SPIRALS IN DISCS OF BINARY SYSTEMS: THE TEMPERATURE STRUCTURE MATTERS!

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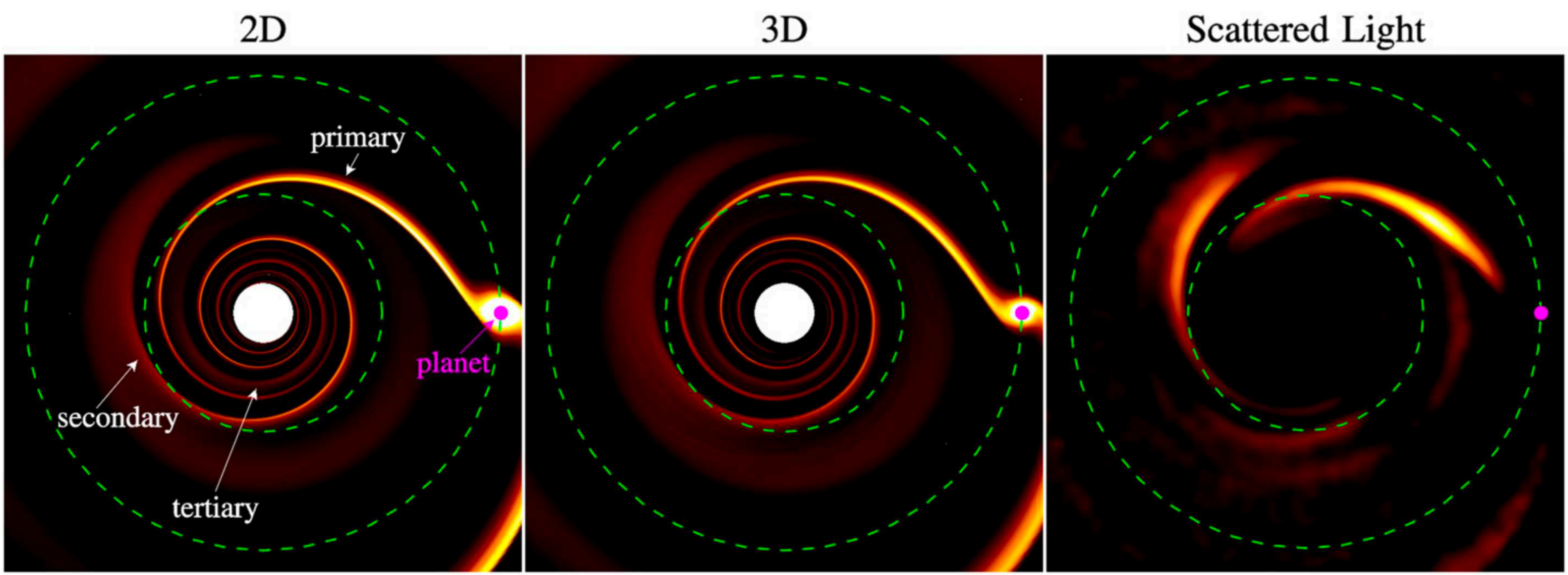
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

COMPANION-GENERATED SPIRAL WAVES

$$
\begin{aligned}
(\Sigma - \Sigma_0)_{\rm lin} &\propto \frac{\Sigma_0}{g(r)} f(\eta) \\
&\propto \left[\frac{\Sigma_0(\Omega - \Omega_p)}{r c_0^3}\right]^{1/2} \\
&\quad \times f\left(\phi + \mathrm{sign}(r - r_p) \int_{r_p}^{r} \frac{\Omega(r') - \Omega_p}{c_0(r')}\, dr'\right)
\end{aligned}
$$

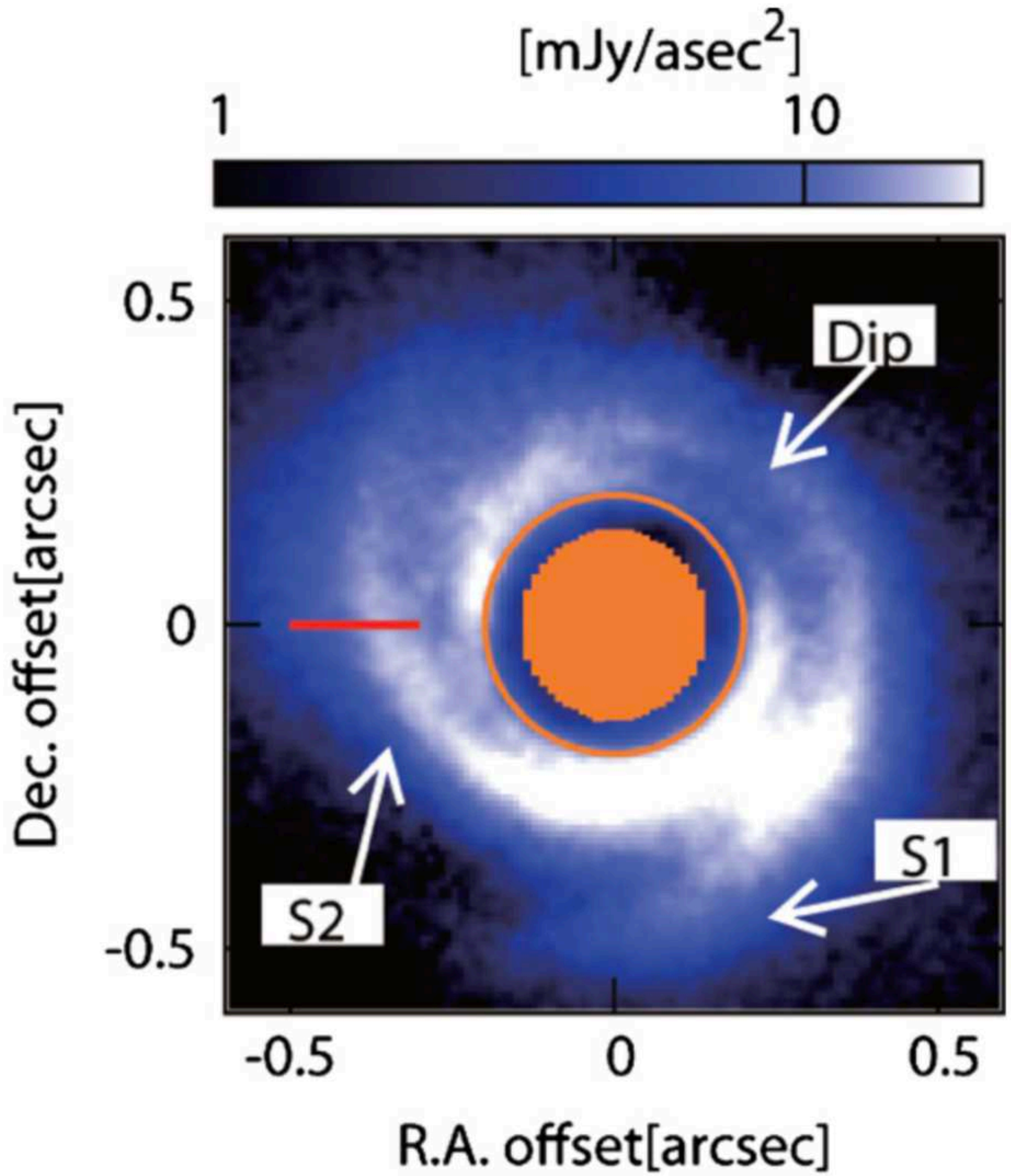
Rafikov+2002

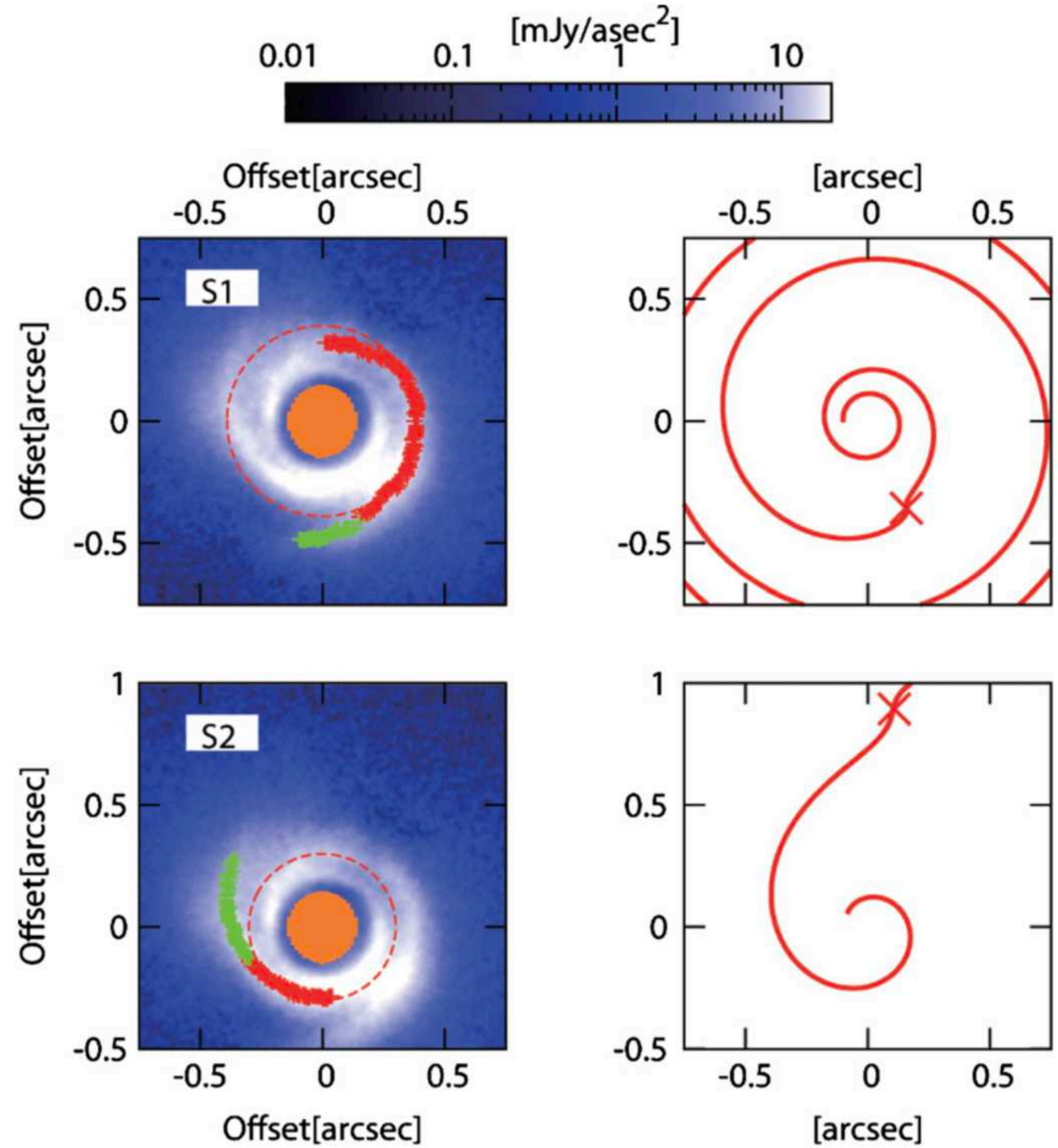


PEnGUIn

Fung+Dong2015

SAO 206462: PLANETARY-DRIVEN SPIRAL ARMS?



