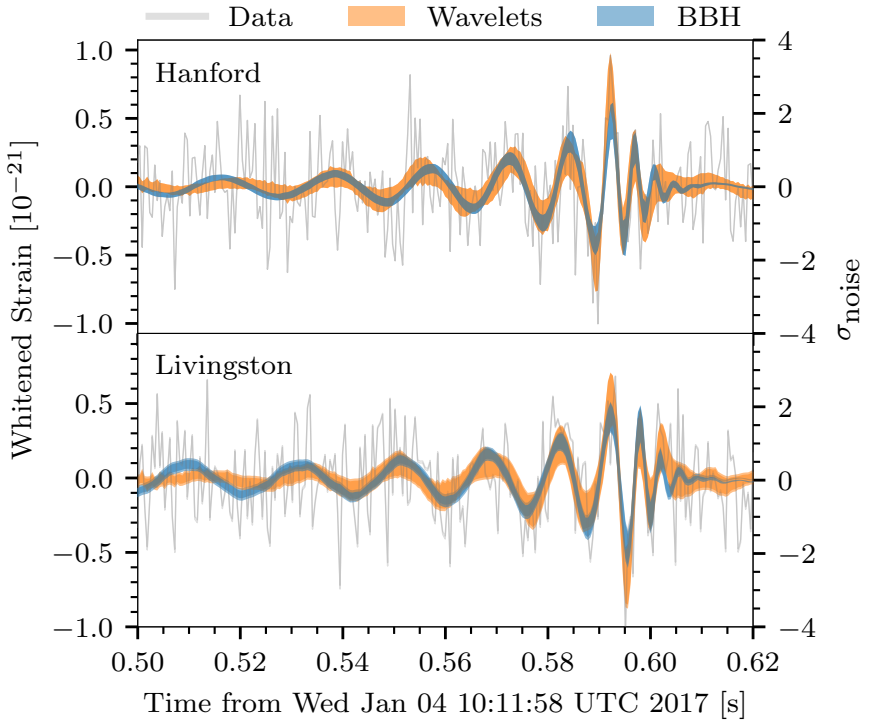
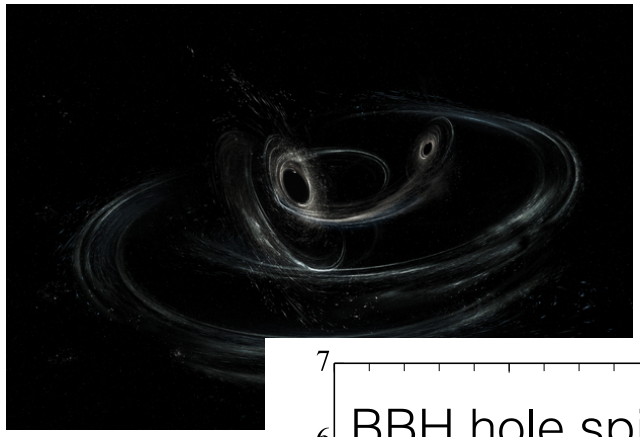
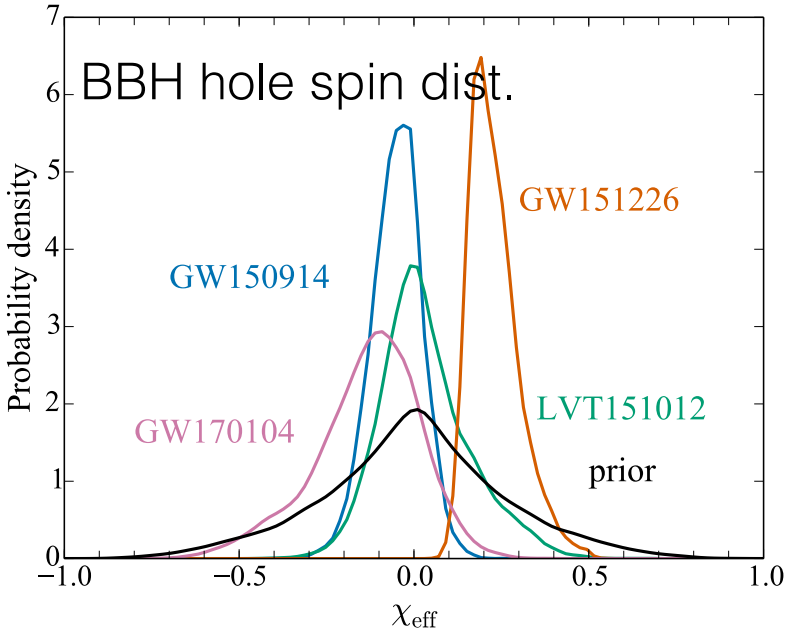
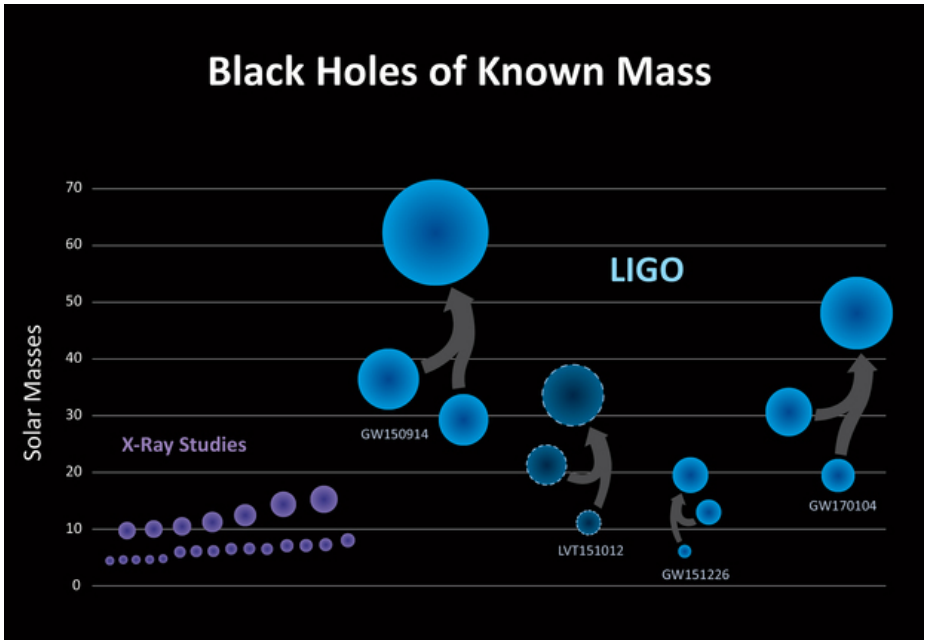
A big discovery! Gifts from the Universe









- From black hole binary
- Relatively heavy and low spin
- PBHs need to merge within cosmic age

