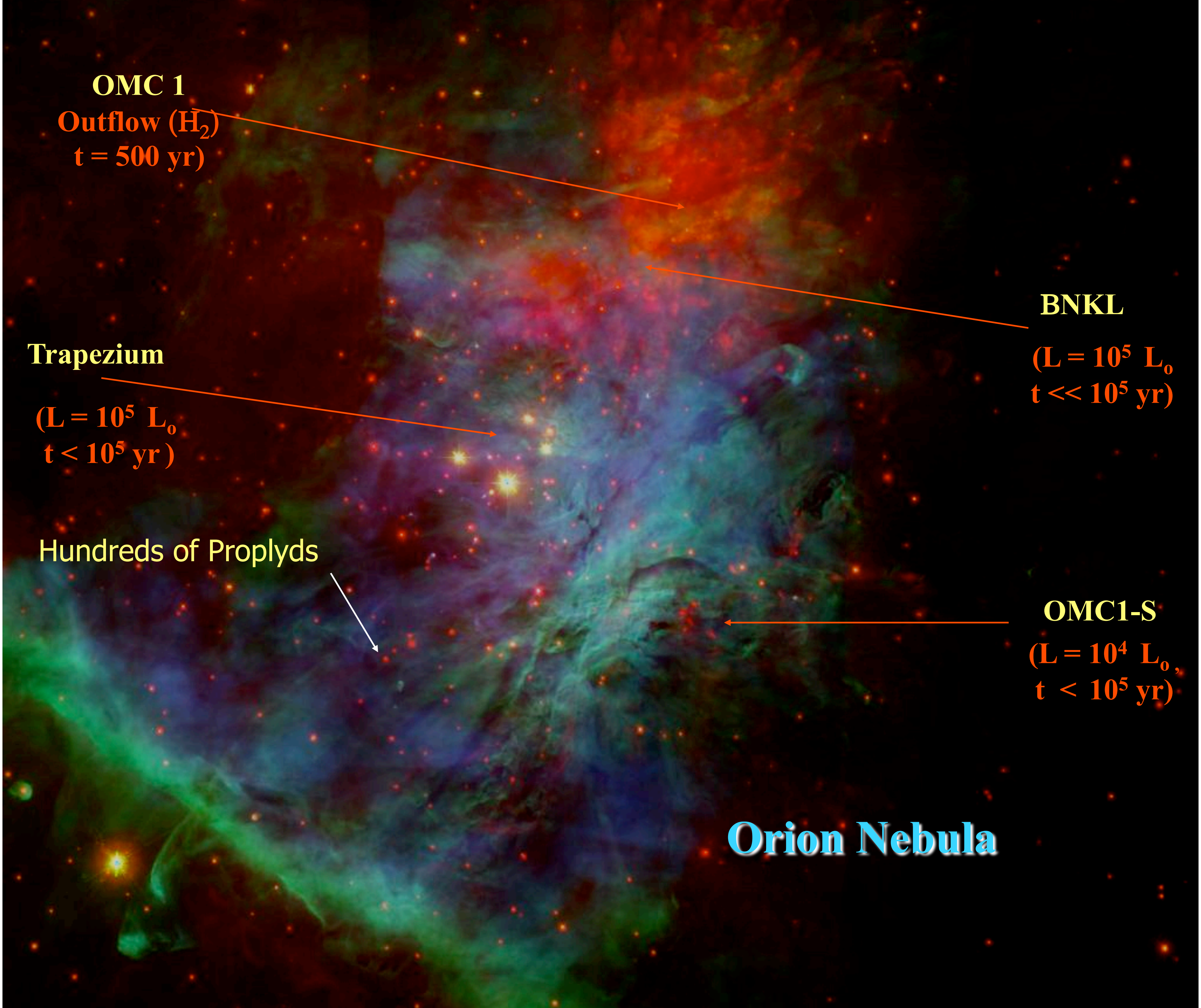
Sensitivity and Angular Resolution





SOFIA is as sensitive as ISO

SOFIA is diffraction limited beyond 25 µm (θmin ~ λ/10 in arcseconds) and can produce images three times sharper than those made by Spitzer


OMC 1
Outflow (H_2)
t = 500 yr)
BNKL
(L = 10^5 L_o
t << 10^5 yr)
Trapezium
(L = 10^5 L_o
t < 10^5 yr)
Hundreds of Proplyds
OMC1-S
(L = 10^4 L_o,
t < 10^5 yr)
Orion Nebula

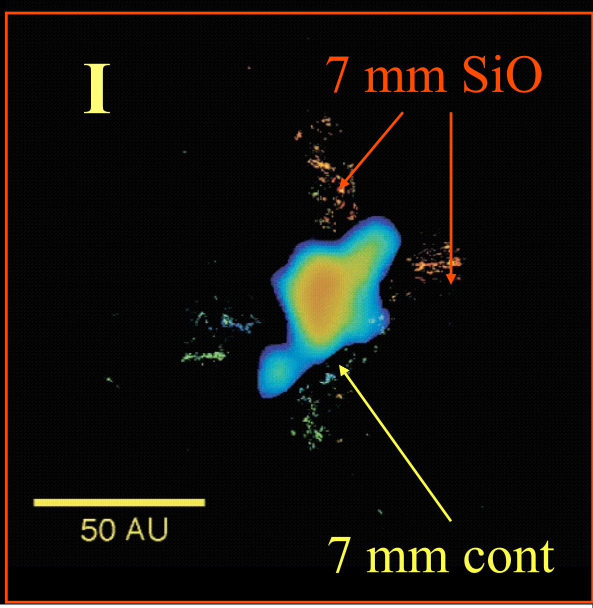
High-velocity stars: I , BN , n (Bally)

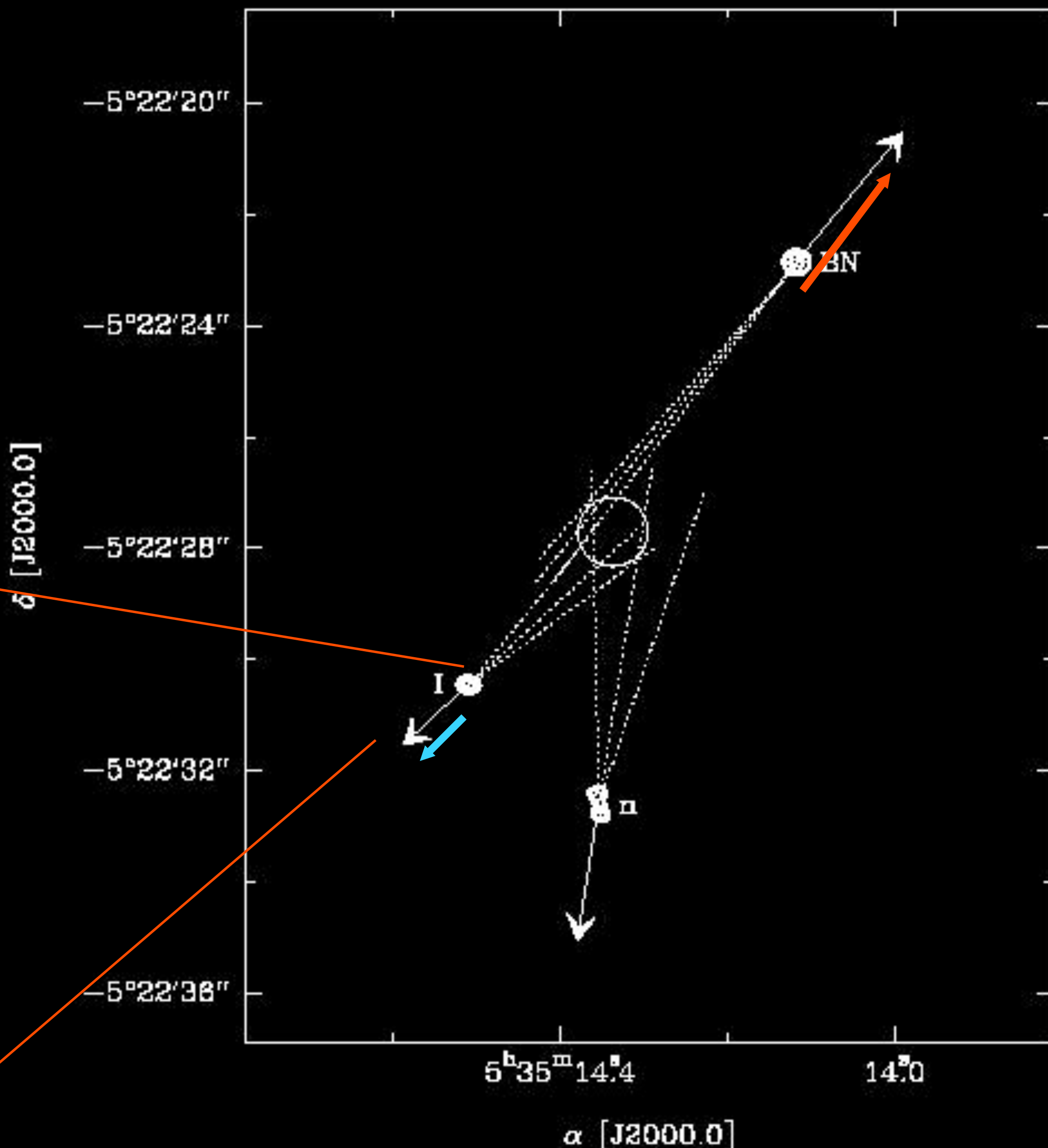
(Gomez et al. 2005, 2008)

