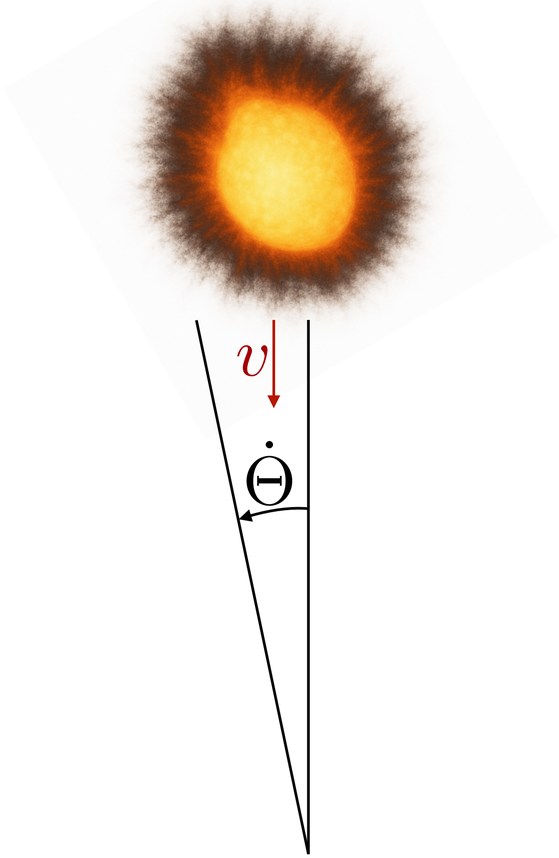
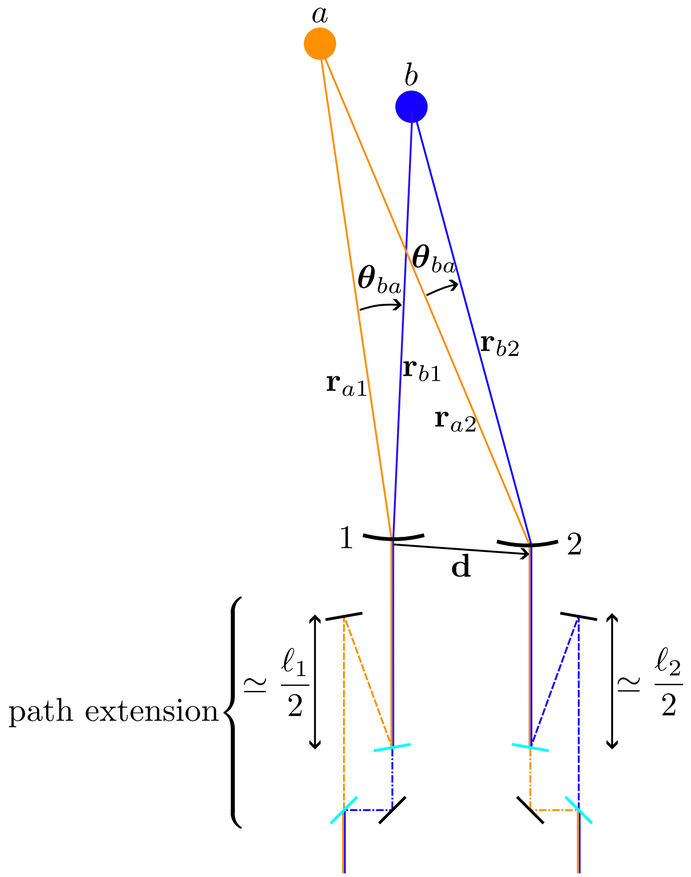
Intensity Interferometry for Cosmology & Fundamental Physics

Supernova Distances



EPIC



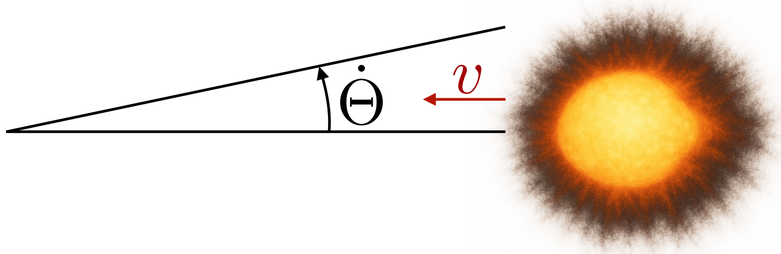
Dark Matter Lensing

Ken Van Tilburg CCPP @ NEW YORK UNIVERSITY | CCA @ FLATIRON INSTITUTE

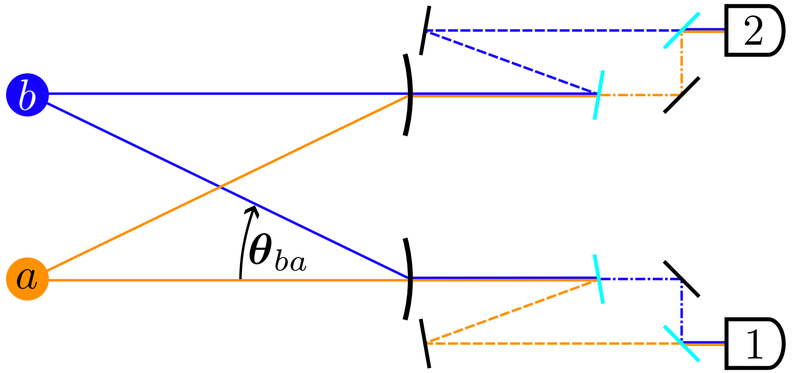
Stellar Intensity Interferometry Workshop— Research Campus Waischenfeld — Oct 17, 2025

Outline

Cosmology: Supernova Distances



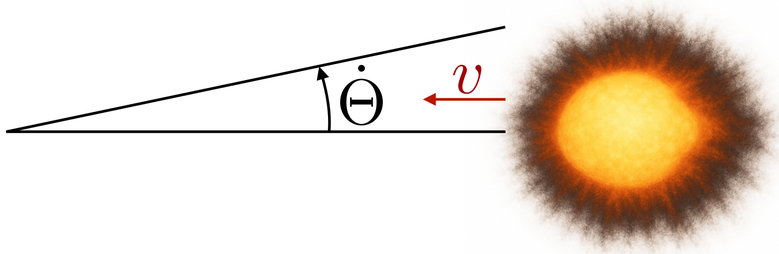
Extended-Path Intensity Interferometry: EPIC



Fundamental Physics: Dark Matter Lensing

Outline

Cosmology: Supernova Distances



🎯 supernova morphology + distance → H_0

[I.-K. Chen, D. Dunsky, KVT, J. Huang, R. V. Wagoner; arXiv:2504.20131]

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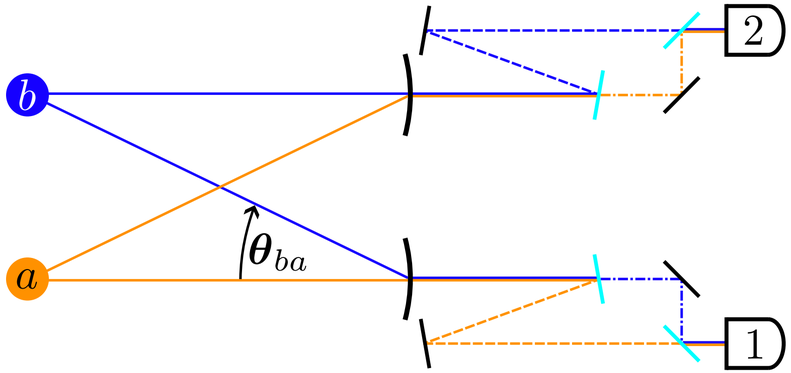
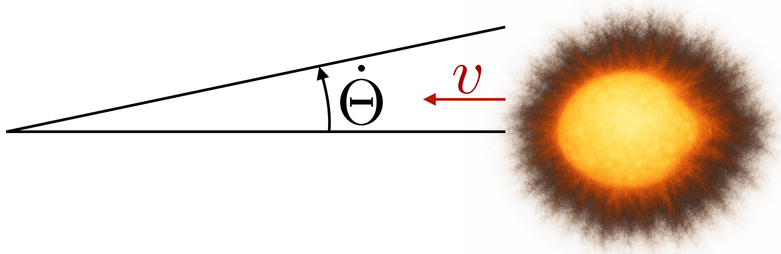


Fundamental Physics: Dark Matter Lensing

Outline

Cosmology: **Supernova Distances**

$$D_A = \frac{\dot{\Theta}}{\upsilon}$$



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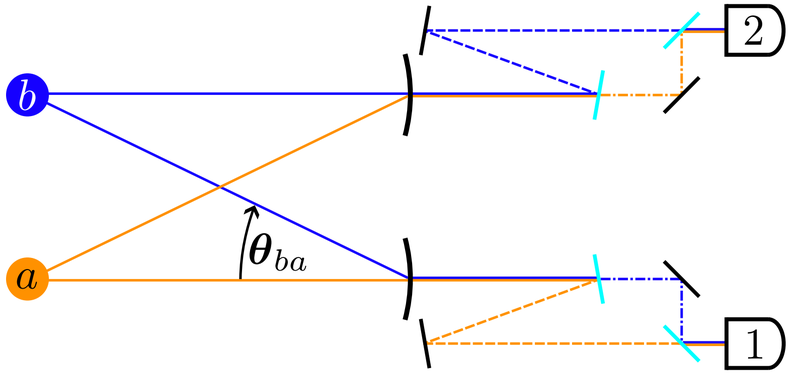

Fundamental Physics: **Dark Matter Lensing**

Outline

Cosmology: Supernova Distances

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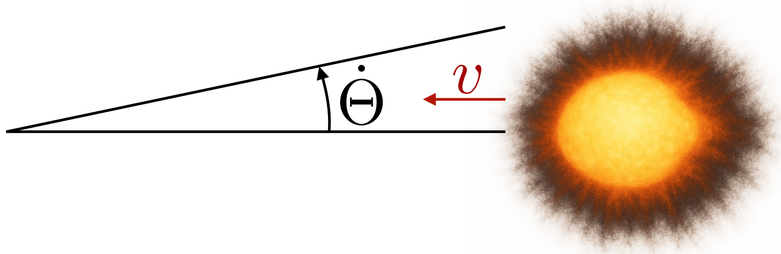

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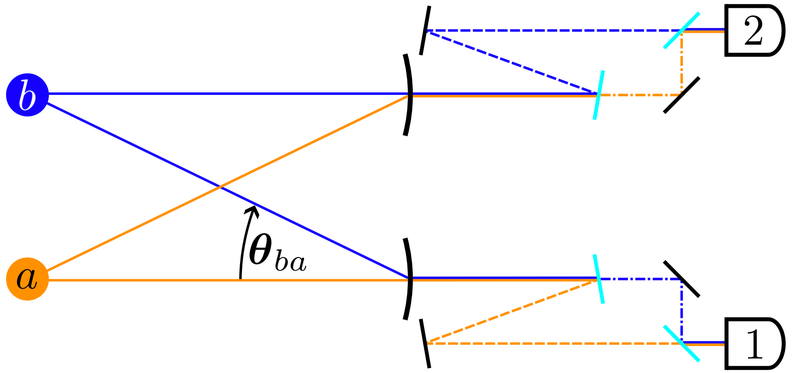

❌ standard II: low SNR + small FOV

✅ **differential astrometry** over "large" FOV

[KVT, M. Baryakhtar, M. Galanis, N. Weiner; arXiv:2307.03221]

[M. Galanis, KVT, M. Baryakhtar, N. Weiner; arXiv:2307.06989]

Fundamental Physics: Dark Matter Lensing

Outline

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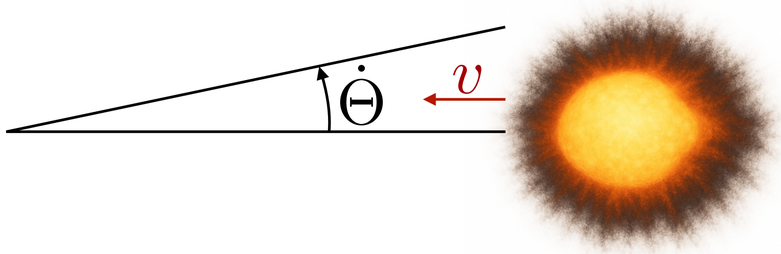

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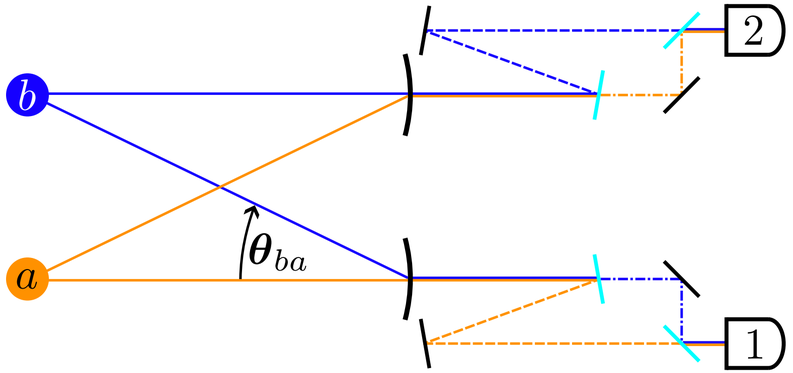

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- 🎯 exoplanets
- 🎯 wide binary orbits
- 🎯 Galactic distances
- 🎯 Galactic microlensing
- 🎯 Galactic kinematics, acceleration

Fundamental Physics: Dark Matter Lensing

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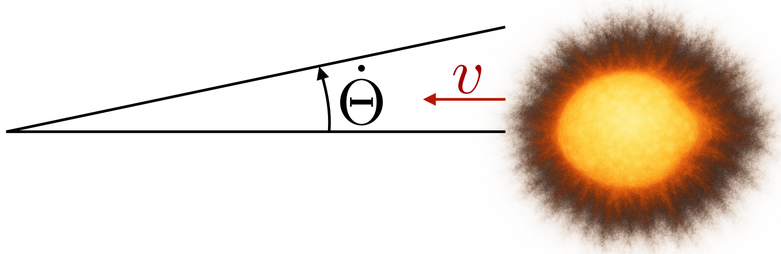

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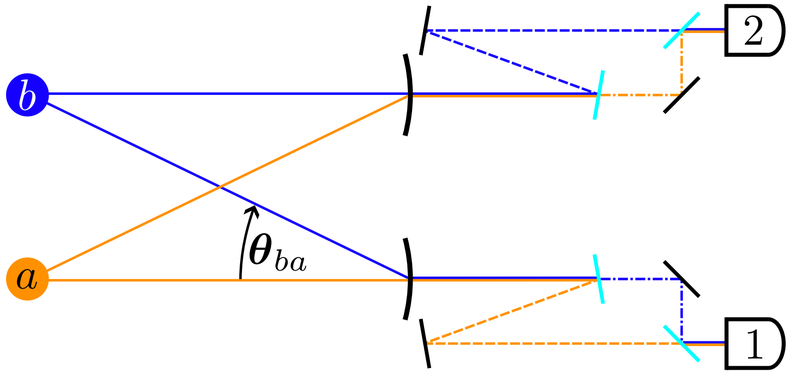

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Fundamental Physics: Dark Matter Lensing

🎯 gravitational lensing by small-scale dark matter structure

[KVT, D. E. Kaplan; in prep]

[A. Moran, KVT; in prep]

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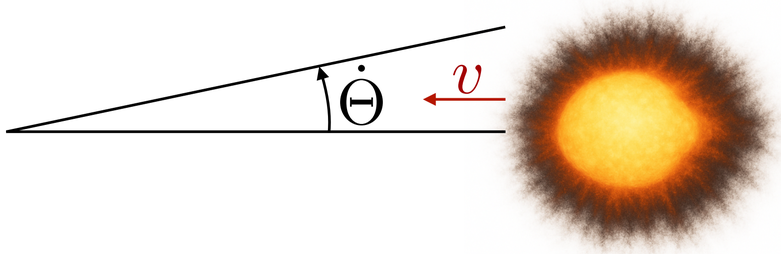

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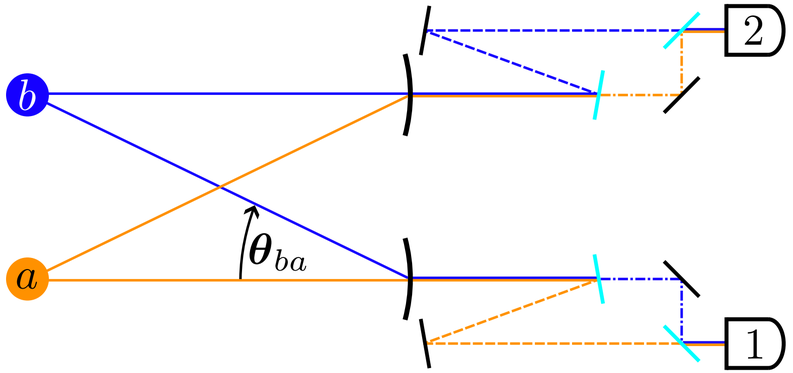

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Fundamental Physics: Dark Matter Lensing

$$\langle \theta_i \theta_j \rangle$$

🎯 gravitational lensing by small-scale dark matter structure

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Astro-Socio-Empirical Observation

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$$\text{Matchlight} \equiv \left(\frac{\sigma_t}{1\,\text{ps}}\right)^{-\frac{1}{2}} \left(\frac{A}{1\,\text{m}^2}\right) \left(\frac{\mathcal{R}}{1}\right)^{\frac{1}{2}} \left(\frac{\epsilon}{1}\right)$$

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	D	σ_t	$\mathcal{R}$	n_{arr}	Matchlight
Phase I	4 m	30 ps	5,000	1	80
Phase II	10 m	10 ps	10,000	1	1,240
Phase III	10 m	3 ps	20,000	10	32,000

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Interestingness vs Difficulty [P. Saha]

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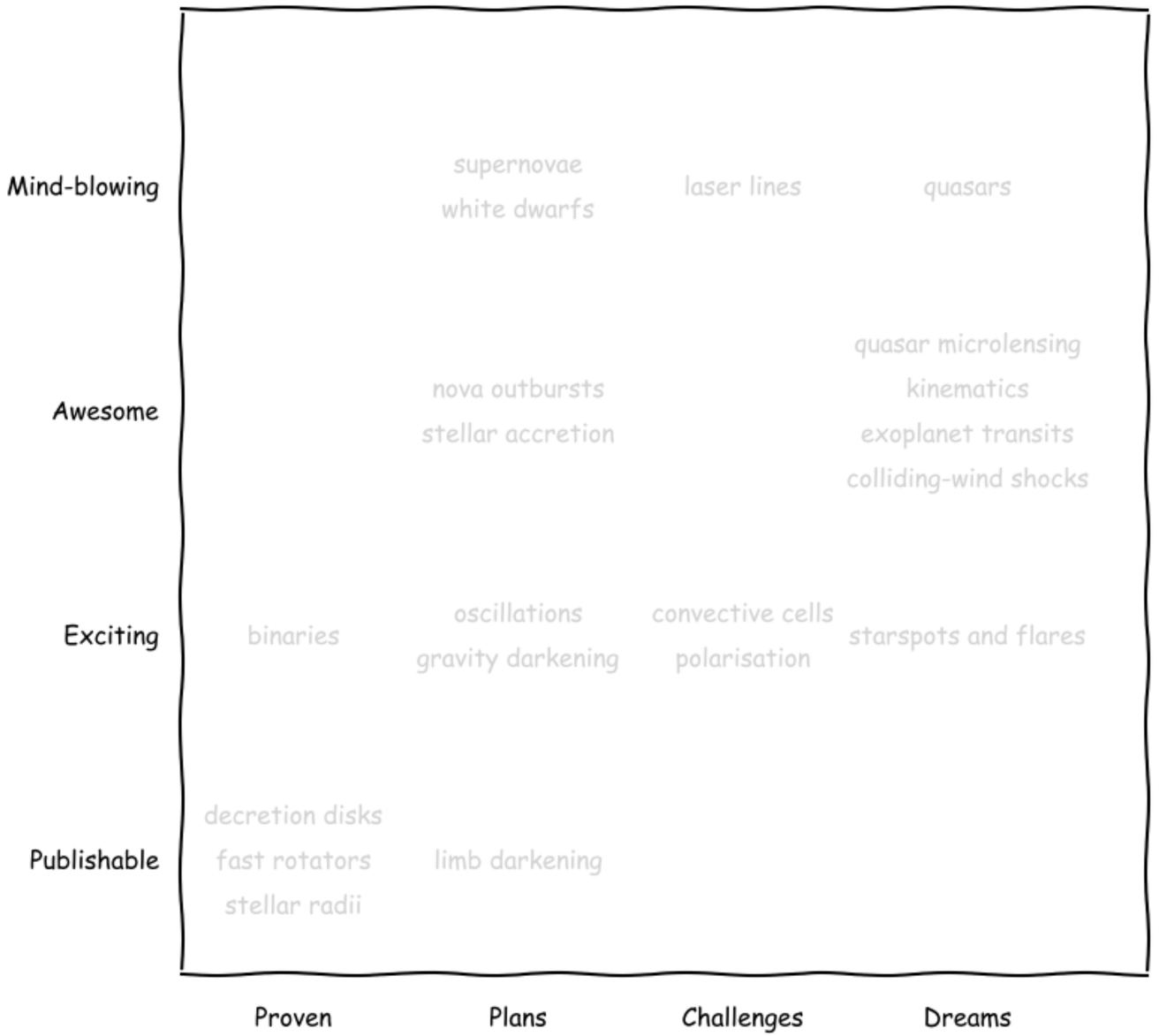

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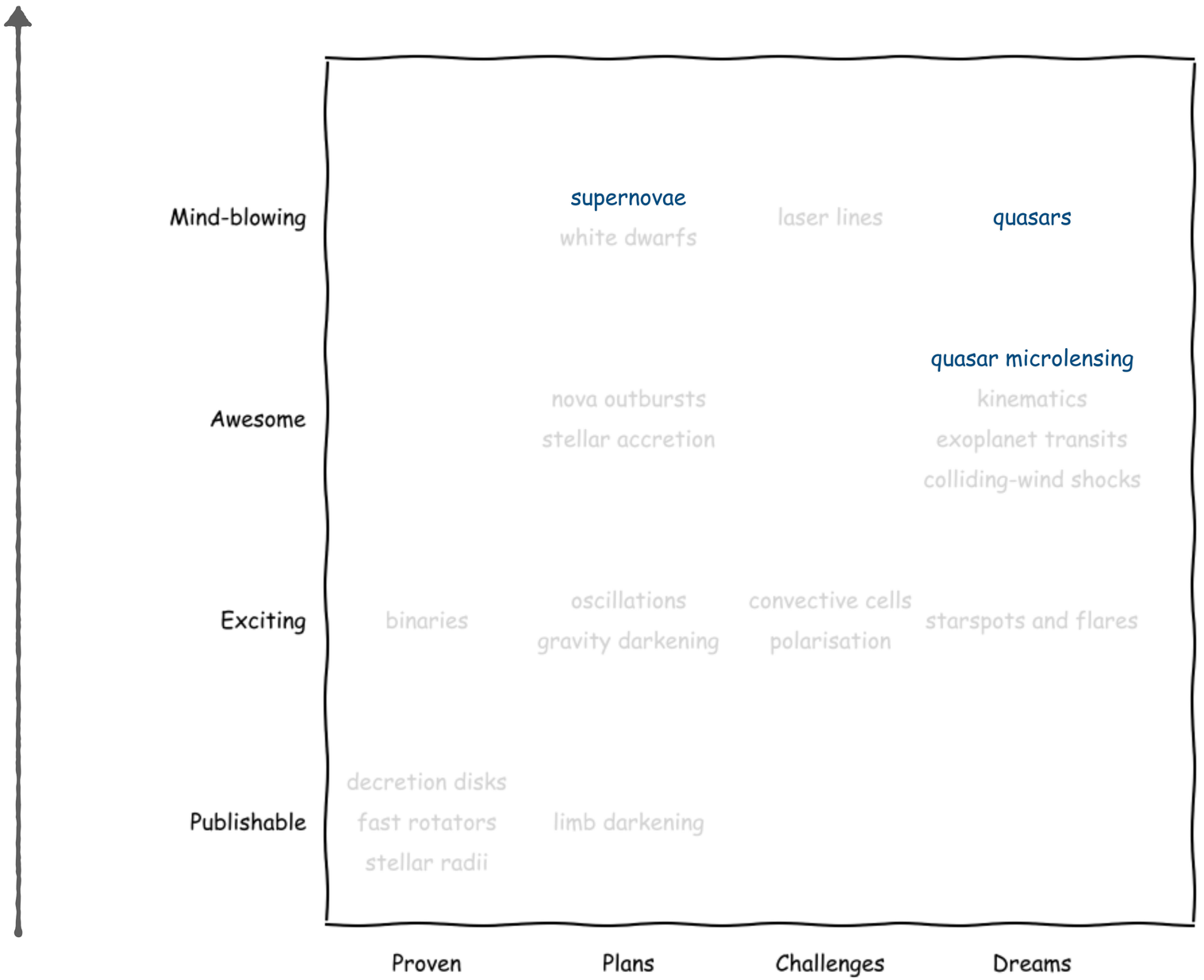

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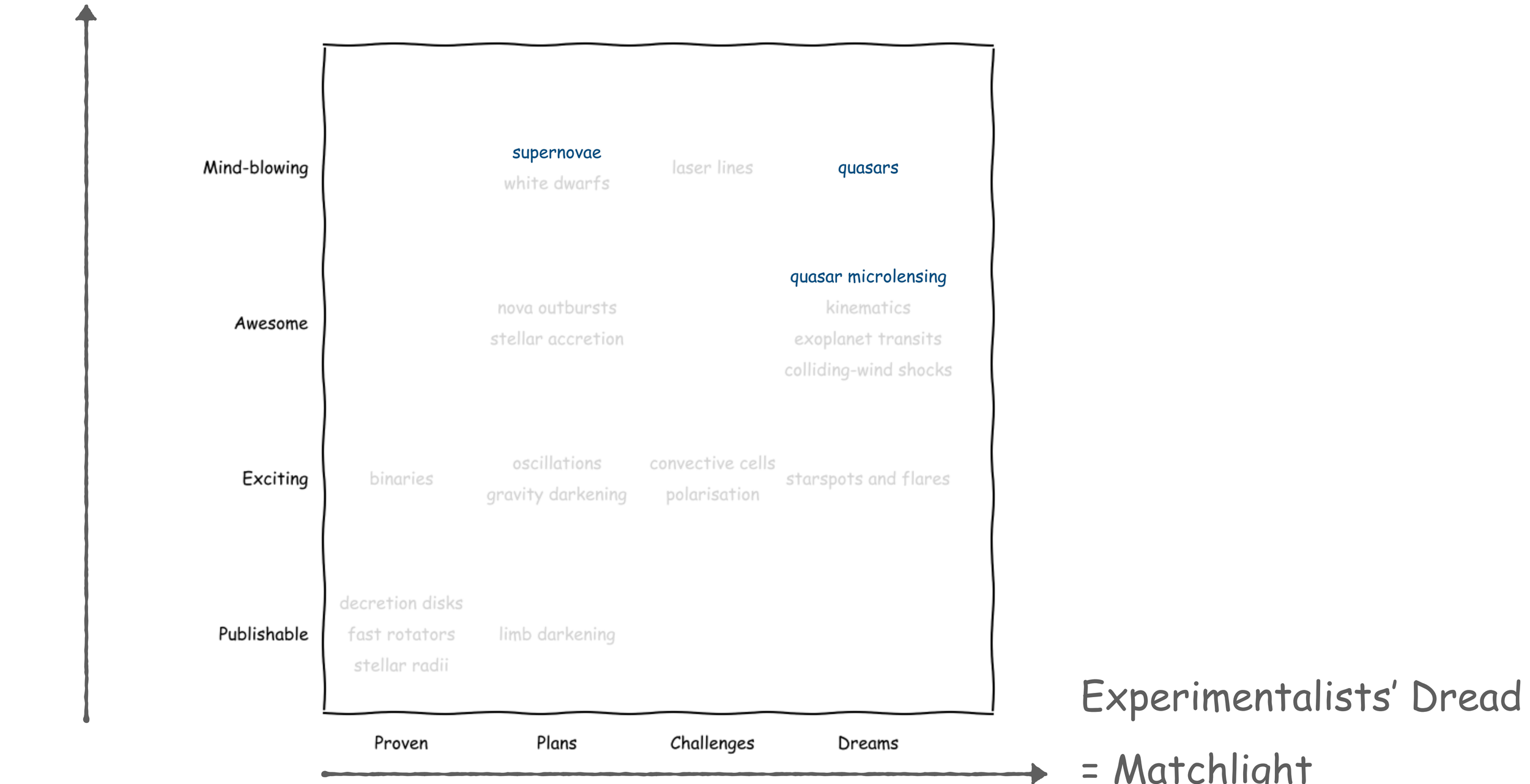

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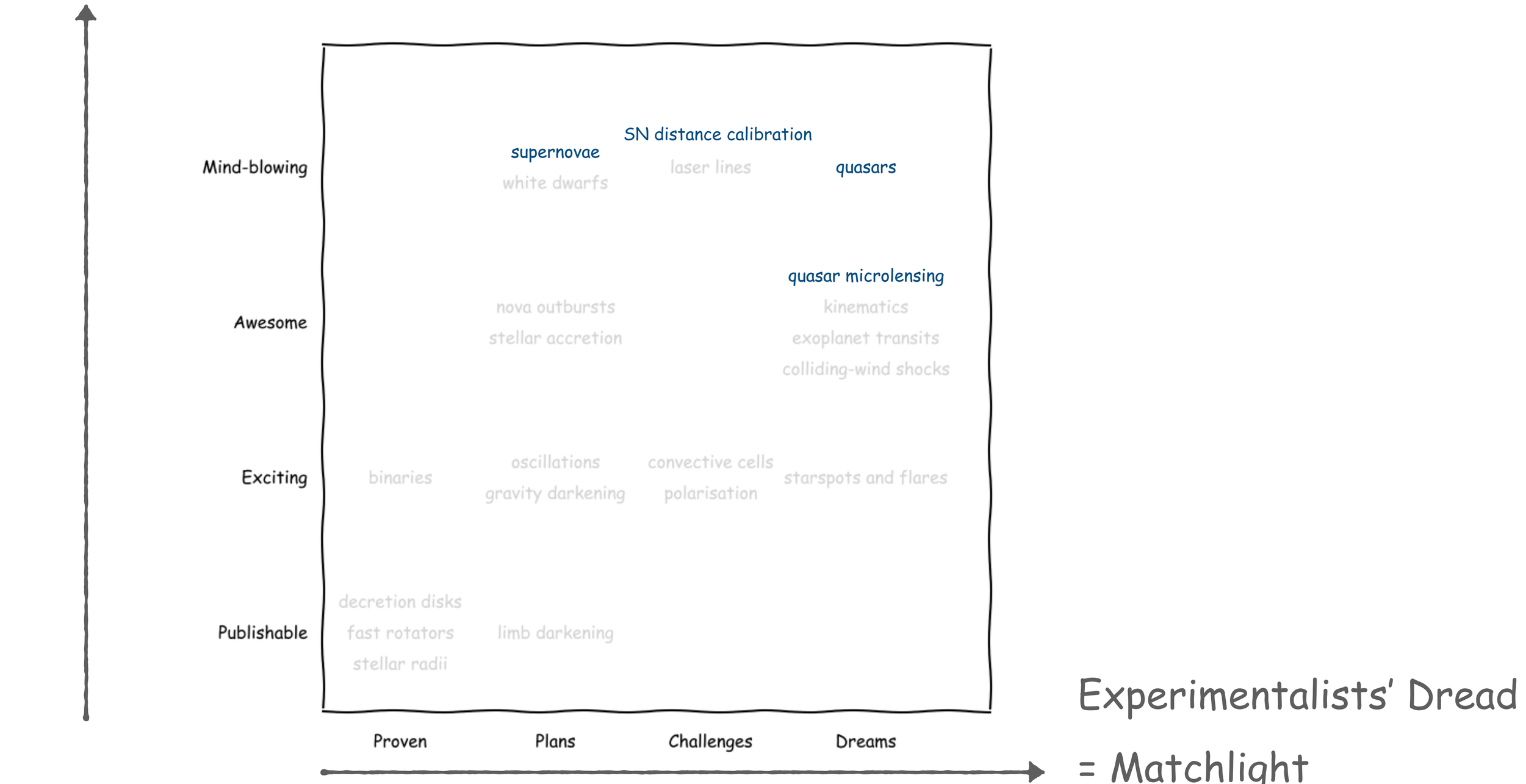

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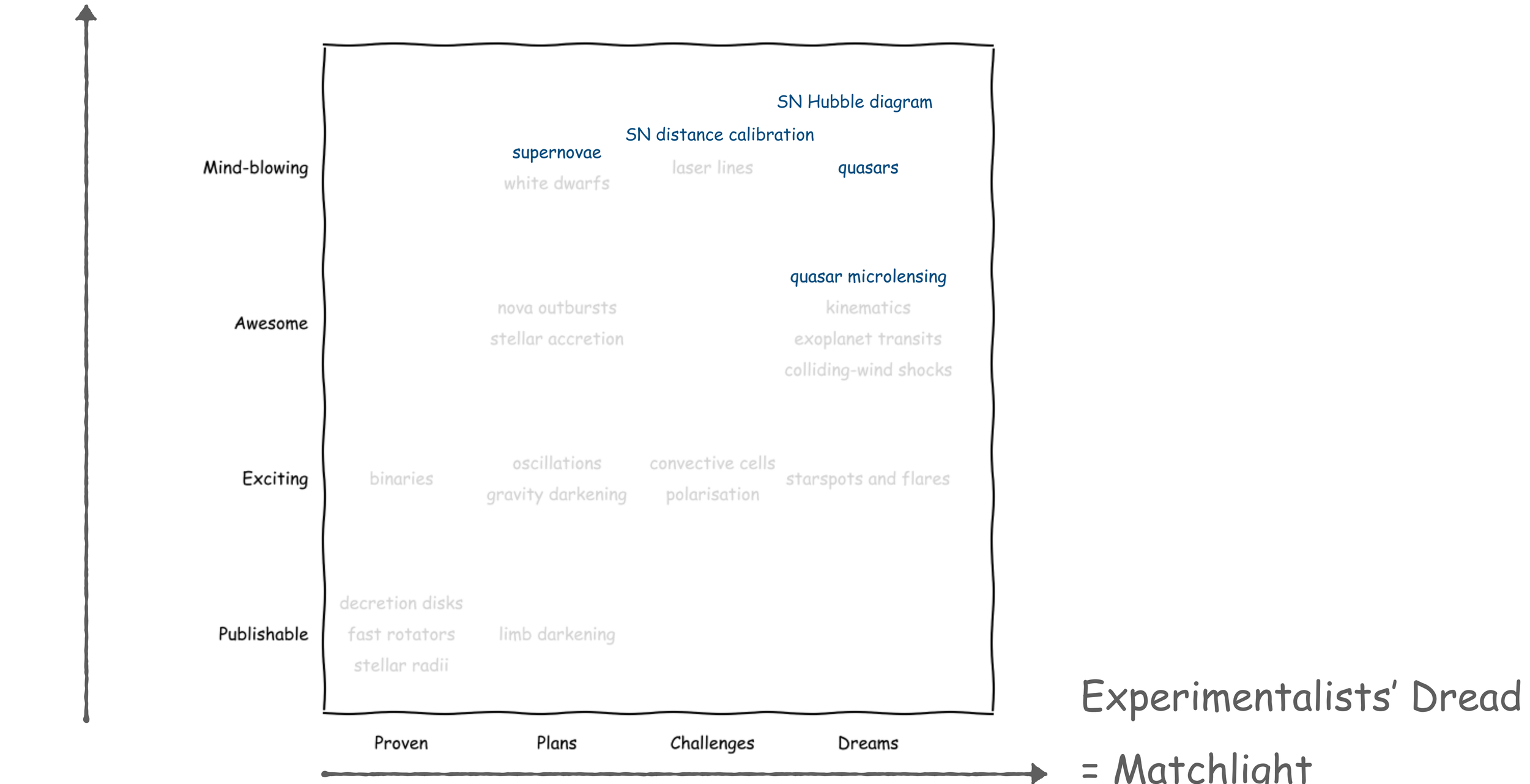

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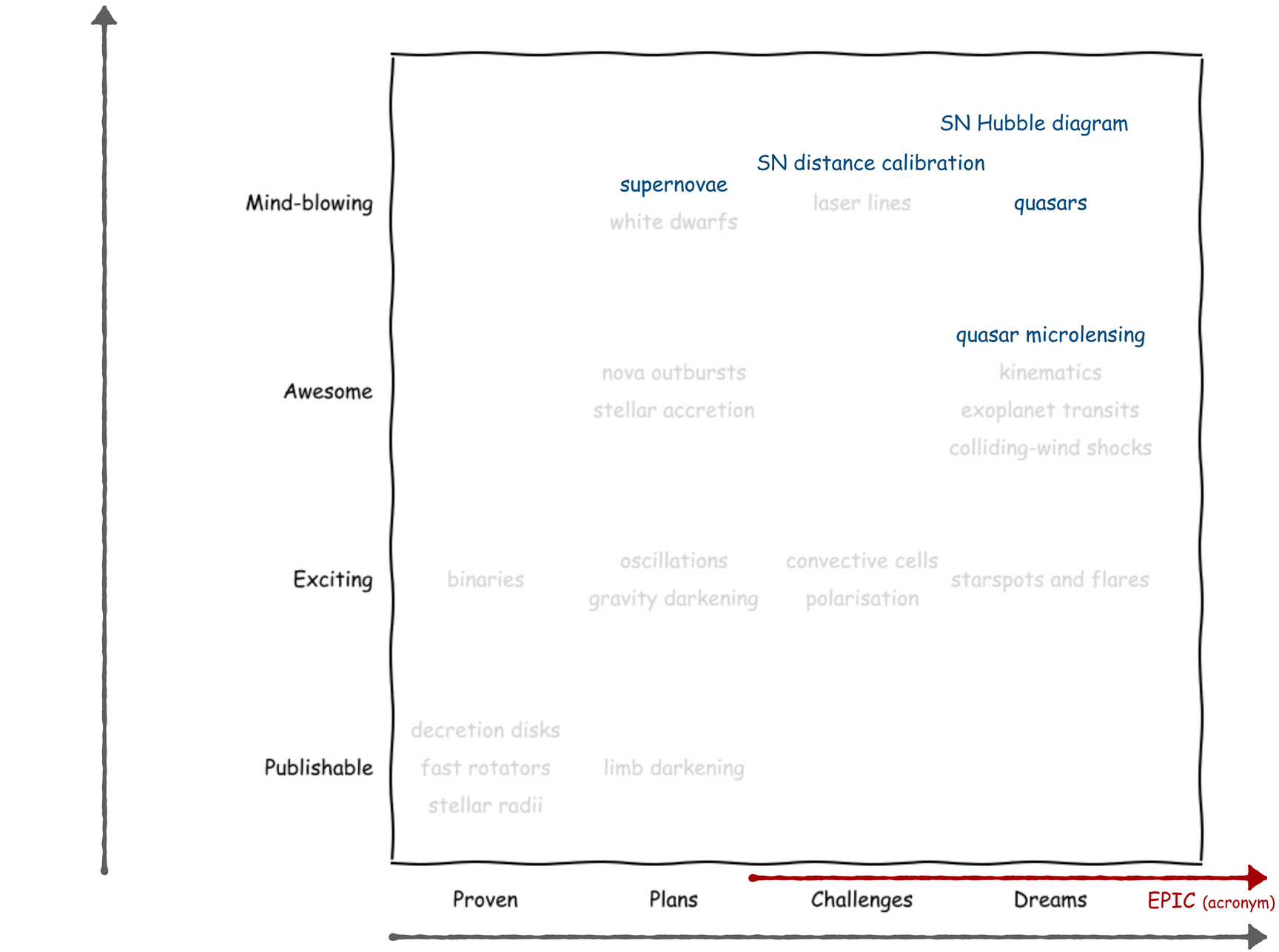

Experimentalists' Dread

= Matchlight + Complexity

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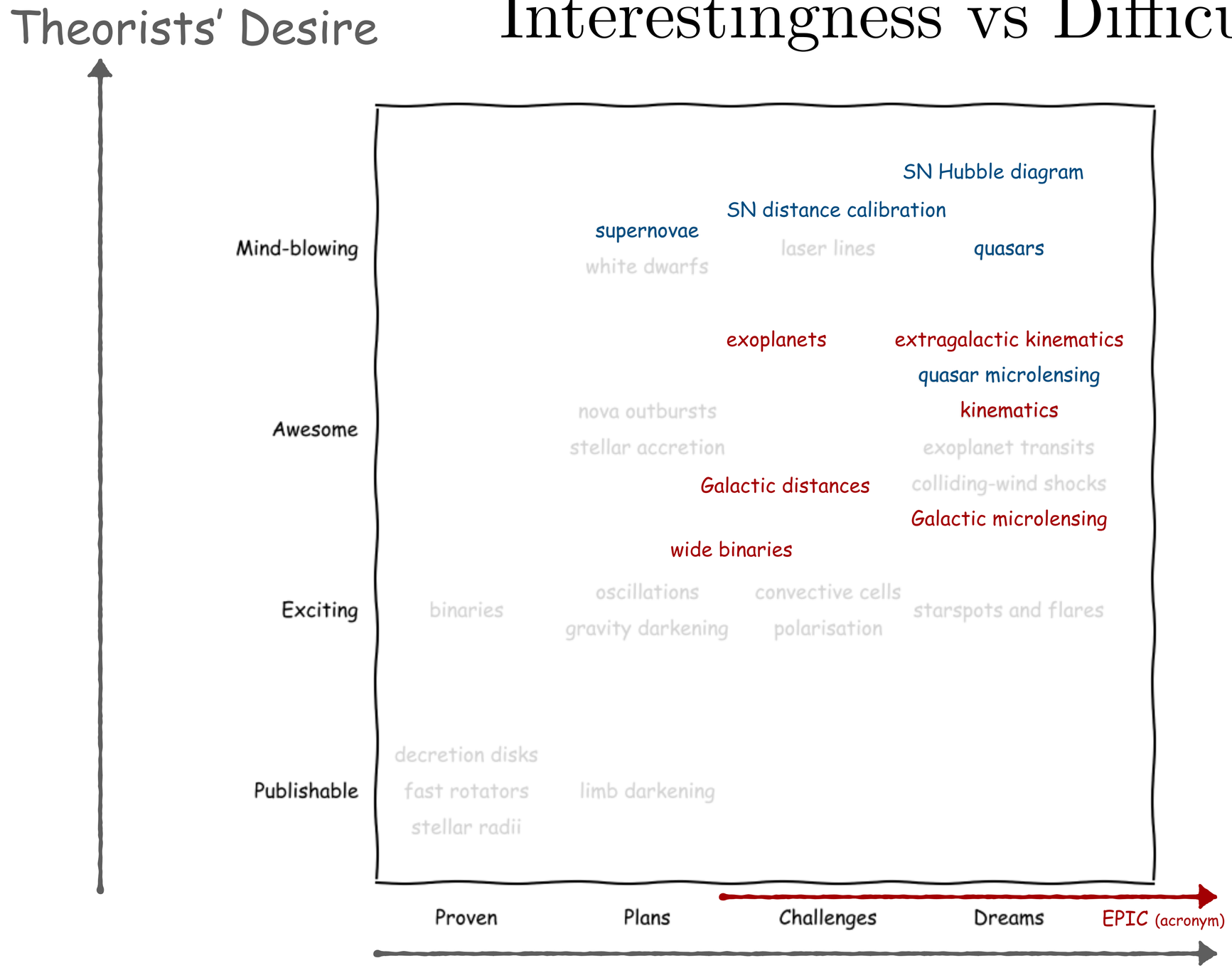

