

# RADIATION PRESSURE IN 3D HYDRODYNAMICAL SIMULATIONS OF COMPANION-PERTURBED AGB OUTFLOWS

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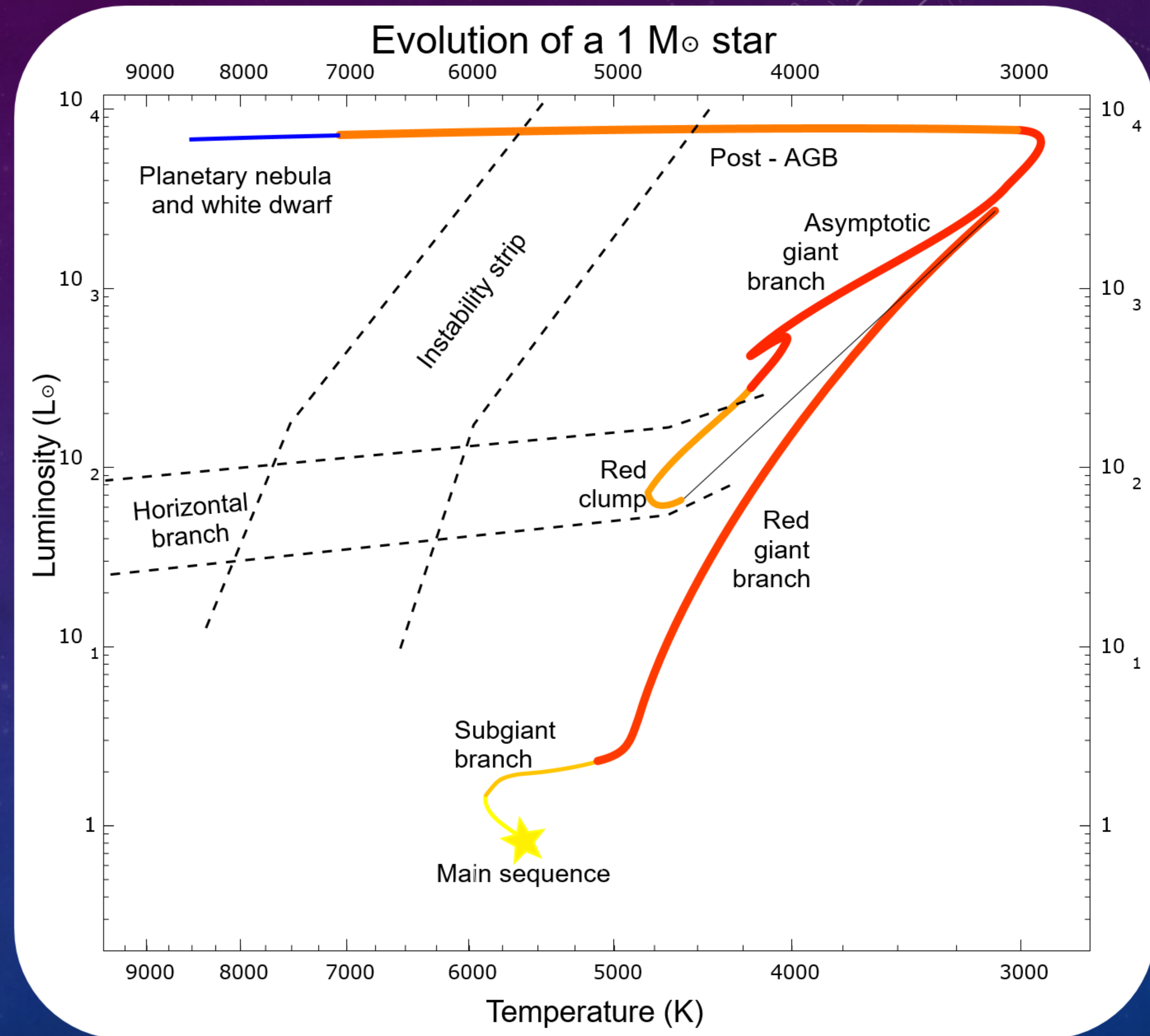
**KU LEUVEN**

**ULB**

UNIVERSITÉ  
LIBRE  
DE BRUXELLES

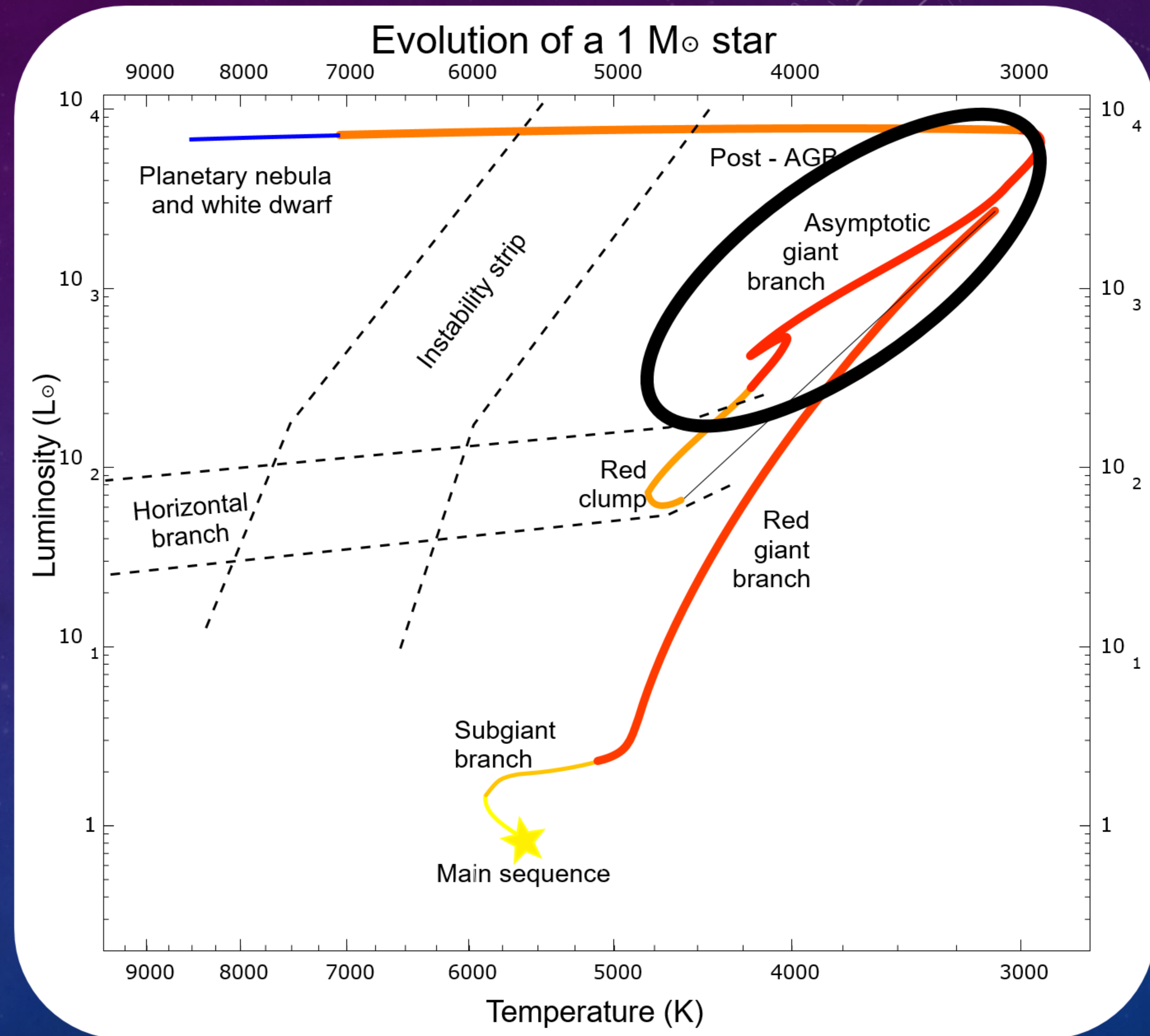
# AGB STARS

- Low and intermediate mass stars
- $M \in [0.8 M_{\odot}, 8 M_{\odot}]$

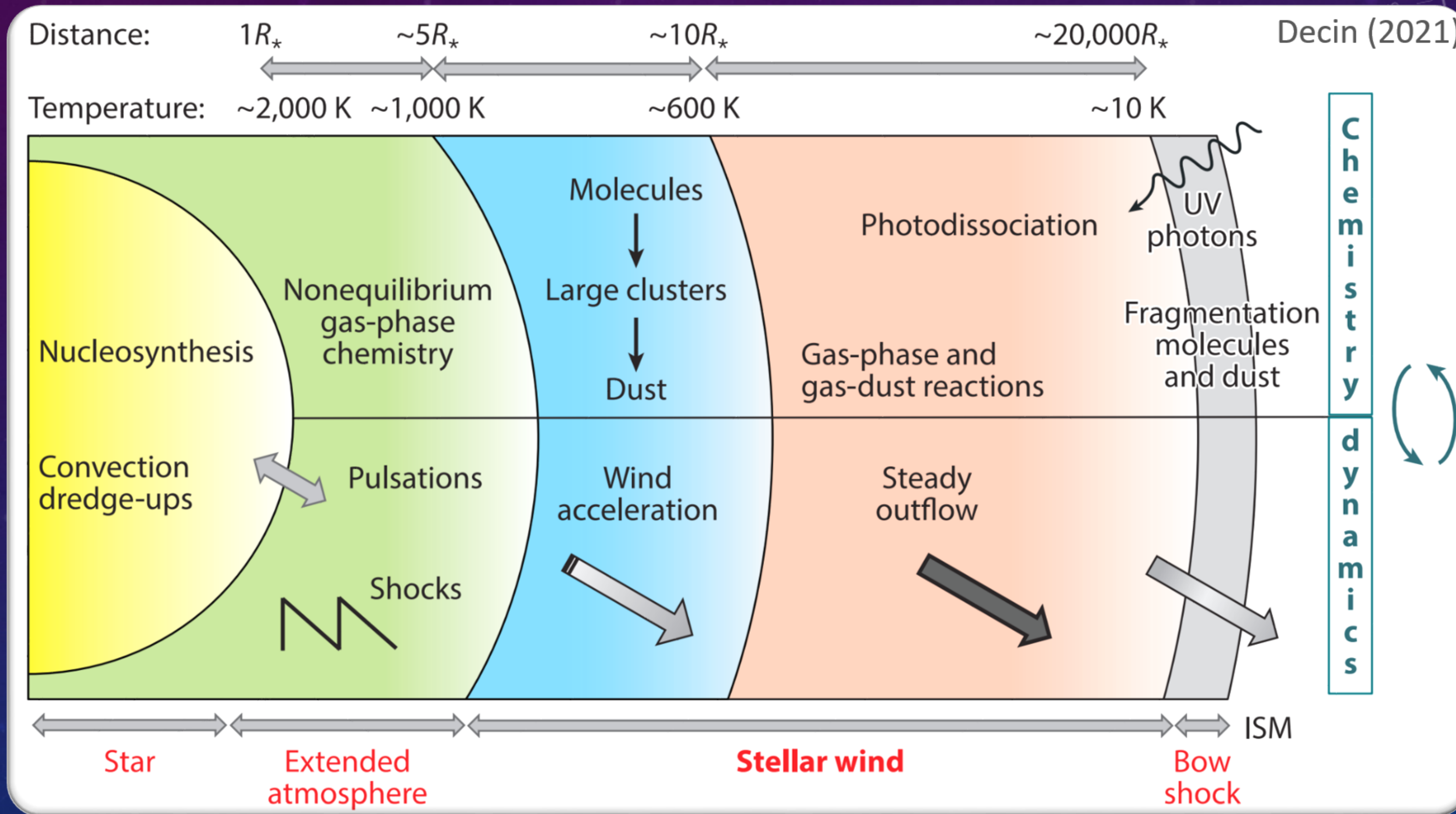


# AGB STARS

- Low and intermediate mass stars
- $M \in [0.8 M_{\odot}, 8 M_{\odot}]$
- Strong winds
- Complex chemistry