BN: V~ 30 km s^{-1}

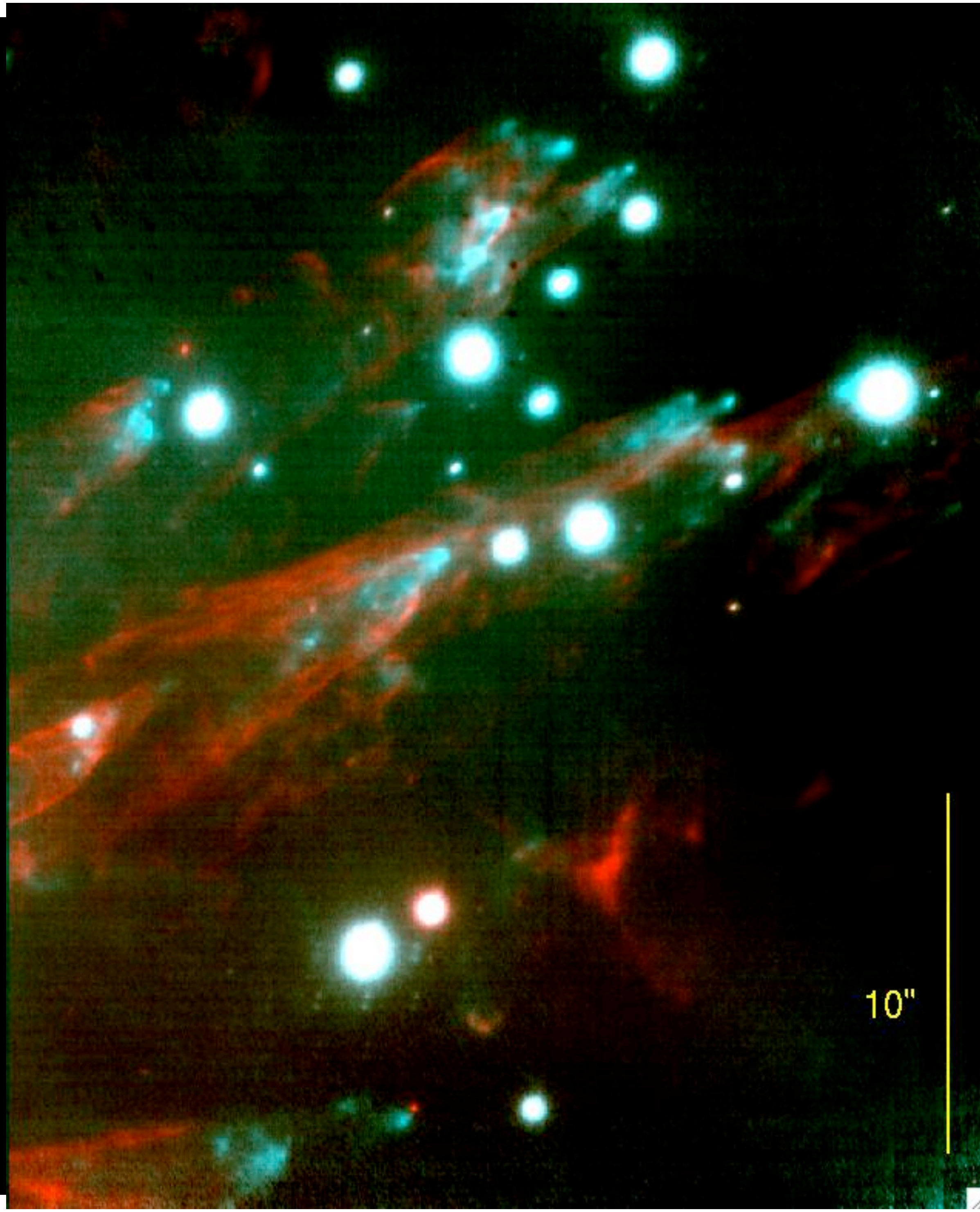
I: V~ 13 km s^{-1}

n: V~ 20 km s^{-1}

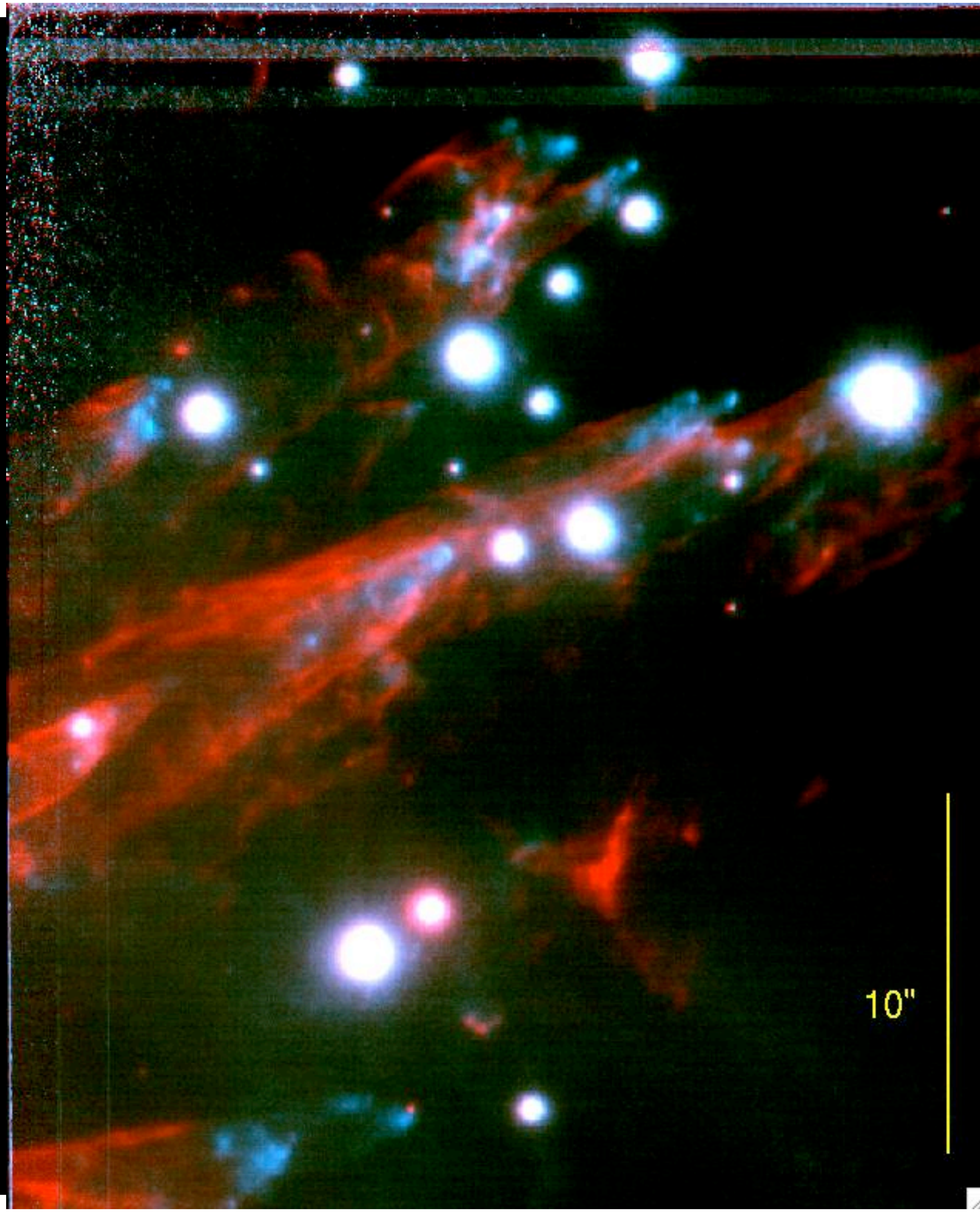




[FeII], H_2
2007



[FeII], H_2
2008



The Feedback Ladder (Bally)

Feedback energy / momentum

- Protostellar jets / outflows - Low Mass
- Soft UV - Moderate Mass
- Stellar Winds - High Mass
- Ionizing UV - High Mass (″)
- Stellar Winds - High Mass (″)
- Radiation Pressure - High Mass (″)
- Supernovae - High Mass (″)

SOFIA Roles (Bally)

Current:

