Interferometry and its applications to the study of PMS stars

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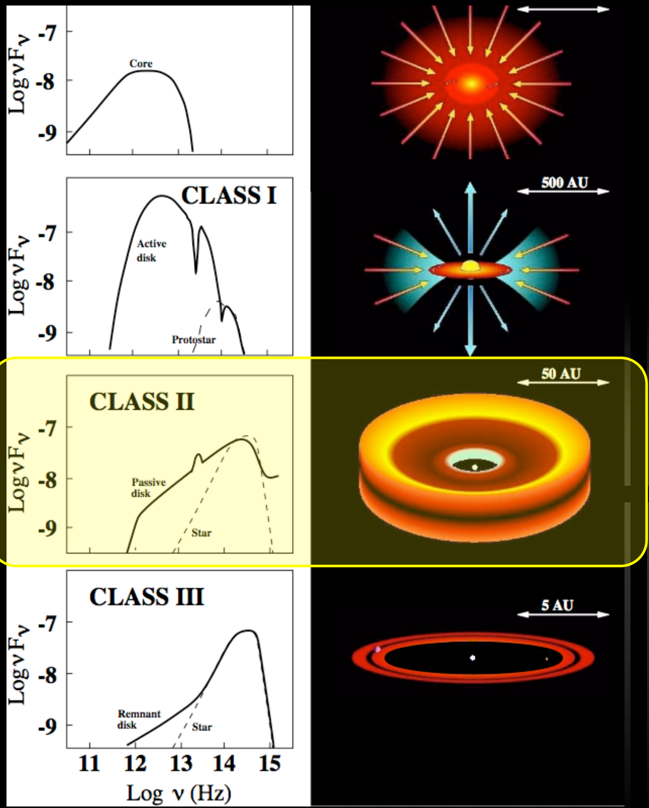
Outline

- ✓ Introduction
  - ✓ Scientific context: star formation
- ✓ Principles of Interferometry
  - ✓ Why use interferometry
  - ✓ What can we observe
  - ✓ Interferometry with the VLTI
- ✓ Interferometric observations of 51 Oph with MIDI
  - ✓ Observing with MIDI
  - ✓ Constraining the 51 Oph circumstellar disk
- ✓ Conclusions and Perspectives

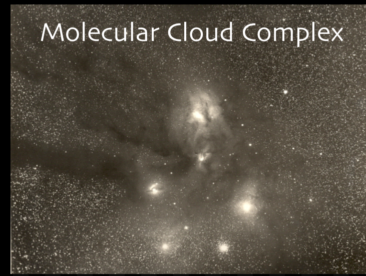
Star Formation



Lada & Wilking (1984), Andre et al. (1993)

Molecular Cloud

H + He
10 - 70 K
100 pc
10^4 - 10^5 $M_\odot$



Prestellar Fragments

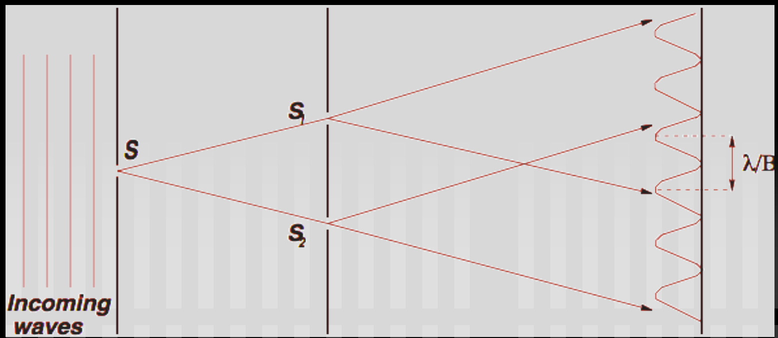
Cloud collapse when the self-gravitation overruns the cloud pressure

