RESOLVING THE FU ORIONIS SYSTEM WITH ALMA

#ALMA #FUOri #Continuum #Kinematics #EpisodicAccretion

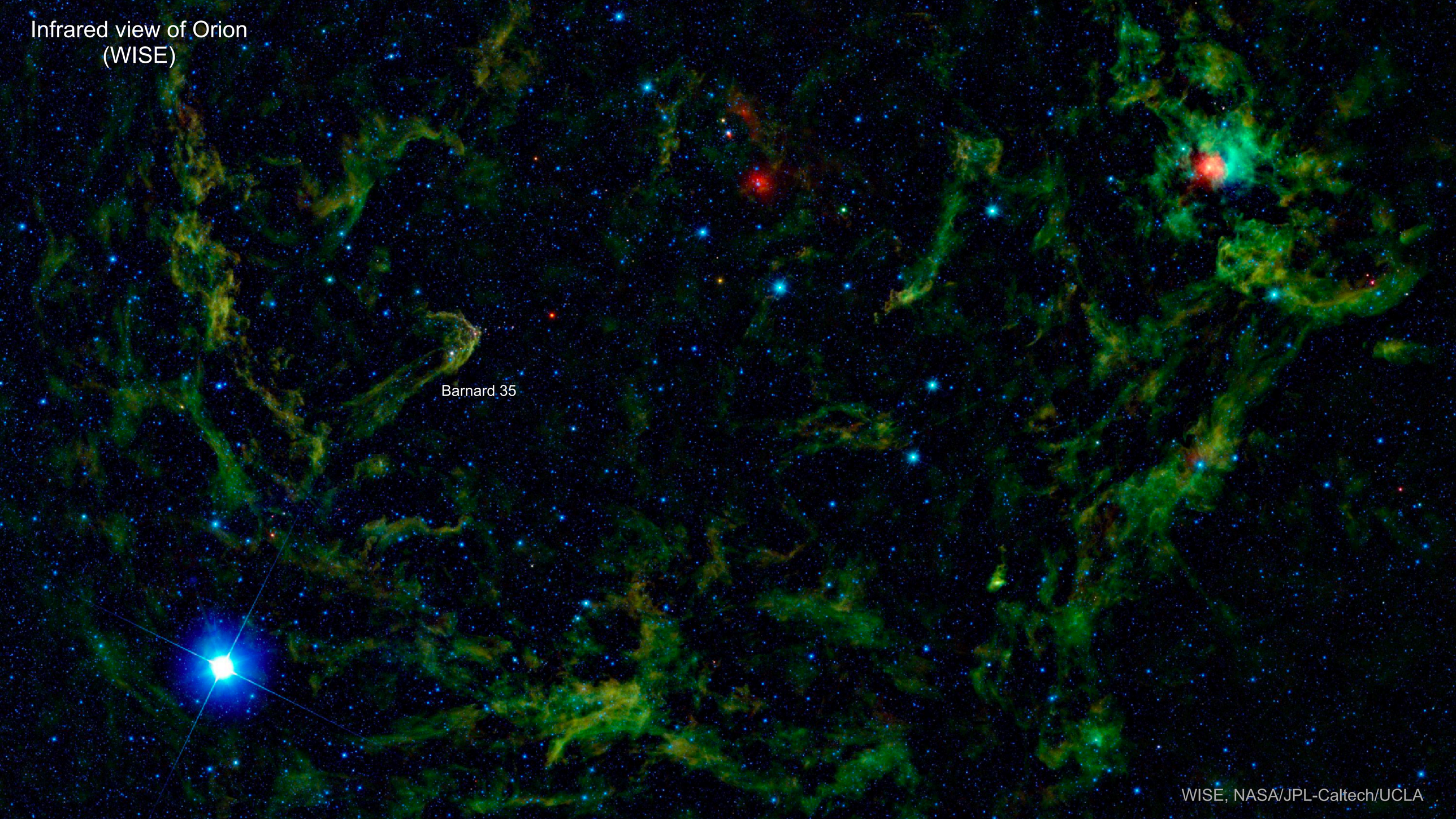
Sebastián Pérez - U. Santiago de Chile

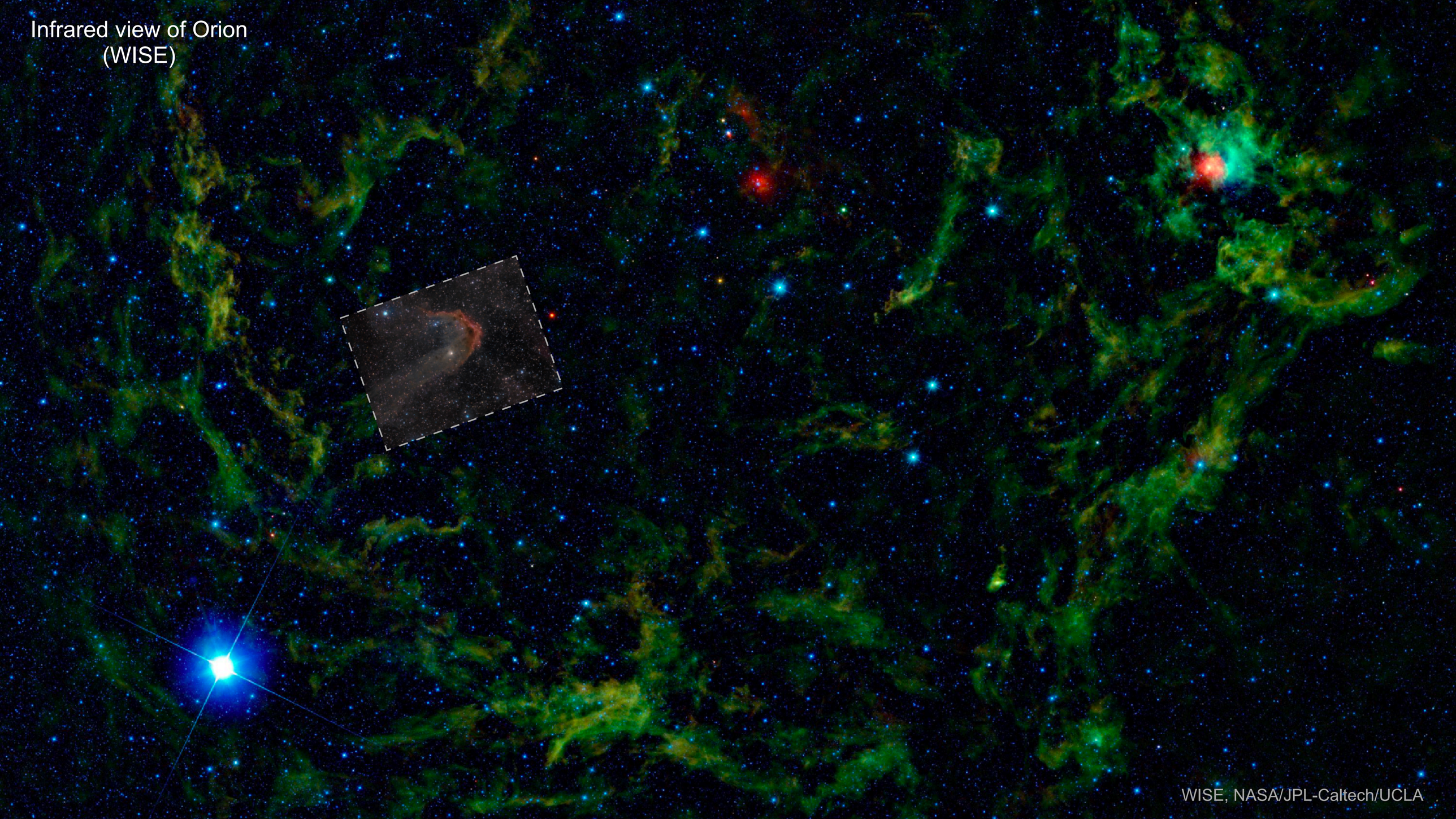
Collabs: Antonio Hales (NRAO/ALMA), H. Baobab Liu (ASIAA), Lucas Cieza (UDP),
Alice Zurlo (UDP), Simon Casassus (UChile), Zhaohuan Zhu (Nevada),
David Principe (MIT), Nicolas Cuello (PUC)

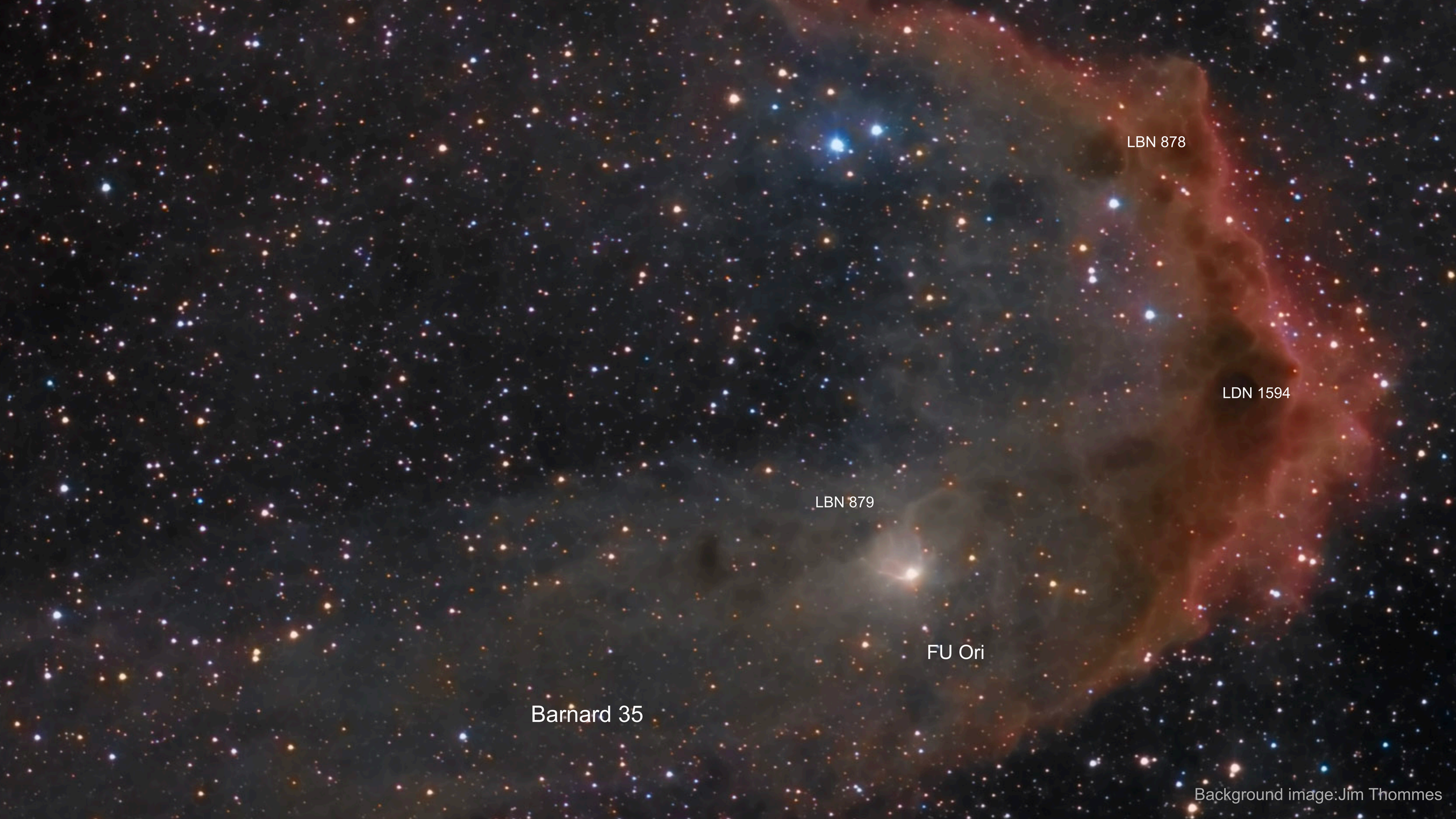
UNIVERSIDAD
DE SANTIAGO
DE CHILE

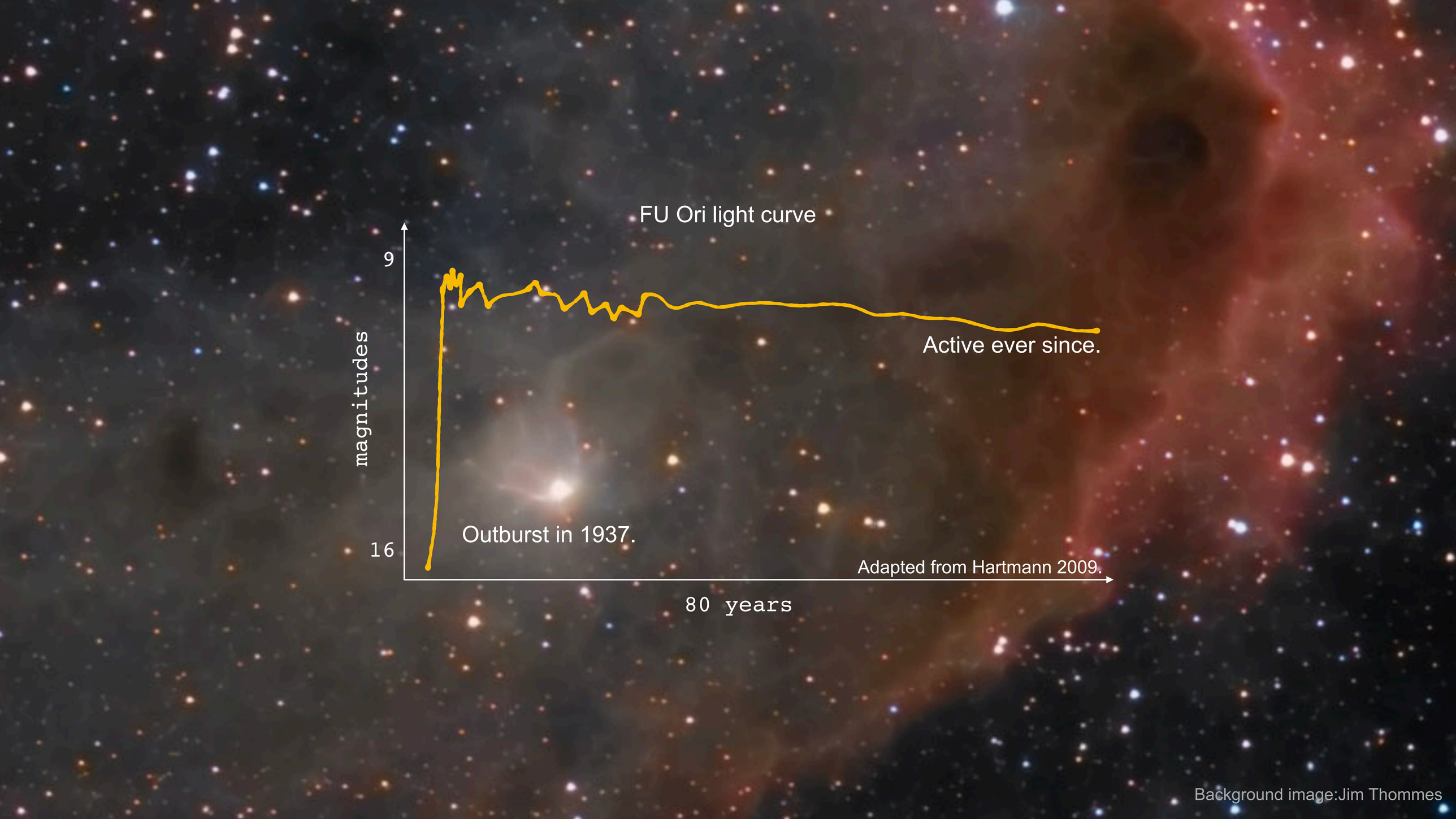

Optical view of Orion
(Hα in red)
Rogelio Bernal Andreo (DeepSkyColors.com)

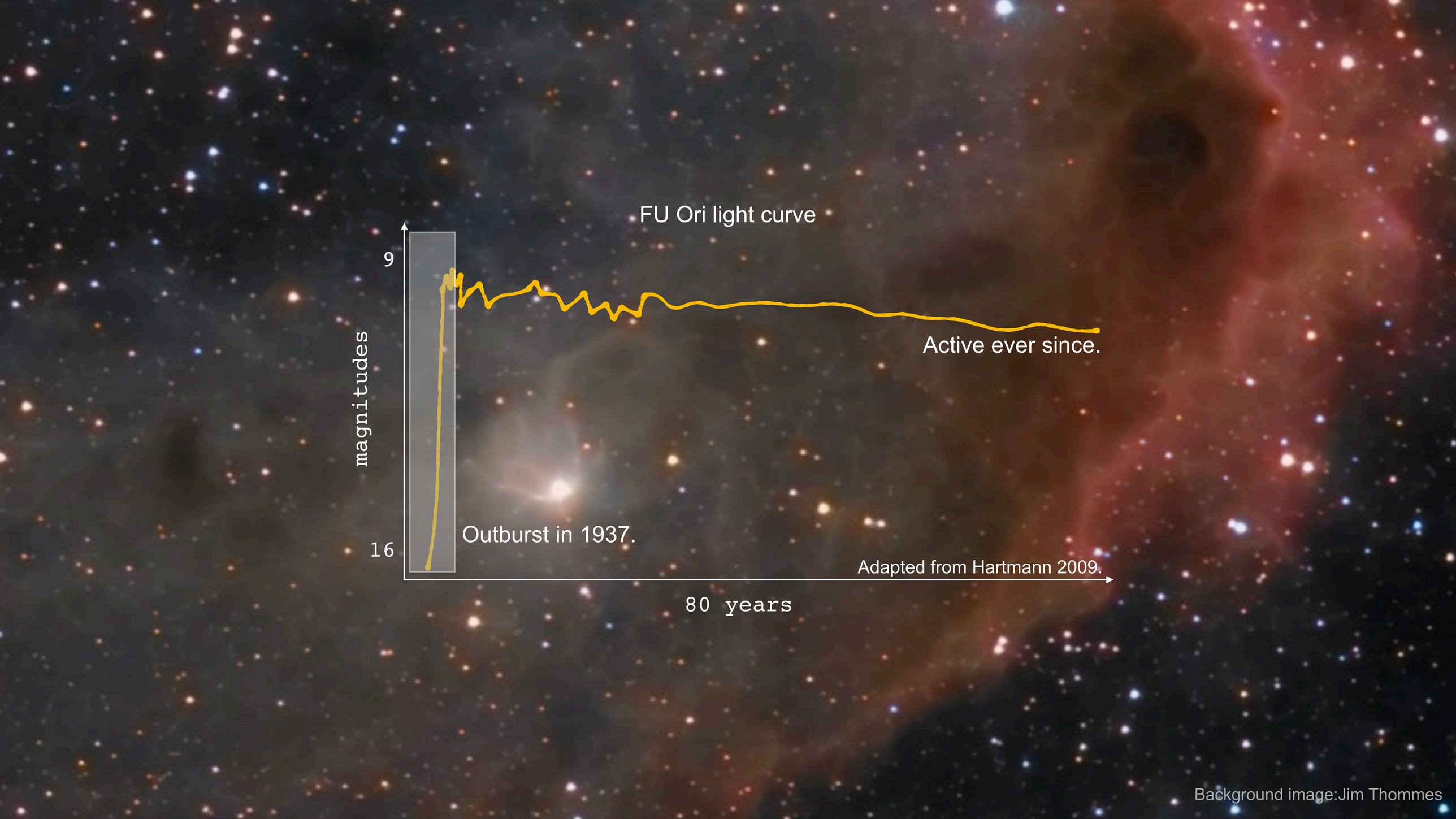

λ Orion
Bellatrix
Betelgeuse
Rogelio Bernal Andreo (DeepSkyColors.com)


Infrared view of Orion
(WISE)
Barnard 35
WISE, NASA/JPL-Caltech/UCLA


Infrared view of Orion
(WISE)
WISE, NASA/JPL-Caltech/UCLA


LBN 878
LDN 1594
LBN 879
FU Ori
Barnard 35
Background image:Jim Thommes


FU Ori light curve
9
magnitudes
16
Active ever since.
Outburst in 1937.
Adapted from Hartmann 2009.
80 years
Background image:Jim Thommes


FU Ori light curve
9
magnitudes
16
Outburst in 1937.
Active ever since.
Adapted from Hartmann 2009.
80 years
Background image:Jim Thommes

Dr Dorrit Hoffleit

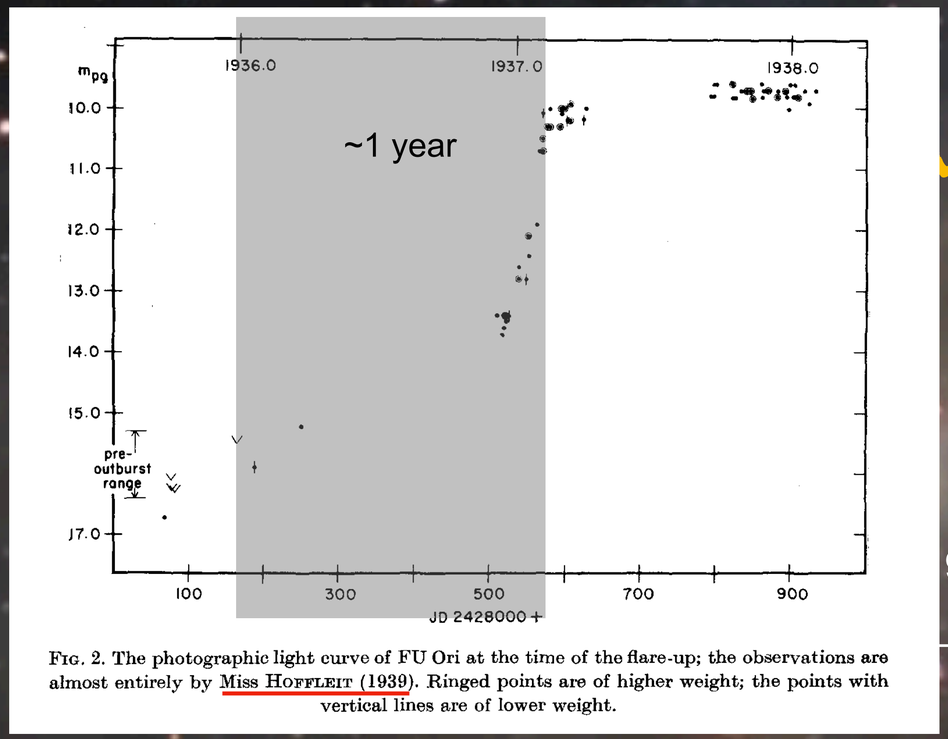


FIG. 2. The photographic light curve of FU Ori at the time of the flare-up; the observations are almost entirely by Miss HOFFLEIT (1939). Ringed points are of higher weight; the points with vertical lines are of lower weight.

