Local Group: Searching for the Origins of Stars, Planets, and Life

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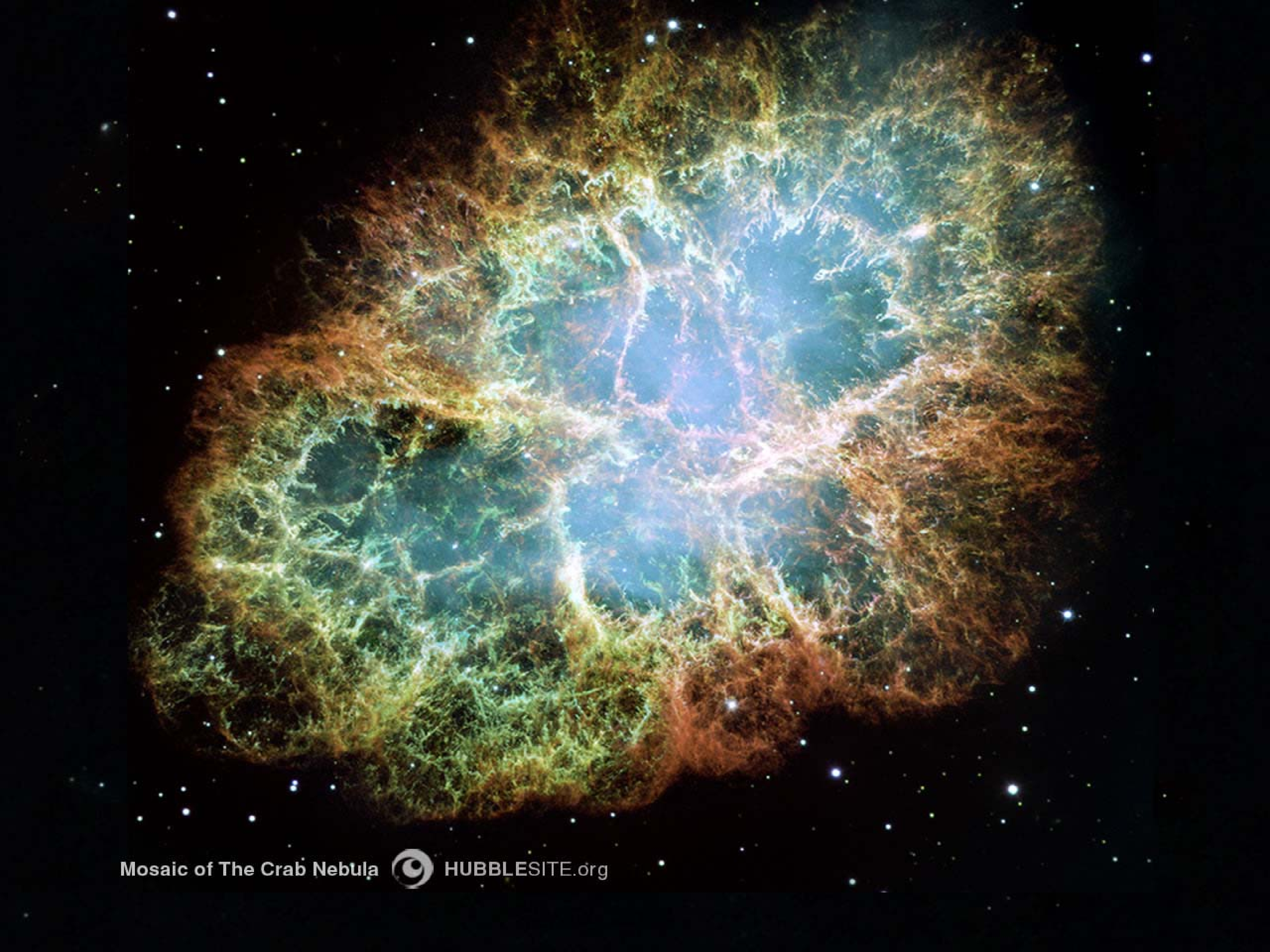
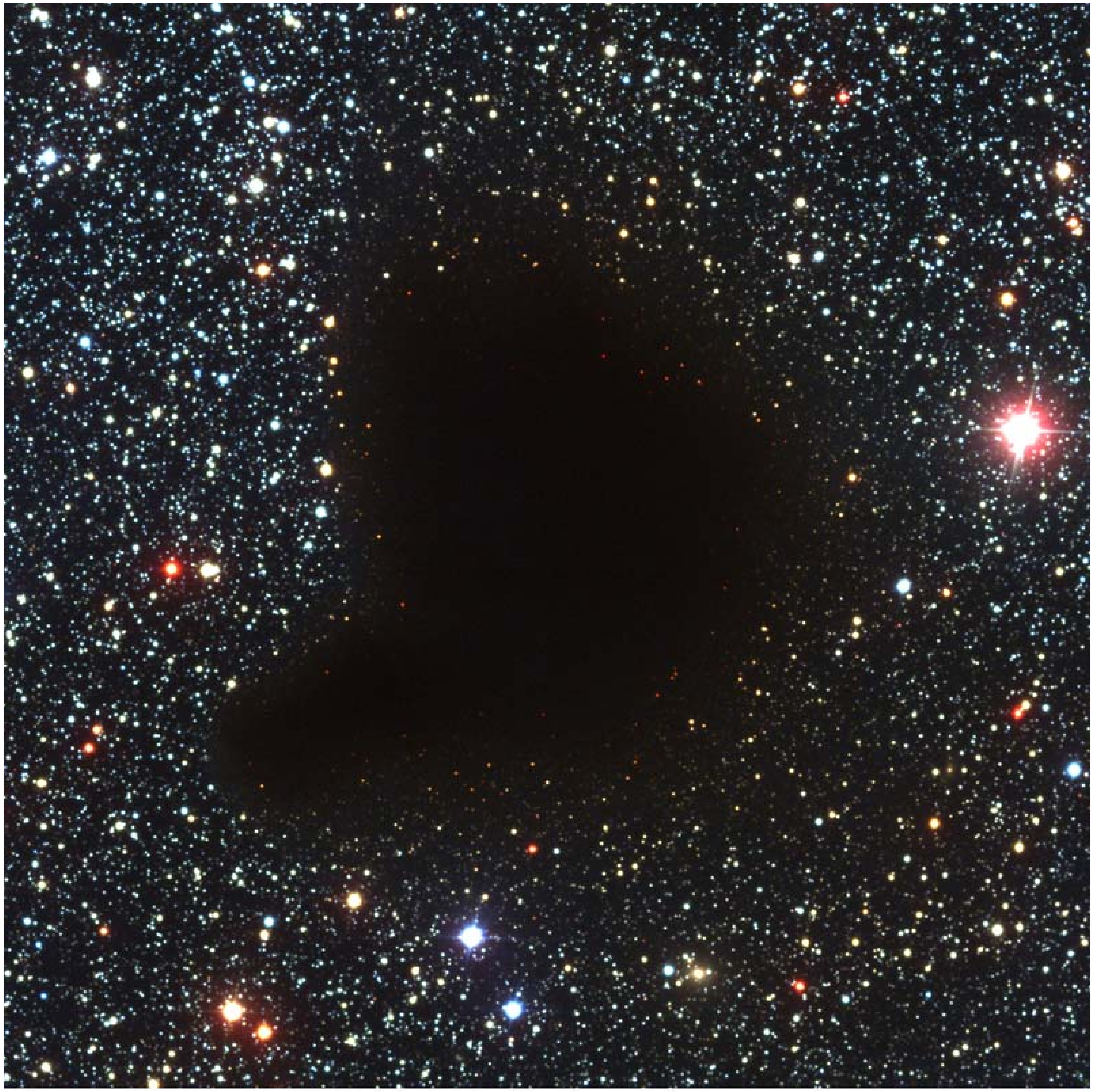
The Origins of Stars, Planets, and Life…

- What is the initial mass function of stars and sub-stellar objects?
- What physical variables control the assembly of stars?
- Are planetary systems like our own common or rare in the Milky Way?
- How do elements evolve into complex organic molecules that could give rise to life?

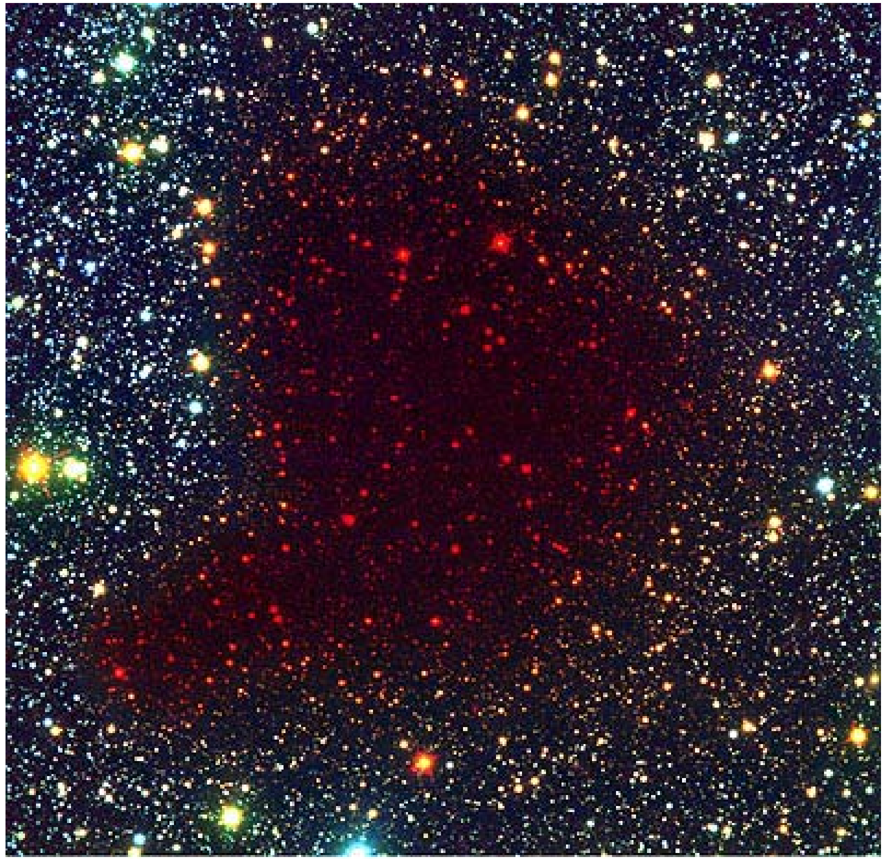

Mosaic of The Crab Nebula
HUBBLESITE.org



The "Black Cloud" B68
(VLT ANTU + FORS1)

ESO PR Photo 20a/99 (30 April 1999)

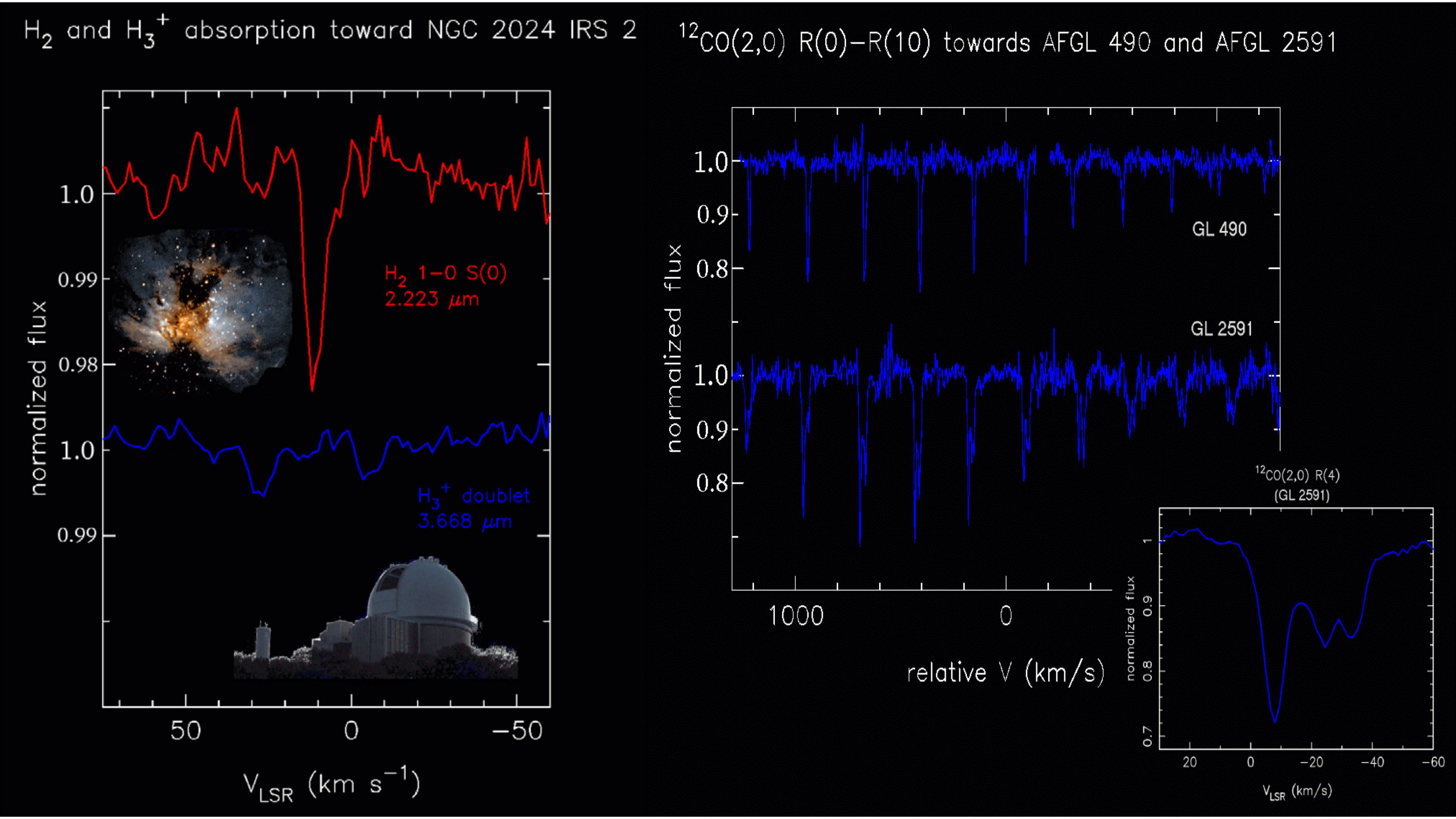
Tearing Away the Cosmic Veil: Infrared Imaging and Spectroscopy



Seeing Through the Pre-Collapse Black Cloud B68
(VLT ANTU + FORS 1 - NTT + SOFI)

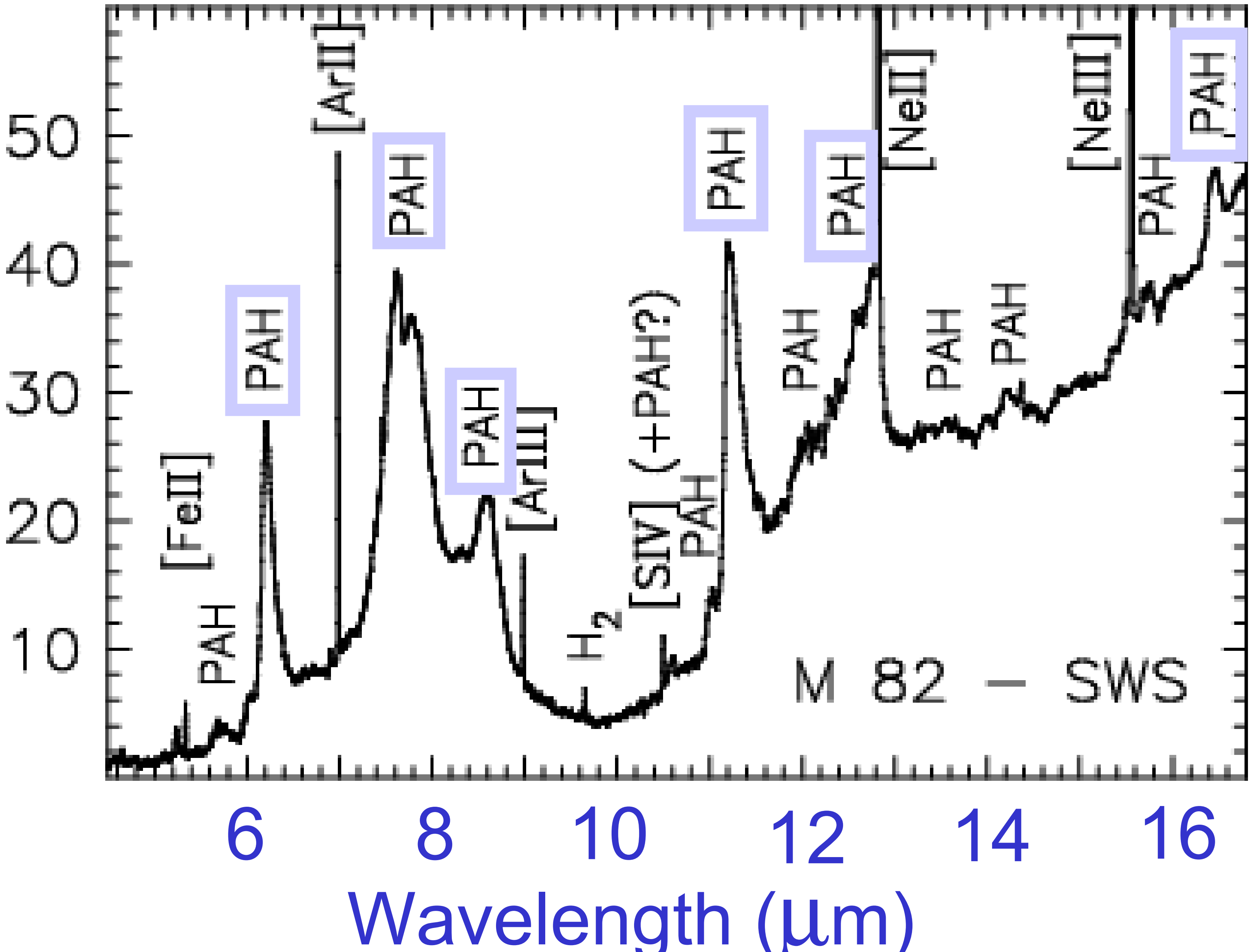
ESO PR Photo 02b/01 (10 January 2001)