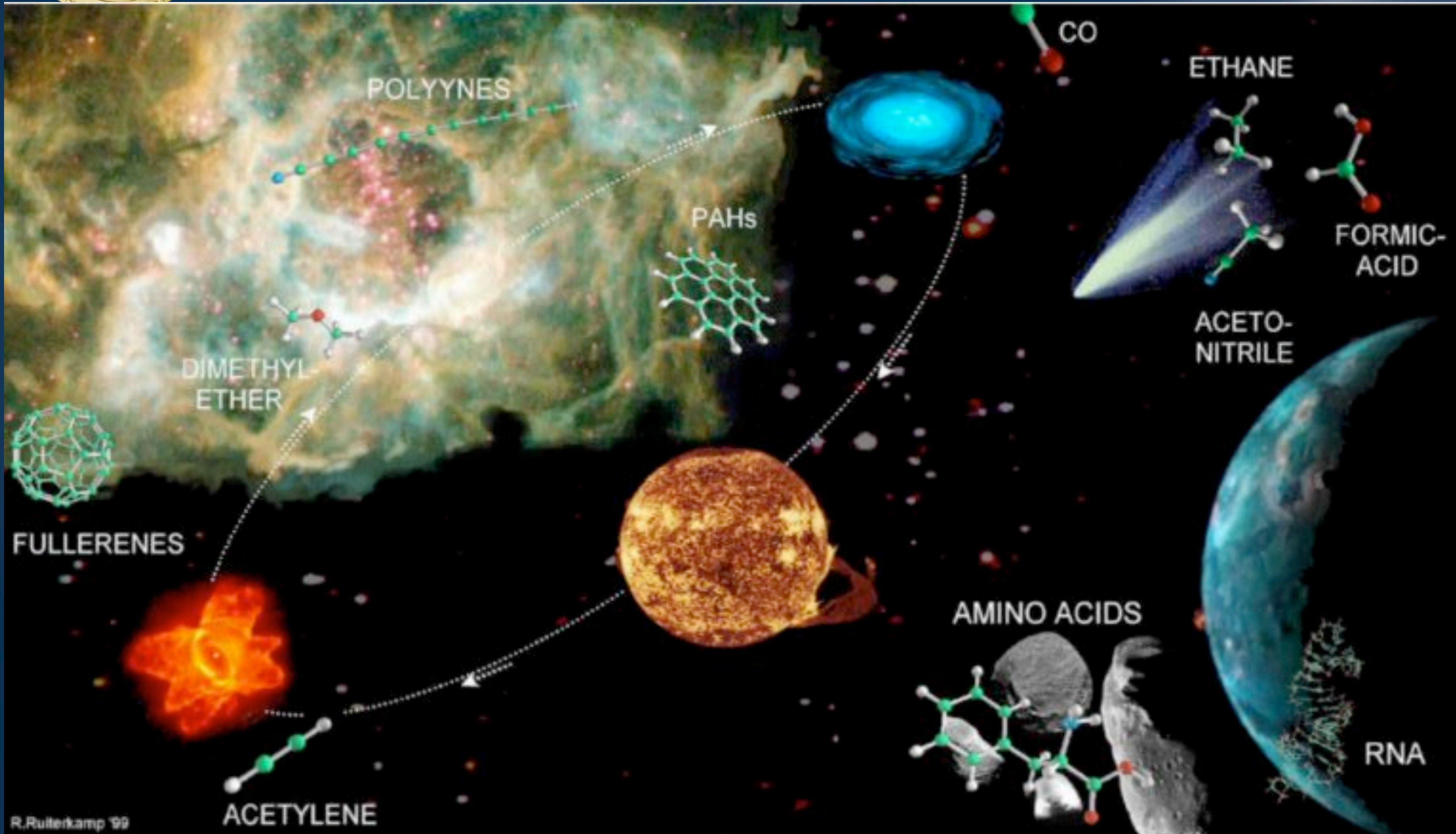
- FORCAST imaging of MYSOs & embedded clusters
- High-resolution spectroscopy of FIR lines
  - Herschel Hi-GAL bright-source follow-up

Next-Gen Needs (wish list):

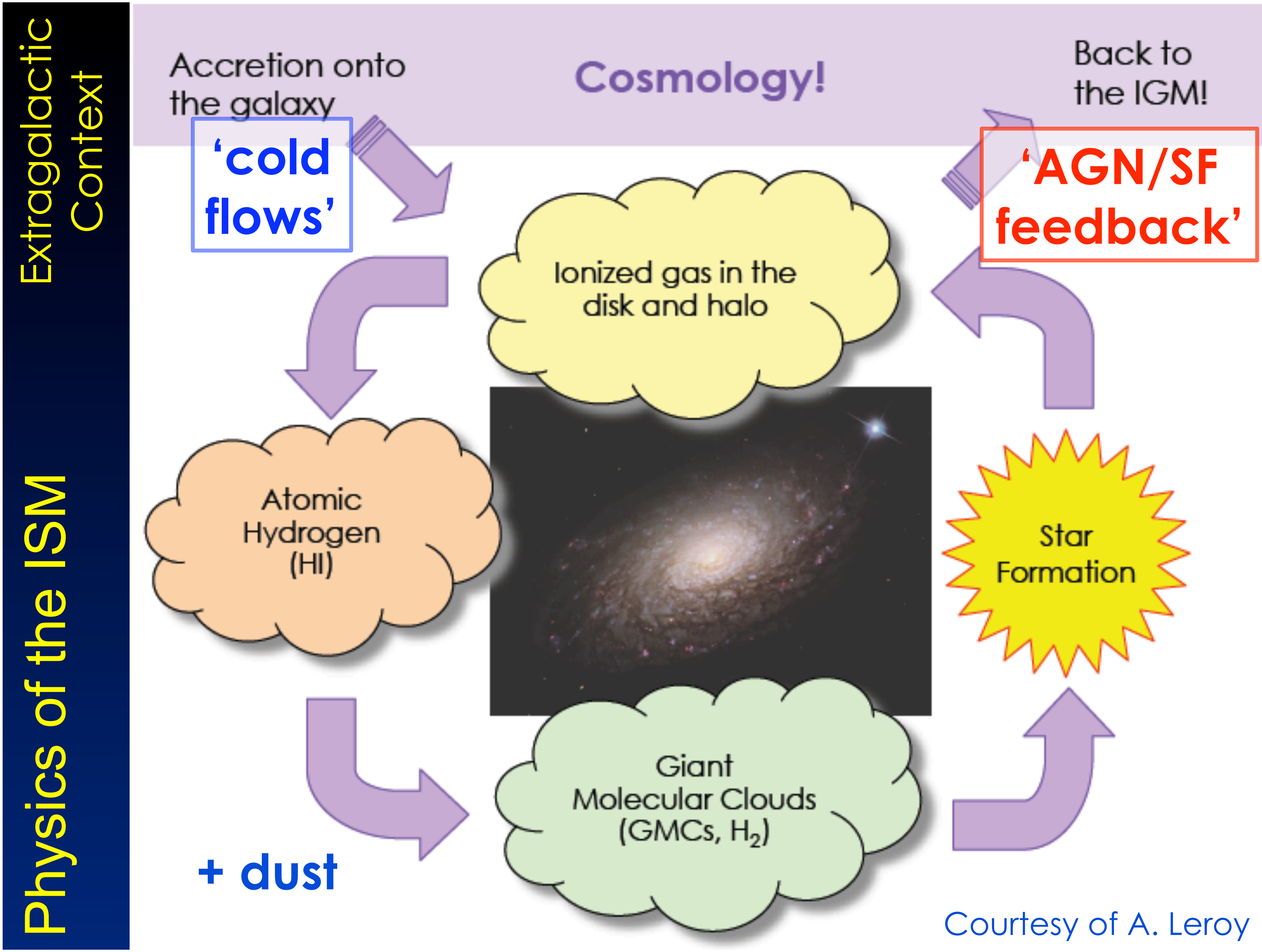
- Narrow-band, velocity resolved wide-field imaging
  - Tunable filters, FPs, Slit-scanning
    - $R \sim 10^4$; $\lambda \sim 3 - 300\ \mu m$
  - Multi-object heterodyne spectroscopy
    - $R > 10^6$; $\lambda \sim 3 - 300\ \mu m$
  - Line & Continuum Polarimetry
    - linear, circular, multi-object, W-FOV
  - Simultaneous Multi-order spectroscopy
    - dichroic split, MKIDs, bolometers?

Physics of the ISM (Schinnerer)

