Theory and Modelling of YSOs

Lucia Klarmann - MPIA - VLTI school - 11.06.21

Theory and Modelling of protoplanetary disks

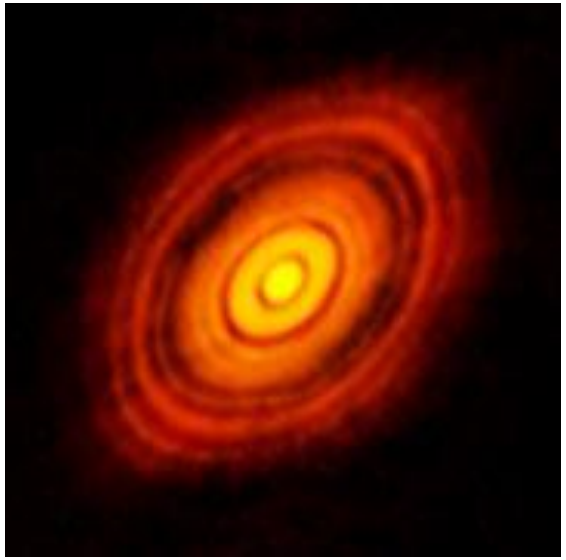
Lucia Klarmann - MPIA - VLTI school - 11.06.21

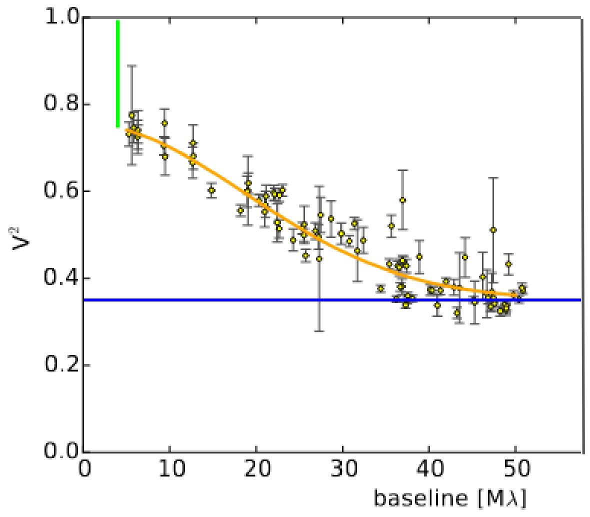
Topics

protoplanetary disks

observations

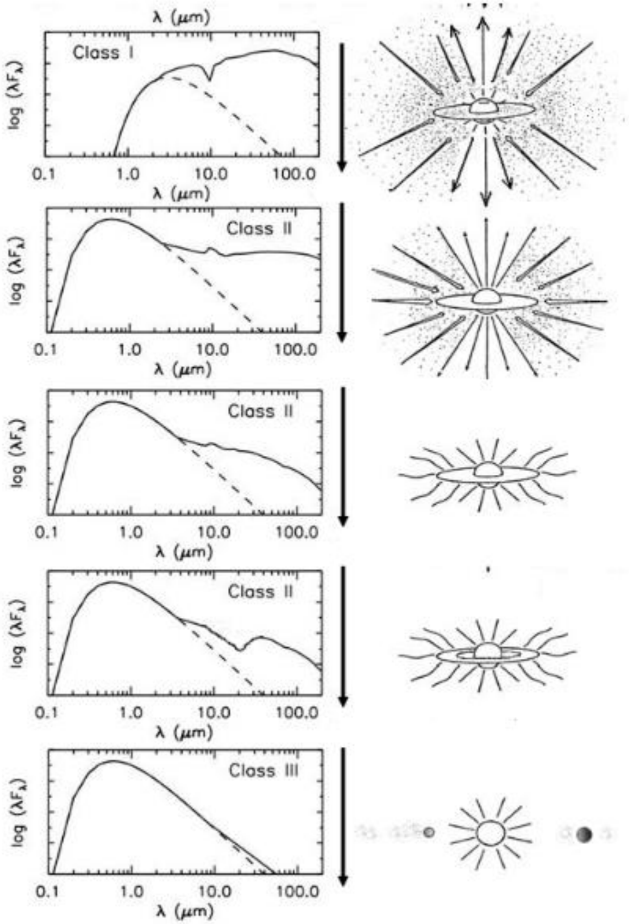
modelling

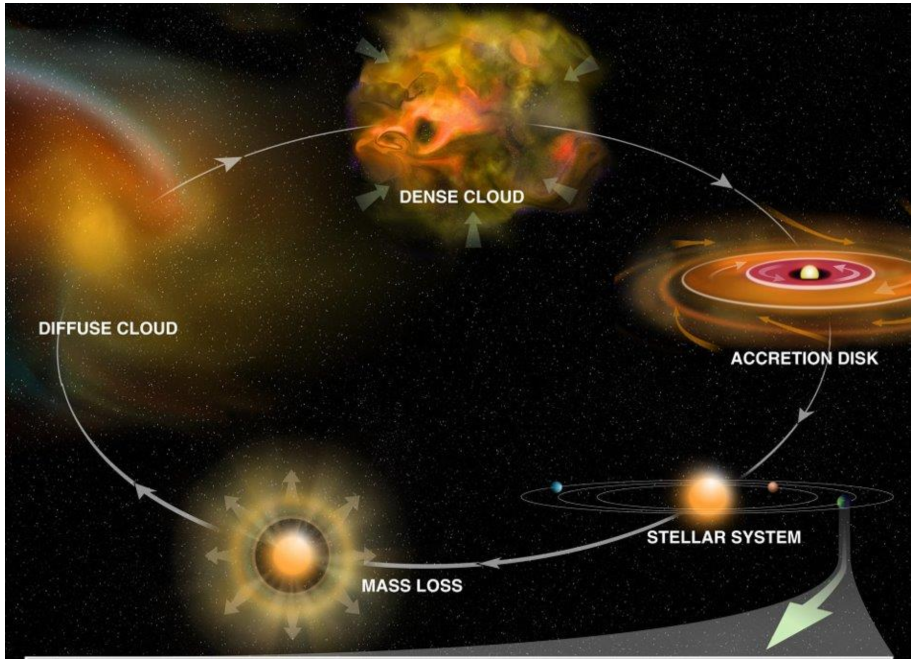




ALMA Partnership+ 2015, Klarmann+ 2017

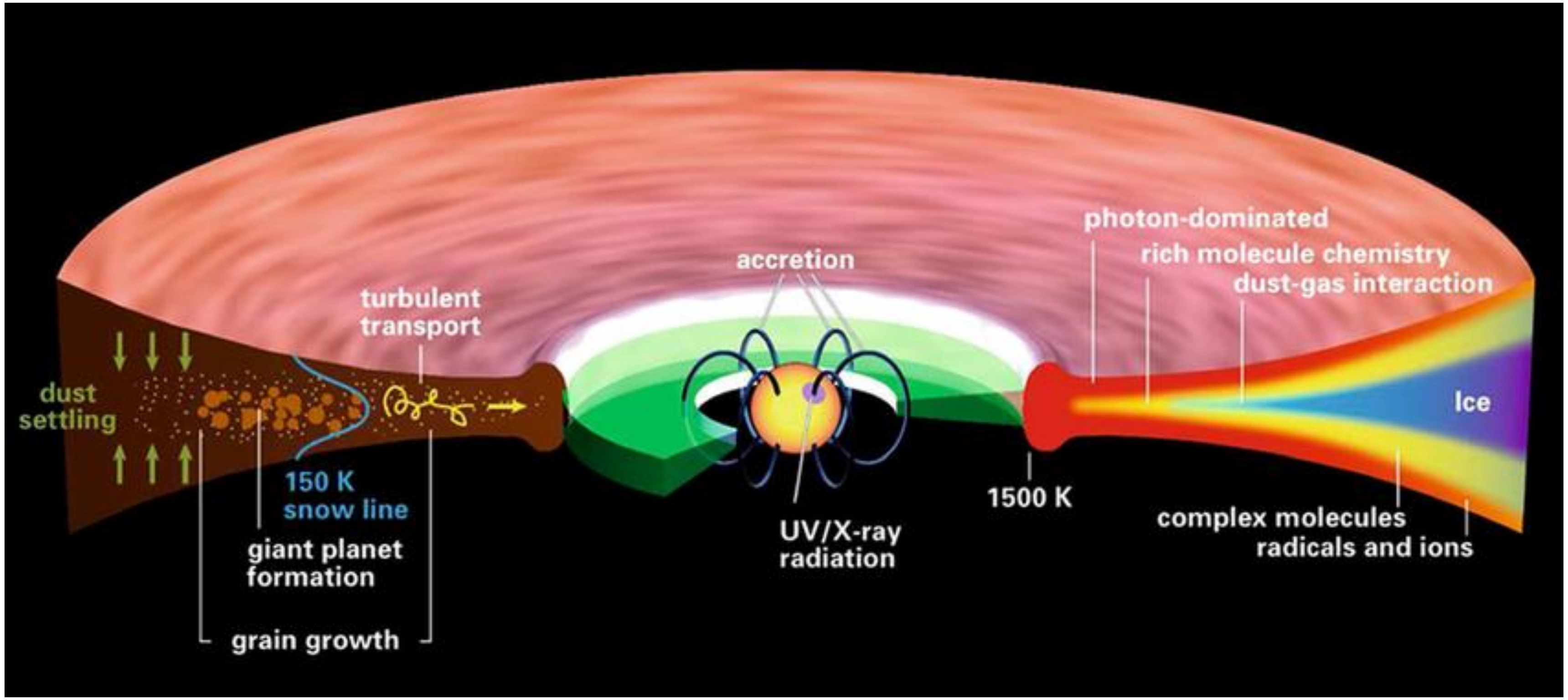
Disk formation





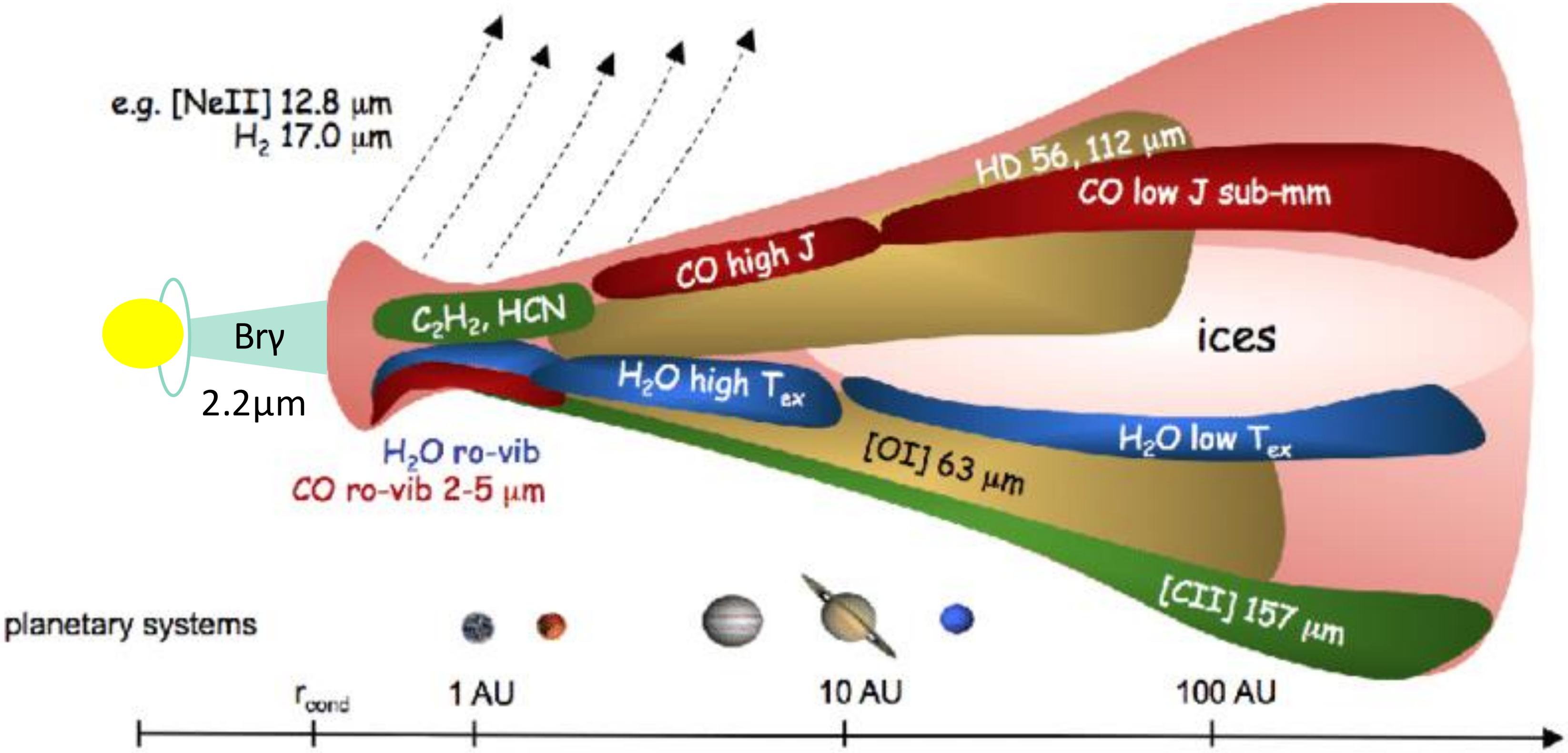
based on Wilking+89, Bill Saxton NRAO/AUI/NSF

