Title: Binary Mergers of Dark Matter Blobs

Speakers: Melissa Diamond

Series: Particle Physics

Date: November 23, 2021 - 3:00 PM

URL: https://pirsa.org/21110041

Abstract: Despite years of research into dark matter, little has been done to explore models which are heavier than most WIMPs and lighter than most primordial black hole models, "blobs". This parameter space is particularly difficult to probe, due to low number densities and low masses. This talk will present a new model-independent mechanism that can be used to probe this difficult to reach region of dark matter parameter space. Blobs form binaries which spin down and merge at high rates in the present and recent past. The abundance of mergers can produce observable gravitational wave and electromagnetic signals. I describe some of these unique signals and show how they already constrain parts of blob parameter space.

Zoom Link: https://pitp.zoom.us/j/98024869740?pwd=eDlPSTB3UzhIcEVYVGNQakRHVUtFQT09

Binary Mergers of Dark Matter Blobs:

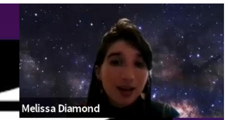
Bridging the Dark Matter Gap

Melissa Diamond

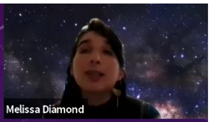
Ongoing work with David Kaplan and Surjeet Rajendran

Johns Hopkins University

Seminar at Perimeter Institute

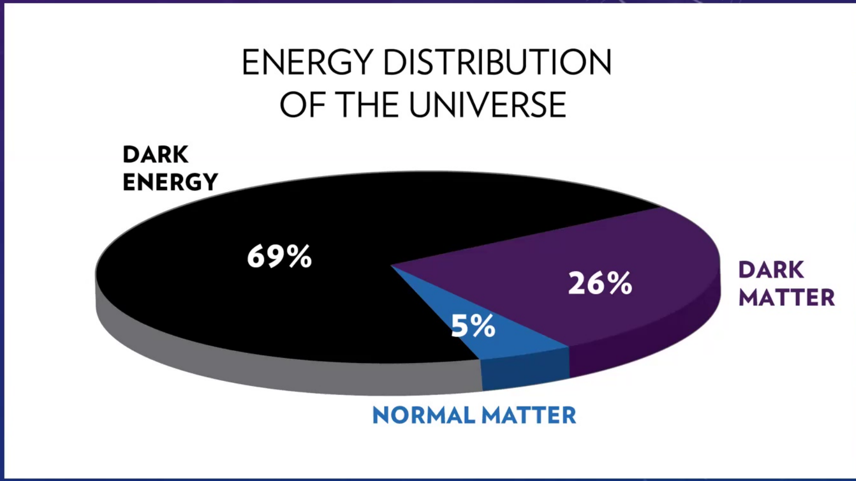


Introduction & Motivation



Dark Matter

- Composes ~26% of mass/energy in Universe
- > 80% of matter in Universe
- Provides scaffolding for galaxies and galaxy clusters
- No strong electromagnetic interactions
- Interacts through gravity



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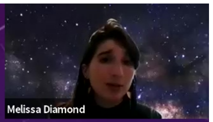
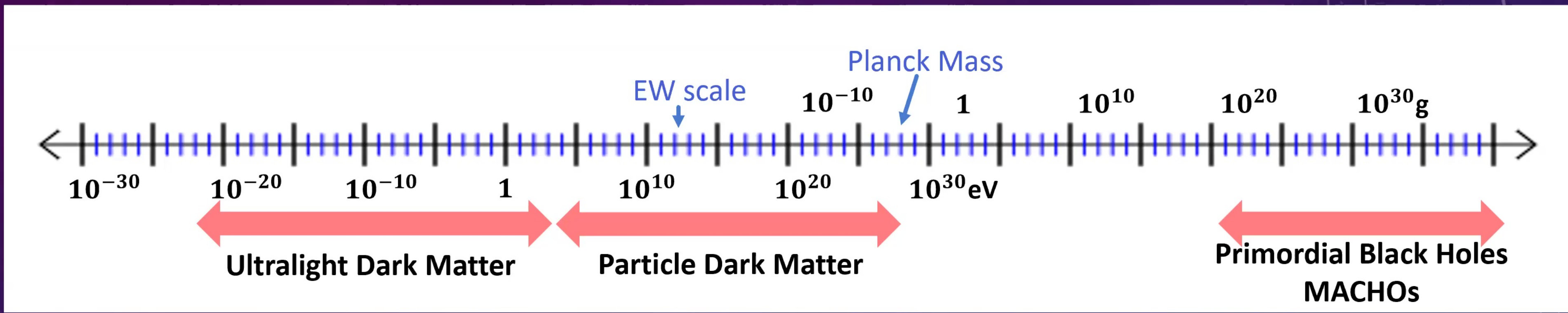
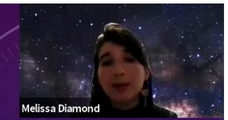


The Landscape of Dark Matter Candidates





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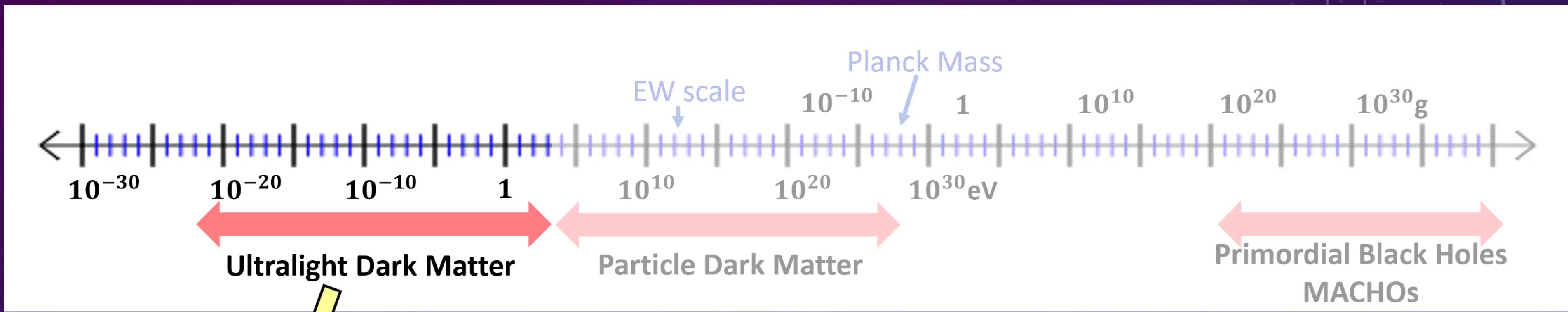
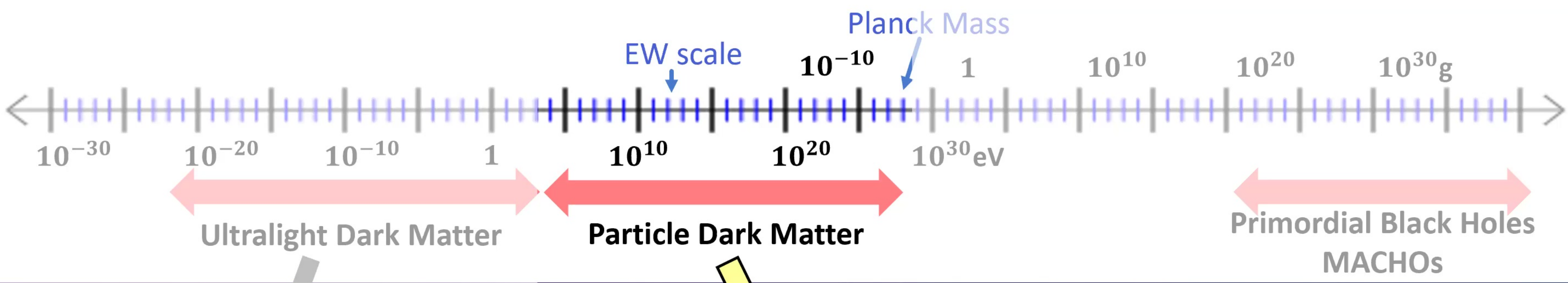


Candidates : Axions & ALPs

Searches

- **Direct Detectors** (ADMX, HAYSTAC, ALPS, CAST, CDMS, XENON1T…)
- **Astrophysical** (Black Hole Superradiance, Neutron star radio Signal)
- **Rotation of Polarized Light from CMB**

The Landscape of Dark Matter Candidates



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Candidates : WIMPs, Asymmetric DM, Freeze-in DM, etc.