Galactic Context

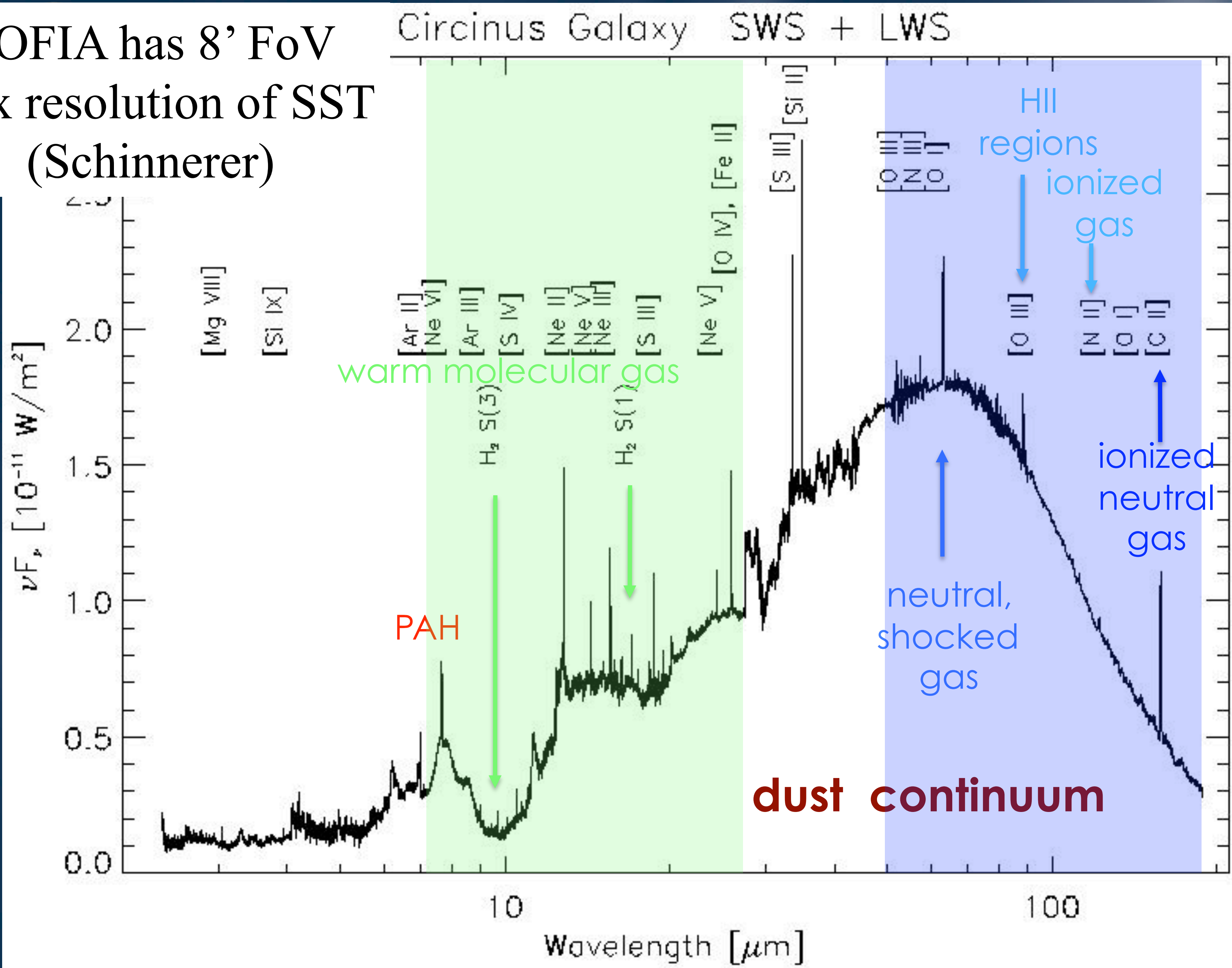


Ehrenfreund & Charnley (2000)



Extragalactic Context
Physics of the ISM
Accretion onto the galaxy
Cosmology!
Back to the IGM!
'cold flows'
'AGN/SF feedback'
Ionized gas in the disk and halo
Atomic Hydrogen (HI)
Star Formation
Giant Molecular Clouds (GMCs, H_2)
+ dust
Courtesy of A. Leroy

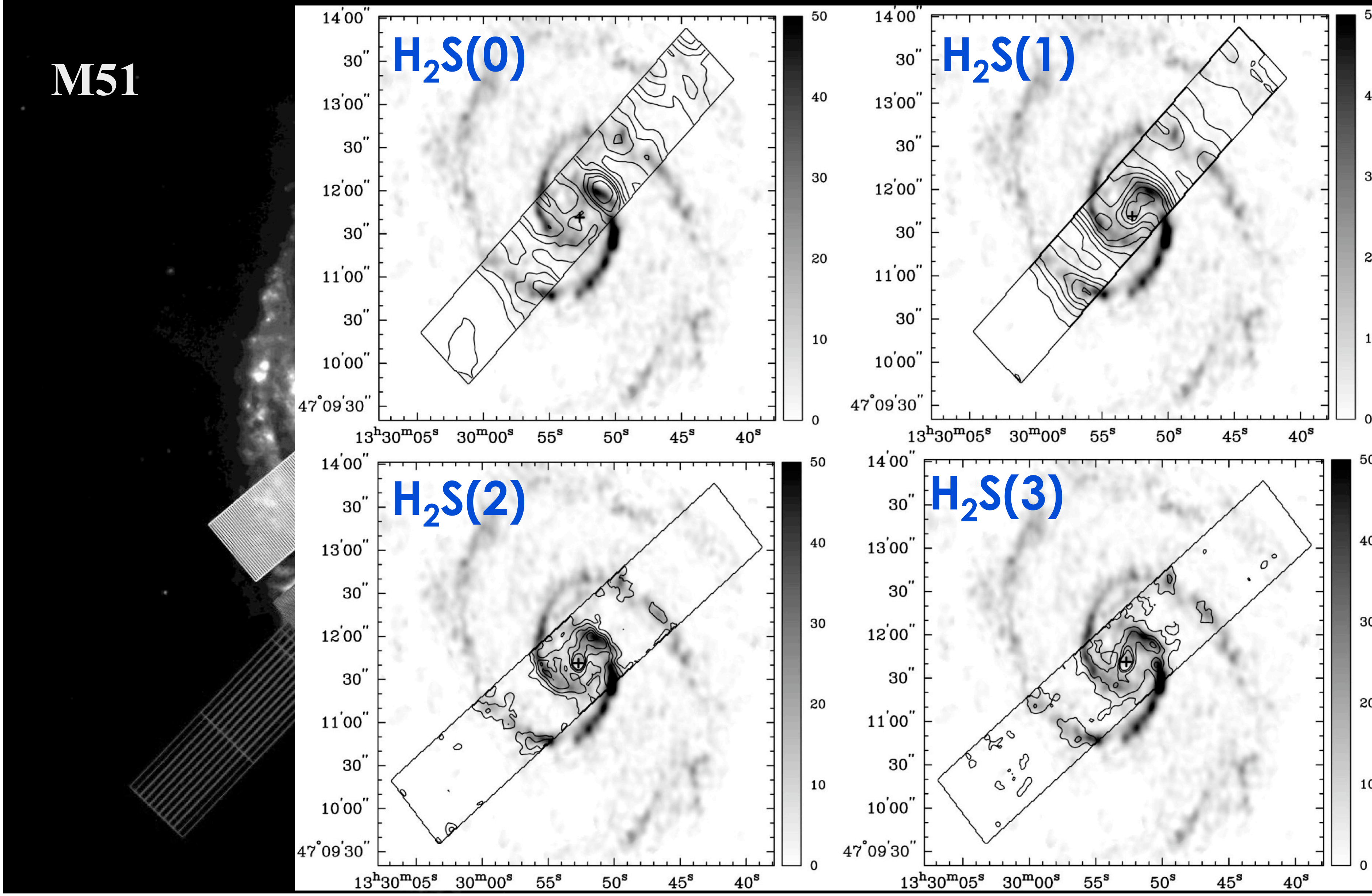
SOFIA has 8’ FoV
7x resolution of SST
(Schinnerer)



Moorwood (1997)

The Case for a (mid-)IR Analog: H_2

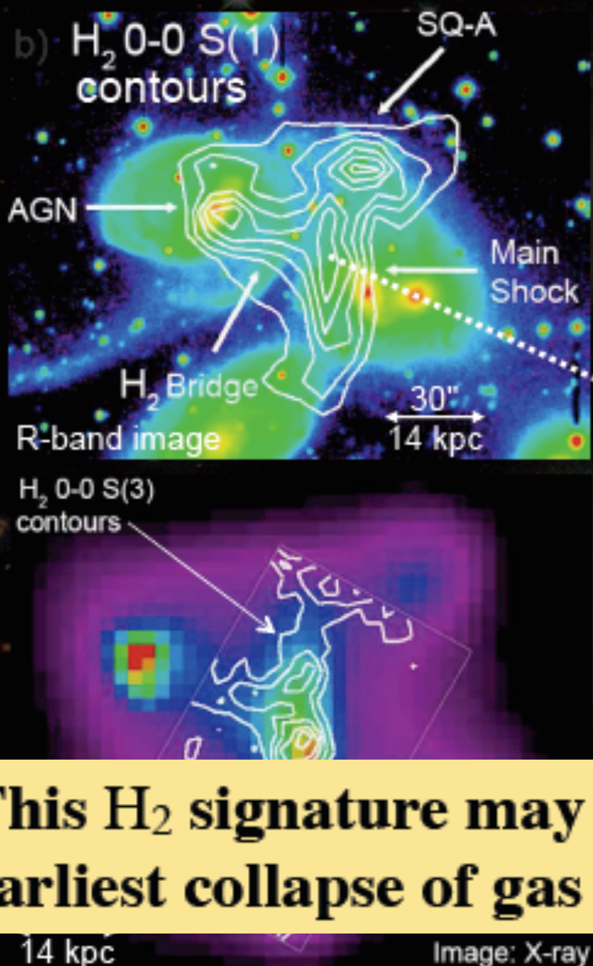
Brunner et al. (2008)



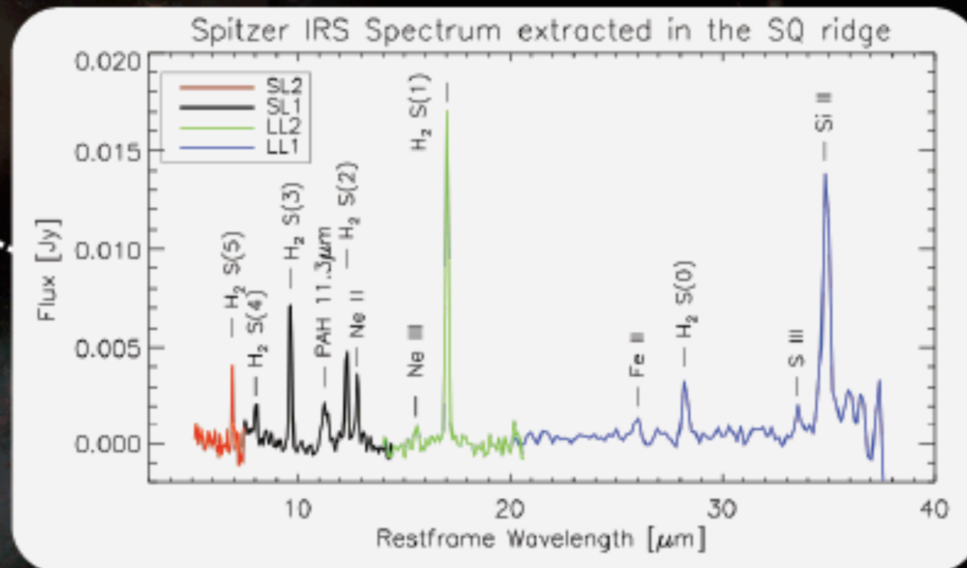
Helou

H_2: IGM Shock in Stephan's Quintet

Discovery of the first galaxy-scale H_2-dominated MIR source



Strong molecular Hydrogen and little else!
(Appleton et al. 06, Cluver et al. 2010).



