MASSIVE STARS seen through optical interferometry

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Why are MASSIVE STARS important?

1. Evolution of galaxies
2. UV radiation sources
3. Producers of heavy elements
4. Deaths as supernovae

The challenge to observe

Massive Stars

1. Rare (IMF)
2. Extinction
3. Short lives (Ma)
4. Distant (>1kpc)

NGC 6193
1.2 kpc

Orion Nebula
500 pc

How to study
Massive Stars?

1 Multiplicity

Near IR long baseline interferometry (AMBER/VLTI)

2 Massive Young Stellar Objects (MYSOs)

Spectro-Astrometry (CRIRES/VLT)

Near-IR Fizeau Interferometry (NACO-SAM/VLT)

Massive Stars and ISM

Sanchez-Bermudez, et al., 2014, A&A, 567, 21

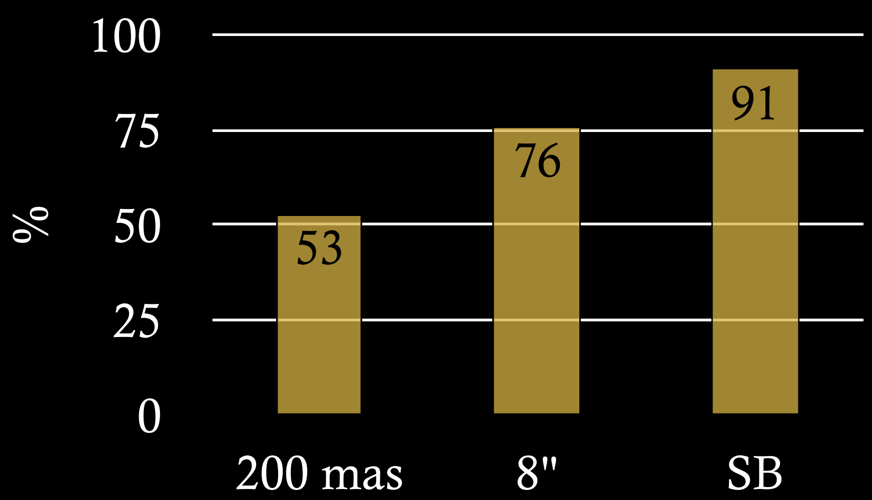
Adaptive Optics Imaging (NACO/VLT)

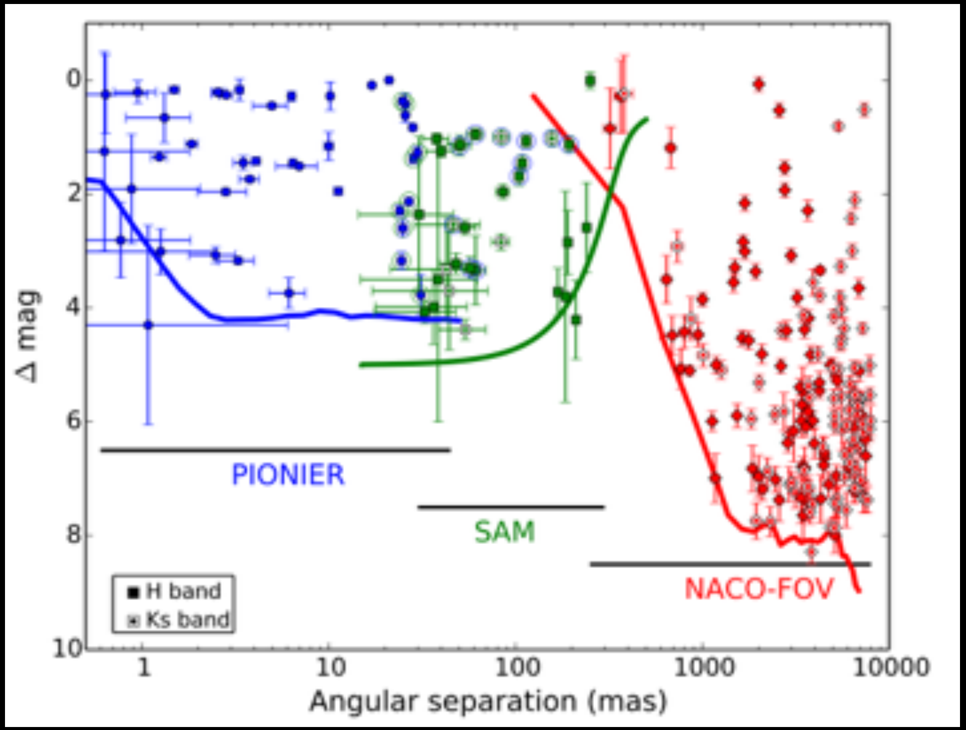
1

Multiplicity of Massive Stars

Massive stars don't like to be alone…

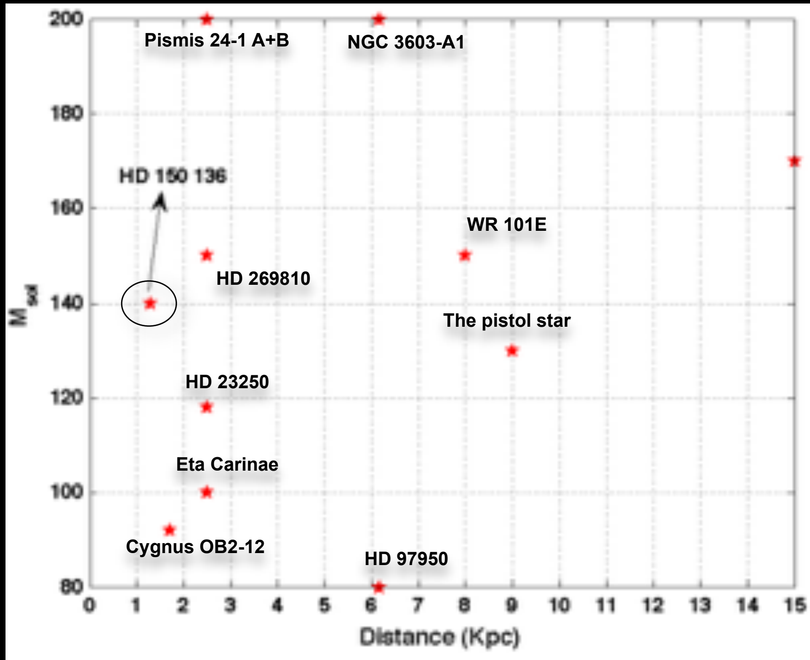
NACO/SAM-PIONIER:
96 O-stars



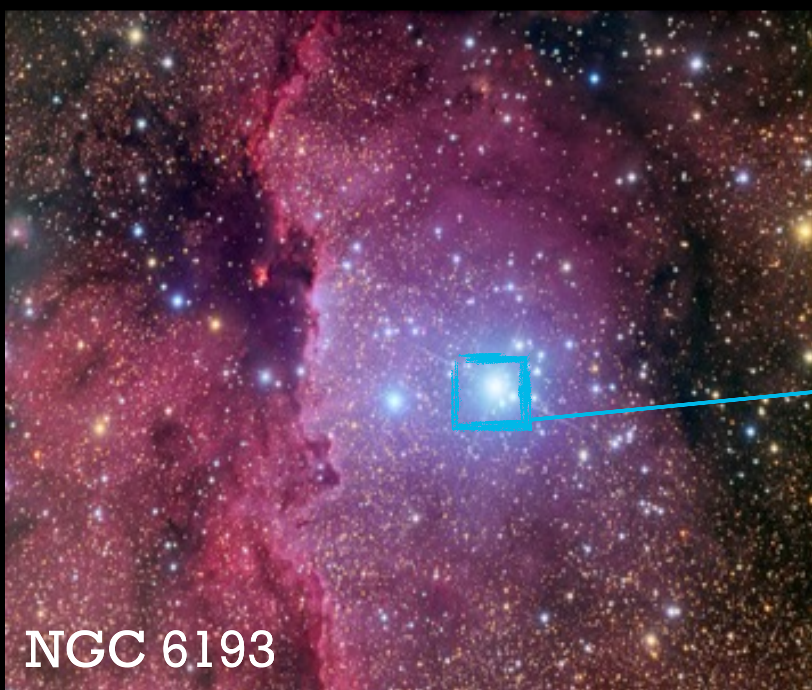


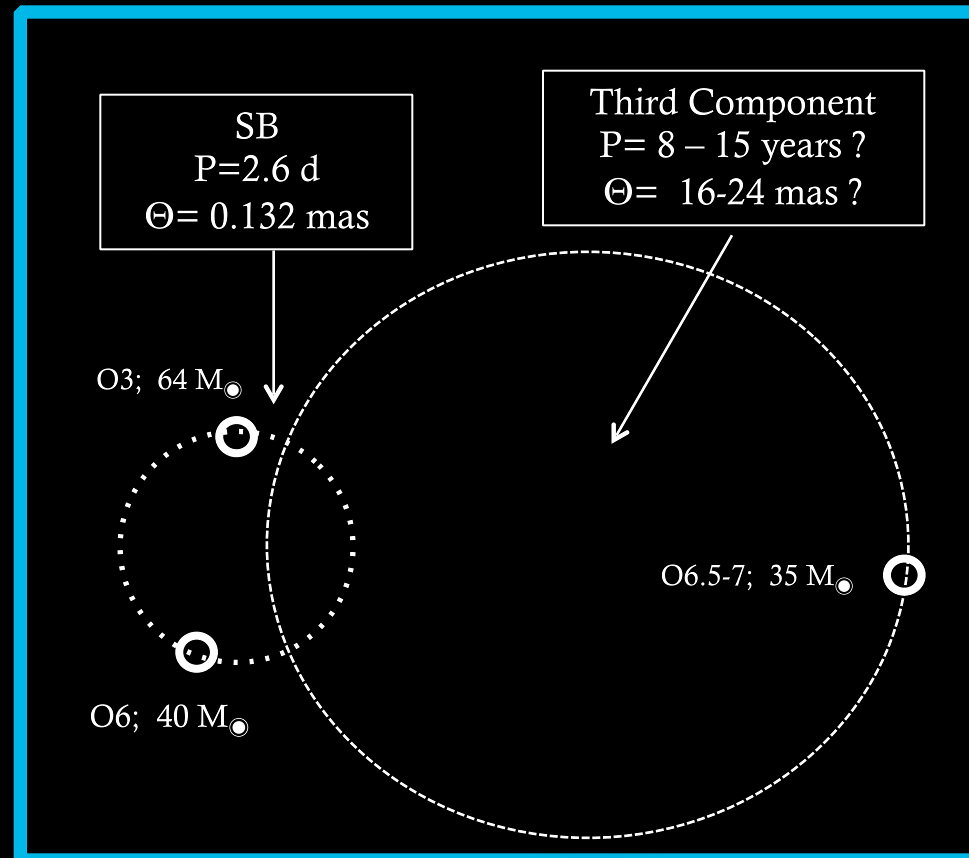
1/3 belongs to hierarchical triple systems !

Sana, et al., 2014, ApJ



HD 150136



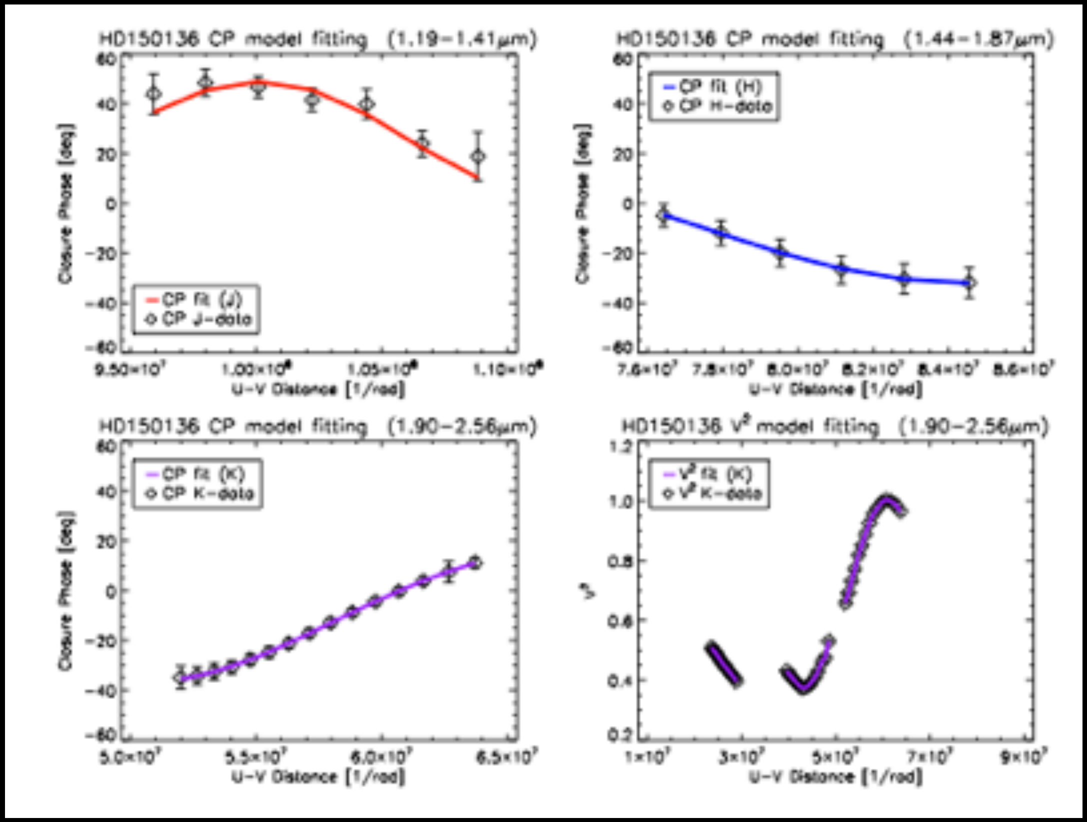


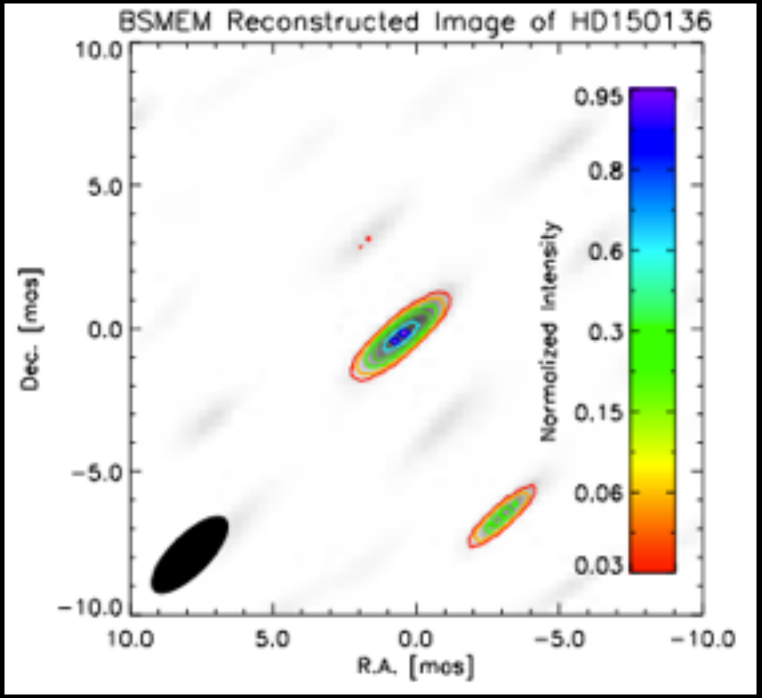
Mahy, et al., 2012, A&A
Niemela & Gamen, 2005, MNRAS

