Gone with the wind: The innermost structure of protoplanetary disks

R. García López (DIAS; MPIA)

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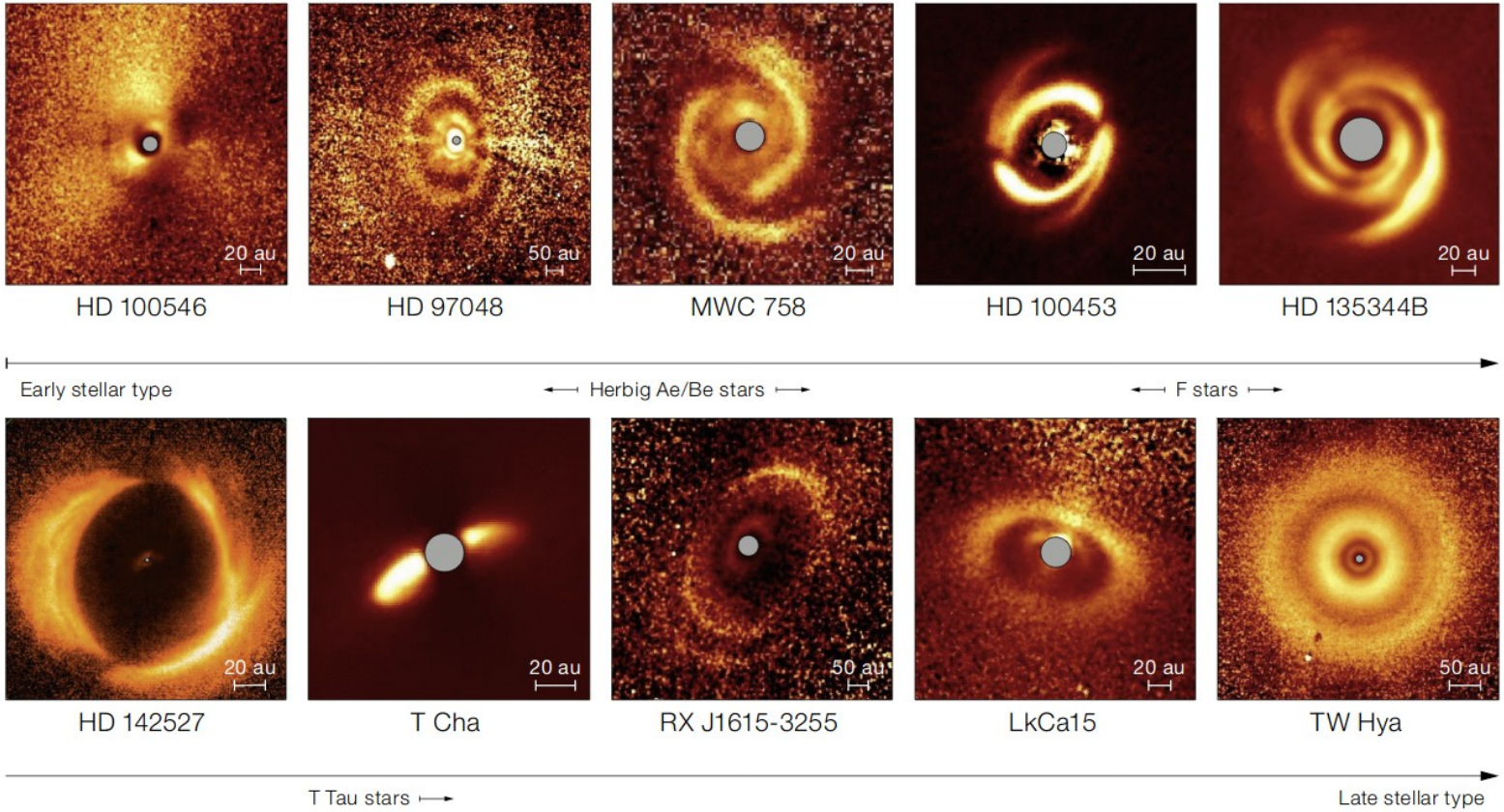
Outline

- Introduction
- The inner disk trough continuum observations
- The inner disk through gas tracers
- Conclusions

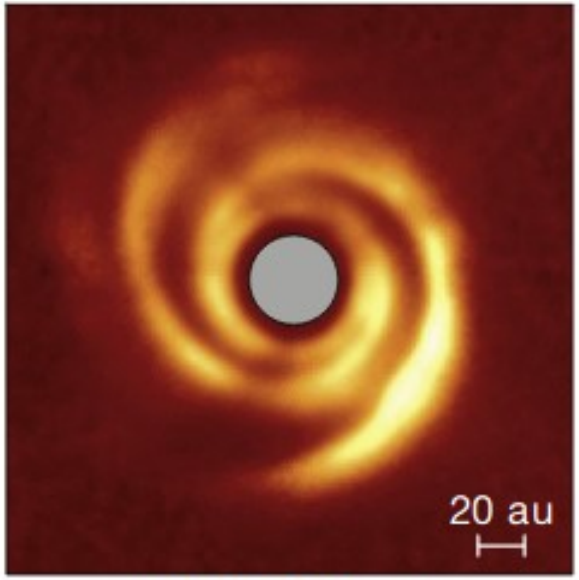
Introduction



Garufi, Benisty et al. 2017, VLT-SPHERE

Introduction

- This talk definition of inner disk: R$\lesssim$5 au

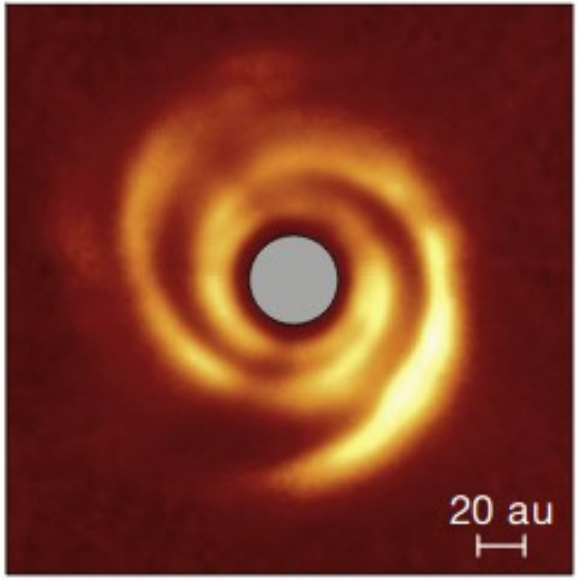


HD 135344B

Garufi, Benisty et al. 2017, VLT-SPHERE

Introduction

- This talk definition of inner disk: $R \lesssim 5$ au



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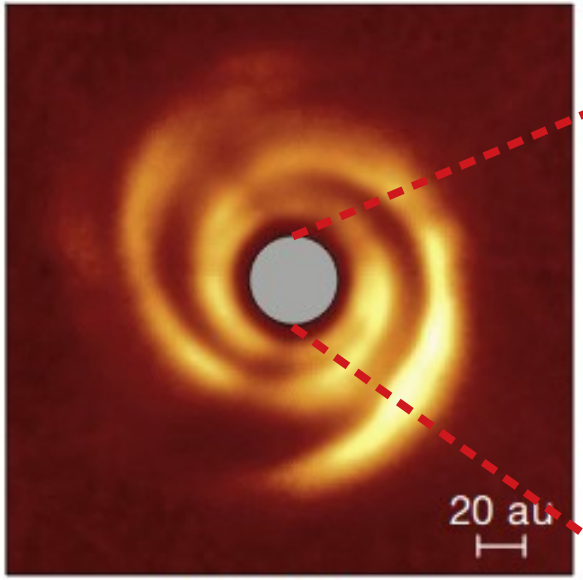

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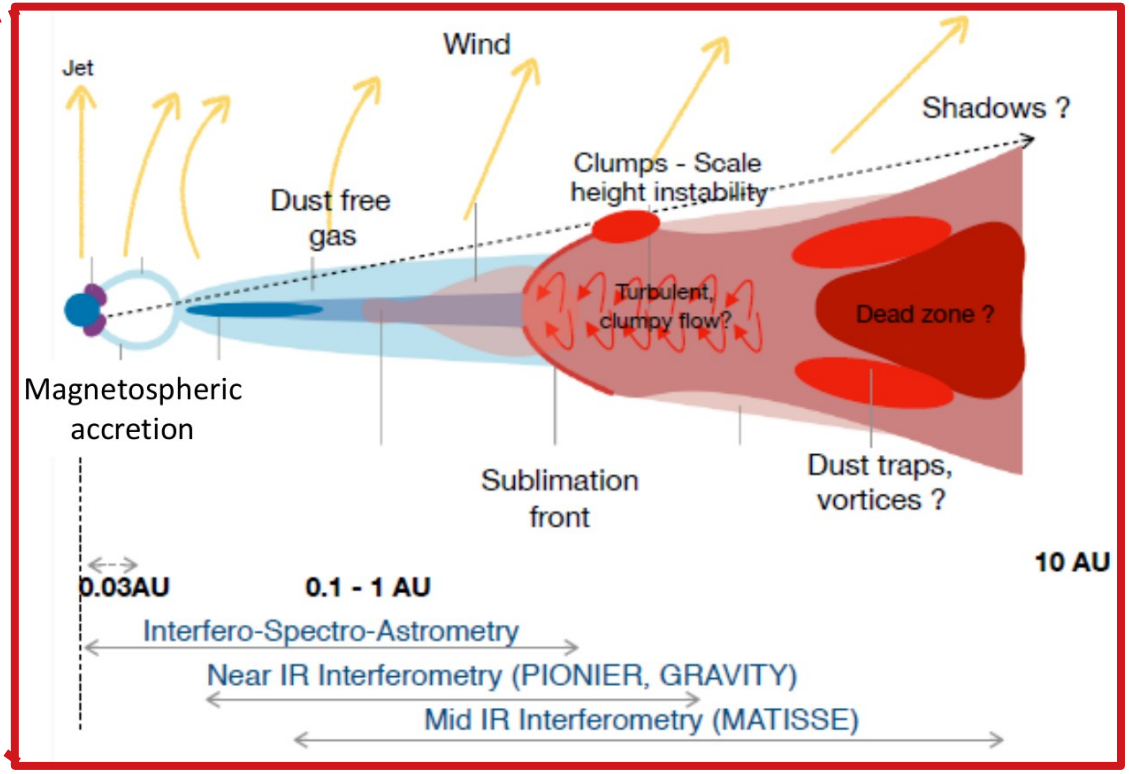
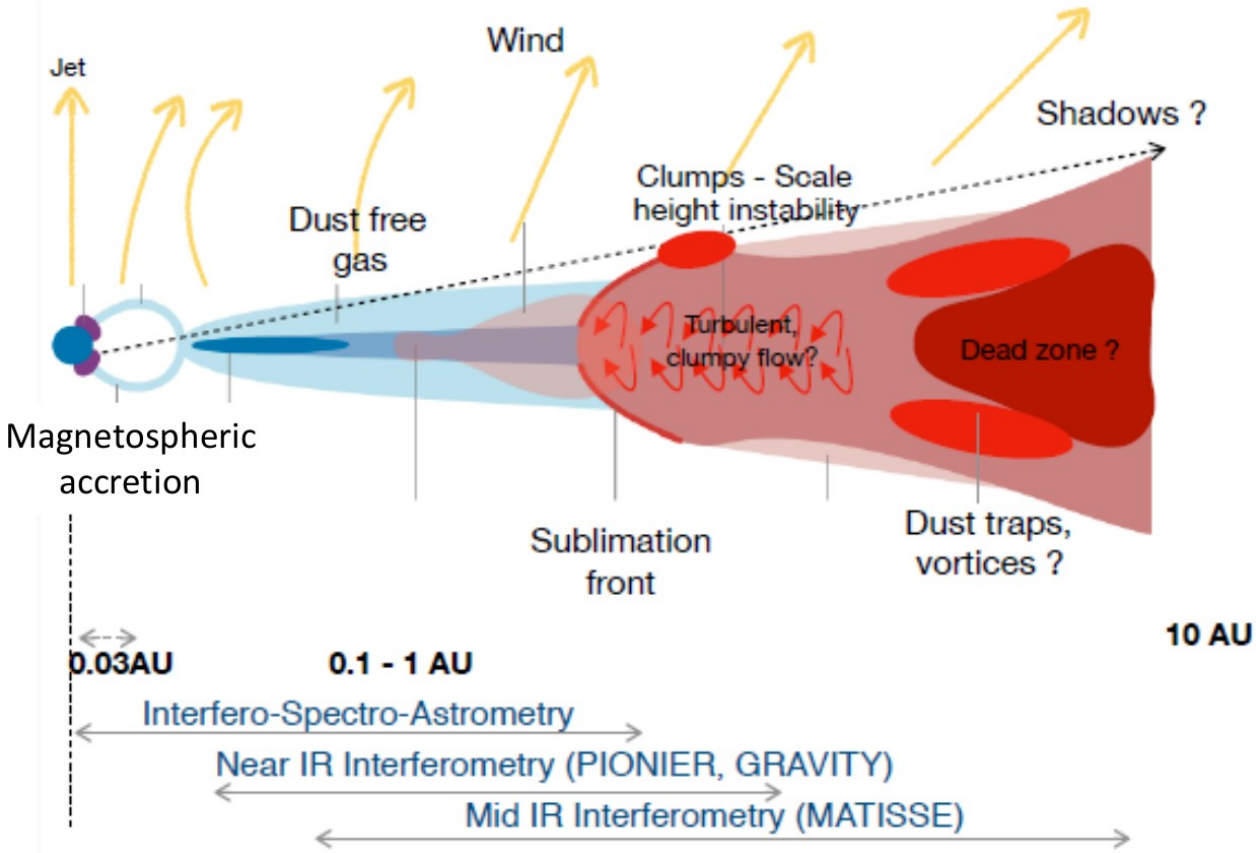


Adpated from Dullemond & Monnier 2010

Introduction

- Accretion and winds:
  - Dominate gas dispersal
  - Drive disk dynamics
- Dust particles evaporate at the sublimation front
- UV, optical and IR radiation determine the energy balance of the full disk



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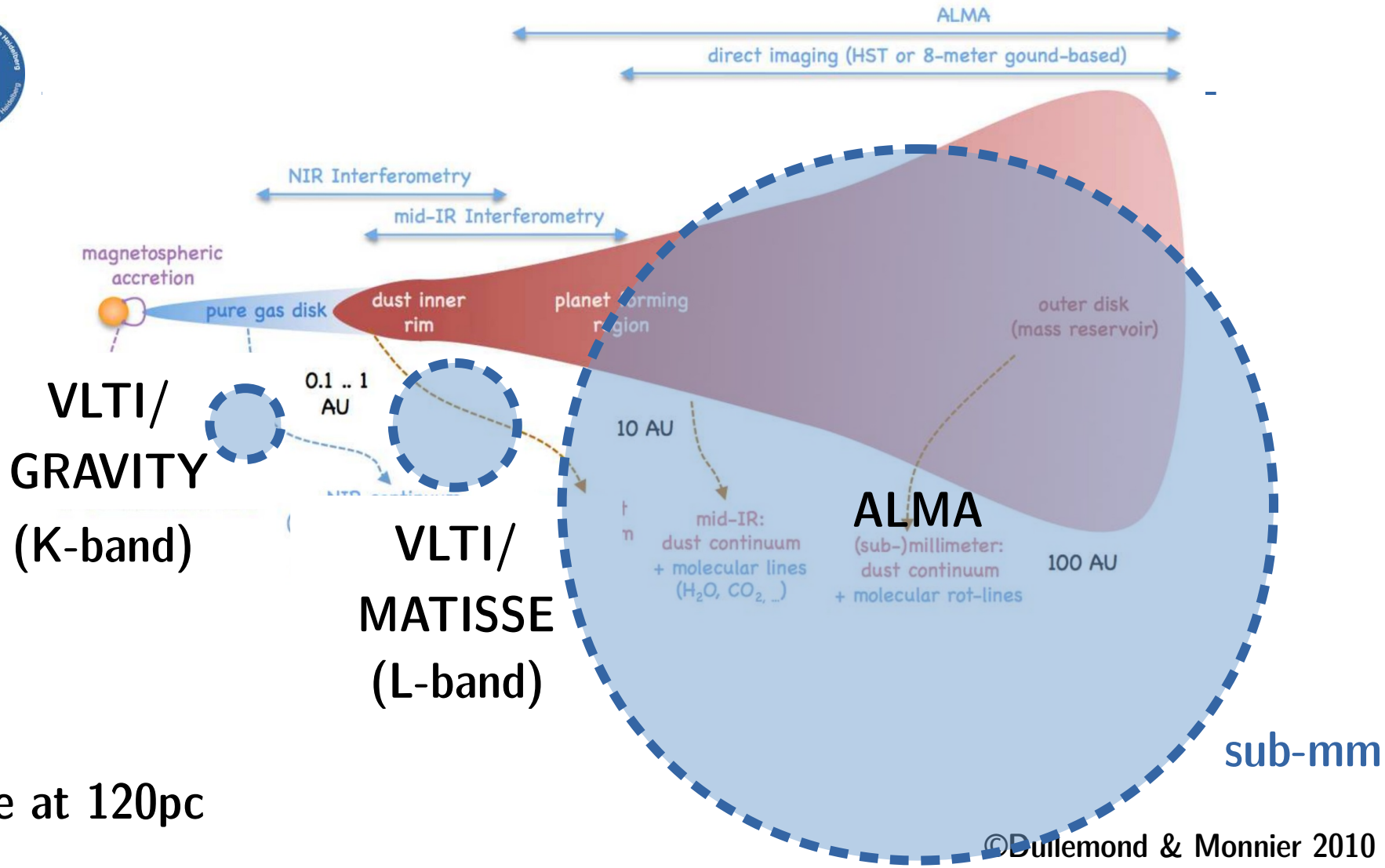
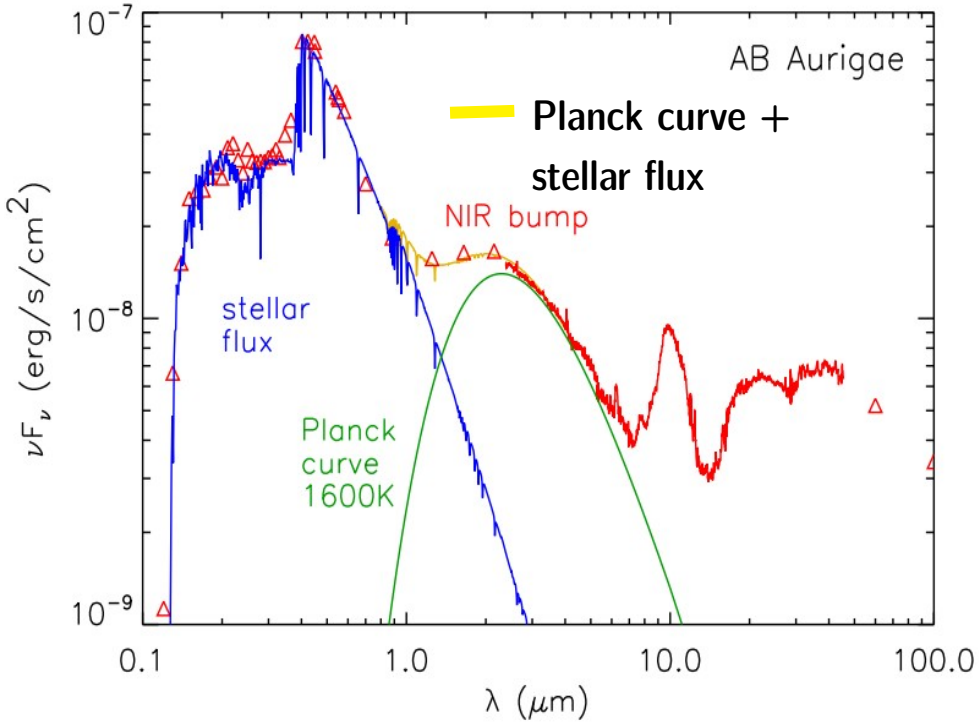


