THE UNIVERSE AT EXTREME MAGNIFICATION

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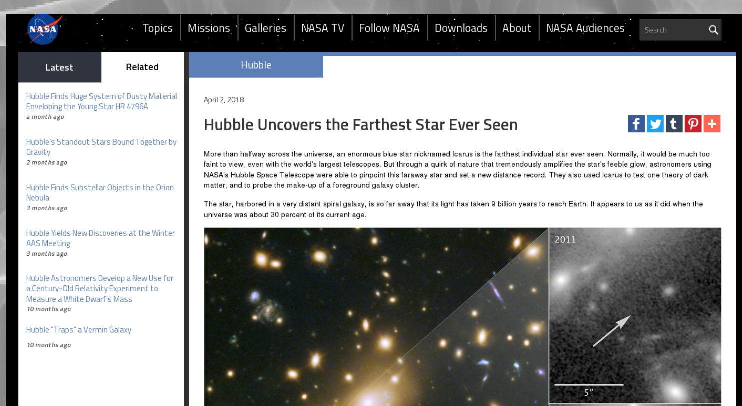
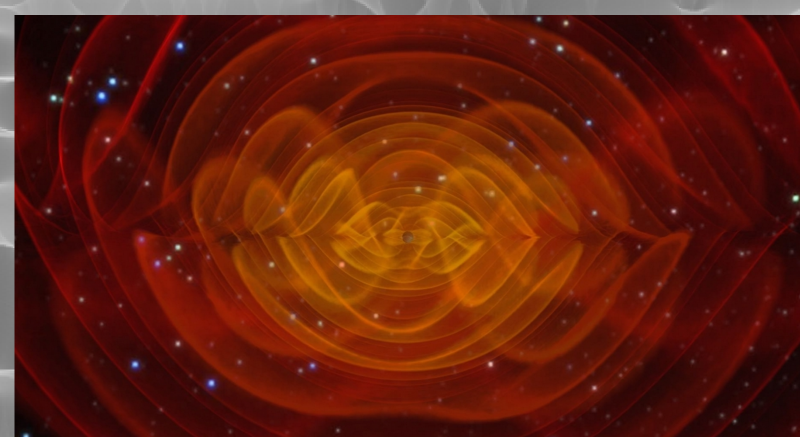
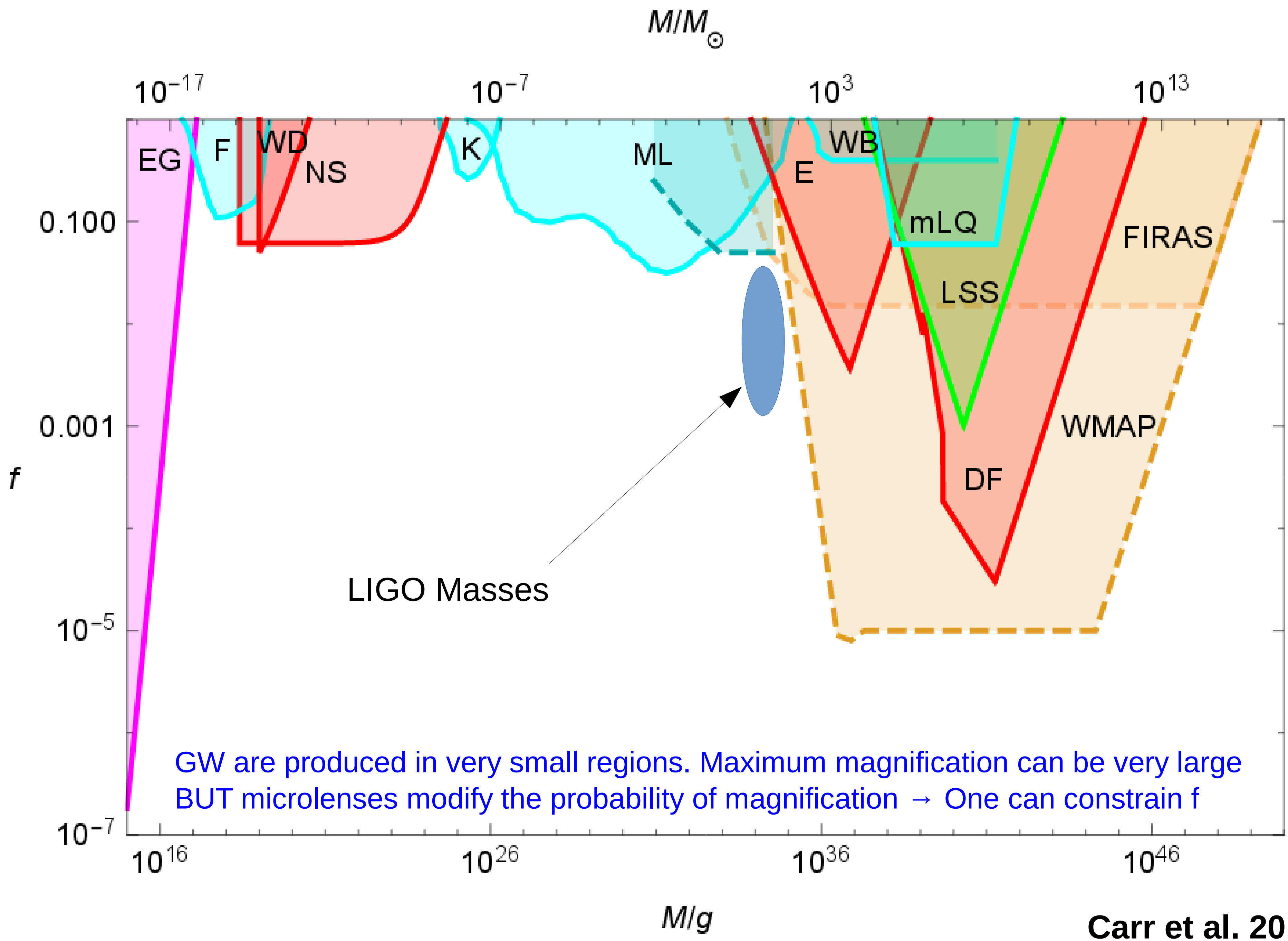
- **P. Kelly, J.M. Diego et al. 2018, Nature Ast., 2, 334**
- **J.M. Diego, N. Kaiser et al. 2018, ApJ, 857, 25**
- **M. Oguri, J.M. Diego et al. 2018, PhRevD, 97, 3518**
- **T. Broadhurst, J.M. Diego, G. Smoot, 2018, arxiv:180205273**
- **J.M. Diego, 2018, arxiv: 180604668**





KIAS, November 7th, 2018

Constraints on the total mass fraction in the form of PBH



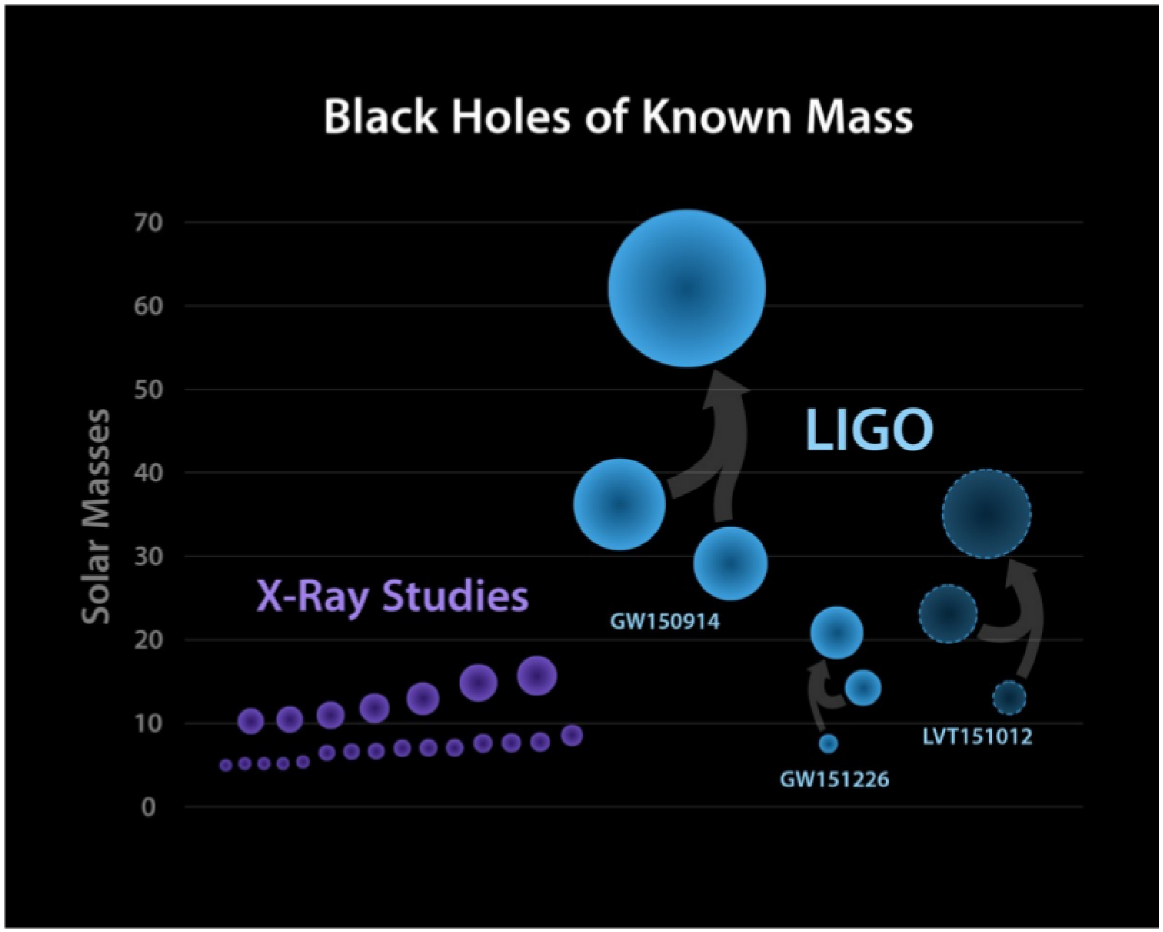
GW are produced in very small regions. Maximum magnification can be very large BUT microlenses modify the probability of magnification → One can constrain f

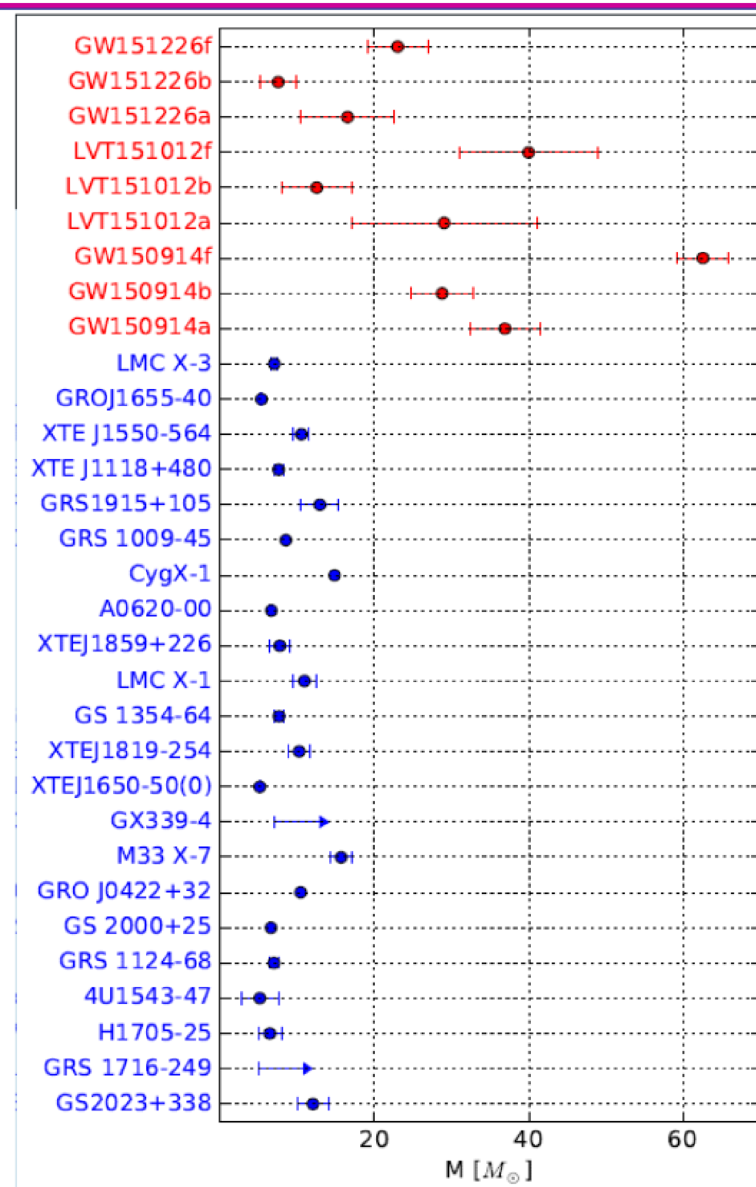
Carr et al. 2016

LIGO suggests the BBH mass function is shallow

If so, then ...

