Primordial Black Holes as DM

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The Question:

The recent observations of gravitational wave signals by LIGO revived interest in massive primordial black holes >10 solar mass as a possible dominant source of dark matter. If the current rate of LIGO observations persists, what new experiments and new observations could support or reject such a scenario?

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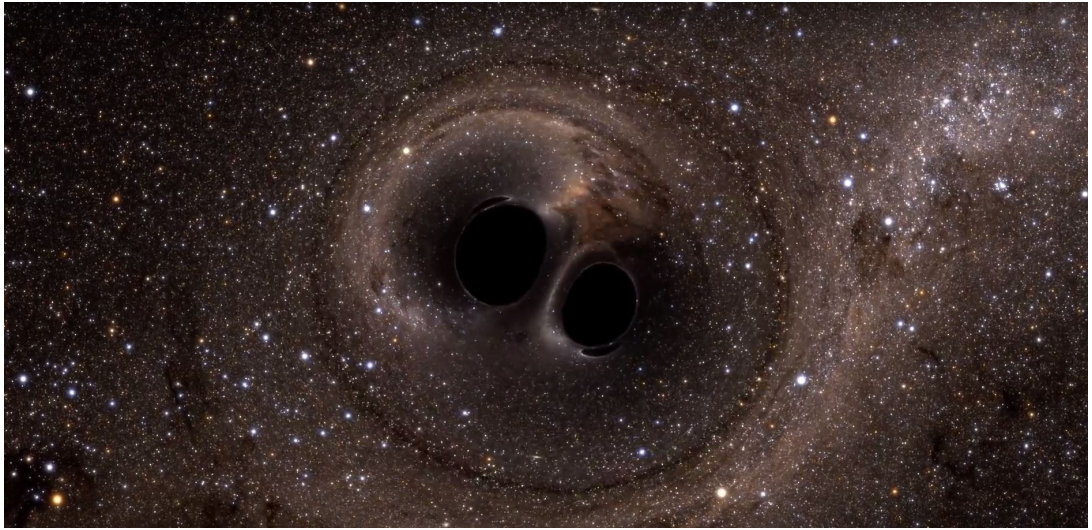
What are Primordial Black Holes?

- Not collapsed stars!
- Primordial BHs are very inhomogeneous perturbations which collapse after rentering the horizon (usually during radiation domination)
- Where do the perturbations come from?



Formation of Primordial Black Holes

Many options, but none stand out…

- Modified inflation: inflection point, mulitple fields, ect…
- Contracting universes
- Non-thermal histories (extra phase transitions)
- ect

See for example 1606.07361,1612.02529, 1610.03763, 1704.03464, 1611.06130, 1702.03901, 1703.04825, 1606.00206, 1705.06225, 0609.04724, 0609.02556...

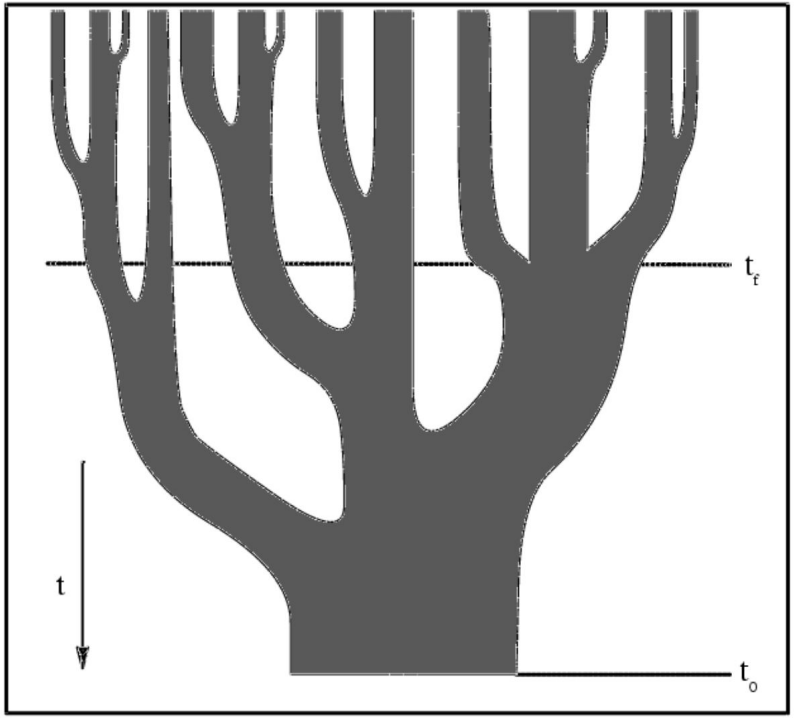
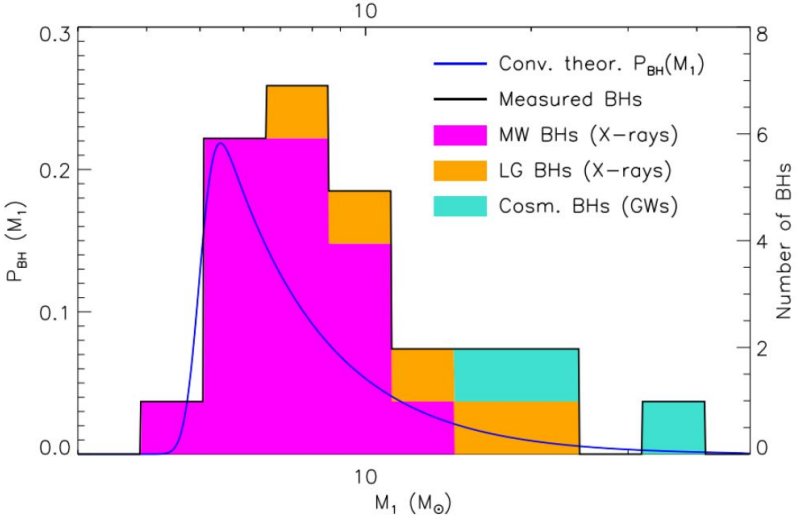
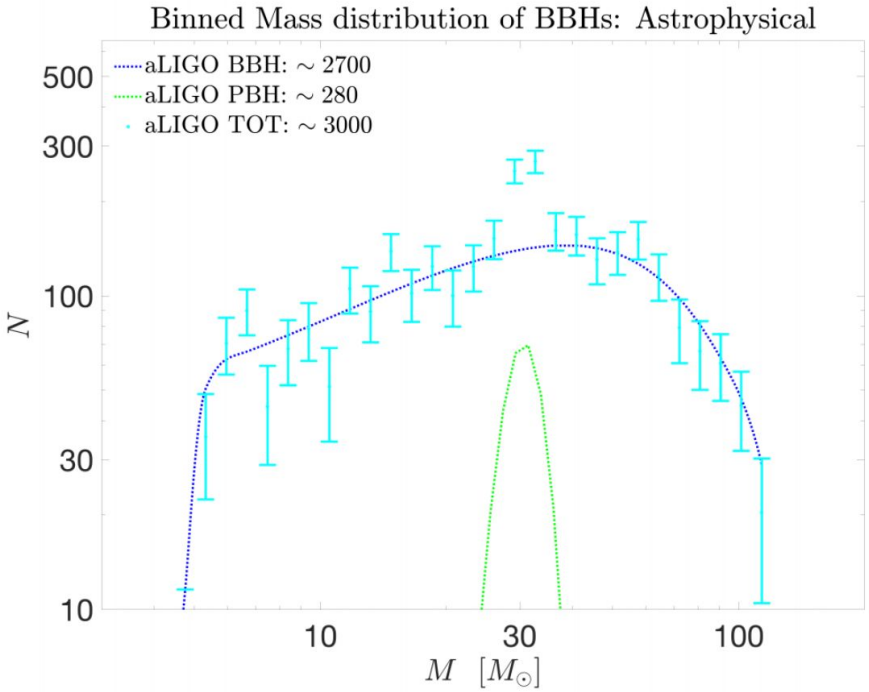


Figure 6. A schematic representation of a "merger tree" depicting the growth of a halo as the result of a series of mergers. Time increases from top to bottom in this figure and the widths of the branches of the tree represent the masses of the individual parent halos. Slicing through the tree horizontally gives the distribution of masses in the parent halos at a given time. The present time t_0 and the formation time t_f are marked by horizontal lines, where the formation time is defined as the time at which a parent halo containing in excess of half of the mass of the final halo was first created.