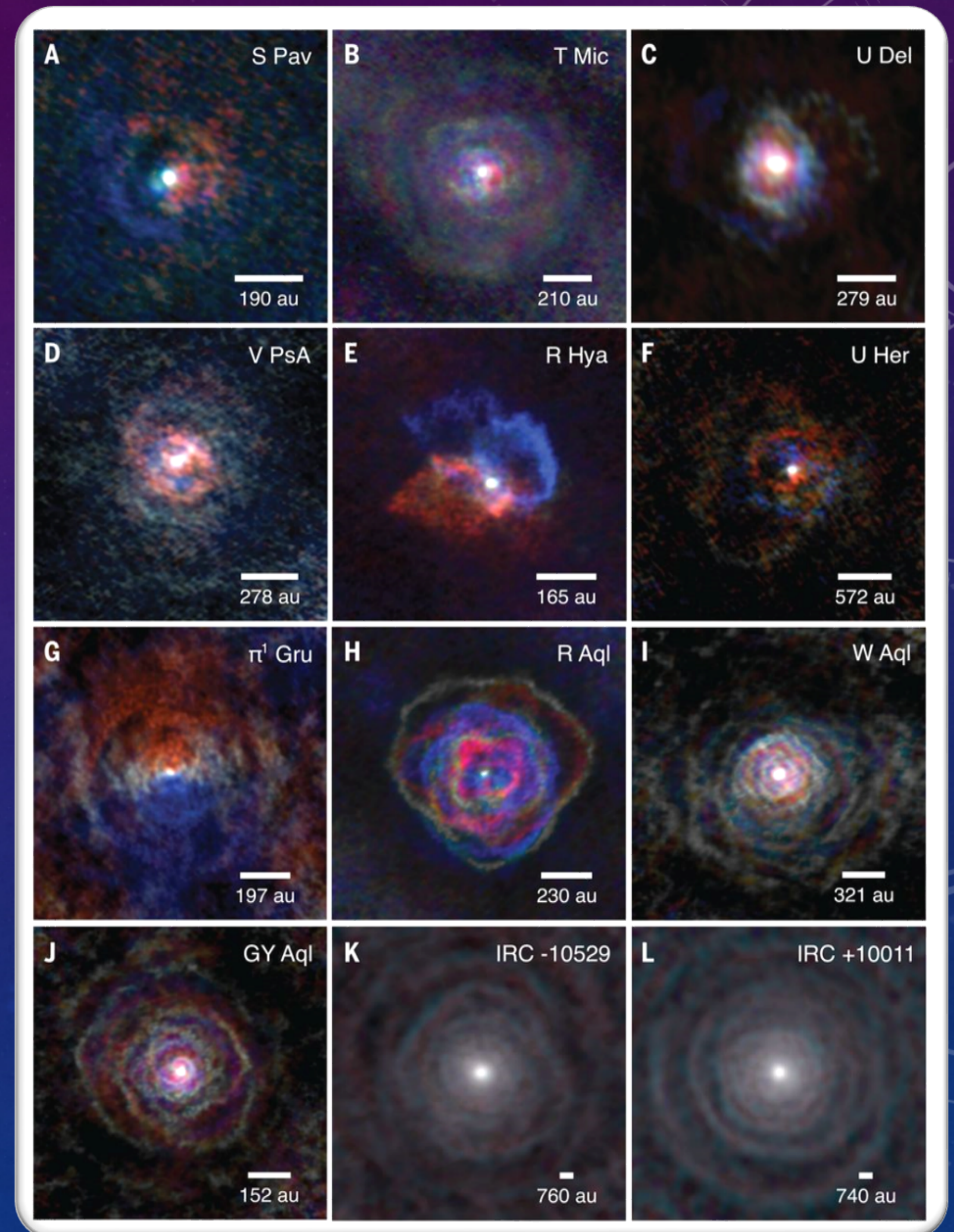


# WIND DYNAMICS OF AGB STARS



# COMPLEX AGB OUTFLOWS

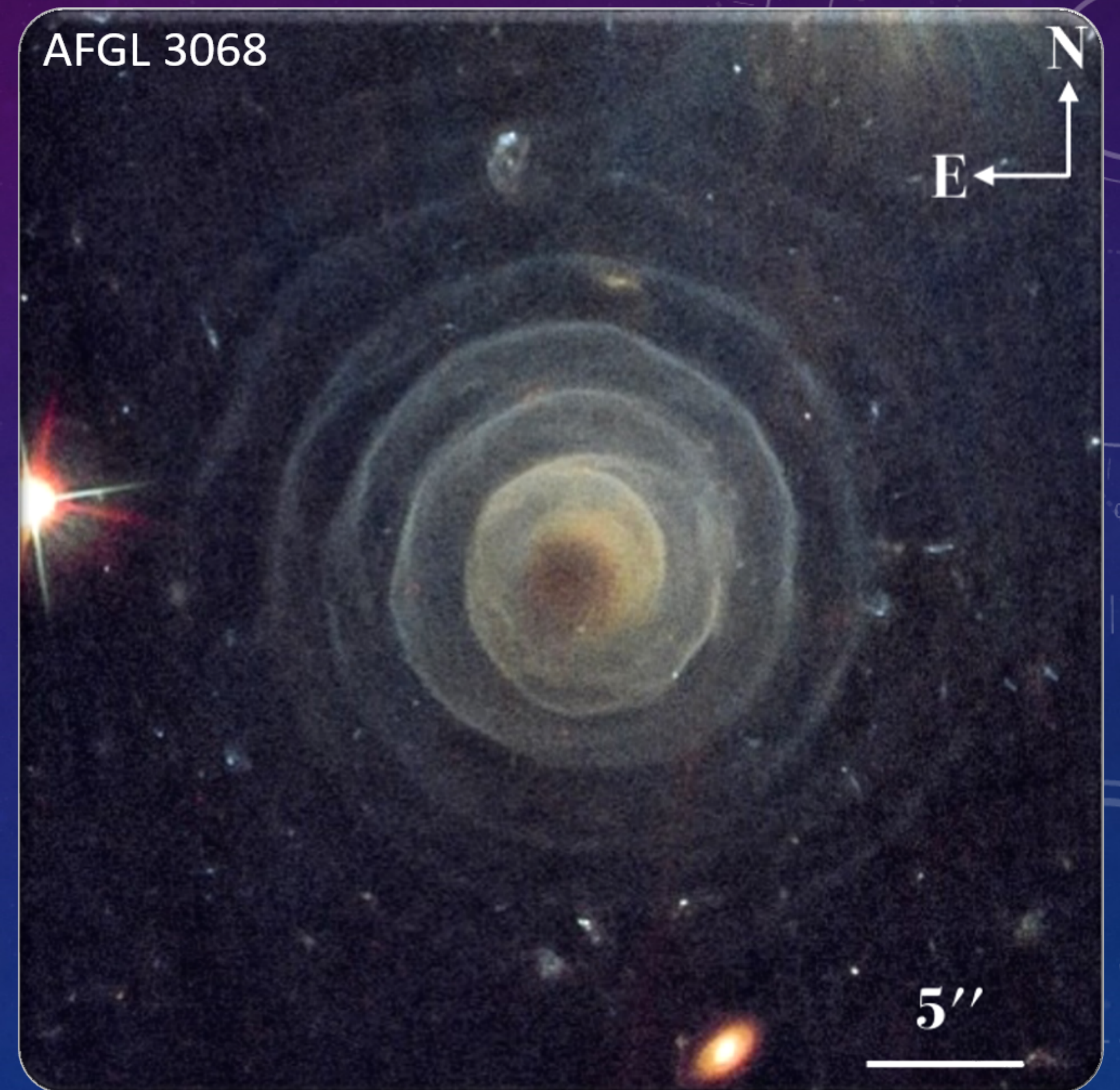
- Complex structures



Decin et al. (2020)

# COMPLEX AGB OUTFLOWS

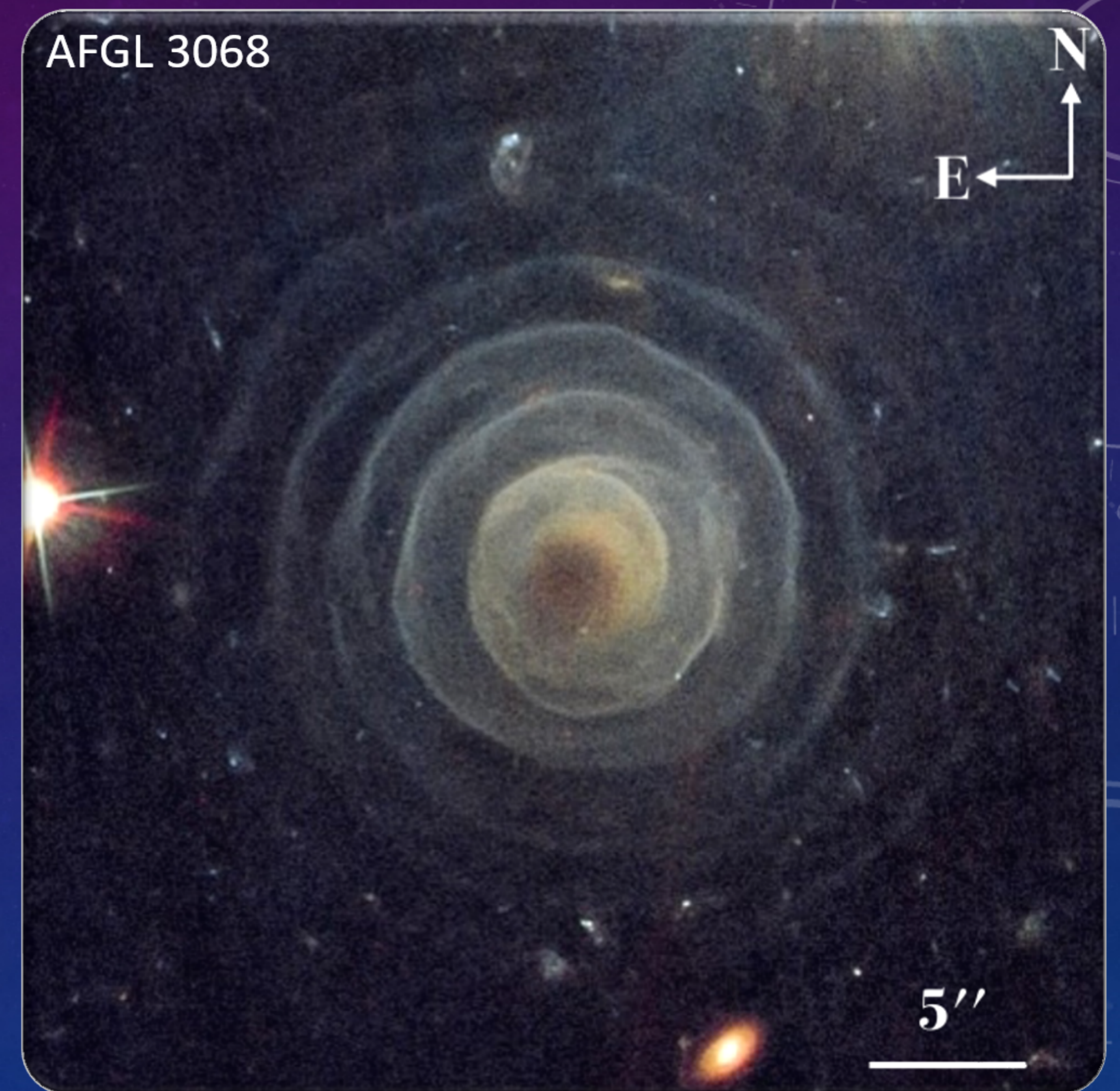
- Complex structures



(Morris et al. 2006; Guerrero et al. 2020)

# COMPLEX AGB OUTFLOWS

- Complex structures
- Wind-companion interactions



(Morris et al. 2006; Guerrero et al. 2020)

# HYDRODYNAMIC SIMULATIONS

- Smoothed Particle Hydrodynamics (SPH)
- Follows individual particles
- PHANTOM by Price et al. (2018)





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- Additional forces

$$F = -\frac{GM_{AGB}}{r_1^2} (1 - \Gamma) - \frac{GM_{comp}}{r_2^2}, \quad \Gamma = 1$$

- Radiation-pressure-free wind
  - Maes et al. (2021), Malfait et al. (2021) ...



# RADIATIVE ACCELERATION

- Radiation-pressure-~~free~~ wind

$$F_r = -\frac{GM_{AGB}}{r_1^2} (1 - \Gamma_d) - \frac{GM_{comp}}{r_2^2}, \quad \Gamma_d = \frac{\kappa L_{AGB}}{4\pi c GM_{AGB}}$$

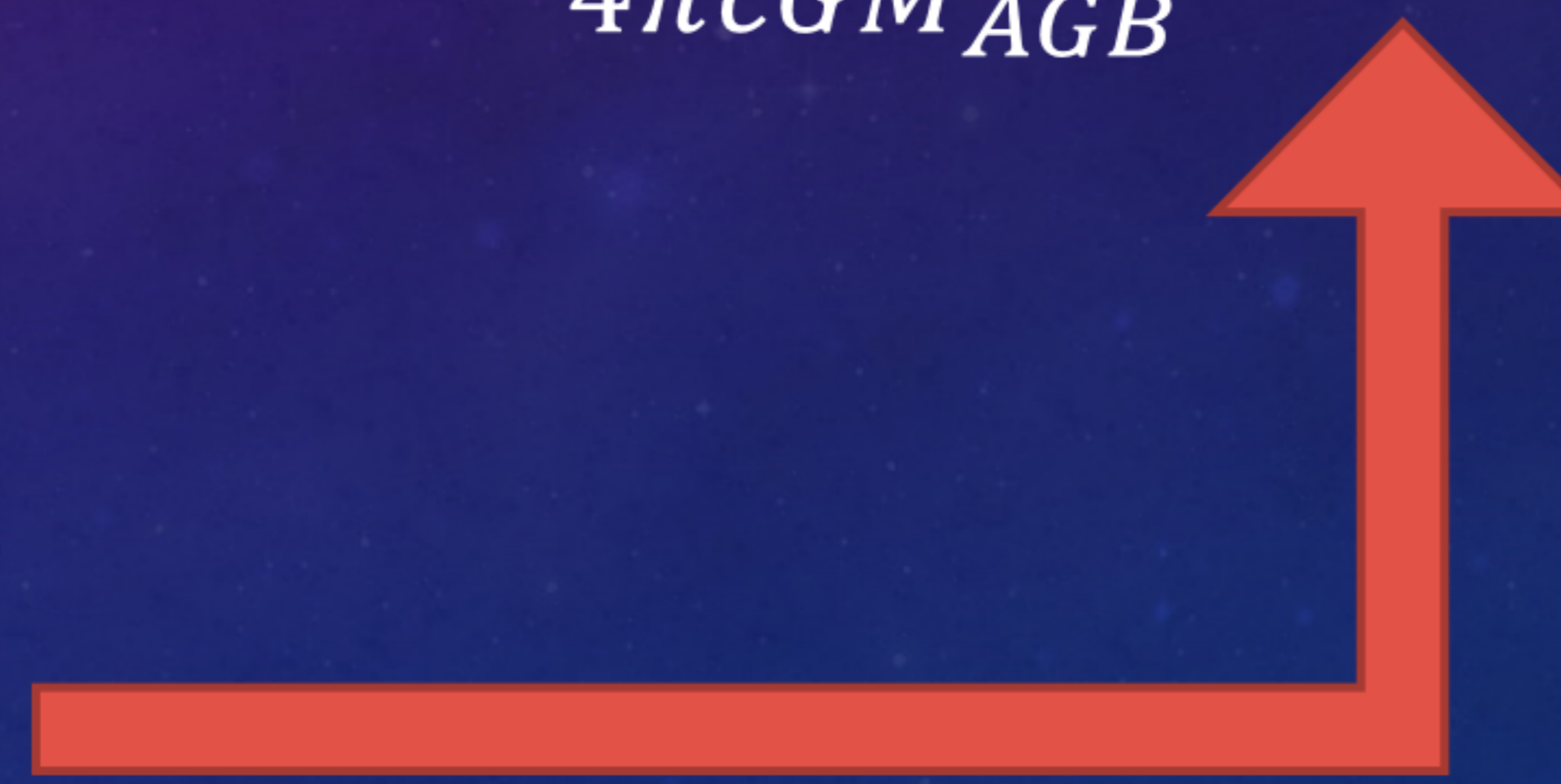
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- Optical depth  $\tau$