Disk structure



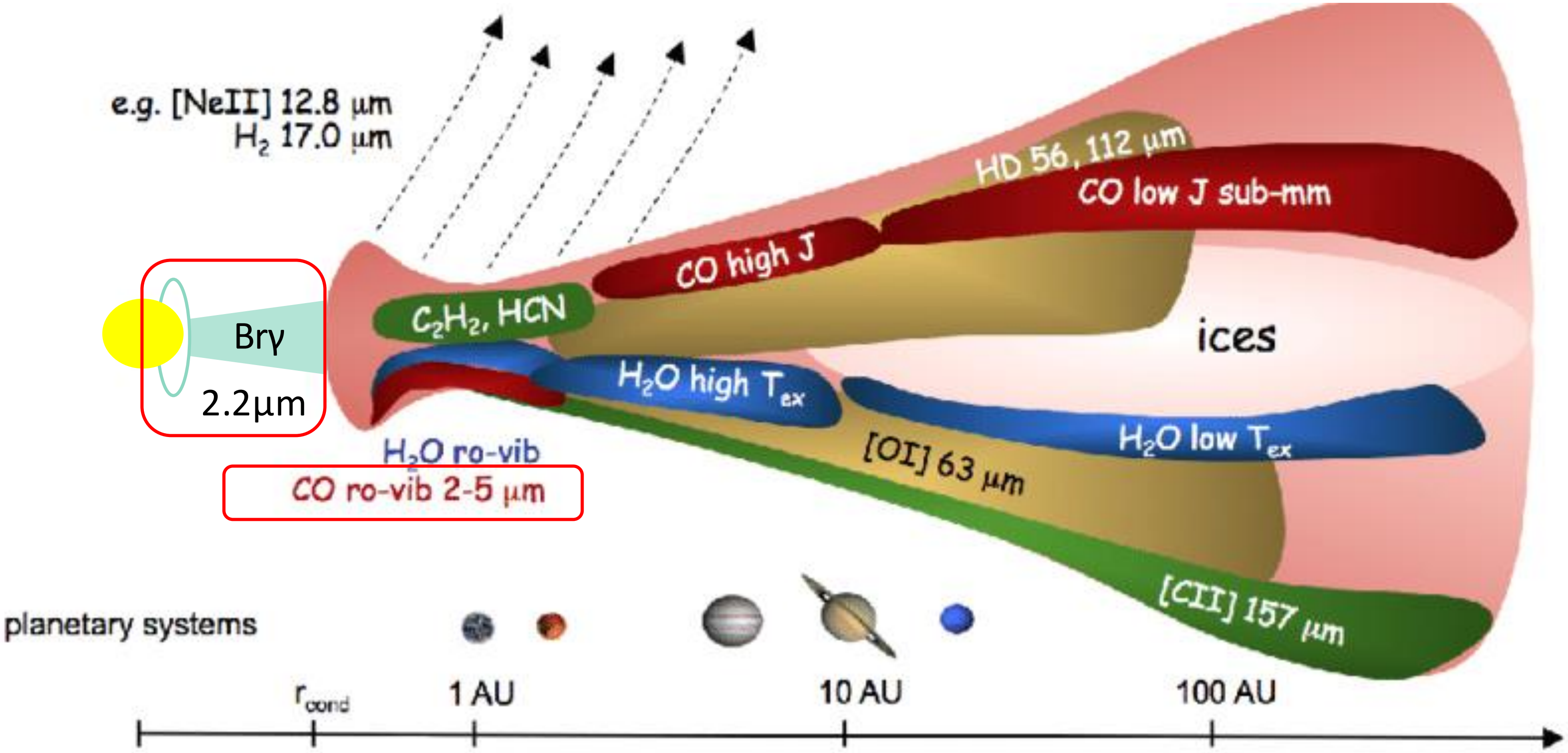
Henning+ 2013

Gas disk



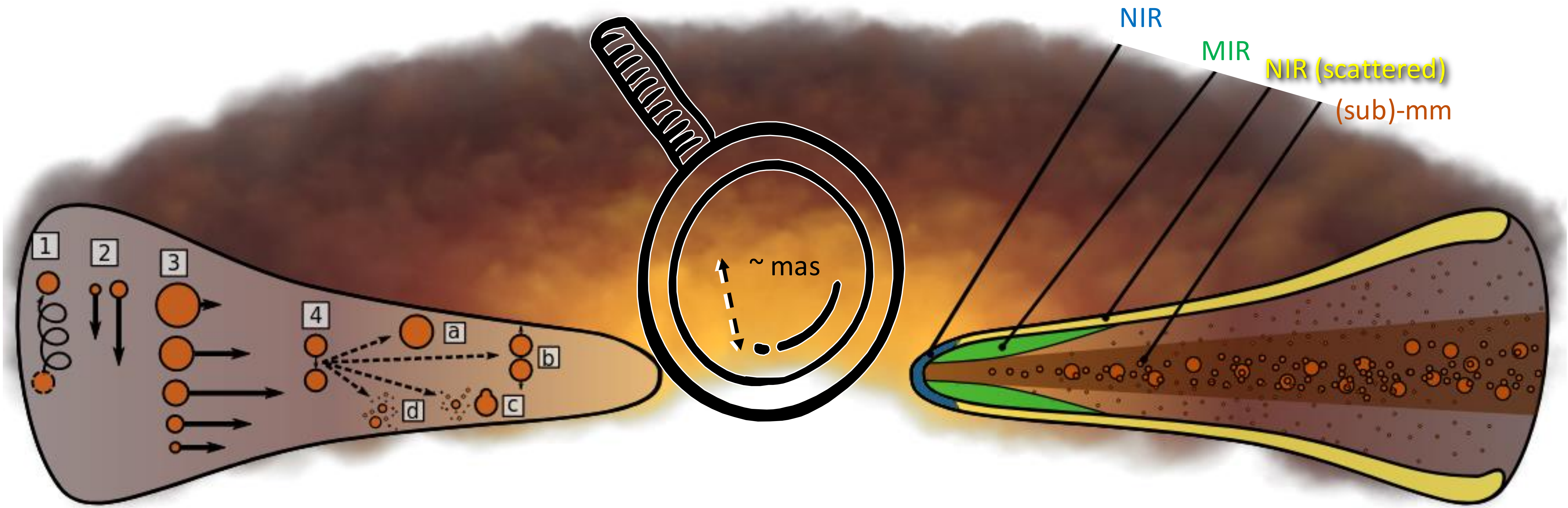
Kamp+ 2017

Gas disk



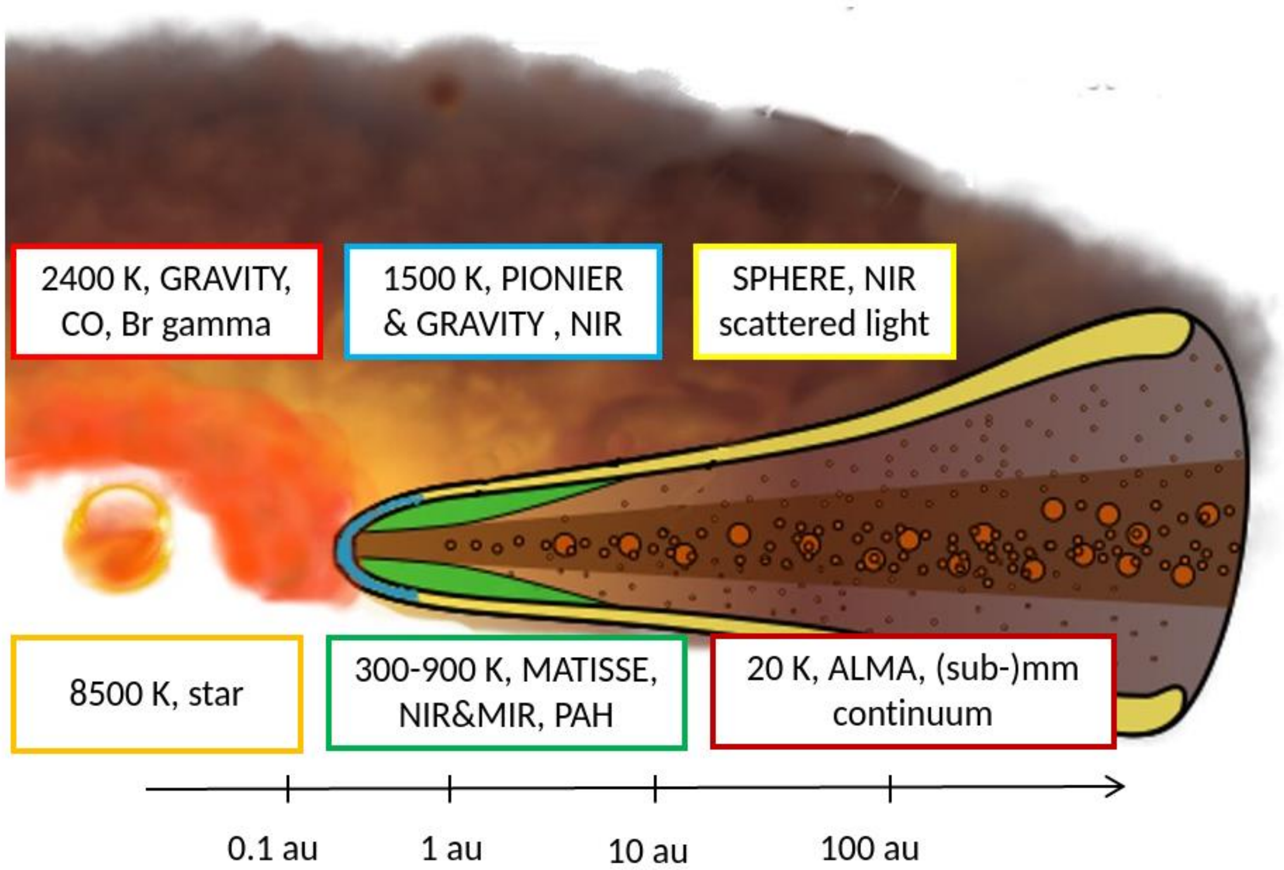
Kamp+ 2017

Dust disk



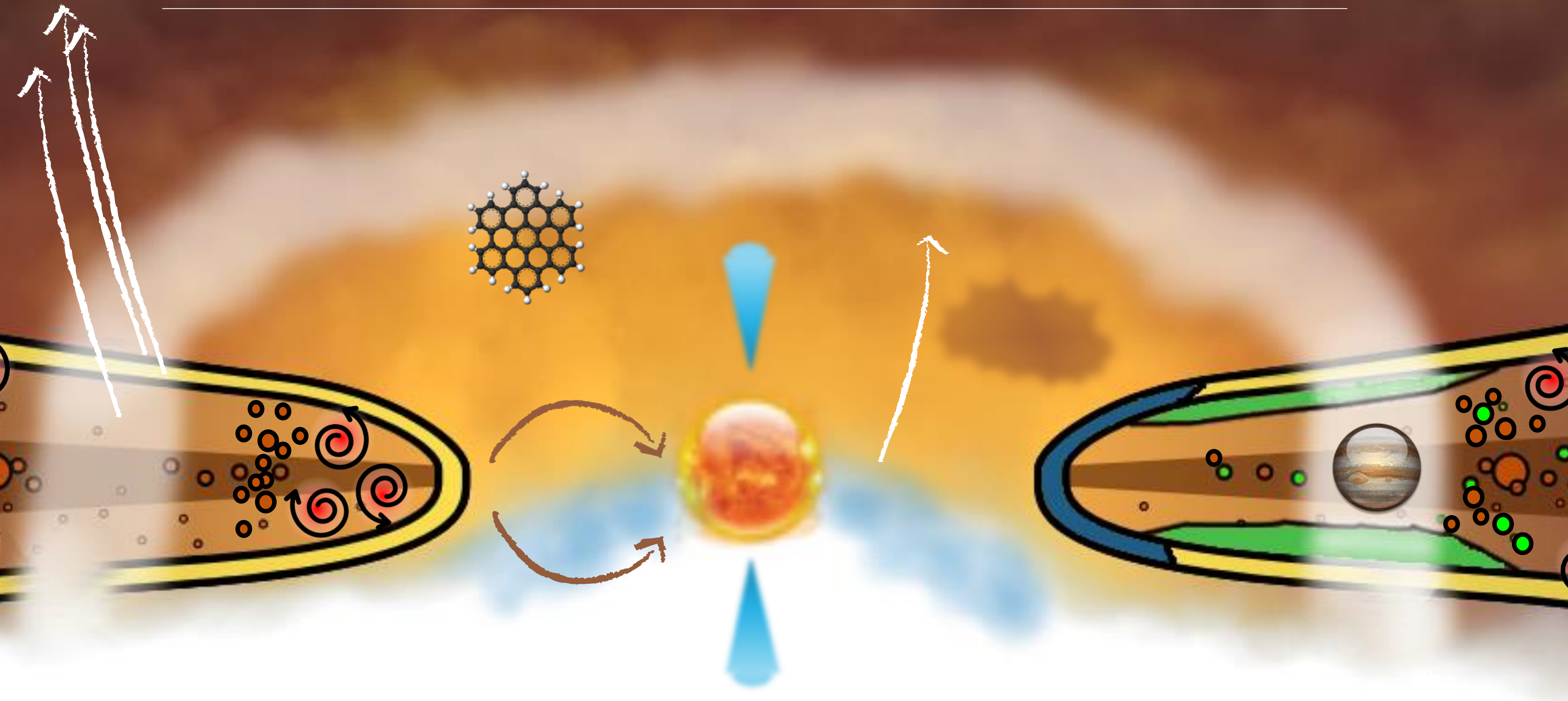
based on Testi et al. 2014

PPD: structure, wavelengths, instruments

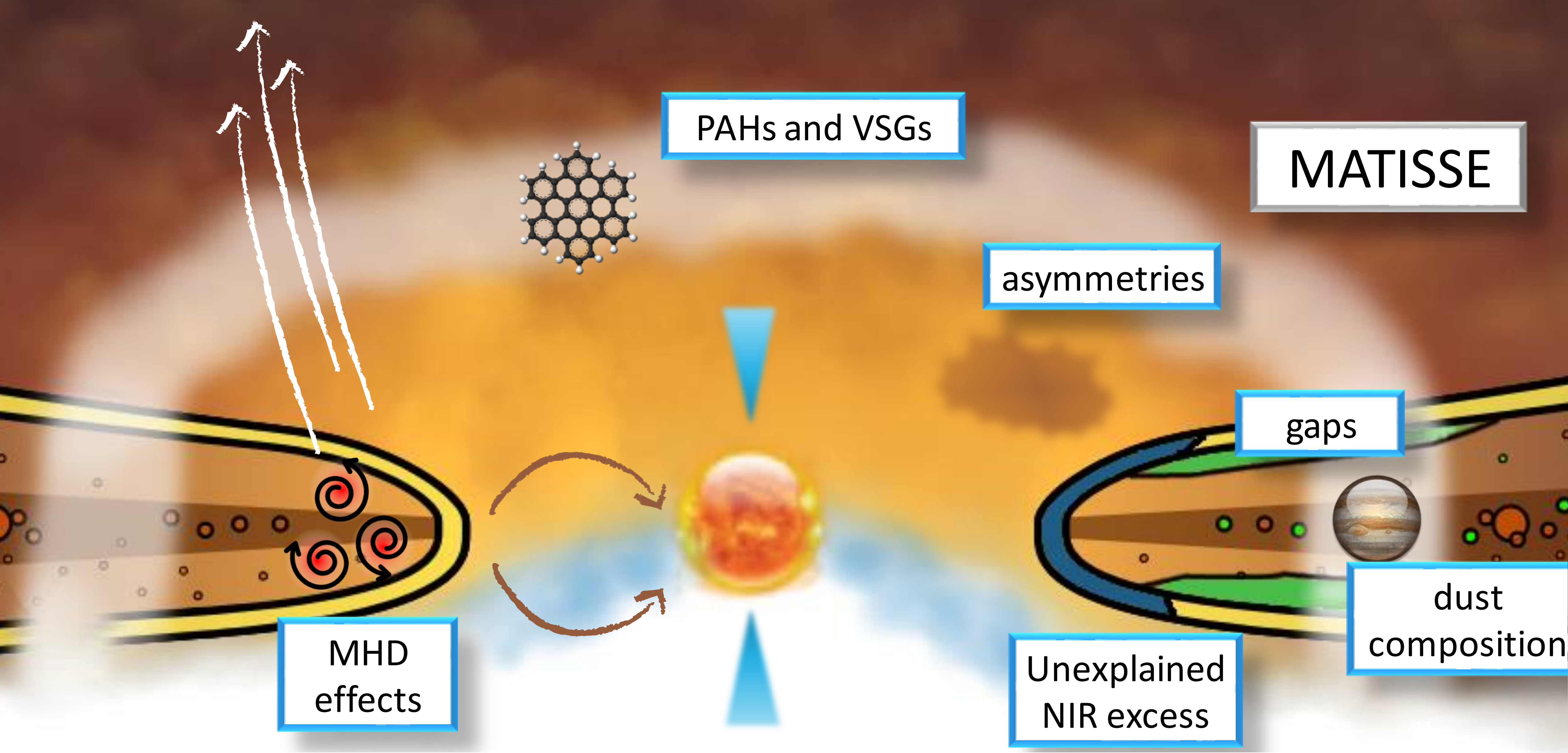


GRAVITY collaboratio+ 2020

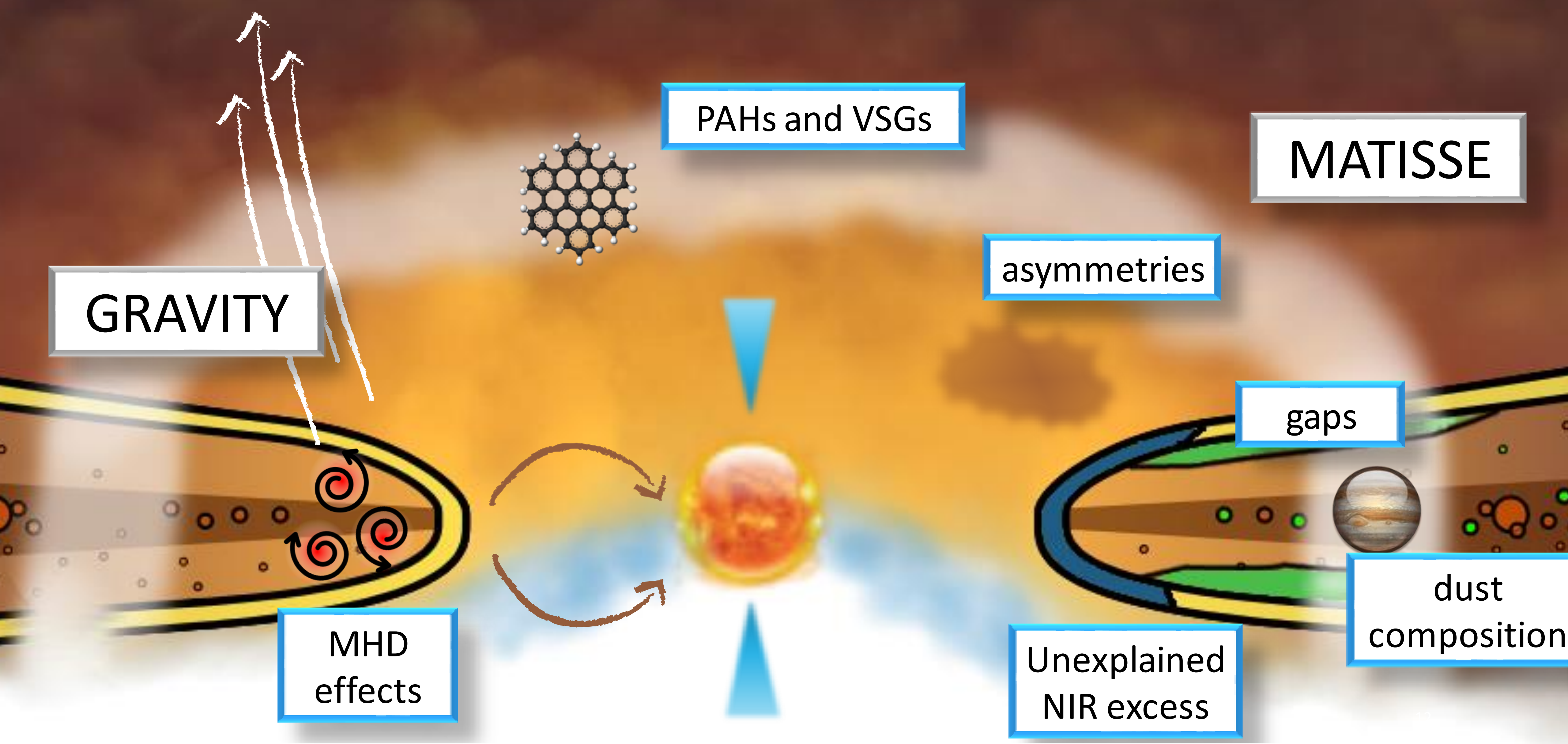
Exploring the inner disk region



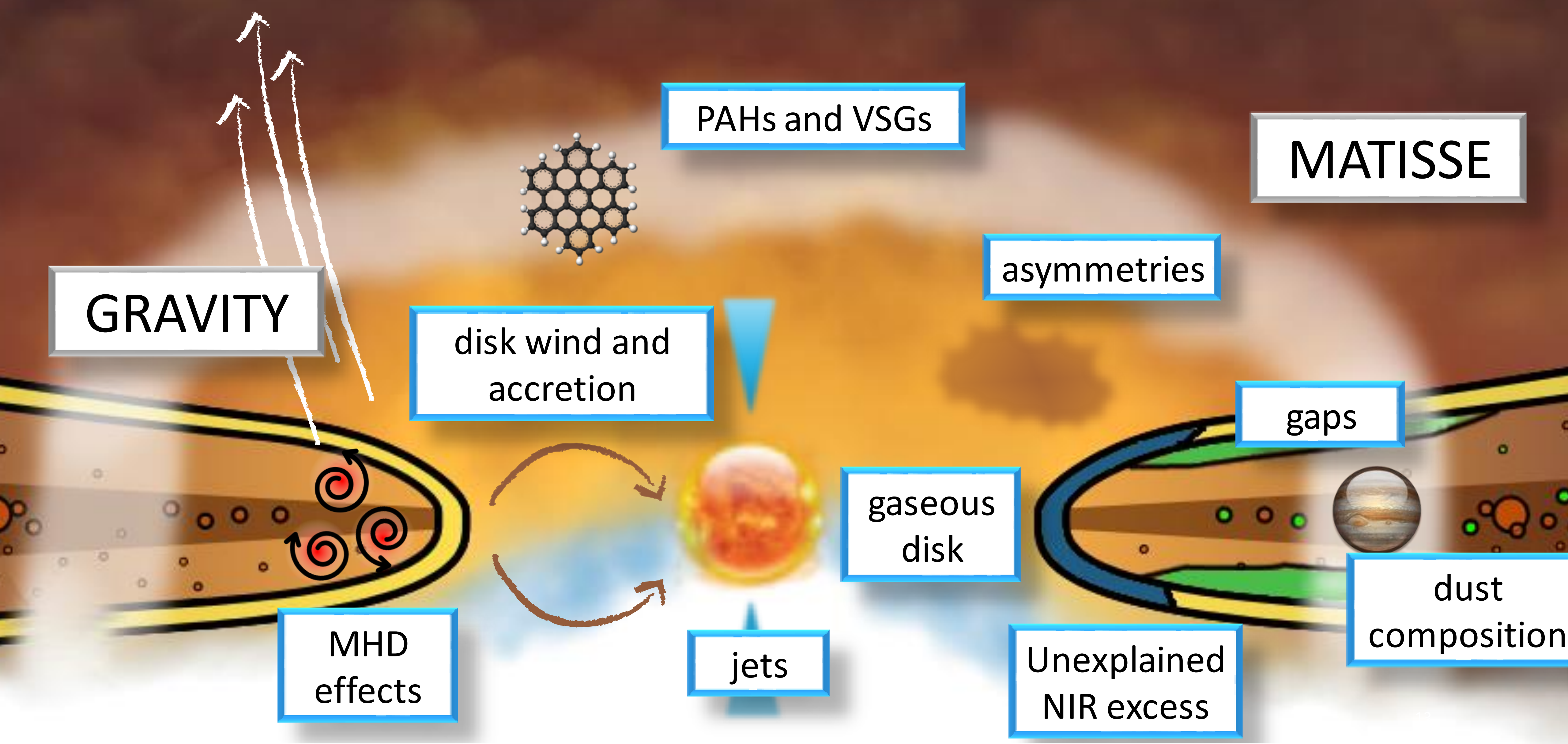
Continuum observations