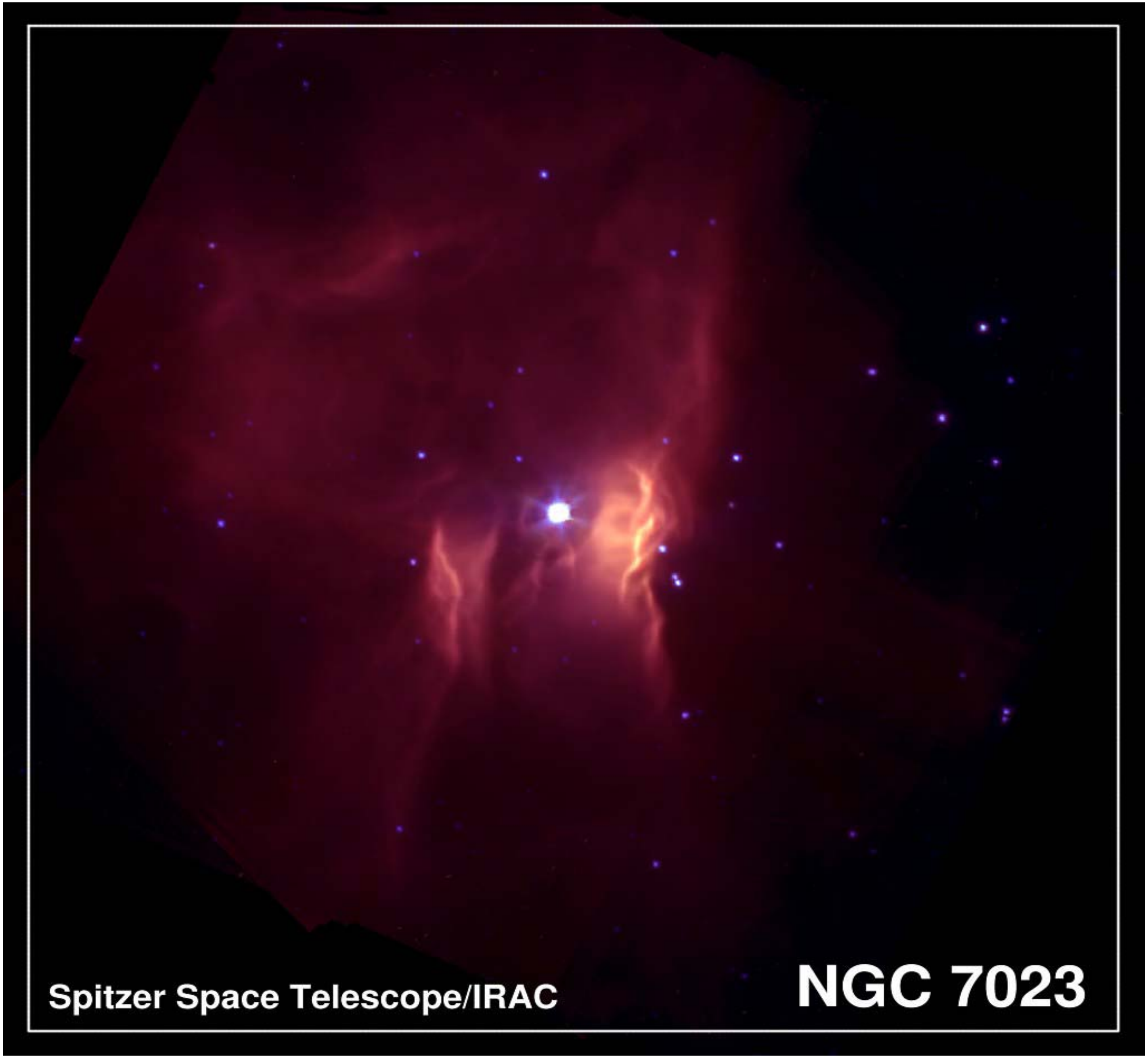
Measuring Gas Phase ISM Abundances:



First detection of H3+ and H2 in same source (Phoenix at KPNO)
Courtesy Craig Kulesa (U. Arizona)

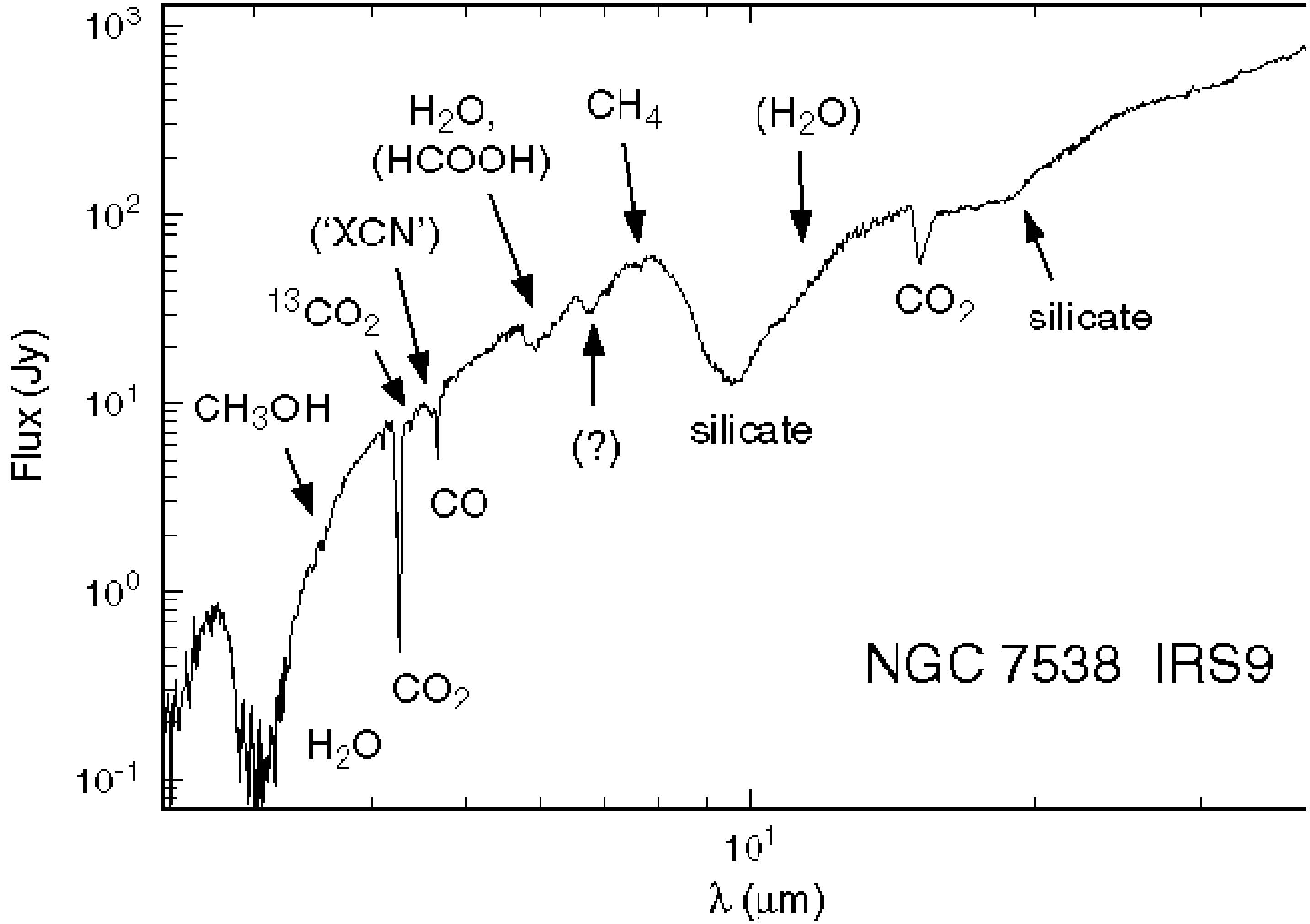
Aromatic emission features (PAHs)





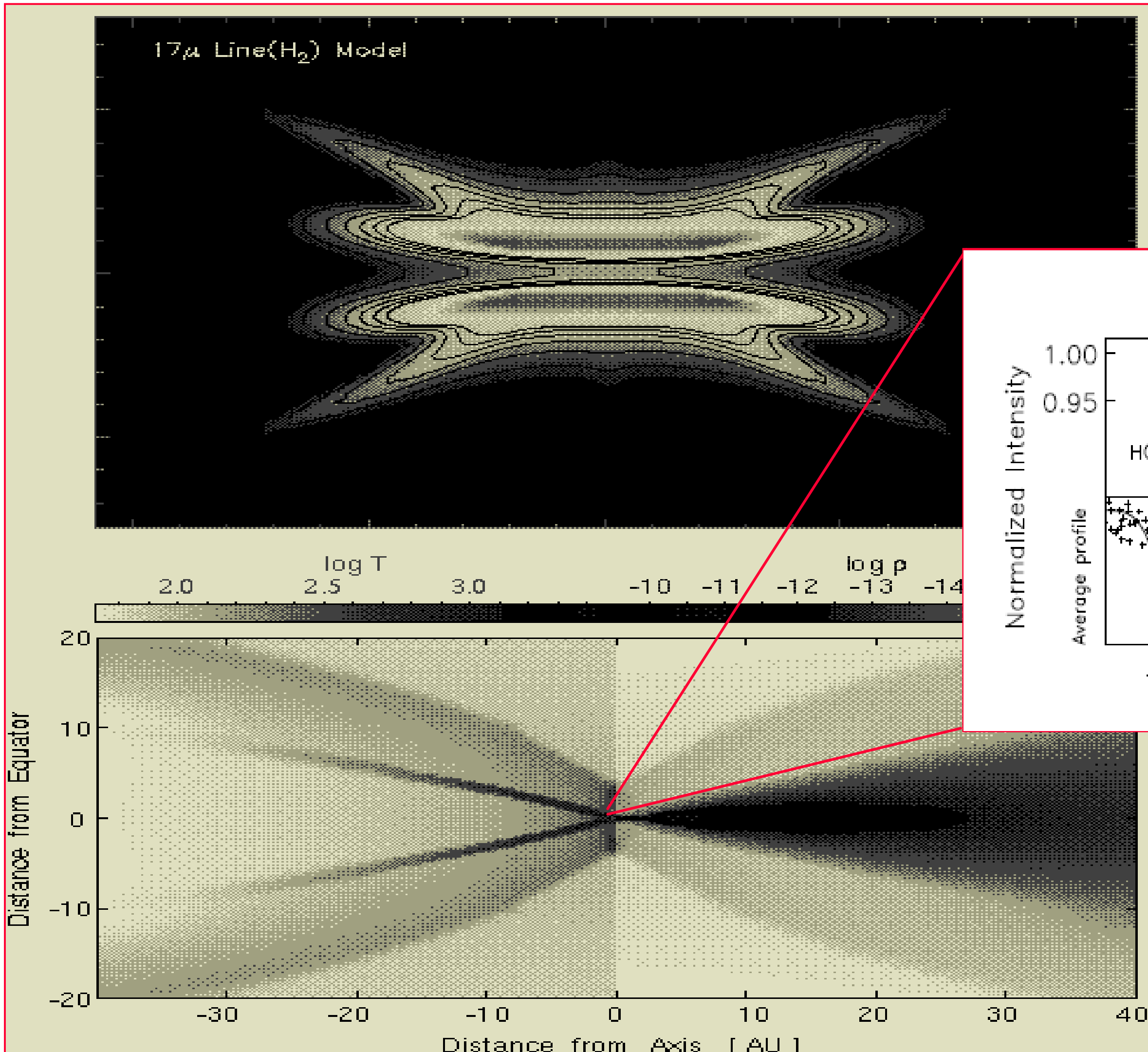
Courtesy Kris Sellgren.

2.4 – 45 μm spectrum of interstellar ices

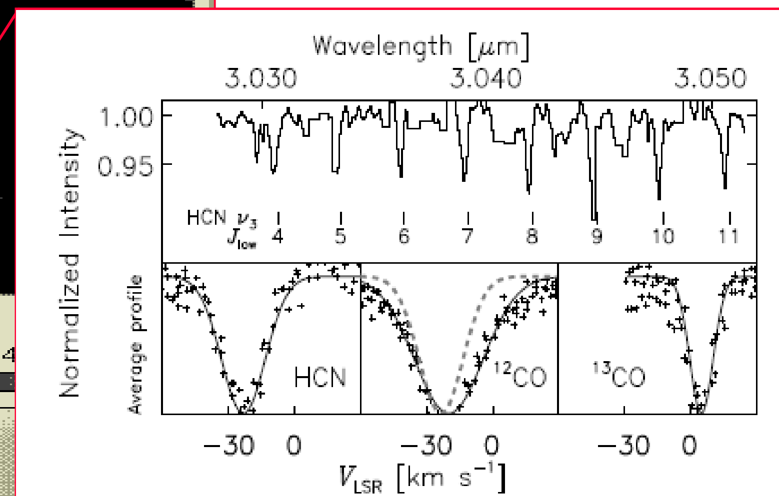


Follow the carbon…

Kinematics and Chemistry of Collapsing Protostars



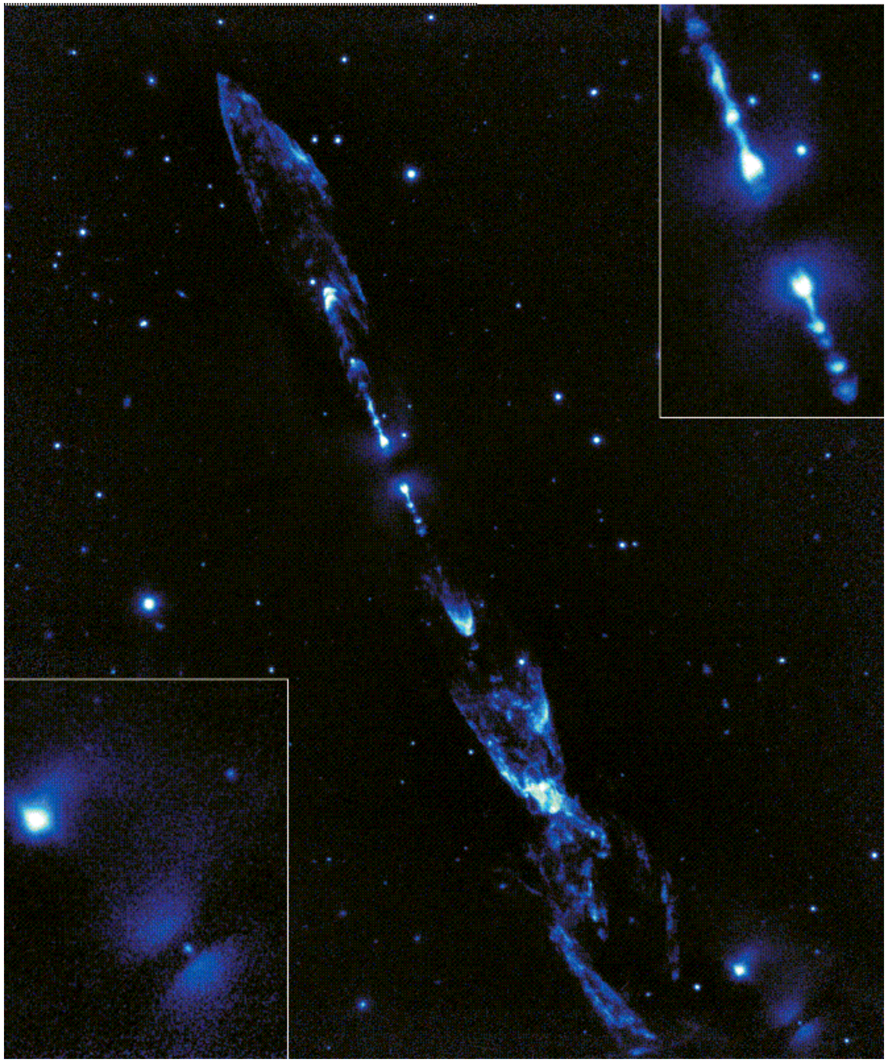
Lahuis et al. (2006).



GMT Resolution will be 2.5 AU for 4 μm of nearest targets at 50 parsecs (e.g. TW Hya)..

Yorke & Bodenheimer (1999)

Herbig Haro 212 in Orion

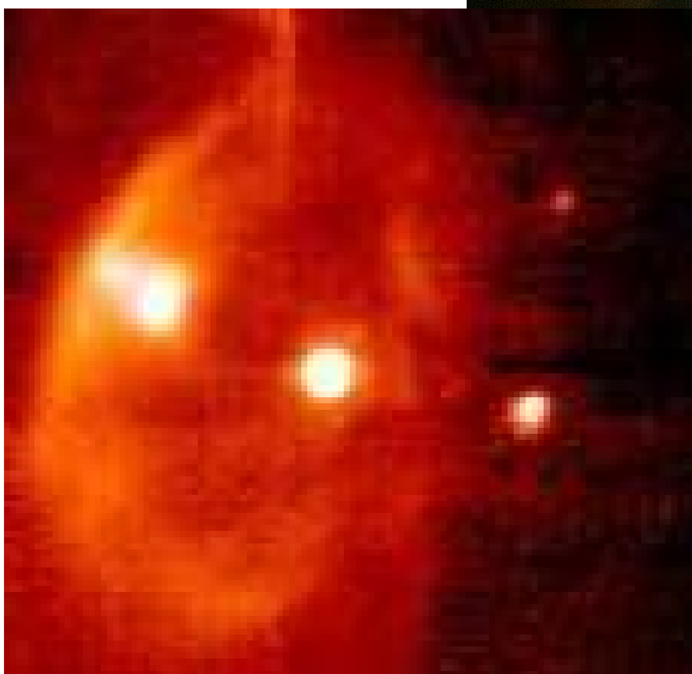


H. Zinnecker et al. H2 Emission from the VLT. Kinematics required!

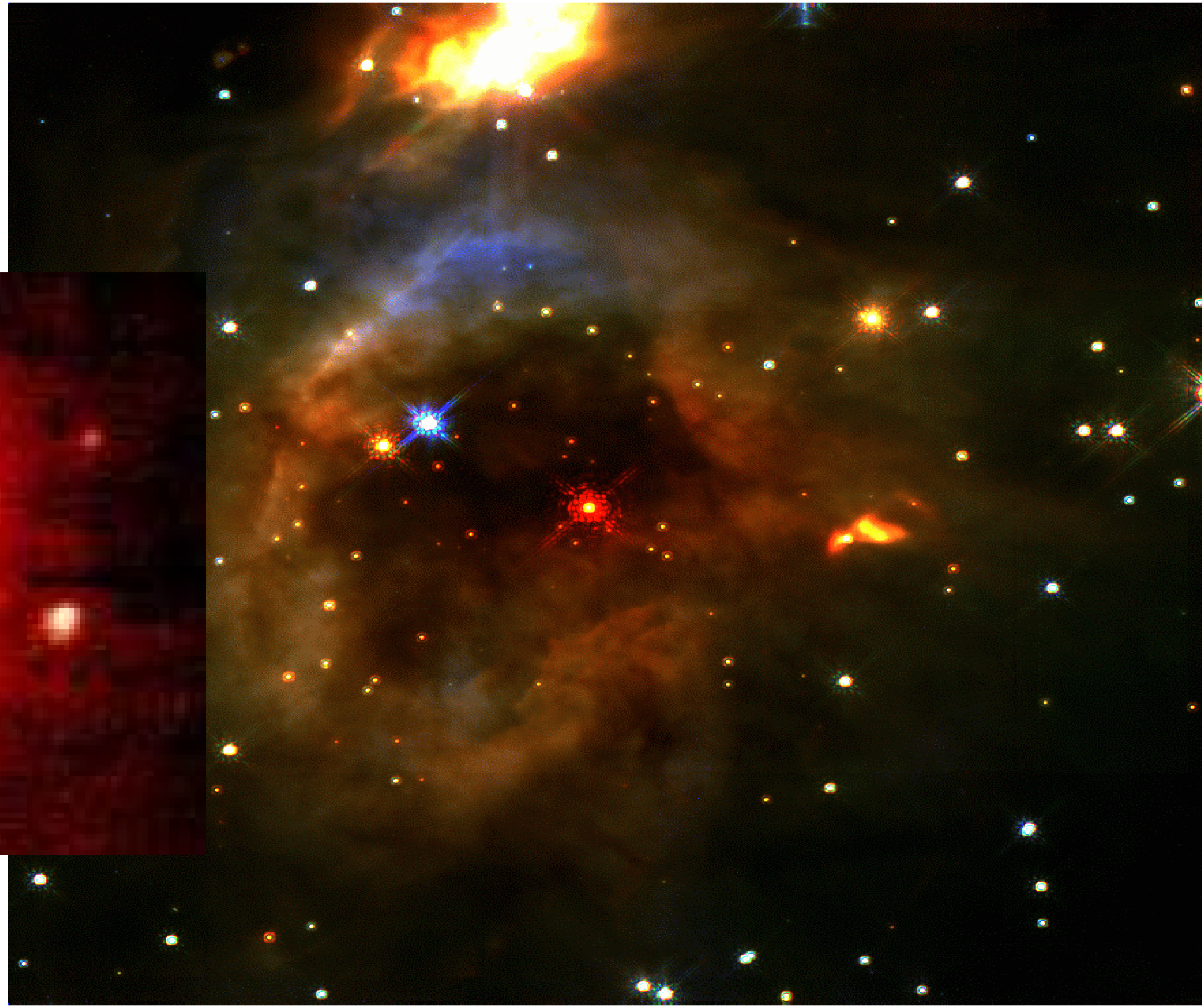
Spitzer Space Telescope 3.6-8.0 μm Images of ***Protostars*** In NGC 1333

LBT-I can study Forming Protostars with ***HST Resolution*** in the Thermal IR

~1 arcmin diameter.

