Star (and planet) Formation with Spitzer

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and the IRAC team

Smithsonian Astrophysical Observatory

August 25, 2003 – Cape Canaveral

Call for instrument proposals issued in 1983
21 years in the making!
(~ 1/4 of a Red Sox duty cycle)

The Observatory

- 85-cm f/12 Beryllium Telescope, T< 5.5 K
- Diffraction Limit 5.5 μm
- Image size 1.66” FWHM at 3.6 μm
- Observatory is 4m tall, mass ~ 865 kg
- Instrumental Capabilities
  - Imaging, 3.6-160 μm
  - Spectroscopy, 5.3-40 μm
- Background Limited 3 – 180 μm
- Field of view 5’ x 5’ (imaging)
- Pointing stability <0.1”
- Pointing accuracy <1.0”
- Solar System Tracking, linear, ≤ 1 ”/s
- Heliocentric Earth-Trailing Orbit
- Launched warm, cooled down **on orbit**
- **>75% of observing time for General Observers: GO-3 proposals due in February 2006**

The Spitzer Legacy Program

- c2d (Evans et al.)

400 hours: Imaging surveys of nearby clouds, spectroscopy of young embedded stars

The evolution of molecular cores into protostars and disks, incidence and evolution of sub-stellar objects, and the spatial structure of groups and clusters

- FEPS (Meyer et al.)

300 hours: Imaging and spectroscopy of hundreds of young stars

Evolution of disks from stellar accretion through planetary debris

- GLIMPSE (Churchwell et al.)

400 hours: 240 sq. degree IRAC survey of inner Galactic plane

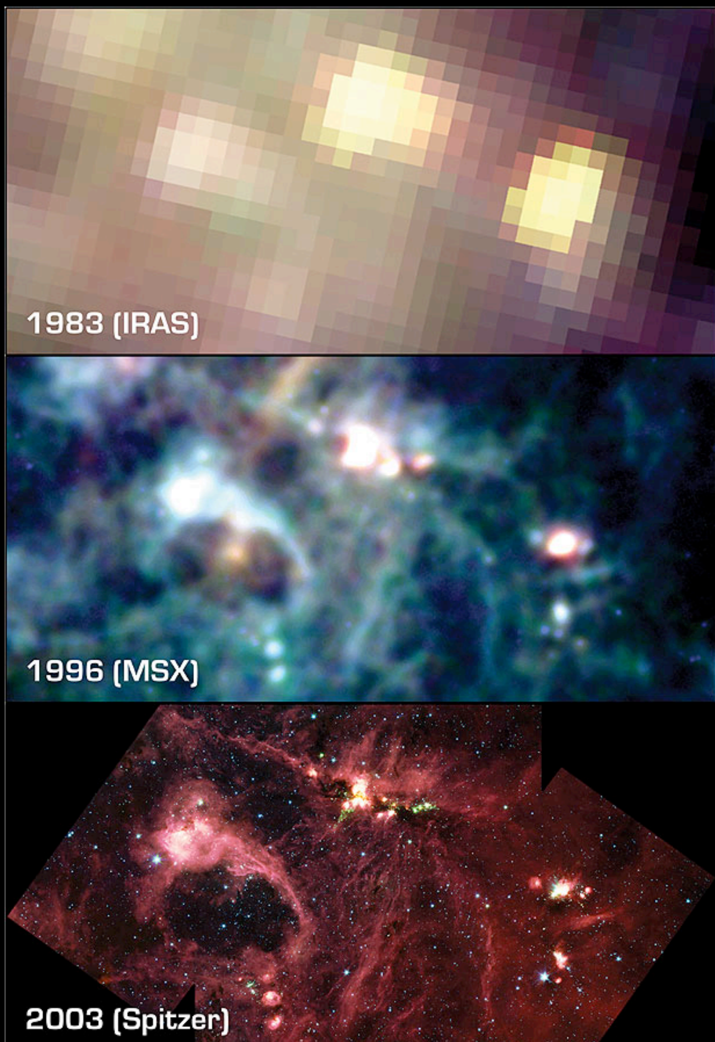
Structure of the inner Galaxy

Instrumentation

- The Infrared Array Camera (IRAC)
  - G.G. Fazio, SAO, Principal Investigator
  - Wide-field (5′x 5′) imaging with *256x256 InSb and Si:As IBC arrays,*
  - Simultaneous at **3.6, 4.5, 5.8, 8.0 μm**
  - *high dynamic range mode.*
  - *32x32 pixel sub-array mode.*
- The Infrared Spectrograph (IRS)
  - J.R. Houck, Cornell, Principal Investigator
  - Staring and spectral mapping modes
  - **R=600**, **10-20** and **20-40 μm**
  - **R=50**, **5-15** and **15-40 μm**
  - Imaging/Photometry 15 μm
  - *128x128 Si:As and Si:Sb IBC arrays*
- Multi-band Imaging Photometer for Spitzer (MIPS)
  - G. Rieke, Arizona, PI.
  - Small-area photometry, and scan maps for large area surveys: **24, 70, 160** μm
  - R~20 SED, 50-95 μm
  - Total power, extended emission
  - *128x128 and 32x32 Si:As IBC and Ge:Ga arrays*
  - *2x20 stressed Ge:Ga array*

Spitzer offers improved resolution and sensitivity

DR21 in Cygnus

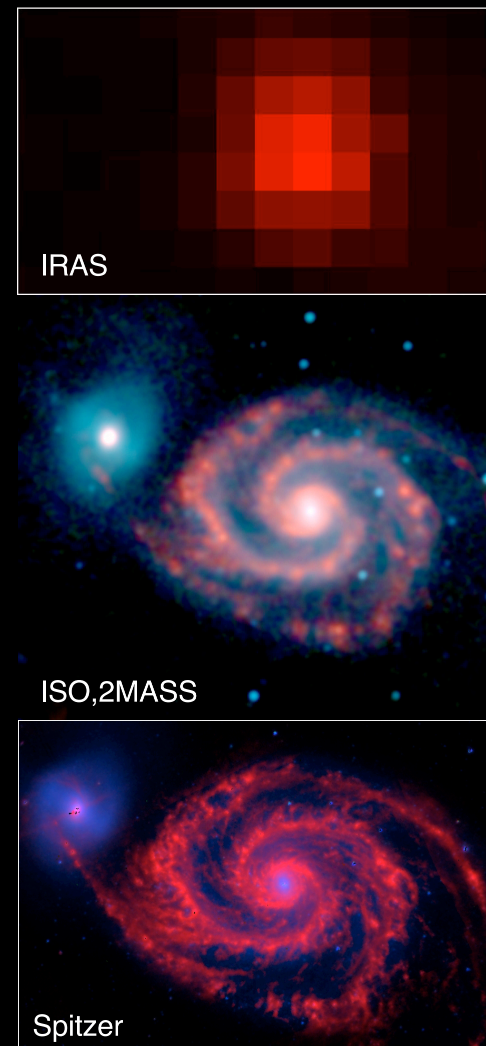


IRAS Satellite
1982-3

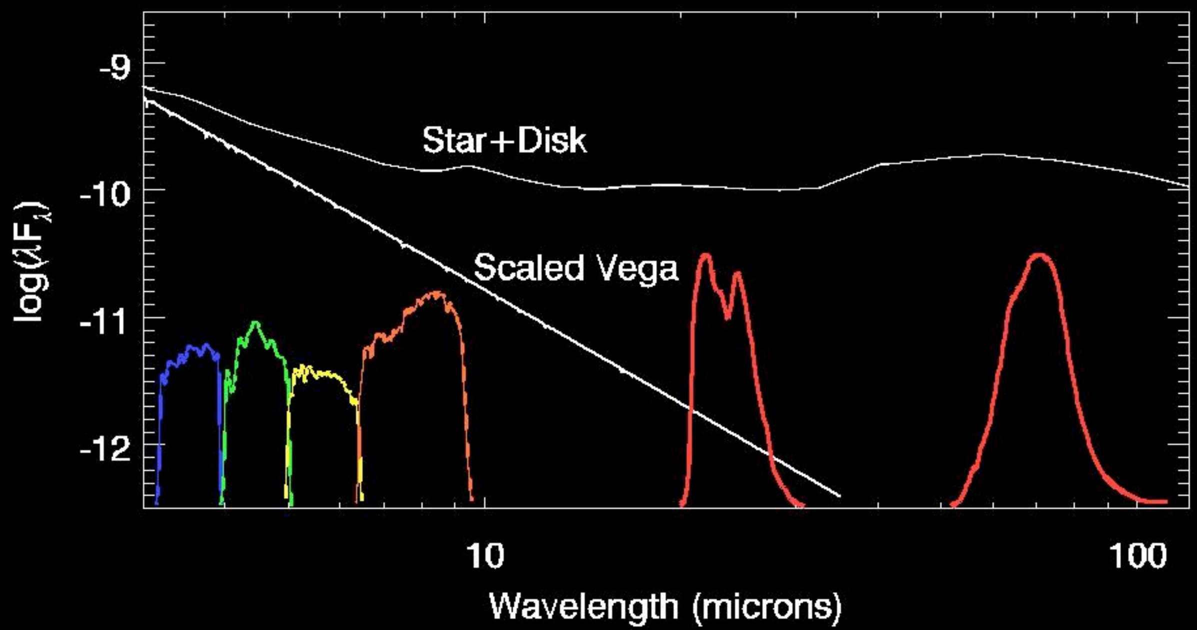
MSX/ISO Satellites
1996-9

Spitzer Space Telescope
2003- (2008?)

Messier 51

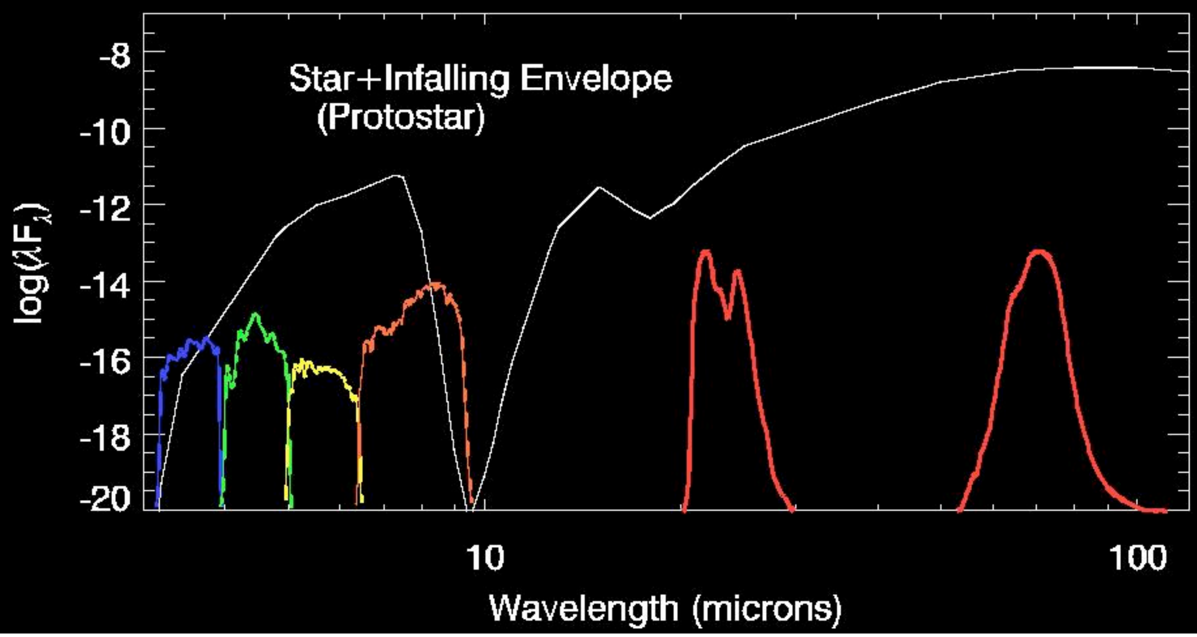


Spitzer colors of young stars and protostars



Disk models (Class II)

