

A Spiral arm in the protoplanetary disk of PDS 70 ?

S.Juillard - supervised by O.Absil and V.Christiaens

Direct / High-contrast imaging

Challenge :

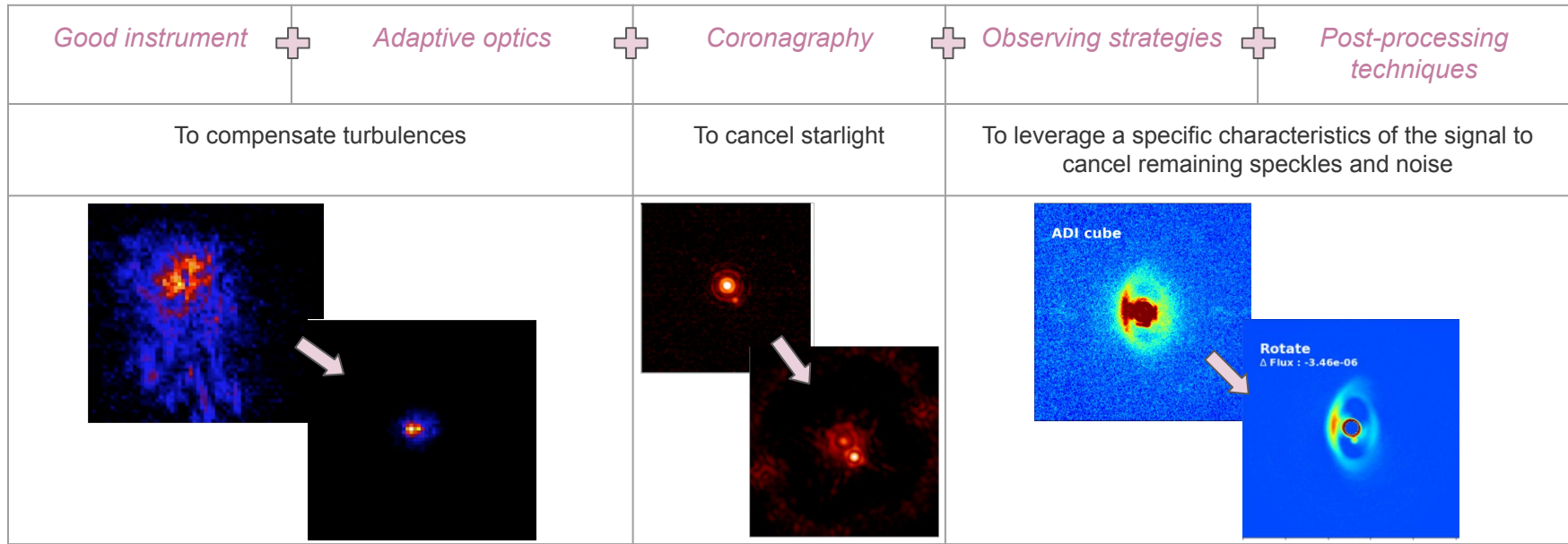
Observing a very faint object near a very bright one
from very far away



Direct / High-contrast imaging

How to make this possible ?

Techniques that enable the observation of planetary systems

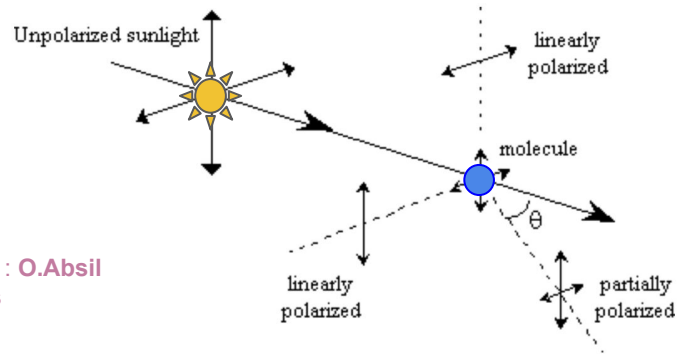


Observation strategies

PDI reduction :

(Polarimetric Differential Imaging)

- rejecting **unpolarized** stellar speckles
- keep the planet/disk in **polarized** light





[Source] : O.Absil
Lectures

Data processing with 

ADI reduction :

(Angular Differential Imaging)

- rejecting **static** stellar speckles
- keep the **rotating** planet/disk light

Calibration and preprocessing V.Christiaens
pipeline (VIP + EsoRex)  