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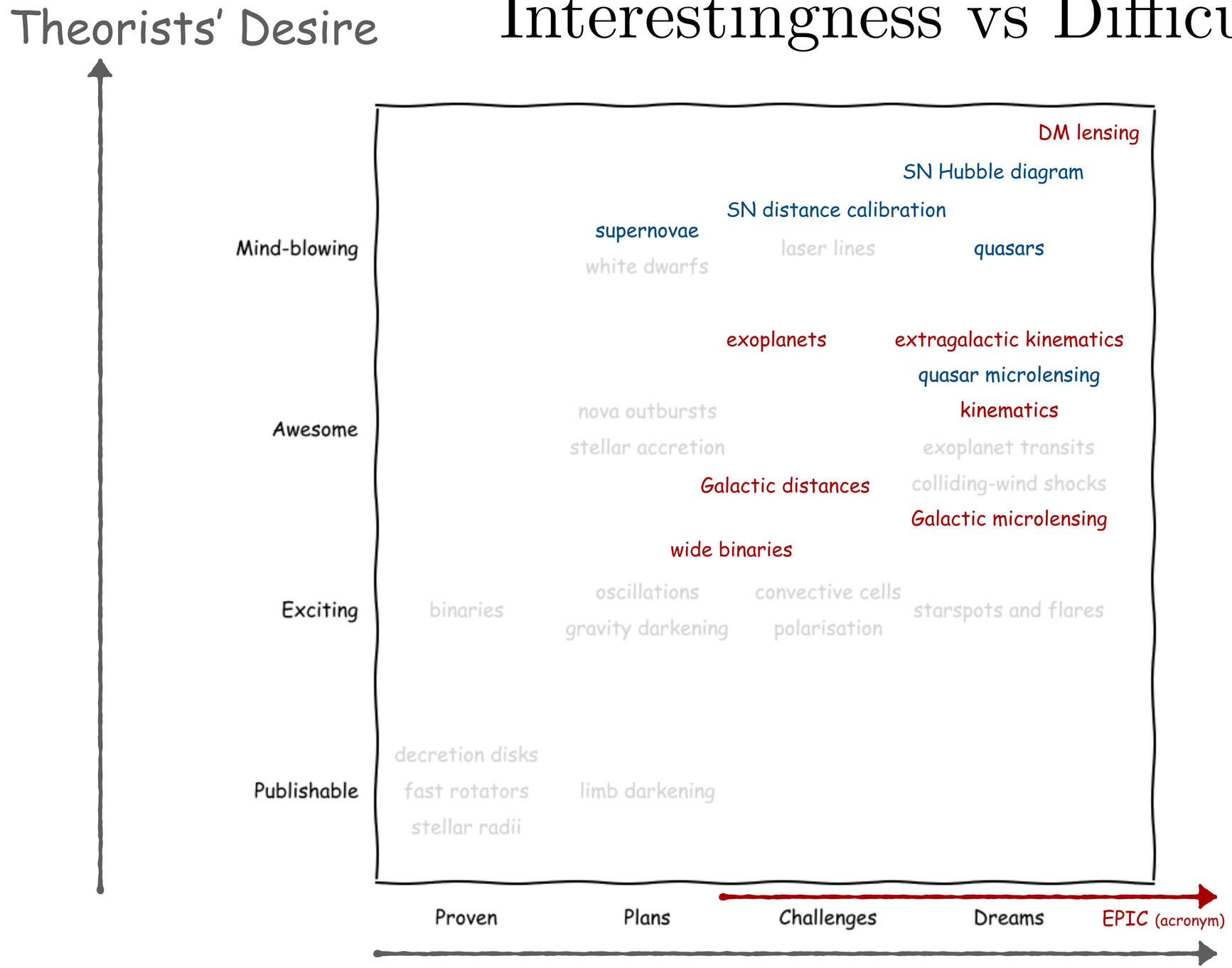

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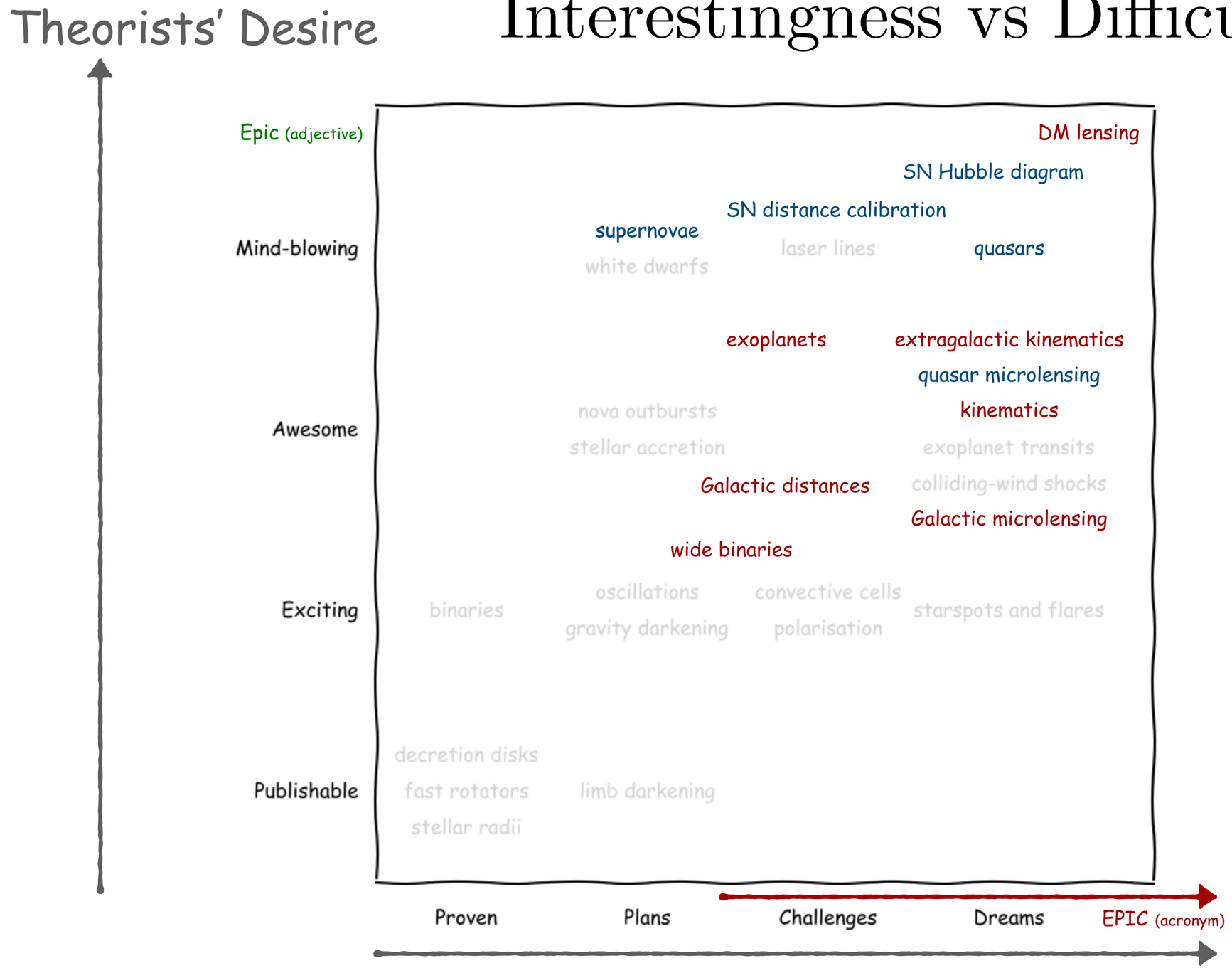

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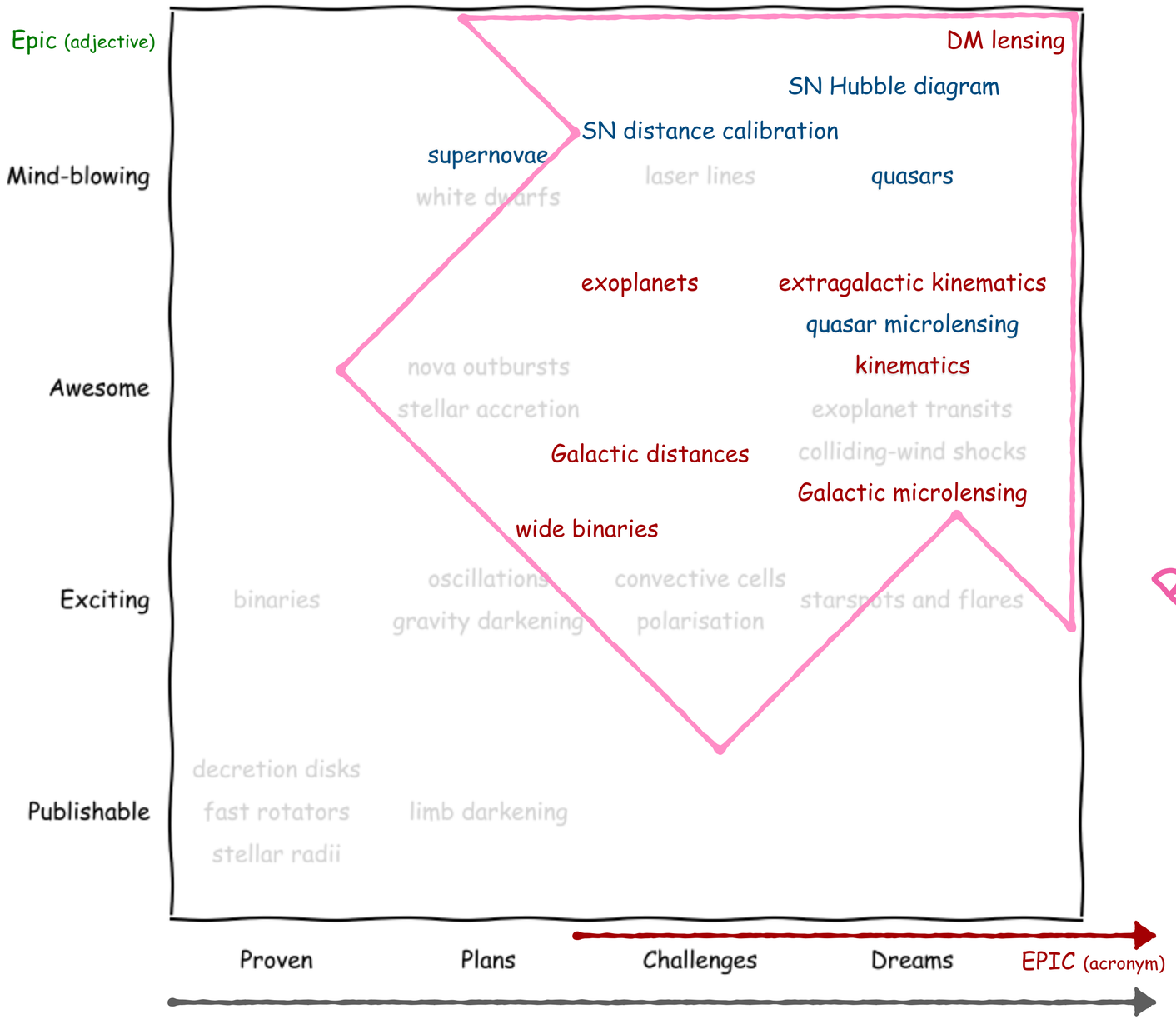
Theorists' Desire



Rosy Roadmap towards the Future

Experimentalists' Dread

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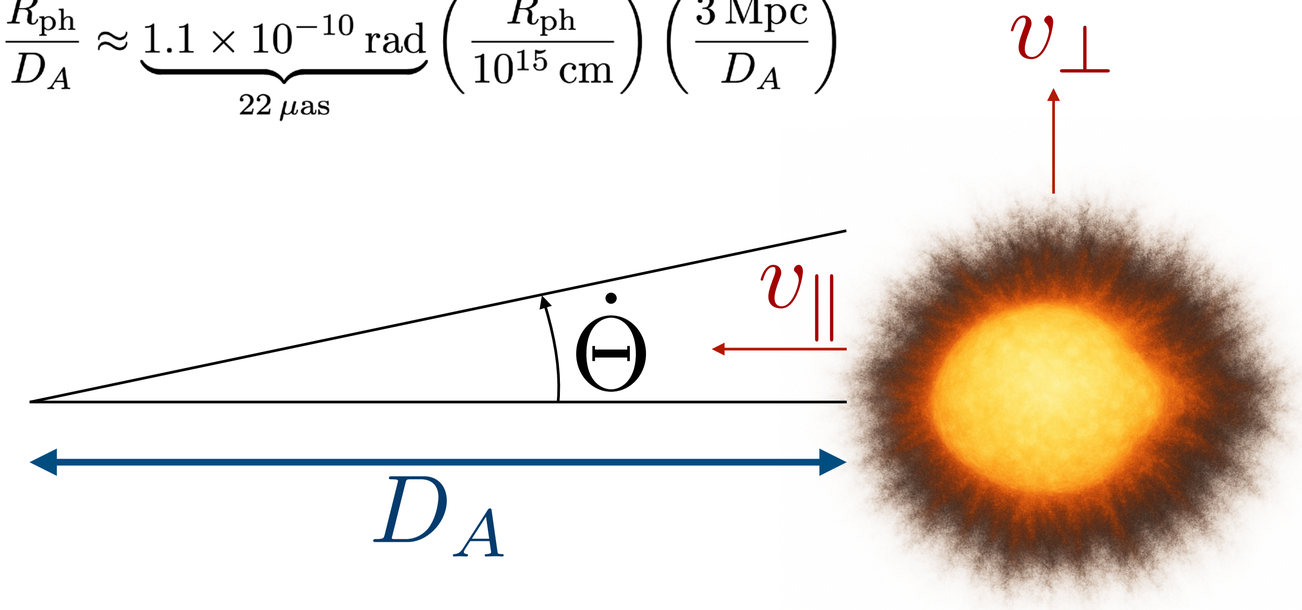
Expanding Ejecta Method (EEM)

$$\Theta_{\rm ph} = \frac{R_{\rm ph}}{D_A} \approx \underbrace{1.1 \times 10^{-10}\,{\rm rad}}_{22\,\mu{\rm as}} \left(\frac{R_{\rm ph}}{10^{15}\,{\rm cm}}\right)\left(\frac{3\,{\rm Mpc}}{D_A}\right)$$



$$D_A \simeq \frac{\dot{\Theta}}{v_\perp}$$

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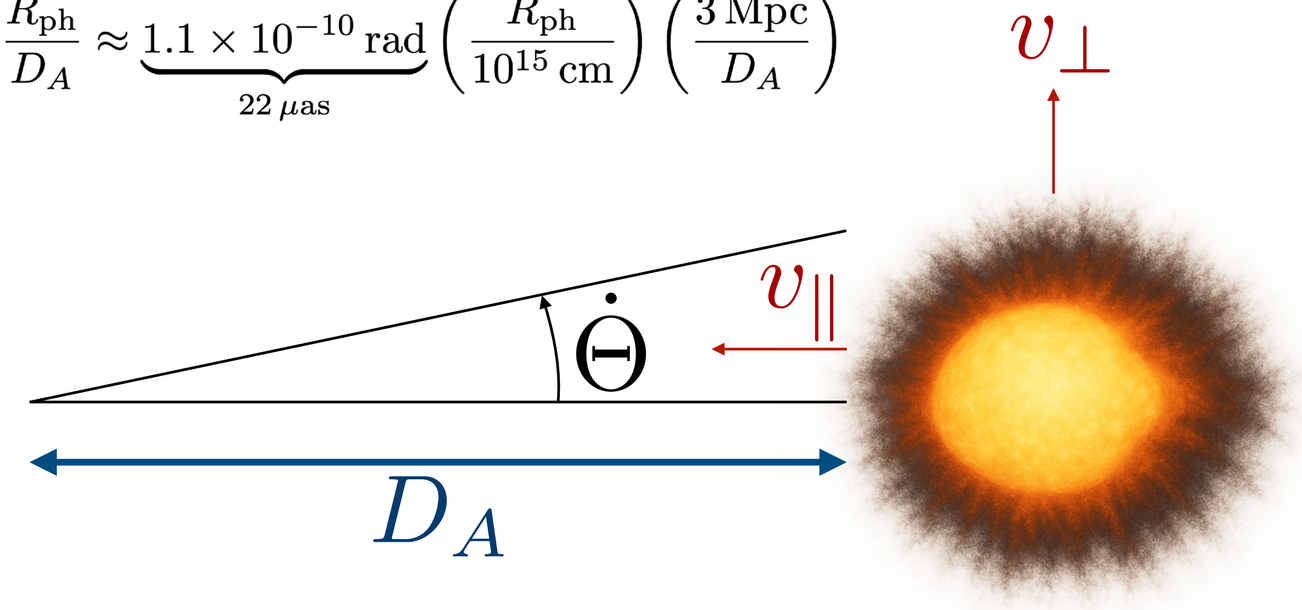

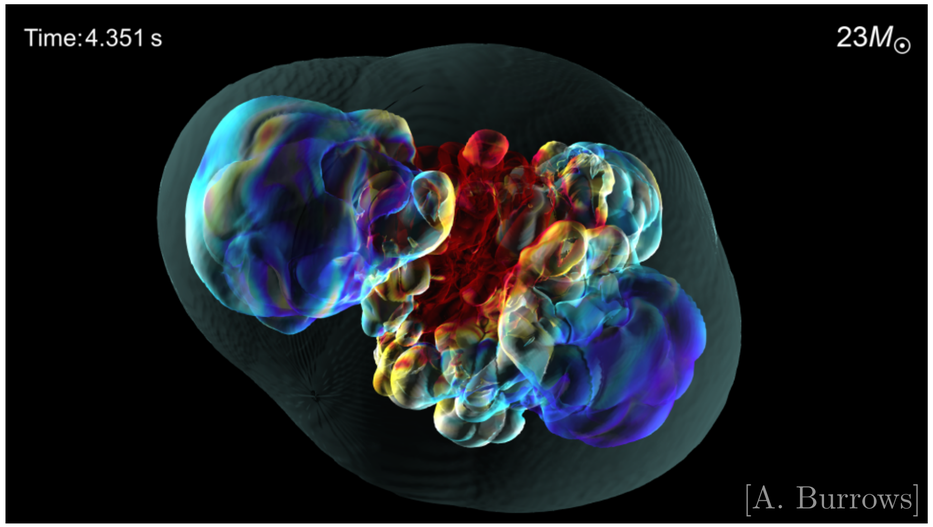

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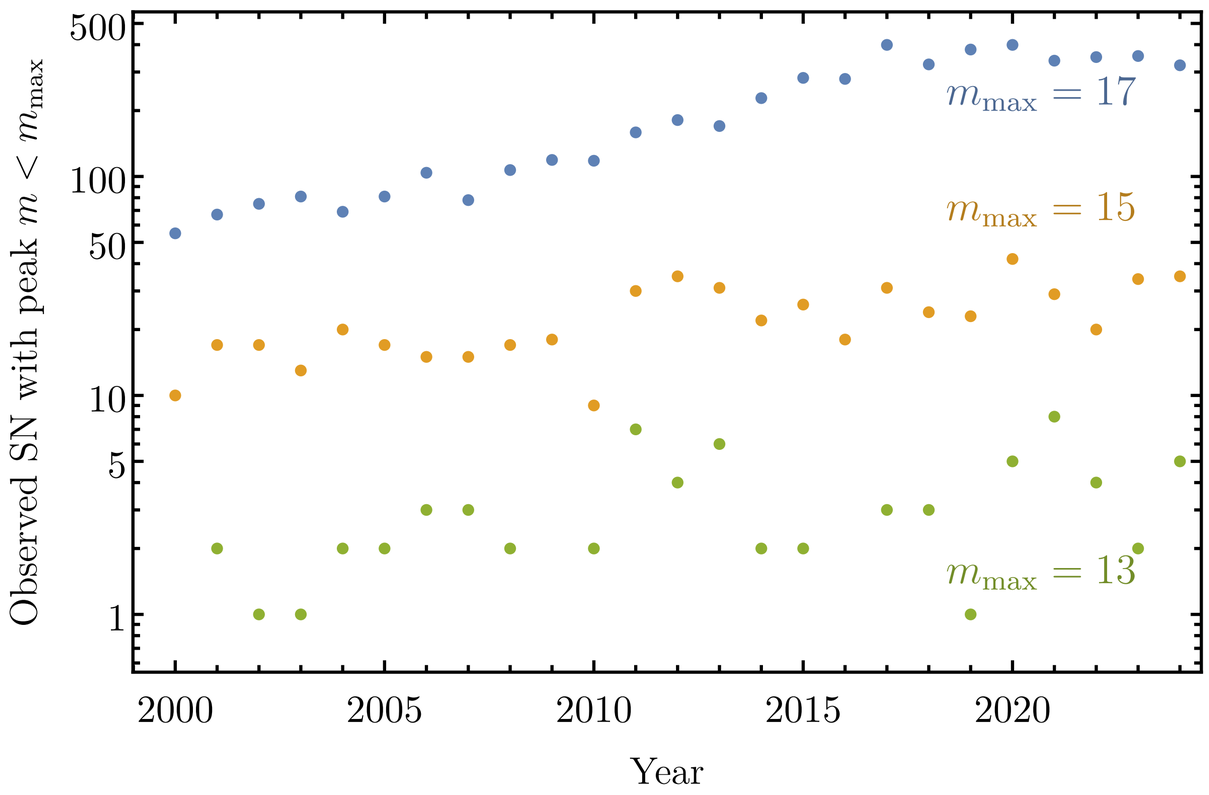
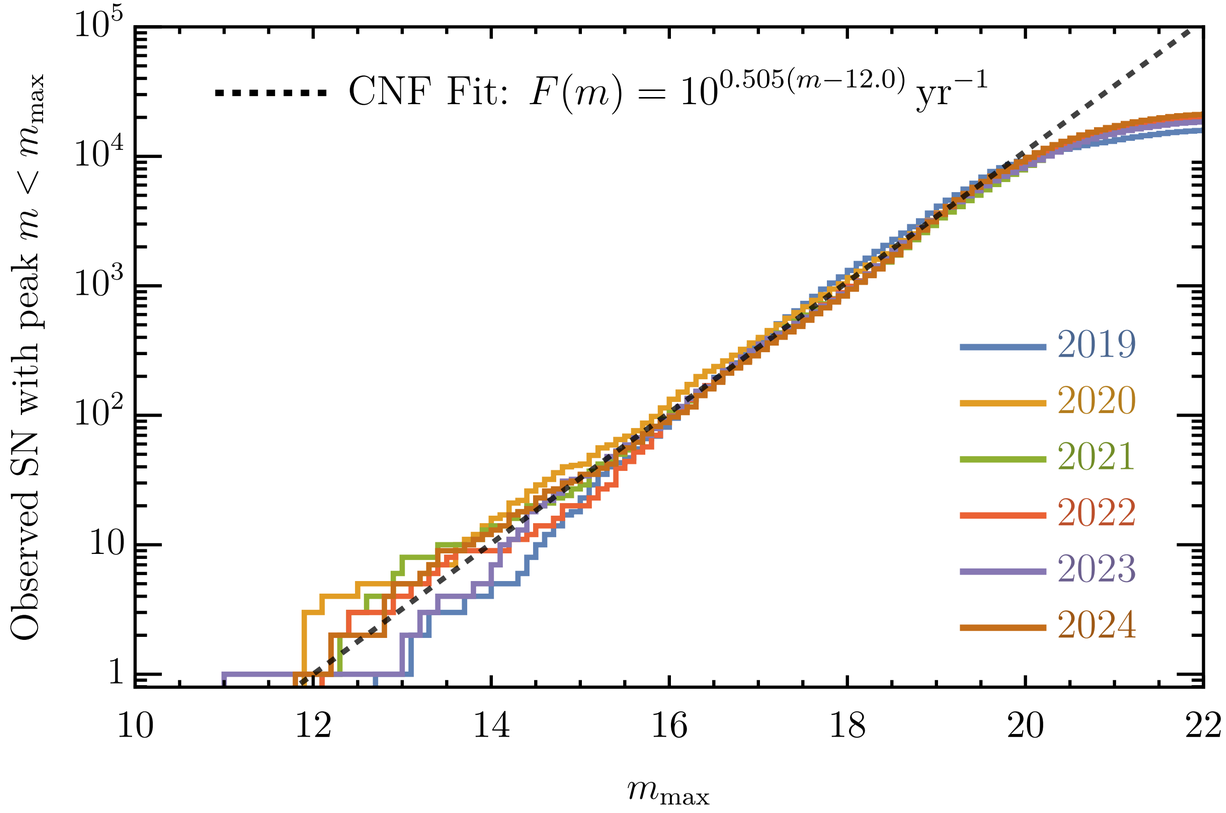
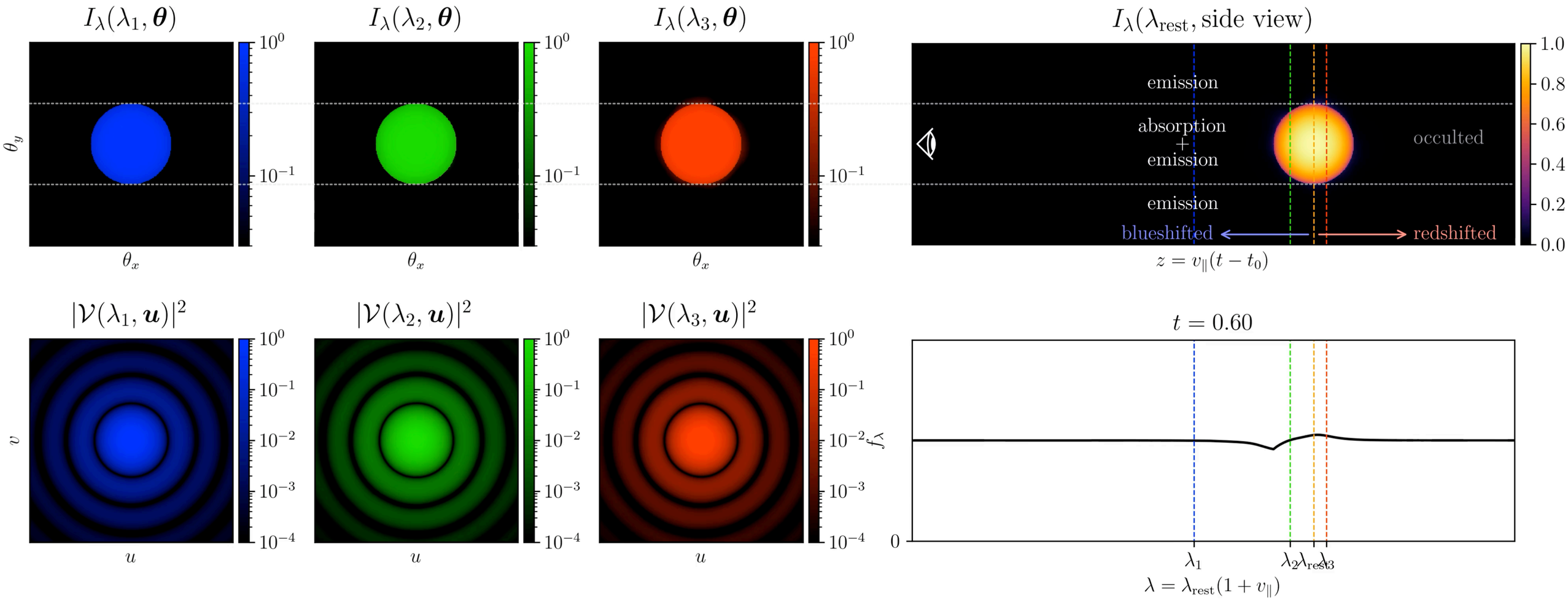
Supernova Census





EEM: Observables



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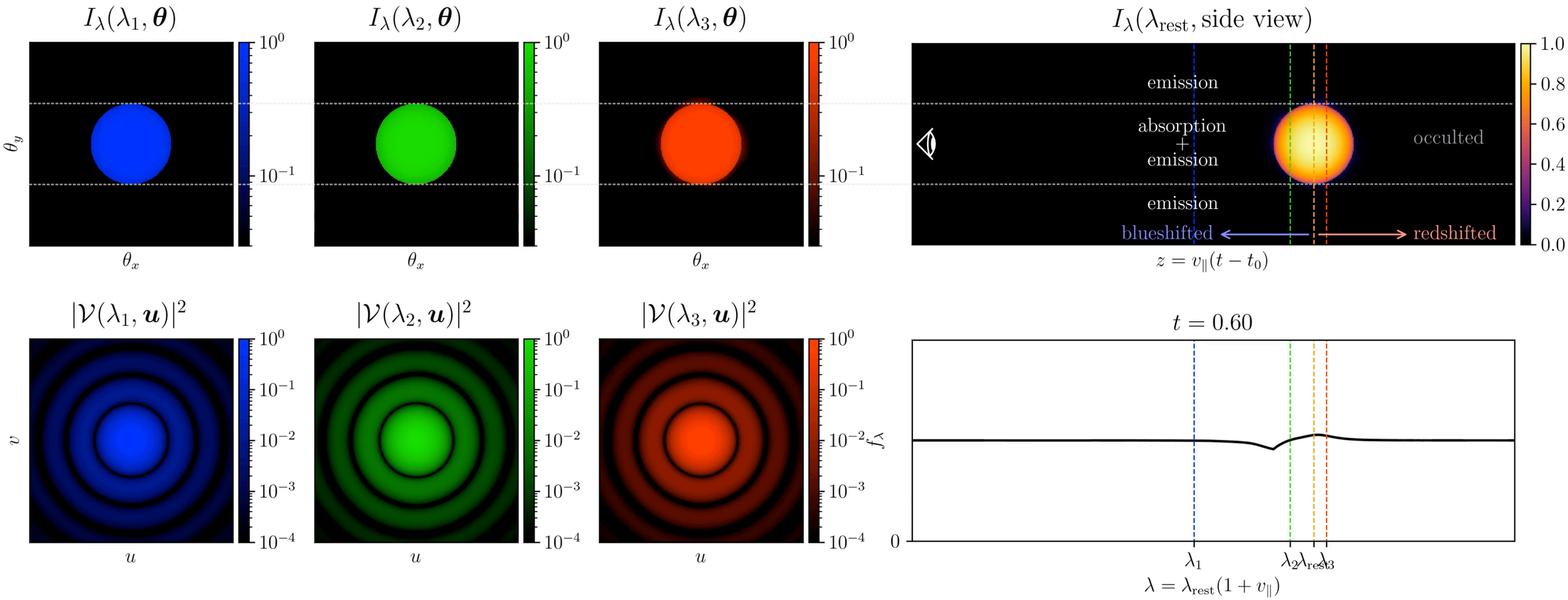
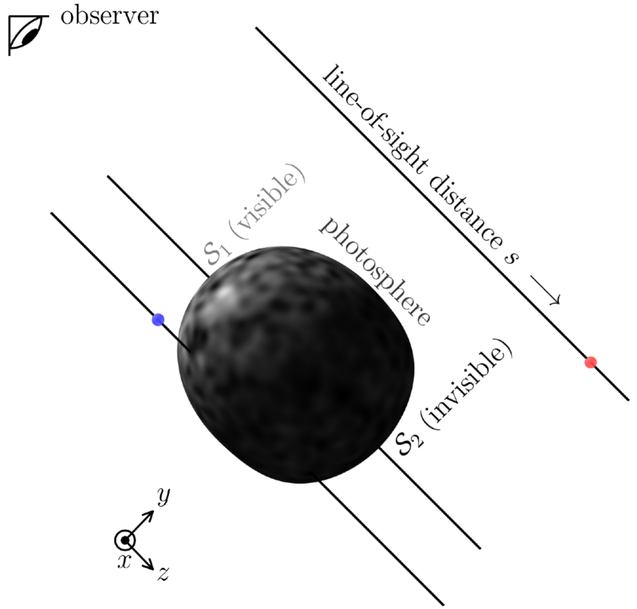
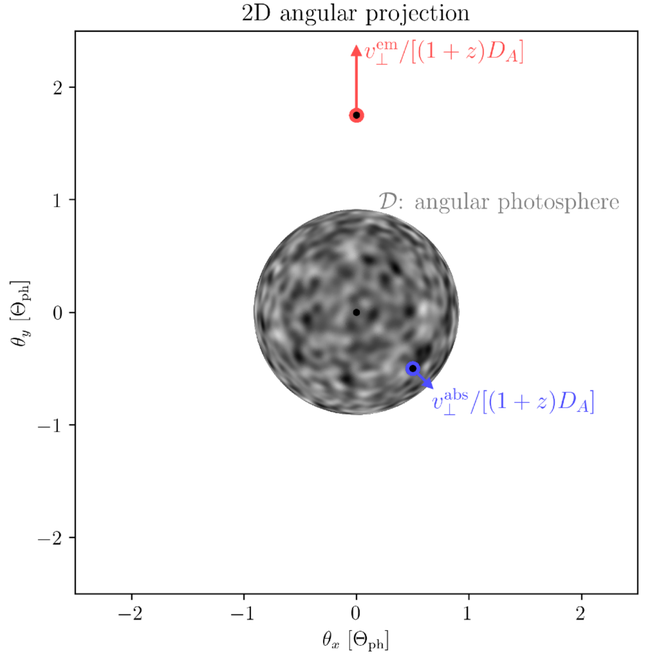
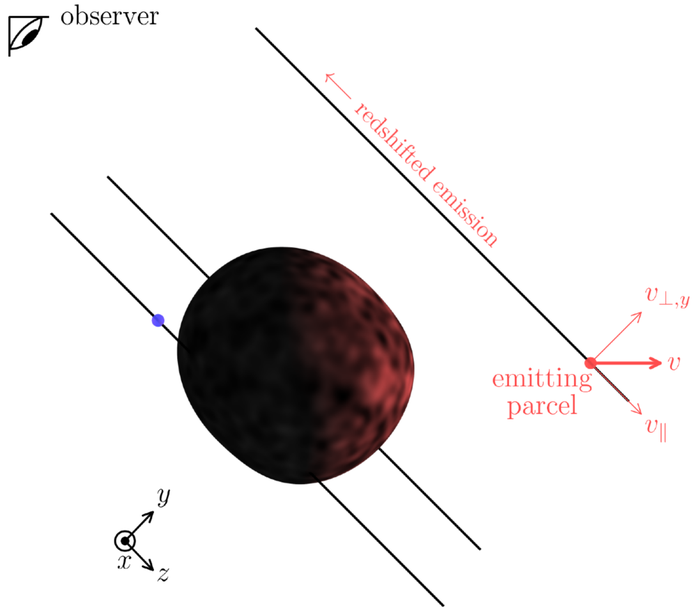
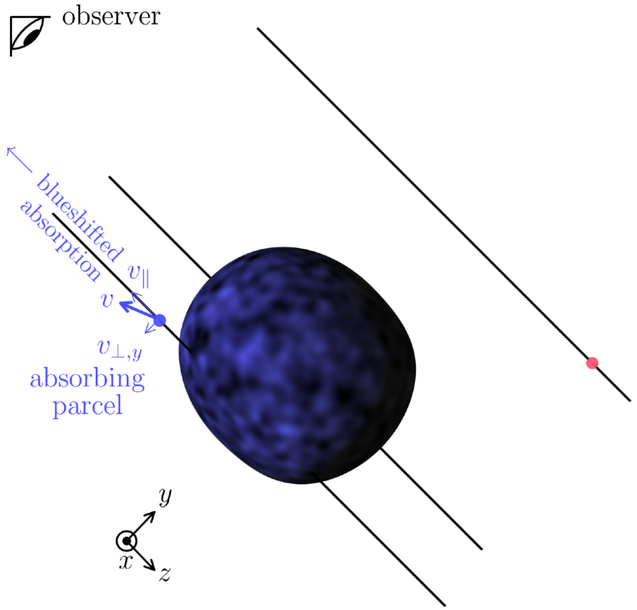