Beam size at 120pc

©Duullemond & Monnier 2010

Indirect tracers of the inner disk: the continuum



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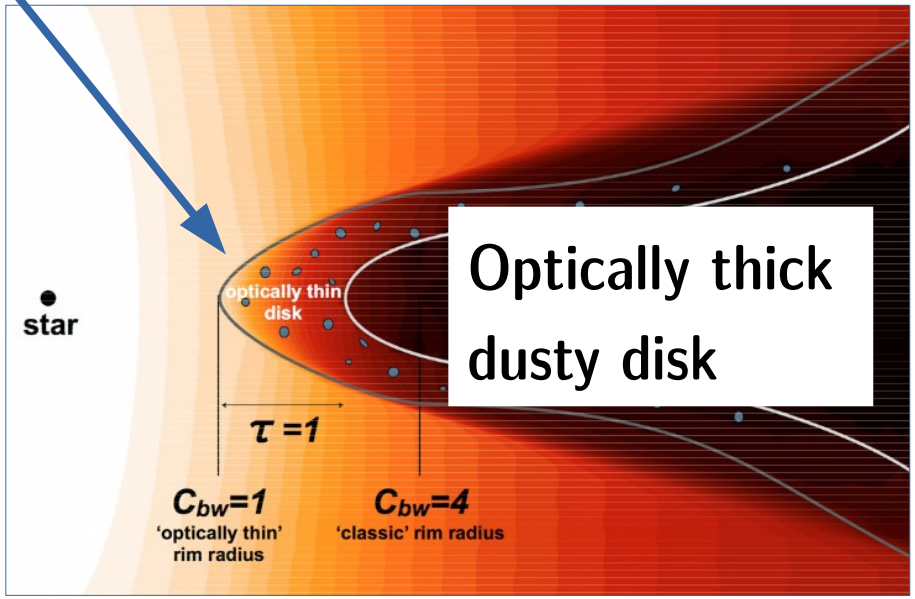
Optically thin disk

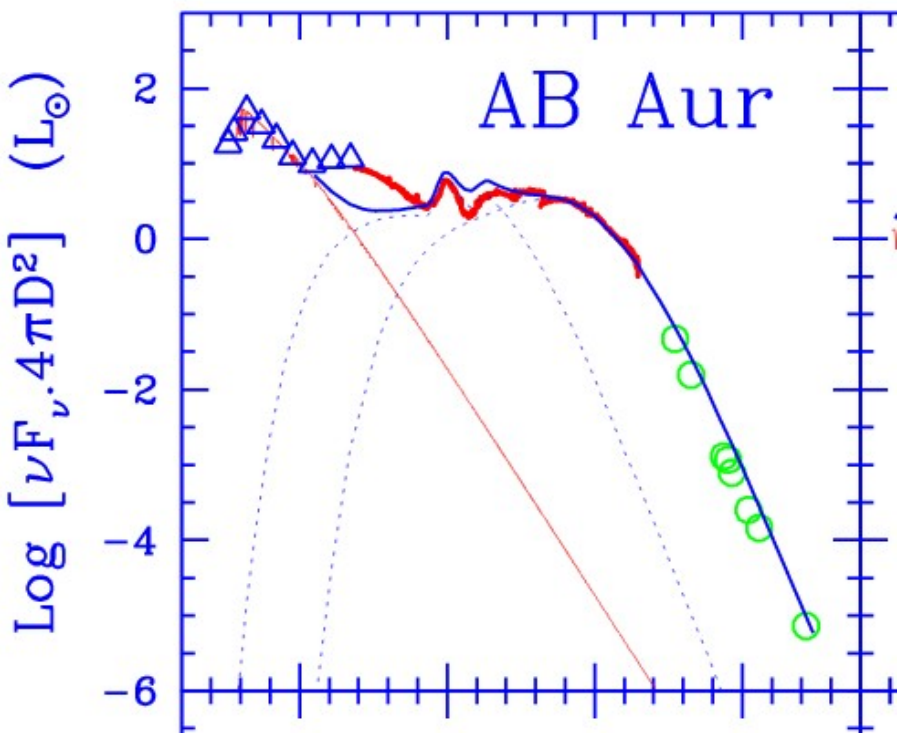


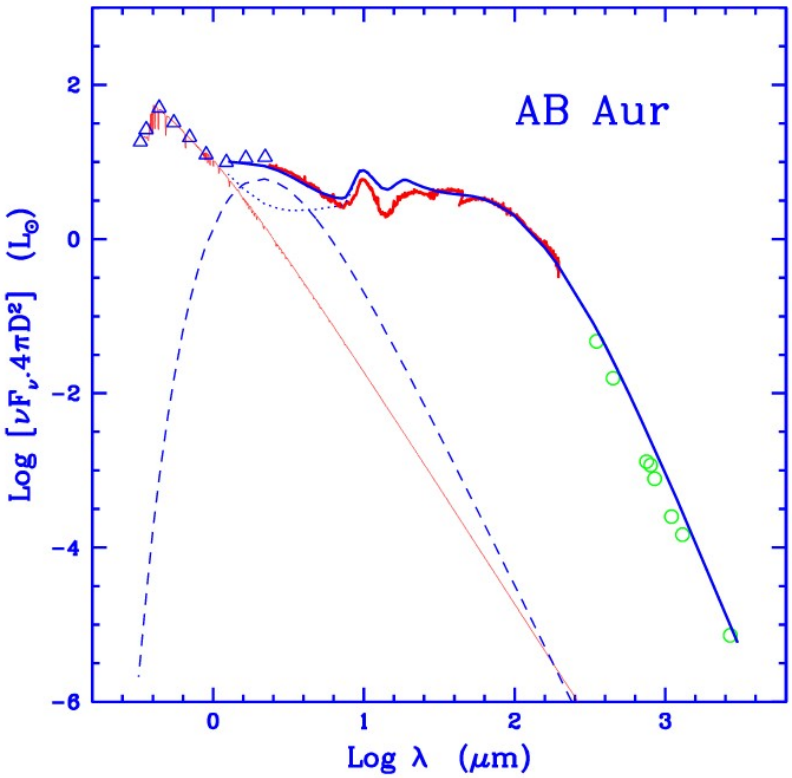
Optically thick dusty disk

©Kama et al. 2009

Indirect tracers of the inner disk: the continuum

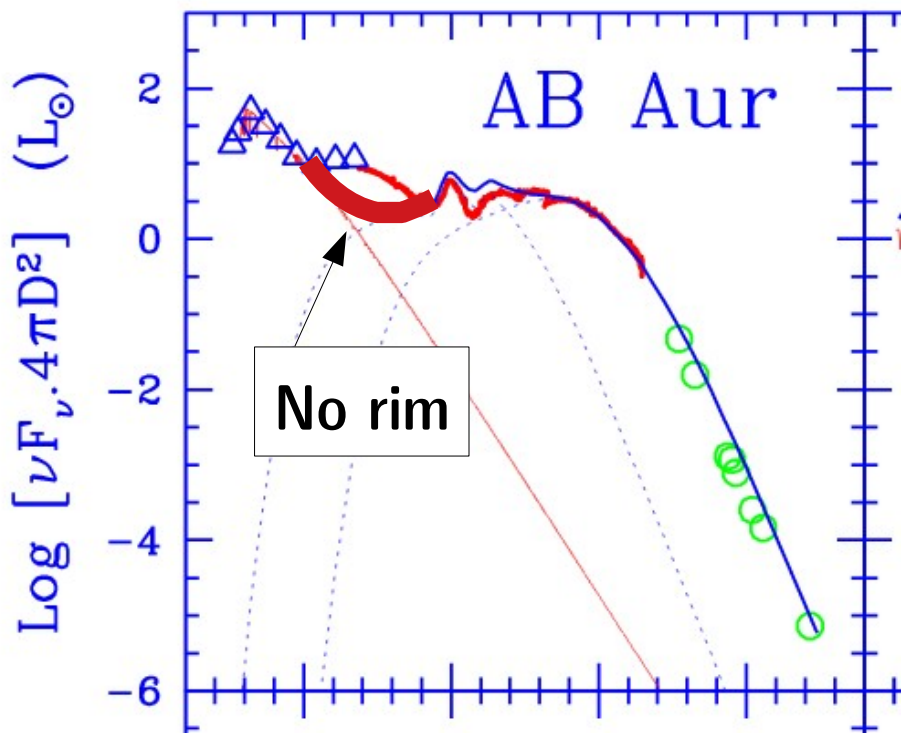
Natta et al. 2001: **A reconsideration of disk properties in Herbig Ae stars**

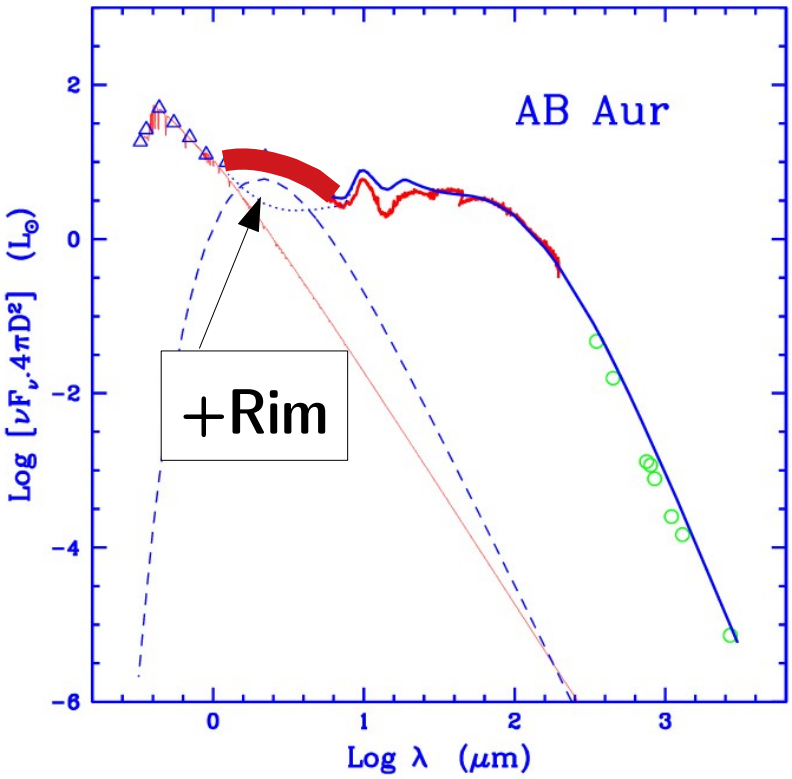




Indirect tracers of the inner disk: the continuum

Natta et al. 2001: **A reconsideration of disk properties in Herbig Ae stars**





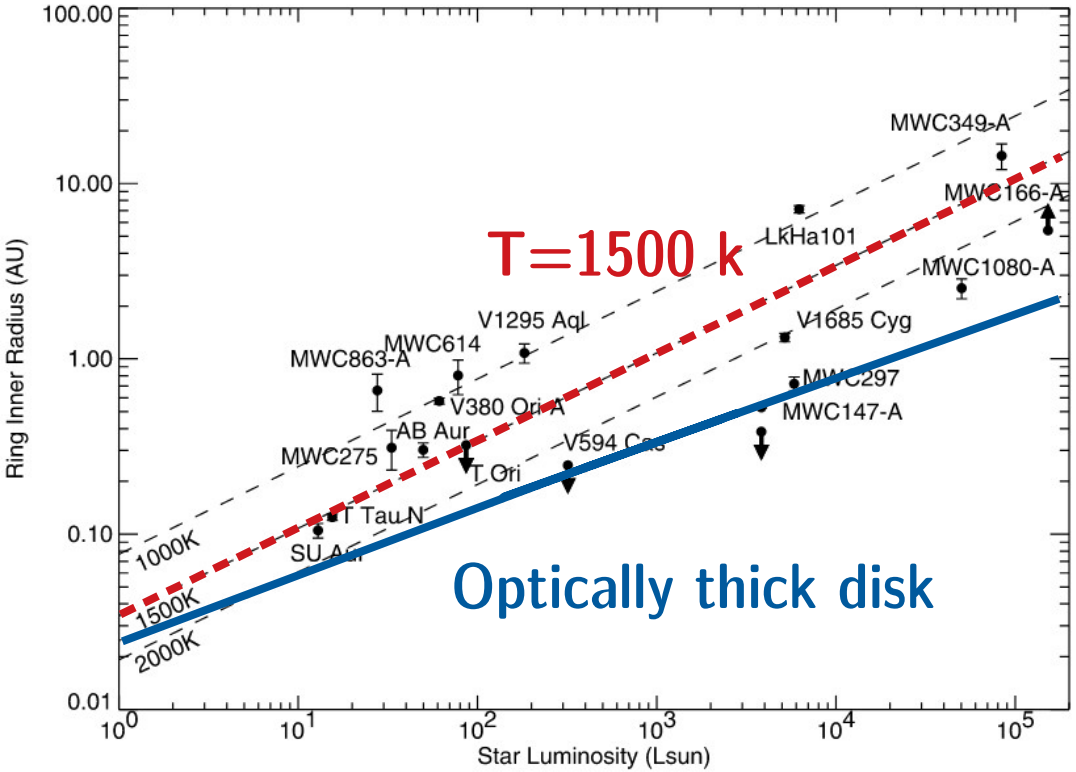
See also: Dullemond, Dominik & Natta (2001)

The inner disk: continuum emission

The size-luminosity diagram agrees with the presence of an optically thin disk surrounded by an inner rim.