Where are the massive BBH in our Galaxy?

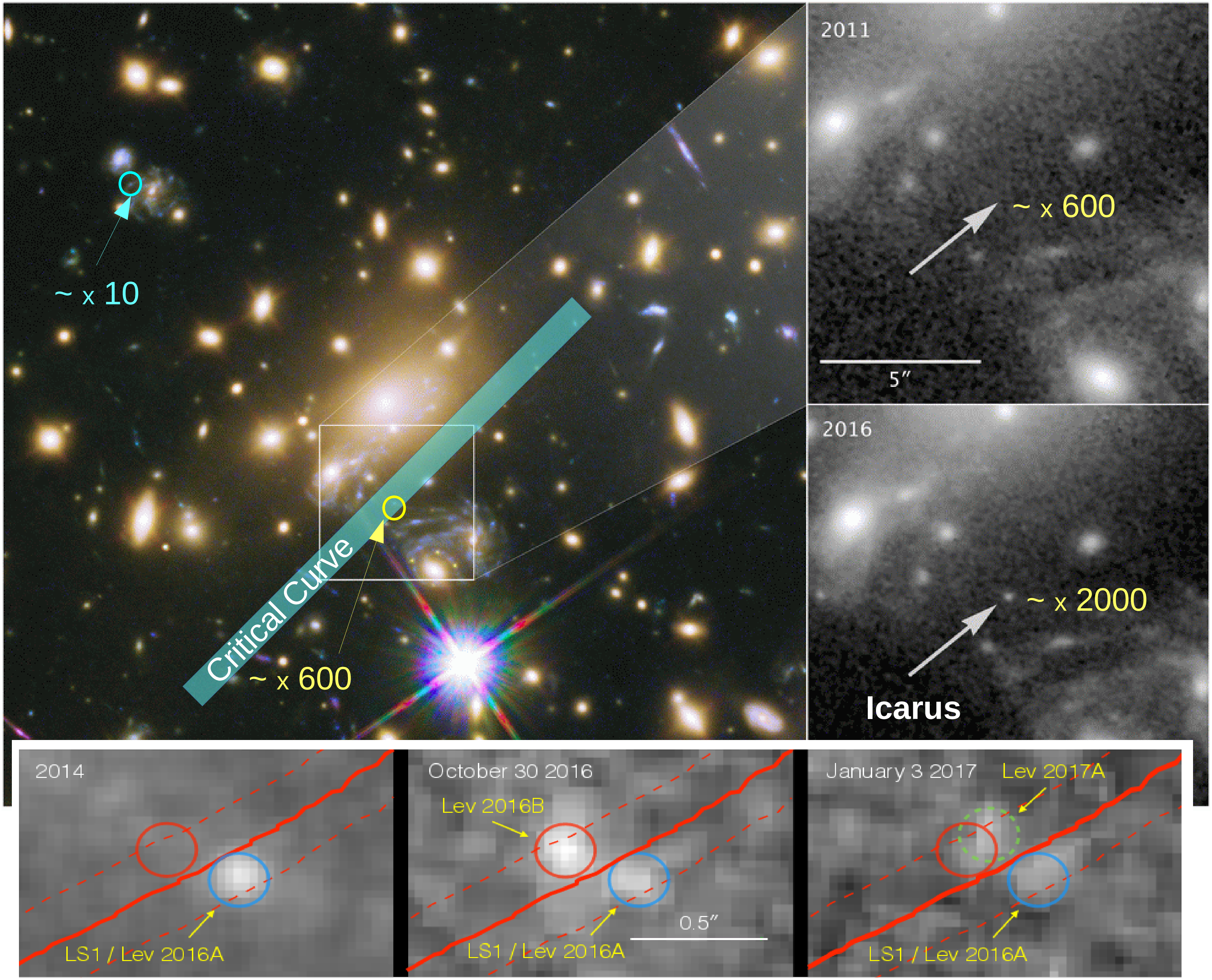




Credit: Marie Anne Bizourad & LIGO collaboration

ICARUS

P. Kelly, J.M. Diego et al 2018, Nature Ast. 2, 334-342

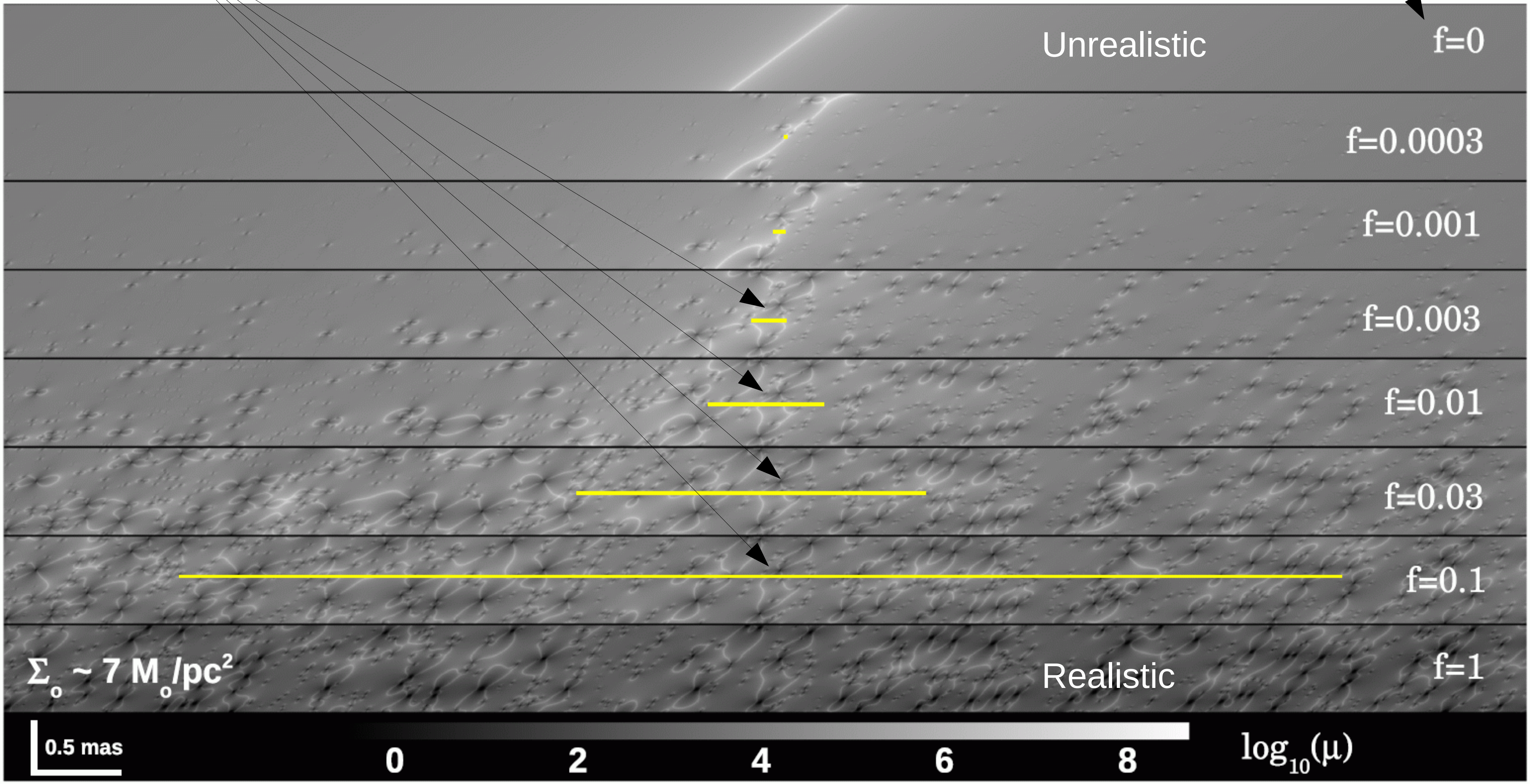


Microlenses near Critical Curves

(always present at extreme magnifications)

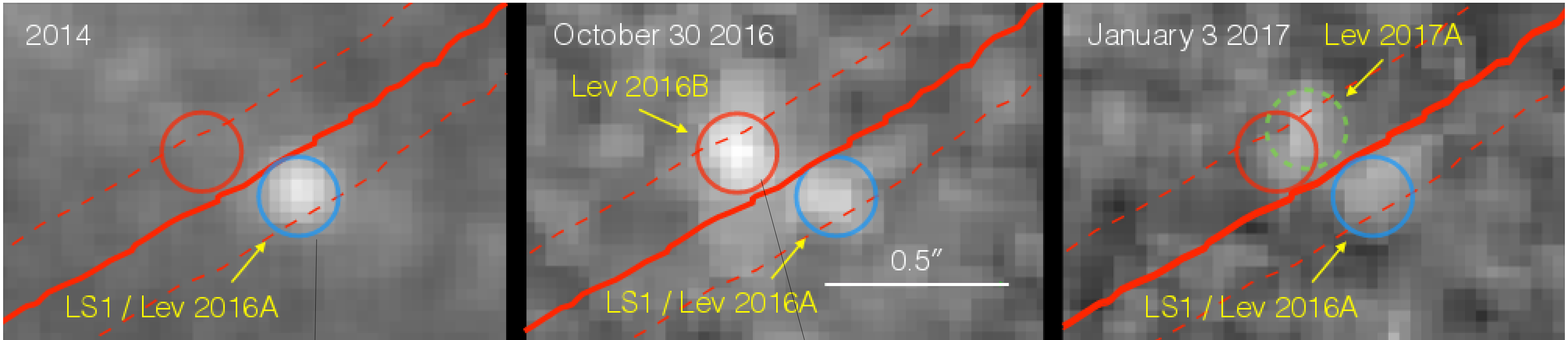
Width of saturation region proportional to Σ (microl. Surface mass density)