$$\tau = \int_{R_*}^r \kappa \rho ds$$



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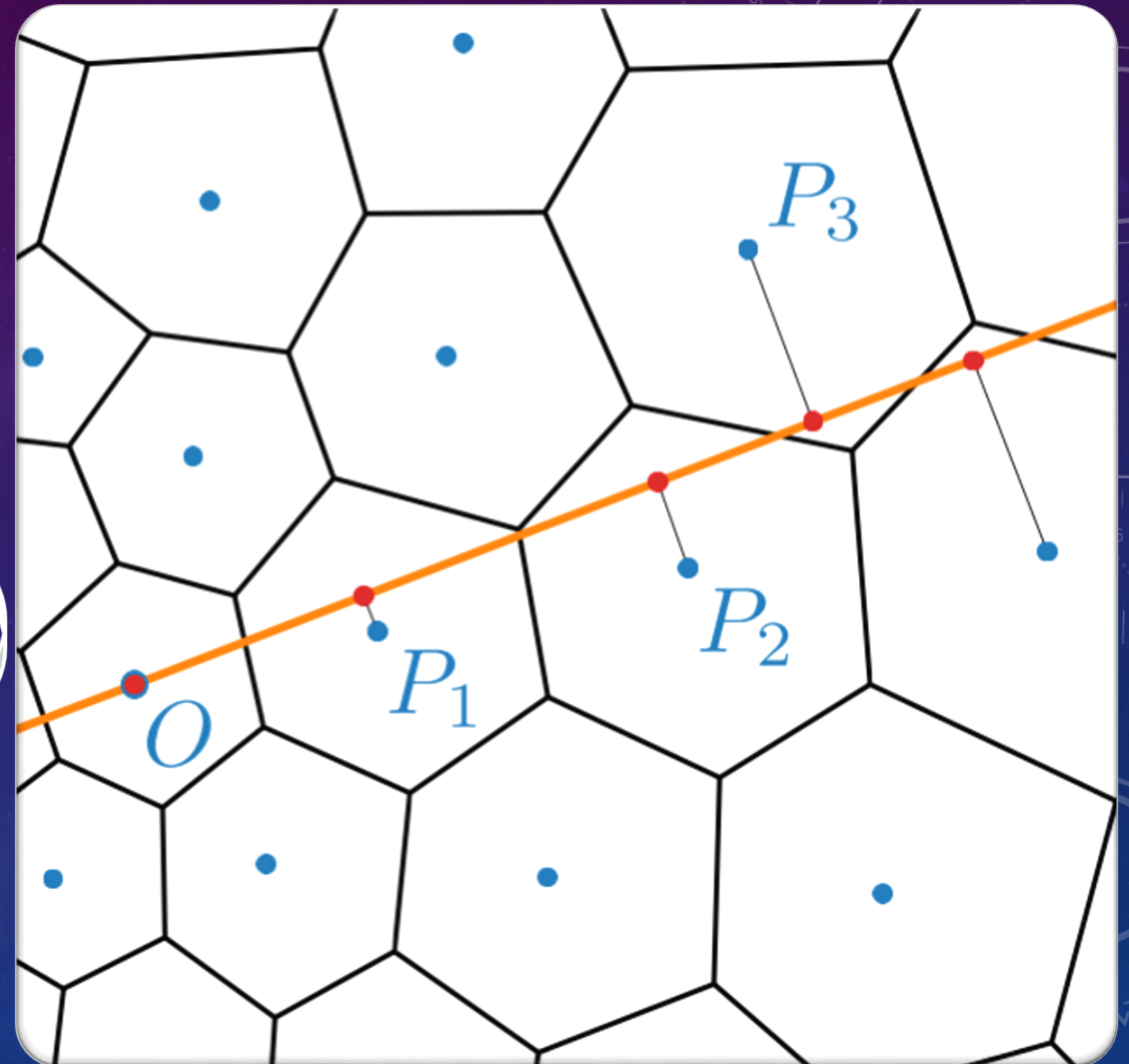
- Ray-tracing (Magritte by De Ceuster et al. 2020)



Magritte

# RAY-TRACER OF MAGRITTE

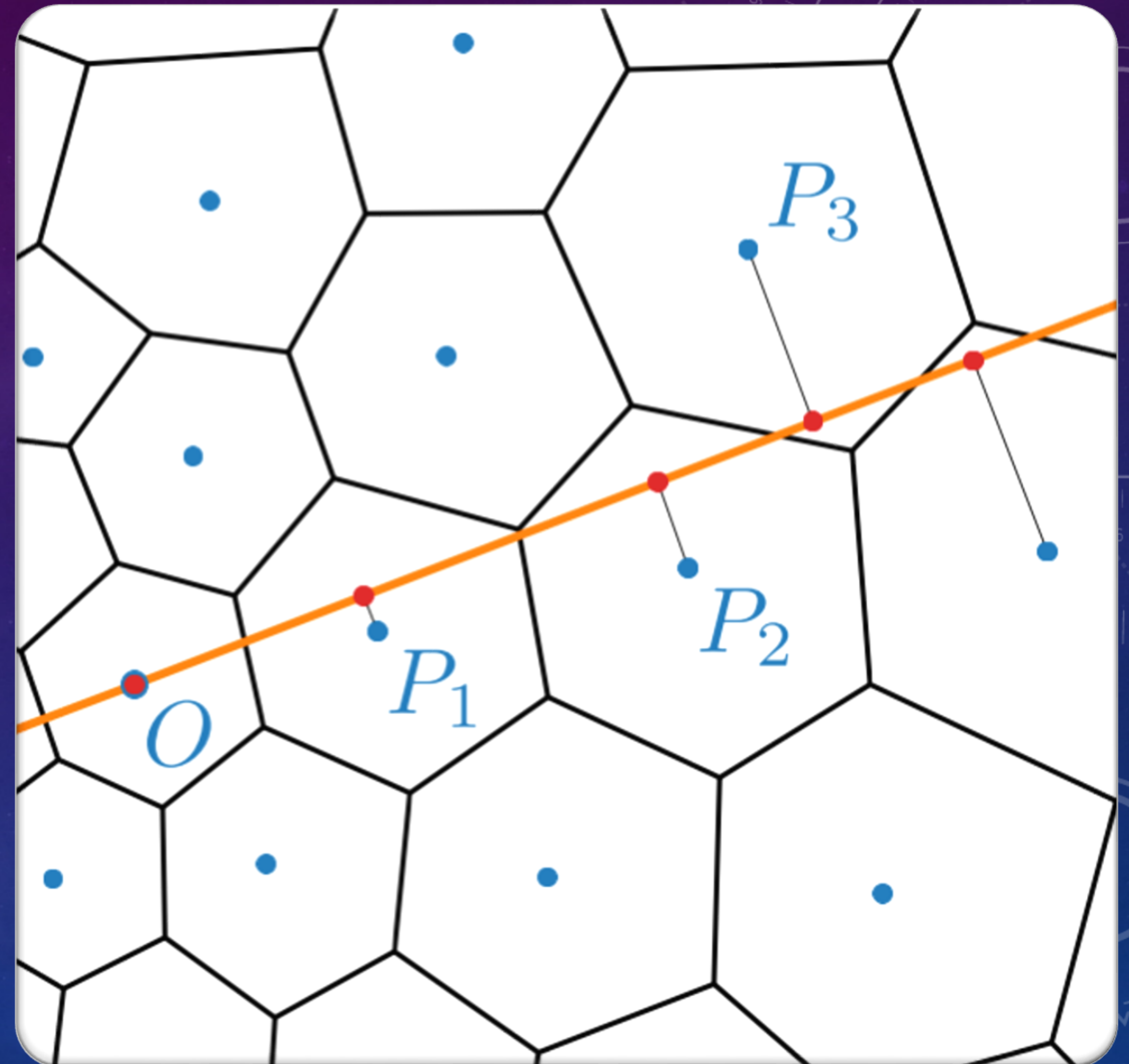
- Start from a point
- Take all the nearest neighbours
- Find the one closest to the ray



De Ceuster et al. (2020)

# OPTICAL DEPTH

$$\Rightarrow \tau = \int_{R_*}^r \kappa \rho \, ds$$

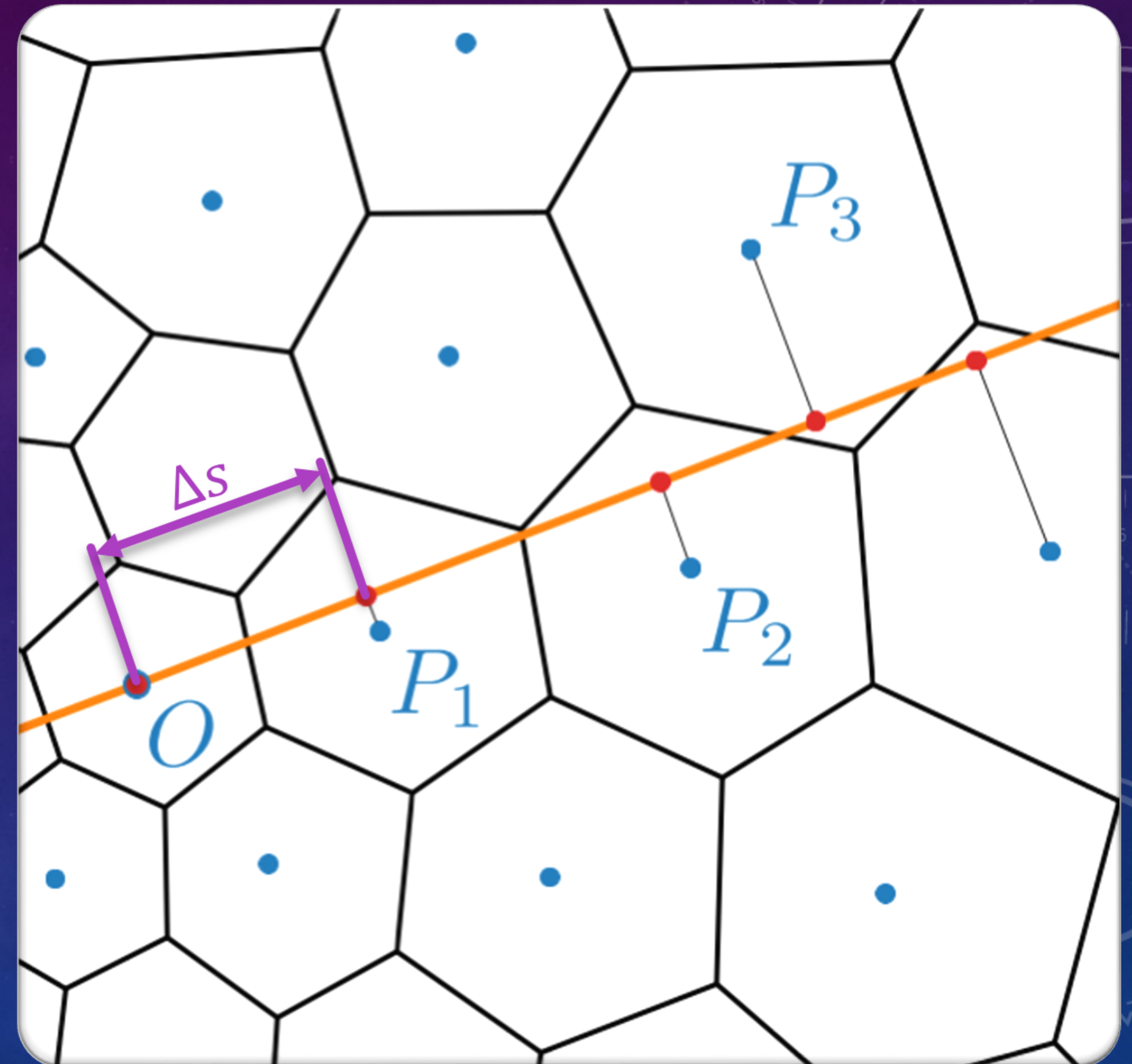


De Ceuster et al. (2020)

# OPTICAL DEPTH

$$\Rightarrow \tau = \int_{R_*}^r \kappa \rho \, ds$$

$$\Rightarrow \tau = \sum_{R_*}^r \langle \kappa_i \rho_i \rangle \Delta s_i$$



De Ceuster et al. (2020)