AMBER/VLTI
LR-JHK

HD150136:

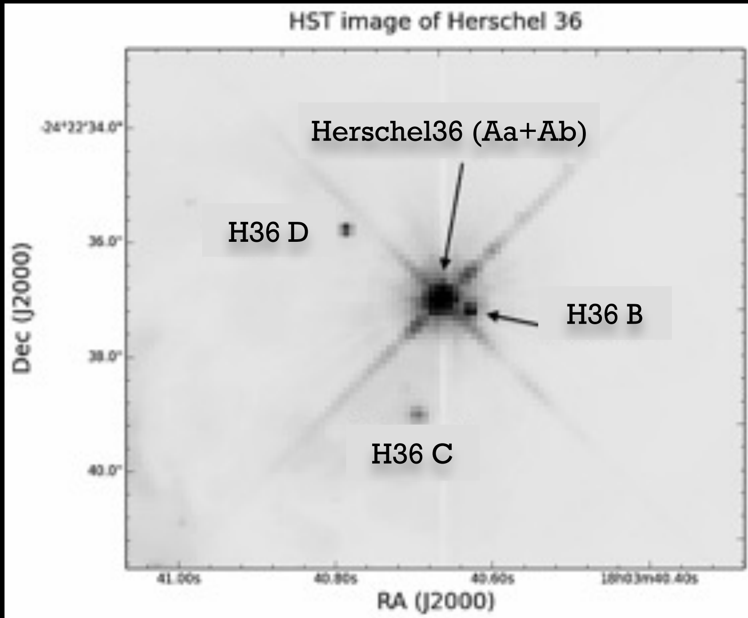
d= 7 mas
Θ=209°
f_T/f_{SB}=0.25

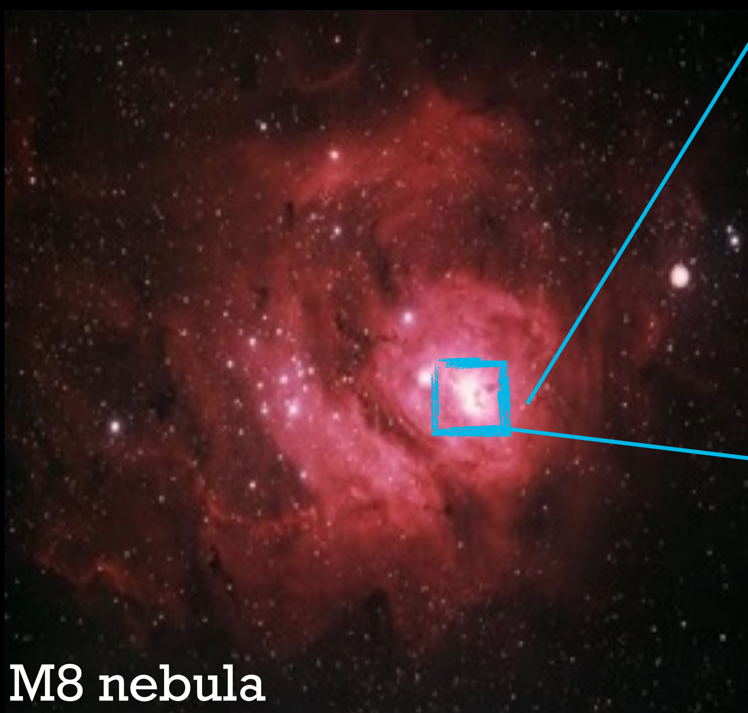


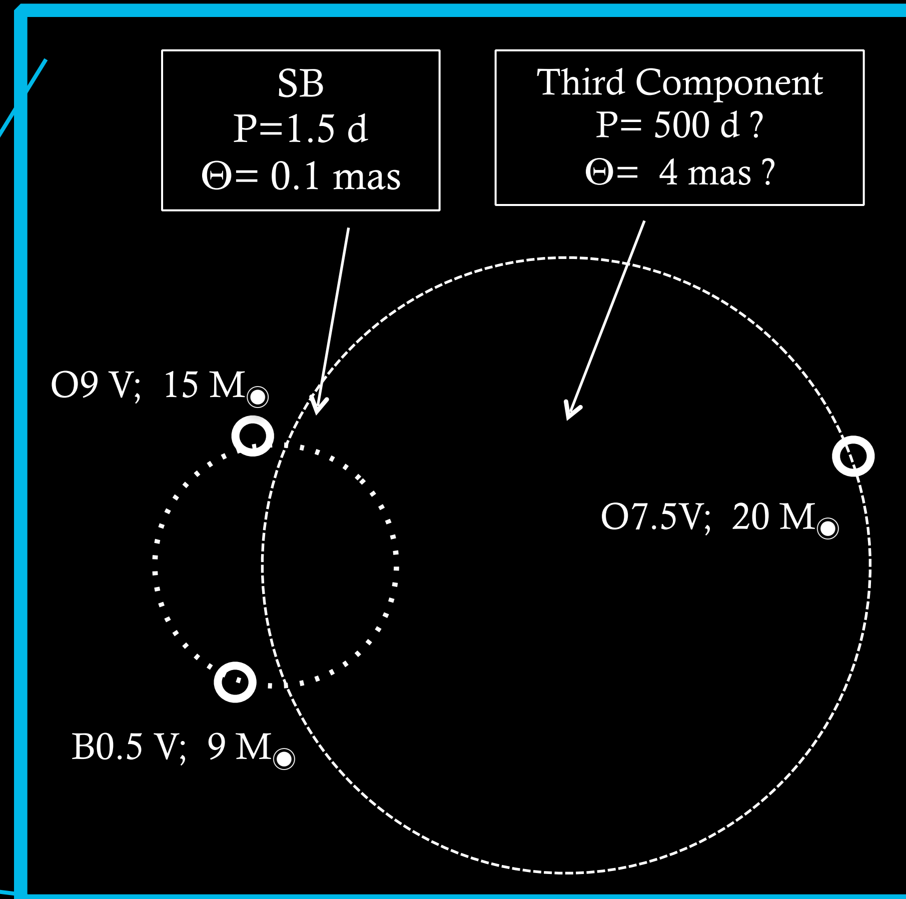


Sanchez-Bermudez et al., 2013, A&A, 554, L4

Herschel36



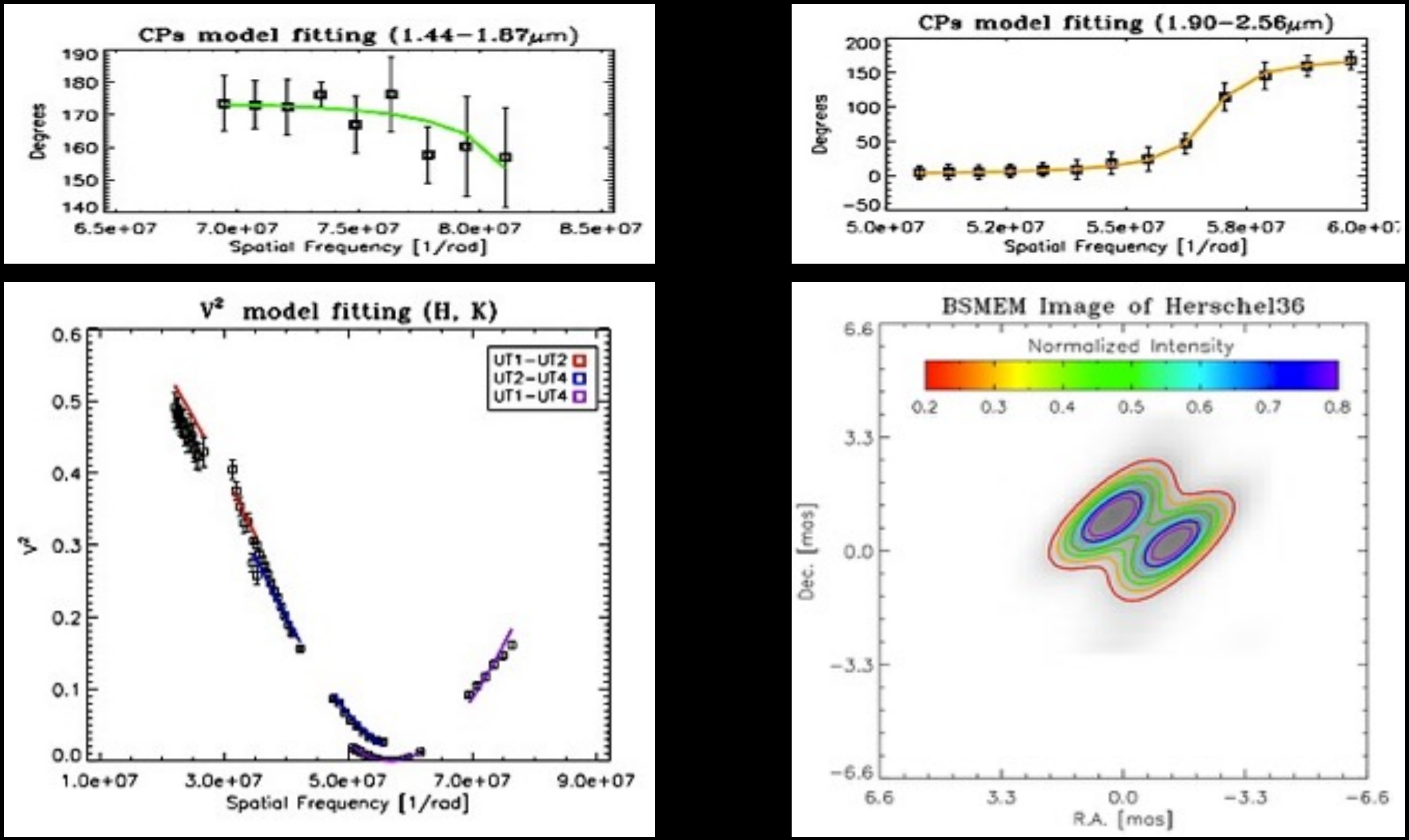




Arias, et al., 2010, ApJ

Herschel36

d= 2 mas
Θ=234°
f_A/f_B=1.0



Sanchez-Bermudez et al., 2014, A&A, 572, L1

Importance & Future work:

1 Characterize young systems (~2Ma; HD150136)

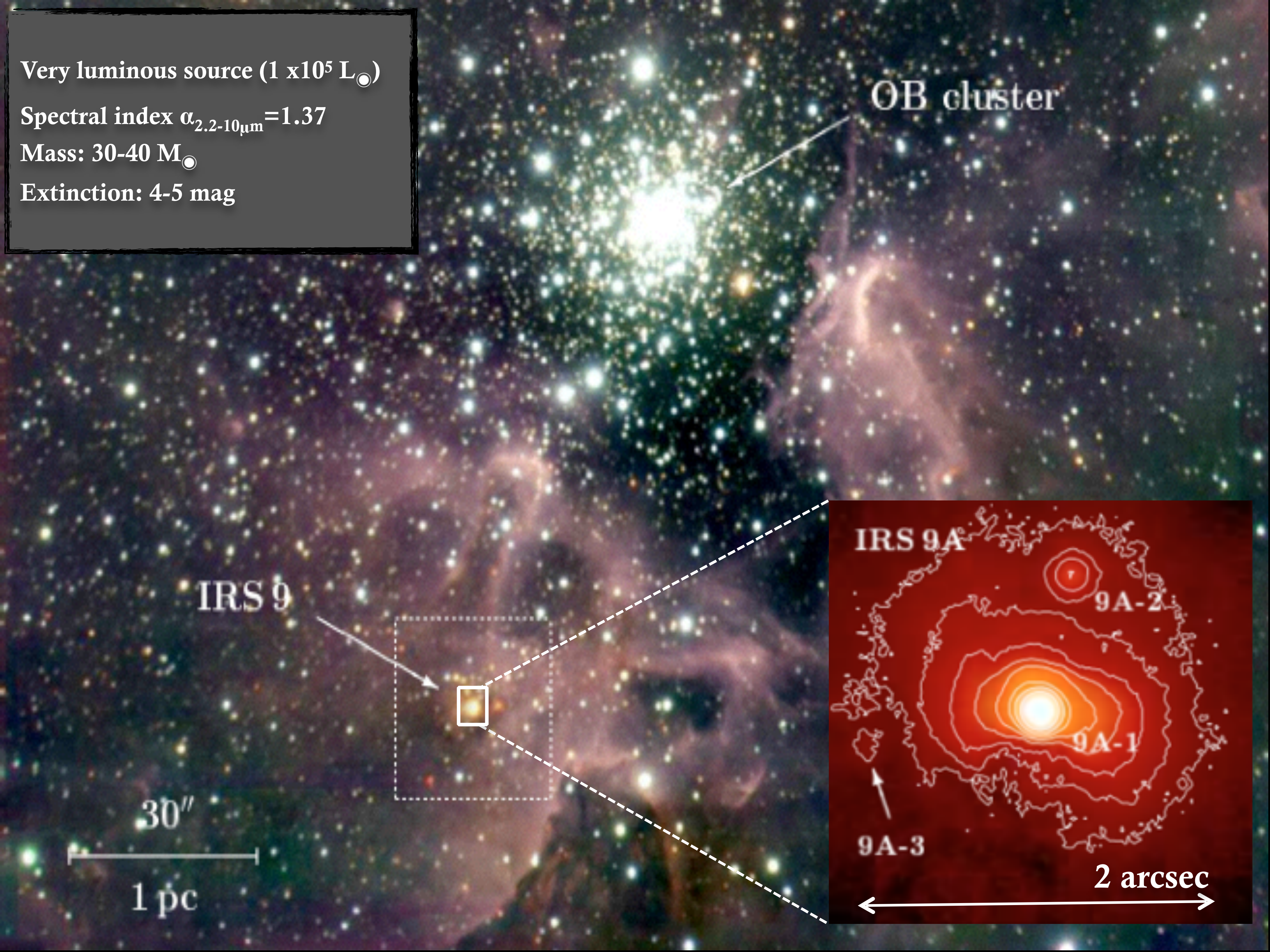
2 Systems at the upper end of the IMF

3 Hints of massive star formation
(Was Herschel36 formed by dynamical interactions?)

1 Follow up the orbits
(interferometry+radial velocities)

2 Test for coplanarity

Young Massive Stars


Very luminous source (1 x10⁵ L☉)
Spectral index α2.2-10μm=1.37
Mass: 30-40 M☉
Extinction: 4-5 mag
OB cluster
IRS 9
30″
1 pc
IRS 9A
9A-2
9A-1
9A-3
2 arcsec

