YSO environments
The VLTI view

Myriam Benisty
IPAG, Grenoble

Outline

1. The inner AU

2. Herbig Ae Be stars

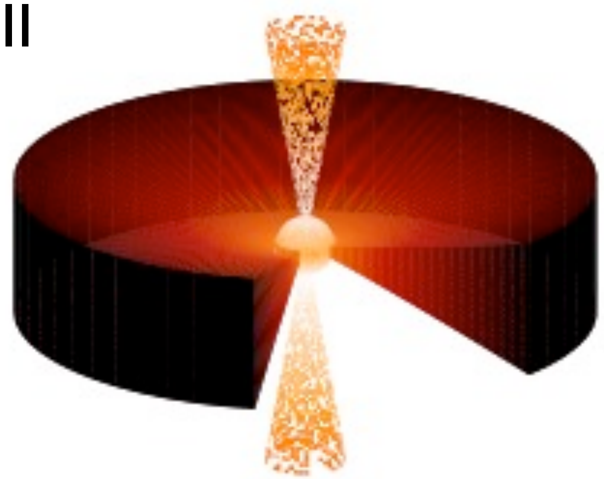
3. Transition disks

4. Massive YSO & Multiplicity

5. Perspectives

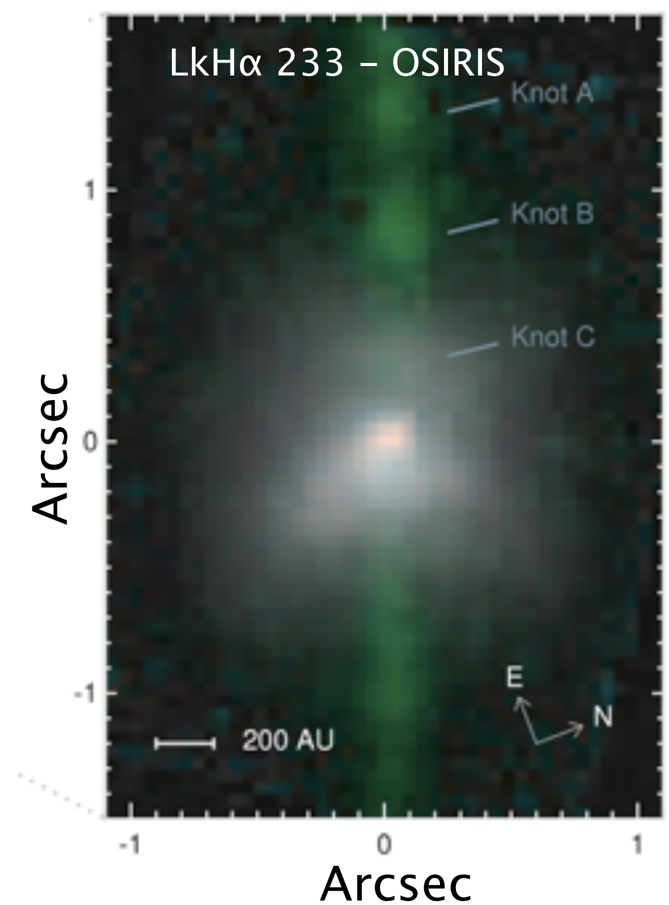
Disks & Jets

Class II



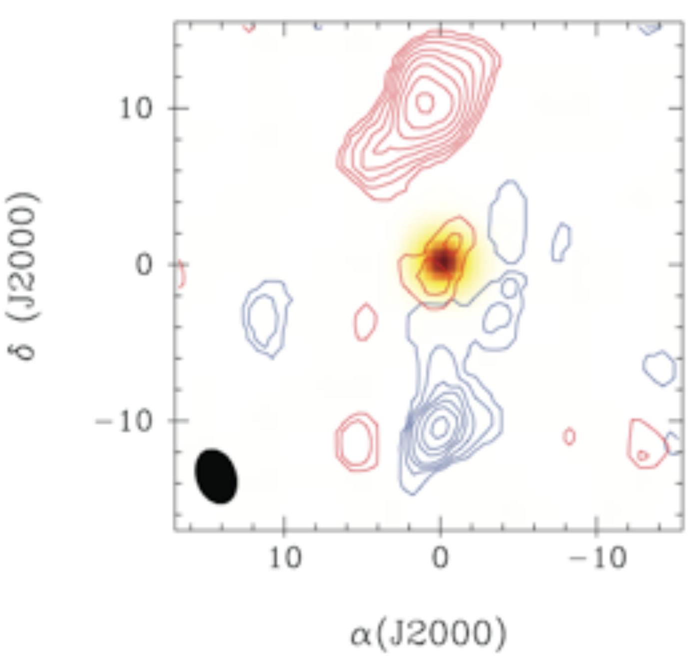
Massive YSO ?

Herbig AeBe stars B-F



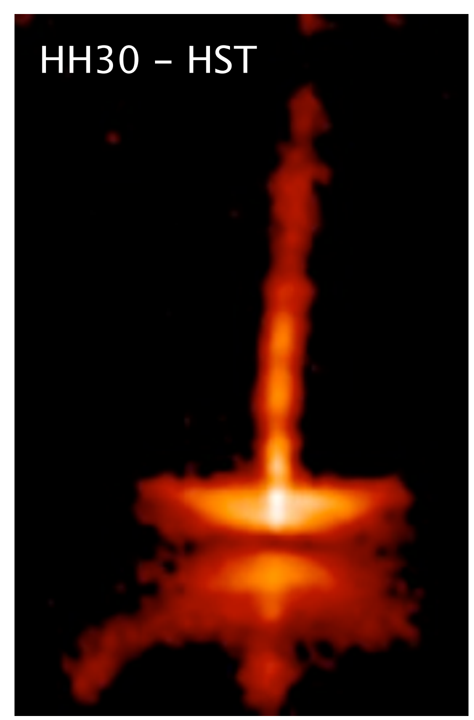
[Perrin et al. 2007]

Brown dwarf M-T



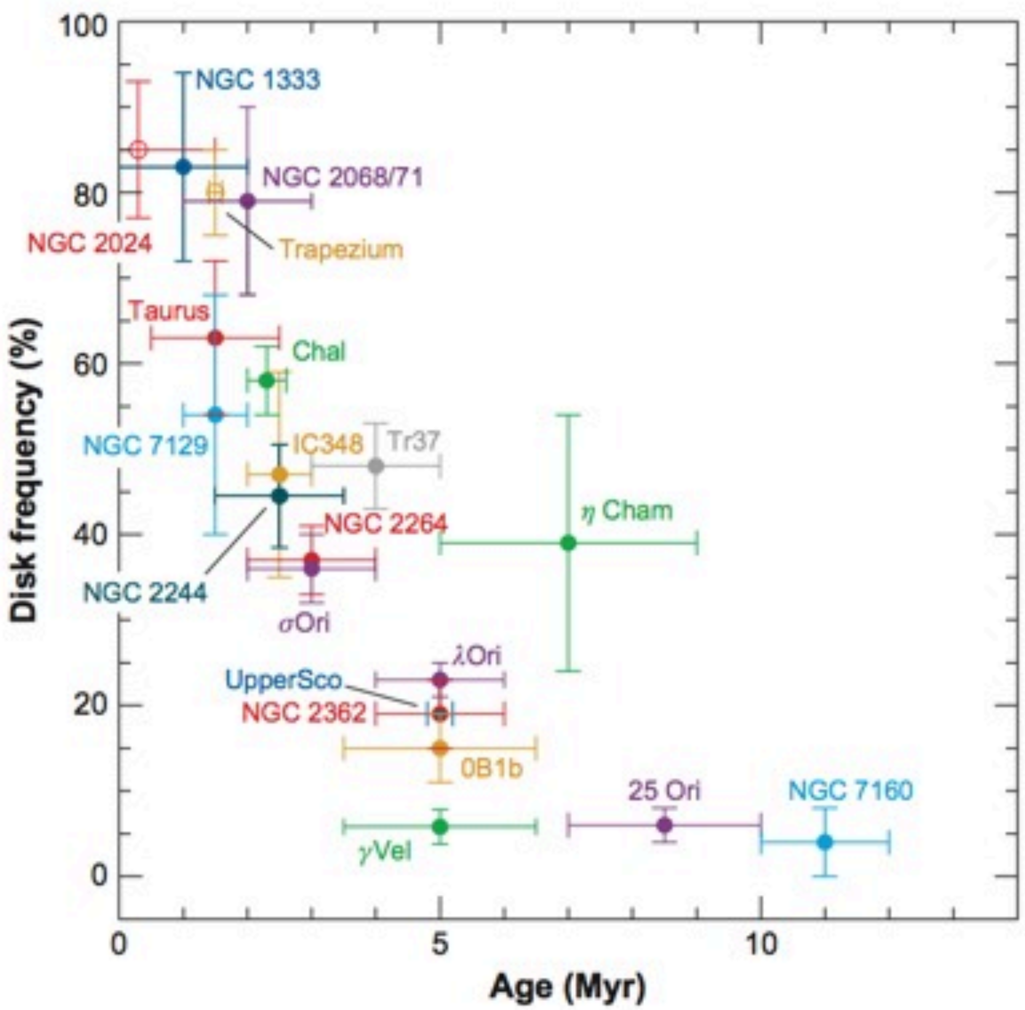
[Phan-Bao et al. 2008]

T Tauri stars G-M

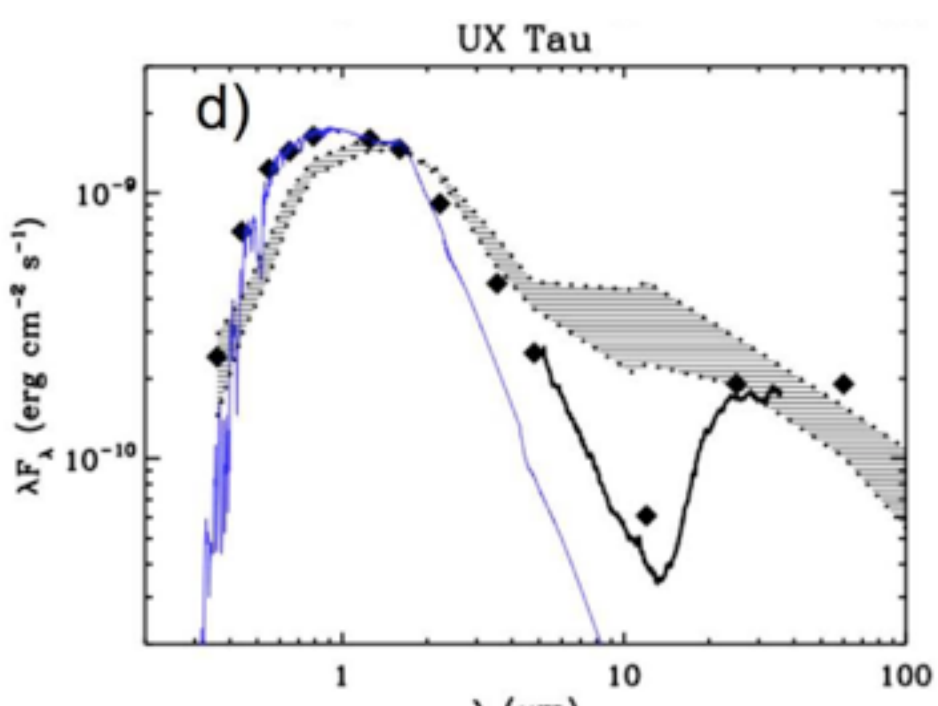


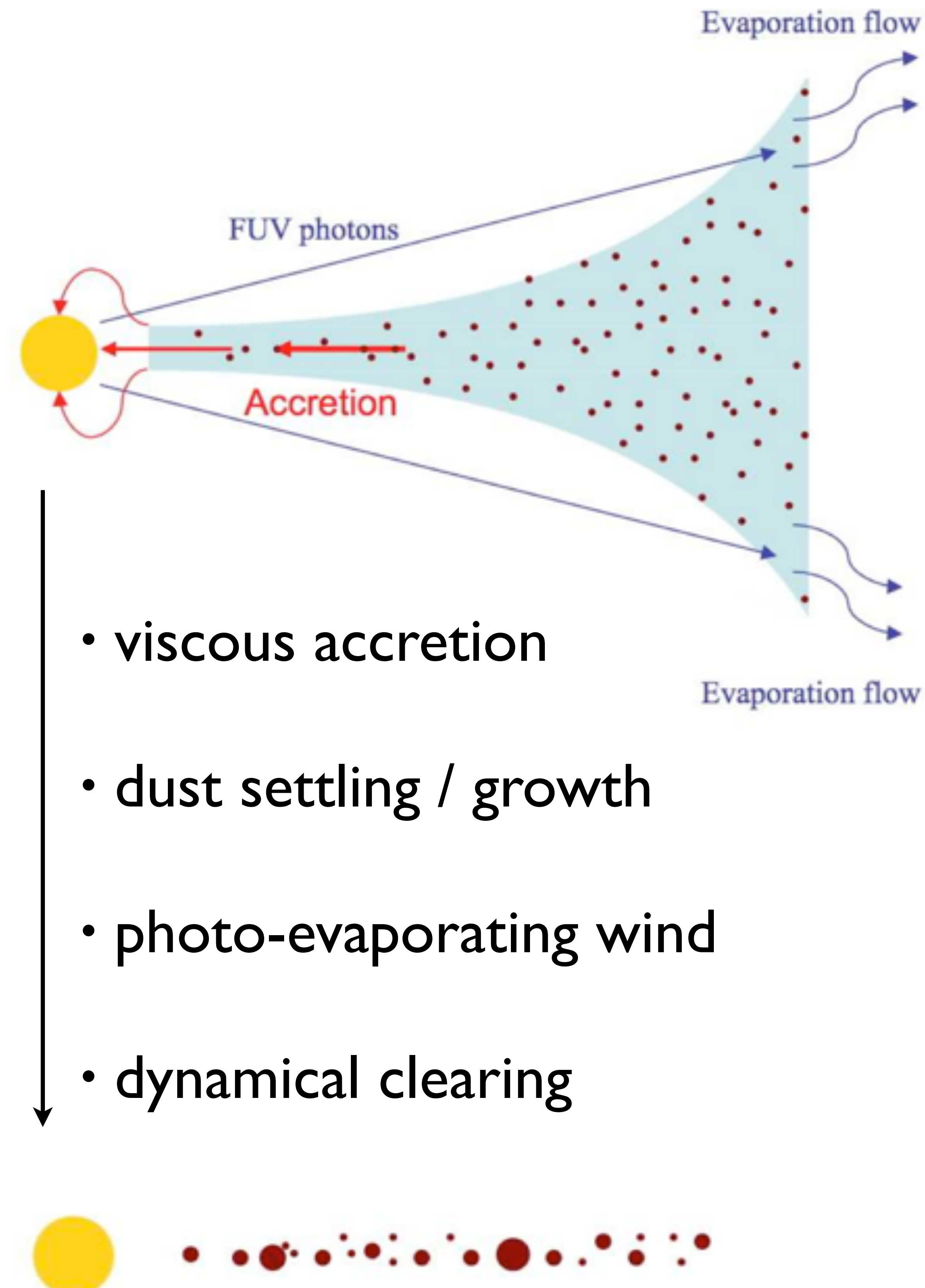
Universal link within the first AU

Disk evolution



[Wyatt et al. 2008]

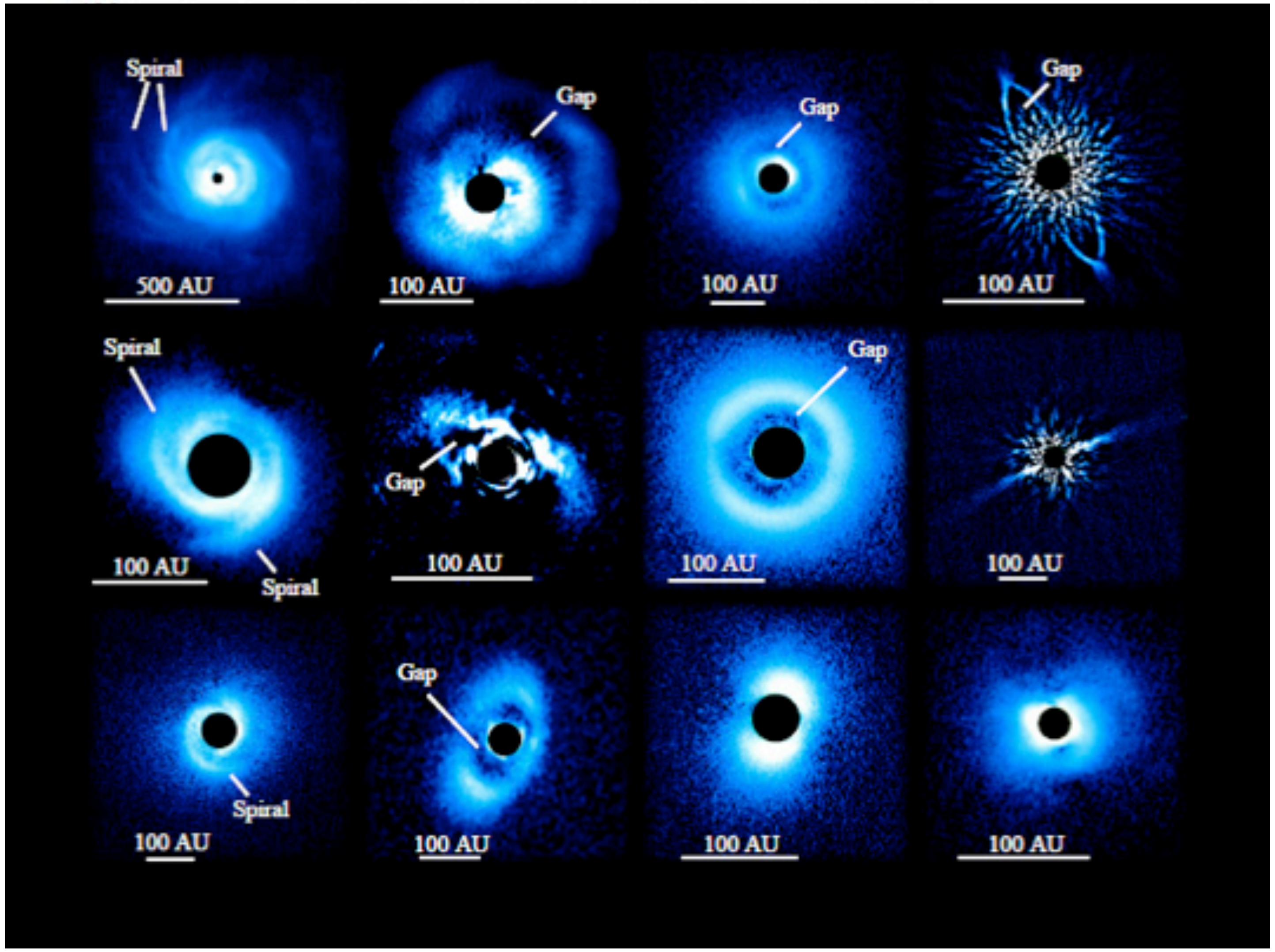


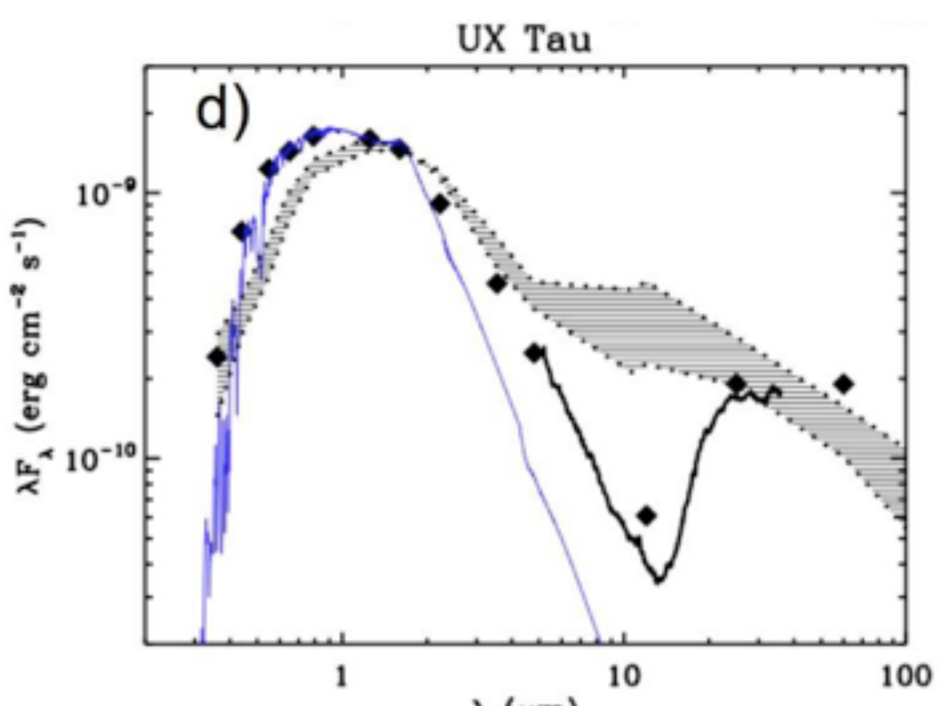


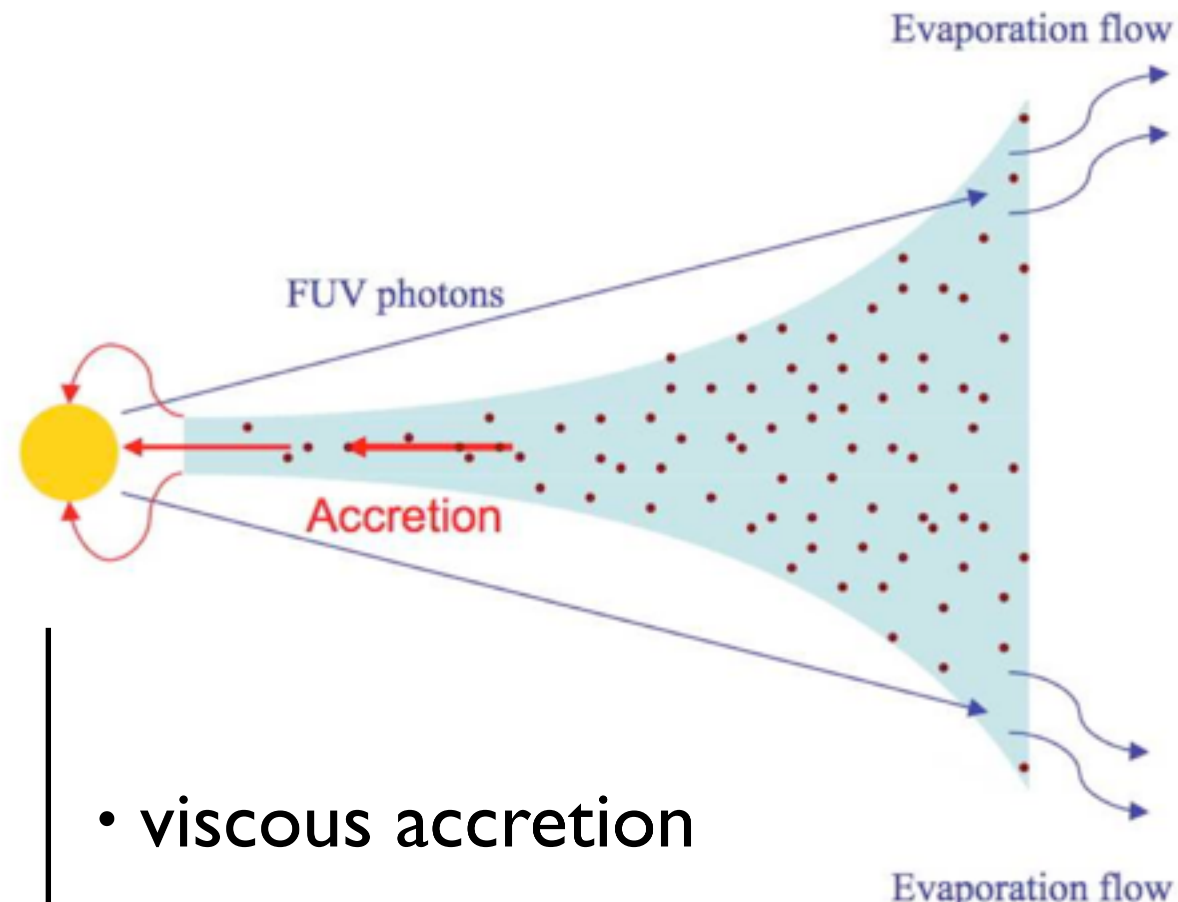
- viscous accretion
- dust settling / growth
- photo-evaporating wind
- dynamical clearing