Stars

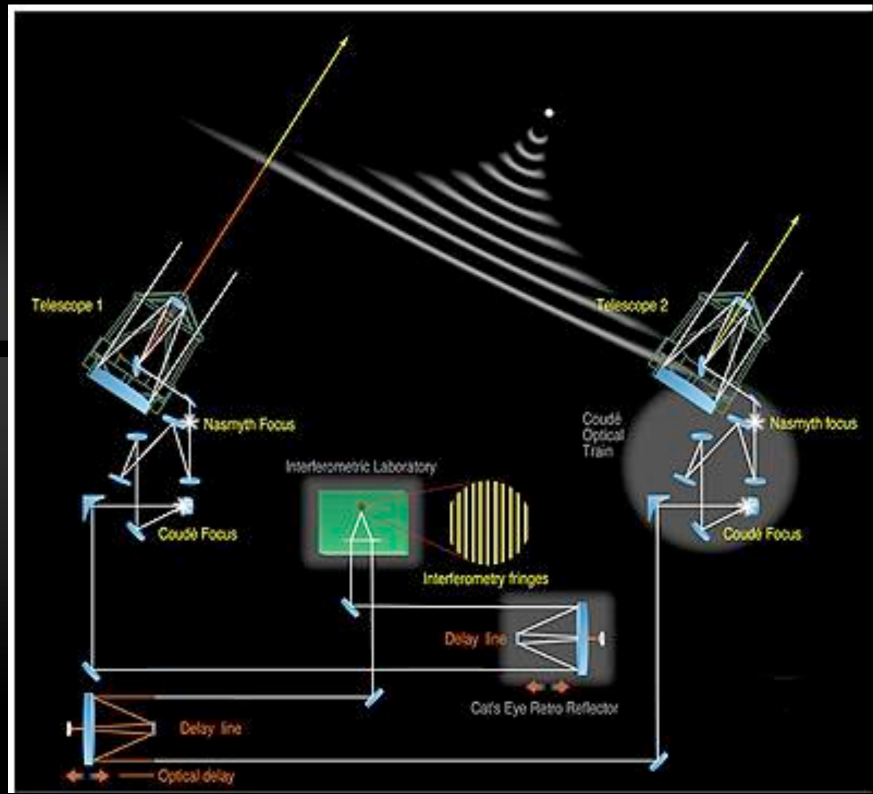
- ✓ Do star formation theory for isolated stars applies for stars in clusters?
- ✓ Are spectral energy distribution measurements enough to constrain models?
- ✓ Is this theory valid for high mass stars?

Need High Angular Resolution

Principles of Interferometry



Young's experiment



Visibility = FT (Source Brightness Distribution)

Van Cittert - Zernike theorem

Resolution = λ/B

Principles of Interferometry

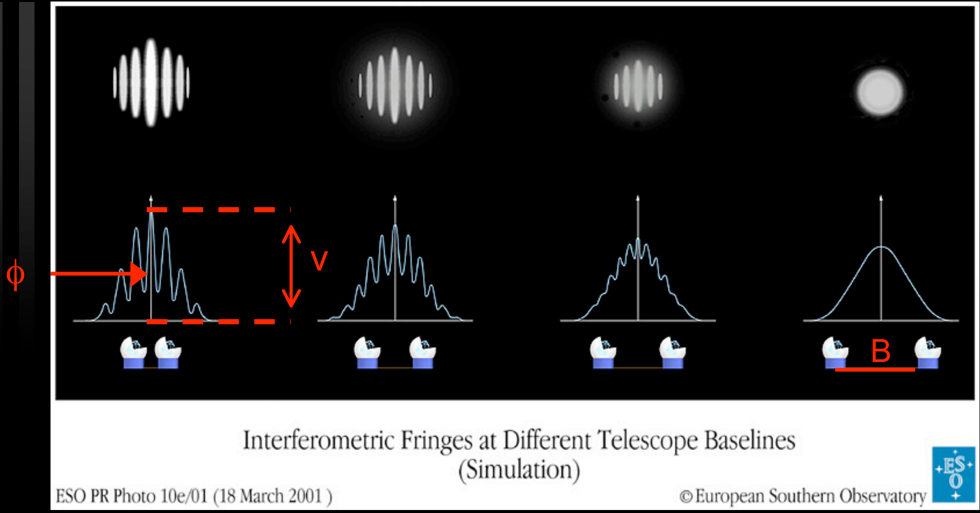
Visibility is related to the object spatial shape.

