Taurus *Spitzer* Survey:
Taking the Bull by the Horns

- With apologies and thanks to Chuck Jones!

Team Members

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- A. Noriega-Crespo - SSC
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- S. Carey – SSC
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- D. Shupe – SSC/SWIRE
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- M. Guedel – Zurich/XMM
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- J. Monin – Grenoble/CFHT
- F. Menard – Grenoble/CFHT
- C. Dougados – Grenoble/CFHT
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- D. Koerner - NAU
- J. Bouvier – Grenoble/CFHT
- N. Evans – Texas/c2d
- P. Harvey – Texas/c2d
- L. Allen – CfA/IRAC/c2d
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- T. Huard – CfA/c2d
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- S. Wolf - MPIA
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- C. McCabe - SSC
- K. Stapelfeldt – JPL
- D. Hines – SSI
- S. Guieu - SSC
- W. Latter - SSC

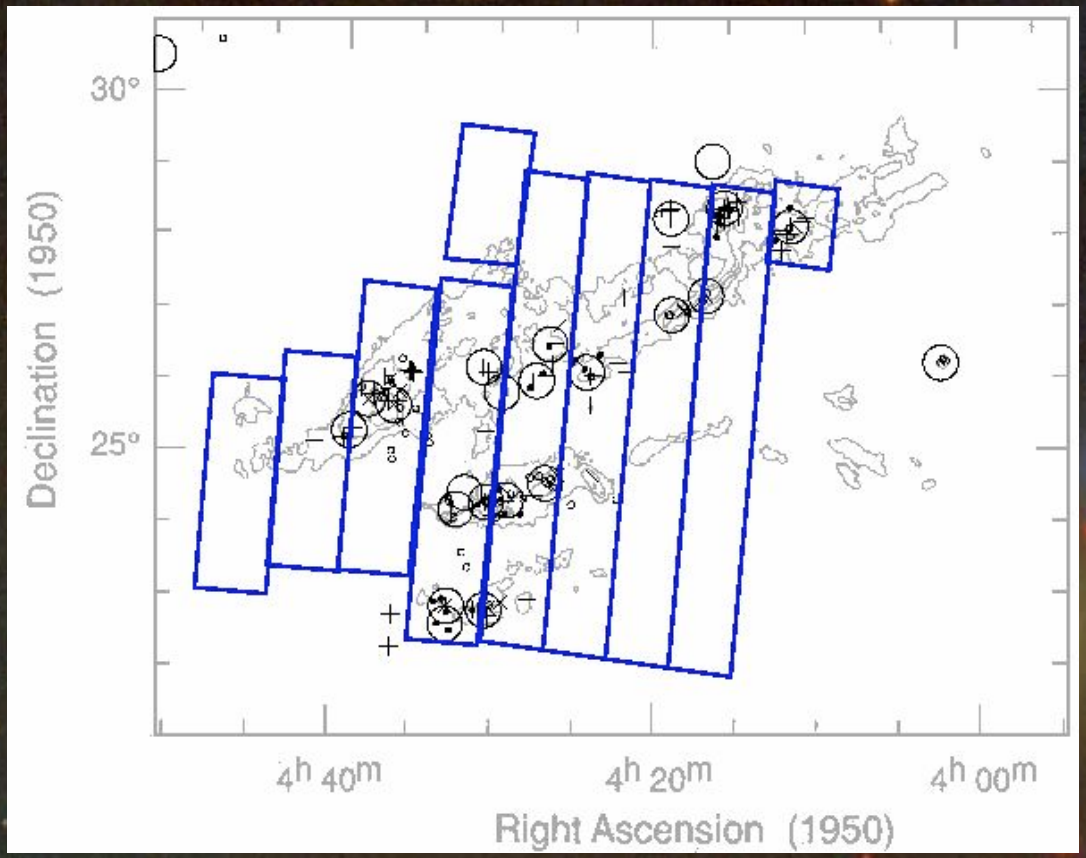
Taurus *Spitzer* Survey Goals

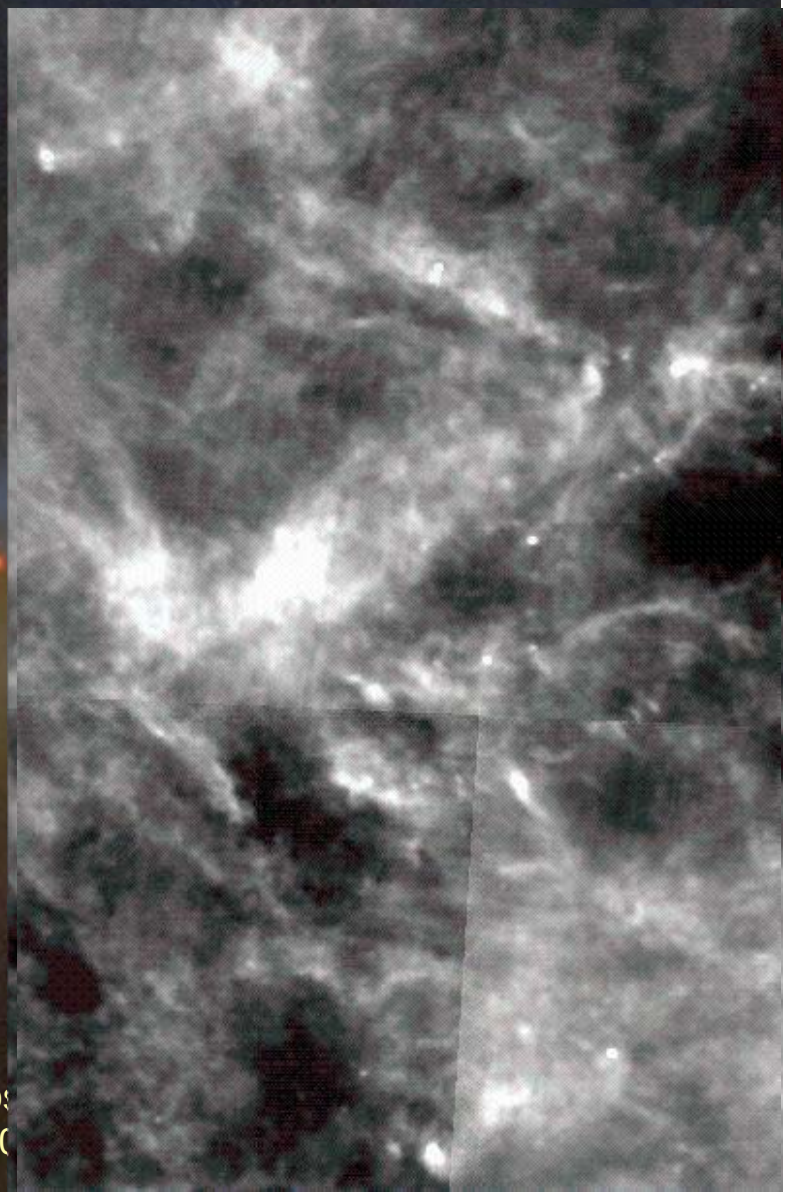
- Map a reasonable fraction of the complex using *Spitzer* imaging instruments (IRAC and MIPS)
- Science goals:
  - Take a census of young stars and disks to below the hydrogen burning limit
  - Determine extent of distributed star formation (disks outside known aggregates)
  - Carry out a definitive search for disks in transition and limit disk lifetimes in this region
  - Cross-ID optical, X-ray, NIR, and MIR objects to determine nature of all sources in region (in collaboration with CFHT and XMM-Newton Taurus surveys); now include SDSS Taurus survey also

Mapping Strategy

- Needed to map large area (30 + 14 sq. deg) of main Taurus clouds in relatively little time (134 hr + 60 hr)
- Two epochs critical due to asteroids (250/sq. deg. down to 1 mJy at 24 microns)
- IRAC - 2 epochs, each one 12 sec HDR (i.e. 0.6 and 12 sec)
- MIPS - 2 epochs; fast scan (15 sec/epoch)
- Crosses ecliptic; chose not to place constraints between AORs due to lack of rotation on ecliptic plane
- Led to gaps in coverage from long strips

Spitzer Taurus I Coverage

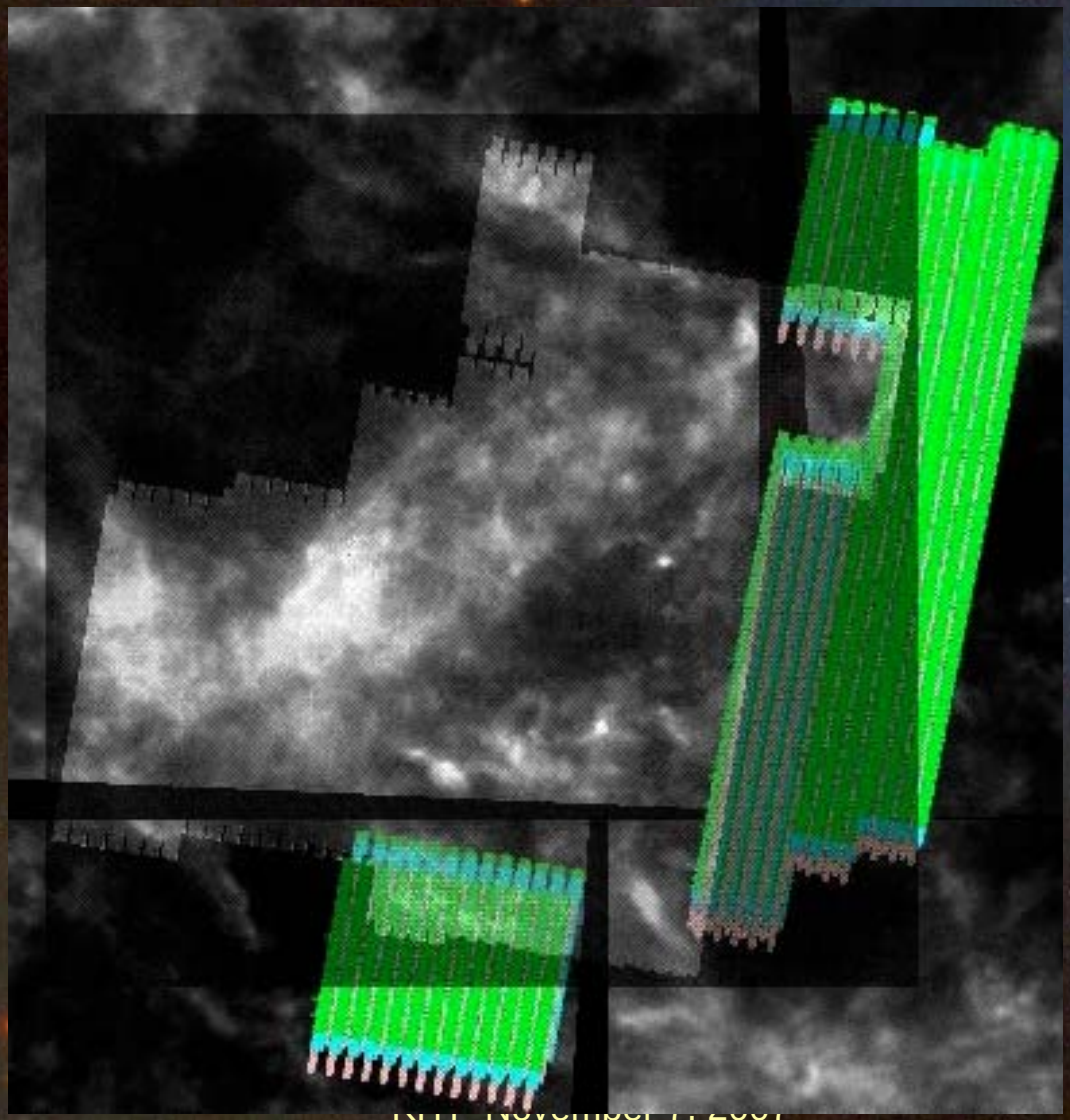




Bands (μm):	3.6	4.5	5.8	8.0	24	70	160
Sensitivity:	0.020	0.030	0.160	0.190	1.2	44	500

