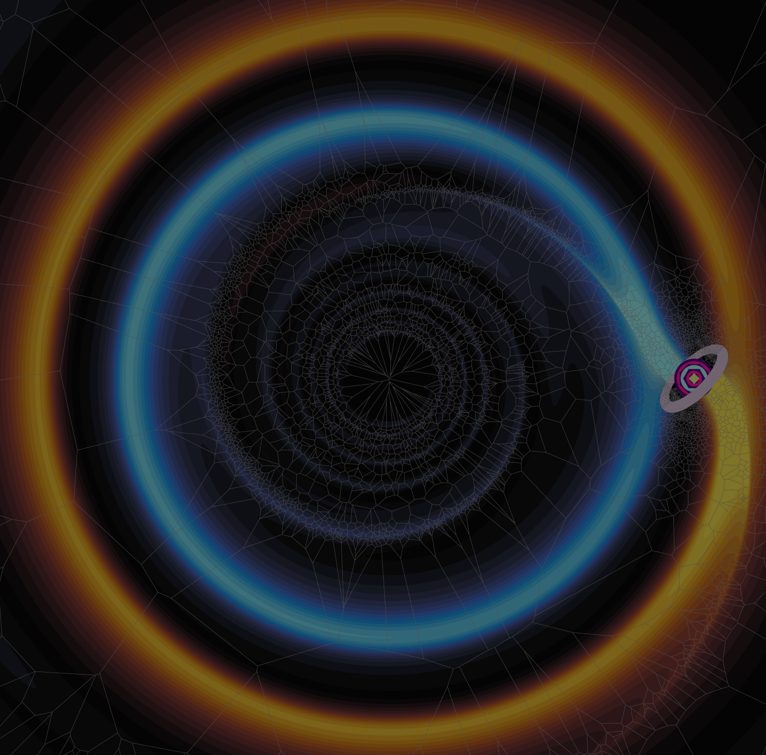
Mining the kinematics of discs to hunt for planets in formation: results from exoALMA



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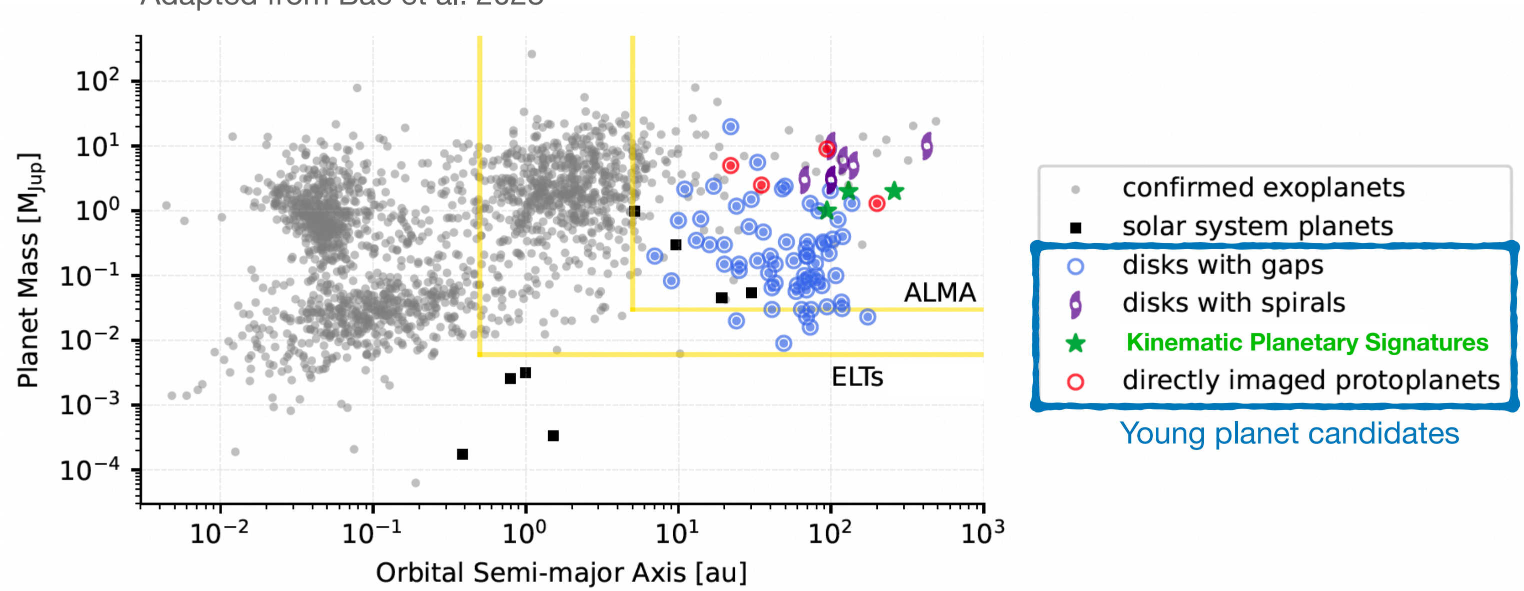
NHFP
NASA Hubble Fellowship Program

UF
UNIVERSITY of FLORIDA

NHFP Symposium — Sep 19 2024

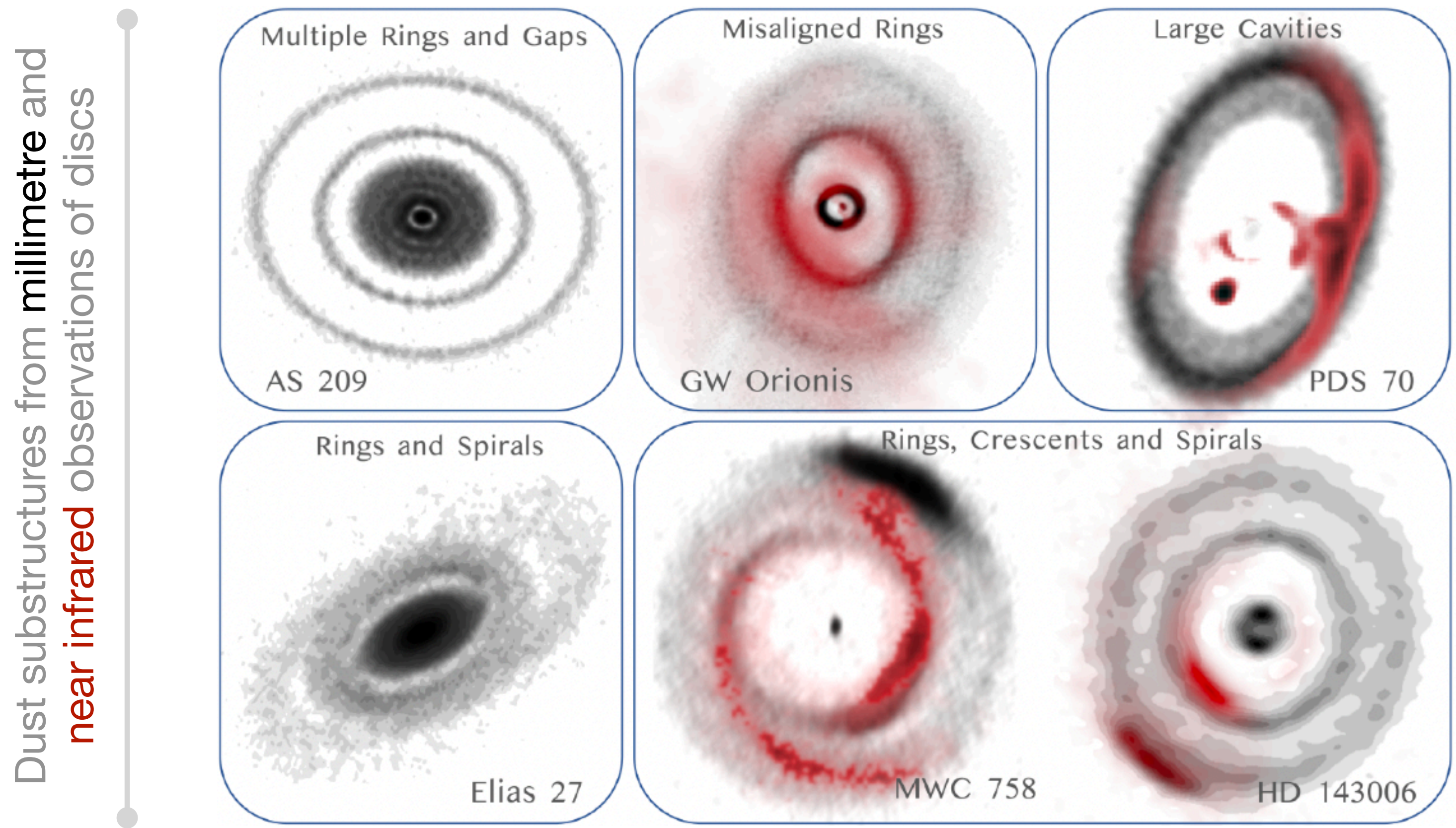
Distribution of mature and young exoplanets

Adapted from Bae et al. 2023



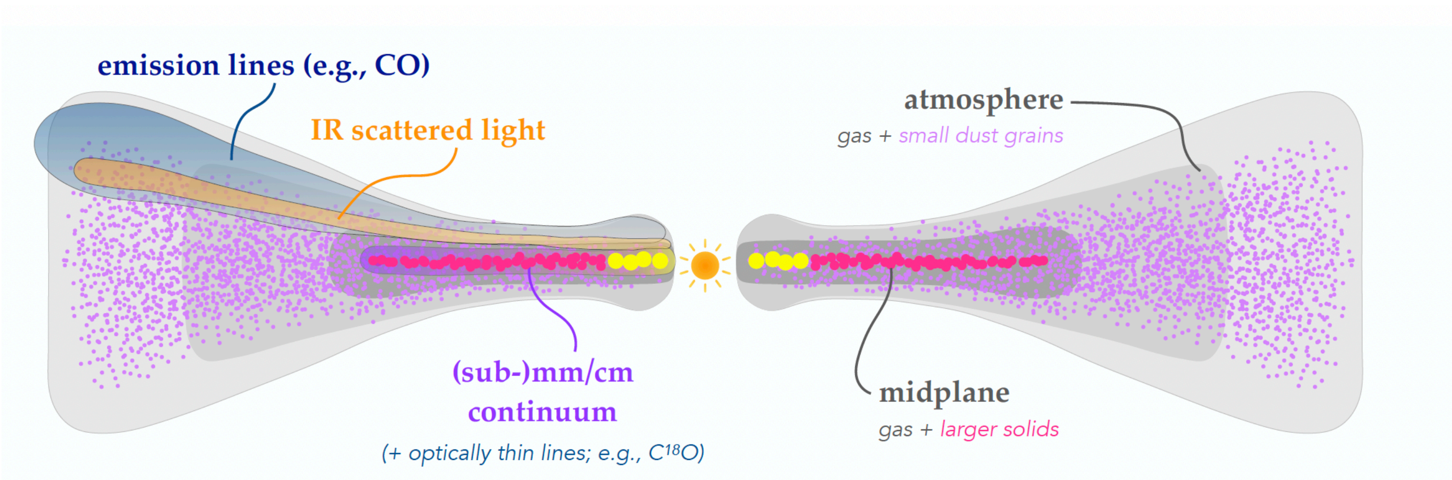
Young massive planets can significantly influence disc evolution and the diversity of fully formed exoplanets