This H_2 signature may well be the best way to detect earliest collapse of gas clouds to form galaxies

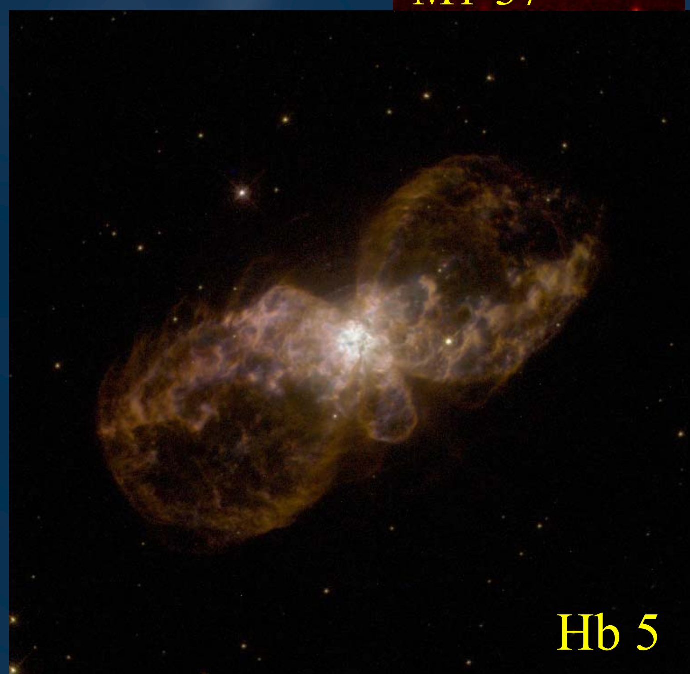
14 kpc

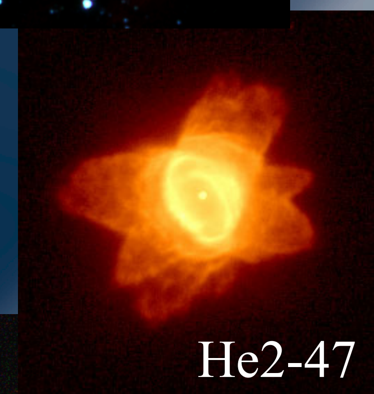
Image: X-ray

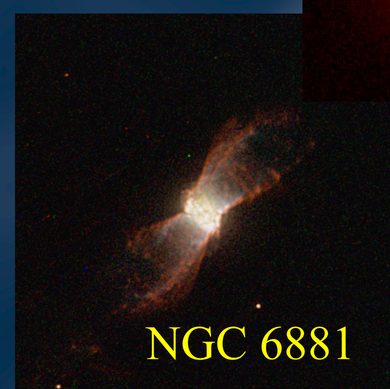
- 17μm S(1) line resolved! FWHM=860±40 km/s
- G_{UV}~1, so low dust emission (Guillard+, '10a)

Cluver et al. 2010

Morphological transformation (Kwok)