Mid-IR observations of IRS9A

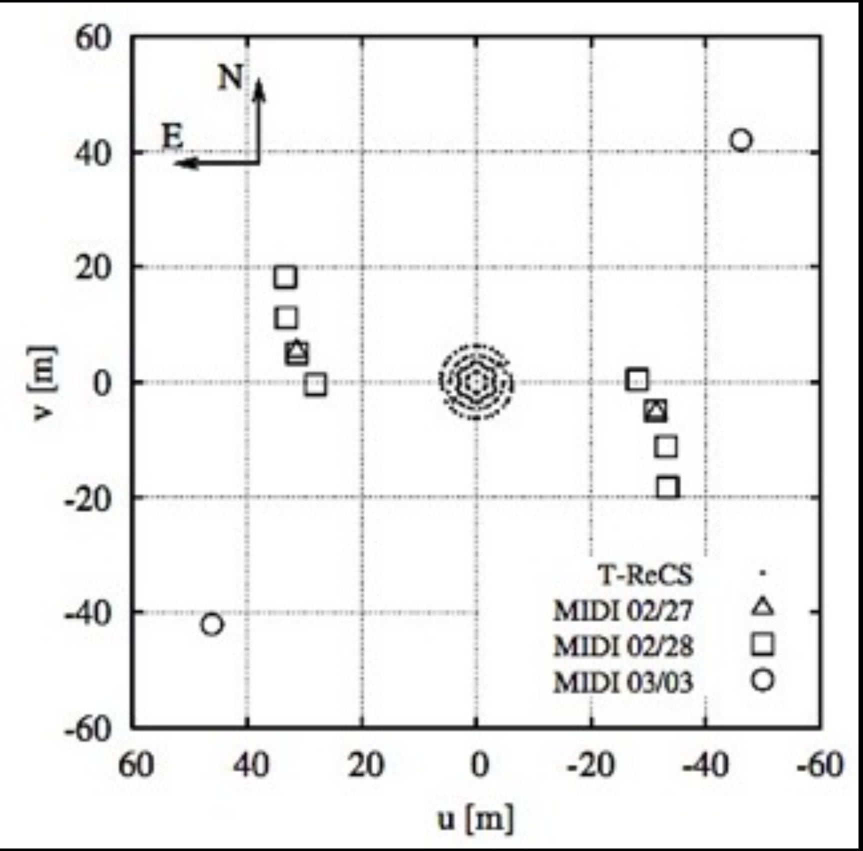
Vehoff et al., 2010

1 MIDI/VLTI

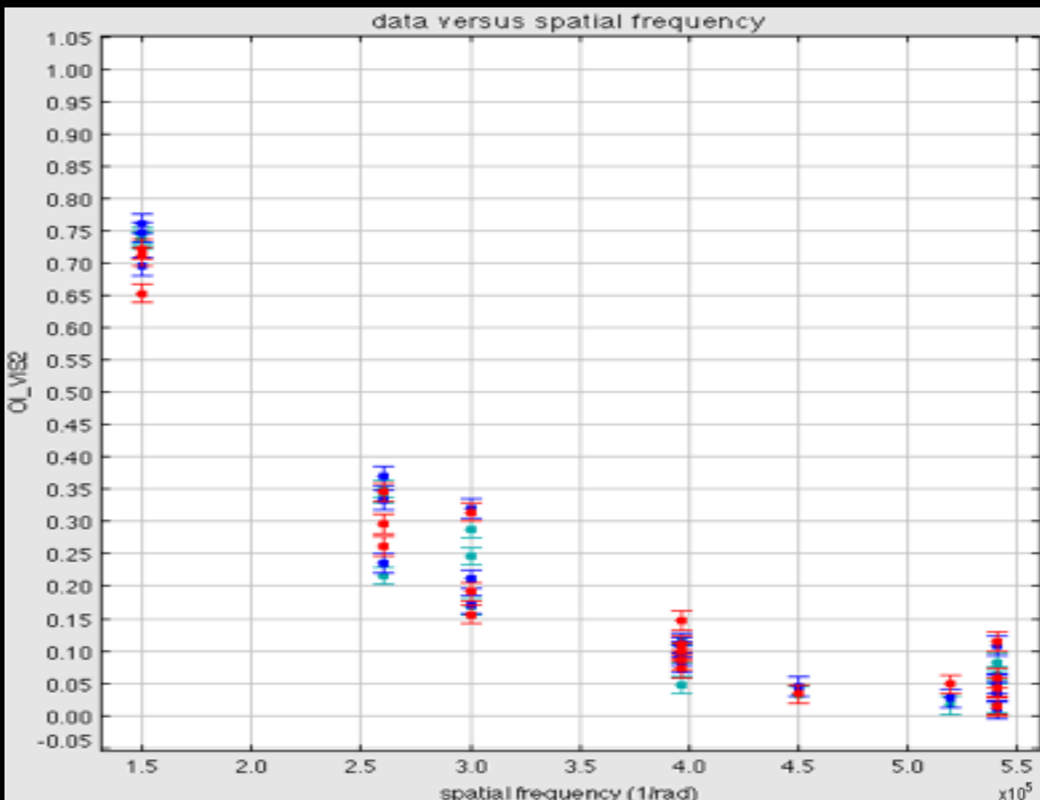
N-band (8um-13um)
Θmax=50 mas

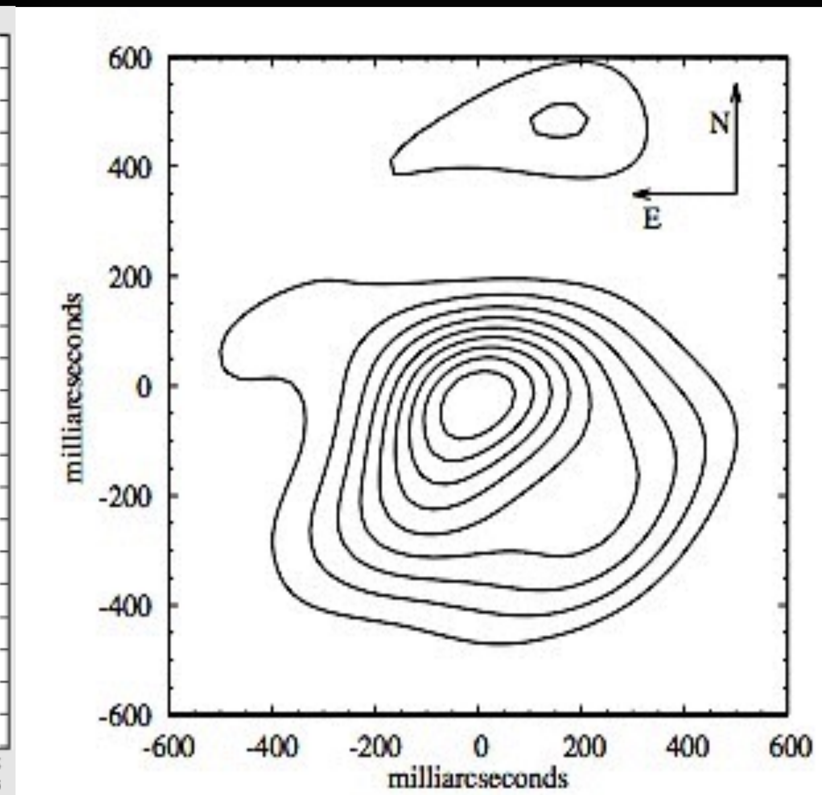
2 T-ReCS/Gemini

N-band (11.7um)
Θmax=300 mas

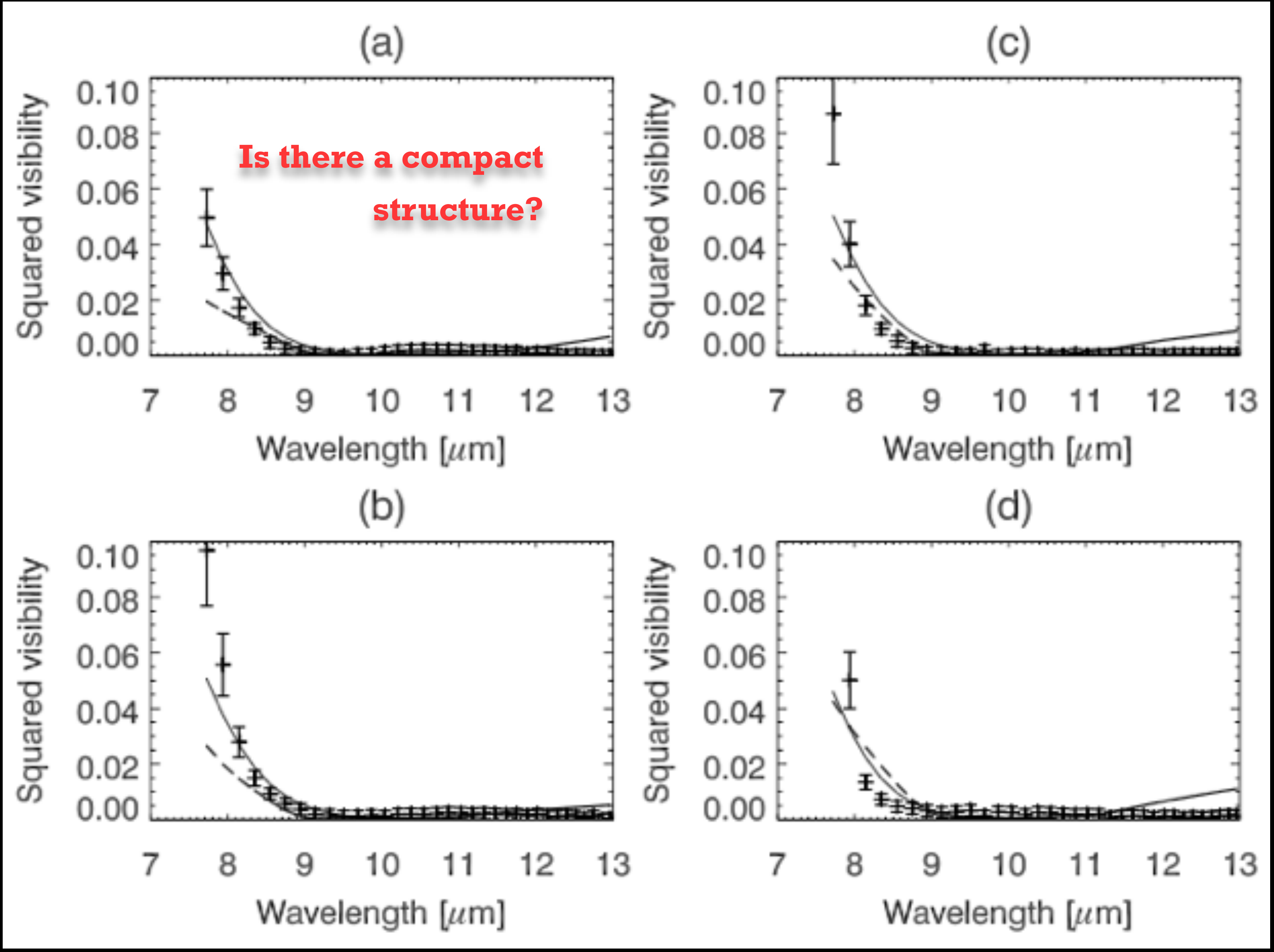


T-ReCS-SAM data of IRS9A

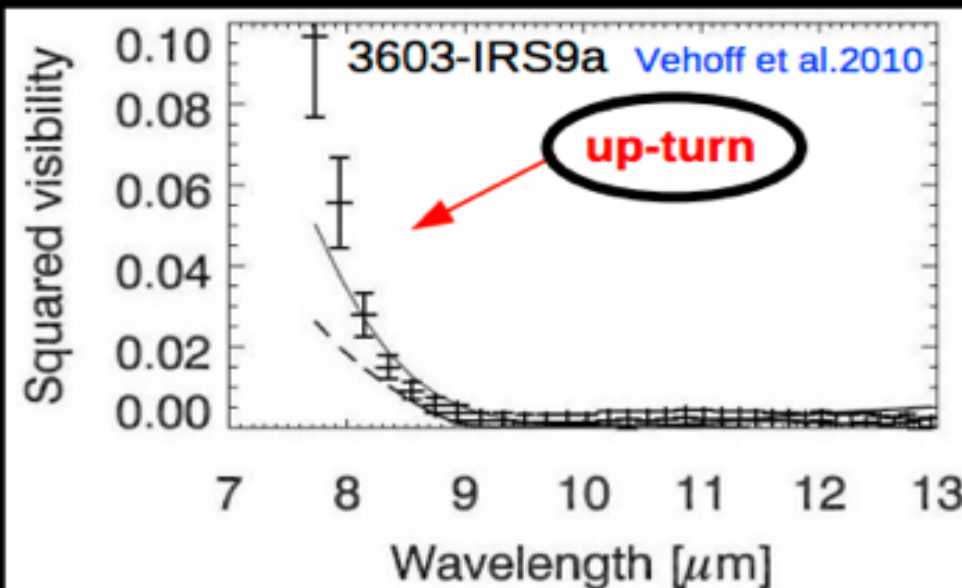


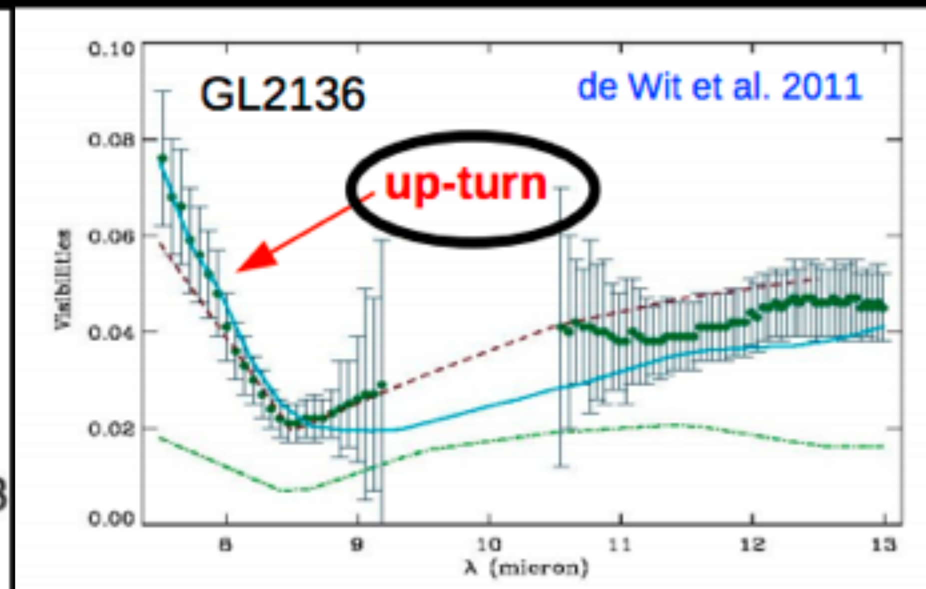


MIDI/VLTI data of IRS9A



Comparison with other targets…

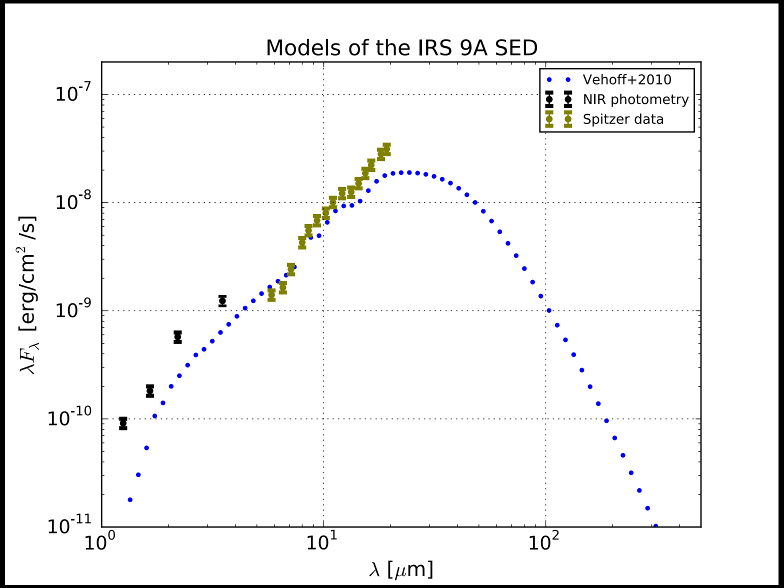




From Robitaille's fitting tool:

Robitaille, et al., 2006

- -Flared Disk
- -Envelope
- -Cavities



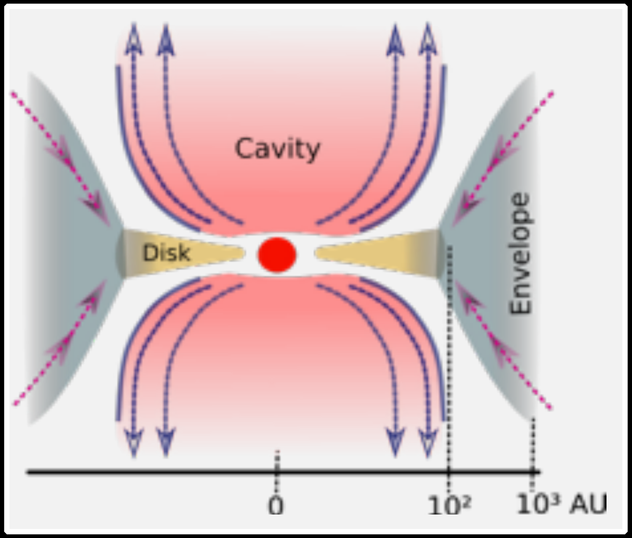
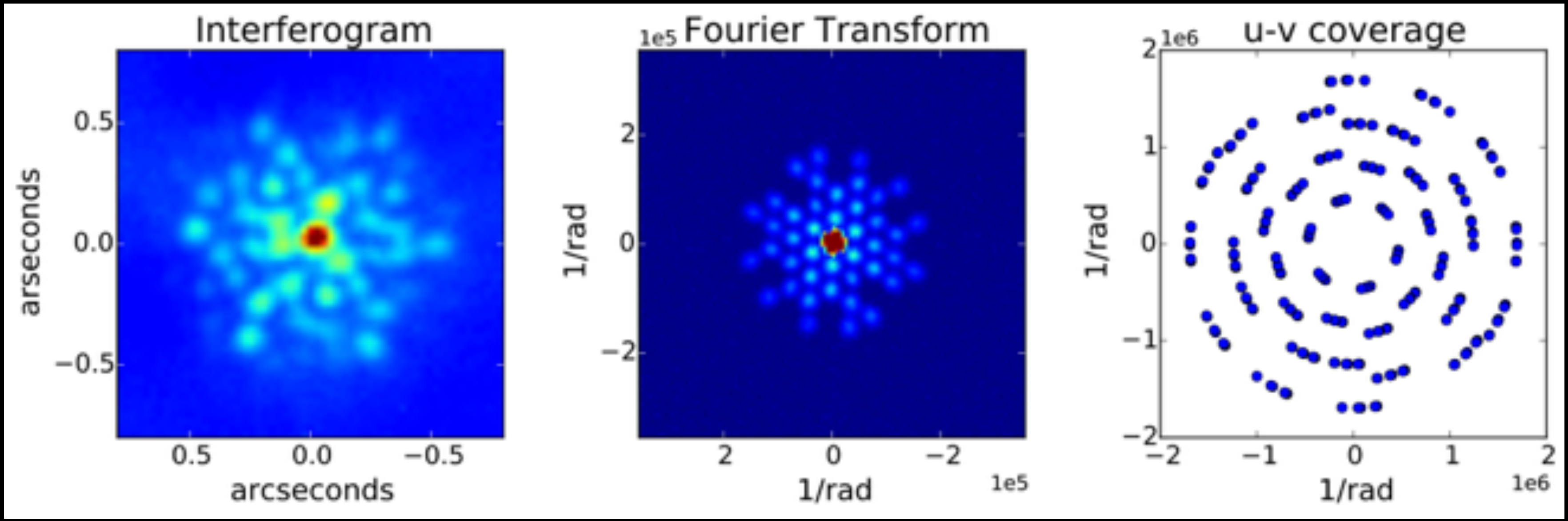


