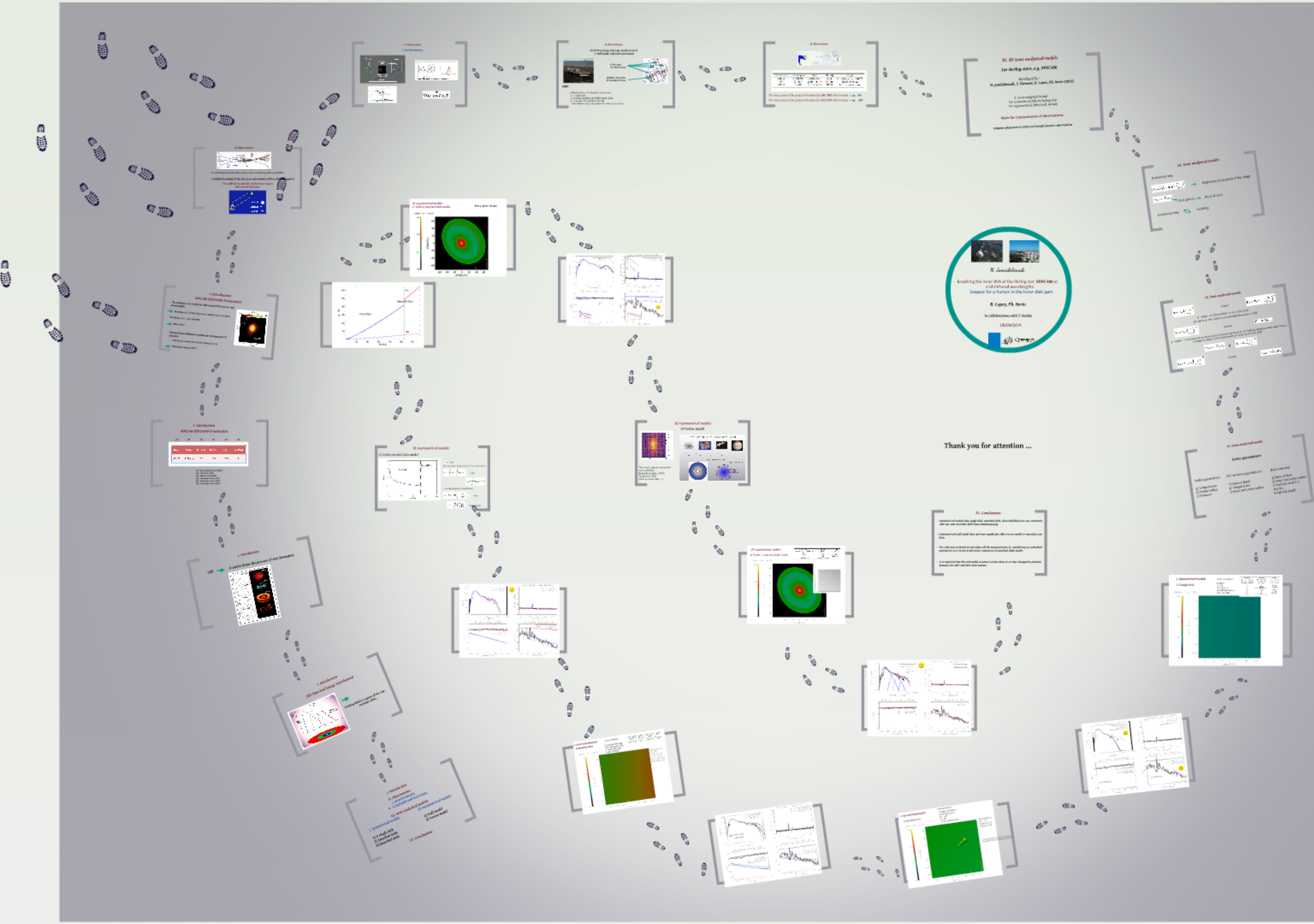


Resolving the inner disk of the Herbig star MWC480 at mid-infrared wavelengths:
Suspect for a Vortex in the inner disk part
B. Lopez, Ph. Berio
Thank you for attention ...

N. Jamialahmadi

Resolving the inner disk of the Herbig star **MWC480** at mid-infrared wavelengths: **Suspect for a Vortex in the inner disk part**

B. Lopez, Ph. Berio

In Collaborations with T. Ratzka

08/04/2014

ESO

Observatoire de la CÔTE d'AZUR

I. Introduction

II. Observations:

i. Interferometry

ii. VLTI/MIDI and Keck data

III. Semi-analytical models:

i. Symmetrical models:

1) A single disk
2) Attached disks
3) Detached disks

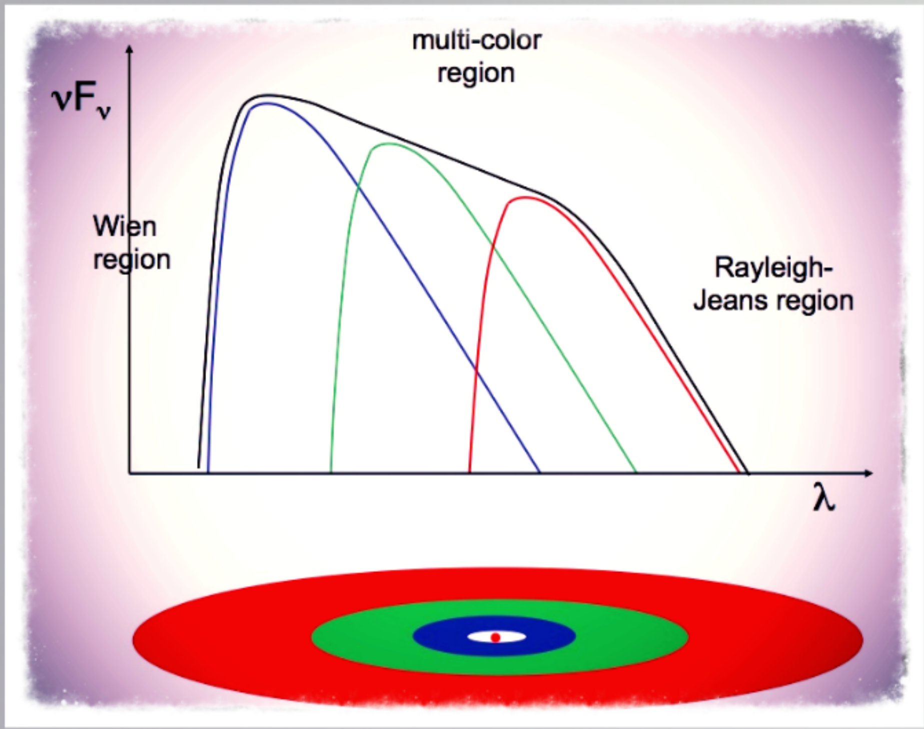
ii) Asymmetrical models:

1) Wall model
2) Vortex model

IV. Conclusions

I. Introduction

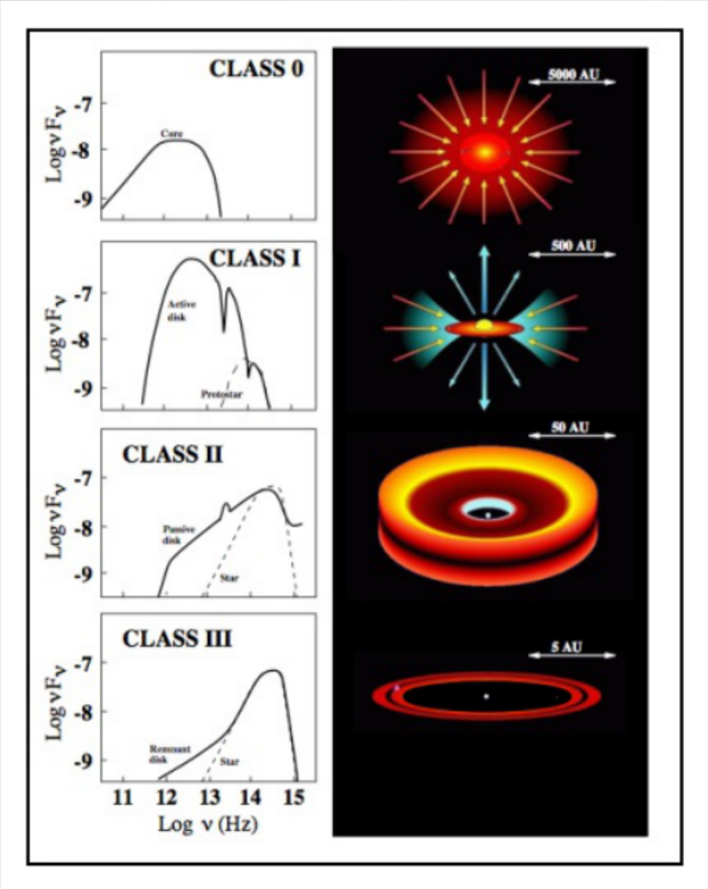
SED (Spectral Energy Distribution)



Probing distinct regions of the star, envelope, disk,....

