Asteroid-Mass Primordial Black Holes as Dark Matter

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Road Map: The whole talk in 20 seconds

Primordial Black Holes (PBHs): natural dark matter candidates

Old microlensing constraints rely on invalid assumptions

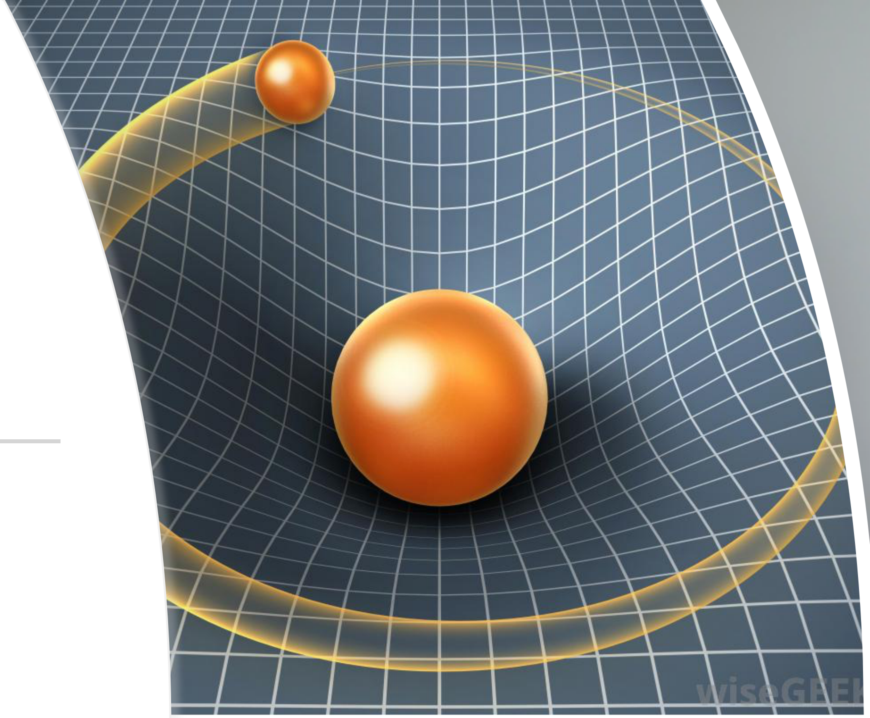
We show that asteroid mass PBHs could make up 100% of the dark matter

Properties of Dark Matter

Interacts through gravity

Invisible

Stable on long timescales



Black Hole: A natural candidate

Interacts through gravity

Invisible

Stable on long timescales

The Event Horizon Telescope Collaboration, 2019

Primordial Black Holes

Formed in the early universe from small over-densities, rather than stellar collapse

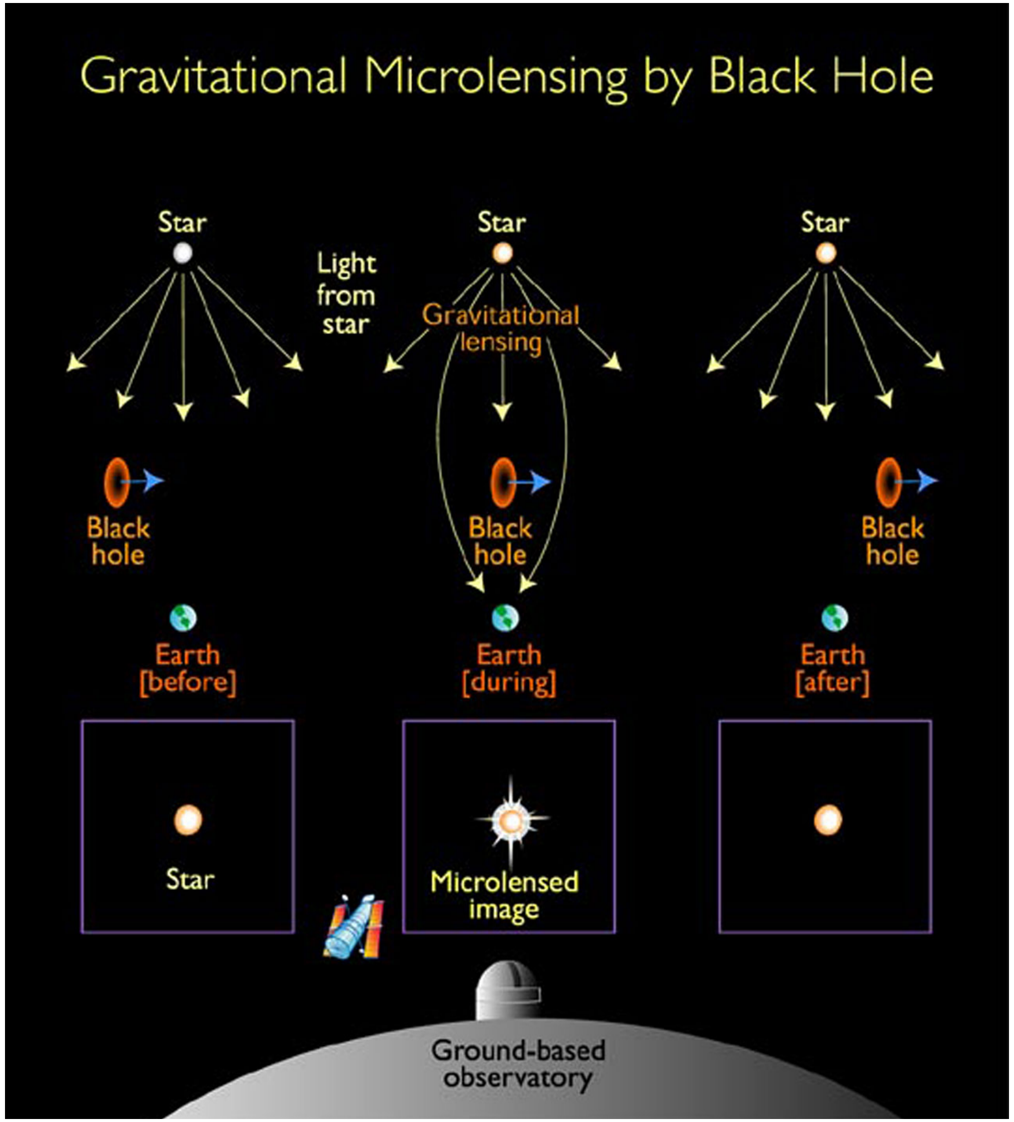
Well-motivated by various inflation models

