Ray Tracing in Fluid Simulations: Enhancing AGB Outflow Simulations

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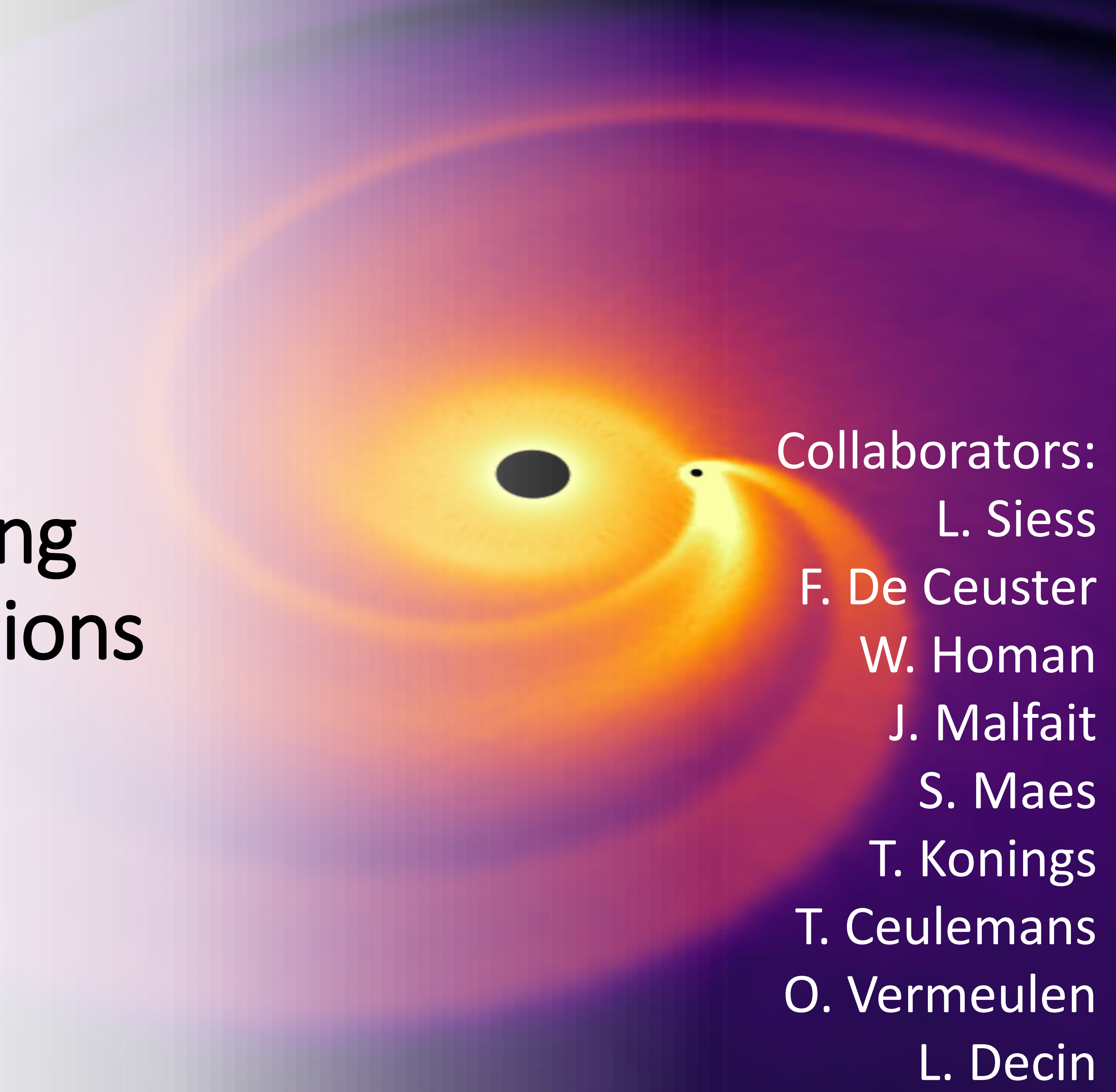

Collaborators:
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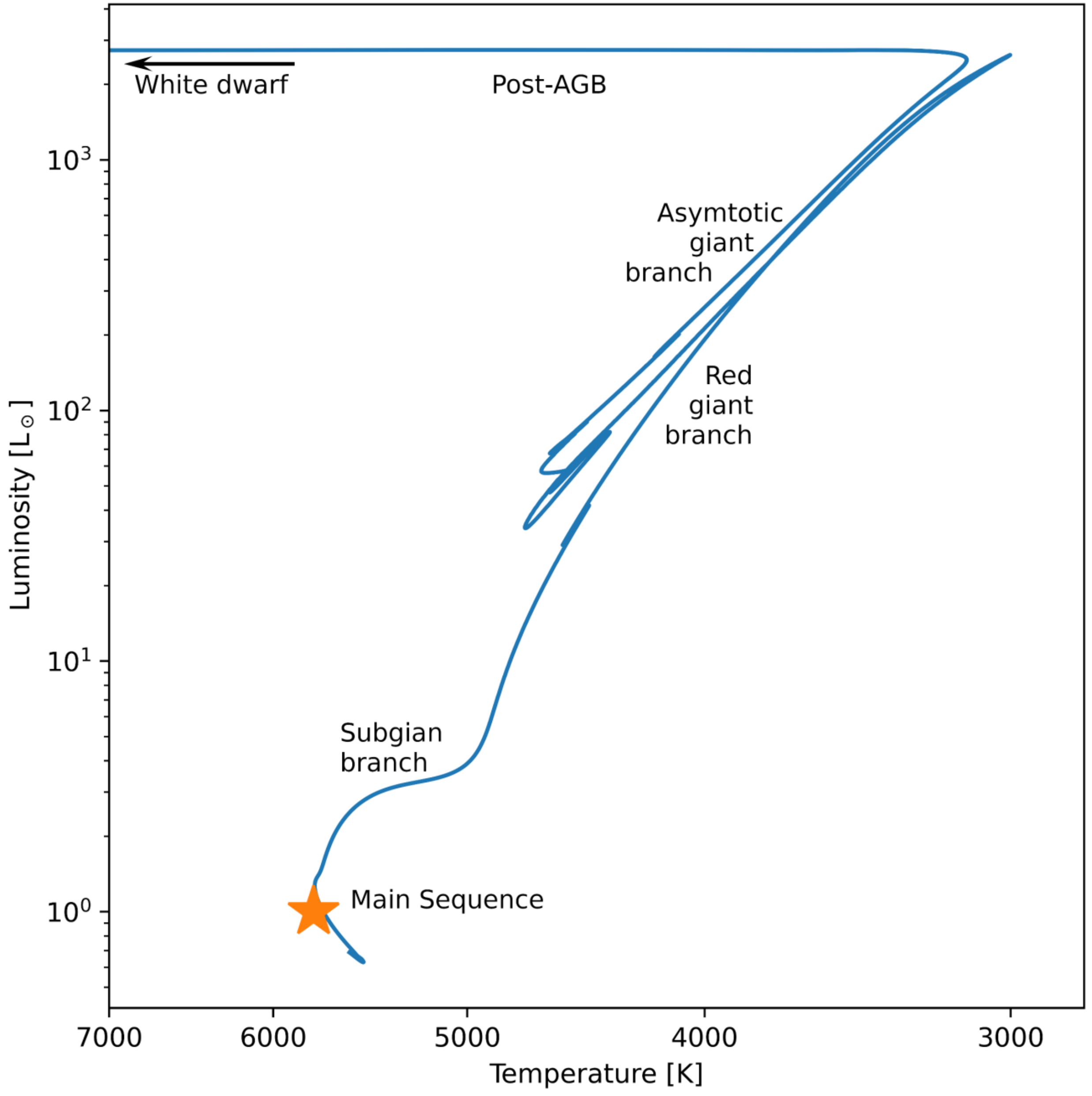
T. Konings
T. Ceulemans
O. Vermeulen
L. Decin

AGB stars

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

Evolution of 1 $M_\odot$ star



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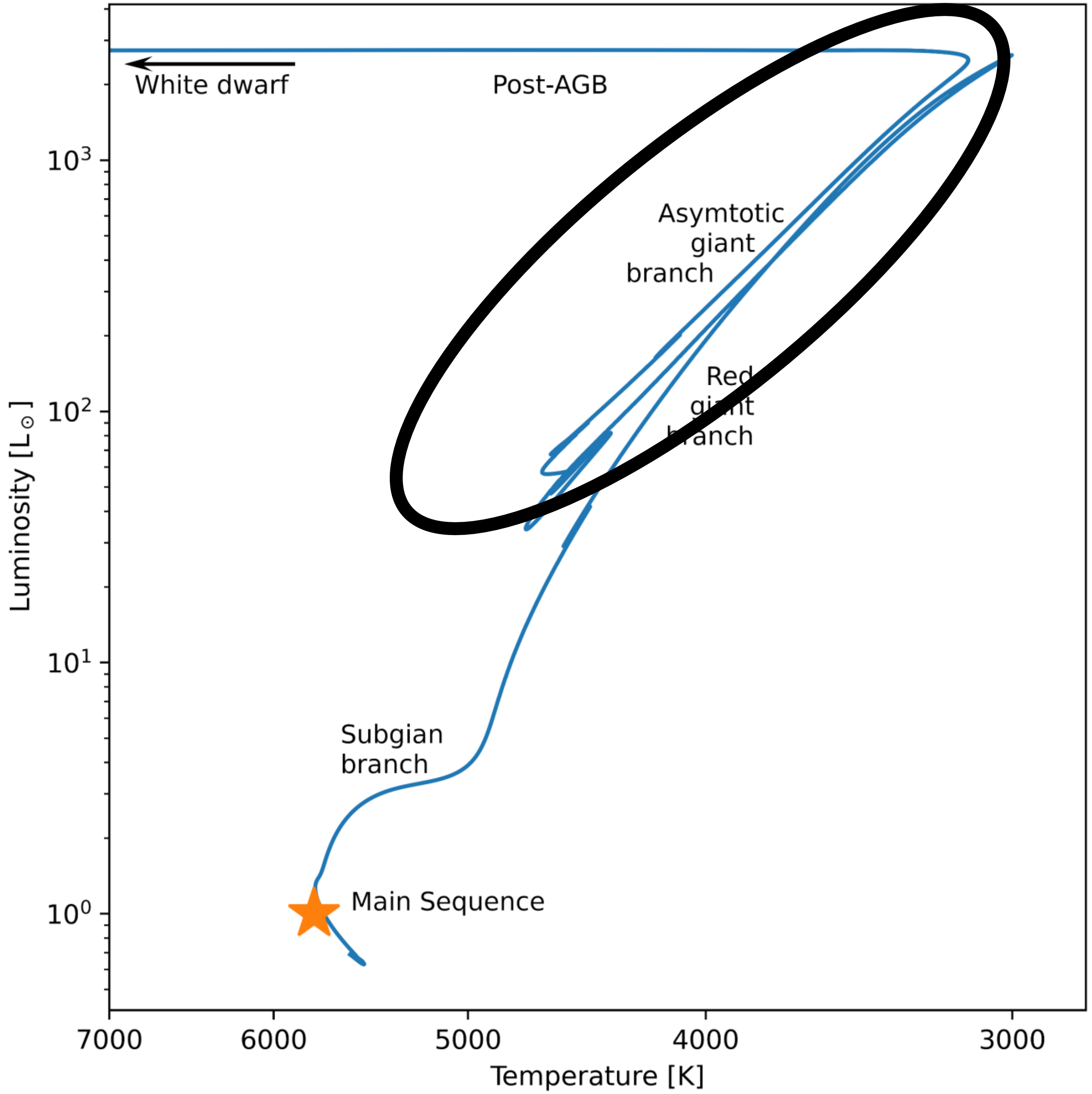
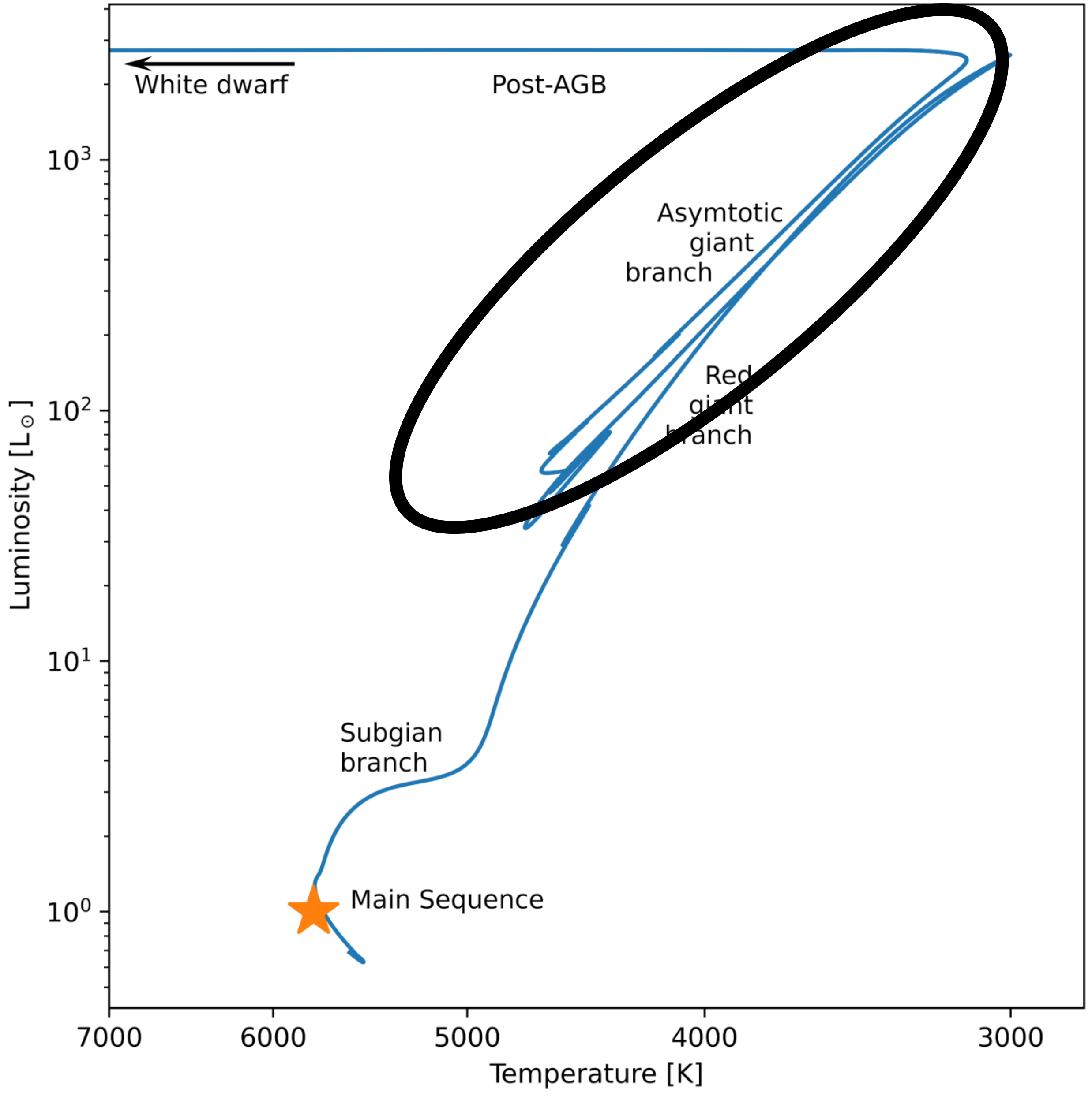