From K. Ioka

Many BHs in Our Galaxy

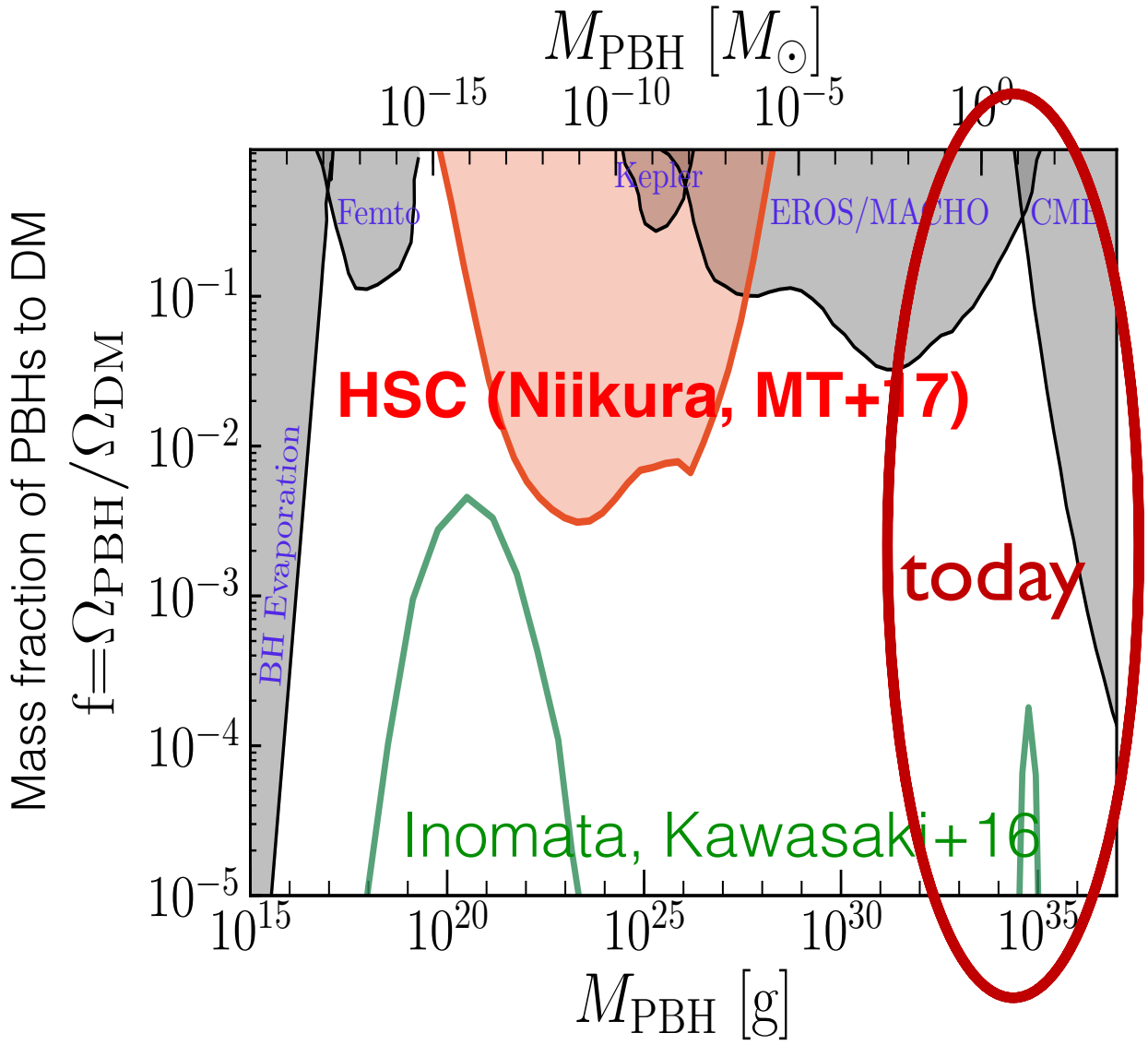
KI, Matsumoto, Teraki, Kashiyama & Murase 16

$70\ \mathrm{Gpc^{-3}\ yr^{-1}} \div 0.01\ \mathrm{galaxy\ Mpc^{-3}} \times 10^{10}\ \mathrm{yr}$

~ 70000 Merged BHs/galaxy

E_{spin}~10^{8} Supernovae

Primordial Black Hole (PBH)

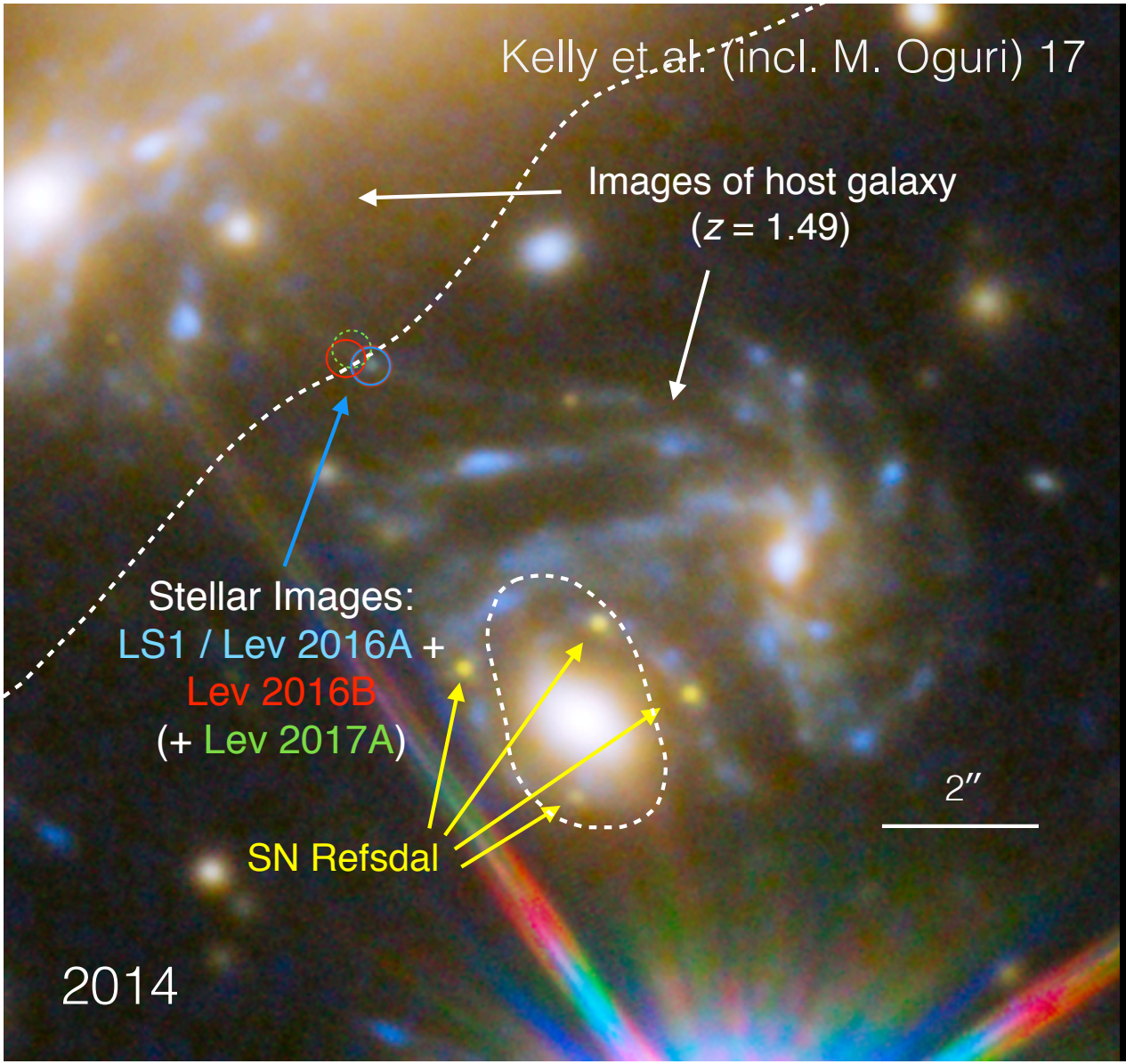


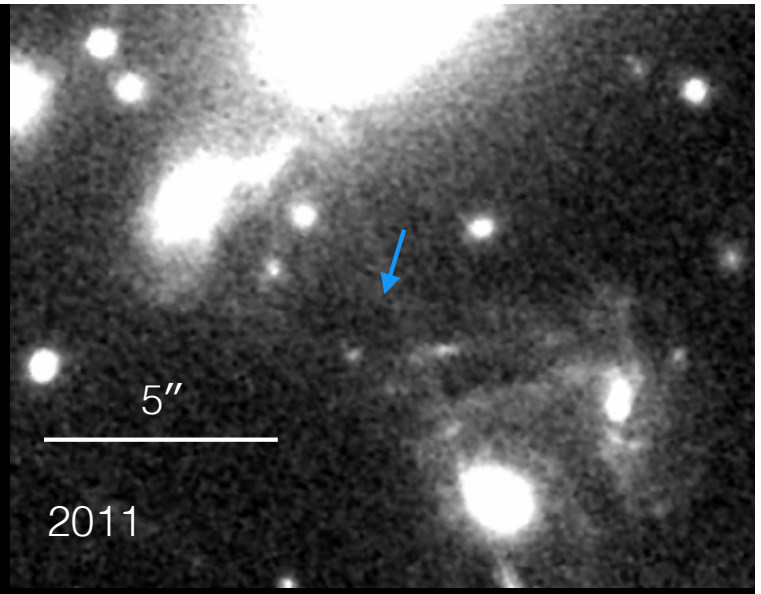
- PBHs can be formed in the early universe
- Need a large primordial fluctuation of O(0.1) at very small scales
- Inomata, Kawasaki+ proposed such an inflationary scenario
- Don't need unknown particle (a minimal model?)
- Can be counterparts of LIGO GWs (Sasaki et al. 16): need f_PBH>~1%

