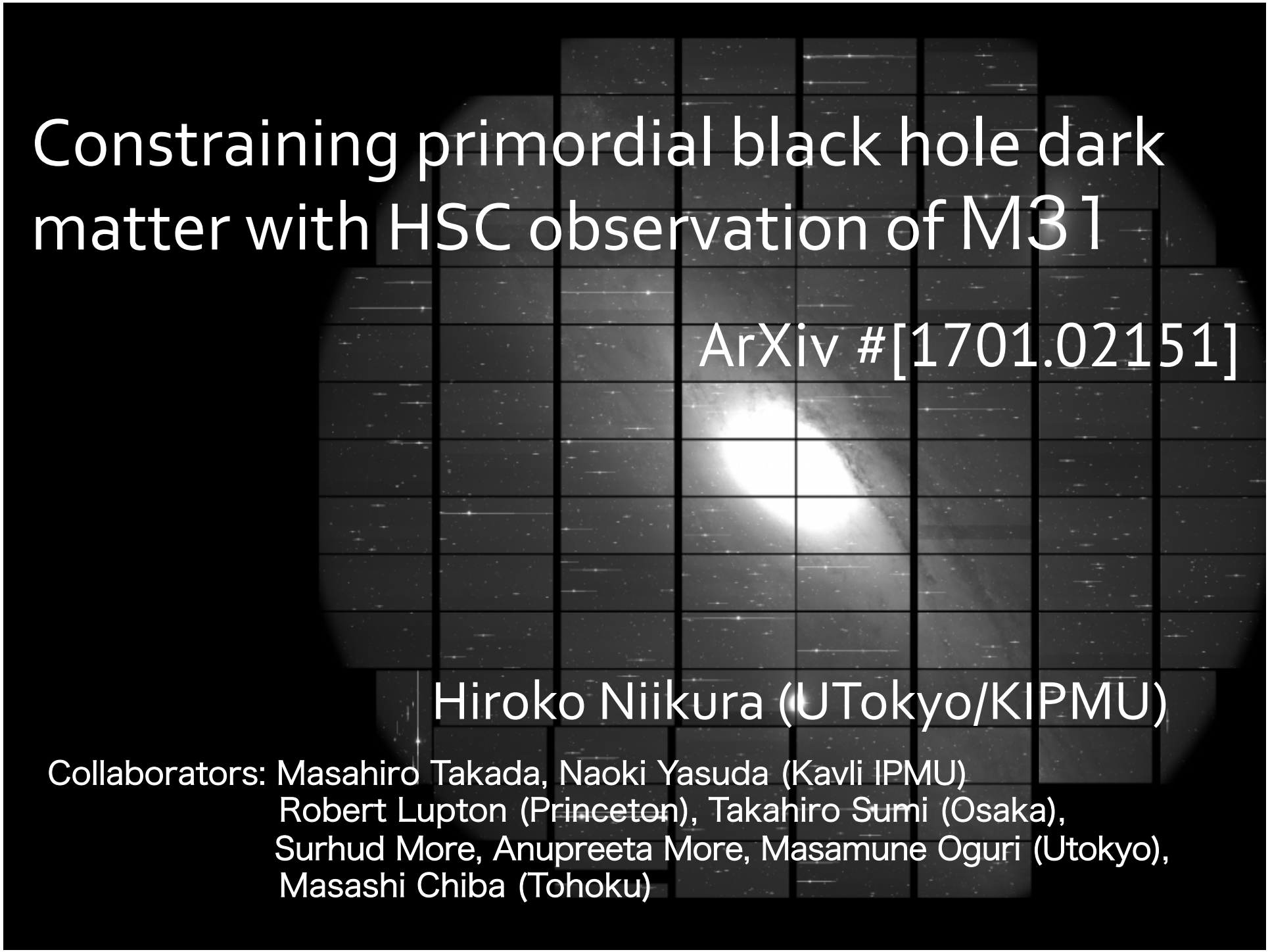

Constraining primordial black hole dark matter with HSC observation of M31

ArXiv #[1701.02151]

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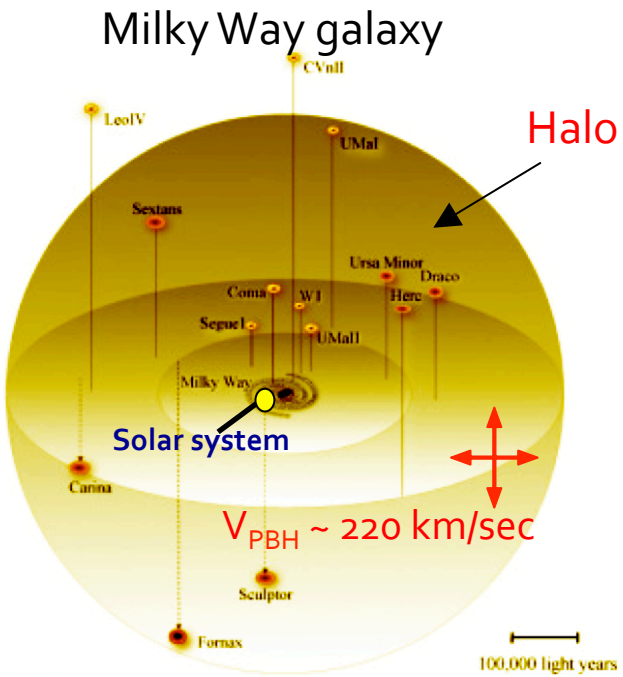
Target: dark matter in the galactic halo

- Searching for dark matter in the local universe
  - Massive Compact Object (MACHO), Weakly Interacting Massive Particle (WIMP), Primordial Black Hole (PBH)
- Primordial black hole (PBH)
  - Proposed to be generated in the early universe, and can survive as dark matter today if not evaporated (Hawking 1974)
  - Previous research still leaves some room for PBH to be a part of dark matter
  - This study, the M31 microlensing search, targets PBHs with $10^{-10}M_{sun}$



Credit: J. Bullock/M. Geha/UCI.

→ Search of magnification event due to microlensing effect

Gravitational microlensing effect due to PBHs

Magnification effect due to microlensing

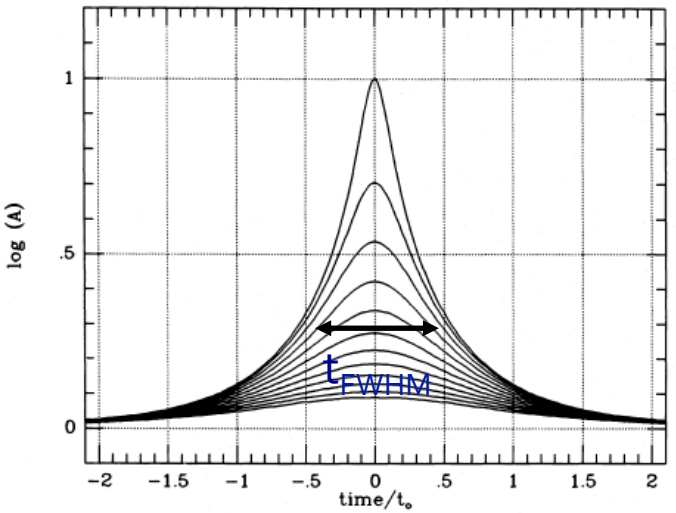
- Gravitational lensing effect, only proved by magnification (separation angle of two images is ~μ arcsec and cannot be separated)
- Time variance of magnification (light curve) depends on lens mass and impact parameter β.
- Time scale: a few months for MACHO($1M_{sun}$), a few hours for PBH($10^{-7}M_{sun}$)

$$t_0 = \frac{R_E}{v} \simeq 1.6\text{hours} \left(\frac{M}{10^{-7}M_\odot}\right)^{\frac{1}{2}} \left(\frac{xDs}{100\text{kpc}}\right)^{\frac{1}{2}} \left(\frac{220\text{km/sec}}{v}\right)$$

