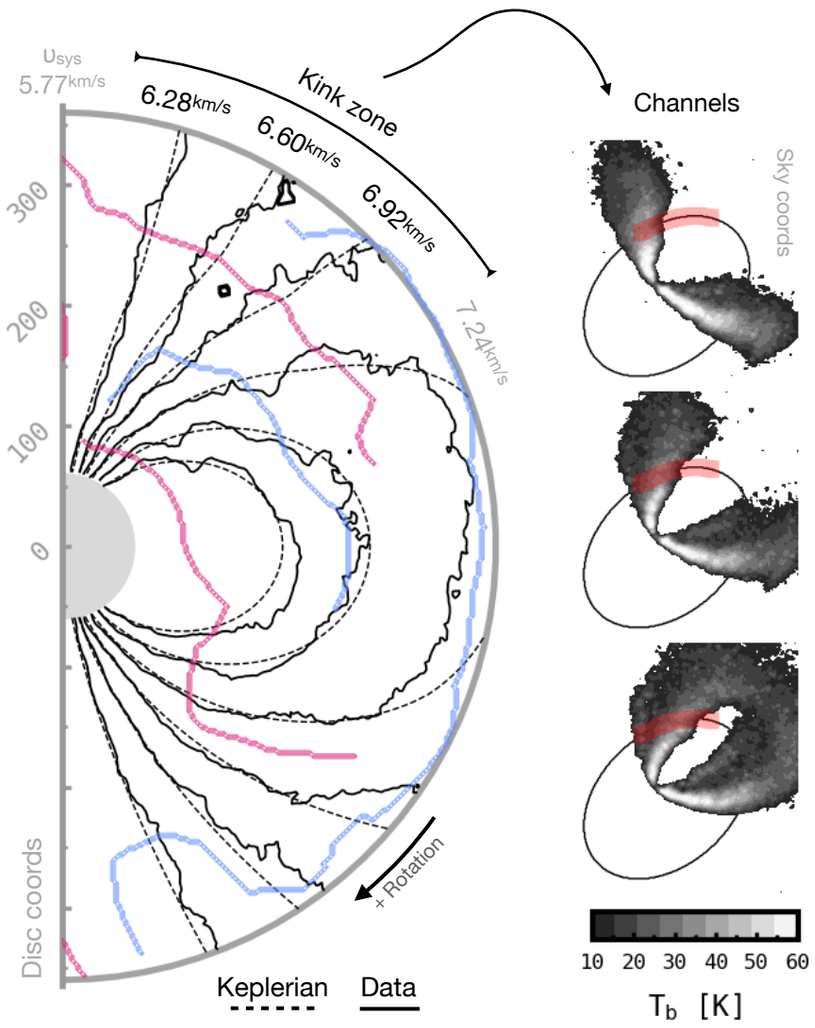
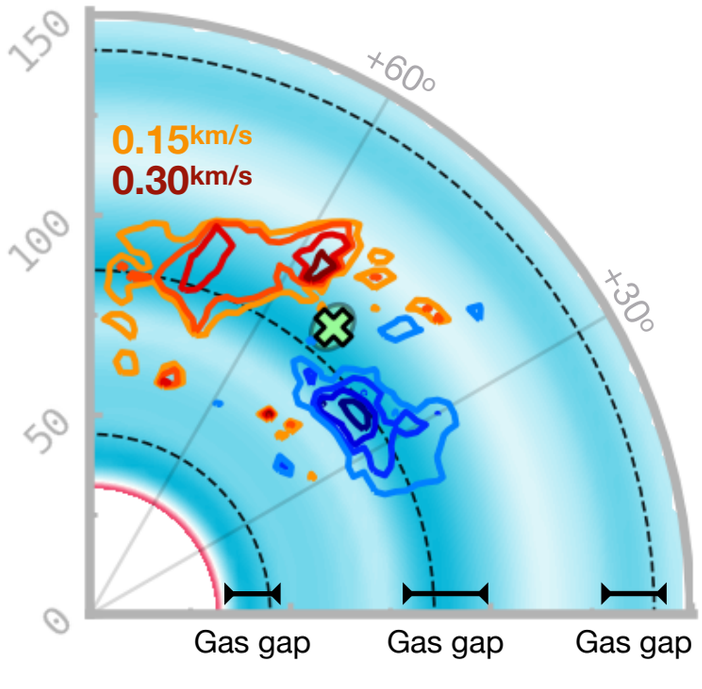
DISCMINER: Hunting planets and substructures in gas discs

Andrés F. Izquierdo

Leonardo Testi, Stefano Facchini, Giovanni Rosotti, Ewine van Dishoeck
Teresa Paneque-Carreño, Lisa Wölfer, Elena Viscardi





andizq

Adapted from Izquierdo et al. subm.

Outline

✓Intro to Discminer ⟵

✓Observables

✓HD 163296

- Gas structure and Planets

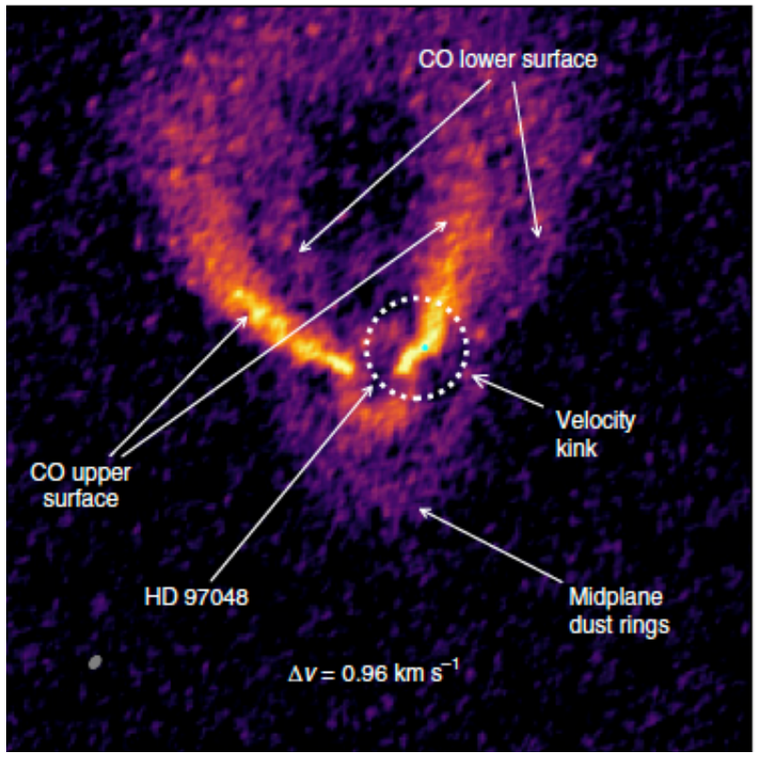
✓Other applications

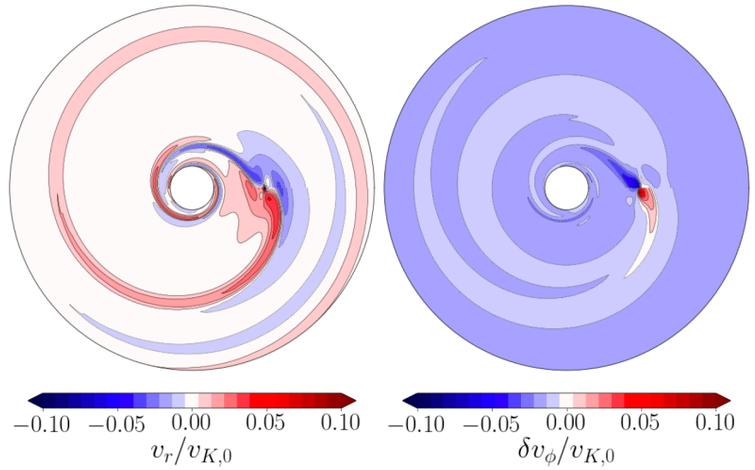
Izquierdo et al. 2021b

Izquierdo et al. subm.

Motivation

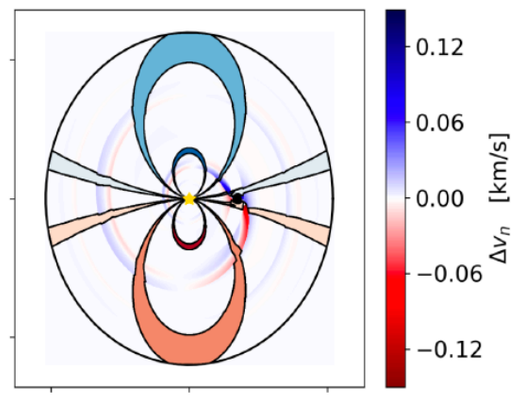
HD 97048 Pinte et al. 2019





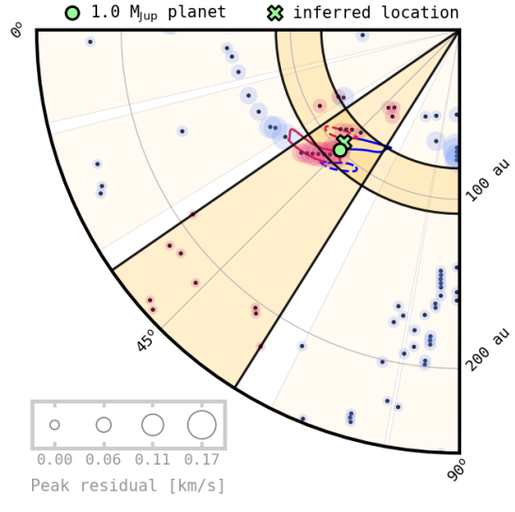
Perturbation vs z/r vs alpha

Rabago & Zhu et al. 2021



Amplitude of the kink

Bollati et al. 2021



Detection using observables

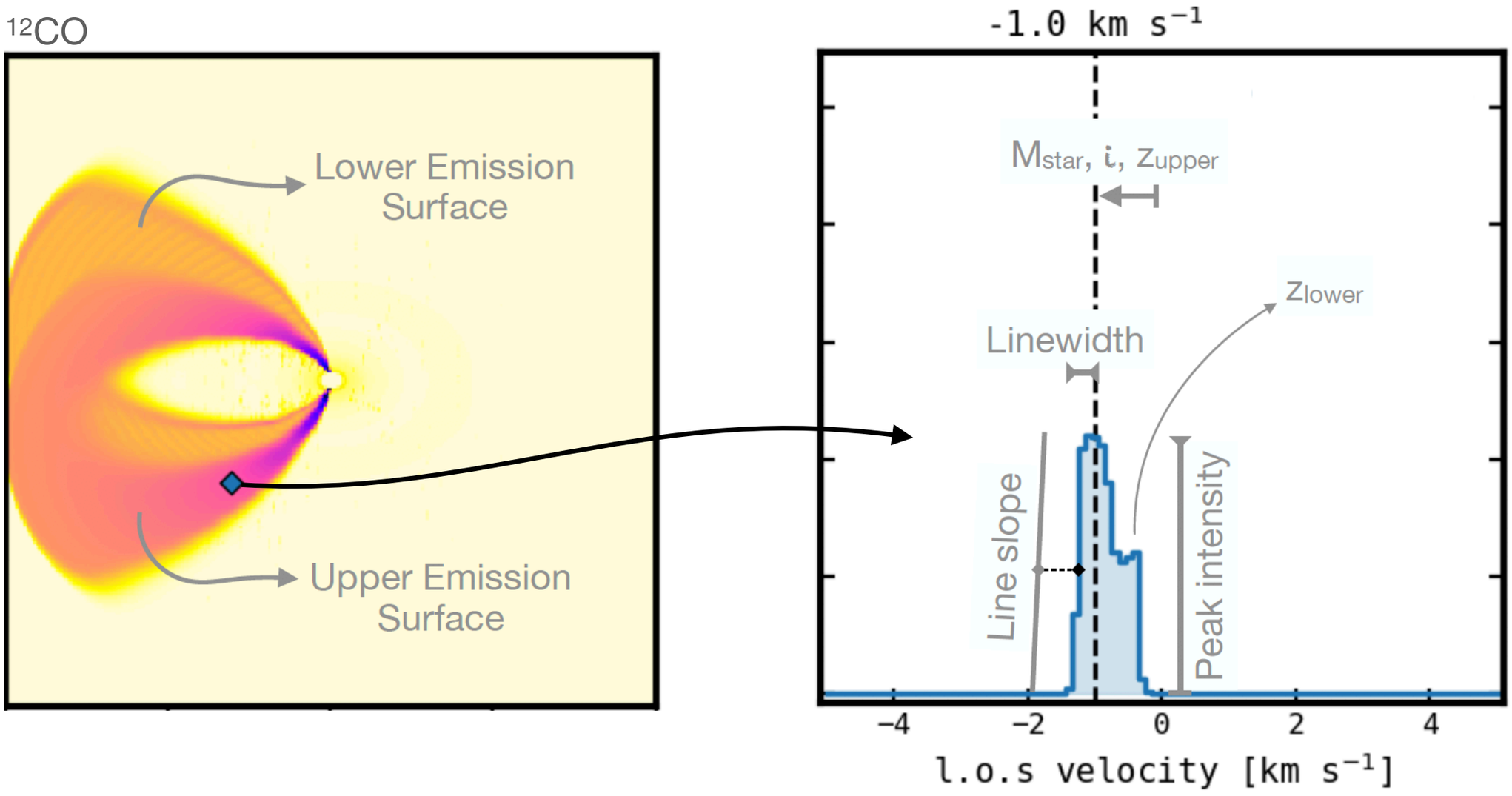
Izquierdo et al. 2021b

DISCSINER

DISCMINER

Model channel maps

✓this scheme implies fitting intensity and rotation velocity simultaneously

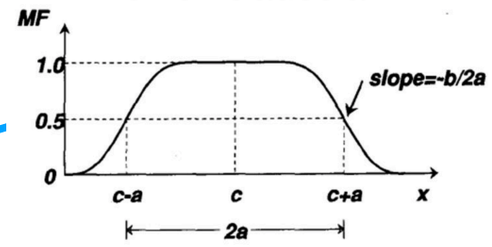


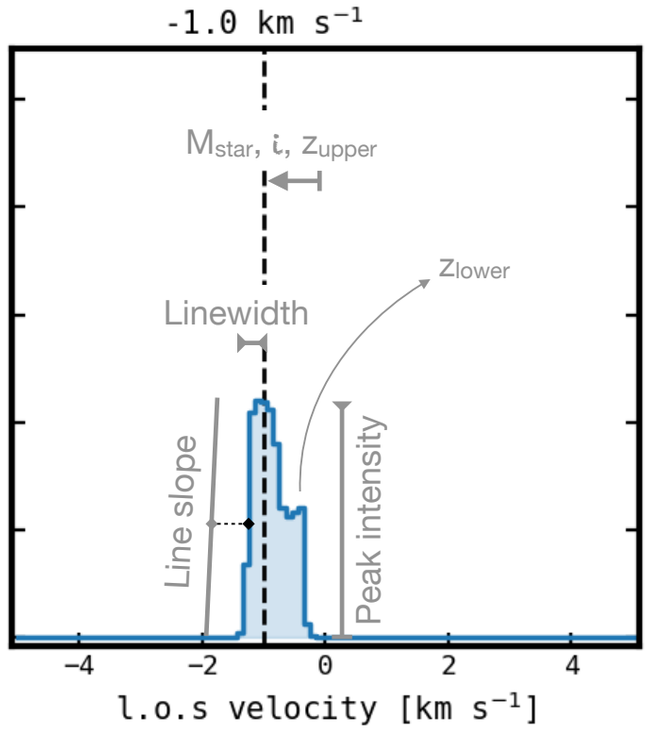
DISCMINER

Attribute	Prescription
Inclination	i
Position angle	PA
Systemic velocity	$v_{\rm sys}$
Rotation velocity	$v_k = \sqrt{\frac{GM_*}{r^3}}R$
Upper surface	$z_U = z_0(R/D_0)^p - z_1(R/D_0)^q$
Lower surface	$z_L = z_0(R/D_0)^p - z_1(R/D_0)^q$
Peak intensity	$I_p = I_0(R/D_0)^p(z/D_0)^q$
Line width	$L_w = L_{w0}(R/D_0)^p(z/D_0)^q$
Line slope	$L_s = L_{s0}(R/D_0)^p$

Parametric attributes

Bell or Gaussian





Emcee

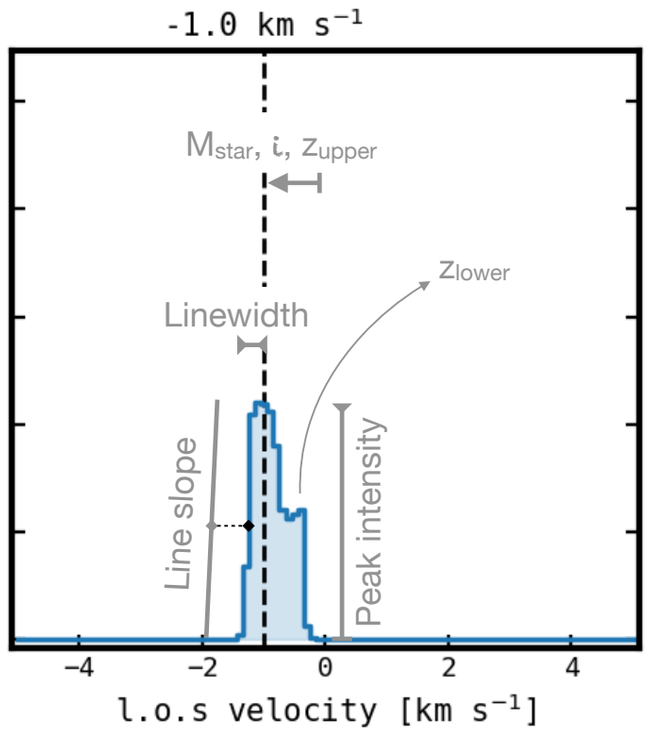
(Foreman-Mackey+2013)

$$\chi^2 = -0.5 \sum_j^{n_{\rm ch}} \sum_i^{n_{\rm pix}} w_{ij}^{-2} \left[I_m(r_i, v_j) - I_d(r_i, v_j) \right]^2$$