I. Introduction

SED → *A tool to know the process of star formation*



I. Introduction

MWC480 (HD31648) Presentation

(1)	(2)	(3)	(4)	(5)	(6)
D (pc)	SpType	$M_\star$ [$M_\odot$]	$R_\star$ [$R_\odot$]	$L_\star$ [$L_\odot$]	Age(Myr)
137±31	A2/3ep+sh	1.8	2.1	23.7	6

(1) : Van Leeuwen et al. (2007)
(2) : Thi et al. (1994)
(3) : Simon et al. (2000)
(4) : Mannings et al. (1997)
(5) : Mannings et al. (1997)
(6) : Mannings et al. (1997)

I. Introduction

MWC480 (HD31648) Presentation

- *The existence of a Keplerian disk around this star at mm wavelengths.*

→ *Mannings et al. (1997); Simon et al. (2000); Pietu et al. (2007)*

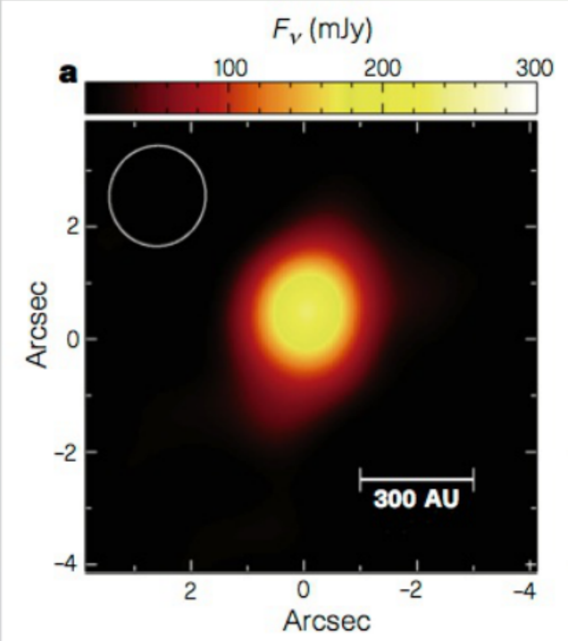
- *IR excess, 2.2 - 12.5 micron*

→ *Sitko (1981)*

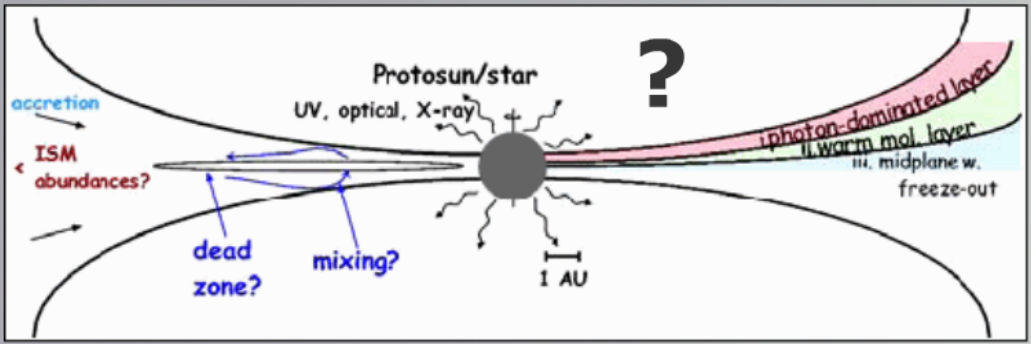
- *Thermal dust millimeter-continuum and gaseous CO emission*

  Disk with an extent of 85 AU and inclination of 30

→ *Mannings & Sargent (1997)*



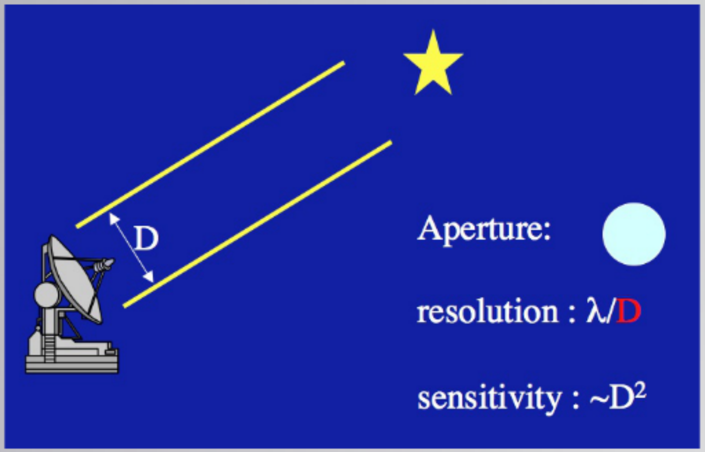
II. Observations



To understand how planetary systems form in the dusty disk around PMS:

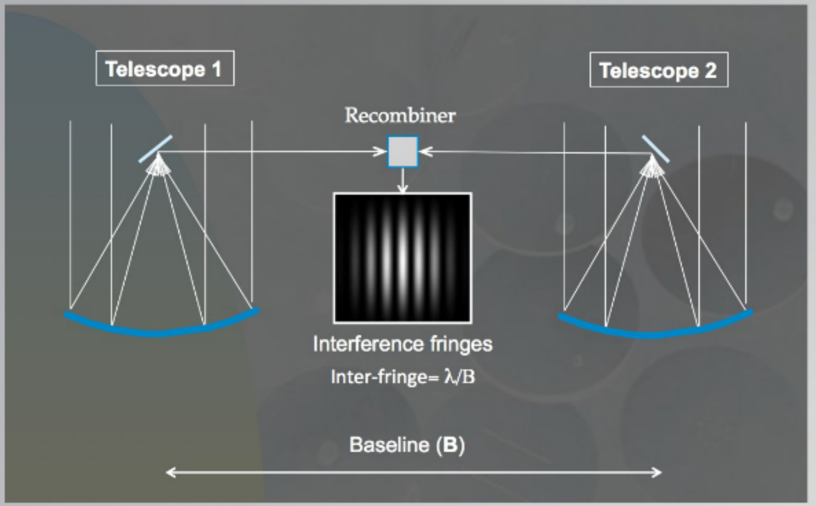
A detailed knowledge of the structure and evolution of these disks is required

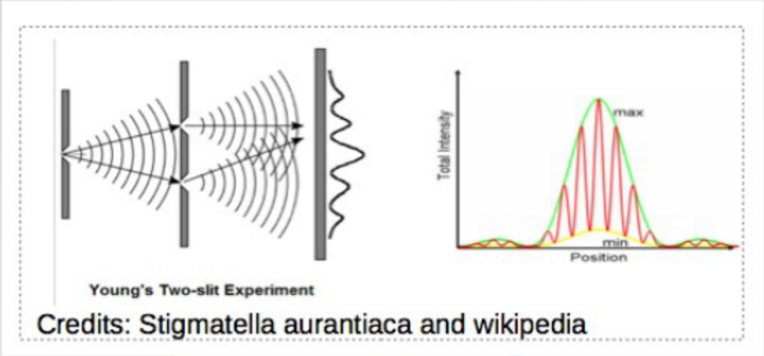
Very difficult to spatially resolve these regions with current telescopes

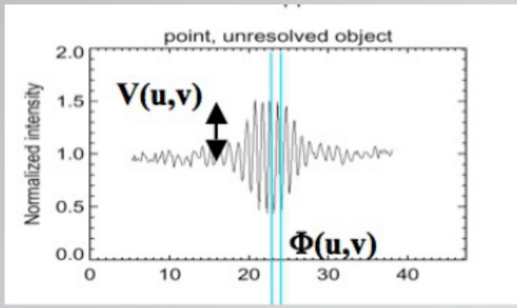


II. Observations

i. Interferometry :



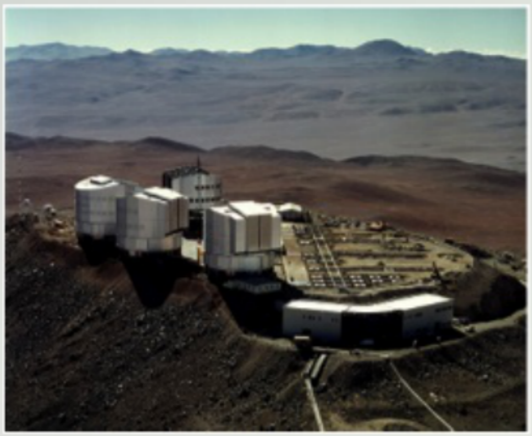




$$\hat{V}(u,v) \overset{FT}{\Leftrightarrow} I(\alpha,\beta)$$

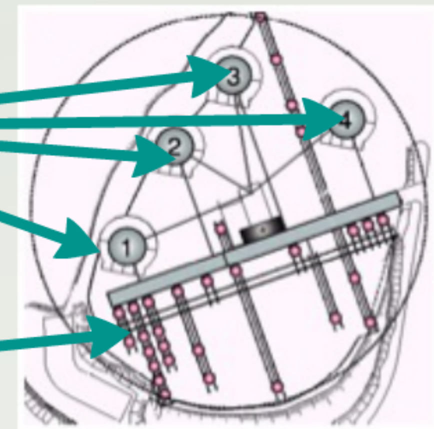
II. Observations

VLTI (Very Large telescope Inerferometer) / MIDI (Mid- Infrared Instrument)



4 Telescopes
UT Fixed D=8.2m

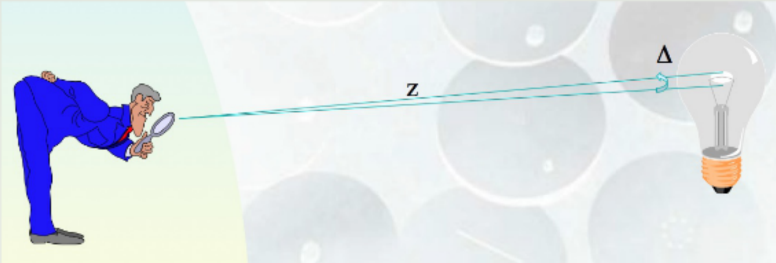
Auxiliary Telescopes
AT movables D=1.6m



MIDI :

1) Mid-infrared (in N band) 8-13 microns
2) 2 telescopes
3) Visibility modulus and differential phase
4) Low spectral resolution (R=200)
5) Maximum spatial resolution of 12 mas at 10 micron