$R_{rim} \propto L_*^{1/2}$

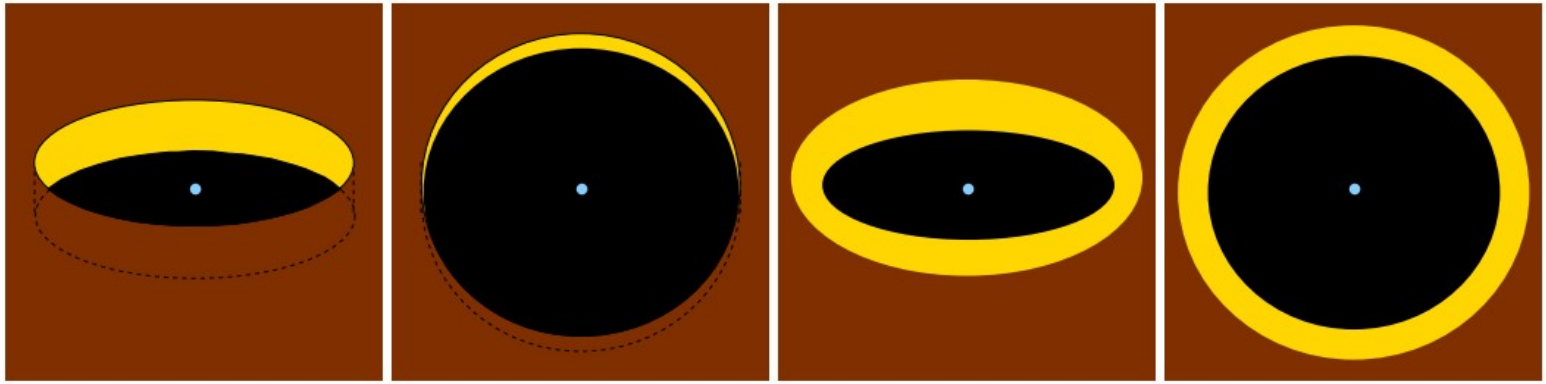
Refs: Millan-Gabet+ 1999, 2001, Akeson+ 2000, Monnier+ 2002



©Monnier & Millan-Gabet et al. 2002

The inner rim shape and composition

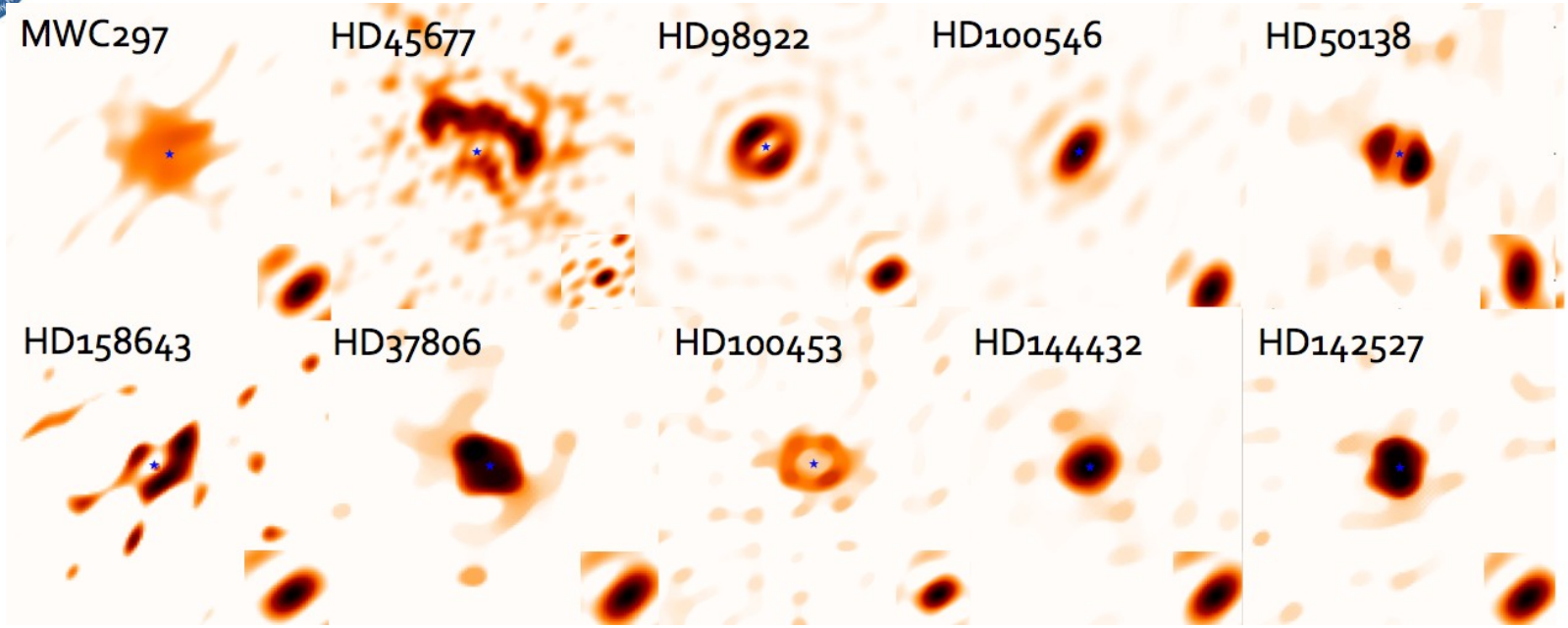
- Prediction: the image of an inclined rim projected on the sky should deviate from point-symmetry.



©Dullemond & Monnier 2010

- Interferometry with at least 3 telescopes: closure phase (CP)

The inner disk: continuum



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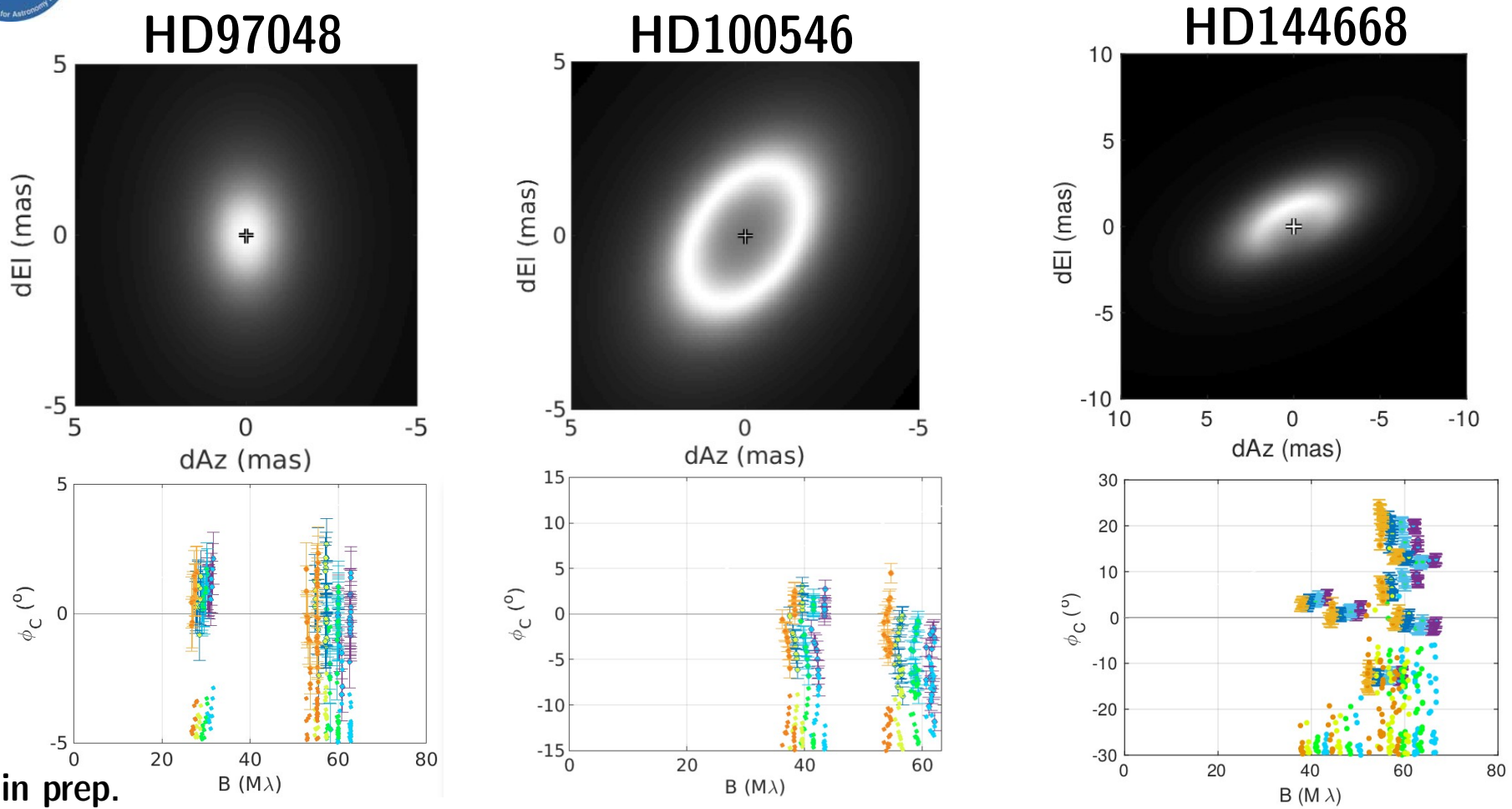
- VLTI-PIONIER (H-band) & GRAVITY (K-band) large program :
  - Variety of morphologies
  - Ring shaped morphologies but very wide

The inner disk: continuum

VLTI-GRAVITY (K-band)



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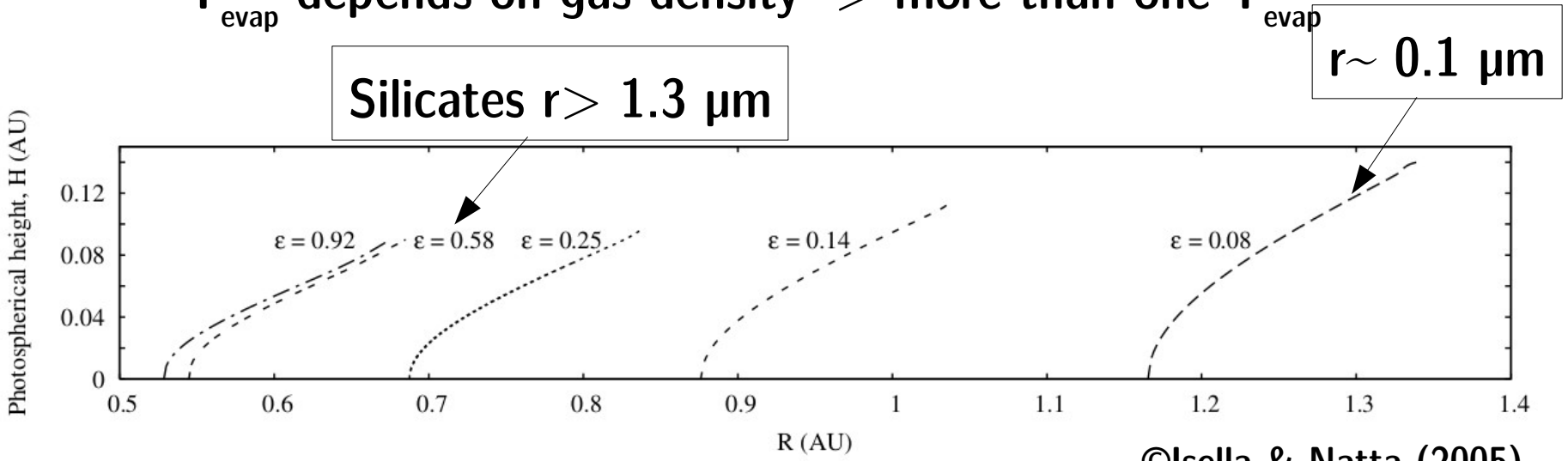
The inner disk: continuum

- CPs point to a smooth rim

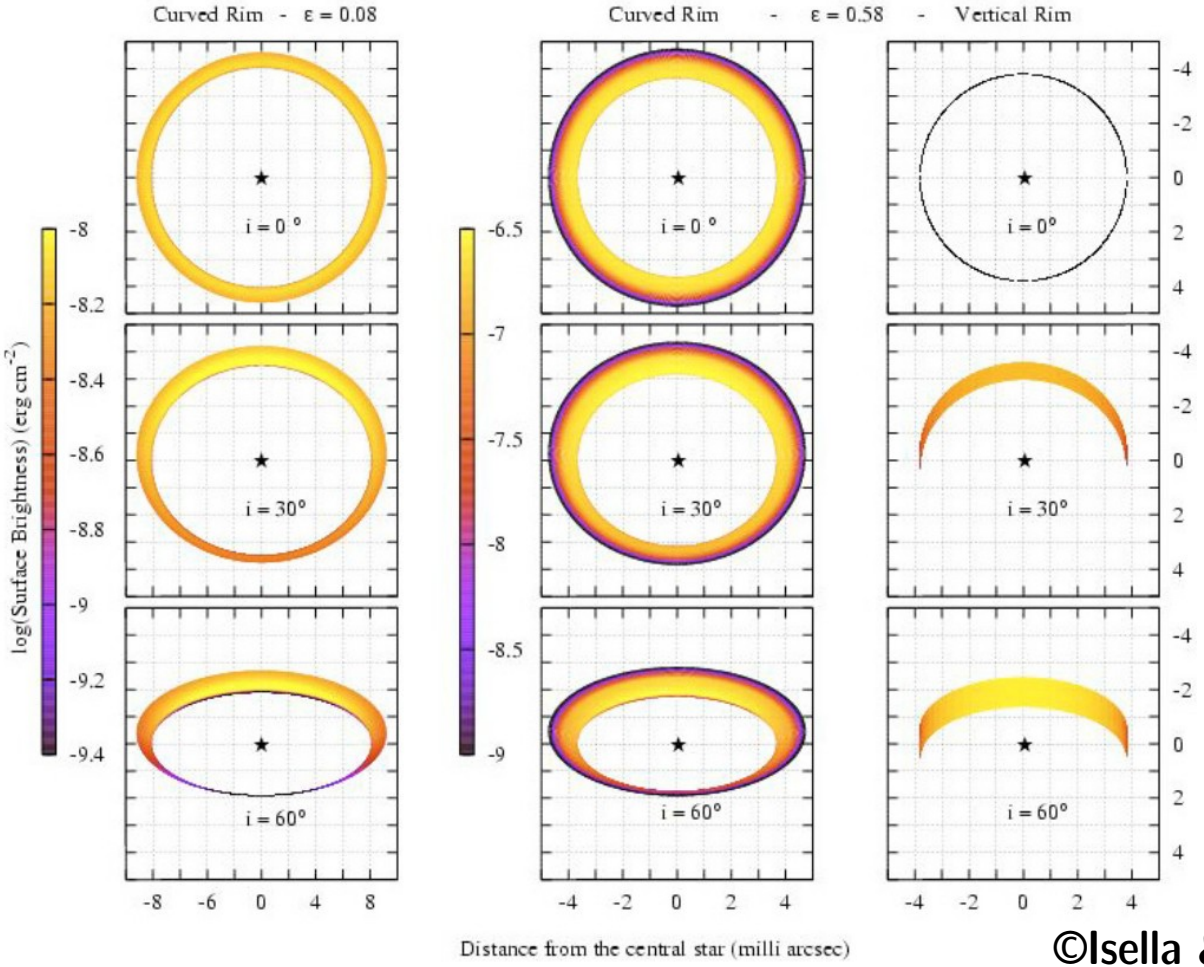
- Isella & Natta (2005), Tannirkulam et a. (2007): curved rim morphology

T_{evap} depends on gas density -> more than one T_{evap}



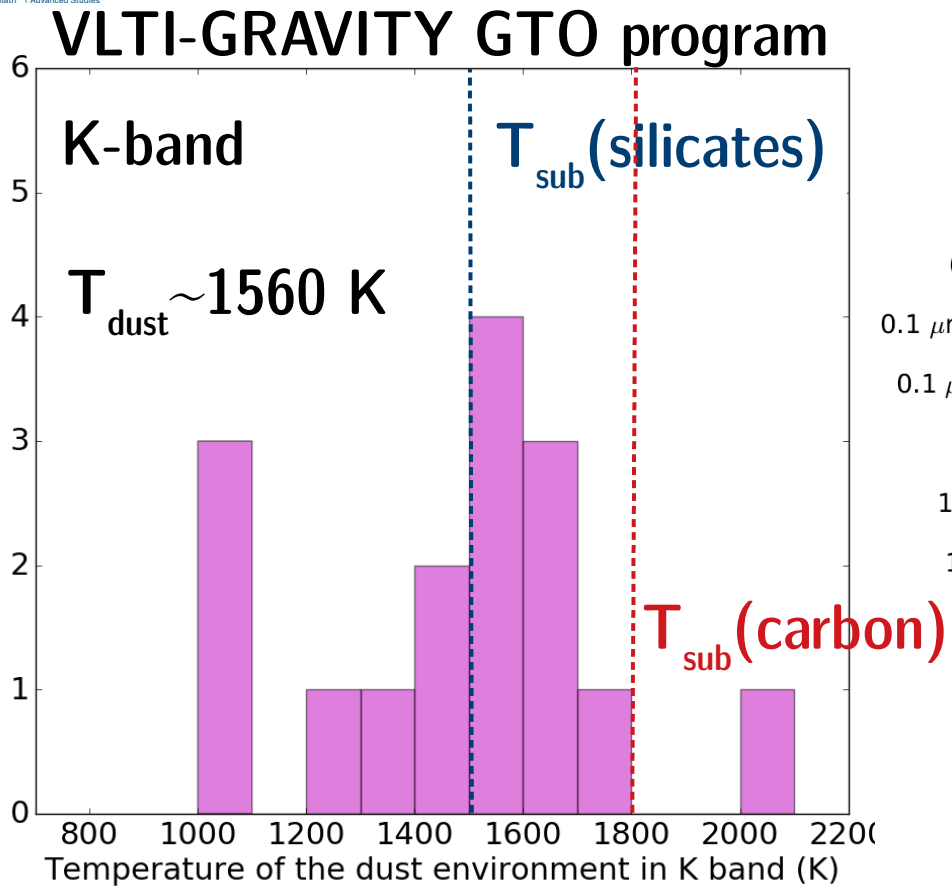
©Isella & Natta (2005)