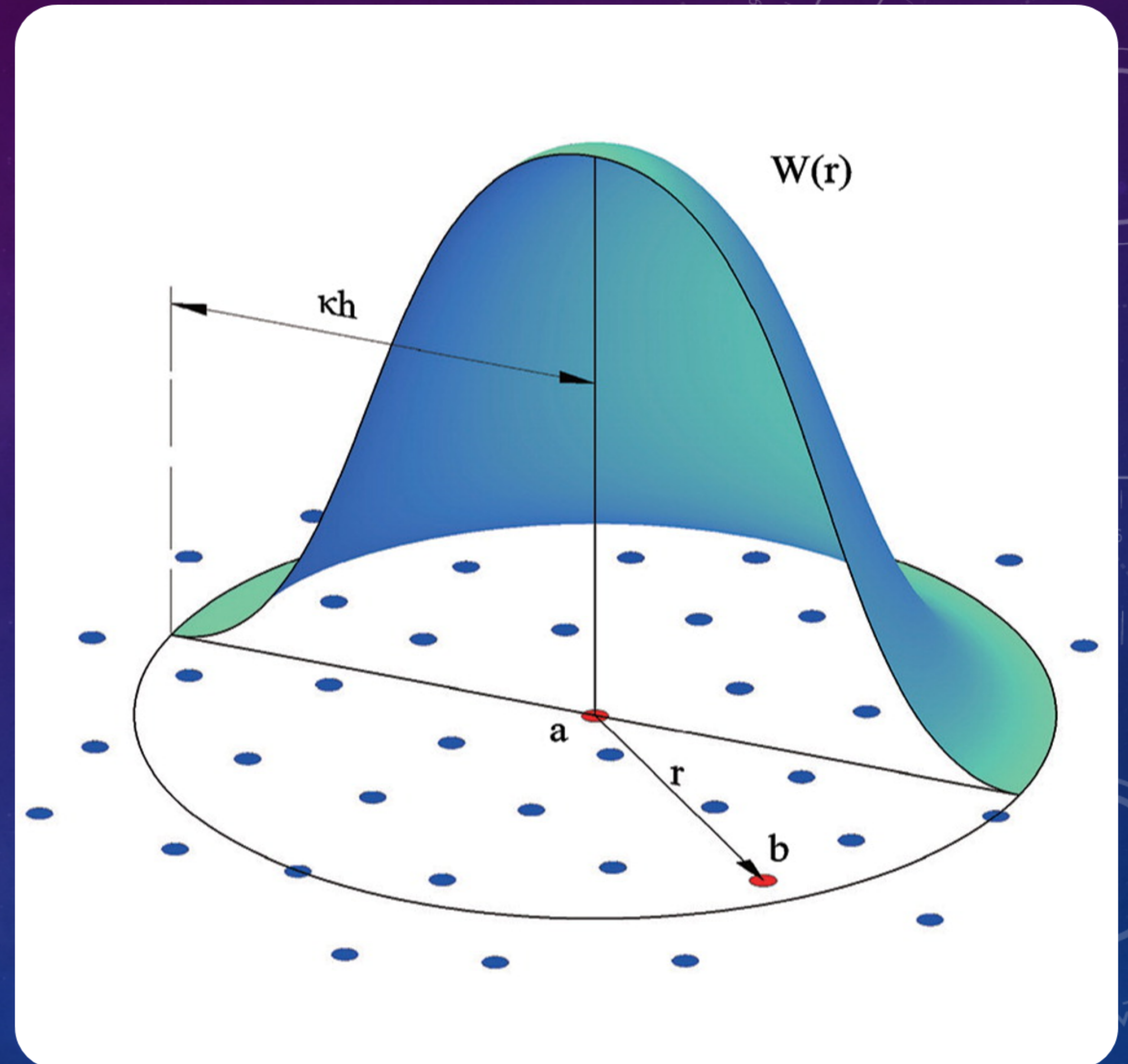


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$$\Rightarrow \tau = \sum_{R_*}^r \langle \kappa_i \rho_i \rangle \Delta s_i$$

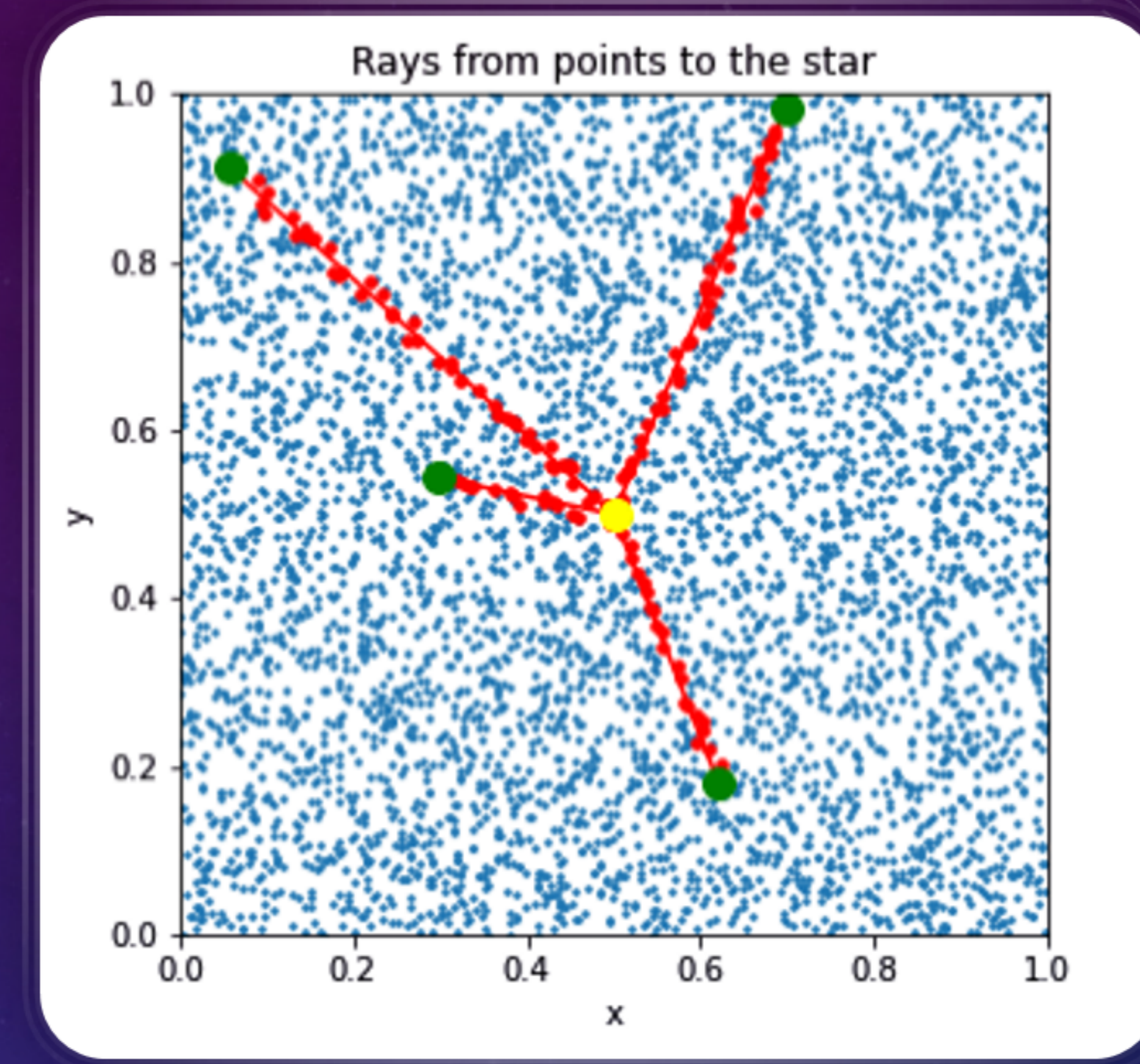
$$\Rightarrow \kappa_j \rho_j = \sum \kappa_k \rho_k W(q_k)$$



Wang et al. (2016)

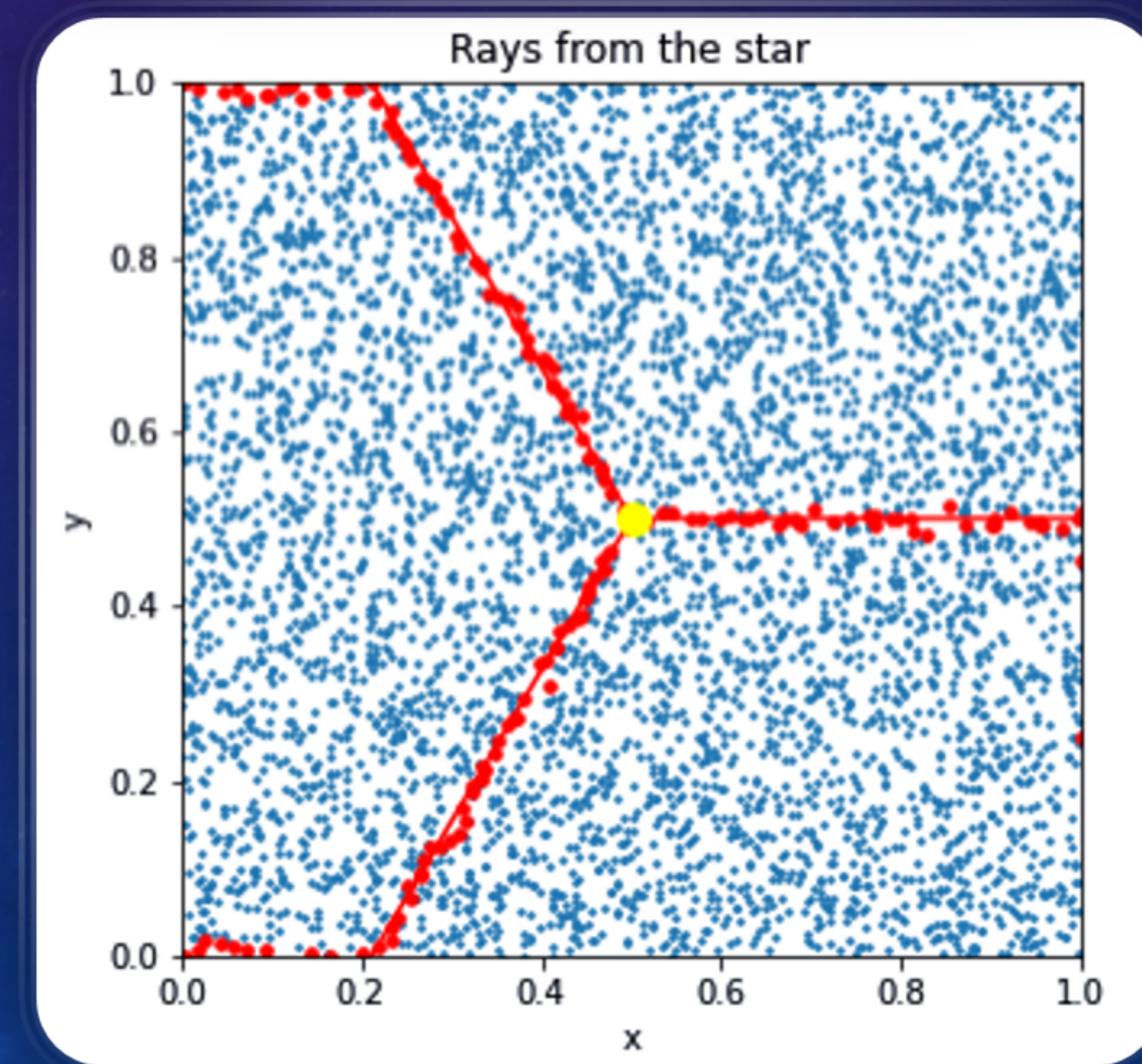
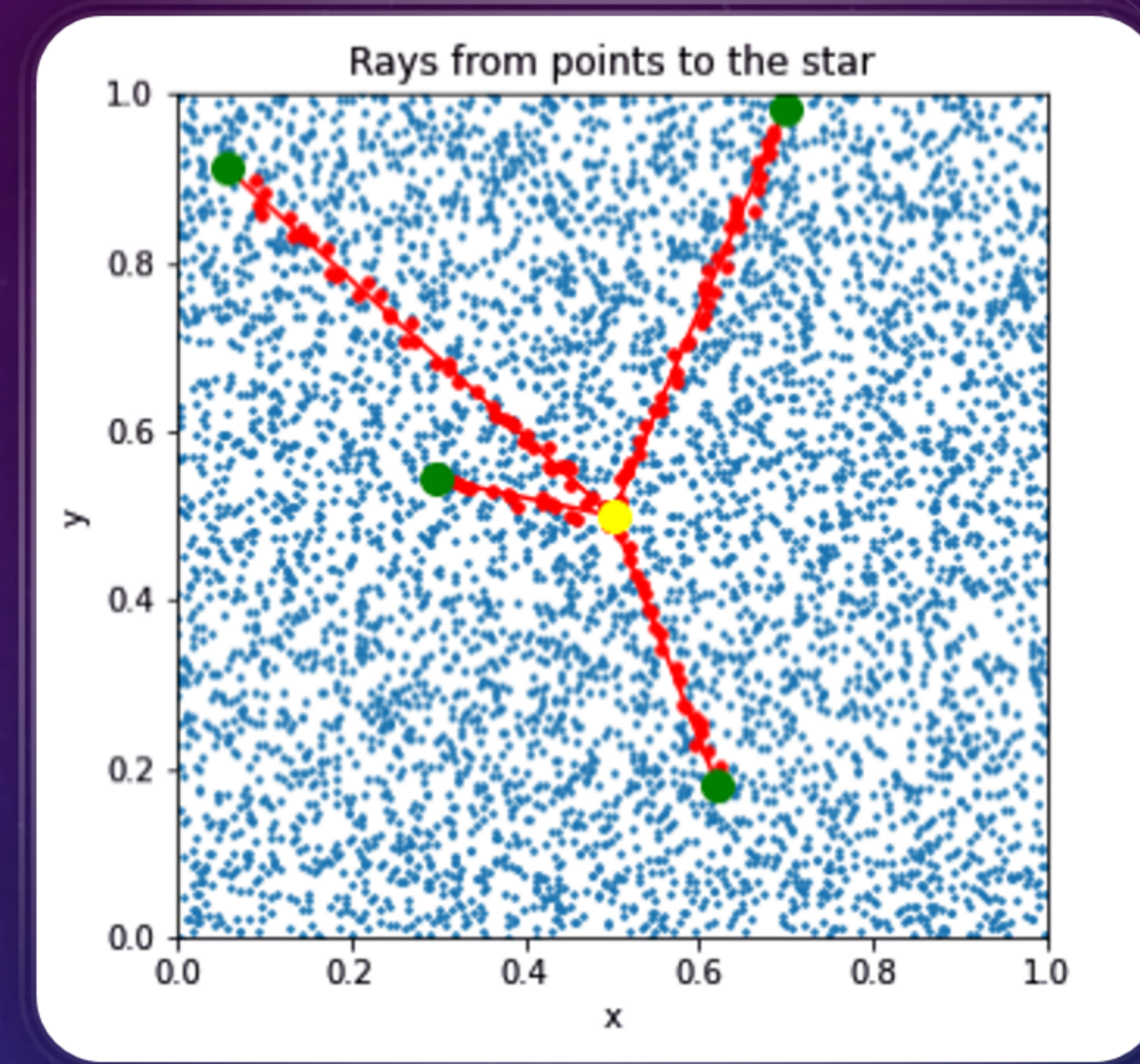
# SPEEDUP