Dust substructures can be indicative of planet presence, but not always…

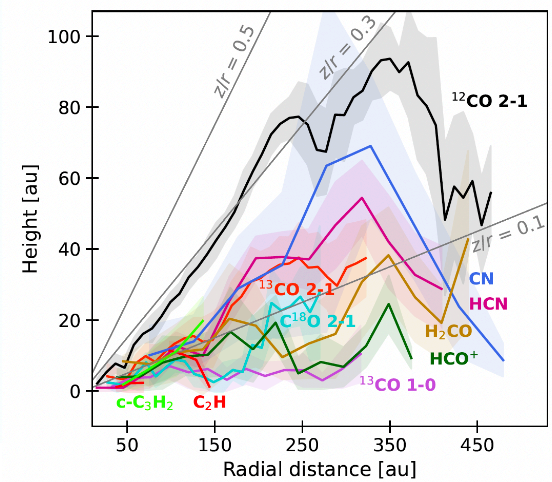


Adapted from Bae et al. 2023

Luckily, we also have access to the gas disc through molecular line emission

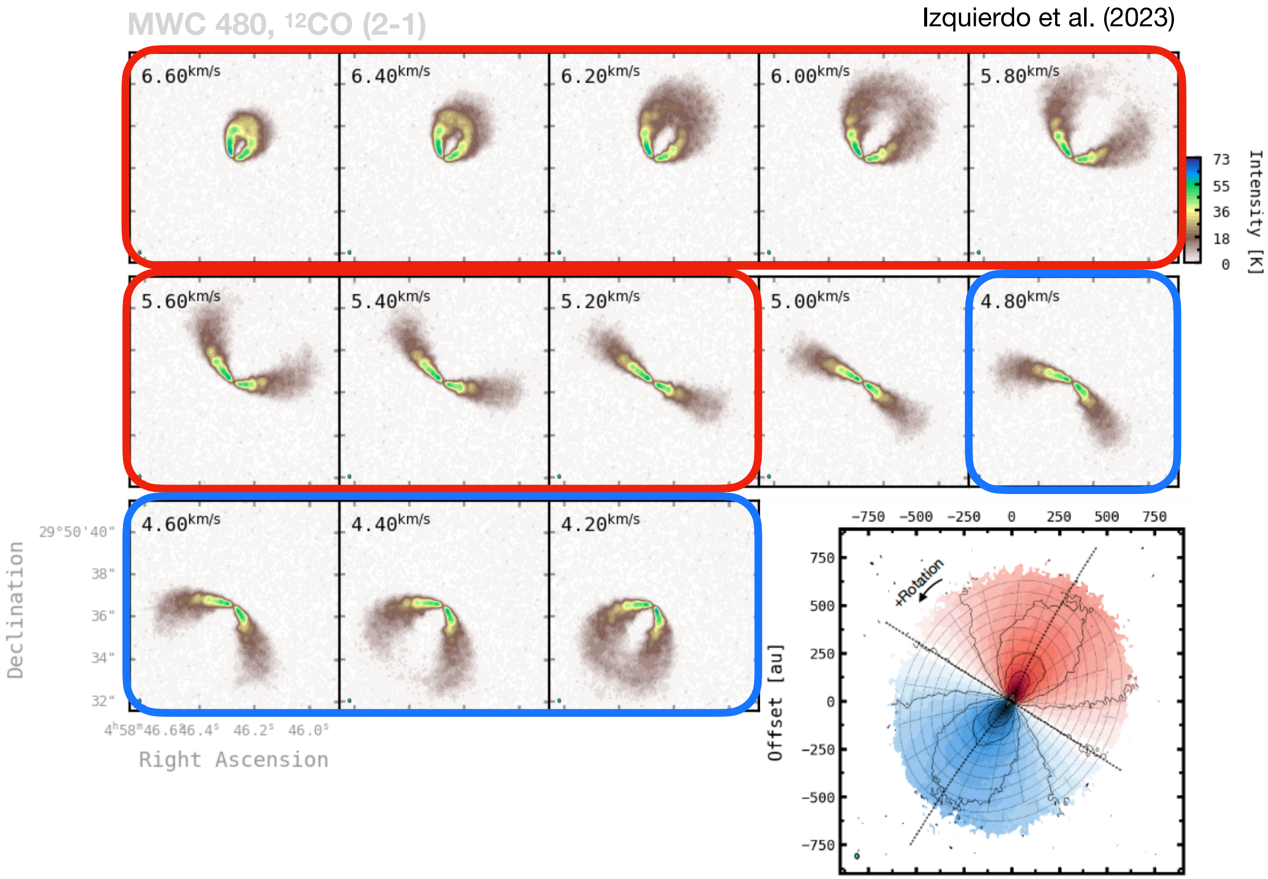


Andrews (2020)



Paneque-Carreño (2023)

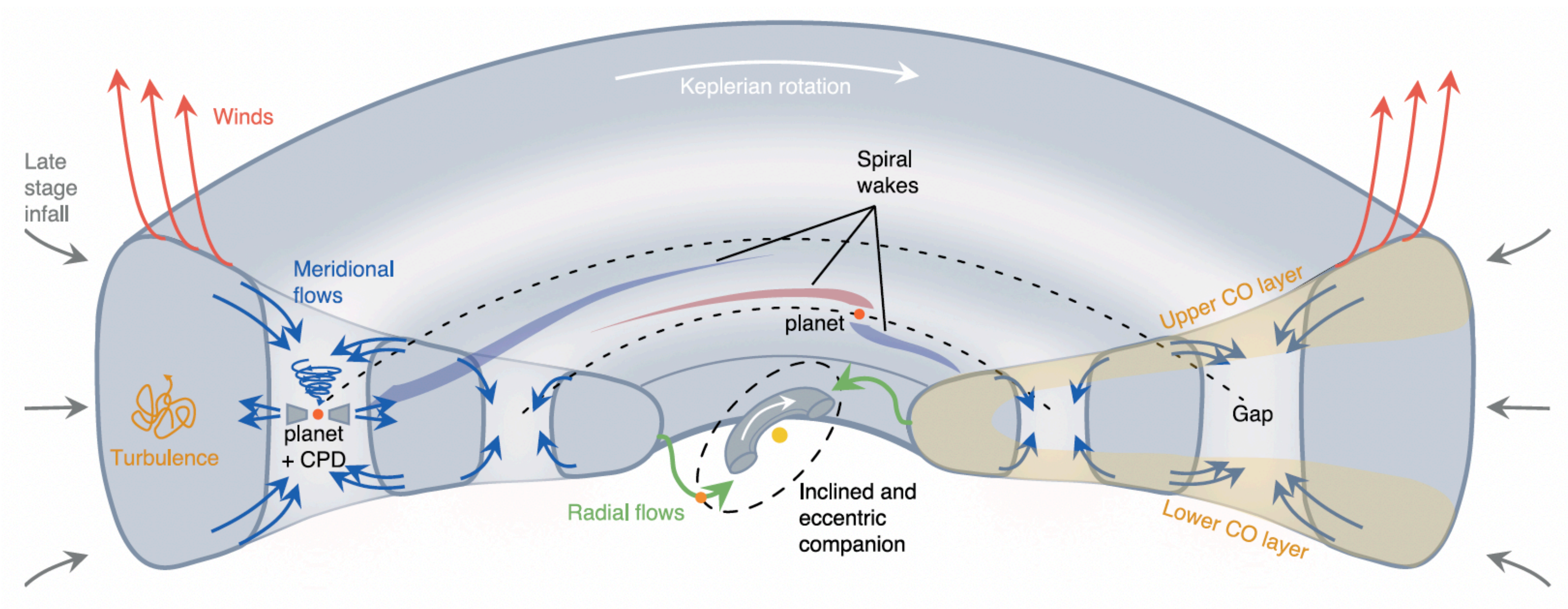
Molecular line emission responds to the disc dynamical structure too



Data from ALMA large program MAPS (Öberg et al. 2021)

Planet-disc interaction results in characteristic kinematic features…

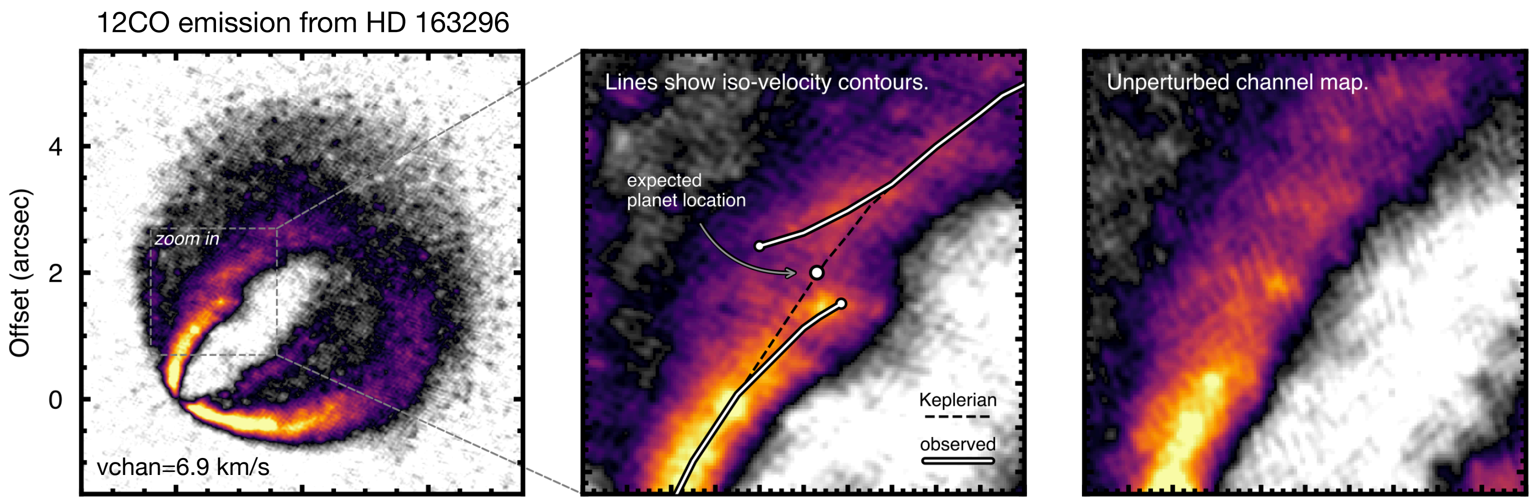
- Azimuthal and meridional flows
- Localised velocity perturbations and spirals
- Increased velocity dispersion

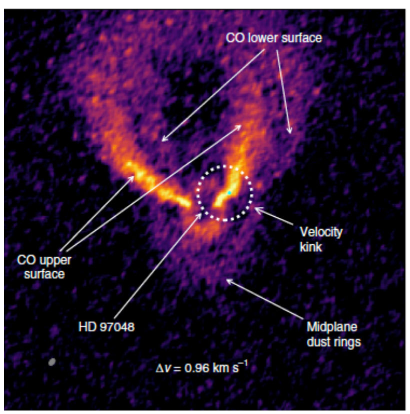


Credits: Pinte et al. (2023 PPVII)

…observable through molecular line emission

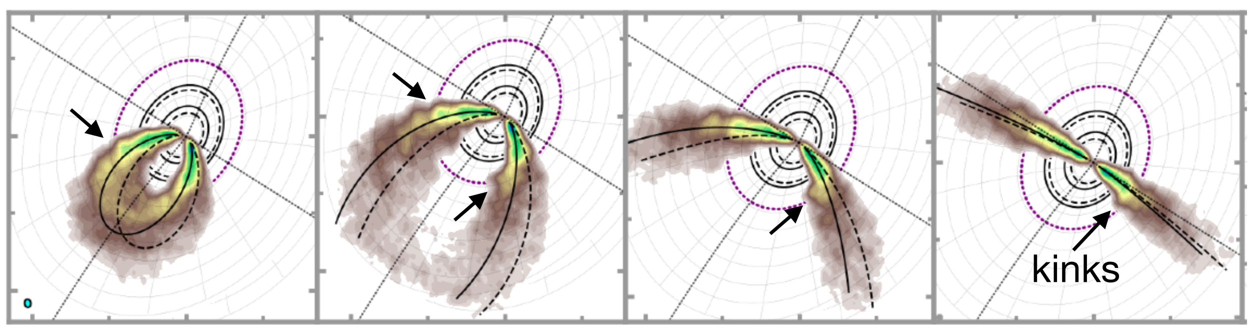
What sets the amplitude of the kinks?





HD 97048

MWC 480



Pinte et al. (2018-2020), DDC. (2020), Teague et al. (2021, 2022), Izquierdo et al. (2022, 2023)

exoALMA

First Results

Myriam Benisty, Stefano Facchini, Misato Fukagawa, Christophe Pinte, Richard Teague

Andrés Izquierdo, Andrew Winter, Cass Hall, Marcelo Barraza- Alfaro, Brianna Zawadzki, Gianni Cataldi, Caitlyn Hardiman, Cristiano Longarini, Daniel Price, Daniele Fasano, David Wildner, Mario Flock, Francois Menard, Gaylor Menard, Geoffroy Lesur, Giovanni Rosotti, Giuseppe Lodato, Himanshi Garg, Hsi-Wi Yen, Iain Hammond, Ian Czekala, Andrea Isella, John Ilee, Jason Terry, Jaehan Bae, Jane Huang, Joe Stadler, Jun Hashimoto, Kazu Kanagawa, Leonardo Testi, Lisa Wölfer, Maria Galloway-Sprietsma, Munetake Momose, Nicolas Cuello, Pietro Curone, Ryan Loomis, Rita Orya, Sean Andrews, Takashi Tsukagoshi, Tom Hilder, Tomohiro Yoshida, Valentin Christiaens, Bill Dent