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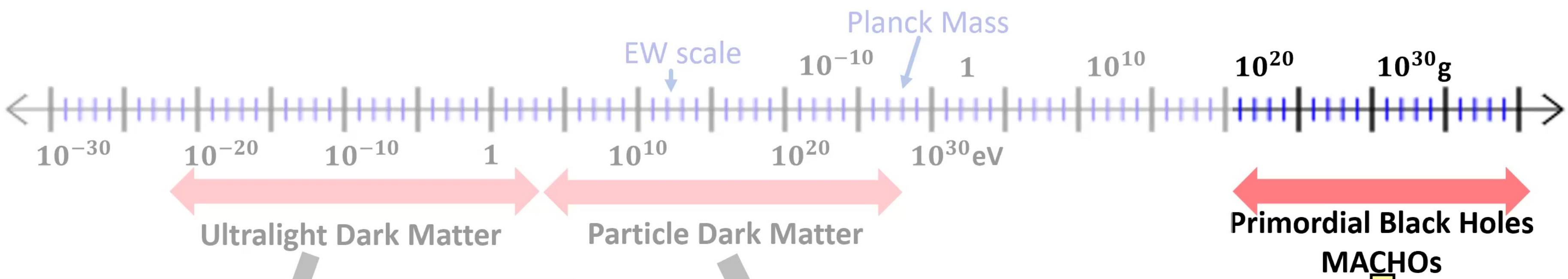

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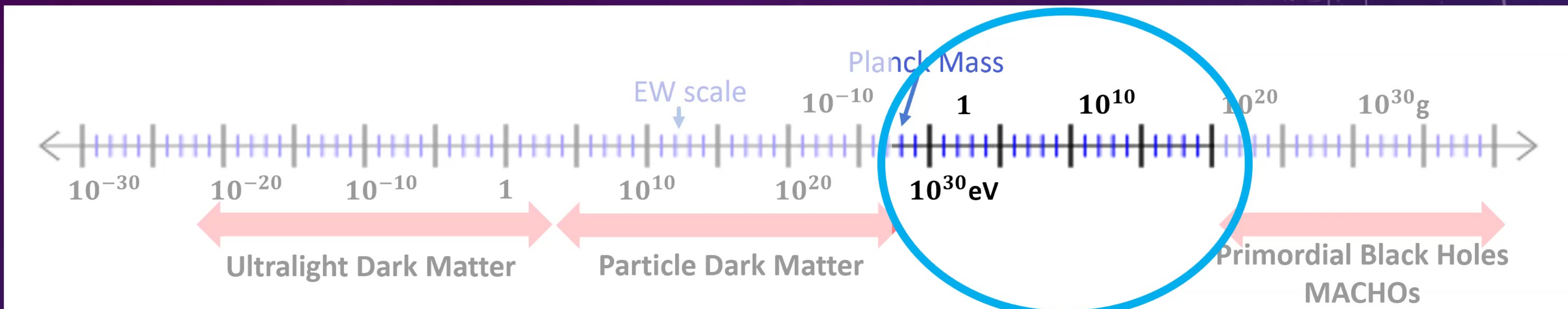
Candidates : Primordial Black Holes & MACHOs

Searches

- **Lensing Searches**
- **Wide Binaries**
- **Excess Radiation**
- **Gravitational Waves**

The Landscape of Dark Matter Candidates



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Candidates : W
DM, Freeze-in

Searches

- **Direct Det**
  XENON1T, P
  SENSEI...)
- **Collider Searches** (ATLAS, CMS)
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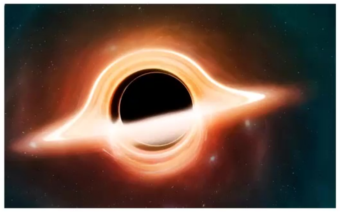
What about this gap?

: Primordial Black
ACHOs

- Lensing Searches
- Wide Binaries
- Excess Radiation
- Gravitational Waves

Candidates in the Gap AKA Blobs

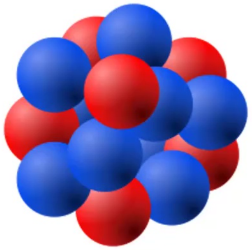


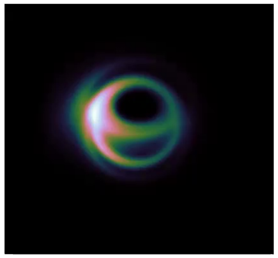
Stable Black Holes

- Extremal charged black holes
- Higher dimensional black holes
- Primordial black holes with masses $10^{17}g < M < 10^{21}g$
- Black Hole Relics

Nuclear Dark Matter

- Also called Nugget / Blob dark matter
- Small constituent particles form dense nuclei-like structure





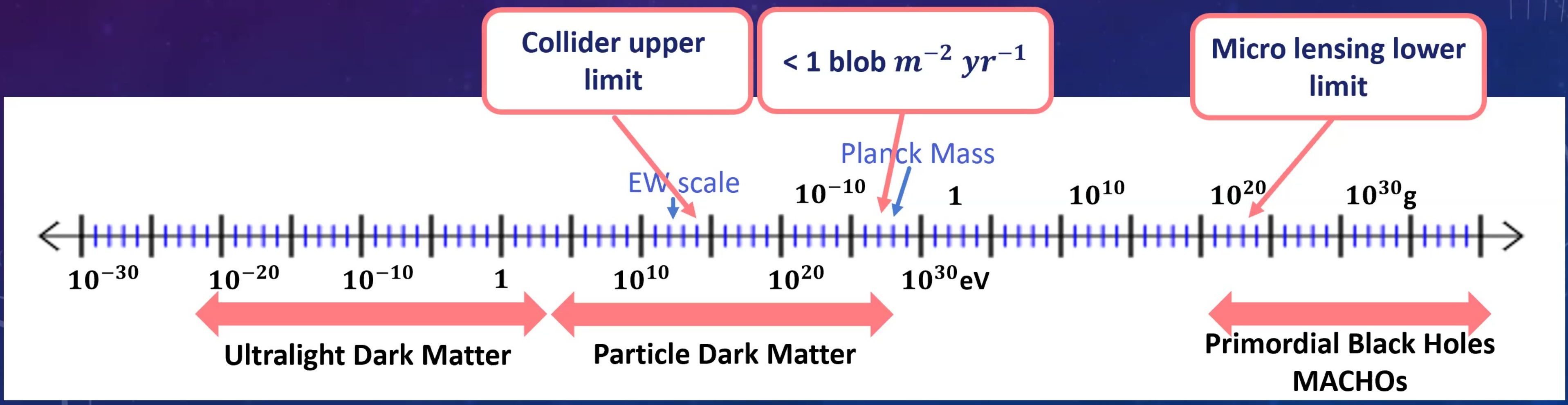
Exotic Compact Objects (ECOs)

- Boson Stars – Bose-Einstein Condensate on Astrophysical Scale
- Dark Fermion Stars – Structure from collapsed cloud of dark fermions

Why neglect the gap?

Blobs are…

- too heavy to be made in colliders
- too scarce to appear in in Earth-based detectors
- too light for current gravitational lensing techniques



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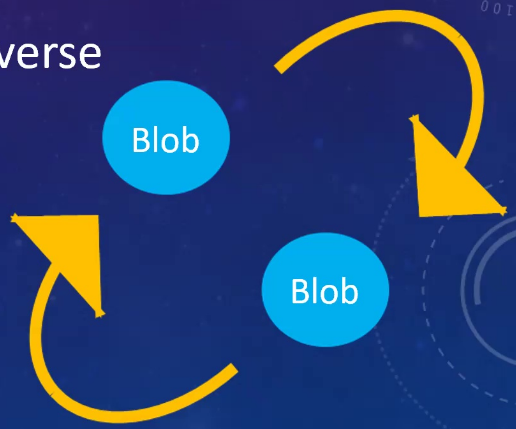
➡ only observable though astrophysical interactions and self-interactions

Blob Binary Mergers to the Rescue!

Blob binaries to the rescue!

1) Blobs form gravitationally bound binaries in the early Universe
2) Lose energy through gravitational radiation
3) Blobs merge



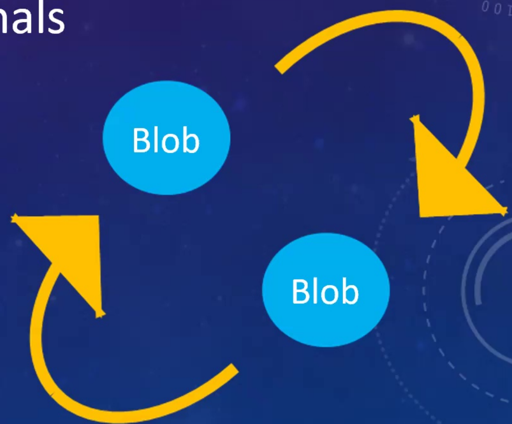
Blob binaries to the rescue!

Mergers may produce observable gravitational or EM signals

More common than random collisions

Reasonably model independent!!

