Constraints on Primordial Black Holes as Dark Matter

KITP Seminar

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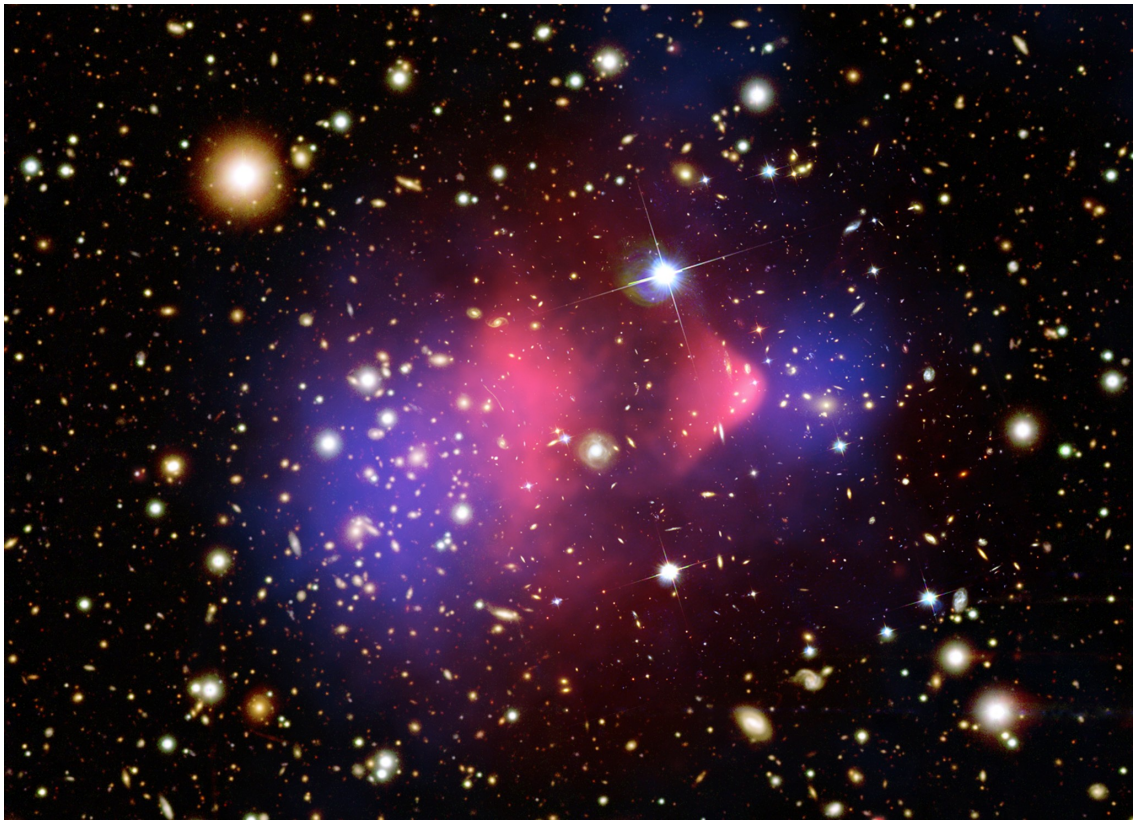
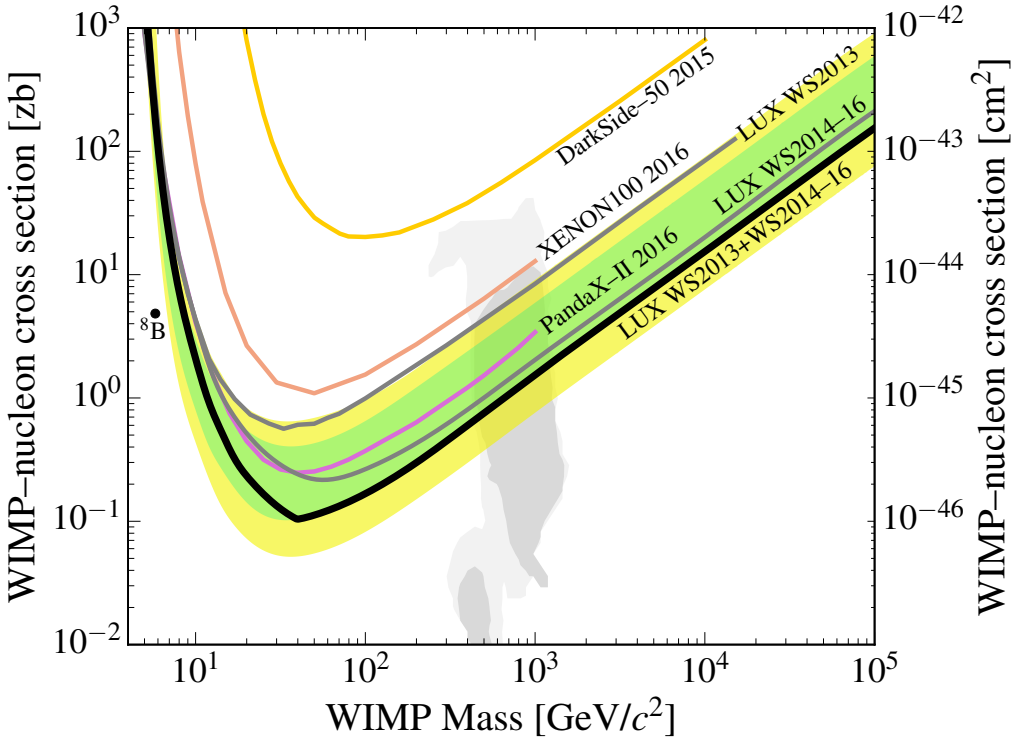


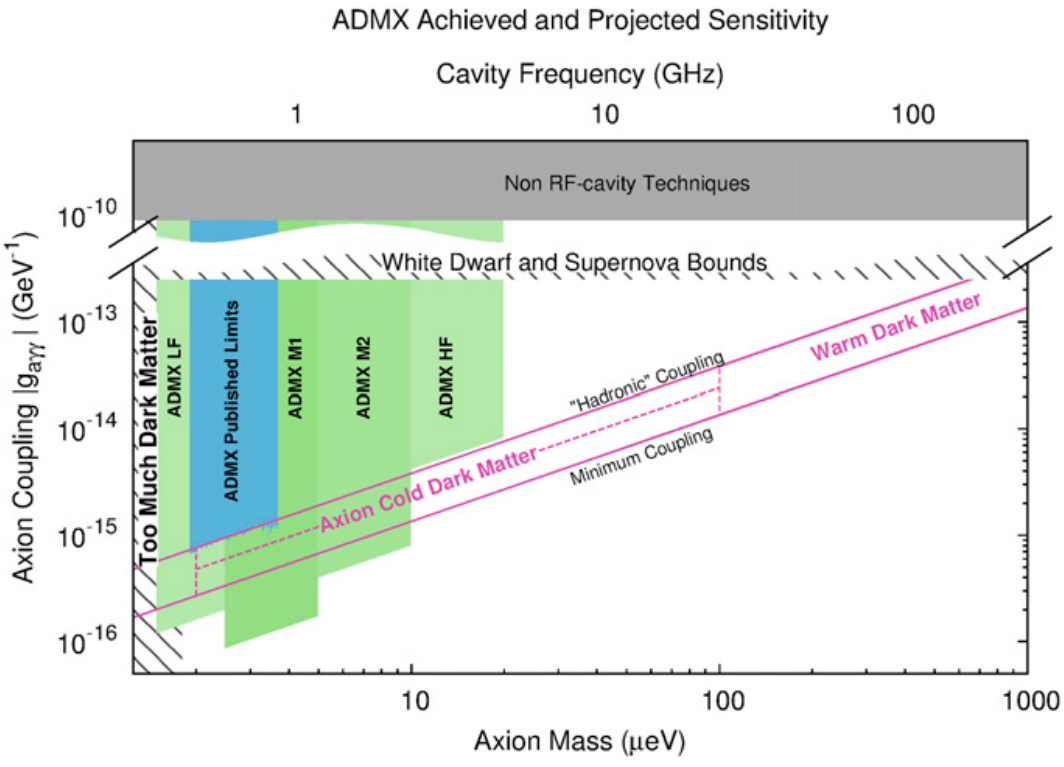
Bullet Cluster, X-ray, optical, and lensing composite