Continuum observations



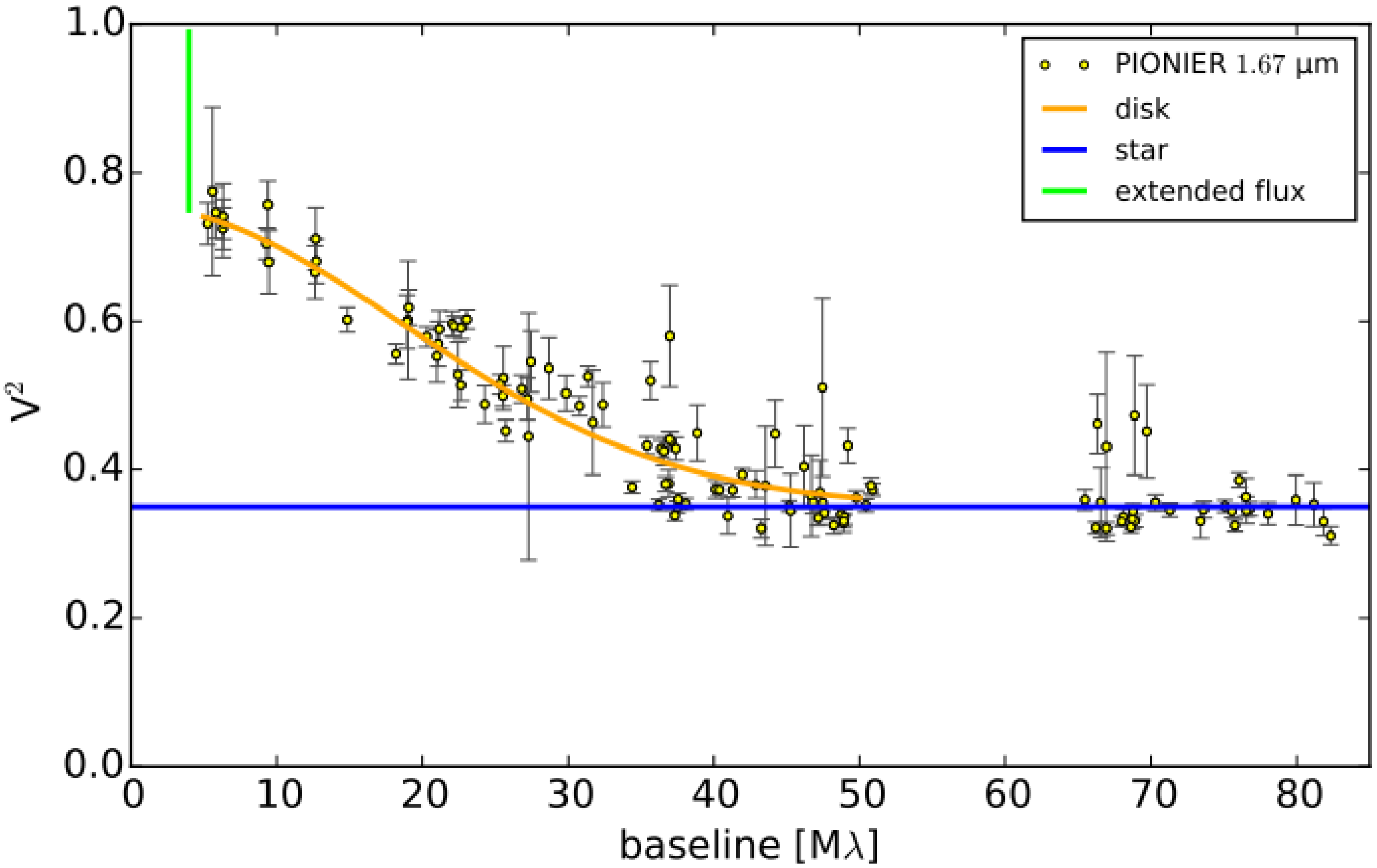
Spectro - Interferometry



What does the data look like?

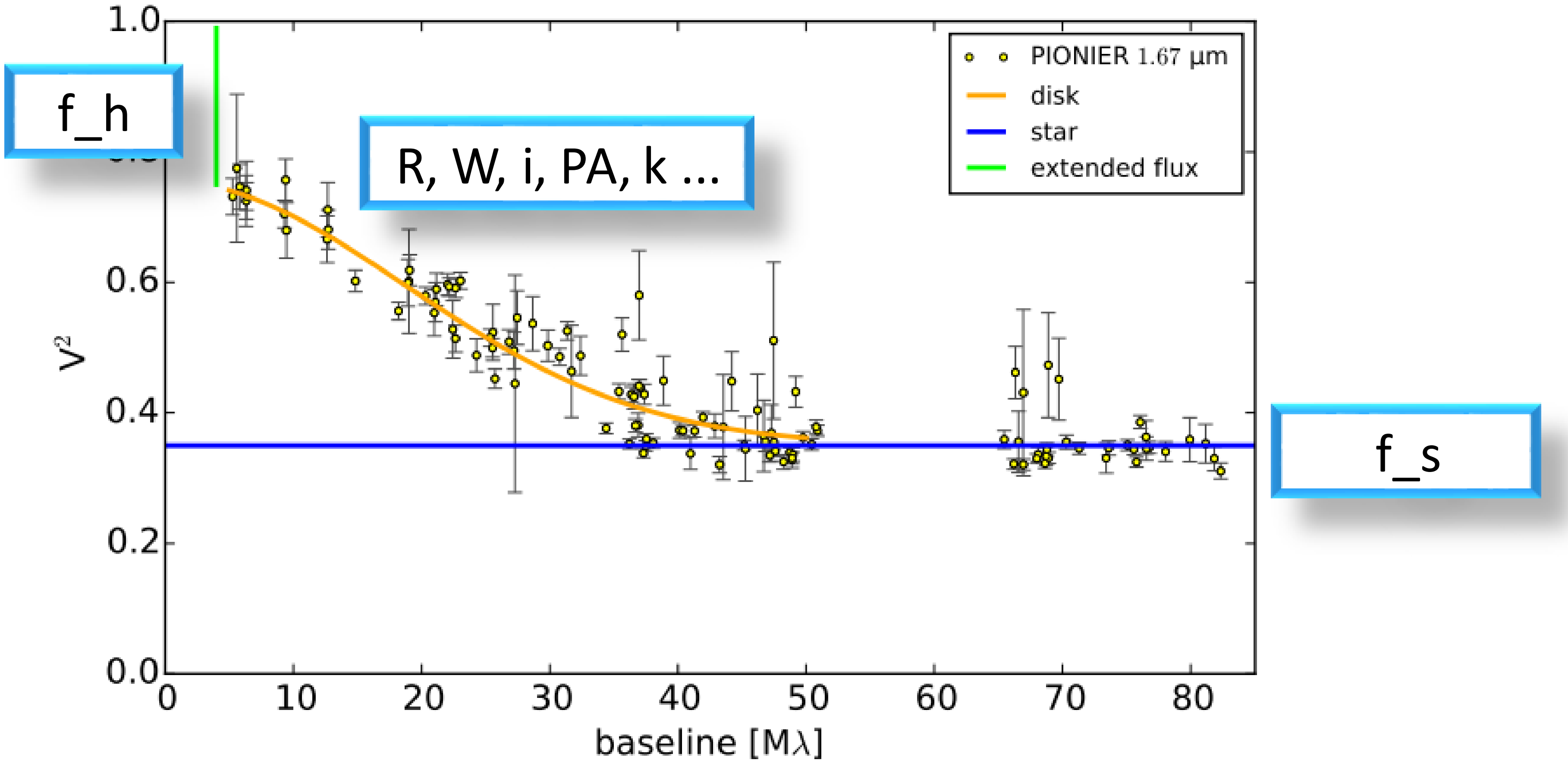
AND WHICH MODELS CAN I USE TO REACH MY SCIENCE GOAL?

A first look at continuum visibilities



Klarmann+ 2017

A first look at continuum visibilities

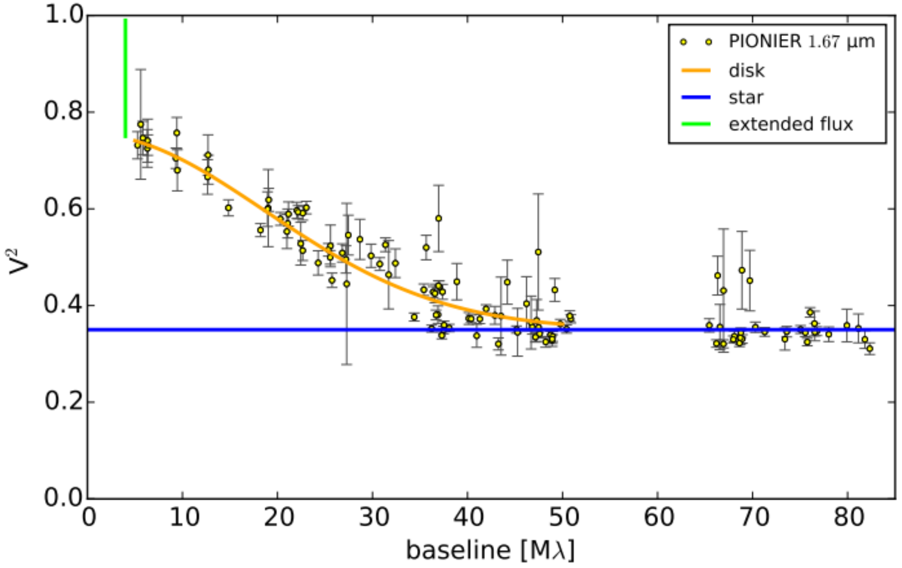


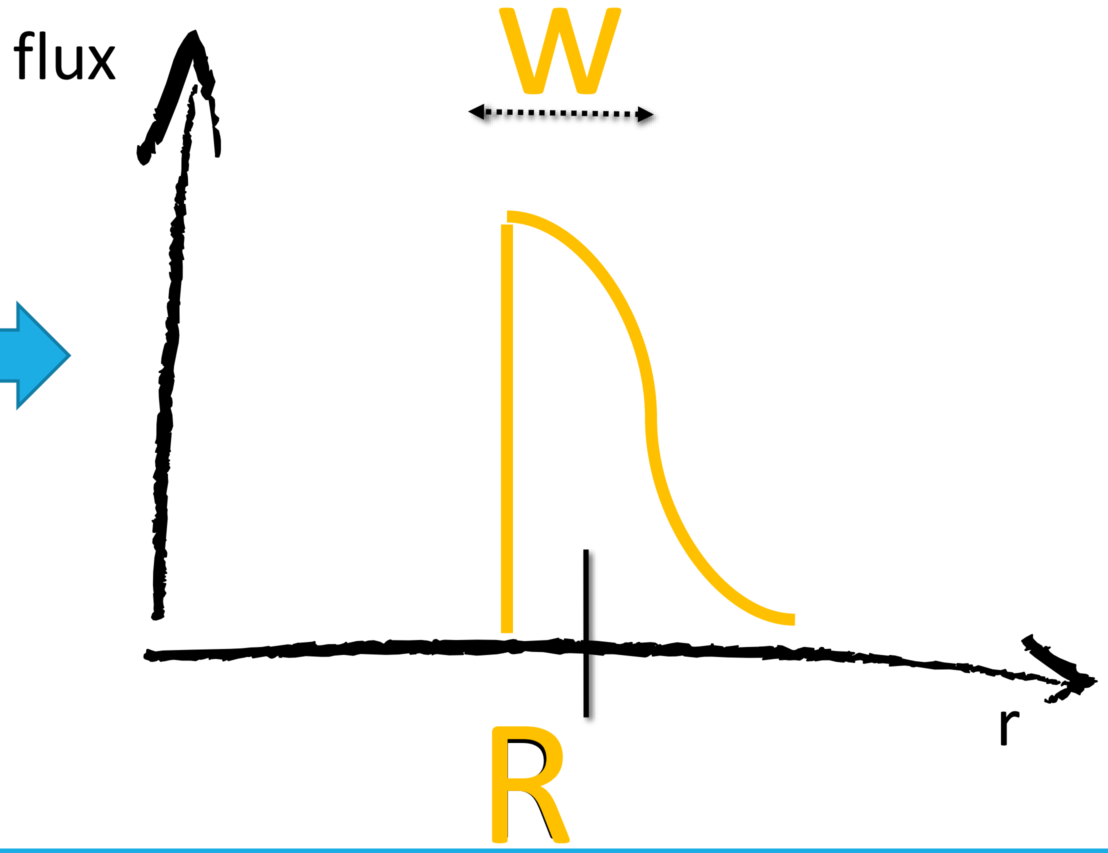
Klarmann+ 2017

A three step modelling approach

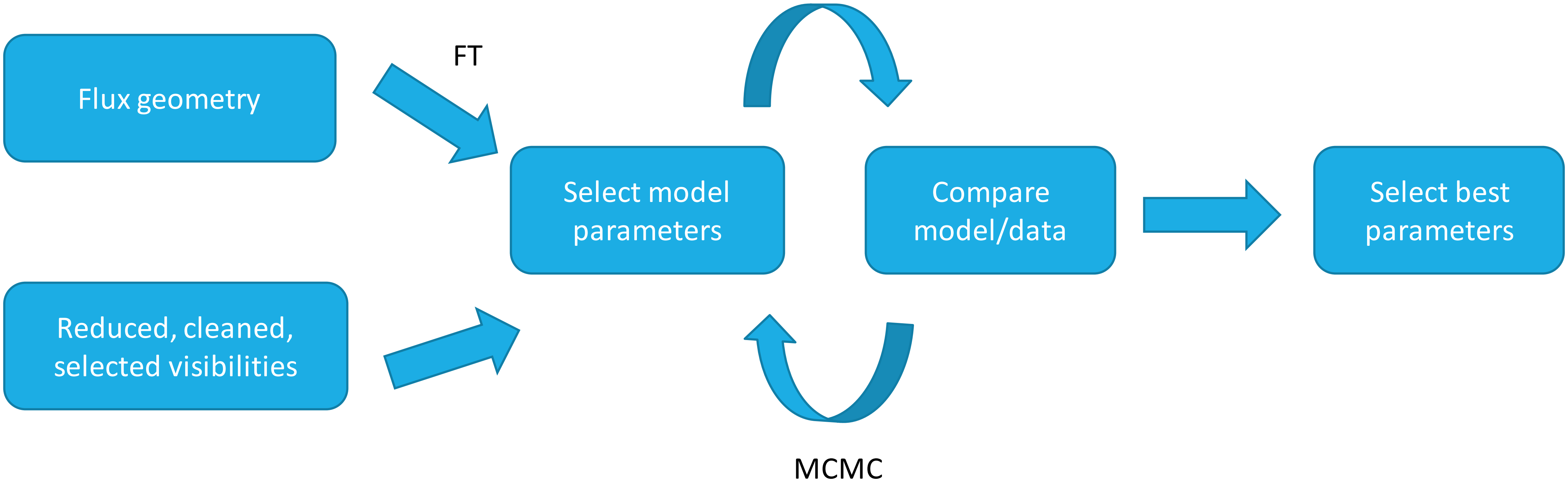
Data → Flux geometry → Disk geometry → Disk physics

