TESTING THE SUPERMASSIVE STAR SCENARIO FOR EARLY MASSIVE CLUSTER EVOLUTION

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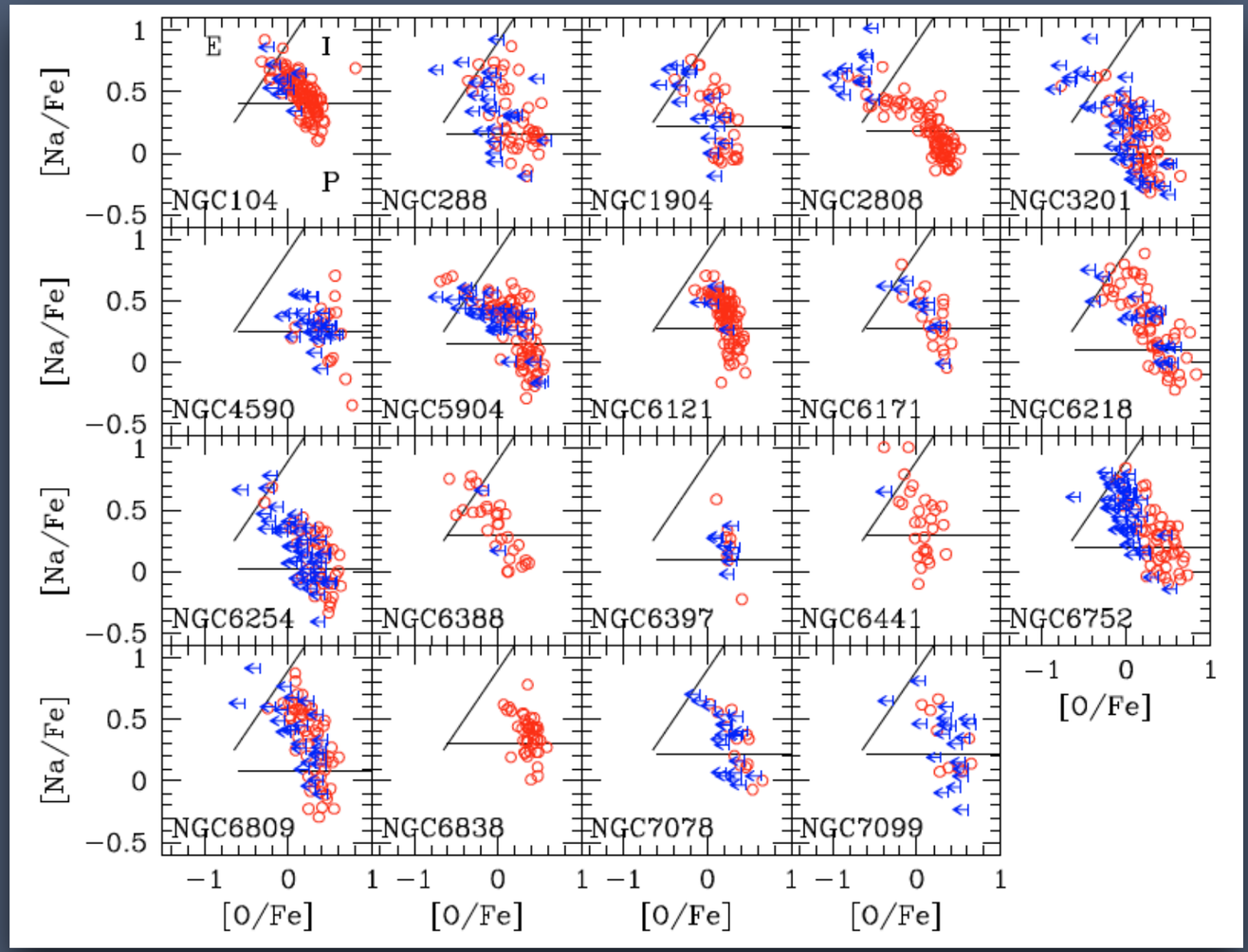
Credit: NASA, ESA

Clusters

- Oldest - up to 13.5 Gyr
- Dense
- Simple
- Single populations

WHAT IS SO PUZZLING ABOUT GLOBULAR CLUSTERS?

- Display anticorrelated O-Na, C-N and Mg-Al abundances
- Host multiple stellar populations located all over the colour-magnitude diagram
- Low level of helium



(Carretta et al., 2010)

Self-enrichment and possible polluters

AGB stars

Build O-Na correlation

Release He-burning products: not observed in GCs

Fast rotating massive stars

Reach Mg-burning temperature

Produce strong He enrichment

Supermassive stars

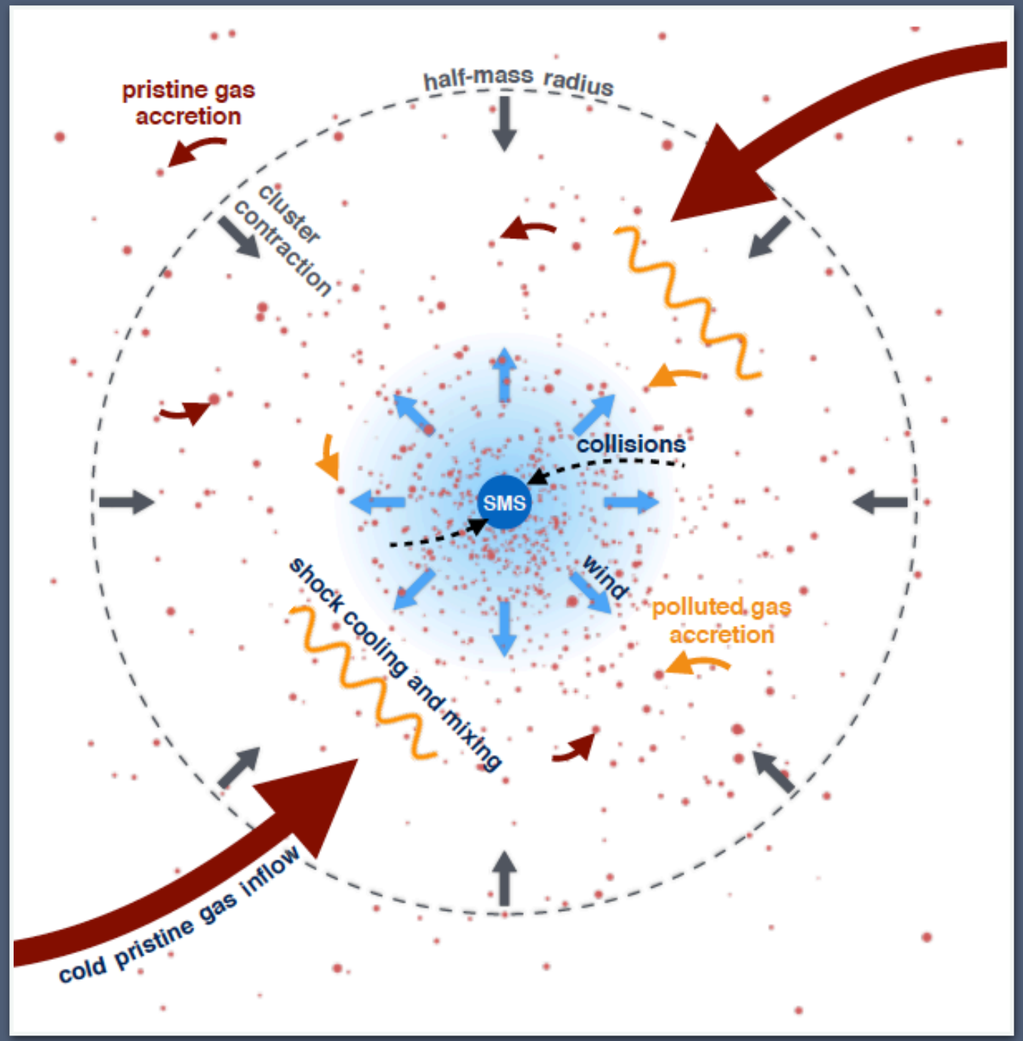
Reach the required Mg burning temperature already at the beginning of their evolution

The H-burning products at the early stage show agreement with observed anomalies

Have not been observed

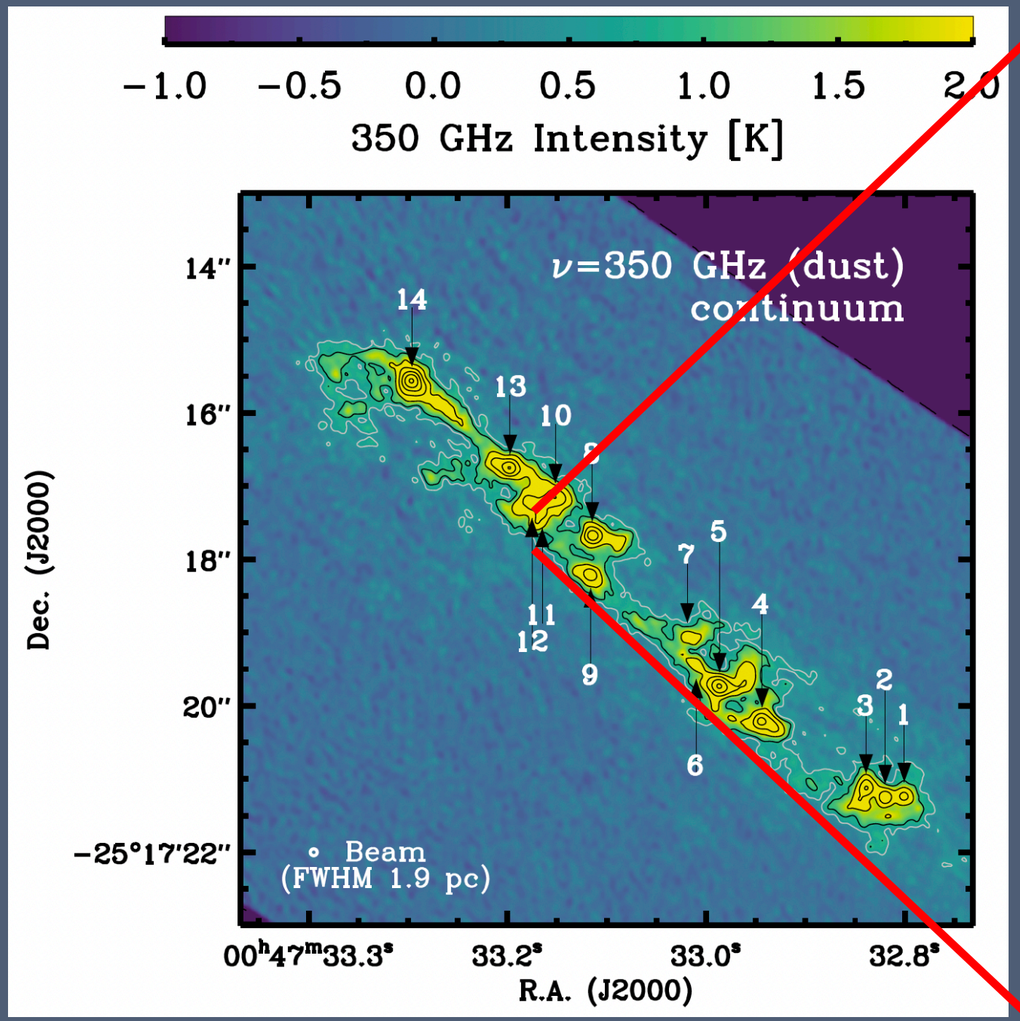
SUPERMASSIVE STAR

- Forms via runaway collision, simultaneously with the globular cluster
- Has a mass of at least $10^3\ M_\odot$
- Assumed to be fully convective
- Releases its material at the very beginning of the main sequence phase in a radiatively driven wind