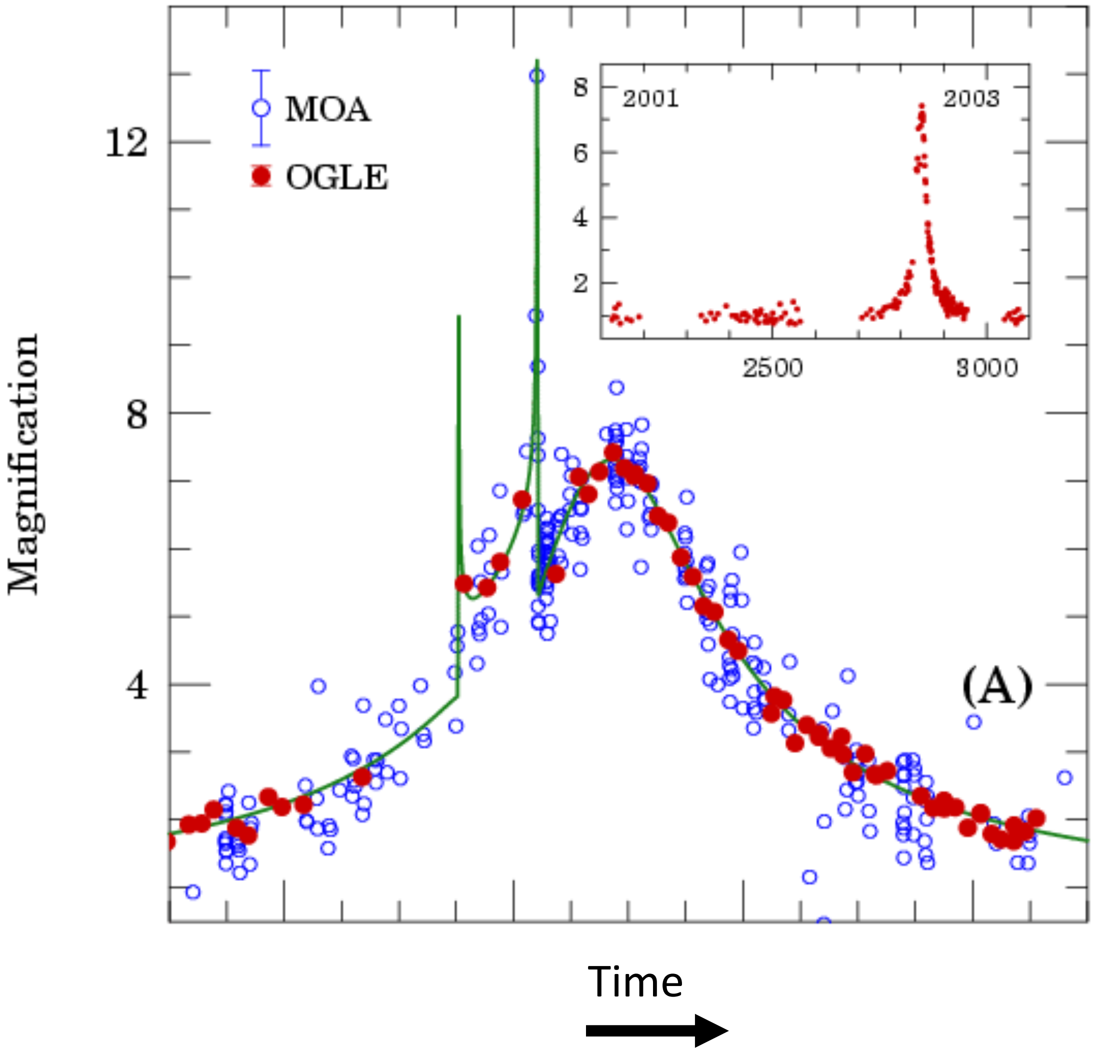
Can exist over a very wide range of masses (10^{-5}g – $10^{3}\ M_{\odot}$ and beyond!)

Planck relics

Asteroid-Mass

Many solar masses (LIGO?)





Bond et al. 2014

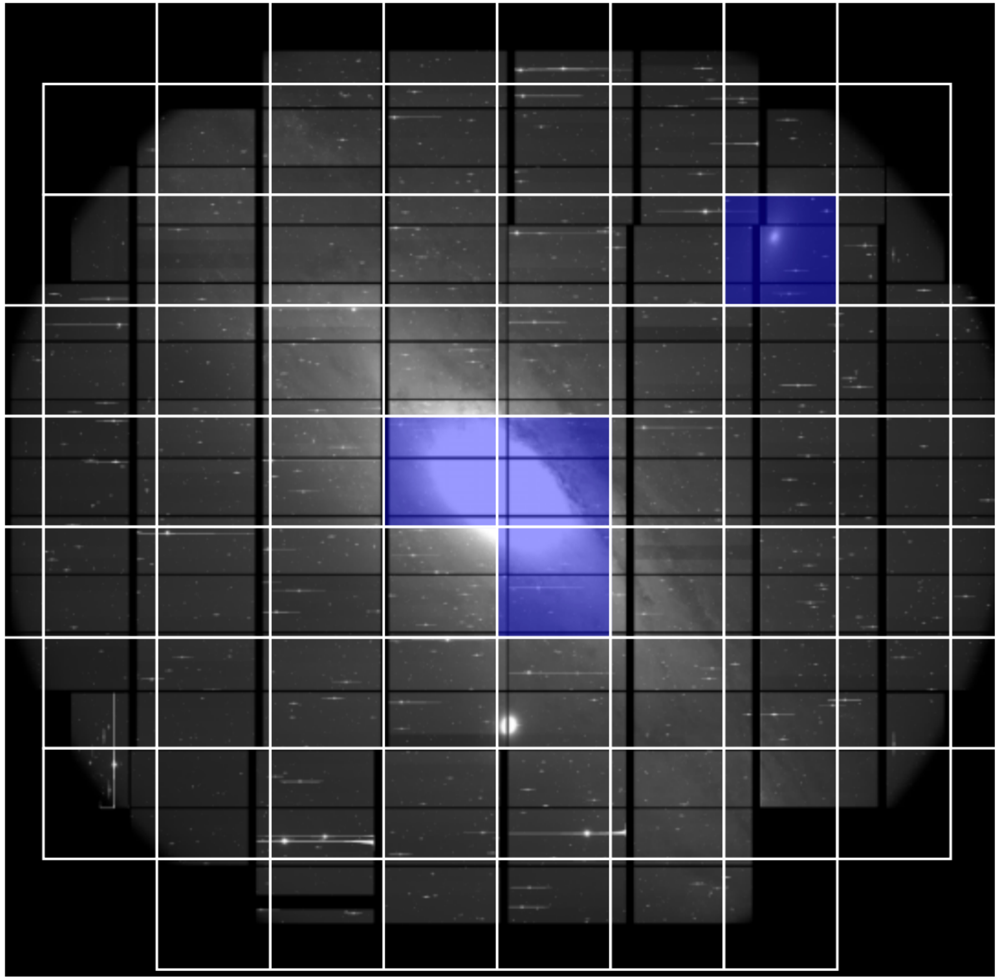
Microlensing

Subaru-HSC

High cadence

Wide field of view

Can see stars as dim as mag ~ 26



Niikura et al. 2019

Placing constraints – Expected # of Events

$$\frac{d\Gamma}{dt} = 2\,\frac{\Omega_{PBH}}{\Omega_{DM}} \int_0^{d_s} dd \int_0^{u_T} \frac{du_{min}}{\sqrt{u_T^2 - u_{min}^2}}\,\frac{\rho_{DM}(d)}{M_{PBH}\, v_c^2}\, v_r^4\, e^{-v_r^2/v_c^2}$$