★ *Since M31 contains many stars (>tens of million stars), we can expect high event rates for PBH microlensing*

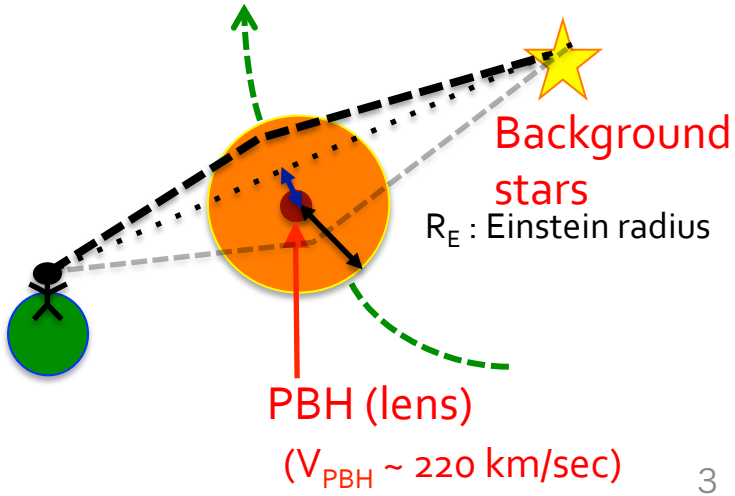
→ Our target (M31) expects high event rate!

Paczynski, 1986, ApJ, 304, 1



t_{FWHM} : time scale of magnification

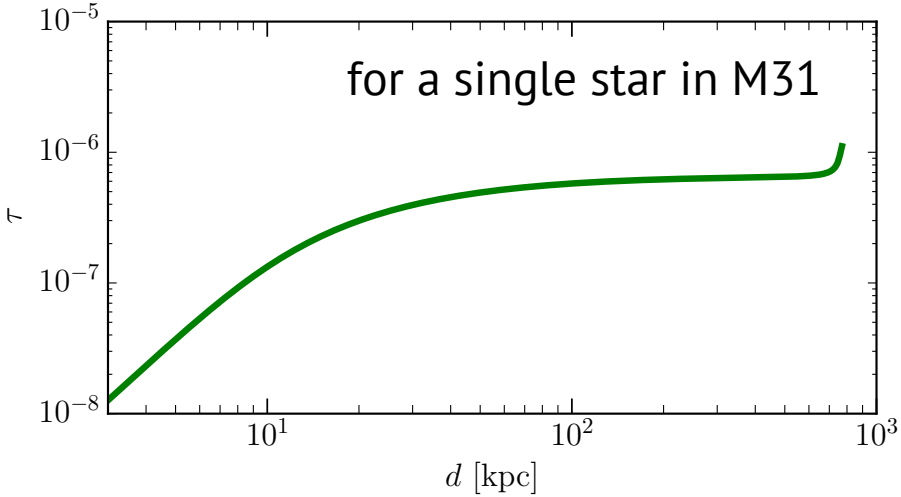
β (=d/R_E): impact parameter



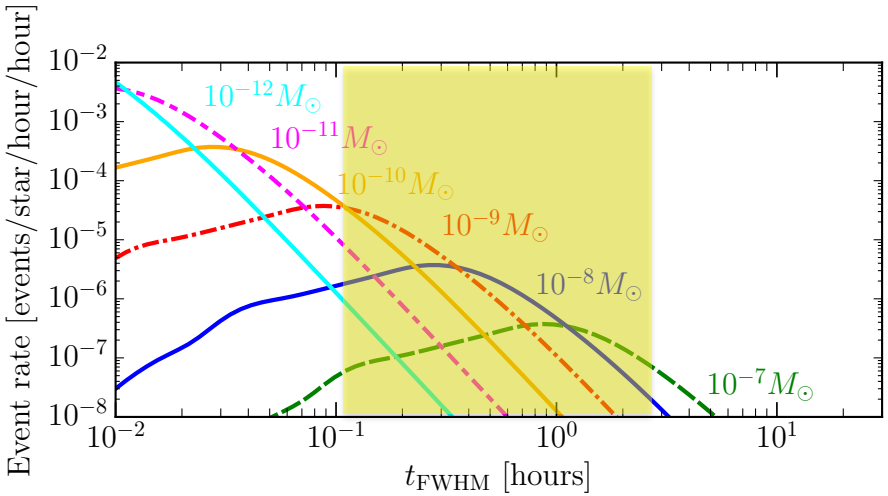
PBH microlensing event rate for one night obs. of M31

Assuming all dark matter is PBH

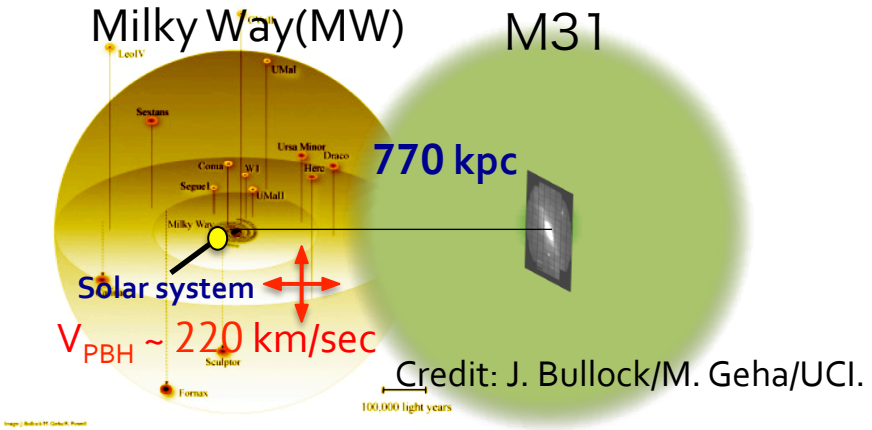
- Cumulative optical depth of microlensing



- Microlensing event rate at M31 region



- Assume NFW model for each of the MW and M31 halos (Klypin 2002)