[Williams&Cieza 2011]

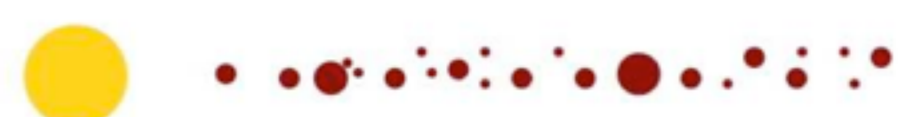
Disk evolution







- viscous accretion
- dust settling / growth
- photo-evaporating wind
- dynamical clearing



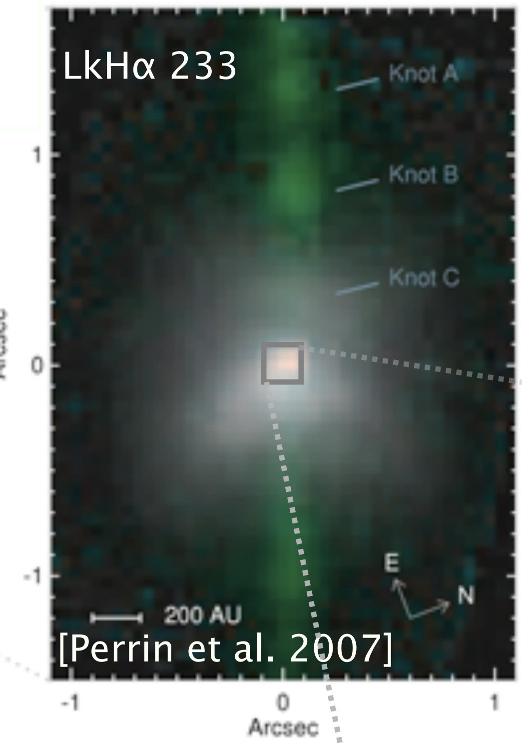
[Williams&Cieza 2011]

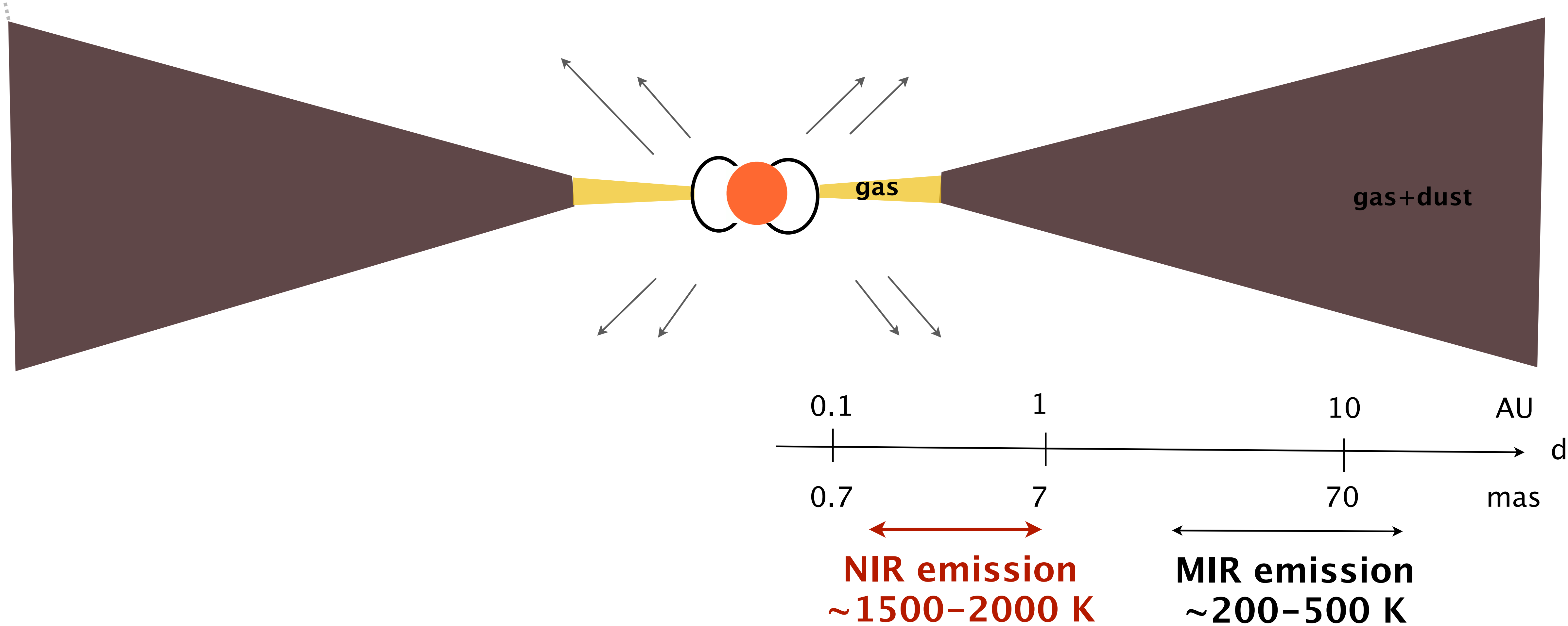
The inner AU

Jet launching and collimation zone.

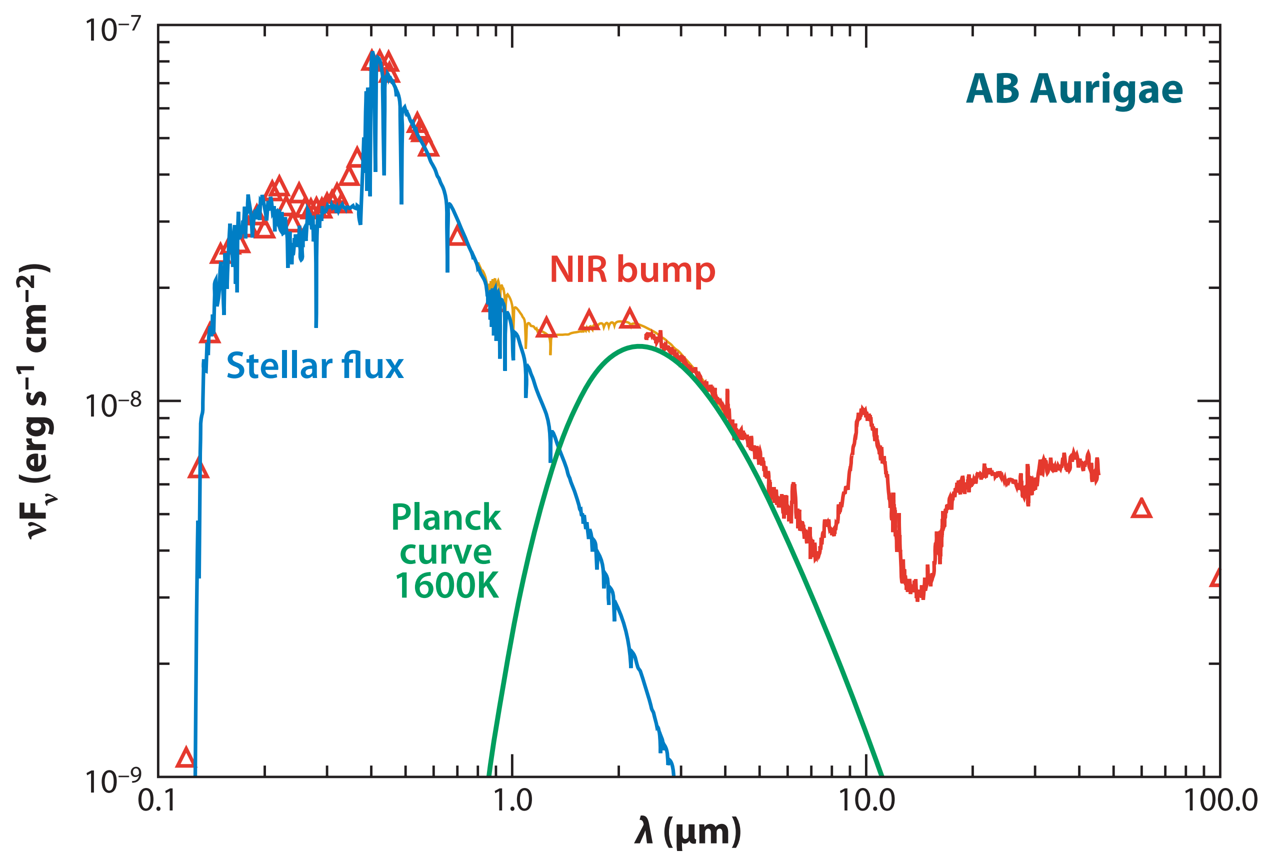
Dust sublimation and accretion zone.

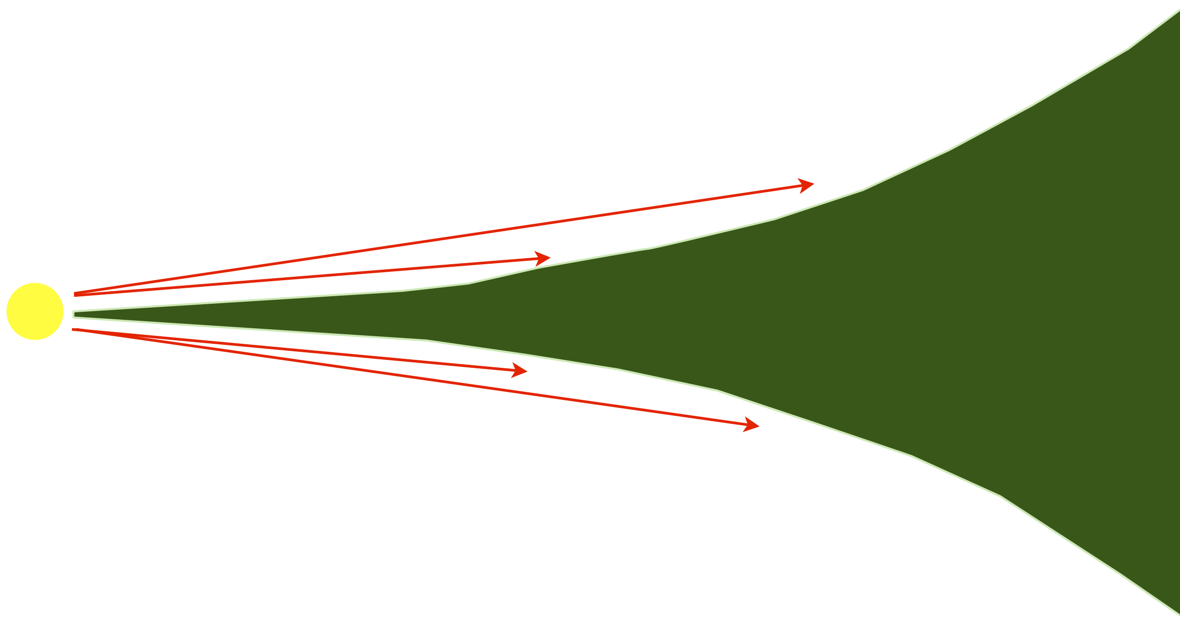
Conditions for planet formation.





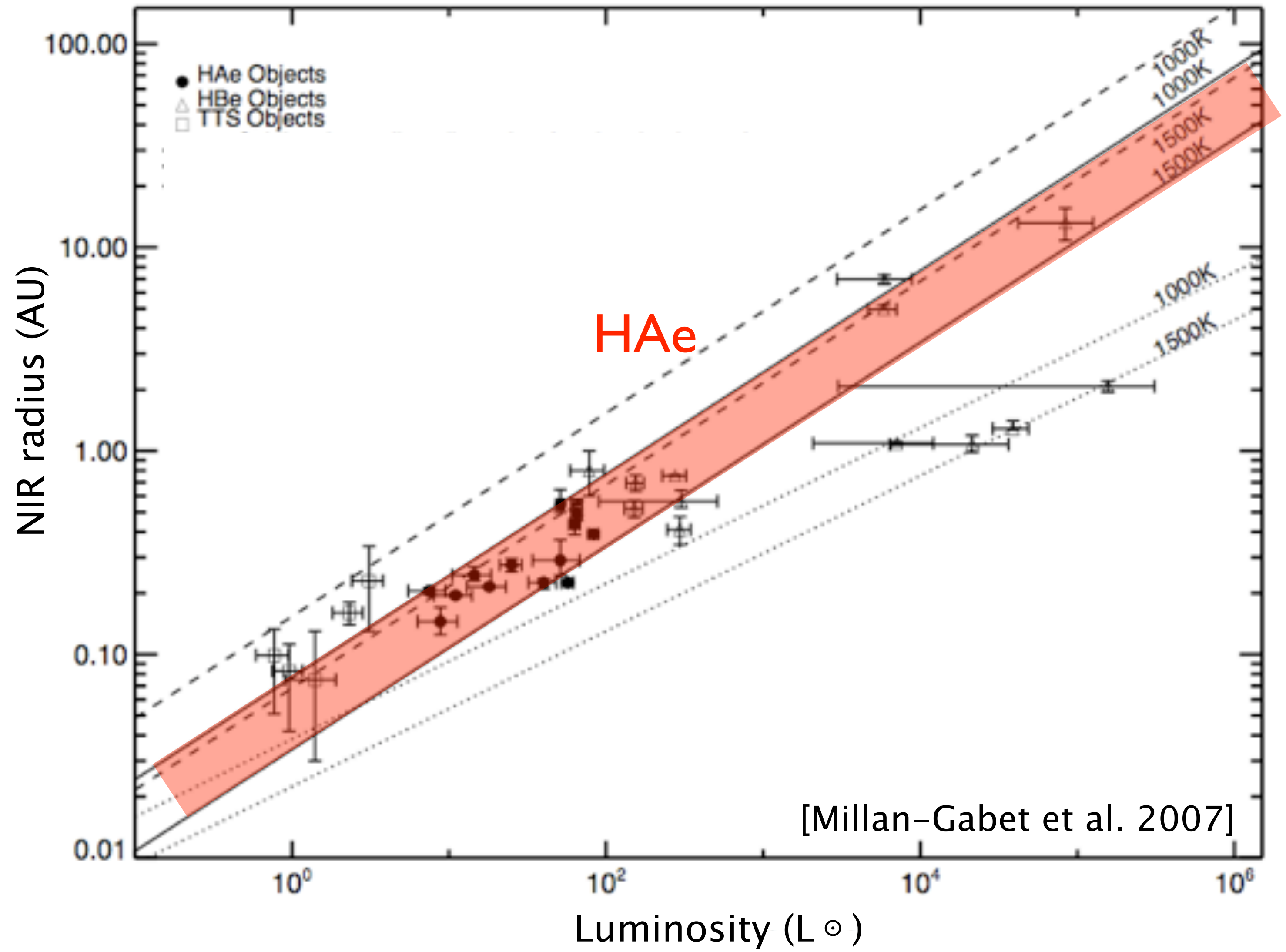
NIR Sizes



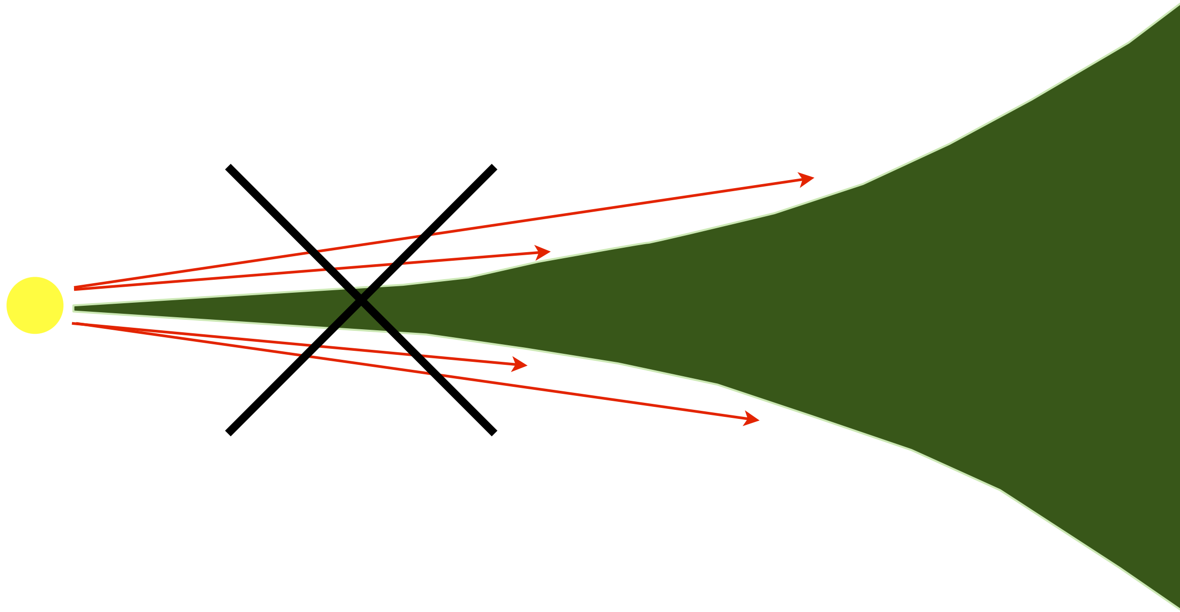


[Lynden-Bell & Pringle 1974
Chiang & Goldreich 1997]

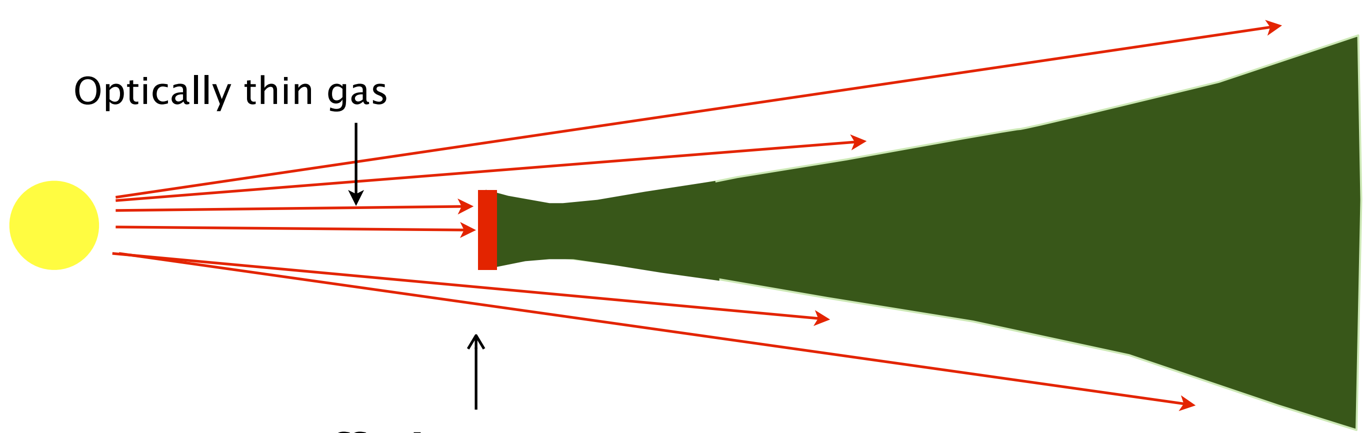
NIR Sizes



$R_{NIR} \propto L_*^{1/2} \propto R_{sub}$



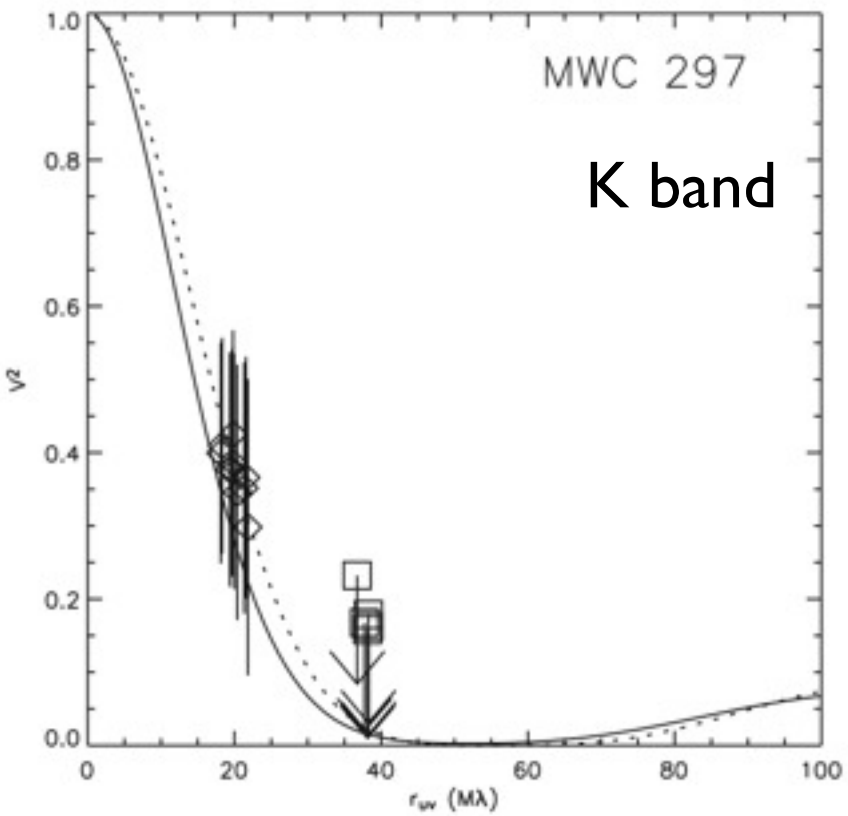
[Lynden-Bell & Pringle 1974
Chiang & Goldreich 1997]



Before the VLTI :
Measurements of NIR sizes
What is the rim shape?