- Trace from points
  - Takes too long



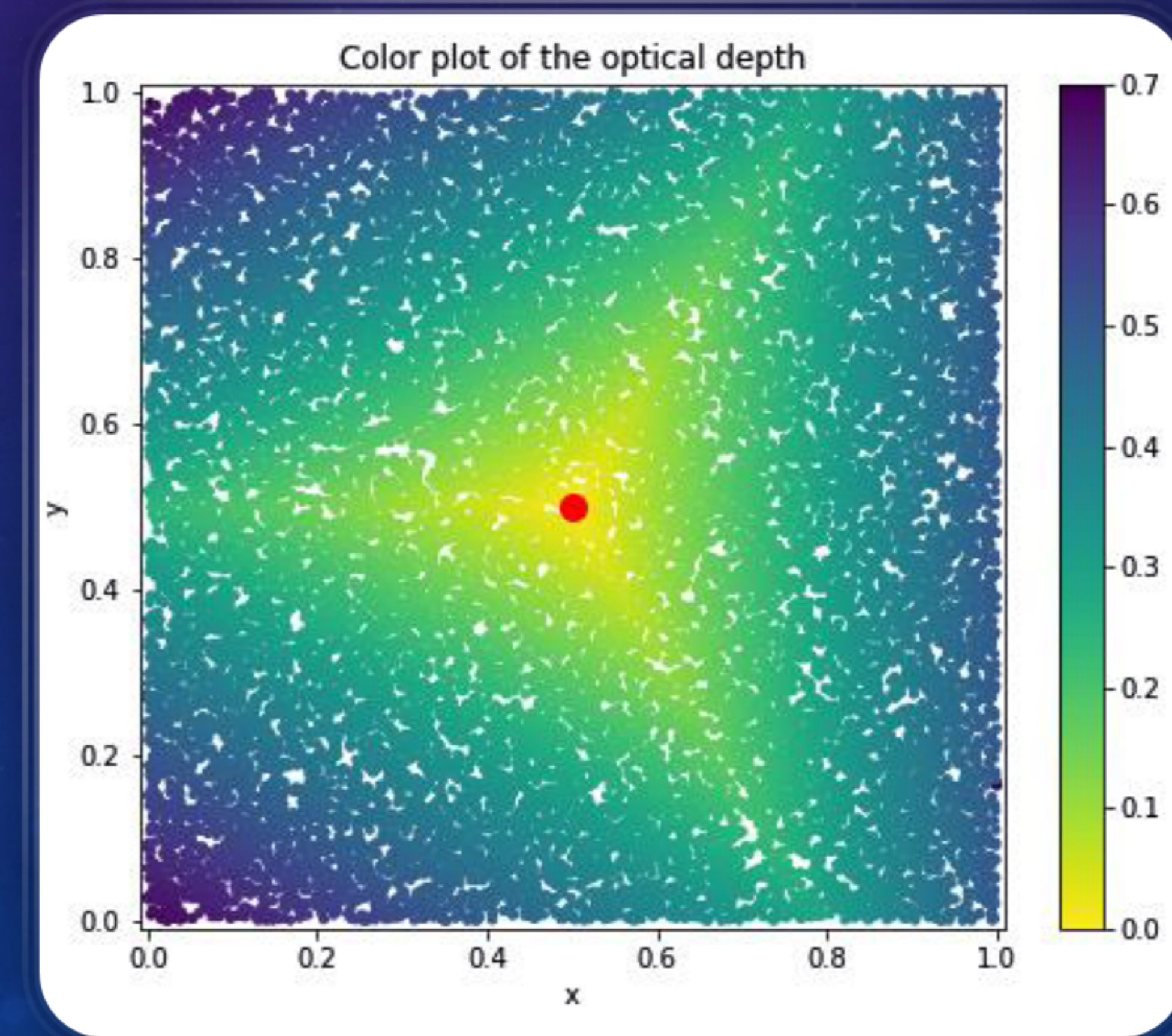
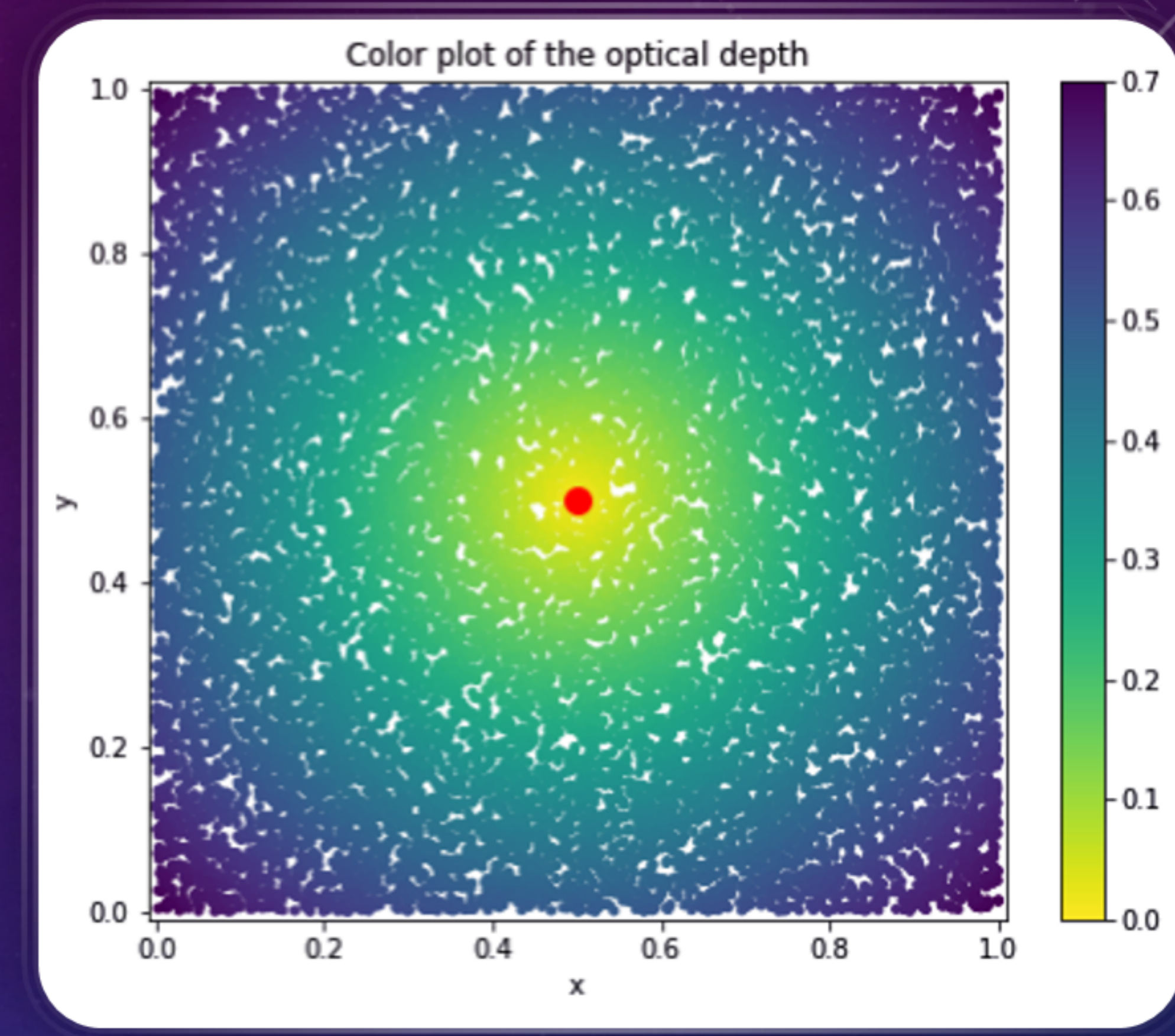
# SPEEDUP

- Trace from points
  - Takes too long
  
- Trace from star
  - Takes less time



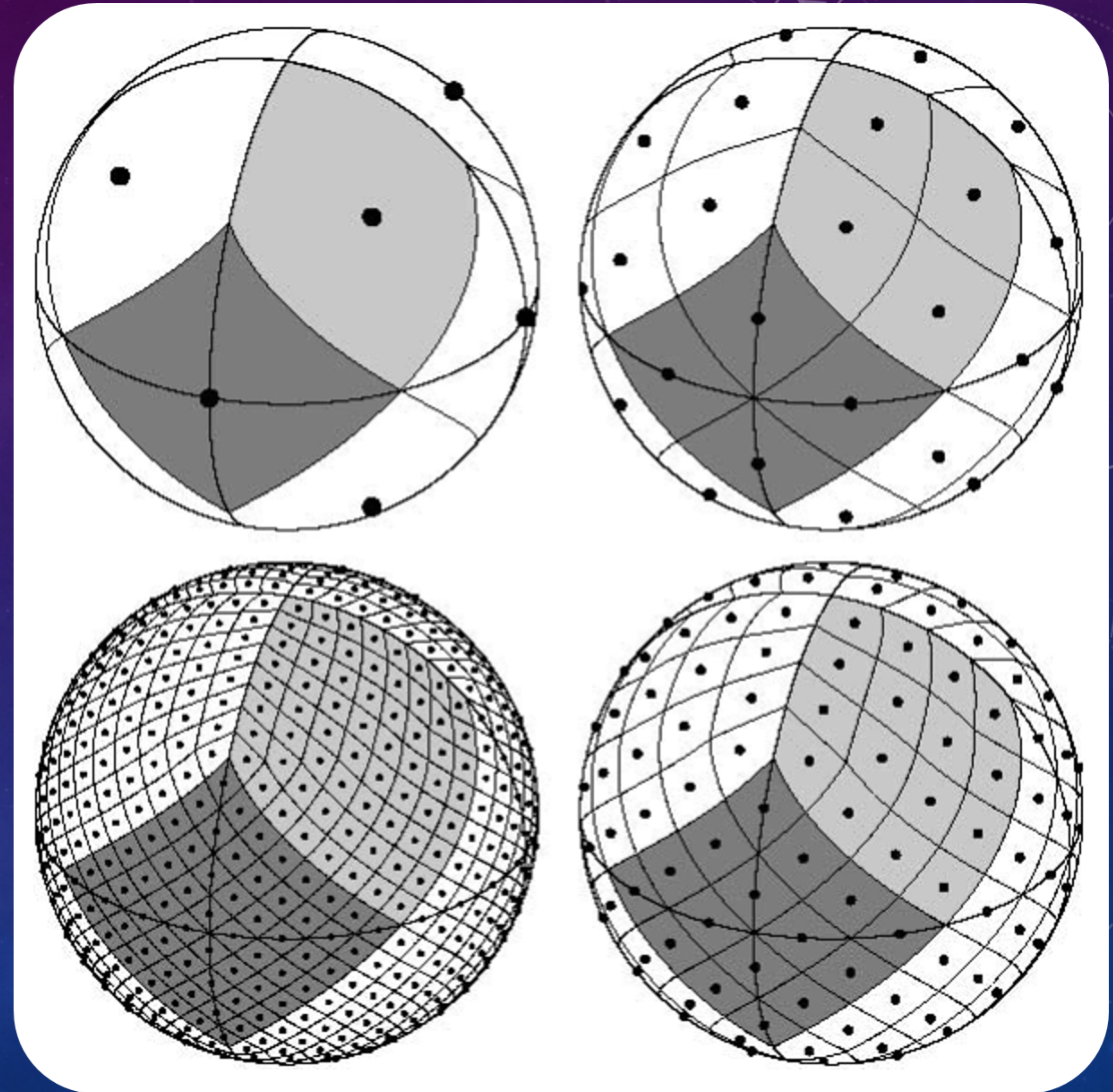
# SPEEDUP

- Trace from points
  - Takes too long
  - More accurate
- Trace from star
  - Takes less time
  - Less accurate



