No Turbulence in DM Tau?!

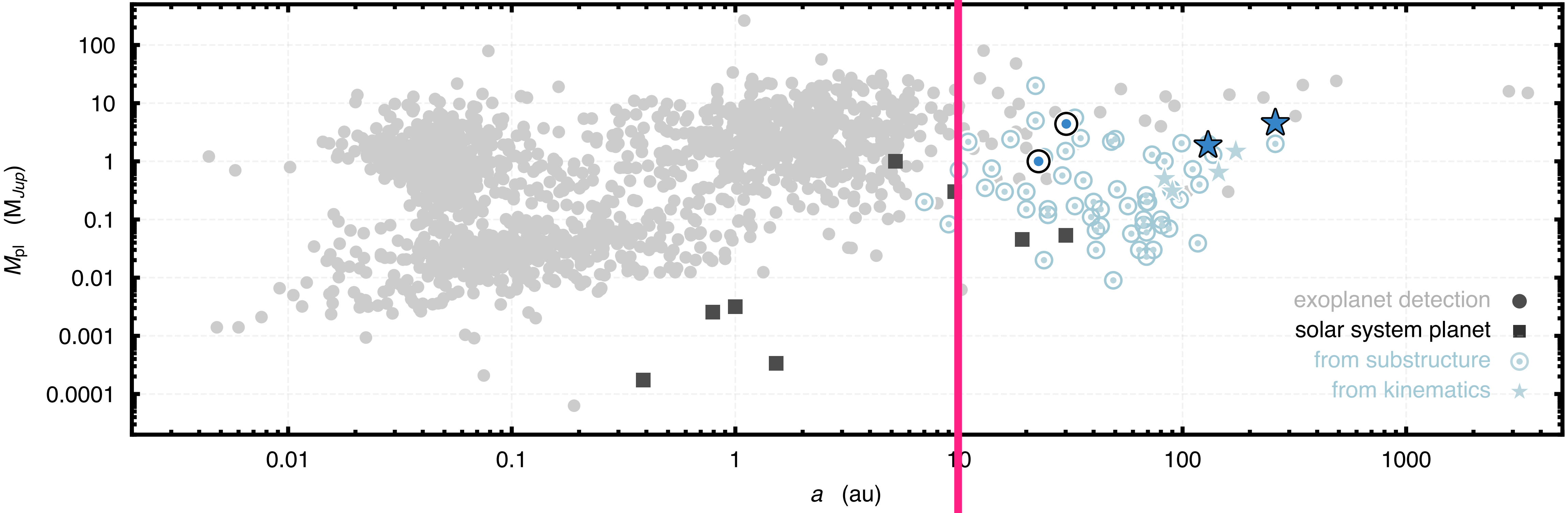
obtaining more accurate protoplanetary disc parameters

Caitlyn Hardiman
Monash University
with Daniel Price and Christophe Pinte

5th Phantom and MCFOST Users Workshop – 13 February 2024

radial velocity, transit method...

interactions with discs!



Pinte et al. (2022)

