Title: Could LIGO's black holes be primordial and what is an easy way to figure that out?

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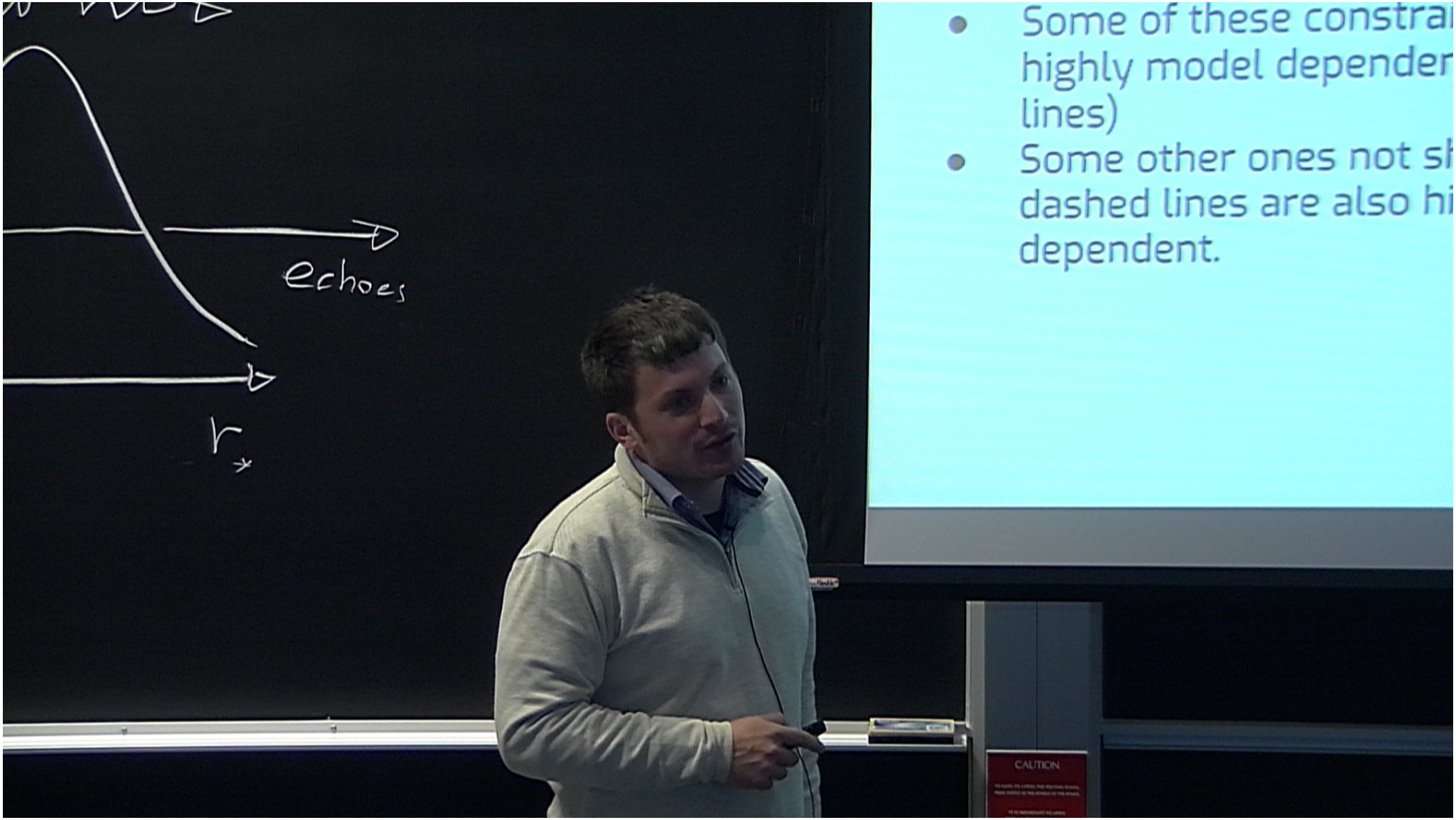
Abstract:

Could LIGO's black holes be primordial and what is an easy way to figure that out?

Chad Hanna - Penn State University - Nov. 8, 2017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CAUTION