# IN 3D: HEALPIX

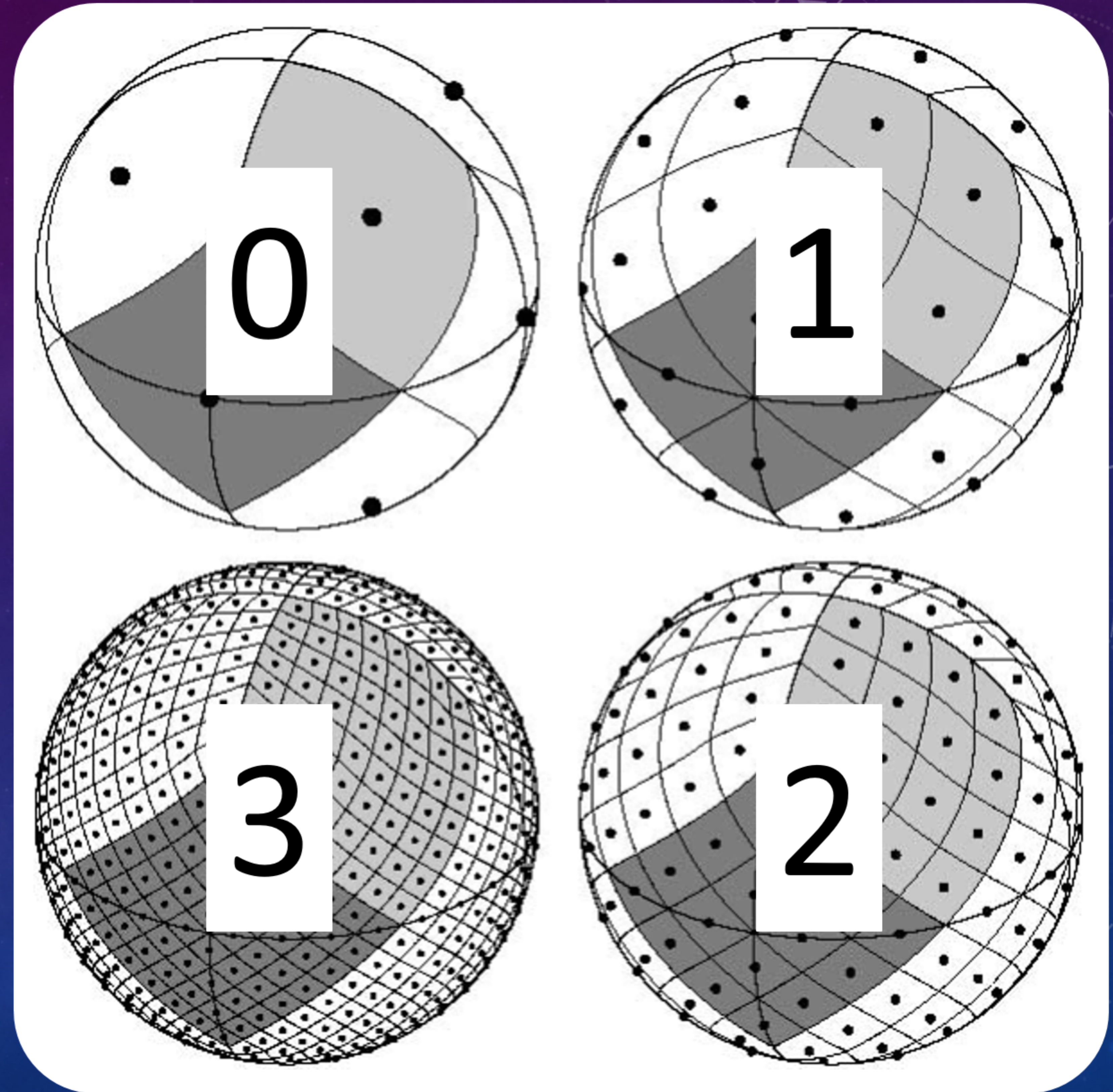
- Uniform in 2-sphere
- Orders



Górski et al. (2004)

# IN 3D: HEALPIX

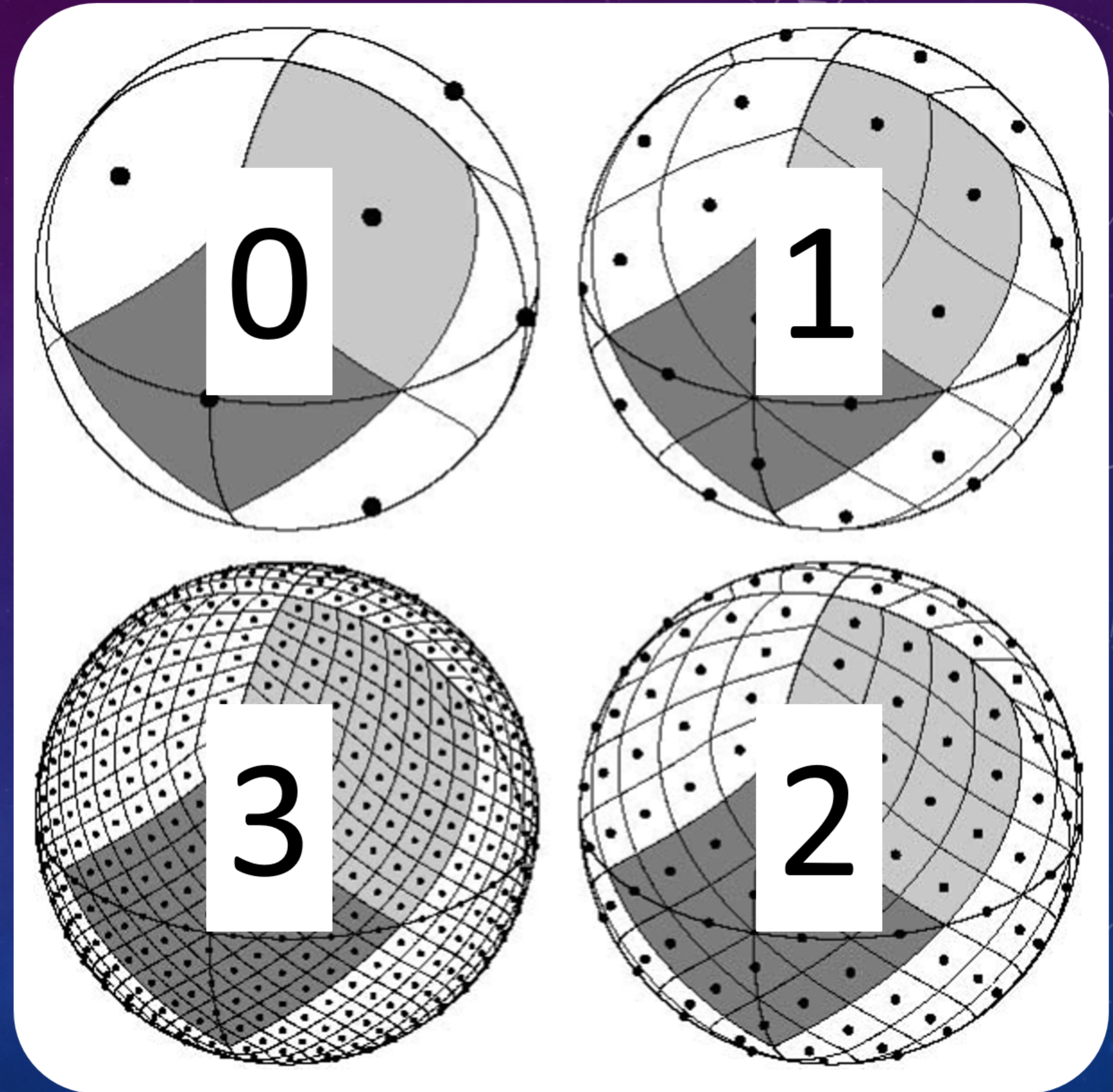
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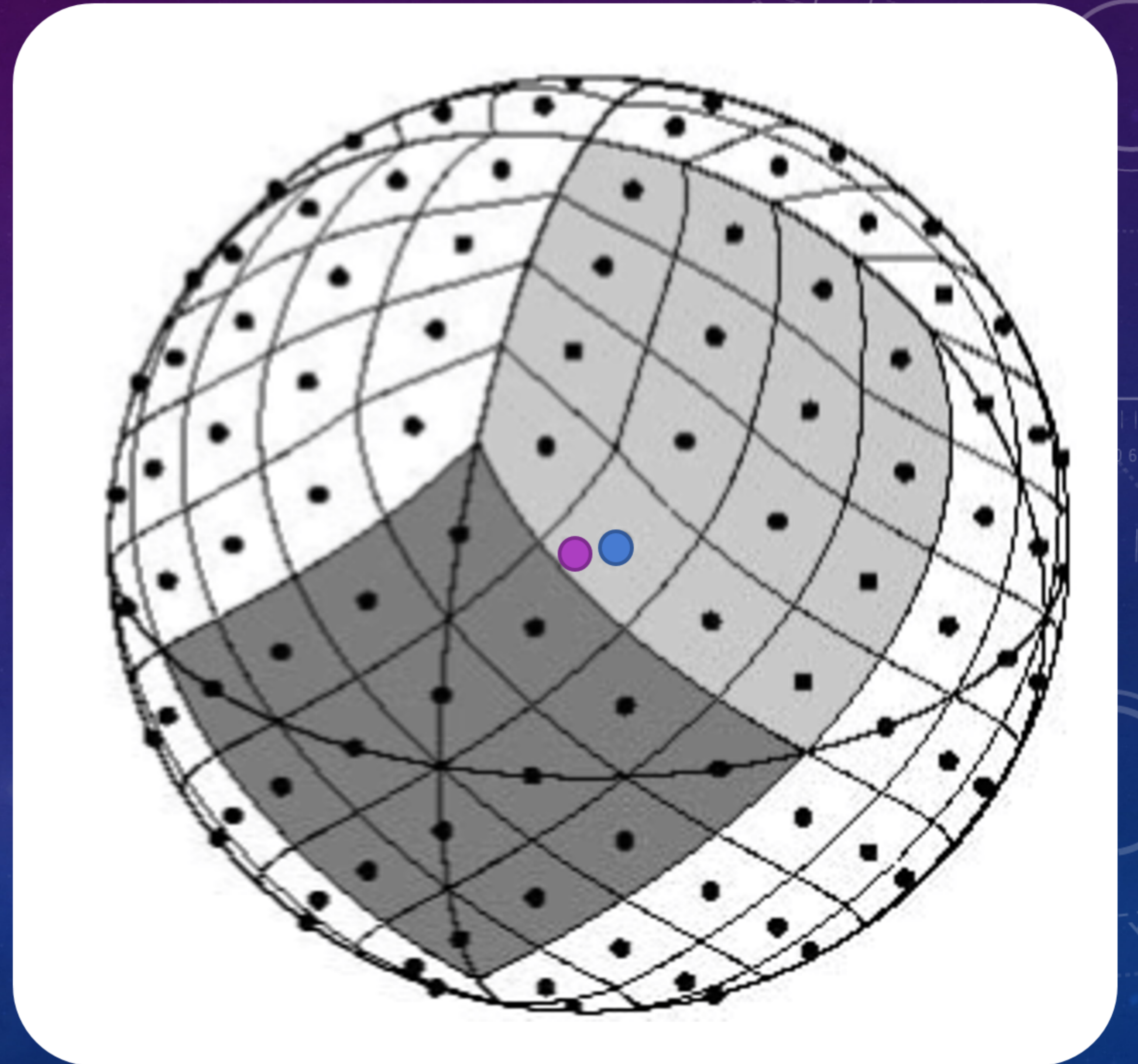
- Uniform in 2-sphere
- Orders
  - Order 5  $\rightarrow$  12.288 rays



Górski et al. (2004)