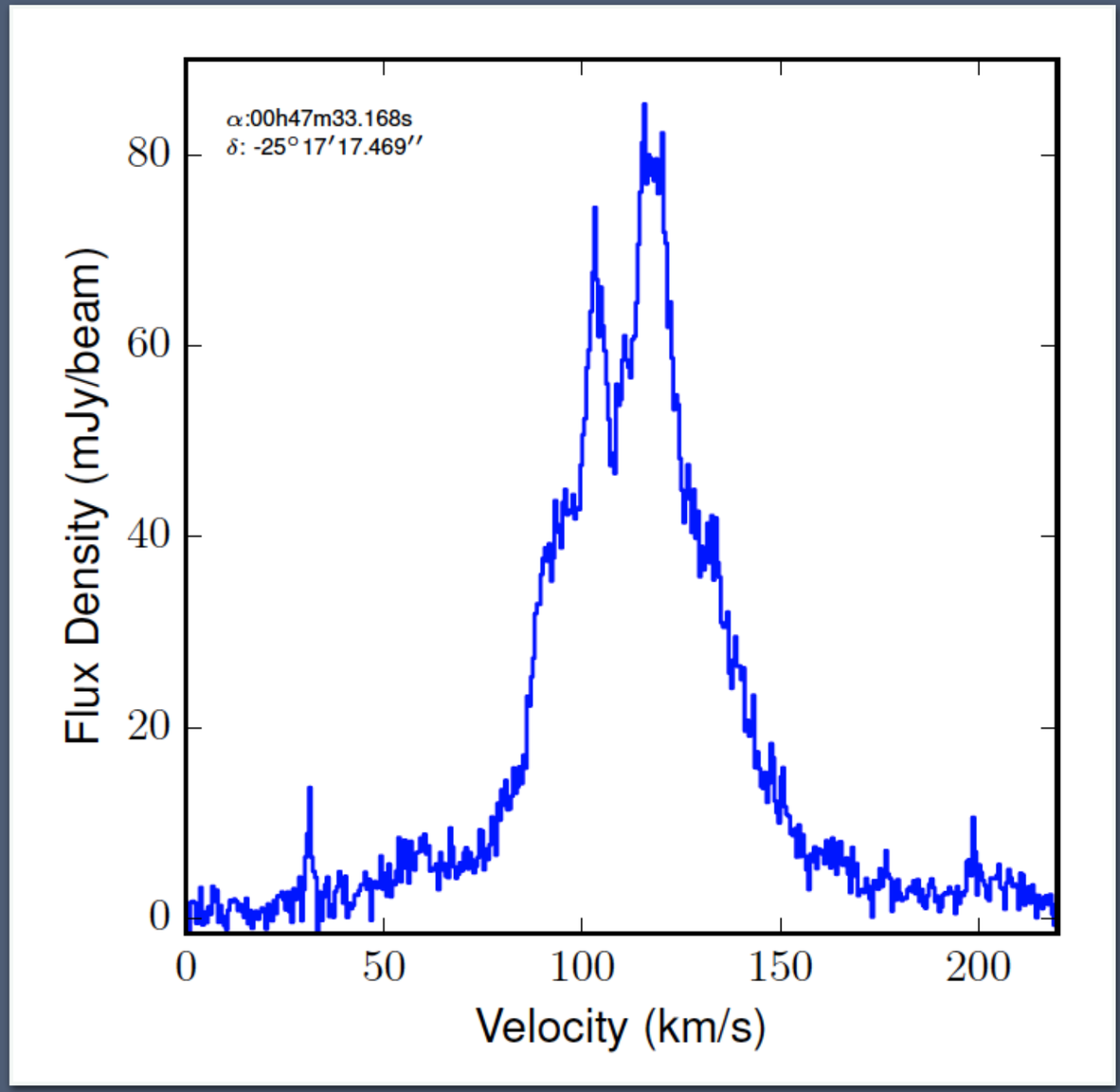


(Gieles et al., 2018)

NGC 253



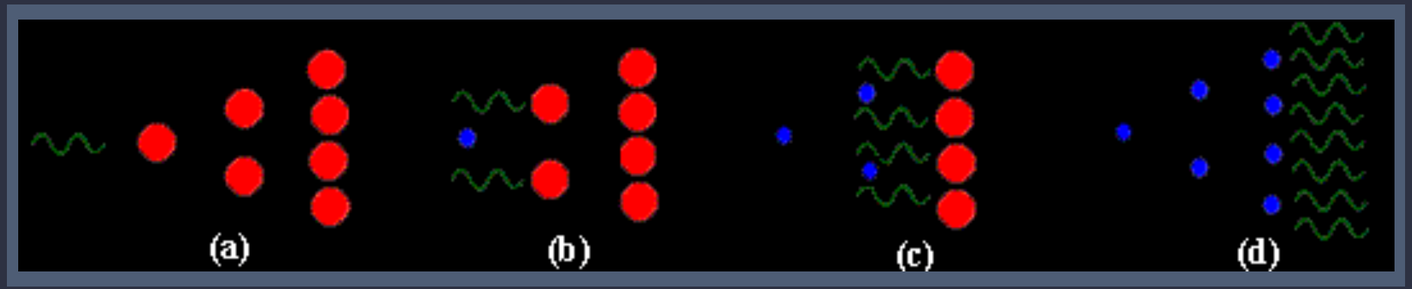
(Leroy et al., 2018)



(Gorski et al., 2018)

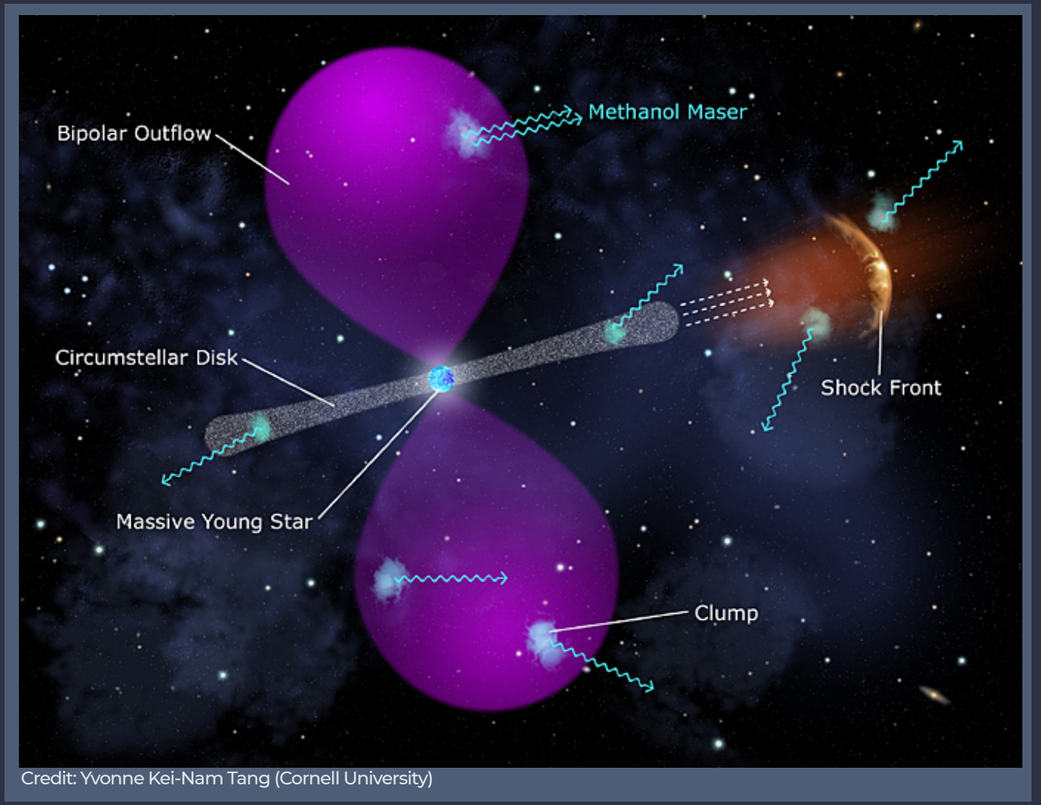
WHAT ARE MASERS?

- radiation amplified by stimulated emission
- population inversion required
- ‘pumping mechanism’ - external energy source



The most common masers in astrophysical environment:

1. Hydroxyl
2. Water
3. Methanol



Credit: Yvonne Kei-Nam Tang (Cornell University)

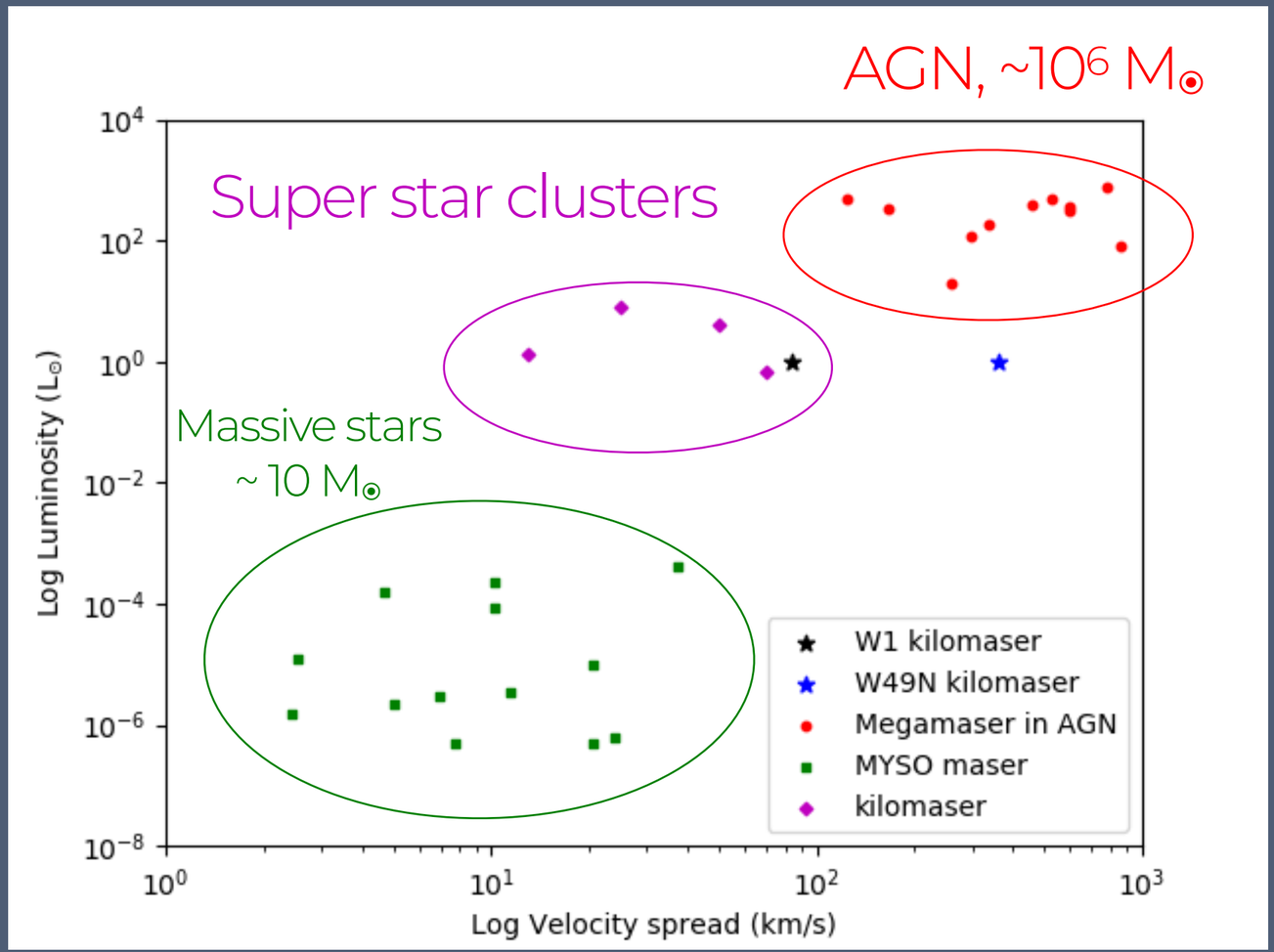
22 GHz H_2O MASERS

Classified as:

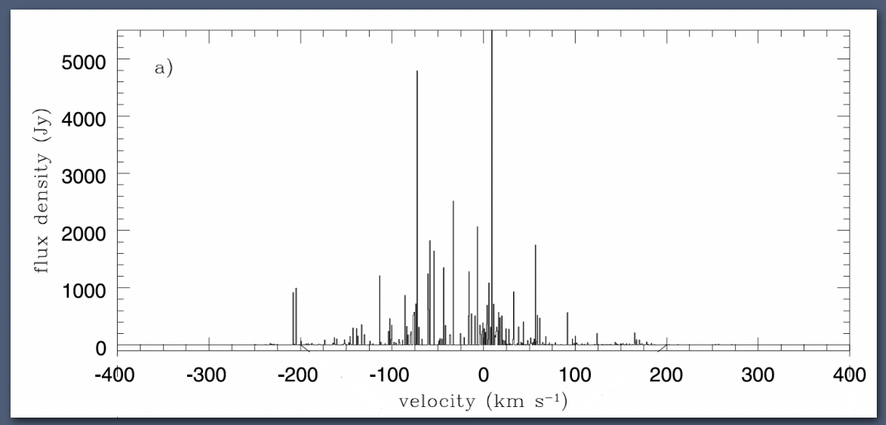
1. Stellar masers: L < 0.1 $L_\odot$
2. Kilomasers: 0.1 $L_\odot$ < L < 1 $L_\odot$
3. Megamasers: L > 20 $L_\odot$

Maser emission requires:

- dense gas: > 10^7 cm^{-3}
- temperature:
  - ✦ ~ 300 K - 1500 K (collisionally pumped)
  - ✦ ~ 1000 K (radiatively pumped)

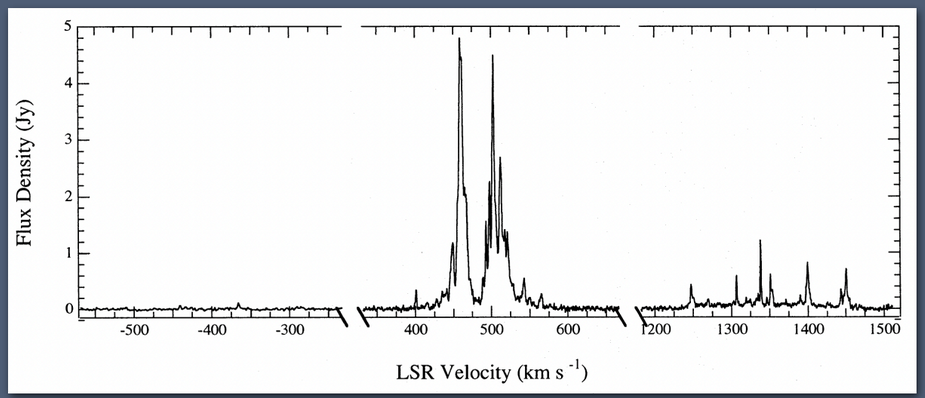


(Nowak et al., 2022)



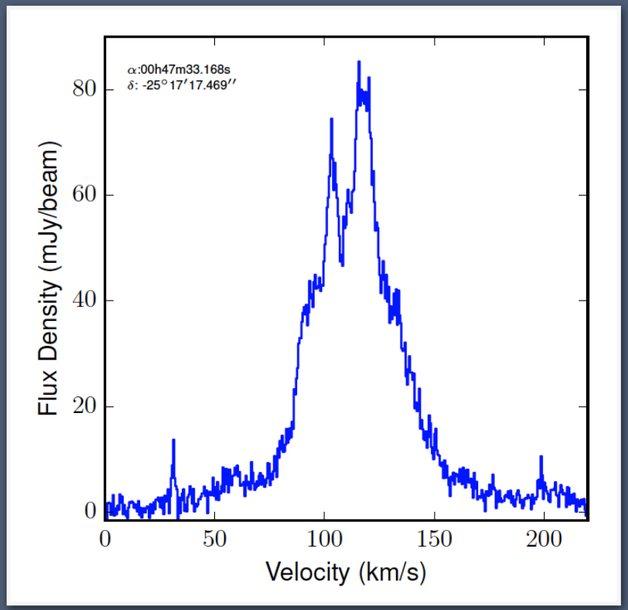
(McGrath et al., 2004)

W49N: Galactic kilomaser



(Greenhill et al., 1995)

NGC 4258: Megamaser

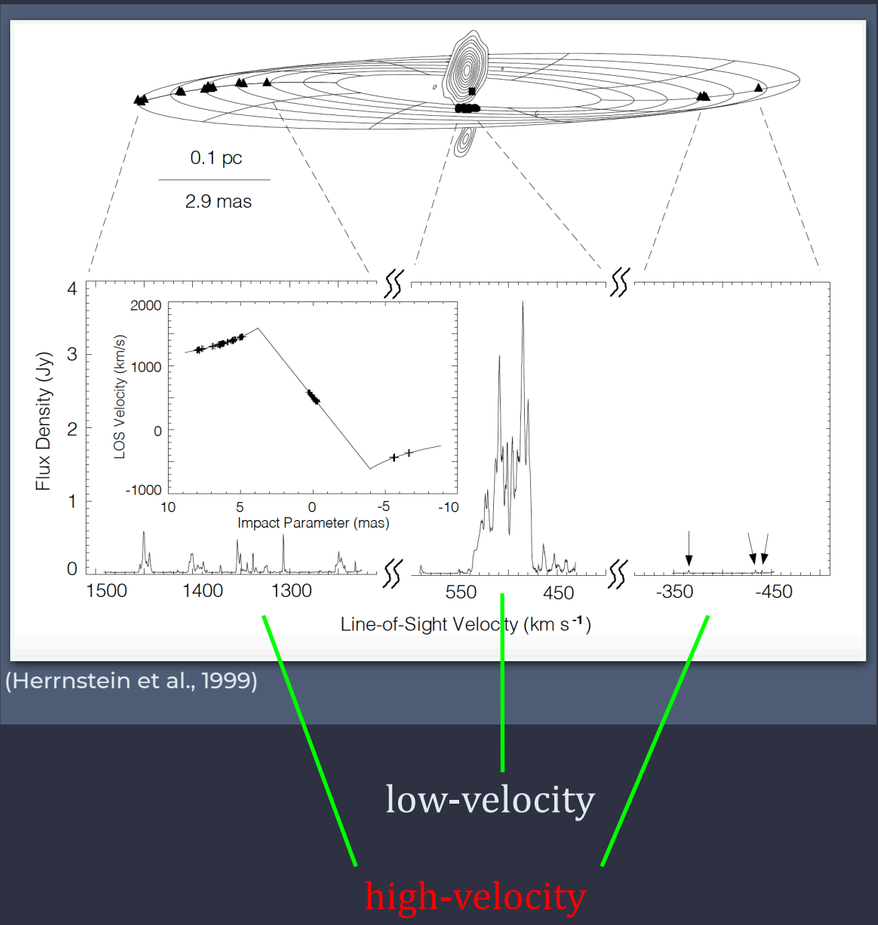


(Gorski et al., 2018)

W1: Extragalactic kilomaser

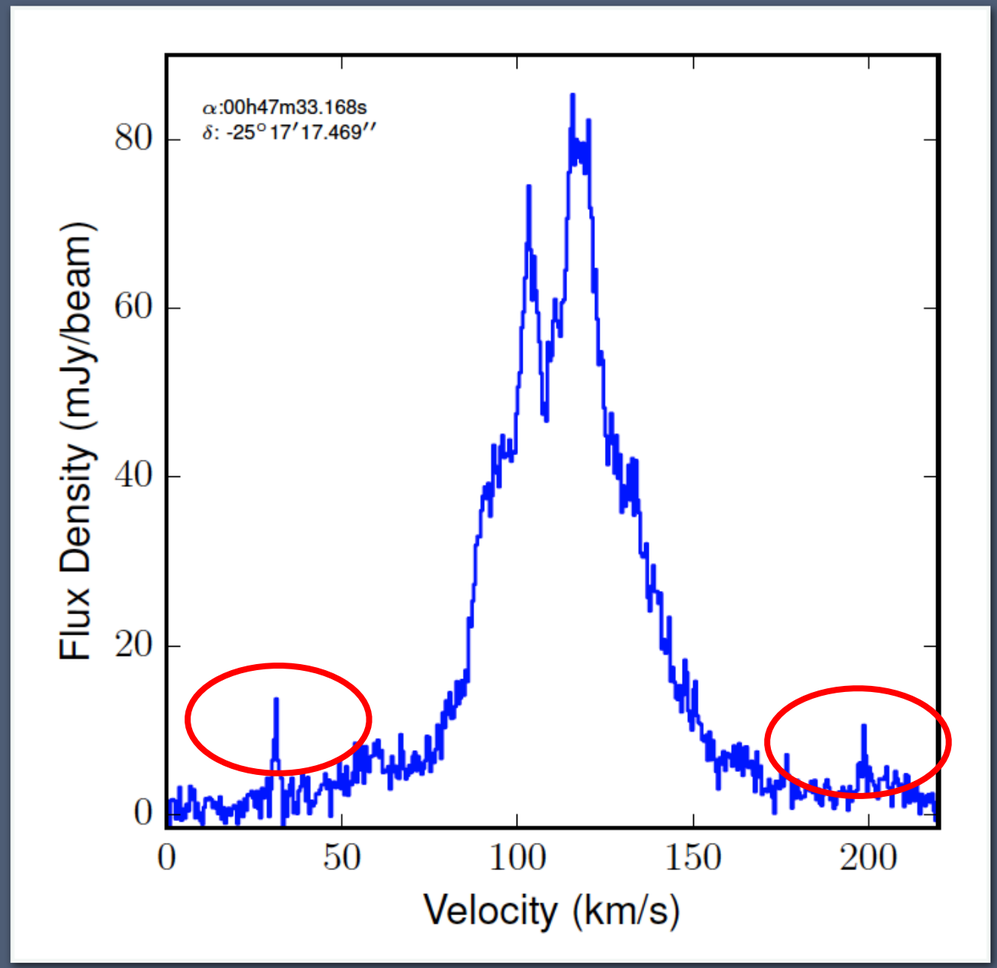
DISC MASER!

“Clean” disc maser in AGN



(Herrnstein et al., 1999)

W1: H_2O kilomaser



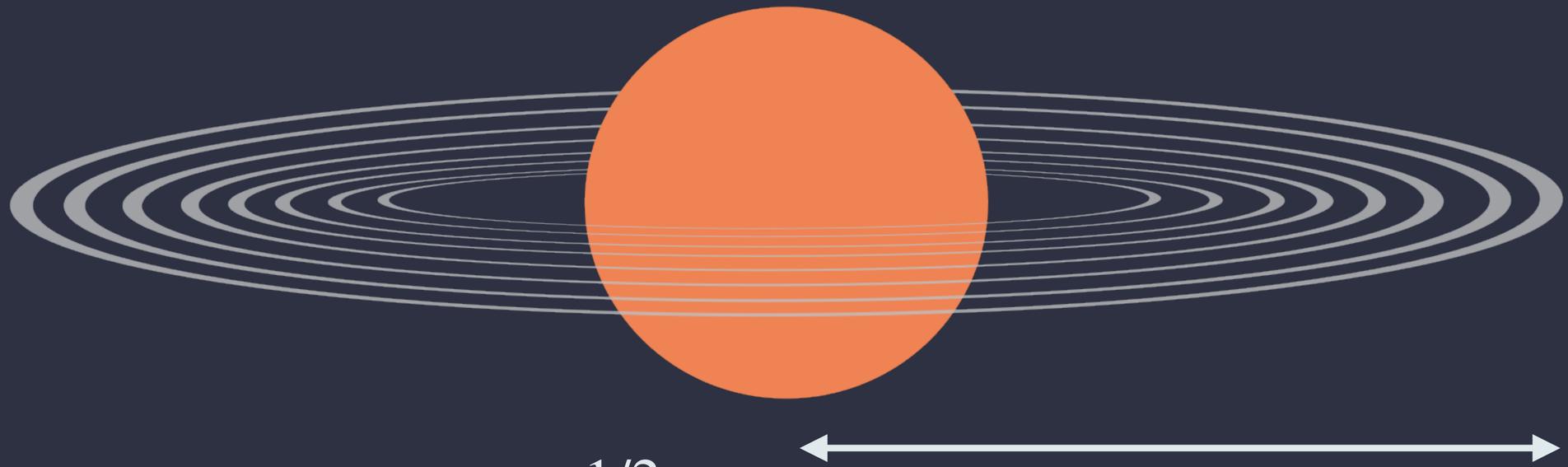
(Gorski et al., 2018)