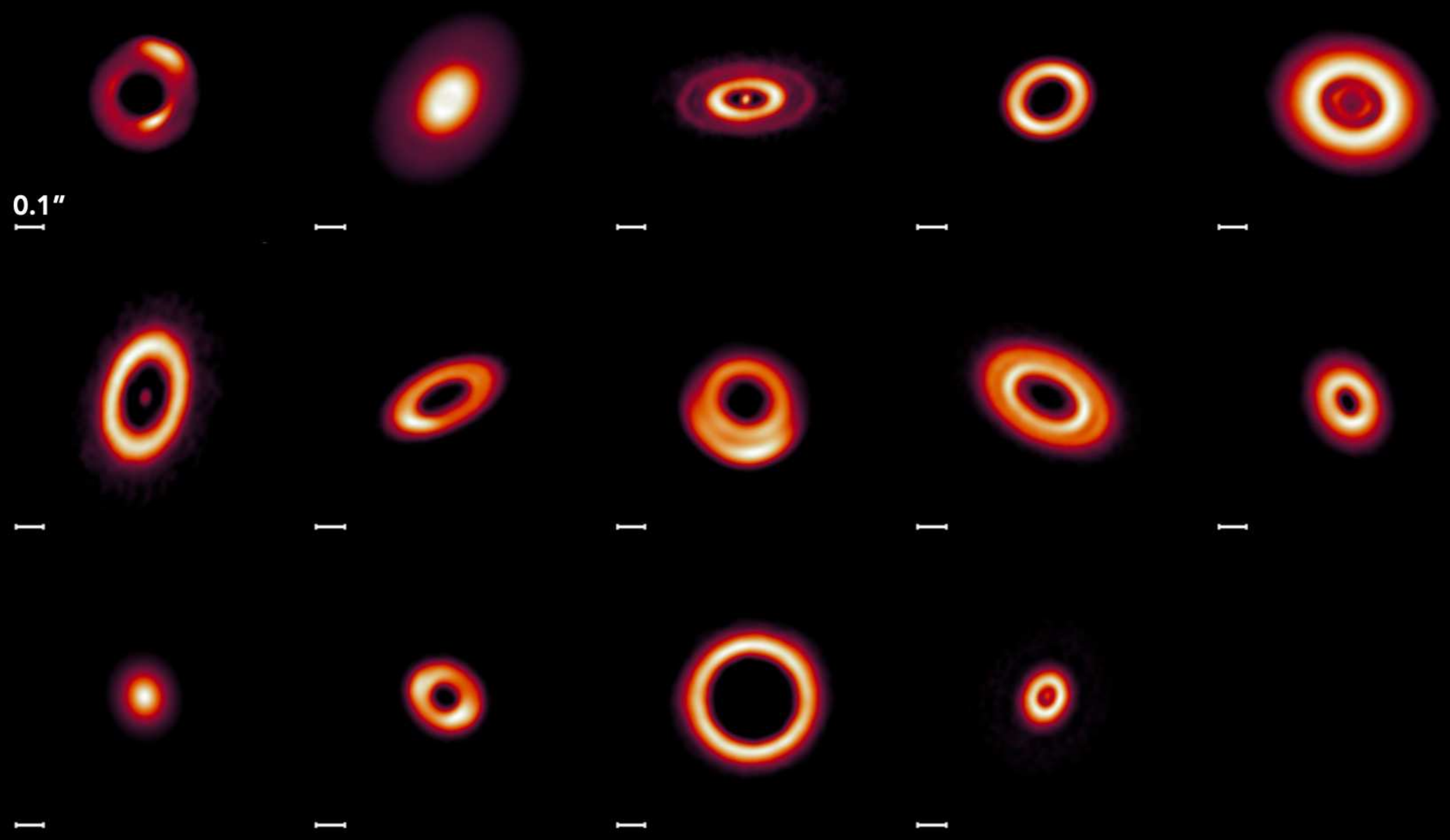
exoALMA

180 hour ALMA large program to characterize disc dynamics

15 discs – 28 m/s, 0.1”, >10h per source

PI: Richard Teague

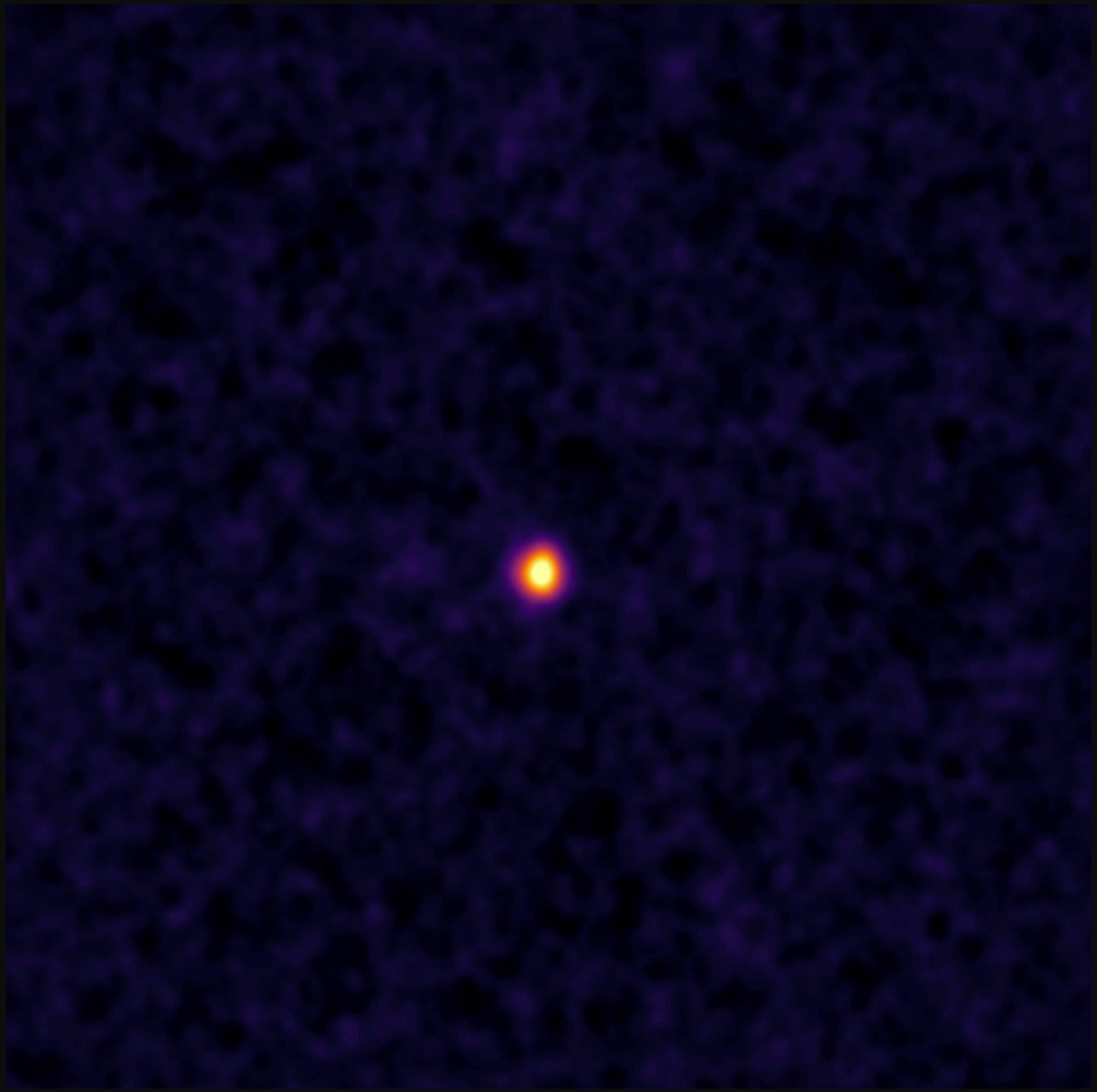
co-PIs: Myriam Benisty, Stefano Facchini, Christophe Pinte, Misato Fukagawa


0.1″

What drives mass accretion and angular momentum transport in discs?

We don’t know!

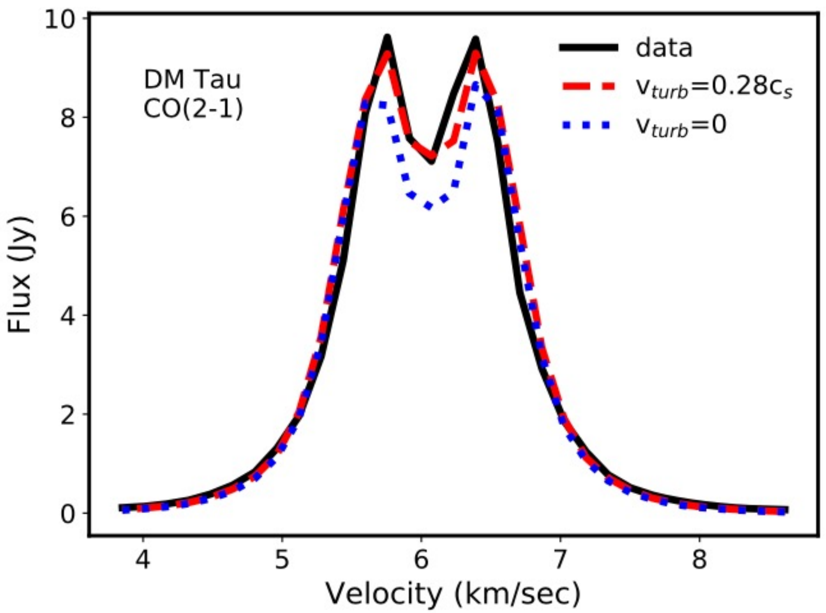
- These processes are important for planet formation (e.g. location and growth of dust grains, planet migration, core accretion)
- Turbulence may be responsible
- Most protoplanetary discs measured to have turbulent velocities of < 5-10% of the sound speed (Flaherty et al. 2015, Teague et al. 2018)