Photosphere and Ejecta

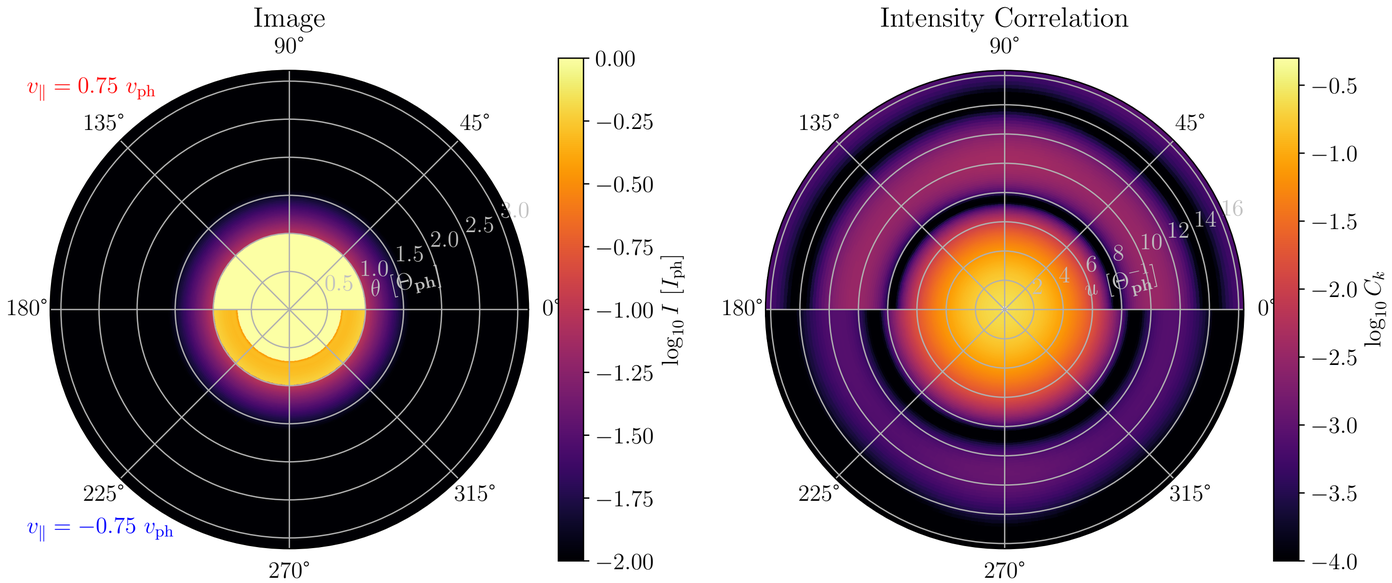


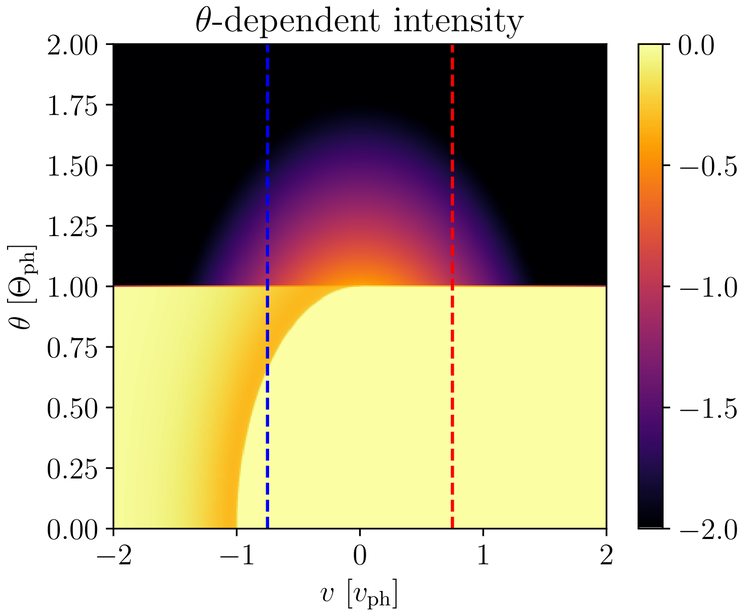


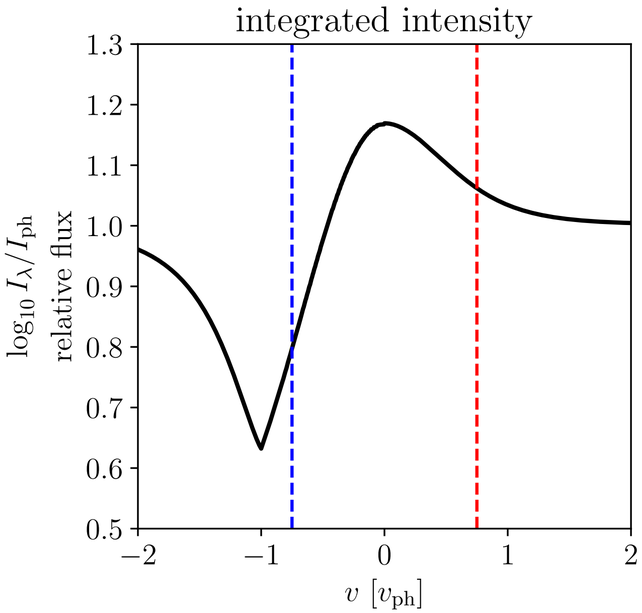




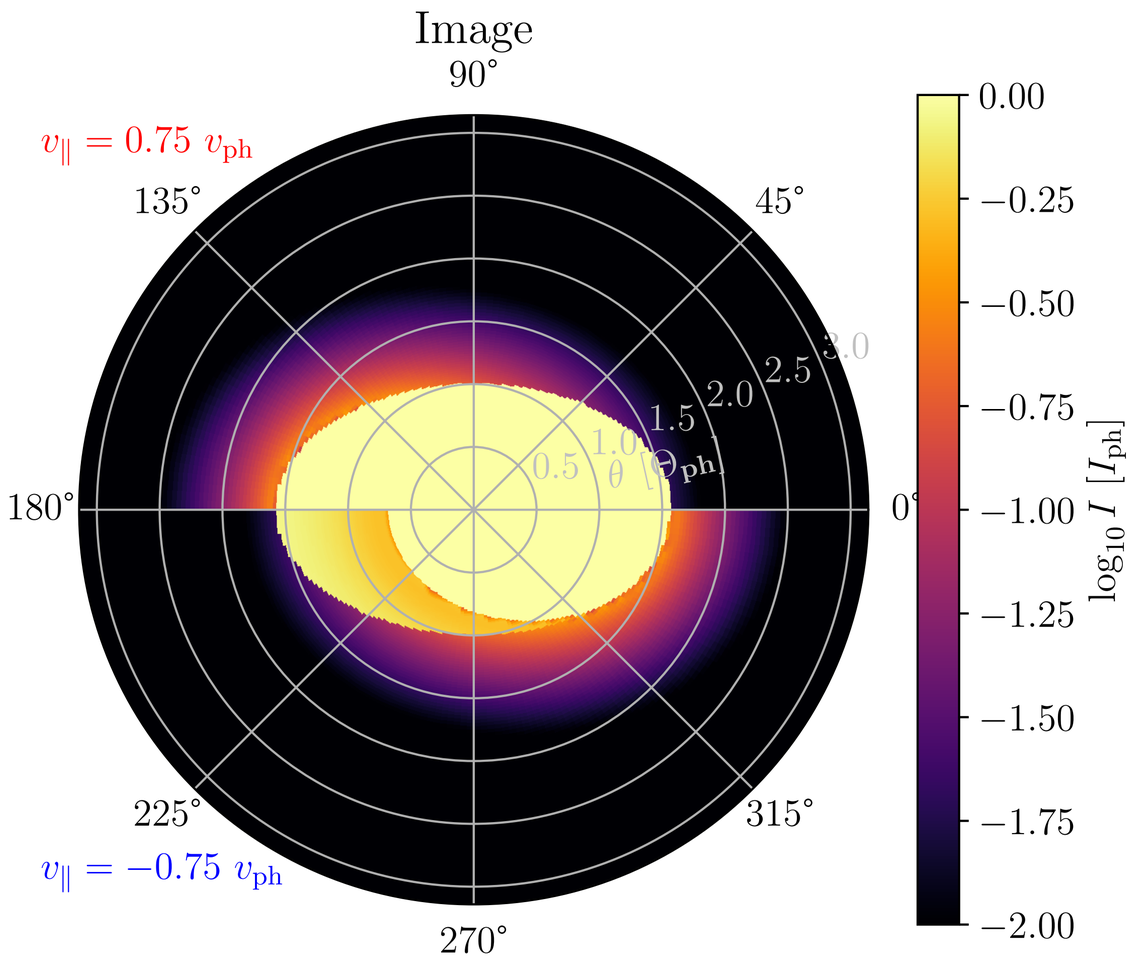
Spherical Supernova

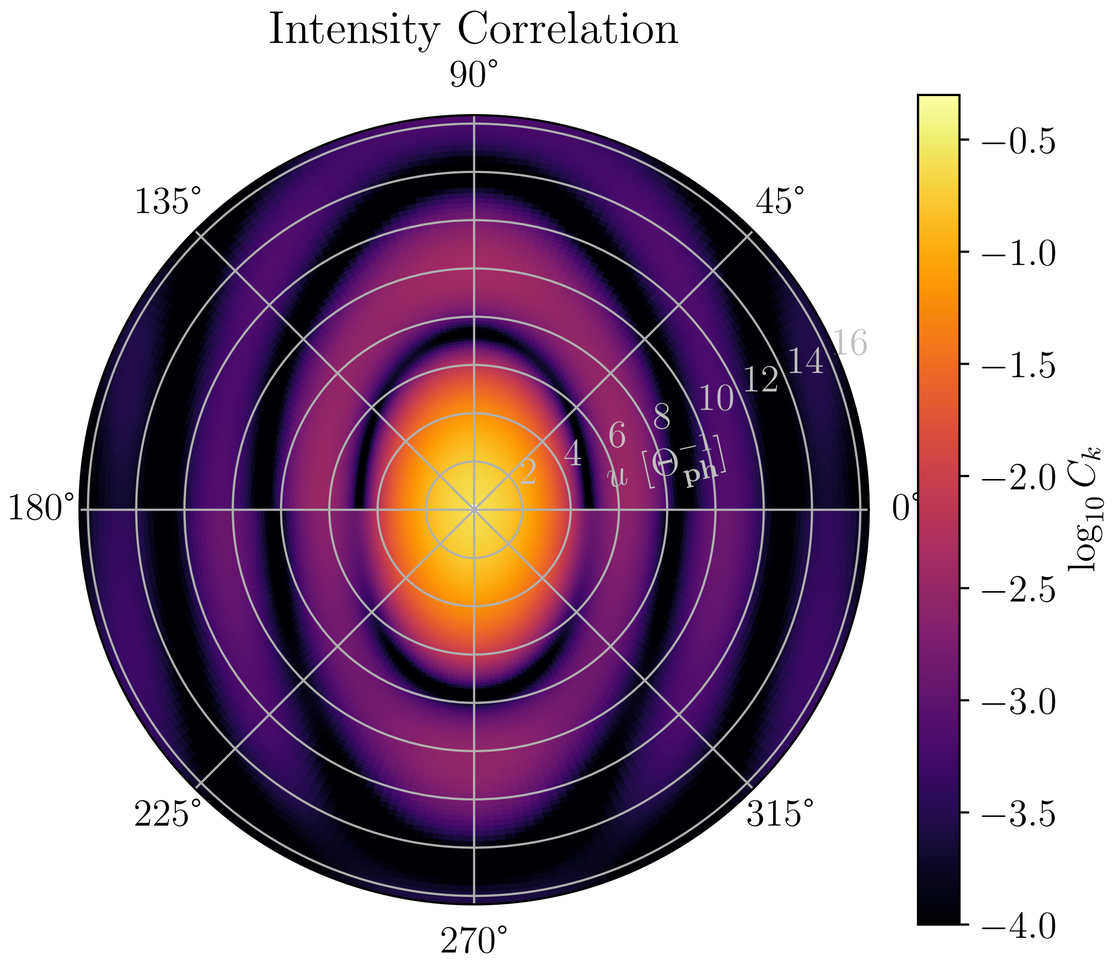




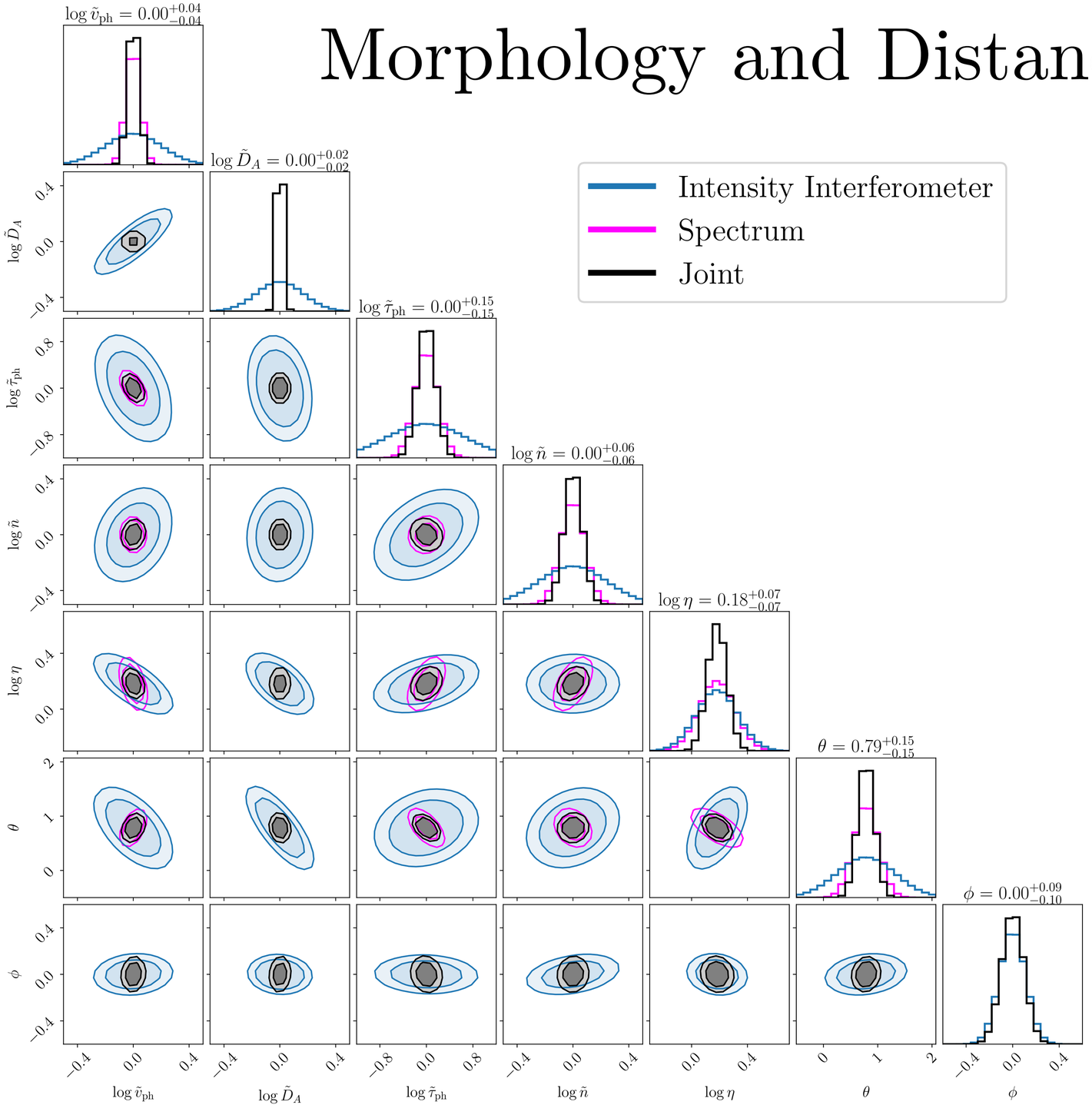


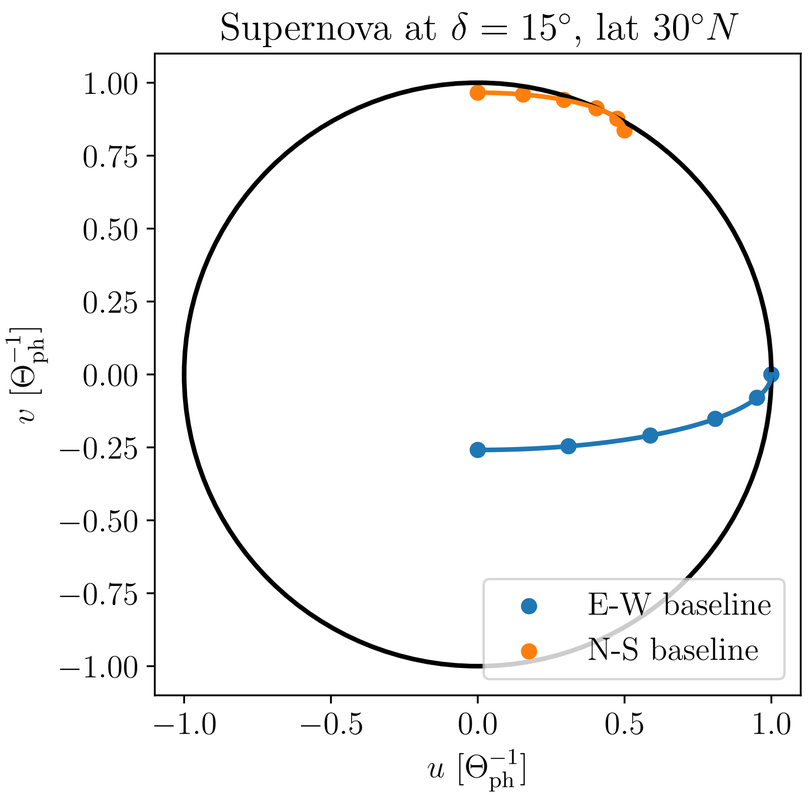
Ellipsoidal Supernova



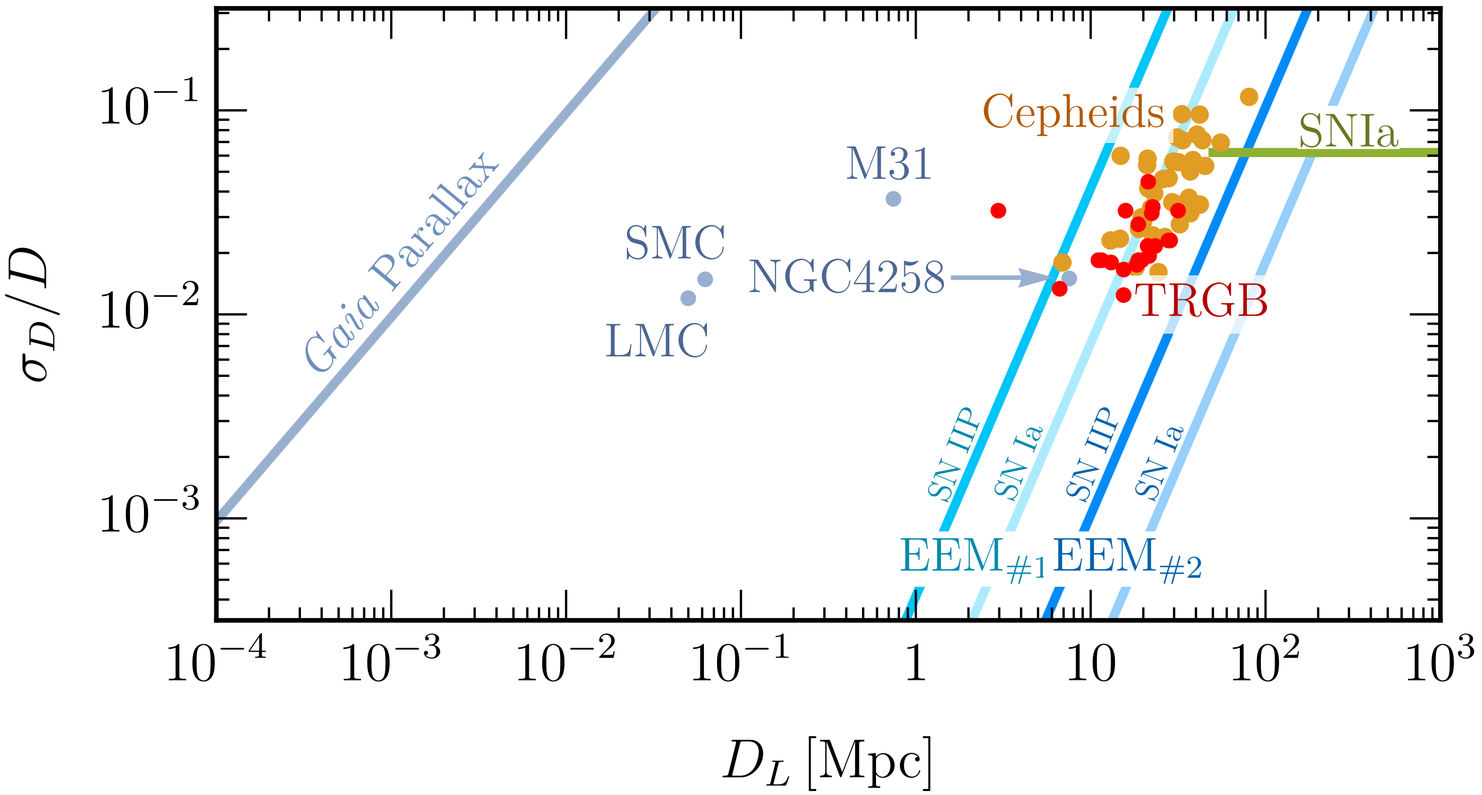


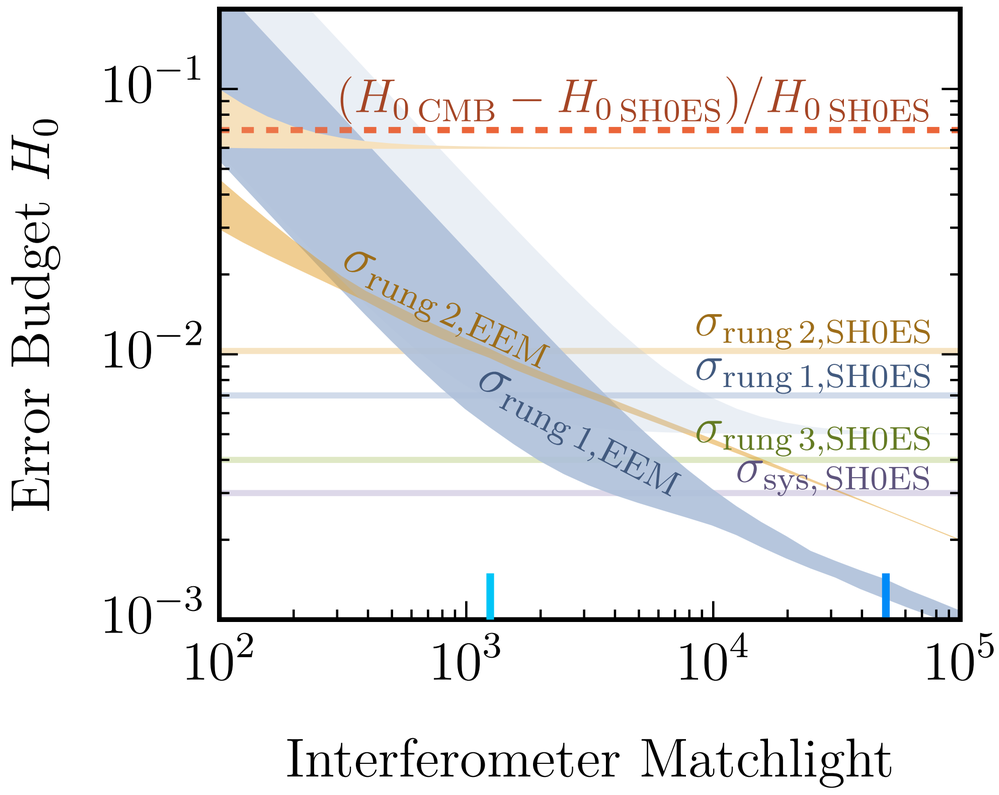
Morphology and Distance Inference





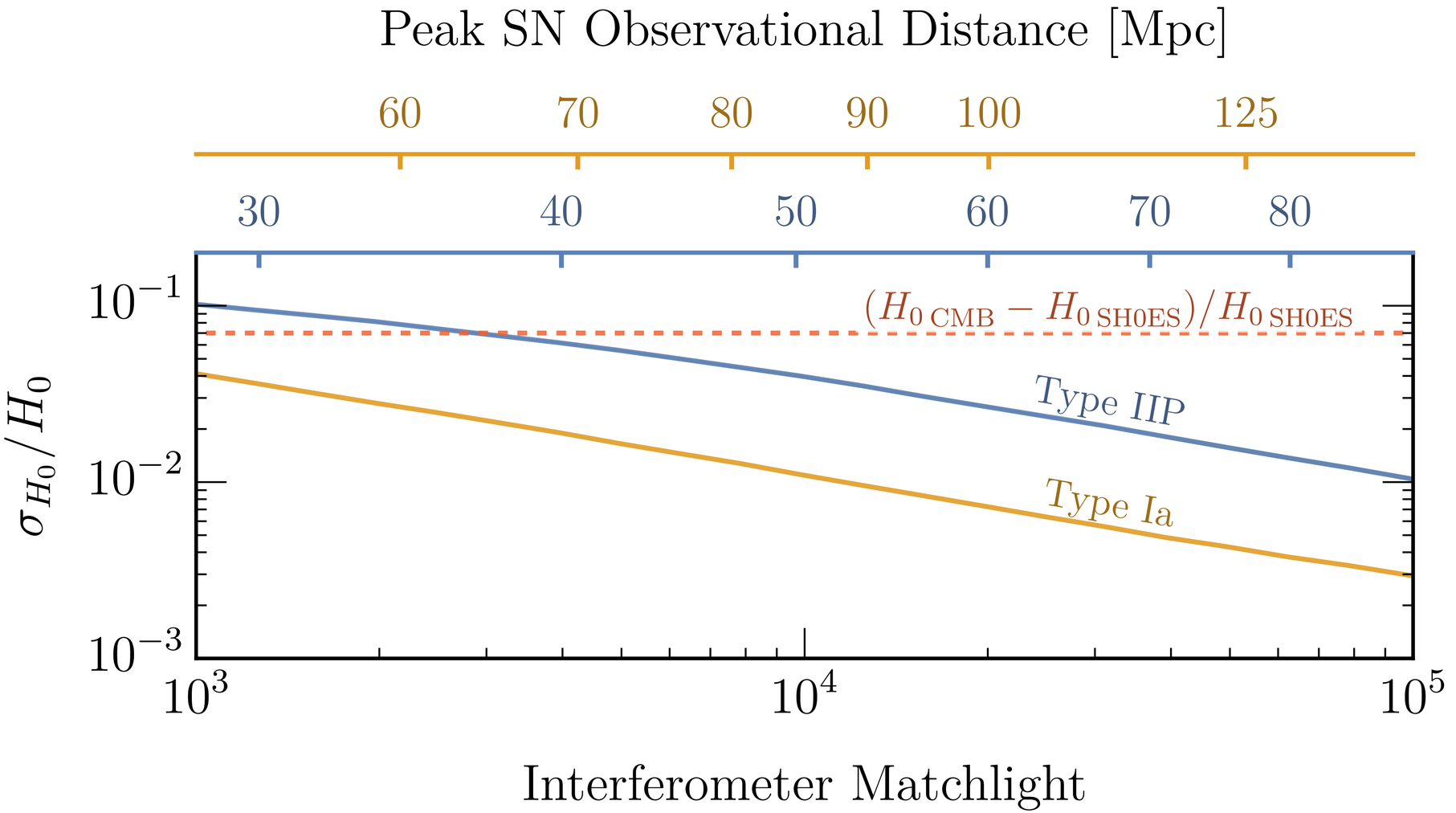
Distance Precision + Cosmic Distance Ladder Calibration



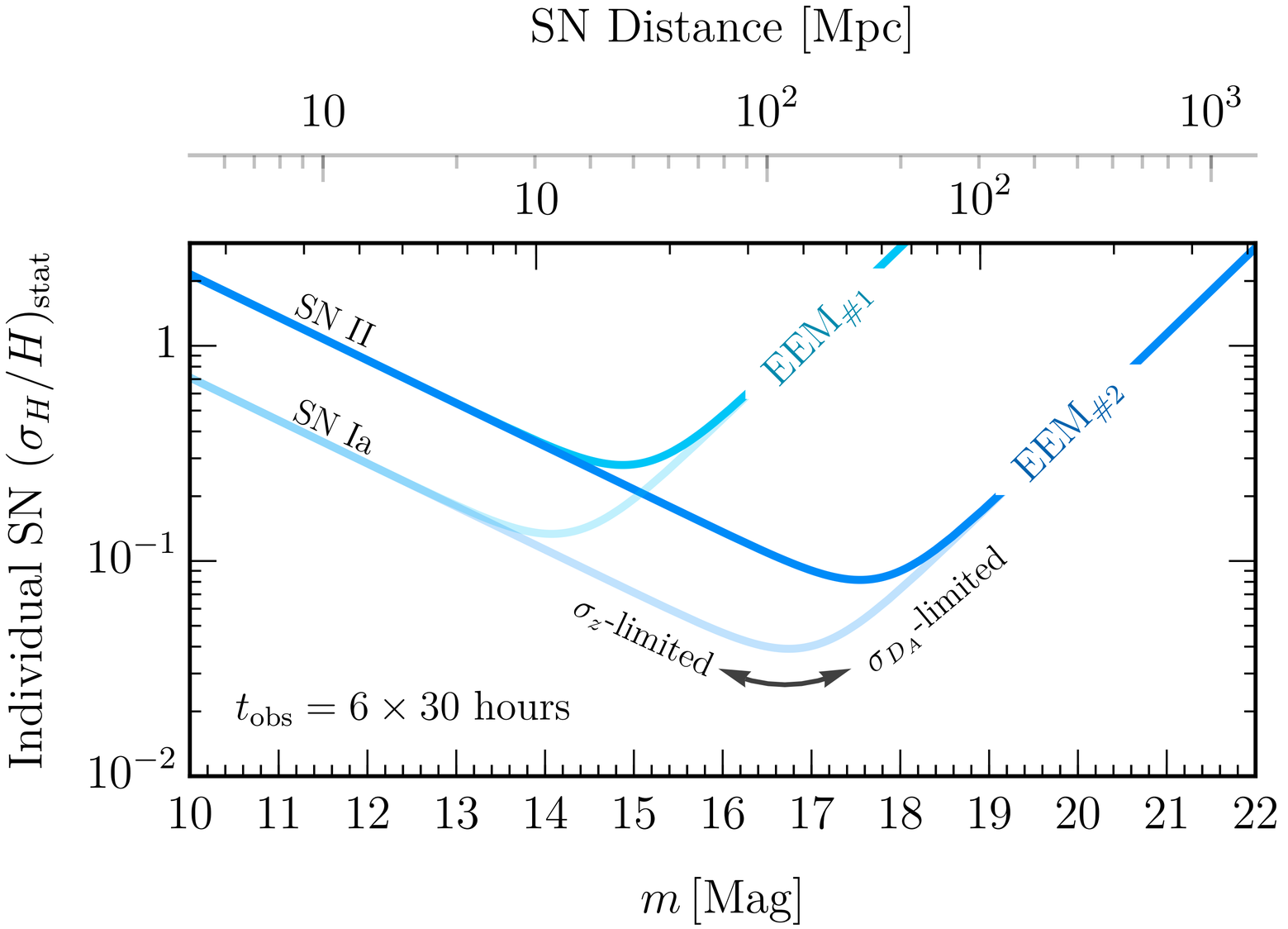


$$\text{Matchlight} \equiv \left(\frac{\sigma_t}{1\,\text{ps}}\right)^{-\frac{1}{2}} \left(\frac{A}{1\,\text{m}^2}\right) \left(\frac{\mathcal{R}}{1}\right)^{\frac{1}{2}} \left(\frac{\epsilon}{1}\right)$$

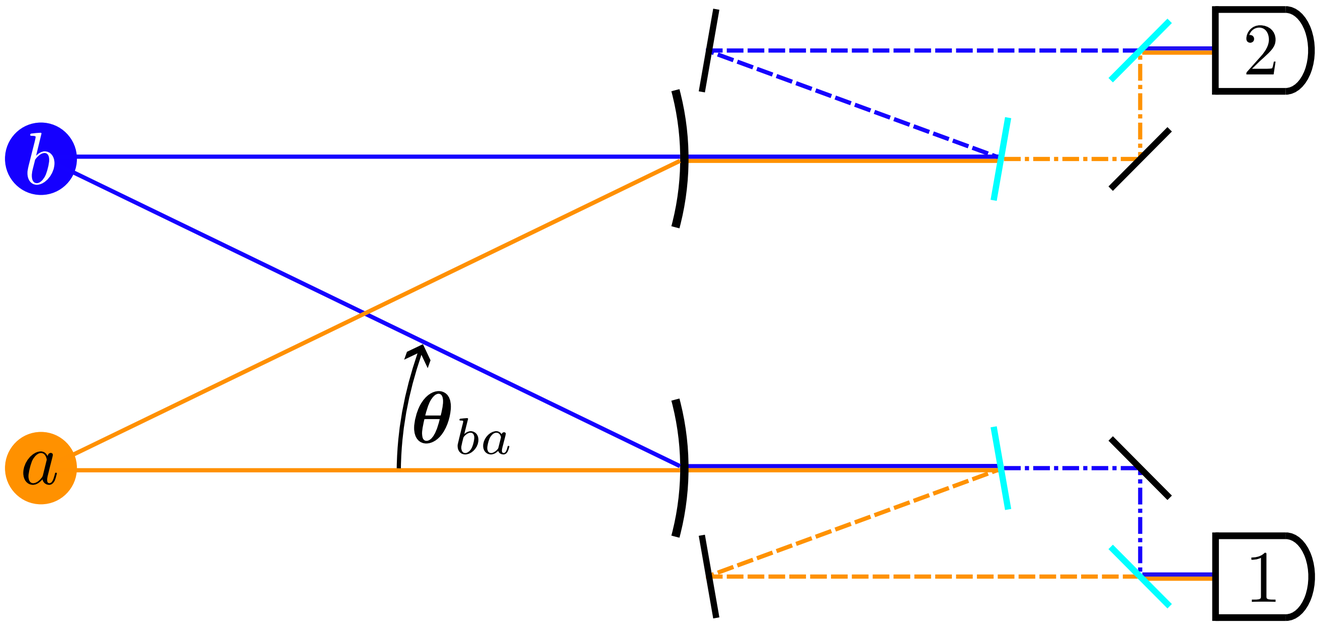
Independent, Geometric Hubble Diagram



Individual Supernova Hubble Inference



Extended-Path Intensity Correlation (EPIC)



✅ differential astrometry over “large” field of view

Masha Baryakhtar

Marios Galanis

Neal Weiner

[KVT, M. Baryakhtar, M. Galanis, N. Weiner; arXiv:2307.03221]

[M. Galanis, KVT, M. Baryakhtar, N. Weiner; arXiv:2307.06989]

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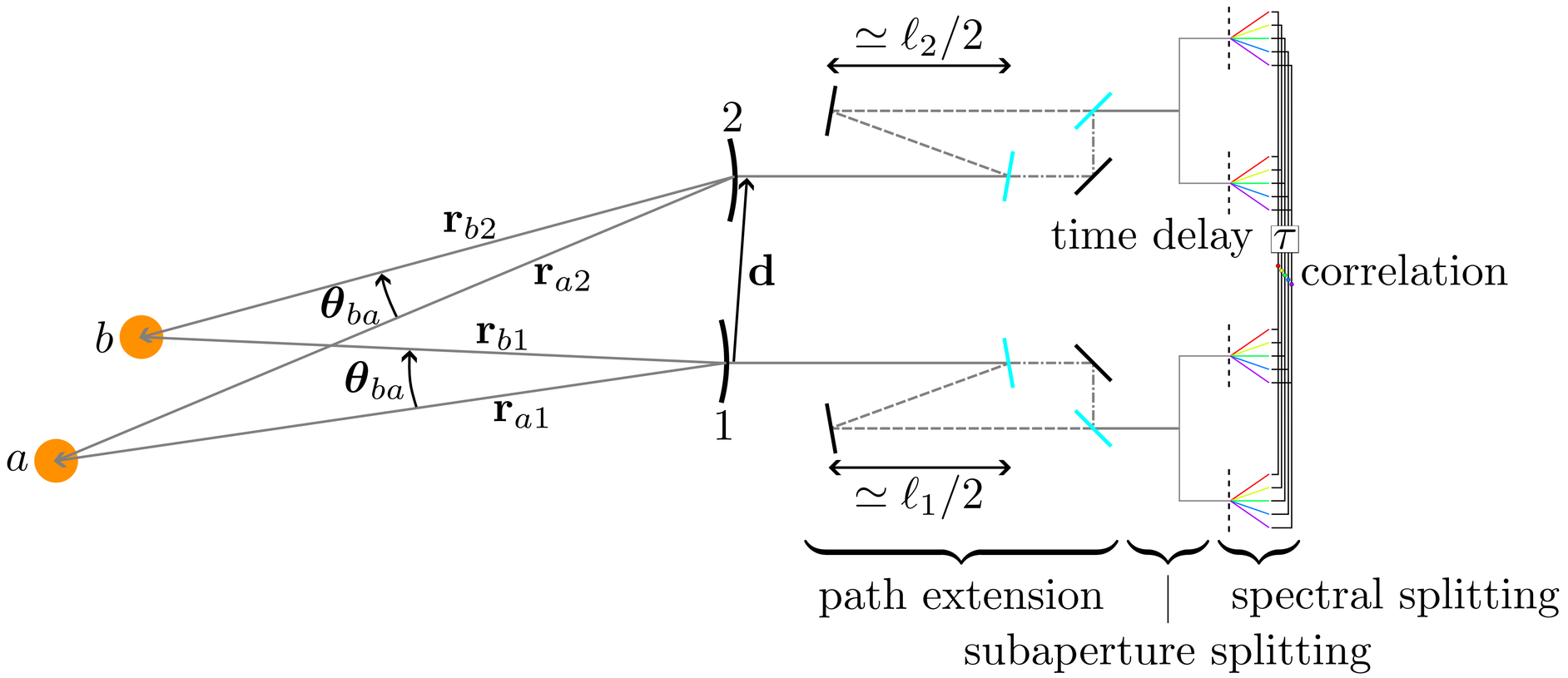

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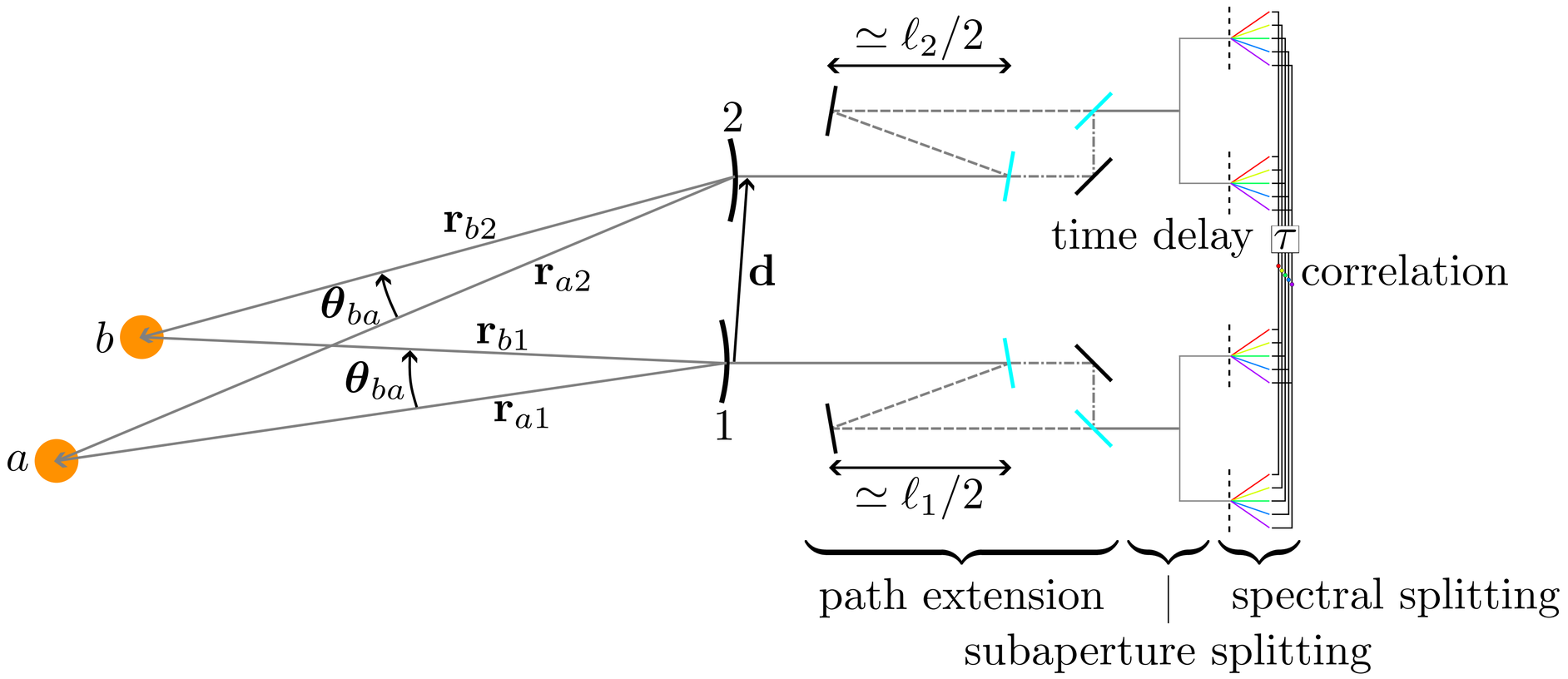

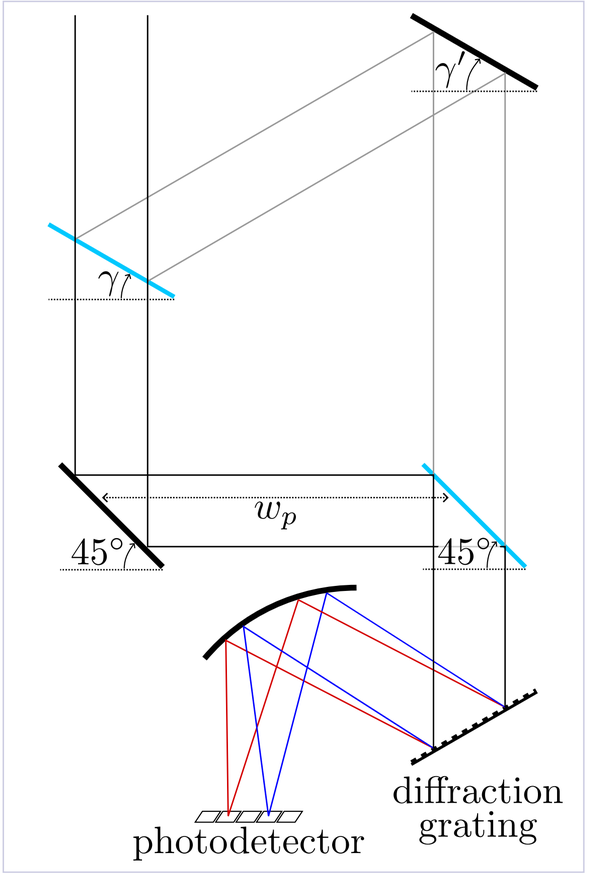

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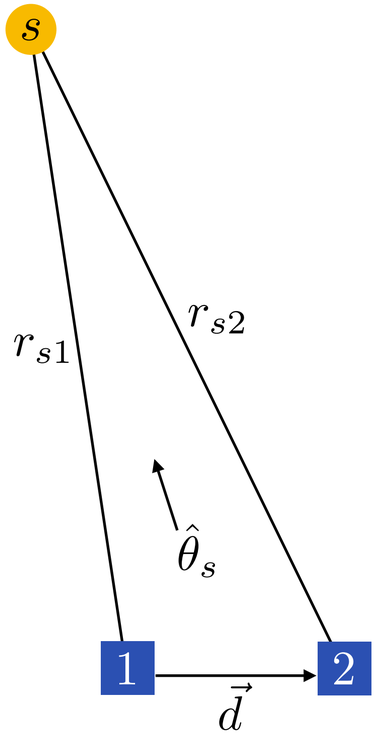
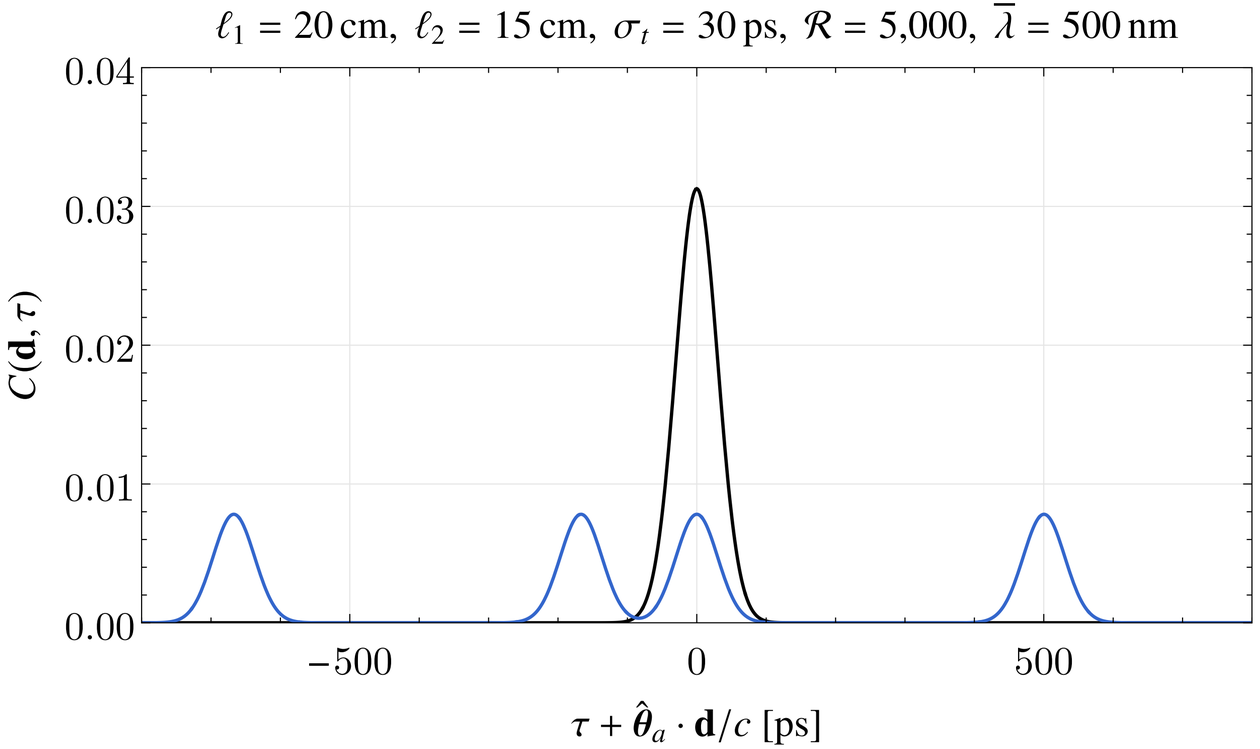
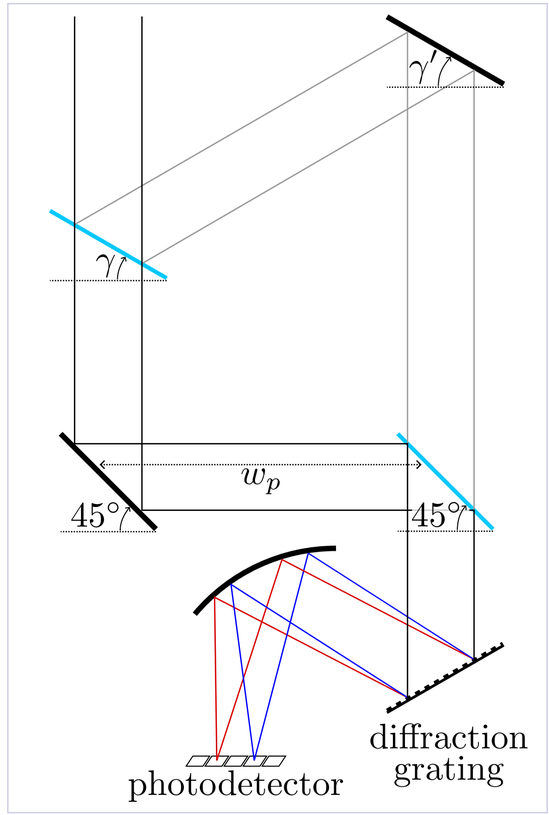
Extended-Path Intensity Correlation (EPIC)

One Source







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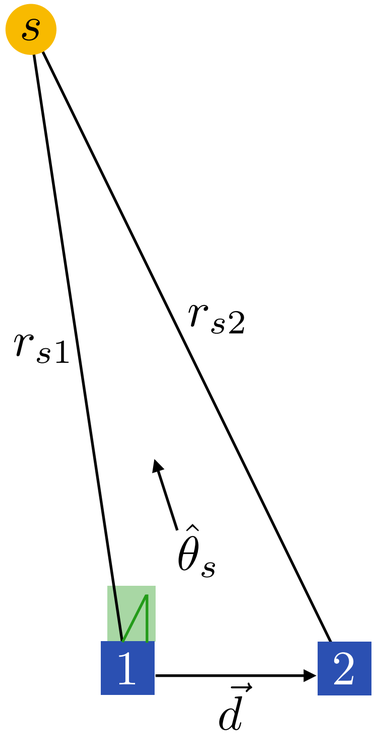