COMPUTATIONAL SETUP

1000 $M_\odot$

10,000 $M_\odot$

COMPUTATIONAL SETUP

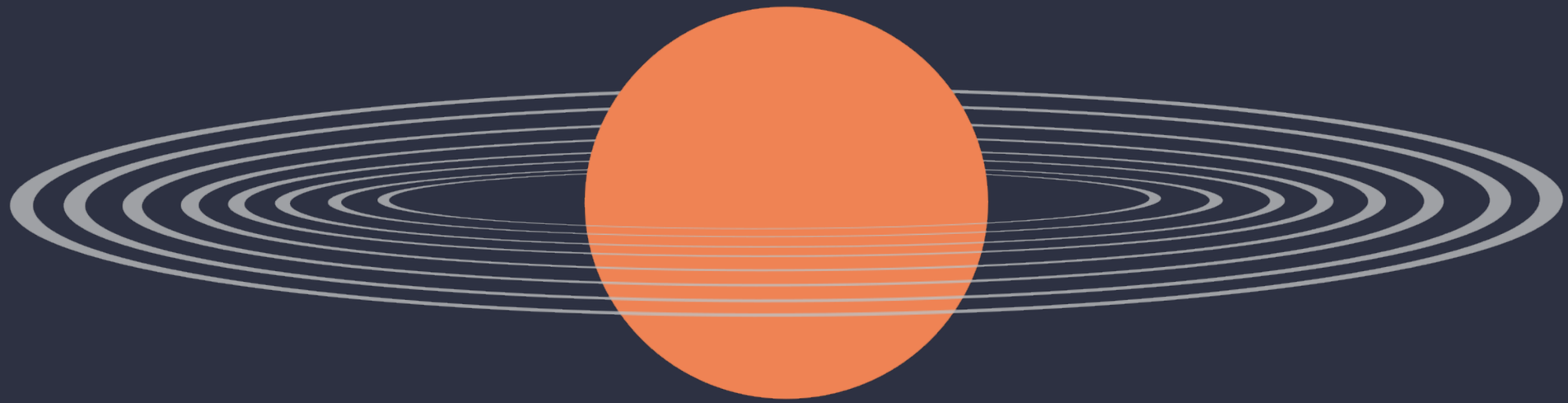


$$T = 1920\ \mathrm{K} \left(\frac{R}{R_{\mathrm{in}}} \right)^{-1/2}$$

R_{SMS}

500 au 1000 au

COMPUTATIONAL SETUP

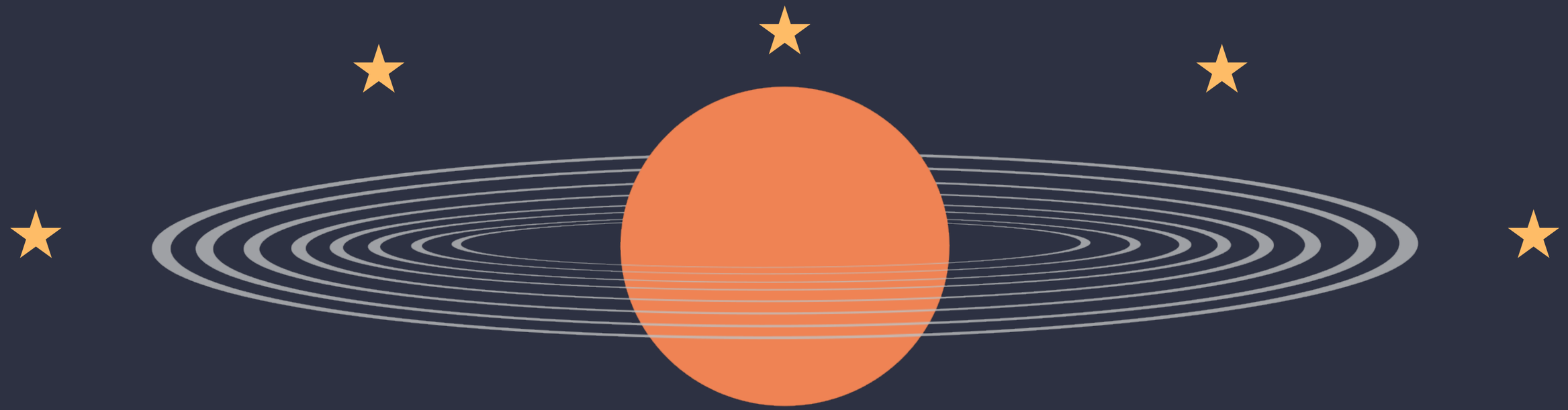


M_{disc}

1% of M_{SMS}

10% of M_{SMS}

COMPUTATIONAL SETUP



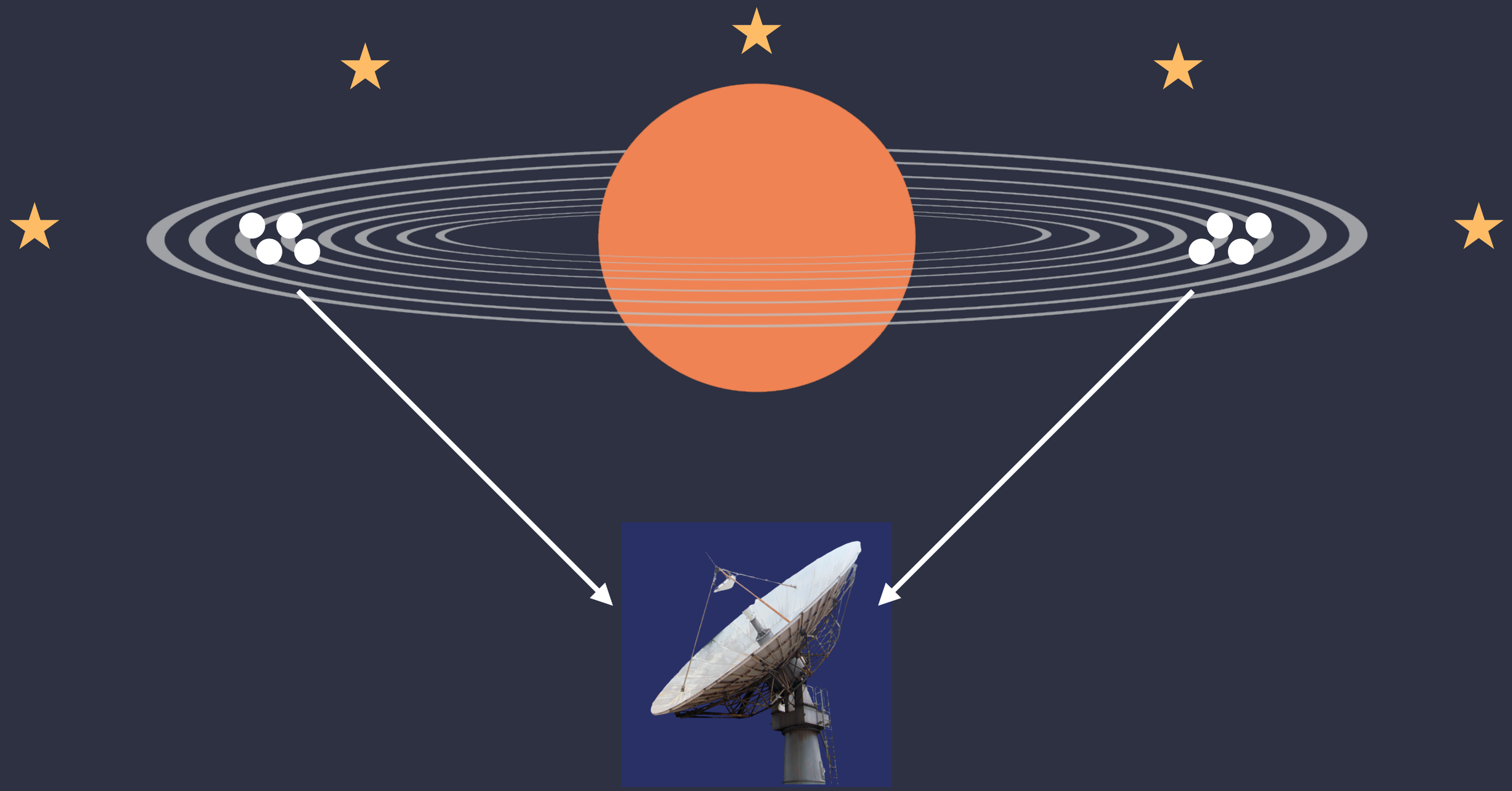
Flyby rate of perturbers

1 per year

1 per 10 years

1 per 100 years

COMPUTATIONAL SETUP



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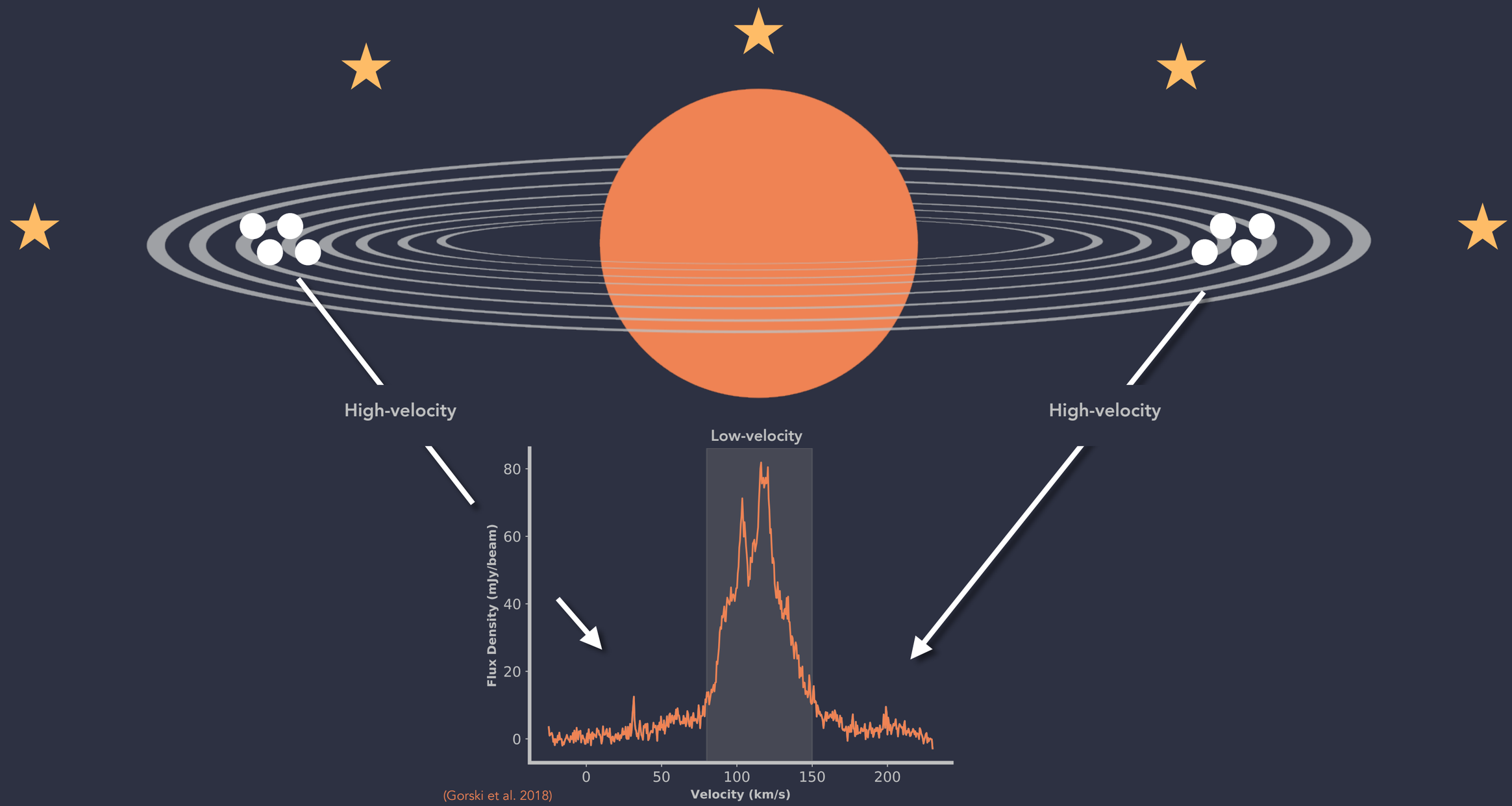
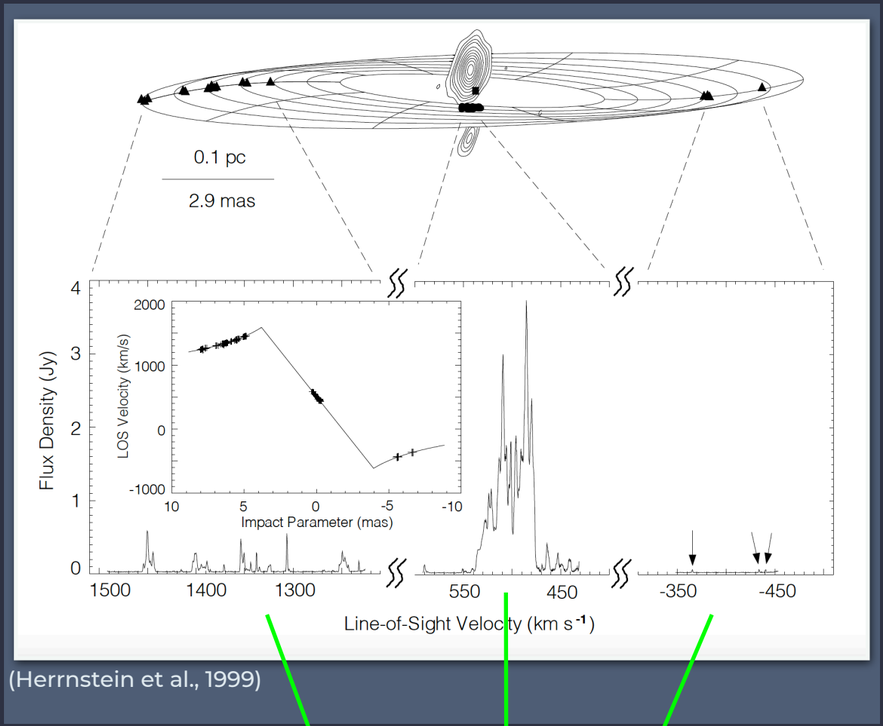