From data to flux geometry





From data to flux geometry

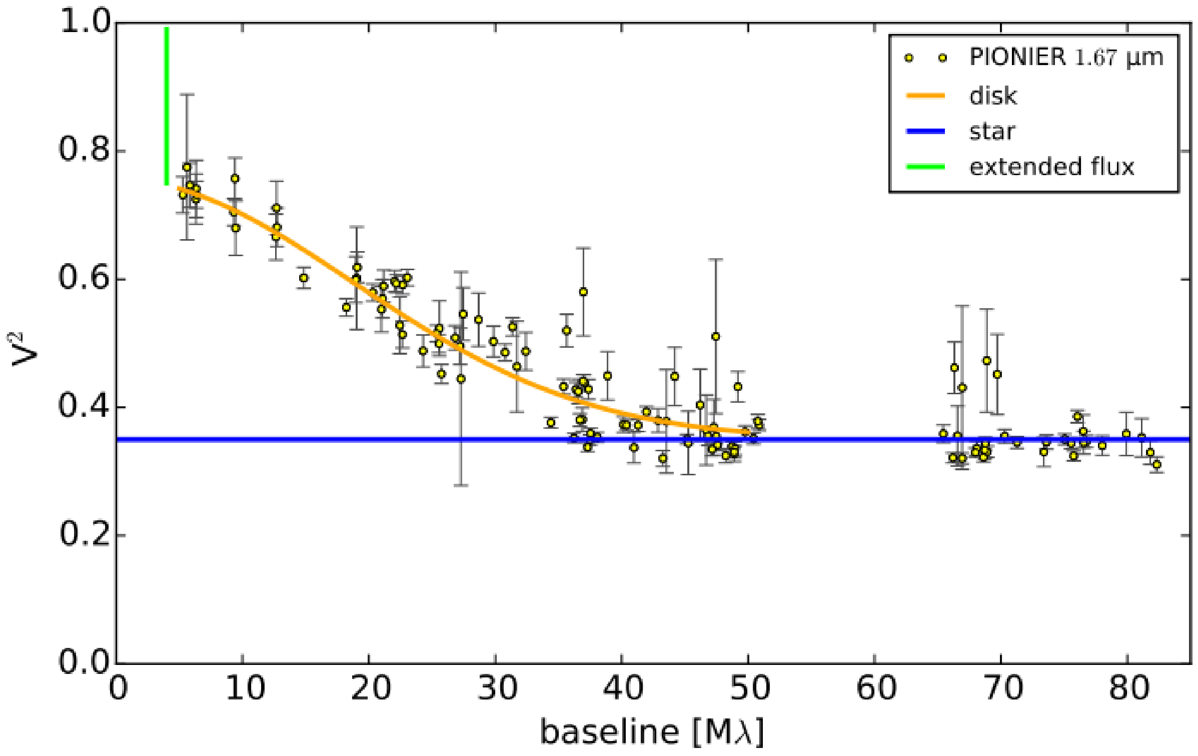


The FT of a multi component model

Flux geometry

FT

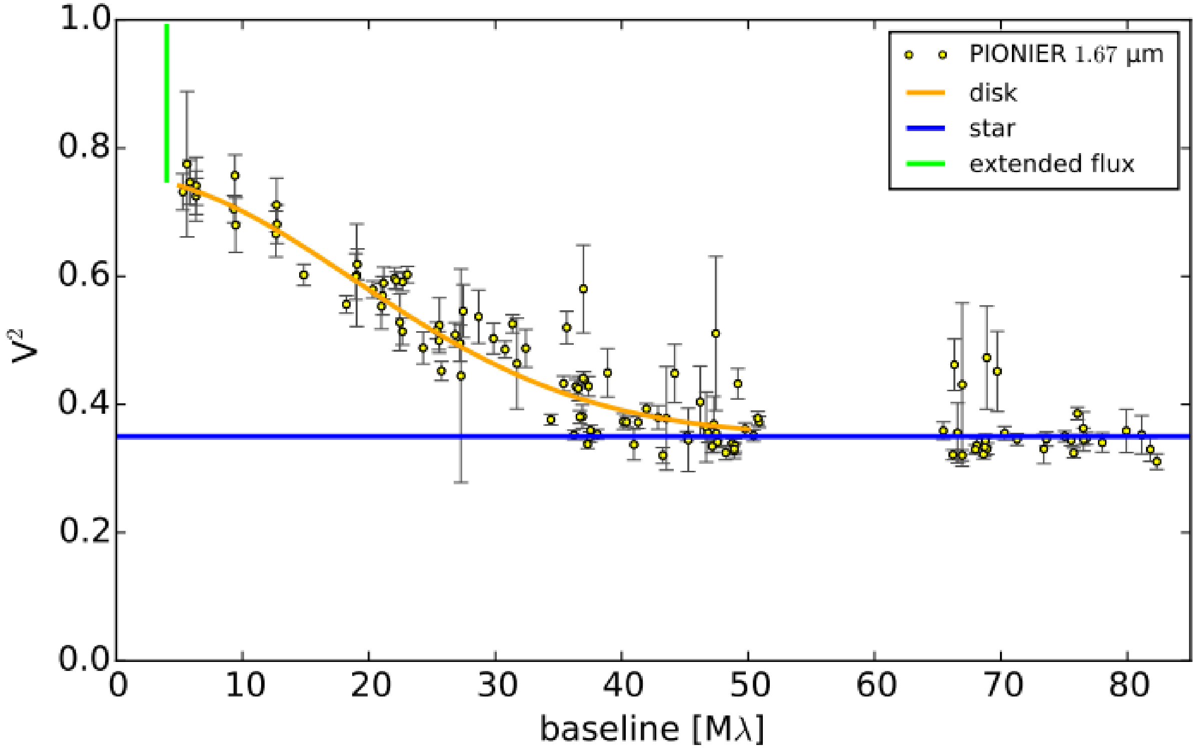
model parameter



$$V = \frac{f_s V_s + f_d V_d + f_h V_h}{f_s + f_d + f_h}$$

Flux geometry $\xrightarrow{\text{FT}}$ model parameter

The FT of a multi component model



$$V = \frac{f_s \overset{=1}{V_s} + f_d V_d + f_h \overset{=0}{V_h}}{\underbrace{f_s + f_d + f_h}_{=1}}$$

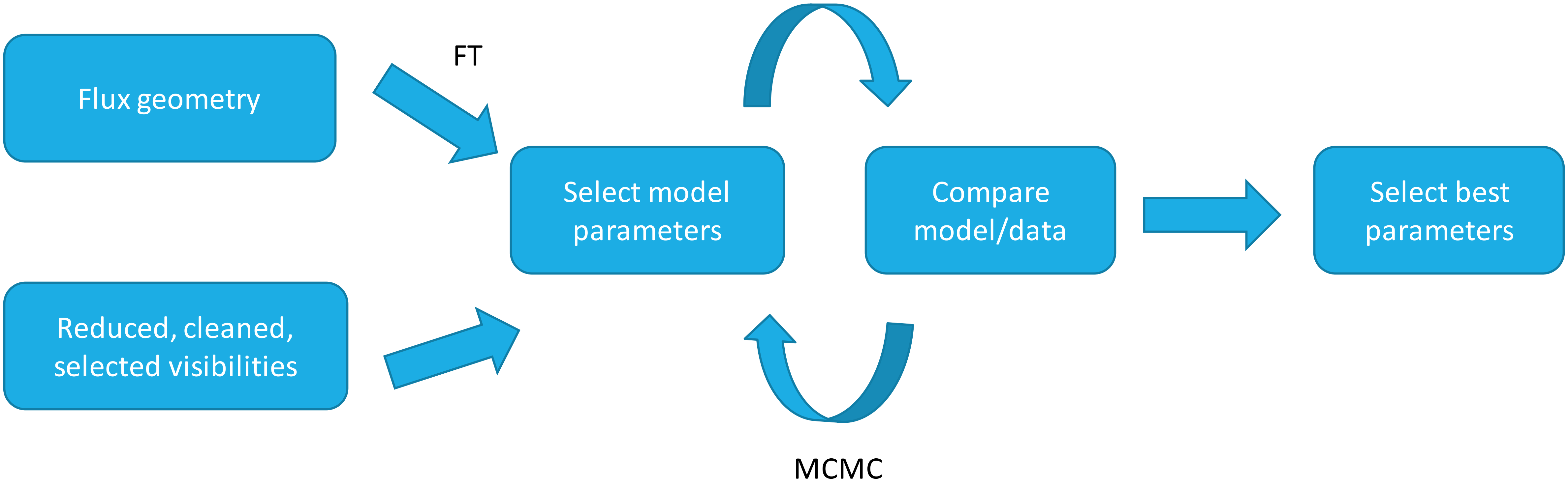
Flux geometry $\xrightarrow{\text{FT}}$ model parameter

The FT of a multi component model

shape	flux geometry	visibility V
point	$\delta(r)$	1
Gaussian	$\sqrt{\frac{\log 2}{\pi R^2}}\exp\left(-\ln 2\frac{r^2}{R^2}\right)$	$\exp\left(-\frac{(\pi R b)^2}{\ln 2}\right)$
infinitely thin ring	$\frac{\delta(r-R)}{2\pi R}$	$\mathrm{J}_0(2\pi R b)$
uniform disk	$\frac{1}{\pi R^2}$ if $r < R$	$\frac{\mathrm{J}_1(2\pi R b)}{\pi R b}$

$$V = \frac{f_\mathrm{s}\overset{=1}{V_s} + f_\mathrm{d}V_\mathrm{d} + f_\mathrm{h}\overset{=0}{V_\mathrm{h}}}{\underbrace{f_\mathrm{s} + f_\mathrm{d} + f_\mathrm{h}}_{=1}}$$

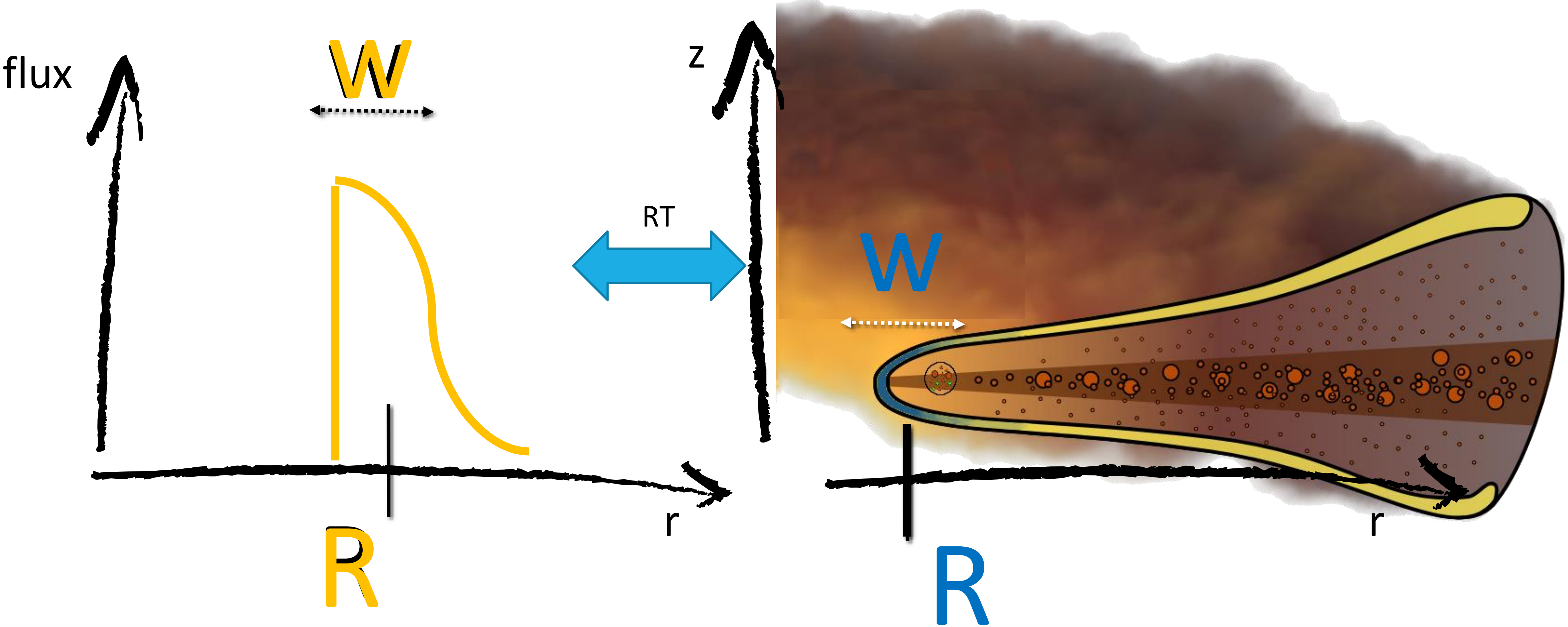
A three step modelling approach



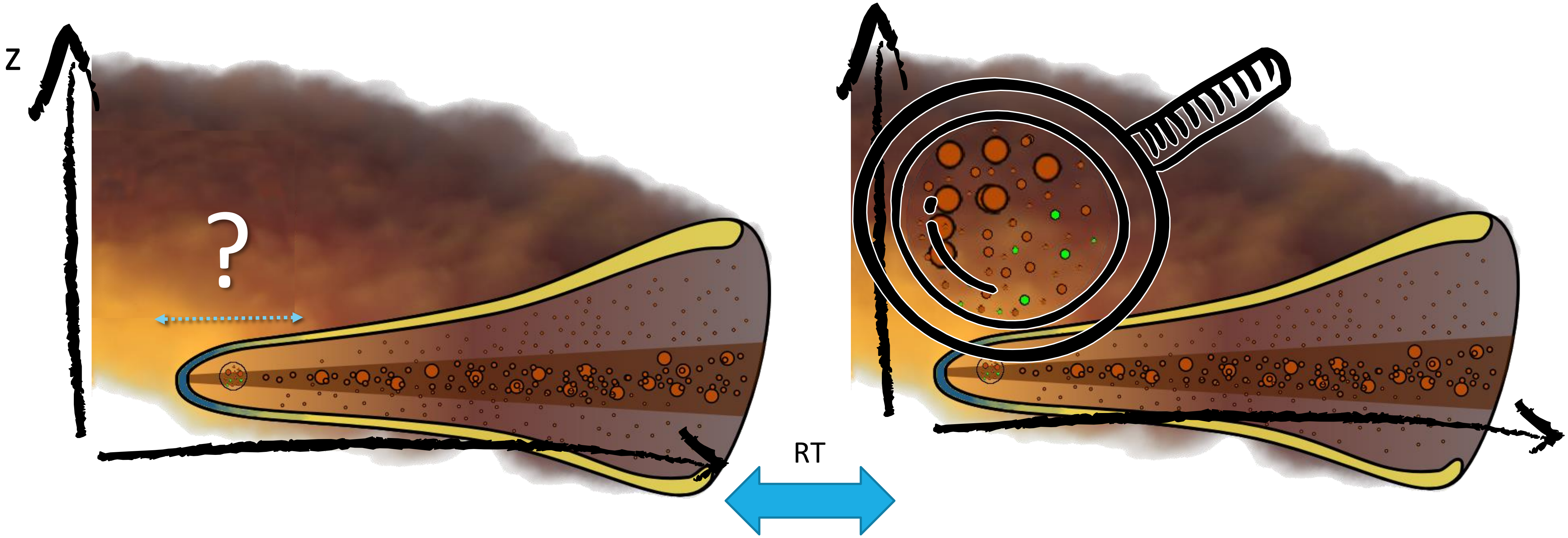
A three step modelling approach

Data → Flux geometry → Disk geometry → Disk physics

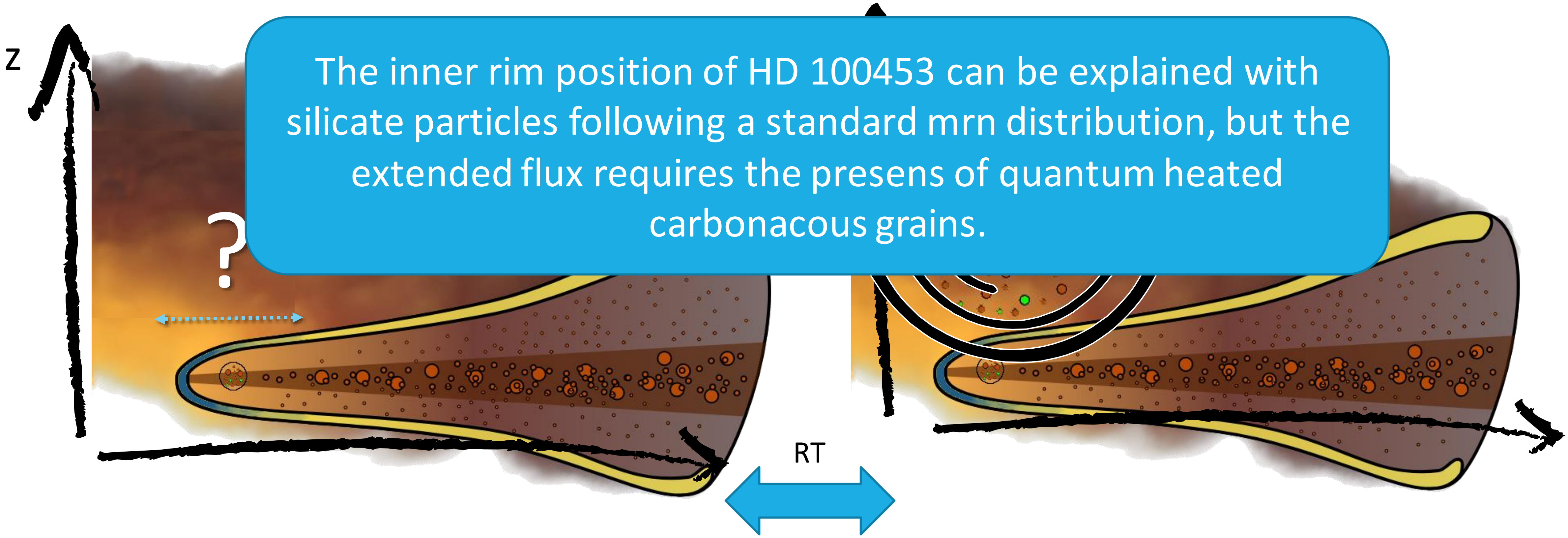
From flux geometry to disk geomtry



From disk geometry to disk physics



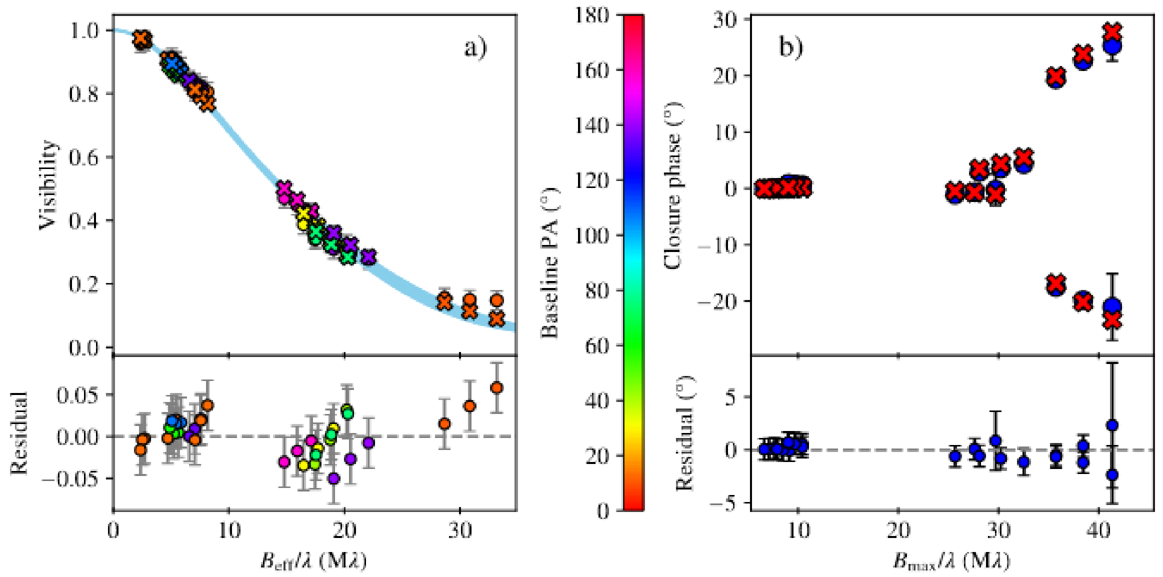
From disk geometry to disk physics



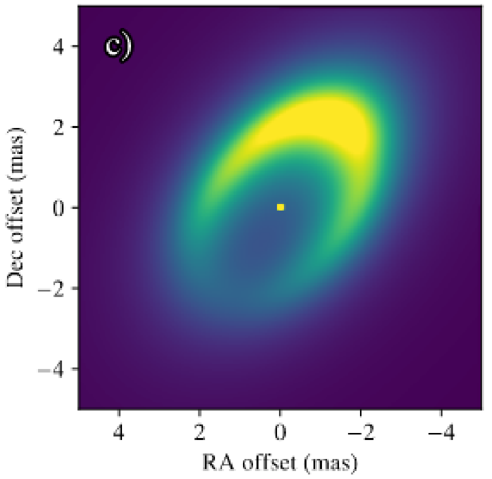
The inner rim position of HD 100453 can be explained with silicate particles following a standard mrn distribution, but the extended flux requires the presens of quantum heated carbonacous grains.