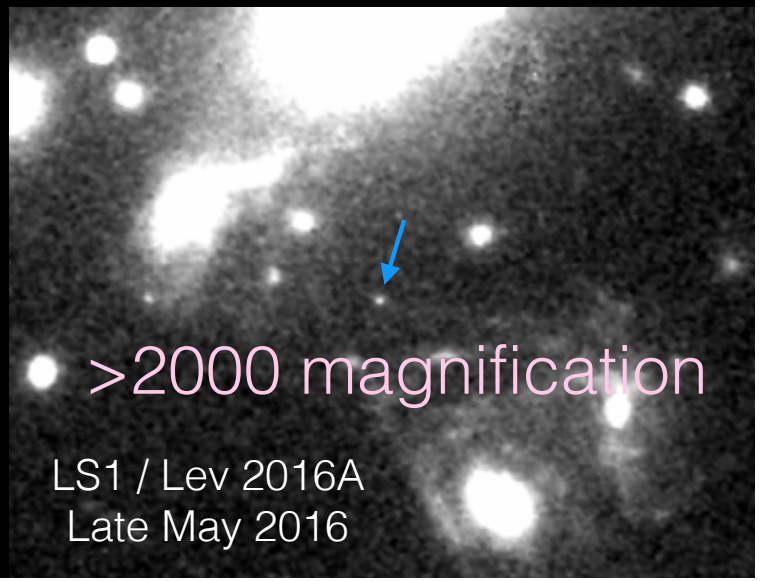
$$\frac{\Omega_{\rm PBH}(M)}{\Omega_{\rm DM}} \sim \left(\frac{\beta}{10^{-8}}\right)\left(\frac{M}{M_\odot}\right)^{-1/2}$$

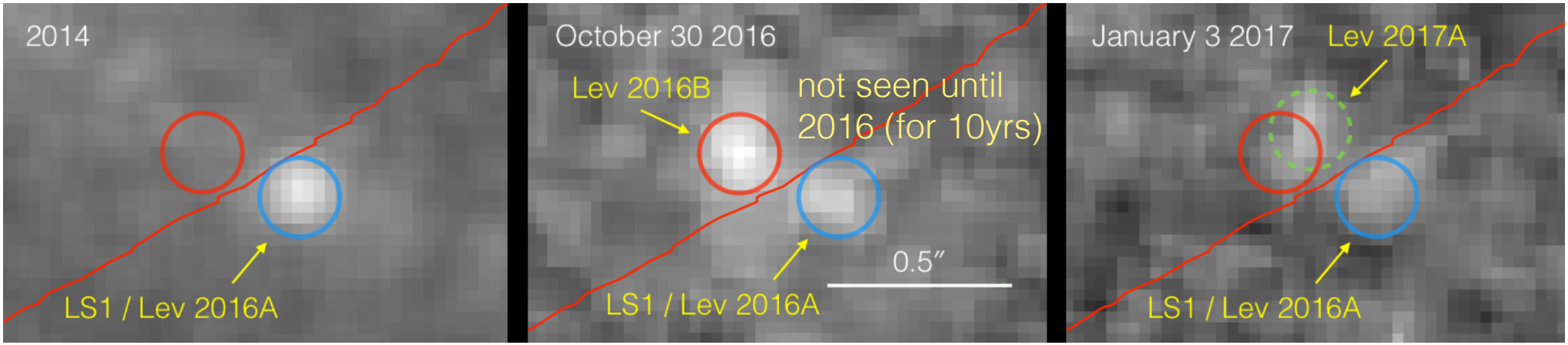
Another gift! Strong lensing of an ***individual star*** at **z=1.5**

Lensing by galaxy cluster and "compact object"