Expected rate of events per observation time

Integrate over line-of-sight to source

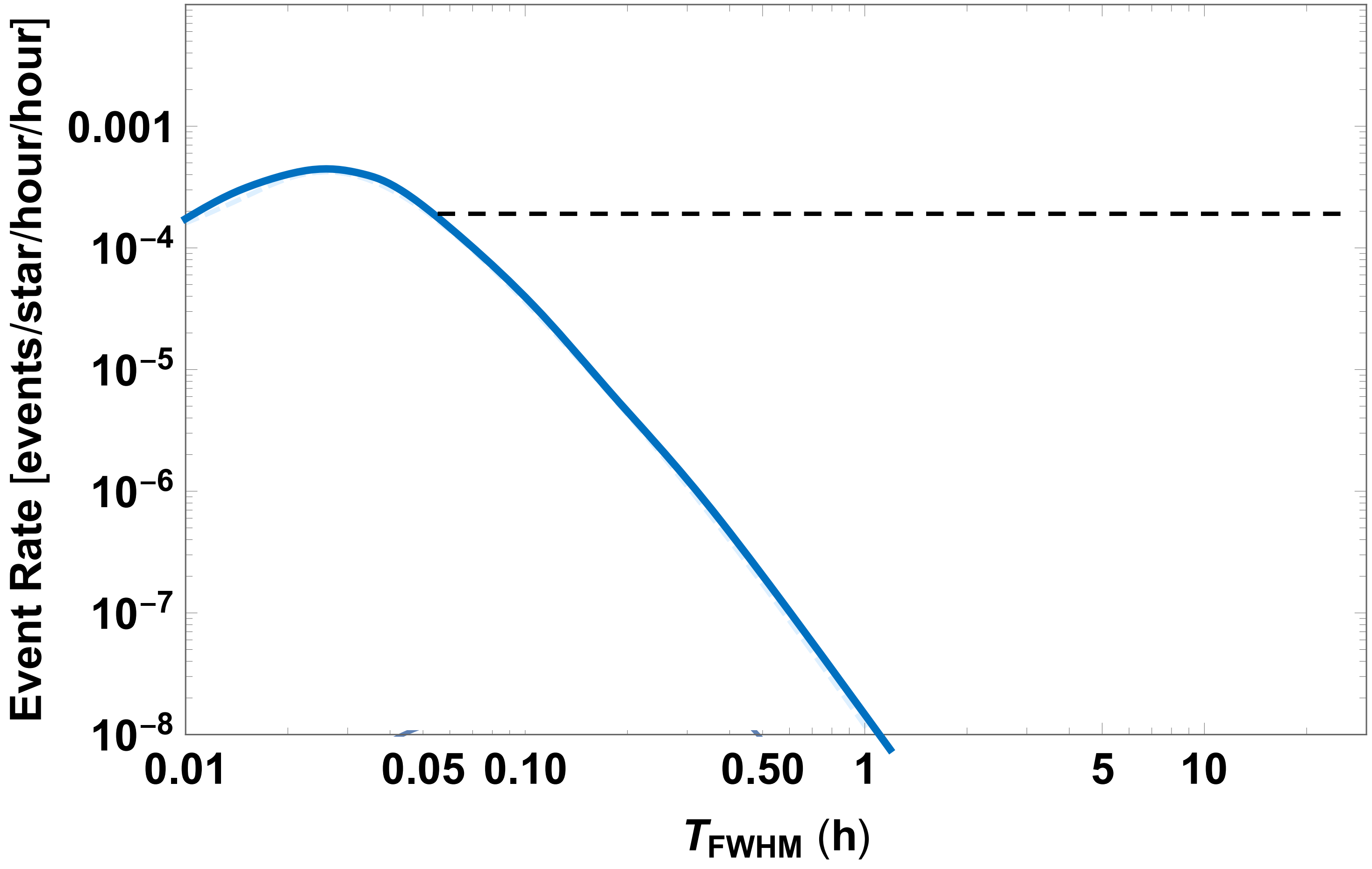
Proportional to density of dark matter (large close to MW and M31, small in the middle)

Fraction of DM comprised of PBHs

Minimum impact parameter for detectable event

Placing constraints – Expected # of Events

$\frac{d\Gamma}{dt}$



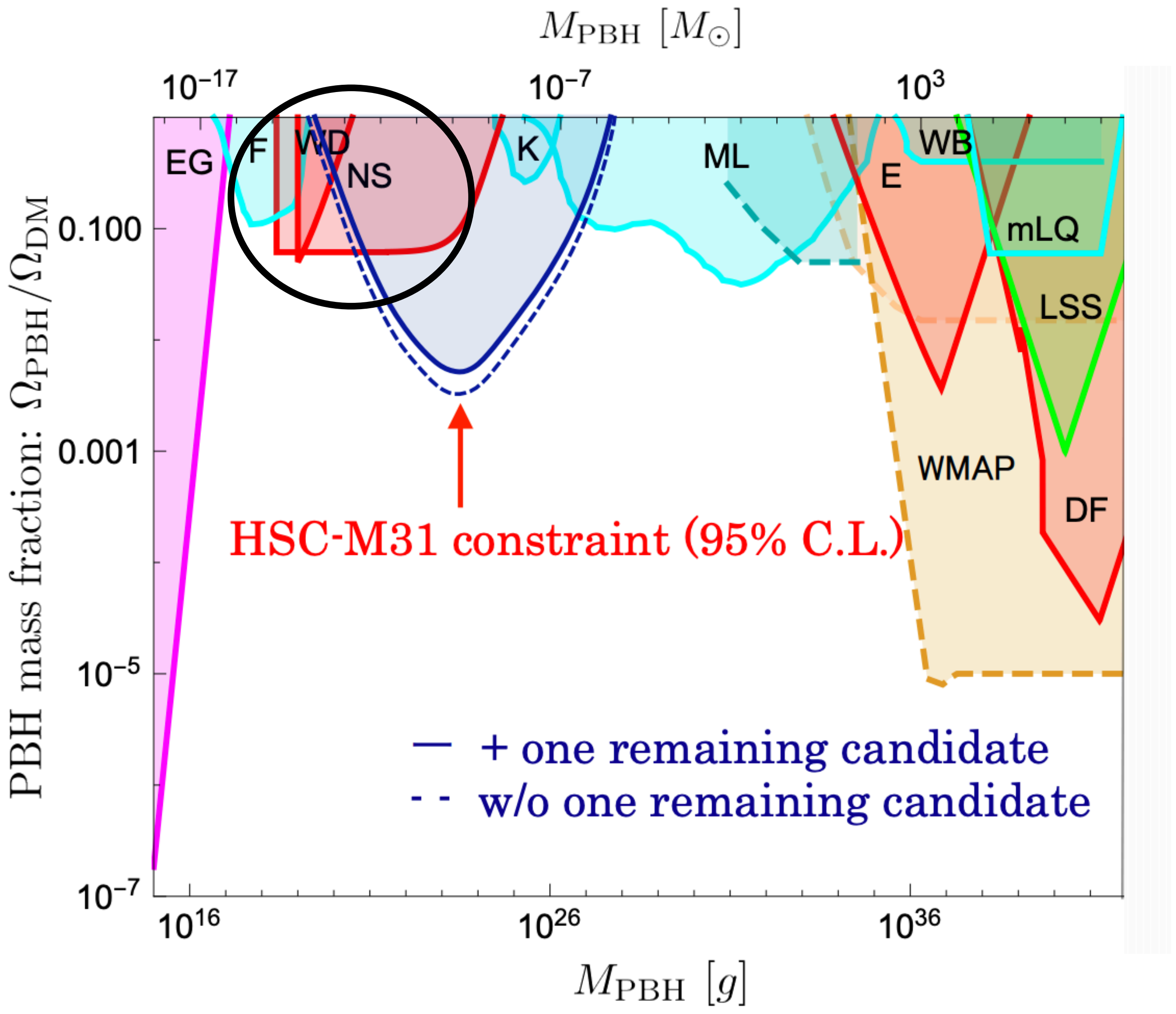
$10^{-4} \times 10^{8}$stars $\times$ .1hours $\times$ 10 hours observation ~ 10^{4}events!