Applies to many blobs heavier than 10^{12}GeV



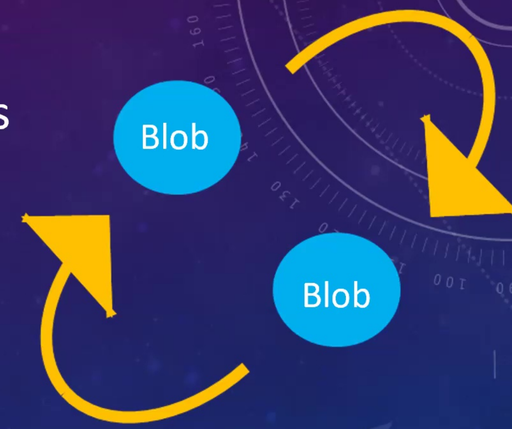
Blob binaries to the rescue!

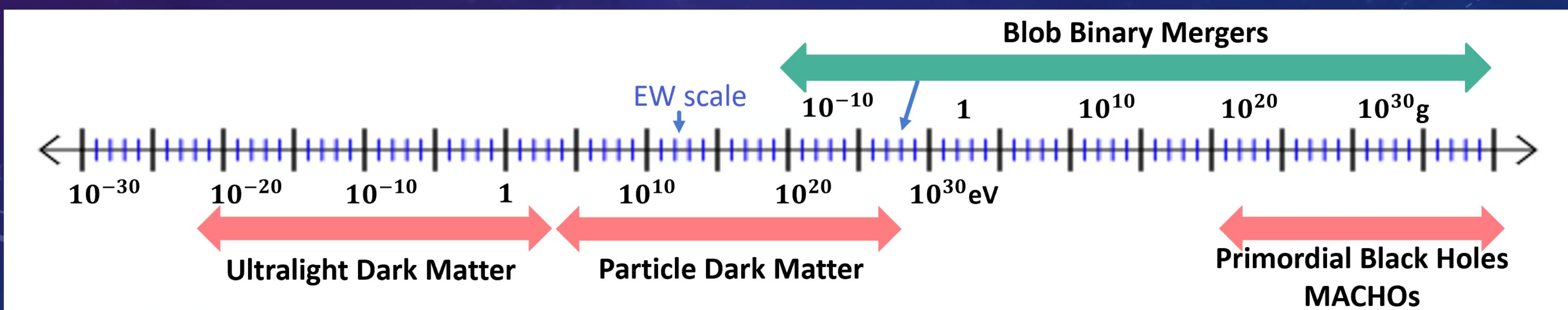
Mergers may produce observable gravitational or EM signals

More common than random collisions

Model Independent!!

Applies to any* blob heavier than 10^{12}GeV





1) Blobs form gravitationally bound binaries

Deep in radiation domination blobs are…

- cold
- tightly packed
- moving with the Hubble flow
- separated by distances described by a **Poisson distribution**

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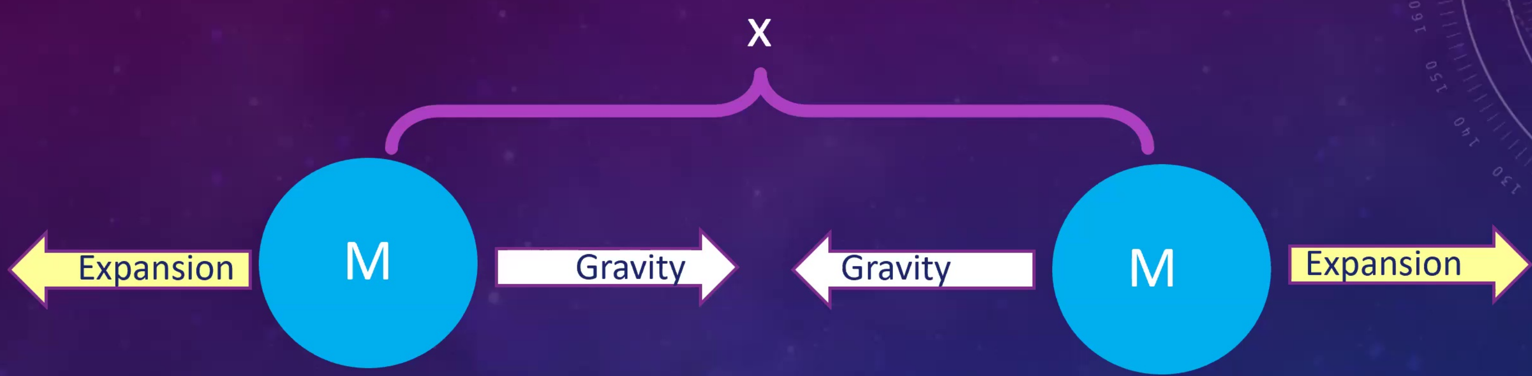


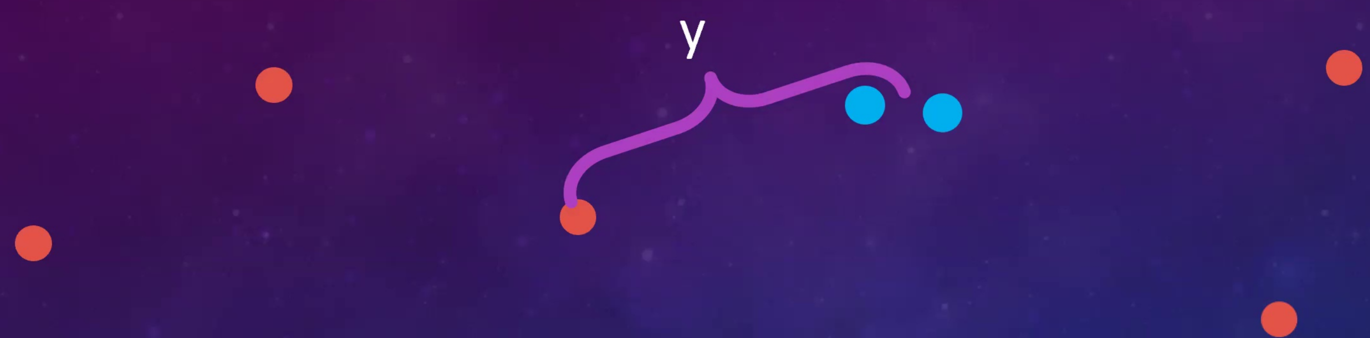
Binary forms when in-fall time ≈ Hubble time

$$z_d \propto \frac{M}{x^3}$$

Semi-Major Axis of binary

$$a \propto \frac{x^4}{M}$$

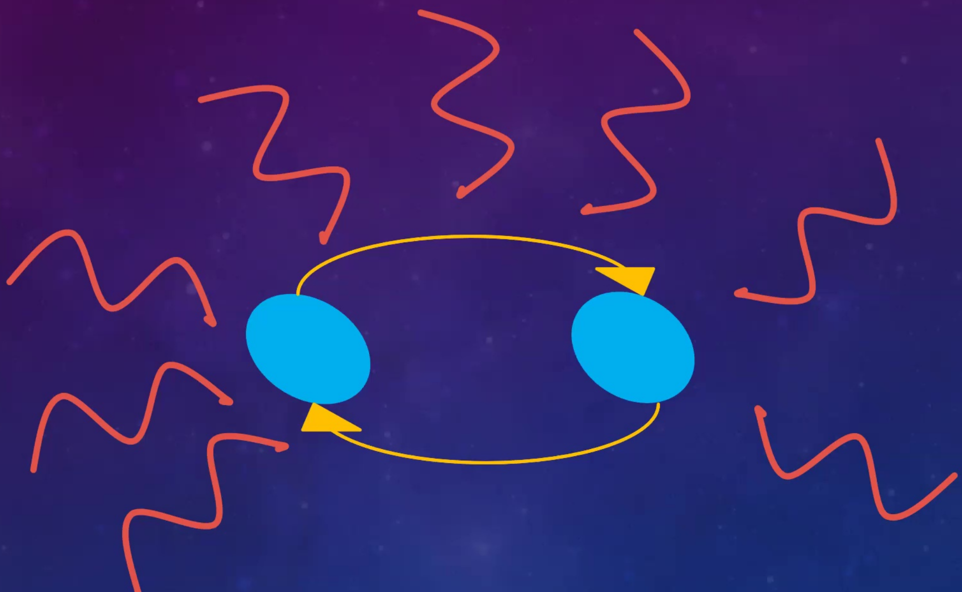
1) Blobs form gravitationally bound binaries



Torques from all the other blobs give the binary an eccentricity and prevent the blobs from immediately colliding

$$e \propto \sqrt{1 - \left(\frac{x}{y}\right)^6}$$

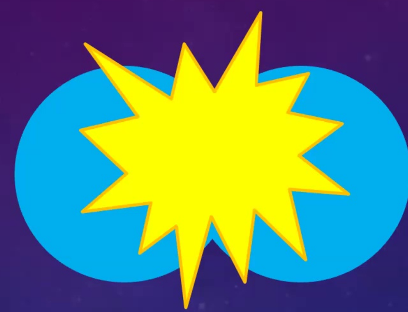
2) Binaries lose energy through gravitational radiation