Table 4. The parameters of the Robitaille disk-envelope model 3012790.

Parameter	Unit	Value
Stellar mass	[$M_\odot$]	25
Stellar radius	[$R_\odot$]	6.5
Effective temperature	[K]	38 000
Luminosity	[$L_\odot$]	92 000
Inner disk/envelope radius	[AU]	25
Outer disk radius	[AU]	94
Outer envelope radius	[AU]	100 000
Disk dust mass	[$M_\odot$]	0.005
Envelope dust mass	[$M_\odot$]	0.9
Inclination	[°]	85
Disk flaring power, β		1.2
Disk scale height	[AU]	9
Cavity cone angle	[°]	29

Near-IR observations of IRS9A

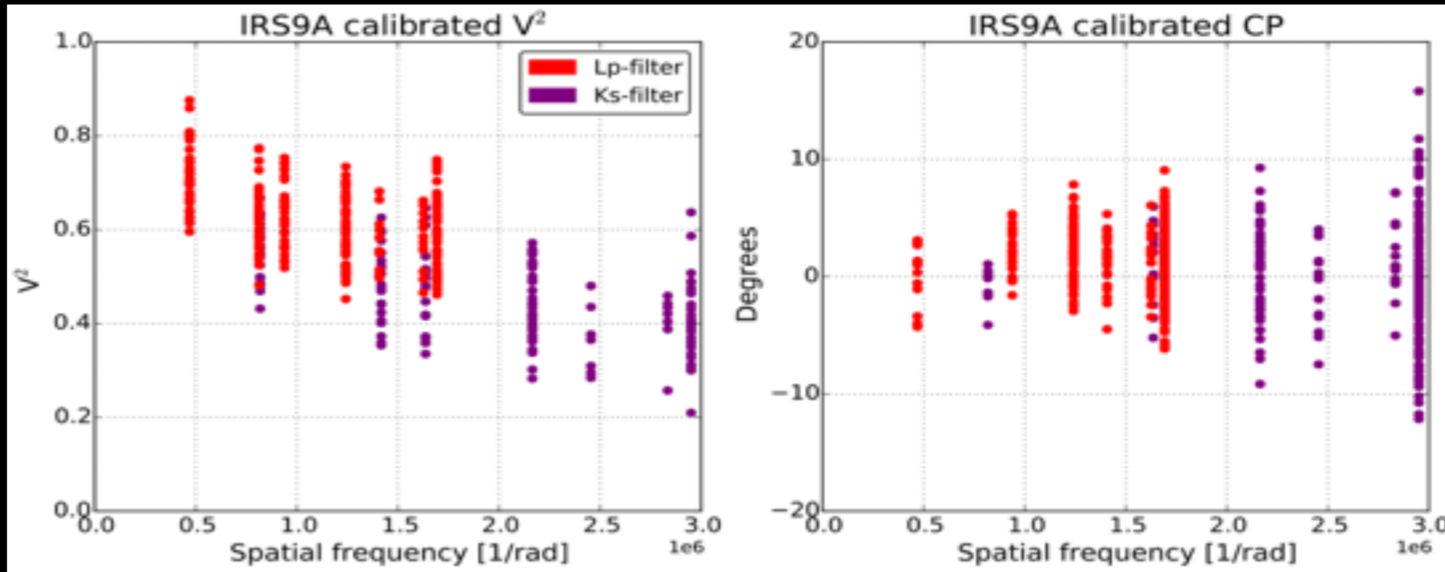


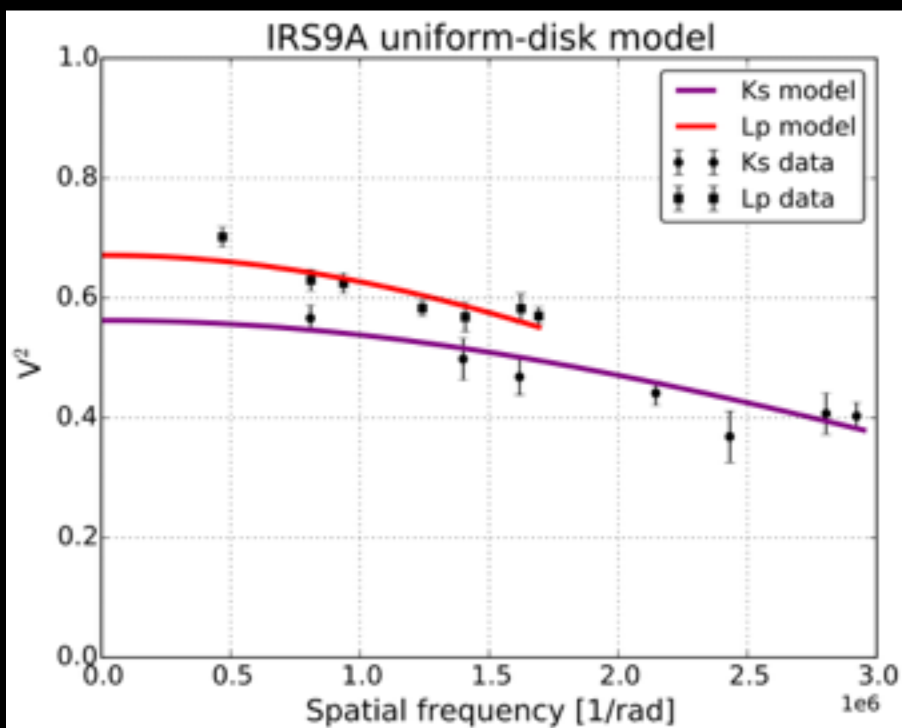
NACO/SAM obs:

- 7holes mask (21 baselines, 36 closure phases)
- Ks (2.2 um), Lp (3.8 um)

CRIRES archive:

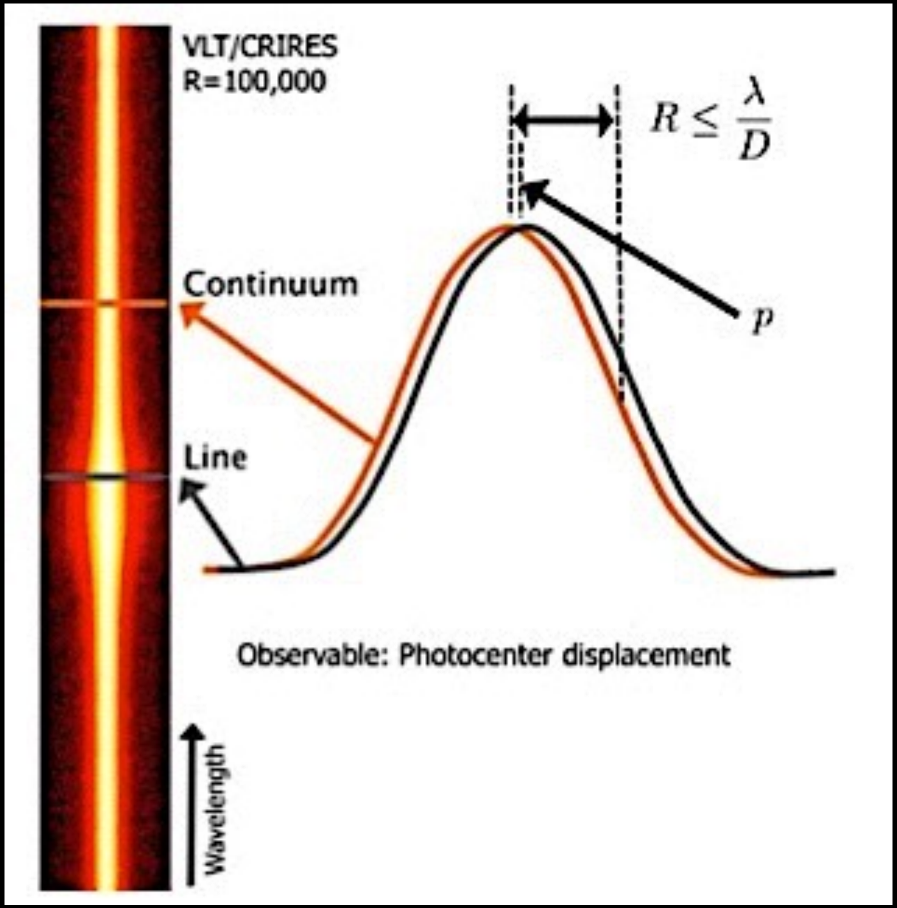
- H2 (2.121 μm) and BrG (2.166 μm)
- R≈33000; 9.0 km/s
- 3 position angles (0°, 90°, 128°)



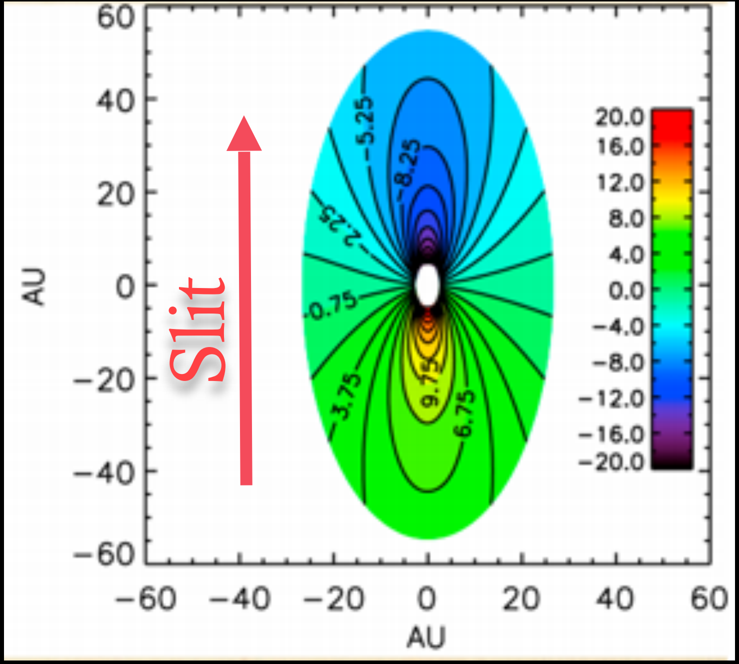


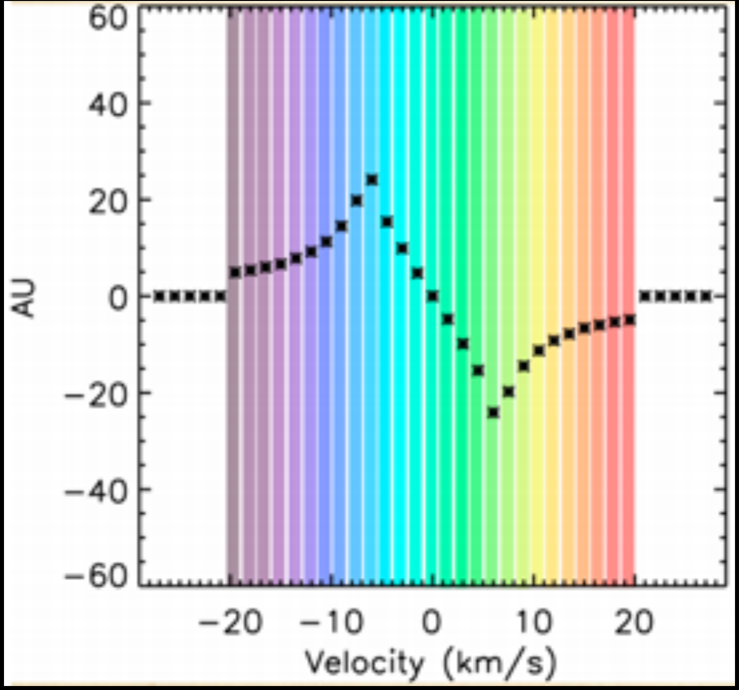
- Disk [diam]: 30 mas (210 AU)
- Over-resolved flux