$$Visibility = ve^{\phi}$$

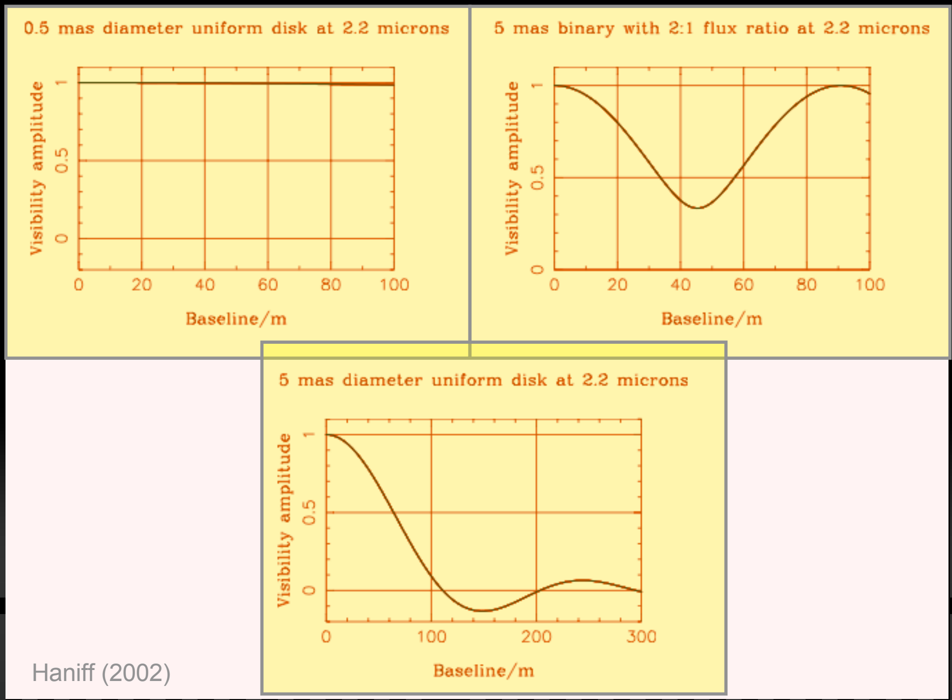
Resolved vs. Partially Resolved

1 AU => 7 mas at the distance of the nearest regions of star formation

Resolution ~ 3 mas in the NIR
(B = 100 m)



Interferometric Fringes at Different Telescope Baselines (Simulation)



Haniff (2002)

- The van Cittert-Zernike theorem gives the relation between the coherence function and the source brightness distribution.
- For an incoherent and quasi-monochromatic source the complex degree of coherence is equal to the normalized Fourier transform of the brightness distribution.

$$I(\alpha,\beta) = \begin{cases} 4/(\pi\theta^2) & \rho \le \theta/2 \end{cases}$$

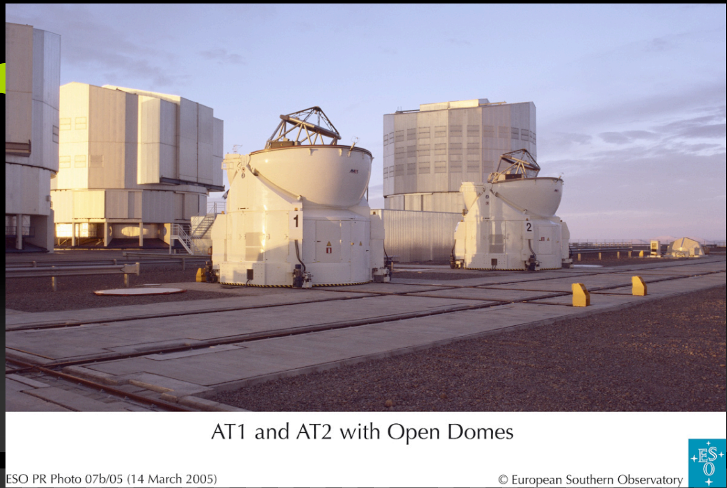
$$- \beta_0)$$

$$I(\alpha,\beta) = F_1\delta(\alpha - \alpha_1, \beta - \beta_1) + F_2\delta(\alpha - \alpha_2, \beta - \beta_2)$$

$$V(u,v) = F_1 \exp(2\pi i(u\alpha_1 + v\beta_1)) + F_2 \exp(2\pi i(u\alpha_2 + v\beta_2))$$

