Inner regions of young stellar objects revealed by optical long baseline interferometry

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Outline

- **Introduction**
  - Physical conditions in the inner regions of YSOs
  - Need for very high angular resolution
  - Physical processes

- **Infrared interferometry**
  - Principles and observables
  - Instruments available for inner regions studies
  - Elements of bibliography

- **Inner disk physics**
  - Sizes of circumstellar structures
  - Constraints on disk structure (T, z,…)
  - Dust mineralogy
  - Gas/dust connection

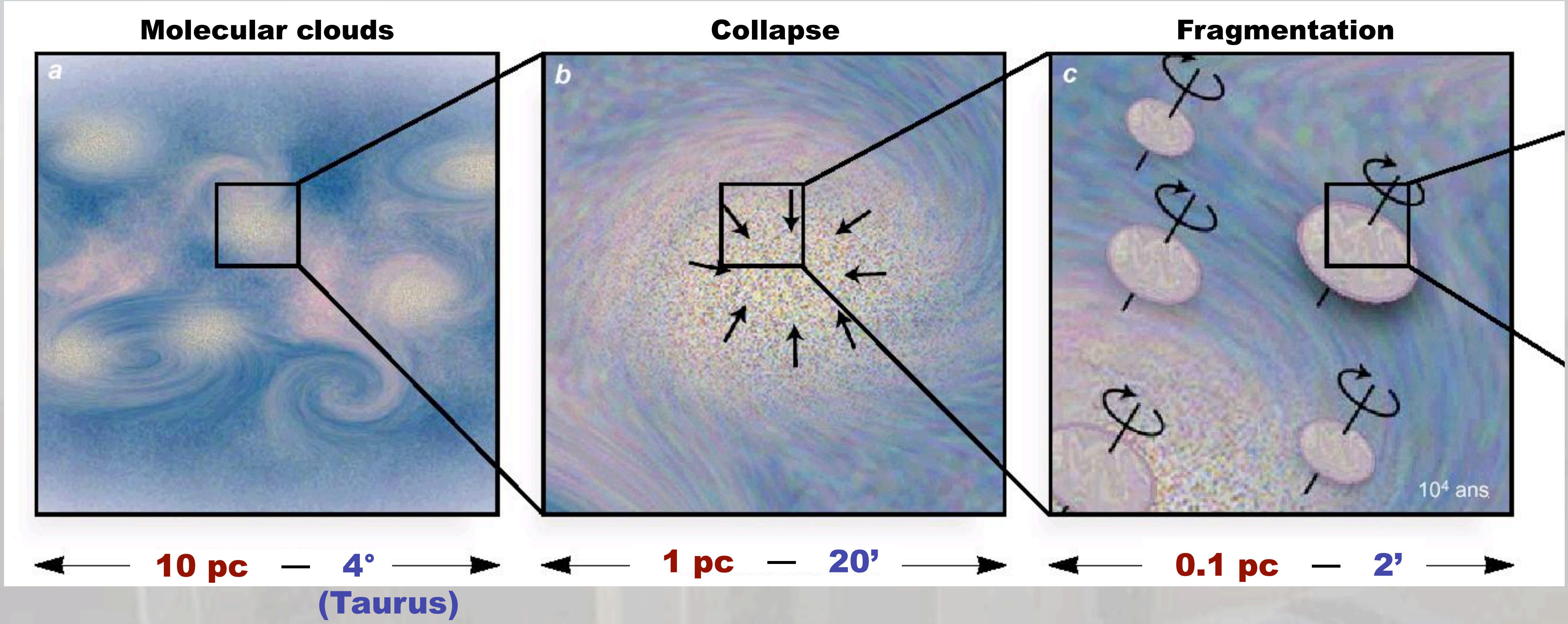
- **Other AU-scale phenomena**
  - Outflows and winds
  - Magnetosphere
  - Binaries and multiple systems

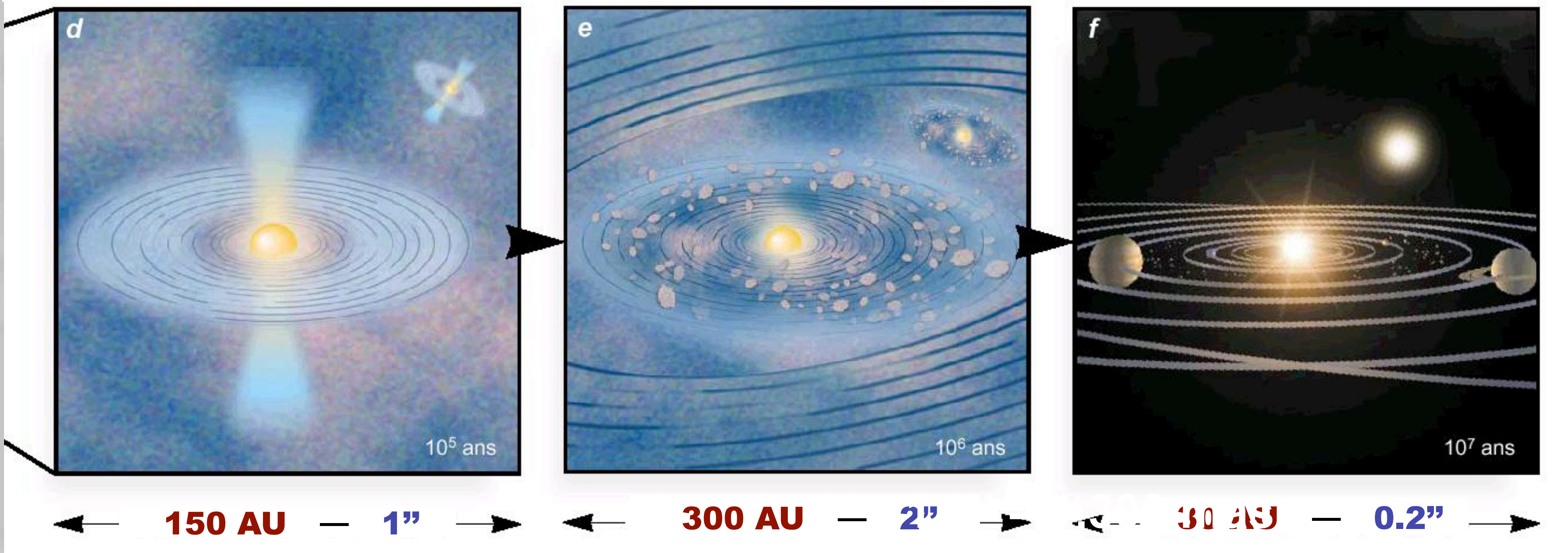
- **Future prospects**

INTRODUCTION

- Formation of stars, disks and planets
- Physical conditions in the inner regions of YSOs
- Need for very high angular resolution
- Physical processes

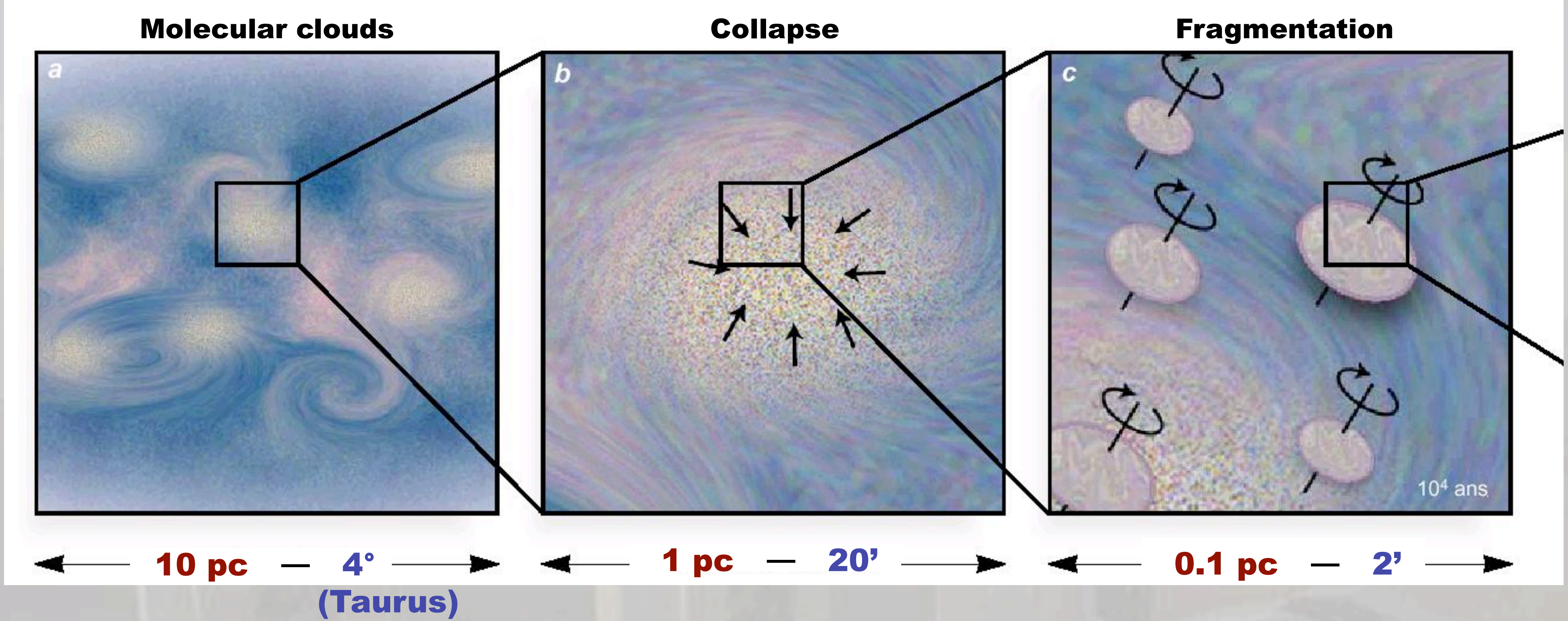
Formation of stars, disks and planets

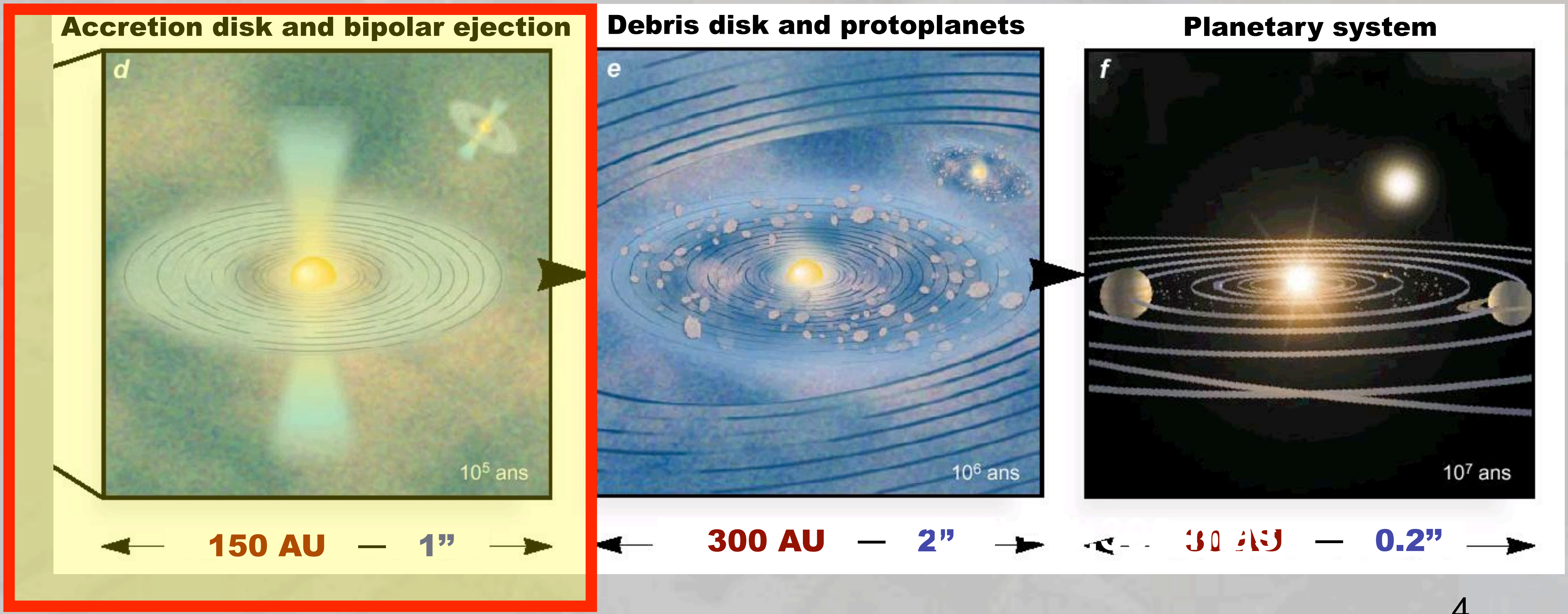




Bouvier & Malbet
(2001, DPLS, 30, 84)

Formation of stars, disks and planets





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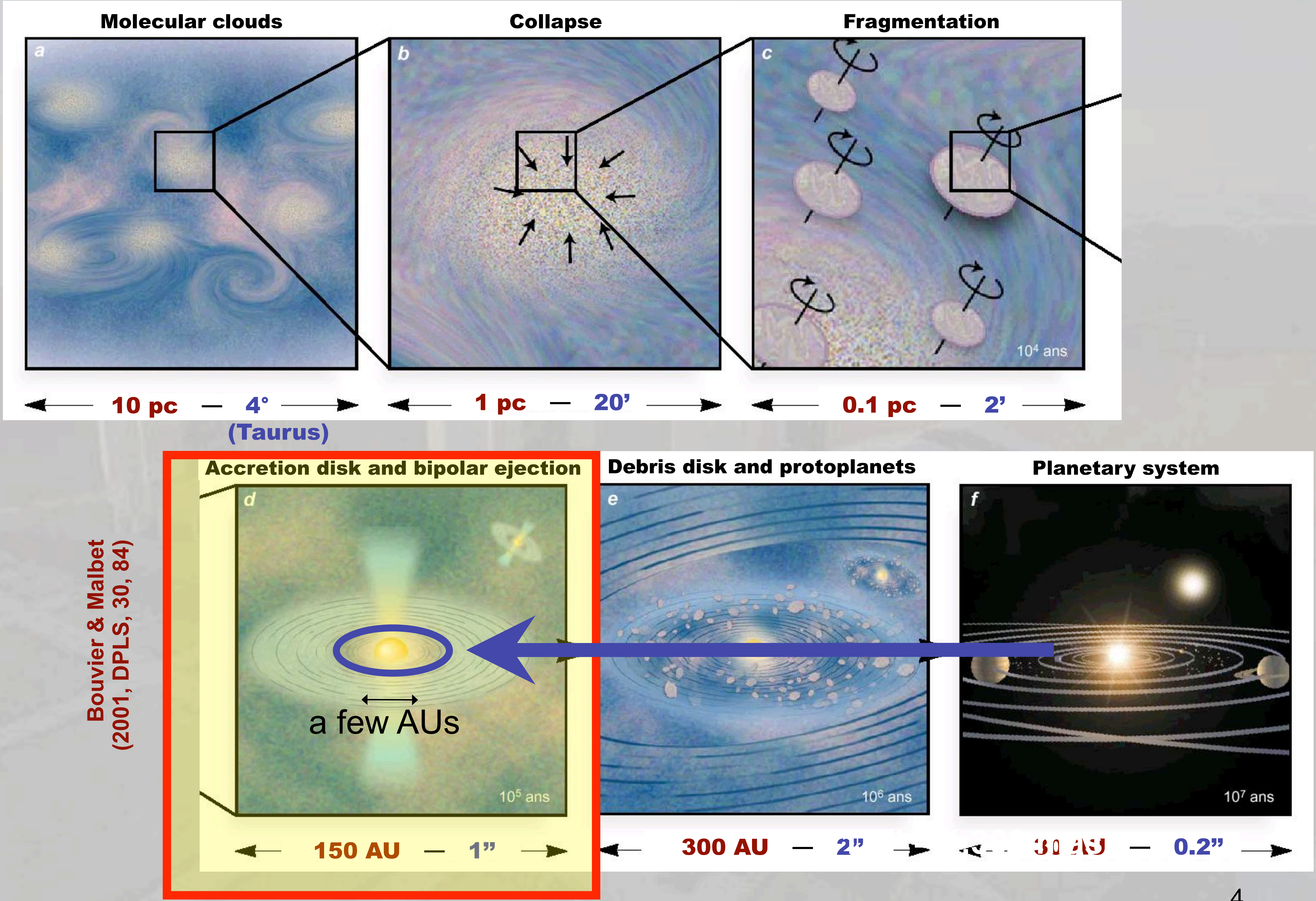
Formation of stars, disks and planets



Molecular clouds

10 pc — 4°

(Taurus)

Collapse

1 pc — 20'

Fragmentation

0.1 pc — 2'

Accretion disk and bipolar ejection

a few AUs

150 AU — 1"

Debris disk and protoplanets

300 AU — 2"

Planetary system

30 AU — 0.2"

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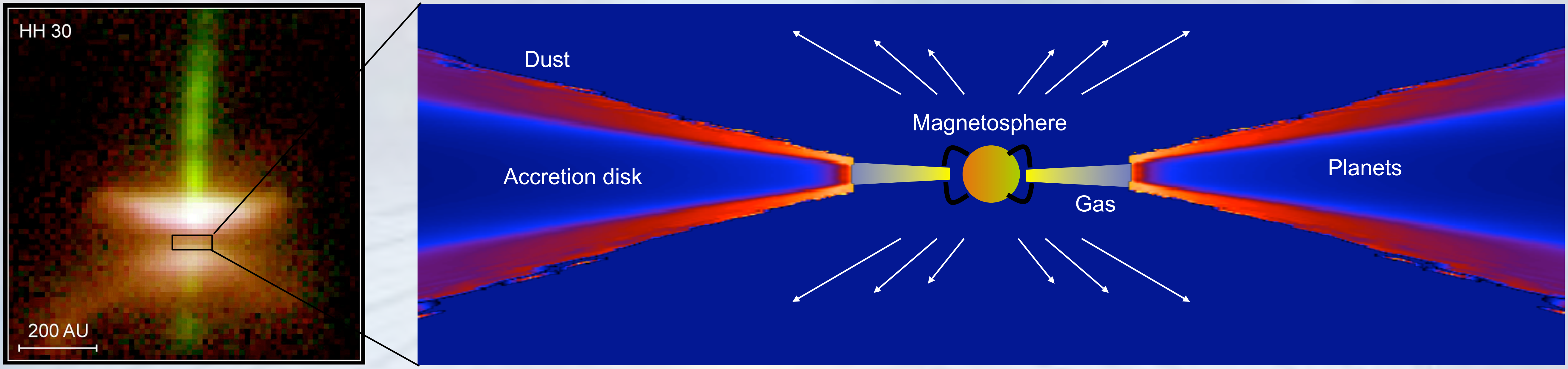
Physical conditions in the close environment of young stellar objects



- **Physical phenomena**
  - Keplerian accretion disk: gas + dust
  - Stars from K to B spectral types (4000K to 10000K)
  - Strong outflowing wind
  - Companions
  - Magnetophere
  - Protoplanets

- **Physical conditions**
  - Radius ranging from 0.1 AU to 10 AU
  - Temperature ranging from 150 K to 4000 K
  - Velocity ranging from 10 km/s to few 100 km/s

➡ At 150 pc (Taurus), this corresponds to :

$1\mu m \lesssim \lambda \lesssim 20\mu m$ and spatial scales between 0.5 et 70 mas

Instrumental requirements

- **Wavelength domain**

  Temperature ranges → **λ ~ 1 to 20 µm:**

- **Angular resolution**

  Spatial scales

1.22 λ/D	**0.1 AU**	**1AU**	**5AU**	**10AU**
75pc	1.5mas	15mas	70mas	150mas
150pc	0.7mas	7mas	30mas	70mas
450pc	0.2mas	2mas	10mas	20mas

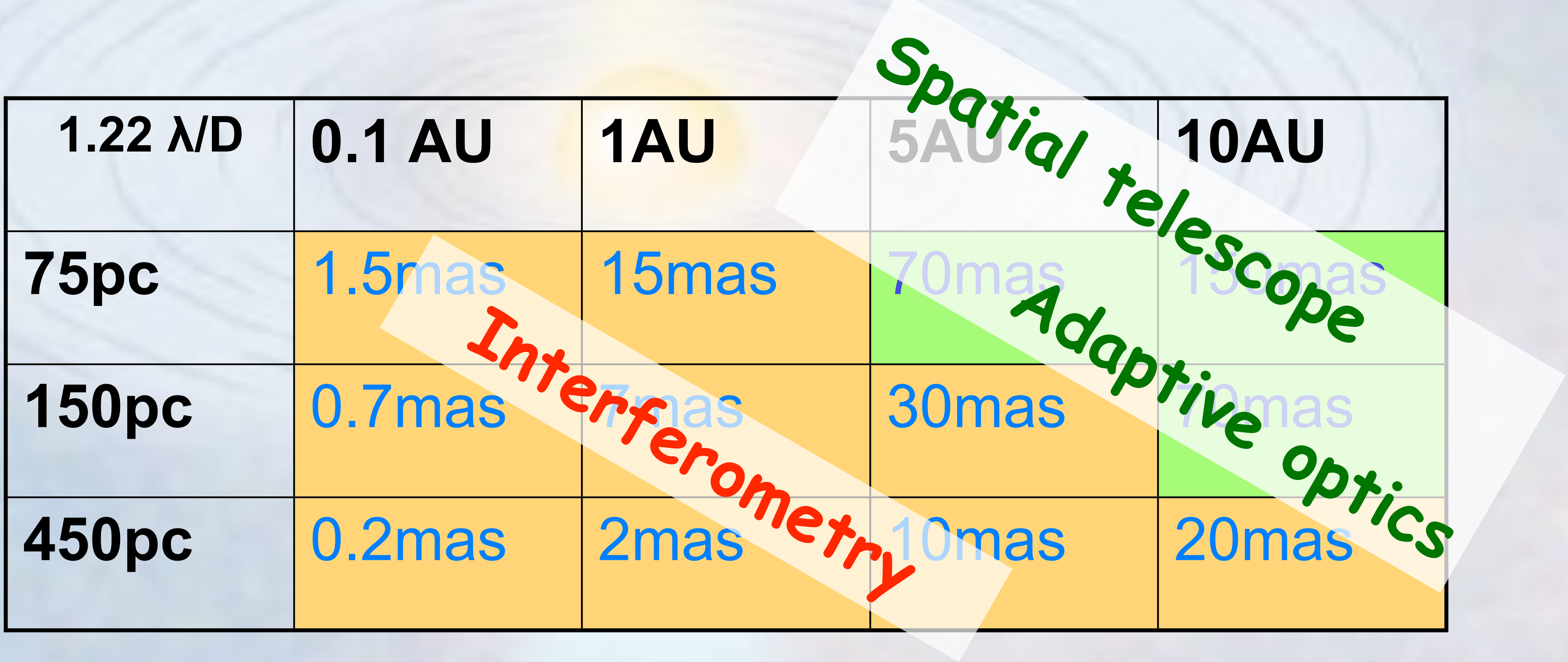
Instrumental requirements

- **Wavelength domain**

  Temperature ranges → **λ ~ 1 to 20 μm:**

- **Angular resolution**

  Spatial scales



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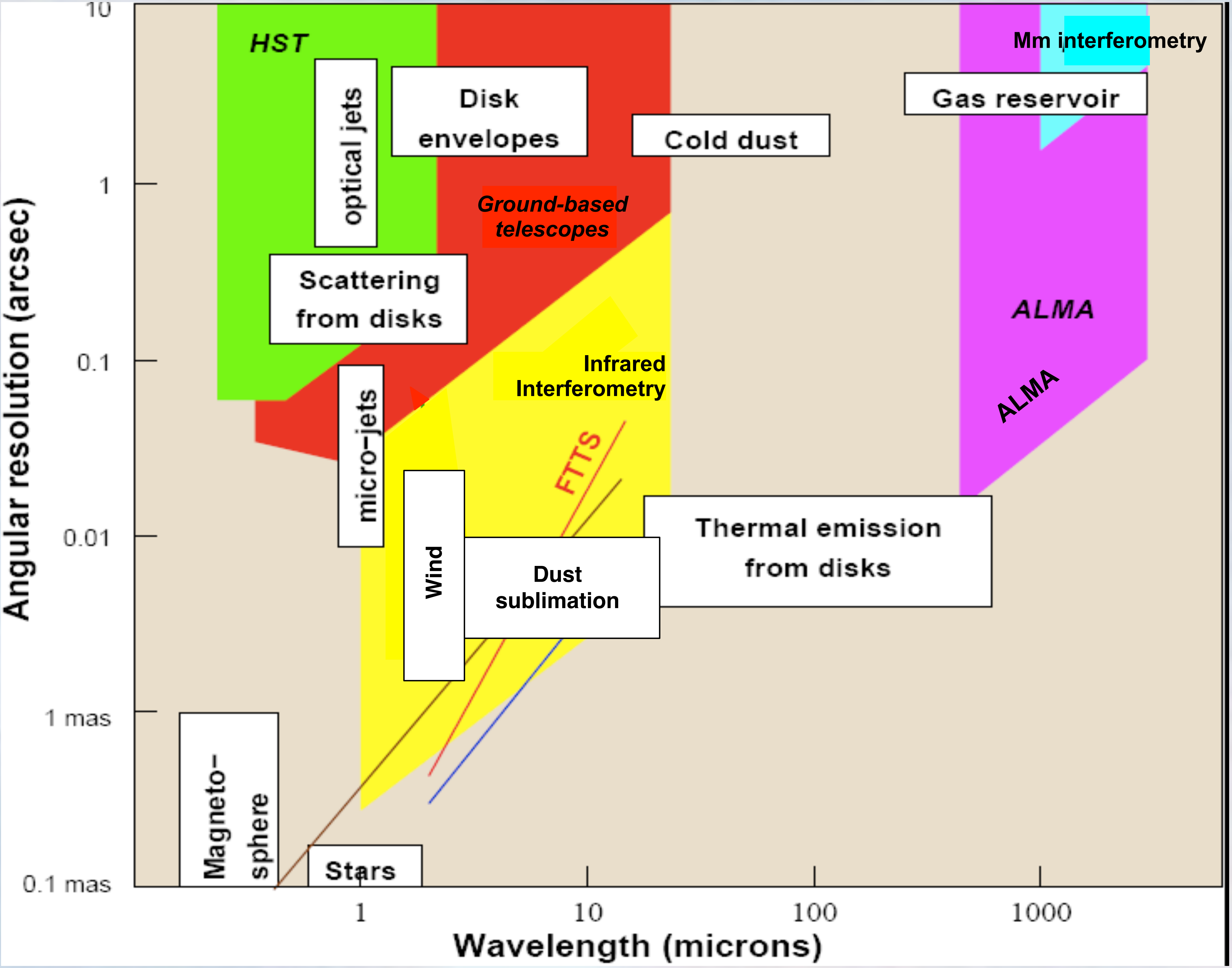
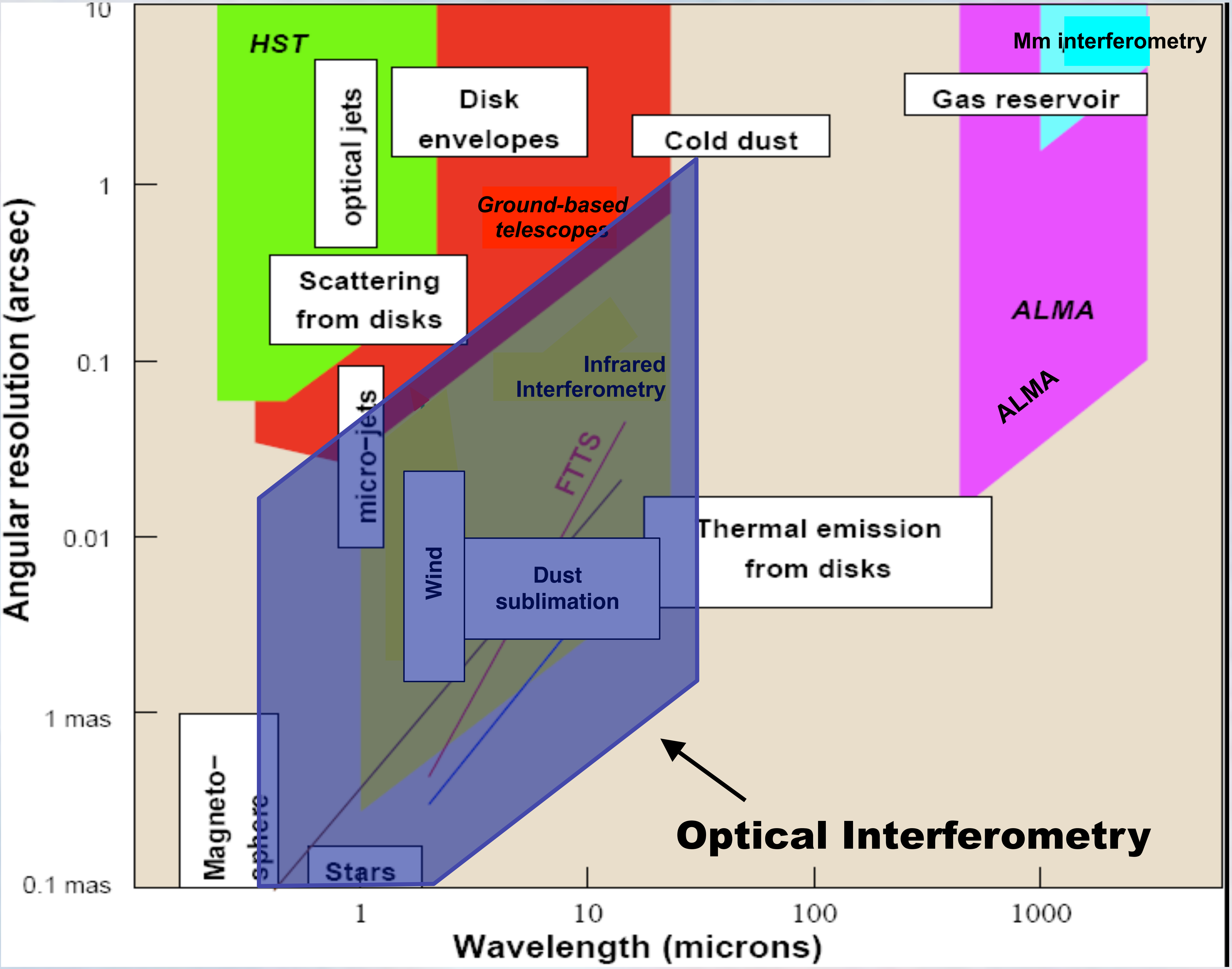

HST
optical jets
Disk envelopes
Cold dust
Gas reservoir
Mm interferometry
Ground-based telescopes
Scattering from disks
Infrared Interferometry
ALMA
ALMA
micro-jets
FTTS
Wind
Dust sublimation
Thermal emission from disks
Magneto-sphere
Stars
10
1
0.1
0.01
1 mas
0.1 mas
Angular resolution (arcsec)
1
10
100
1000
Wavelength (microns)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Angular resolution (arcsec)
10
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0.1
0.01
1 mas
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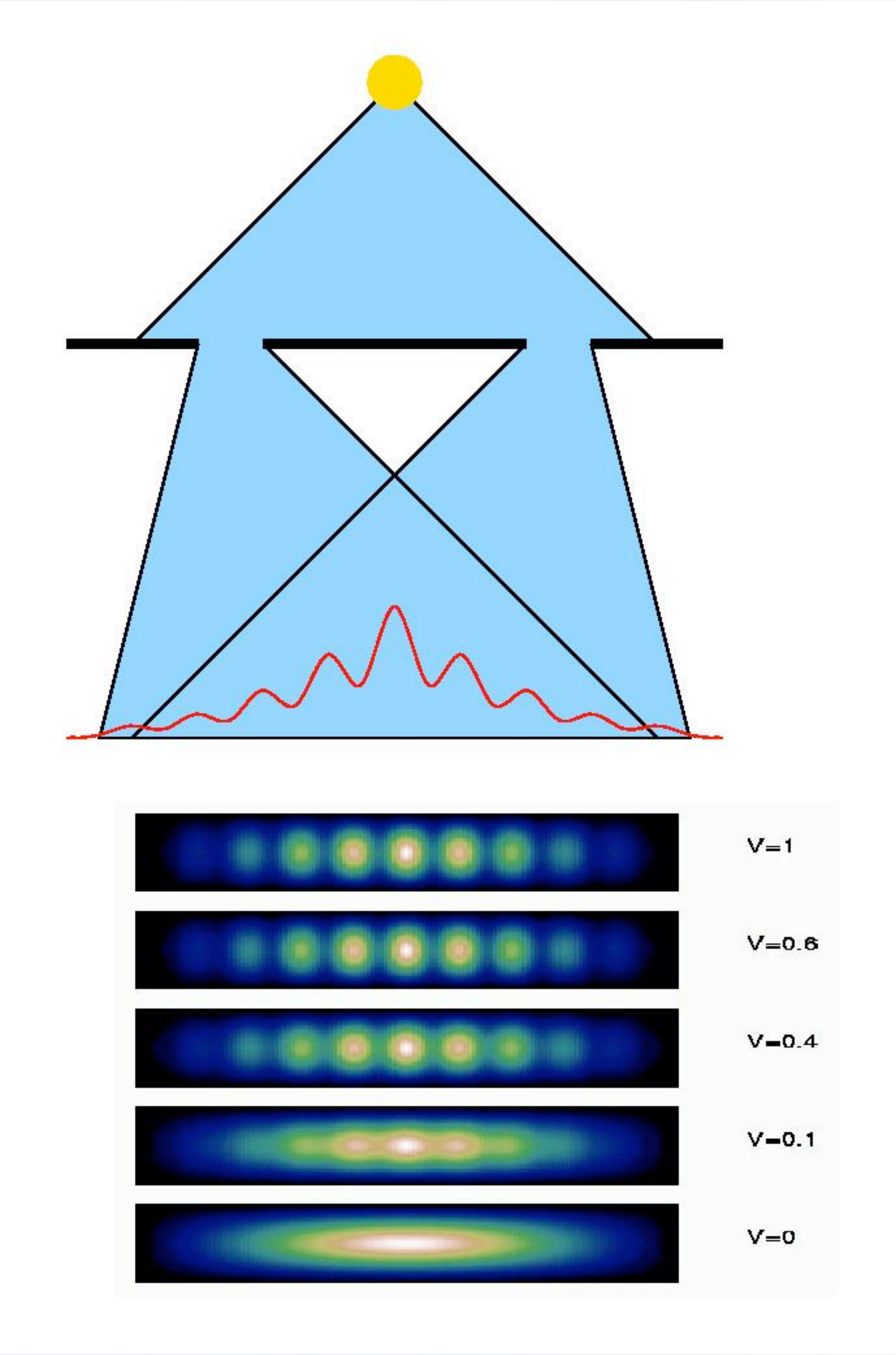
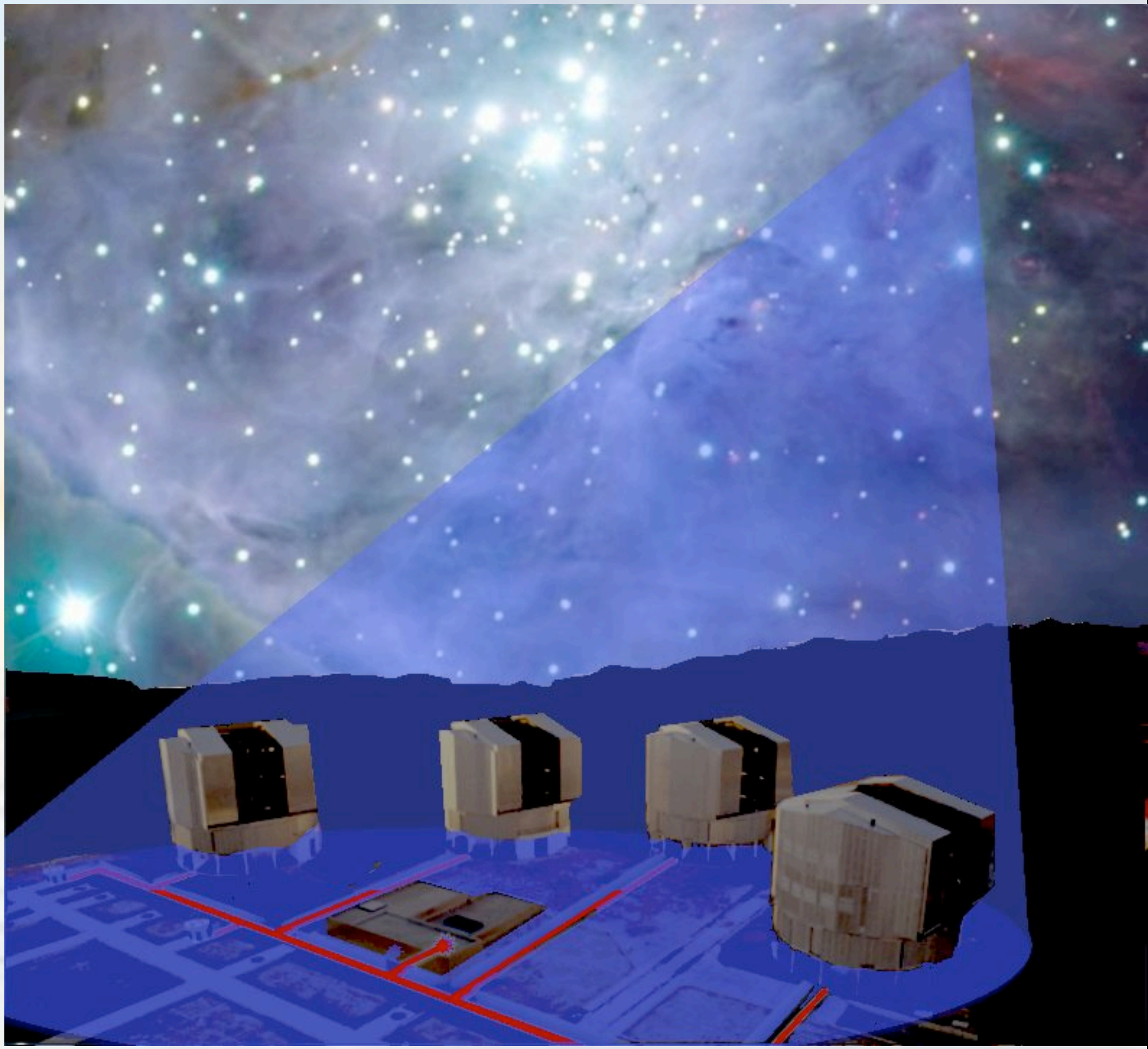
Wavelength (microns)
1
10
100
1000

Infrared and visible Interferometry

- Principles and observables
- Instruments available for YSO studies
- Elements of bibliography on YSO science results