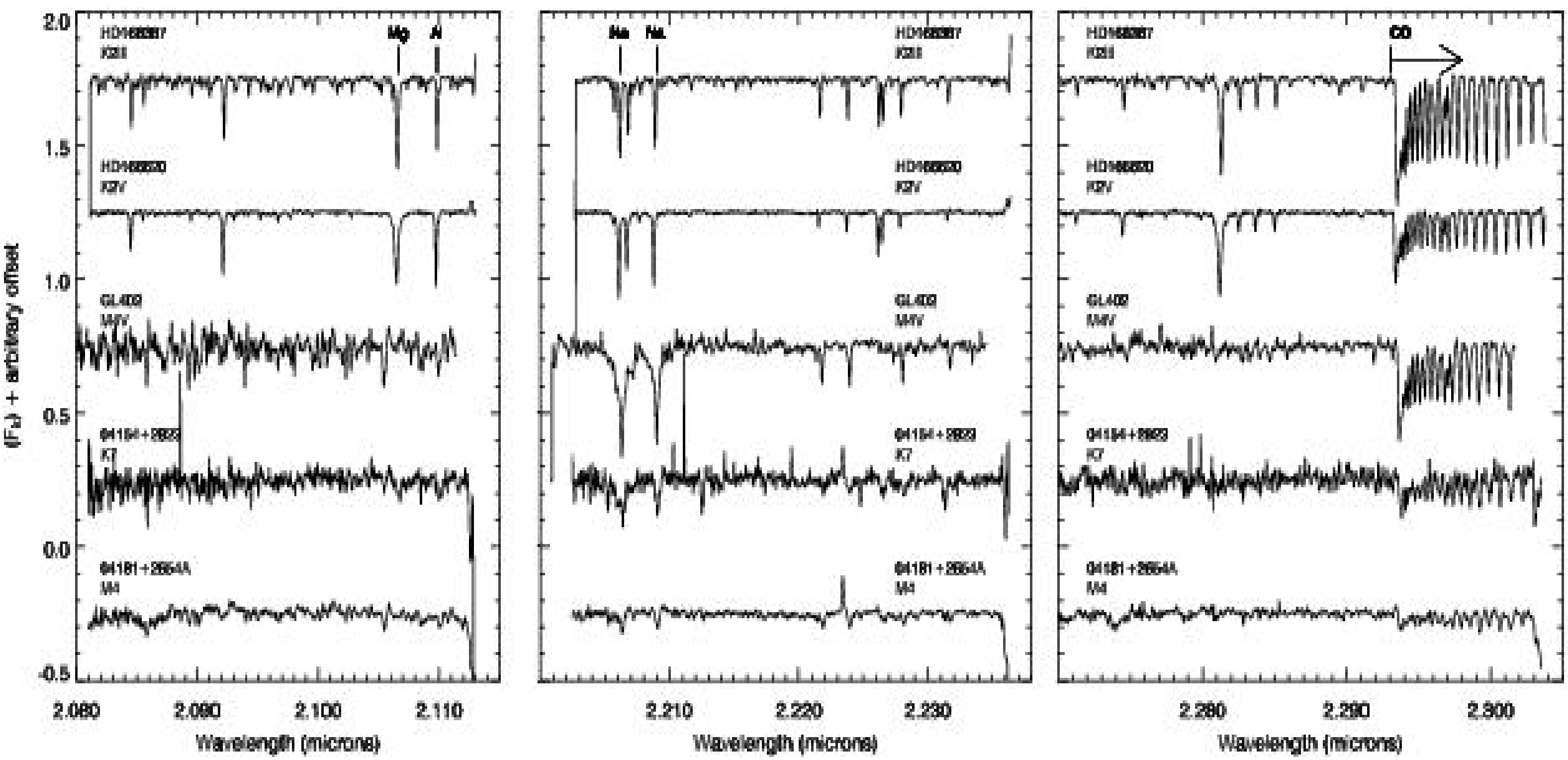


OSCIR @ N-band
UFL on 3-4m



Andersen, Meyer, Oppenheimer, Dougados, and Carpenter (2006)

Pre-Main Sequence Stellar Astrophysics Machine

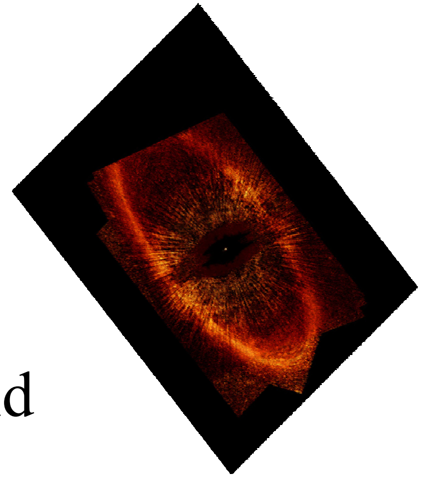


- Rotational Properties (vsini)
- Magnetic Field Strength (Zeeman splitting)
- Accretion Rates (Brackett Line Profiles)
- Cluster Kinematics (radial velocities)
- Fundamental Parameters (Teff, log-g, abundances)

- Courtesy K. Covey (U. Washington/CfA)

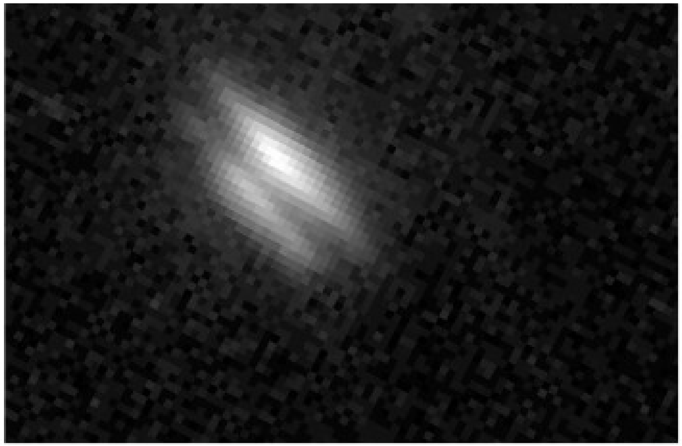
From Active Accretion to Planetary Debris Disks...

Images courtesy of K. Stapelfeldt, P. Kalas, and NASA.



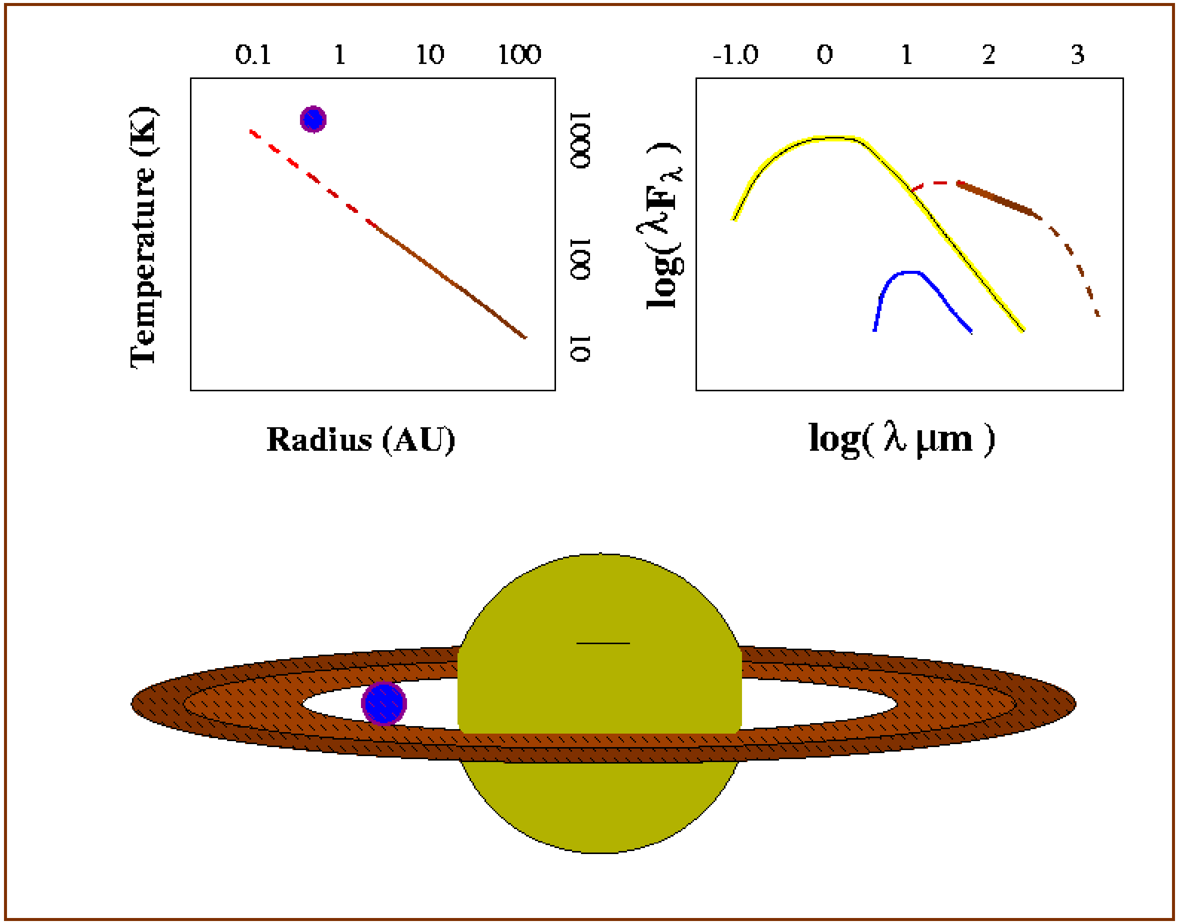
Planetary debris disk ~ 100 Myr old

Solar system debris disk 4.65 Gyr old!

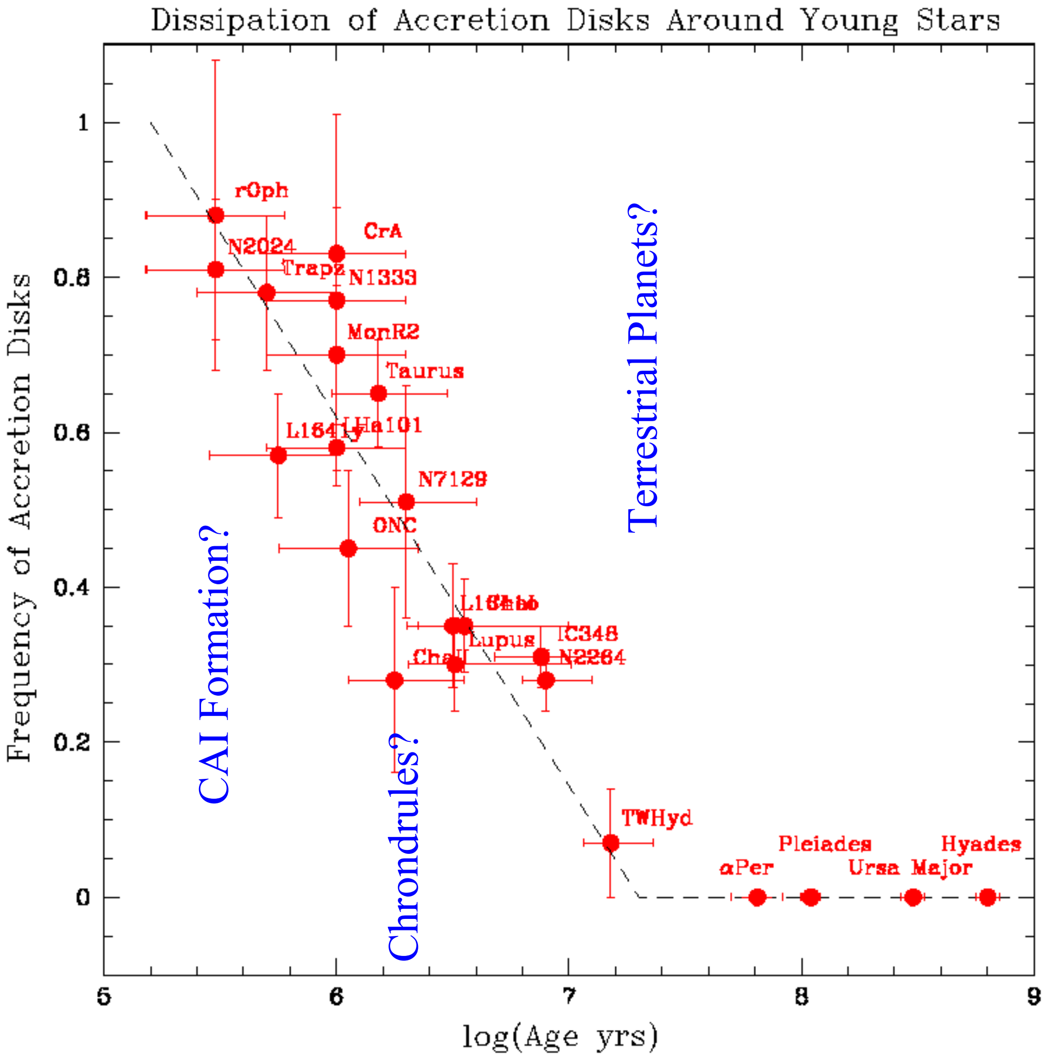


Gas-rich disk ~ 1 Myr old

Blackbody Disk with Dynamically Cleared Gap

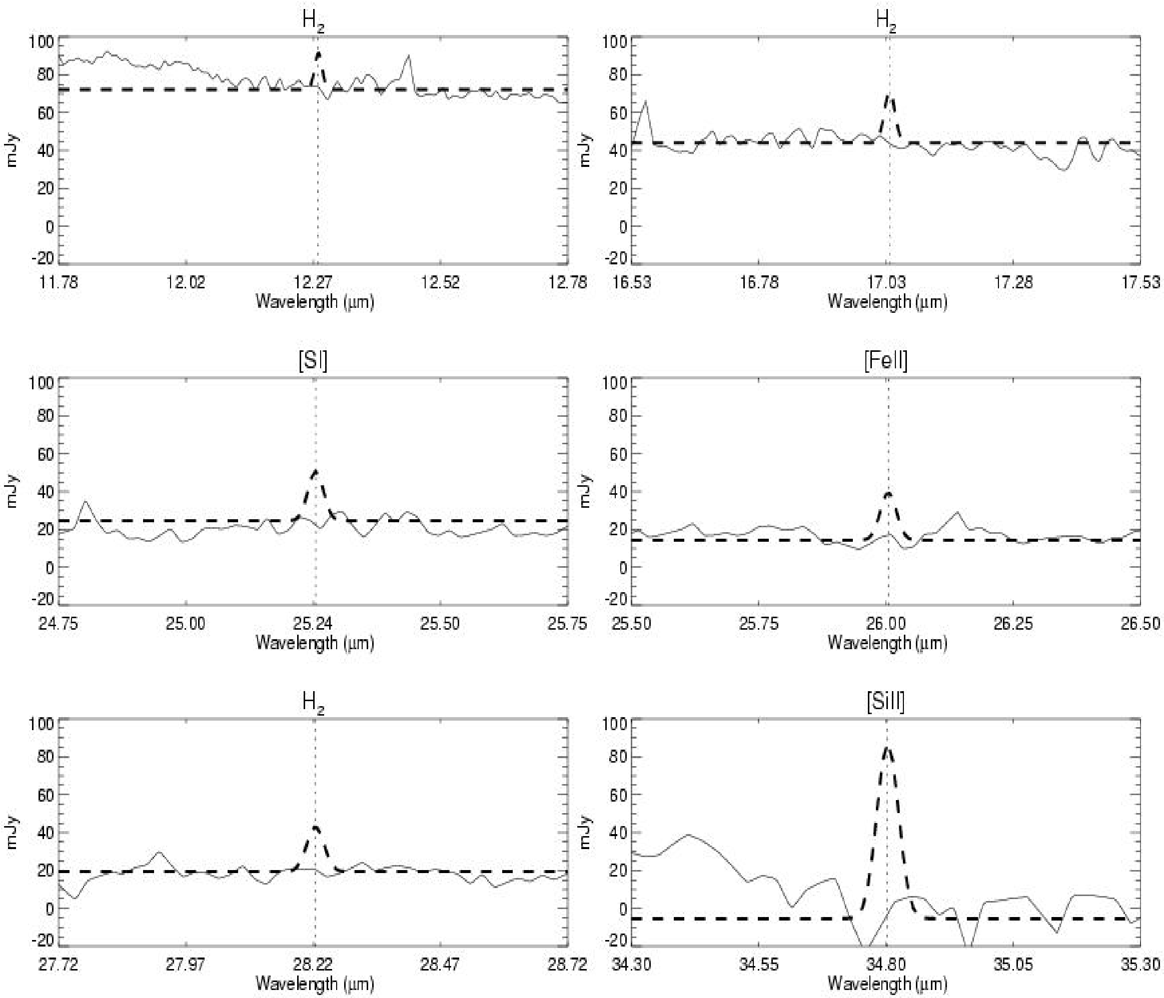


Diversity in Primordial Disks:
Masses and Lifetimes



Haisch etal. 2001; see also Hillenbrand (2002).

Warm Gas disk lifetimes appear to be < 10 Myr.