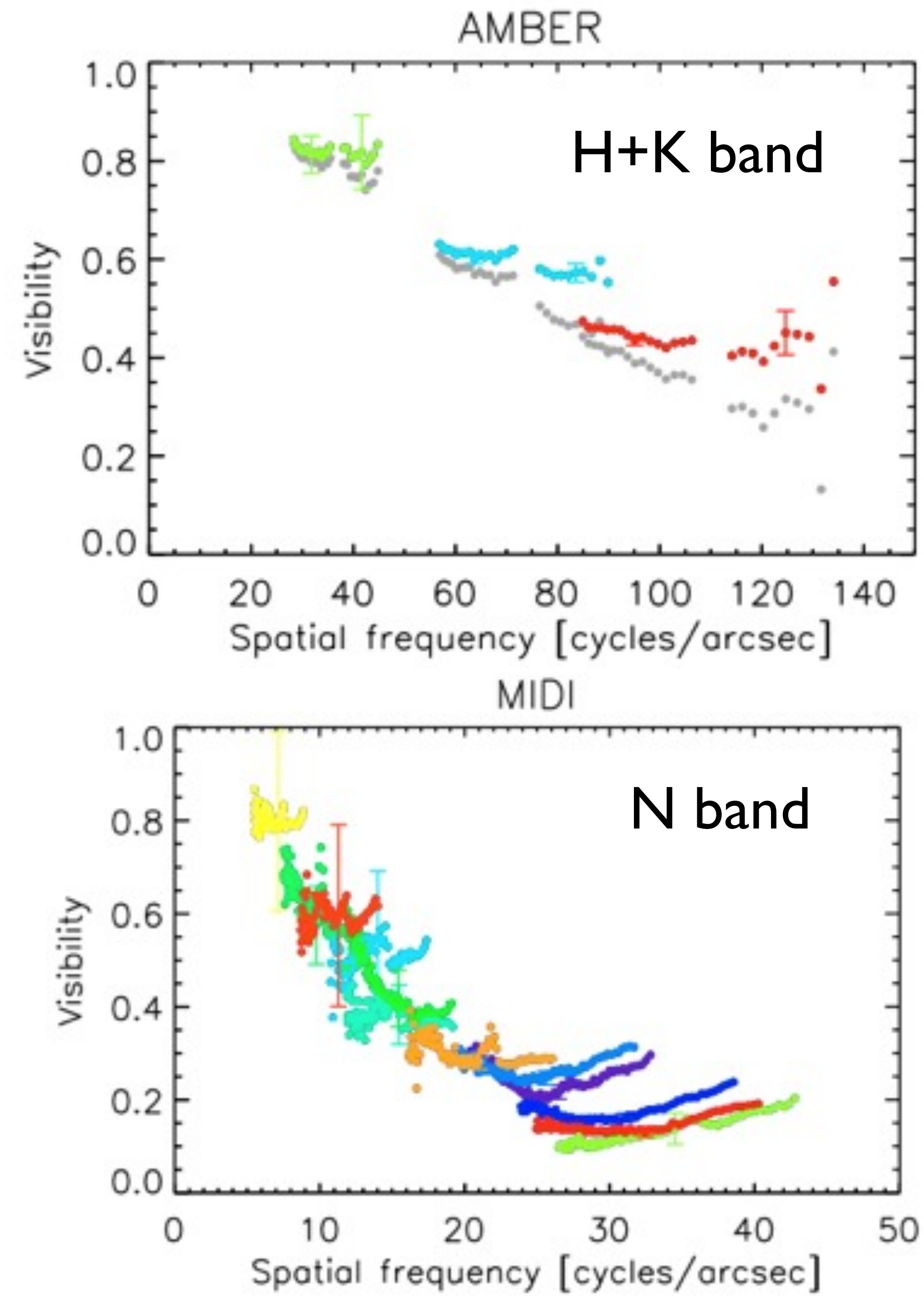
Dullemond, Dominik & Natta 2001, Isella & Natta 2005

Before VLTI



Eisner et al. 2004

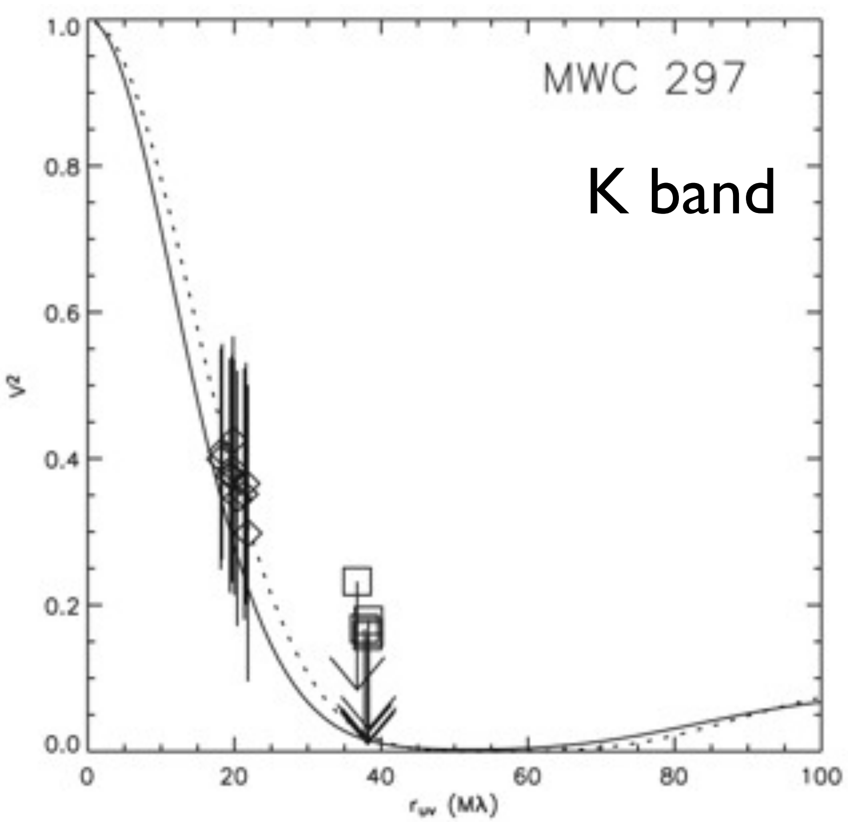
VLTI



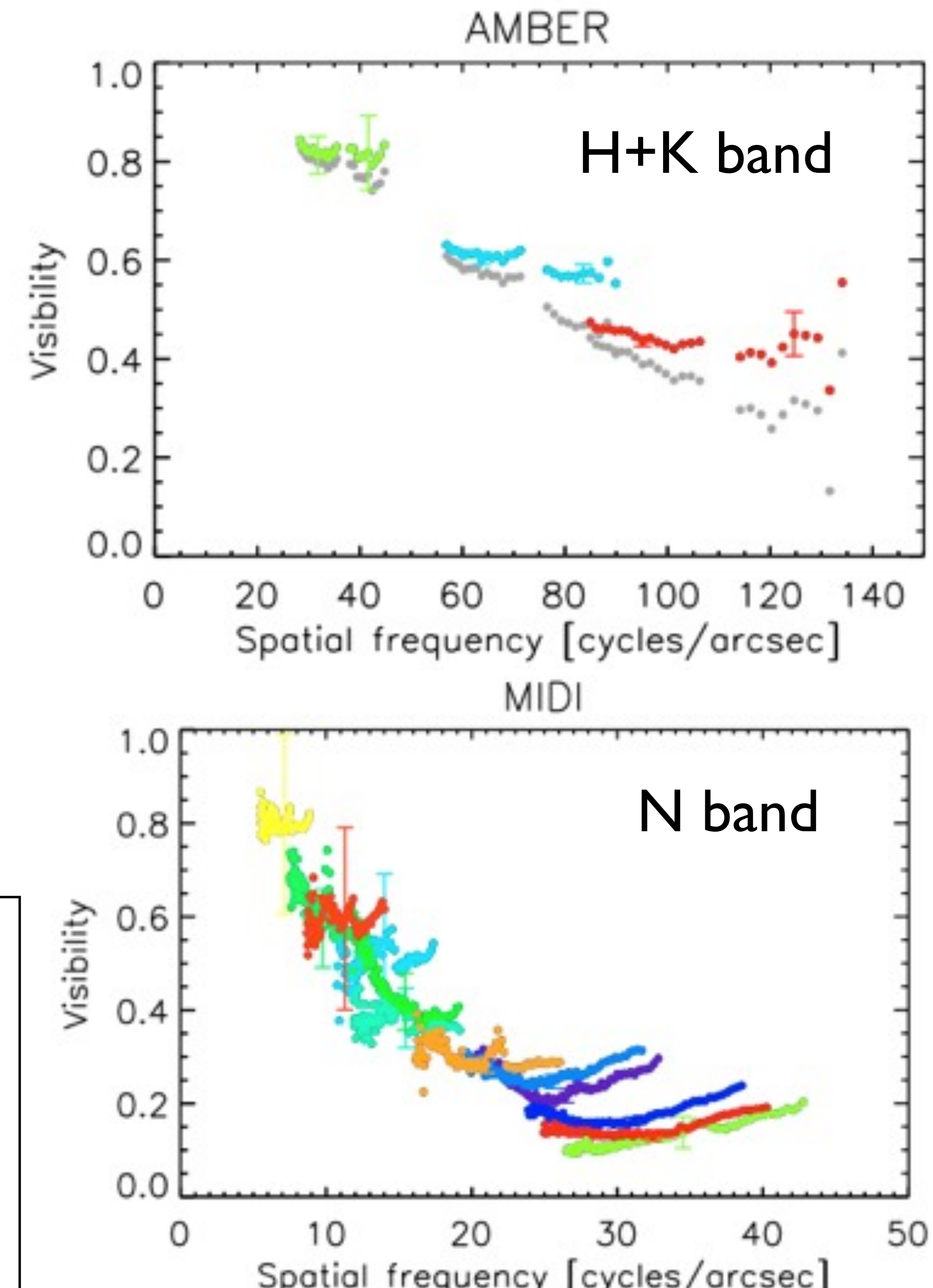
Acke et al. 2007

Before VLTI

VLTI



Eisner et al. 2004



Acke et al. 2007

New Era:
- Better UV coverage
- Multi-wavelength obs
- Spectral dispersion...
- ... with detailed analysis

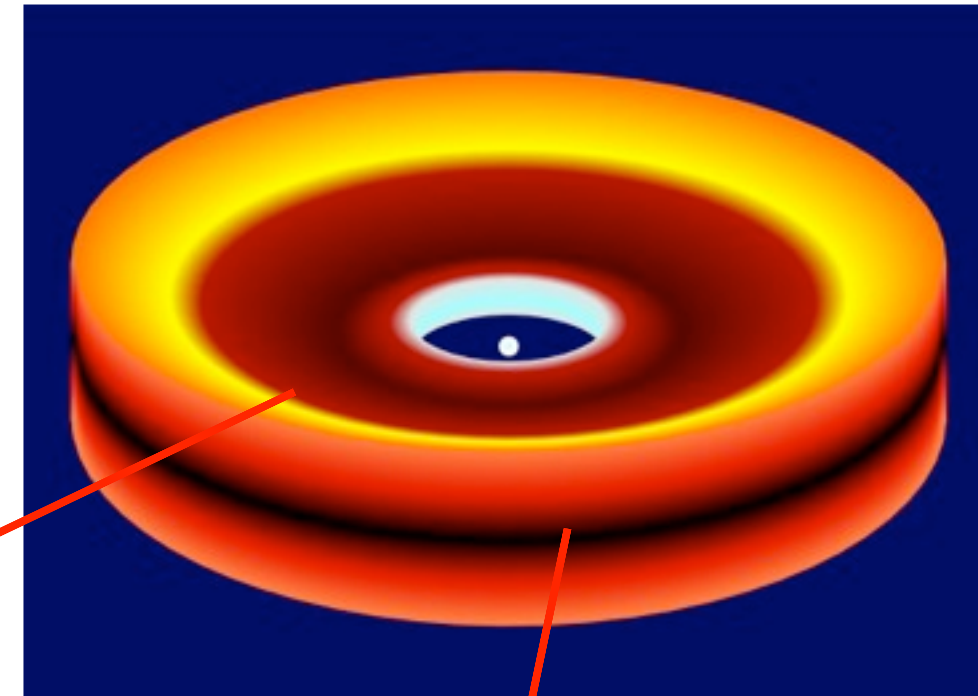
Outline

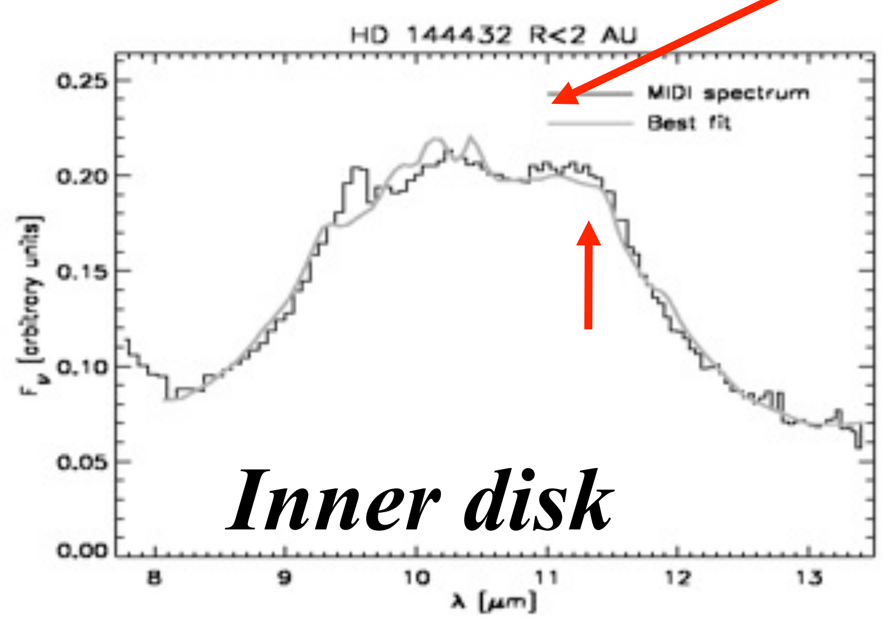
1. The inner AU
2. Herbig Ae Be stars
3. Transition disks
4. Massive YSO & Multiplicity
5. Perspectives

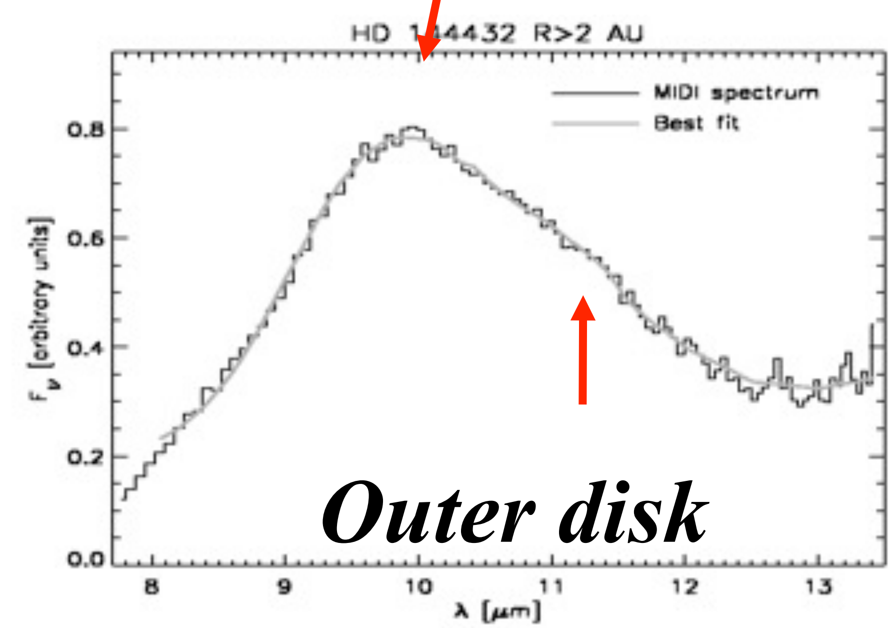
Dust size distribution

Inner disks (< 2 AU) have:

- larger silicate grains
- high fraction of silicates is crystalline (40-100%)



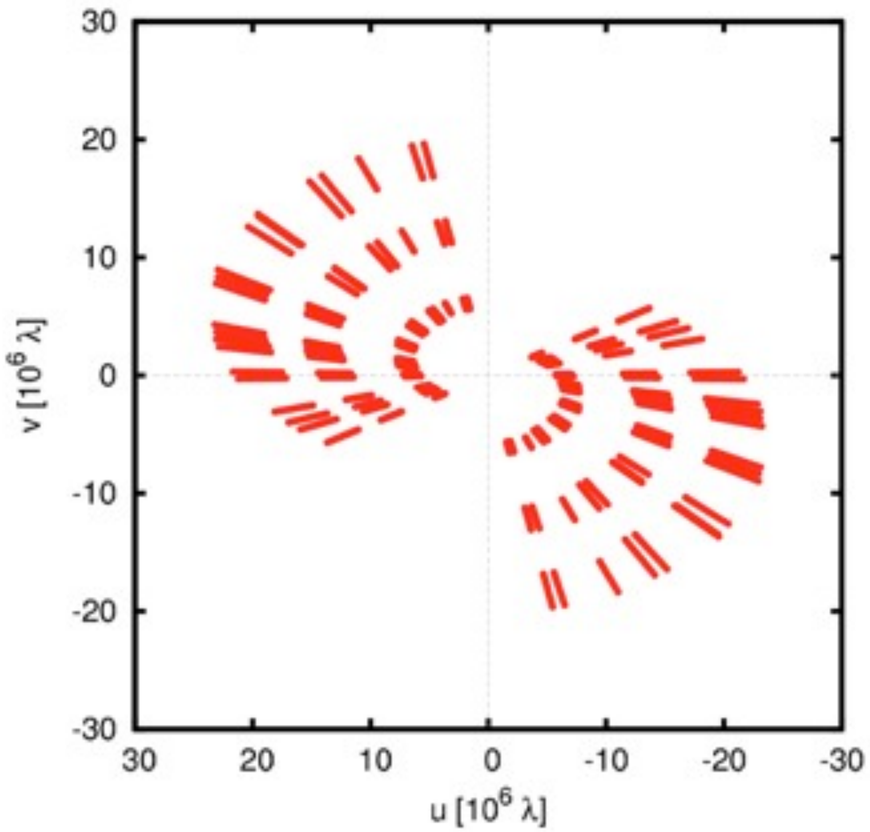


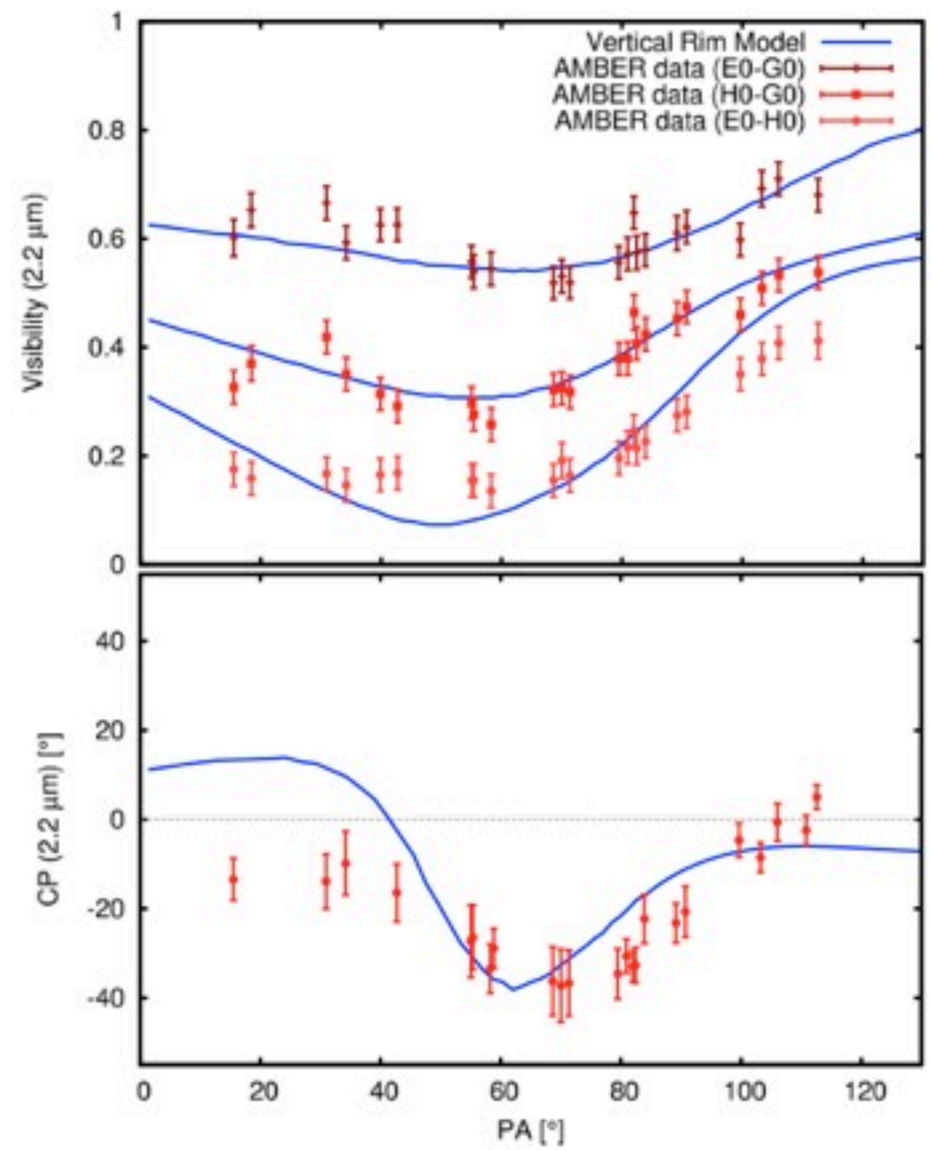


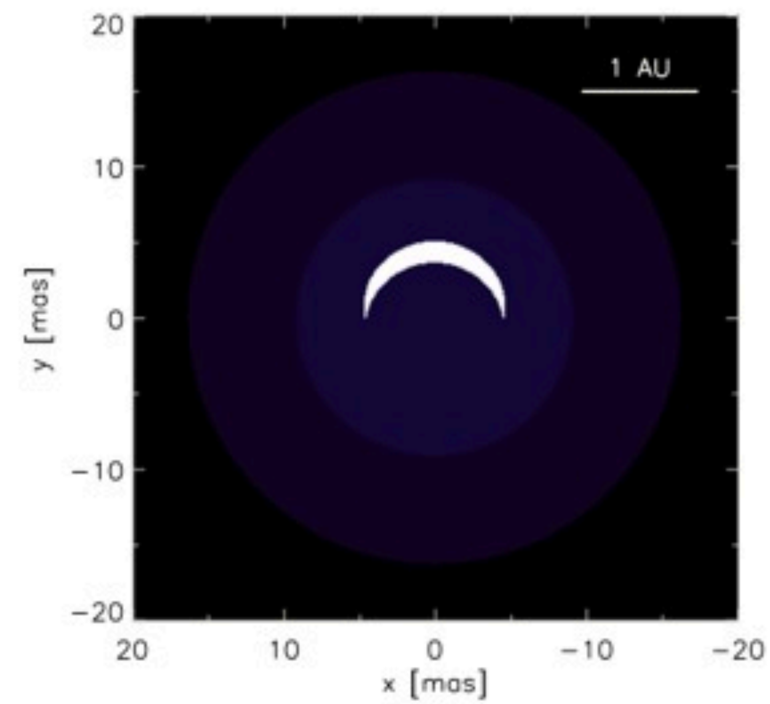
van Boekel et al. 2004; also Ratzka et al. 2007, Schegerer et al. 2007

Rim morphology

RCrA (F5-B8)