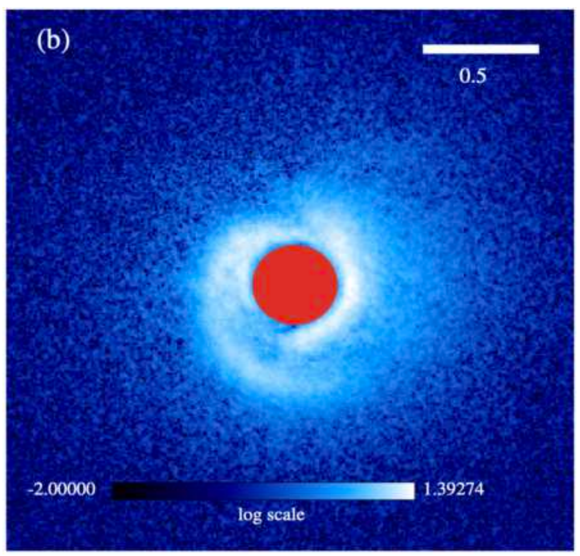


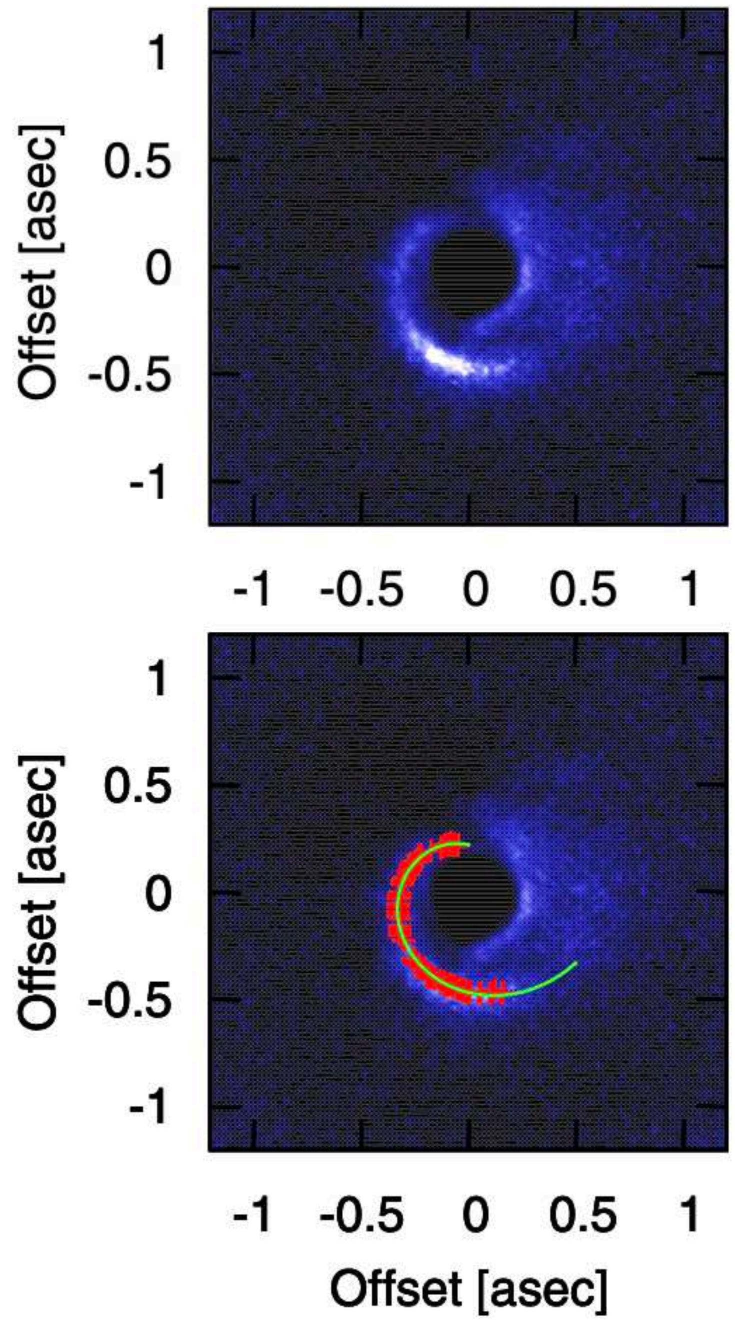
$$\theta(r) = \theta_0 - \frac{\mathrm{sgn}(r - r_c)}{h_c} \times \left[\left(\frac{r}{r_c}\right)^{1+\beta} \left\{ \frac{1}{1+\beta} - \frac{1}{1-\alpha+\beta} \left(\frac{r}{r_c}\right)^{-\alpha} \right\} - \left(\frac{1}{1+\beta} - \frac{1}{1-\alpha+\beta} \right) \right]$$

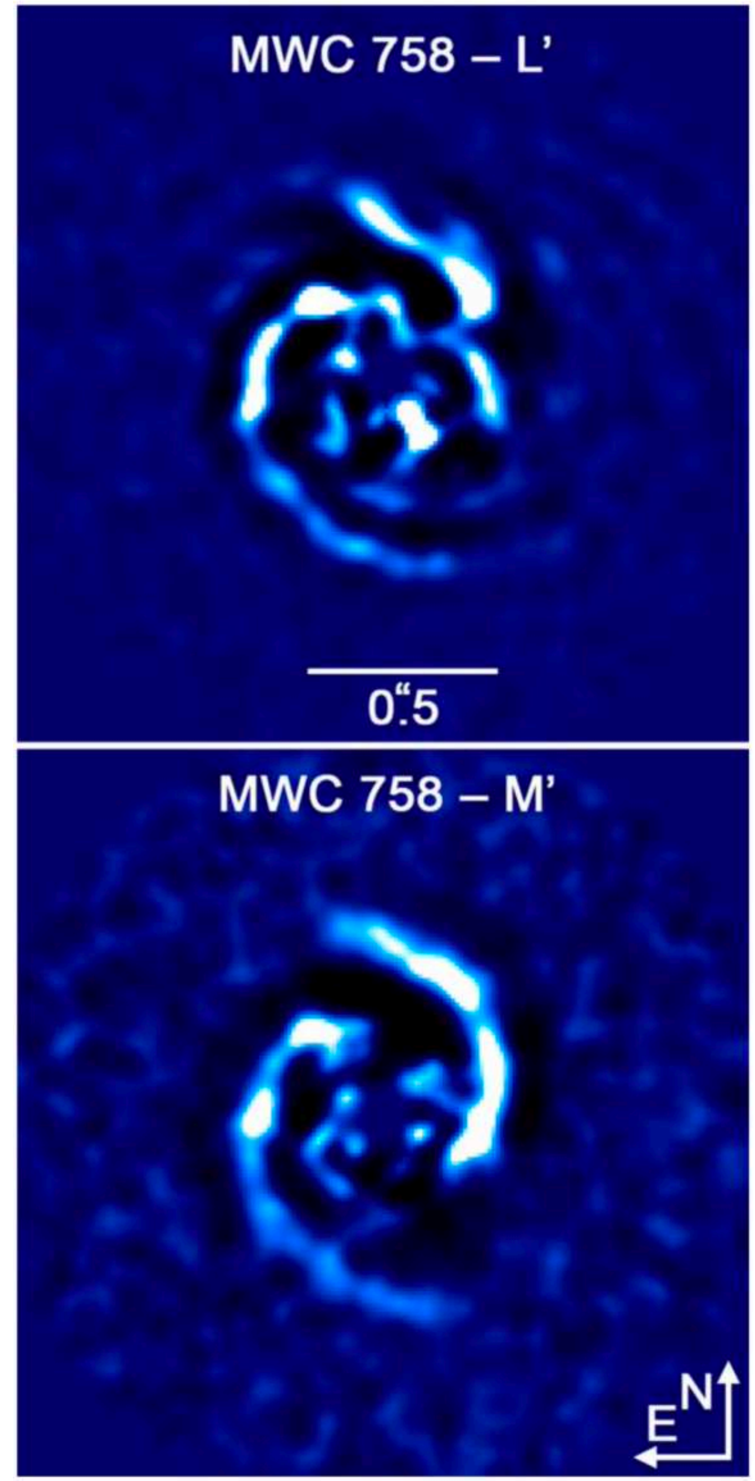
Subaru/HiCIAO *H* band

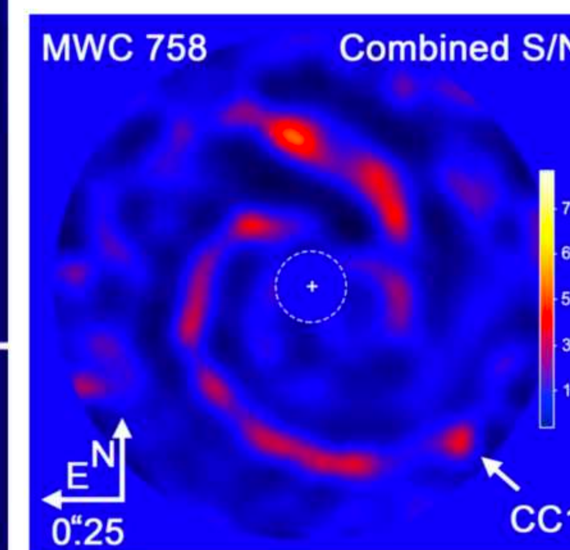
Muto+2012

MCW 758: PLANETARY-DRIVEN SPIRAL ARMS?