Disk recovery with **MUSTARD**

Disk recovery with MUSTARD

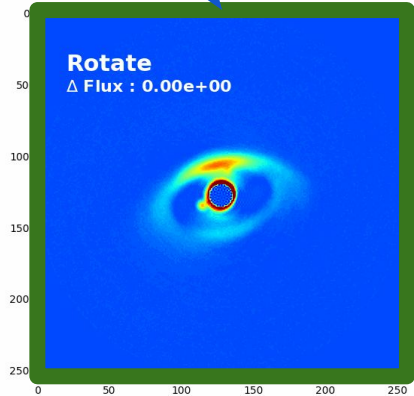
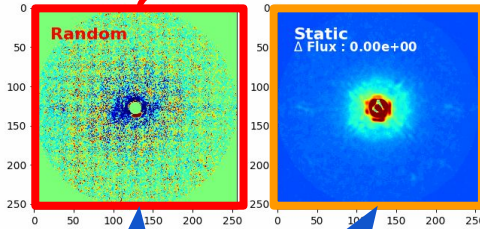
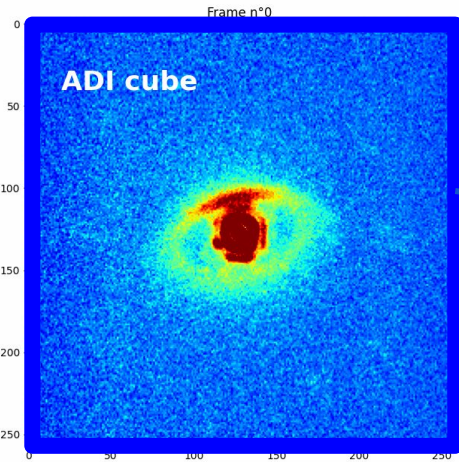
E_k : Residual and noise (unique to each frame)

L : Static contribution – Starlight and speckles common to all frames

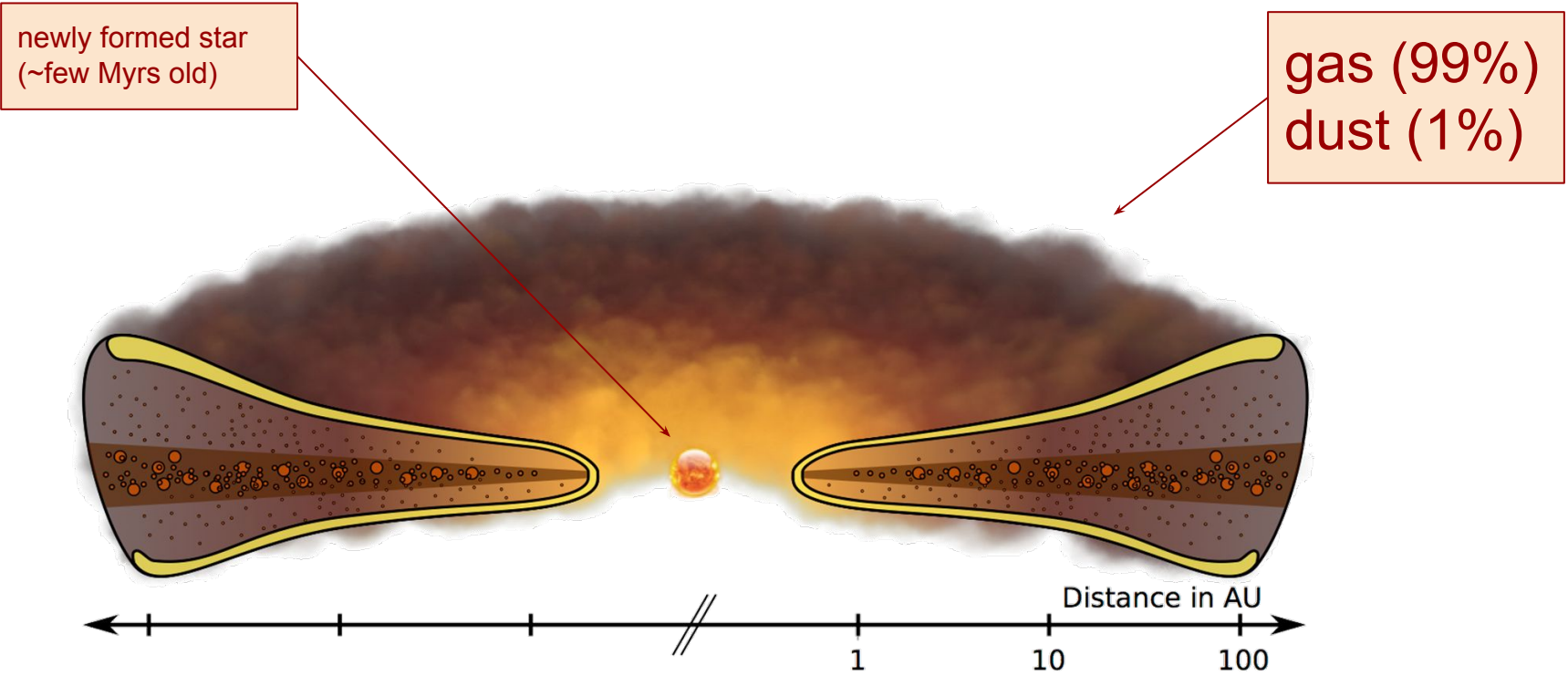
$R_k(X)$: Rotating contribution – circumstellar common to all frames