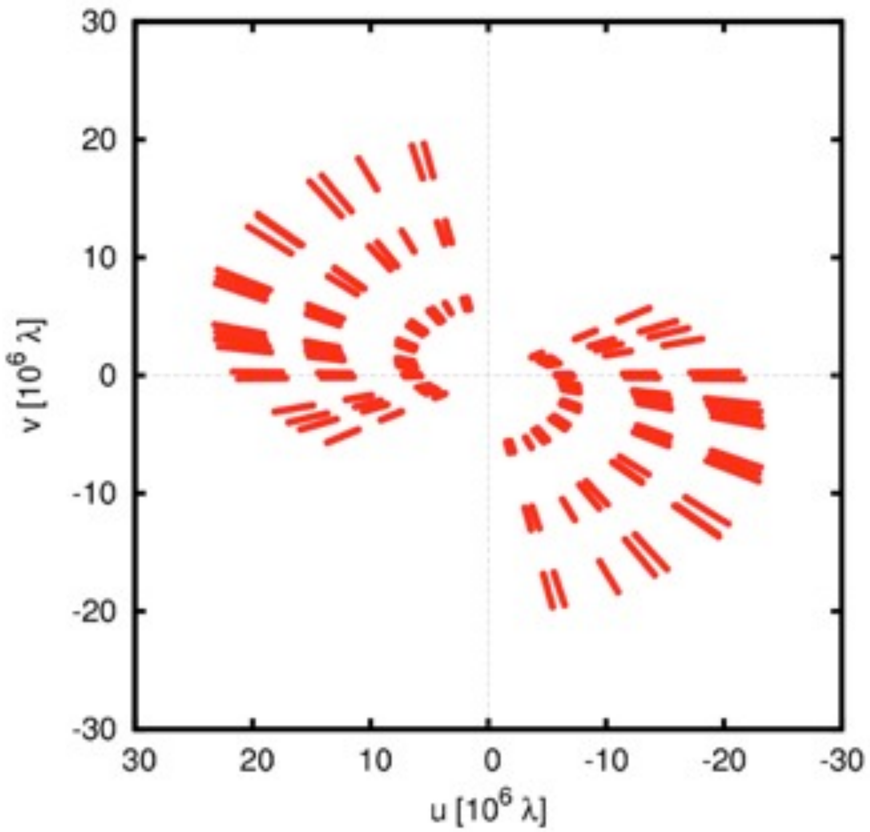


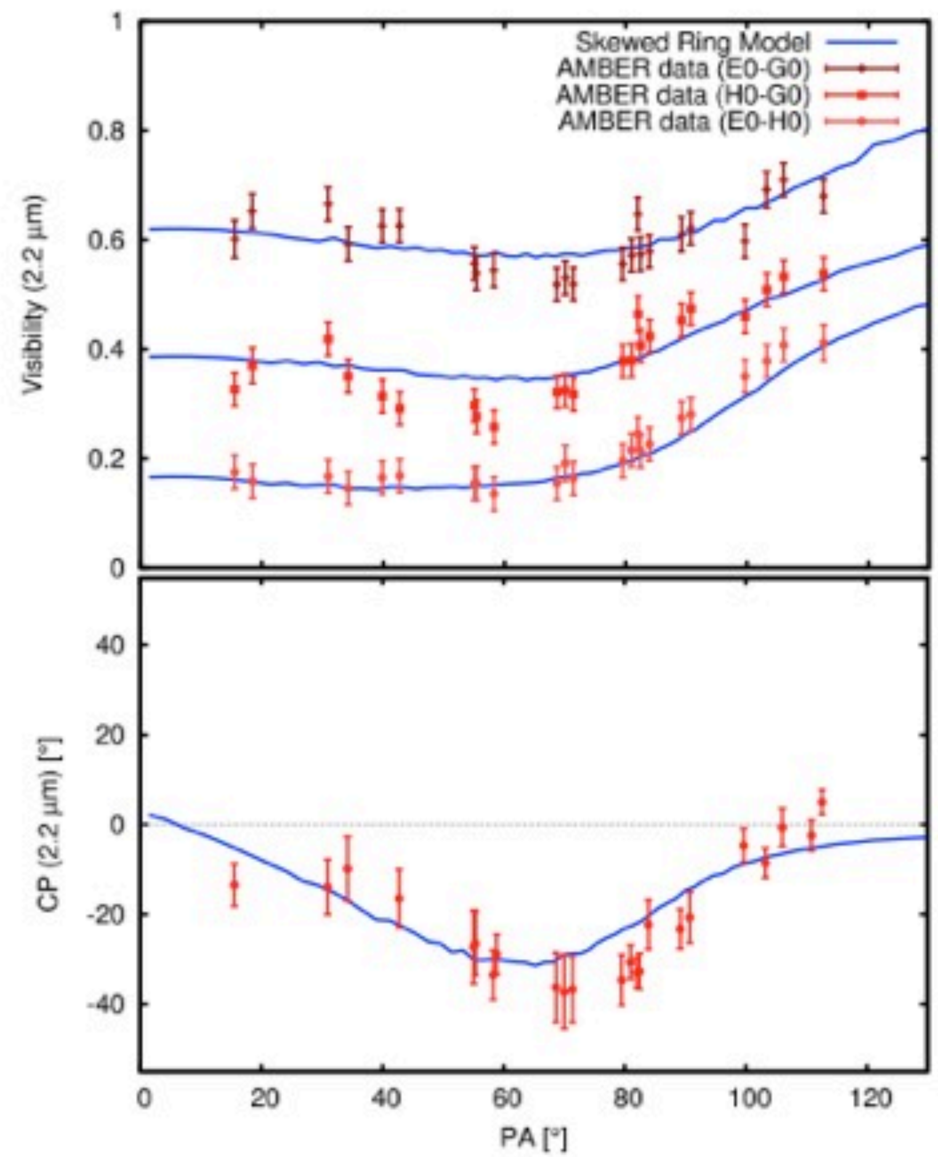
Strong CP traces the vertical structure

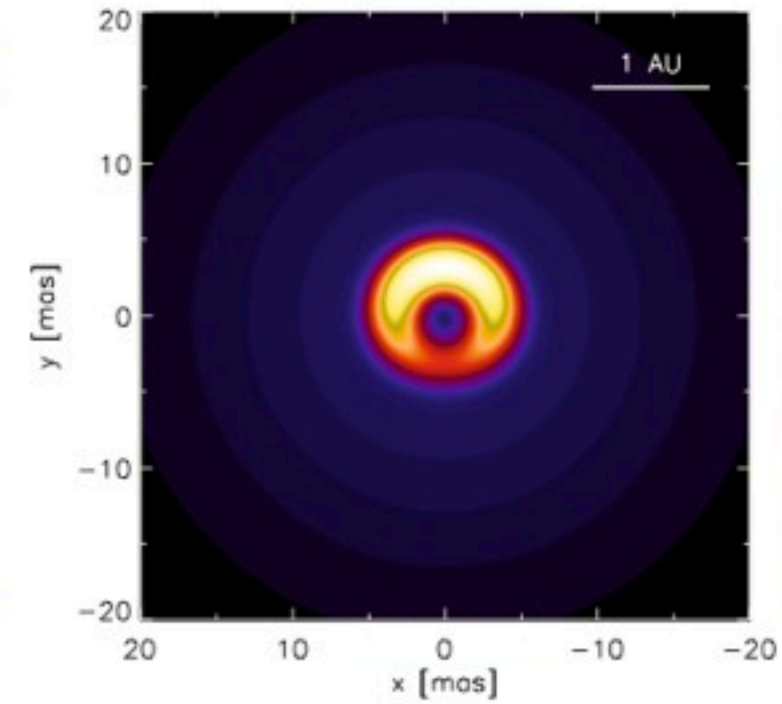
Kraus et al. 2007

Rim morphology

RCrA (F5-B8)







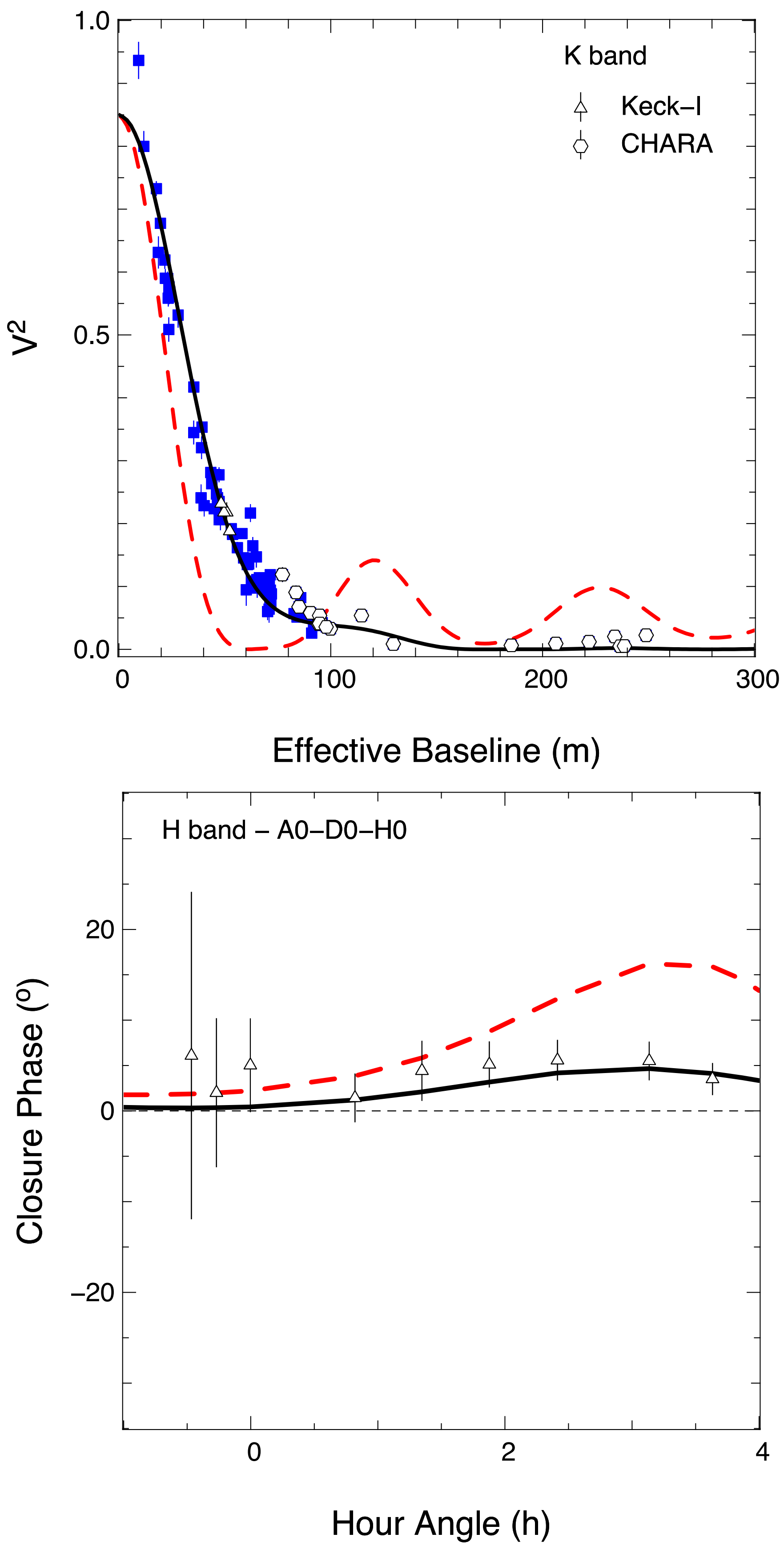
Strong CP traces the vertical structure

Curved and smooth inner rims are favored

Kraus et al. 2007

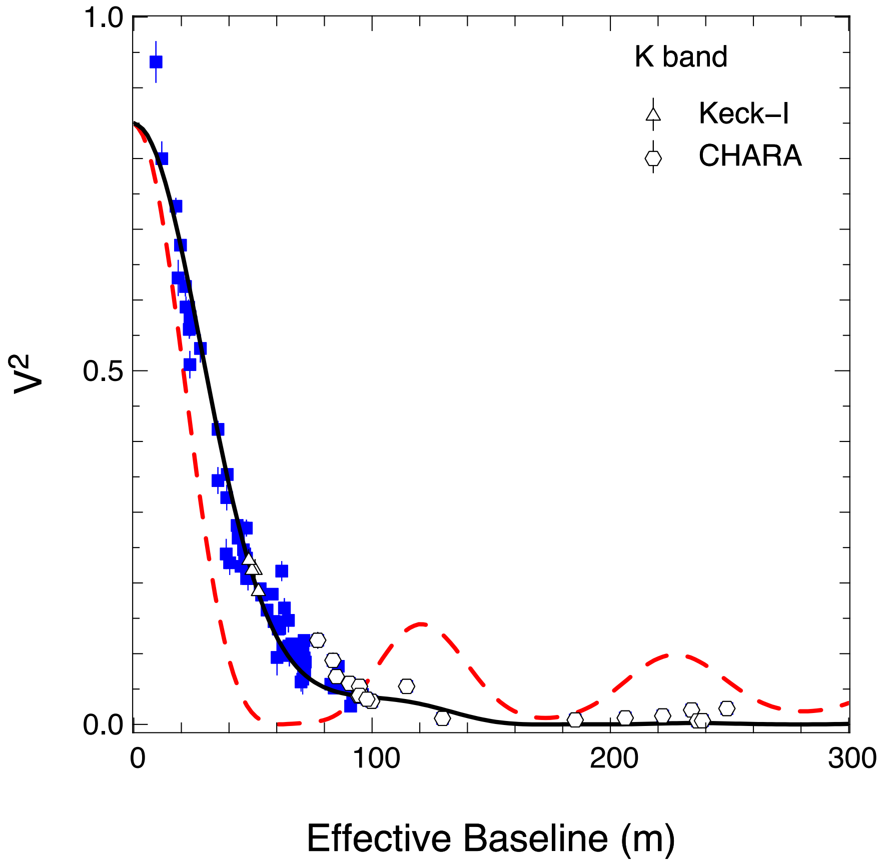
A complex inner disk

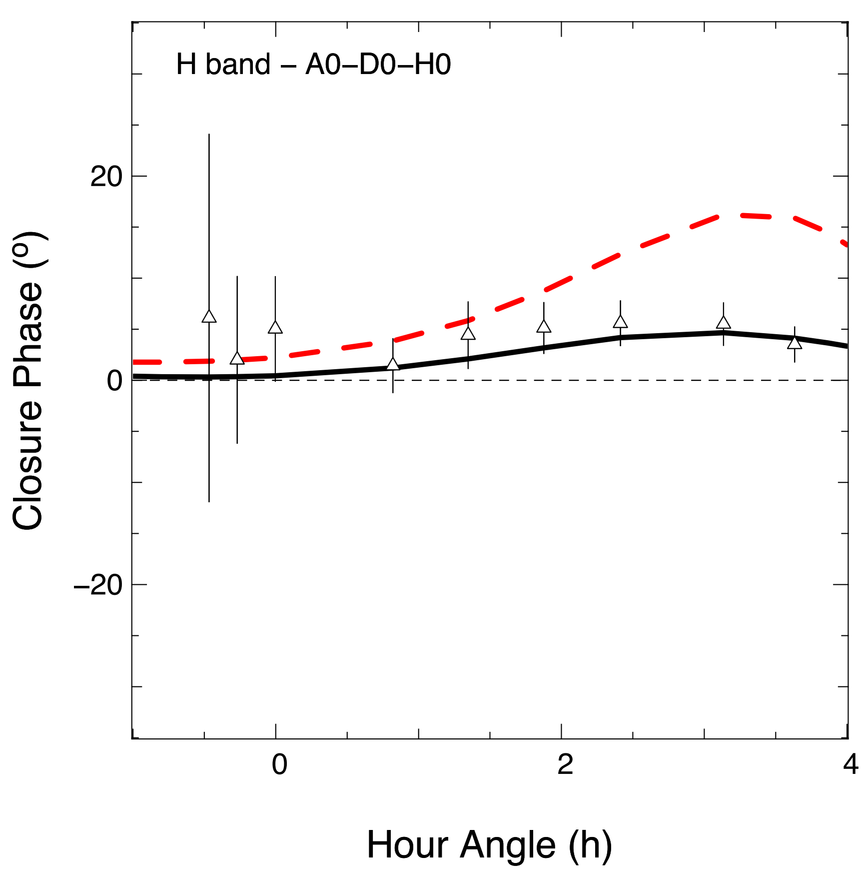
HD163296 (A1)

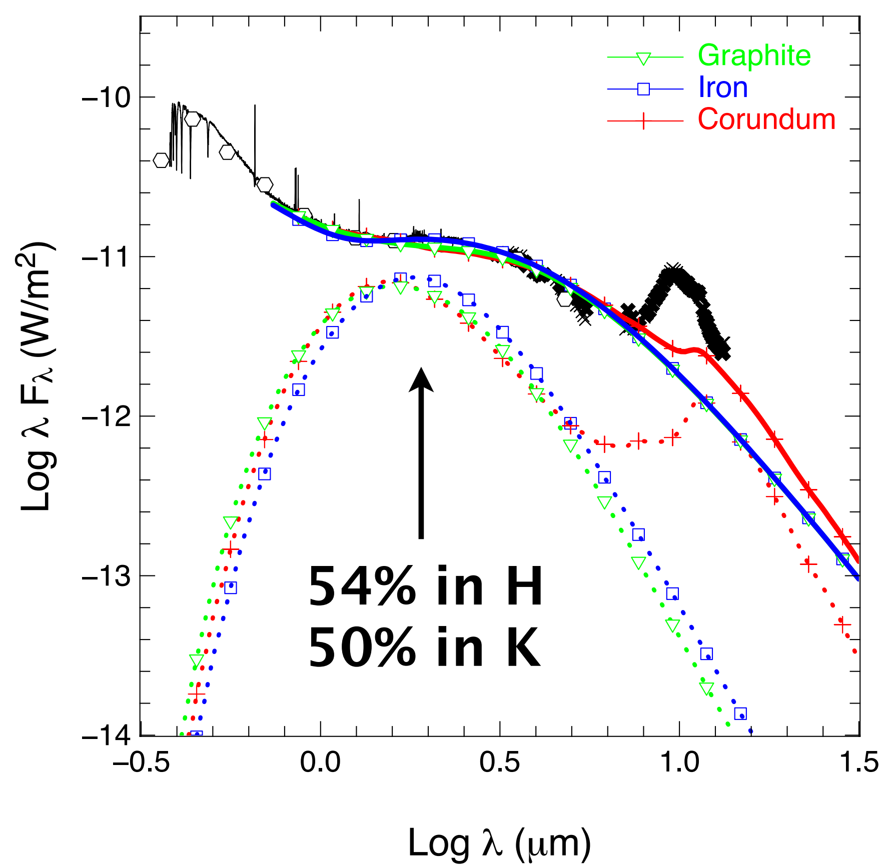


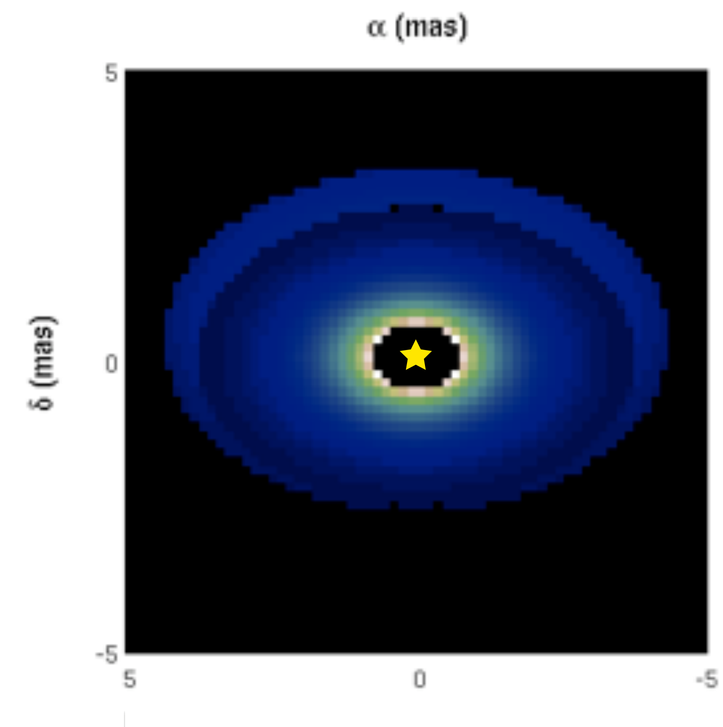
A complex inner disk

HD163296 (A1)









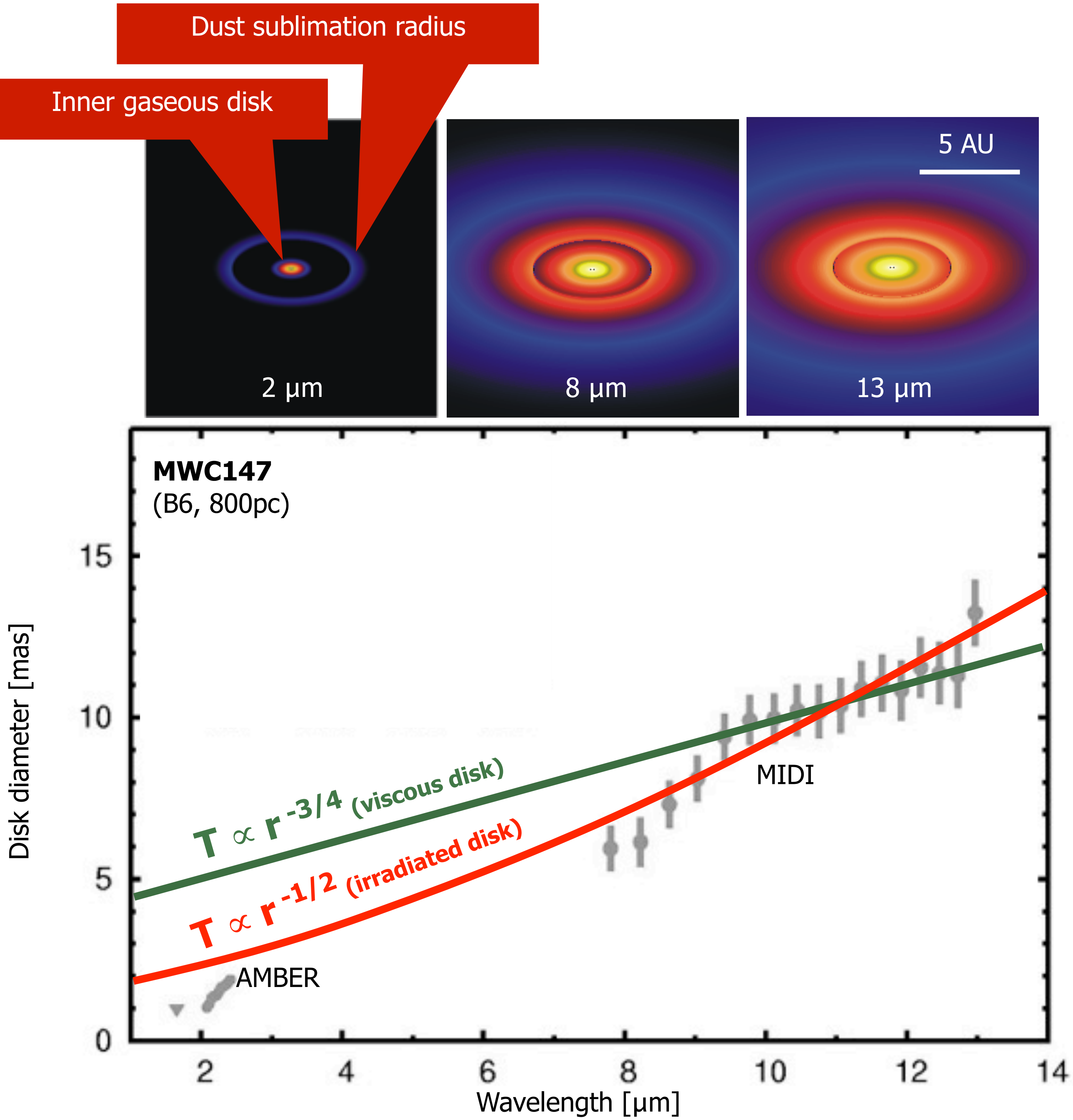
An additional component to the rim

Refractory dust species ...?