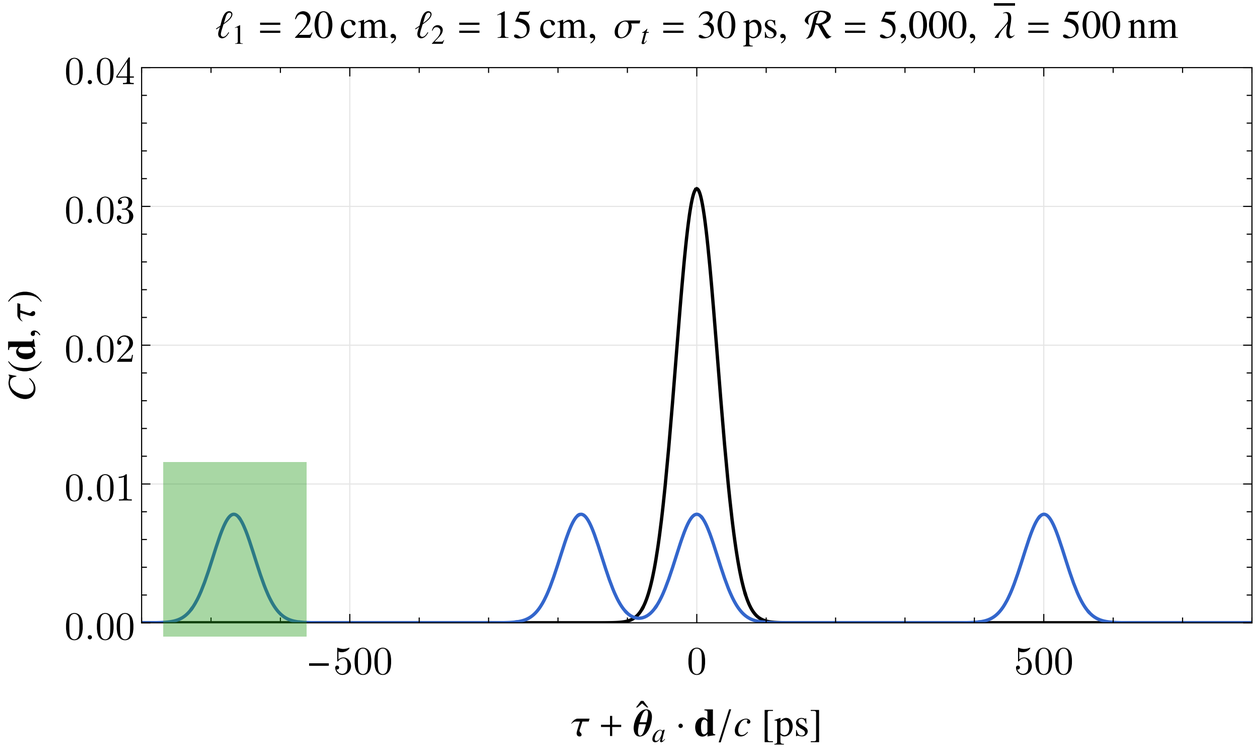

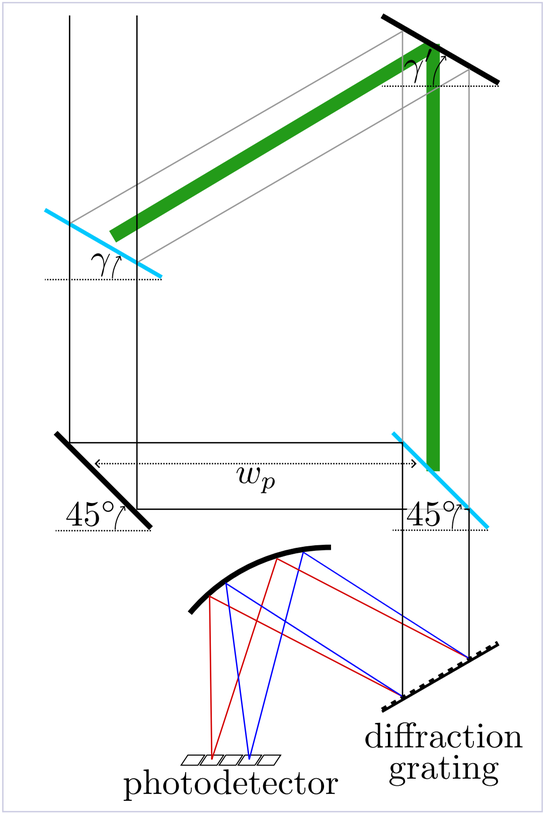

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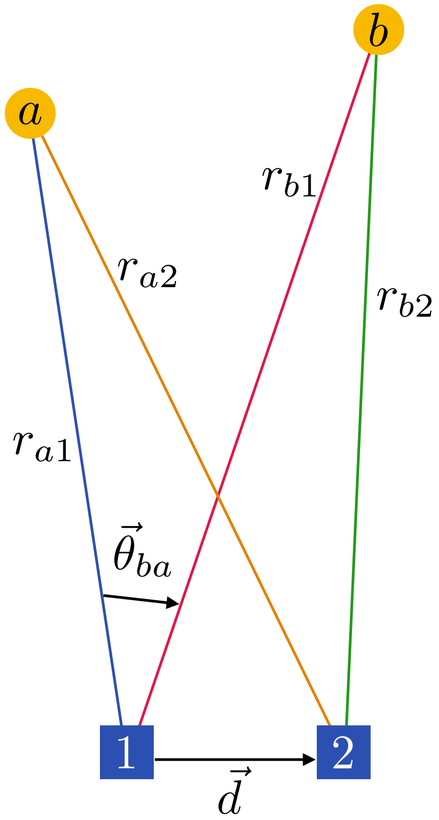
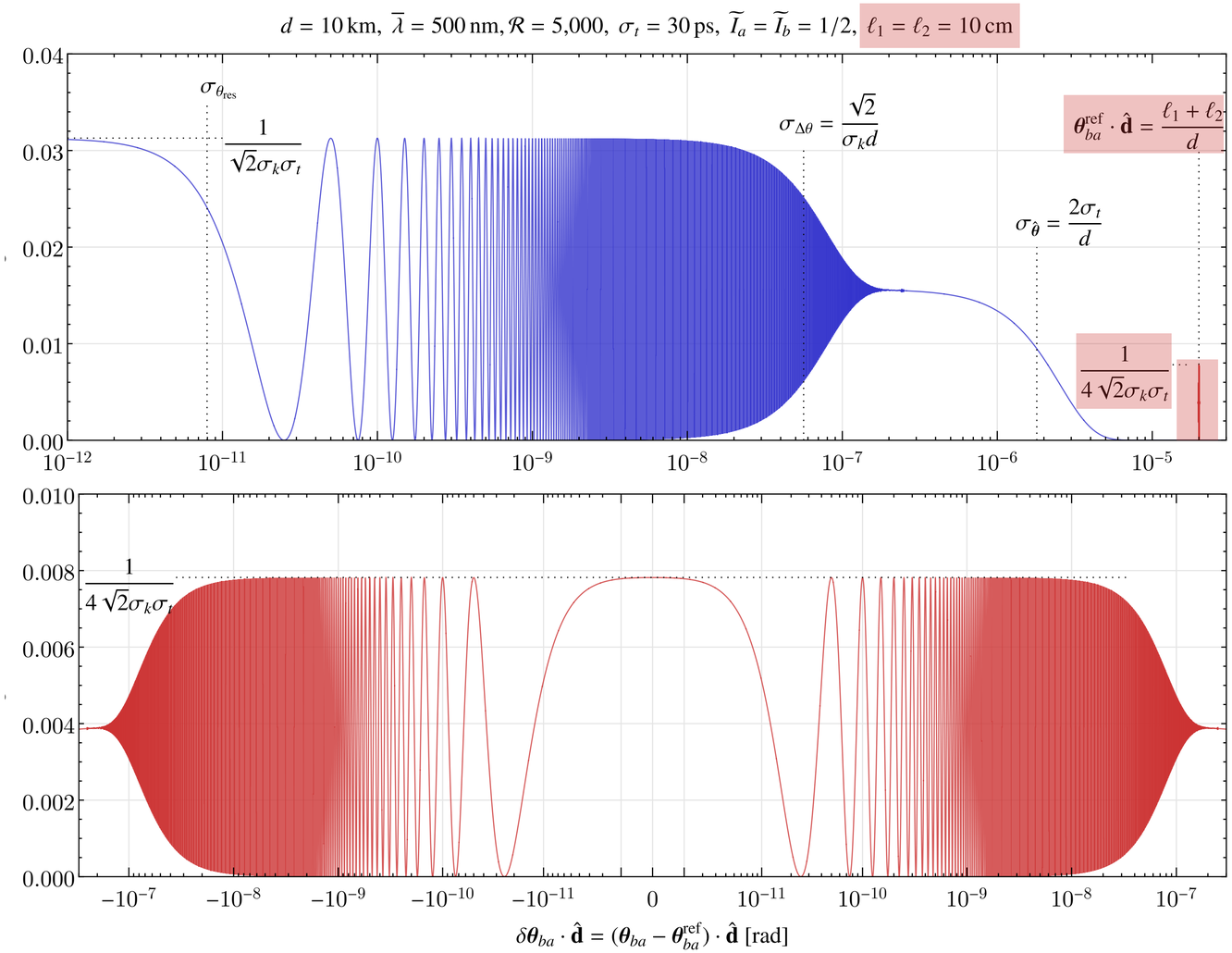
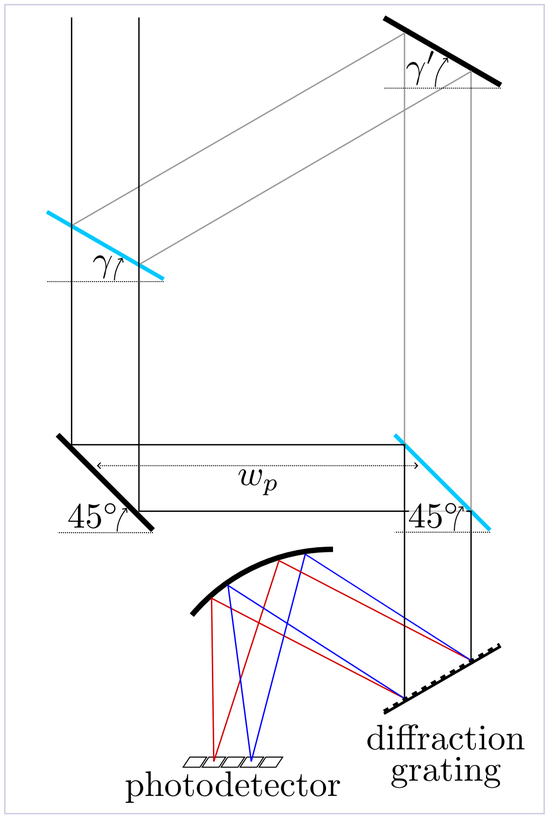
Two Sources







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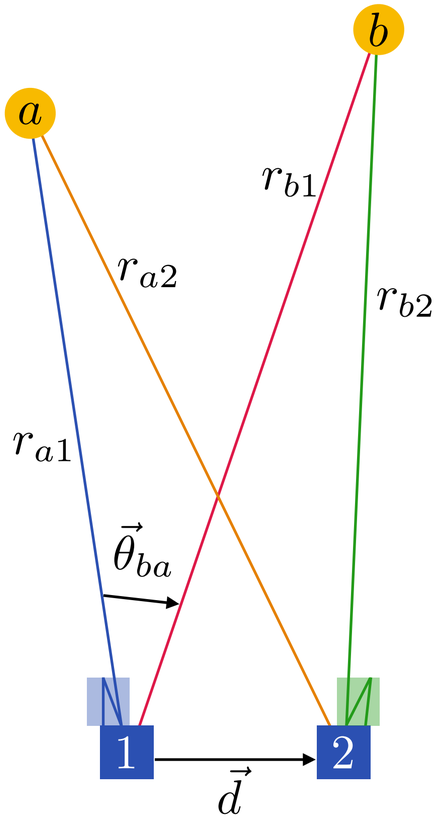
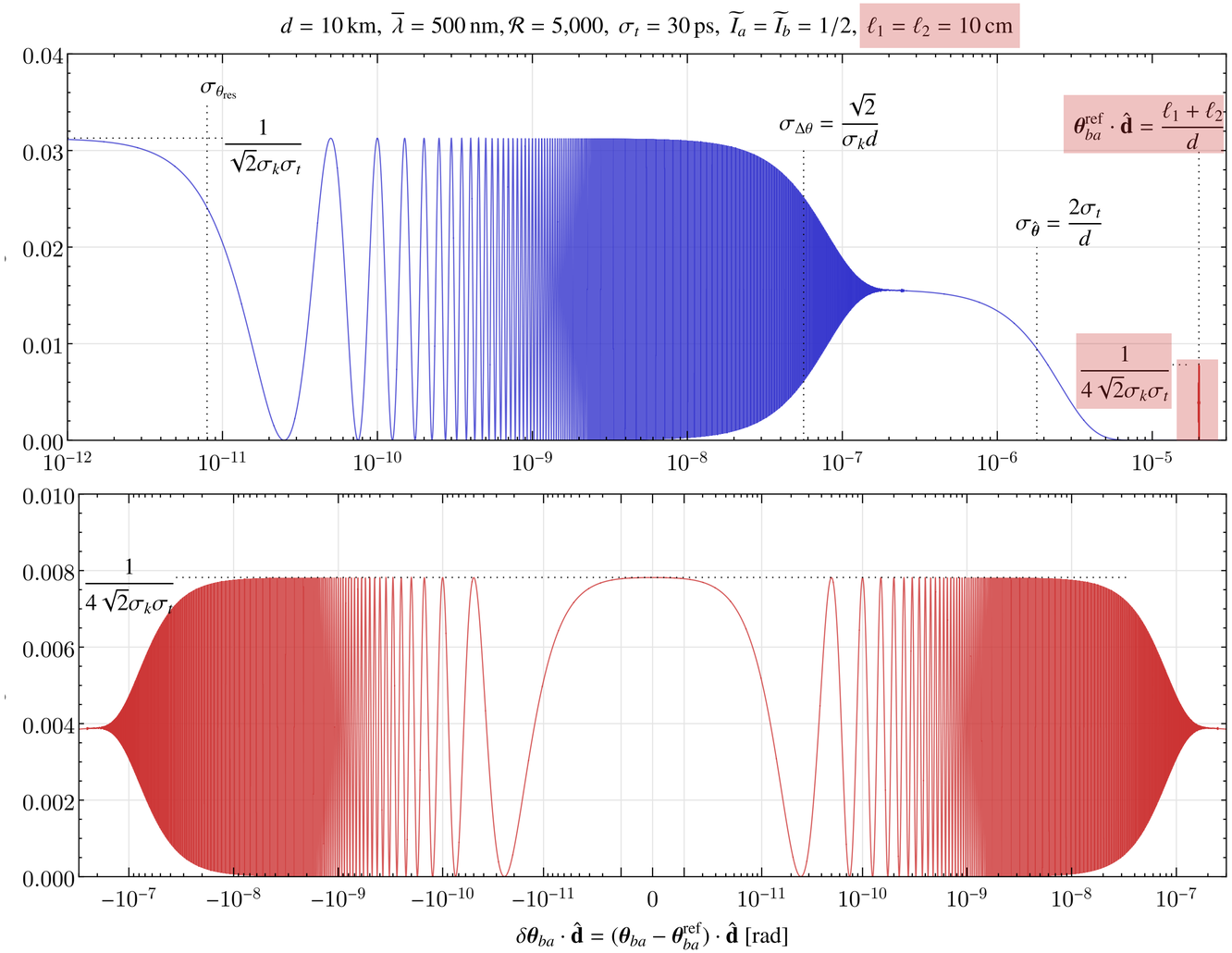
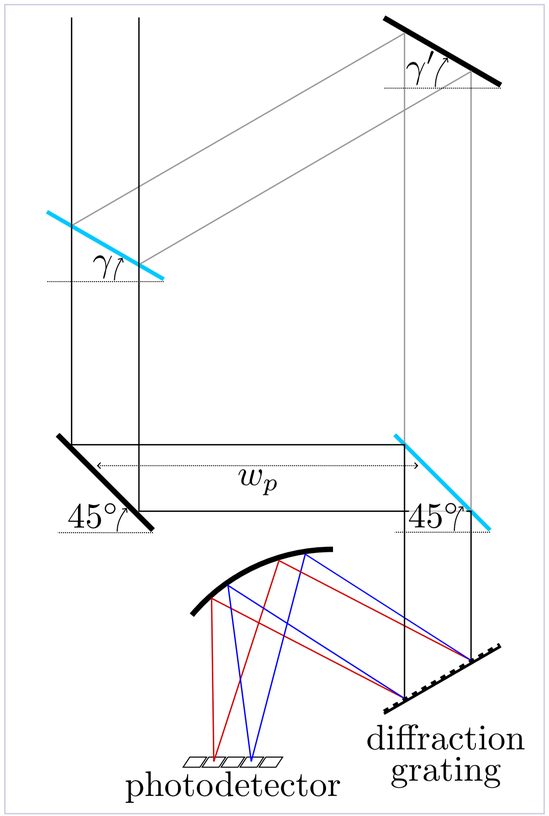






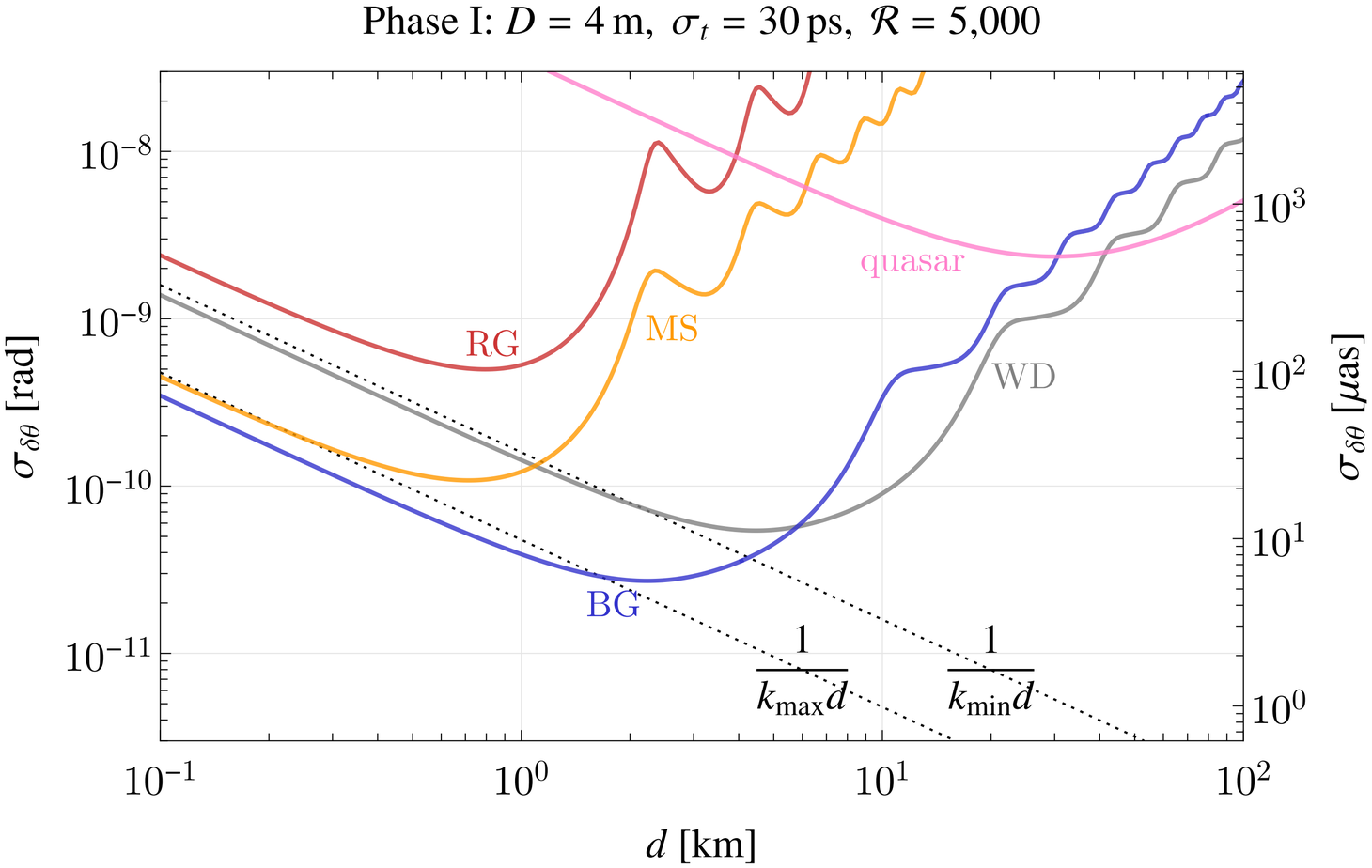
Future Phases of EPIC

	D	σ_t	$\mathcal{R}$	n_{arr}	$\sigma_{\delta\theta}$ [μas]	$\sigma_{\hat{\boldsymbol{\theta}}}$ [arcsec]	$\sigma_{\Delta\theta}$ [arcsec]	Matchlight
Phase I	4 m	30 ps	5,000	1	22.3	5.24	0.164	80
Phase II	10 m	10 ps	10,000	1	1.46	1.75	0.327	1,240
Phase III	10 m	3 ps	20,000	10	0.0564	0.524	0.656	32,000

Light-Centroiding Precision

$$\sigma_{\theta_{\rm res}} \sim \frac{\lambda}{d} \sim \underbrace{10^{-11}\,{\rm rad}}_{2\,\mu{\rm as}} \left(\frac{\lambda}{500\,{\rm nm}}\right)\left(\frac{10\,{\rm km}}{d}\right)$$

$$\sigma_{\delta\theta} \sim \frac{1}{\sqrt{N_1 N_2}}\frac{1}{Ad}\sqrt{\frac{\sigma_t}{t_{\rm shot}}}\sqrt{\frac{\sigma_k}{k}}\frac{1}{T_s^3\theta_s^2}$$



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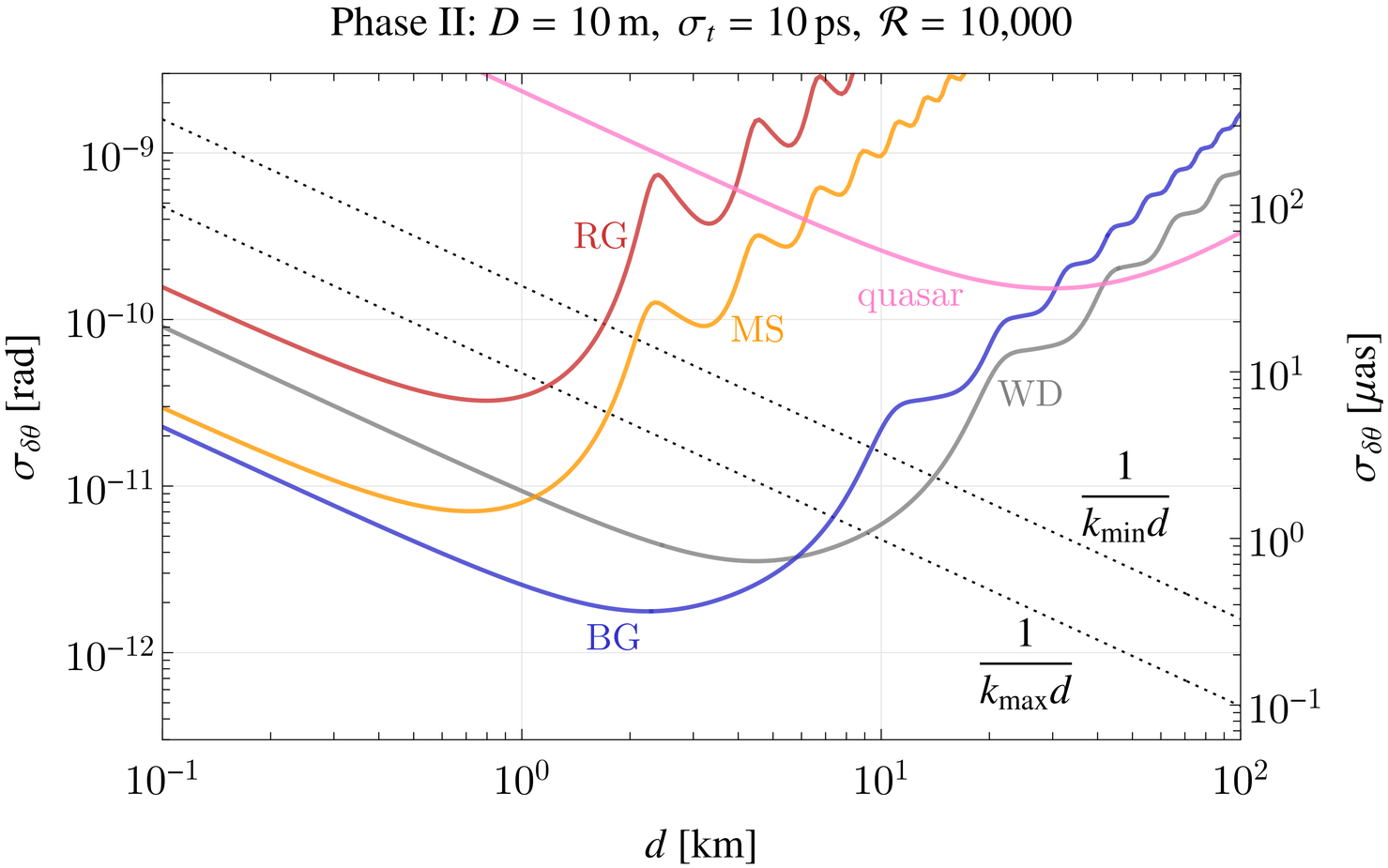

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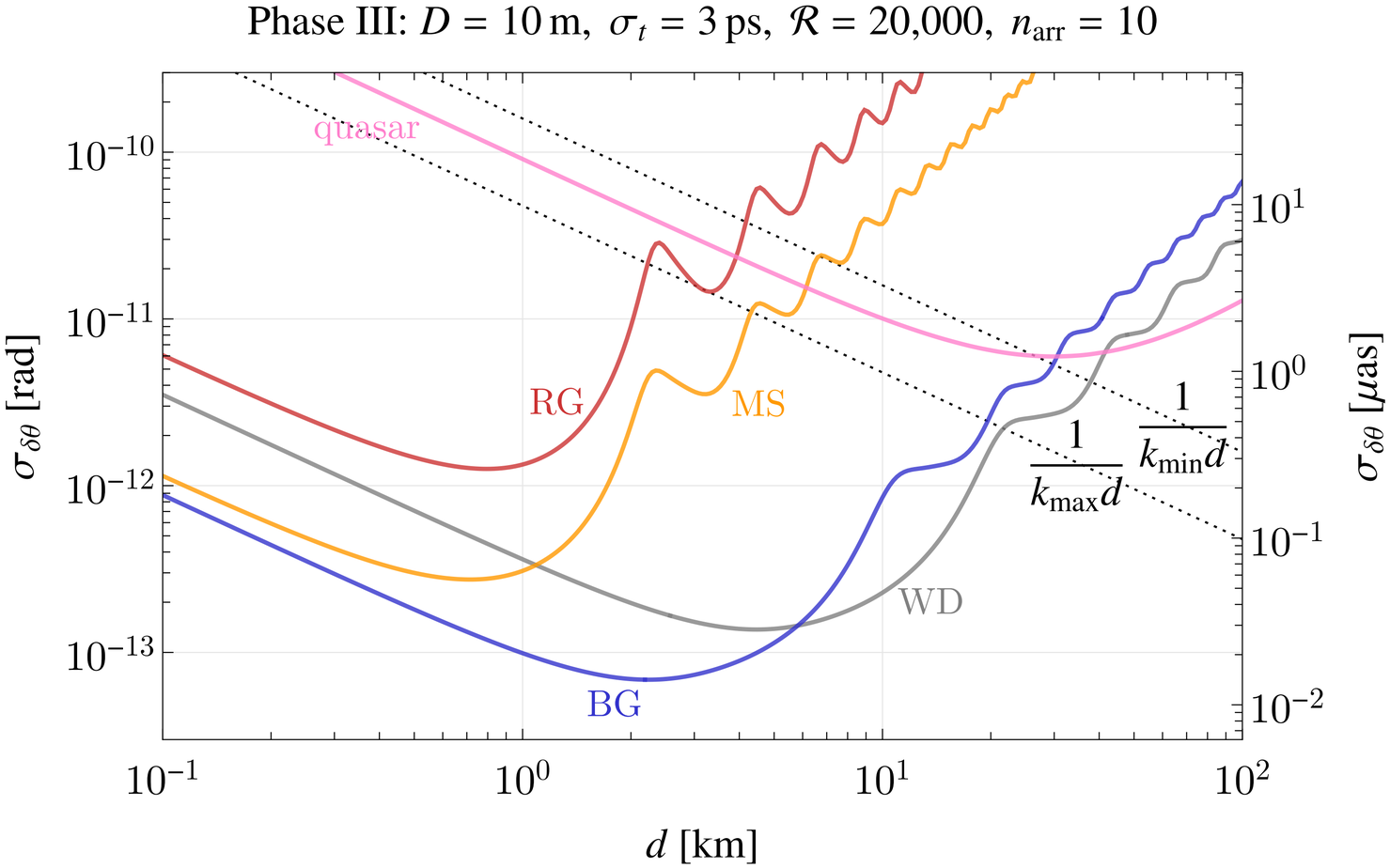
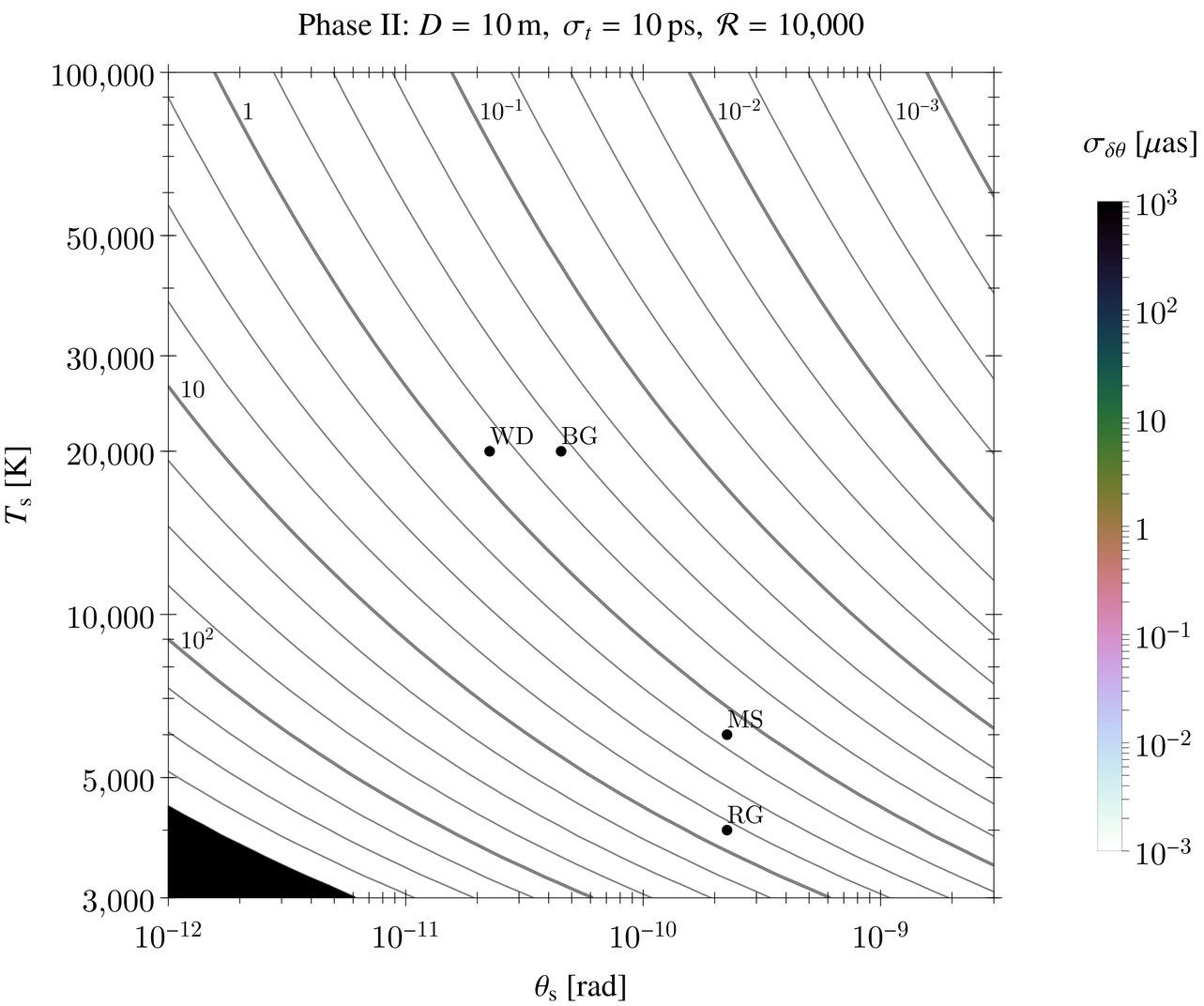
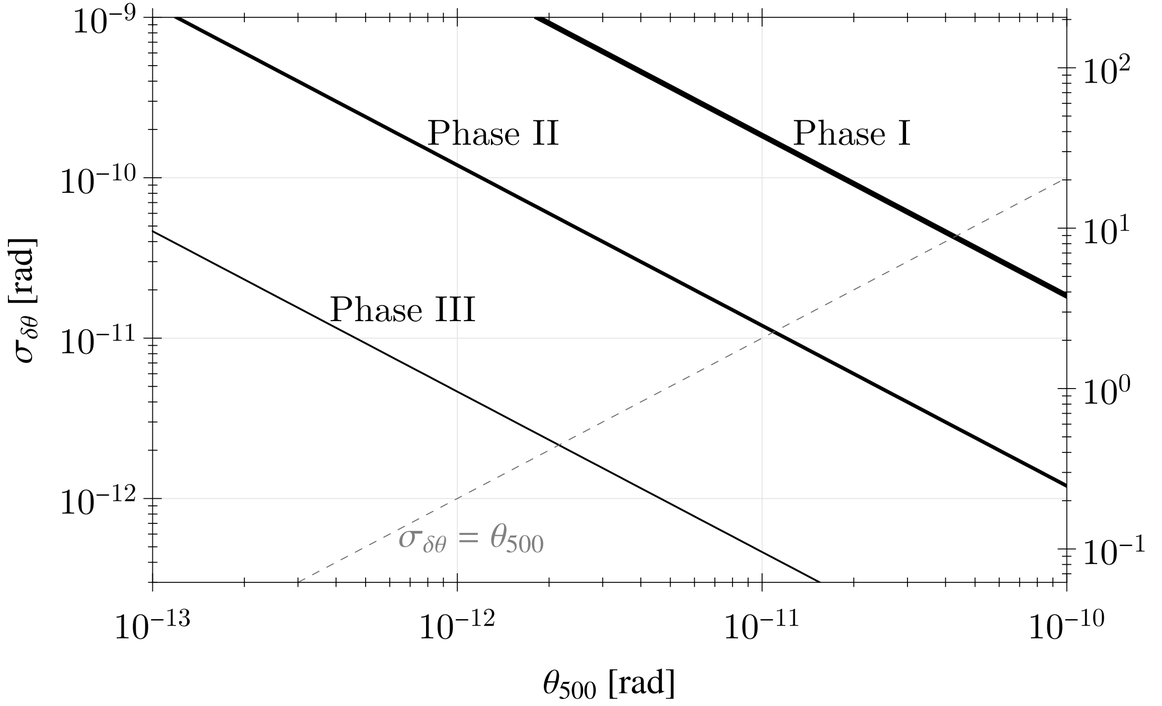


Light-Centroiding Precision

Stars

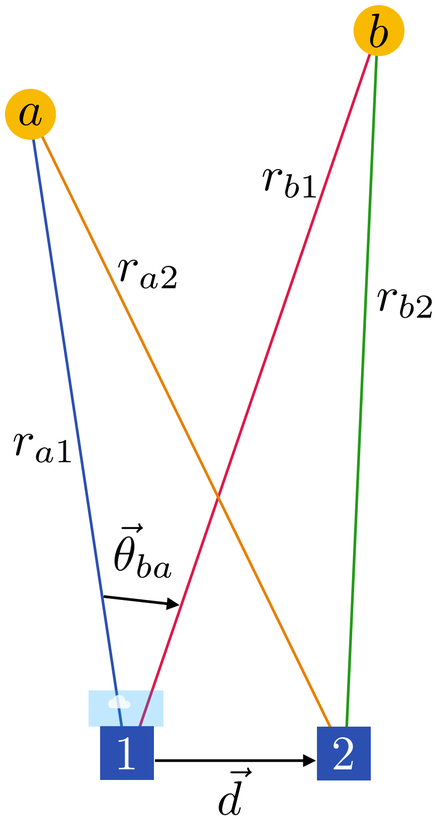


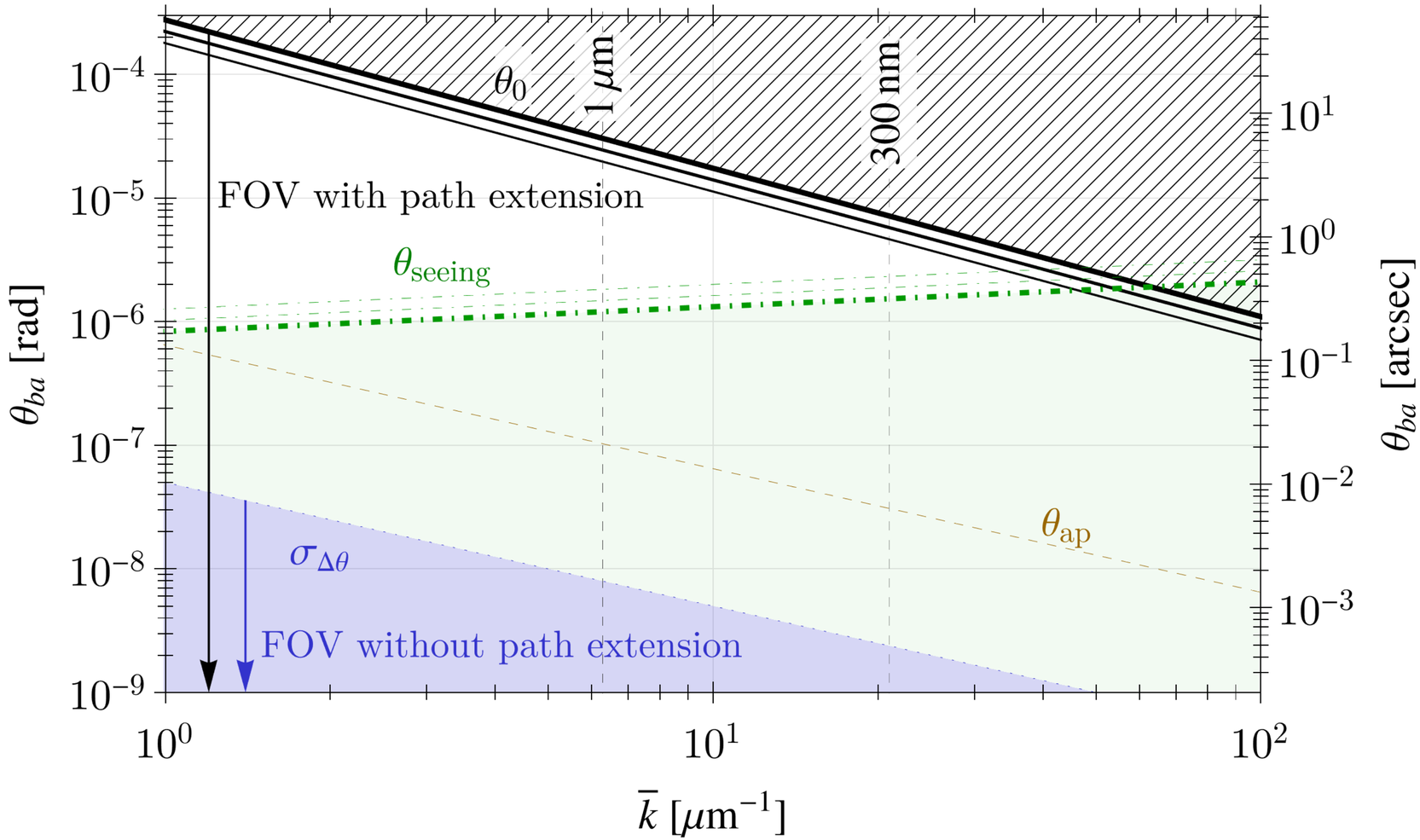
Quasars



Atmospheric Aberrations

$$\exp\left\{-\left(\frac{\theta}{\theta_0}\right)^{5/3}\right\}$$ fringe contrast suppression