Discminer

Attribute	Prescription
Inclination	i
Position angle	PA
Systemic velocity	v_{sys}
Rotation velocity	$\frac{v^2}{r} = \frac{GM_* r}{(r^2+z^2)^{3/2}} + \frac{1}{\rho_{gas}}\frac{\partial P_{gas}}{\partial r} + \frac{\partial \phi_{gas}}{\partial r}$,
Upper surface	$z_U = z_0(R/D_0)^p - z_1(R/D_0)^q$
Lower surface	$z_L = z_0(R/D_0)^p - z_1(R/D_0)^q$
Peak intensity	$I_p = I_0(R/D_0)^p(z/D_0)^q$
Line width	$L_w = L_{w0}(R/D_0)^p(z/D_0)^q$
Line slope	$L_s = L_{s0}(R/D_0)^p$

Kernel(z, R; v_{chan})



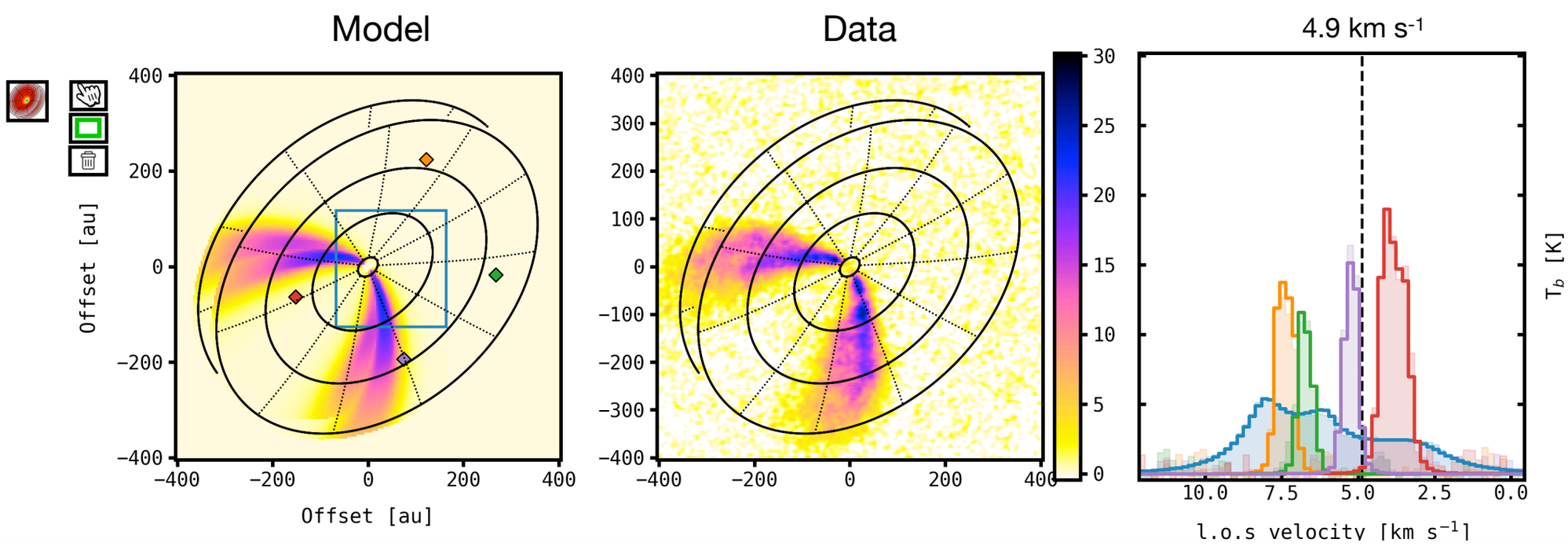
Emcee
(Foreman-Mackey+2013)

$$\chi^2 = -0.5 \sum_j^{n_{ch}} \sum_i^{n_{pix}} w_{ij}^{-2} \left[I_m(r_i, v_j) - I_d(r_i, v_j) \right]^2$$

Pixel —> {R, Z_{upper} [, phi]}
—> {R, Z_{lower} [, phi]}

DISCMINER

Example best-fit model channels for HD 163296 in ^{13}CO



Solid lines —> Model
Shades —> Data

Using MAPS data (Öberg et al. 2021)

Outline

✓Intro to Discminer

✓Observables ←

✓HD 163296

- Gas structure and Planets

✓Other applications

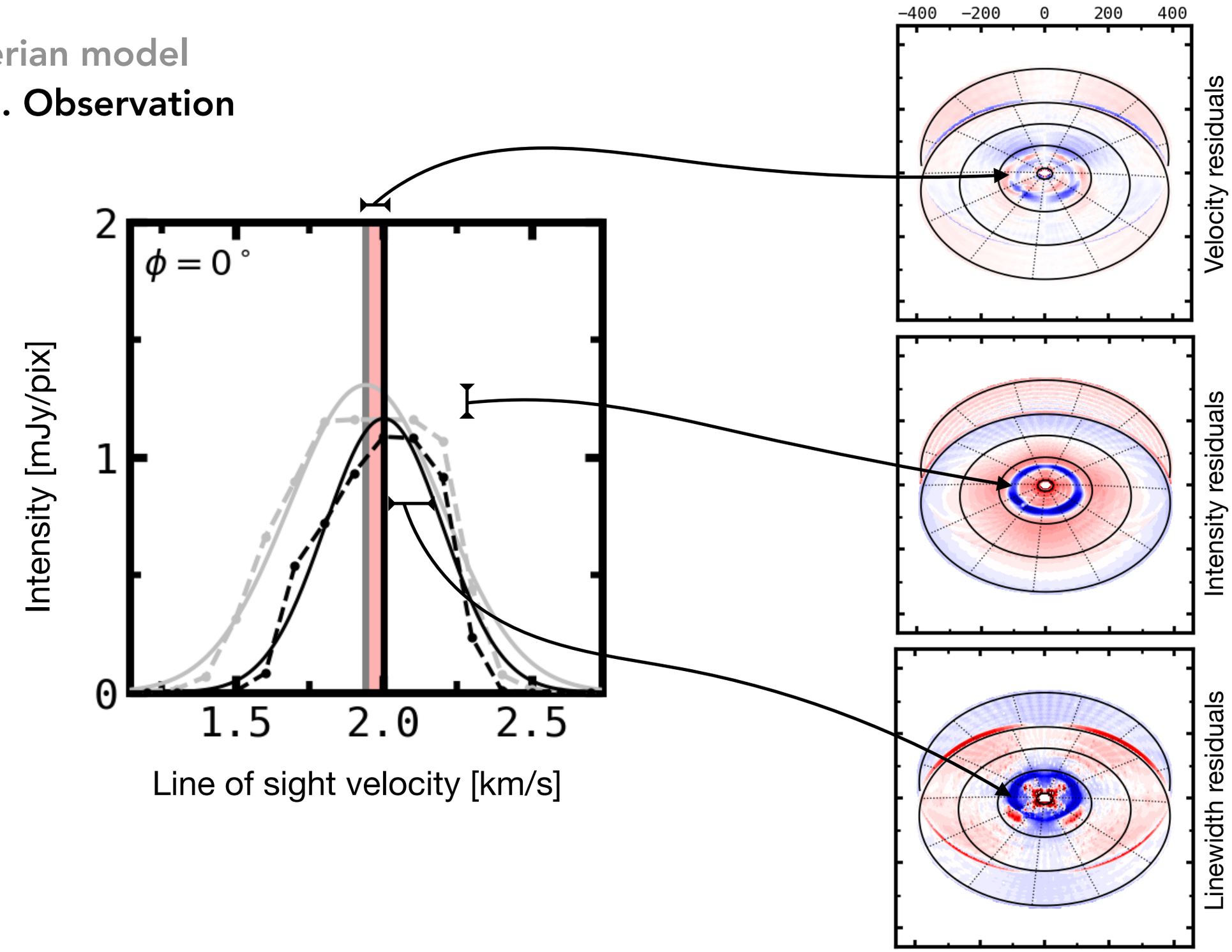
Izquierdo et al. 2021b

Izquierdo et al. subm.

Observables

Keplerian model

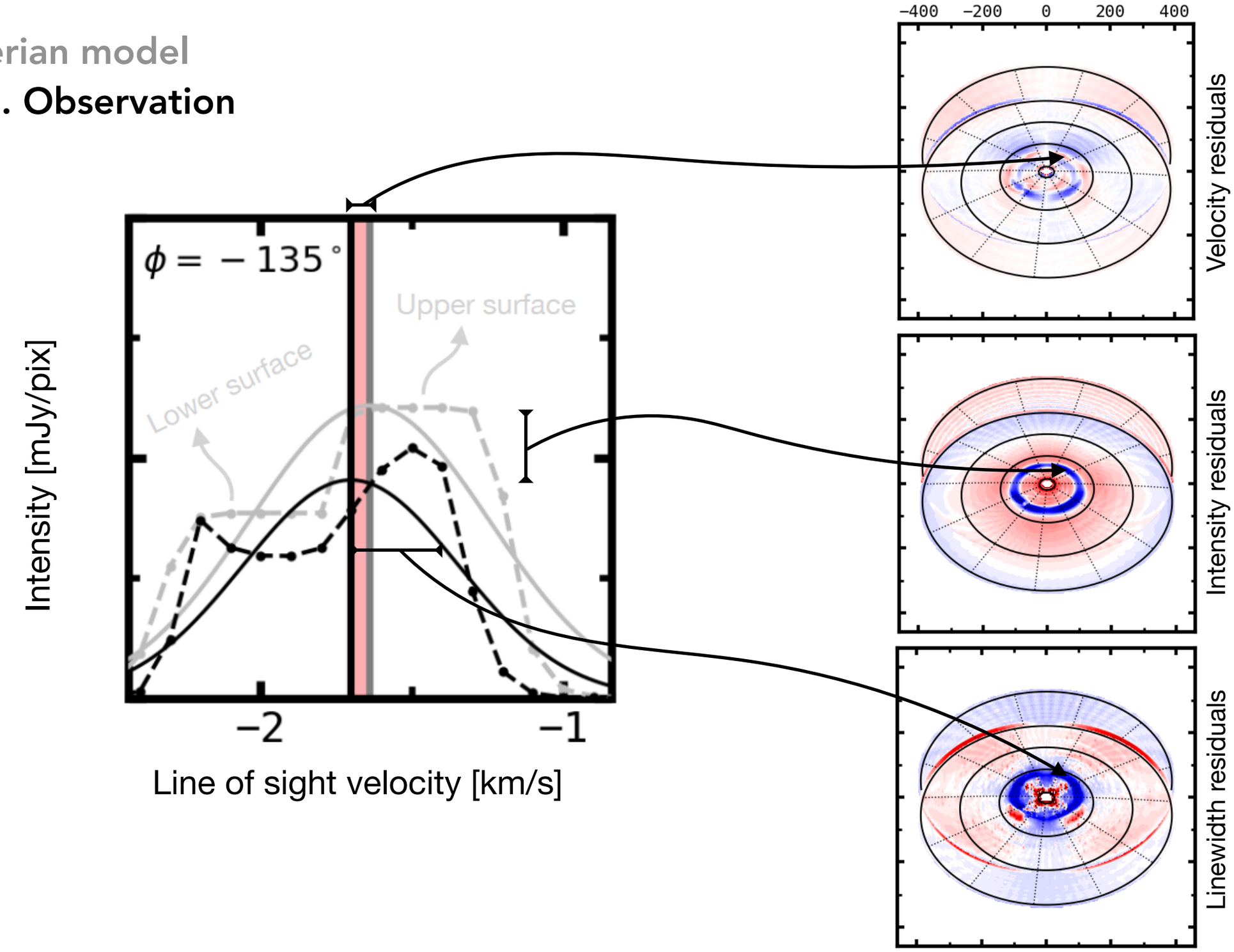
Synth. Observation



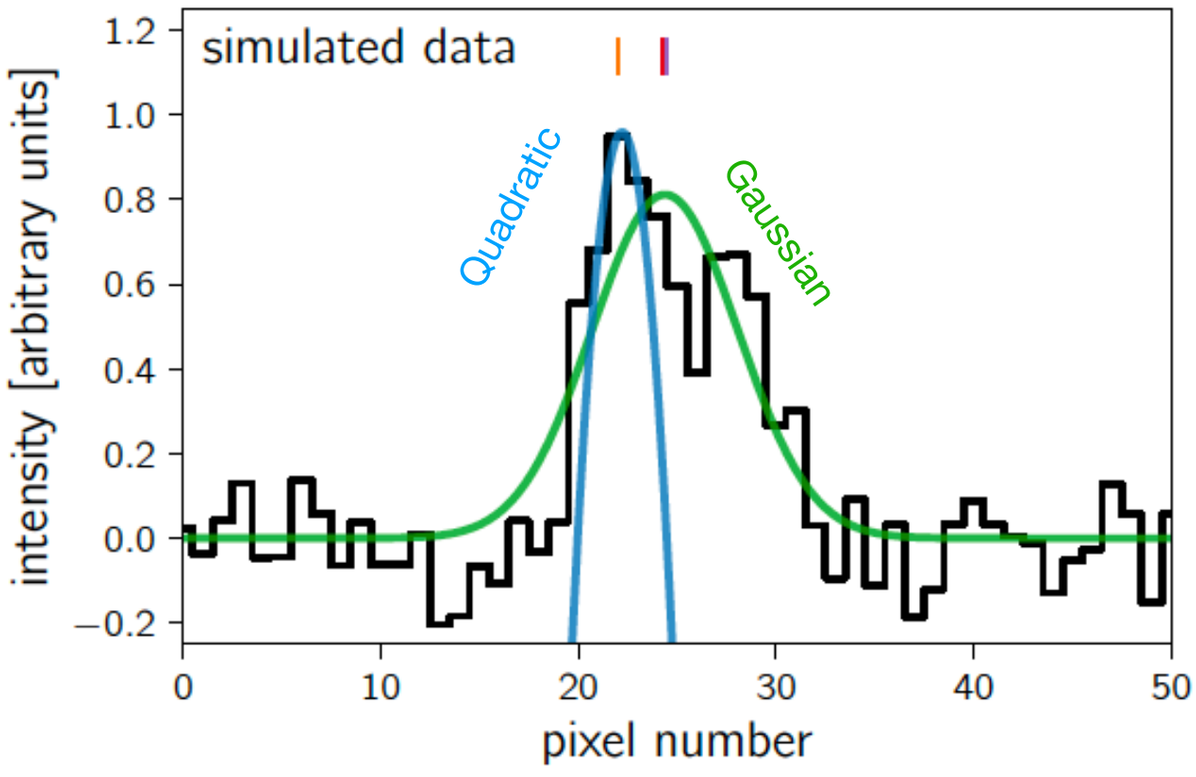
Observables

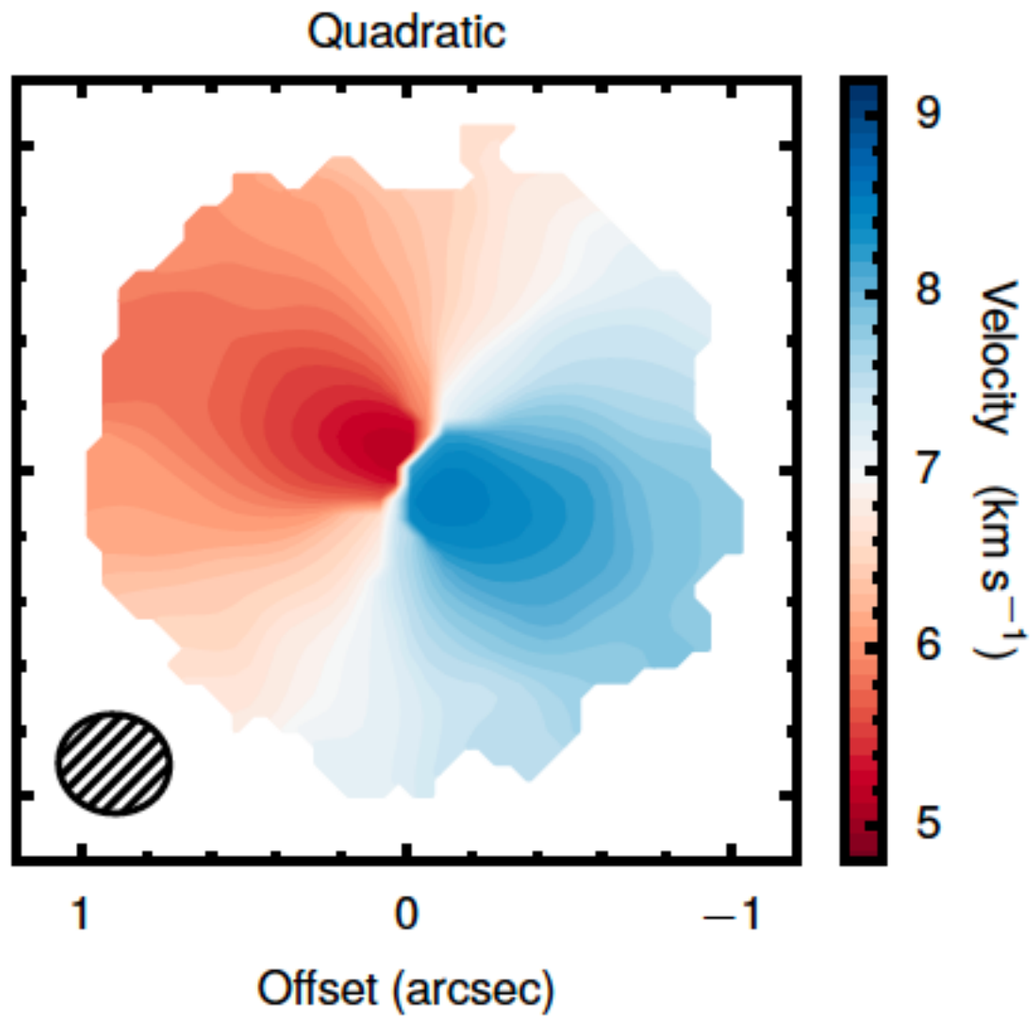
Keplerian model

Synth. Observation



Velocity residuals 2.0





Adapted from Teague et al. 2018 (Bettermoments)
See also R. Teague's talk

Outline

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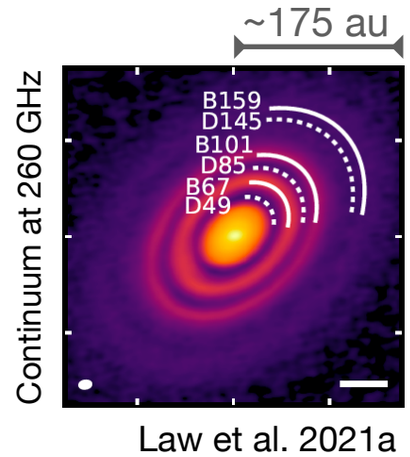
Izquierdo et al. 2021b