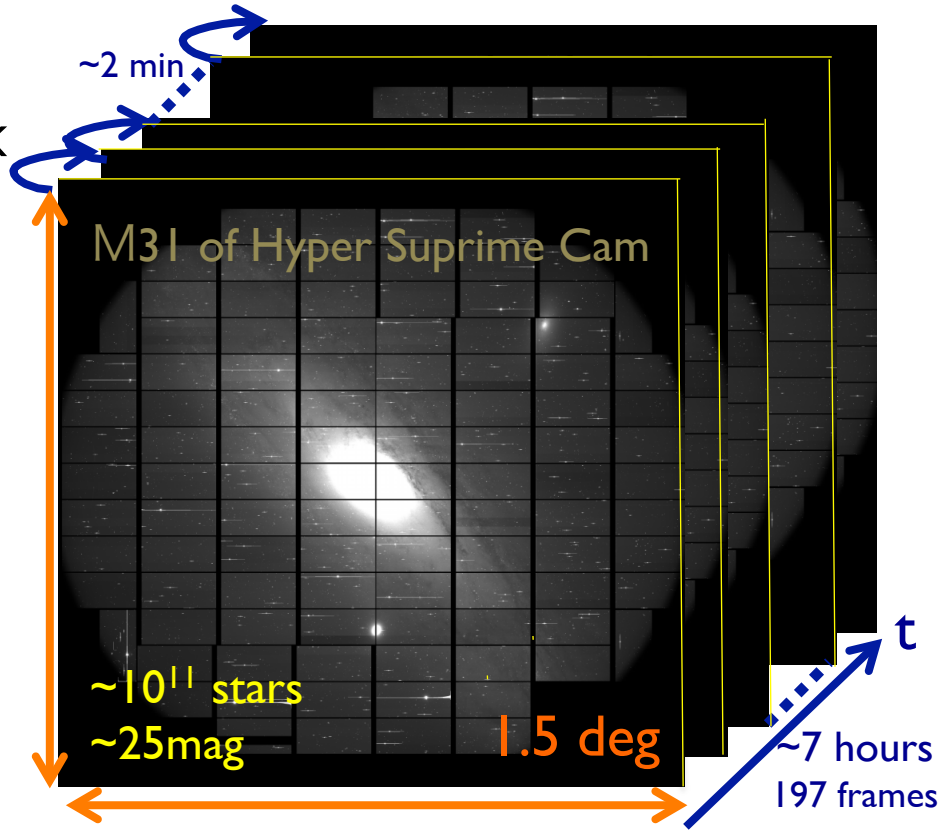


If all the dark matter in the MW and M31 halos are PBHs with M_PBH ~$10^{-10}M_{sun}$, we expect more than one microlensing event of a few tens mintuite timescale for ~ 10^6 stars, for 7 hour long observation

M31 has ~10^{11} stars, highly expected!

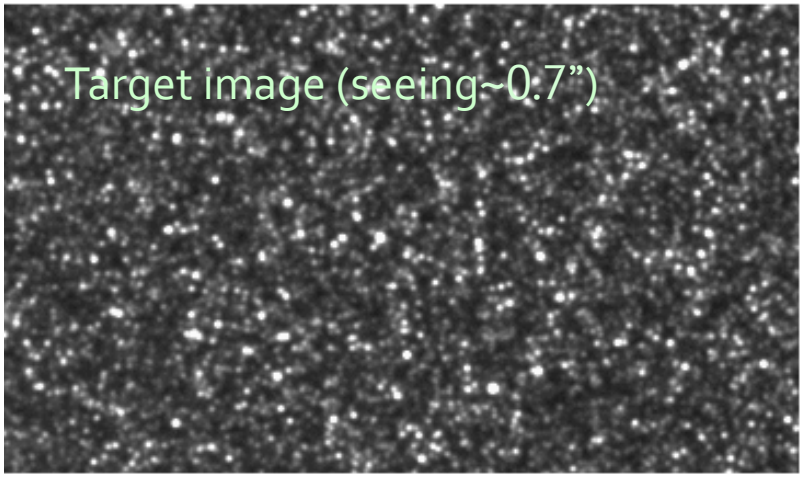
Observation: wide field survey of PBH microlensing events using HSC

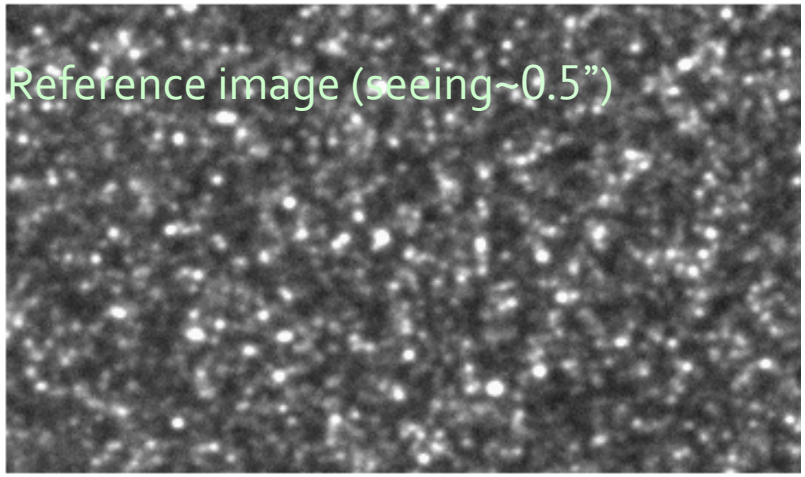
- Search for gravitational lensing effect by PBH, a candidate of dark matter (or put constraint on the abundance of PBH.)
- The wide and deep imaging with Hyper Suprime-Cam; HSC
  - ★ Can cover the entire disk and bulge regions of M31 with its one pointing
  - ★ 90sec exposure can reach to ~26mag depth for a star
- Observation for 7-hours, taking images every 2 minutes at M31-disk region (r-band)

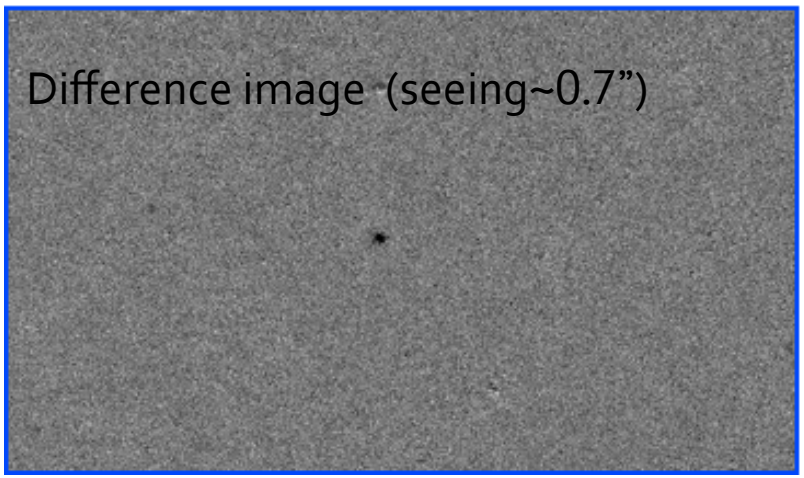


Detection of transients: difference images

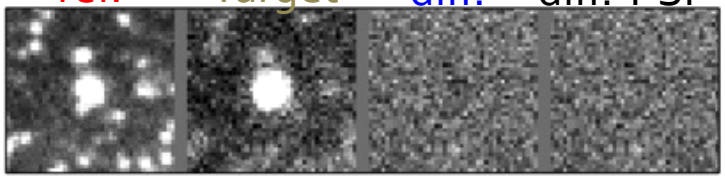
Pixel lensing regime: multiple stars in each CCD pixel







