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

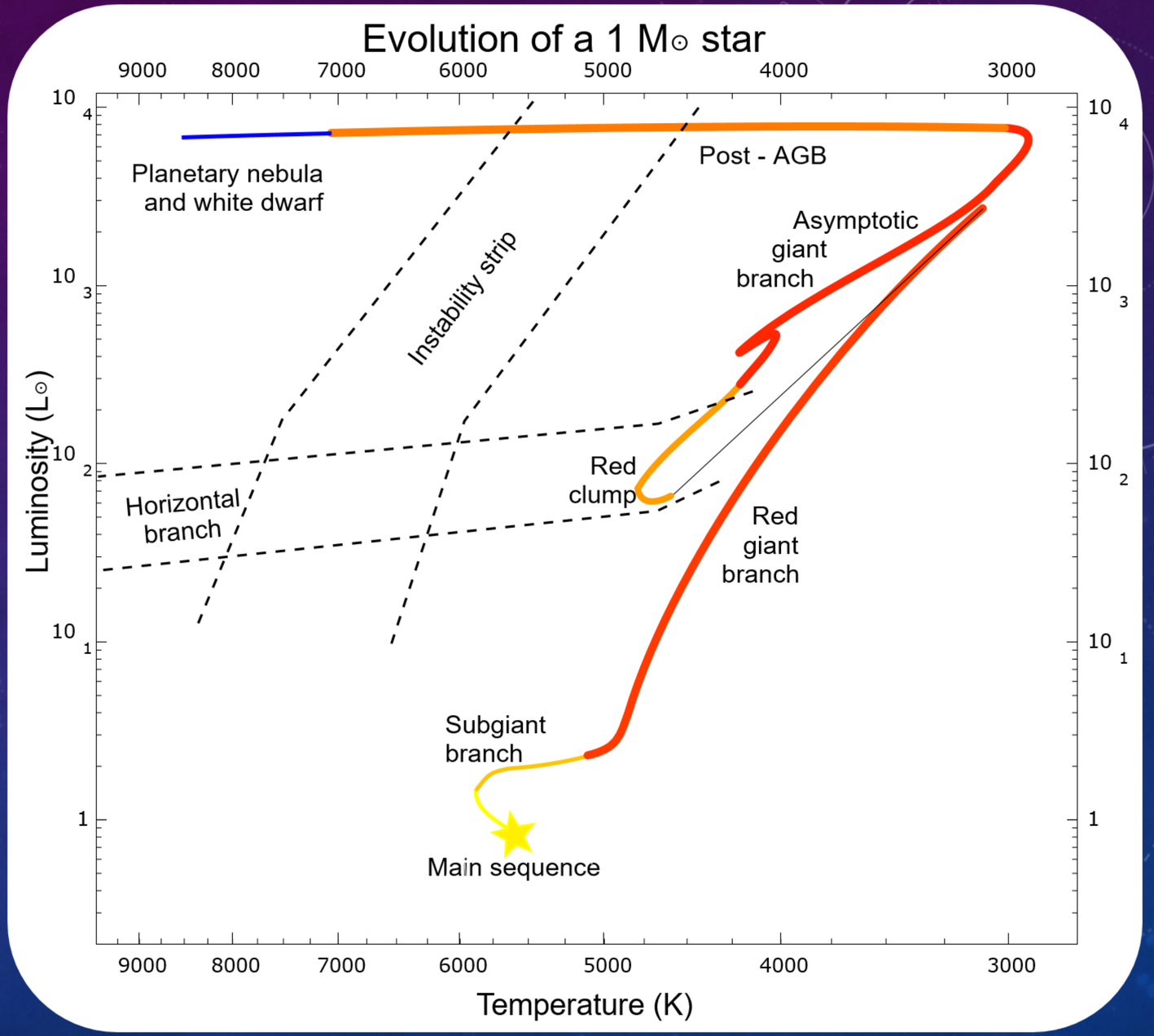
BY: MATS ESSELDEURS
EMAIL: MATS.ESSELDEURS@STUDENT.KULEUVEN.BE

PROMOTOR: DR. WARD HOMAN
CO-PROMOTOR: DR. FREDERIK DE CEUSTER
DR. LIONEL SIESS

KU LEUVEN ULB UNIVERSITÉ LIBRE DE BRUXELLES

AGB STARS

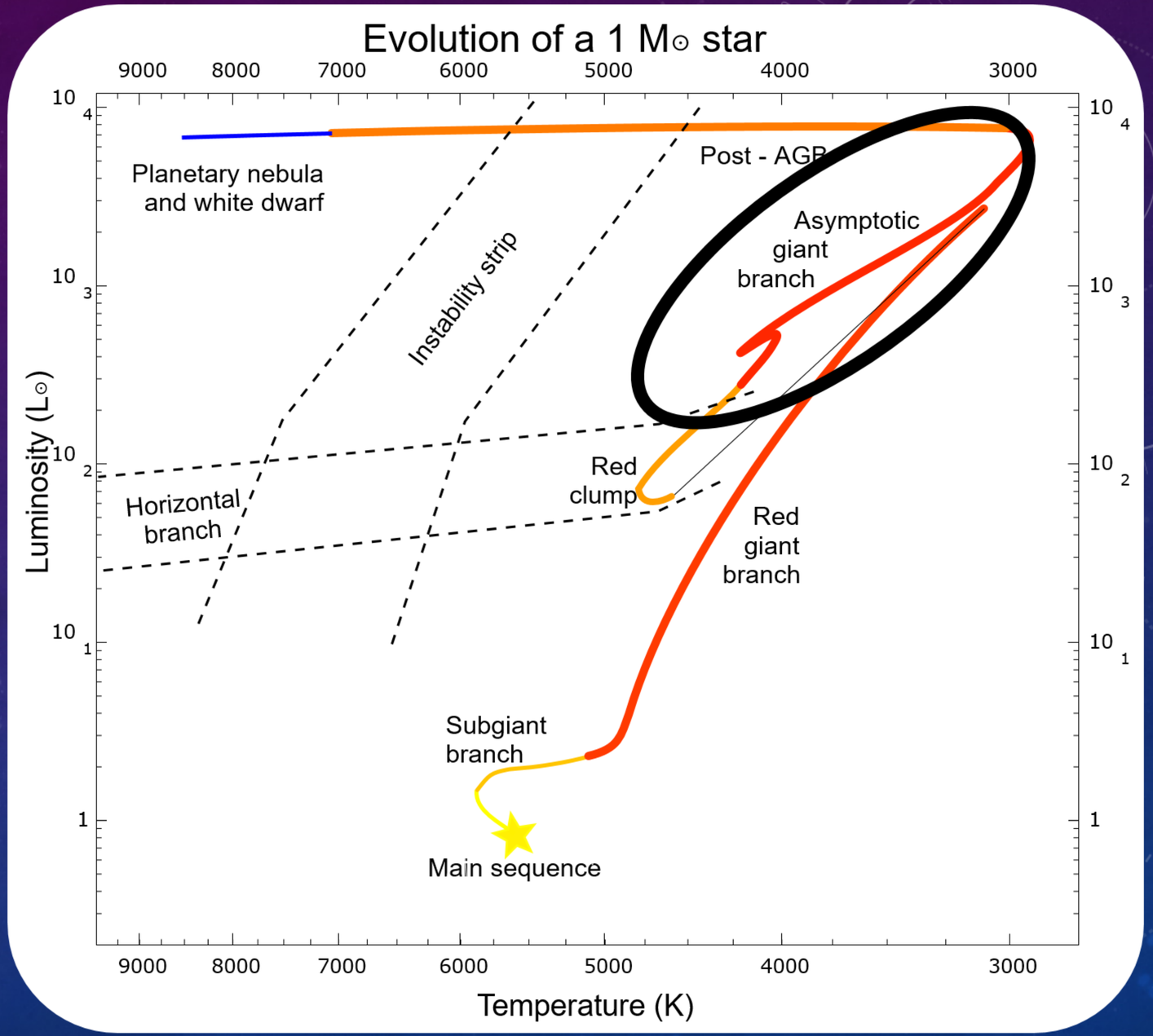
- Low and intermediate mass stars
- $M \in [0.8\ \mathrm{M}_\odot, 8\ \mathrm{M}_\odot]$