WIMP Dark Matter?



LUX collaboration, Akerib et al. PRL, 118, 1303 (2017)

Axion Dark Matter?



ADMX, Rosenberg, PNAS, 112, 40 (2014)

Is dark matter primordial black holes?

- ✓ Black holes exist
- ✓ Scenario makes testable predictions

- Black hole mergers
- Microlensing
- CMB distortions
- Dynamical heating

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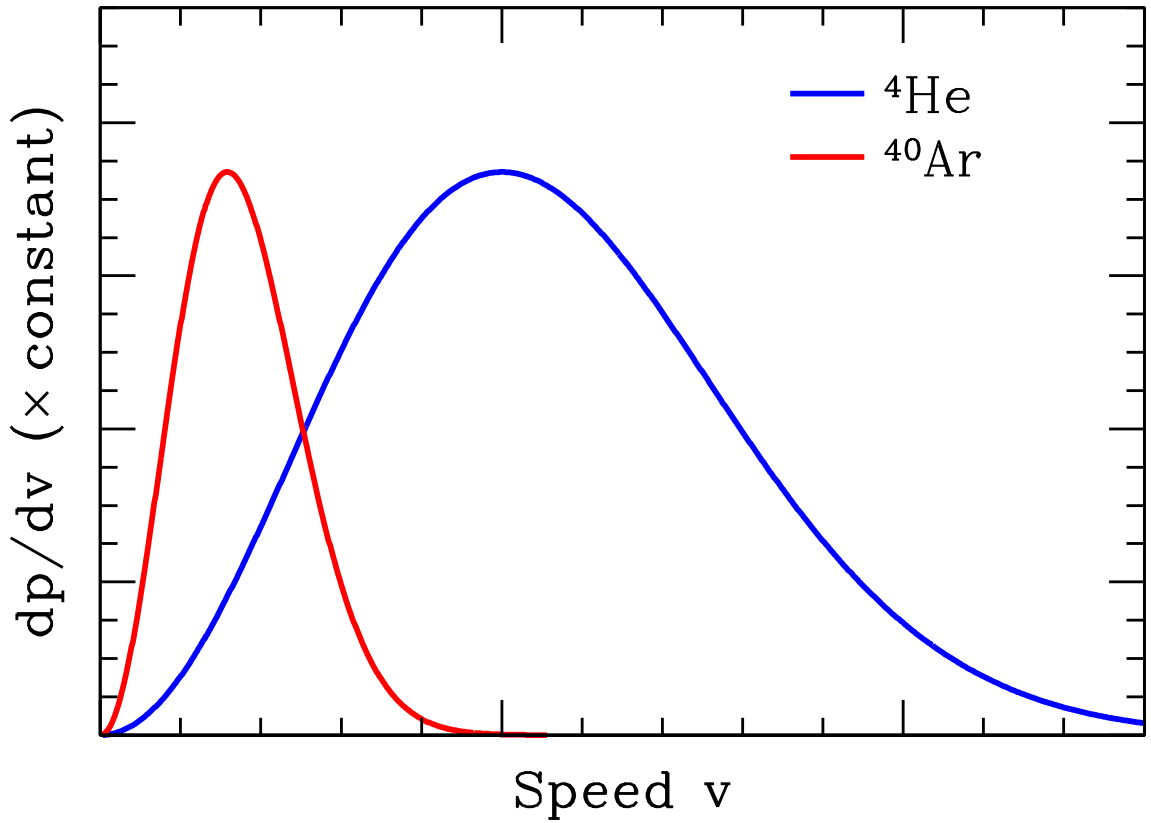
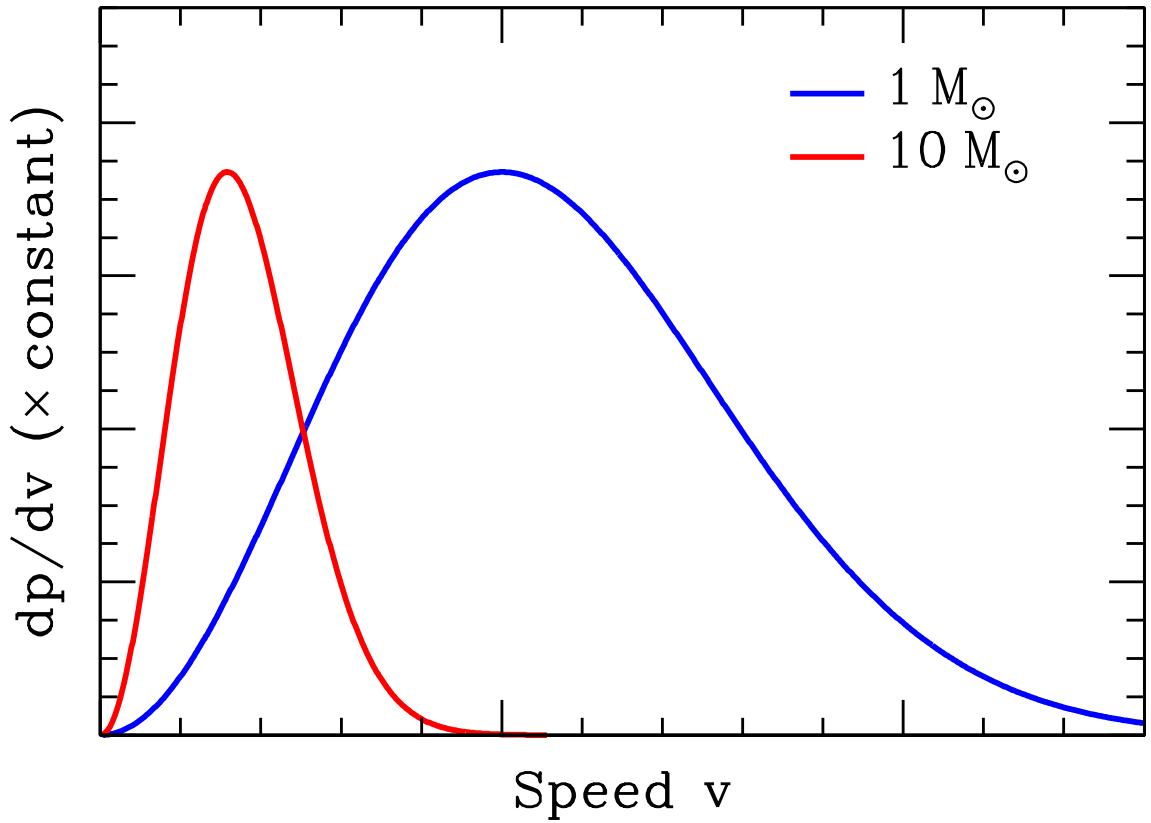
Equipartition: gas in a box