Herbig (1966)

FU Ori light curve

Active ever since.

937.

Adapted from Hartmann 2009.

80 years

Background image:Jim Thommes

Dr Dorrit Hoffleit

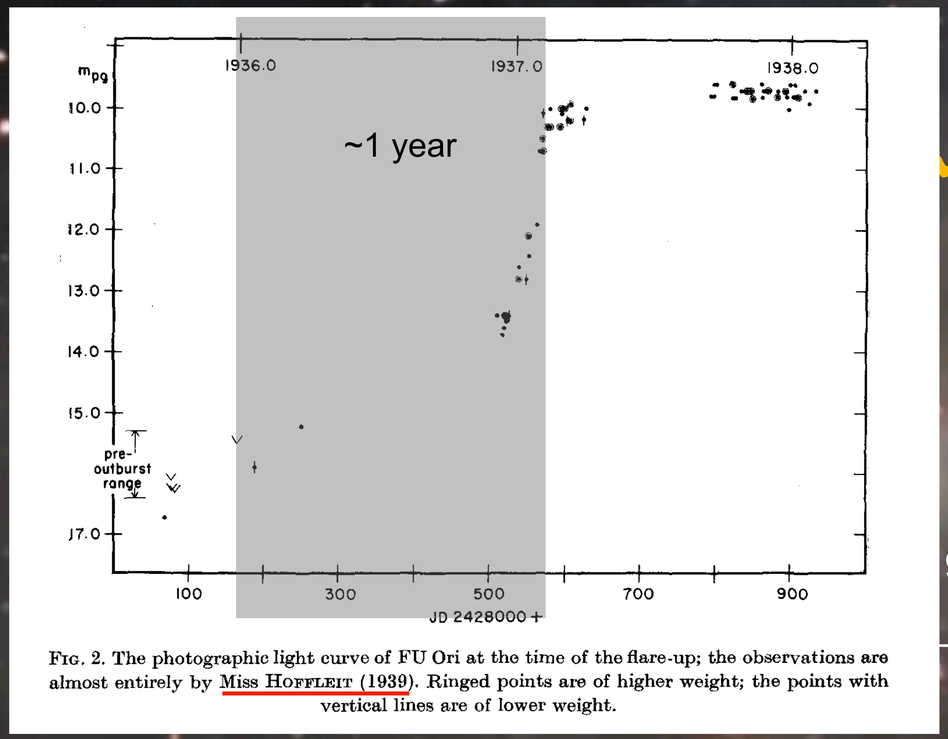


FIG. 2. The photographic light curve of FU Ori at the time of the flare-up; the observations are almost entirely by Miss HOFFLEIT (1939). Ringed points are of higher weight; the points with vertical lines are of lower weight.

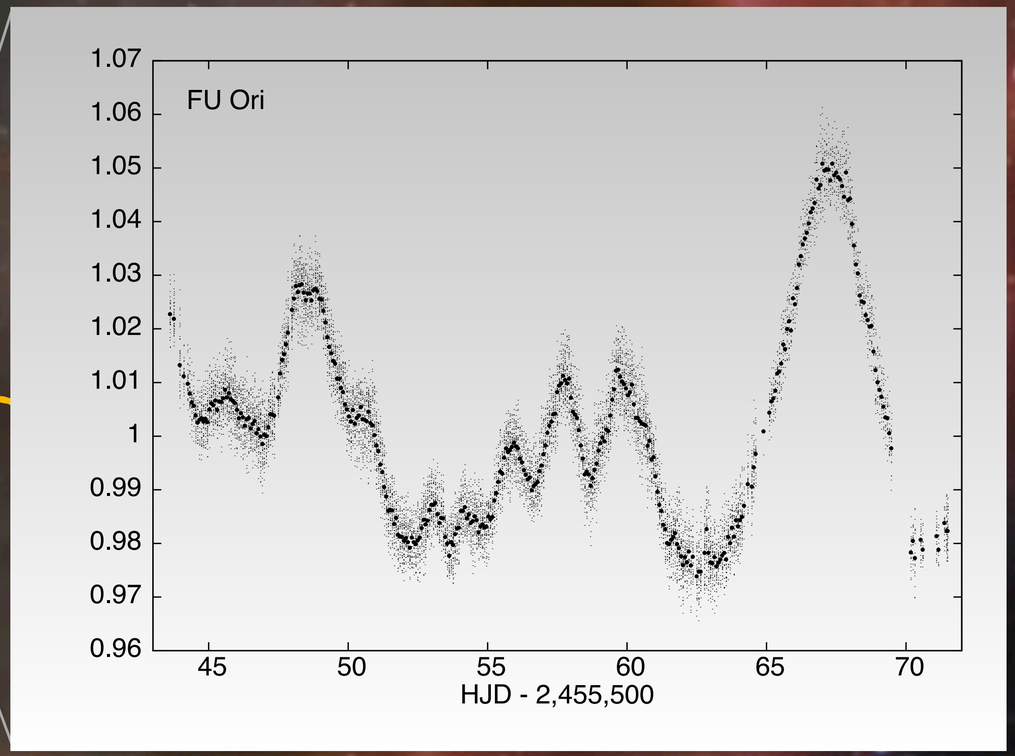
Herbig (1966)

FU Ori light curve

937.

80 years

MOST light curve. Siwak et al. (2013)

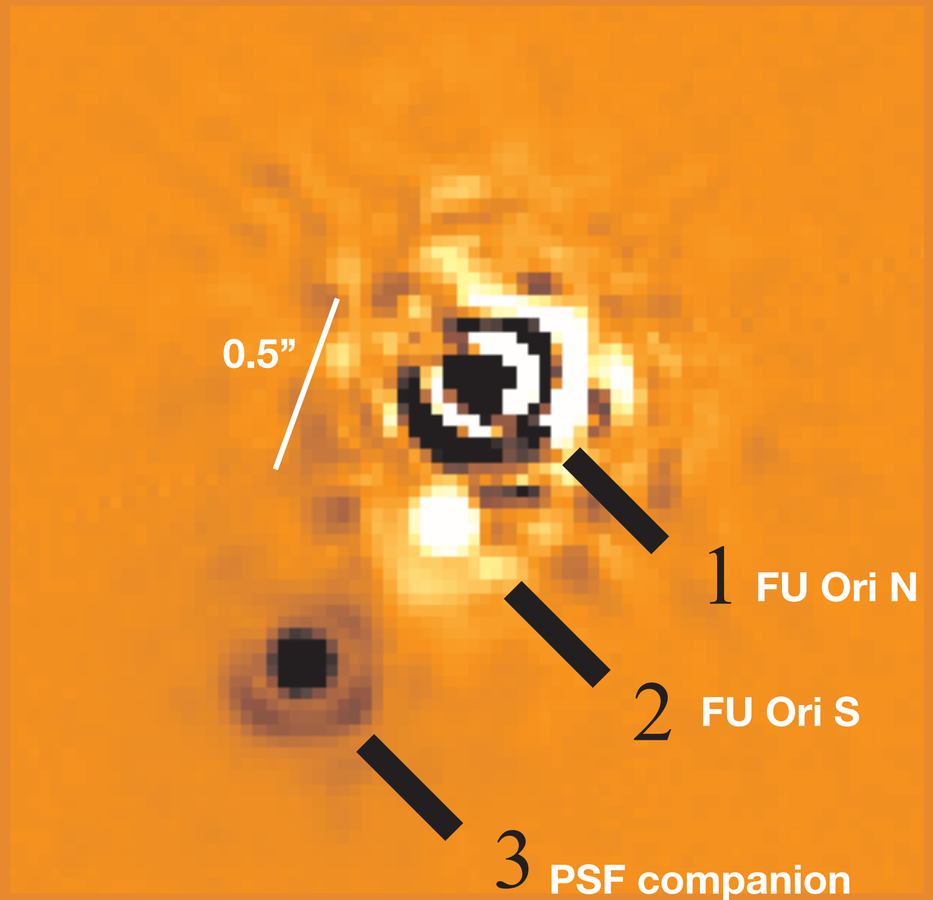


Adapted from Hartmann 2009.

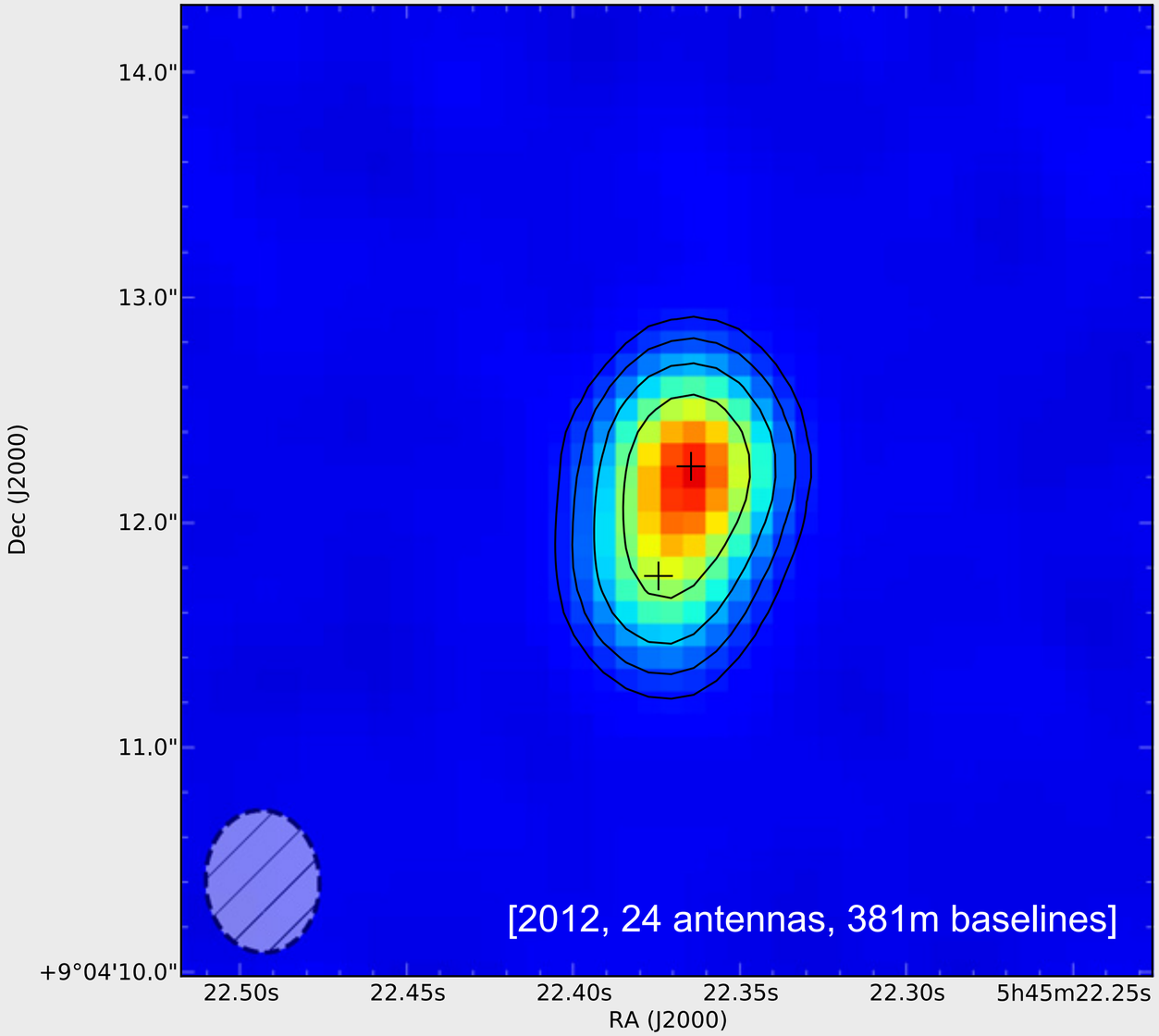
Background image:Jim Thommes

2007: FU Ori is realized as a binary system
(3.6m Calar Alto telescope \\ AO+laser)

Wang et al. 2007



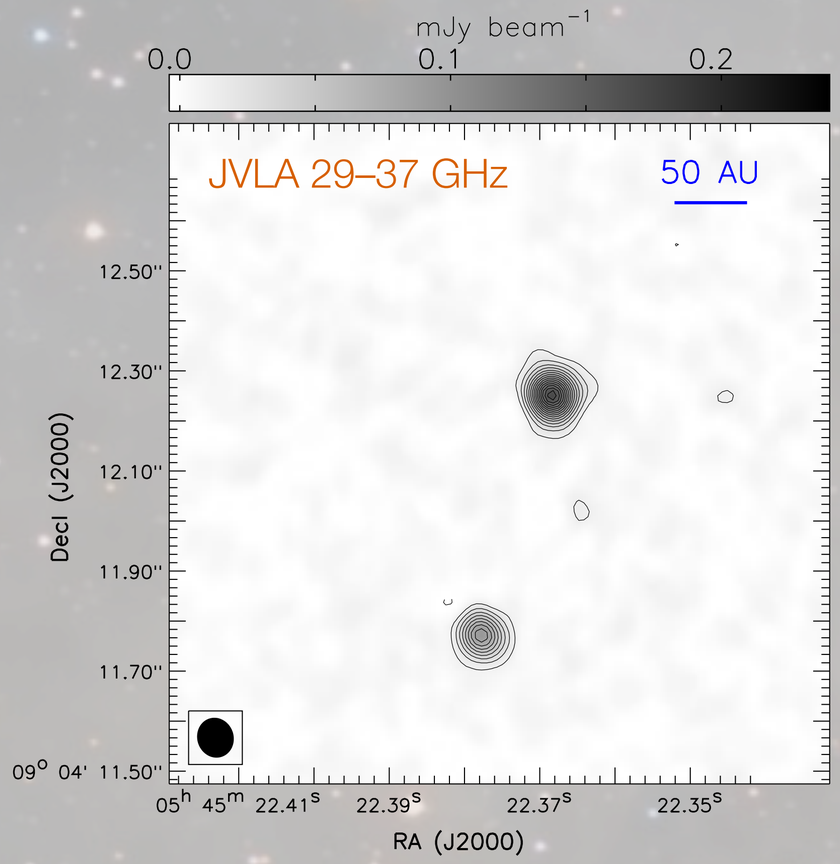
Early Science ALMA observations. 0.8 mm images shows dust around both stars