Spectroastrometry



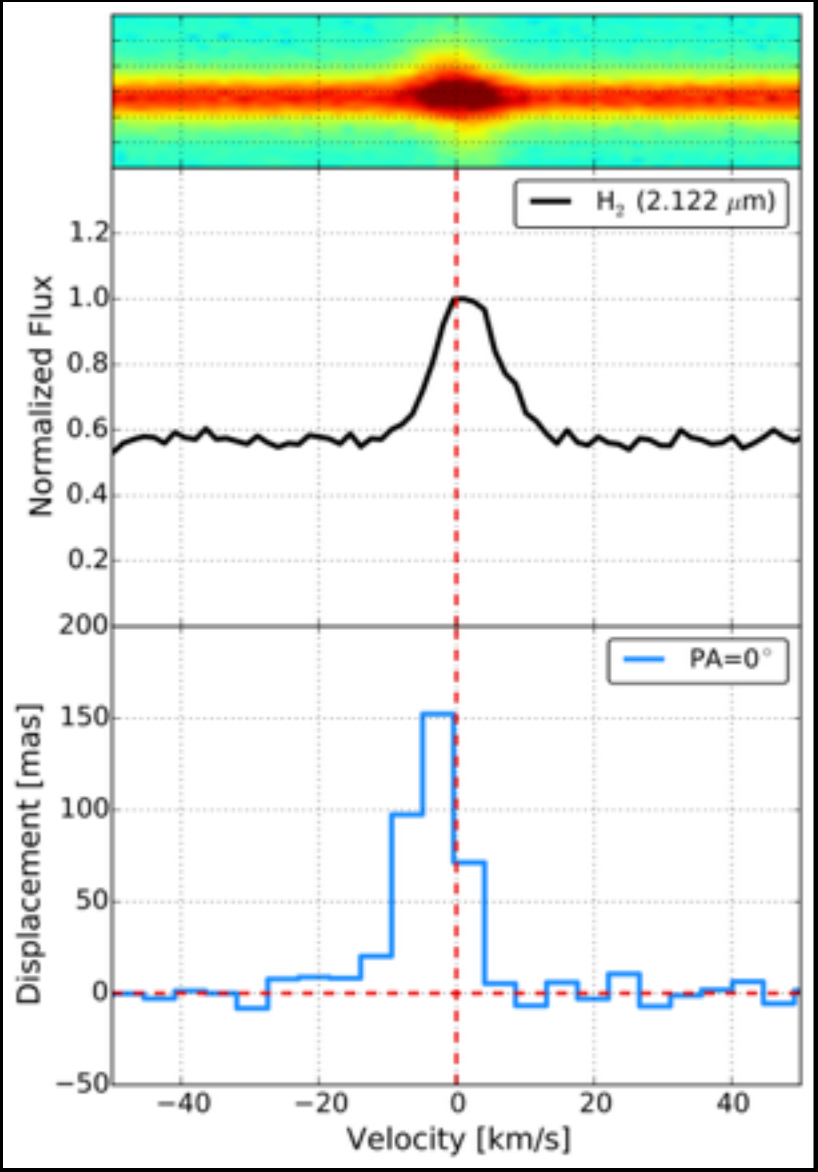
Adapted from Kraus et al., 2014

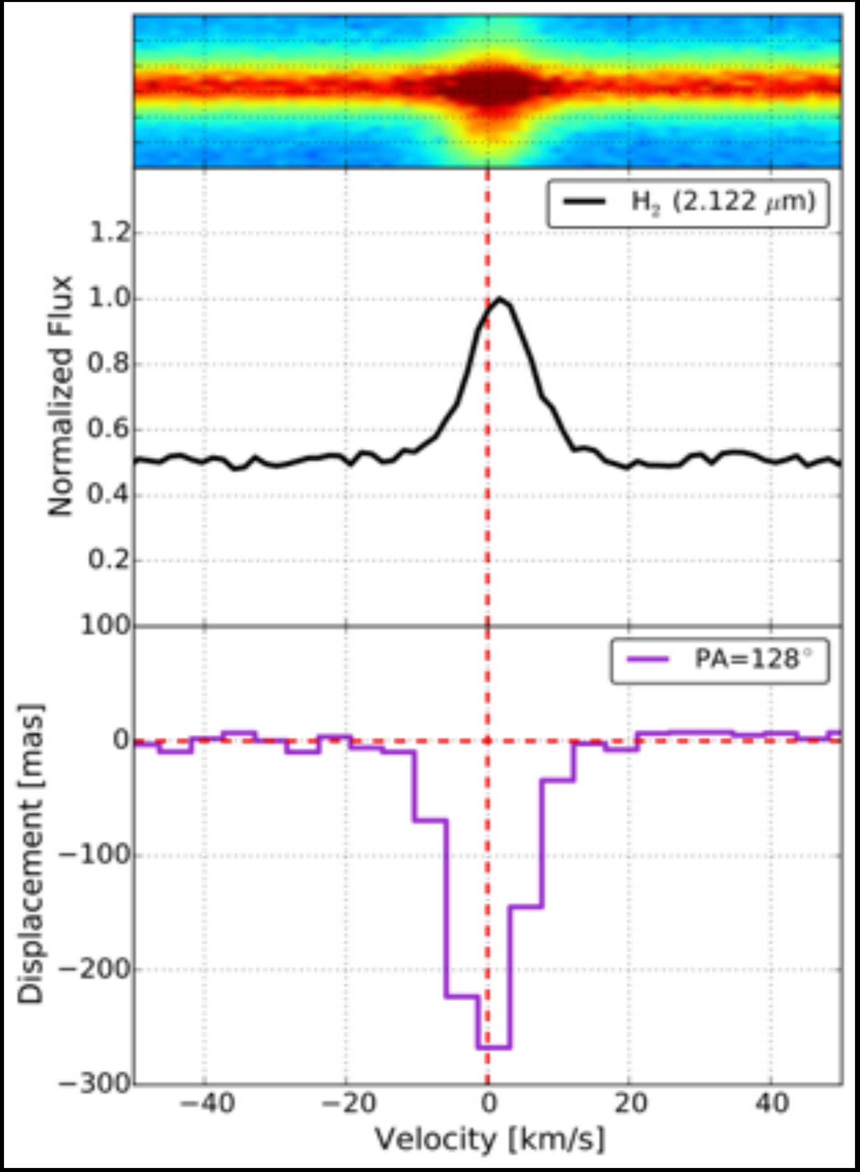




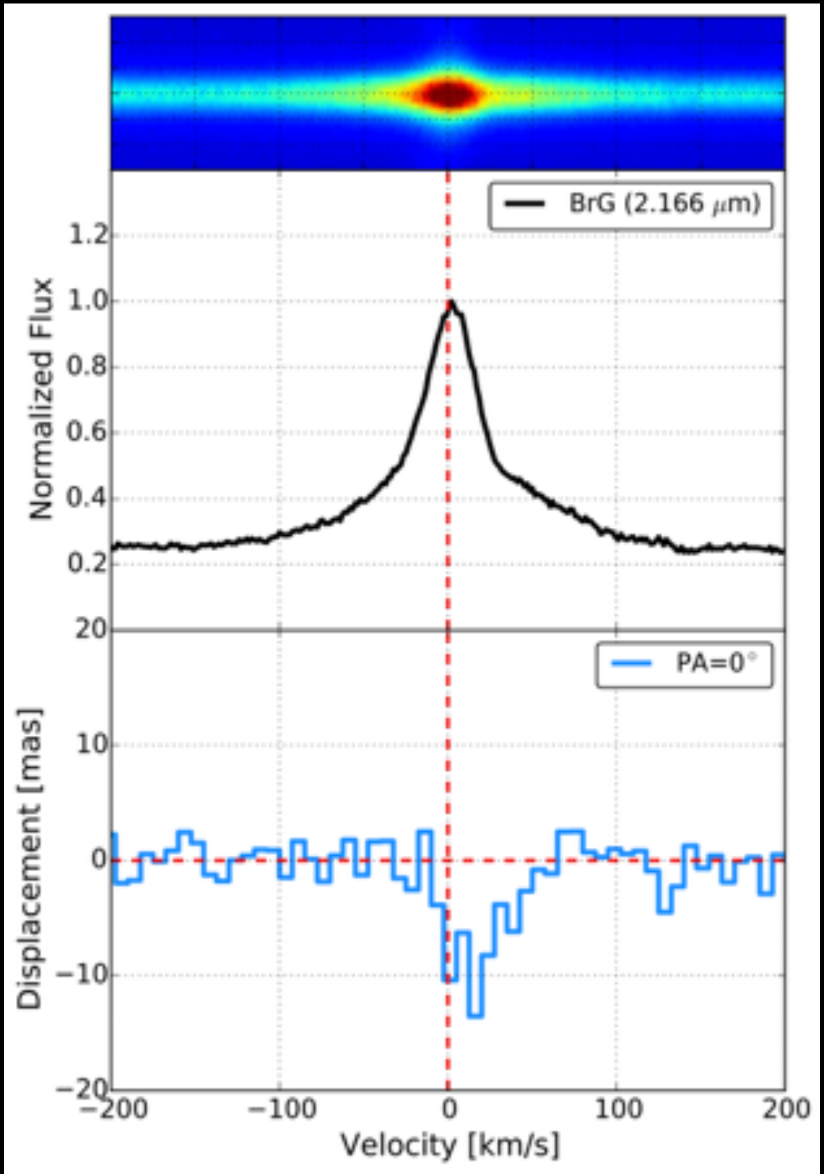
Adapted from Troutman et al., 2009

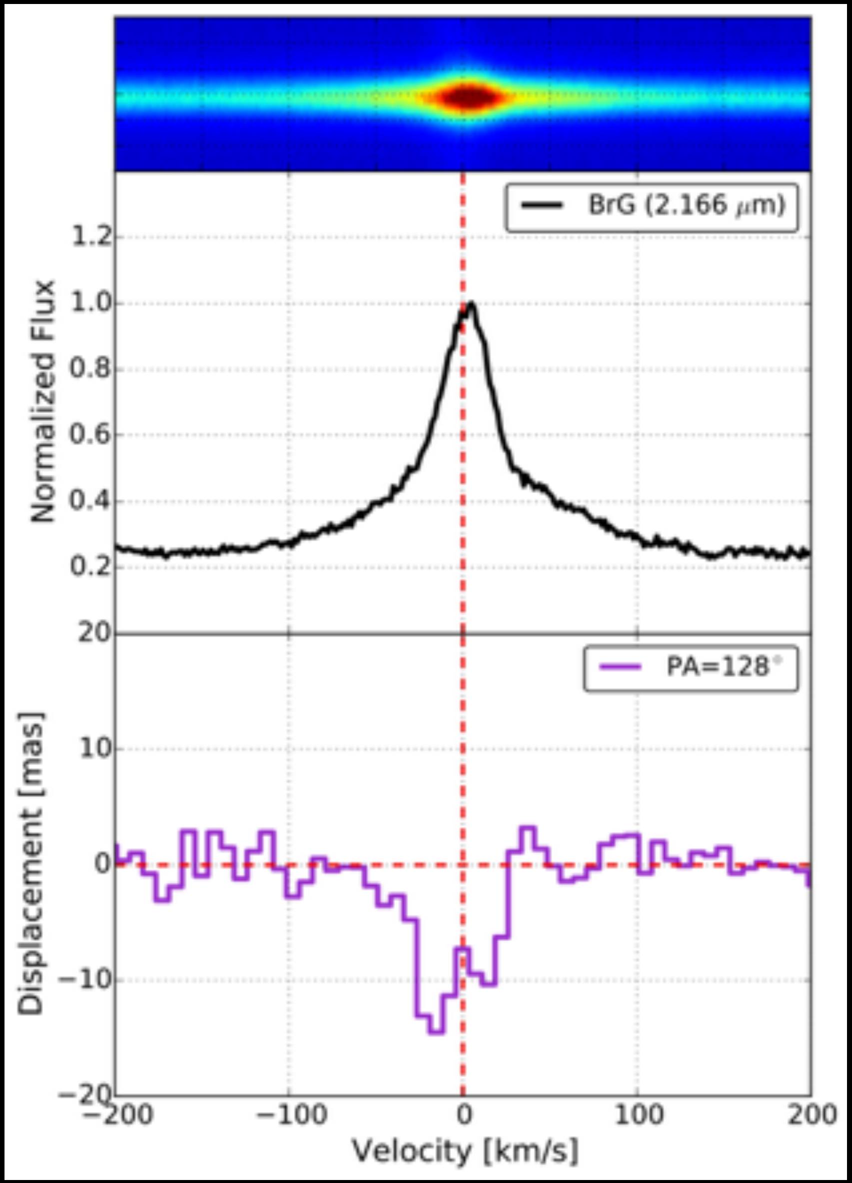
H2: 150-300 mas

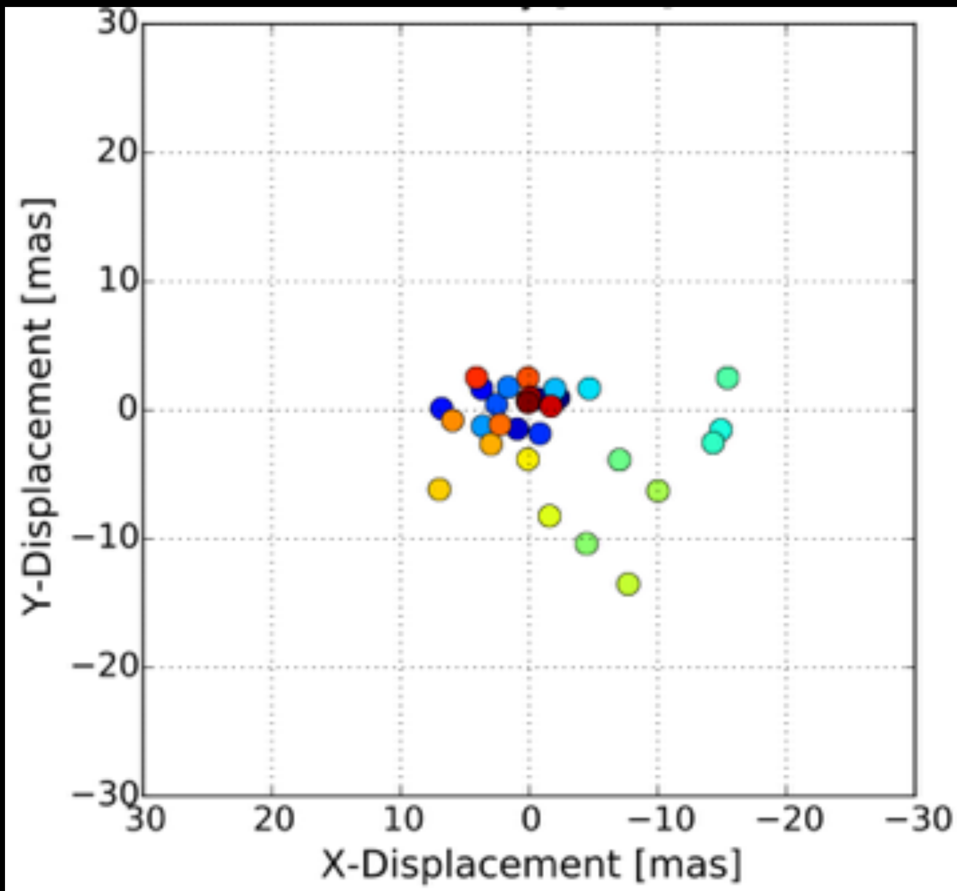




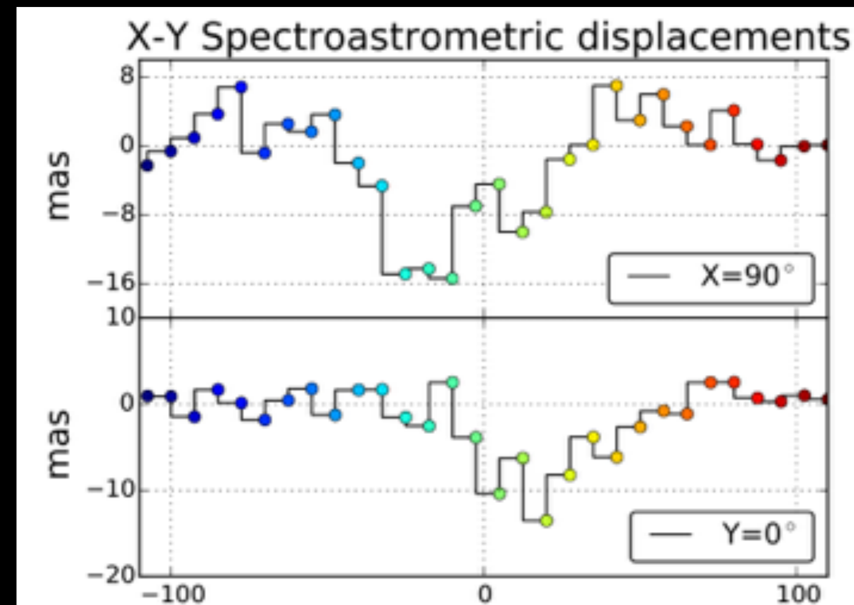
BrG: ≈20 mas


BrG (2.166 μm)
Normalized Flux
PA=0°
Displacement [mas]
Velocity [km/s]


BrG (2.166 μm)
Normalized Flux
PA=128°
Displacement [mas]
Velocity [km/s]

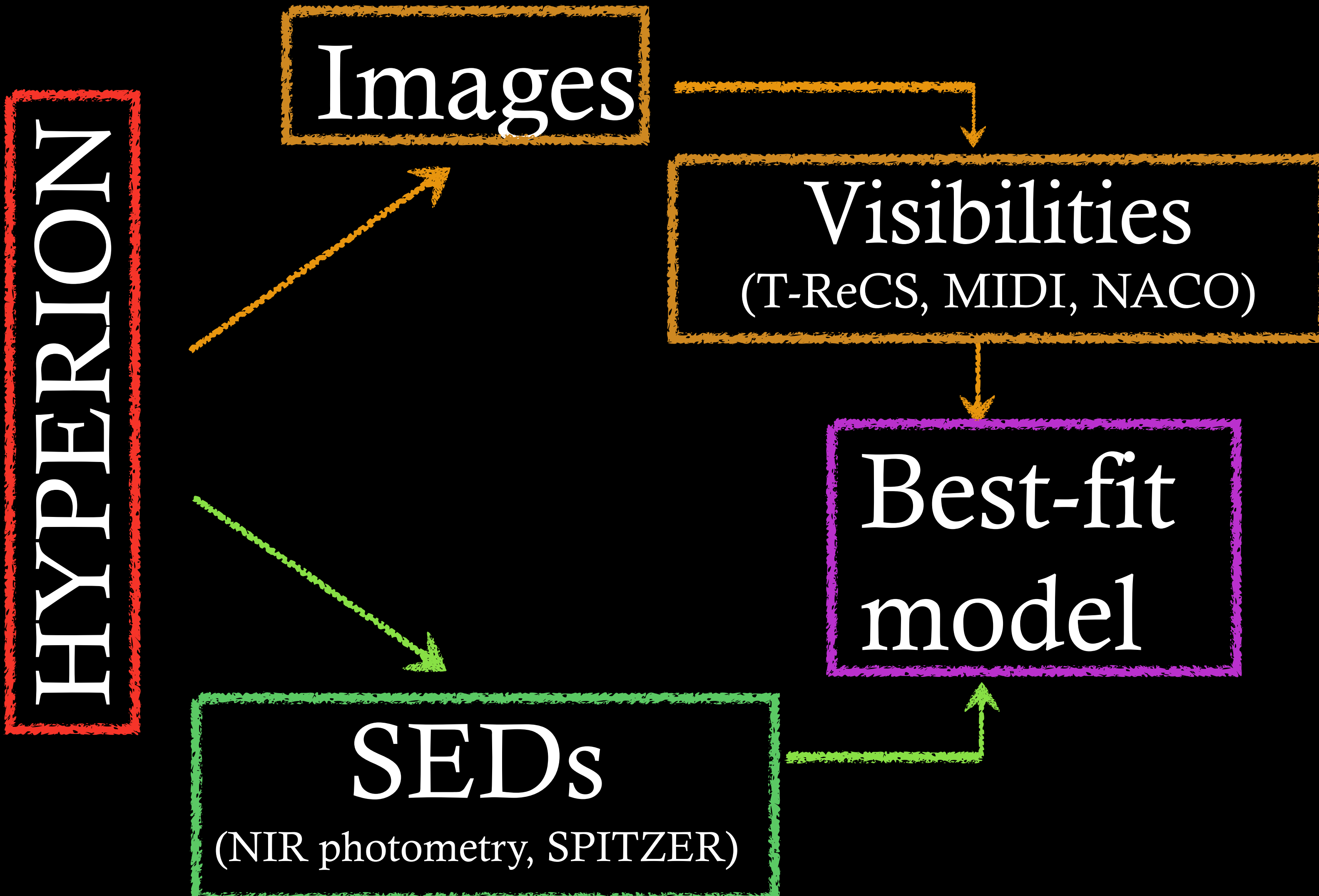


Y-Displacement [mas]
X-Displacement [mas]
30
20
10
0
−10
−20
−30



X-Y Spectroastrometric displacements
mas
8
0
−8
−16
X=90°
10
0
−10
−20
Y=0°
−100
0
100