$$S_k = L + R_k(X) + E_k$$

S_k : Frame n°k
of the ADI cube



Protoplanetary disk : the birthplace of planets



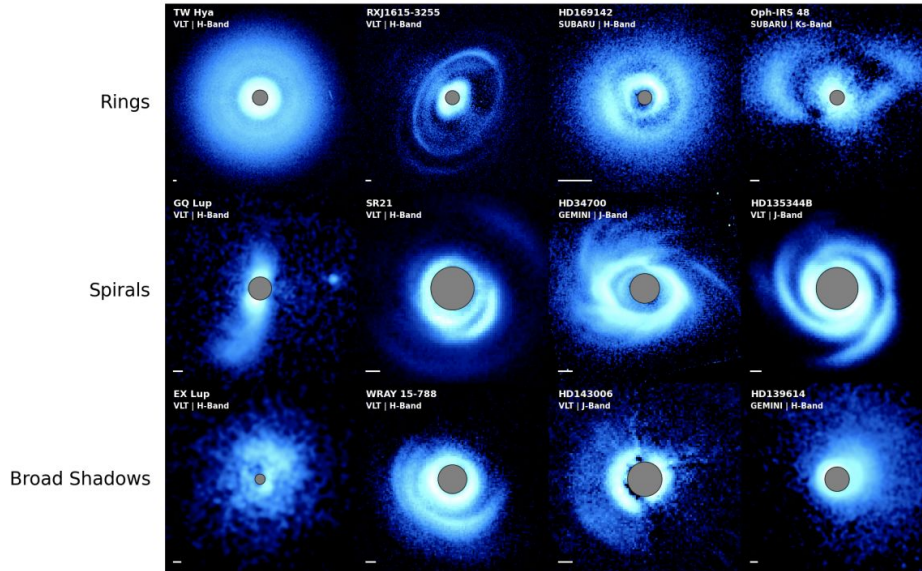
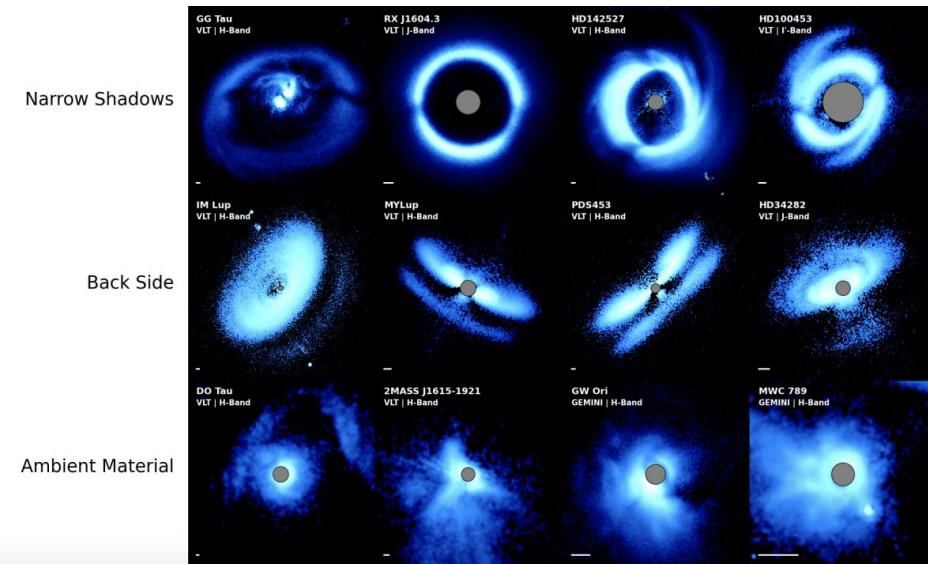
Disk schematic from <http://www.til-birnstiel.de>

Theory : Dynamics in protoplanetary disks

Variety of protoplanetary disk structures

■ [Source] : Benisty - 2021

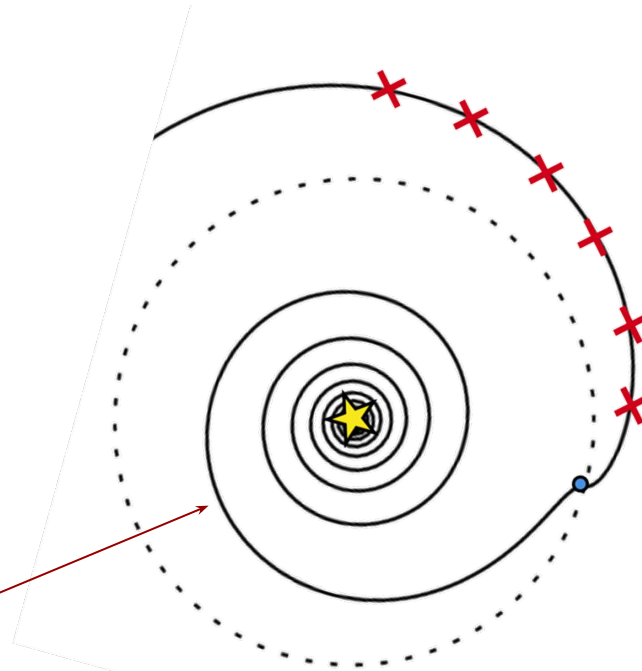
“Optical and Near-infrared View of Planet-forming Disks and Protoplanets”