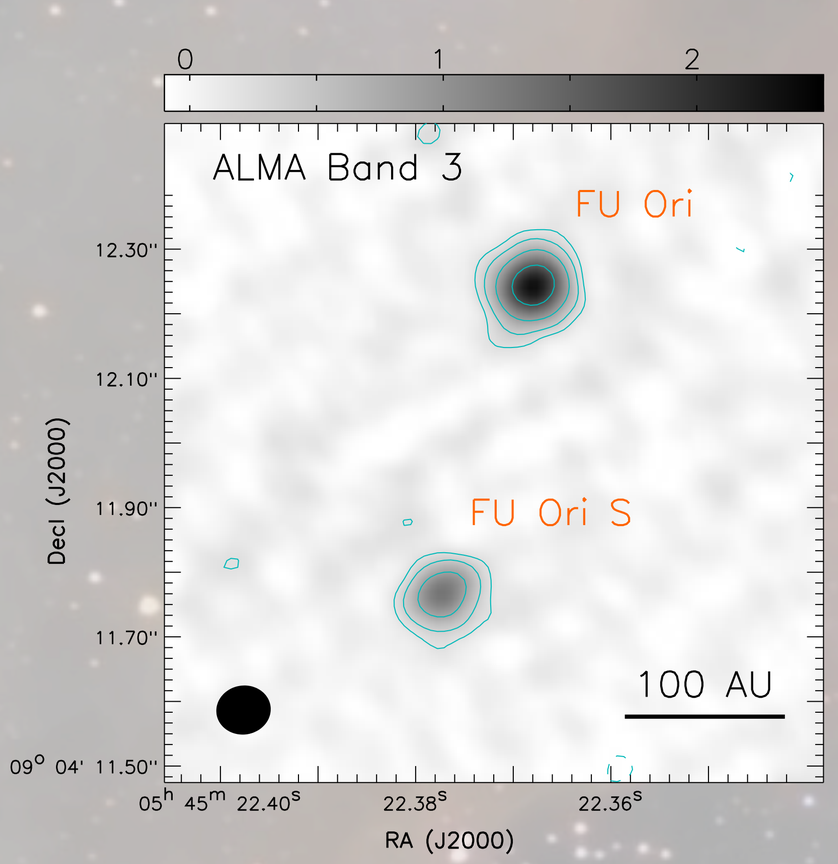


Antonio Hales
NRAO/ALMA

Hales et al. 2015

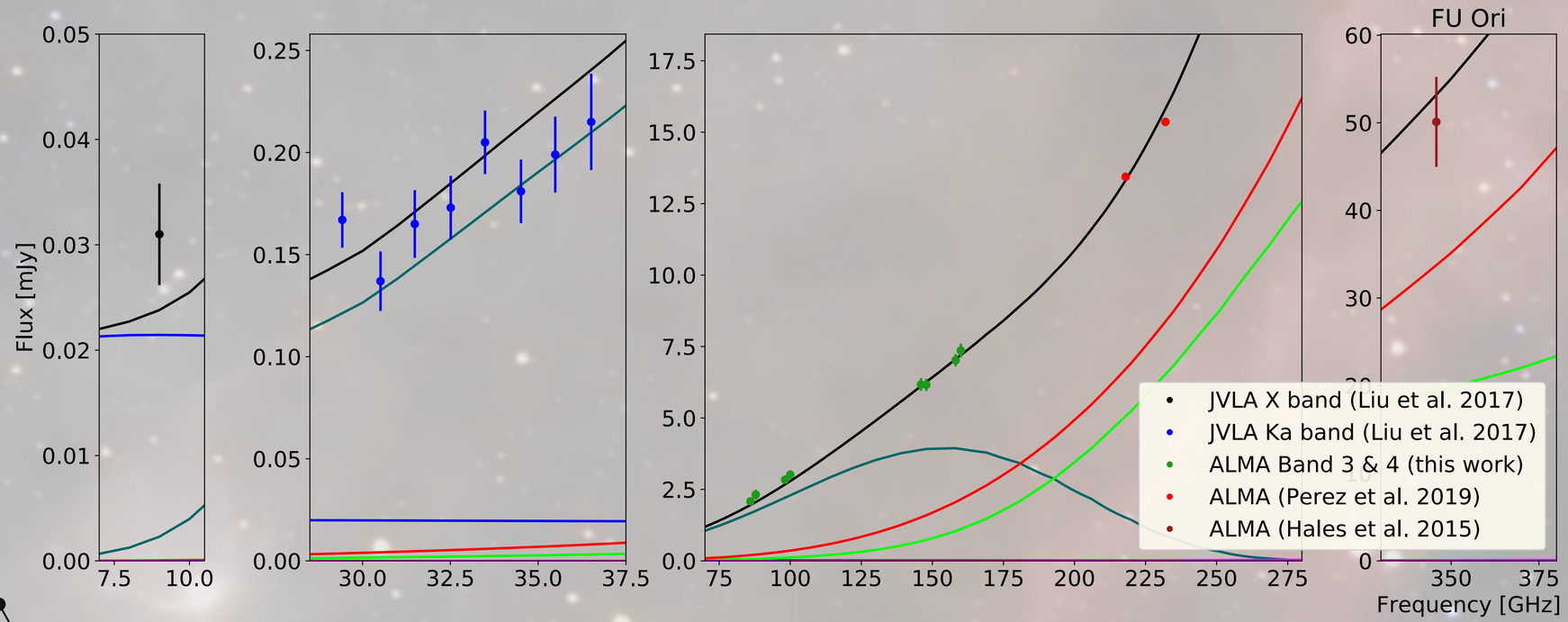
Liu, H. B. et al. 2017/2019



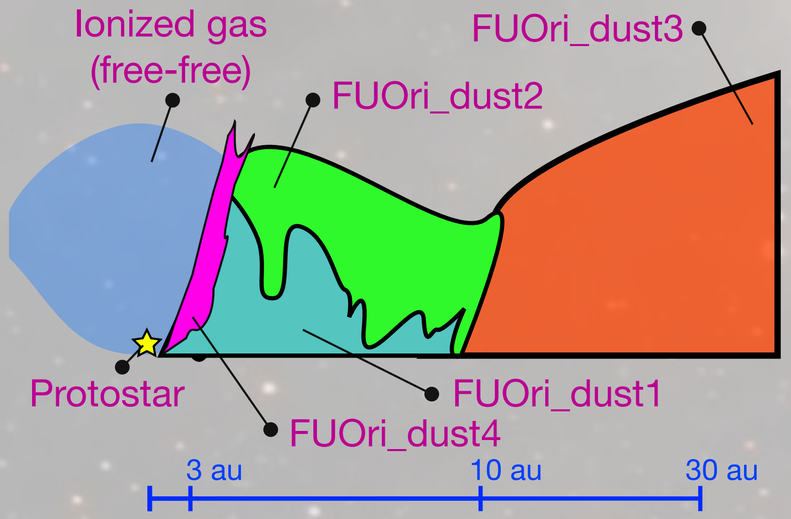


H. Baobab Liu
ASIAA Taiwan

Liu, H. B. et al. 2017/2019



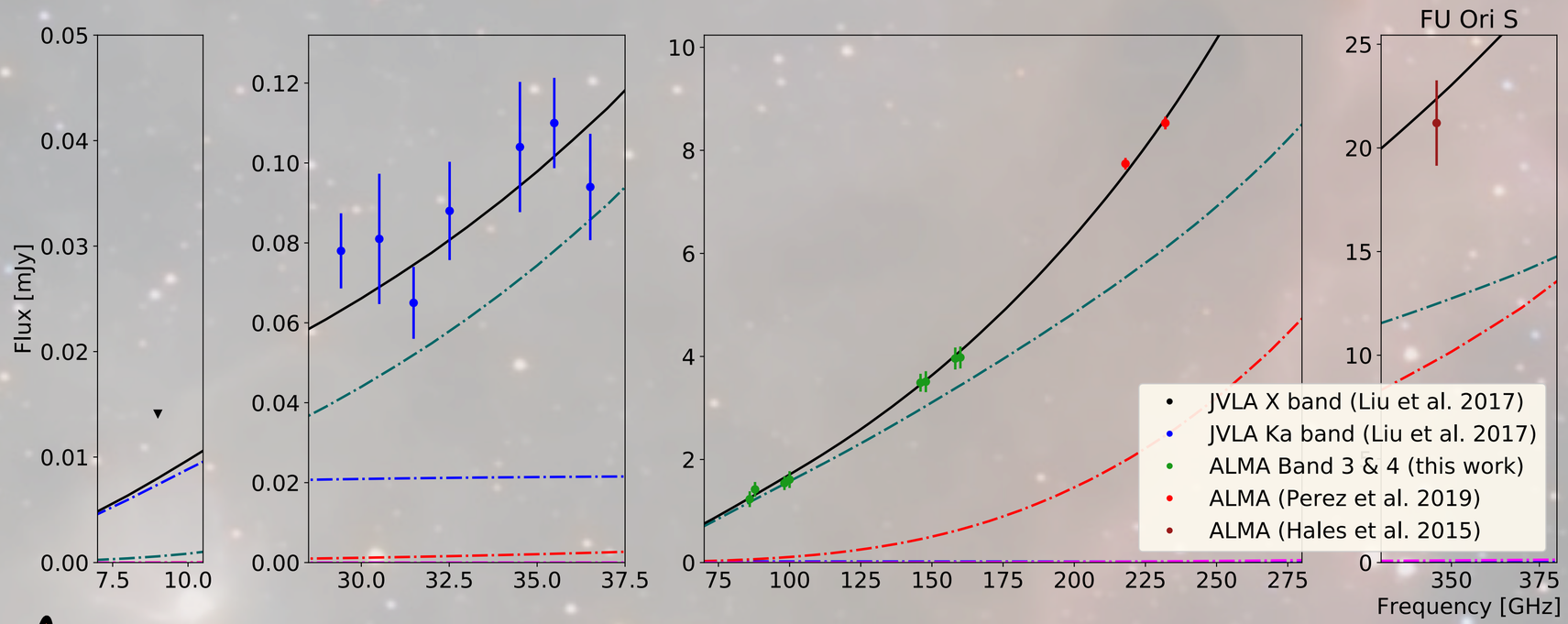
FU Ori N (primary/outbursting)



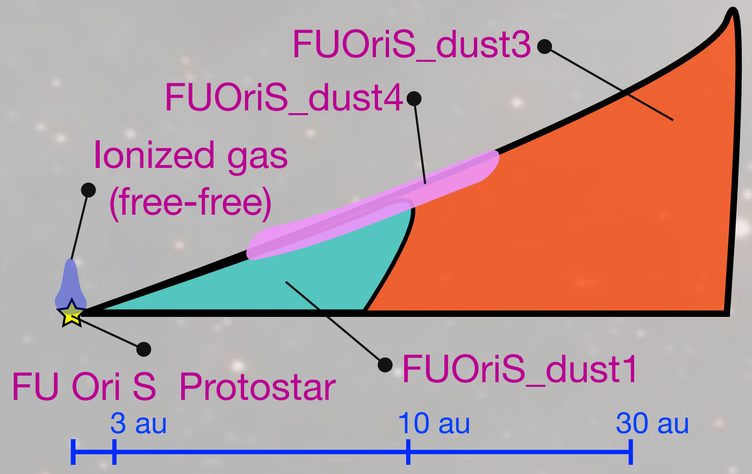
Multicomponent model based on SED fitting (mainly resolved photometry)

Temperature inversion required (as in V883 Ori shown yesterday by S. Casassus)

Liu, H. B. et al. 2017/2019



FU Ori S (secondary/quiescent)



Multicomponent model based on SED fitting (mainly resolved photometry)

No temperature inversion required

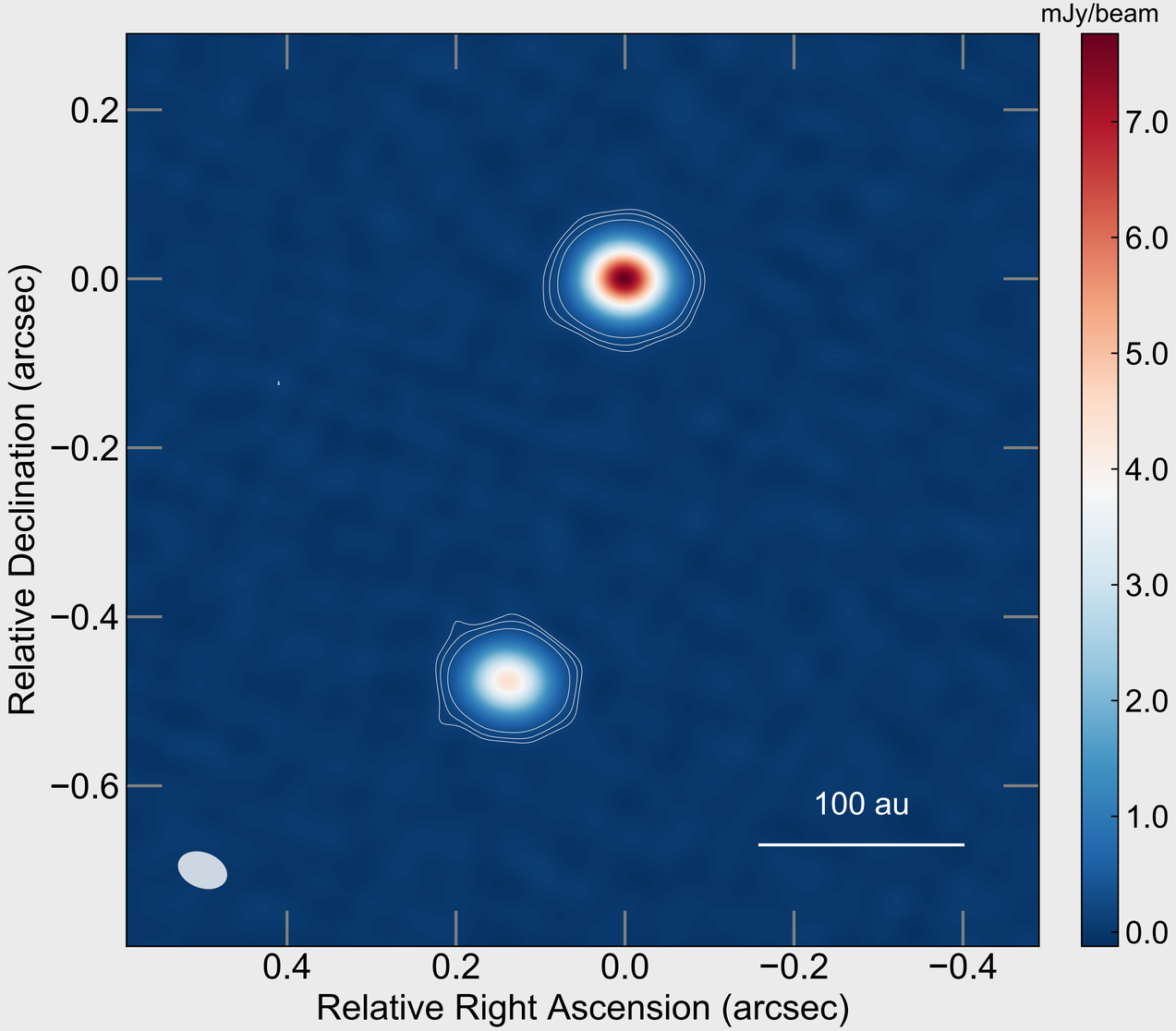
Motivation for ALMA observations:

1) measure disk sizes / geometry

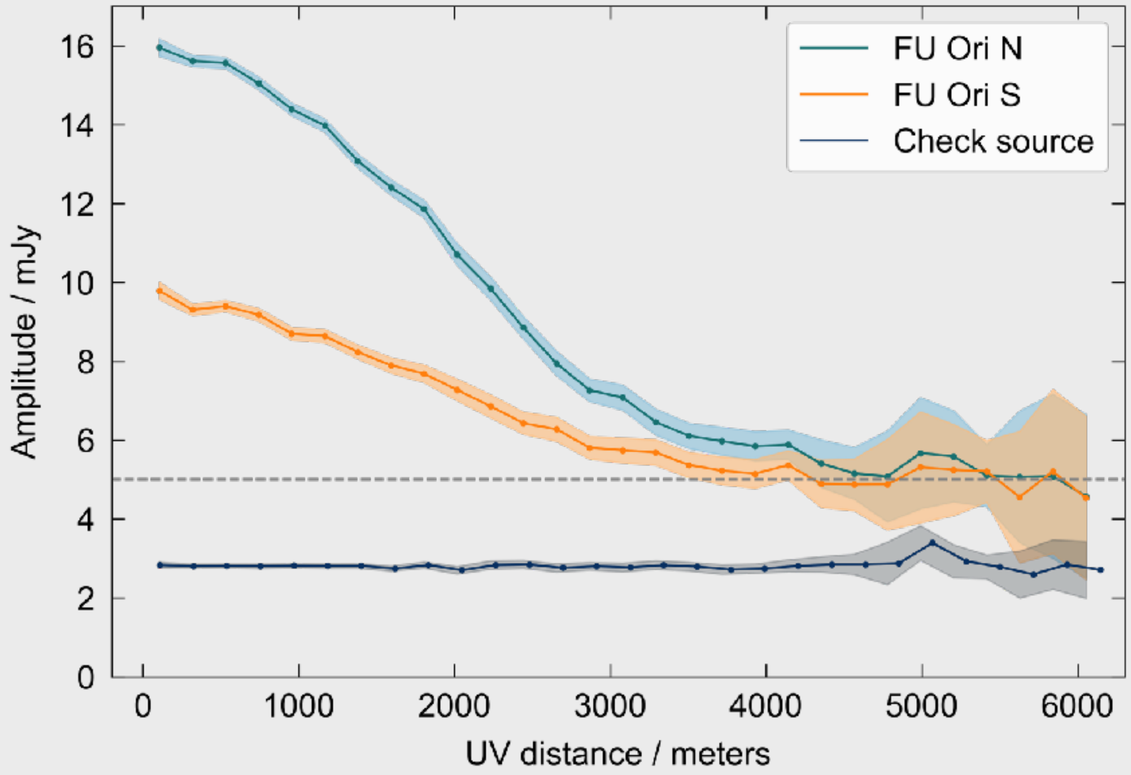
2) probe kinematics for interaction/encounter

Cycle 4 ALMA observations. 1.3 mm images. **Resolved** twin disks at 40 mas resolution

Pérez, Hales, Liu et al. submitted

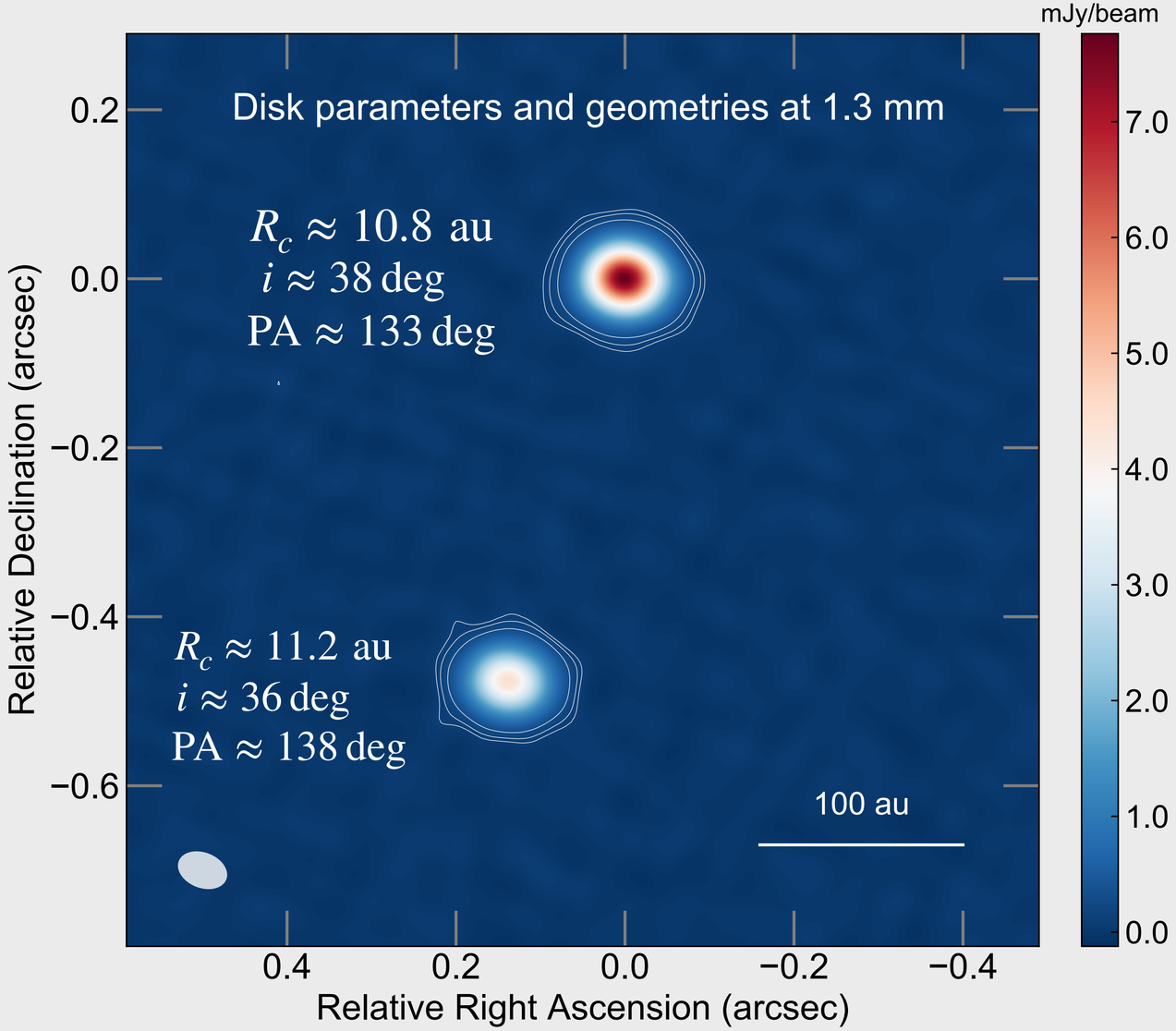


Perez, Hales, Liu et al. submitted

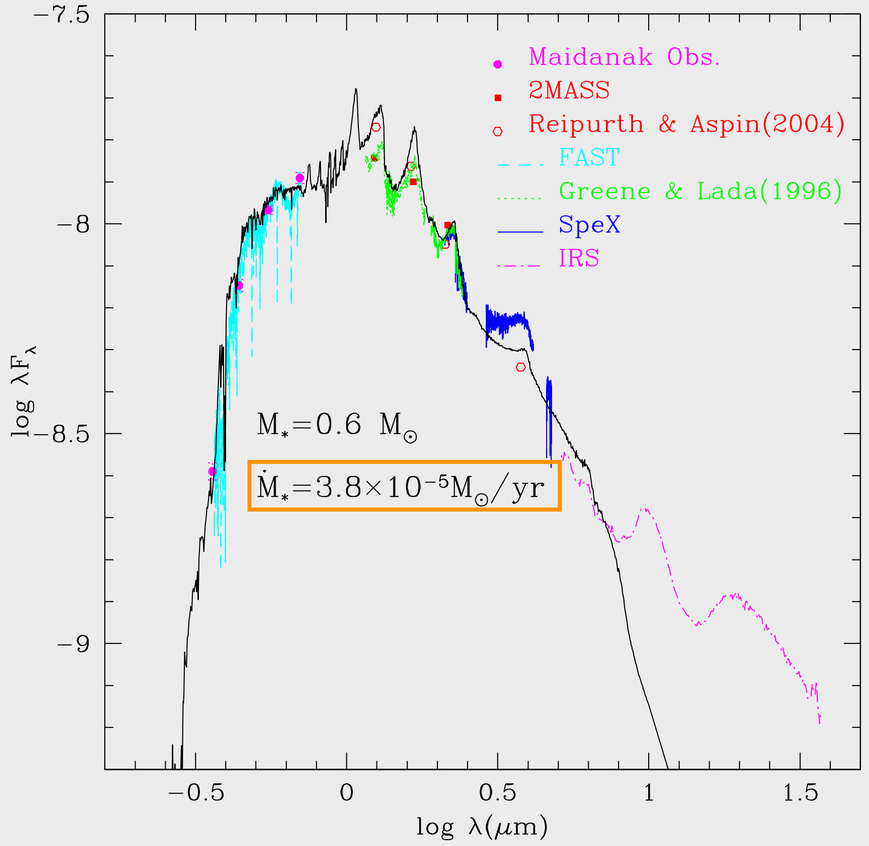


Cycle 4 ALMA observations. 1.3 mm images. **Resolved** twin disks at 40 mas resolution

Pérez, Hales, Liu et al. *submitted*



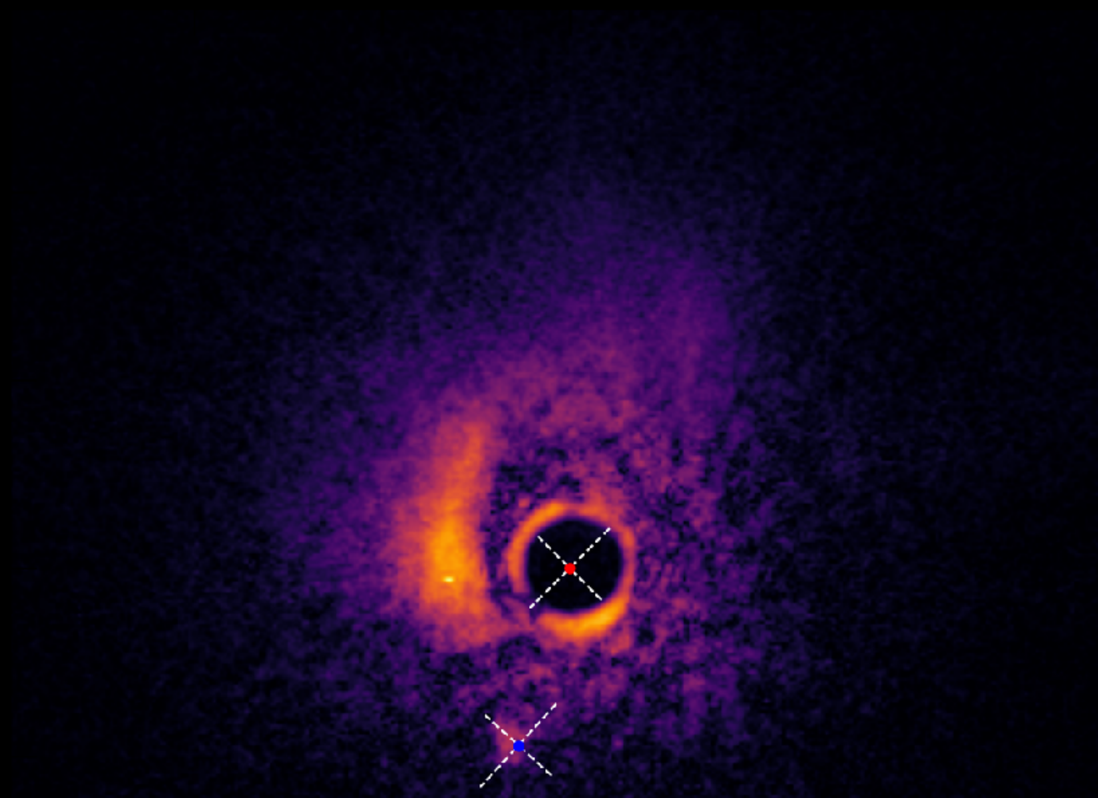
Updated Zhu (2009) model with inclination and GAIA2 distance