Simultaneous fit to SED+V^2



Robitaille et al., 2011

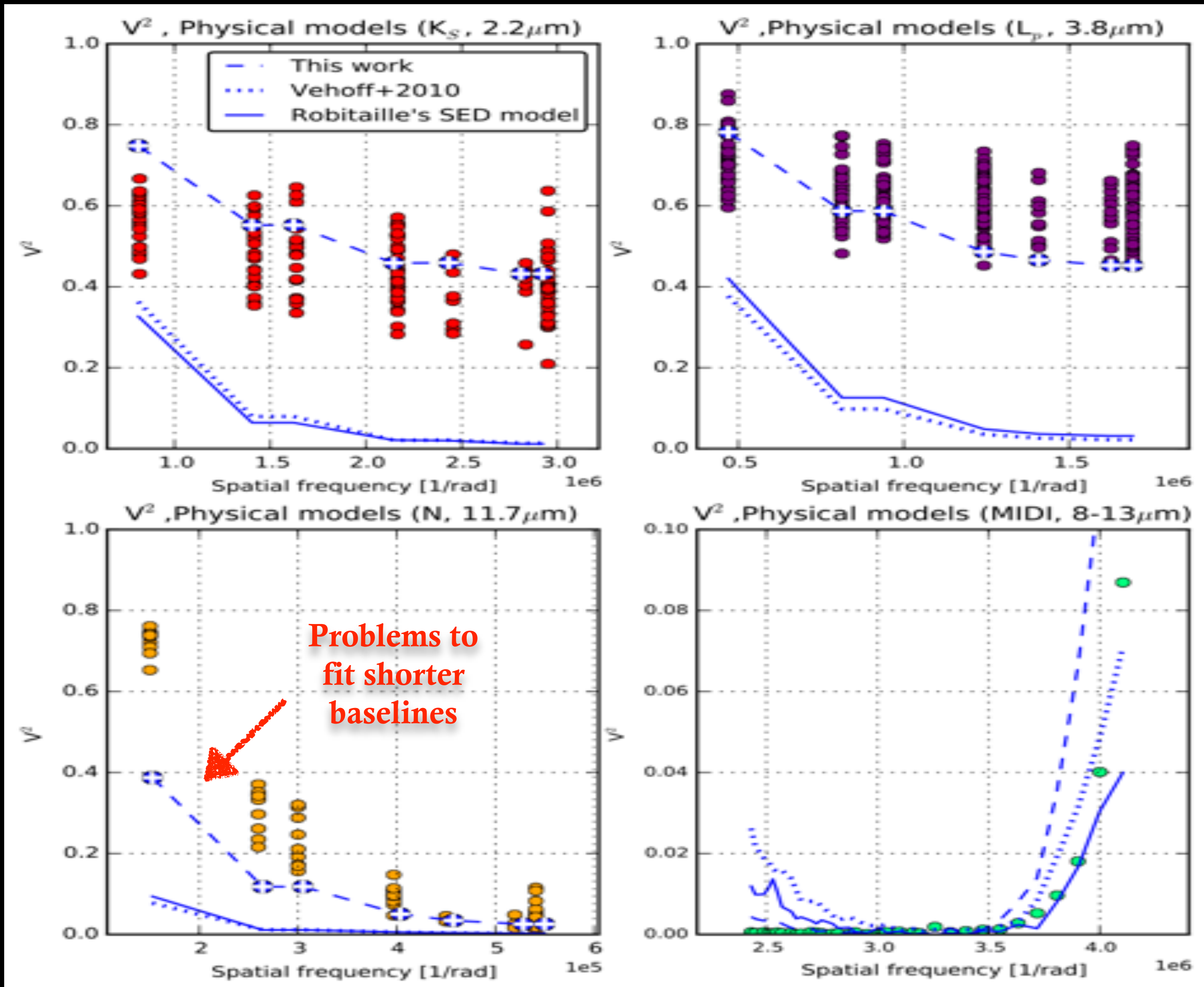
Simultaneous fit to SED+V^2

Initial parameters from Vehoff+2010

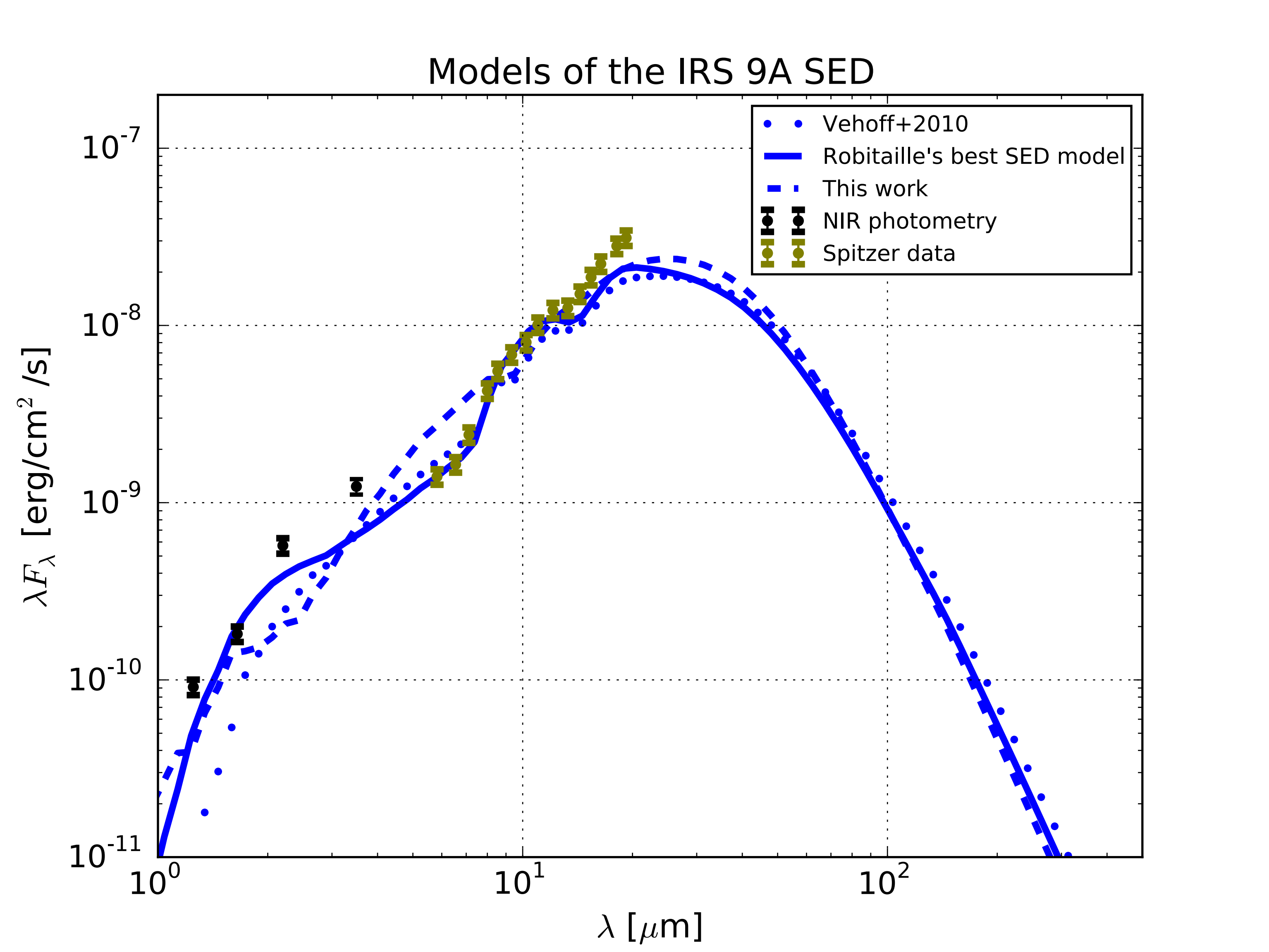
↓

Small grid of models:

- Rout (disk)
- Rin (disk)
- h (disk)
- Rout (envelope)
- Inclination

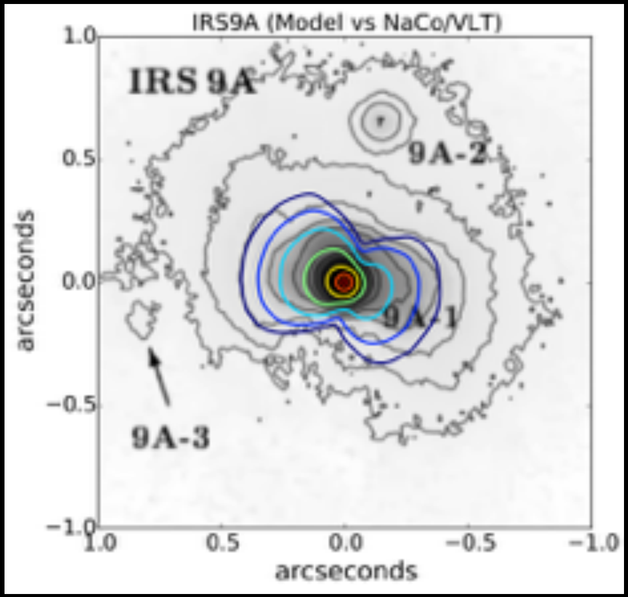


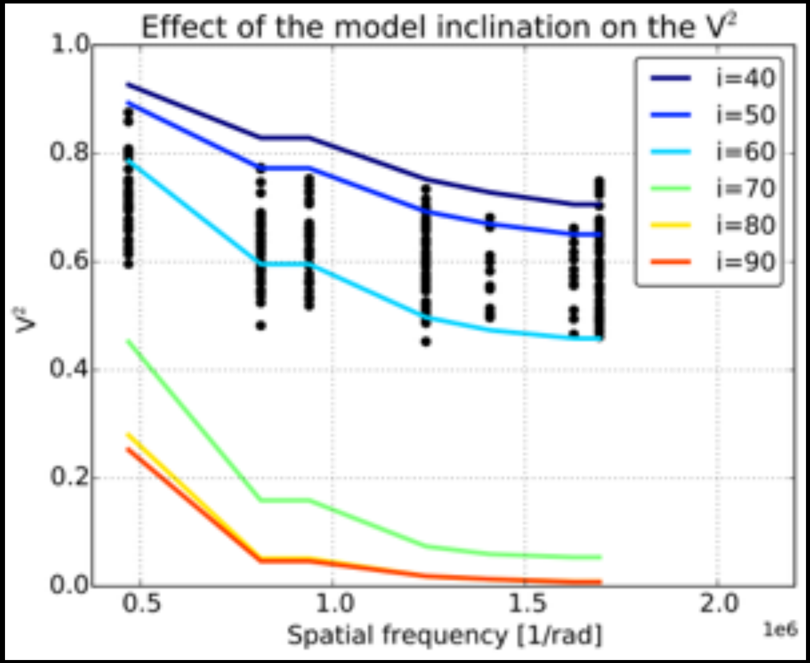
Sanchez-Bermudez et al., 2014 (submitted to A&A)

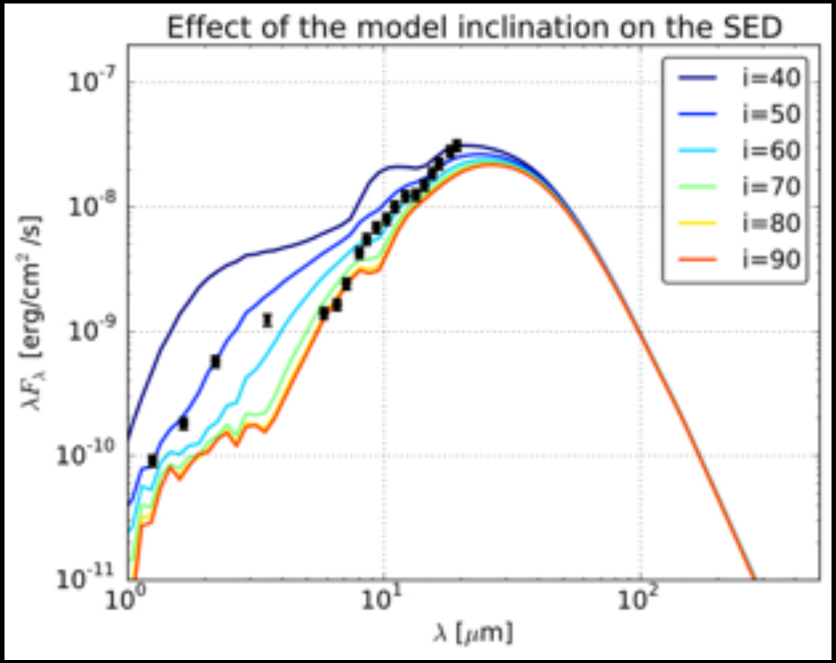


Models of the IRS 9A SED
Vehoff+2010
Robitaille's best SED model
This work
NIR photometry
Spitzer data
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{0}
10^{1}
10^{2}
λF_λ [erg/cm^2 /s]
λ [μm]

- **Disk (outer radius):** 80+/- 20 AU
- **Disk (inner radius):** 10 AU [prev: 25 AU]
- **Envelope:** 7000 AU [prev:10^5 AU]
- **Inclination:** 60˚ [prev: ~85˚ AU]