This causes binary to merge after

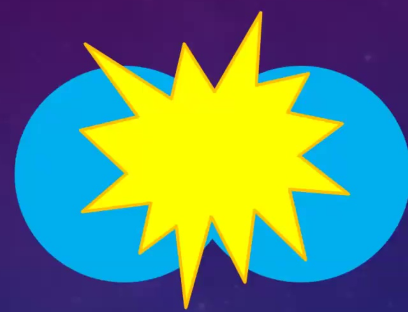
$$t \propto \frac{a^4(1-e^2)^{7/2}}{M^3}$$

3) Blobs merge!



blob spatial distribution => distribution of binary parameters => distribution of merger times => merger rate

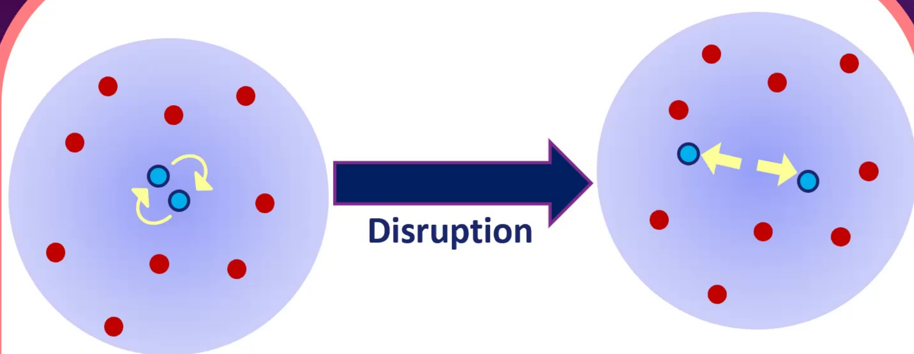
3) Blobs merge!



$$R \simeq 9 \times 10^4 \left(\frac{M}{10^{15} g}\right)^{-\frac{32}{37}} f^{\frac{53}{37}}\ s^{-1}$$

Merger rate in the Milky Way

Caveats and Complications



Binary Disruptions

- During matter domination, blobs form gravitationally bound clusters
- Most binaries that fall into these clusters are disrupted

Finite Size Effects

- Blobs that are too big collide too early
- Not a problem if

$$r < 10^9 \mathrm{r_s} \left(\frac{\mathrm{M}}{10^{15}\mathrm{g}}\right)^{-8/37}$$

Observable Signals

Gravitational Wave Signal (Individual Events)

$$h \propto \frac{M^{\frac{5}{3}} v^{2/3}}{d_L}$$

Strain

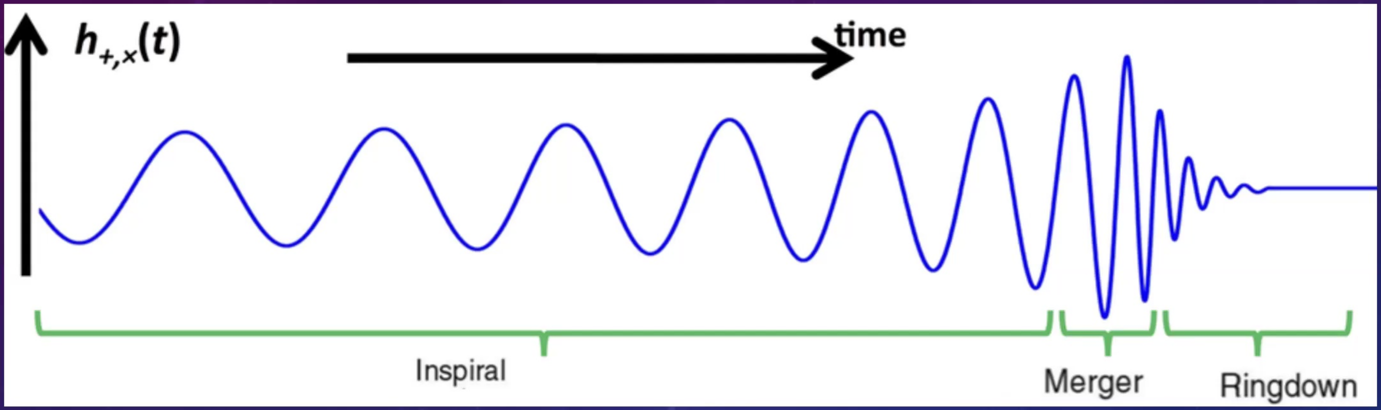
$$v^{ISCO} \propto \frac{M^{1/2}}{r^{3/2}}$$

ISCO Frequency

Blob mergers should look different from black hole mergers

- Much lower masses = higher frequencies
- Finite size = earlier than expected mergers
- No event horizon = different ringdown

Gravitational Wave Signal (Individual Events)



M. Favata/SXS/K. Thorne

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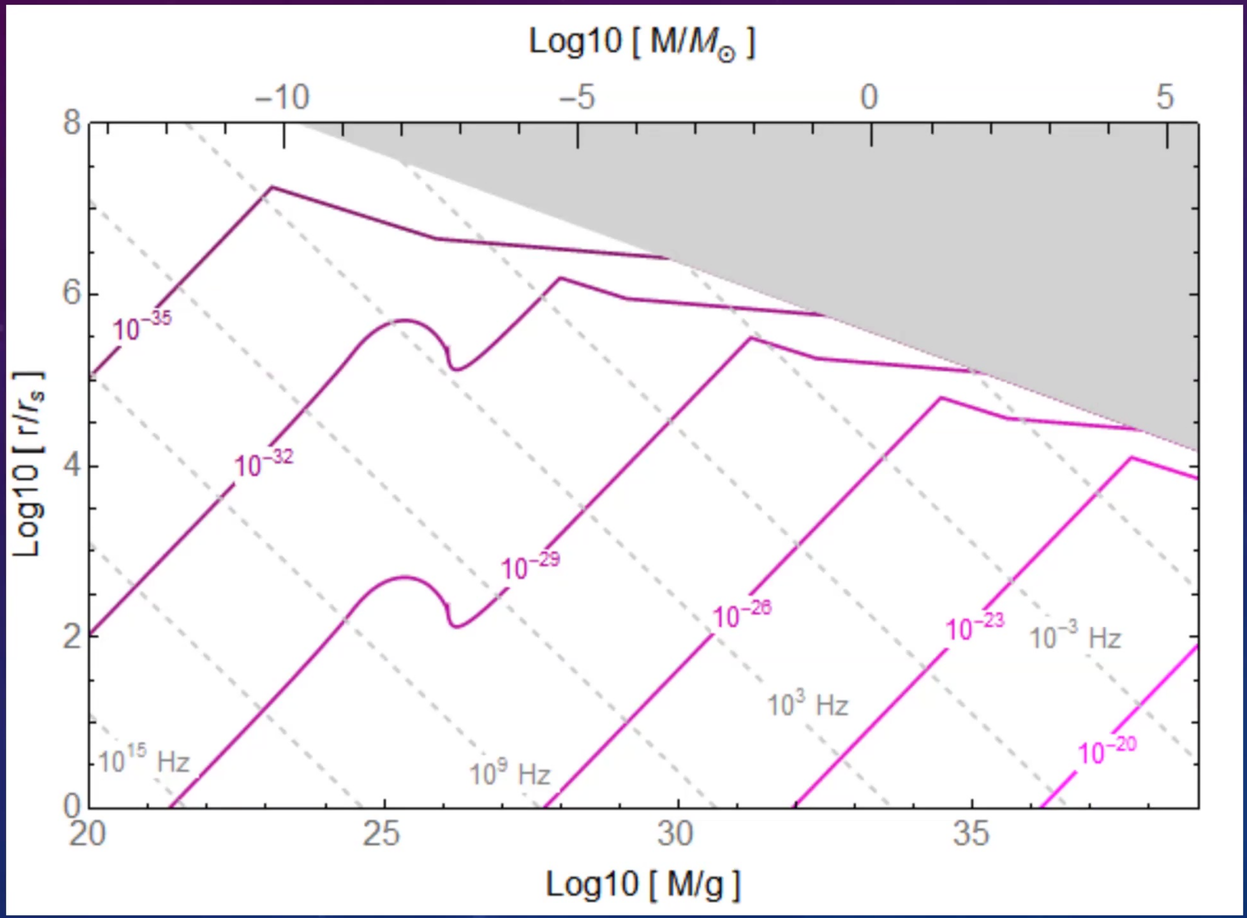
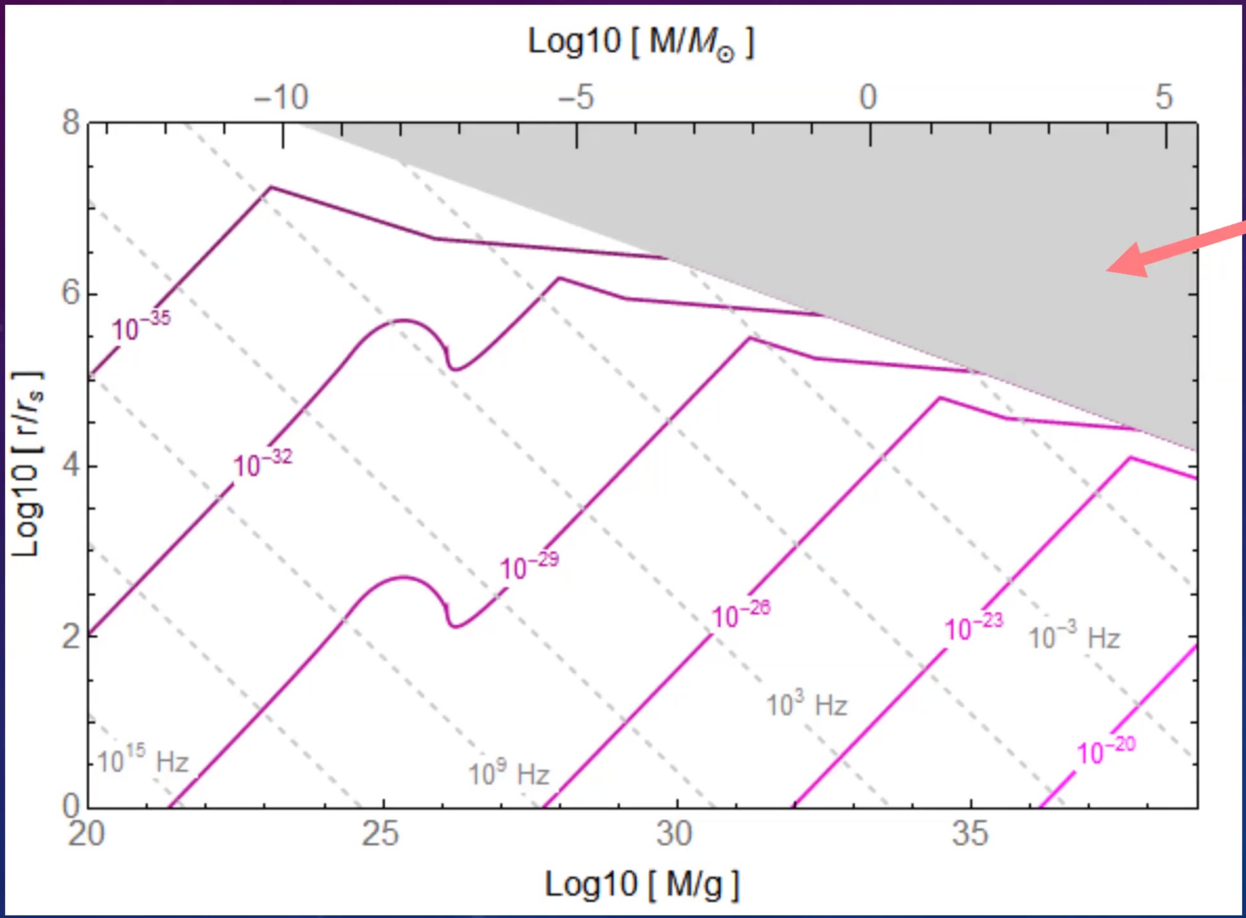