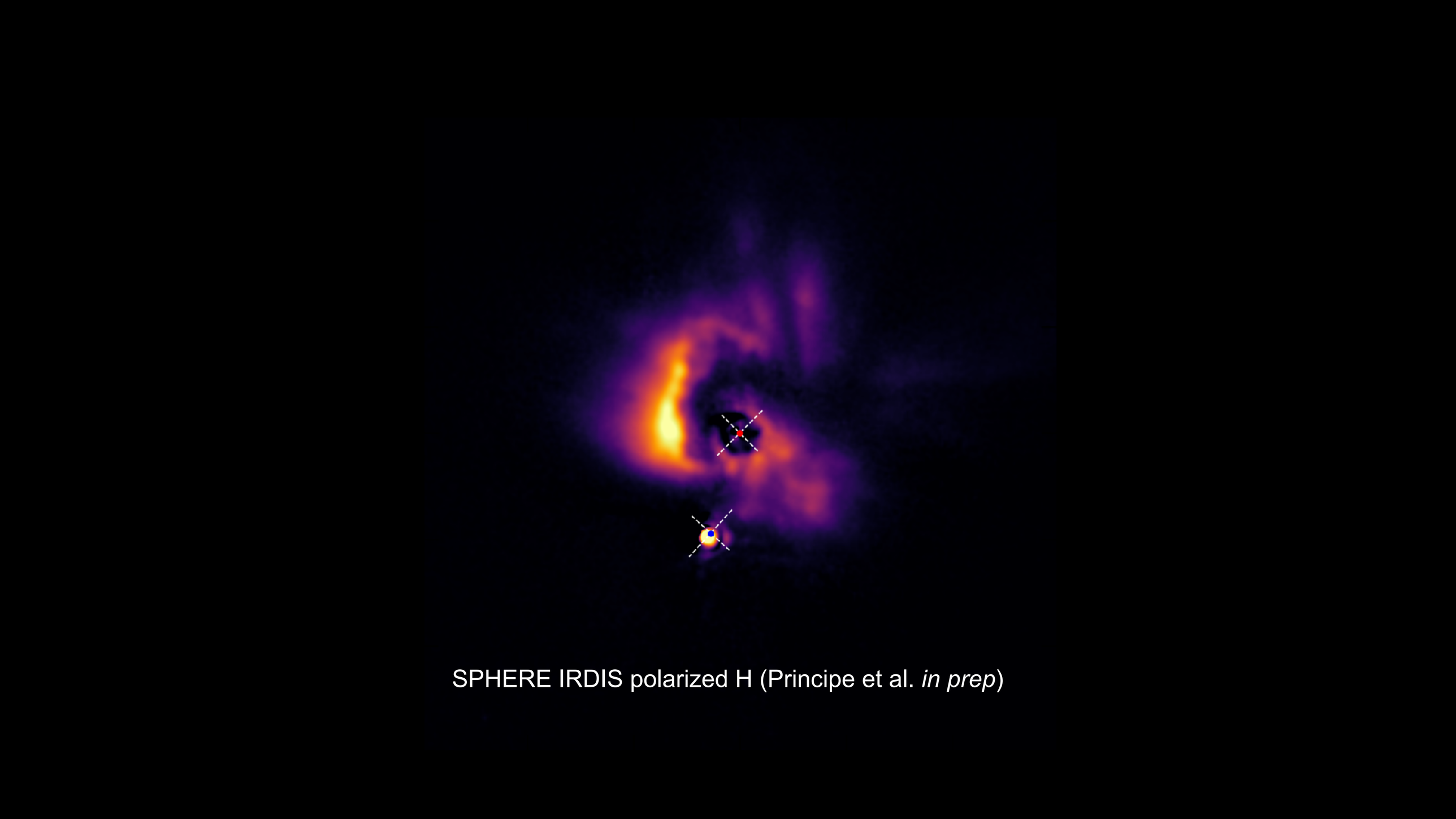
Motivation for ALMA observations:

1) measure disk sizes / geometry

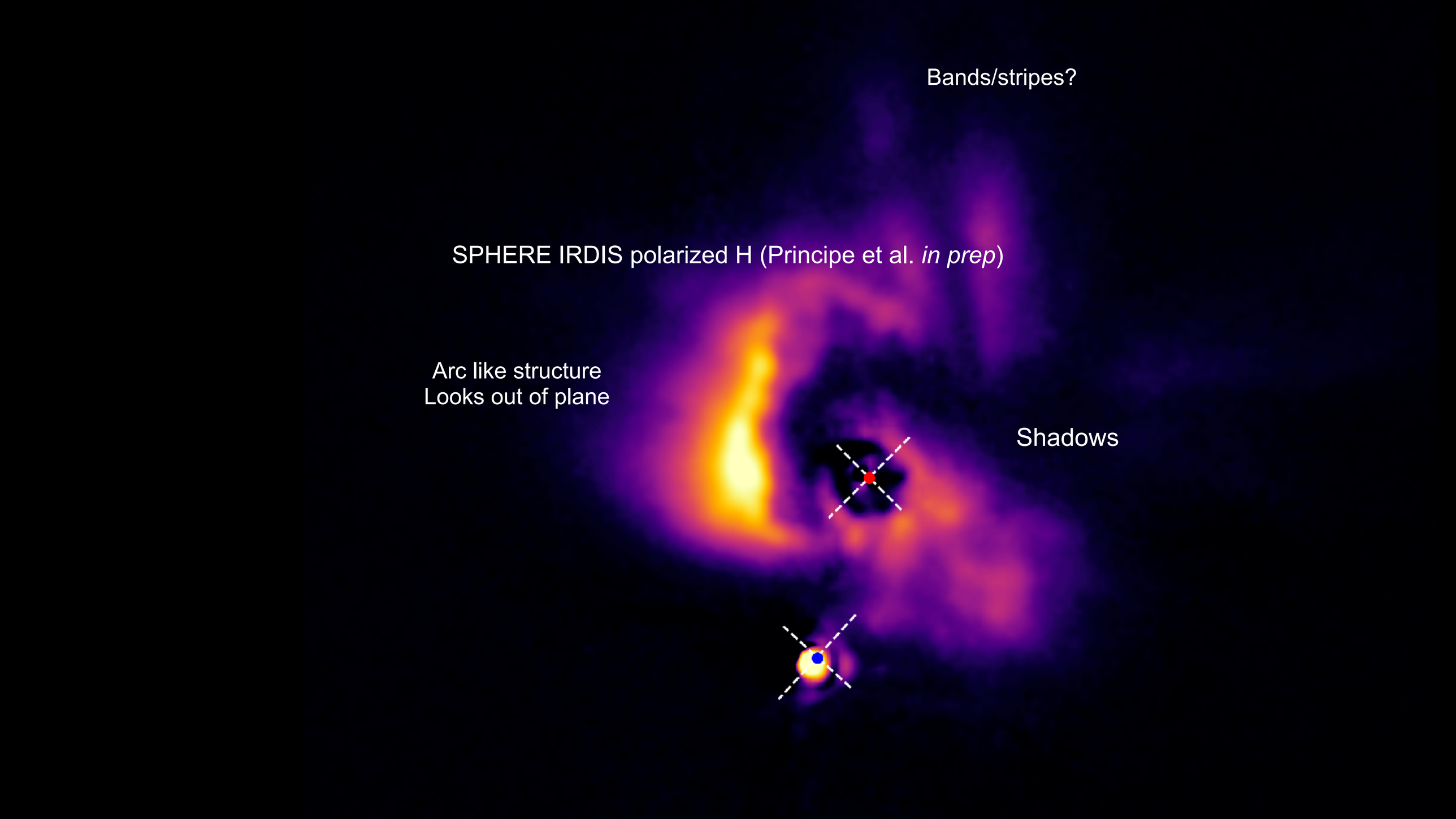
2) probe kinematics for interaction/encounter



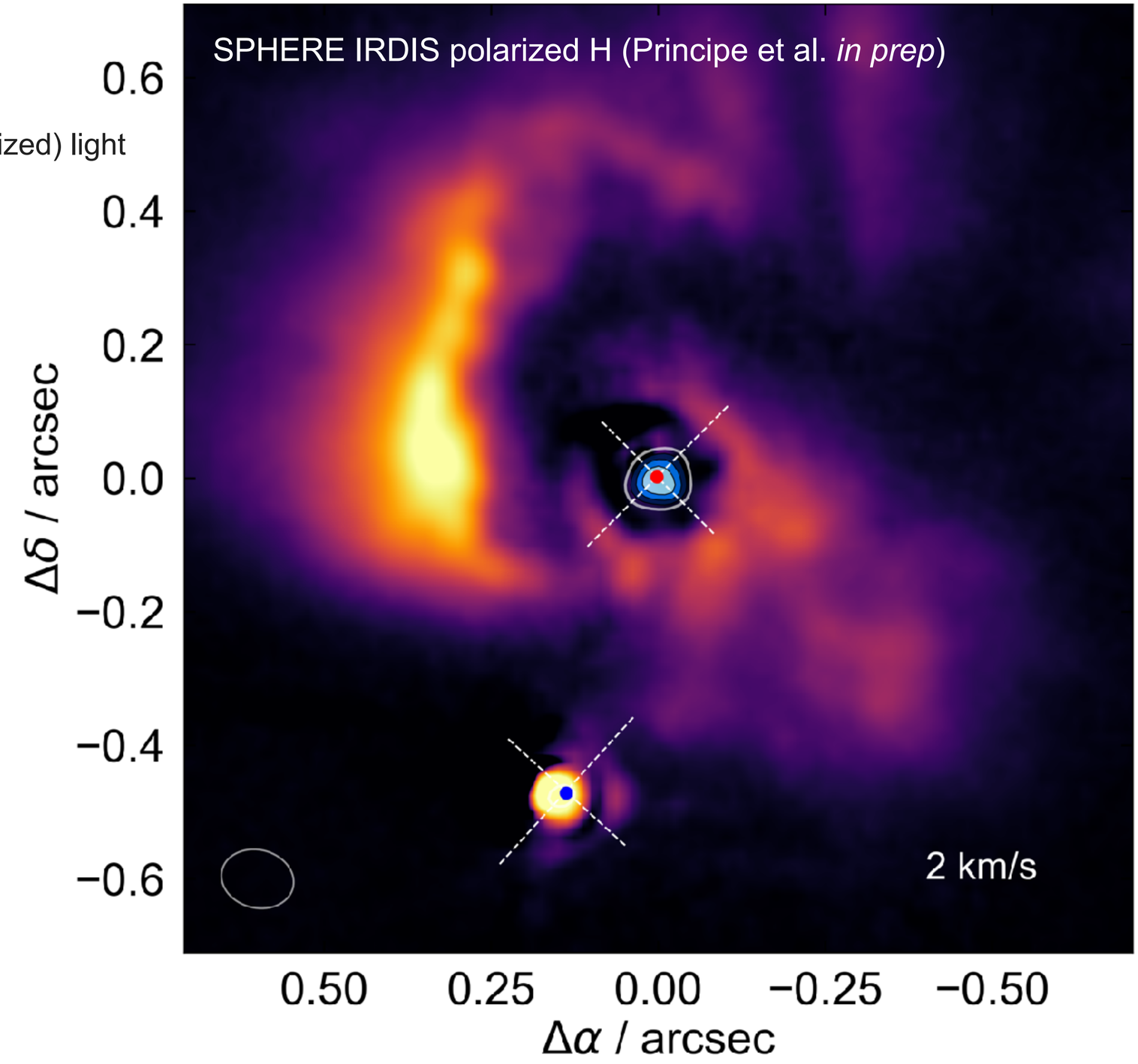
HiCIAO polarized H (Liu et al. 2016, Takami et al. 2018)

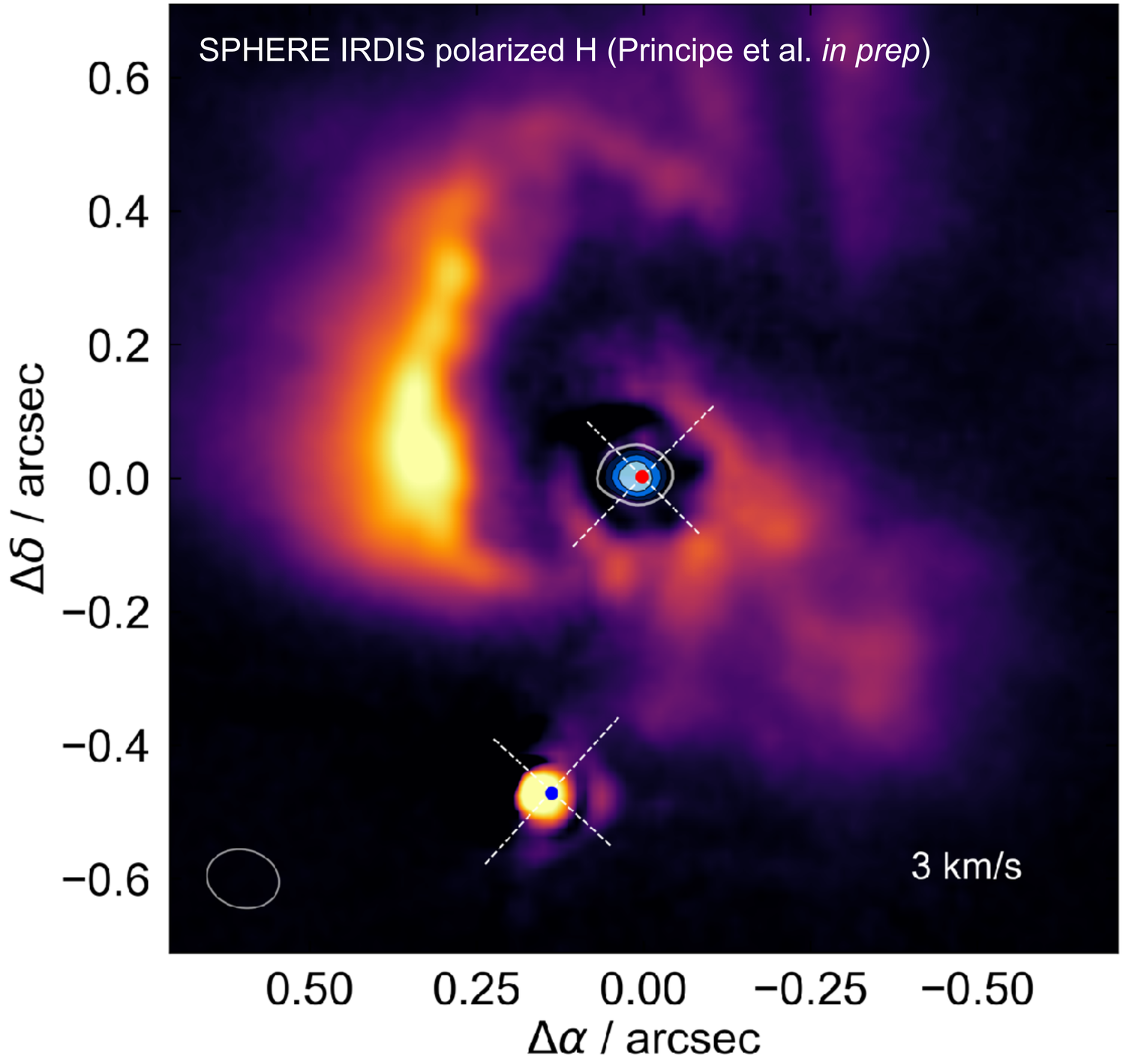


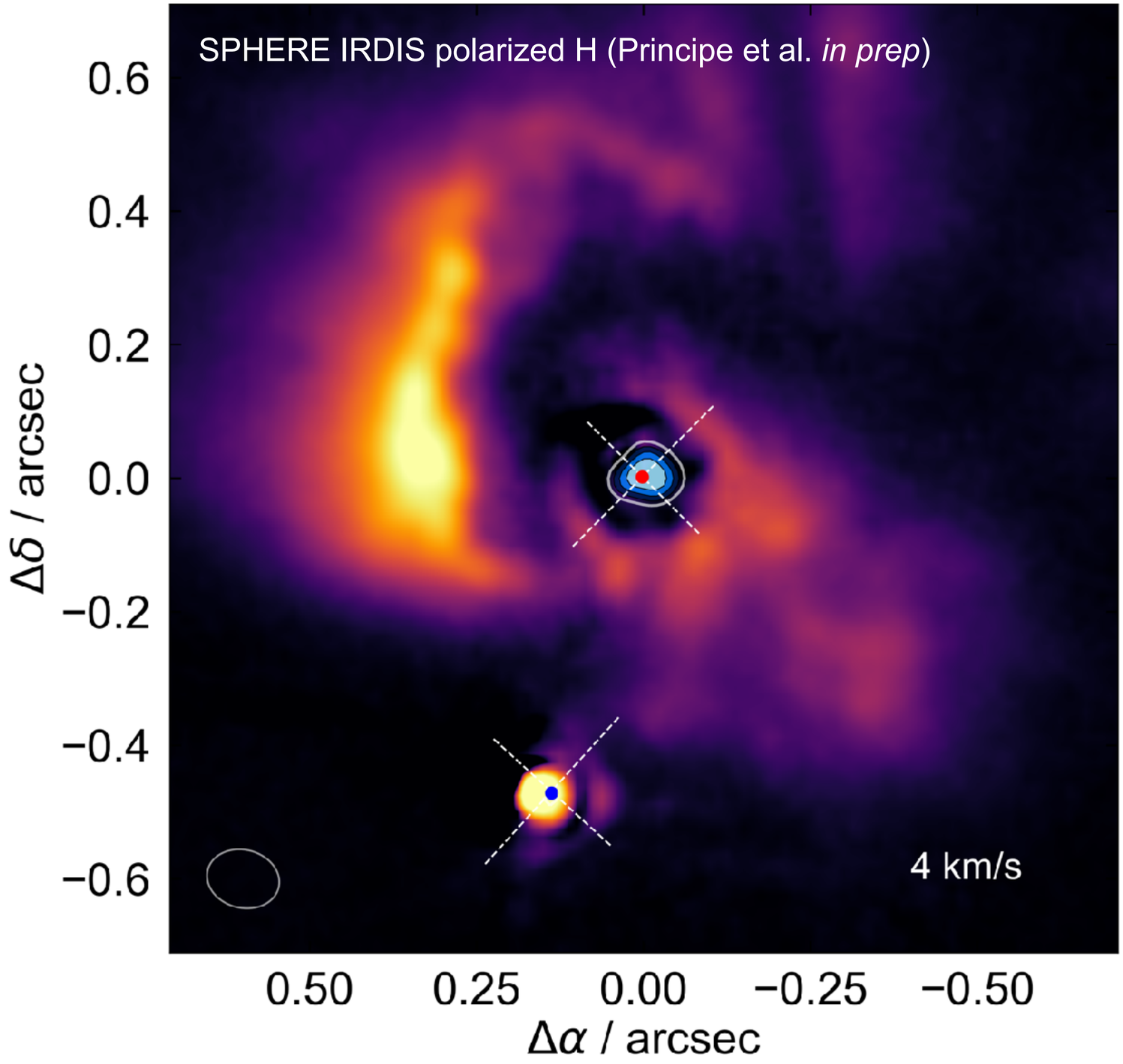
SPHERE IRDIS polarized H (Principe et al. *in prep*)

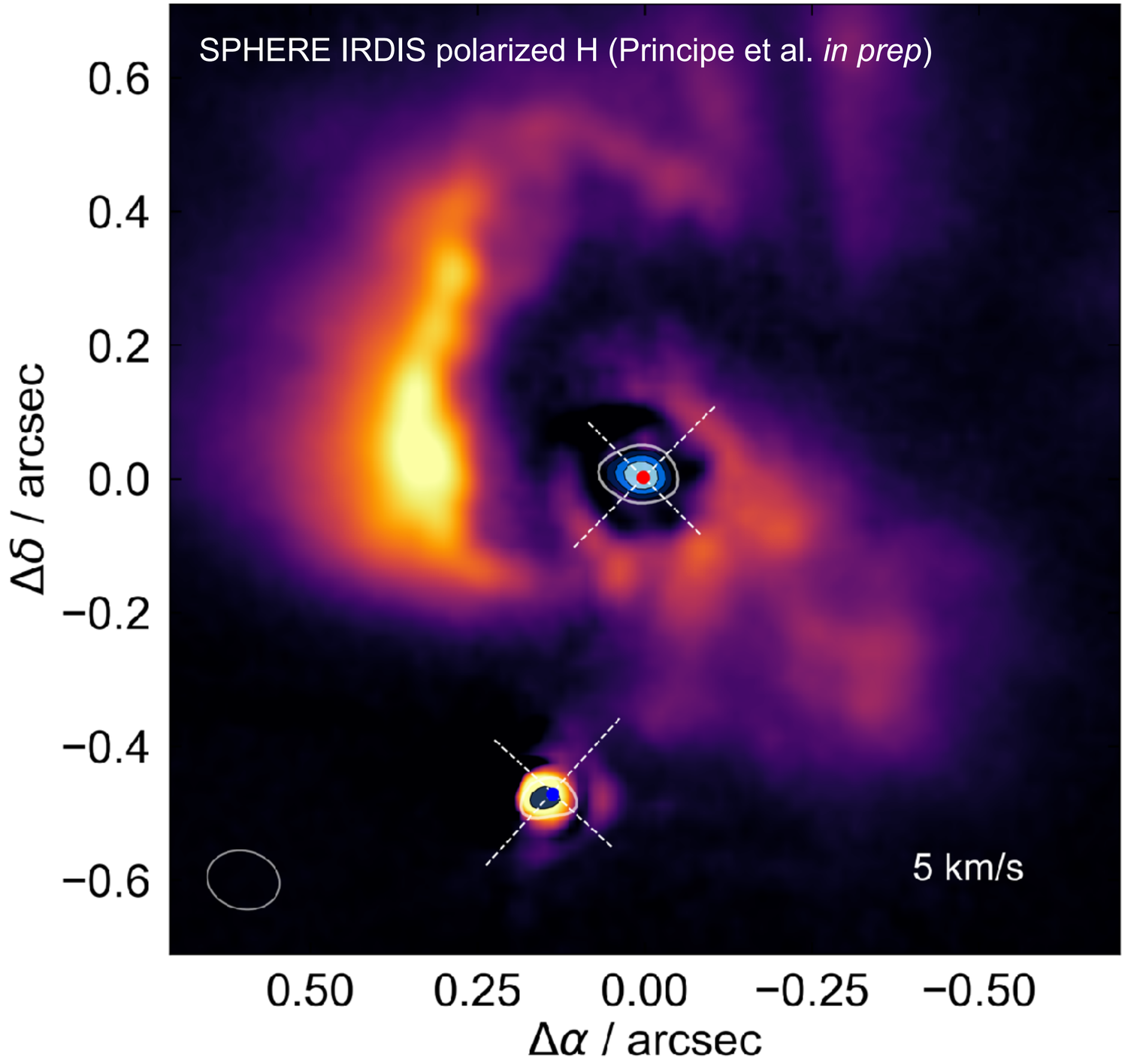

Bands/stripes?
SPHERE IRDIS polarized H (Principe et al. *in prep*)
Arc like structure
Looks out of plane
Shadows