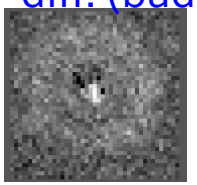
○



×

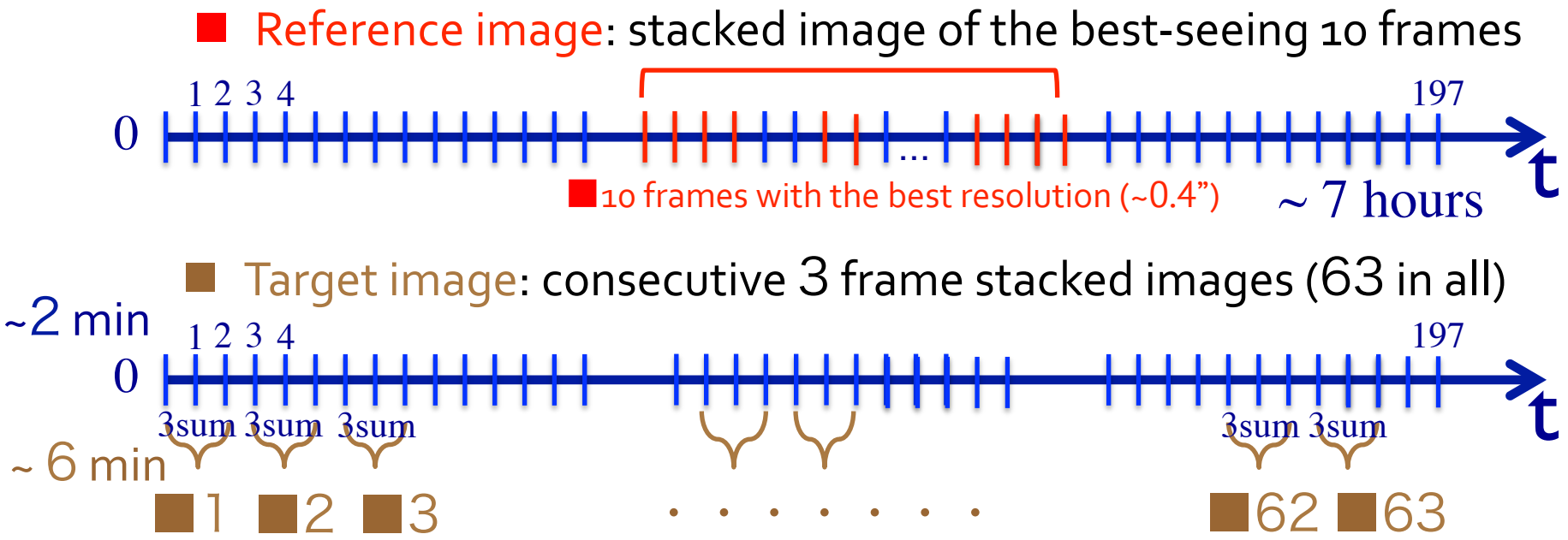
-tiny objects (< pixel size)
-distorted object
-object with flux distribution unsimilar to stars

diff. (bad)



Detection of variable star candidates: difference images (time scale>6 min.)

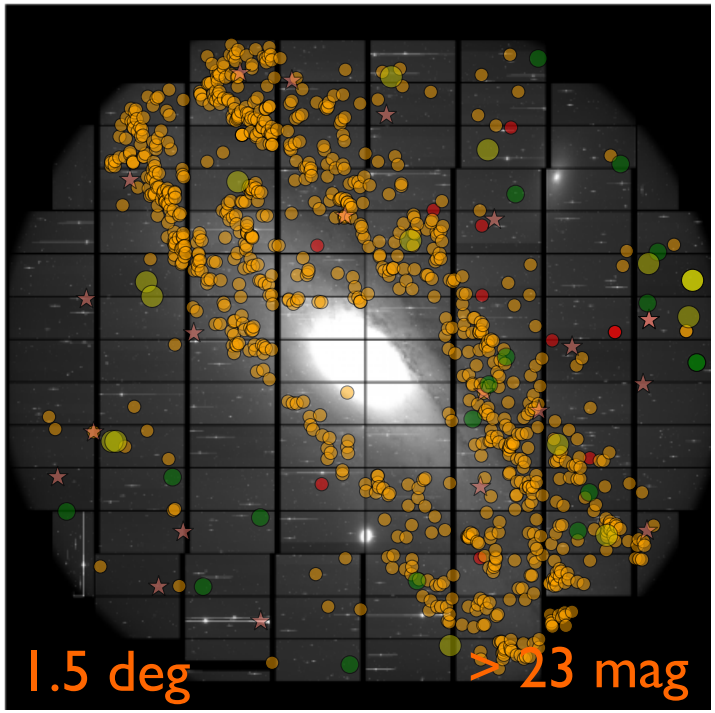
- Observation: 188 images (+three focusing)

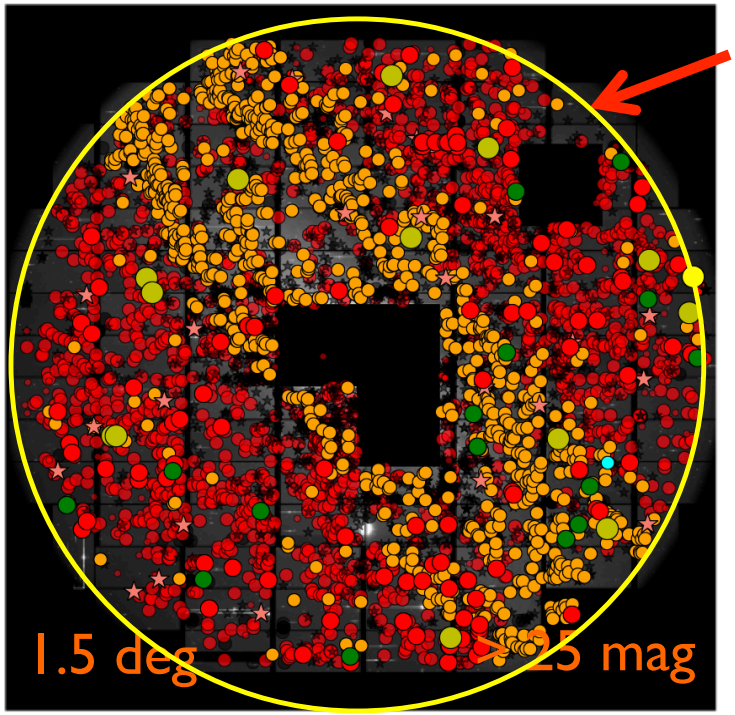


detect transients on every 63 difference images created from a Reference and Target images.

- Transient candidates are those detected more than twice among 63 difference images (time scale > 6 min.)
- Photometry on one-visit image (194 warp images) for light curves

Result: Distribution of transient candidates

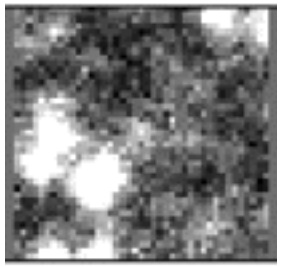


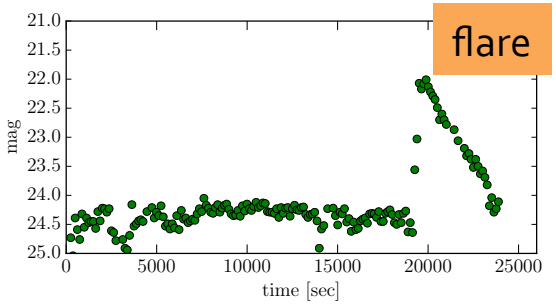


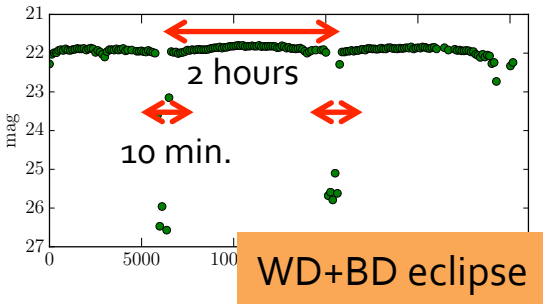
HSC-M31 focal plane

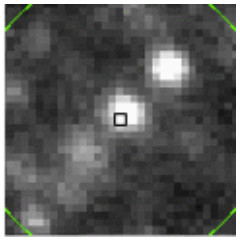
More than 10,000 transient candidates in one field-of-view of HSC. (6 min.-)

- fake (incl. RR-Lyrae)
- Cepheid variable
- asteroid
- stellar flare
- eclipsing binary
- contact binary









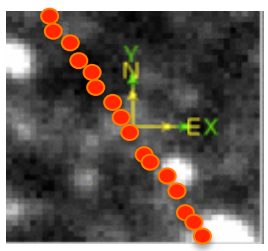
Analysis: Selection of microlensing candidates (6 min.-4 hours)

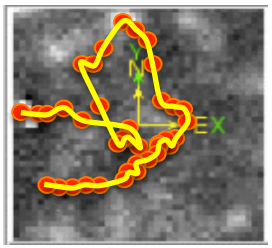
followed by Griest et al., 2014, ApJ, 786, 158