Assuming all the PBH are a single specific mass

Constraints
A first pass

Very optimistic constraints!
Does not yet consider *finite size effects*

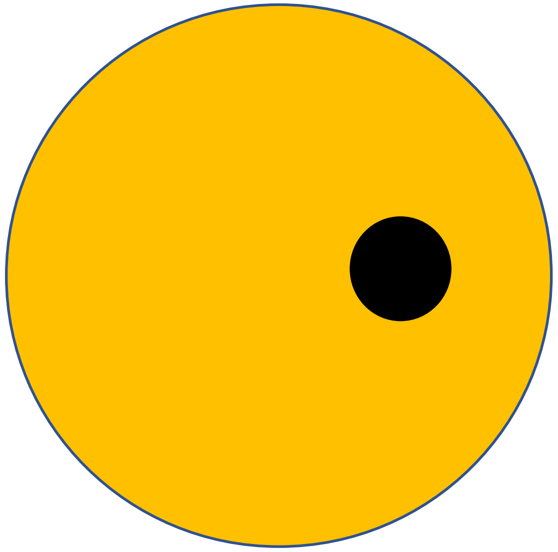
(We now know that all the lower mass constraints have issues)

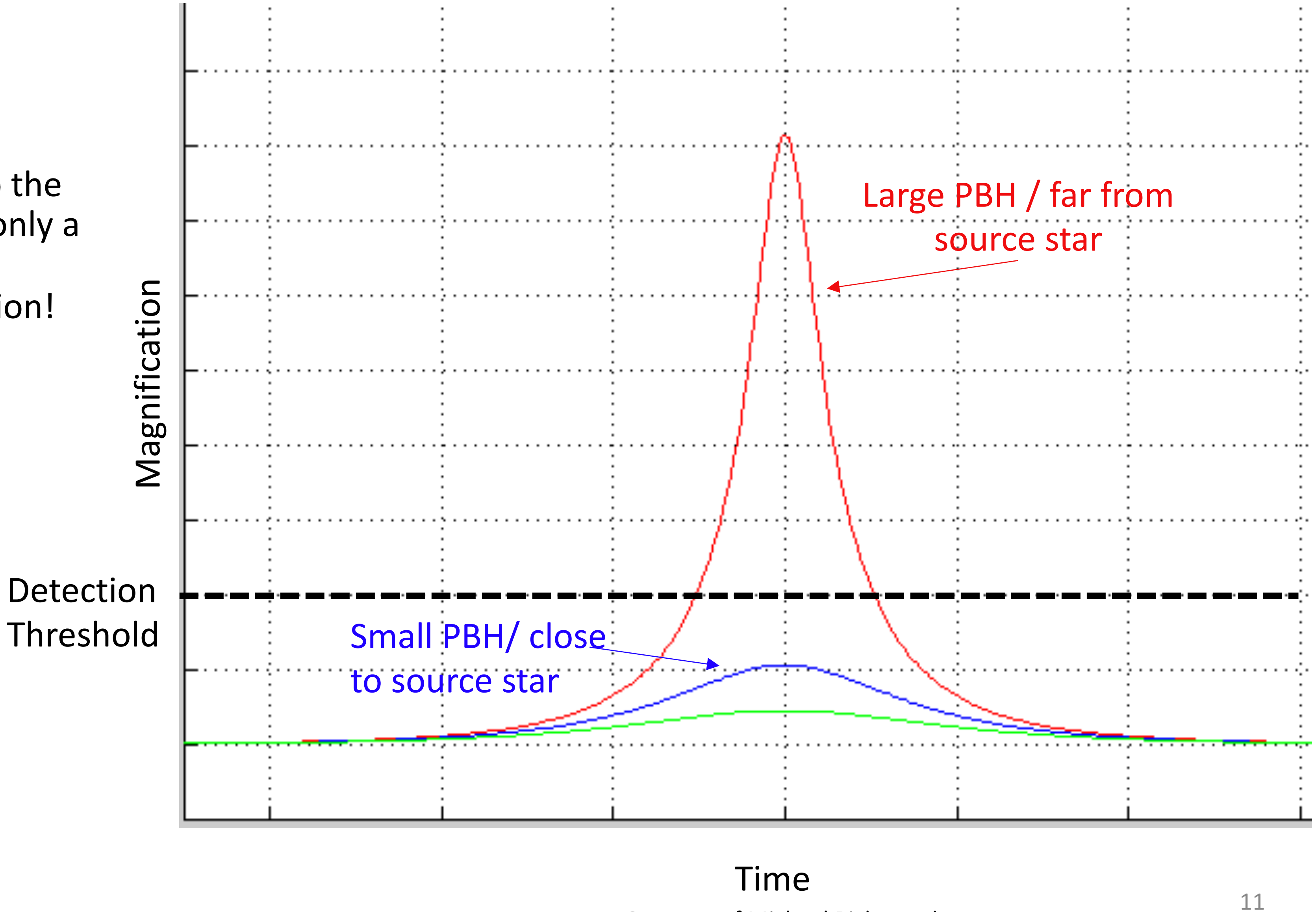


Niikura et al. 2017

Finite Size Effects

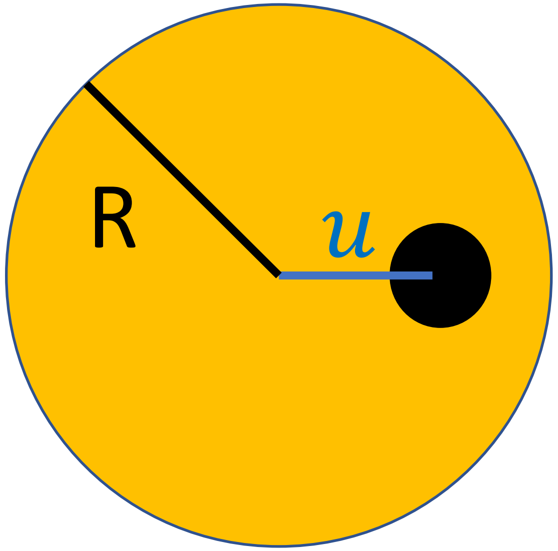
If the PBH is small compared to the star in the lensing plane, then only a fraction of the star is lensed, suppressing the net magnification!