$$V(u,v) = 2\frac{J_1(\pi\theta r)}{\pi\theta r}$$

Interferometry at the VLTI

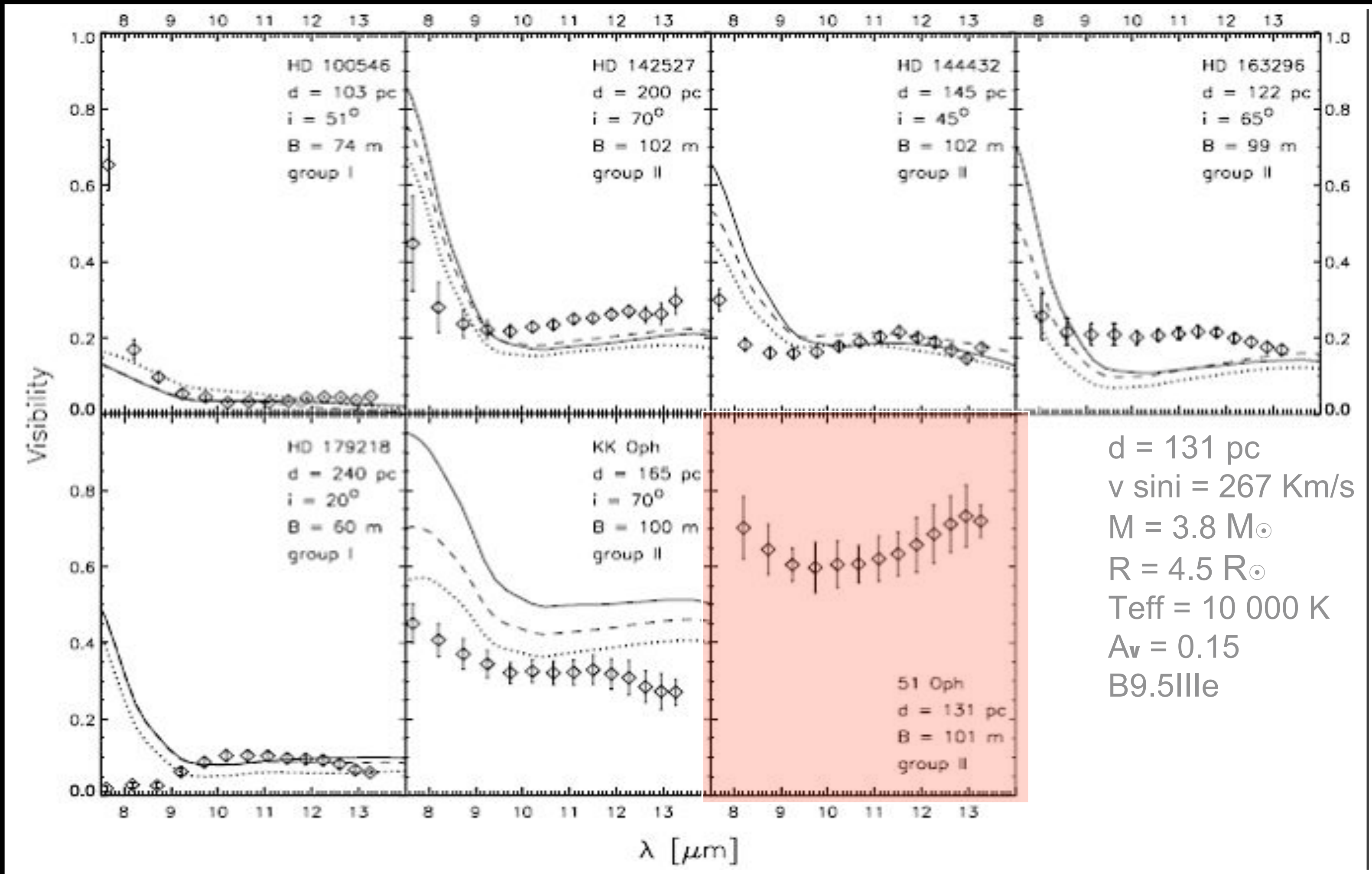


AT1 and AT2 with Open Domes

ESO PR Photo 07b/05 (14 March 2005) © European Southern Observatory

- 4 UTs of 8.2 m
- 4 ATs of 1.8 m
- Baselines 8-200 m
- Resolution 1-20 mas

MIDI SDT: Sizes of disks around Herbig Ae/Be stars



Observing 51 Oph with MIDI

UT Date	Projected Baseline (m)	Position Angle (deg.)	Calibrators
15/Jun/03	101.2	23	HD 168454, HD 168454, HD 167618
15/Jun/03	101.4	38	HD 168454, HD 168454, HD 167618
15/Jun/03	85.6	45	HD 168454, HD 168454, HD 167618
16/Jun/03	98.8	-7	HD 165135, HD 152786, HD 165135
16/Jun/03	99.6	14	HD 165135, HD 152786, HD 165135

- ✓ 51 Oph was observed in SDT, 2003
- ✓ UT1-UT3 = 102 m
- ✓ Maximum Full Spatial Resolution = 20 mas
- ✓ Spectral Resolution = 30
- ✓ Good uv coverage (-7 to 45º)