Outline

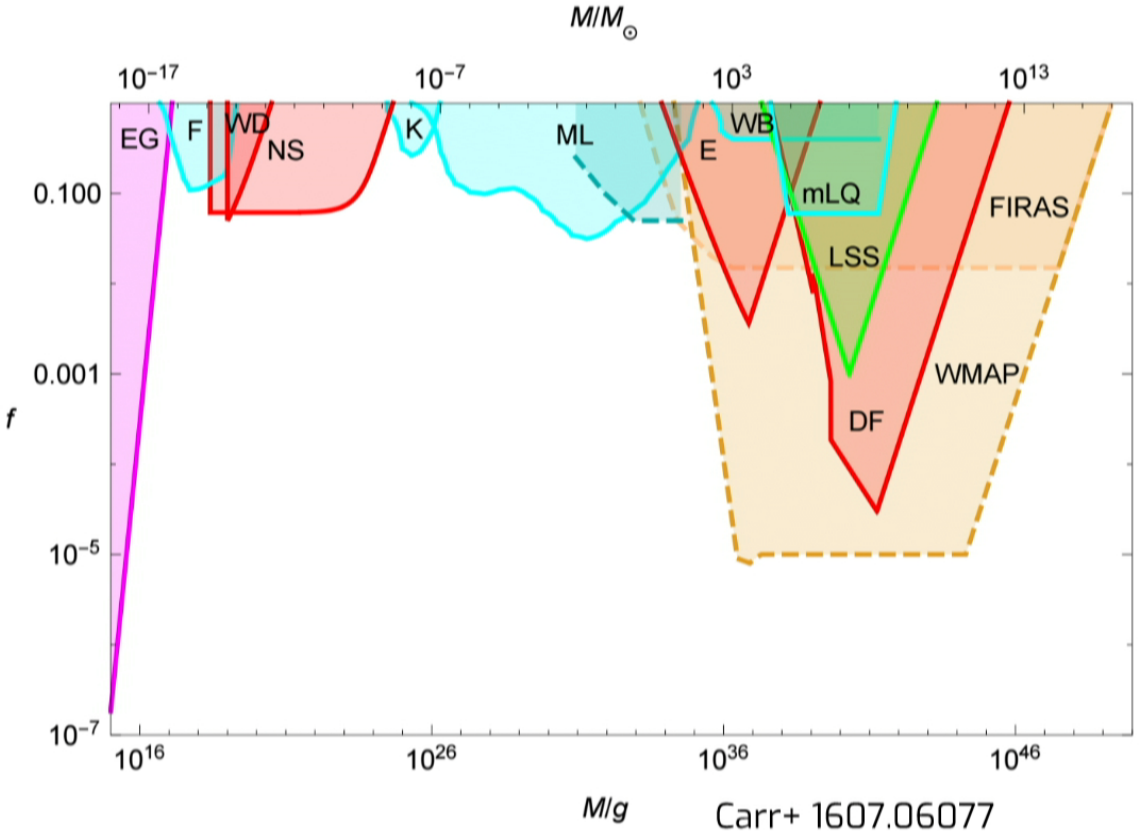
- Primordial black holes as dark matter
- The ~30 $M_\odot$ window
- The suggested connection to LIGO / problems
- Another look at the microlensing regime
- A new hypothesis to test
- Conclusions

Primordial black holes as dark matter

Conventional wisdom is that primordial black holes (PBH) are excluded as making up "most" of dark matter (DM) with f=1 meaning the "fraction" of dark matter is 1.

Caveats:

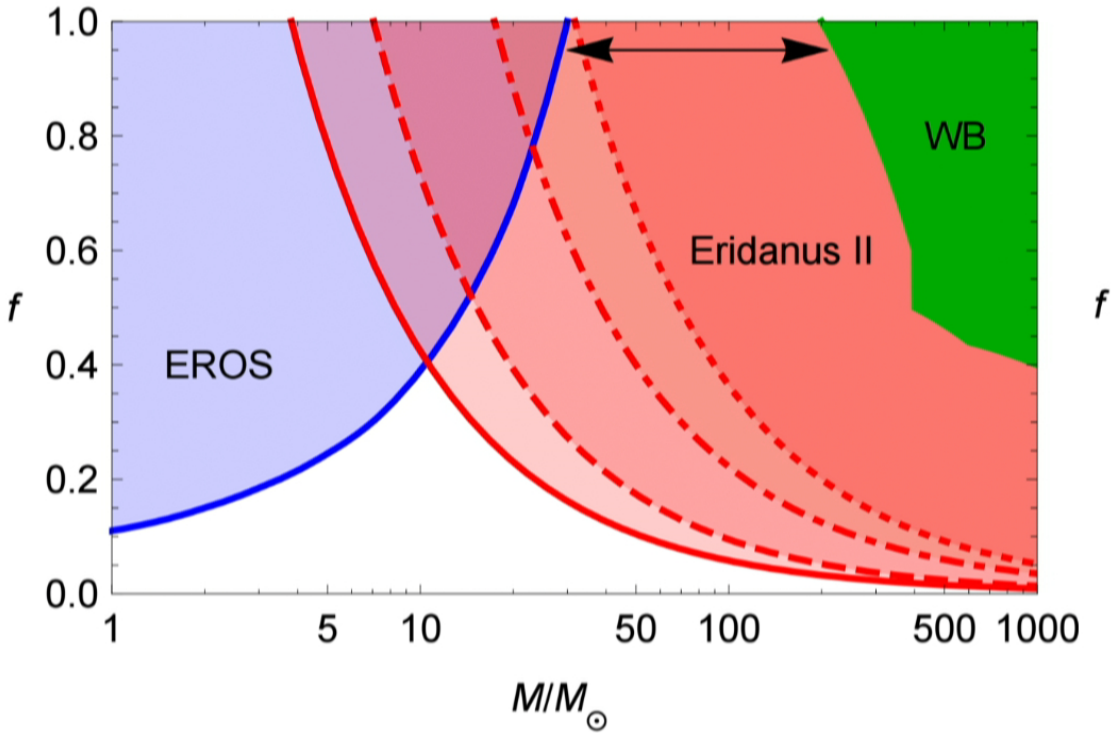
- These constraints are (mostly) for monochromatic mass functions
- Some of these constraints are highly model dependent (dashed lines)
- Some other ones not shown as dashed lines are also highly model dependent.



So PBH are excluded as dark matter, right?

Well...maybe

- Constraints on many of the mass ranges are very model dependent.
- Example: Eridanus constraints. Which line is correct?