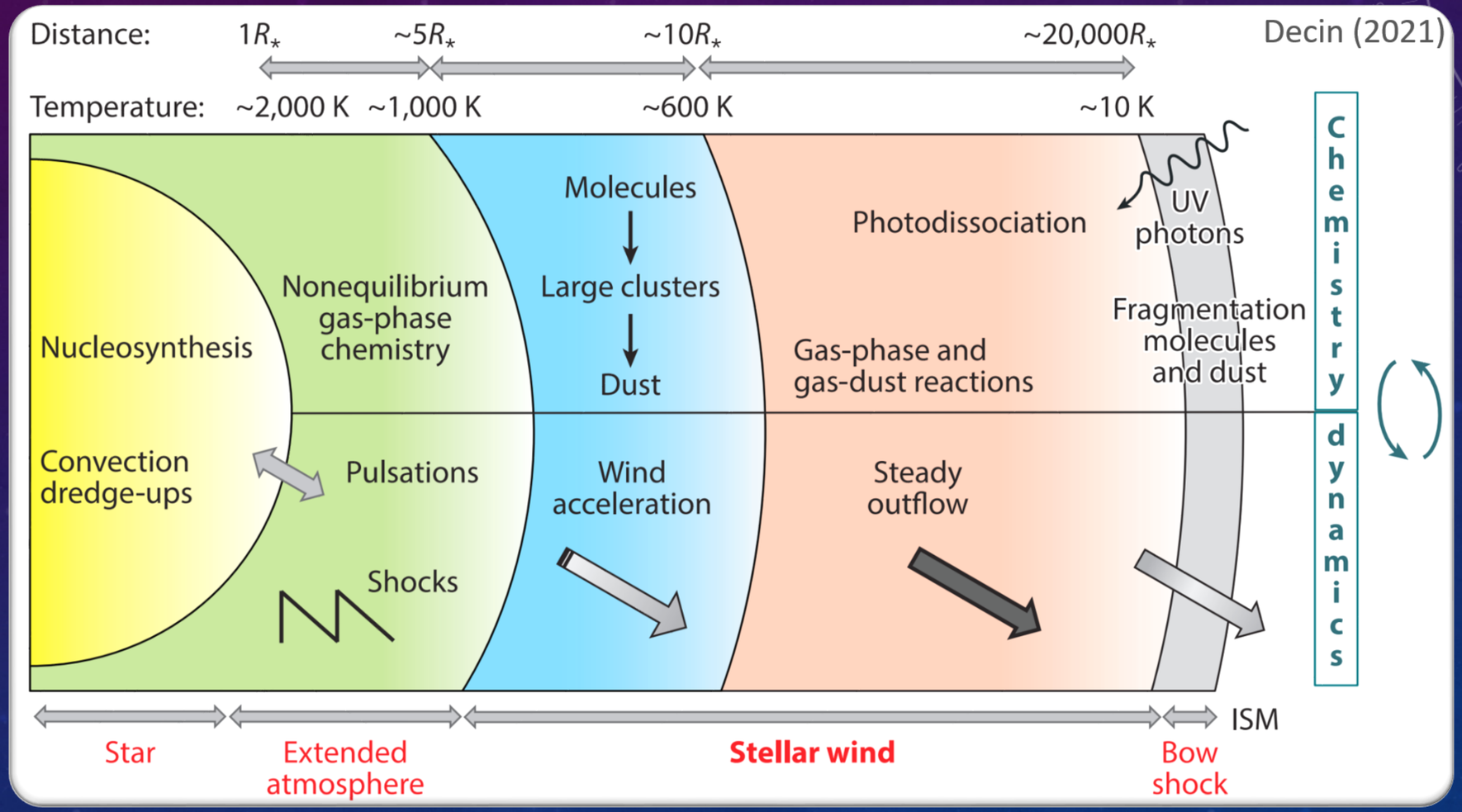
AGB STARS

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

- Strong winds
- Complex chemistry

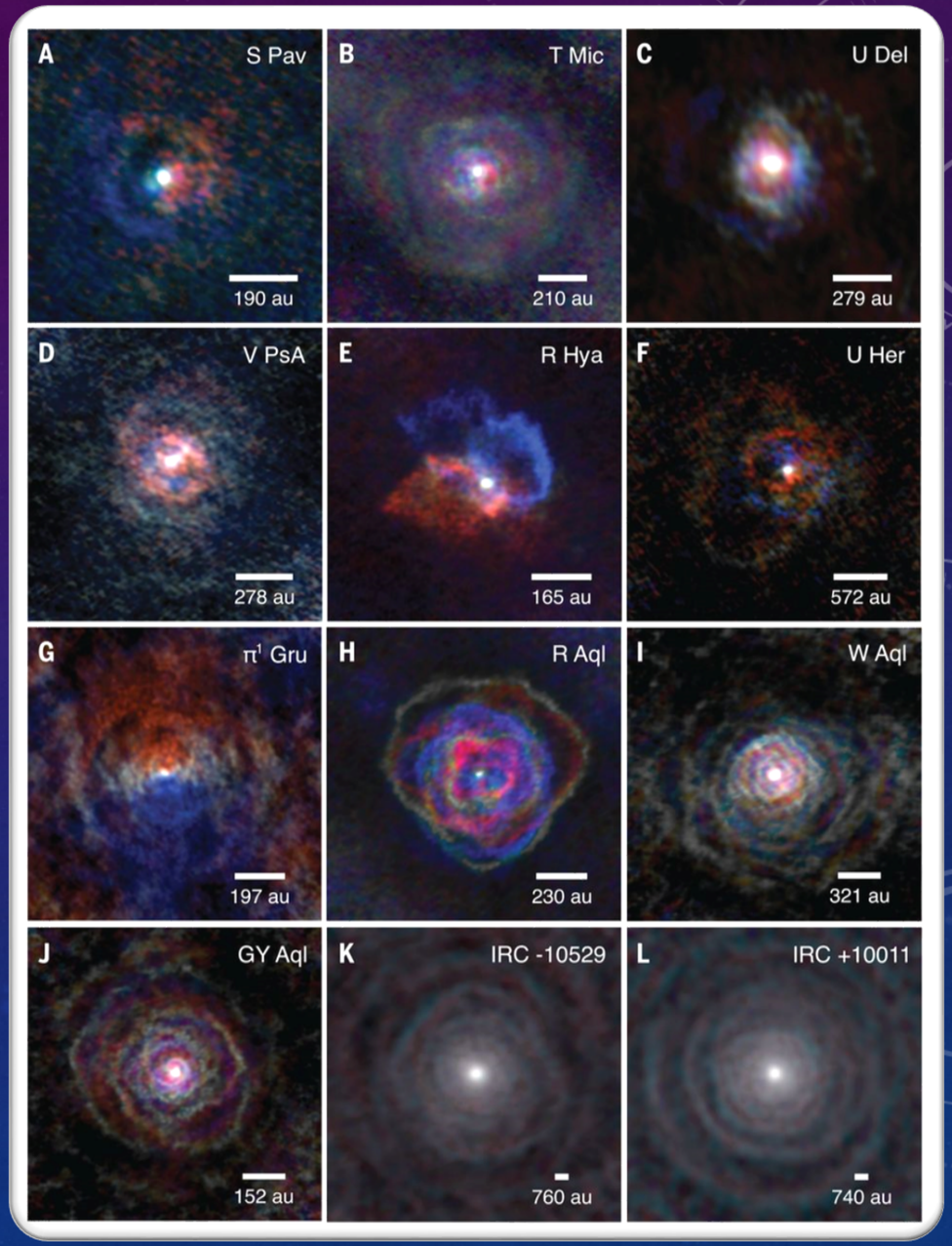


WIND DYNAMICS OF AGB STARS



COMPLEX AGB OUTFLOWS

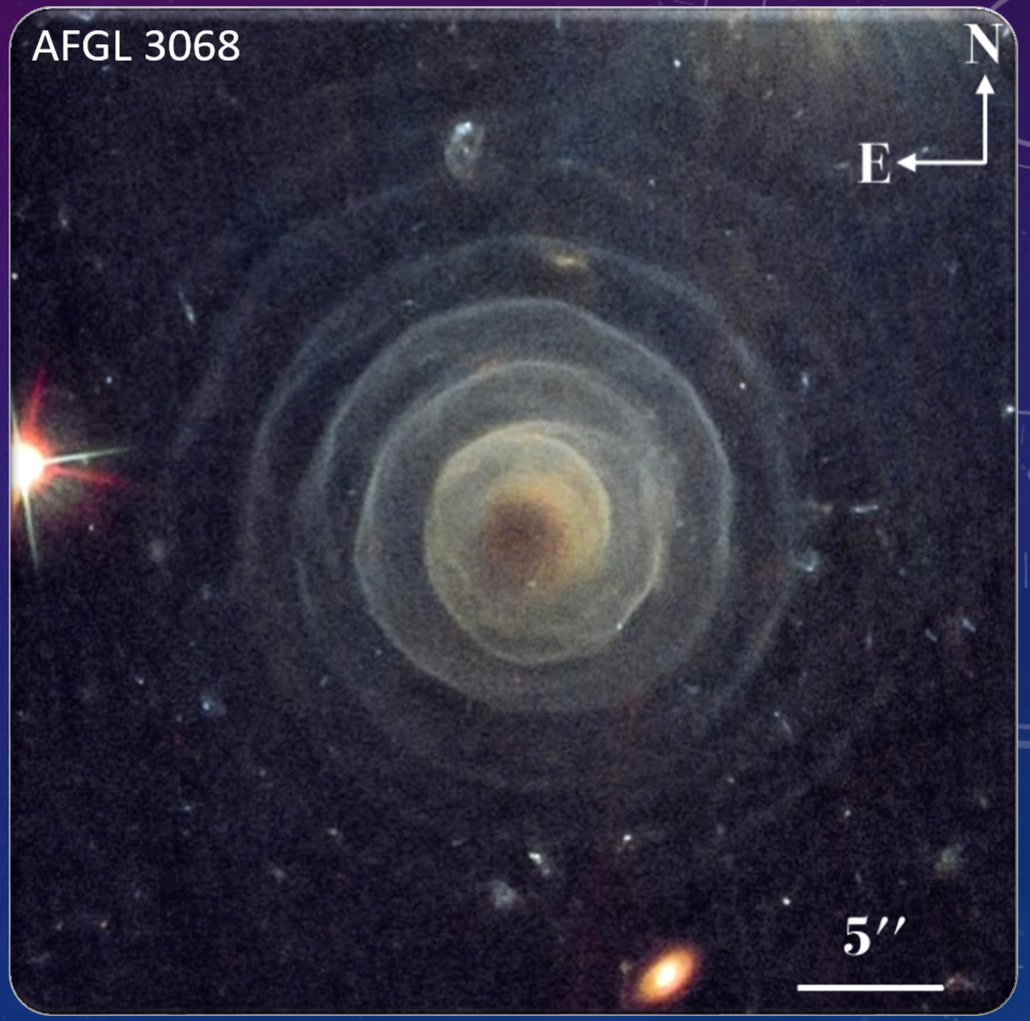
- Complex structures



Decin et al. (2020)

COMPLEX AGB OUTFLOWS

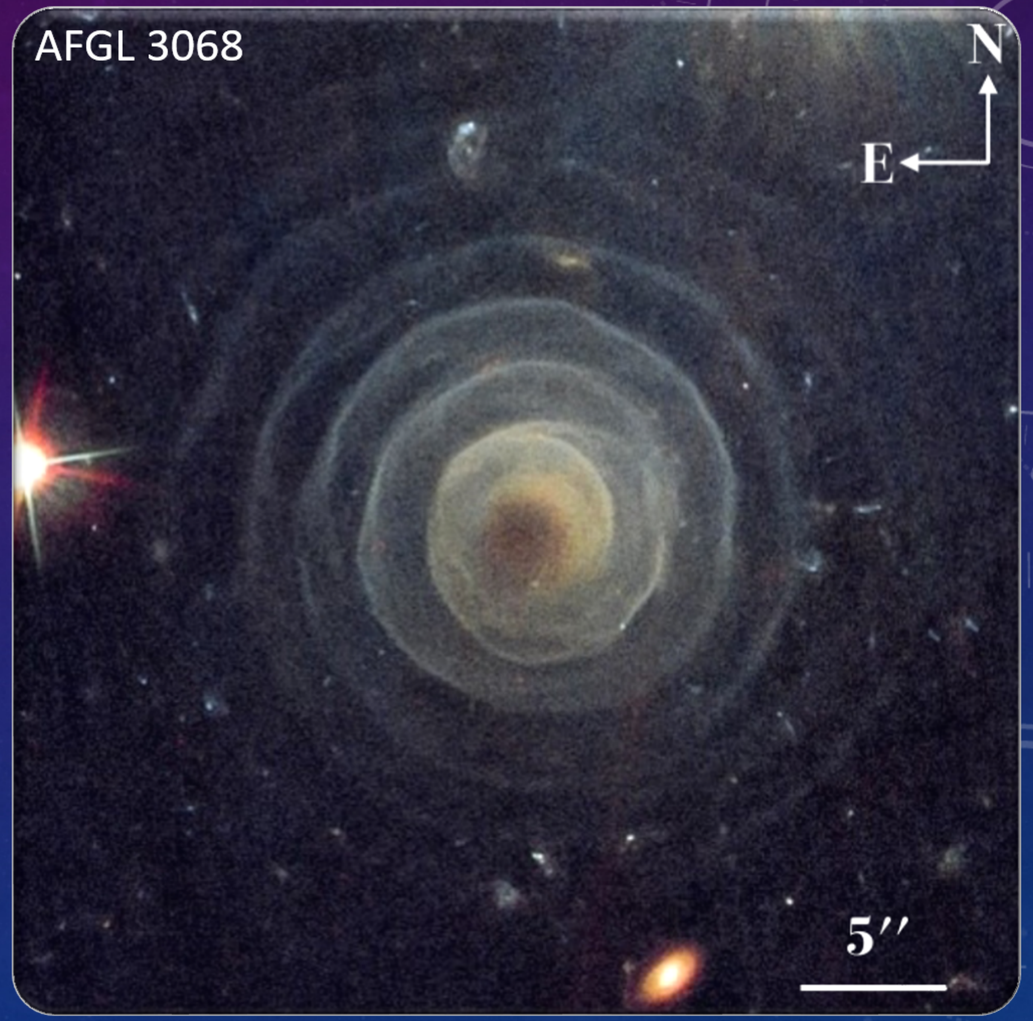
- Complex structures



(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)