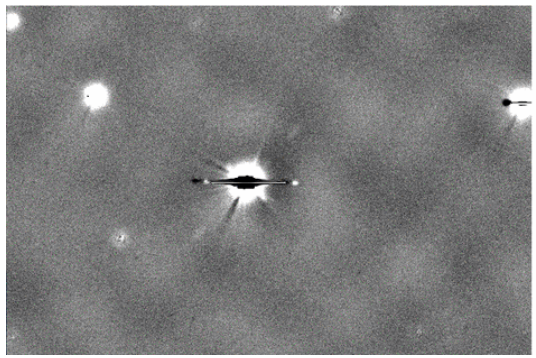
Total number of events : 15,571

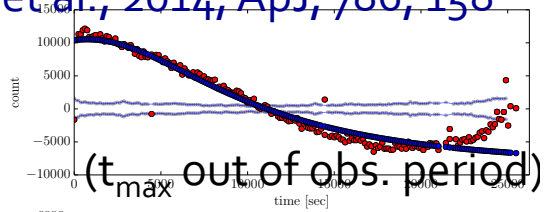
# of candidates	
11,703	Noise threshold (S/N > 5 for 3 consecutive visits)
	Apart from CCD edge — fake events, binary stars
	Fitting of ML lightcurve model (for lightcurves in difference images)
227	Symmetric shape of peak around the peak in the light curve — flare stars, fake events
146	significant peaks — noisy events
66	Visual inspection — spikes, asteroid or some defects
1	

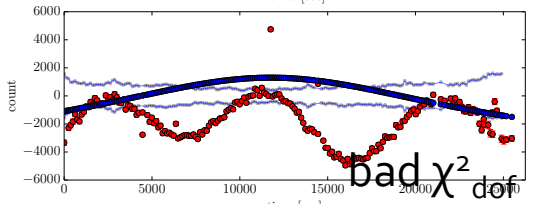
One remaining candidate

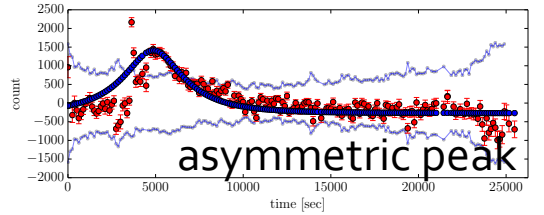


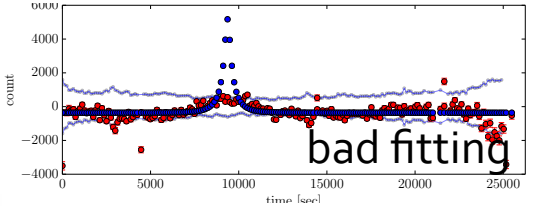


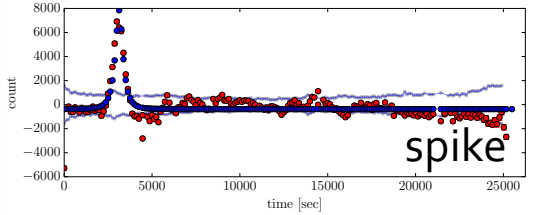


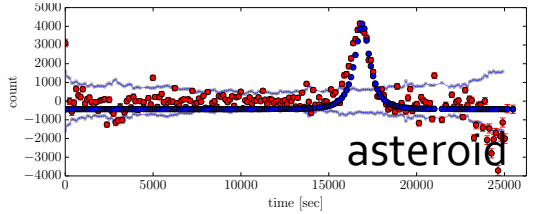








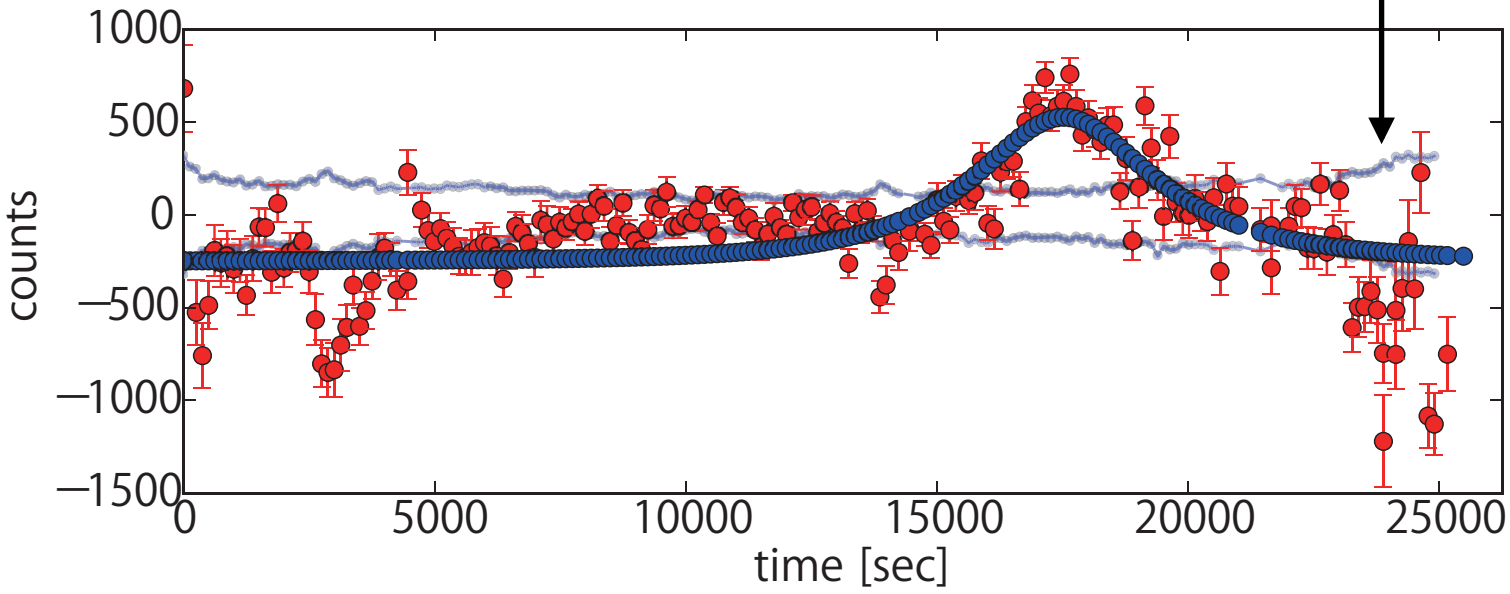


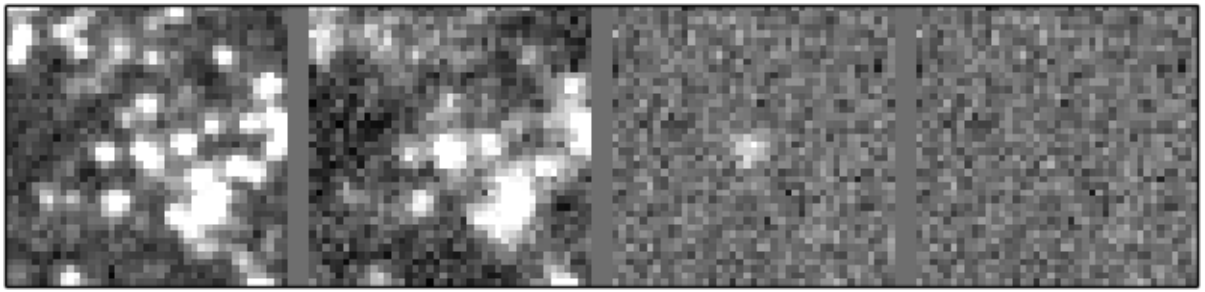


One remaining candidate..