Astrophysical vs Primordial

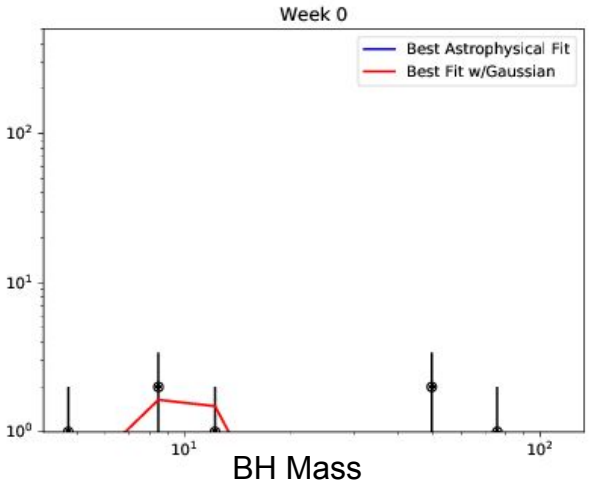
Don't know the primordial mass spectra…
but we at least have an educated guess
for the astrophysical one

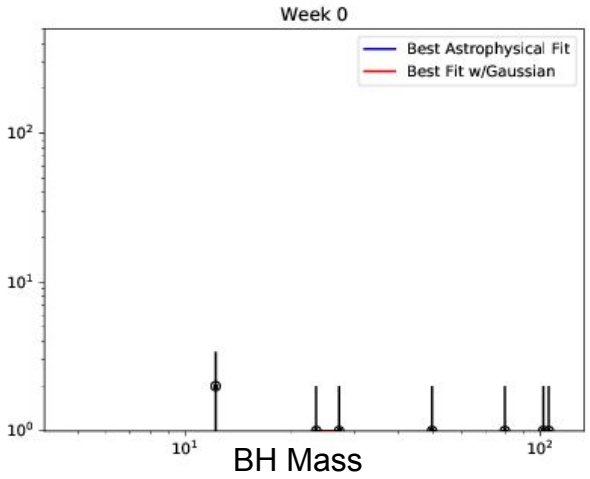


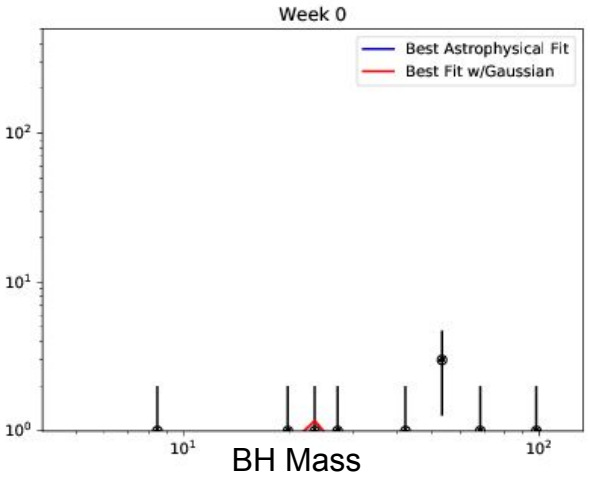


E. Kovetz et al, arXiv:1611.01157

Projected Advanced LIGO O3 Sensitivity







DM is 100% PBHs
Time to detection: >1 year

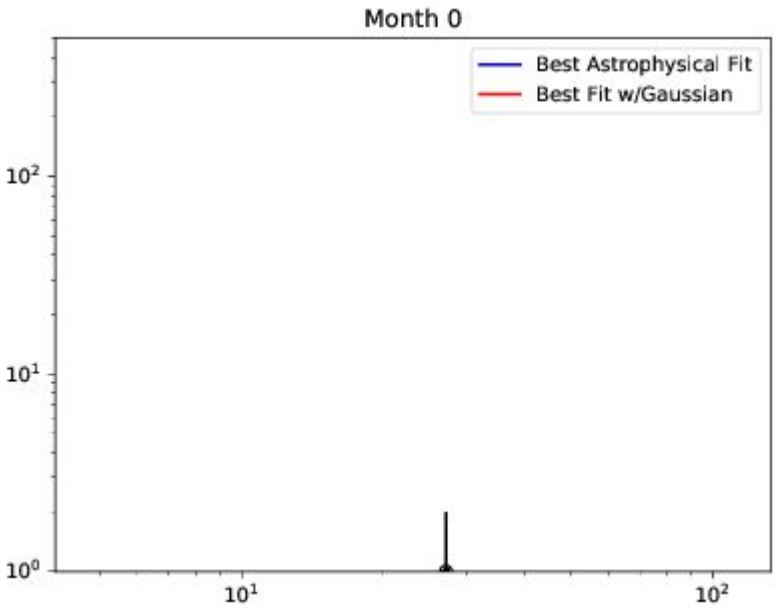
DM is 50% PBHs
Time to detection: >5 years

DM is 10% PBHs
Time to detection: >>10 years

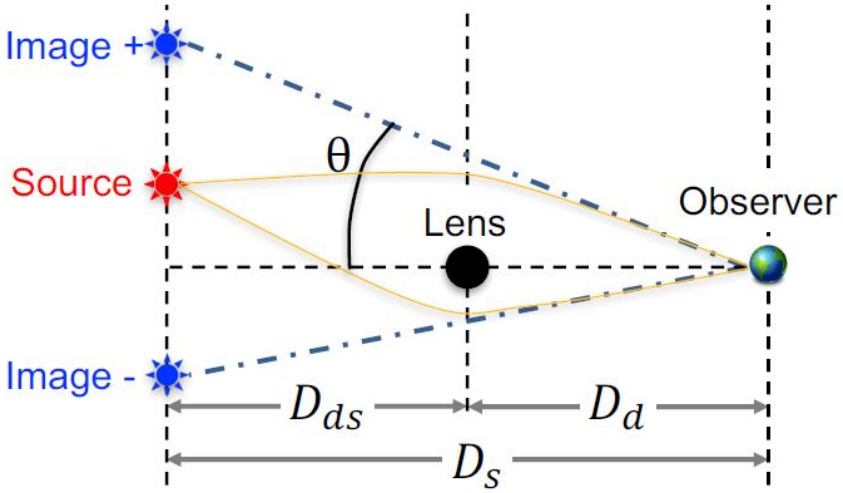
Projected ALIGO O1 Sensitivity

Assumption: DM is 100% PBHs

LIGO time to reach detection: ?



Microlensing



Dawson 2017

$$t_e \equiv \frac{D_d \theta_e}{v_\perp}$$

$$\theta_e = \sqrt{\frac{4GM}{c^2}\frac{D_{ds}}{D_d D_s}}$$

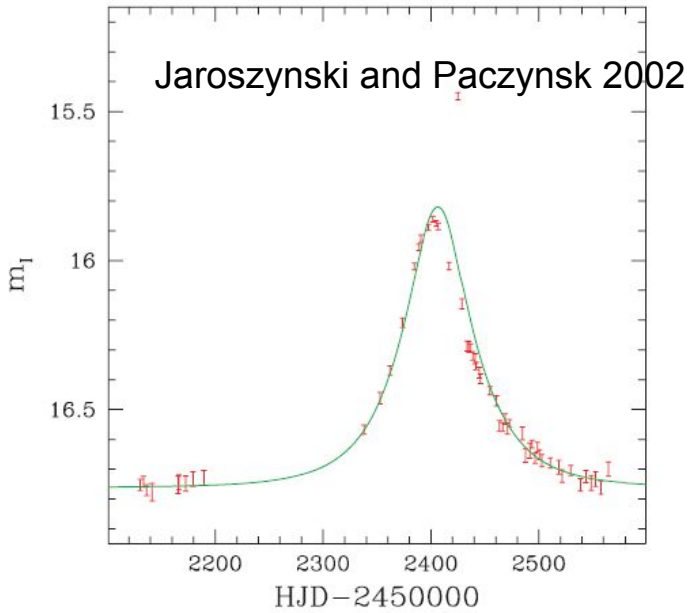
Sources:

Galactic bulge:

Ds=8kpc, v⊥=200m/s

LMC:

Ds=50kpc, v⊥=200m/s



Microlensing

Expected events

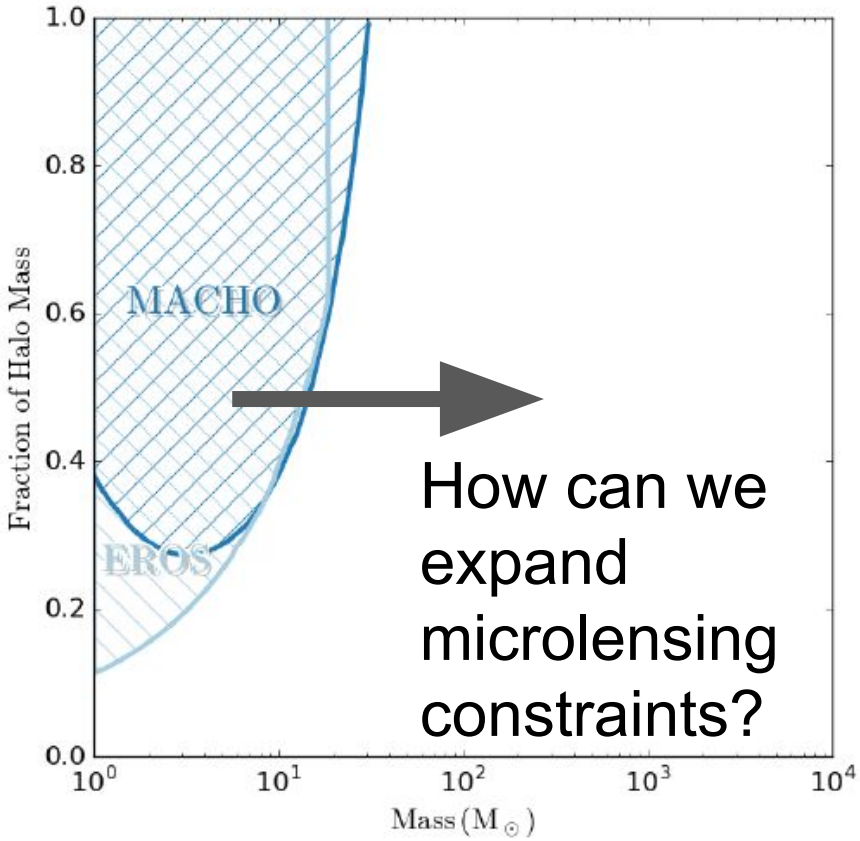
monitored stars

Survey timescale

$$N = \frac{2}{\pi} n \tau \frac{\delta t}{t_o}$$

Optical depth

Event timescale



How can we expand microlensing constraints?

Dawson 2017

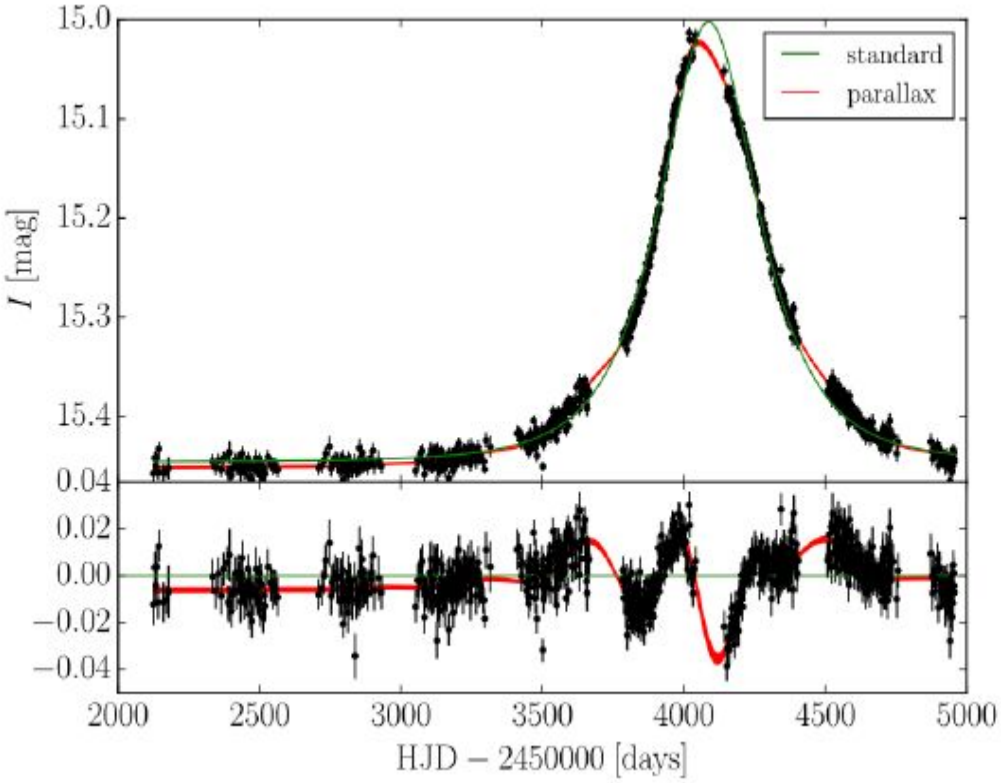
Microlensing

Parallax: detect event in months instead of years

Better telescopes: Resolving multiple images, break degeneracy

Astrometric follow-up: measure centroid shift to break degeneracy

Ogle III 9.3M⊙ Black Hole



Wyrzkowski et al. 2016

PBHs shine on CMB

The effects:

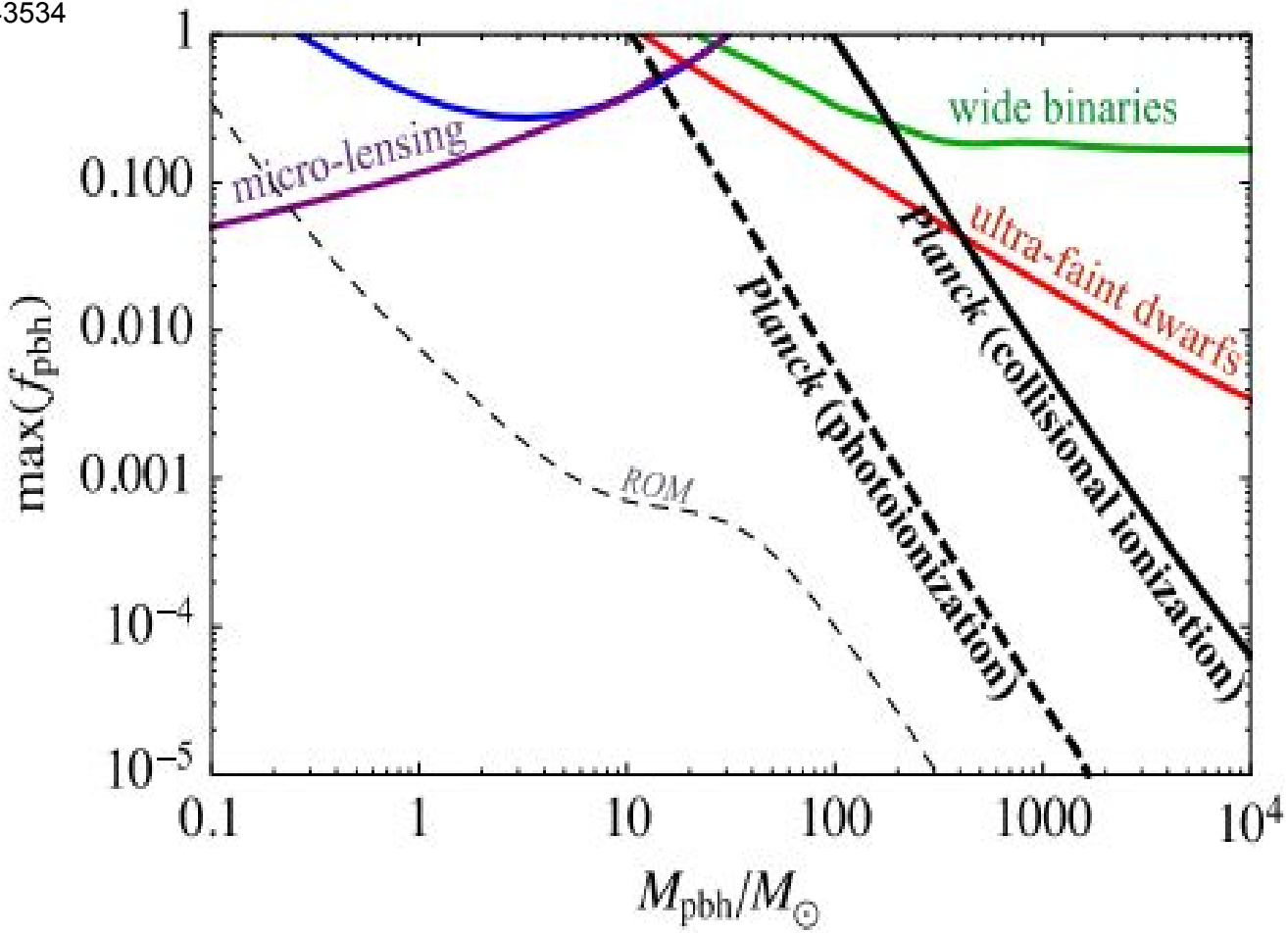
- Energy injection →
  - Recombination is delayed
  - Shift in the acoustic peaks
  - Deviations from blackbody spectrum