Equipartition: **stars** in a box



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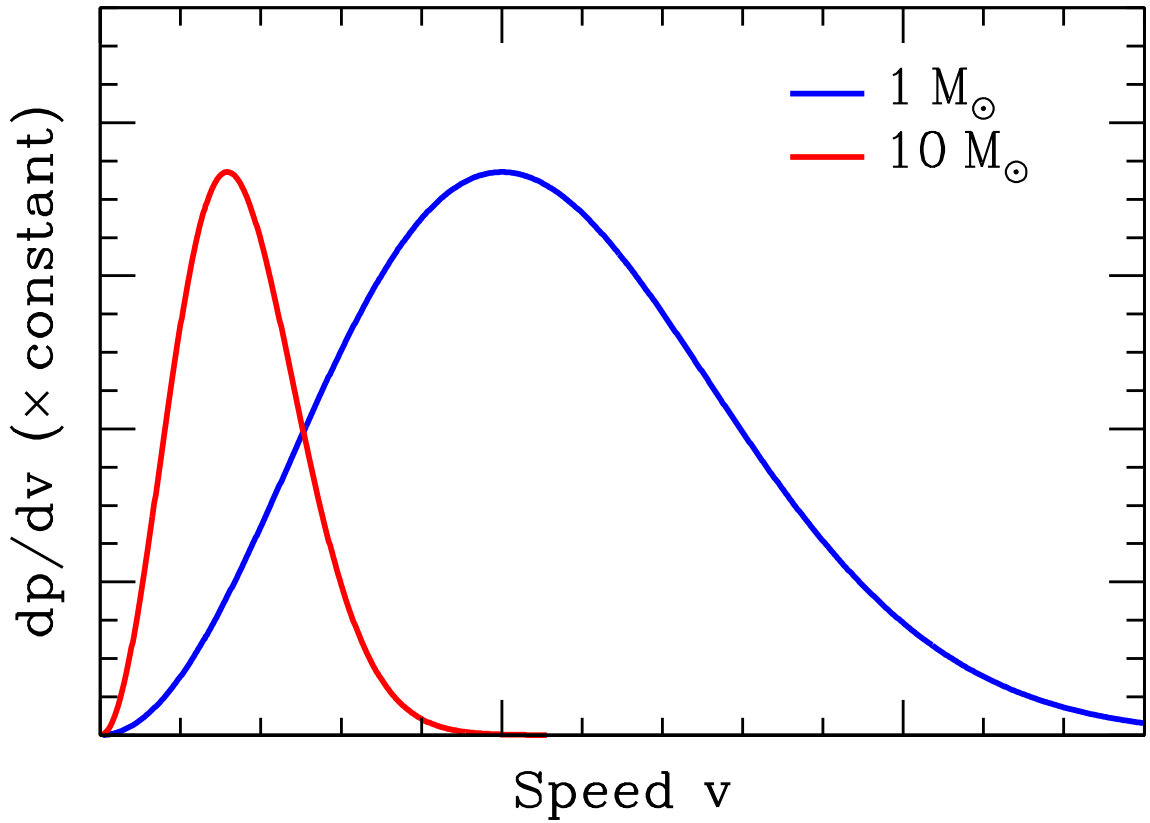
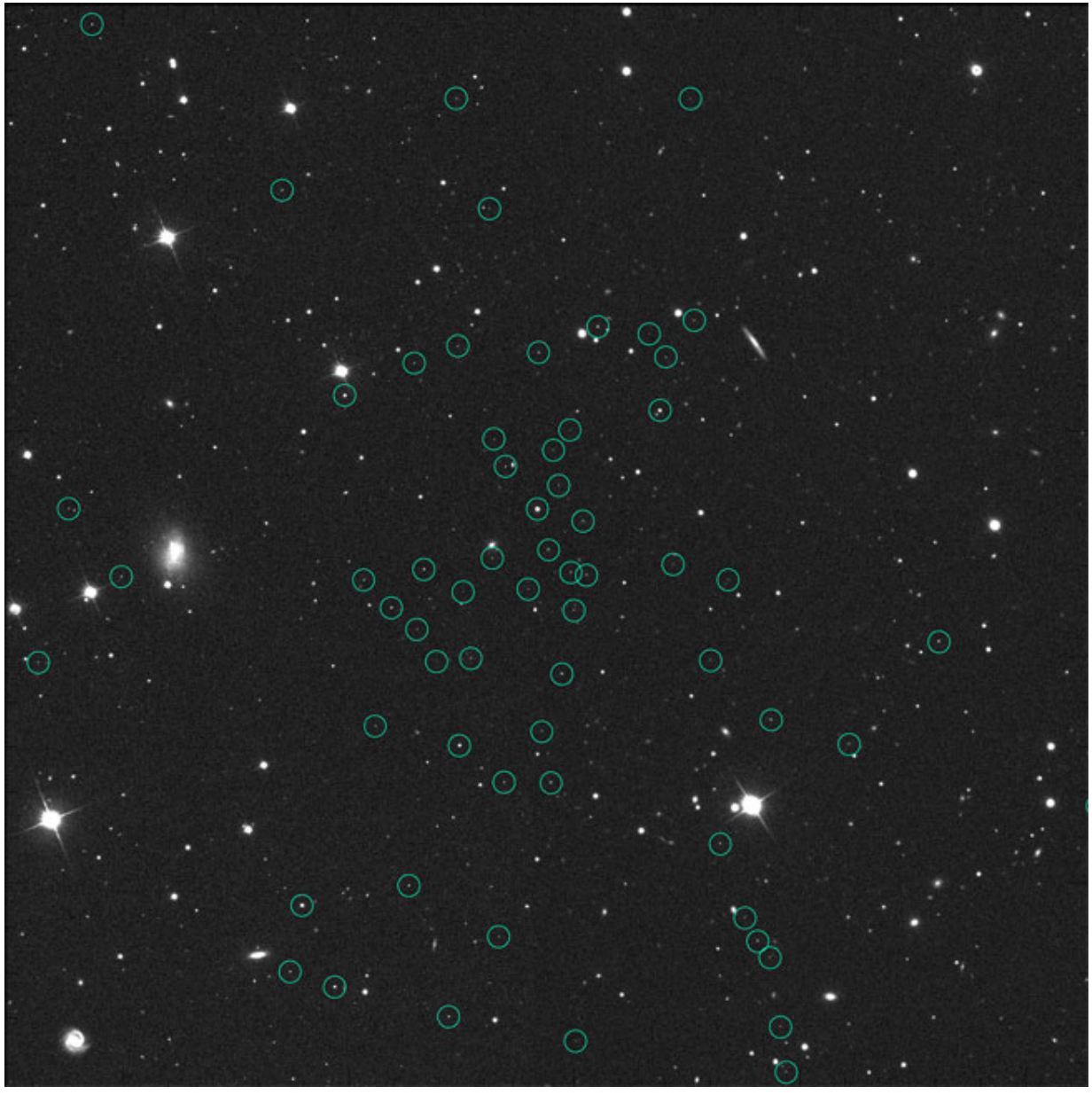


If both MACHOs $\gtrsim 1\,M_\odot$ and stars are present,
the equilibrium distribution of the stars will be puffier than that of the MACHOs.