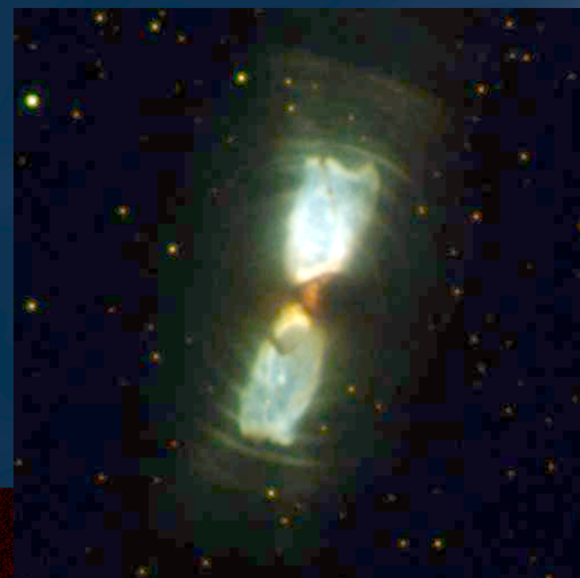




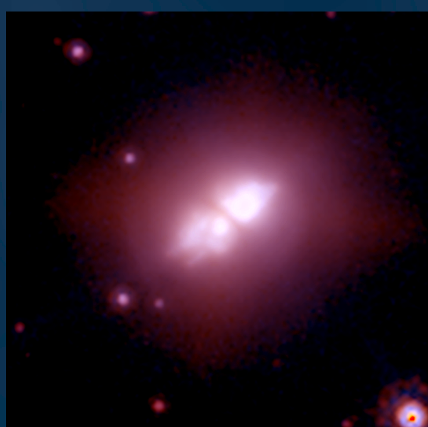


Shaping occurs early in PPN stage

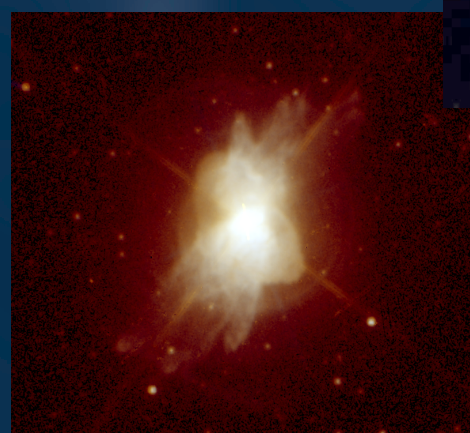
The Silkworm Nebula



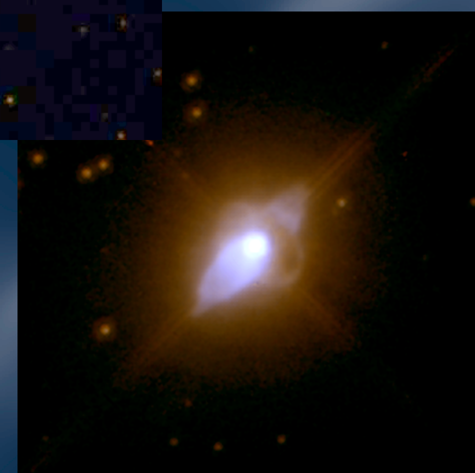
The Cotton Candy Nebula



The Walnut Nebula

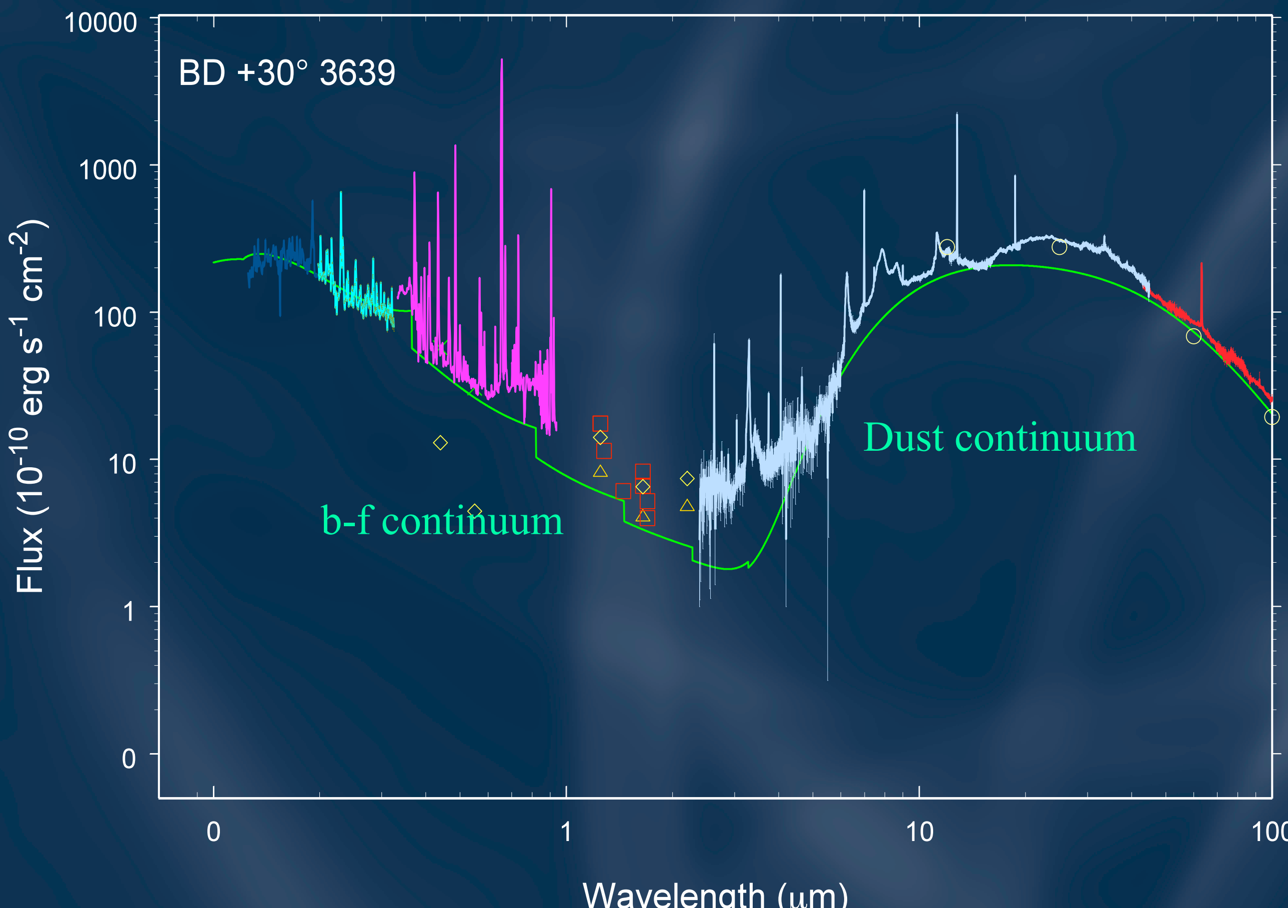


The Water Lily Nebula

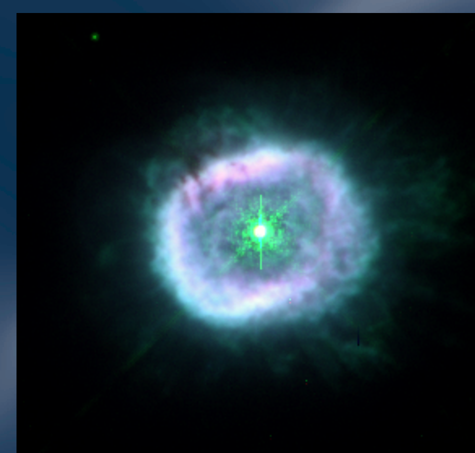


The Spindle Nebula

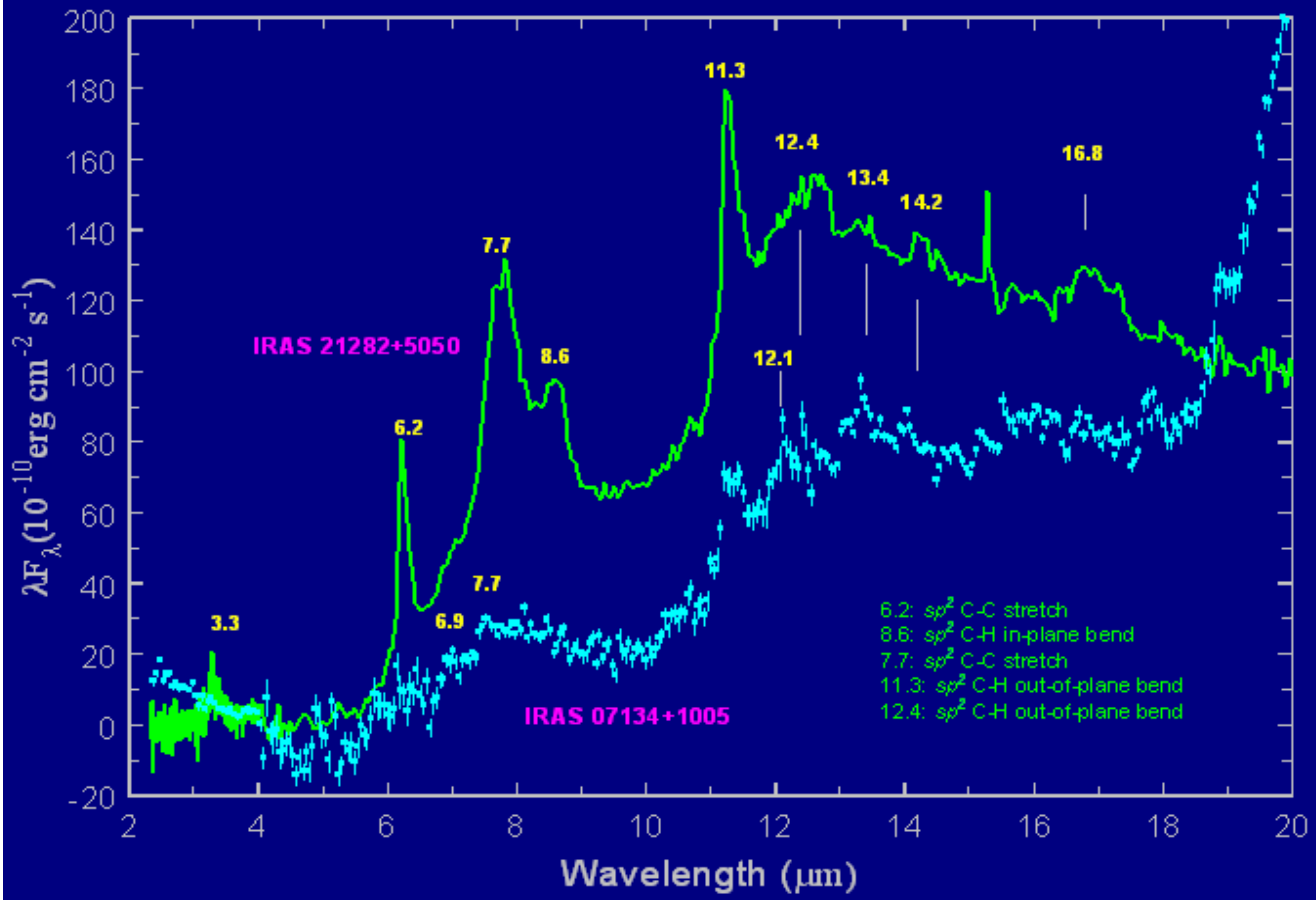
AGB dust envelope in PN (Kwok)



Ionized (10^4-10^6 K), molecular (10^1-10^2 K) and dust (10^2 K) components



Aromatic and aliphatic features in PPN



Molecular Astrophysics (Neufeld)