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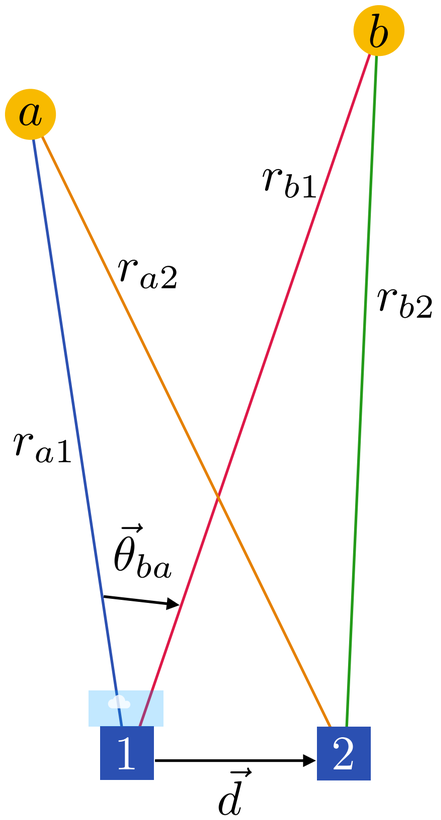
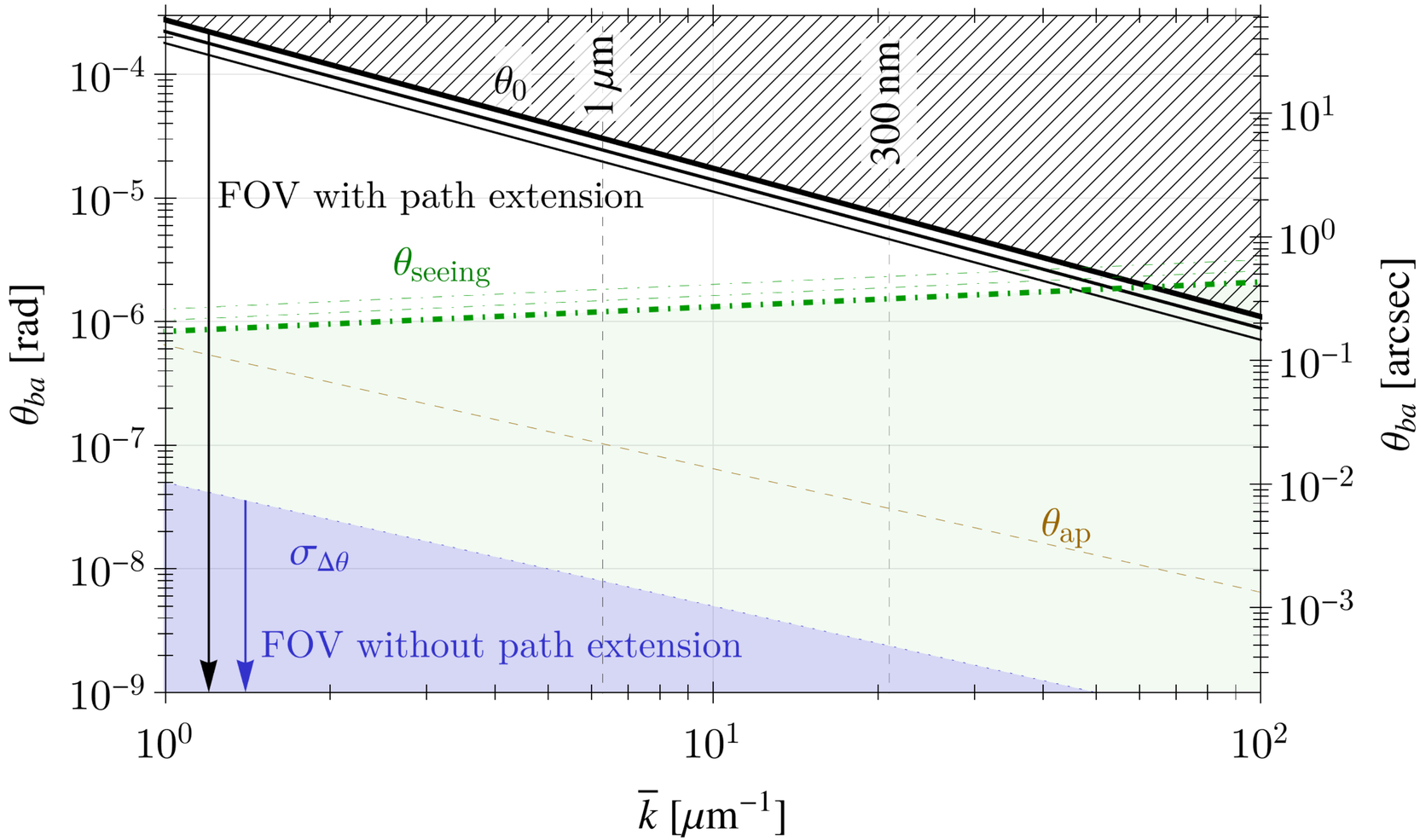
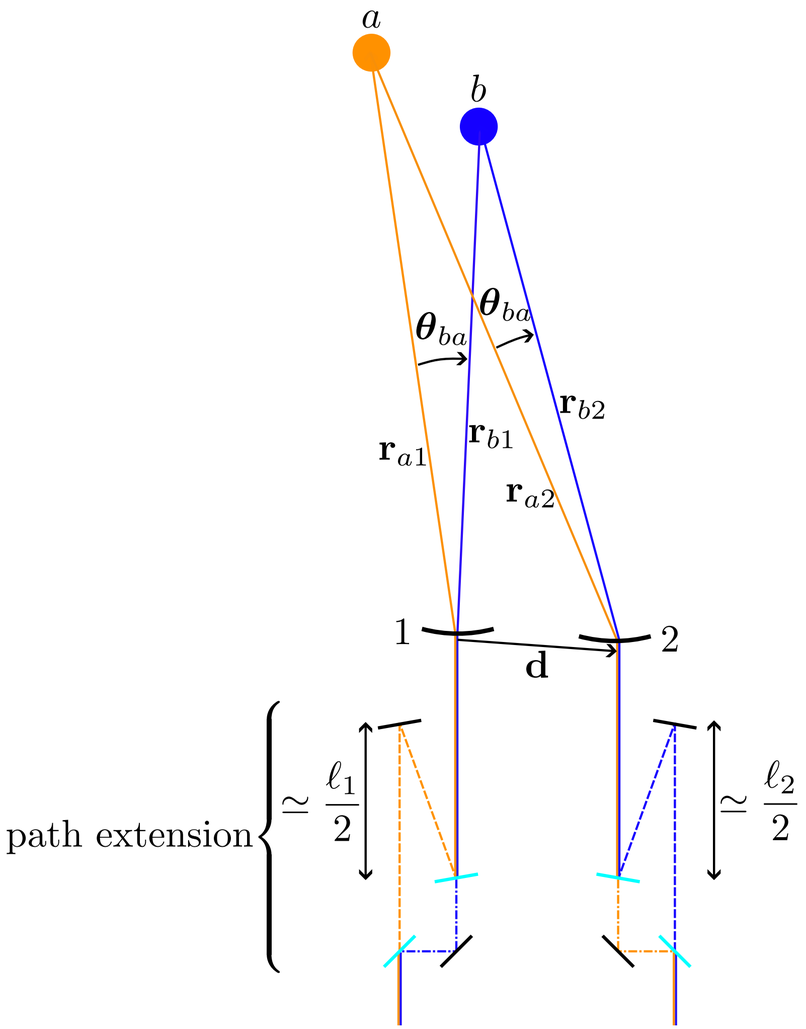




Extended-Path Intensity Correlation (EPIC)

sub-μas resolution and even better *differential* light-centroiding precision

on sources separated by less than a few arcseconds



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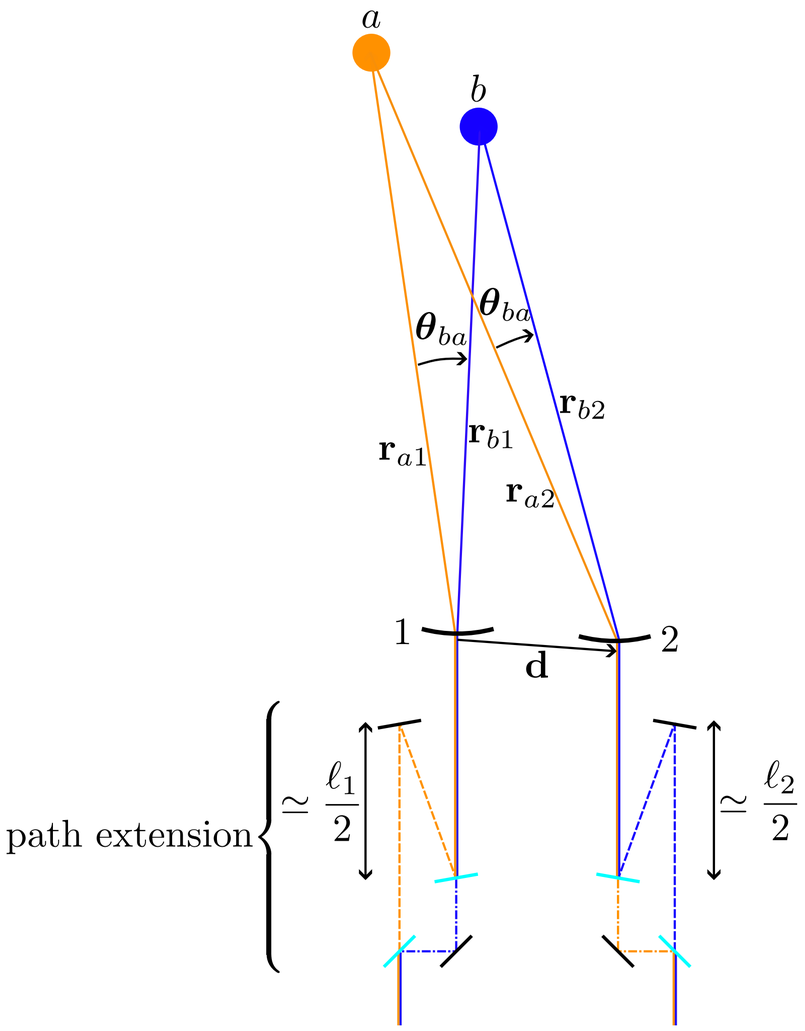
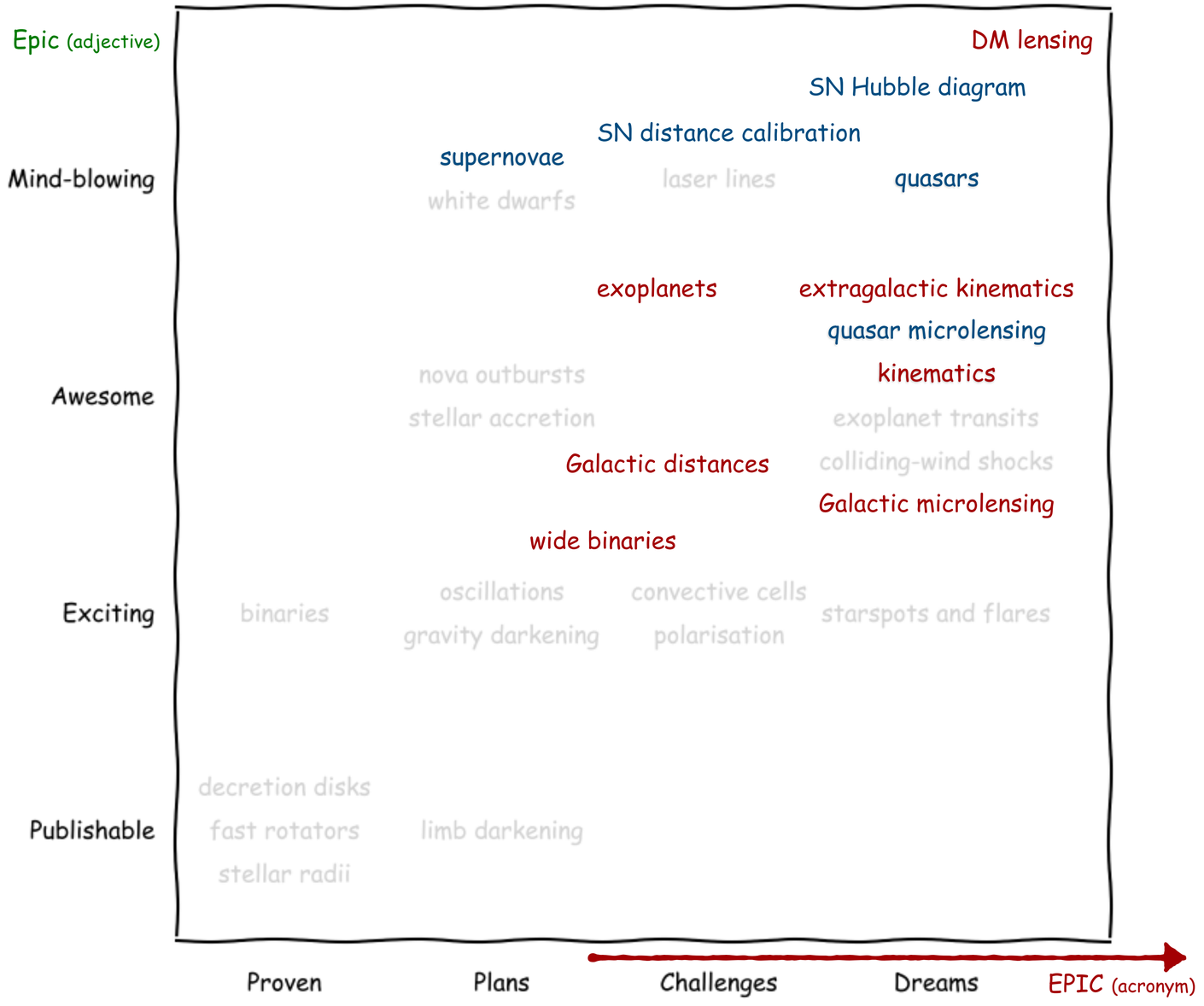
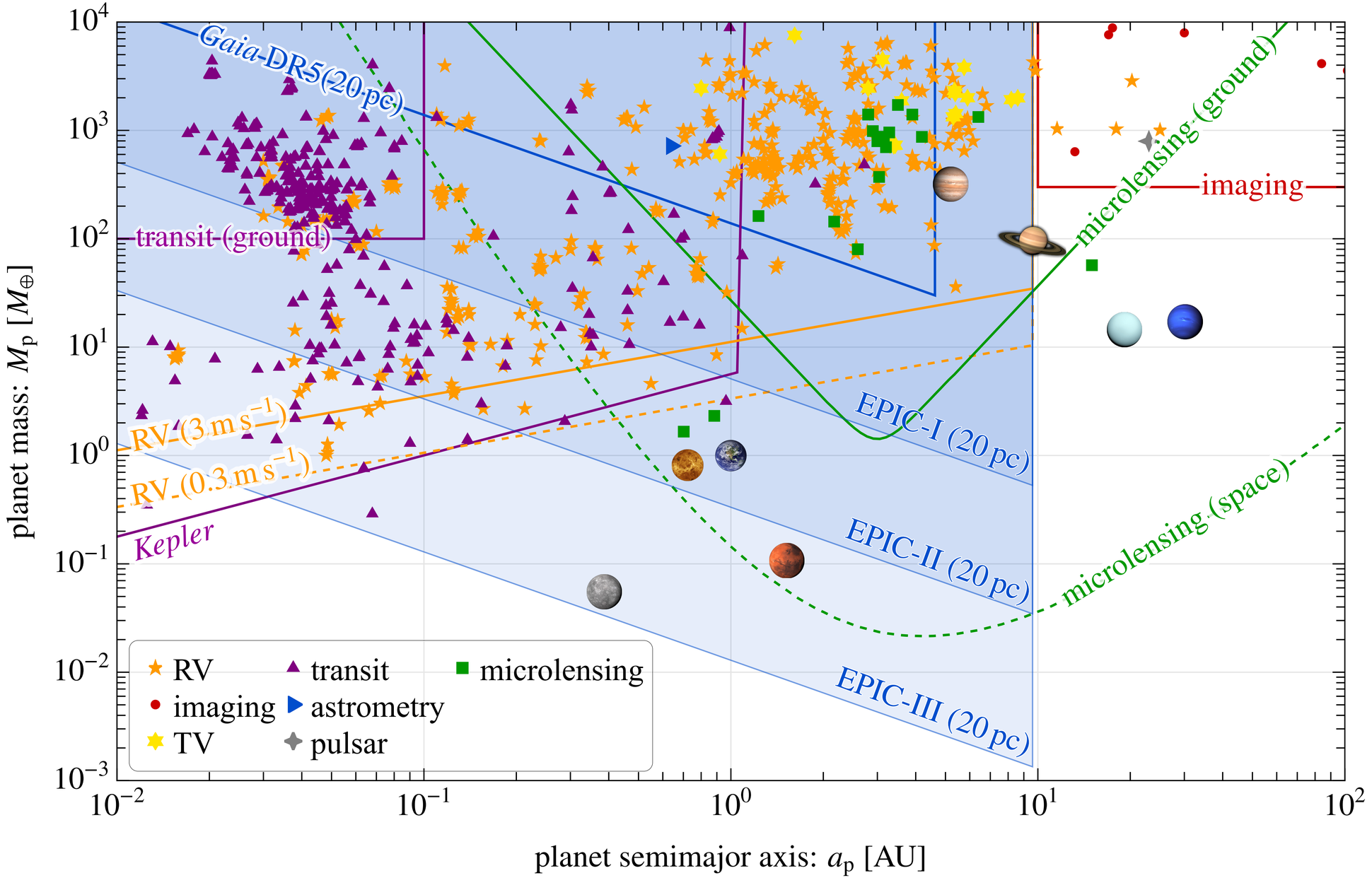




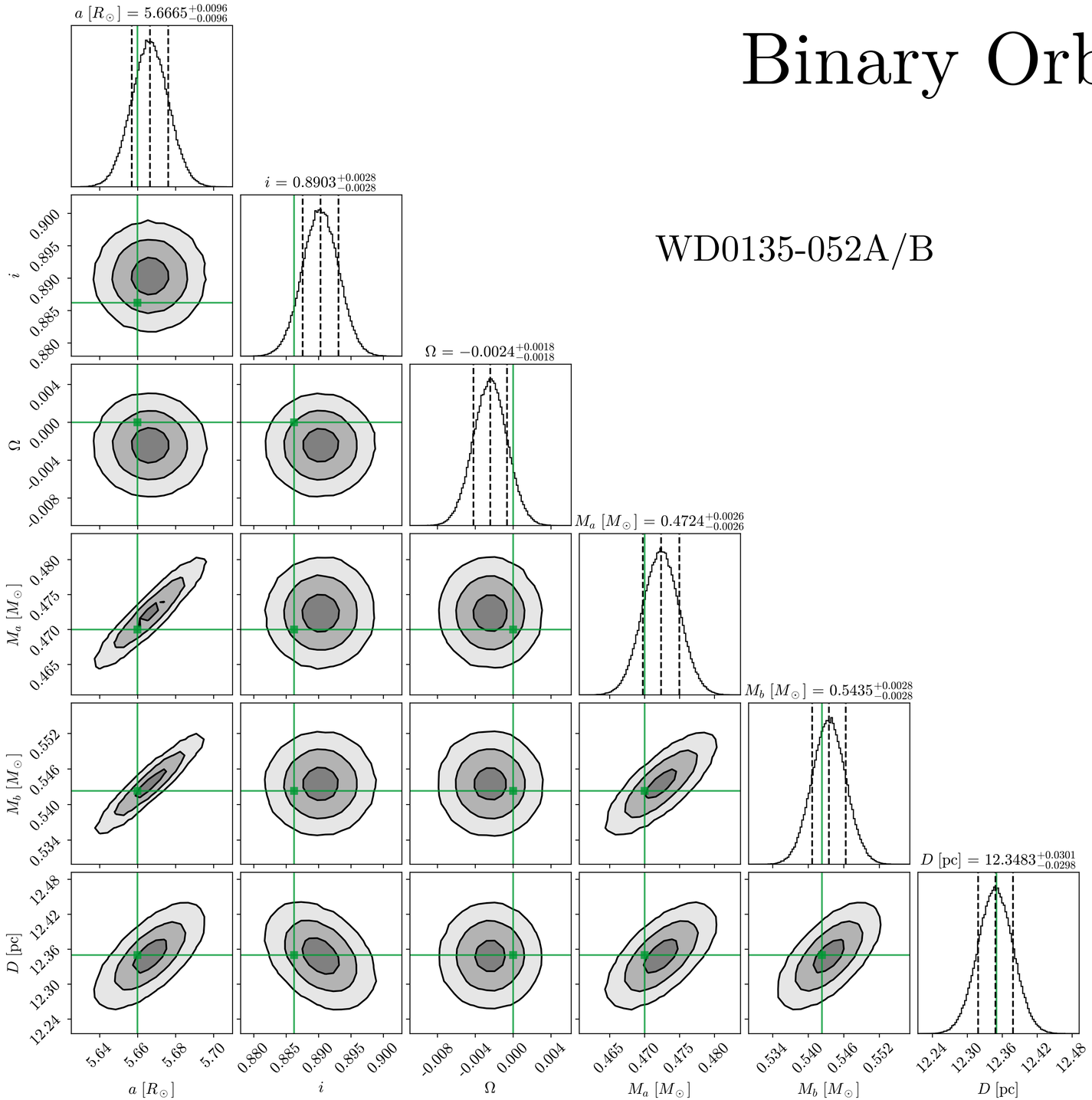
Exoplanets

$$\Delta\theta_{\rm star} \sim \frac{M_{\rm p}}{M_{\rm star}}\frac{a_{\rm p}}{D}$$

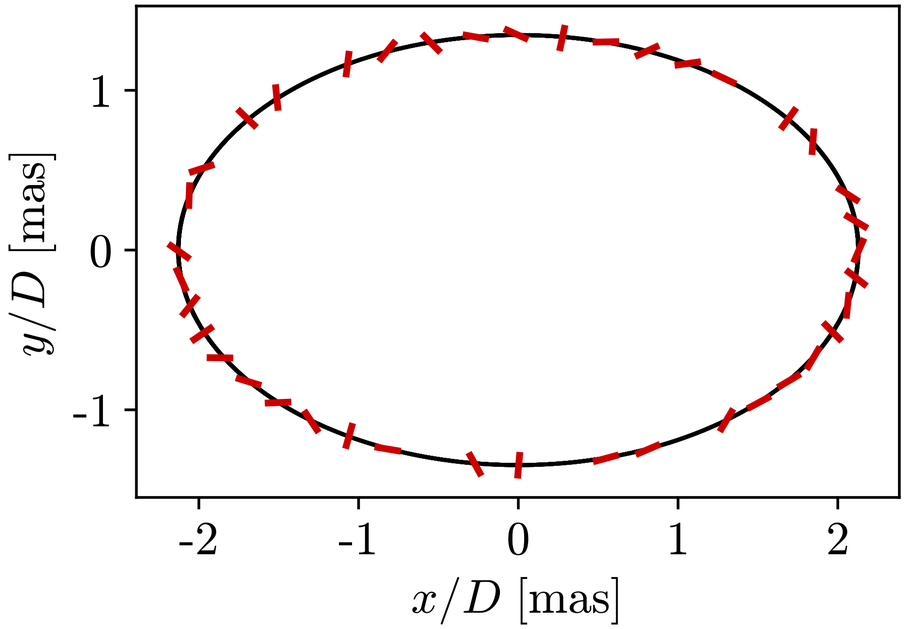


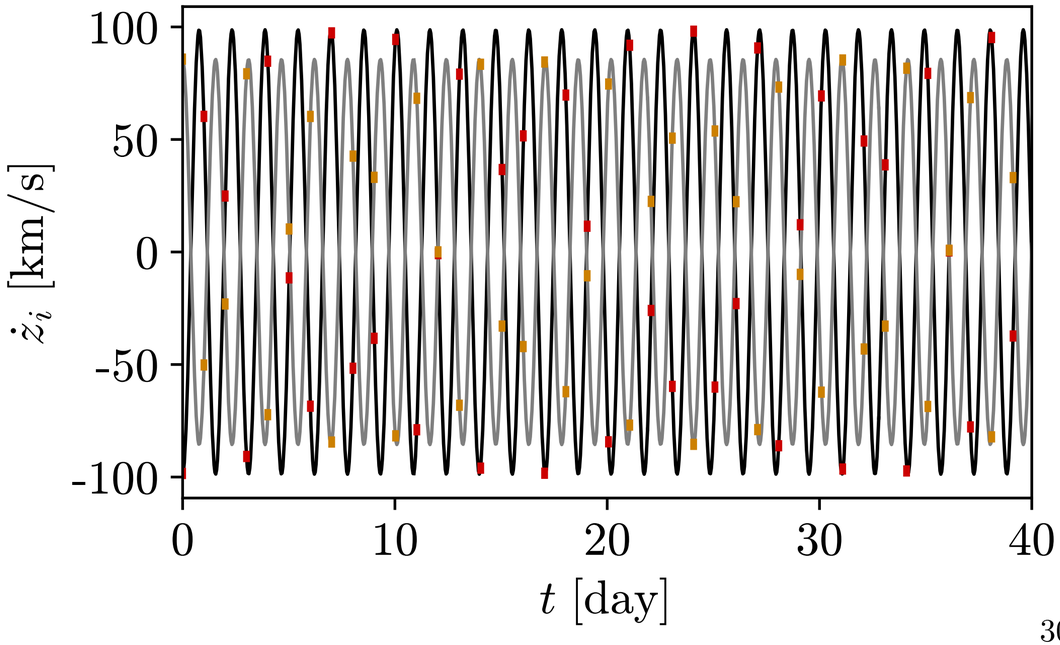
Binary Orbits

WD0135-052A/B



Phase I errors multiplied by 10 for clarity!





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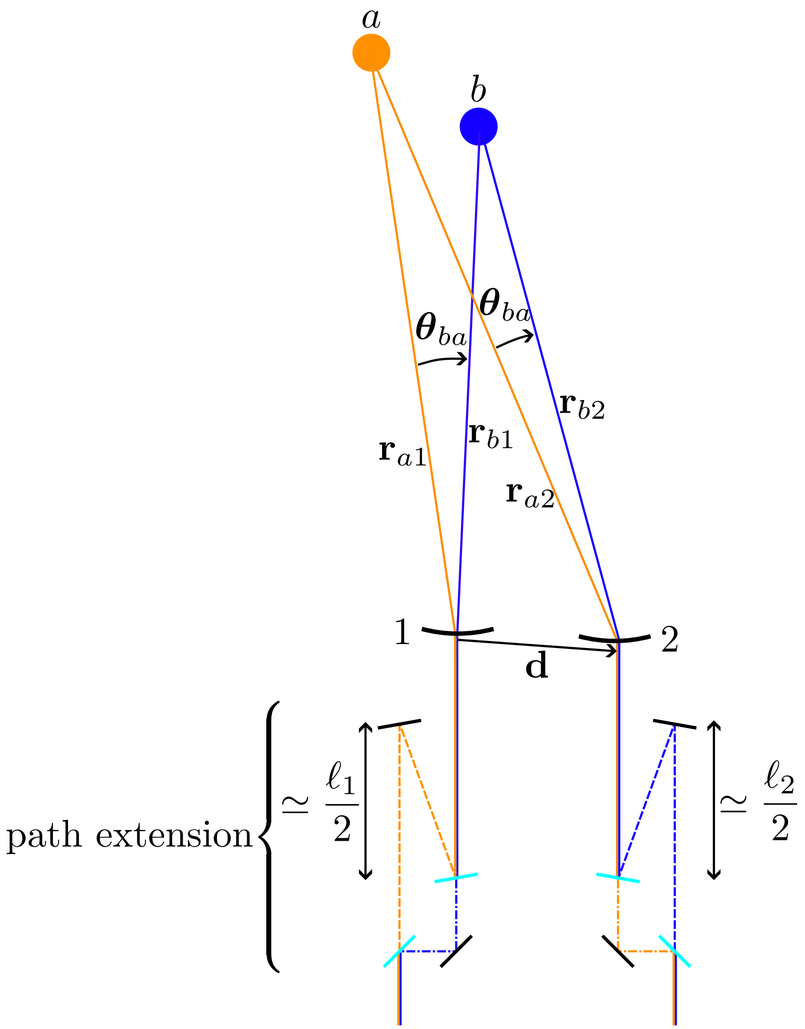

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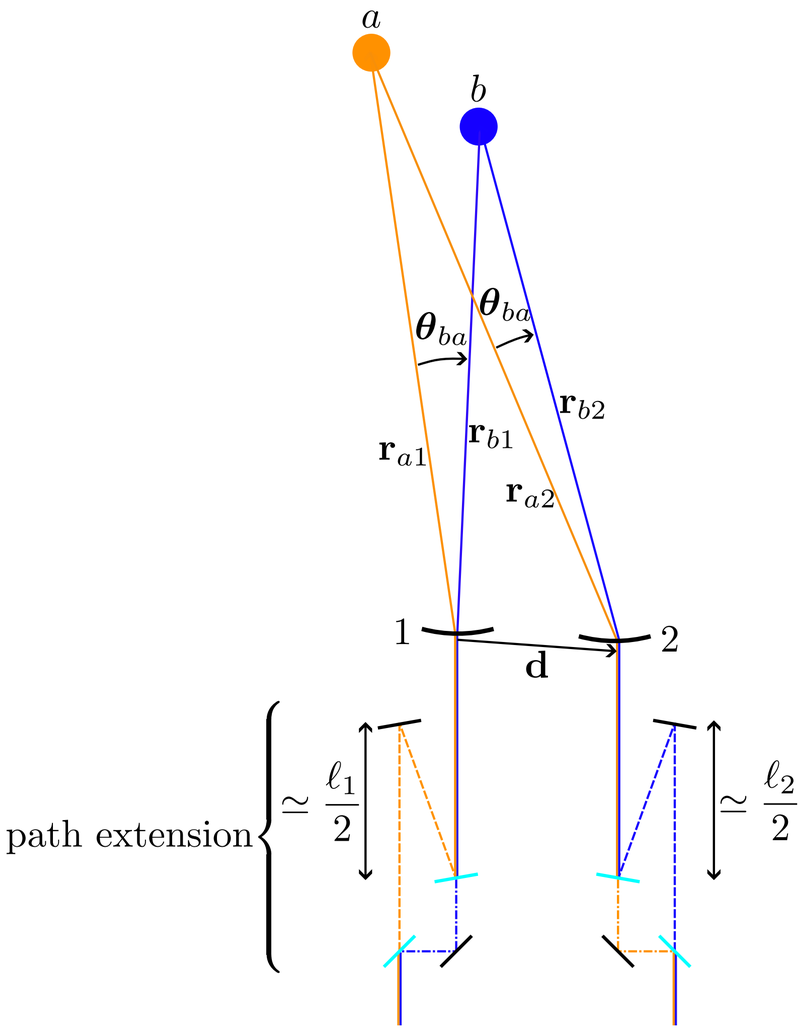

Probing Structures

All evidence for DM is gravitational in nature

Probing Structures

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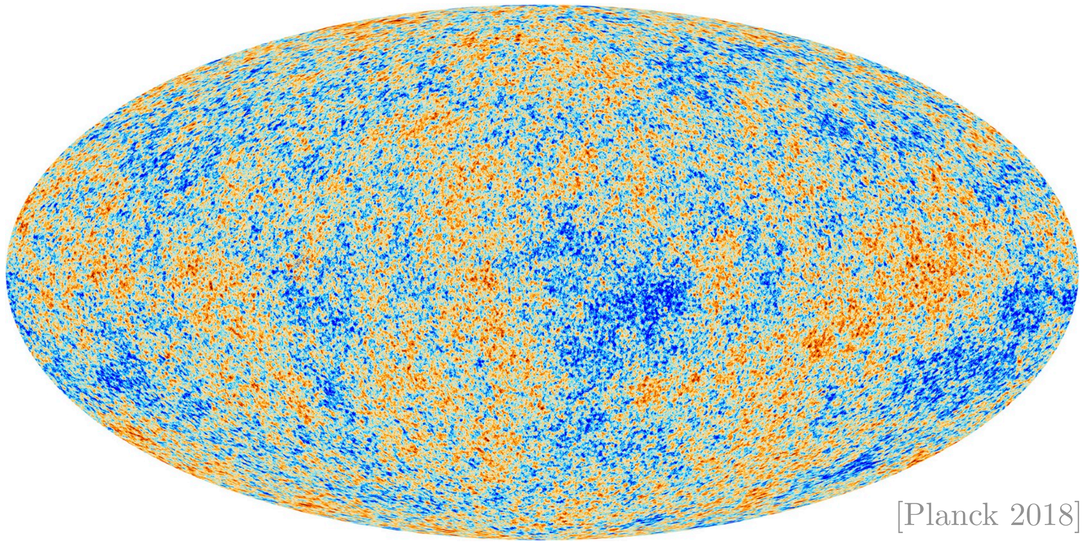

[Planck 2018]

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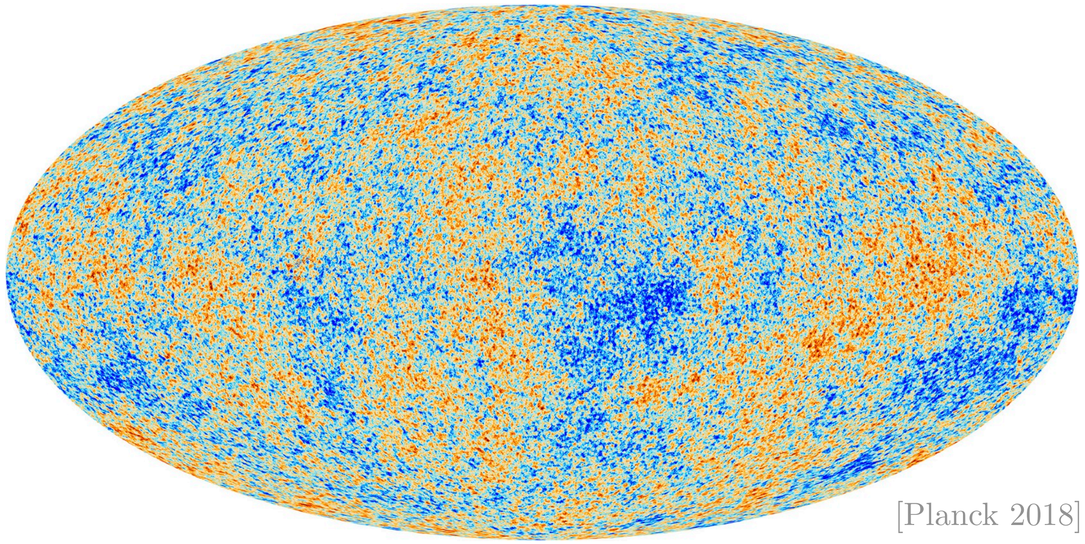

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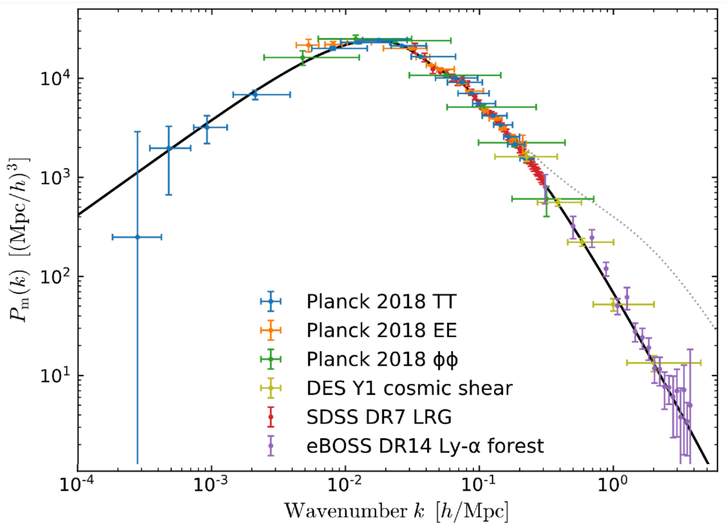

[Chabanier+ 2019]

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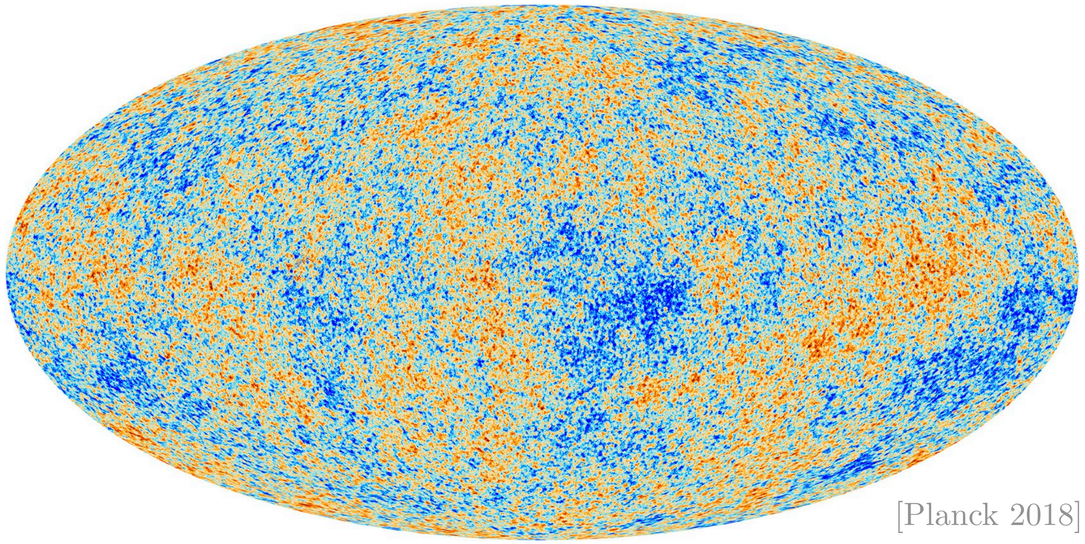

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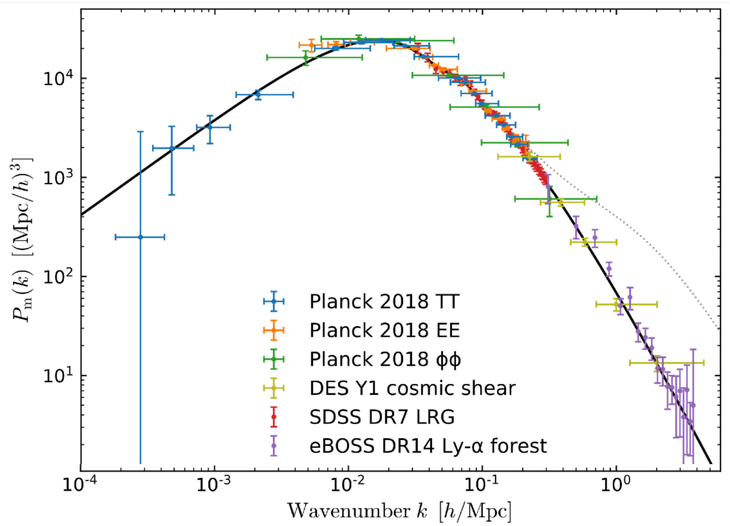

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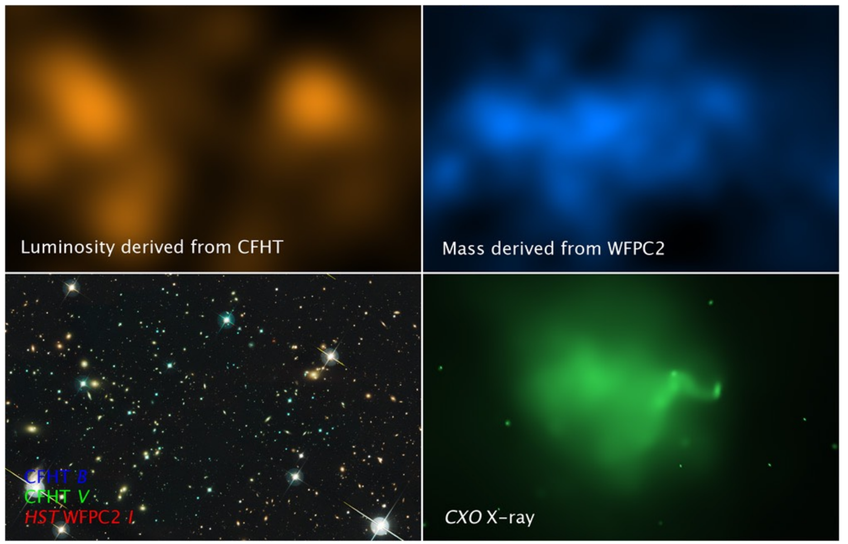

[NASA 2014]

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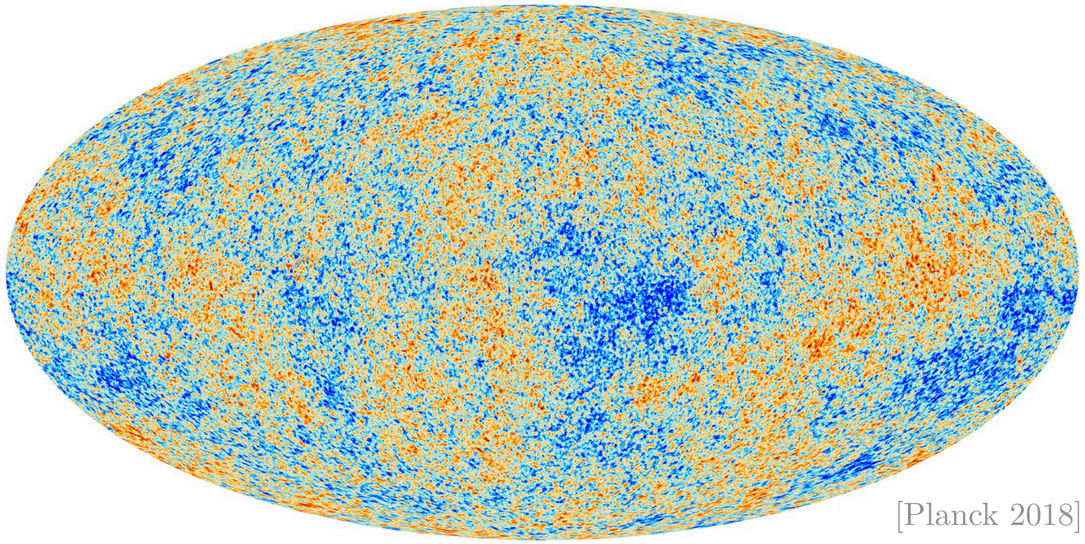

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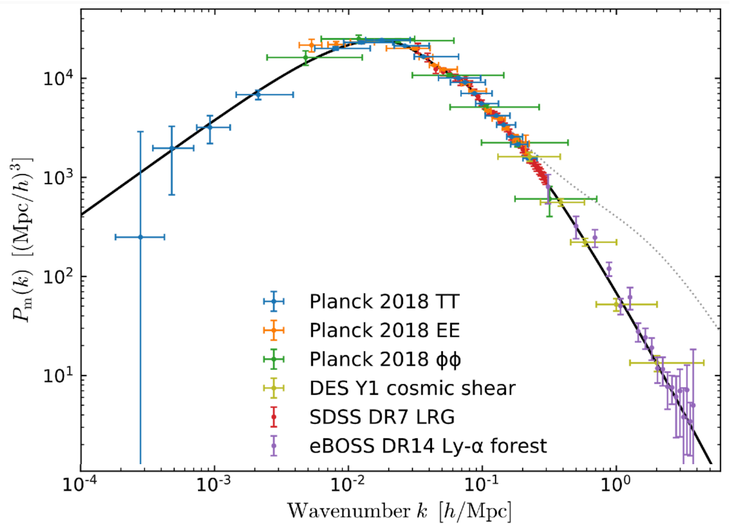

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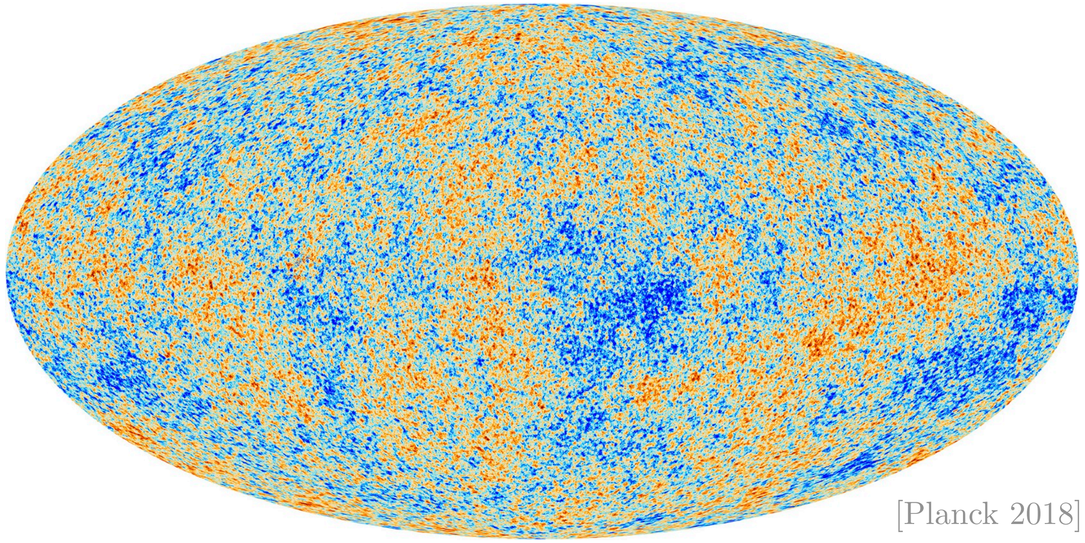

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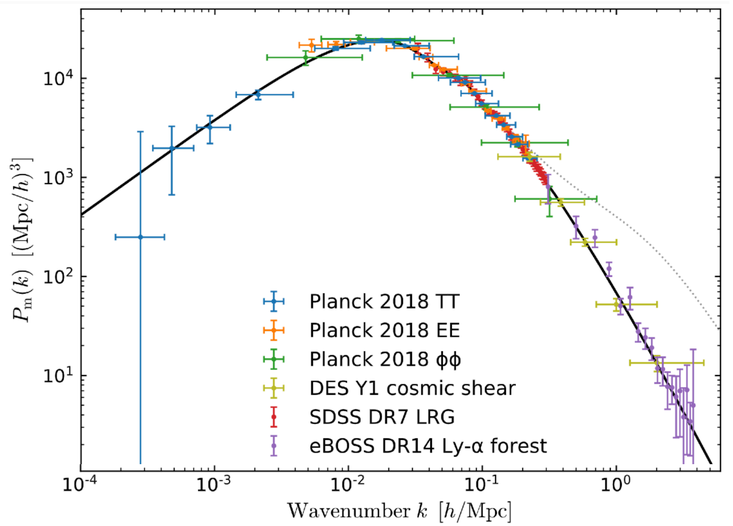