Segue 1: Marla Geha

How transient is Segue 1?

Inject energy from a uniform MACHO background

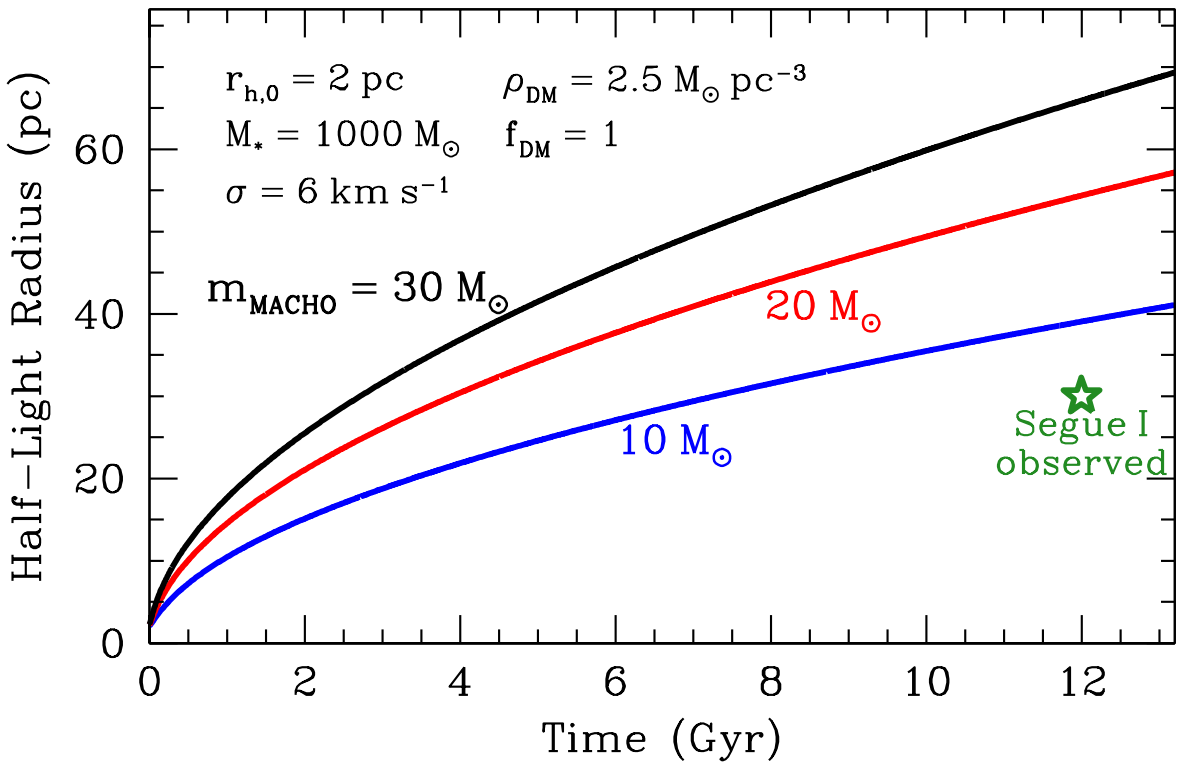
Implicit equation for half-light radius r_h:

$$\frac{dr_h}{dt} = \frac{4\sqrt{2}\pi G f_{DM} m_{MACHO}}{\sigma} \ln\Lambda \left(\alpha \frac{M_*}{\rho r_h^2} + 2\beta r_h \right)^{-1}$$

Constraining for **massive MACHOs** in **galaxies with low velocity-dispersions**