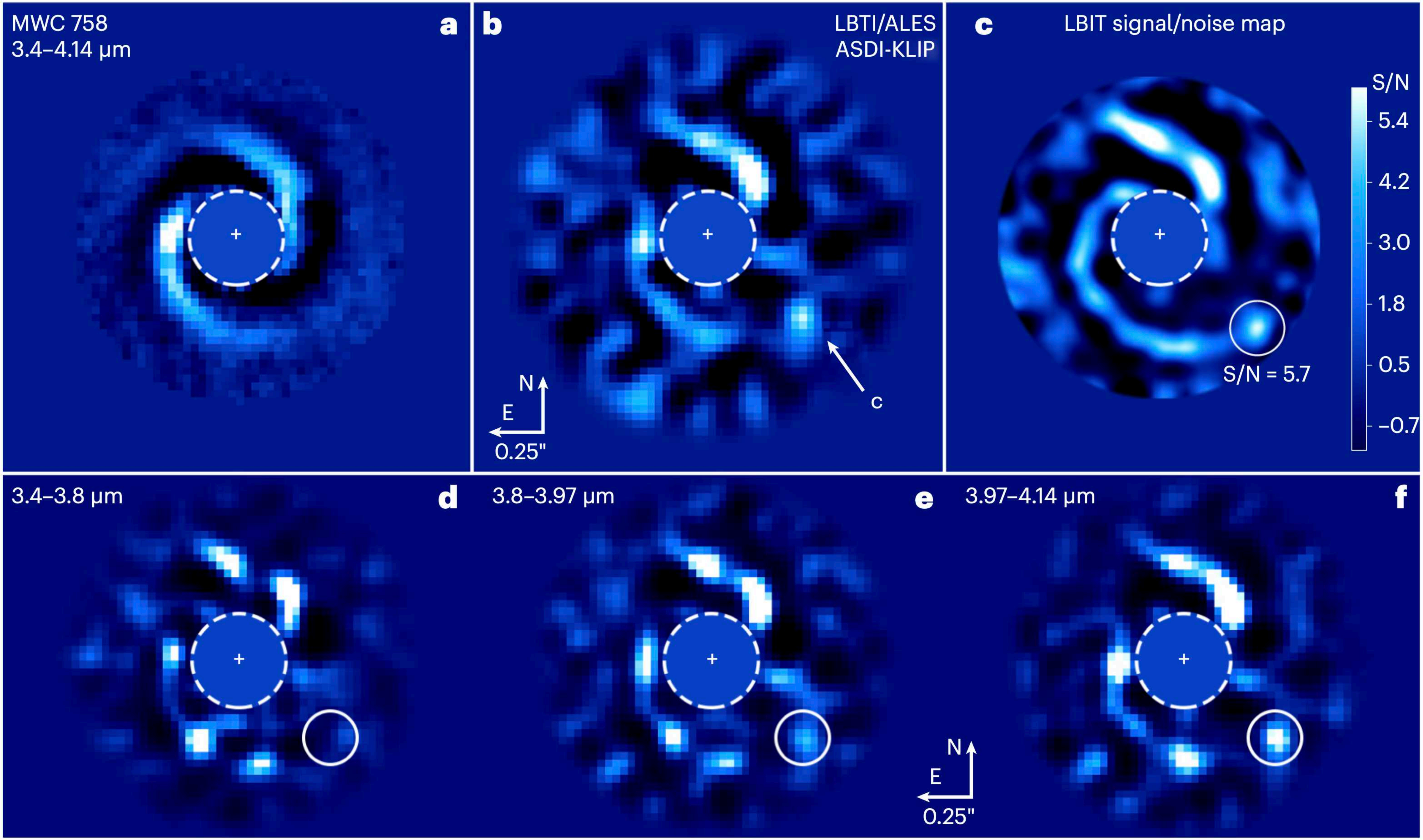
Subaru/HiCIAO *H* band

Grady+2013

LBT/MLIRCam *L′*, *M′* bands

Wagner+2019

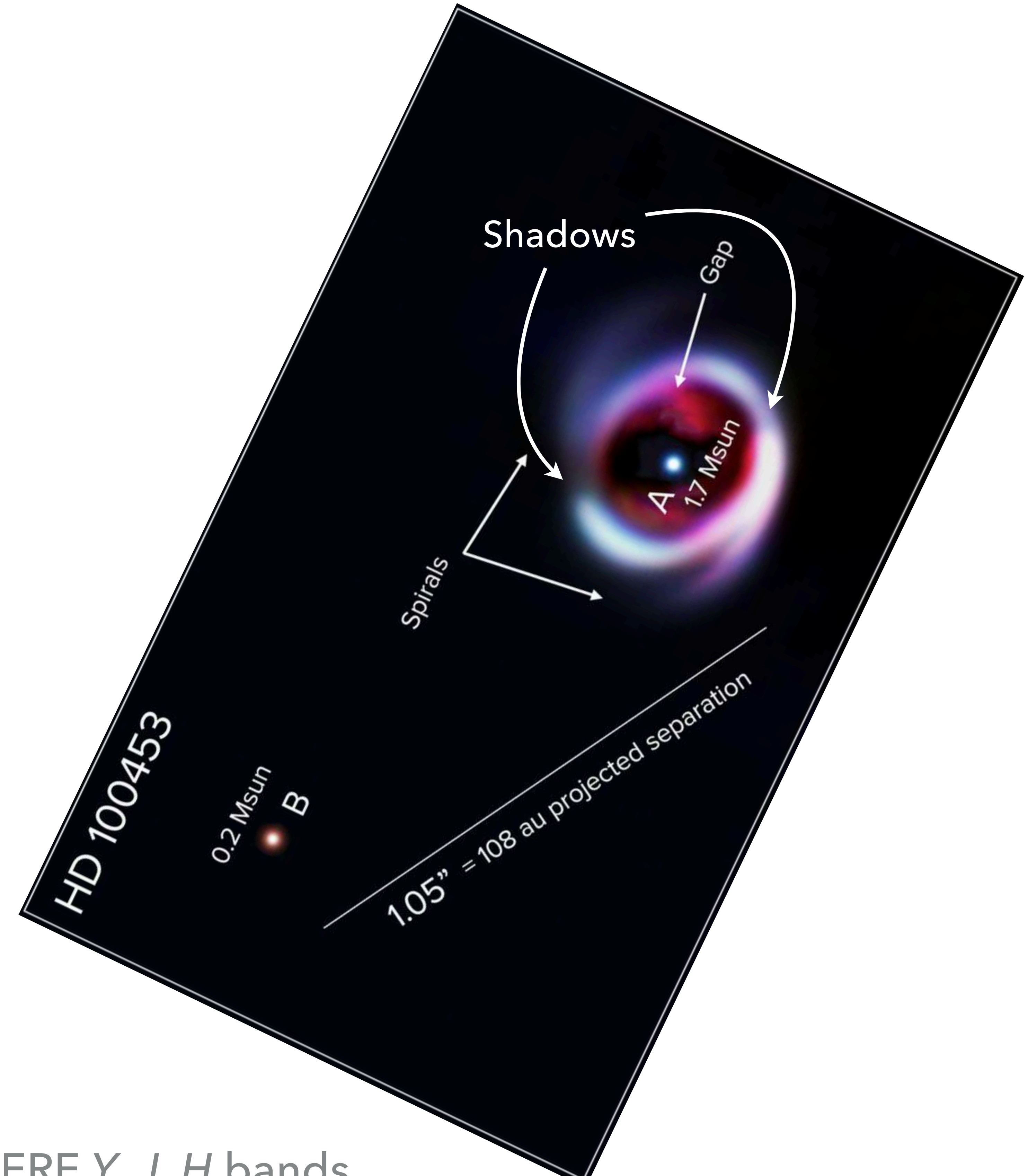
MCW 758: A GIANT PROTOPLANET DRIVING SPIRAL ARMS



LBT/MLIRCam+ALES

Wagner+2023

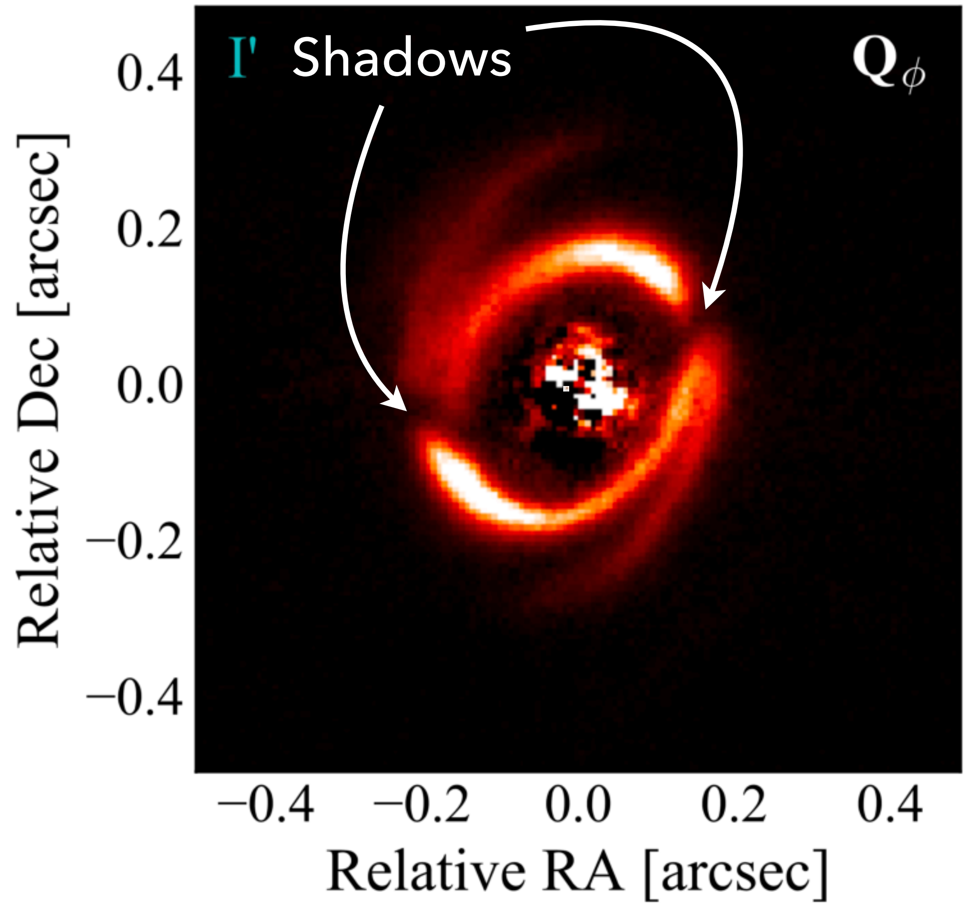
HD 100453: SPIRALS, SHADOWS & PRECESSION



VLT/SPHERE *Y*, *J*, *H* bands

Wagner+2018

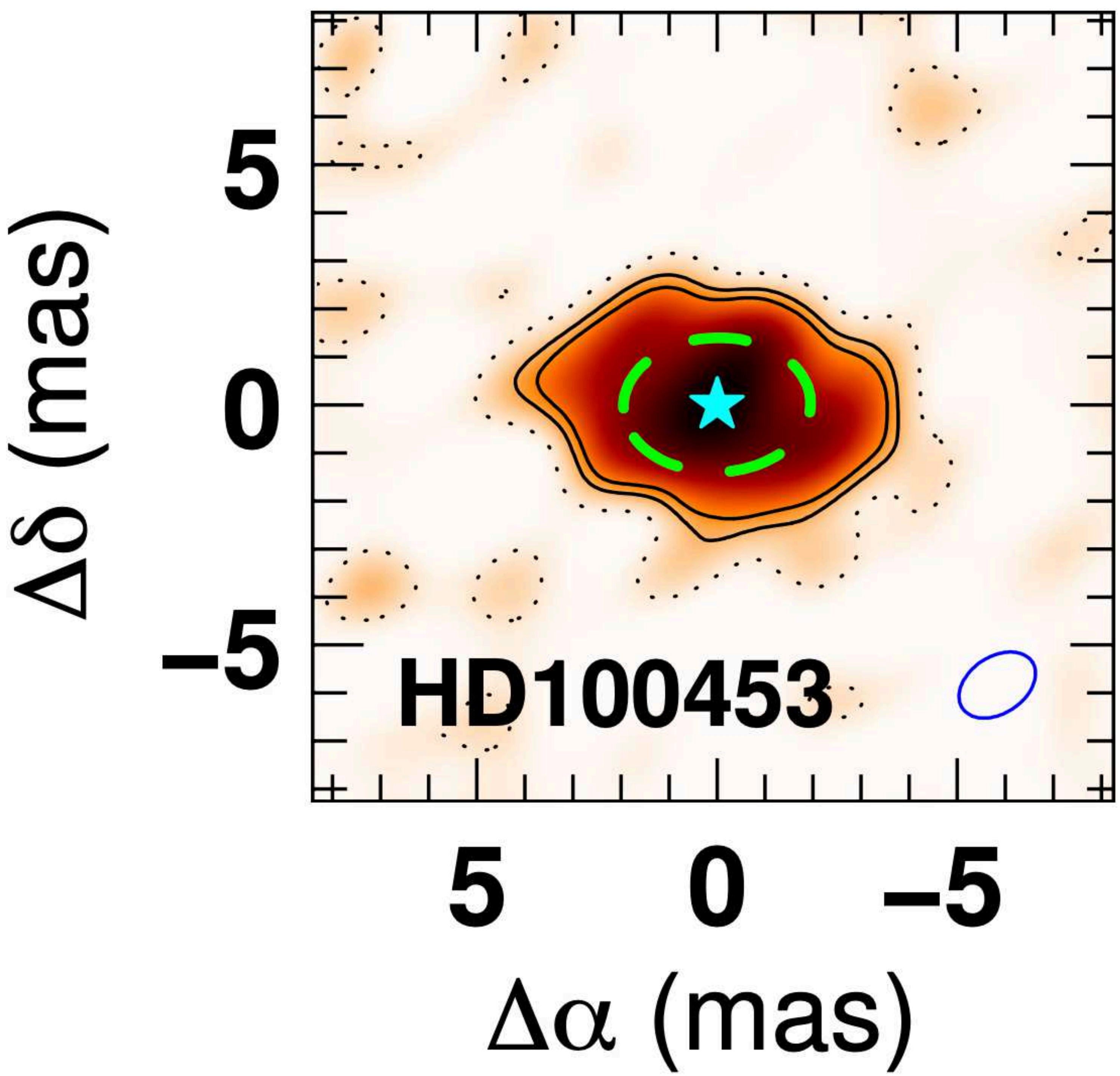
HD 100453: SPIRALS, SHADOWS & PRECESSION



VLT/SPHERE *I′* band

Benisty+2017

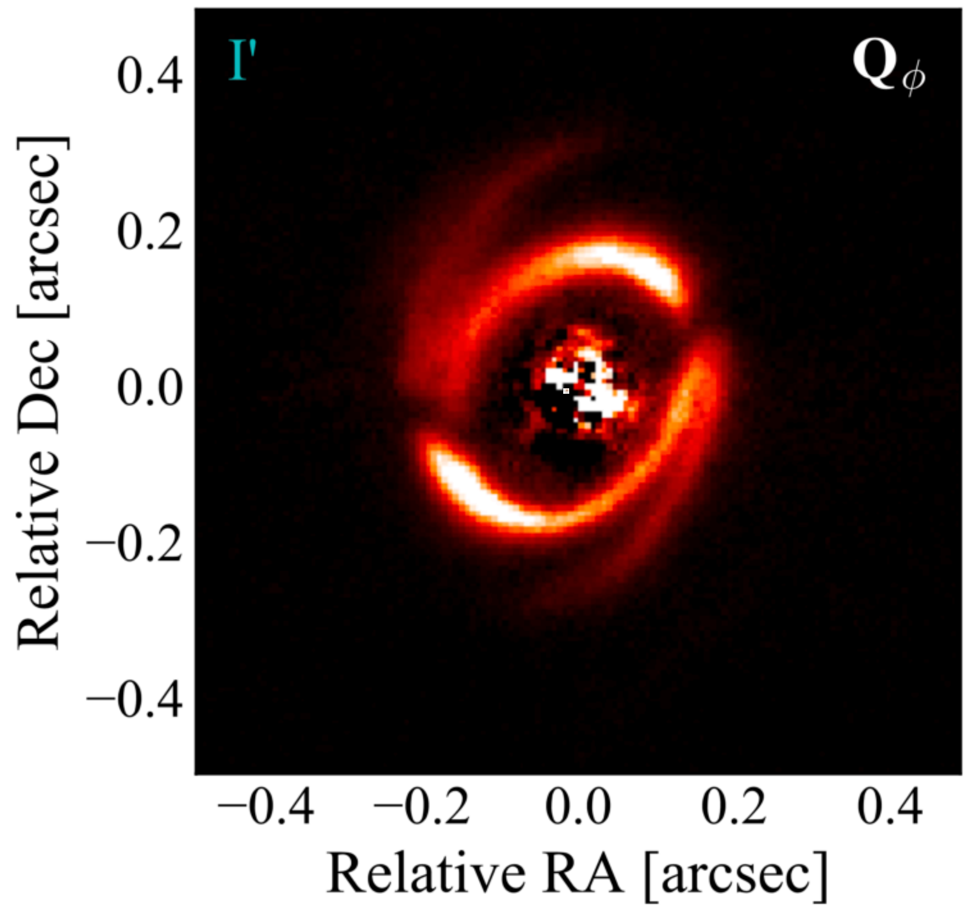
HD 100453: SPIRALS, SHADOWS & PRECESSION