AGB stars

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

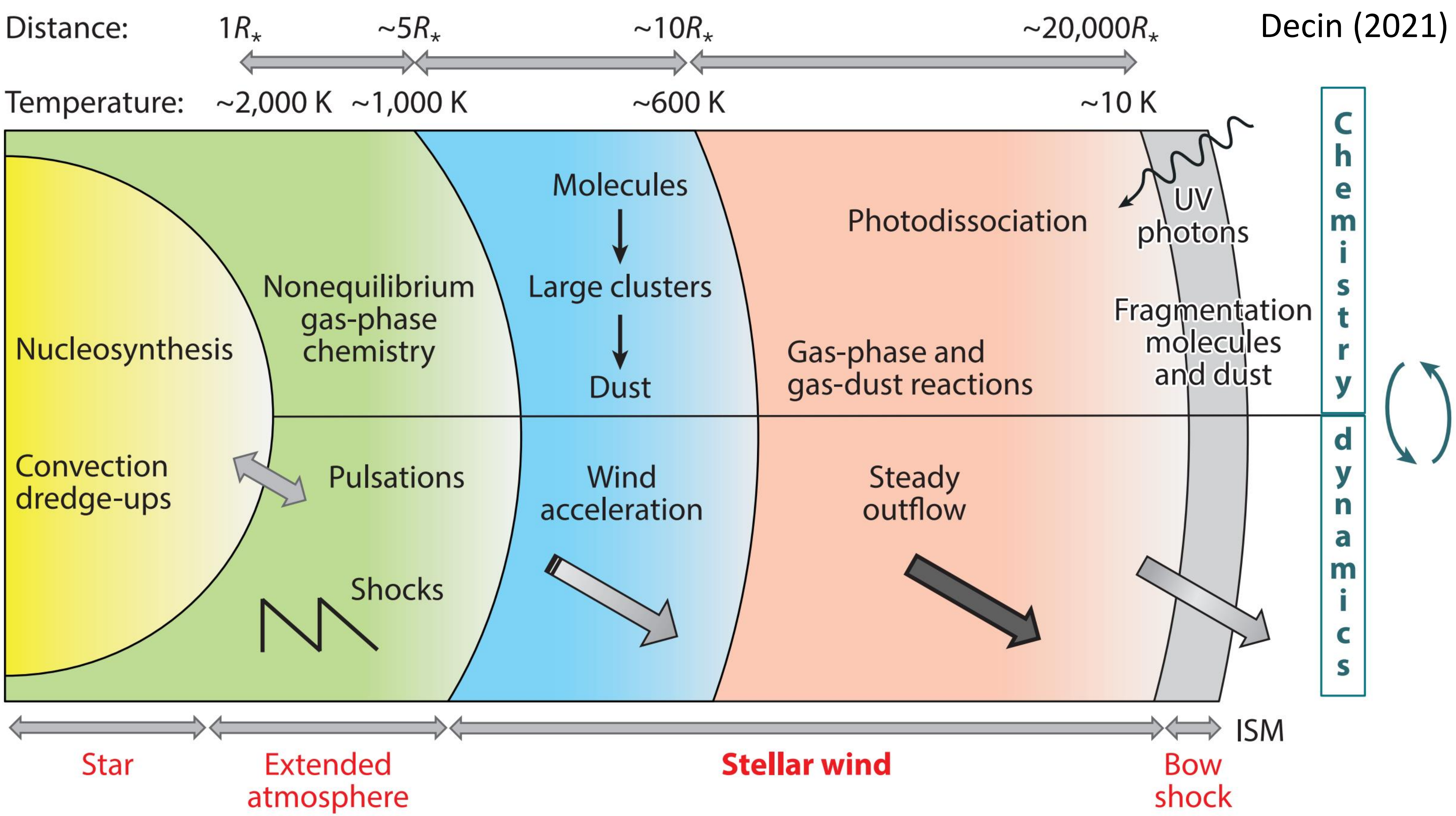
- Significant mass loss
  - $\dot{M} = 10^{-8} - 10^{-4}\,\mathrm{M}_\odot/\mathrm{yr}$
  - $v_\infty = 5 - 25\,\mathrm{km/s}$
- Dust-driven wind

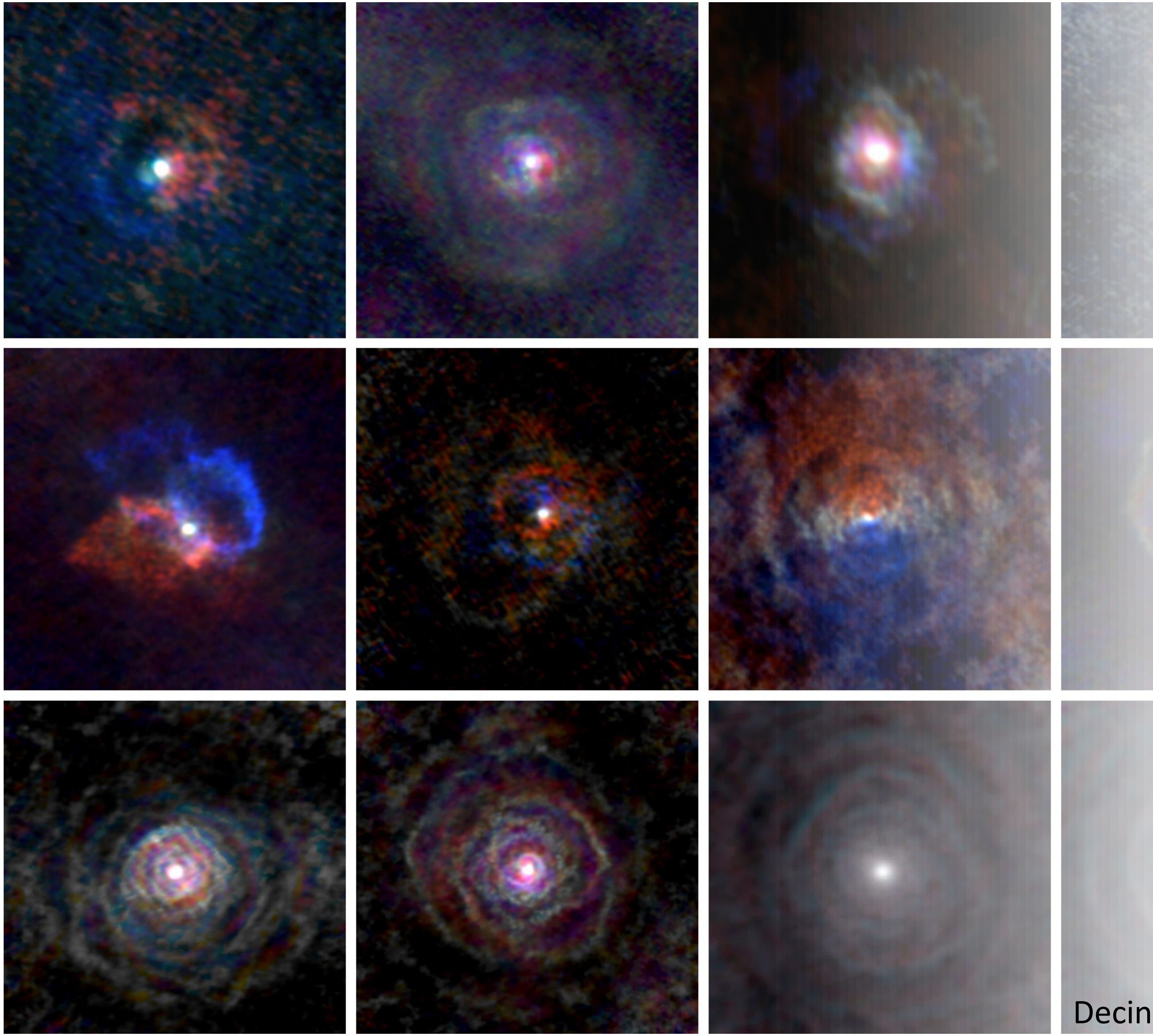
Evolution of 1 $\mathrm{M}_\odot$ star



AGB’s dust-driven wind

Decin (2021)





AGB outflows

- Non-spherically symmetric
- Companion perturbed
- understanding through simulations

Decin et al. (2020)

Hydrodynamic setup

- 3D Smoothed Particle Hydrodynamics (SPH)

- External acceleration
  - $\vec{a} = -\frac{GM_{AGB}}{r_1^2}(1-\Gamma)\hat{r}_1 \; - \; \frac{GM_{comp}}{r_2^2}\hat{r}_2$

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- Eddington factor: radiative acceleration
  - $\Gamma = \frac{\kappa F/c}{GM_{AGB}/r_1^2}, \quad \kappa(T_{eq}) = \frac{\kappa_{max}}{1+exp[(T_{eq}-T_{cond})/\delta]} + \kappa_g$

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Prescription	Γ	T_{eq}
Free-wind	$\Gamma = 1$	X

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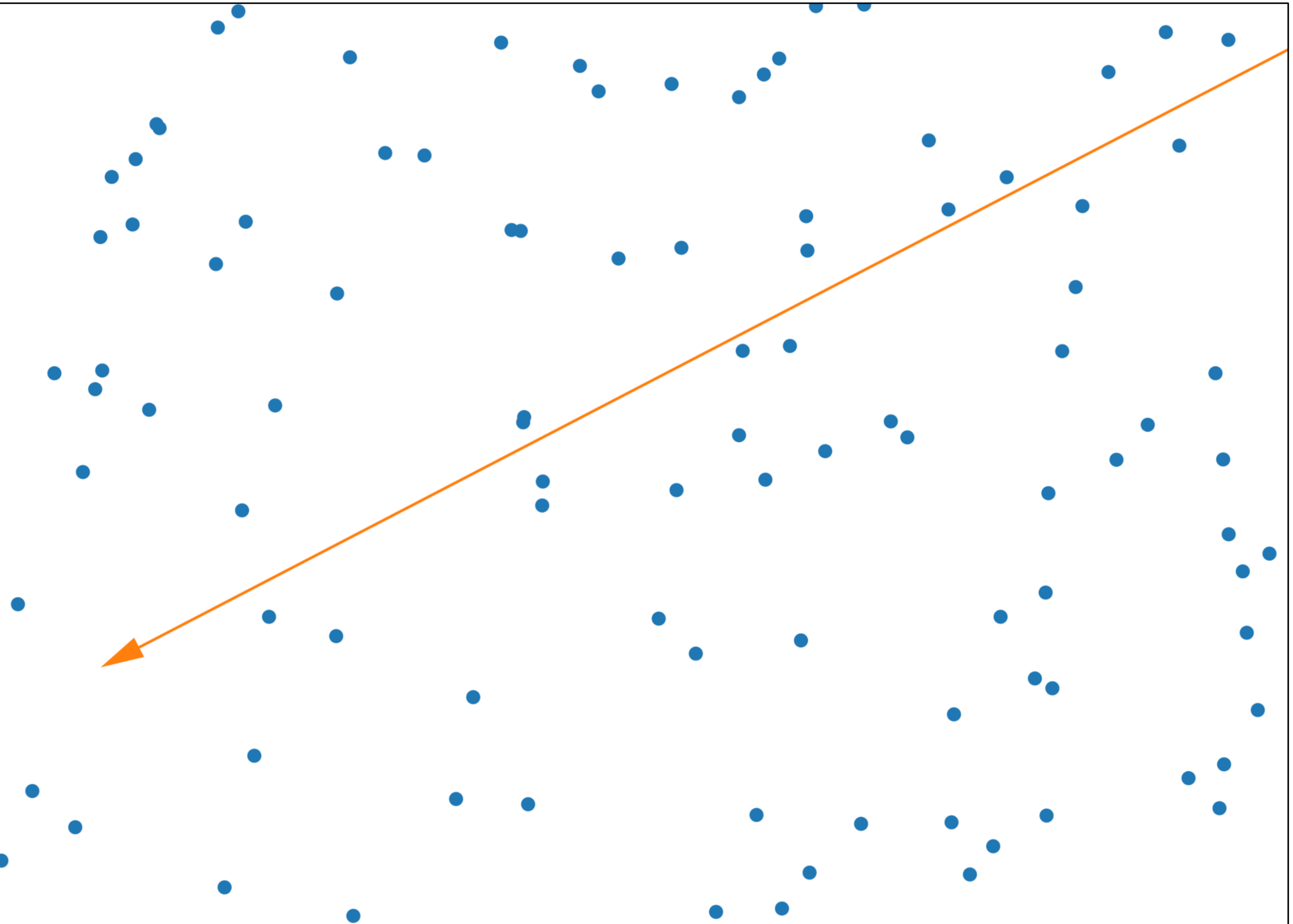
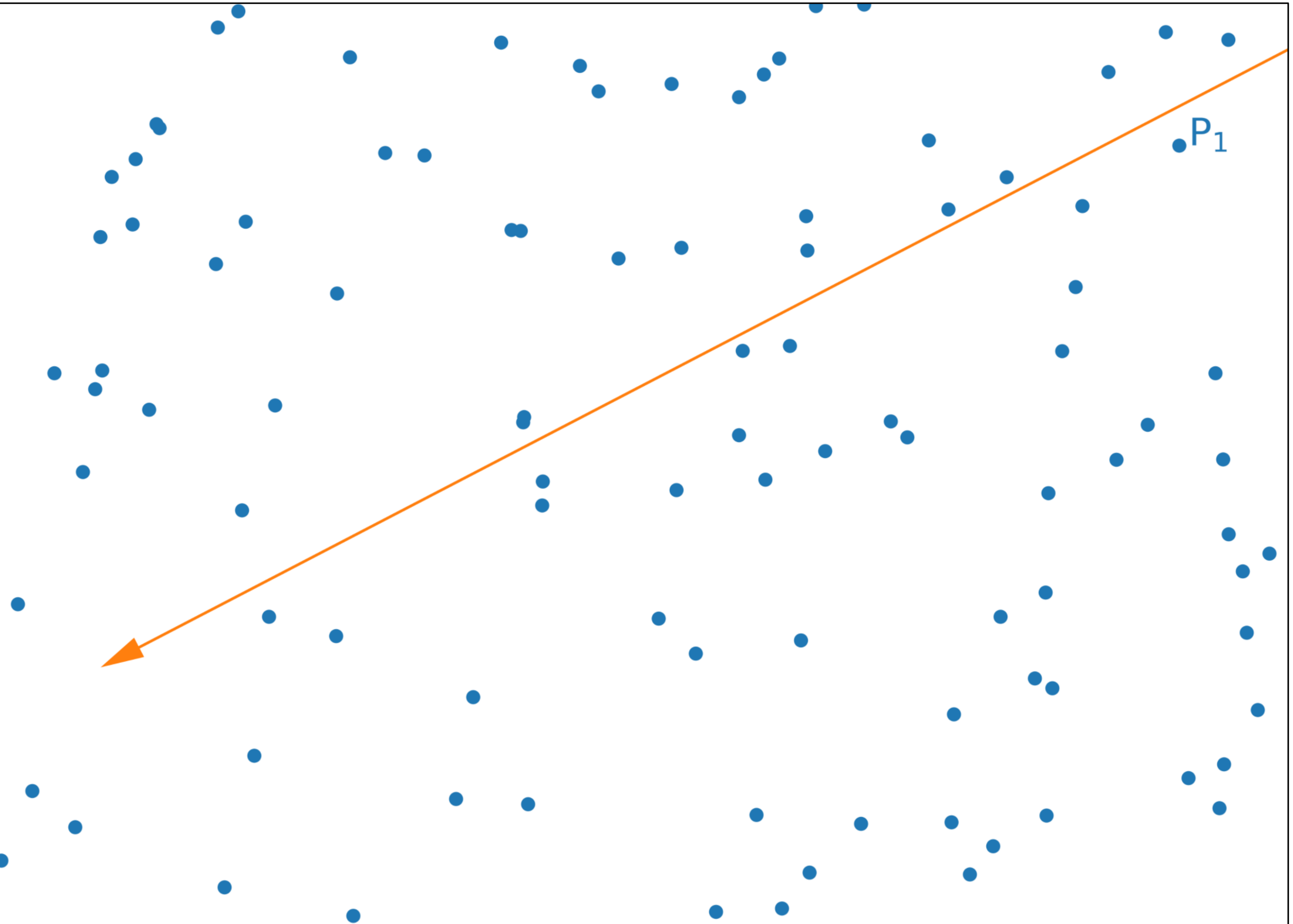
Attenuation	$\Gamma = \frac{\kappa L_{AGB}}{4\pi c G M_{AGB}} e^{-\tau}$	$T_{eq}^4 = \frac{1}{2}\left(1 - \sqrt{1 - \left(\frac{R_\star}{r}\right)^2}\right) e^{-\tau} T_\star^4$