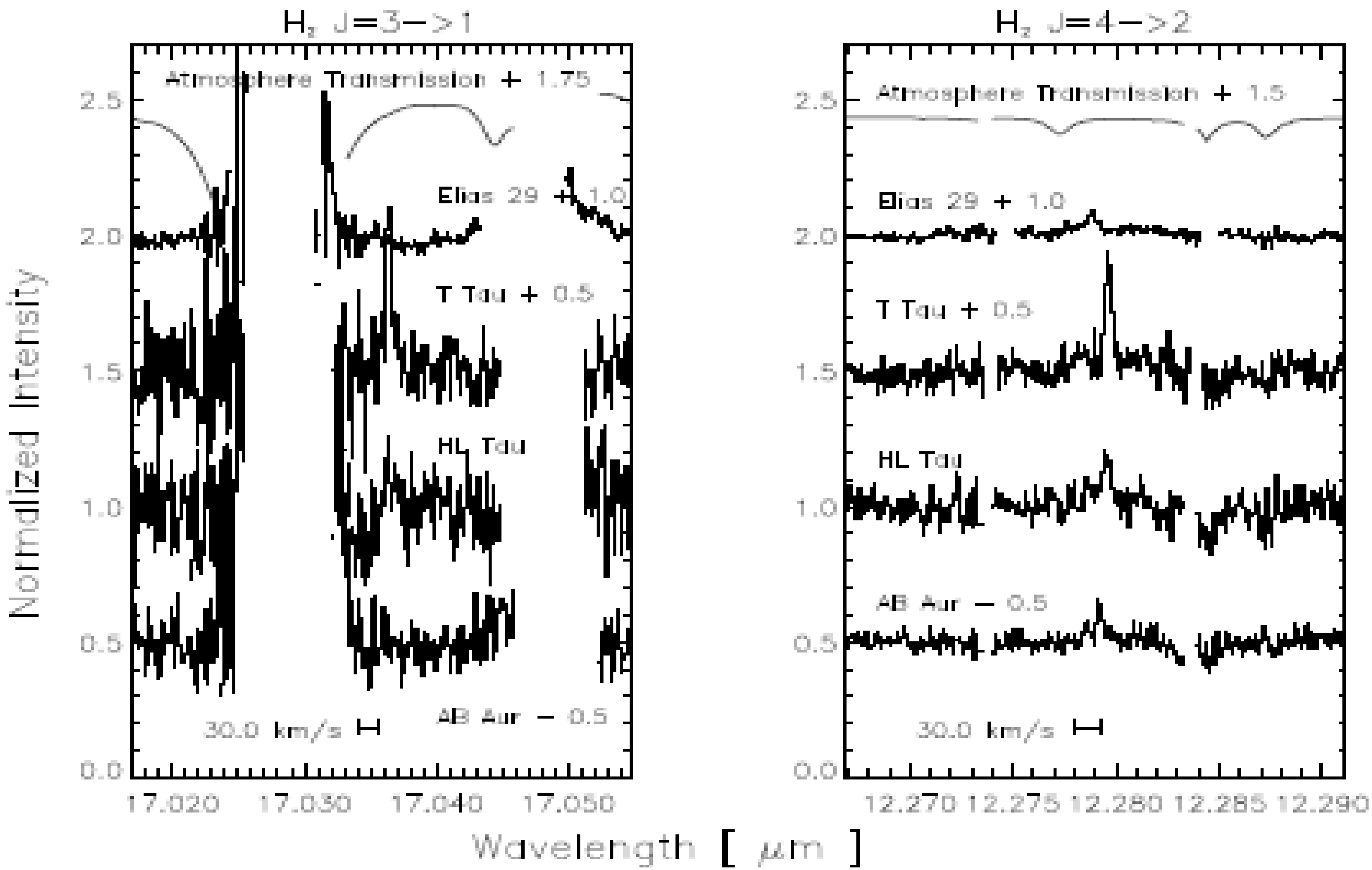


=> No gas rich disk (> 0.1 Mjup) detected.

Spitzer IRS 11-37 um

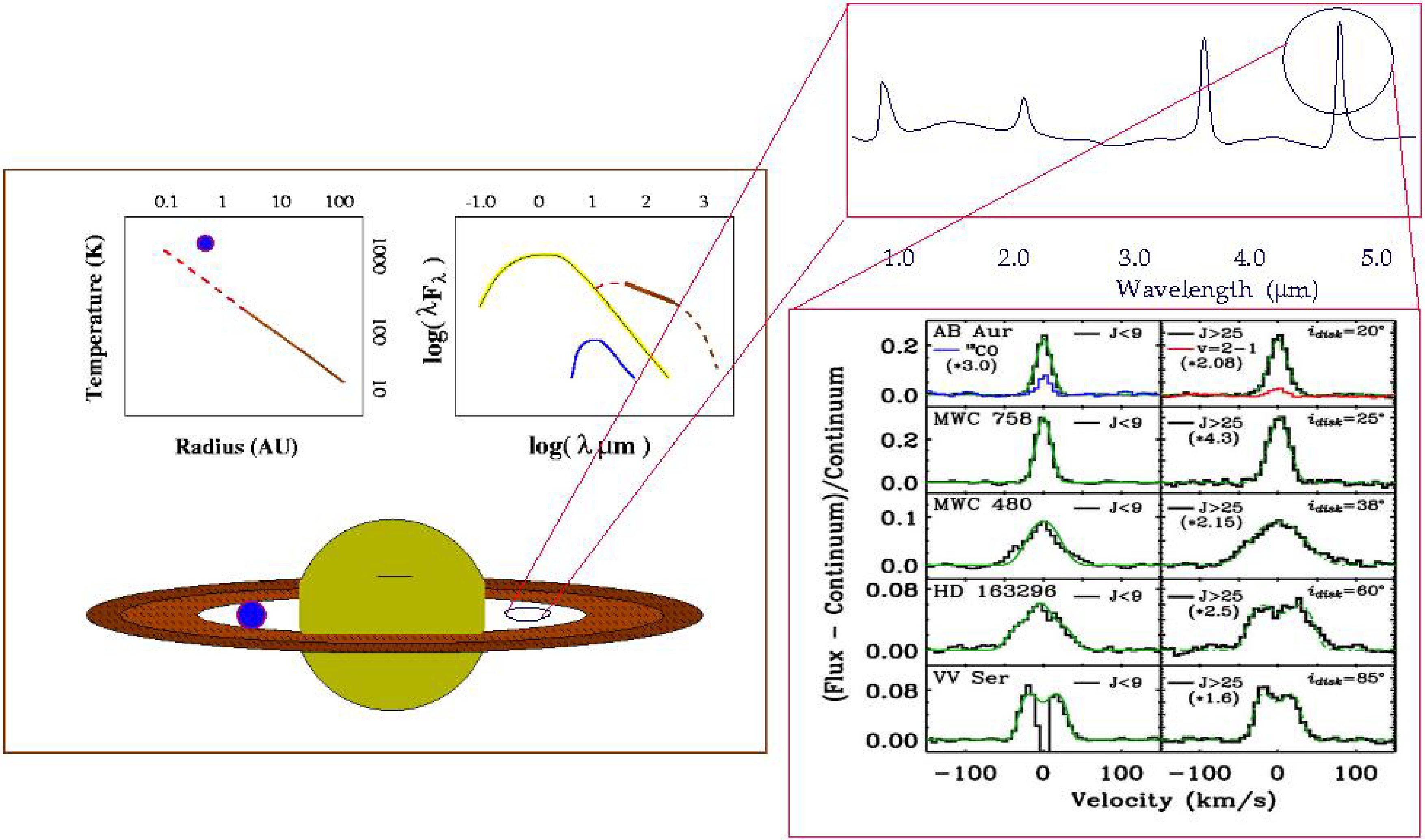
Hollenbach et al. (ApJ, 2005); Pascucci et al. (2006).

Science of the Cold and Slow: Ground-based Mid-IR Echelle Wins!



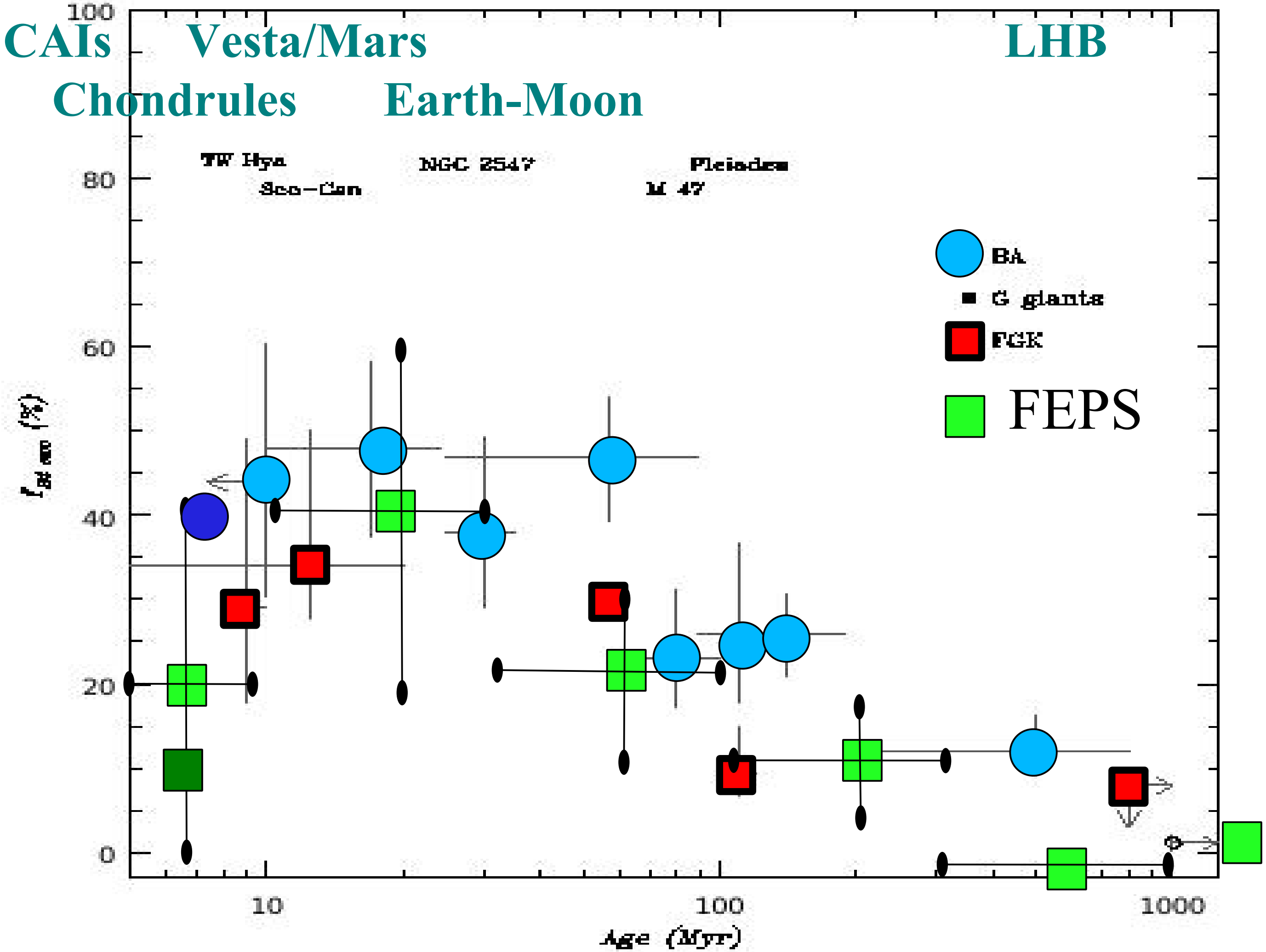
TEXES on Gemini Lacy et al. (2006); Richter et al. (2004)

Gas content as a function of radius and age.

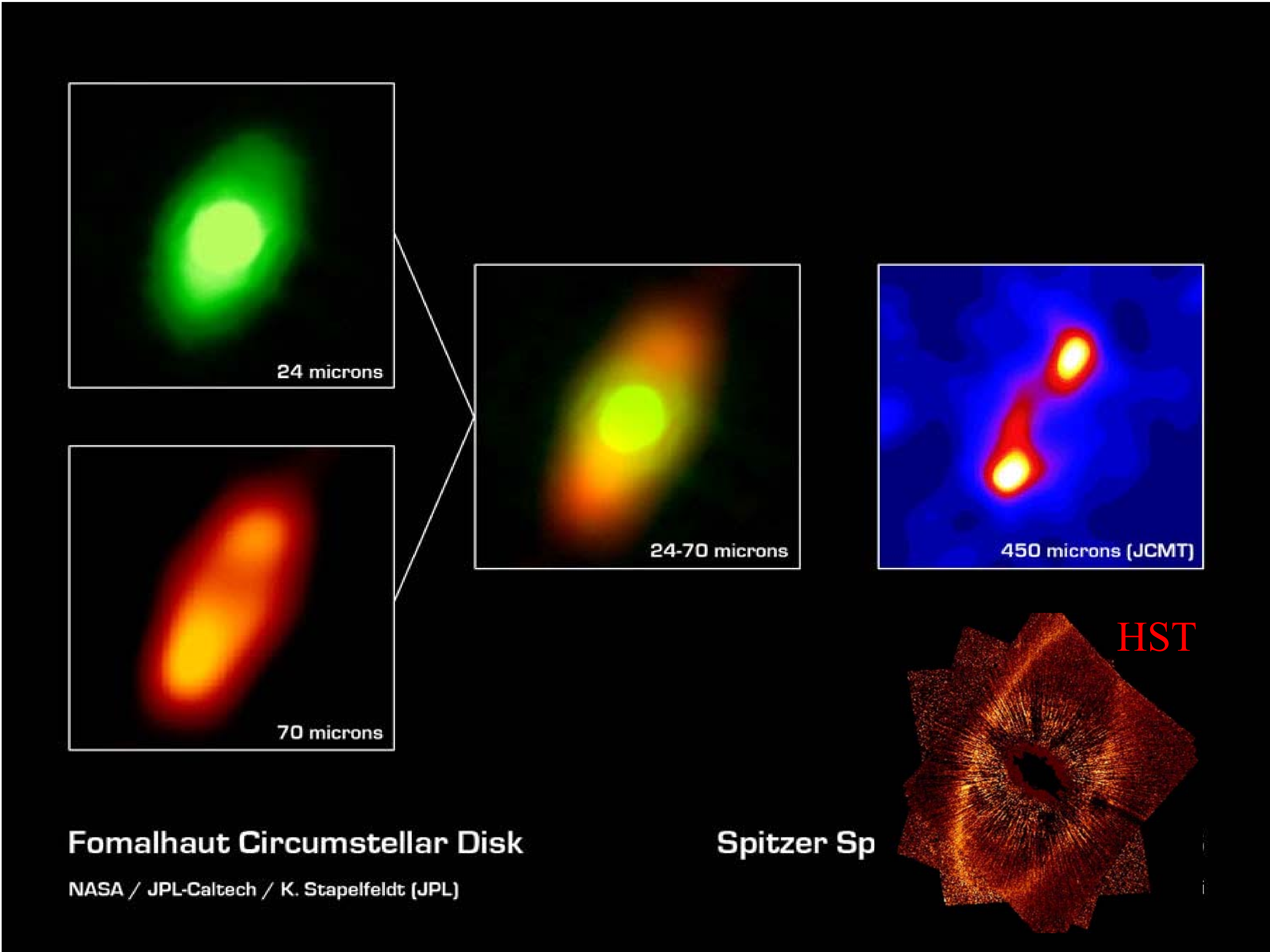


Velocity resolved CO emission at 4.7 microns from Blake and Boogert (2004)

Spitzer Observations of Warm Debris Frequency Around Normal Stars: Clues to Terrestrial Planet Formation?

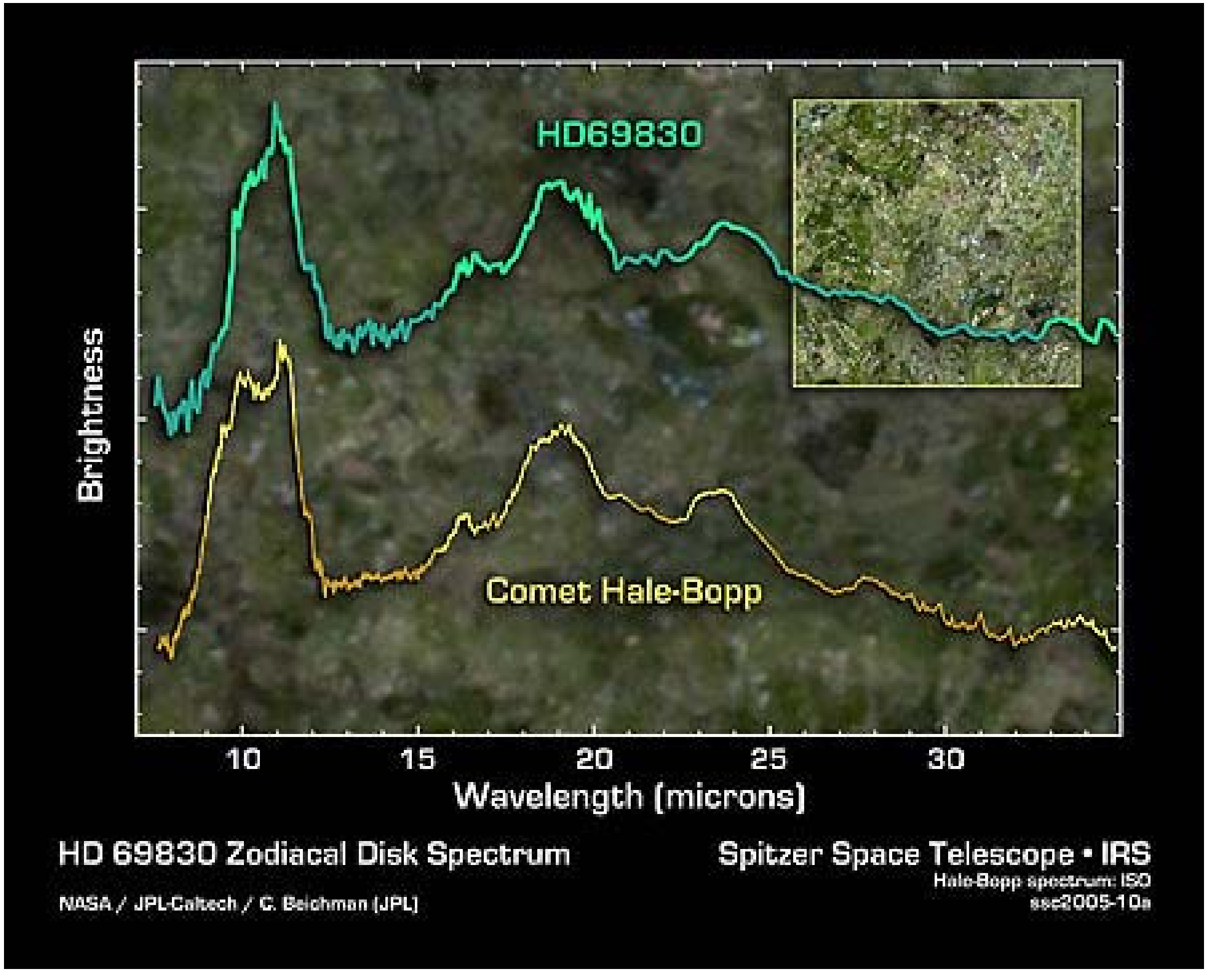


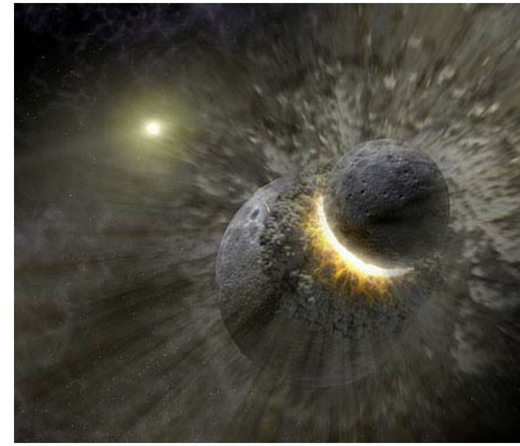
Meyer et al. (in preparation).