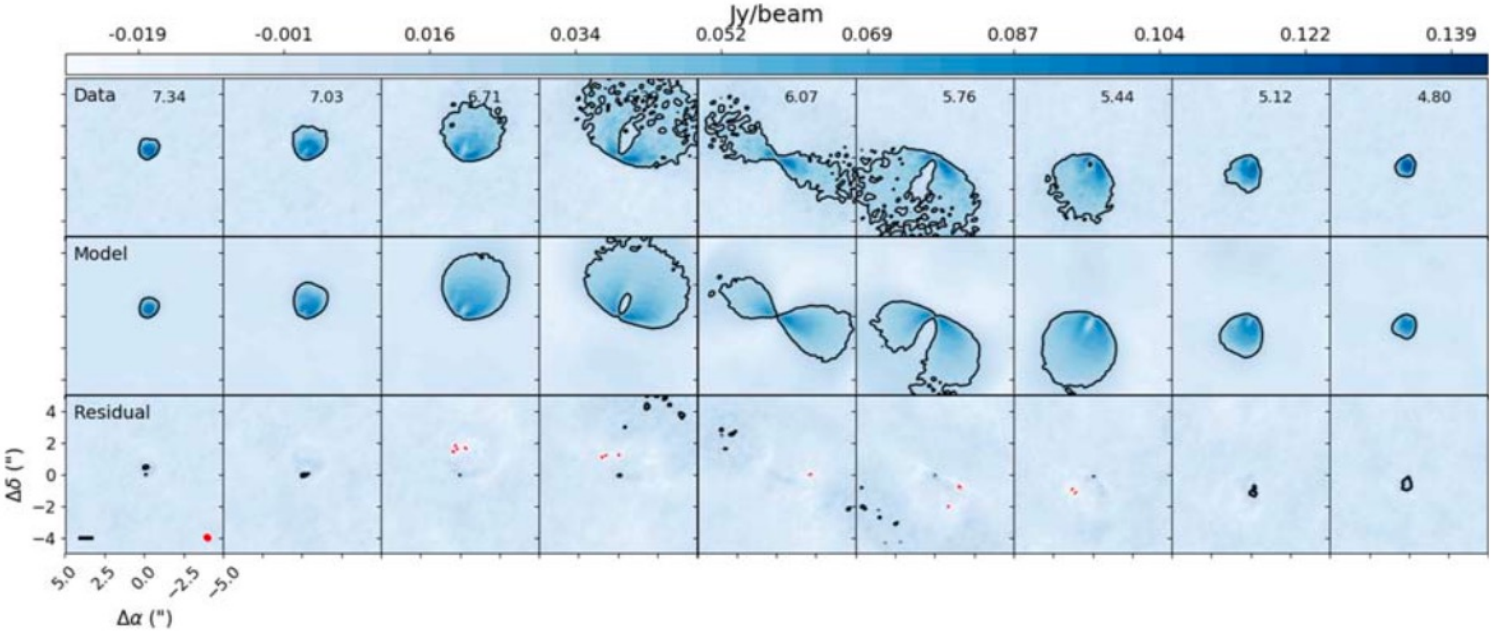


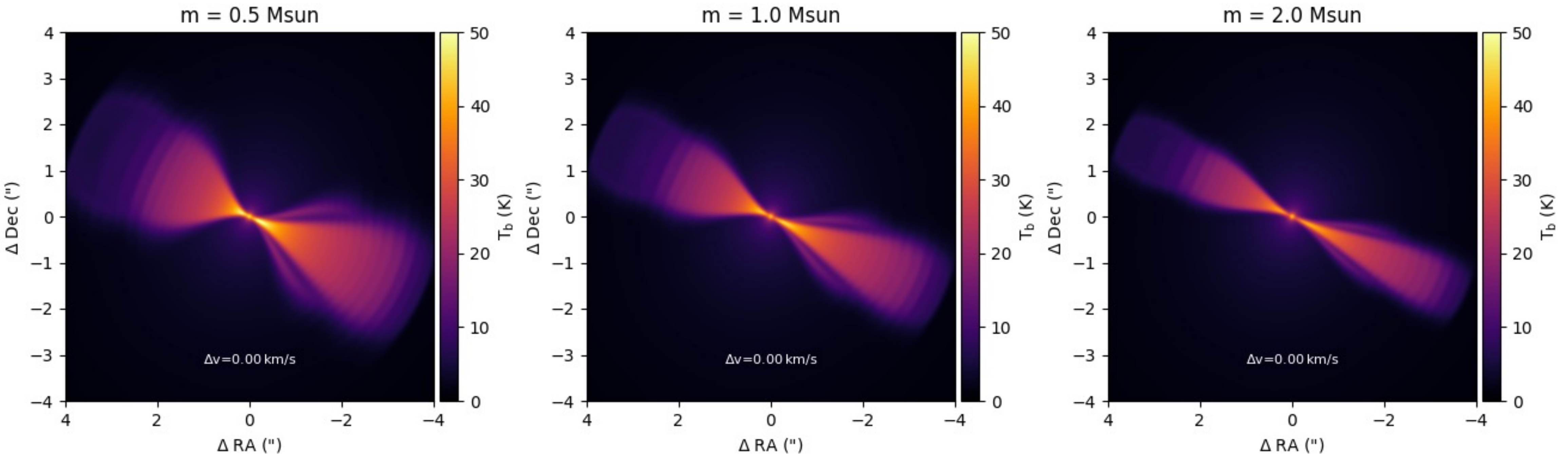
Credit: exoALMA collaboration

From Flaherty et al. (2020):