II. Observations



Instrument	Telescopes	Date	B_p [m]	Origin
MIDI	UT2-UT3	2007–02–4	42.8	Di Folco et al. (2007)
KI	K1-K2	2008–11–18	84.90	Keck Archive
MIDI	K0-J3	2013–12–29	28.55	Our observations

The orientation of the projected baseline for **2007** MIDI observations → **50°**

The orientation of the projected baseline for **2013** MIDI observations → **140°**

III. 2D Semi-analytical models

For Herbig stars, e.g. MWC480

Developed by :

N. Jamilahmadi, S. Flament, B. Lopez, Ph. Berio (2012)

A Semi-analytical model:
For symmetrical disks including dust
For asymmetrical disks (wall, vortex)

Made for interpretation of observations:

Compute photometric (SED) and interferometric observations

III. Semi-analytical models

1) Intensity map

$$B_\lambda(T_r)\left[1 - exp(-\frac{\tau_{\lambda,r}}{cosi})\right]$$ → Brightness of the pixels of the image

$$\tau_{\lambda,r} = \Sigma_r \kappa_\lambda$$

→ Dust opacity → Thi et al. 2010

1) Intensity map ⇄ Visibility

III. Semi-analytical models

$$T_r = T_{in} \left(\frac{r}{r_{in}} \right)^{-q}$$

Where

$$T_{in} = T_g = T_\star \left(\frac{R_\star}{2r_{in}} \right)^{\frac{1}{2}}$$

q ranges 0.5 (flared disks) to 0.75 (flat disks)

(Pringle et al. 1981; Adams et al. 1988; Hillenbrand et al. 1992)

$$\Sigma_r = \Sigma_{in} \left(\frac{r}{r_{in}} \right)^{-p}$$

Where

$$\Sigma_{in} \propto M_{dust}$$

p ranges 1 (constant mass accretion rate at constant viscosity) to 1.5 (MMSN : Minimum Mass Solar Nebula)

(Chiange & Goldrich 1997; Dullemond et al. 2001; Eisner et al. 2009)

$$\tau_{\lambda,r} = \Sigma_r \kappa_\lambda \quad \& \quad \Sigma_r = \Sigma_{in} \left(\frac{r}{r_{in}} \right)^{-p}$$

$$\tau_{\lambda,r} = \tau_{\lambda,in} \left(\frac{r}{r_{in}} \right)^{-p}$$

Where

$$\tau_{\lambda,in} = \Sigma_{in} \kappa_\lambda$$

III. Semi-analytical models

Enter parameters

Stellar parameters:

1) Temperature
2) Stellar radius
3) Distance

BrY emission parameters:

1) Optical depth
2) Temperature
3) Inner and outer radius

Dust emission:

1) Mass of dust
2) Inner and outer radius
3) Inclination & P.A.
4) p & q
5) Optical depth

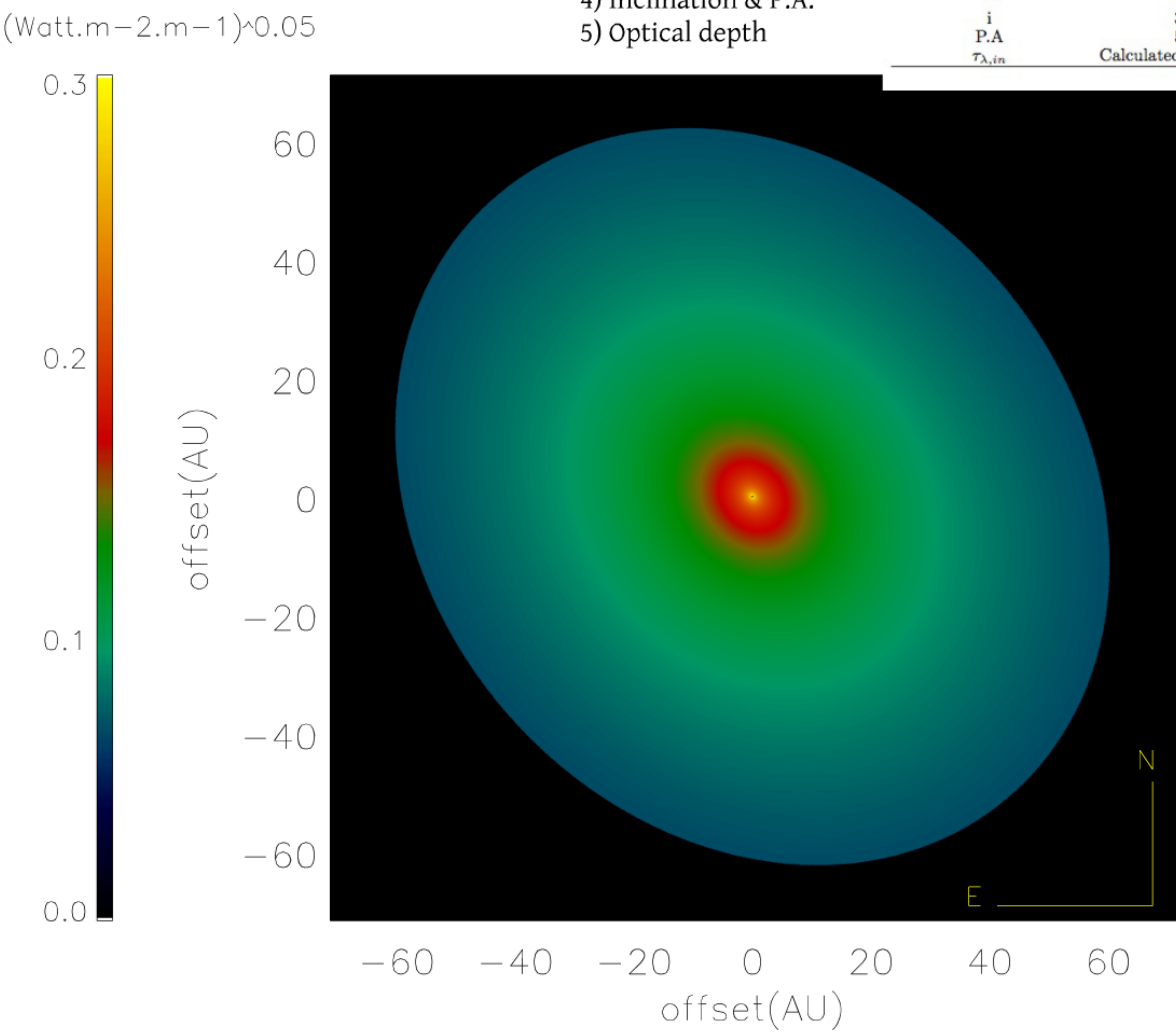
i. Symmetrical models

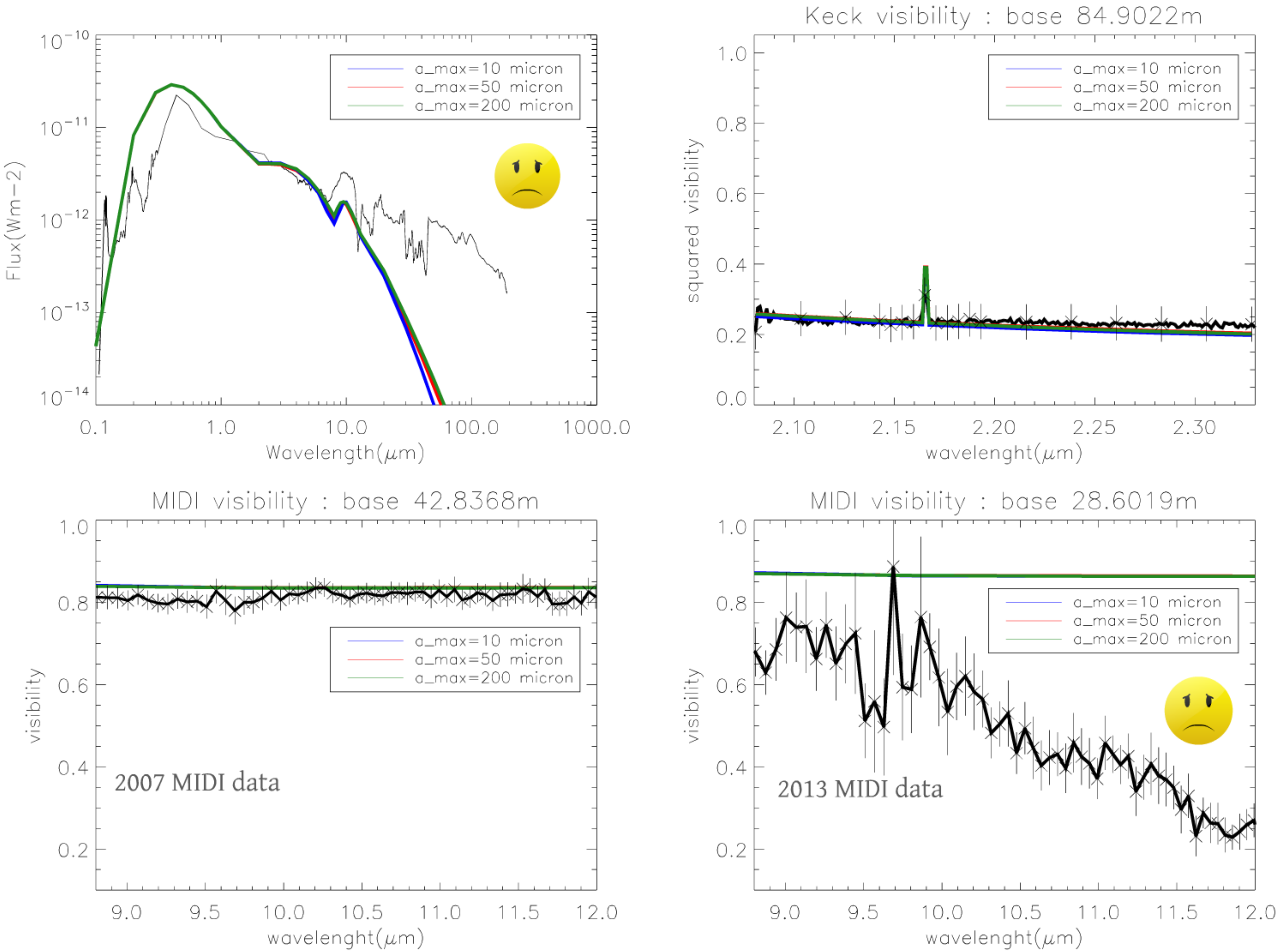
1) Single disk

Free parameters:

1) Mdust
2 p & q
3) r_in & r_out
4) Inclination & P.A.
5) Optical depth

Parameters	Best value	Range
M_{dust} (a_{max}=10 μm)	2.4×10^{-11} $M_\odot$	$10^{-12}...10^{-9}$ $M_\odot$
M_{dust} (a_{max}=50 μm)	0.5×10^{-10} $M_\odot$	$10^{-12}...10^{-9}$ $M_\odot$
M_{dust} (a_{max}=200 μm)	10^{-10} $M_\odot$	$10^{-12}...10^{-9}$ $M_\odot$
p	1.5	0.1...1.98
q	0.5	0.4...0.9
r_{in}	0.22AU	0.1...0.4AU
T_{in}	Calculated from Eq.4	
r_{out}	60AU	8...100AU
i	37°	20°...80°
P.A	58°	10°...300°
$\tau_{\lambda,in}$	Calculated from $\Sigma_{in}\kappa_\lambda$	



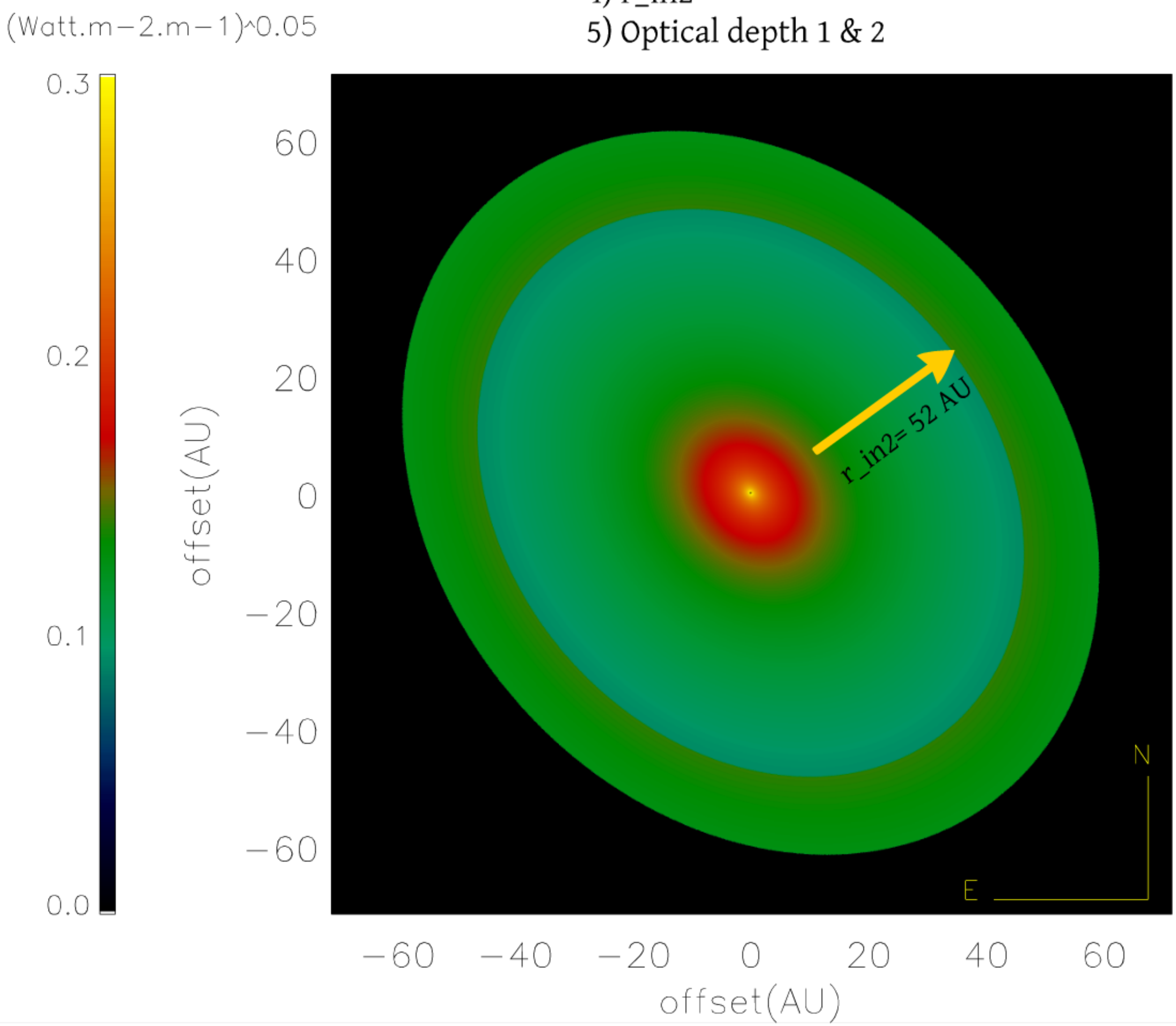

Flux(Wm−2)
Wavelength(μm)
a_max=10 micron
a_max=50 micron
a_max=200 micron
Keck visibility : base 84.9022m
squared visibility
wavelenght(μm)
MIDI visibility : base 42.8368m
visibility
2007 MIDI data
MIDI visibility : base 28.6019m
2013 MIDI data

i. Symmetrical models

2) Attached disks

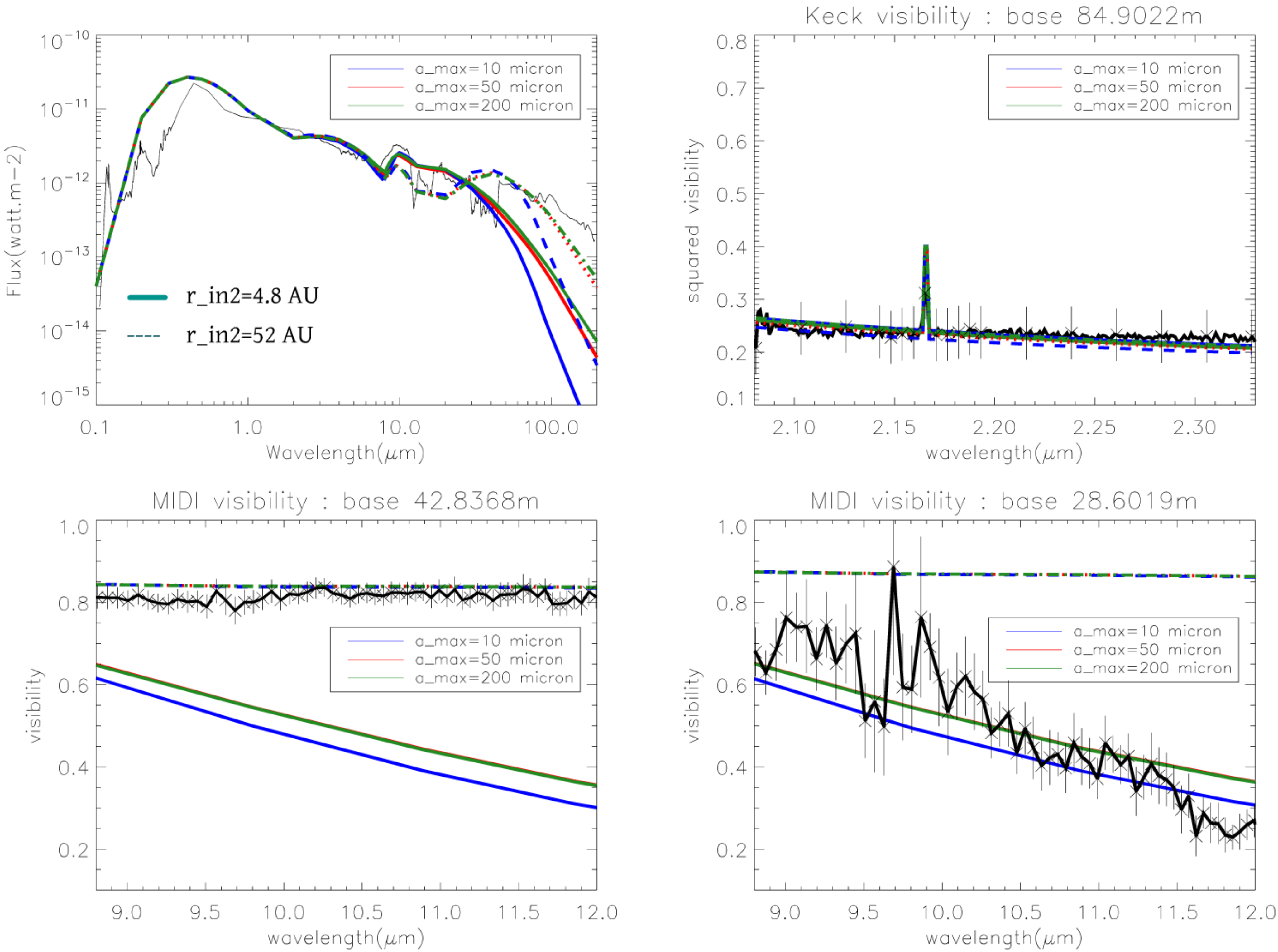
Free parameters :