- Additional Thomson scattering →
  - Enhanced power in the polarization spectrum
  - Damping of temperature anisotropies

Warning: a lot of theory uncertainties ahead!

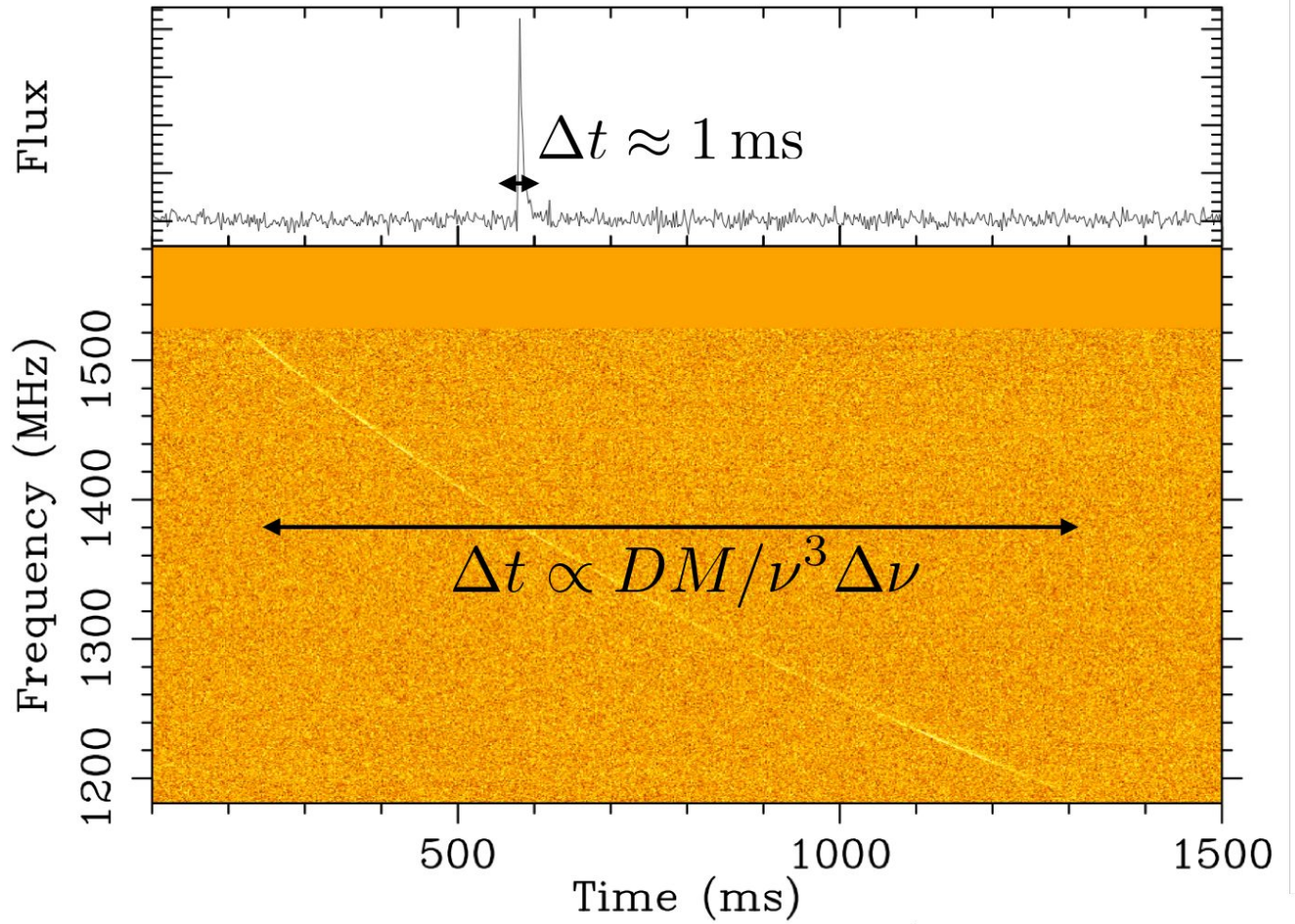
CMB Constraints

Phy. Rev. D **95**, 043534 (2017)