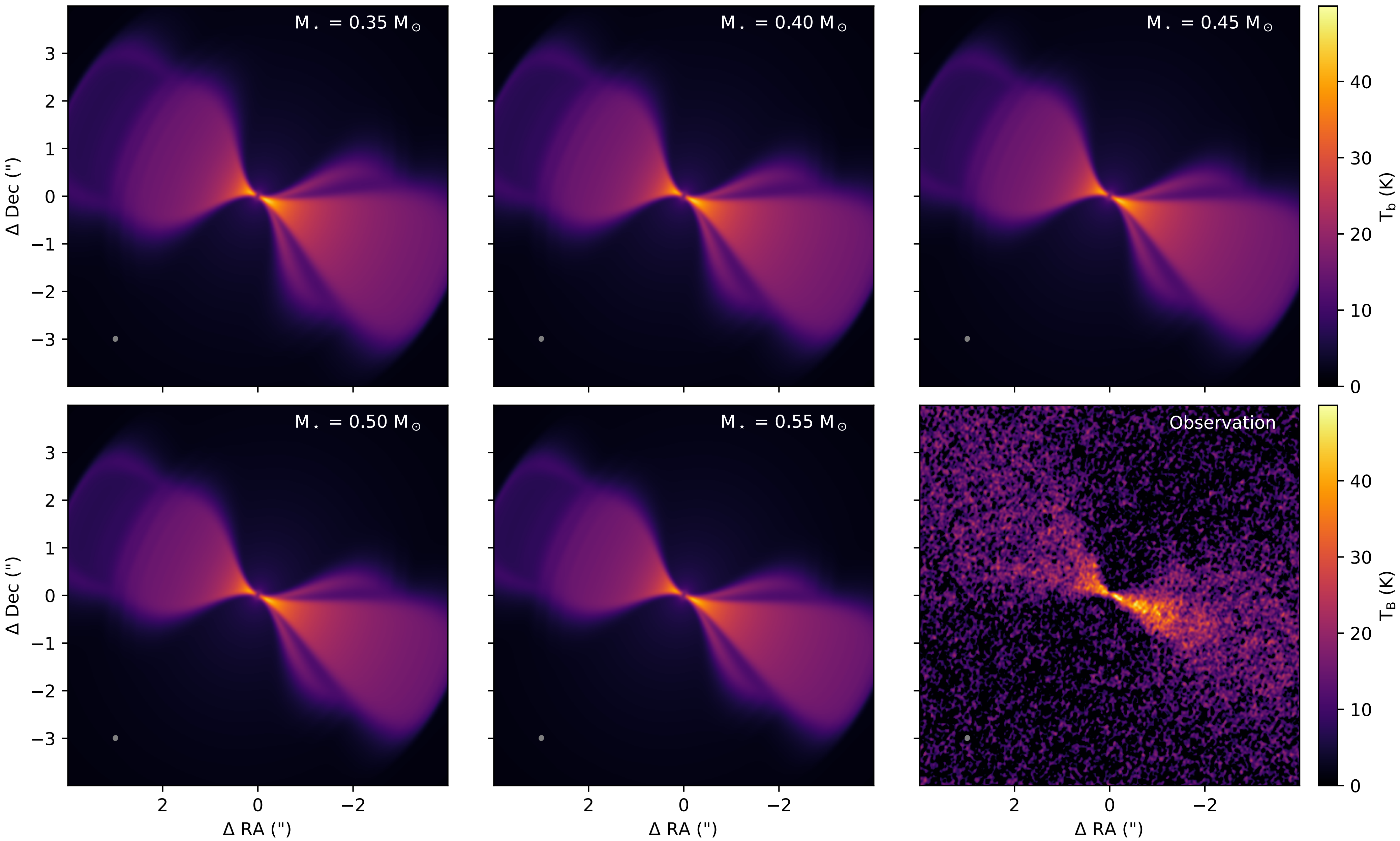
- Fixed stellar mass – 0.54 M_{sun}
- Fitting for: q, R_c, δ_{vturb}, T_{atm0}, T_{mid0}, inclination, R_{in}, v_{syst}
- Find v_{turb} ~ 60 - 80 m/s (25-33% sound speed)