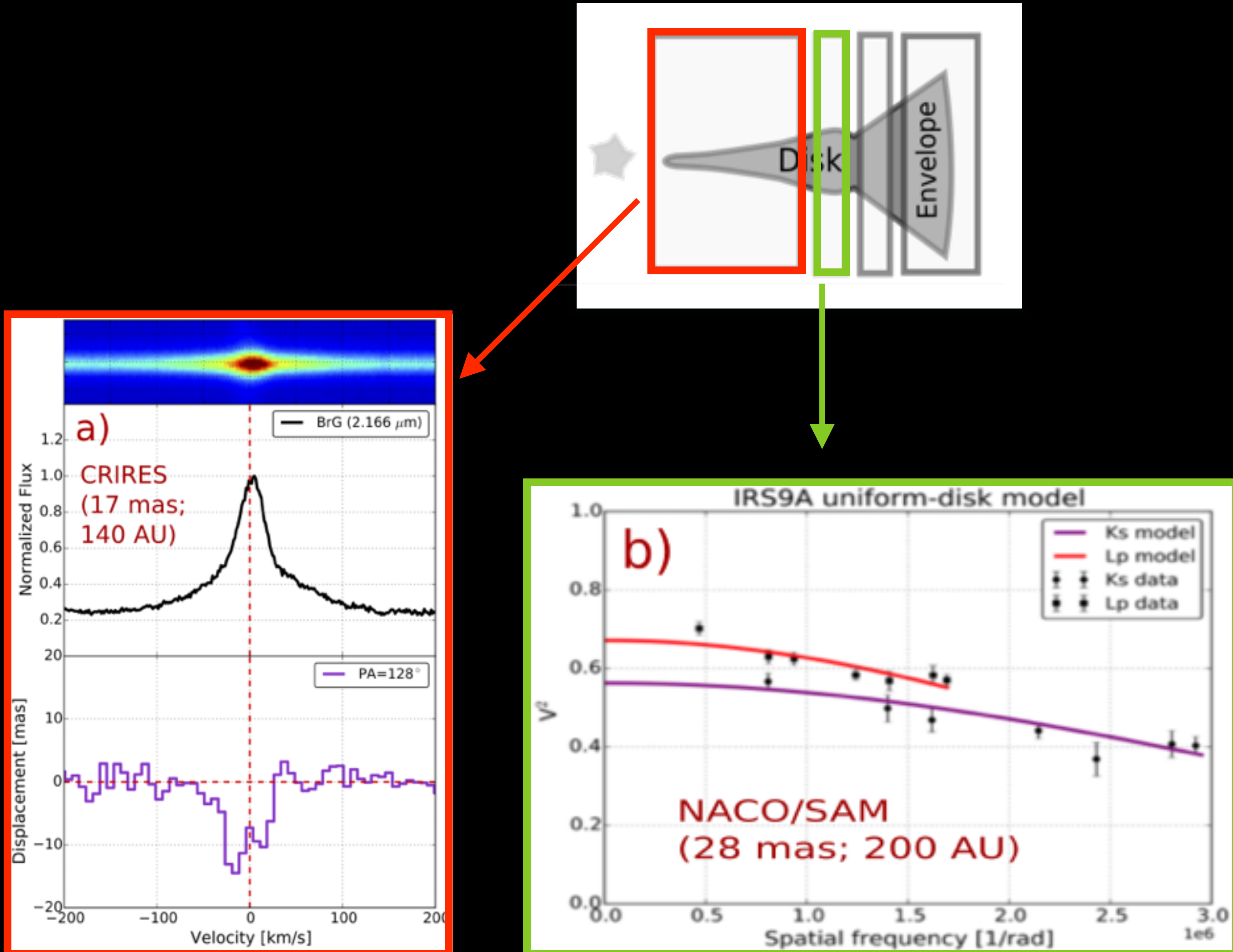


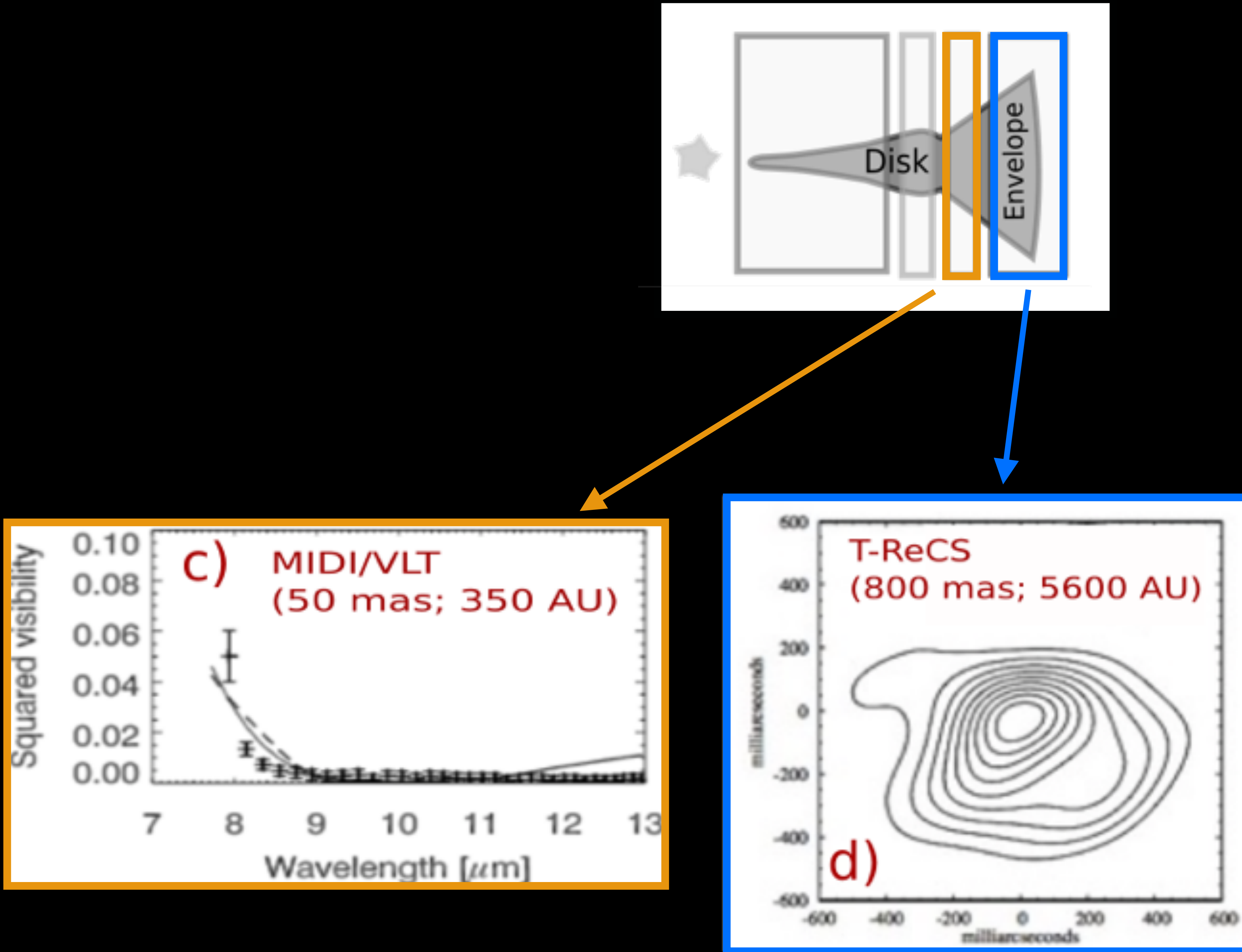


SUMARIZING…

1

Optical interferometry allows to study the physics and morphology of MYSOs (e.g., IRS9A)


Disk
Envelope
a)
CRIRES
(17 mas;
140 AU)
BrG (2.166 μm)
Normalized Flux
PA=128°
Displacement [mas]
Velocity [km/s]
b)
IRS9A uniform-disk model
Ks model
Lp model
Ks data
Lp data
V²
NACO/SAM
(28 mas; 200 AU)
Spatial frequency [1/rad]
1e6

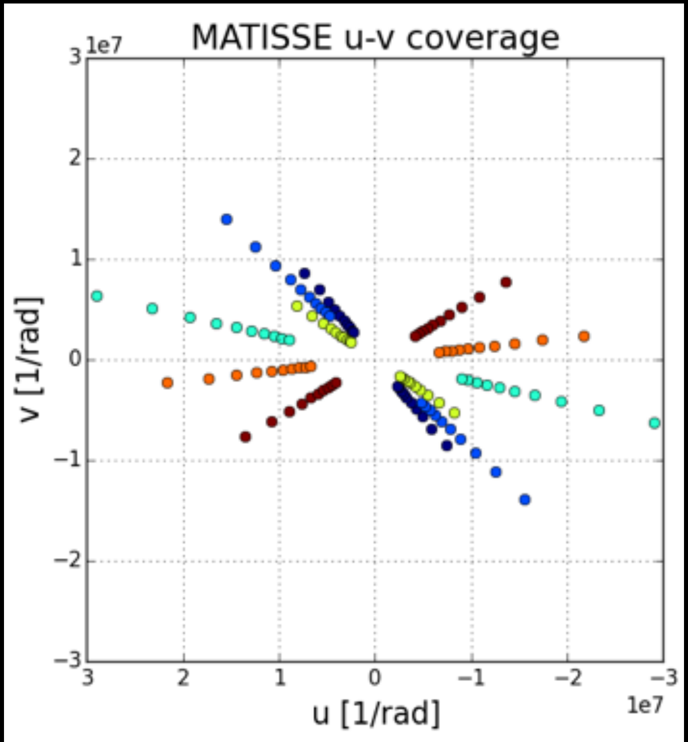

Disk
Envelope
c)
MIDI/VLT
(50 mas; 350 AU)
Squared visibility
0.10
0.08
0.06
0.04
0.02
0.00
7
8
9
10
11
12
13
Wavelength [μm]
T-ReCS
(800 mas; 5600 AU)
d)
600
400
200
0
-200
-400
-600
milliarcseconds
milliarcseconds

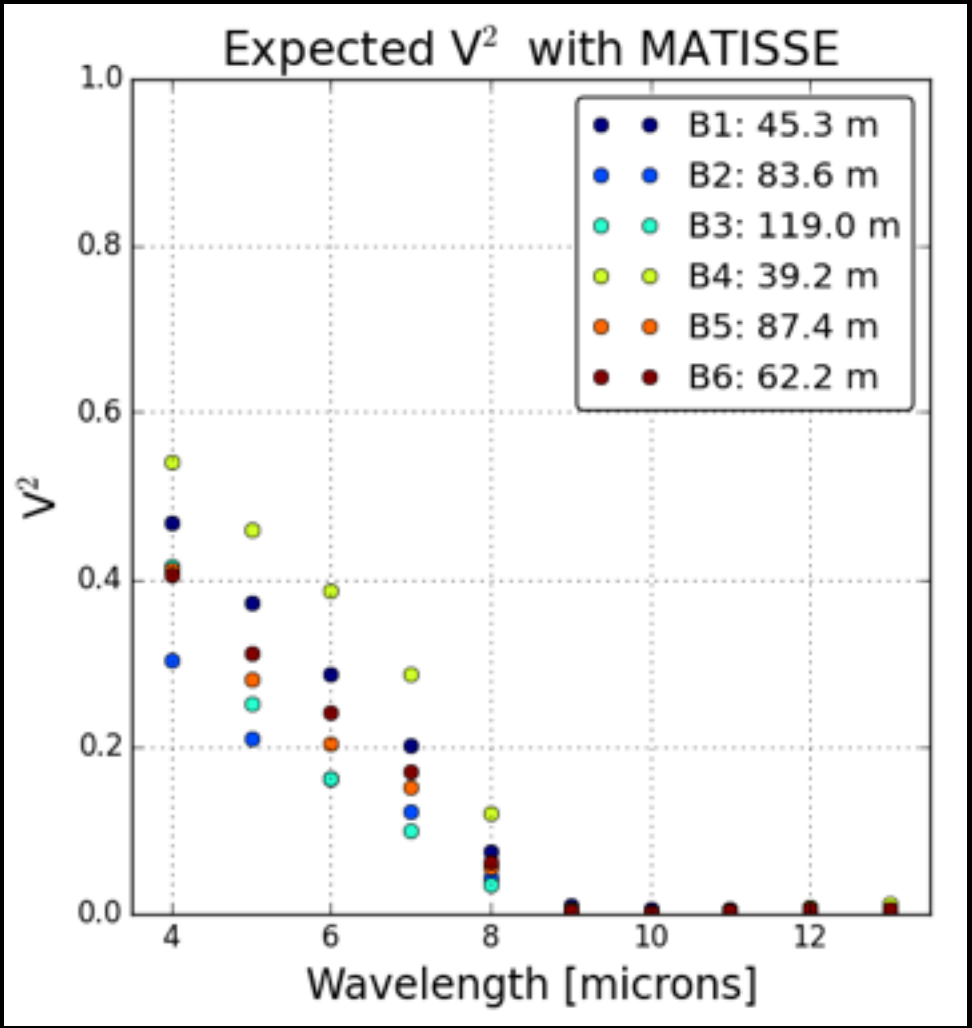
2

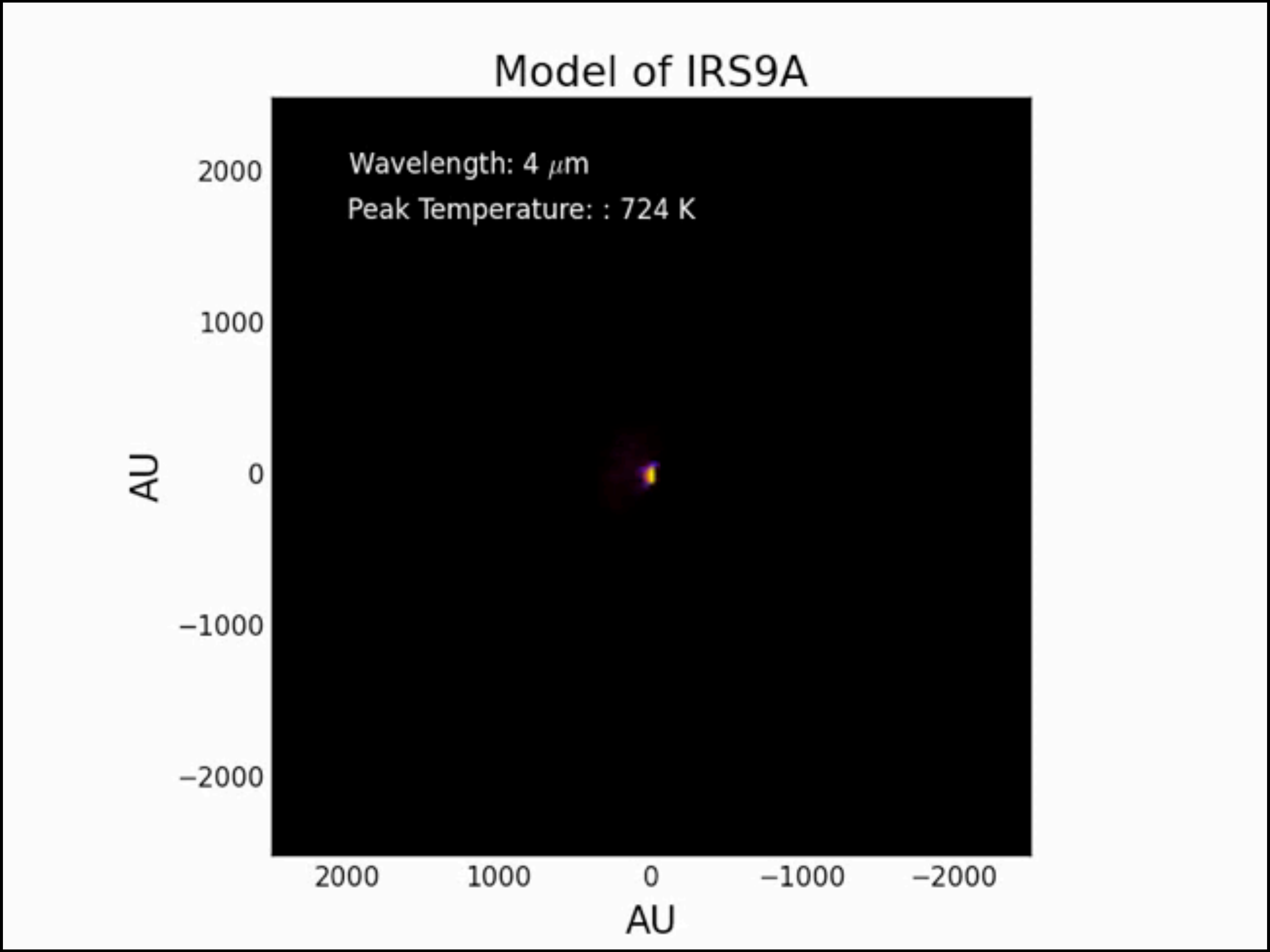
New observations with the 2nd. generation of VLTI instruments will serve to better constrain our models

Observations of IRS9A with MATISSE

- (u-v) coverage with ASPRO
- 6 baselines (UTs)
- 4um-13um (L-N)
- Θmax=7mas (49 AU)







Model of IRS9A
Wavelength: 4 μm
Peak Temperature: : 724 K
2000
1000
0
−1000
−2000
AU
2000
1000
0
−1000
−2000
AU

Thank you!