Witnessing Planetary formation? The case of T Chamaeleontis

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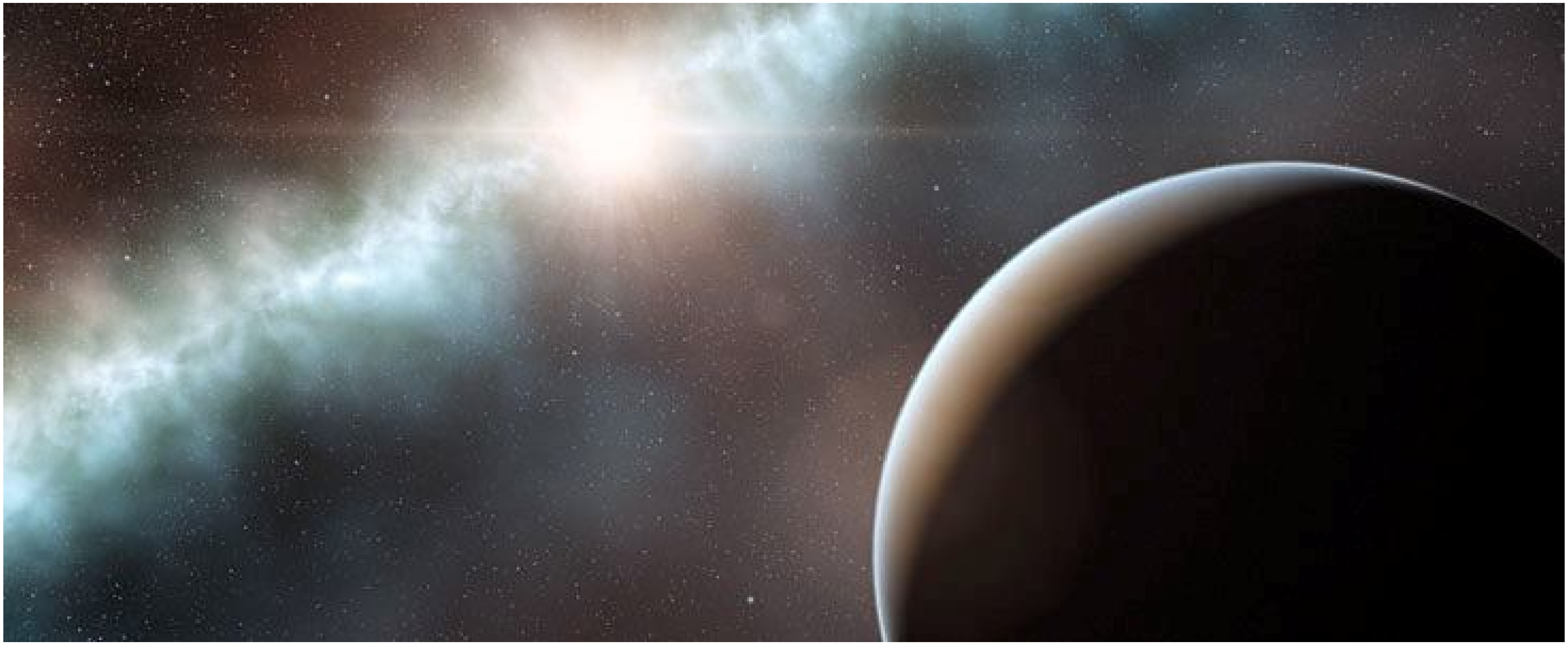
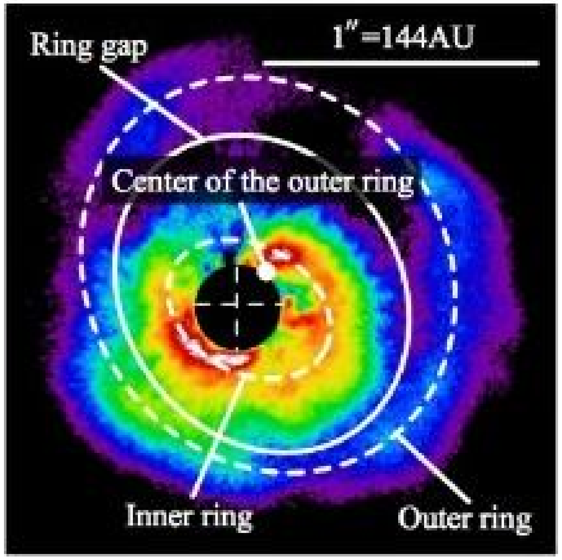


Scientific Background

Circumstellar disks: cradles of planetary systems
Open questions: when and how planets form?

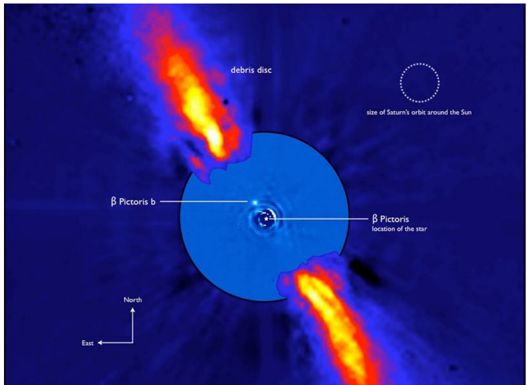
Protoplanetary disks



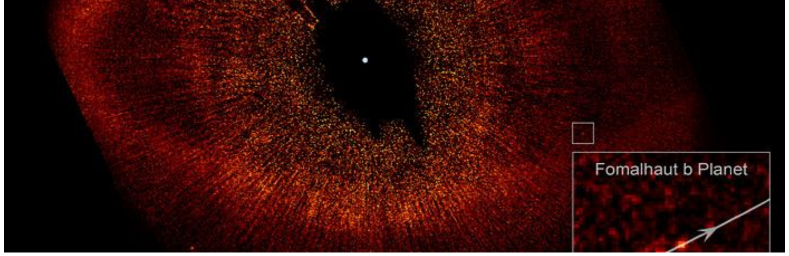
AB Aur (Tamura et al. 2011)

