AMPM

Asteroid-Mass Primordial Black Hole Microlensing

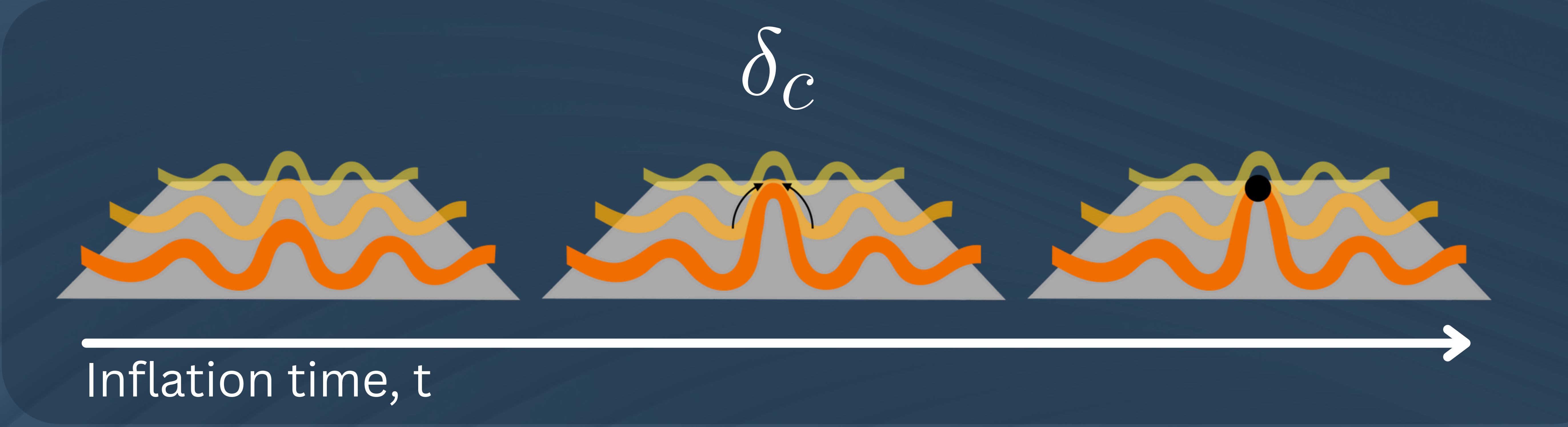
IDM, 2024

Renee Key
Swinburne University of Technology, Melbourne Australia
with Ken Freeman, Alan Duffy, Edward Taylor, Anais Moller

Created by primordial density fluctuations

Require critical denity threshold to collapse

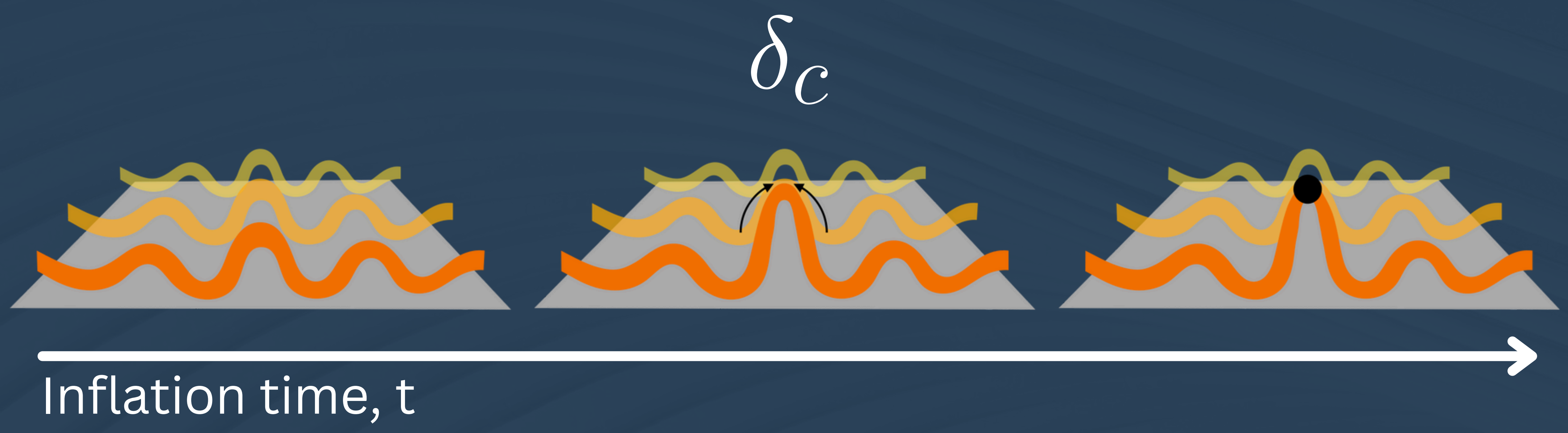
Primordial
Black
Hole



Created by primordial density fluctuations

Require critical denity threshold to collapse

Primordial Black Hole



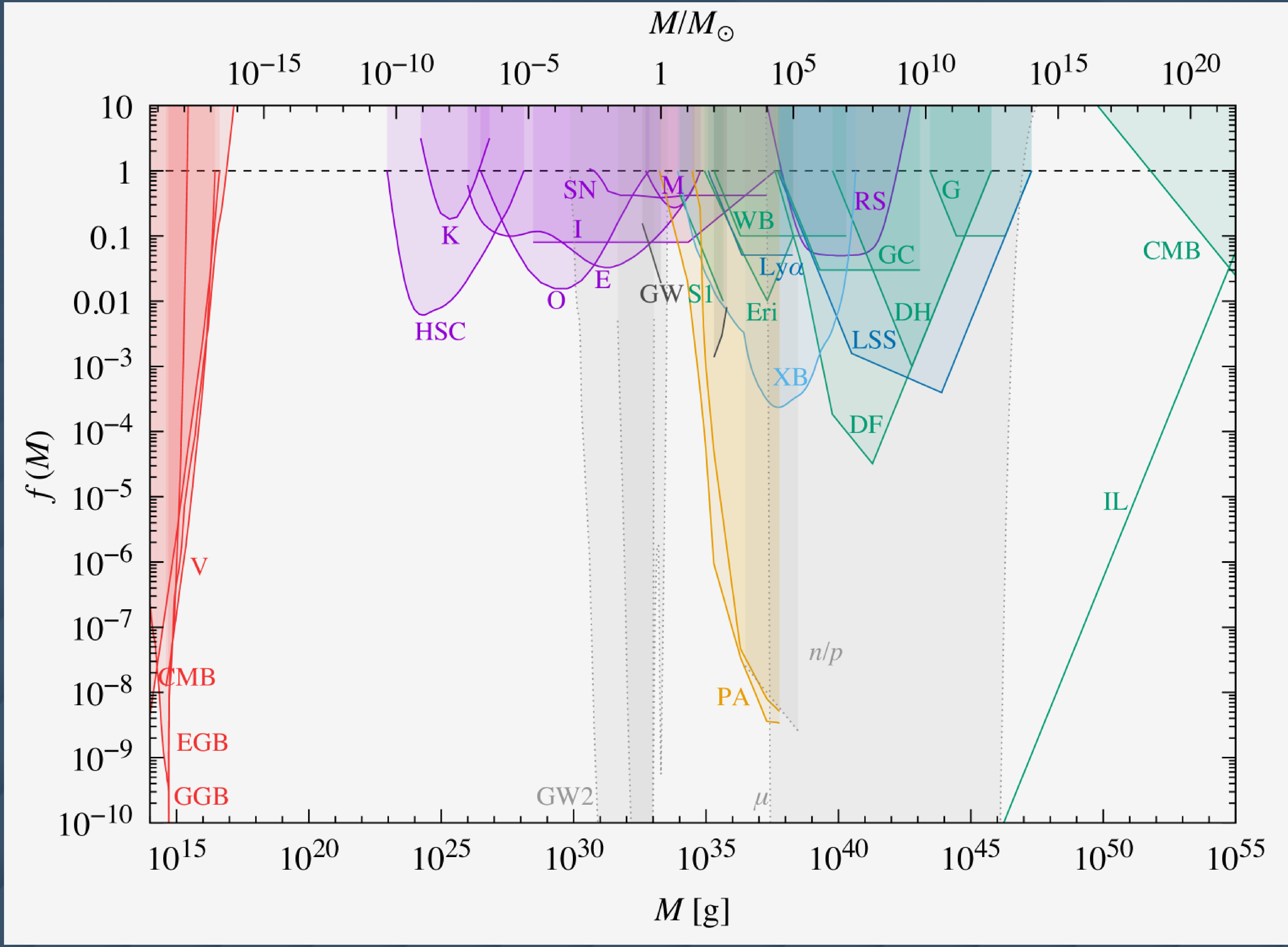
‘Optically’ Dark

Have matter/ mass

Non-baryonic

$$f = \frac{\Omega_{PBH}}{\Omega_{DM}}$$

MW dark matter density



B. Carr (2021) arXiv:2002.12778

Microlensing:

Amplification

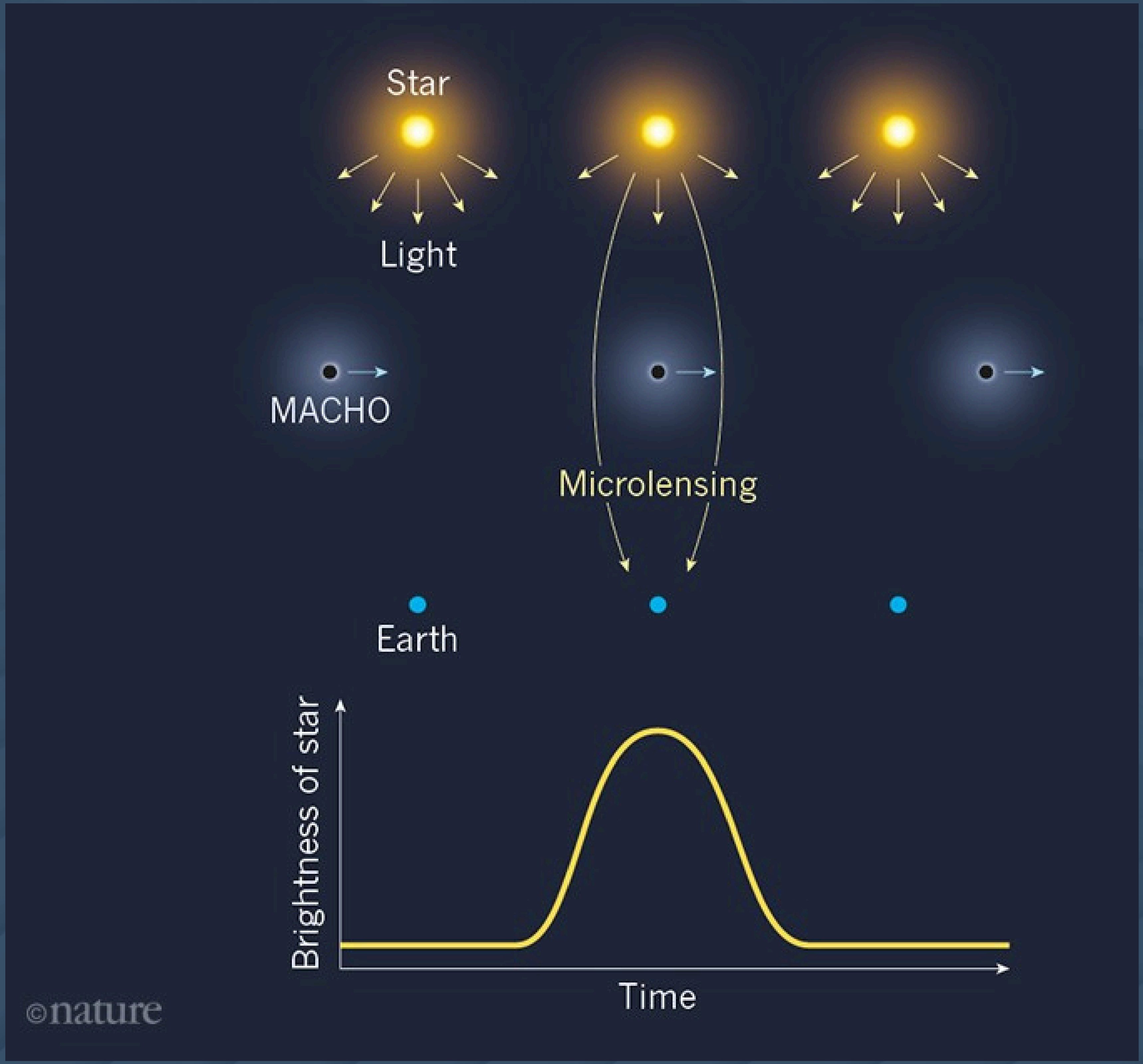
$$A(u(t)) = \frac{u^2 + 2}{u\sqrt{u^2 + 4}}$$

Trajectory

$$u(t) = \sqrt{\frac{(t - t_0)^2}{t_E^2} + u_0^2}$$

Timescale

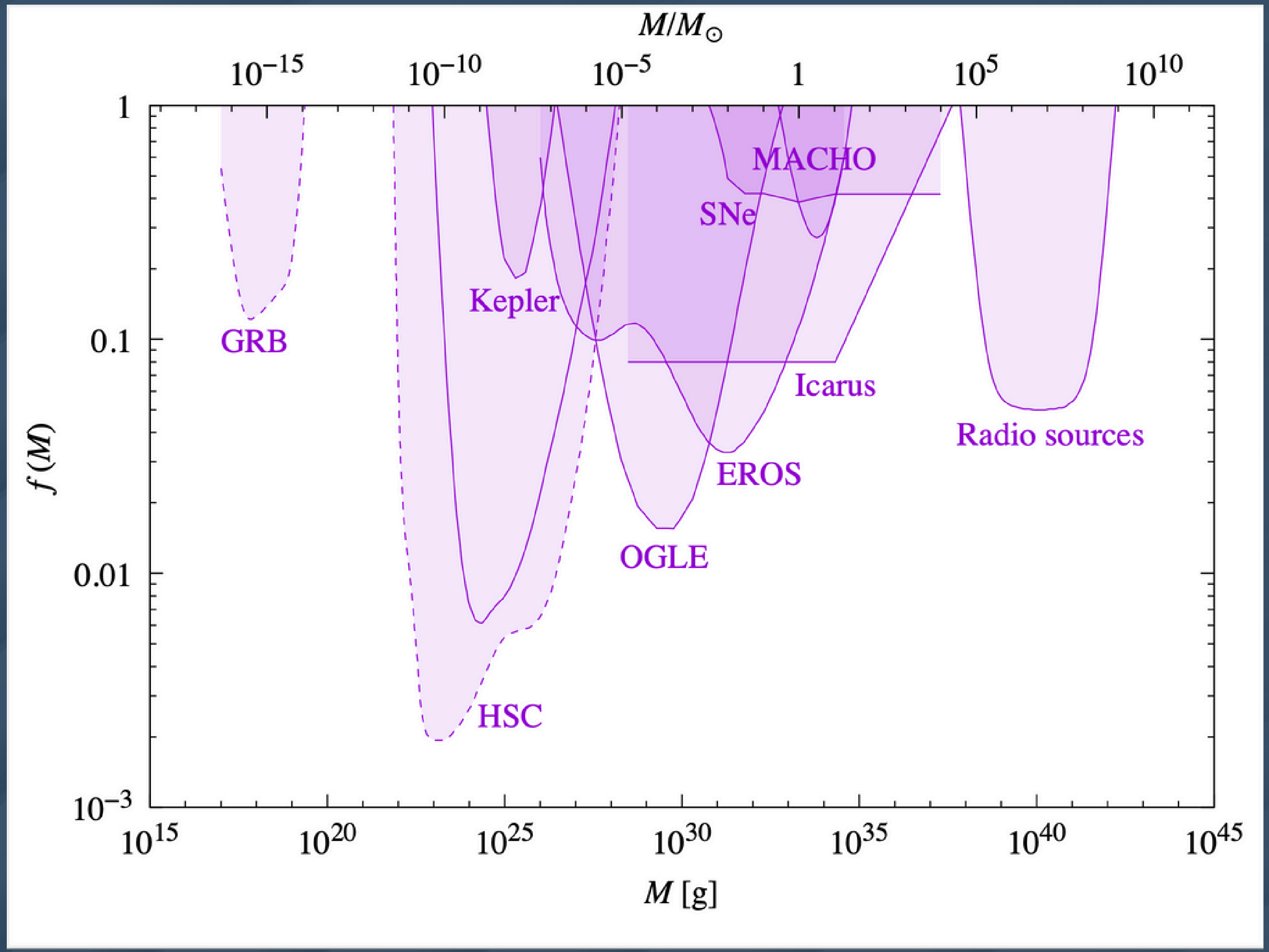
$$t_E = \frac{1}{V_T}\sqrt{\frac{4\,G\,M\,D_L(D_S - D_L)}{c^2\,D_S}}$$