exoALMA was designed to understand the ubiquity of velocity perturbations

- Planet hunting
- Dynamical structure of discs
- Physical structure of discs

exoALMA collaboration

exoALMA was designed to understand the ubiquity of velocity perturbations

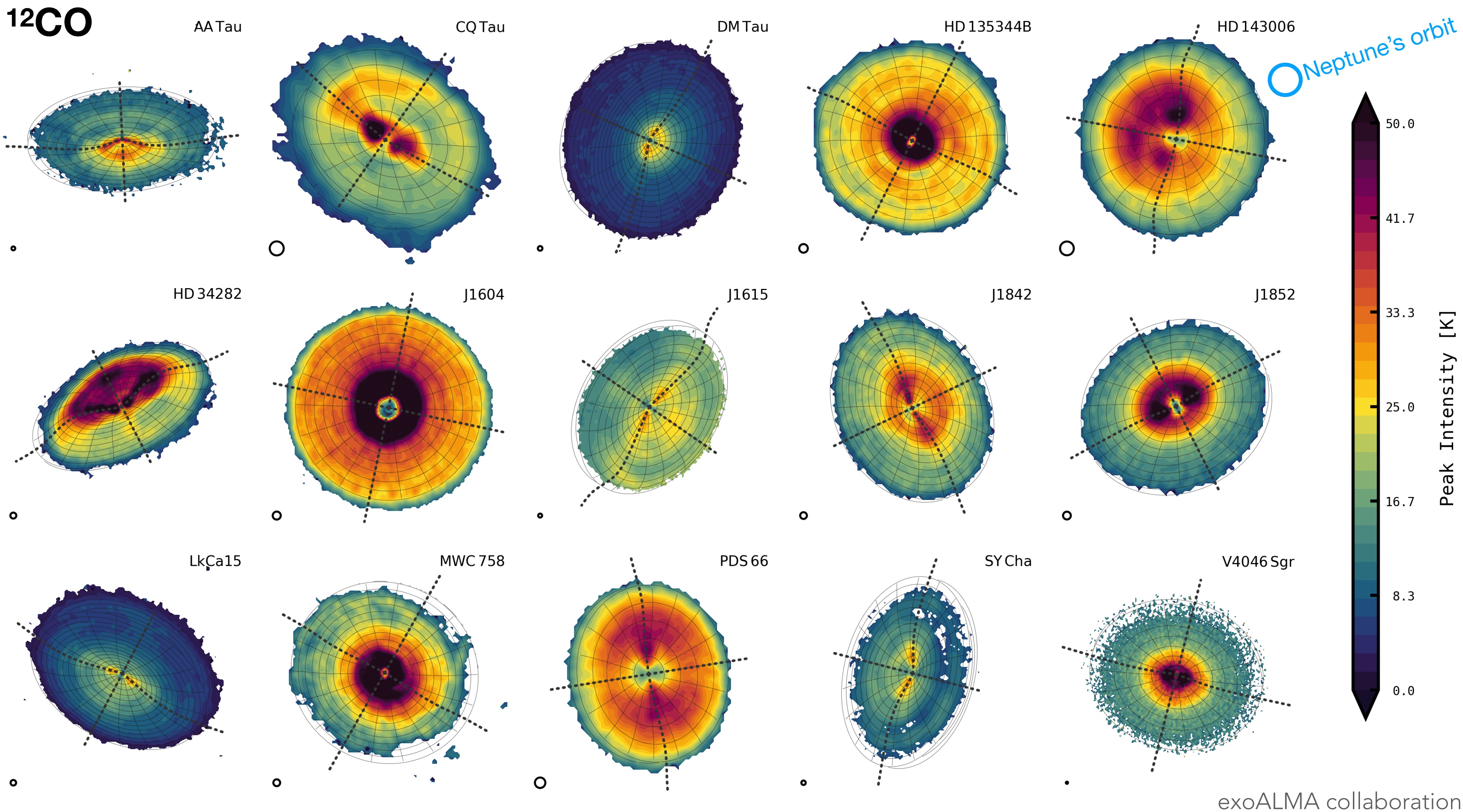
15 sources (the biggest and brightest)

3 lines (^{12}CO, ^{13}CO and CS)

180+ hours (12m and 7m arrays)

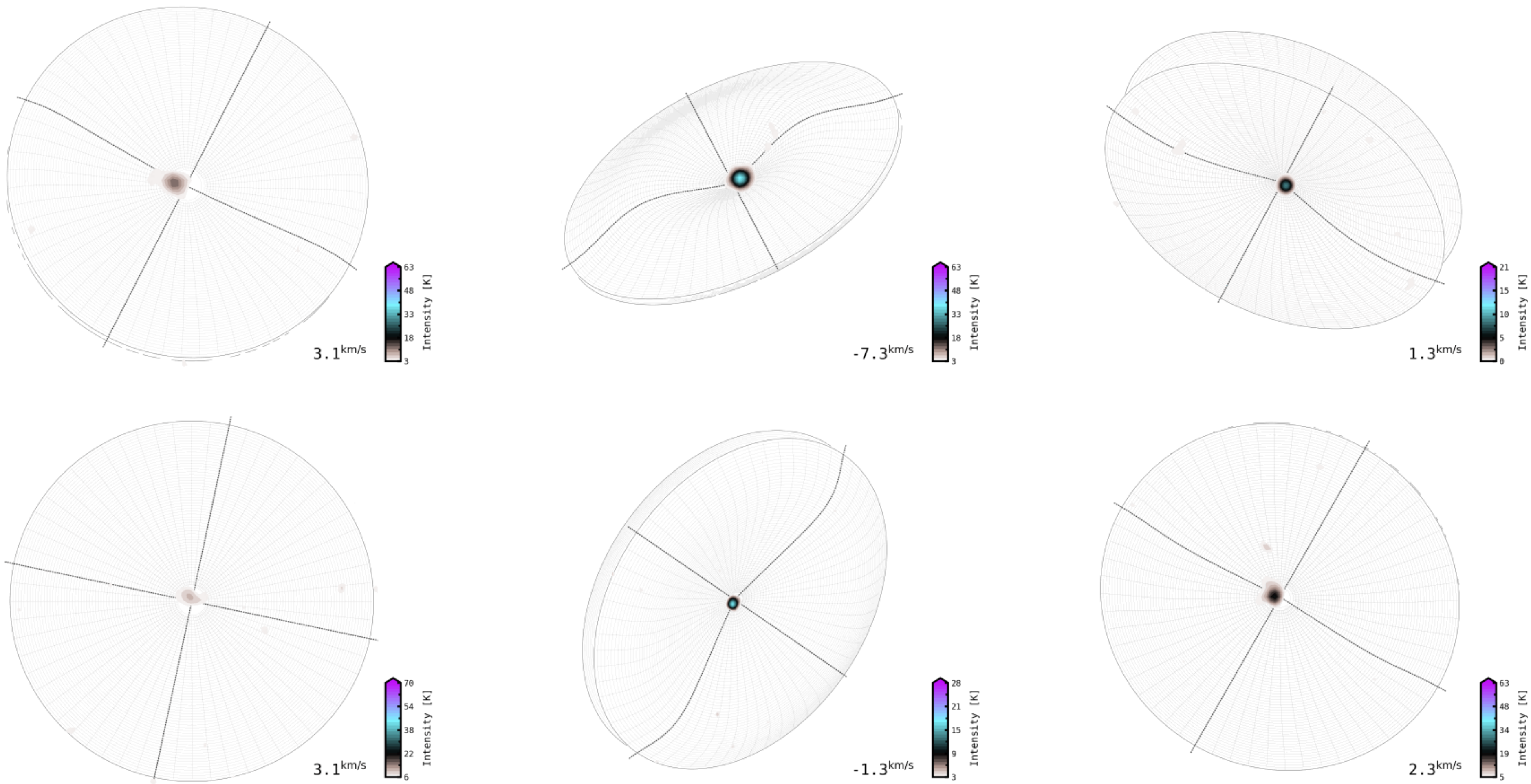
Imaging and calibration built on DSHARP and MAPS approaches

Andrews et al. (2018), Öberg et al. (2021), Leeroy et al. (2021), Teague et al. (exoALMA I), Loomis et al. (exoALMA II)



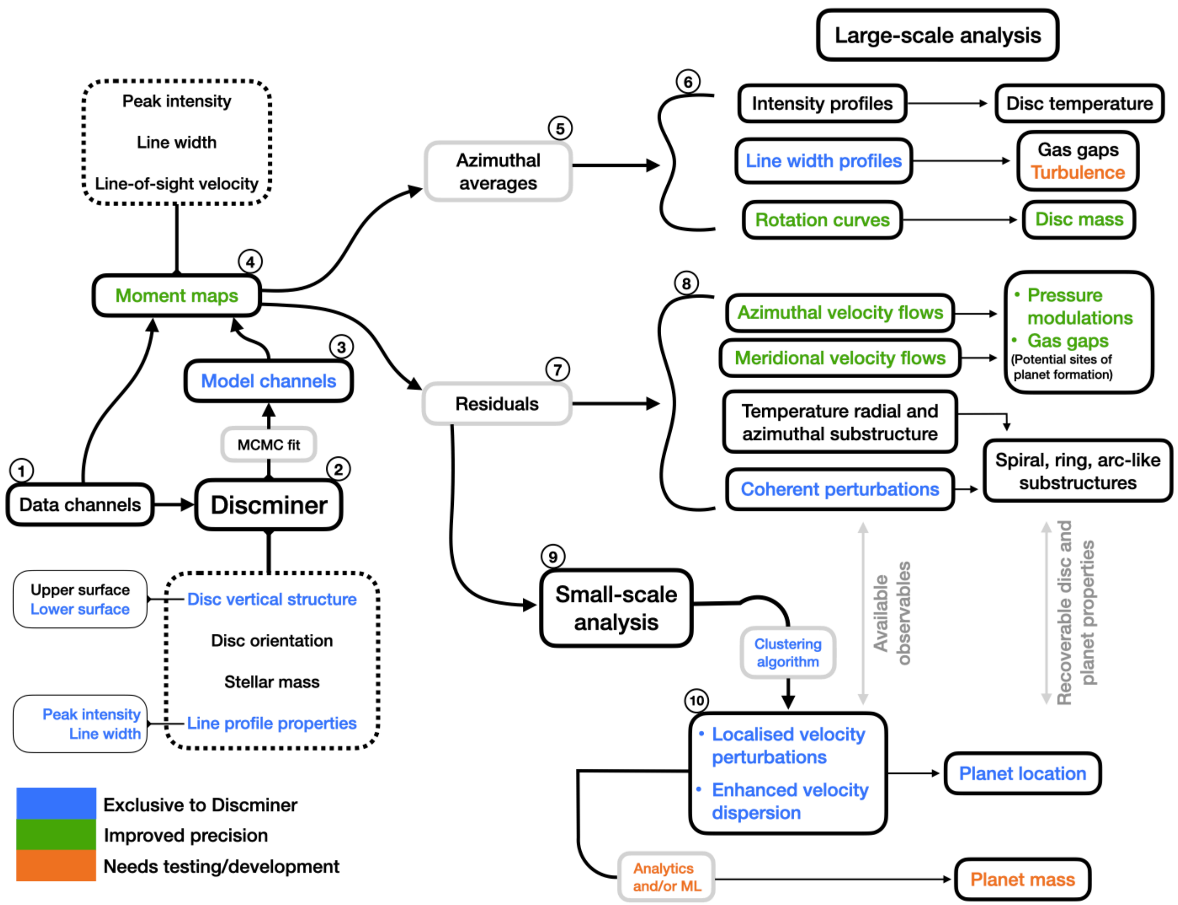
12CO
AA Tau
CQ Tau
DM Tau
HD 135344B
HD 143006
Neptune's orbit
HD 34282
J1604
J1615
J1842
J1852
LkCa15
MWC 758
PDS 66
SY Cha
V4046 Sgr
50.0
41.7
33.3
25.0
16.7
8.3
0.0
Peak Intensity [K]
exoALMA collaboration