Example: measured properties of Segue I

- Conservatively assume stars started out in a compact cluster



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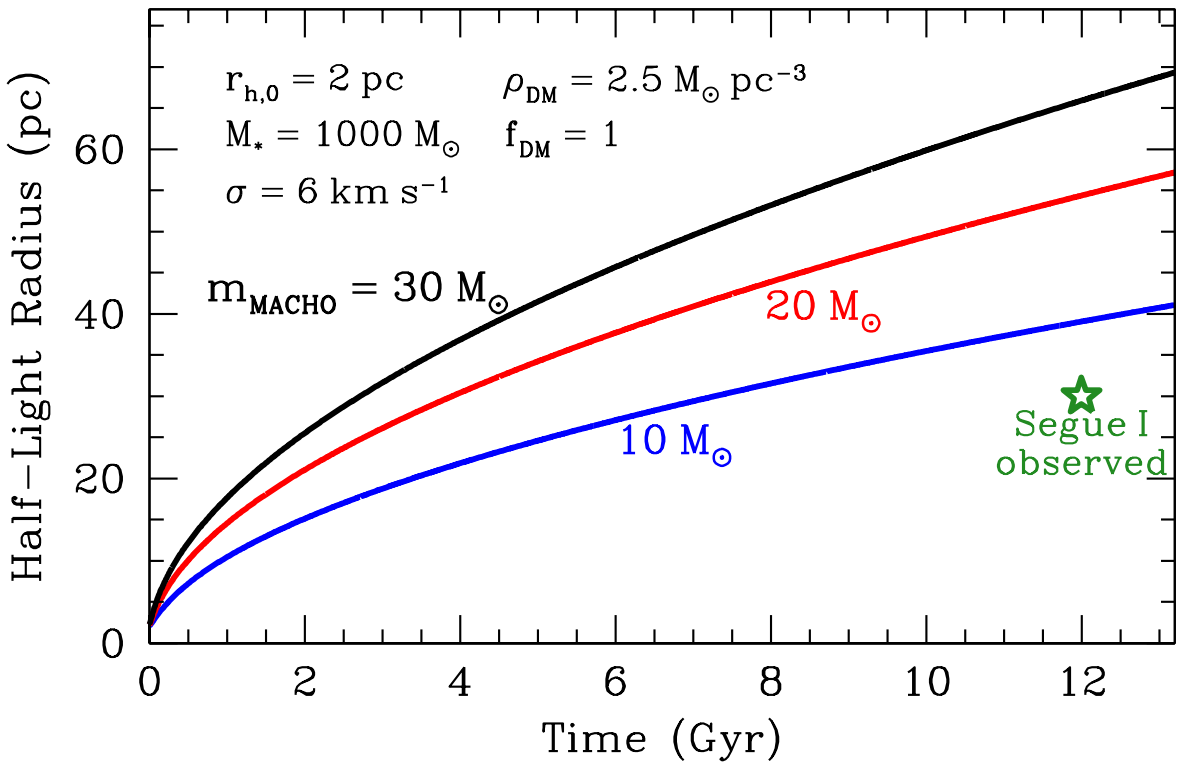
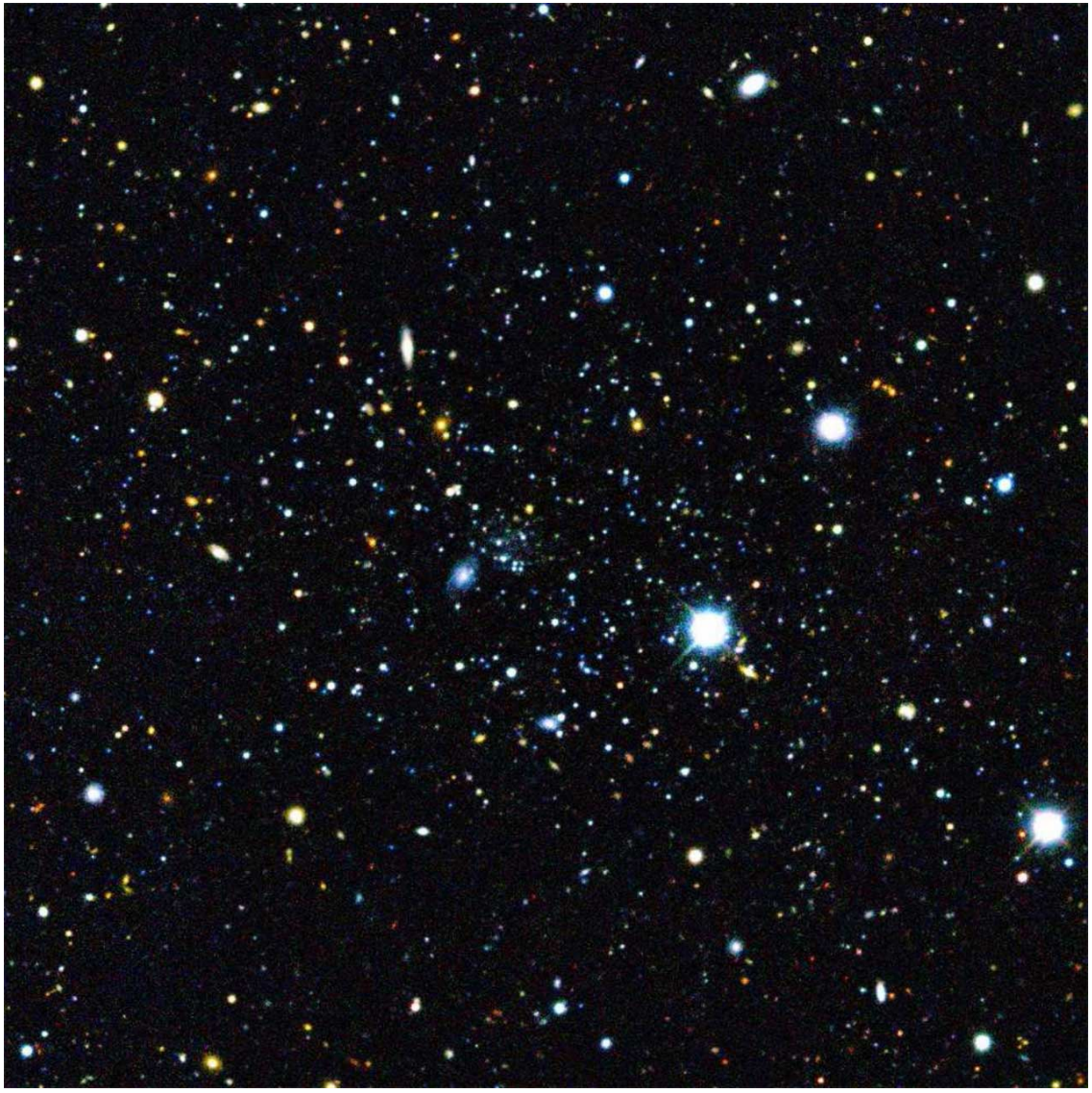


MACHO dark matter $\gtrsim 10\,M_\odot$ doesn't work

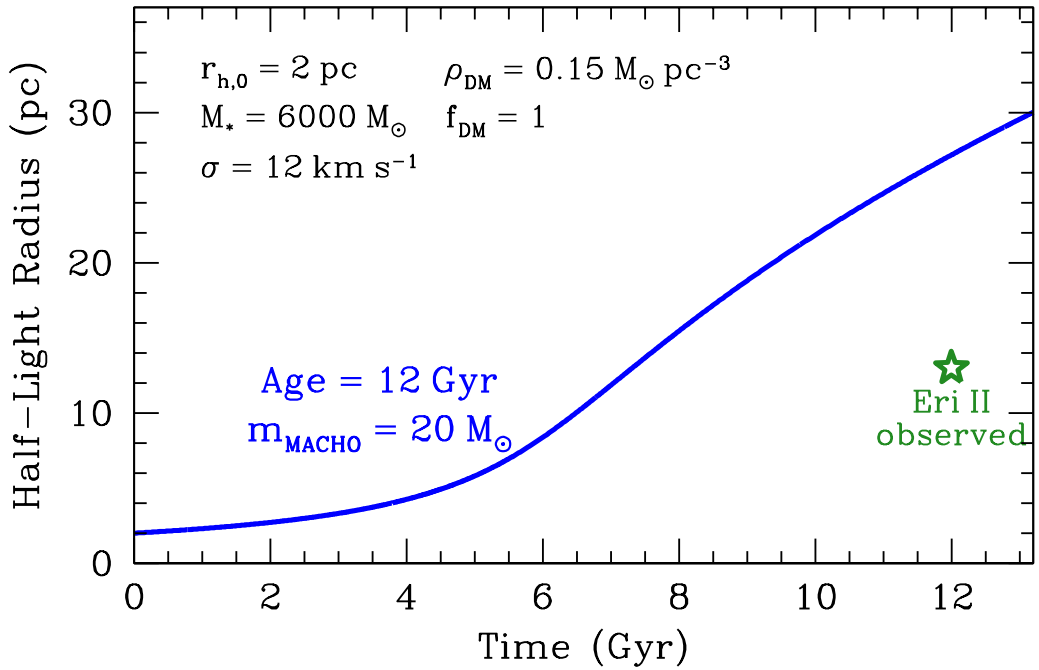
A low-mass, diffuse cluster in an ultra-faint dwarf



Eridanus II: Crnojević et al. (2016)