$f = \Sigma / \Sigma_o$

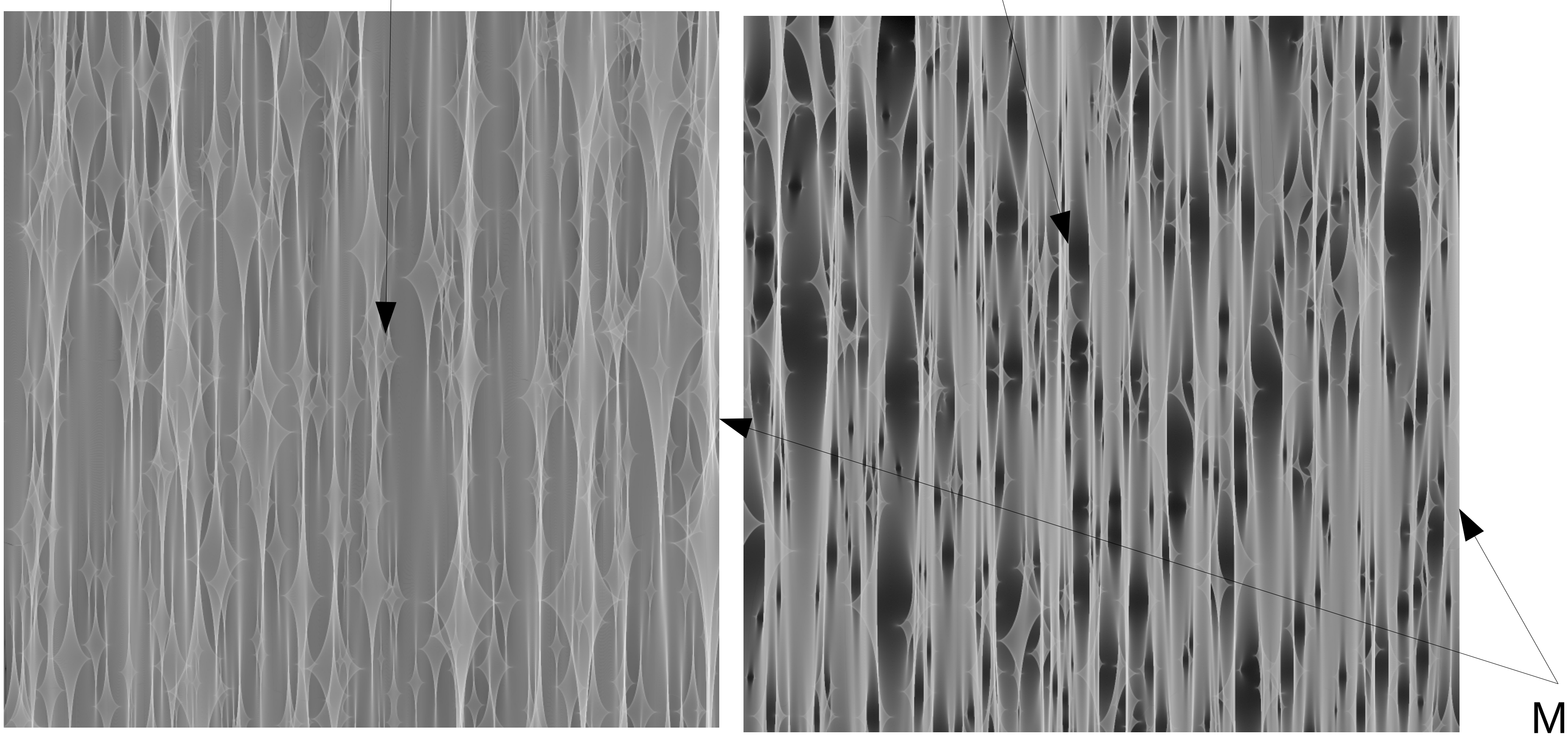


J.M. Diego, N. Kaiser et al. 2018, ApJ, 857, 25

Interpretation



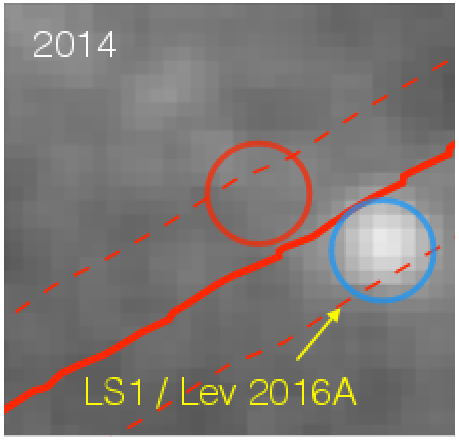
Kelly et al. 2018

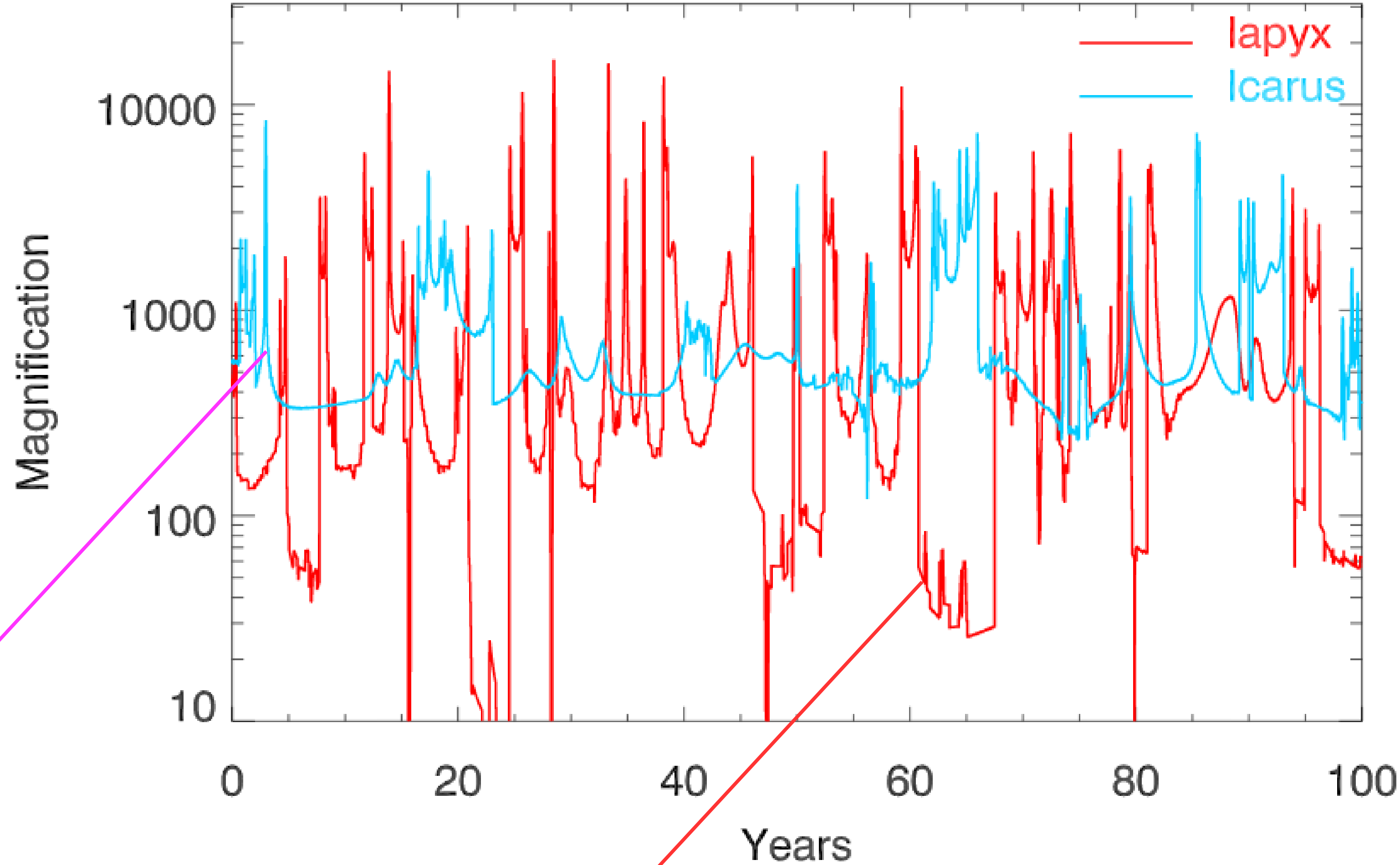


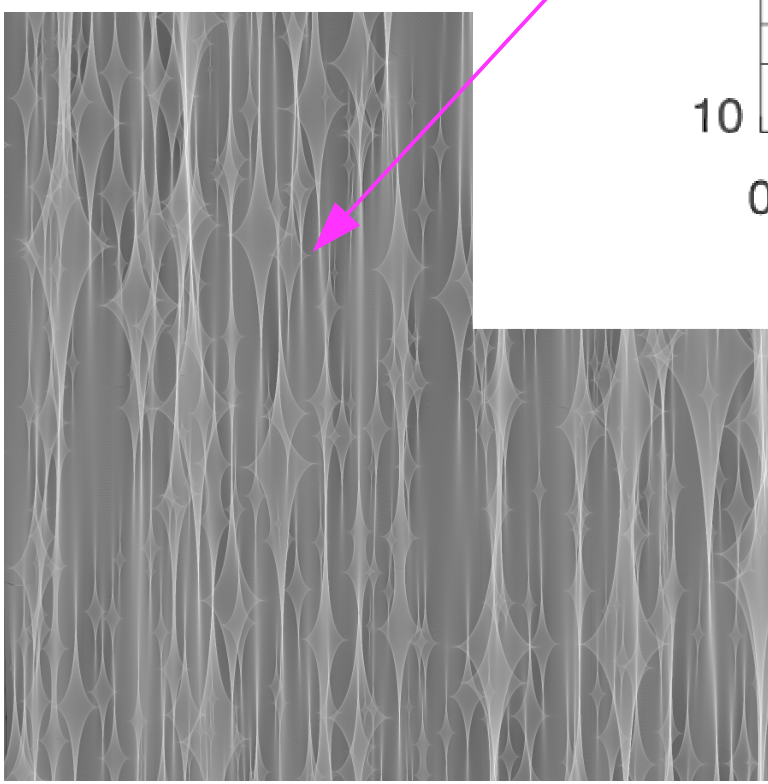
Diego et al. In prep.

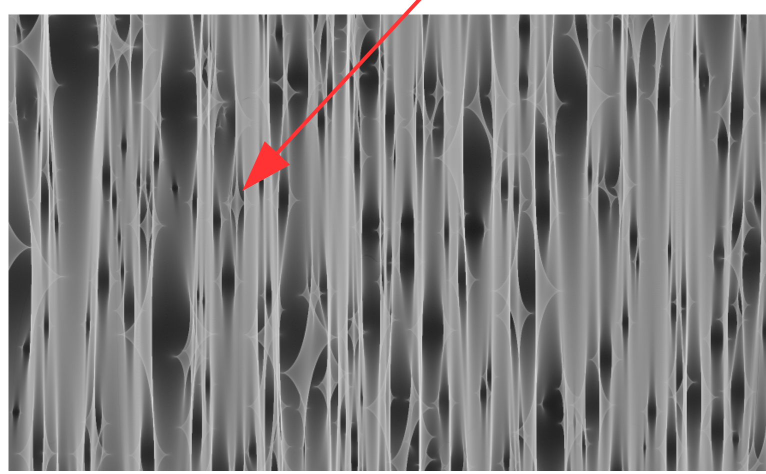
Magnification from stars in the ICM

Interpretation





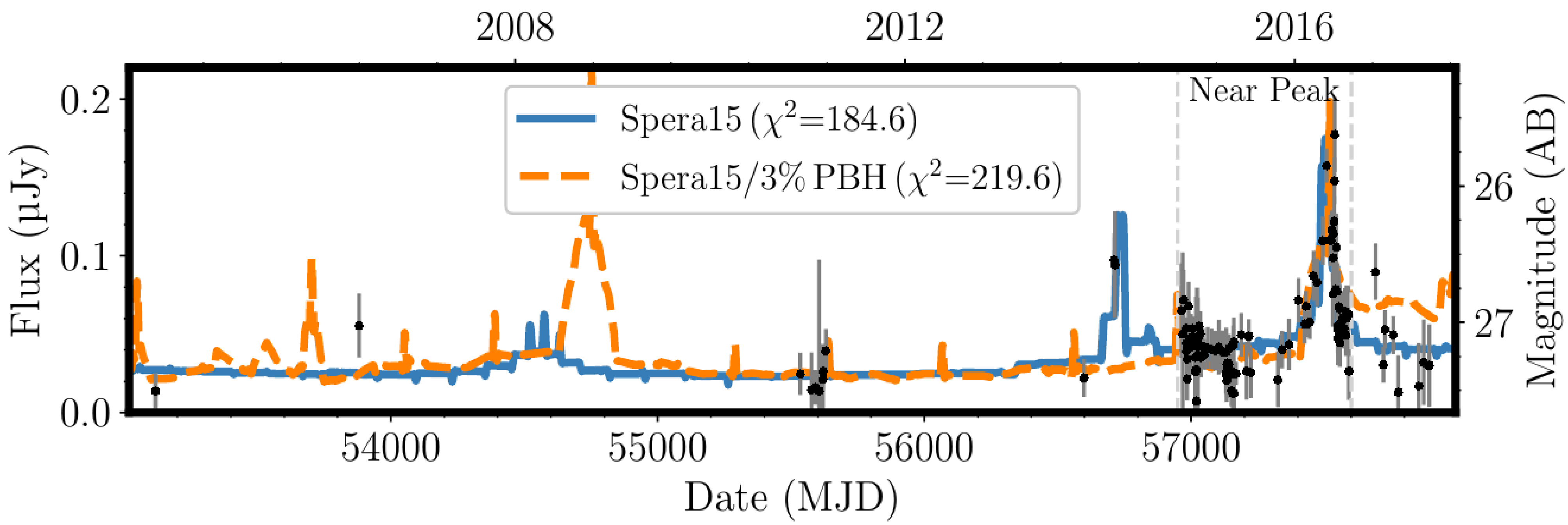




Images on this side can remain “hidden” for long periods

Diego et al. In prep.