VLTI/PIONIER *H* band

Kluska+2020

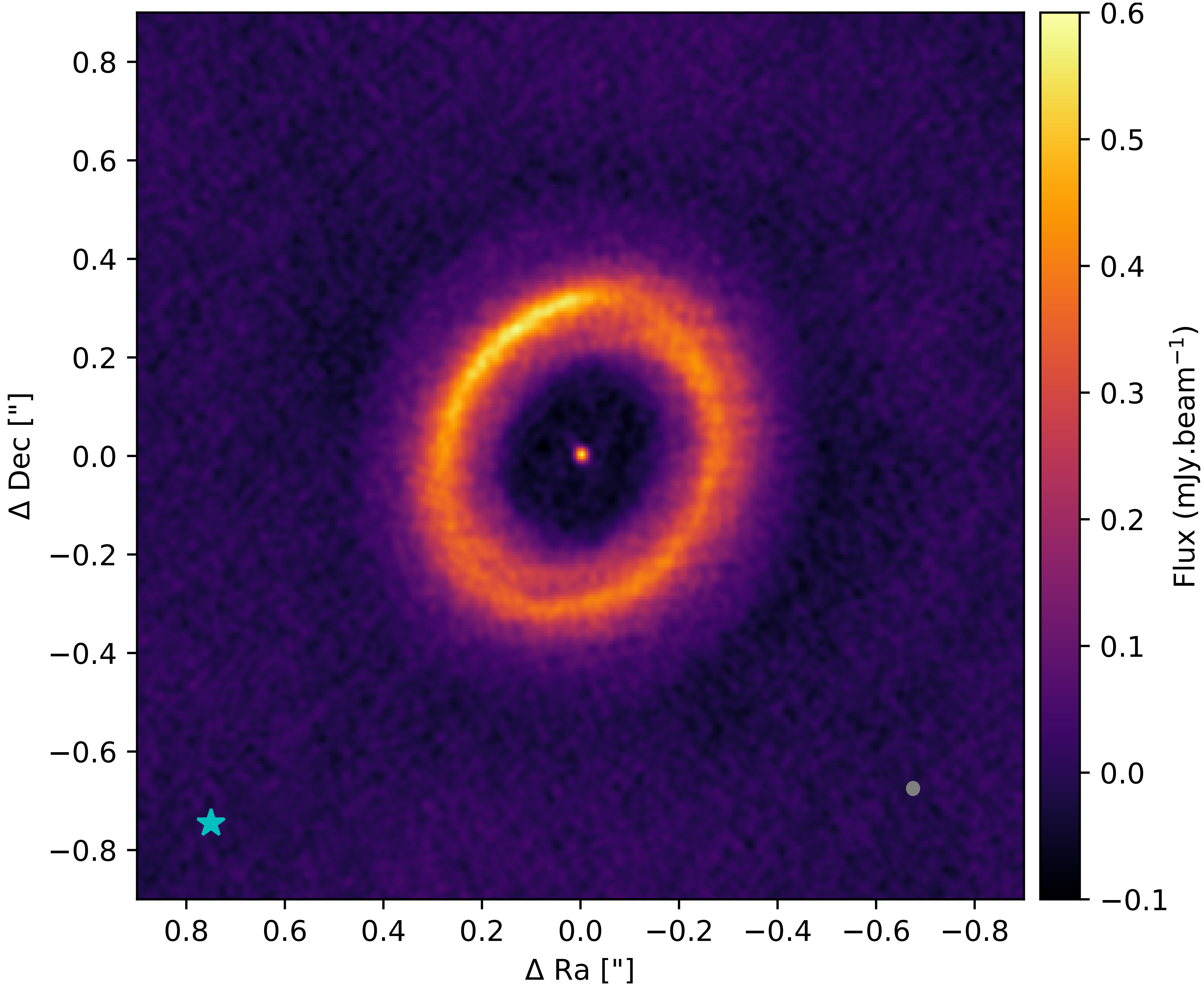
HD 100453: SPIRALS, SHADOWS & PRECESSION



VLT/SPHERE *I′* band

Benisty+2017

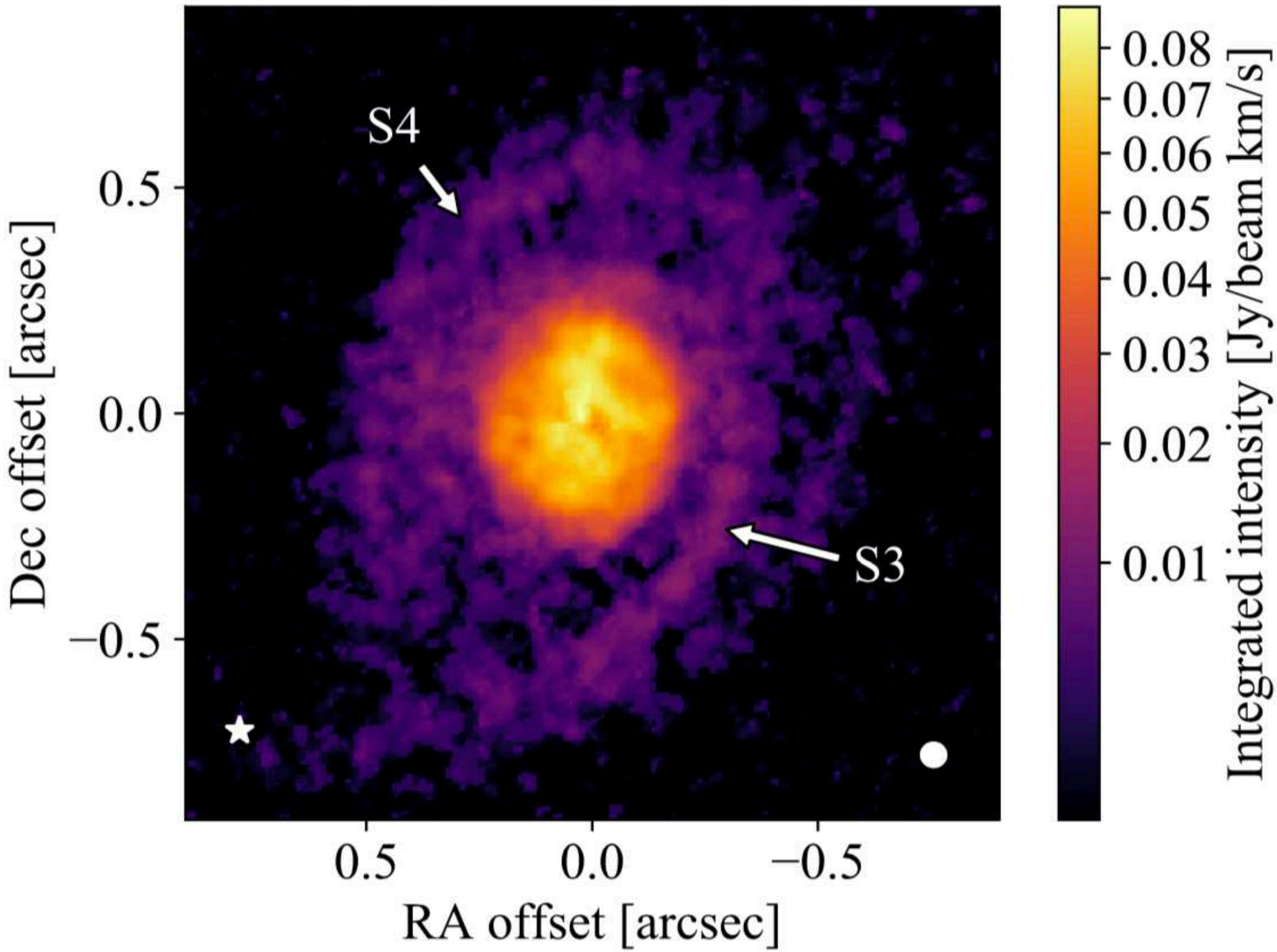
HD 100453: SPIRALS, SHADOWS & PRECESSION



ALMA Band 6 dust continuum

Gonzalez+2020

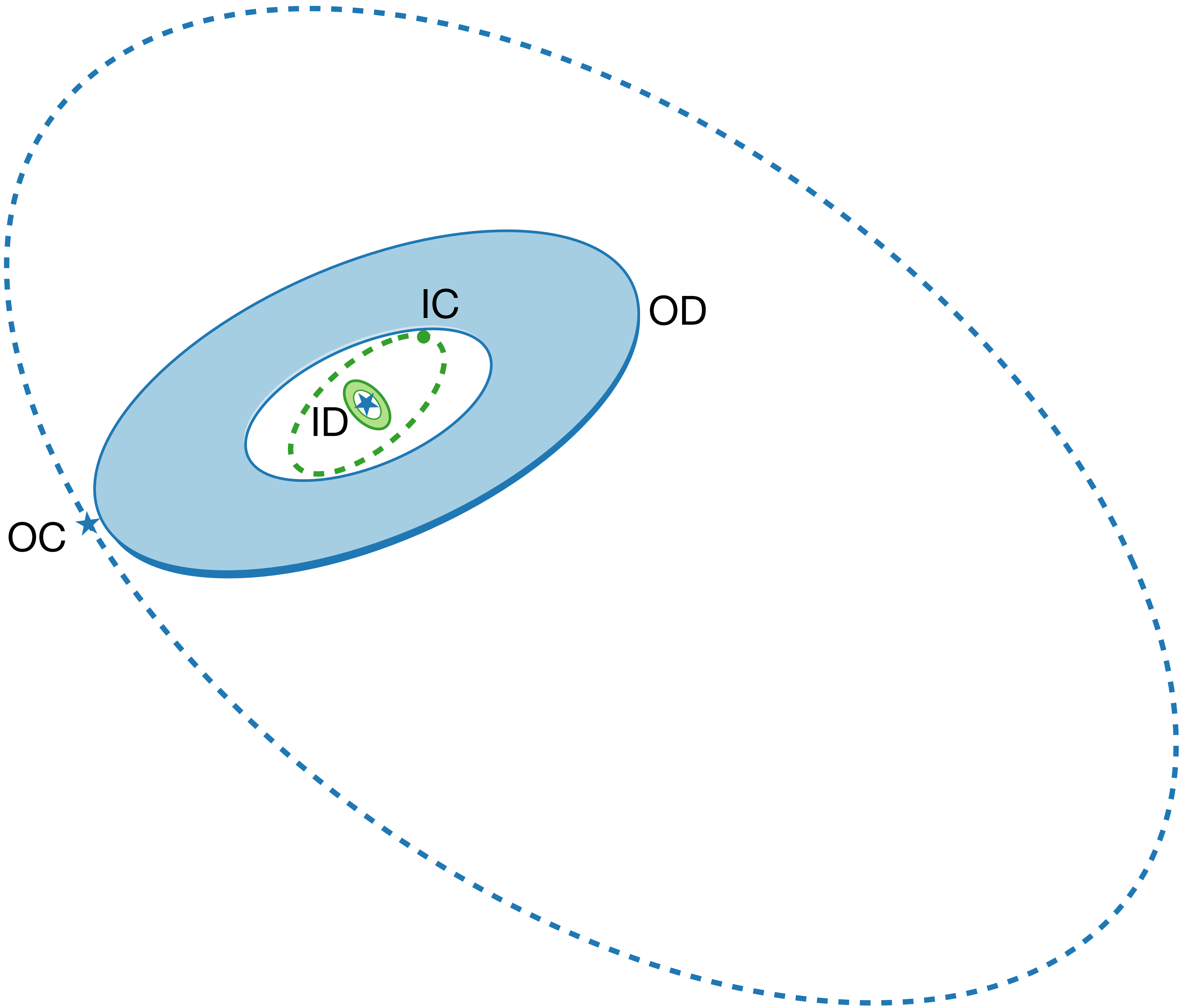
HD 100453: SPIRALS, SHADOWS & PRECESSION