G.Pietrzyński Nature 562, 349-350

$$t_E \propto \sqrt{M_{PBH}}$$

Name	Year	Cadence	Detections
MACHO	1995-2005	~ Day	17
EROS	2003	1 Day, 15 mins	4
OGLE	2009-now	~ Day, 15 mins	2
KEPLER	2013	30 mins	0
HSC	2019	2 mins	1



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Microlensing is best for asteroid mass to sub-solar PBHs

Survey efficiency

$$N_{exp} = \frac{2}{\pi} \frac{Tobs}{< t_E >} \tau \, N_* \, \epsilon$$

Optical depth integrated along line-of-sight with particular DM halo model

The Usual Assumptions

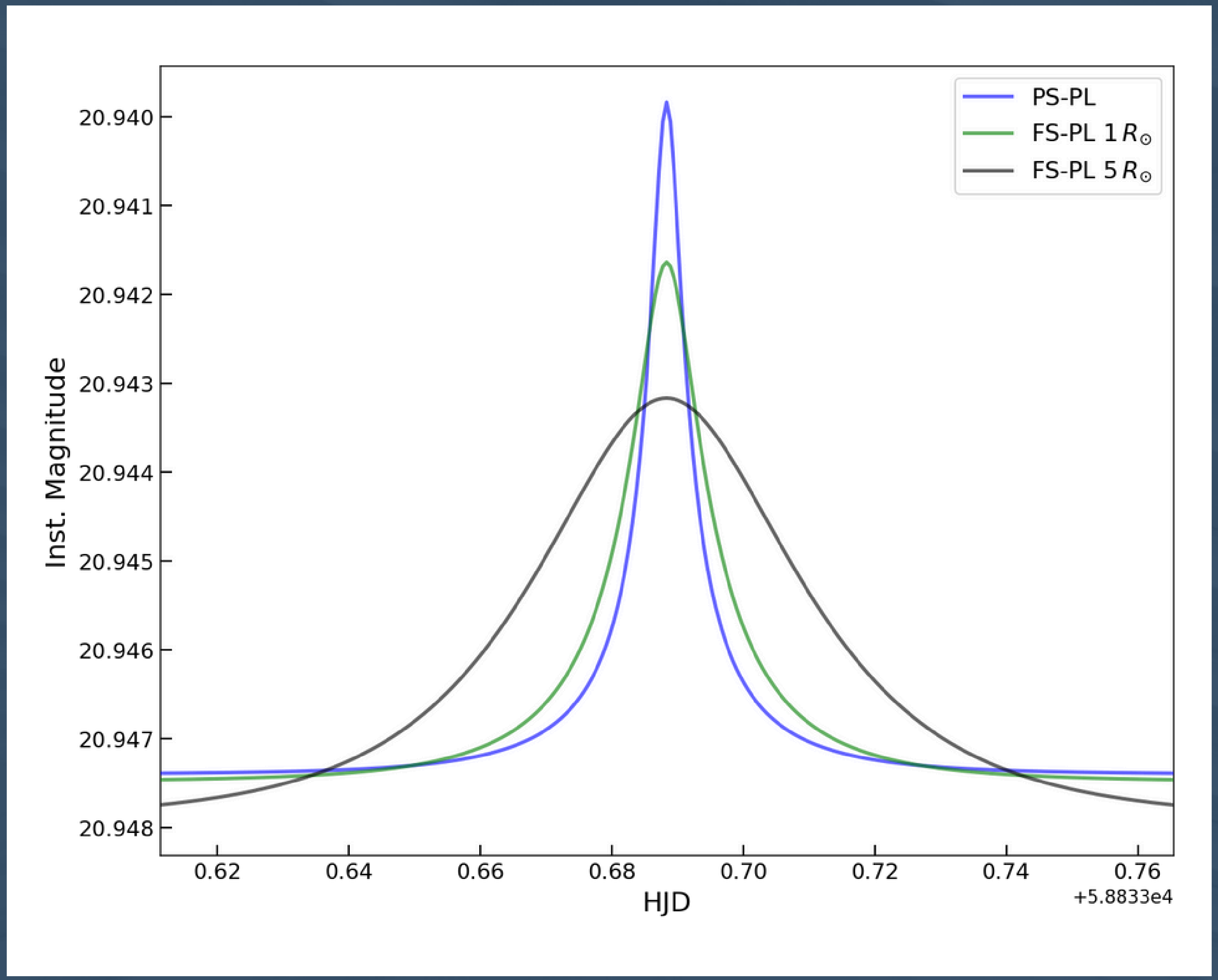
- Monochromatic PBH mass
- ITS halo model (better is NFW)
- No clumping of PBH
- Real detections = PBH (other DCO?)
- Point-like stars (no finite size) !!
- DM is 100% PBH

Finite source size matters for small lenses

$$A(u(t)) = \frac{u^2 + 2}{u\sqrt{u^2 + 4}}$$

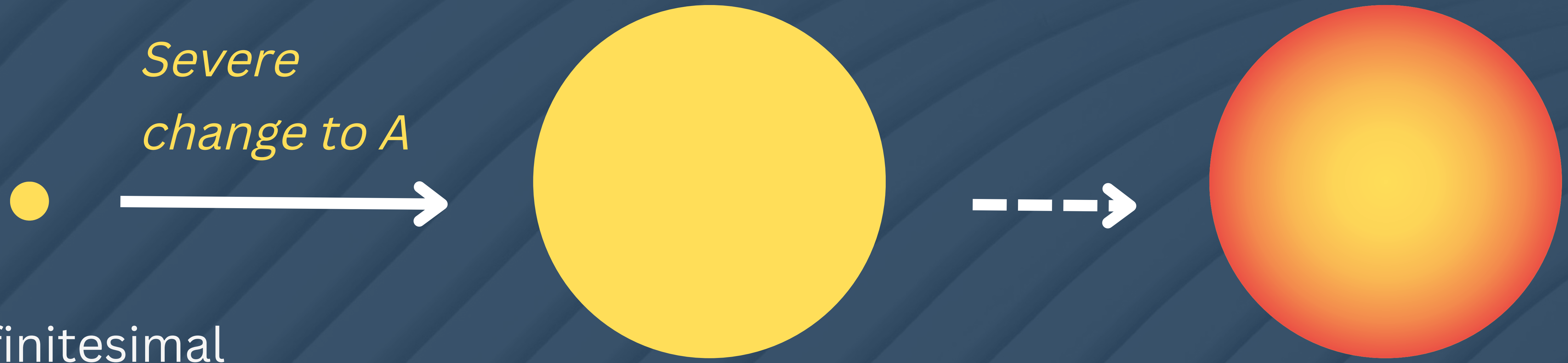
$$A_{FS}(u, \rho) = \frac{1}{\pi\,\rho} \int_{(|\mathbf{y}| \leq \rho)} A_{PS}(|\mathbf{u} - \mathbf{y}|)\; d^2y$$

Integrate lensing amplification over the normalised angular radius of the star ρ



Severe change to A

~few % deviation to A



Infinitesimal Point

Real radius

Limb Darkened Star

Finite source size matters for small lenses

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$$A_{FS}(u,\rho) = \frac{1}{\pi\,\rho}\int_{(|\mathbf{y}|\le\rho)} A_{PS}(|\mathbf{u}-\mathbf{y}|)\; d^2y$$

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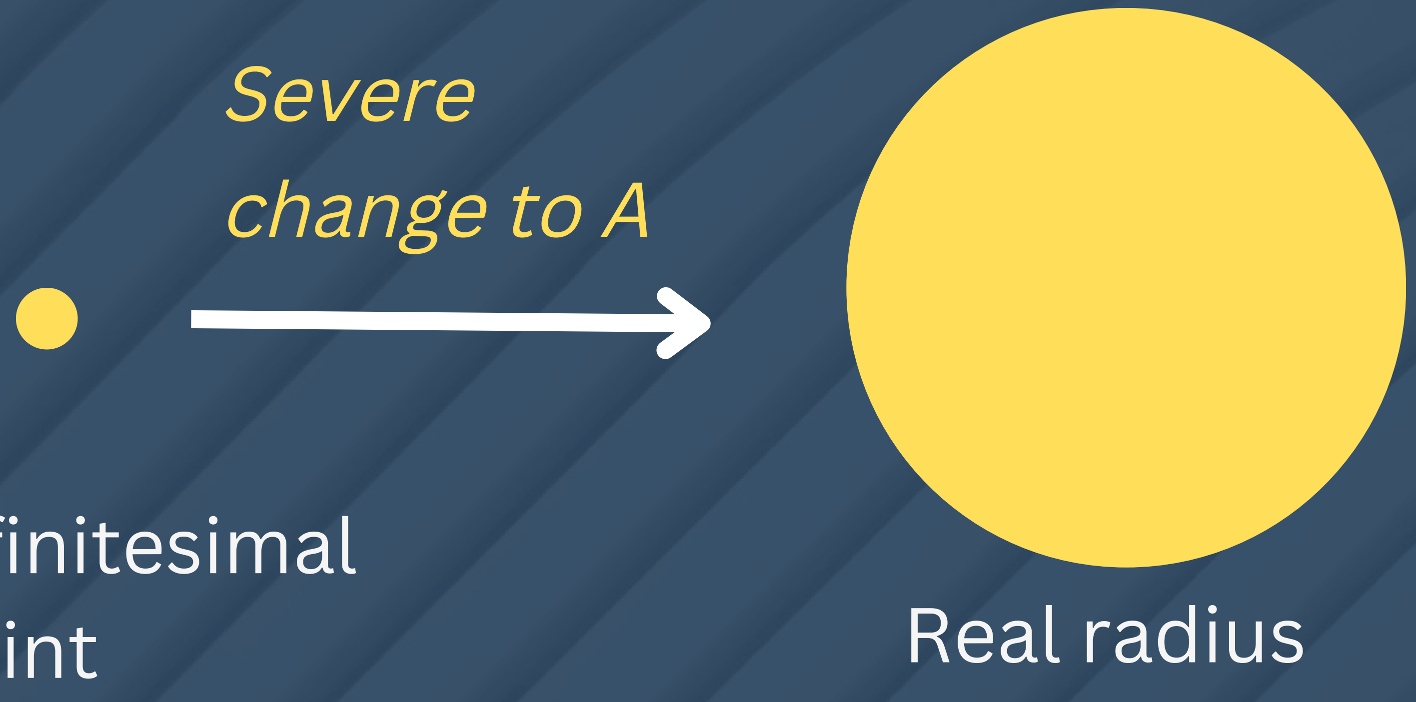
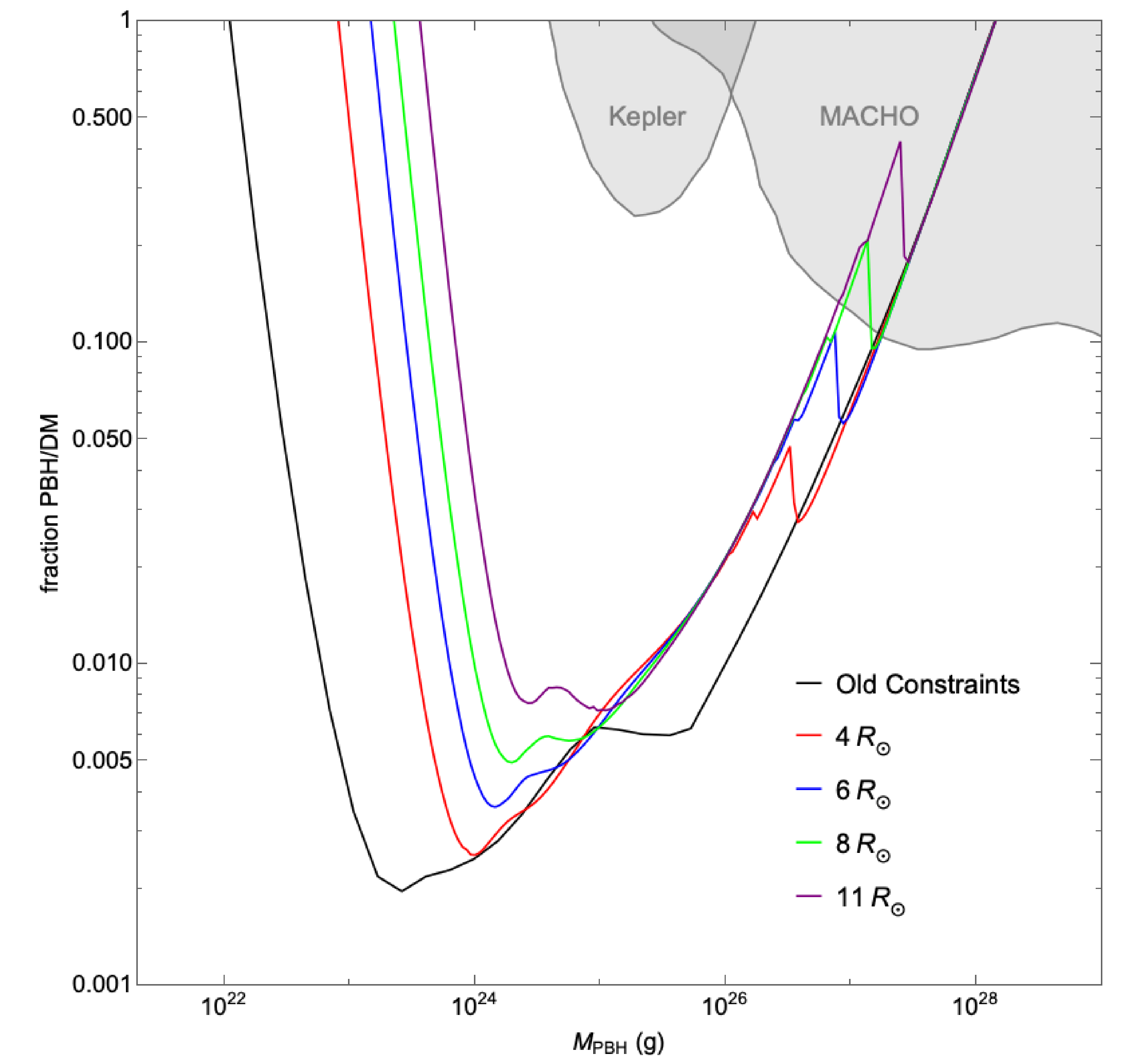