24 microns
70 microns
24-70 microns
450 microns (JCMT)
HST
Fomalhaut Circumstellar Disk
Spitzer Sp
NASA / JPL-Caltech / K. Stapelfeldt (JPL)

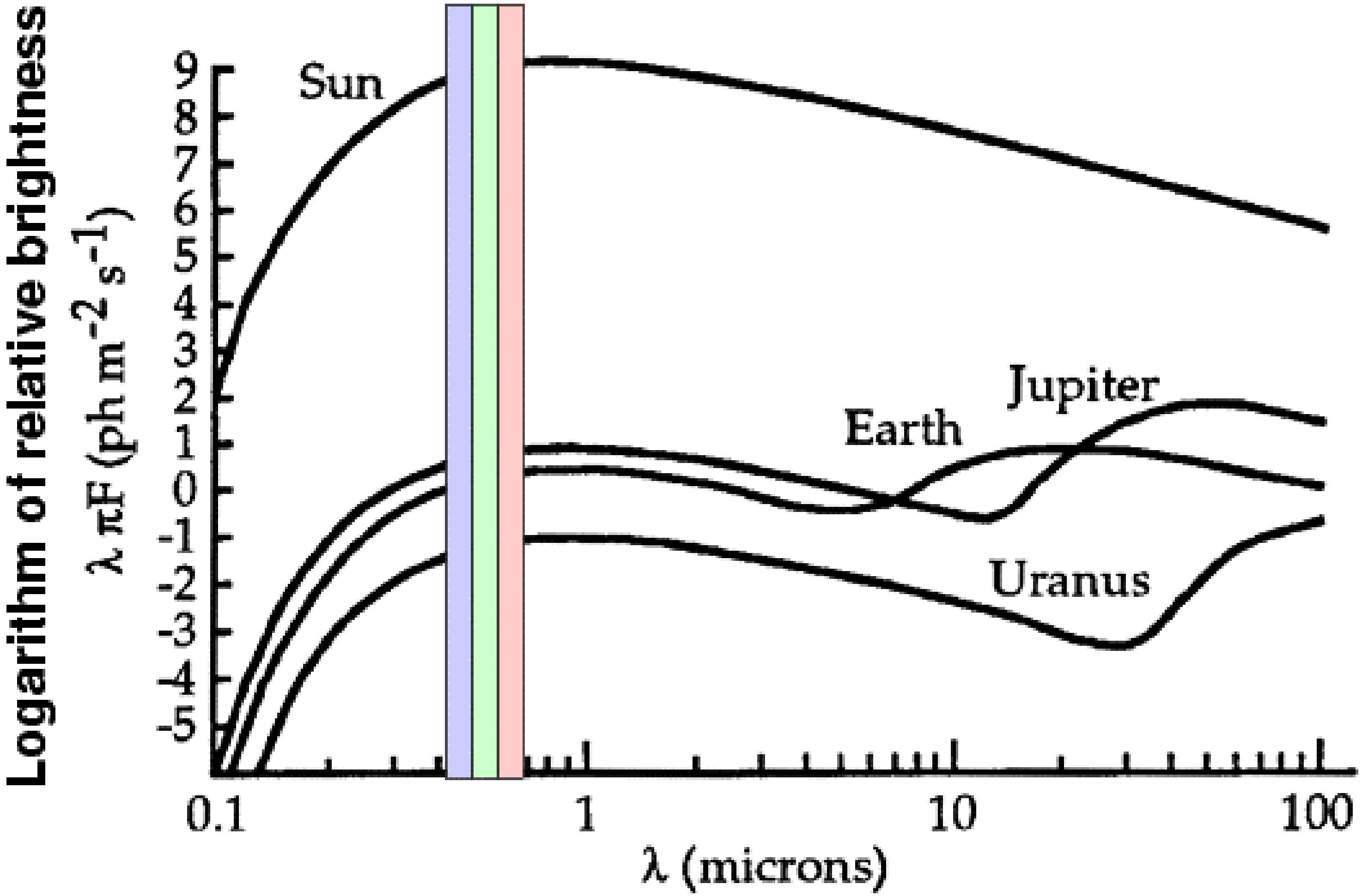
Resolved Spectroscopy of Debris Surrounding Sun-like Stars



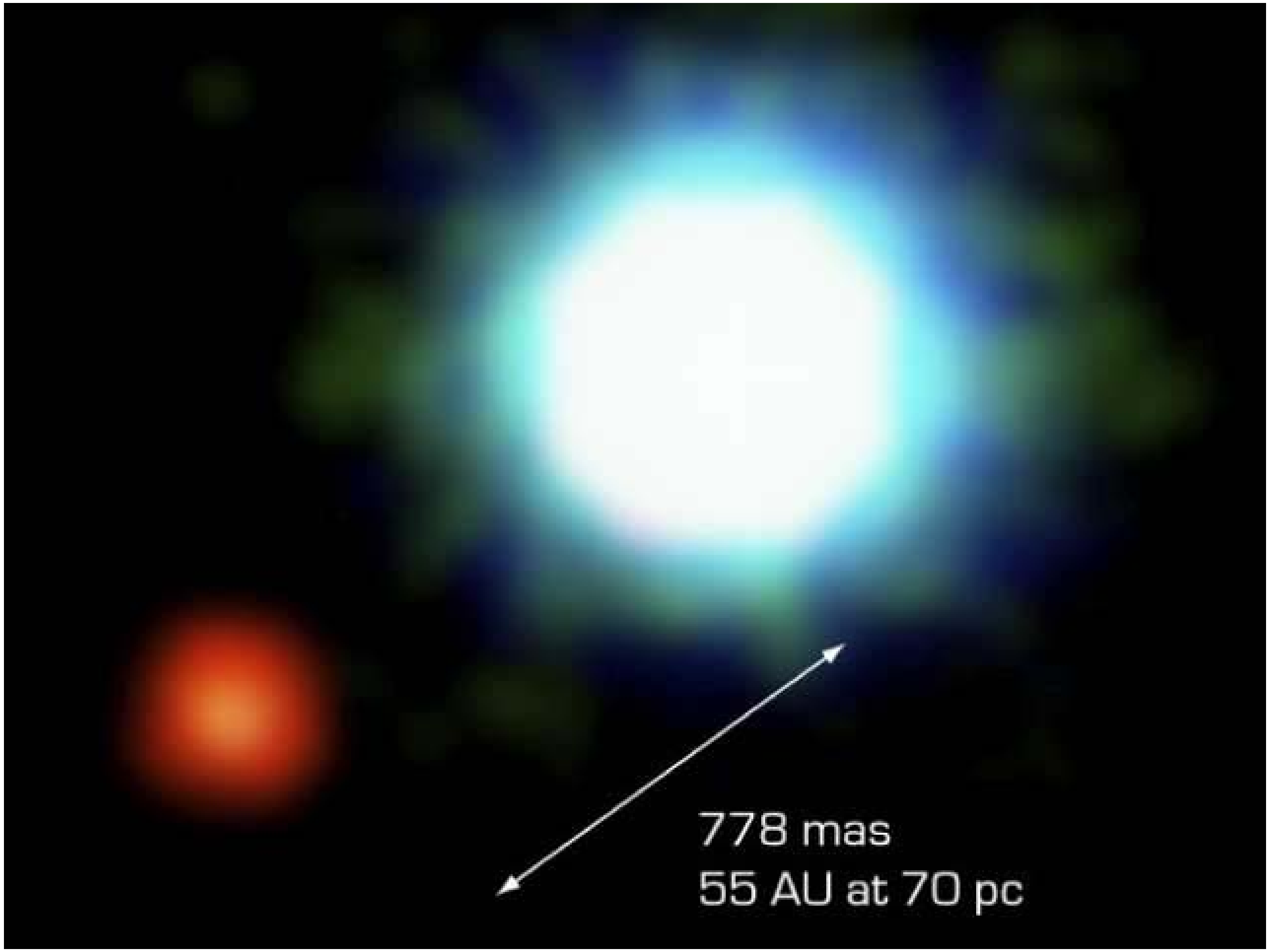


Beichman et al. (ApJ, 2005); Song et al. (Nature, 2005); Weinberger et al. (2003); Telesco et al. (2004).

Direct Detection of Planets: The Problem

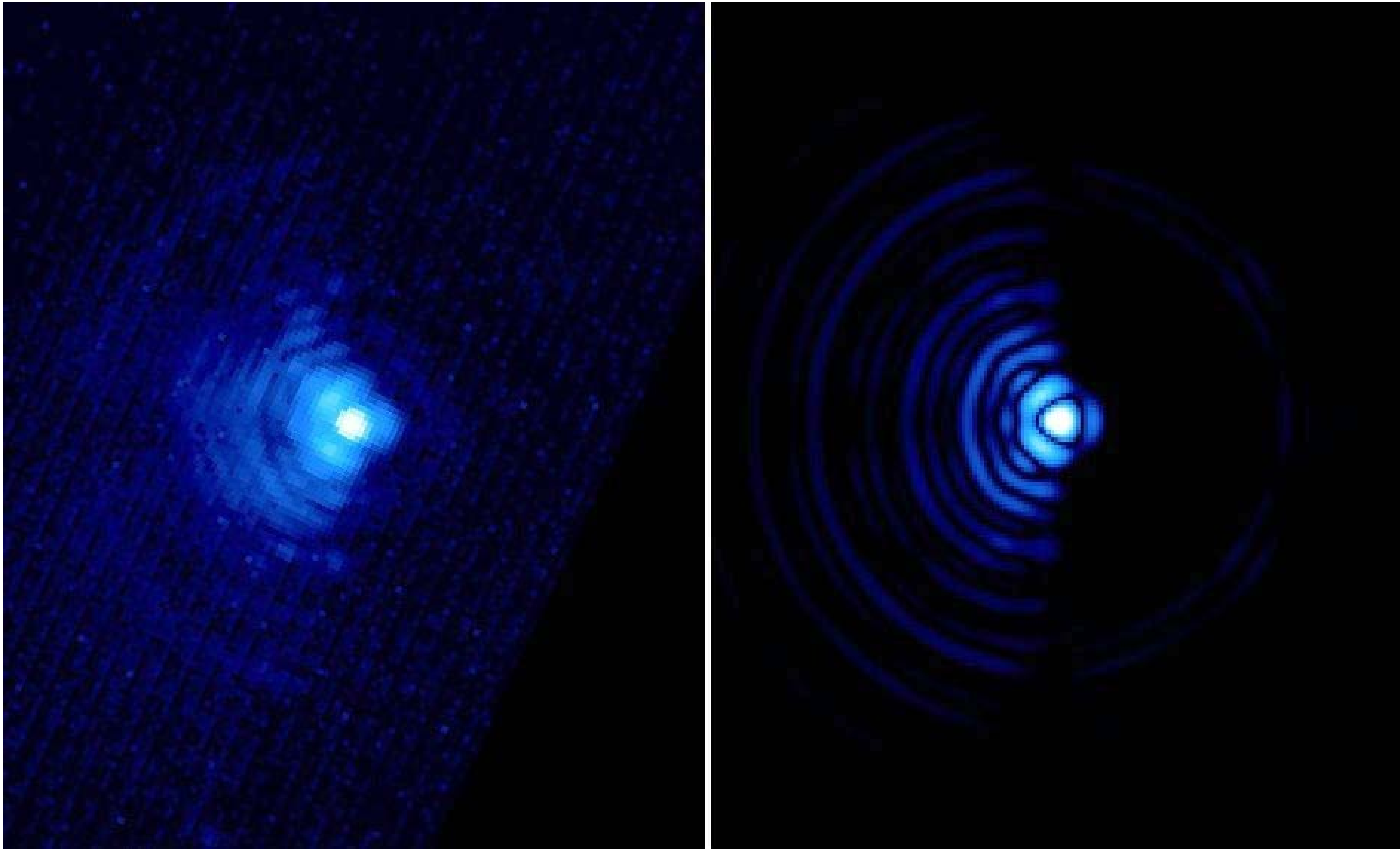


Direct Detection: Show me a planet!



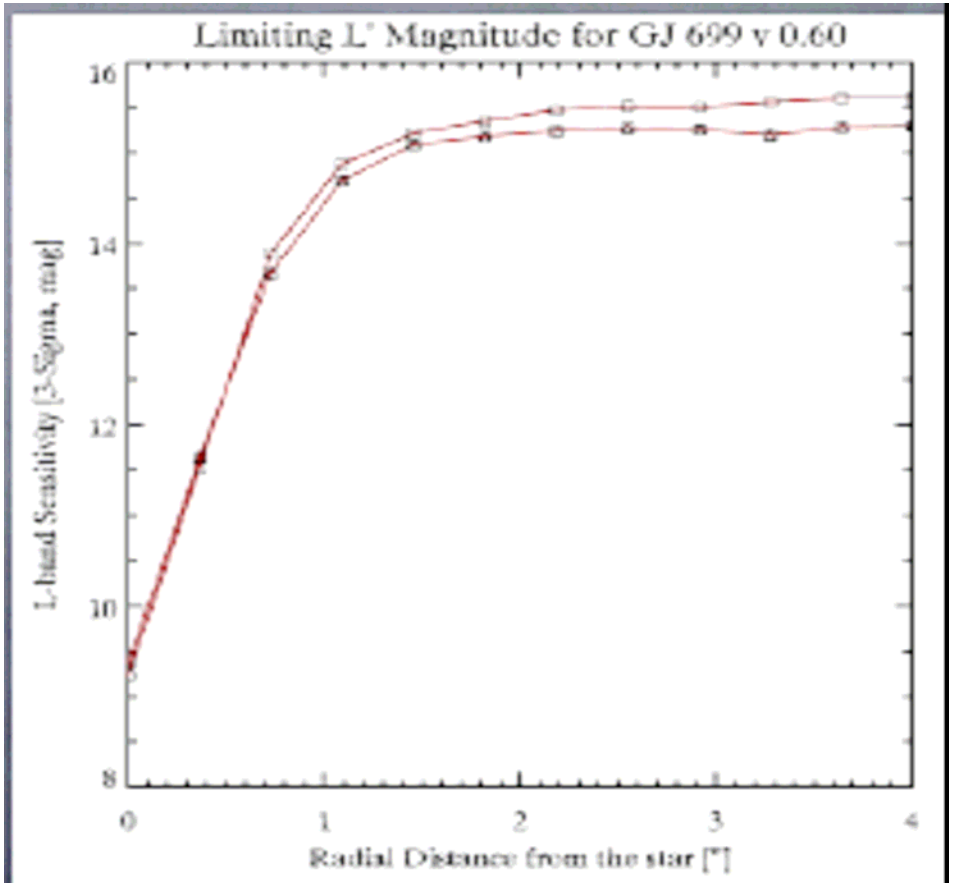
NACO/VLT (Chauvin et al. 2004).

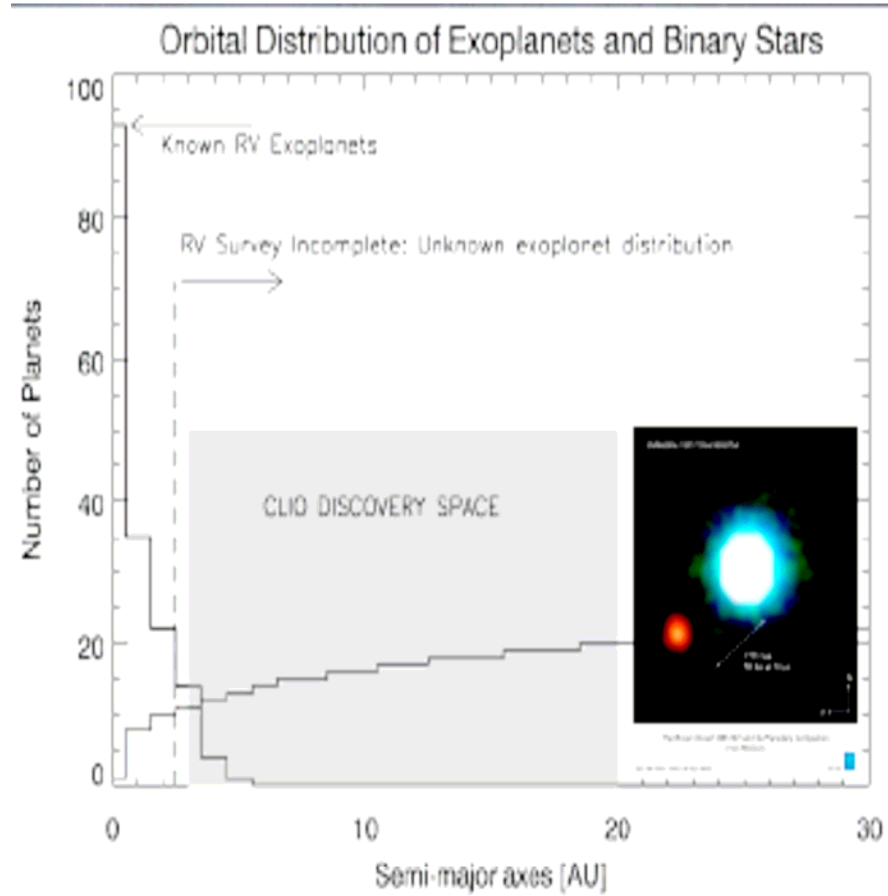
Direct Detection: Current State of the Art.



MMT-AO with CLIO Courtesy Phil Hinz (Kenworthy et al. 2006).

Direct Detection: Current State of the Art.