ALMA Band 7 ^{12}CO J=3–2 moment 0

Rosotti+2020

HD 100453: SPIRALS, SHADOWS & PRECESSION



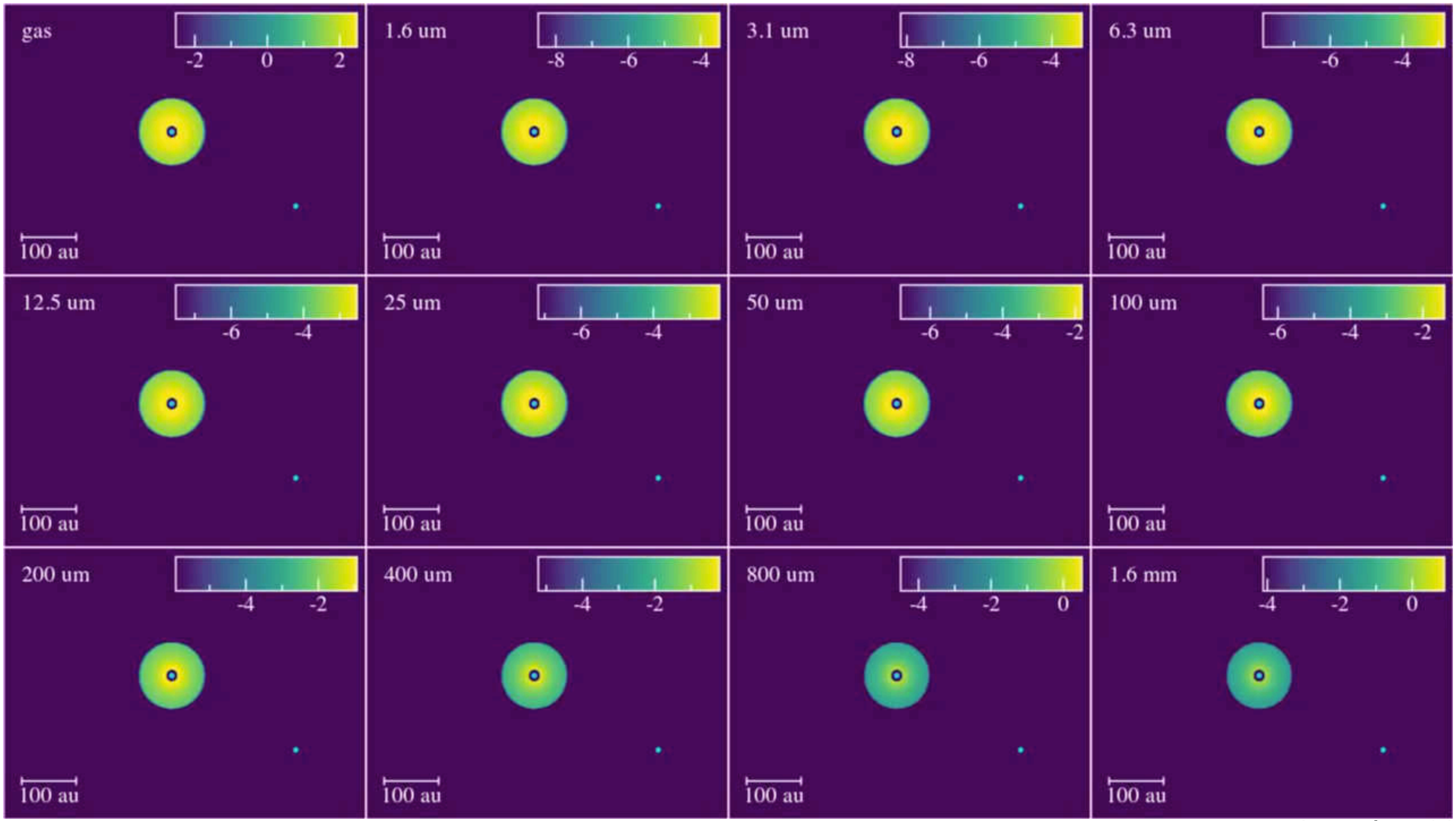
Nealon+2020

HD 100453: STELLAR COMPANION-DRIVEN SPIRAL ARMS

Price+2018

SPH simulations

Gas + 11 grains sizes from 1.6 μm to 1.6 mm



Made with SPLASH (Price2007)