I. Heterodyne spectroscopy at frequencies above 2 THz (GREAT):

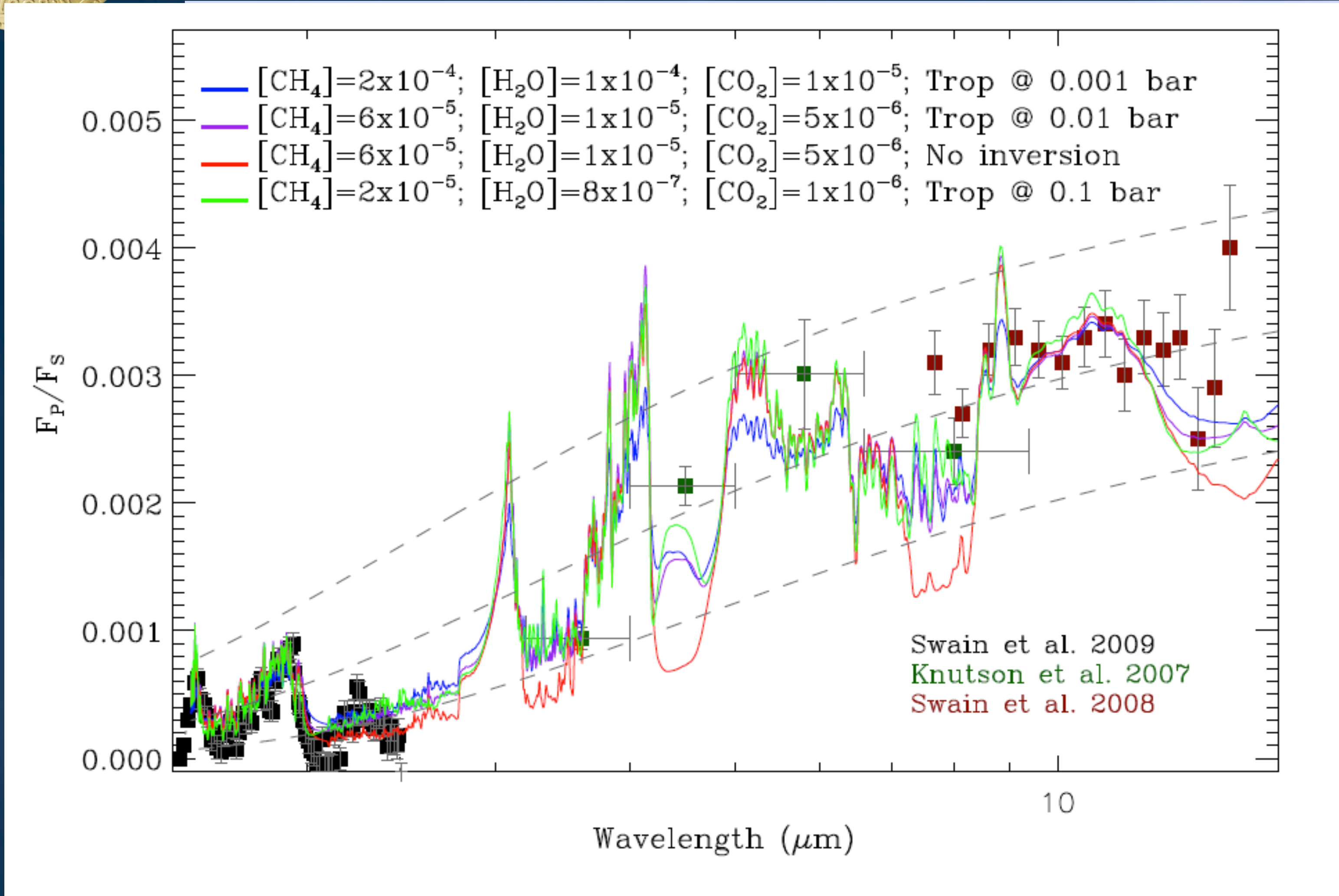
   access to HD, OH, [OI] etc…

II. Very high resolution mid-IR spectroscopy (EXES): access to vibrational bands

III. Spatial multiplex advantage:

   Heterodyne arrays for mapping

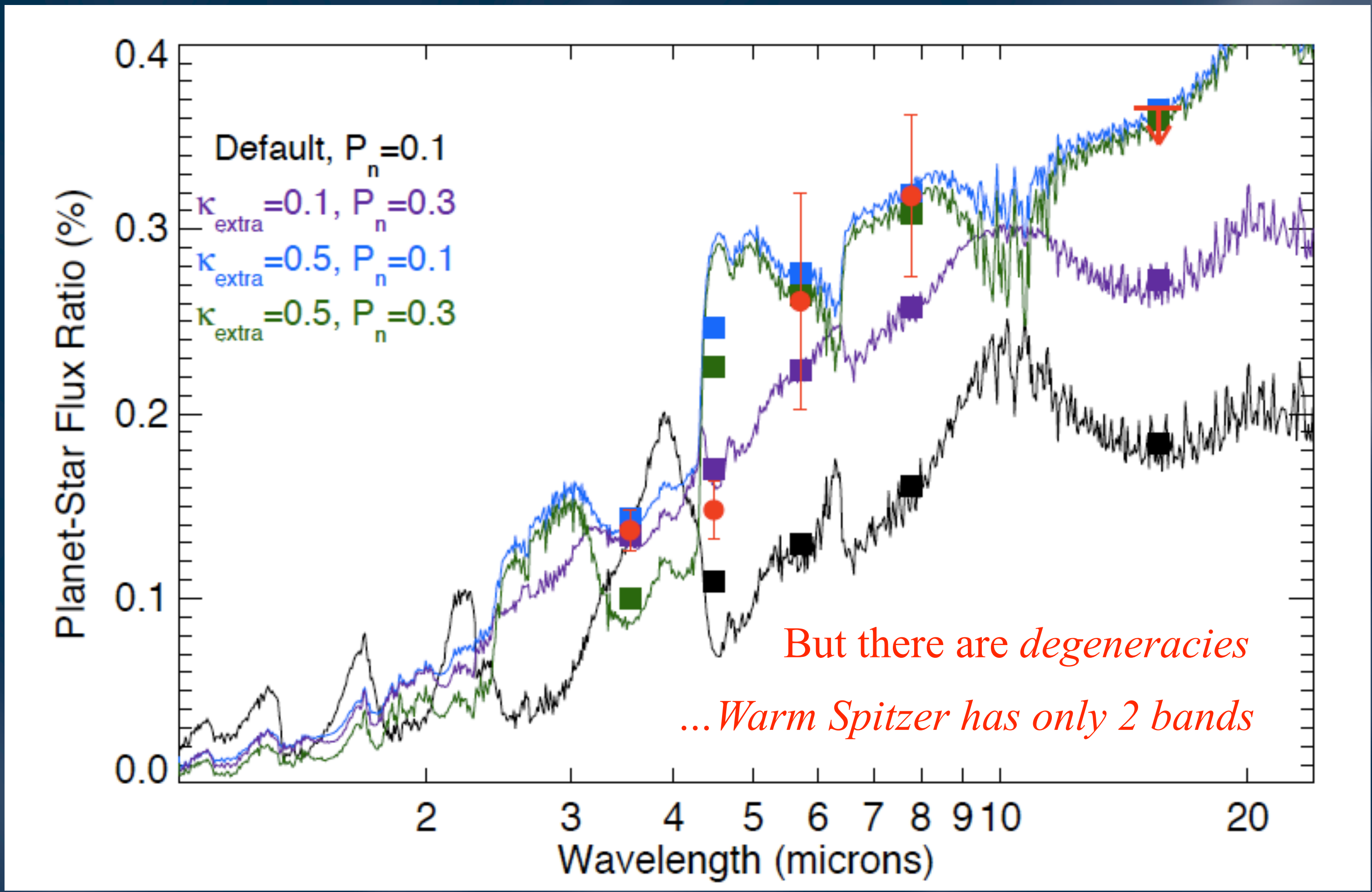
IR spectroscopy of the exoplanet HD 209458b (Neufeld)



Swain et al. 2009, ApJ

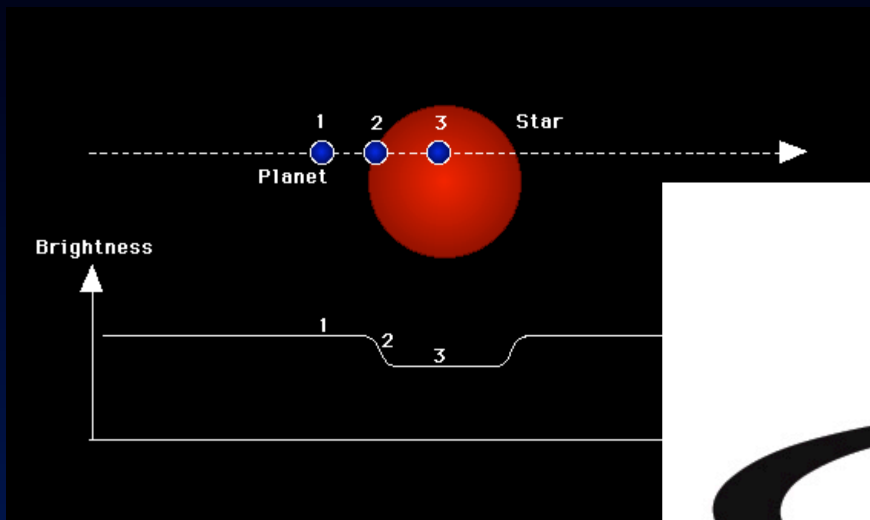
TrEs-4 – apparently an inverted atmosphere

Deming

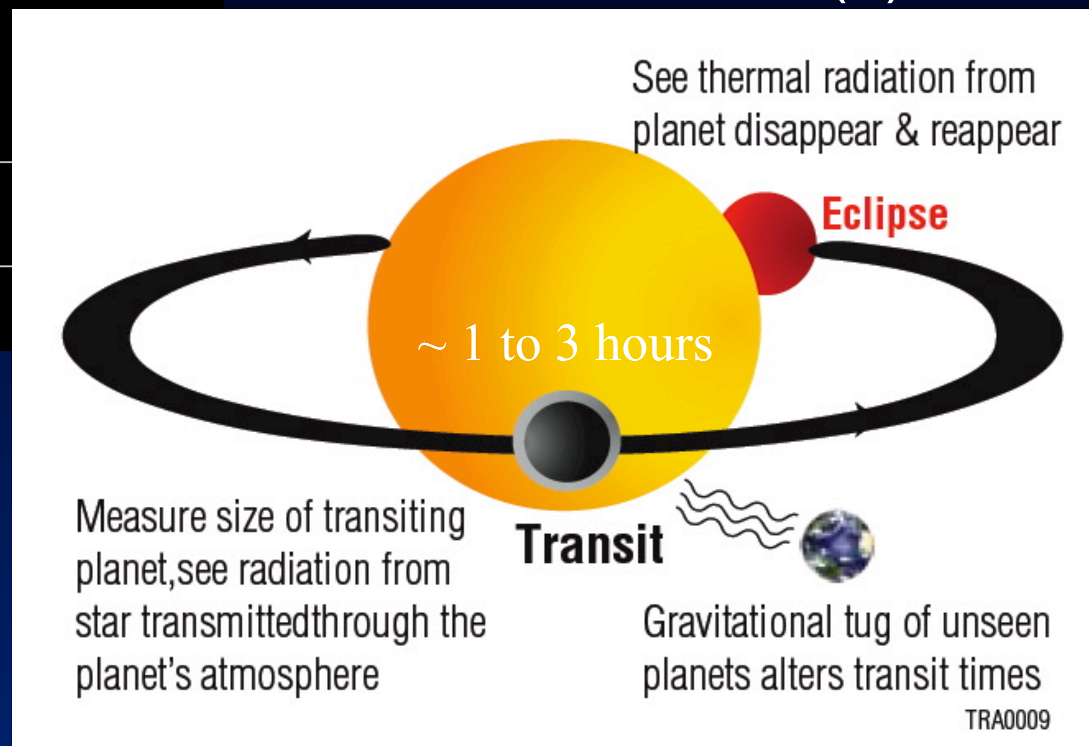


Knutson et al. ApJ 691, 866 (2009)