ICARUS

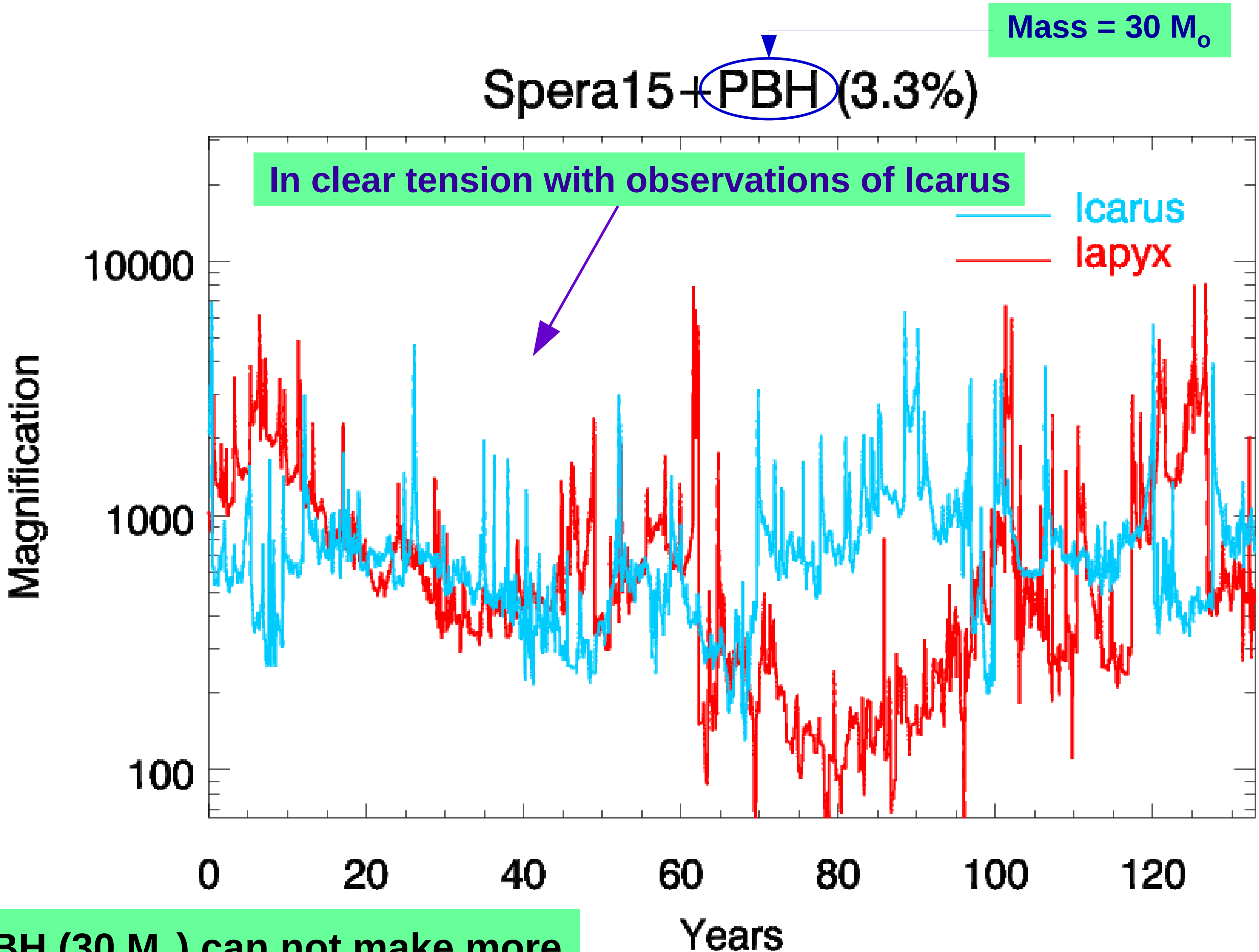


Icarus events fully consistent with scenario where microlenses are stars and remnants from the intra-cluster medium.

The amount of allowed compact dark matter (for instance PBH) in the galaxy cluster can not account for more than a few percent of the total mass of the cluster.

More data on the continuous fluctuations of Icarus would set tighter constraints in the abundance of compact dark matter, including PBH.

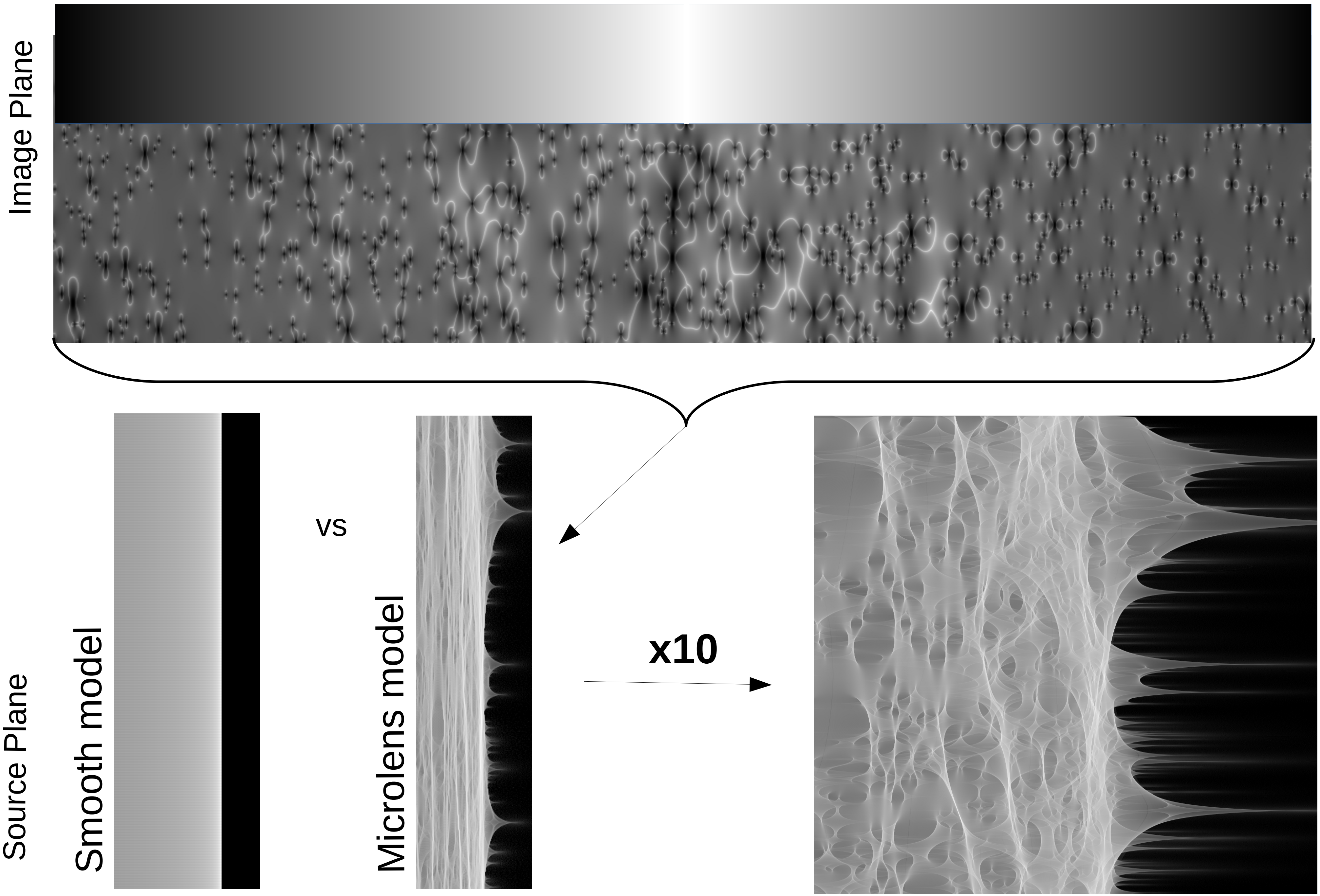
P. Kelly, J.M. Diego et al 2018, Nature Ast. 2, 334-342



PBH (30 M$_o$) can not make more than ~ 3% of all dark matter

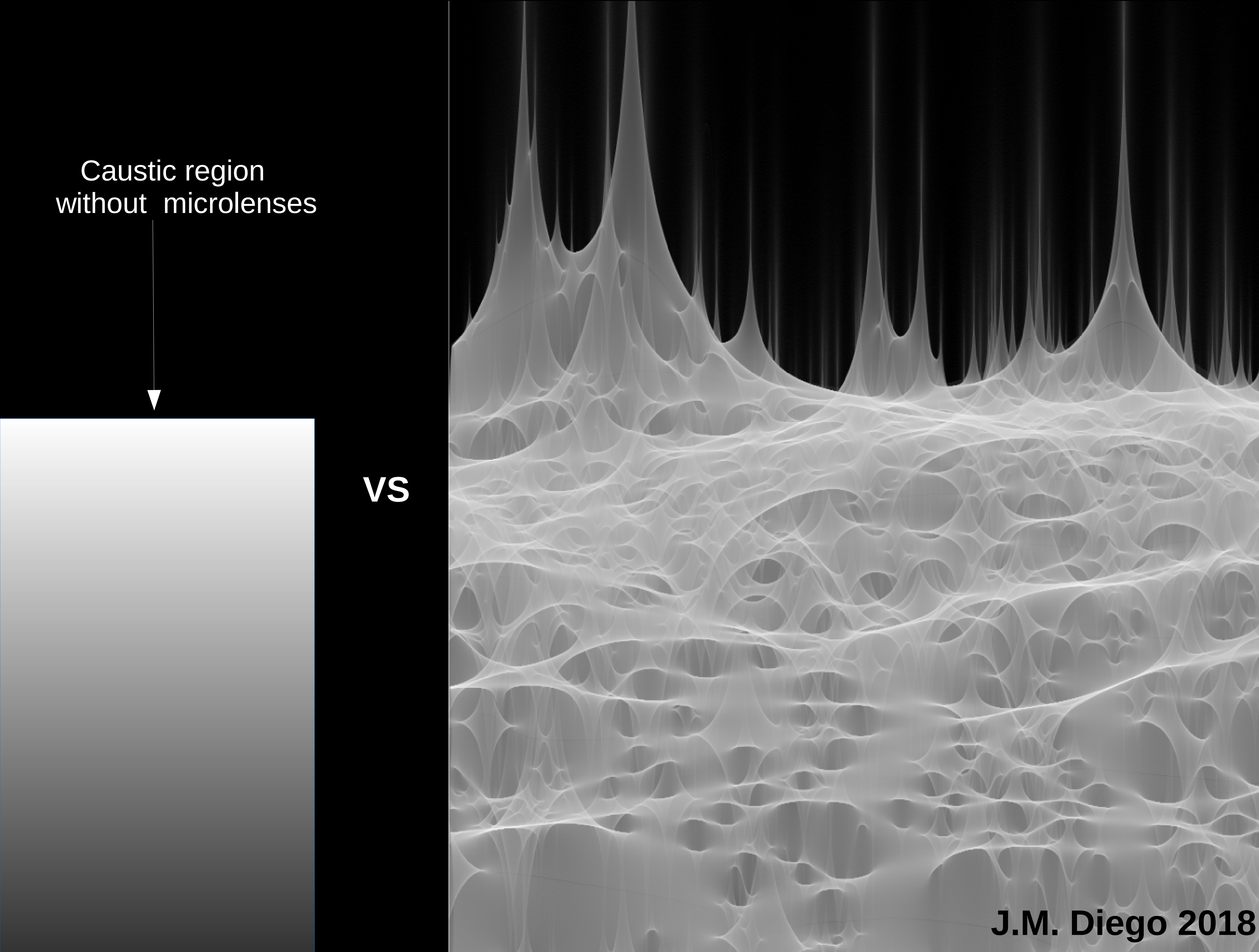
Diego, Kaiser et al. 2018, ApJ, 857, 25
Oguri, Diego, et al. 2018, PhRevD,97, 3518

Can we do better?