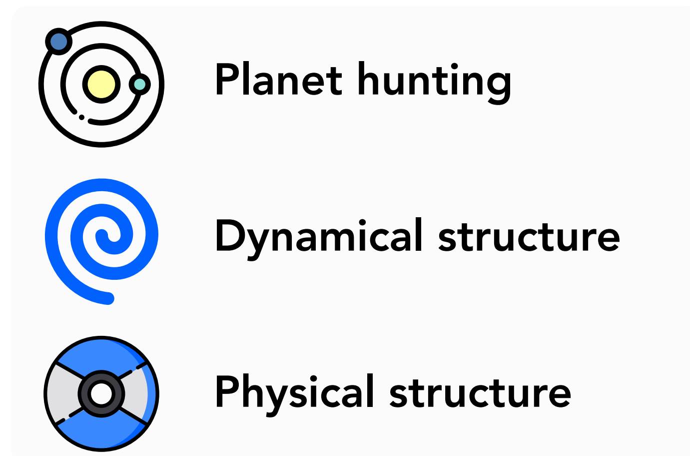
Kinks are common across exoALMA targets



exoALMA collaboration

DISCMINER enables a uniform 3D (de-)composition of the data



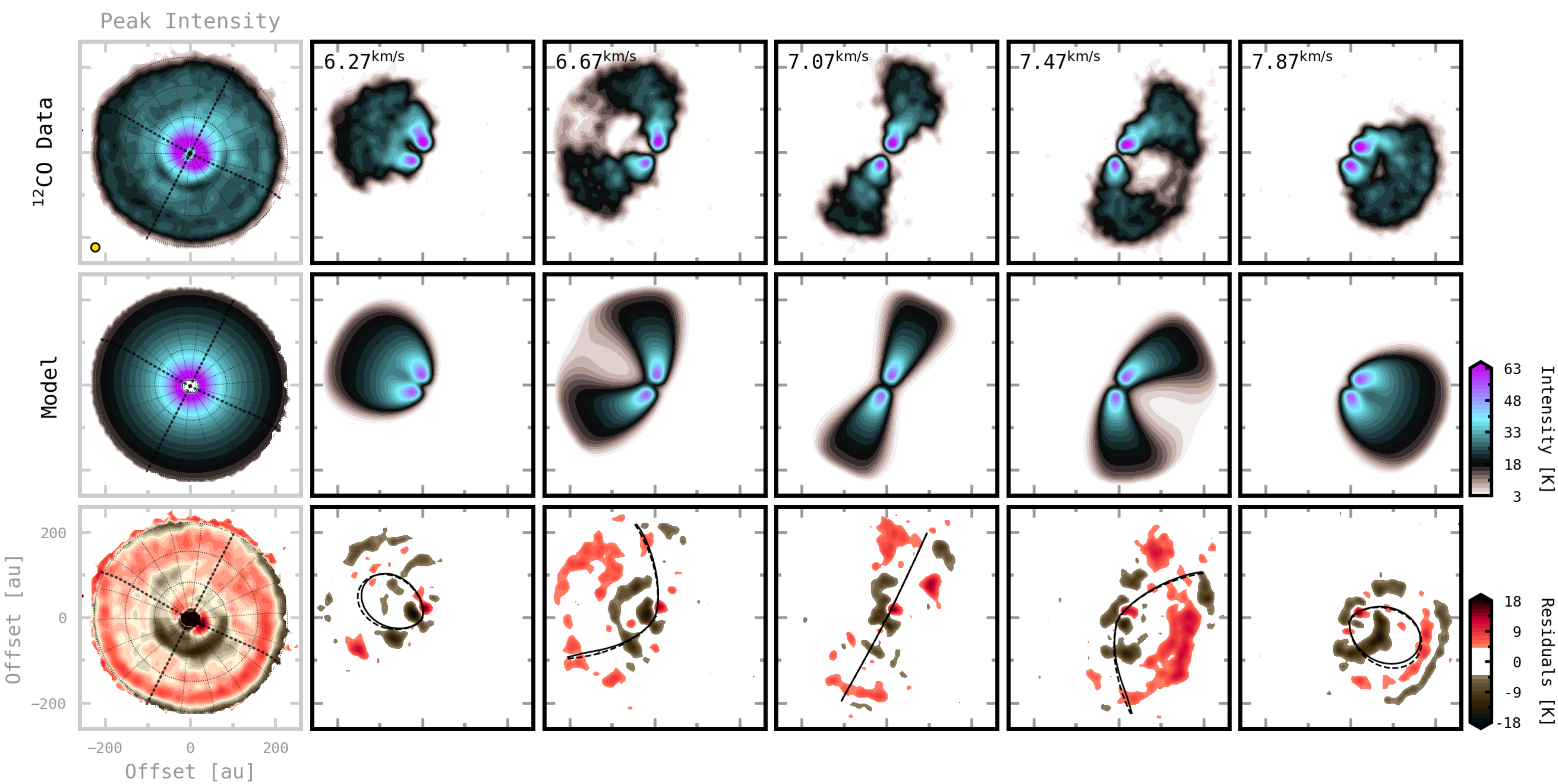


exoalma.com/software for the full array of software developed and used by exoALMA

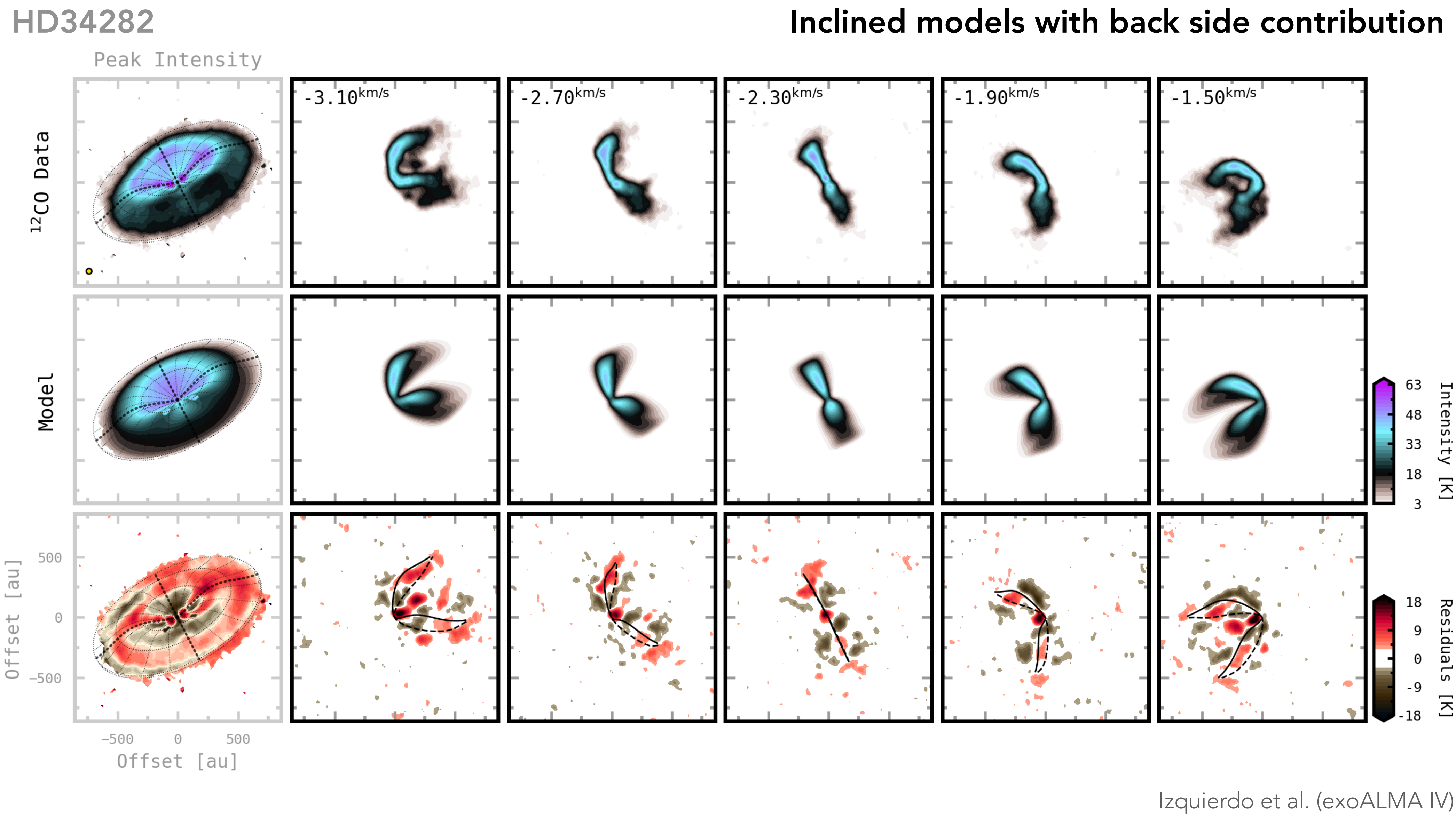
Izquierdo et al. (exoALMA IV)

HD135344B

Face-on models

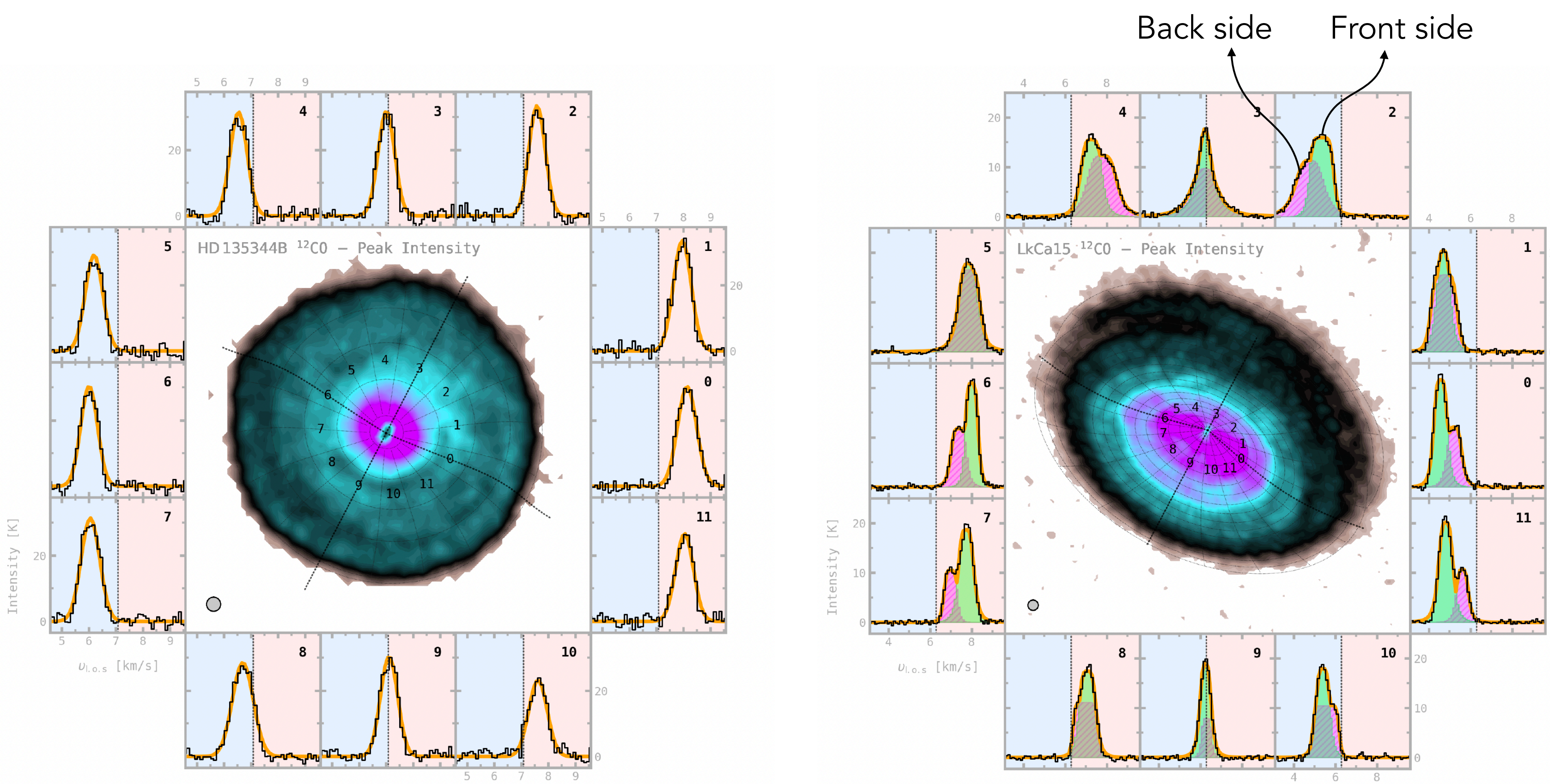


Izquierdo et al. (exoALMA IV)



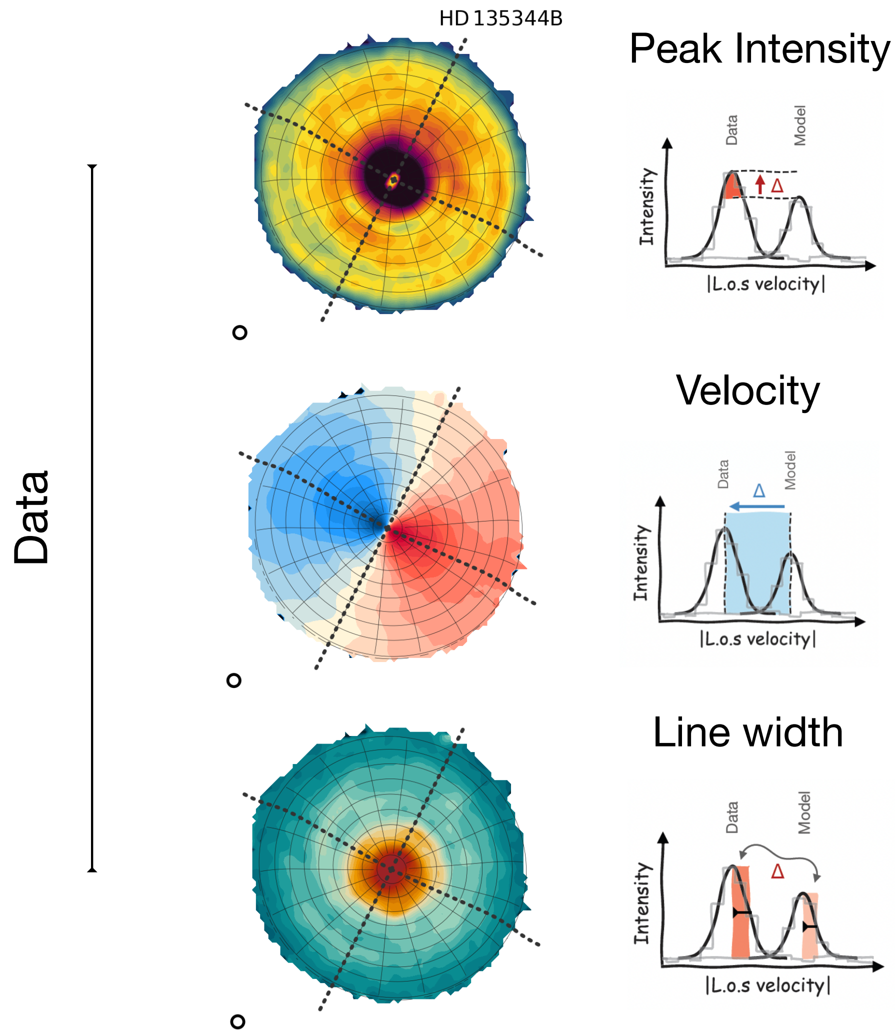
HD34282
Inclined models with back side contribution
Peak Intensity
^{12}CO Data
Model
-3.10km/s
-2.70km/s
-2.30km/s
-1.90km/s
-1.50km/s
Intensity [K]
63
48
33
18
3
Residuals [K]
18
9
0
-9
-18
Offset [au]
500
0
−500
Offset [au]
−500
0
500
Izquierdo et al. (exoALMA IV)