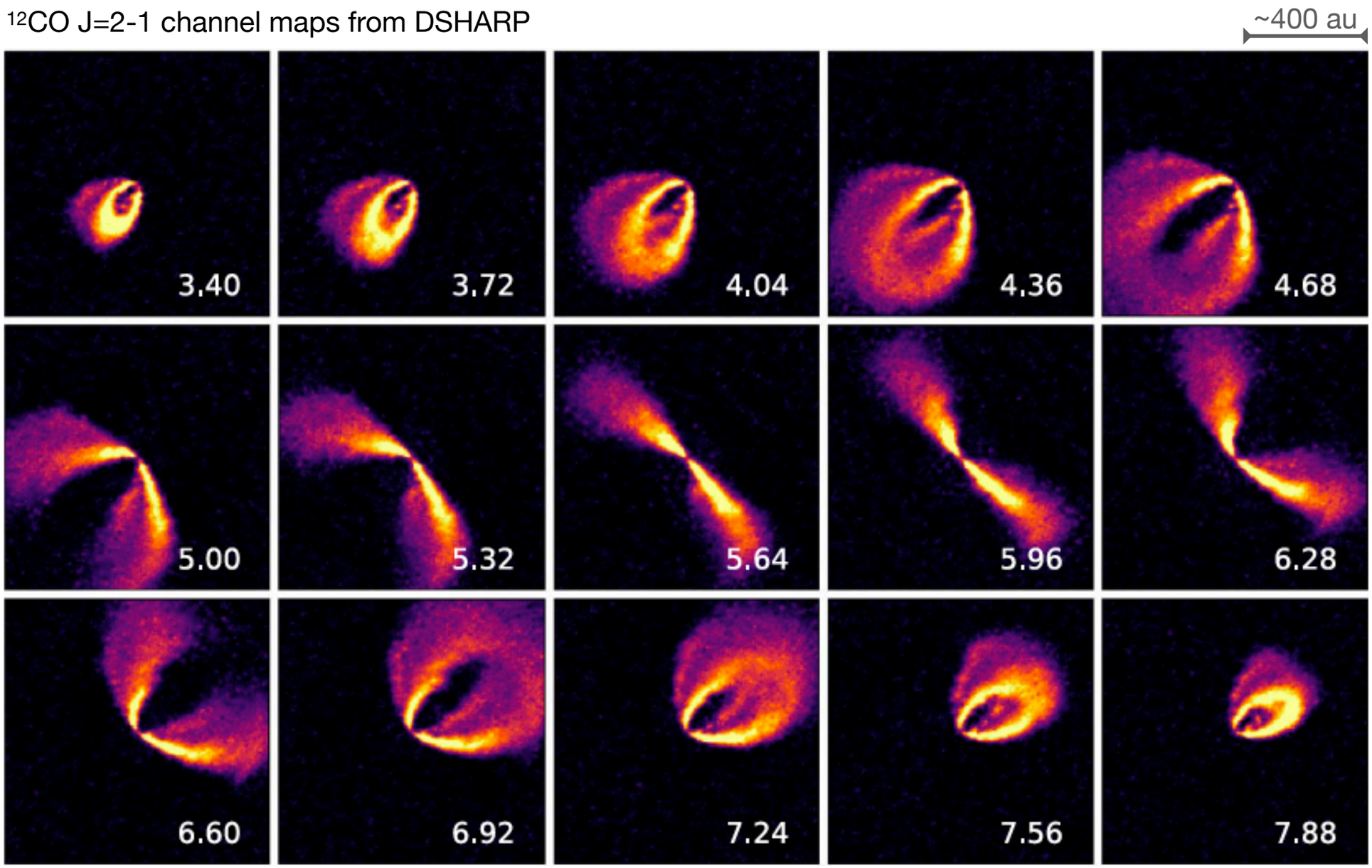
Izquierdo et al. subm.

HD 163296



Law et al. 2021a

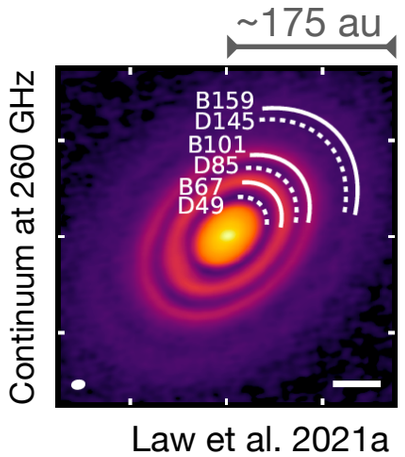
^{12}CO J=2-1 channel maps from DSHARP



Adapted from Isella et al. 2018
Andrews et al. 2018

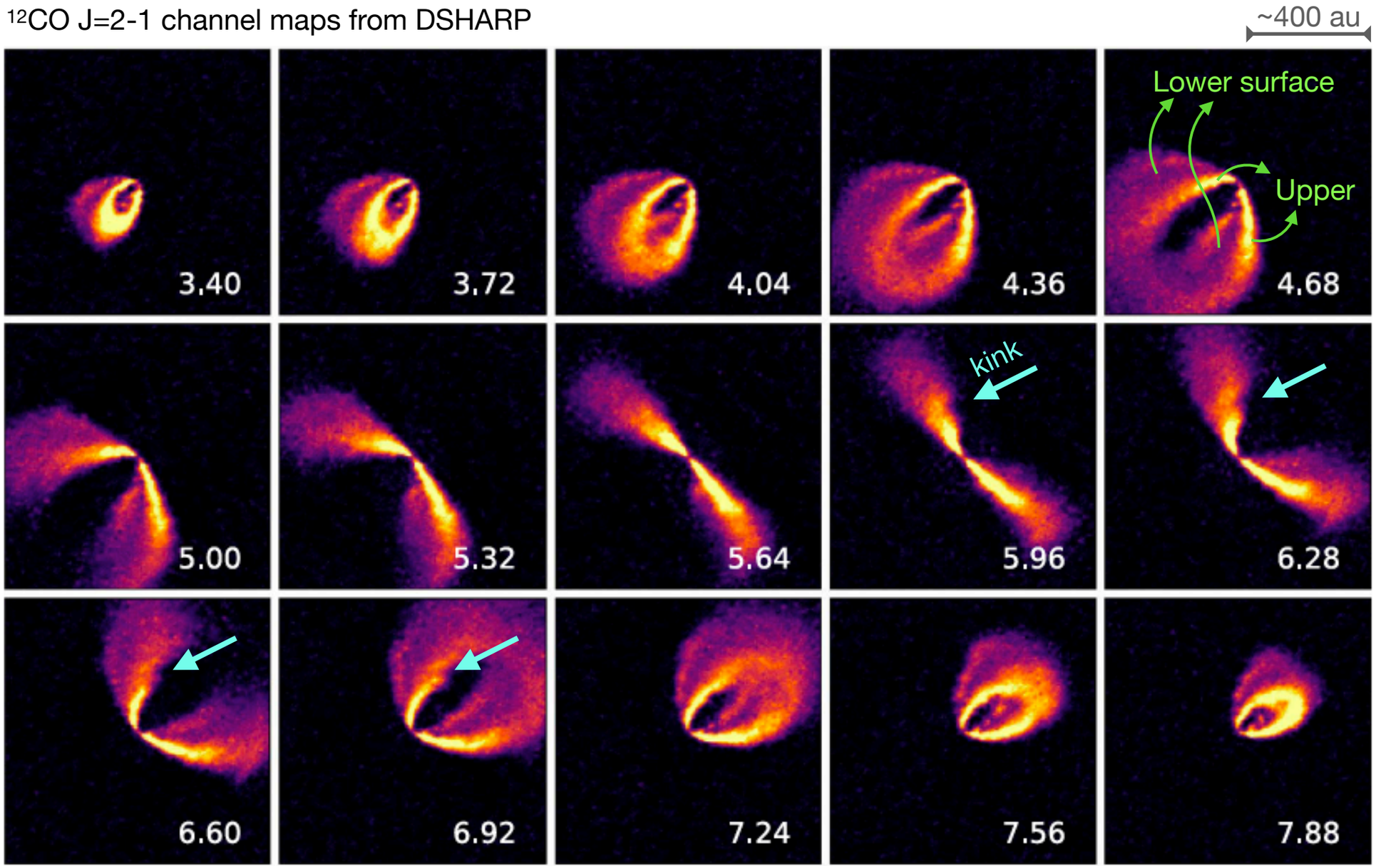
Beam size ~10 au
Channel width 0.32 km/s

HD 163296



Law et al. 2021a

^{12}CO J=2-1 channel maps from DSHARP



Adapted from Isella et al. 2018
Andrews et al. 2018

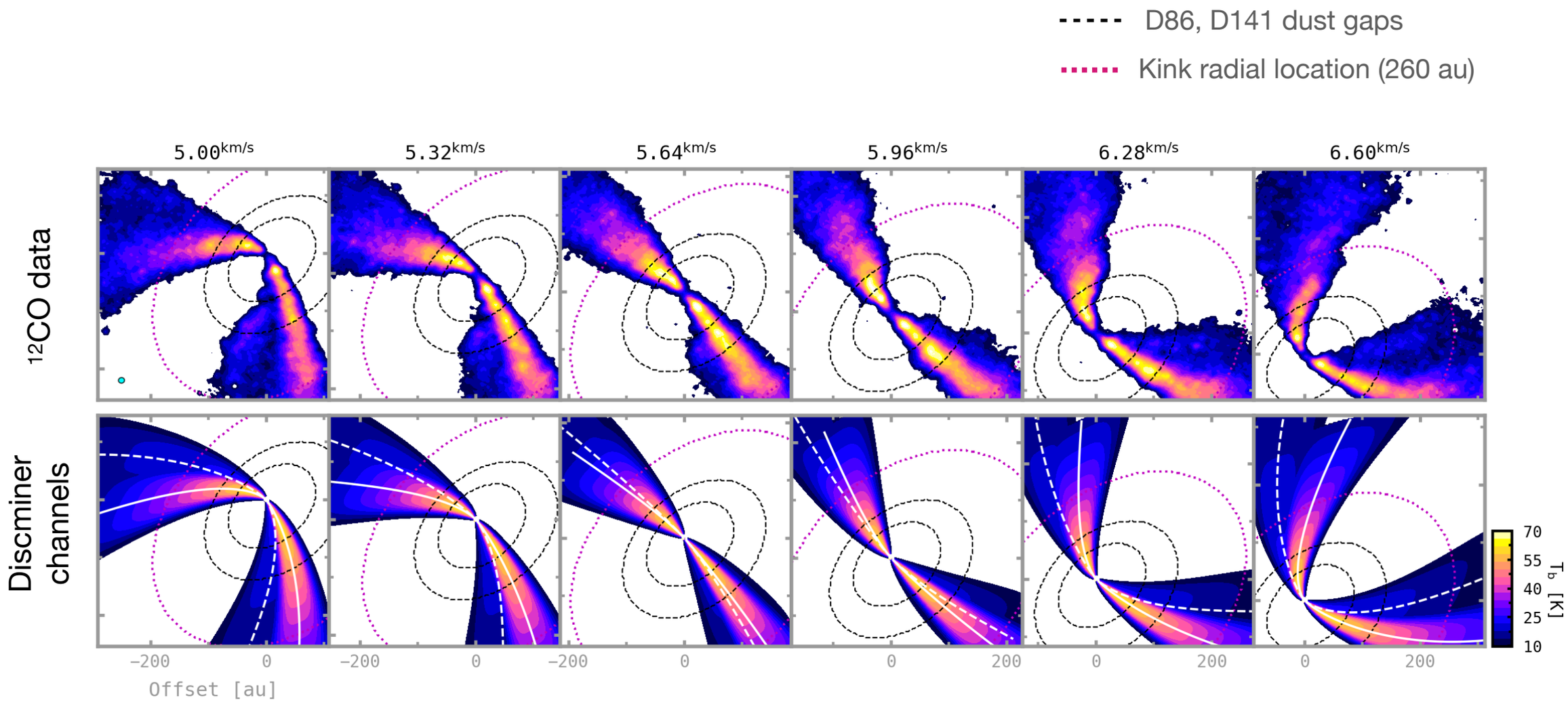
Pinte et al. 2018a —> Kink at R=260 au, planet?
Dullemond et al. 2020 —> Lower surface temperature
Teague et al. 2018, 2019, 2021 —> Kinematical substructures, planets?

HD 163296

- Tb (Upper and lower surfaces)
- Height (Upper surface)
- Is the kink detected?
  - Height (Lower surface)
  - Line widths?
  - Other localised perturbations?

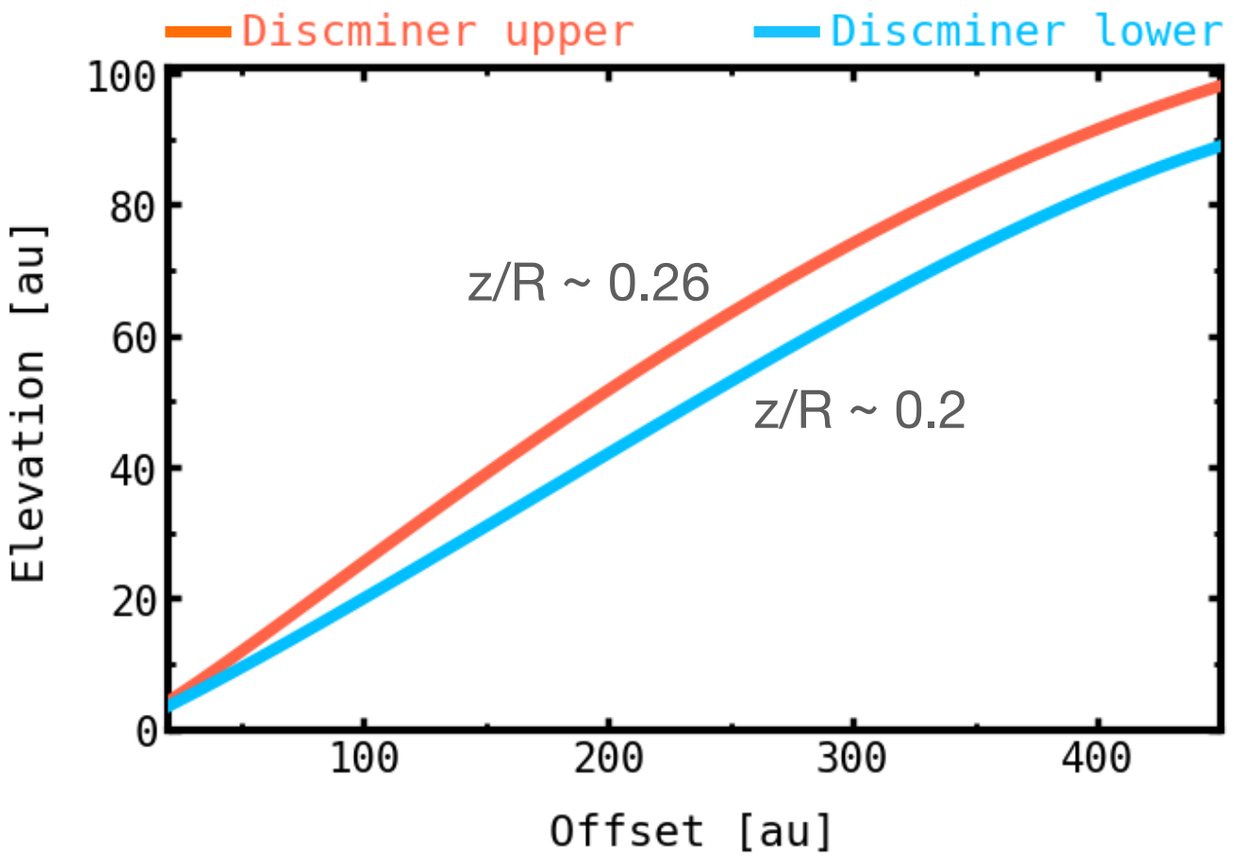
Izquierdo et al. subm.