The inner disk: continuum



©Isella & Natta (2005)

The inner rim shape and composition



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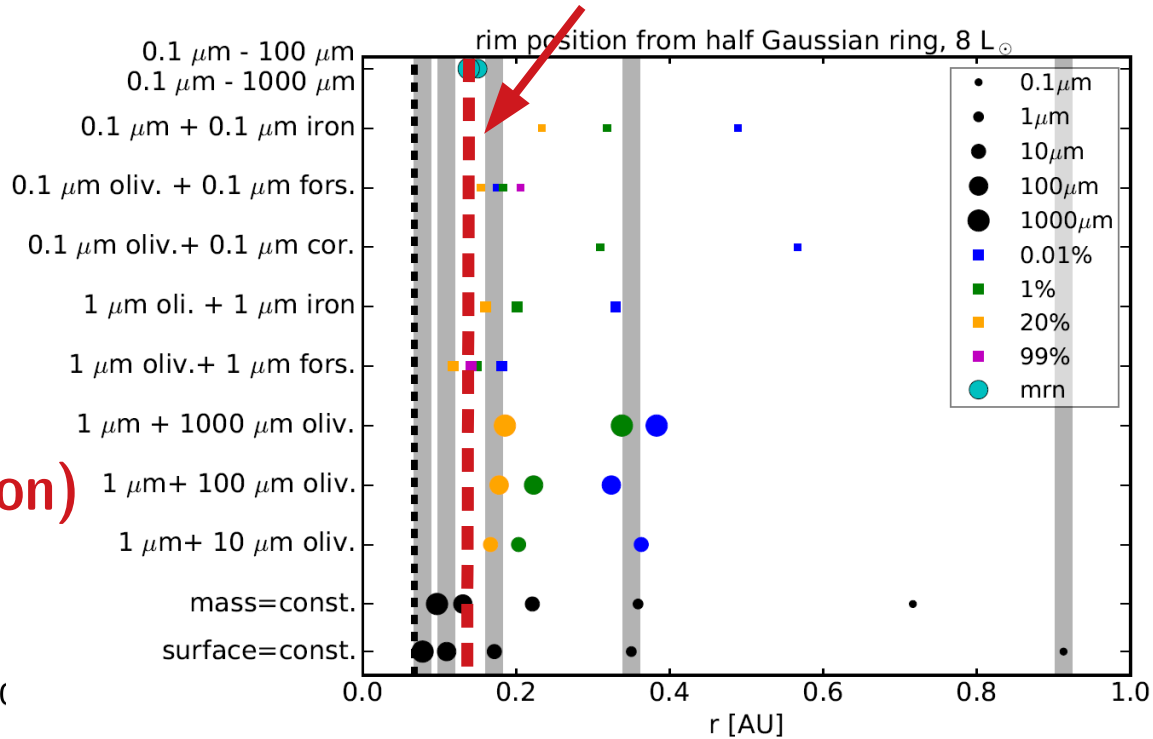
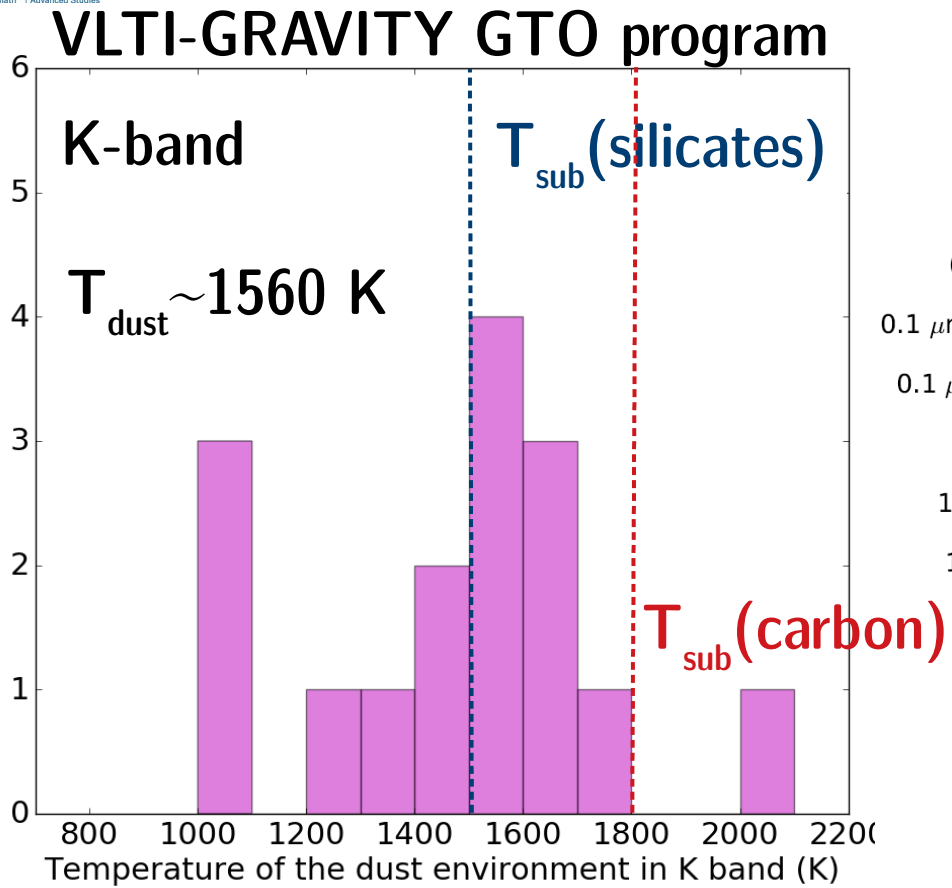
VLTI-PIONIER/GRAVITY

Average rim position



©Klarmann+ to be sub.

The inner rim shape and composition



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VLTI-PIONIER/GRAVITY

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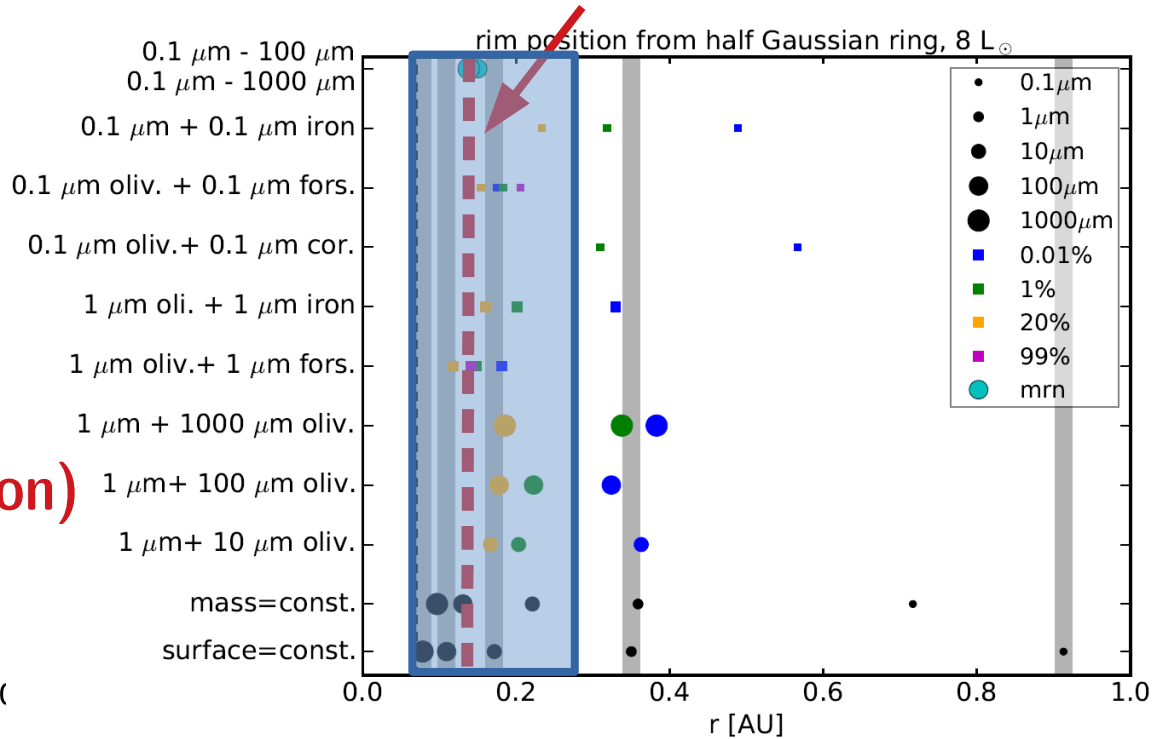

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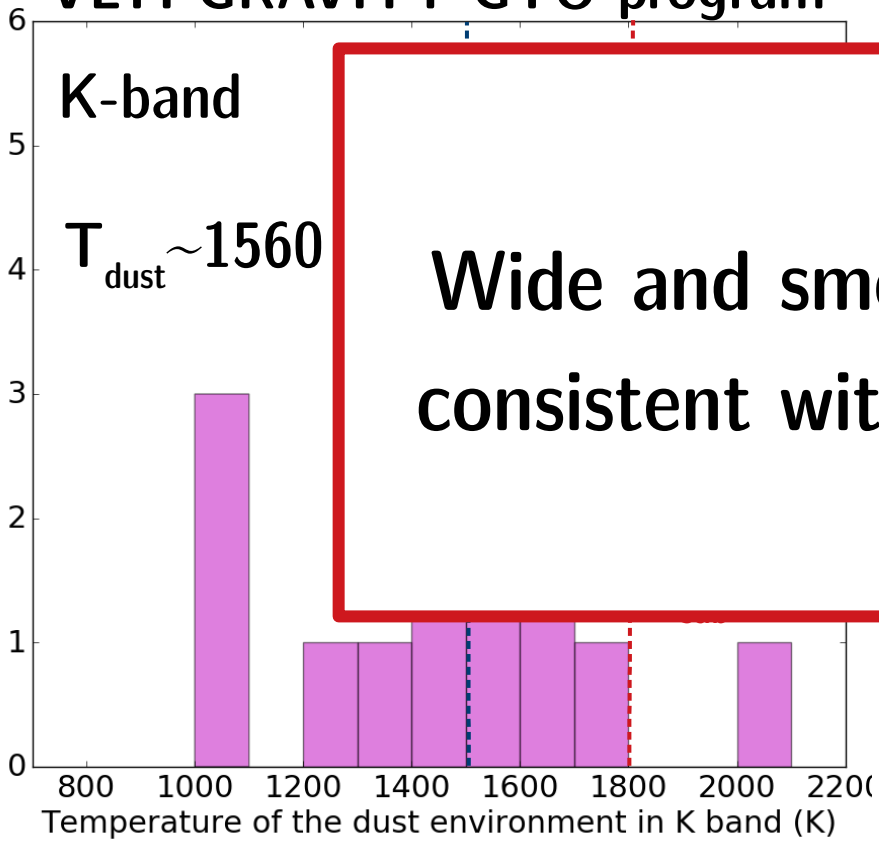
The inner rim shape and composition

VLTI-PIONIER/GRAVITY

Average rim position

VLTI-GRAVITY GTO program



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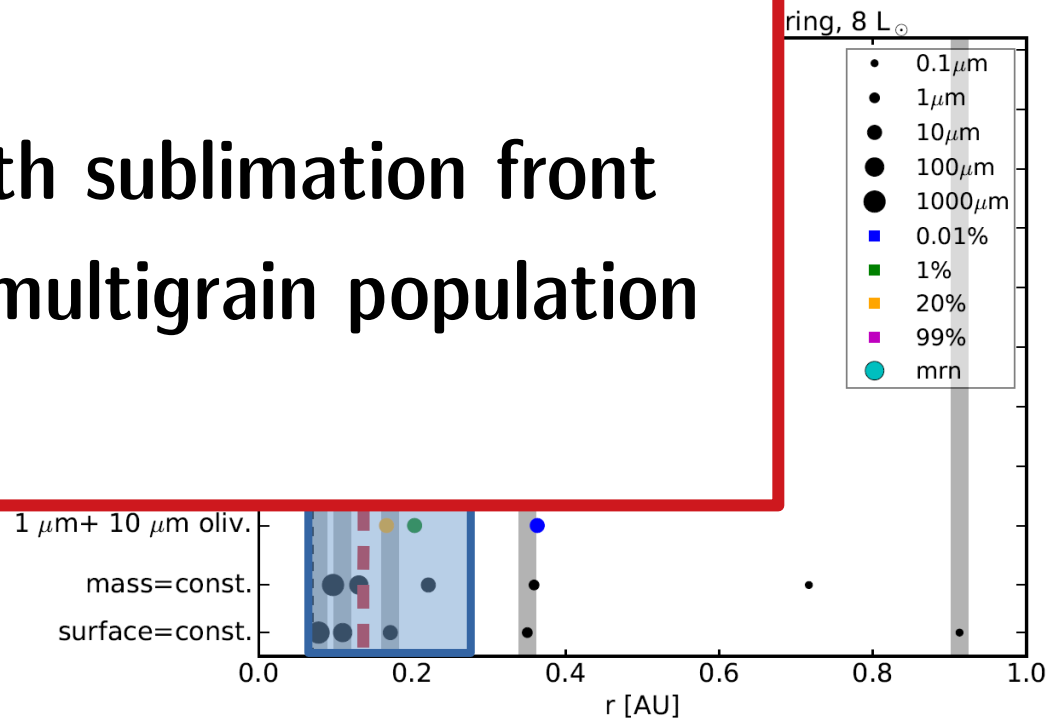
Wide and smooth sublimation front consistent with multigrain population



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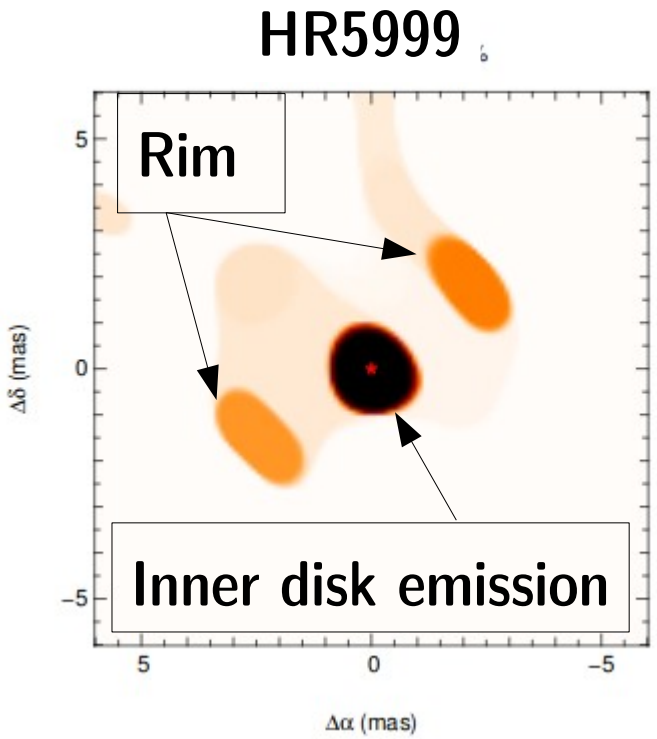
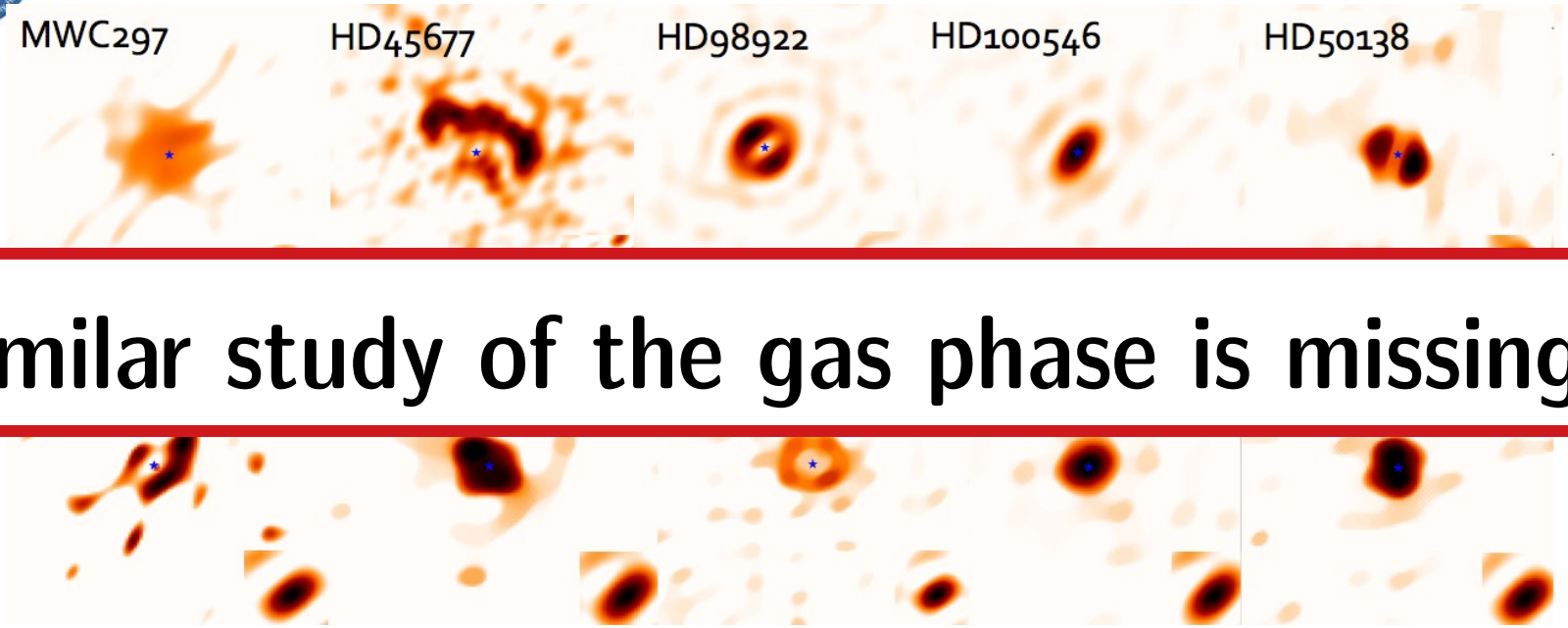
The inner inner-disk