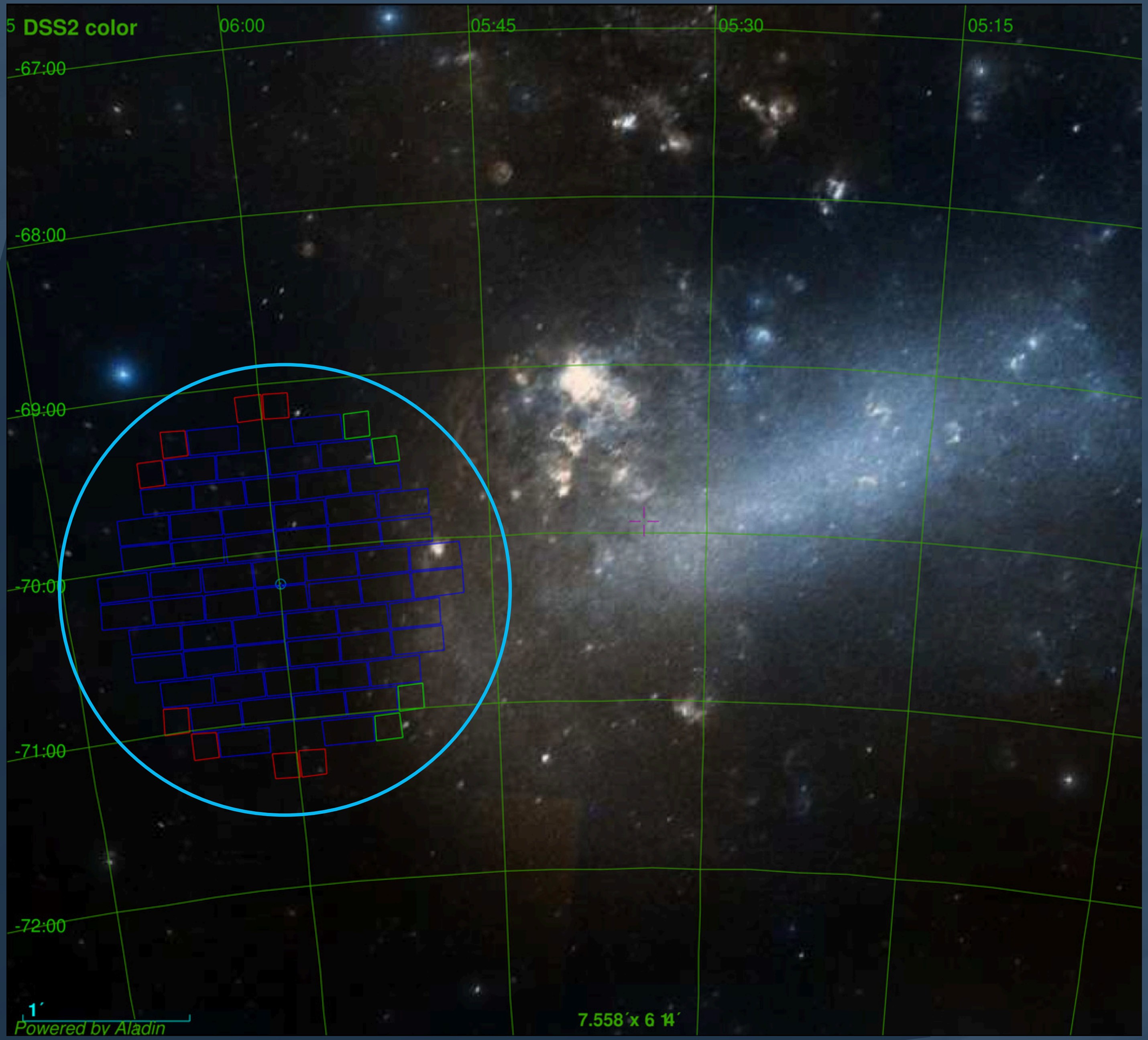


Updated Constraints on Asteroid-Mass Primordial Black Holes as Dark Matter

Nolan Smyth,[1,2,*] Stefano Profumo,[1,2] Samuel English,[1] Tesla Jeltema,[1,2] Kevin McKinnon,[3] and Puragra Guhathakurta[3]

[1]*Department of Physics, University of California, Santa Cruz, CA 95064, USA*
[2]*Santa Cruz Institute for Particle Physics, Santa Cruz, CA 95064, USA*
[3]*Department of Astronomy and Astrophysics, University of California, Santa Cruz, CA 95064, USA*

(Dated: April 30, 2020)



LMC (50kpc)

3 deg sq. FOV

3 million+ stars

VR filter (626 nm)

5 consec. nights

40 hours

1 min cadence

~10% amplification

CTIO Dark Energy Camera (DECam)

4m World-class Telescope on Cerro Tololo, Chile

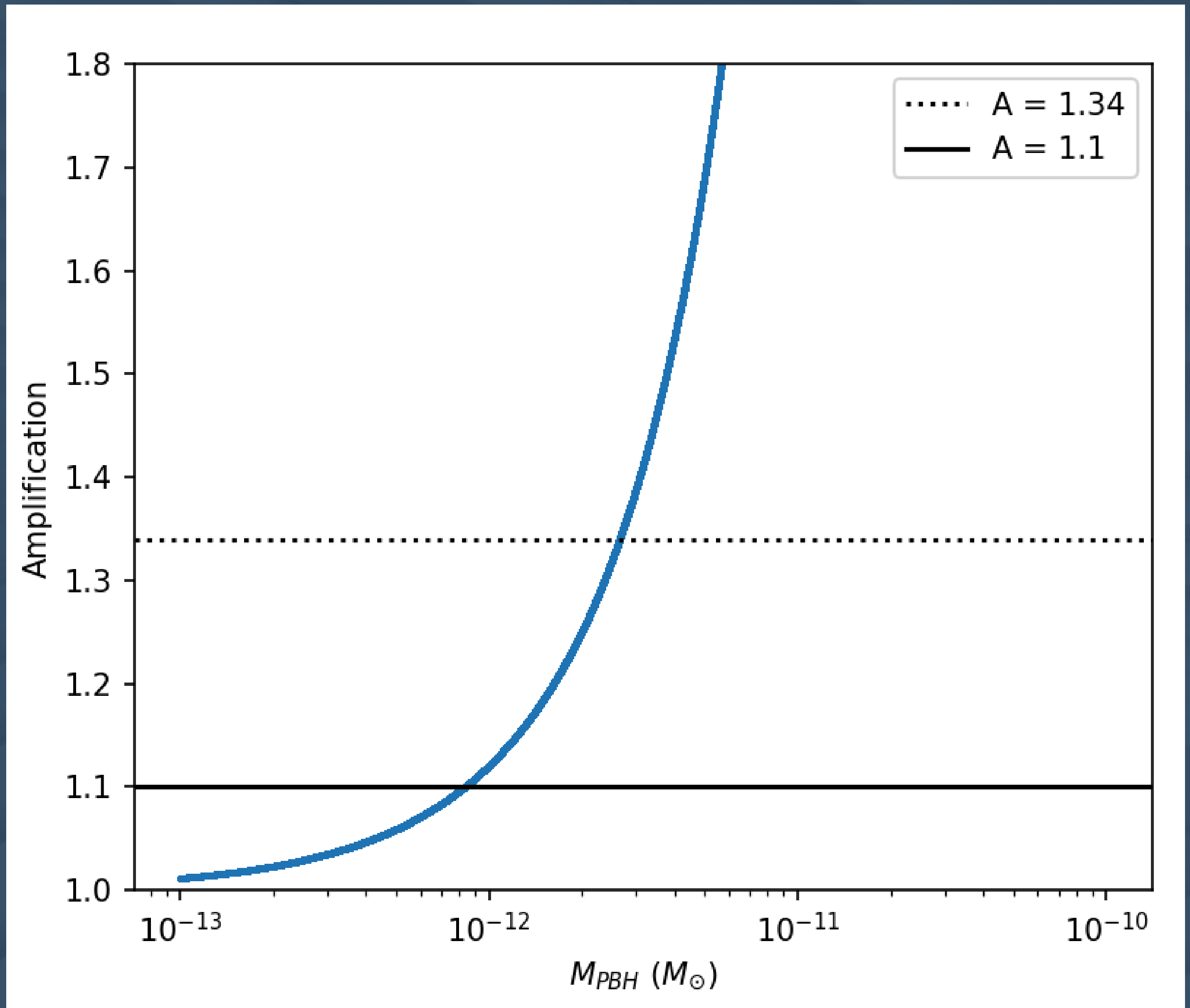
AMPM: Theoretical Limit

'Wave Optics'
Images are projected on a radius comparable to the physical wavelength of the starlight

Constructive AND destructive inteference of images

$$A^{wo}_{max} = \frac{\pi\omega}{1 - e^{-\pi\omega}}$$

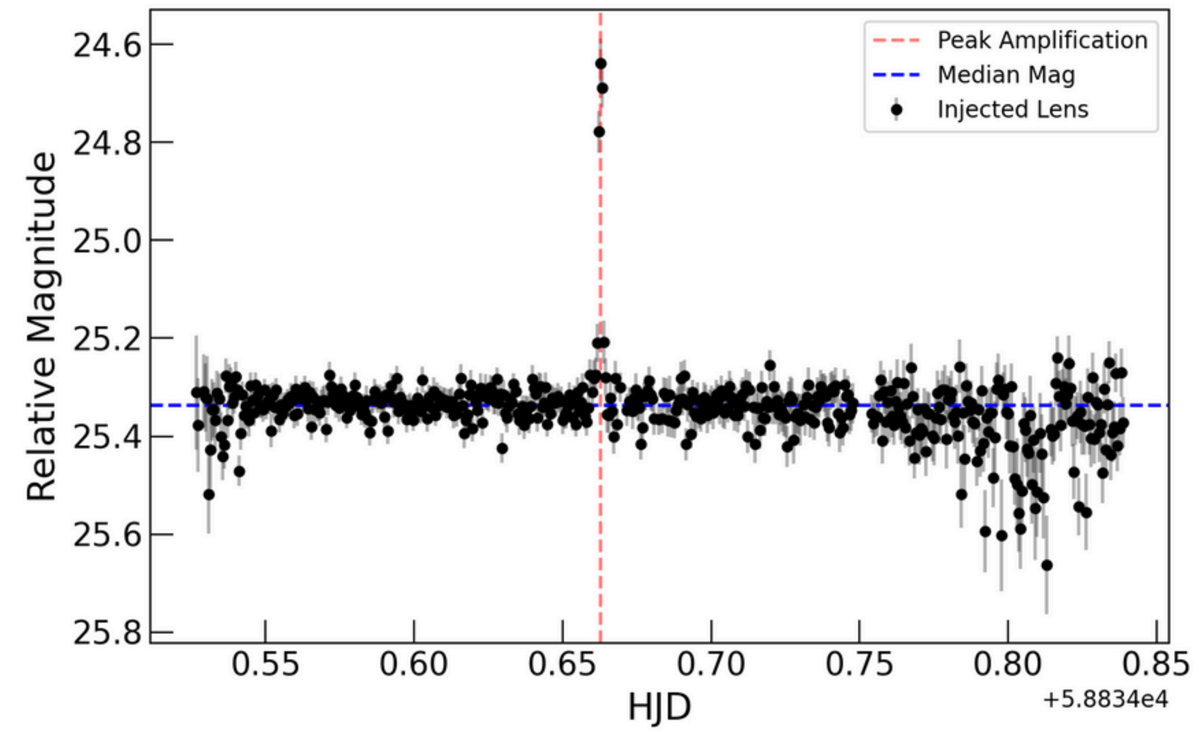
$$\omega \equiv \frac{8\pi G M_{PBH}}{\lambda}$$



AMPM: Expected microlensing

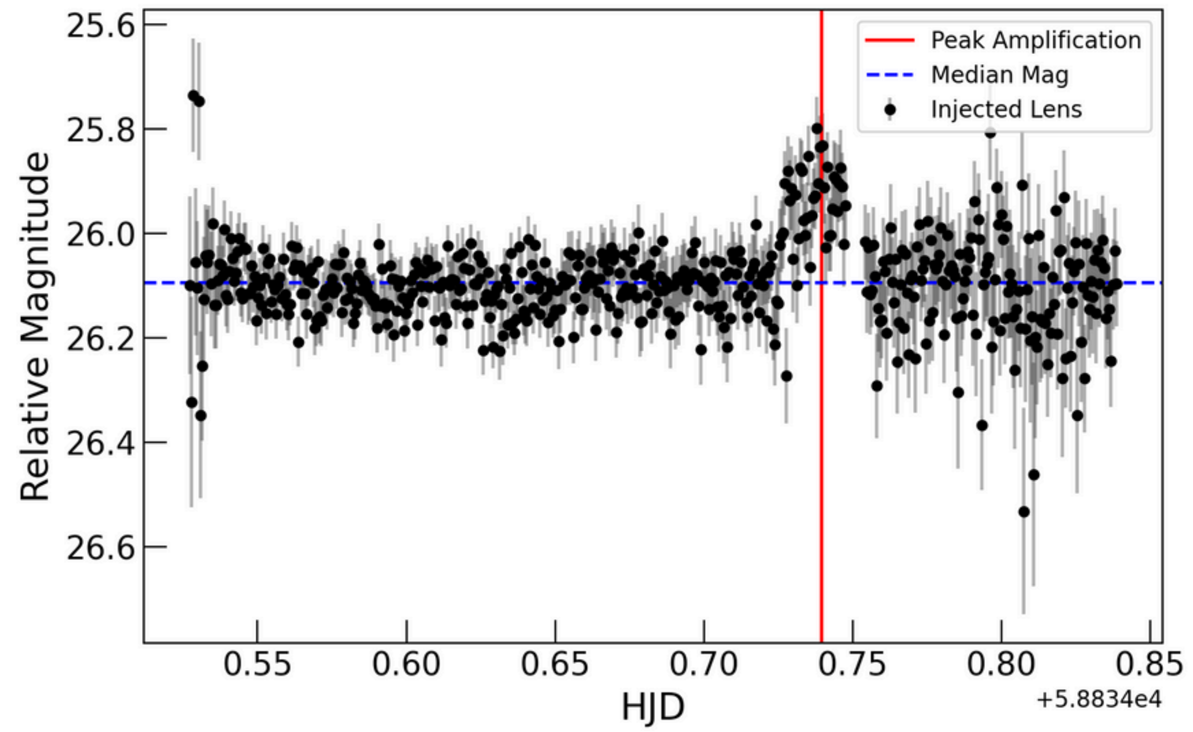
Generated with MulensModel (R. Poleski, 2018, via GitHub)

For just a PBH mass of **1e-09** solar masses but different star/distance/traj.