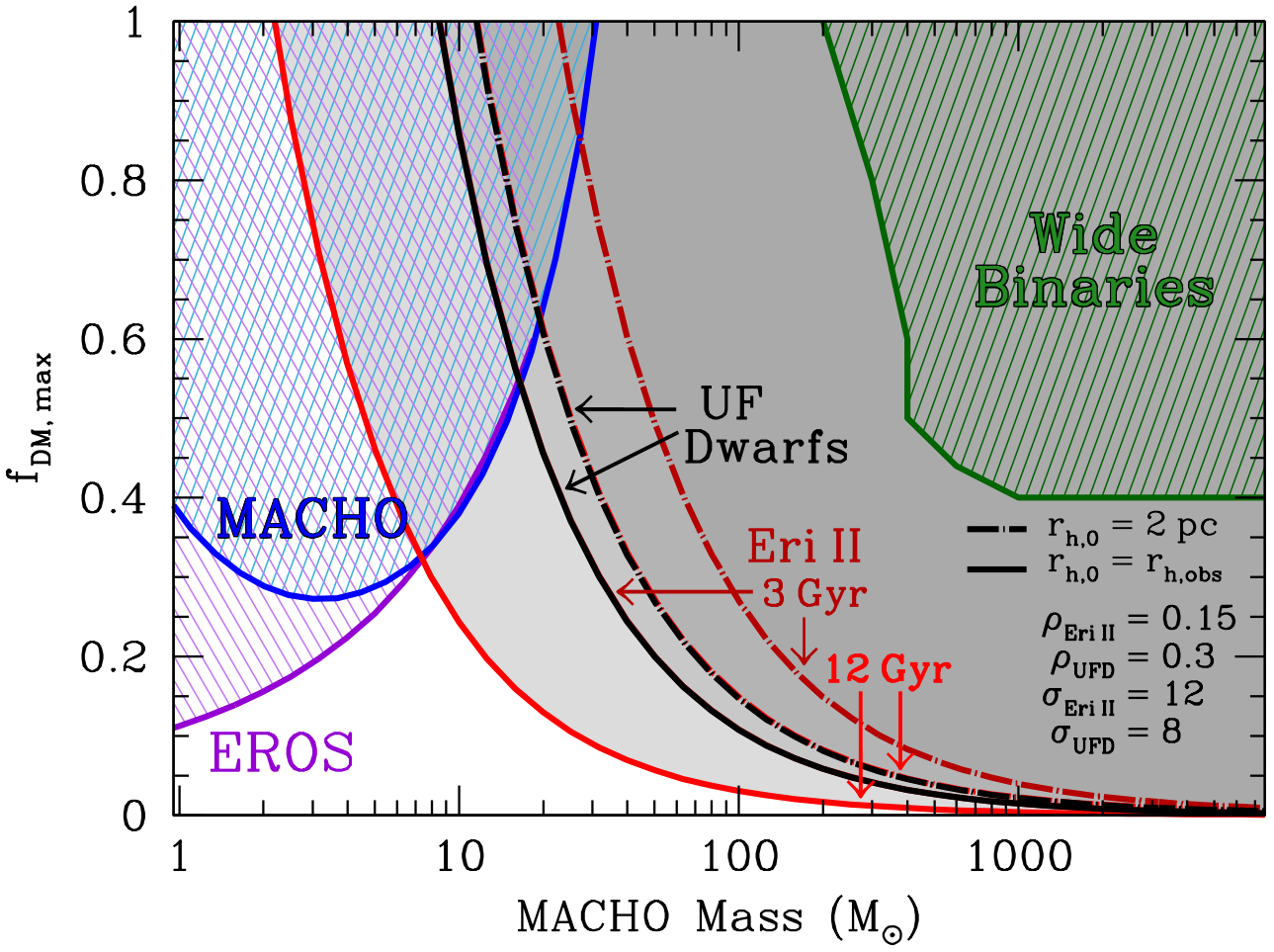
Eridani II's Cluster

- Half-light radius $\approx 13\,\mathrm{pc}$
- Luminosity $\approx 2000\,L_\odot$
- $\rho_{DM} \approx 0.15\,M_\odot\,\mathrm{pc}^{-3}$
- $\sigma \approx 12\,\mathrm{km\,s}^{-1}$
- Age uncertain (~3–12 Gyr)



r_h increases slowly until $\rho_{MACHO} \sim \rho_*$, then grows as $\sqrt{t}$

$r_h \approx 13\,\mathrm{pc}$ is very transient for almost any assumptions



Bottom line: Very hard to reconcile MACHO dark matter with compact ultra-faint dwarfs

Caveats for Eridani II:

- Intermediate-mass black hole (several $1000\,M_\odot$)??
- Chance alignment with galaxy center??
- Luck: initially compact cluster is now expanding

. . . but there are ∼10 other compact ultra-faint dwarfs

- Dynamical masses largely provided by single $\sim 10^{4-5}\,M_\odot$ black holes?

Recent work refines the picture

- Radius inflation $\sim t^{0.4}$ rather than $\sim t^{0.5}$ (Zhu+ 2018)
- Spectroscopic confirmation of Eri II cluster (Zoutendijk+ 2020)
- Faintest dwarfs remain incompatible with $\gtrsim$10 $M_\odot$ black holes as all of the dark matter (Stegmann+ 2020)

Basic conclusions remain:

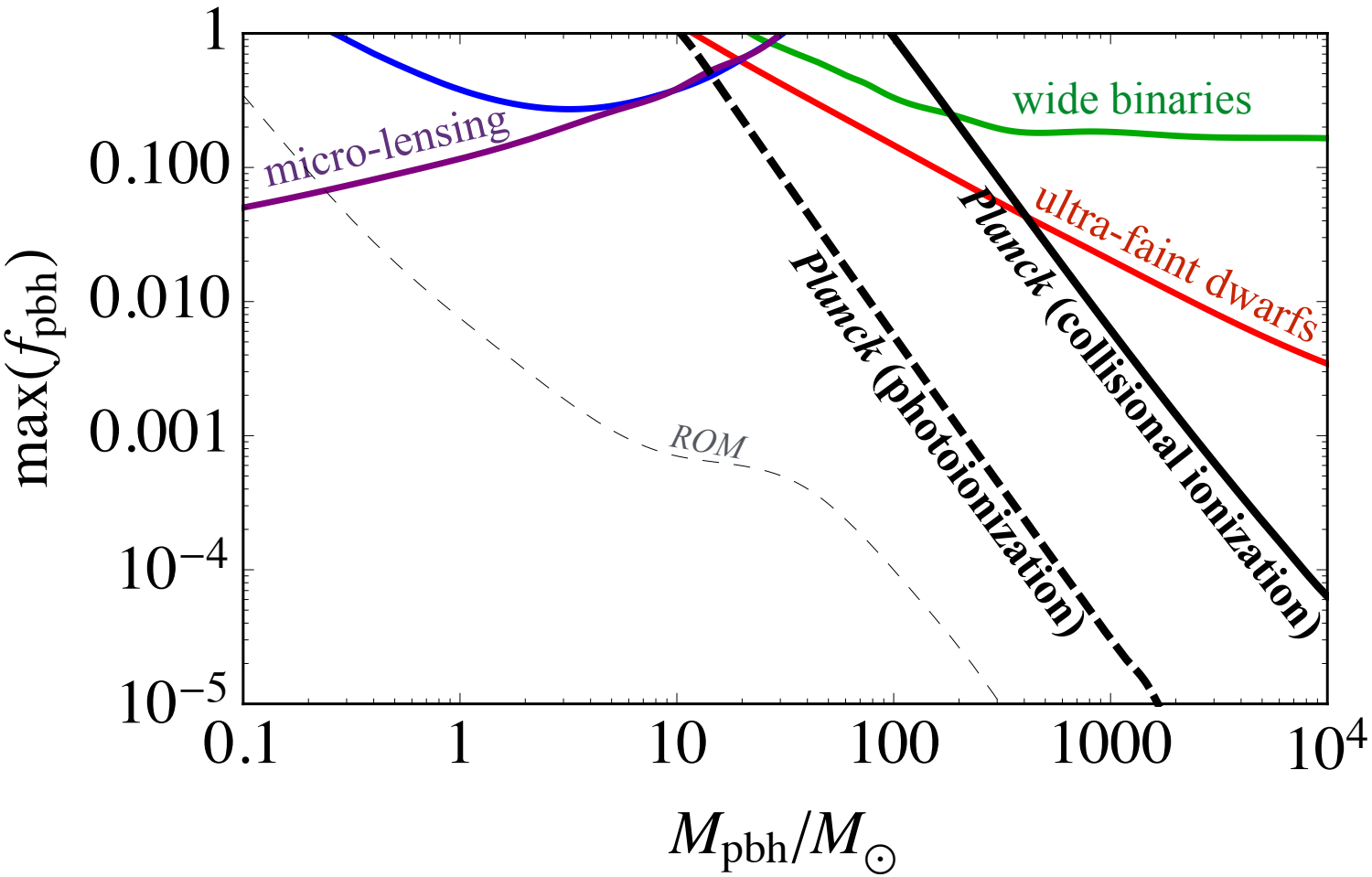
$\gtrsim$10 $M_\odot$ black holes are hard to reconcile with being all of the dark matter