Benisty et al. 2010a

A complex inner disk

MWC147, B6



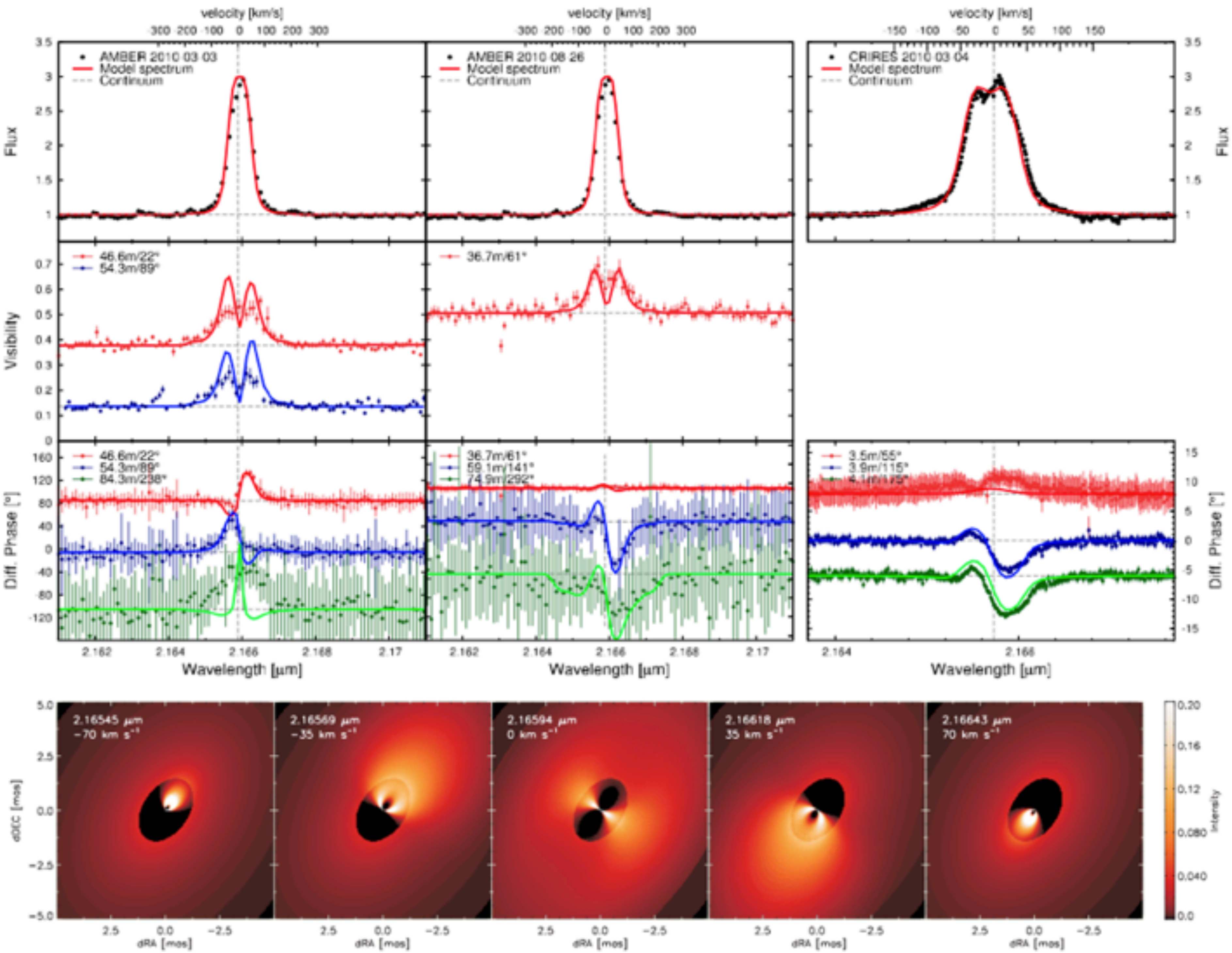
Kraus et al. 2008a

.... or ***optically thick gas*** ?

- Temperature power laws do not fit the wavelength-dependent sizes.
- Passive disk+inner accretion disk reproduce SED+NIR+MIR interferometry
- NIR emission dominated by accretion luminosity
- MIR emission also from outer disk

also Wheelwright et al. 2013

Inner disk kinematics



Luminous

Herbig Be star

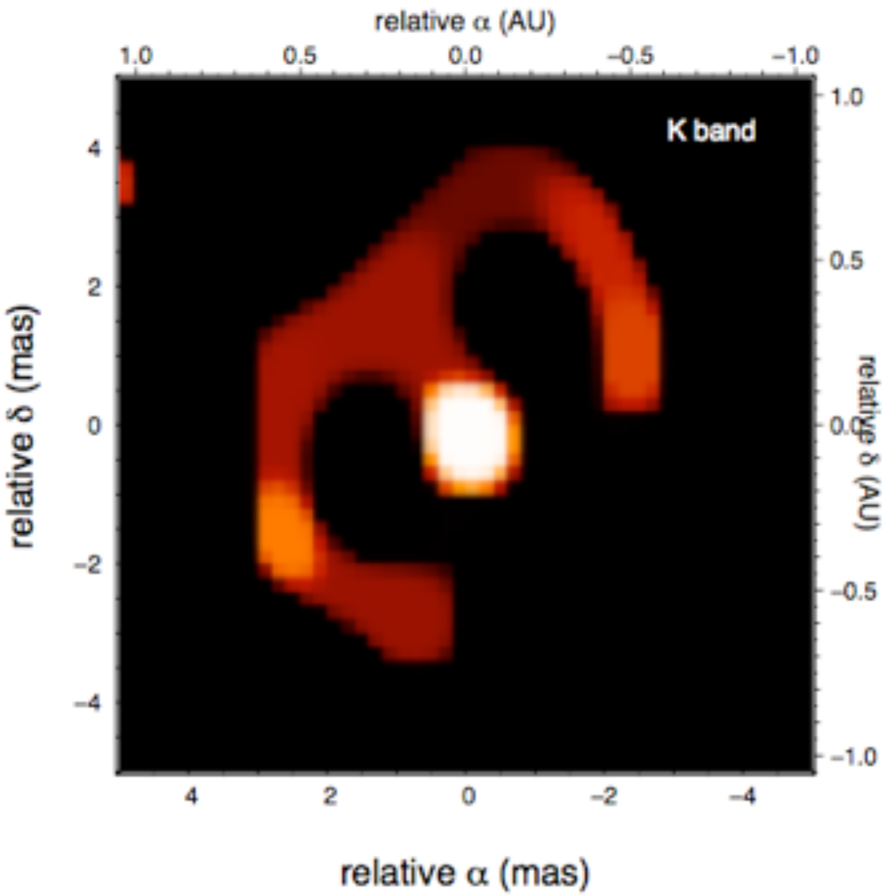
V921 Sco

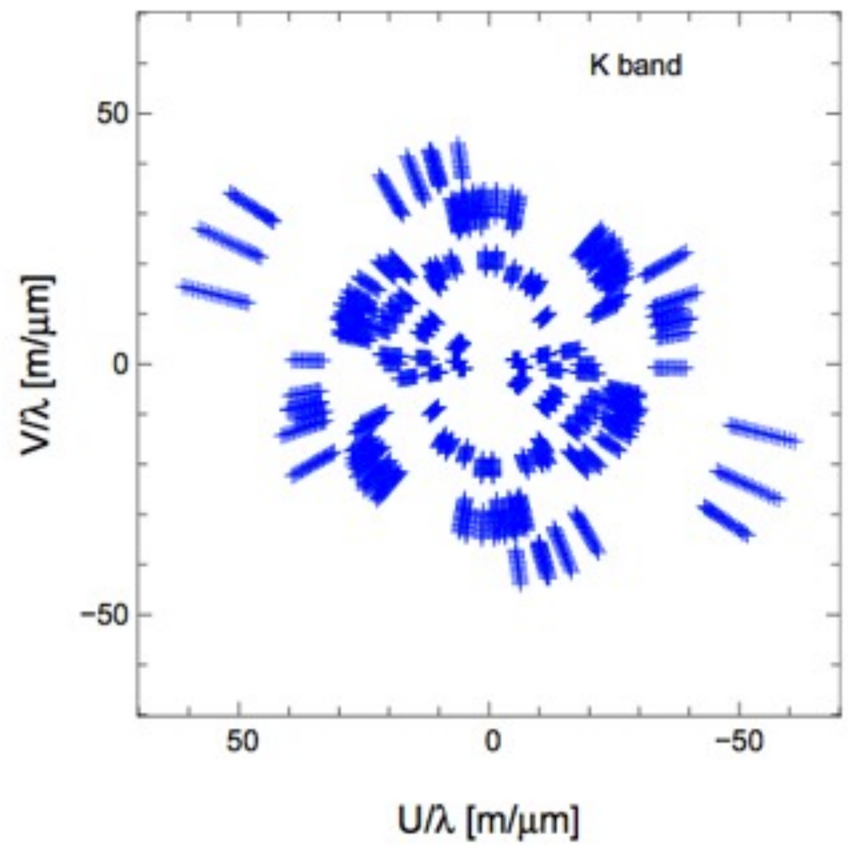
Brγ emitted in a disk in Keplerian rotation inside the dust rim

Kraus et al. 2012b

also, Ellerbroek et al. 2014

In the imaging era





HR5999 (A7)

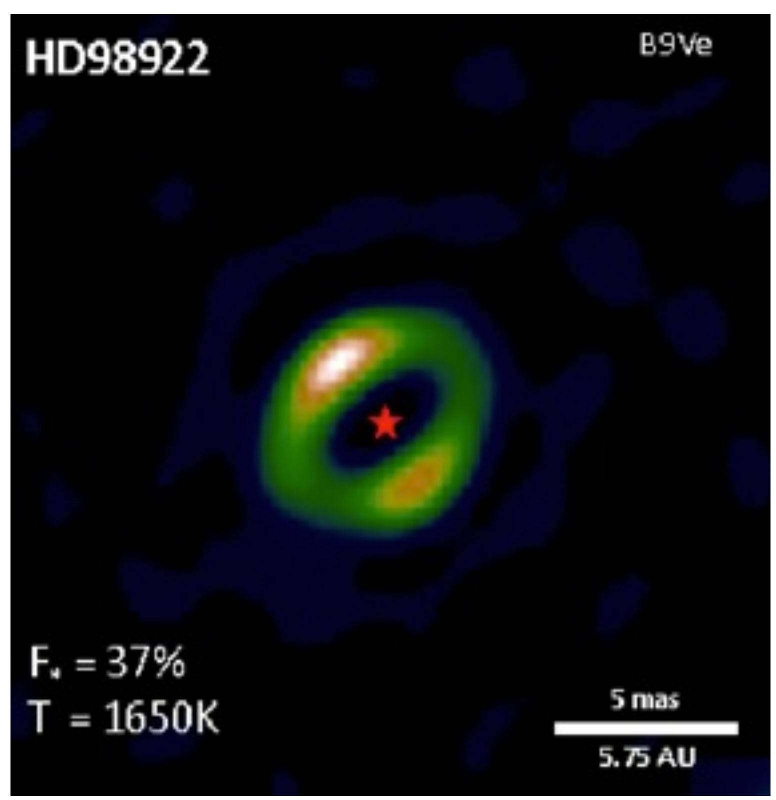
AMBER 3T

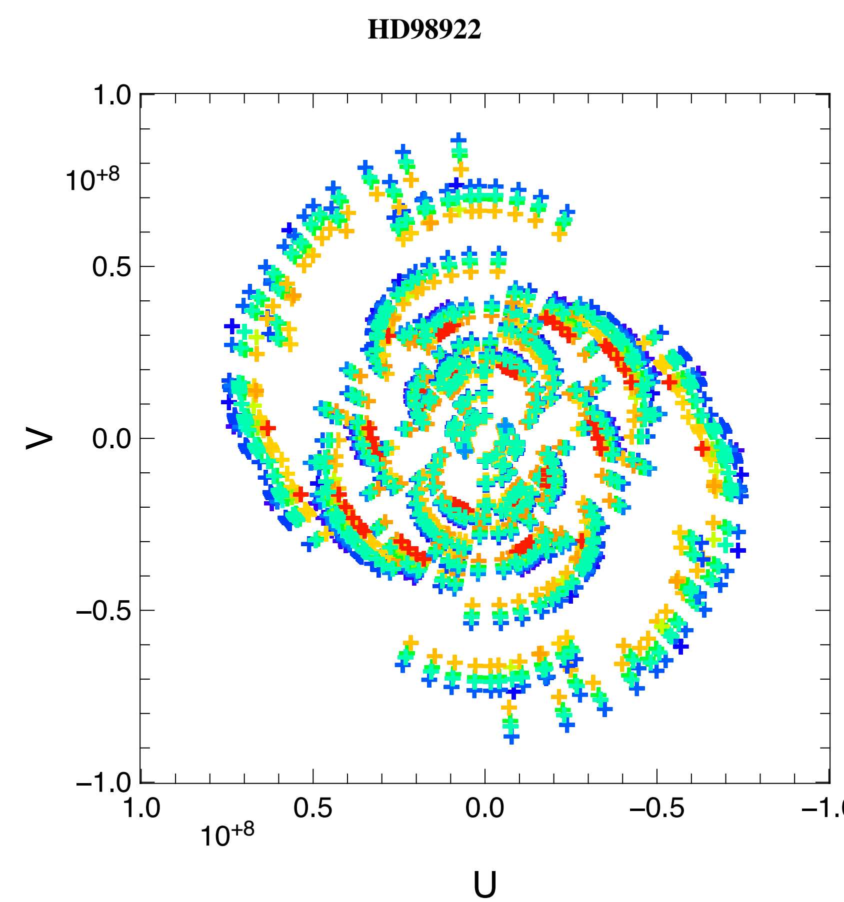
Benisty et al. 2011

HD98922 (B9)

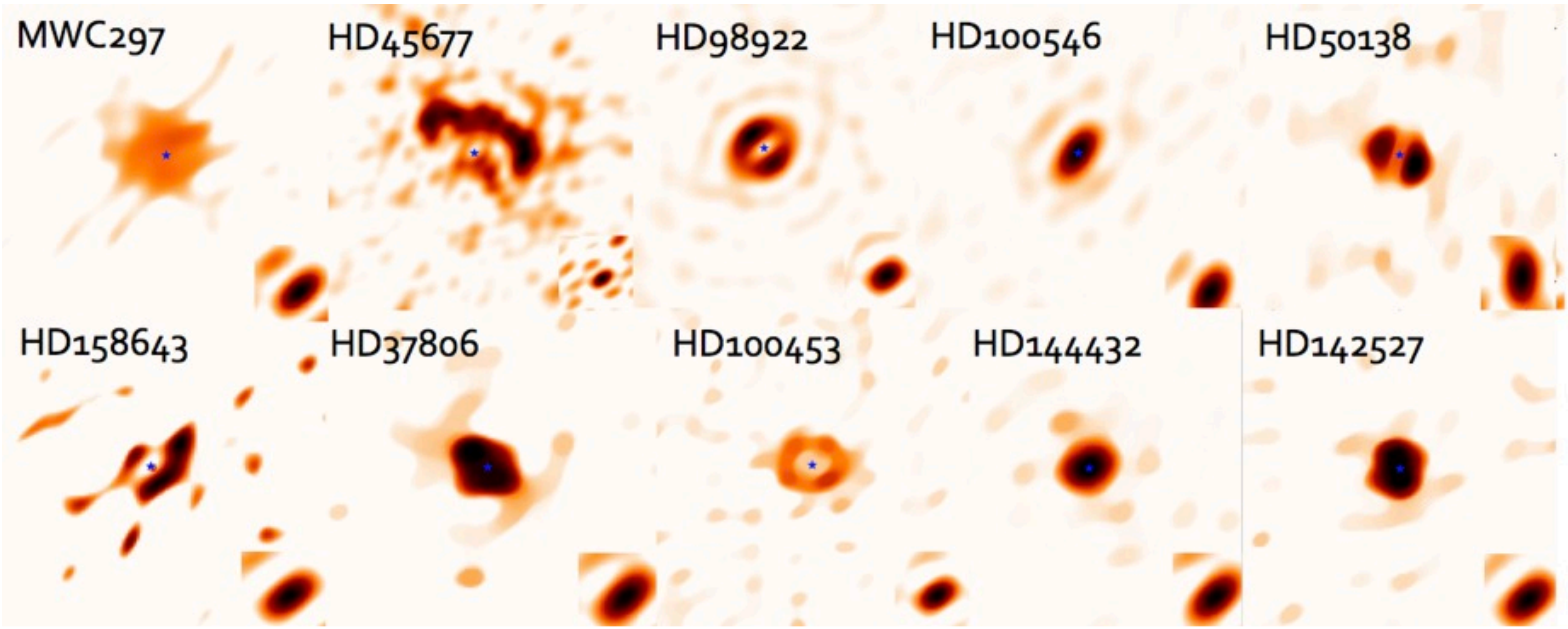
PIONIER 4T

from J. Kluska, JP Berger





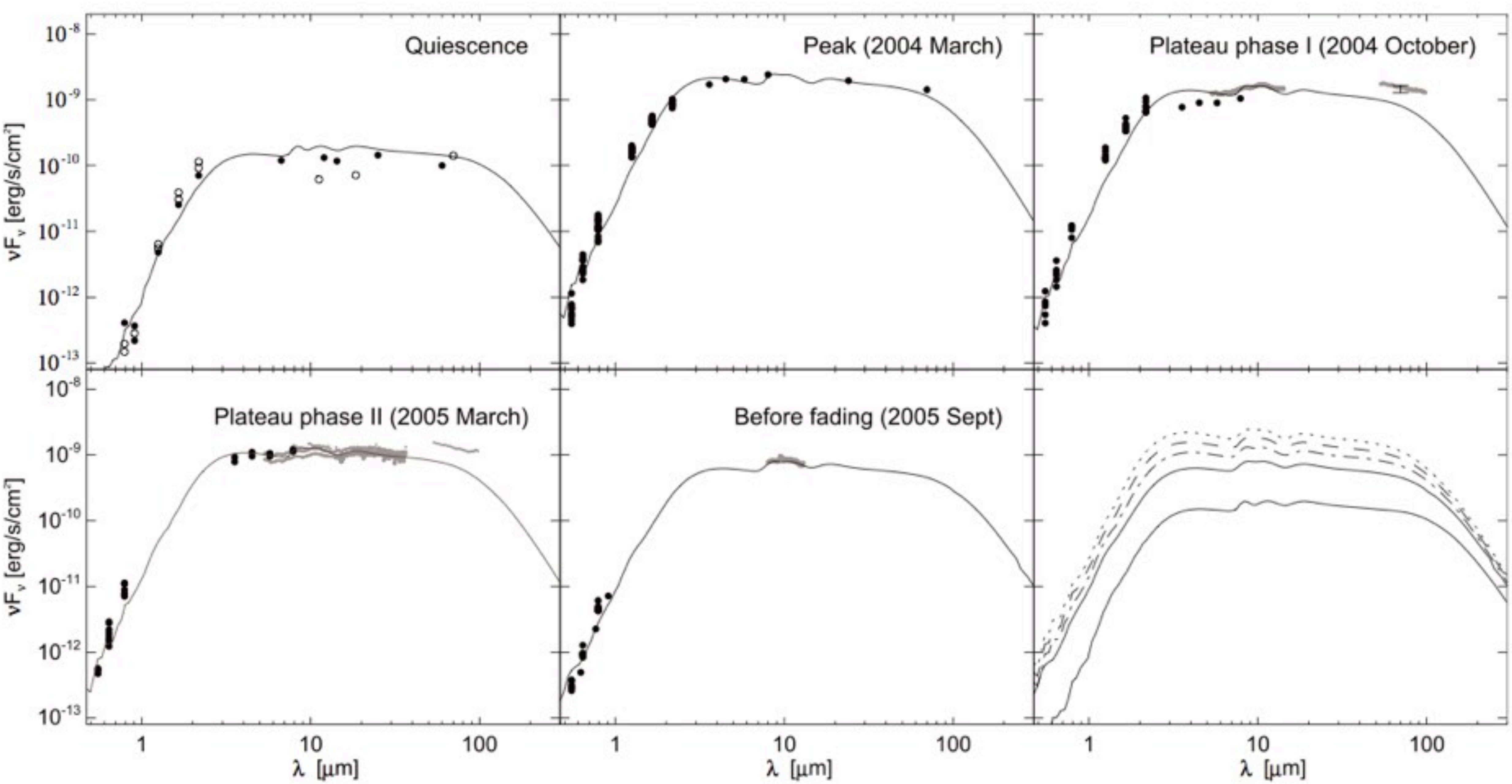
A variety of morphologies



From J. Kluska, JP Berger
Large Program PIONIER

Dynamics during outburst

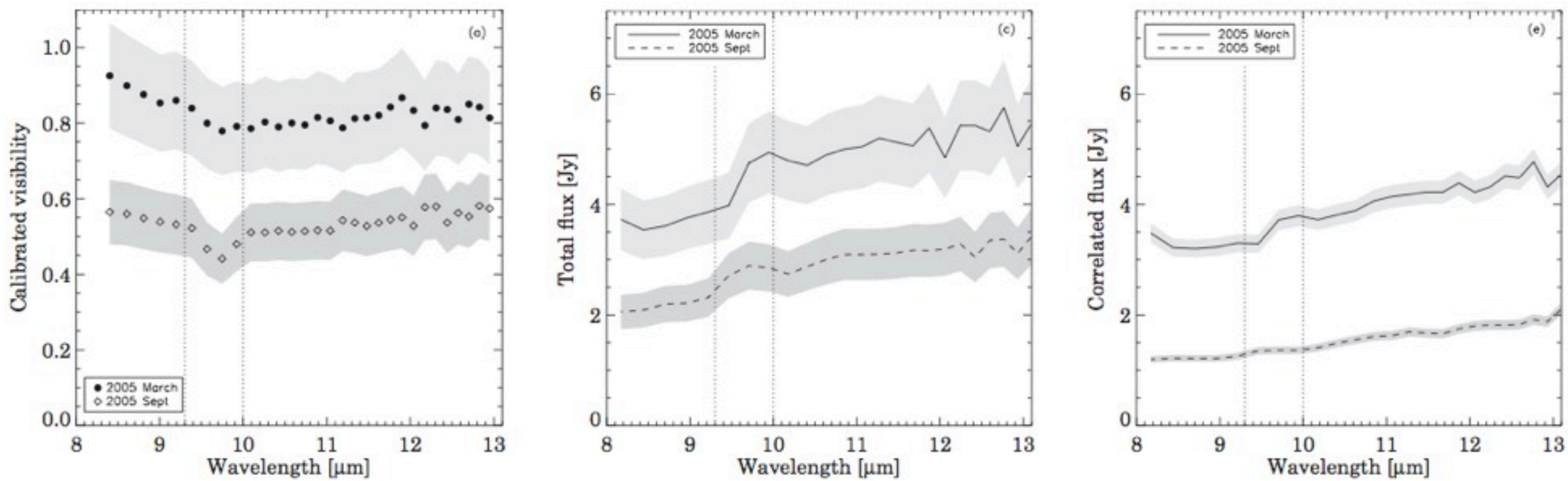
V1647 Orionis (TTS)