Basics of optical interferometry





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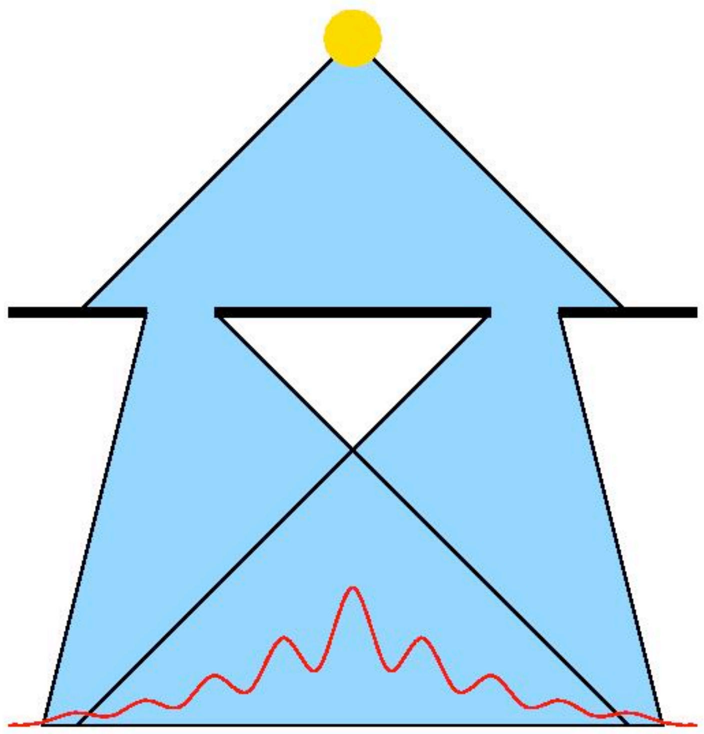
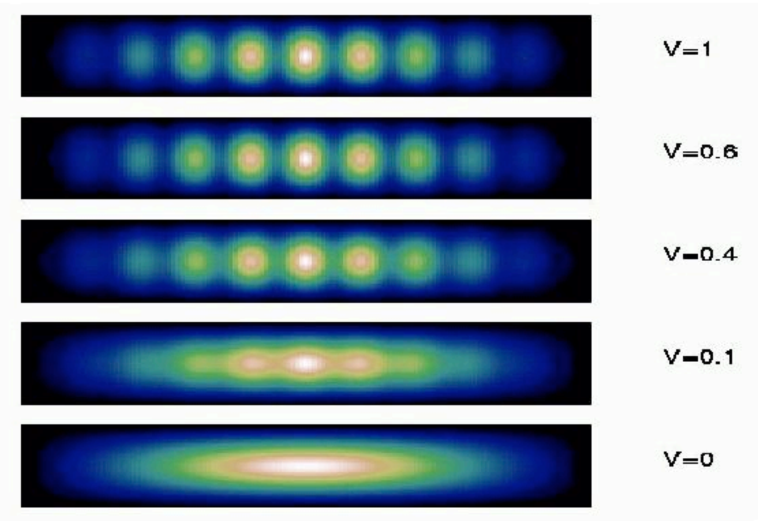
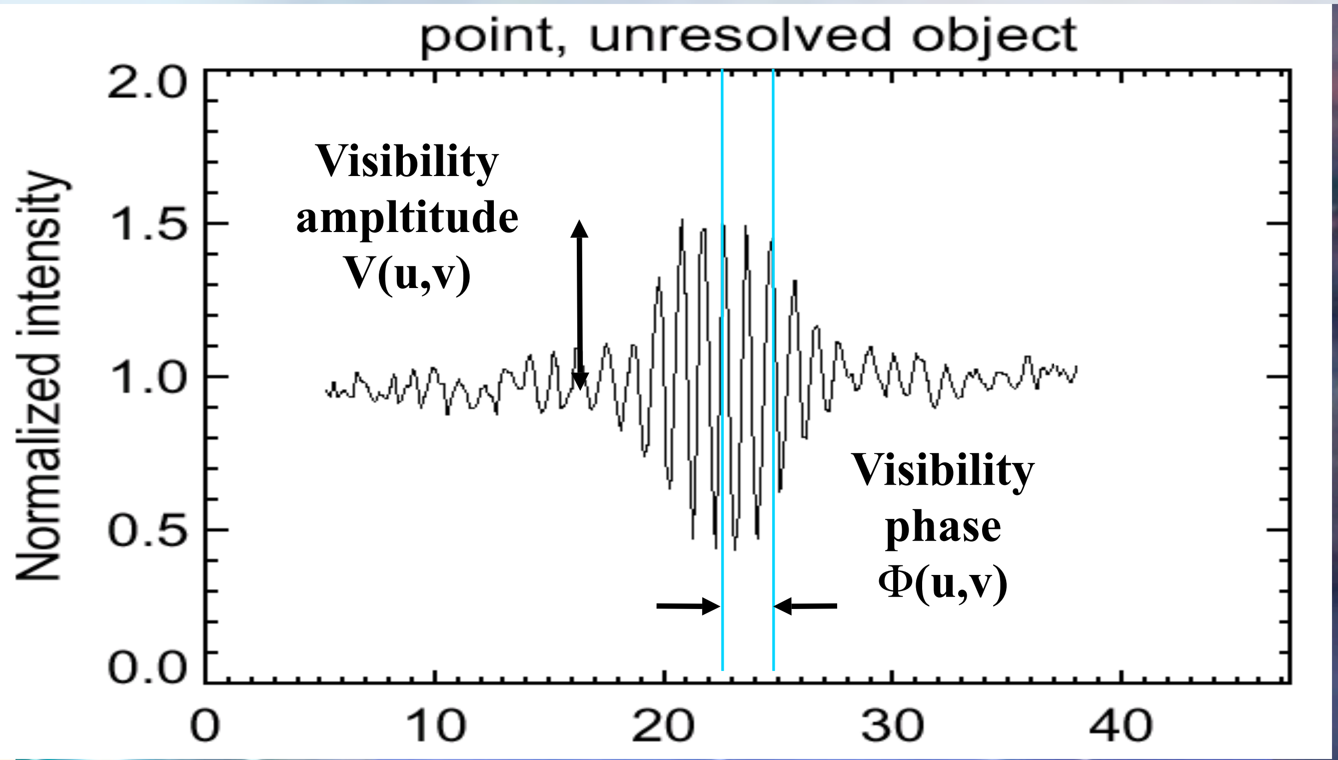
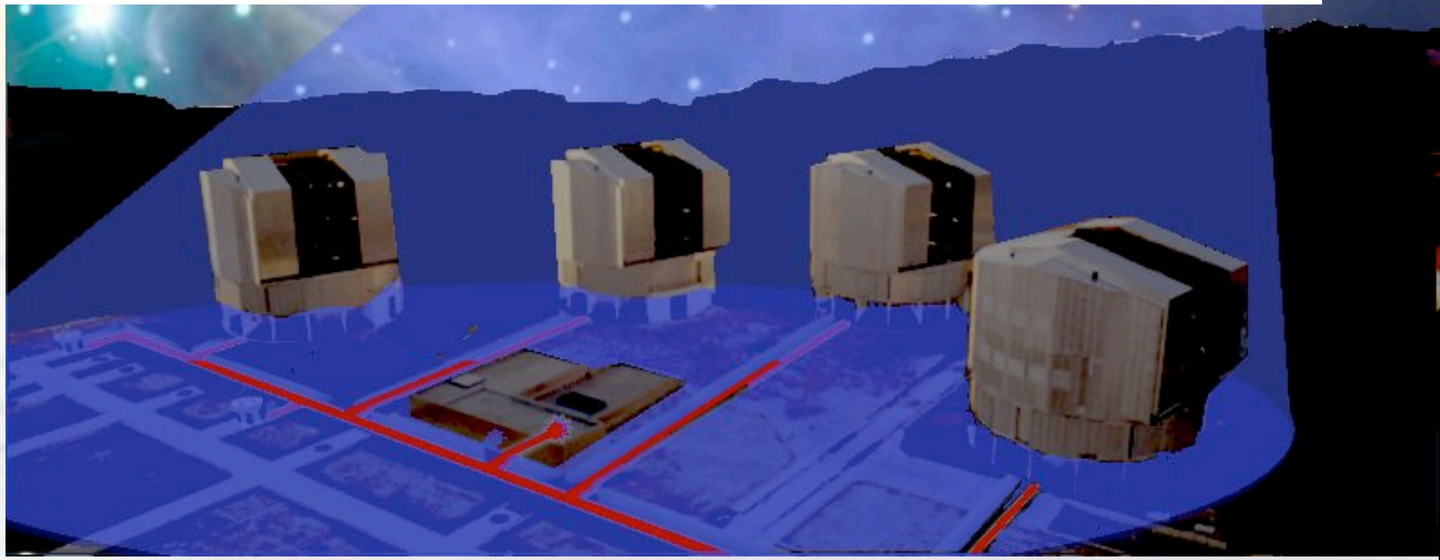
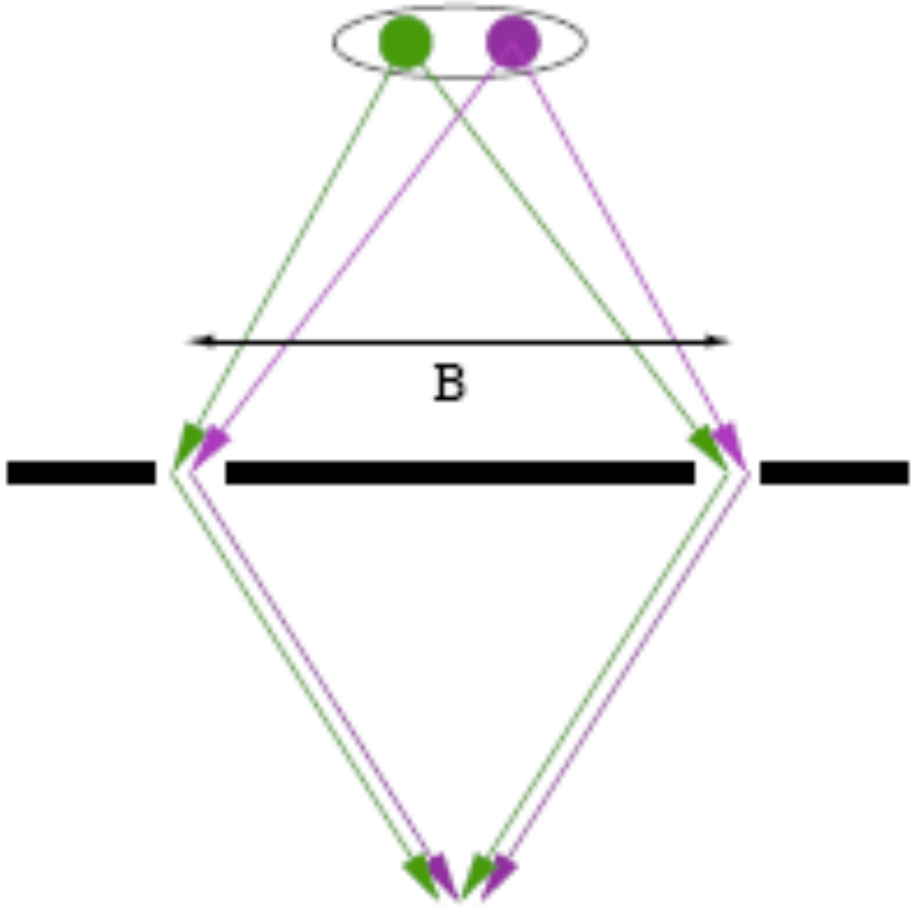


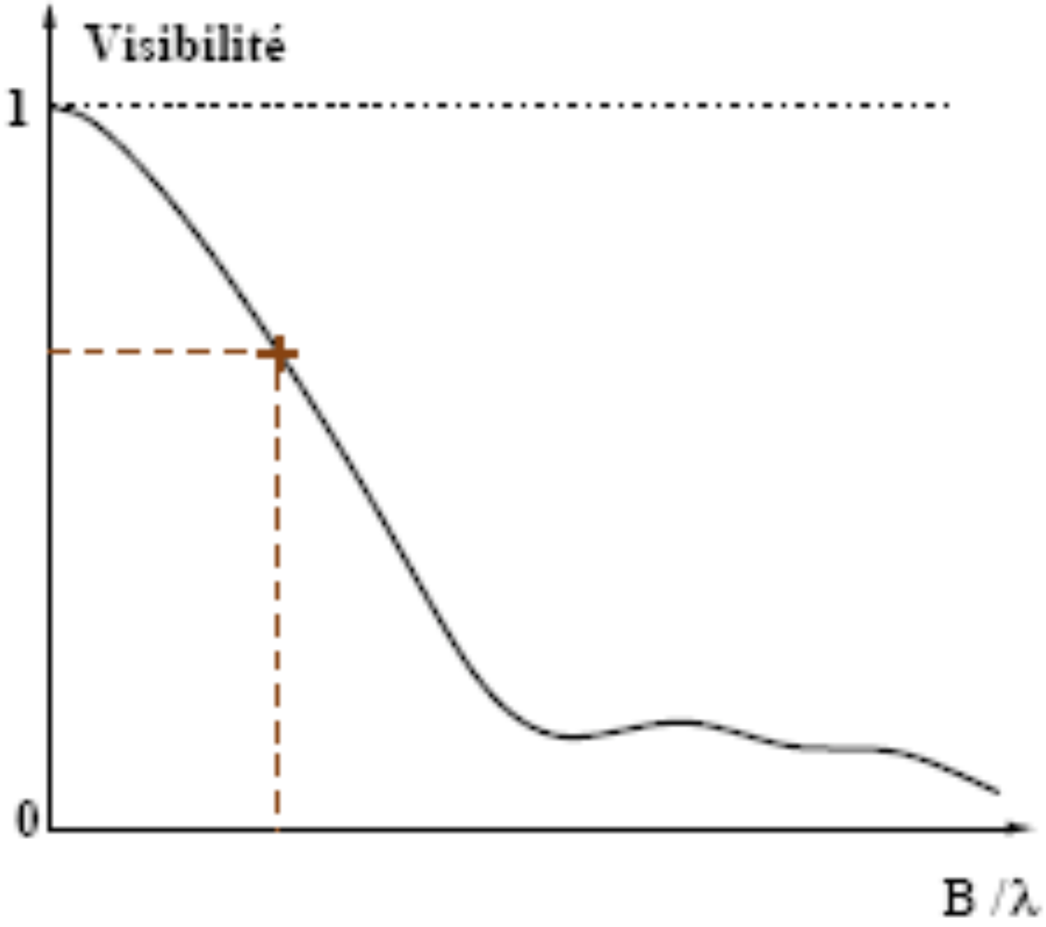


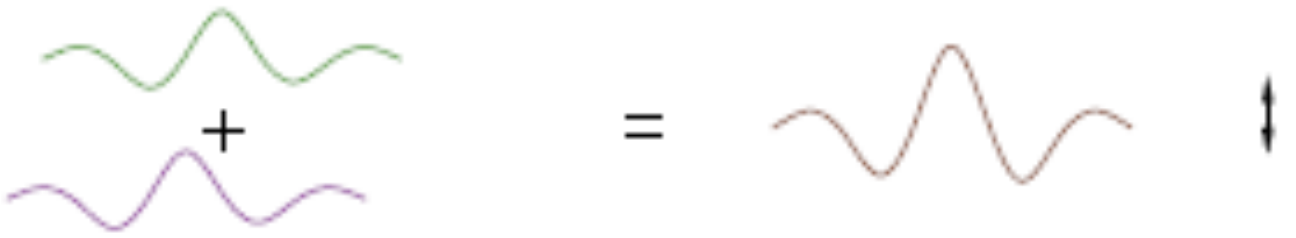




Spatial coherence







Interferogram 1

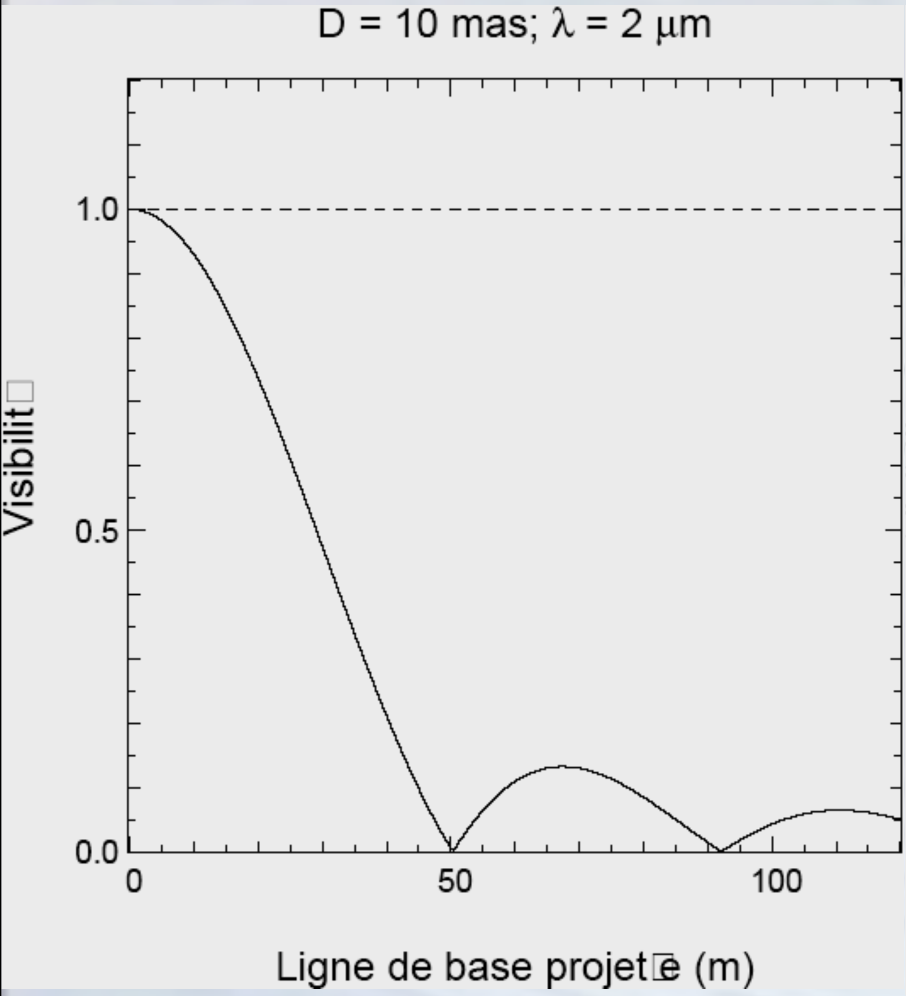
Interferogram 2

Reduced contrast
Shifted phase

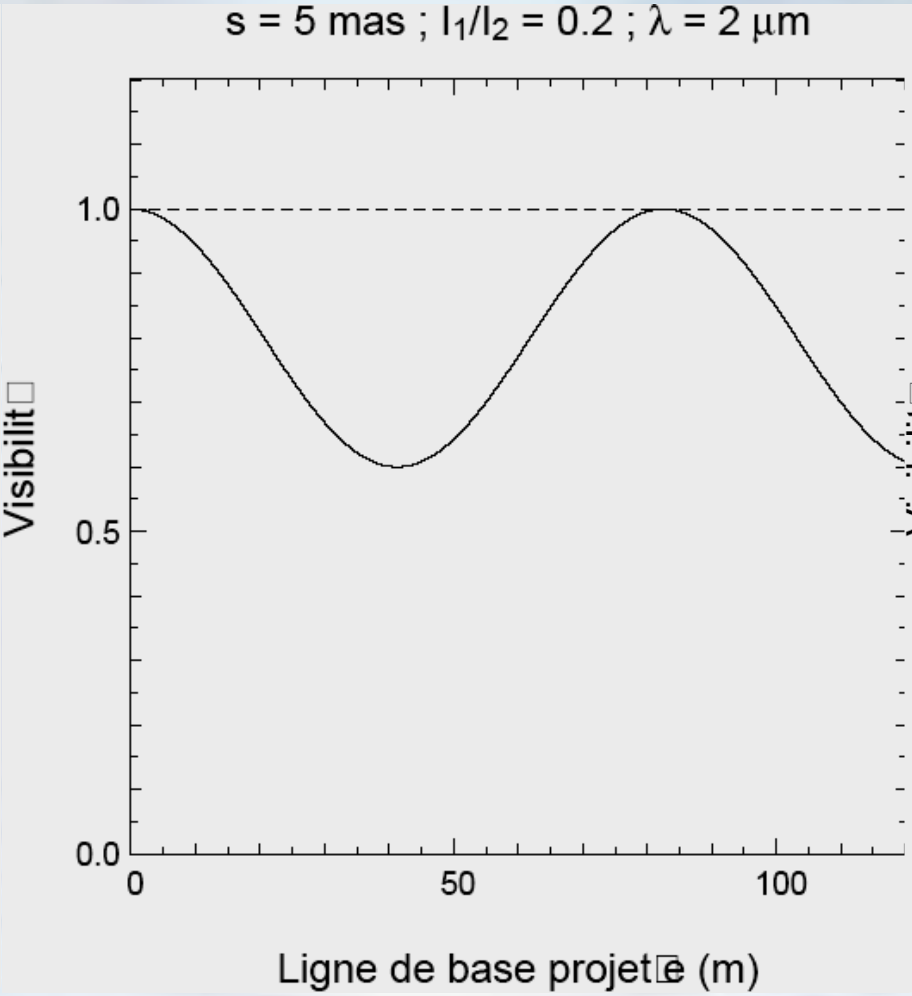
Zernicke-van Cittert theorem

Visibility = Fourier transform of the brightness spatial distribution

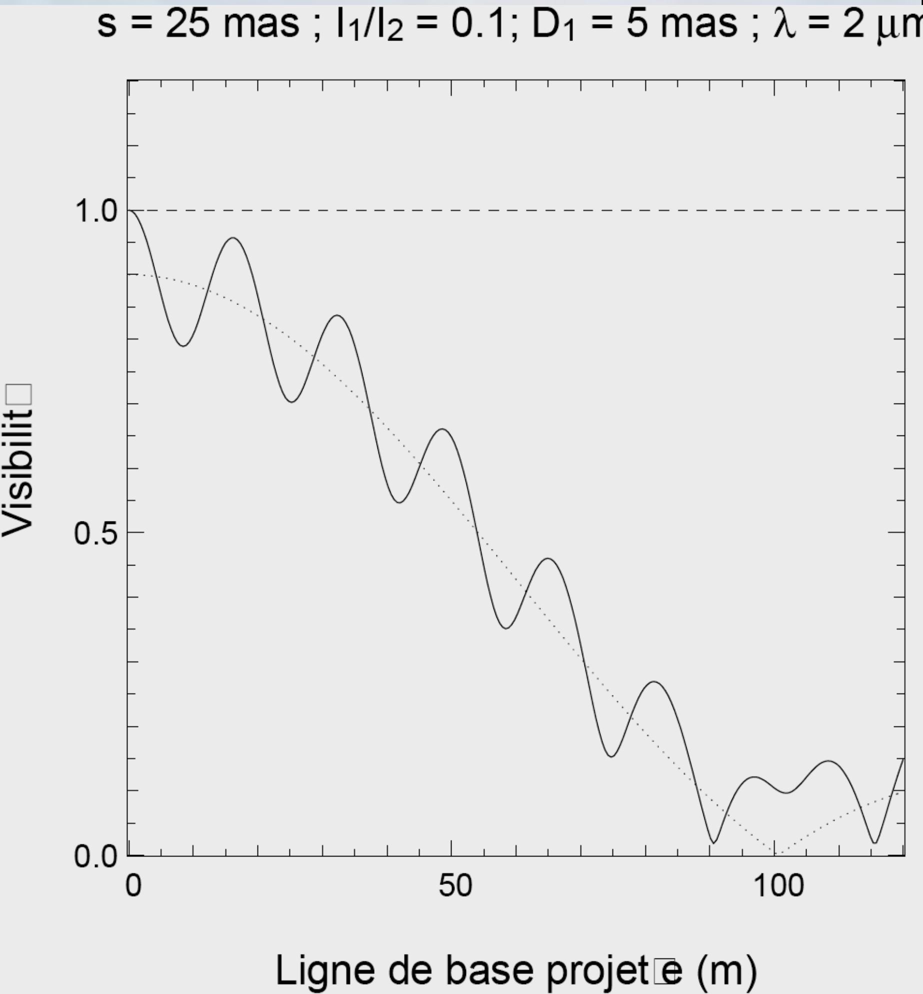
Visibilities



Uniform disk



Binary with unresolved components



Binary with resolved component

Interferometers involved in YSO research

Facility	Instrument	Wavelength (microns)	# tel.	Tel. Diam. (m)	Baseline (m)
Existing facilities					
PTI	V^2	H, K	3	0.4	80-110
IOTA	V^2, CP	H, K	3	0.4	5-38
ISI	Heterodyne	11	2 (3)	1.65	4-70
KI	V^2	K	2 (4/6)	10 (1.8)	80 (135)
	(nulling)	(10)			
VLTI	AMBER: V^2, CP	1-2.5 / spectral	3 (8)	8.2 (1.8)	40-130 (8-200)
	MIDI: V^2, V	8-13 / spectral	2 (4)		
CHARA	V^2, CP, Imaging	1-2.5 (/ spectral)	2/4-(6)	1	50-350
Future facilities					
LBT	V^2, nulling	1-12 µm	2	8.4	6-23
MROI	V^2, CP, imaging	V, NIR	6 (10)	1.4	7.5-340

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Small apertures

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Spectral resolution

Interferometers involved in YSO research

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Imaging

Census of results

Object	Type	Instrument	Band	Spect. Resol.	Observables	References
FU Ori	FUOr	PTI, IOTA, VLTI/MIDI	H, K, N	BB, LR	V^2	01, 12, 24
AB Aur	HAeBe	IOTA, PTI, CHARA	H, K	BB, LR	V^2, CP	02, 04, 06, 10, 22, 23, 25, 36
T Tau N	TTS	PTI	K	BB	V^2	03
SU Aur	TTS	PTI	K	BB	V^2	03
MWC 147	HAeBe	IOTA, PTI, VLTI/ AMBER, VLTI/MIDI	H, K, N	BB, LR	V^2	03, 04, 08, 35
V380 Ori	HAeBe	IOTA	H	BB	V^2	04
MWC 166	HAeBe	IOTA	H	BB	V^2, CP	04, 23
Omega Ori	HAeBe	IOTA	H, K	BB	V^2	04
MWC 863	HAeBe	IOTA	H, K	BB	V^2, CP	04, 23
MWC 361	HAeBe	IOTA	H, K	BB	V^2, CP	04, 23
V1685 Cyg	HAeBe	IOTA, PTI, KI	H, K	BB, LR	V^2	04, 06, 10, 15, 25
MWC 1080	HAeBe	IOTA, PTI	H, K	BB, LR	V^2, CP	04, 06, 10, 23, 25
MWC 297	HAeBe	IOTA, PTI, VLTI/ AMBER, VLTI/MIDI	H, K, N	BB, MR, LR	V^2, CP	04, 08, 10, 23, 26, 38
V1295 Aql	HAeBe	IOTA, PTI	H, K	BB, LR	V^2, CP	04, 08, 10, 23, 25
MWC 614	HAeBe	IOTA, PTI, VLTI/MIDI	H, K, N	BB, LR	V^2, CP	04, 08, 09, 23
V594 Cas	HAeBe	IOTA, PTI	H, K	BB	V^2	04, 08
MWC 275	HAeBe	IOTA, VLTI/MIDI, KI, CHARA	H, K, N	BB, LR	V^2, CP	04, 09, 11, 15, 23, 36
T Ori	HAeBe	IOTA, PTI	H, K	BB, LR	V^2	04, 10, 25
LkHa 101	HAeBe	ISI	N	BB	V^2	05
VV Ser	HAeBe	PTI	K	BB, LR	V^2	06, 10, 25
AS 442	HAeBe	PTI, KI	K	BB, LR	V^2	06, 10, 15, 25
DG Tau	TTS	KI	K	BB	V^2	07, 17
V1057 Cyg	FUOr	PTI, KI	K	BB	V^2	08, 19
HD 142527	HAeBe	VLTI/MIDI	N	LR	V^2	09, 11
HD 144432	HAeBe	VLTI/MIDI, KI, IOTA	N, K, H	BB, LR	V^2, CP	09, 11, 15, 23
HD 100546	HAeBe	VLTI/MIDI	N	LR	V^2	09
HD 179218	HAeBe	VLTI/MIDI	N	LR	V^2	09
KK OPh	HAeBe	VLTI/MIDI	N	LR	V^2	09
51 Oph	HAeBe	VLTI/MIDI	N	LR	V^2	09
CQ Tau	HAeBe	PTI	K	BB, LR	V^2	10, 25
MWC 120	HAeBe	PTI	K	BB, LR	V^2	10, 25
HD 158352	HAeBe	PTI	K	BB	V^2	10
MWC 480	HAeBe	PTI, KI, IOTA	K, H	BB, LR, MR	V^2, CP	10, 23, 25, 30
MWC 758	HAeBe	PTI, VLTI/AMBER	K, H	BB, LR	V^2, CP	10, 15, 25, 37
HD 141569	HAeBe	PTI	K	BB	V^2	10, 15
RY Tau	TTS	PTI	K	BB	V^2, CP	13, 23
DR Tau	TTS	PTI	K	BB	V^2	13
AS 207A	TTS	KI	K	BB	V^2	14

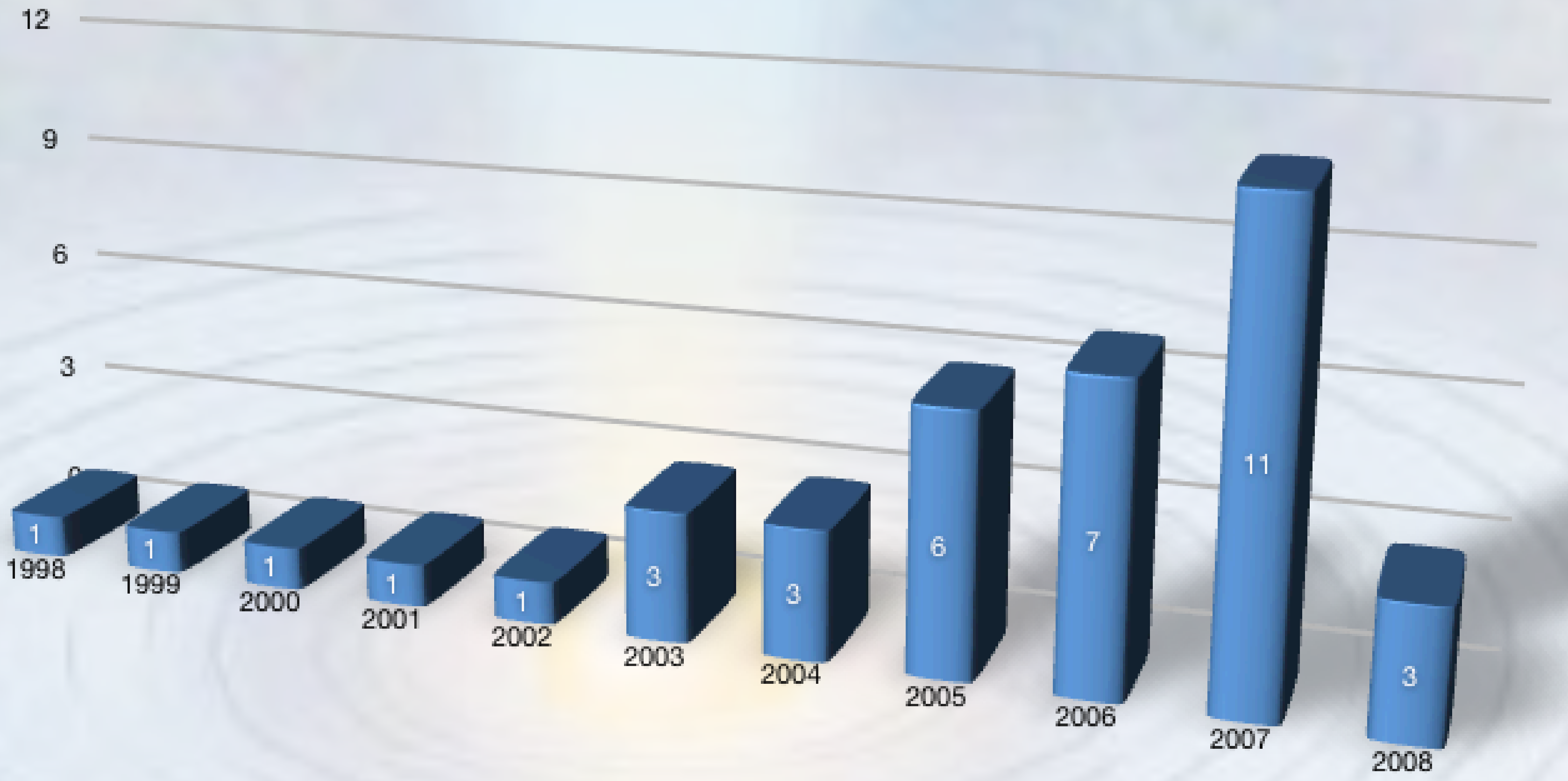
Object	Type	Instrument	Band	Spect. Resol.	Observables	References
V2508 Oph	TTS	KI	K	BB	V^2	14
AS 205A	TTS	KI	K	BB	V^2	14
PX Vul	TTS	KI	K	BB	V^2	14
UX Ori	HAeBe	KI	K	BB	V^2	15
ZCMa-NW	HAeBe	KI, VLTI/AMBER	K	BB, LR	V^2	15, 34
HD 58647	HAeBe	KI	K	BB	V^2	15
HD 146666	HAeBe	KI	K	BB	V^2	15
HD 143006	HAeBe	KI	K	BB	V^2	15
HD 150193	HAeBe	KI	K	BB	V^2	15
WW Vul	HAeBe	KI	K	BB	V^2	15
AS 477	HAeBe	KI	K	BB	V^2	15
HD 98800B	TTS	KI	K	BB	V^2	16
BP Tau	TTS	KI	K	BB	V^2	17
DI Tau	TTS	KI	K	BB	V^2	17
GM Aur	TTS	KI	K	BB	V^2	17
LkCa15	TTS	KI	K	BB	V^2	17
RW Aur A	TTS	KI	K	BB	V^2	17, 33
V830 Tau	TTS	KI	K	BB	V^2	17
TW Hya	TTS	KI, VLTI/MIDI	K, N	BB, LR	V^2	18, 31
V1515 Cyg	FUOr	KI	K	BB	V^2	19
ZCMa-SE	FUOr	KI	K	BB	V^2	19
HR 5999	HAeBe	VLTI/MIDI	N	LR	V^2	20
V1647 Ori	FUOr	VLTI/MIDI	N	LR	V^2	21
HD 45677	HAeBe	IOTA	H	BB	V^2, CP	23
MWC 342	HAeBe	IOTA	H	BB	V^2, CP	23
HD 104237	HAeBe	VLTI/AMBER	K	MR	V^2	27
Theta1 Ori C	HMS	IOTA	H	BB	V^2, CP	28
Hen 3-1191	HAeBe	VLTI/MIDI	N	LR	V^2	29
V773 Tau A	TTS	KI	K	BB	V^2	32
CI Tau	TTS	KI	K	BB	V^2	33
DK Tau A	TTS	KI	K	BB	V^2	33
DK Tau B	TTS	KI	K	BB	V^2	33
AA Tau	TTS	KI	K	BB	V^2	33
RW Aur B	TTS	KI	K	BB	V^2	33
V1002 Sco	TTS	KI	K	BB	V^2	33
V1331 Cyg	TTS	KI	K	BB	V^2	33
DI Cep	TTS	KI	K	BB	V^2	33
BM And	TTS	KI	K	BB	V^2	33

→ **76 young stellar objects** observed and published to date,

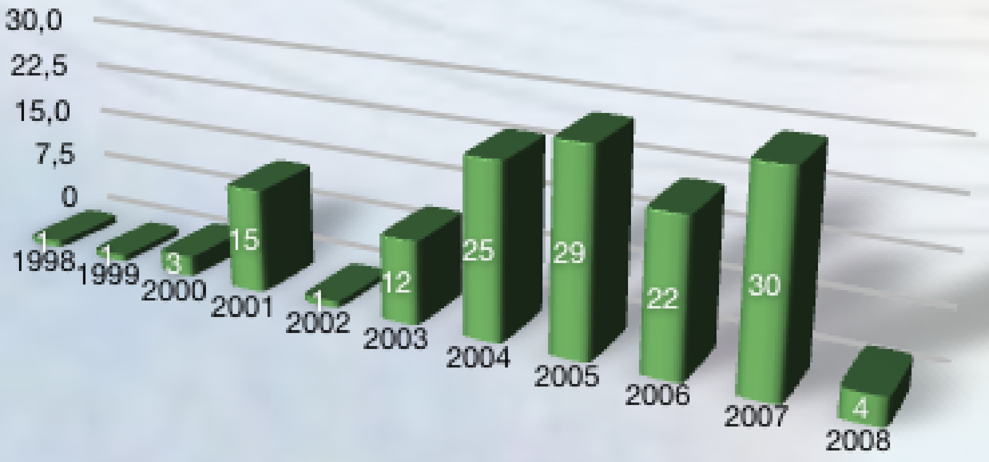
→ **38 refereed articles**

1	**Malbet, Berger, Colavita** et al.	**1998**	ApJ, 507, L149	*FU Orionis Resolved by Infrared Long-Baseline Interferometry at a 2 AU Scale*
2	**Millan-Gabet, Schloerb, Traub** et al.	**1999**	ApJ, 513, L131	*Sub-Astronomical Unit Structure of the Near-Infrared Emission from AB Aurigae*
3	**Akeson, Ciardi, van Belle** et al.	**2000**	ApJ, 543, 313	*Infrared Interferometric Observations of Young Stellar Objects*
4	**Millan-Gabet, Schloerb & Traub**	**2001**	ApJ, 546, 358	*Spatially Resolved Circumstellar Structure of Herbig AE/BE Stars in the Near-Infrared*
5	**Tuthill, Monnier, Danchi** et al.	**2002**	ApJ, 577, 826	*Imaging the Disk around the Luminous Young Star LkHa 101 with Infrared Interferometry*
6	**Eisner, Lane, Akeson** et al.	**2003**	ApJ, 588, 360	*Near-Infrared Interferometric Measurements of Herbig Ae/Be Stars*
7	**Colavita, Akeson, Wizinowich** et al.	**2003**	ApJ, 592, L83	*Observations of DG Tauri with the Keck Interferometer*
8	**Wilkin & Akeson**	**2003**	Ap&SS, 286, 145	*Palomar Testbed Interferometer Observations of Young Stellar Objects*
9	**Leinert, van Boekel, Waters** et al.	**2004**	A&A, 423, 537	*Mid-infrared sizes of circumstellar disks around Herbig Ae/Be stars measured with MIDI on the VLTI*
10	**Eisner, Lane, Hillenbrand** et al.	**2004**	ApJ, 613, 1049	*Resolved Inner Disks around Herbig Ae/Be Stars*
11	**van Boekel, Min, Leinert** et al.	**2004**	Nature, 432, 479	*The building blocks of planets within the ‘terrestrial’ region of protoplanetary disks*
12	**Malbet, Lachaume, Berger** et al.	**2005**	A&A, 437, 627	*New insights on the AU-scale circumstellar structure of FU Orionis*
13	**Akeson, Walker, Wood** et al.	**2005**	ApJ, 622, 440	*Observations and Modeling of the Inner Disk Region of T Tauri Stars*
14	**Eisner, Hillenbrand, White** et al.	**2005**	ApJ, 623, 952	*Observations of T Tauri Disks at Sub-AU Radii: Implications for Magnetospheric Accretion and Planet Formation*
15	**Monnier, Millan-Gabet, Billmeier** et al.	**2005**	ApJ, 624, 832	*The Near-Infrared Size-Luminosity Relations for Herbig Ae/Be Disks*
16	**Boden, Sargent, Akeson** et al.	**2005**	ApJ 635, 442	*Dynamical Masses for Low-Mass Pre-Main Sequence Stars: A Preliminary Physical Orbit for HD 98800 B*
17	**Akeson, Boden, Monnier** et al.	**2005**	ApJ 635, 1173	*Keck Interferometer observations of classical and weak line T Tauri stars*
18	**Eisner, Chiang & Hillenbrand**	**2006**	ApJ 637, L133	*Spatially Resolving the Inner Disk of TW Hydrae*
19	**Millan-Gabet, Monnier, Akeson** et al.	**2006**	ApJ 641, 547	*Keck Interferometer Observations of FU Orionis Objects*
20	**Preibisch, Kraus, Driebe** et al.	**2006**	A&A 458, 235	*A compact dusty disk around the Herbig Ae star HR 5999 resolved with VLTI / MIDI*
21	**Ábrahám, Mosoni, Henning** et al.	**2006**	A&A 449, L13	*First AU-scale observations of V1647 Orionis with VLTI/MIDI*
22	**Millan-Gabet, Monnier, Berger**, et al.	**2006**	ApJ 645, L77	*Bright Localized Near-Infrared Emission at 1?4 AU in the AB Aurigae Disk Revealed by IOTA Closure Phases*
23	**Monnier, Berger, Millan-Gabet**, et al.	**2006**	ApJ 647, 444	*Few Skewed Disks Found in First Closure-Phase Survey of Herbig Ae/Be Stars*
24	**Quanz, Henning, Bouwman,** et al.	**2006**	ApJ 648, 472	*FU Orionis: The MIDI VLTI Perspective*
25	**Eisner, Chiang, Lane,** et al.	**2007**	ApJ 657, 347	*Spectrally Dispersed K-Band Interferometric Observations of Herbig Ae/Be Sources: Inner Disk Temperature Profiles*
26	**Malbet, Benisty, de Wit** et al.	**2007**	A&A 464, 43	*Disk and wind interaction in the young stellar object MWC 297 spatially resolved with VLTI/AMBER*
27	**Tatulli, Isella, Natta**, et al.	**2007**	A&A 464, 43	*Constraining the wind launching region in Herbig Ae stars: AMBER/VLTI spectroscopy of HD 104237*
28	**Kraus, Balega, Berger,** et al.	**2007**	A&A 466, 649	*Visual/infrared interferometry of Orion Trapezium stars: Preliminary dynamical orbit and aperture synthesis imaging of the Theta 1 Orionis C system*
29	**Lachaume, Preibisch, Driebe,** et al.	**2007**	A&A 469, 587	*Resolving the B[e] star Hen 3-1191 at 10 microns with VLTI/MIDI*
30	**Eisner**	**2007**	Nature, 447, 562	*Water vapour and hydrogen in the terrestrial-planet-forming region of a protoplanetary disk*
31	**Ratzka, Leinert, Henning,** et al.	**2007**	A&A 471, 173	*High Spatial Resolution Mid-Infrared Observations of the Low-Mass Young Star TW Hya*
32	**Boden, Sargent, Torres,** et al.	**2007**	ApJ 670, 1214	*Dynamical Masses for Pre-Main Sequence Stars: A Preliminary Physical Orbit for V773 Tau A*
33	**Eisner, Hillebrand, White,** et al.	**2007**	ApJ 669, 1072	*Near-Infrared Interferometric, Spectroscopic, and Photometric Monitoring of T Tauri Inner Disks*
34	**Li Causi, Antoniucci & Tatulli**	**2007**	A&A 479, 589	*De-biasing interferometric visibilities in VLTI-AMBER data of low SNR observations*
35	**Kraus, Preibisch & Ohnaka**	**2007**	ApJ 676, 490	*Detection of an inner gaseous component in a Herbig Be star accretion disk: Near- and mid-infrared spectro-interferometry and radiative transfer modeling of MWC 147*
36	**Tannirkulam, Monnier, Millan-Gabet** et al.	**2008**	ApJ 677, L51	*Strong Near-Infrared Emission Interior to the Dust Sublimation Radius of Young Stellar Objects MWC 275 and AB Aur*
37	**Isella, Tatulli, Natta** et al.	**2008**	A&A 483, L13	*Gas and dust in the inner disk of the Herbig Ae star MWC 758*
38	**Acke, Verhoelst, van den Ancker** et al.	**2008**	A&A in press	*MWC 297: a young high-mass star rotating at critical velocity*

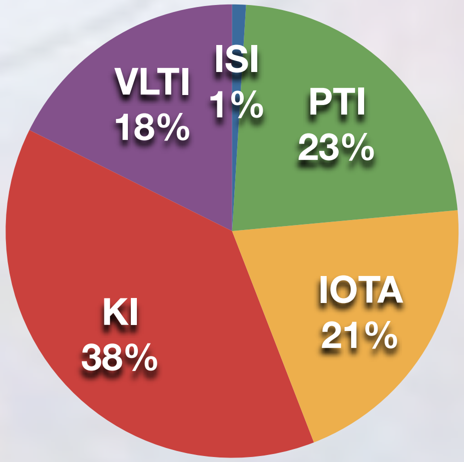
YSOs observed (1998-2008)