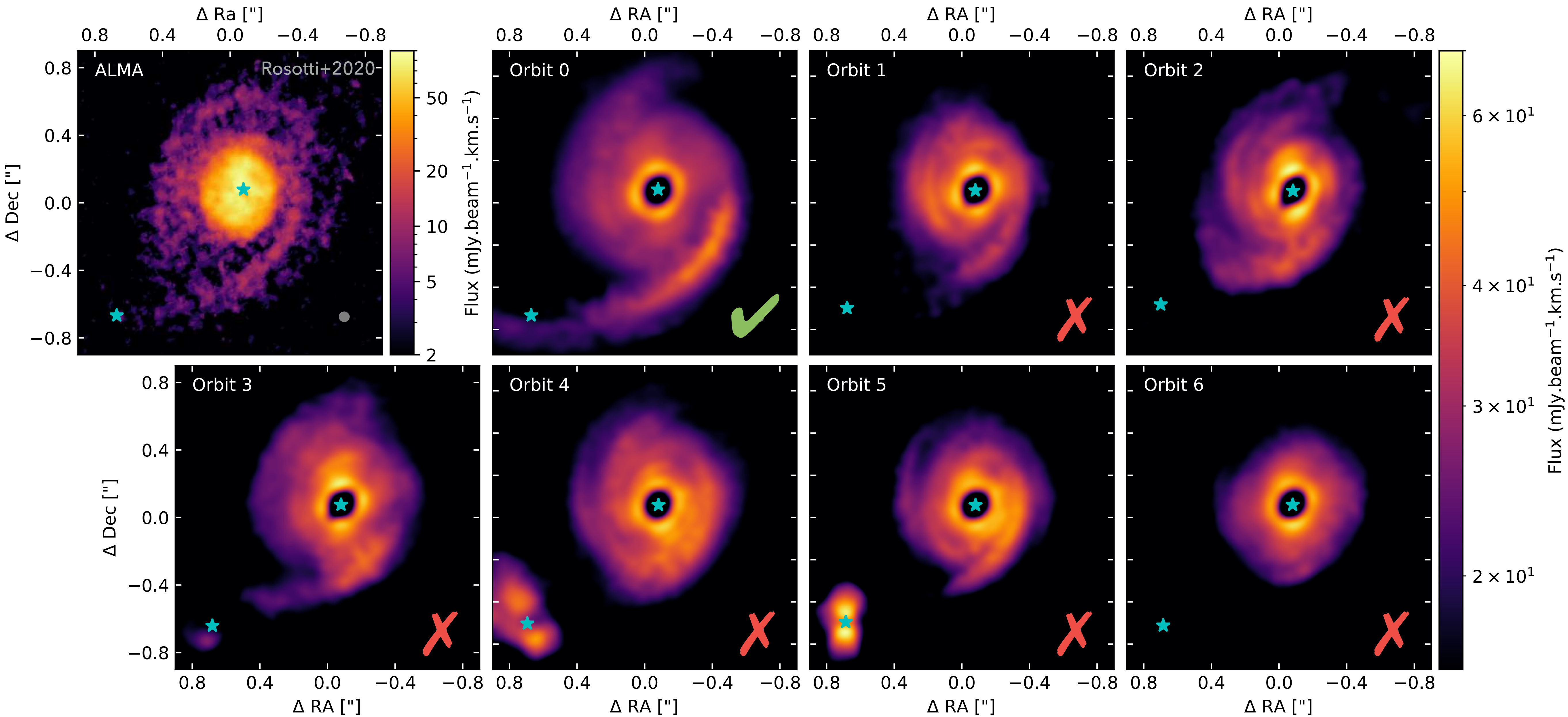
Orbit 0

Gonzalez+2020

HD 100453: STELLAR COMPANION-DRIVEN SPIRAL ARMS

Pinte+2006,2009

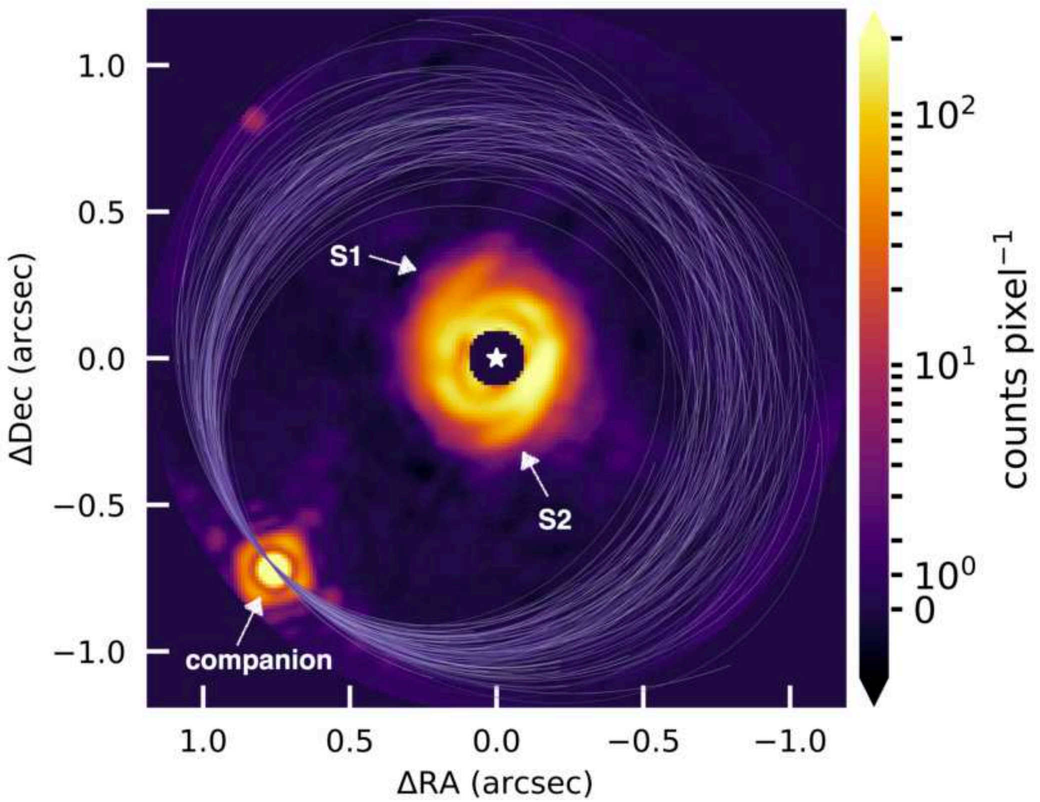
Synthetic observations

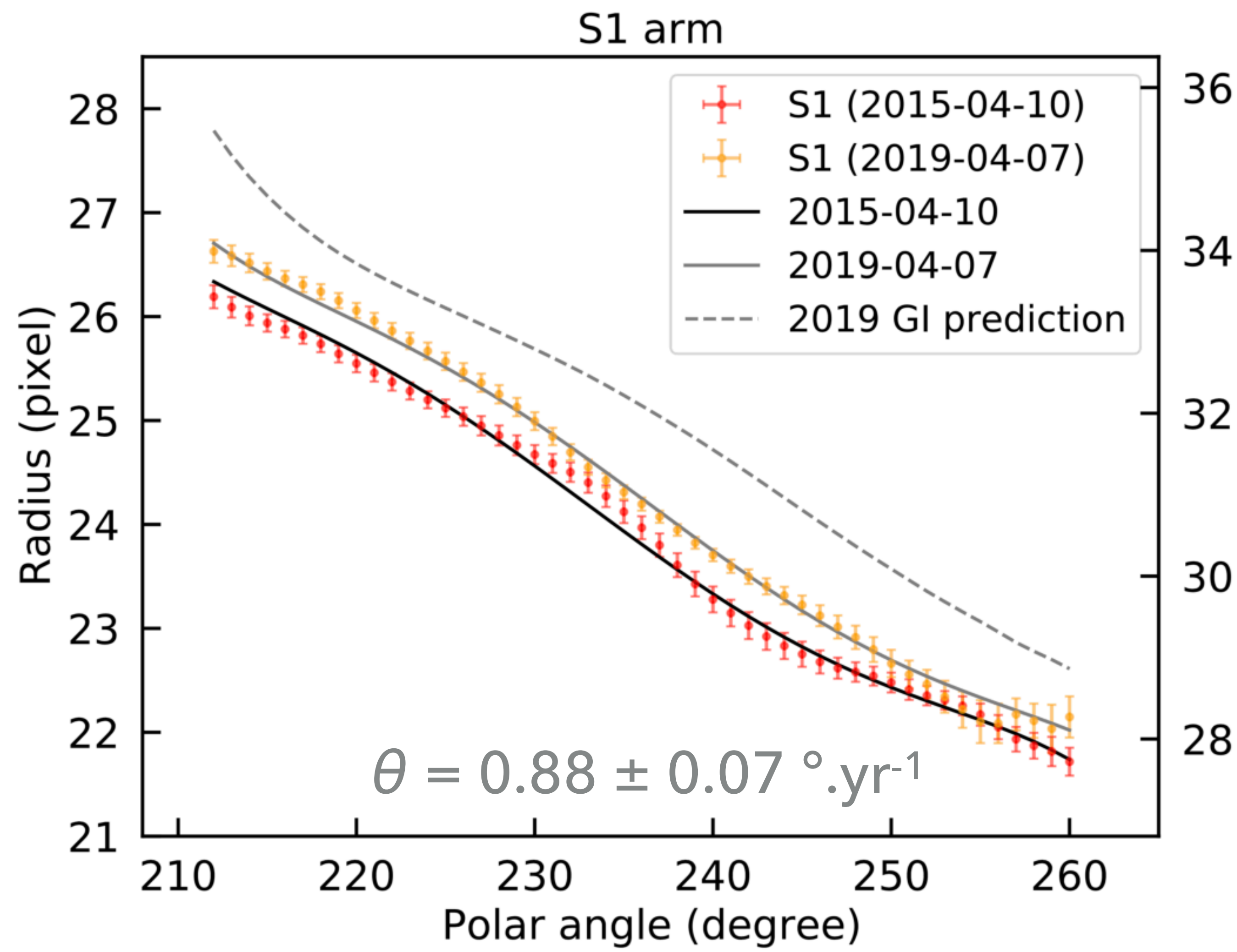


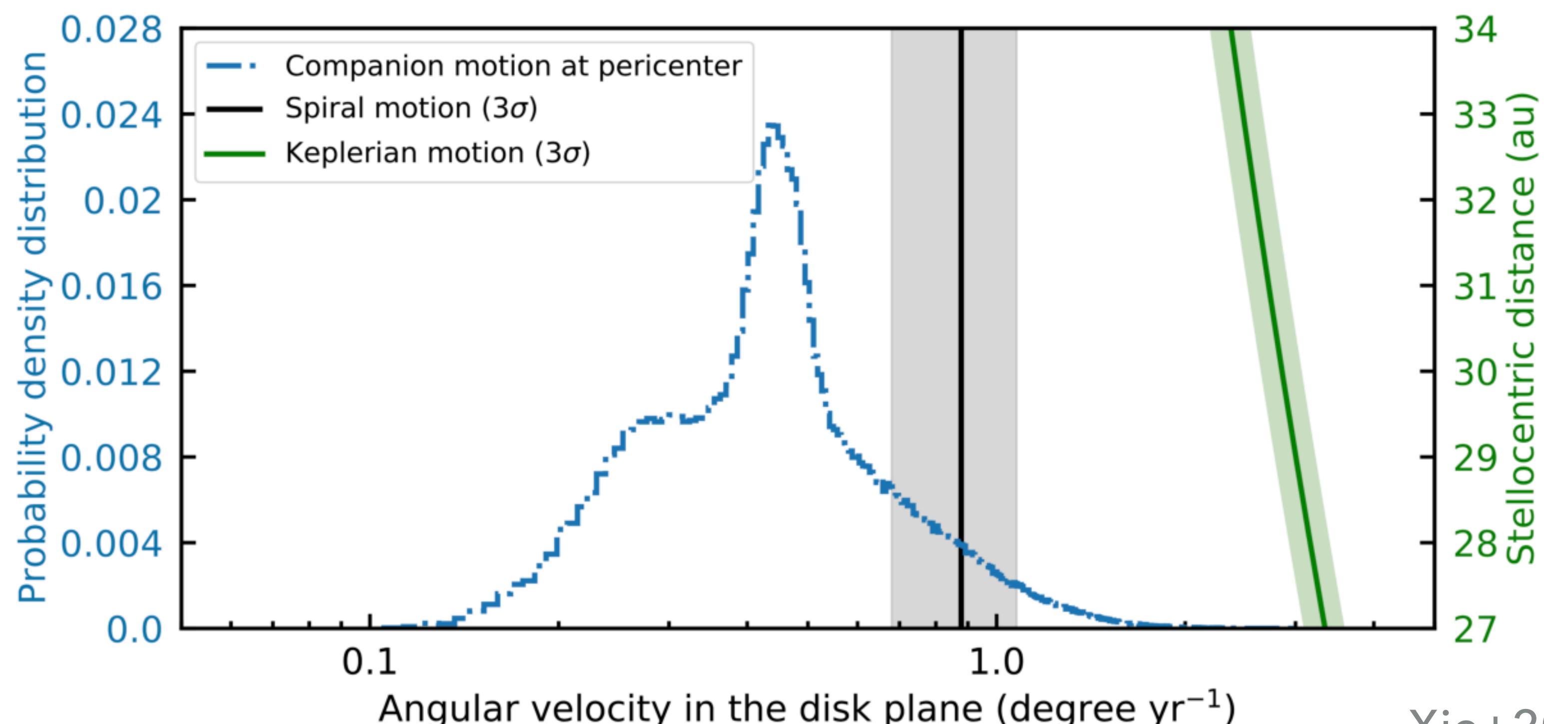
MCFOST – ^{12}CO J=3-2 moment 0 – θ = 0.025″

Gonzalez+2020

HD 100453: MEASUREMENT OF THE SPIRAL MOTION OVER 4 YR







VLT/SPHERE *K* band

Xie+2023

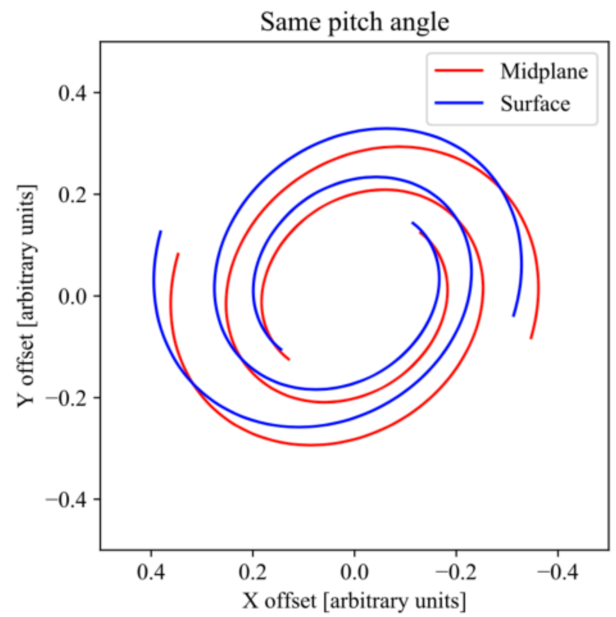
HD 100453: VARYING PITCH ANGLE WITH ALTITUDE

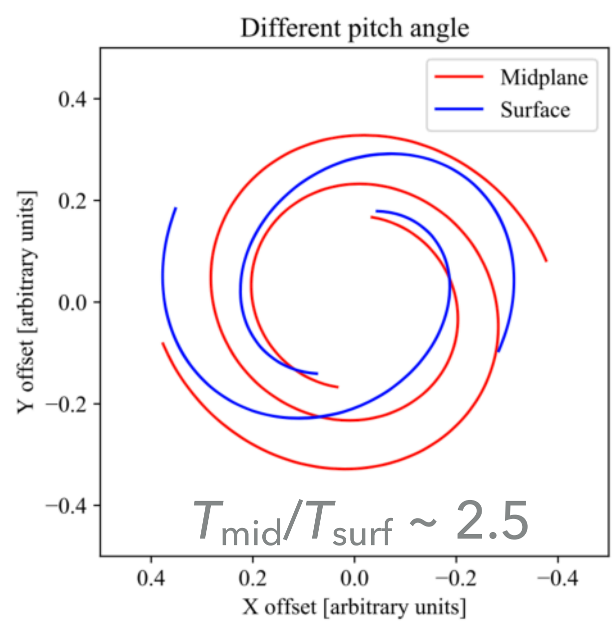
Pitch angle ~6° in ALMA continuum, ~19° in SPHERE images

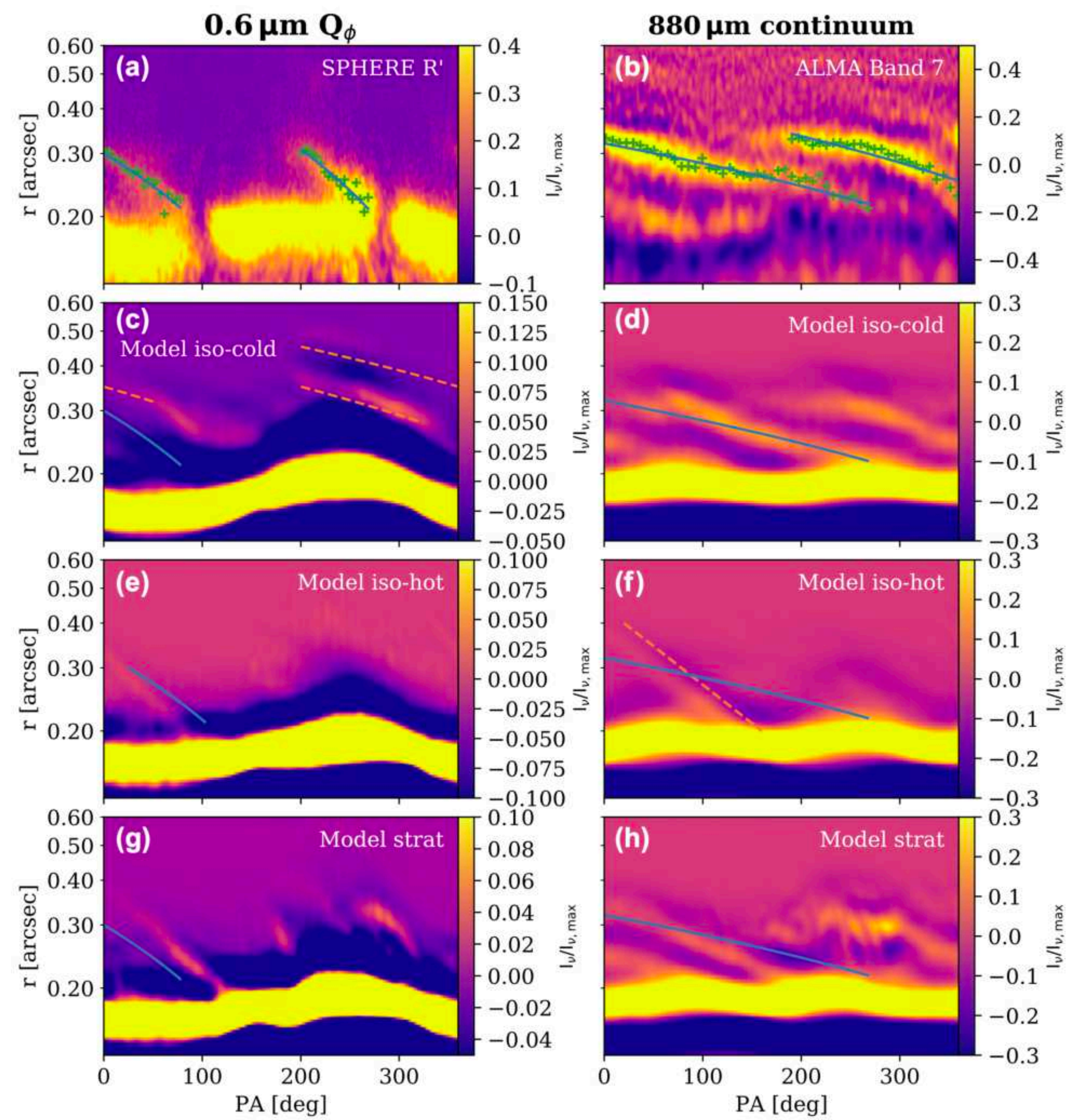
$$\phi(r) = \phi_{\rm p} - \frac{\mathrm{sgn}(r-r_{\rm p})}{h_{\rm p}}\left(\frac{r}{r_{\rm p}}\right)^{1+\beta} \times \left\{\frac{1}{1+\beta} - \frac{1}{1-1.5+\beta}\left(\frac{r}{r_{\rm p}}\right)^{-1.5}\right\} + \frac{\mathrm{sgn}(r-r_{\rm p})}{h_{\rm p}}\left(\frac{1}{1+\beta} - \frac{1}{1-1.5+\beta}\right)$$

Aspect ratio ⇒ temperature

$c_s \propto r^{-\beta}$ ⇒ temperature







FARGO3D + RADMC-3D

Rosotti+2020

PROJECT: SPIRALS WITH PHANTOM + MCFOST

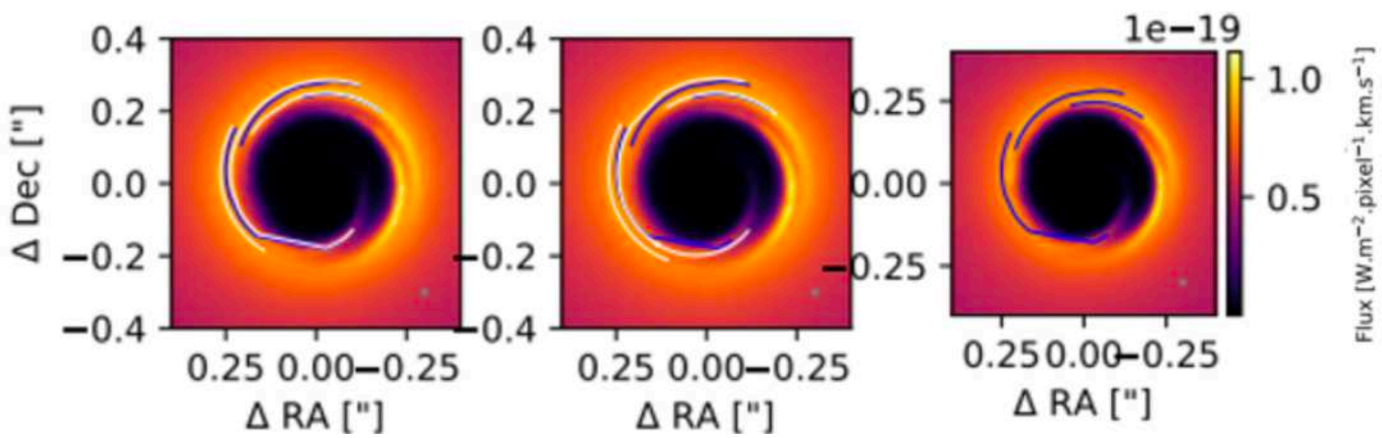
Simulations of companion-induced spirals with a "proper" *T* structure