(5σ mJy) - IRAC is √ 2 less sensitive than c2d

Taurus 2 AORs: 60 hr



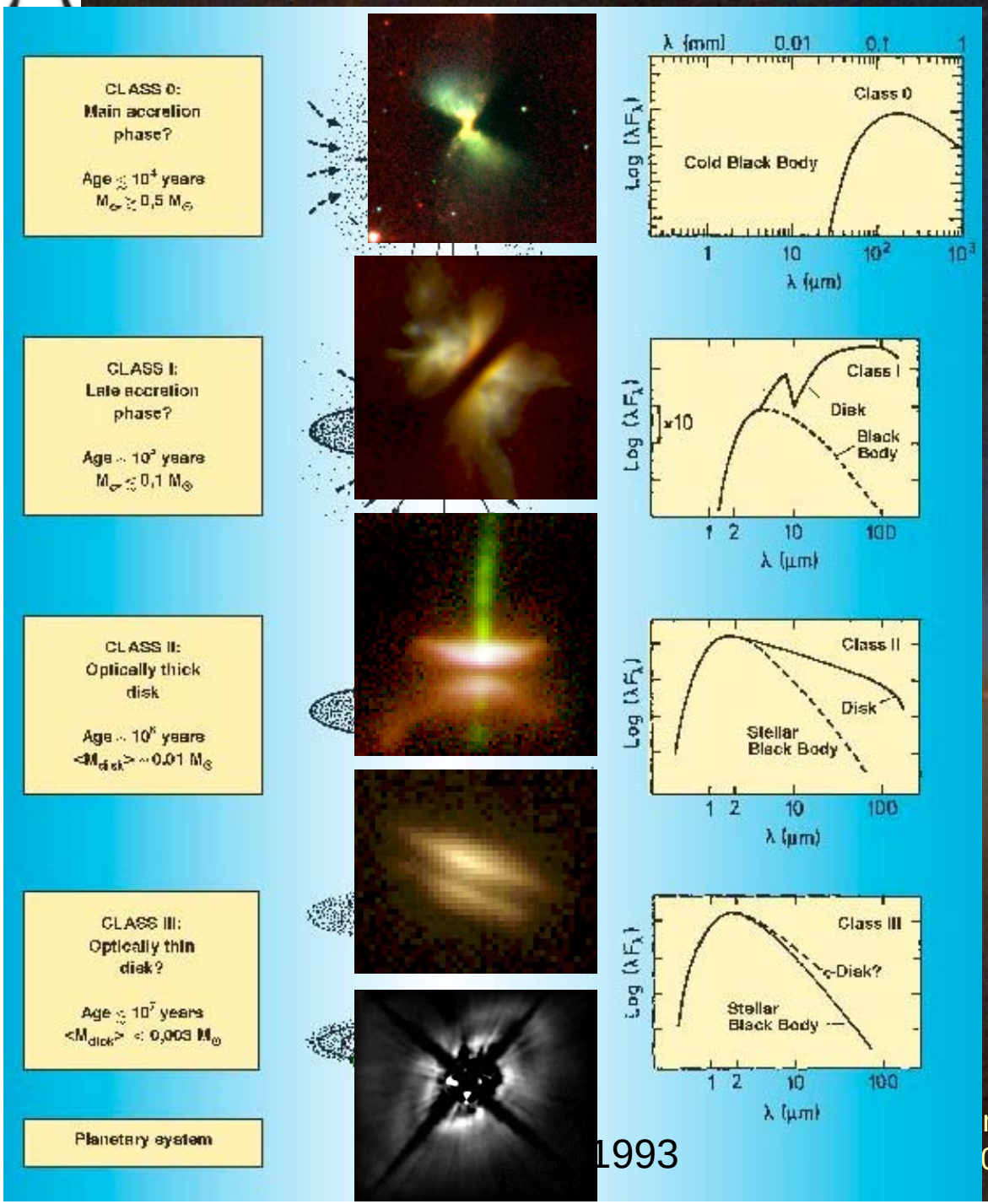
As implemented, Feb. - March 2007; 14 sq. deg.

Sample of IRAC Data

IRAC 3 Color Image: 3.6 μm, 4.5 μm, 8.0 μm

Disk Evolution redux

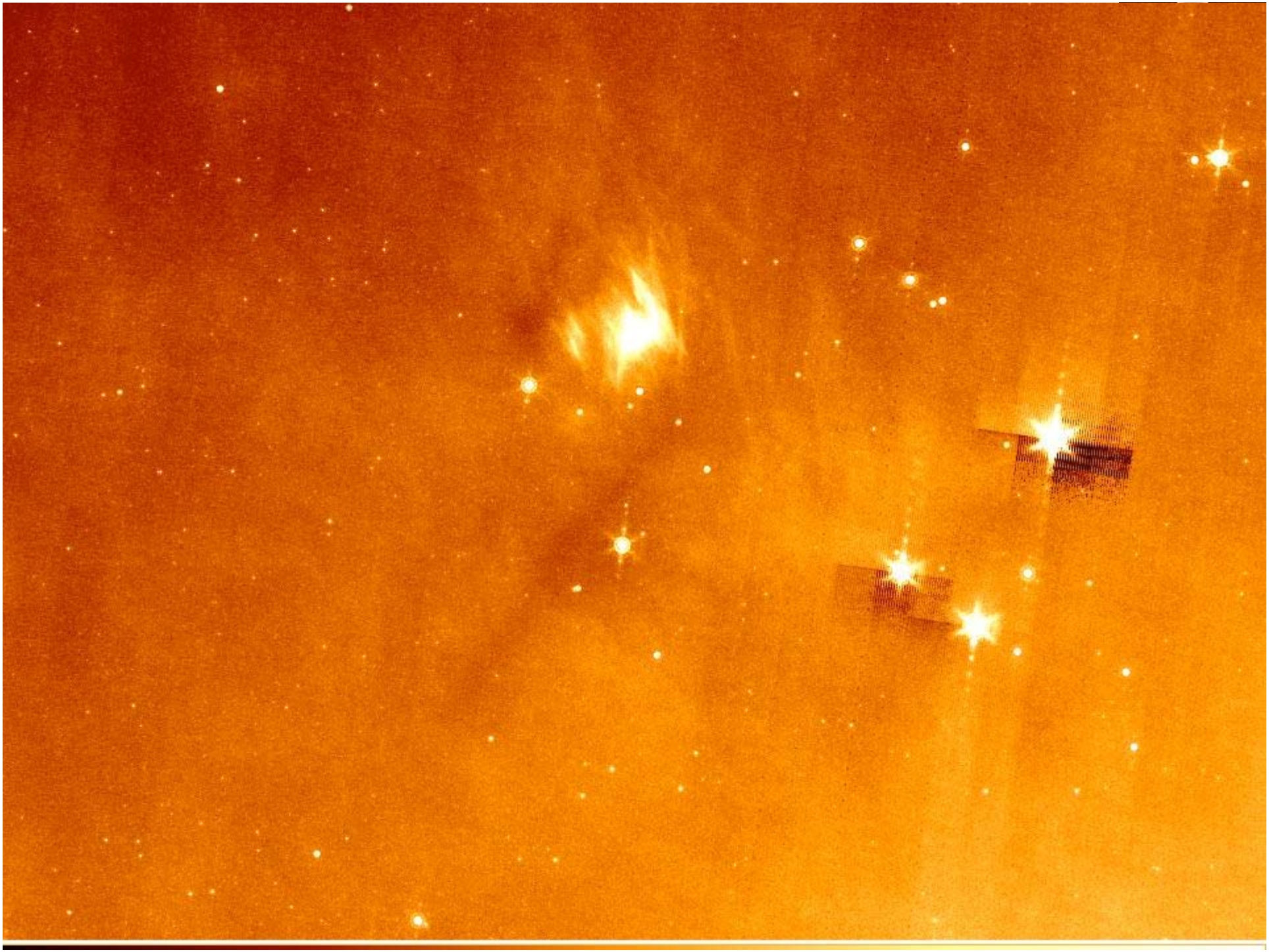
Spitzer gives some of the first well-resolved images of Class 0/I sources in mid-IR (other pics from HST)