HYDRODYNAMIC SIMULATIONS

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

- Additional forces

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

HYDRODYNAMIC SIMULATIONS

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

- Additional forces

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

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

RADIATIVE ACCELERATION

- Radiation-pressure-~~free~~ wind

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

RADIATIVE ACCELERATION

- Radiation-pressure-free wind

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

- Optical depth τ

$$\tau = \int_{R_*}^{r} \kappa\rho \, \mathrm{d}s$$

RADIATIVE ACCELERATION

- Radiation-pressure-~~free~~ wind

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

- Optical depth τ

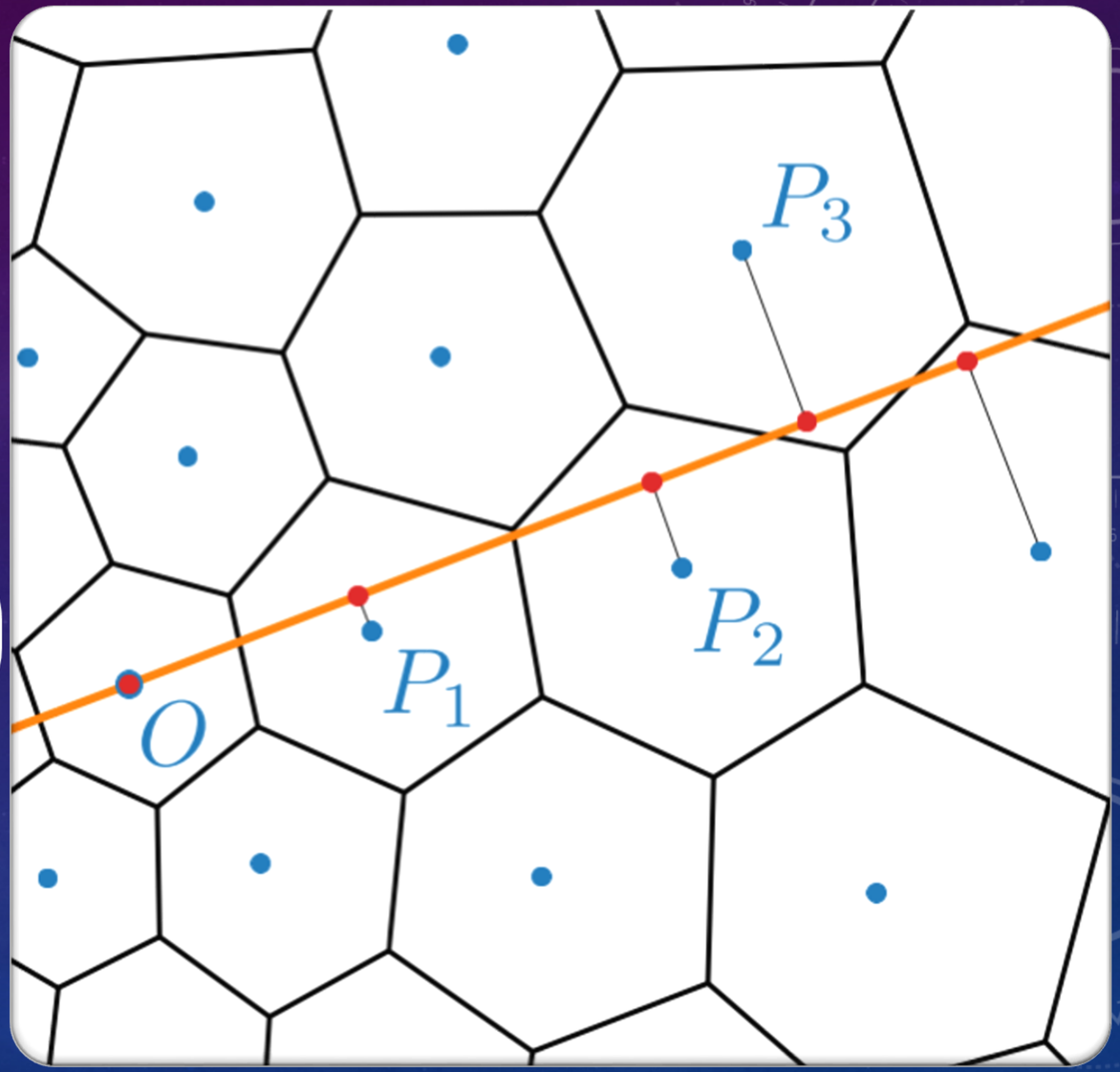
$$\tau = \int_{R_*}^{r} \kappa\rho \, \mathrm{d}s$$

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

Magritte

RAY-TRACER OF MAGRITTE

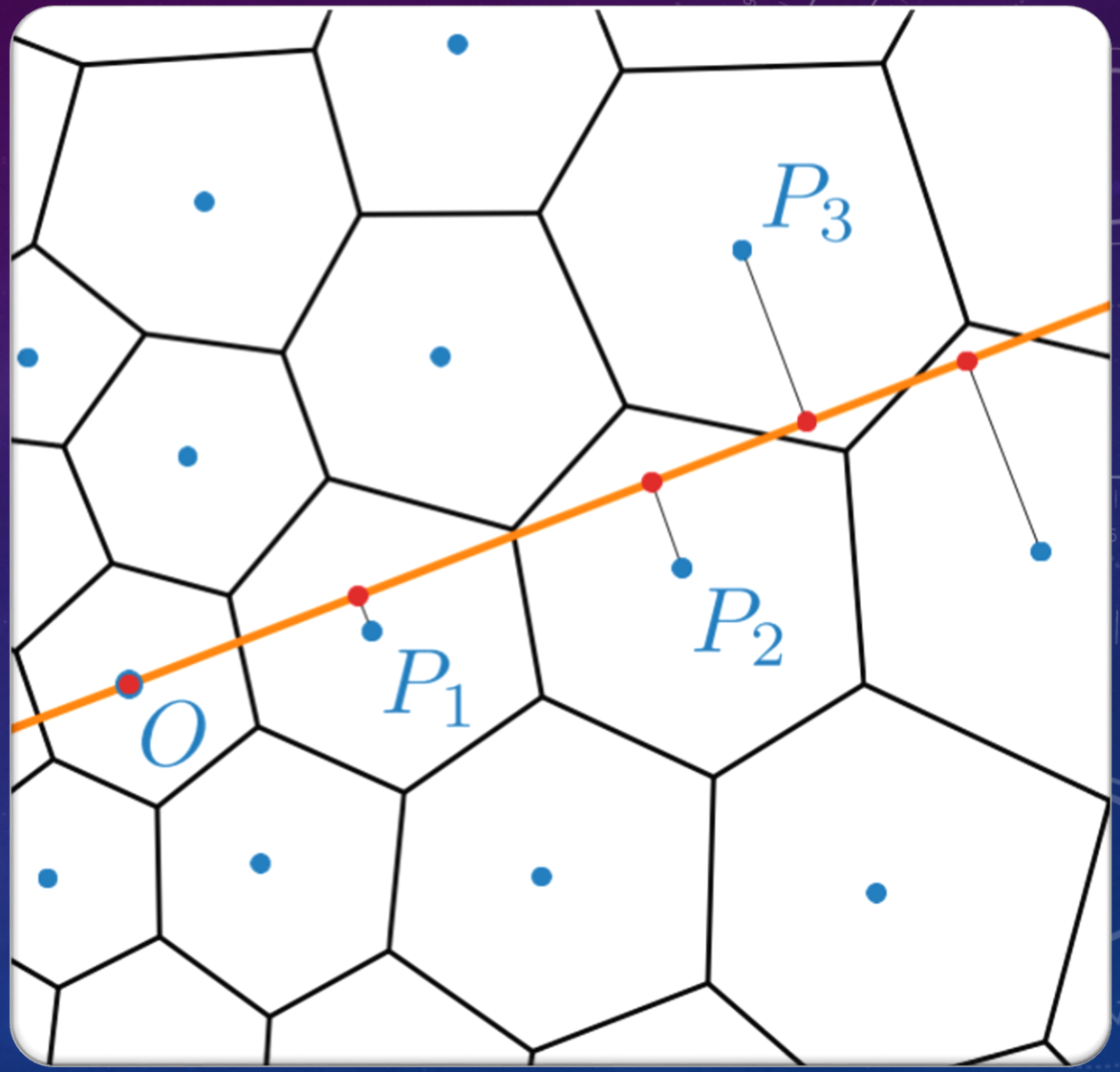
- Start from a point
- Take all the nearest neighbours
- Find the one closest to the ray



De Ceuster et al. (2020)