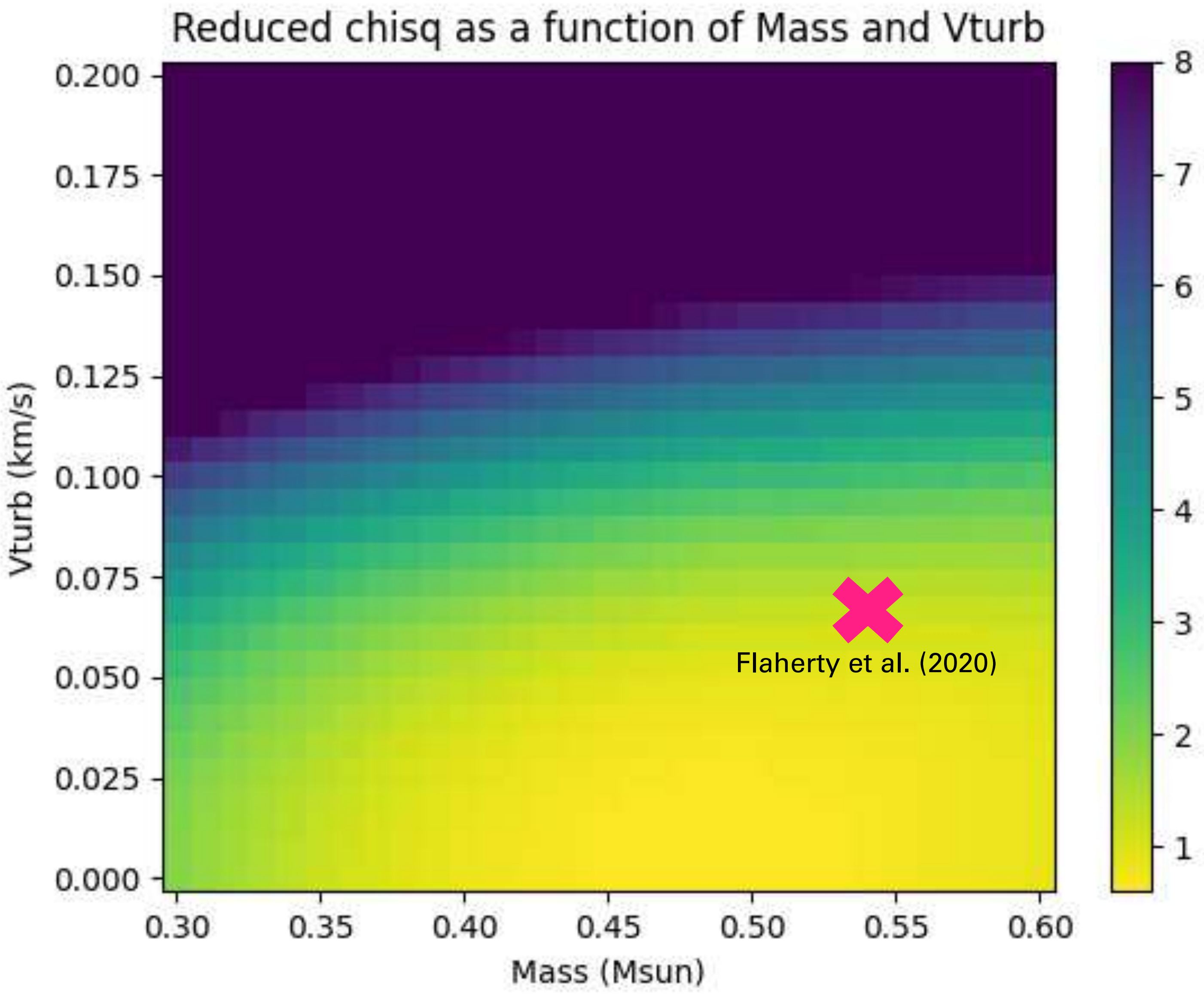






Disc modelling with MCFOST (Pinte et al. 2006, 2009)


M⋆ = 0.35 M⊙
M⋆ = 0.40 M⊙
M⋆ = 0.45 M⊙
M⋆ = 0.50 M⊙
M⋆ = 0.55 M⊙
Observation
Δ Dec (")
Δ RA (")
T_b (K)
T_B (K)


Reduced chisq as a function of Mass and Vturb
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Vturb (km/s)
0.30
0.35
0.40
0.45
0.50
0.55
0.60
Mass (Msun)
8
7
6
5
4
3
2
1
Flaherty et al. (2020)

RADIO ASTRONOMY

an extremely brief and non-comprehensive interlude

(for more please watch David Wilner's 2015 ANITA lectures on Radio Interferometry:
https://www.youtube.com/watch?v=0TwnZhiEc3A, https://www.youtube.com/watch?v=mRUZ9eckHZg&t=2740s)

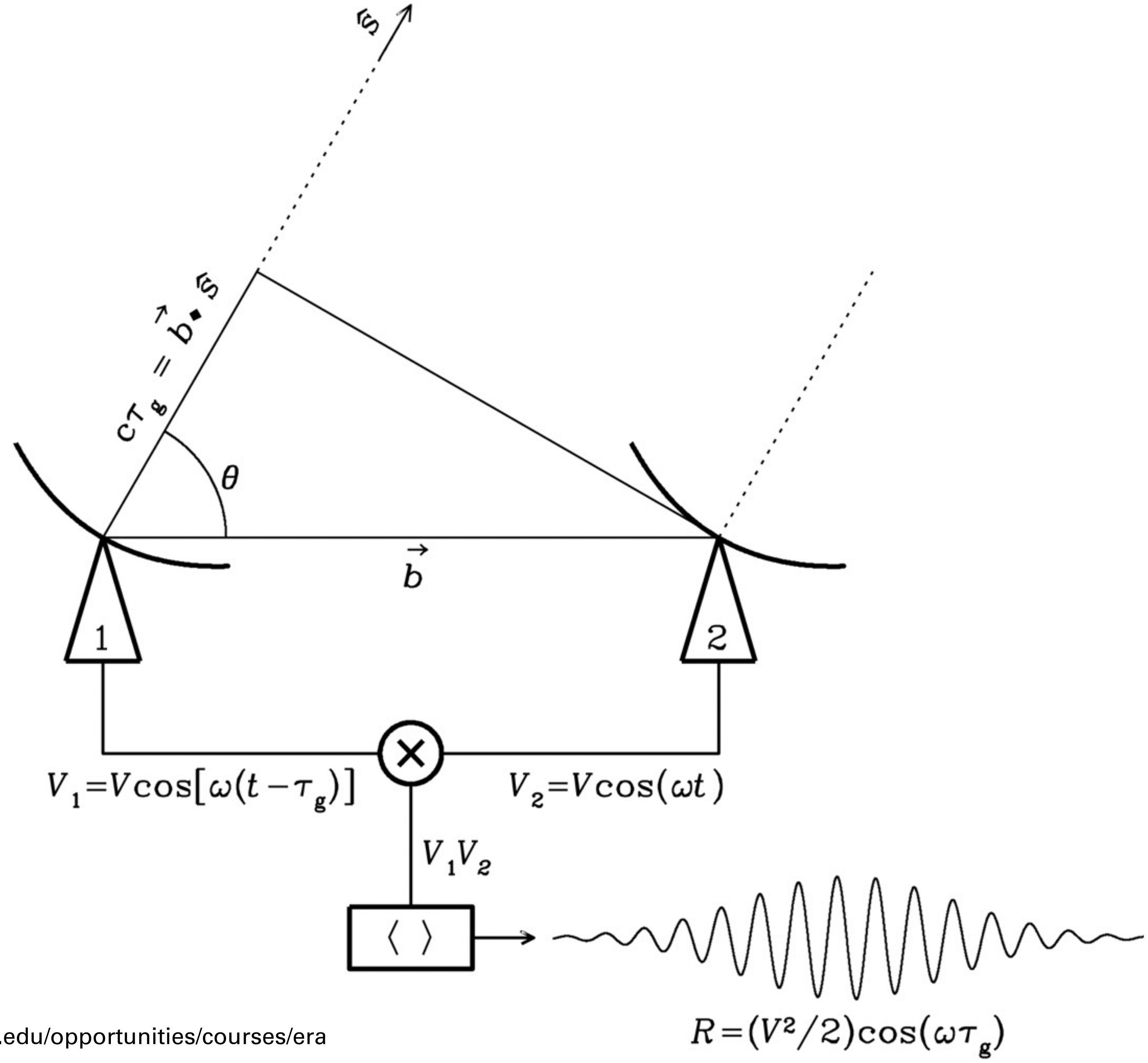


Image credit: https://science.nrao.edu/opportunities/courses/era

What are visibilities??