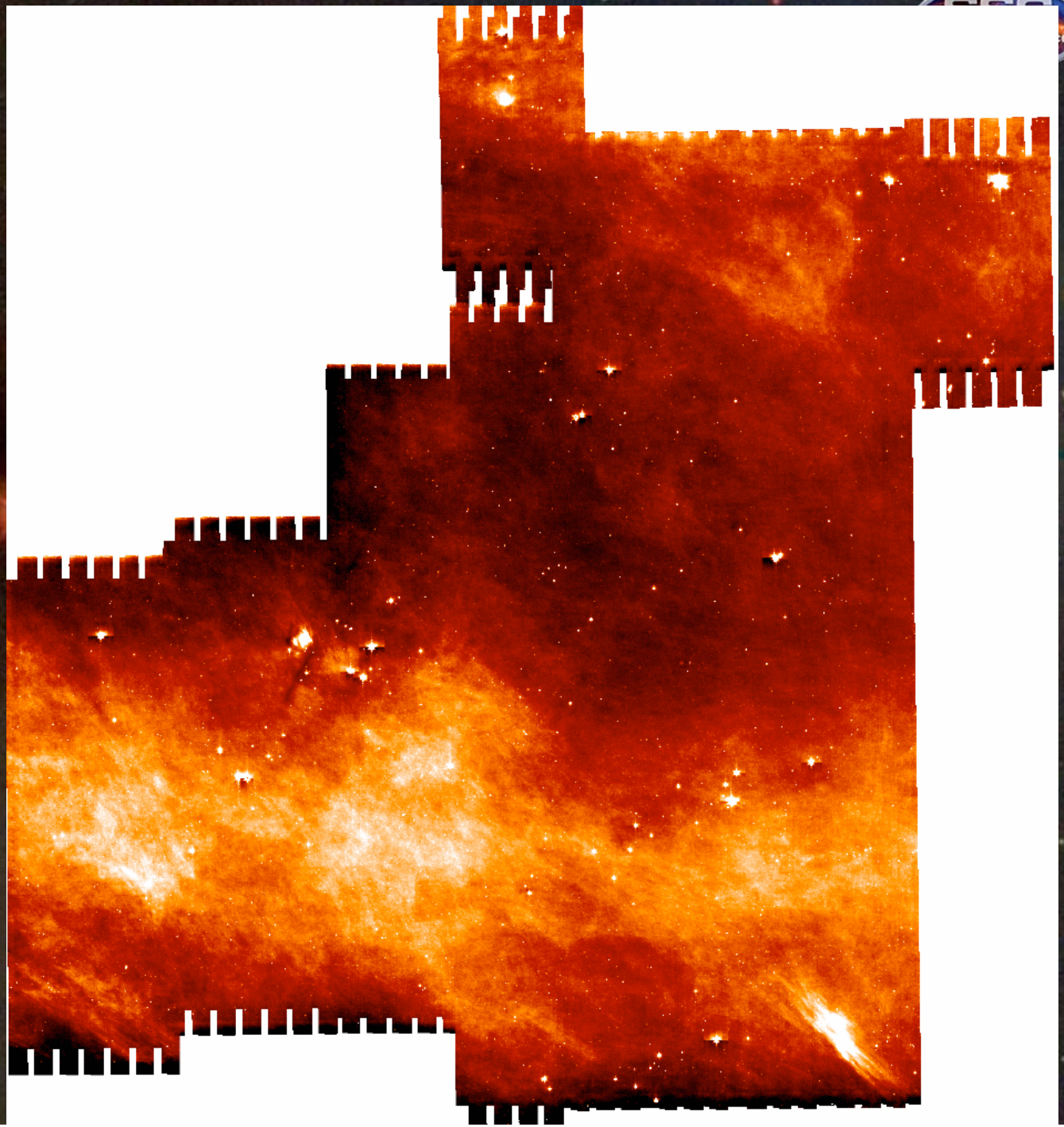
1993

mic Time
07

Taurus Central Cloud
IRAC 1, 4, MIPS-24

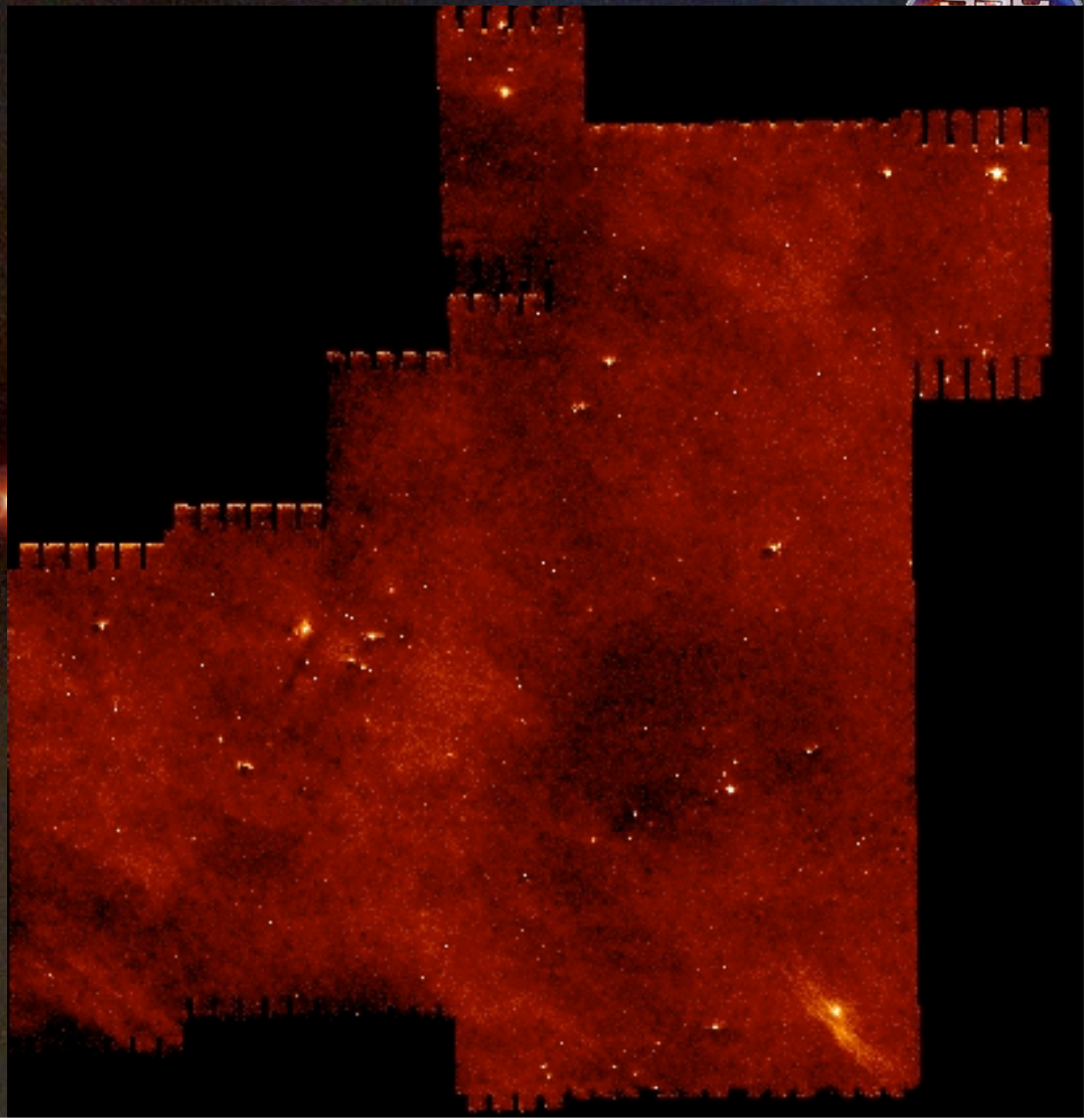


- Taurus I MIPS 24: destriped and large-scale zodiacal emission subtracted
- Large feature is zodiacal dust band