Spiral : Dynamics in protoplanetary disk

Spiral arms :
Constructive
interference of density
waves form spirals

Density waves



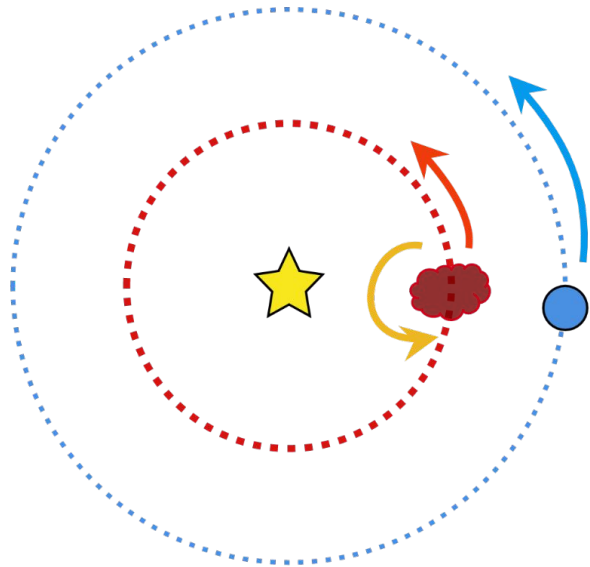
✕ spiral arm
● planet

Spiral in a 1-planet system
(Ogilvie, Lubow 2002)

Theory : Dynamics in protoplanetary disk

Lindblad resonances :

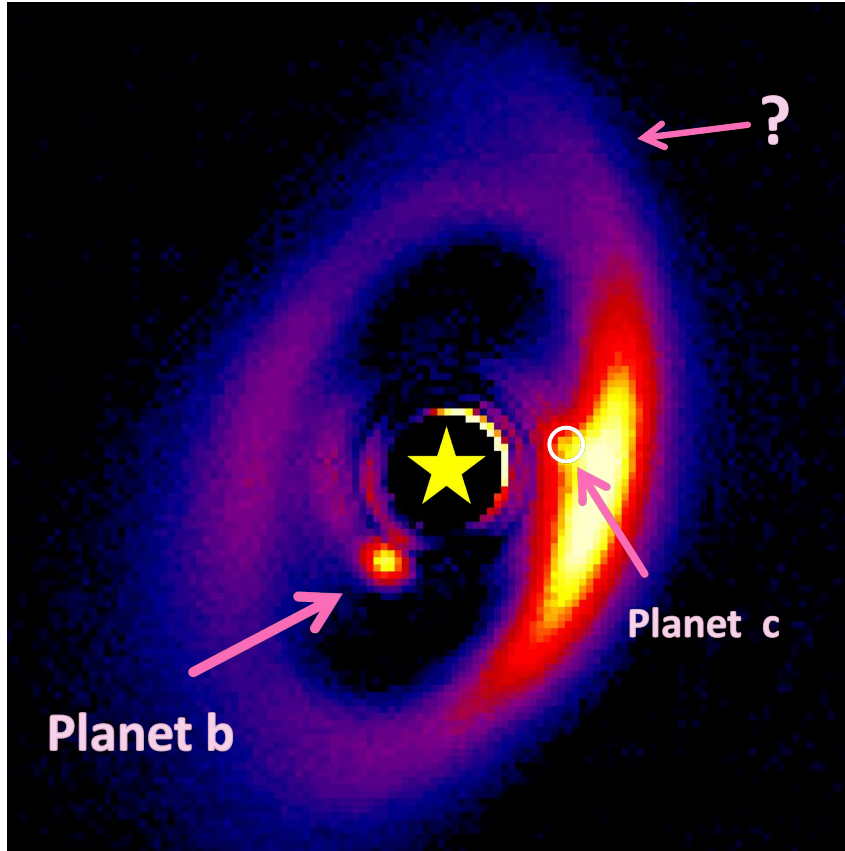
Planet/disk dynamic that create density waves



Resonances occurs when :

$$\underbrace{m|\Omega_d - \Omega_p|}_{\text{Planet's Doppler orbital frequency}} = \underbrace{k}_{\text{Gas blob epicyclic frequency}}$$

Application : PDS-70



Hypothesis :

- This is a spiral arm driven by PDS 70 c
 - It follows the planet with a rigid-object like motion
-