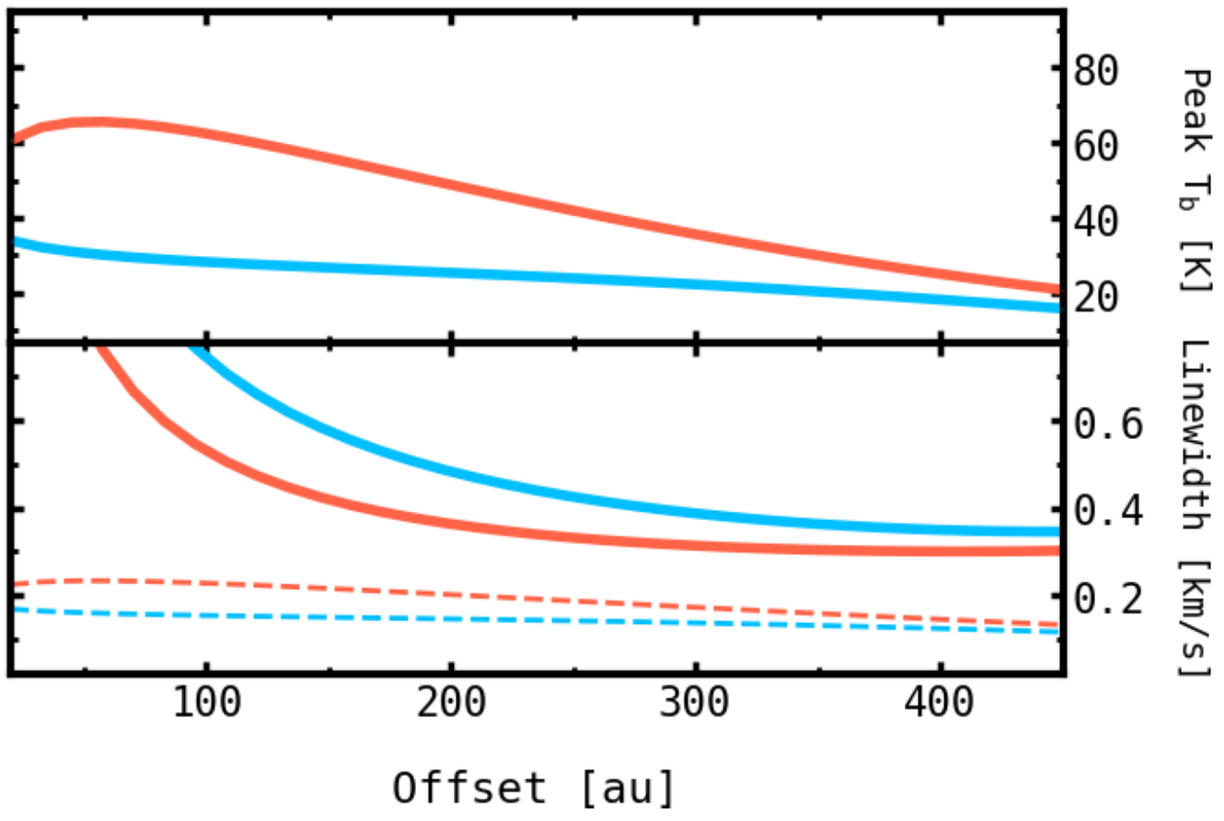
HD 163296



Izquierdo et al. subm.

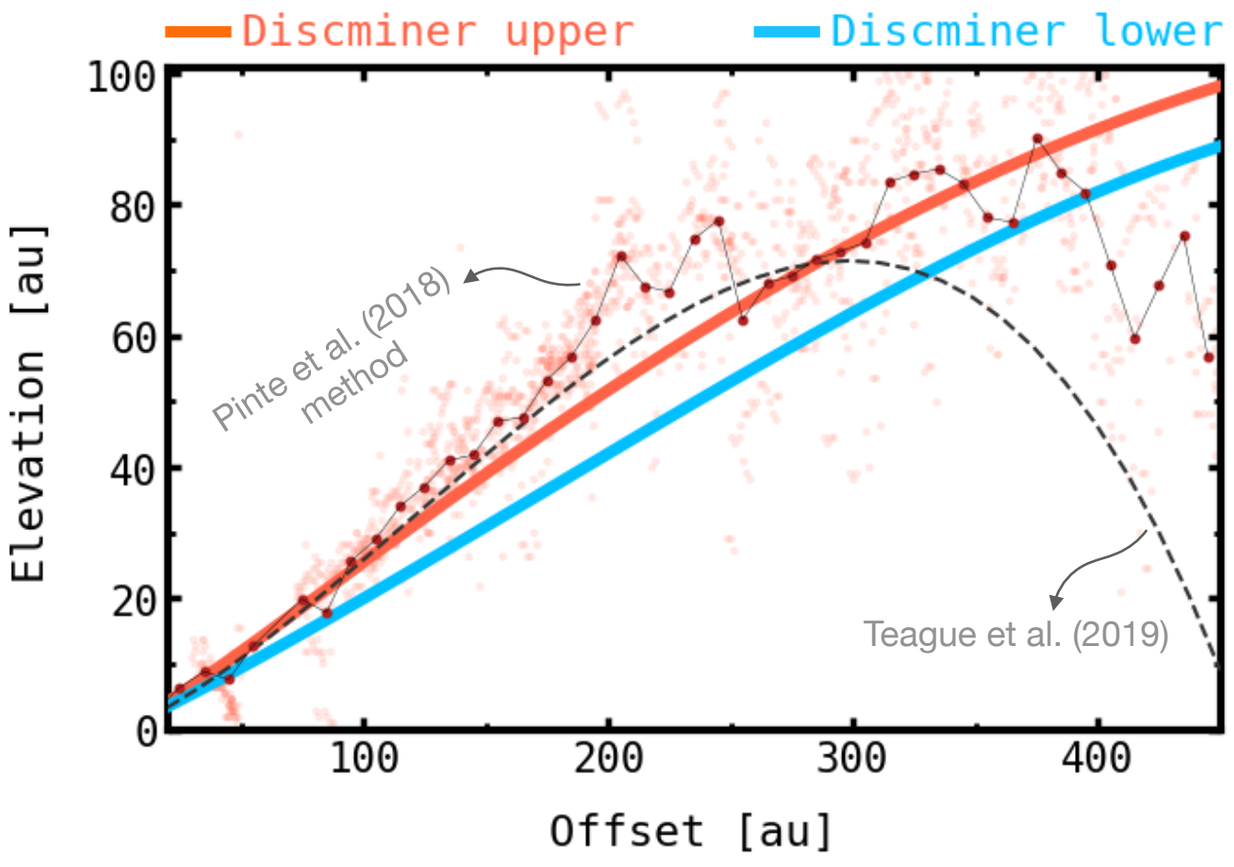
Attributes

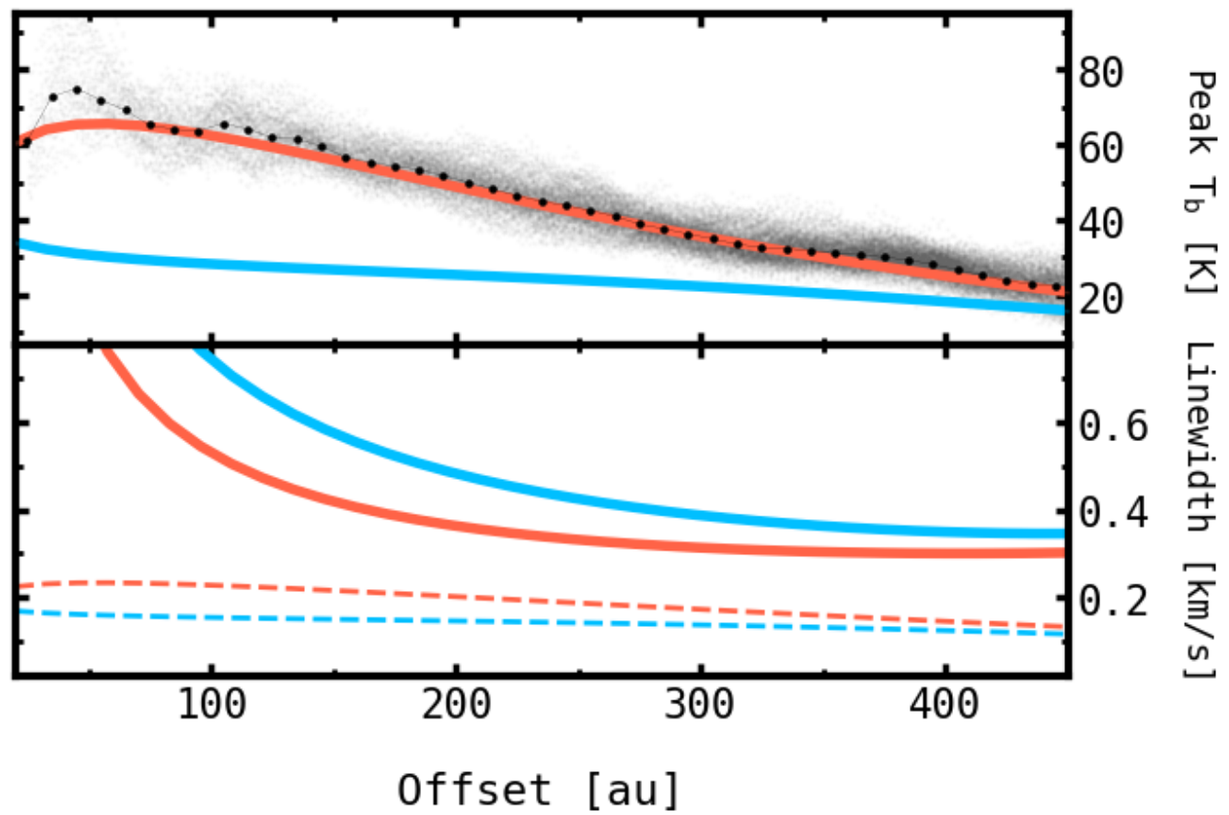




Izquierdo et al. subm.

Attributes

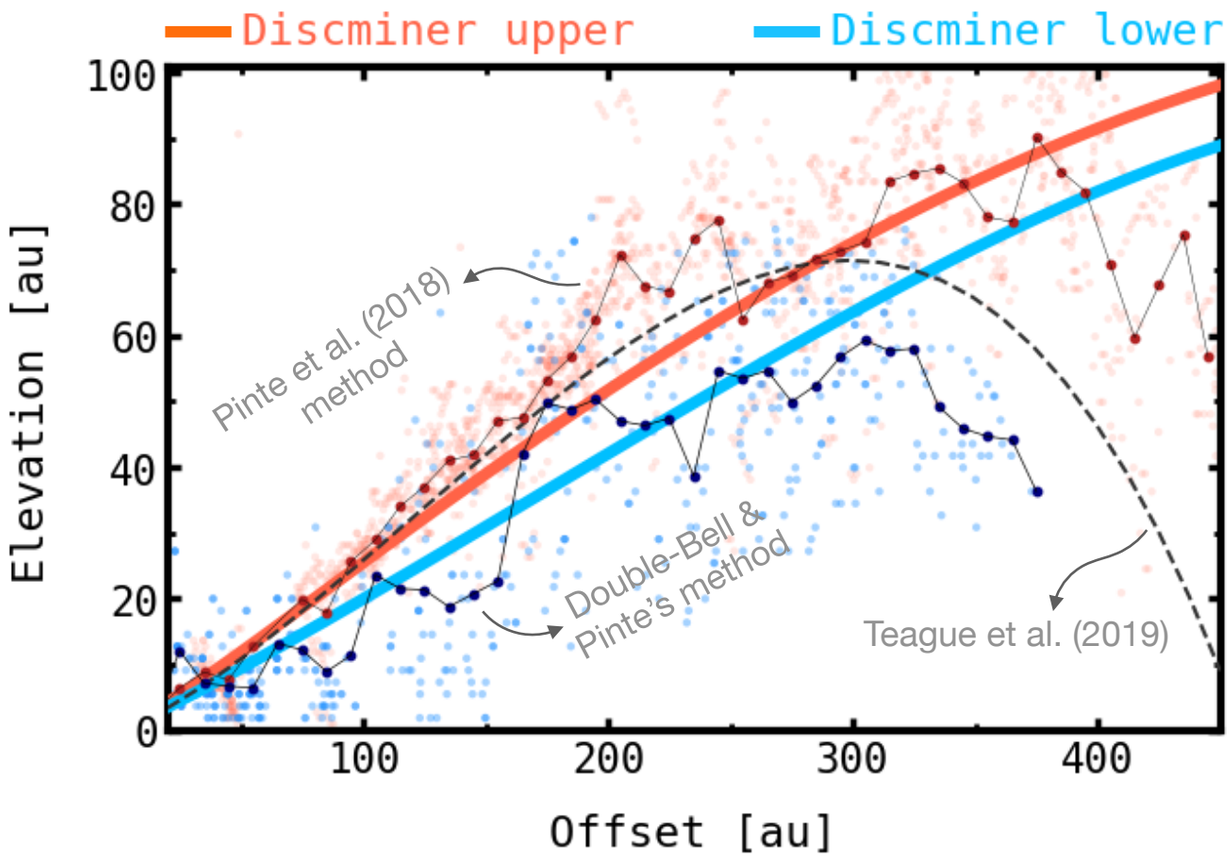


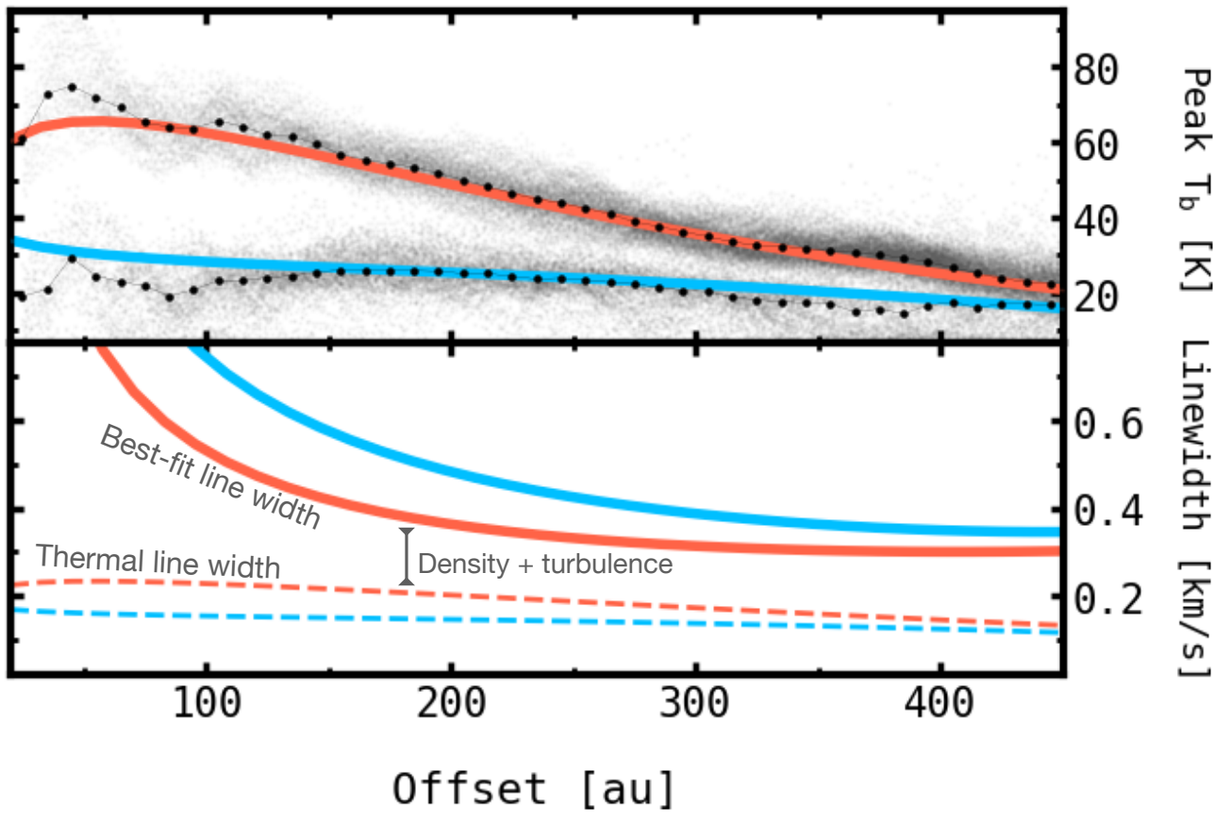


- Upper surface elevation extracted with **DiskSurf** —> R. Teague implementation of C. Pinte's method (Pinte et al. 2018b)

Izquierdo et al. subm.