YSO refereed papers

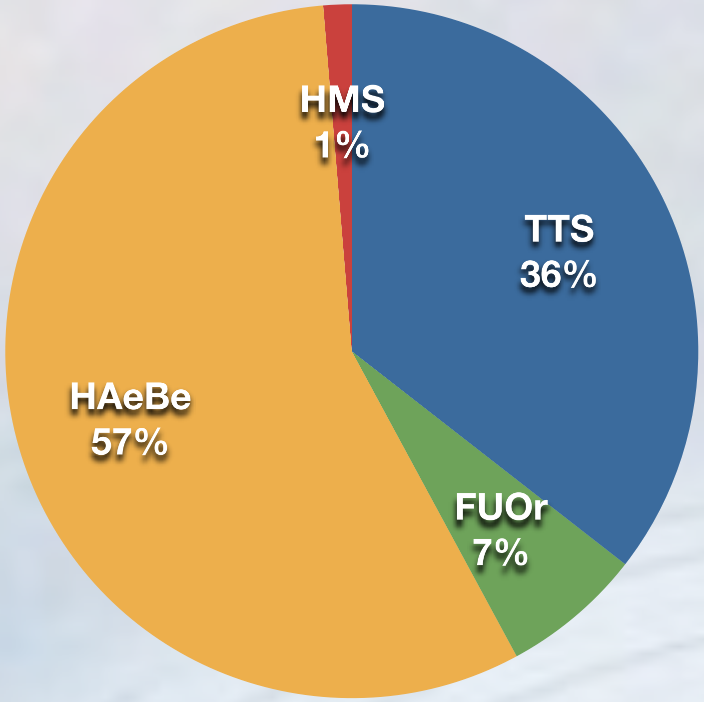


YSO number of observations

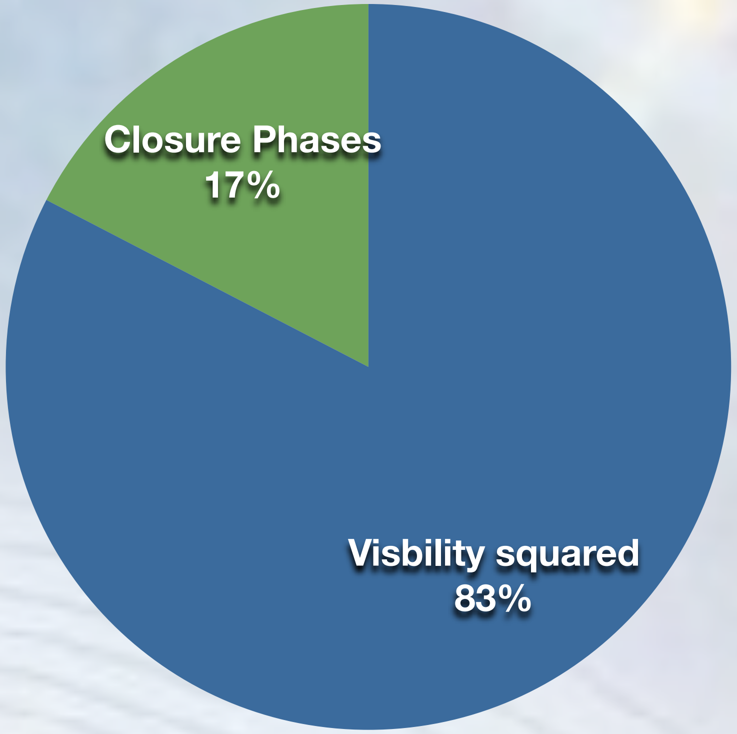


YSOs by interferometer

YSOs by type

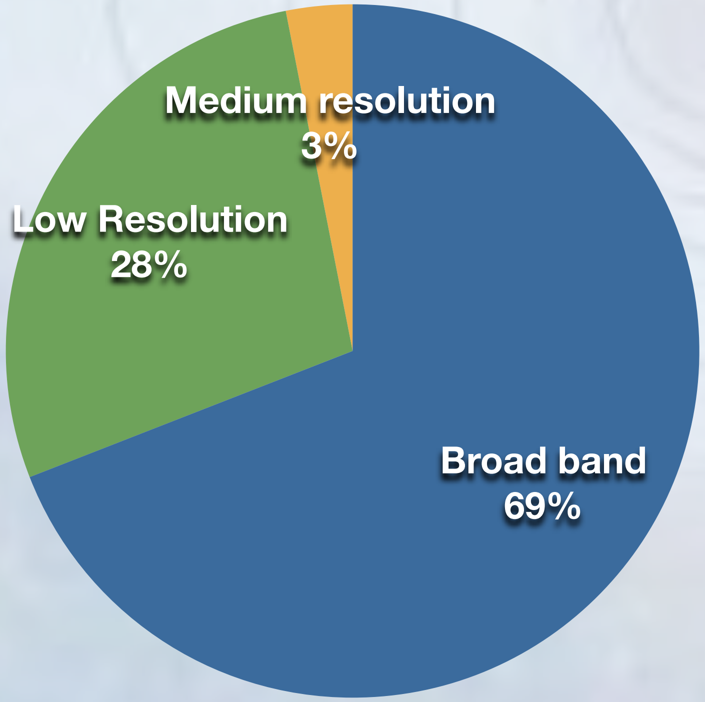


YSOs by observable

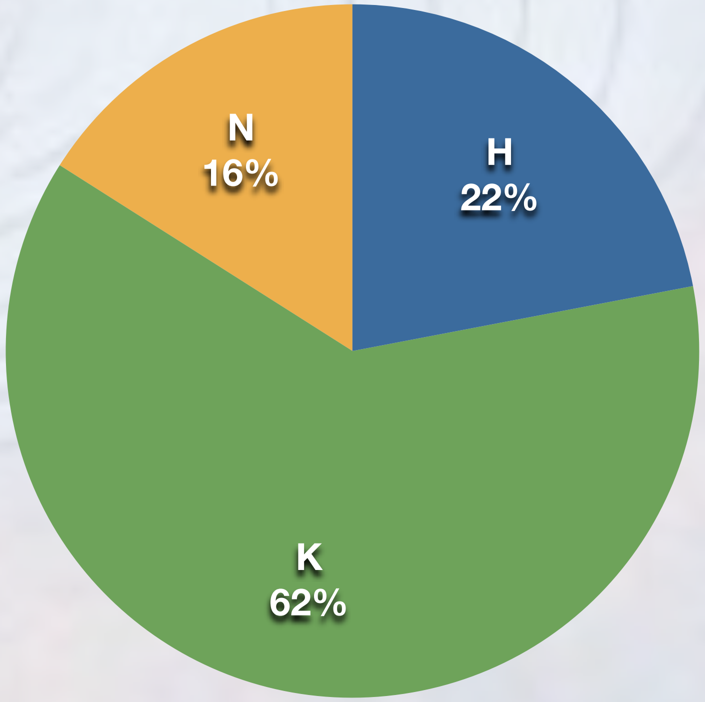


1998-2008

YSOs by spectral resolution



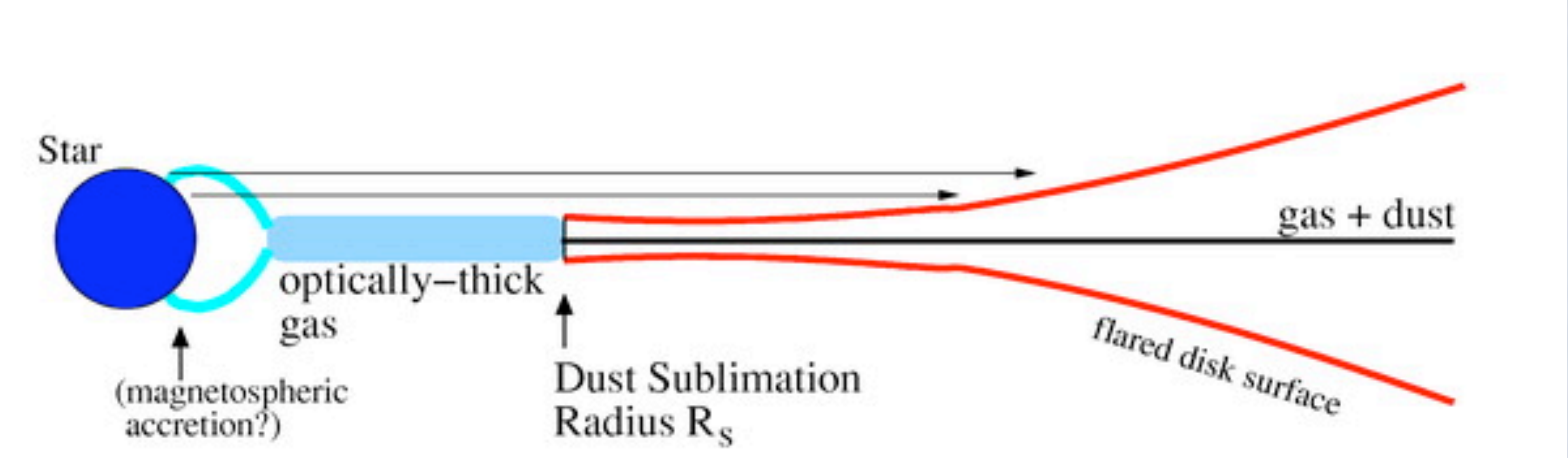
YSOs by spectral band



INNER DISK PHYSICS

- Sizes of circumstellar structures
- Constraints on disk structure (T, z,…)
- Dust mineralogy
- Gas/dust connection

Original disk concept

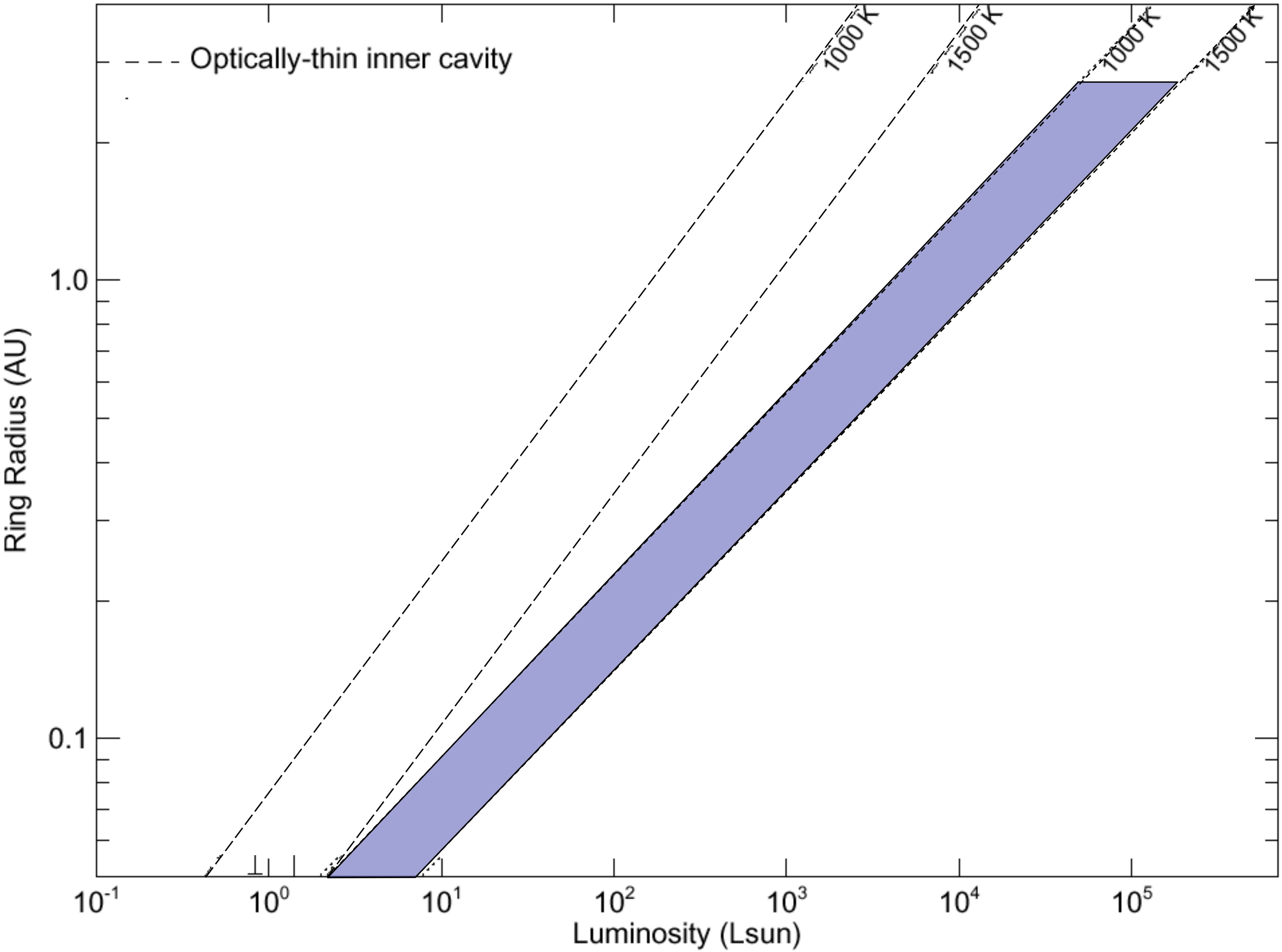


e.g. Malbet & Bertout (1995, A&AS 113, 369)

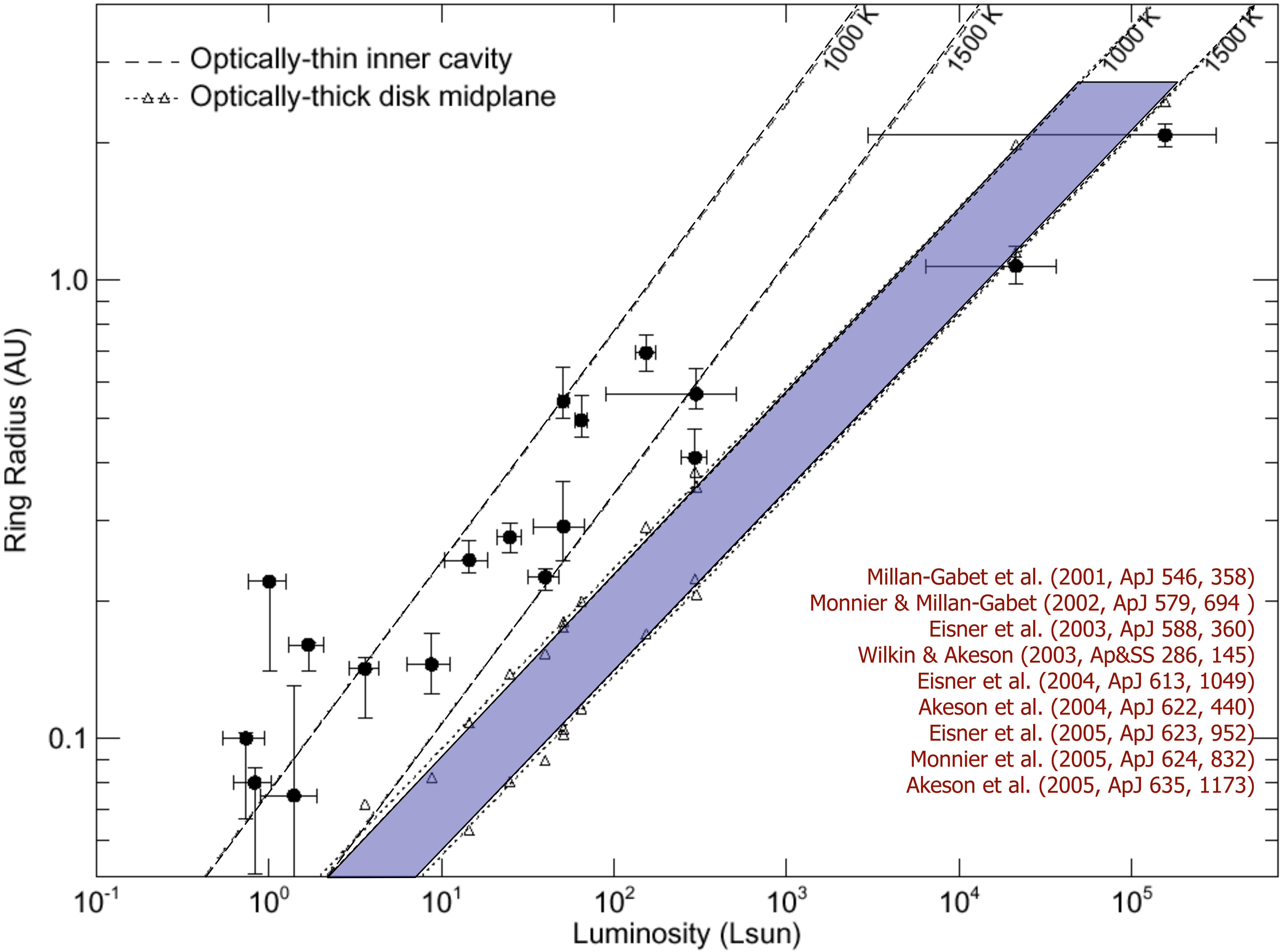
- **Optically thick disk both for inner gas and outer dust**
- **Simple power-law temperature distribution ($T \propto r^{-0.75}$, $T \propto r^{-0.5}$)**
- **Oblique disk heating**

→ fits rather well **spectral energy distributions (SEDs)**

Near-IR Sizes of TTS and Herbig Ae/Be stars

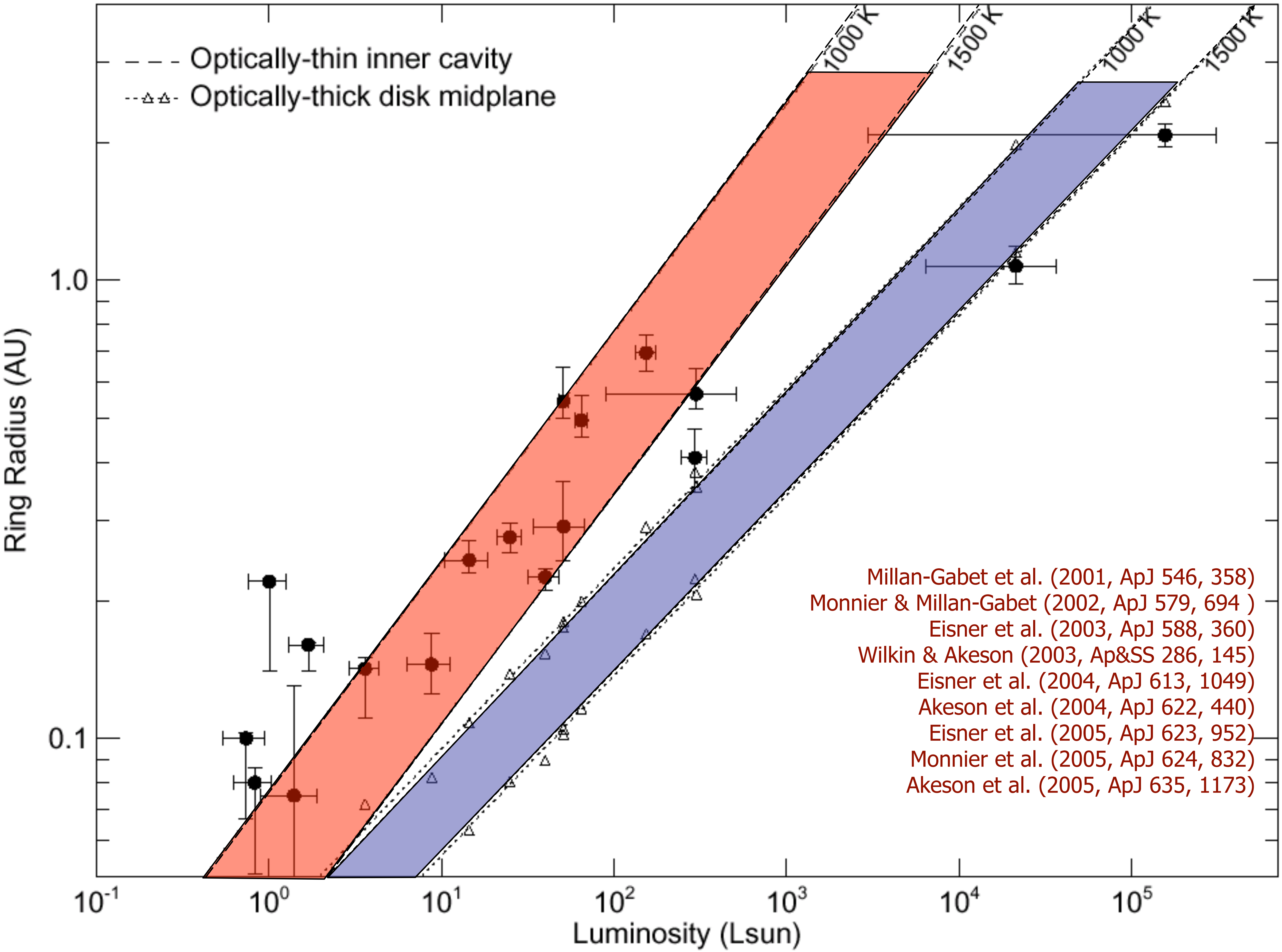


Near-IR Sizes of TTS and Herbig Ae/Be stars

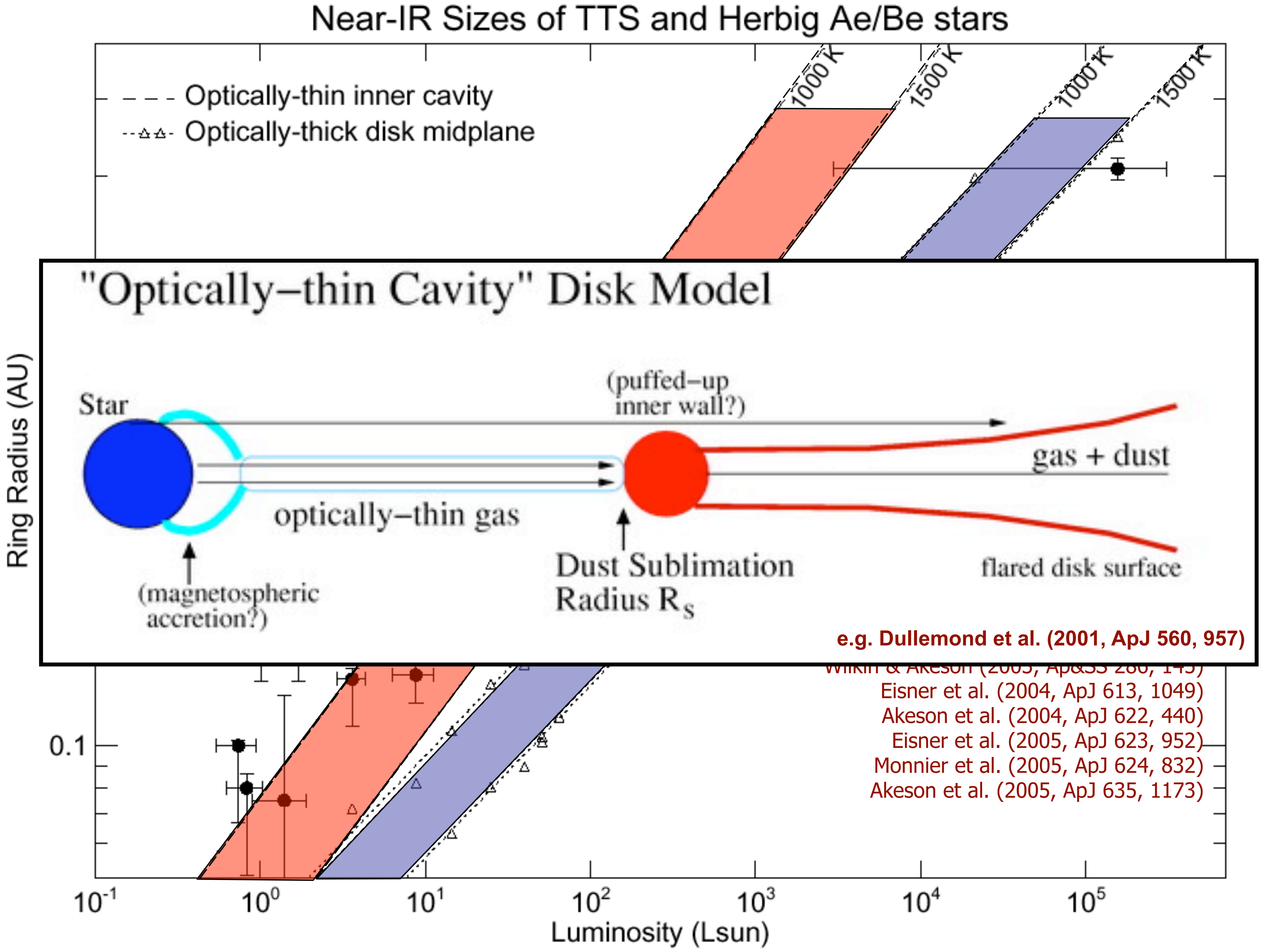


Millan-Gabet et al. (2001, ApJ 546, 358)
Monnier & Millan-Gabet (2002, ApJ 579, 694)
Eisner et al. (2003, ApJ 588, 360)
Wilkin & Akeson (2003, Ap&SS 286, 145)
Eisner et al. (2004, ApJ 613, 1049)
Akeson et al. (2004, ApJ 622, 440)
Eisner et al. (2005, ApJ 623, 952)
Monnier et al. (2005, ApJ 624, 832)
Akeson et al. (2005, ApJ 635, 1173)

Near-IR Sizes of TTS and Herbig Ae/Be stars



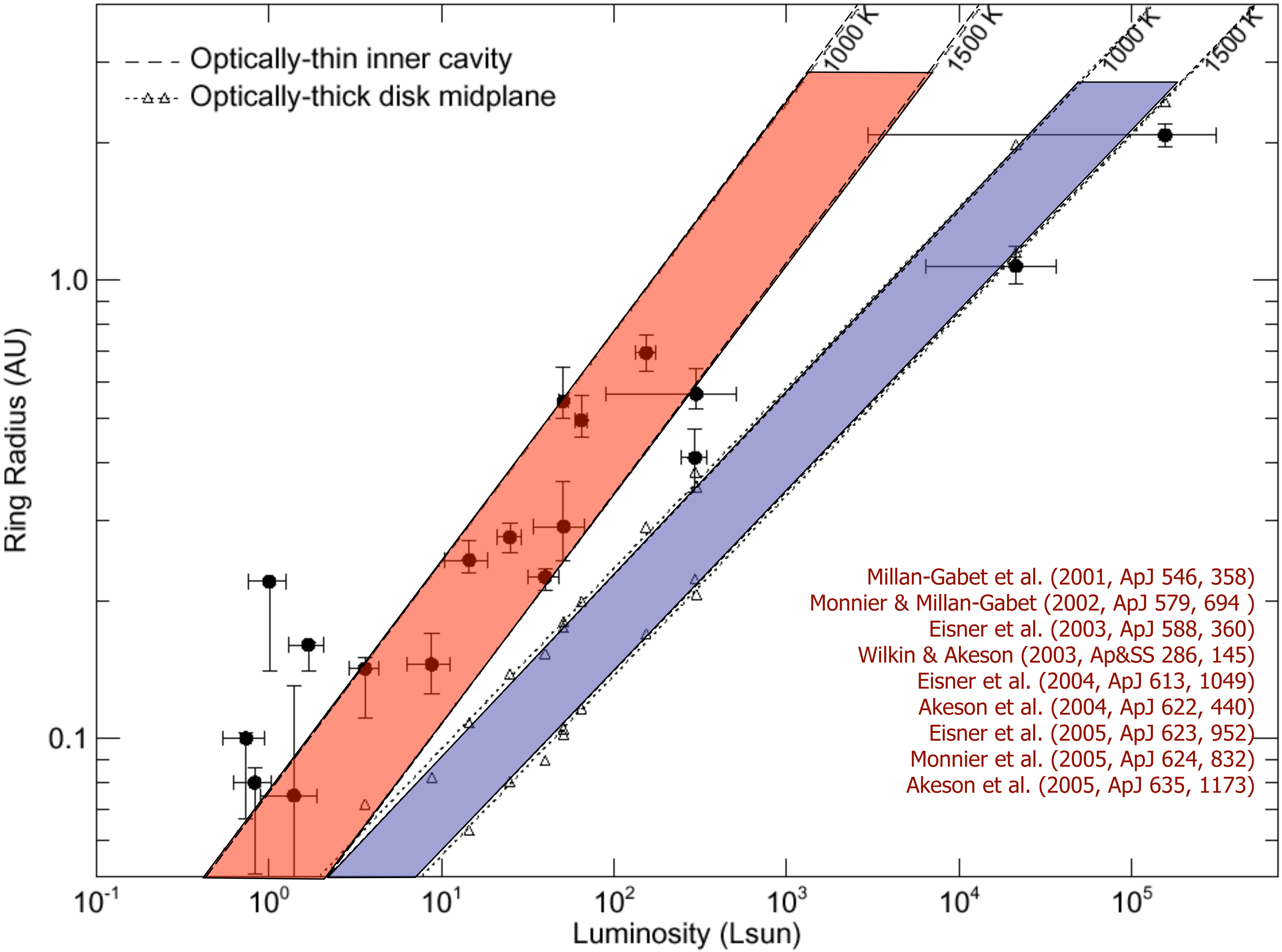
Millan-Gabet et al. (2001, ApJ 546, 358)
Monnier & Millan-Gabet (2002, ApJ 579, 694)
Eisner et al. (2003, ApJ 588, 360)
Wilkin & Akeson (2003, Ap&SS 286, 145)
Eisner et al. (2004, ApJ 613, 1049)
Akeson et al. (2004, ApJ 622, 440)
Eisner et al. (2005, ApJ 623, 952)
Monnier et al. (2005, ApJ 624, 832)
Akeson et al. (2005, ApJ 635, 1173)



e.g. Dullemond et al. (2001, ApJ 560, 957)

Wilkin & Akeson (2003, Ap&SS 286, 145)
Eisner et al. (2004, ApJ 613, 1049)
Akeson et al. (2004, ApJ 622, 440)
Eisner et al. (2005, ApJ 623, 952)
Monnier et al. (2005, ApJ 624, 832)
Akeson et al. (2005, ApJ 635, 1173)

Near-IR Sizes of TTS and Herbig Ae/Be stars



Millan-Gabet et al. (2001, ApJ 546, 358)
Monnier & Millan-Gabet (2002, ApJ 579, 694)
Eisner et al. (2003, ApJ 588, 360)
Wilkin & Akeson (2003, Ap&SS 286, 145)
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Eisner et al. (2005, ApJ 623, 952)
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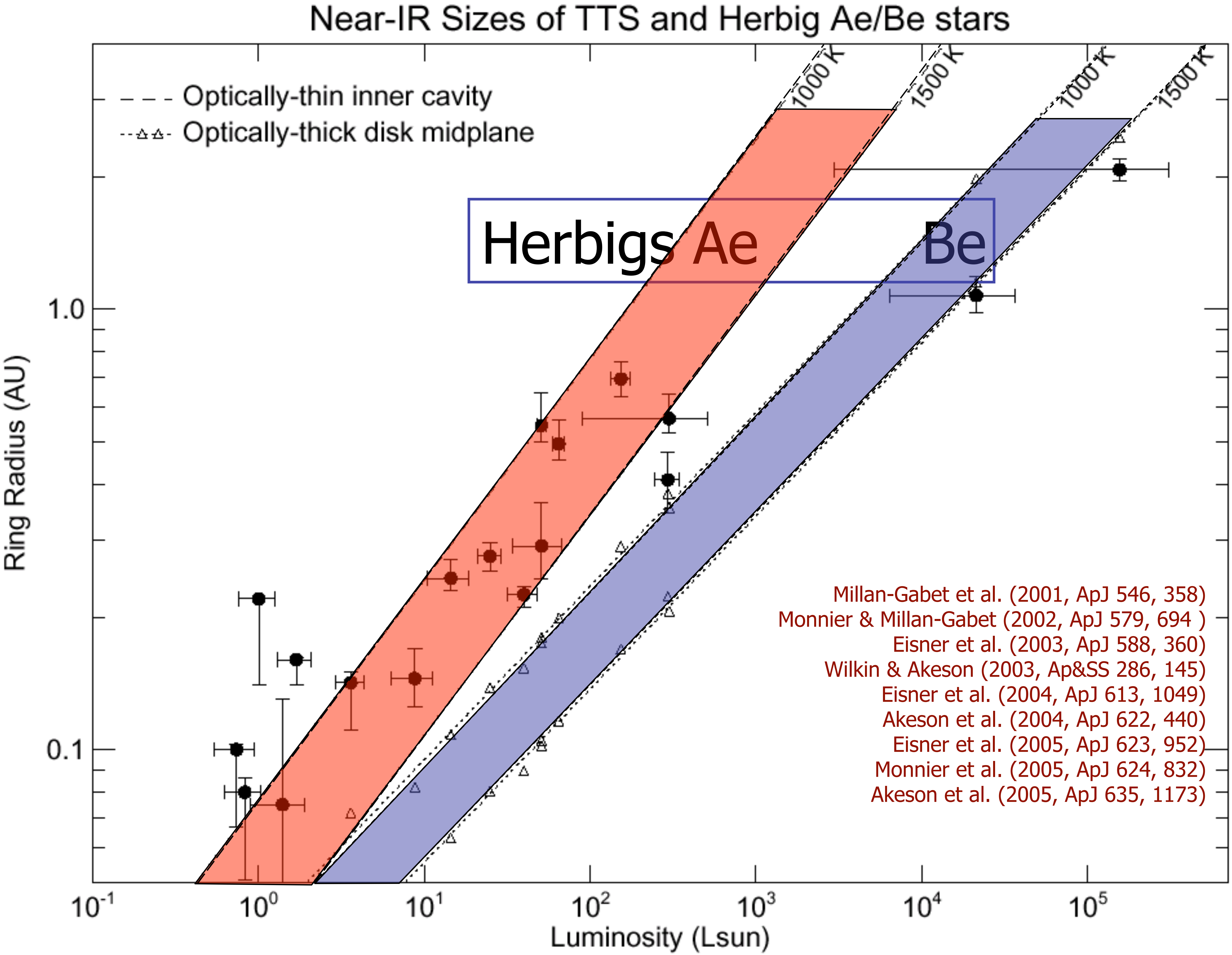

Herbigs Ae Be

Millan-Gabet et al. (2001, ApJ 546, 358)
Monnier & Millan-Gabet (2002, ApJ 579, 694)
Eisner et al. (2003, ApJ 588, 360)
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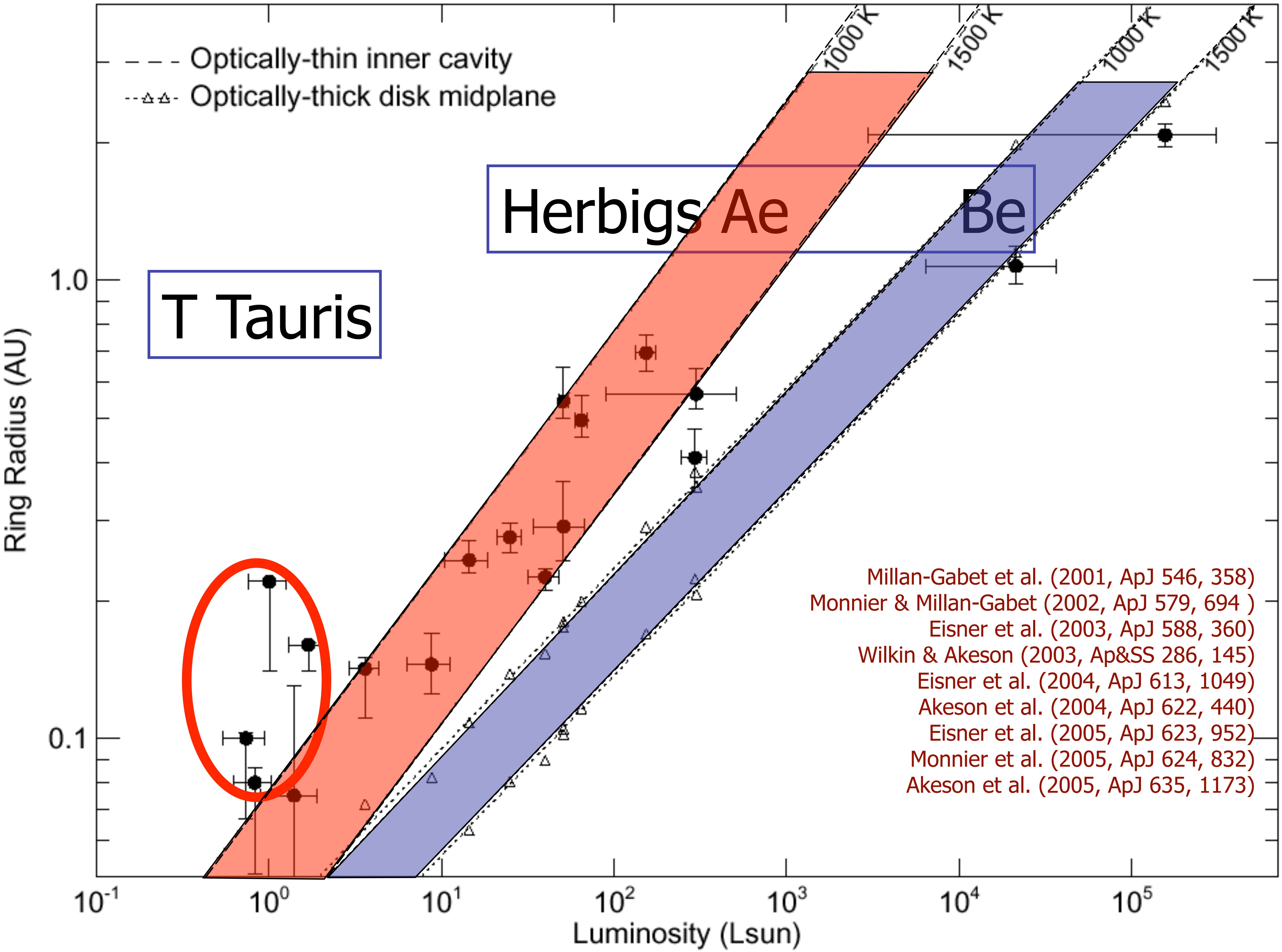
Near-IR Sizes of TTS and Herbig Ae/Be stars



T Tauris

Herbigs Ae Be

Millan-Gabet et al. (2001, ApJ 546, 358)
Monnier & Millan-Gabet (2002, ApJ 579, 694)
Eisner et al. (2003, ApJ 588, 360)
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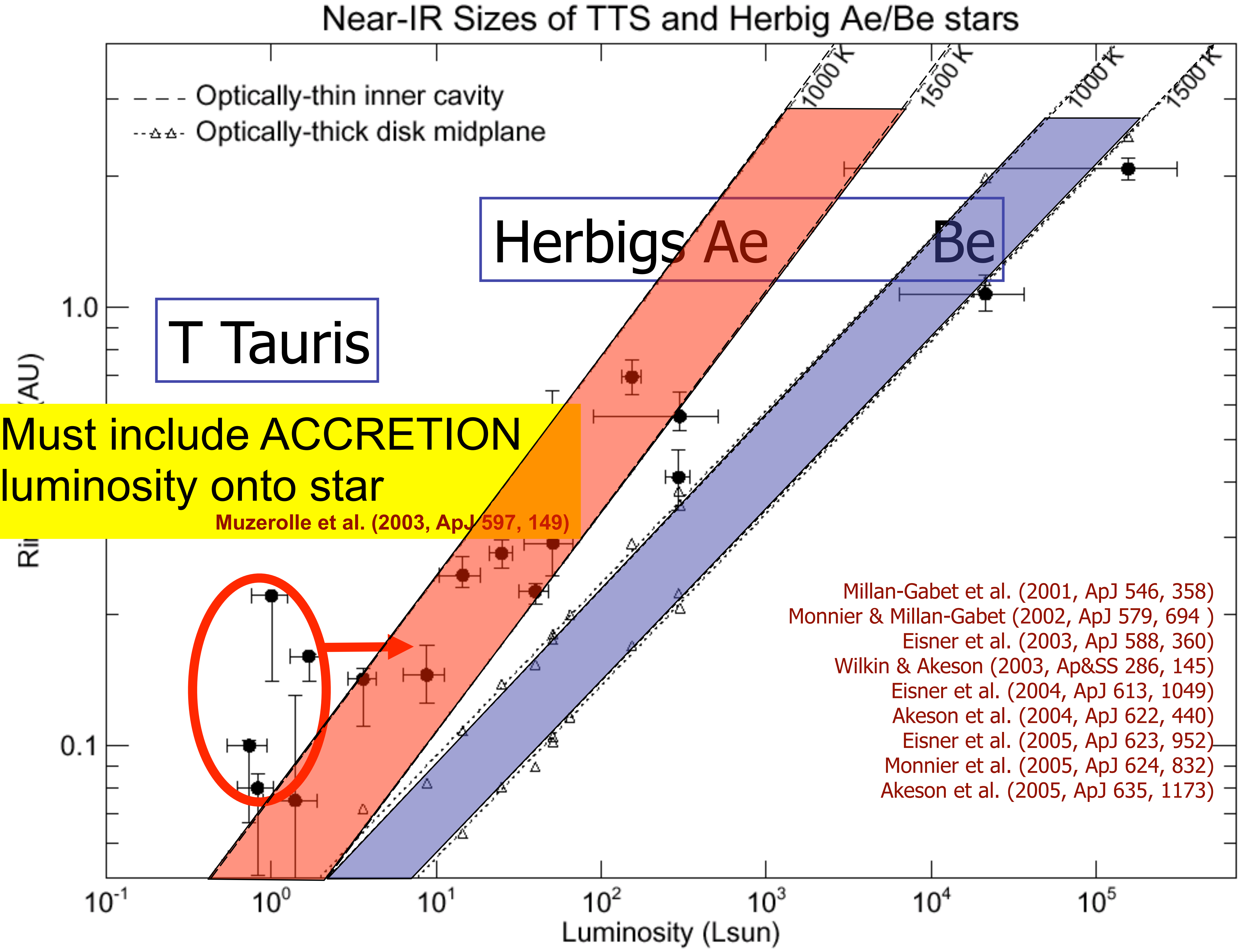


Herbigs Ae Be

T Tauris

Must include ACCRETION luminosity onto star

Muzerolle et al. (2003, ApJ 597, 149)

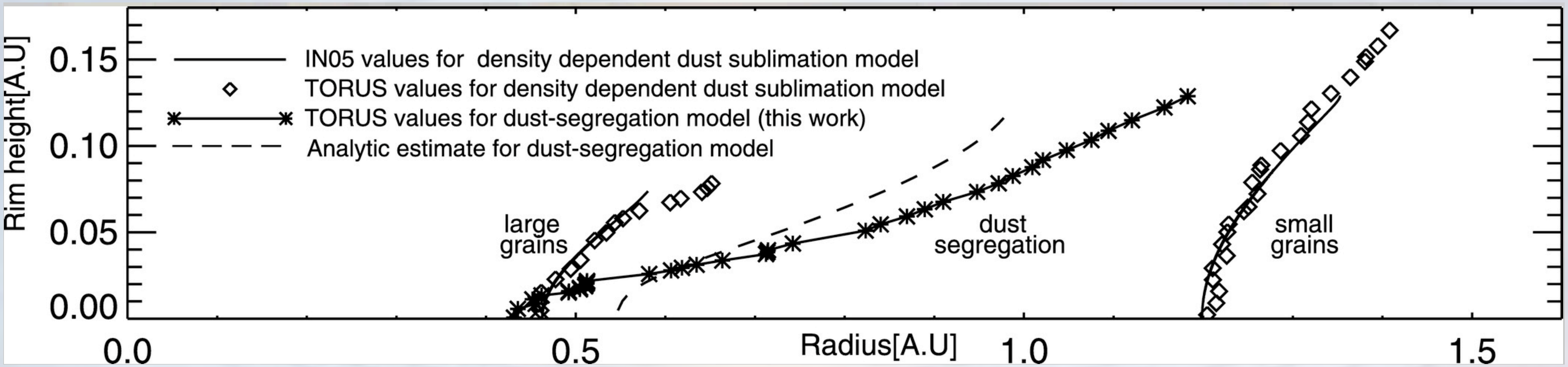
Millan-Gabet et al. (2001, ApJ 546, 358)
Monnier & Millan-Gabet (2002, ApJ 579, 694)
Eisner et al. (2003, ApJ 588, 360)
Wilkin & Akeson (2003, Ap&SS 286, 145)
Eisner et al. (2004, ApJ 613, 1049)
Akeson et al. (2004, ApJ 622, 440)
Eisner et al. (2005, ApJ 623, 952)
Monnier et al. (2005, ApJ 624, 832)
Akeson et al. (2005, ApJ 635, 1173)

Inner region discussion

- Inner rim shapes: how sharp is it?

  Dust sublimation **Isella & Natta (2005, A&A 438, 899)**

  vs Dust settling & grain growth **Tannirkulam et al. (2007, ApJ 661, 374)**



Inner region discussion

- Inner rim shapes: how sharp is it?