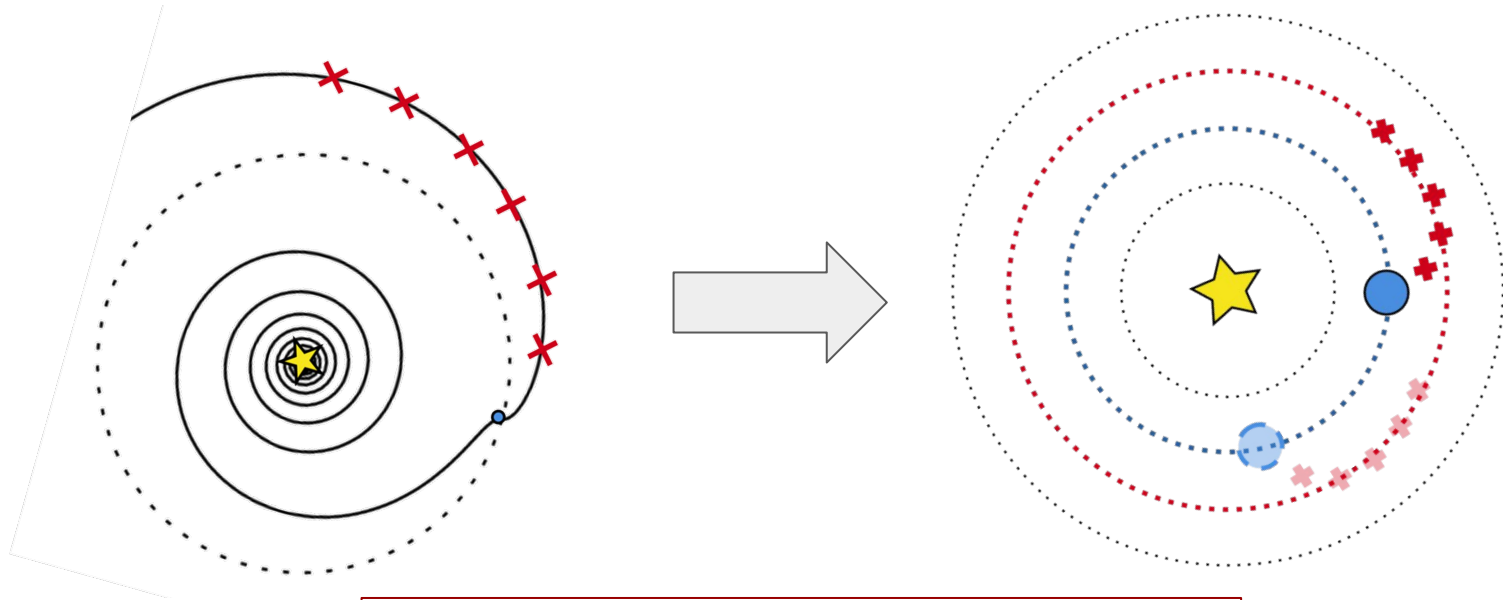
PDS 70 is a unique system !

It's the only observation of a protoplanetary disk with confirmed exoplanets detected

Theory : Dynamics in protoplanetary disk


Hypothesis : Rigid-body like motion.

!/\ This is an approximation !