Dynamical and physical structure are encoded in molecular line properties



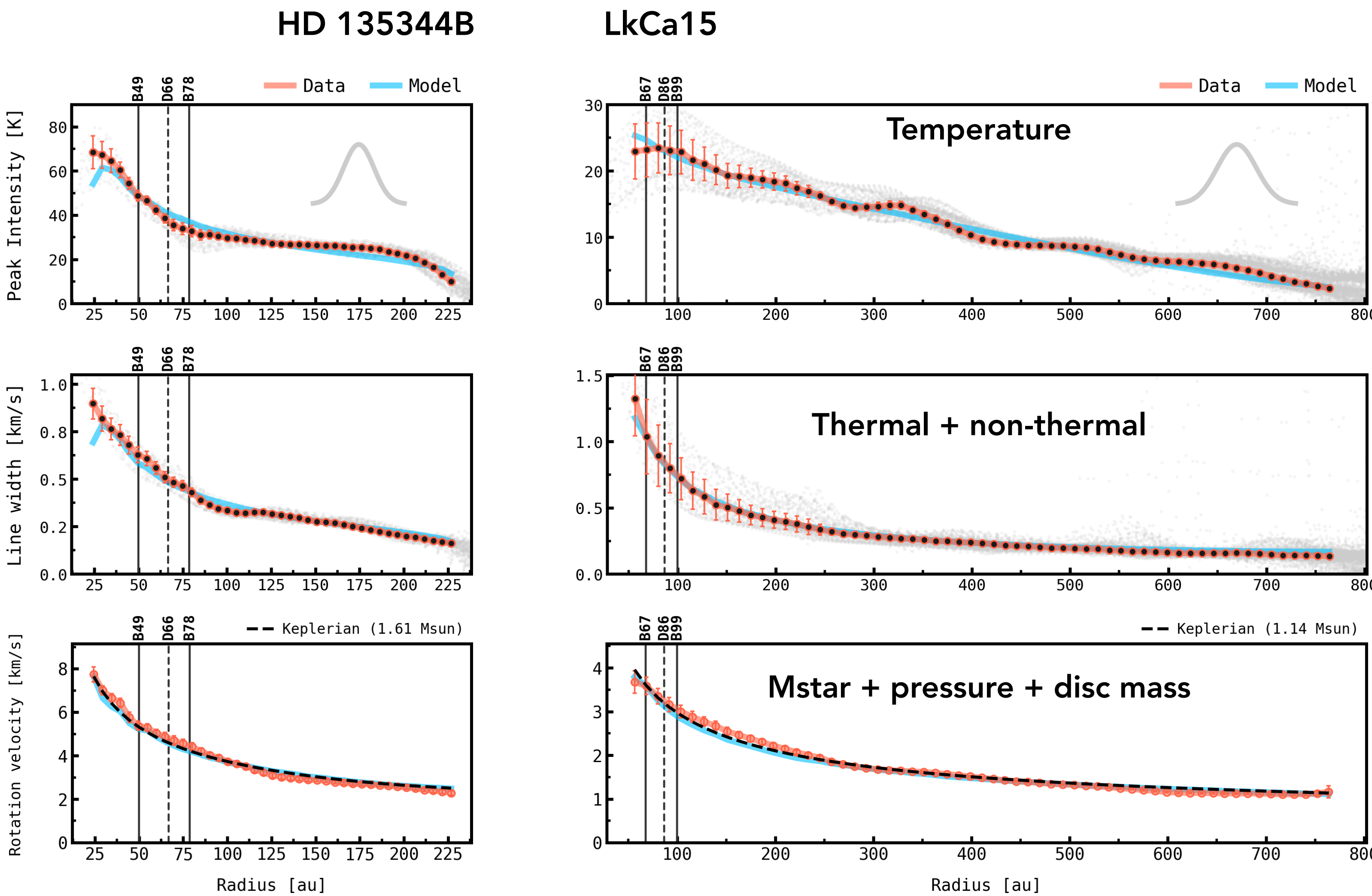
Izquierdo et al. (exoALMA IV)

Extraction of line profile properties



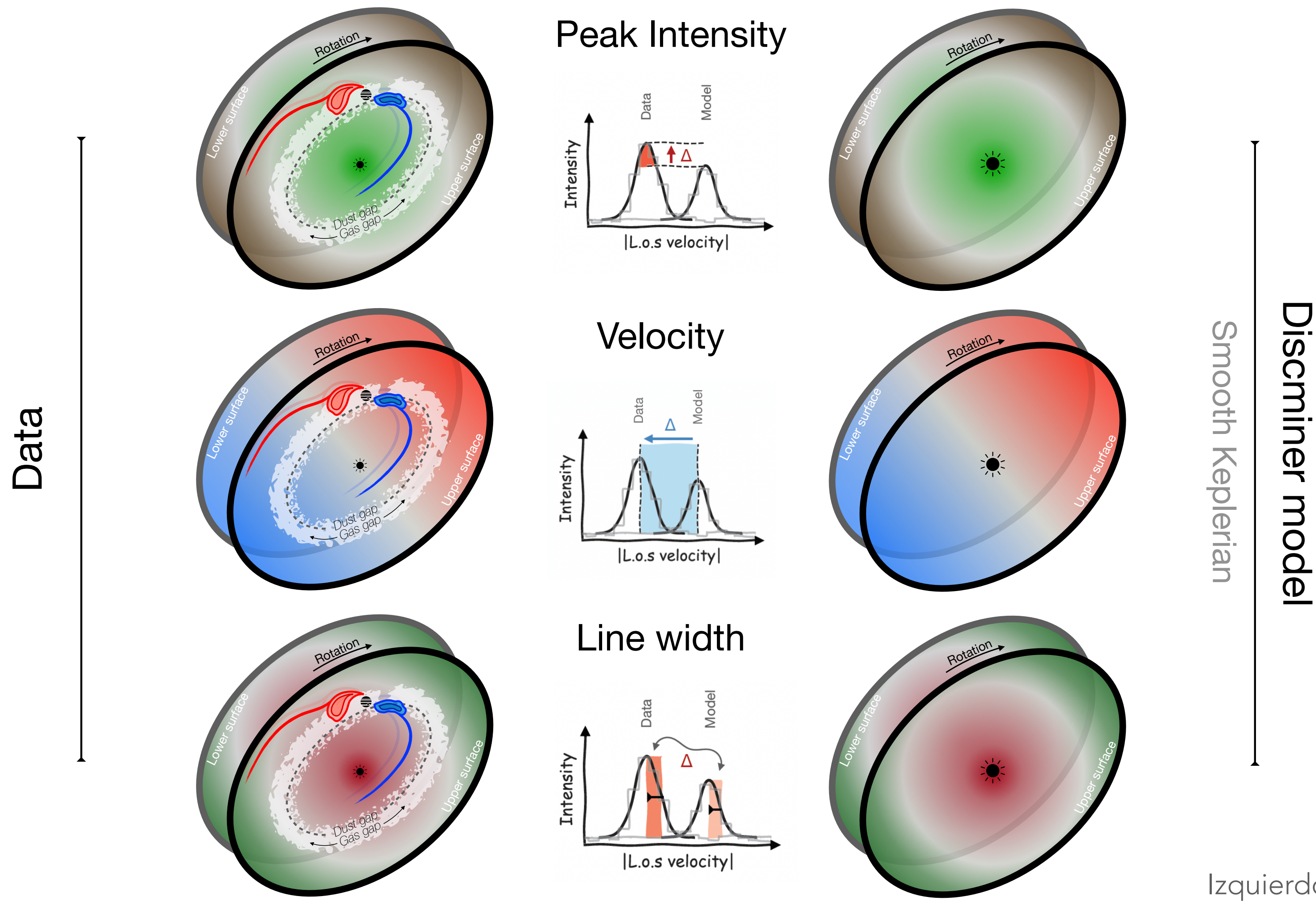
Izquierdo et al. (exoALMA IV)

^{12}CO



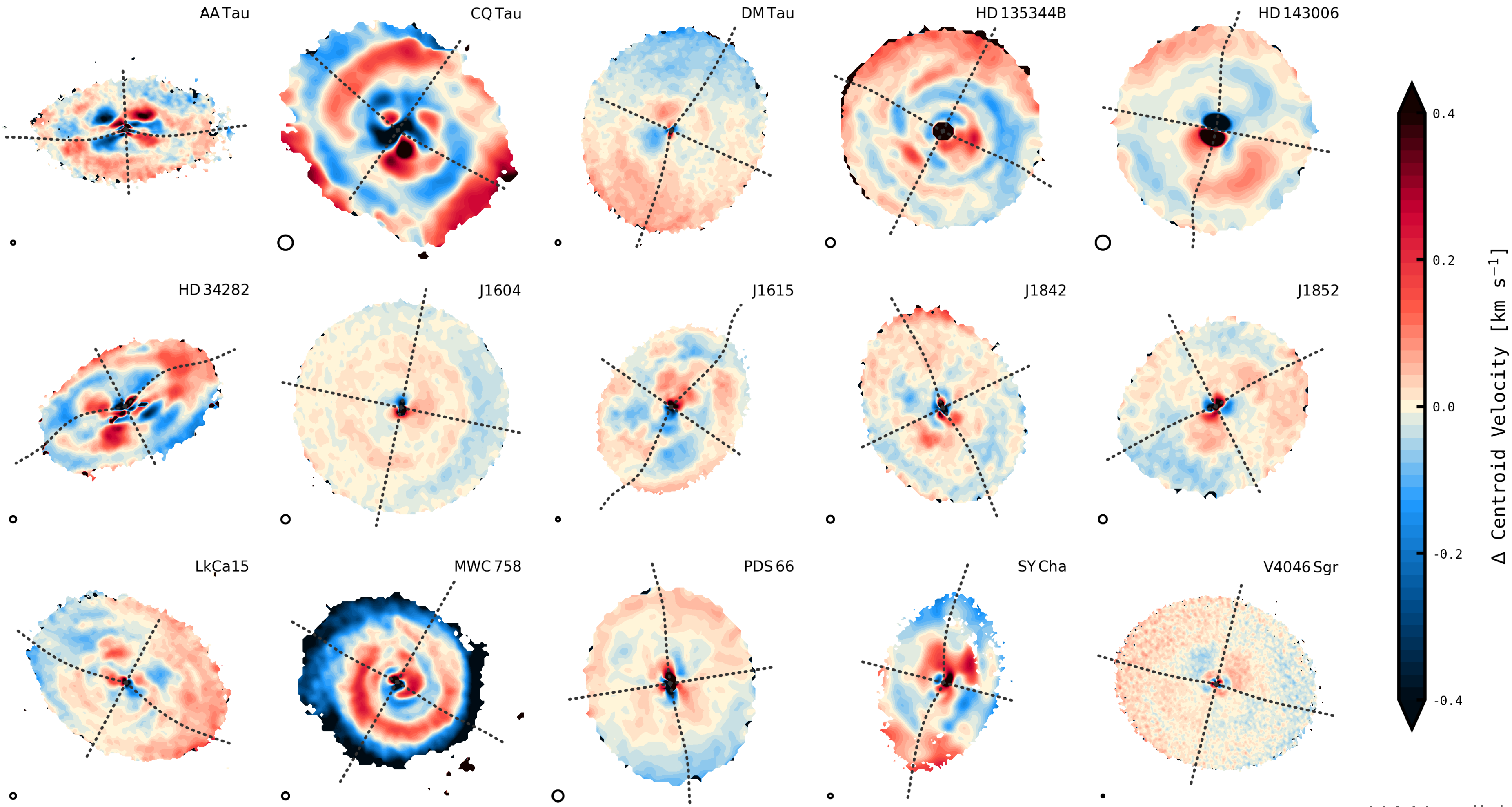
Izquierdo et al. (exoALMA IV), exoALMA collaboration