Attributes

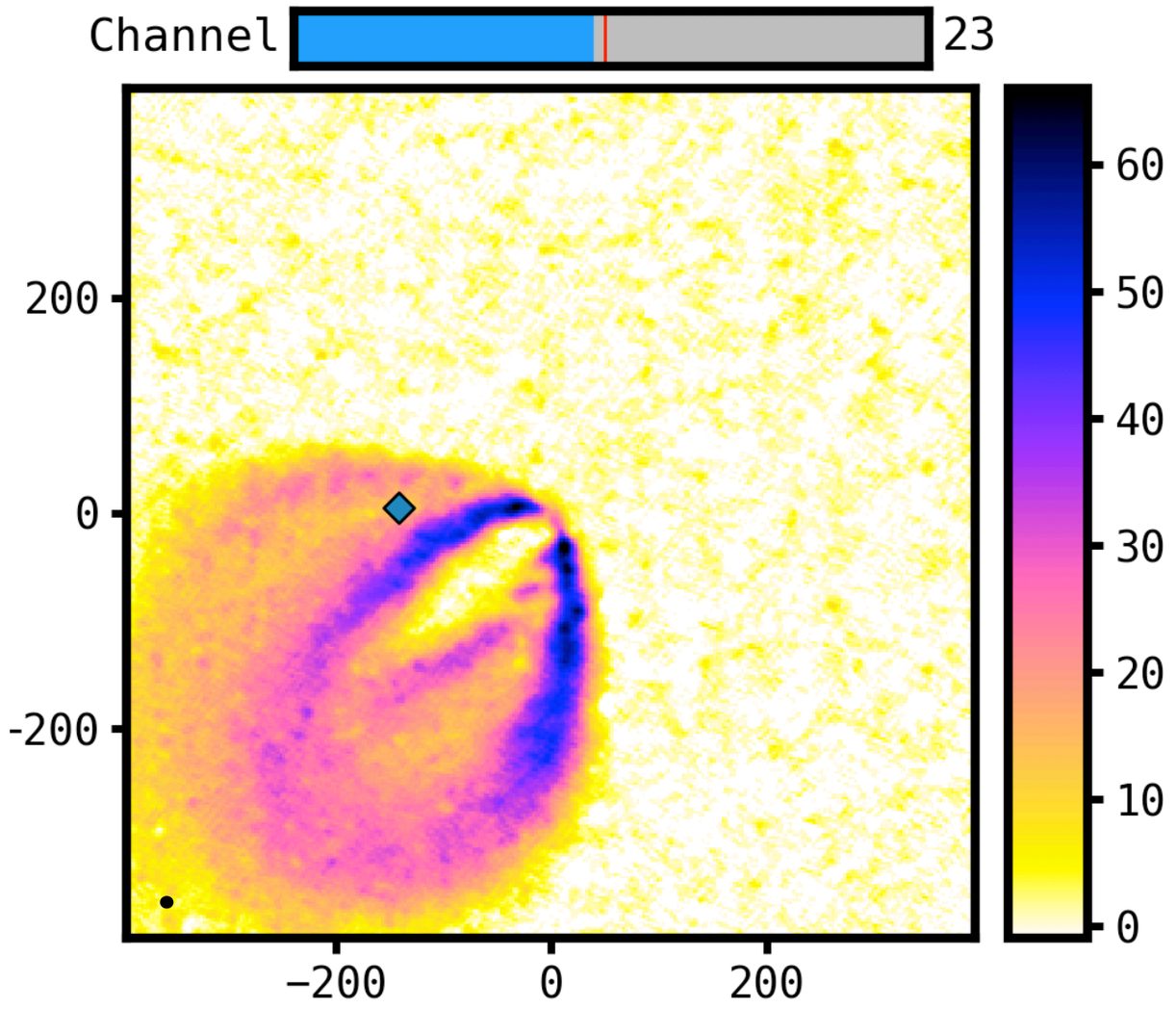


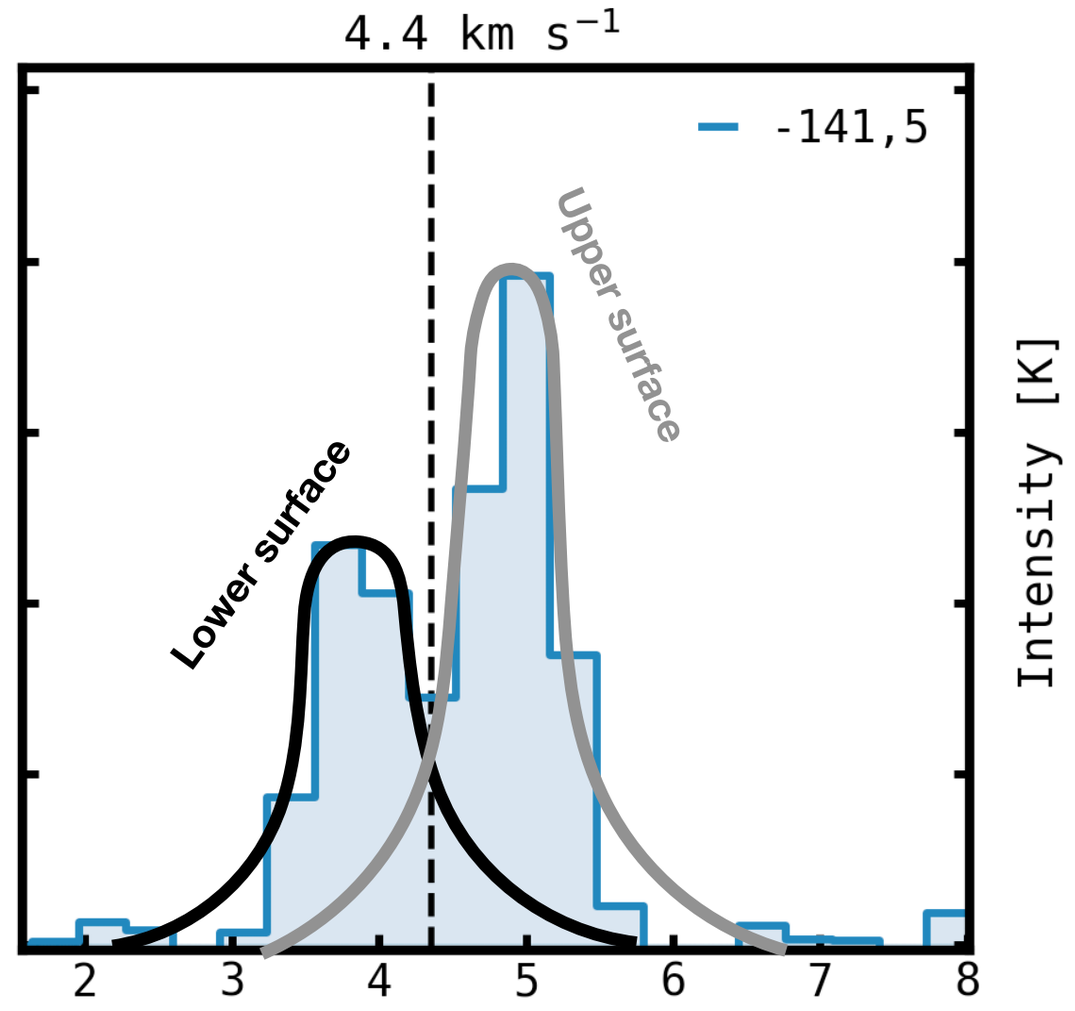


- Lower surface elevation extracted with **DiskSurf** using channels from lower surface alone…

See discussion on opacity broadening in Hacar et al. 2016

Lower surface?

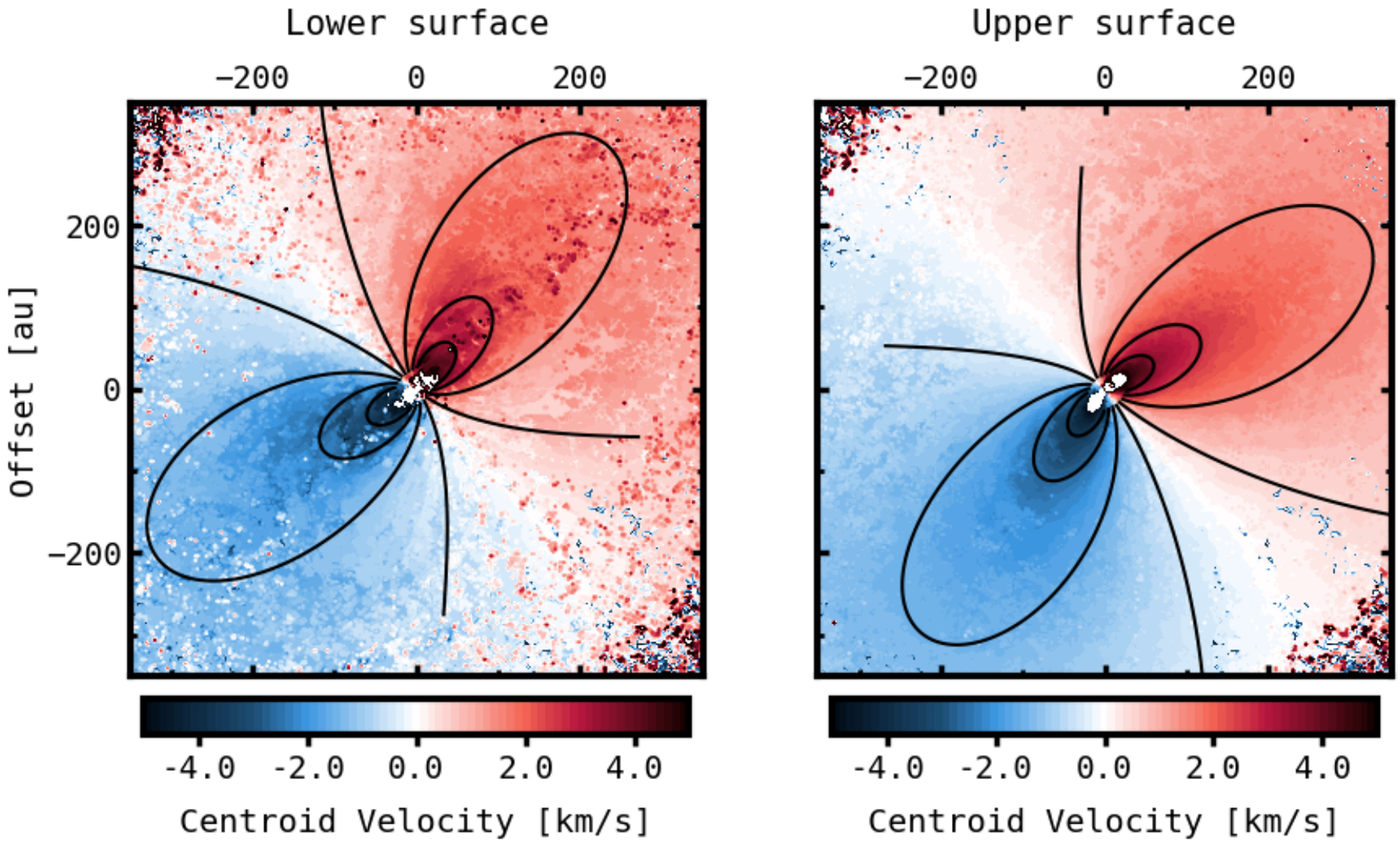




Double-bell fit to the line profile

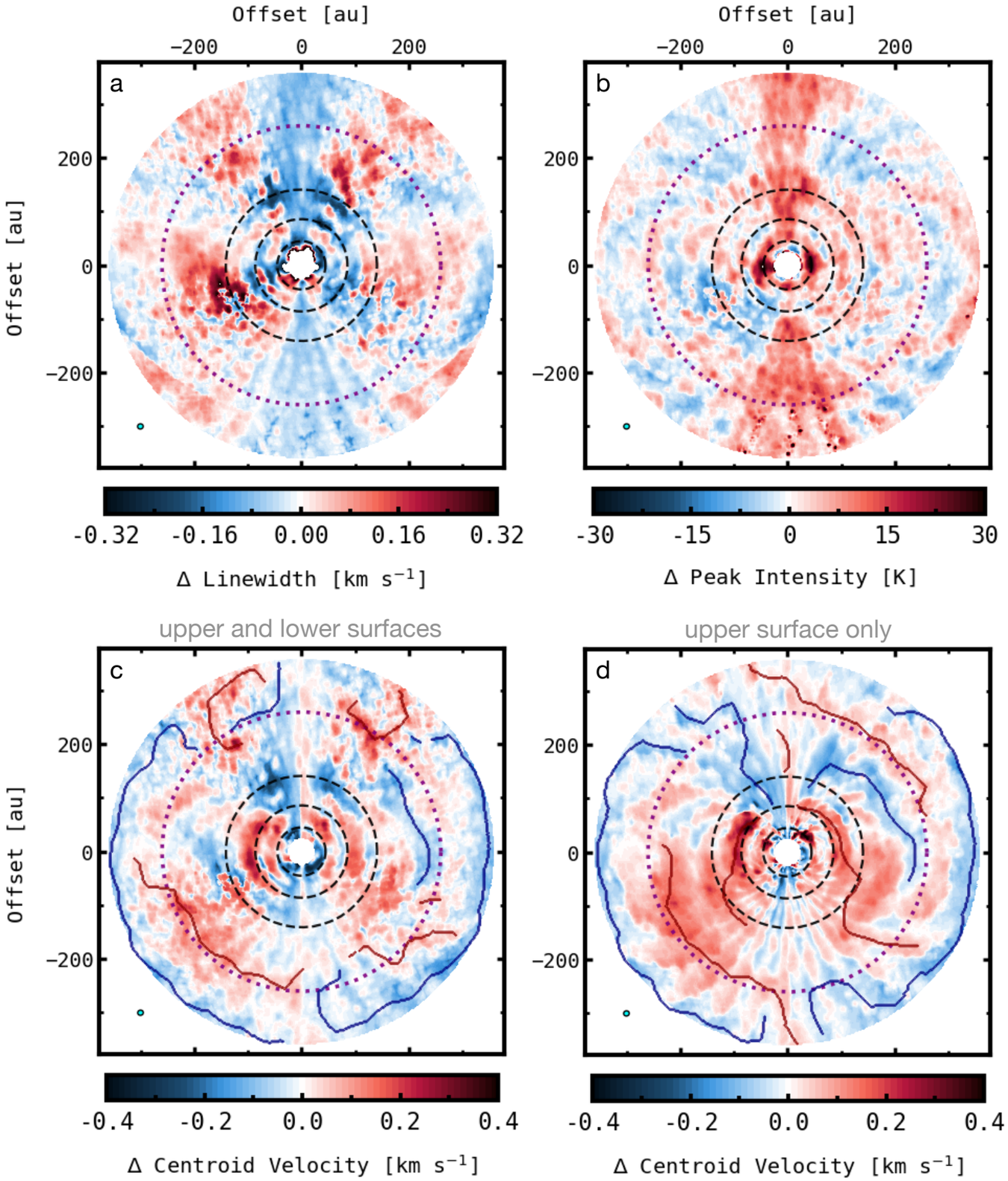
Izquierdo et al. subm.

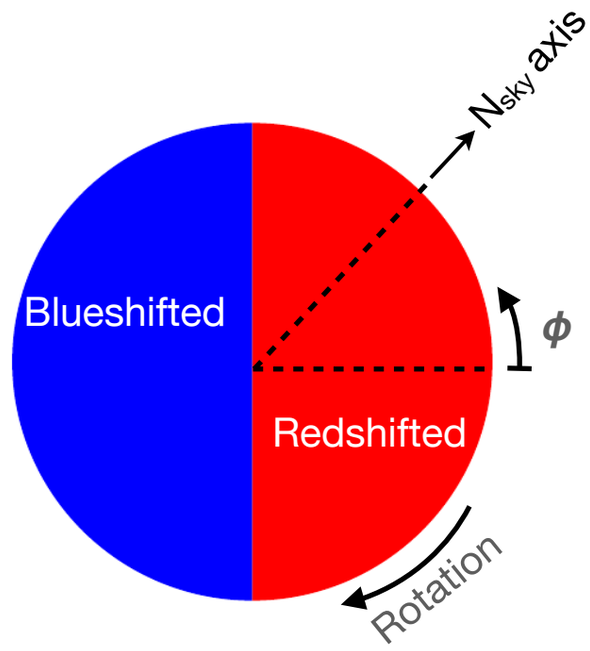
Lower & Upper velocities



See also R. Teague's talk
& Casassus et al. 2021

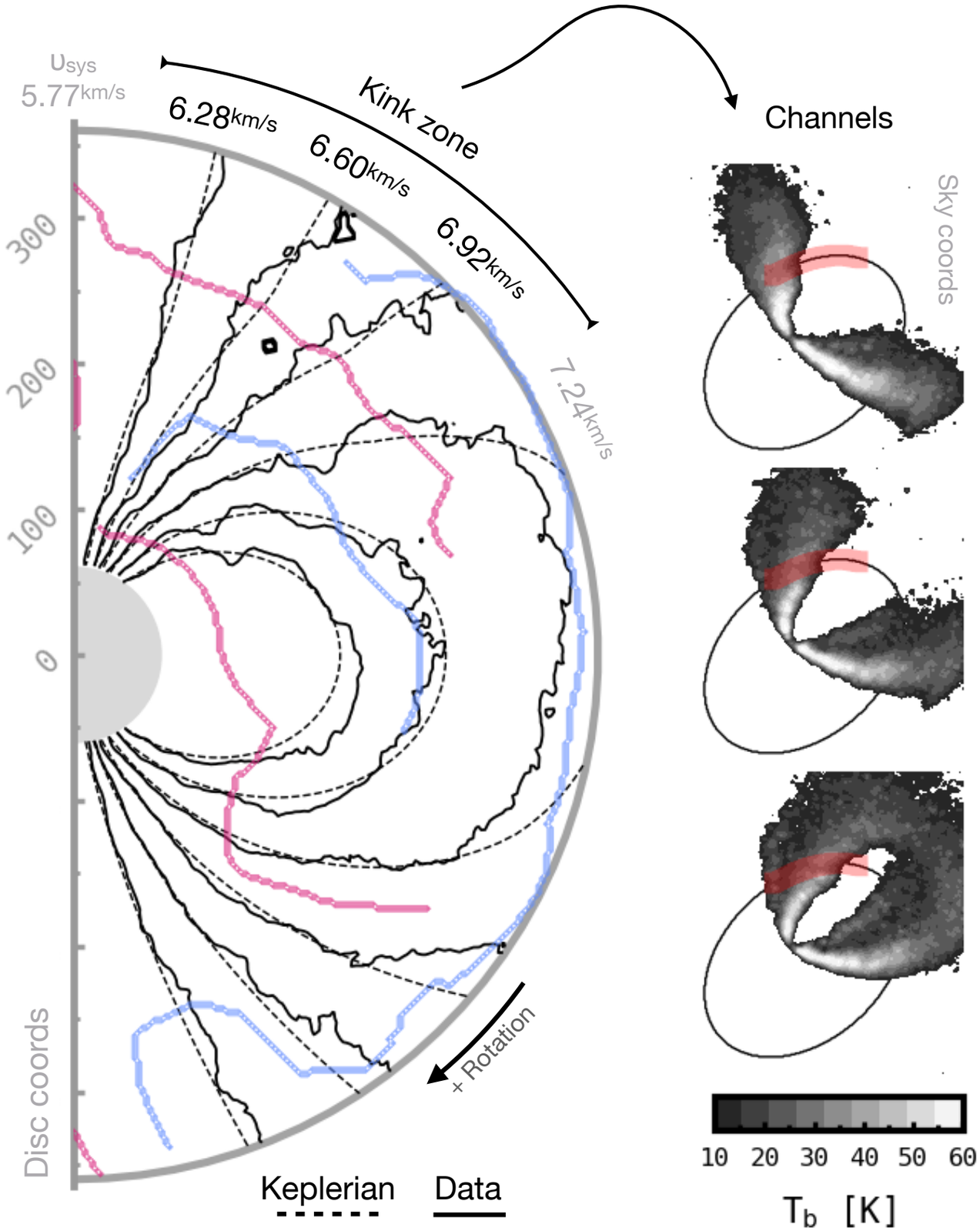
Residuals





Filamentary structures found with **FilFinder** (Koch & Rosolowsky 2015)