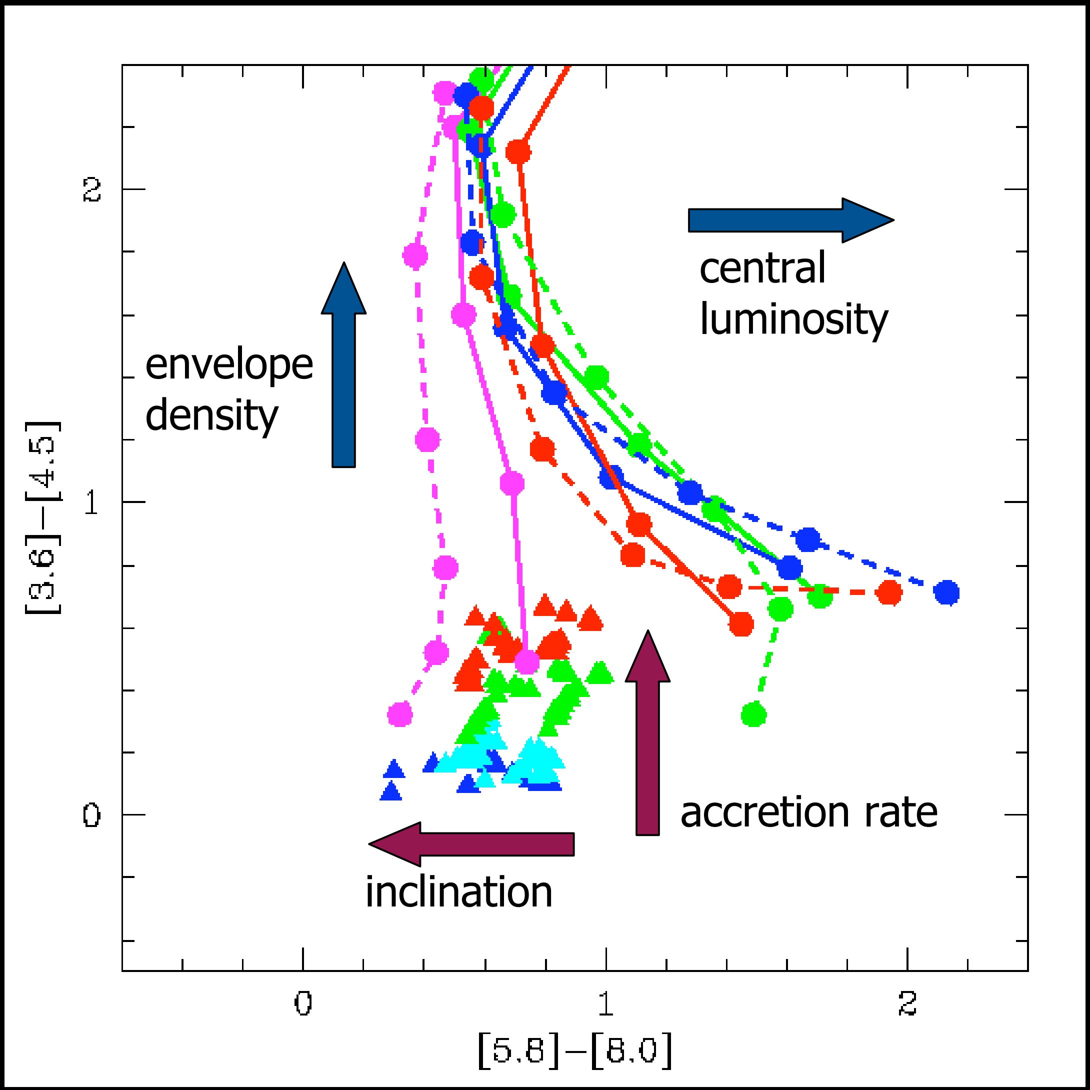
D'Alessio 2004



Disk + protostellar Envelope models (Class I)

Calvet 2004

Model IRAC colors



Allen et al. 2004 ApJS 154

Disk + envelope models "Class I" (Calvet 2004)

L = 0.1 - 100 Lsun

log ρ = -14 -- -12.5 g/cm^3

Rc = 50, 300 AU

Disk models "Class II" (D'Alessio 2004)

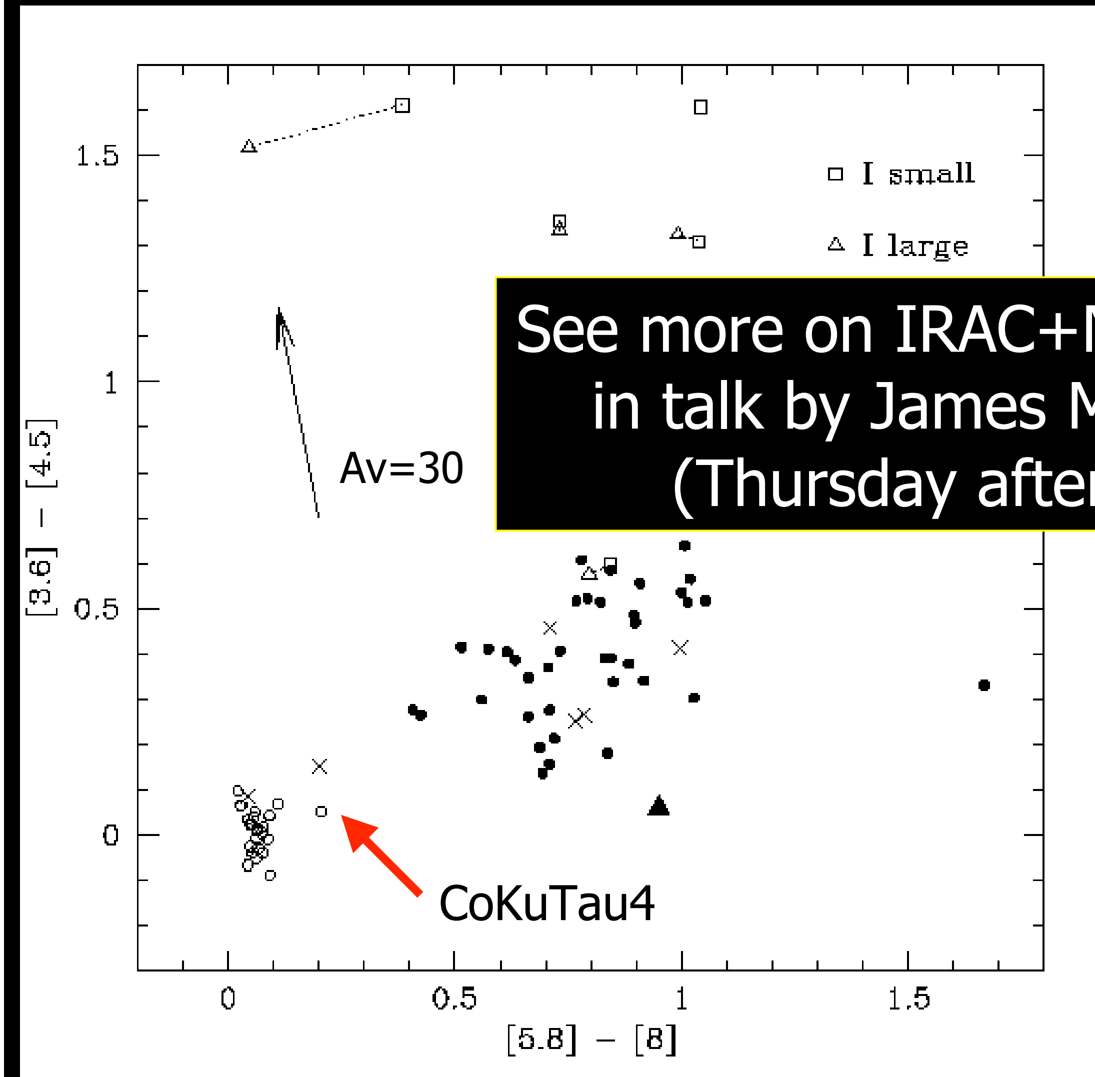
T_{eff} = 4000 K, t = 1 Myr

log (dM/dt) = -9 -- -6 Msun/yr

i = 30, 60 deg

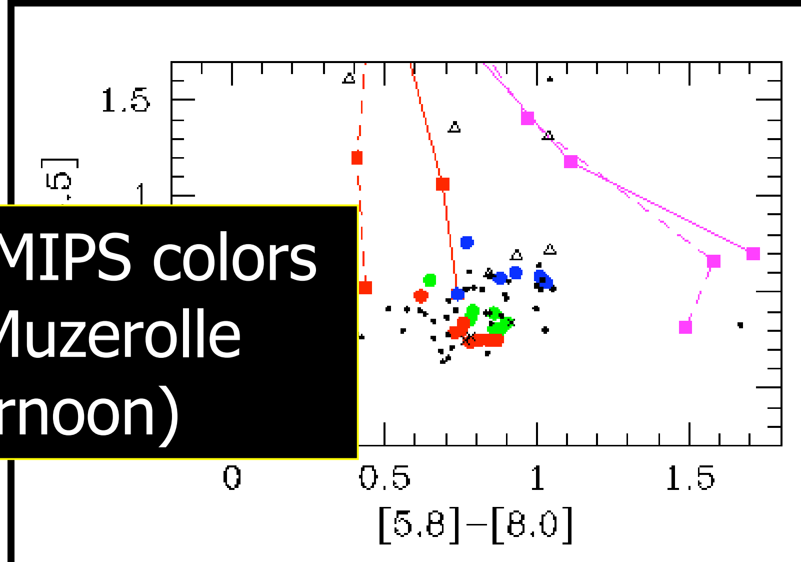
grain size distribution, disk radius, wall at disk inner rim

Young stars and protostars in Taurus



Hartmann et al. 2004

See more on IRAC+MIPS colors in talk by James Muzerolle (Thursday afternoon)