(Gorski et al. 2018)

DERIVATION OF H_2O MASER SPECTRUM



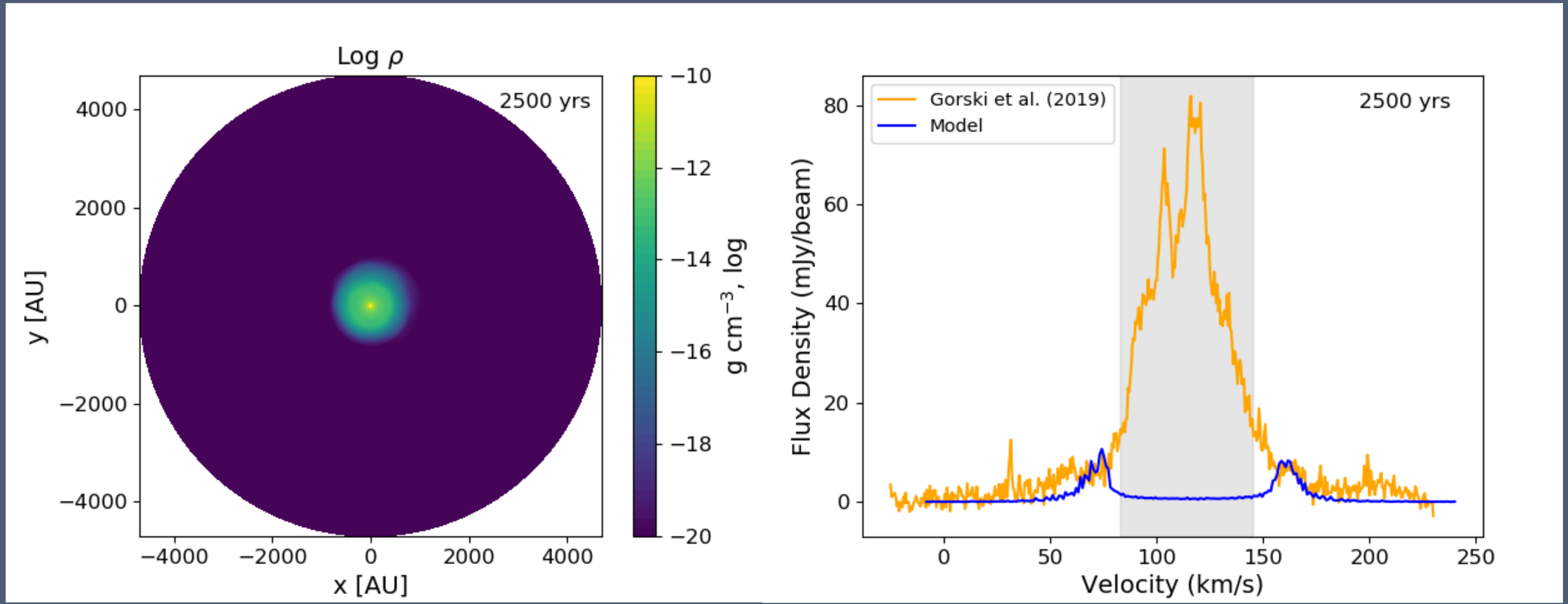
(Herrnstein et al., 1999)

- High-velocity features produced from collisional pumping
- Model spectrum plotted with flux against velocity along the line of sight
- Flux calculated using equation from Kartje et al. (1999):

$$F = 4.7 \times 10^{17} \left(\frac{\mathrm{n}dy}{2D} \right)^2 Jy$$

- Density: at least 10^7 cm^{-3}
- Temperatures: in the range of 300 K - 1500 K

RESULTS FOR M_{SMS} = 1000 $M_\odot$



(Nowak et al., 2022)

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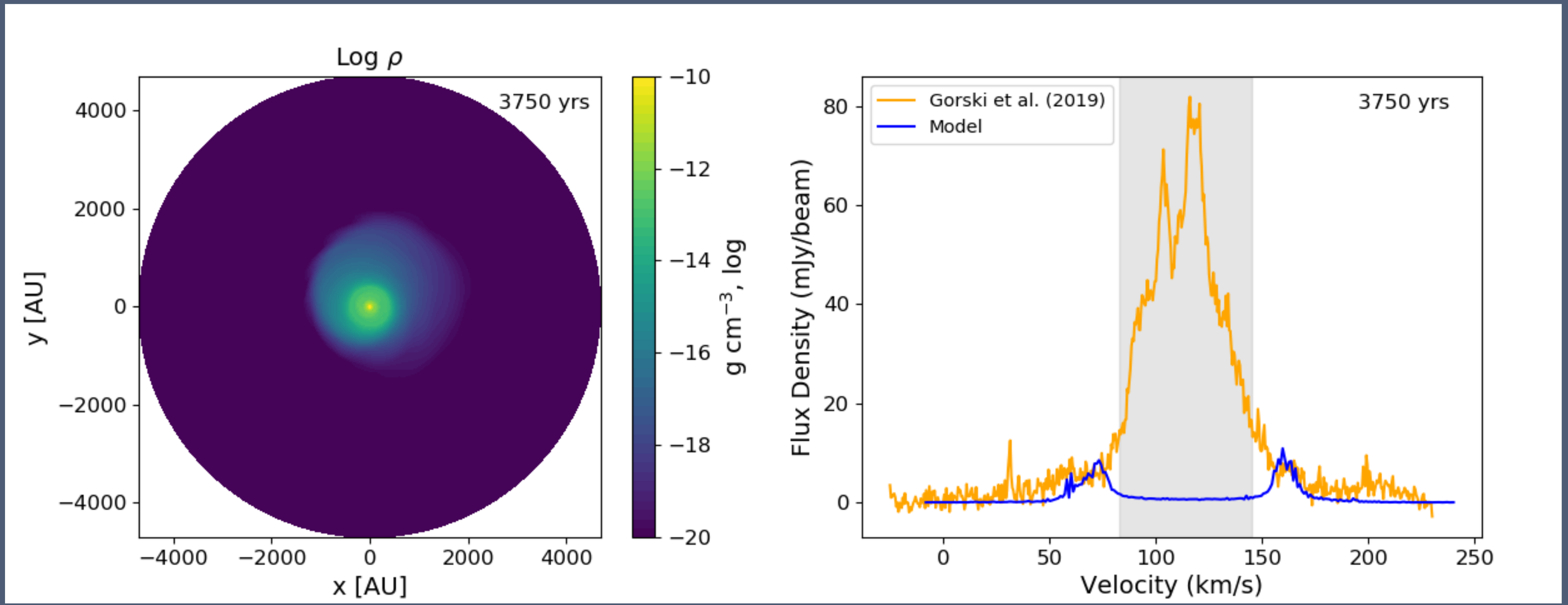
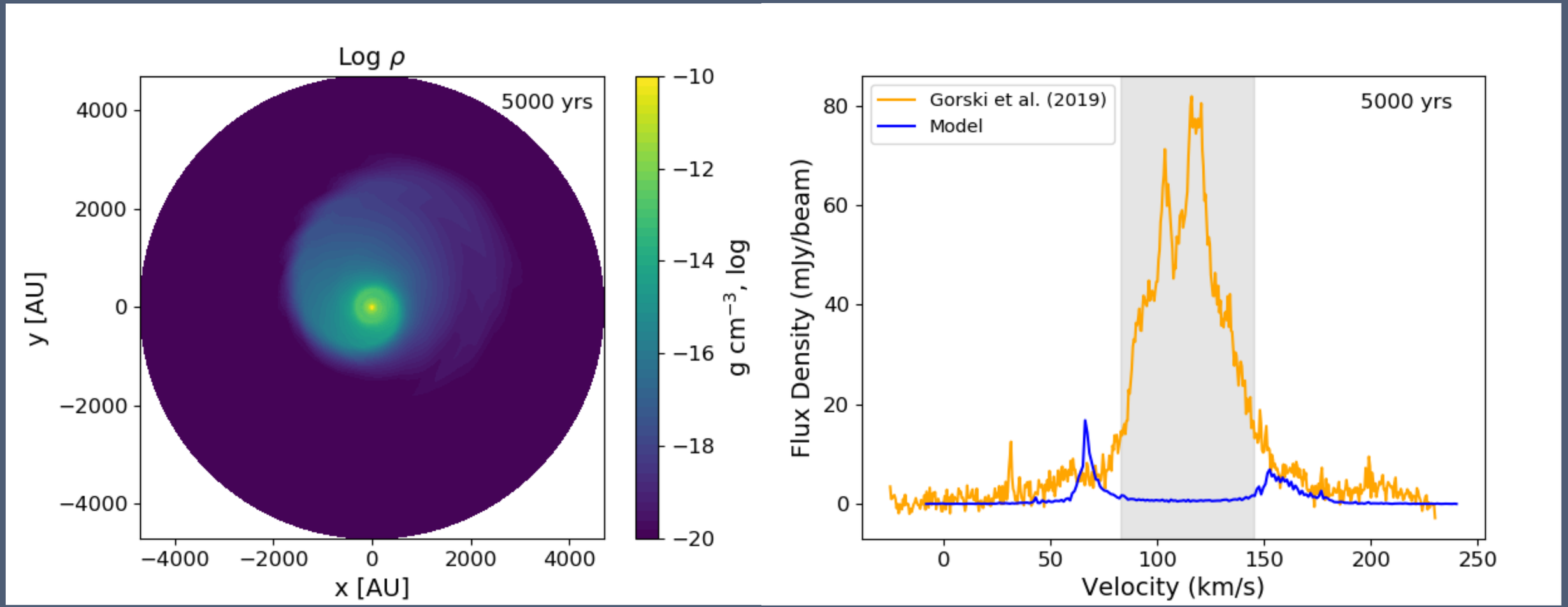