Courtesy of Michael Richmond

Finite Size Effects

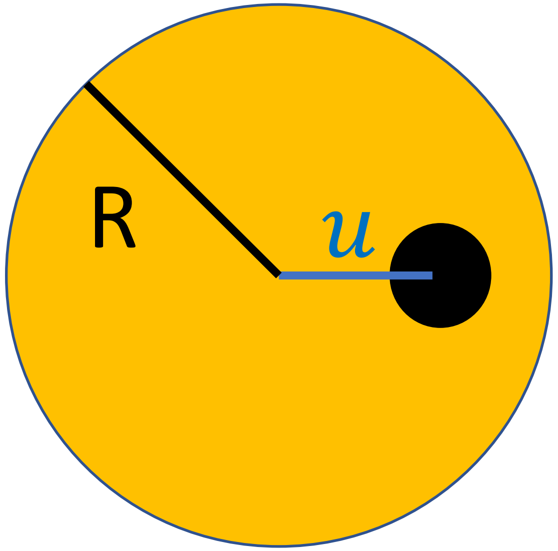


Calculate new magnification by effectively averaging over the entire source (assuming uniform surface brightness)

$$A = \frac{1}{\pi R^2} \int_{|y| < R} d^2y \, A_p(|u - y|)$$

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

Finite Size Effects



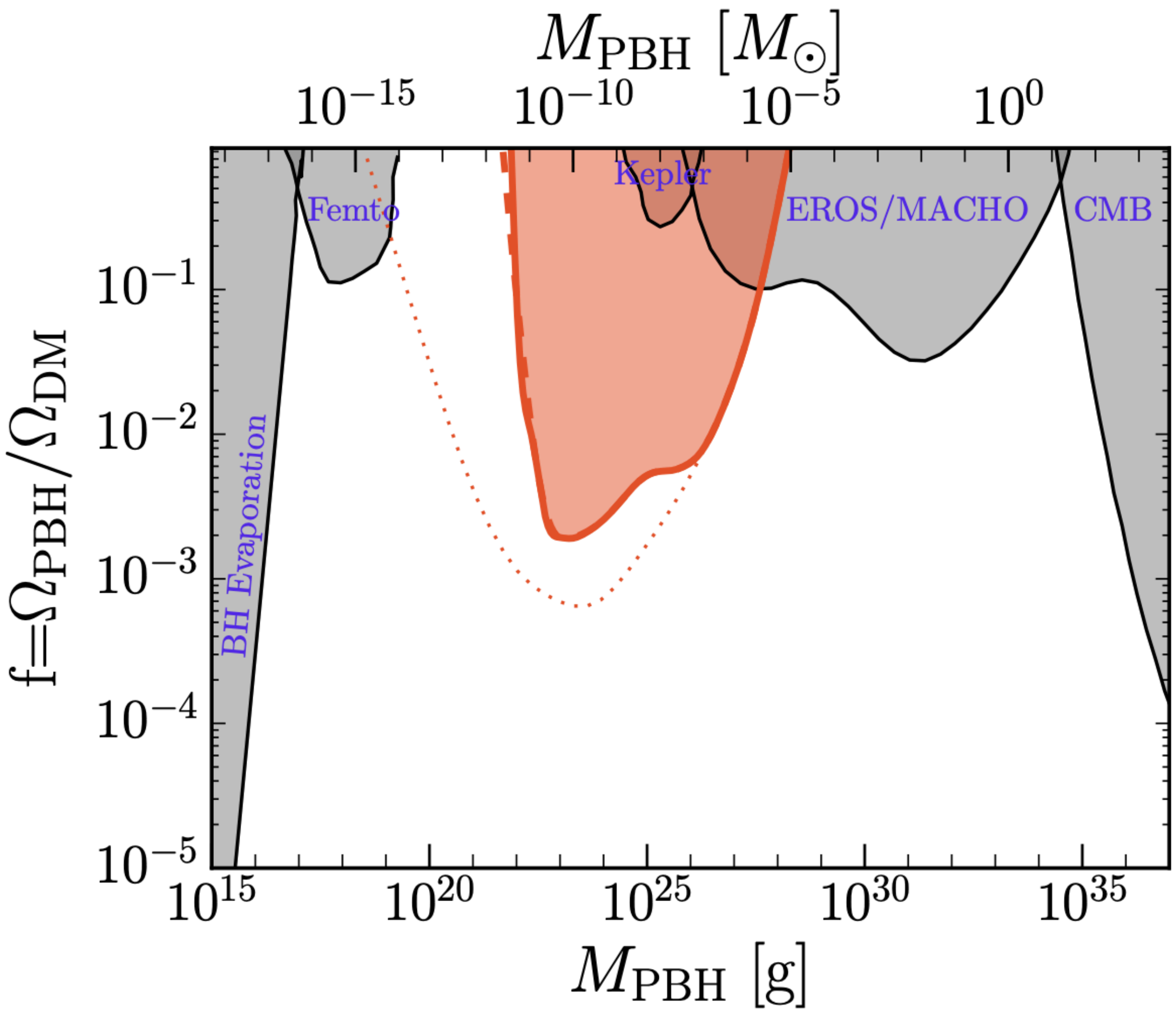
$$A = \frac{1}{\pi R^2} \int_{|y|< R} d^2y \, A_p(|u - y|)$$

Changes threshold impact parameter!

$$\frac{d\Gamma}{dt} = 2\,\frac{\Omega_{PBH}}{\Omega_{DM}} \int_0^{d_s} dd \int_0^{u_T} \frac{du_{min}}{\sqrt{u_T^2 - u_{min}^2}} \frac{\rho_{DM}(d)}{M_{PBH} v_c^2}\, v_r^4\, e^{-v_r^2/v_c^2}$$

Constraints Round 2!

Still overly-optimistic constraints! Assumes all stars in M31 have radius $R_\odot$