Is dark matter primordial black holes?

- ✓ Black holes exist
- ✓ Scenario makes testable predictions

- Black hole mergers LIGO
- Microlensing Long history!
- CMB distortions Ali Haïmoud+Kamionkowski 2017
- Dynamical heating

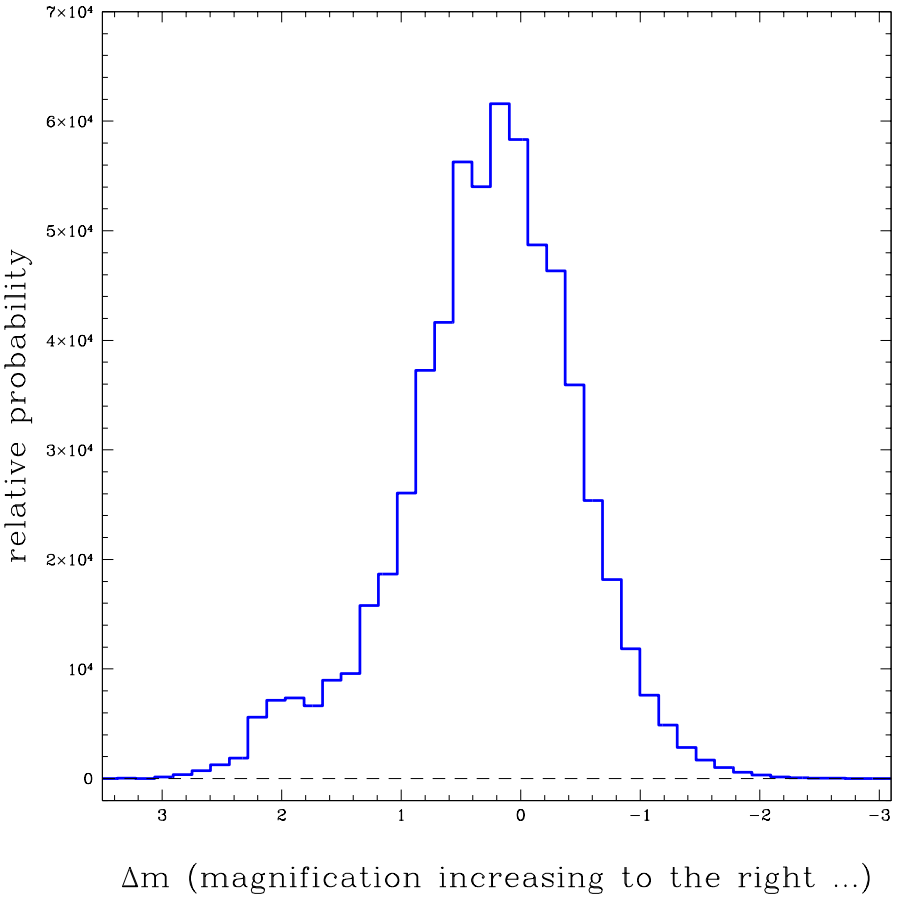
CMB Distortions

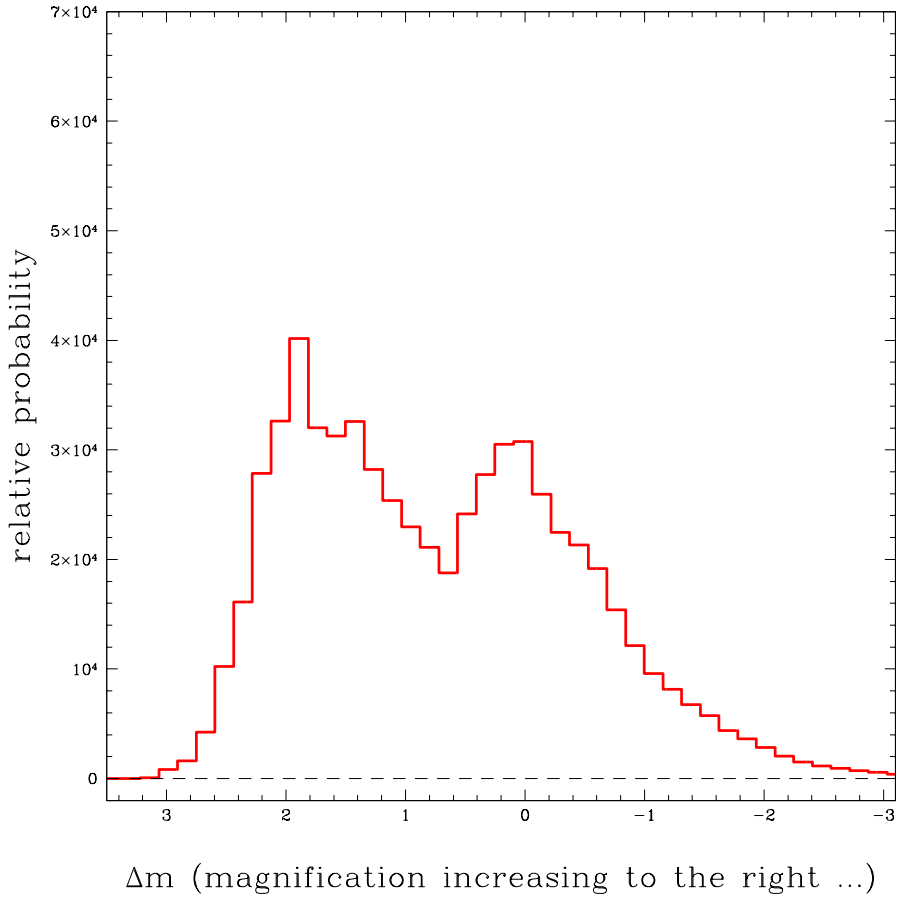


Ali Haïmoud & Kamionkowski (2017)