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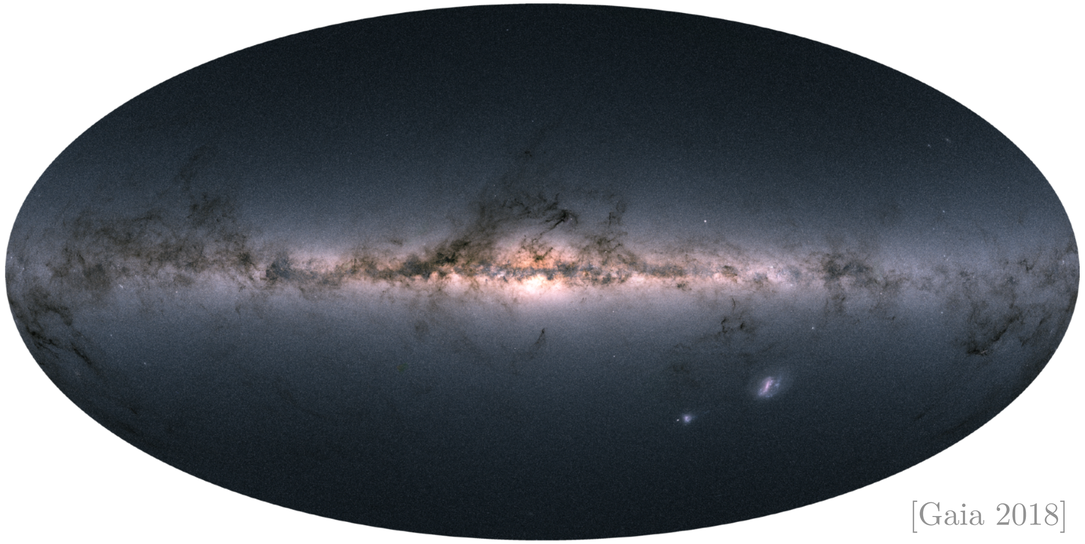

[Gaia 2018]

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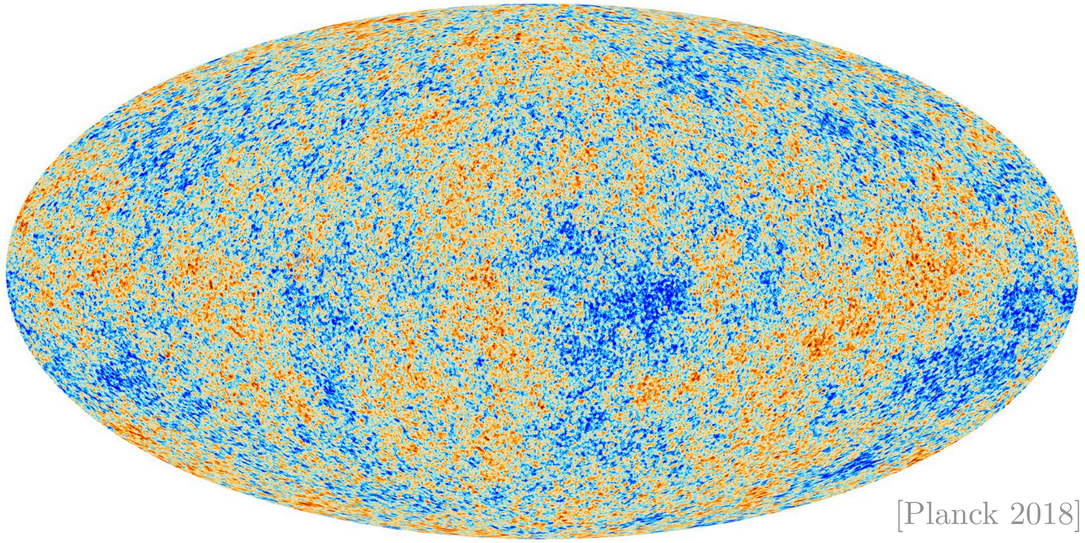

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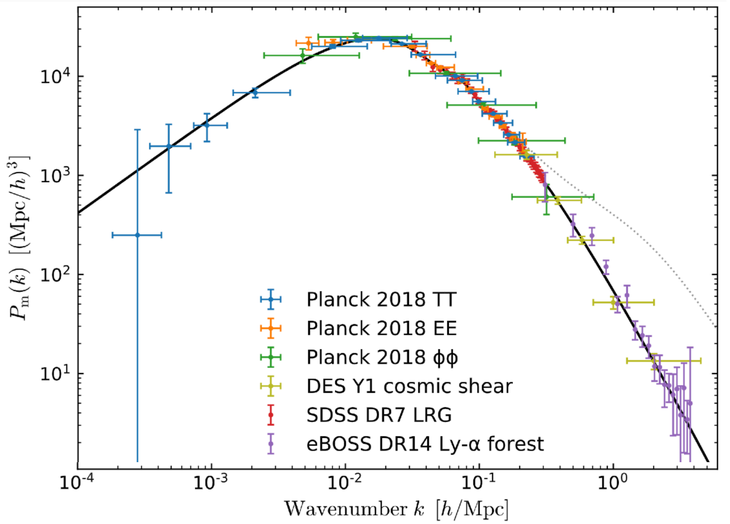

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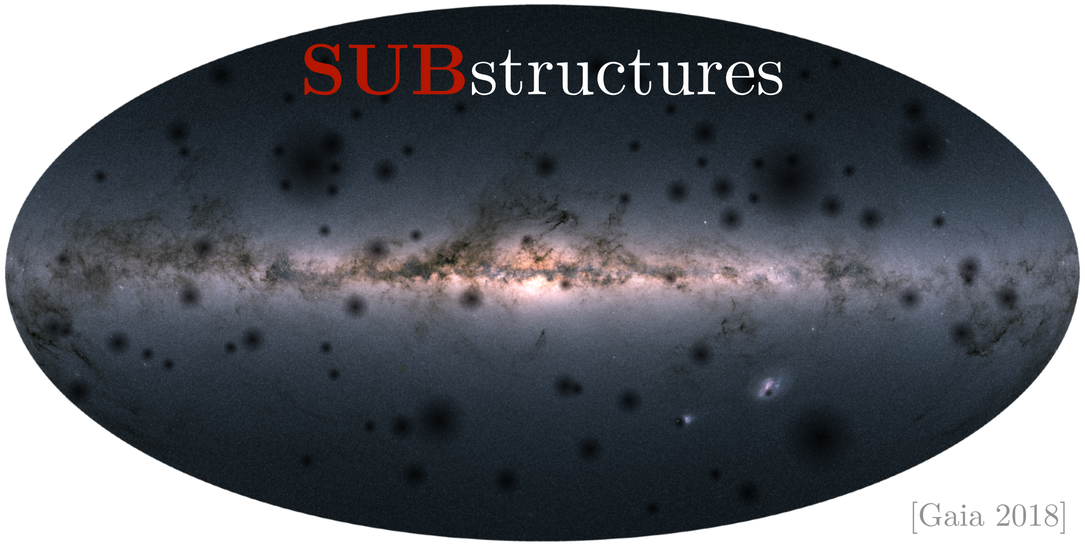

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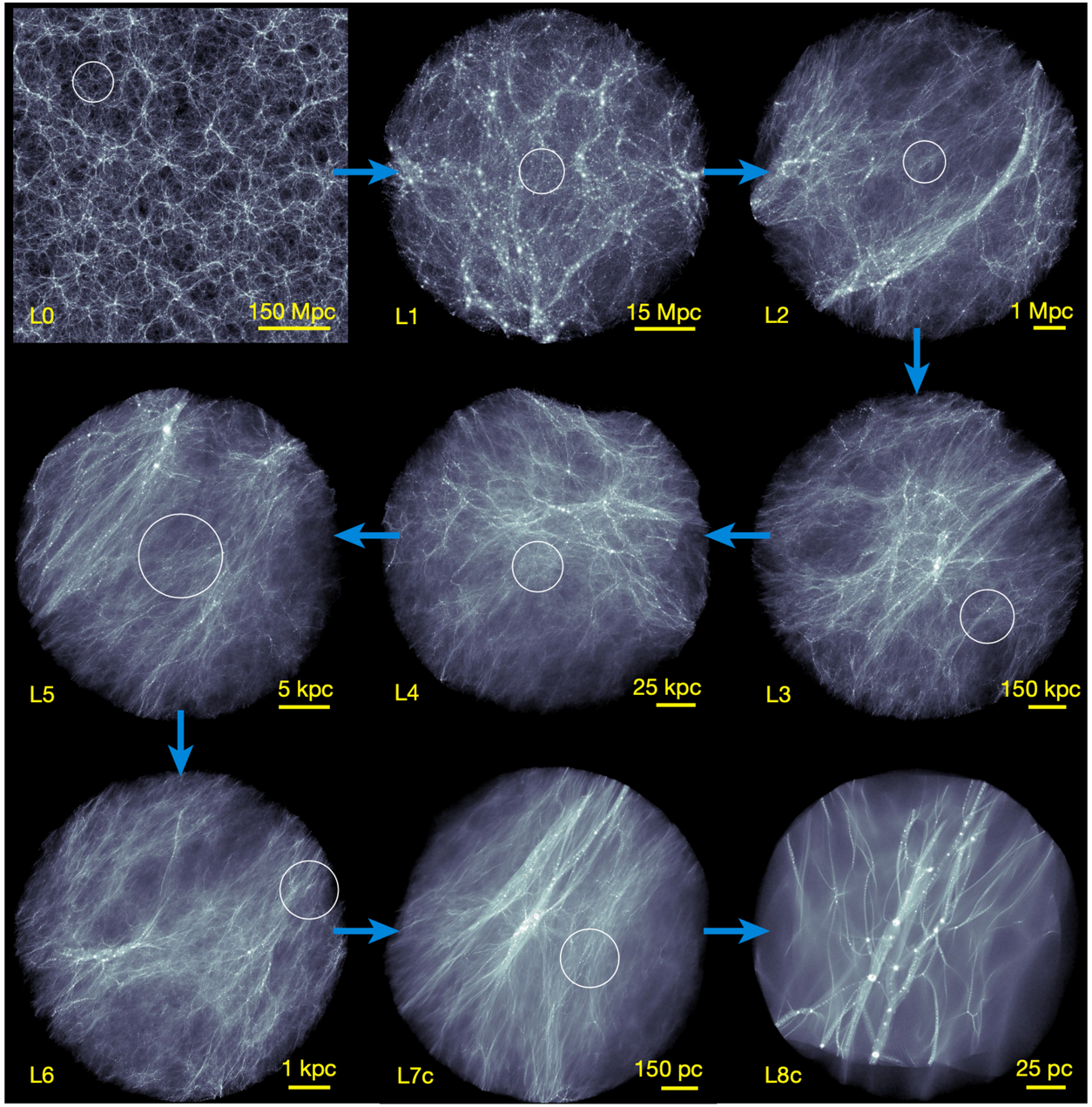
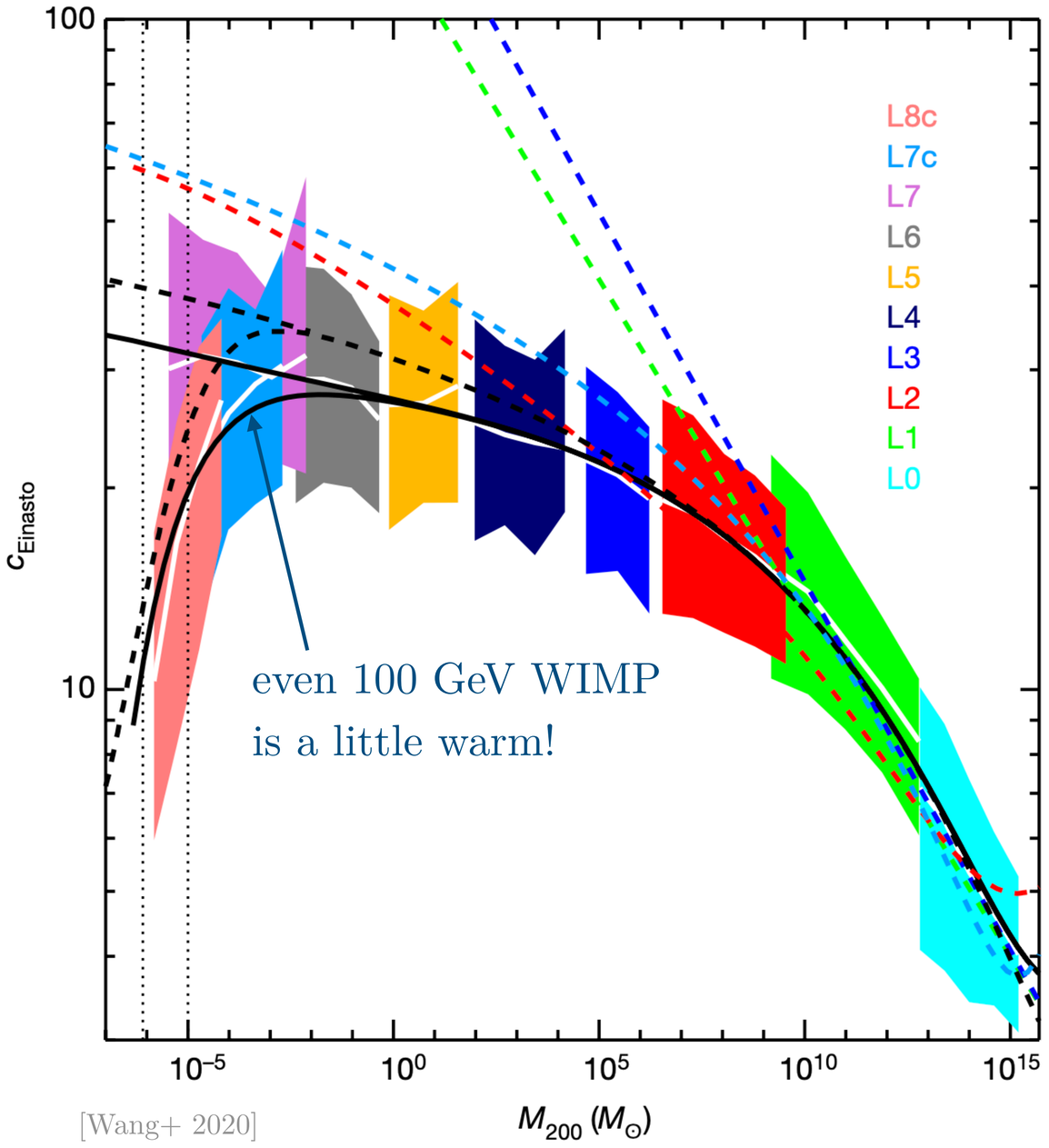
[NASA 2014]

Probing SUBstructures





[Wang+ 2020]

Probing SUBstructures

Why?

Primordial fluctuations

inflation, DM-inflaton coupling, phase transition

Early, linear evolution

warm / fuzzy DM
axion interactions
kinetic decoupling

Late, nonlinear evolution

dissipative / self-interacting DM
interference fringes
instabilities

"Gravity always wins on large scales,
new physics stands a chance on small scales"

How?

Gravitational lensing

weak | strong
astrometric | photometric | temporal
transient | collective

Gravitational interactions

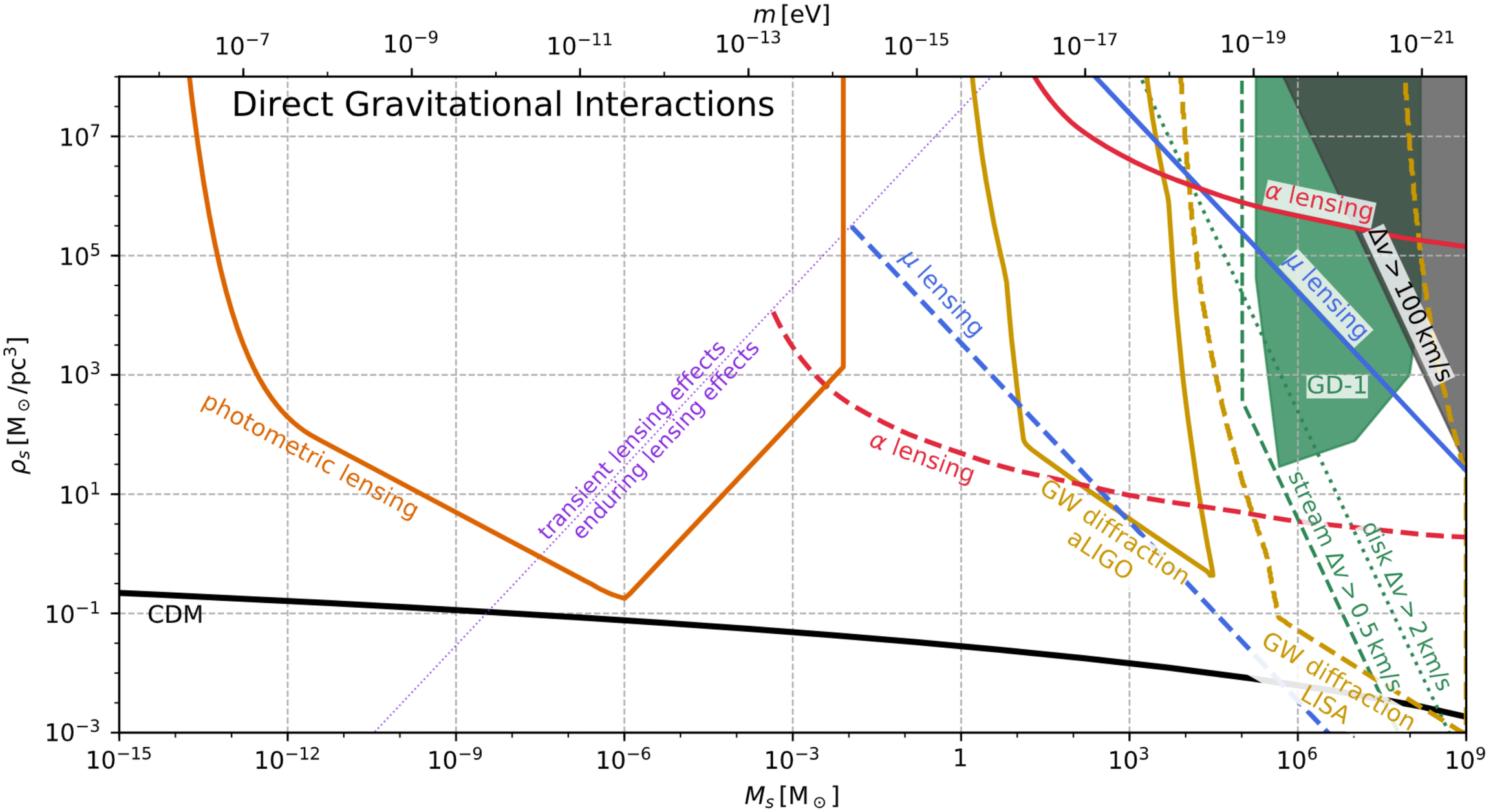
streams, pulsars, stars

Gravitational waves

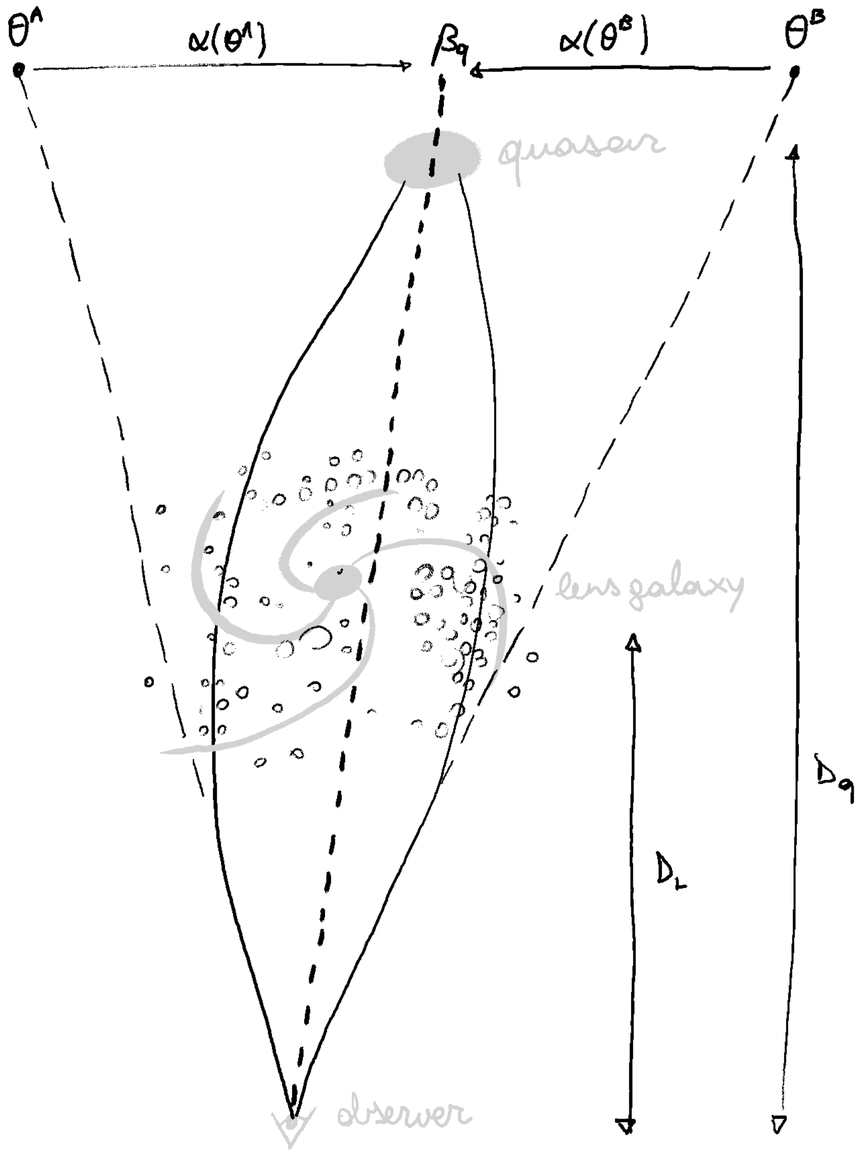
Nonminimal couplings

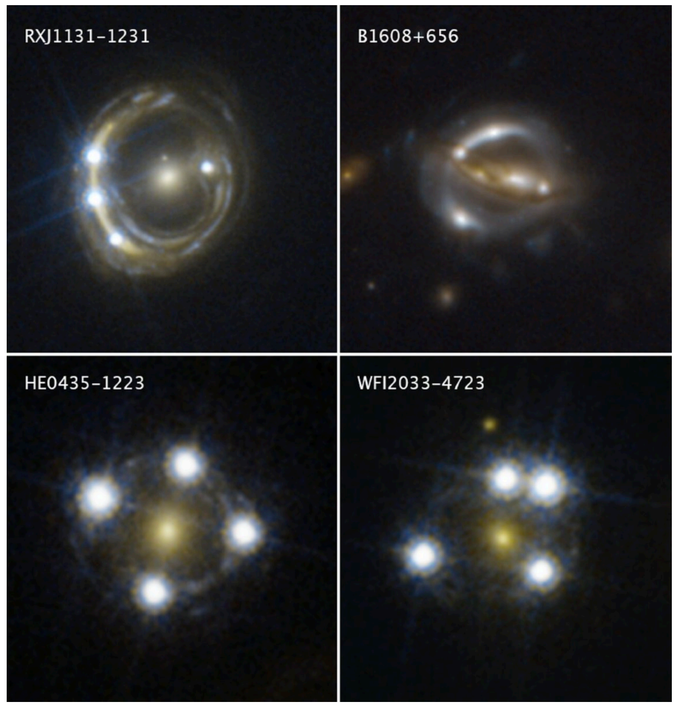
[Arvanitaki, Dimopoulos, Galanis, Lehner, Thompson, KVT; PRD 101 083014 (2020)]

Emergence of New Probes



Astrometric Microlensing of Quasars





$$\theta_E = \sqrt{\frac{4GM_L}{D_L}\frac{D_{LS}}{D_S}} \sim 2\,\mu\text{as}\sqrt{\frac{M_L}{M_\odot}\frac{\text{Gpc}}{D_L}}$$

motion + stochastic noise: $\delta\theta^{\text{I}} \sim B^{\text{I}}\theta_E\sqrt{\kappa_L}$

[KVT, Kaplan; in prep]

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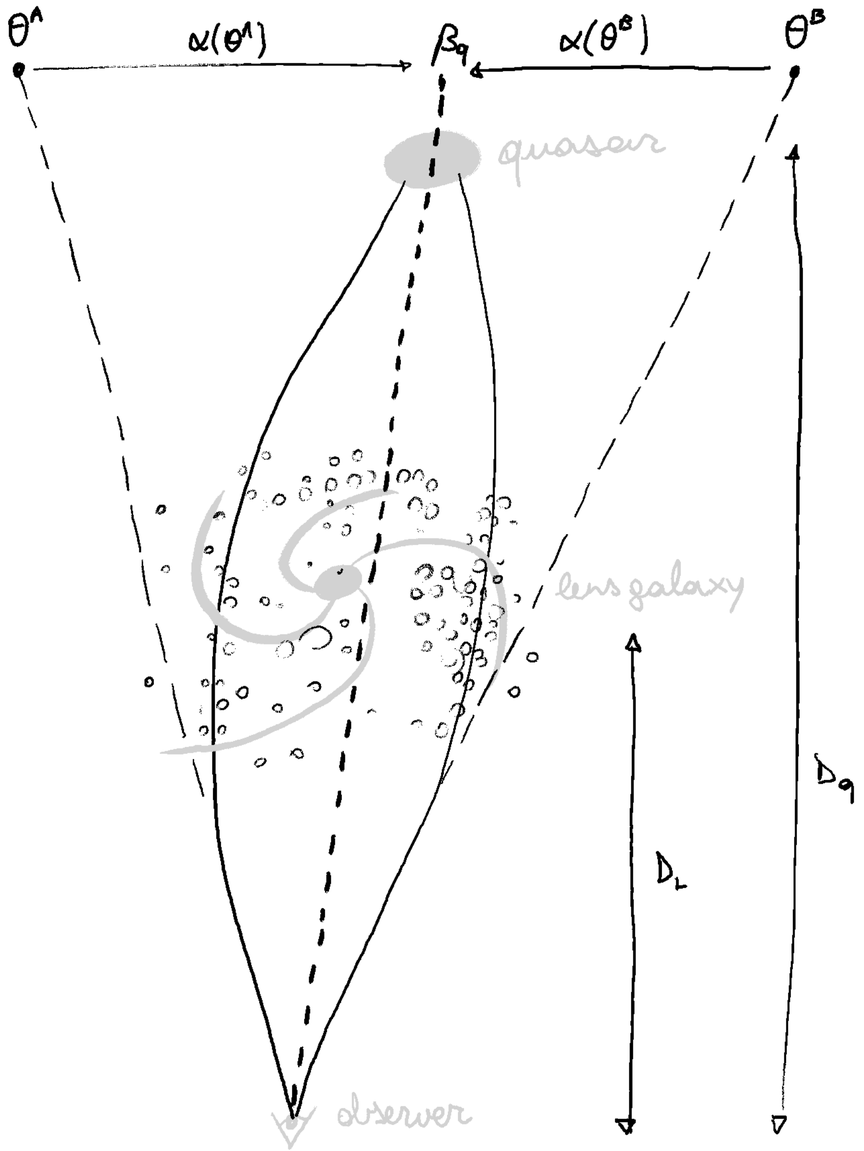

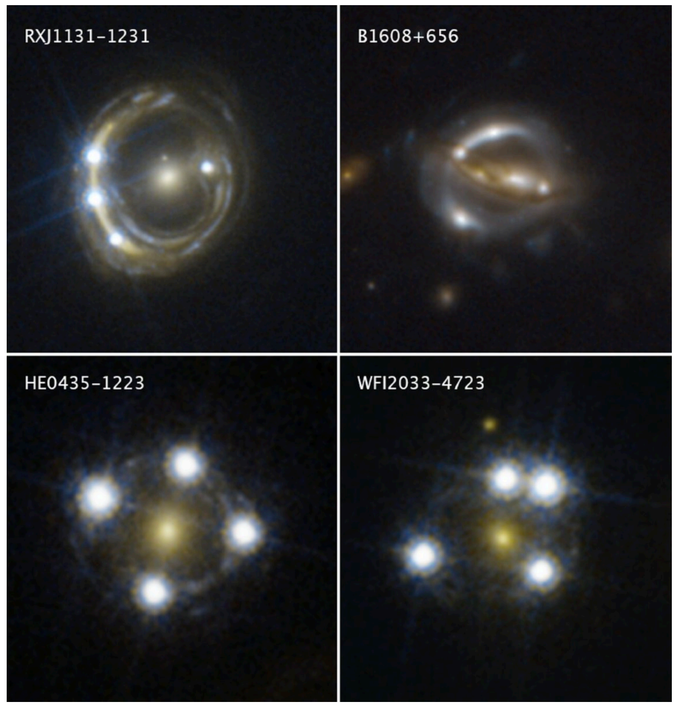

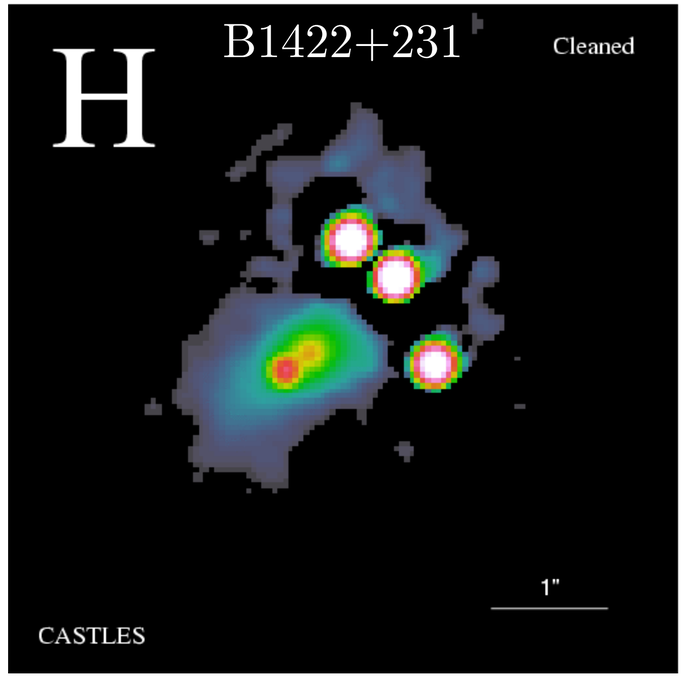

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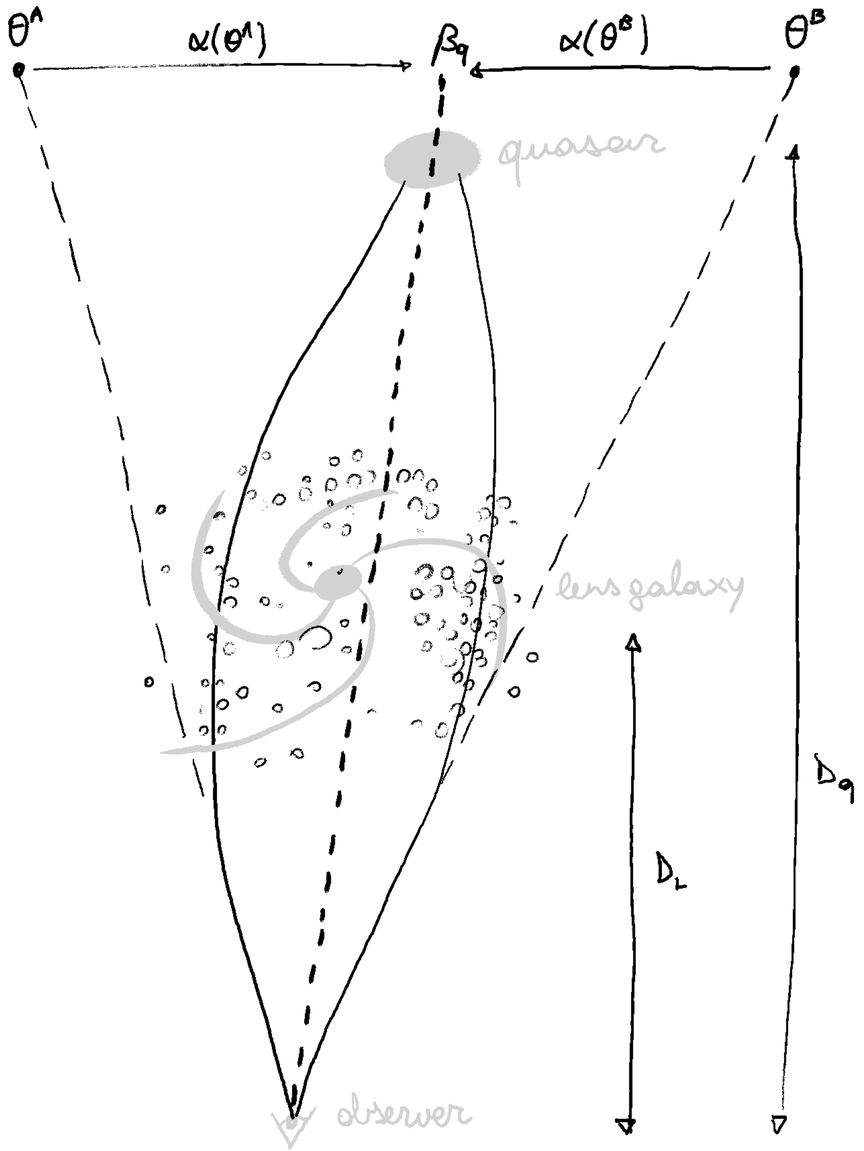

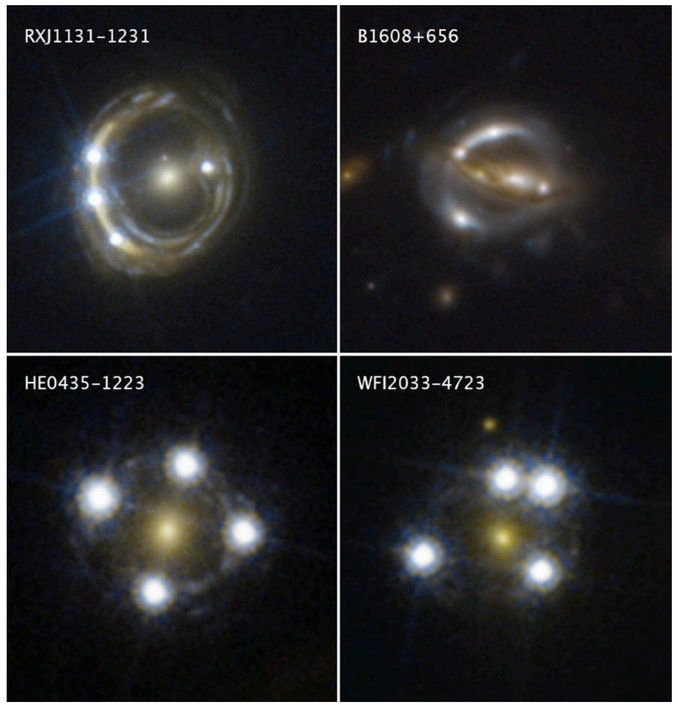

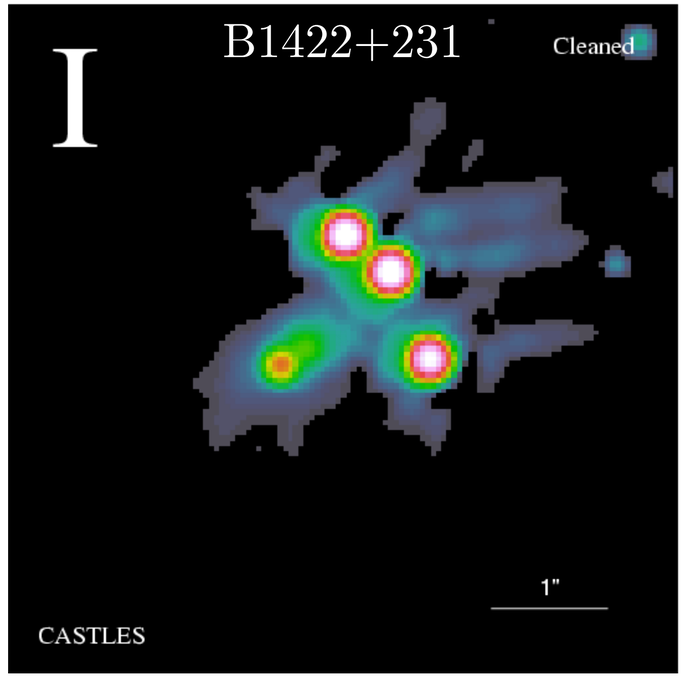

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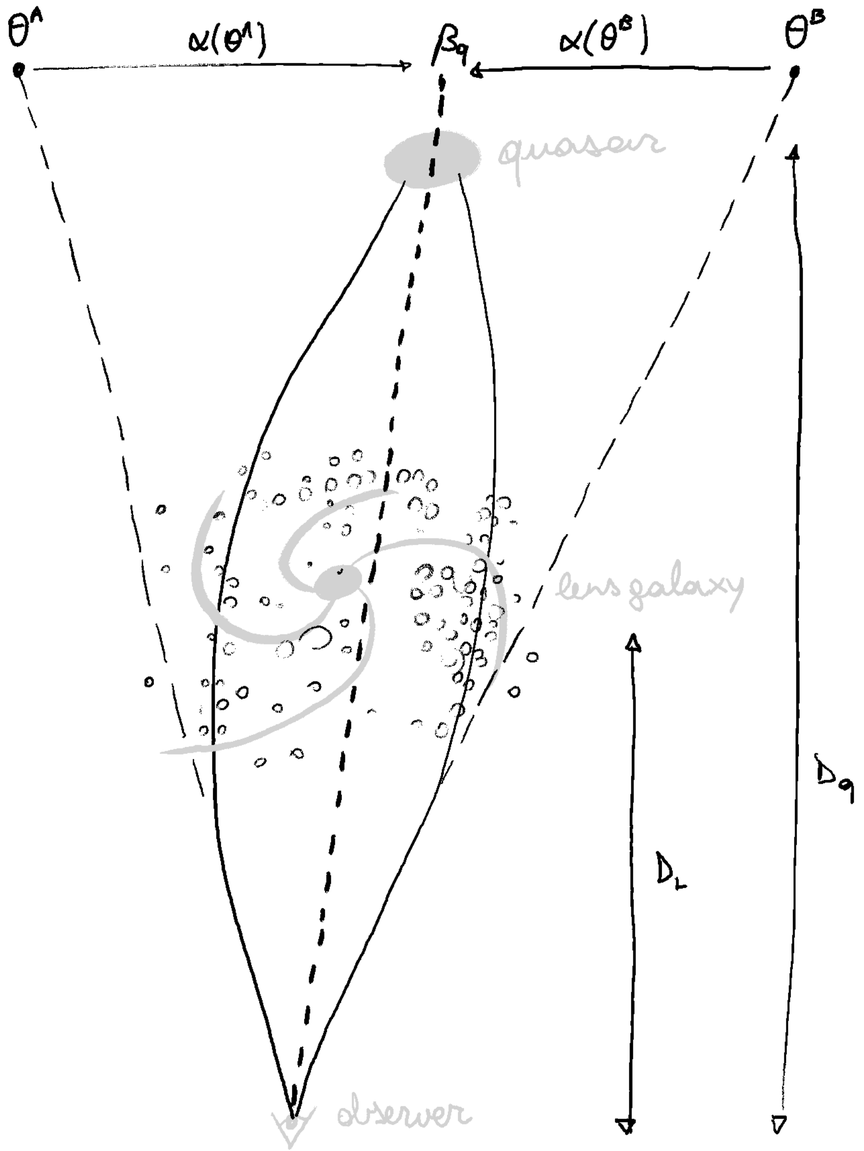

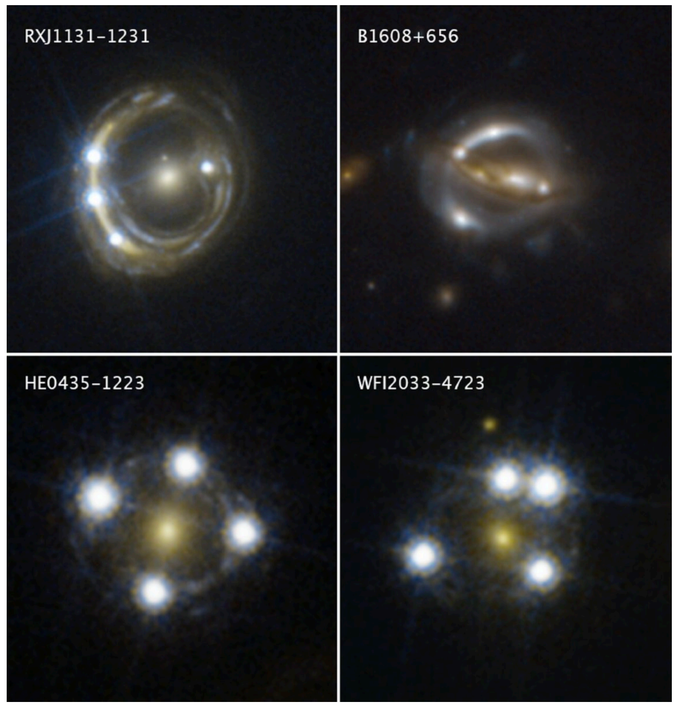

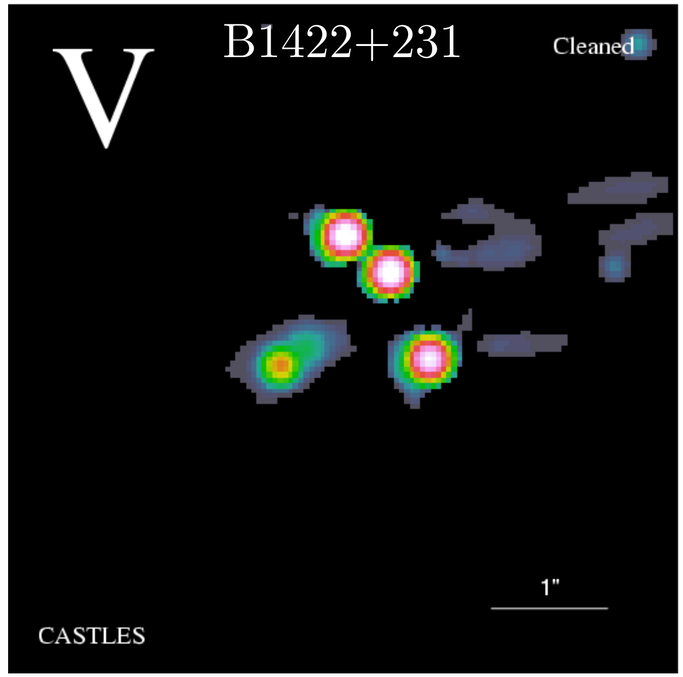

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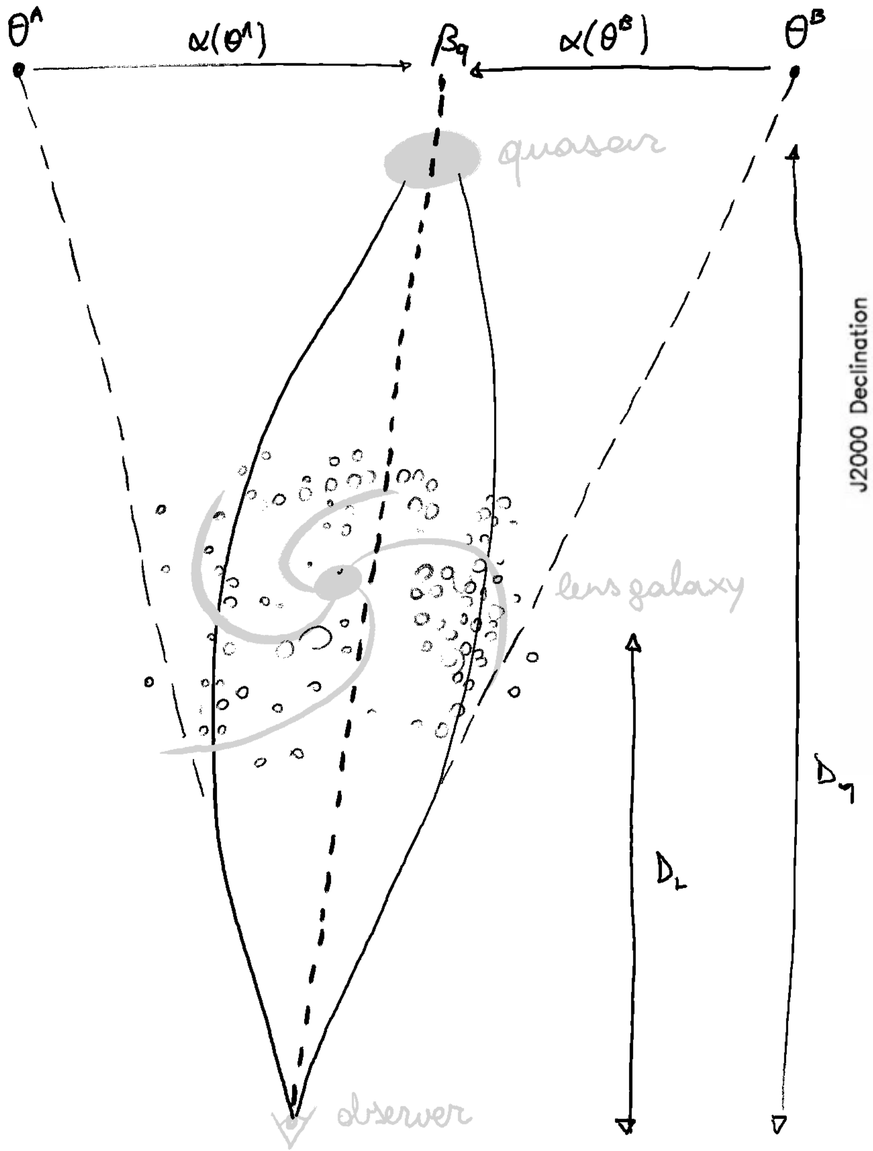