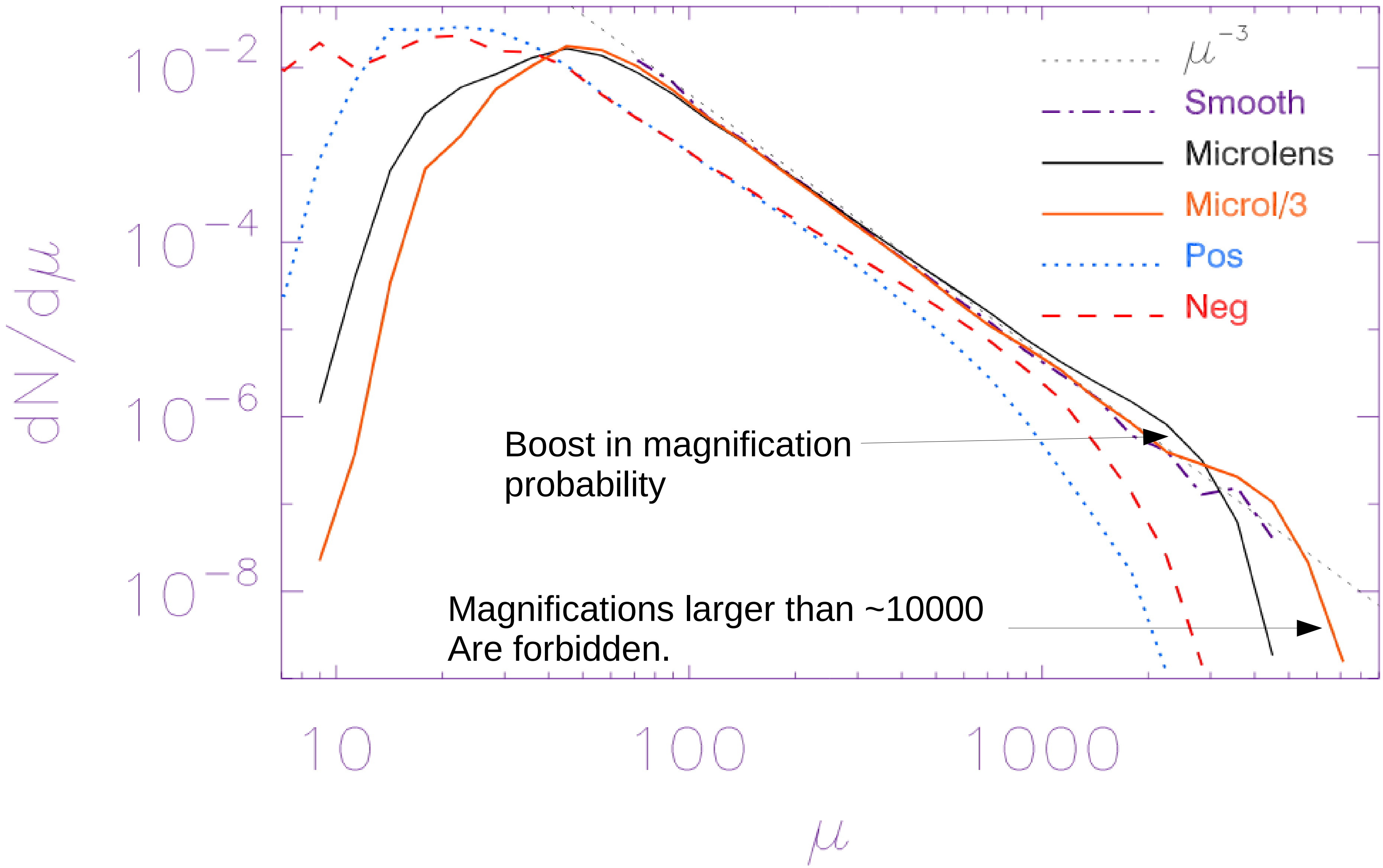


More microlenses → More distortion

J.M. Diego, 2018


Caustic region
without microlenses
VS
J.M. Diego 2018

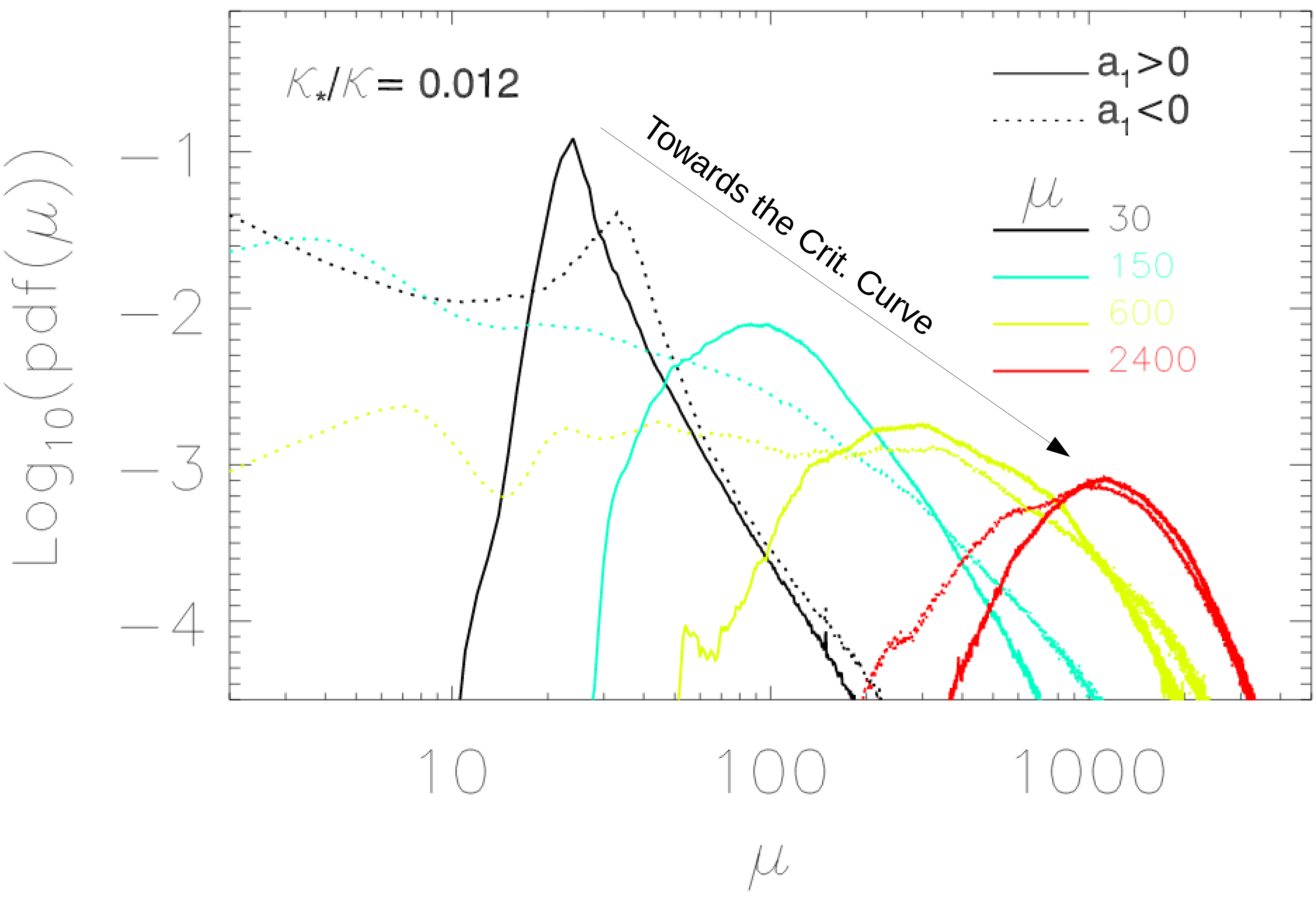
Lensing probability at critical curves in the presence of microlenses



Looking for events in regions with relatively low contribution from "stellar" microlenses is more sensitive to the abundance of compact dark matter

J.M. Diego 2018

Lensing probability at critical curves in the presence of microlenses



J.M. Diego, N. Kaiser et al. 2018

Is LIGO really seeing >20 M_{o} black holes?