Disk evolution

Debris disks

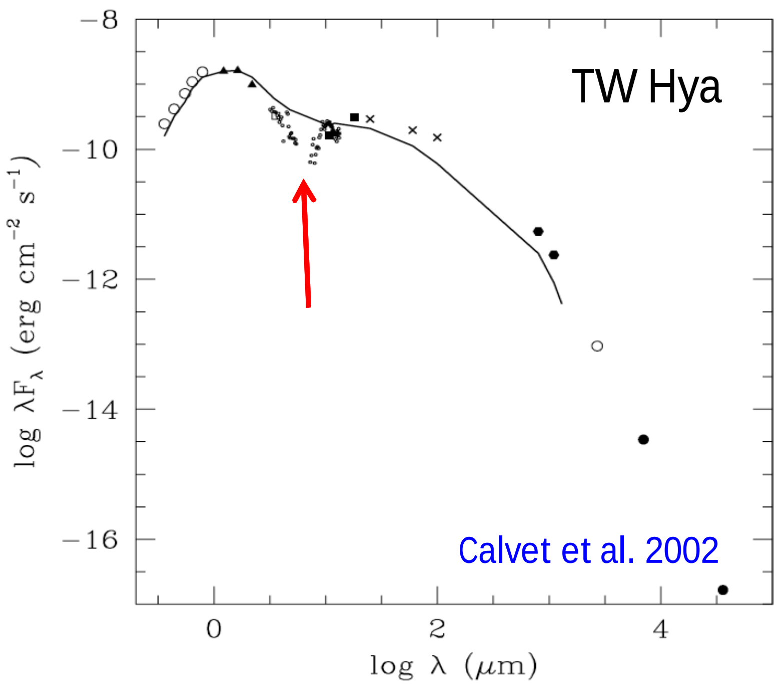


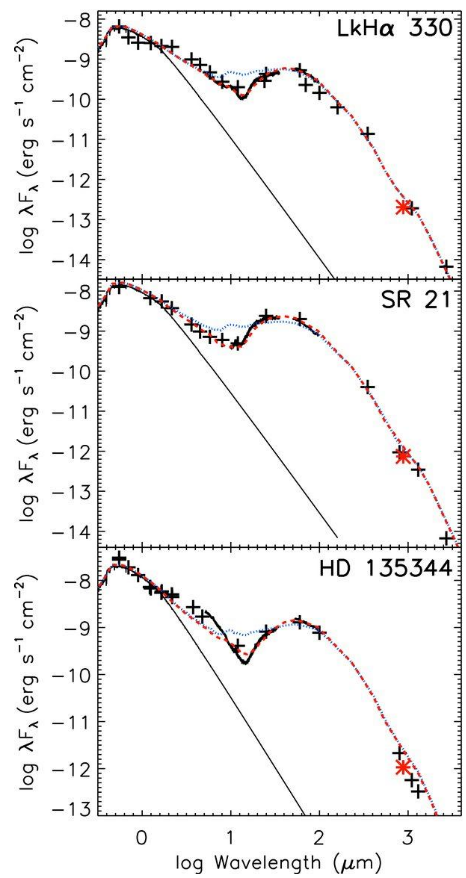
Beta Pic, Lagrange et al. 2010



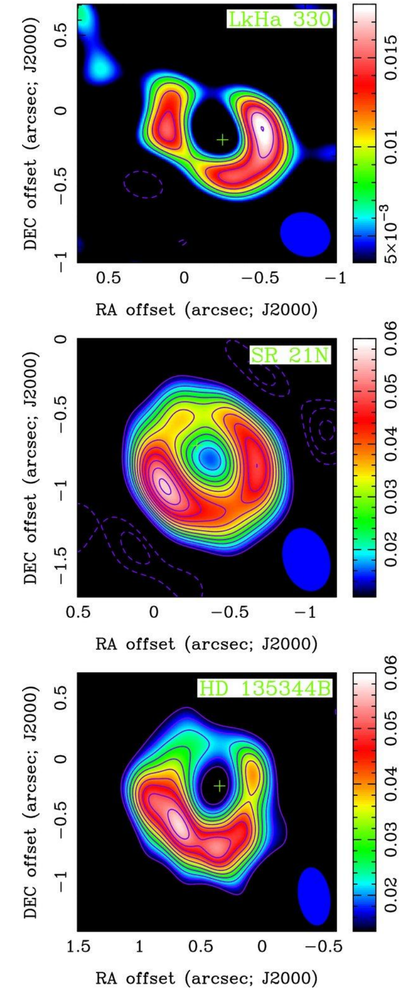
Fomalhaut, Kalas et al. 2008

Transitional disks





Brown et al. 2009



- Transitional disks show a deficit of emission at mid-IR wavelengths
- The most accepted explanation is dust clearing due to inner holes or gaps

Sub-mm obs.