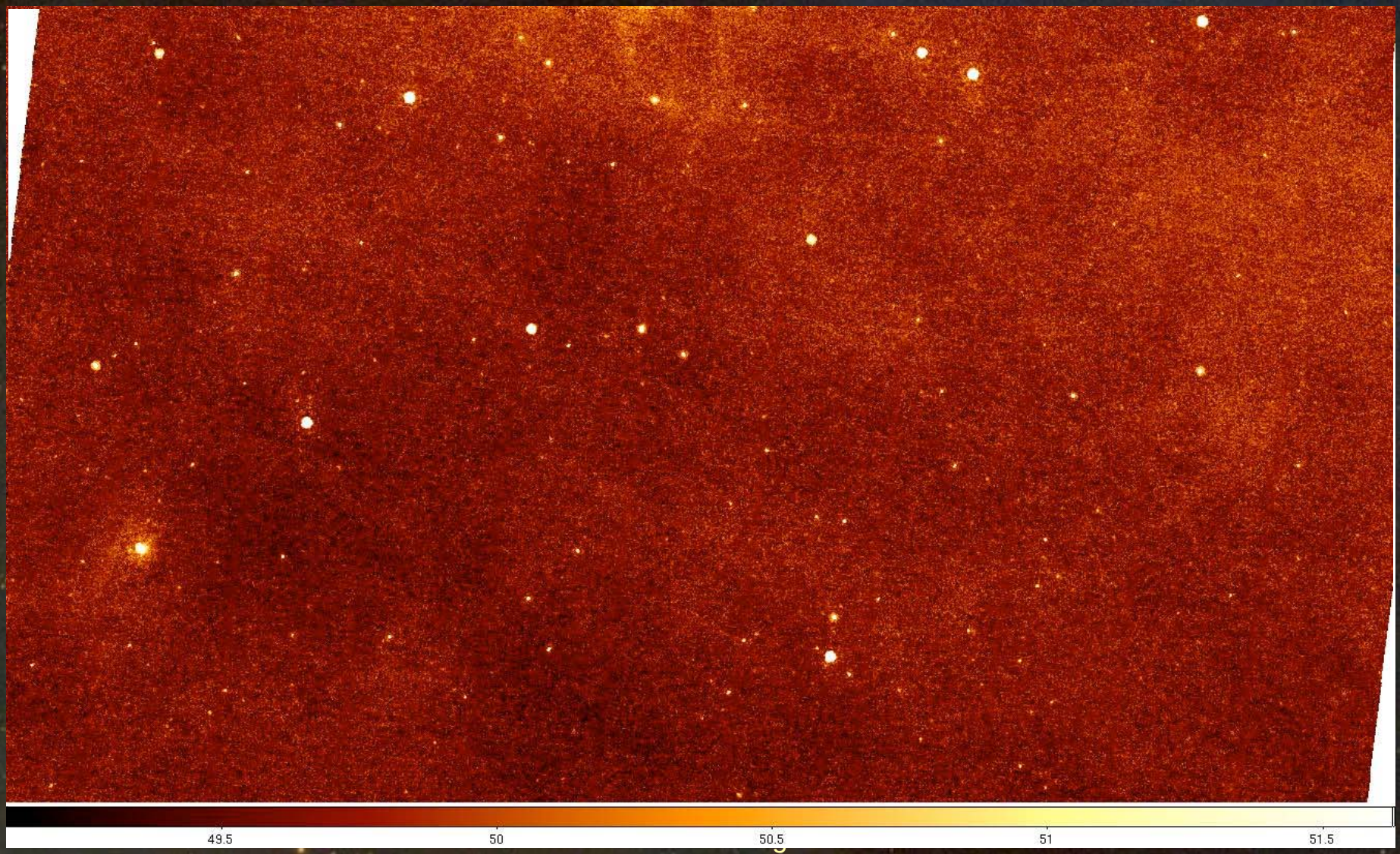


Taurus 1
MIPS 24
micron map

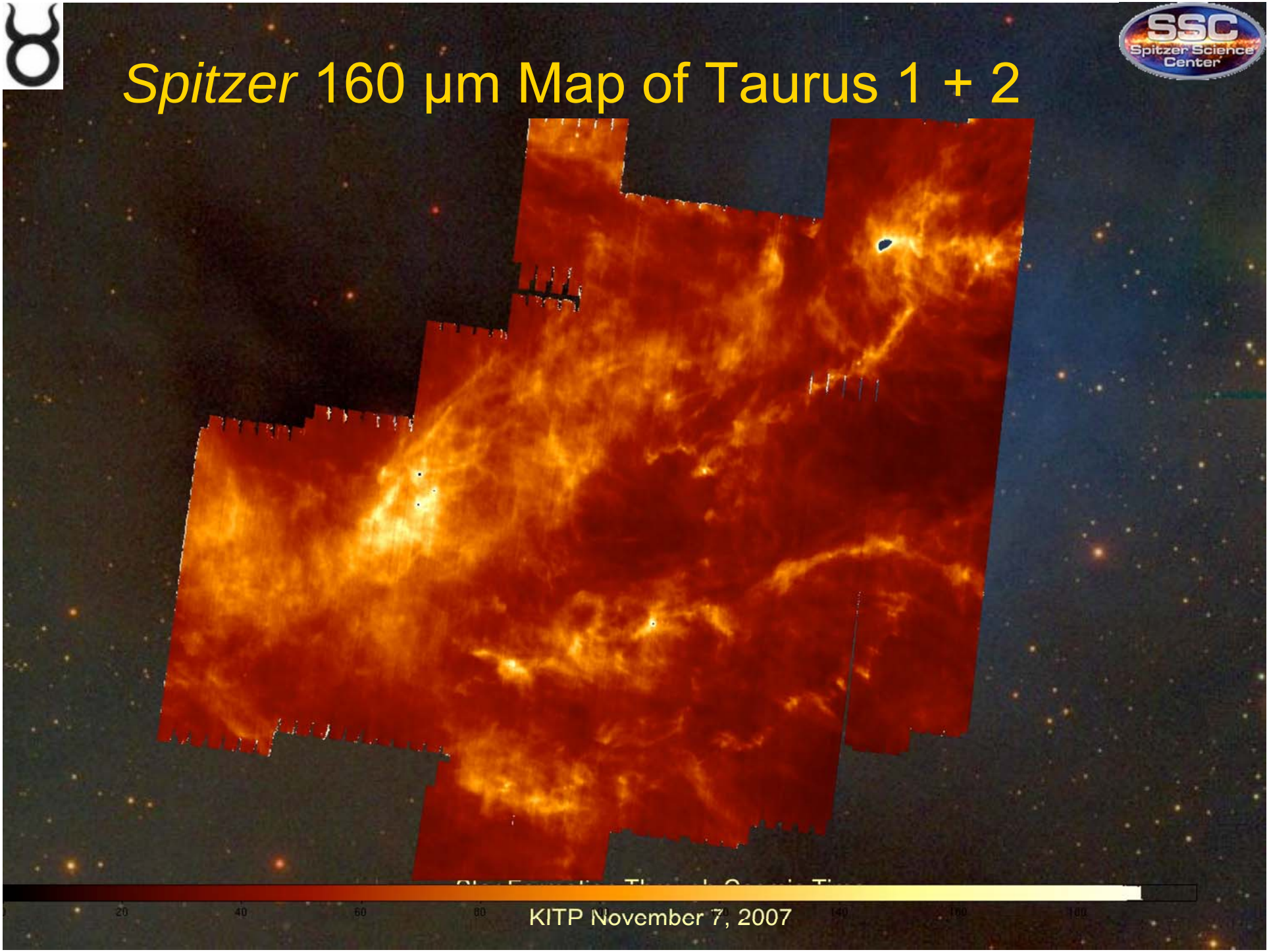
Zodiacal
dust band
subtracted

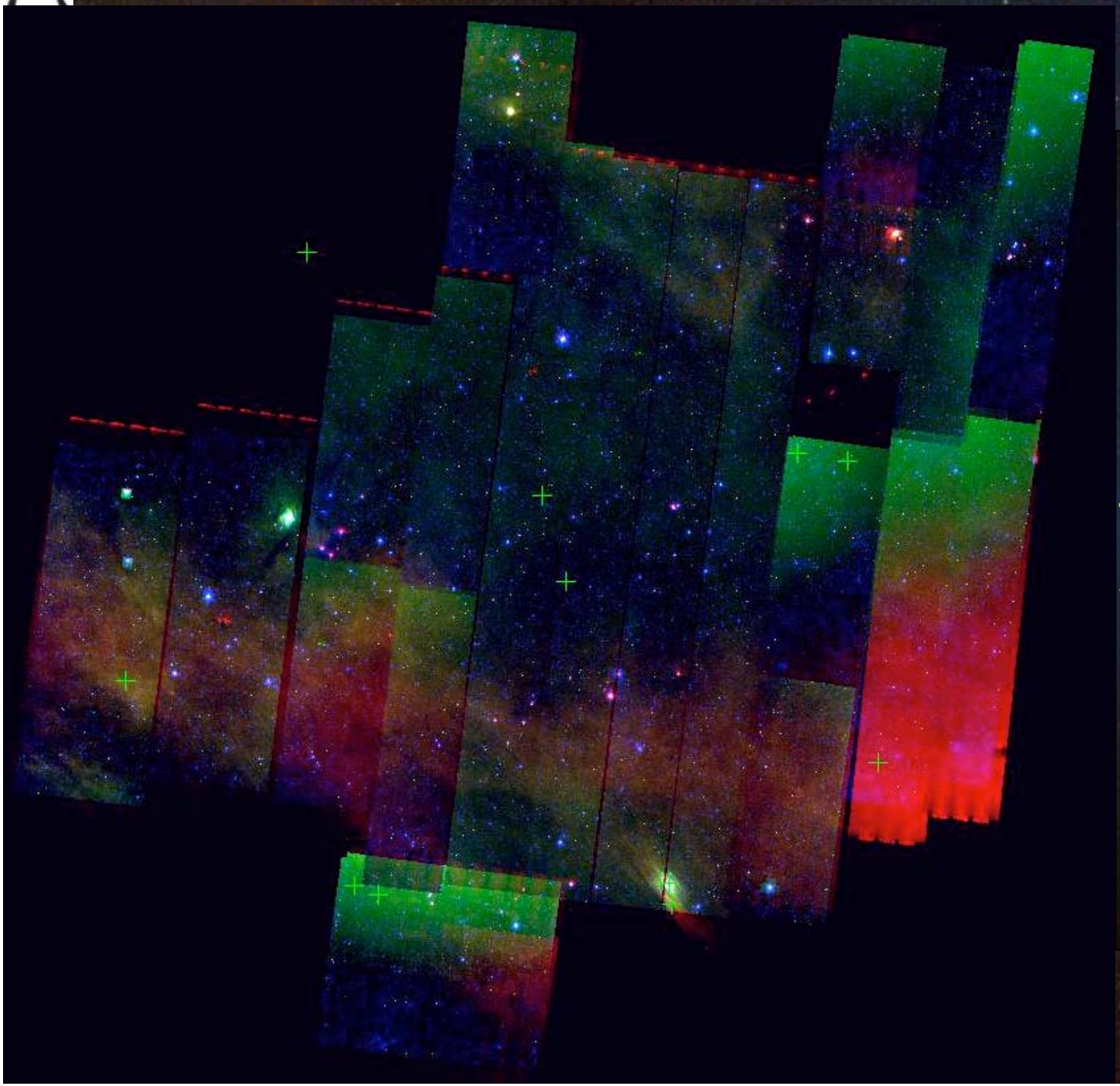


Taurus Asteroids at 24 μm



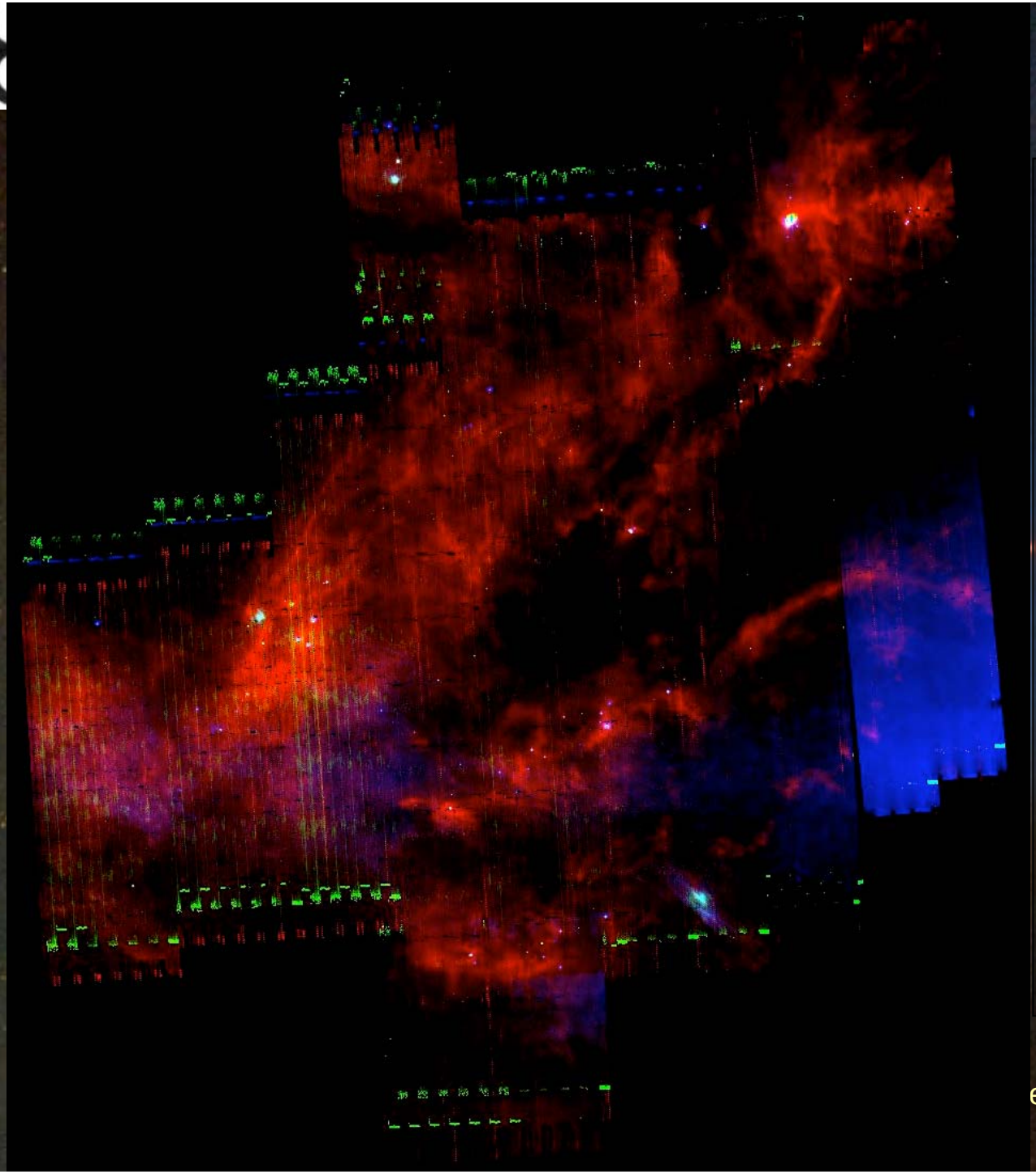
Spitzer 160 μm Map of Taurus 1 + 2





Preliminary IRAC 4.5 (blue), 8 (green), and 24 μm (red) image of Taurus 1 + 2 surveys

IRAC gaps will mostly be filled in the fall



MIPS 24 (blue), 70 (green), and 160 μm (red) image of Taurus 1 + 2

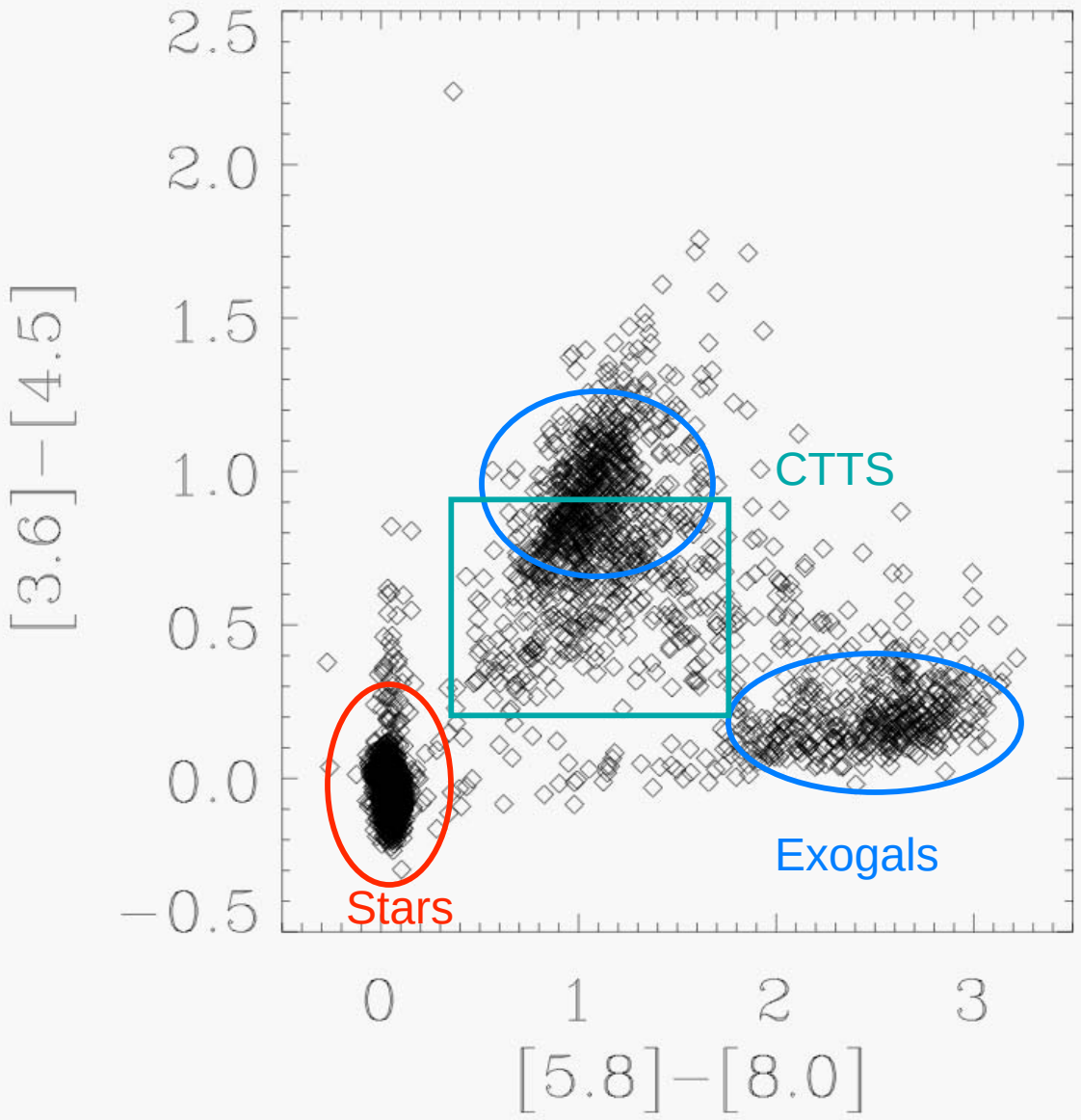
Note as before that zodi has not been subtracted from Taurus 2 24 micron images