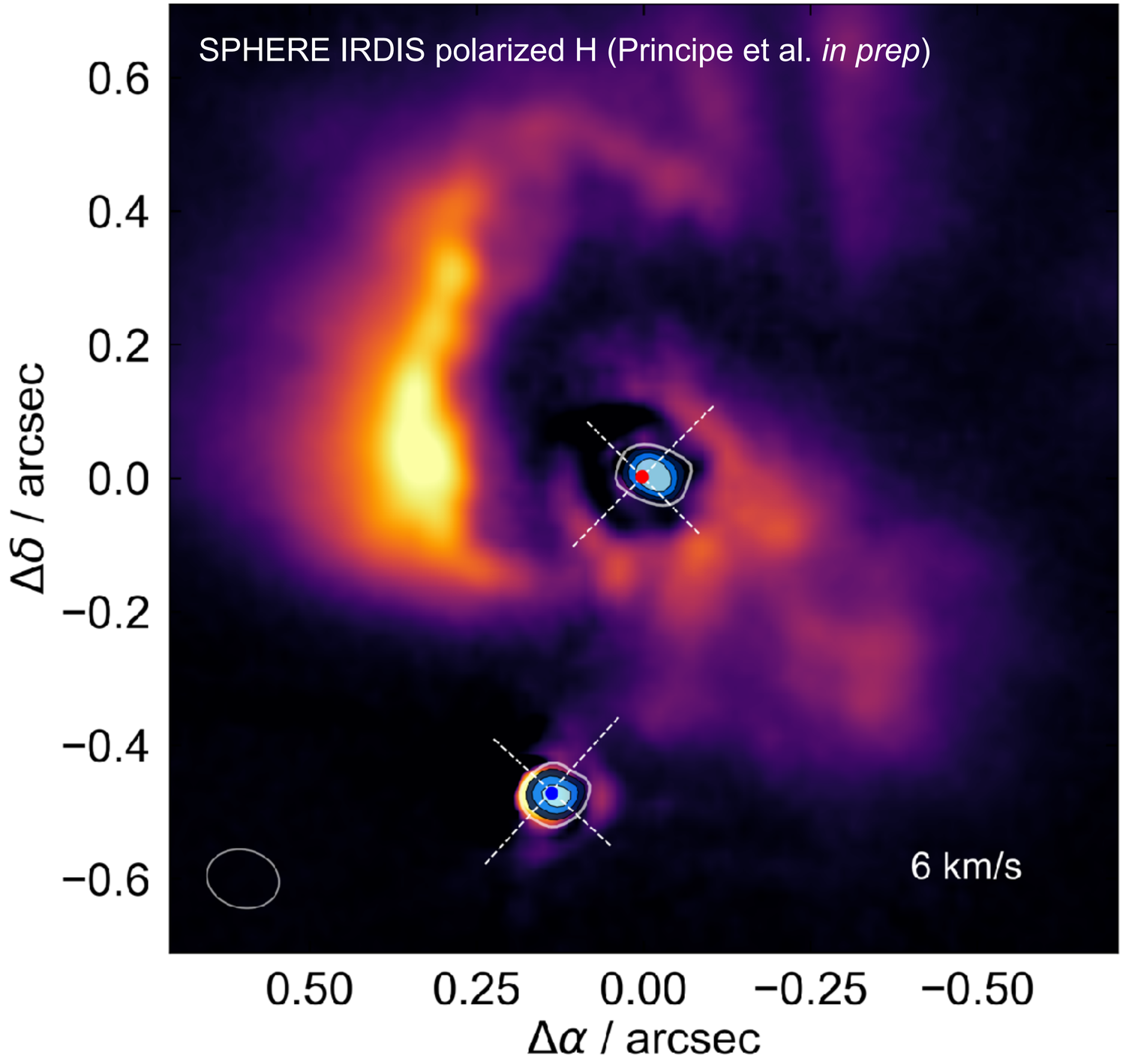
ALMA 12CO kinematics
SPHERE scattered (polarized) light