Microlensing

Statistical brightness variations in multiply-imaged quasars



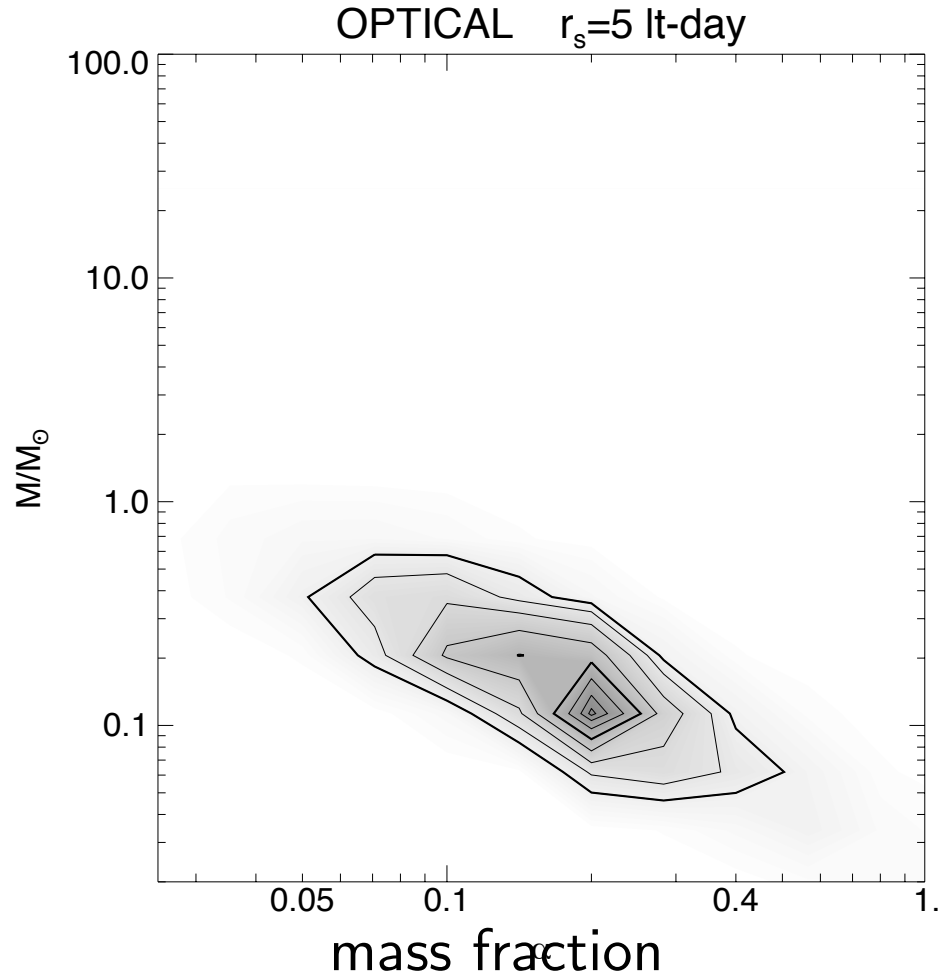


Left: all mass in 1 $M_\odot$ stars; Right: 80% in a smooth distribution

Schechter+ (2004)

Microlensing

Application to primordial black holes from 24 images:



Mediavilla+ (2017)

Microlensing

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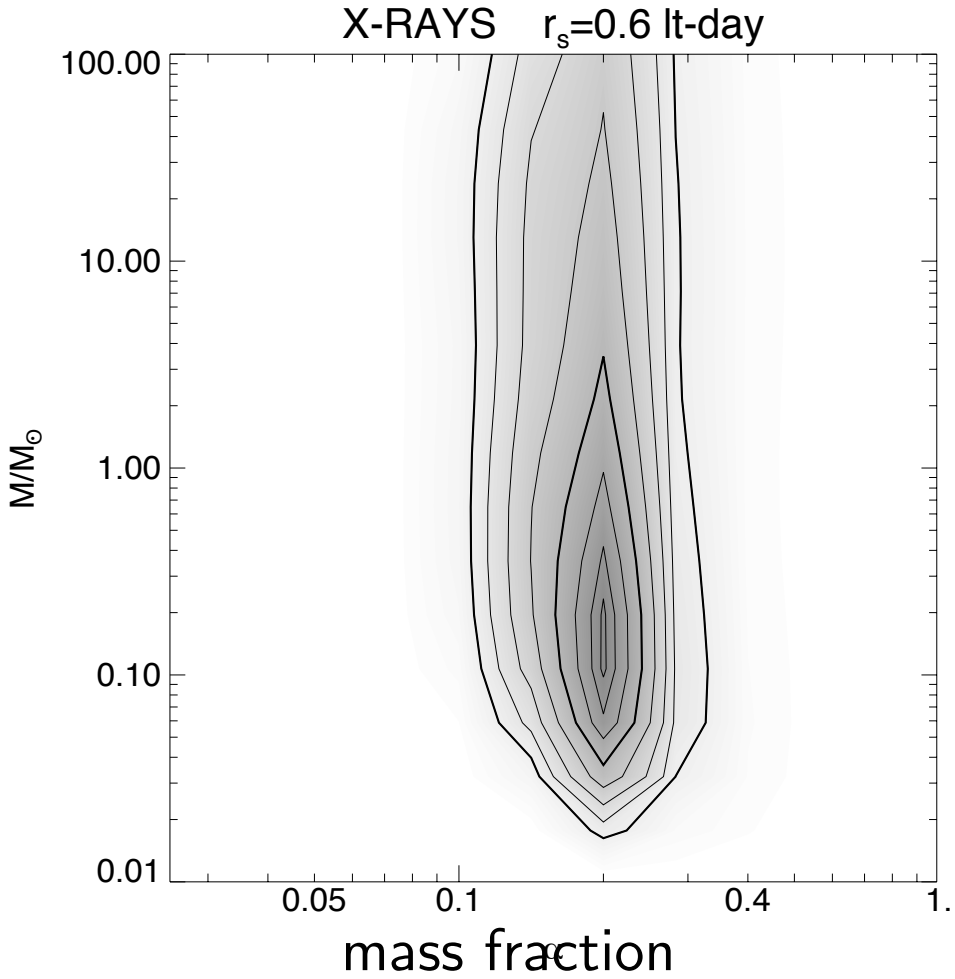

Mediavilla+ (2017)

Is dark matter primordial black holes?

- ✓ Black holes exist
- ✓ Scenario makes testable predictions

- Black hole mergers — Maybe?
- Microlensing — Not looking good
- CMB distortions — Questionable
- Dynamical heating — Not looking good

Caveat: There is still an ∼asteroid-mass window between Hawking evaporation and microlensing constraints . . .

Thank you!