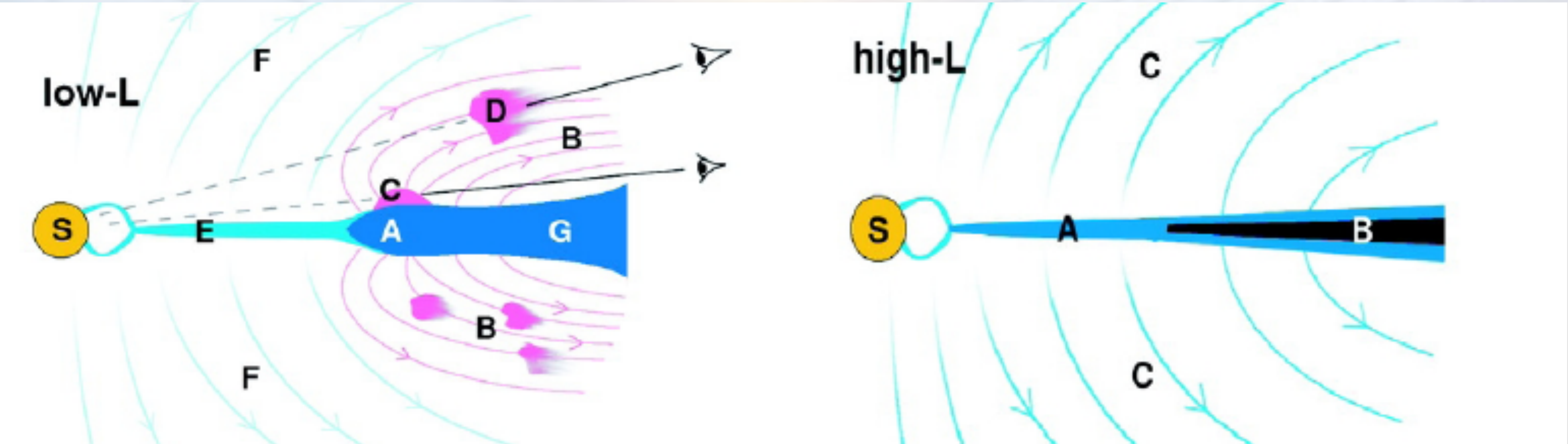
  Dust sublimation Isella & Natta (2005, A&A 438, 899)

  vs Dust settling & grain growth Tannirkulam et al. (2007, ApJ 661, 374)

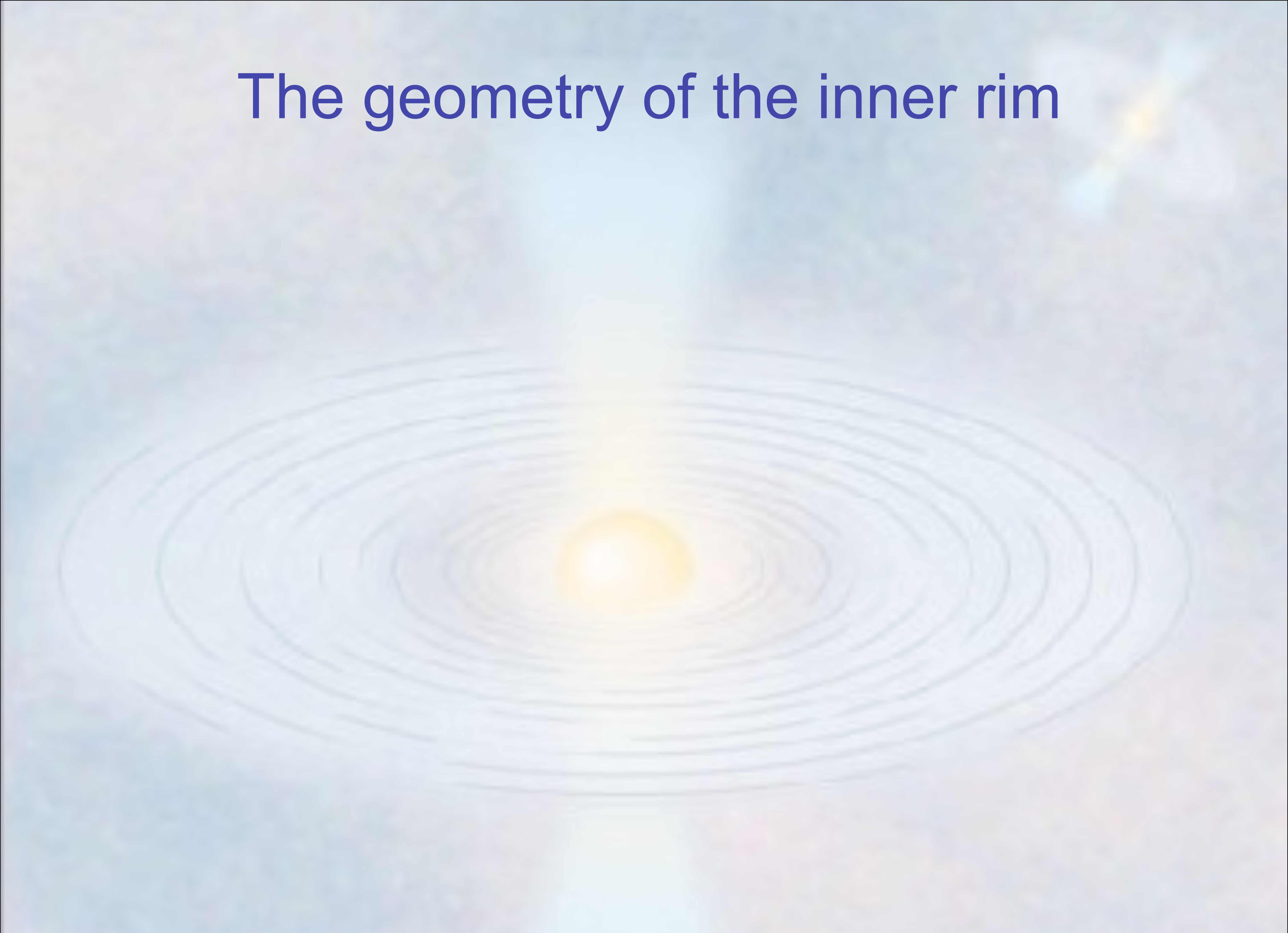
- Inner hole? but
  - optically thick disk beyond the dust sublimation barrier

    e.g. TTS Akeson et al. (2006, ApJ 635, 1173)
  - disk halo with 0.15-0.8 optical depths

    Vinkovic & Jurkic (2007, ApJ 658..462)

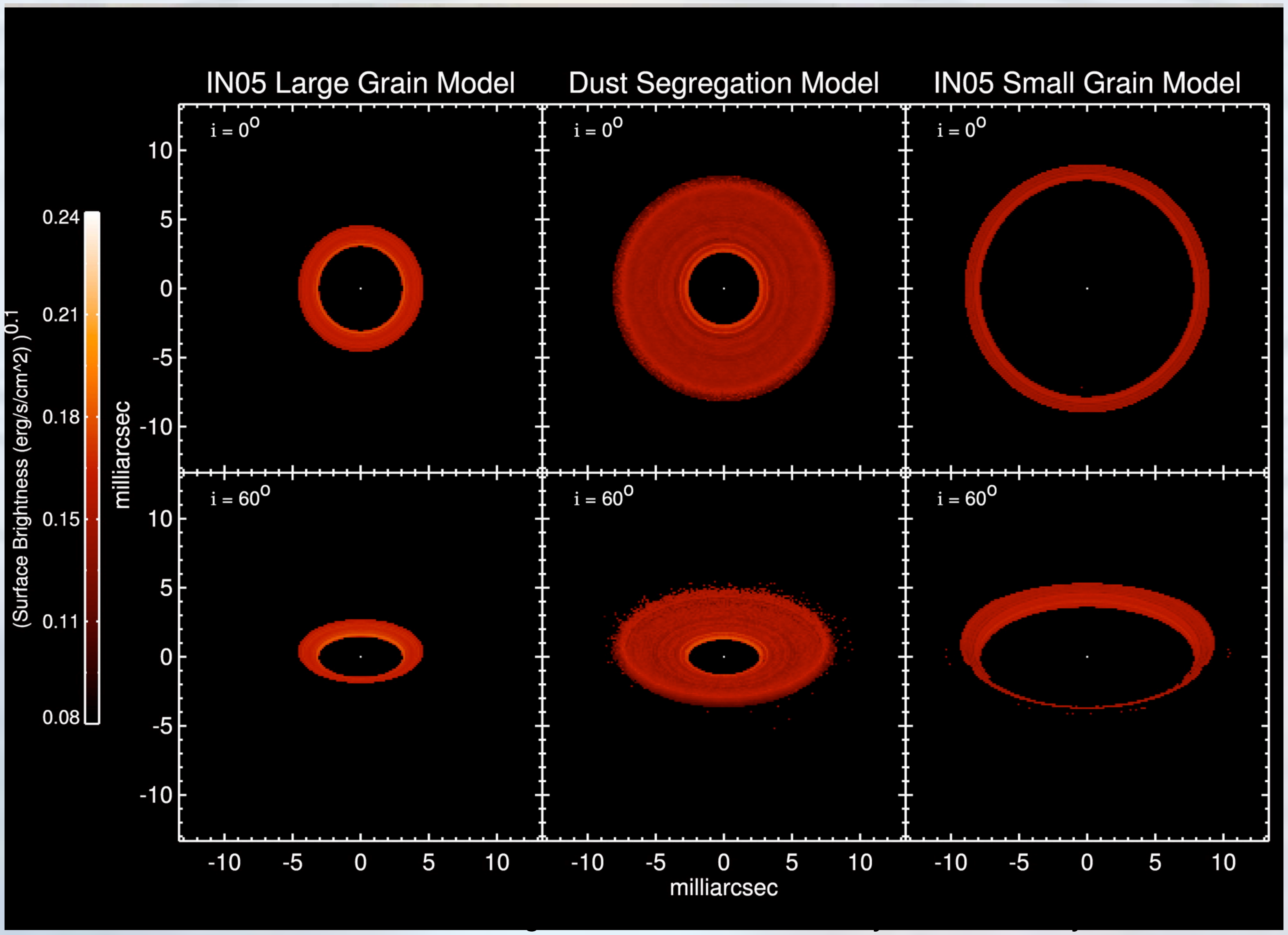


The geometry of the inner rim



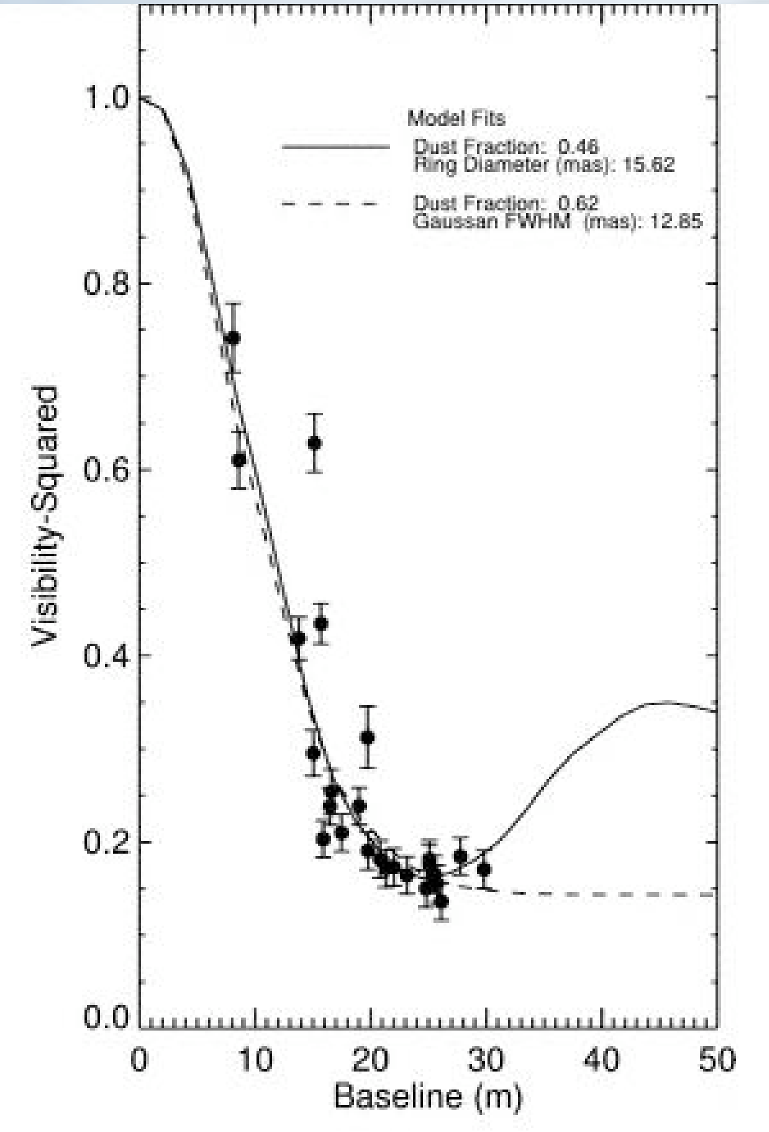
The geometry of the inner rim

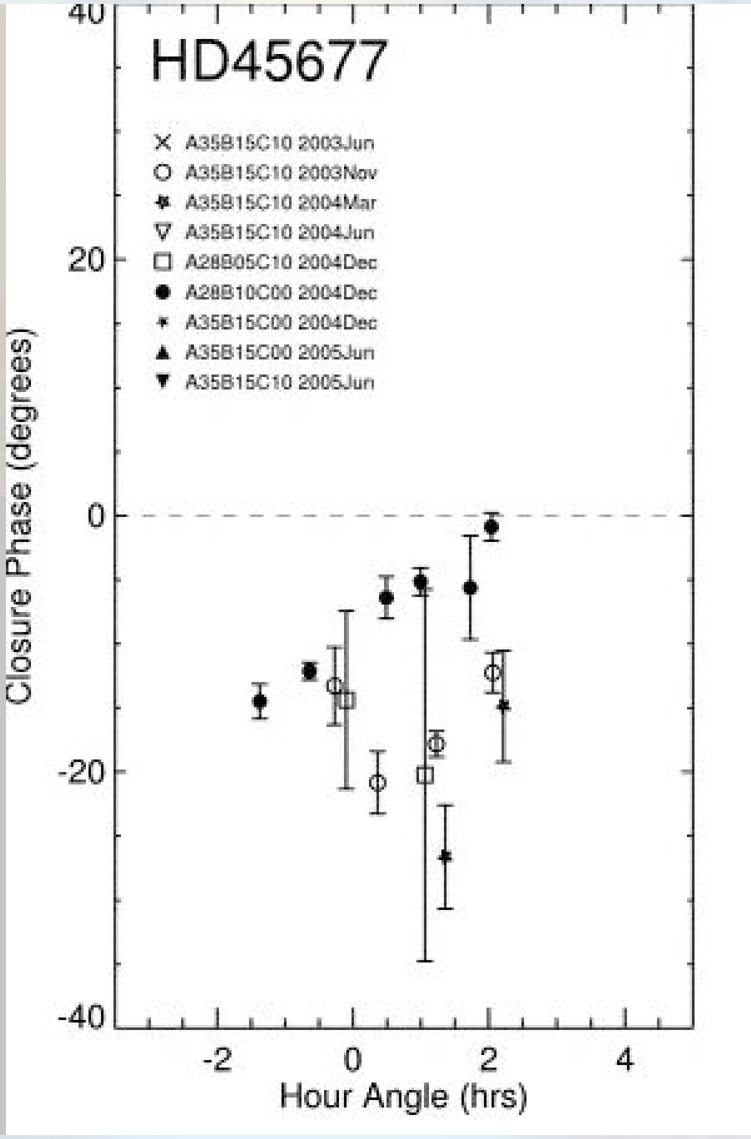
- If inclined disk: asymmetries (skewness) depending on dust characteristics **Tannirkulam et al. (2007, ApJ 661, 374)**

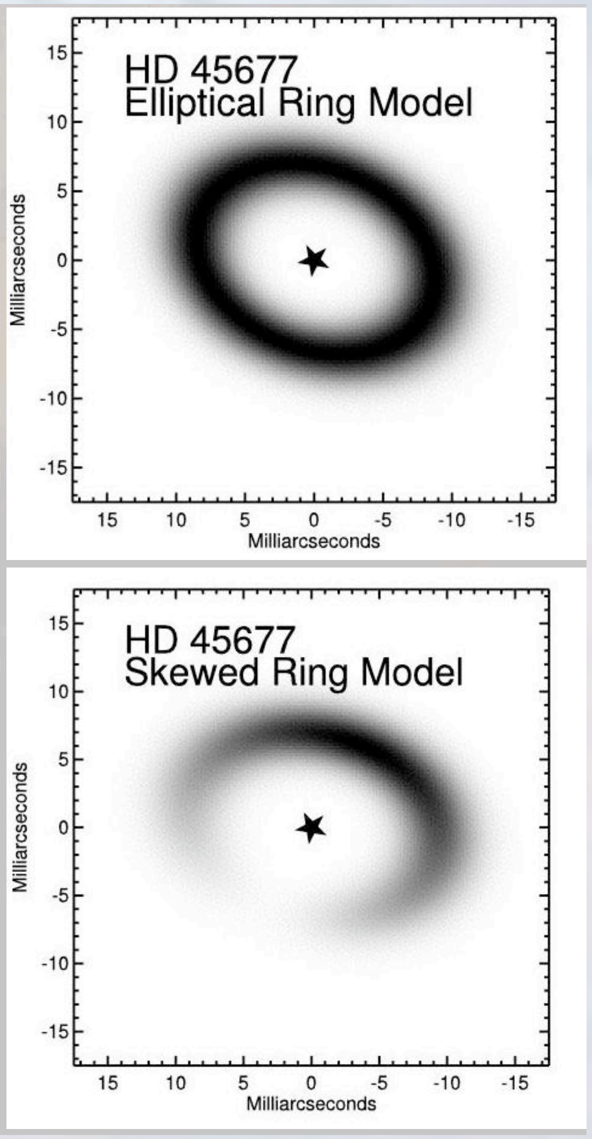


The geometry of the inner rim

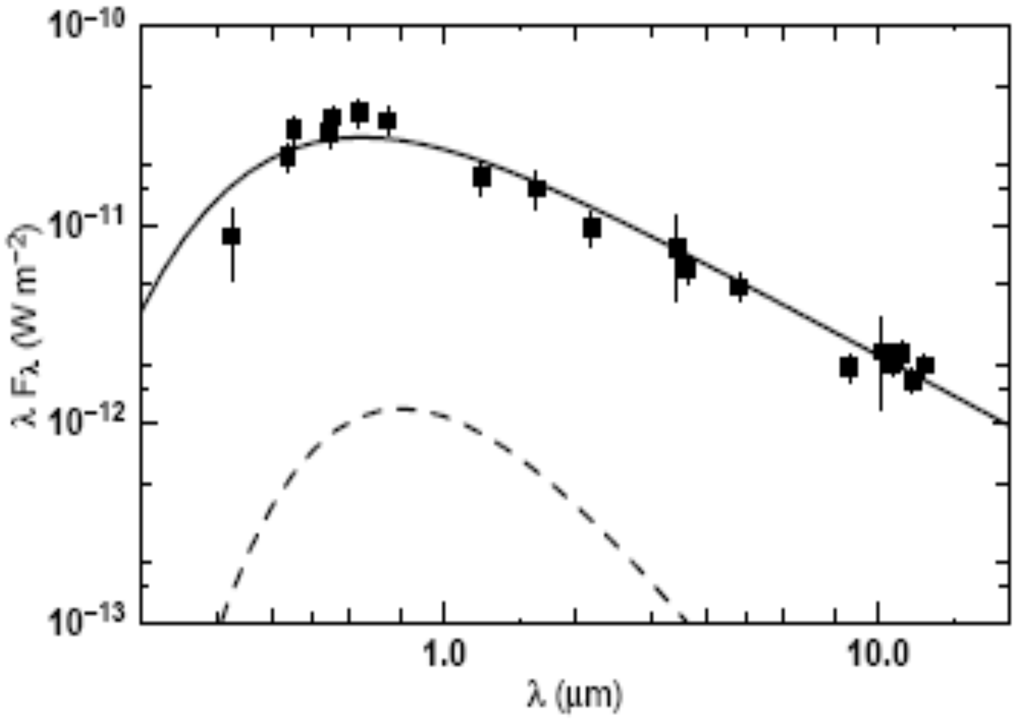
- If inclined disk: asymmetries (skewness) depending on dust characteristics **Tannirkulam et al. (2007, ApJ 661, 374)**
- Closure phase is a powerful observable to probe such asymmetries **Monnier et al. (2006, ApJ 646, 444)**

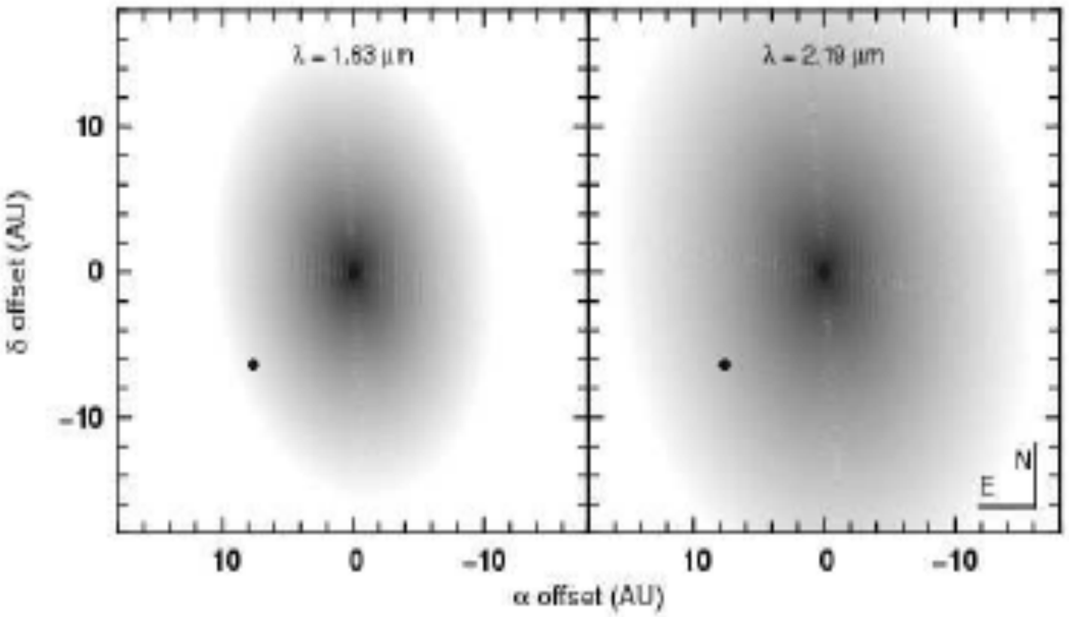


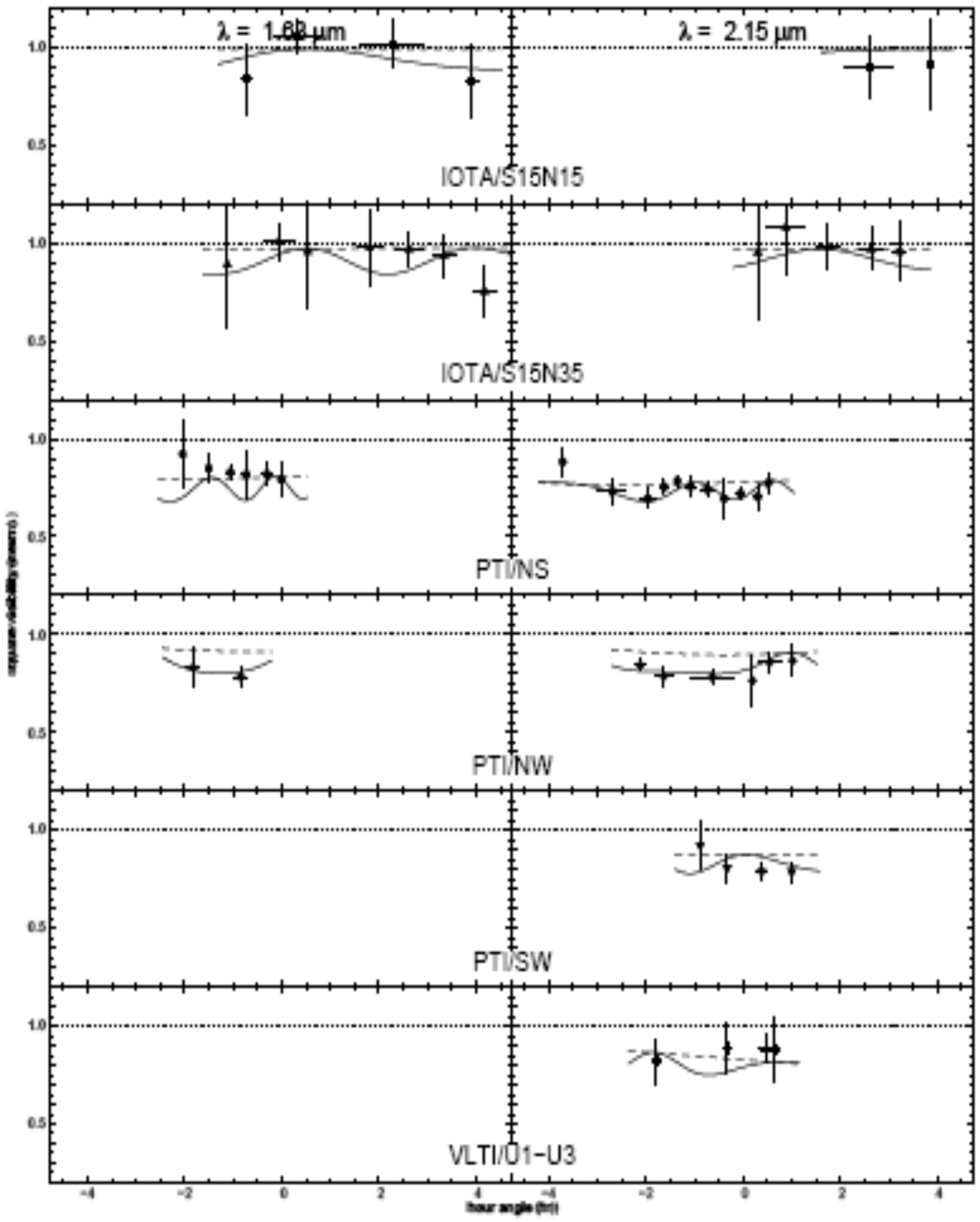




FU Orionis

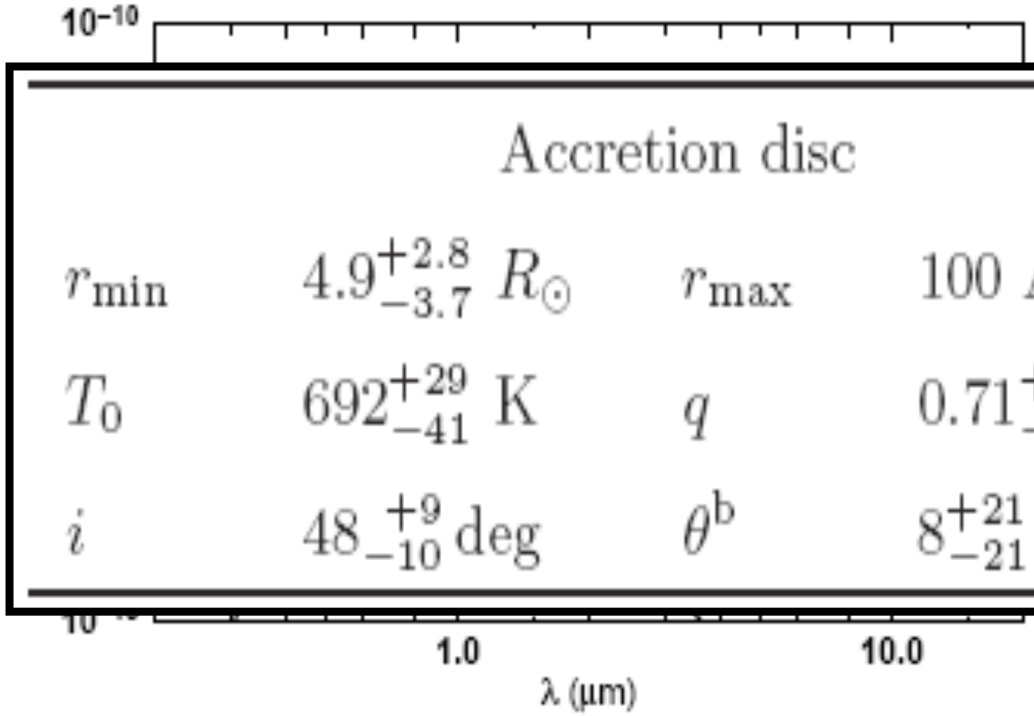




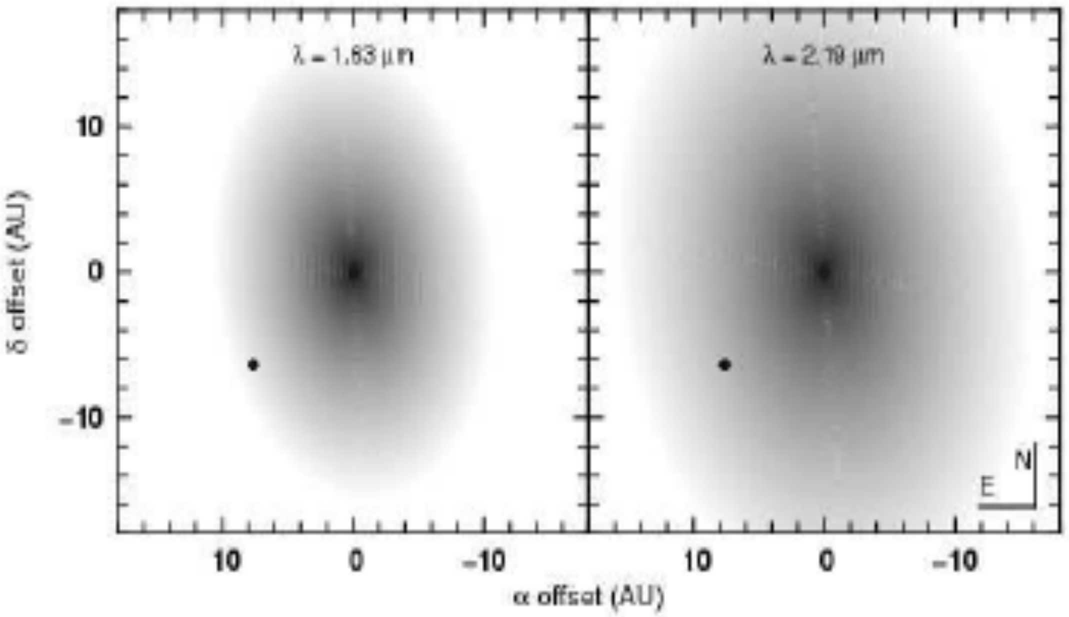


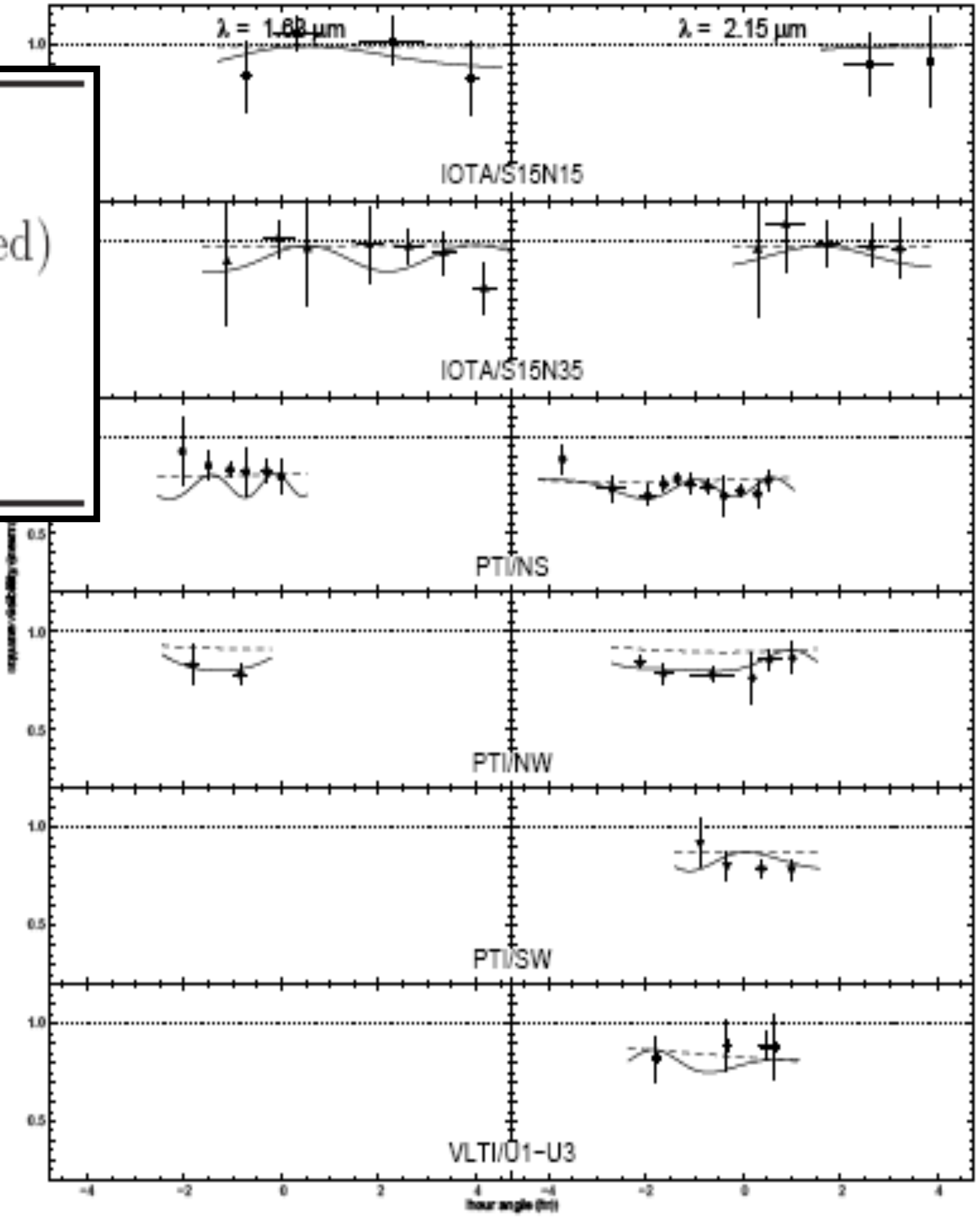
Malbet et al. (2005, A&A, 437, 627)

FU Orionis



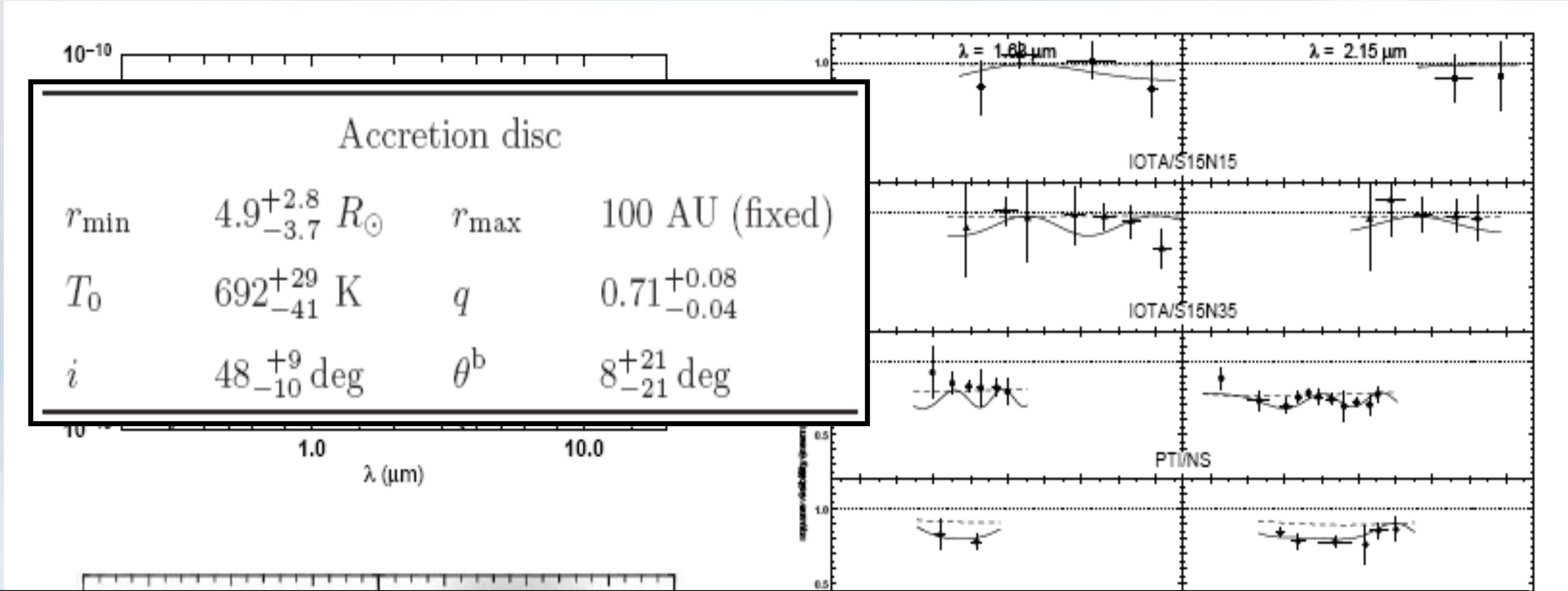
Accretion disc			
$r_{\min}$	$4.9^{+2.8}_{-3.7}\ R_{\odot}$	$r_{\max}$	100 AU (fixed)
T_0	692^{+29}_{-41} K	q	$0.71^{+0.08}_{-0.04}$
i	48^{+9}_{-10} deg	θ^{b}	8^{+21}_{-21} deg





Malbet et al. (2005, A&A, 437, 627)

FU Orionis



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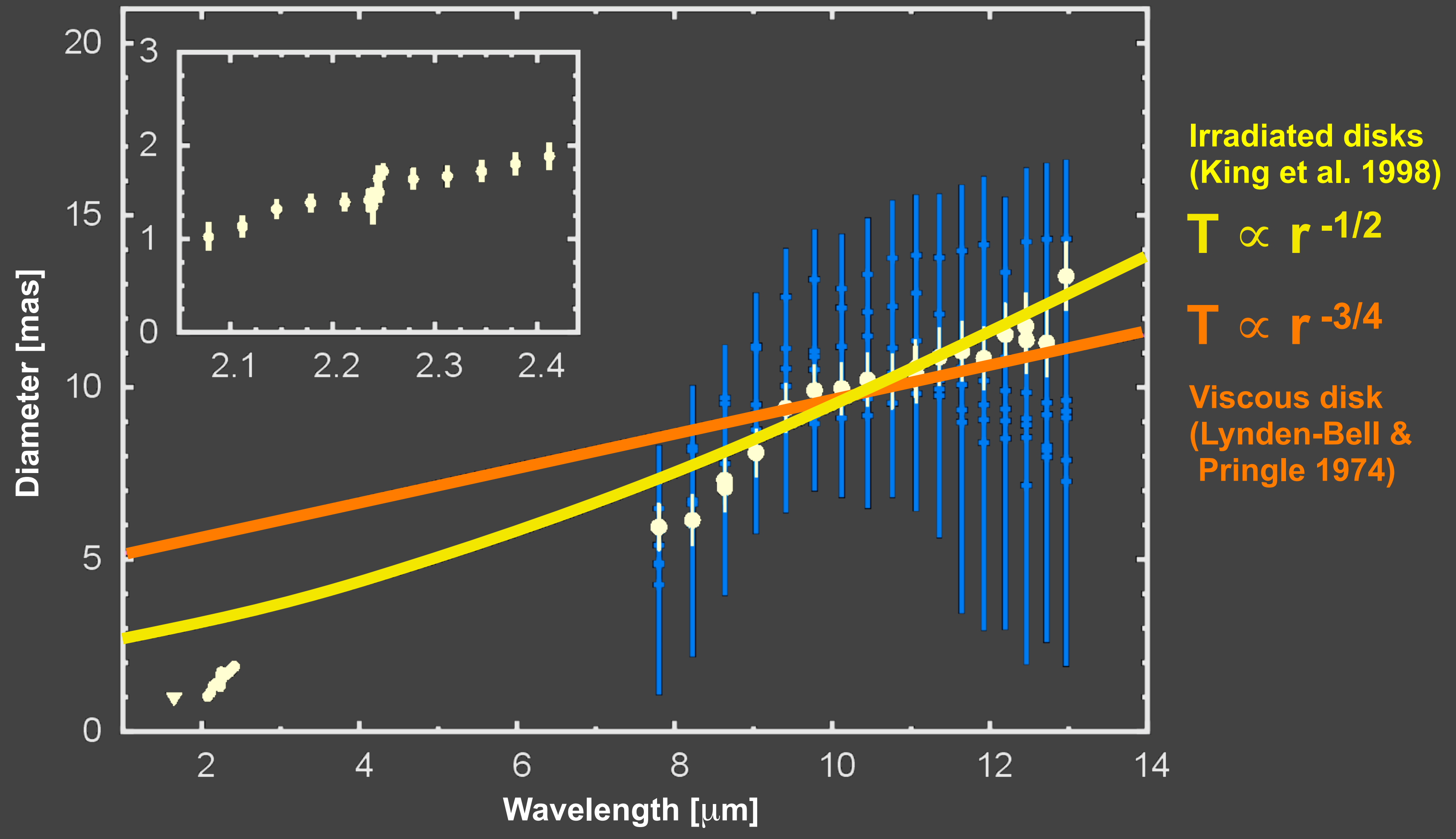
T_0	692^{+29}_{-41} K	q	$0.71^{+0.08}_{-0.04}$
i	48^{+9}_{-10} deg	θ^{b}	8^{+21}_{-21} deg

- **The 4 brightest FUors have been observed**
- **FU Ori well constrained** Quanz et al. (2006, ApJ 648, 472)
- **Others like Z CMa appear more extended: background emission or companion?** Millan-Gabet et al. (2006, ApJ 645, L77)
- **Recent FUOr: V1647 Ori** Ábrahám, Mosoni, Henning et al. (2006, A&A 449, L13)

A tool to probe the radial temperature distribution of disks

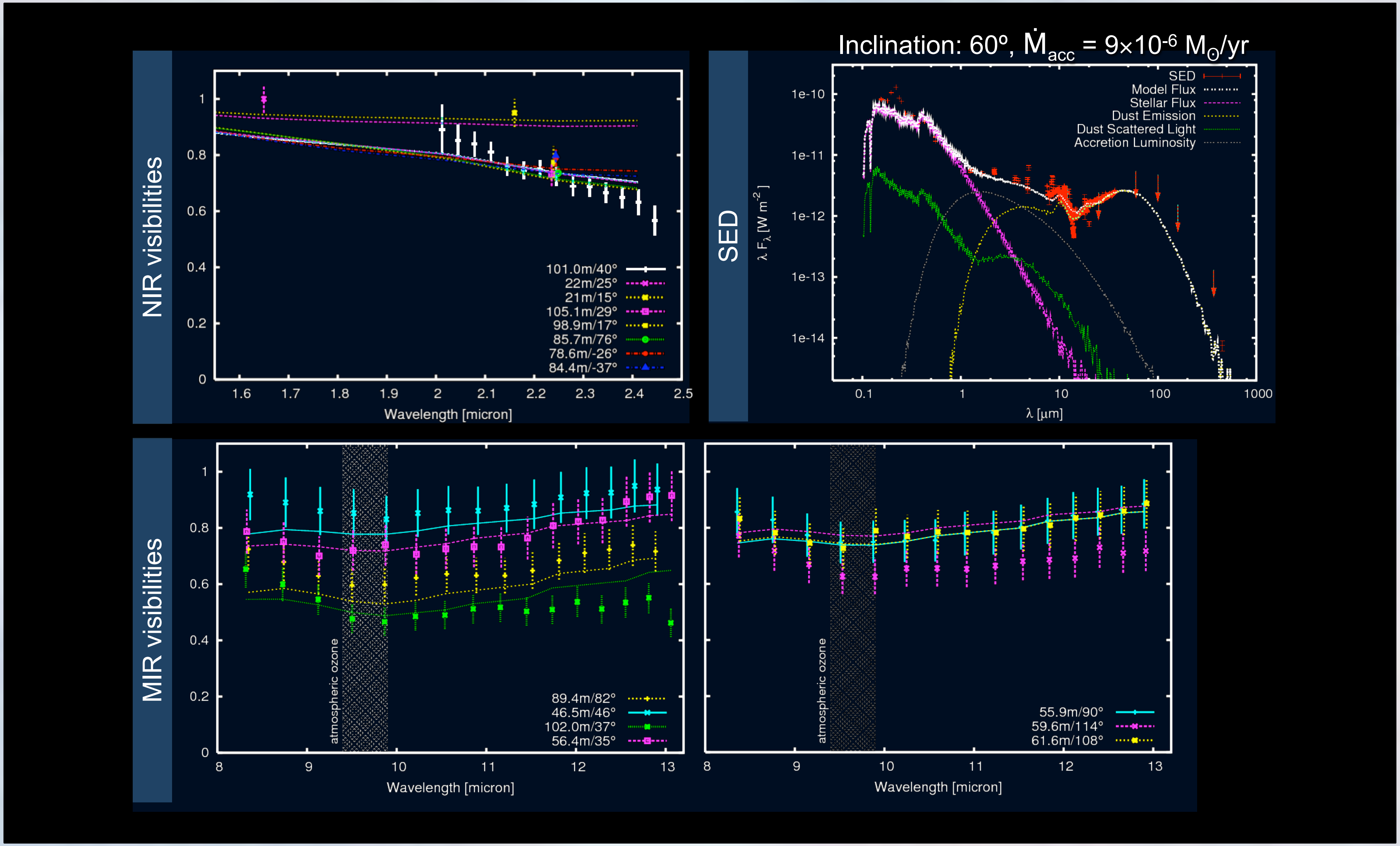


Commonly used analytic temperature-power-law disk models ($T \propto r^{-1/2}$ or $T \propto r^{-3/4}$) cannot describe the measured wavelength-dependence of the apparent size