$f = 10^{-2}$

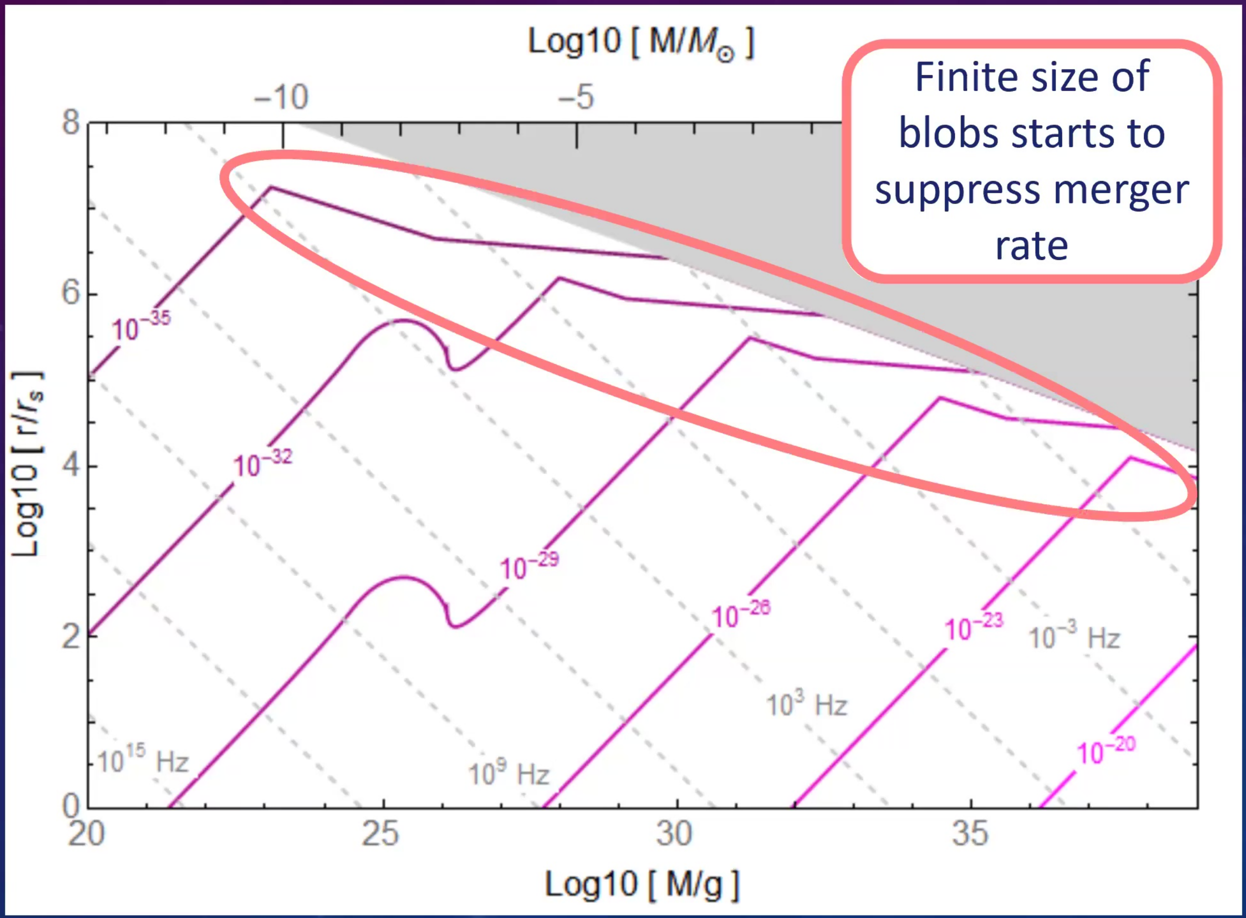
Gravitational Wave Signal (Individual Events)



Finite size of blobs suppress merger rate

$f = 10^{-2}$

Gravitational Wave Signal (Individual Events)