Ray-tracer



Ray-tracer

Magritte



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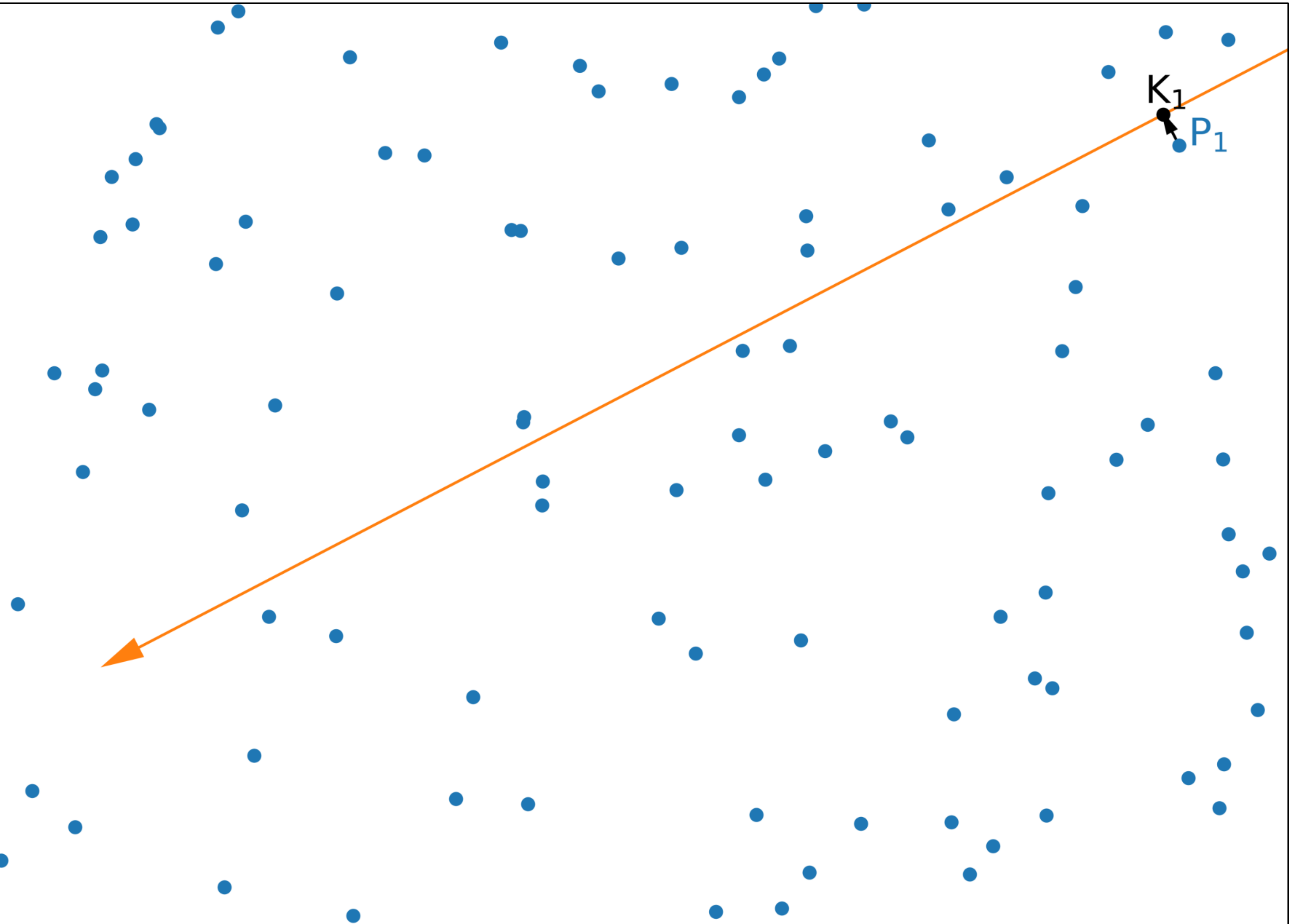

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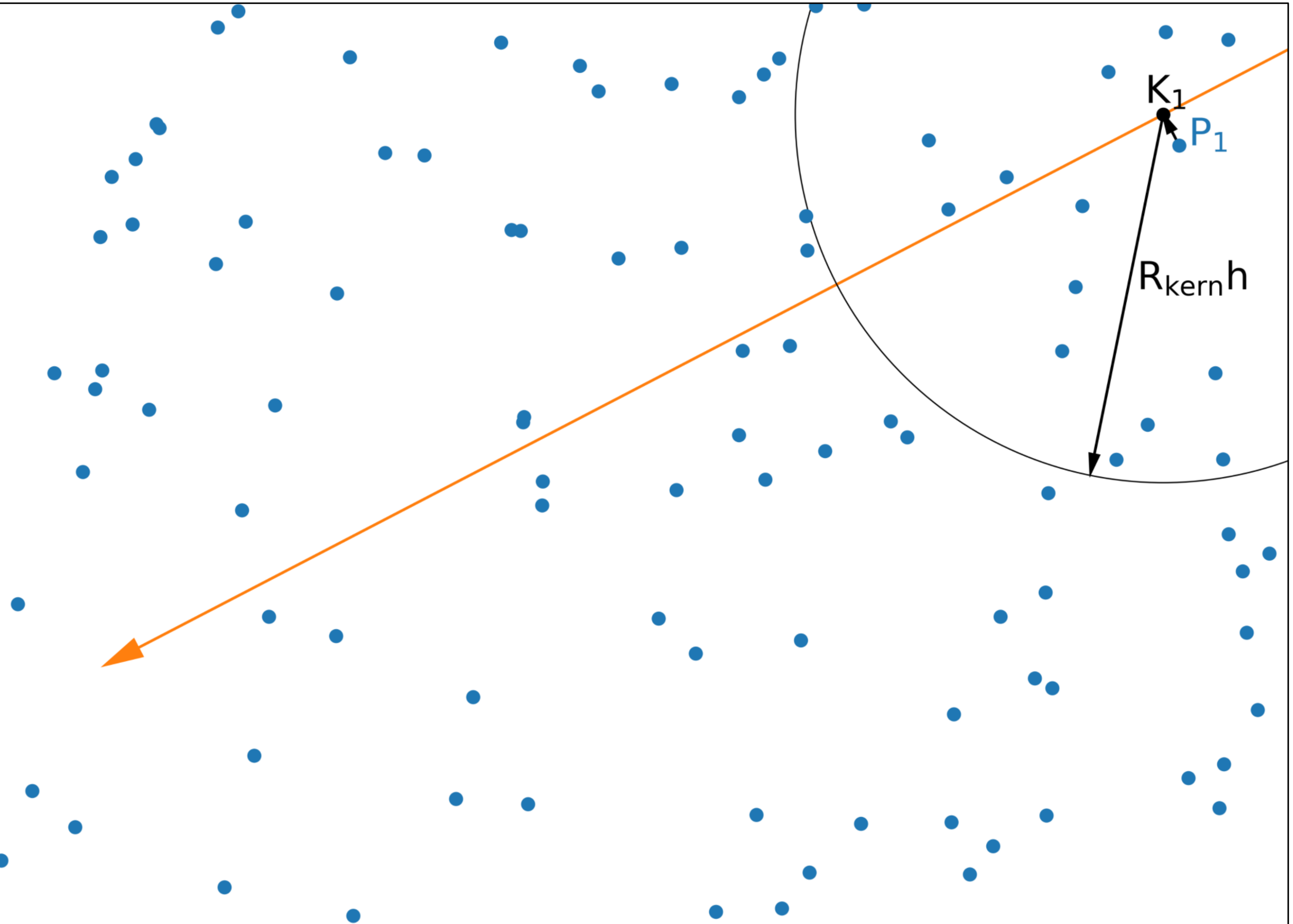

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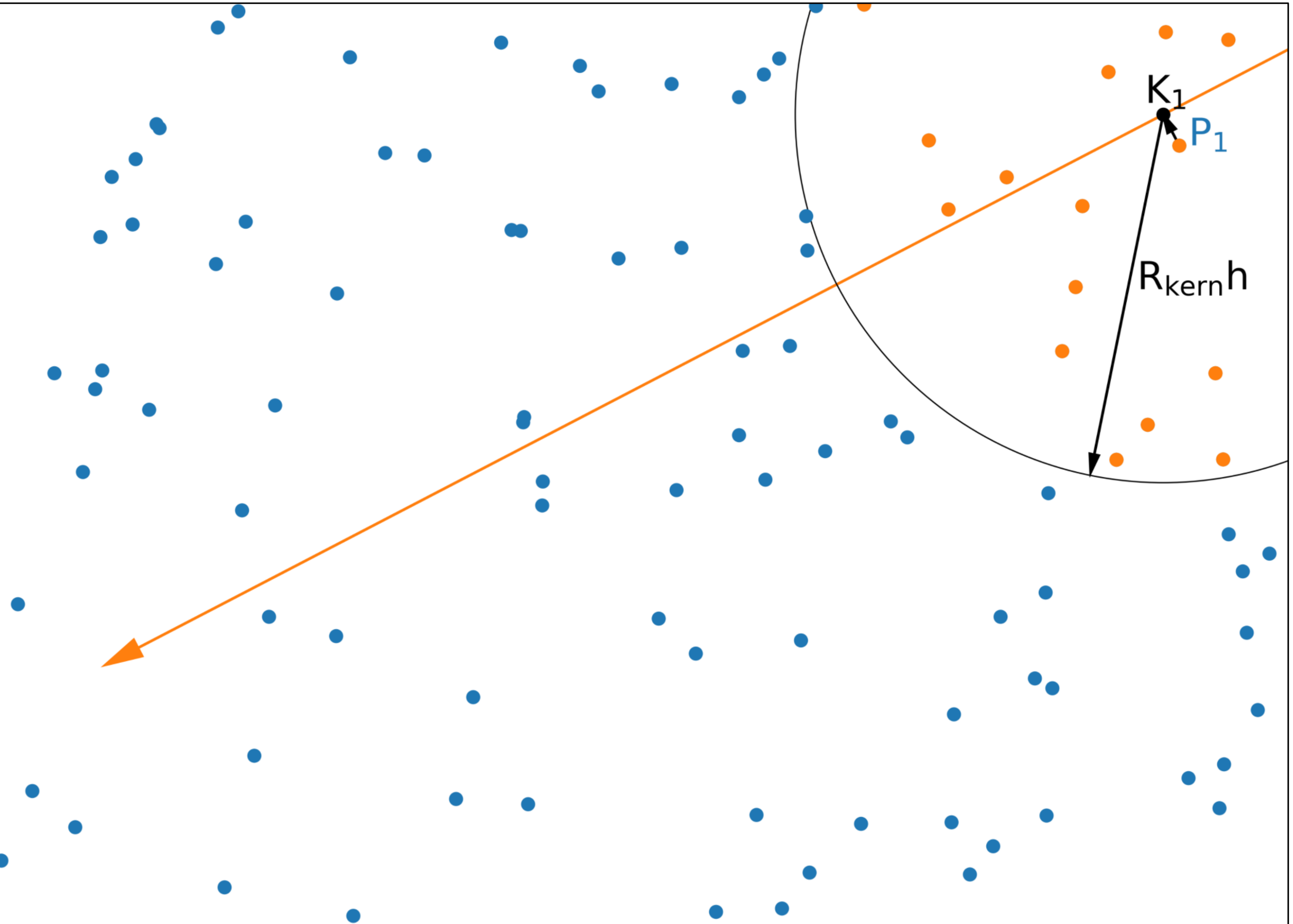

At each point K:

- $\kappa_i \; \rho_i$
- d_i

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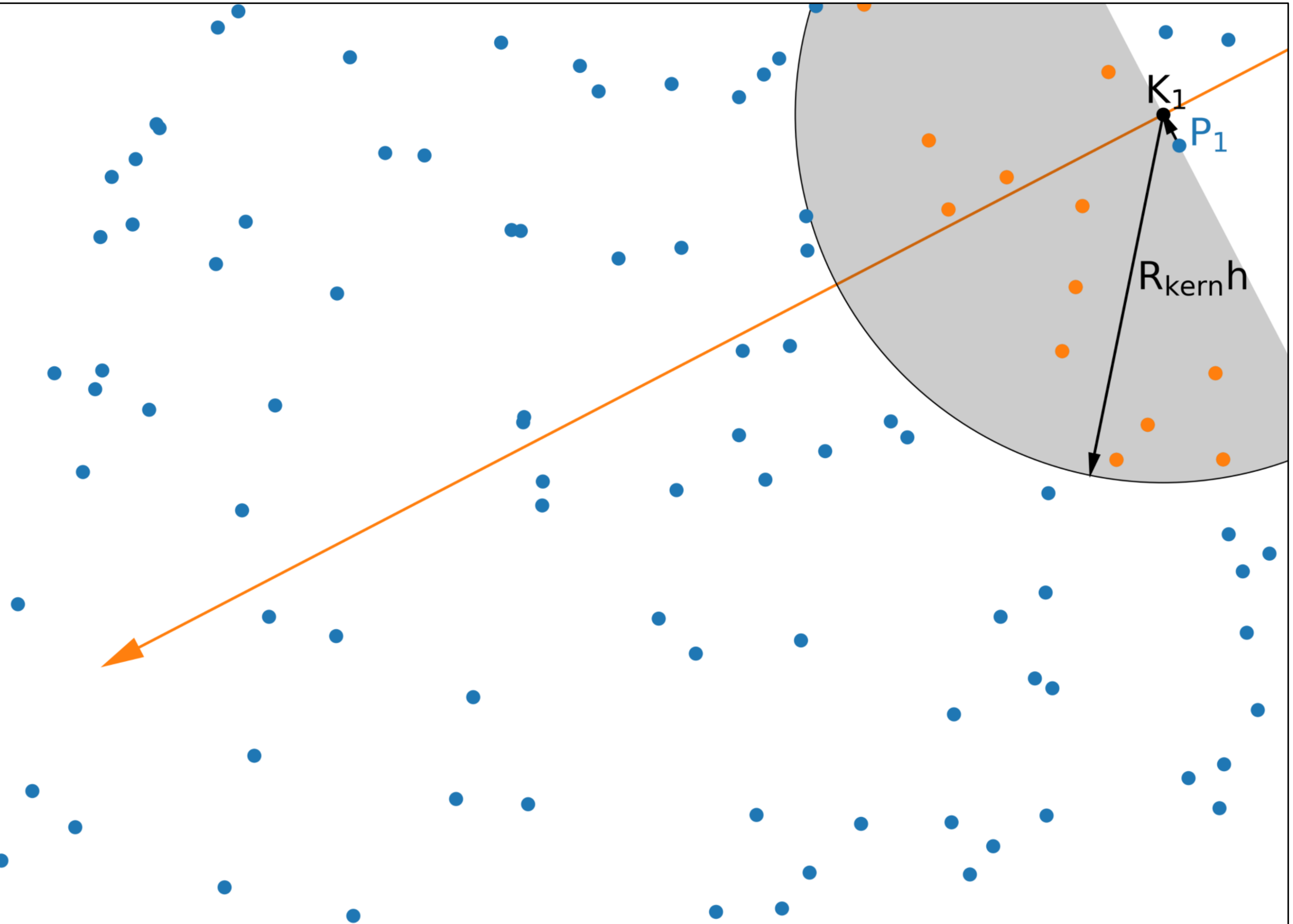

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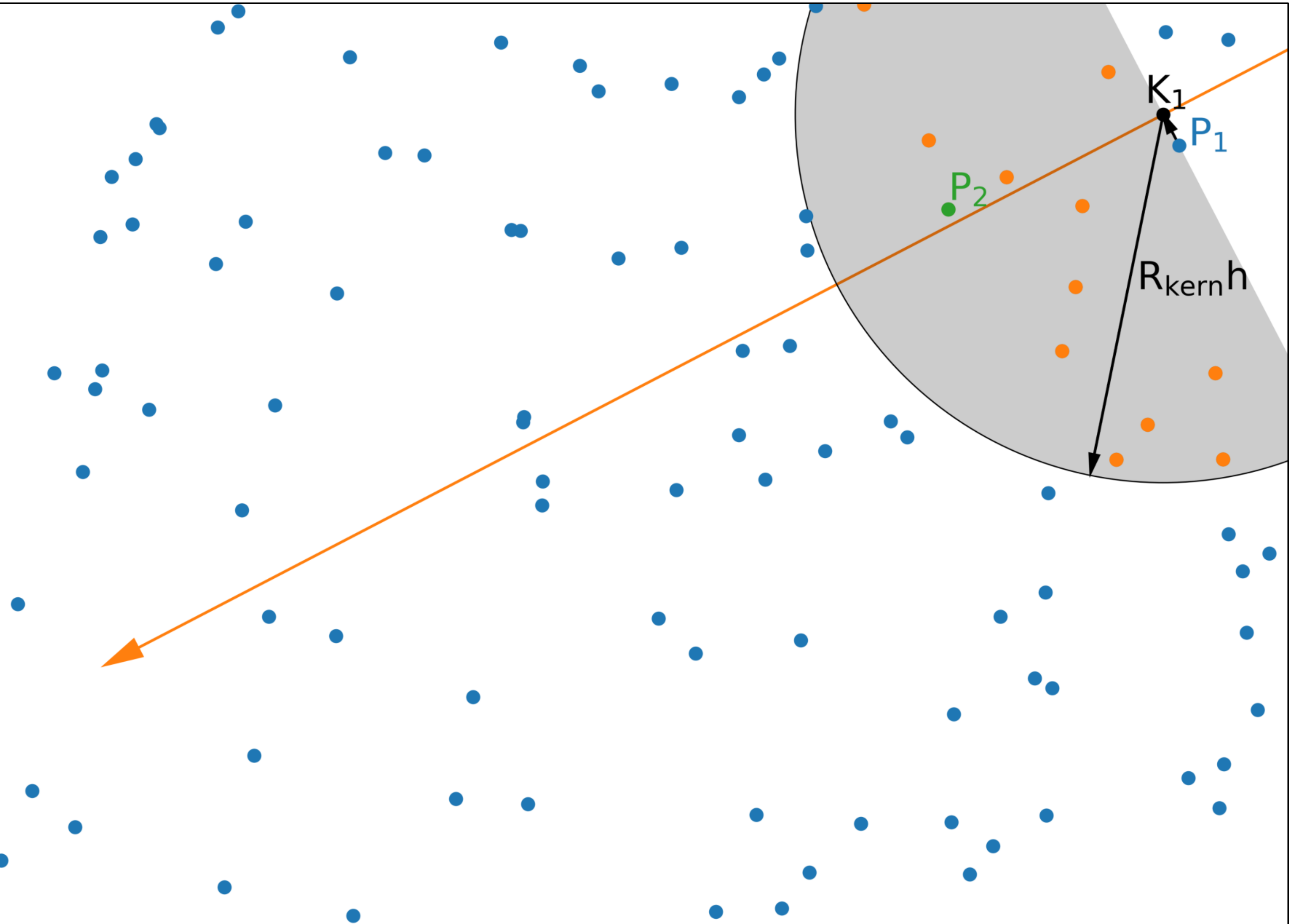

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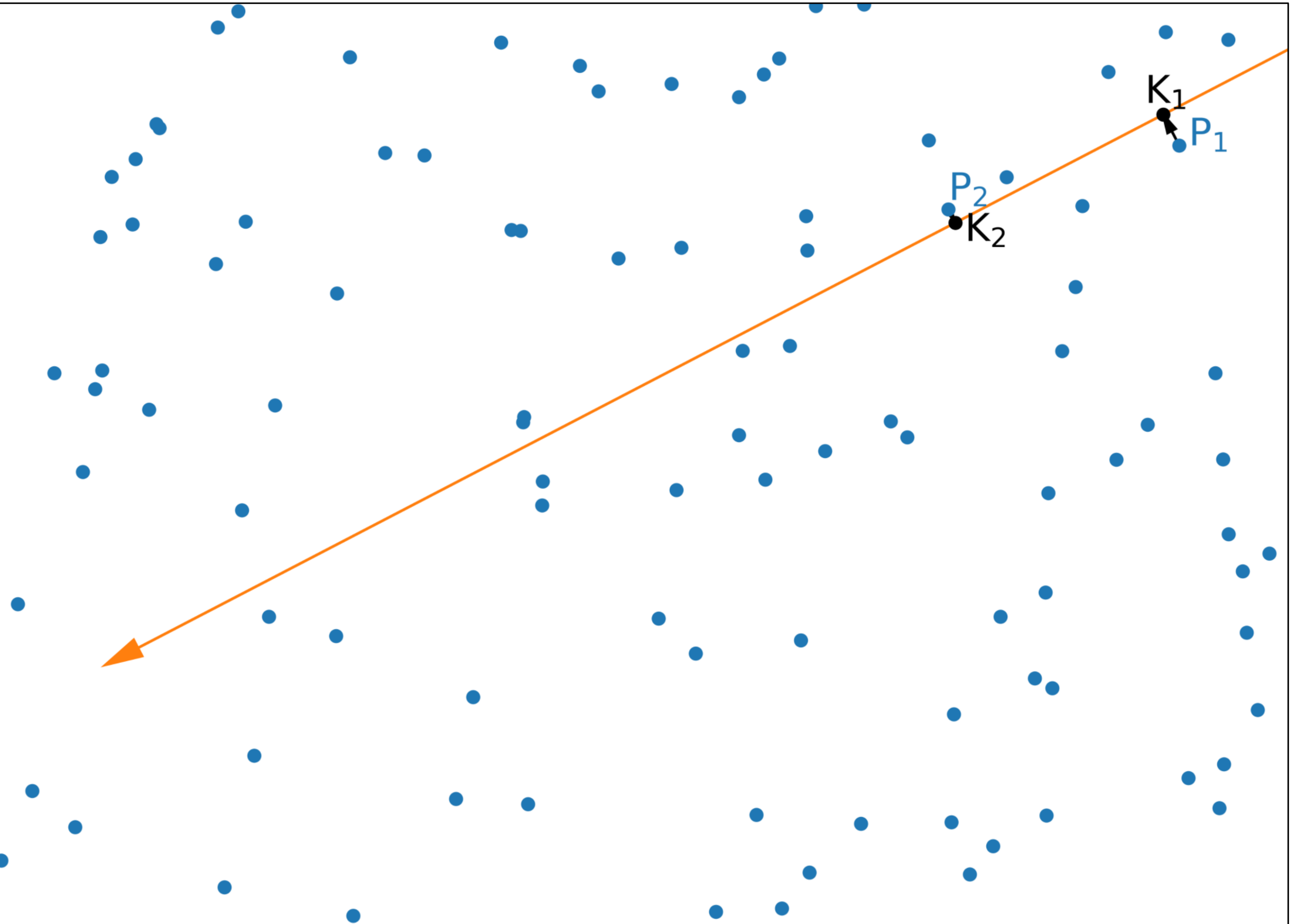

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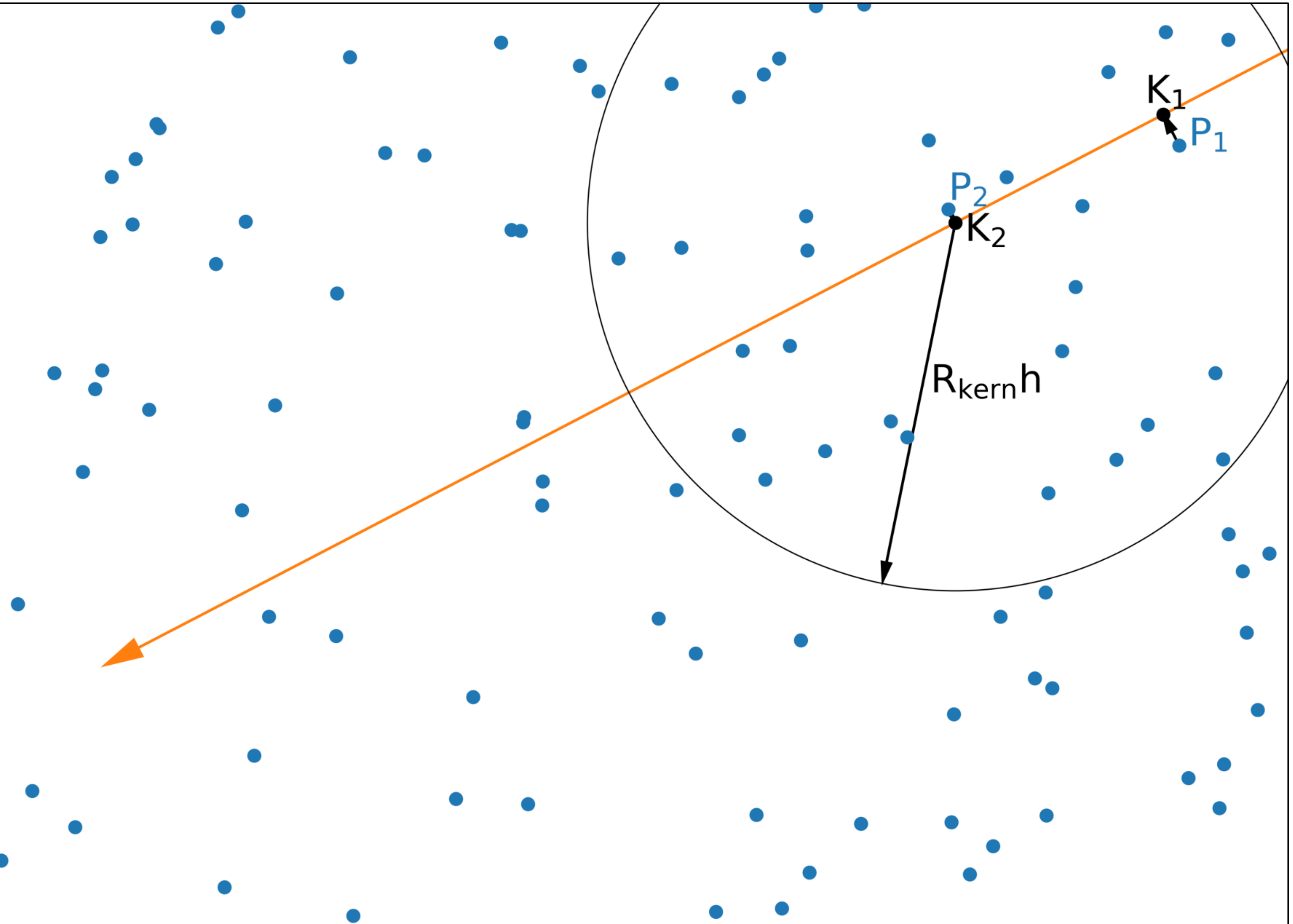