Extraction of line profile properties



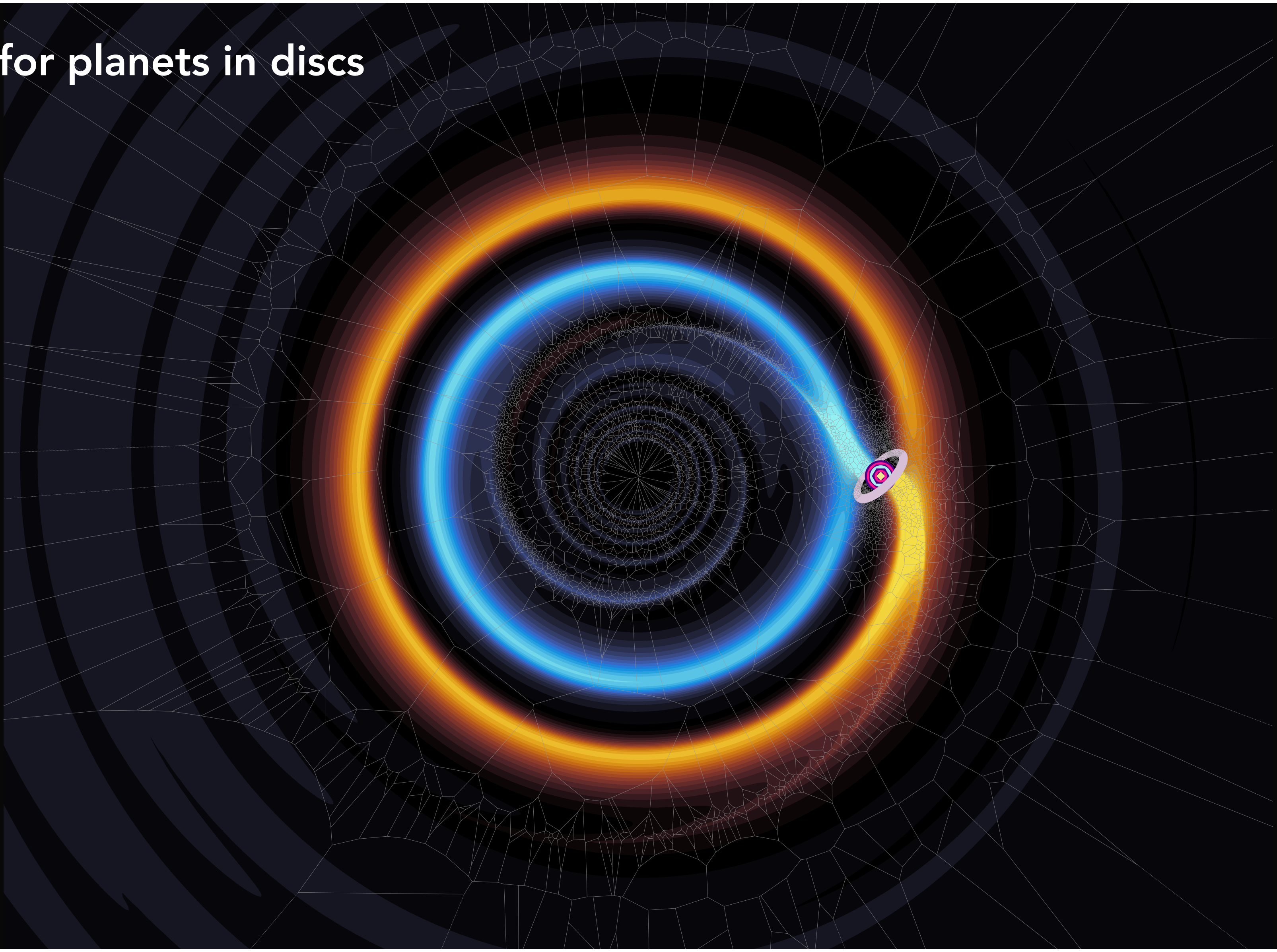
Izquierdo et al. (exoALMA IV)

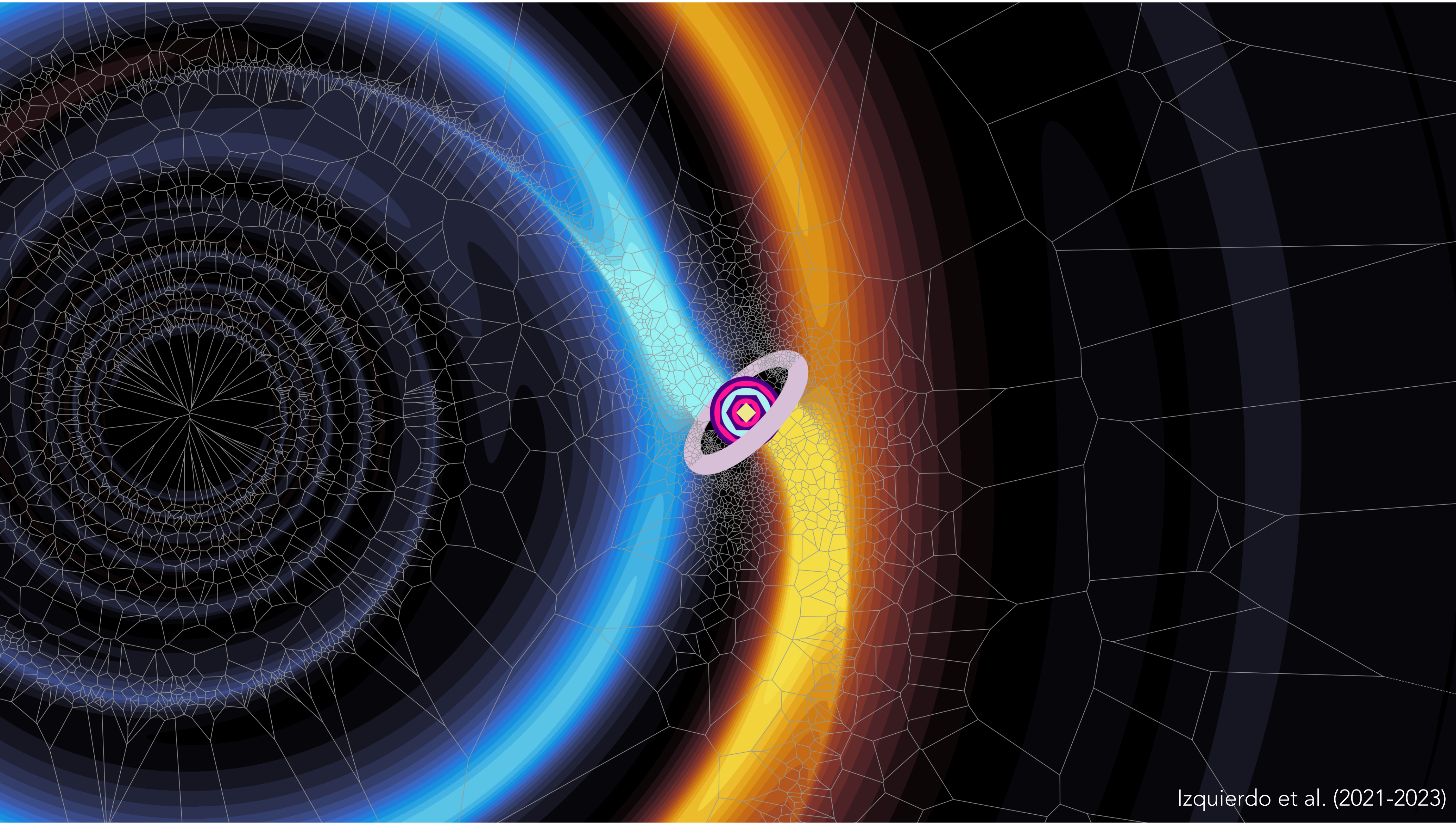
Prominent non-Keplerian motions



exoALMA collaboration

Hunting for planets in discs

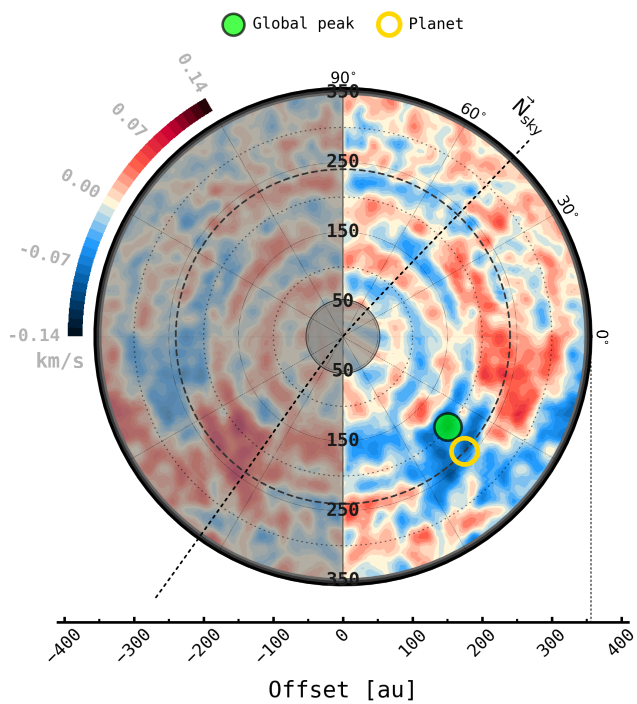


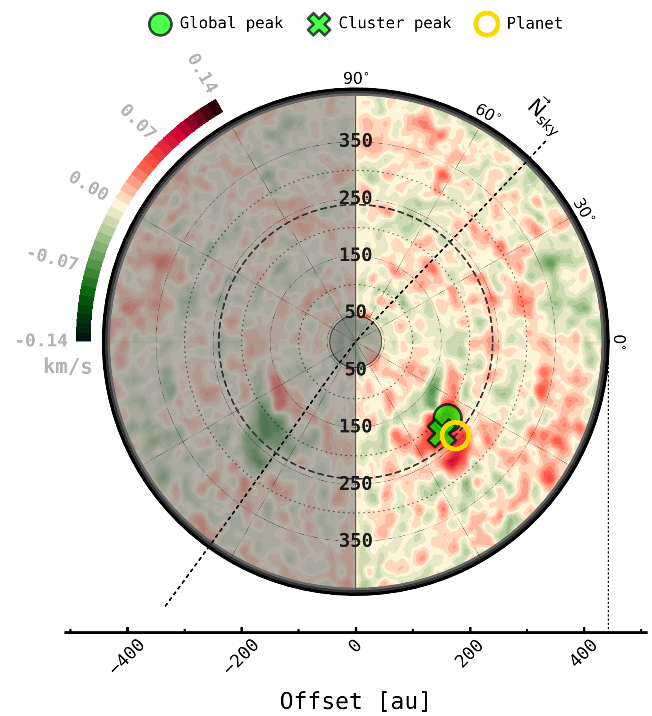

Izquierdo et al. (2021-2023)

Observable planet-driven signatures

Localised high-amplitude velocities and line width increments
are great tracers of the planet location

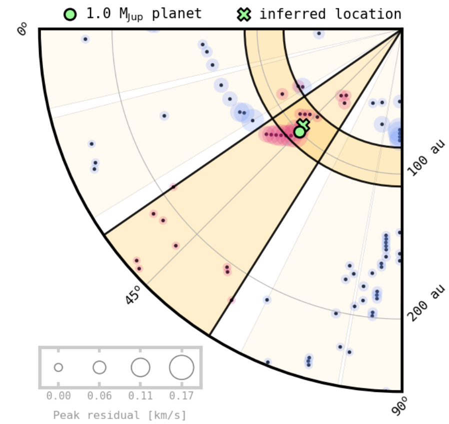
Peak and clustered folded residuals around planet



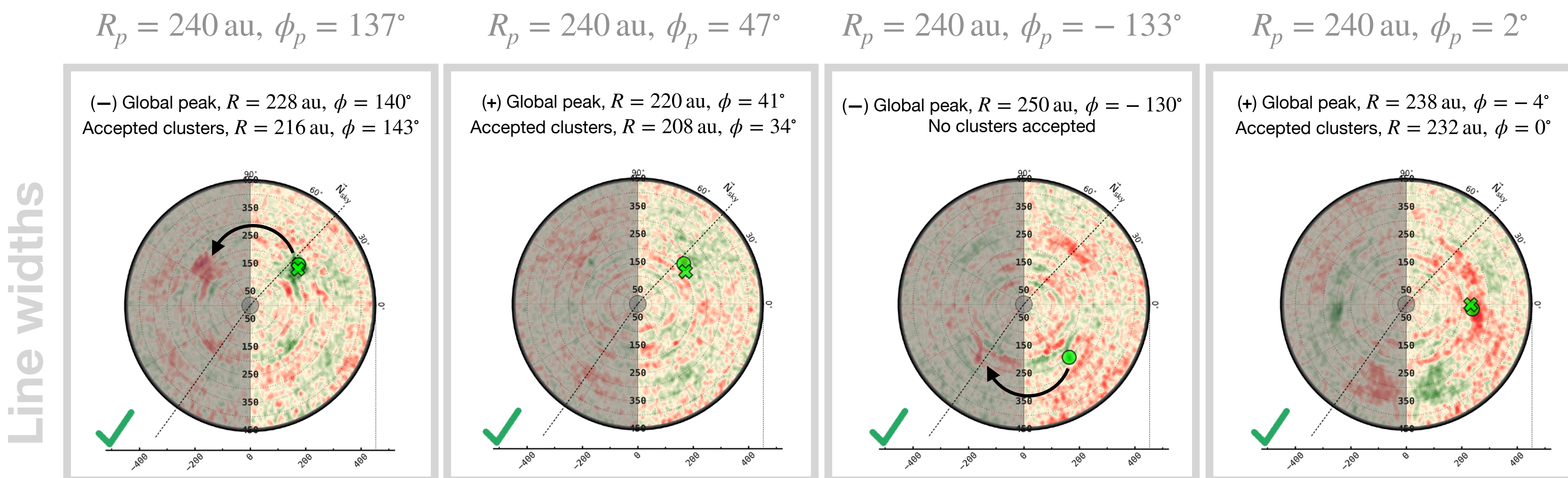


Izquierdo et al. (2023+exoALMA IV)