Carr+ 1607.06077

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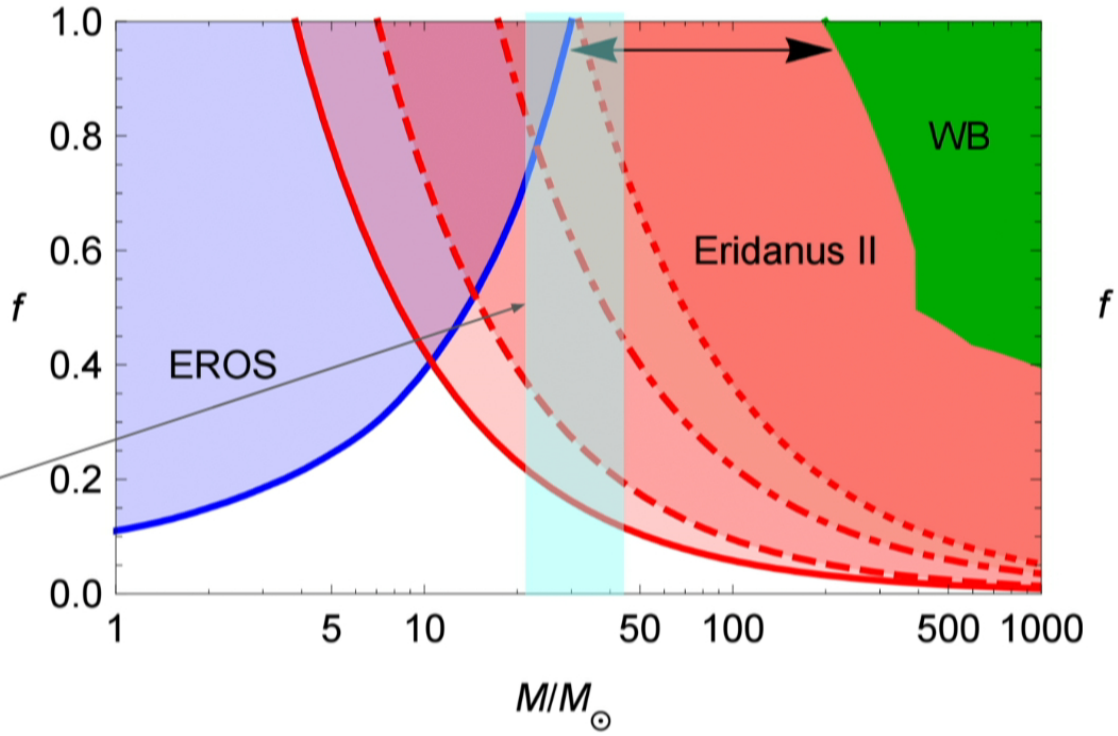
- Constraints on many of the mass ranges are very model dependent.
- Example: Eridanus constraints. Which line is correct?

Perhaps there is a window at ~30 solar masses?



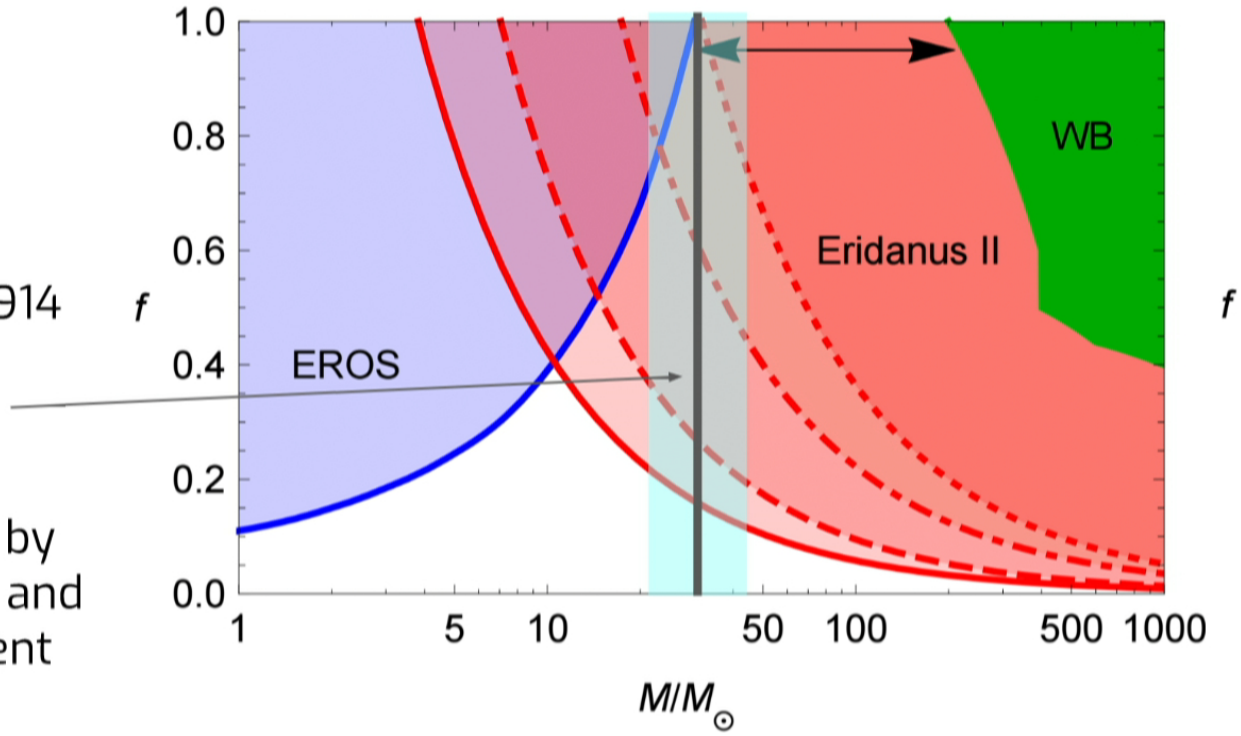
Carr+ 1607.06077

LIGO is detecting 30 solar mass black holes

Bird et al (PRL 2016) asked the question: "Did LIGO detect dark matter?"