Holes & gaps in circumstellar disks

MECHANISMS	Holes/gaps?	Stellar Accretion
Close binary	Clear out a large hole completely	NO
Planet (< 10 Mjup)	Few dust and gas in a gap	YES, but smaller than in TTS
Photoevaporation	Clear out a large hole completely	NO or very small
Grain Growth	Dust hole filled with GAS	YES, normal

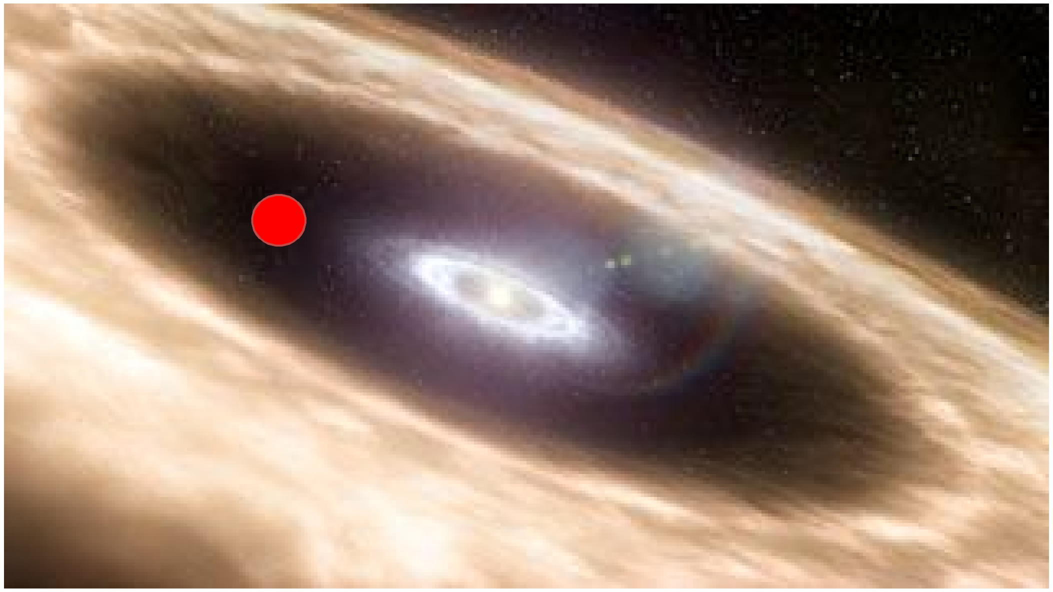
Each mechanism is related with different stellar and disk gap/hole properties

(e.g. Alexander & Armitage 2007, Najita et al. 2007, Pontoppidan et al. 2009)

Our project

- We designed a project to search for companions around stars with transitional disks.

- Our initial sample included 4 stars. T Chamaeleontis was one of them.



T Cha: general properties

The central object

G8-- K1 star

Teff = 5520 K

Mass = 1.3 – 1.5 $M_\odot$ (based on evol. Tracks)

- Strong Lithium absorption line (PMS star)
- Strong Variability – ERRATIC
- Variable H_α line; $M_{acc} = 4.9 \times 10^{-9}$ $M_\odot$/yr

(Alcalá et al. 1993, Schisano et al. 2009)

The Disk

SED modeling: i~60-70 degrees, gap of ~ 14 AU
(Brown et al. 2007, Schisano et al. 2009)

VLTI/AMBER (Olofsson et al. 2011)
Optically thick INNER disk (0.13-0.17 AU) resolved

Herschel data (Cieza et al. 2011)
Peculiar external disk:
either too small, or very steep surface density

Photoevaporation (Pascucci & Sterzik 2009)
Detection of Ne II line in the mid-IR

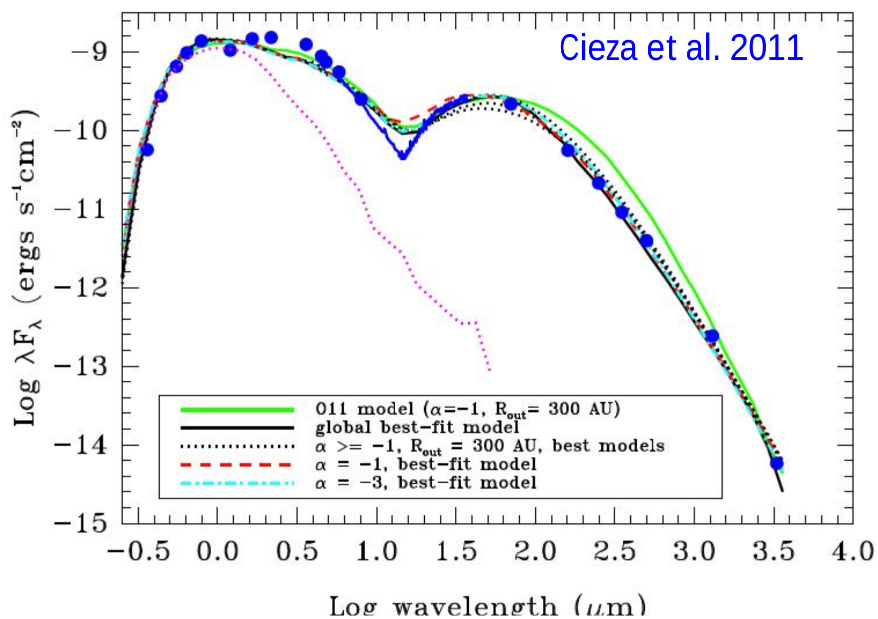
Distance, age, membership

It was thought to belong to one of the Cha clouds, d=160 pc (Alcalá et al. 1993)

Distance: ~100 pc --proper motion study
(Frink et al. 1998)

Membership: High probable member of the ε Cha association (Torres et al. 2008)

We assume 7±2 Myr and 108±9 pc.



Companions around T Cha?

Searching for companions around T Cha:

Optical Radial Velocity techniques:

RV variation with 10 km/s amplitude. Not periodic.

(Schisano et al. 2009)

Direct Imaging Techniques:

NACO/Adaptive Optics observations

(Chauvin et al. 2010, Vicente et al. 2011)

No companions detected

Our observations have to fill the gap between RV and AO direct imaging

(Gap width = 0.17 – 14 AU at 108 pc means 0.002-0.13 arcsec)

NACO/SAM observations

NAOS-CONICA (NACO) + Sparse Aperture Masking (SAM)

NAOS: Adaptive Optics system at the VLT
CONICA: near-IR camera

SAM: Sparse Aperture masking
- Interferometry with a single telescope.