Klarmann+ 2017

Modelling disk asymmetries



MATISSE L-band data of HD 163296 (3.2 µm)



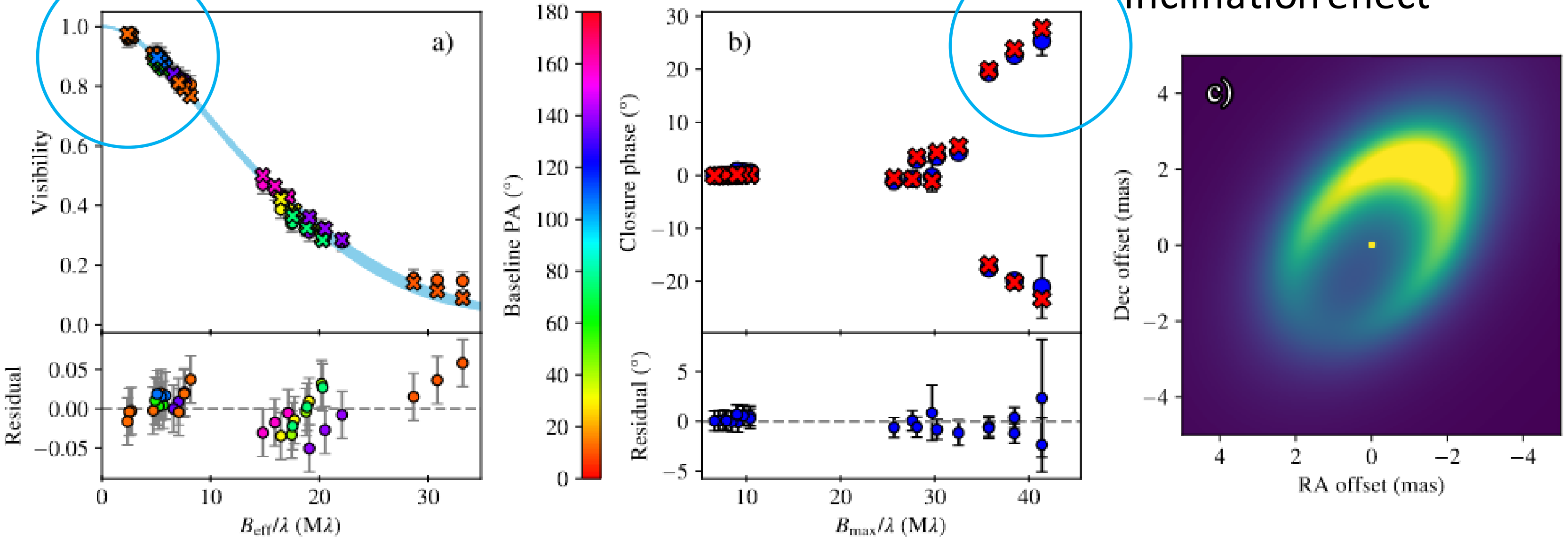
Gaussian ring model
(with azimutal variation)

Varga+ 2021

Modelling disk asymmetries

no extended flux

CP too high for inclination effect



MATISSE L-band data of HD 163296 (3.2 µm)

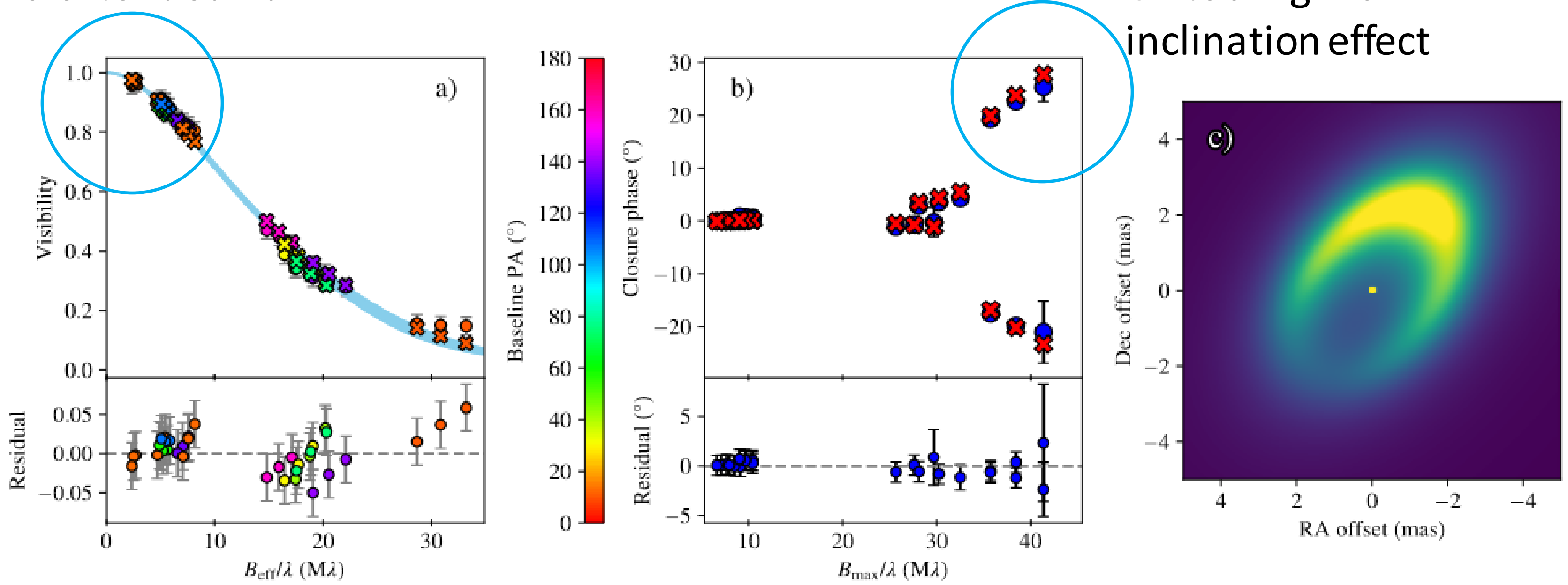
Gaussian ring model (with azimutal variation)

Varga+ 2021

Analytical vs discret FT

no extended flux

CP too high for inclination effect



MATISSE L-band data of HD 163296 (3.2 µm)

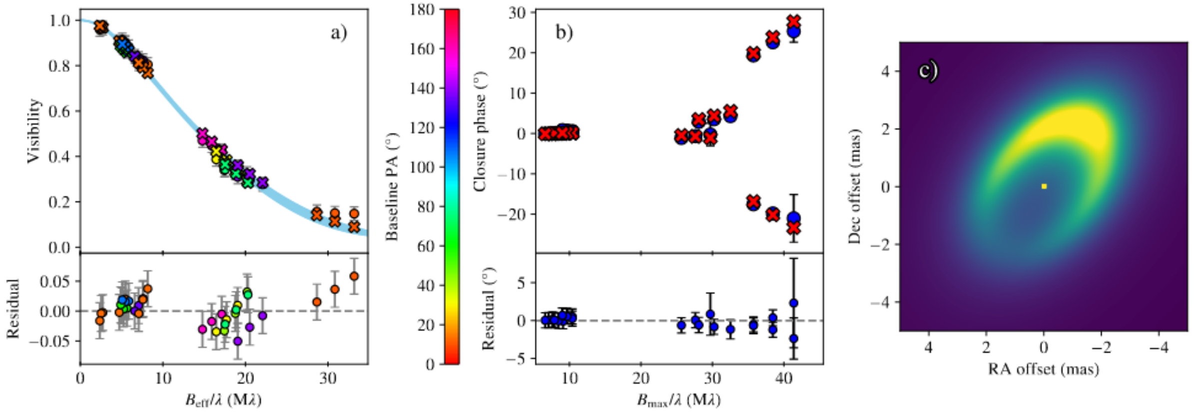
Gaussian ring model (with azimutal variation)

Discrete FT of image
- more shape options
- more cpu time

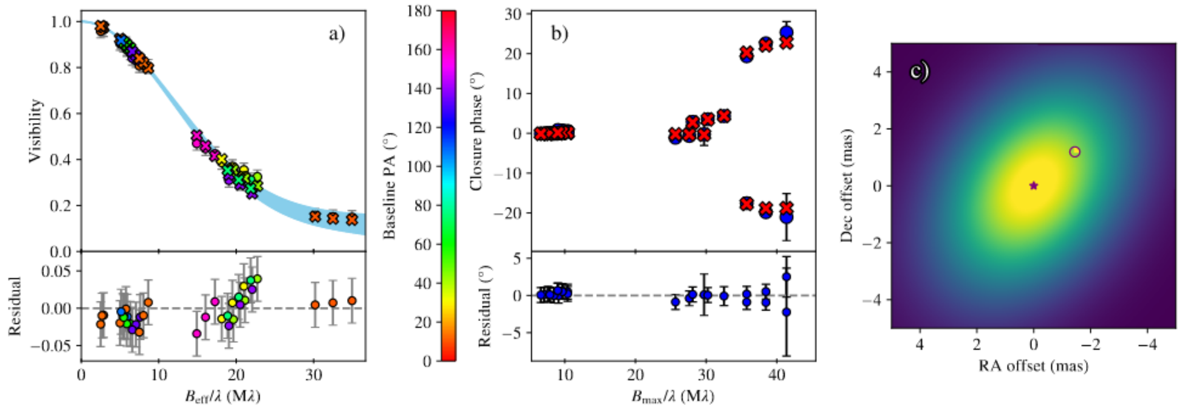
Varga+ 2021

Degeneracy of fit solutions

Gaussian ring model
(with azimutal variation)



Symmetric gaussian and
(additional) point source

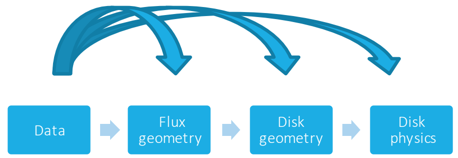


How to proceed?

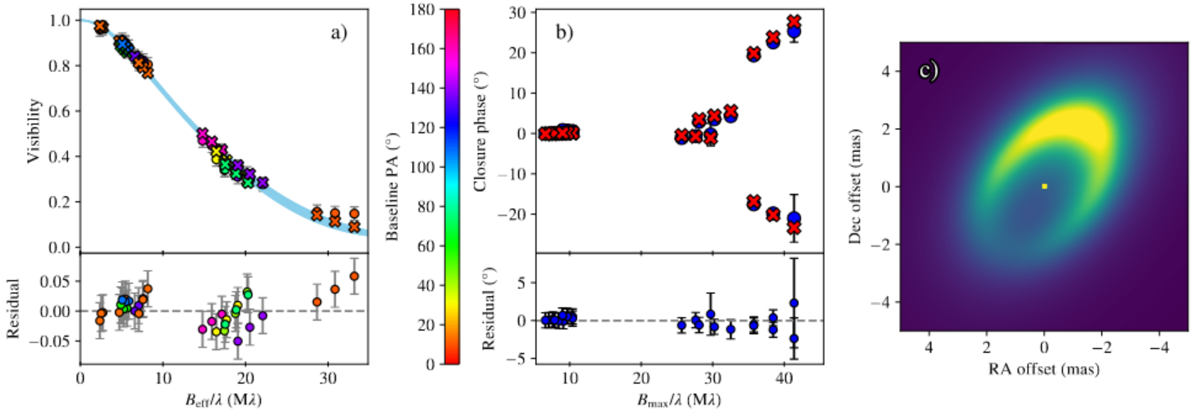
Data → Flux geometry → Disk geometry → Disk physics

Varga+ 2021

Directly from data to physics

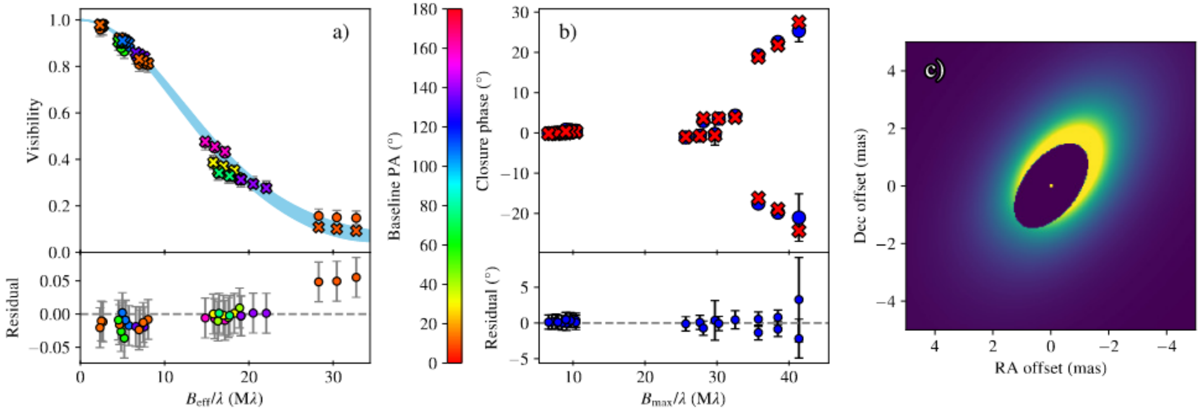


Gaussian ring model
(with azimutal variation)



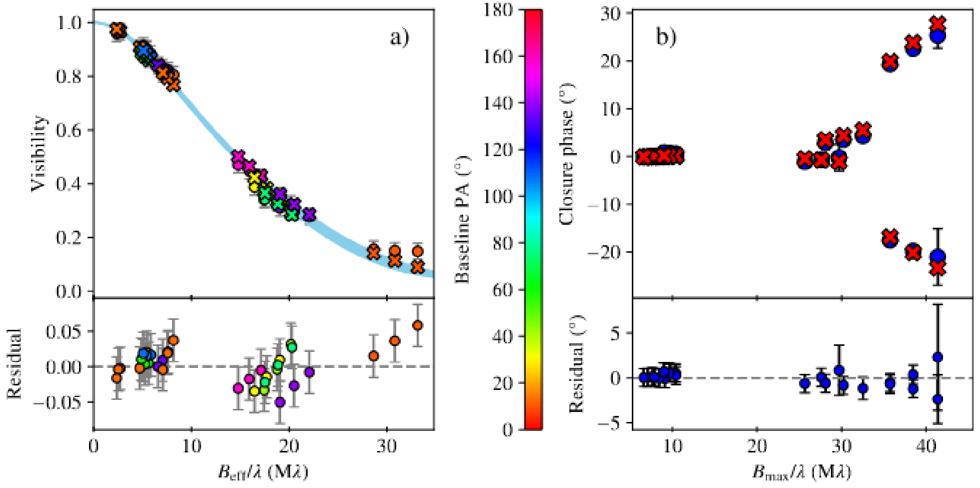
Flat disk model

$$I_\nu(r) \propto B_\nu\left(T_{\mathrm{in}}\left(\frac{r}{R_{\mathrm{in}}}\right)^{-q}\right)$$

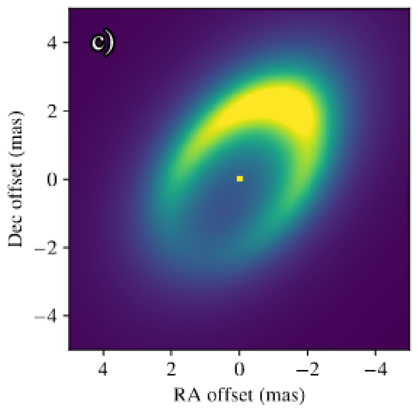


Varga+ 2021

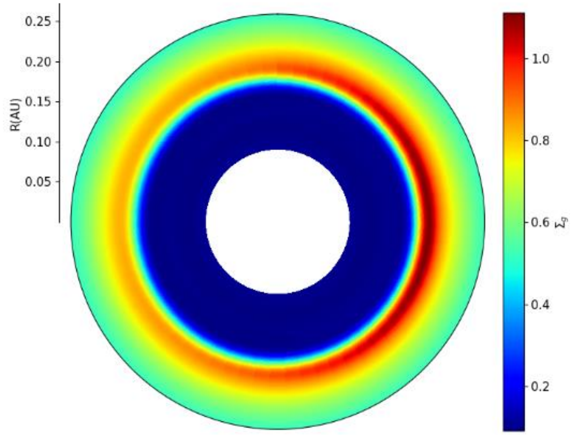
Qualitative comparison, more observations



MATISSE L-band data of HD 163296 (3.2 µm)



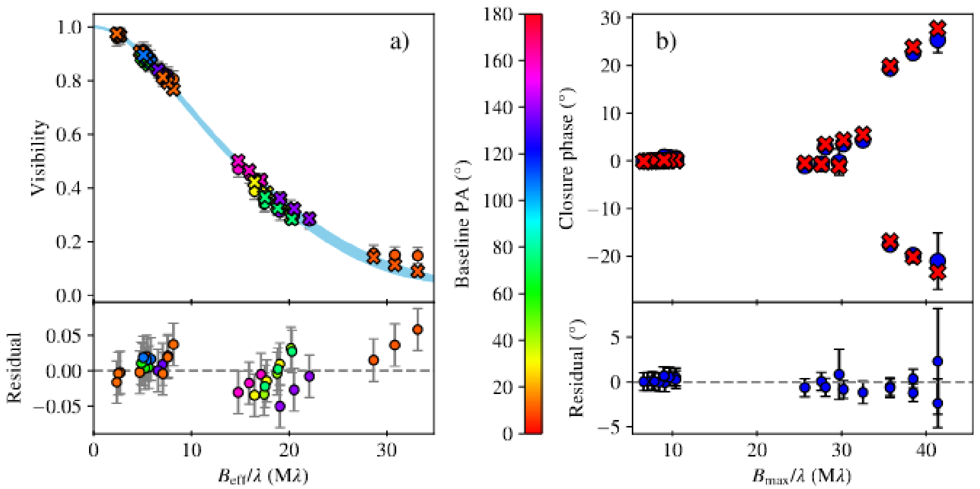
Gaussian ring model
(with azimutal variation)