Niikura et al. 2019

Sanity Check: The Sun

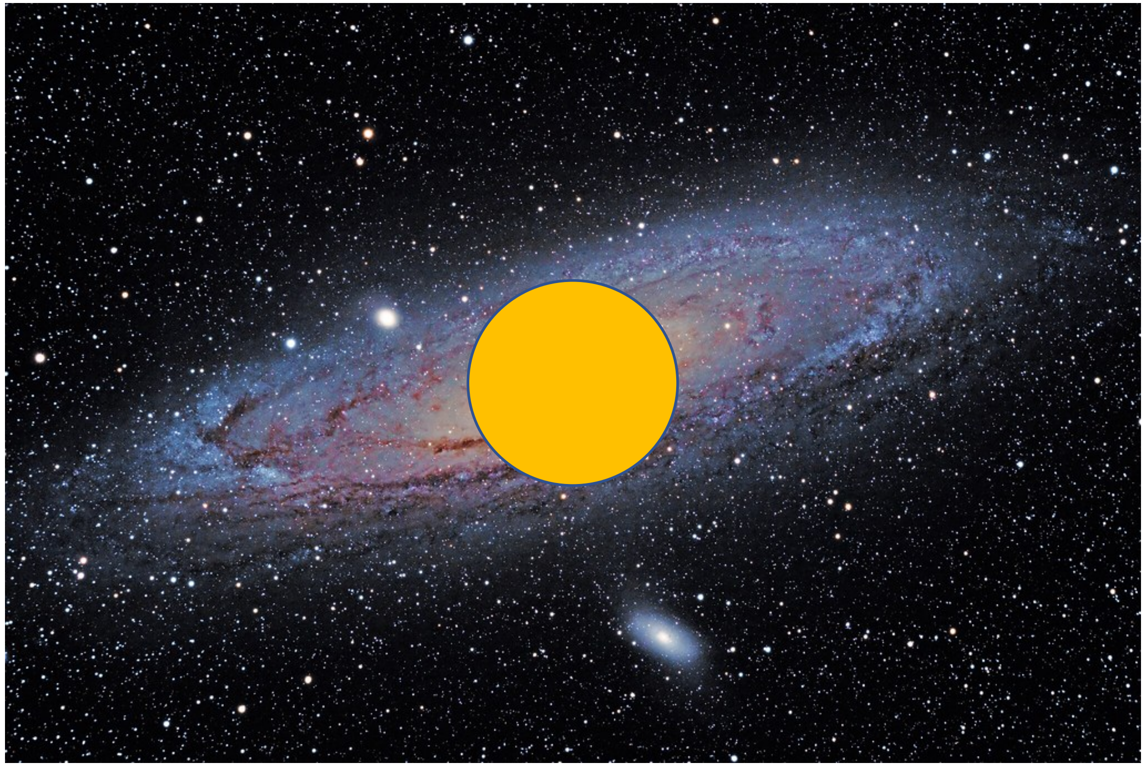
How bright would a $1\ R_{\odot}$ star appear?

HSC sensitive to mag ~26 (best case)

Sun would be mag ~29. Orders of magnitude dimmer in astronomy units. Invisible to HSC!

HSC

(Not to scale)