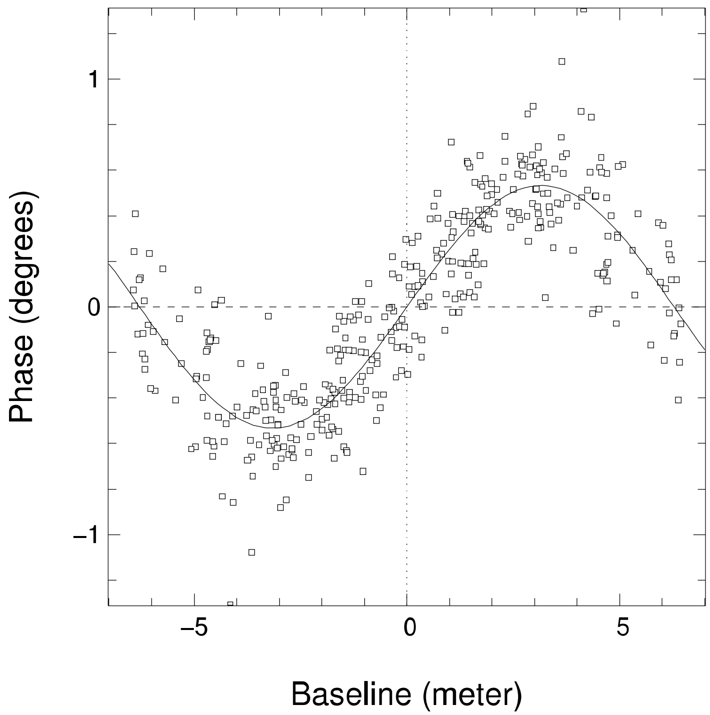
We obtain the best spatial resolution at the diffraction limit of the telescope

NACO data:
L-prime (March 2010, extremely good weather)
Ks (July 2010, moderate to bad weather)
7-hole mask
Pupil tracking mode

- We detected an object in L'
- No object detected in Ks

NACO/SAM L' observations

Fit to a model of a binary system



Best fit:

Sep = 61.8±7.4 mas

PA = 78.5 ±1.2 deg

FR = 0.009 ± 0.002

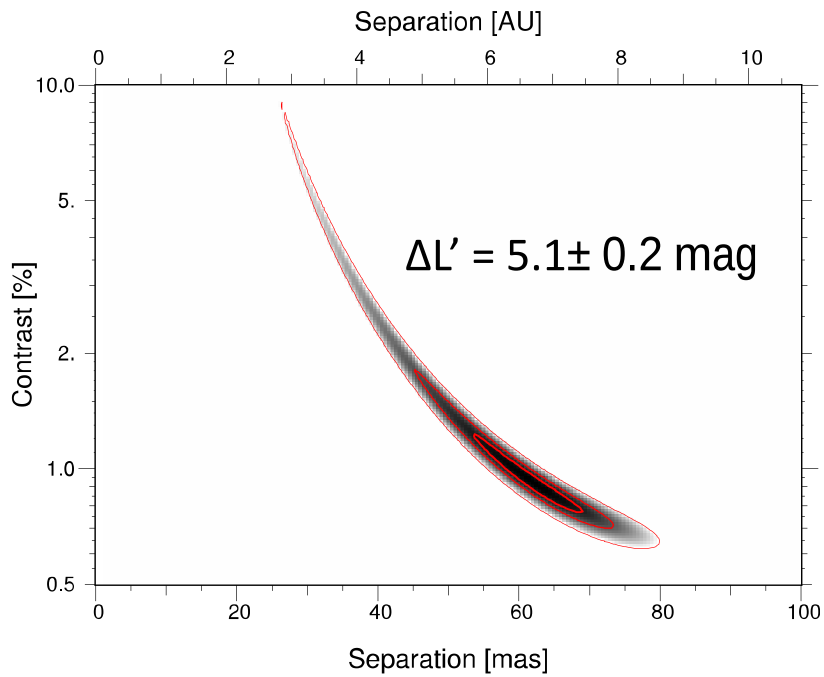
3 free parameters:

Flux ratio, Separation and PA

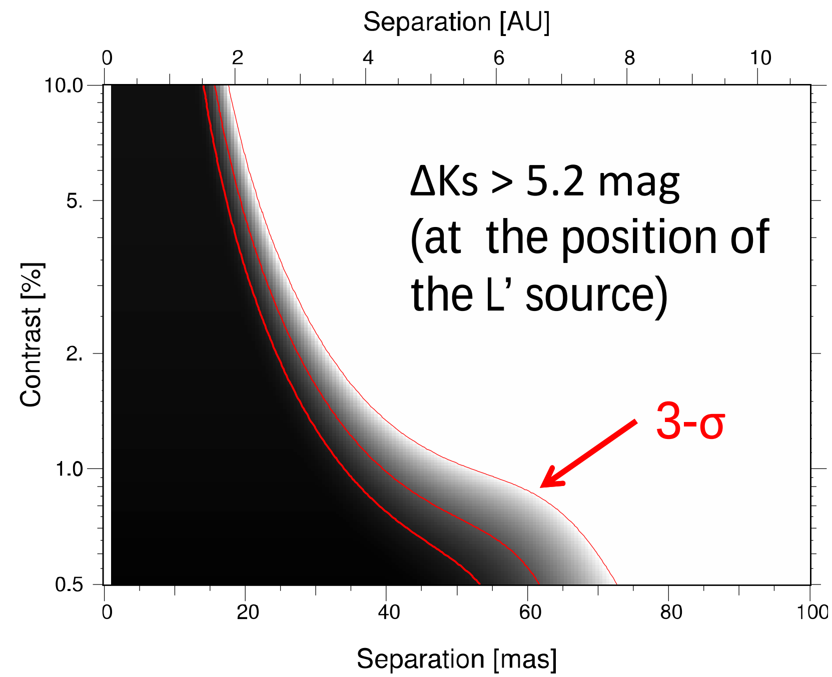
d = 108+- 9 pc --> Projected separation= 6.7± 1 AU