A natural question given GW150914 consisted of two 30 solar mass black holes

Bird+ predicted a rate of merger by interactions of these black holes and conclude that the rate is consistent



Carr+ 1607.06077

Problems with LIGO PBH being dark matter

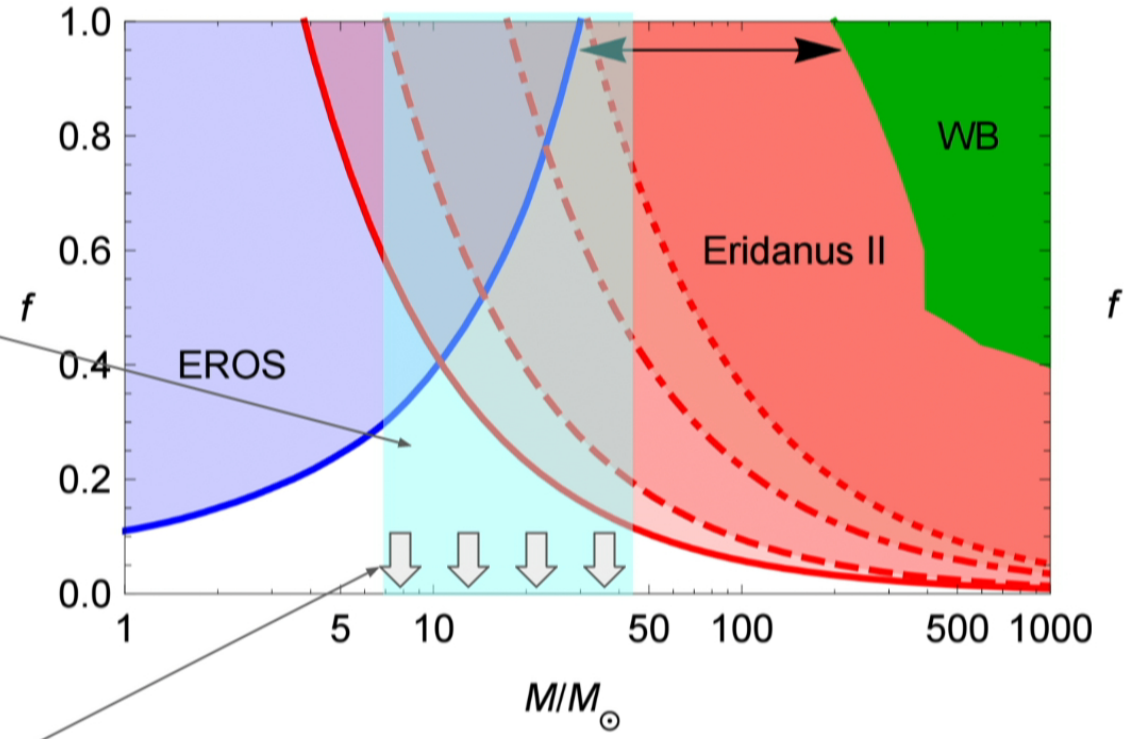
Problem 1:

The original model proposed by Bird et al assumed monochromatic mass function.

LIGO is observing a power law

Problem 2:

The original model proposed by Bird et al had a consistent merger rate, but others (Eroshenko+ 2016, Sasaki+ 2016, Carr+ 2016) say LIGO's rate is *too low*.