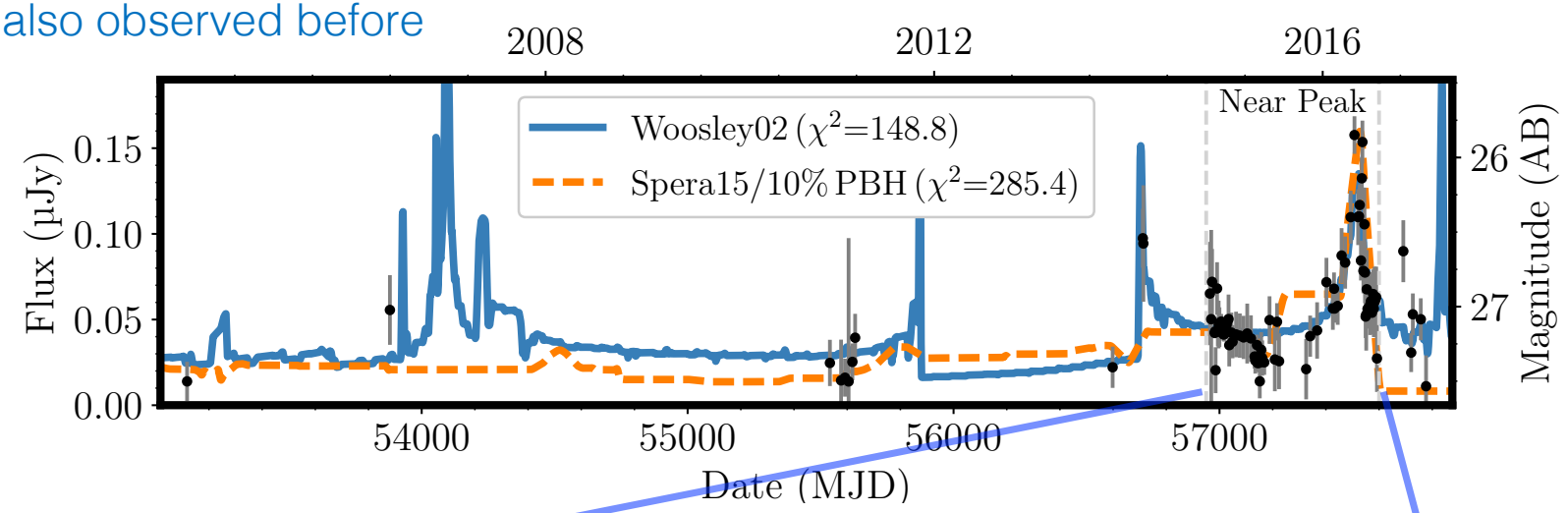


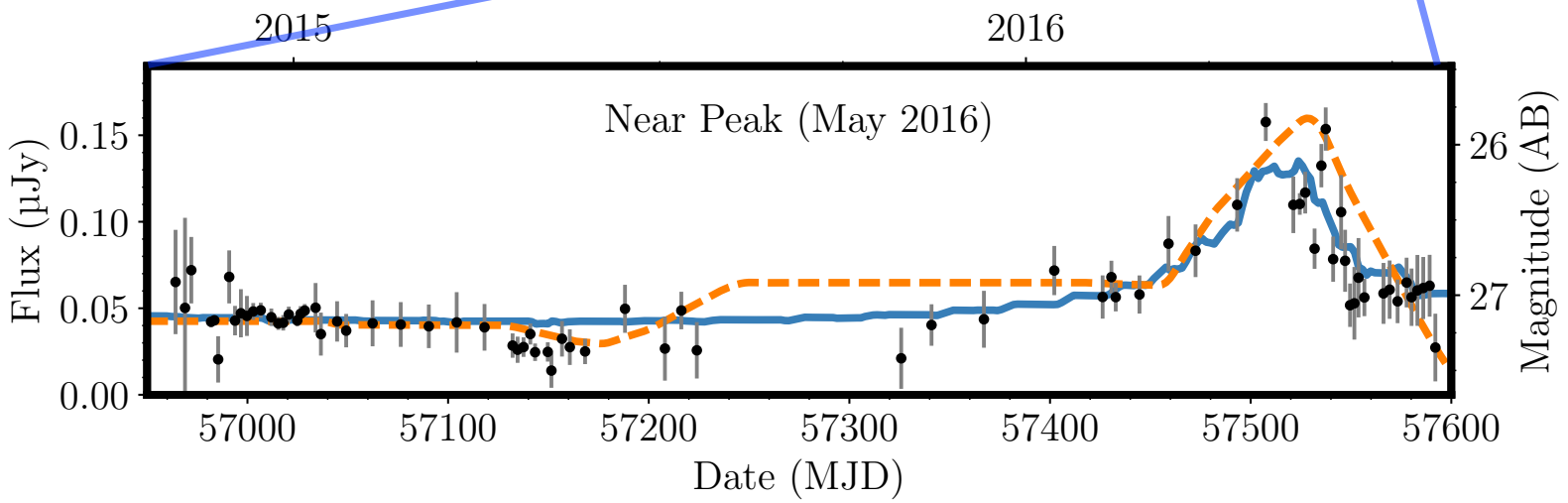






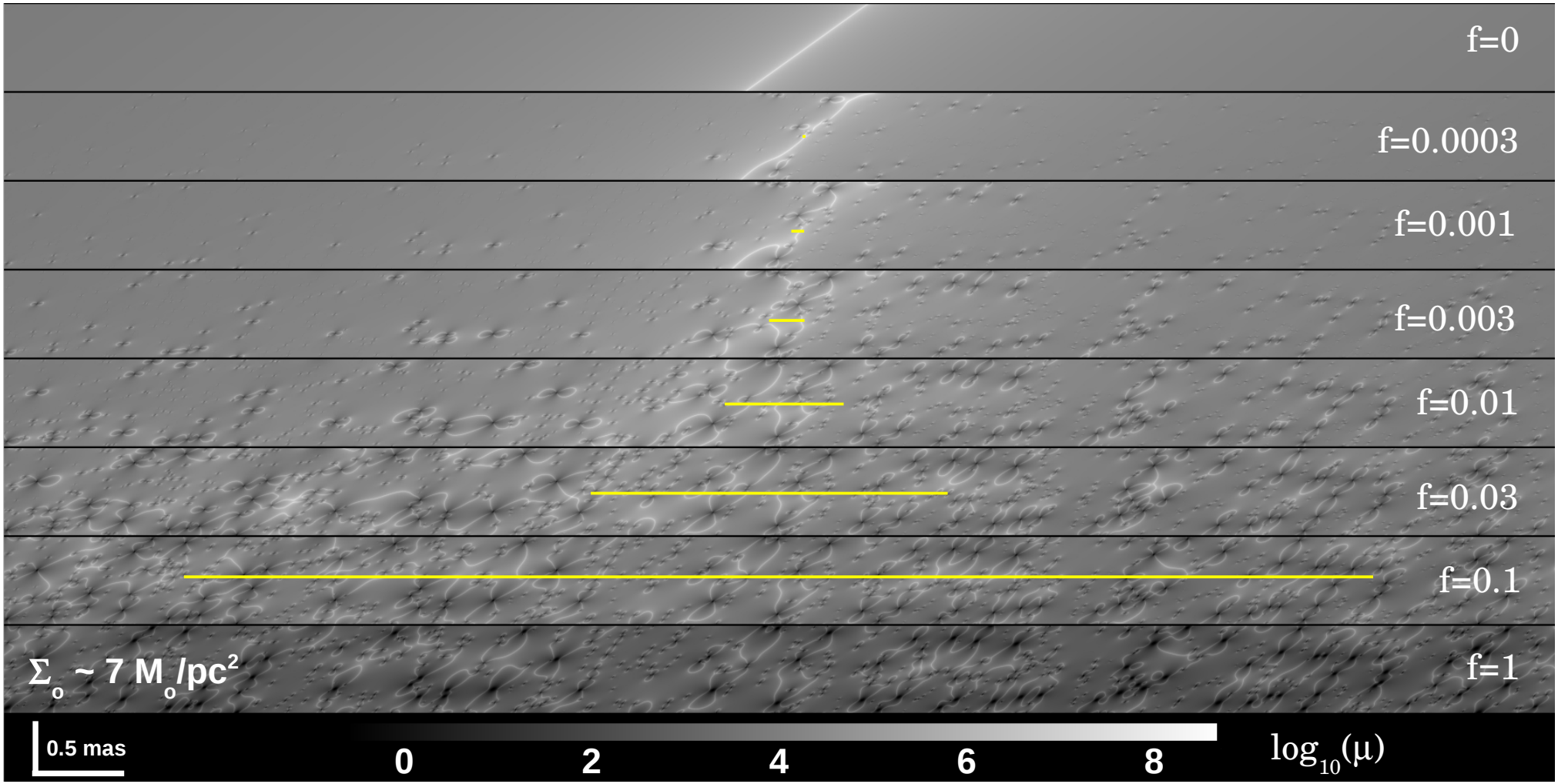
also observed before

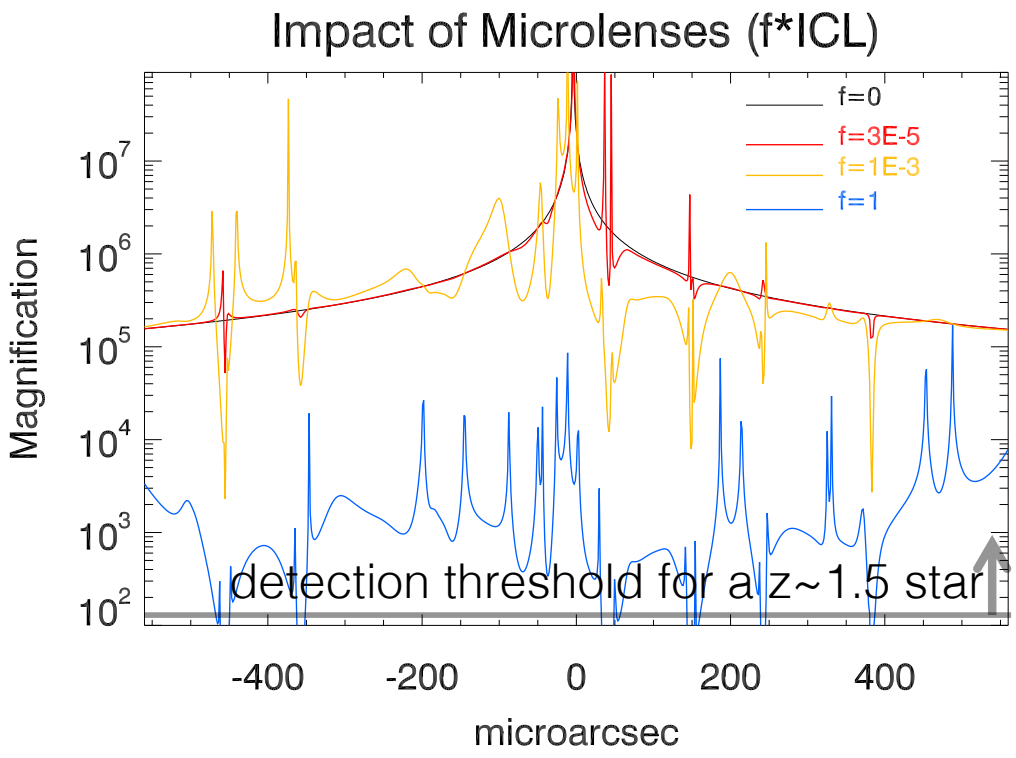


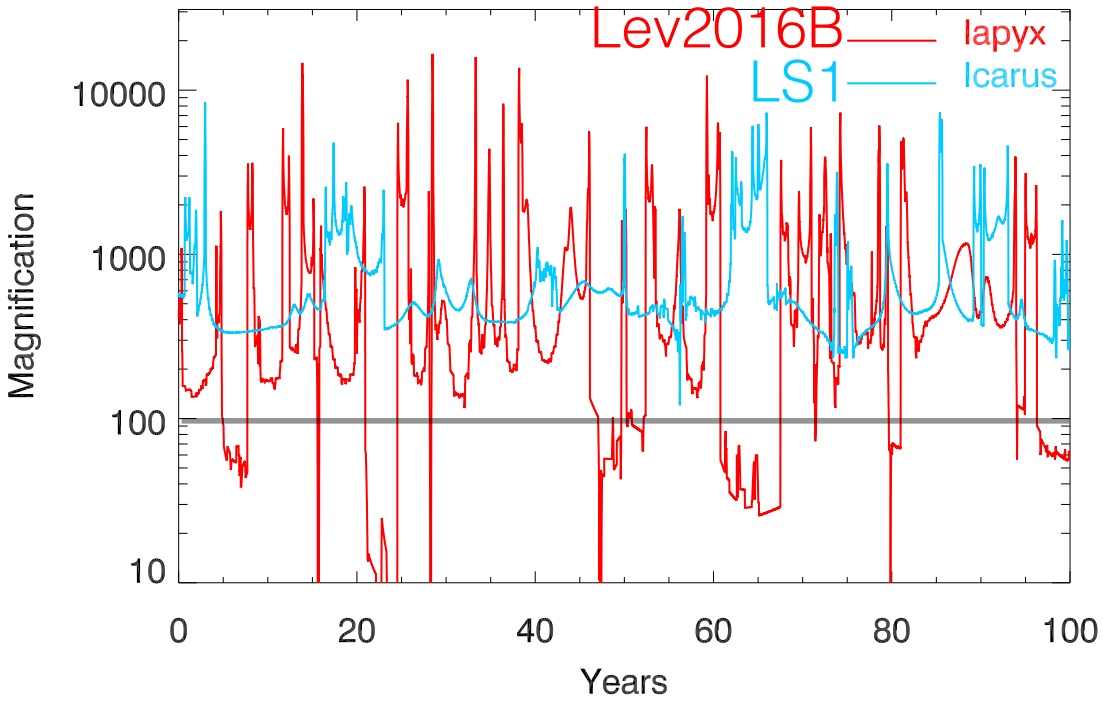


Evidence of microlensing due to "compact objects"

- Adding compact objects (stars, NSs, BHs, …) even by a tiny mass fraction (in intracluster or intergalactic space) distrupts the smooth macro-cluster caustic into a network of corrugate micro-caustics
- Transients due to macro-caustic magnification: ~long (~a few 100 years)
- Transients due to micro-caustic magnification: short







- Smooth model: a long-time scale (~400 yrs) single-peak transient
- Adding compact objects (here objects for an intra-cluster light) causes “multiple” peaks, with smaller magnification for each event, around the macro-cluster caustic (critical) region

$$t \sim \frac{d_L \theta_{\rm ML}}{v}$$