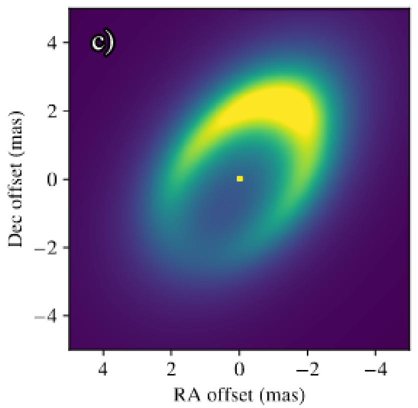
hydro-dynamical
numerical simulations
with AMRVAC

Varga+ 2021, Xiaet al. 2018

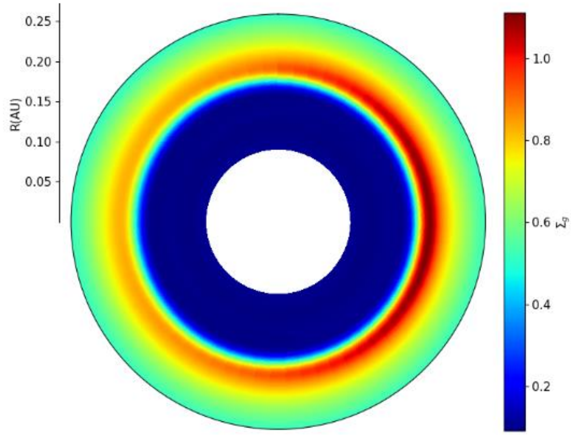
Qualitative comparison, more observations



MATISSE L-band data of HD 163296 (3.2 µm)



Gaussian ring model
(with azimutal variation)



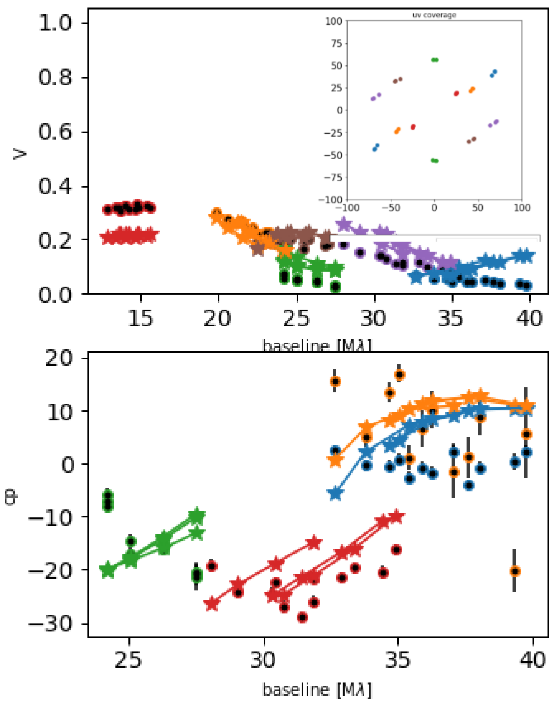
hydro-dynamical
numerical simulations
with AMRVAC

GRAVITY and PIONIER observations exlude a planet as flux source and indicate variablility.

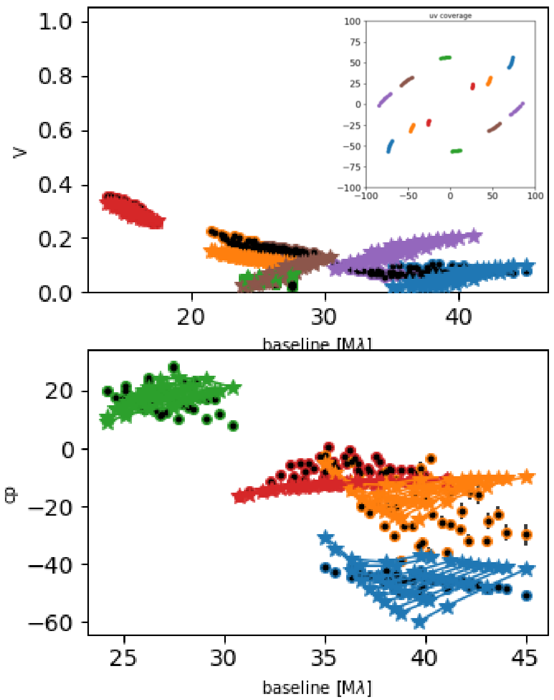
Varga+ 2021, Xiaet al. 2018

Variablity with geometric flux modelling

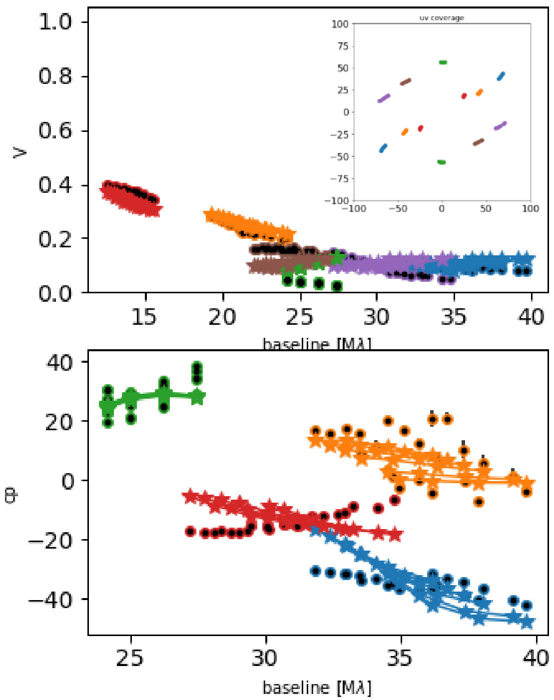
8.7.2018



11.7.2019



14.7.2019

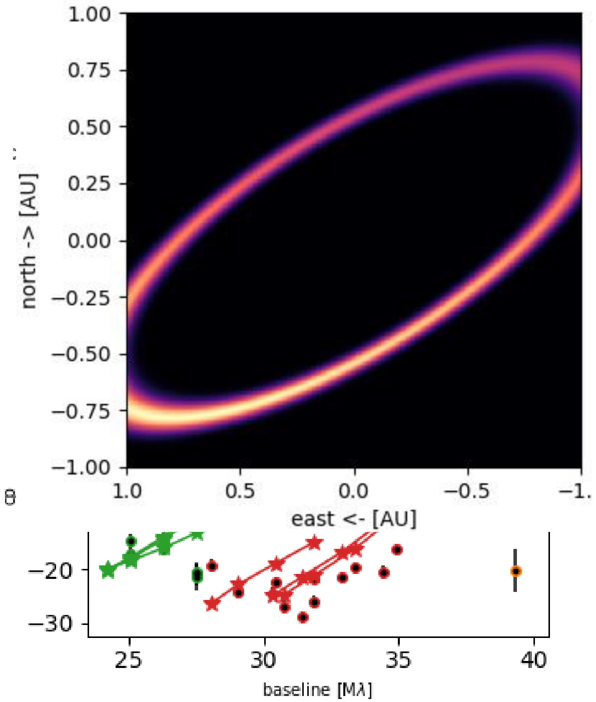


GRAVITY fring tracker data, YSO, medium baselines

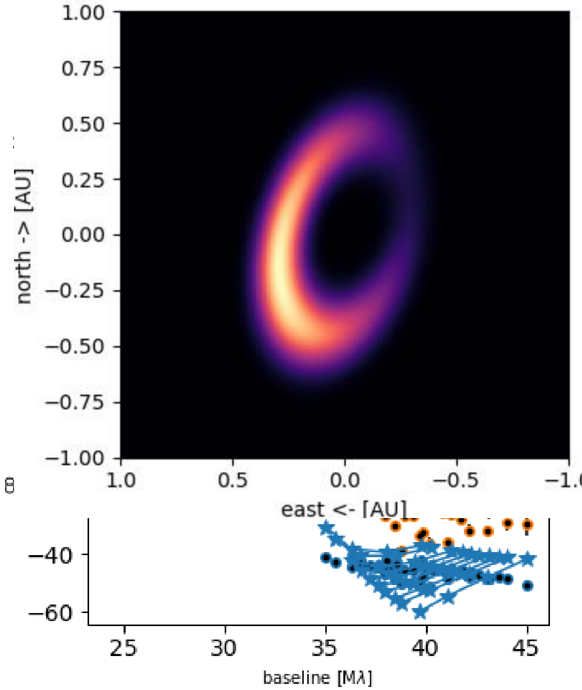
Klarman+ in prep.

Variablity can be difficult to interpret

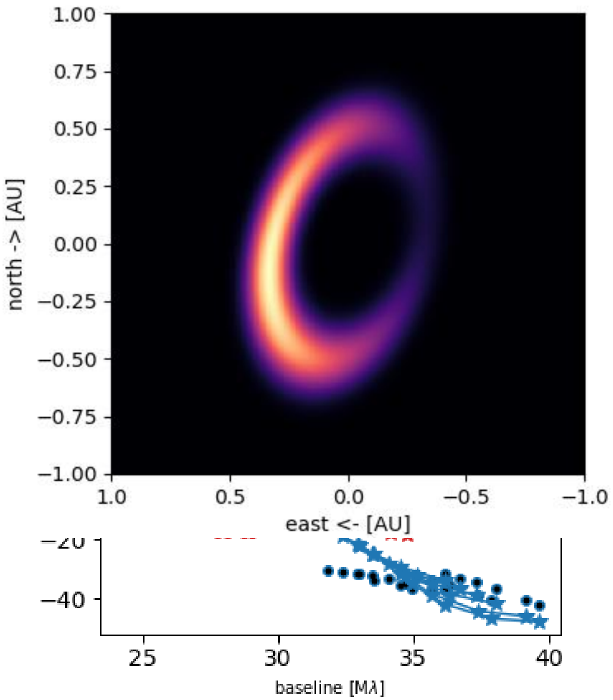
8.7.2018



11.7.2019



14.7.2019

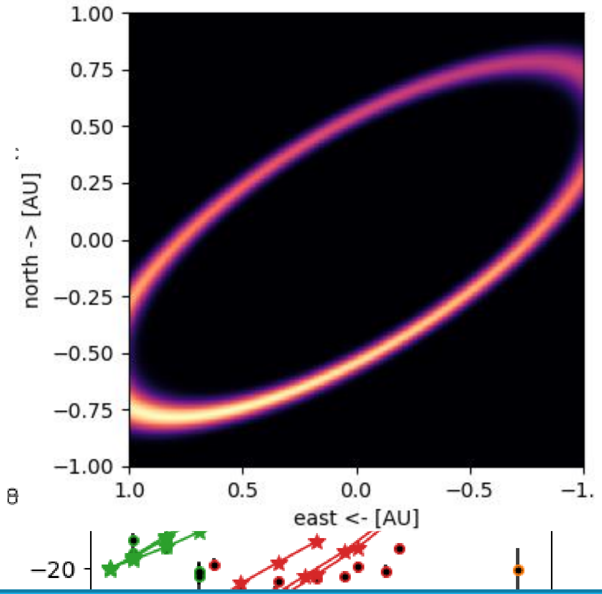


GRAVITY fring tracker data, YSO, medium baselines

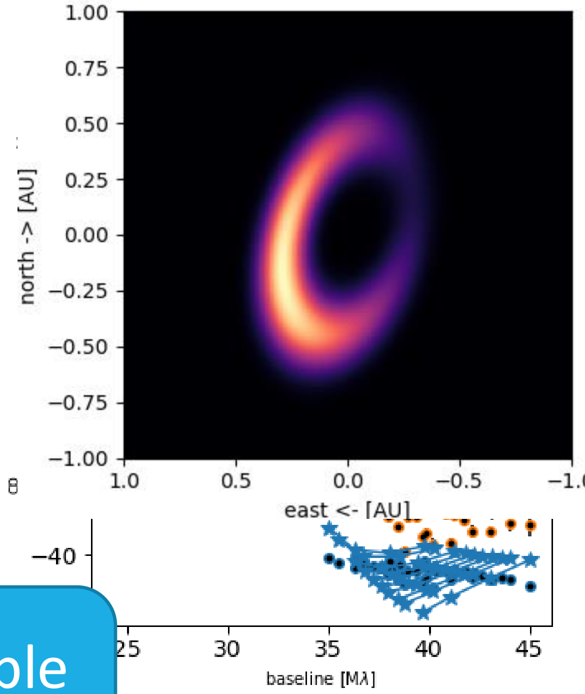
Klarman+ in prep.

Variability can be difficult to interpret

8.7.2018



11.7.2019



14.7.2019

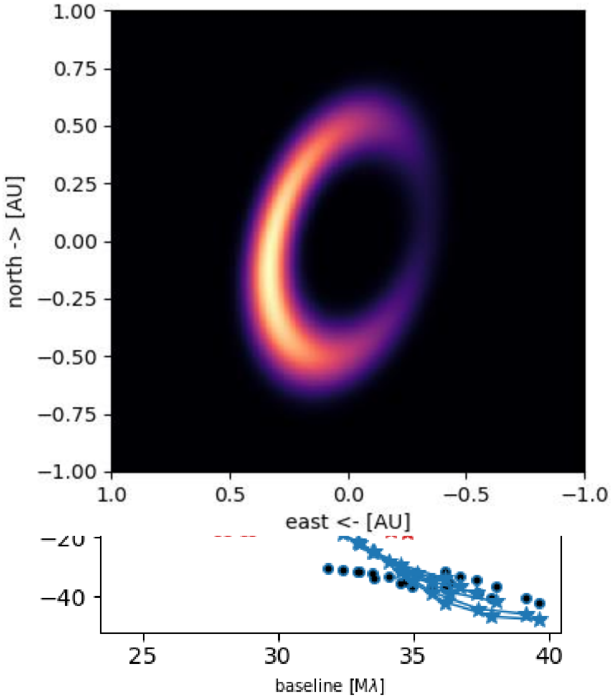


Image reconstruction is very valuable if uv coverage is good enough.

Klarman+ in prep.

Spectro-interferometry: basic line analysis

$$V_{Br\gamma} = \frac{\sqrt{|F_{tot}V_{tot}|^2 + |F_{cont}V_{cont}|^2 - 2F_{tot}V_{tot}F_{cont}V_{cont}cos\phi}}{F_{line}}$$

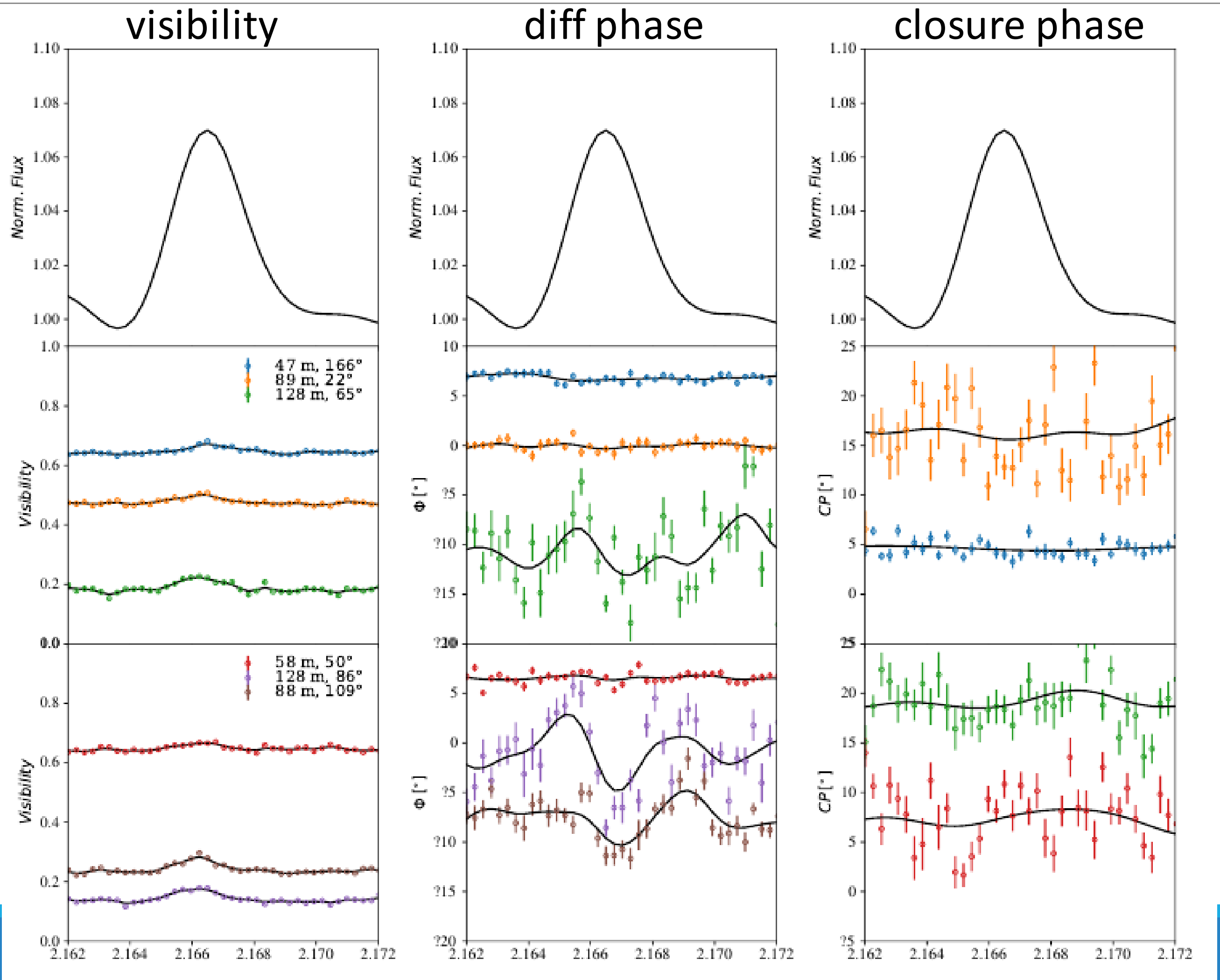
F: flux
V: visibility
Φ: differential phase