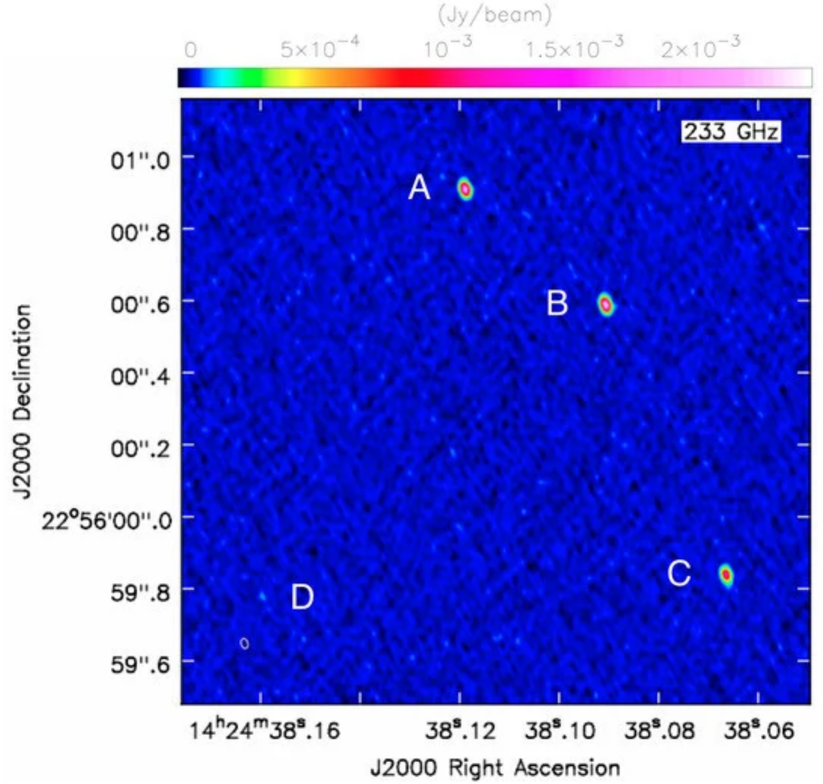

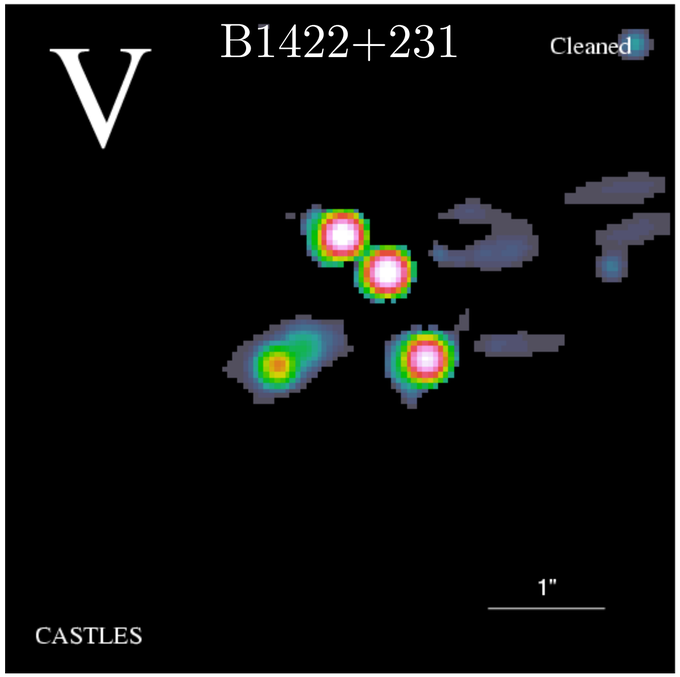

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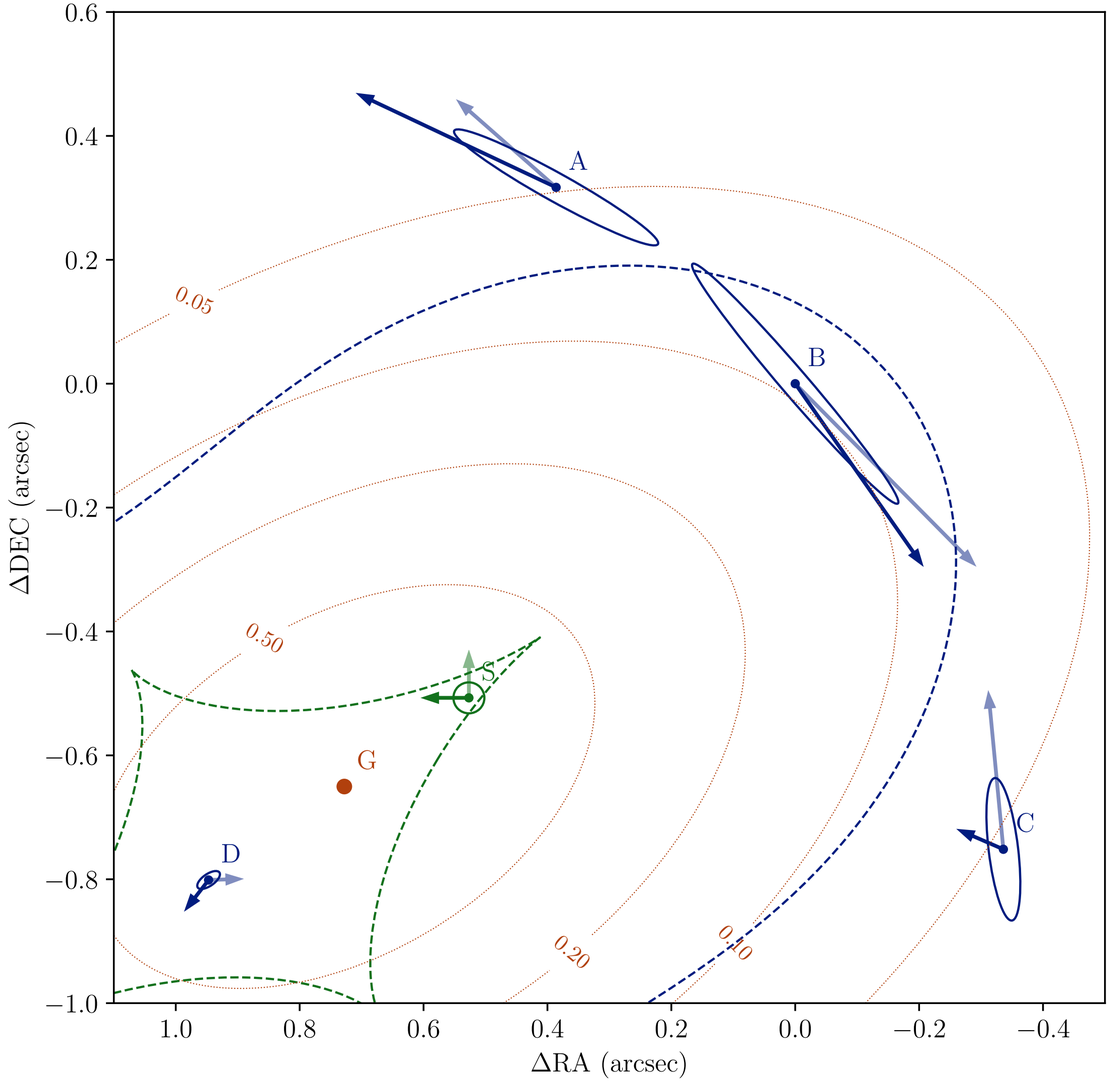

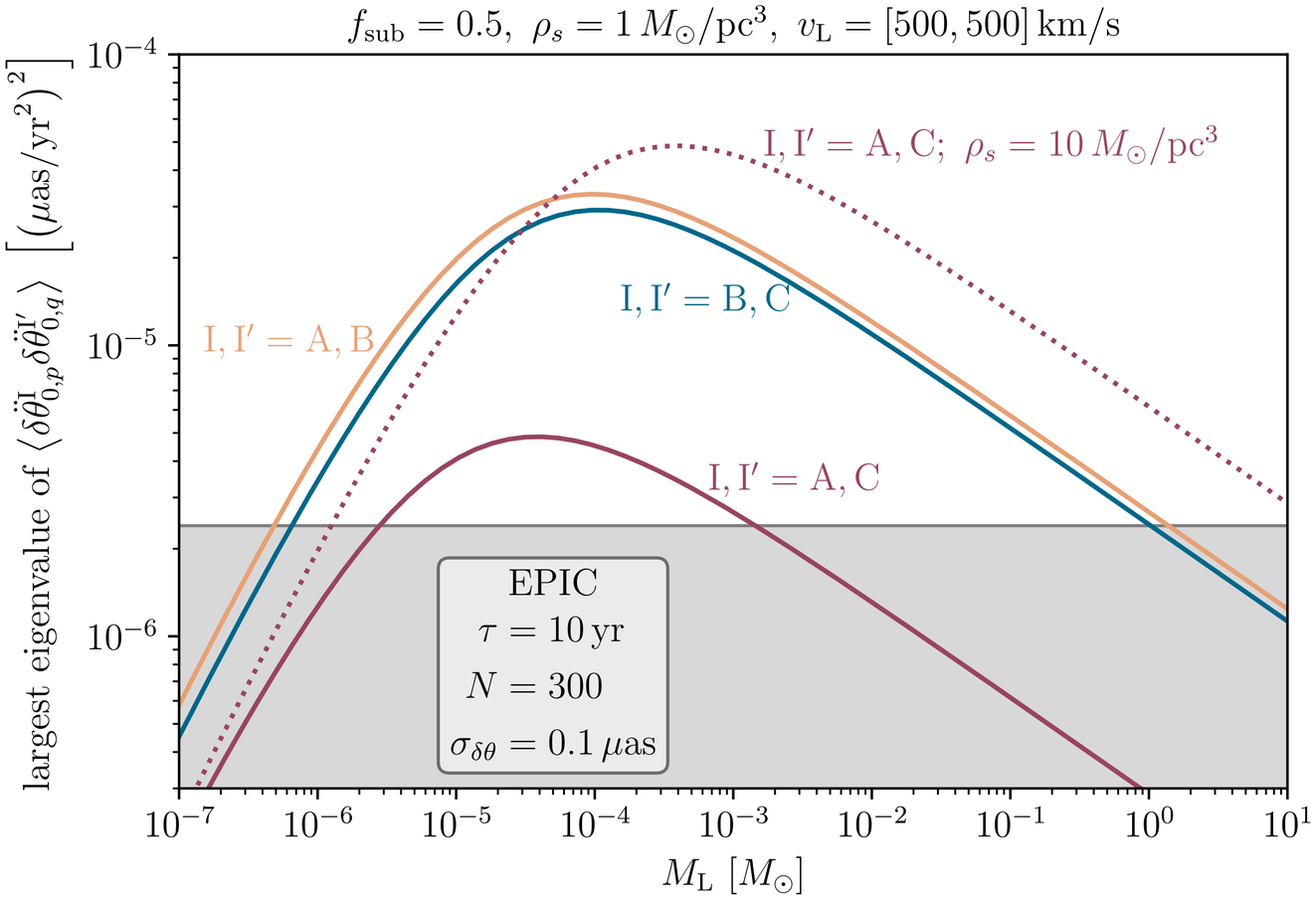

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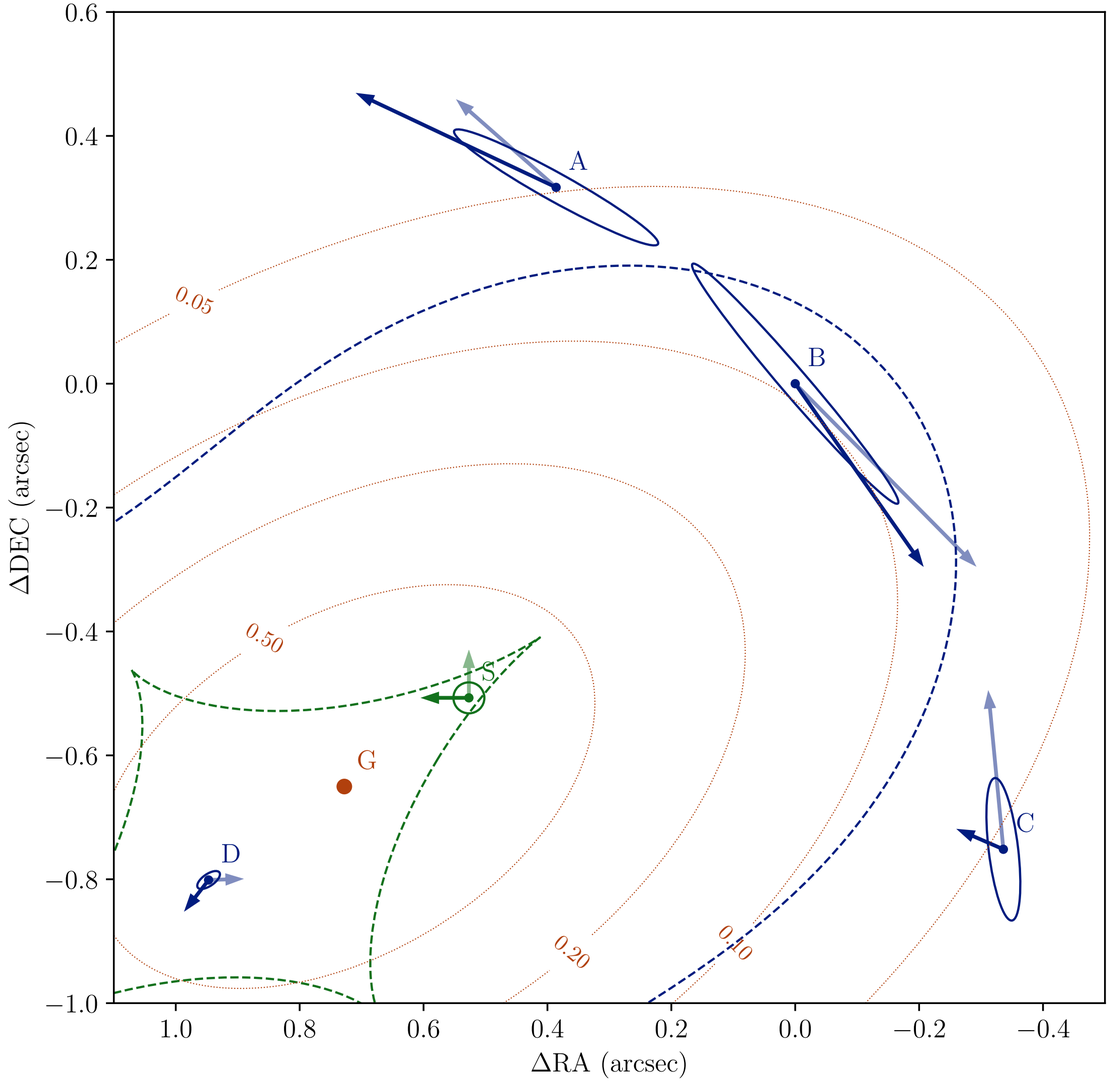

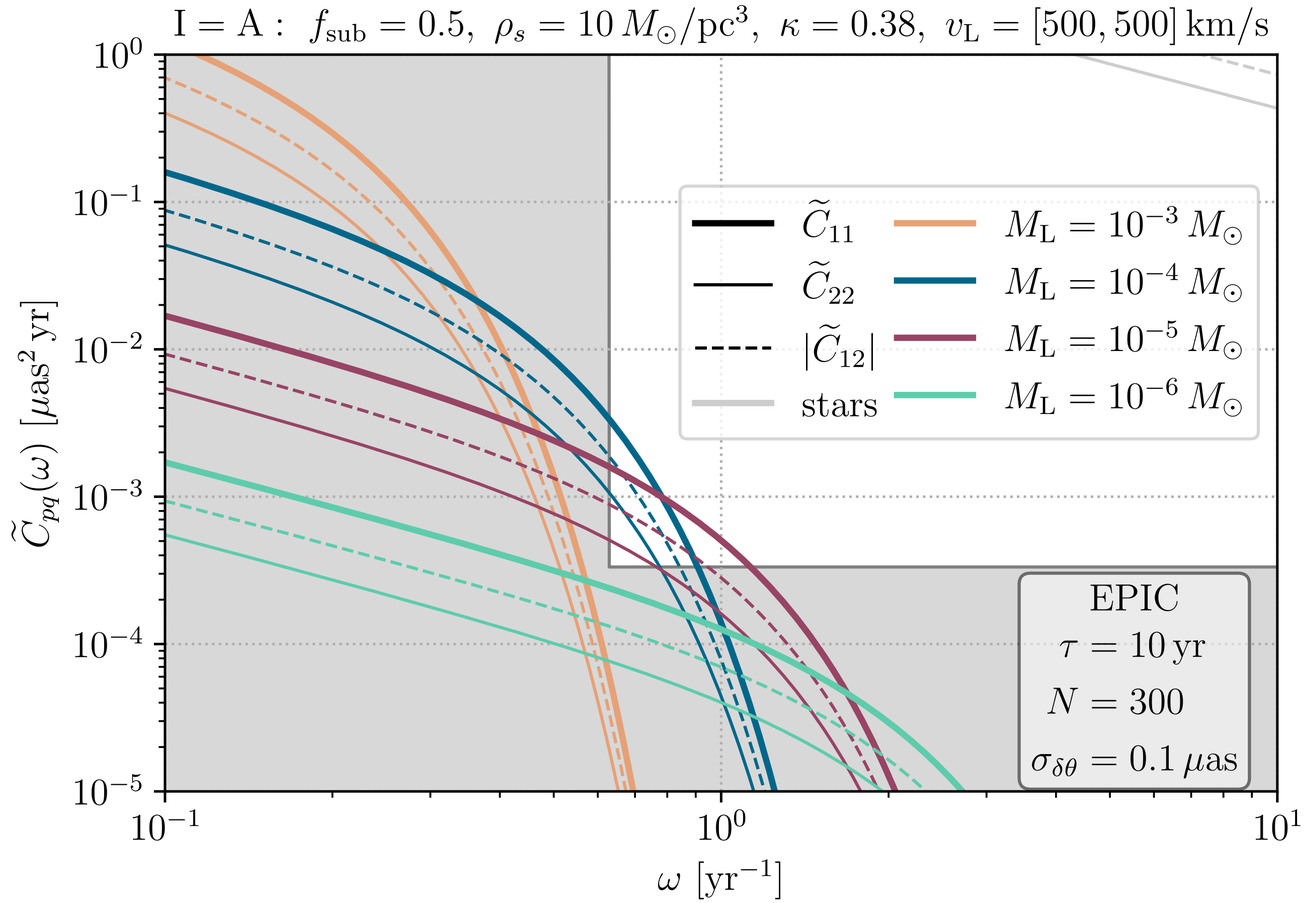

stellar microlensing background subtraction [A. Moran, KVT; in prep]

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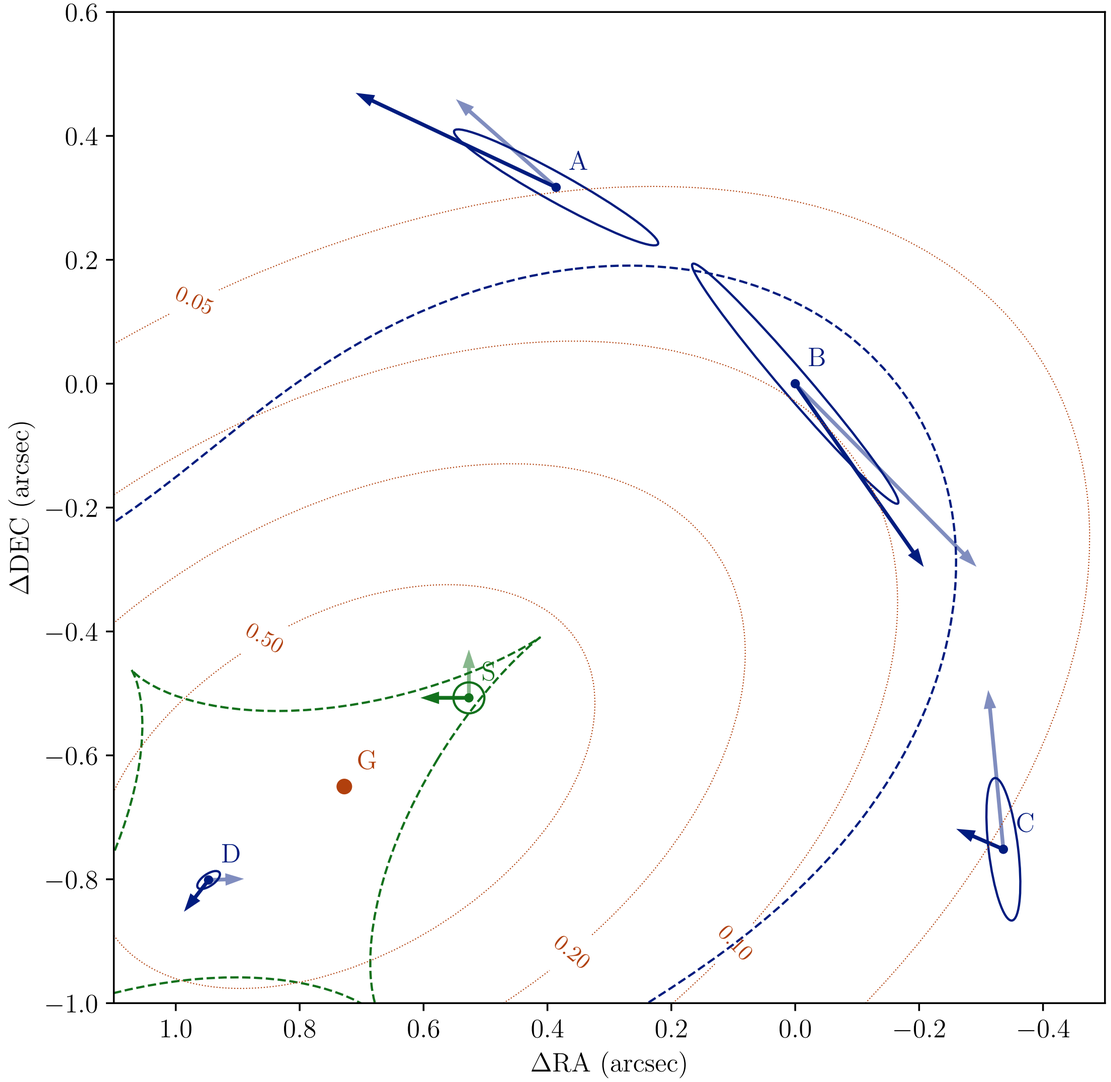

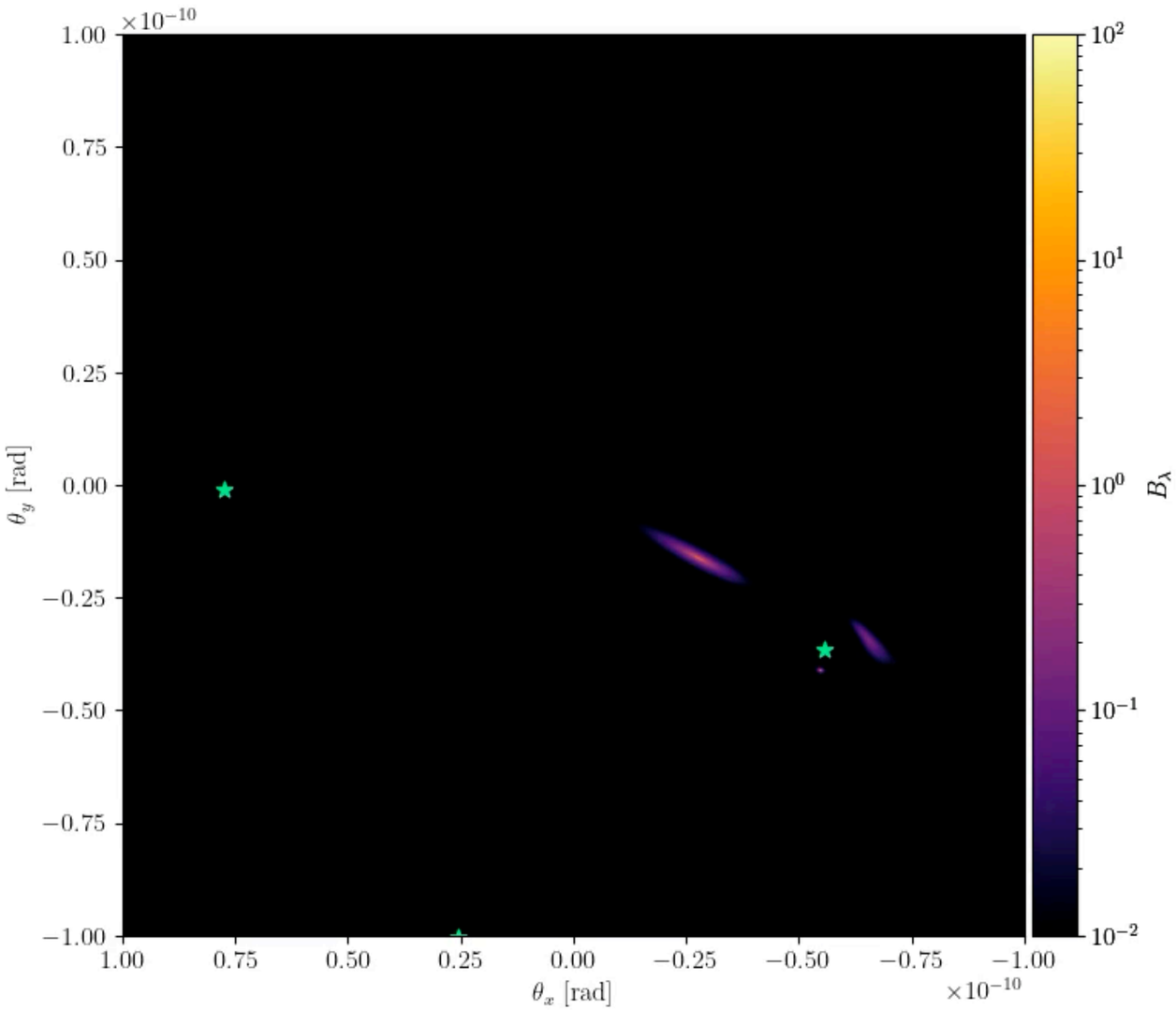

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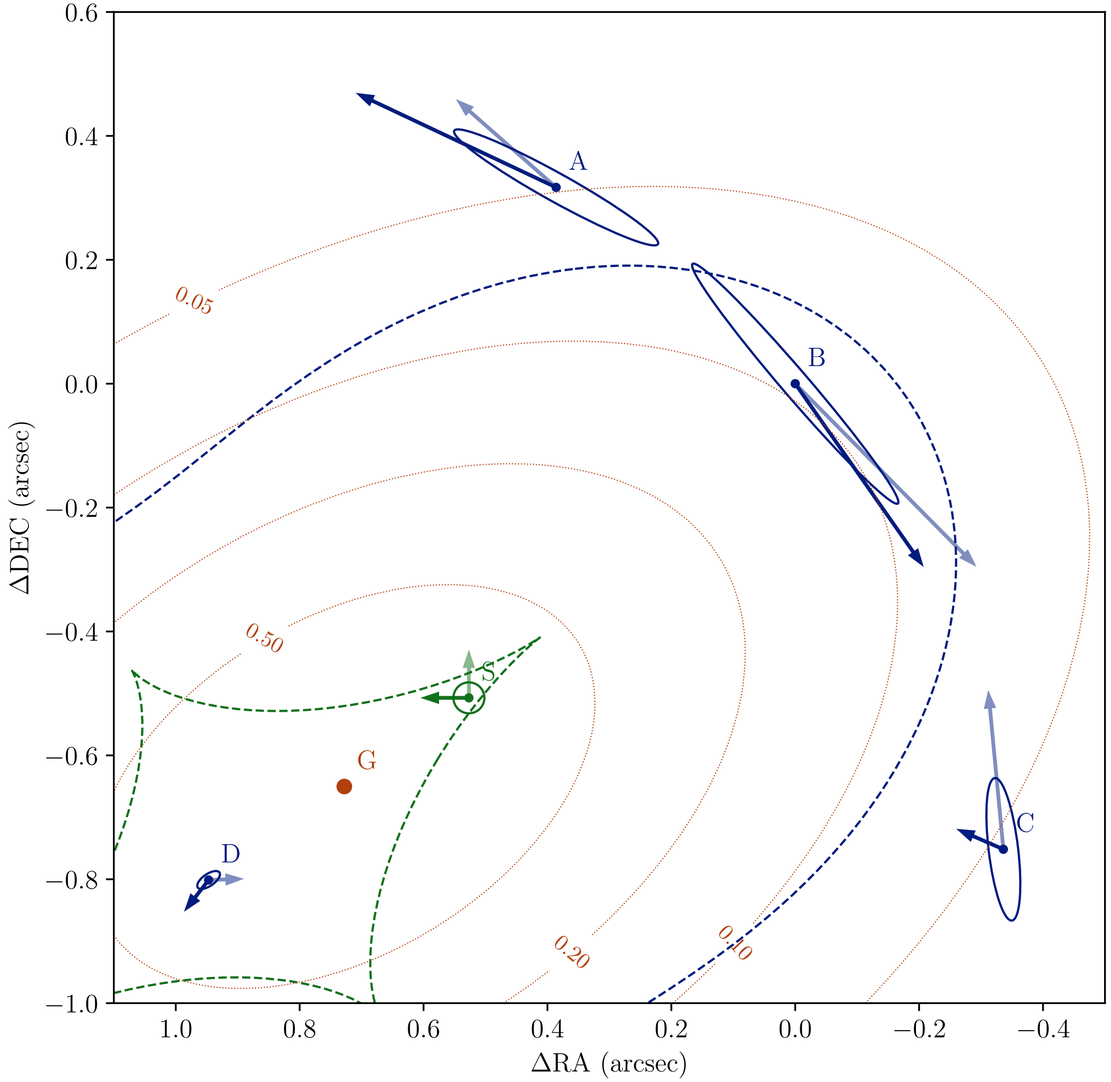

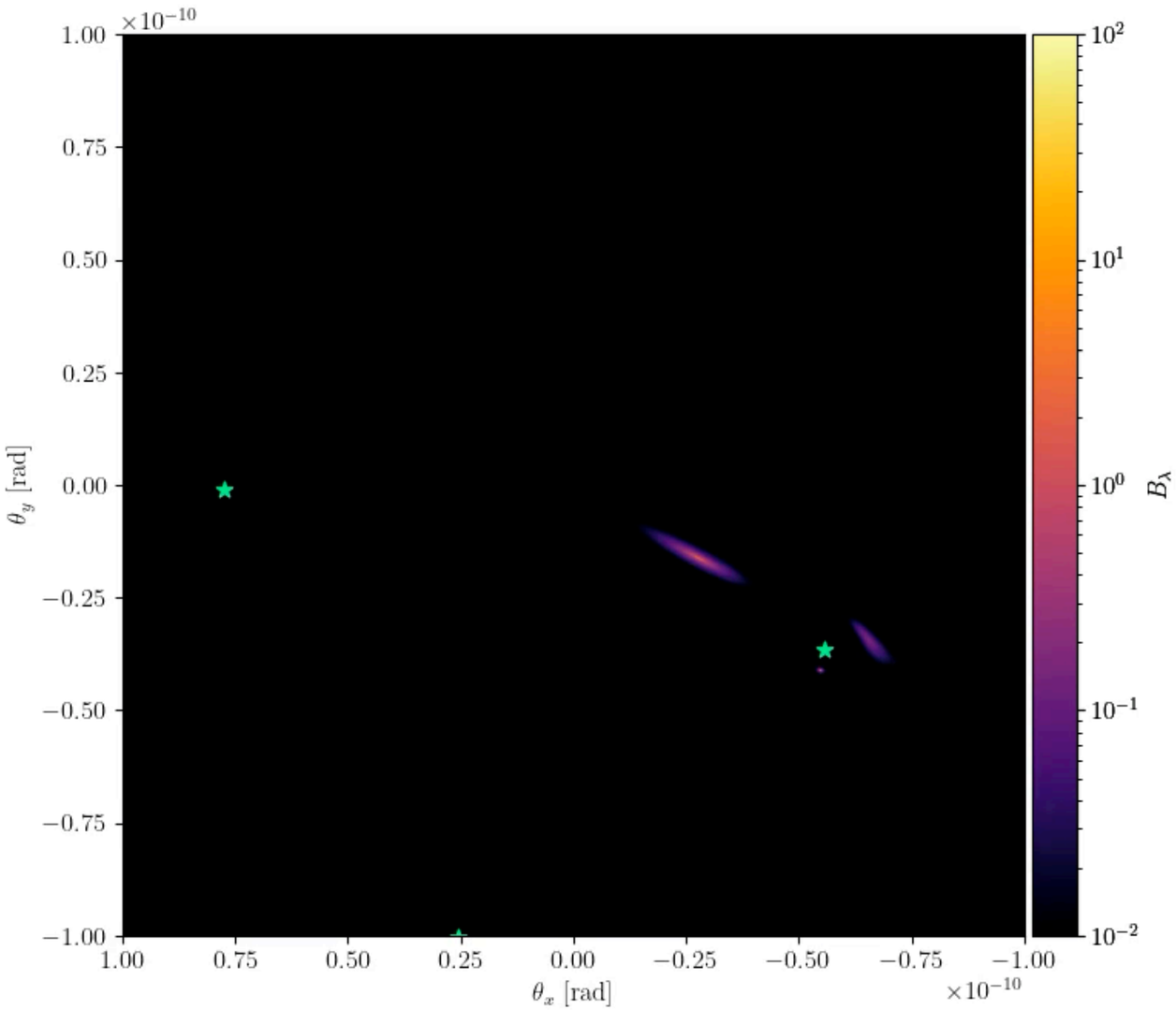

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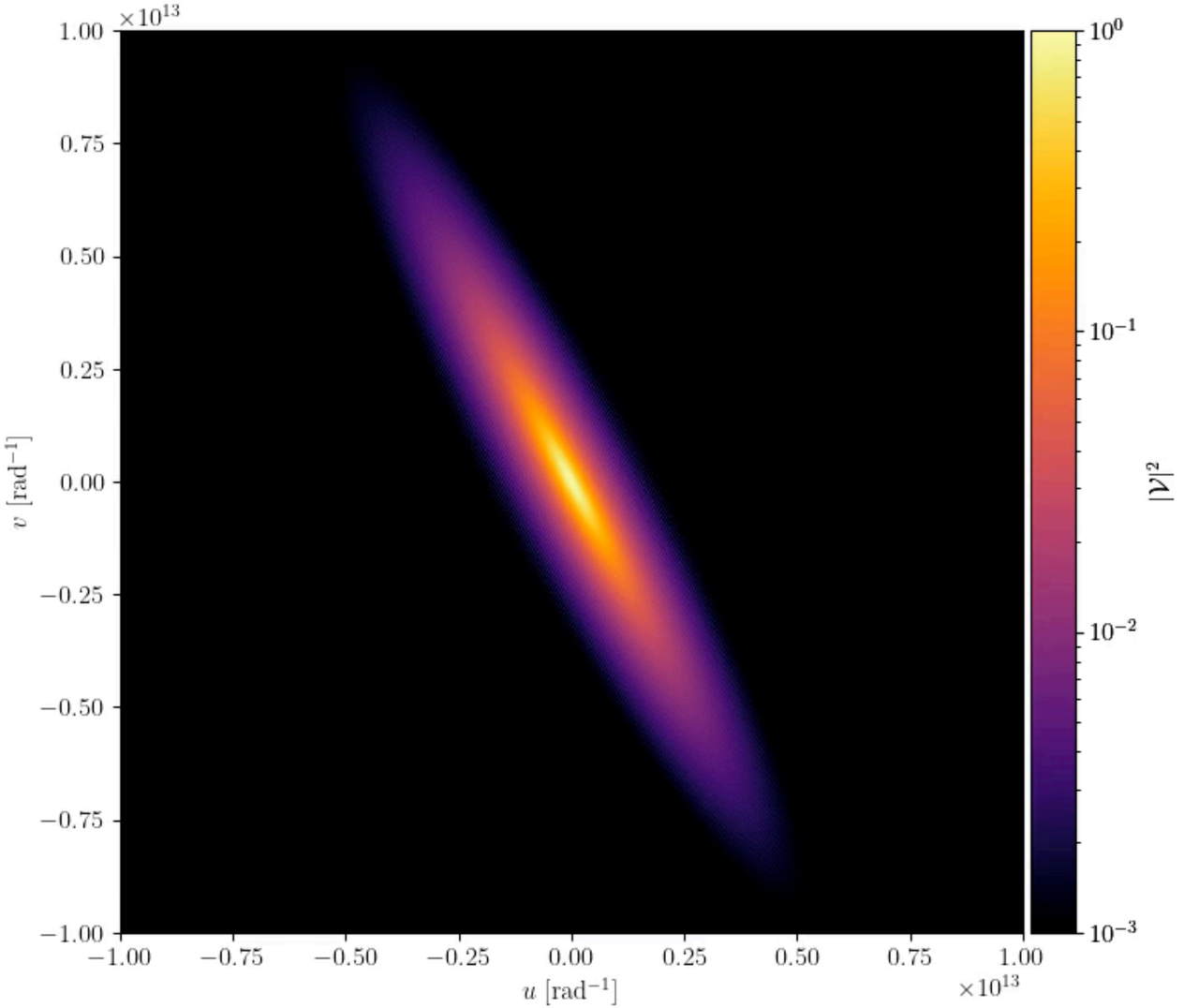