$$\sim 5 \text{ years} \left(\frac{d_L}{1 \text{ Gpc}}\right)\left(\frac{\theta_{\rm ML}}{1\ \mu \text{ arcsec}}\right)\left(\frac{v}{1000 \text{ km/s}}\right)$$

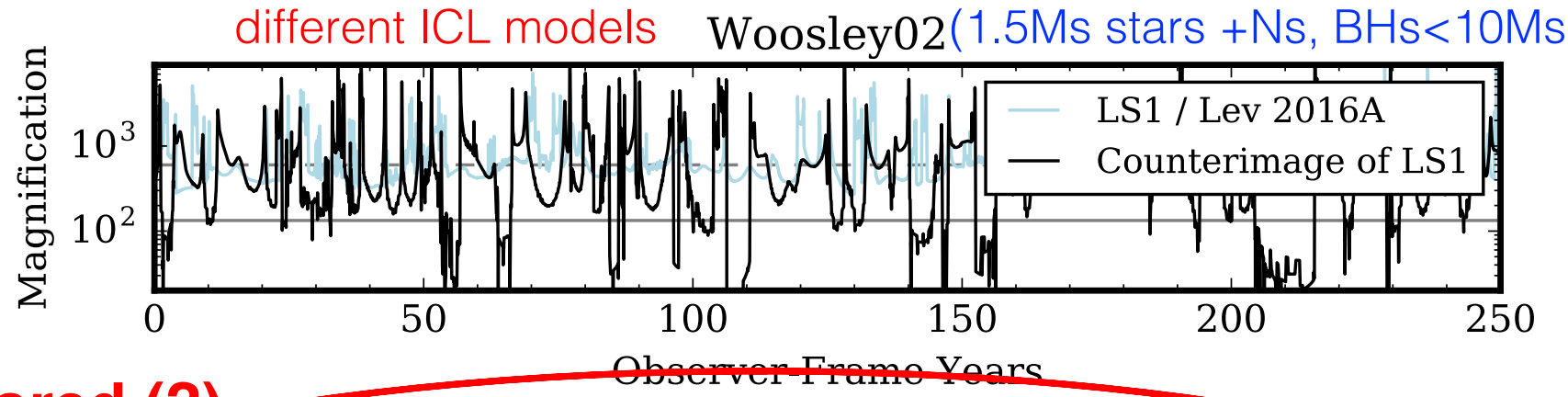
Diego et al. 2017

summary up to here

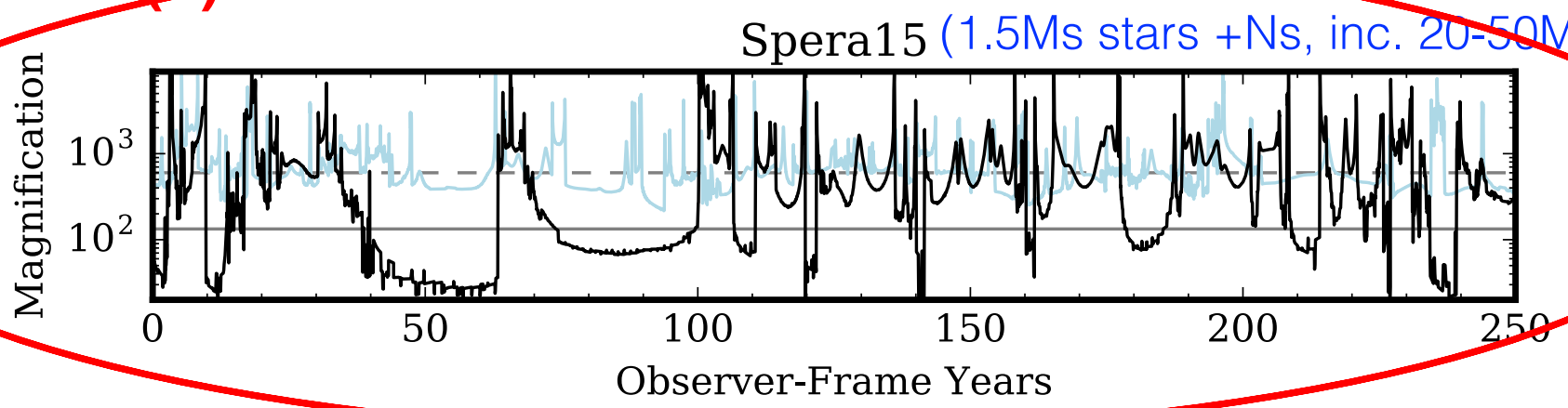
- ***Very interesting results!*** a new way to study BHs
- **Clear evidence**: existence of **"compact" objects** in front of two images for a single source star (in intracluster or inter-galactic space)
- ***What are the compact objects?***
  - Compact objects as a source of **intra cluster light (ICL)**
    - ICL is still uncertain; not know yet how much light exists in ICL
    - Stars and stellar remnants (NSs, BHs) would be expelled from tidally-destroyed galaxies in a cluster region
    - However, **surviving stars in ICL should be old and small** (<1.5Msun) (the dynamical crossing time of a galaxy across a cluster is ~Gyrs, while a life time of massive stars is <<~Gyrs
    - Massive objects such as BHs (stellar remnants) are needed?
  - **~30Msun PBHs help or are needed?**