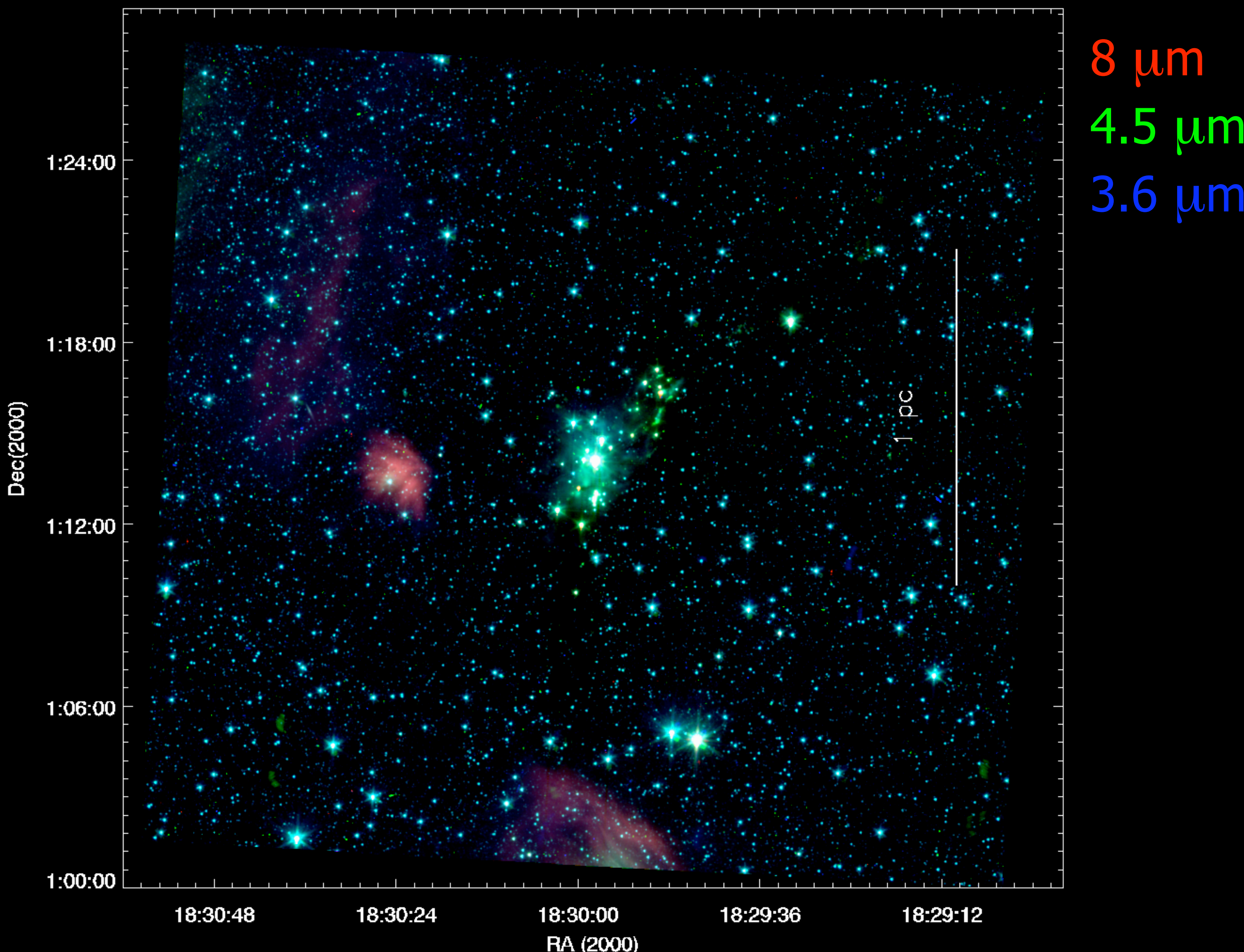


log (dm/dt) = -9, -8, -7 Msun/yr

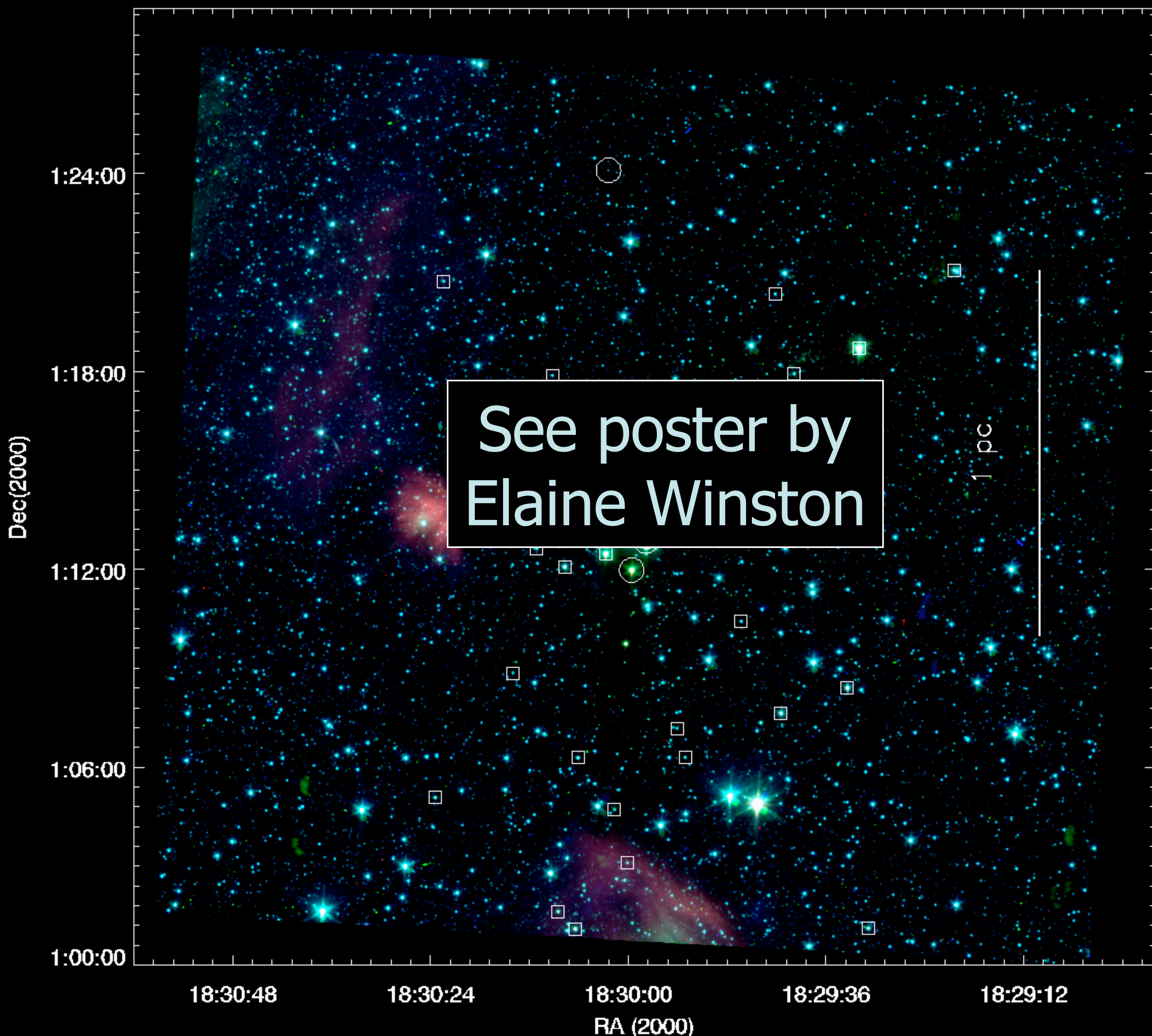
Class II sources have well-defined locus. Class I show more dispersion.

Mapping the distributions of young stars and protostars

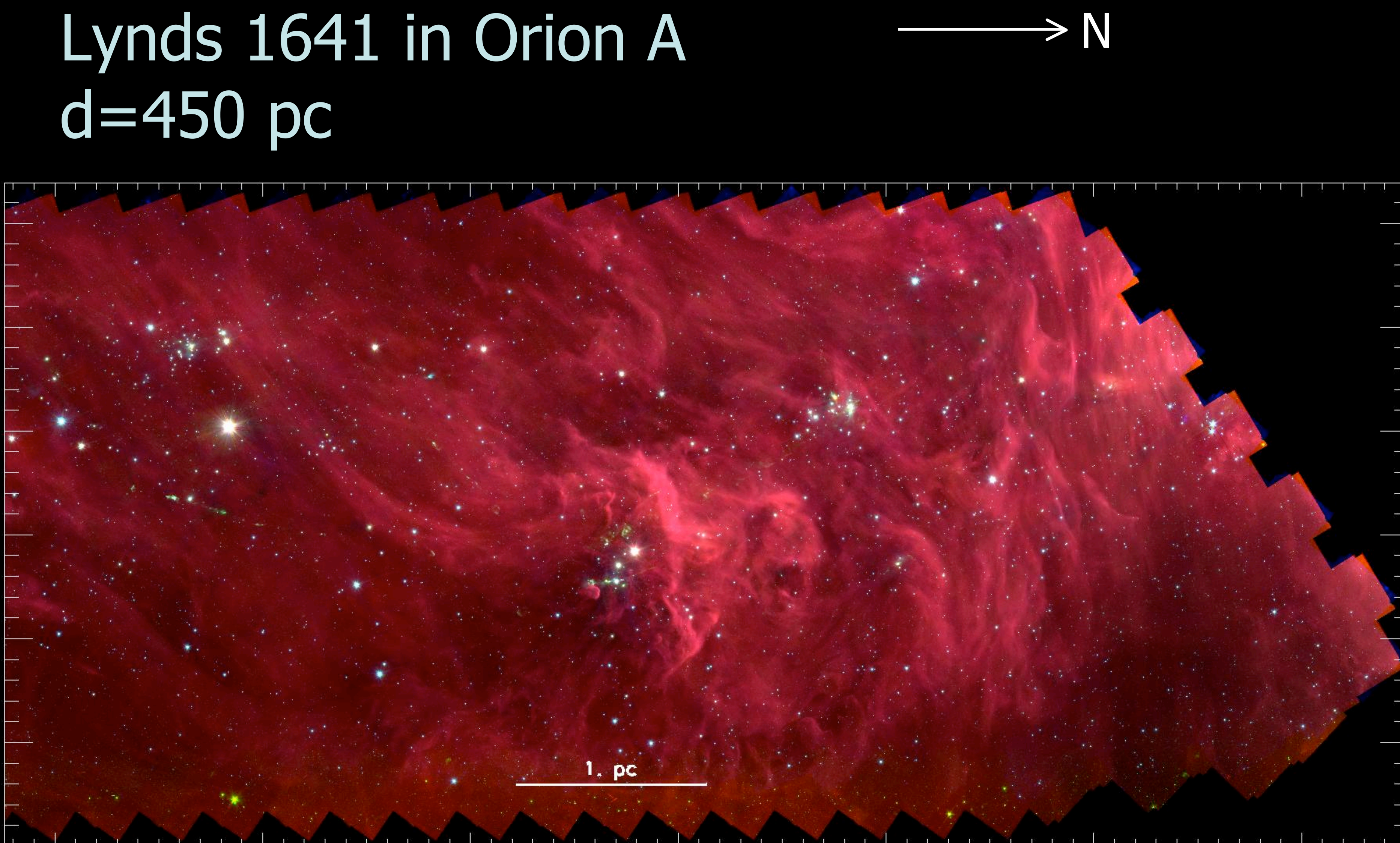
Serpens d=300 pc



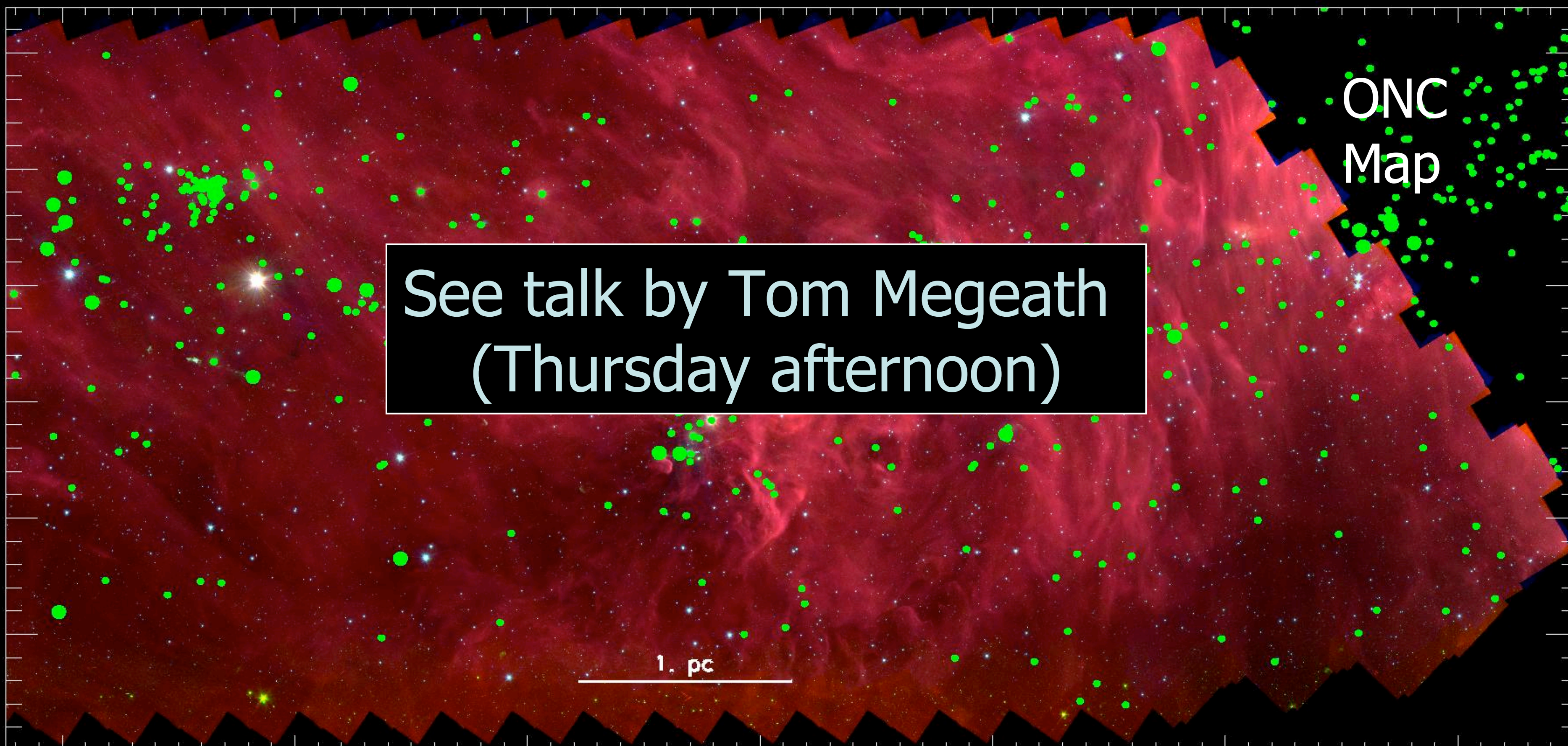
circles=protostars, squares = stars with disks