NACO/SAM contrast

Contrast in L’



Contrast in Ks

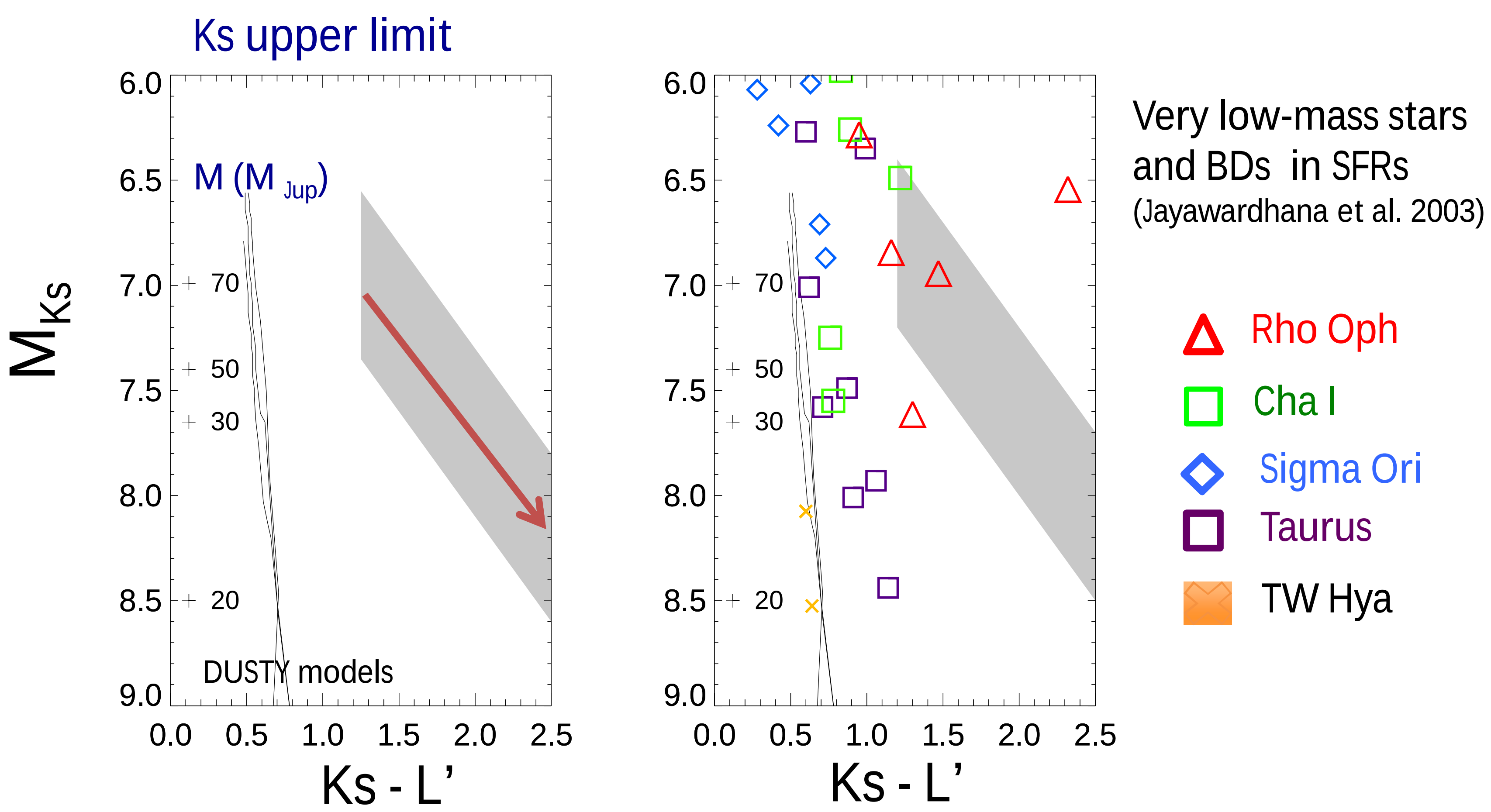


[T Cha b]