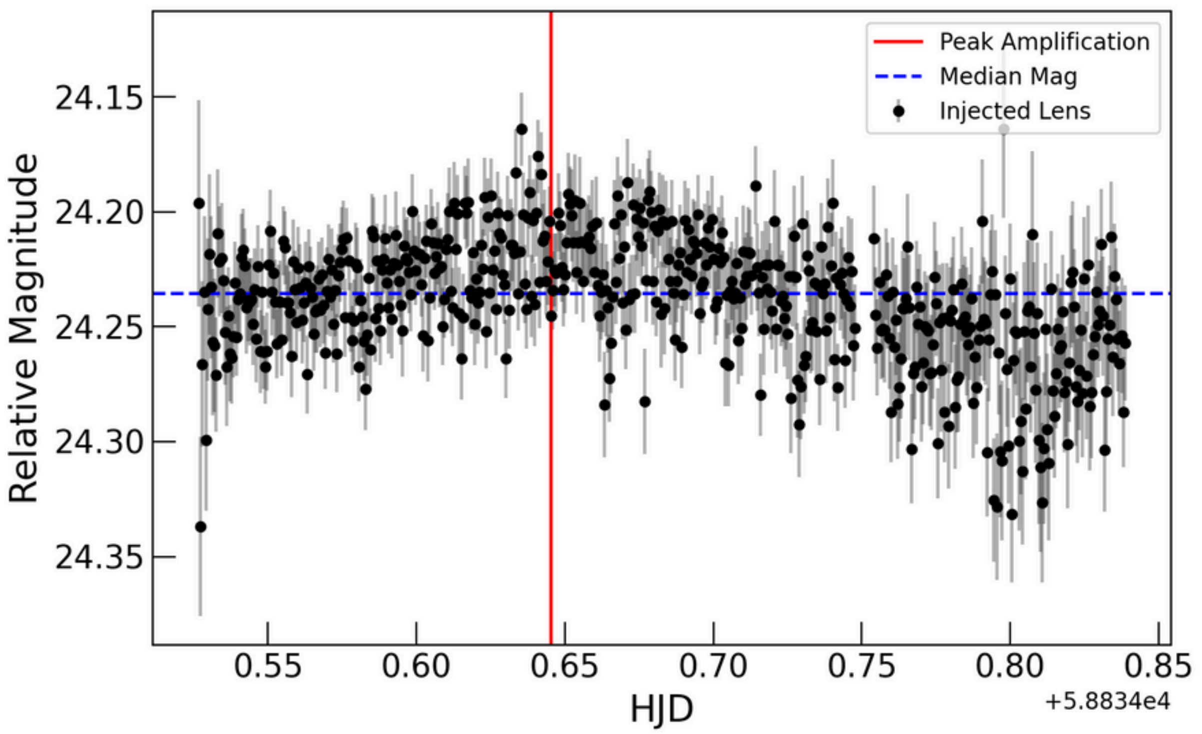
DL = 0.7 kpc
V = 78 km/s

u0 = 0.5
R = 1.18 Rsun



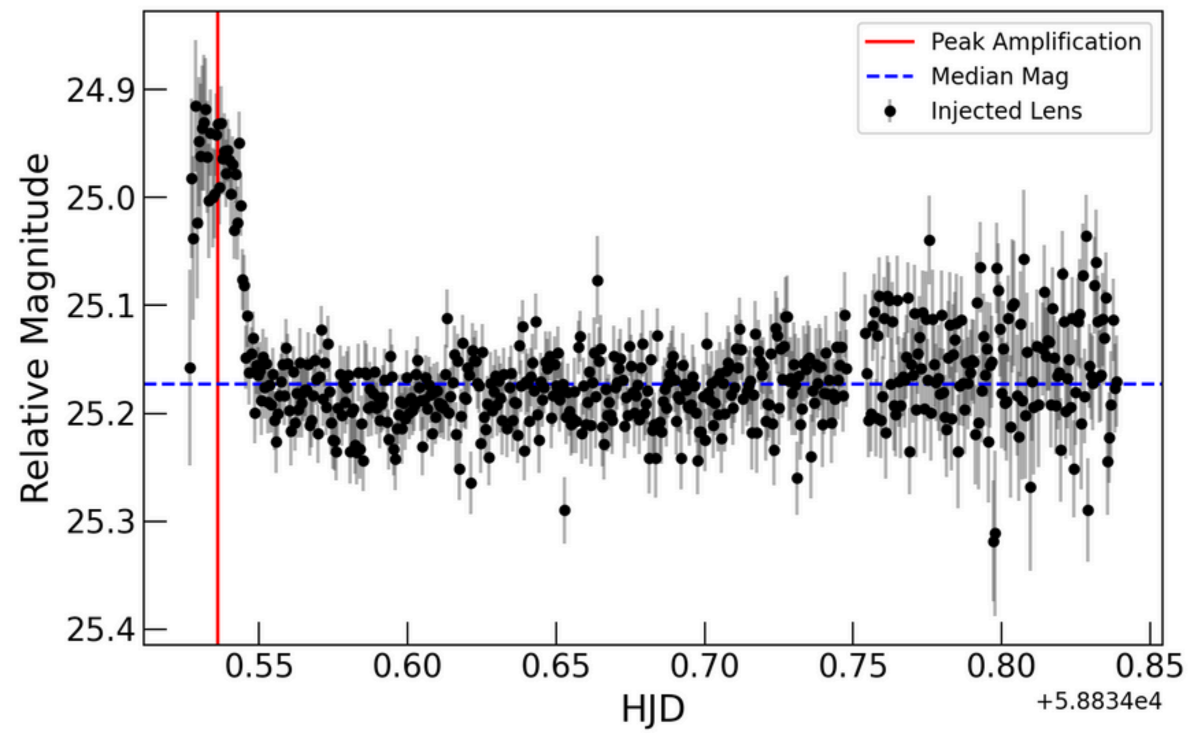
DL = 4 kpc
V = 57 km/s

u0 = 1.4
R = 1.4 Rsun



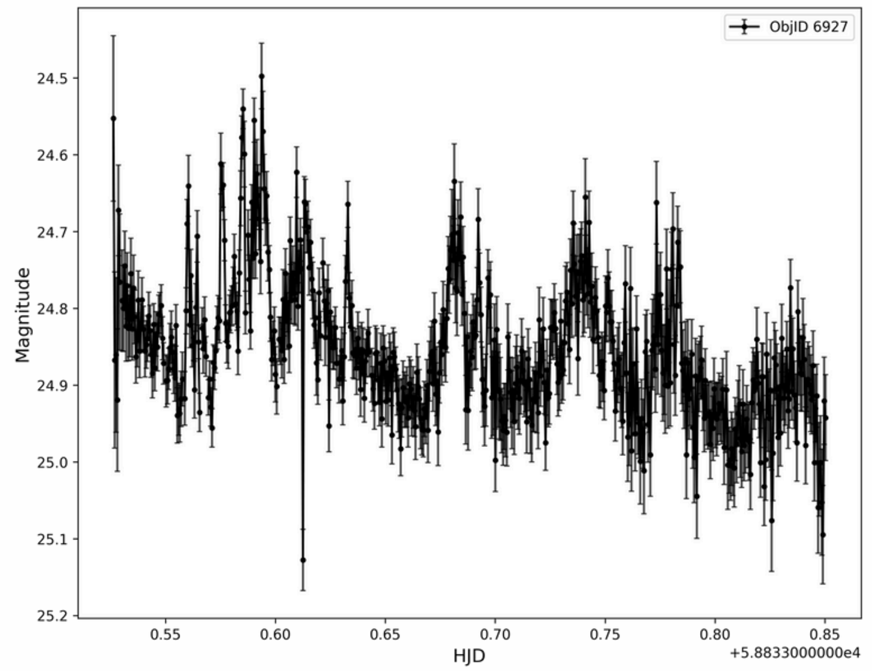
DL = 16 kpc
V = 163 km/s

u0 = 3.37
R = 0.5 Rsun



DL = 31 kpc
V = 303 km/s

u0 = 1.5
R = 1.5 Rsun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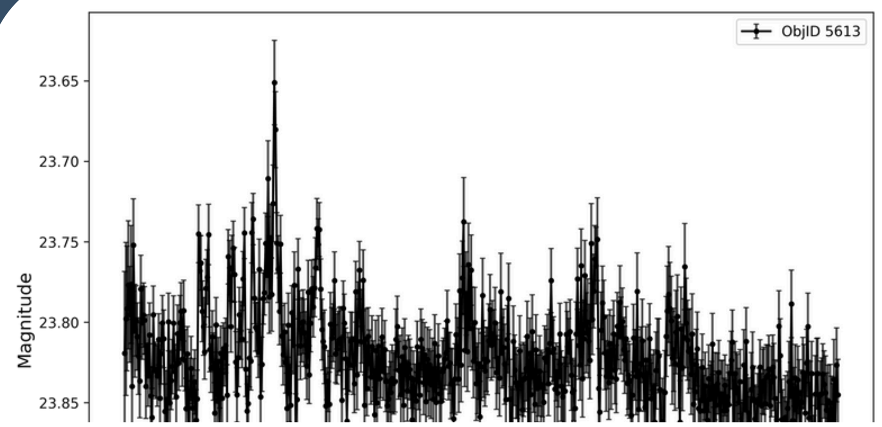
24.6
24.7
24.8
24.9
25.0
25.1
25.2
0.55 0.60 0.65 0.70 0.75 0.80 0.85
HJD
+5.8833000000e4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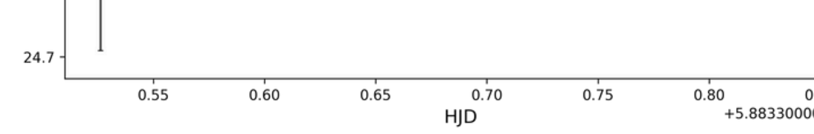
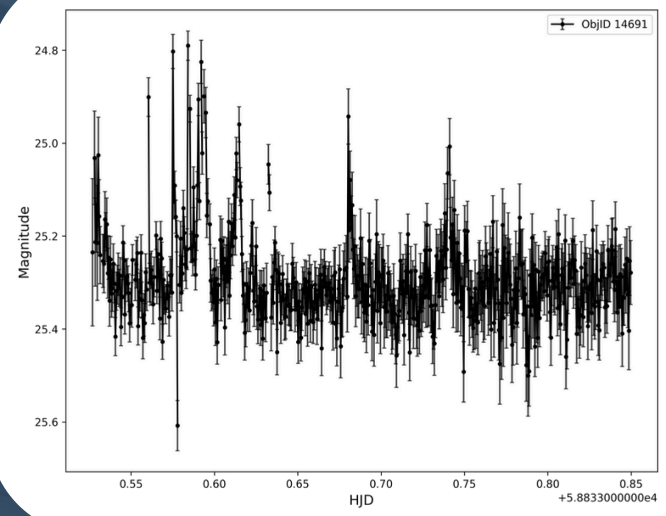