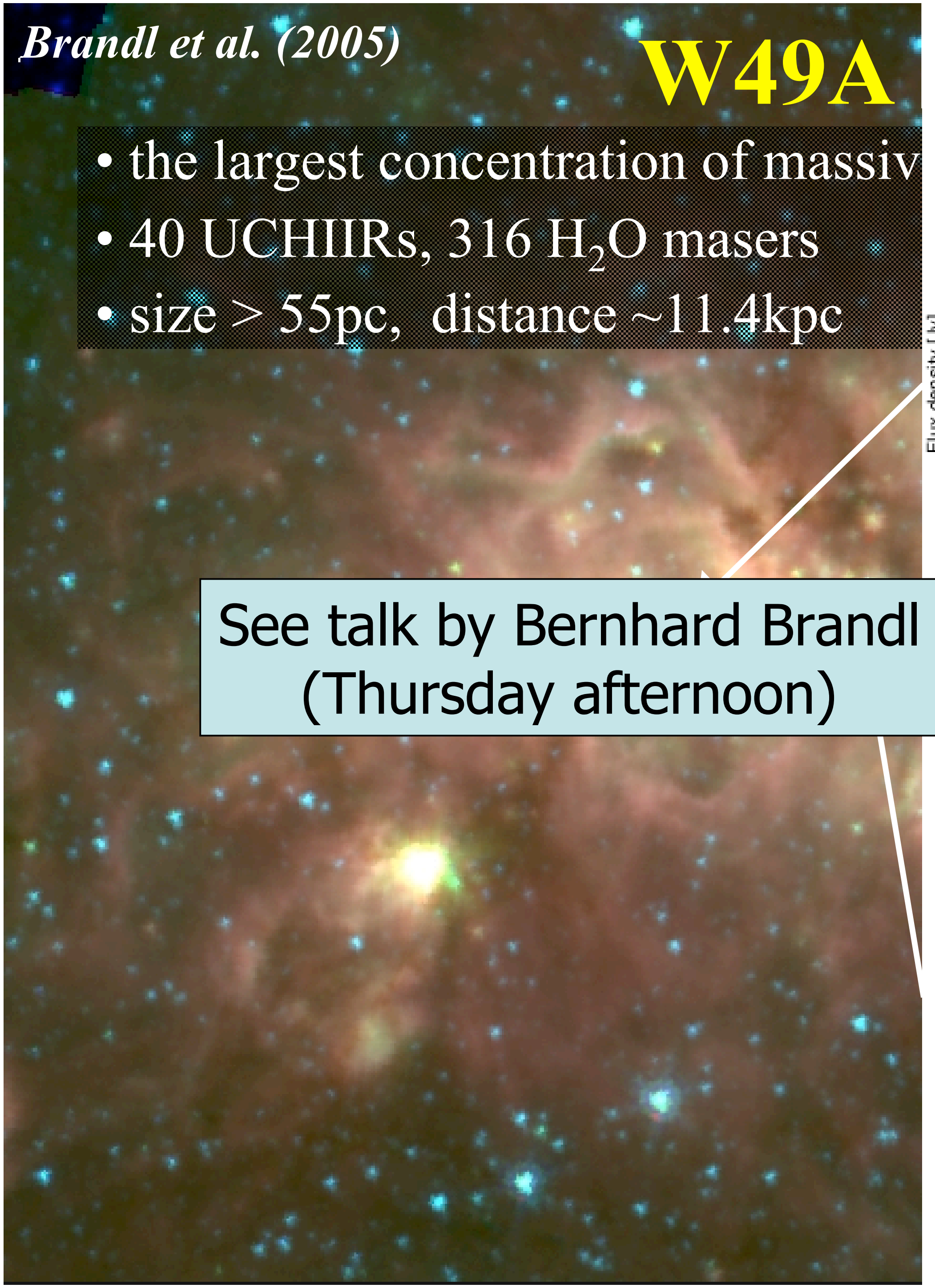


Lynds 1641 in Orion A
d=450 pc

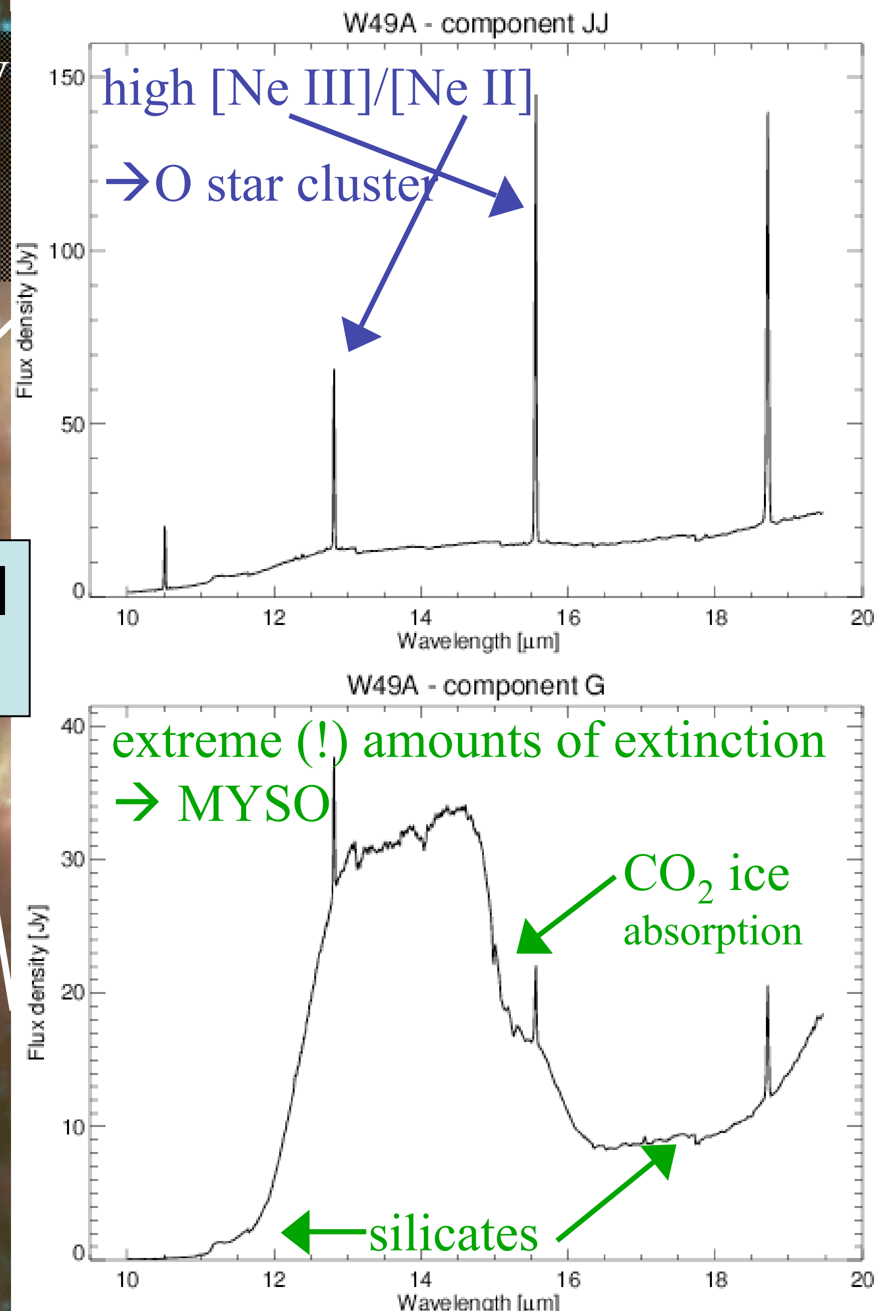


Small Green Circles: IR-ex source, Big Circles: Protostars

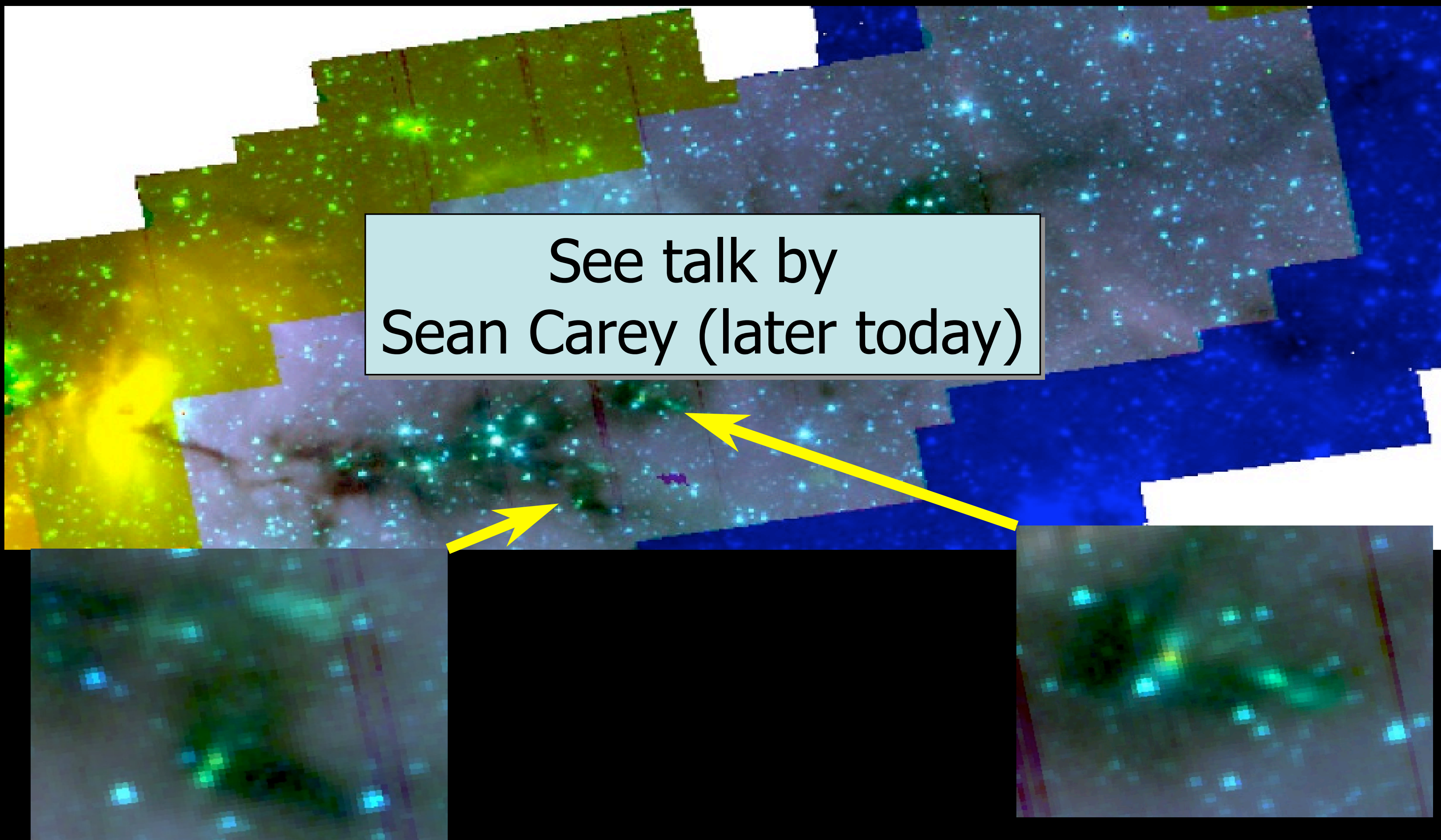




Spitzer-IRS low-res.