$$V(u,v) = \int\int T(l,m)e^{-i2\pi(ul+vm)}dldm$$

2D Fourier transform

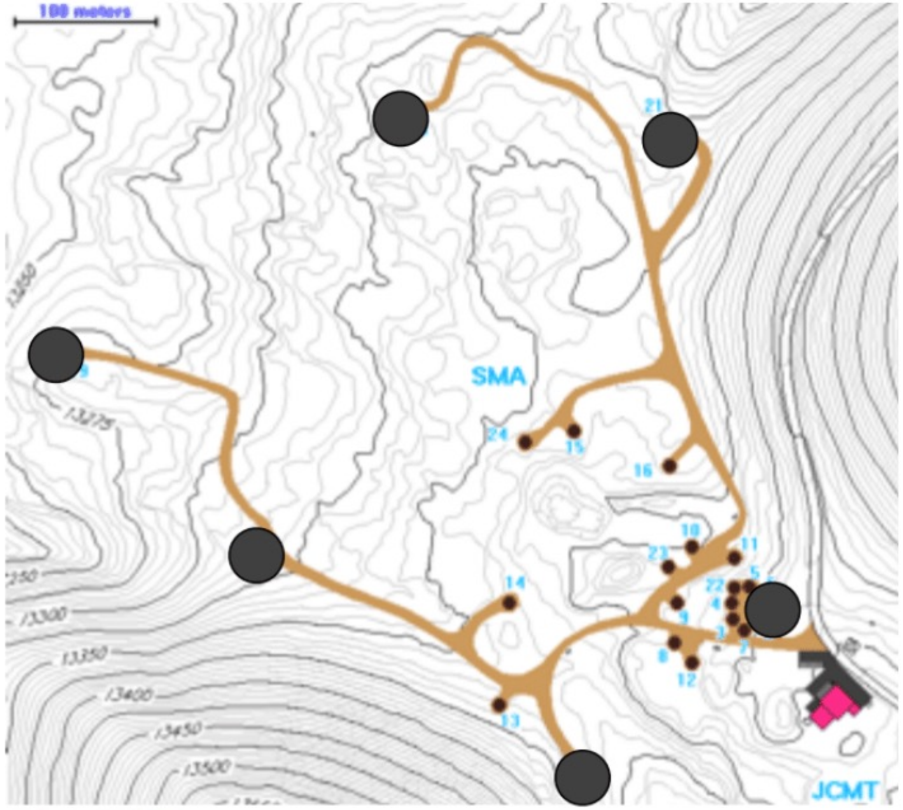
$V(u,v)$ = complex visibility function

$T(l,m)$ = sky brightness distribution

u, v = E-W, N-S spatial frequencies (wavelengths) Earth-based coordinates

l, m = E-W, N-S angles in the tangent plane (radians) sky-based coordinates

(u-v) plane sampling



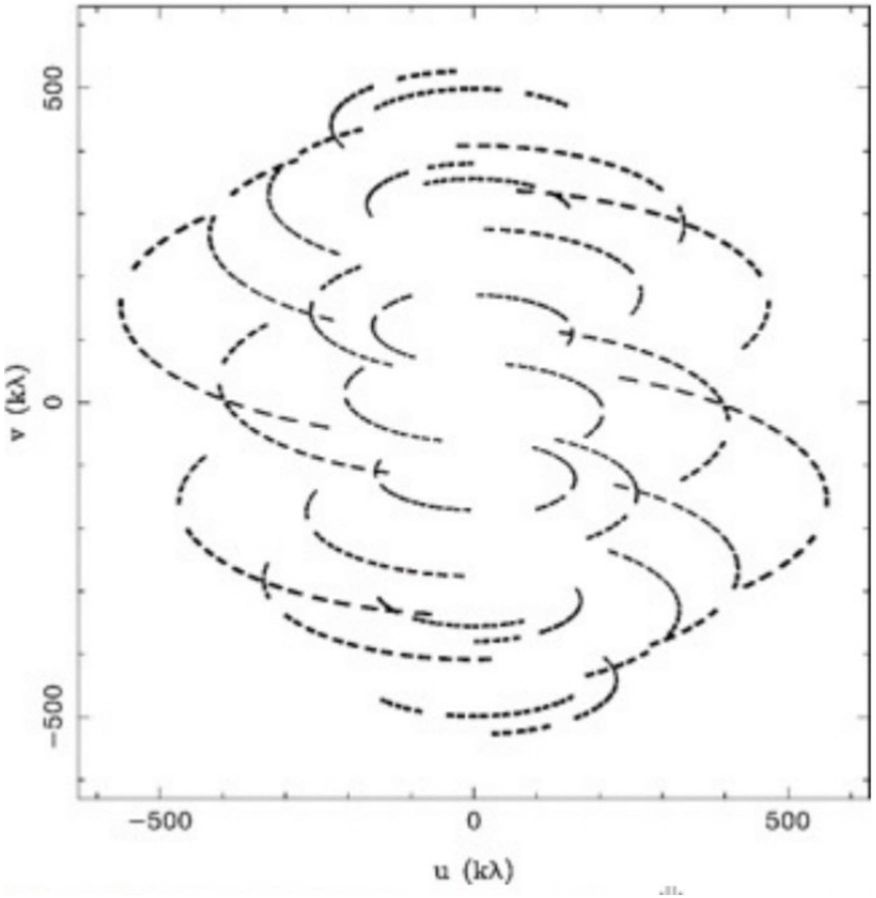
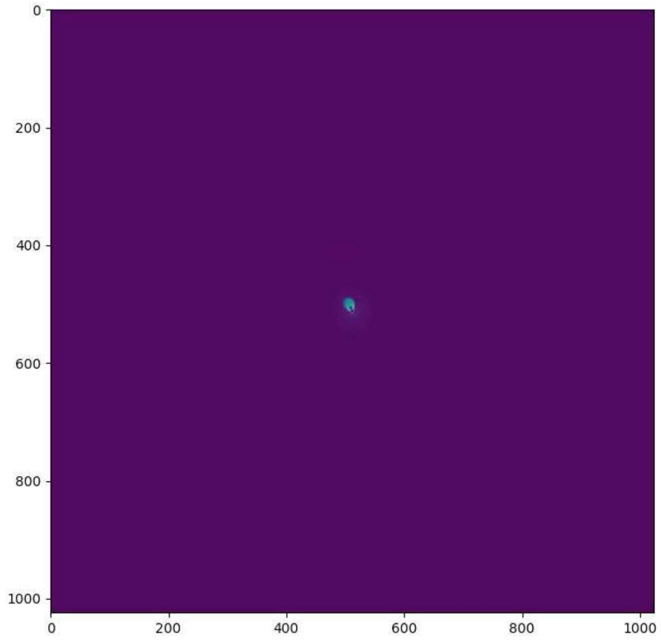