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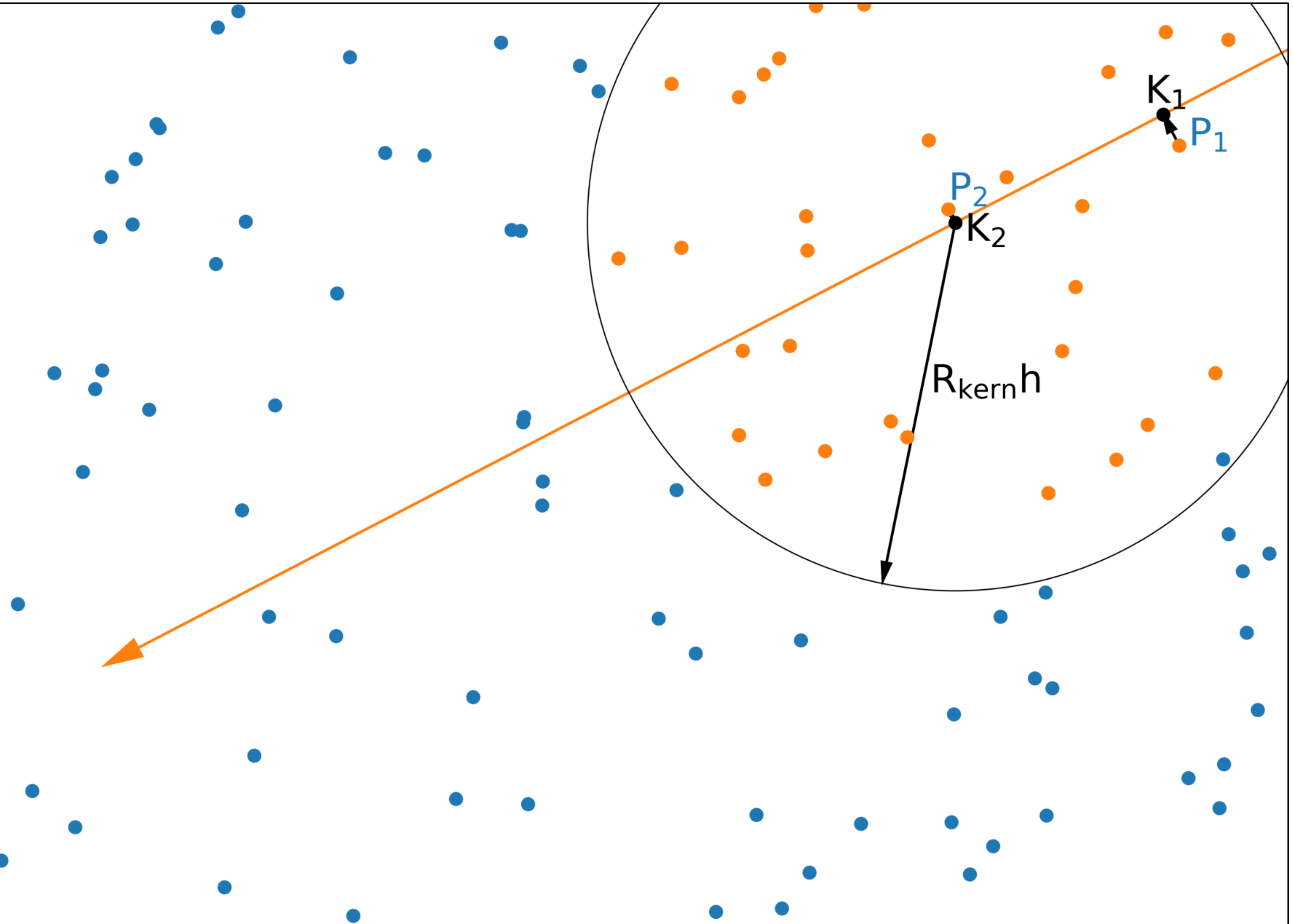

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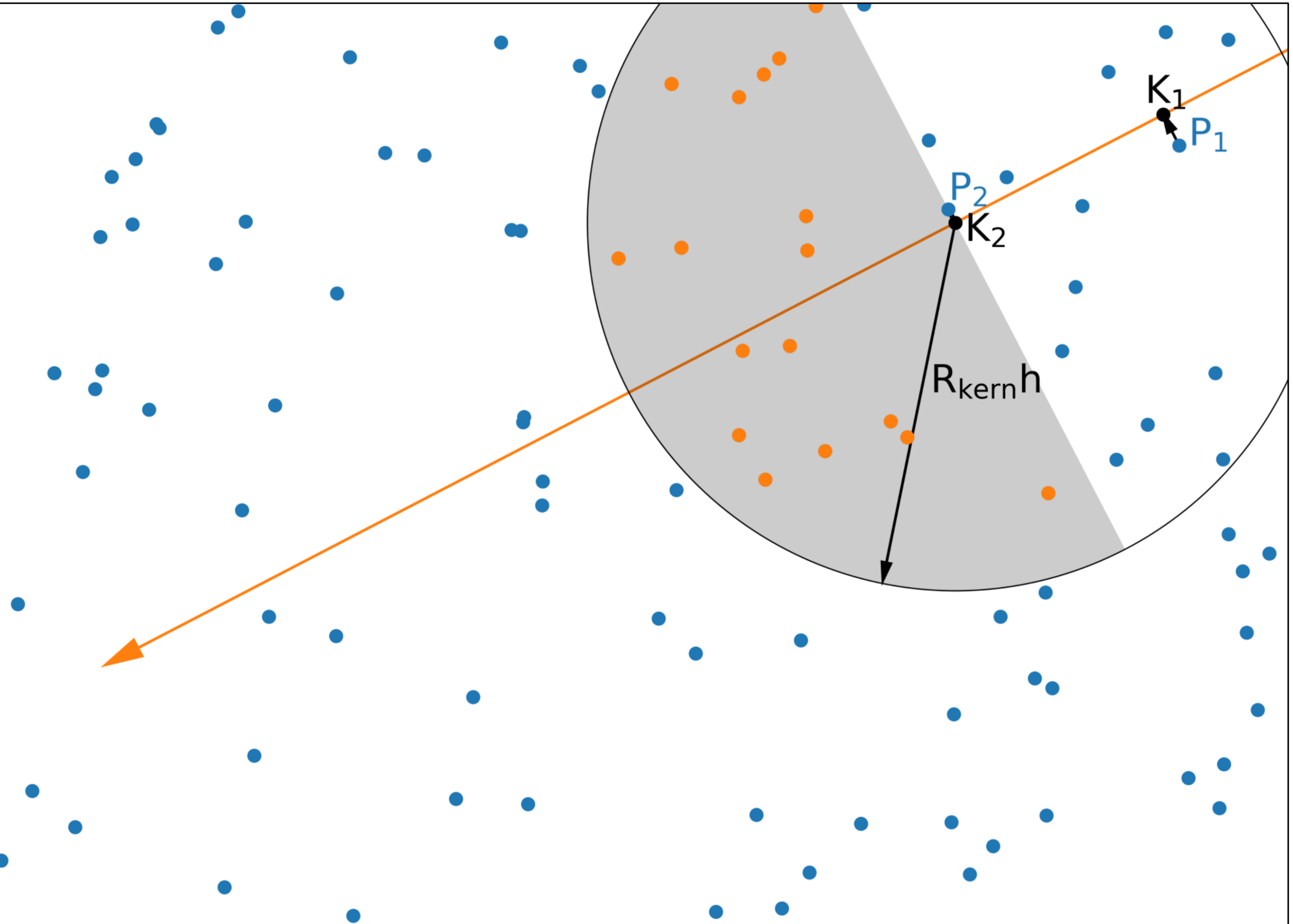

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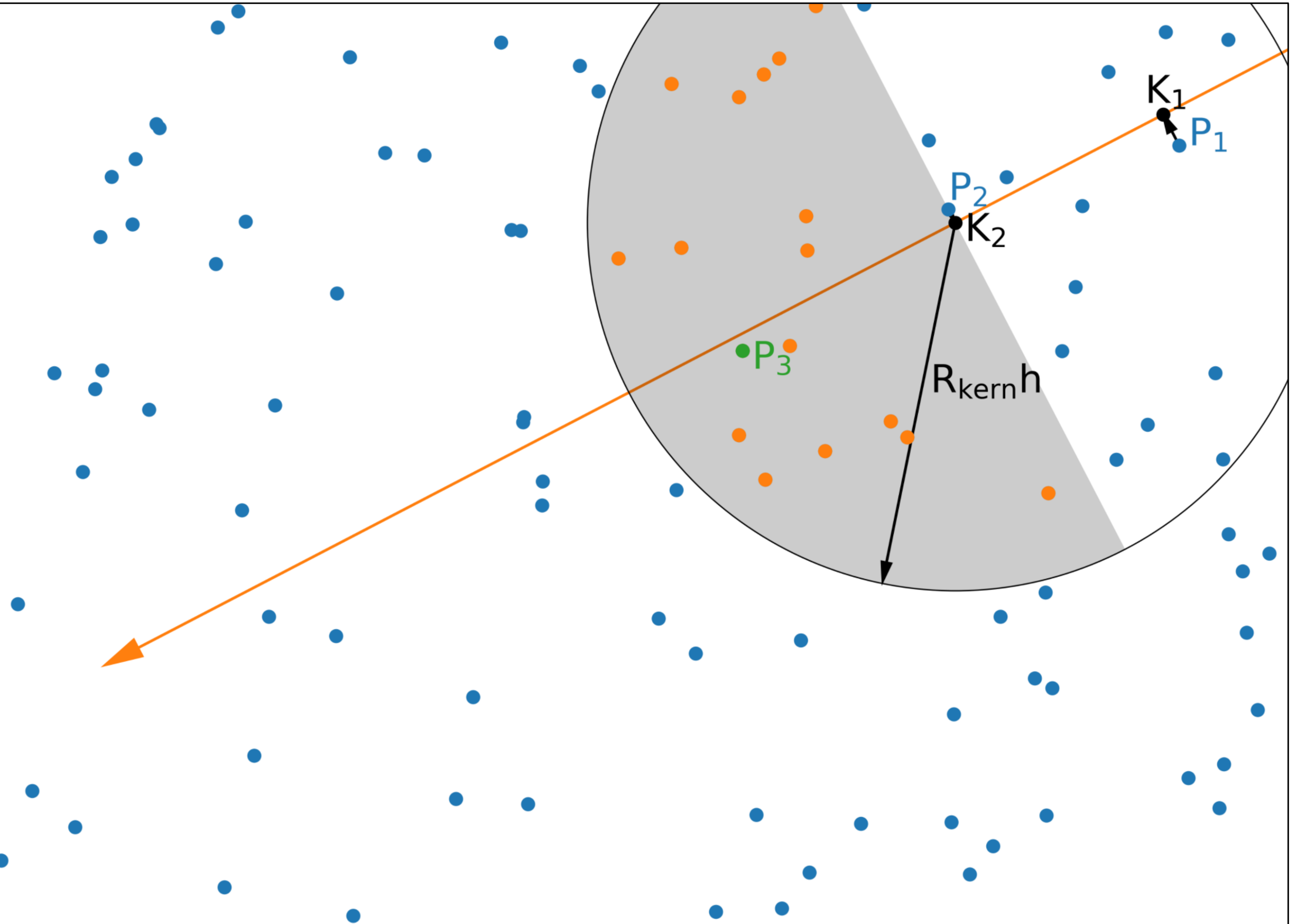

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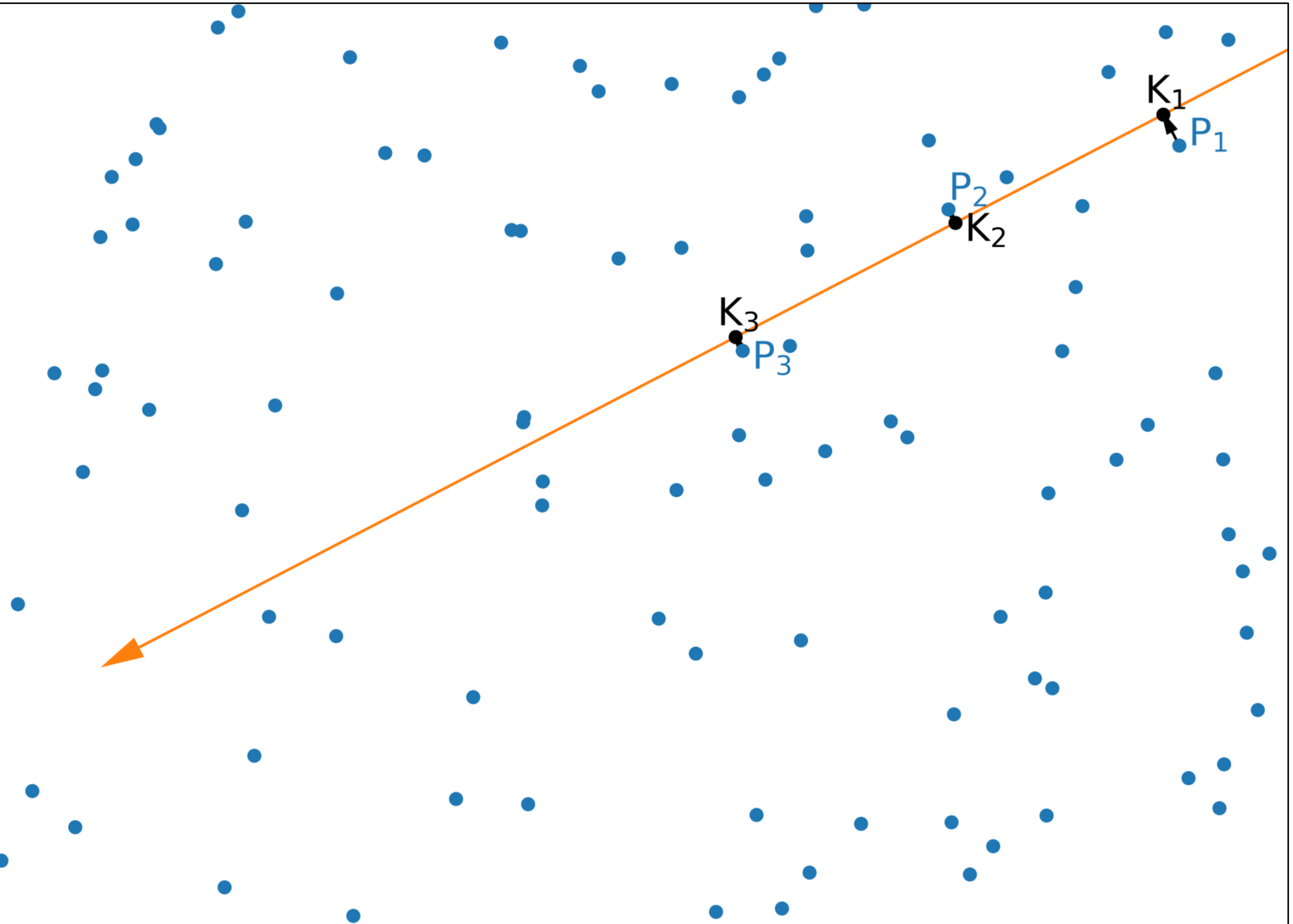