Observable planet-driven signatures

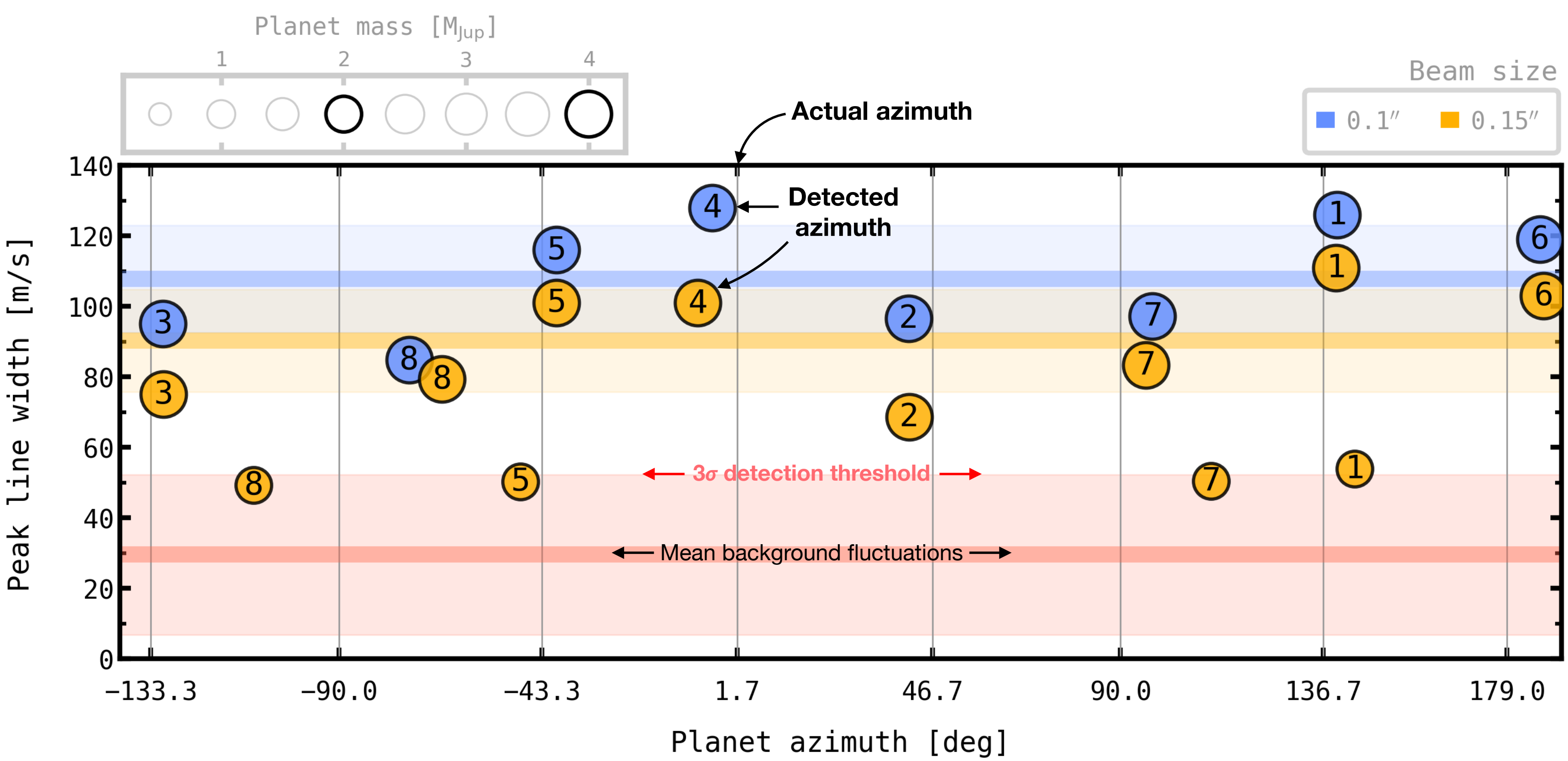


Validated the use of line width increments as planet tracers using synthetic observations



Izquierdo et al. (exoALMA IV), Facchini et al. (exoALMA TBD)

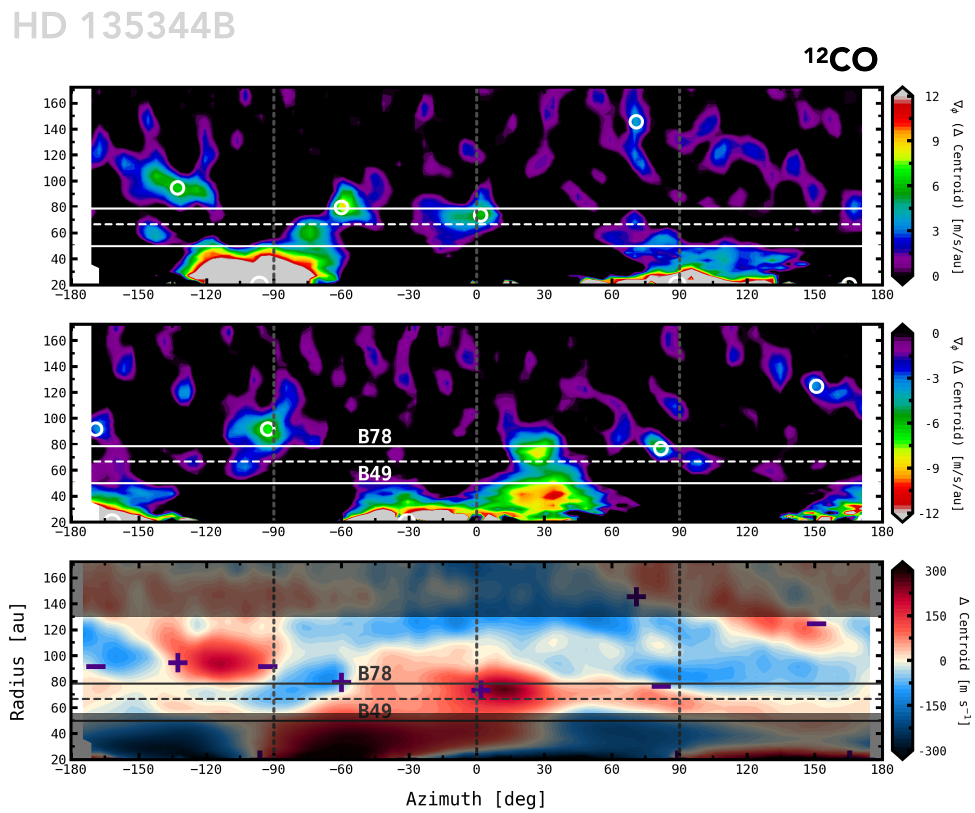
Peak line width vs planet azimuth and mass

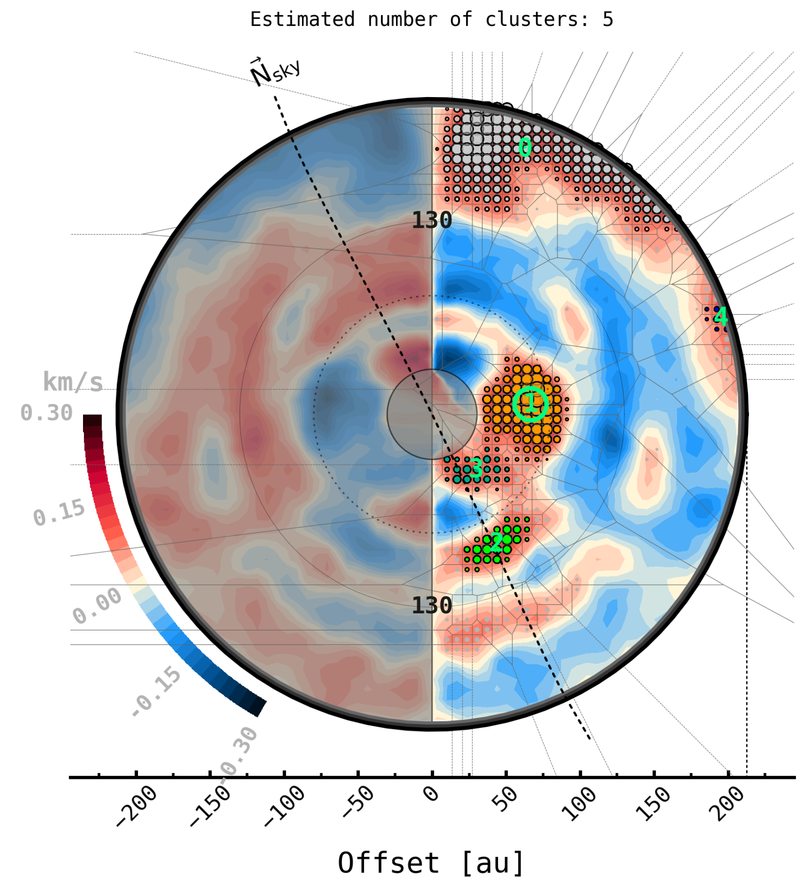


Detection technique yields a precision of ~5deg and ~10 au.
Minimum recoverable planet mass ~2Mjup

Izquierdo et al. (exoALMA IV)

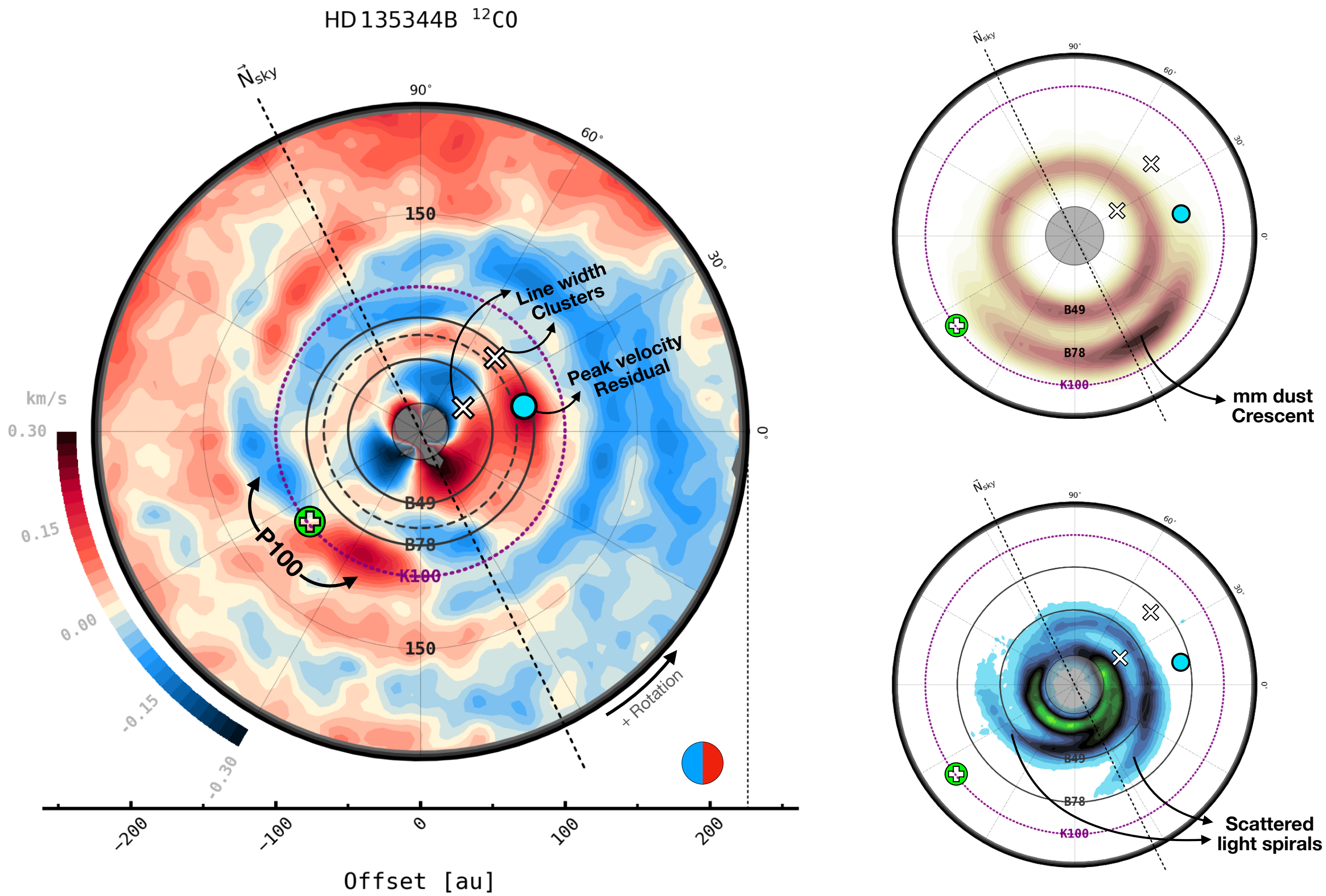
Currently looking for planet signals in exoALMA targets