OPTICAL DEPTH

$$\Rightarrow \tau = \int_{R_*}^{r} \kappa\rho \, \mathrm{d}s$$

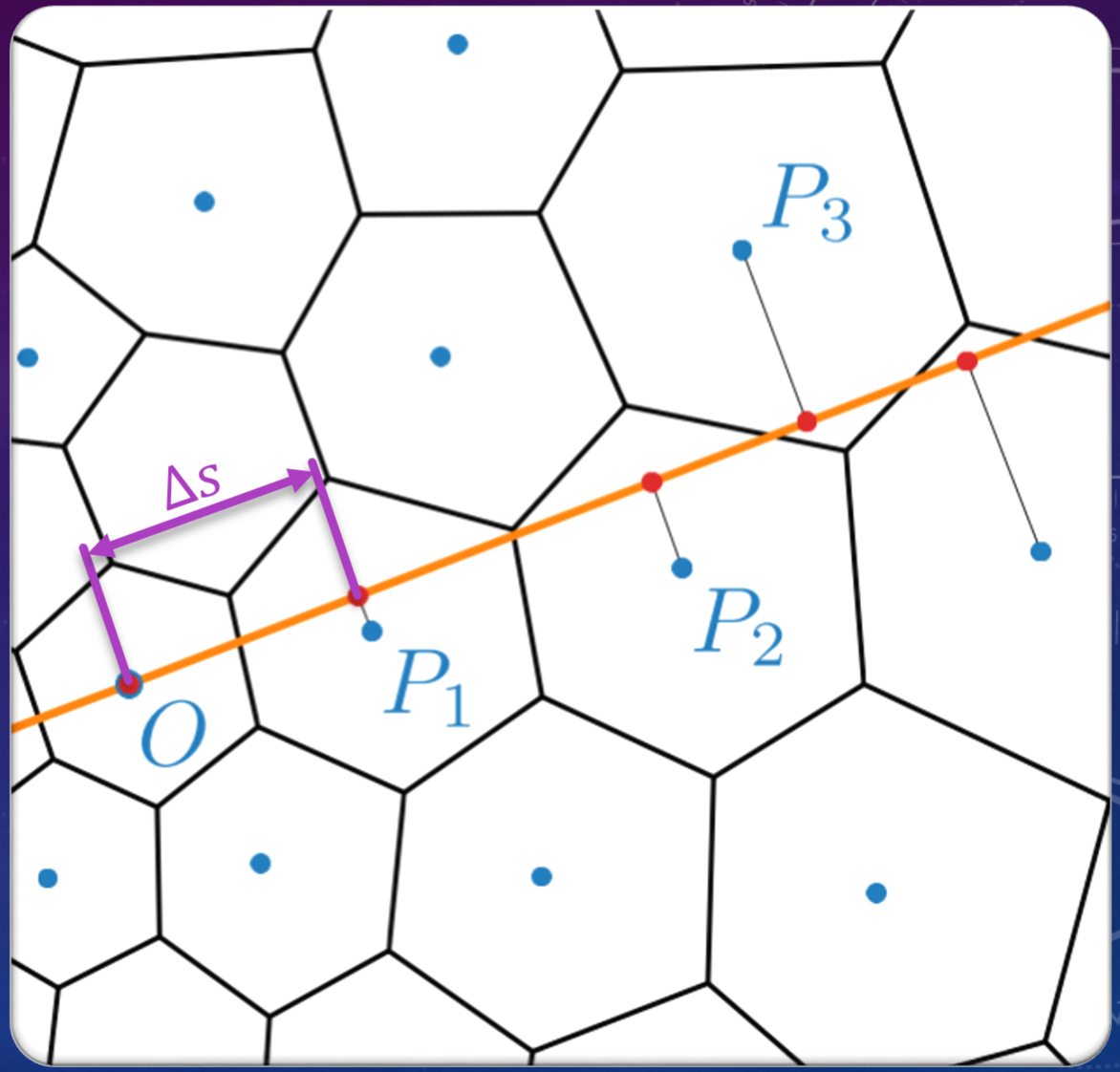


De Ceuster et al. (2020)

OPTICAL DEPTH

$$\Rightarrow \tau = \int_{R_*}^{r} \kappa\rho \, \mathrm{d}s$$

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



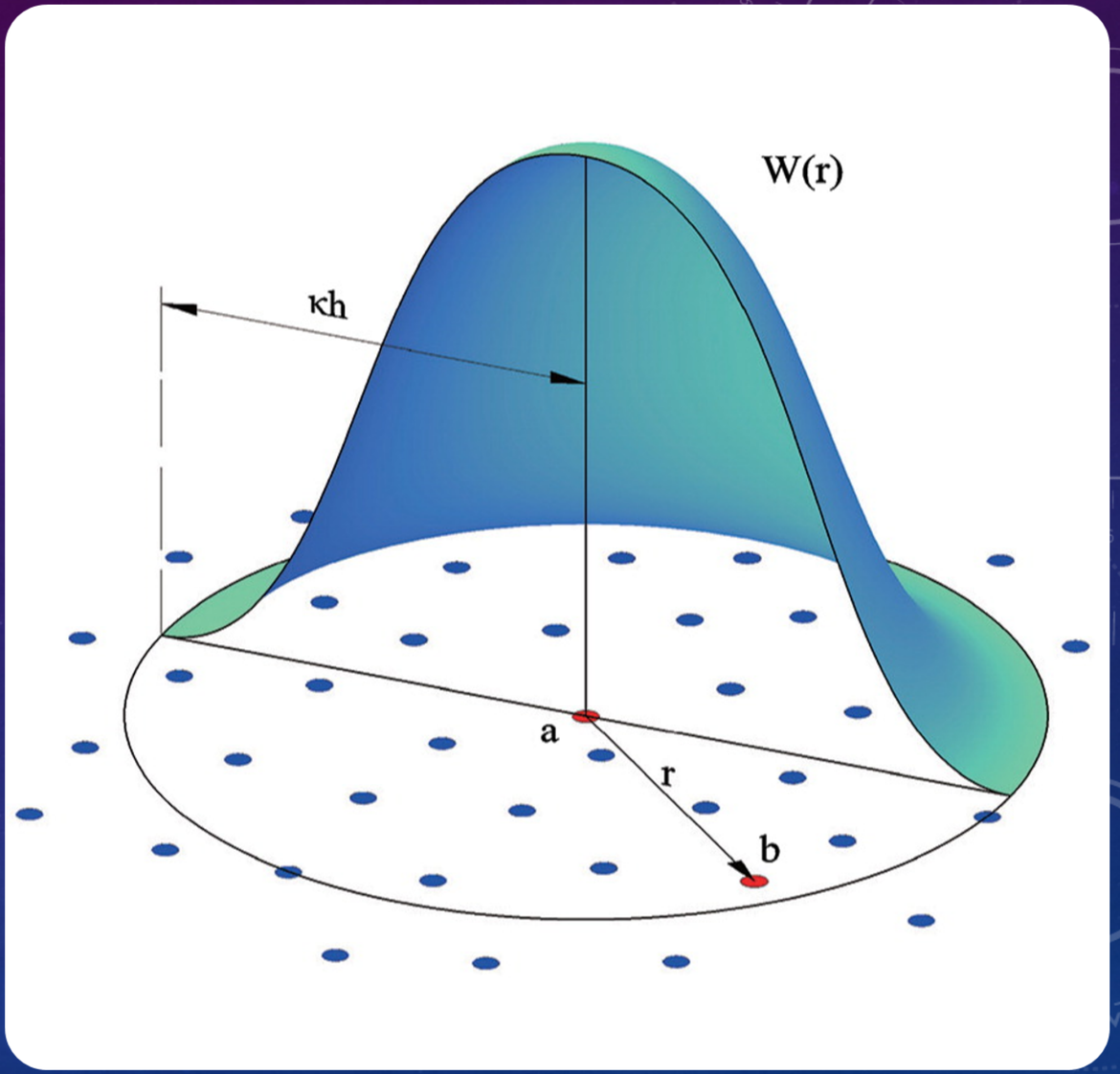
De Ceuster et al. (2020)

OPTICAL DEPTH

$$\Rightarrow \tau = \int_{R_*}^{r} \kappa\rho \, \mathrm{d}s$$

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

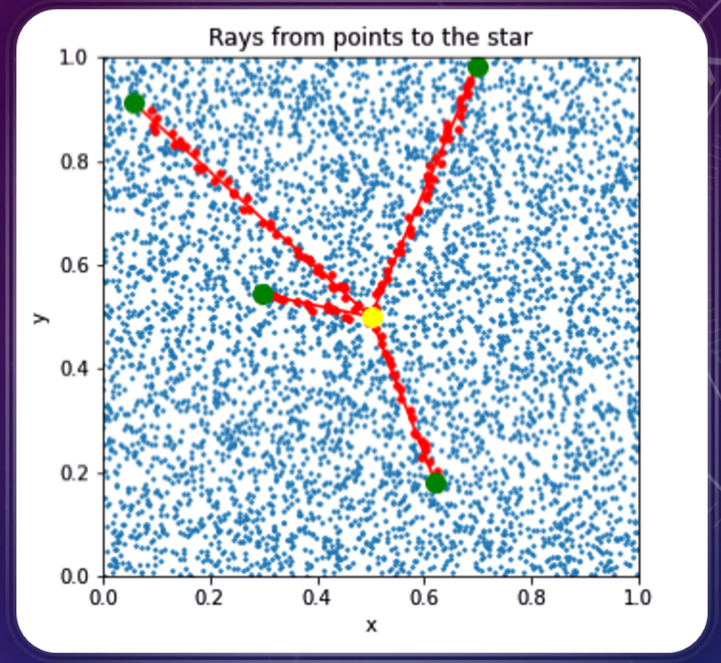
$$\Rightarrow \kappa_j \rho_j = \sum \kappa_k \rho_k W(q_k)$$



Wang et al. (2016)

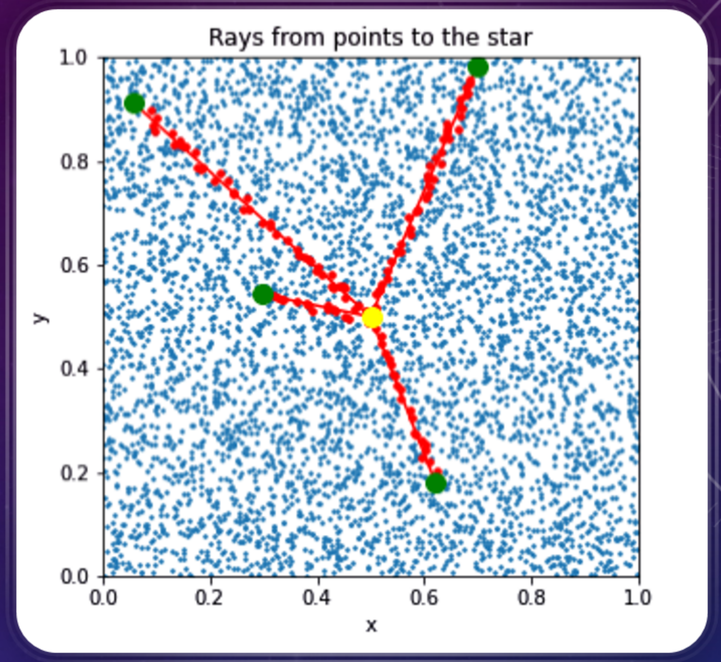
SPEEDUP

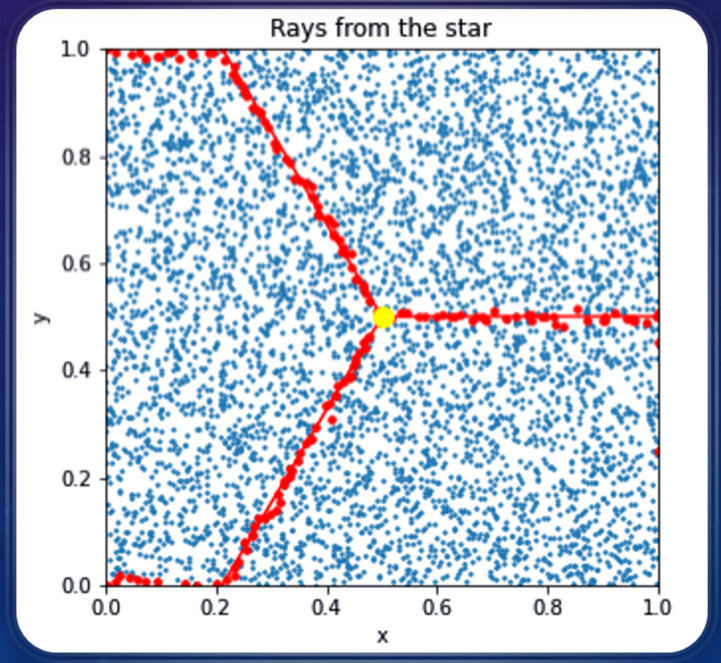
- Trace from points
  - Takes too long



SPEEDUP

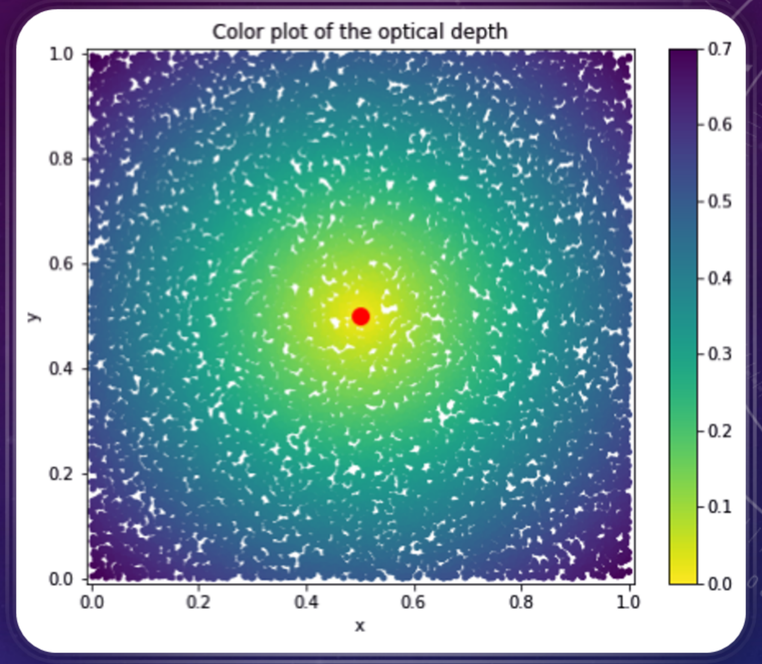
- Trace from points
  - Takes too long
- Trace from star
  - Takes less time