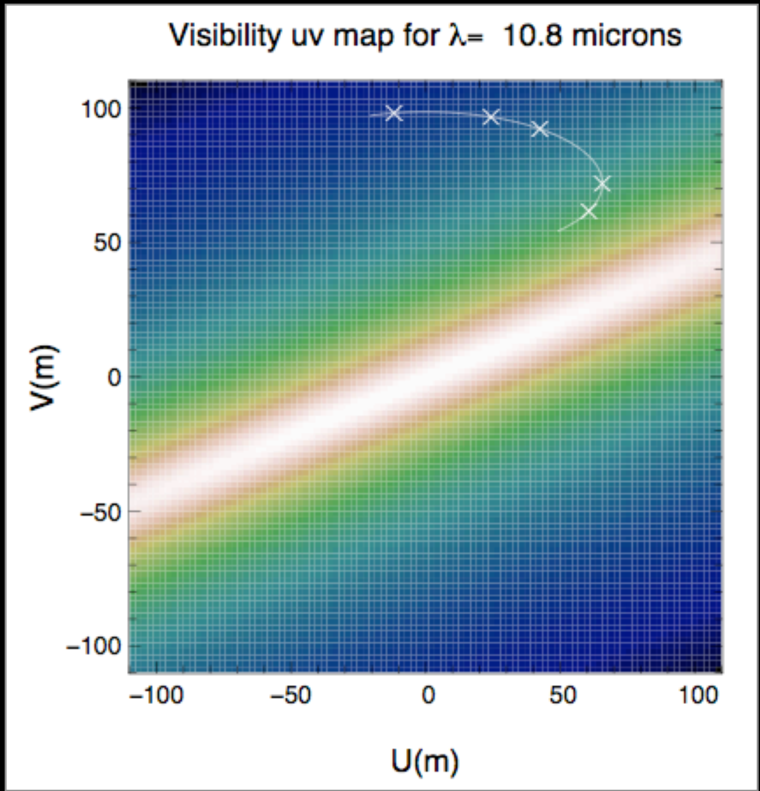
Observing 51 Oph with MIDI

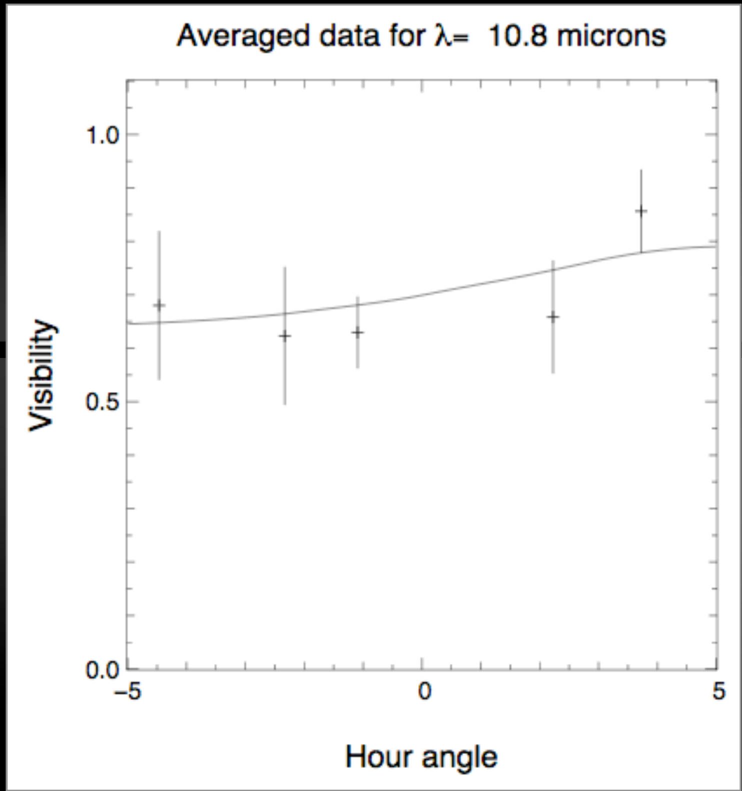
d = 131 pc
v sini = 267 Km/s
M = 3.8 M8
R = 4.5 R8
Teff = 10 000 K
Av = 0.15
B9.5IIIe

Spectral classification?

- ✓ 10 μm silicate feature (Fajardo-Acosta et al. 1993) .
- ✓ Variable, accreting gas in the system (Grady and Silvis 1993).
- ✓ Not resolved with Keck at 18 μm (Jayawardhana et al. 2001) .
- ✓ Composition of the infalling gas highly nonsolar (Roberge et al. 2002)
- ✓ First MIDI observations of Herbig Ae/Be circumstellar disks by Leinert et al. (2004)
- ✓ Disk is essentially warm and small (CO disk: 0.15 to 0.35 AU, inclination~88º, T~2850 K). Thi et al. (2005).
- ✓ Recently, near-IR CO observations support the edge-on disk scenario (Berthoud et al. 2007).