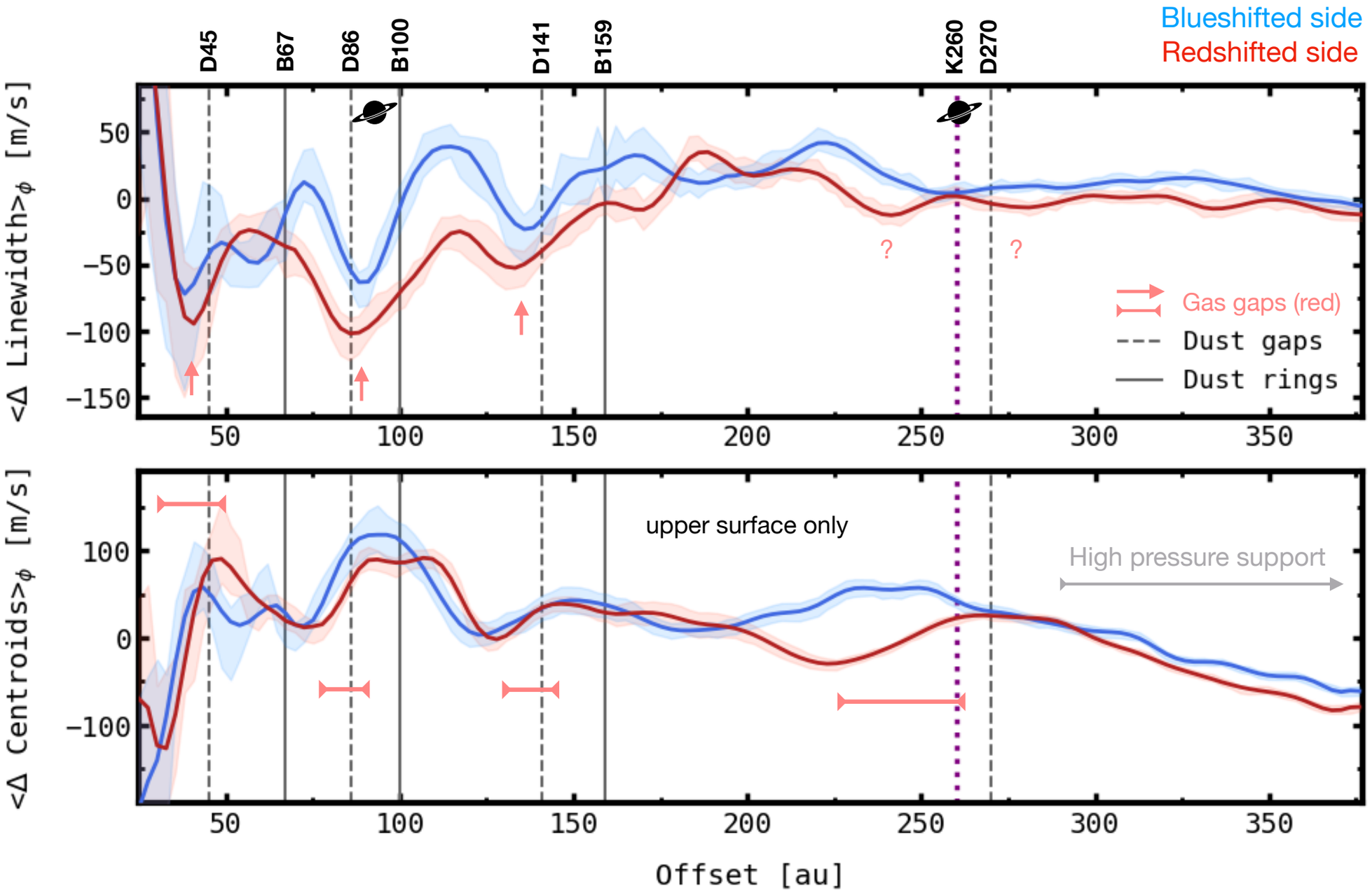
K260 kink



K260 kink is the result of a long filamentary structure

See also Teague et al. 2021 (MAPS)

Gas Substructure

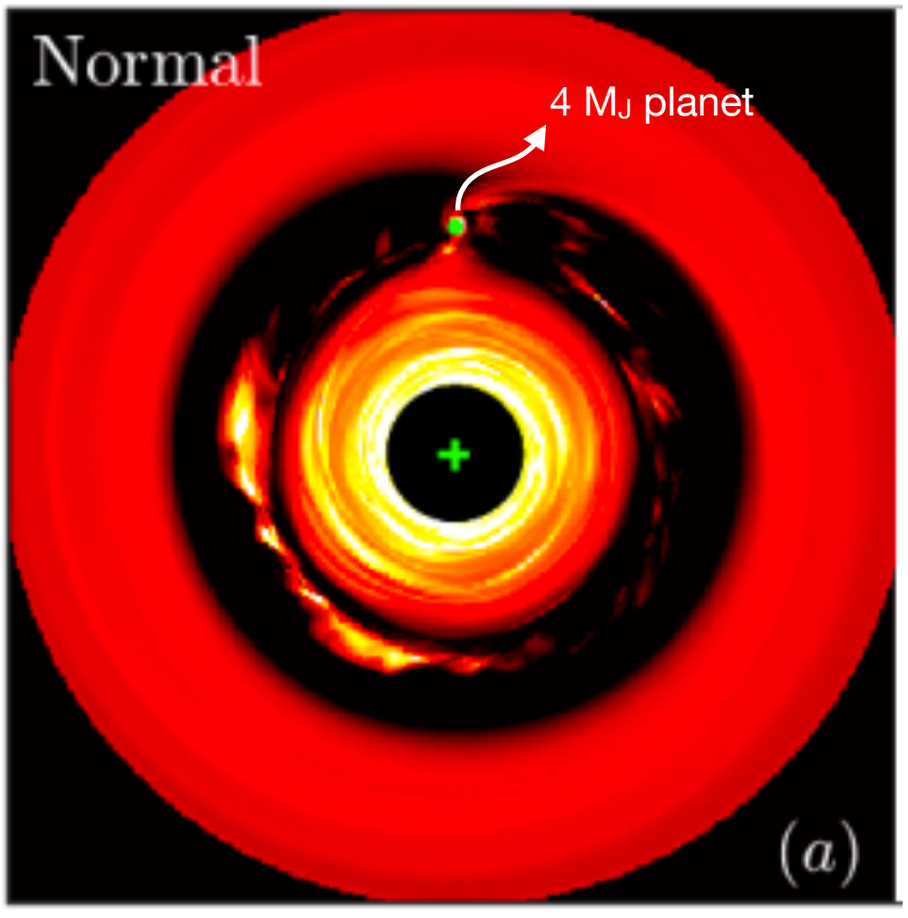


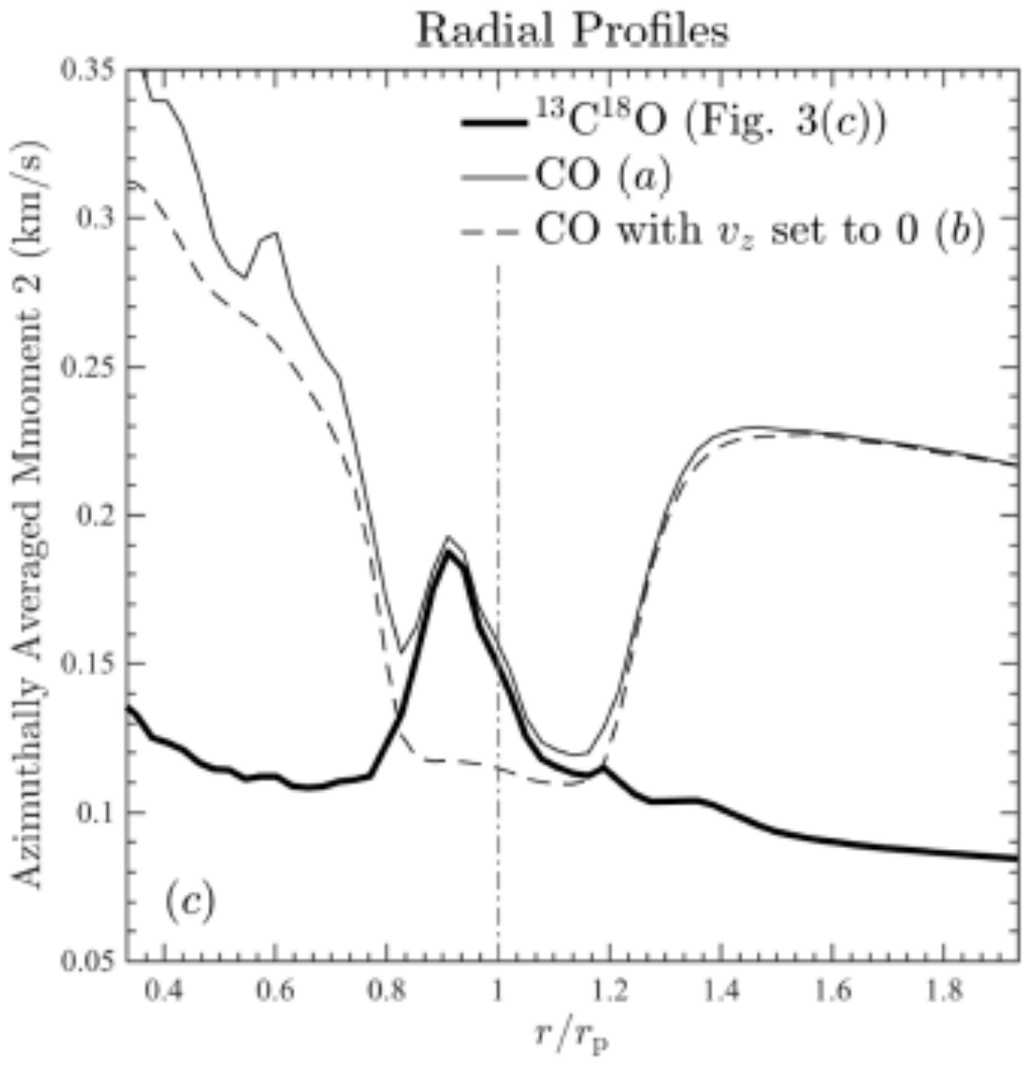
- **Kinematical** and **Line width** gaps coexist
- Line widths are azimuthally asymmetric, planet-related?

Izquierdo et al. subm.