e

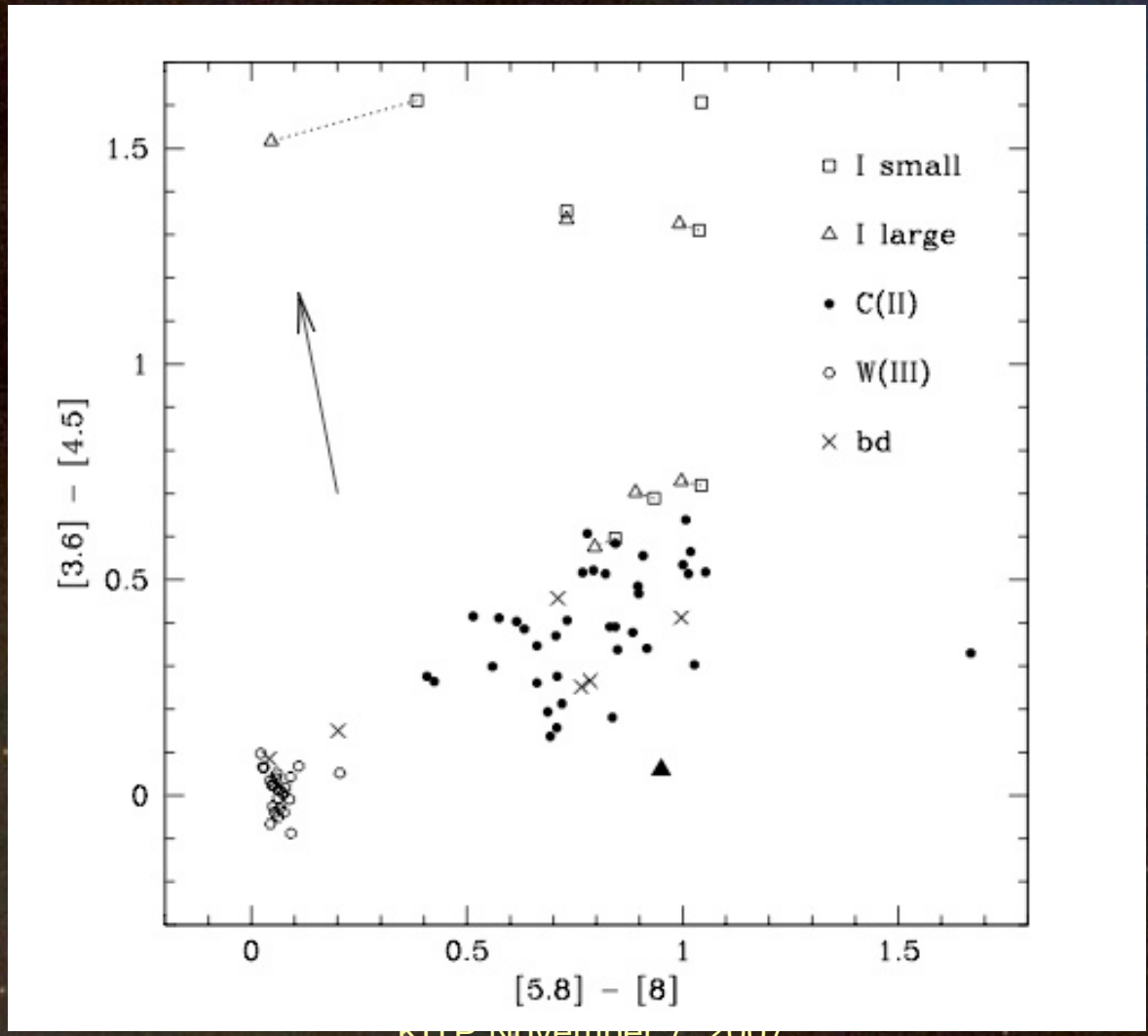
Taurus 1 10σ Catalog Statistics

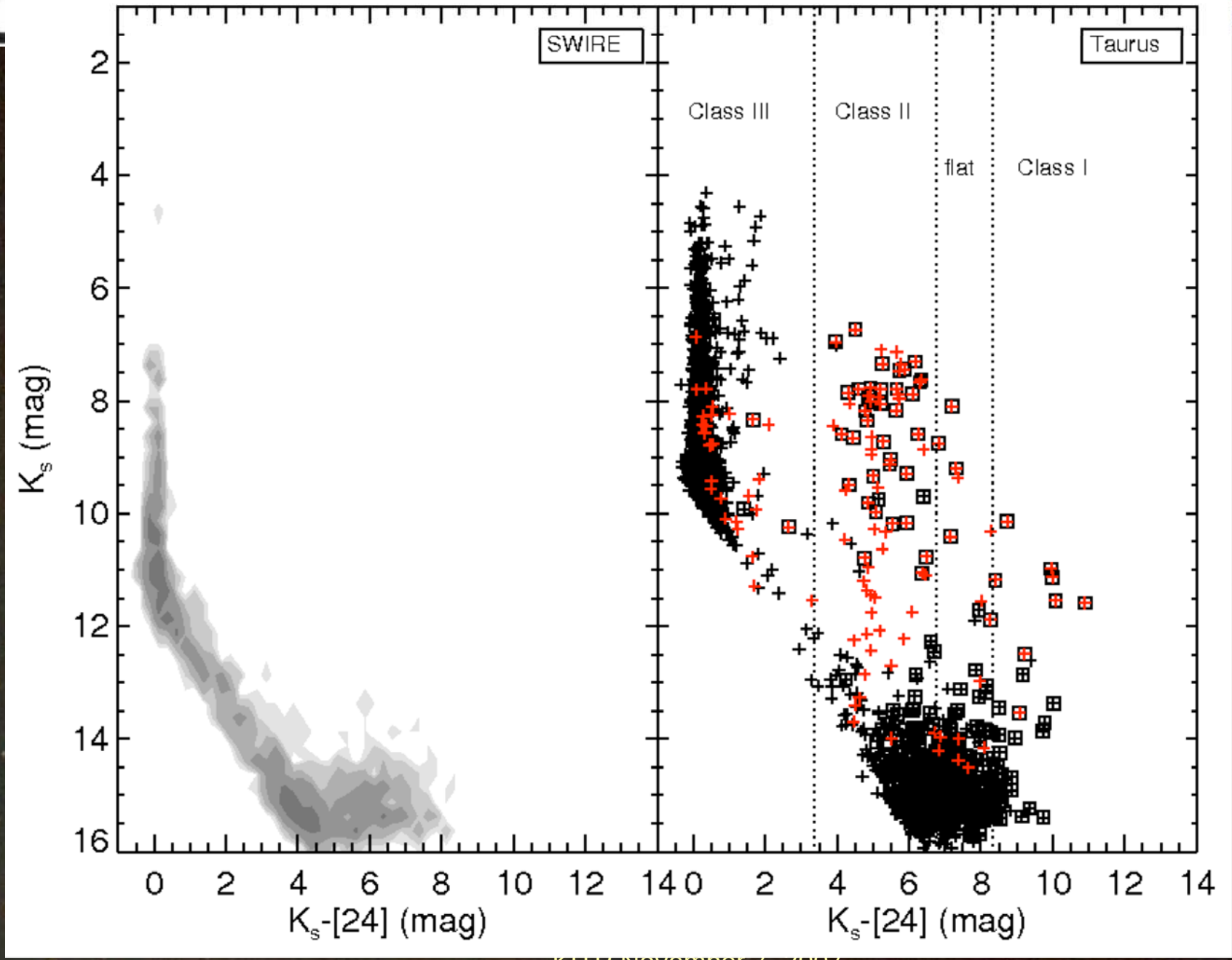
- Source numbers
  - 522493 with IRAC band 1 (~188000 15σ released)
  - 501949 with IRAC band 2
  - 151215 with IRAC band 3
  - 118623 with IRAC band 4
  - 9069 with MIPS 24
- Bandmerged source numbers
  - 78636 with all 4 IRAC bands
  - 5122 with all 4 IRAC + MIPS 24
  - 532 with MIPS 24 and 70
  - Now combined with 2MASS, SDSS, CFHT, and XMM

IRAC Color-Color Diagram for S/N > 10 Taurus Sources



Known Taurus YSOs (Hartmann et al. 2005)




SWIRE
Taurus
Class III
Class II
flat
Class I
K_s (mag)
K_s-[24] (mag)
K_s-[24] (mag)

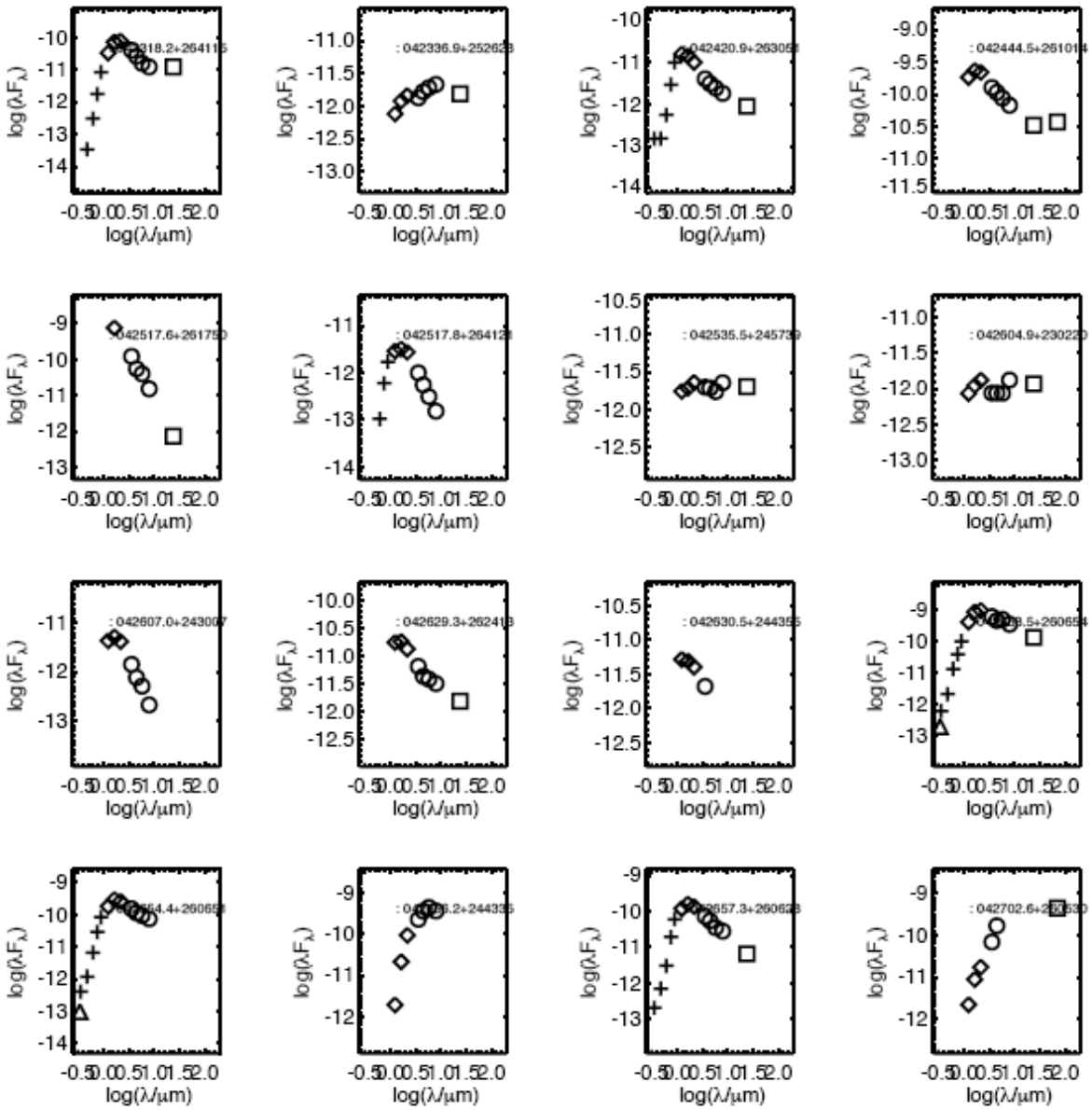
Ground-based followup to *Spitzer*

- Keck optical and NIR spectroscopy in February 2007 for Taurus 1 YSO candidates NOT vetted by morphology
- Keck run revealed many AGN and star-forming galaxies among faint new YSO candidates; colors more extreme than 6 sq. deg SWIRE field
- Morphological information is critical, pointing out need for short wavelength imaging data - now using CFHT and SDSS surveys to help
- Preliminary assessment is ~20 - 30 new low mass T Tauri stars based on *Spitzer* data + many brown dwarfs

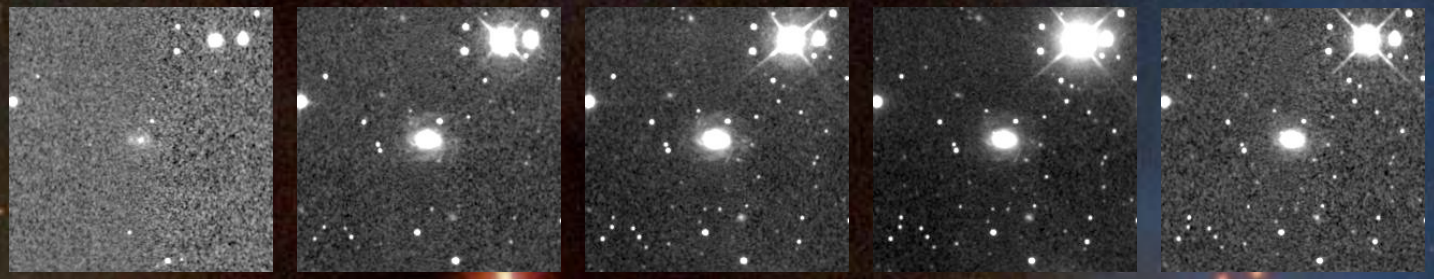
Complementary Multiwavelength Datasets

- 2MASS NIR imaging
- SDSS ugriz imaging and spectroscopy (48 sq. deg.)
- CFHT i & z imaging (34 sq. deg.)
- XMM deep observations (5 sq. deg.)
- FCRAO CO survey (100 sq. deg)

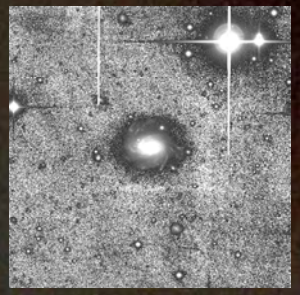
Source SEDs (*Spitzer*+CFHT+2MASS)