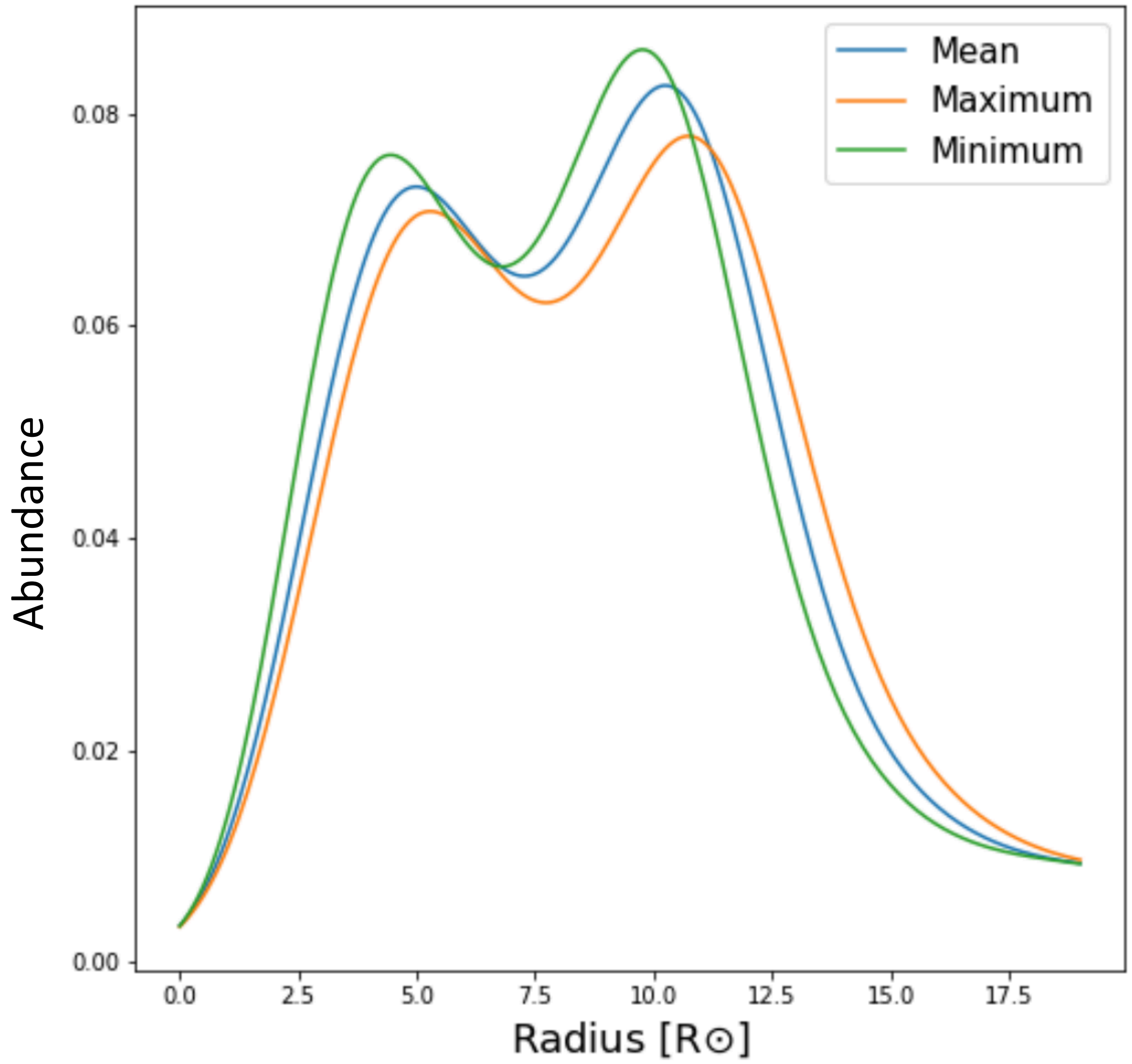


M31

Relevant stellar population

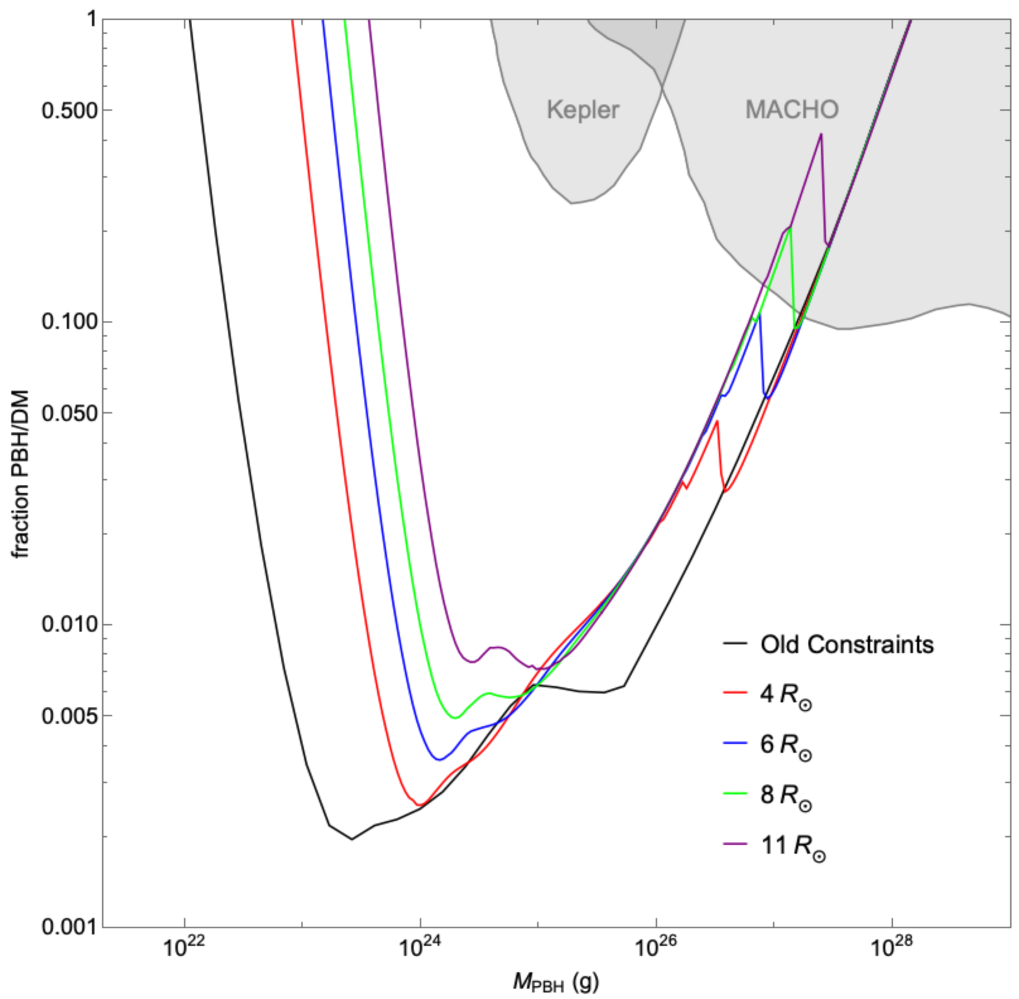
We compare stars from the Panchromatic Hubble Andromeda Treasury (PHAT) catalog with the Mesa Isochrones and Stellar Tracks (MIST) stellar evolution package

Determine the population of stars to which the HSC is sensitive to microlensing events



Smyth et al. 2020

Full Finite Size Treatment



Smyth et al. 2020

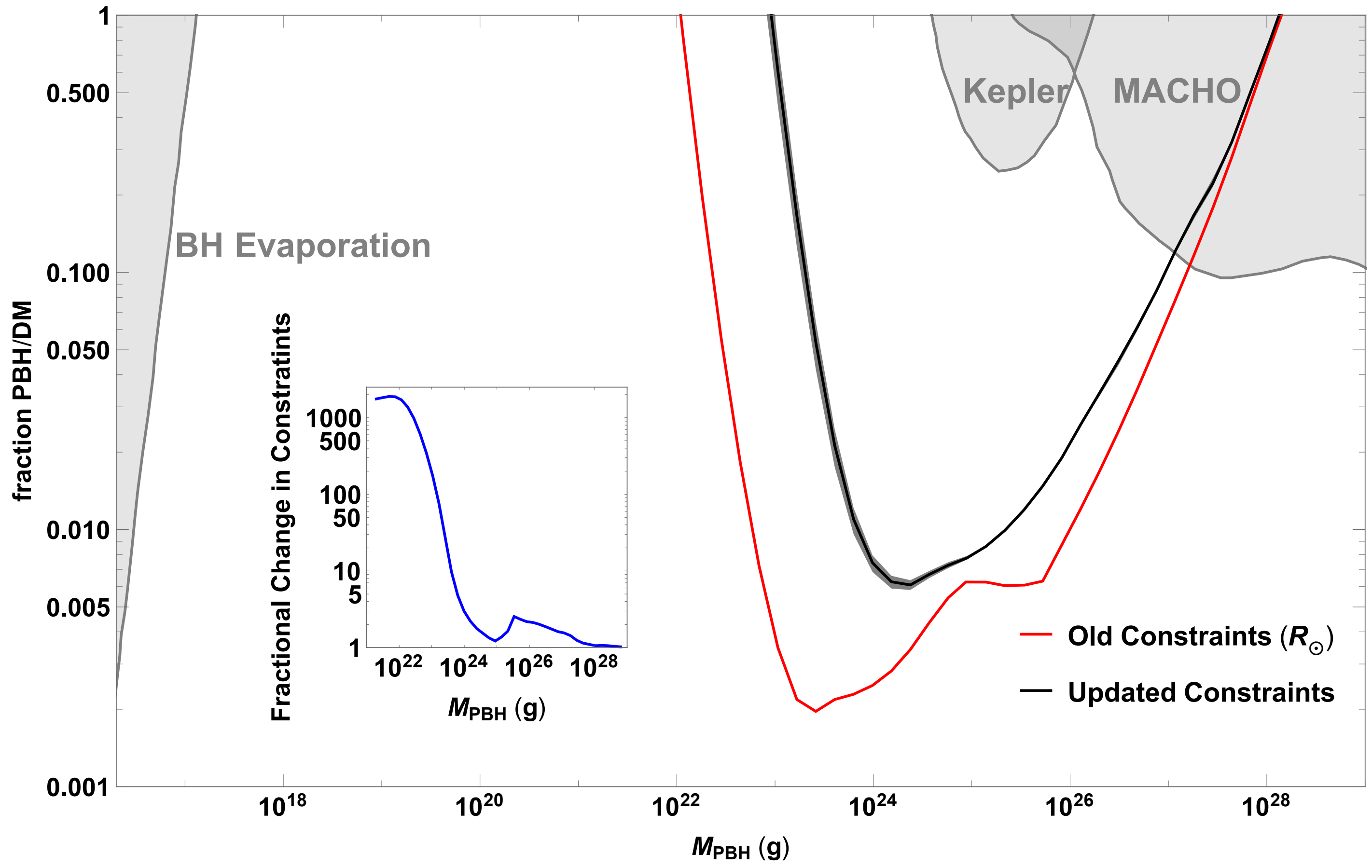
Assuming the entire population is a single size, we can see how the constraints scale with stellar radius