L’ = 10.9 ± 0.2 mag

Ks > 12.15 mag

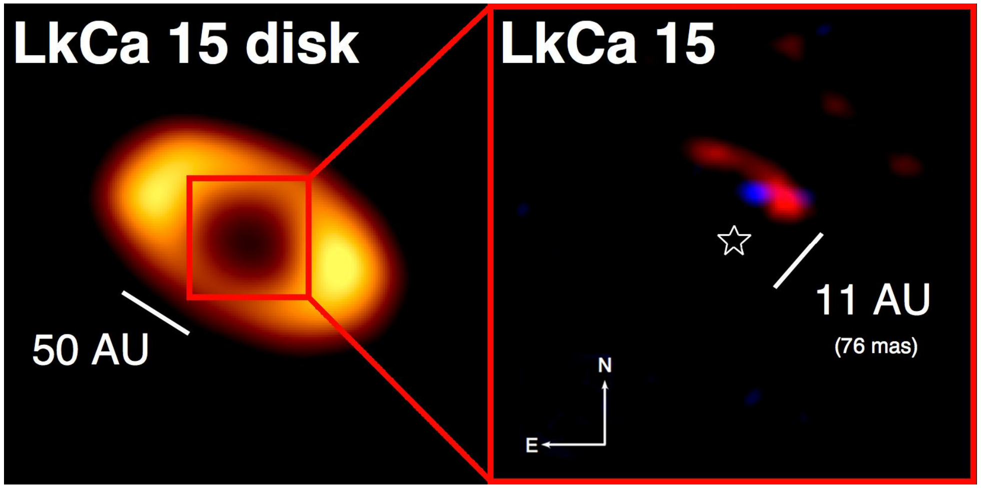
Data Analysis: mag-color diagram



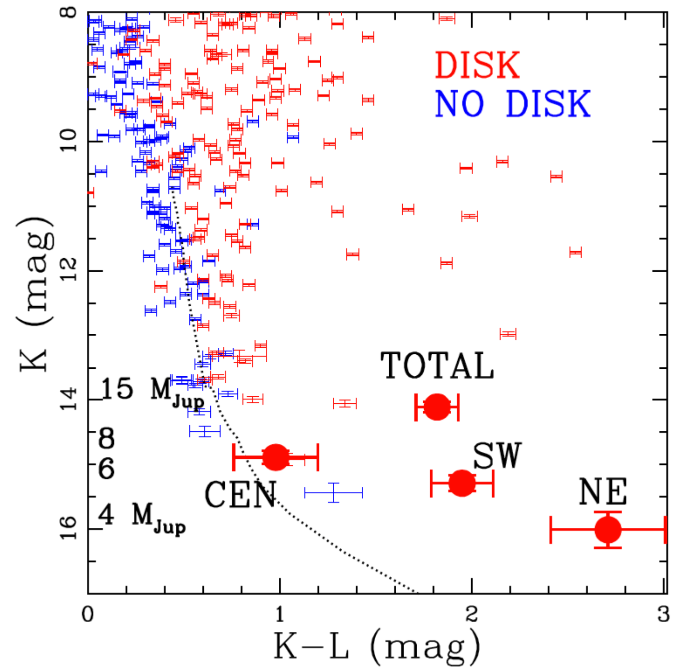
-- Extremely red K_s-L' color: excess due to dust around the source?

-- Ks upper limit: Mass in the substellar regime

Lk Ca 15: mag-color diagram



Kraus & Ireland 2011



- Another substellar companion detected within a transitional disk in Taurus
- Similar photometric properties as T Cha b

T Cha disk:
ATCA high-resolution observations

In order to resolve spatially the dust emission from T-Cha disk (size ≤1”), we need high-resolution and high-sensitivity observations.

Australia Telescope Compact Array

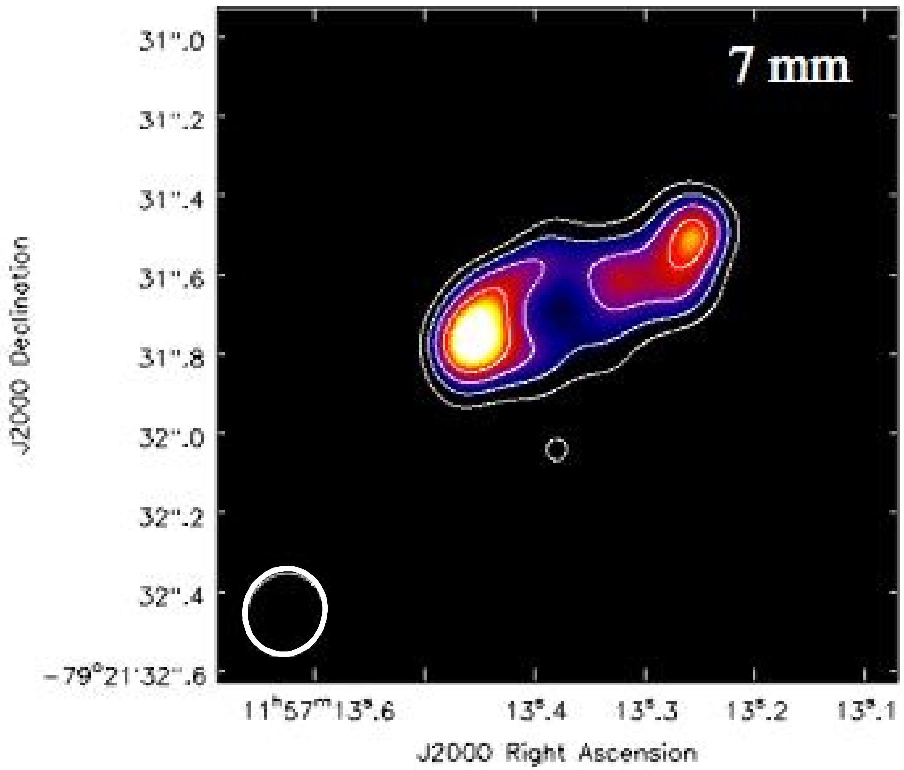
We performed 36 hours observations with ATCA interferometer at 3mm, 7mm and 1.7 cm.