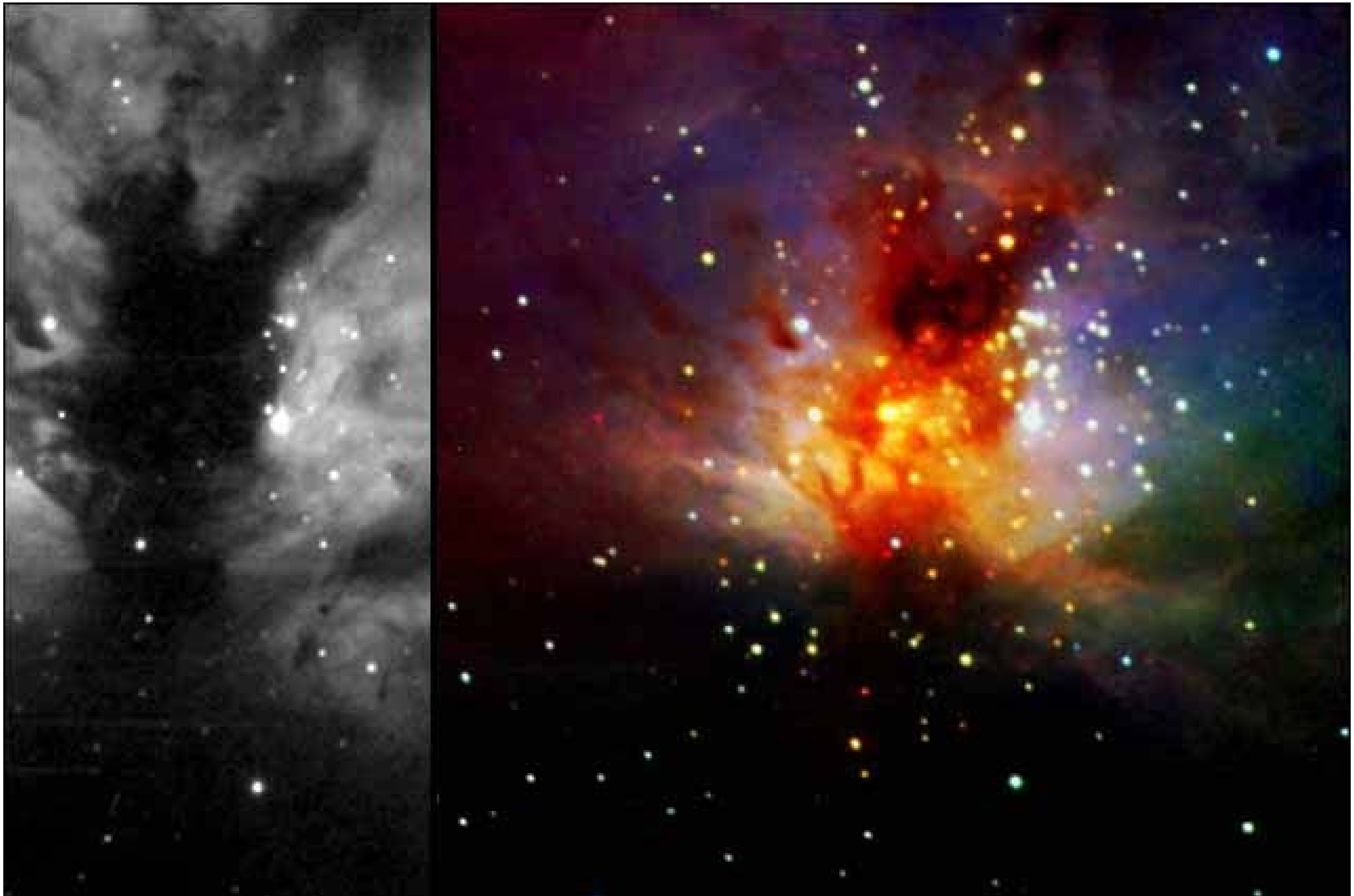




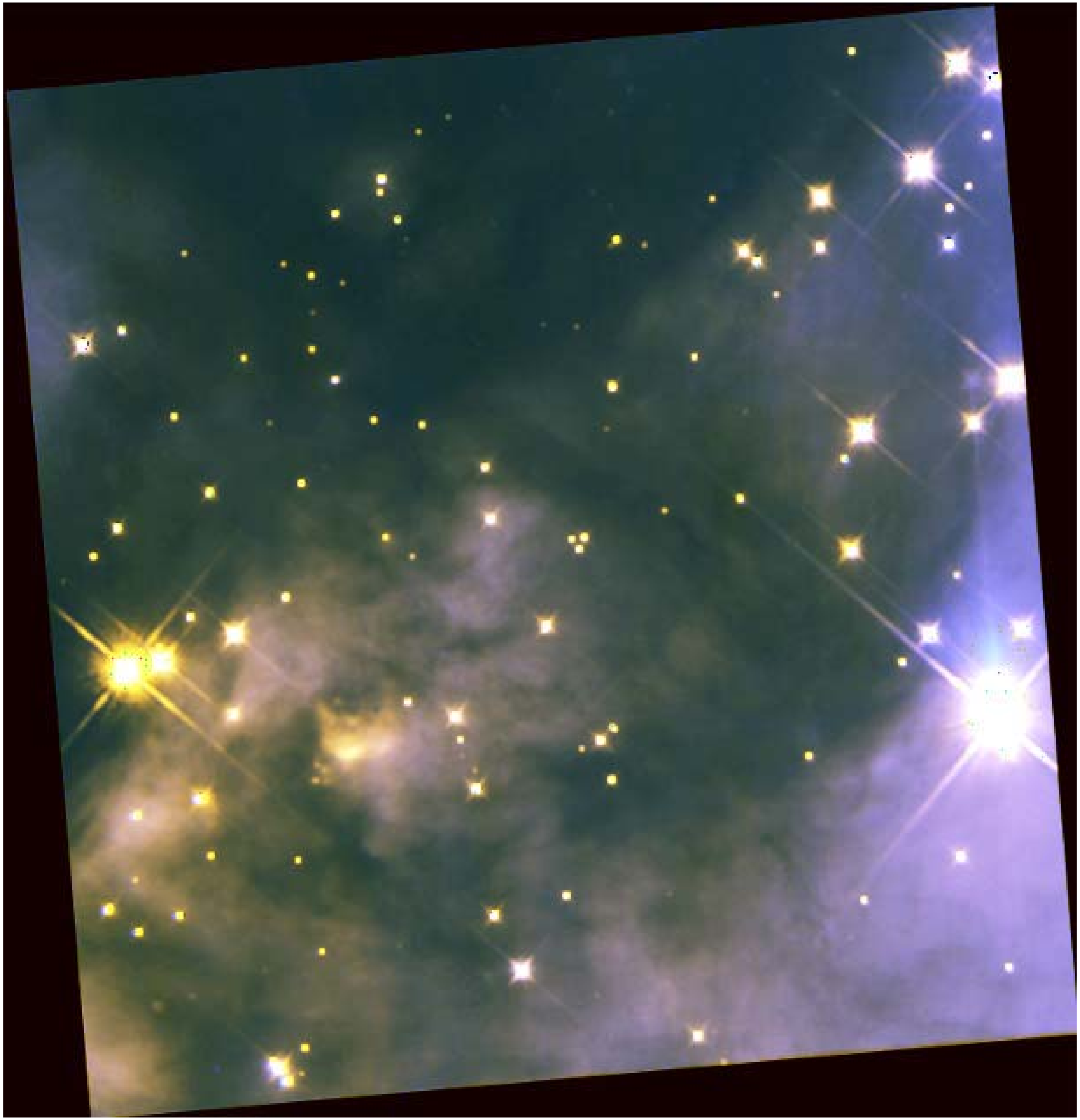
MMT-AO with CLIO/VLT with NACO

Courtesy Daniel Apai (see also Heinze et al. 2006).

No Natural Guide Stars in Key Dark Cloud Targets, But ***Tip-Tilt Stars Available***.



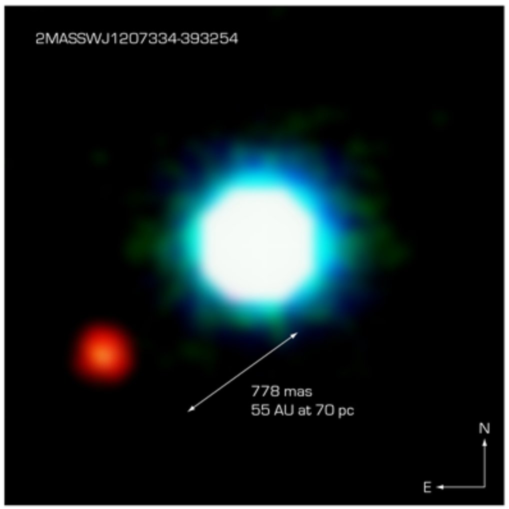
NOAO 1.3 meter SQIID (1990):   I. Gatley, R. Probst.



$m_I < 18^m$
~1 arcmin
Diameter.

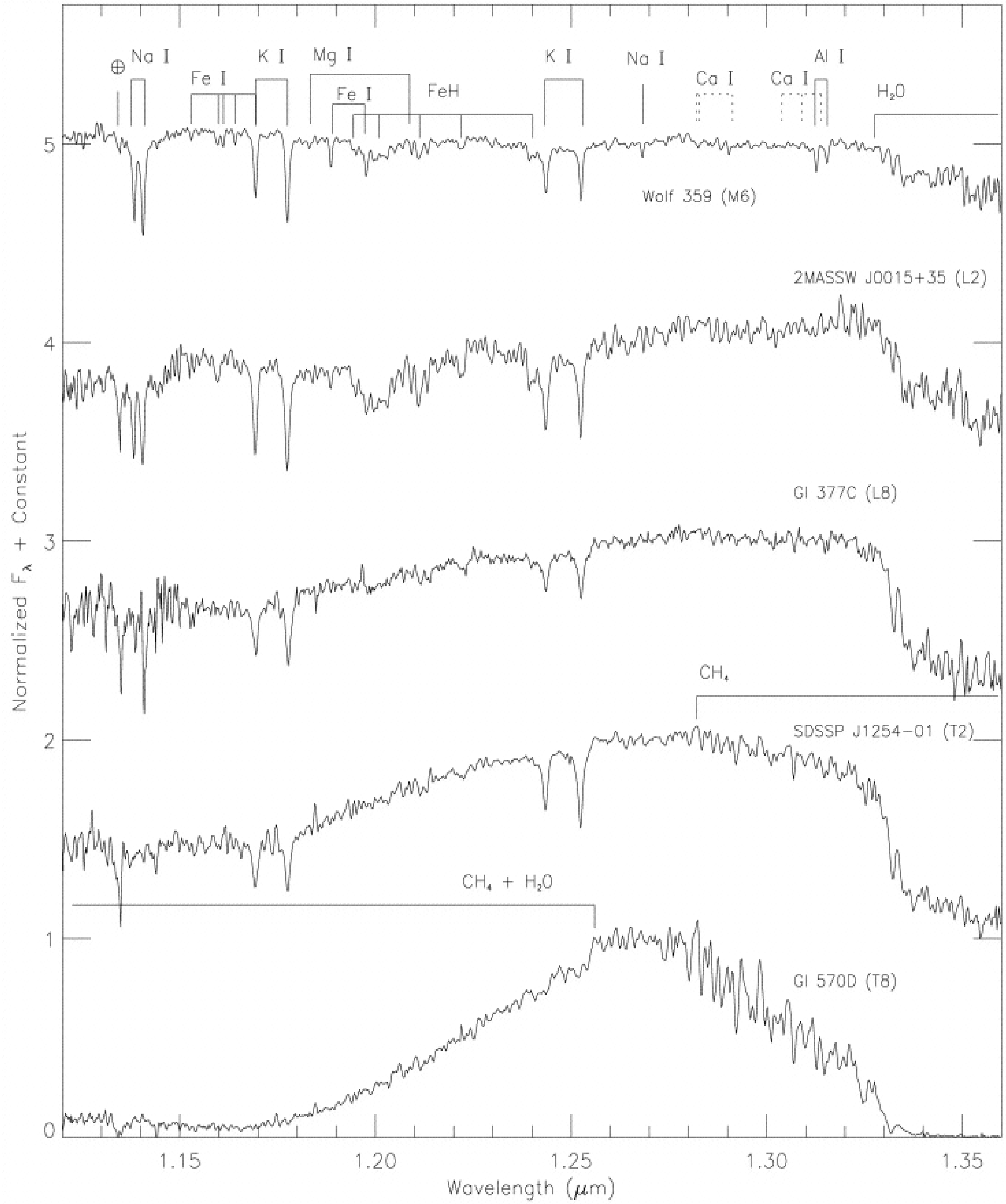
NICMOS/HST Mosaic F810W/F110W/F150W of NGC 2024 (Liu, Meyer, Cotera, and Young 2003, AJ).

Near-IR Spectra can Distinguish Candidate ***Planetary Companions*** from Background Stars



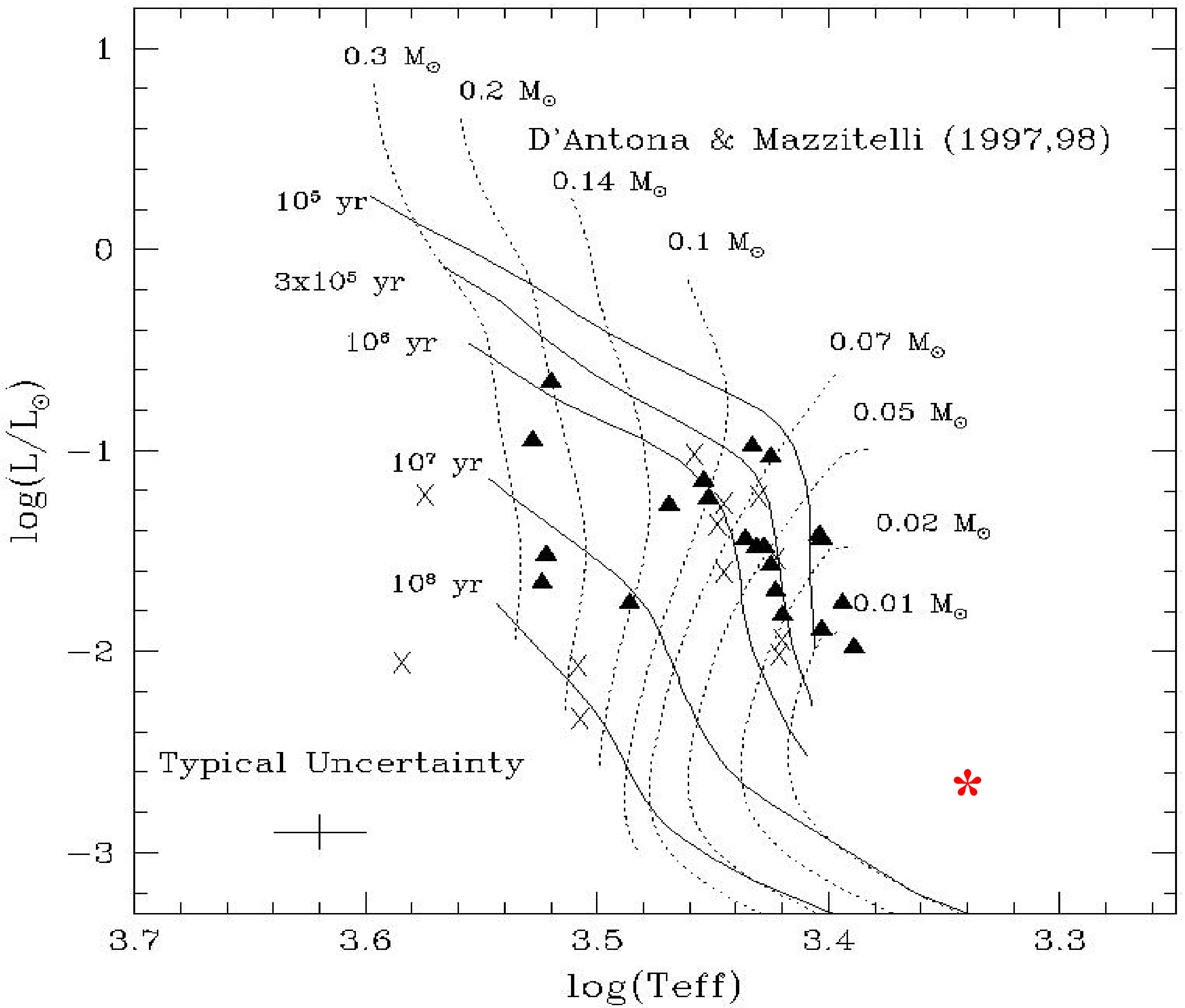
NACO Image of the Brown Dwarf Object 2M1207 and GPCC

ESO PR Photo 26a/04 (10 September 2004)