Constraints dramatically weaken for larger stars

Our constraints

Up to 3 orders of magnitude weaker

Opens a large window where PBHs can make up the totality of DM



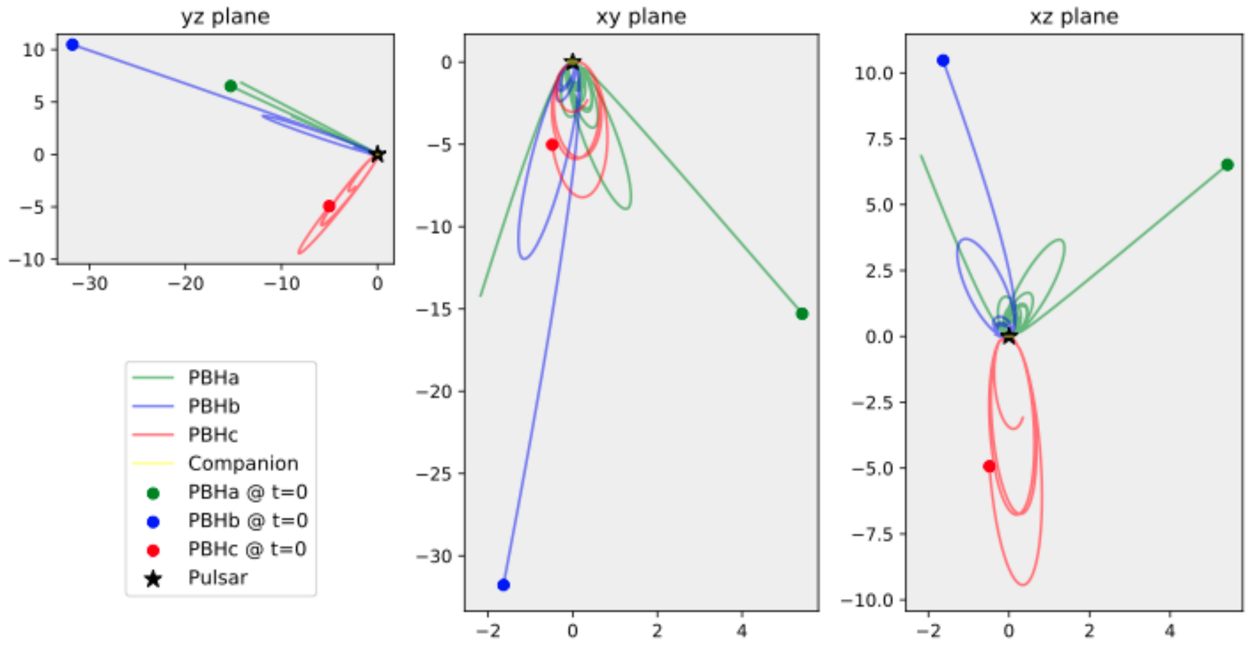
Smyth et al. 2020

How to probe newly opened parameter space?

Future microlensing (femtolensing) prospects will have diminishing returns due to finite size effects (eg. Katz et al.)

Neutron star capture / quiet kilonovae

Perturbed orbits from capture of light PBHs



Lehmann, Ross, Webber (in preparation)

Summary: The whole talk in 20 seconds again

Primordial Black Holes (PBHs): natural dark matter candidates

We derive the relevant population of source stars and give the finite-size effects a thorough treatment

We show that asteroid mass PBHs could make up 100% of the dark matter

Thank you!

Wonderful Collaborators

Stefano Profumo

Tesla Jeltema

Sam English

Raja Guhathakurta

Kevin McKinnon

Our recent paper on this subject:

Smyth, Profumo, Jeltema, Guhathakurta, English, McKinnon, 2020

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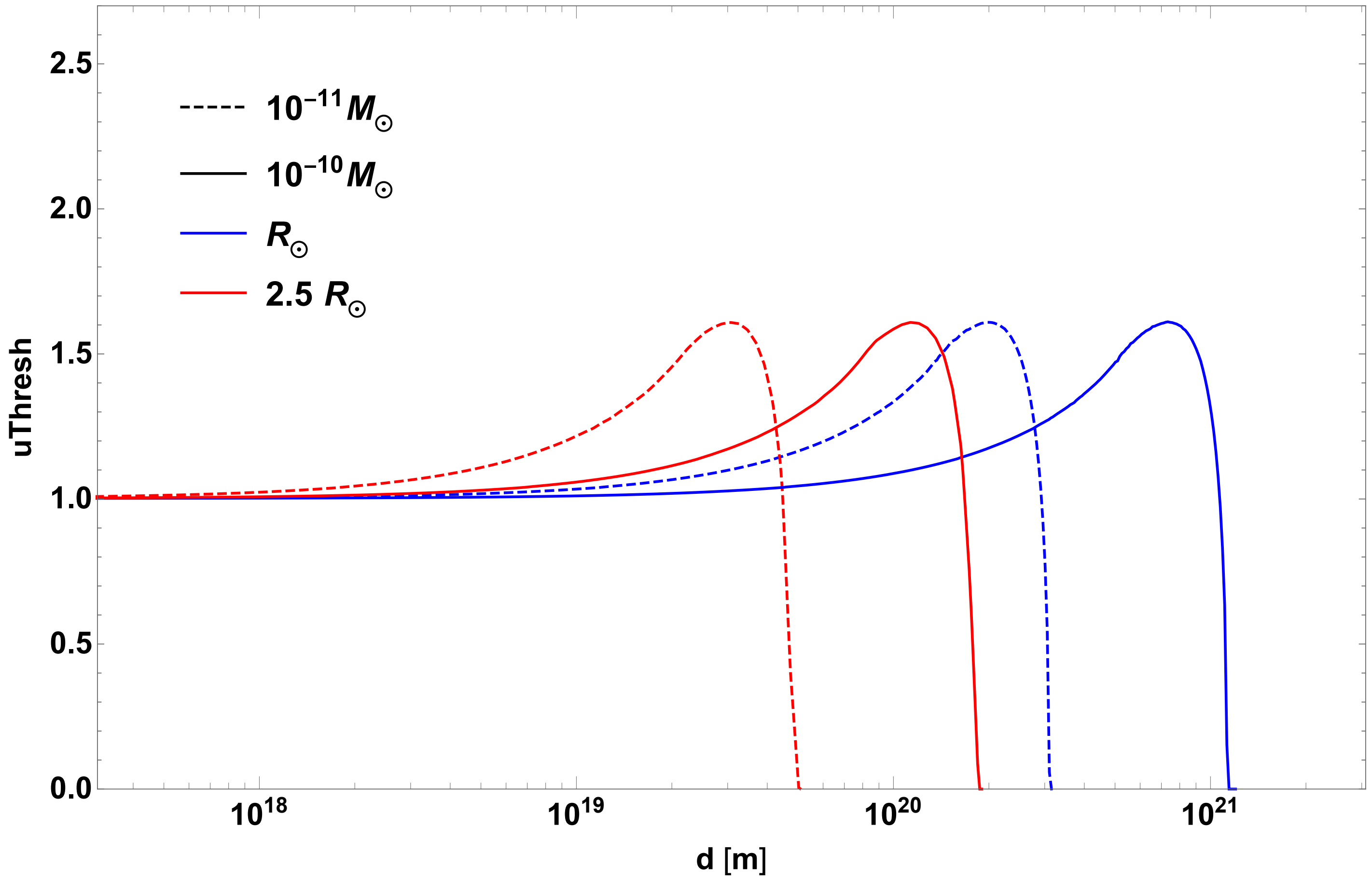
Bonus Slides

Distance and Size. When can we detect lensing?

$$\frac{d\Gamma}{dt} \sim \int_0^{\not{d}_s} dd$$



Finite Size + Wave effects

Maximum magnification strongly suppressed when $\lambda \sim r_S$