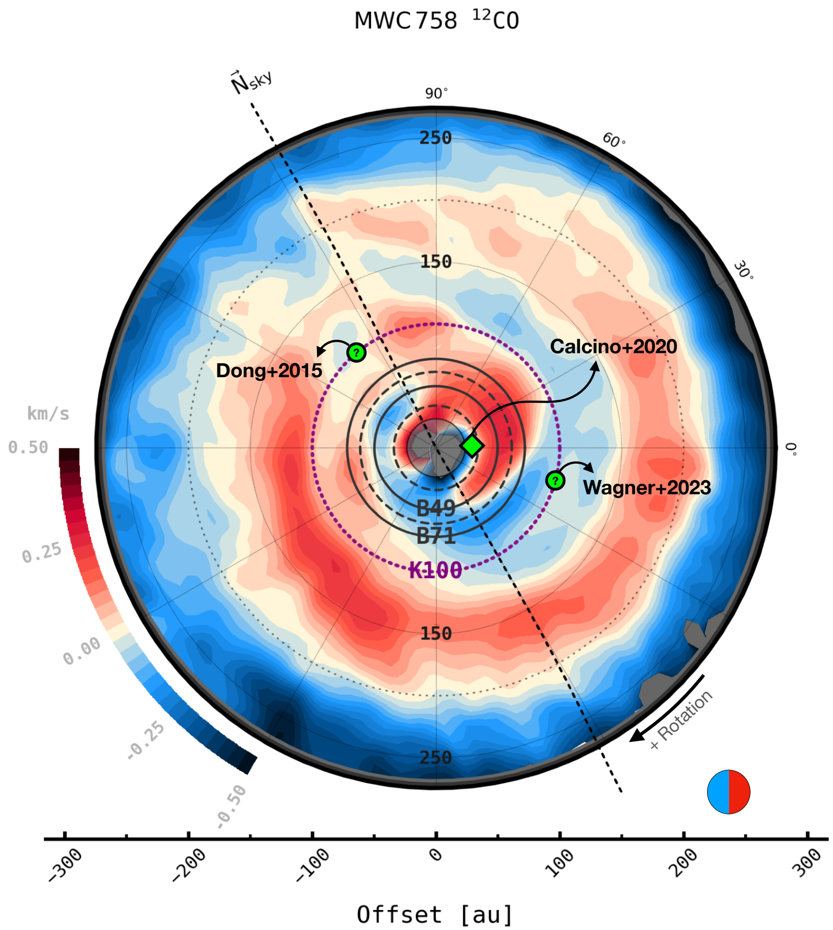
Izquierdo et al. (exoALMA IV), Facchini et al. (exoALMA TBD)

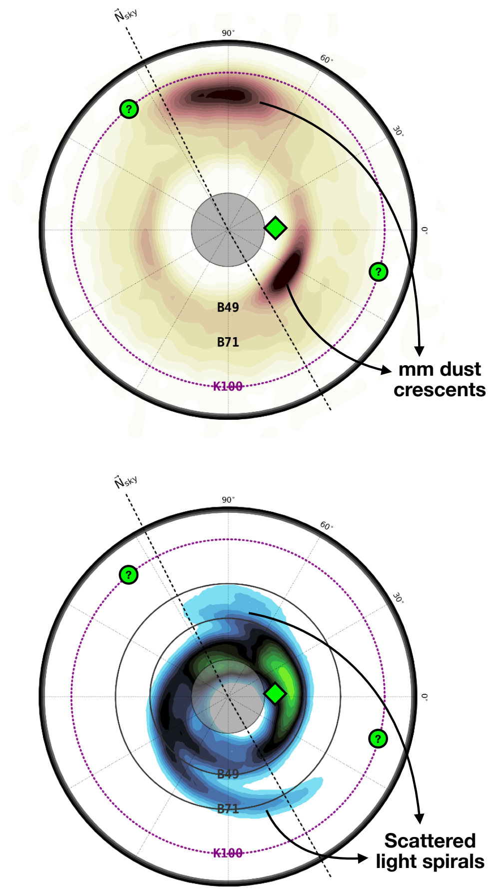
HD135344B: Localised signatures in the vicinity of dust substructures



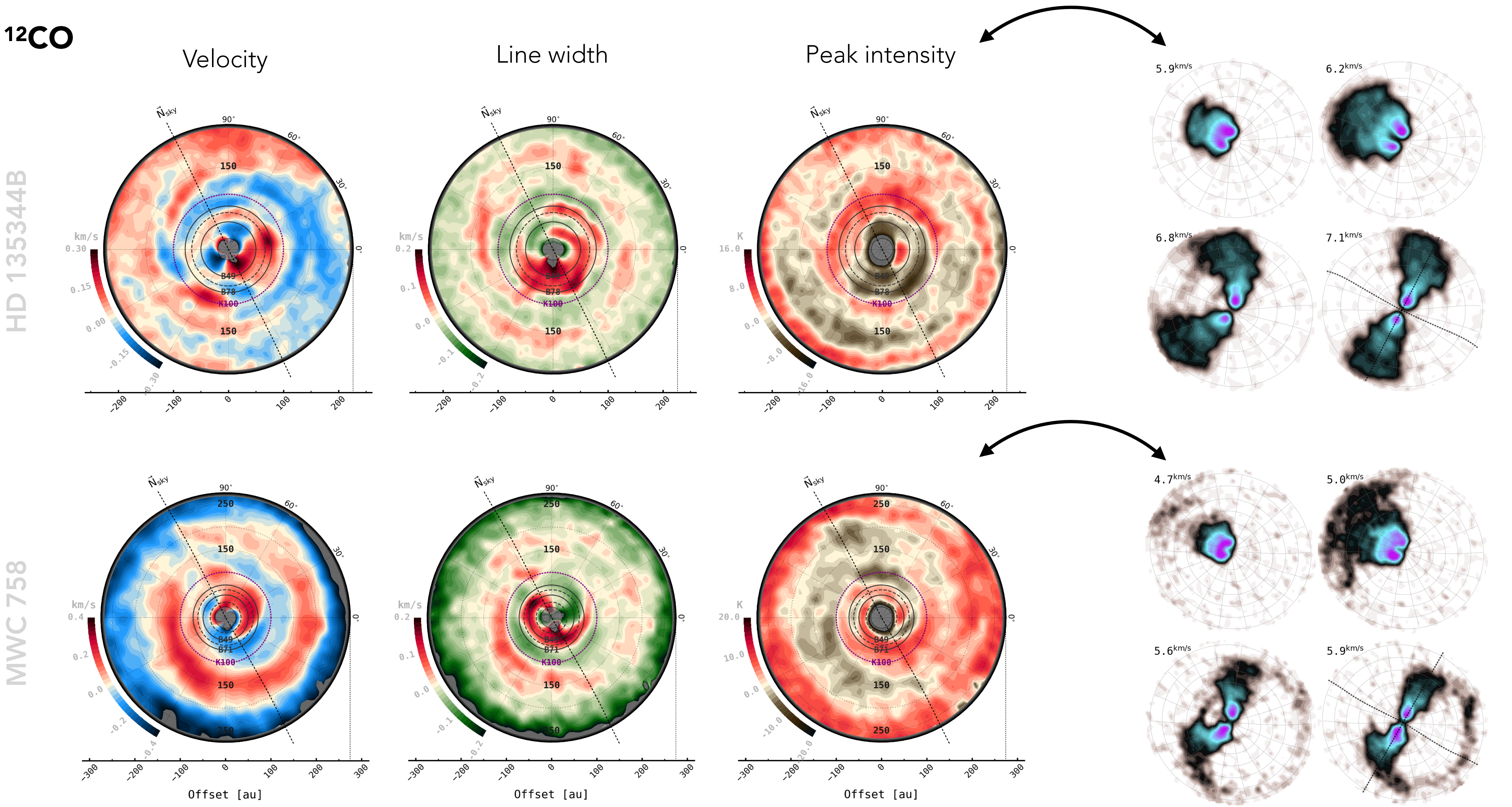
Izquierdo et al. (exoALMA IV), Facchini et al. (exoALMA TBD)

MWC758: Large-scale signatures; inner massive companions?





Izquierdo et al. (exoALMA IV), Benisty et al. (exoALMA TBD)



Izquierdo et al. (exoALMA IV)

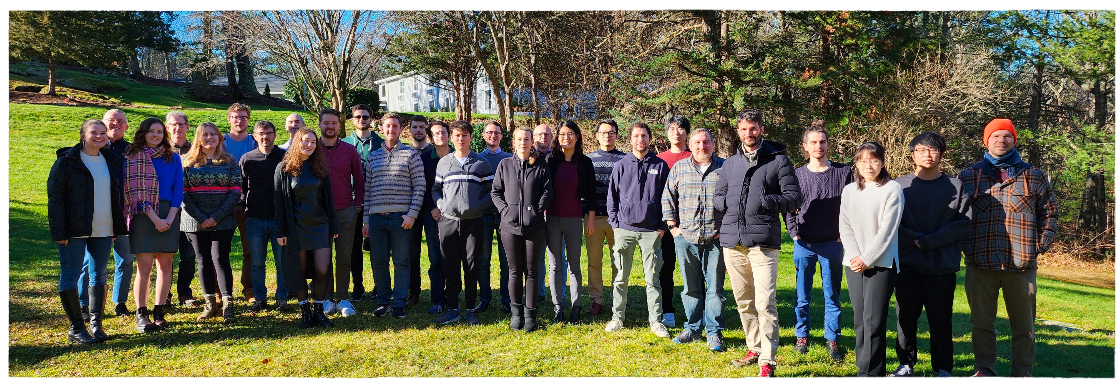
Summary

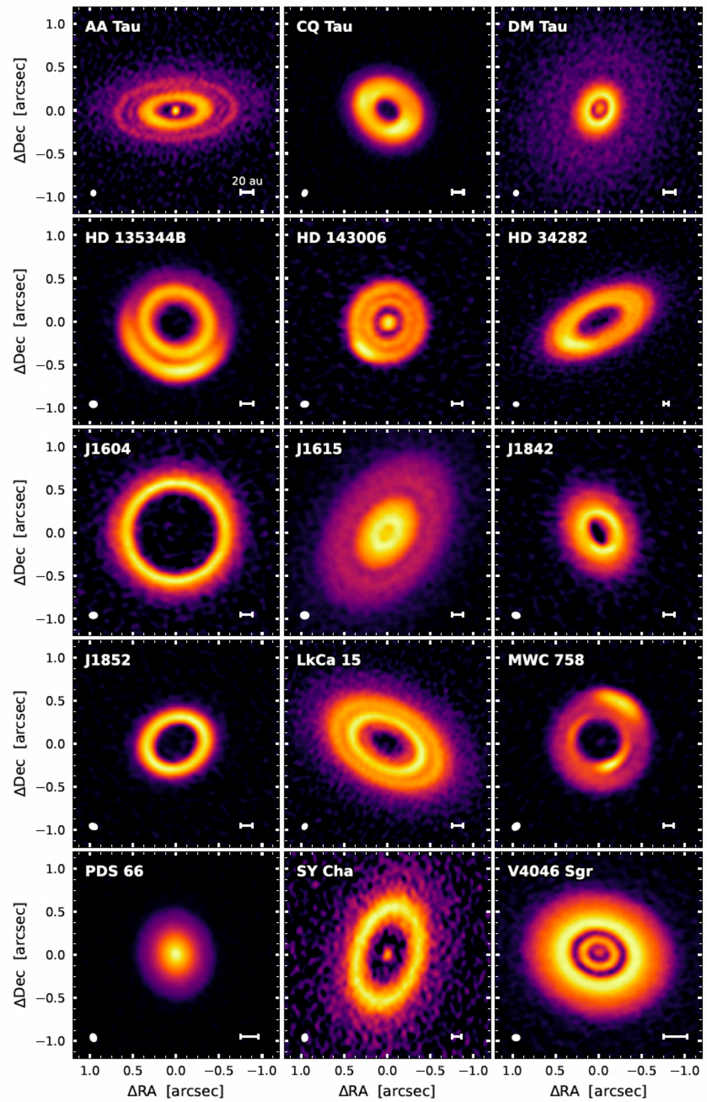
- ✓ The majority of our discs are exceptionally dynamic. Nearly all discs appear to host gas temperature and kinematic substructures.
- ✓ Precise mapping of multiple molecular lines allows us to **hunt for planets** and to perform a **3D tomography** of the **disc's physical structure**.
- ✓ Line broadening is a solid tracer of planets. When coupled with velocity analysis, it provides a robust method to determine both planet **azimuth** and **radial location**.

exoALMA

First Results

[First wave of papers expected early 2025]




AA Tau
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MWC 758
PDS 66
SY Cha
V4046 Sgr
20 au
ΔDec [arcsec]
ΔRA [arcsec]