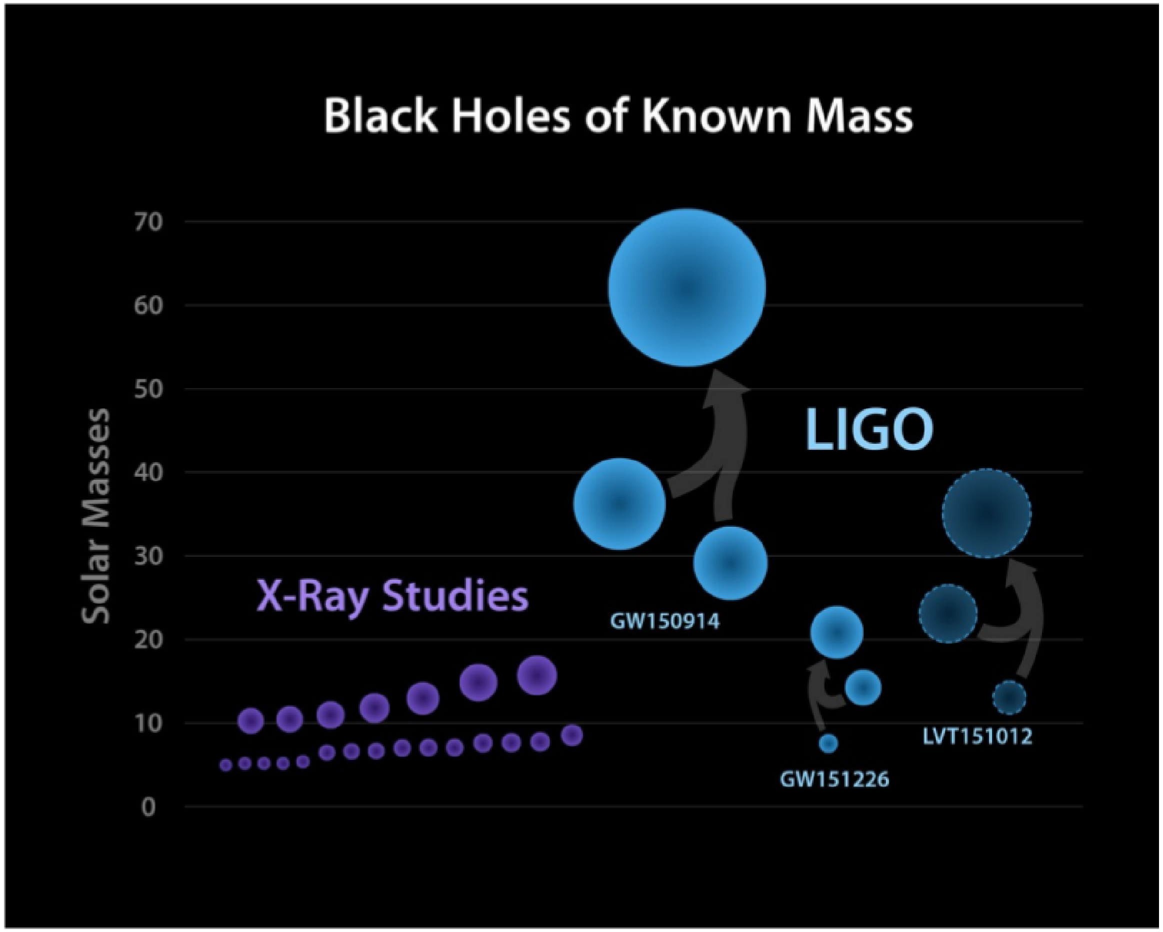
Broadhurst, Diego & Smoot

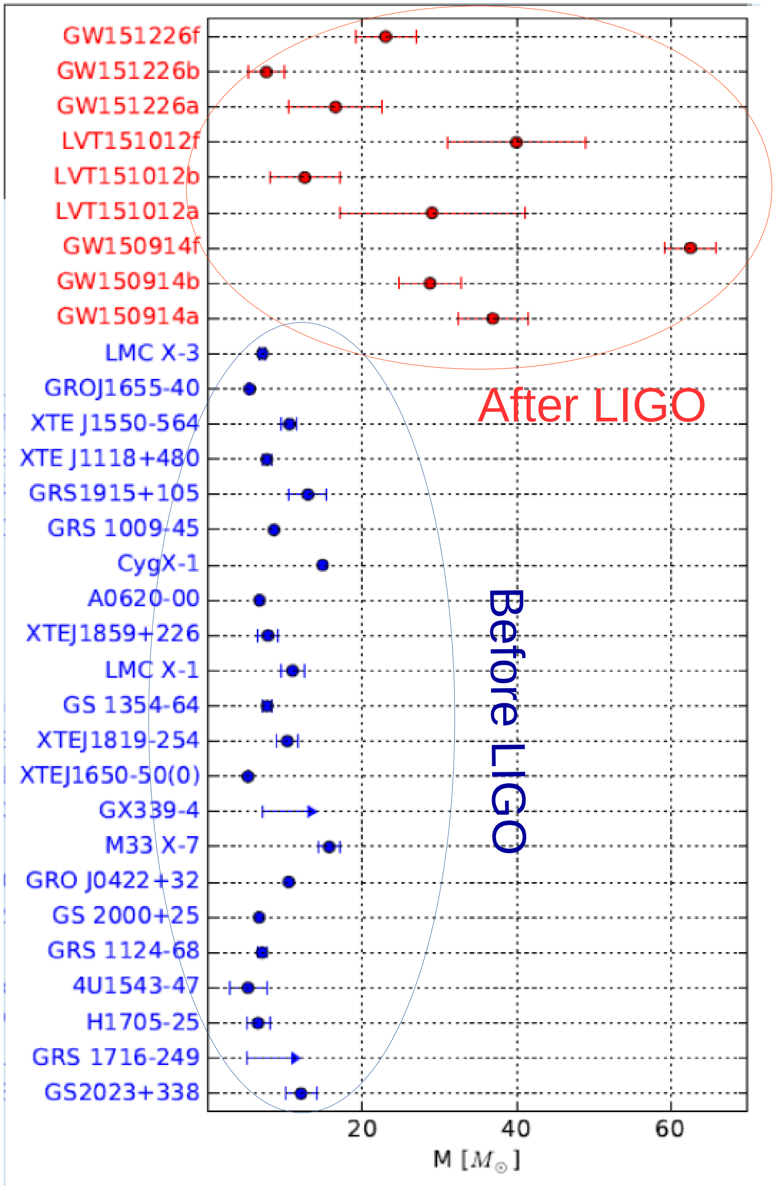
ArXiv:1802.05273

LIGO-> Massive (M>20) are as common as less massive (M<20)

If so, then ...

Why don't we see the heavy LIGO's masses in our Galaxy and in local galaxies?





Credit: Marie Anne Bizourad & LIGO collaboration

LIGO basics

Observed

$$M = M_c(1+z)$$

Inferred

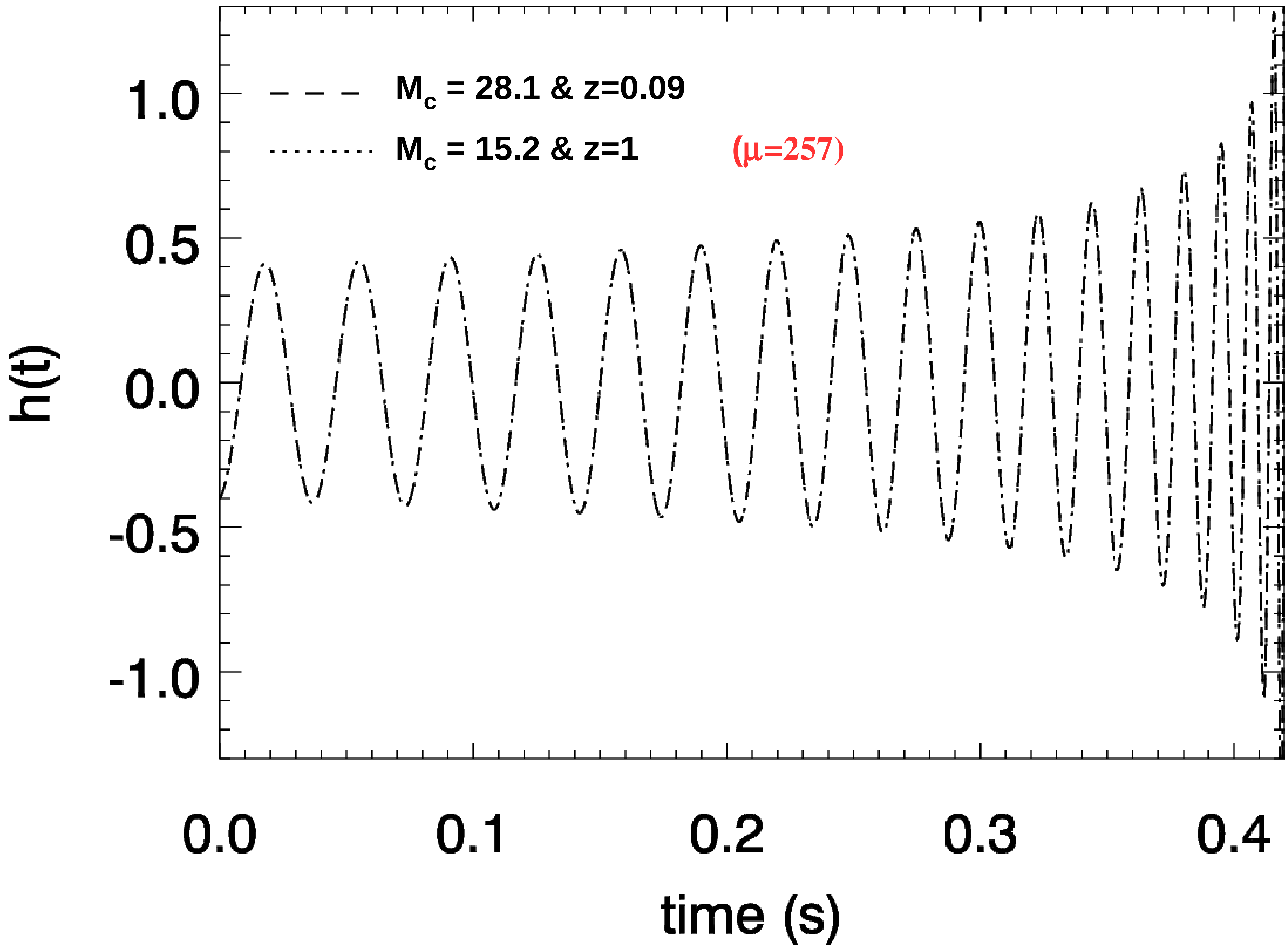
$$h(t) \sim \mathrm{sqrt}(\mu)\left(M^{5/6}/D(z)\right)F(t,M,\theta)$$

$$D(z_{est}) = D(z_{true})/\mathrm{sqrt}(\mu)$$

IF an event at high z is magnified by a large factor, μ, then if lensing is ignored, it will appear as a much closer event with a larger mass.

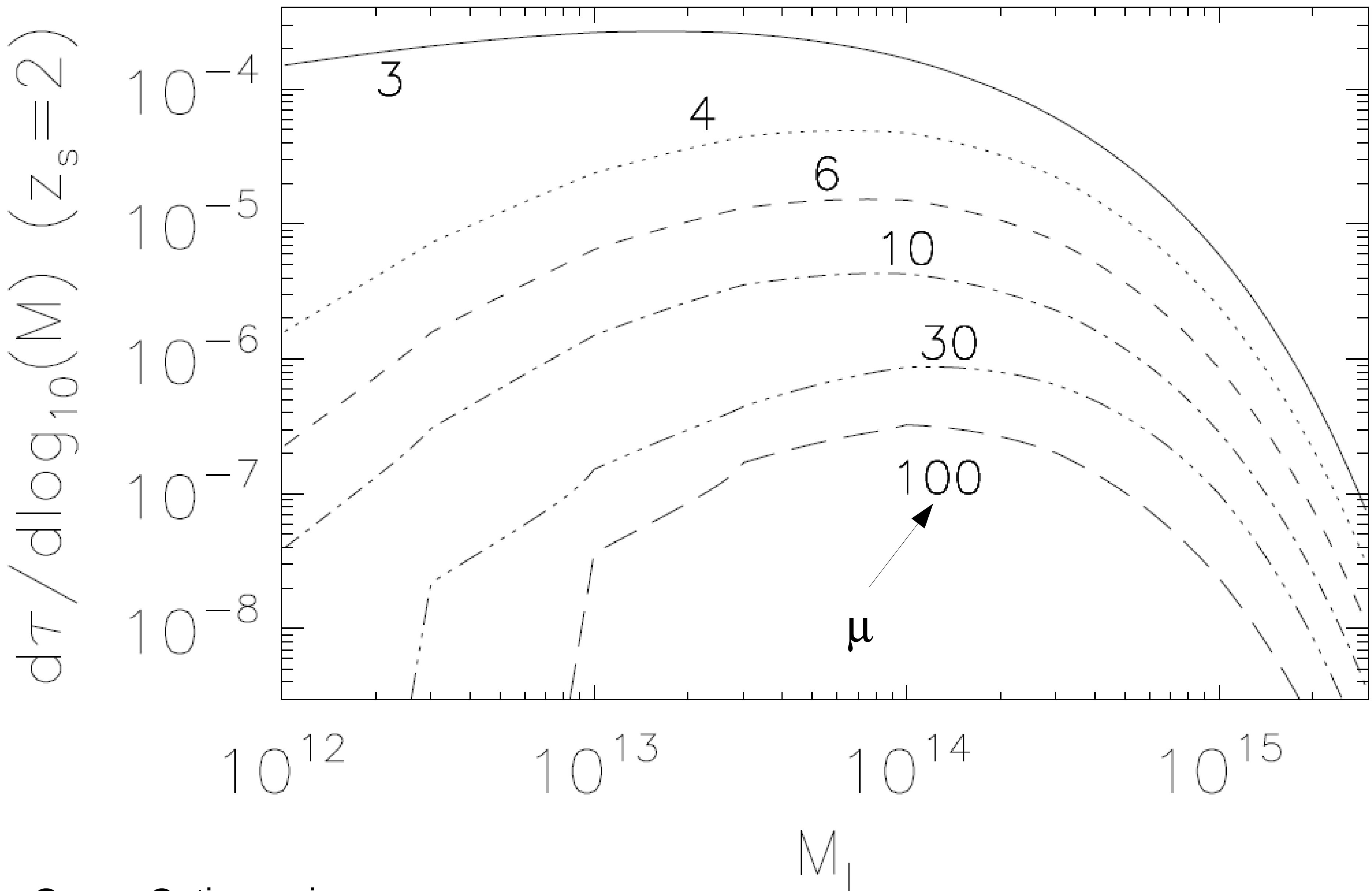
Then, **IF** the probability of lensing is reasonable, some of the LIGO events may be actually distant lensed events with smaller masses

Unlike other events (SNe, GRB, etc) all sky is observed at once. The only limitations are dictated by the geometric factor, θ.