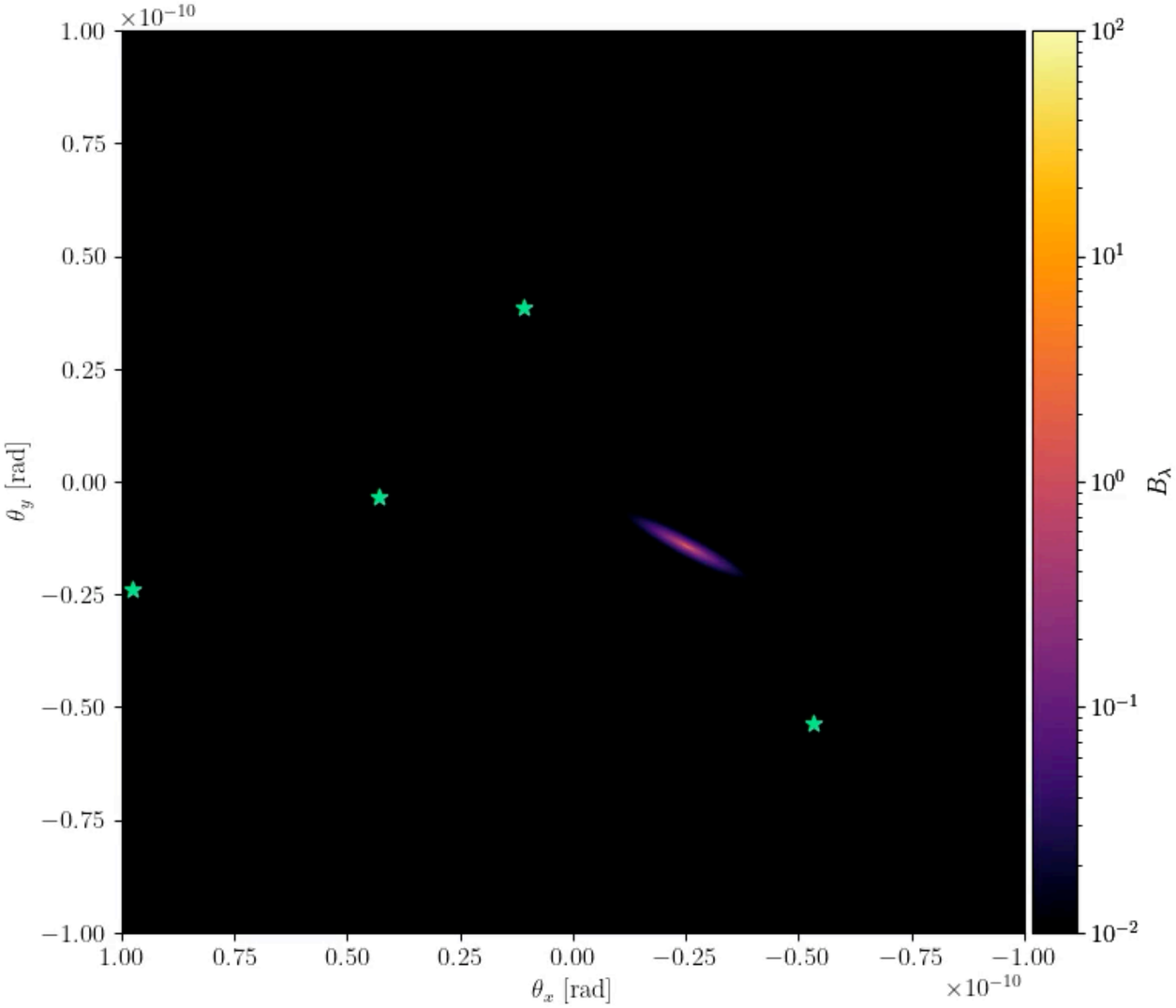

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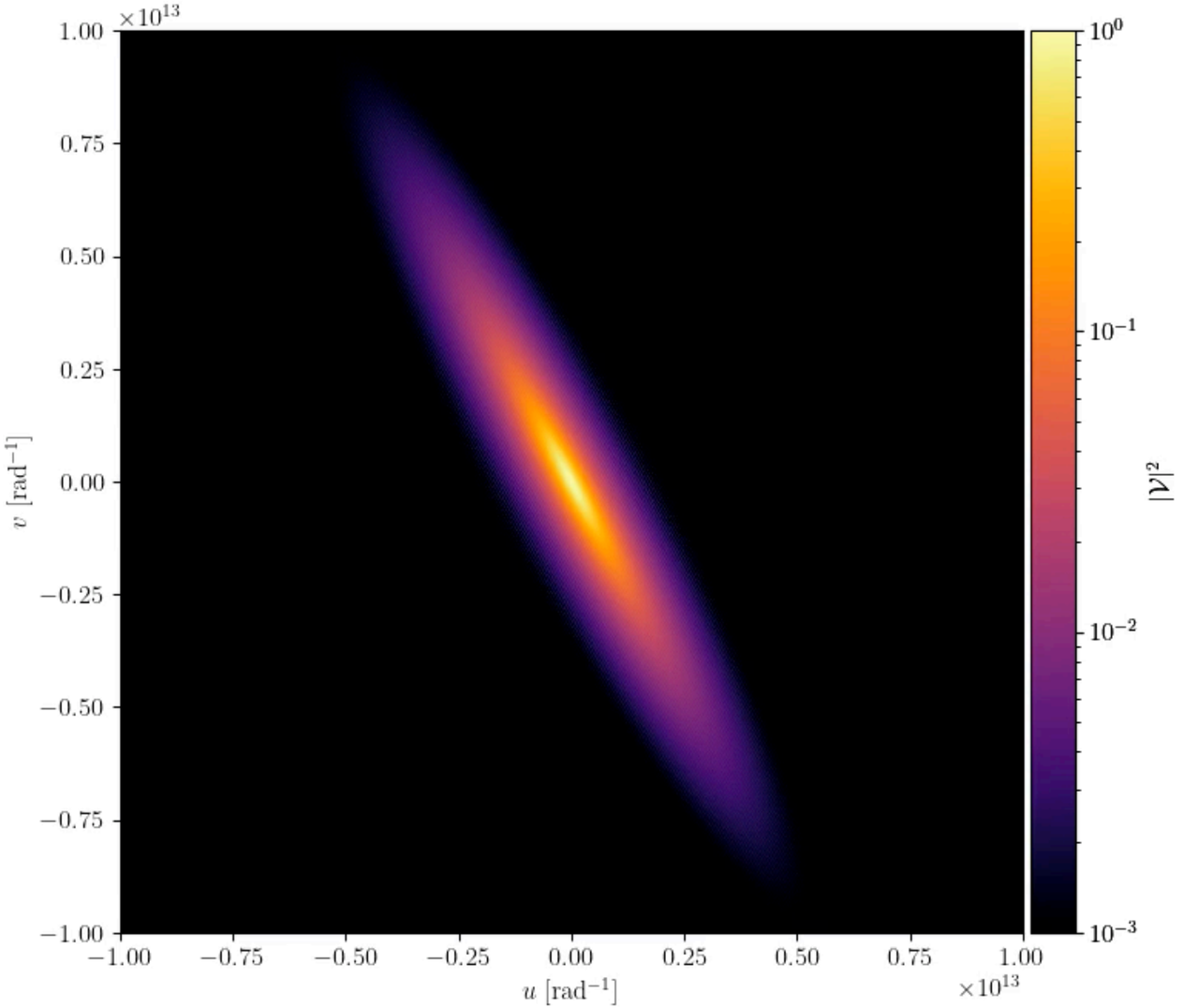

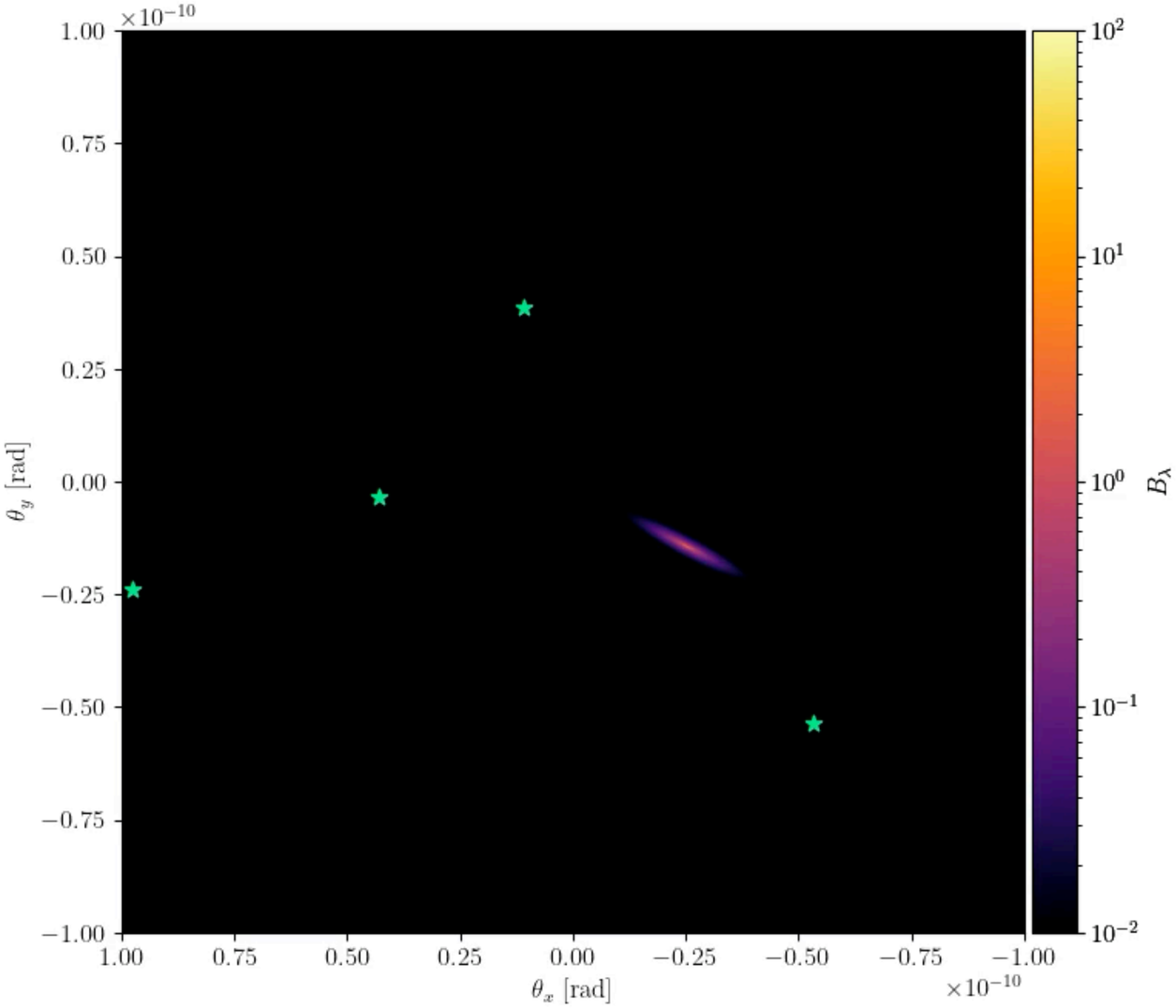

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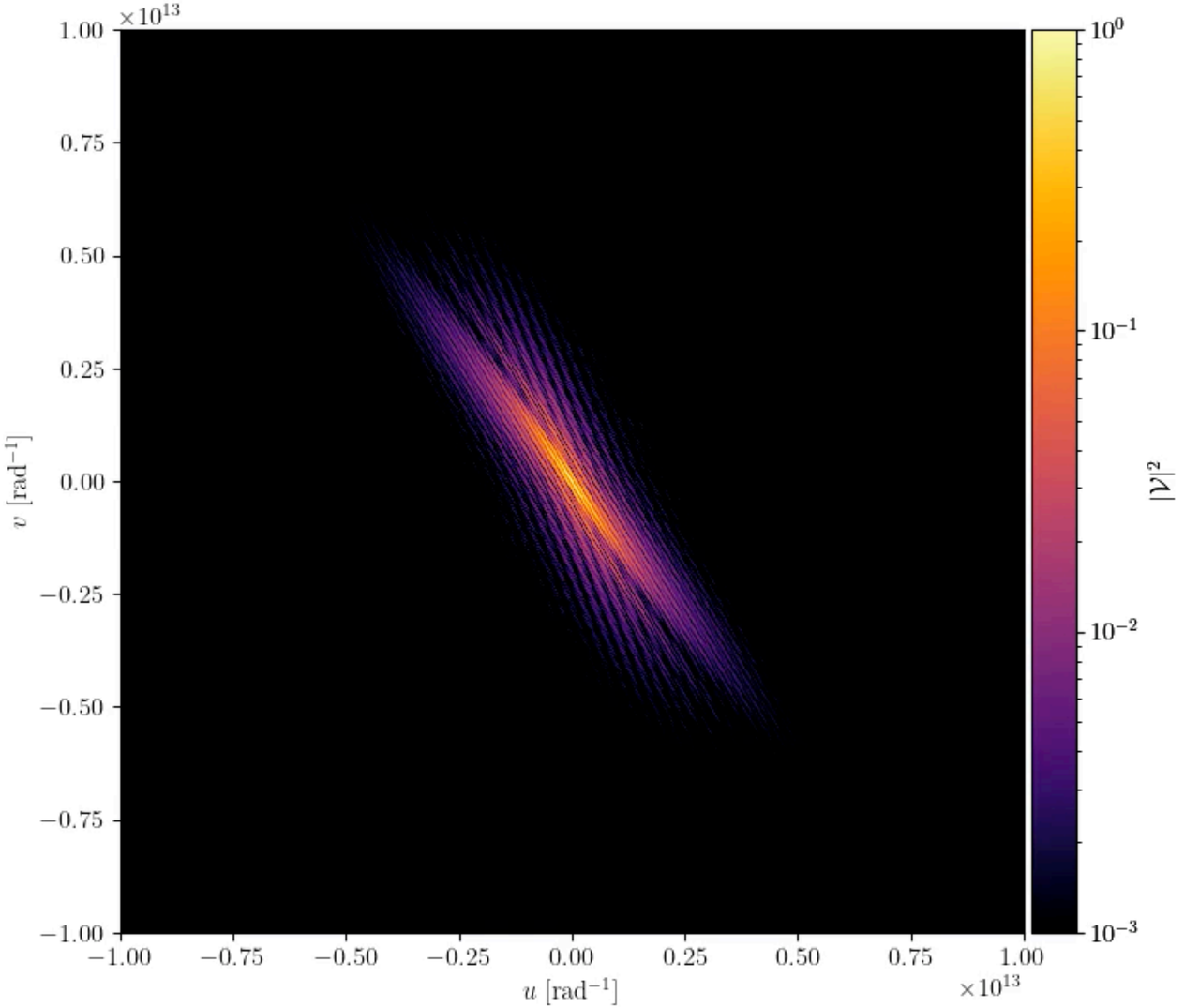

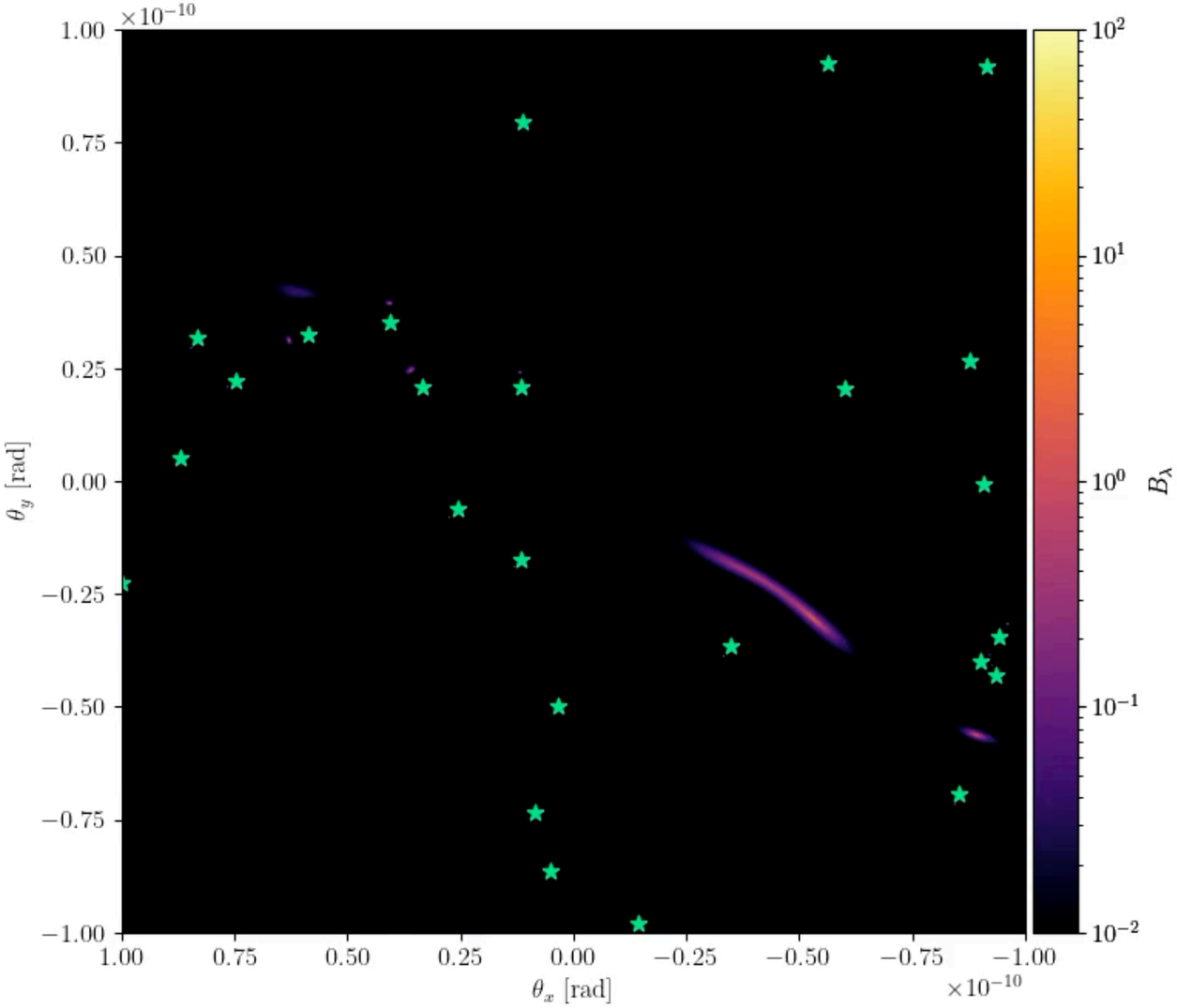

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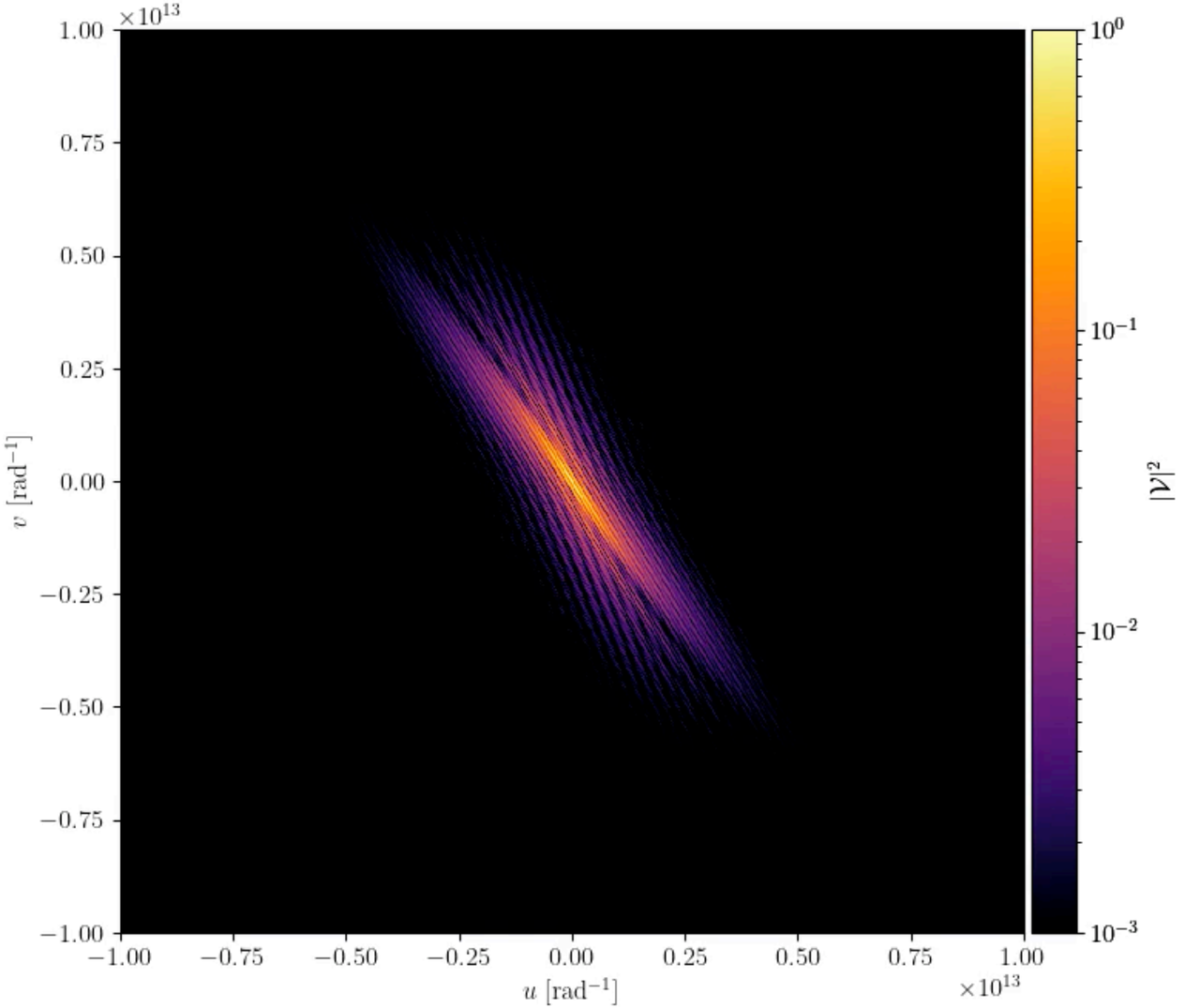

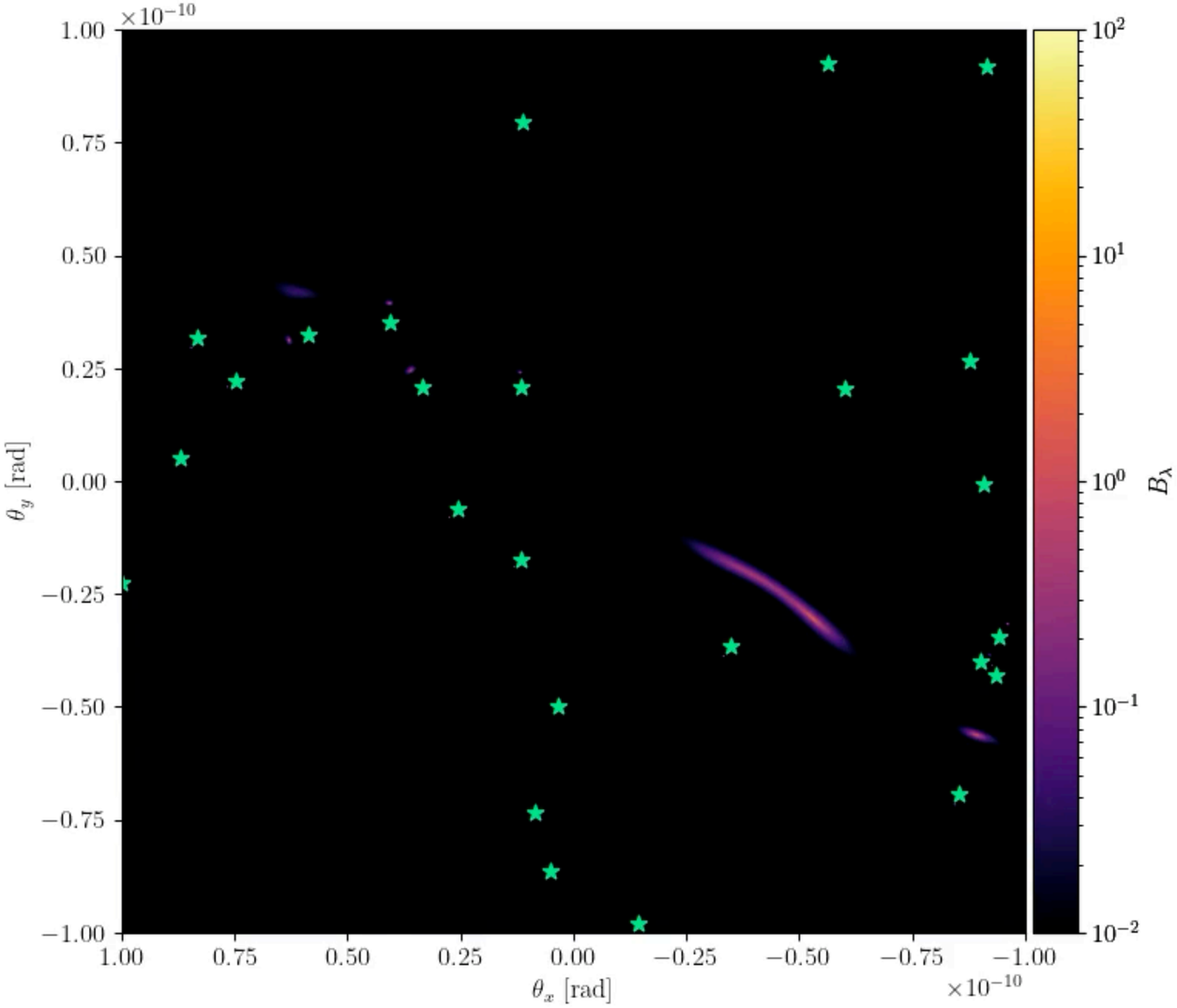

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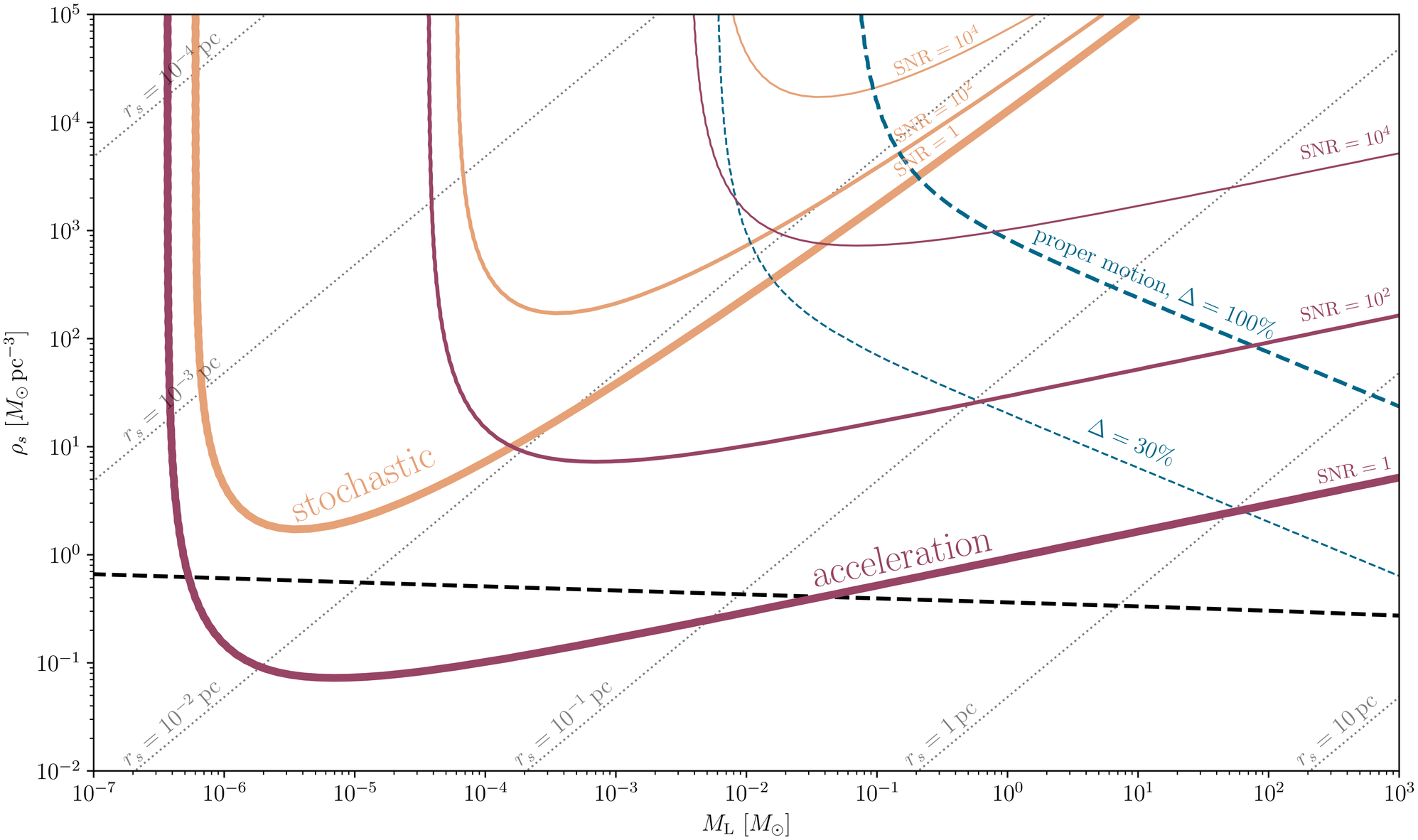
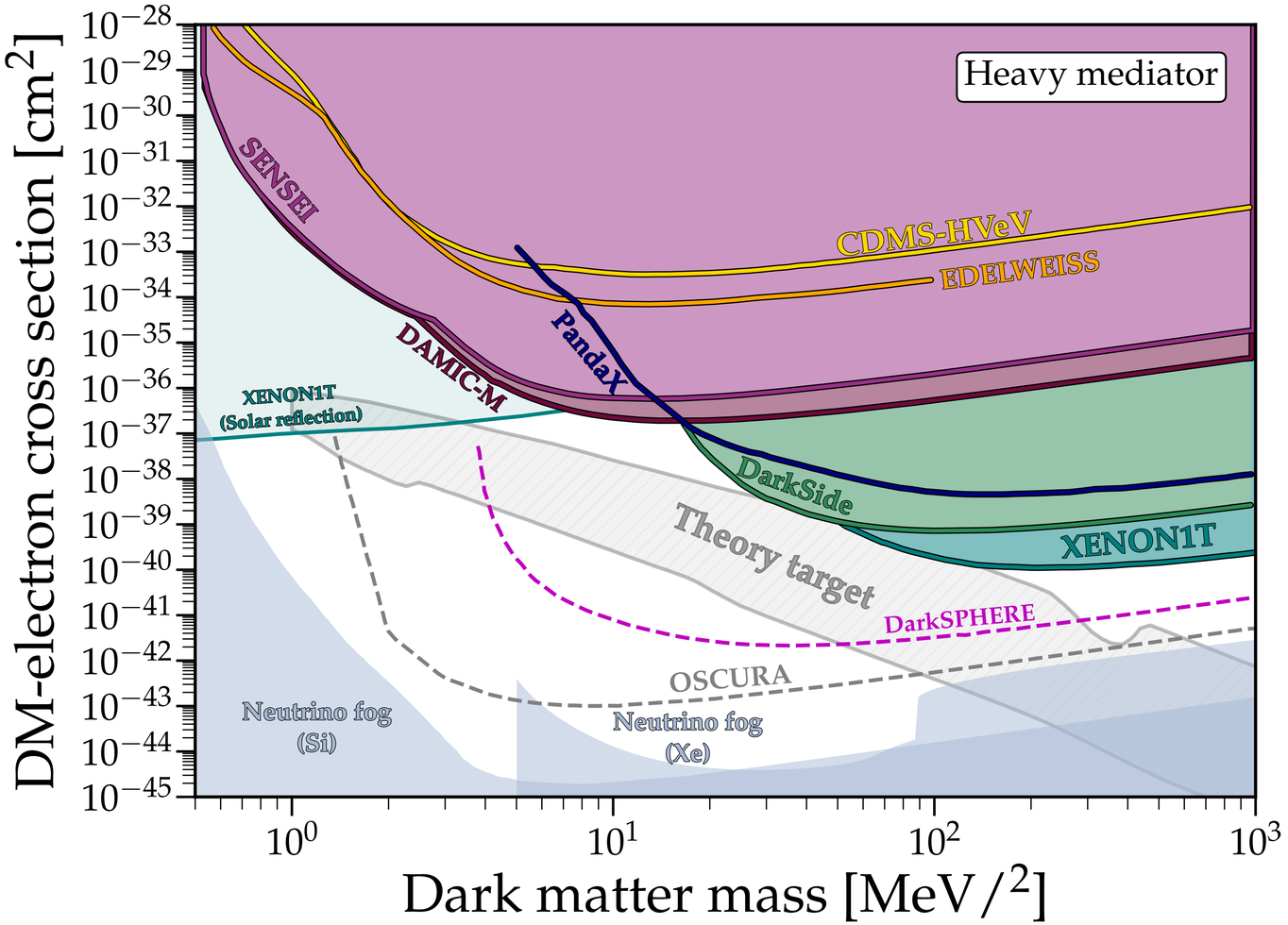
Dark Matter Subhalo Sensitivity



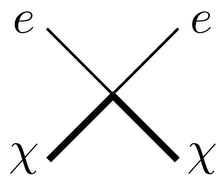
[KVT, D. E. Kaplan; in prep]

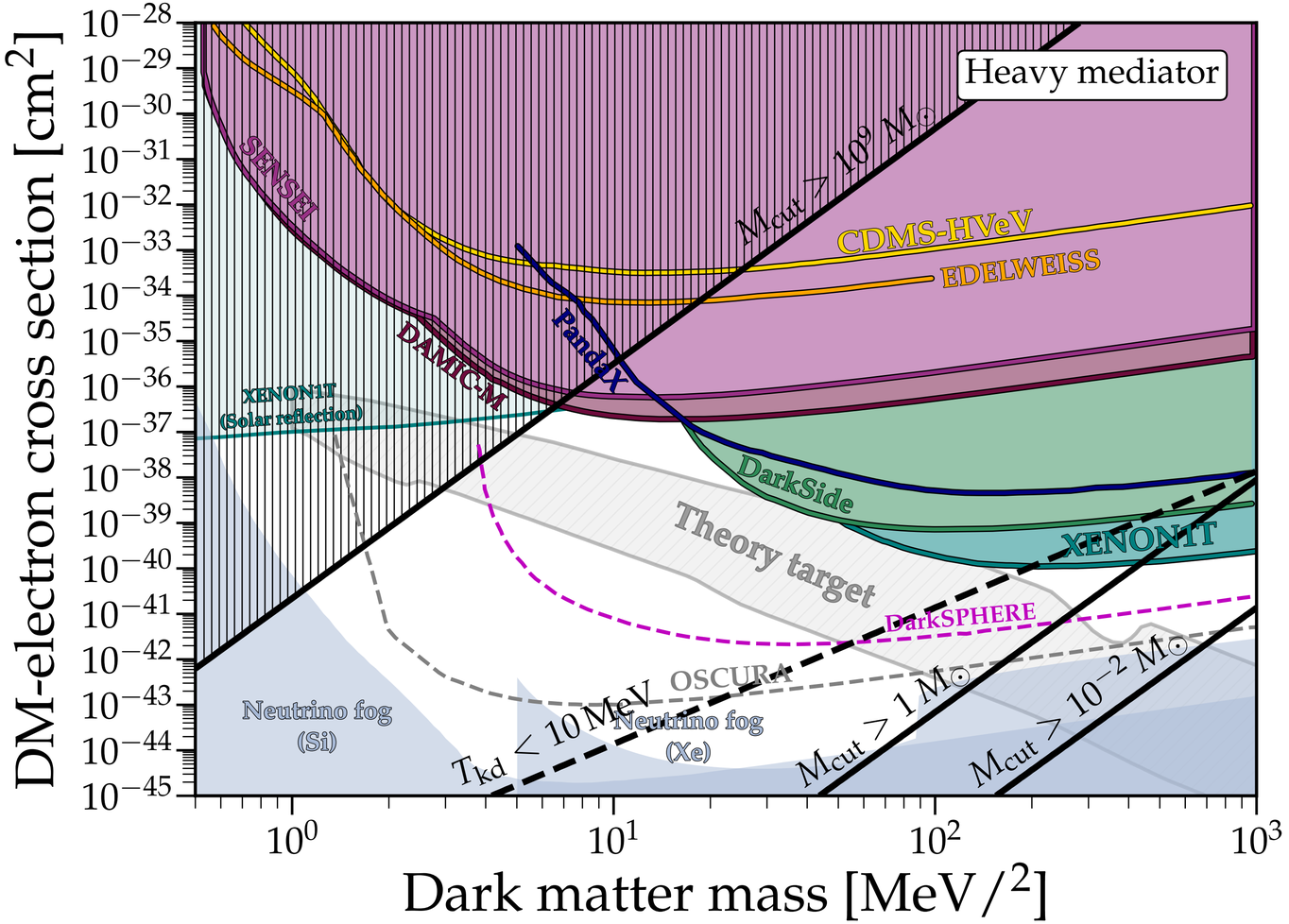
Dark Matter Microphysics Implications



[github.com/cajohare]

Dark Matter Microphysics Implications





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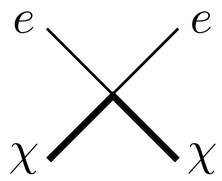
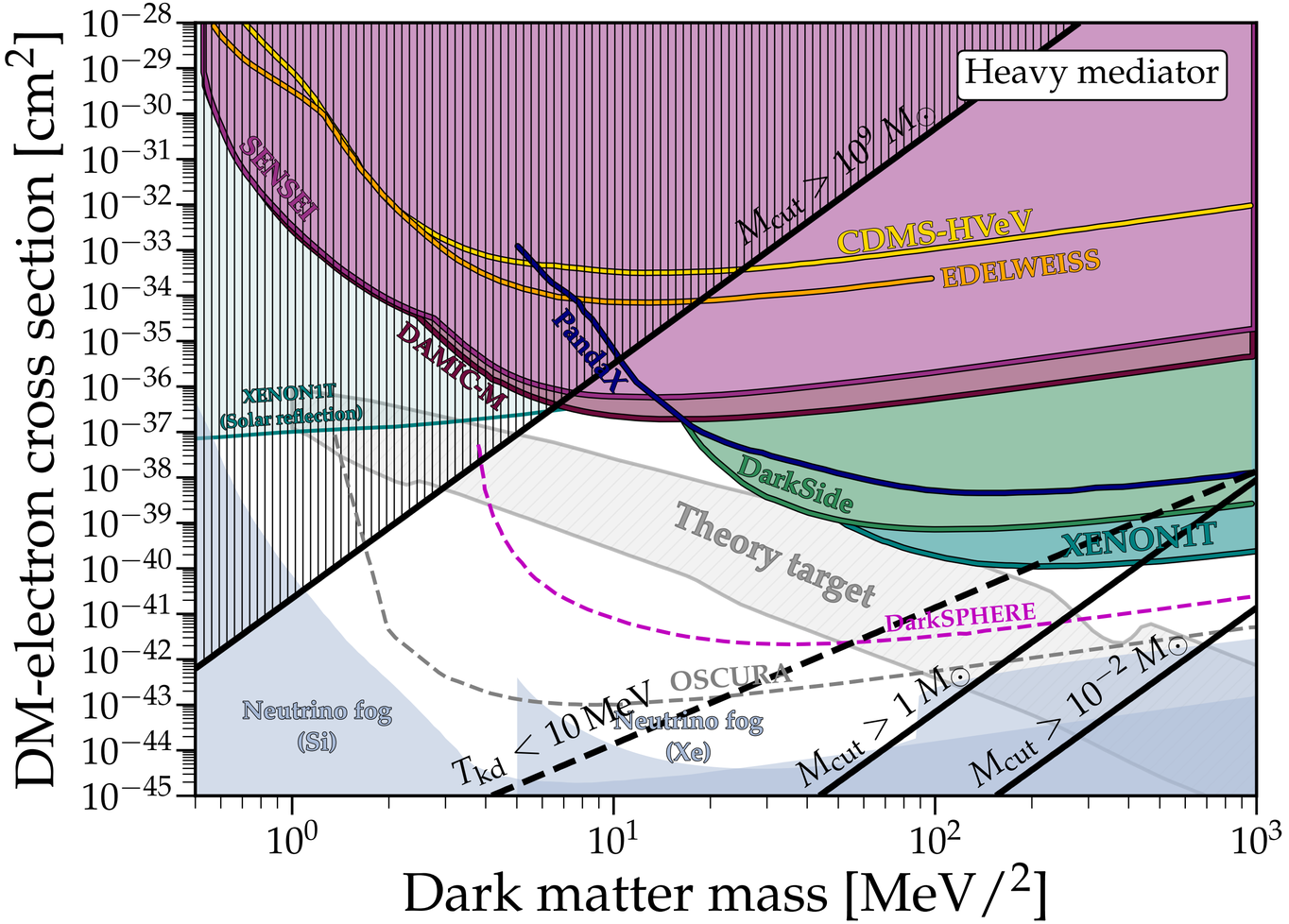
Dark Matter Microphysics Implications





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Universal lower DM mass limit

$$M_{\rm cut} \lesssim 10^{-6}\,M_\odot$$

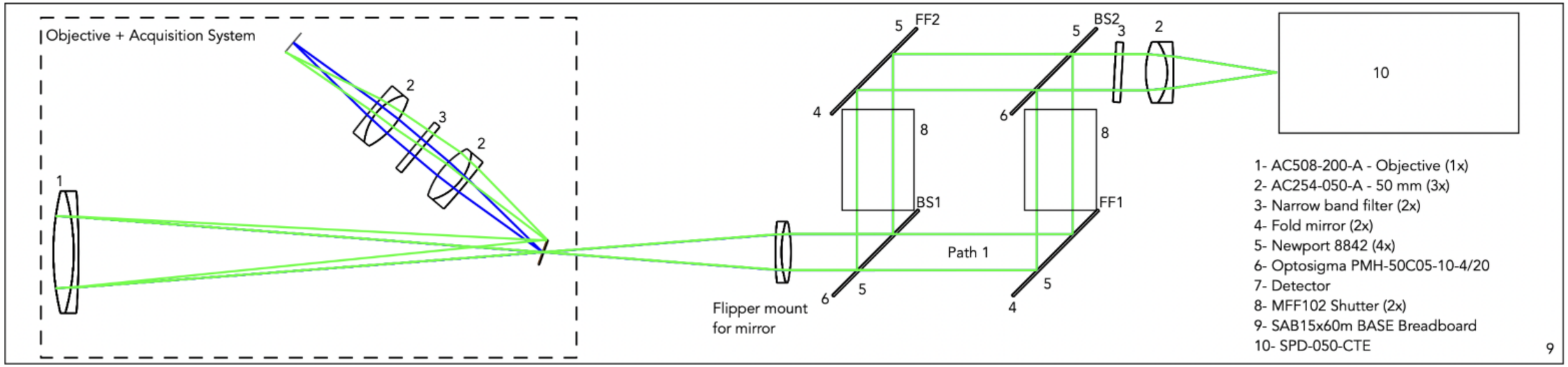
$$\Downarrow$$

$$m_{\rm fermion} \gtrsim \frac{\rho_s^{1/8} M_{\rm Pl}^{3/4}}{M_{\rm cut}^{1/4}} \sim 400\,{\rm keV}$$

$$m_{\rm boson} \gtrsim \frac{H_{\rm eq}^{1/3} M_{\rm Pl}^{4/3}}{M_{\rm cut}^{2/3}} \sim 10^{-12}\,{\rm eV}$$

Experimental Directions

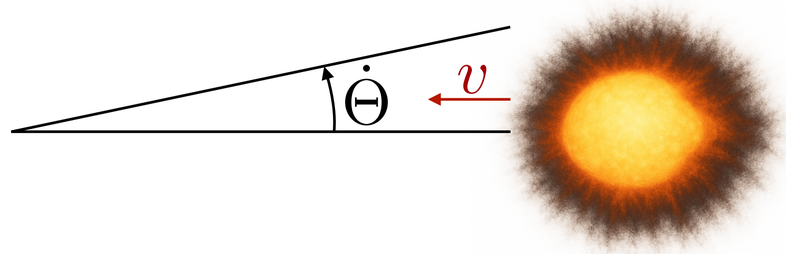
EPIC Demonstration



Summary

Cosmology: Supernova Distances

$$D_A = \frac{\dot{\Theta}}{\dot{\upsilon}}$$

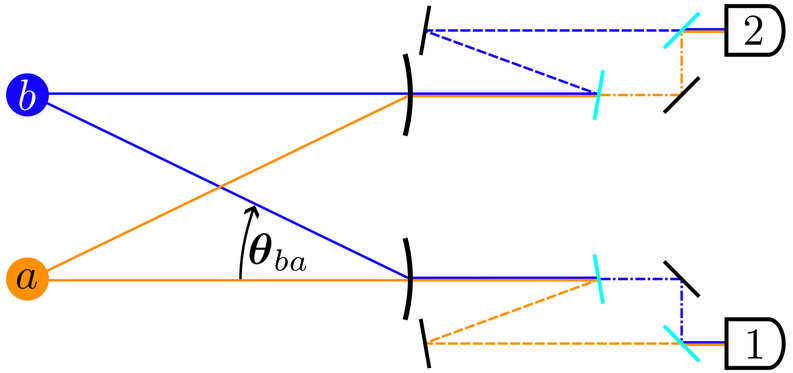


🎯 supernova morphology + distance → H_0

[I.-K. Chen, D. Dunsky, KVT, J. Huang, R. V. Wagoner; arXiv:2504.20131]

[D. Dunsky, I.-K. Chen, J. Huang, KVT, R. V. Wagoner; arXiv:2505.08856]

Extended-Path Intensity Interferometry: EPIC



❌ standard II: low SNR + small FOV

✅ **differential astrometry** over "large" FOV

[KVT, M. Baryakhtar, M. Galanis, N. Weiner; arXiv:2307.03221]

[M. Galanis, KVT, M. Baryakhtar, N. Weiner; arXiv:2307.06989]

🎯 exoplanets
🎯 wide binary orbits
🎯 Galactic distances
🎯 Galactic microlensing
🎯 Galactic kinematics, acceleration

Fundamental Physics: Dark Matter Lensing

$$\langle \theta_i \theta_j \rangle$$

🎯 gravitational lensing by small-scale dark matter structure

[KVT, D. E. Kaplan; in prep]

[A. Moran, KVT; in prep]