1) Mdust1 & Mdust2
2 p1 & q1 ; p2 & q2
3) r_out1
4) r_in2
5) Optical depth 1 & 2



Inclination= 37°
P.A. = 58°
r_in1= 0.22 AU
r_out2= 62 AU

A first immediate interes
the model infrared radia



Flux(watt.m−2)
Wavelength(μm)
a_max=10 micron
a_max=50 micron
a_max=200 micron
r_in2=4.8 AU
r_in2=52 AU
Keck visibility : base 84.9022m
squared visibility
wavelength(μm)
MIDI visibility : base 42.8368m
visibility
MIDI visibility : base 28.6019m

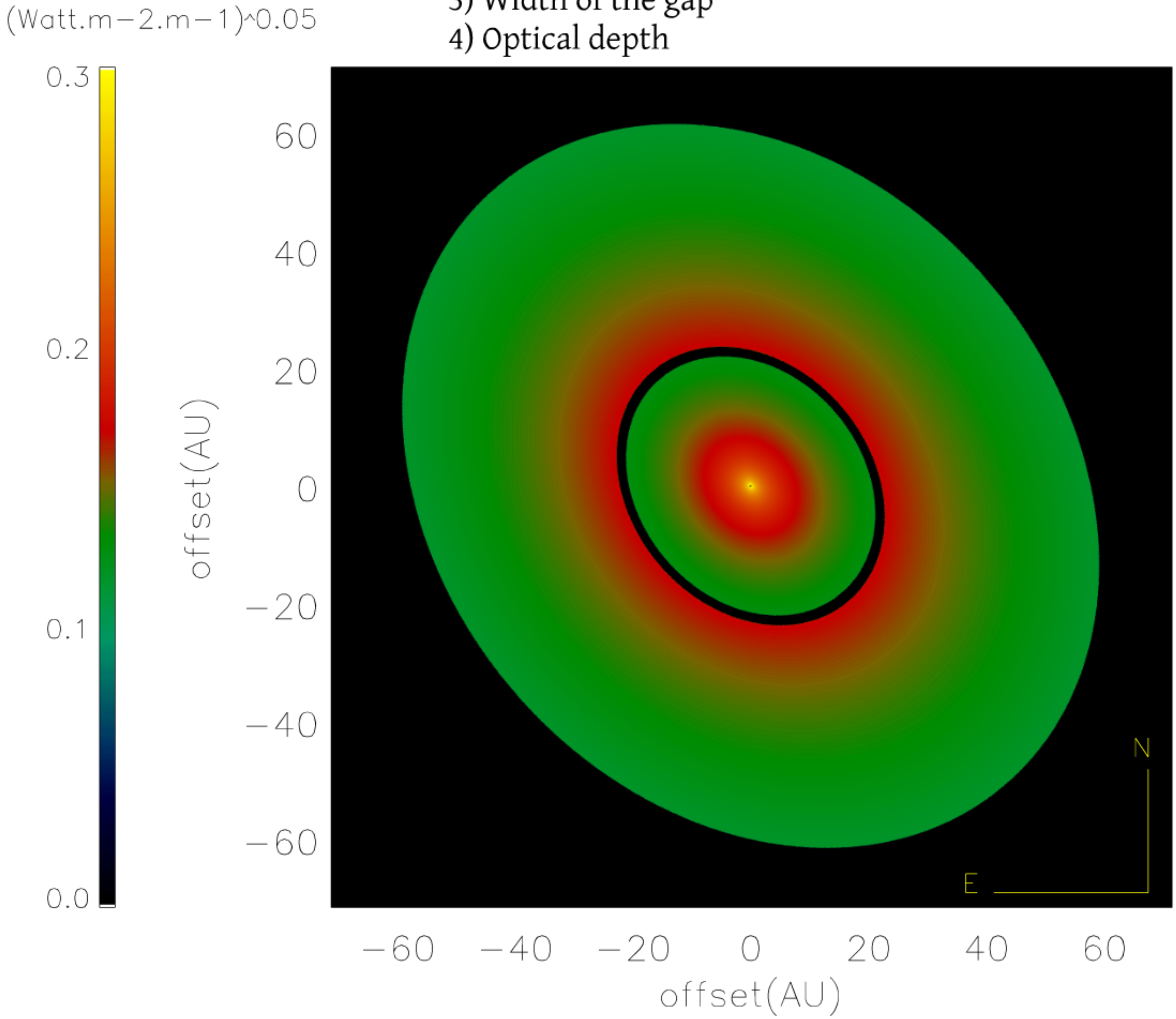
i. Symmetrical models

3) Detached disks

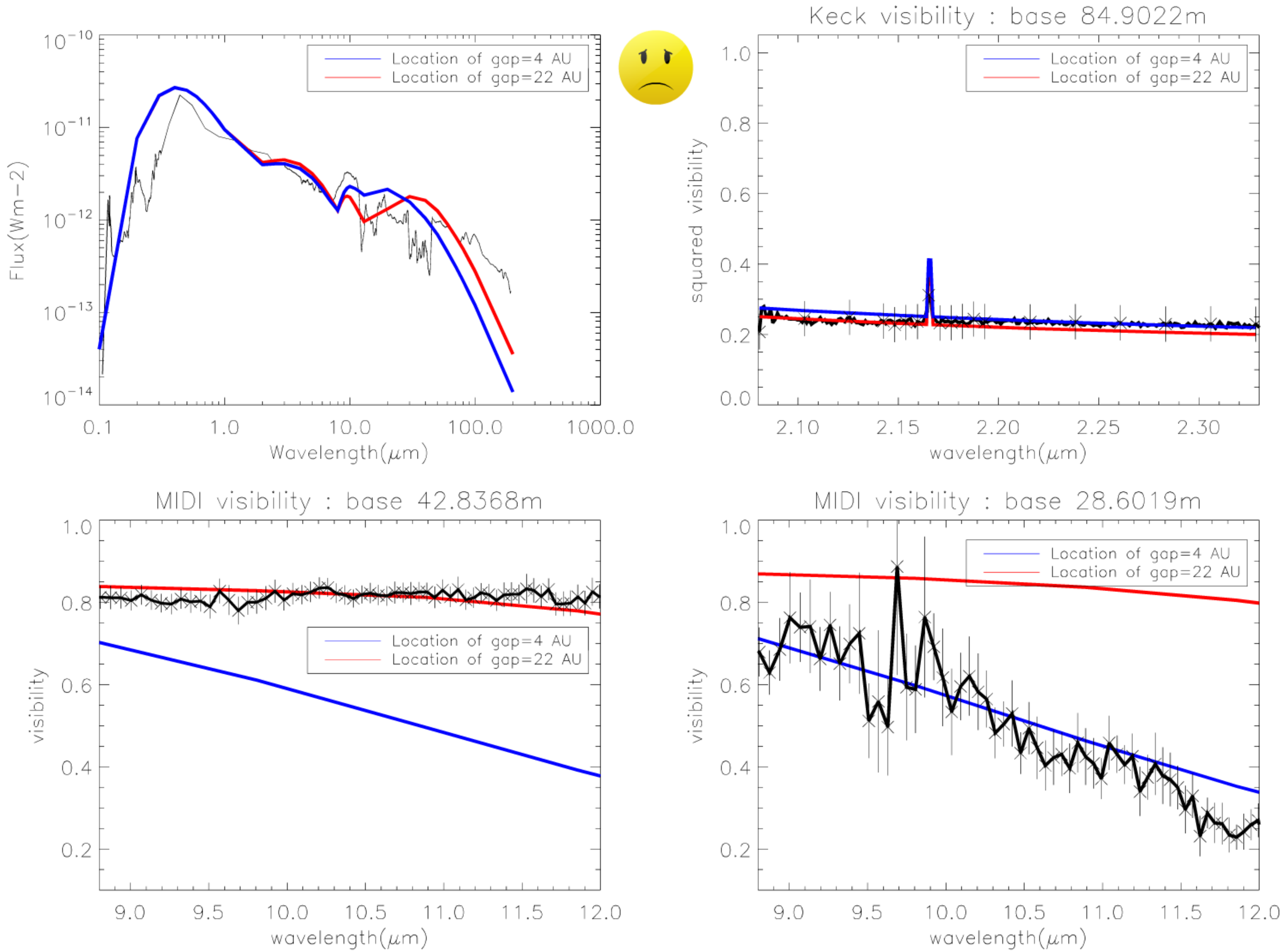
Free parameters :

1) Location of the gap
2) M_dust1 & M_dust2
3) Width of the gap
4) Optical depth

Parameters	Best value	Best value	range
Location of the gap	r_{out1}=4 AU	r_{out1}=22 AU	
M_{dust1}	$2 \times 10^{-11}\ M_{\odot}$	$4 \times 10^{-8}\ M_{\odot}$	$10^{-12}...10^{-7}\ M_{\odot}$
M_{dust2}	$0.6 \times 10^{-10}\ M_{\odot}$	$0.6 \times 10^{-7}\ M_{\odot}$	$10^{-11}...10^{-6}\ M_{\odot}$
Width of the gap	2 AU	3 AU	1–6 AU