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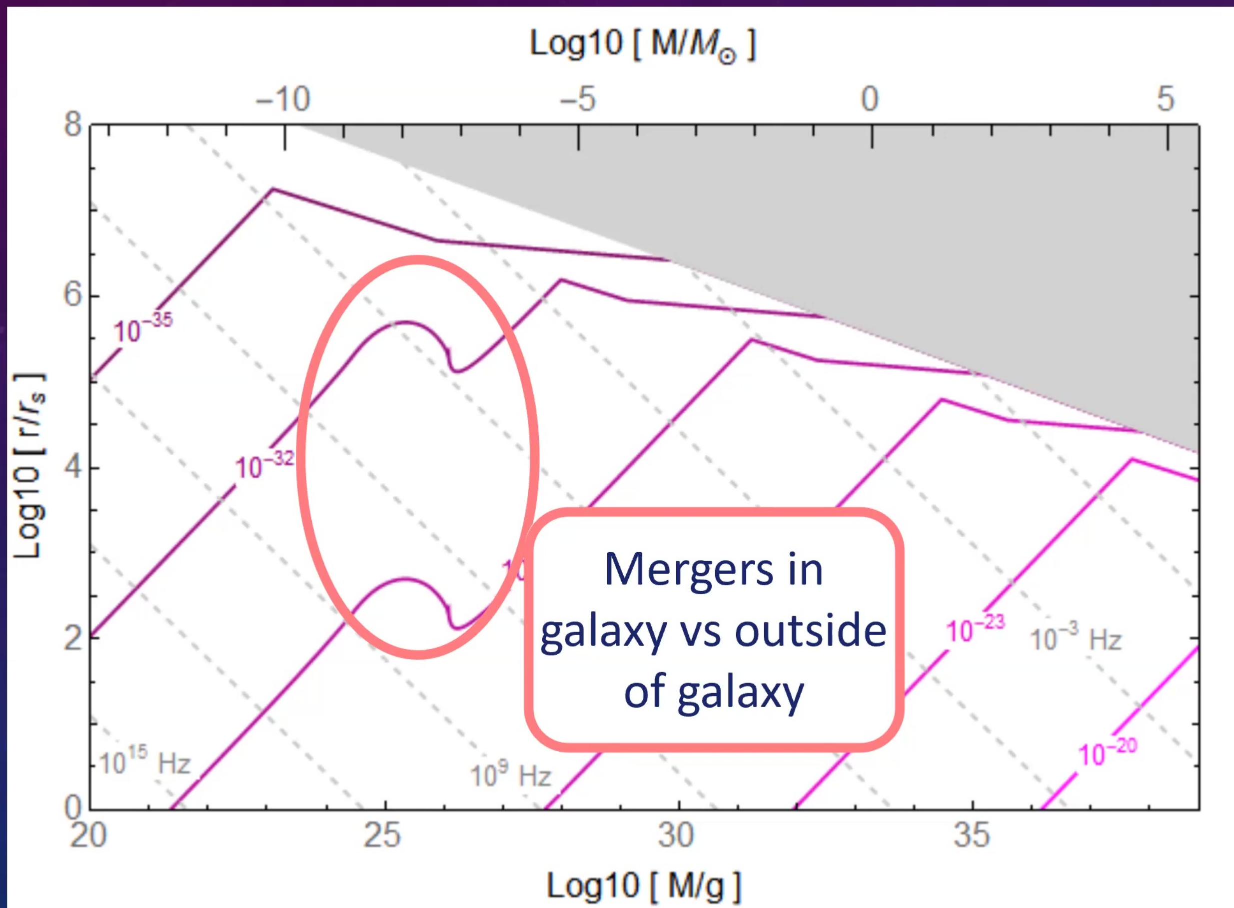

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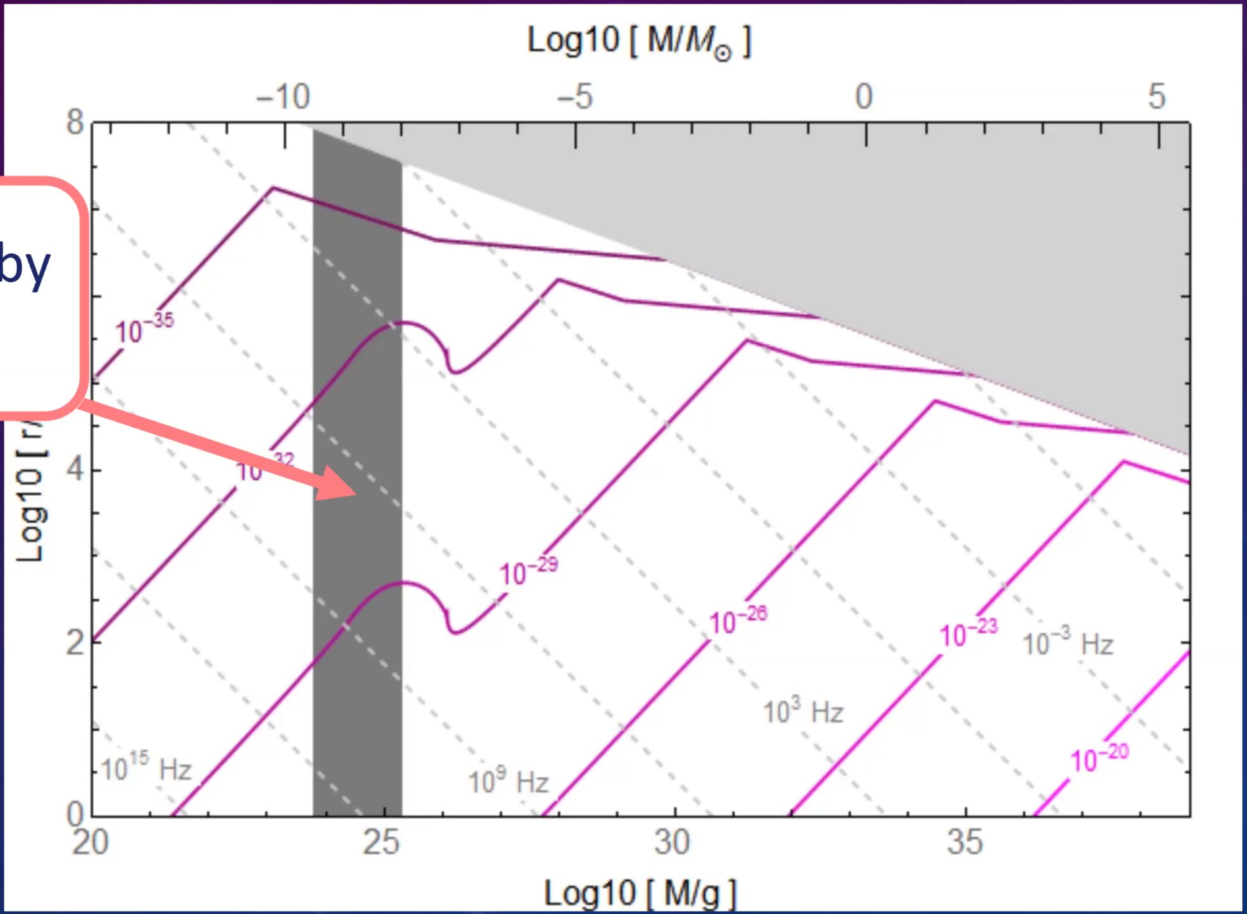
Gravitational Wave Signal (Individual Events)

Ruled out by lensing



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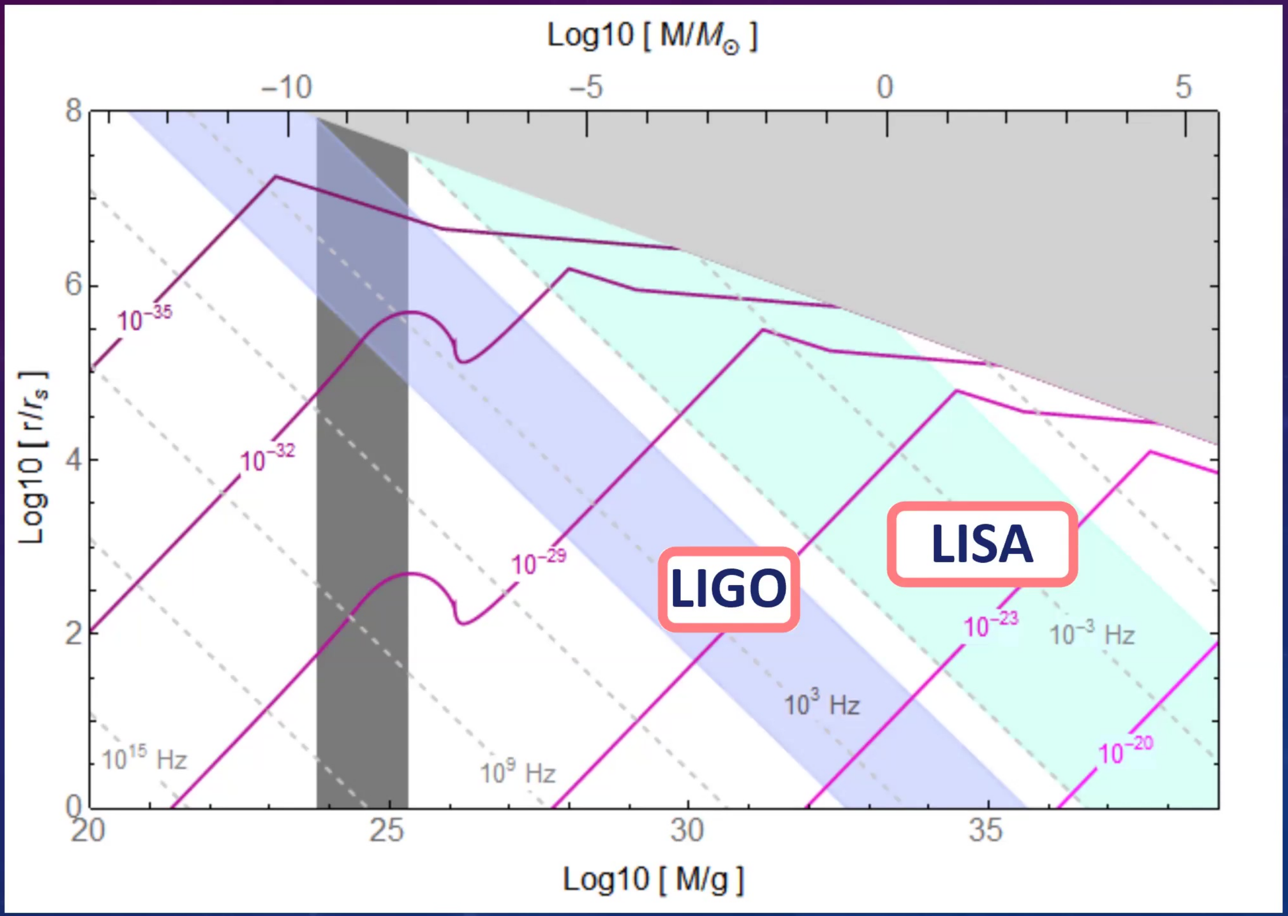