Exploit *transits* to characterize exoplanet atmospheres (Deming)



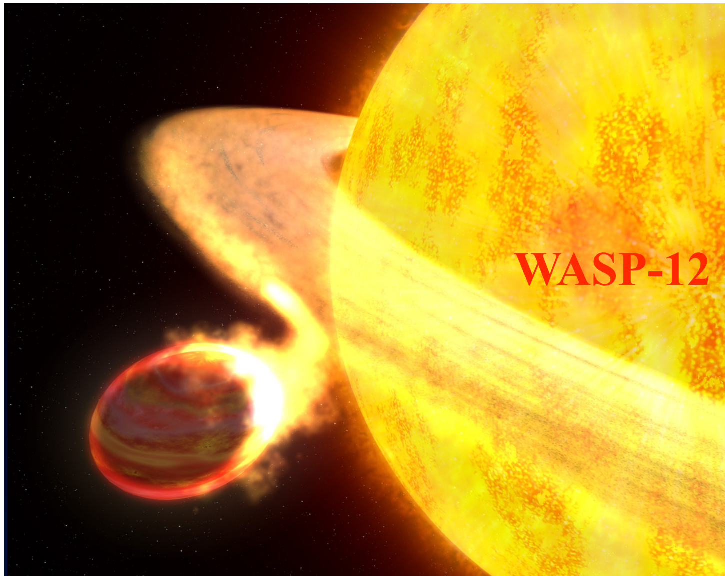
few x 10^{-3} FLITECAM & FORCAST(?)



Transits require photometric stability

But tolerate poor image quality

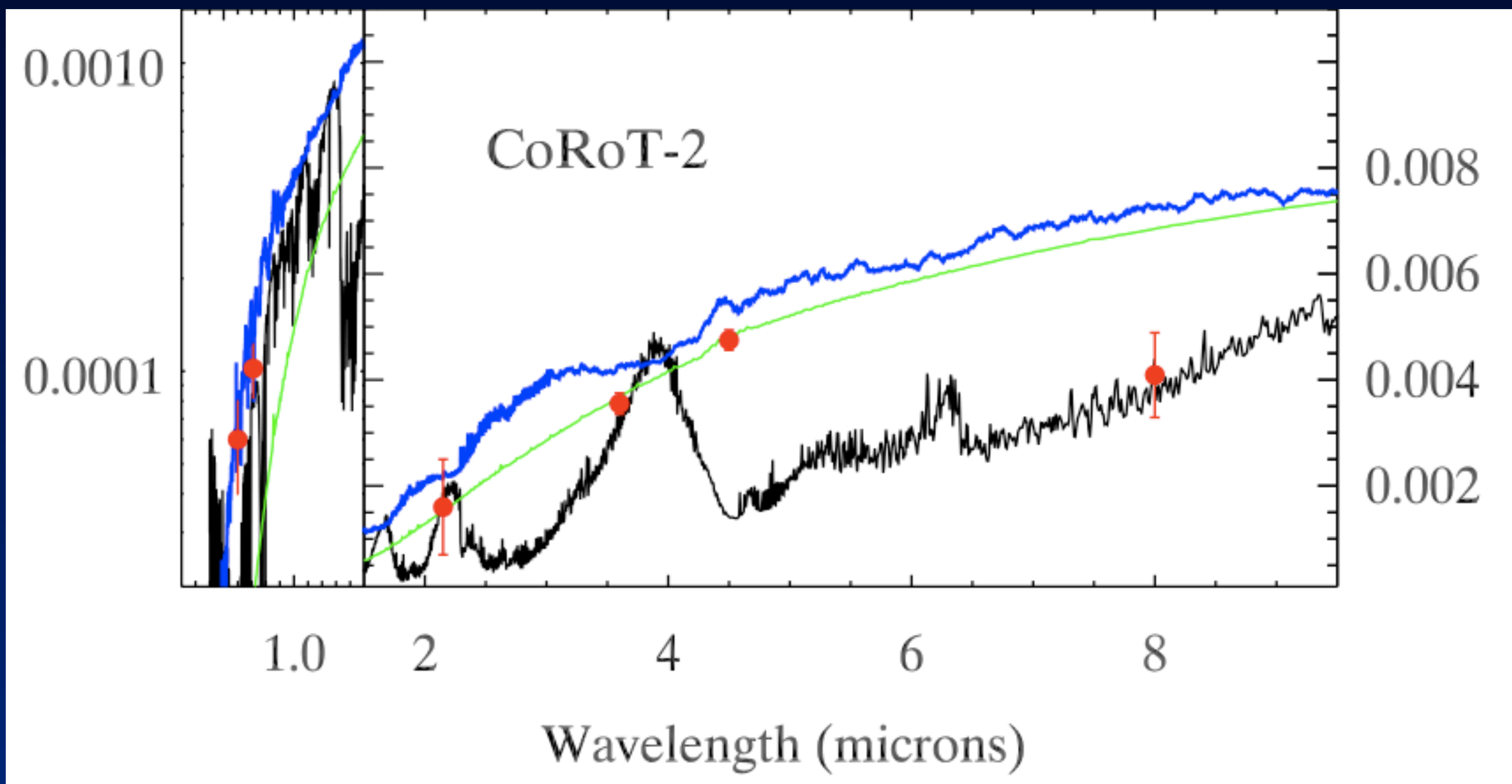
few x 10^{-4} HIPO + FLITECAM



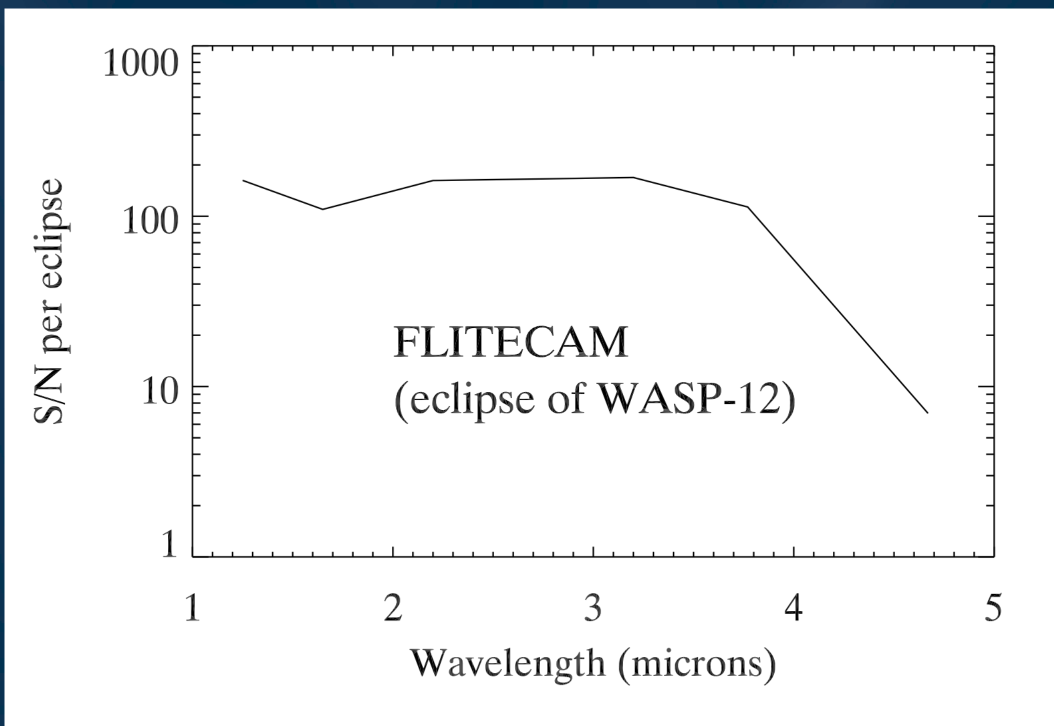
The *very hot* Jupiters

atmospheres perturbed
by strong irradiation?

losing mass by tidal stripping?



High S/N for WASP-12 at filter resolution



Instrument considerations:
maximize the spectral range
R ~ 100 is OK
maximize stability
consider λ-dithering

hot super-Earths?

SOFIA: Long operational life

The "Sweet Spots"

- Tackle hard, important problems not solved by limited-life missions:
  - Star formation, esp. high mass SF (Orion et al.)
  - Creation and destruction of dust, molecules, and interaction with sites of creation (AGB, PN, SN, maybe clouds)
  - Understand cloud collapse, cooling (H_2), possibly early universe
- Exploit time variable phenomena:
  - Proper motions at all $\lambda/\Delta\lambda$ (continuum, lines, esp. FIR)
  - Rare transits of exo-planets in interesting orbits (large) & stars
- Exploit targets of opportunity, esp. new exo-planets
  - There will be many in an era of many observatories on the ground and in space: ALMA, TMT, JWST (eventually)
- Continually upgrade capabilities to exploit all photons (FOV, ΔE) at quantum limit; train the next generation
  - It's (almost) all about focal plane detectors, but also about phase space (e.g. polarization)