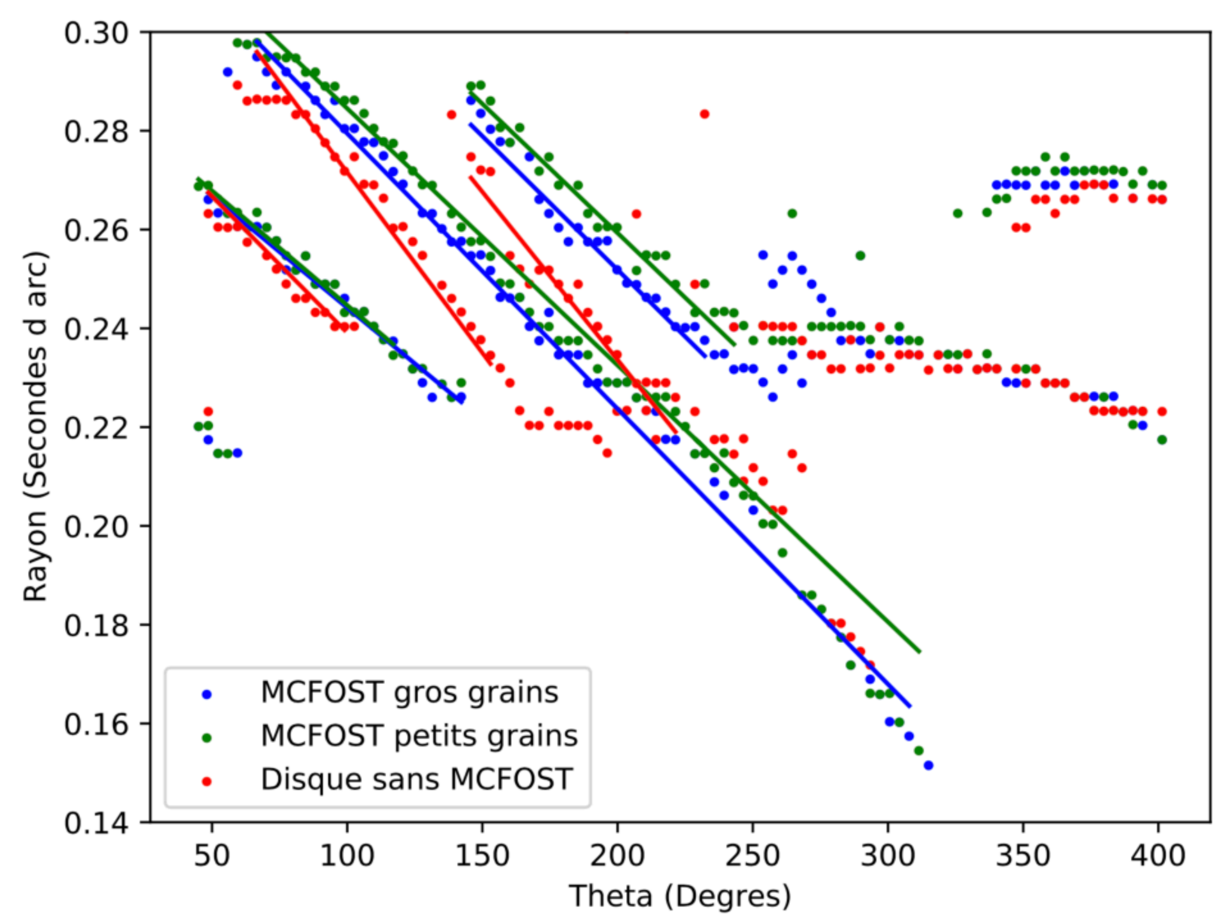
- Goals
  - what is the opening angle of spirals?
  - is the difference with isothermal discs observable?
  - can we better characterize the companion?

PROJECT: SPIRALS WITH PHANTOM + MCFOST

Simulations of companion-induced spirals with a "proper" *T* structure

- Pilot study
  - radiative transfer with stellar irradiation heating
  - case of a companion inside the disc (in the cavity)





Bedes+2021

PROJECT: SPIRALS WITH PHANTOM + MCFOST

Simulations of companion-induced spirals with a "proper" *T* structure

- Pilot study
  - radiative transfer with stellar irradiation heating
  - case of a companion inside the disc (in the cavity)

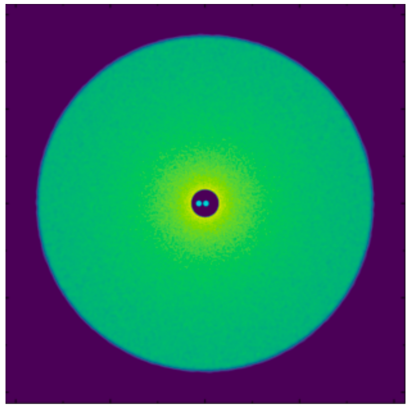
- Dustbusters secondment Feb-Mar 2024
  - PdV work and shock heating added
  - more cases: inner and outer companions
  - detectability in synthetic observations

SIMULATION SETUPS

- 1 M particles, dust as mixture,
- 11 grain sizes from 1.6 μm to 1.6 mm
- $\varepsilon_0 = 1\%$
- $M_1 = 1.7\ \mathrm{M}_\odot$, $M_2 = 0.3\ \mathrm{M}_\odot$
- $M_{\mathrm{disk}} = 0.01\ \mathrm{M}_\odot$
- $\Sigma \propto r^{-1}$, $T \propto r^{-1/2}$
- $\alpha = 5\mathrm{x}10^{-3}$
- $H/R = 0.05$ @ R_{in}

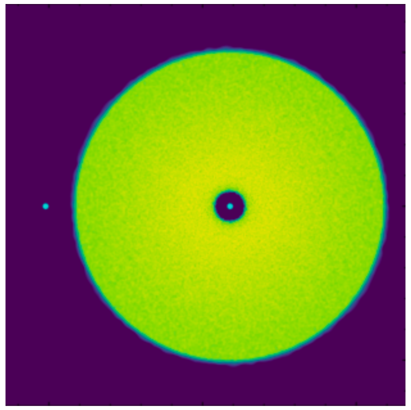
Inner companion

- $a = 10$ au, $e = 0.5$
- $R_{\mathrm{in}} = 30$ au, $R_{\mathrm{out}} = 350$ au

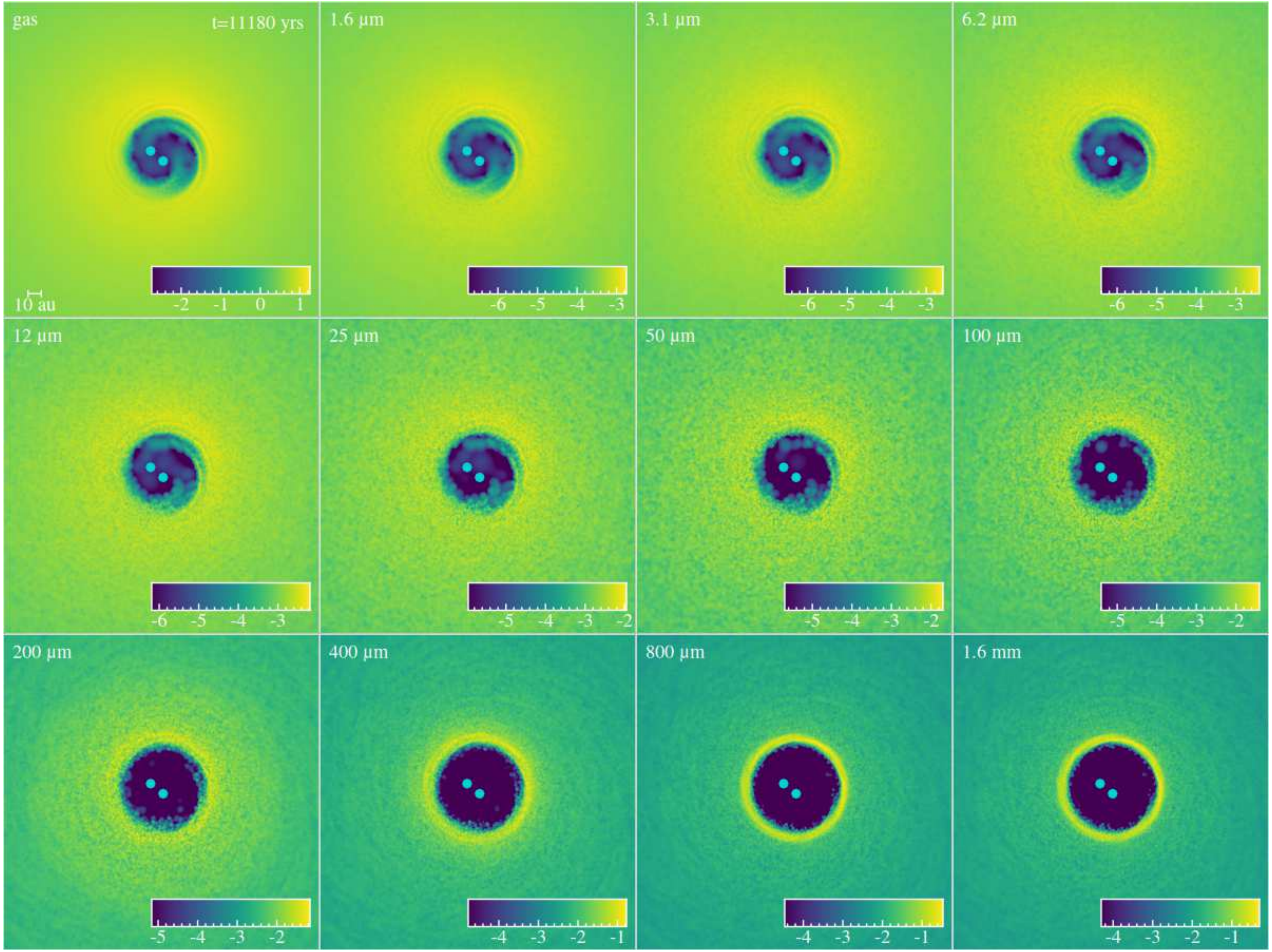


Outer companion

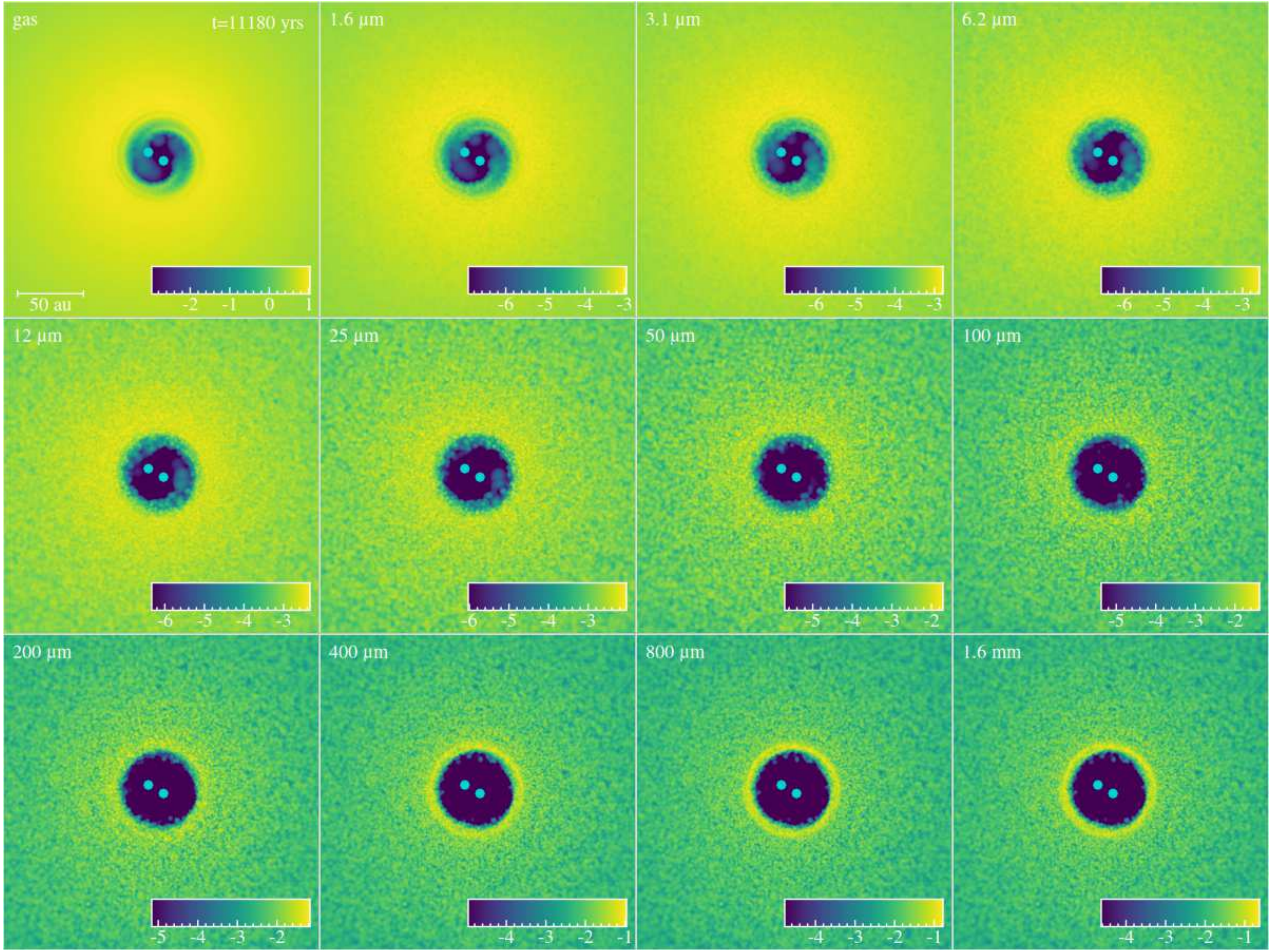
- $a = 120$ au, $e = 0$
- $R_{\mathrm{in}} = 10$ au, $R_{\mathrm{out}} = 100$ au