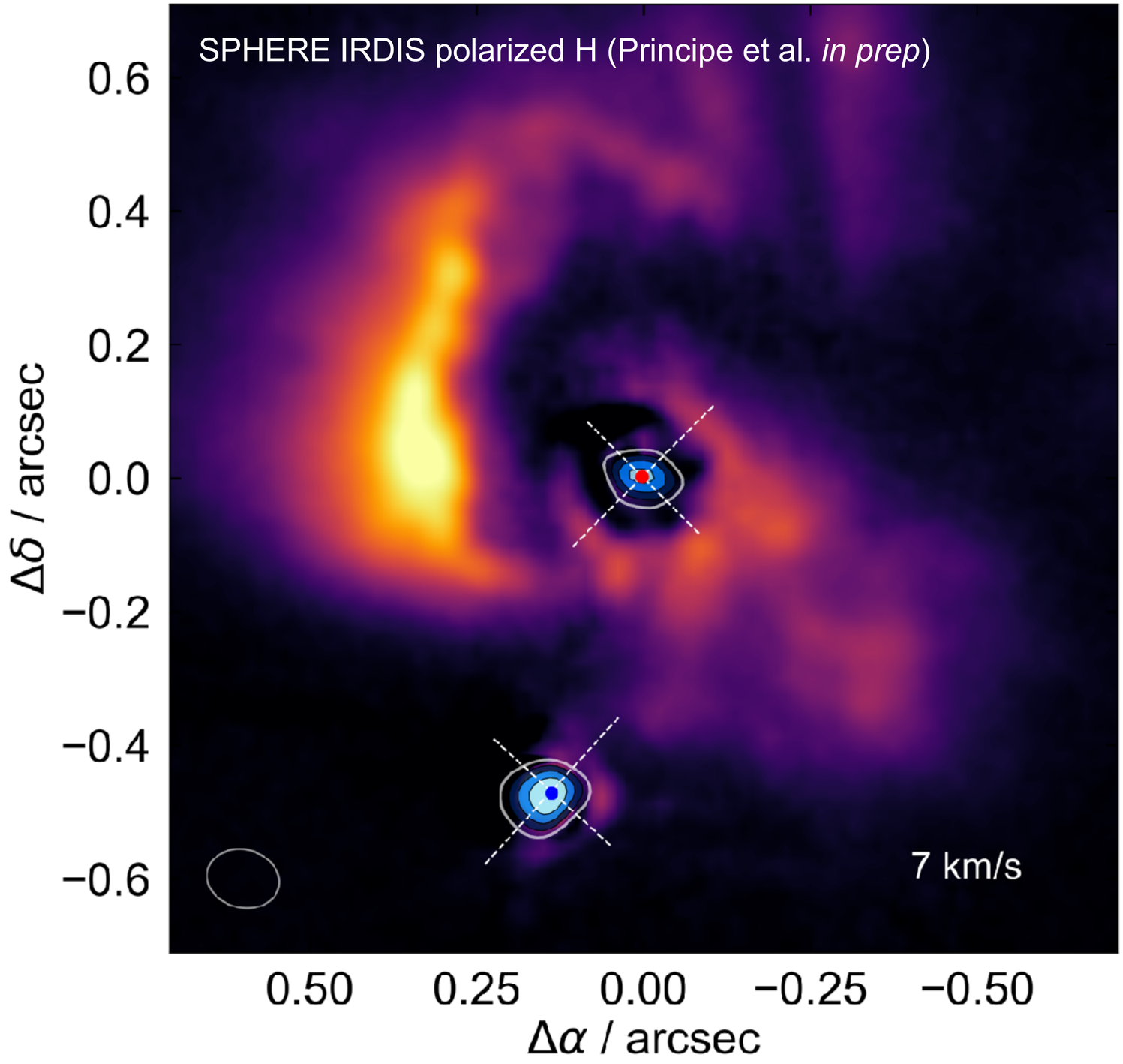


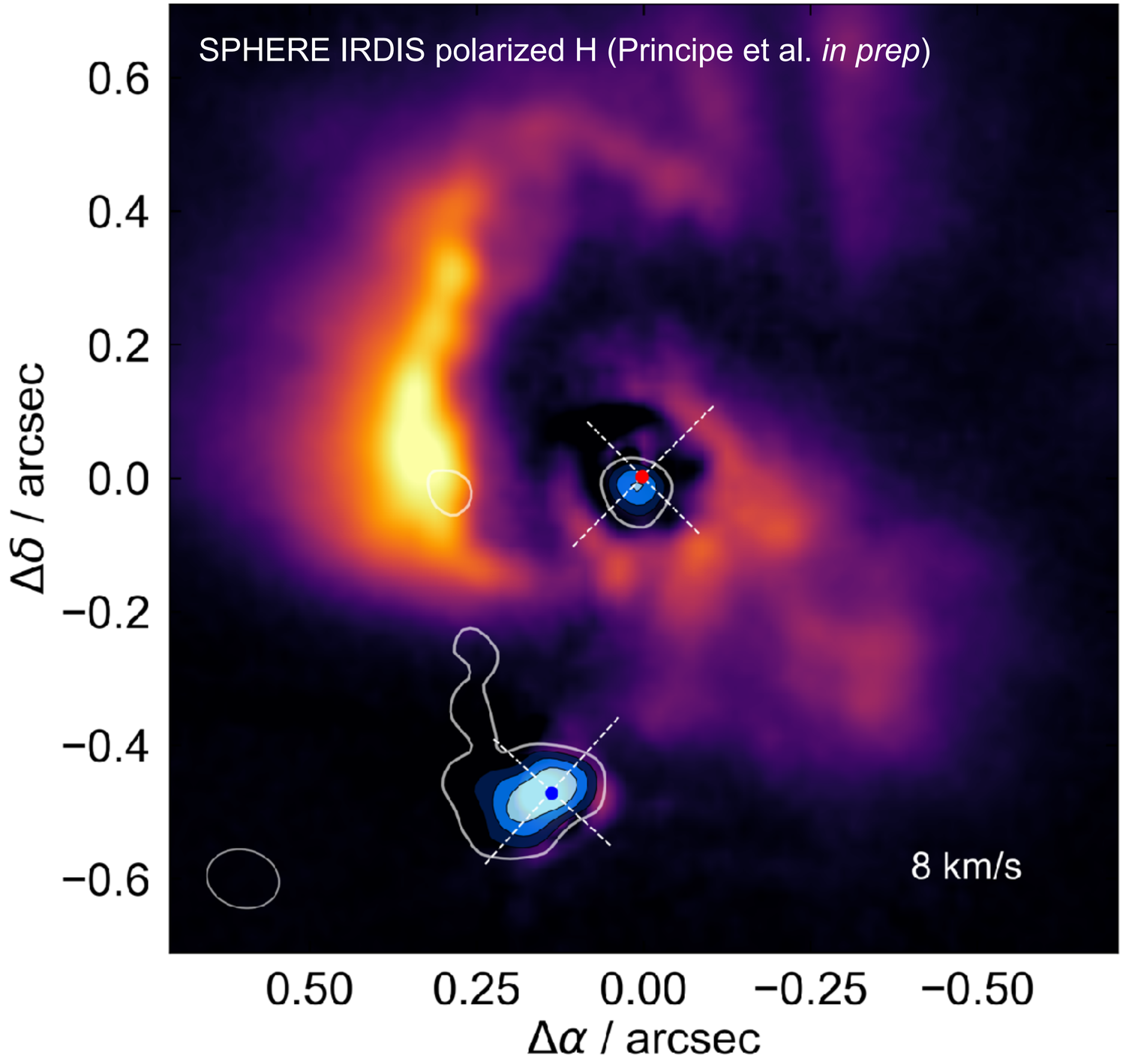

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
3 km/s

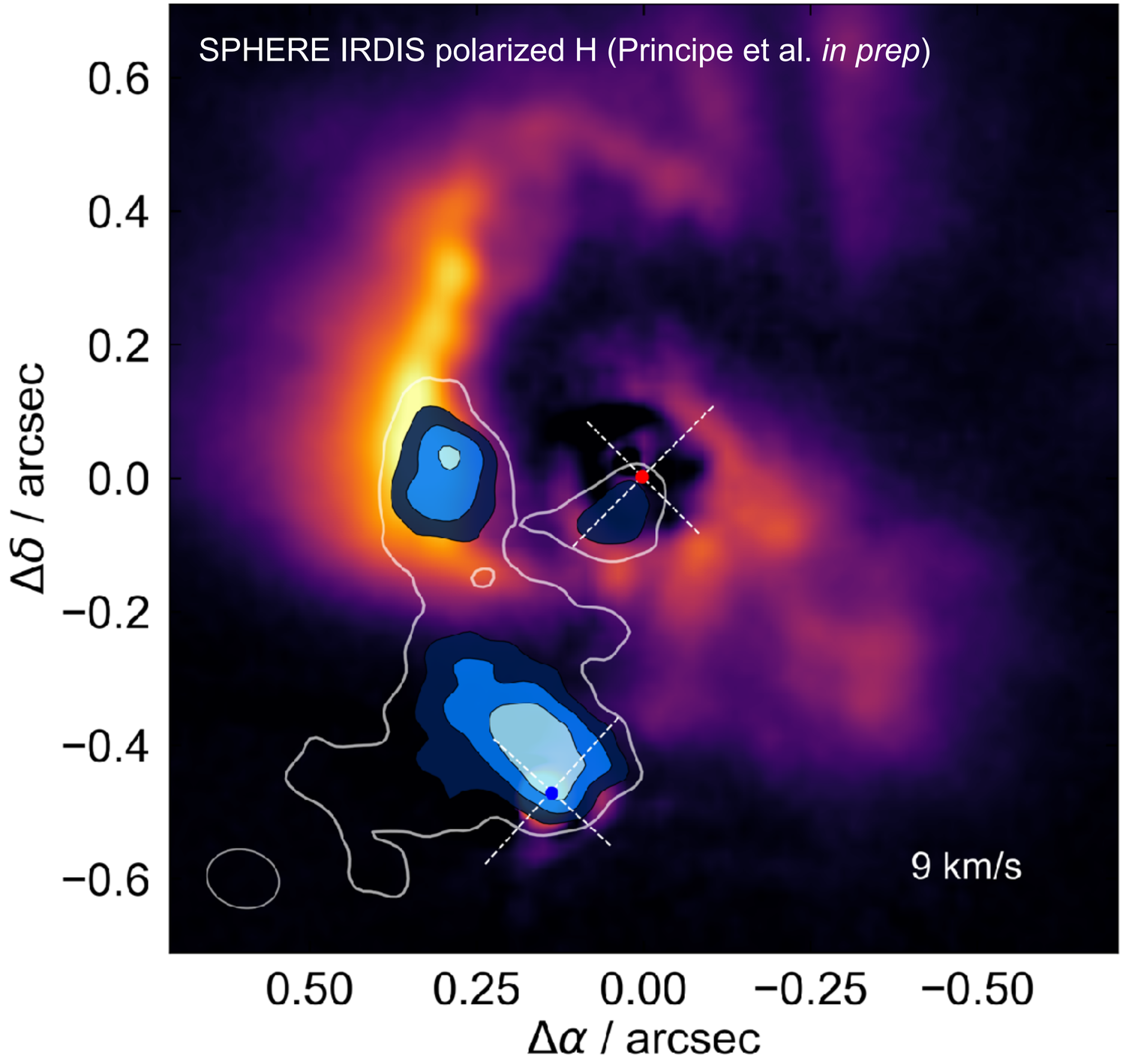

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
4 km/s

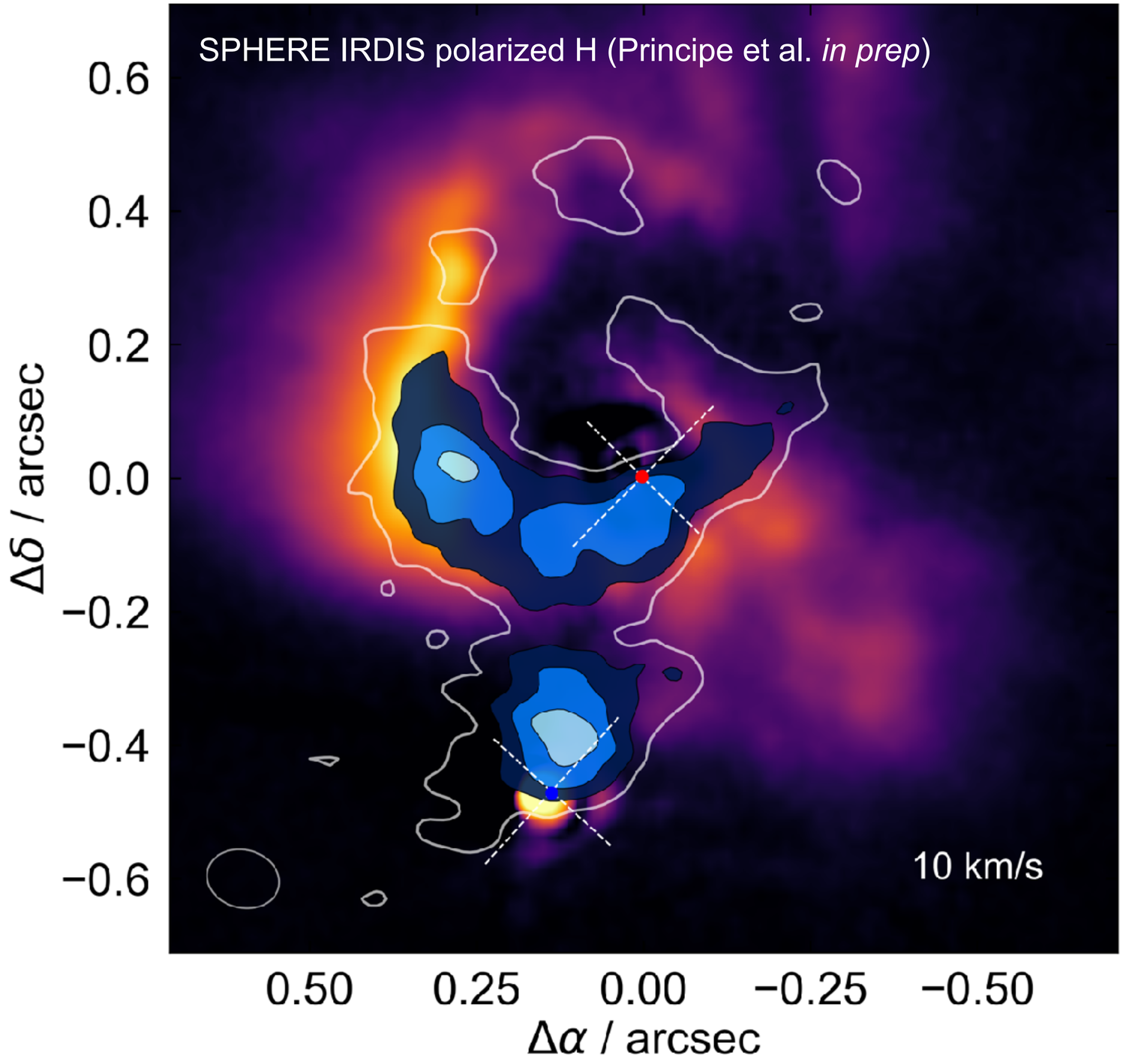

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
5 km/s

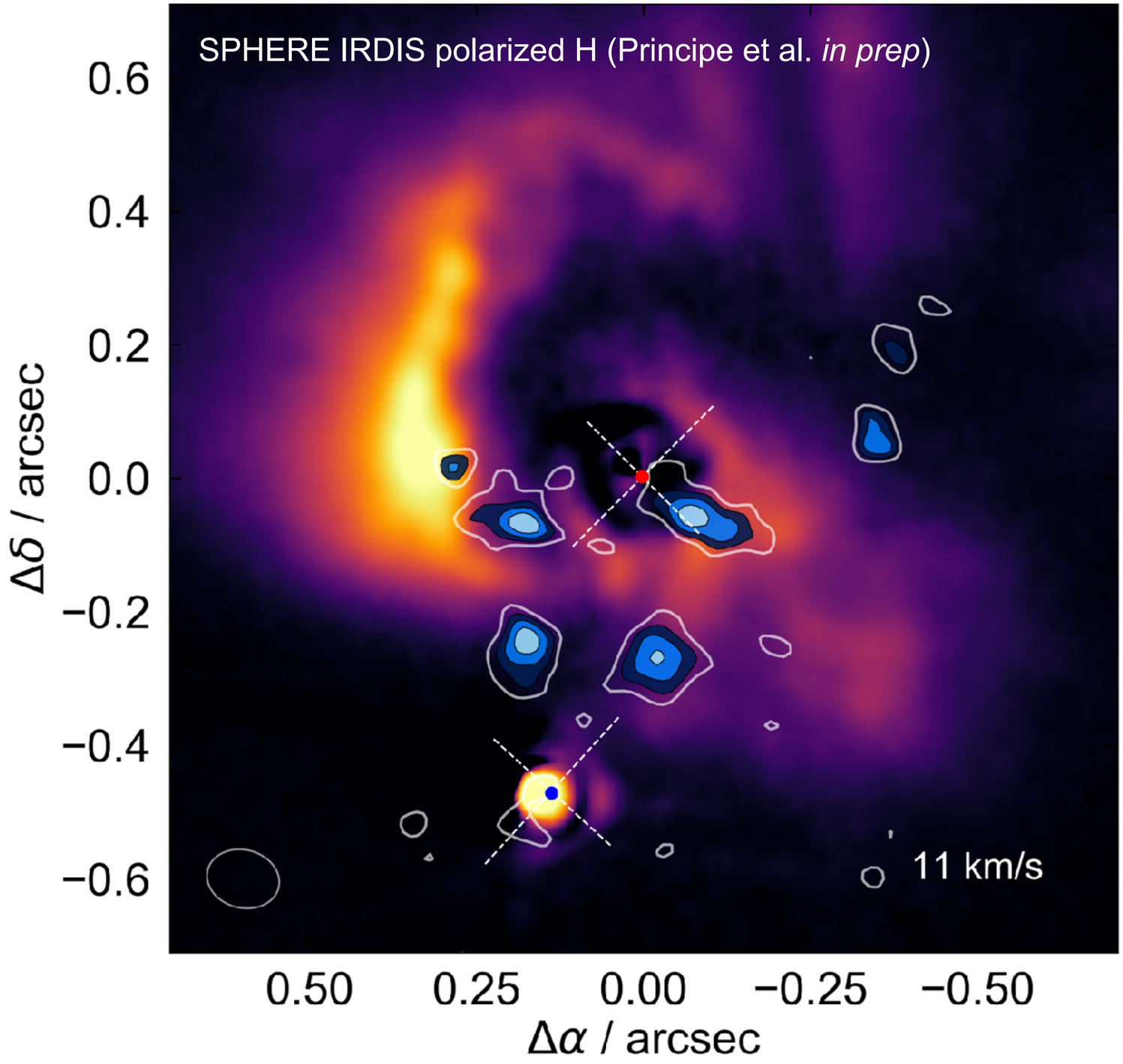

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
6 km/s

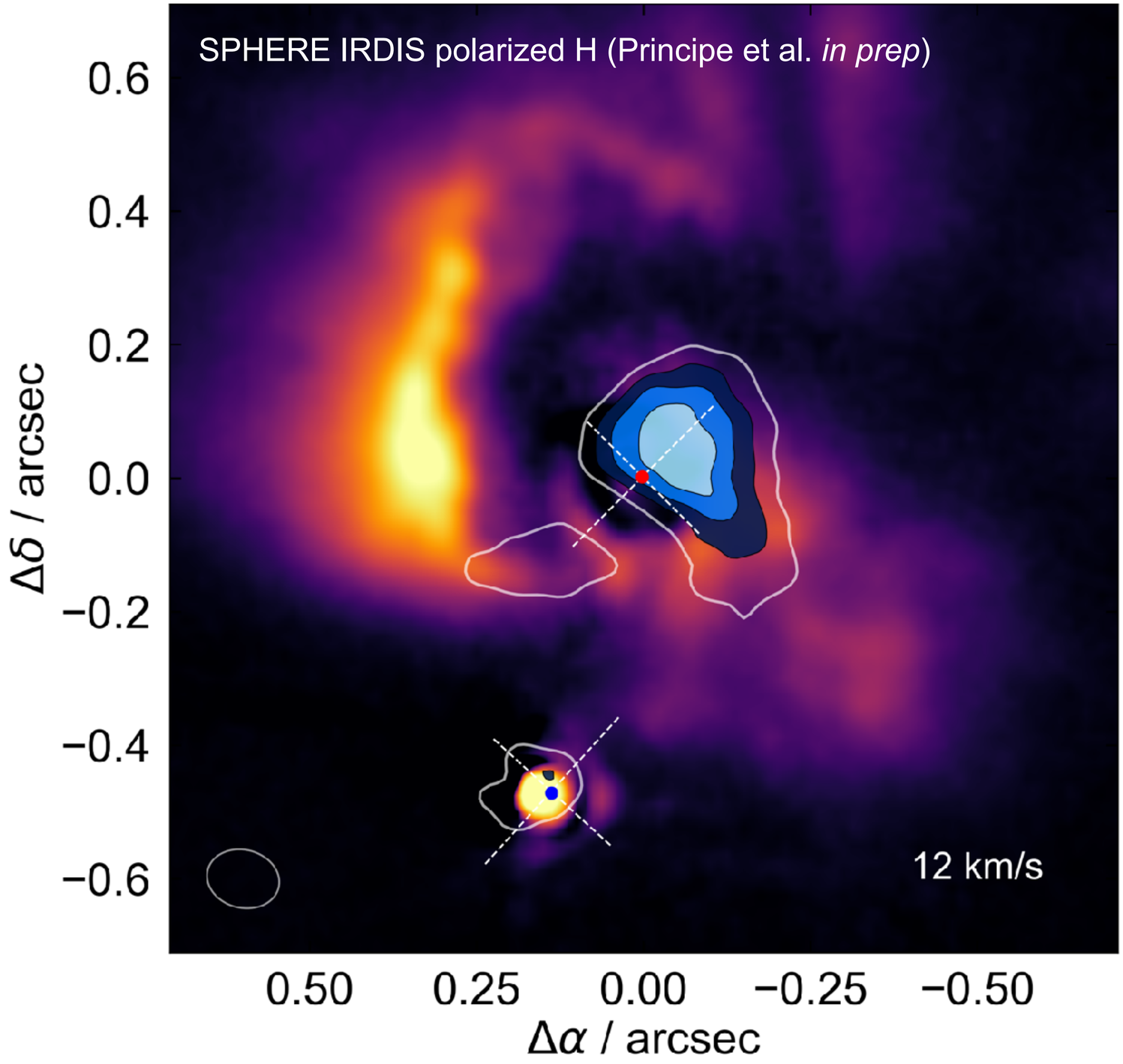

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
7 km/s

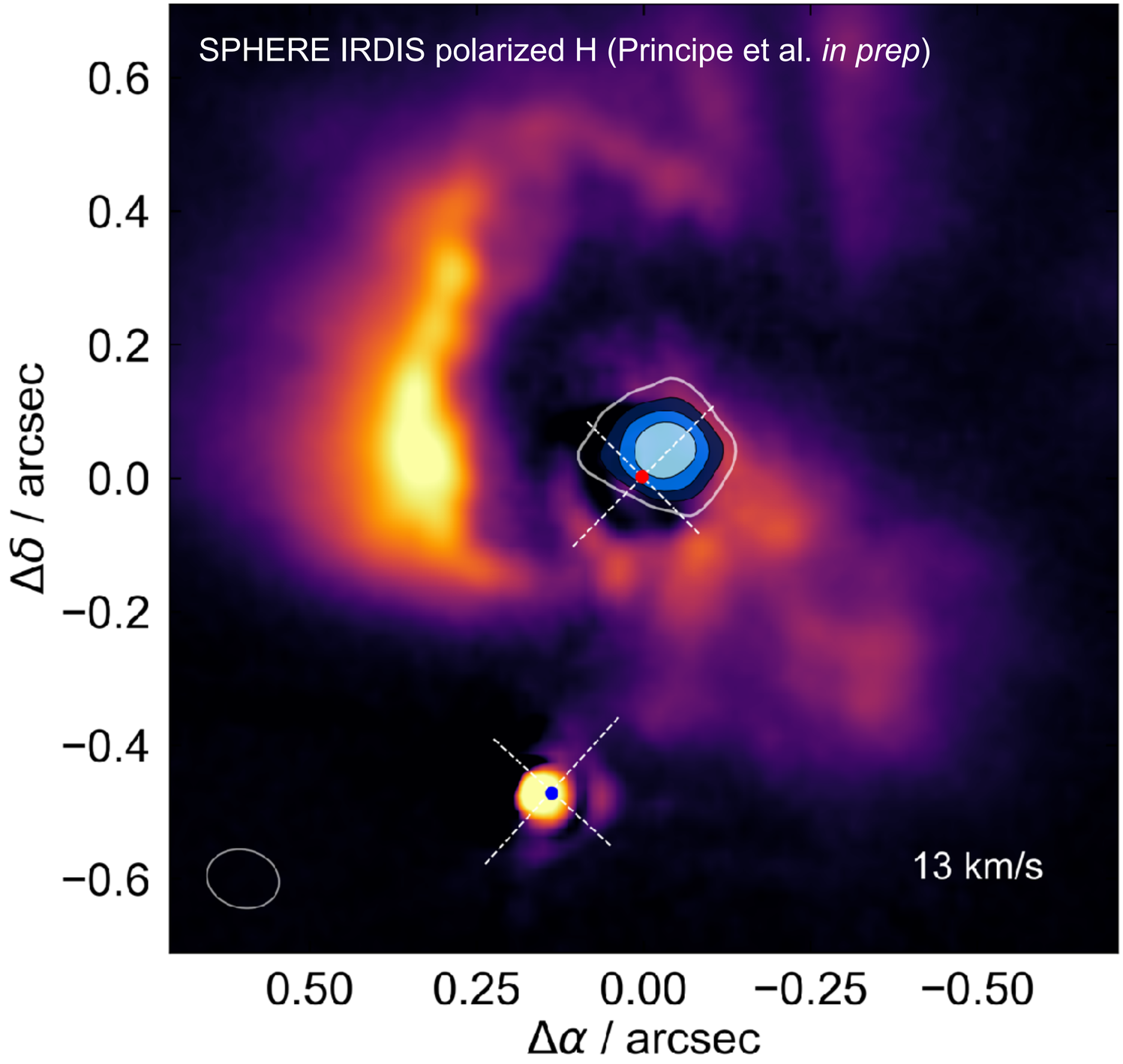

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
8 km/s

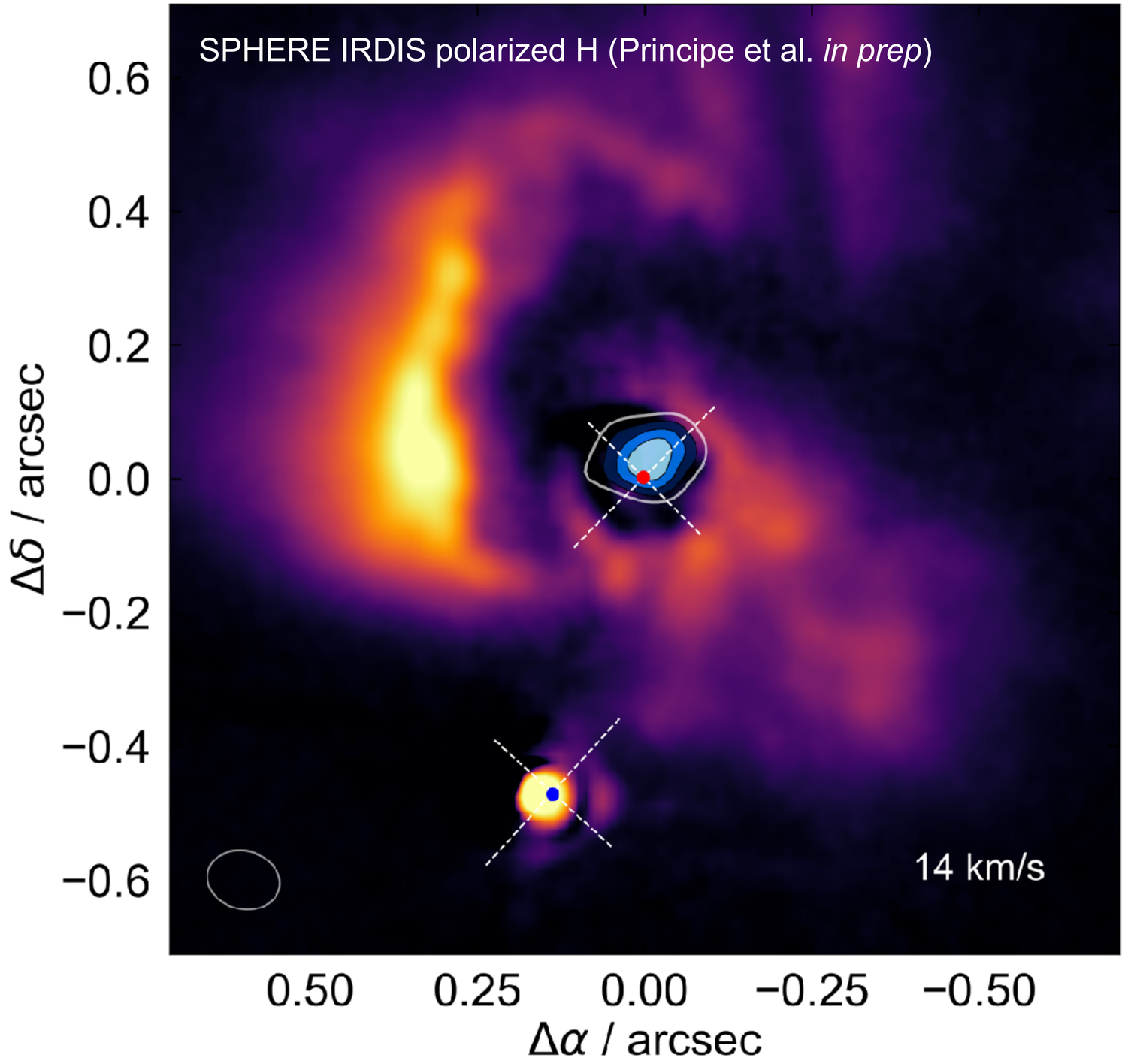

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
9 km/s
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec

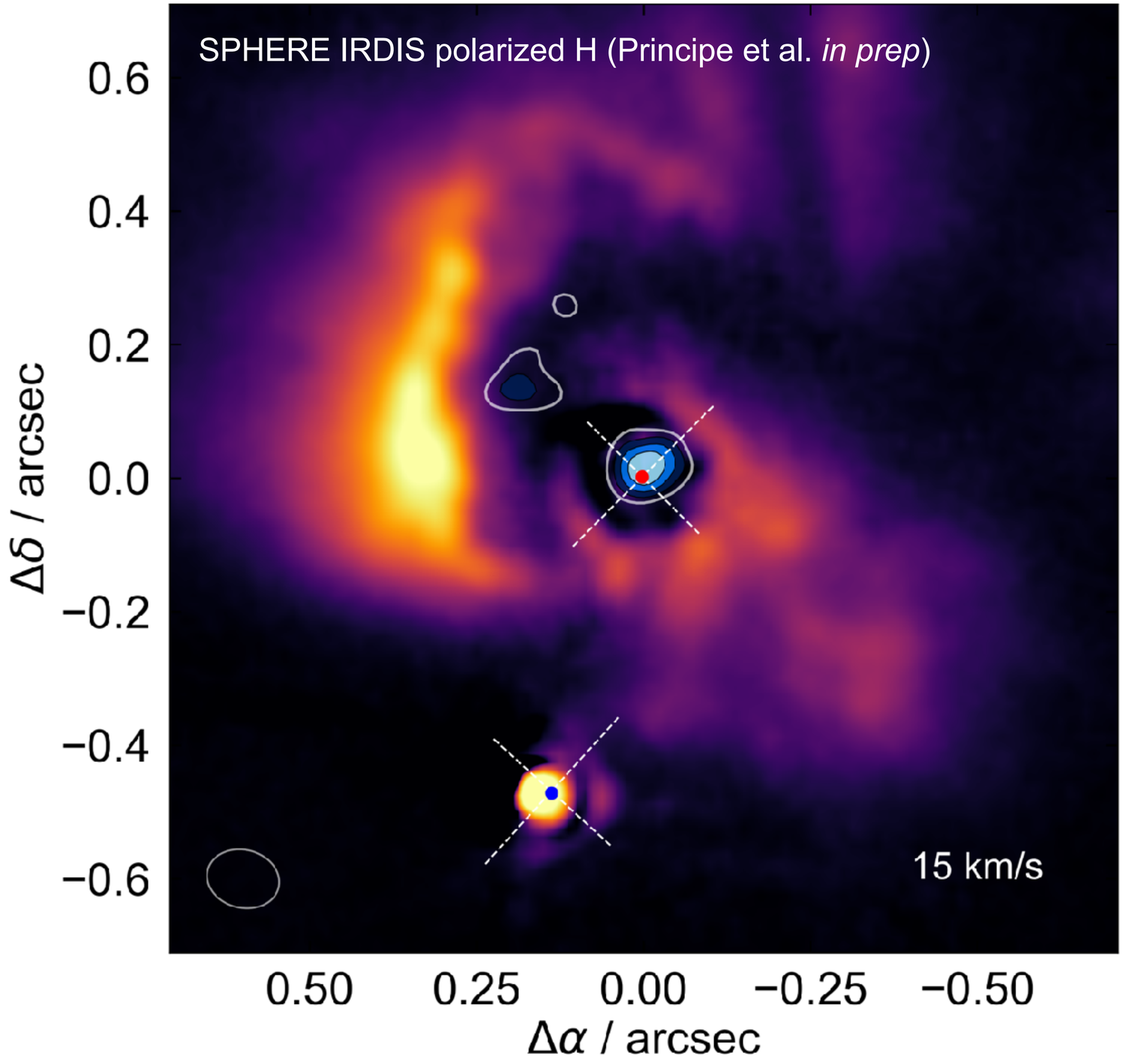

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
10 km/s
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec

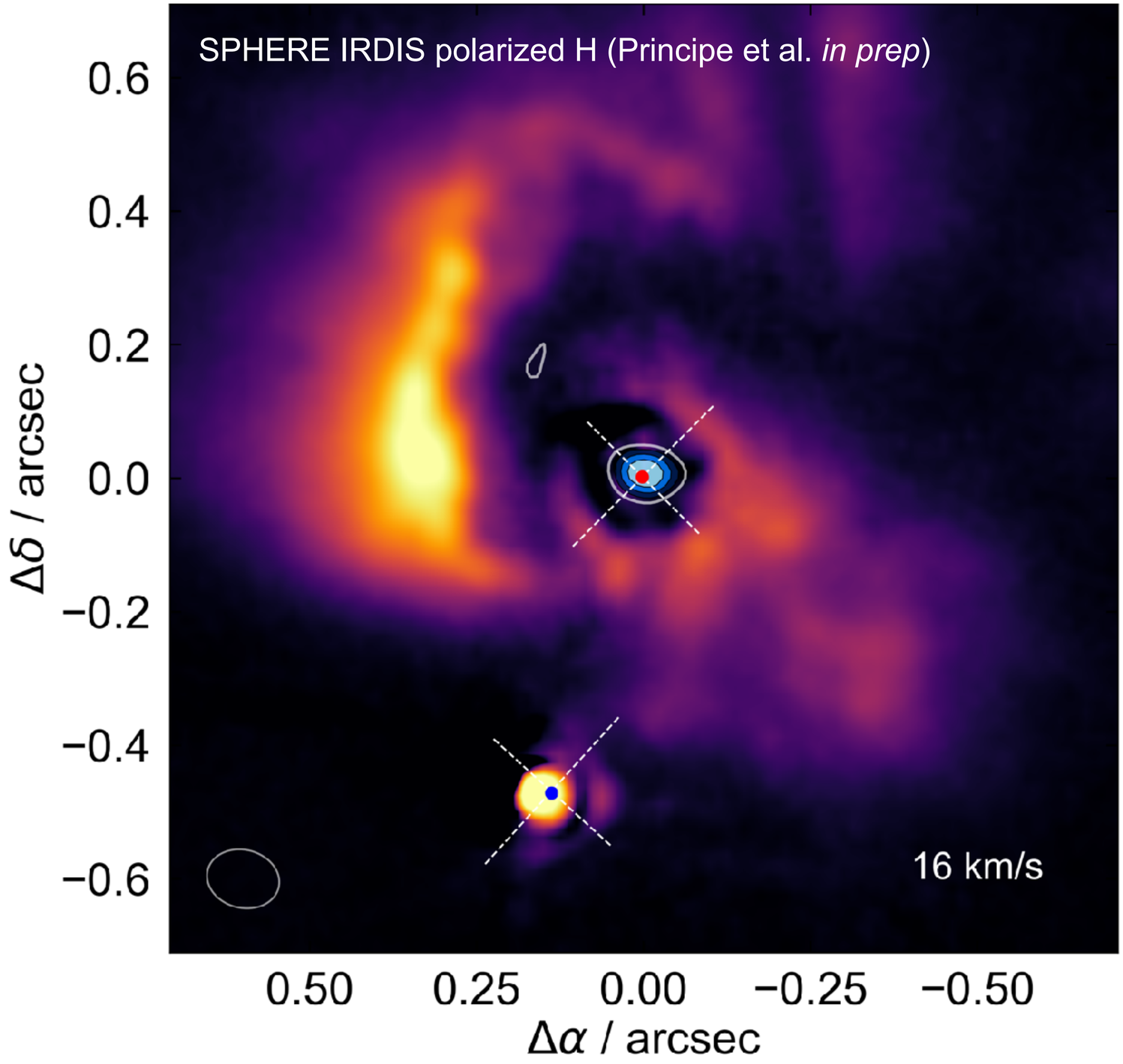

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
11 km/s

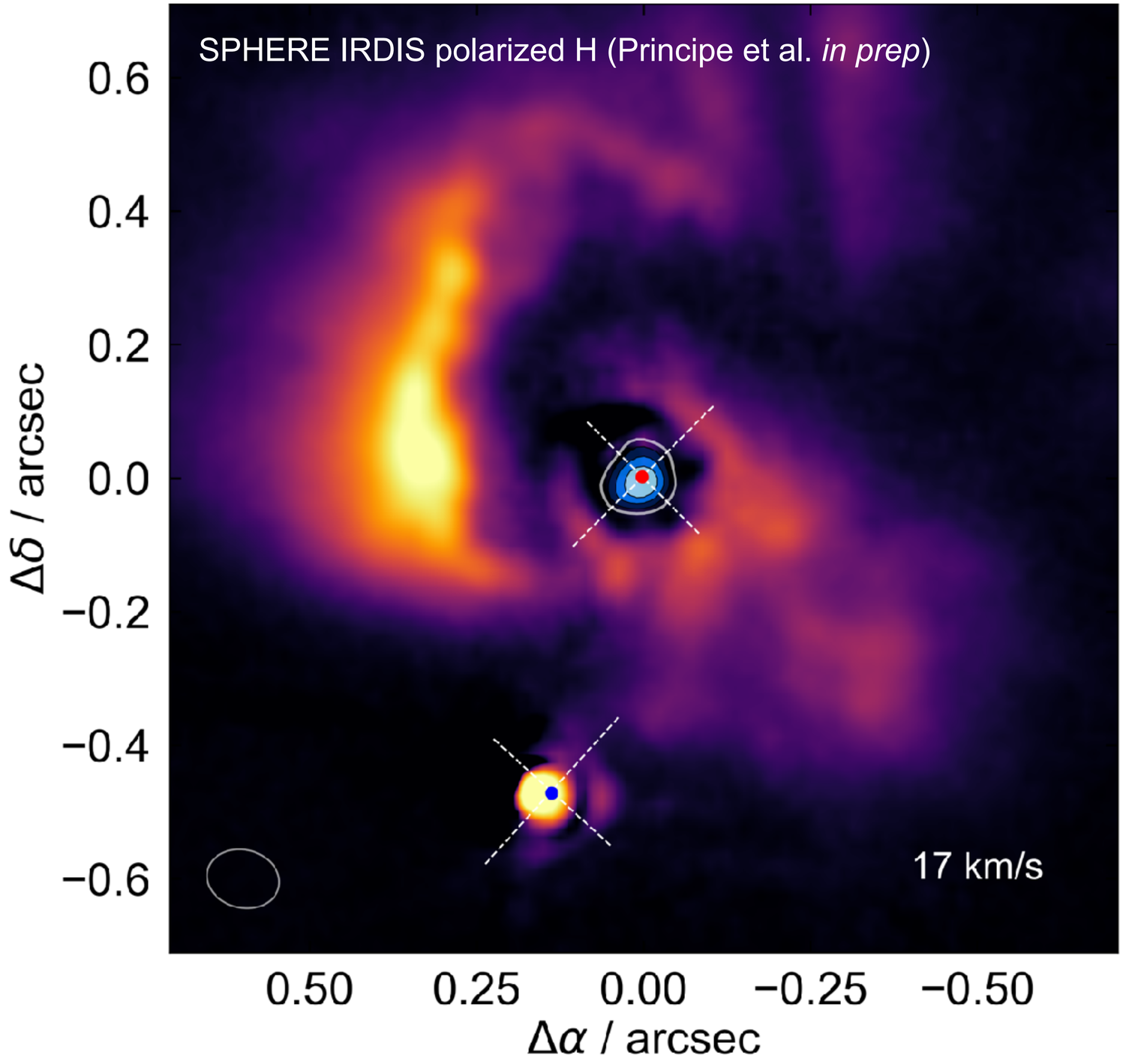

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
12 km/s

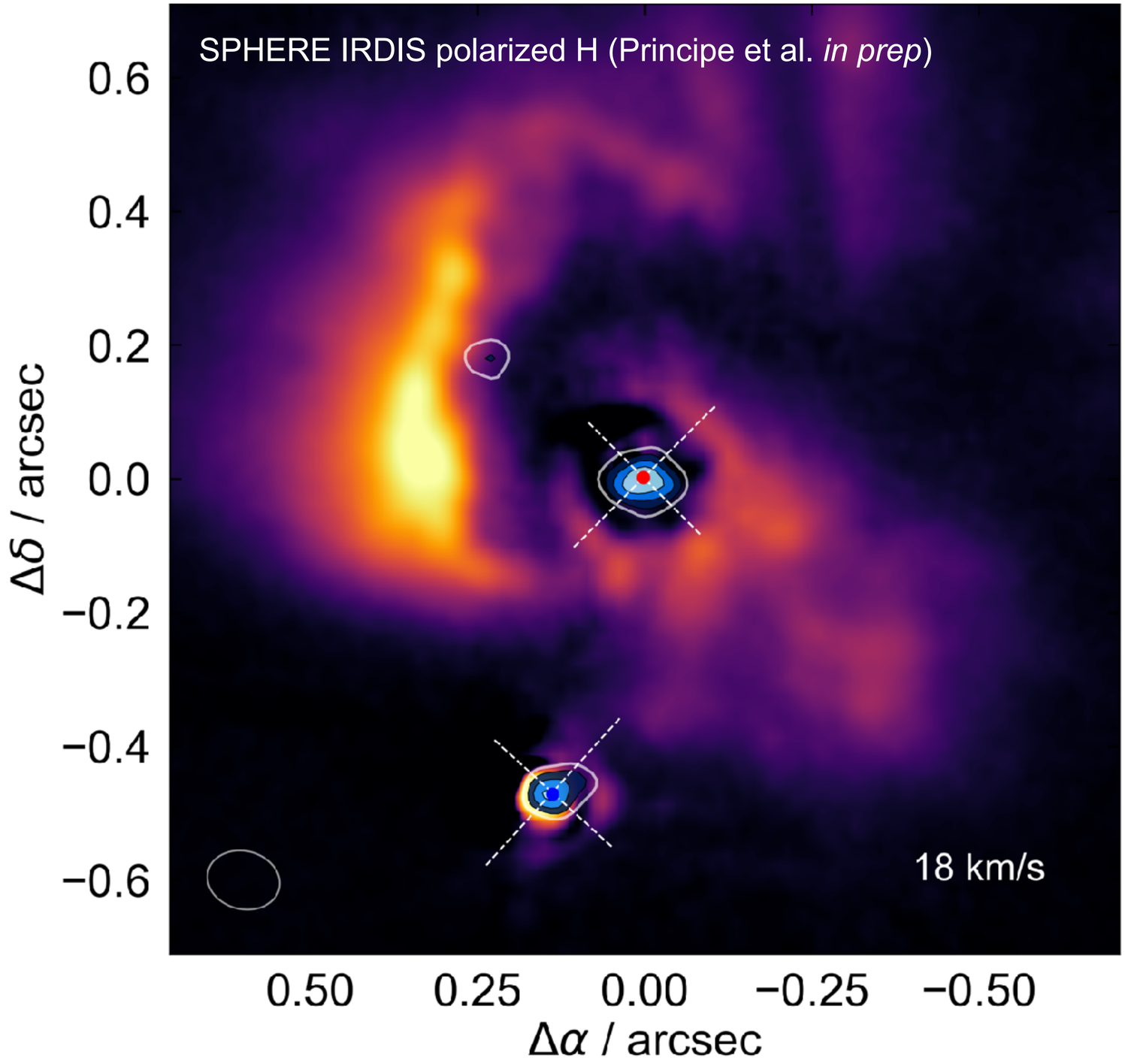

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
13 km/s

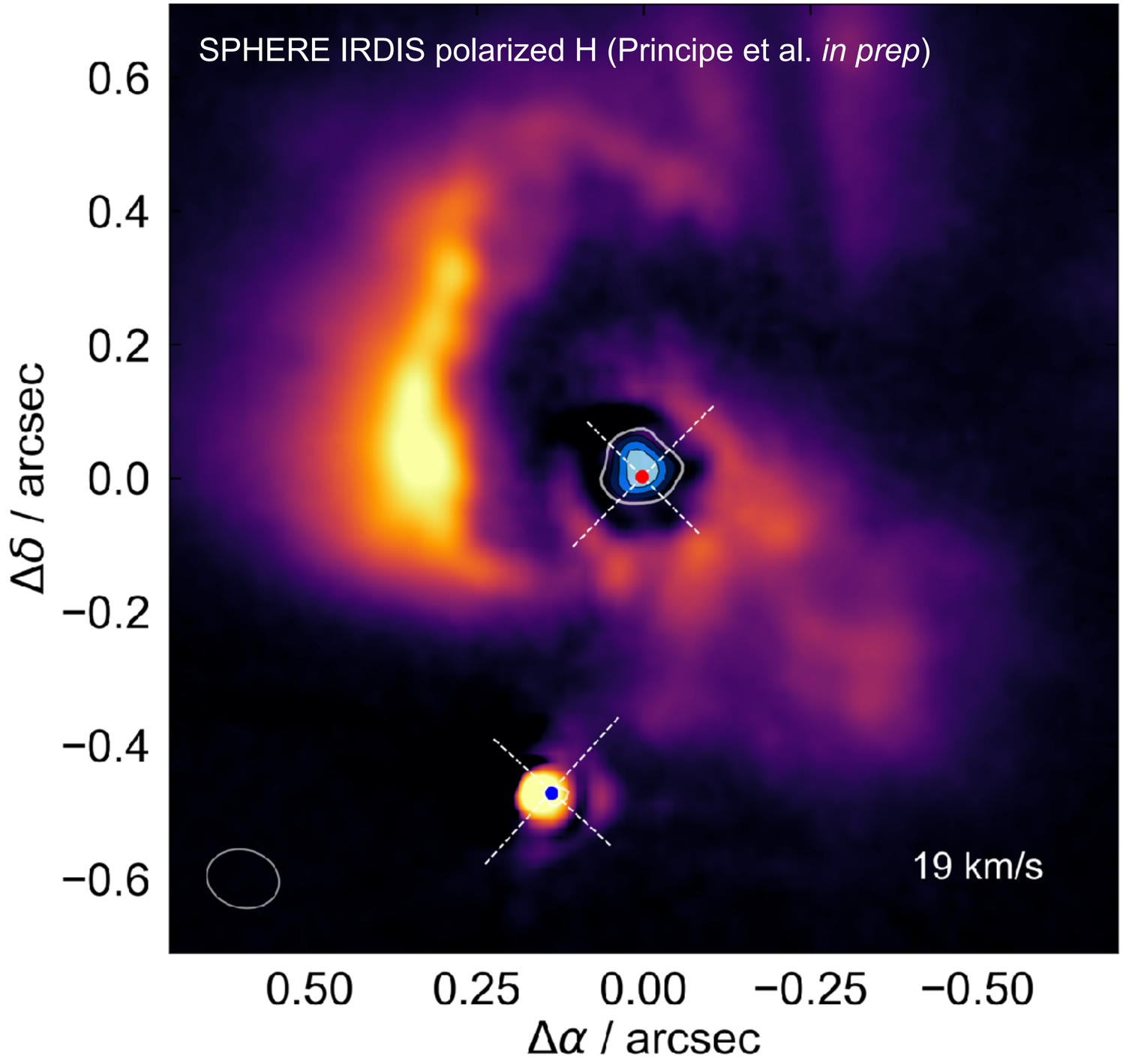

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
14 km/s

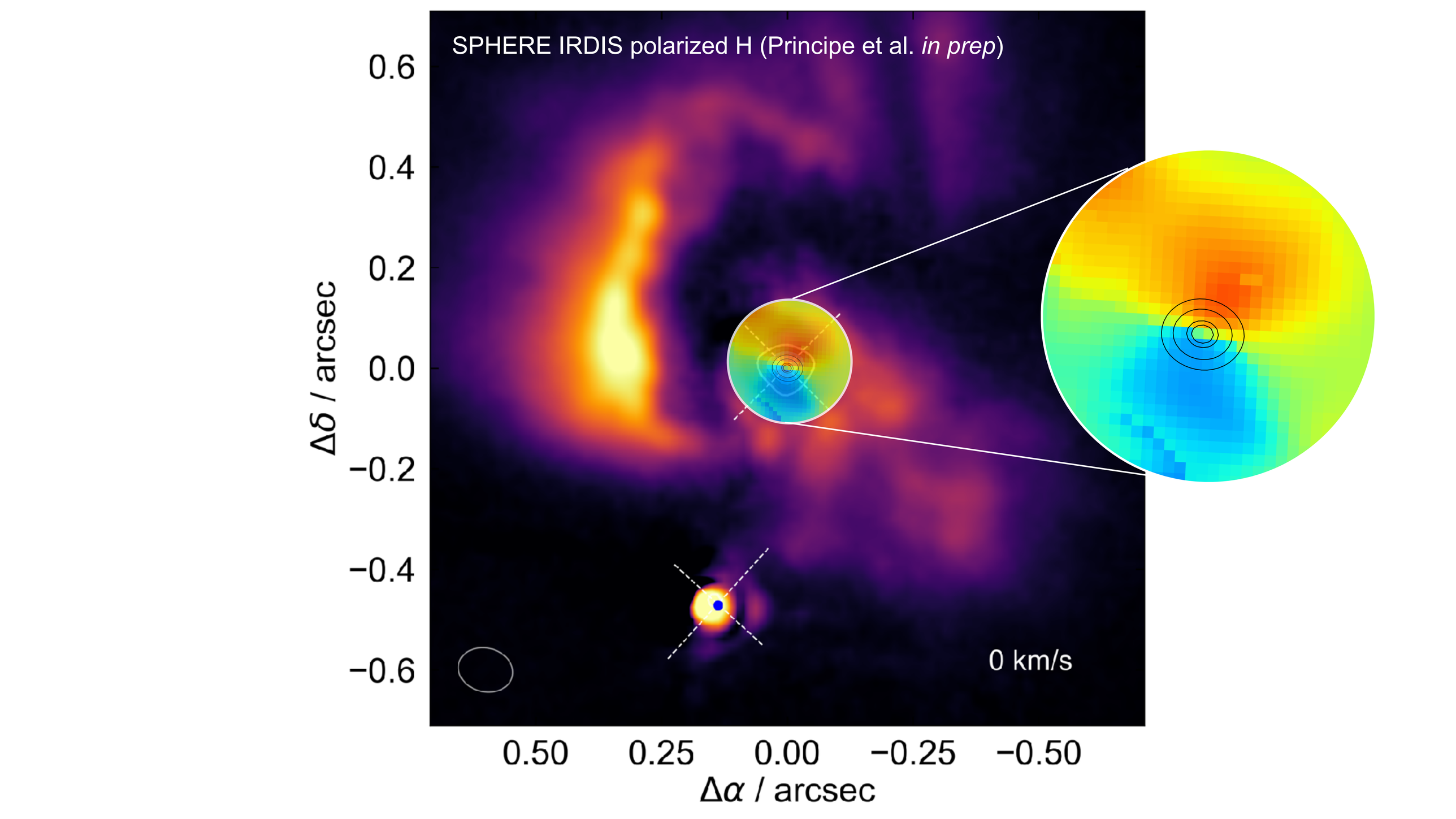

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
15 km/s

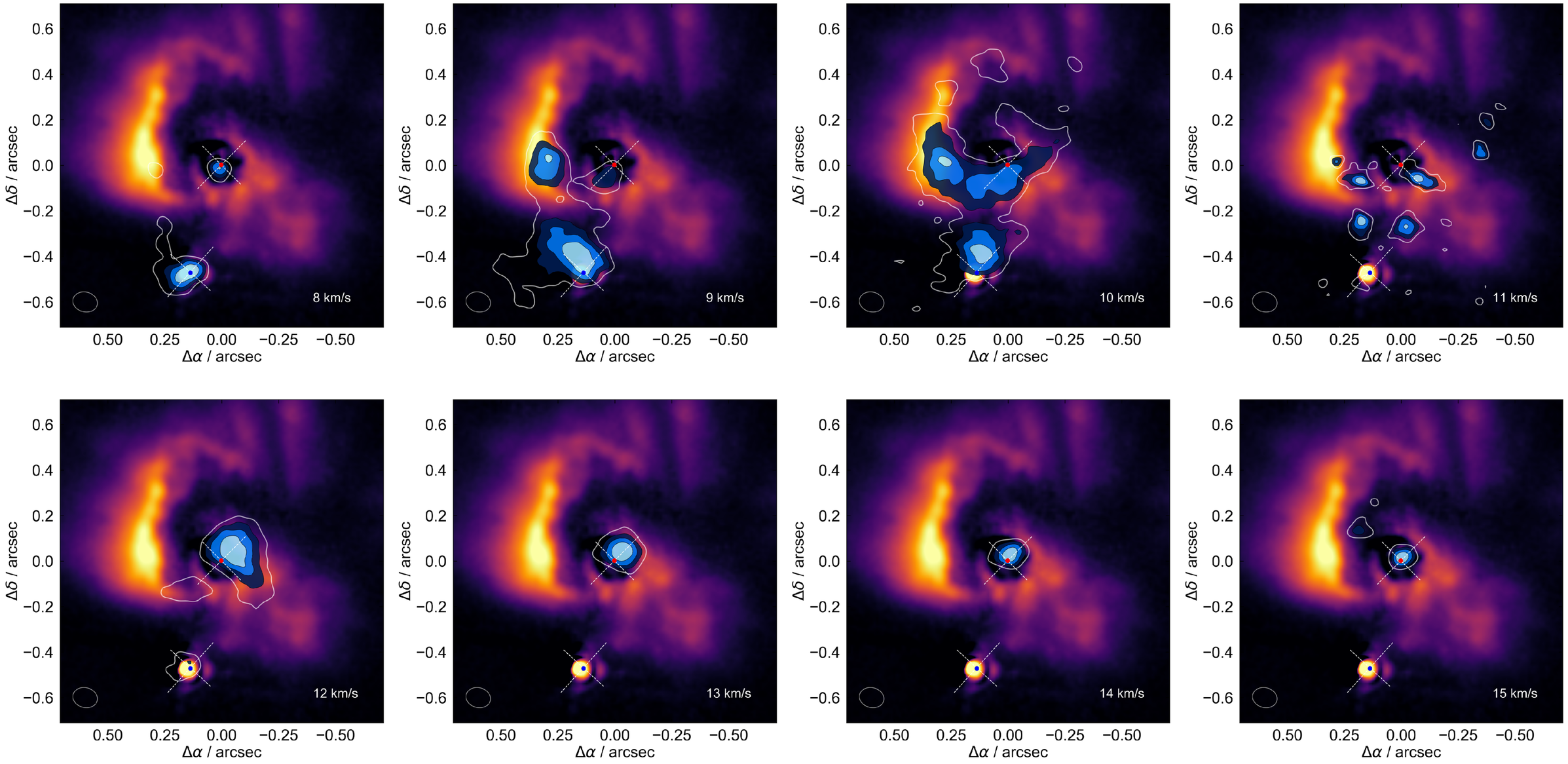

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
16 km/s


SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
17 km/s


SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
18 km/s

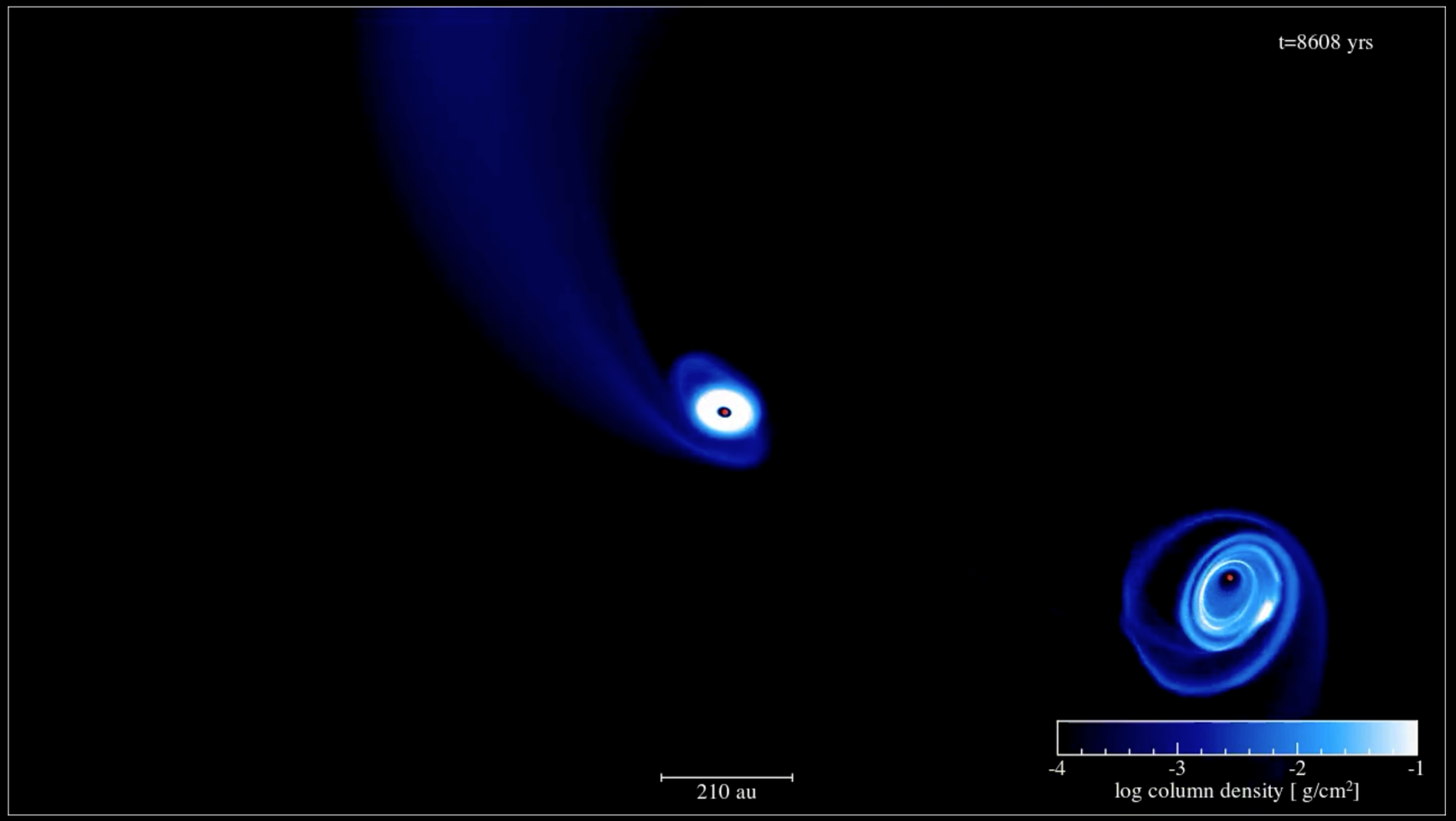

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
19 km/s

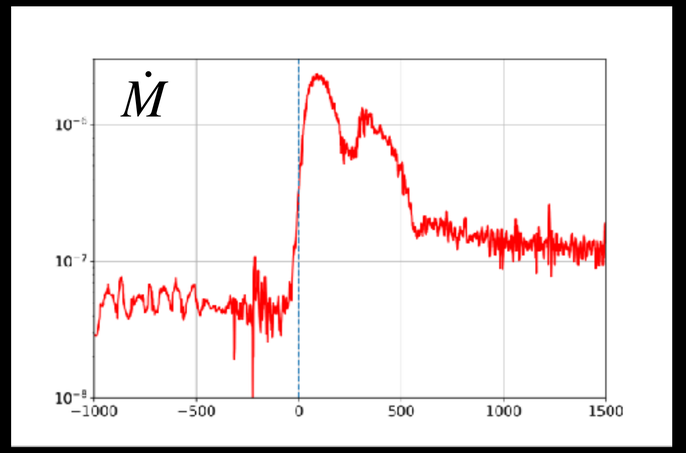

SPHERE IRDIS polarized H (Principe et al. *in prep*)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Δδ / arcsec
0.50
0.25
0.00
−0.25
−0.50
Δα / arcsec
0 km/s