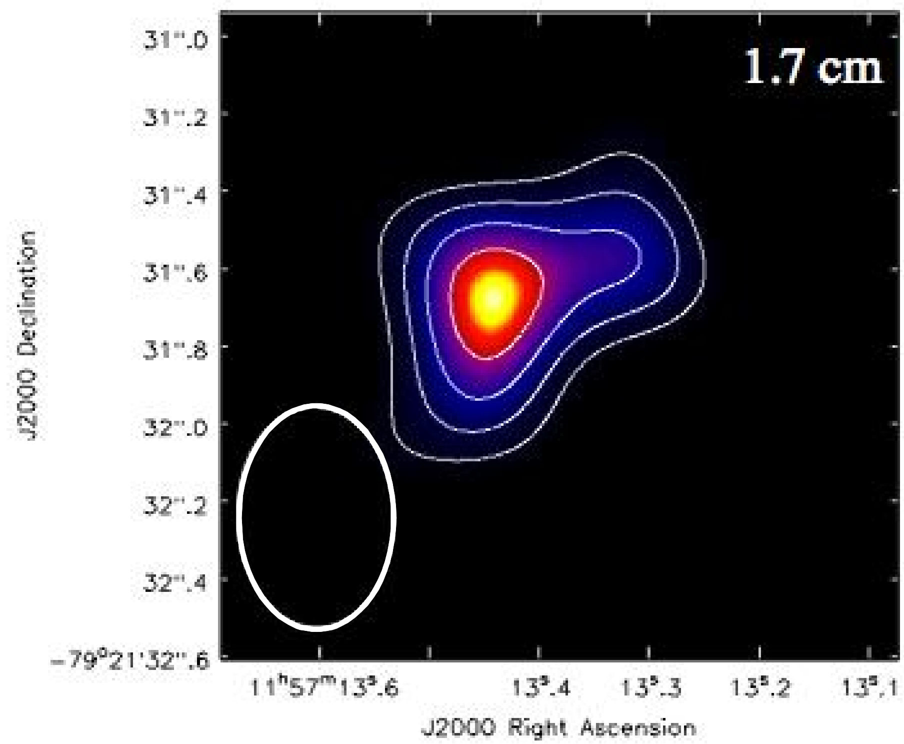
Aims: To study the morphology and physical properties of the dusty disk surrounding T-Cha.

- Millimeter wavelengths trace thermal emission from dust.
- Centimeter wavelengths traces mostly free-free radiation from winds.

Only observations at 7 mm and 1.7 cm were successful due to bad weather conditions.

T-Cha emission at 7 mm and 1.7 cm





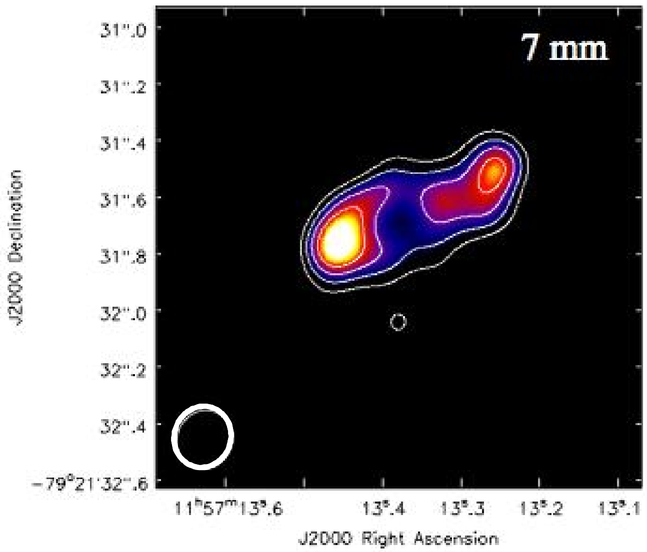
7 mm observations:

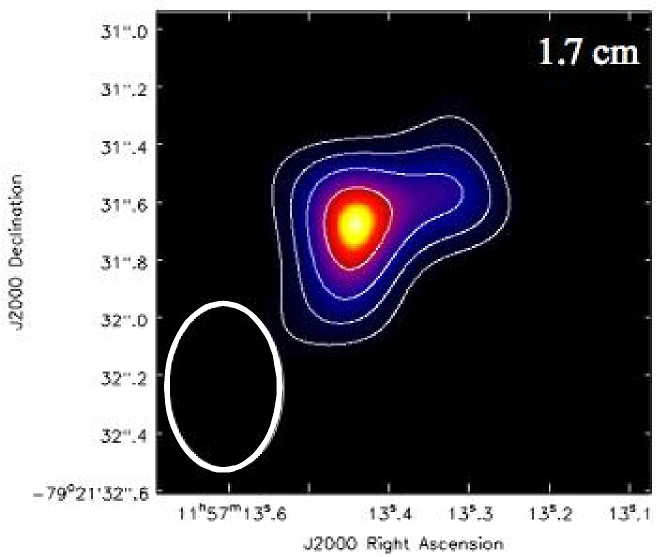
- Disk detected at 14σ (rms = 0.03 mJy)
- Spatially resolved (beam 0.2" x 0.2")
  1" size → 94 AU

1.7 cm observations:

- Disk detected at 7σ (rms = 0.02 mJy)
- Barelly resolved in the main axis
  (beam 0.6" x 0.4")
- Traces the same structure observed
  at 7mm.

T-Cha emission at 7 mm and 1.7 cm





Spectral indexes:

$\alpha_{1.3\text{-}3.3\ \mathrm{mm}} = 2.9 \pm 0.6$	Thermal dust emission (from literature)
$\alpha_{3.3\text{-}7\ \mathrm{mm}} = 2.6 \pm 0.8$	Thermal dust emission

(2.9 after correction from 20% of free-free emission; Rodmann 2006)

$\alpha_{7\text{-}17\ \mathrm{mm}} = 1.5 \pm 0.6$	Dust emission + free-free

Dust opacity law $\beta=(\alpha_{(3.3\text{-}7)}-2) \leq 1$, can be naturally explained by grain growth to mm and cm size

(Beckwith & Sargeant 1991)

Gregorio-Monsalvo et al., in prep.