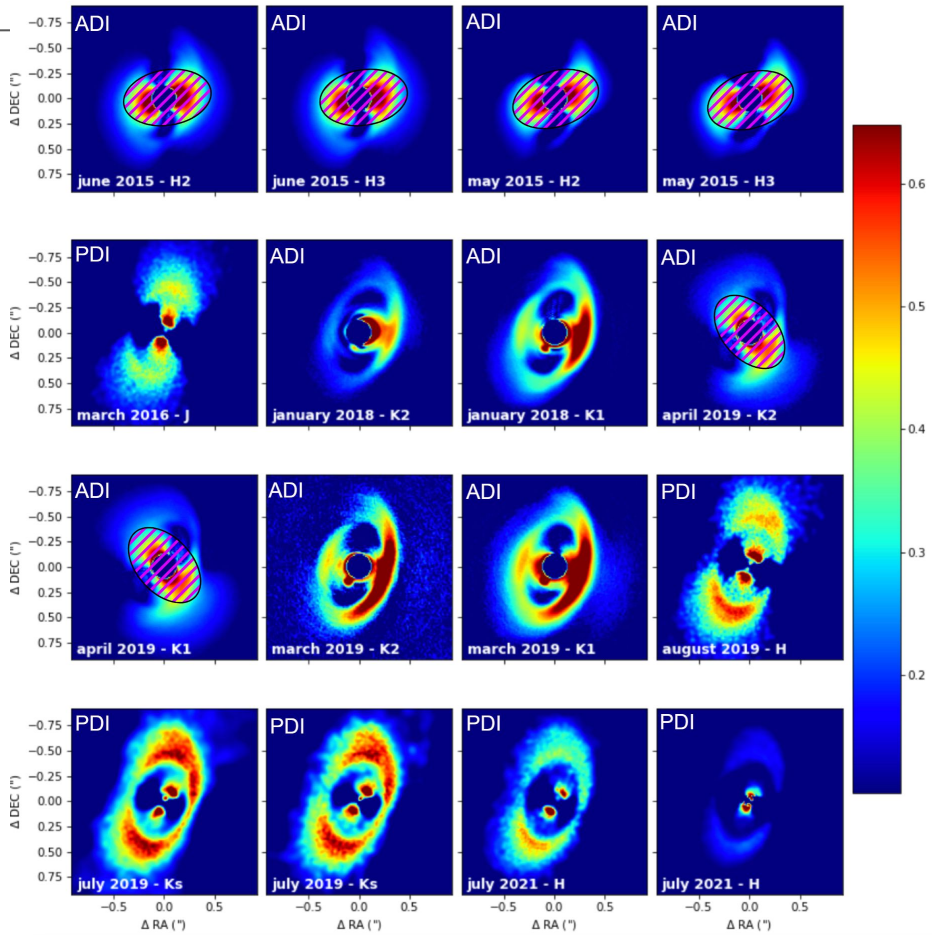
Planet c rotates by 11° in 6 years

DATASET - 6 years of observation

 area corrupted by wind-driven halo

Summary :

- 2015 : 2 H2/H3 ADI
- 2016 : J band PDI
- 2018 : 1 K1/K2 ADI
- 2019 :
 - 2 K1/K2 ADI
 - 2* H band PDI
 - Ks band PDI
- 2021 : 2 Ks* band PDI