Cycle 4 ALMA observations. 12CO kinematics (Pérez S. et al. submitted) // SPHERE scattered (polarized) light (Principe et al. in prep)

Phantom SPH simulation





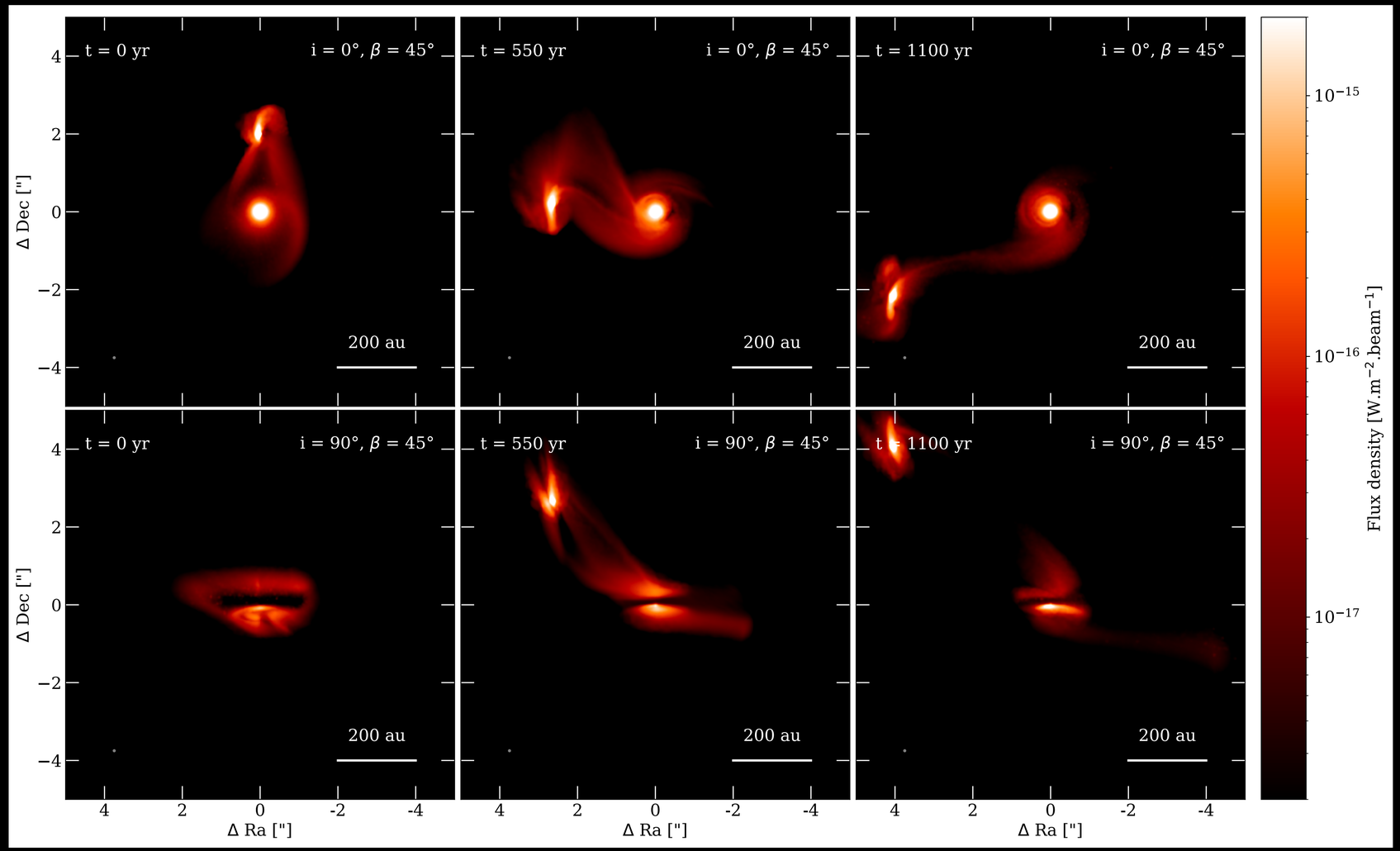
Explains out of plane structure

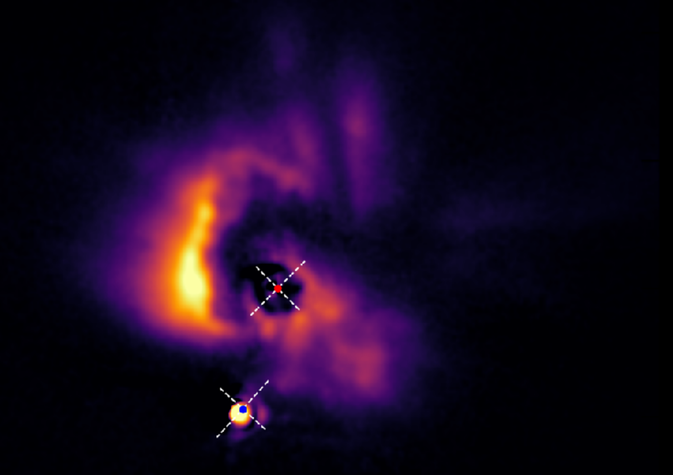
helps explaining small sizes of the dust disks

but who's the trigger?
(E. Vorobyov's talk)

Simulations by Nicolas Cuello
(see Cuello et al. 2019)

Scattered light predictions from SPH simulation (phantom+mcfost)





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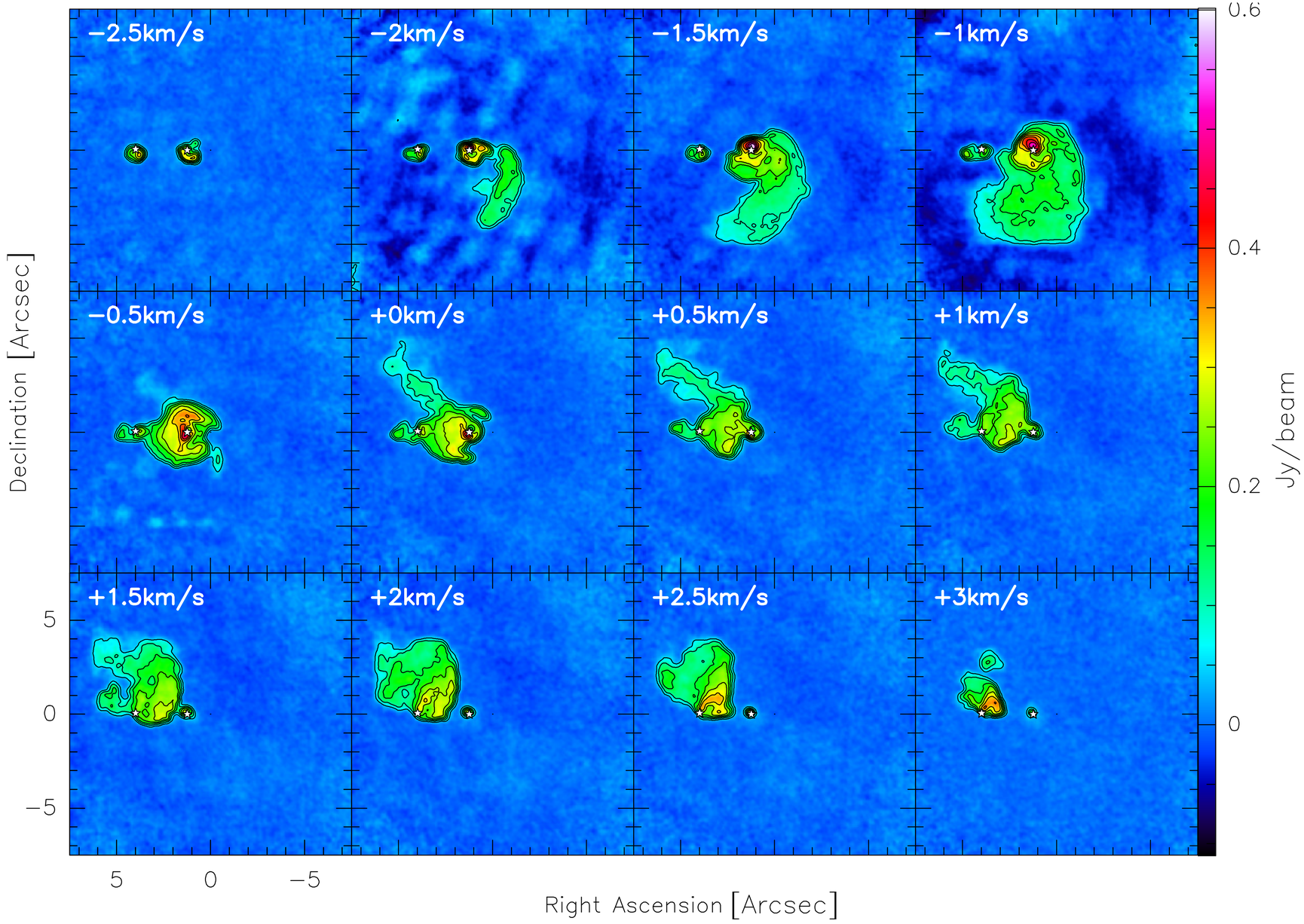
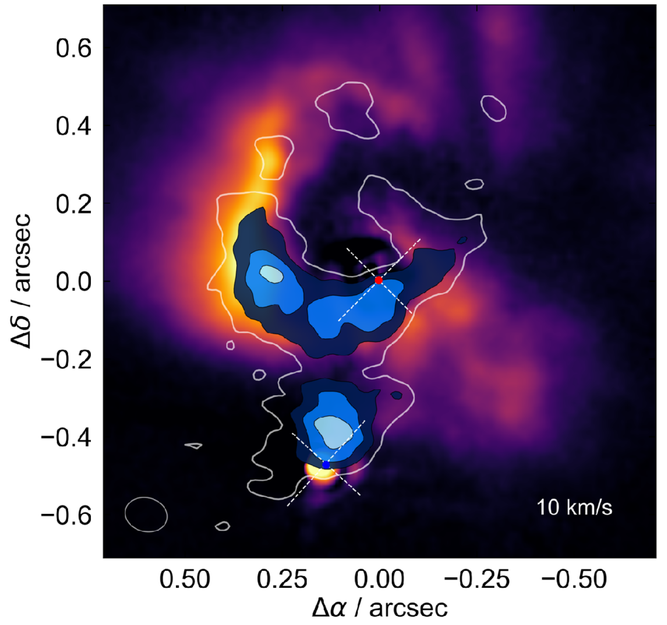
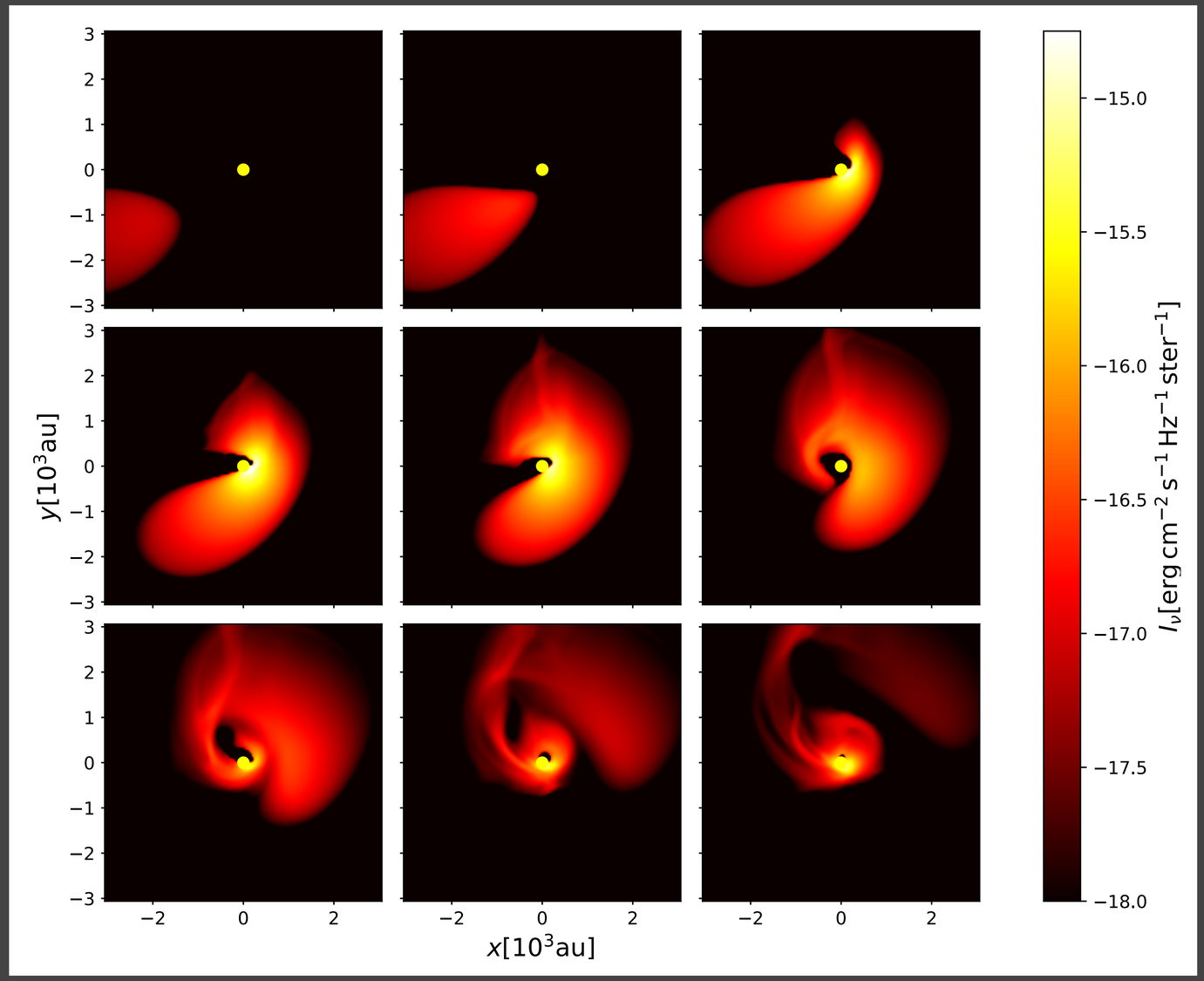
12CO kinematic predictions from SPH simulation (phantom+mcfost)





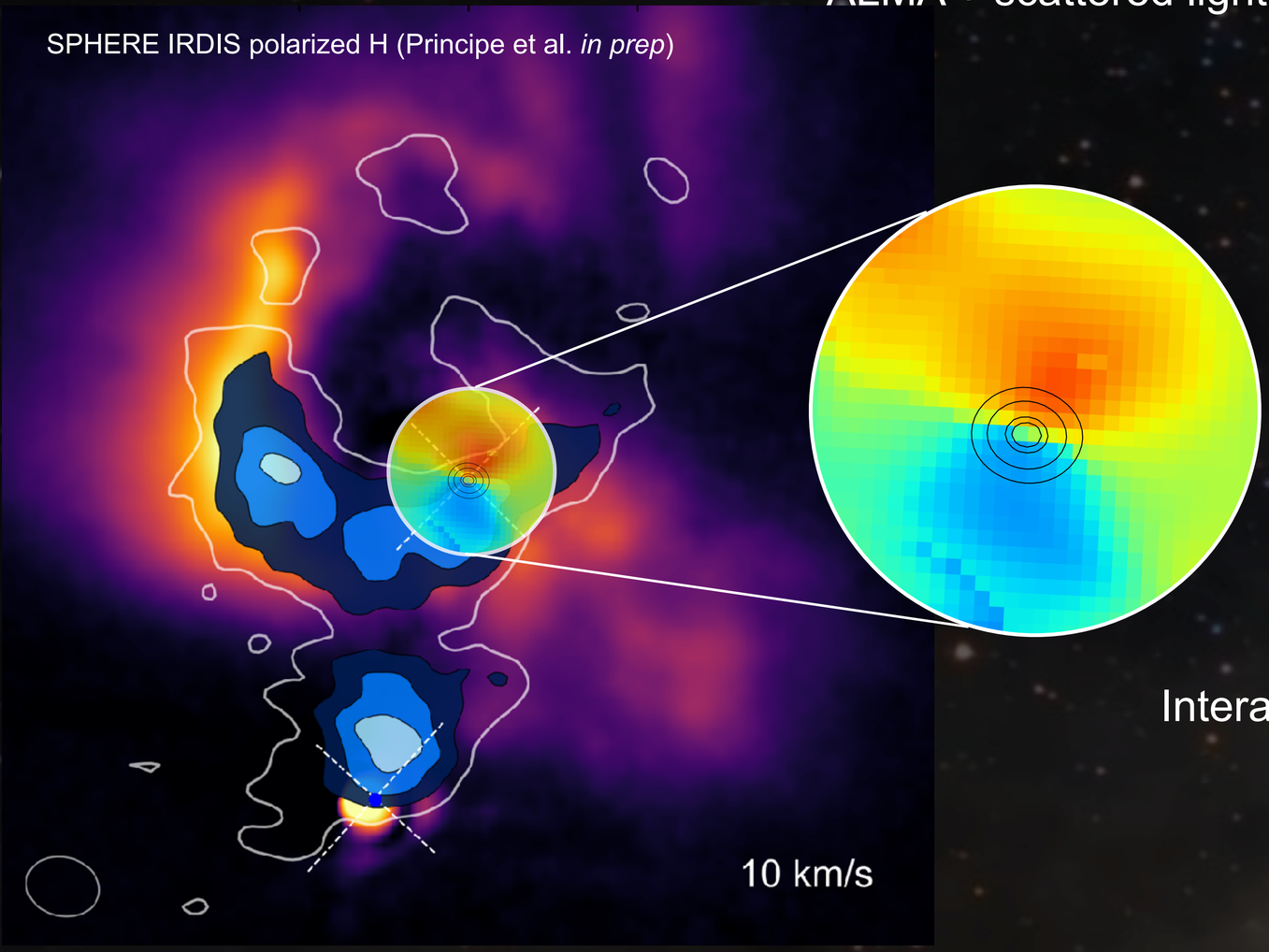
Scattered light prediction of cloudlet capture (Dullemond et al. 2019)



Dullemond et al. (2019): Cloudlet capture?

“Rejuvenated” disk

ALMA + scattered light's FU Ori picture



At 1.3 mm, dust disks are ~10 au in radius and share similar orientations

~Keplerian rotation around both component

Out of plane arm/structure suggests non-coplanar encounter.

Cloudlet capture situation could work too.
FU Ori gets 'fed' and disk is 'rejuvenated'.

Interaction could potentially trigger outbursting mechanisms (E. Vorobyov's talk)

Спасибо

Collaborators:
Antonio Hales (NRAO/ALMA), H. Baobab Liu (ASIAA),
Lucas Cieza (UDP), Alice Zurlo (UDP),
Simon Casassus (UChile), Zhaohuan Zhu (Nevada),
David Principe (MIT), Nicolas Cuello (PUC)