24.7
0.55 0.60 0.65 0.70 0.75 0.80
HJD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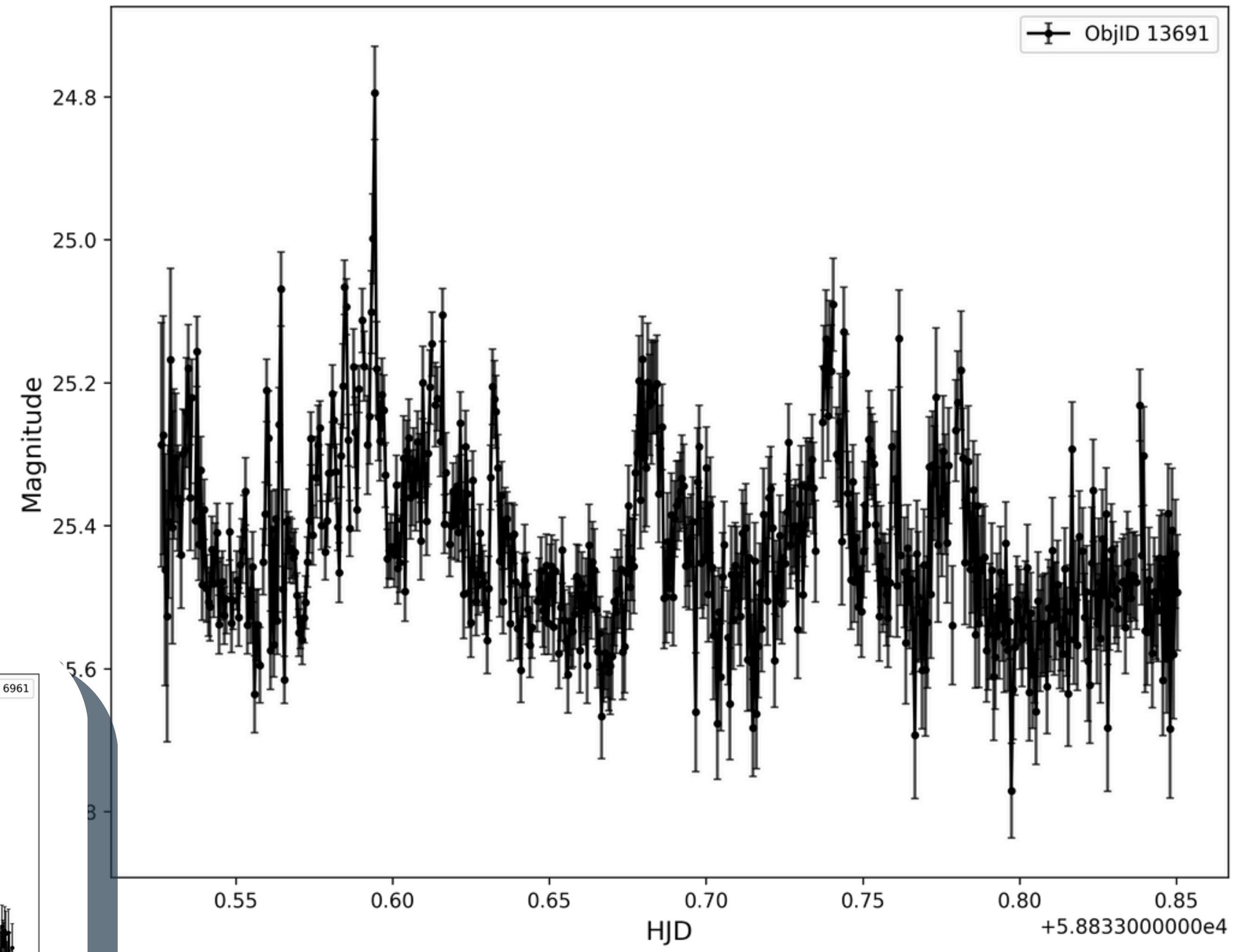
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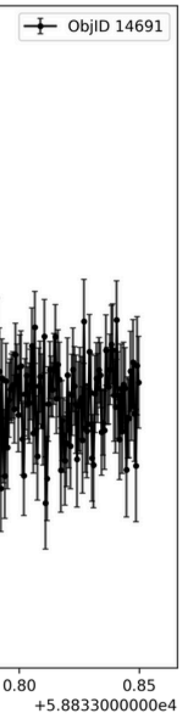
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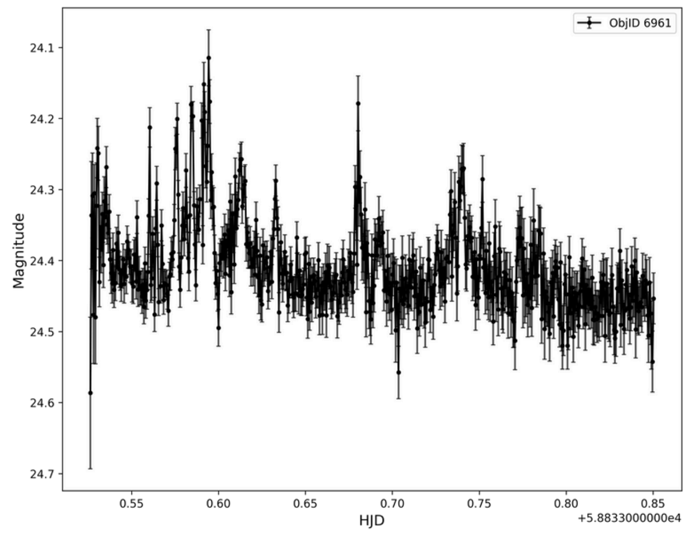
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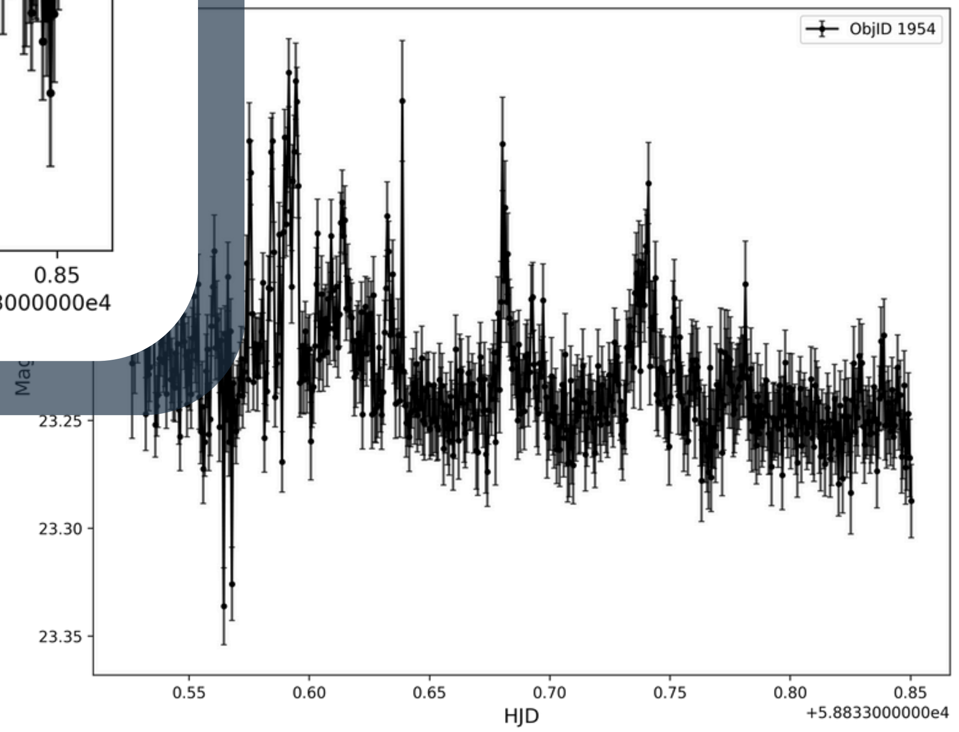
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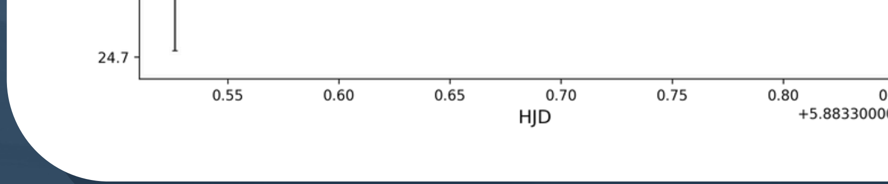
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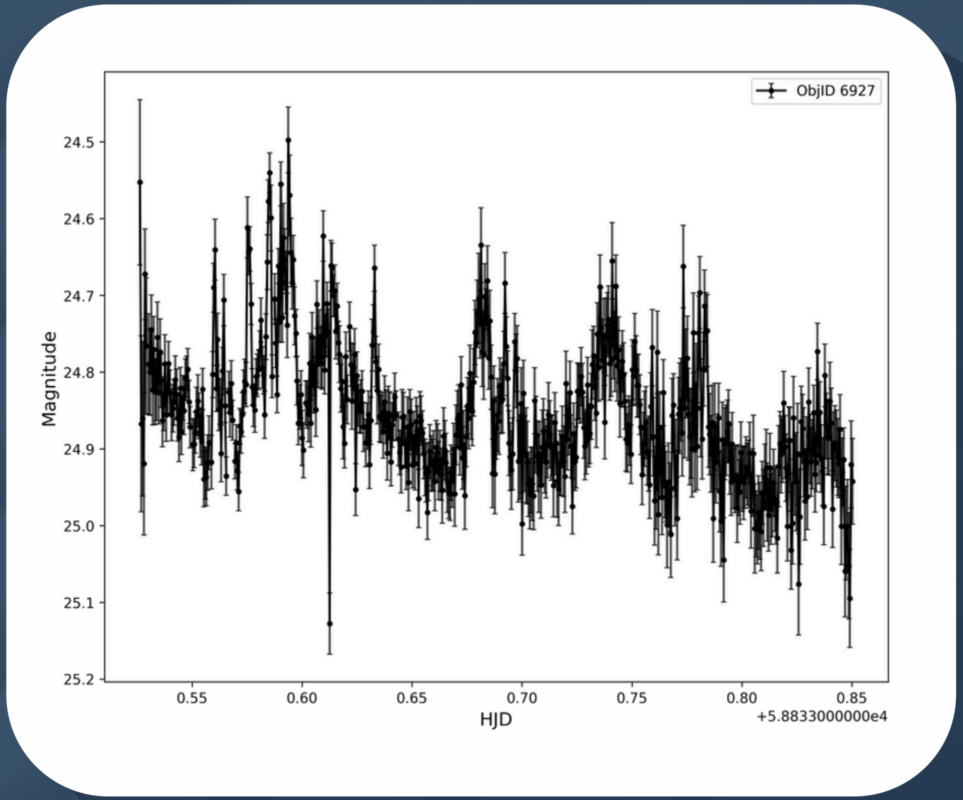
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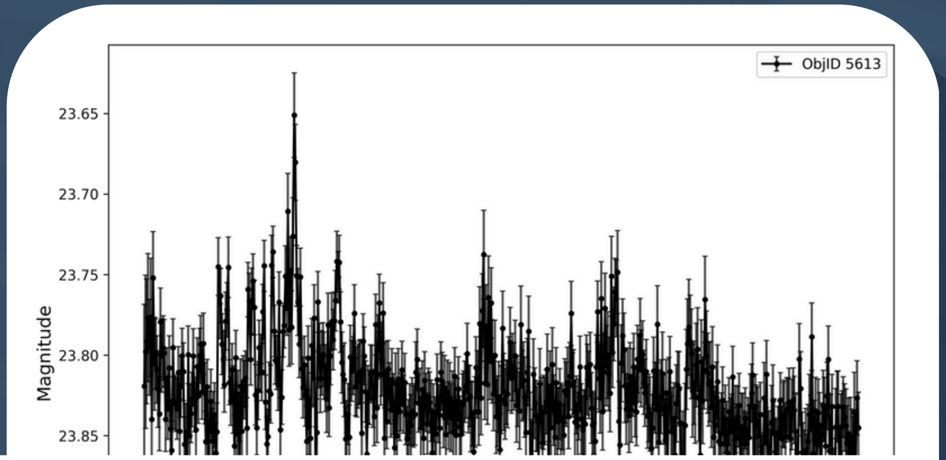
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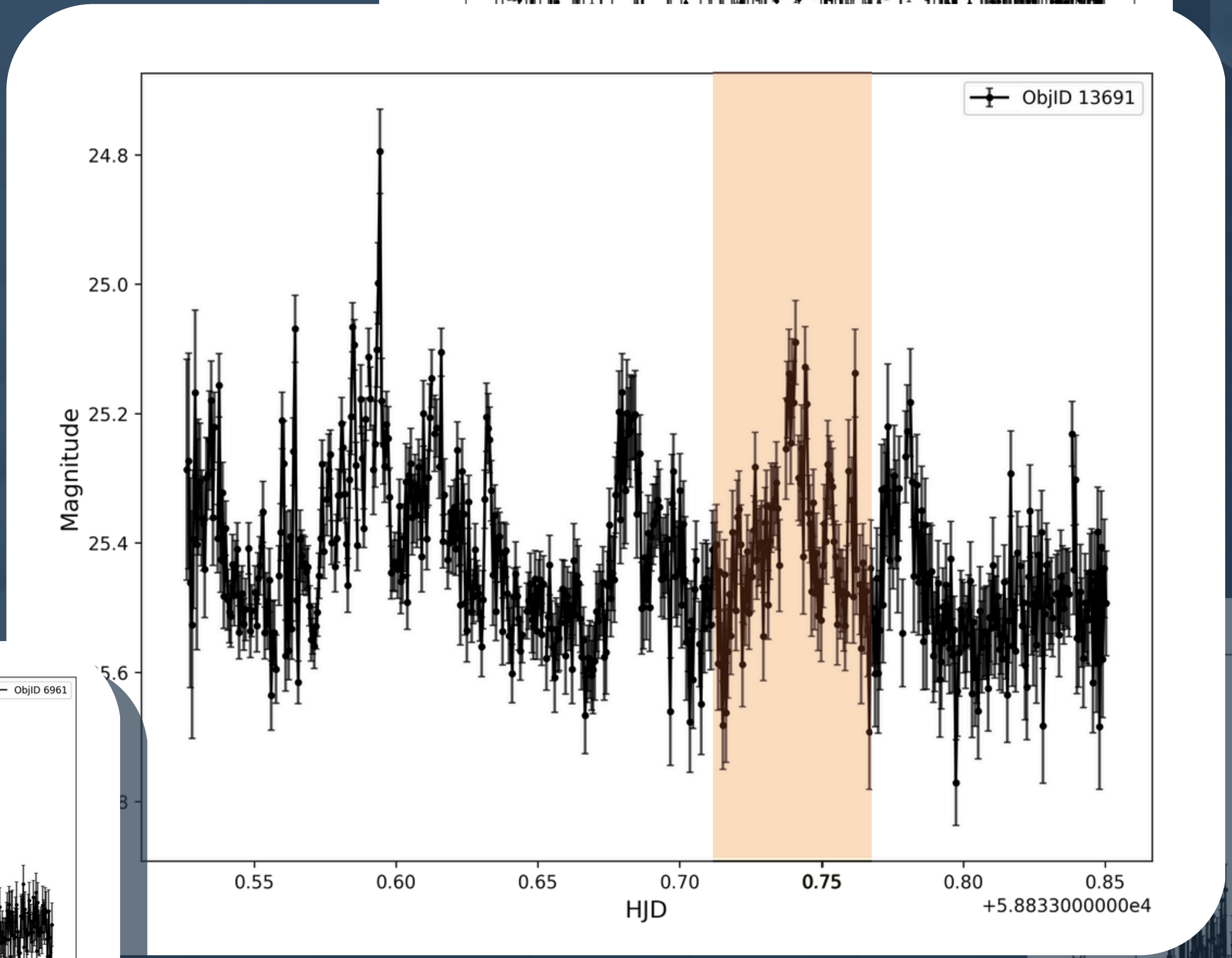
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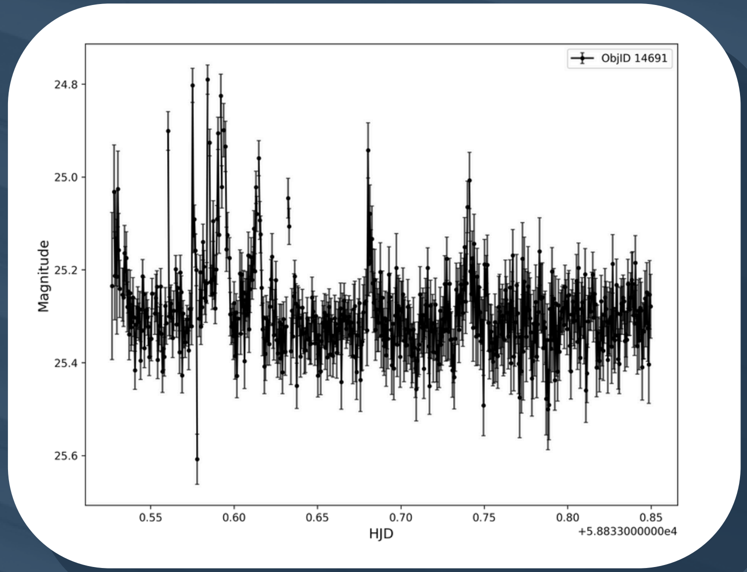
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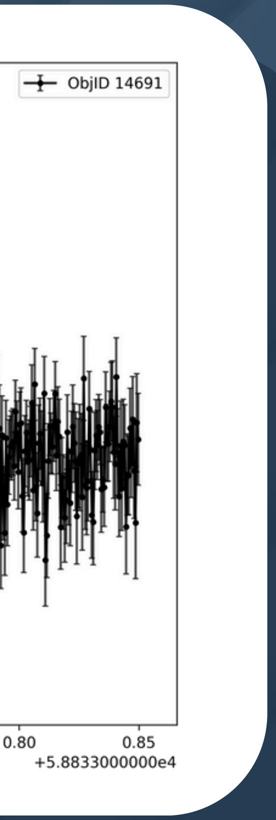
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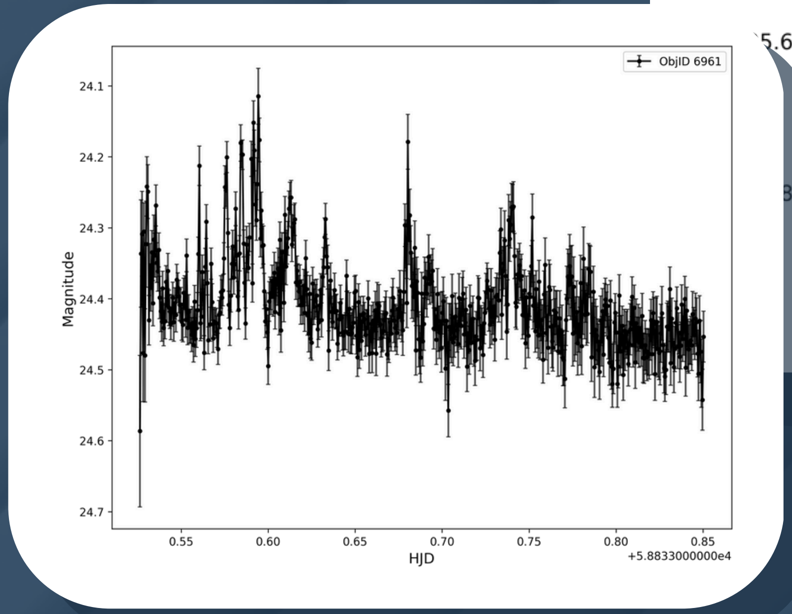
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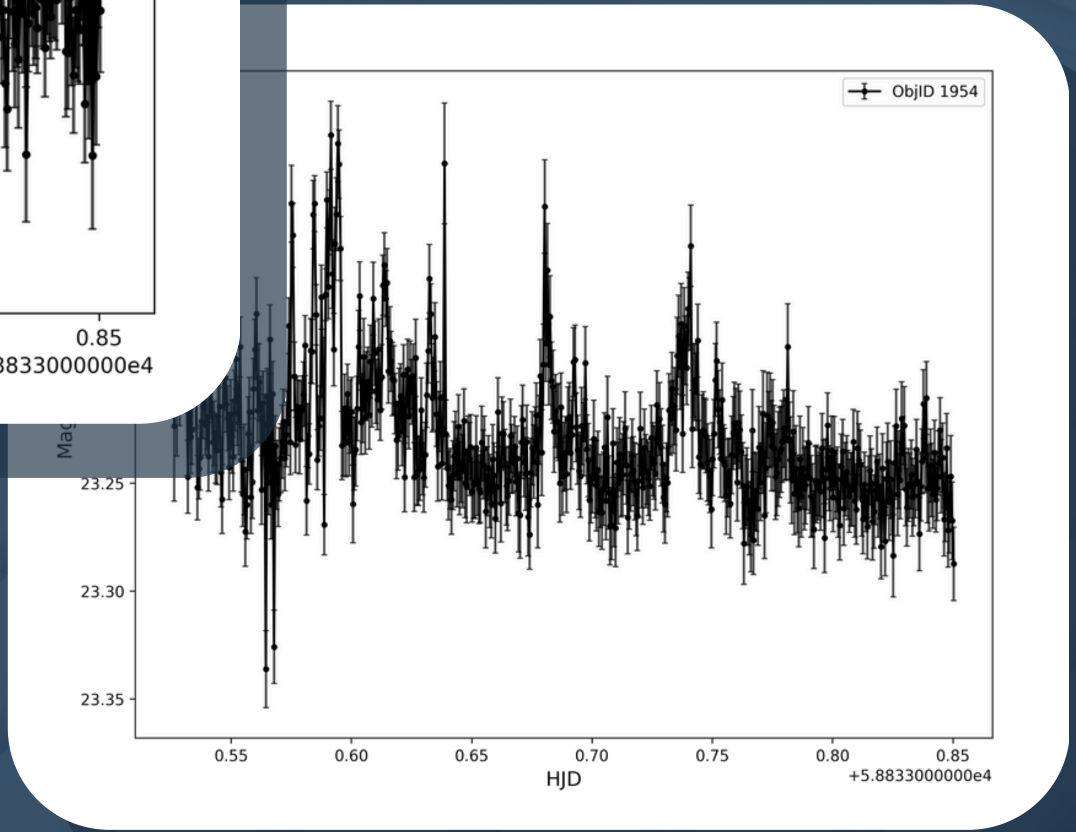