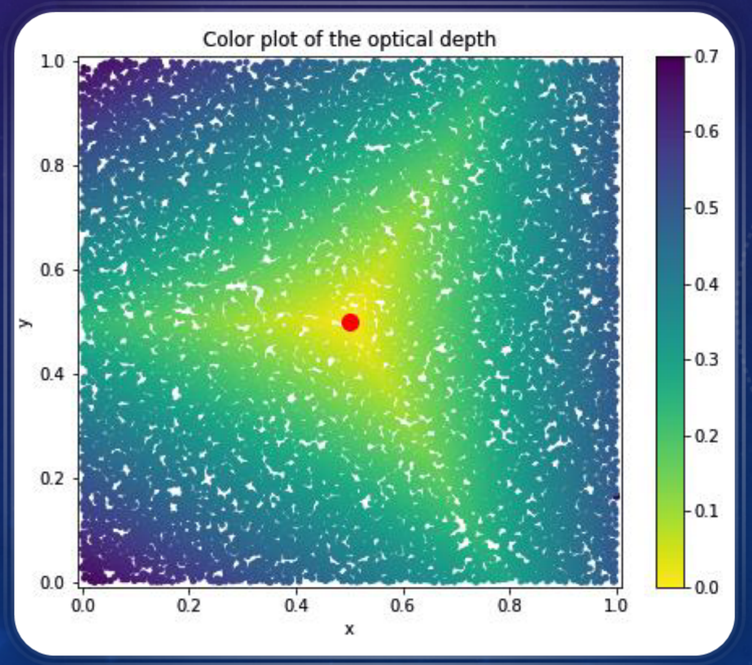




SPEEDUP

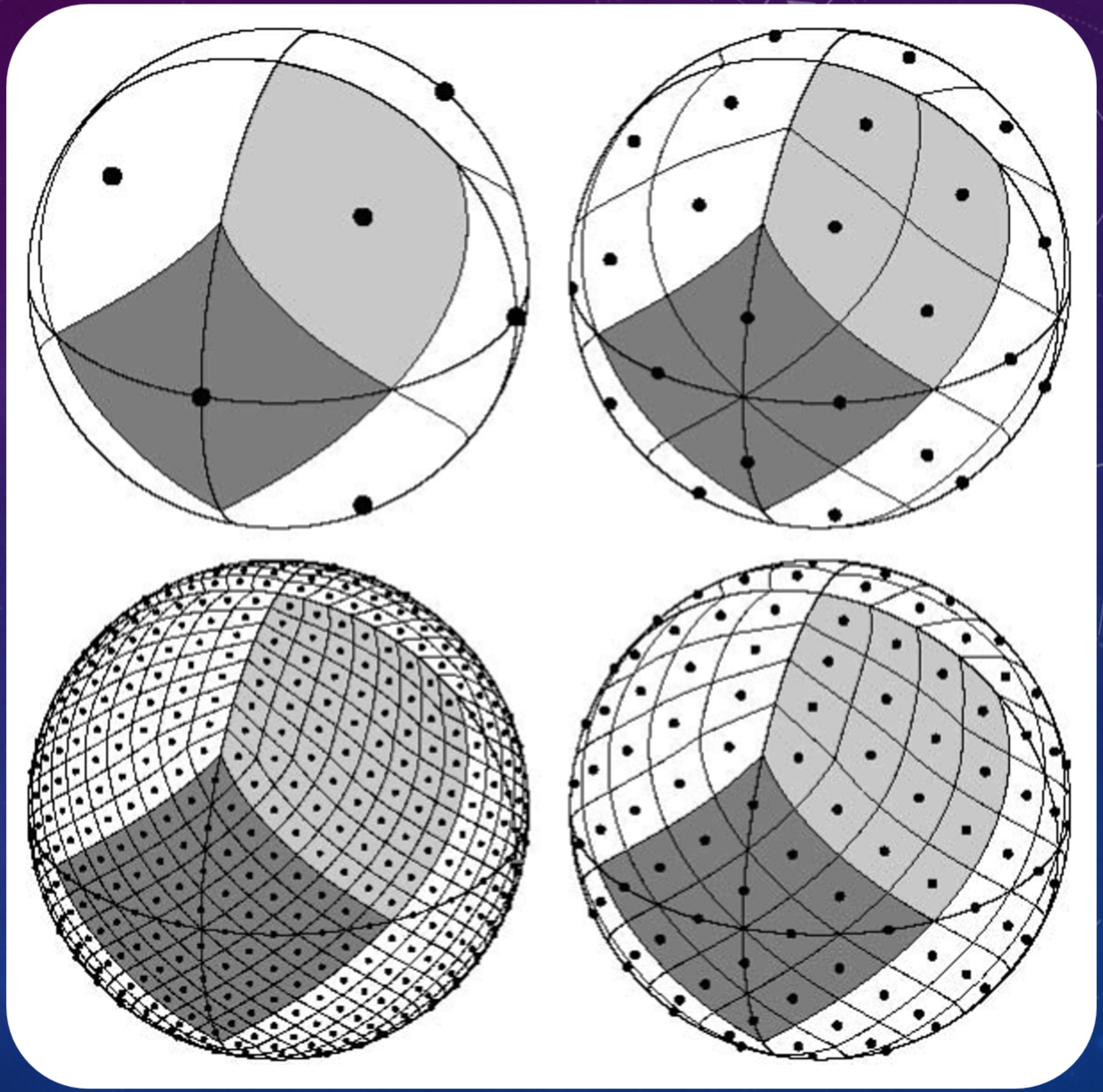
- Trace from points
  - Takes too long
  - More accurate
- Trace from star
  - Takes less time
  - Less accurate





IN 3D: HEALPIX

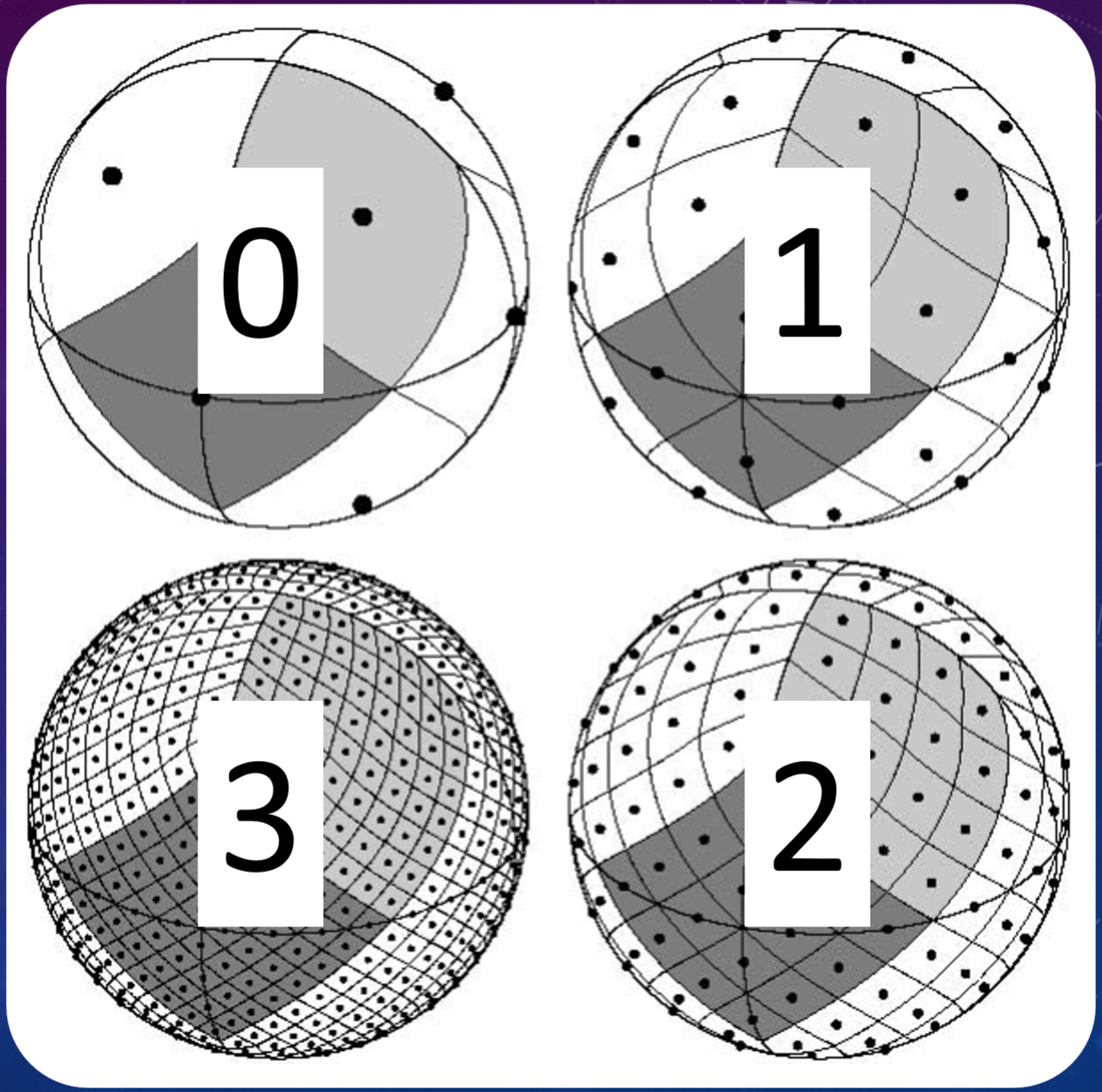
- Uniform in 2-sphere
- Orders



Górski et al. (2004)