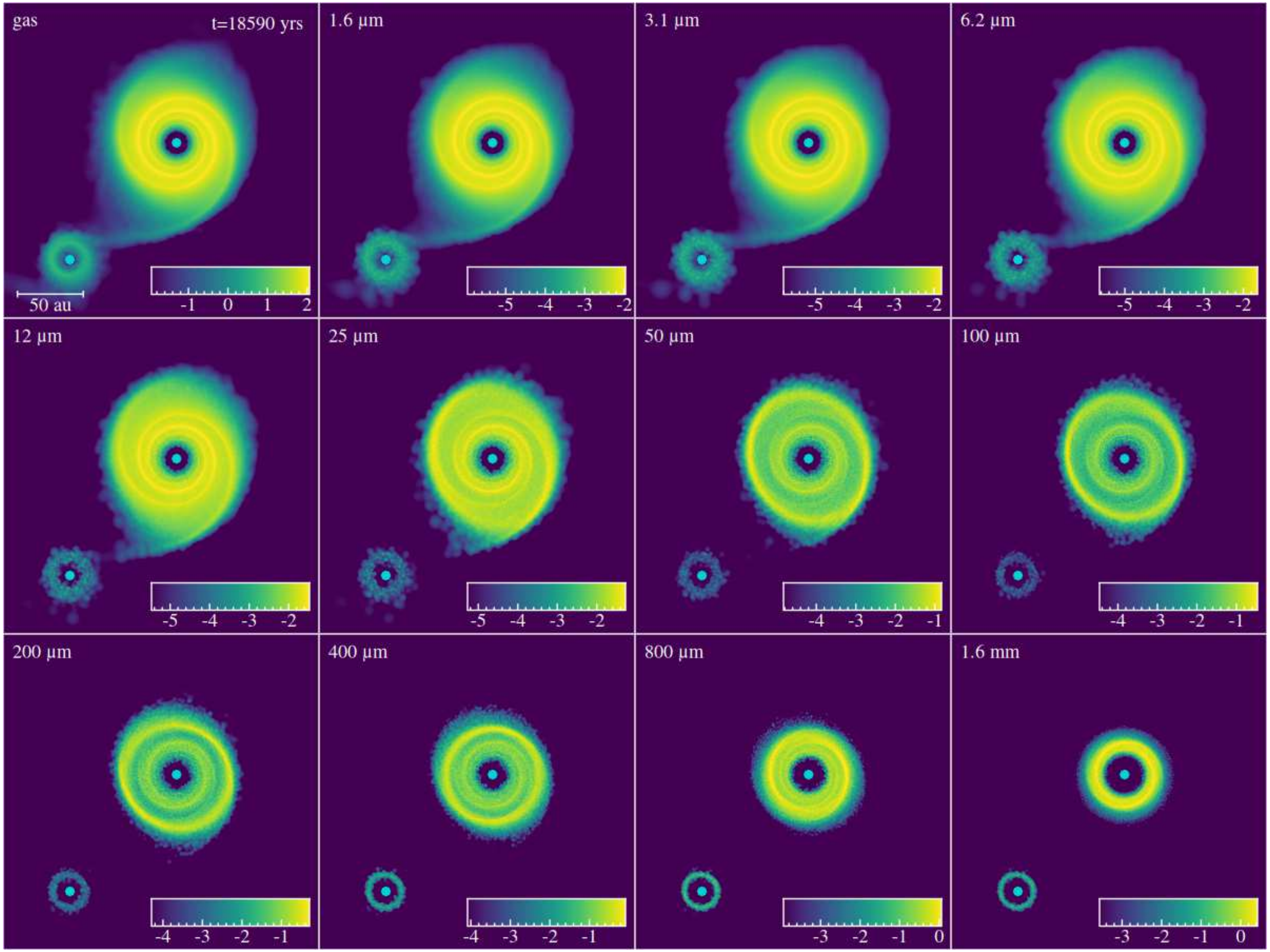
INNER COMPANION



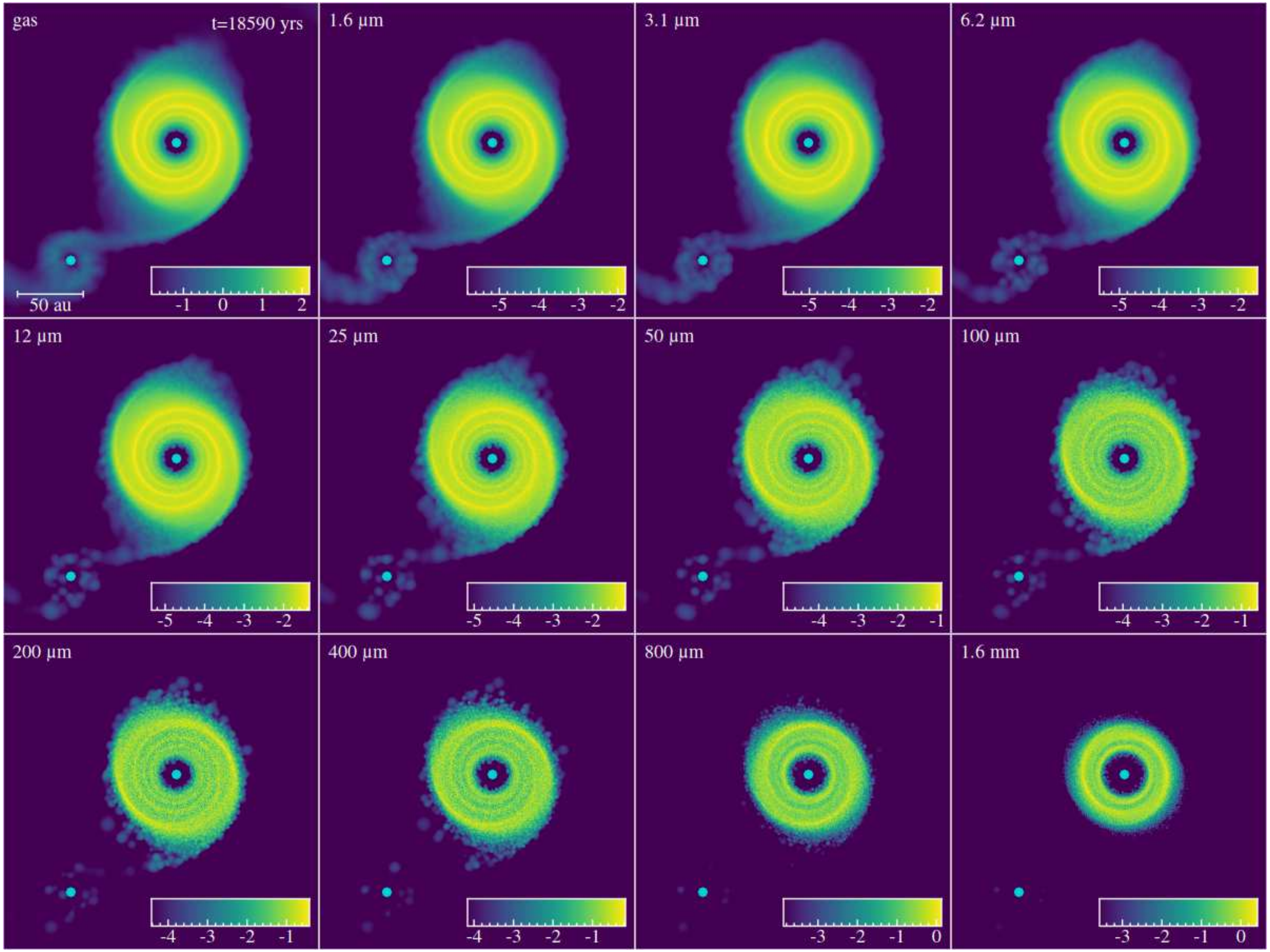
INNER COMPANION



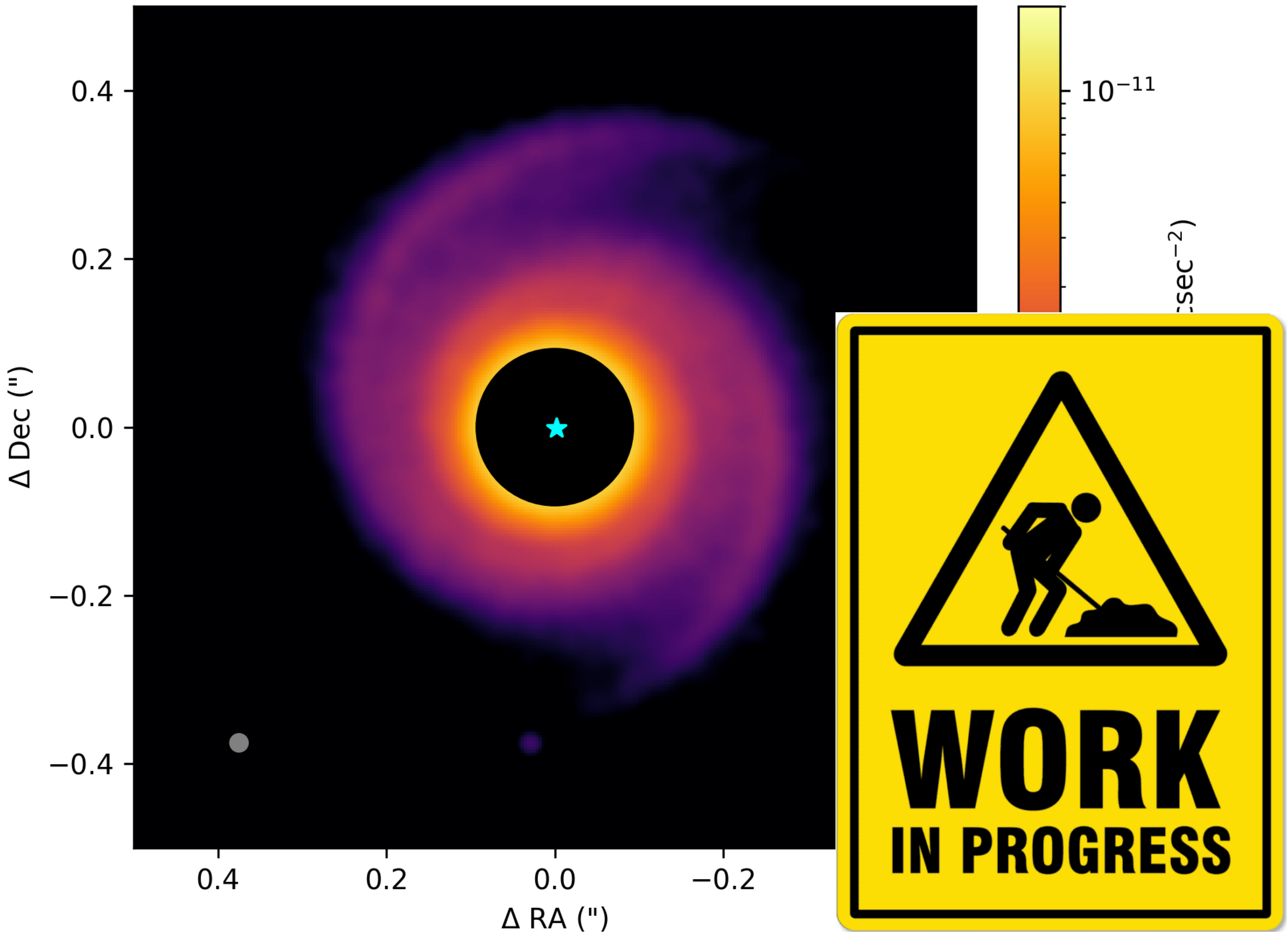
OUTER COMPANION



OUTER COMPANION



OUTER COMPANION



MCFOST – Scattered light – λ = 1.6 µm

FUTURE WORK

- Compute synthetic images for all cases
  - Scattered light
  - Continuum emission
  - Gas emission
- Trace the spirals, measure pitch angles
- Assess detectability of isothermal/ RT difference