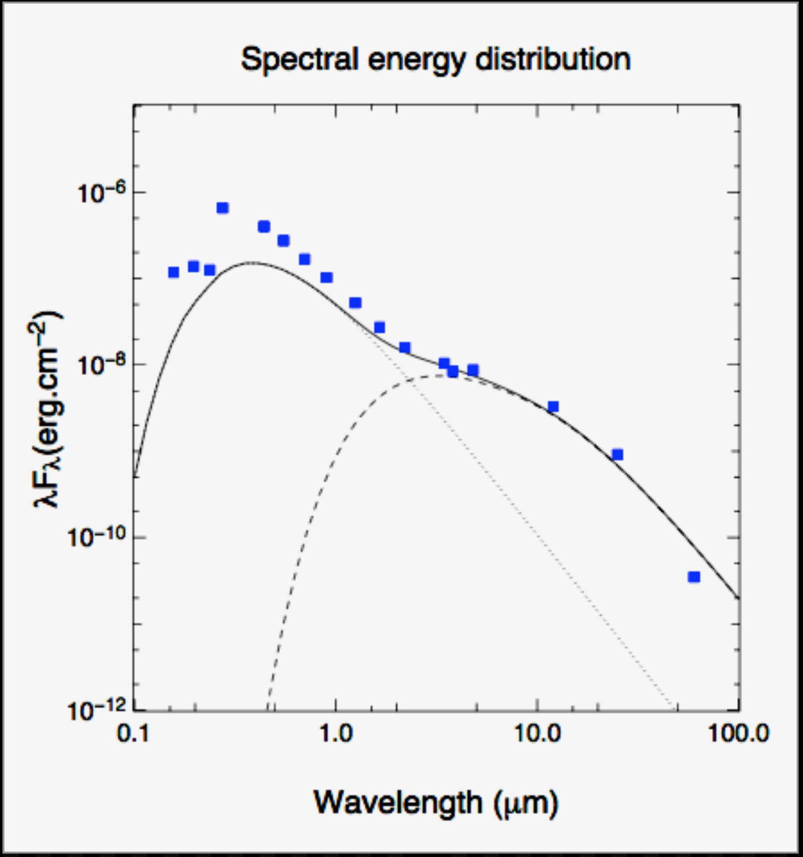
51 Oph Results

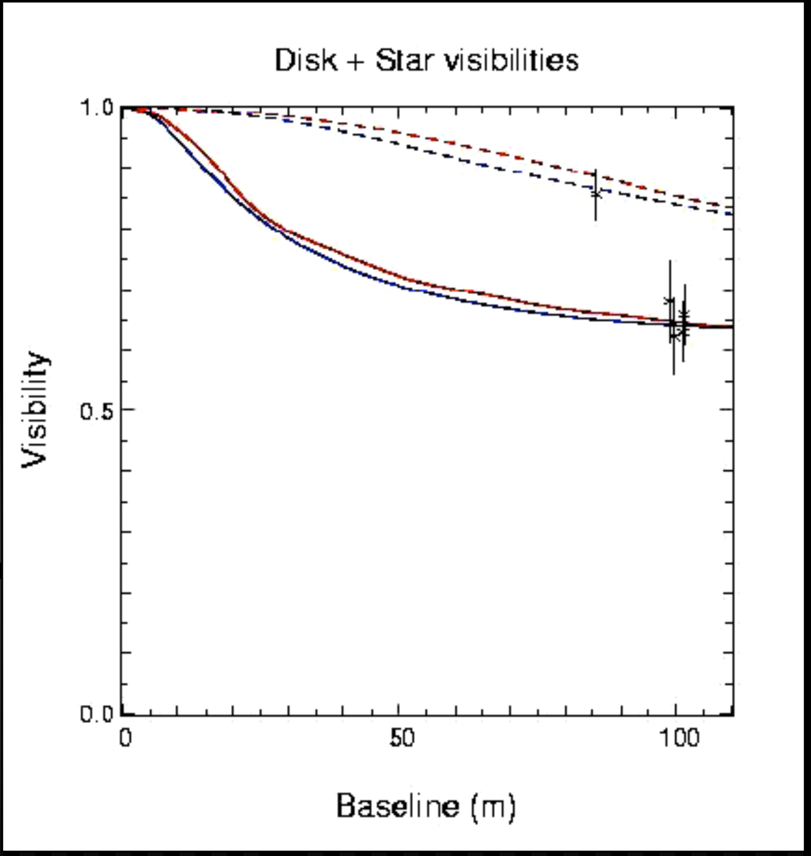




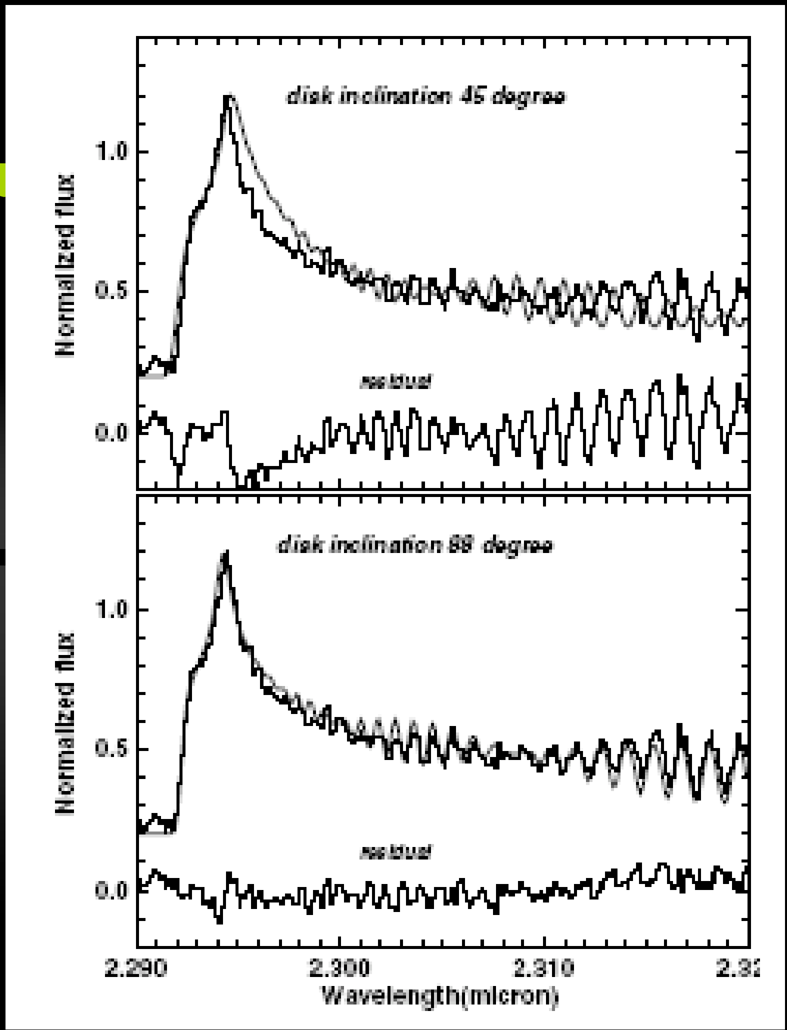
Gil et al. 2007 (submitted)

Through the van Cittert - Zernike theorem => Determine source brightness distribution





Rstar / Rsun	Disk Outer Radius (AU)	Disk Inner Radius (AU)	Inclination (°)	Position Angle (°)
7	7	0.55	88	157

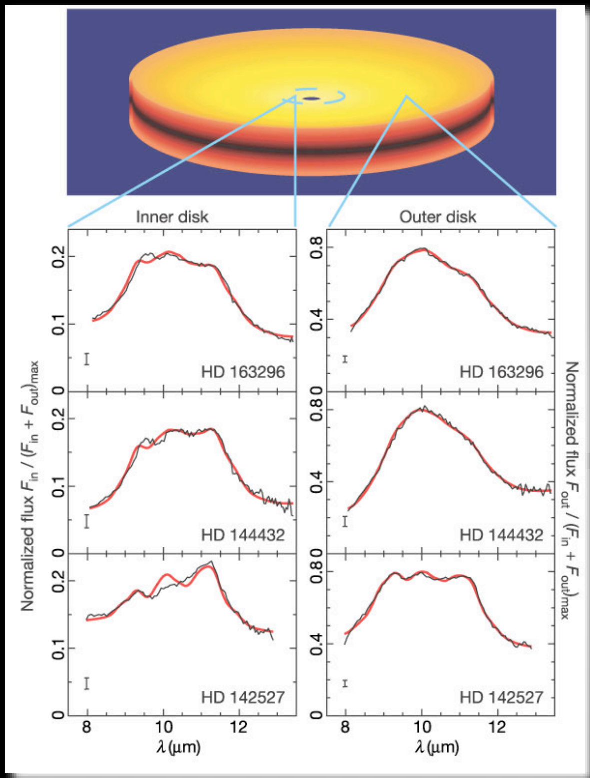


Thi et al. (2005)