ObjID 1954
HJD
+5.8833000000e4

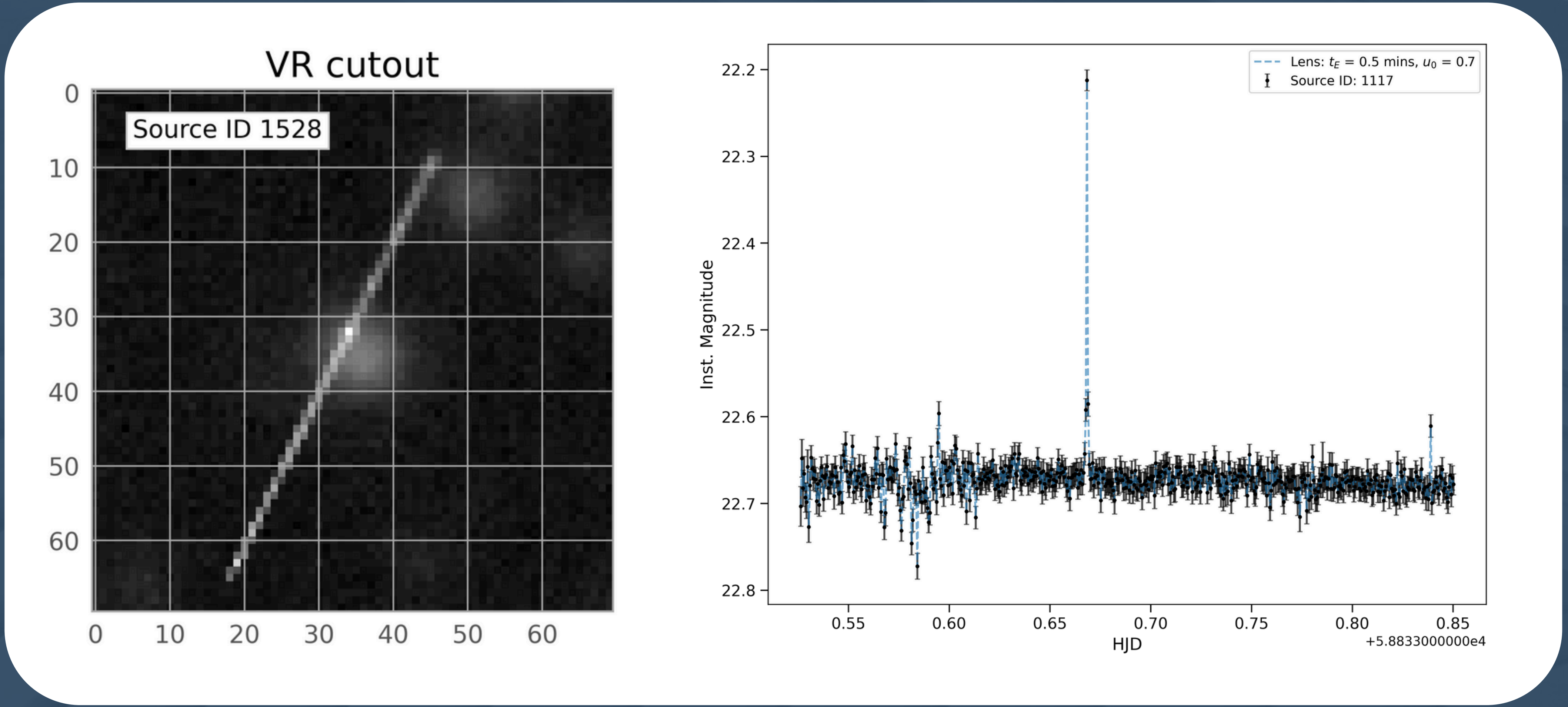
AMPM: Pipeline

Find ANY/ALL microlensing, avoid systematic and atmospheric noise.
Do this over terrabytes of data quickly and efficiently.

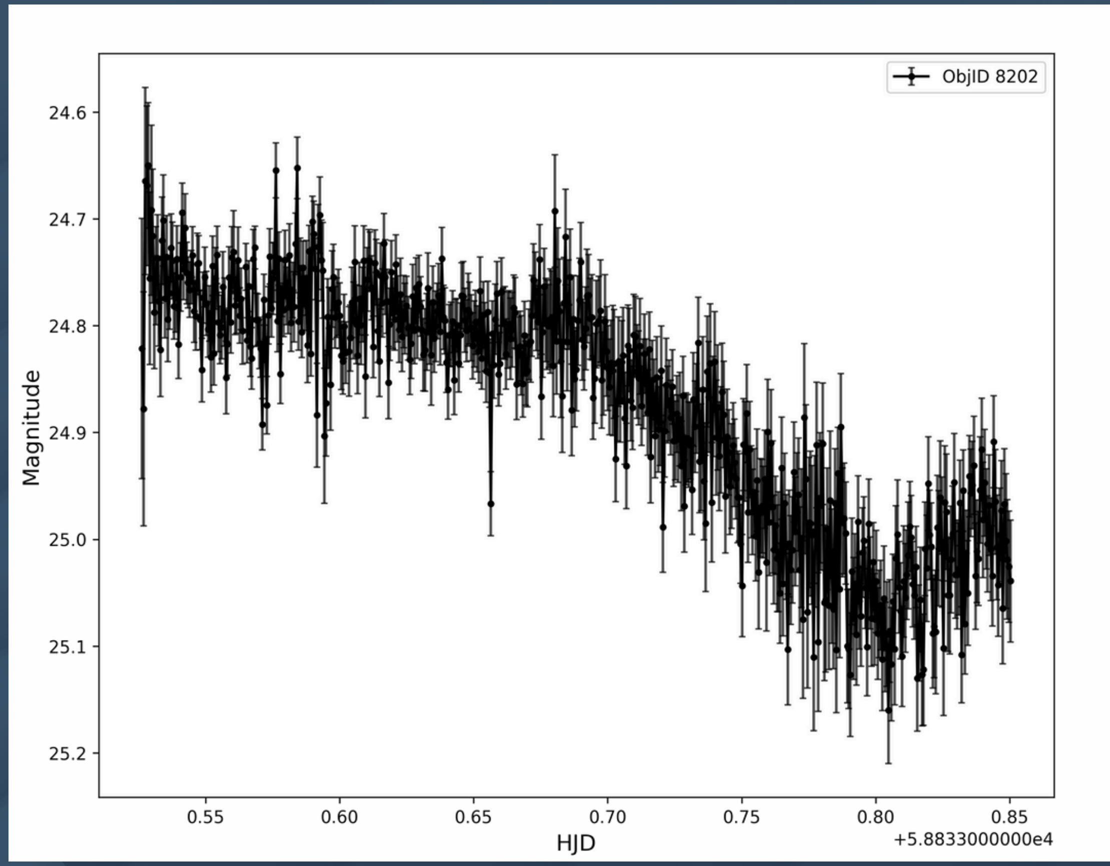
Gaia DR3 Cross-Match

Cosmic Ray Check

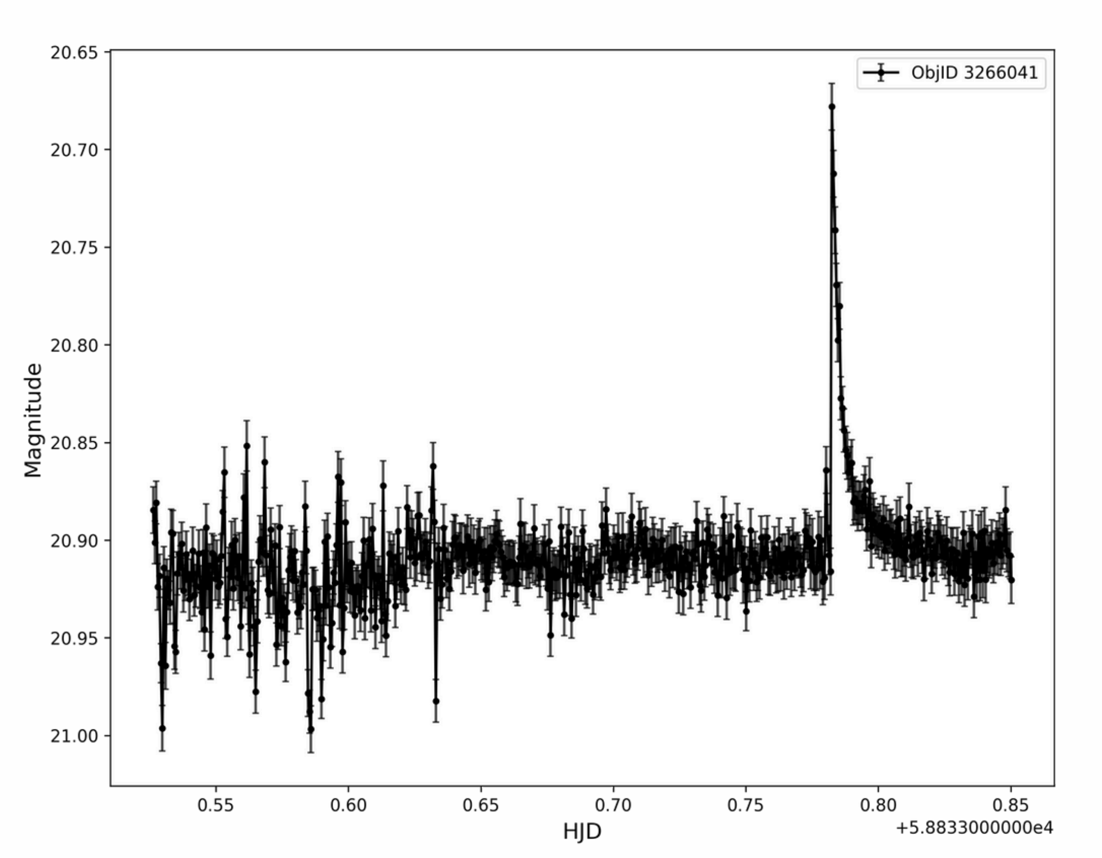
Generalised Trend



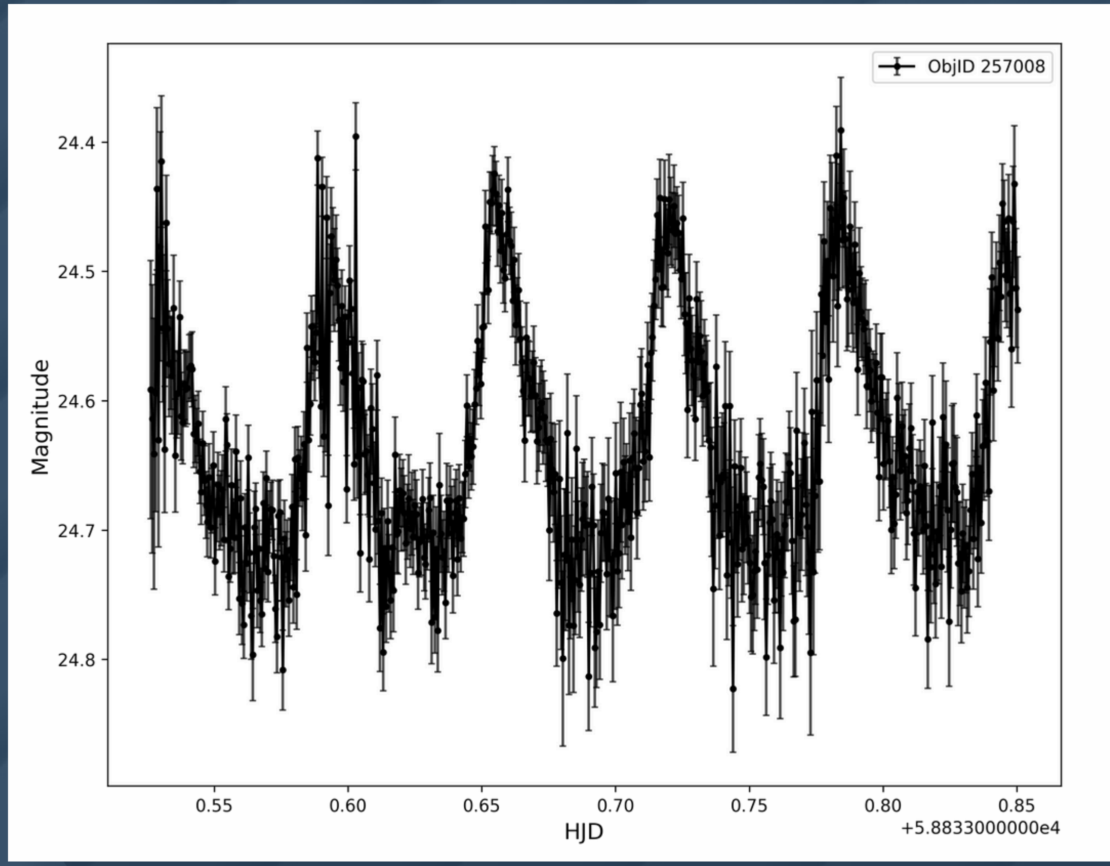
Cosmic Ray Check	Von Neumann (VN)	Serial Displacement
Existing Variability	Automated Smoothing	Atmospheric Disturbance