Carr+ 1607.06077

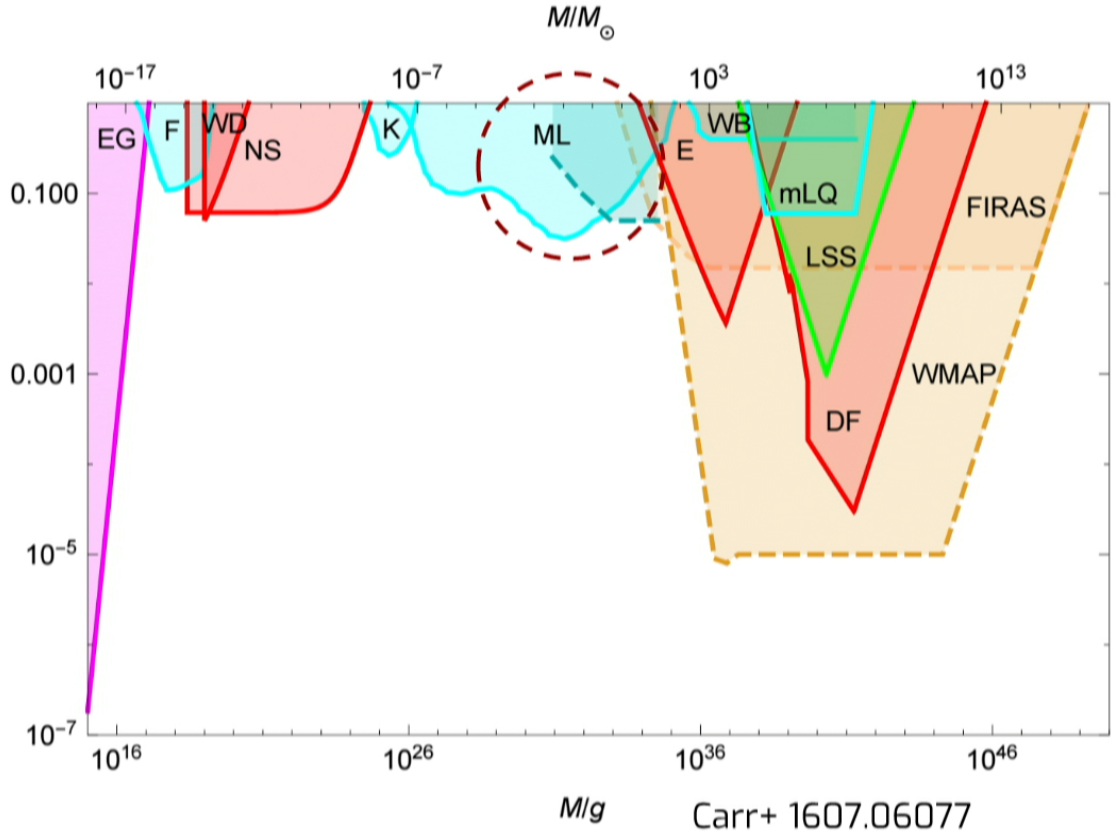
Conclusion for LIGO PBH dark matter

It seems that LIGO seeing PBH in present mass range that explains all of dark matter is not viable.

But what about other constraints?

The microlensing regime seems to exclude PBH as dark matter. Alcock+ ApJ (2000)

"A 100% MACHO halo is ruled out at the 95% confidence level **for all except our most extreme halo model**"

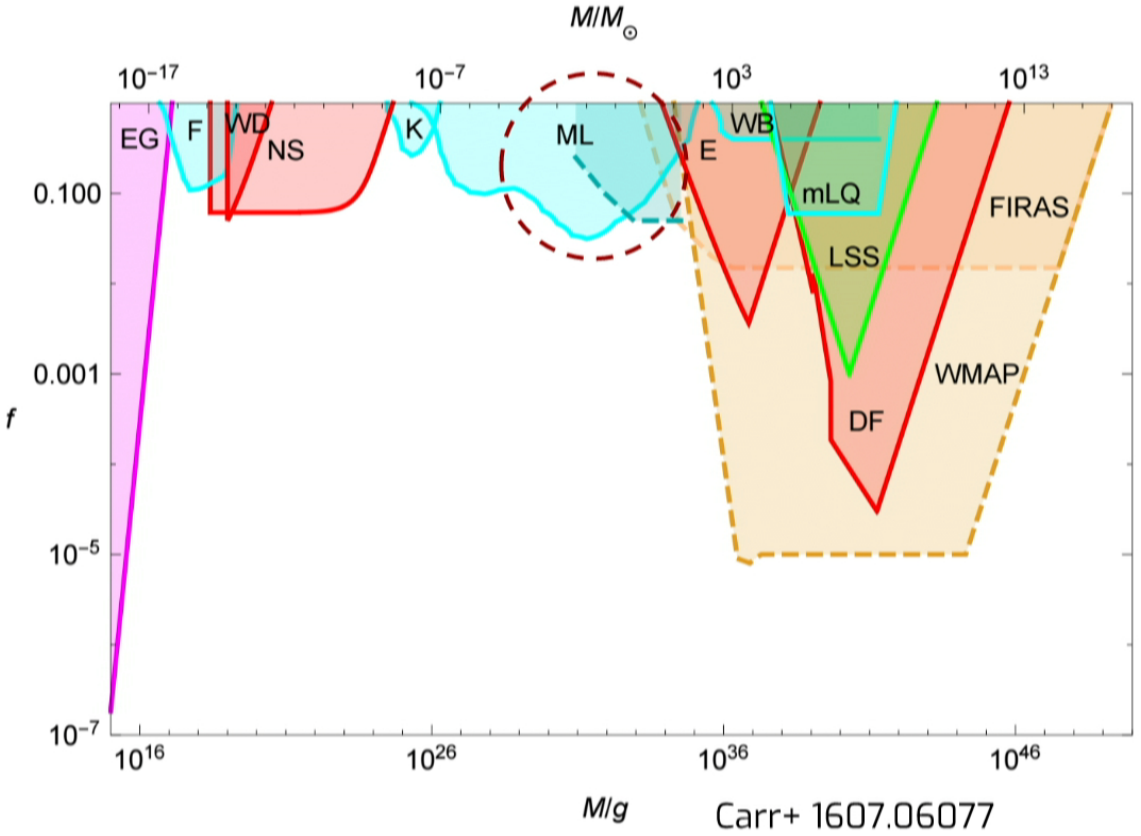


Microlensing region

Hawkins A&A 2015:

"Conclusions: Limits placed on the MACHO content of the Galactic halo from microlensing surveys in the Magellanic Clouds are inconsistent and model dependent, and do not provide a secure basis for rejecting an all-MACHO halo."

In fact, the MACHO collaboration claimed a *detection* 0.15 - 0.9 $M_\odot$



Hypothesis to test

Ingredients:

- Enforce all of DM to be PBH
- Assume all LIGO BBH are dark matter
- Believe at least one of the MACHO candidates is real
- Allow microlensing "constraints" to be relaxed, but enforce higher mass constraints and a low dark matter fraction associated with LIGO's BBH so far.