Total number of events : 15,571

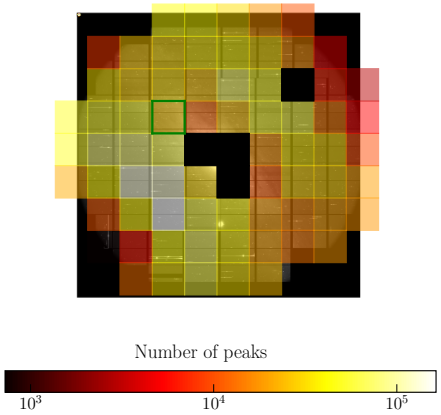
blue: ±1σ noise on difference images





Discussion: Constraint on the PBH abundance

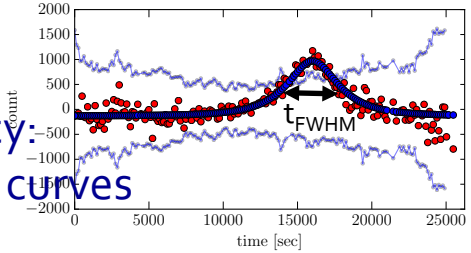
★ The expected number of events (from 7-hour observation)



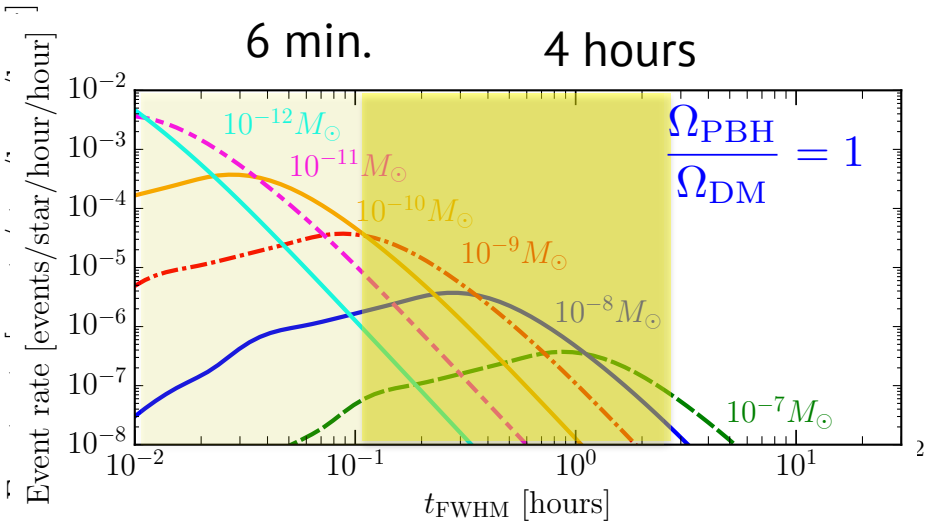
$$N_{\rm exp}(M) = E \int_0^\infty \frac{d\Gamma}{d\hat{t}}(\hat{t}, M)\epsilon(\hat{t})d\hat{t}$$

The number of stars at HSC-M31 region: evaluated as the number of peaks (10^5/patch)

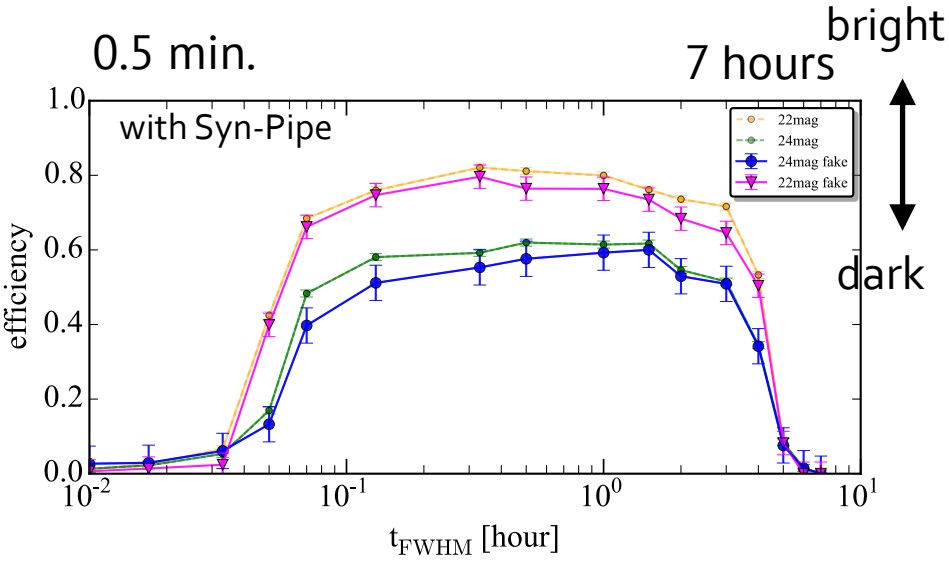
detection efficiency: simulation of light curves