IN 3D: HEALPIX

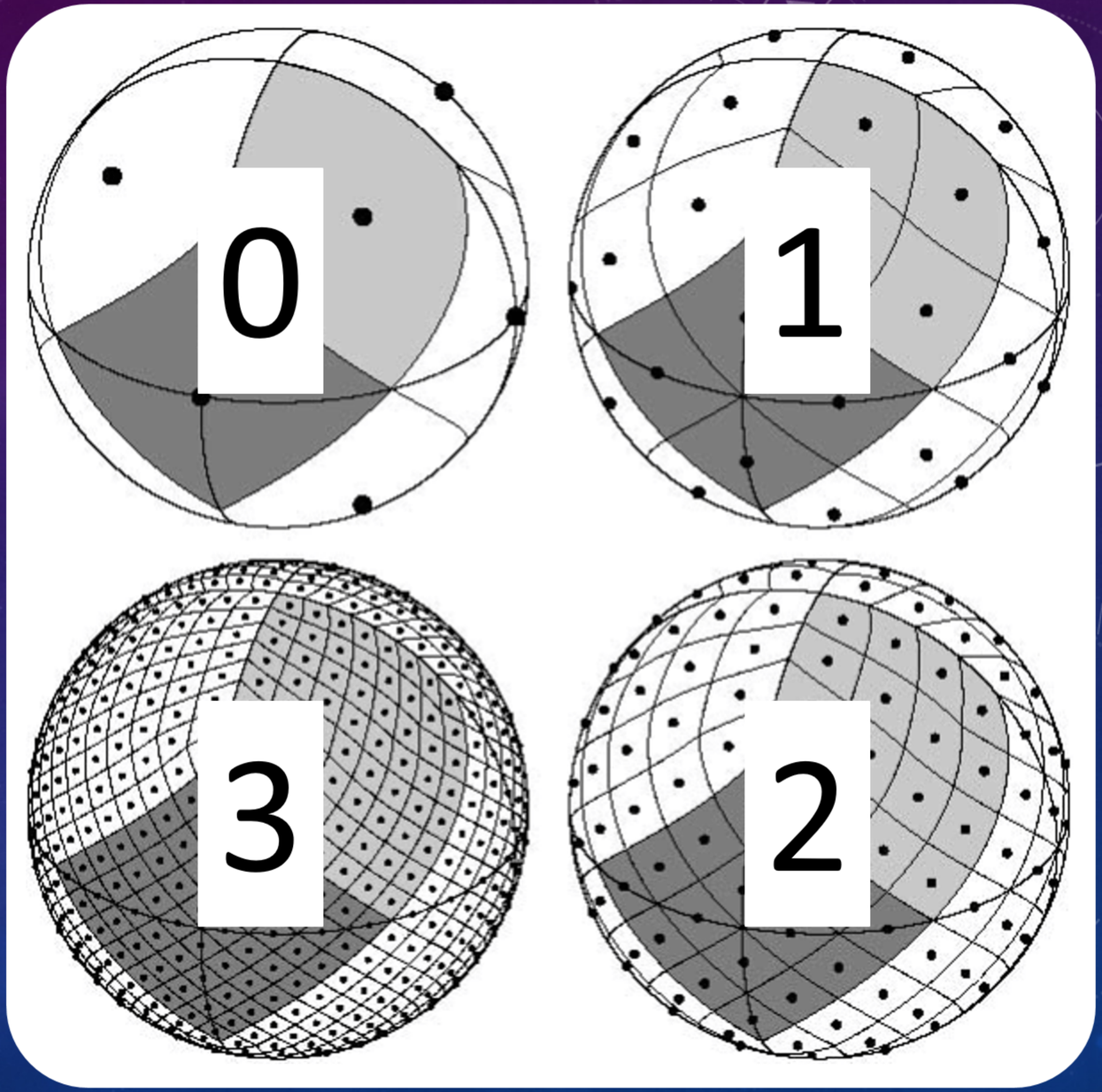
- Uniform in 2-sphere
- Orders



Górski et al. (2004)

IN 3D: HEALPIX

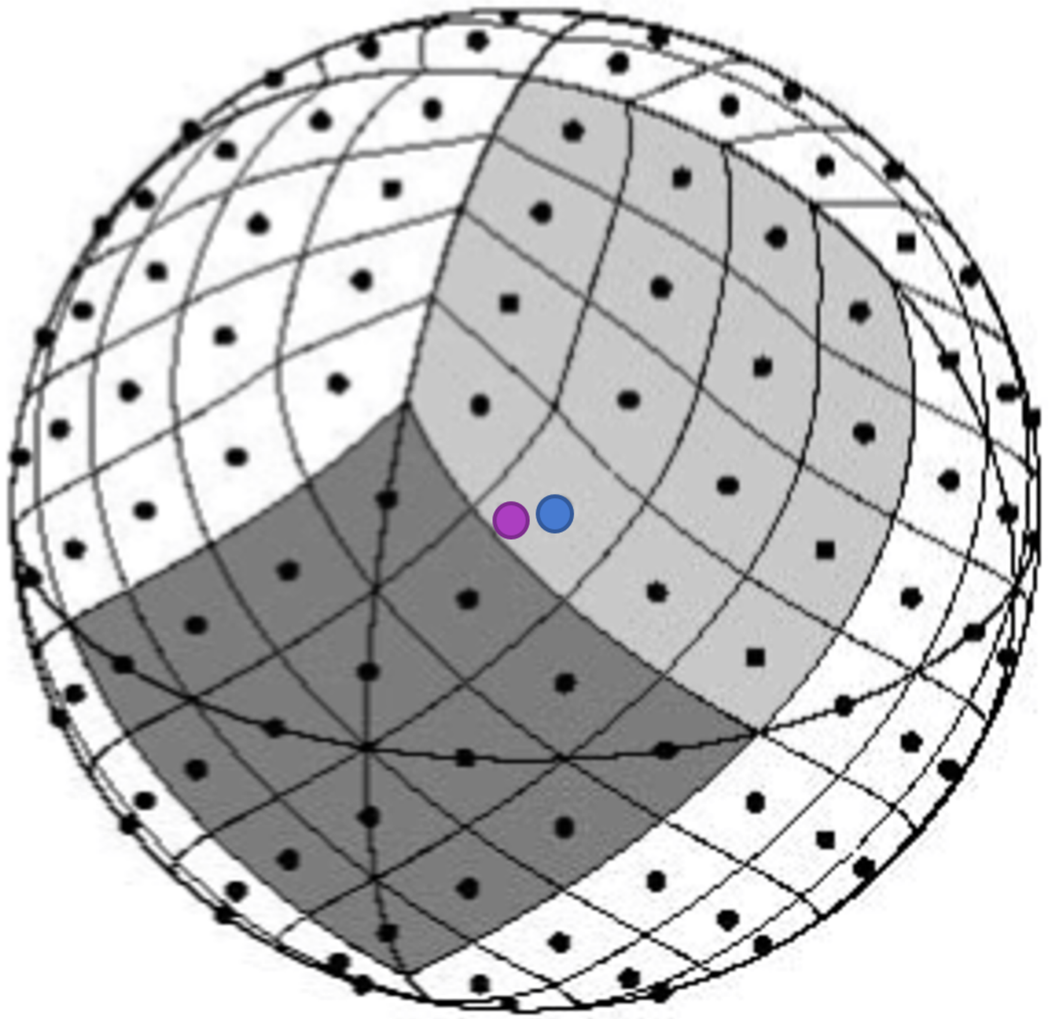
- Uniform in 2-sphere
- Orders
  - Order 5 → 12.288 rays



Górski et al. (2004)