# RAY INTERPOLATION

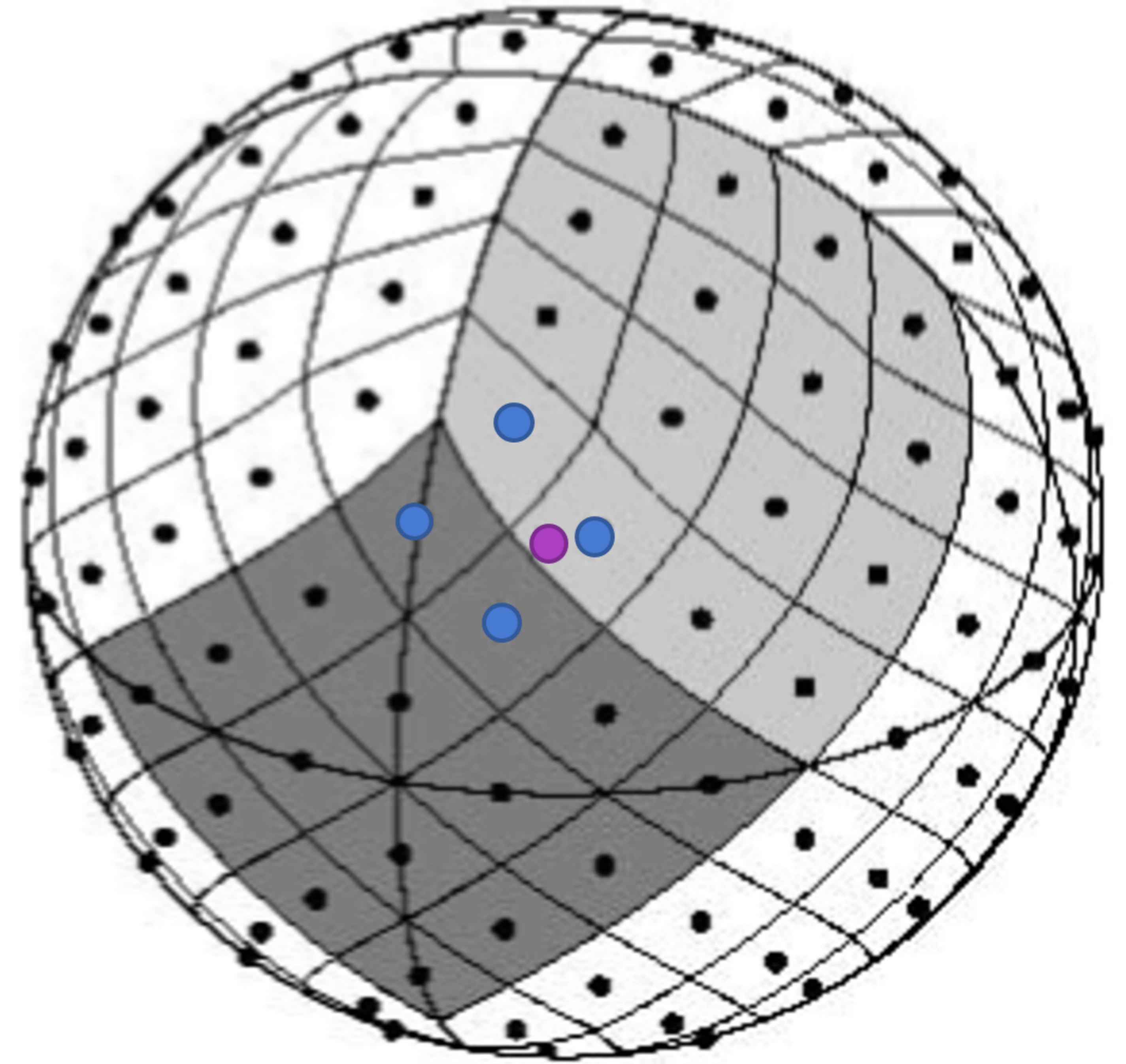
- Closest ray





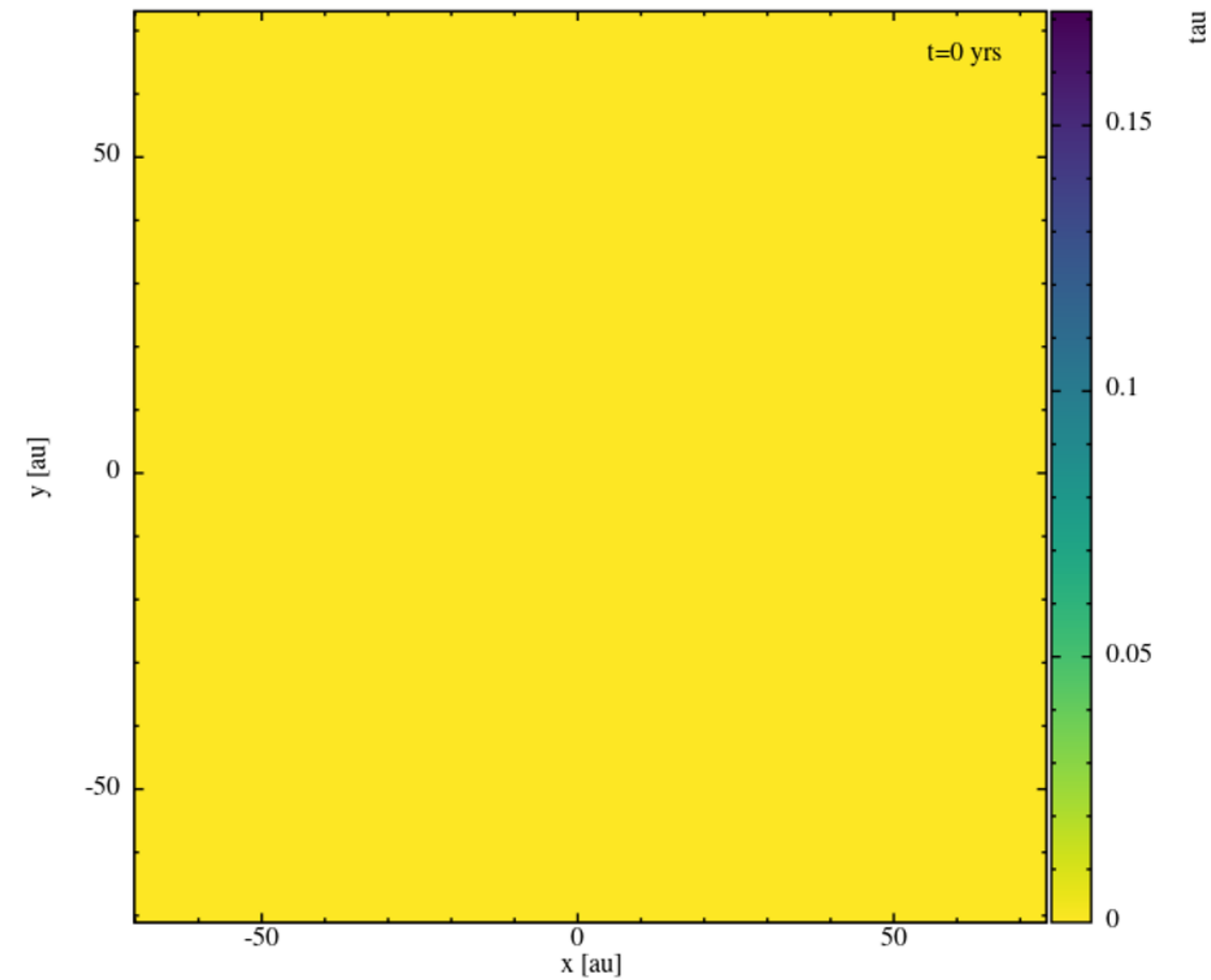
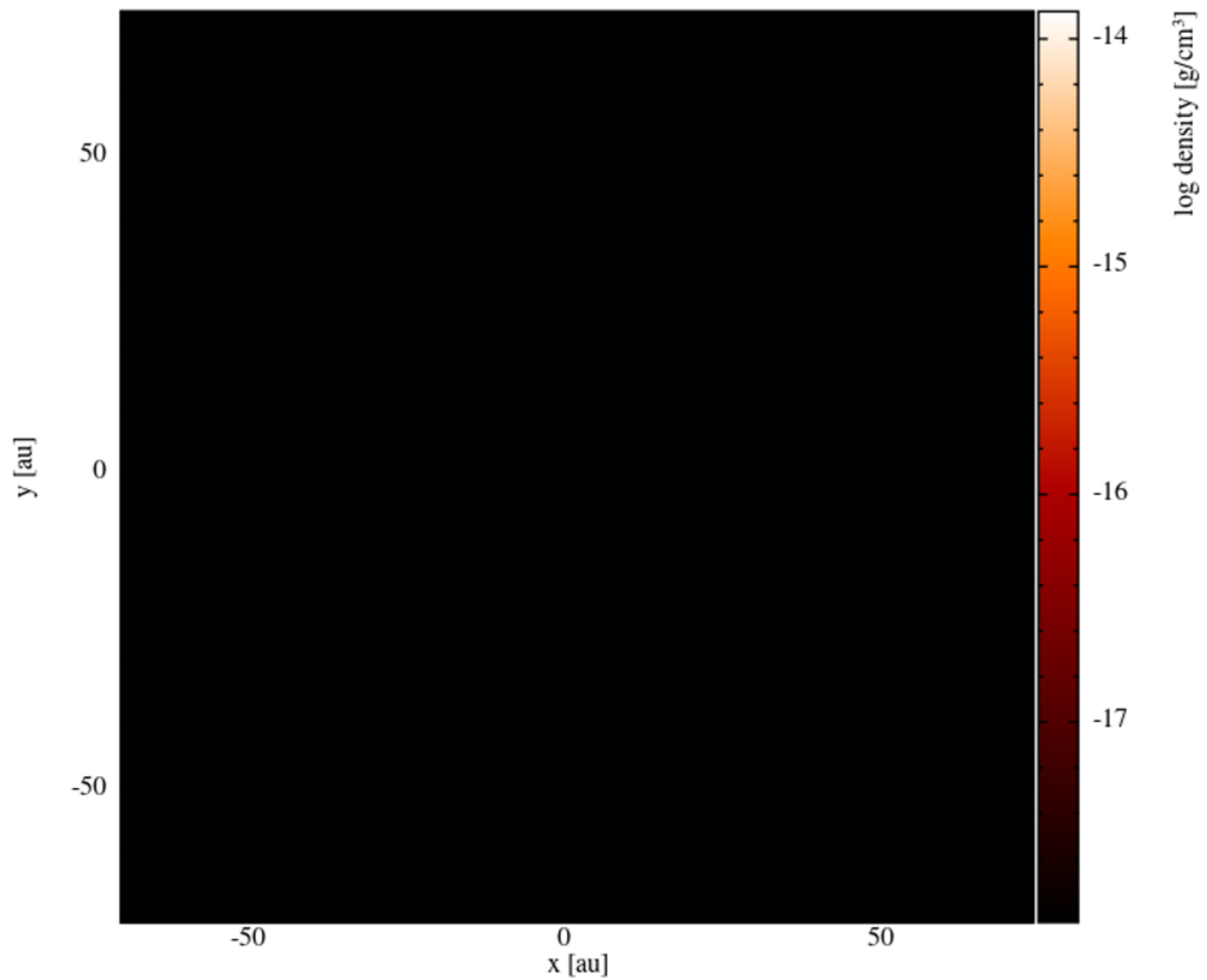
# RAY INTERPOLATION

- Closest ray
- Closest 4 rays
- $\tau_i = \frac{1}{\sum r_j^{-2}} \sum \frac{1}{r_j^2} \tau_j$



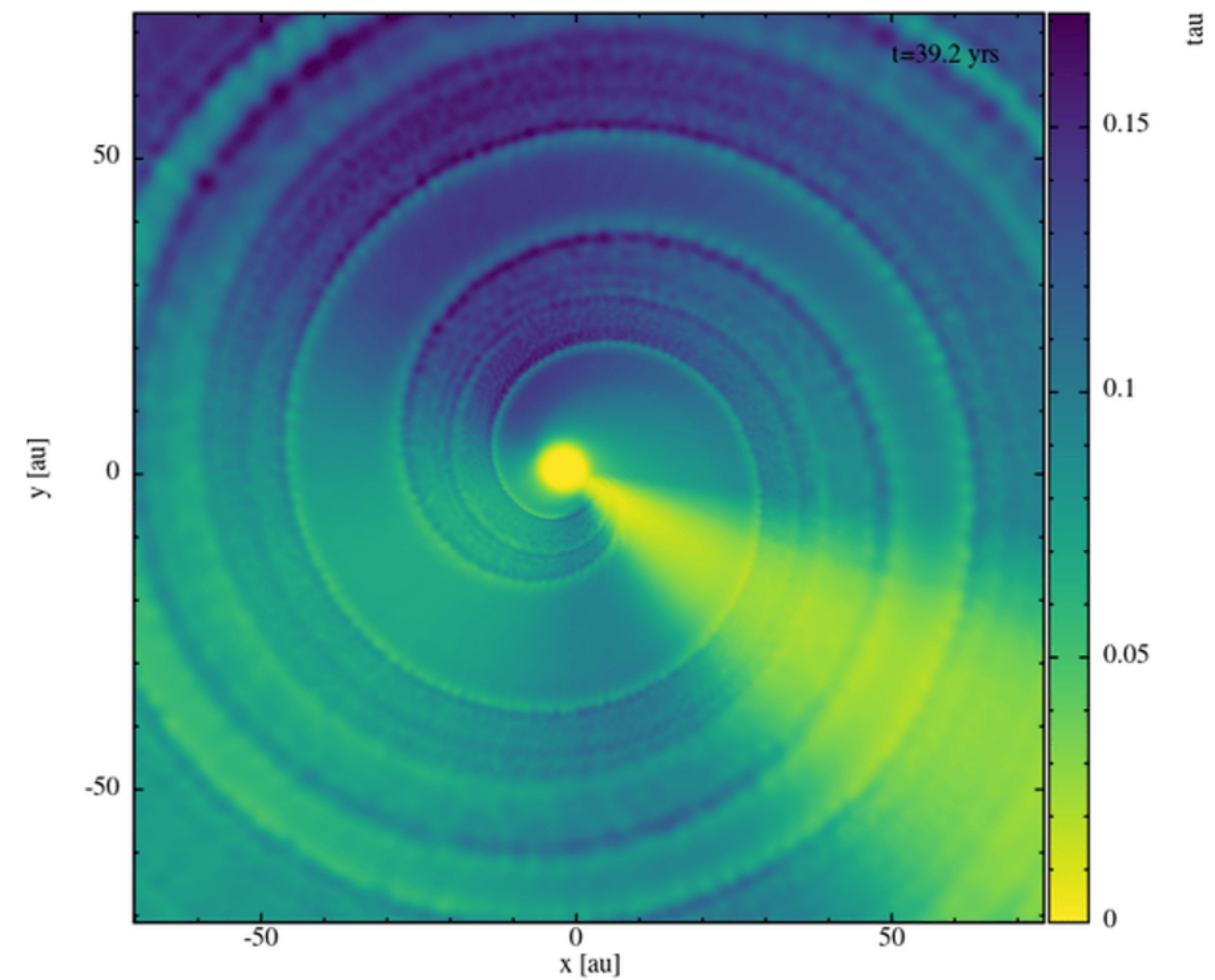
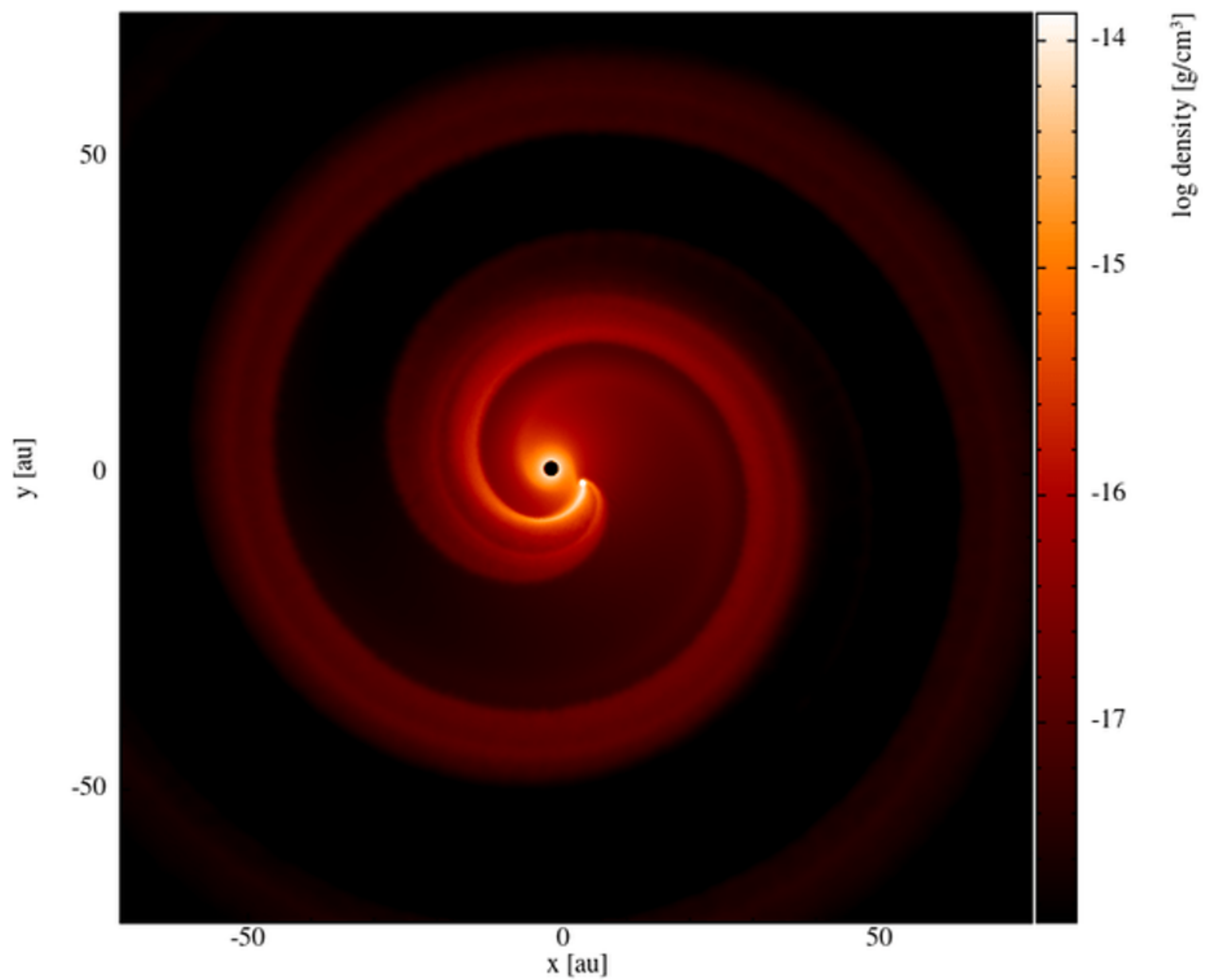
# SIMULATIONS