Event rate:
Higher event rate for PBHs with 10^{-7}-10^{-9}Msun

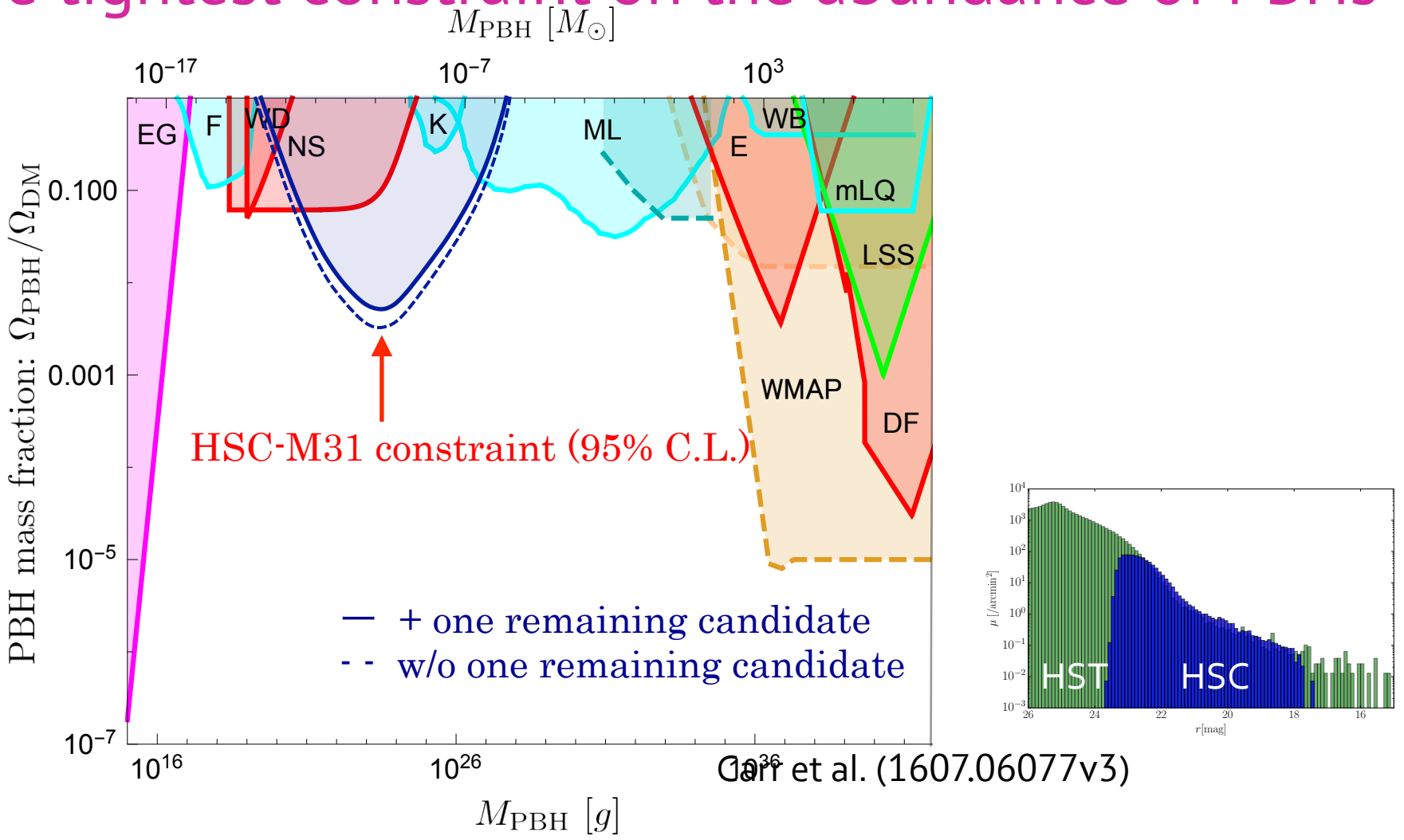


Event rate of microlensing (per background star)



detection efficiency

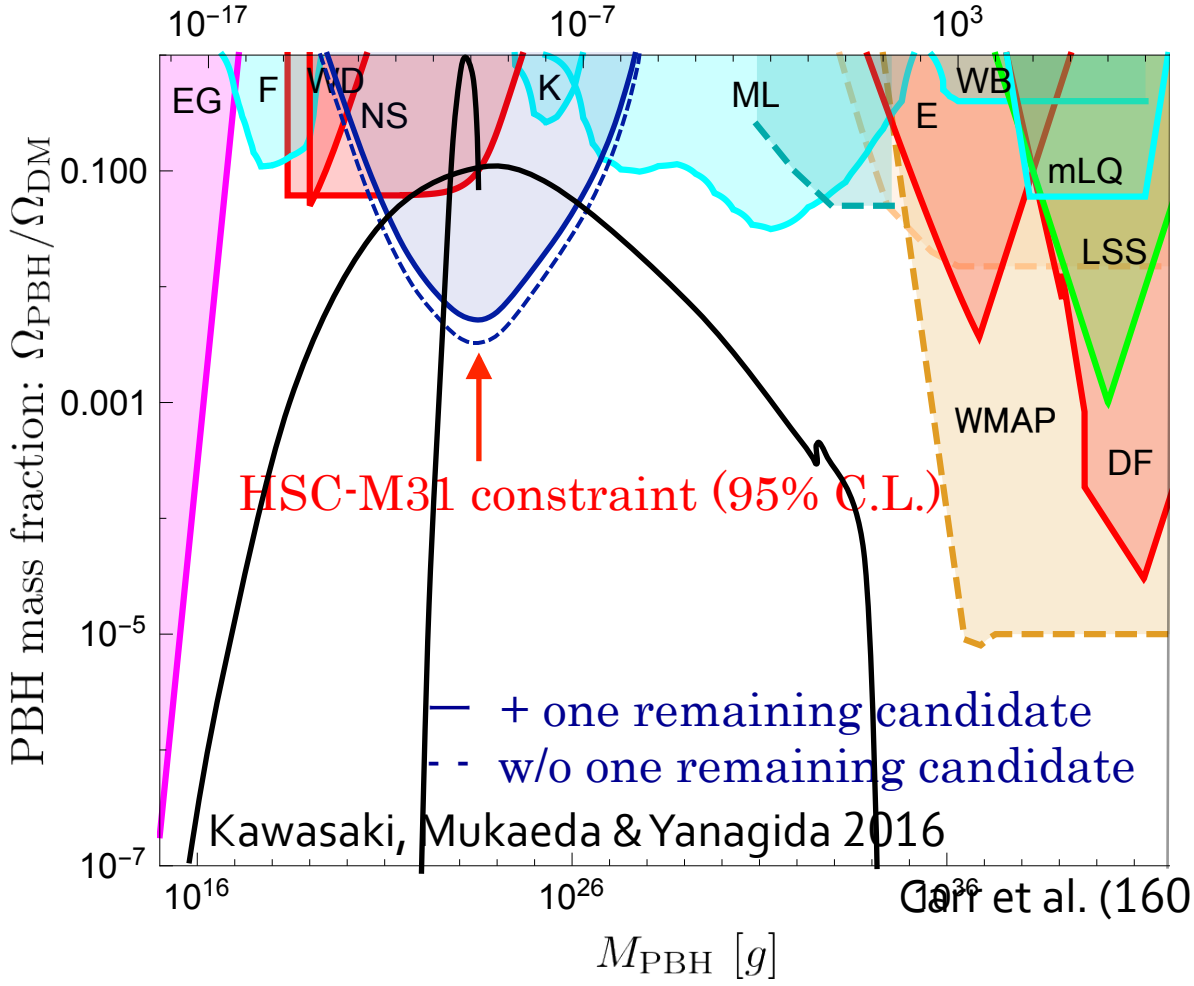
The tightest constraint on the abundance of PBHs



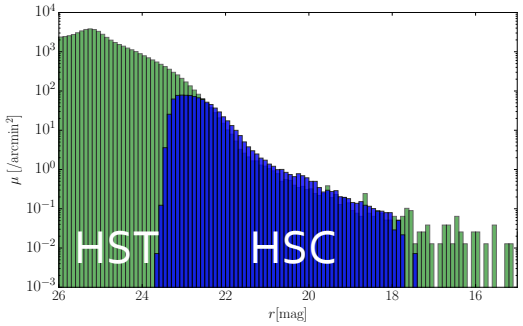
Carr et al. (1607.06077v3)

- From null-detection of microlensing events from PBHs, we can put constraint on the upper limit on the abundance of PBH to the total dark matter