→ Detailed physical modeling required

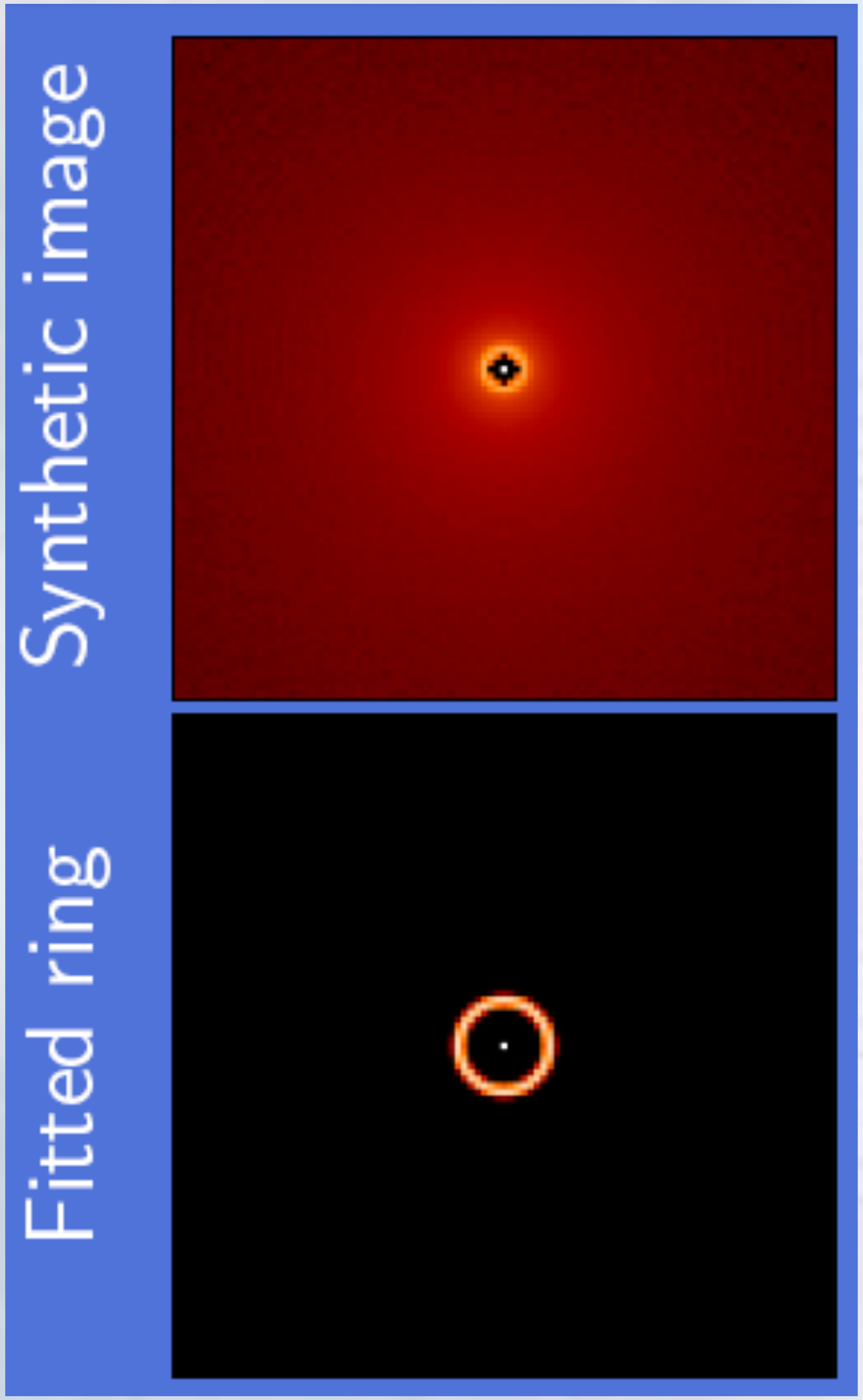
Kraus et al. (2007, ApJ 676, 490)

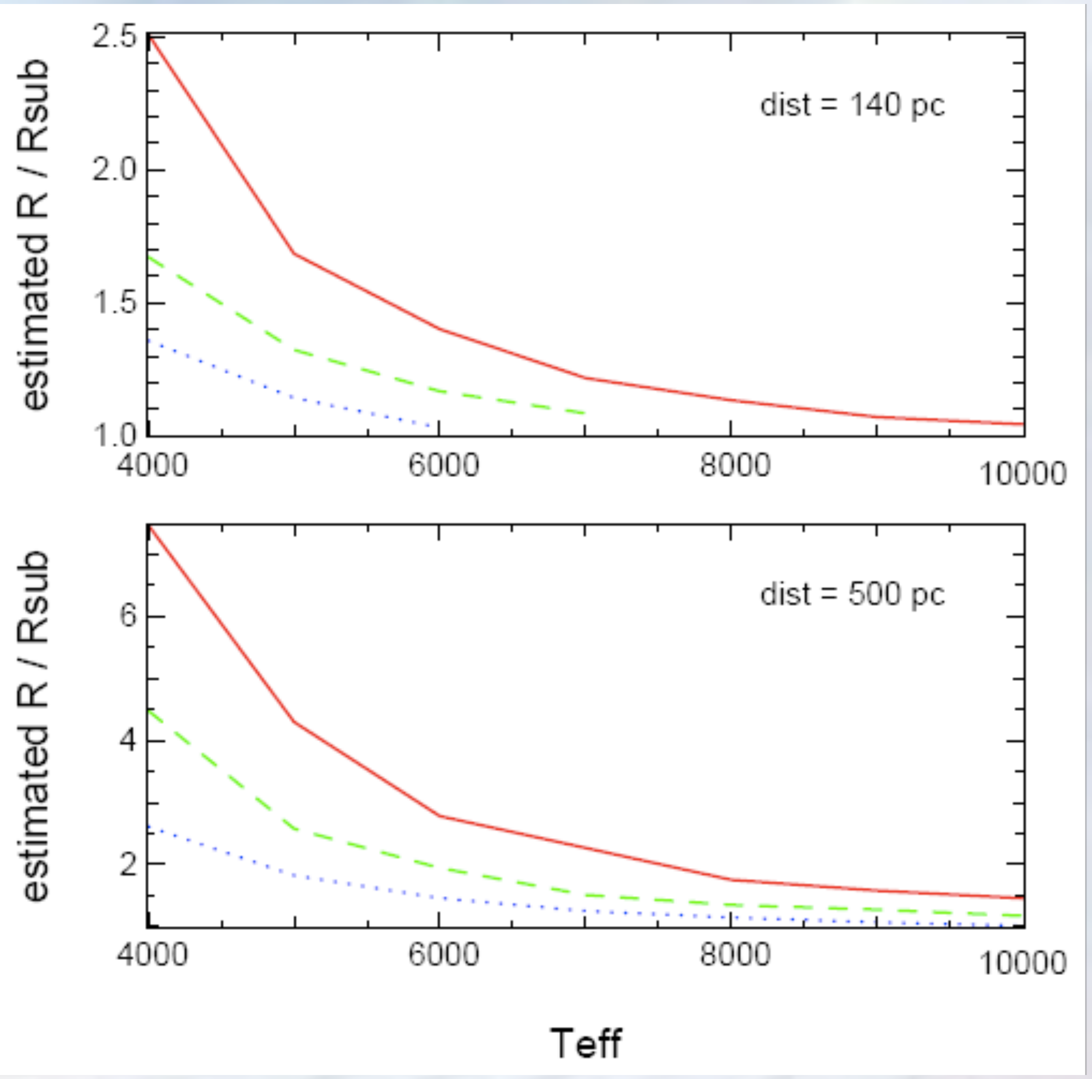
MWC 147: a full disk model to understand NIR and MIR measurements


Inclination: 60°, $\dot{M}_{acc} = 9\times10^{-6}\ M_\odot/yr$

Kraus et al. (2007, ApJ 676, 490)

Effect of extended scattered light

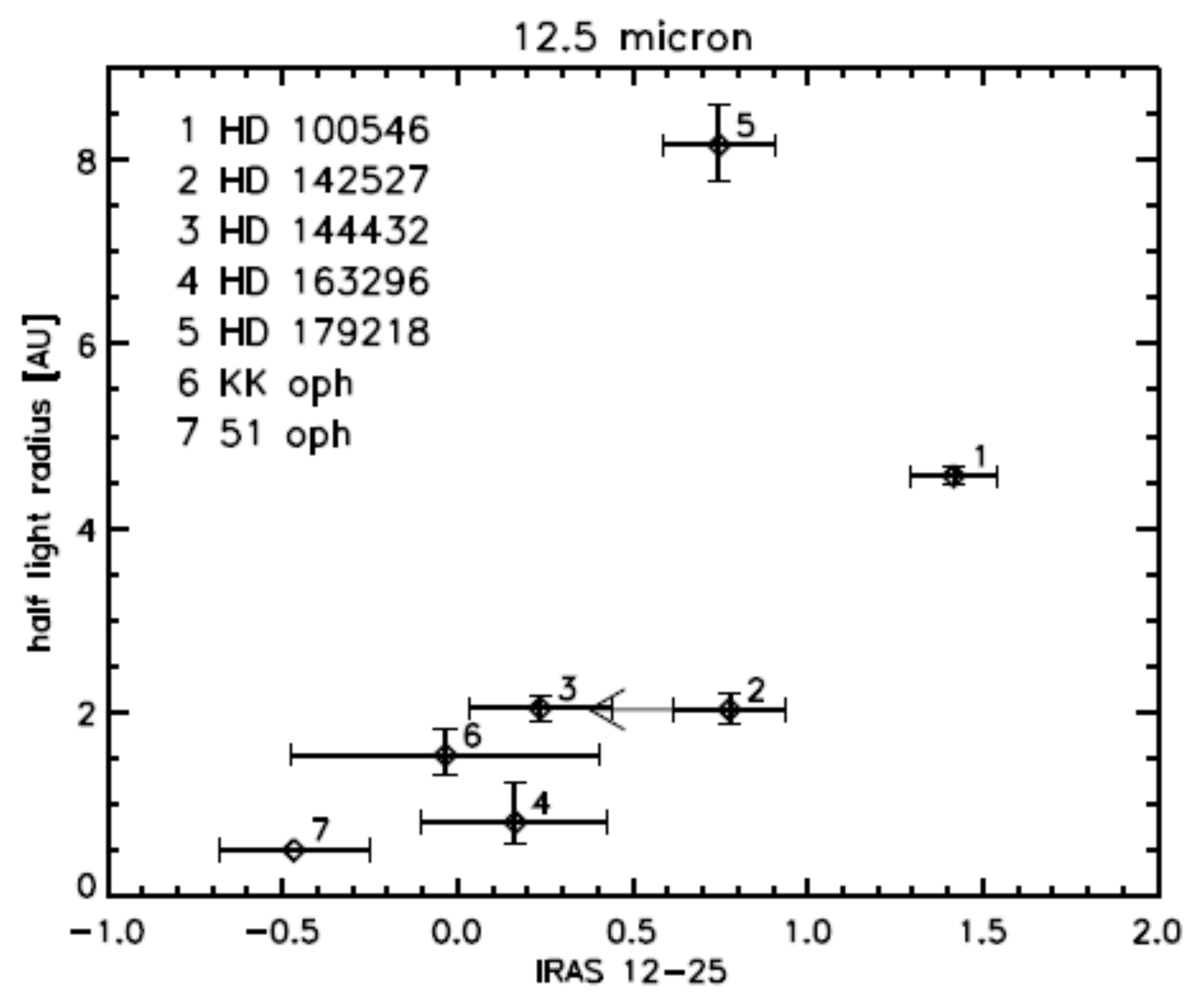




- Ring radius fitting can lead to overestimated sizes
- Careful modeling must be performed including all sources of radiation

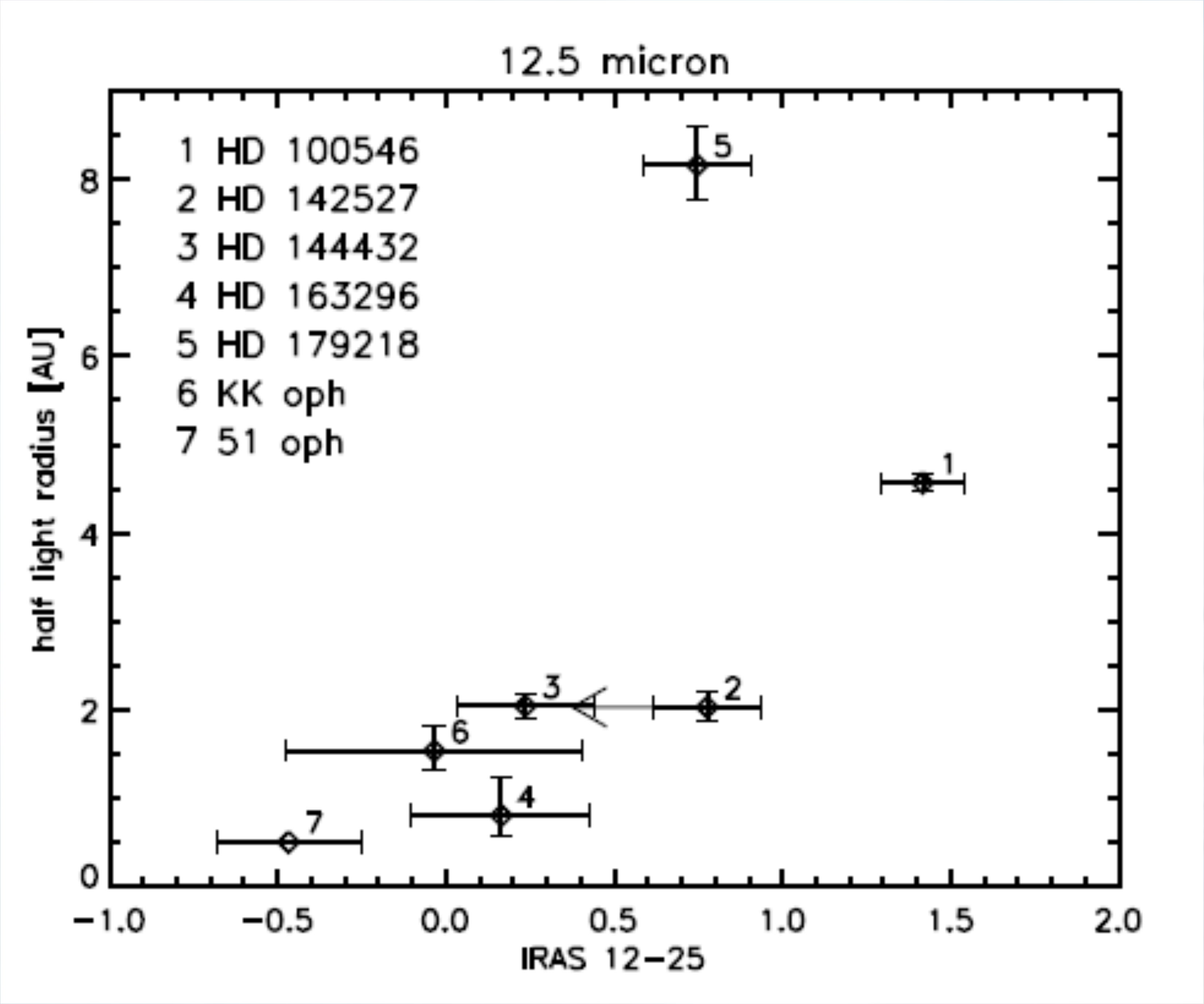
Pinte et al. (2007, ApJ 673, L63)

Vertical structure @ 10 microns

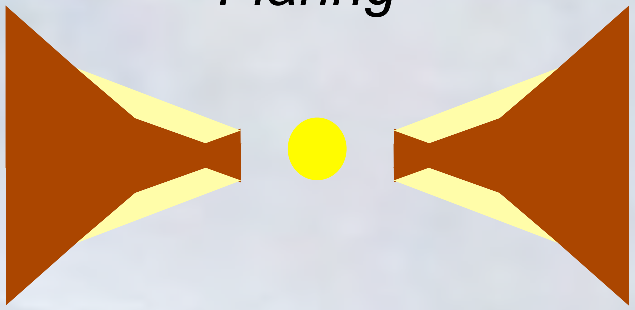


Leinert et al. (2004, A&A, 423, 537)

Vertical structure @ 10 microns



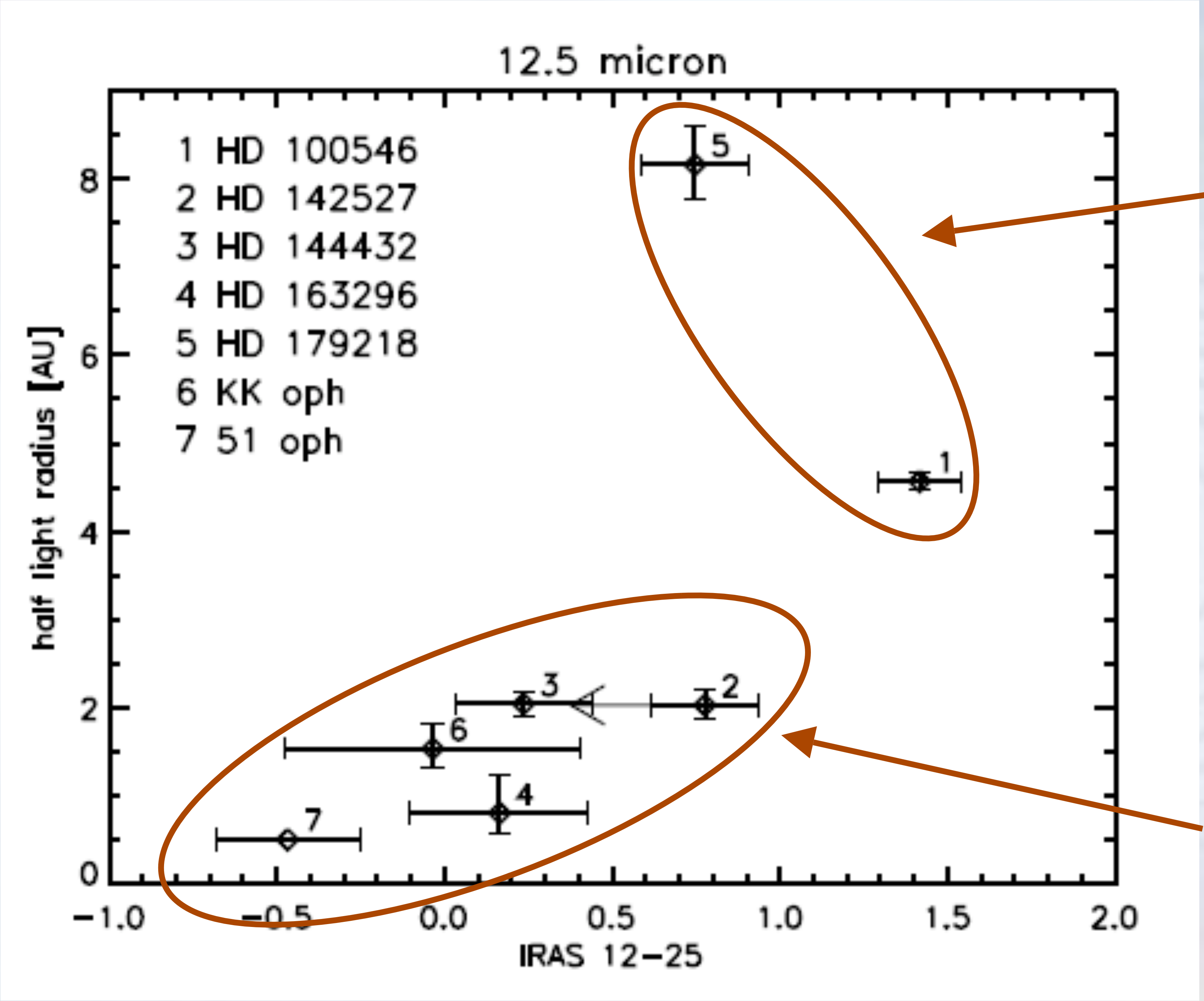
Flaring



Self-shadowed

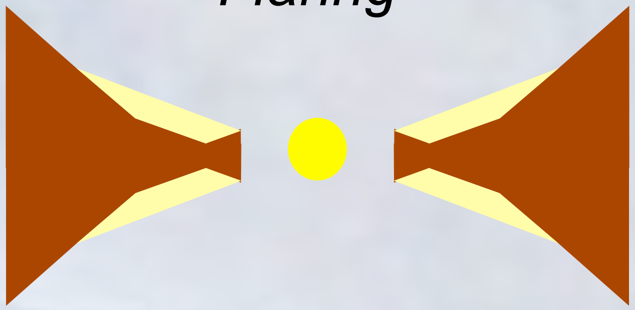
Leinert et al. (2004, A&A, 423, 537)

Vertical structure @ 10 microns



Leinert et al. (2004, A&A, 423, 537)

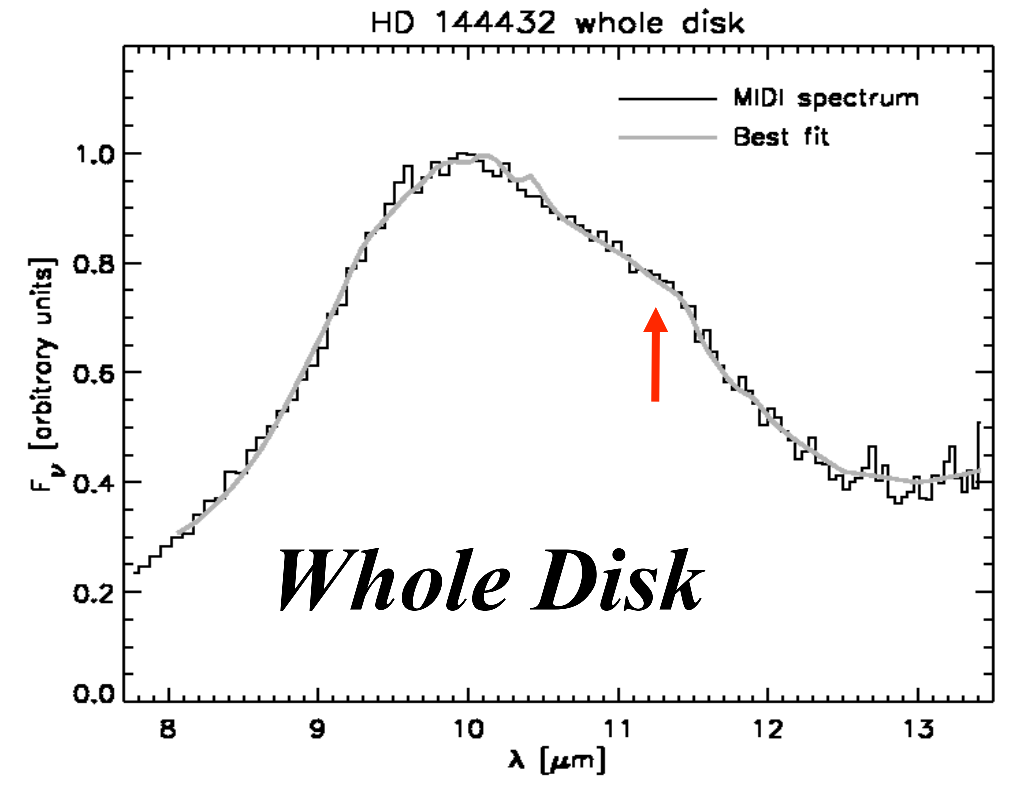
Flaring

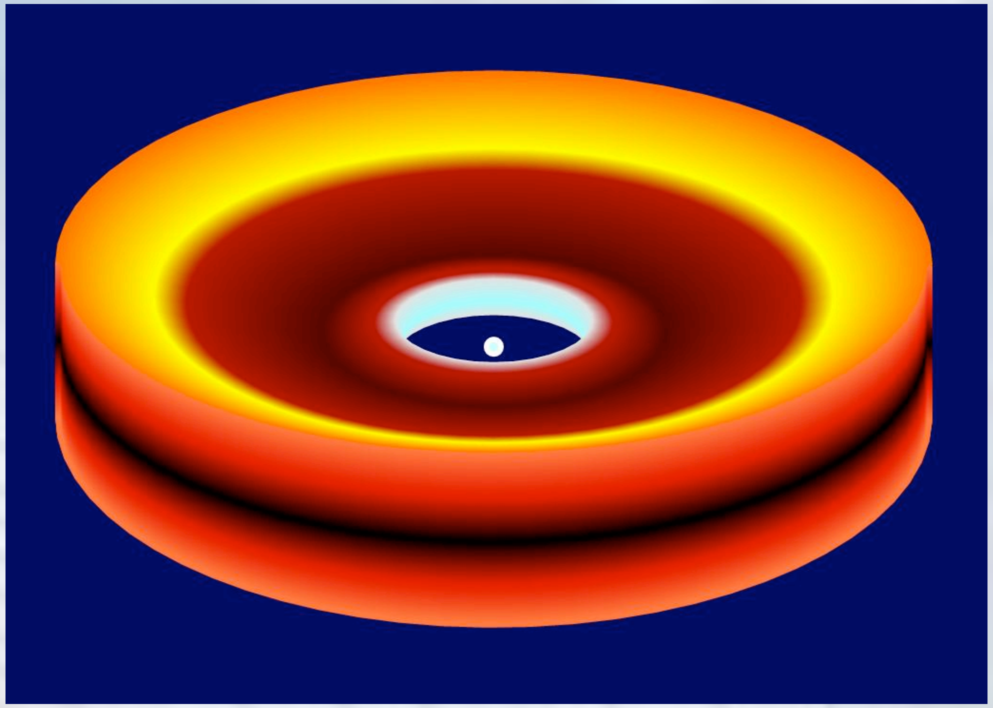


Sizes consistent with flat self-shadowed / flaring disk model SED classification

Self-shadowed

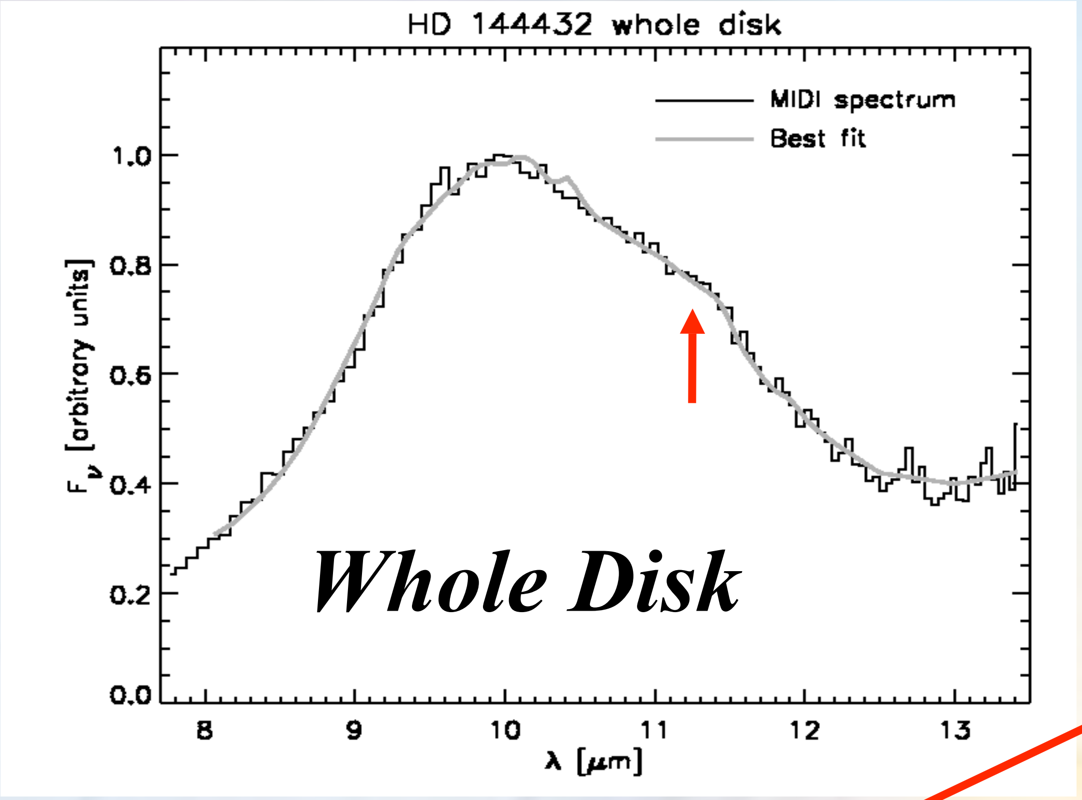
Dust mineralogy in HAeBe

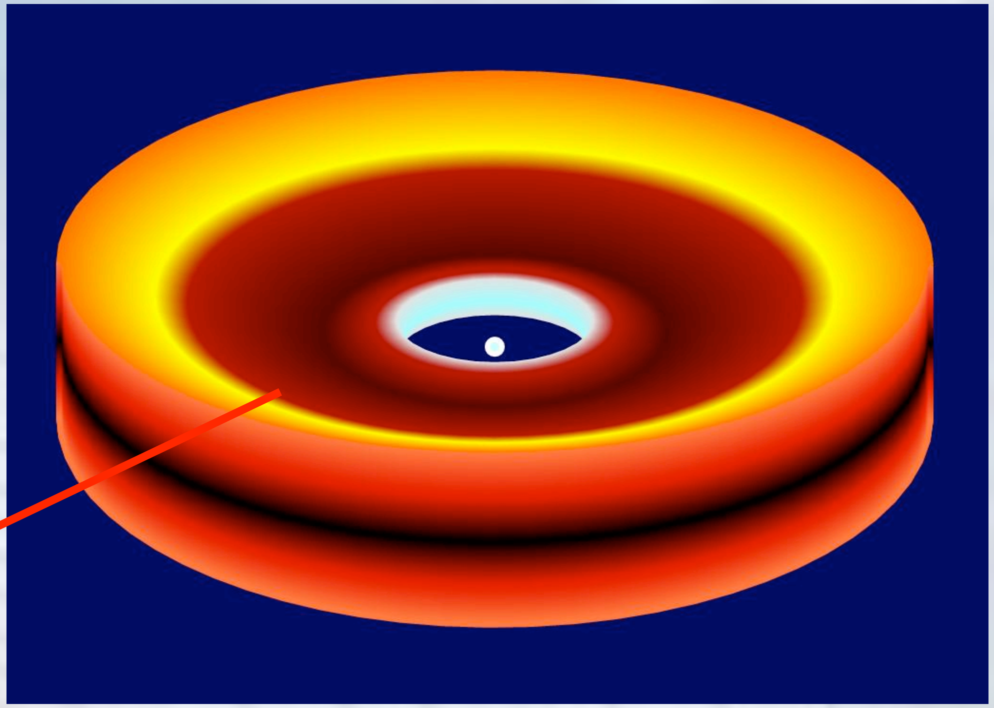


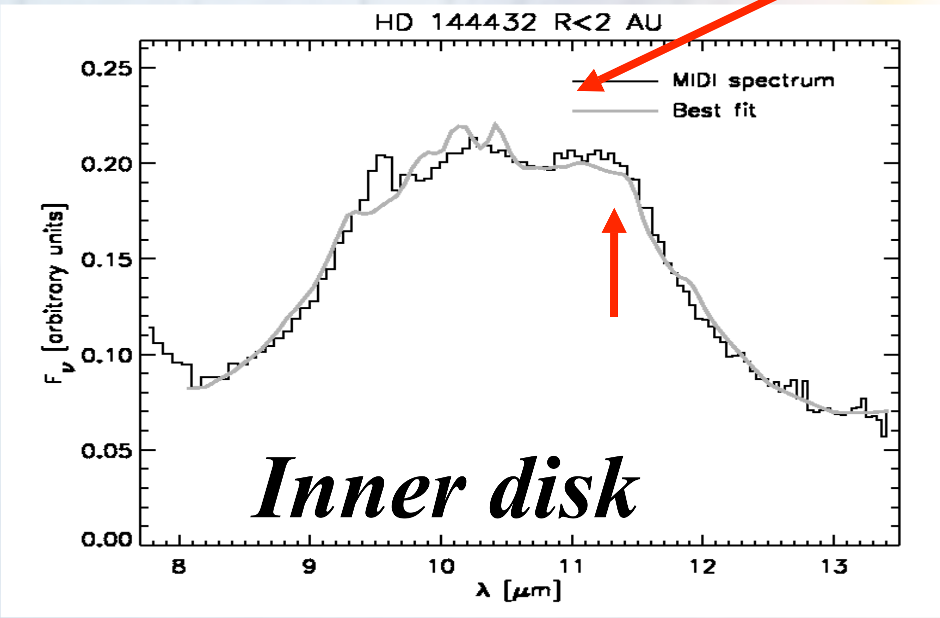


Van Boekel et al. (2004, Nature, 432, 479)

Dust mineralogy in HAeBe

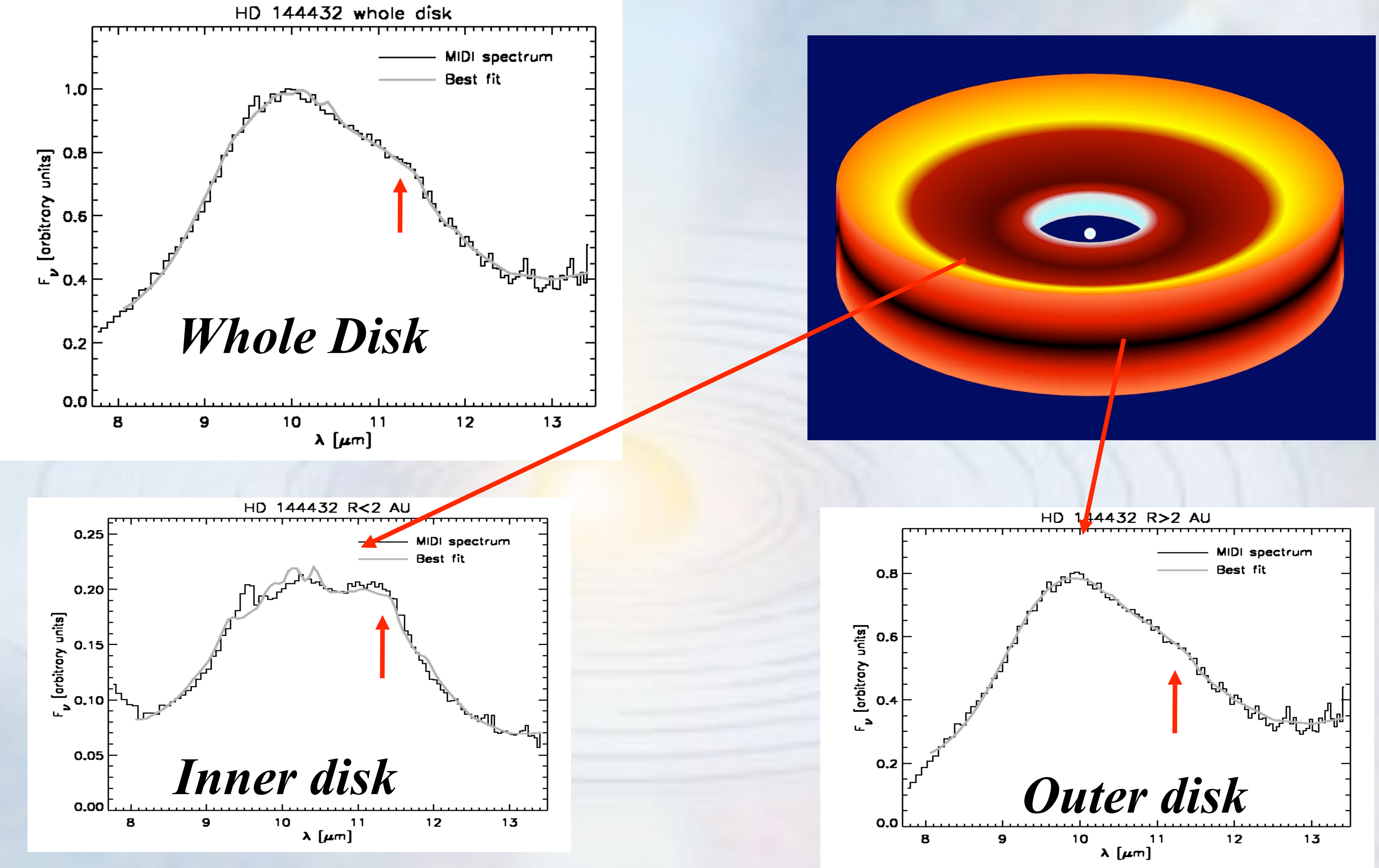






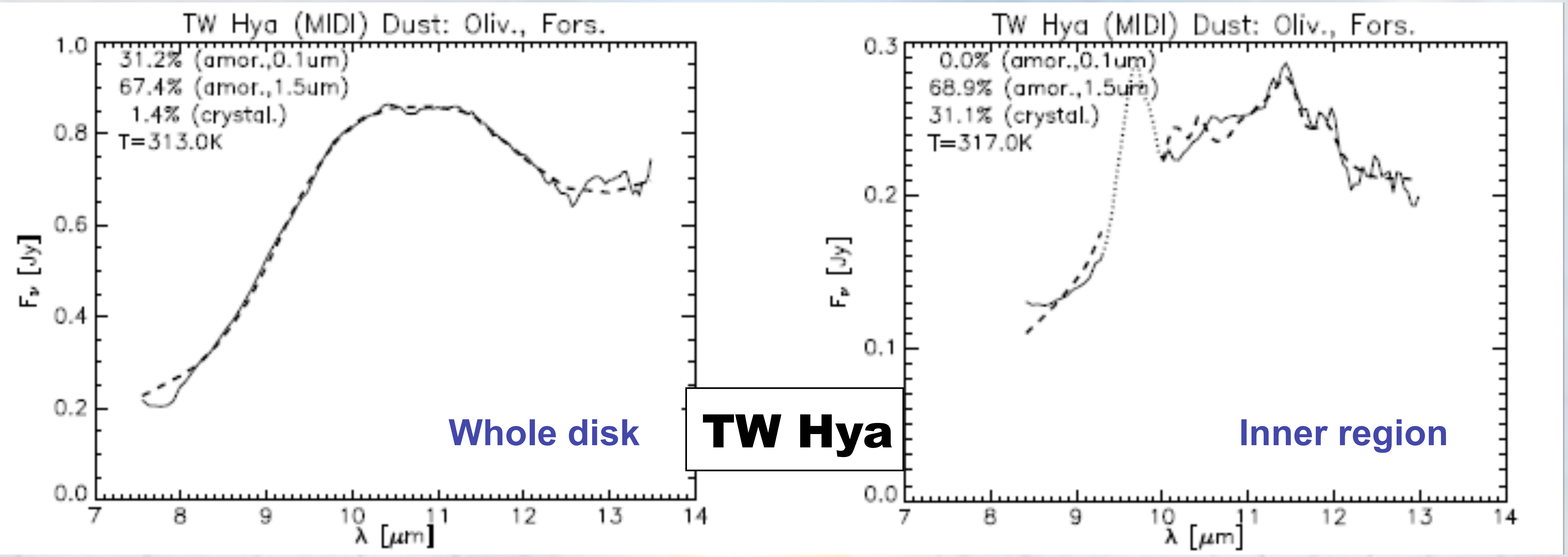
Van Boekel et al. (2004, Nature, 432, 479)

Dust mineralogy in HAeBe



Van Boekel et al. (2004, Nature, 432, 479)

… also in T Tauri disks!