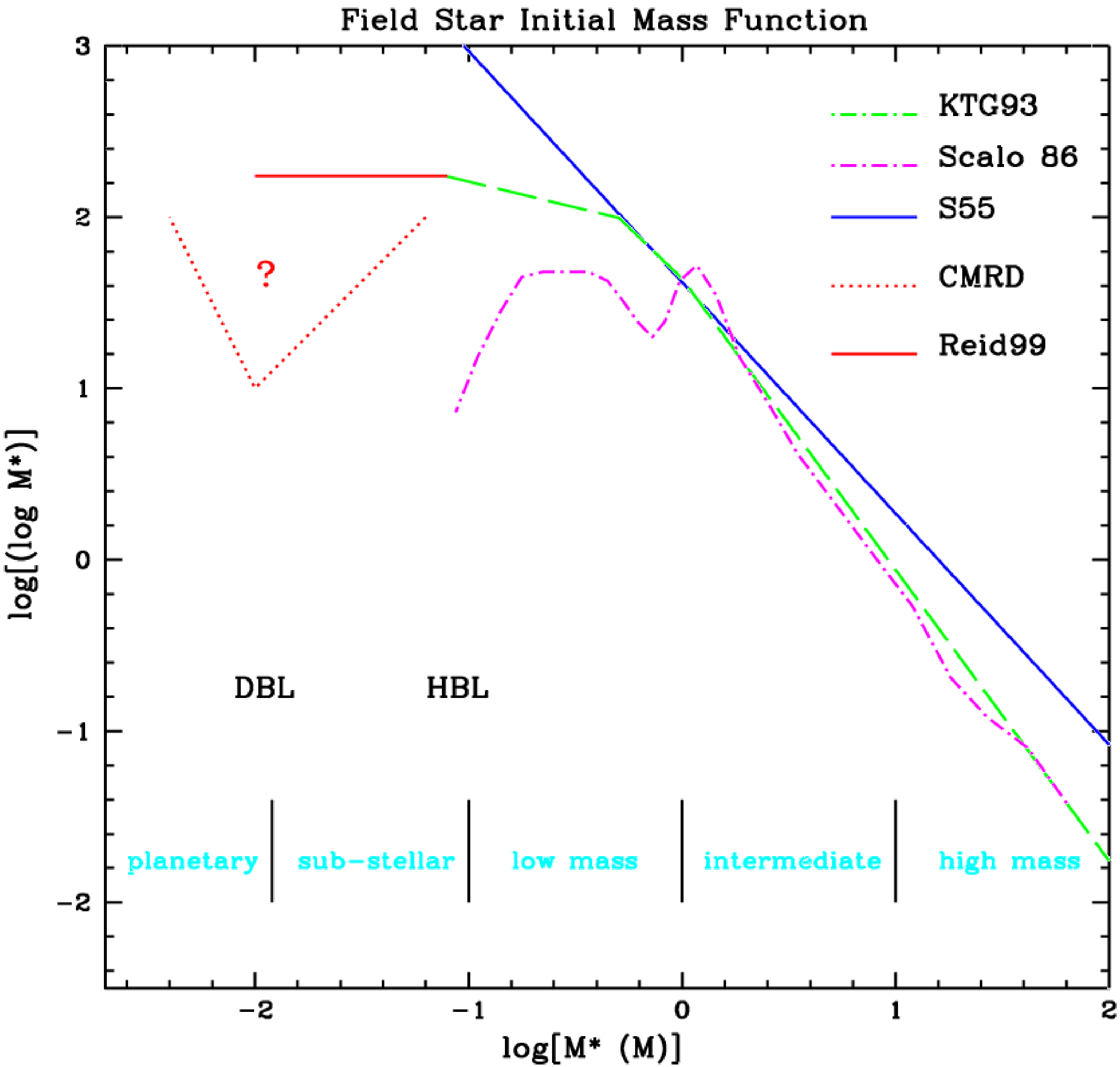


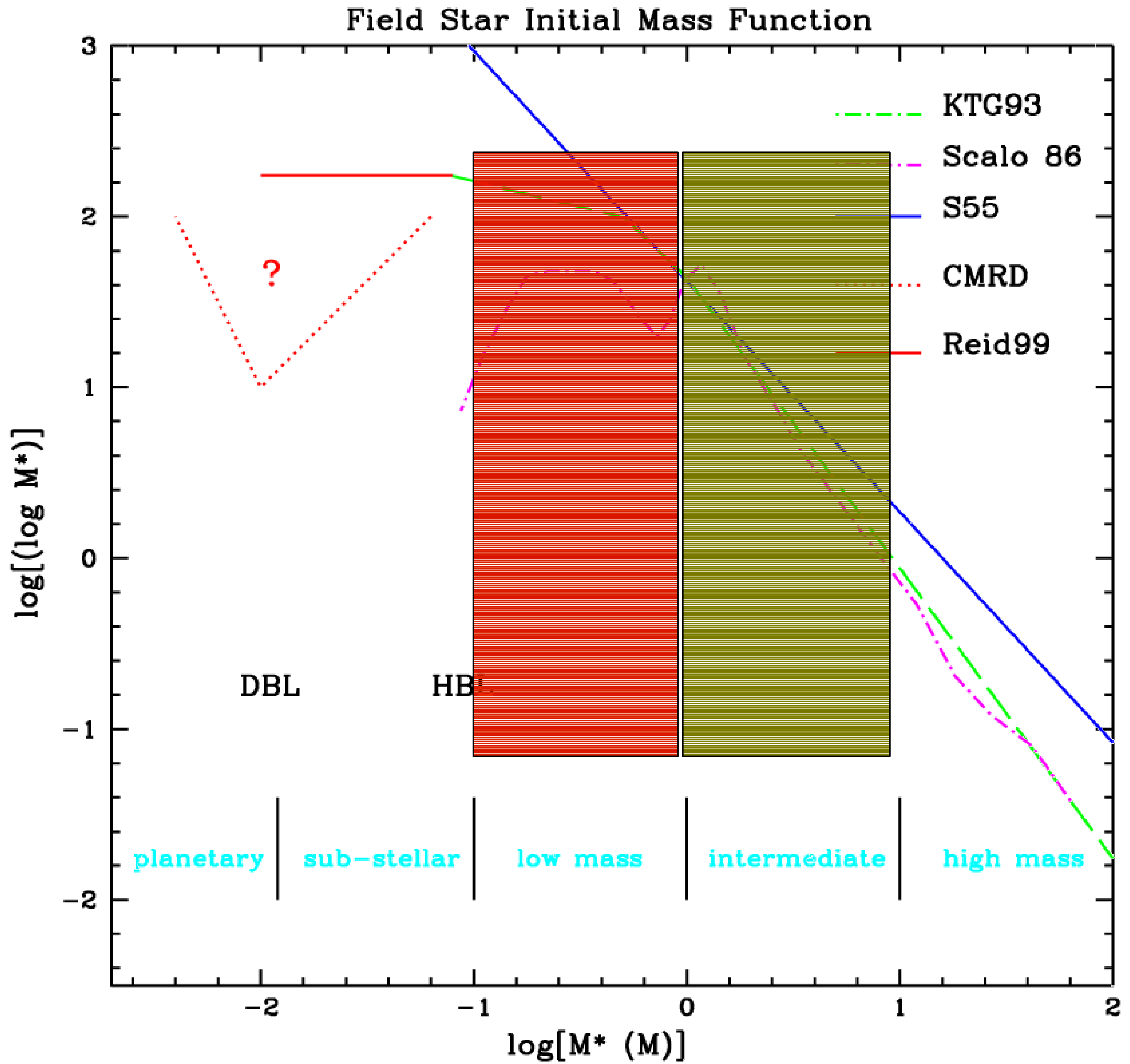
Chauvin et al. (2005)
McLean et al. (2003)

H-R Diagrams for ***Planetary Mass*** Objects in NGC 1333



Greissl, Meyer, Wilking, Fanetti, Greene, Scheider, Young (2006)


Field Star Initial Mass Function
KTG93
Scalo 86
S55
CMRD
Reid99
?
DBL
HBL
planetary
sub-stellar
low mass
intermediate
high mass
log[(log M*)]
log[M* (M)]
3
2
1
0
−1
−2
−2
−1
0
1
2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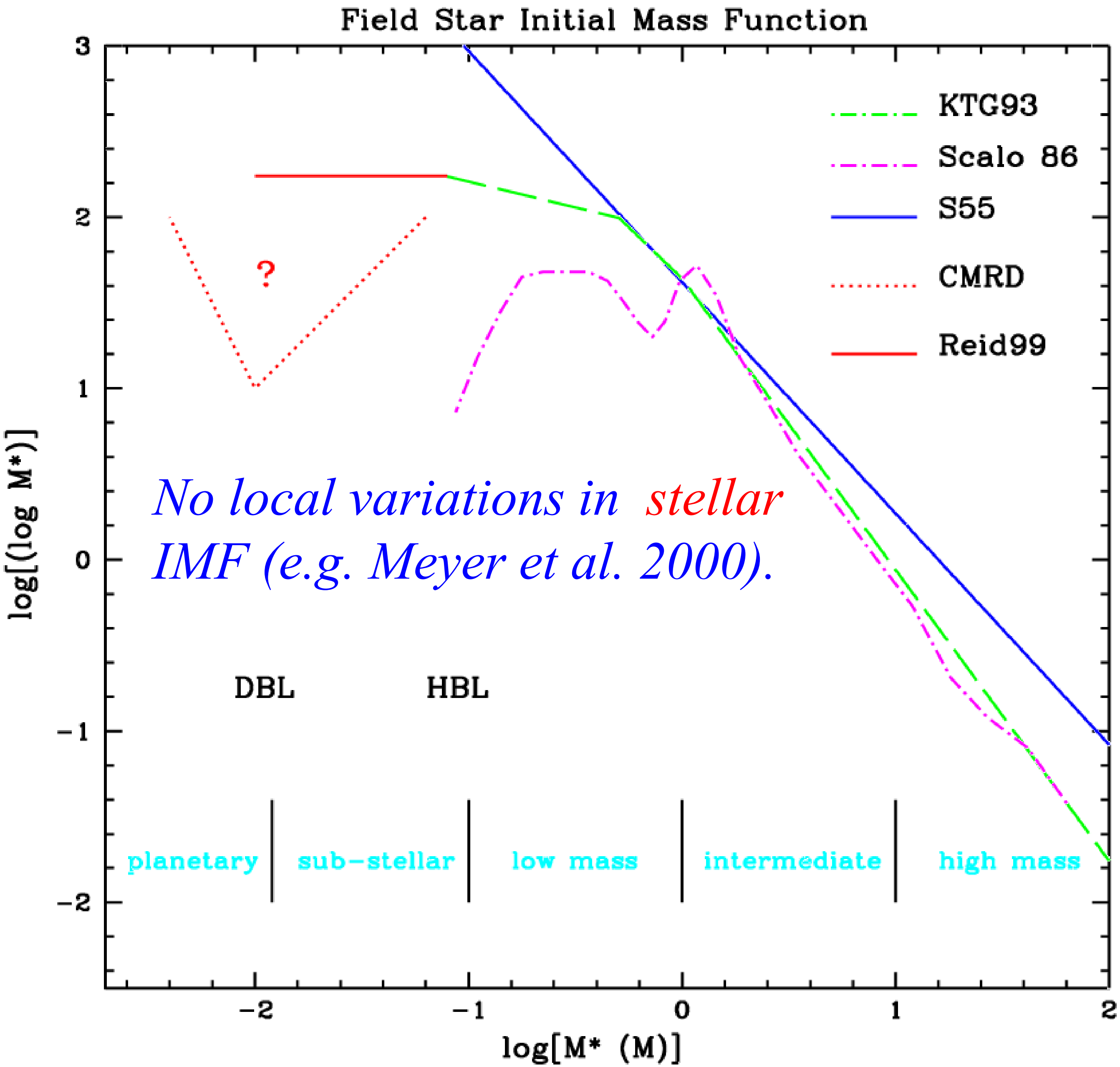
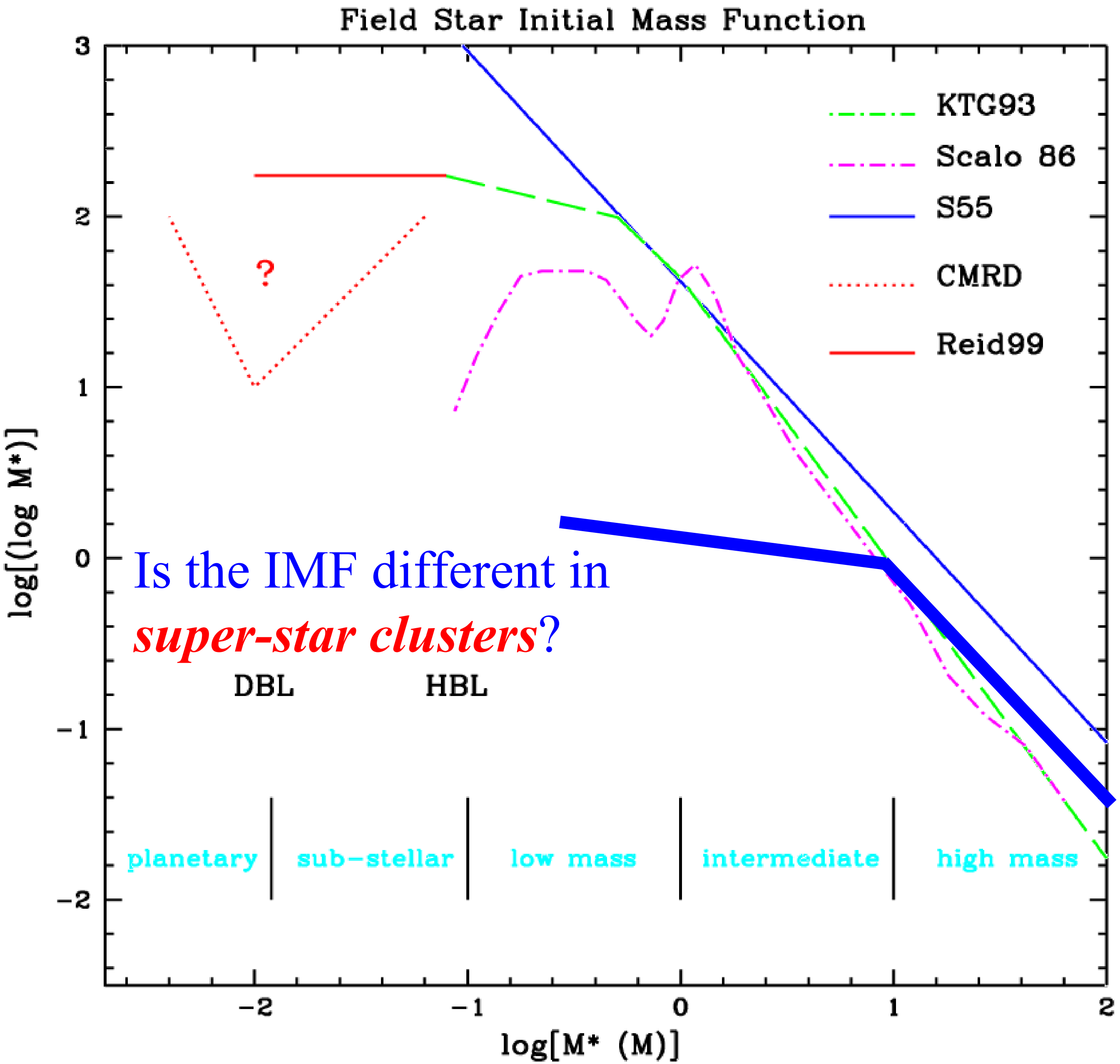
−2
−1
0
1
2

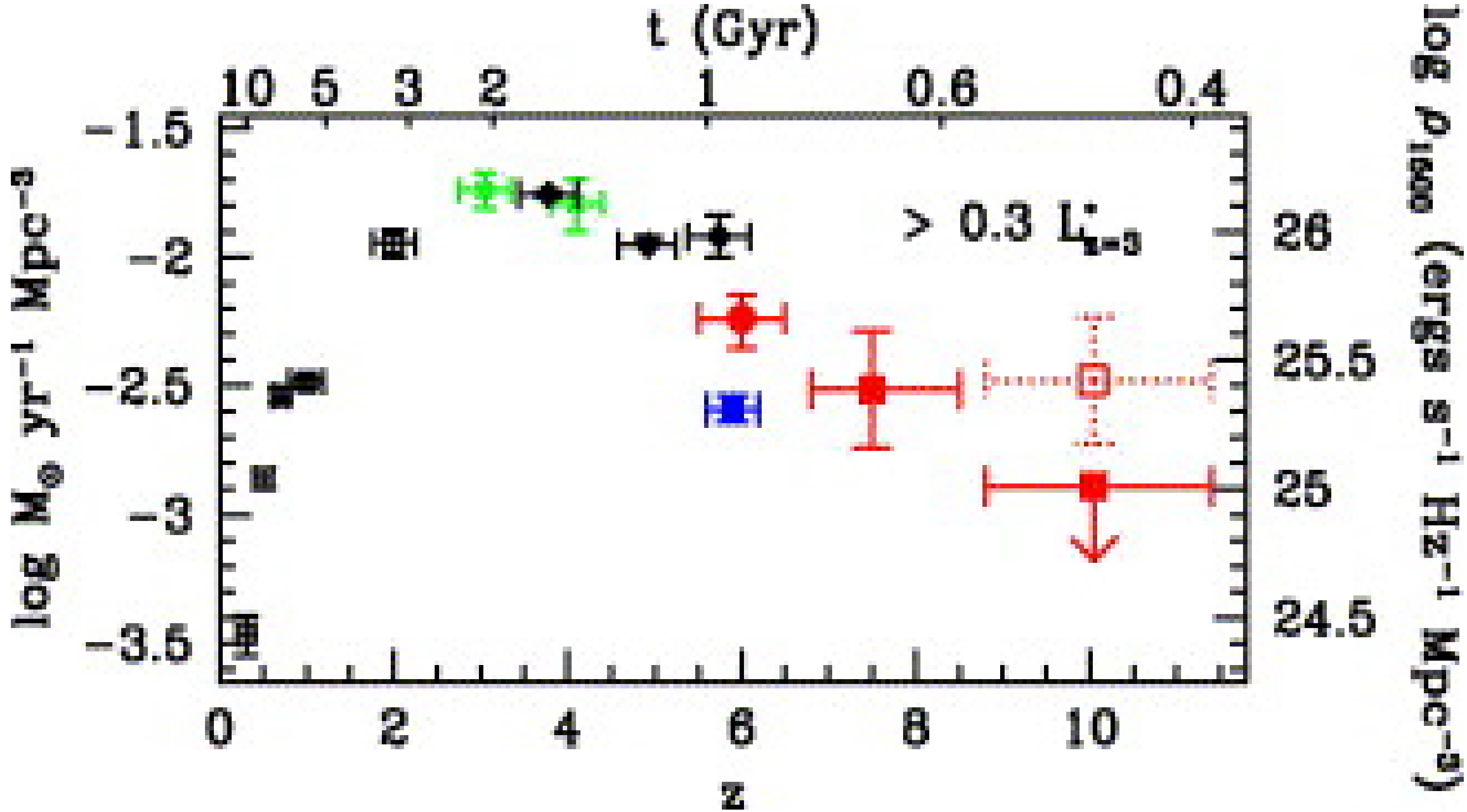


No local variations in stellar IMF (e.g. Meyer et al. 2000).


Field Star Initial Mass Function
KTG93
Scalo 86
S55
CMRD
Reid99
?
Is the IMF different in
super-star clusters?
DBL
HBL
planetary
sub-stellar
low mass
intermediate
high mass
log[(log M*)]
log[M* (M)]
3
2
1
0
-1
-2
-2
-1
0
1
2

Star Formation Rate of the Universe?

Assumes a Salpeter IMF that is constant in time!