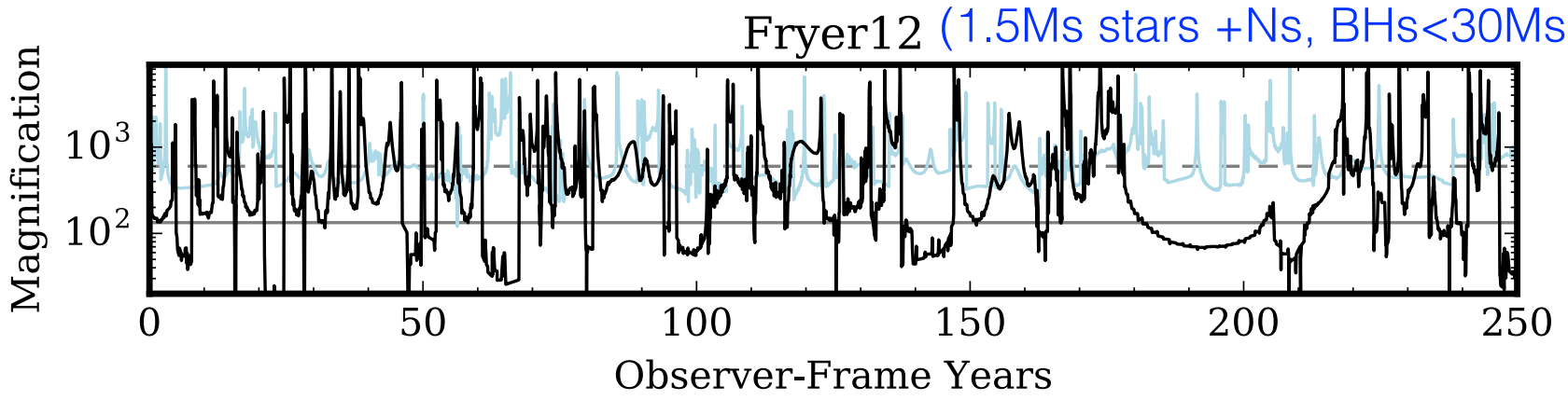
Simulated light curves (assuming the fixed amount of compact mass)

different ICL models

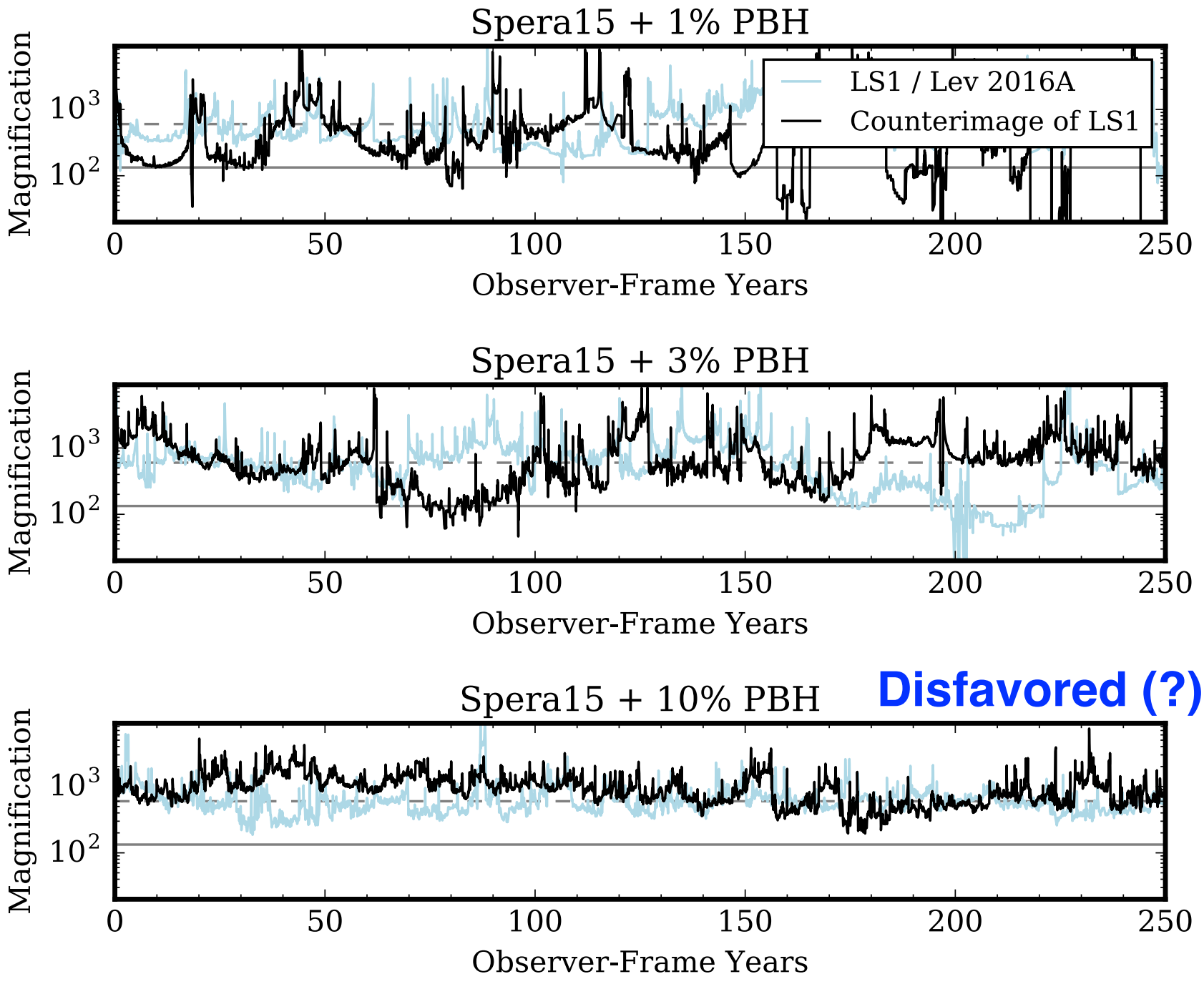


favored (?)

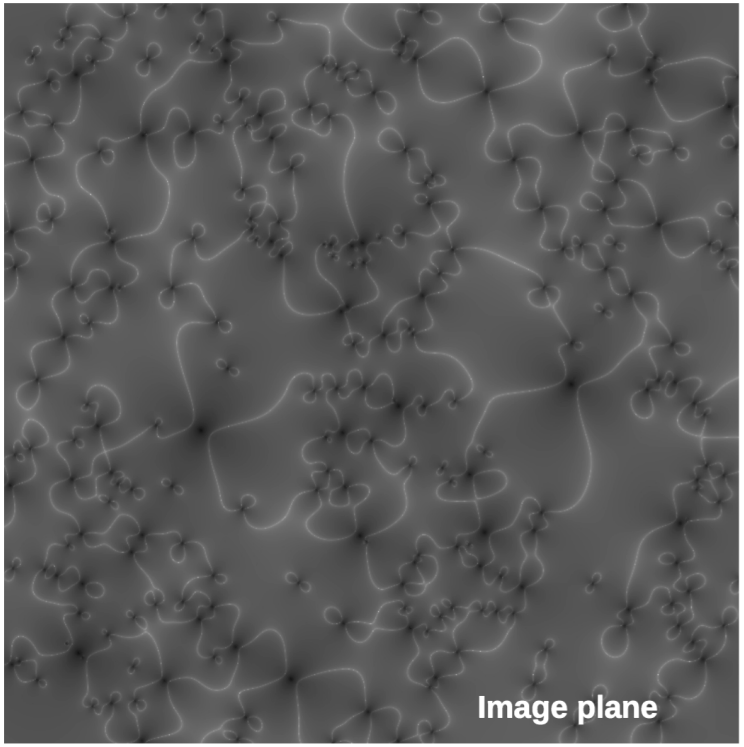


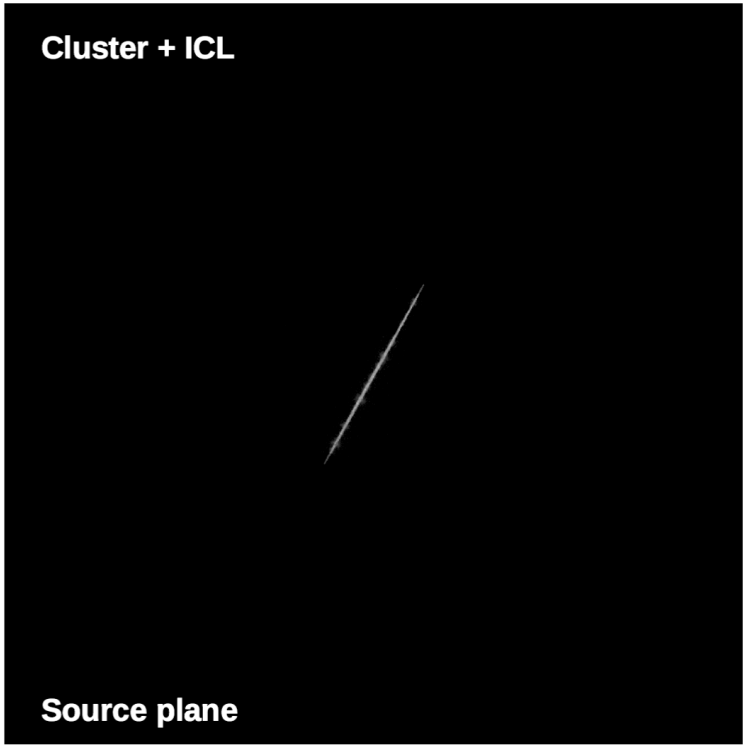


~30Msun PBHs needed?