- Most of the NIR emission comes from inside R_{dust}
- Possible solutions:
  - Refractory dust grains
  - Inner gasseous disk
  - Dusty wind



Refs: Benisty, Natta+ 2010; Benisty+ 2011; Bans & Königl 2012

The inner disk: continuum



Similar study of the gas phase is missing

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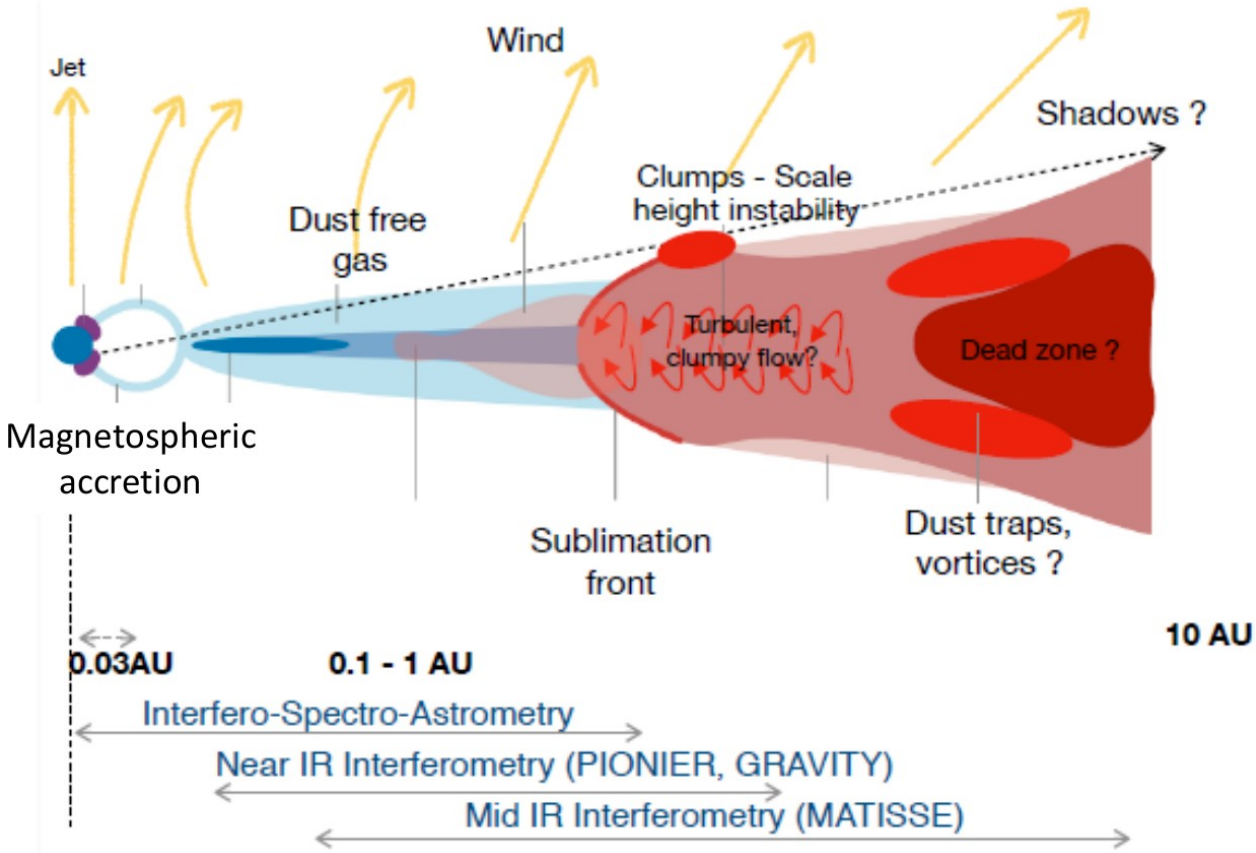
- VLTI-PIONIER large program (50 sources)

The inner disk: gas

- Accretion and winds:
  - Dominate gas dispersal
  - Drive disk dynamics
- Dust particles evaporate at the sublimation front
- UV, optical and IR radiation determine the energy balance of the full disk



Adpated from Dullemond & Monnier 2010

The inner disk: gas

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  the sublimat
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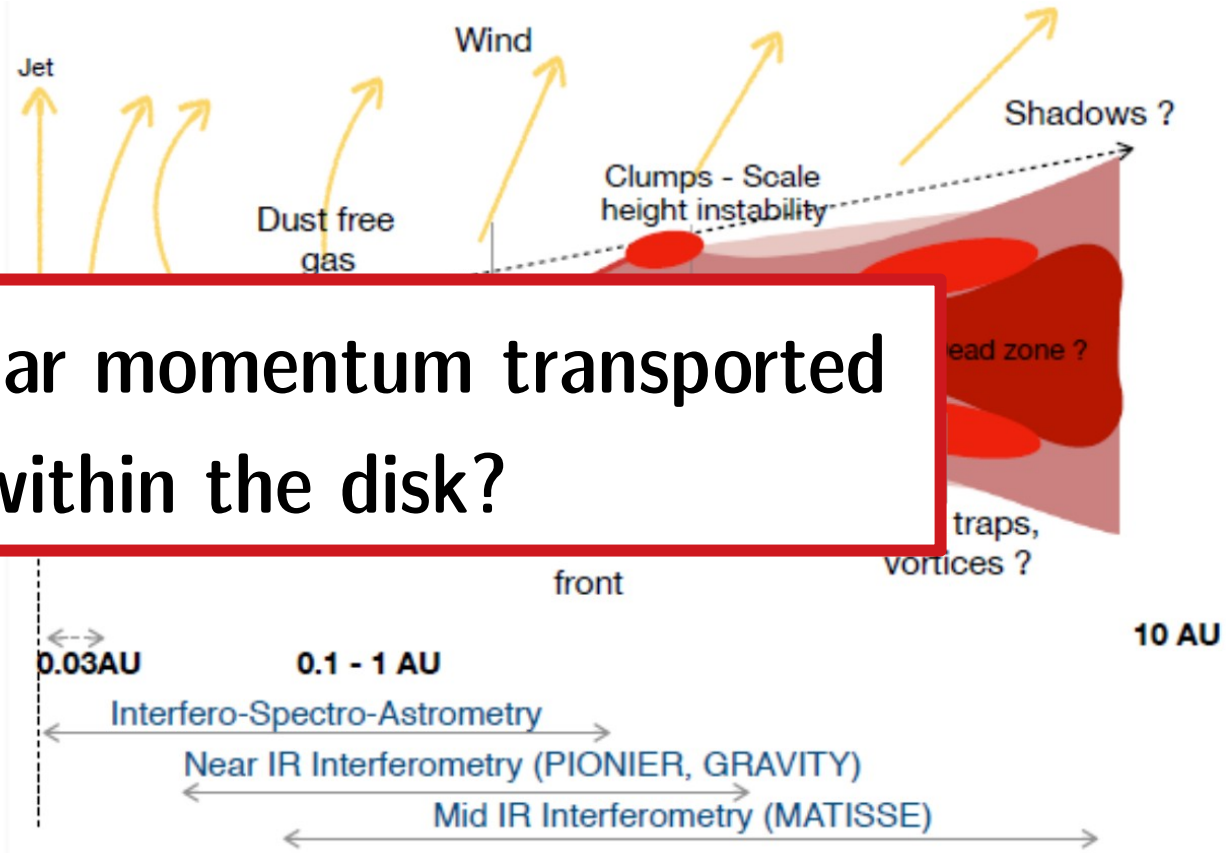
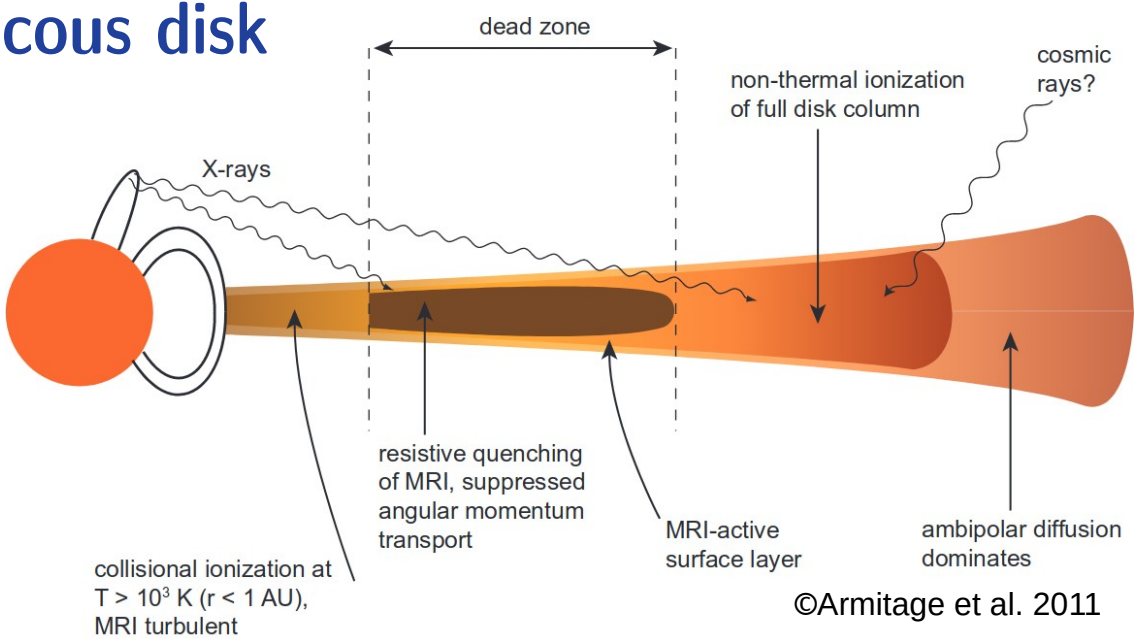
How is angular momentum transported within the disk?



Adpated from Dullemond & Monnier 2010

Angular momentum transport
Standard picture: viscous disk

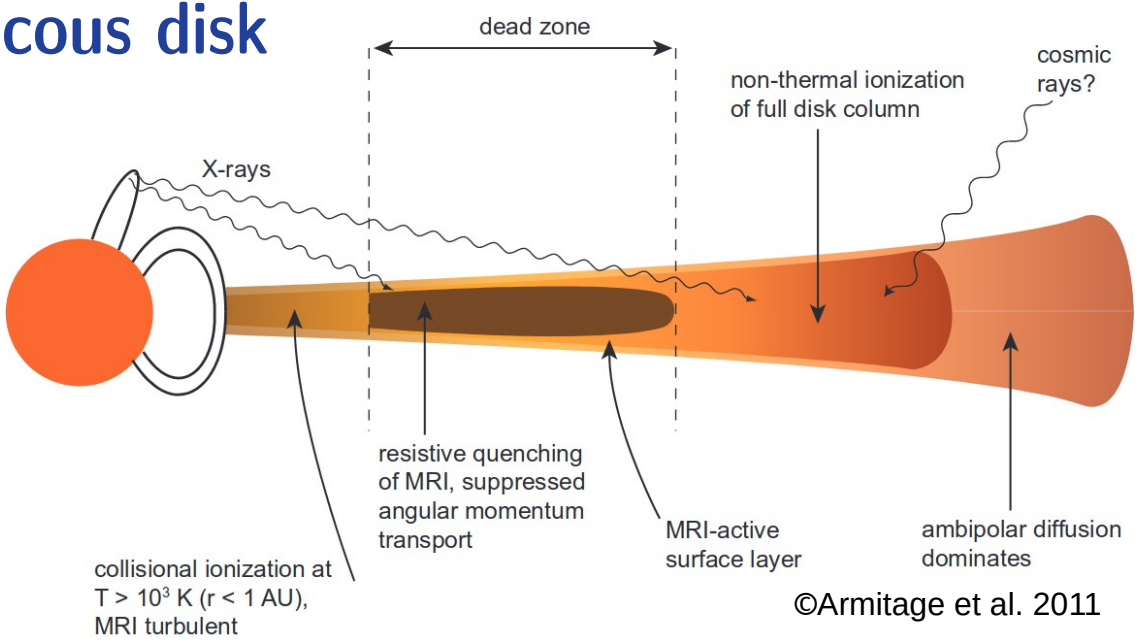


©Armitage et al. 2011

- Gas dynamics is dominated by accretion, followed by photoevaporation at later stages.
- Turbulence: MRI instability
- MRI disk "ingredients": weakly magnetised, angular velocity decreases with distance from the rotation centre, ionisation

(See e.g. Gammie et al. 1996; Ercolano et al. 2017; Najita et al. 2018,...)

Angular momentum transport
Standard picture: viscous disk



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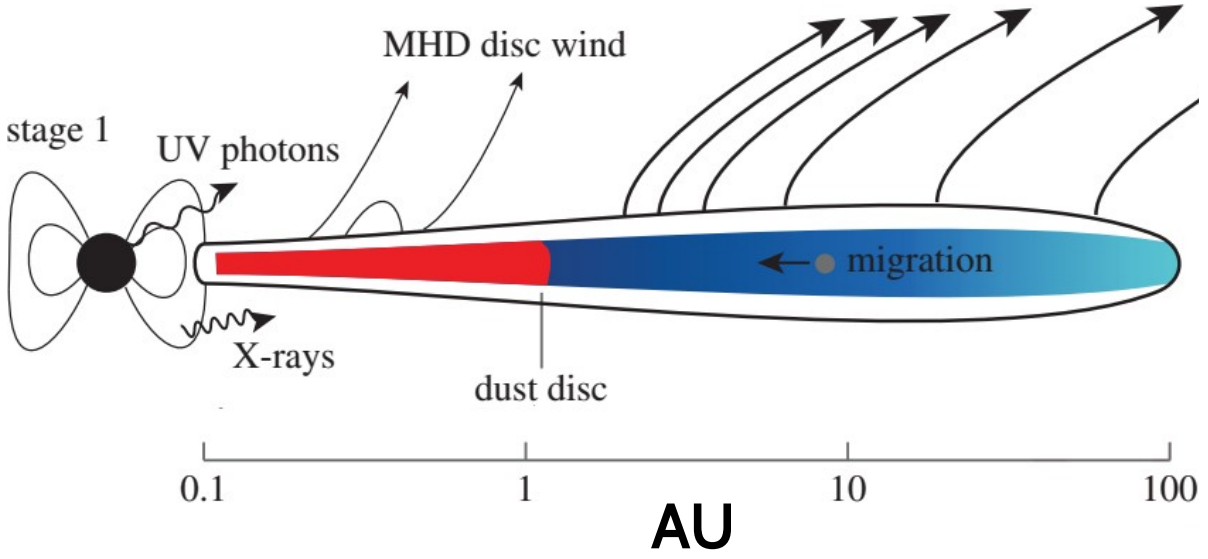
(See e.g. Gammie et al. 1996; Ercolano et al. 2017; Najita et al. 2018,...)

Angular momentum transport

New paradigm: MHD winds

- Non-ideal MHD simulations: MRI supressed, but strong MHD wind is generated.
- Efficiency of angular momentum transport depens on: ionization fraction, magnetic field strength.