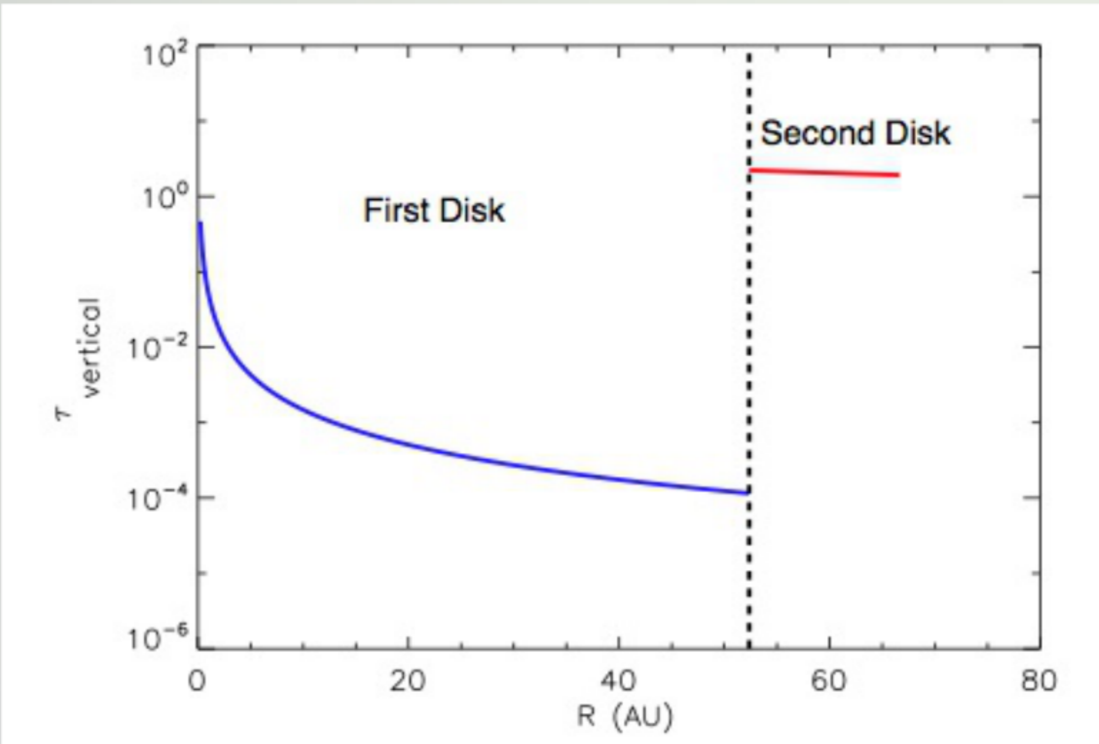
Inclination: 37°
P.A. : 58°
r_in1= 0.22 AU
r_out2= 62 AU
p1=1.5 & p2= 0.6
q1=0.5 & q2= 0.5



Location of gap=4 AU
Location of gap=22 AU
Flux(Wm−2)
Wavelength(μm)
0.1
1.0
10.0
100.0
1000.0
Keck visibility : base 84.9022m
squared visibility
wavelength(μm)
2.10
2.15
2.20
2.25
2.30
MIDI visibility : base 42.8368m
visibility
wavelength(μm)
MIDI visibility : base 28.6019m
visibility
wavelength(μm)
9.0
9.5
10.0
10.5
11.0
11.5
12.0

ii) Asymmetrical models:

1) Wall in attached disks model



h_τ →

The atmosphere height wherever the optical depth =1

$$\tau_{\lambda,r} = \int_{-\infty}^{\infty} d\tau_\lambda = \int_{-\infty}^{\infty} \kappa_\lambda \rho_{r,z} dz$$ →

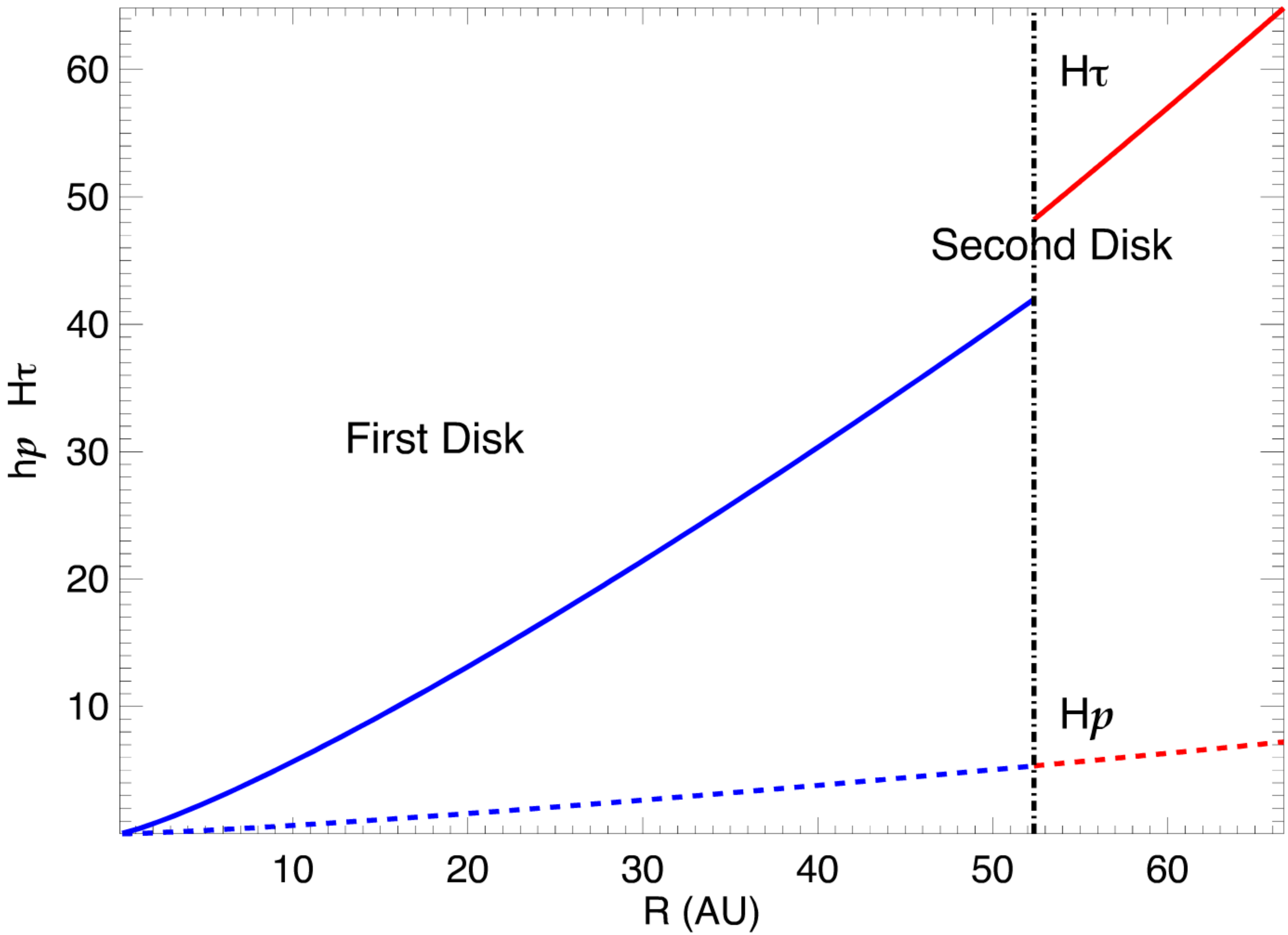
$$\tau_{\lambda,r} = \int_{h_\tau}^{\infty} \kappa_\lambda \rho_{r,z} dz \approx 1$$

From Hydrodynamical equilibrium:

$$\rho_{r,z} = \rho_r exp\left(-\frac{z^2}{2h_p(r)^2}\right)$$ →

$$h_p(r) = \left(\frac{T_r}{T_c}\right)^{\frac{1}{2}} \left(\frac{r^{\frac{3}{2}}}{R_\star^{\frac{1}{2}}}\right)$$