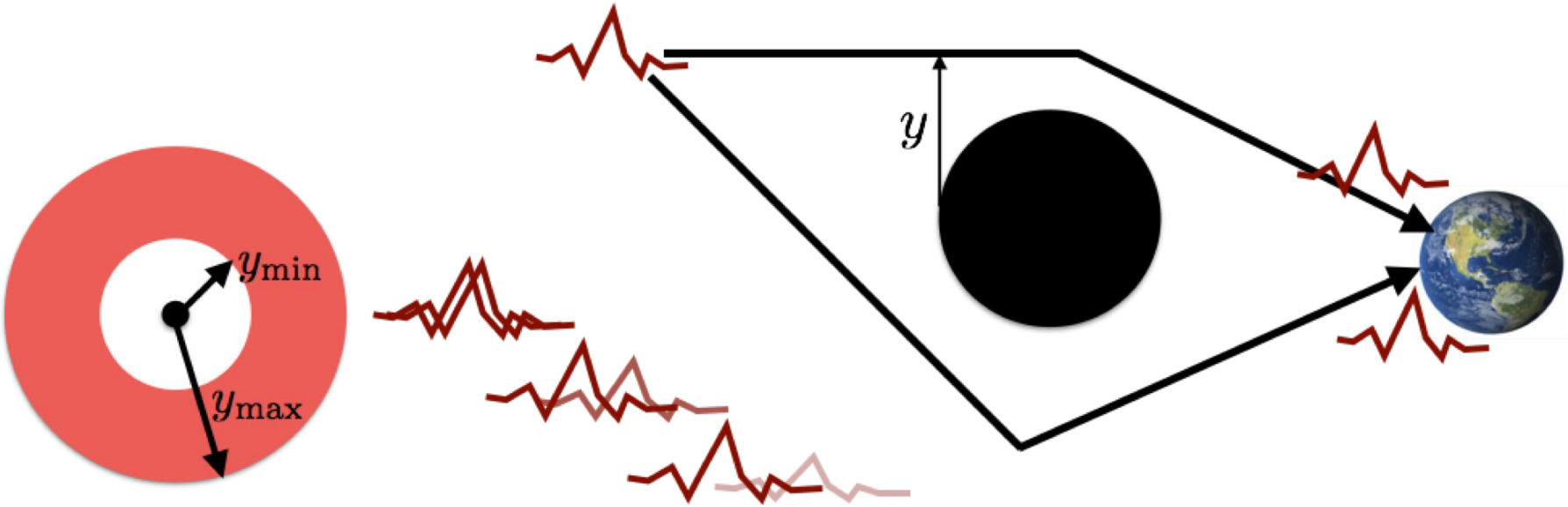


arxiv:1707.04206

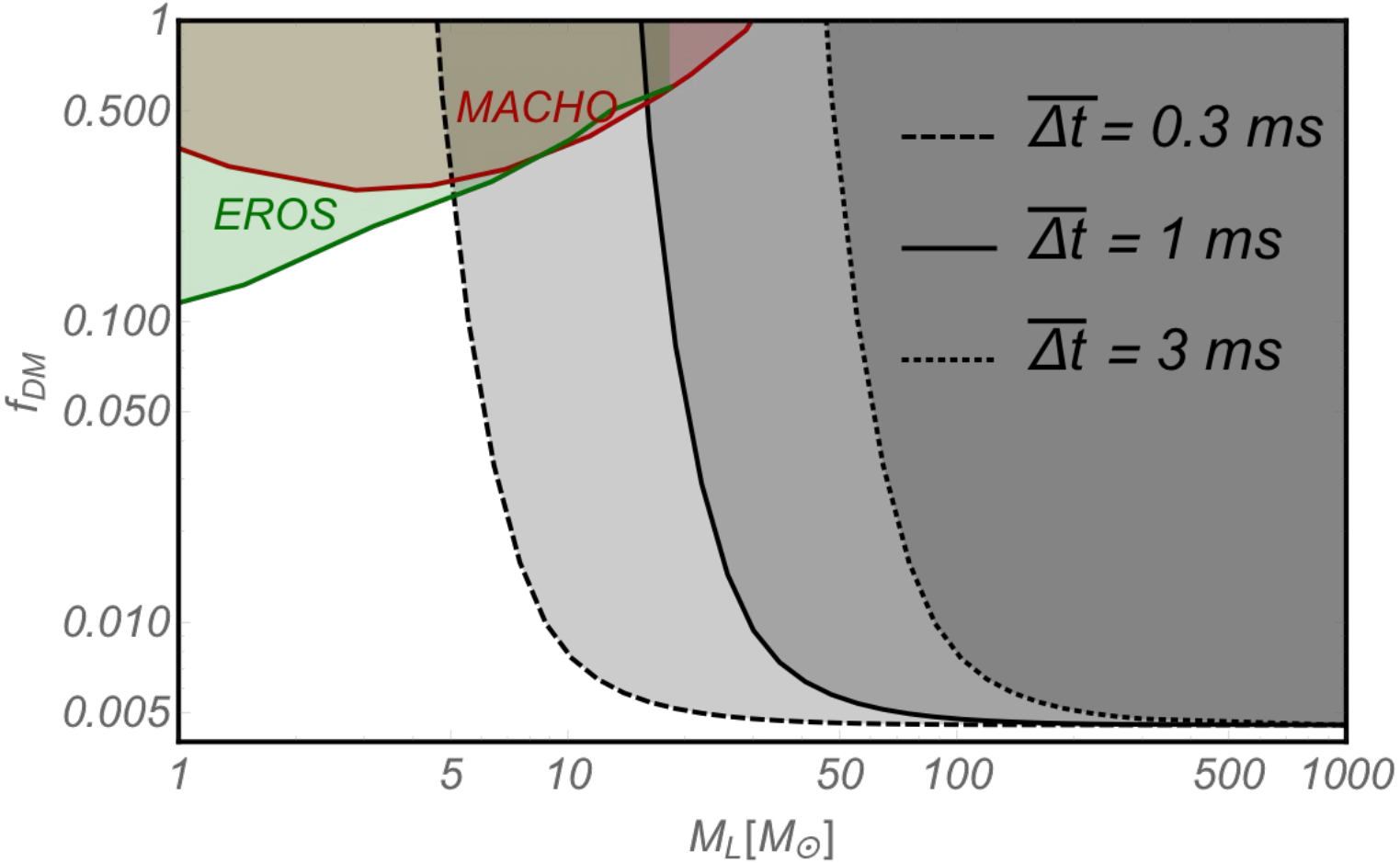
Fast Radio Bursts



Lensed FRBs



If no lensed FRBs are detected out of 1000 FRBs arXiv: 1605.00008



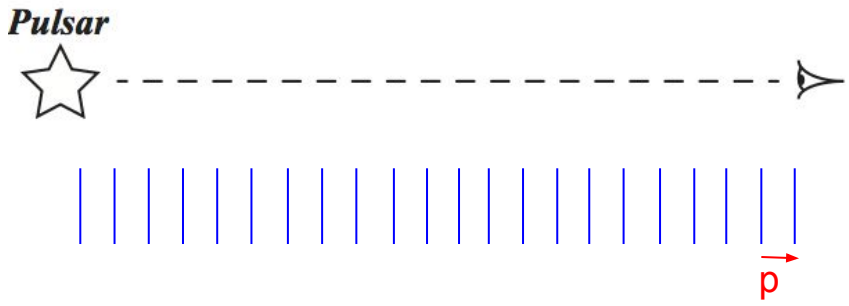
Pulsar Timing Constraints

From Non-Detection of Shapiro Time Delay

Shapiro time delay

$$ds^2 = -\left(1 + 2\frac{\phi}{c^2}\right)c^2 dt^2 + \left(1 - 2\frac{\phi}{c^2}\right)d\mathbf{x}^2$$

Geometric time delay

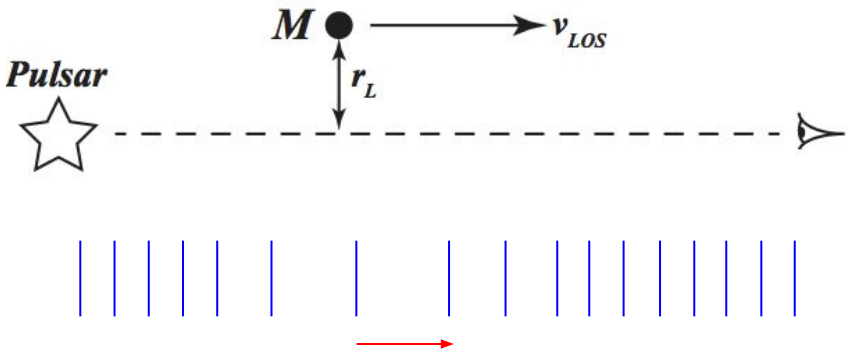


Degeneracies in

1. Period of the pulsar P
2. Spin down rate dP/dt

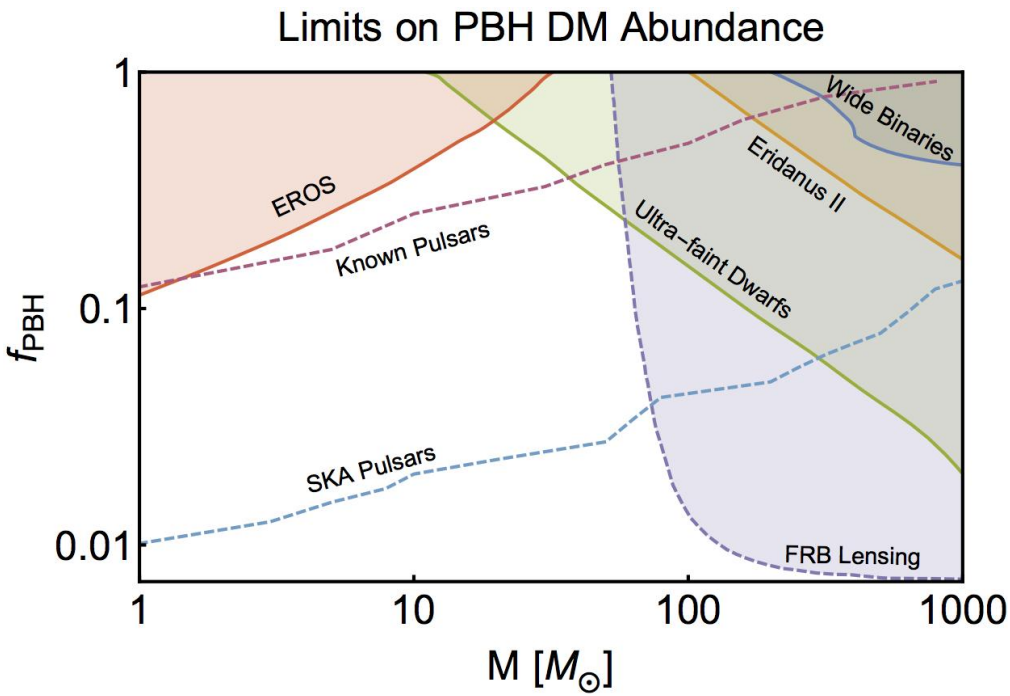
Measure the third-order Shapiro time delay:

$$\Delta t_{\text{Shapiro}} \equiv t(n = T/P) - t(n = 0) \approx \frac{4GMv_r^3T^3}{3c^3r_{L,0}^3} + \ldots$$