M_c = 28.1 & z=0.09
M_c = 15.2 & z=1
(μ=257)
1.0
0.5
0.0
-0.5
-1.0
h(t)
0.0
0.1
0.2
0.3
0.4
time (s)

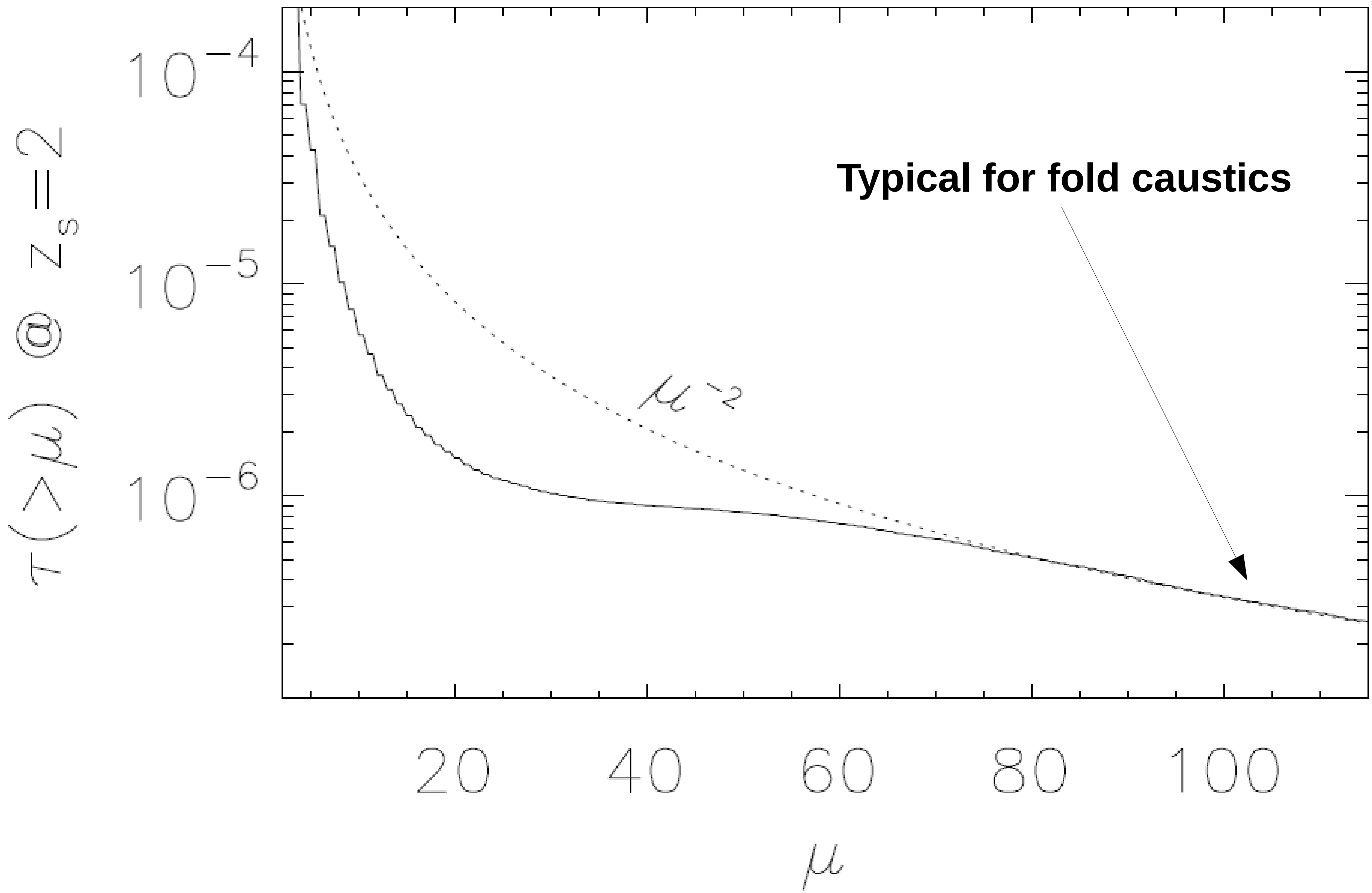
Massive halos are more relevant for extreme magnifications



Geom. Optics regime

Diego 2018

Net probability by all halos & at all redshifts for a source at z=2



Broadhurst, Diego & Smoot 2018

A back of the envelope calculation

Probability of having magnification larger than 100 : ~3E-7

Volumen between z=1.9 and 2.1 : ~ 100 Gpc^3

Rate of events at z=2 : ~ 3E4 /(yr Gpc^3)

Compare with $\sim 10^6$ per yr & Gpc^3 for SNe

Total Number of events between z=1.9 and 2.1 : 3E6 per year

Total Number of lensed events between z=1.9 and 2.1 : ~ **1 per year**

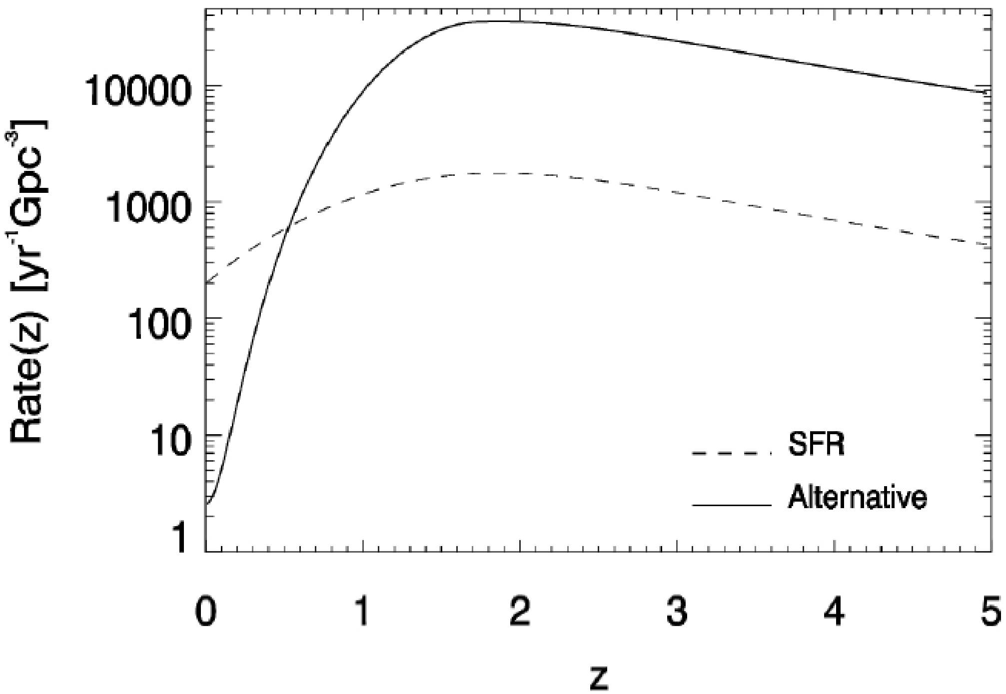
Rate needs to be of order 10^4 for lensing hypothesis to work

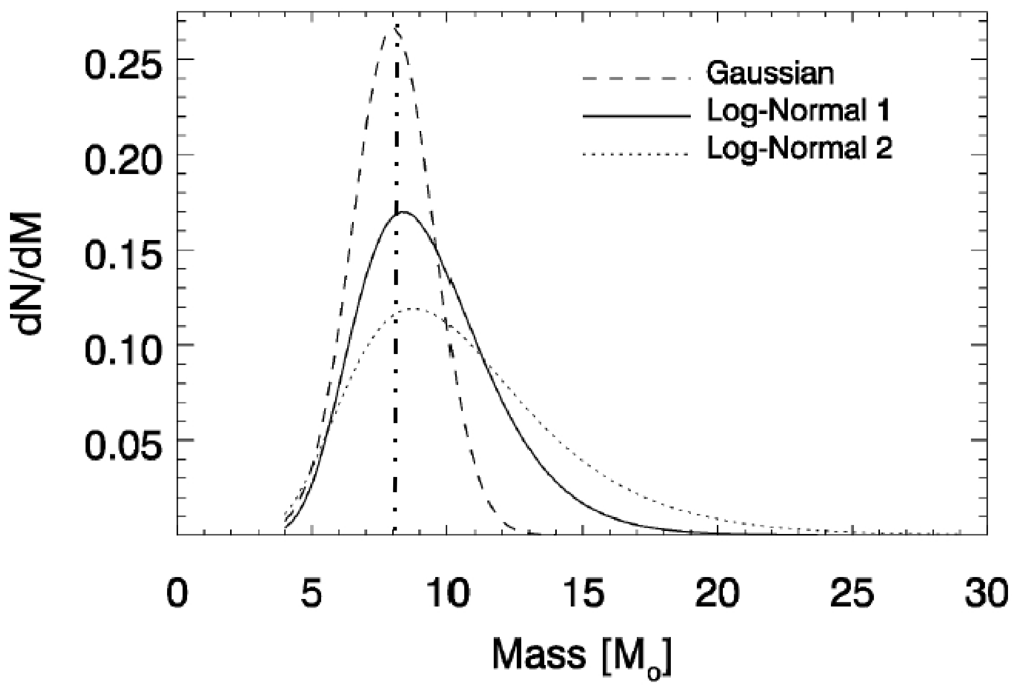
We do not know what the actual rate is !

Model elements: Rates and BBH mass function

Basic assumption is that the rate of events at high-z is high to compensate the small probability for lensing

Mass function is assumed to be “natural”, that is, consistent with observational constrains from our Galaxy

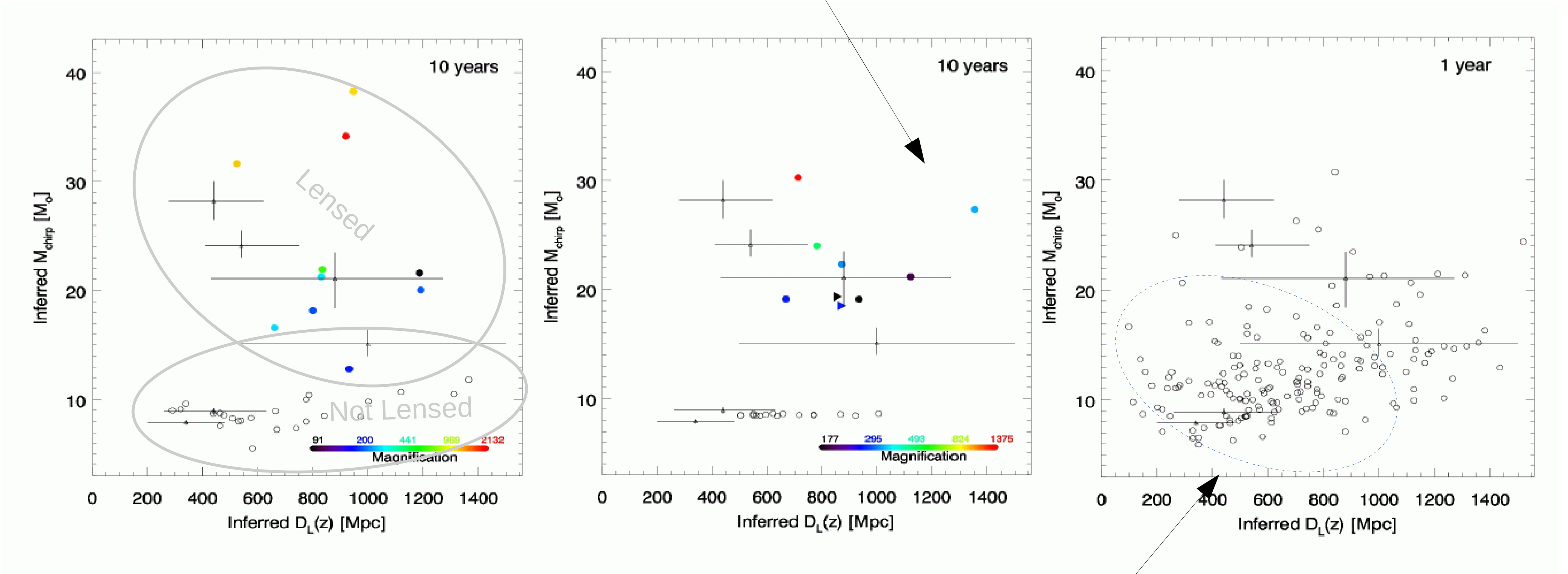




Broadhurst, Diego & Smoot 2018

Strong Evolution + Monochromatic MF

A simple monochromatic mass function already does a decent job at reproducing the data



Modest Evolution +Broad MF

Many events should have been detected by LIGO in this regime. Where are they?