(See e.g. Bai et al. 2017 and refs. there in)



Adapted from Ercolano et al. 2017

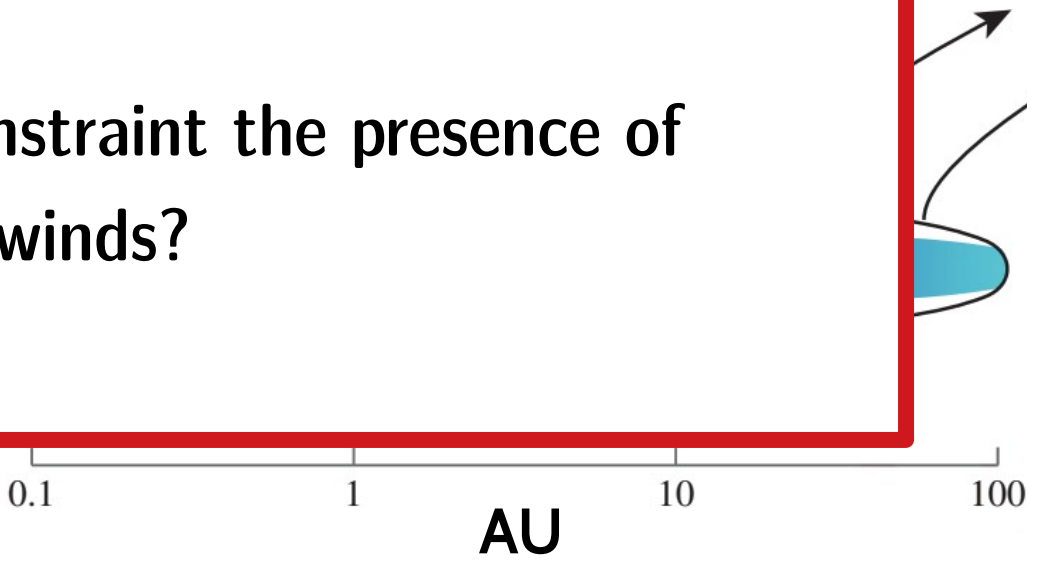
Angular momentum transport

New paradigm: MHD winds

- N
  w
- E
  m
  de
  fraction, magnetic field strength.

(See e.g. Bai et al. 2017 and refs. there in)

Can we observational constraint the presence of MHD-winds?



Adapted from Ercolano et al. 2017

Observational constraints

MHD winds

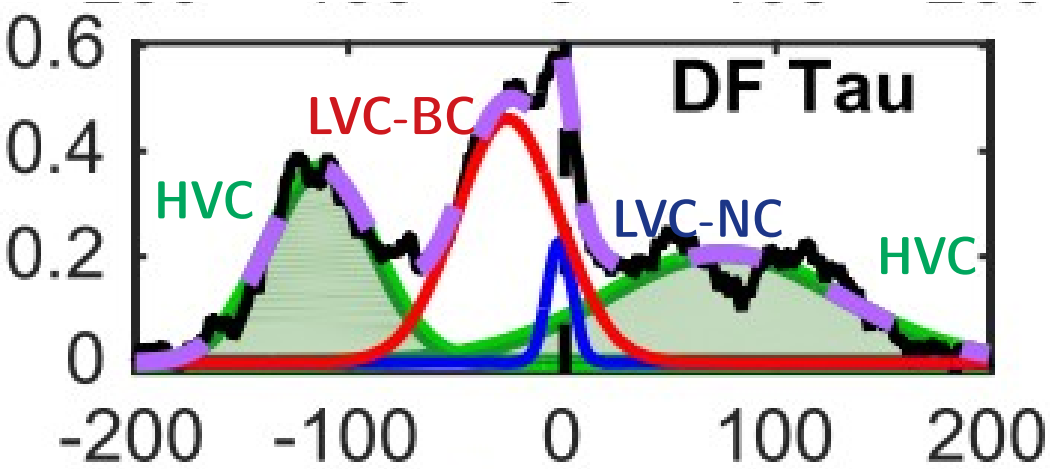
See Elisabetta Rigliaco's talk

- HVC: Jet emission
- LVC-BC: R<0.5 au

lower inclinations:

narrower+bluer line.

MHD-wind?



©Simon et al. 2016

LVC-NC: R<5 au, always observed in TDs

photoevaporative wind?

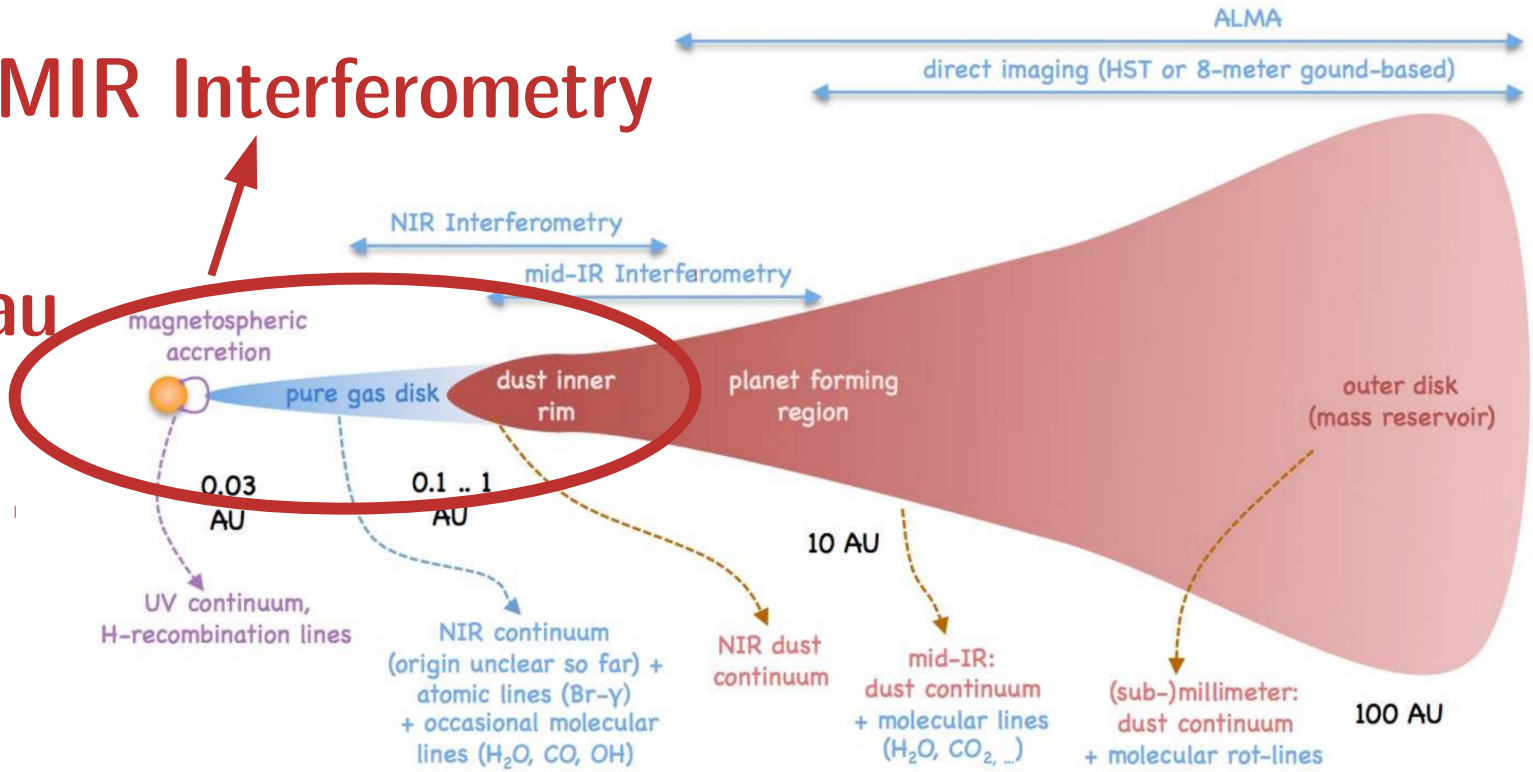
(e.g. Simon+ 2016; McGinnis+ 2018, Fang+ 2018, Banzatti+ 2019)

Observational constraints

Spatially resolved observations

NIR/MIR Interferometry

R$\lesssim$ 5au



©Dullemond et al. 2011

Observational constraints

Spatially resolved observations

Most interferometers work in the K-band

+

YSOs are red objects

↓

Brγ is our favourite line!!

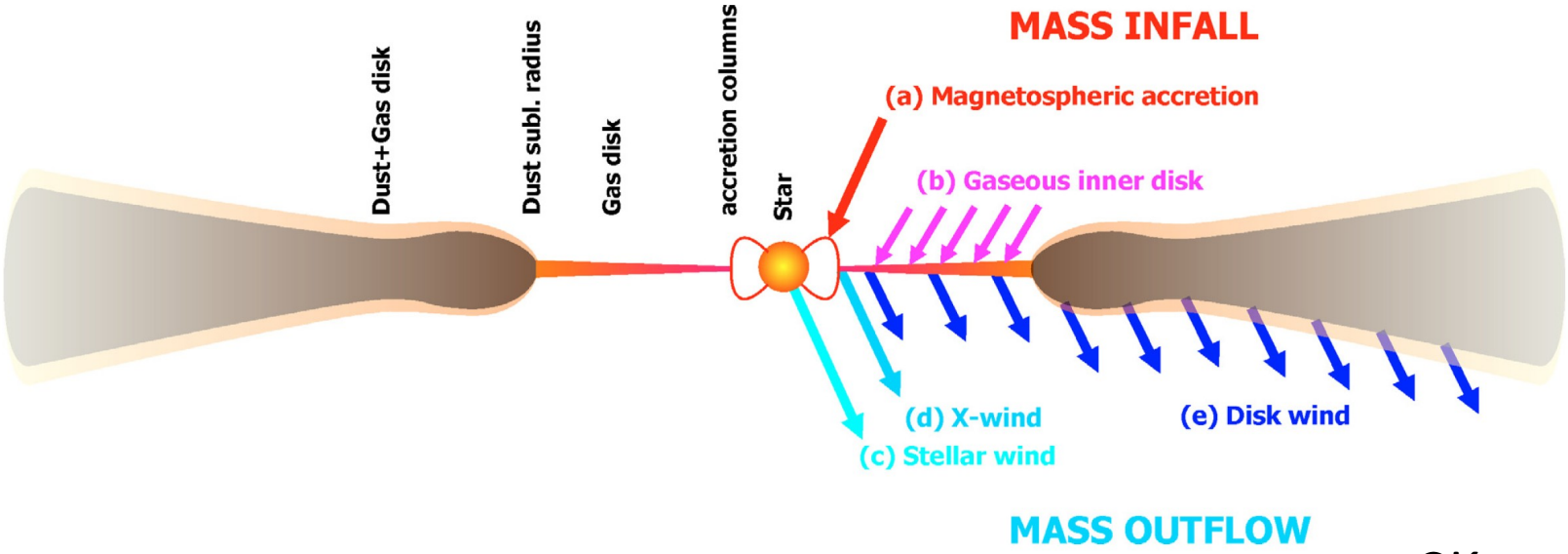
Can we constraint the origin of this line/associate it with winds/accretion?

Observational constraints

Spatially resolved observations

- Emitted in a compact region (few tenths of mas) within R_{dust}

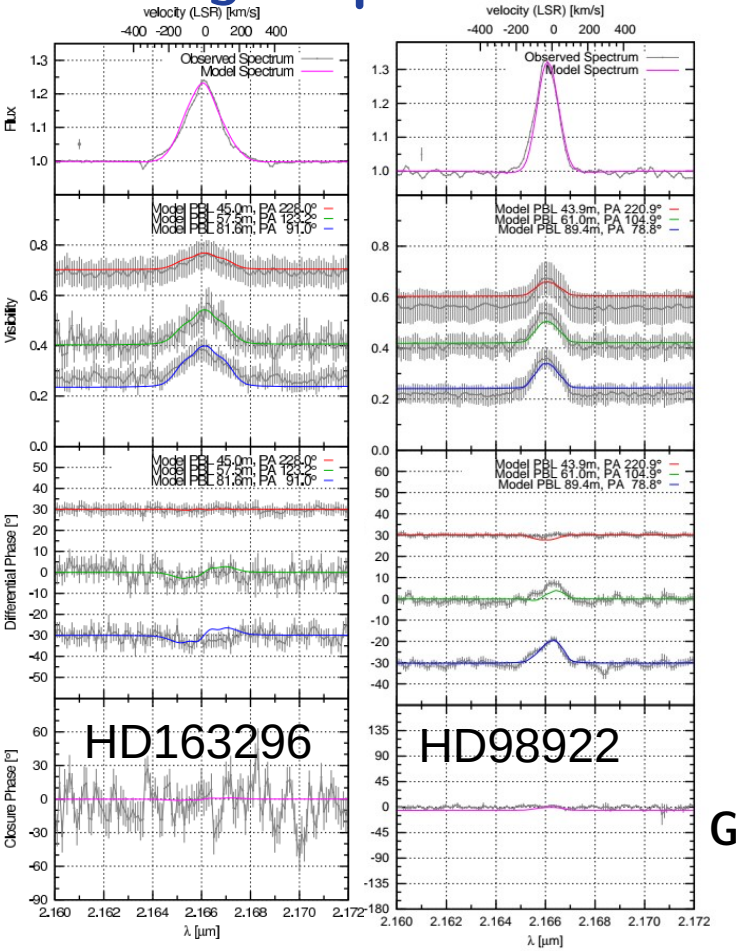
(see e.g. Kraus et al. 2008, Eisner et al. 2009)



©Kraus et al. 2008

Spatially resolved observations

Modelling Brγ emission



$$V_{line} > V_{cont} = R_{line} < R_{cont}$$

Photocenter shift of the line vs continuum

Garcia Lopez + 2015; Caratti o Garatti+ 2015

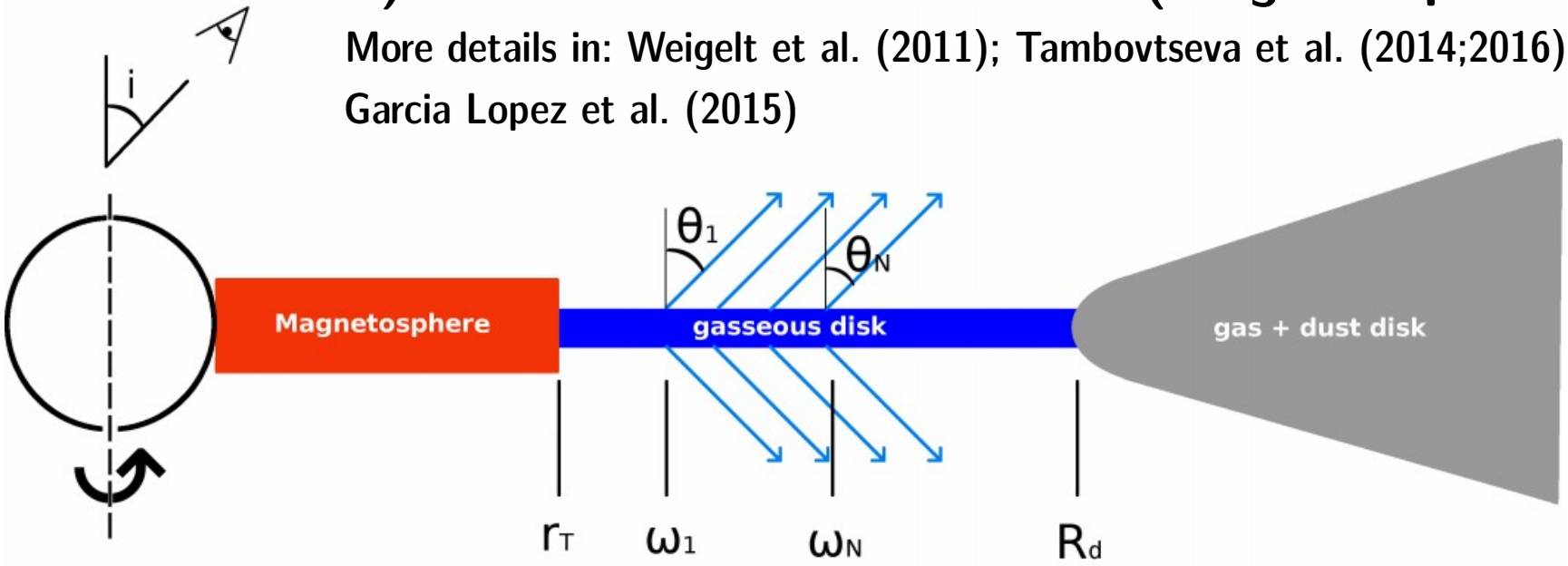
Spatially resolved observations

Modelling Brγ emission

Contributions: 1) continuum emission: star + disc

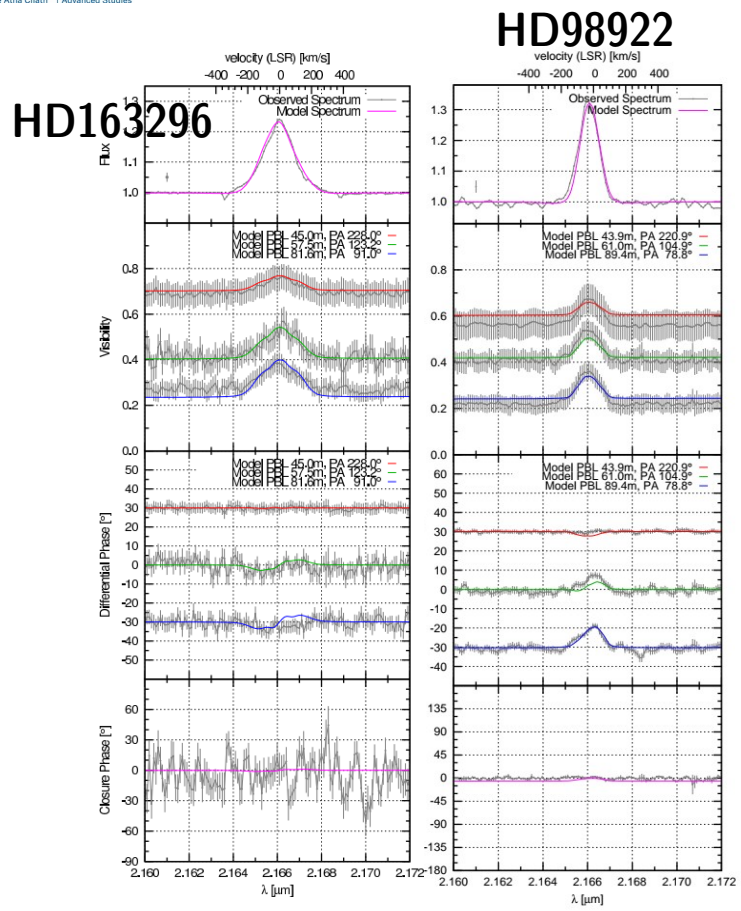
2) line emission: disc wind + (magnetosphere)