Longer time-of-flight

Constraints from Non-Detection of Shapiro Time Delay



Schutz & Lui,
Phys. Rev. D**95**, 023002 (2017)

- Need T = 30 years observation
- Need timing residuals $\Delta t \gtrsim 50$ ns
- Known Pulsars:

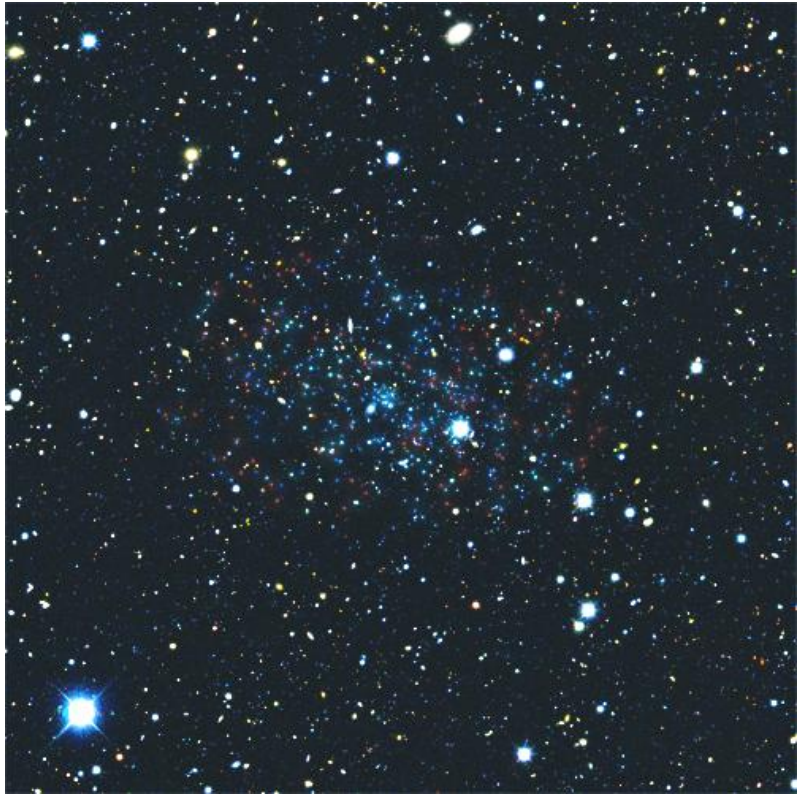
  143 distinct LOS stable MSPs
- Square Kilometer Array (SKA):