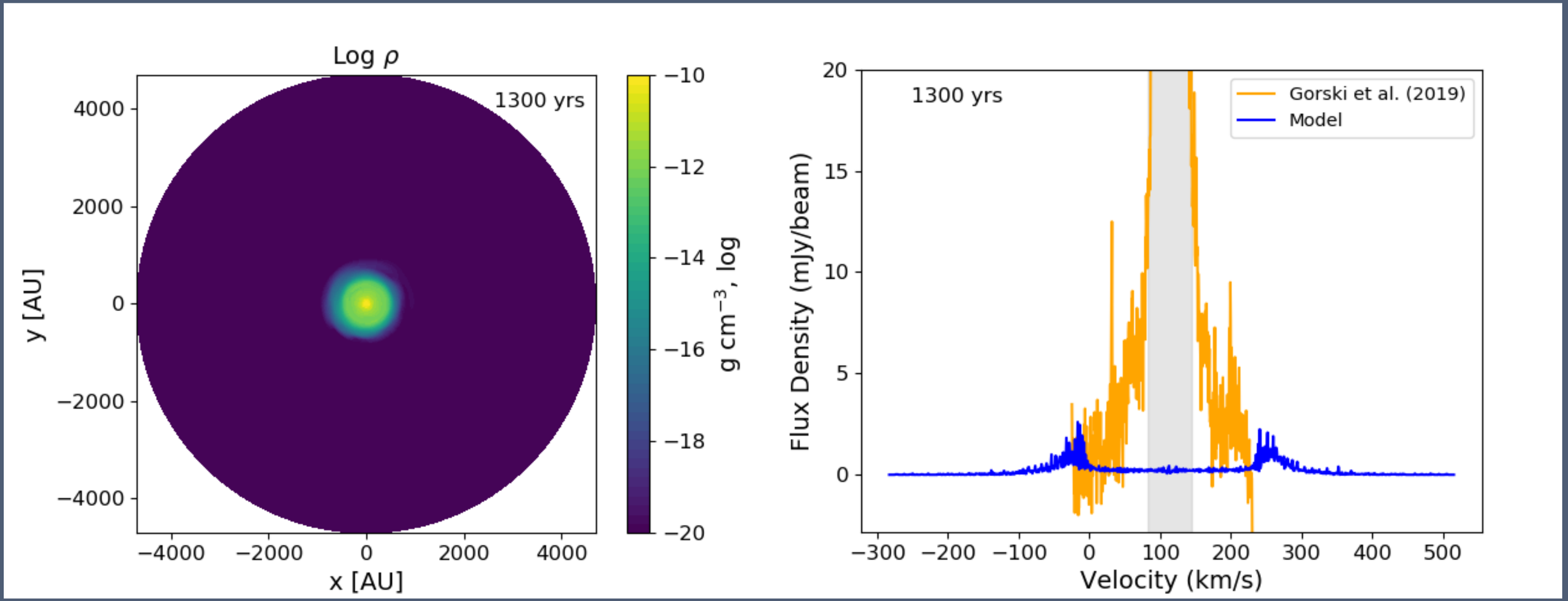
(Nowak et al., 2022)

RESULTS FOR M_{SMS} = 1000 $M_\odot$



(Nowak et al., 2022)

RESULTS FOR M_{SMS} = 10,000 $M_\odot$



(Nowak et al., 2022)

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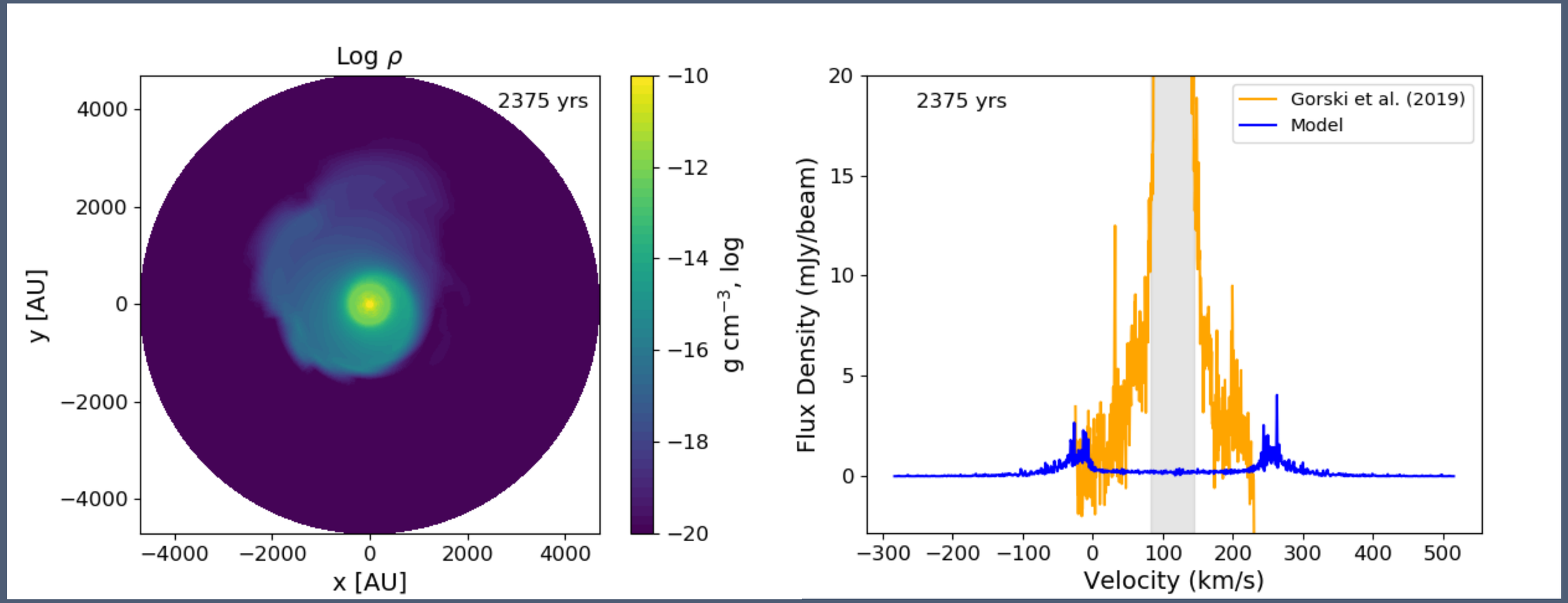

(Nowak et al., 2022)

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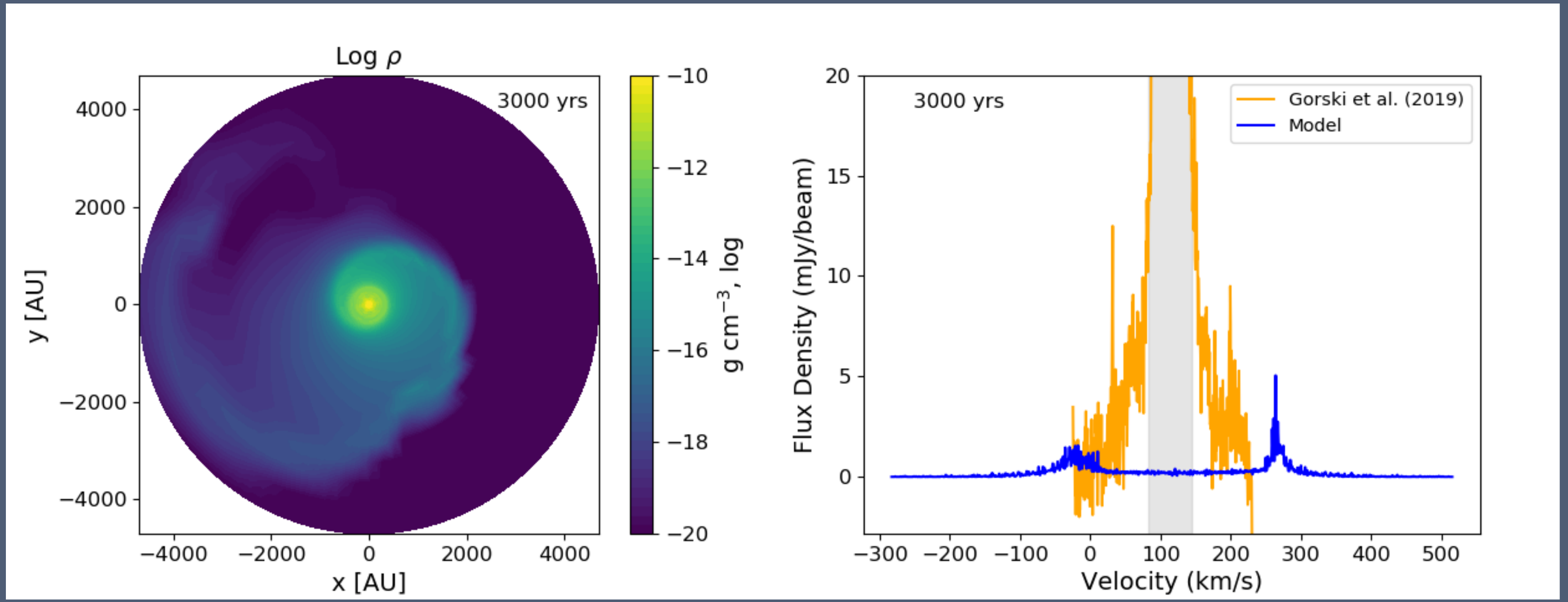


(Nowak et al., 2022)