Data → Flux geometry → Disk geometry → Disk physics

GRAVITY observations of HR5999

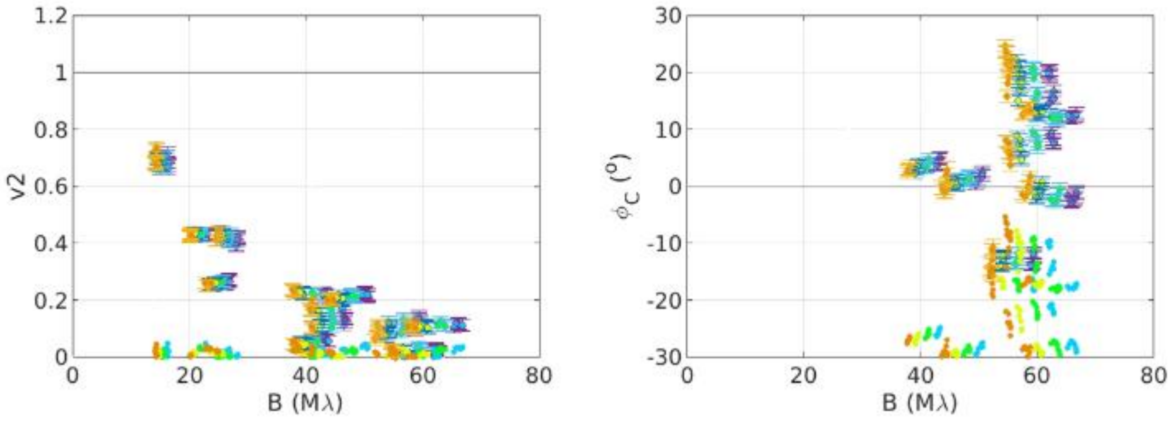
normalised flux

Zoom around
2.166 µm (Brγ)

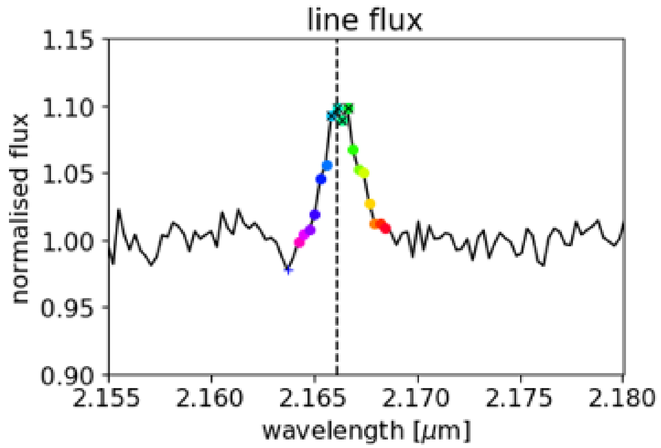


Klarman+ in prep.

Continuum and spectrum



continuum data + geometric model

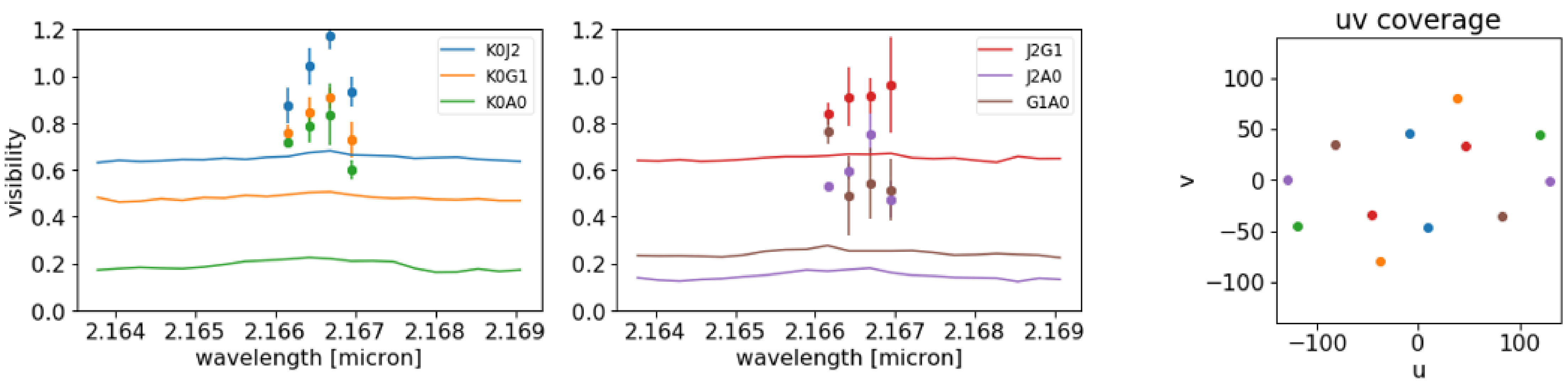


photsphere corrected line flux

$$V_{Br\gamma} = \frac{\sqrt{|F_{tot}V_{tot}|^2 + |F_{cont}V_{cont}|^2 - 2F_{tot}V_{tot}F_{cont}V_{cont}cos\phi}}{F_{line}}$$

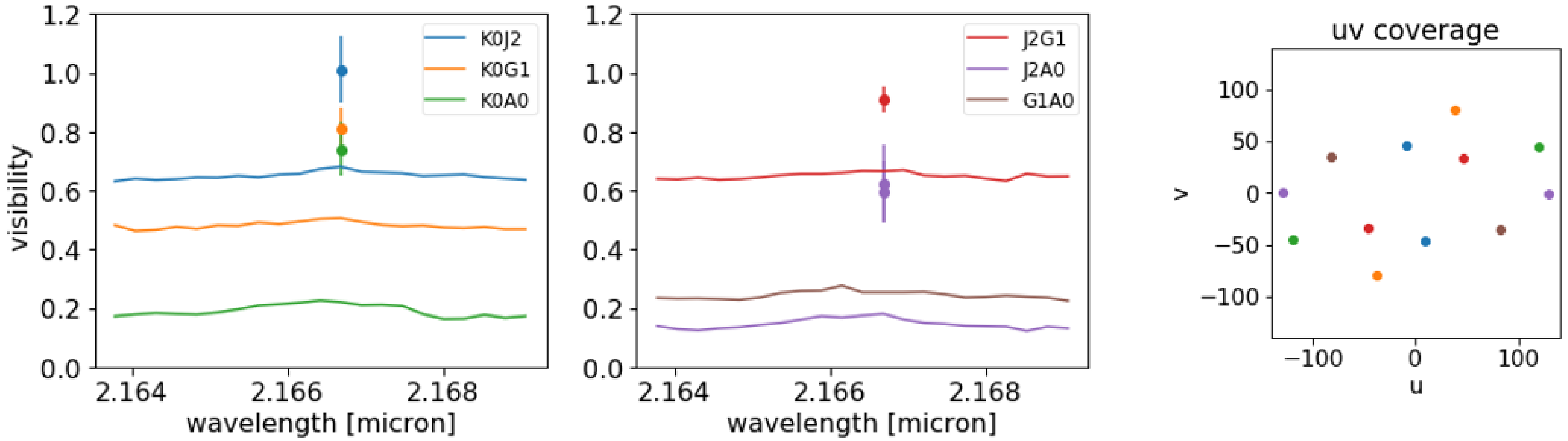
Klarman+ in prep.

Pure line visibilities



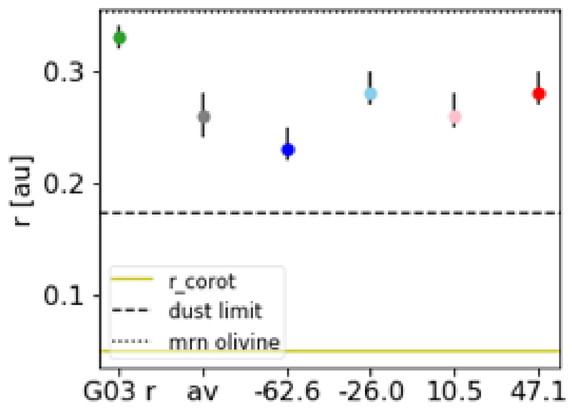
Klarman+ in prep.

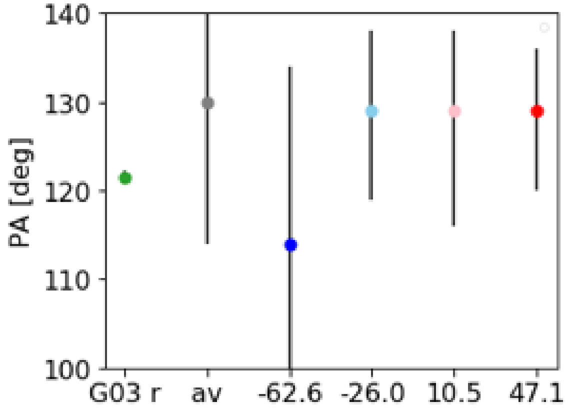
Average line visibility

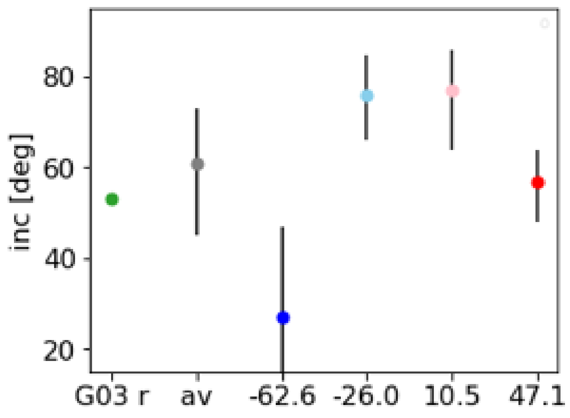


Klarman+ in prep.

Geometric model results with context:

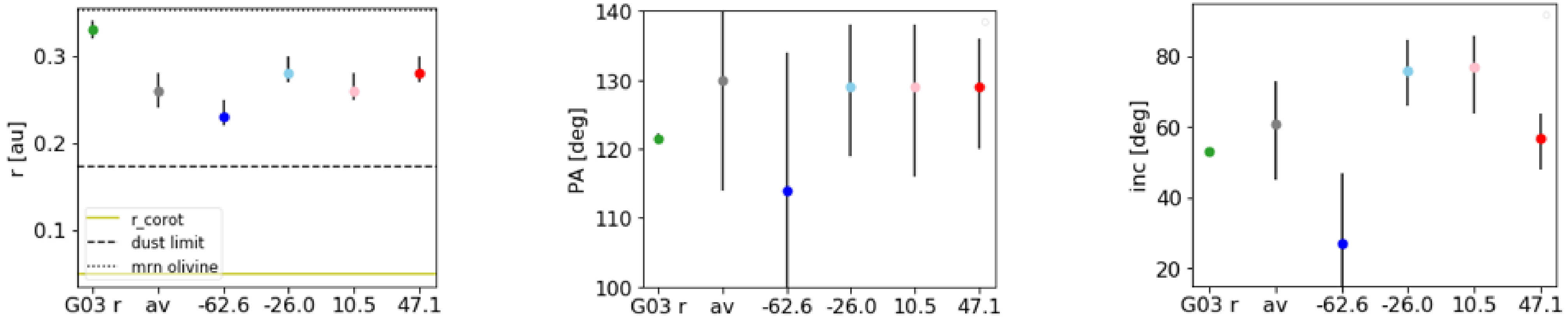






Klarman+ in prep.

Geometric model results with context:



Preliminary!

The Bry line traces a gas accretion disk just inside the dust sublimation radius.

Klarman+ in prep.

How to get the right dataset

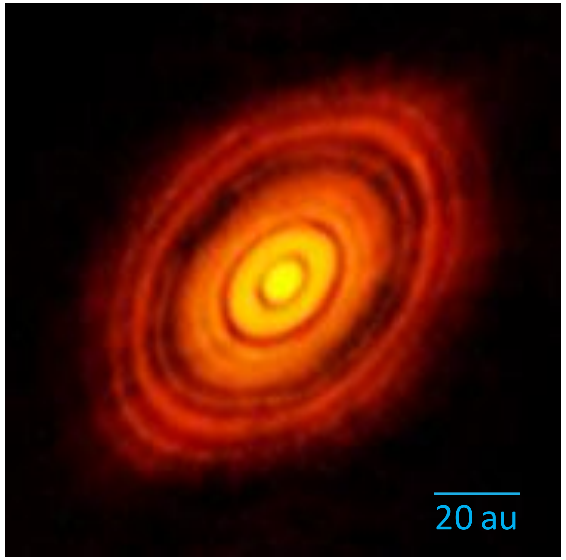
Question → Model → Observation → Data → Flux geometry → Disk geometry → Disk physics

How to get the right dataset

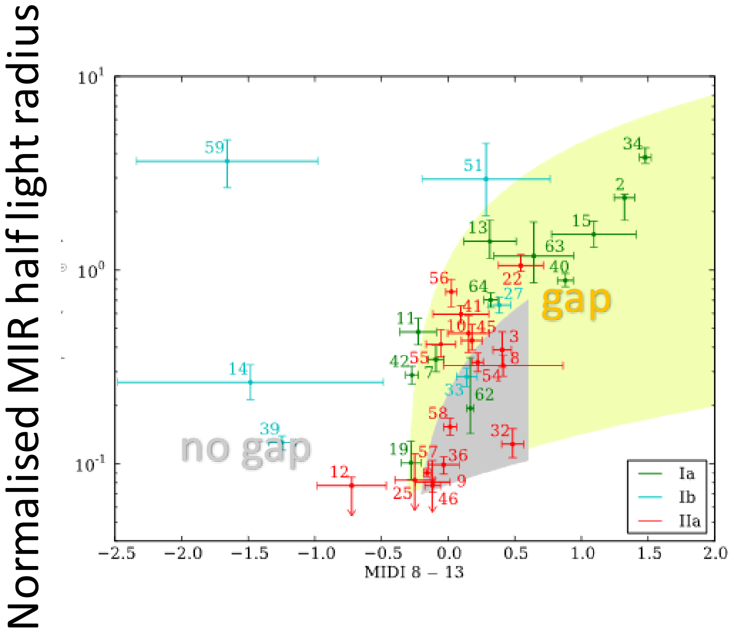
Question → Model → Observation → Data → Flux geometry → Disk geometry → Disk physics

Explore parameterspace → RT model → Synthetic observations → Instrument setup → Observation time

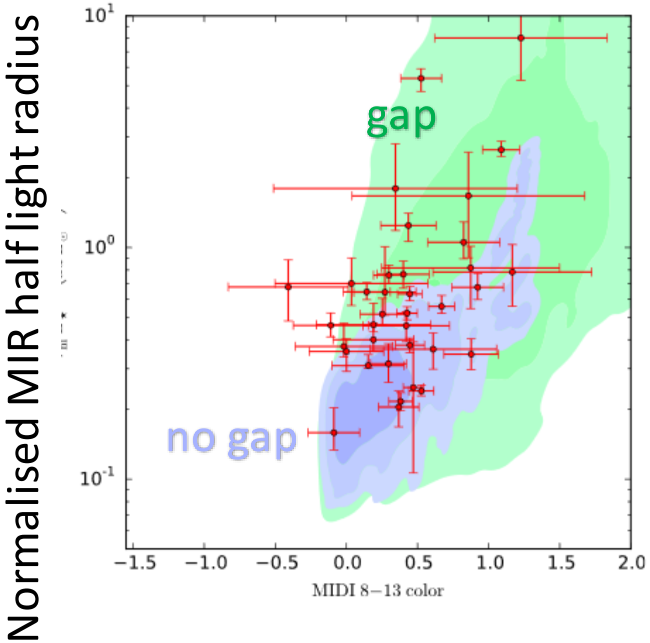
Are there gaps in the inner disk region?