  ~ 2000 MSPs

Shooting Stars

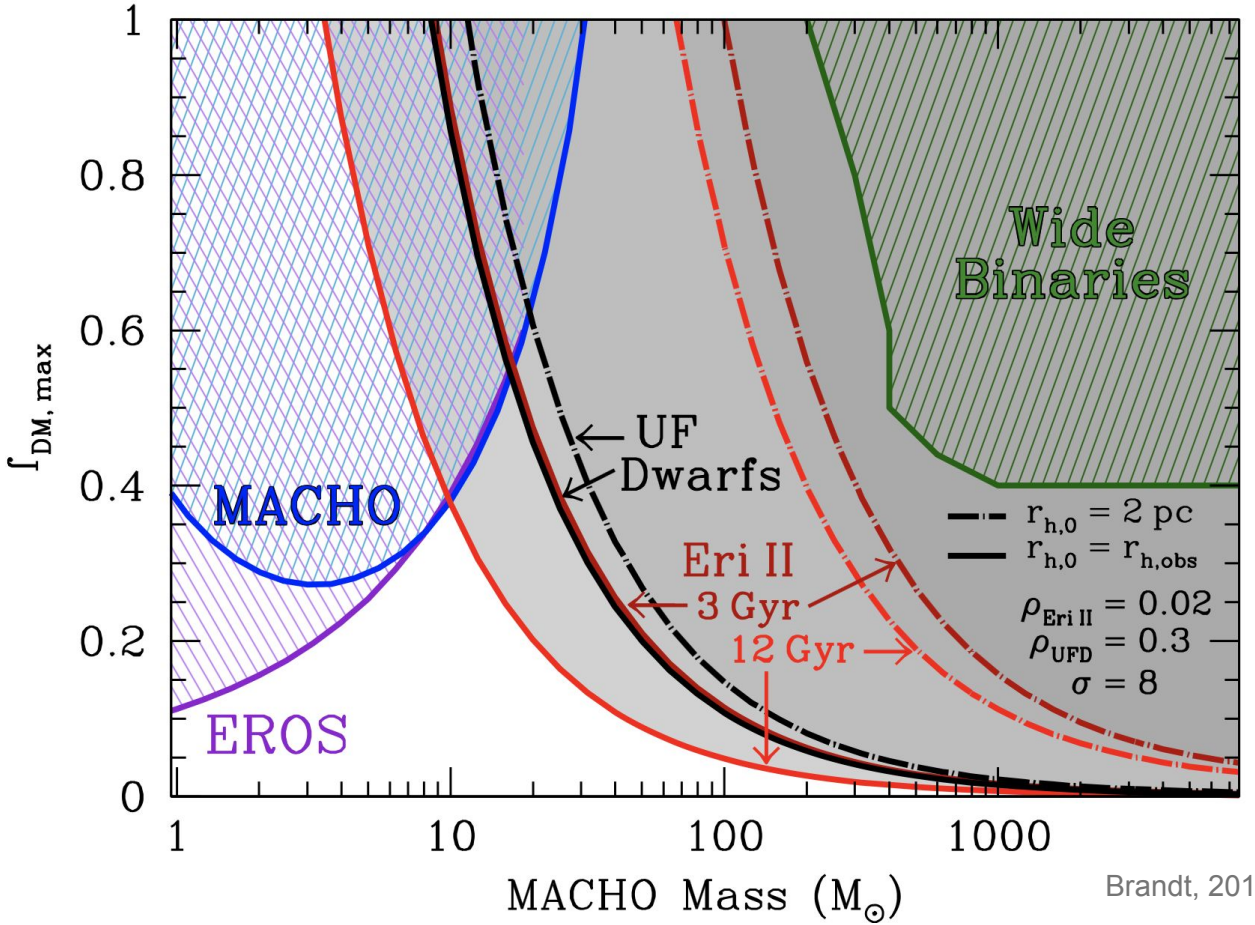
Expect: Dynamical Heating

Stellar cluster at core puffed up

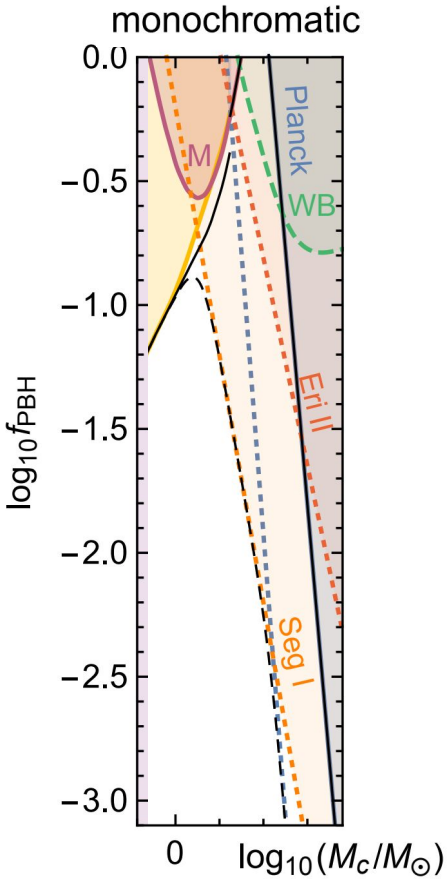


V. Belokurov & S. Koposov

Dwarf Galaxy Constraints



Brandt, 2016



Carr *et al.*, 2017

Ambitious astrophysics: accretion in galaxies

Ambitious astrophysics: accretion in galaxies

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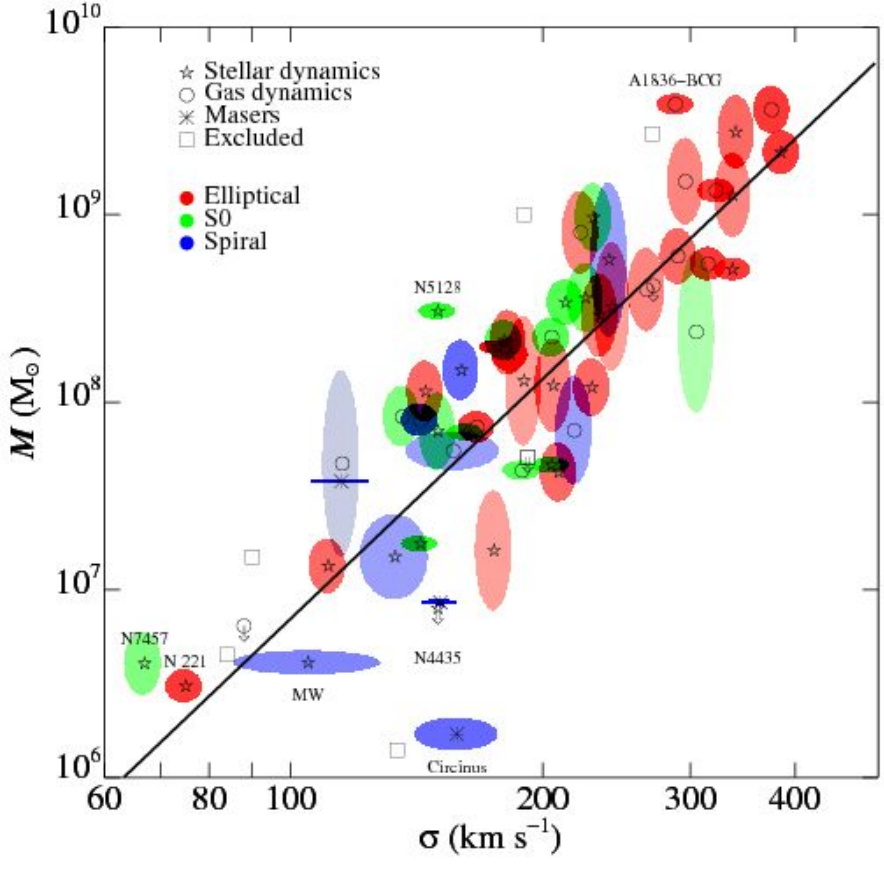


Gultekin (2009) [0912.3898]

Thanks NASA!

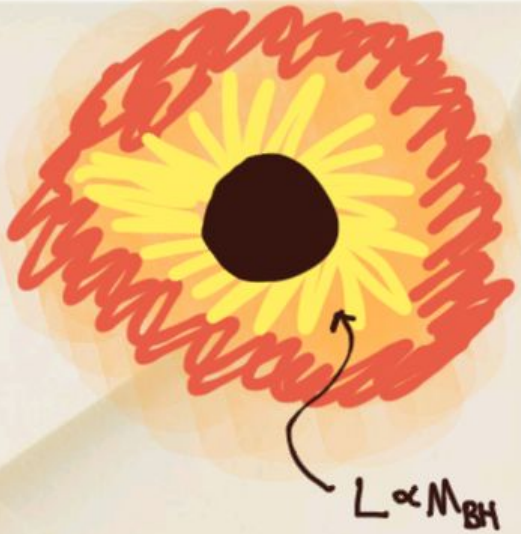
[See e.g. King 2003]

Outflow velocity: $v^2 \approx \frac{GL}{2 f_g \sigma^2 c}$

Suppose $L \sim L_{Edd} \propto GM_{BH}$

Accretion halts when $v \sim \sigma$ [gas blown away]

$$\sigma^2 \sim \frac{GM_{BH}}{2 f_g \sigma^2 c}$$



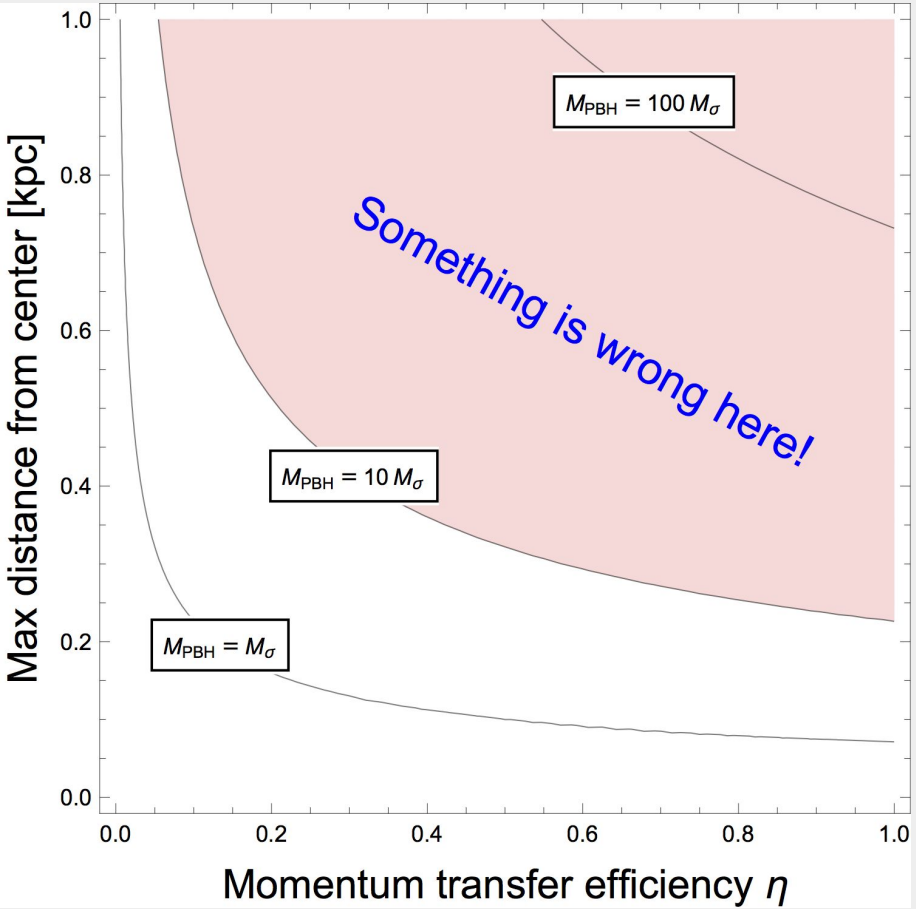
Central SMBH only

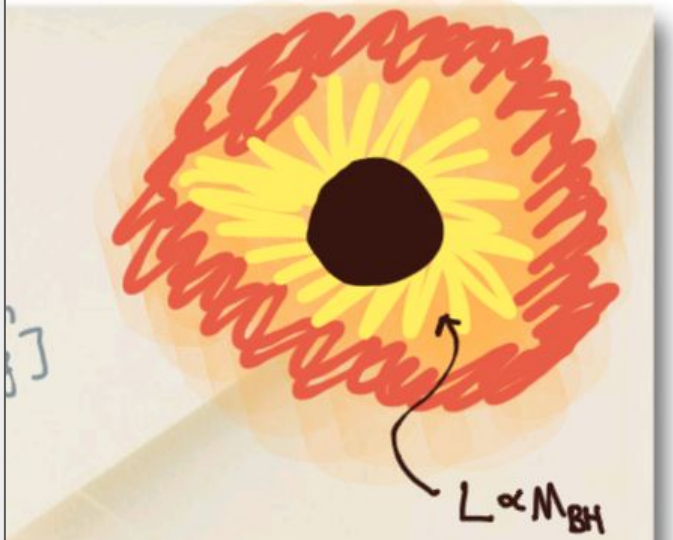
$$M_{SMBH} = \frac{\sigma^4 f_g}{2\pi G^2 \kappa}$$