Galaxy, pt src MIPS with 70 um excess

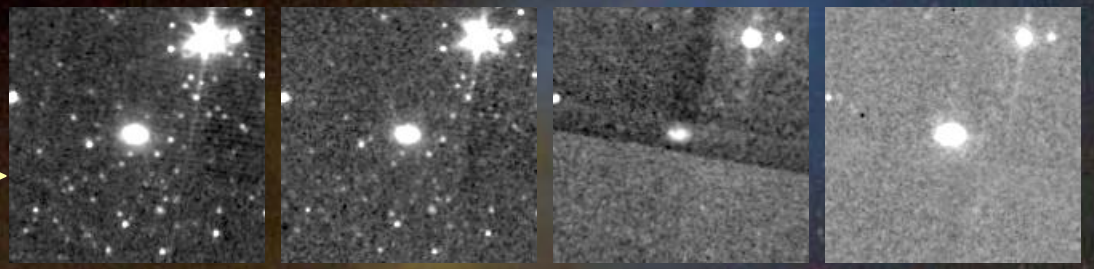


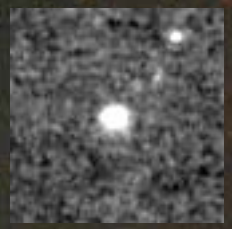
SDSS ugriz



<-CFHT I

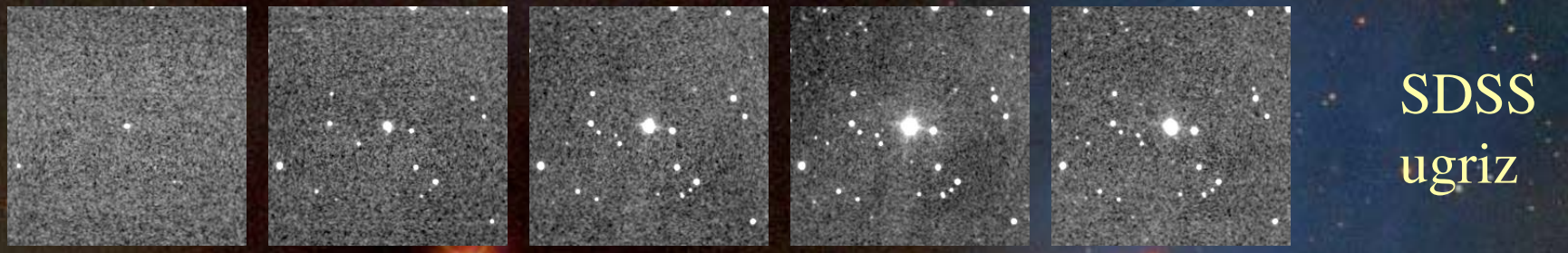
IRAC1234->





MIPS 1-2

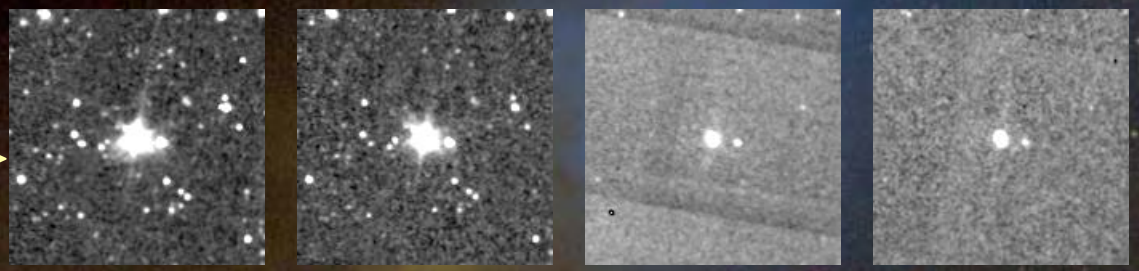
Point source all bands (YSO?) with 70 um excess

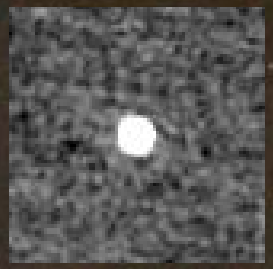


SDSS
ugriz

<-CFHT I

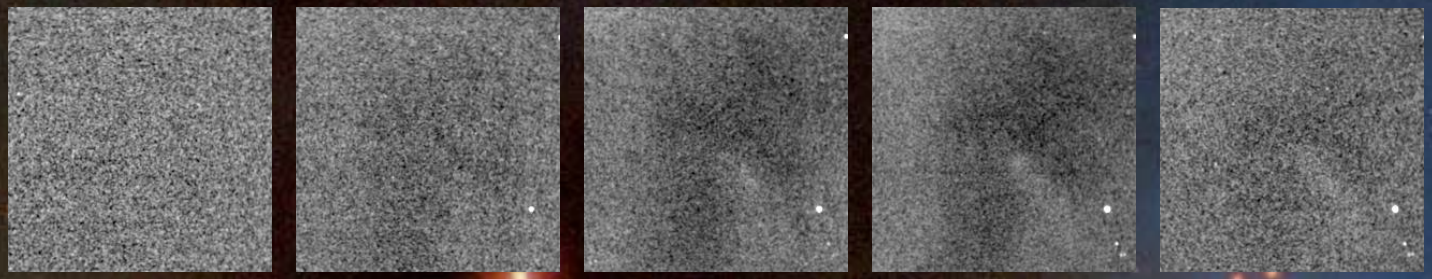
IRAC1234->





MIPS1,2

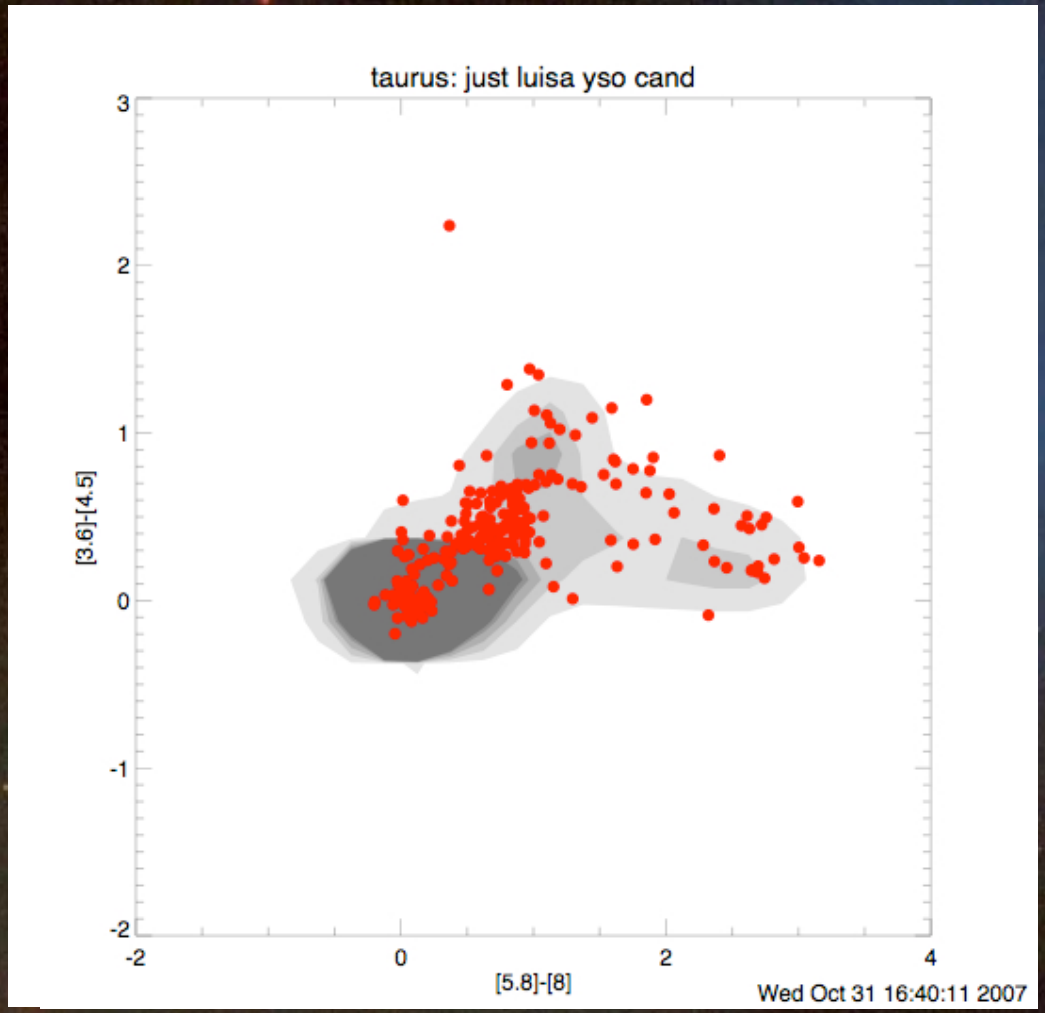
IRAS 04169+2702



SDSS
ugriz

IRAC 1,3
MIPS 1,2

Exogals vs. YSOs: IRAC



Exogals vs. YSOs: MIPS-24

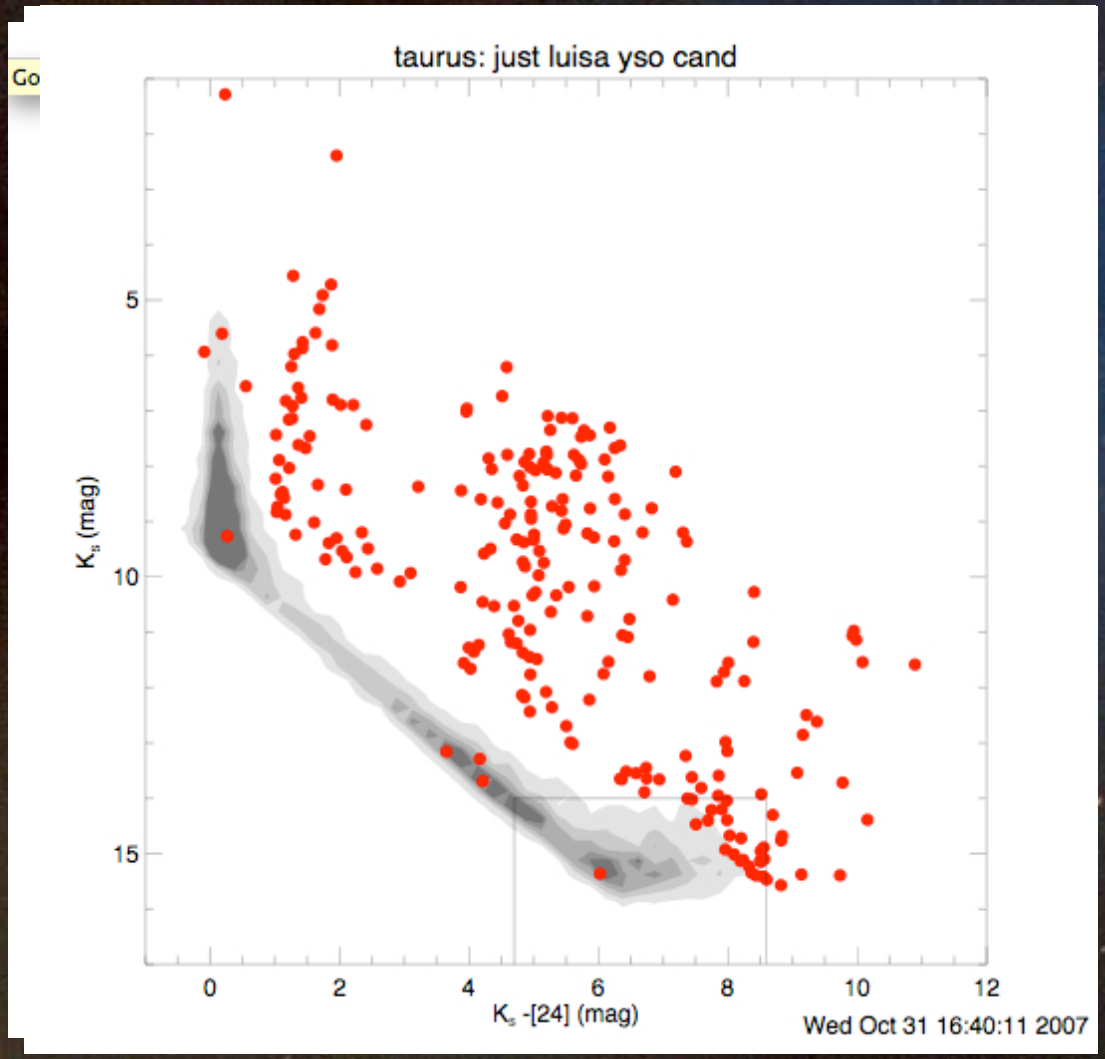
Hot off the presses:

419 YSO candidates based on color and brightness;

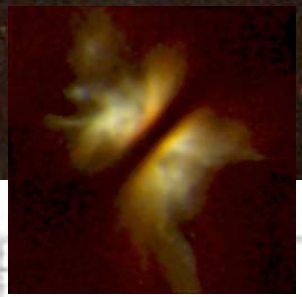
144 of these are resolved galaxies

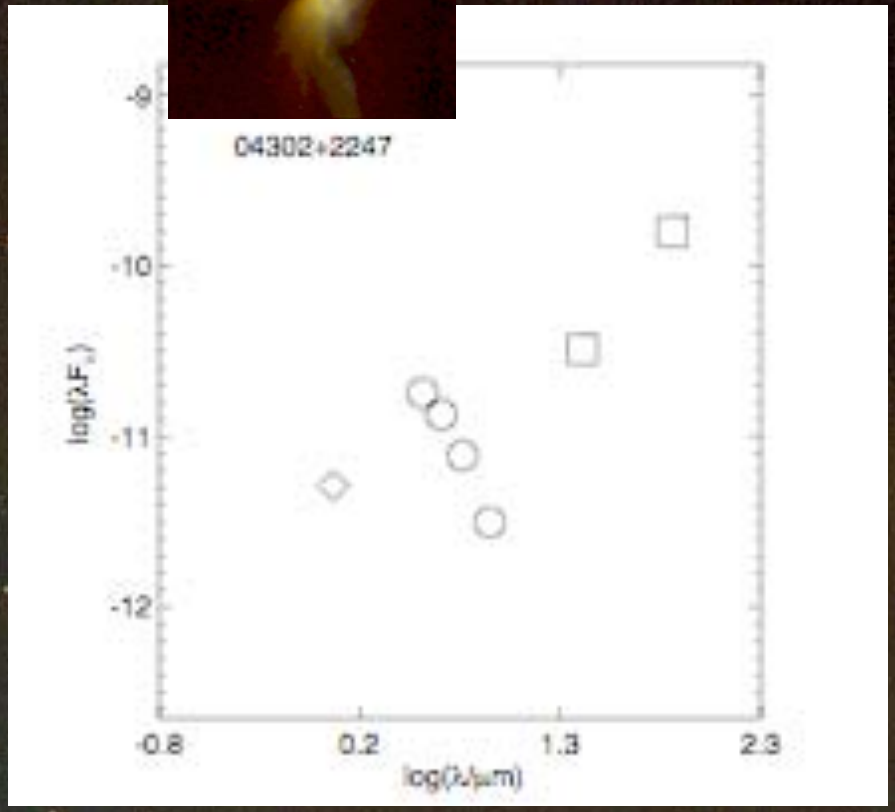
272 YSOc

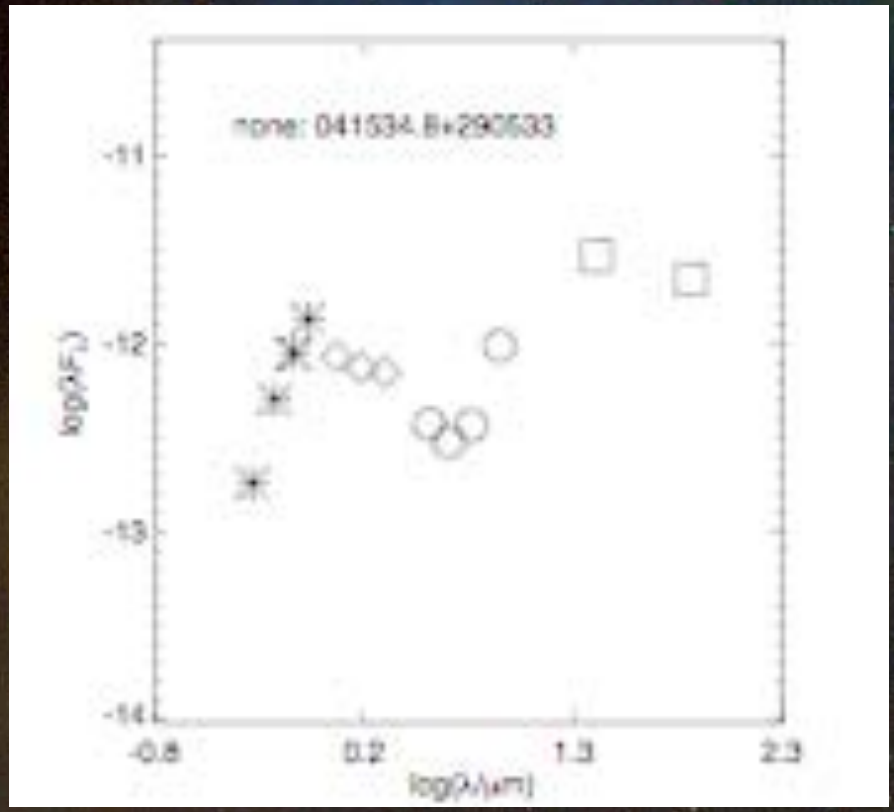
104 unidentified in literature (thus far)



Edge-on Disks Look Like Galaxies!

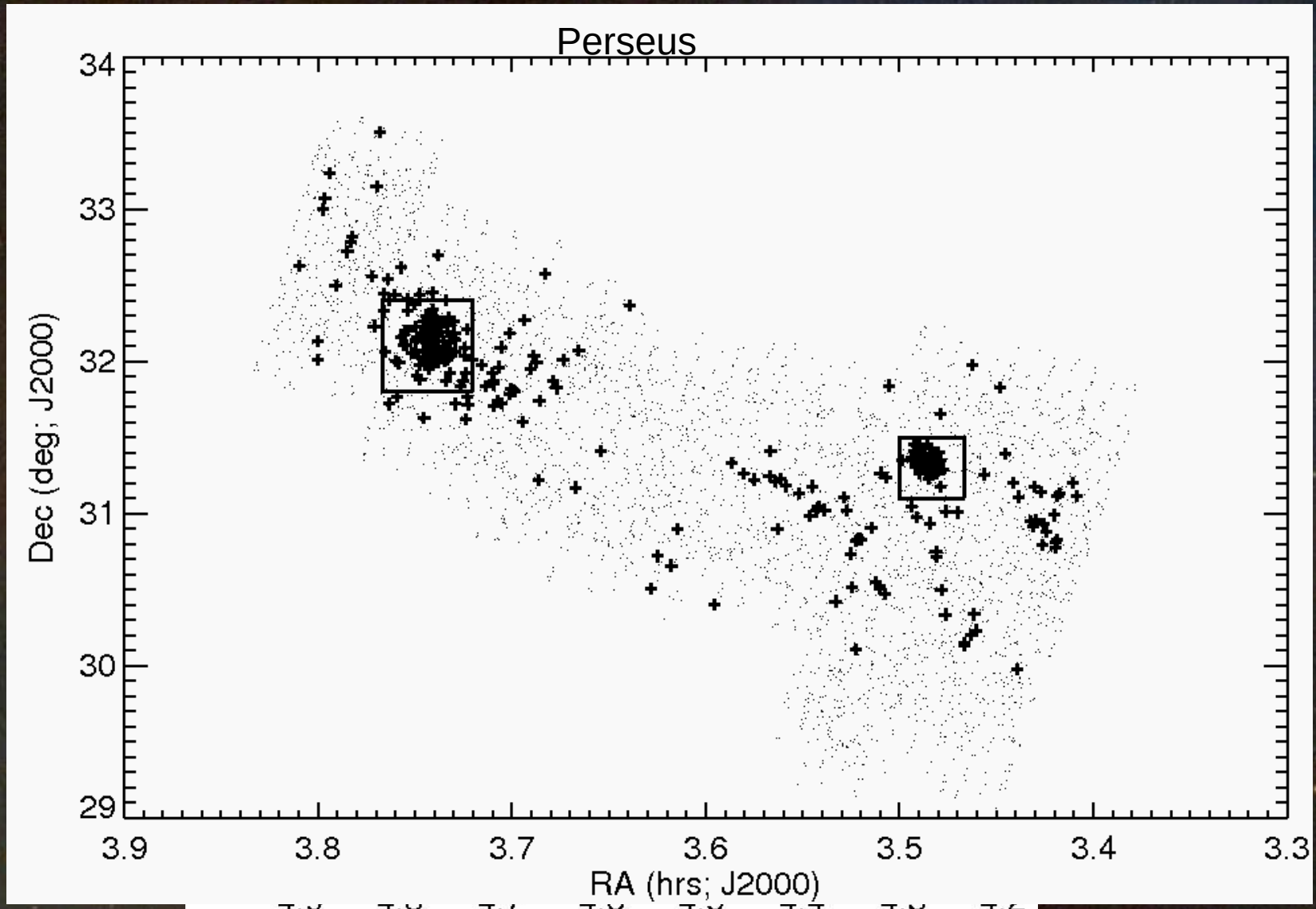




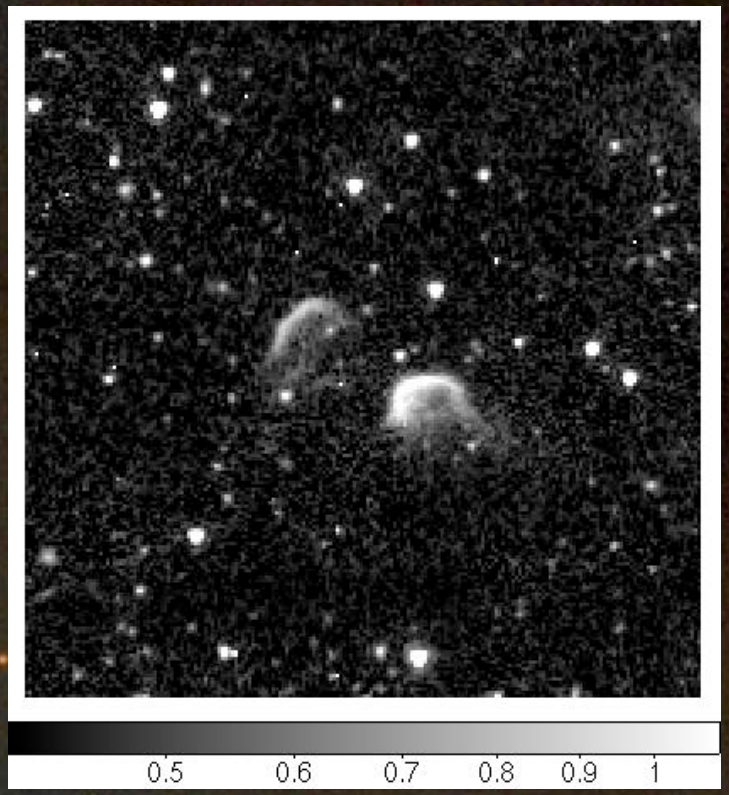


In fact, I found a known EOD yesterday in our “confirmed galaxy by morphology” list

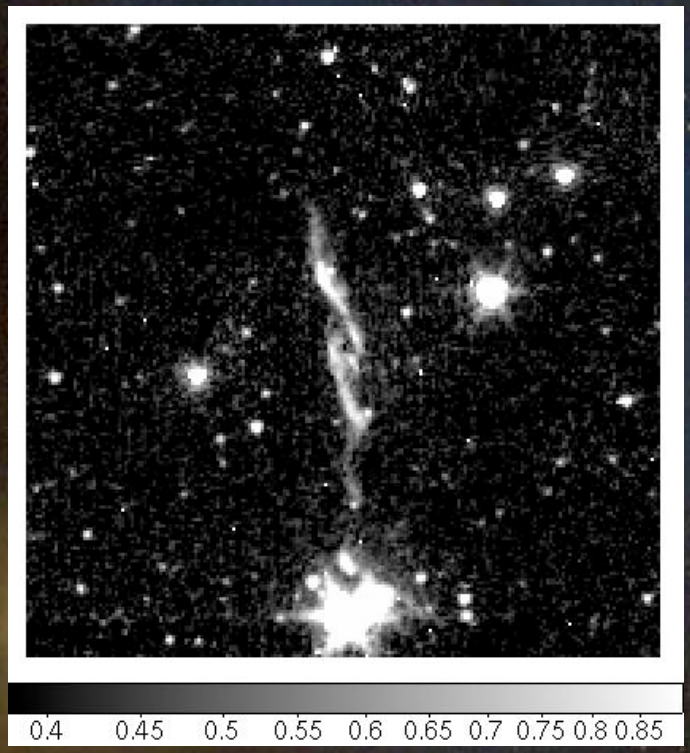
Location of Candidate YSOs



Spitzer HH object examples



- No SIMBAD association
- No YSO within half degree
- L1506 cloud is to the W, with several YSOs, but at a distance of 2.9 degrees (7 pc) !