The tightest constraint on the abundance of PBHs



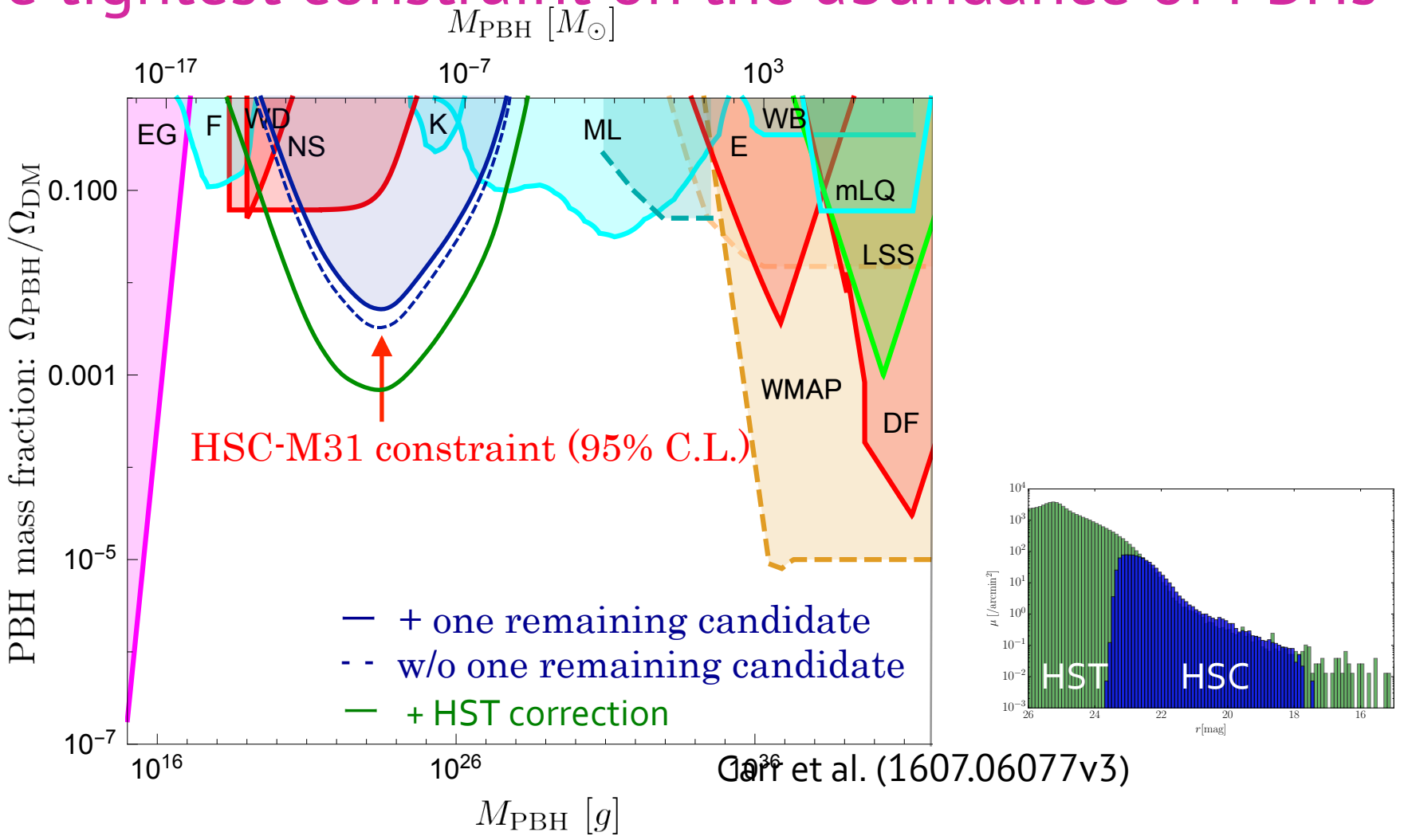
(※Point source approx.)



Carr et al. (1607.06077v3)

- From null-detection of microlensing events from PBHs, we can put constraint on the upper limit on the abundance of PBH to the total dark matter

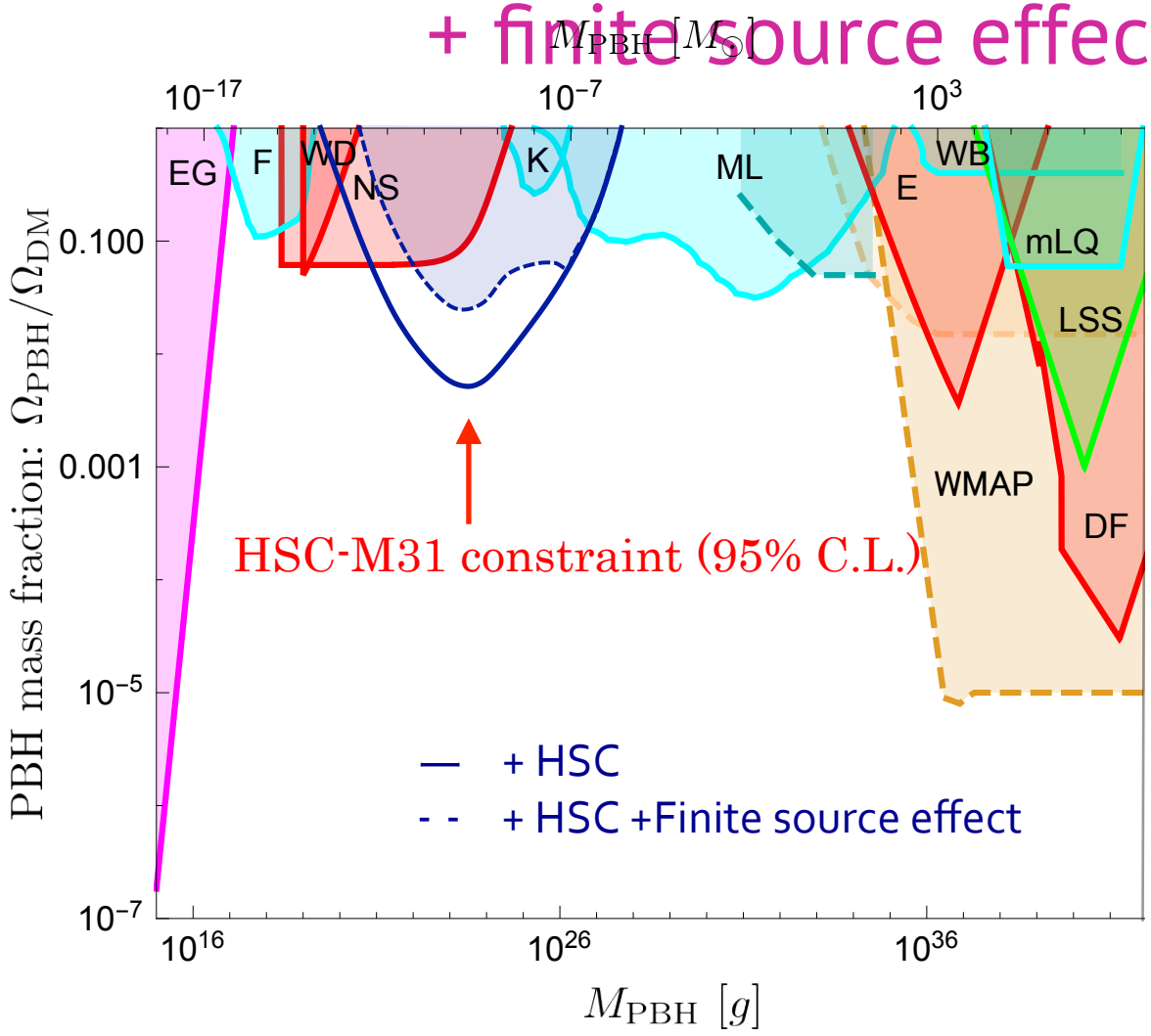
The tightest constraint on the abundance of PBHs



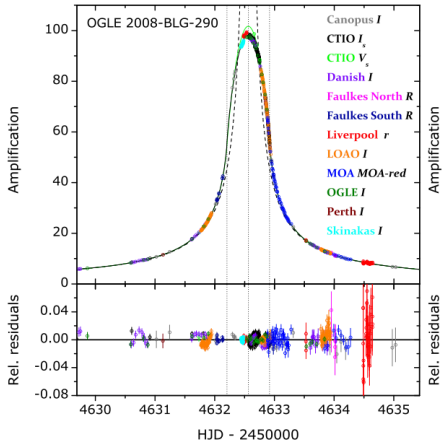
Carr et al. (1607.06077v3)

- From null-detection of microlensing events from PBHs, we can put constraint on the upper limit on the abundance of PBH to the total dark matter

The tightest constraint on the abundance of PBHs + finite source effect



Fouque et al. (2010)



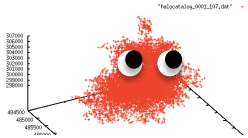
- Assumed the solar radius for source star size (can be optimistic)

Summary

- Used the image difference technique to identify variable star candidates; indeed found many secure variable stars (>3,000) such as stellar flares and contact/eclipse binaries
- One remaining candidate of PBH microlensing; need additional observation to reveal the nature of the candidate
- Use the microlensing search results to obtain the tightest upper bound on the abundance of PBHs
- When combined with other observational constraints, our results rule out almost all the window of PBH mass scales

Future works :

- Tighter constraint from further observation (one more HSC night for closing the PBH window..?)



Thank you for listening!