gaps in HL Tau, ALMA



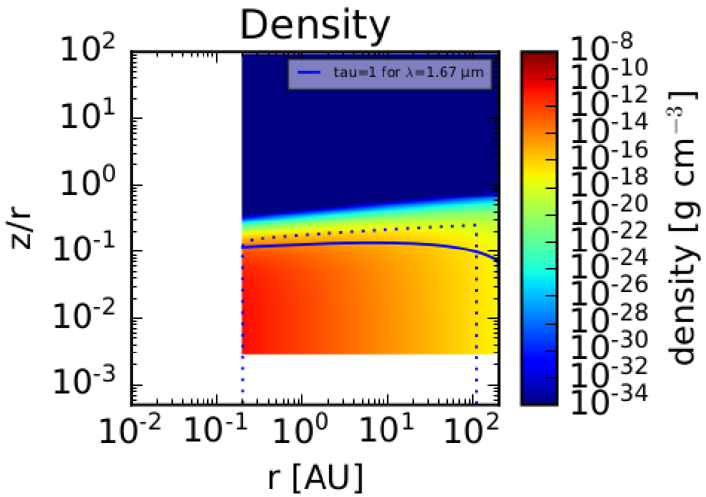
gaps in Herbig disks, MIDI

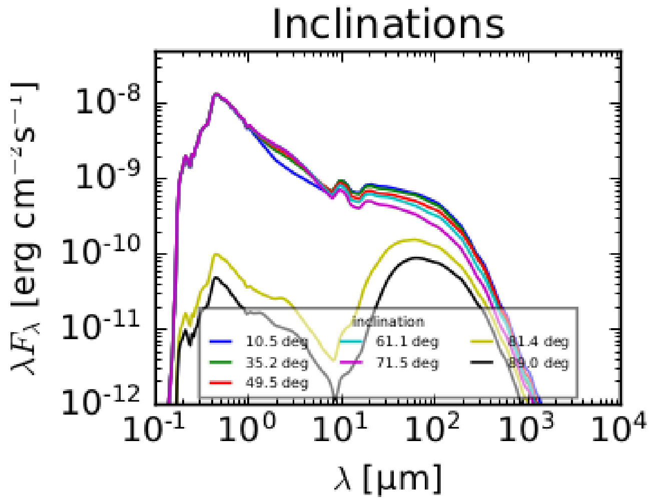


gaps in T Tauri disks, MIDI

Varga+ 2018, Menu+ 2015, AMA partnership+ 2015

RT model grid with relevant parameters

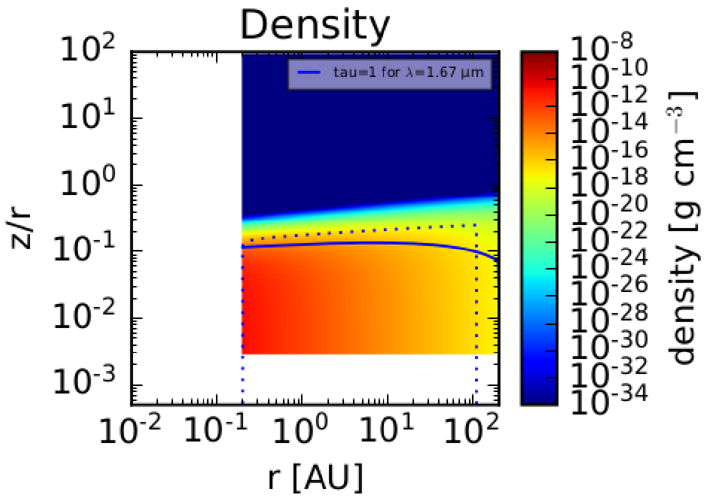


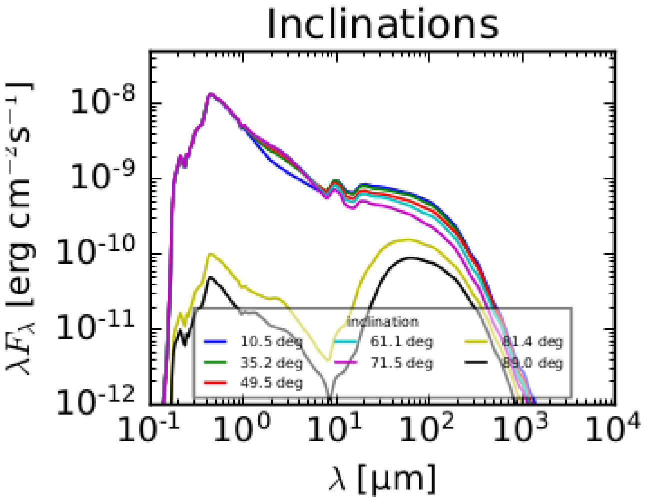


parameter	values
declination	-20, 20, 60 degrees
inclination	10, 45, 60 degress
gap size	0.5, 1, 2, 4 au
gap position	0.3, 0.48, 0.76, 1.2 au

Klarmann+ in prep

RT model grid with relevant parameters



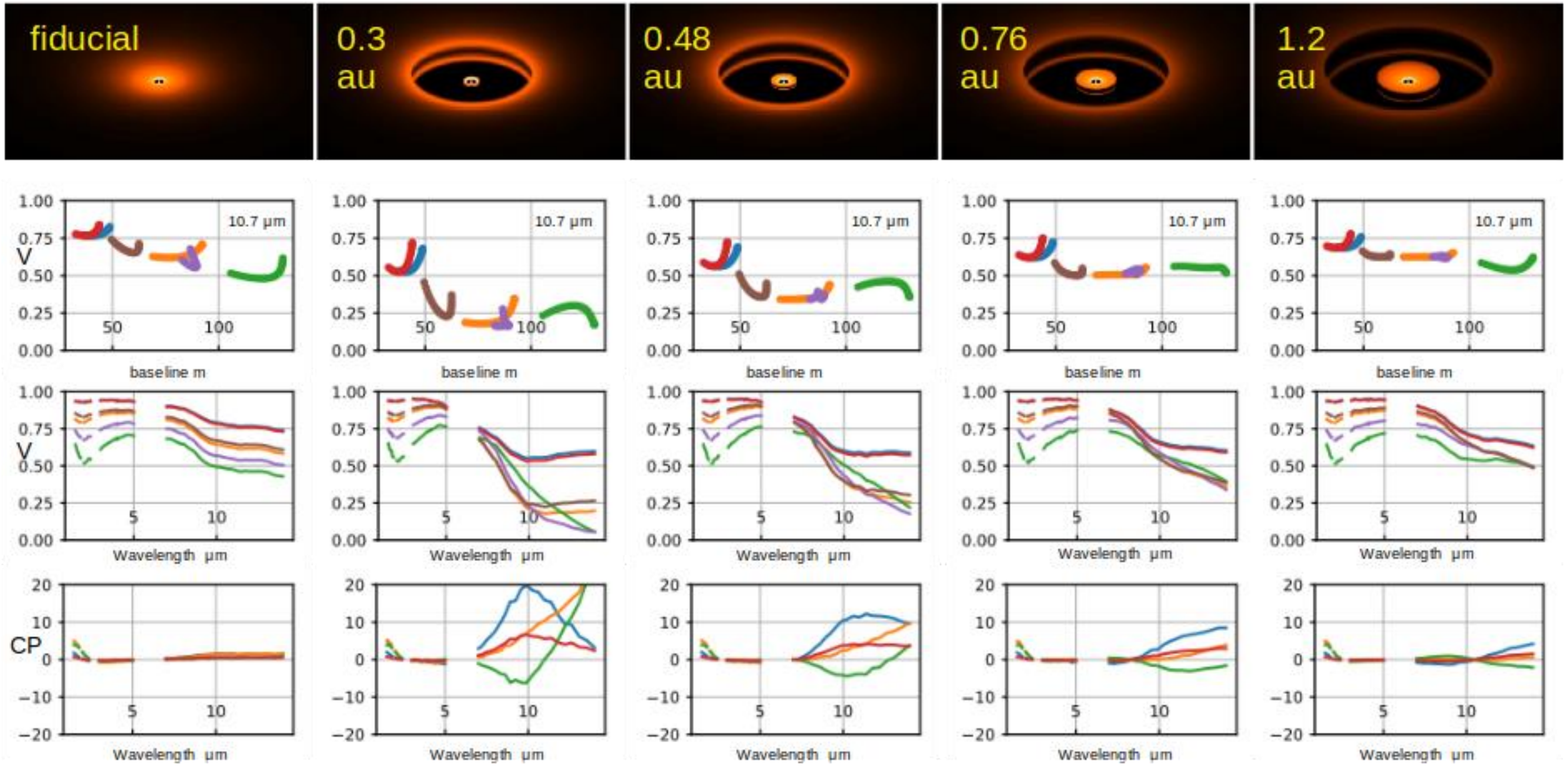


parameter	values
declination	-20, 20, 60 degrees
inclination	10, 45, 60 degress
gap size	0.5, 1, 2, 4 au
gap position	0.3, 0.48, 0.76, 1.2 au

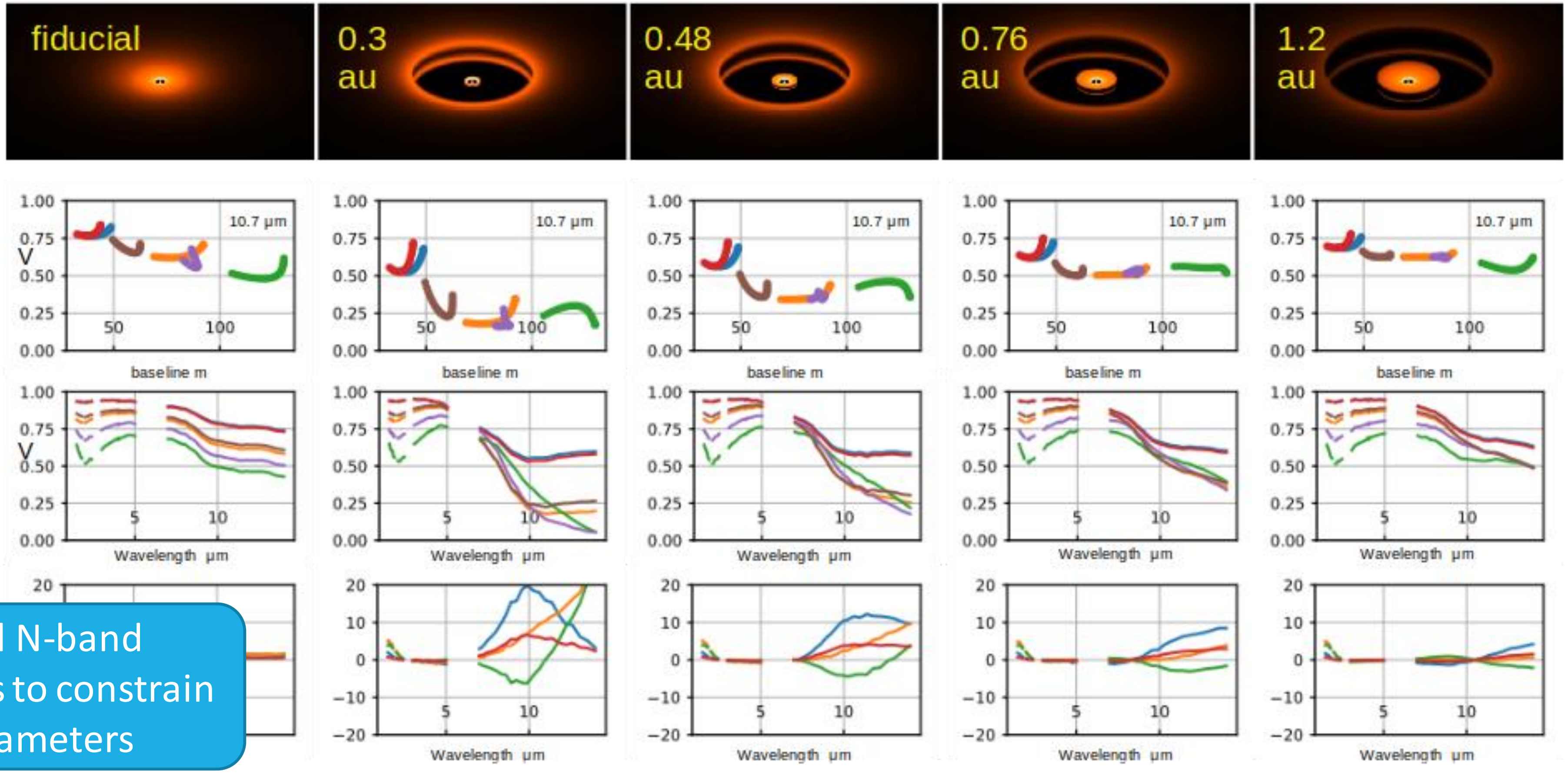
Synthetic PIONIER, GRAVITY and MATISSE observations

Klarmann+ in prep

Visibilities and CP for a 2 au gap



Visibilities and CP for a 2 au gap



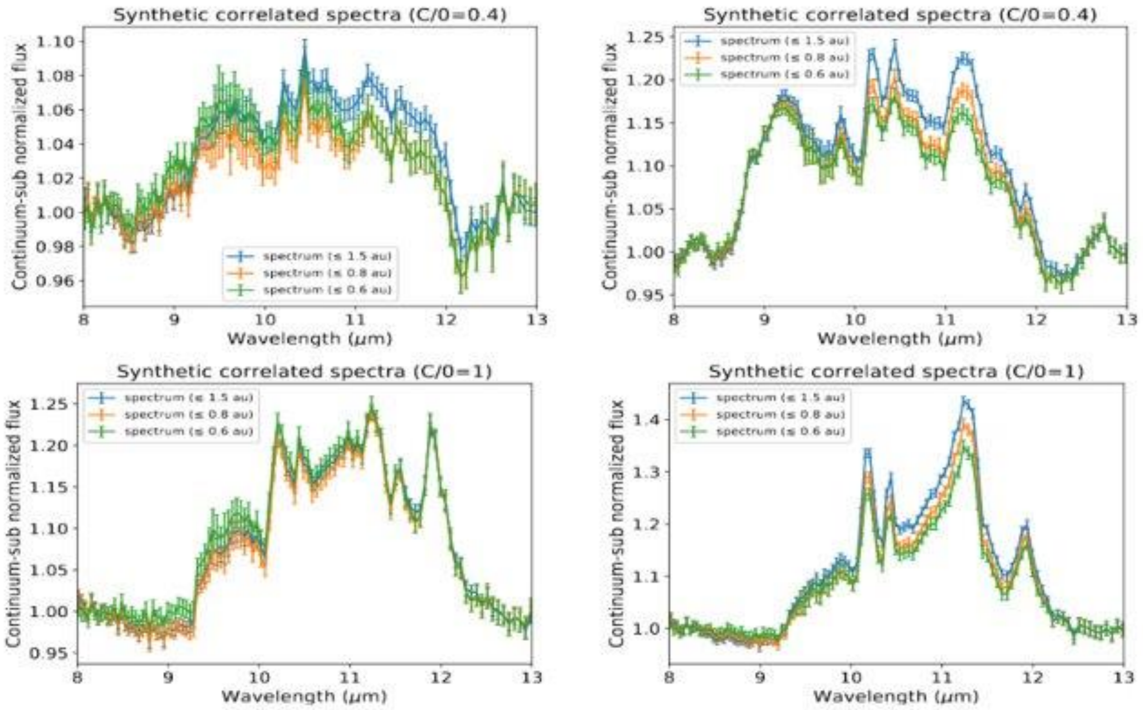
We need N-band observations to constrain gap parameters

Primordial composition of disk material

- Focus on C/O
- condensation sequences computed at LTE and in 1d
- -> different disk mineralogy
- Minerals have features in the N-band
- Grain size effects the features
- -> RT models with different grain sizes for each C/O ratio
- Basis for MATISSE observations

Matter+ 2020

Primordial composition of disk material



- Focus on C/O
- condensation sequences computed at LTE and in 1d
- -> different disk mineralogy
- Minerals have features in the N-band
- Grain size effects the features
- -> RT models with different grain sizes for each C/O ratio
- Basis for MATISSE observations

Matter+ 2020

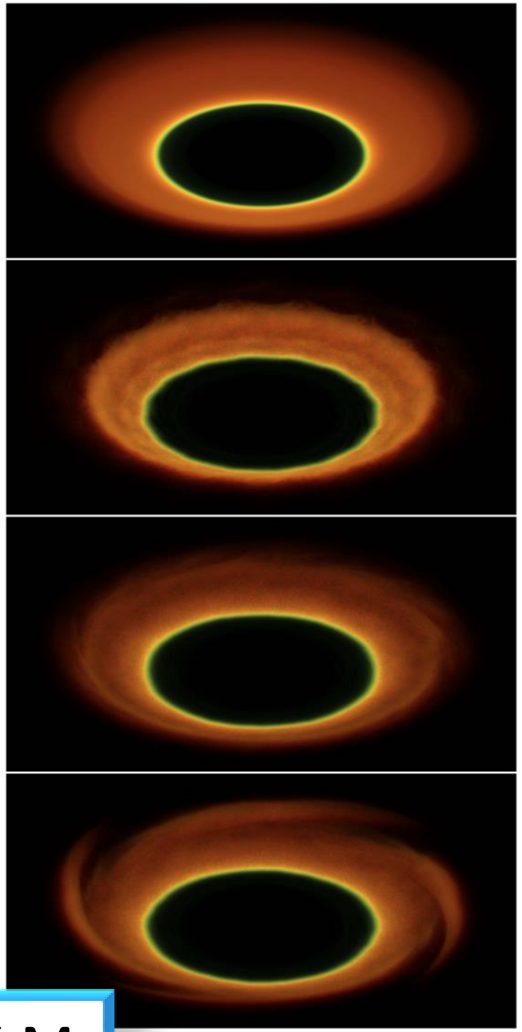
What about magnetic fields?

Pure hydro

+ strong B

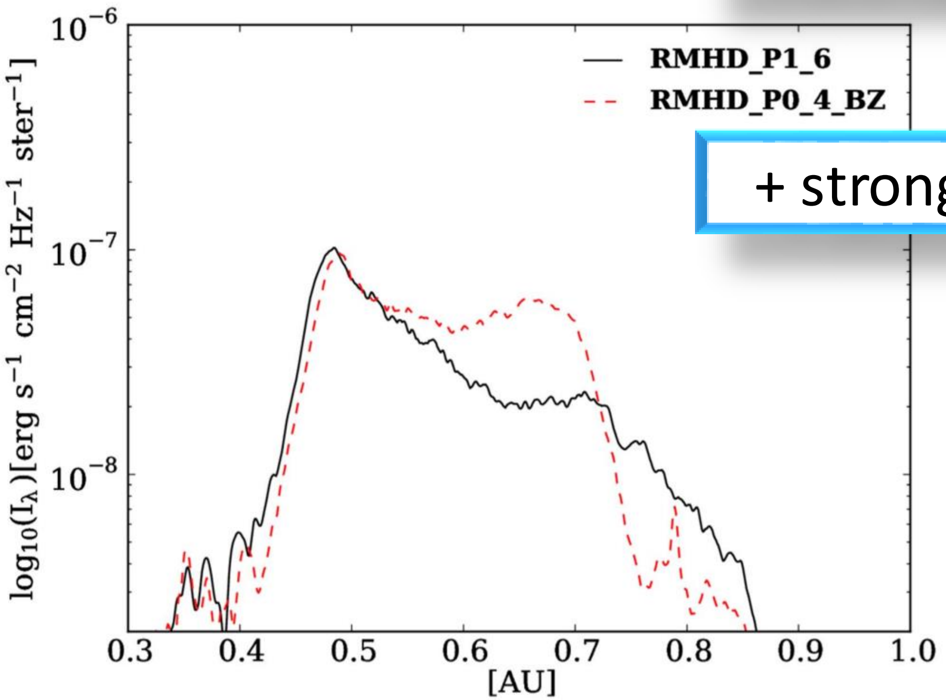
+ weak B

+ vortex



J,K,M

Pure hydro



+ strong B

Flock+ 2012, 2016

Additional comments

- remember the limited interferometric field of view
- look at your data against baseline and wavelength
- model the SED in parallel with the interferometric data
- use the SED to constrain the star to disk flux ratio
- determin inclination and position angle from the interferometric data
- write your own code to fit size, inclination and position angle
- consider existing code for more detailed models
- get collaborators for physical models
- start modelling even if you don't understand everything

I have NIR/MIR interferometry data. How do I exploit it?

- attend the vlti school
- collect all existing observations/models of your object(s)
- learn what you can from looking at the data
- understand the basic flux geometry with a simple model
- test for variability
- understand the basic geometry of lines/features
- start to explore the disk structure, composition and physics

Exploring the inner disk region