Things we know:

- LIGO's black holes are well described by a power law for the primary mass: $dN/dM \propto M^{-\alpha}$
- Constraints at high mass > 100 are the most constraining and come from several independent methods

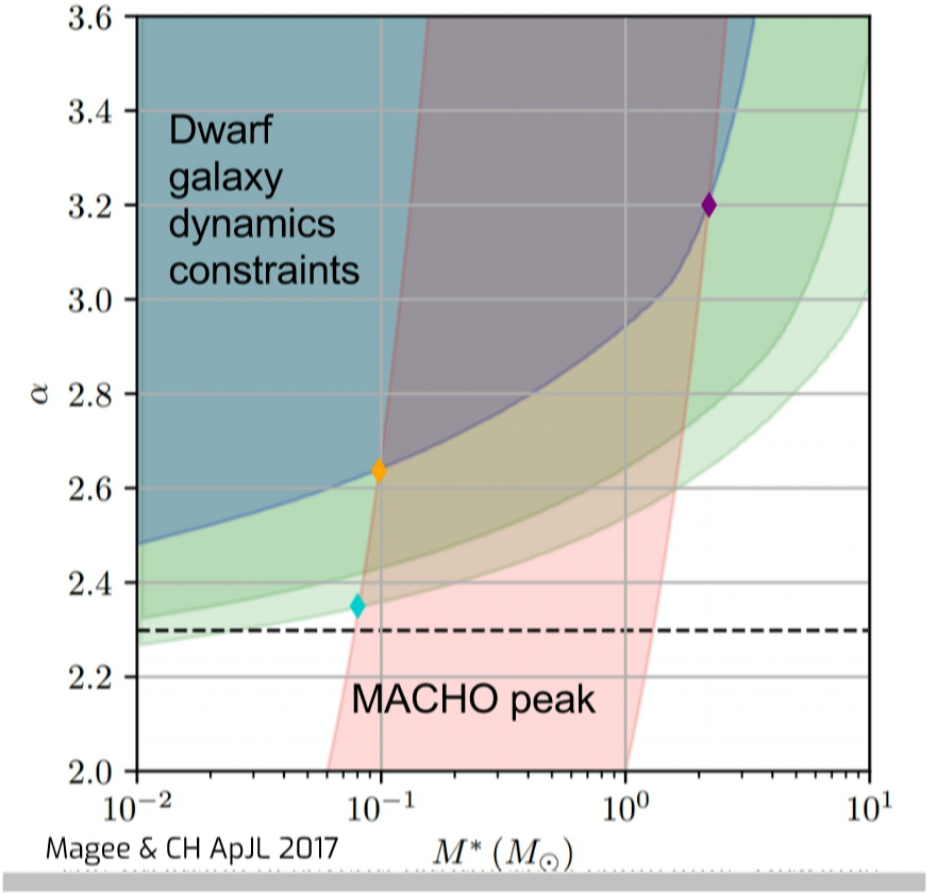
Hypothesis to test

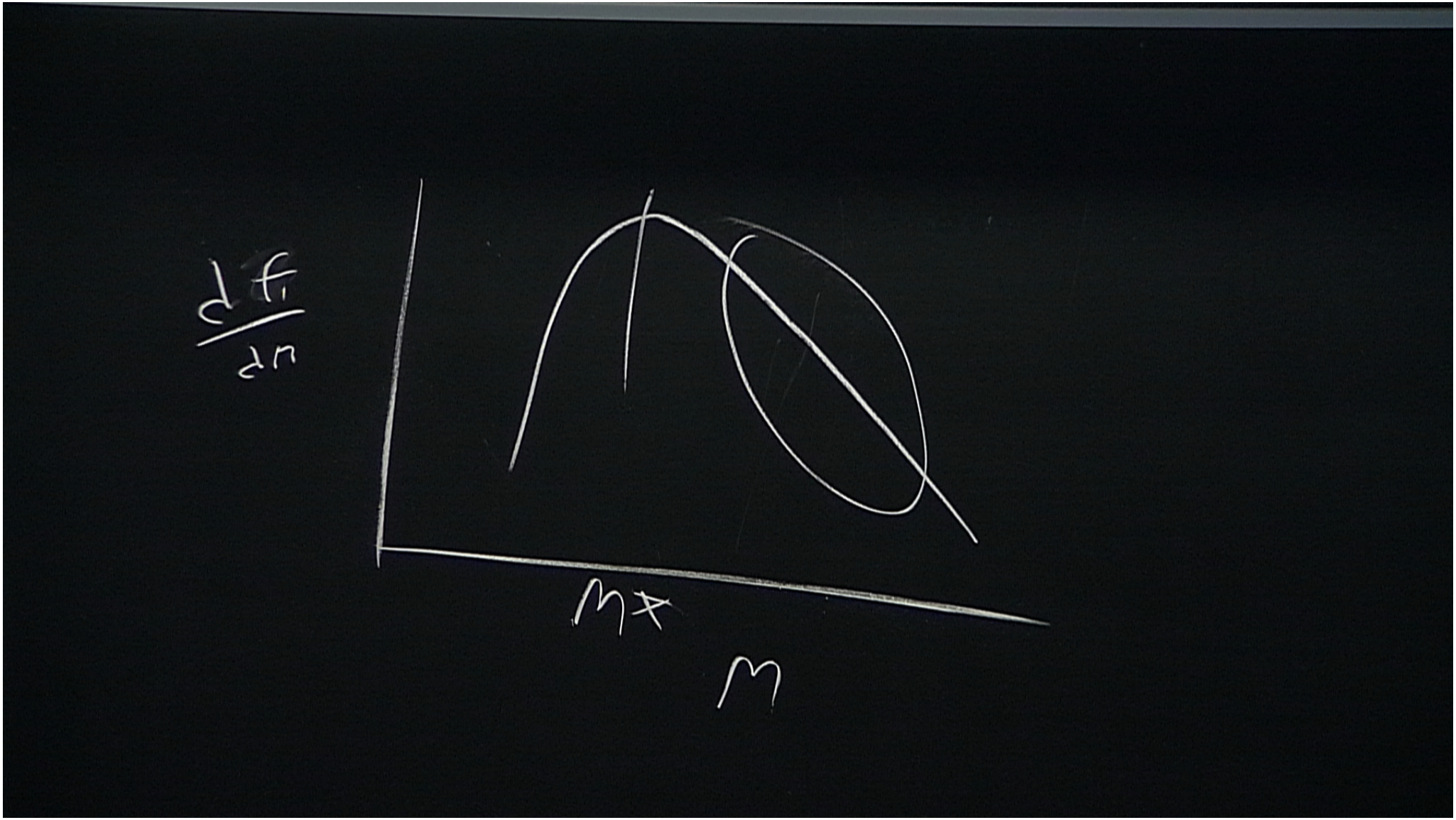
Assume a dark matter mass function that is a power law with an exponential cut-off at low mass