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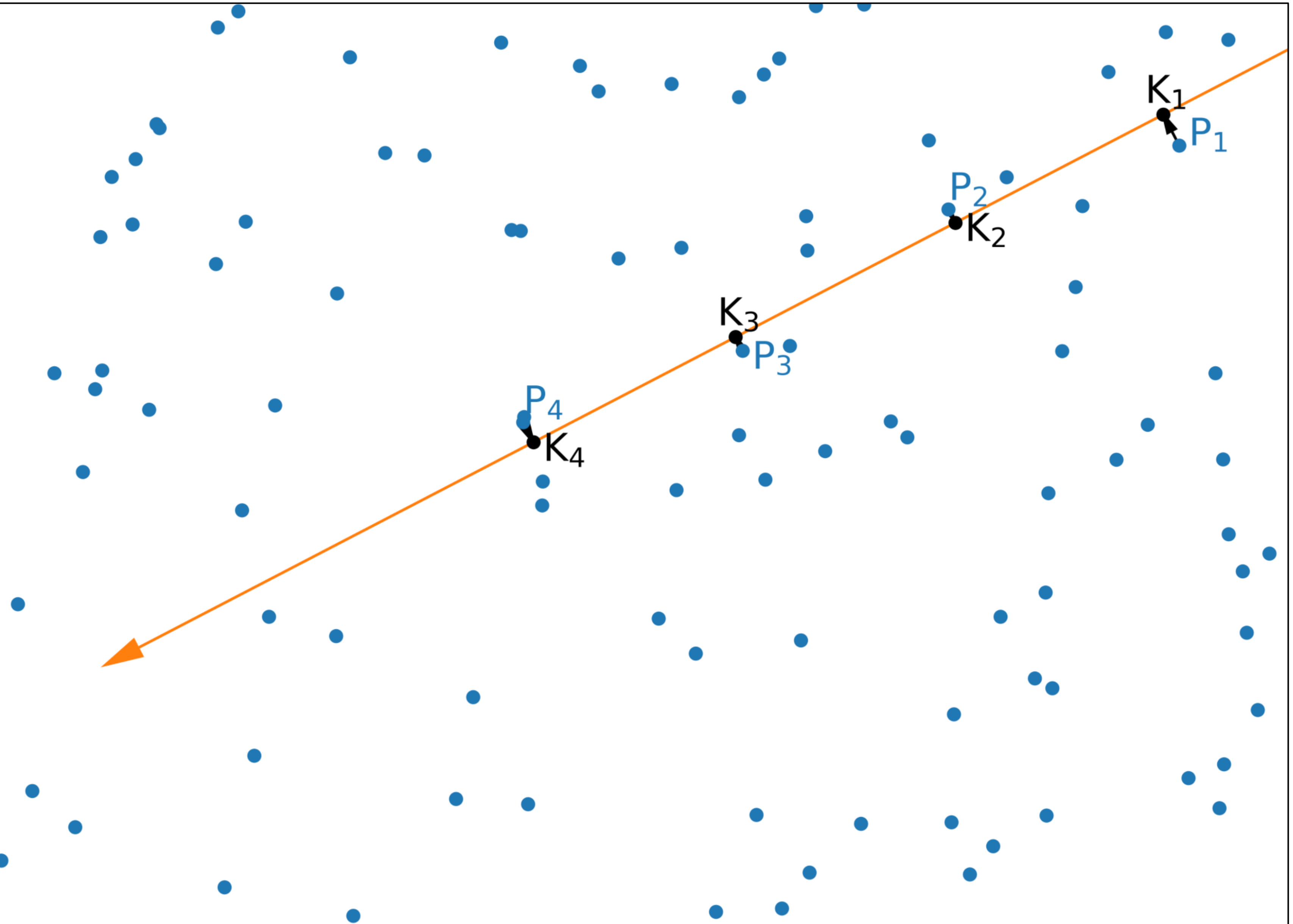

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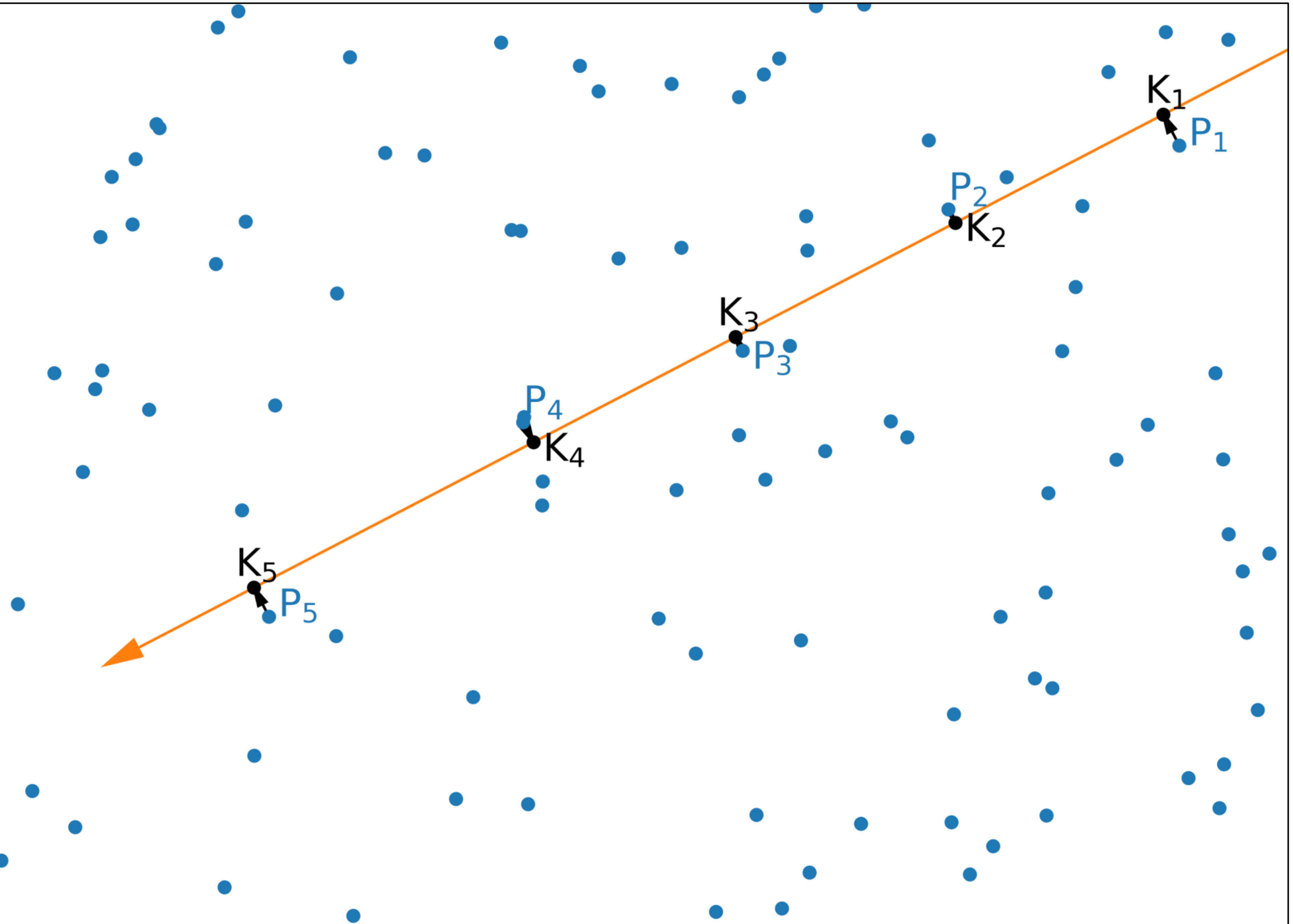

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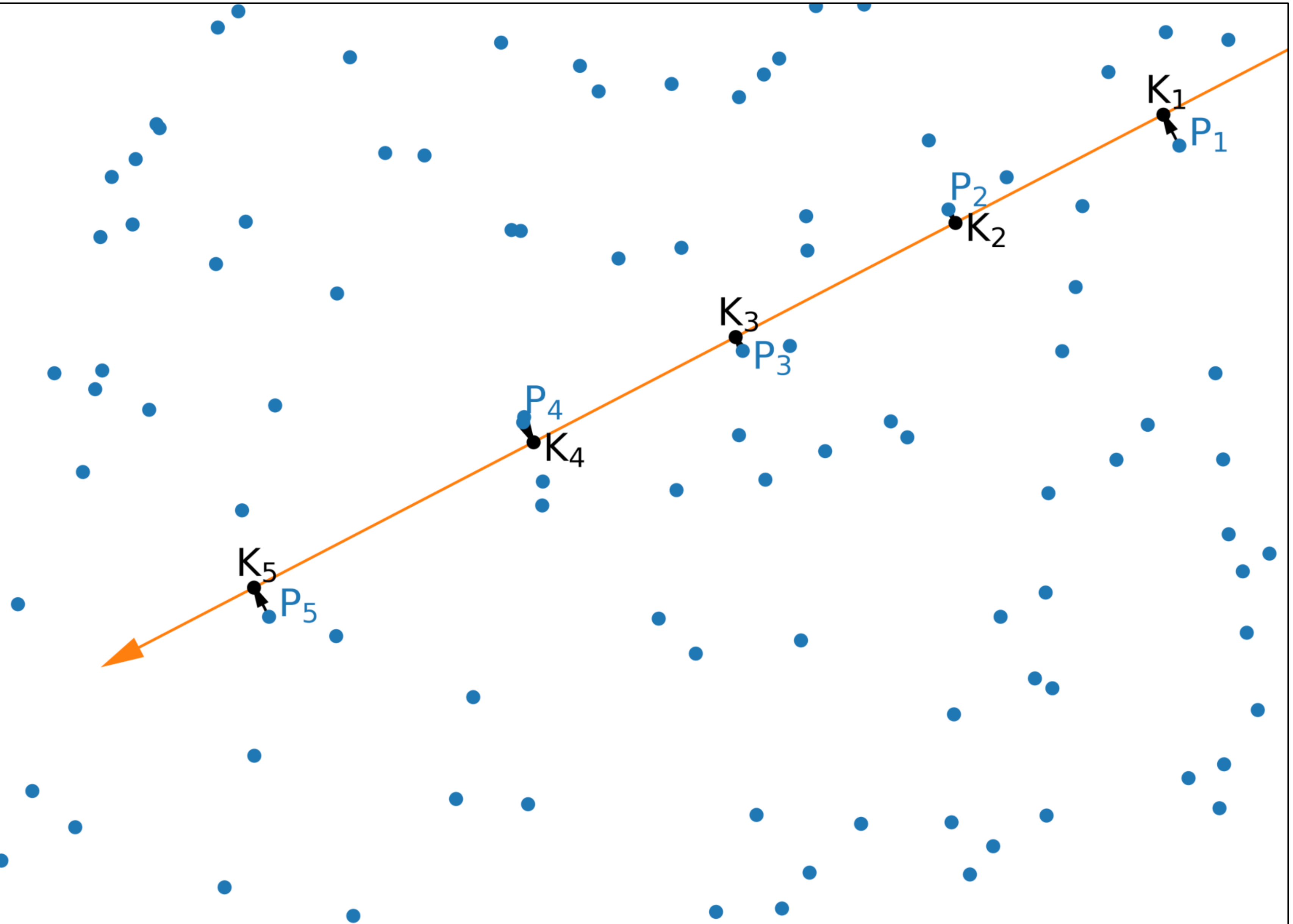


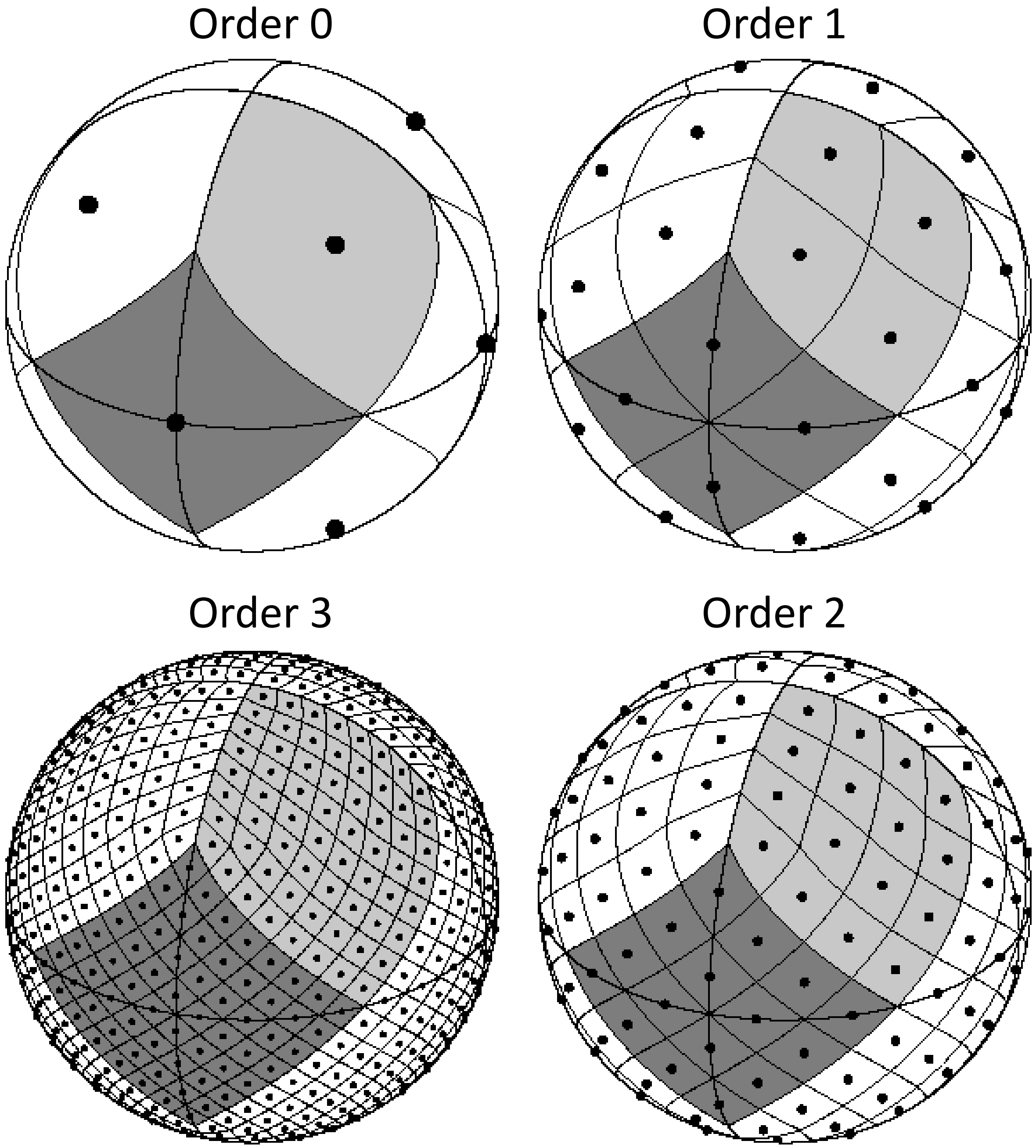
At each point K:

- $\kappa_i \; \rho_i$
- d_i
- τ_i

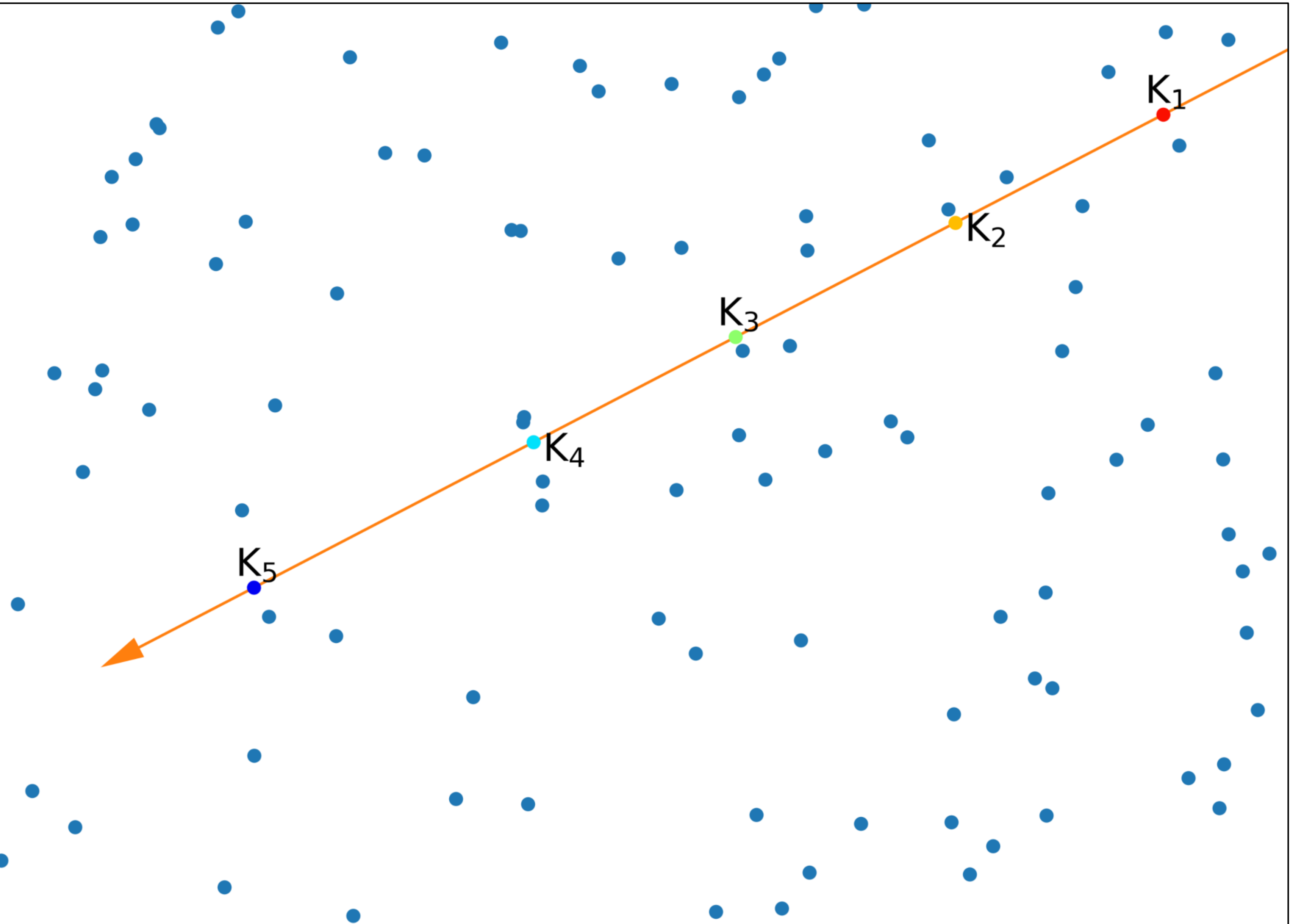
$$\tau = \int_{R_\star}^{r} \mathrm{d}\tau \approx \sum_i \Delta\tau_i$$

$$= \sum_i \left(\frac{\kappa_i \; \rho_i + \kappa_{i+1} \; \rho_{i+1}}{2} \right) \Delta s_i$$

3D → Healpix



Interpolation along a ray



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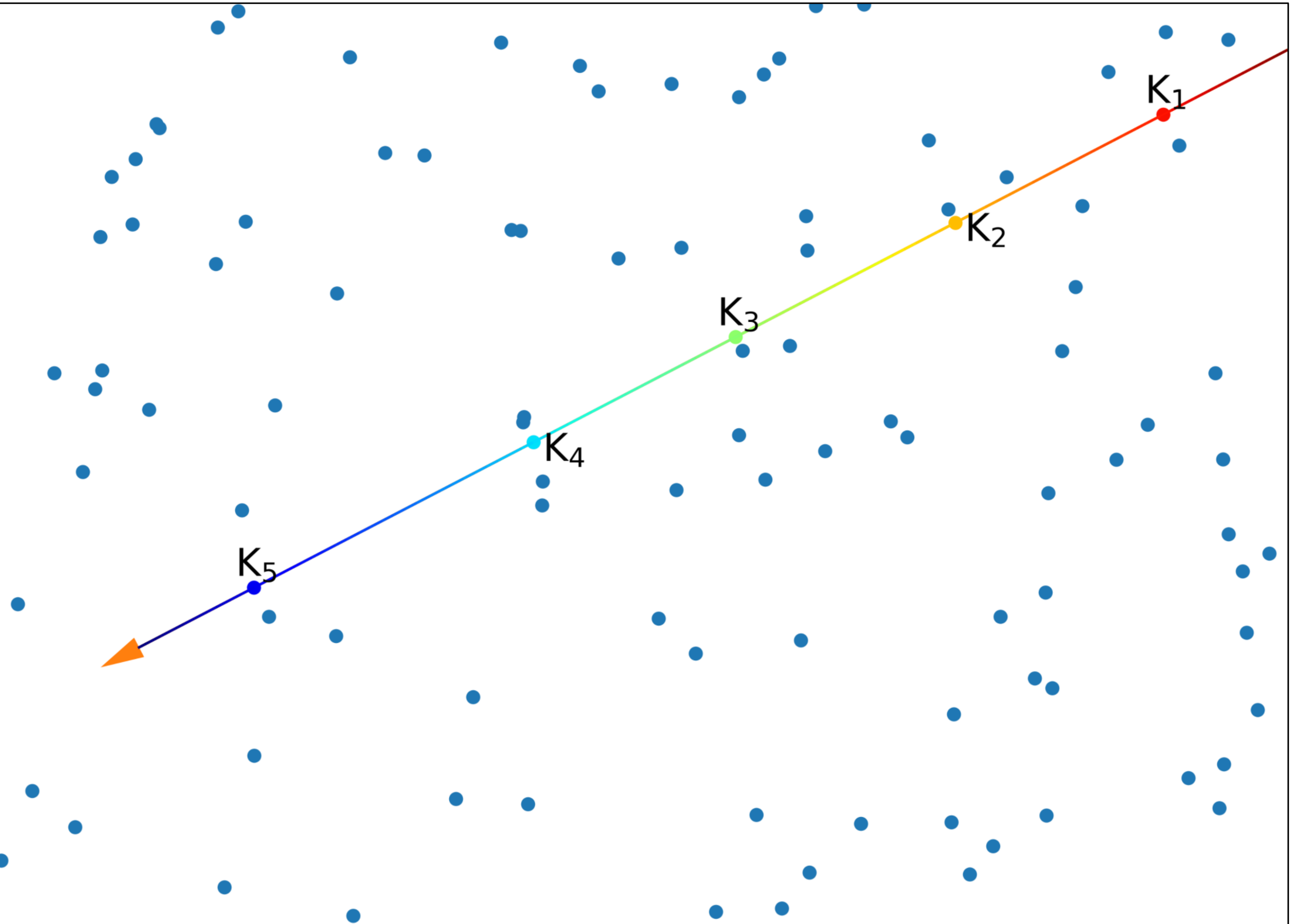

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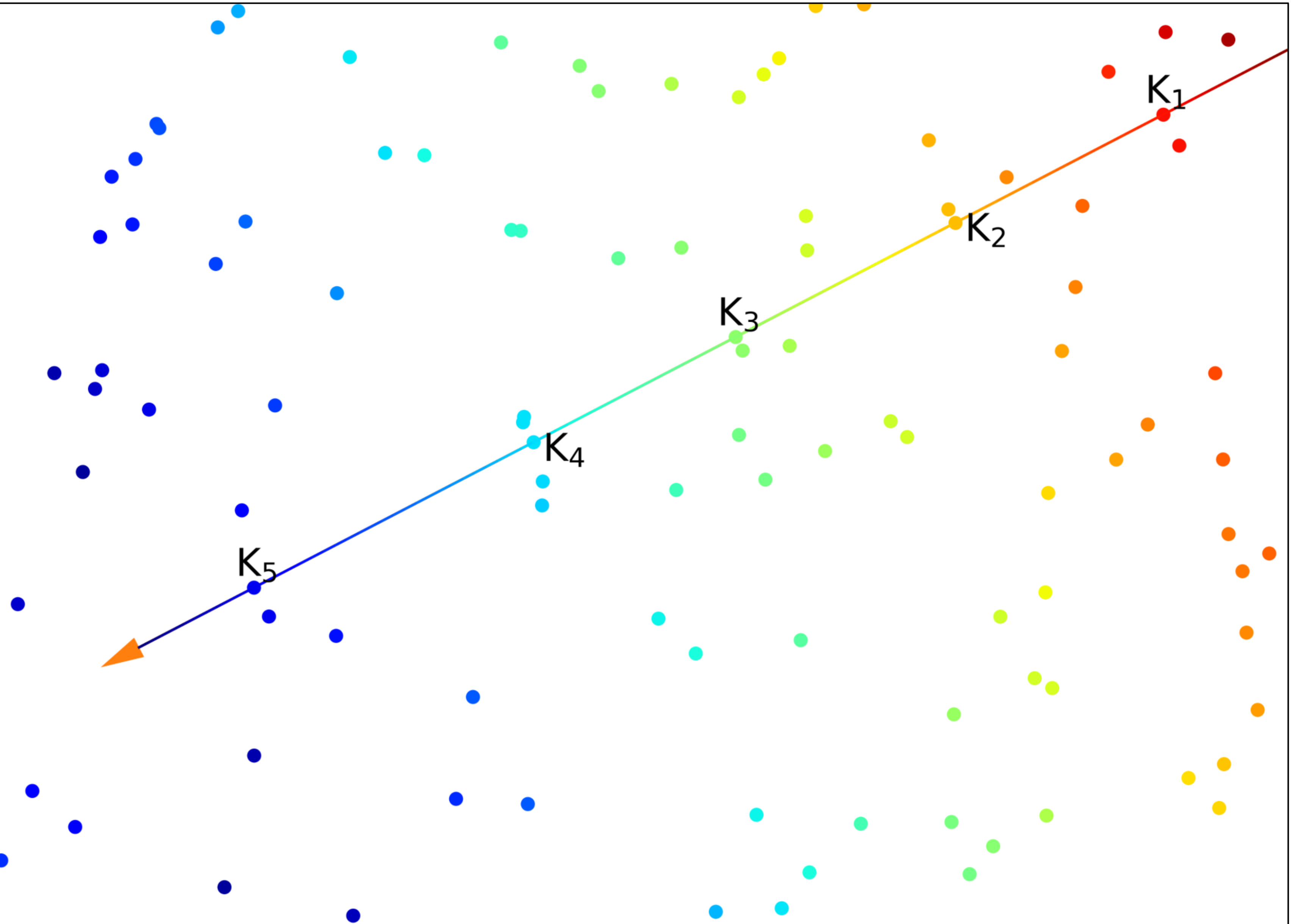
Linear interpolations between points

Interpolation along a ray



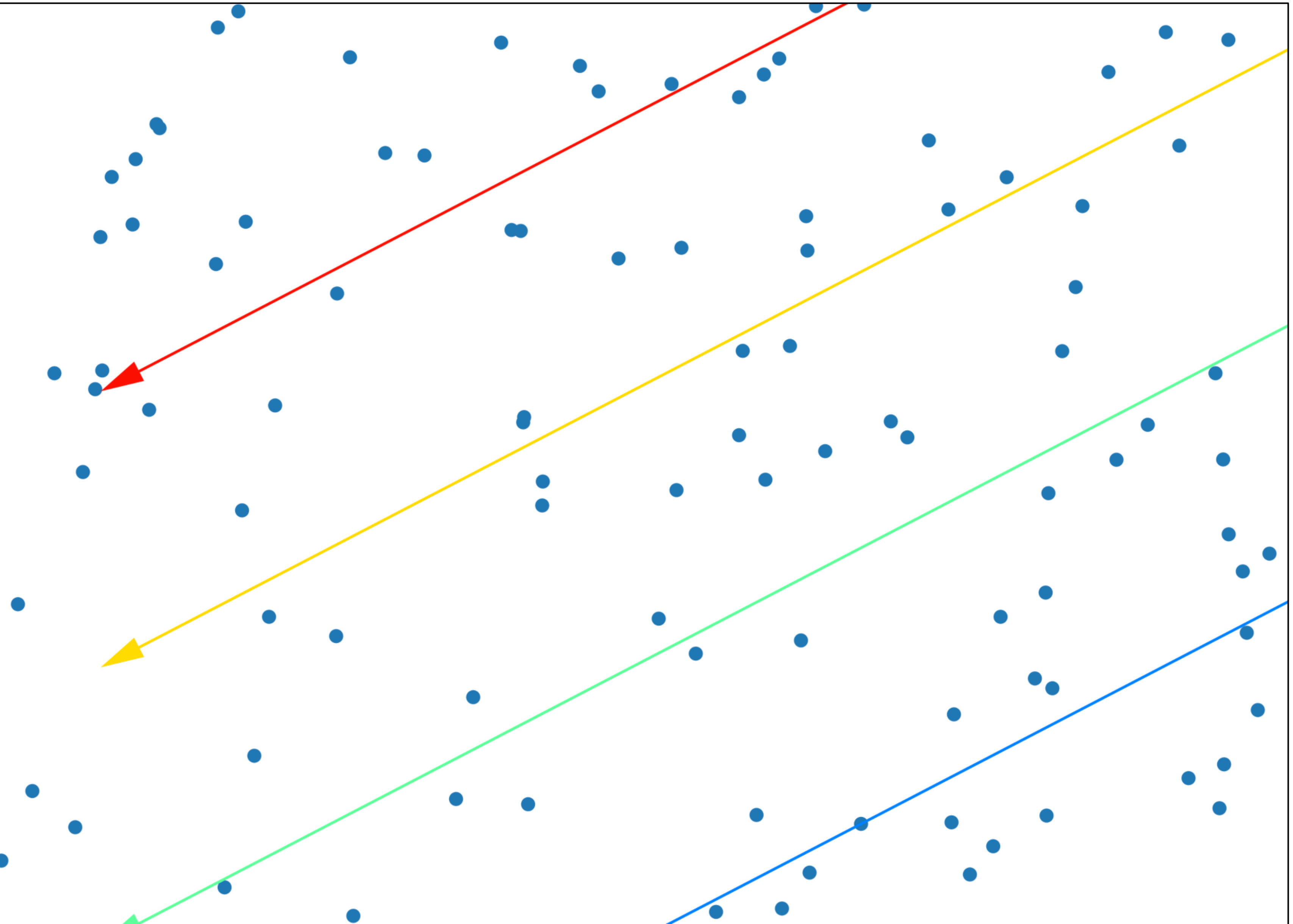
At each point K:

- τ_i

Linear interpolations between points

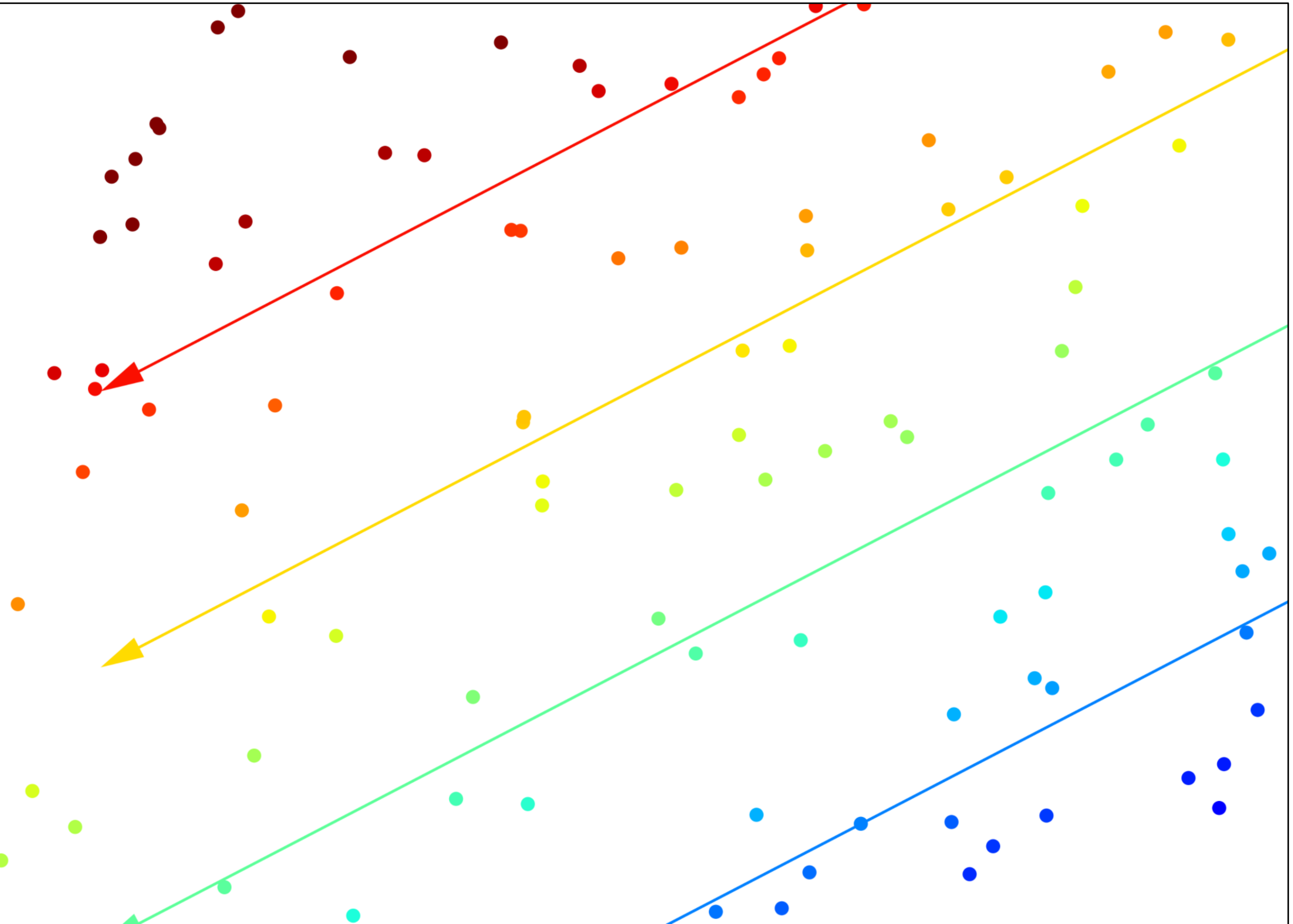
τ at closest point along the ray

Interpolation in between rays



Trace more rays

Interpolation in between rays

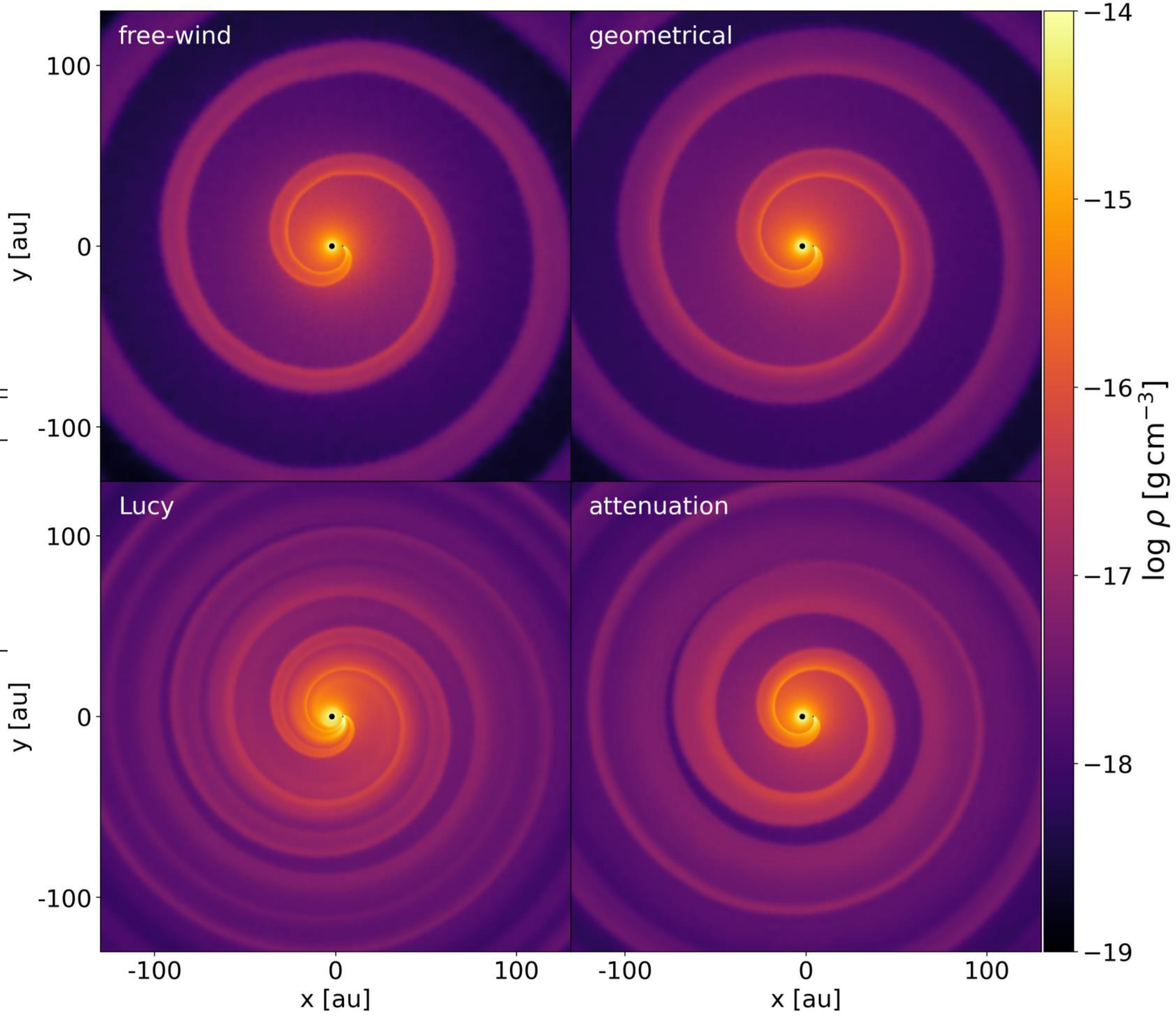


Trace more rays

Interpolate τ between closest rays

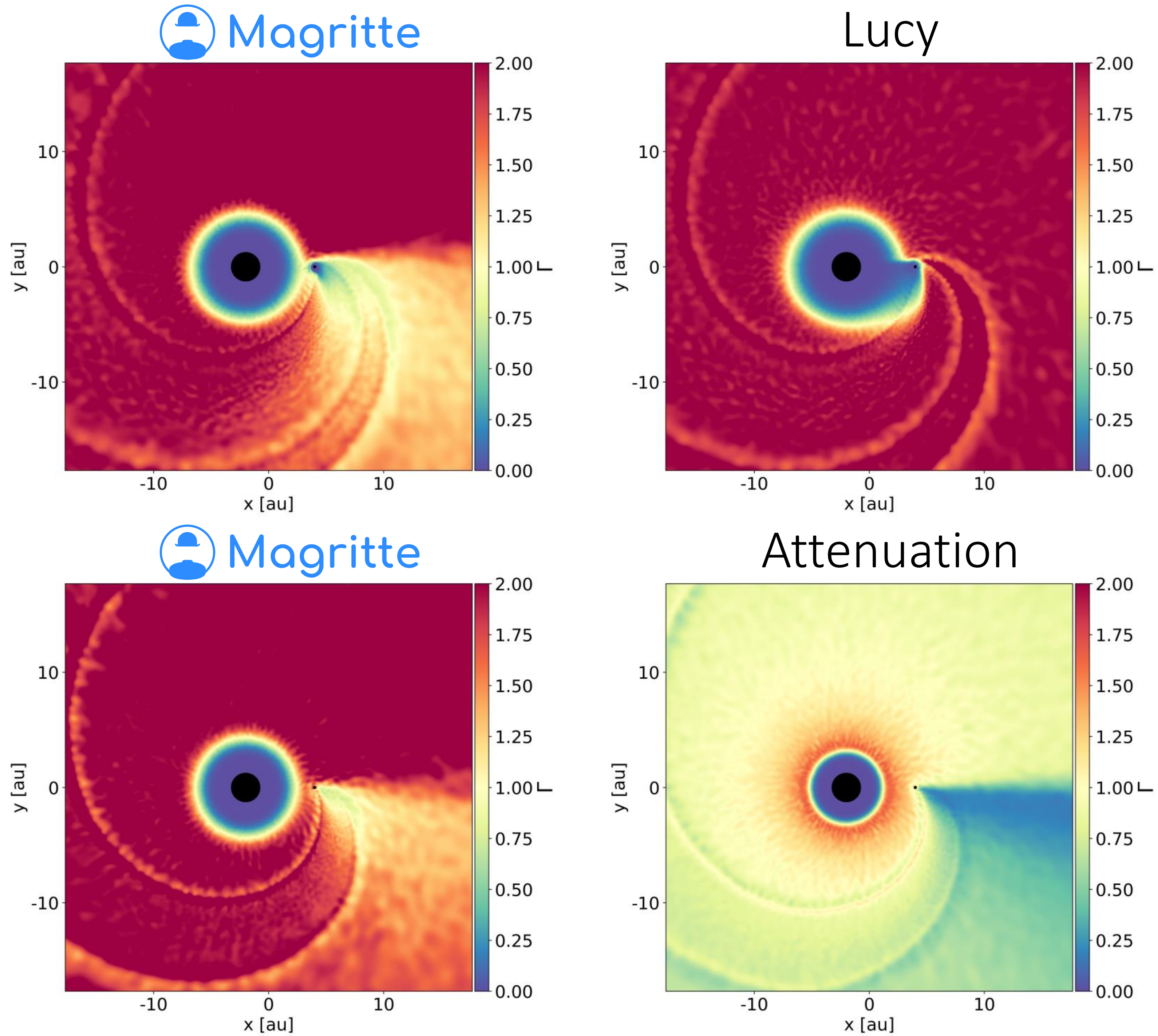
Morphological structures

Parameter	Value	Unit
$\dot{M}_{\rm AGB}$	3×10^{-6}	$M_{\odot}\,yr^{-1}$
$M_{\rm AGB}$	1.02	$M_{\odot}$
$L_{\rm AGB}$	4384	$L_{\odot}$
$T_{\rm eff,AGB}$	2874	K
$R_{\rm AGB}$	1.24	au



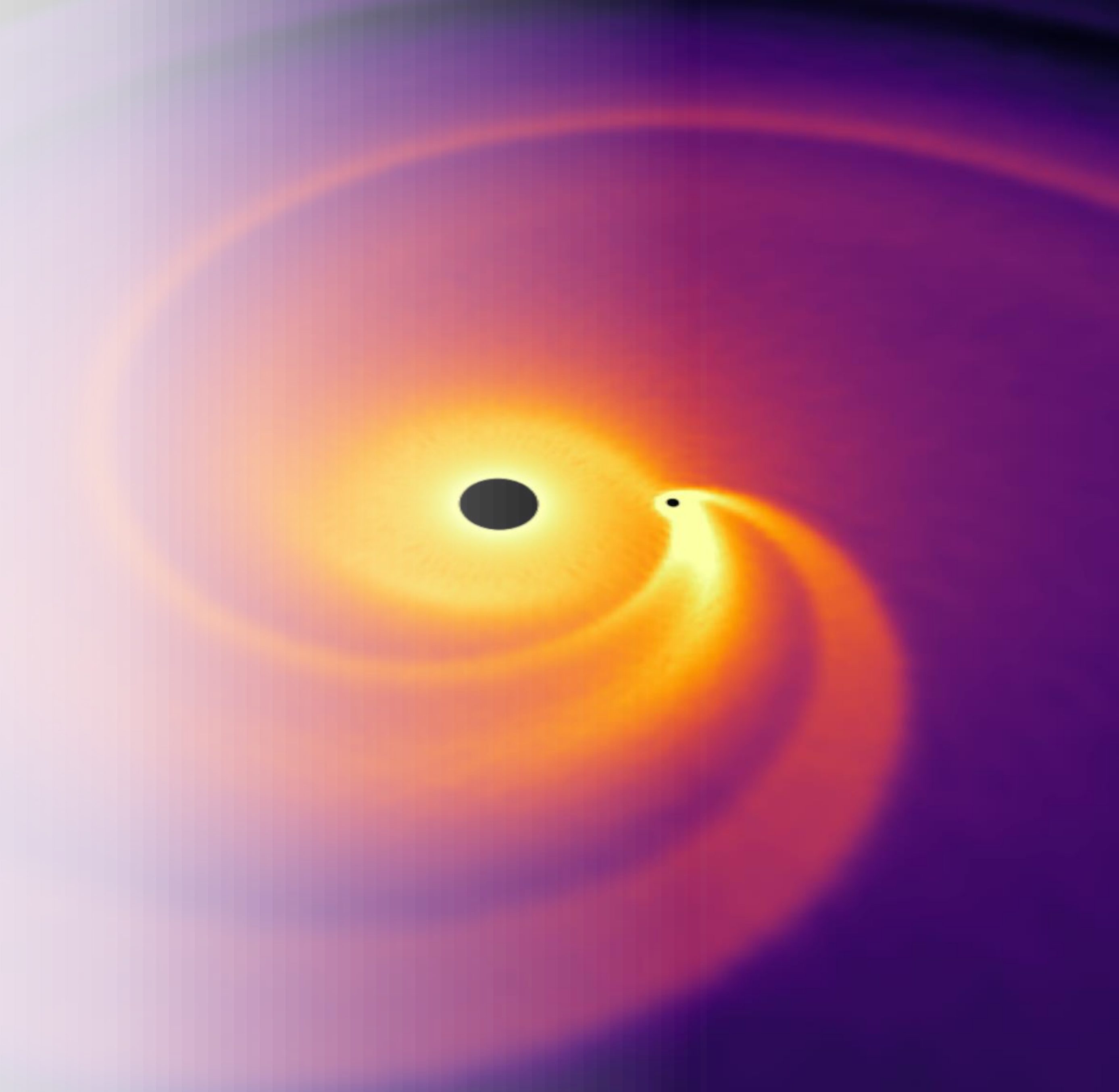
Validation Study

- Full 3D radiation transfer code Magritte
- Lucy approximation most accurate



Conclusions

- Dust formation and radiative transfer is crucial
- Different approximations can make significant changes
- Lucy approximation most accurate, but a combination might give even better results



Esseldeurs et al. (2023)