Physical parameters of the disk

ATCA observations

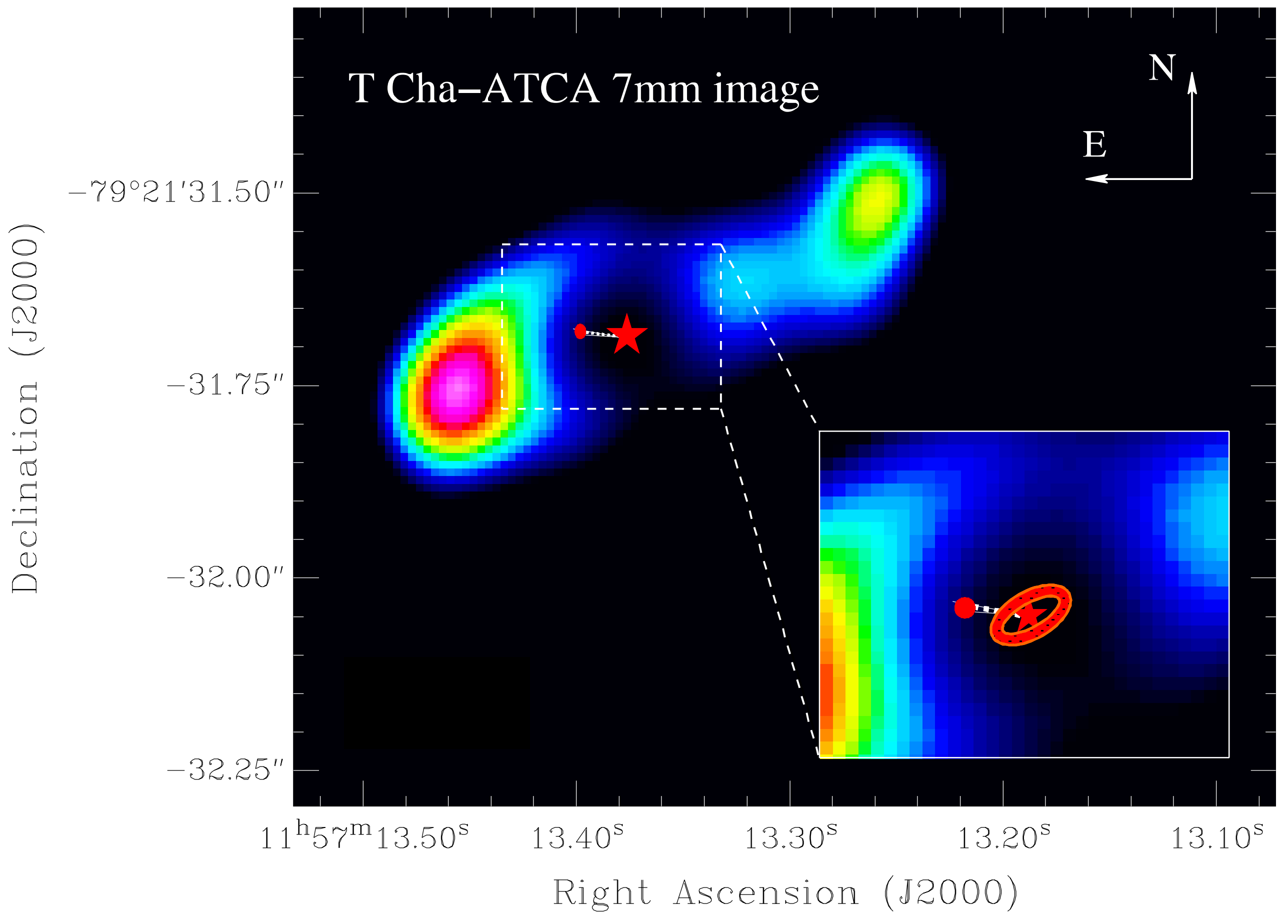
R_{ext}= 47 AU
R_{hole}= 14 AU
i= 68 deg.
P.A. = 117 deg
p = 0.95
β = 1
K_{7mm}= 0.0044 cm^2 gr^{-1}
M_{disk} = 0.7 M_{Jup}

Cieza et al. 2011 models

R_{ext} = 20 - 300 AU
R_{hole}= 10 - 18 AU
i= 75 deg.
p = 0.75 – 3
M_{disk} = 100 – 2 M_{Jup}

Our observations constrain directly some of the degenerated parameters in the theoretical models from the literature (see more info in de Gregorio-Monsalvo et al. poster).

The T Cha system



R_{ext}= 47 AU

R_{gap}= 14 AU

i= 68 deg.

P.A. = 117 deg.

T Cha b

Deprojected separation.

12 AU

- External radius and inner gap are resolved.
- There is still some dust within the disk gap
- T Cha b lies within the gap

The nature of T Cha b

Formation Scenarios?

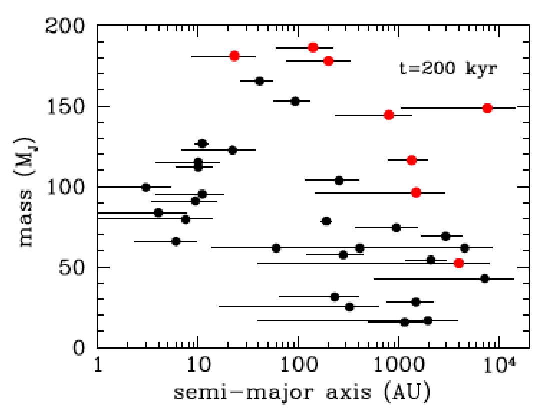
1. star-like scenario

Simultaneous formation of a binary with small ‘q’, and:
- circumbinary disk
- circumsubstellar disk
- and preserving the inner disk.

2. disk fragmentation

- Low-mass stars and massive BDs found at small separations
- Low-mass BDs are ejected.

(Stamatellos & Withworth 2009)



3. Core accretion

Recently formed planet

- Evol. Tracks not valid
- Accretion Luminosity

- Red color – dust around protoplanet, confined within the Hill sphere, and being accreted by the object.
- Consistent with the stellar accretion rate
- Dust within the gap

Conclusions

- SAM/NACO is a powerful instrument to look for companions within transitional disks. It fills the gap between RV and direct imaging techniques

- T Cha shows a companion candidate that is probably the first substellar object detected within the gap of a transitional disk.

- We have spatially resolved the disk using ATCA. The disk is warped and shows structures within it. We have derived parameters previously unconstrained

- We are already analyzing NACO/SAM second epoch observations of T Cha

- We will learn more about the disk with ALMA observations.