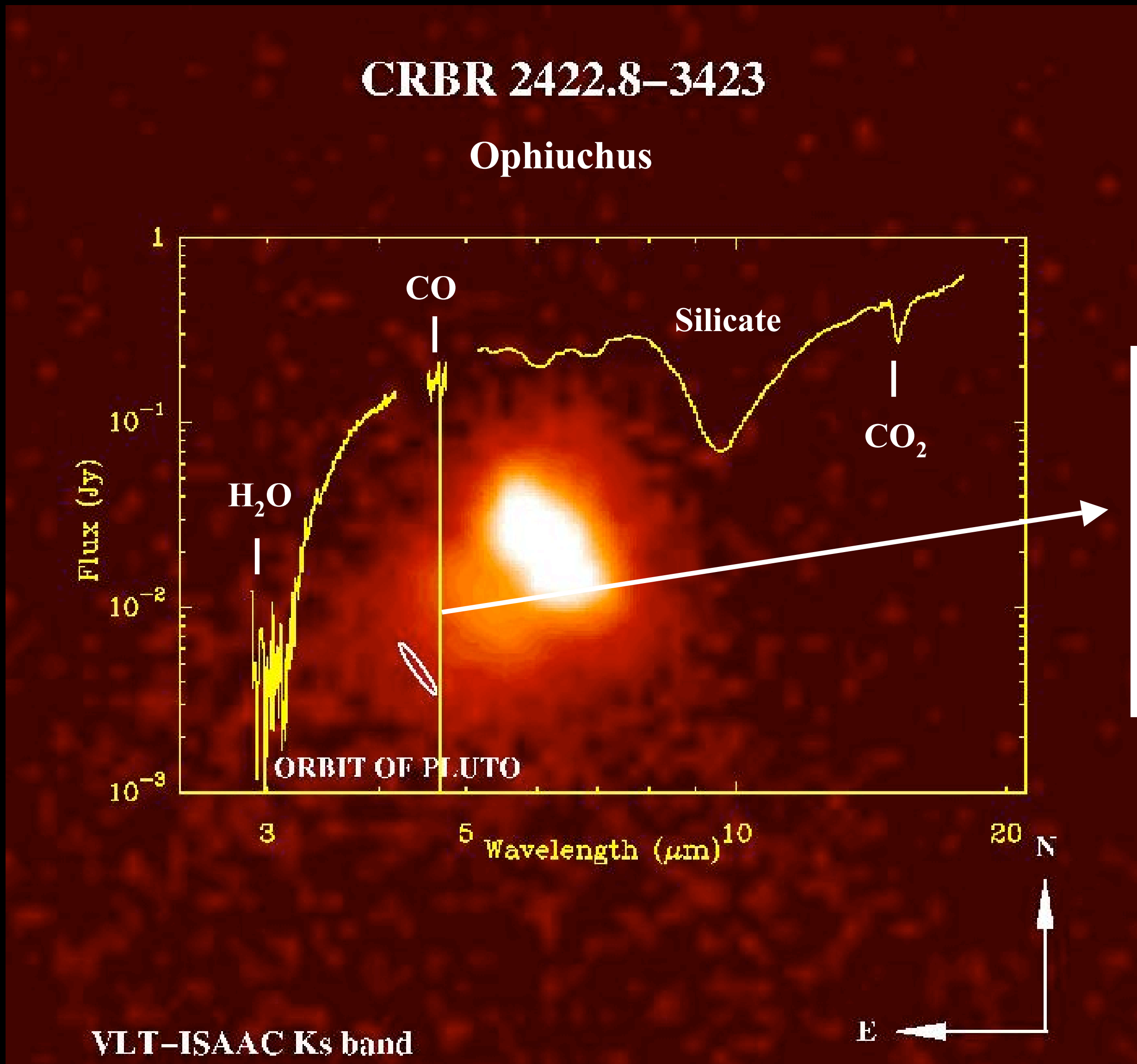


Protoclusters in IRDC G79.3

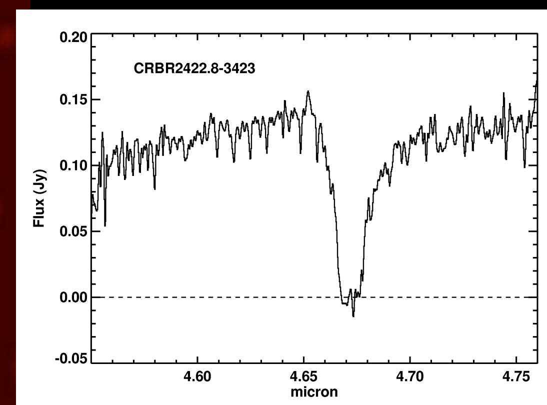


Disk Evolution

Edge-on disk around embedded protostar



Very strong solid CO absorption



CO_{solid}/CO_{gas}~1

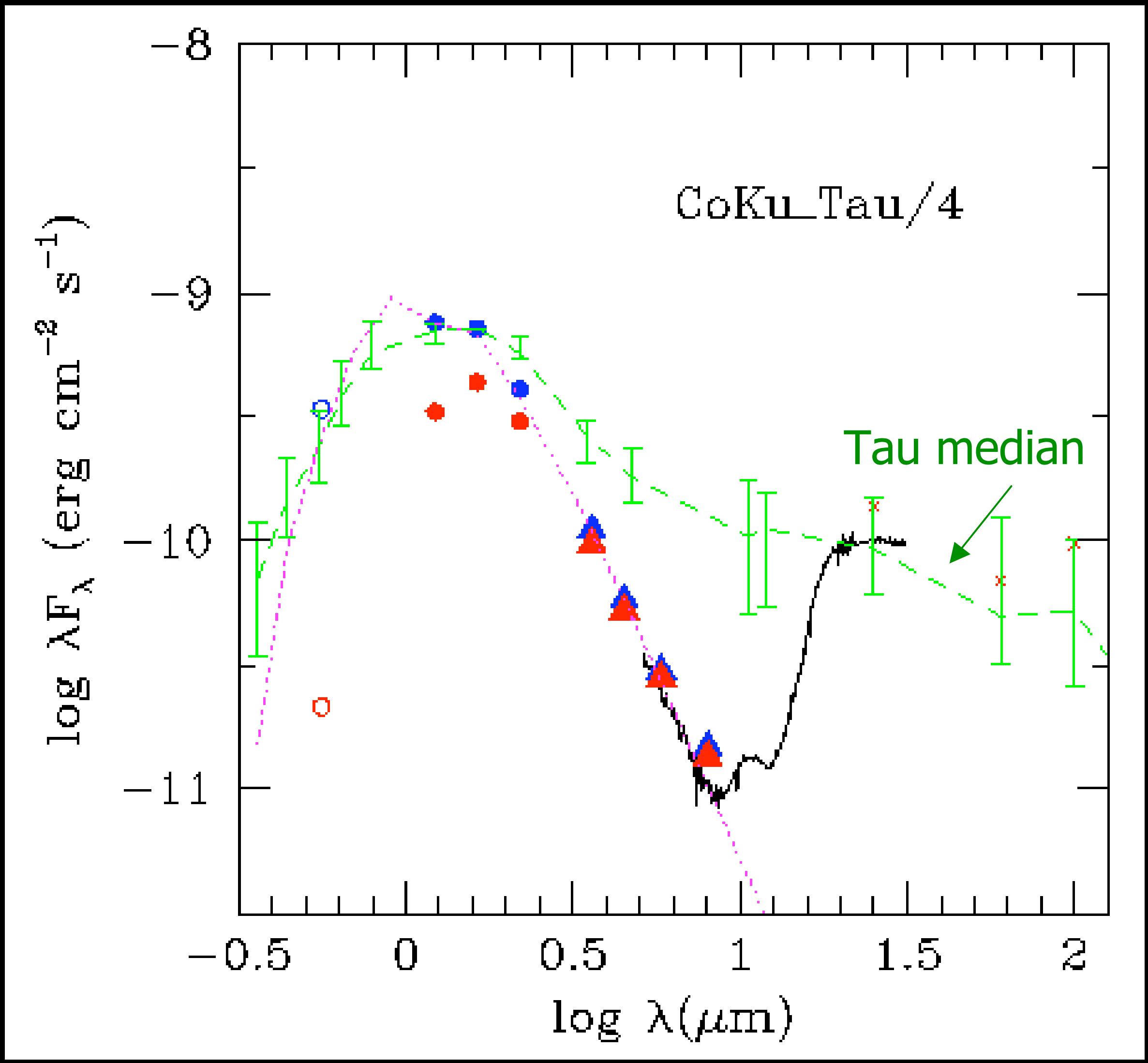
$T_{ex}(CO)$~50 K

Thi et al. 2002

Pontoppidan et al. 2004

- **Detailed modeling of disk + surroundings indicates that up to 50% of ice absorptions arise in disk**
- **Ices in disk heated to >40 K**

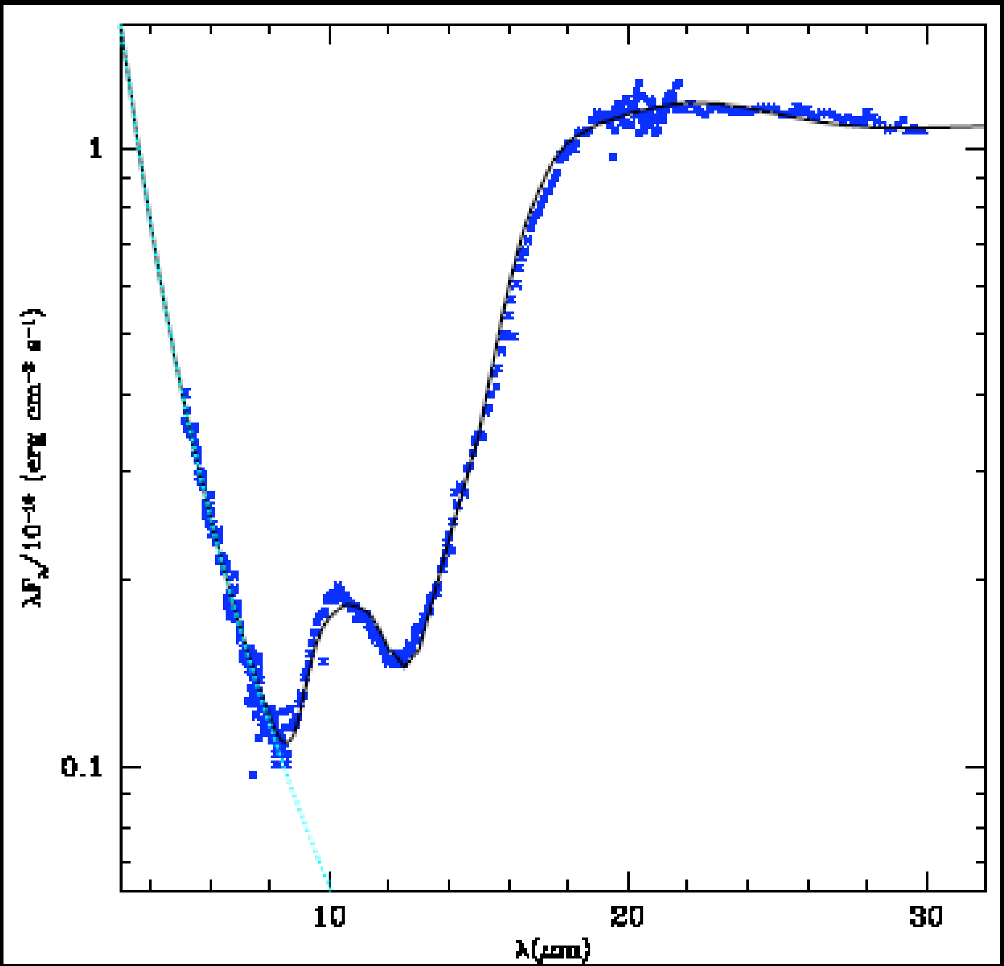
CoKu Tau 4: Giant-planet formation before 1 Myr?



SED is roughly photospheric through 8 μm, then rises, exhibiting large excess at λ > 10 μm

Forrest et al. 2004 ApJS 154

Giant-planet formation before 1 Myr ?