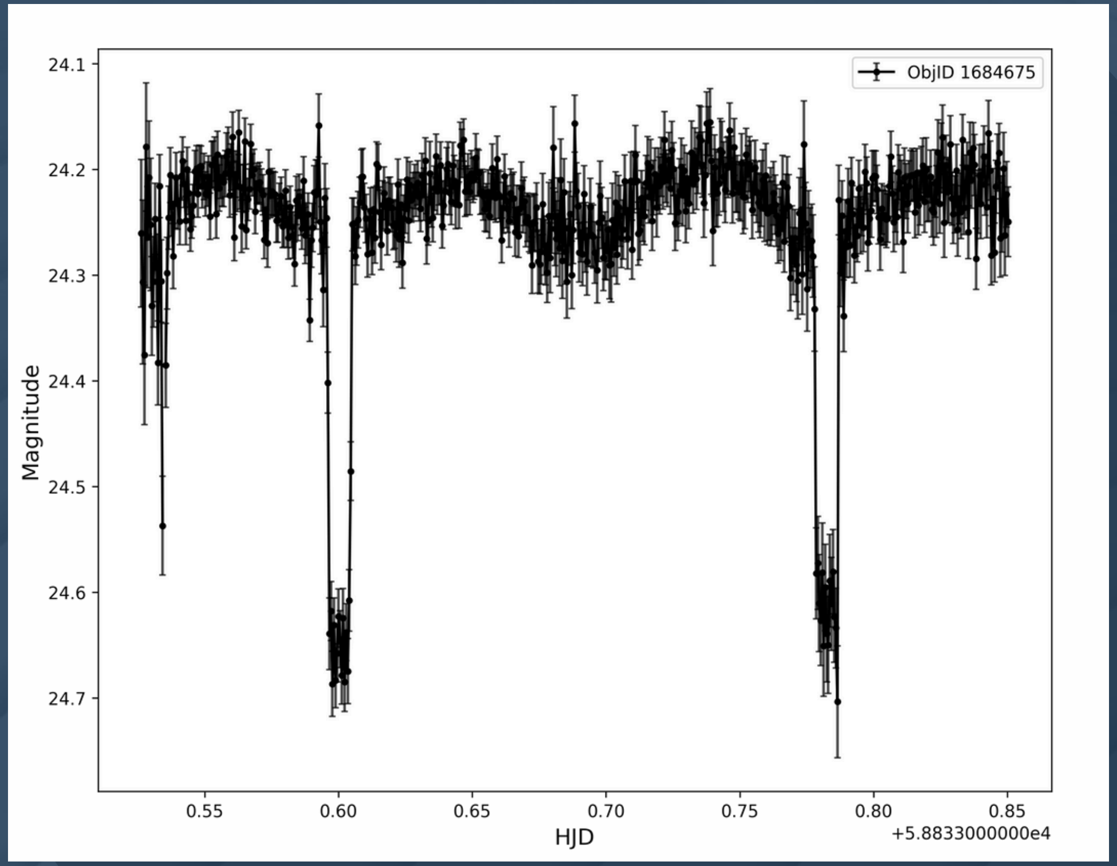
Ecl. Binary



Solar Flare



Delta Scuti

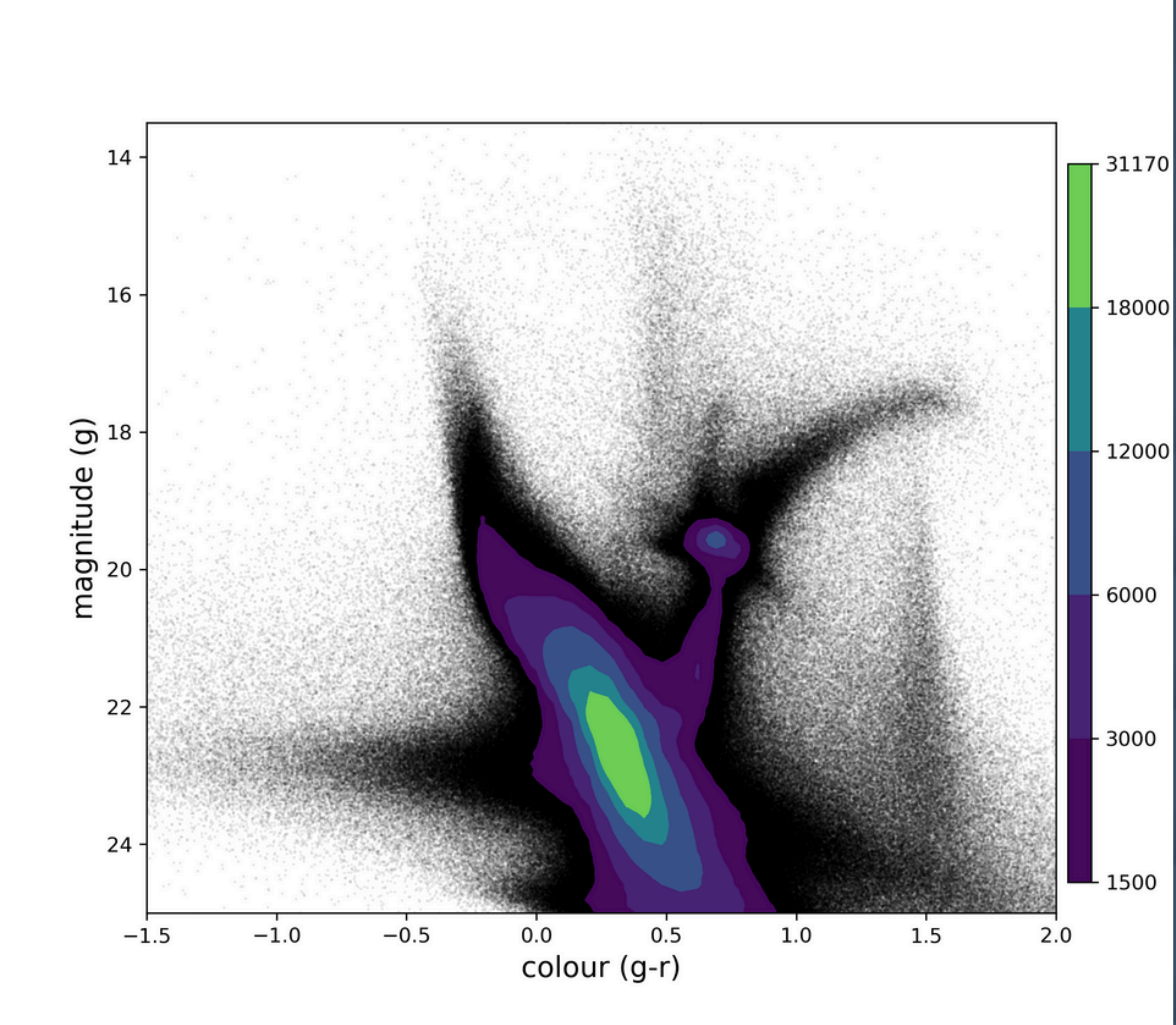


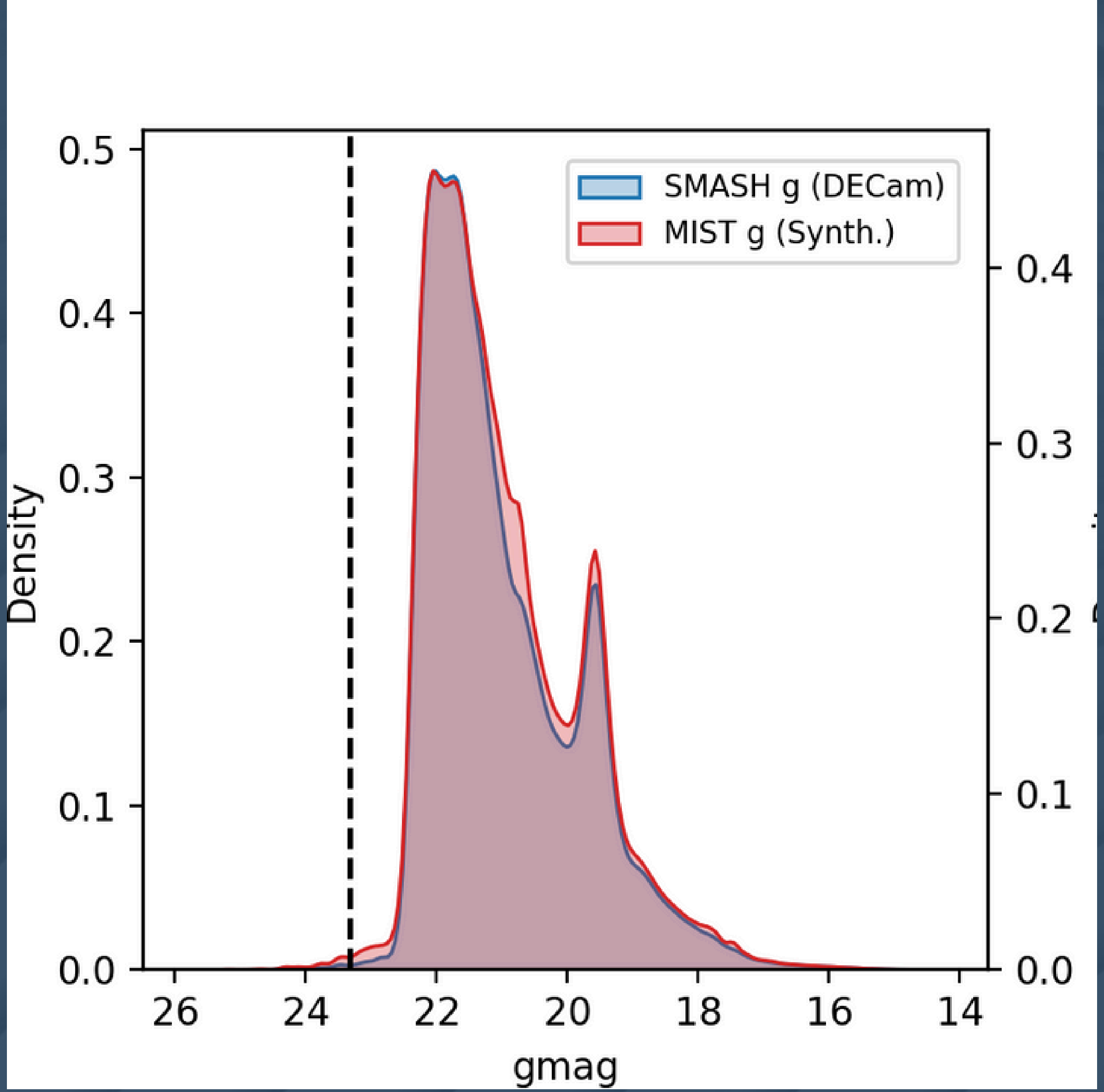
Close Orbit Binary

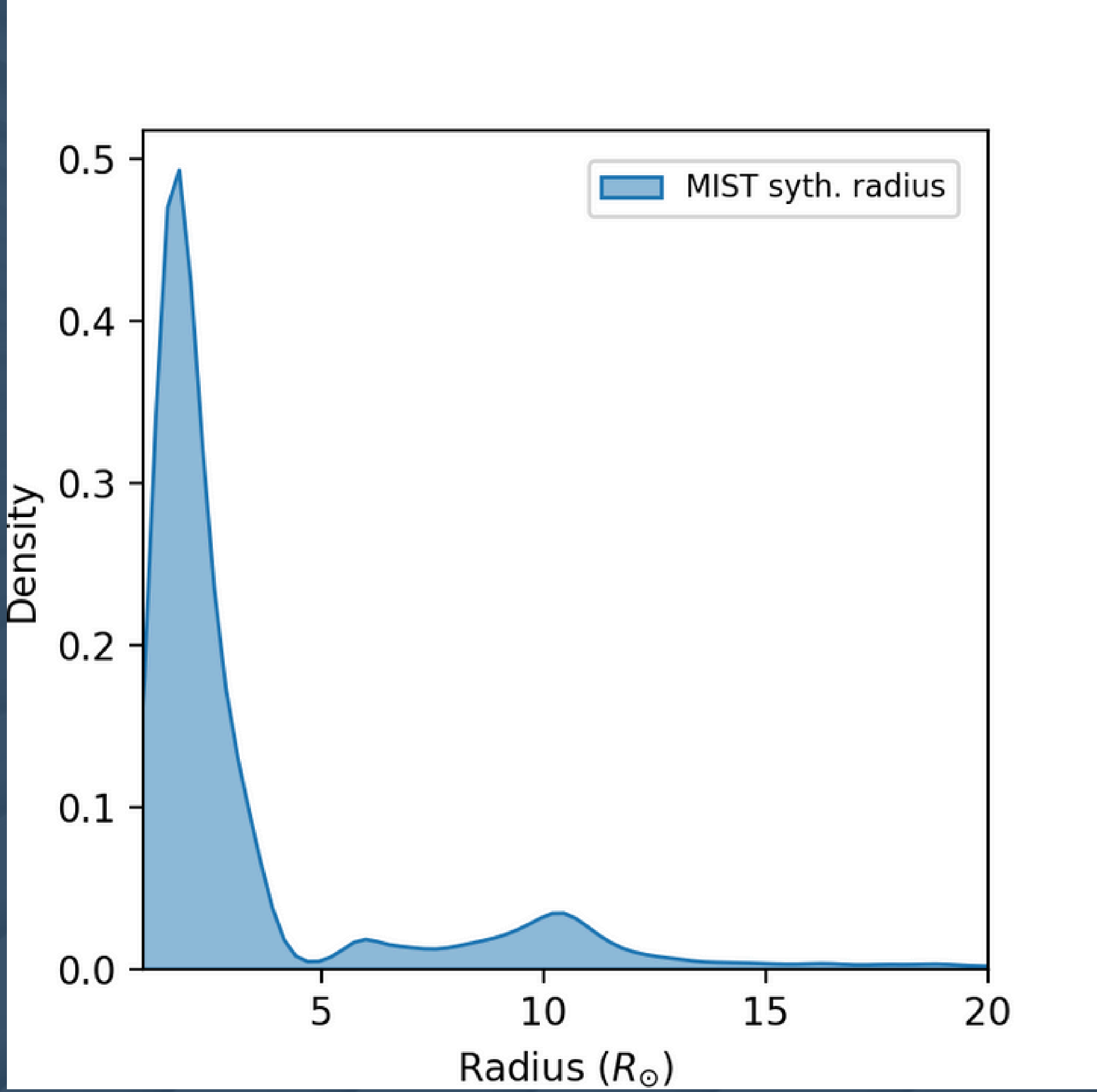
AMPM: Stars on the 4th Night

How does the finite radius of LMC stars 'hurt' microlensing detection?

Archival LMC SMASH DR2 *(Nidever+ 2021)* and MIST Synth. radii







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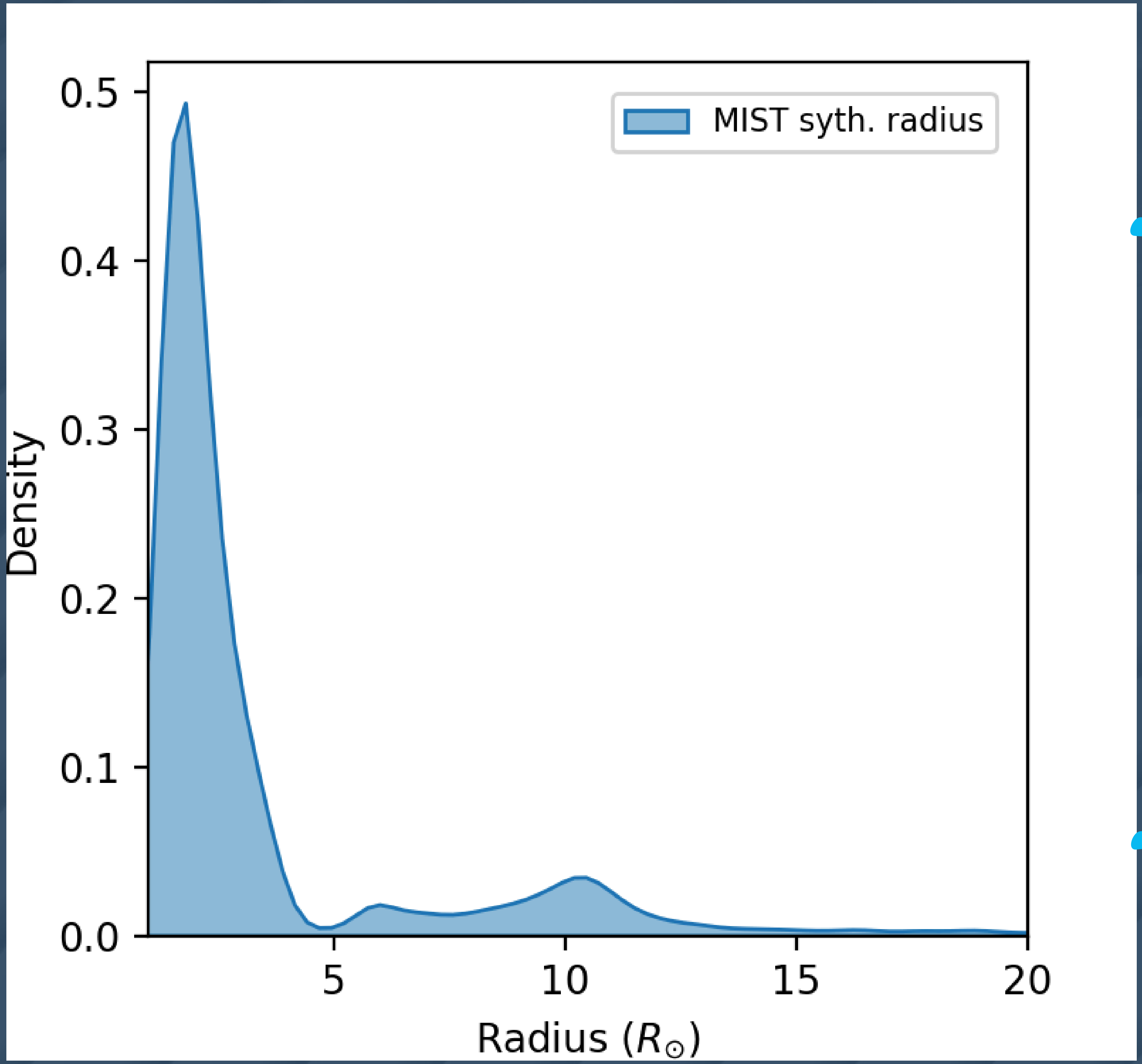