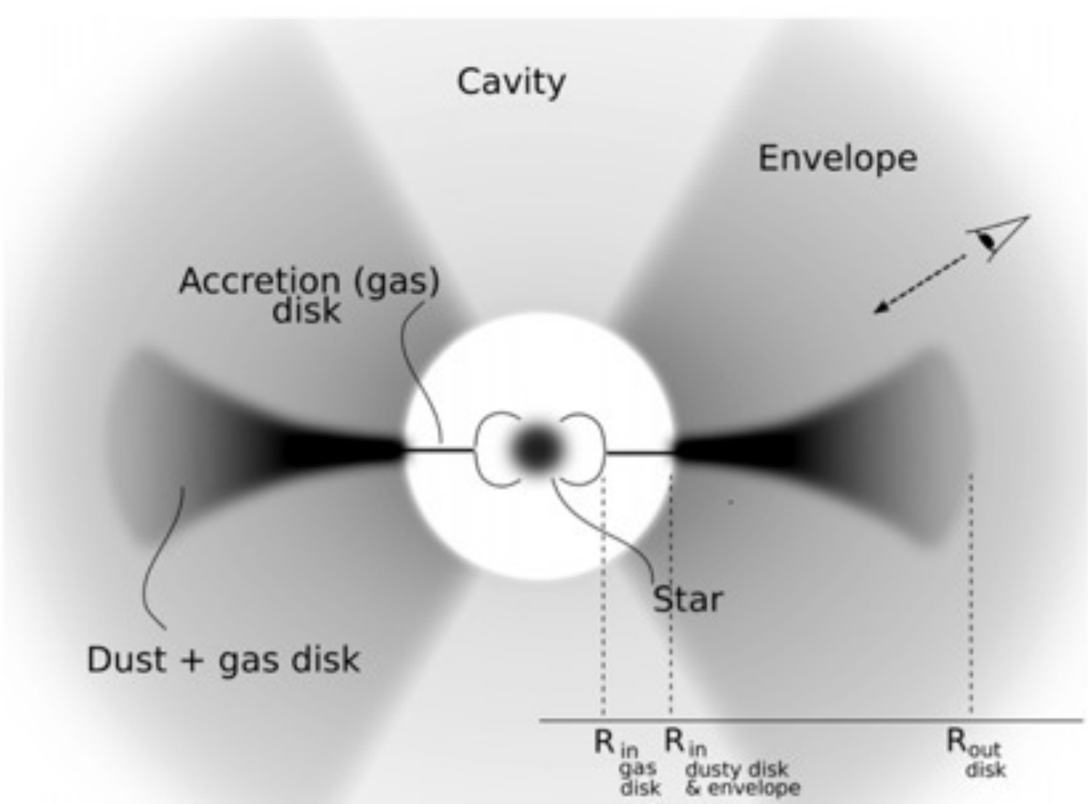


Mosoni et al. 2013

Dynamics during outburst

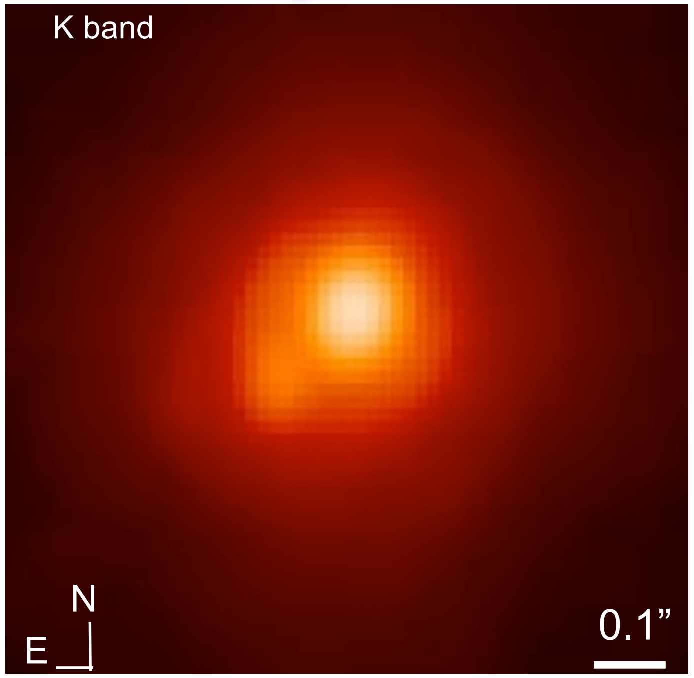
V1647 Orionis (TTS)



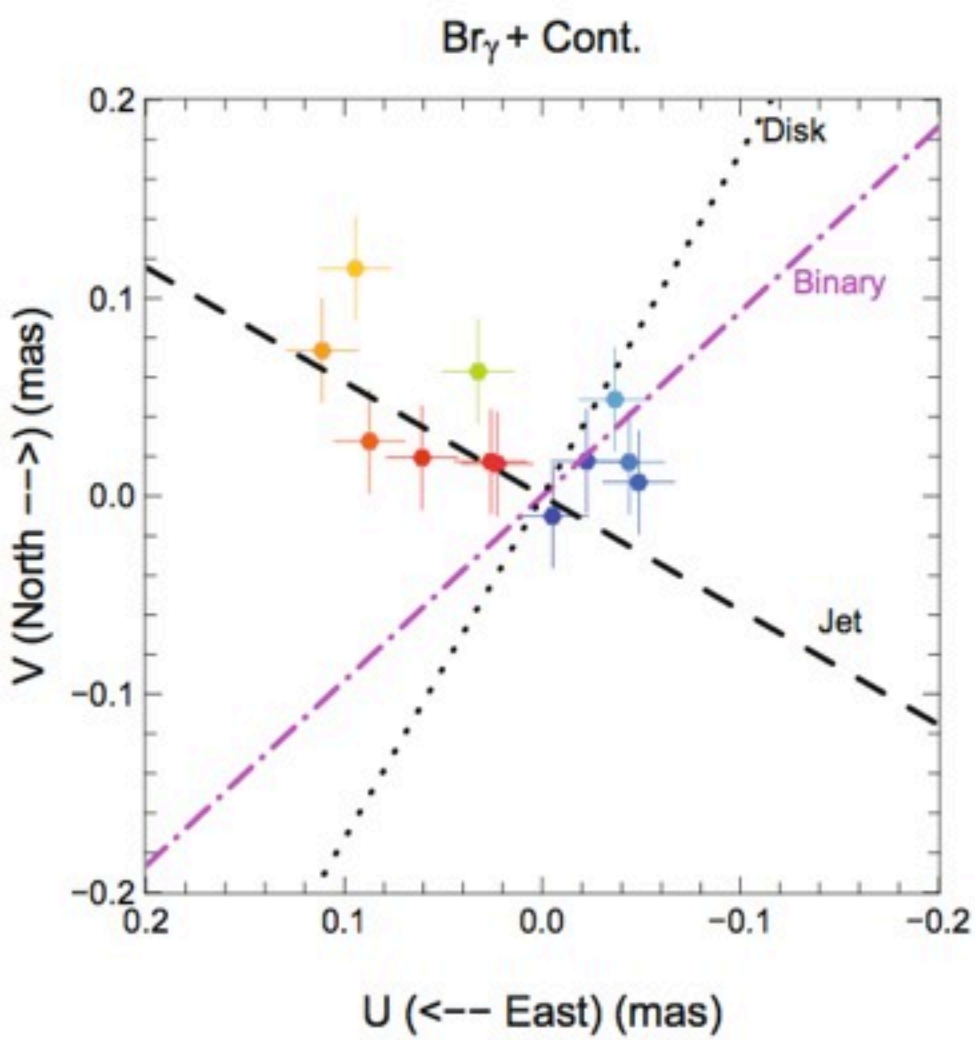


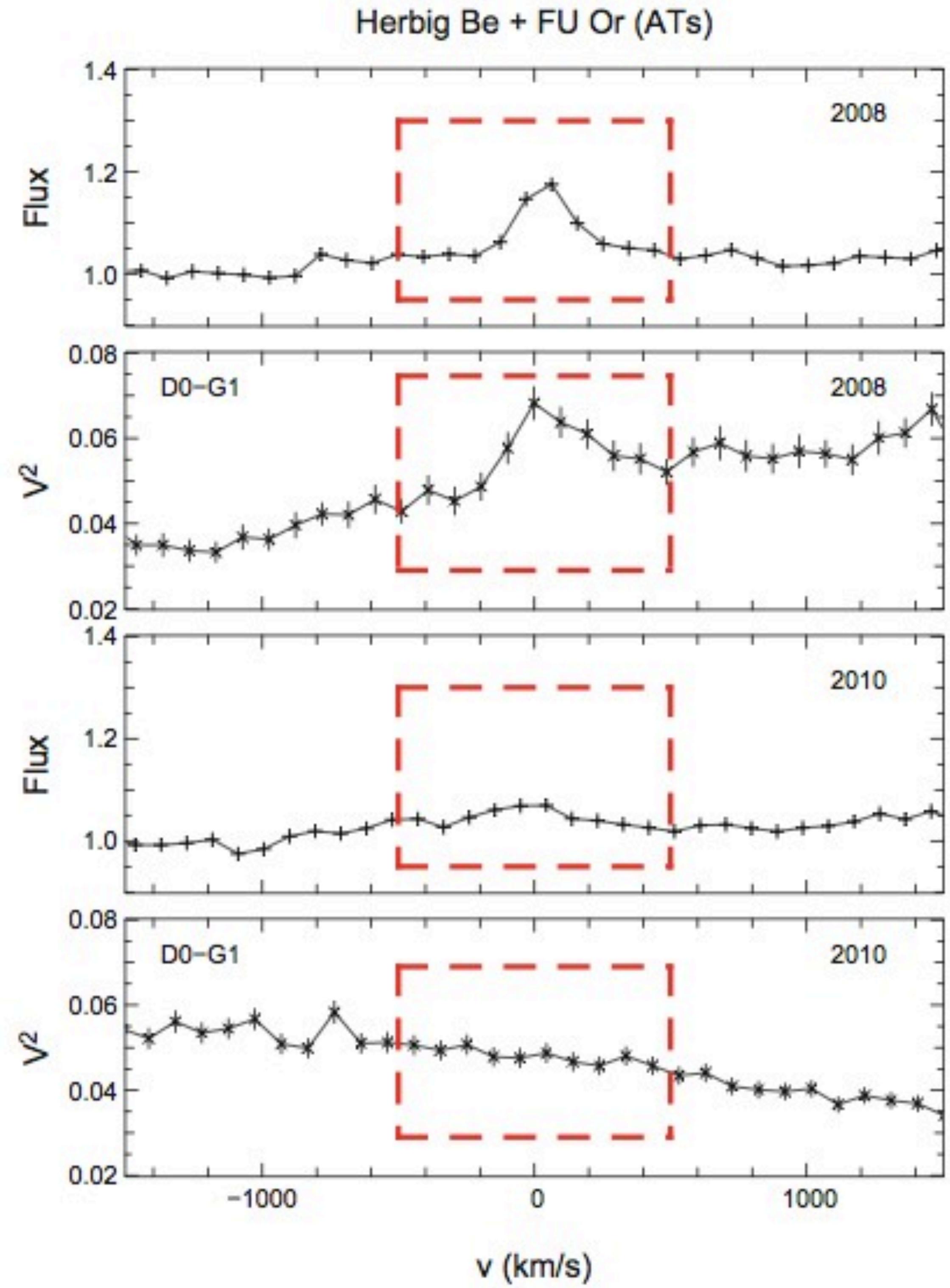
- Structural changes traced on AU-scales.
- Accretion rate, disk/enveloppe radii increased during outburst.

Dynamics during outburst



ZCMa

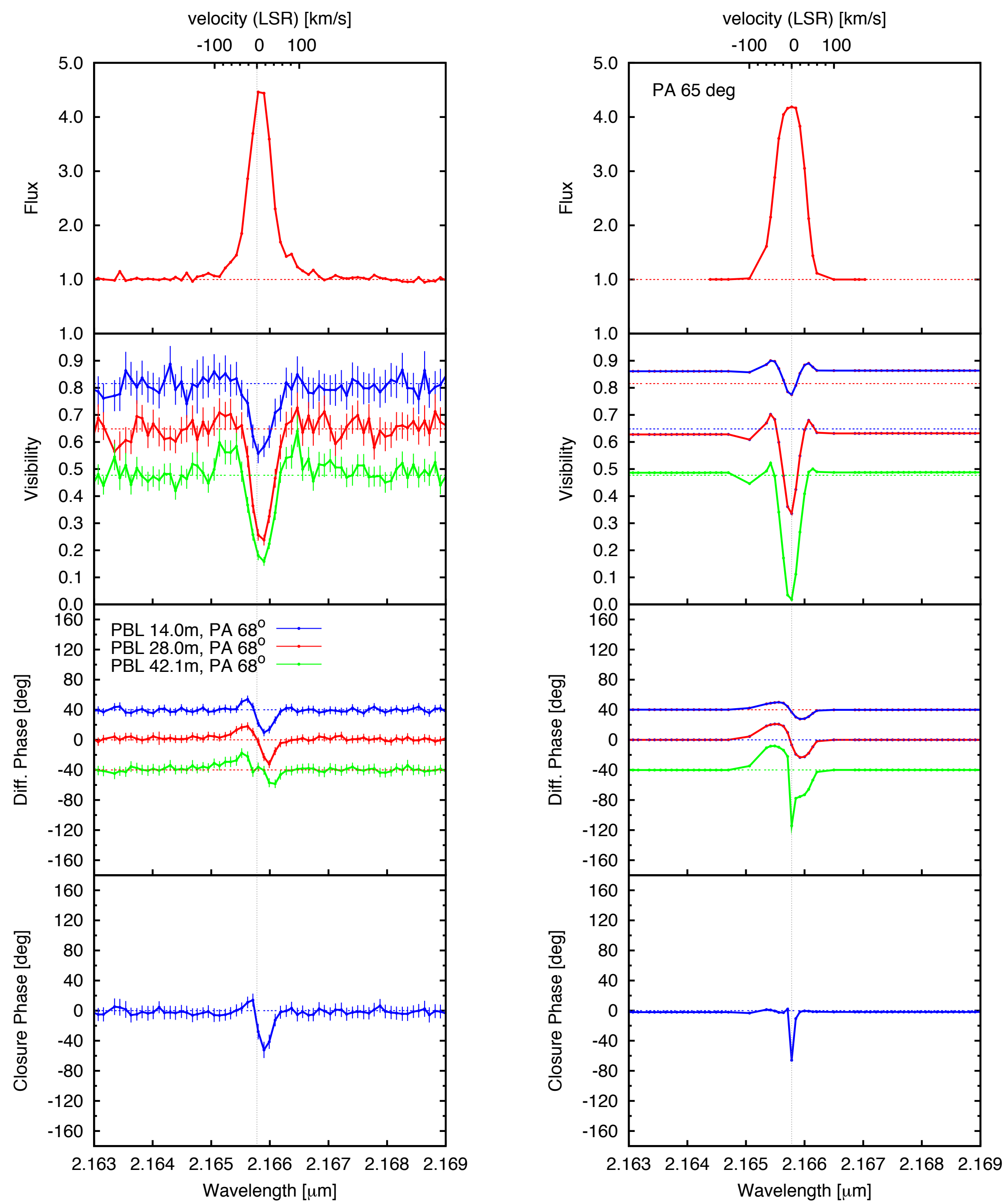




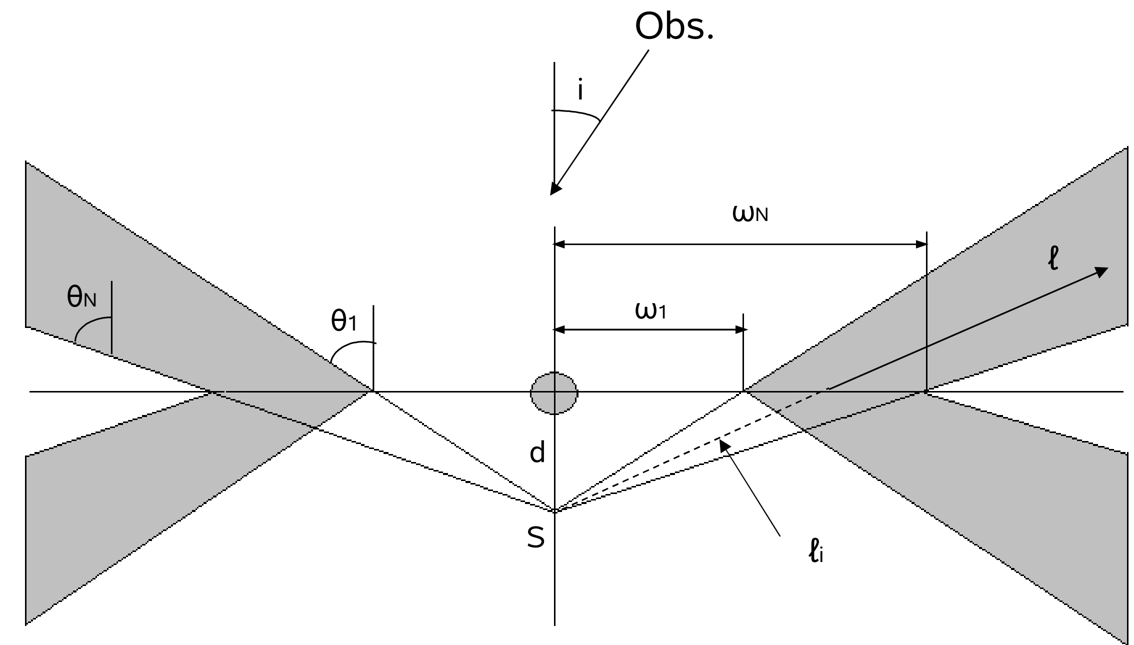
Benisty et al. 2010

Jet launching region

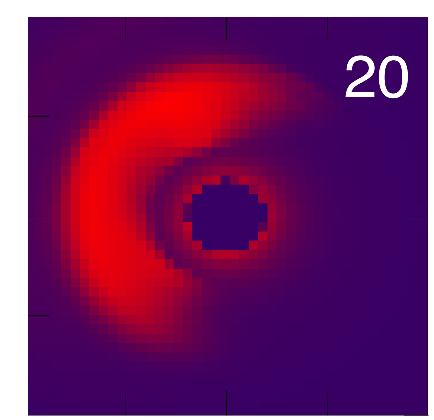
MWC297



Magneto-centrifugally driven disk wind



Brɣ indirect tracer of accretion ?