(d'Alessio et al. 2005)

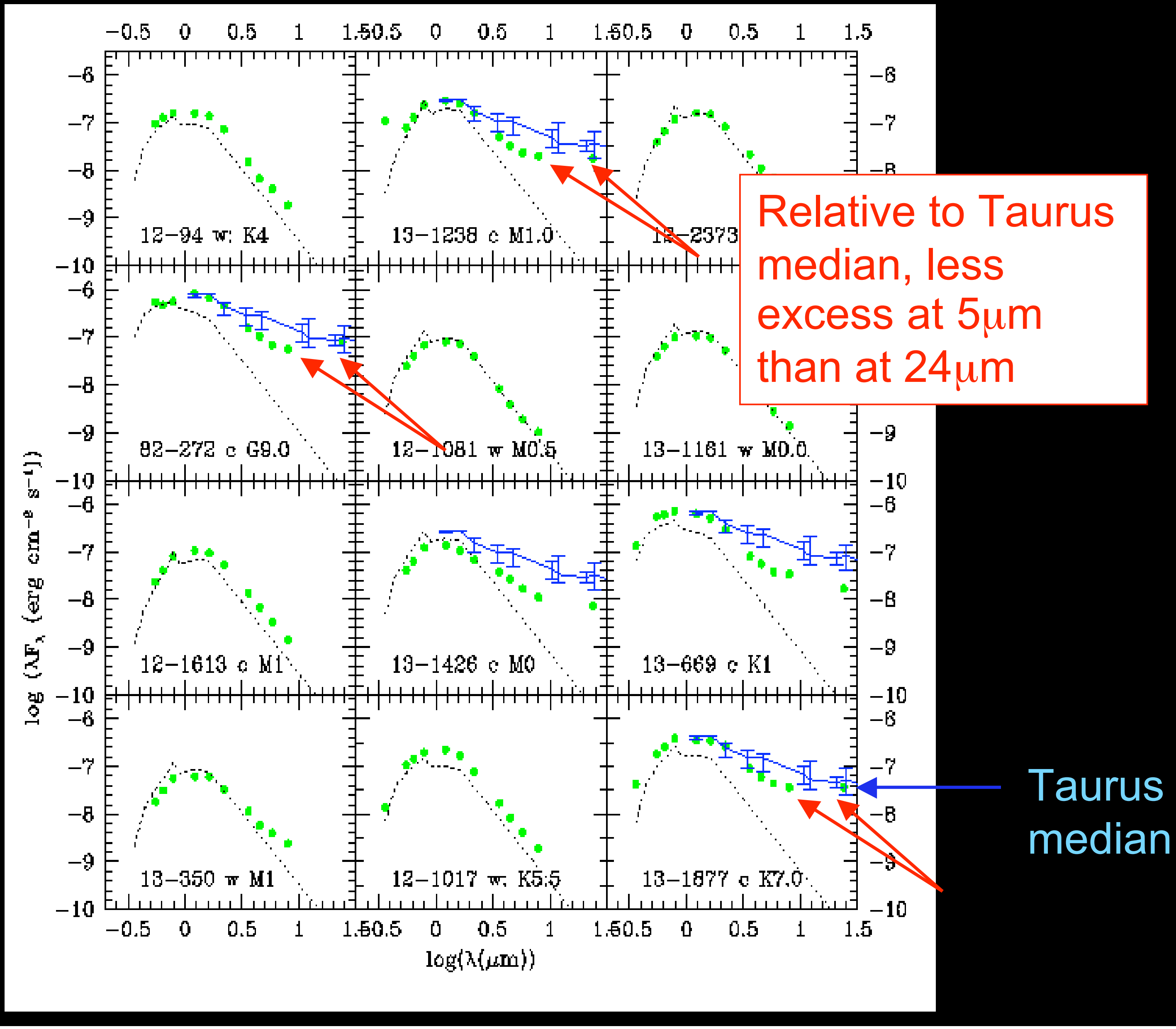
Model fit to the spectrum of CoKu Tau/4:

- inner edge ("wall") of the disk lies 10 AU from the star, and is 4 AU high (in uv/vis optical depth).
- Less than 0.007 lunar masses of small dust left inside (compared to about 250 in a normal disk).
- Outer disk optically thick.
- Can't do this with radiative processes.
- Easy to do with a companion, at least as massive as Neptune, according to dynamical simulations (Quillen *et al*. 2004).
- There is no stellar companion.

Rapid giant-planet formation ?

Disk evolution in 3 Myr old cluster (Tr 37)

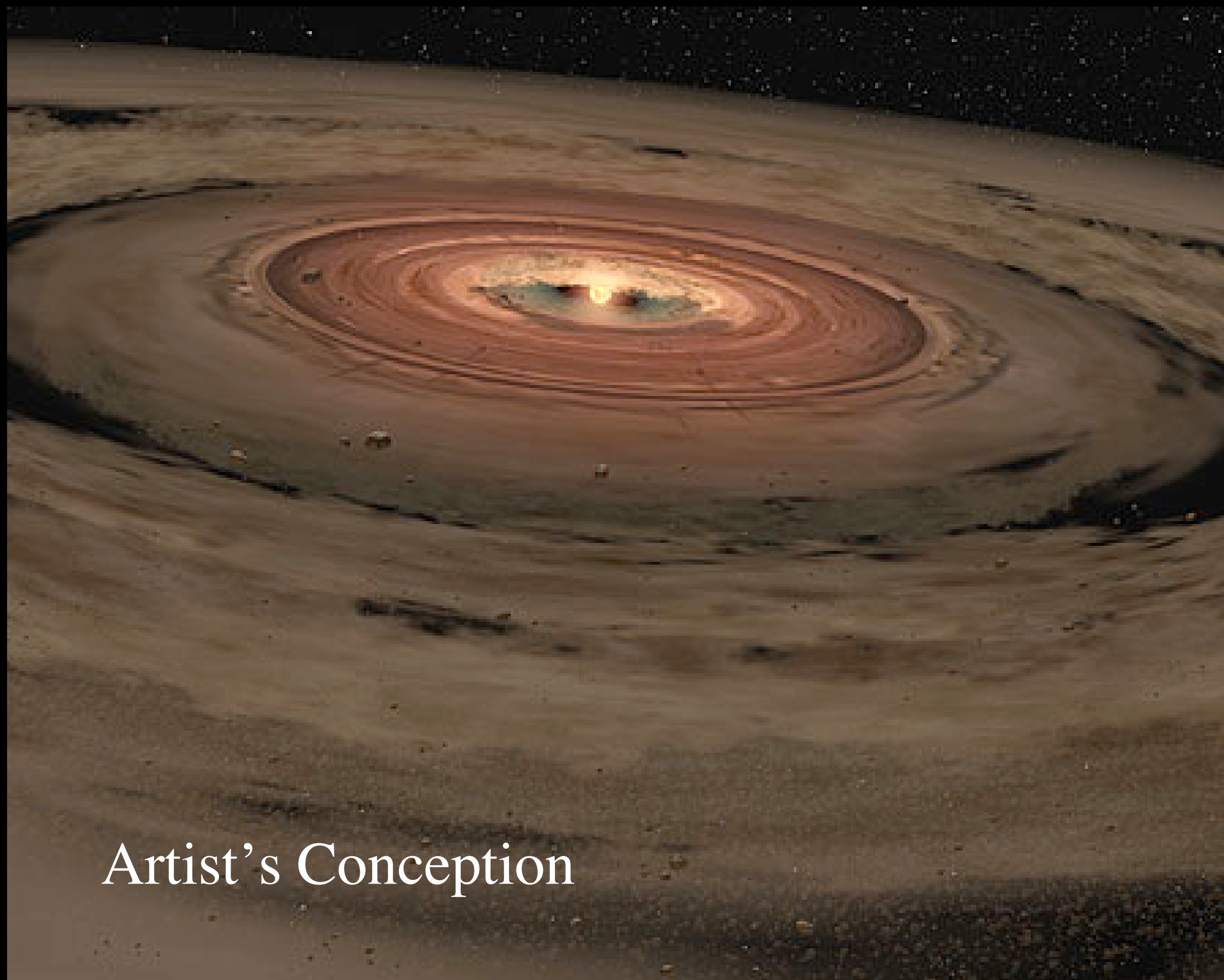
Sicilia-Aguilar et al. 2004, 2005



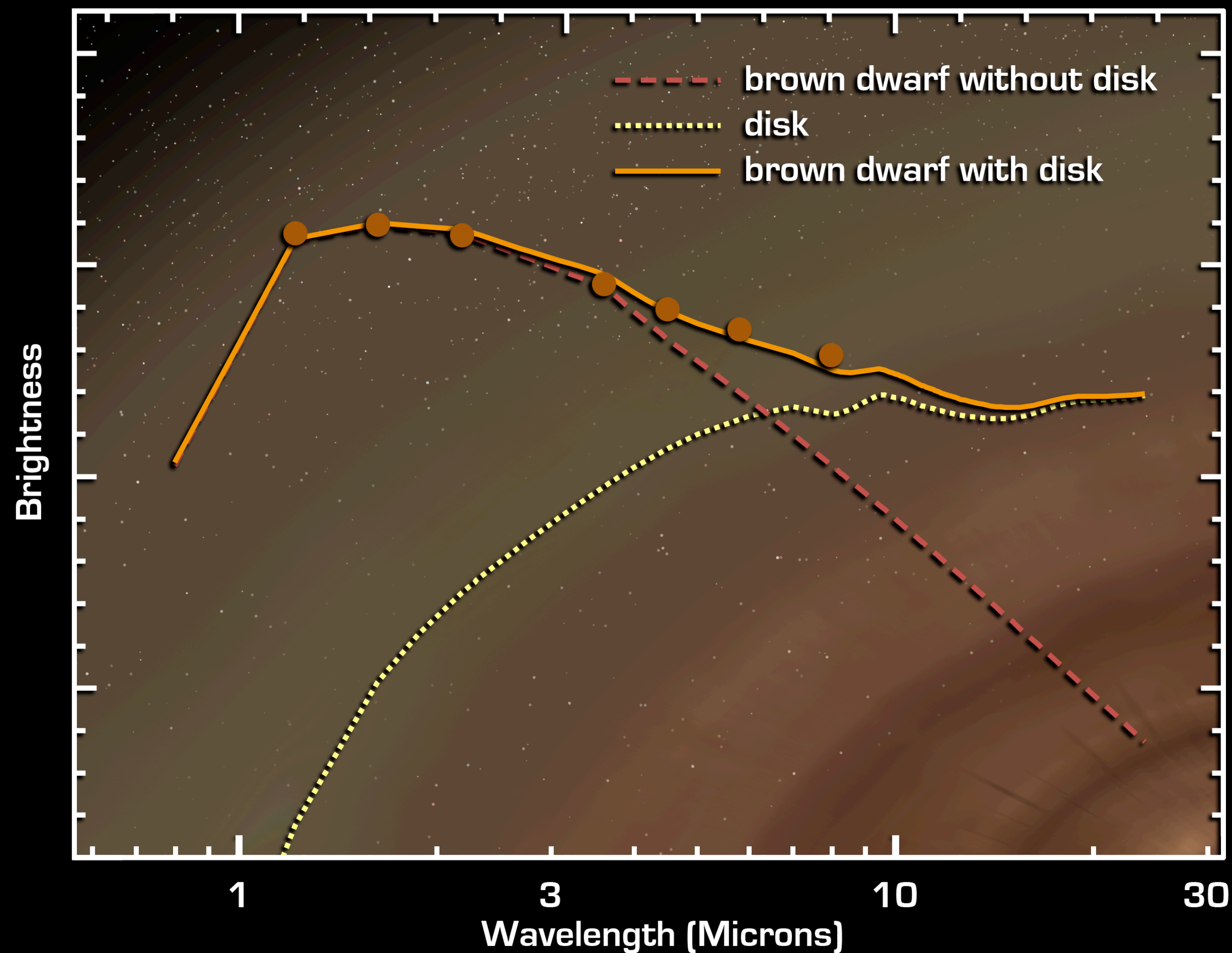
Brown dwarfs
and
hot Jupiters

OTS 44: young brown dwarf with a disk

- 15 times the mass of Jupiter
- 0.015 times the mass of our sun



Disks Around Brown Dwarfs

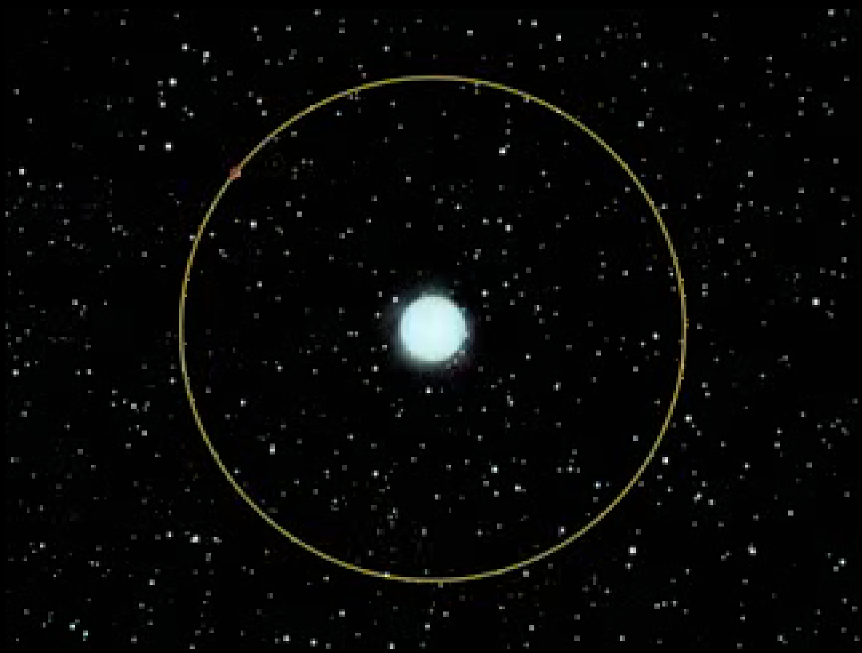


At 15 M_{JUP}, OTS 44 is the least massive object known to have a disk.