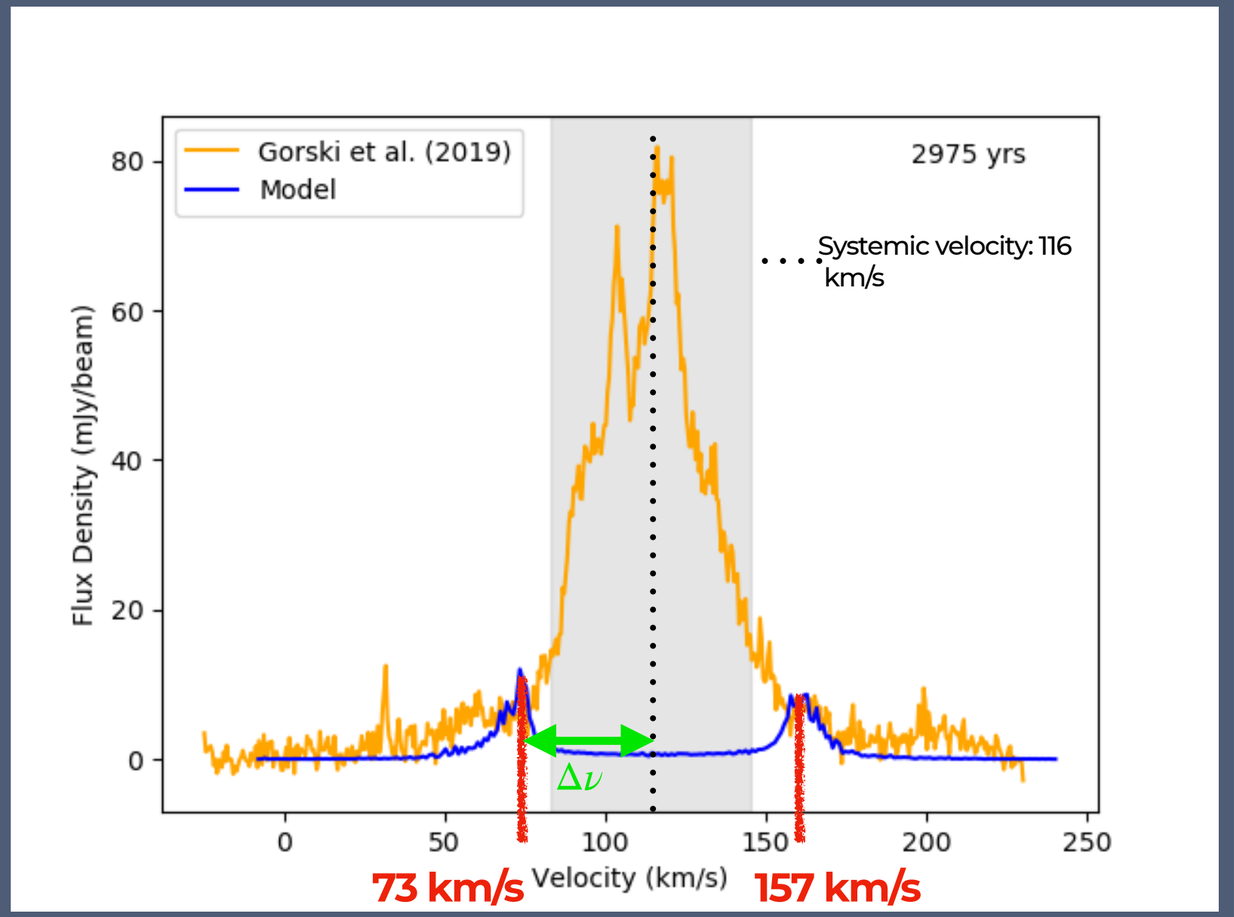
MODEL MASER SPECTRUM

Radius of the maser spots

$$R_{maser} = \frac{GM_{SMS}}{(\Delta\nu)^2} \sim 500 \text{ AU}$$

1000 $M_\odot$

~ 42 km/s

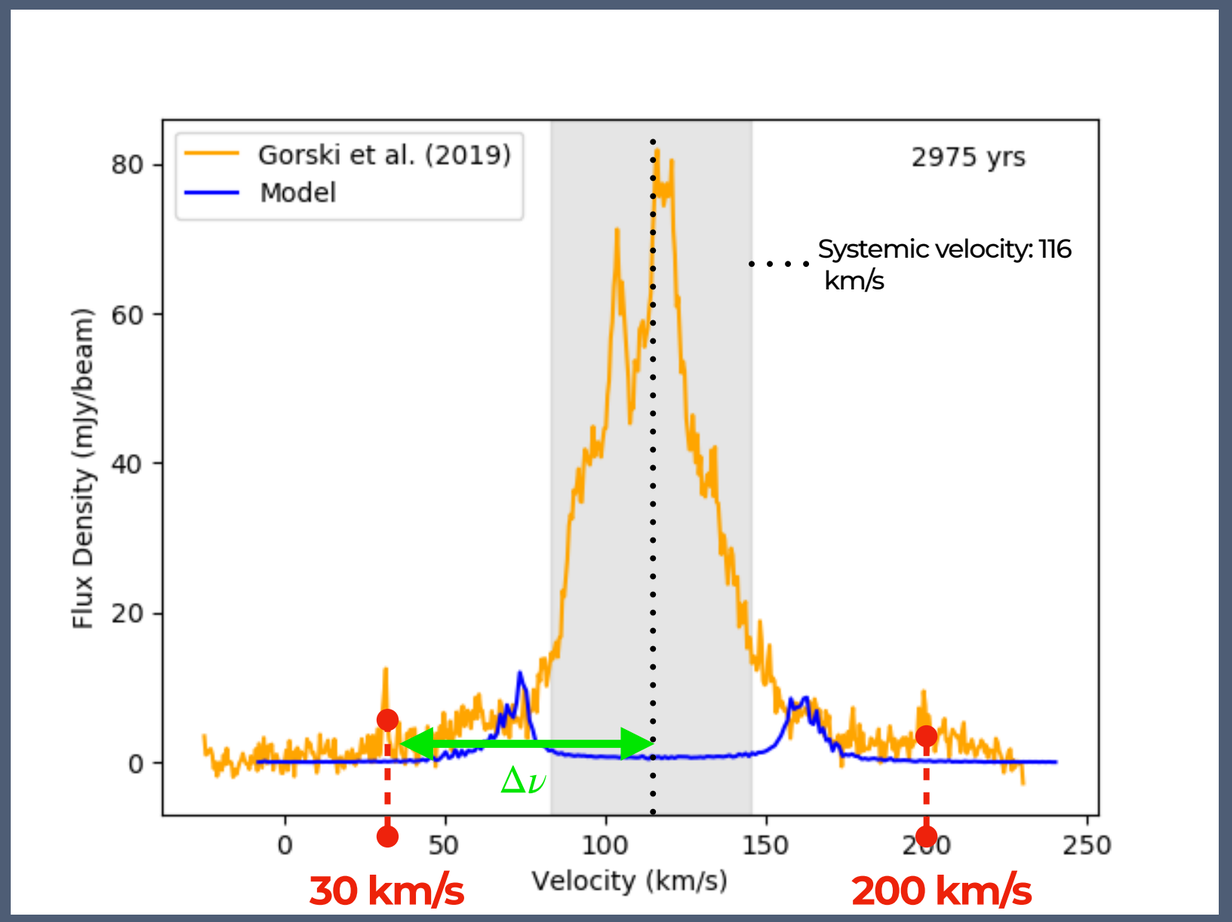


(Nowak et al., 2022)

MODEL MASER SPECTRUM

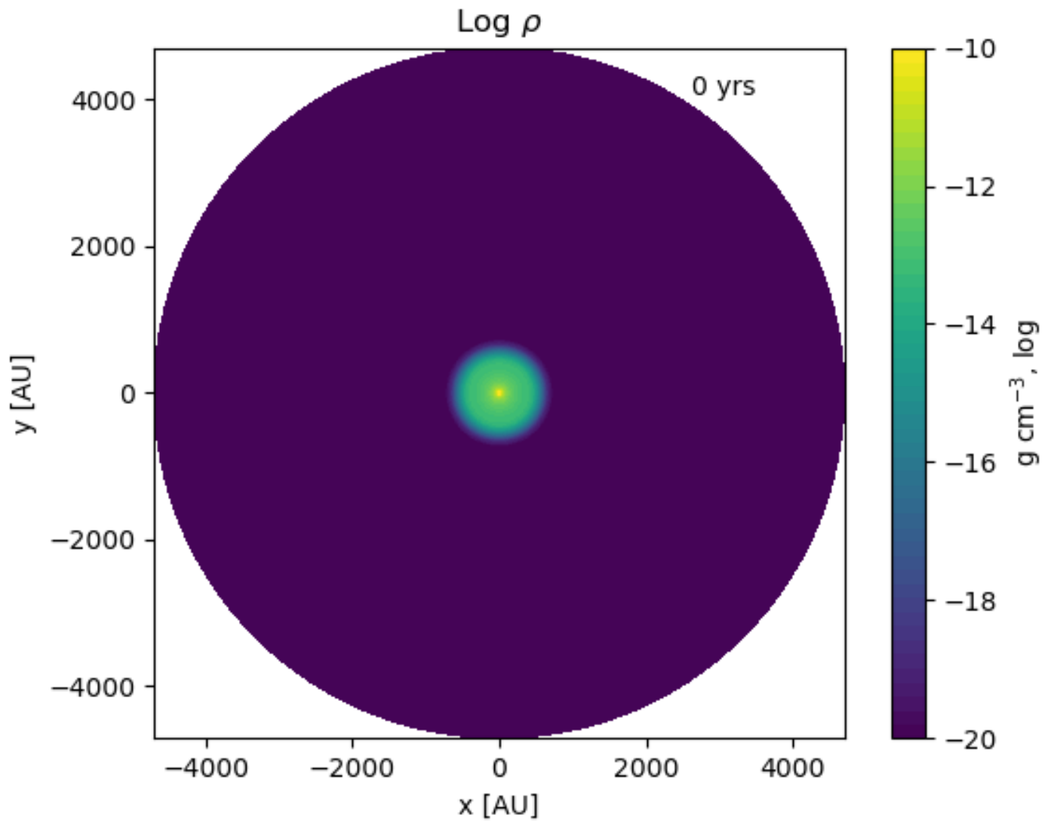
~ 500 AU ~ 85 km/s

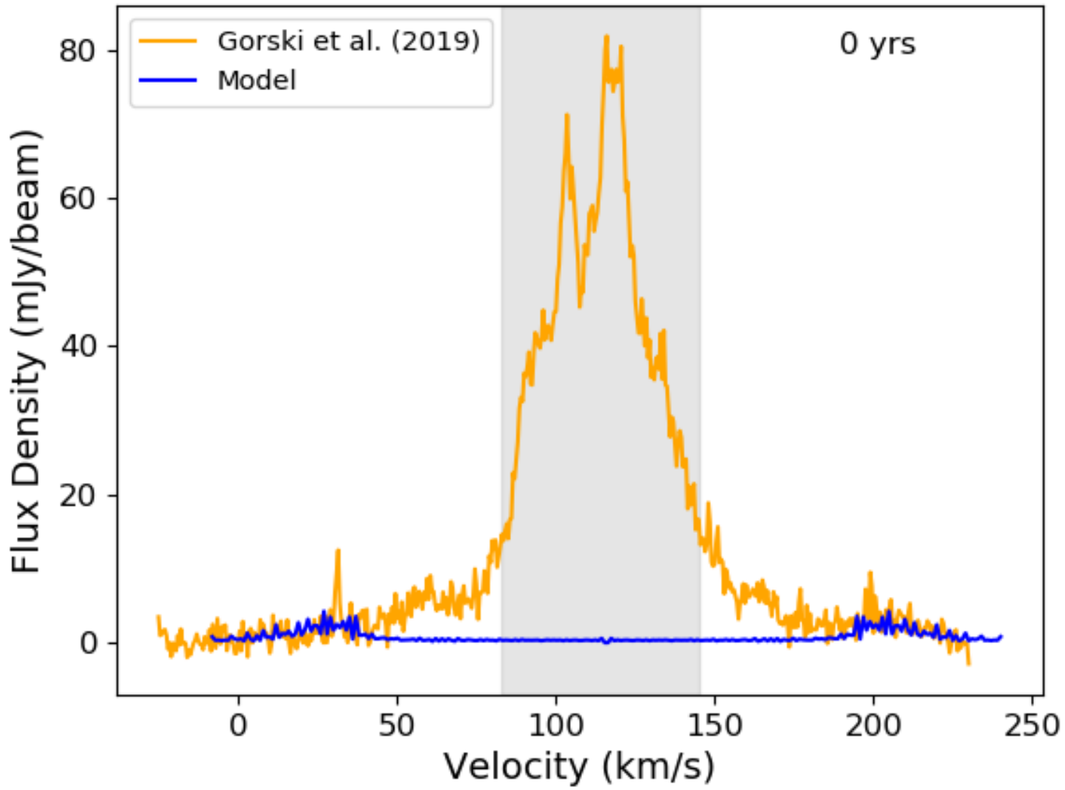
$$M_{SMS} = \frac{R_{maser}(\Delta\nu)^2}{G} \sim 4000\ M_\odot$$



(Nowak et al., 2022)

RESULTS FOR M_{SMS} = 4000 $M_\odot$





(Nowak et al., 2024)

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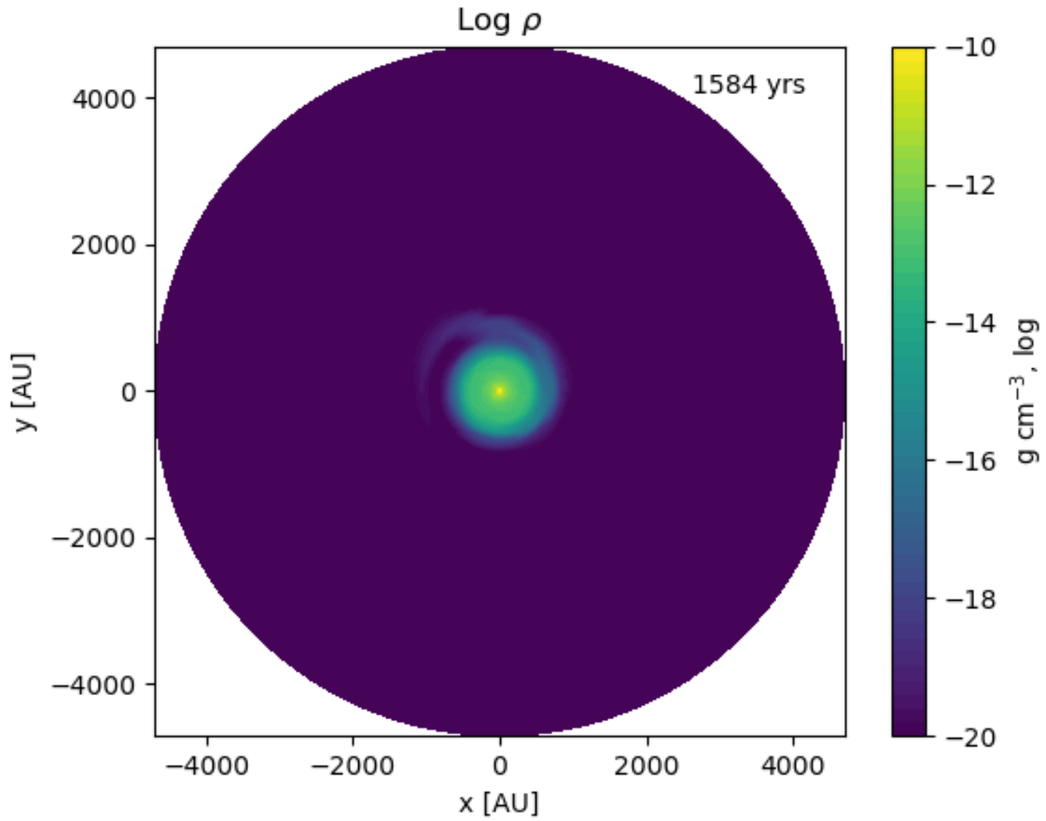