SMBH + PBH DM

Assume near-center BH contribute to L with efficiency η

$$M_{BH}^{eff} = M_{SMBH} + \eta M_{PBH}(R)$$

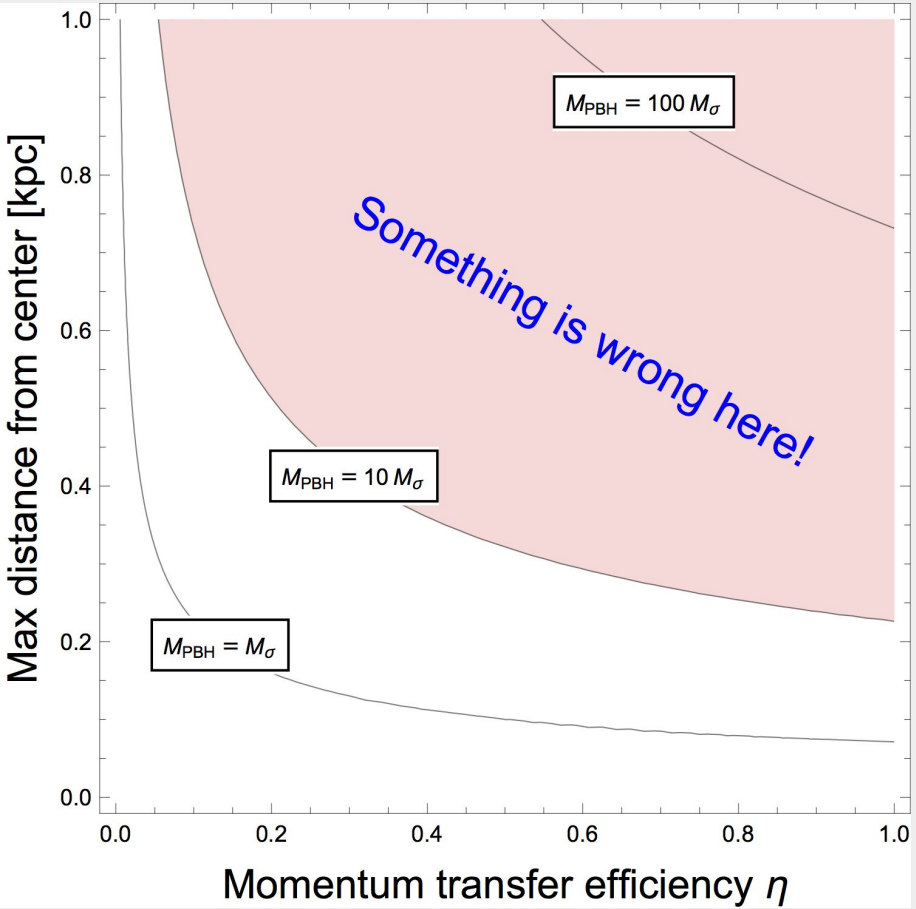


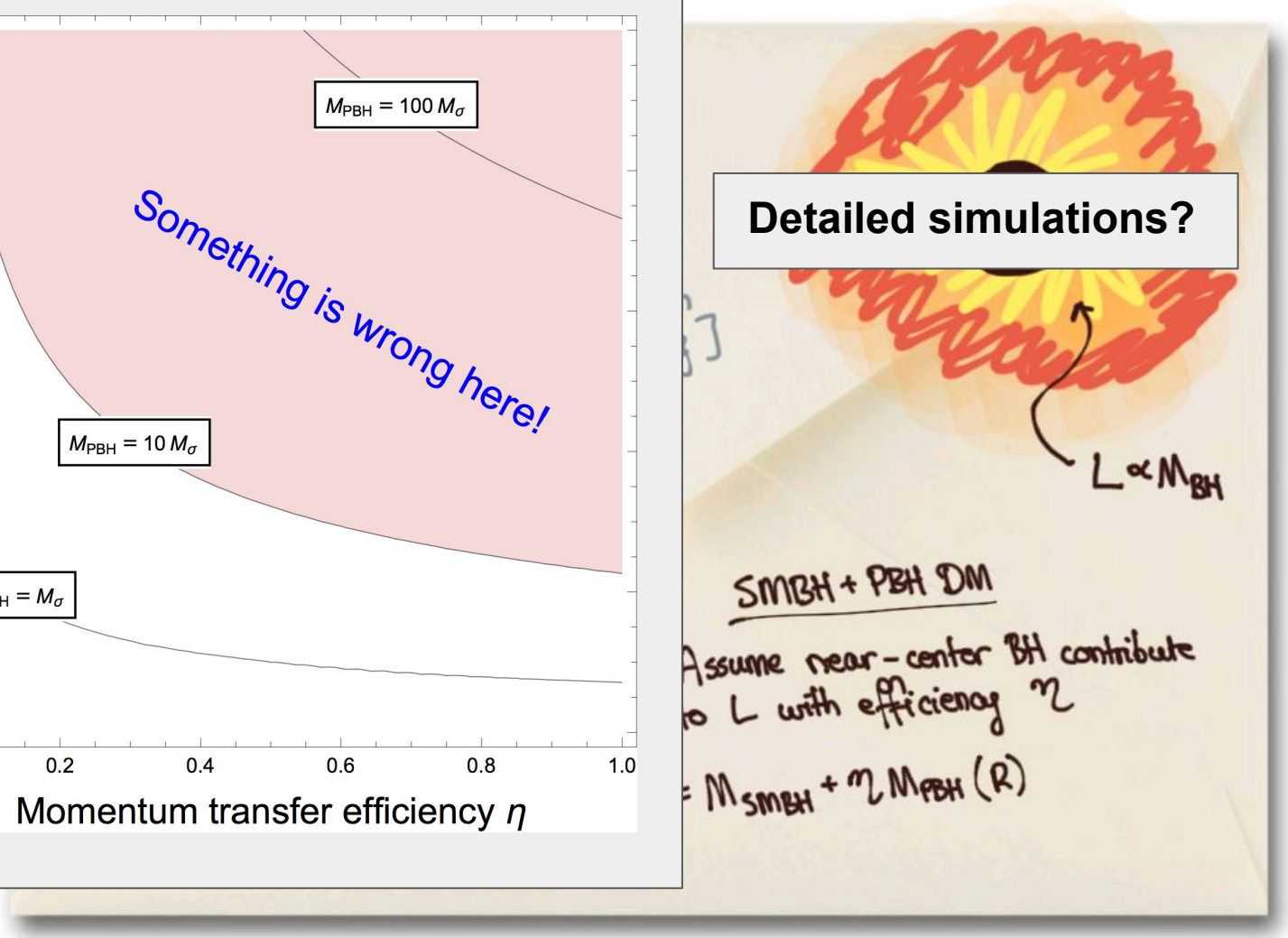


SMBH + PBH DM

Assume near-center BH contribute to L with efficiency η

$= M_{SMBH} + \eta M_{PBH}(R)$


Max distance from center [kpc]
Momentum transfer efficiency η
$M_{PBH} = 100\, M_\sigma$
$M_{PBH} = 10\, M_\sigma$
$M_{PBH} = M_\sigma$
Something is wrong here!
0.0
0.2
0.4
0.6
0.8
1.0


Detailed simulations?
$L \propto M_{BH}$
SMBH + PBH DM
Assume near-center BH contribute
to L with efficiency η
$= M_{SMBH} + \eta M_{PBH}(R)$

Conclusion

Current constraints “rule out” the considered mass range already, but require assumptions about astrophysics that may not be true

Future experiments can possibly rule out MACHOs as a dominant source of dark matter after a few years of observations assuming null detections

Find out what type of dark matter you are using our scientifically made Buzzfeed quiz!

Take the quiz here!