Gas Substructure

Moment 2 map, ^{12}CO

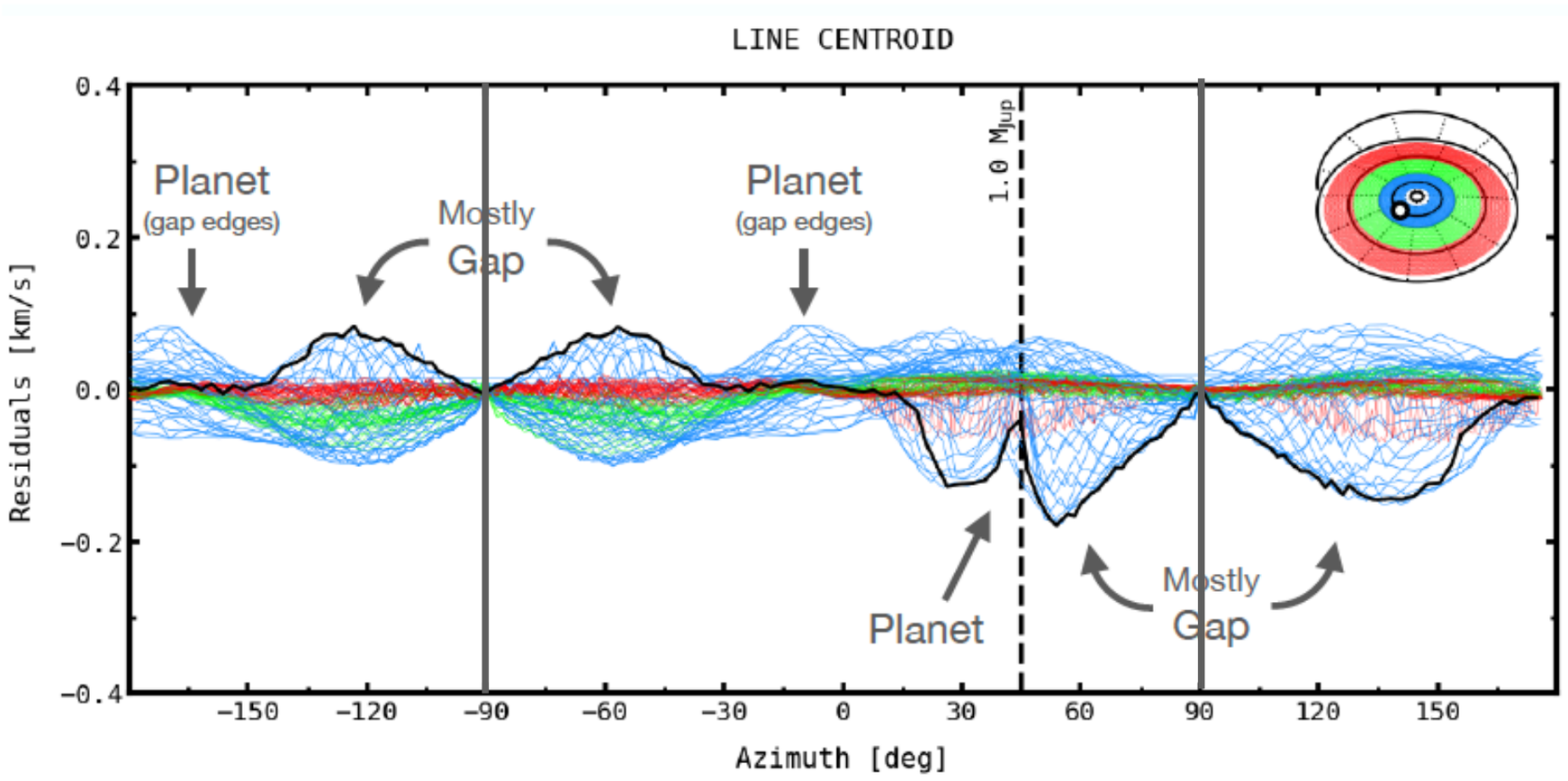


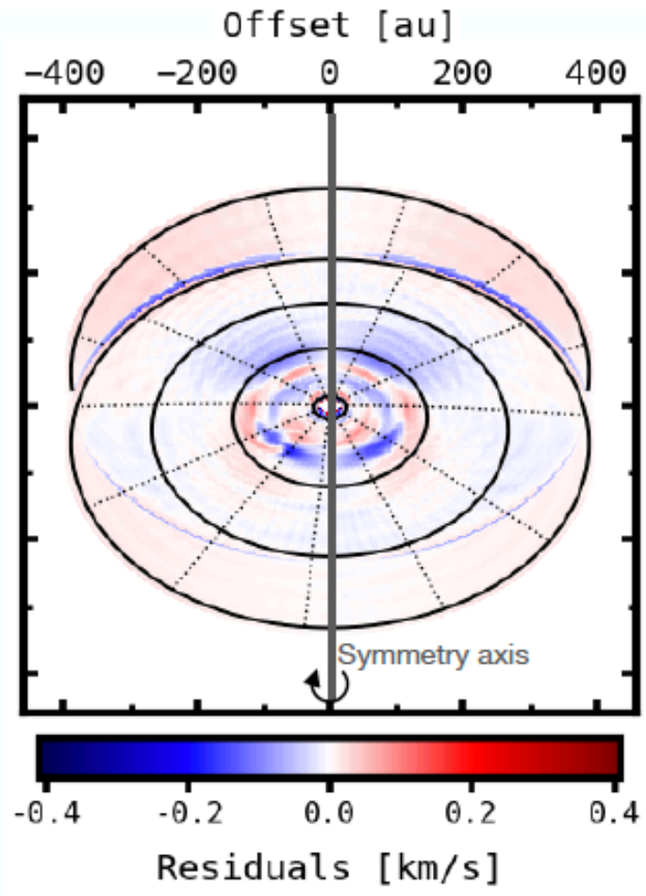


Adapted from Dong et al. 2019

Localised Perturbations

Fold centroid residuals

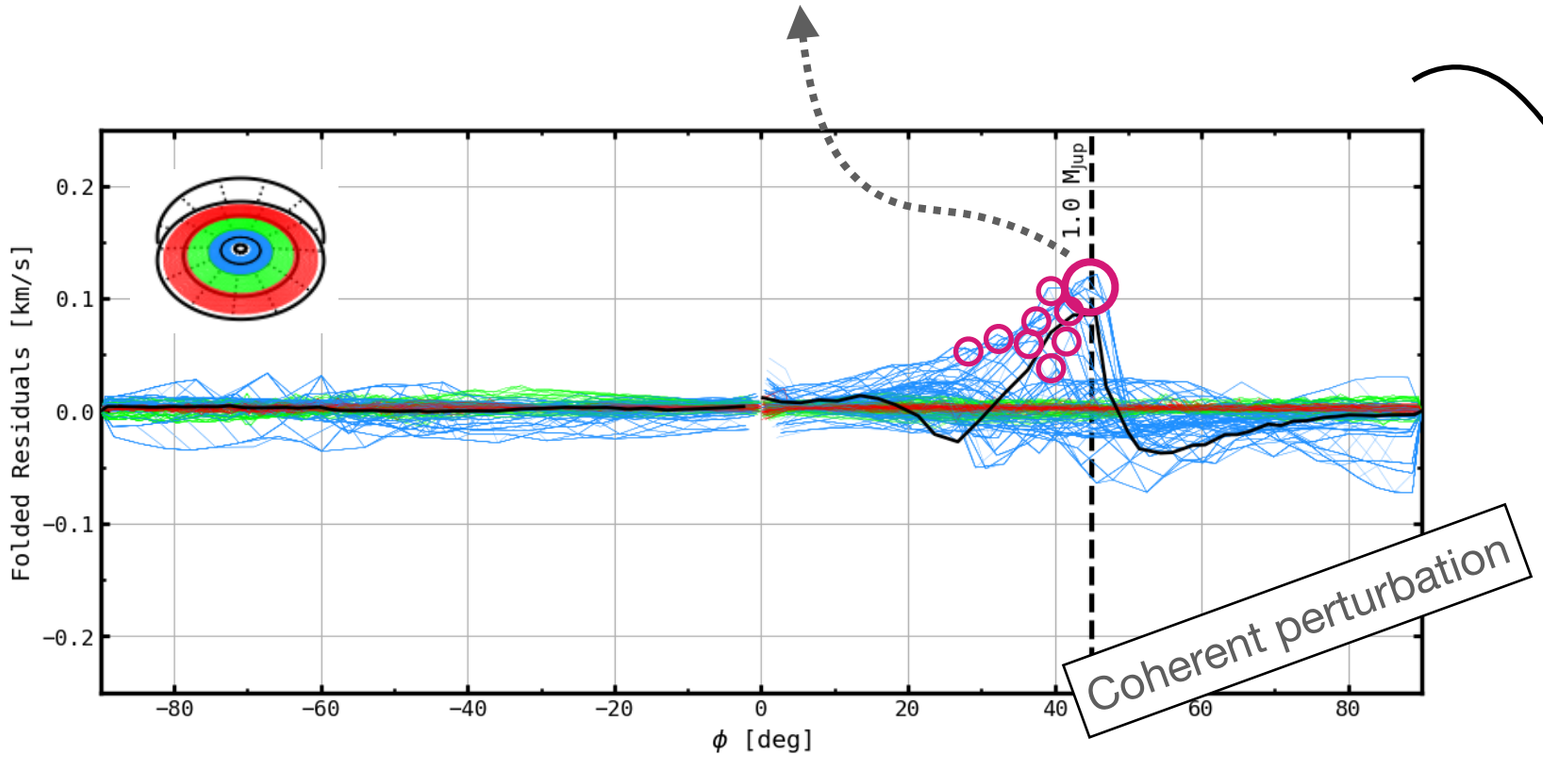


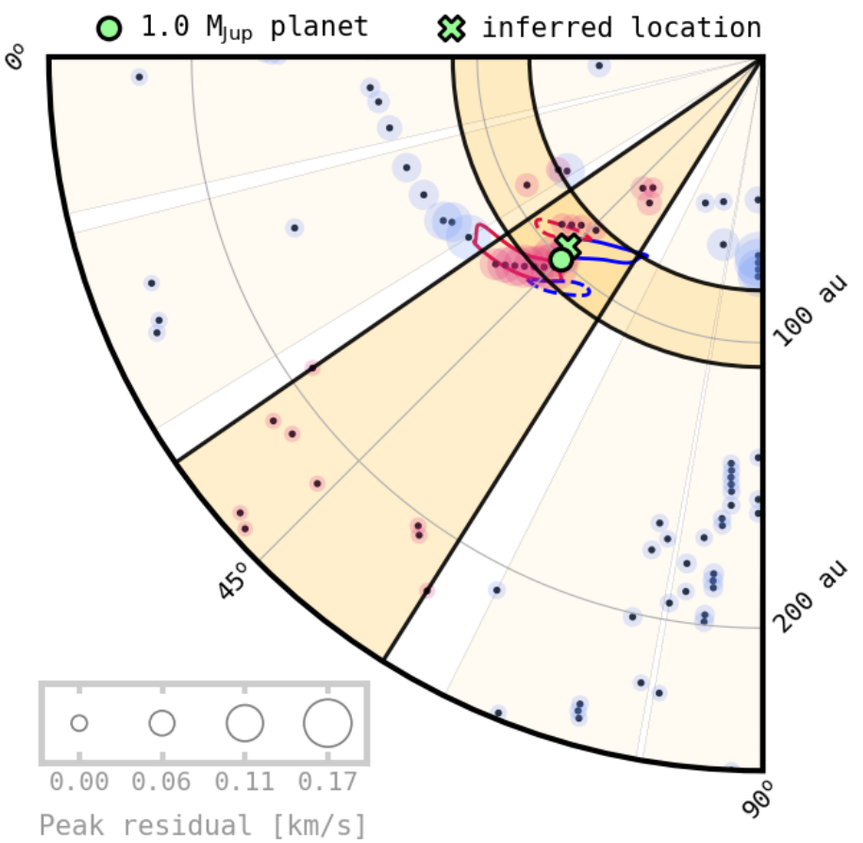


Izquierdo et al. 2021b

Localised Perturbations

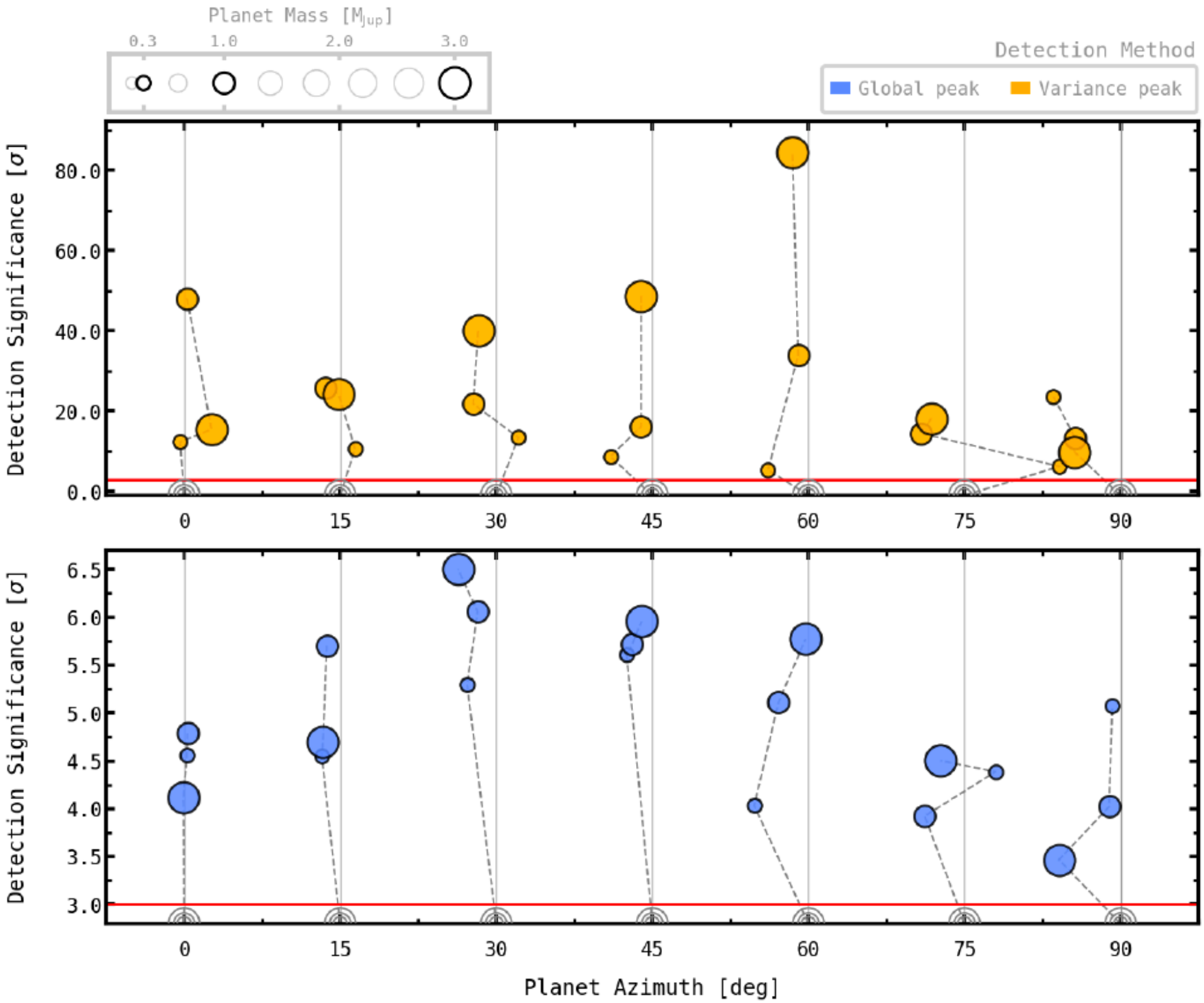
v_{max} is just a piece of the cake;
Many peak velocities around planet.