Weigelt et al. 2011

also, Malbet et al. 2007, Kraus et al. 2008, Garcia et al. 2013

Outline

1. The inner AU

2. Herbig Ae Be stars

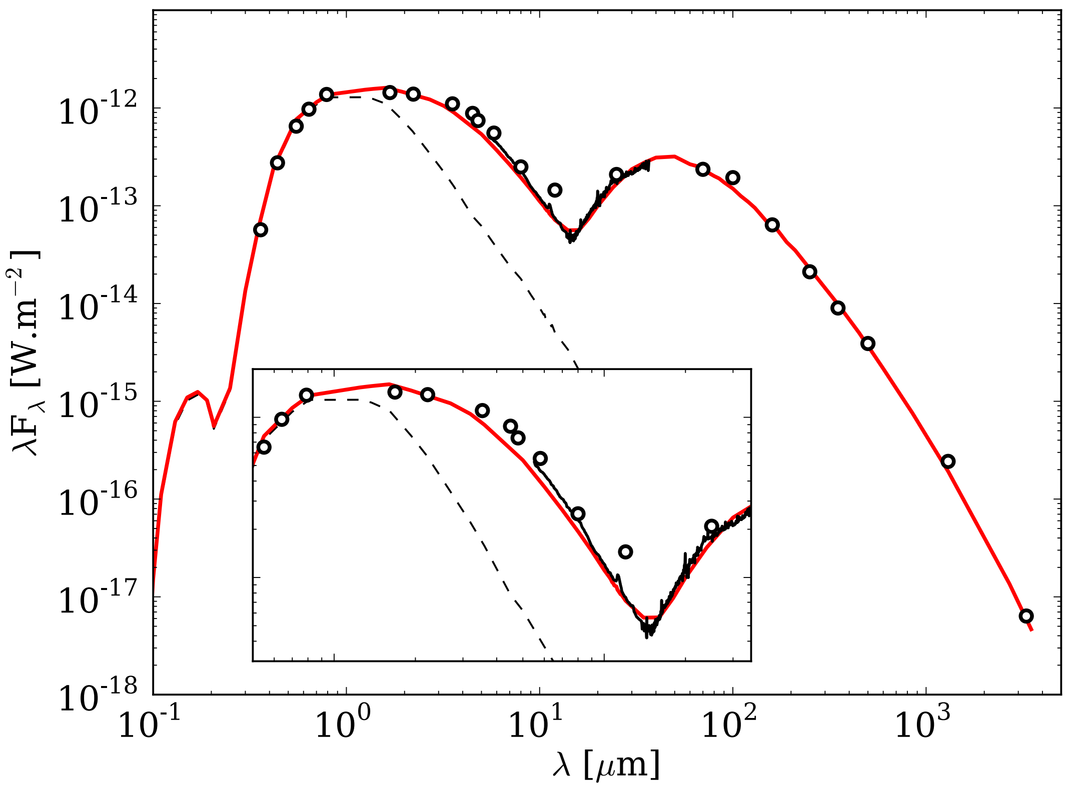
3. Transition disks

4. Massive YSO & Multiplicity

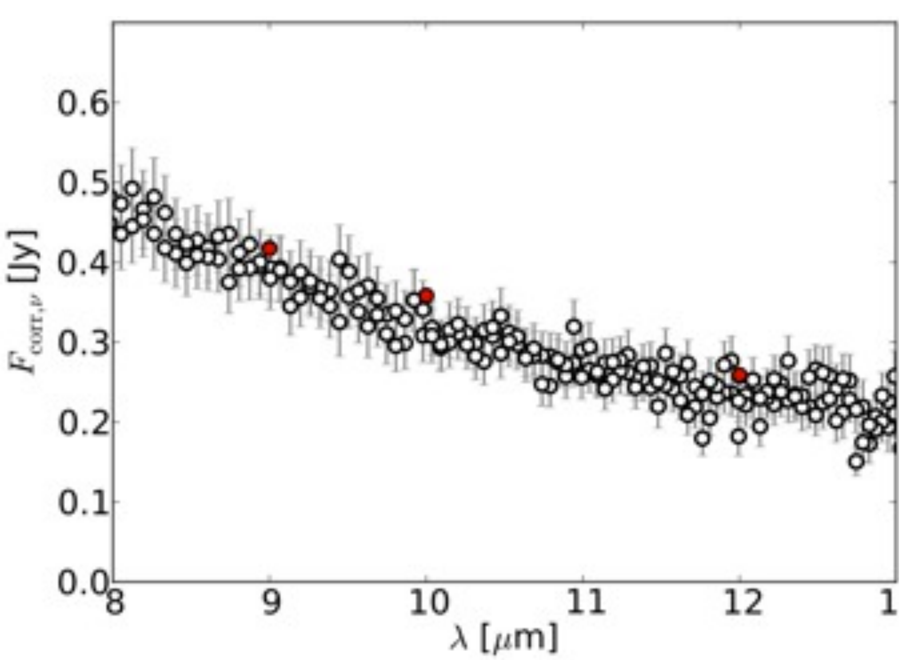
5. Perspectives

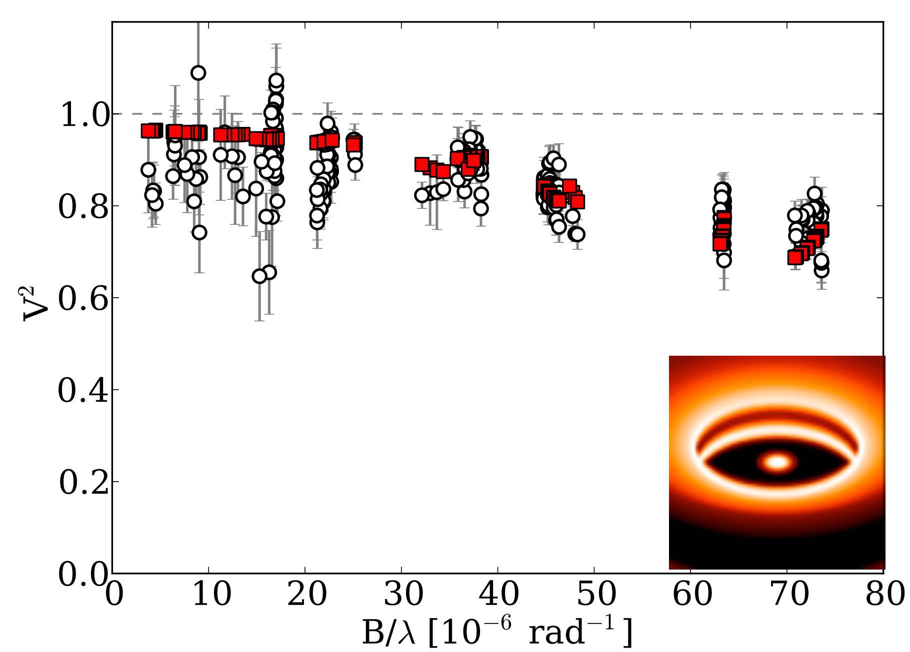
Transition disks

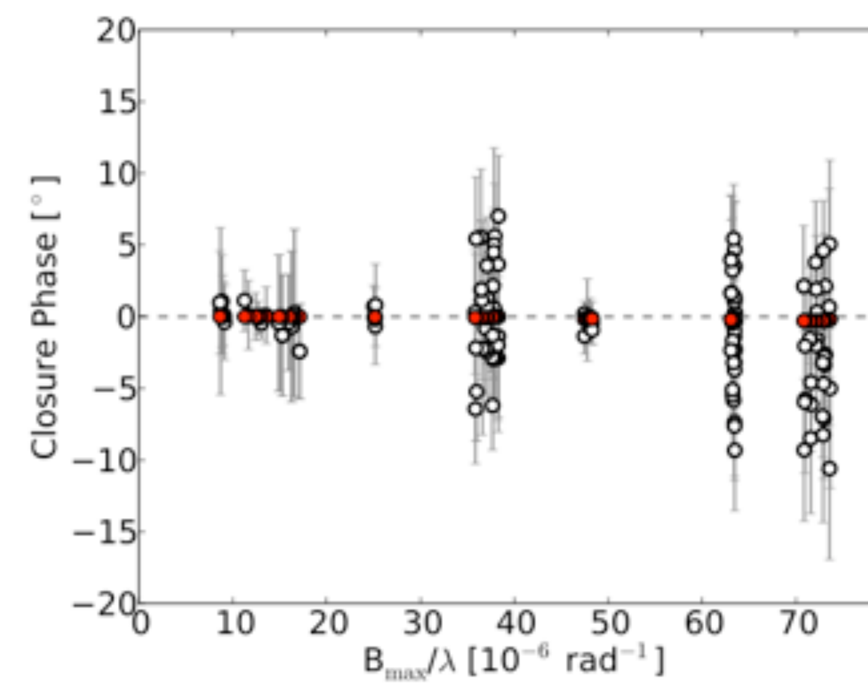
T Cha



- Tiny inner disk : 0.07-0.13 AU
- M = 3 10^{-11} $M_\odot$ of carbon
- H=0.2 AU @ 1 AU sets outer disk radius
- Anisotropic scattering



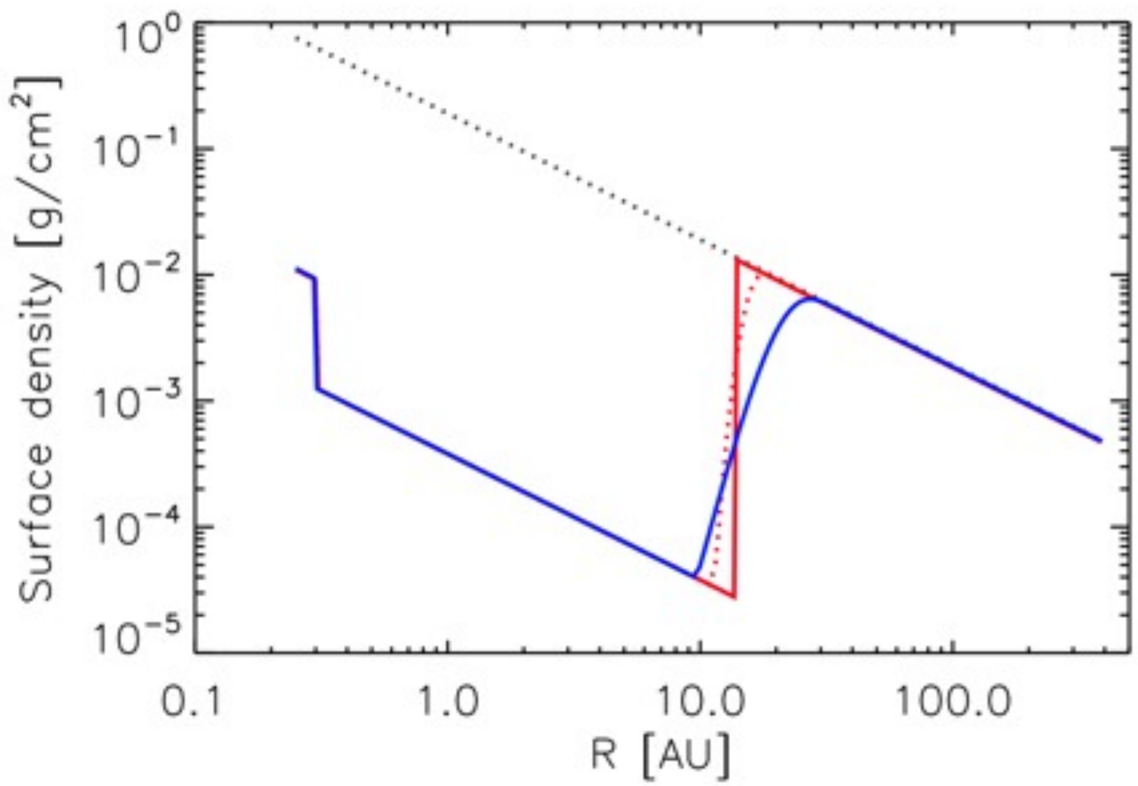


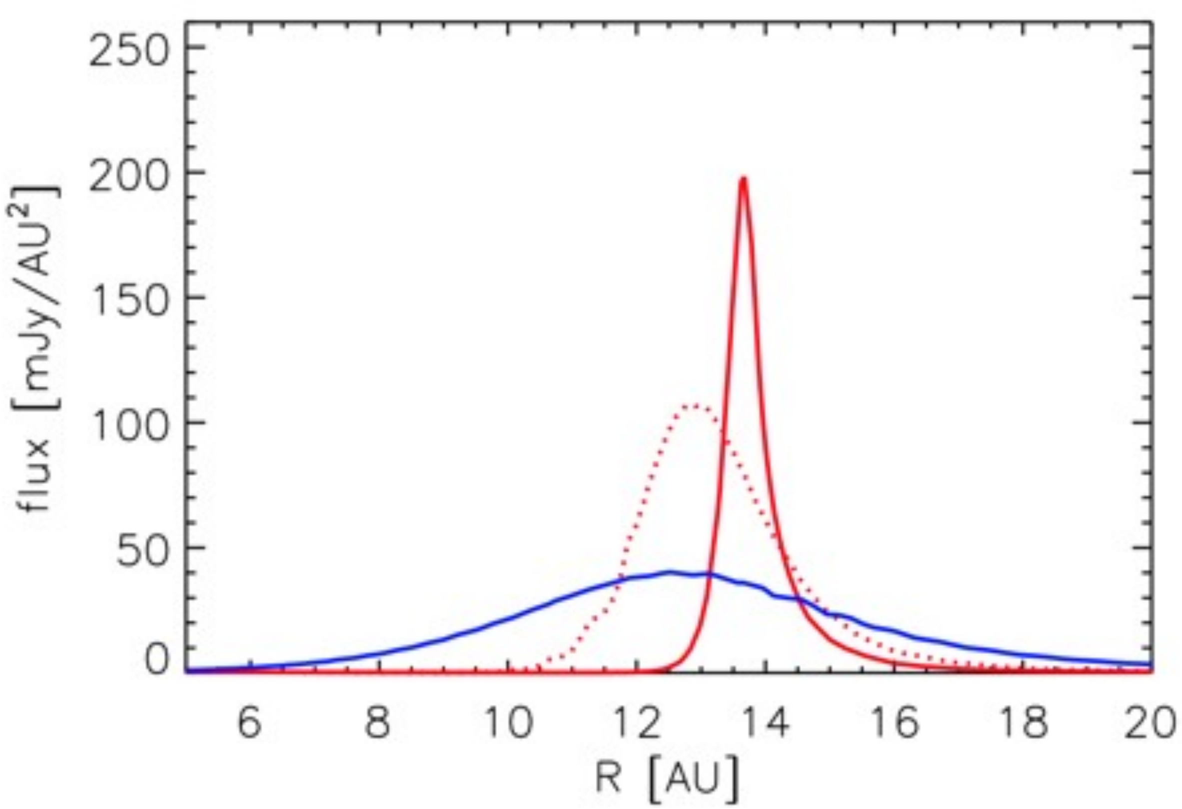


Olofsson et al. 2011, 2013; also Matter et al. 2014, Benisty et al. 2010b, Tatulli et al. 2011

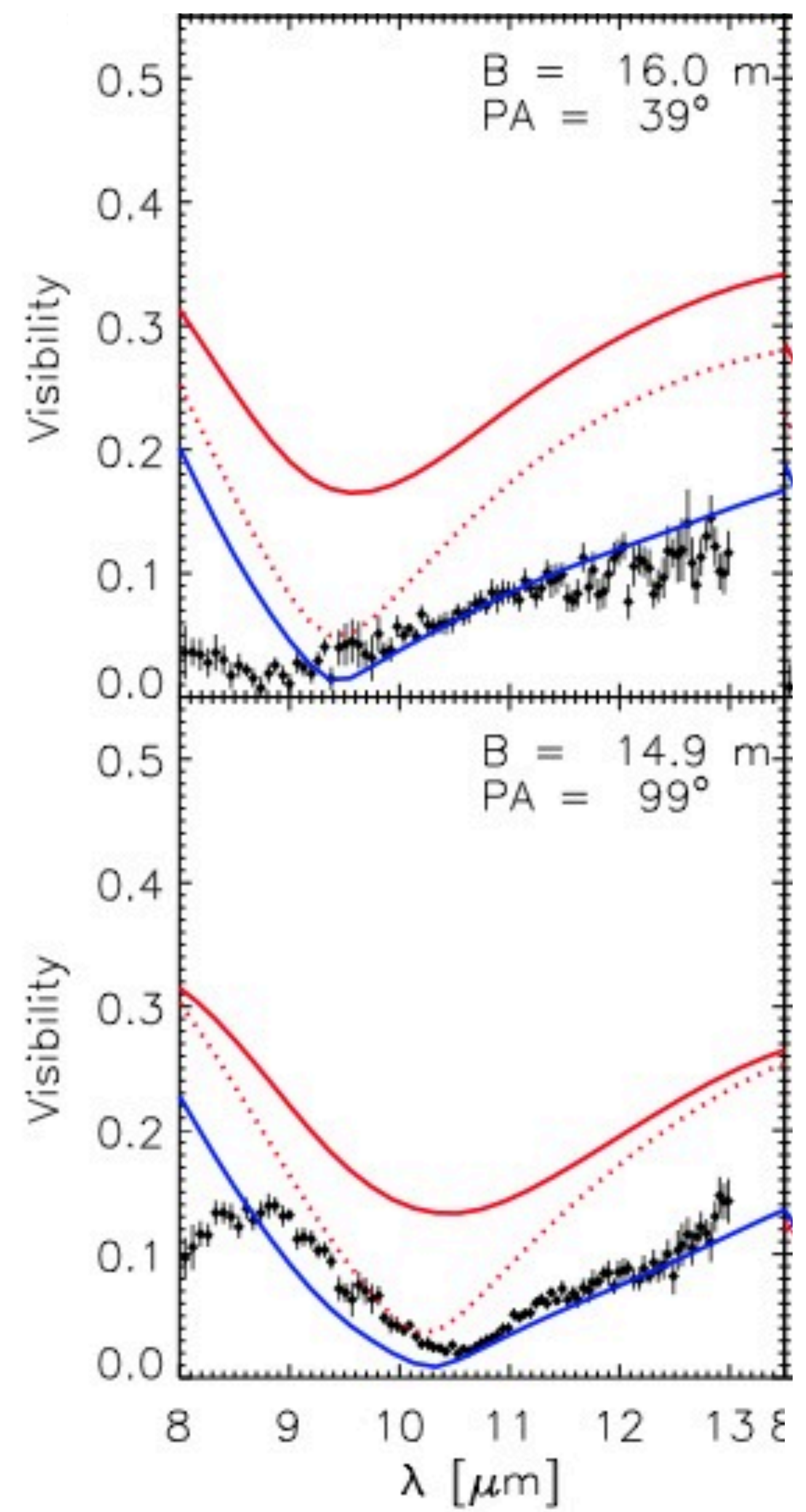
Transition disks

HD100546





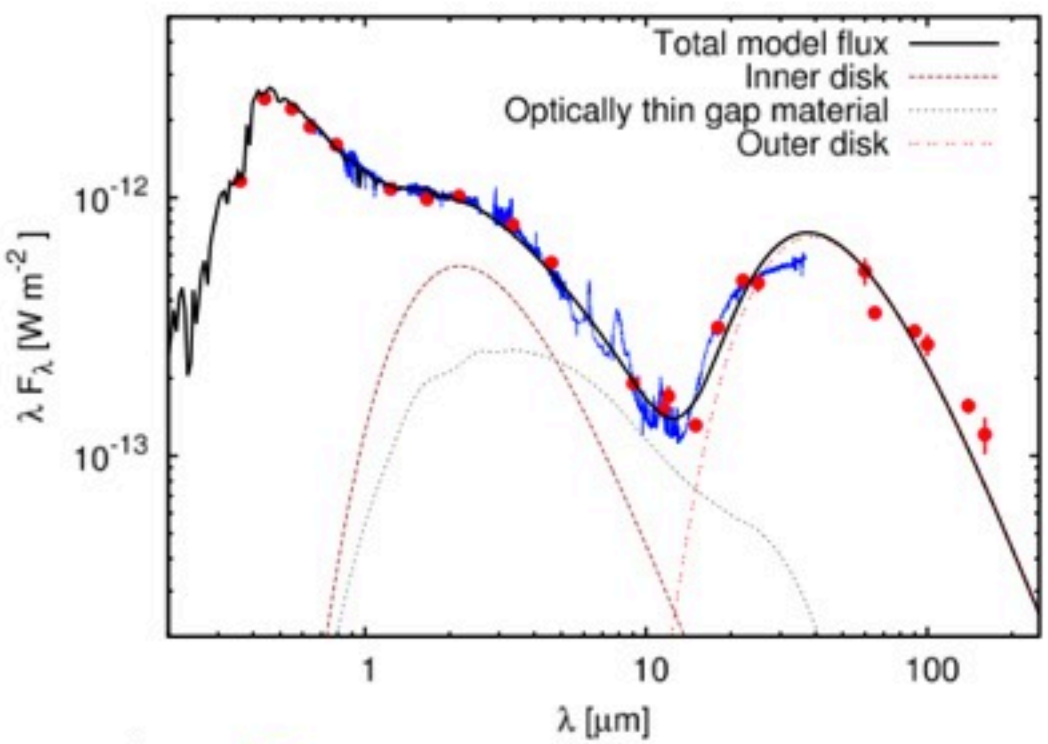
- Rounded wall
- Massive planet

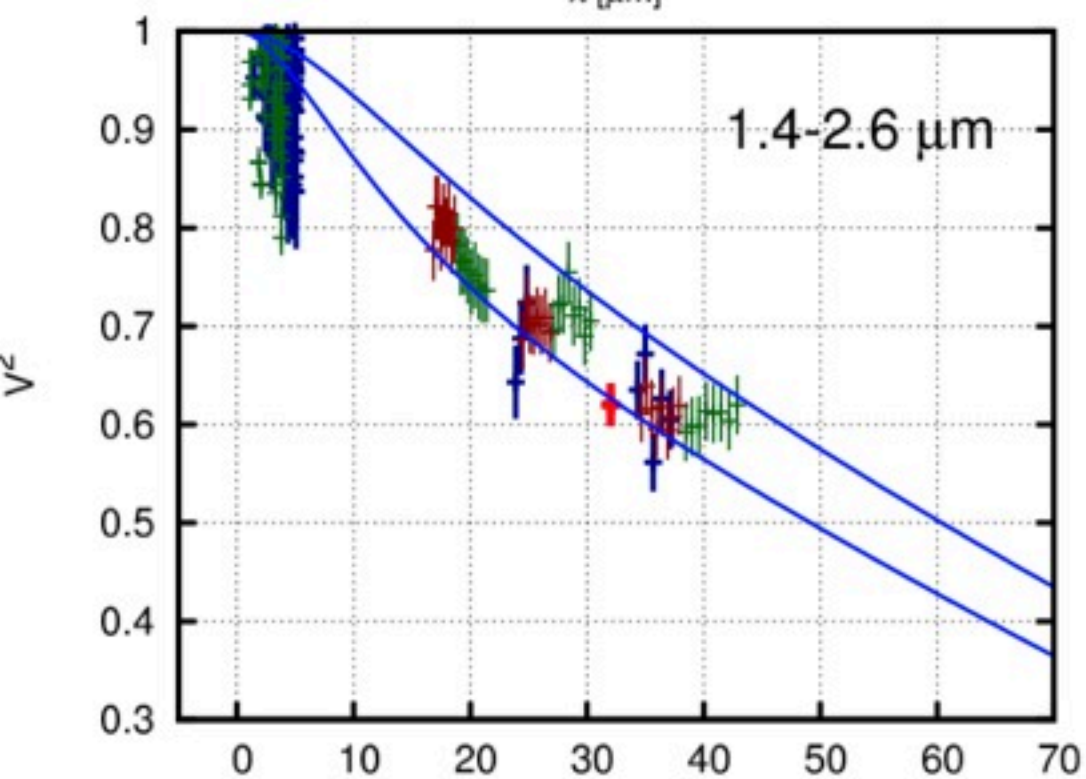


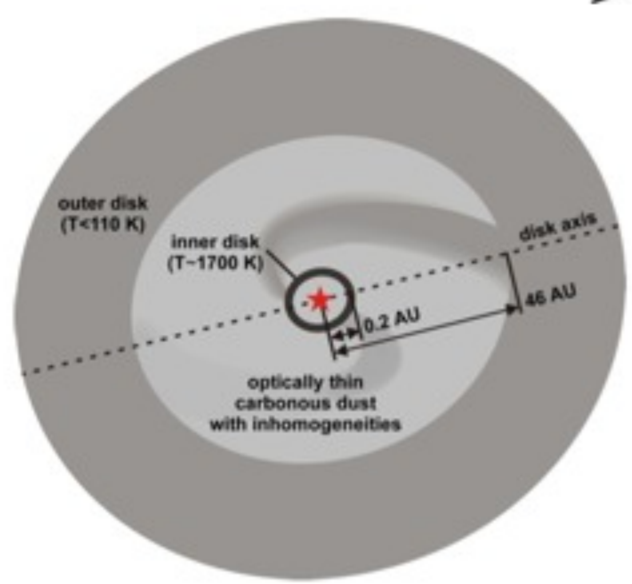
Mulders et al. 2013, also Panic et al. 2012