Image credit: Wilner ANITA lecture

disc modelling

generate synthetic observations using radiative transfer code MCFOST (Pinte et al. 2006, 2009)



disc modelling

generate synthetic observations using radiative transfer code MCFOST (Pinte et al. 2006, 2009)

- inclination
- stellar mass
- scale height
- tapering radius
- inner radius
- flaring exponent
- position angle (PA)
- dust settling
- turbulent velocity
- dust mass
- gas to dust mass ratio

disc modelling

generate synthetic observations using radiative transfer code MCFOST (Pinte et al. 2006, 2009)

pass model into csalt (circumstellar spectral analysis with line tomography – Sean Andrews)

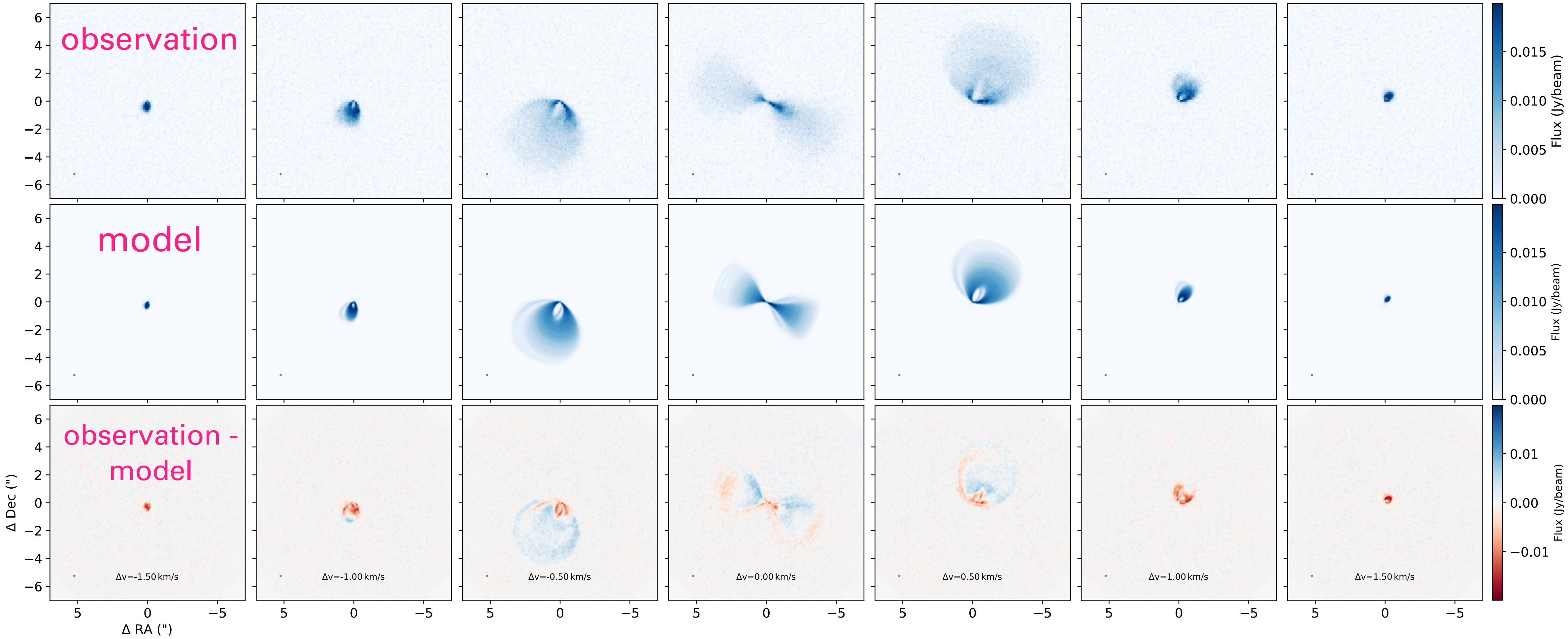
transform the model into visibility space

compare model with ALMA visibilities

run mcmc to find best fit parameters

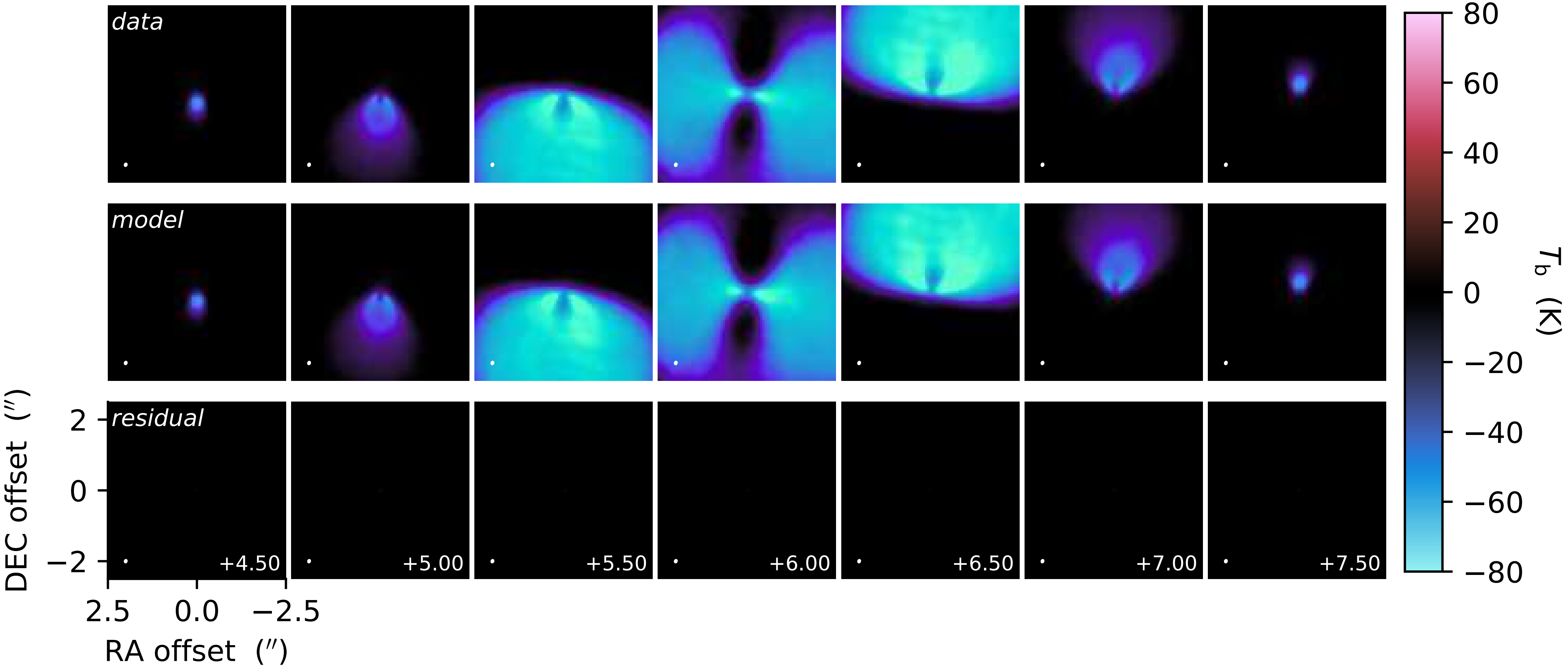
best image plane fit

Stellar mass = 0.328 Msun
Vturb = 23 m/s



visibility fitting - model to model

wow! great!