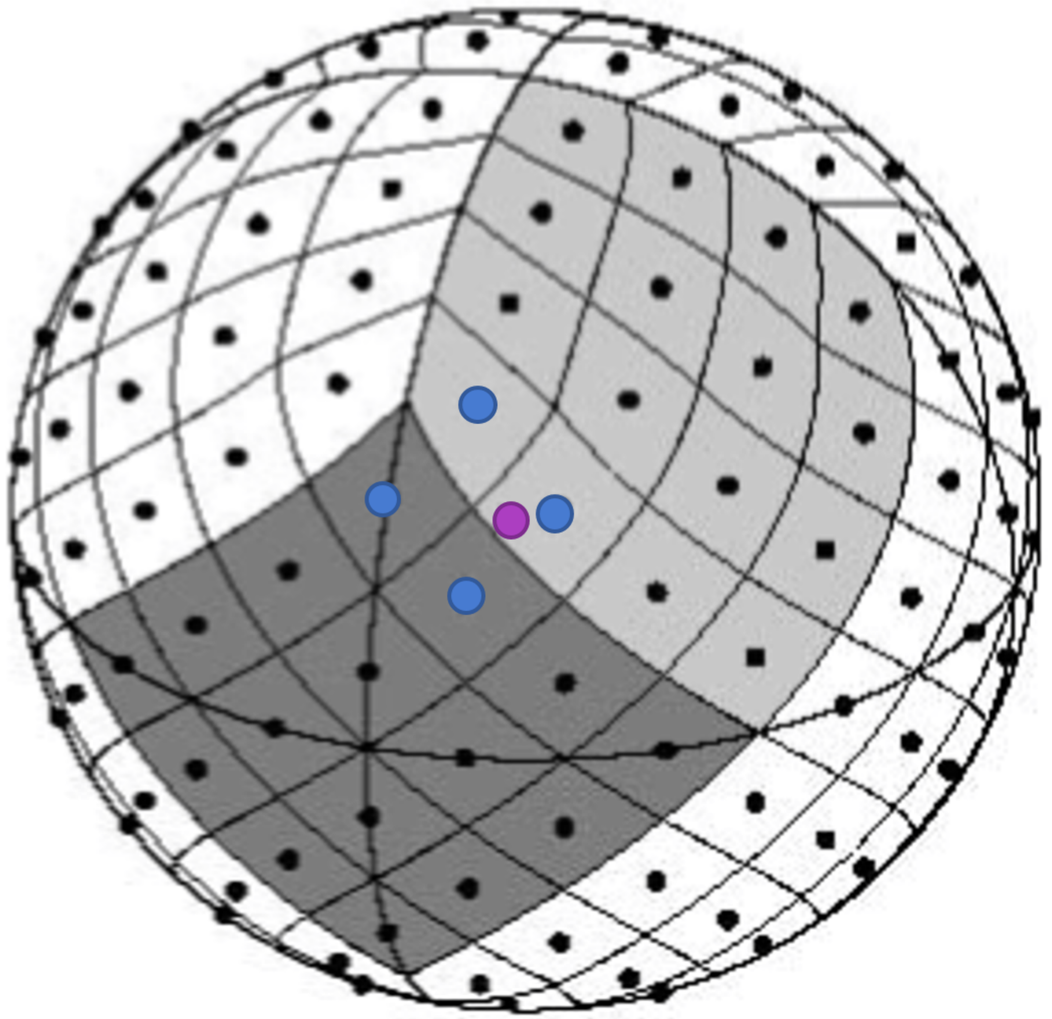
RAY INTERPOLATION

- Closest ray



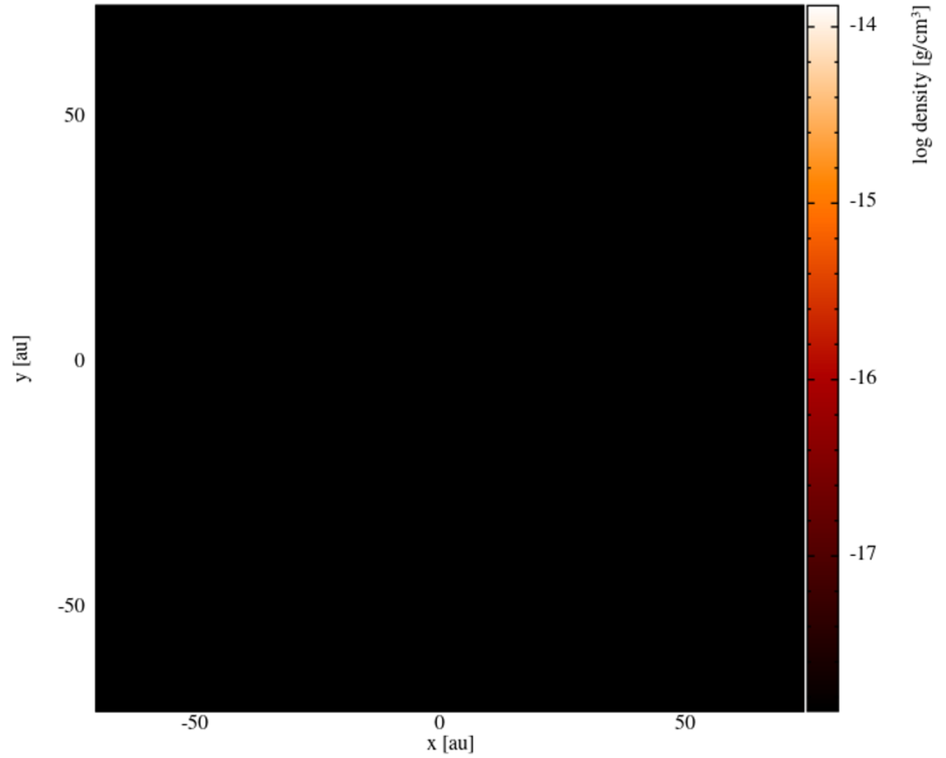
RAY INTERPOLATION

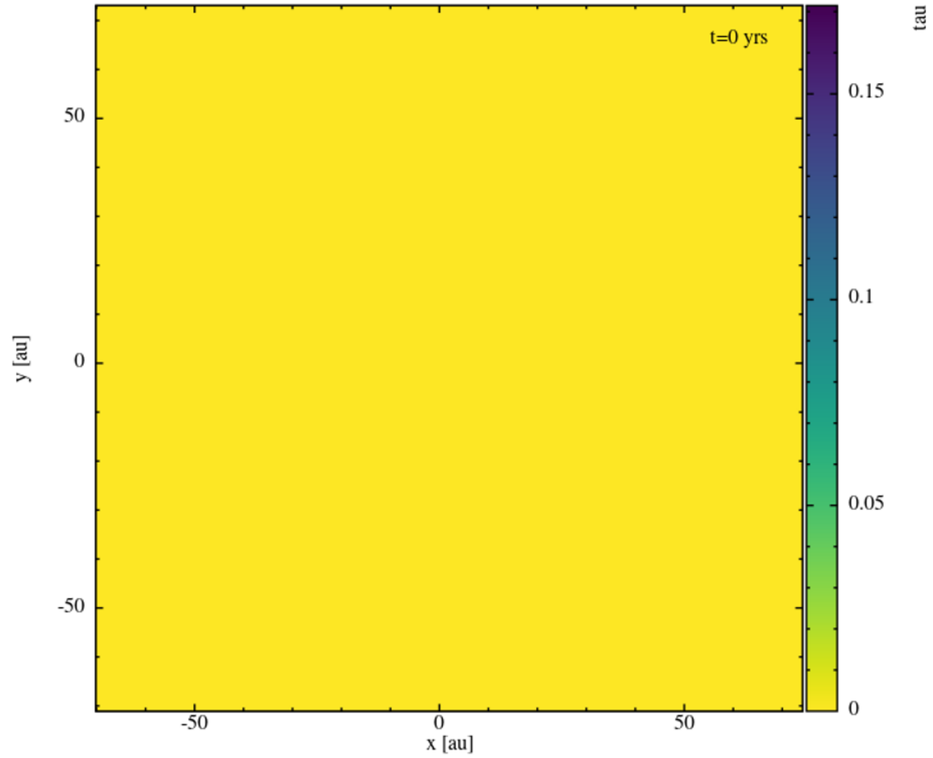
- Closest ray
- Closest 4 rays
- $\tau_i = \frac{1}{\sum r_j^{-2}} \sum \frac{1}{r_j^2} \tau_j$



SIMULATIONS

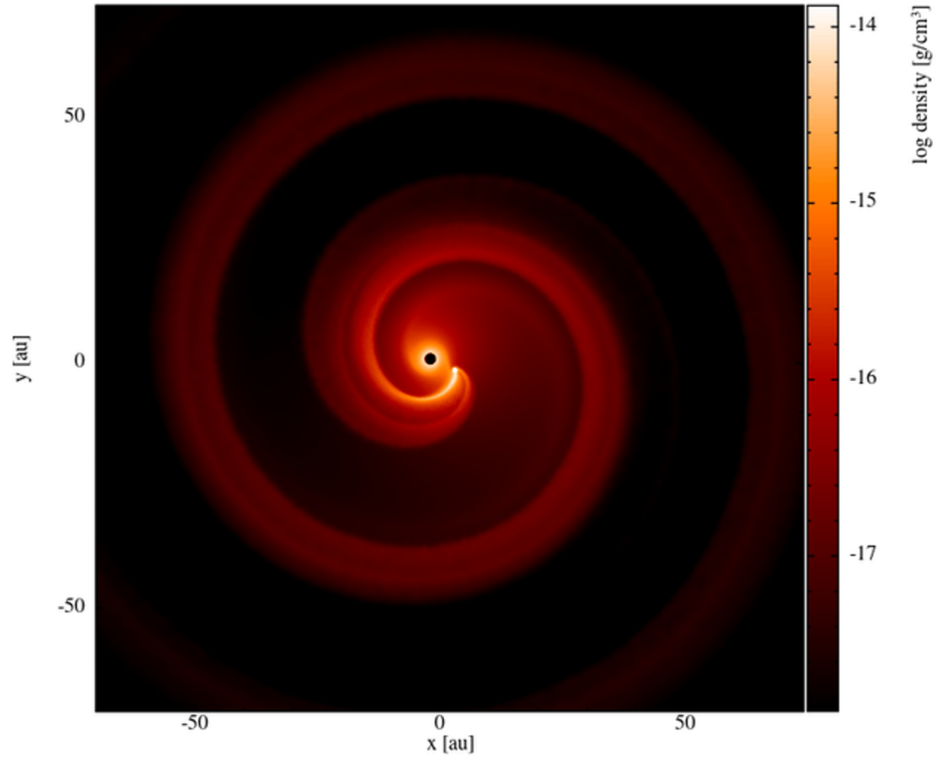
$$M_1 = 1.5\,\mathrm{M}_\odot, \qquad M_2 = 1\,\mathrm{M}_\odot, \qquad a = 5.4\,\mathrm{au}$$