- HH 704 100 arcseconds long !!
- Star at bottom has no IR excess (Luisa)
- Nearest YSO is GN Tau, 28 arcmin away, but wrong PA. ITG 36 is along the flow PA, 32´ to the E

Other science in work

- Overview - Guedel et al. (2006) PPV .
- Population, new and old: Rebull et al.
- Transitional disks: McCabe et al.
- Very low mass stars with disks: Fukagawa et al
- HH objects: Stapelfeldt & Knapp et al.
- Low mass embedded sources: Terebey et al.
- Asteroids: Hines et al.
- Brown dwarfs: Guieu et al. (2007); Monin et al.
- X-ray sources: Guedel et al.
- SDSS young stars: Knapp et al.
- See all at Austin AAS

SDSS Survey of Taurus

PI: Jill Knapp - Princeton

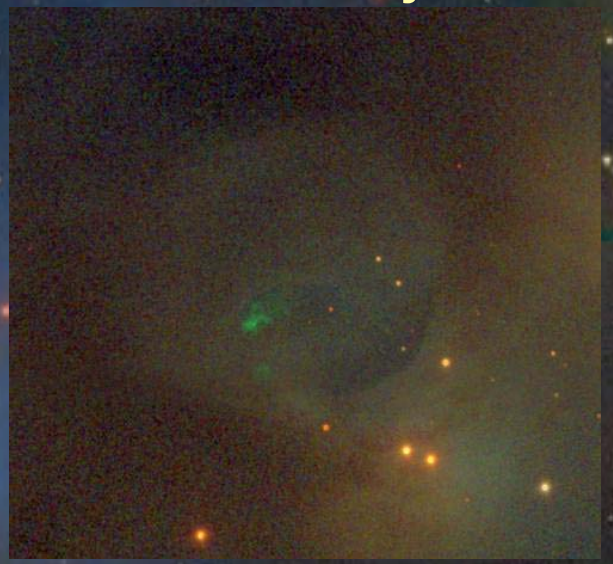
SDSS Consortium

48 square deg. of short integration images

and 6400 spectra of M stars

HH objects in SDSS Taurus

SDSS r filter has Hα and [S II] so can see HH objects



SDSS Young Stars

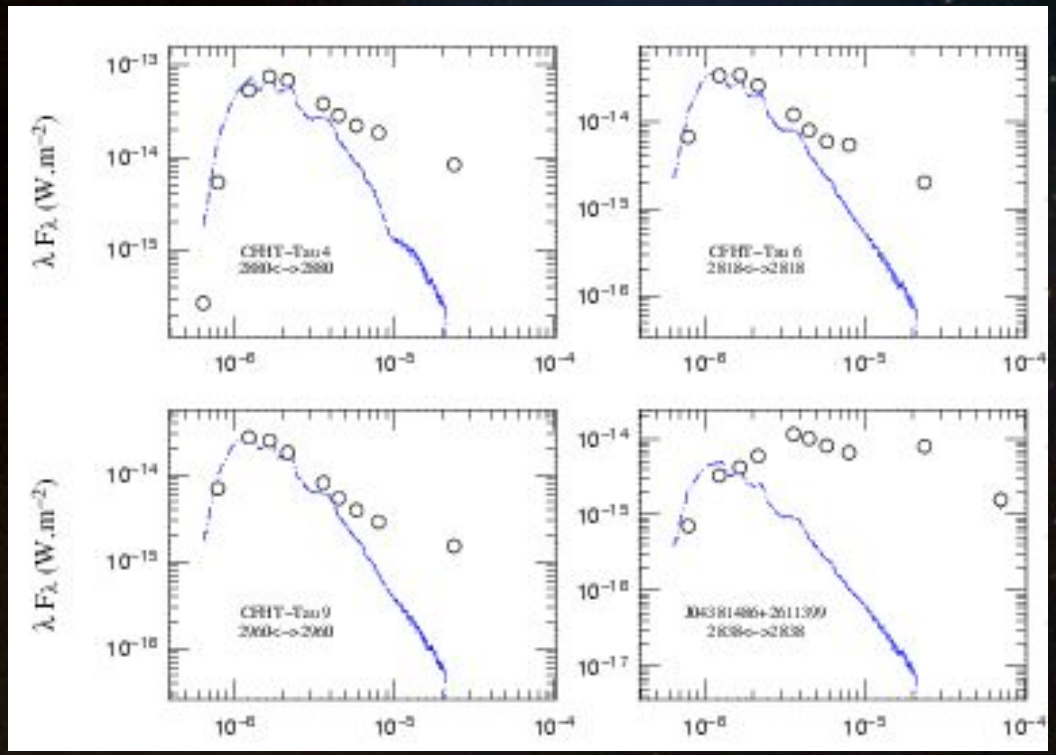
- SDSS spectroscopic scans identified many low mass stars in periphery of Taurus
- Potential new T Tauri stars identified by Hα emission and low gravity lines (cf .Slesnick et al. 2007)
- Out of about 80 candidate young stars, *Spitzer* survey has found MIR excesses for 19

The Optical CFHT Taurus Survey

- PI: Catherine Dougados (Observatoire Grenoble)
- Co-Is: J. L. Monin, F. Menard, J. Bouvier, E. Martin, et al
- 34 deg^2 (overlaps) observed in I, z
- 1400000 point sources; 10% accurate to I = 23
- FWHM ~0.8”; position accuracy 0.3”
- Primarily a brown dwarf survey, but great MK seeing and depth makes very useful for morphological studies

Guieu et al. (2007) CFHT/2MASS/*Spitzer* BD SEDs

- Half of Taurus BD have infrared excess
- This agrees with estimates based on Hα, but some stars with large excess have relatively low Hα
-



XEST = X-ray Emission Survey of Taurus

PI: Manuel Güdel

Co-Is:

- **Kaspar Arzner, Marc Audard, Jerome Bouvier, Kevin Briggs, Elena Franciosini, Nicolas Grosso, Sylvain Guieu, Giusi Micela, Deborah Padgett, Francesco Palla, Ignazio Pillitteri, Luisa Rebull, Luigi Scelsi, Beate Stelzer, Alessandra Telleschi**

Large project with XMM-Newton:

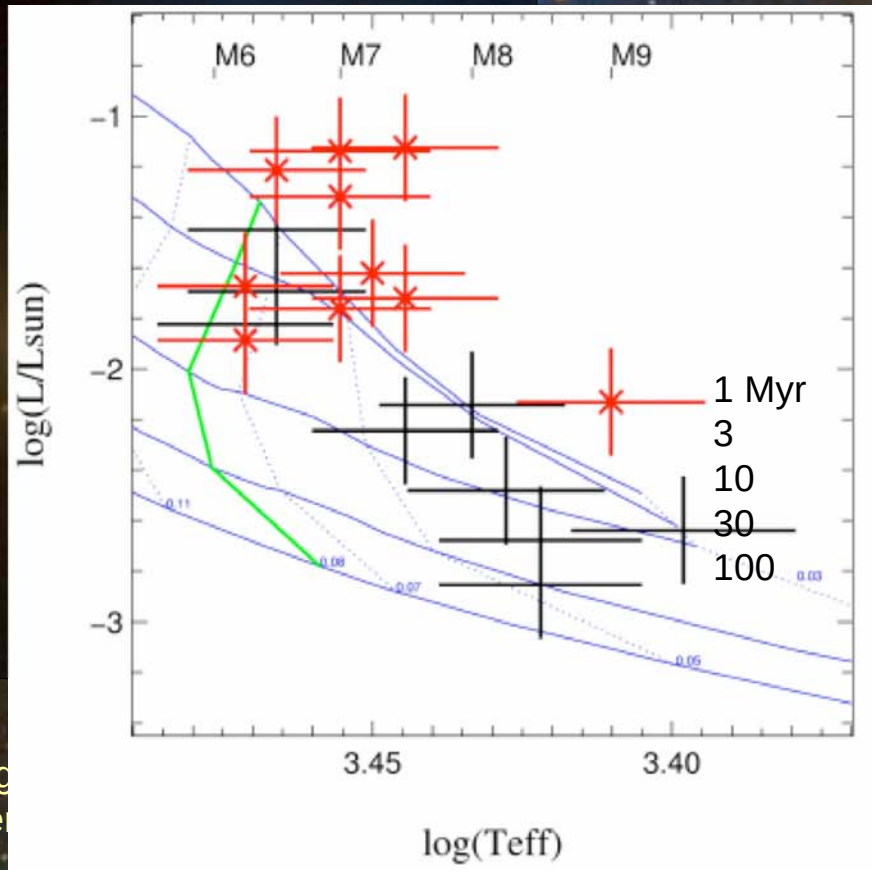
19 exposures @ 30 ksec each (630 ksec total)

8 archival fields

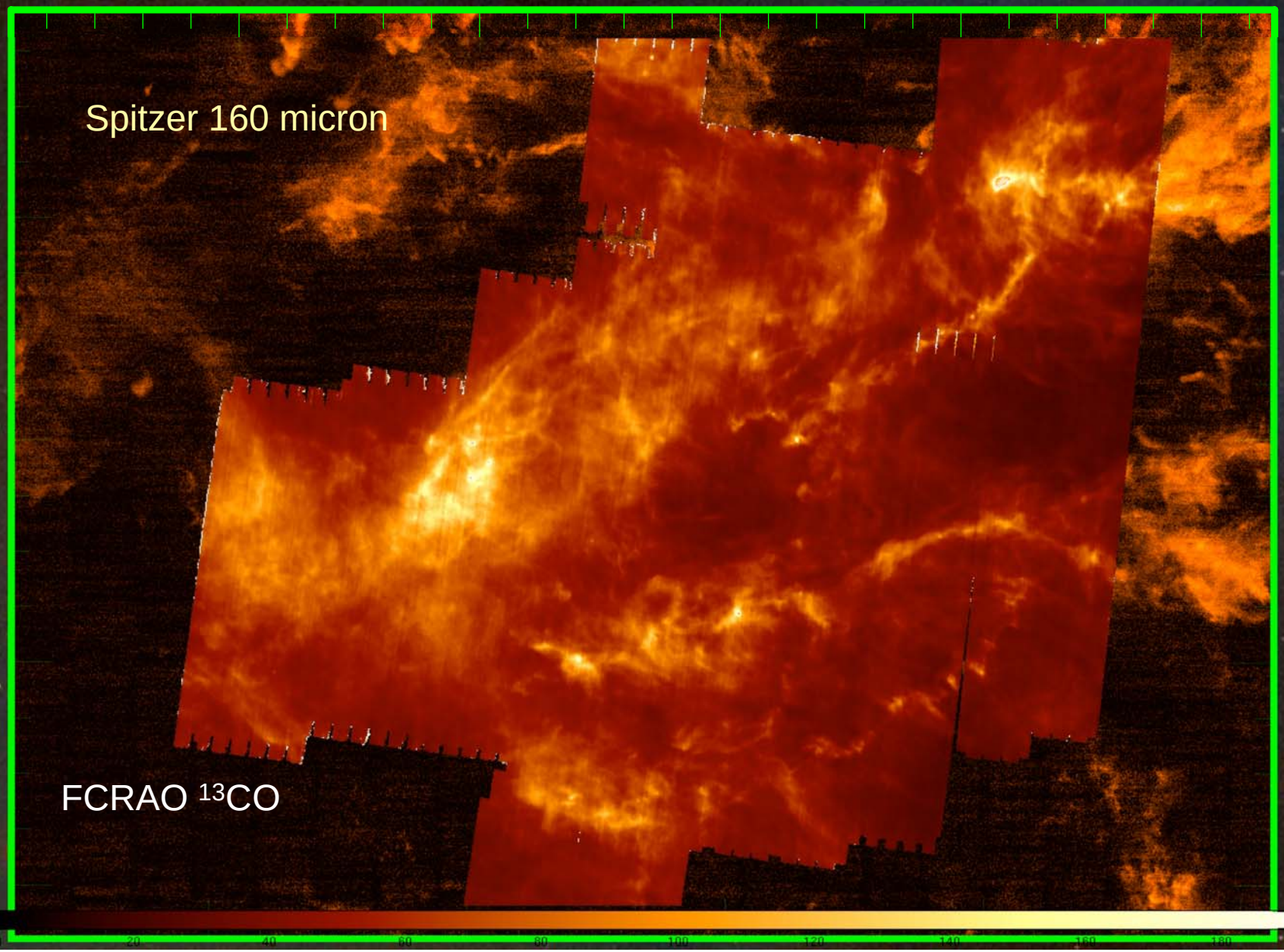
Mapping approximately 5 square degrees of the densest regions in the Taurus Clouds (all new fields within *Spitzer* coverage)

X-ray Brown Dwarfs

Known (bona fide) BDs in TMC: 29
Surveyed here: 19
X-ray detections: 10 = 53%
spec. M6.5-M9
Luminosities from spectral fits:
$L_X \approx 10^{28}$-10^{30} erg s^{-1}
(limiting $L_X \approx 10^{28}$ erg s^{-1})
Not correlated with IR excess



FCRAO ^{13}CO vs. 160 μm



Summary

- Five large area surveys of Taurus have been performed recently using *Spitzer,* CFHT, *XMM-Newton*, SDSS, and FCRAO (also H I)
- Each survey reaches much higher sensitivity levels than previous surveys in their respective bands.
- The individual surveys have taken a census of low luminosity objects. An initial cross-survey paper on brown dwarfs has been published.
- Special session of the AAS on Taurus surveys in Jan.

WISE will cover all of Taurus

- *WISE* launches November 2009
- 40 cm solid H cooled telescope in sun-synchronous orbit
- All sky survey in 3.3, 4.7, 12, 23 microns
- Sensitivities within a factor of a few of the Taurus *Spitzer* survey
- Will finally connect main Taurus clouds with L1551 and other outlying regions