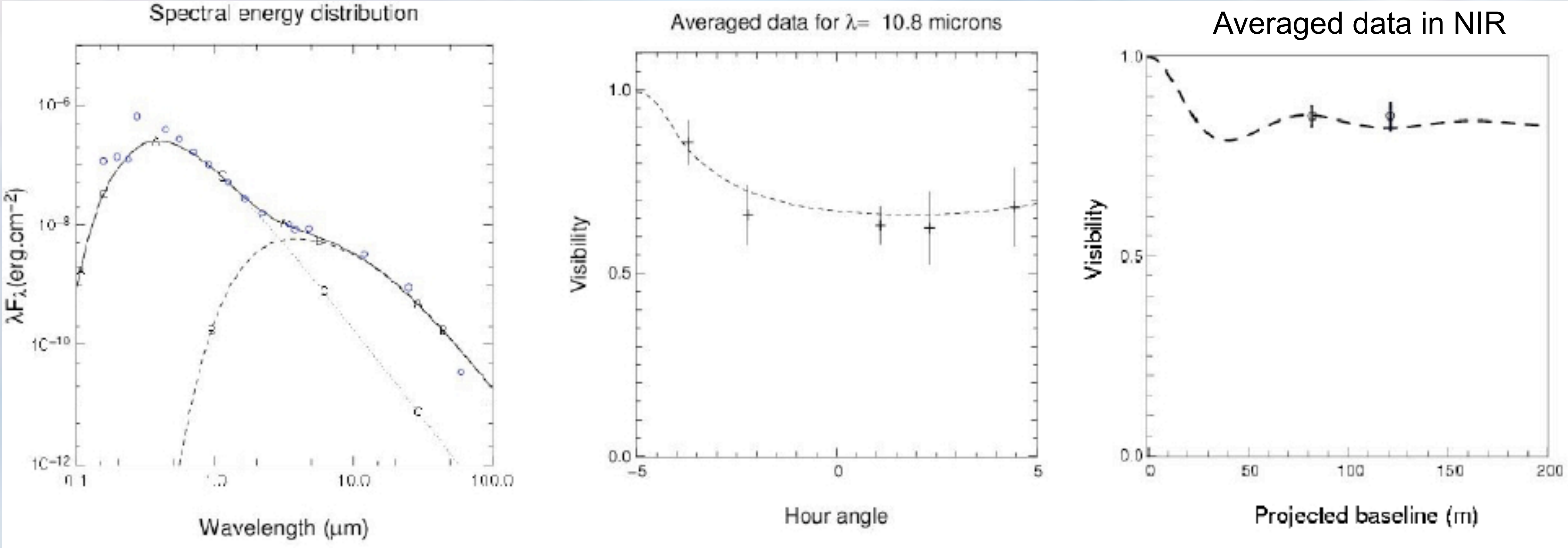


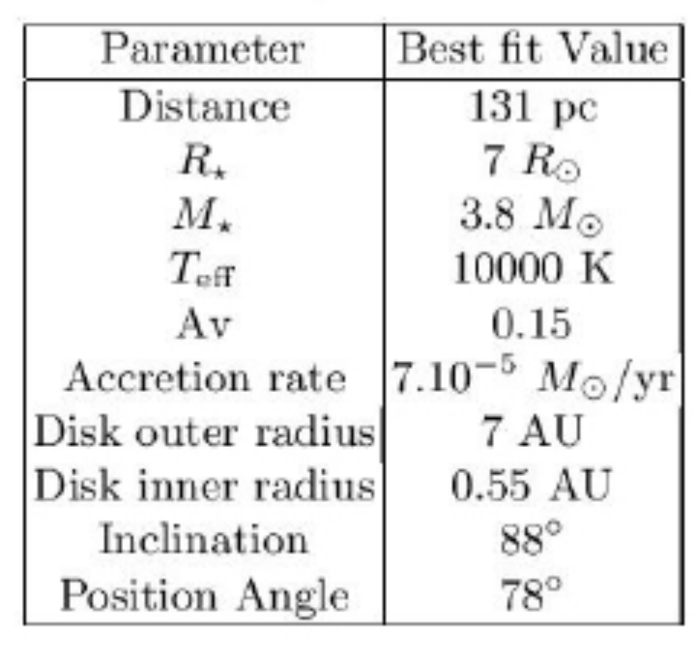
Ratzka et al. 2007, A&A in press

→ Inner disks (< 2 AU) have:

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

51 Oph: NIR CO overtone emission

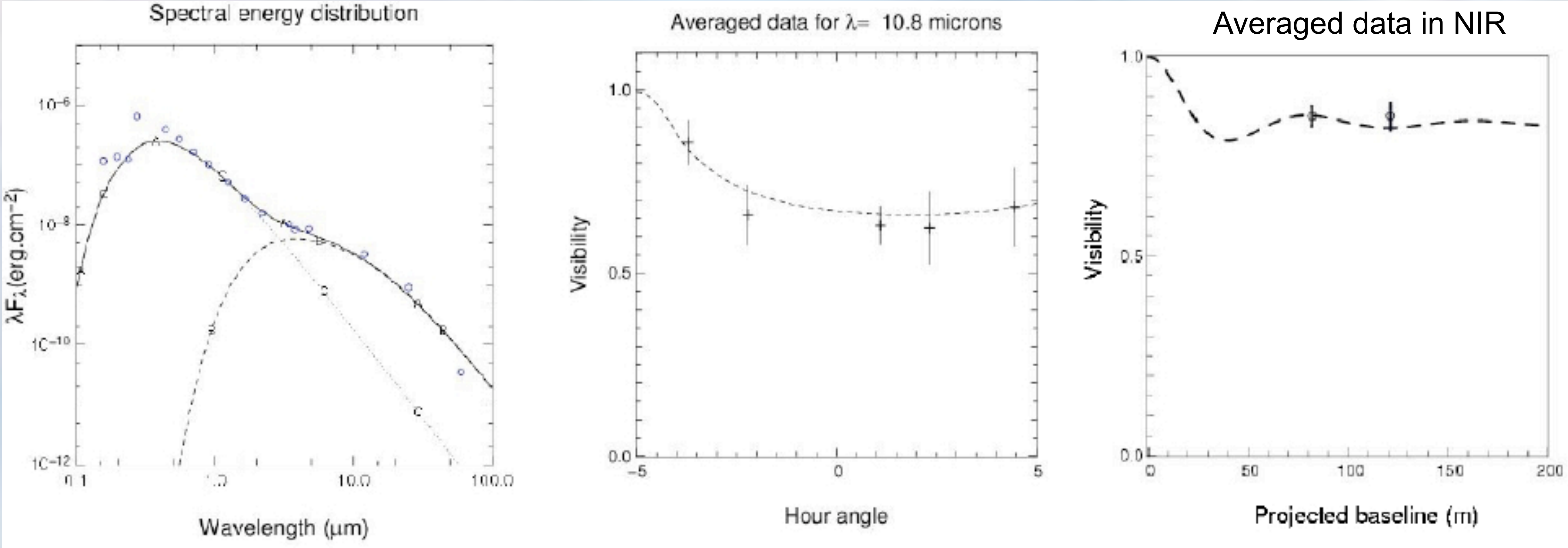




Parameter	Best fit Value
Distance	131 pc
$R_\star$	7 $R_\odot$
$M_\star$	3.8 $M_\odot$
$T_{\rm eff}$	10000 K
Av	0.15
Accretion rate	7.10^{-5} $M_\odot$/yr
Disk outer radius	7 AU
Disk inner radius	0.55 AU
Inclination	88°
Position Angle	78°

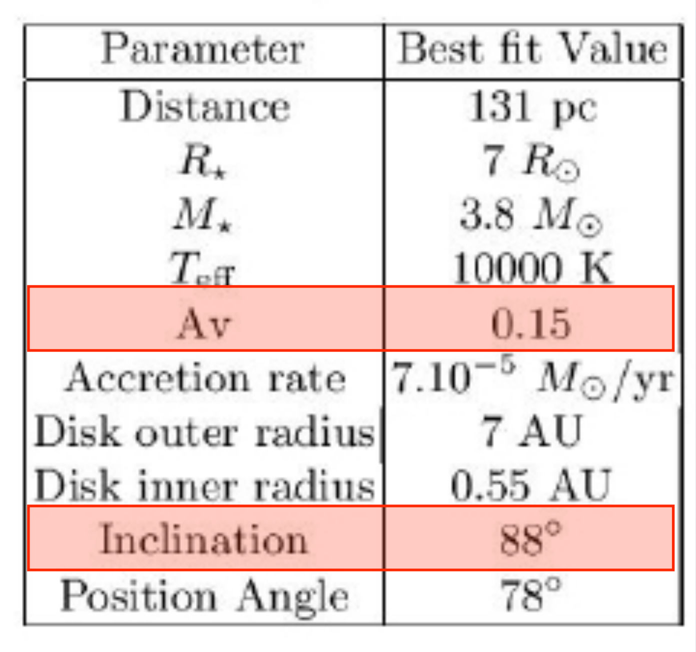
Tatulli, et al. (2007, in prep.)

51 Oph: NIR CO overtone emission



All observations fitted by the standard disk model!

but it seems not to be physically possible



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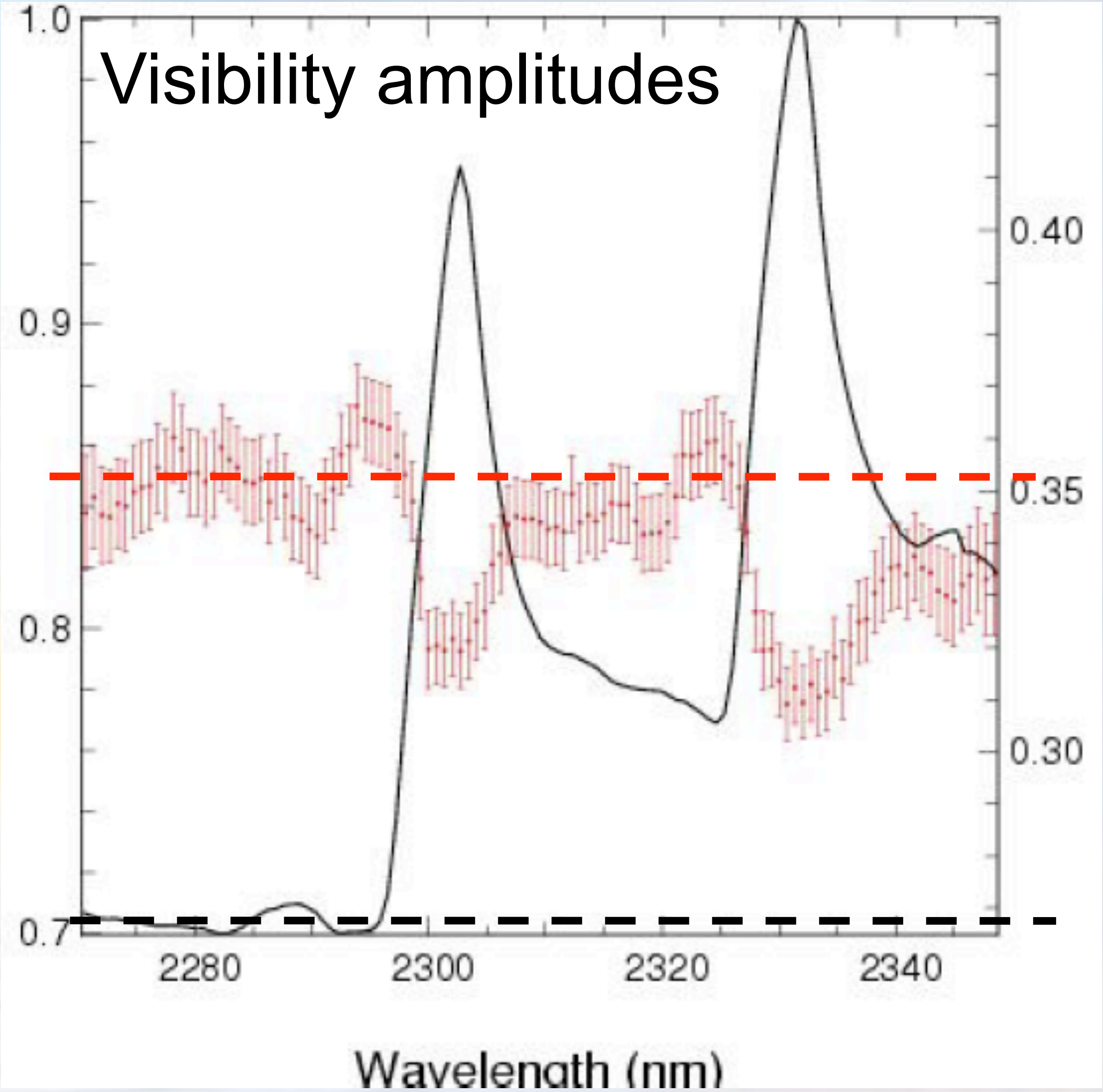
Tatulli, et al. (2007, in prep.)

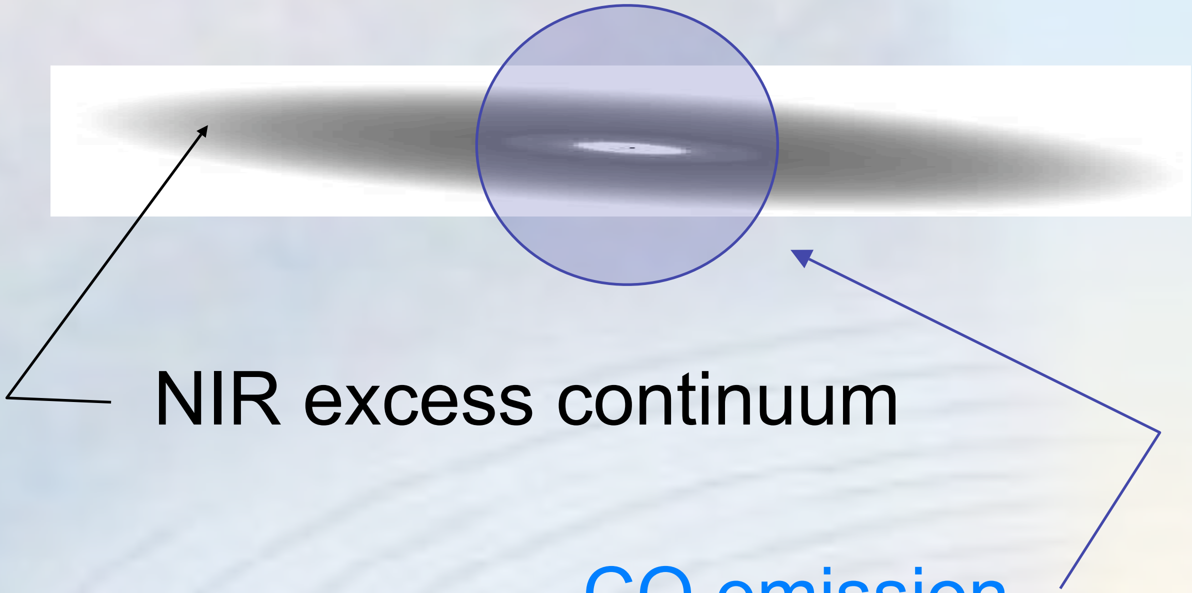
Region of CO emission in 51 Oph

NIR excess continuum



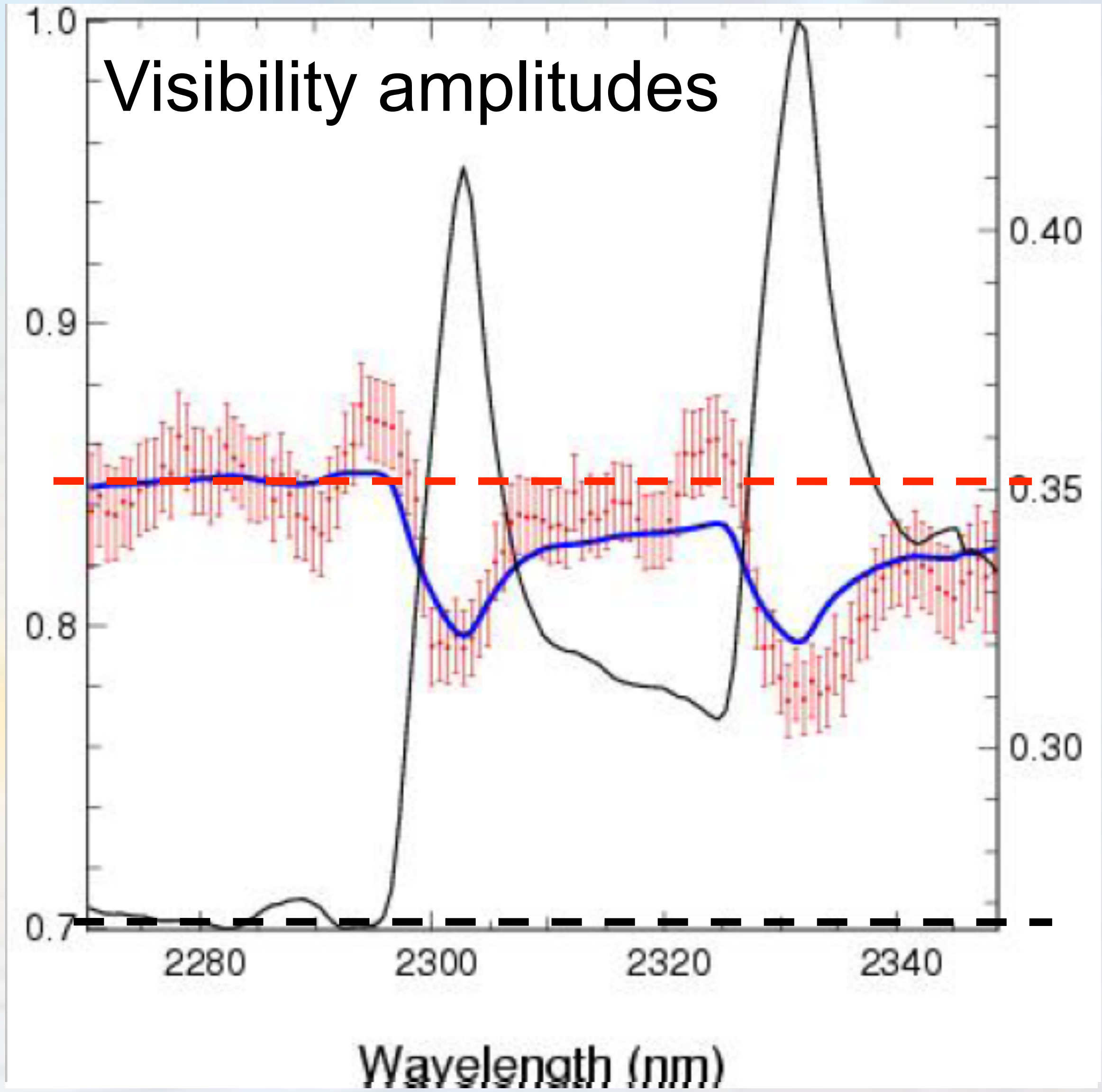
Tatulli, et al. (2007, in prep.)

Region of CO emission in 51 Oph



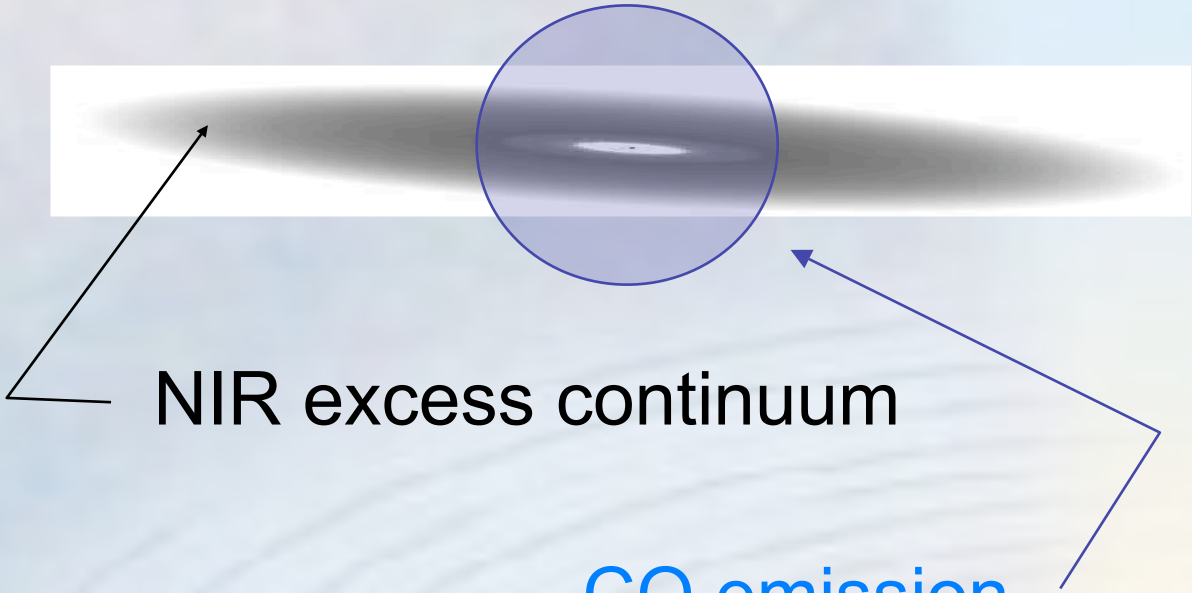
NIR excess continuum

CO emission
0.3AU size



Tatulli, et al. (2007, in prep.)

Region of CO emission in 51 Oph



NIR excess continuum

CO emission
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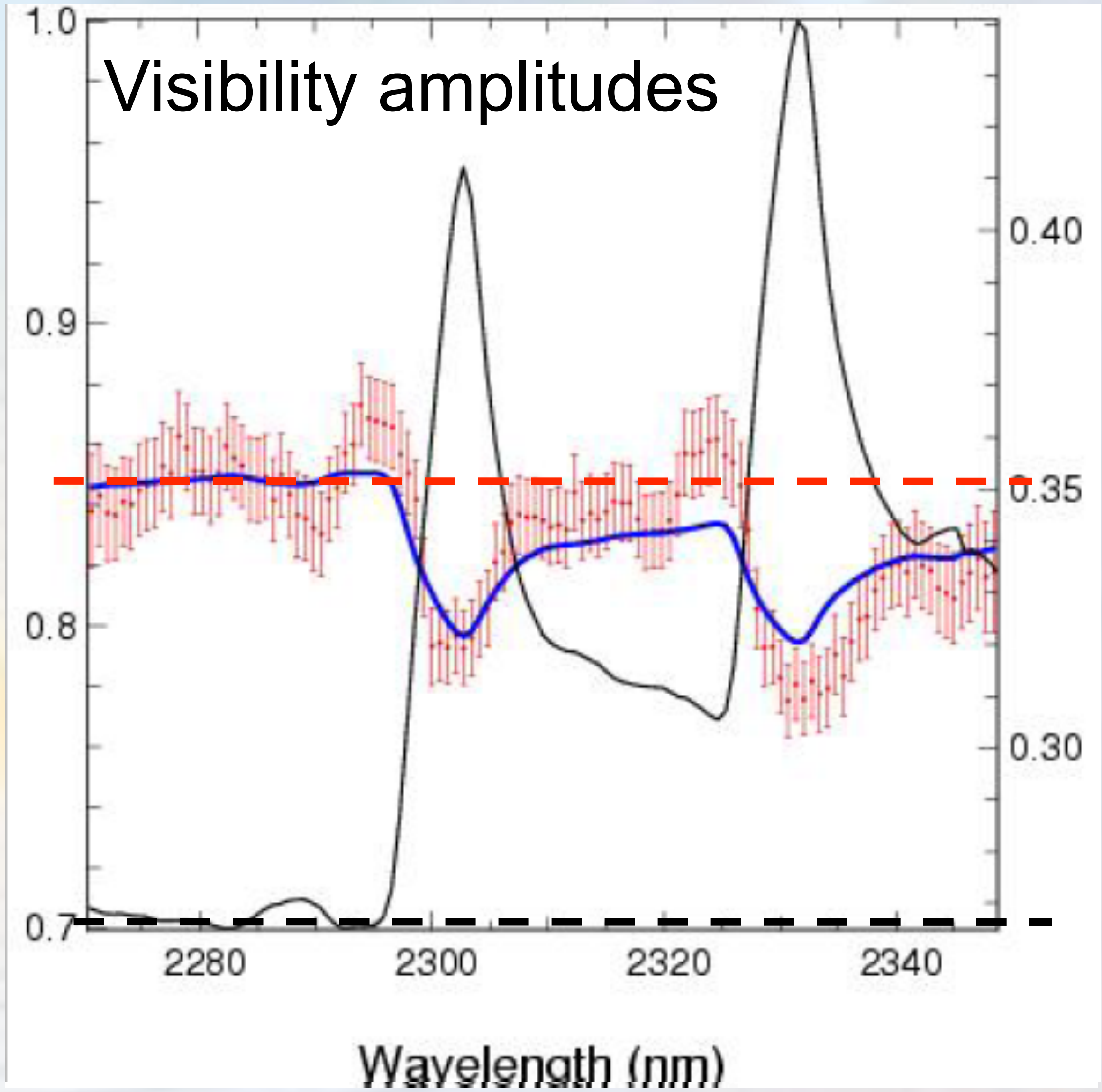
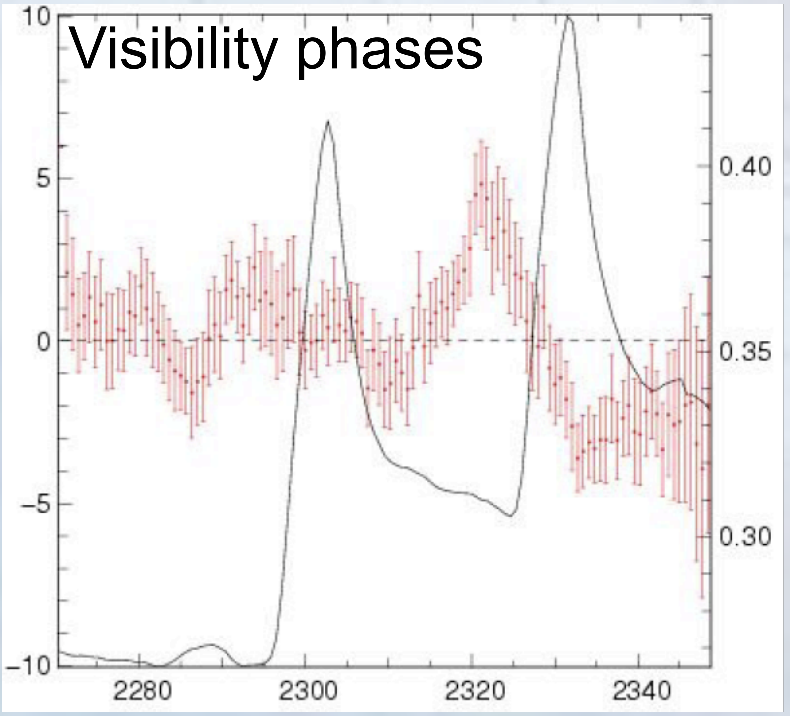
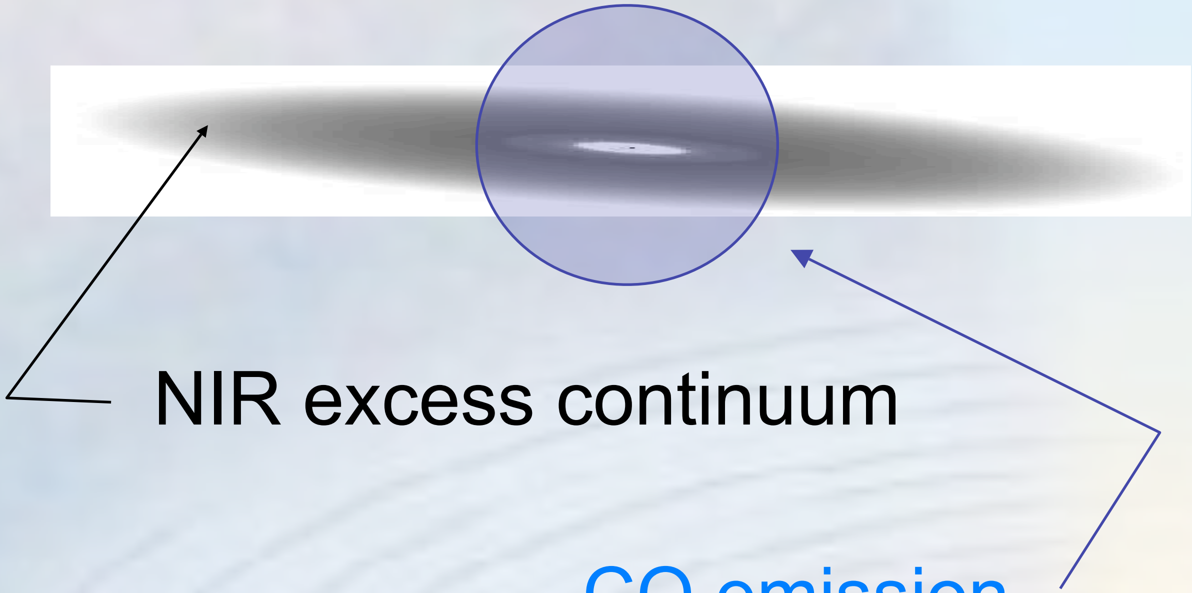




Tatulli, et al. (2007, in prep.)

Region of CO emission in 51 Oph



NIR excess continuum

CO emission

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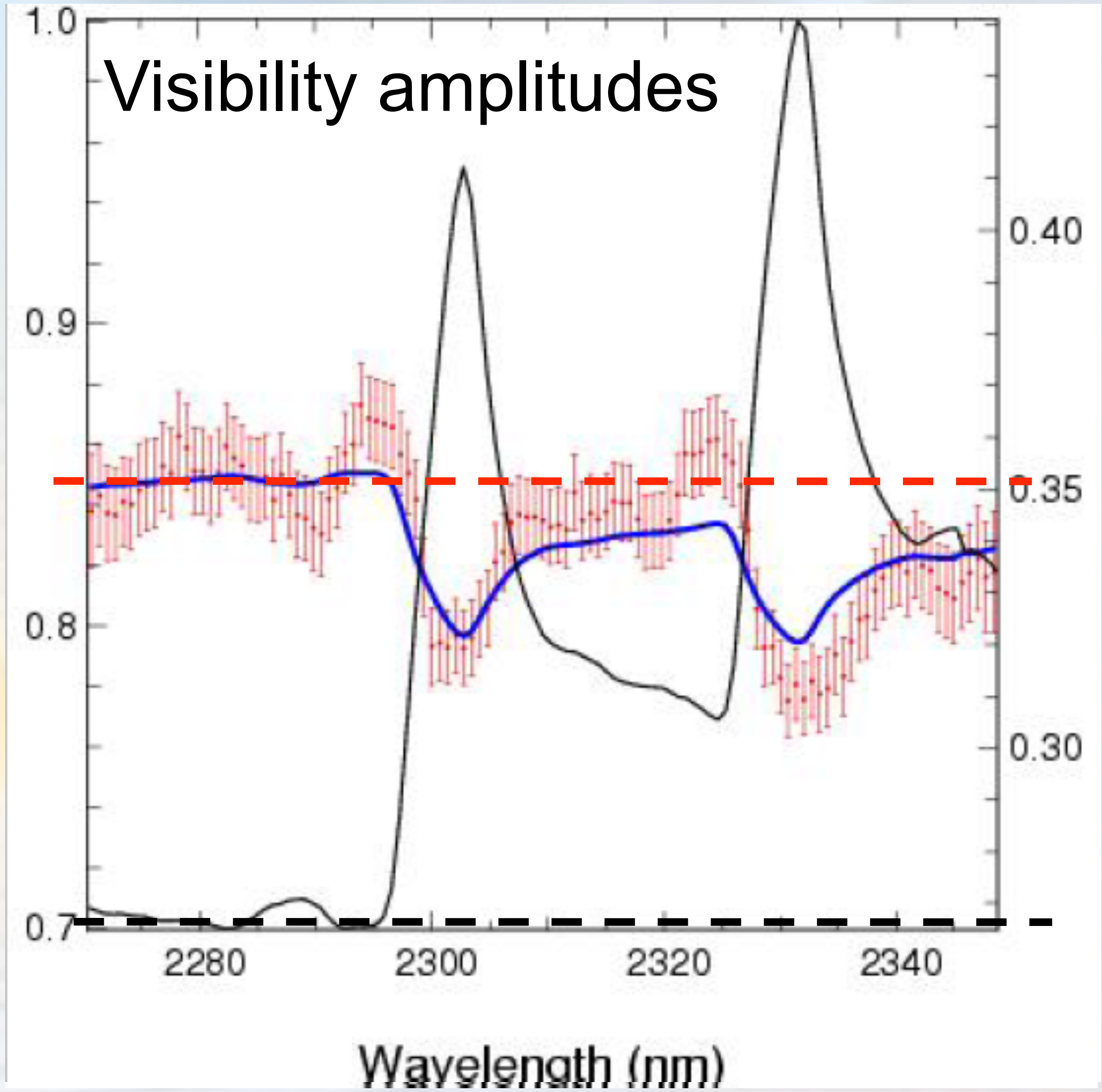
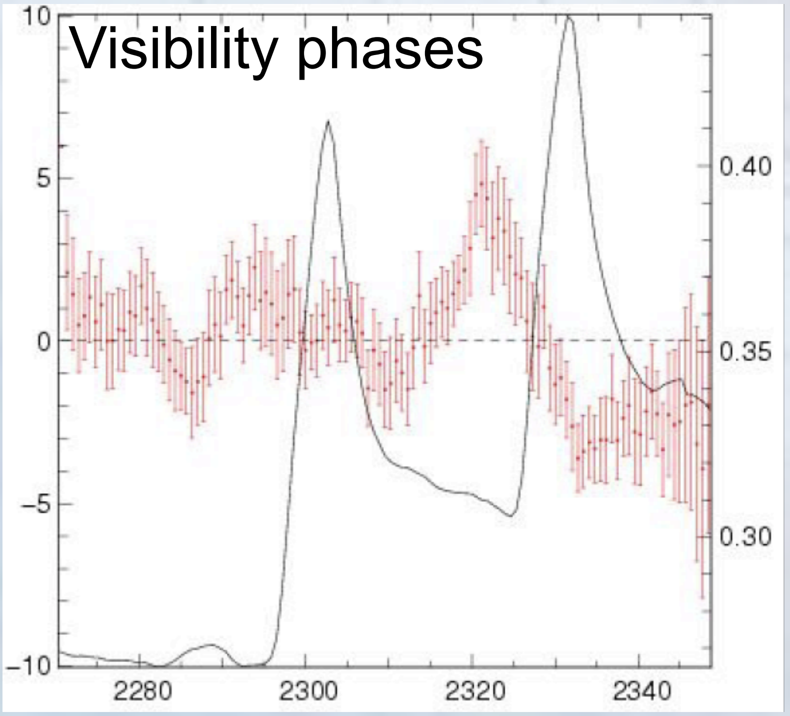




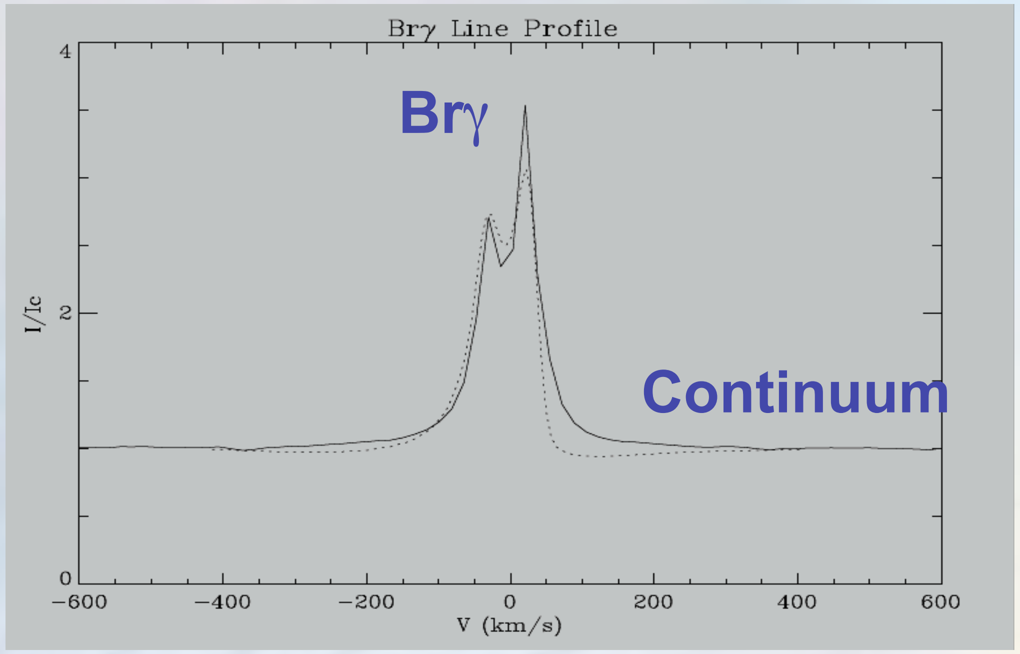
Comprehension of the dust vs gas morphology will increase with better coverture.

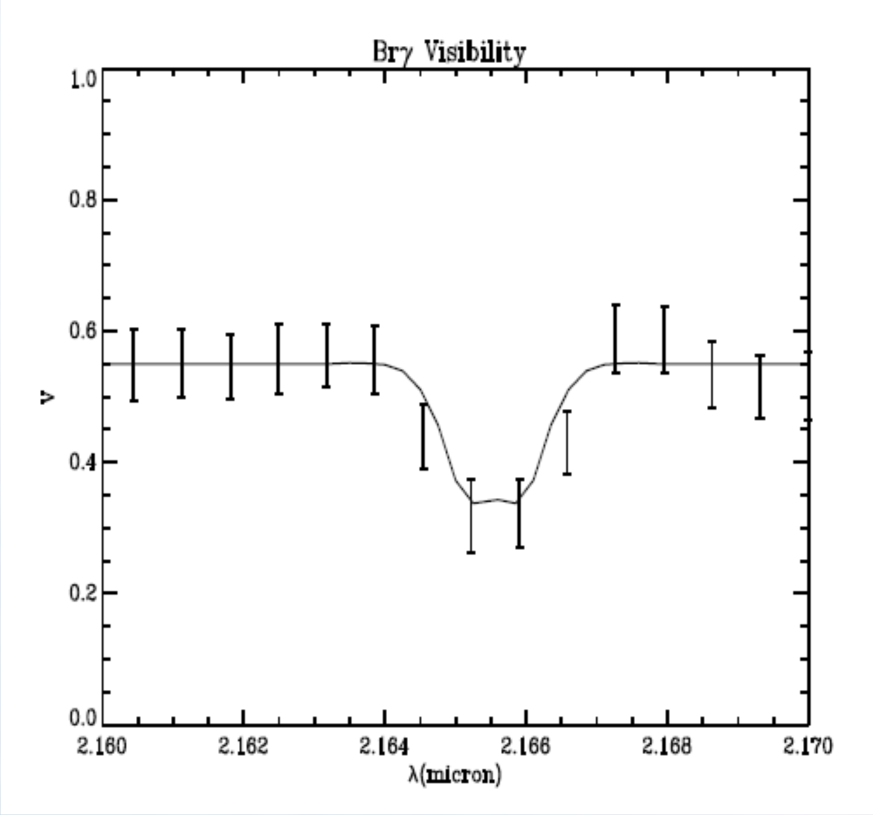
Tatulli, et al. (2007, in prep.)

OTHER AU-SCALE PHENOMENA

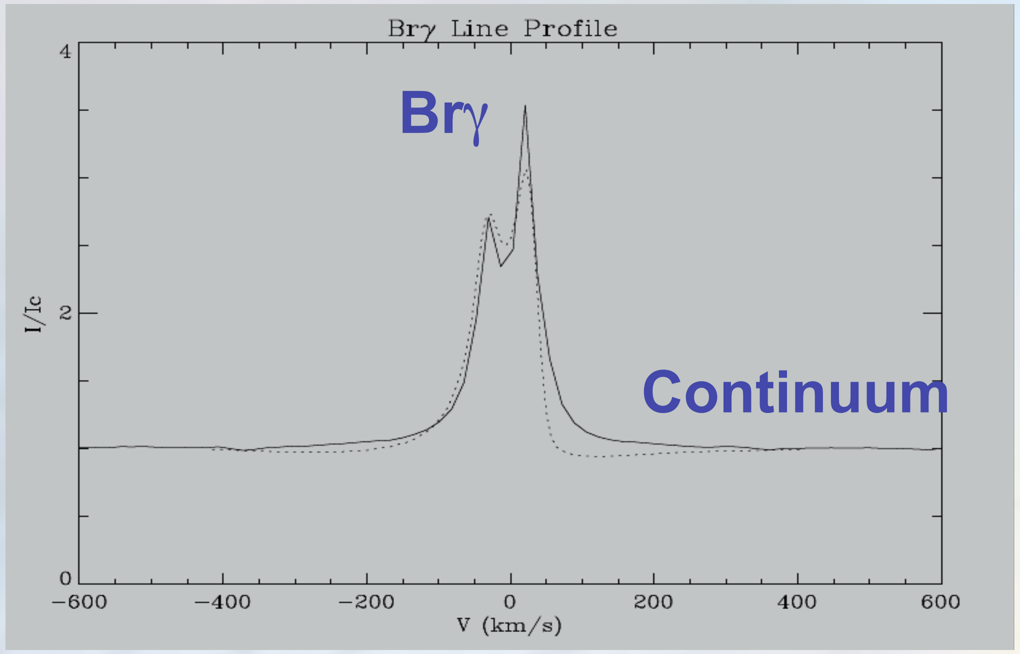
- Outflowing winds
- Magnetospheres
- Binaries and multiple systems

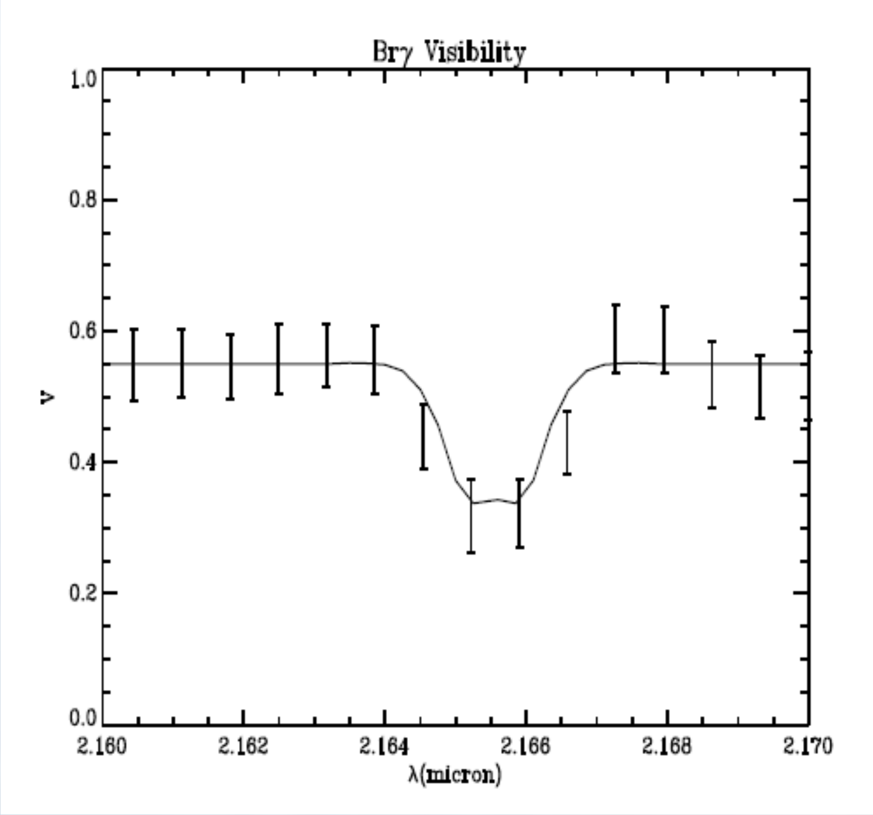
Disk and wind spatially are spectrally resolved in MWC 297