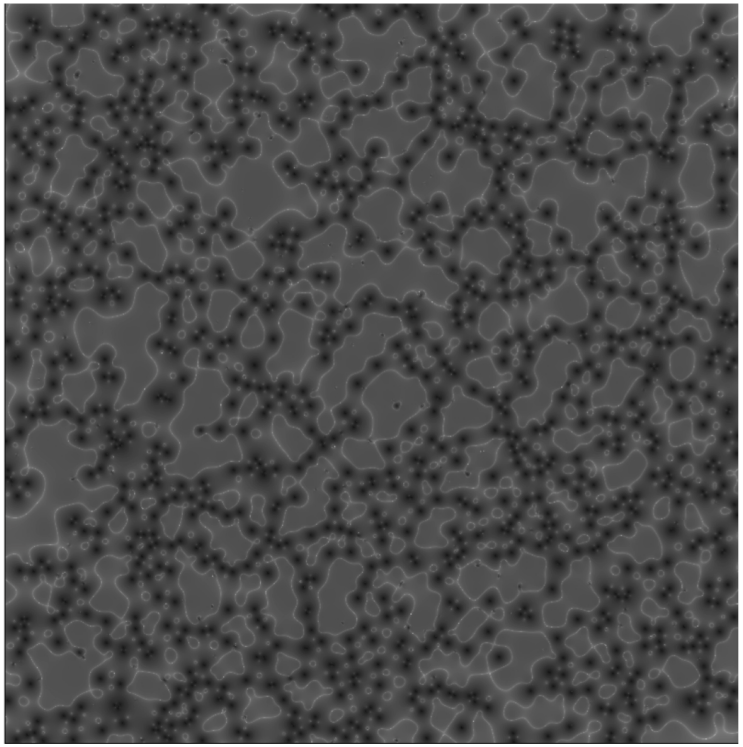


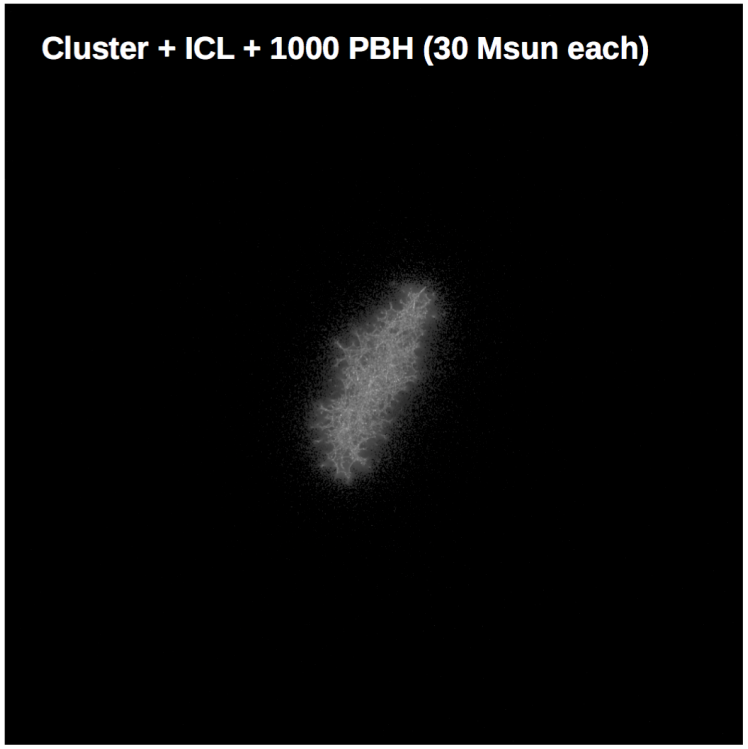
w/o PBHs





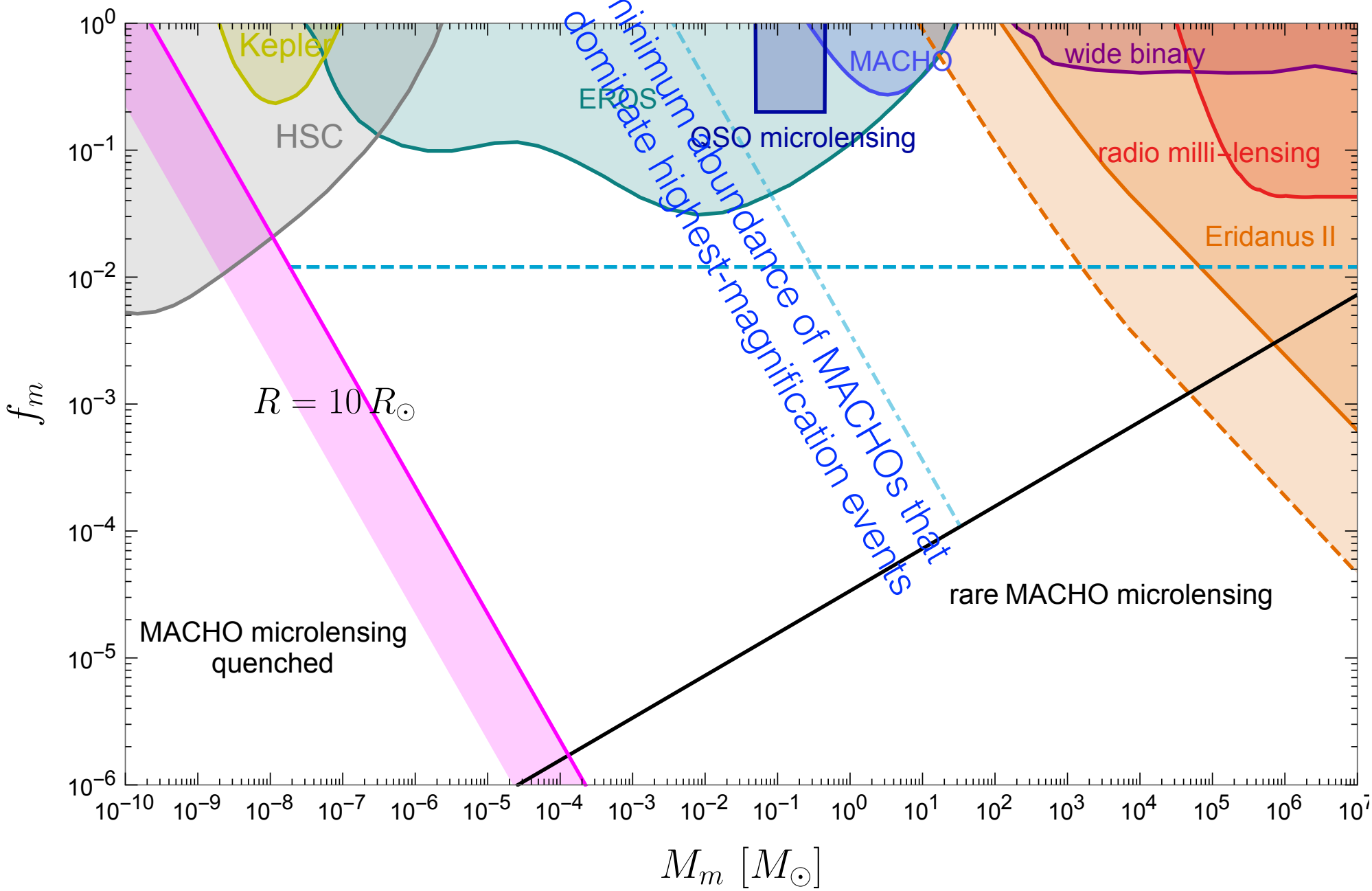
w PBHs

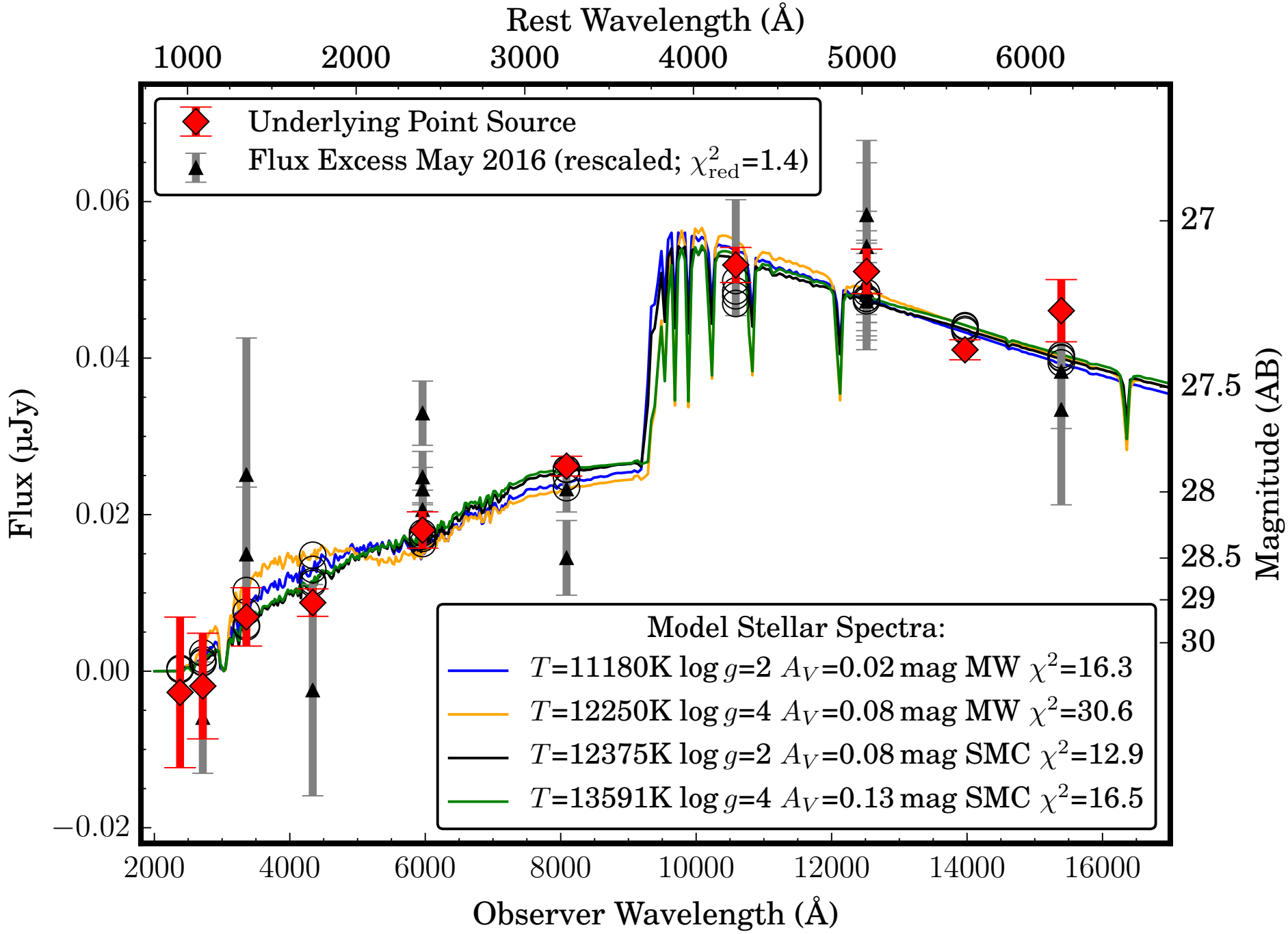


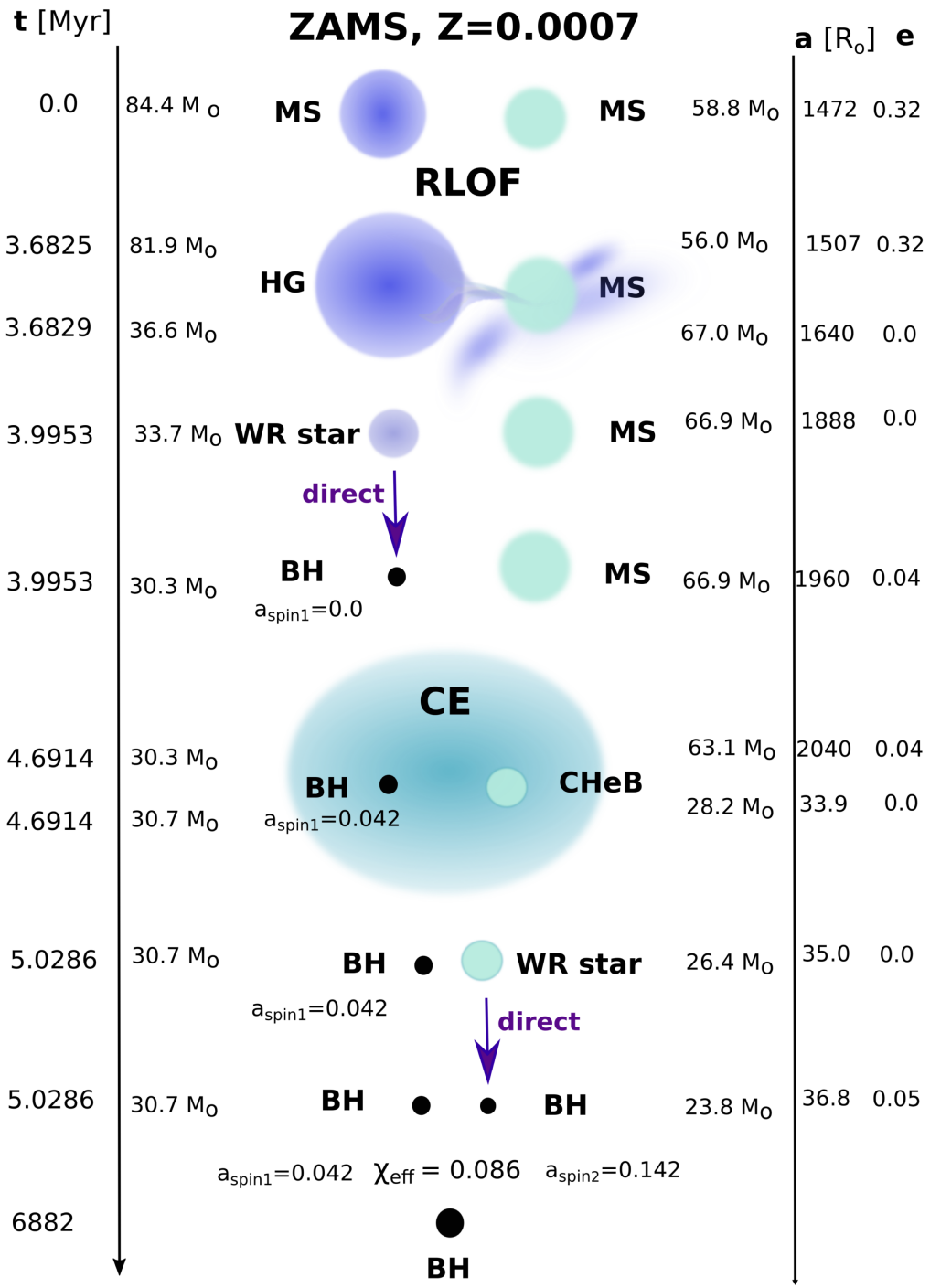


Backup

Another theory paper: Venumadhav et al. 17




Rest Wavelength (Å)
1000
2000
3000
4000
5000
6000
Underlying Point Source
Flux Excess May 2016 (rescaled; $\chi^2_{\rm red}$=1.4)
Model Stellar Spectra:
T=11180K log g=2 A_V=0.02 mag MW χ^2=16.3
T=12250K log g=4 A_V=0.08 mag MW χ^2=30.6
T=12375K log g=2 A_V=0.08 mag SMC χ^2=12.9
T=13591K log g=4 A_V=0.13 mag SMC χ^2=16.5
Flux (μJy)
0.06
0.04
0.02
0.00
−0.02
Magnitude (AB)
27
27.5
28
28.5
29
30
2000
4000
6000
8000
10000
12000
14000
16000
Observer Wavelength (Å)



Belczynski et al. 16, 17

- Direct collapse of a massive star?
- Stellar wind (spin ↓)
- Low metallicity in a binary system (spin ↑)
- The distributions of BH mass and spin