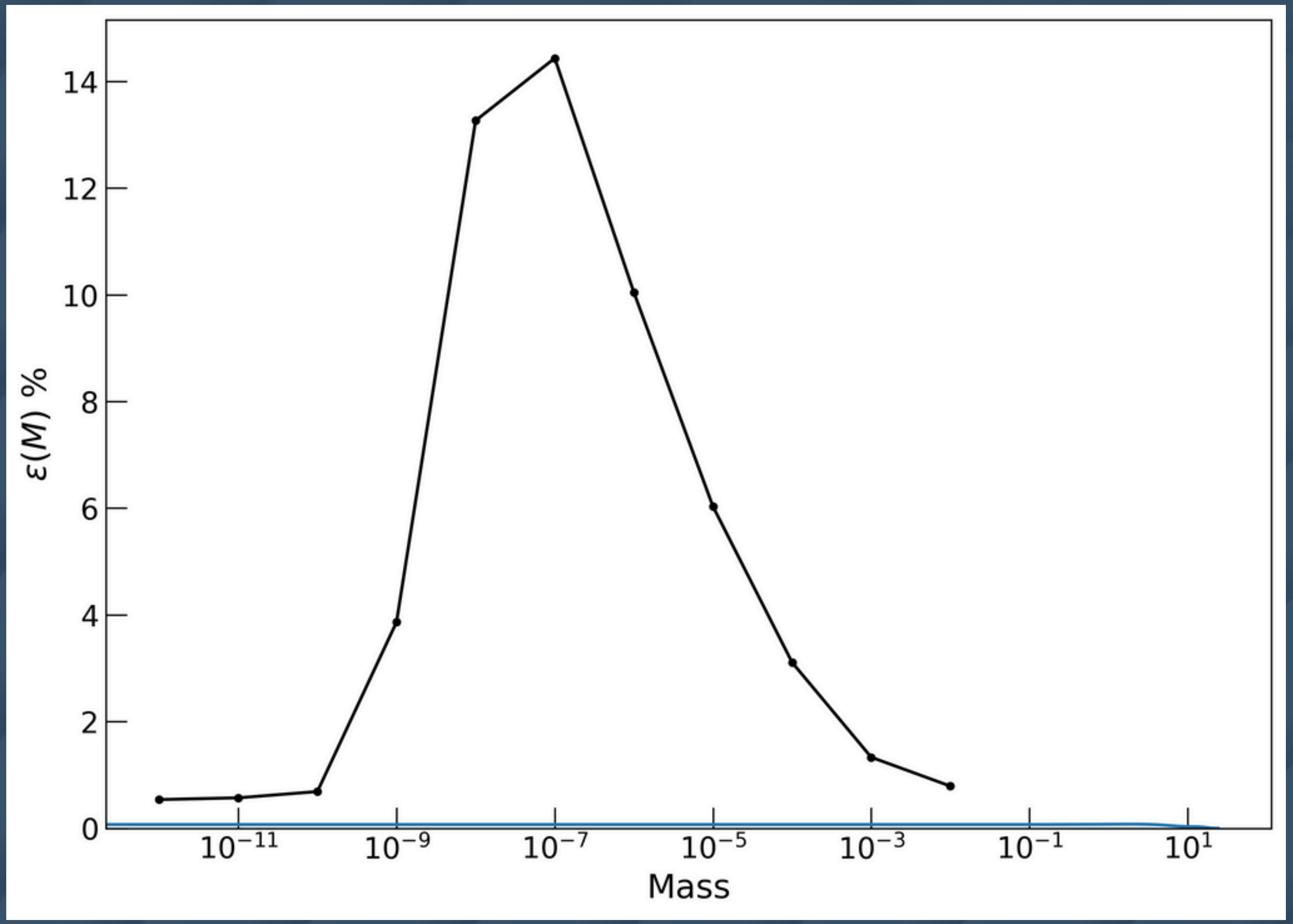
Mostly MS stars as solar analogues + some Red Giants

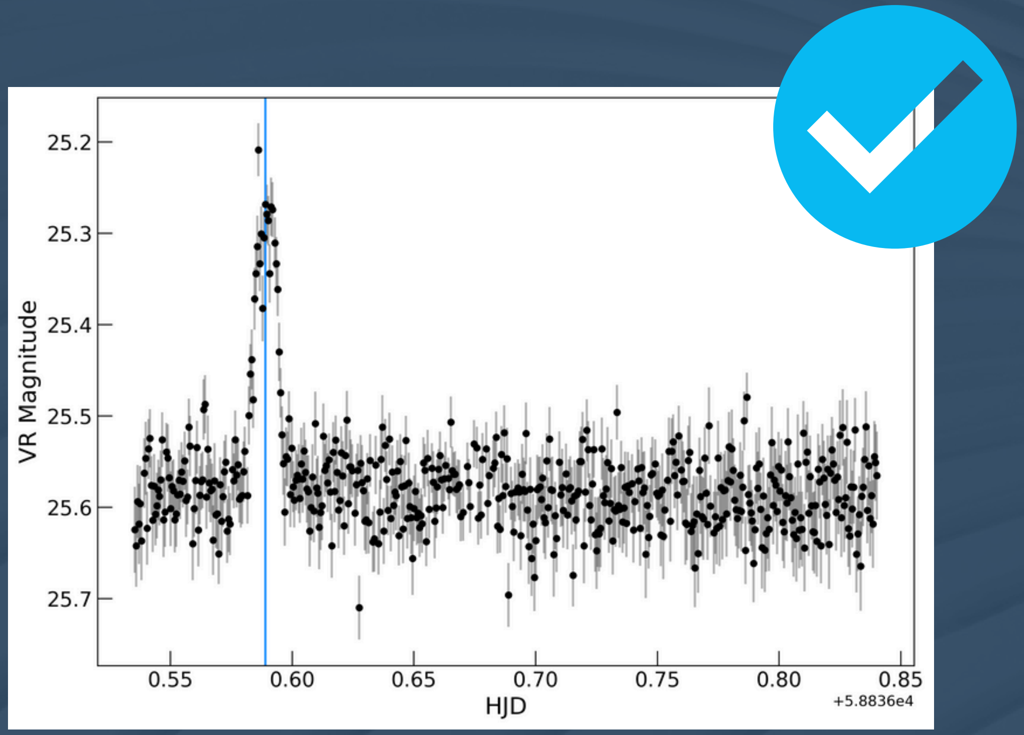
Run efficiency of pipeline in bins across radius distr.

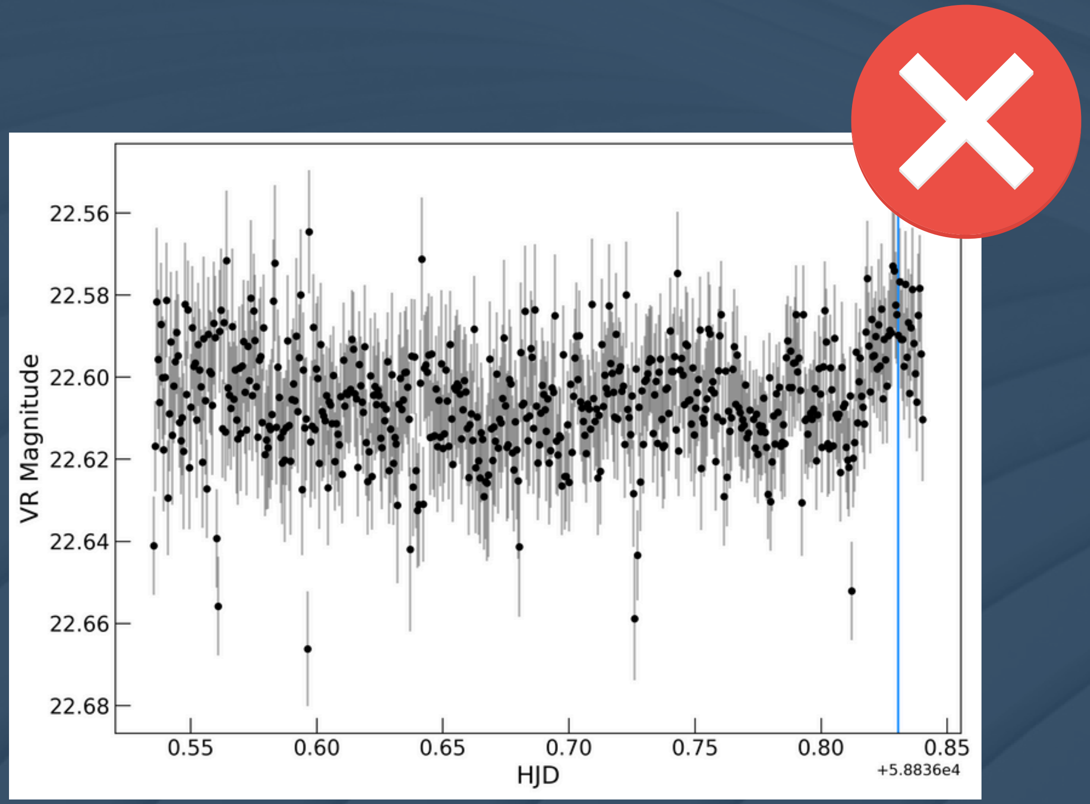
Use MIST radius distr. for a weighted efficiency

AMPM: Efficiency on the 4th Night

PBH Masses between (logspace) -12 to -5 solar masses
Stellar radius information + proper motion of LMC stars (Kallivayalil+ 2013)
Lens distances between 0-50kpc, use NFW model with halo velocities
100,000 lenses generated for each dex mass step repeated each radii bin



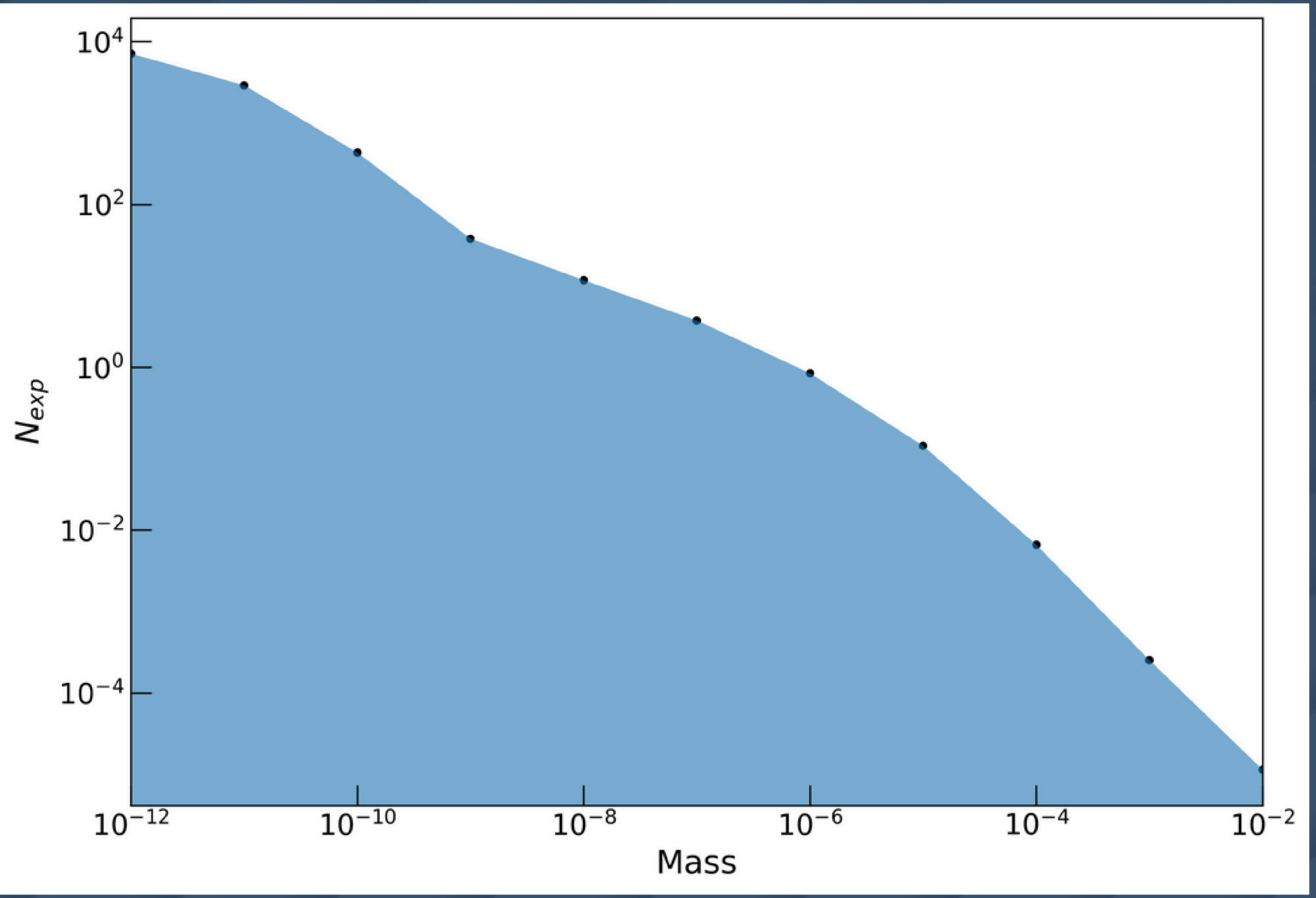




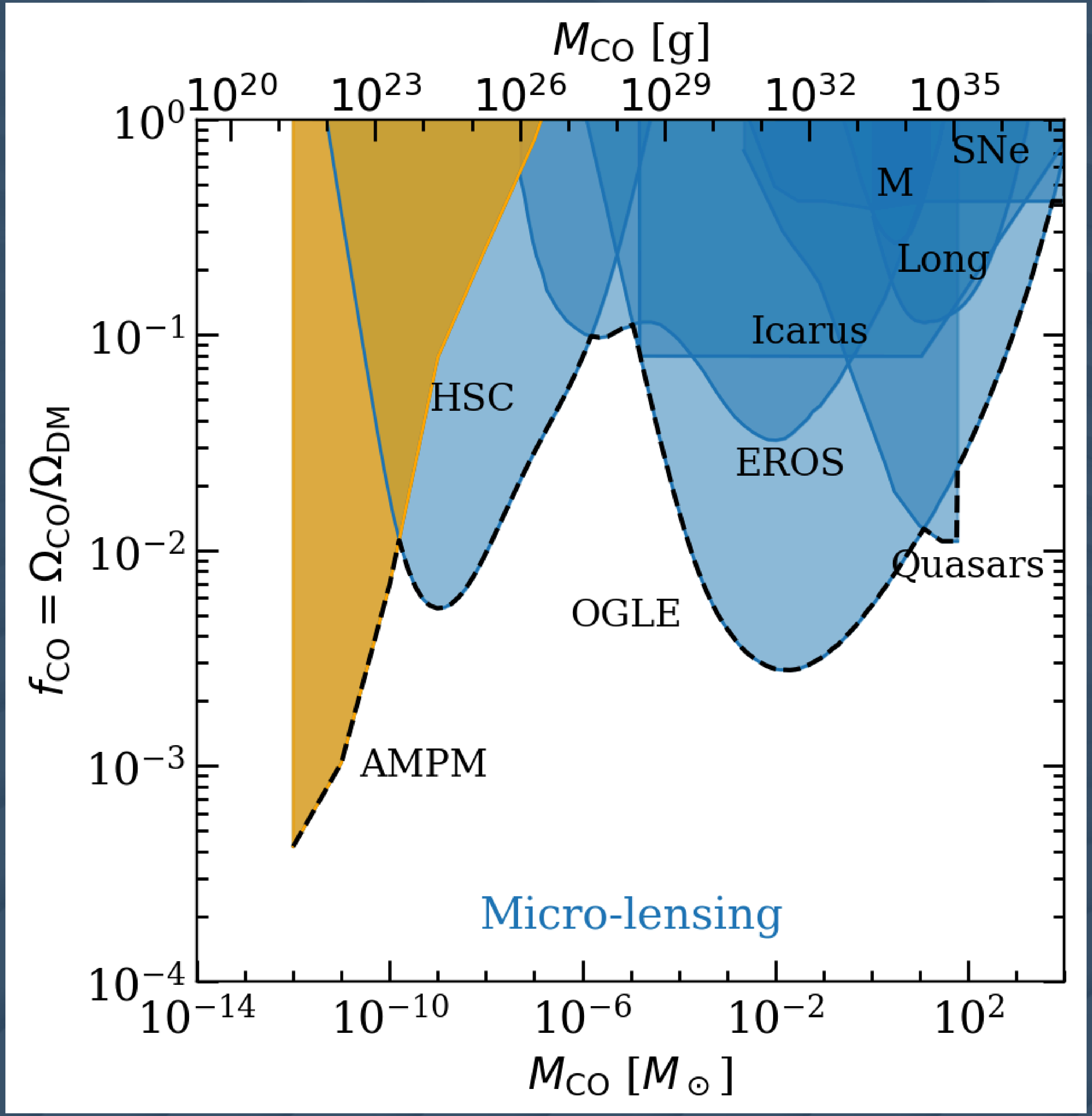
AMPM: Expected events and Null Limits

NFW DM Profile (MW only)

Weighted event rate at stellar radii



Asteroids Jupiters



Strong limits on Asteroid mass PBH-DM for December 18th

Stay tuned for Key et al. 2024 for limits on the full 5 nights

Uncertainty on limits given uncertainty on models

NFW vs the MACHO/EROS ITS

Towards the Future

PBH Clustering? DM streams? Extended PBH Masses?

Ask how realism weakens the existing PBH limits

What about FFP rates? (bulge distributions different to halo)

More data gives better distributions of baryonic and DM compact objects