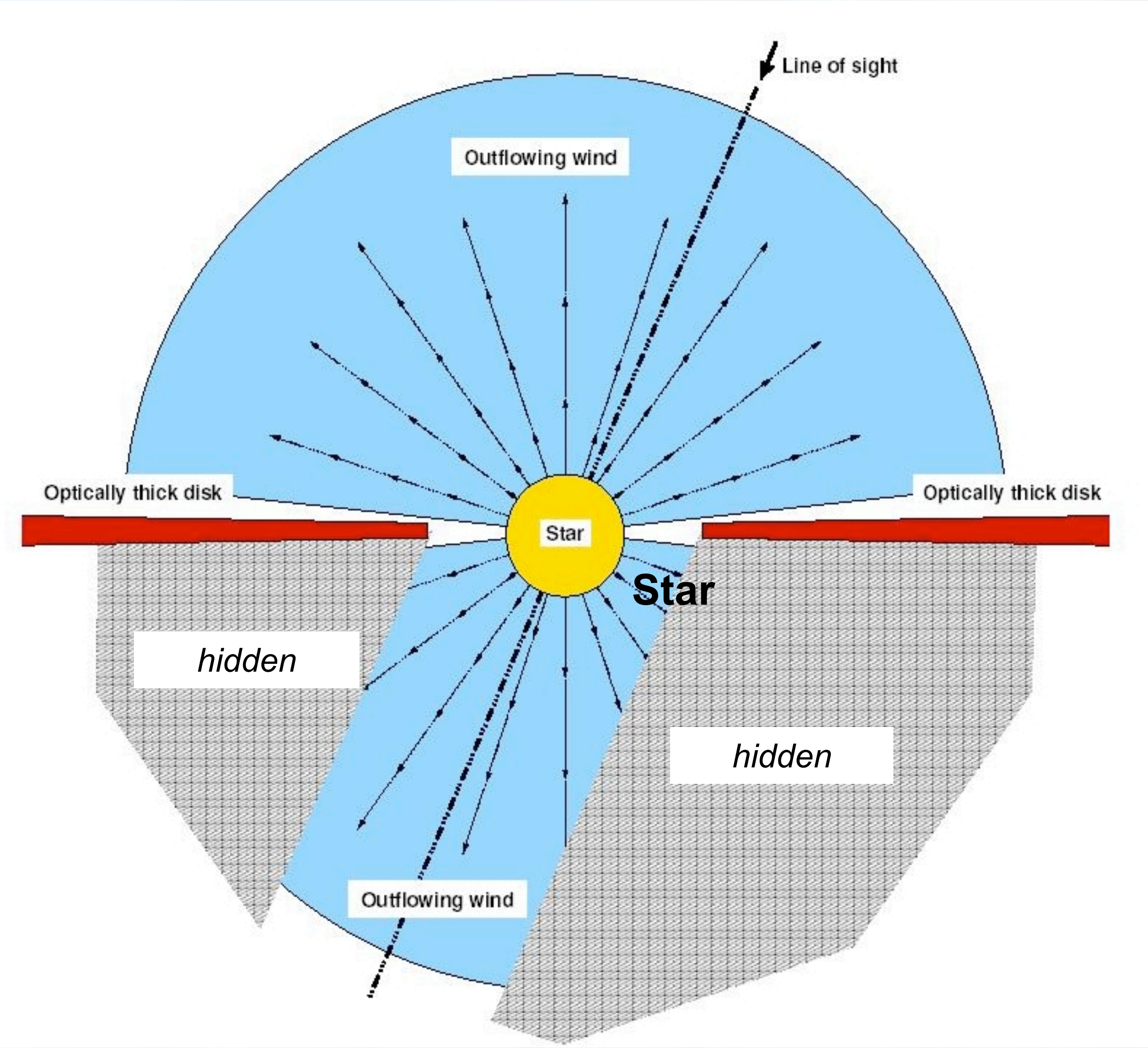




Disk and wind spatially are spectrally resolved in MWC 297

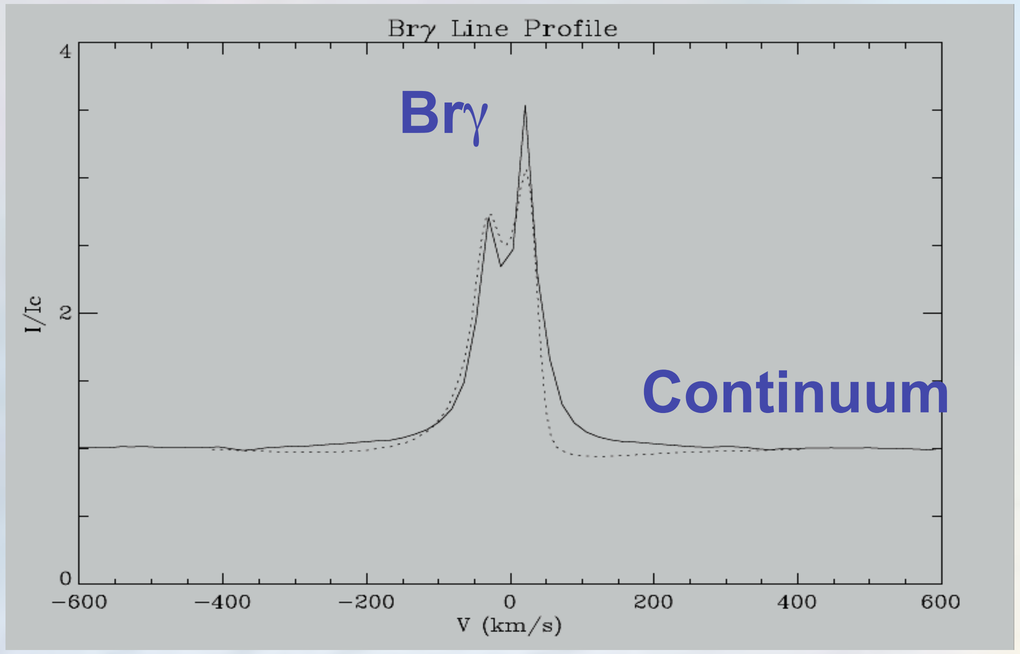


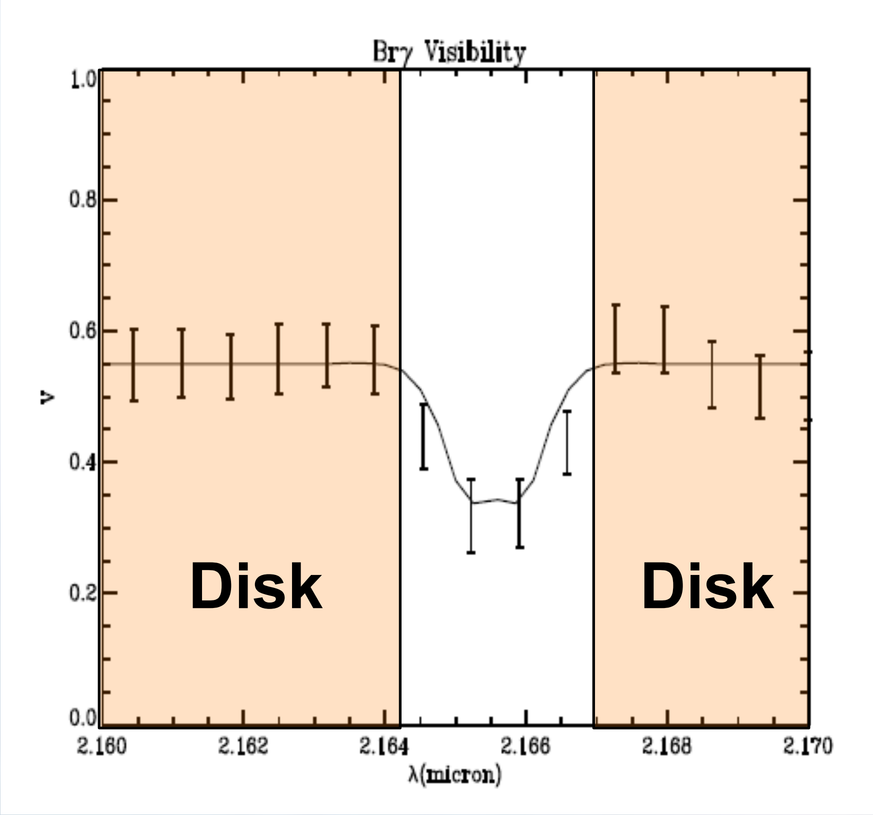


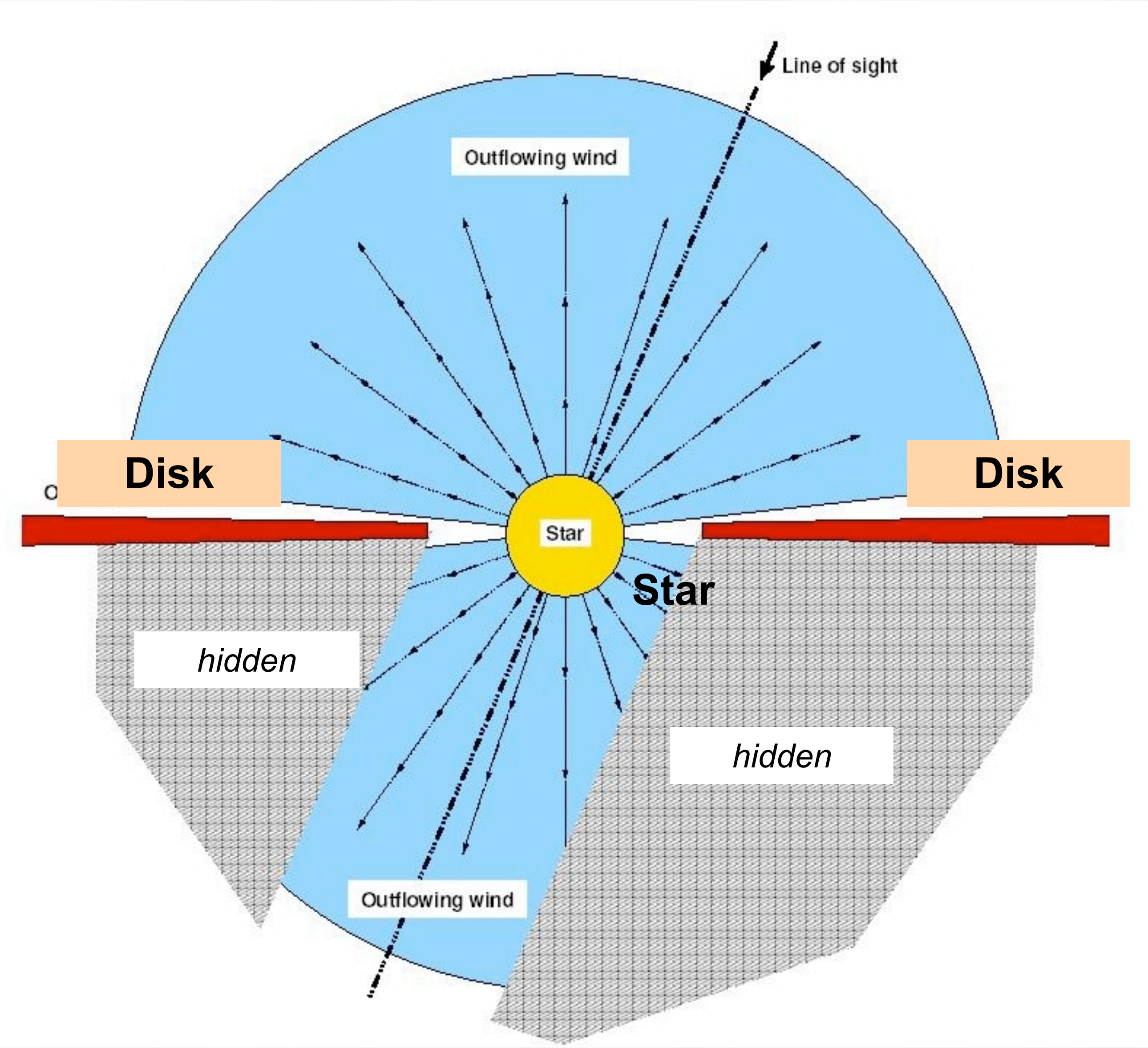


Malbet et al. (2007, A&A 464, 43)

Disk and wind spatially are spectrally resolved in MWC 297







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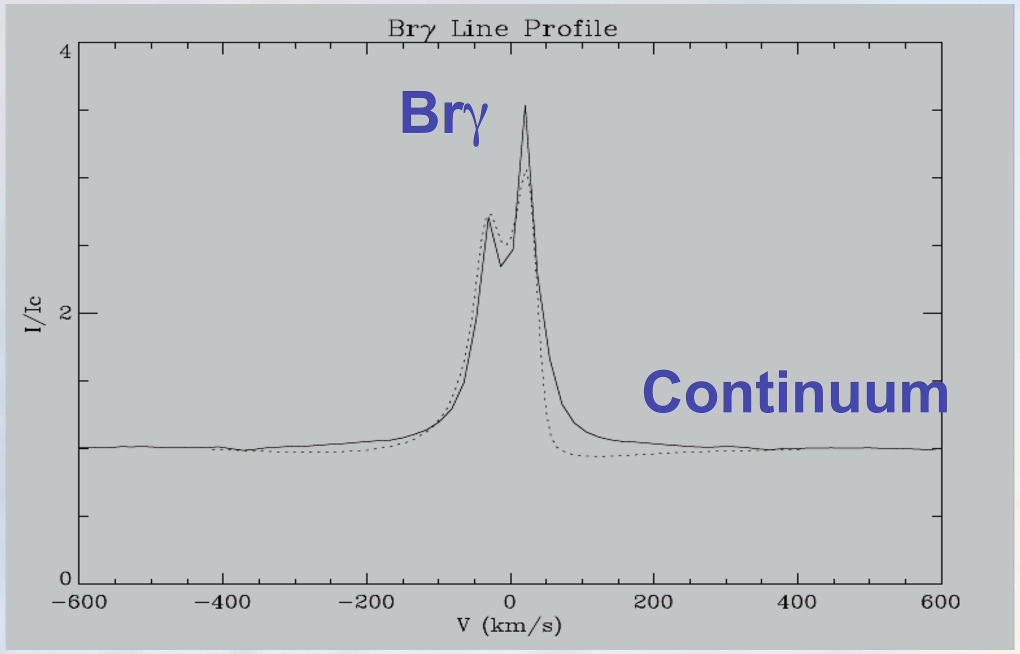

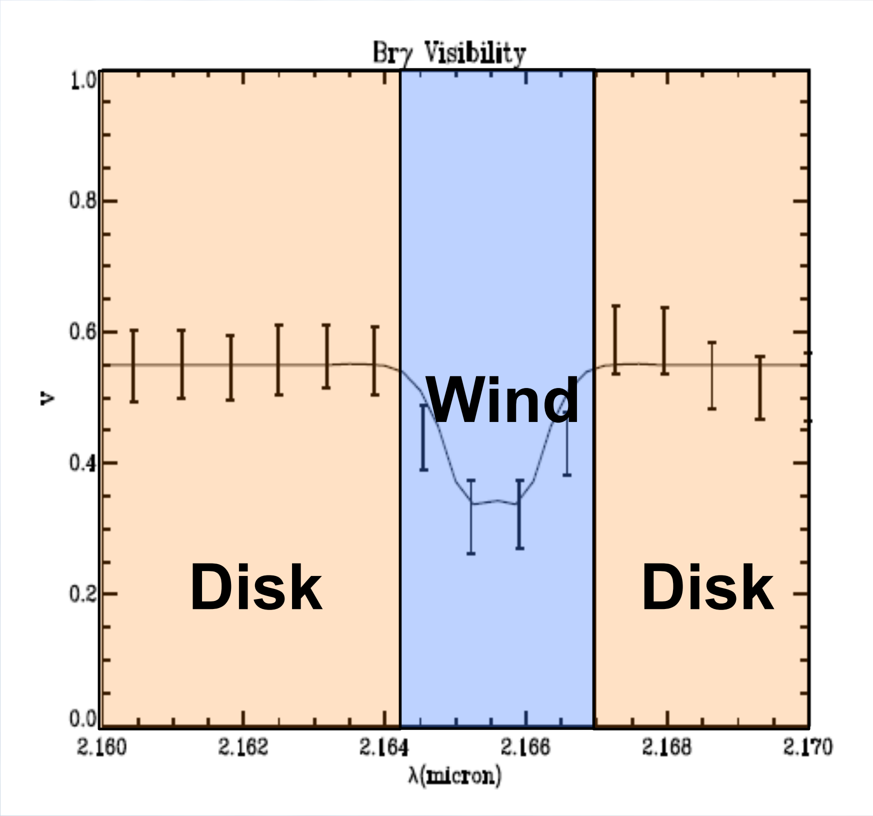

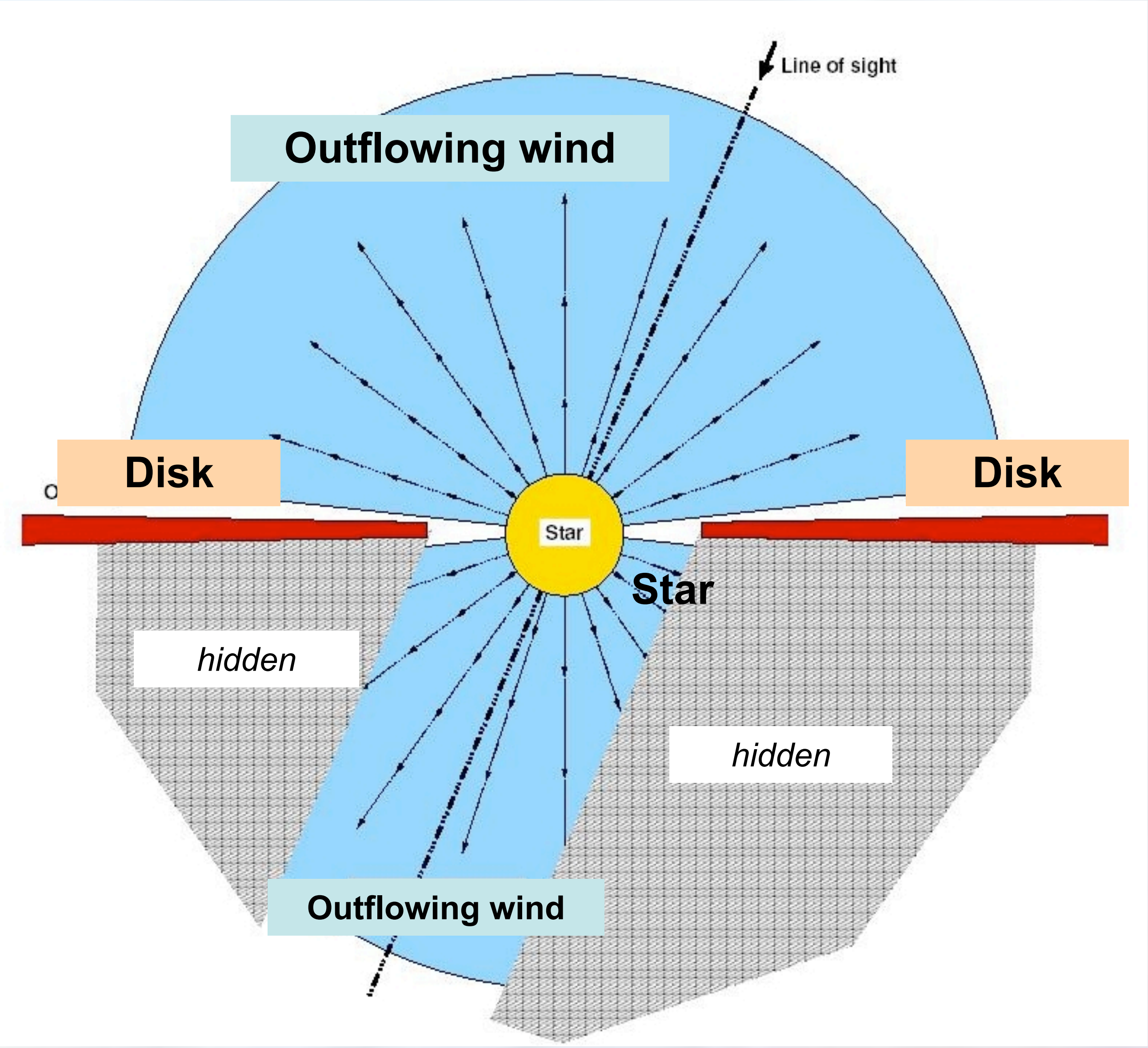

Malbet et al. (2007, A&A 464, 43)

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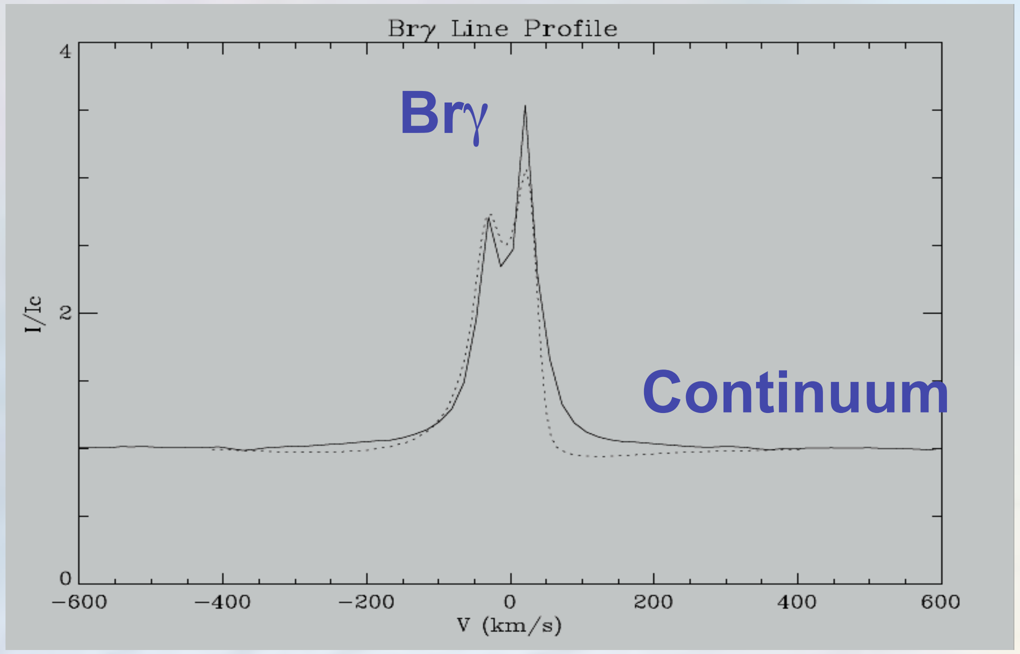
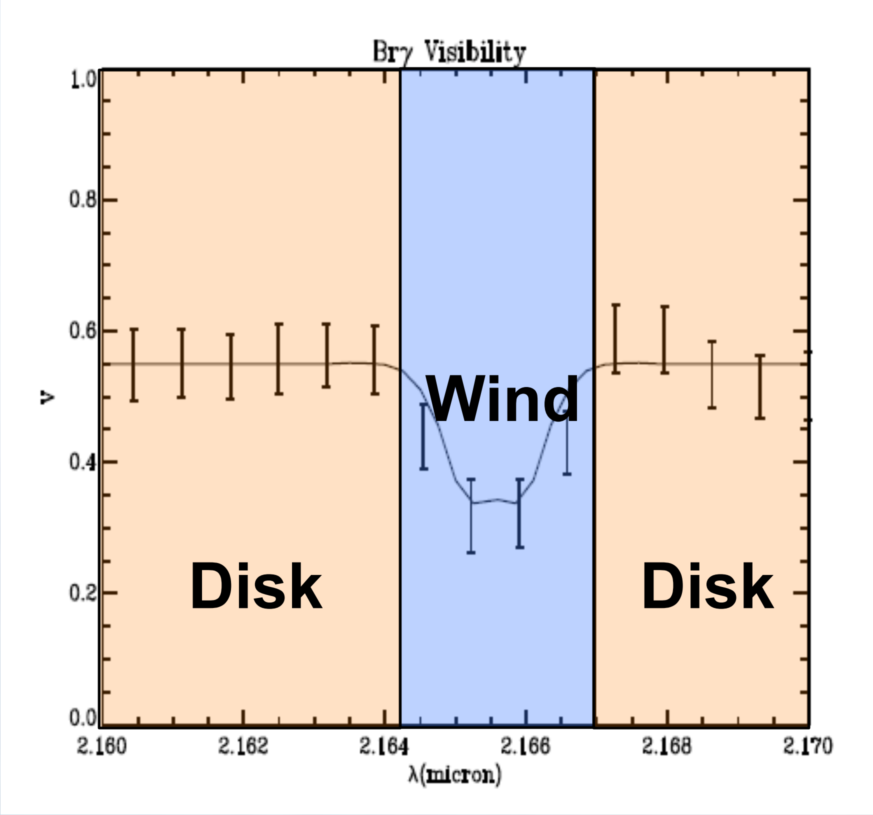
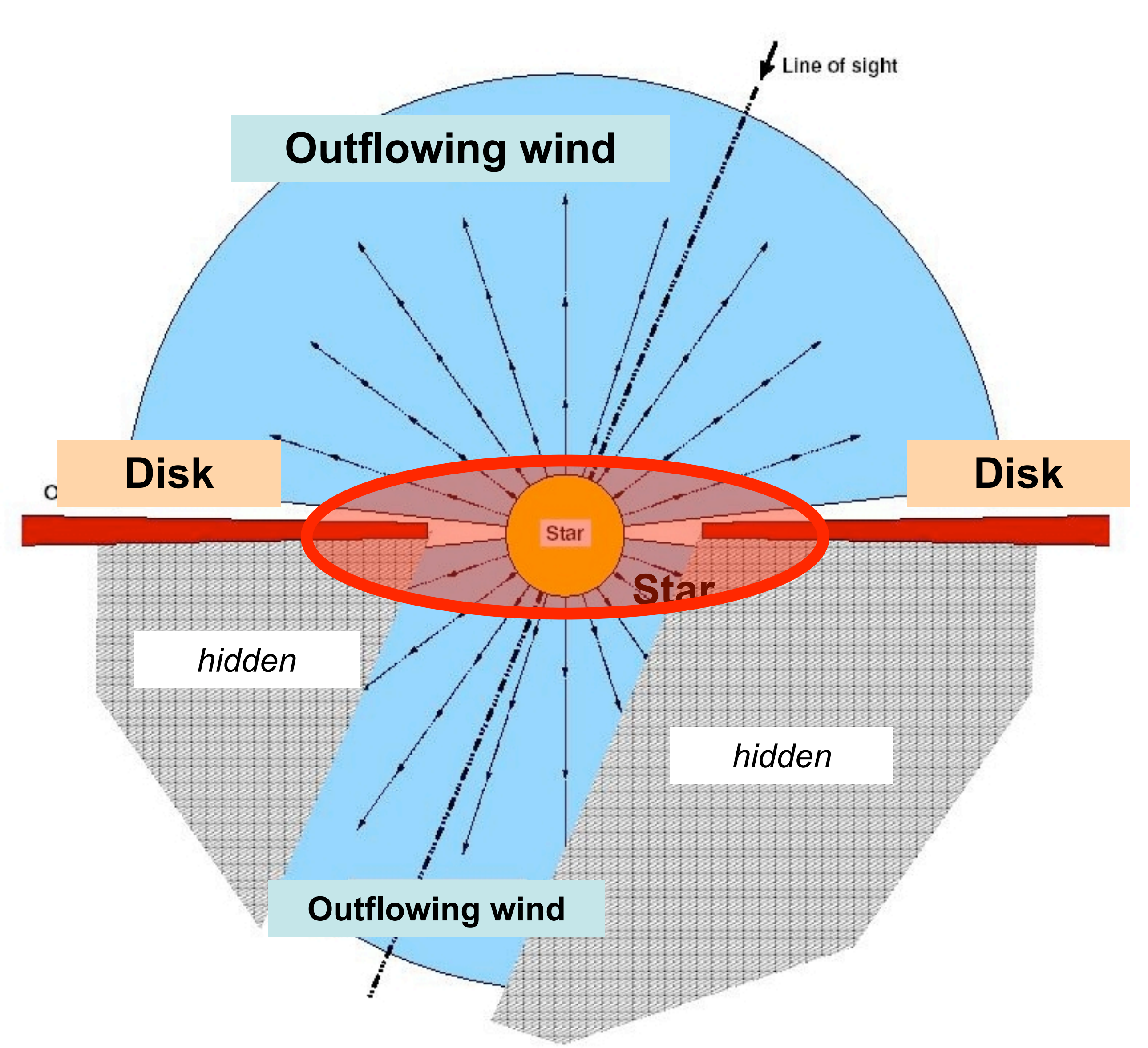


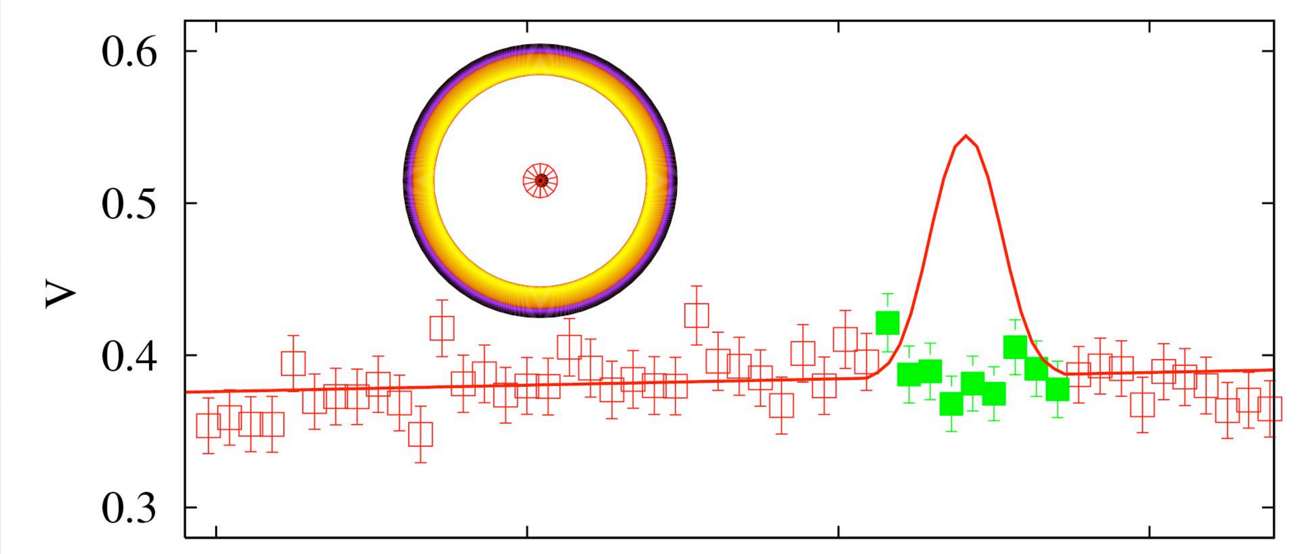




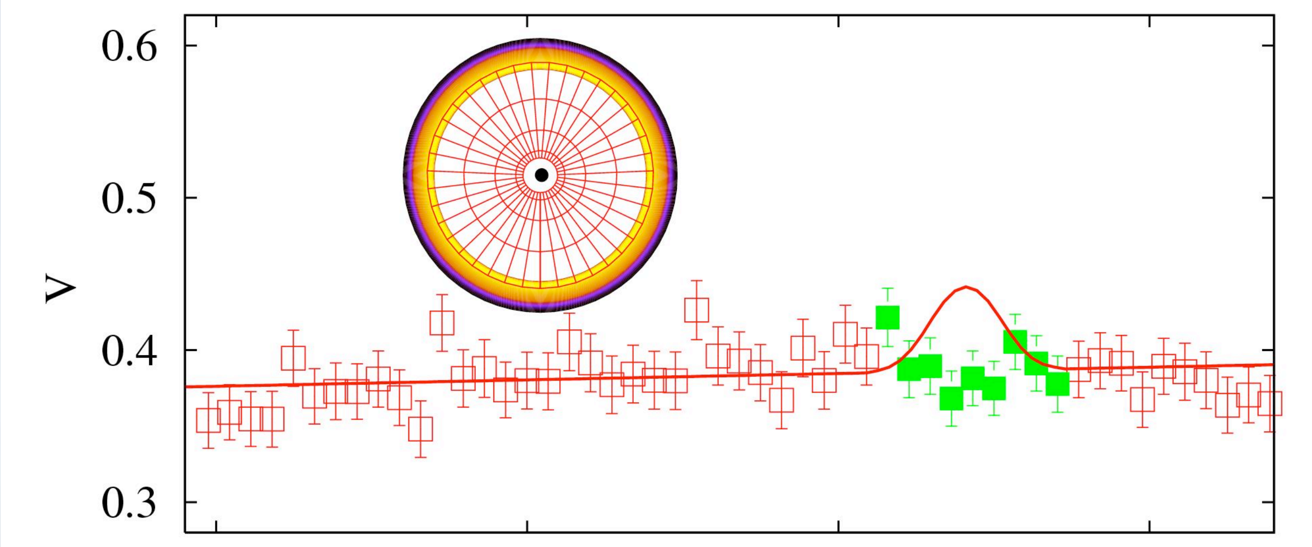
Malbet et al. (2007, A&A 464, 43)

→ Investigate the link between disk, star and wind

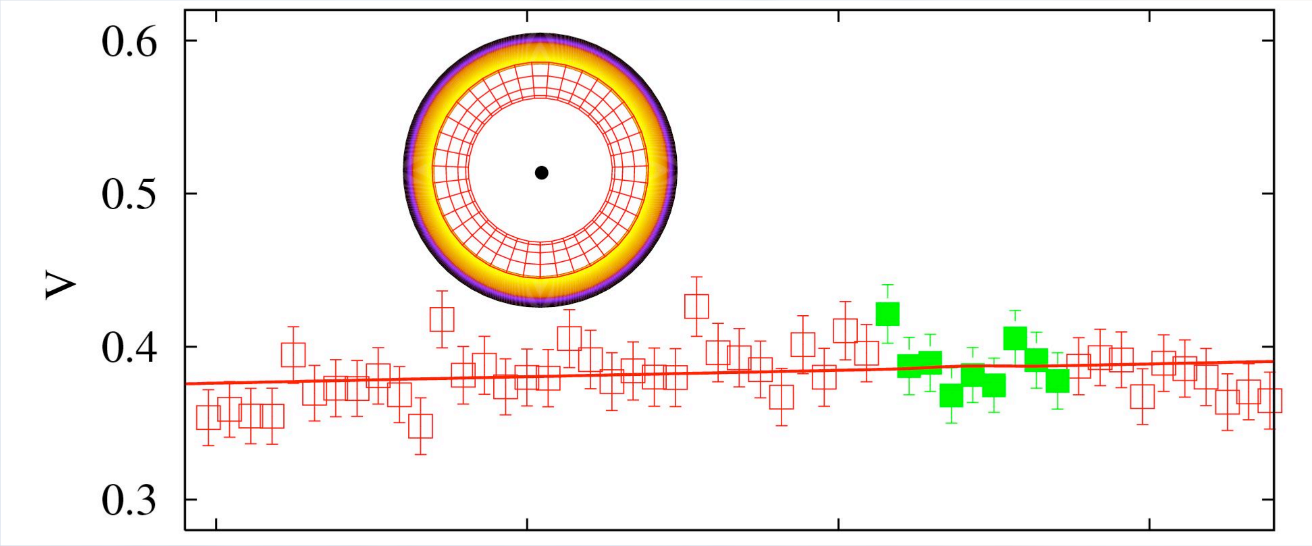
Nature of Brγ in the HAe star HD104237



Disk truncated by magnetosphere



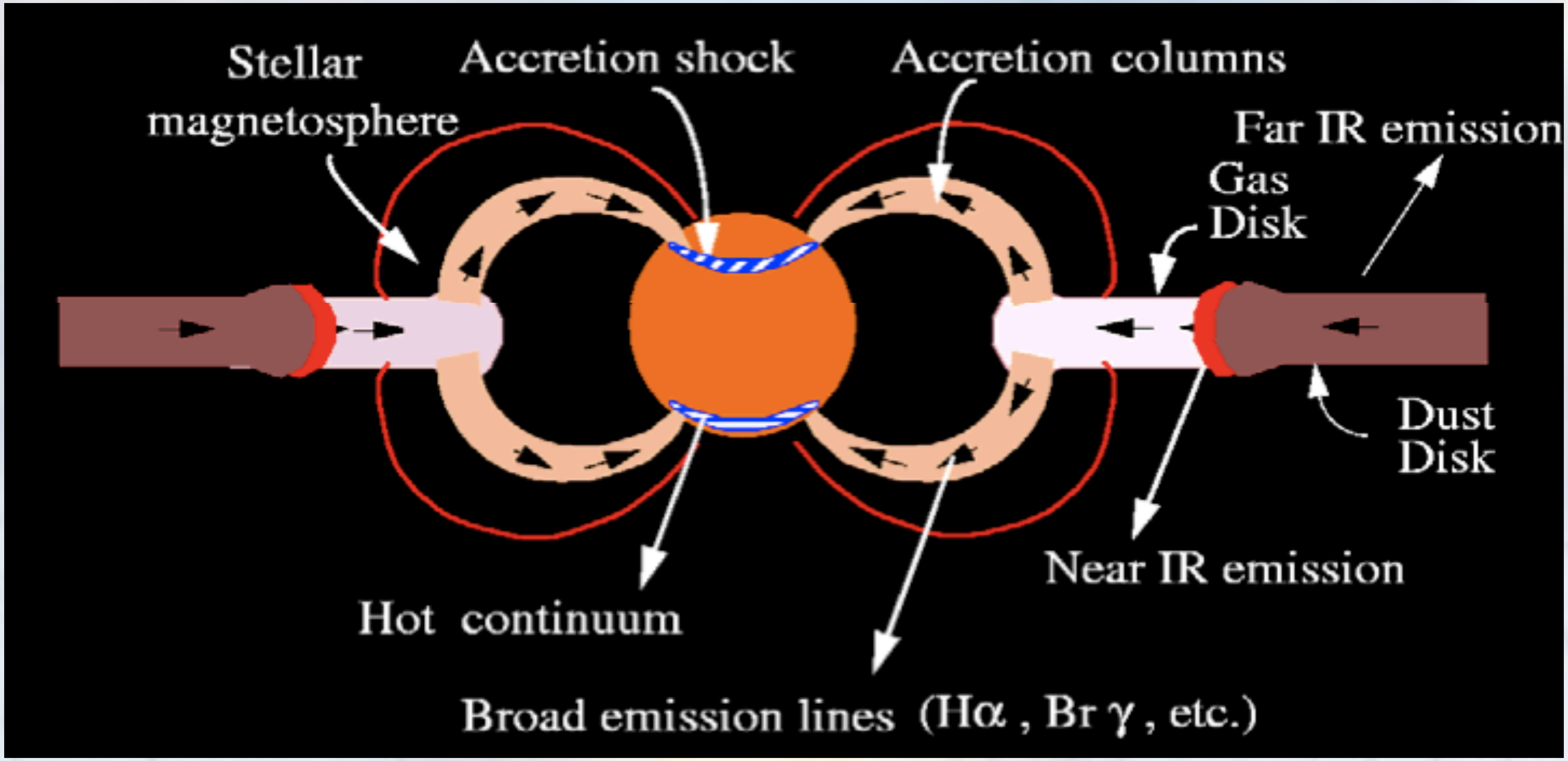
Gas within the disk

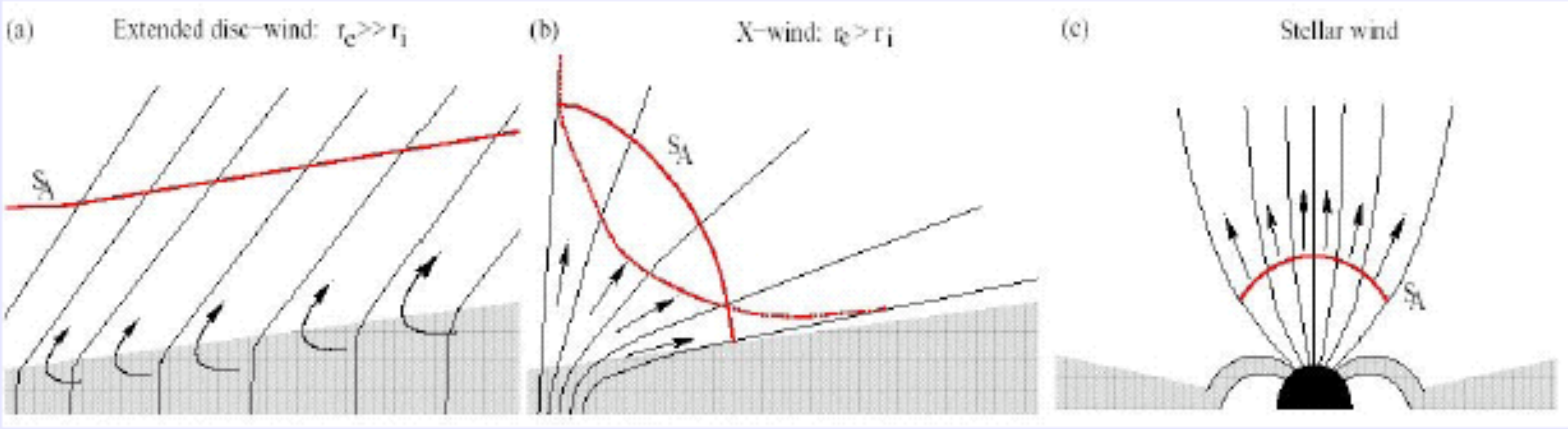


Outflowing wind

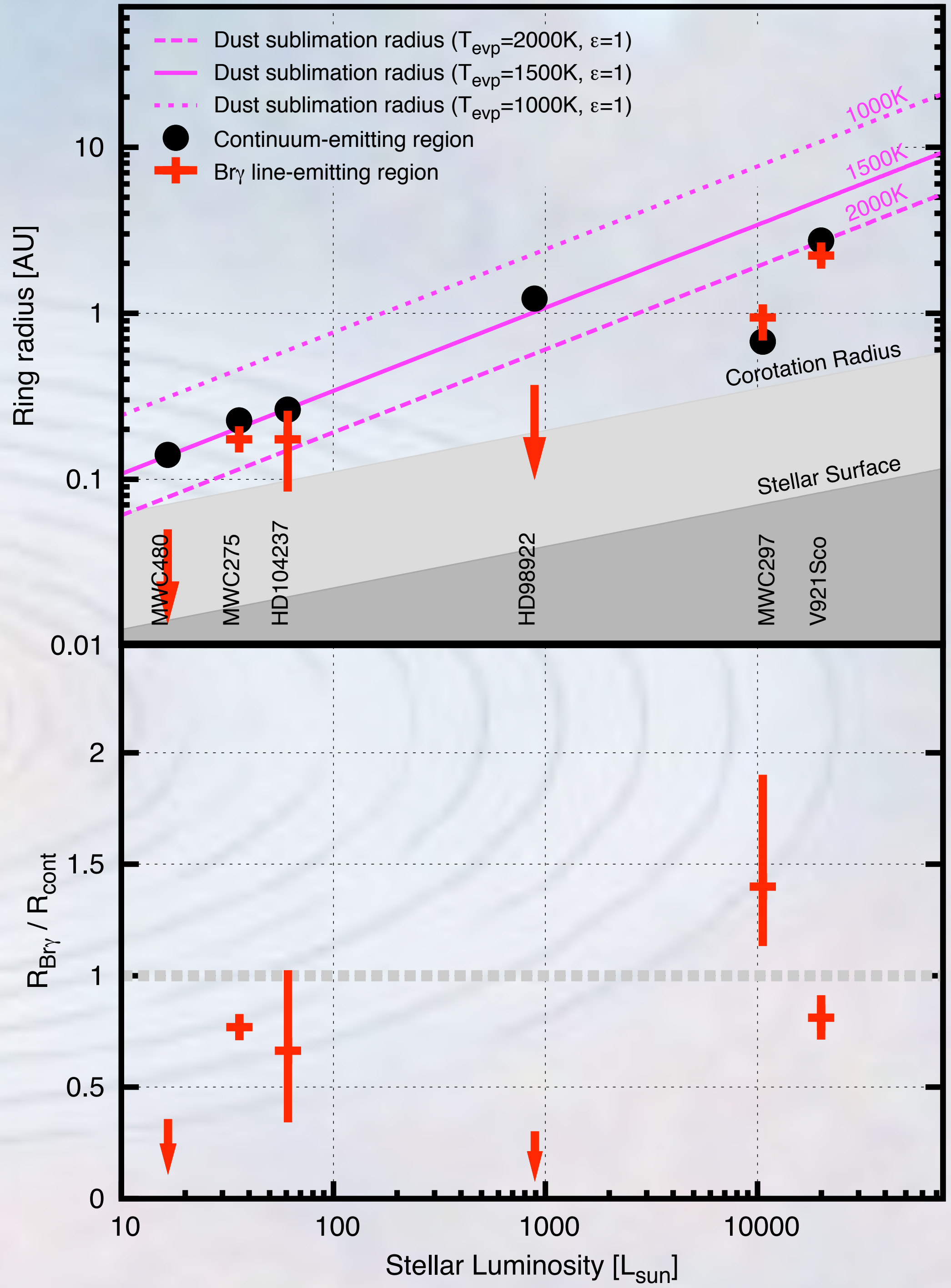
Tatulli et al. (2007, A&A 464, 55)

Disk/star interaction ?