*same program splitted in two

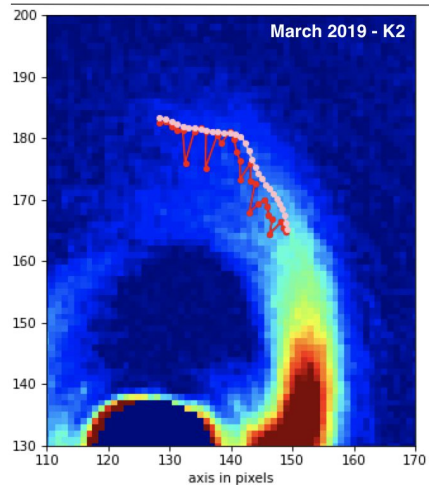
Spiral measurement

Trace by local radial maxima

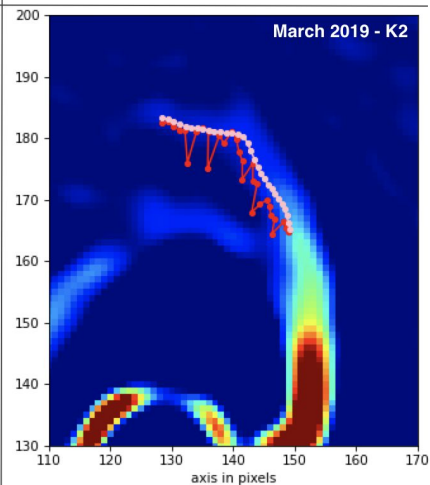
Effect of the Laplacian filter

Observation from march 2019

Raw science image

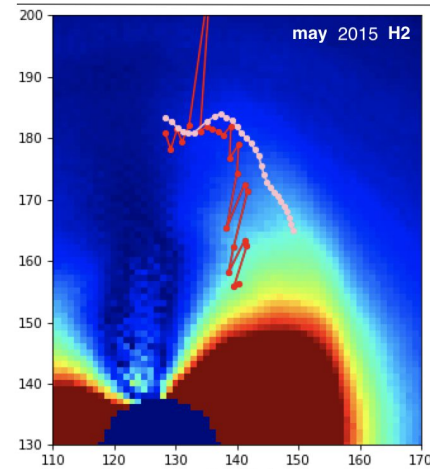


Filtered image

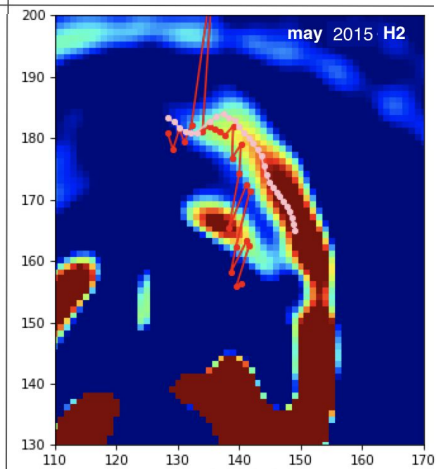


Observation from may 2015

Raw science image

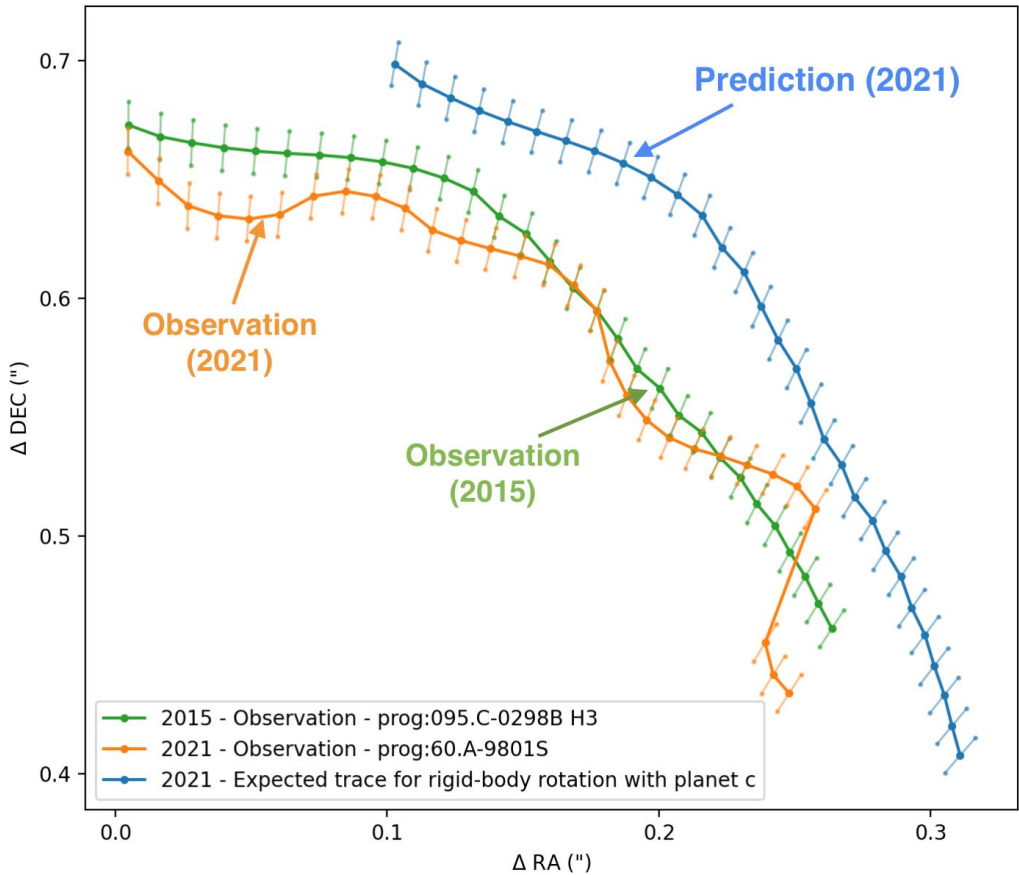


Filtered image



- Measured on raw image
- Measured on filtered image

Results - No significant motion is detected !



Conclusion ?

Does that mean it is not a spiral arm ?

No, we can't concluded anything yet.

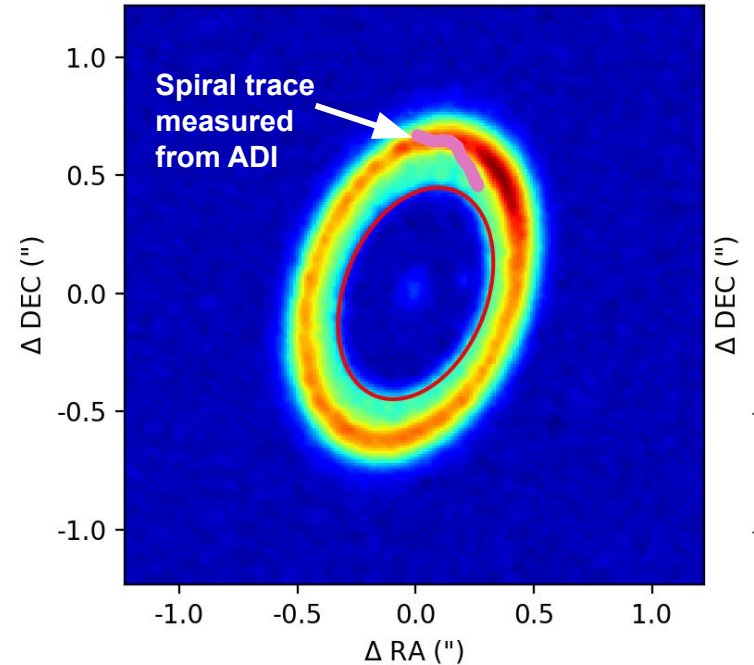
If it is a spiral arm, what went wrong ?

If yes, it means that the **rigid-body hypothesis** was inappropriate.

If it is not a spiral, what could it be ?

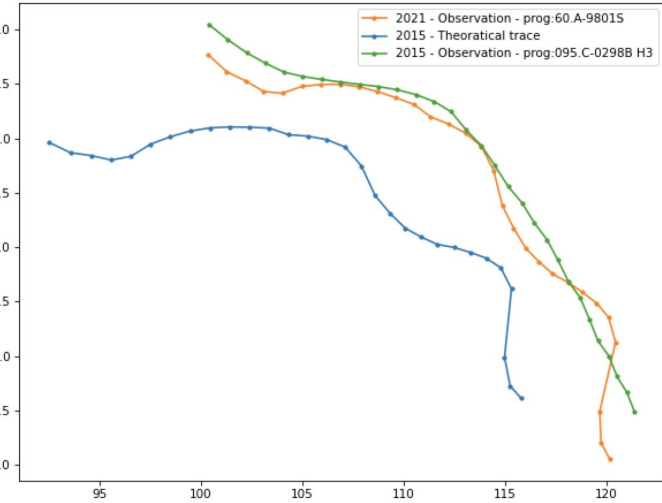
The best hypothesis given the information we have is the **Vortex**.