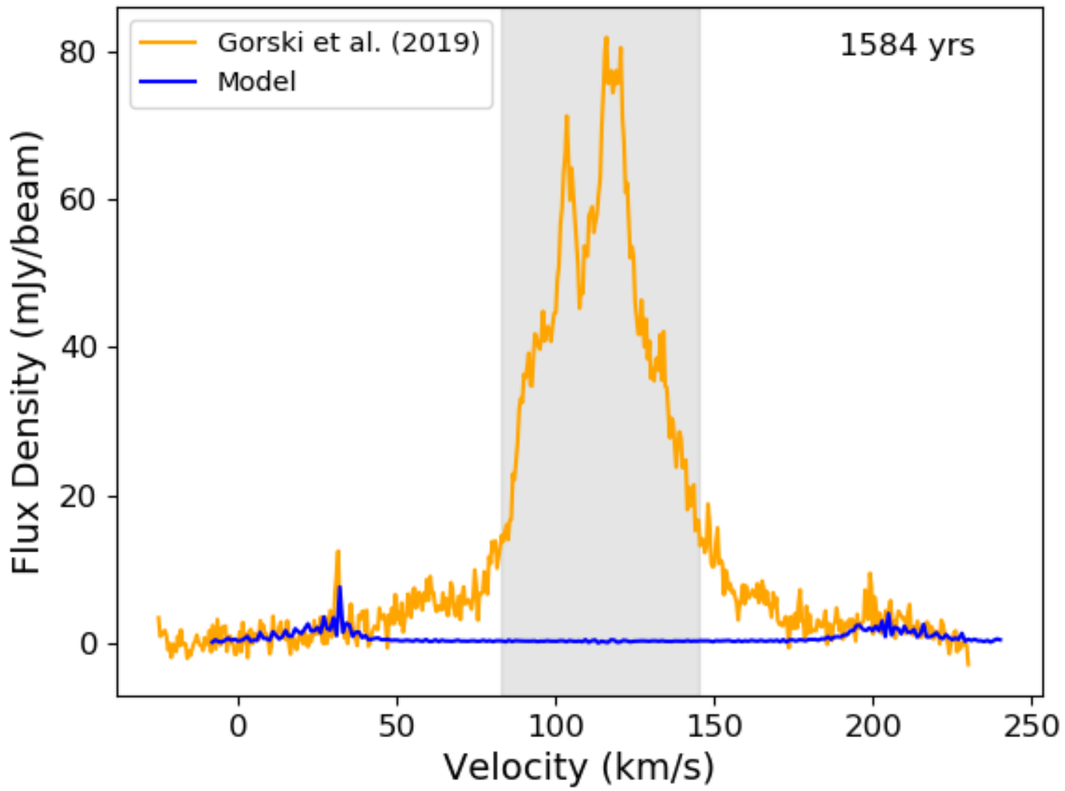

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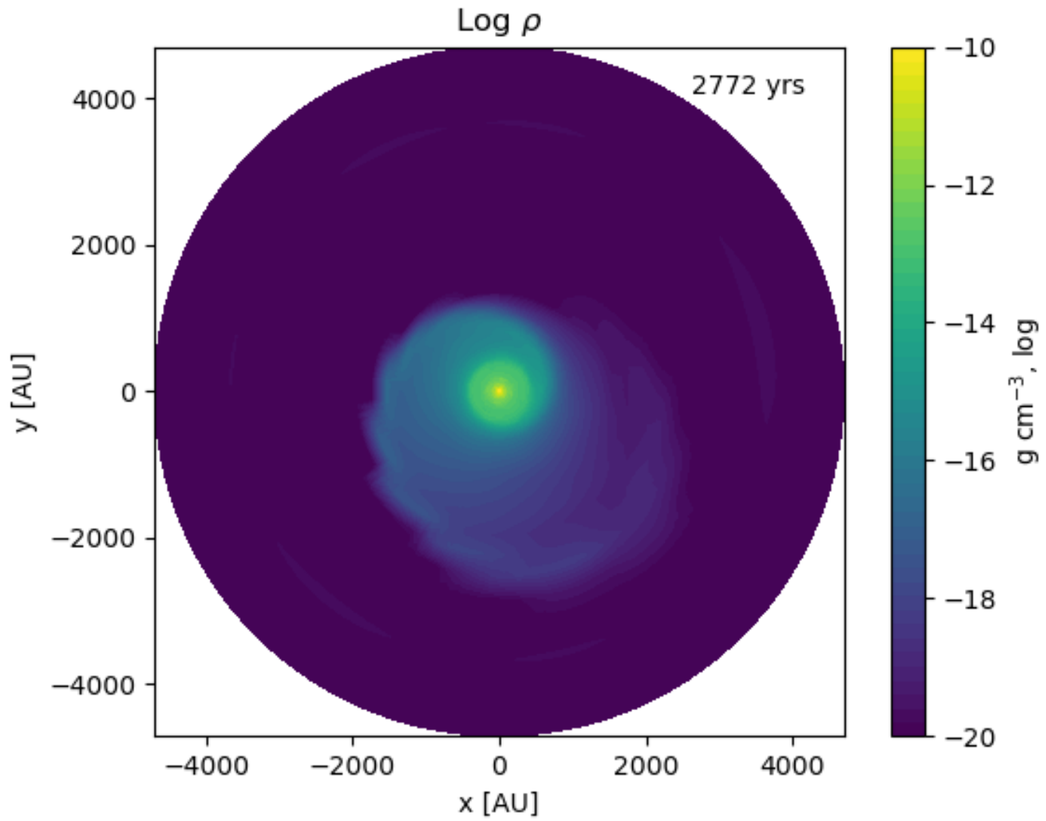
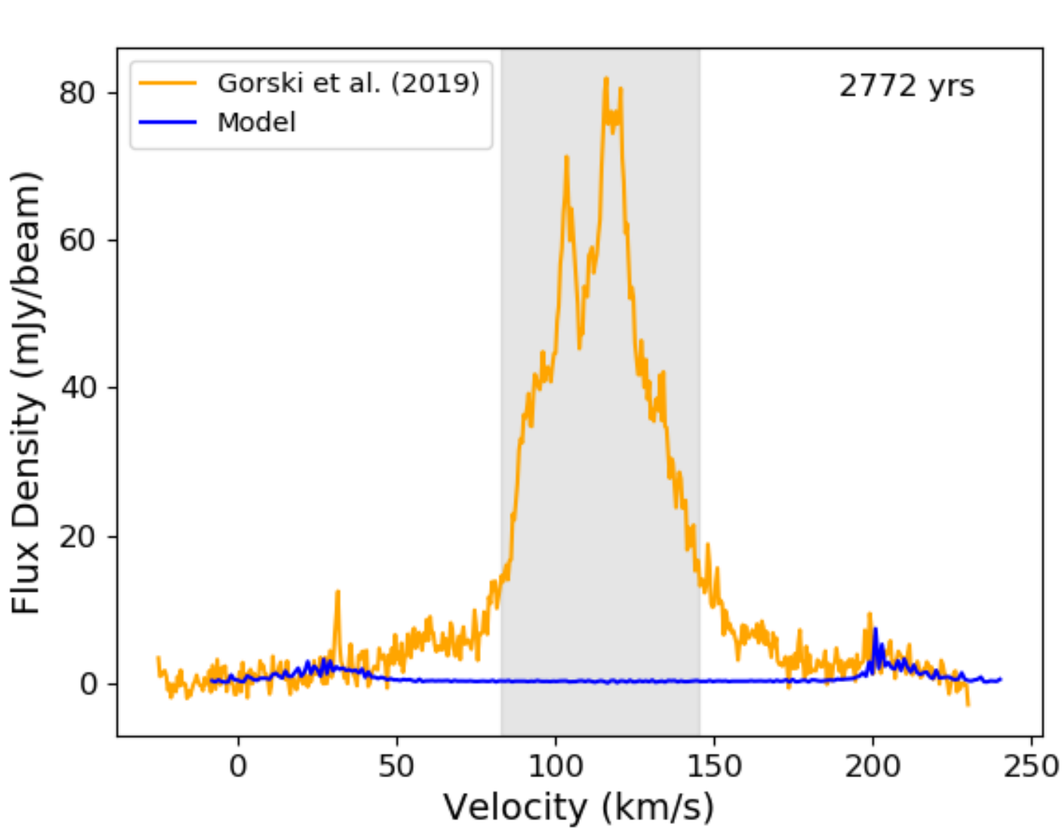




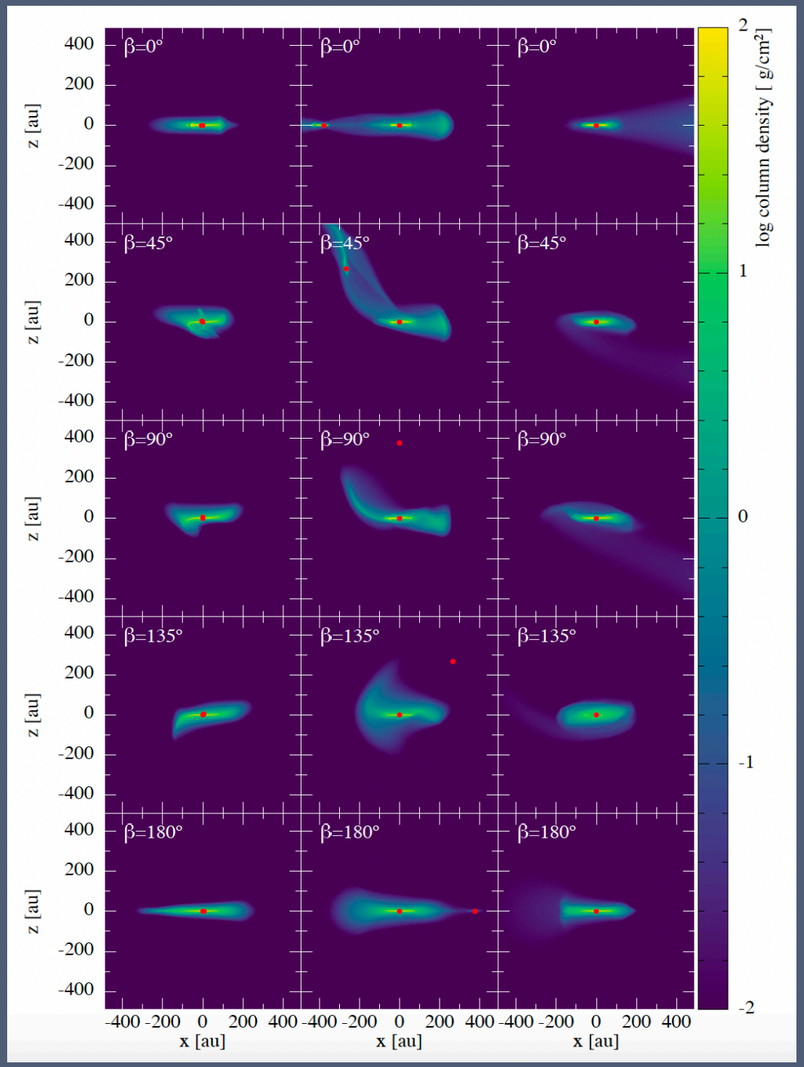
(Nowak et al., 2024)

3D SETUP FOR M_{SMS} = 1000 $M_\odot$

?

3D SETUP FOR M_{SMS} = WHAT DO WE EXPECT

- Stellar flybys on inclined orbits
- Warped disc (Clarke & Pringle, 1993; Cuello et al., 2018)
- Warped AGN disc can produce megamasers (Kartje et al., 1999)
- Kilomaser produced from a disc at inclined angles



(Cuello et al., 2018)

SUMMARY

Maser model for M_{SMS} = 1000 $M_\odot$ shows similarities to W1 kilomaser

Model spectrum for M_{SMS} = 10,000 $M_\odot$ resembles an AGN megamaser

Outward and inward movement of the peaks due to the spiral arm

M_{SMS} ~ 4000 $M_\odot$ could produce spectrum with high-velocity peaks matching W1 kilomaser

Next thing: 3D simulations with warped disc
Can the disc produce a kilomaser?!