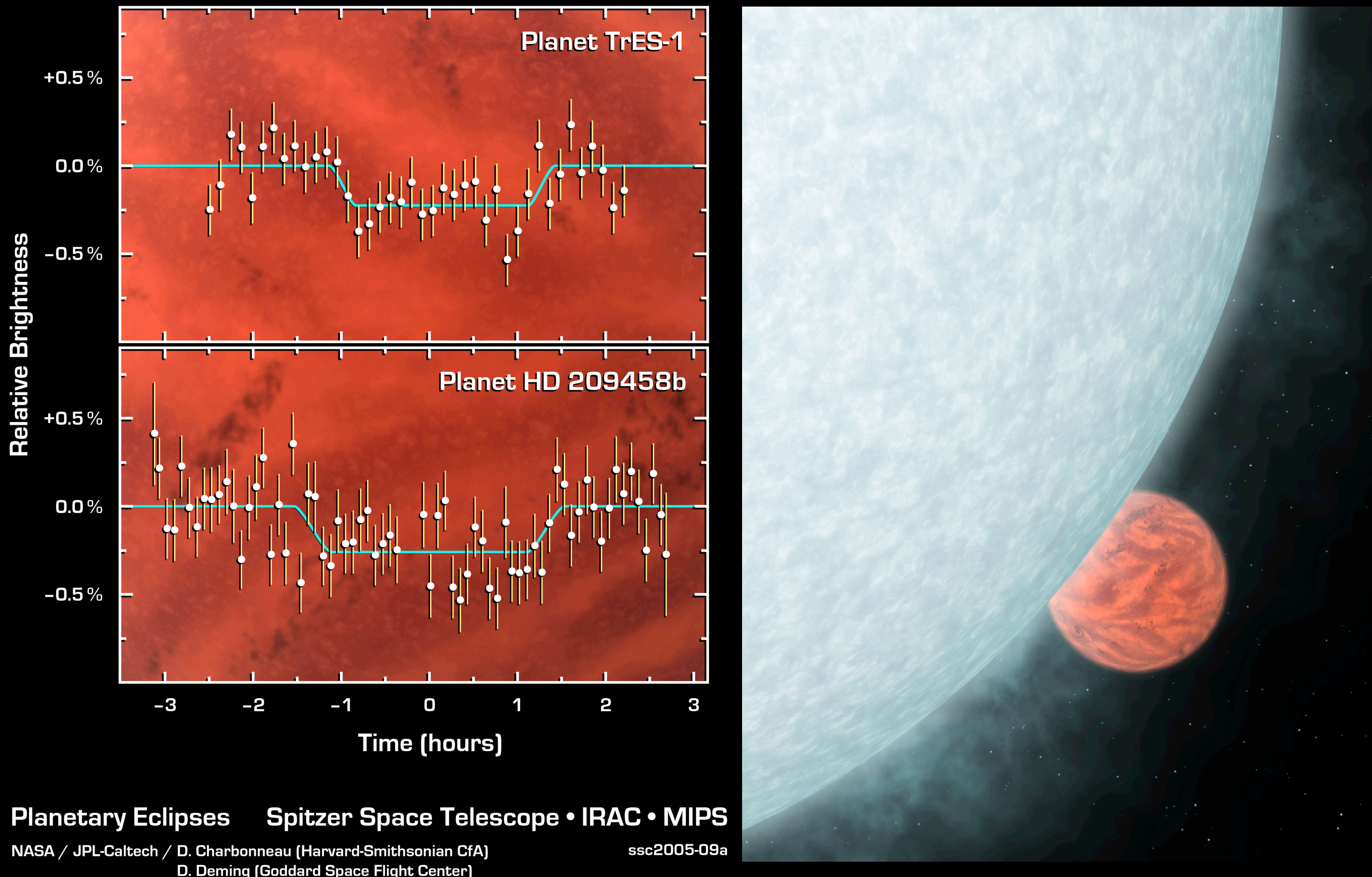
Brown Dwarf With Protoplanetary Disk **Spitzer Space Telescope • IRAC**

NASA / JPL-Caltech / K. Luhman (Harvard-Smithsonian CfA) ssc2005-06a

Could Spitzer detect an extrasolar PLANET ?



Spitzer observations of extrasolar PLANETS



More Spitzer results

Today:

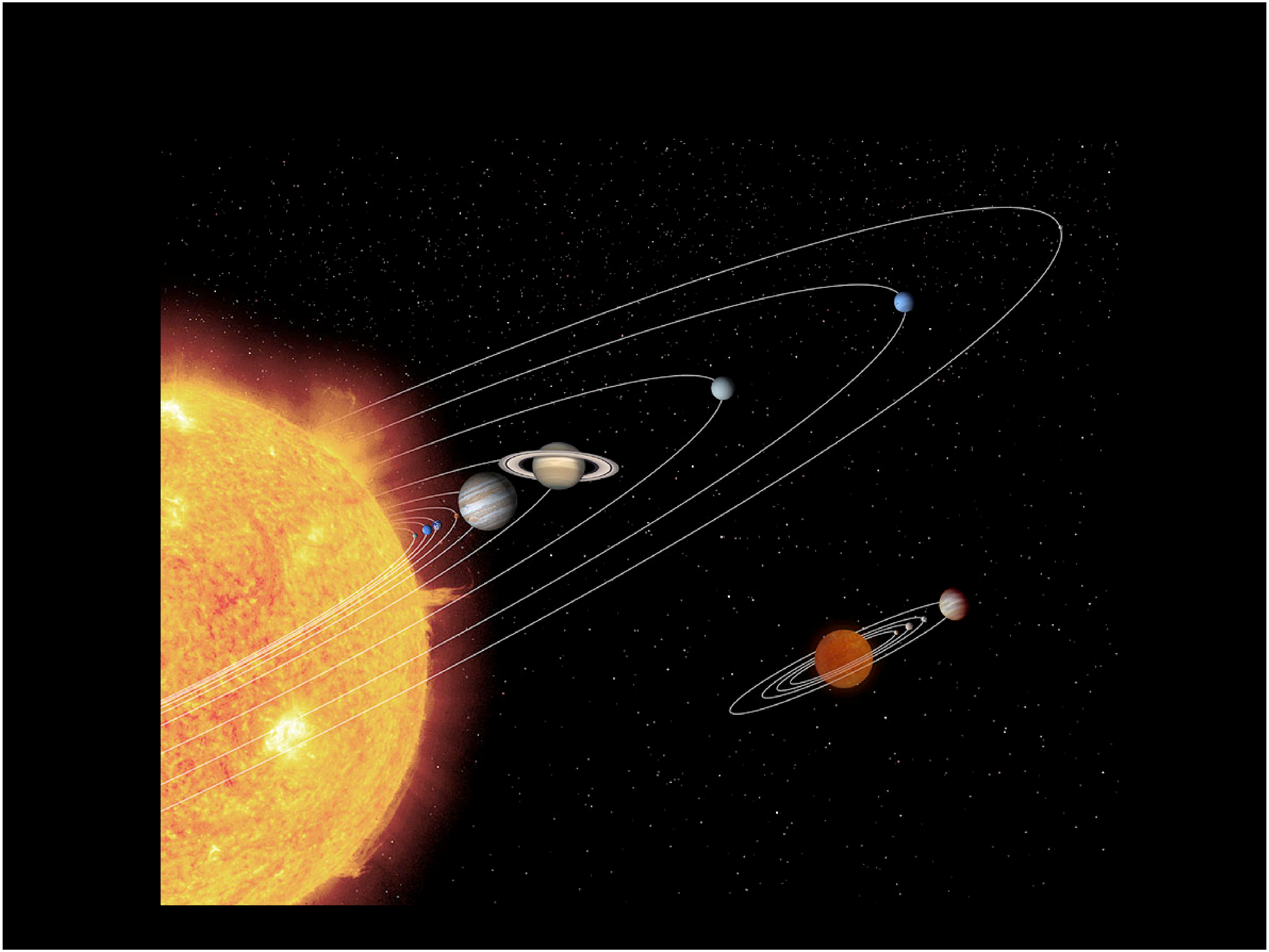
Waller - multi-λ diagnostics of starbirth in starbursts
Rho - Star formation in the Trifid nebula
Bourke - Proto-brown dwarf in L1014 molecular core
Young - Star-forming core in NGC2264

Thursday:

Rebull - Rotation in Orion
Gagne - X-ray and IR Surveys of star forming regions
Gutermuth - Spitzer survey of young stellar clusters
Peterson - Brown dwarfs in OMC2/3
Muzerolle - Star formation and disk evolution in NGC2068/71
Briceno - Survey of Orion OB 1 association
Chu - Star formation in the LMC

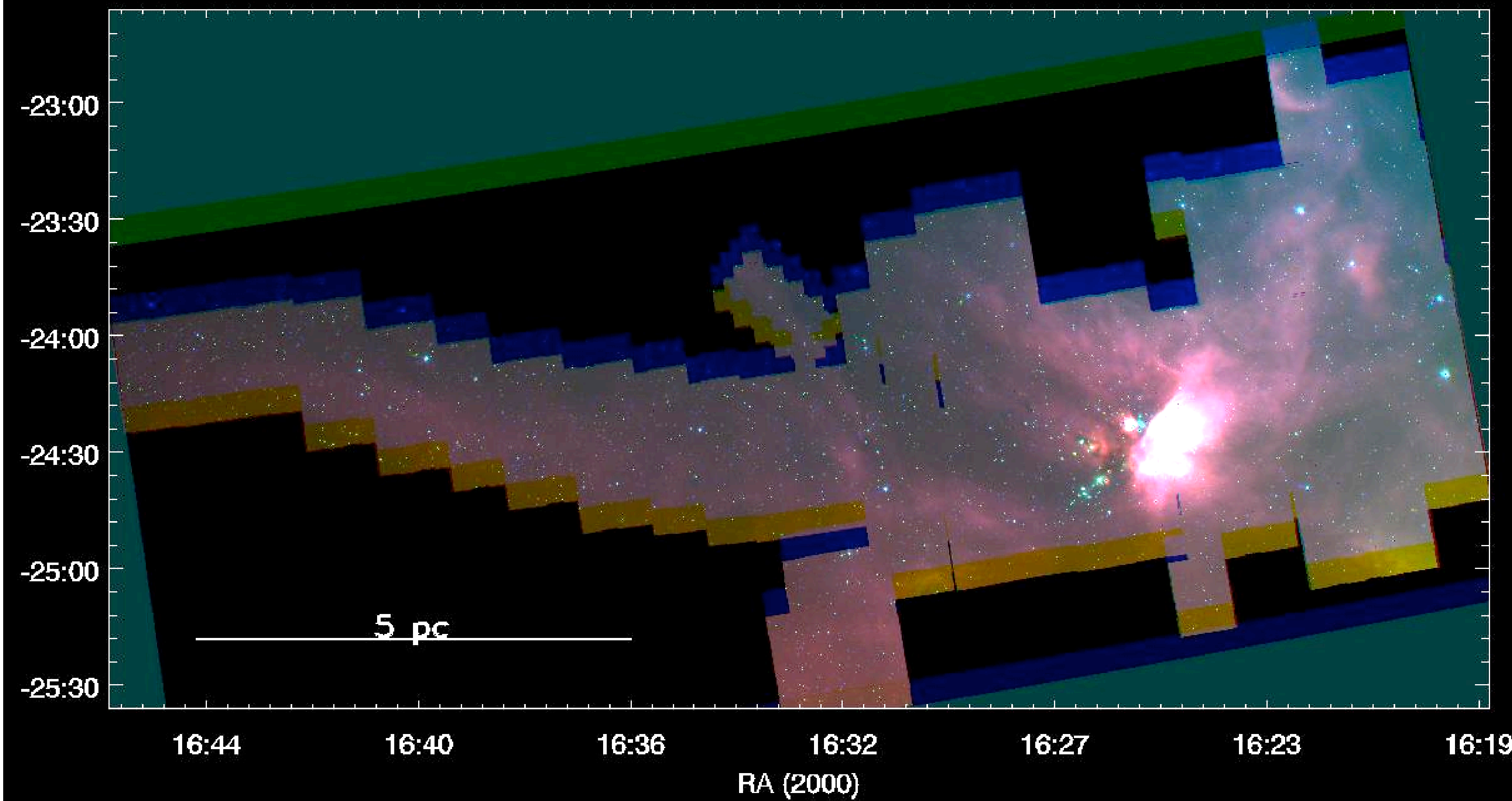
Friday:

“Splendid” splinter sessions

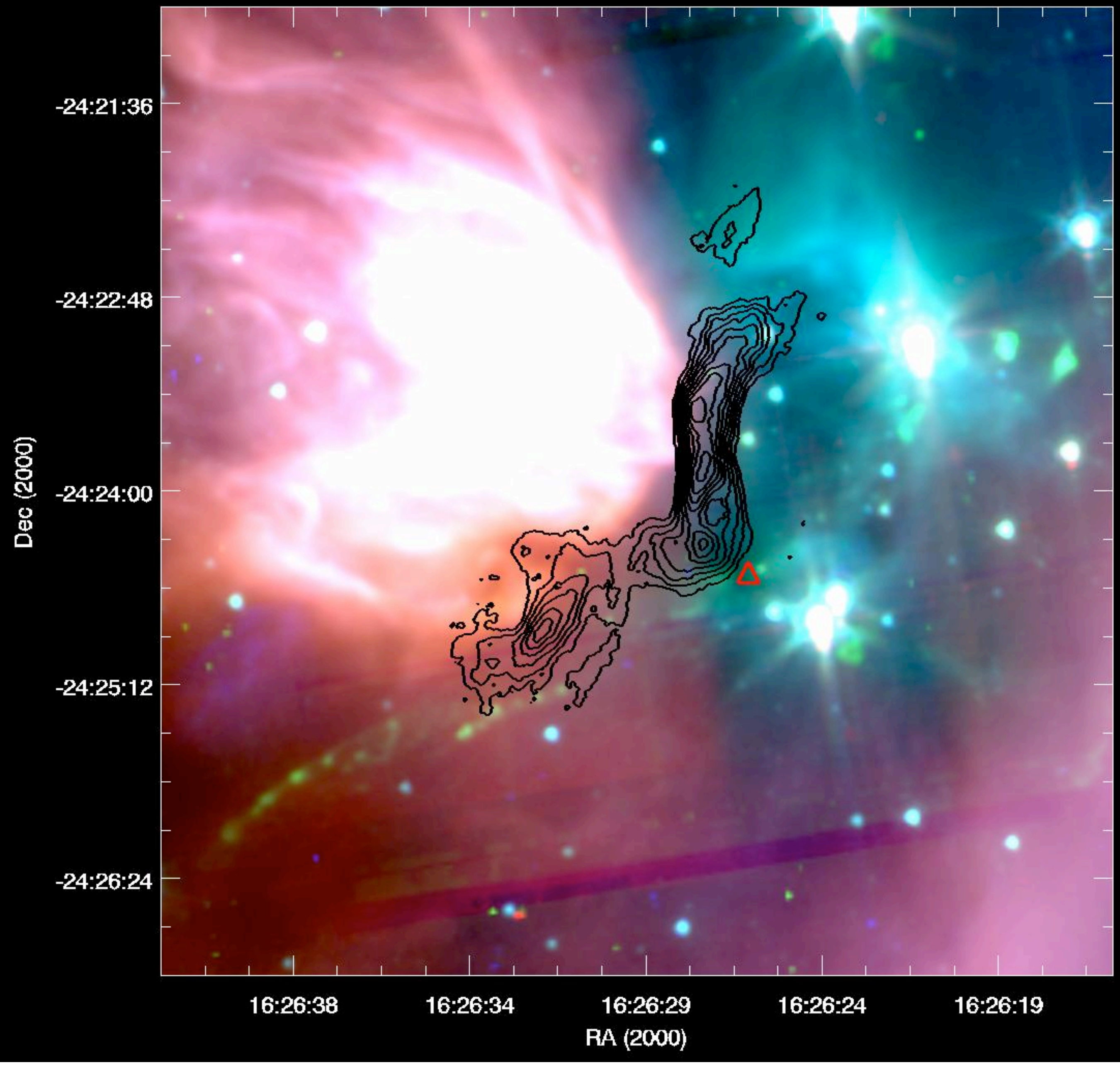


> 30,000 IRAC images (2 epochs, ~46 hrs)

IRAC 3.6, 4.5, 8 μm



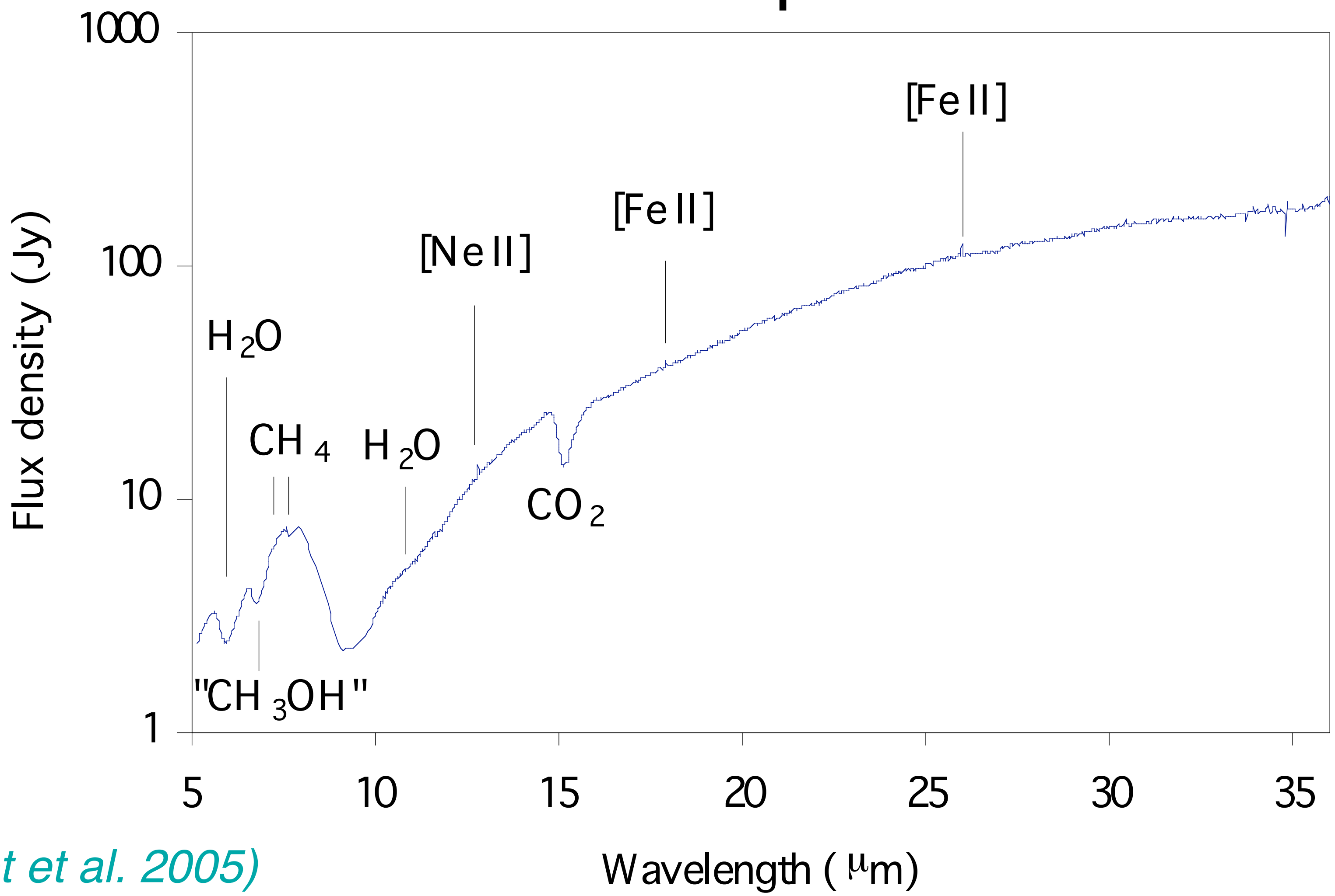
[Di Francesco, Andre & Myers 2004]



N_2H^+ contours show distribution of cold, dense molecular gas

Triangle marks position of VLA 1623

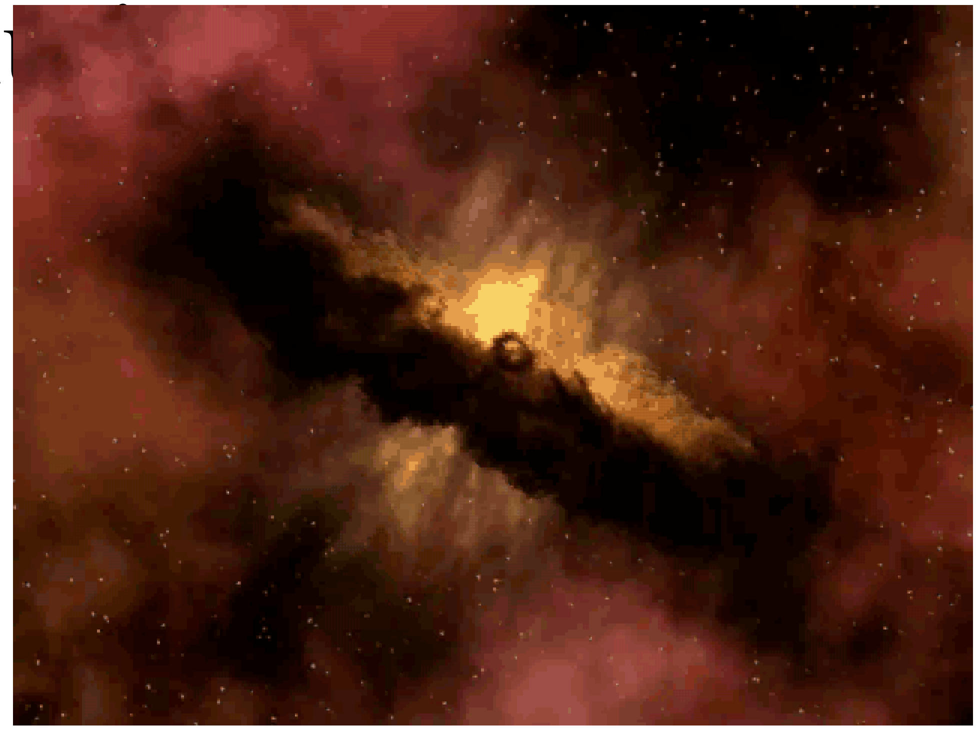
“Typical” IRS spectrum of a Taurus Class I protostar



(Calvet et al. 2005)

Conclu

- **Several interesting aspects of protoplanetary evolution observed spectroscopically:**
  - Central clearings in young disks, possibly indicating rapid giant-planet formation (cf. Boss 2001).
  - Thermal processing of grain material (core *and* ice mantle) observed, but its origin is obscure.
  - We've probably even reached the bottom of the mass function for "future habitable" planetary systems.



Animation by Robert Hurt, SSC