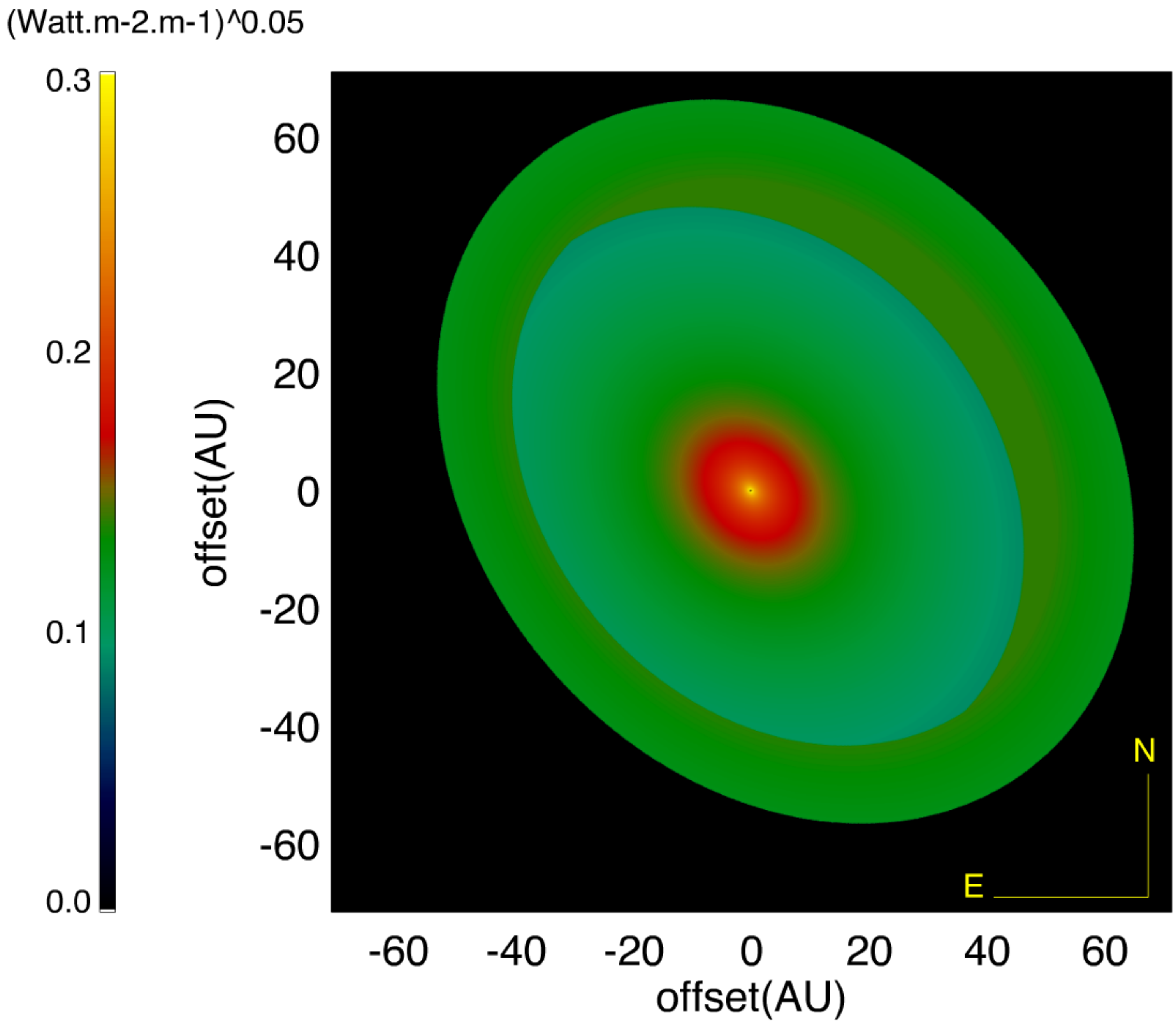
Pressure scale

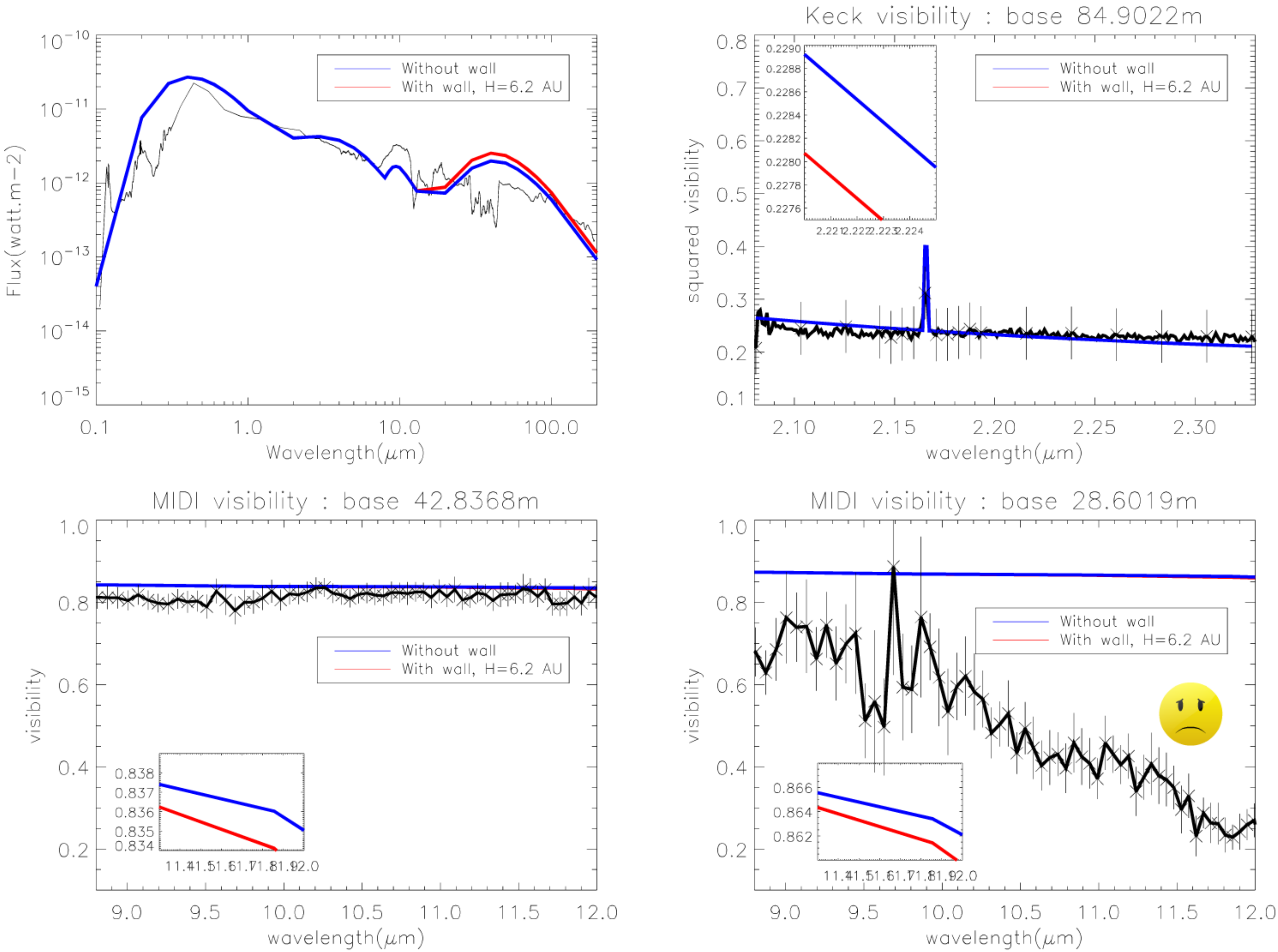


60
50
40
30
20
10
hp Hτ
10
20
30
40
50
60
R (AU)
Hτ
Second Disk
First Disk
Hp

ii) Asymmetrical models:
1) Wall in attached disk models

For r_in2= 52 AU

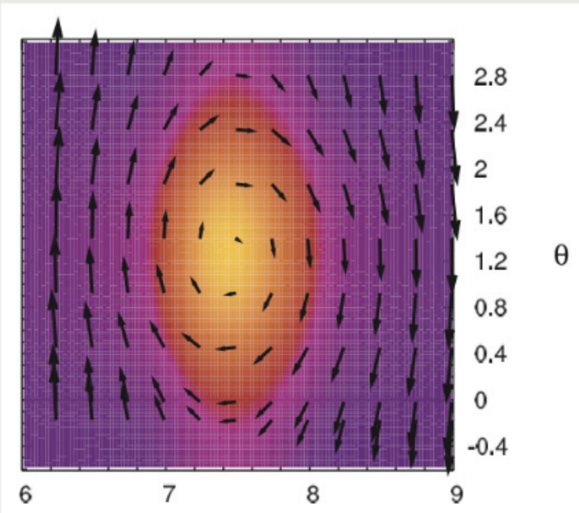


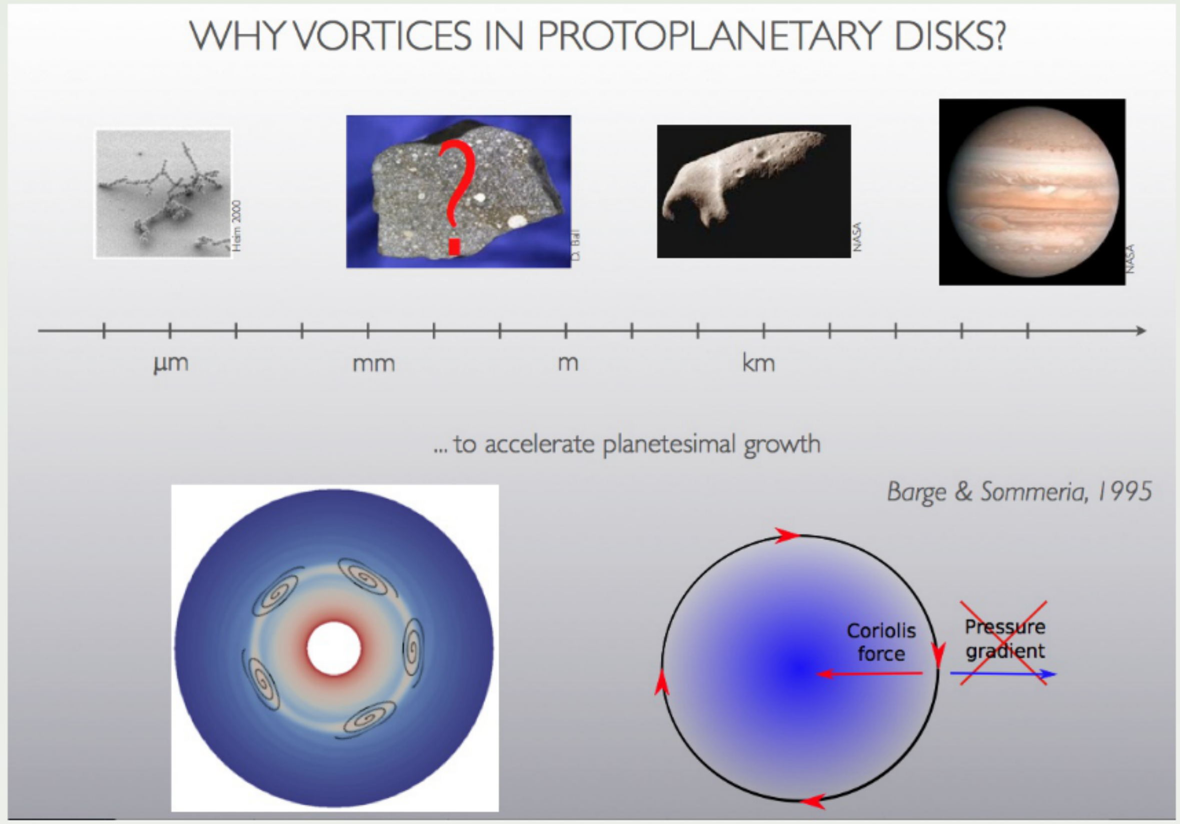


Without wall
With wall, H=6.2 AU
Flux(watt.m−2)
Wavelength(μm)
Keck visibility : base 84.9022m
squared visibility
wavelength(μm)
MIDI visibility : base 42.8368m
visibility
wavelength(μm)
MIDI visibility : base 28.6019m
visibility
wavelength(μm)

ii) Asymmetrical models:

3) Vortex model



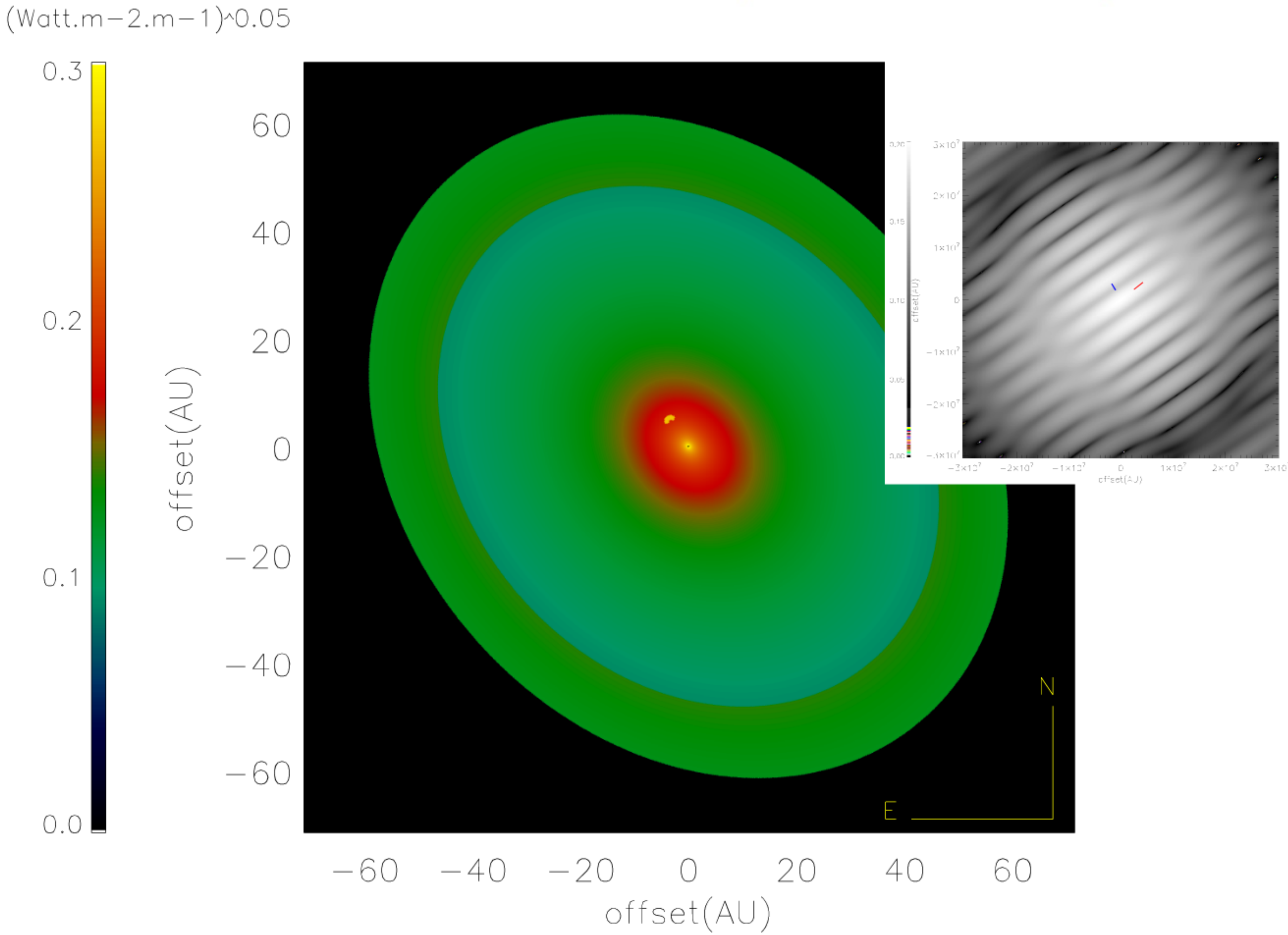


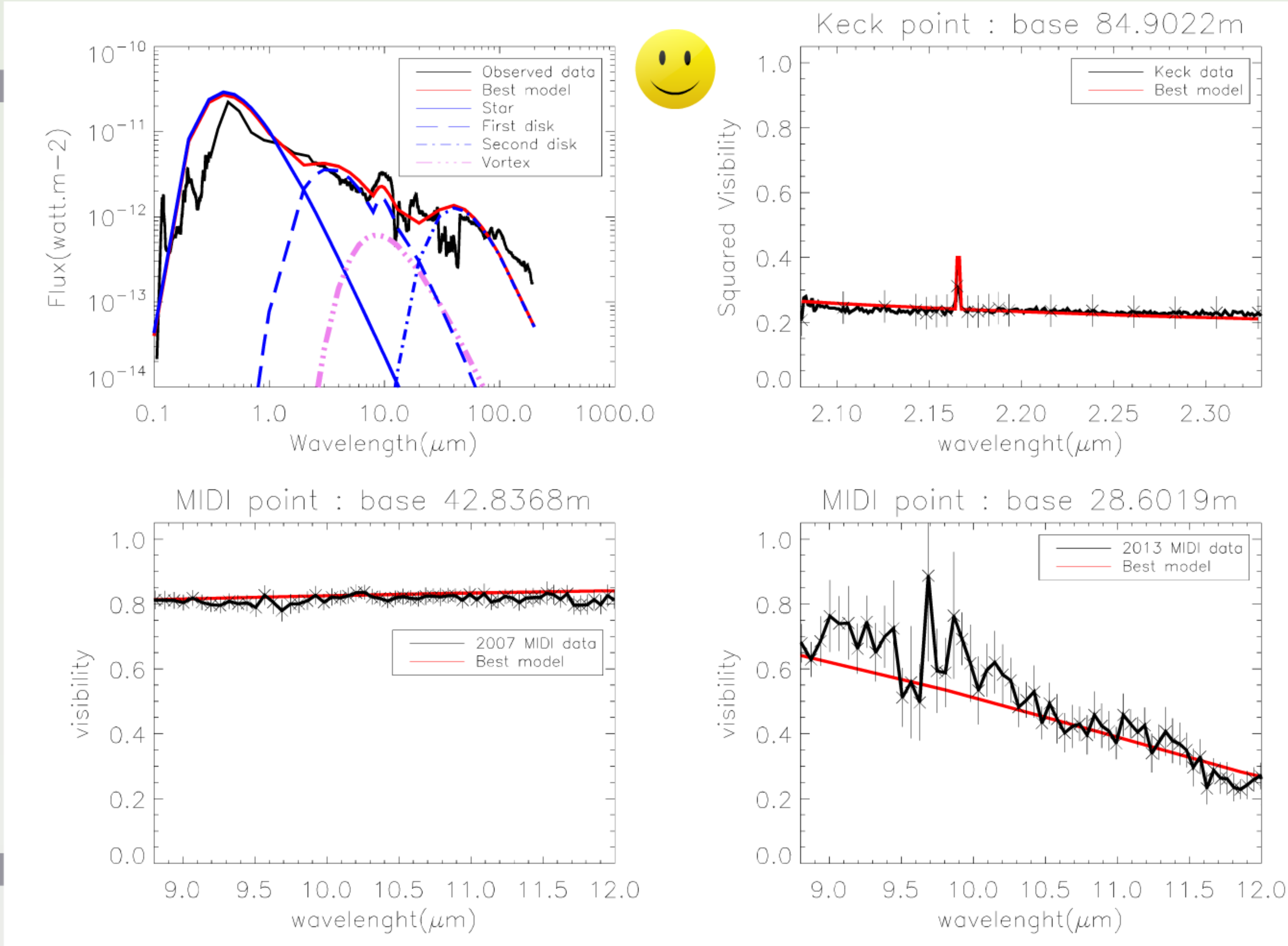
The vortex capture mechanism was studied by :
(Barge & Sommeria 1994;
Tanga et al. 1996;
Johanson et al. 2004, ...)

ii) Asymmetrical models:

2) Vortex in attached disks model

Parameters	Best value	ranges
Distance from the central star	5.5 AU	1–10 AU
Radius	0.8 AU	0.1–2 AU
Width	0.1 AU	0.02–0.8 AU
P.A.	−85°	−180°...200°
Temperature	Calculated from Eq.3	





Observed data
Best model
Star
First disk
Second disk
Vortex
Flux(watt.m−2)
Wavelength(μm)
0.1
1.0
10.0
100.0
1000.0
Keck point : base 84.9022m
Keck data
Best model
Squared Visibility
wavelenght(μm)
2.10
2.15
2.20
2.25
2.30
MIDI point : base 42.8368m
2007 MIDI data
Best model
visibility
wavelenght(μm)
MIDI point : base 28.6019m
2013 MIDI data
Best model
visibility
wavelenght(μm)
9.0
9.5
10.0
10.5
11.0
11.5
12.0

IV. Conclusions

- *Symmetrical models (One single disk, attached disks, detached disks) are not consistent with our 2007 and 2013 MIDI data simultaneously.*

- *Asymmetrical wall model does not have significant effect in our model to reproduce our data.*

- *The only way we found to reproduce all the measurements is, considering an azimuthal asymmetry as a vortex in the inner component of attached disks model.*

- *It is expected that this azimuthal structure at less than 10 AU has changed its position between the 2007 and 2013 observations.*

Thank you for attention …