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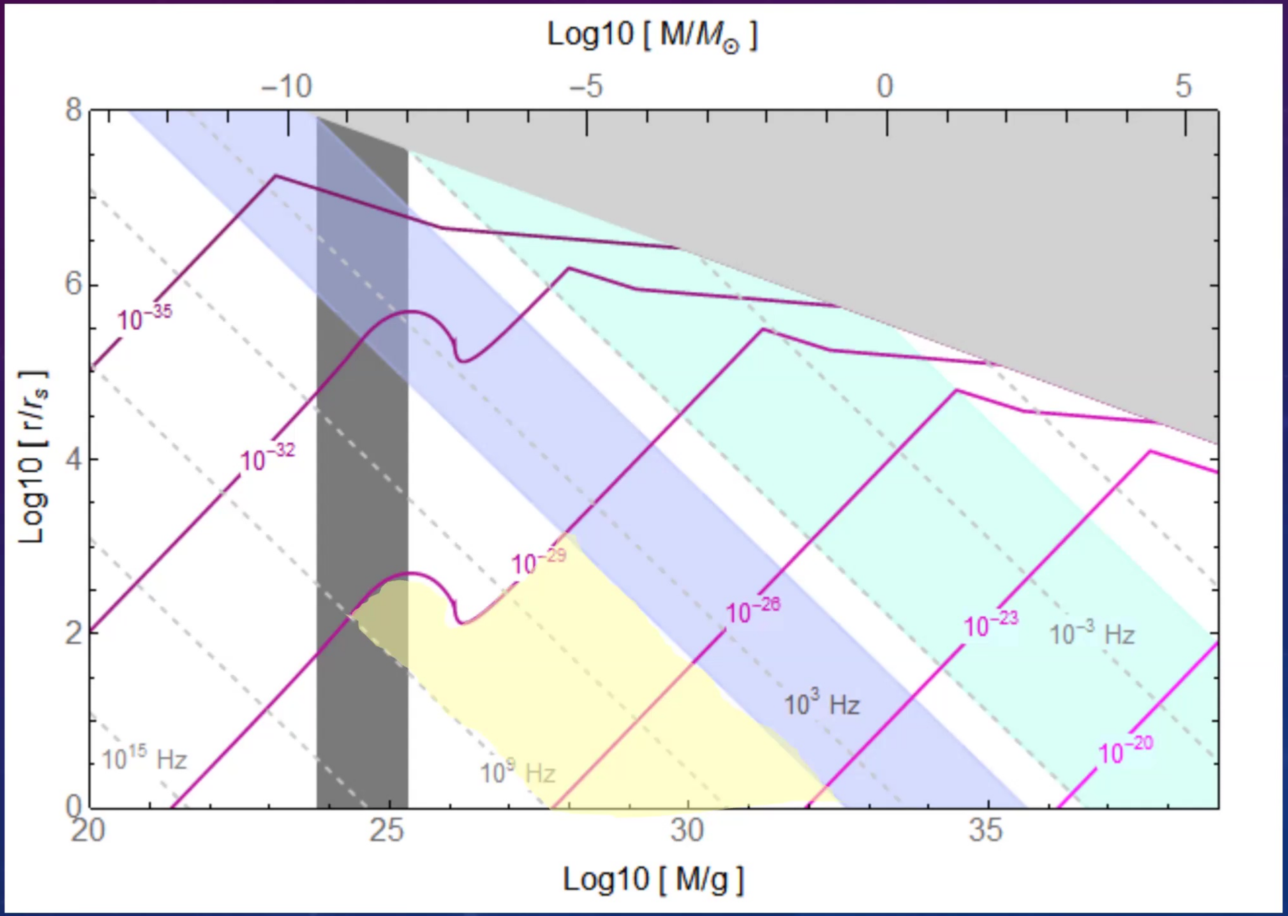

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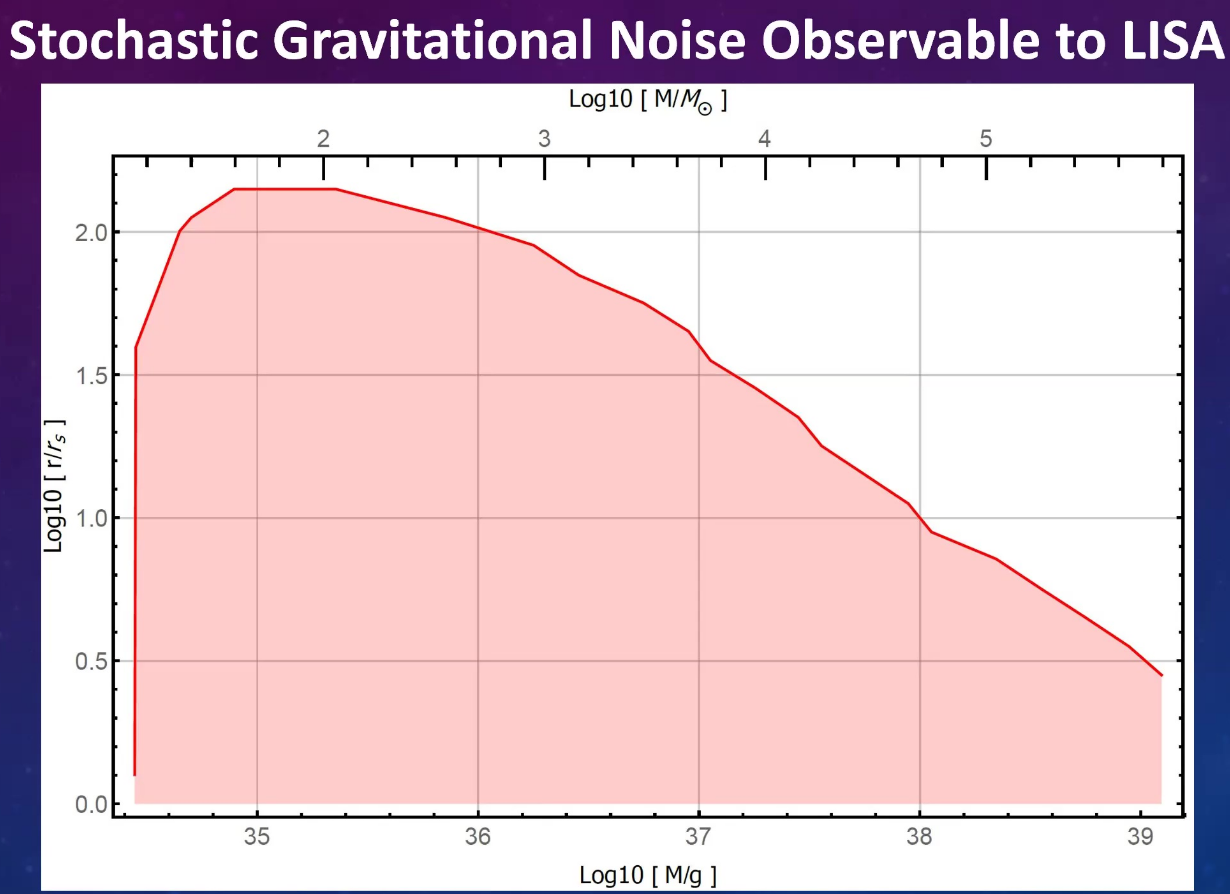
Stochastic Gravitational Wave Signal