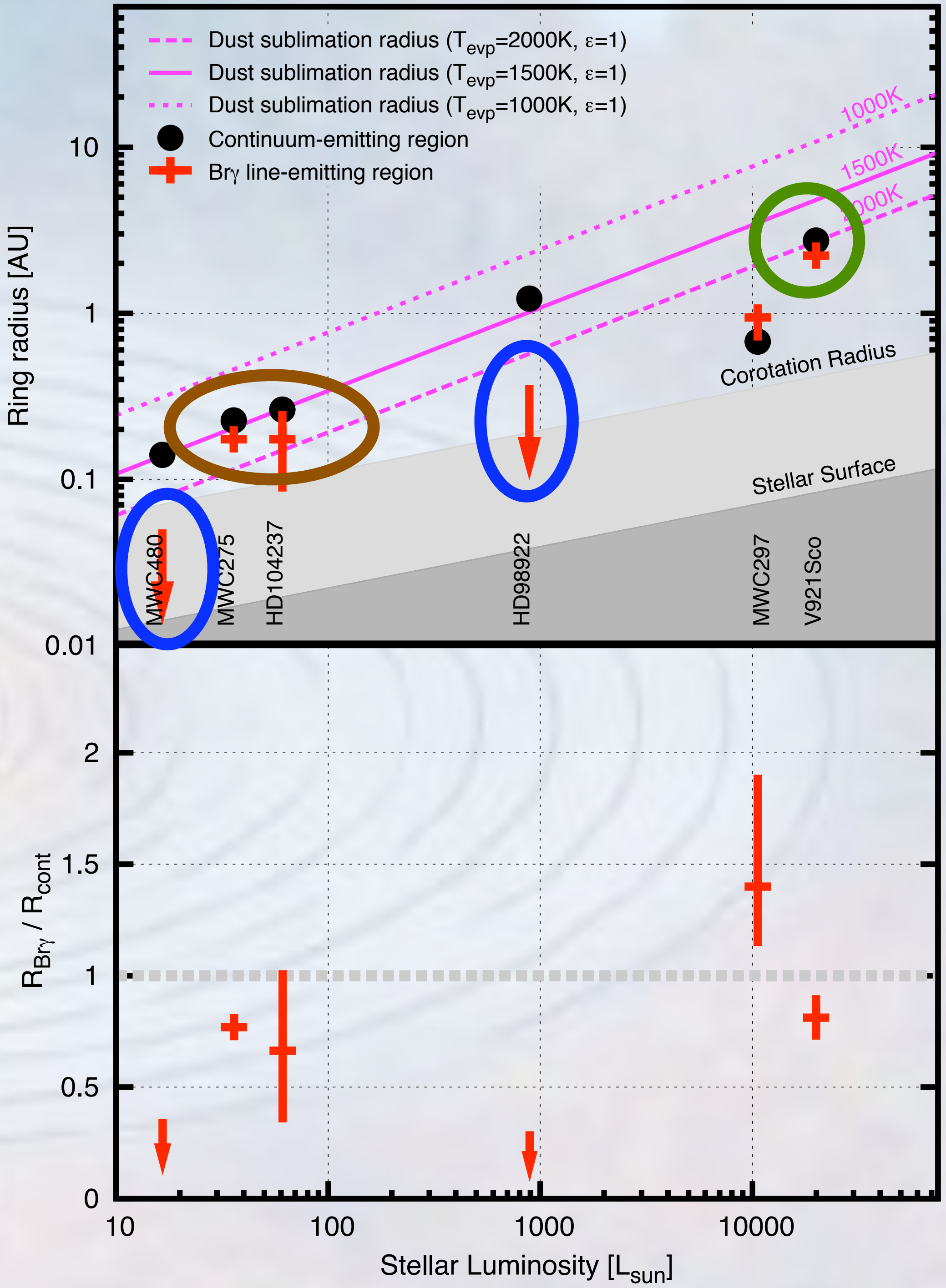
A systematic study of the origin of the BrϒY emission in Herbig Ae/Be stars



Kraus et al. (2008, A&A in press)

A systematic study of the origin of the Brϒ emission in Herbig Ae/Be stars

- **magnetospheric accretion**
- **disk wind**
- **X-wind or disk wind ?**



Kraus et al. (2008, A&A in press)

A systematic study of the origin of the Brϒ emission in Herbig Ae/Be stars

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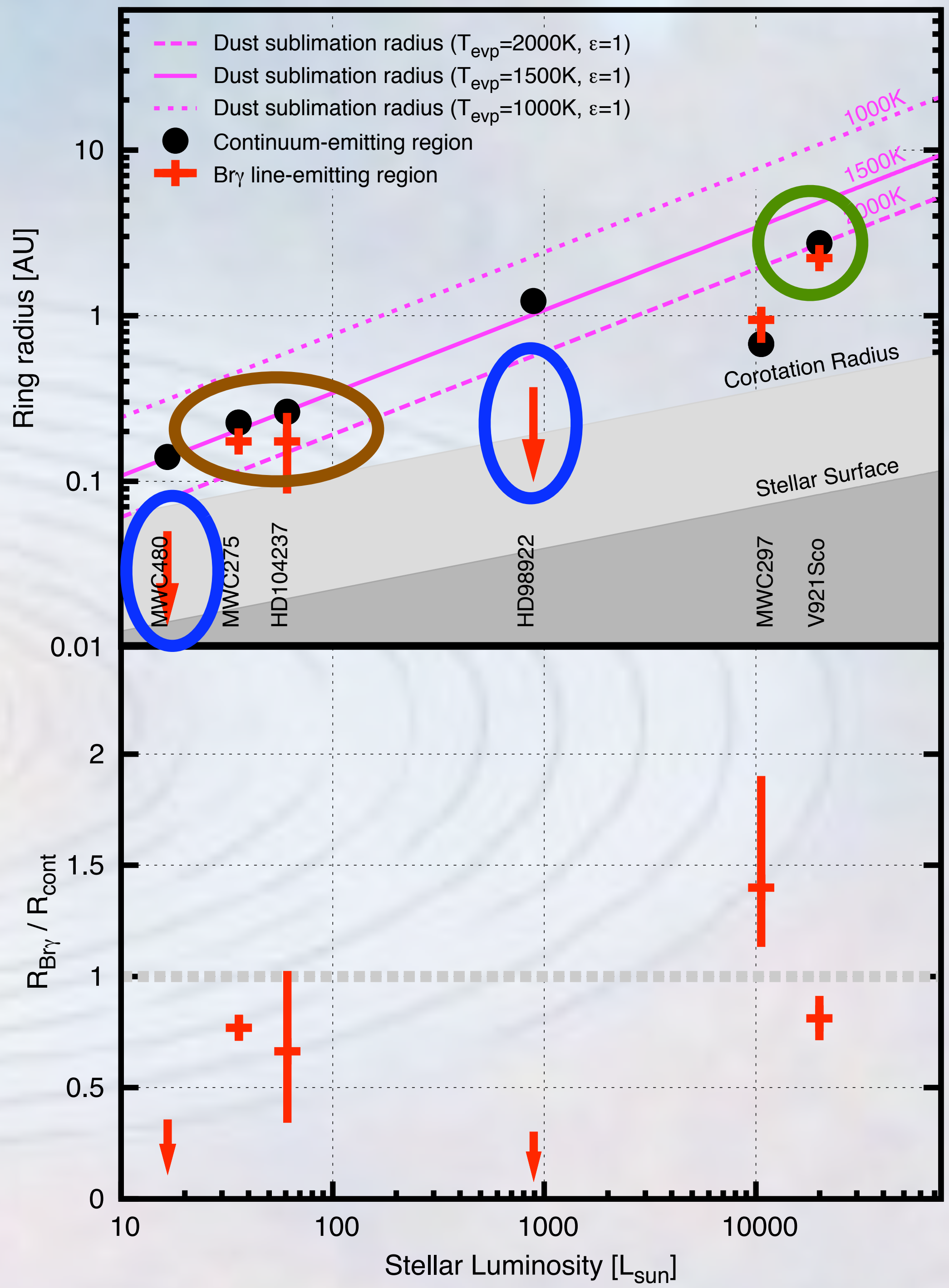
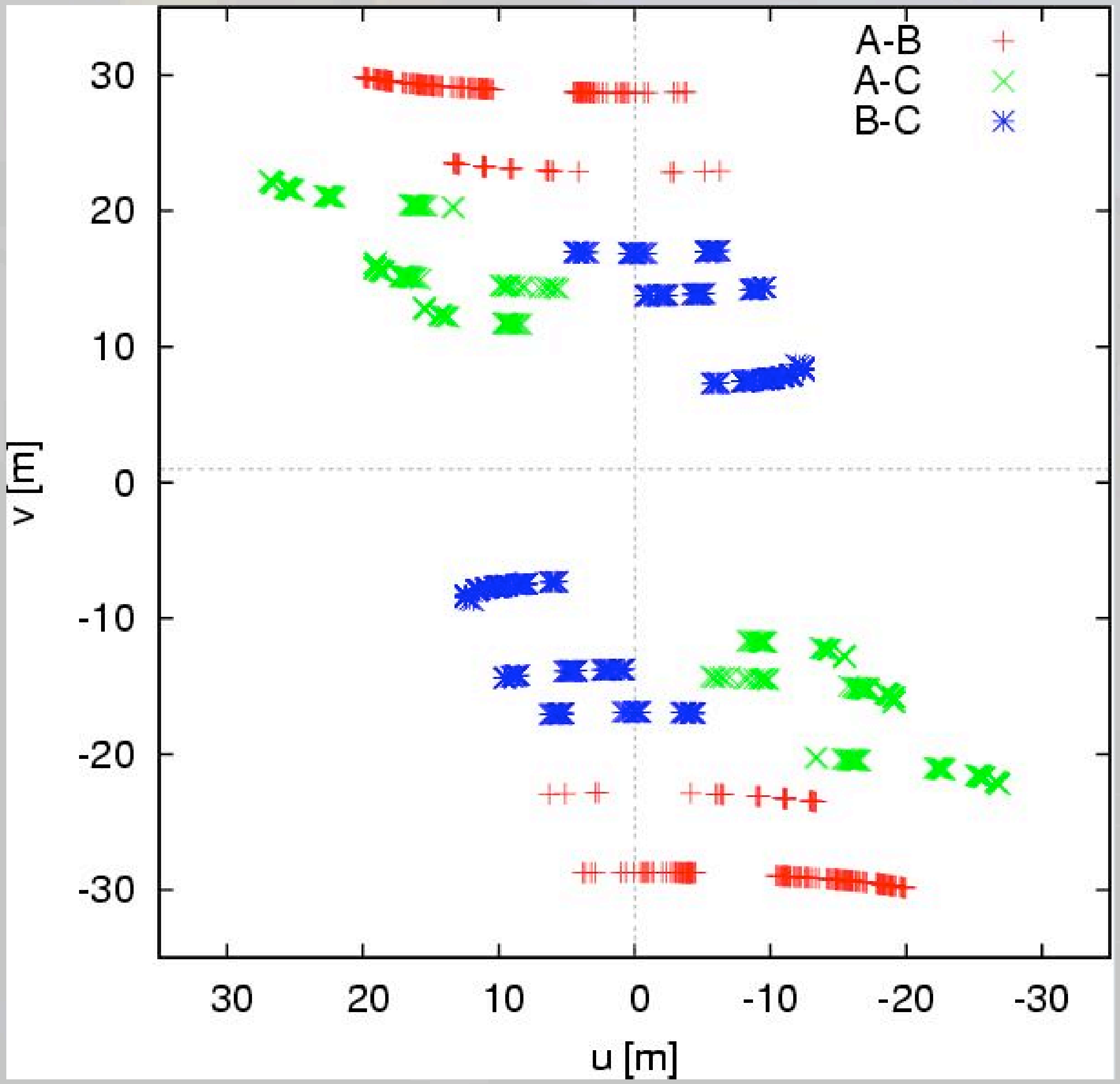


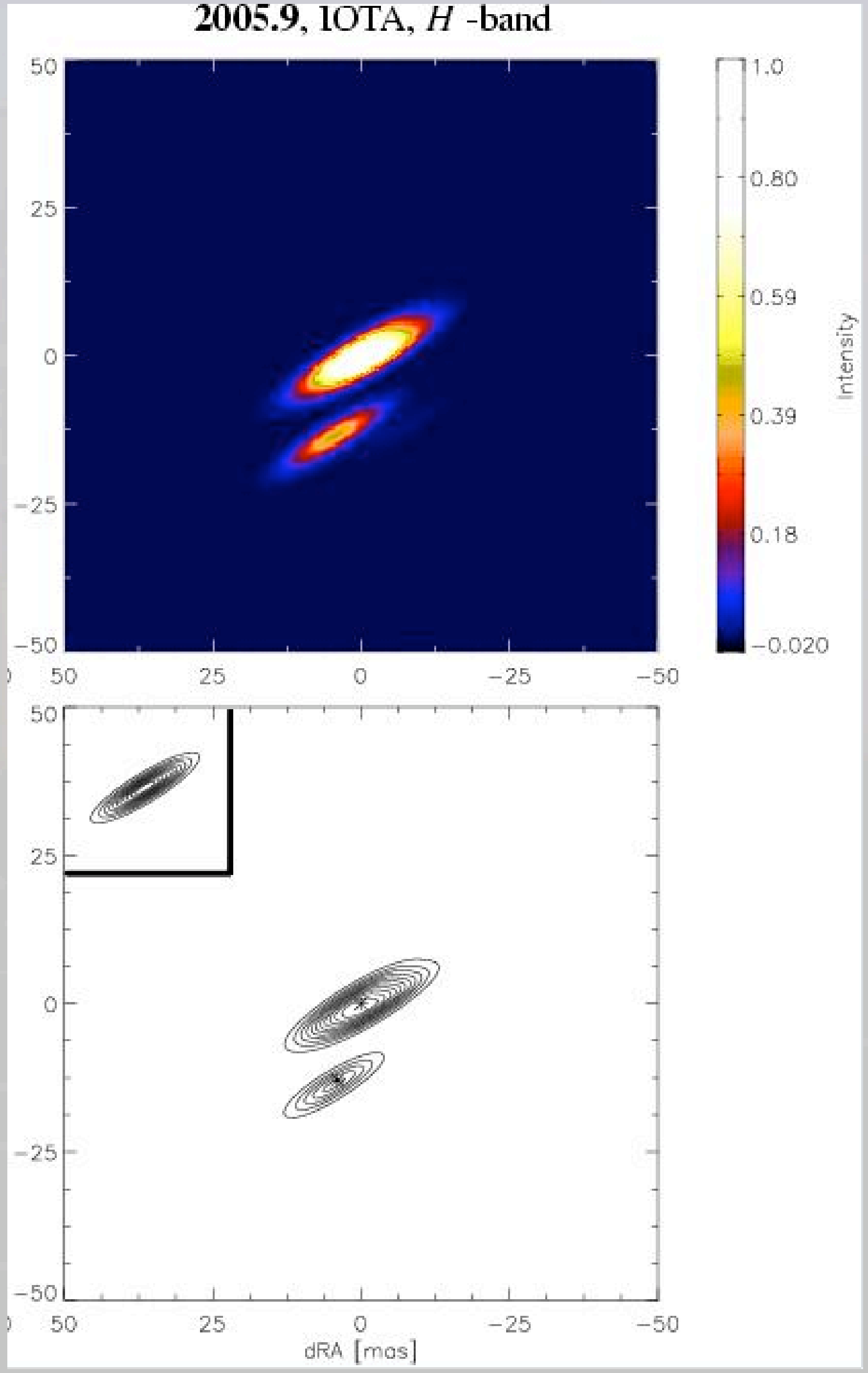
Kraus et al. (2008, A&A in press)

➡ No correlation with L_* as suggested by Eisner et al. 2007

➡ We are probing mostly outflows phenomena:
Brγ indirect accretion tracer through accretion-driven mass loss?

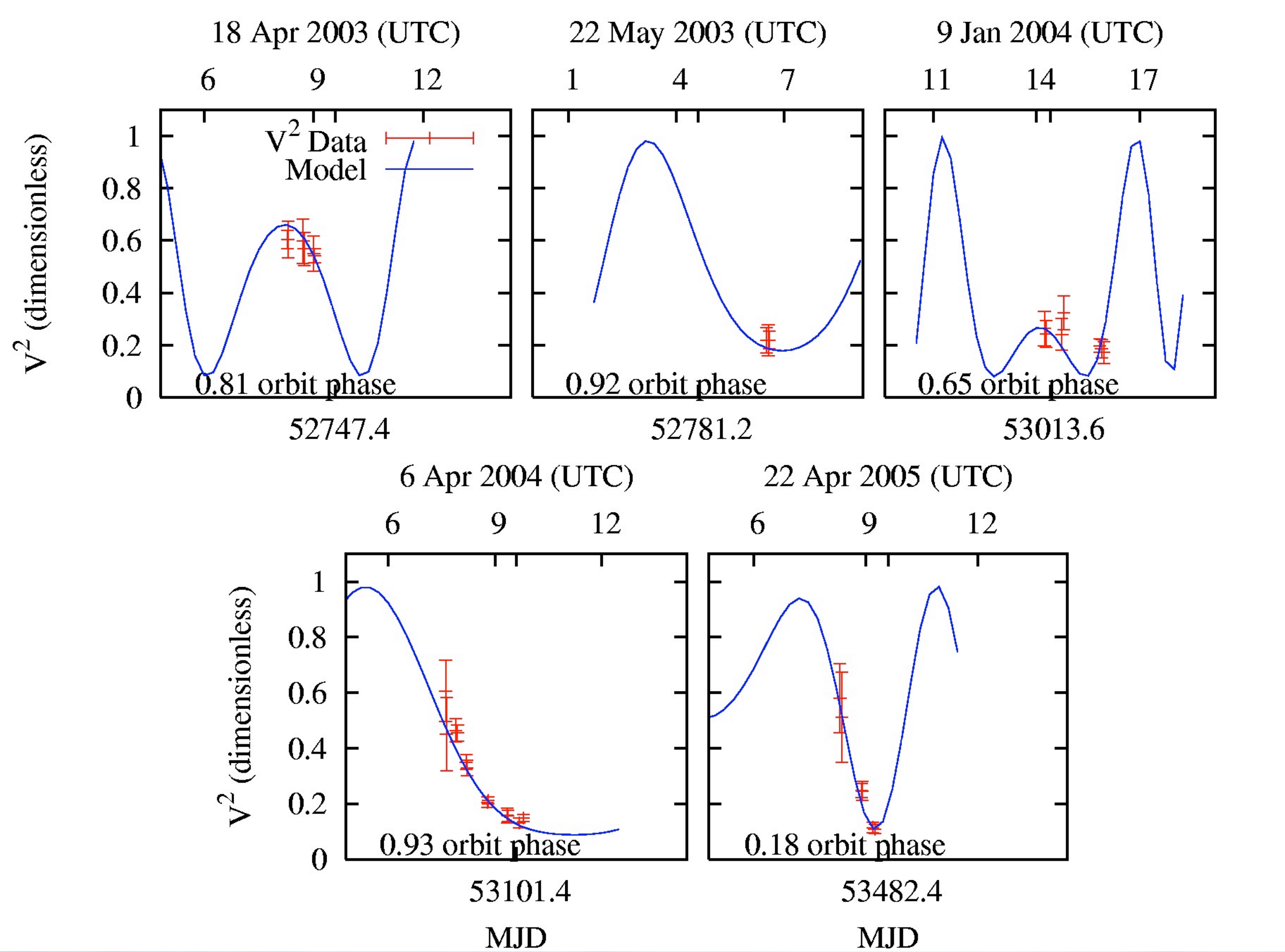
Aperture synthesis imaging of the θ^1 Orionis C system with IOTA

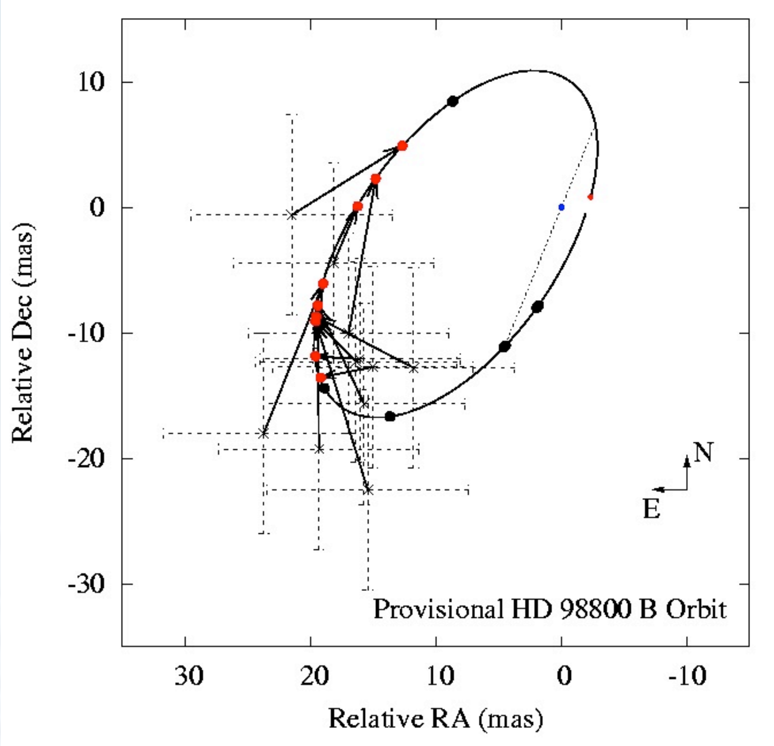


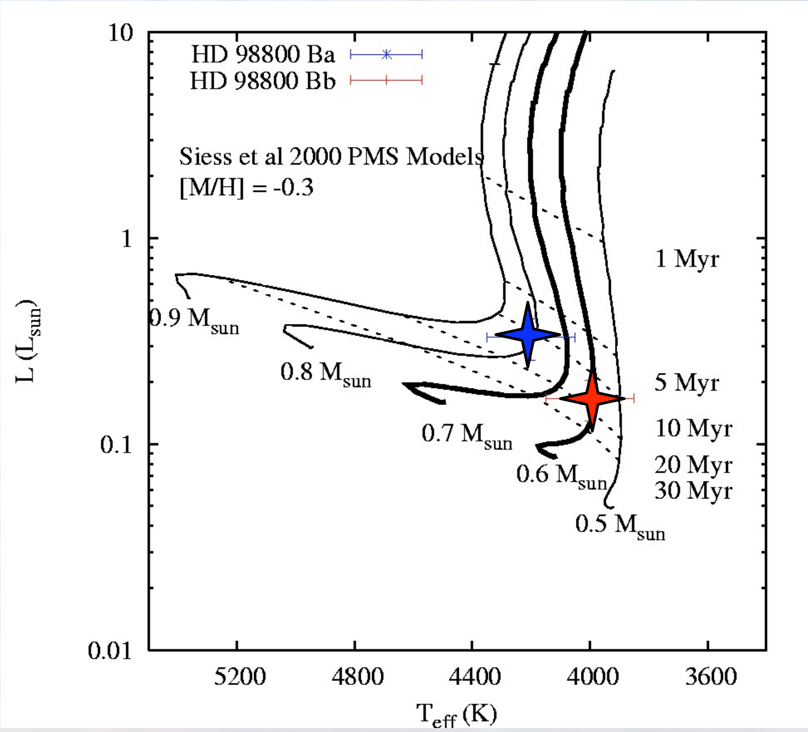


Kraus et al. (2007, A&A 466, 649)

HD 98800B: orbit and masses



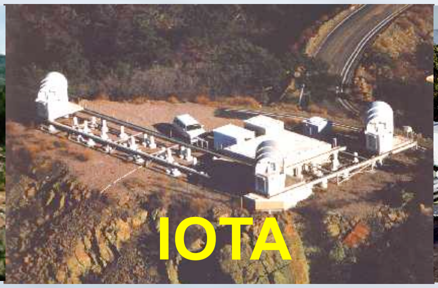


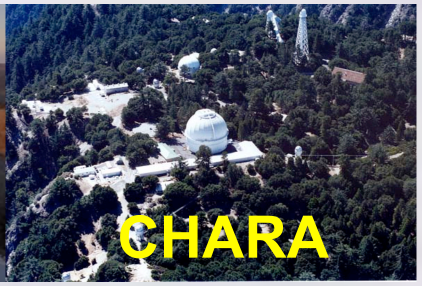


Boden et al. (2005, ApJ 635, 442)

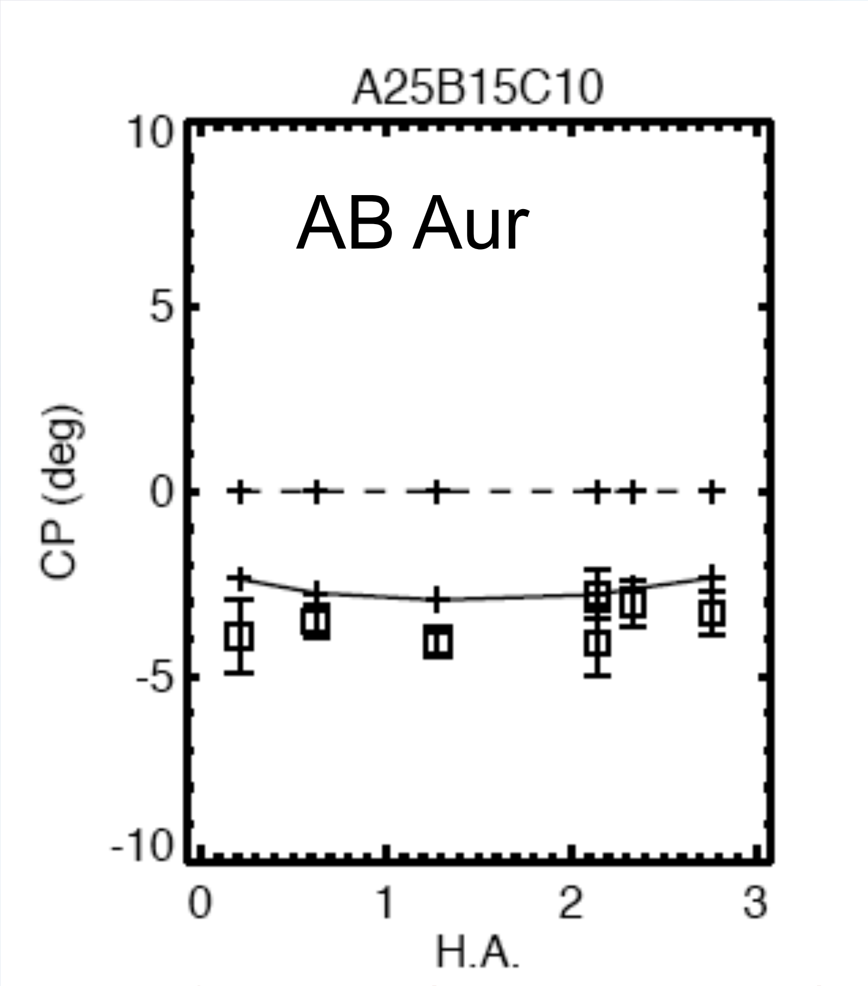
+ radial velocities

FUTURE PROSPECTS

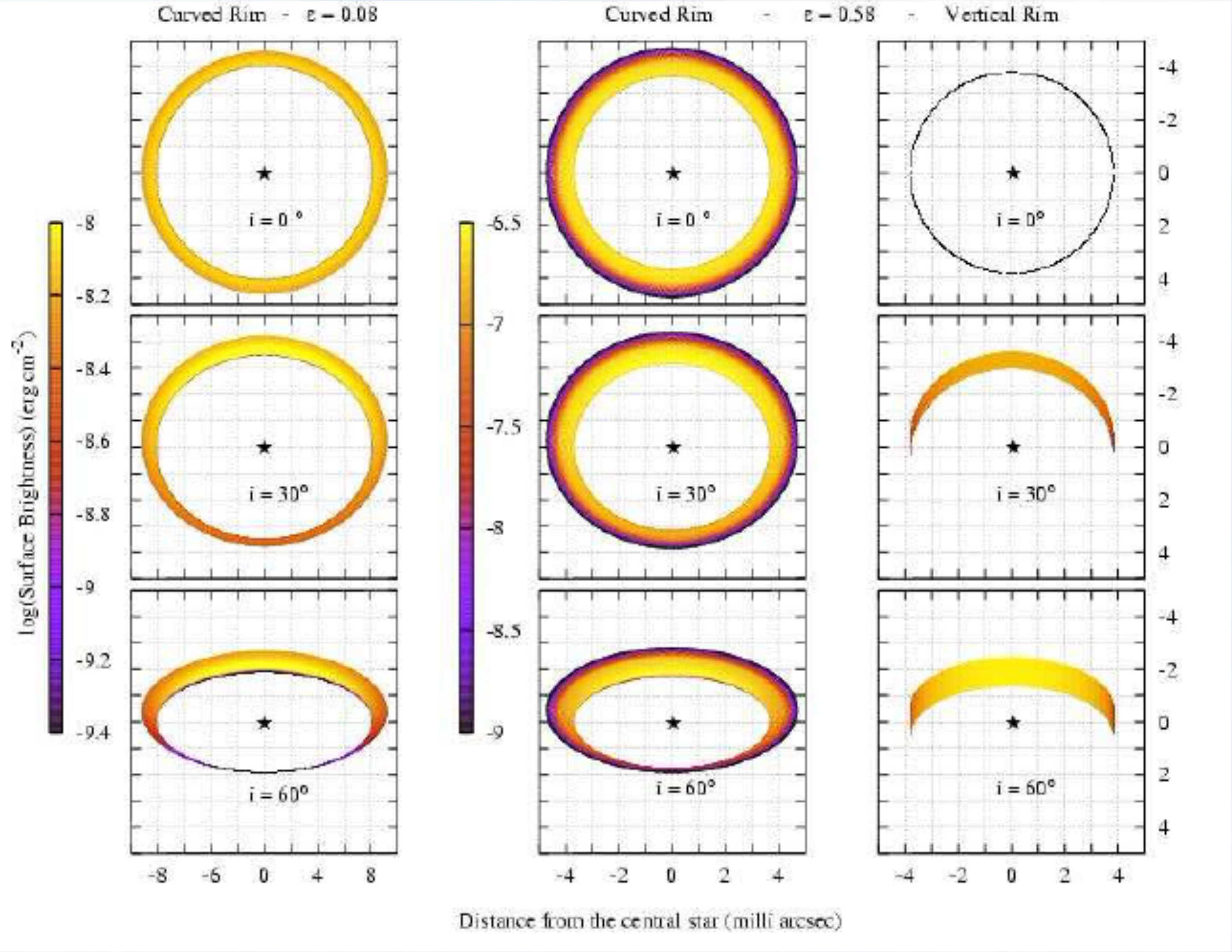




First steps to imaging



Millan-Gabet et al. (2006, ApJ 645, L77)

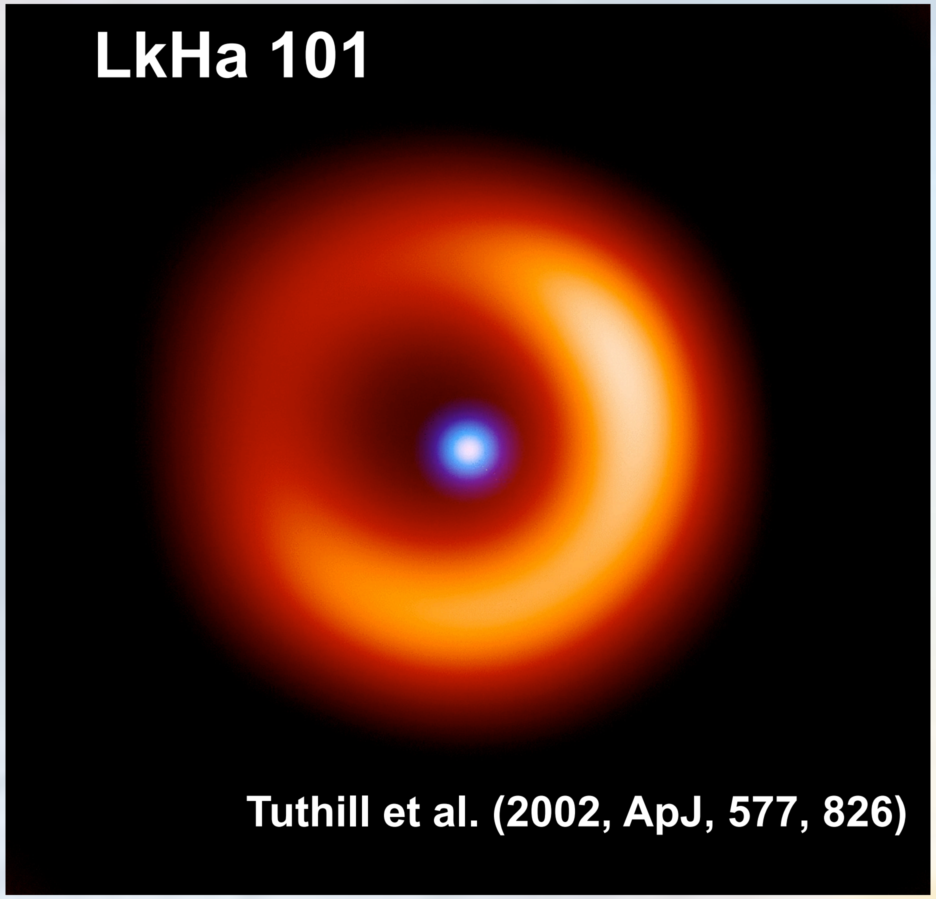


Isella & Natta (2005, A&A 438, 899)

Closure phase provides information on departure from centro-symmetry

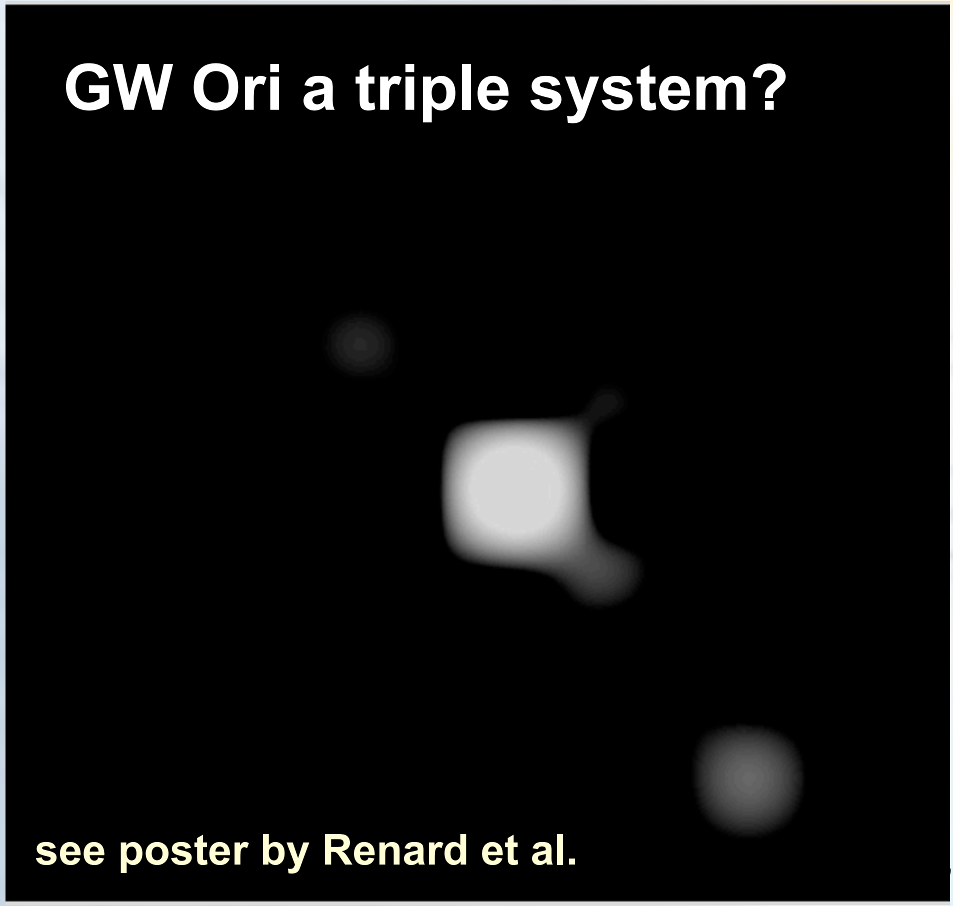
Imaging

Actual Imaging Data



LkHa 101

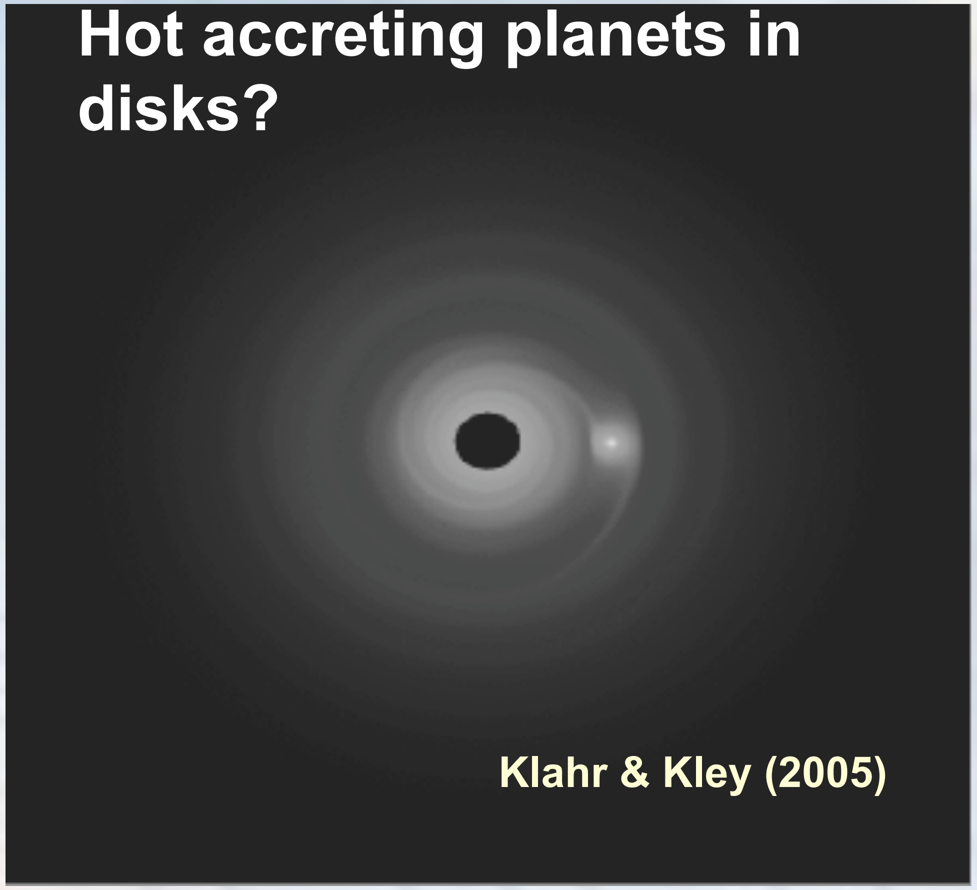
Tuthill et al. (2002, ApJ, 577, 826)



GW Ori a triple system?

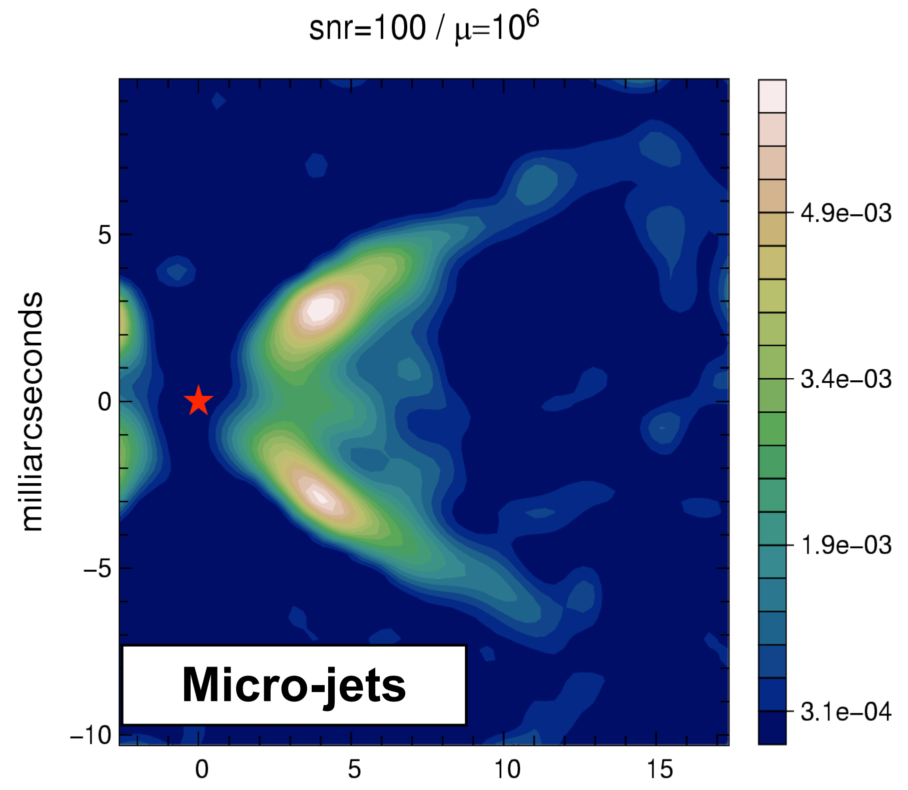
see poster by Renard et al.

Image simulations



Hot accreting planets in disks?

Klahr & Kley (2005)



Thiébaut et al. (2005, Ap&SS, 286, 171)

Conclusion

- A **major leap** in less than 10 years:
  - –76 objects observed so far,
  - –38 refereed papers (mainly with **one baseline broad-band** observations, but it is changing).
  - –new types of observations with **spectral resolution, closure phases, imaging**
- Observations are **mature enough** to allow **detailed modeling**.

Open issues in YSO physics

- NIR emitting zone larger than corotation / magnetospheric radii .

  What implications for disk/star connection?

- Which implications do these measurements have for the **initial conditions of planetary formation?**

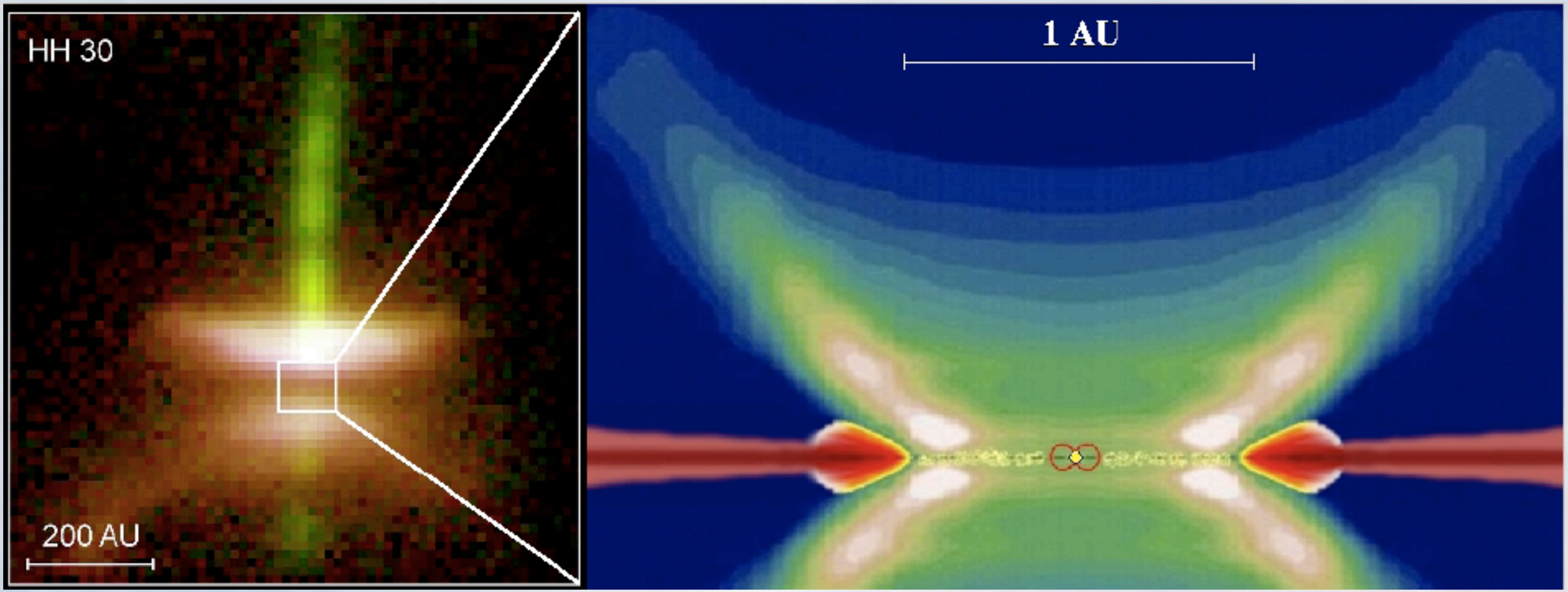
- Need to combine **NIR+MIR** to secure the disk structure.

- Can we apply this technique to **gas disk** ?

- Origin of the **BrY emission** ?

- Companions, formation of planets

A tool to study the inner regions of Young Stellar Objects



From Isella et al. (2007)