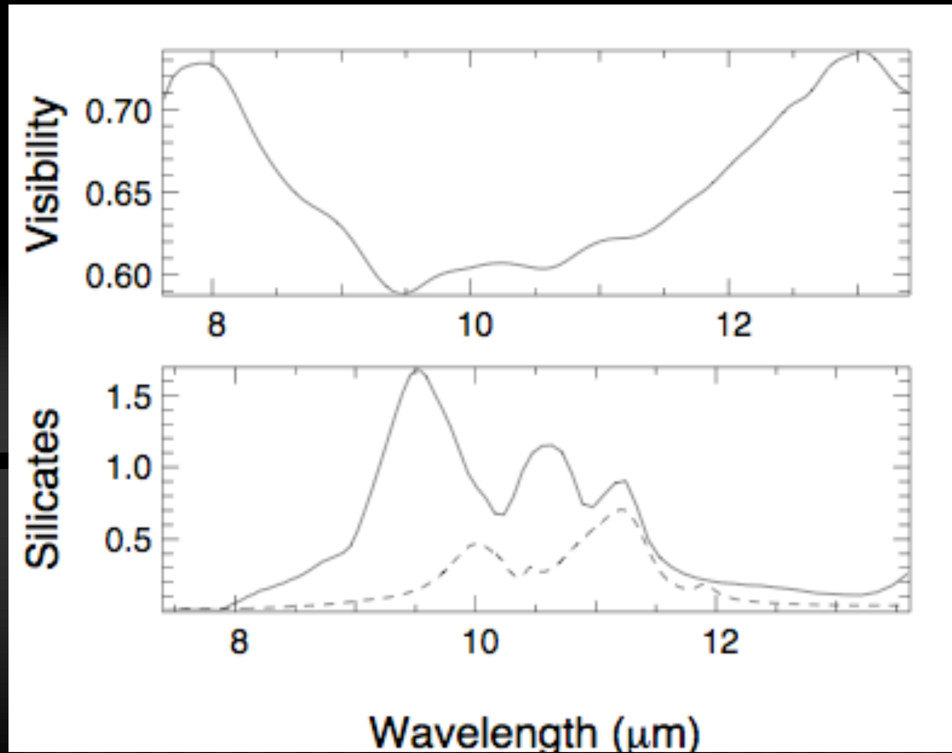
- ✓ Our results confirm the ones published by Thi et al 2005. In this paper the authors have reported observations of CO around 51 Oph and have found a best fit for a disk tilted of 88º, Rmin = 0.15 AU and Rmax = 0.35 AU.

- ✓ We have found a best fit for the same disk inclination, determined the PA, and confirm the non-existence of dust in the inner AU of the disk.

Silicates



Van Boekel et al. 2004



Gil et al. 2007 (submitted)

Higher concentration of crystalline dust in the inner regions (1 to 2 AU) than in the outer regions of Herbig Ae/Be circumstellar disks.

51 Oph - Open Questions

- Is this a young system or a more evolved one?
- Is it a protoplanetary system?
- Is it a binary system?

Conclusions

- ✓ 51 Oph was observed for the first time in the mid-infrared at high-angular resolution.
- ✓ We have modeled 51 Oph visibilities and were able to constrain the inclination and position angle of the dust circumstellar disk.
- ✓ The best fit to our data corresponds to a flat circumstellar disk (0.55 to 7 AU), tilted of 88º with a position angle of 157º and an accretion rate of 7×10^{-5} solar masses per year.
- ✓ We confirm the non-existence of dust in the inner circumstellar radius of 51 Oph.

Future Plans at ESO

✓ Observing Jets in Young Stellar Objects with AMBER/VLTI

Understanding the physical mechanisms by which mass is ejected from protostellar system and collimated into jets.

- ✓ Current status: differences in jet origin models: X-winds (Shu et al. 2000); disk-winds (Konigl and Pudritz 2000), and stellar winds (Sauty et al. 2003).

- ✓ Perspectives: Imaging a Classical T Tauri star harboring a jet, with the ATs (AMBER GTO, Foy et al.). Paβ , [Fe II] 1.257μm, 1.53μm and 1.64μm, and He I 1.08μm probe various conditions and will allow us to obtain information on the excitation of the jet.

✓ Disk Evolution

✓ Grain growth or disk structure?

Using MIDI to find the cause for the absence of the silicate feature in some Herbig Ae stars.

✓ We plan to use MIDI on the VLTI to decide between the two scenarios - disk structure up to 25-50 AU, including the region where the silicate emission is expected to arise from.

✓ Determining the nature of the circumstellar material of 51 Oph

- ✓ New observations obtained with the AMBER instrument and 2 more visibility measurements with MIDI will help us to solve this mistery (binary nature?).

To be continued…

Thank you for your attention!