$$\frac{df}{dM} = \frac{M}{\rho_{\rm CDM}} n(M) \quad = \frac{CM^*}{\rho_{\rm CDM}} \left(\frac{M^*}{M}\right)^{\alpha-1} e^{-\frac{M^*}{M}}$$

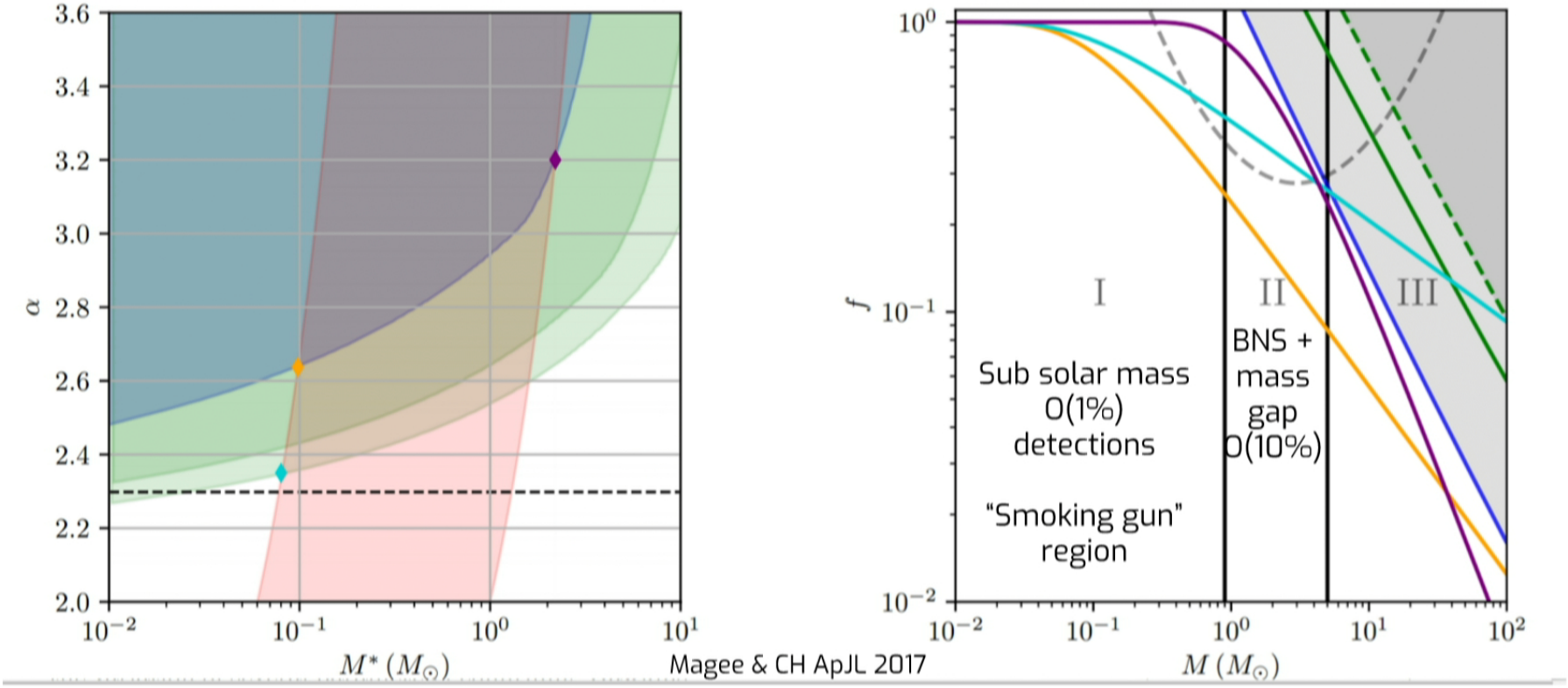
Normalize, *C*, to integrate to all of dark matter.

We want the power law to agree with LIGO BBH and the peak to be in the MACHO range to explain detections there.




$\frac{d f_i}{dn}$
m^*
m

Hypothesis to test



Magee & CH ApJL 2017

How do we do it?