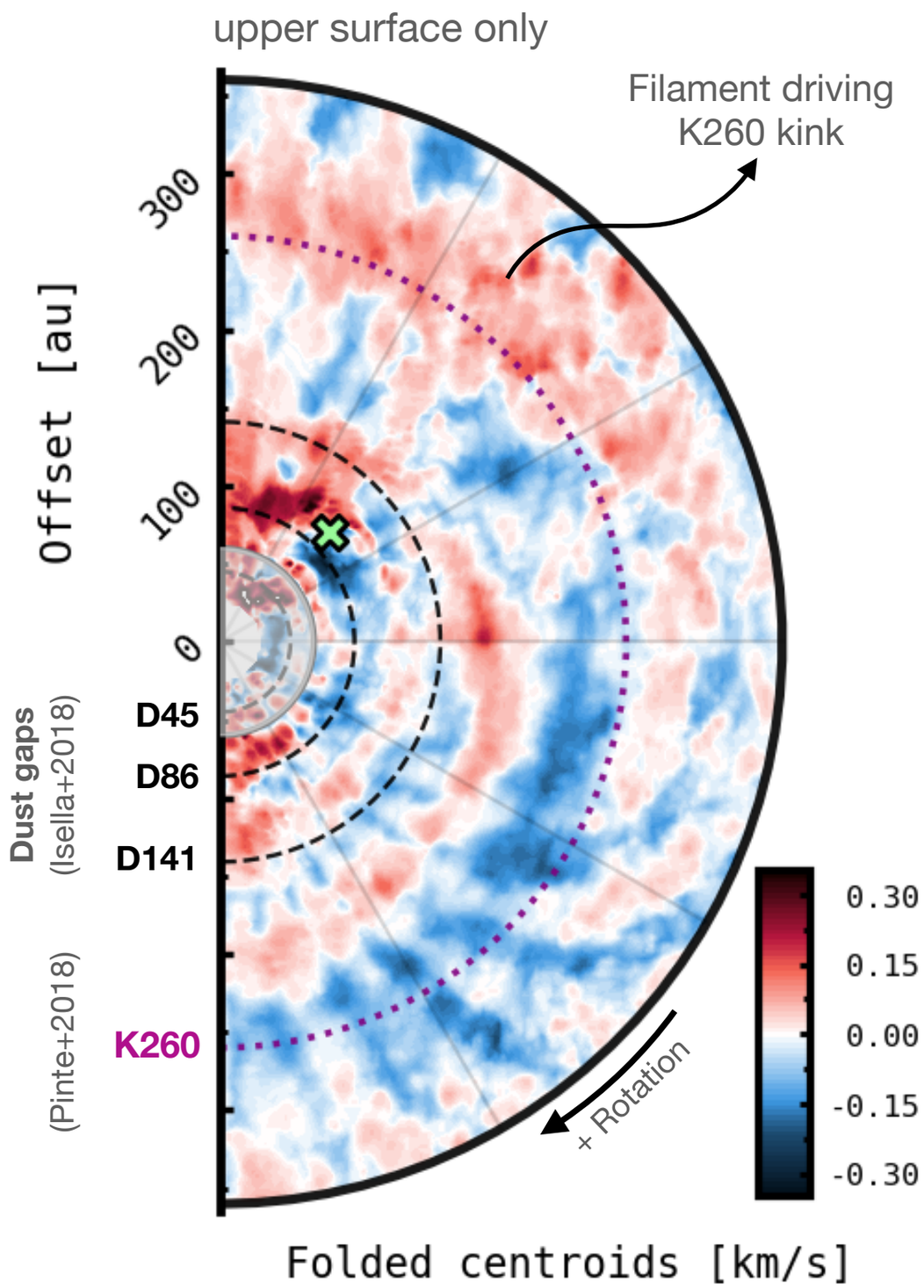
Izquierdo et al. 2021b

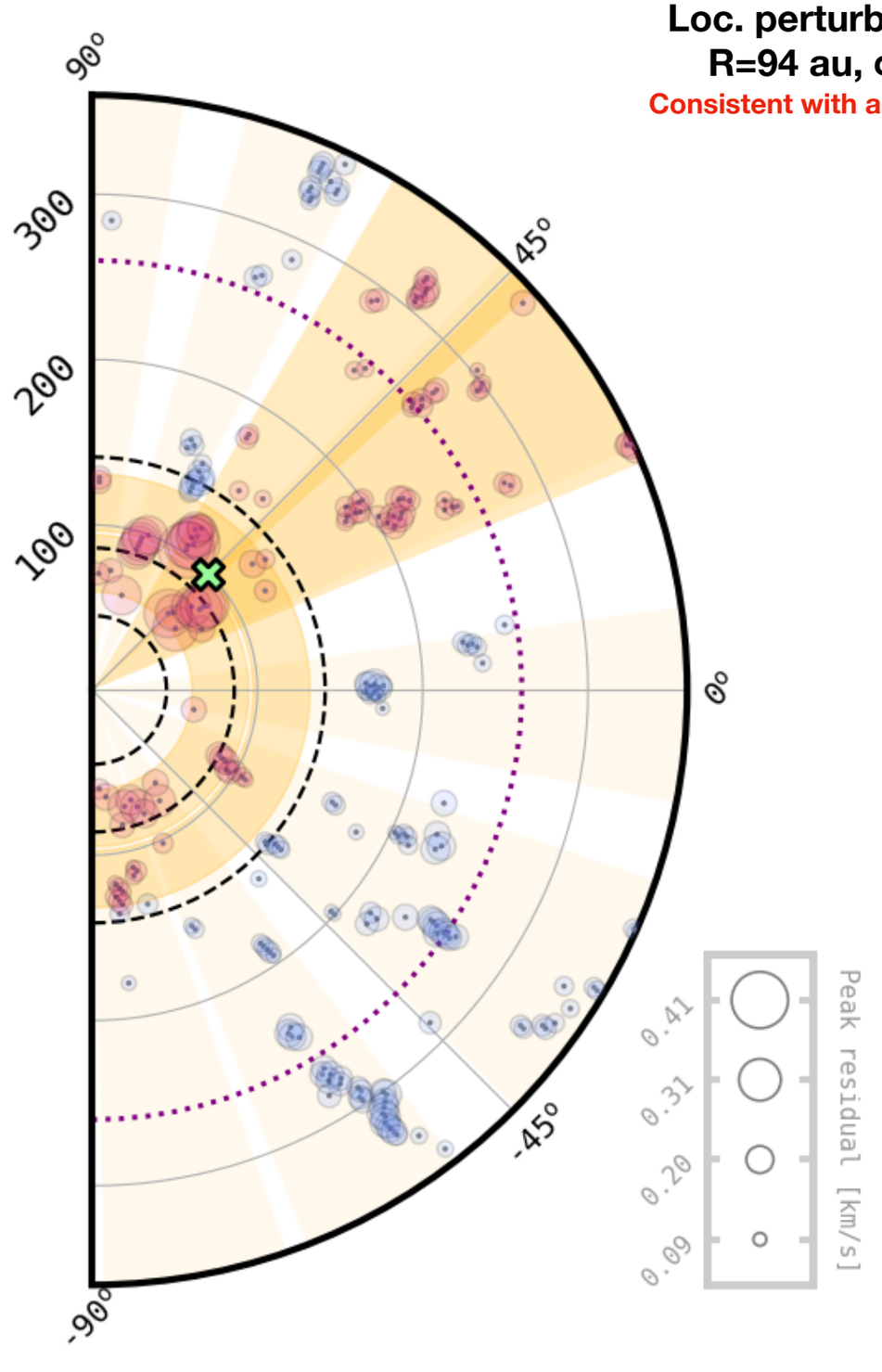
Significance



Izquierdo et al. 2021b

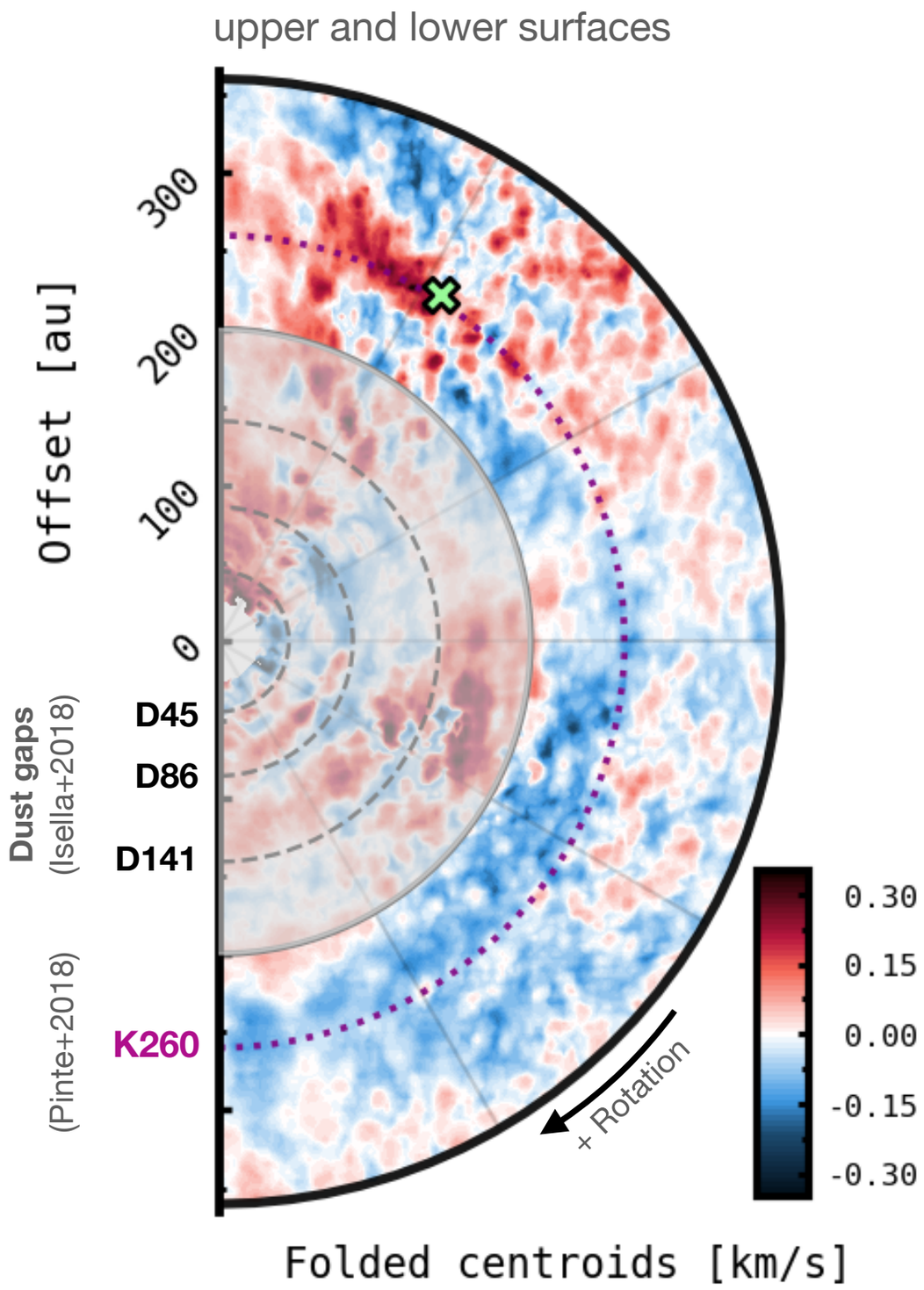
Localised Perturbations (HD163296)

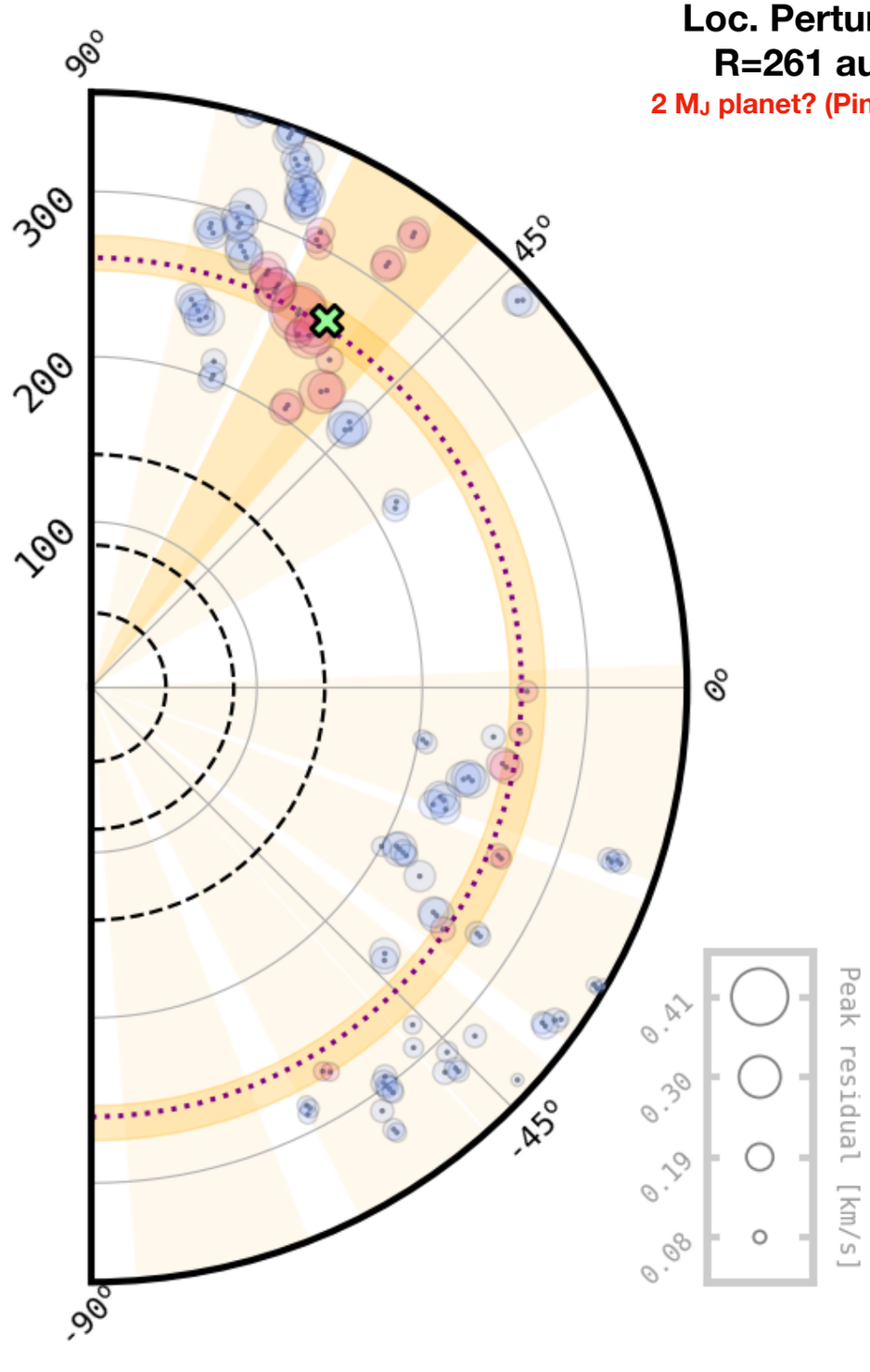




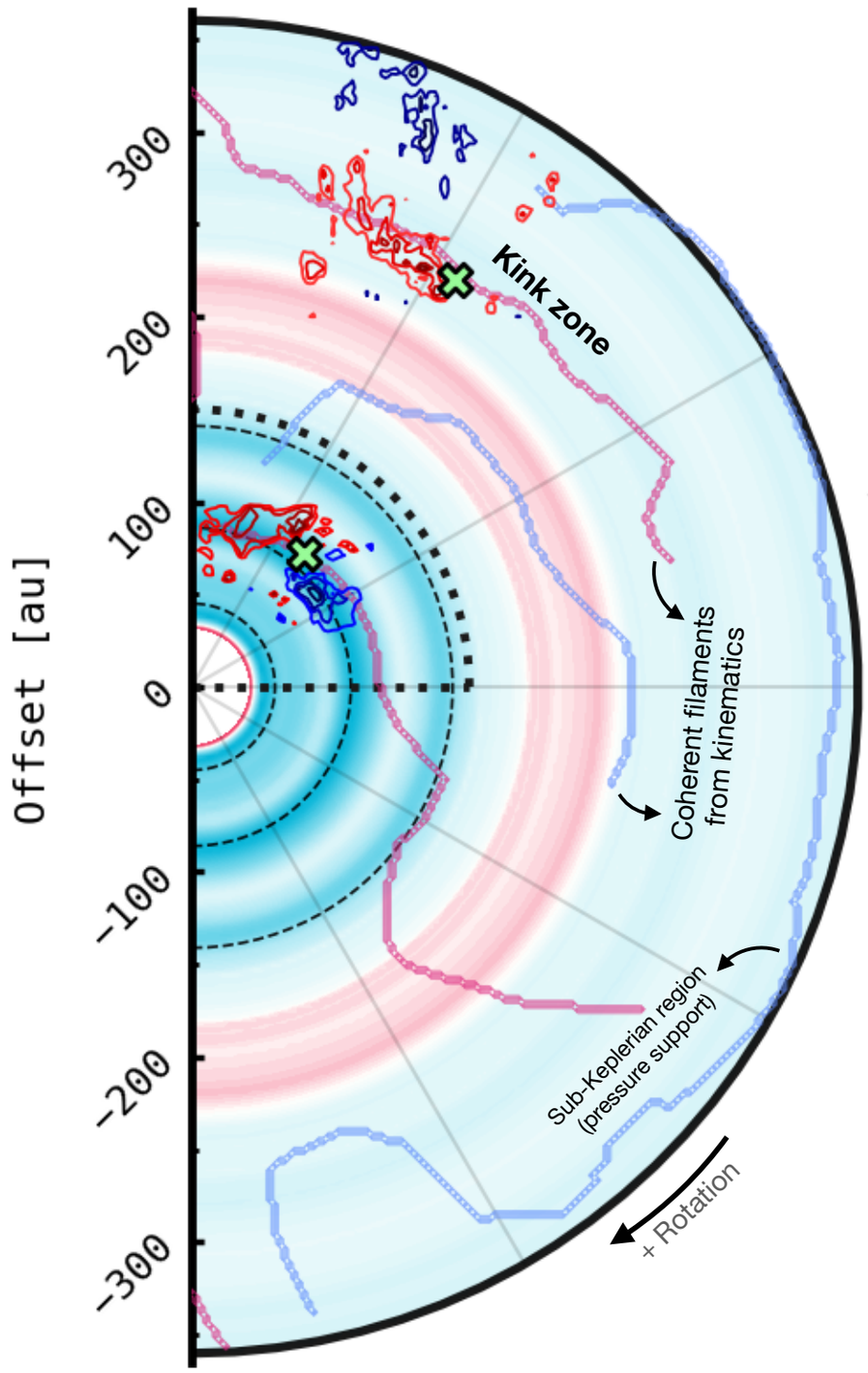
Izquierdo et al. subm.

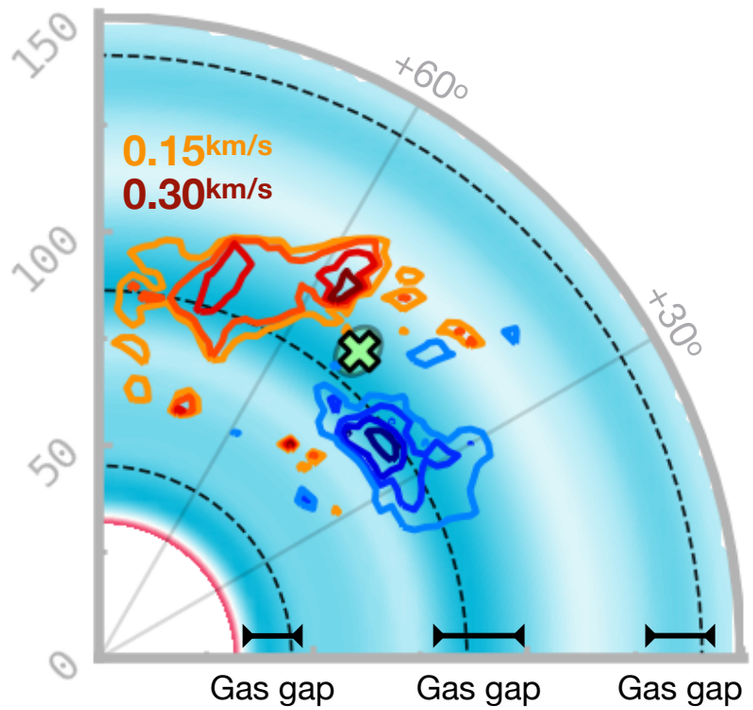
Localised Perturbations (HD163296)





SUMMARY (HD163296)

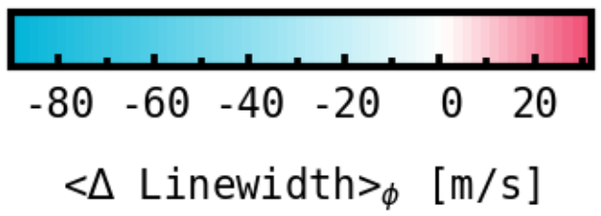




------ Dust gaps

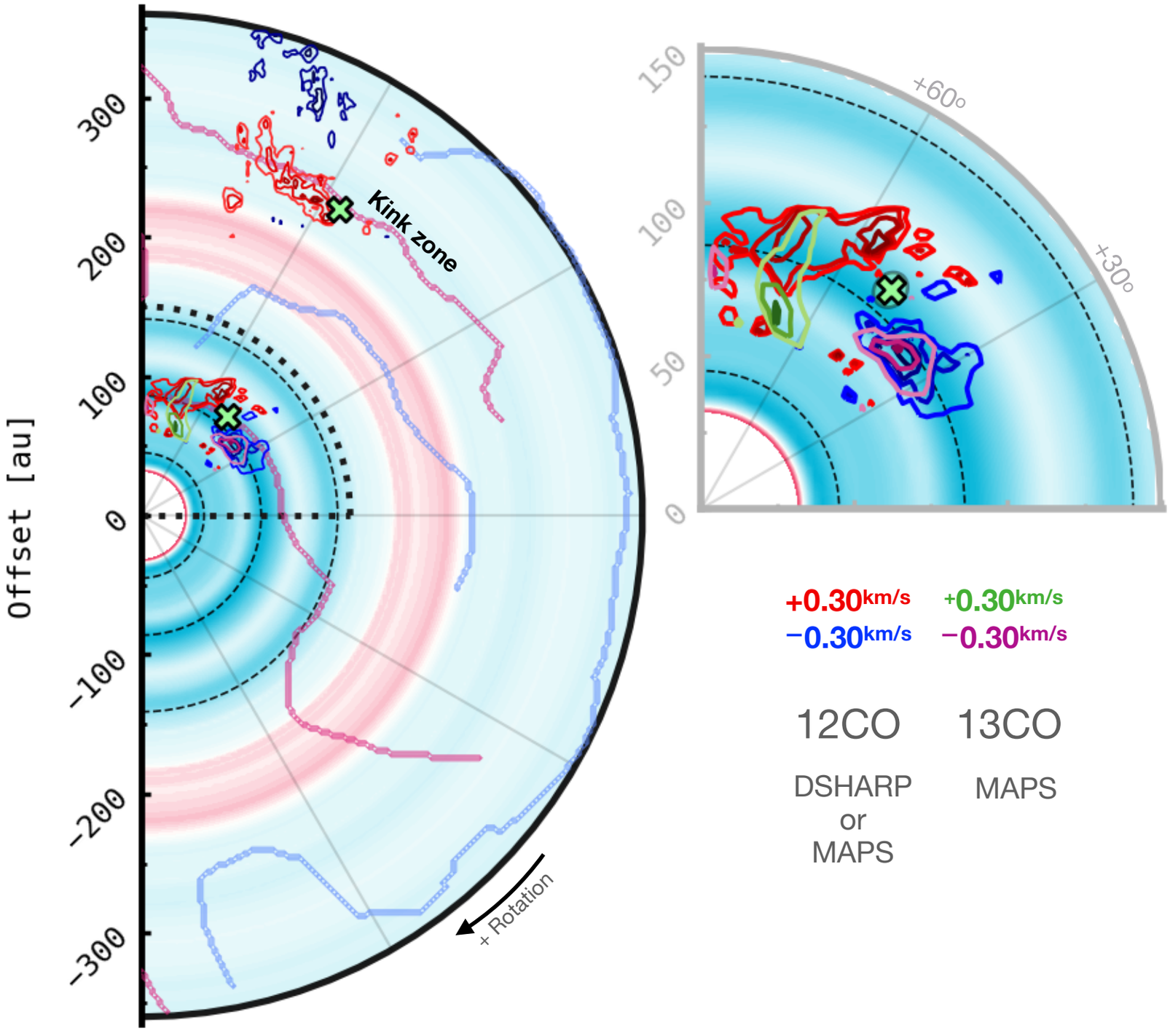
▪▪▪▪▪ Zoomed-in region

Inferred planets



Izquierdo et al. (subm.)

Summary + 13CO



Izquierdo et al. in prep.

Actual Summary

✓ Robust kinematical detection of planets. Discminer paper 1 (method), application to HD 163296 (subm.)

✓ Line width, temperature and velocity residuals (substructures - spirals, gaps).

✓ Vertical structure of discs, including lower surface analysis.

➡ Discminer paper 2, application to larger sample of discs (MAPS?), release code to public.

➡ Planet perturbations at different scale-heights, constrain planet mass? local viscosity?

➡ Line width and temperature gradients to measure turbulence.

➡ Use self-gravity prescription to estimate gas disc masses. (Paneque-Carreño, Lodato's group)

➡ Waoph6, Elias 2-27 (Paneque-Carreño); CQ Tau, V4046 Sgr (Wölfer)