Transition disks

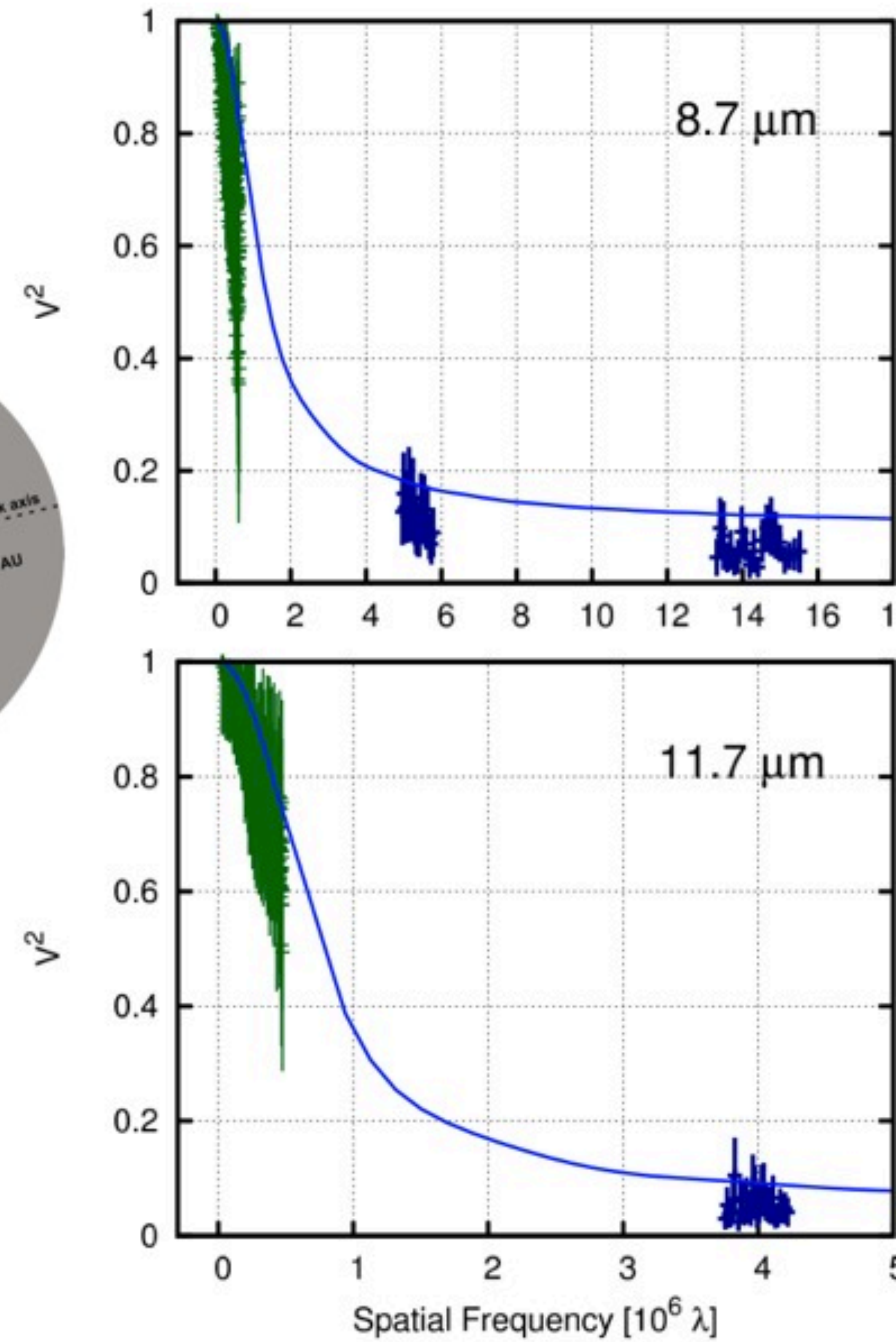
V1247 Ori







Carbonaceous material inside the gap



Kraus et al. 2013

see also Carmona et al. 2014

Outline

1. The inner AU

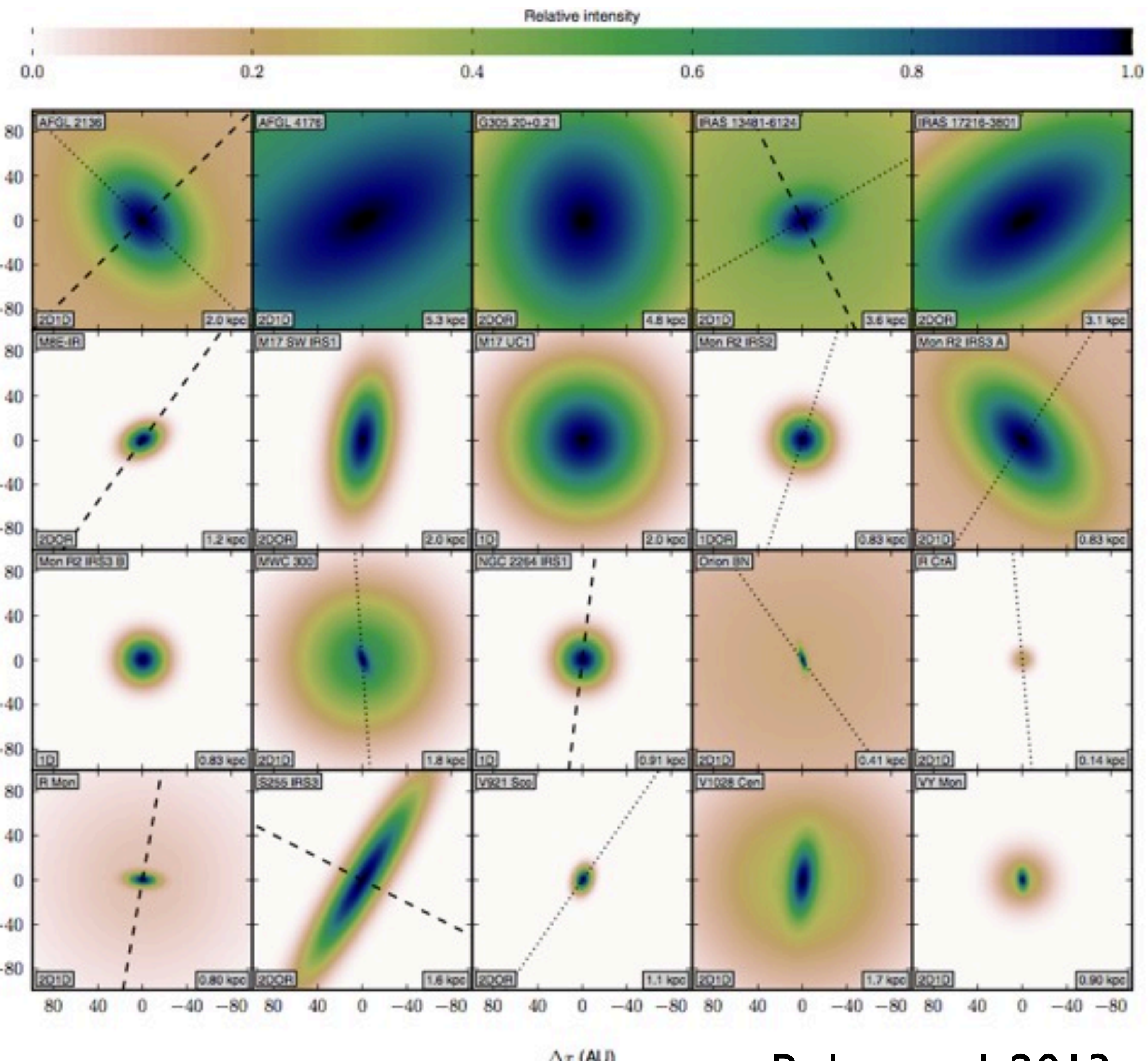
2. Herbig Ae Be stars

3. Transition disks

4. Massive YSO & Multiplicity

5. Perspectives

Massive YSOs

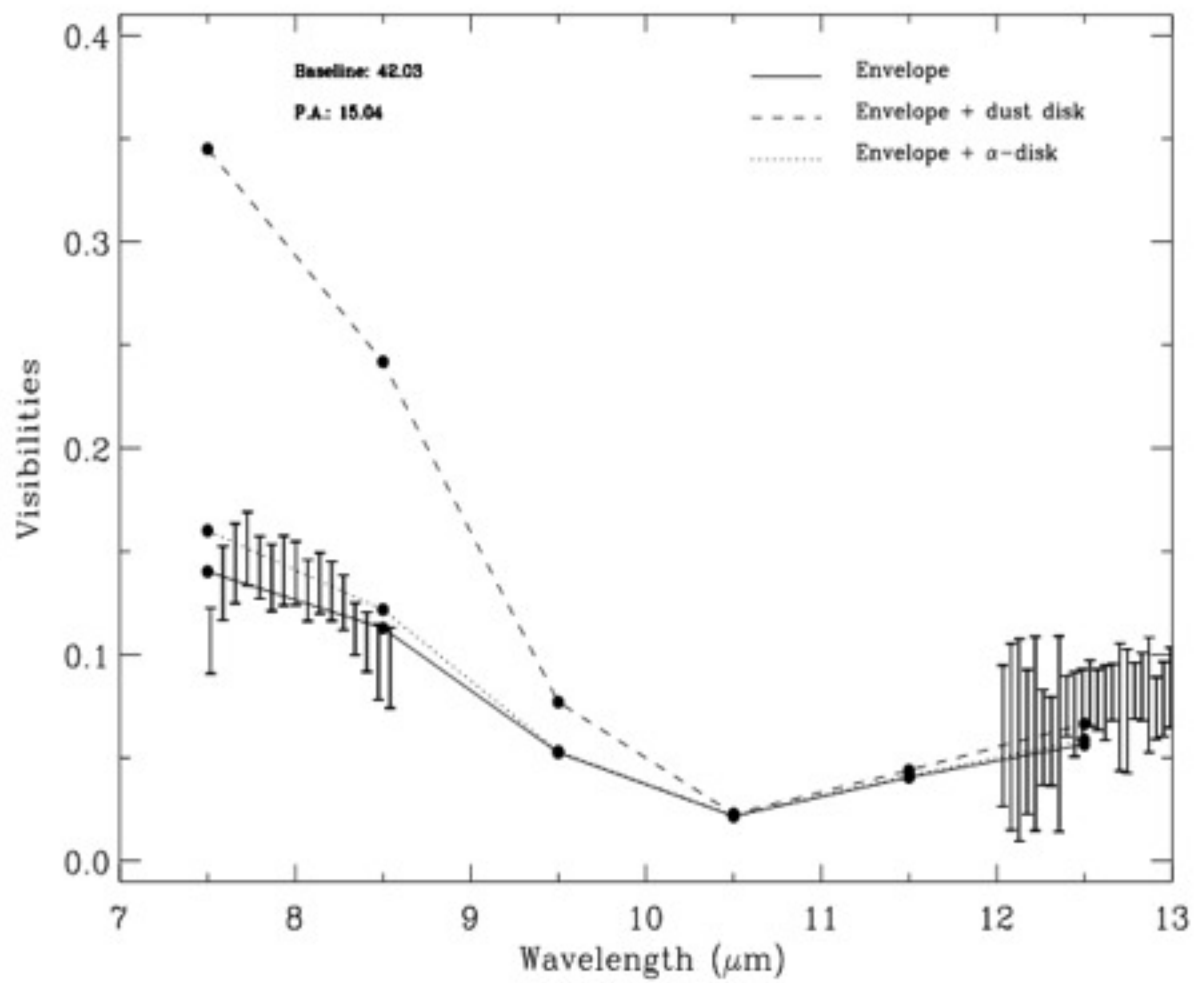


Boley et al. 2013

- Early evolutionary phases not well understood
- Distribution of infalling/ outflowing materials?
- Significant deviations from spherical symmetry
- Supports scenario of MYSO formation via accretion from disks

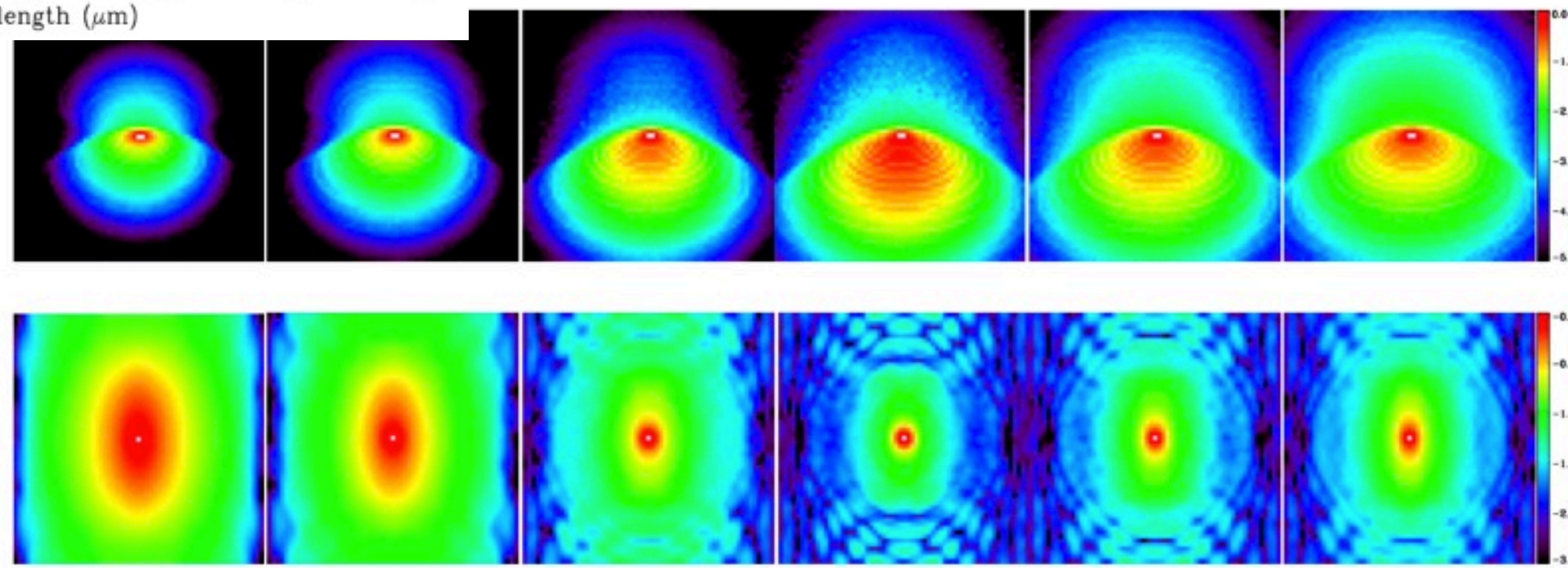
Also, Kraus et al. 2010, Boley et al. 2012, Grellmann et al. 2011

Massive YSOs



- Non spherically symmetric emitting structure at 100 AU
- MIR emission from cavity walls
- MIDI rules out presence of disk more massive than 0.01 Msun

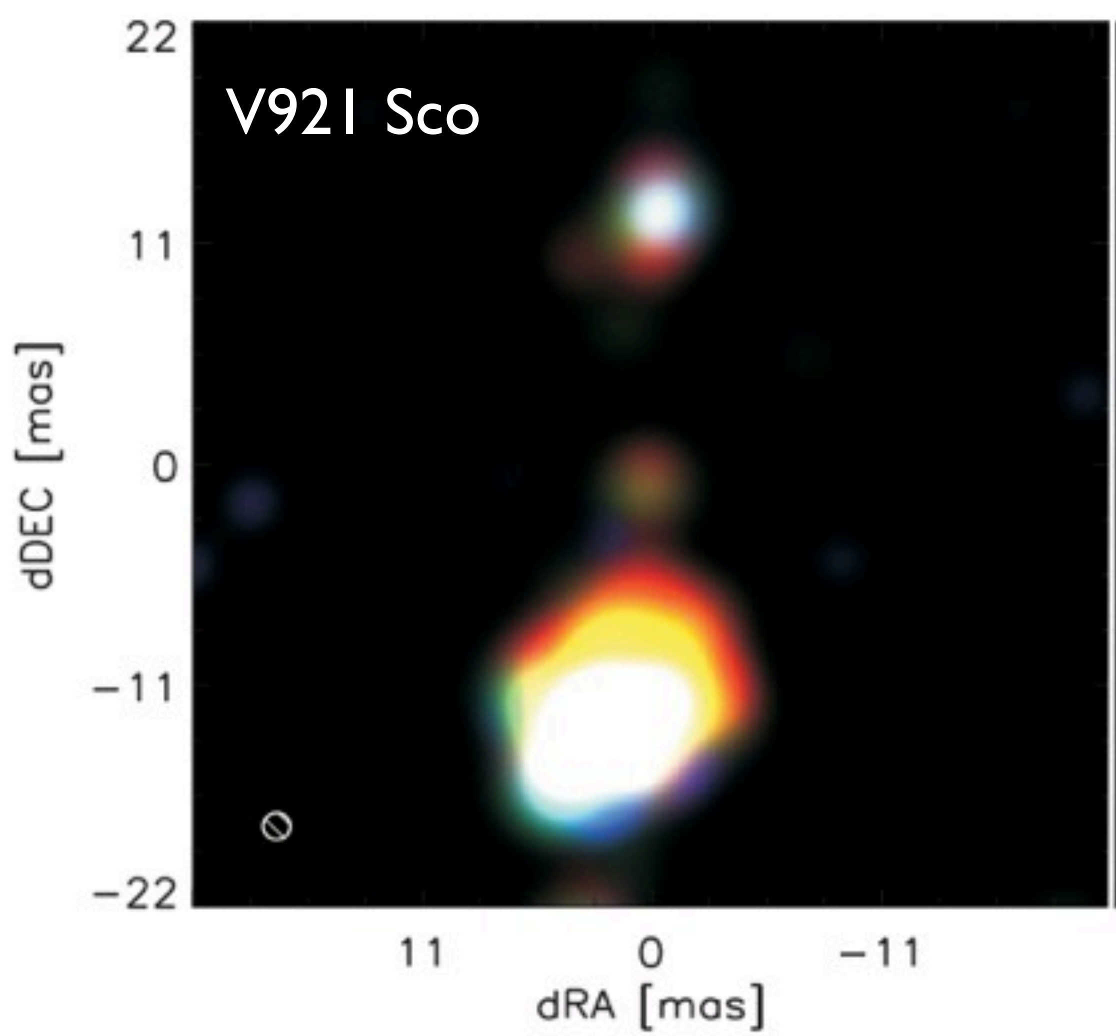
W33A (O7.5)



de Wit et al. 2010,2013

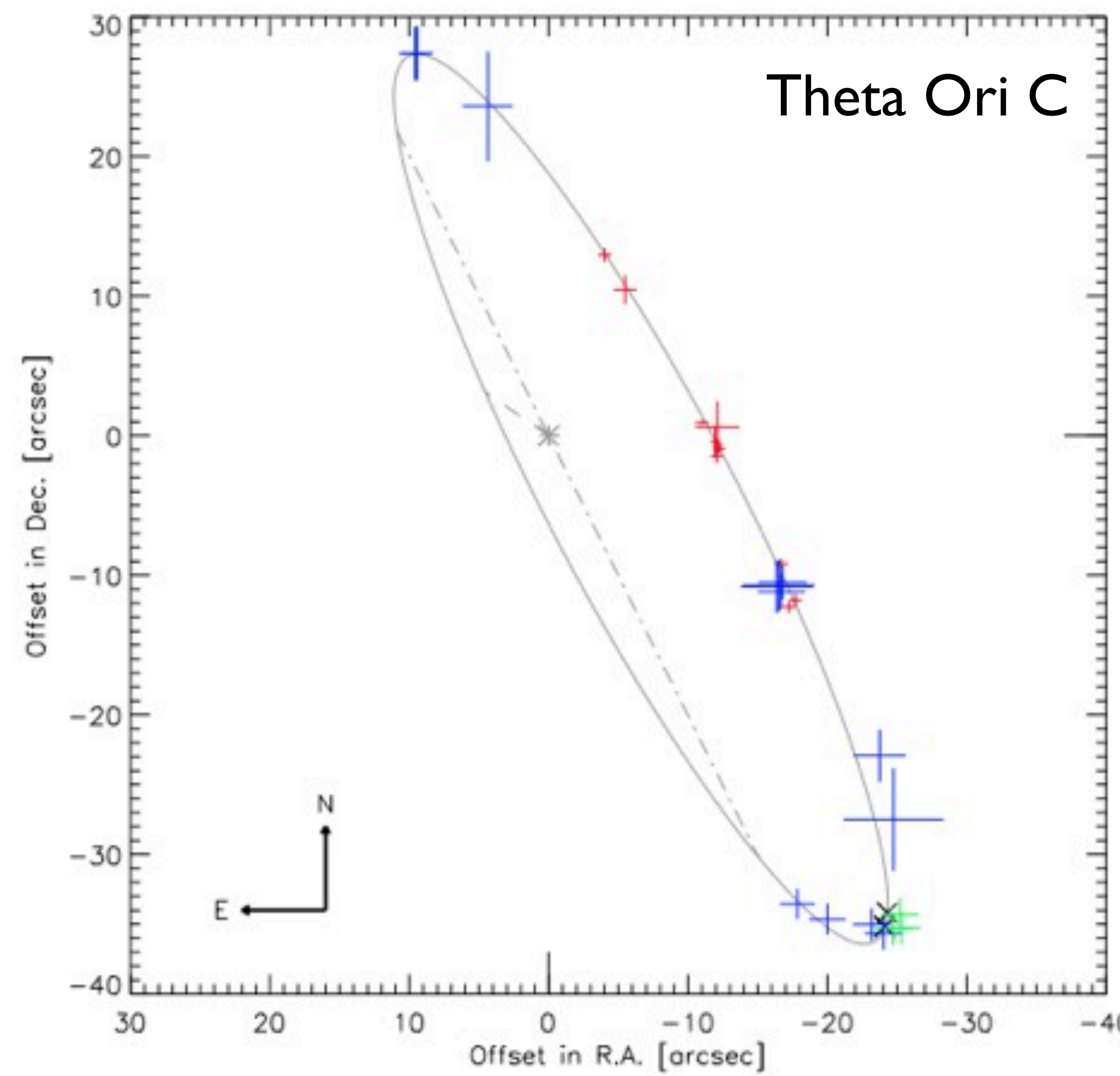
Multiplicity

Discover of a 25 mas companion



Kraus et al. 2012a
also Kreplin et al. 2012

Orbit and stellar parameters



Grellmann et al. 2013

Conclusions

- Multi-wavelength observations are insightful
- Detailed studies confirm that the inner AUs of YSOs are complex (rim+additional component)
- Transition disks show compact inner disks (in small grains) and interferometry can bring strong constraints on the amount of material located inside the gap
- MYSOs environments show deviations from spherical symmetry
- TTS models require active disks and (sometimes) envelopes

- Second generation instruments will provide better sensitivity, better UV coverage, a good wavelength coverage for disk-studies

Perspectives

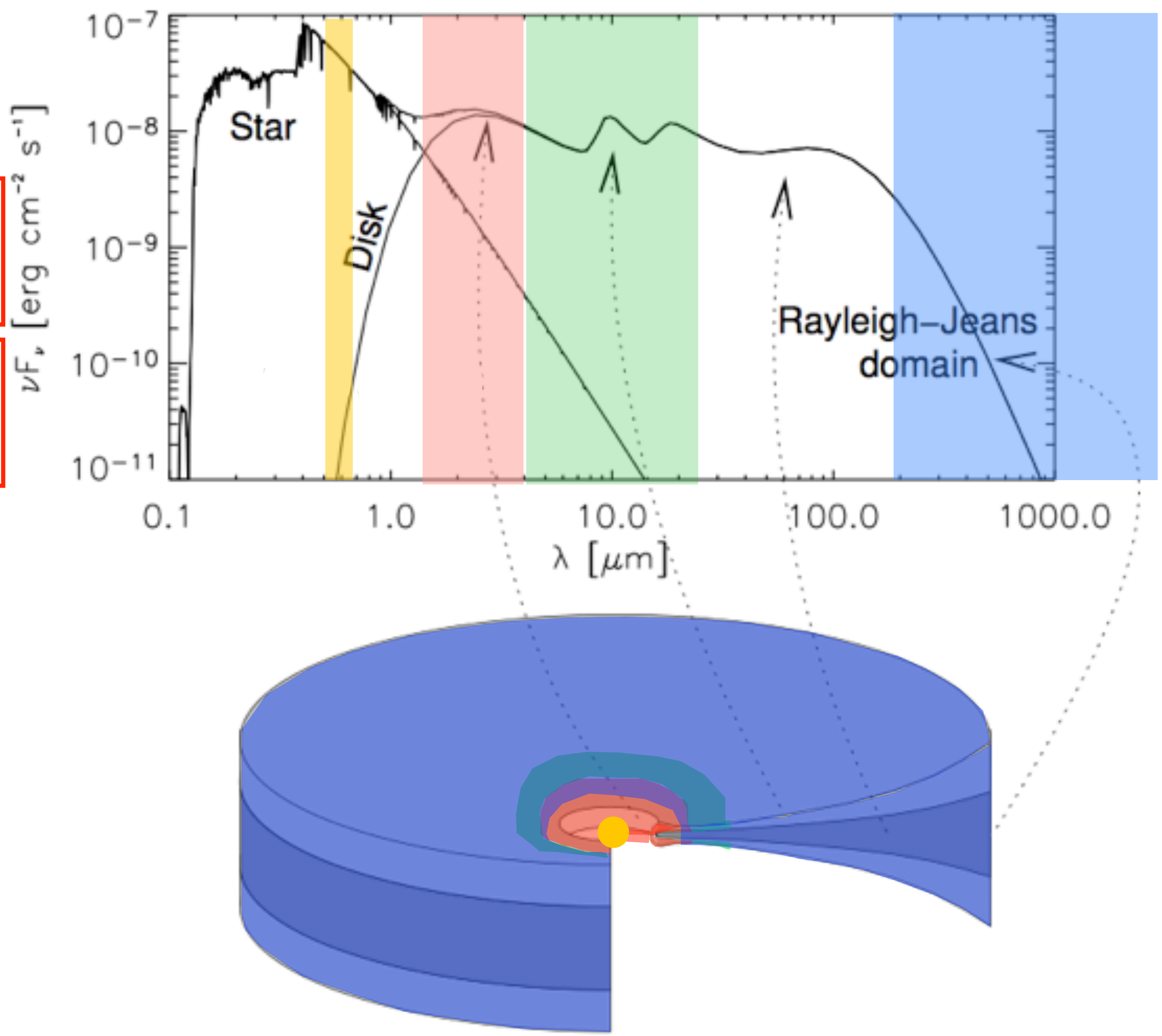
VEGA-CHARA (V)
0.4–4 mas

MATISSE/VLTI (L,M,N,Q)
5–20 mas

ALMA (mm)
5–100⁺ mas

PIONIER/VLTI (H)
2–5 mas

GRAVITY/VLTI (K)
2–5 mas



Planet forming region

Jet launching