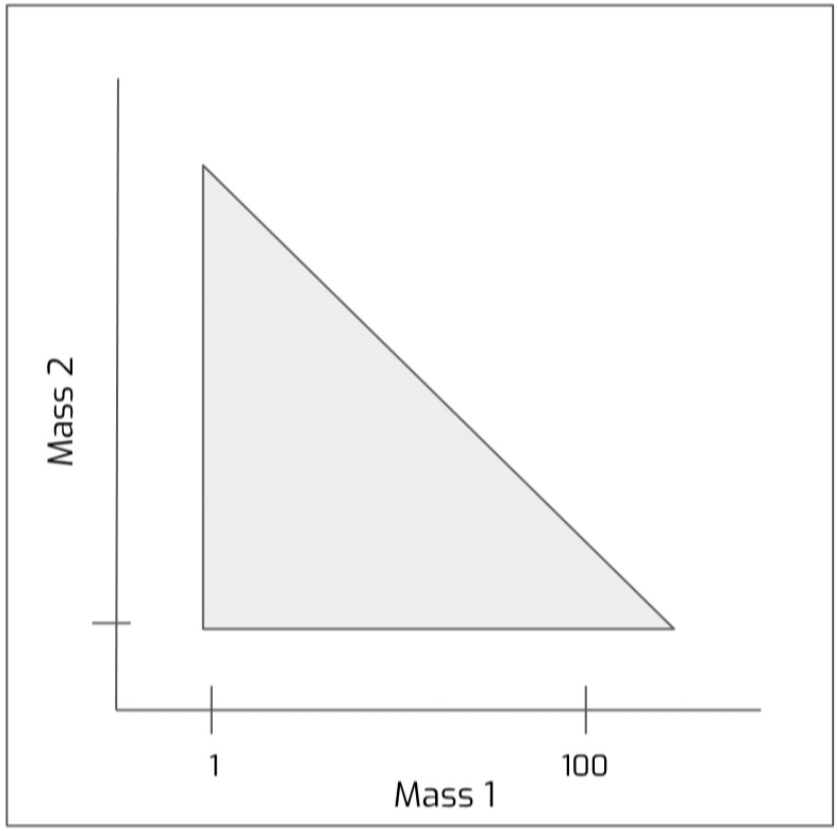
Presently we search for compact binary mergers within the mass range of ~1-400 solar masses.

A smoking gun signature of PBH would be to find binaries with components below 1 solar mass (since we don't expect stellar evolution to give us)

In Advanced LIGO we can see e.g., 0.2 $M_{\odot}$ binaries to the Virgo cluster. Maybe after ~100 BBH detections (which will be very soon) we will see something below a solar mass

Problems:

None of our present searches are sensitive to these. We need a targeted search. It will be 10-100 times more costly depending on assumptions about component spin.



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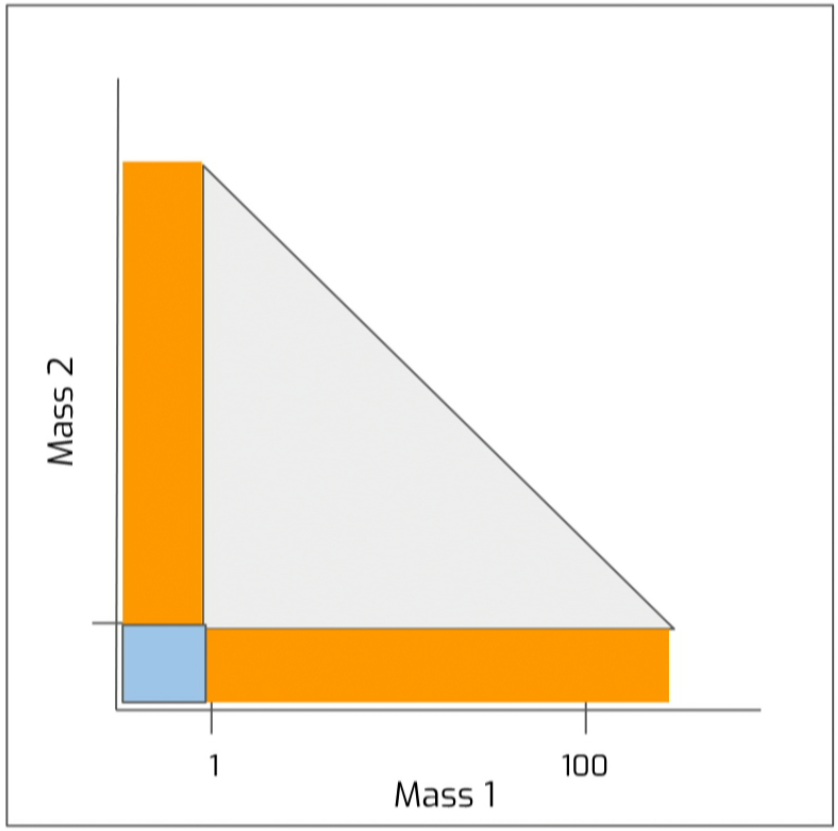

Conclusions

- If LIGO is detecting PBH, then it seems that we are only detecting a fraction of the dark matter.
- To explain all of the dark matter we need an extended mass function
- High masses are constrained but lower masses (below one solar mass) might not be.
- LIGO can provide unique constraints below a solar mass and probably rule out PBH as dark matter across a wide range - OR
- LIGO can detect black holes below a solar mass. That would be smoking gun evidence and we could potentially solve dark matter.