ALMA observation (Benisty et al. 2021)

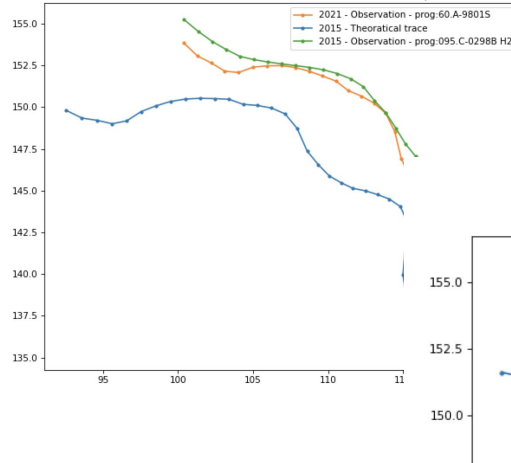


ALMA observation capture a slice of the disk (With ADI/PDI image we have effect of height/projection)

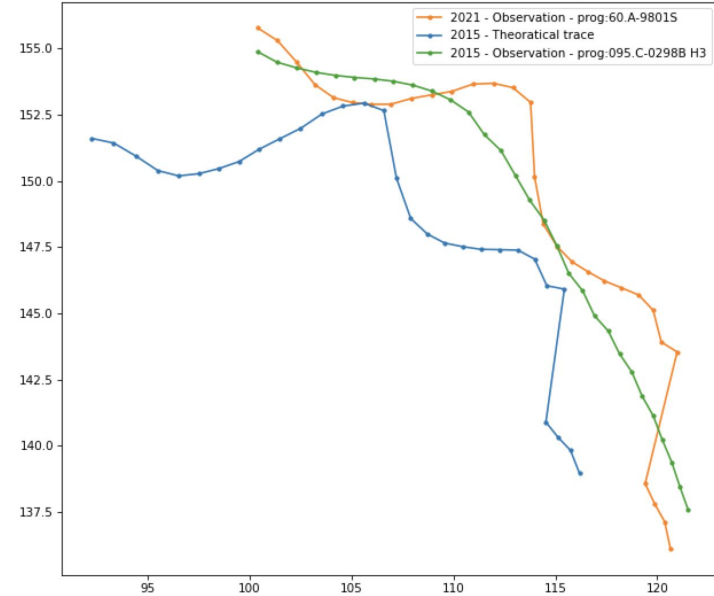
Distance 2021-Obresvation / 2015-Theoretical = 2.14px
Distance 2015-Obresvation / 2015-Theoretical = 3.81px
Distance 2021-Obresvation / 2015-Obresvation = 0.54px



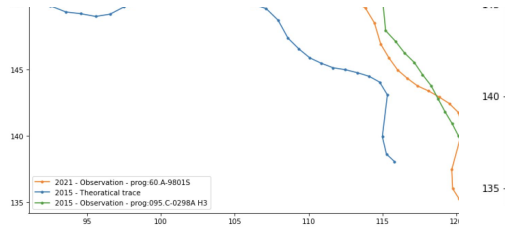
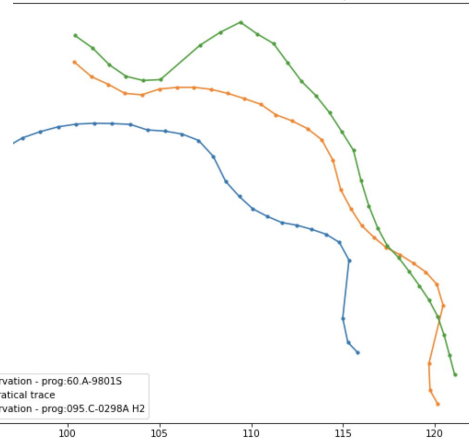
Distance 2021-Obresvation / 2015-Theoretical = 2.14px
Distance 2015-Obresvation / 2015-Theoretical = 3.81px
Distance 2021-Obresvation / 2015-Obresvation = 0.54px



Distance 2021-Obresvation / 2015-Theoretical = 2.75px
Distance 2015-Obresvation / 2015-Theoretical = 2.82px
Distance 2021-Obresvation / 2015-Obresvation = 1.21px



Distance 2021-Obresvation / 2015-Theoretical = 2.14px
Distance 2015-Obresvation / 2015-Theoretical = 4.79px
Distance 2021-Obresvation / 2015-Obresvation = 1.52px



Hypothèse double-ring