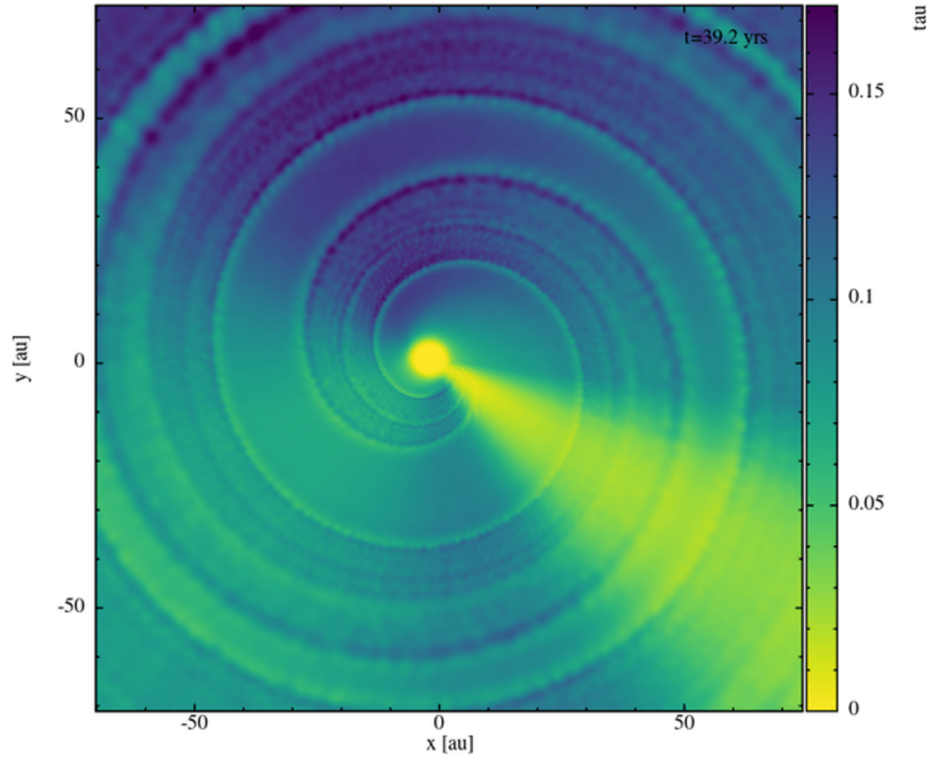




SIMULATIONS

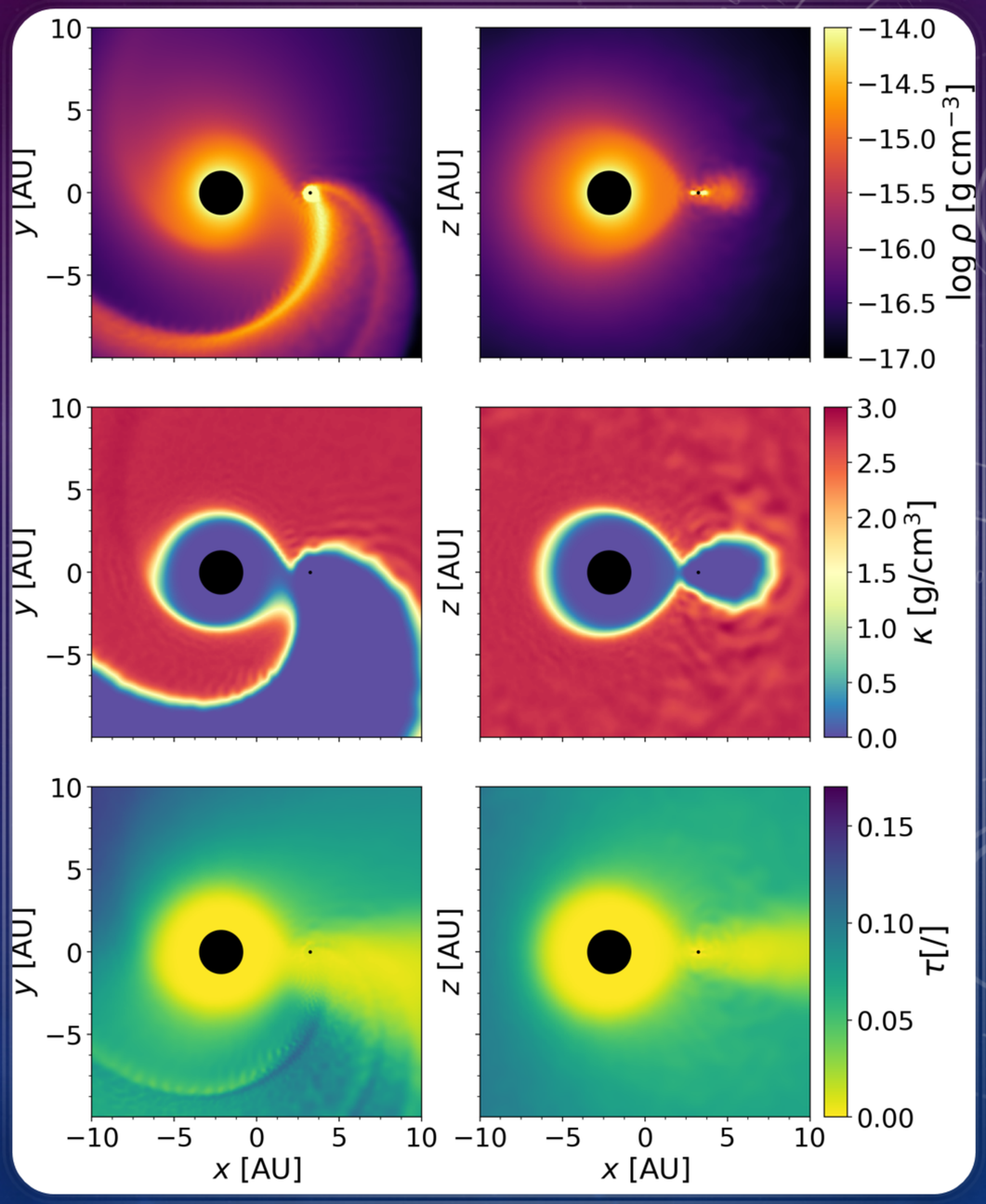
$M_1 = 1.5\,\mathrm{M}_\odot, \qquad M_2 = 1\,\mathrm{M}_\odot, \qquad a = 5.4\,\mathrm{au}$





TUNNEL

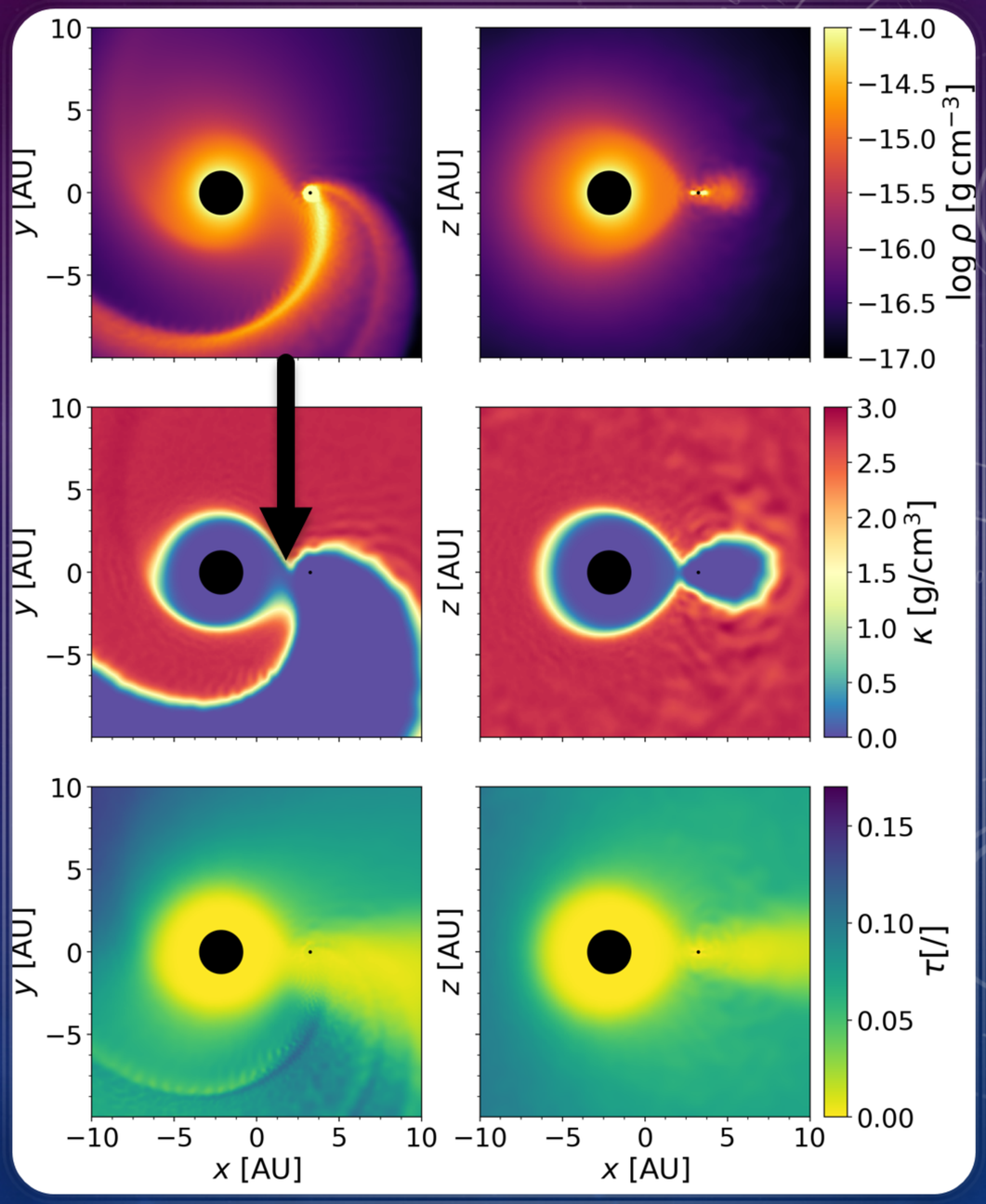
- Accretion disk
- Too hot for dust



TUNNEL

- Accretion disk
- Too hot for dust

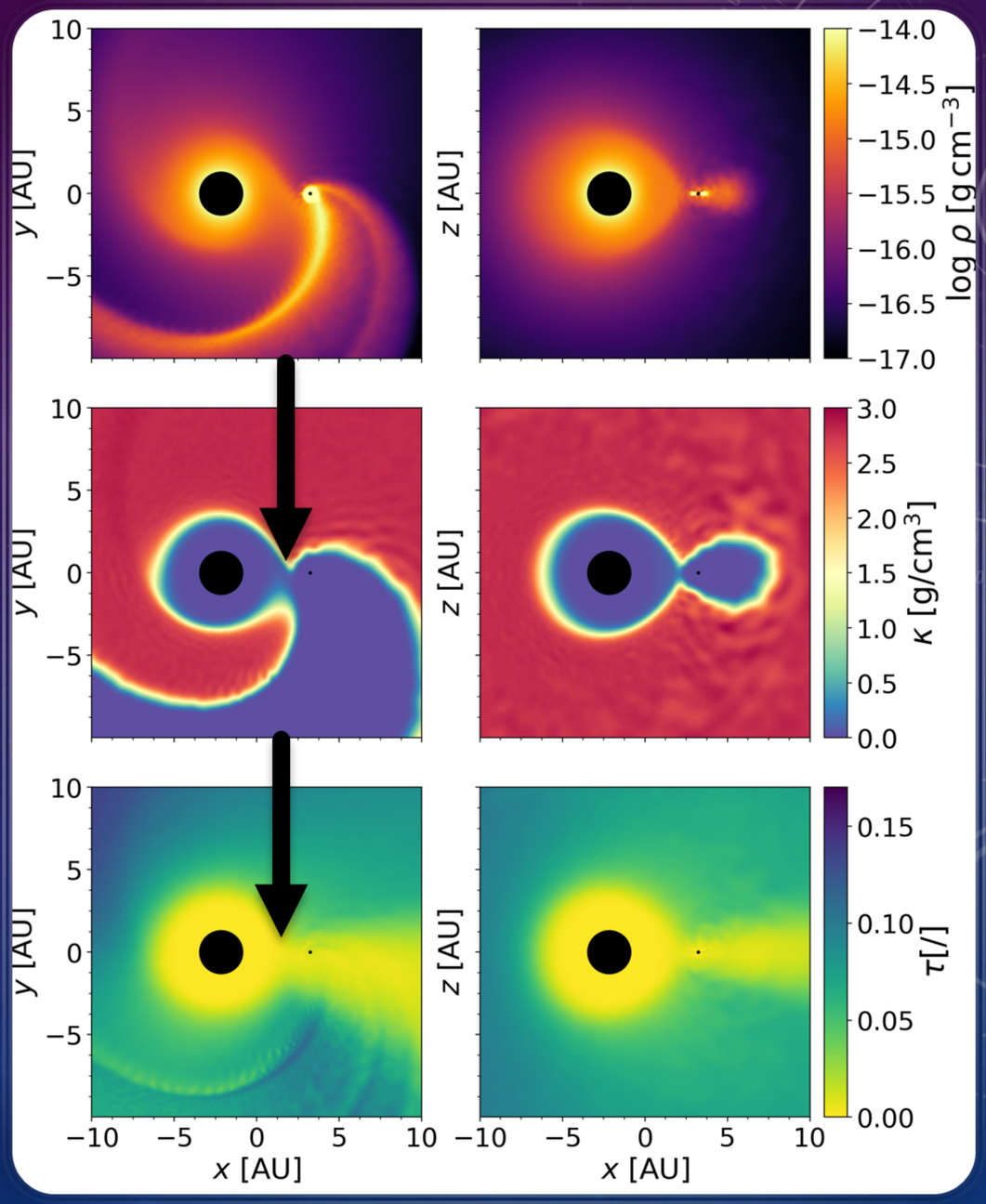
- Connected to star



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

- De Ceuster, F., Homan, W., Yates, J., et al. 2020a, MNRAS, 492, 1812
- De Ceuster, F., Bolte, J., Homan, W., et al. 2020b, MNRAS, 499, 5194
- Decin, L. 2021, ARA&A, 59, 337
- Decin, L., Montargès, M., Richards, A. M. S., et al. 2020, Science, 369, 1497
- Górski, K. M., Hivon, E., Banday, A. J., et al. 2005, ApJ, 622, 759
- Maes, S., Homan, W., Malfait, J., et al. 2021, A&A, 653, A25
- Malfait, J., Homan, W., Maes, S., et al. 2021, A&A, 652, A51
- Price, D. J., Wurster, J., Tricco, T. S., et al. 2018, PASA, 35, e031