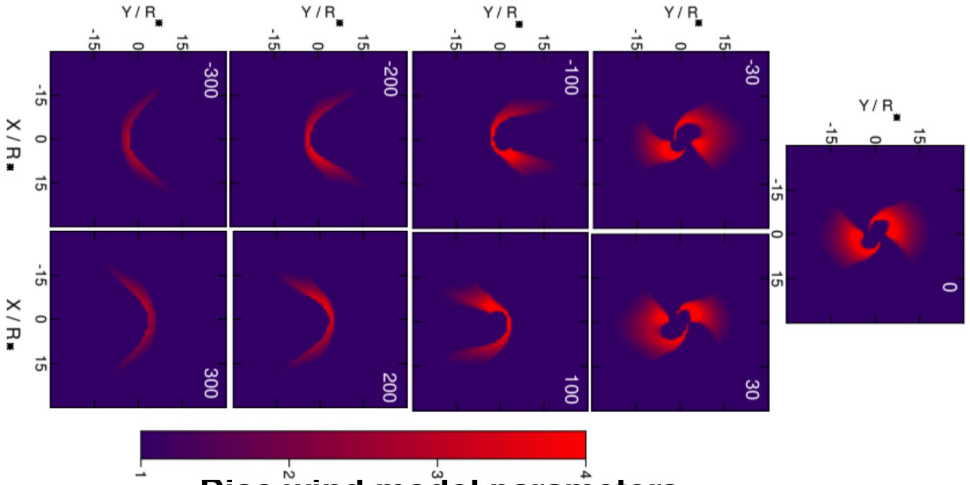
More details in: Weigelt et al. (2011); Tambovtseva et al. (2014;2016); Garcia Lopez et al. (2015)



Spatially resolved observations

Modelling Brγ emission





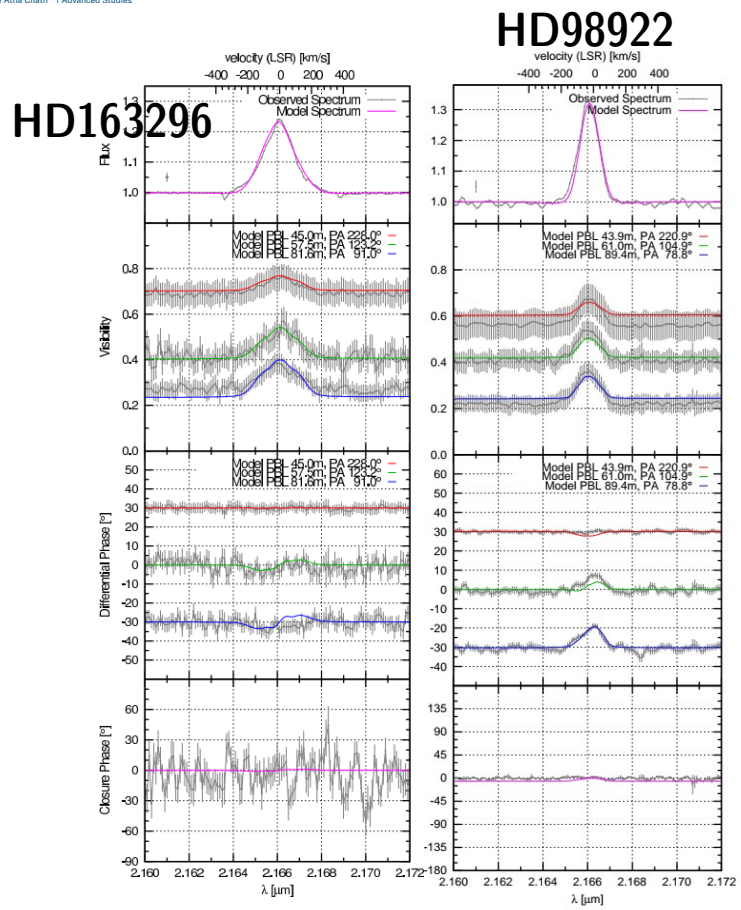
Disc wind model parameters

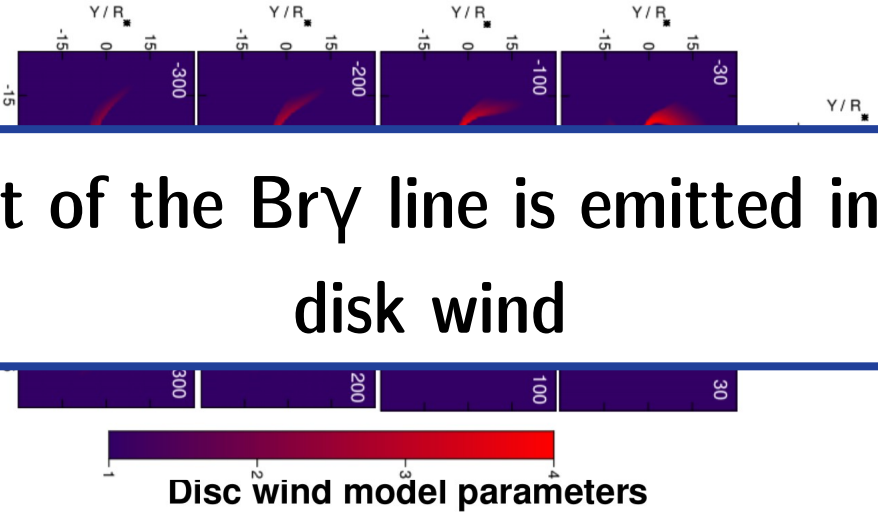
	HD163296	HD98922
Temperature (K)	10 000	10 000
Half opening angle (θ)	45°	30°
Inner radius (ω_1 (R_*))	2.0 (0.02 AU)	3.0 (0.1 AU)
Outer radius (ω_N (R_*))	4.0 (0.04 AU)	30.0 (1 AU)
Mass loss rate ($\dot{M}_w$ ($M_\odot$/yr))	5×10^{-8}	2×10^{-7}

Garcia Lopez et al. 2015; Caratti o Garatti et al. 2015

Spatially resolved observations

Modelling Brγ emission





Most of the Brγ line is emitted in a disk wind

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Garcia Lopez et al. 2015; Caratti o Garatti et al. 2015

Spatially resolved observations

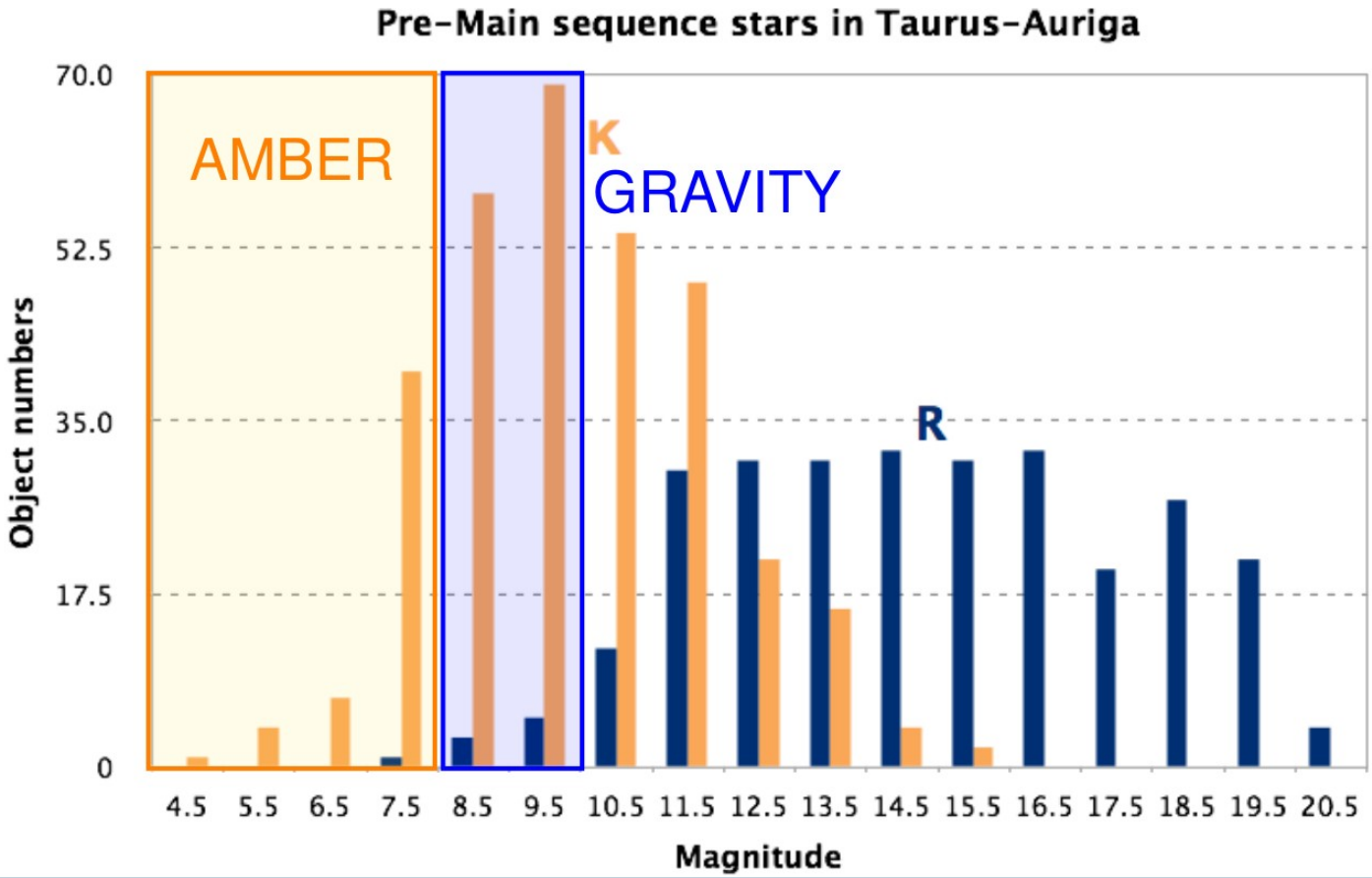
A statistical approach – VLTI-GRAVITY GTO program

Can we study the presence of inner winds in a statistical and homogeneous ways accross the mass and age spectrum?

- Aim: Statistical study of the gas content in YSO disks to spatially resolve the hot (Brγ) and warm (CO) gas in disks.
- Large sample of YSOs (~100) spanning a wide range of stellar masses (very low-, high-mass), ages (10^4 -10^7) and disk properties (full and TDs).

Spatially resolved observations

A statistical approach



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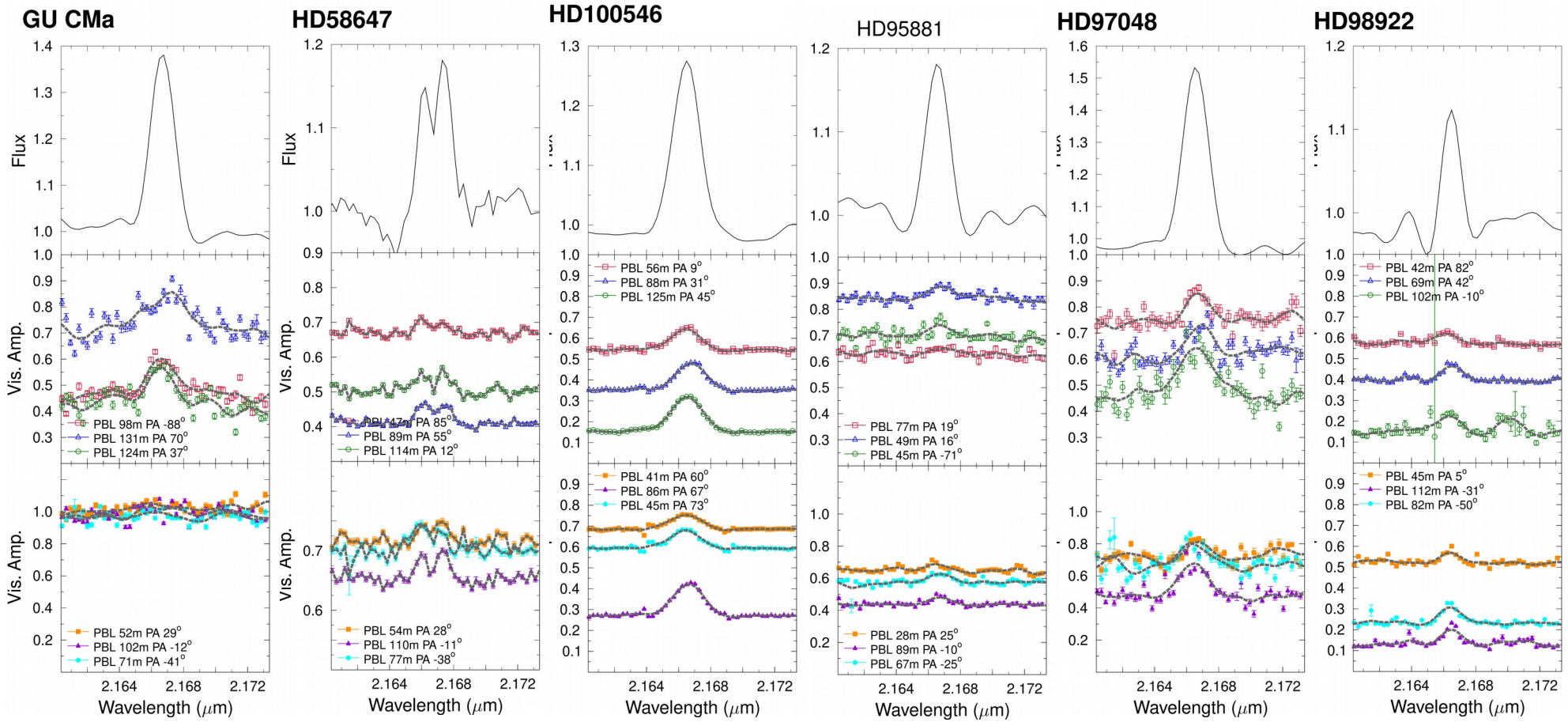
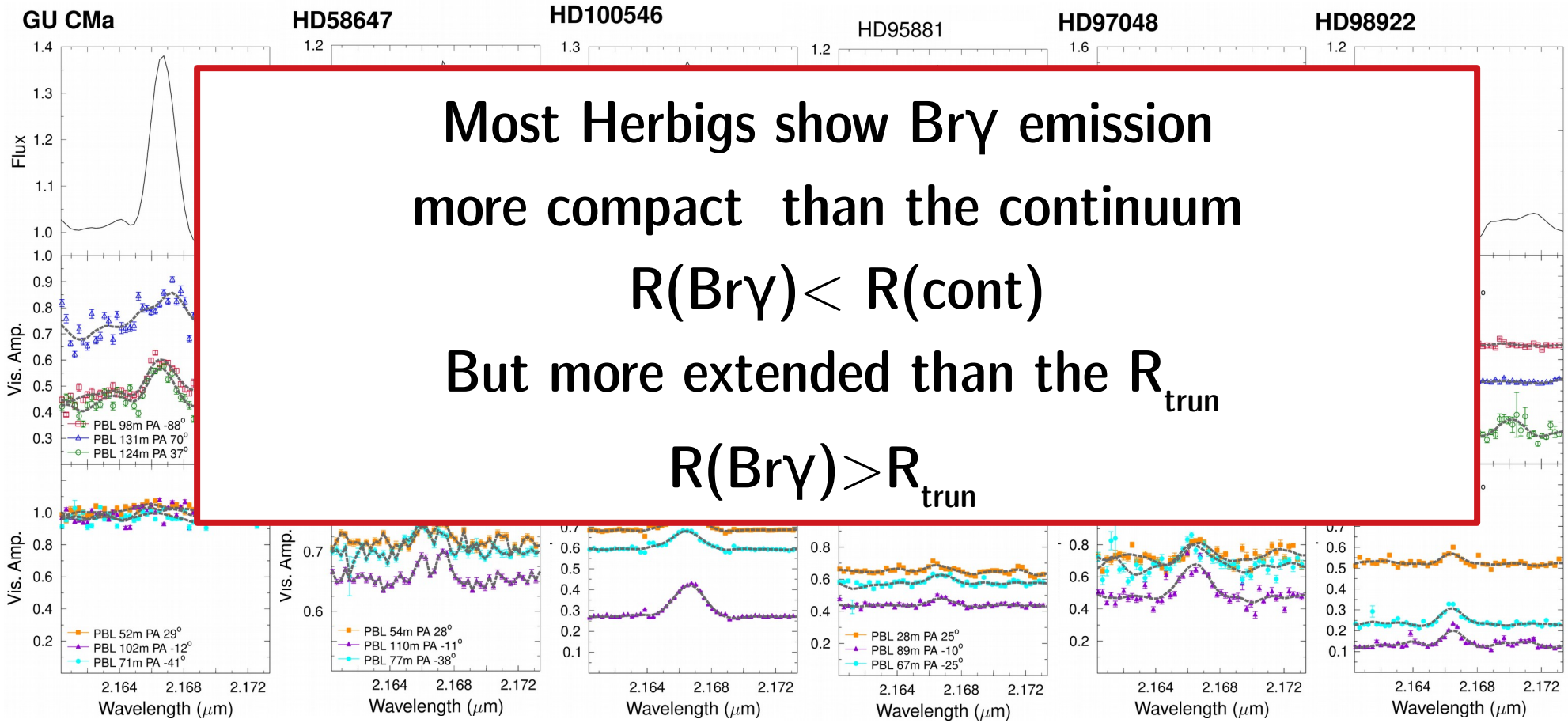
Spatially resolved observations