Bouwens and Illingworth (2006) astro-ph/051069

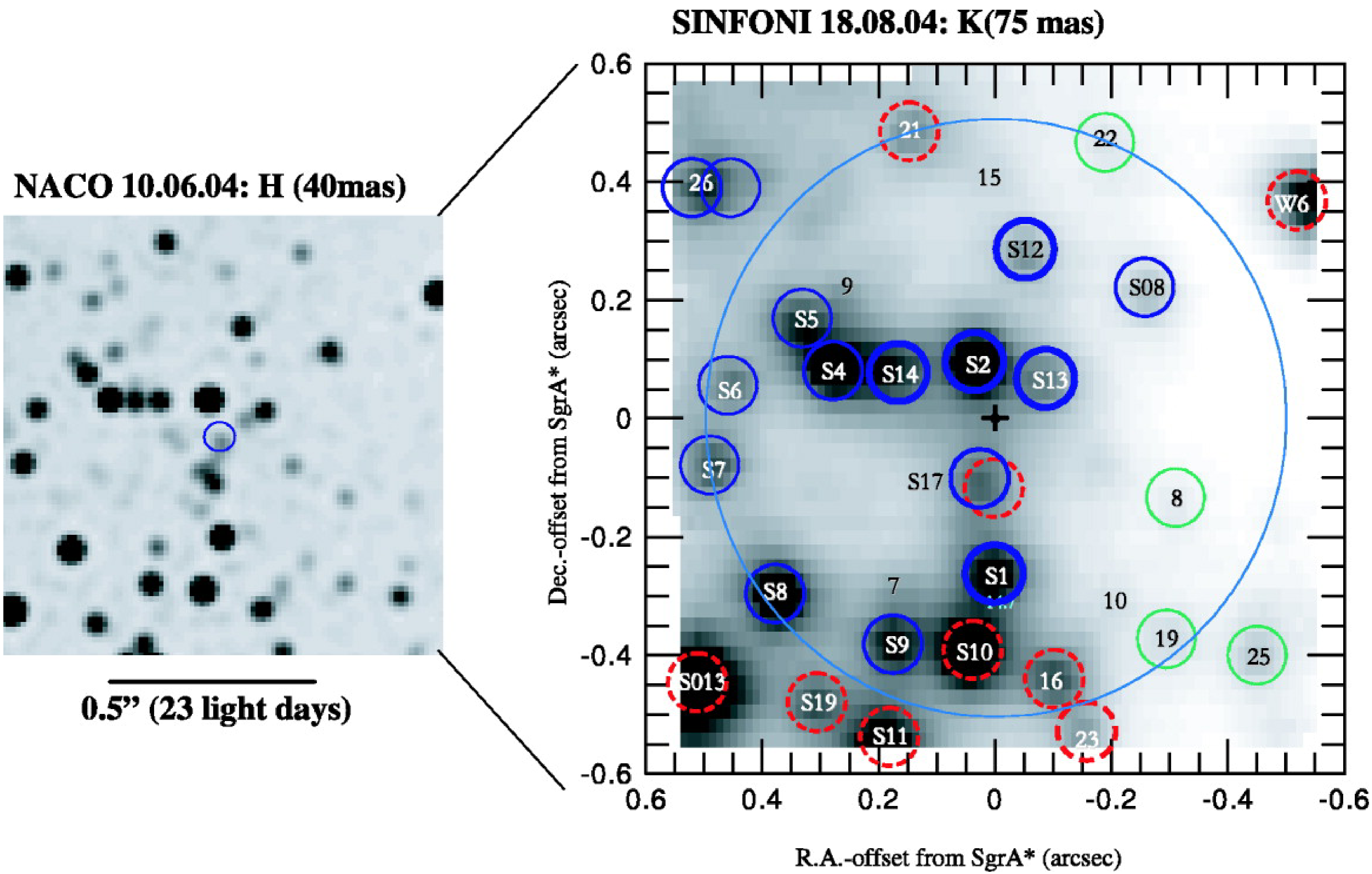
Milky Way Cluster Westerlund 1

The Super Star Cluster Westerlund 1
(2.2m MPG/ESO + WFI)

ESO PR Photo 09a/05 (22 March 2005)

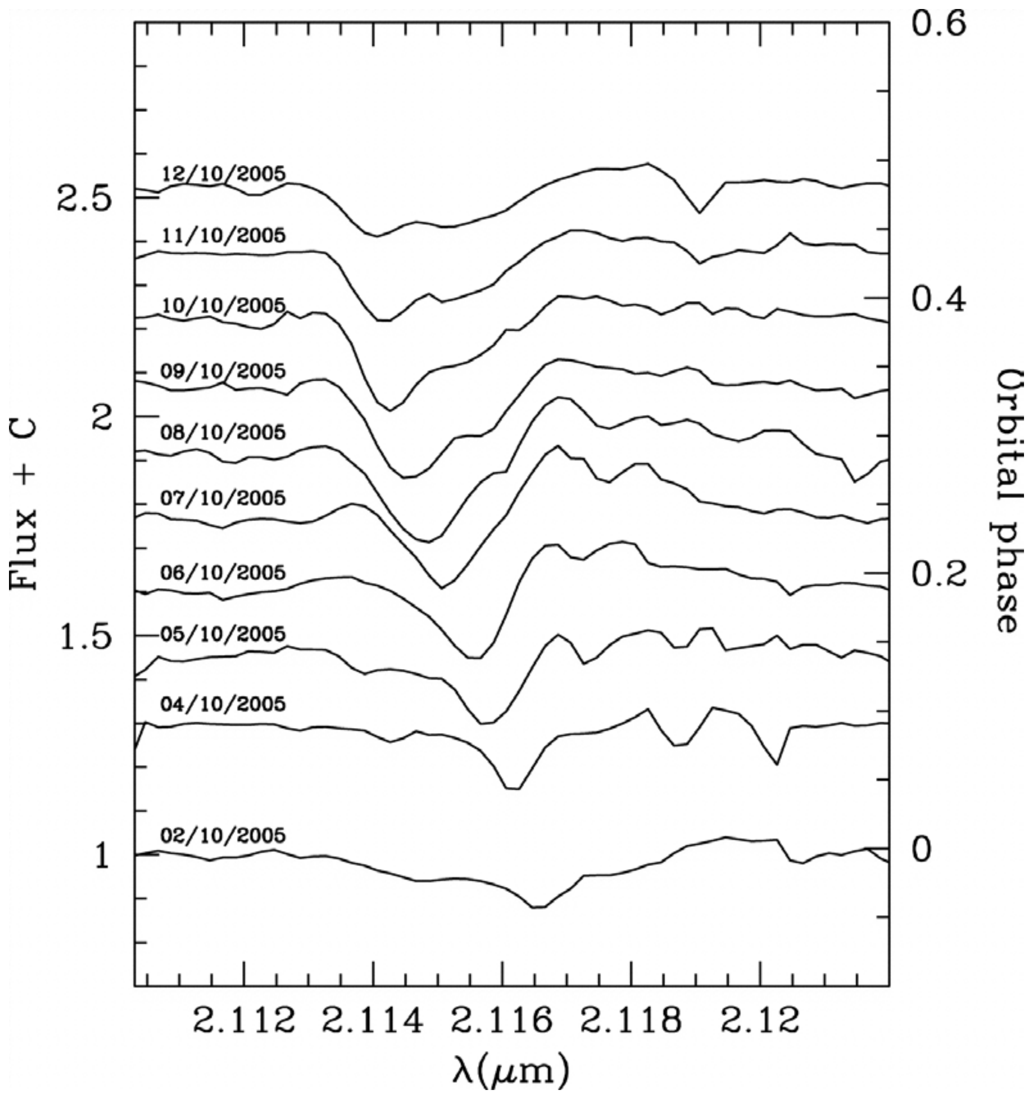
VLT NACO Observations:
Andersen et al. (2006)

IFU Spectra of GC Stars, 75 mas resolution

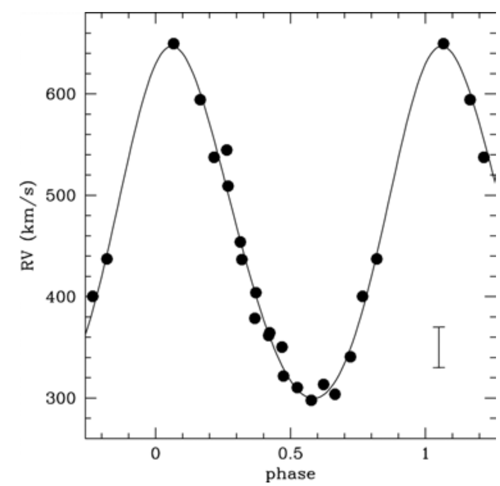


Courtesy Kris Sellgren.

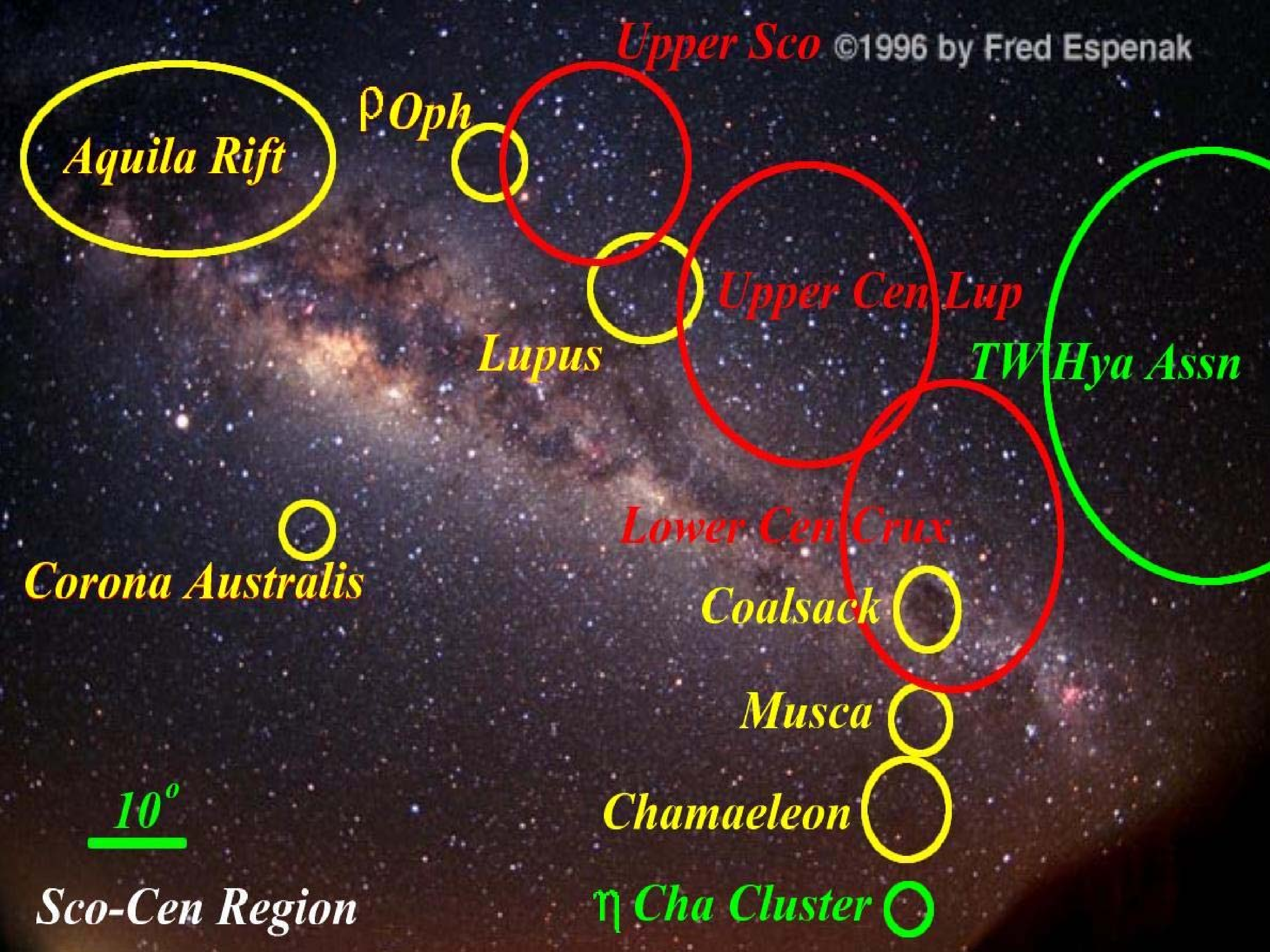
IFU Spectra of Stars With 75 mas resolution



Eclipsing Binary IRS 16SW in the Galactic Center: radial velocity curve from He I line

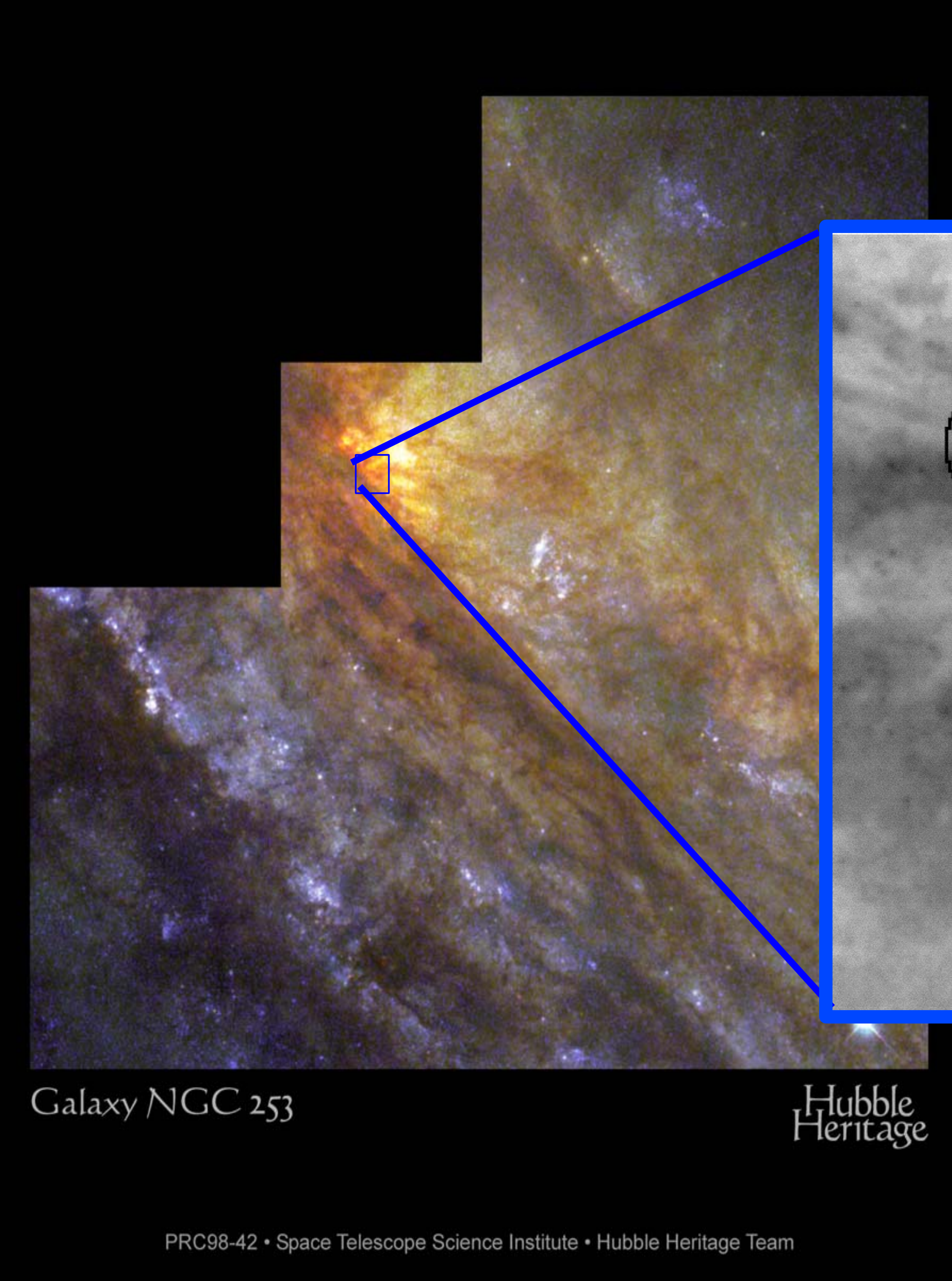


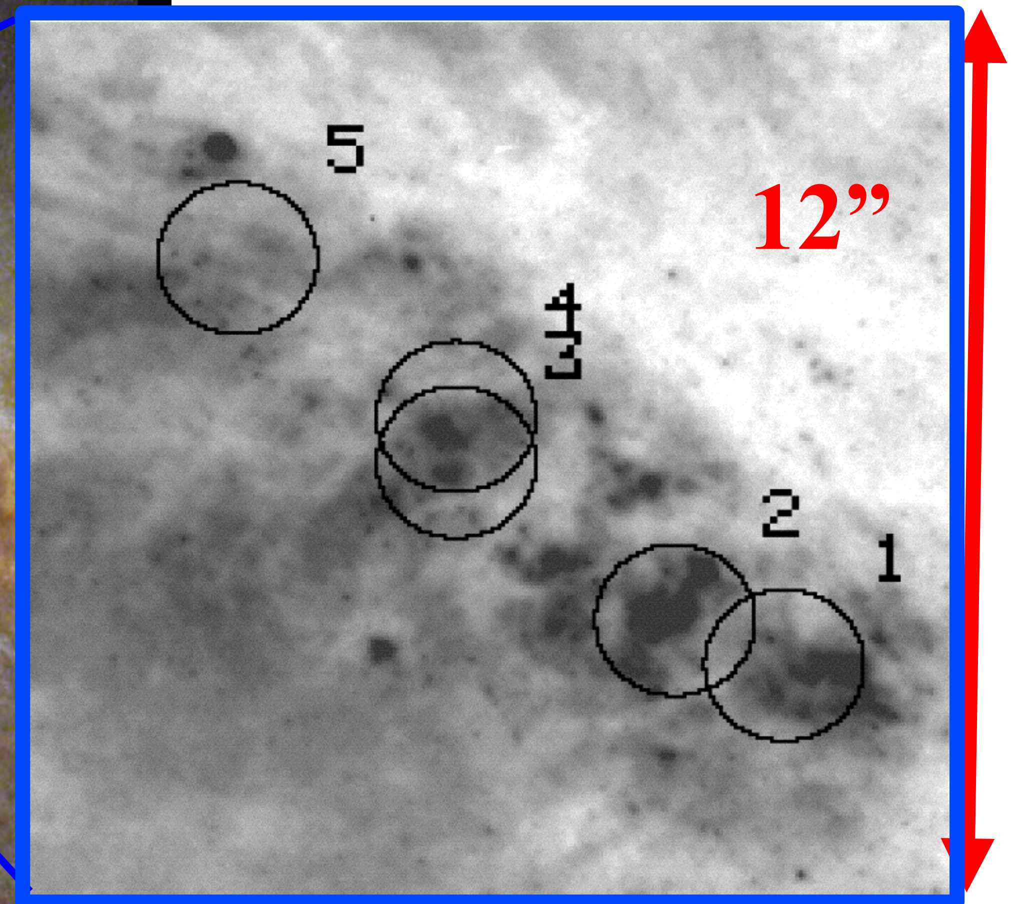
Courtesy Kris Sellgren.


Upper Sco
©1996 by Fred Espenak
Aquila Rift
ρ Oph
Upper Cen Lup
Lupus
TW Hya Assn
Lower Cen Crux
Corona Australis
Coalsack
Musca
Chamaeleon
η Cha Cluster
10°
Sco-Cen Region

Extreme Star-Formation in NGC 604 in M 33 at 1 Mpc

gions





Johnson et al. (2001)

Capabilities Needed in the System:

1) *Cross-dispersed echelle spectrographs in NIR at R > 30,000 and mid-IR at R > 50,000 required on 6-10 meter telescopes.*

2) *Multi-object near-IR spectroscopy 2-4 arcminute fields at R.> 2000 required for characterization of young stellar pops (OH fibers with GLAO?). R > 10,000 would provide tremendous break-through in PMS Astrophysics (6-10m).*

3) *Diffraction-limited thermal IR imaging/spectroscopy (0.5-2’) on 6-10m probes the initial conditions with resolution comparable to HST and enables compositional studies of disks where planets form.*

4) *All-sky adaptive optics required for high spatial resolution imaging/spectroscopy of unique objects (6-10m).*

5) *High contrast imaging (> 10^{-7}) for debris disks and planets.*

Capabilities Needed in the System:

6) *Near-IR spectral imagery of star clusters in nearby galaxies over 2-20 arcsecond FOV will enable determination of the IMF down to solar mass stars in regions of extreme star formation (LBT-I).*

7) *MOAO targets of < 1” over 1-2’ fields of view of interest (6-10m).*

8) *Wide-field narrow-band imaging in OIR (2-4 meter).*

9) *Acquisition of OIR photometry of bright sources using 1-2 meter telescopes as well as R > 500 spectra for variable sources crucial.*

10) *Synoptic monitoring programs with 1-2 meters in UBVRIJHK can yield valuable insights into processes of star and planet formation.*

Strategies for Success?

- Community access to OIR facilities is a fundamental principle of the system.
- Public/private partnership can create a whole greater than the sum of the parts (avoid redundancy).
- Universities can provide innovation in instrumention, and training opportunities for students.
- National Centers can provide base capabilities (standard data products of high quality) and portals for community access to rest of system.
- Future investments in programs of scale require flexibility during development, buy-in from entire community, and commitments for life-cycle costs.