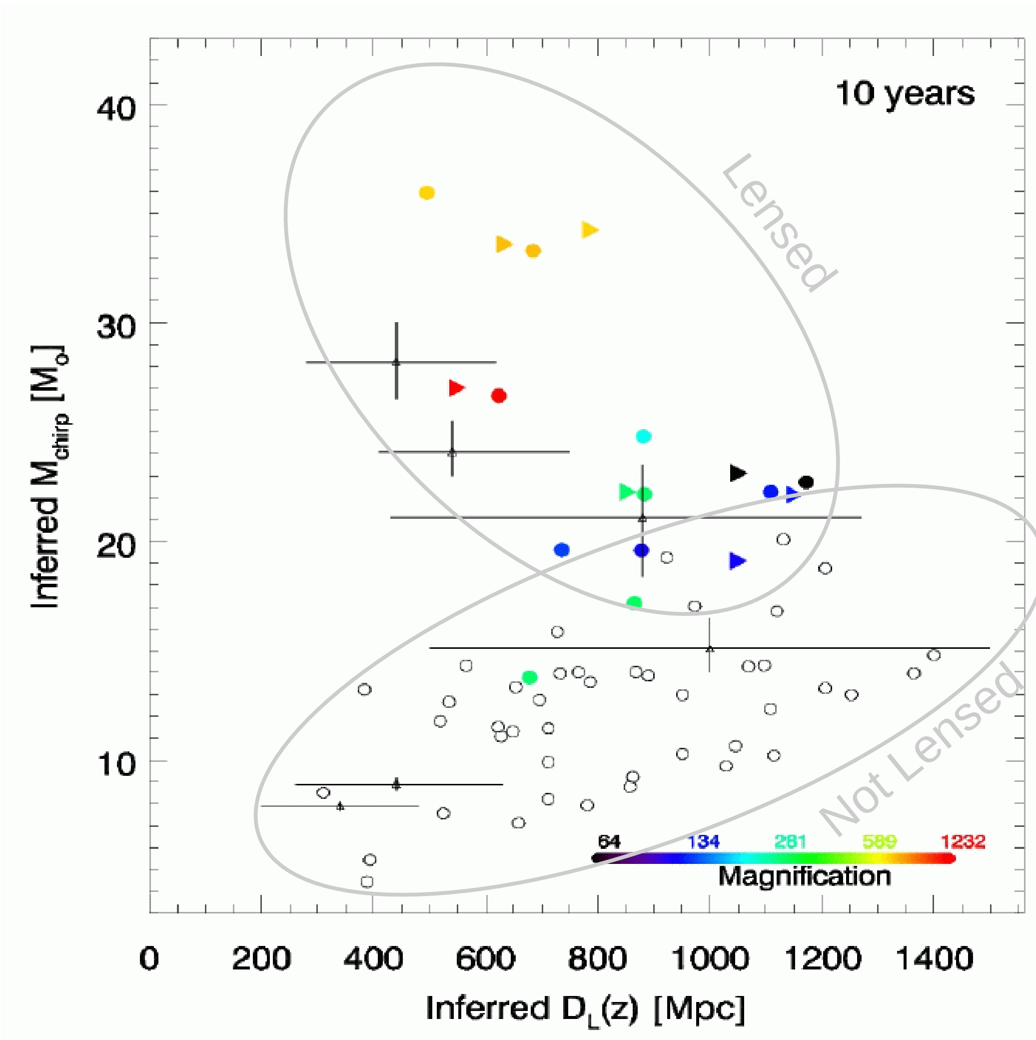
Strong Evolution + Gauss MF

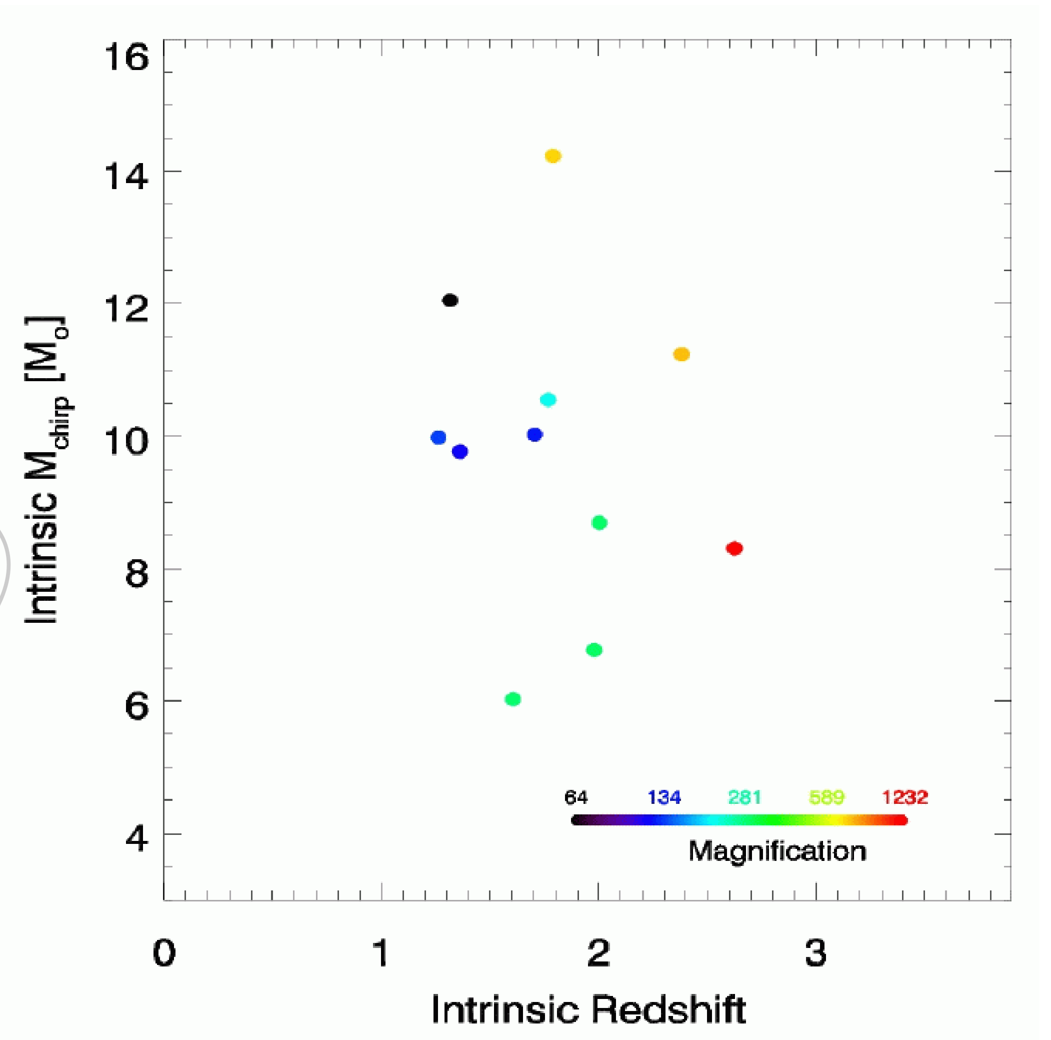
A Gaussian mass function goes in the right direction

Broadhurst, Diego & Smoot 2018

O U R   B E S T   M O D E L

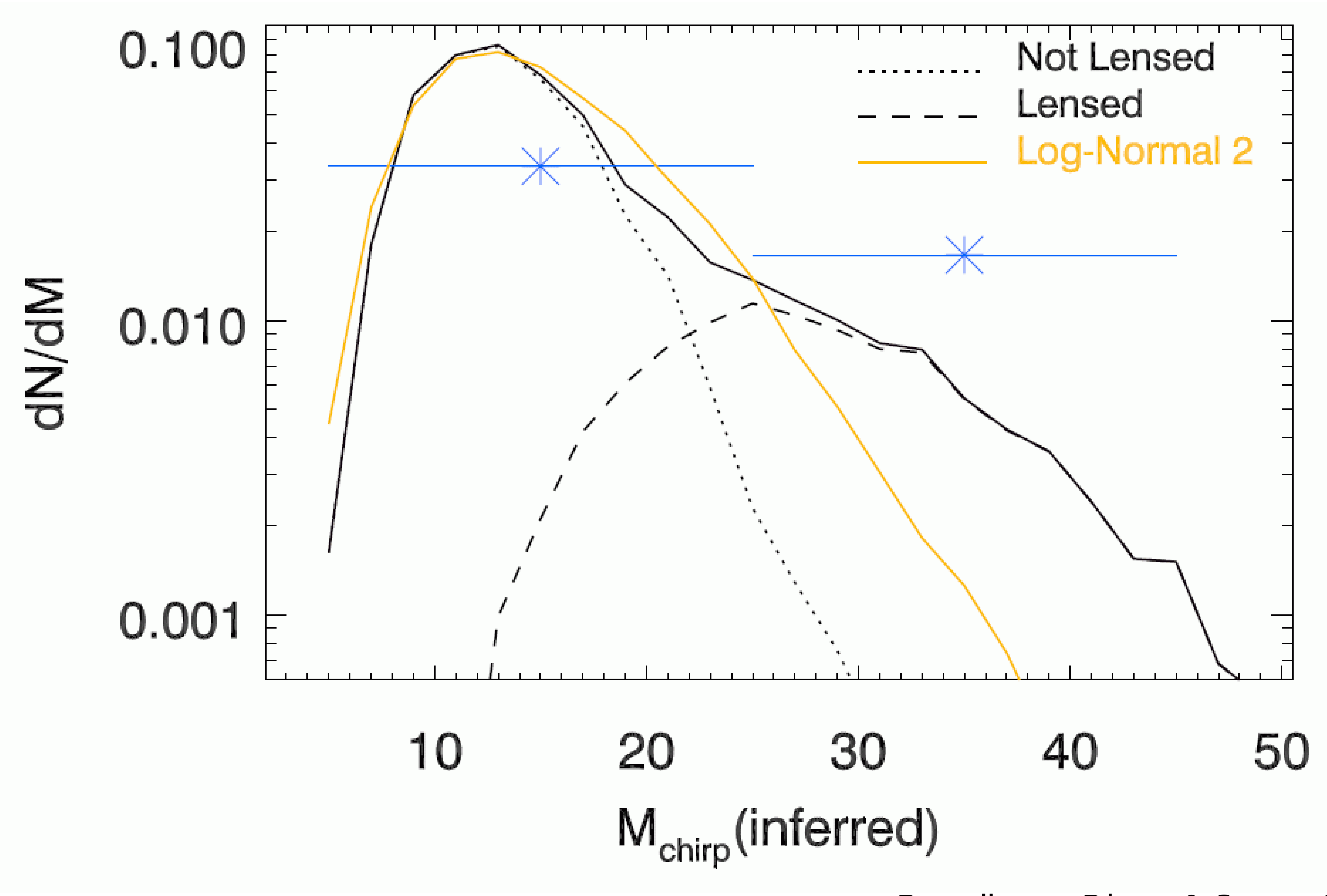
Strong Evolution + Natural MF
Rate of low and high frequency events in reasonable agreement with observations





Broadhurst, Diego & Smoot 2018

Observed mass function should be bi-modal or have a long tail



Broadhurst, Diego & Smoot 2018

C O N C L U S I O N S

PBH are a candidate for DM which become popular after LIGO detected a relatively abundant of BH with >20 M_o

Microlensing can set limits on the abundance of BH (including PBH)

LIGO → IF the rate of events at z~2 is in the range of 10^4, the low frequency events observed by LIGO are (likely) gravitationally lensed WG at z>1 with BH masses ~ 10 Msun.

If LIGO-lensing is taking place, should see even more massive events in the future at *troublesome* small distances (are we living in a special Galaxy?) and interference effects.

Events at extreme magnification are more likely than previously thought (specially for bright objects).