A statistical approach



Spatially resolved observations

A statistical approach



Most Herbigs show Brγ emission

more compact than the continuum

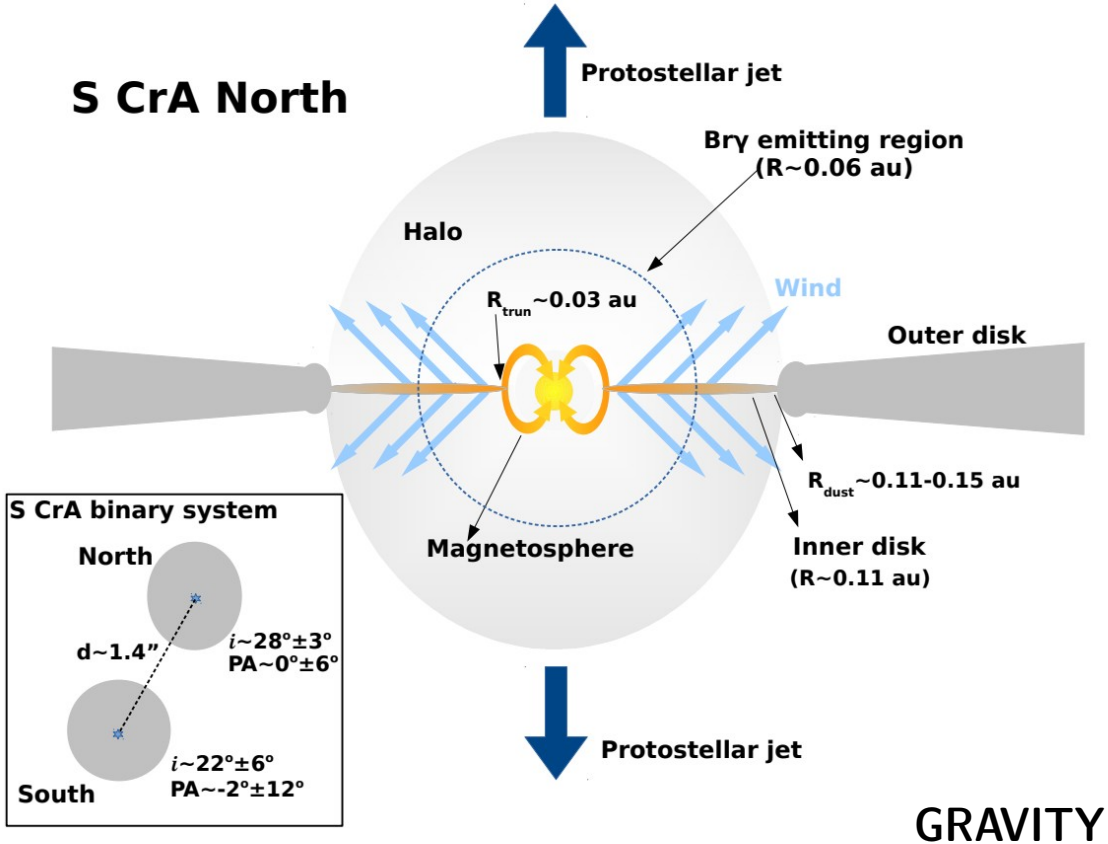
$R(Br\gamma) < R(cont)$

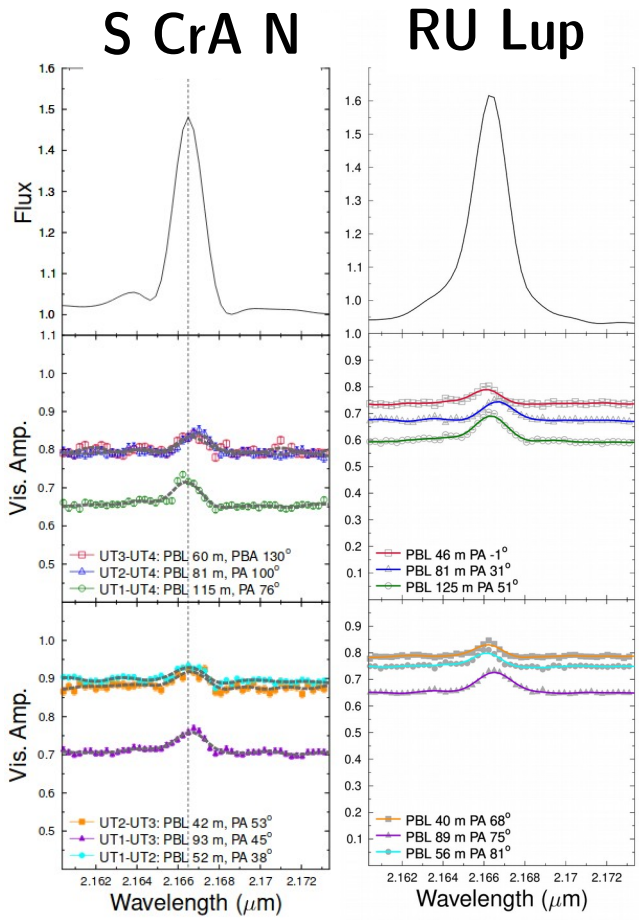
But more extended than the R_{trun}

$R(Br\gamma) > R_{trun}$

Spatially resolved observations

A statistical approach

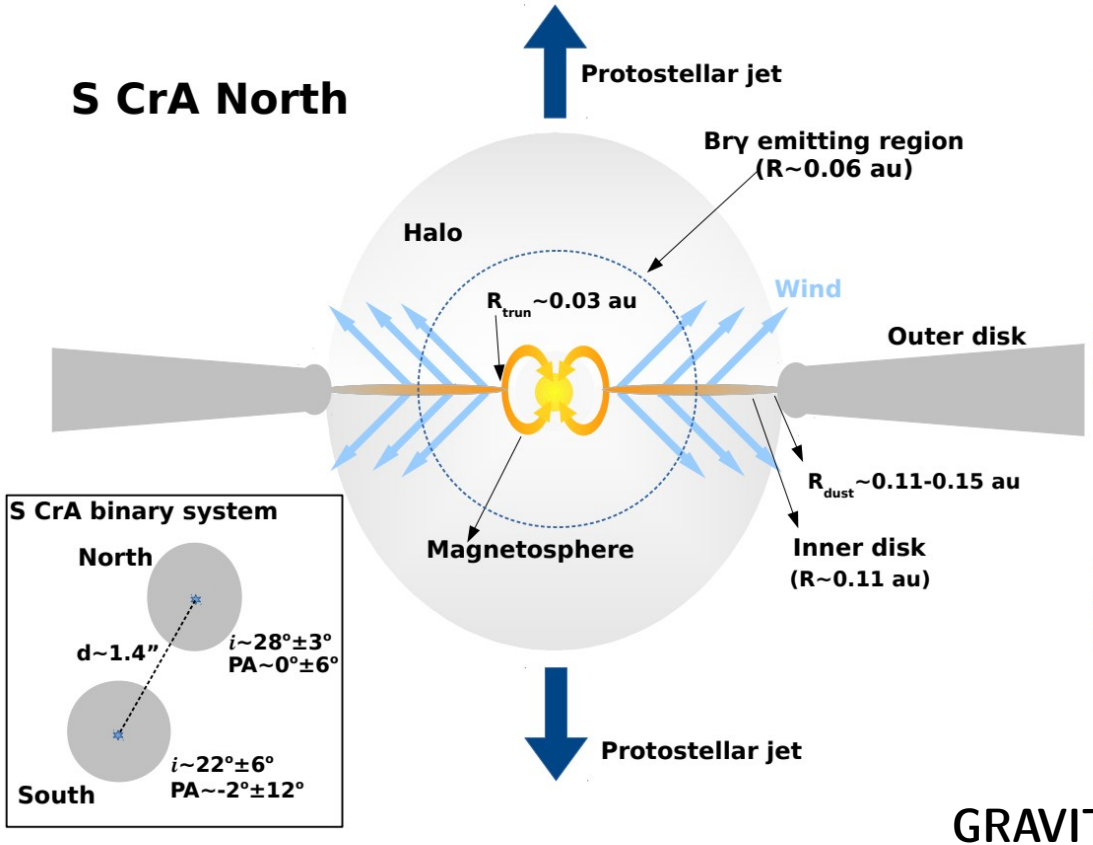


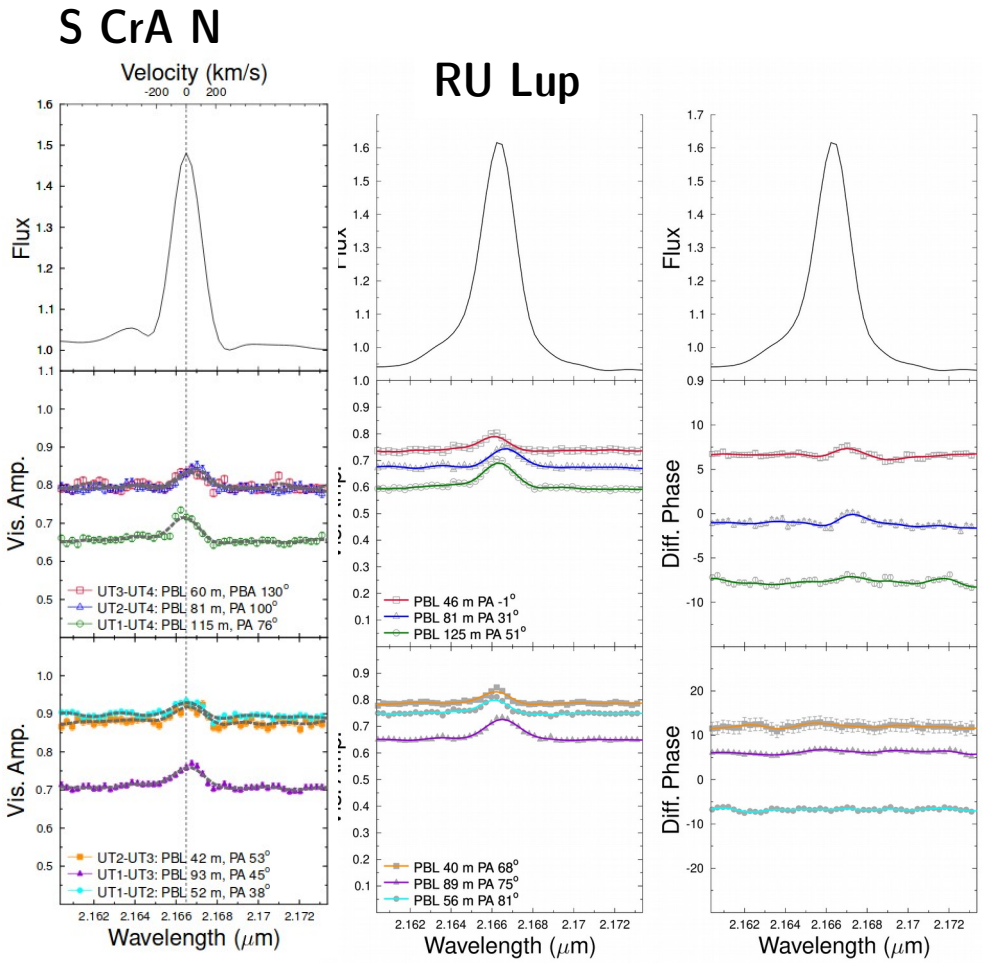


GRAVITY Collaboration: Garcia Lopez et al. 2017; in prep.

Spatially resolved observations

A statistical approach

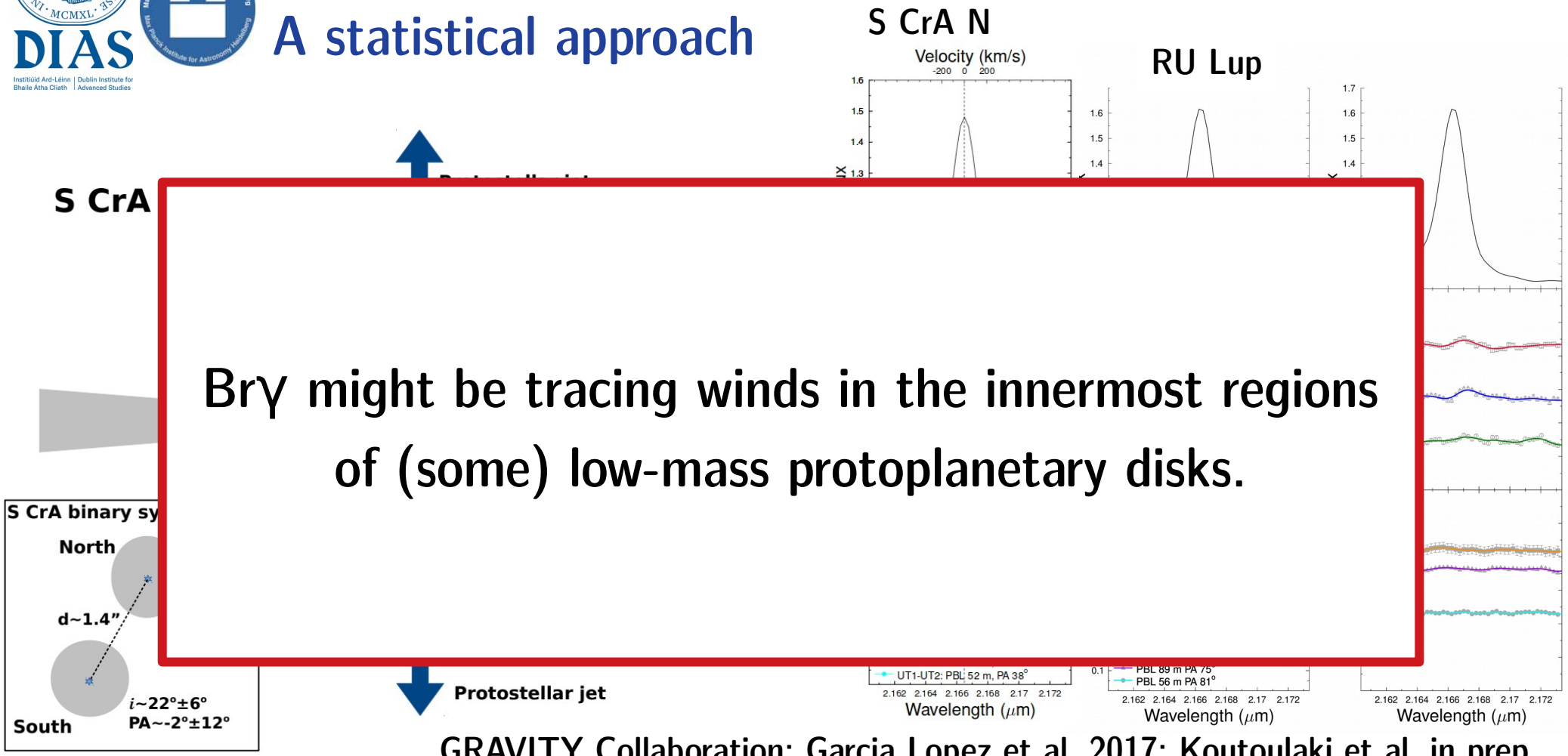




GRAVITY Collaboration: Garcia Lopez et al. 2017; in prep.

Spatially resolved observations

A statistical approach



Brγ might be tracing winds in the innermost regions of (some) low-mass protoplanetary disks.

GRAVITY Collaboration: Garcia Lopez et al. 2017; Koutoulaki et al. in prep.

Conclusions

- Antonella loves infrared interferometry (although she will never admit it)
- Rims exit and they are wide and smooth consitent with a multigrain population.
- Most of the NIR emission is coming from an unknown source within the rim.
- NIR interferometry has came to age.
  - Brγ might be mostly originated in a disk wind, tracing the presence of winds in the innermost disk region.