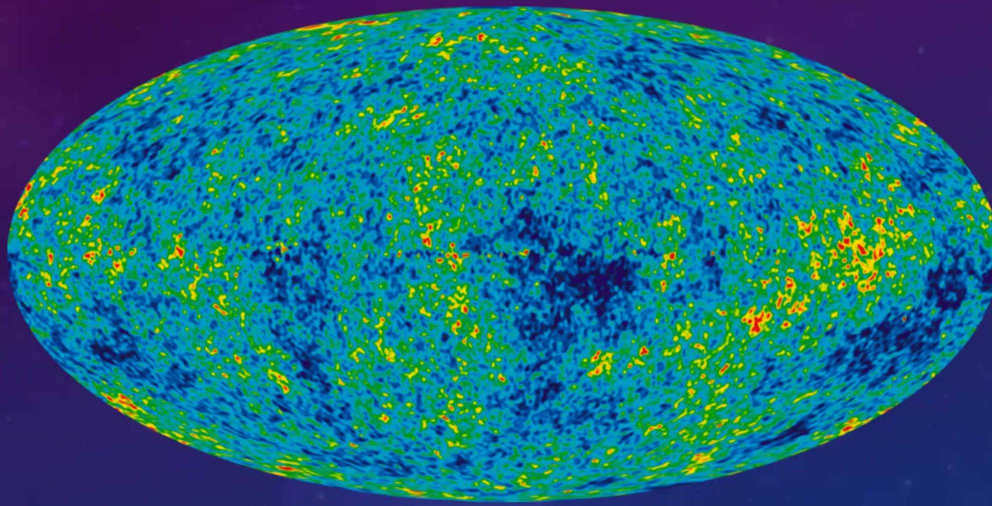


$f = 10^{-2}$

Electromagnetic Signals

- Blobs coupled to the Standard Model can produce an EM signal when they merge
- We can limit the fraction of the blob mass transformed into EM particles, χ_{EM}, based on
  - Distortions to the CMB (particles with E>10 keV)
  - Gamma-Ray Flux (particles with E>36 TeV)
  - Other model dependent signals

CMB Anisotropy Angular Distortions



EM radiation with E>10 keV released after recombination drives up the free electron fraction

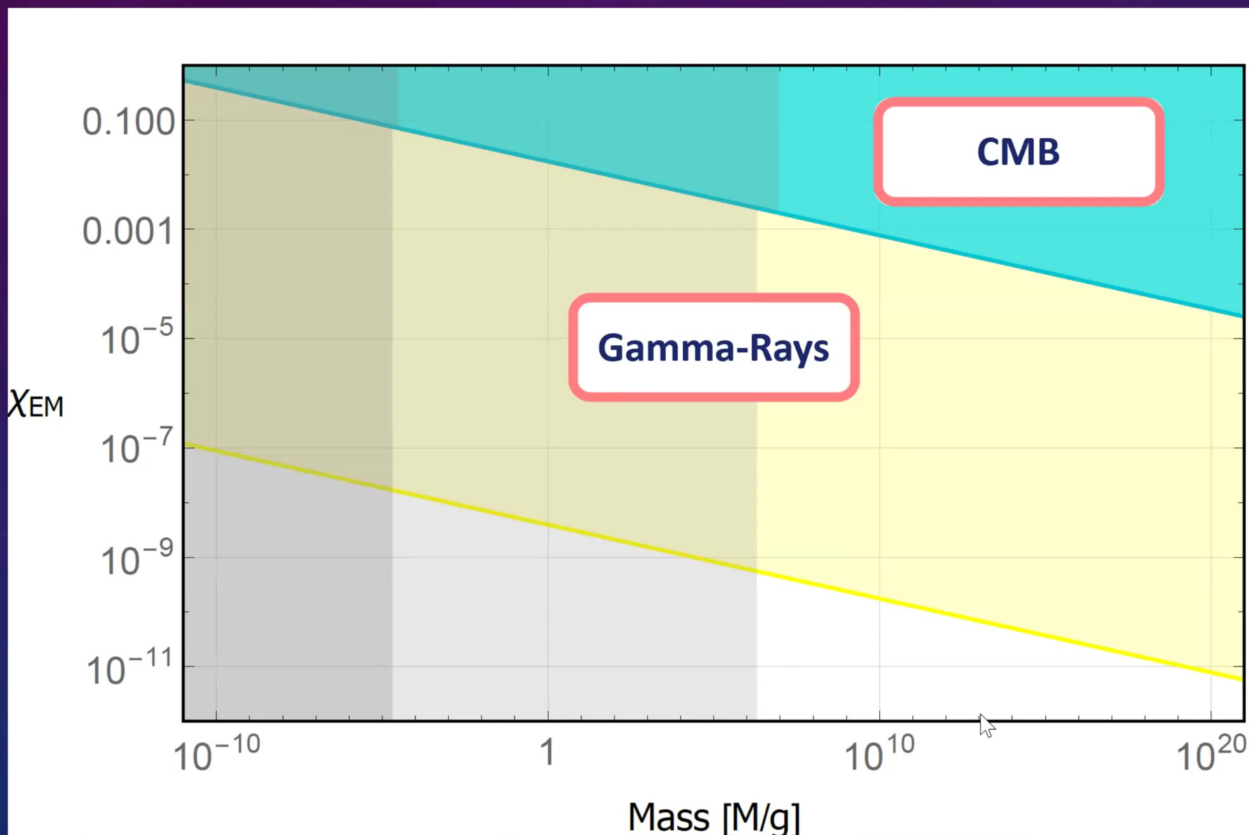
Extra electrons distort the CMB

Gamma-Rays

- High energy EM particles (E> 36 TeV) scatter off of CMB photons
- Create gamma-ray spectrum independent of starting particles
- Should not produce more gamma-rays than observed

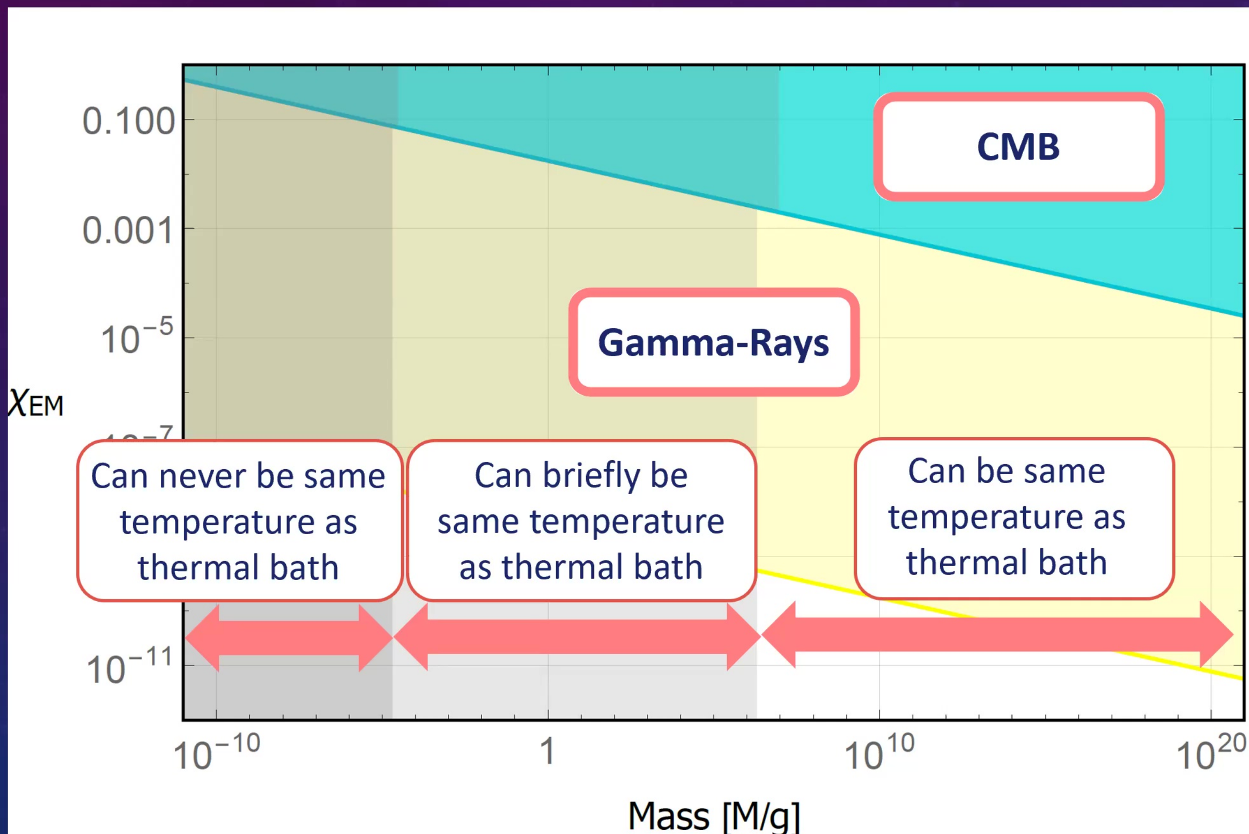
Fermi gamma-ray telescope

Electromagnetic Signals



$f = 1$

Electromagnetic Signals



$f = 1$

Future Work

- Make gravitational waveforms for blob mergers
- Find merger rate from binaries that form in clusters
- Find merger rate from disrupted binaries
- Consider specific models
- Consider charged blobs

Thank You!