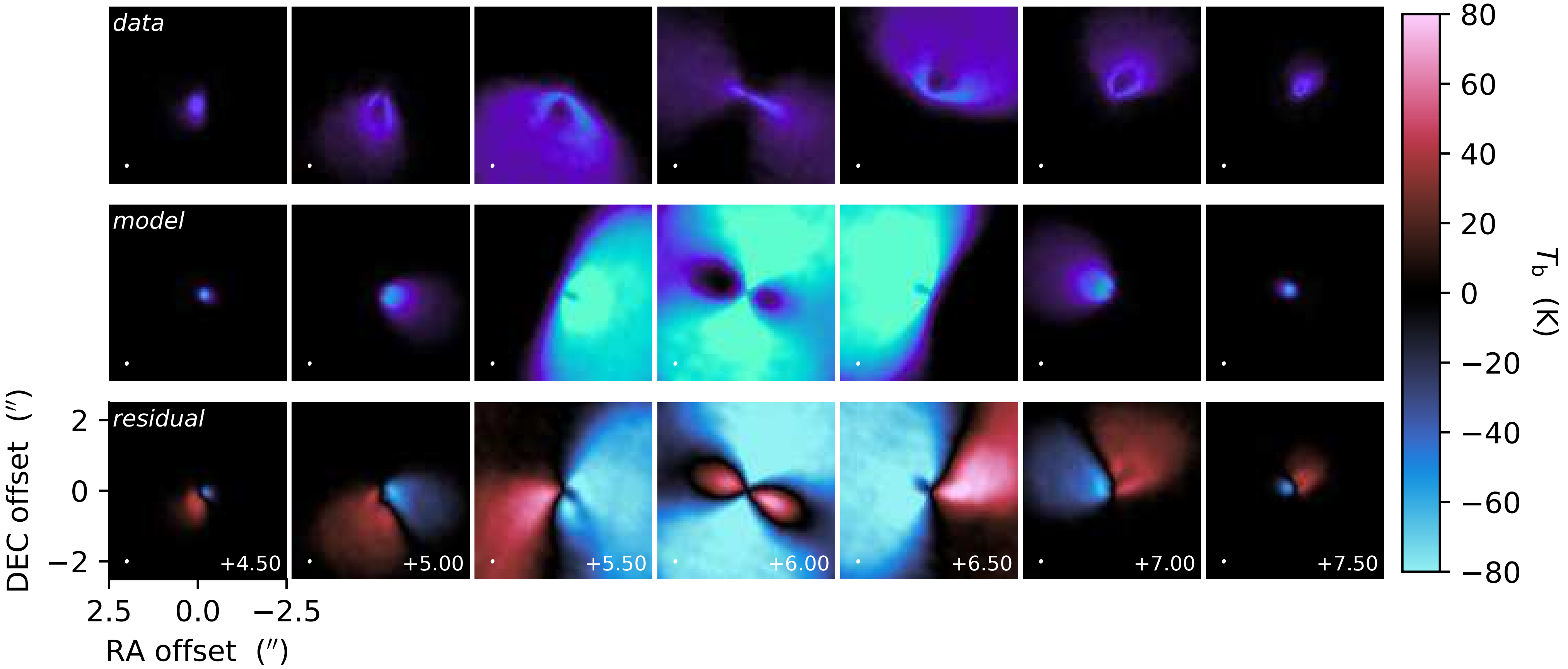


visibility fitting - model to model

Parameters	Model	Retrieved
Inc	32.5	32.6
Mstar	0.423	0.42
h	18.6	17.4
rc	247	243.7
rin	5	9.8
psi	1.315	1.334
PA	172.5	172.5
α	1e-5	2.3e-5
vturb	0	0.004
Mdust	4e-4	3.5e-4
G/D ratio	100	139.8

visibility fitting – model to data

wow! not great!



```python
def vis_sample(imagefile=None, uvfile=None, uu=None, vv=None, mu_RA=0, mu_DEC=0, src_distance=None, gcf_holder=None, corr_cache=None, mode="interpolate", outfile=Non
    """Sample visibilities from a sky-brightness image

    vis_sample allows you to sample visibilities from a user-supplied sky-brightness image.

    (u,v) grid points can either be supplied by the user, or can be retrieved from a template uvfits file / measurement set.

    The results can be output either to a uvfits file or returned back to the user (for scripting)


    Parameters
    __________
    imagefile : the input sky brightness image, needs to be in a valid FITS format with units of DEG for the RA and DEC,
    a RADMC3D image.out file (ascii format), or a SkyImage object (use with caution)

    for uv points use:
        uvfile - uvfits file or measurement set with visibilities that the sky brightness will be interpolated to
      OR
        uu, vv - numpy arrays - they need to be in units of lambda (i.e. number of wavelengths)

    mu_RA - (optional, default = 0) right ascension offset from phase center in arcseconds (i.e. visibilities are sampled as if the image is centered at (mu_RA, mu_D

    mu_DEC - (optional, default = 0) declination offset from phase center in arcseconds (i.e. visibilities are sampled as if the image is centered at (mu_RA, mu_DEC)
```

`or a SkyImage object (use with caution)`

takeaway points

- Using new high resolution ALMA data we aim to constrain protoplanetary disc parameters better than ever before
- We model discs using MCFOST and compare to observations in both the image plane and visibility space using csalt
- Model to model visibility fitting works!
  - We can retrieve turbulence consistent with 0 m/s
- Model to data fitting still needs some extra prayers – stay tuned for the rest of the week…