$$M_1 = 1.5 M_{\odot}, \quad M_2 = 1 M_{\odot}, \quad a = 5.4 \text{ au}$$



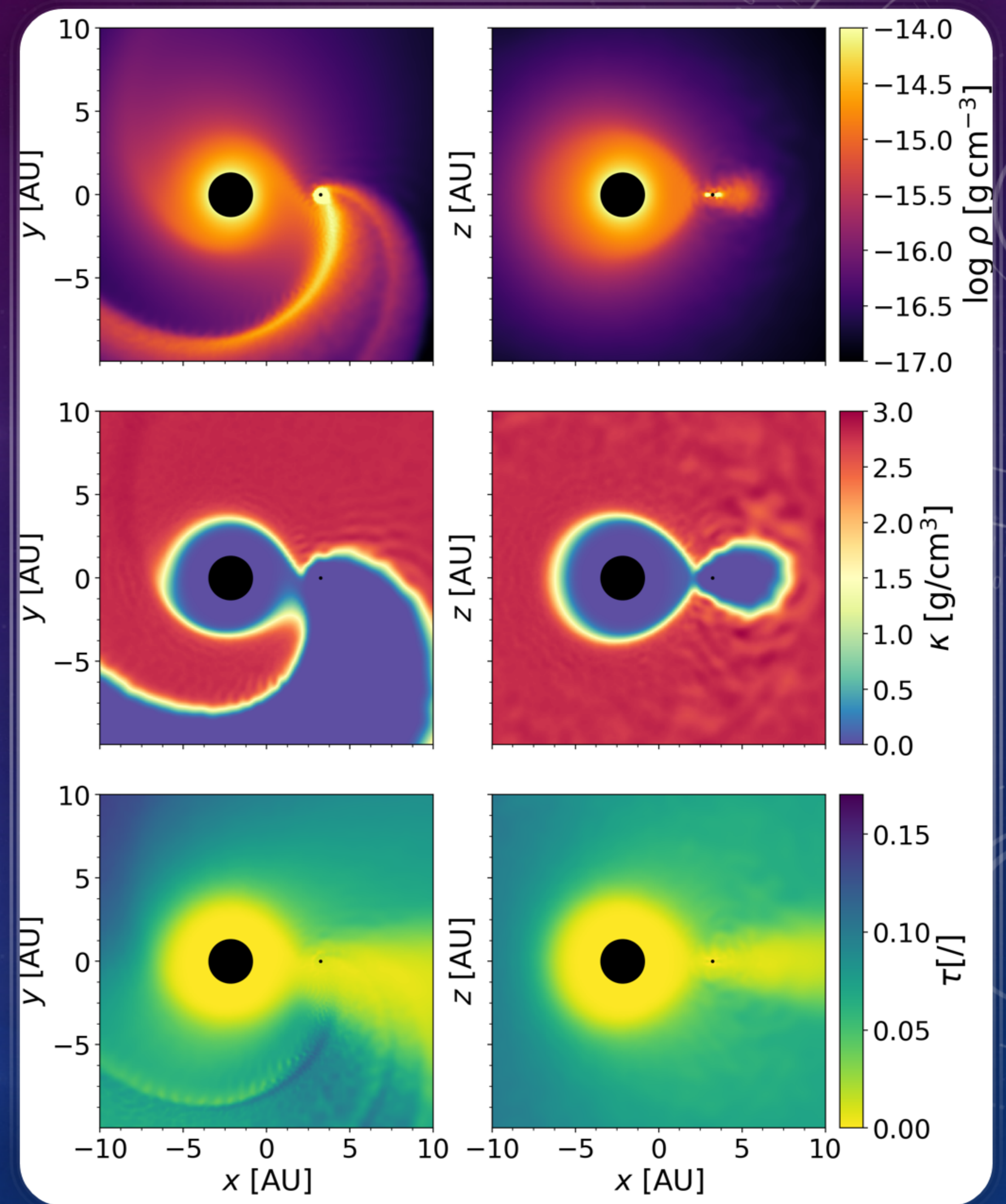
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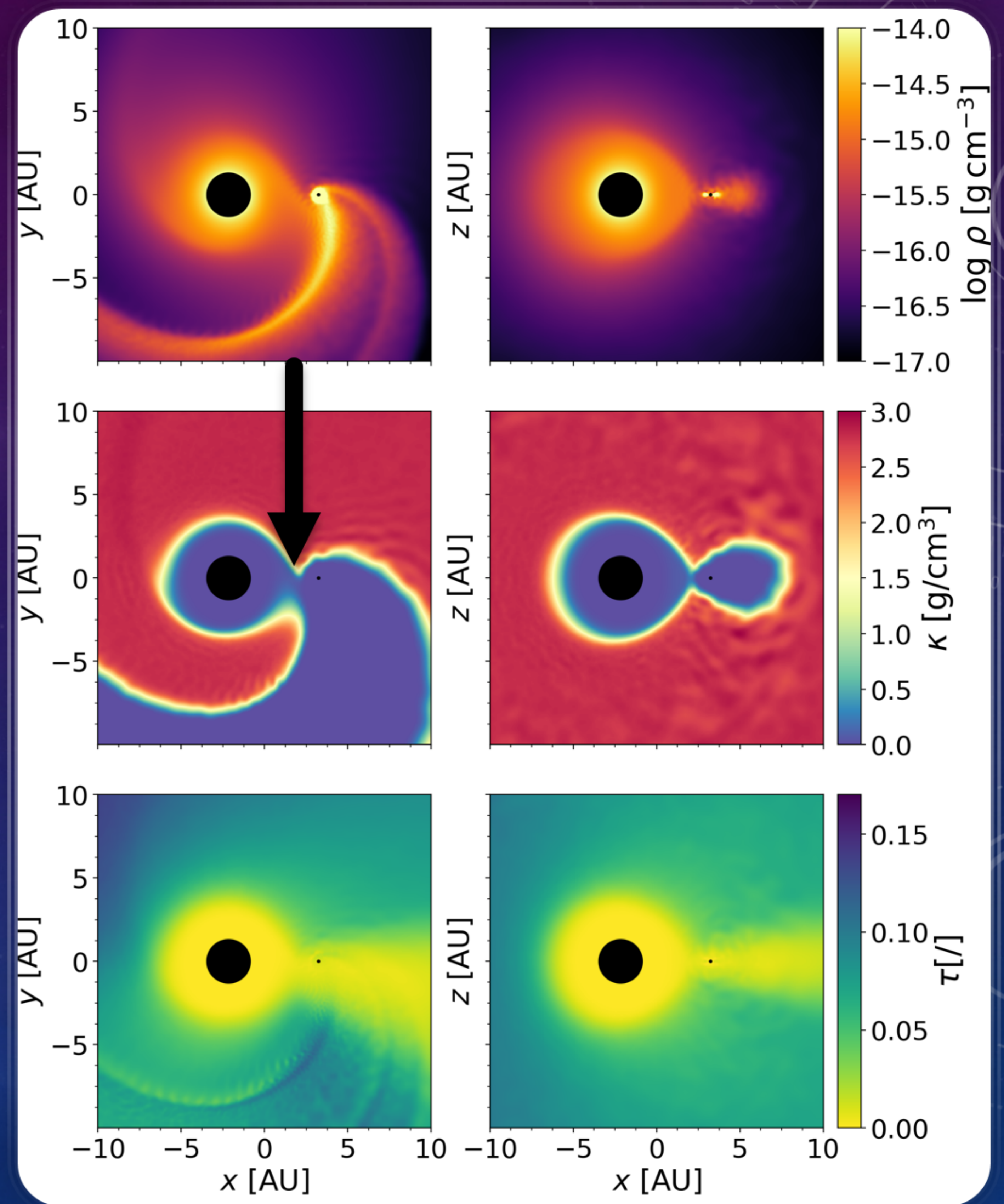
# TUNNEL

- Accretion disk
- Too hot for dust



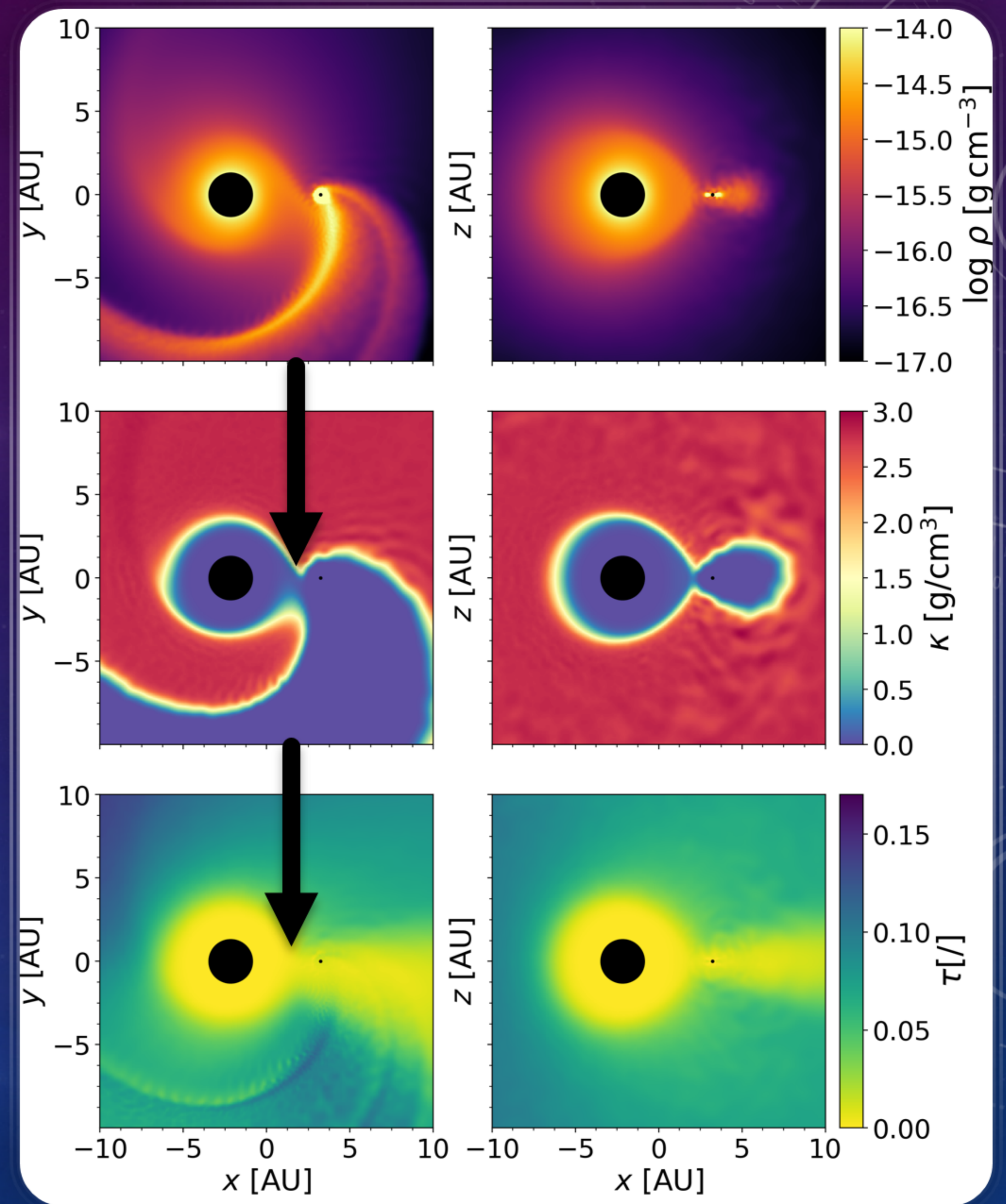
# TUNNEL

- Accretion disk
- Too hot for dust
- Connected to star



# TUNNEL

- Accretion disk
- Too hot for dust
- Connected to star
- Creates tunnel



# SUMMARY

- Modelling AGB outflows requires 3D simulations
- Calculating the attenuation in radiation pressure is important in simulating these systems
- To make this calculation computationally feasible
  - Outwards rays with a ray interpolation gives the best and fastest results
- In simulations, accretion disks are too hot to condensate dust, resulting in a tunnel of light behind the companion

# REFERENCES

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