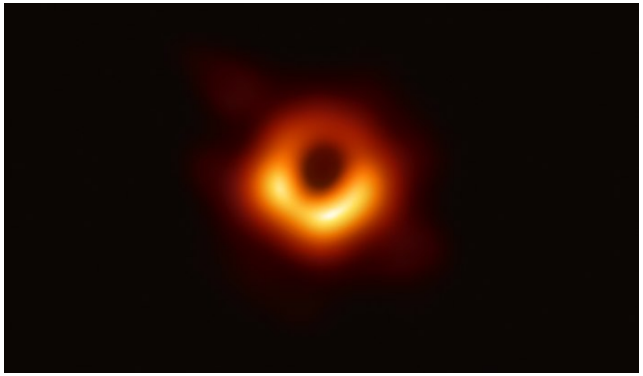
Constraining ~10Msun primordial black holes with HSC microlensing search of M31 stars (S18B-093I – S21B?)

PI: Masahiro Takada (Kavli IPMU)

Co-I's: N. Niikura, T. Sumi, N. Yasuda, H. Aihara, M. Chiba, K. Kashiyama, R. Lupton, A. More, S. More, H. Murayama, A. Nishizawa, M. Oguri, M. Kawasaki, R. Murata, M. Tanaka, M. Sasaki, Y. Suto, T. Suyama, K. Akitsu, T. Kurita, N. Sugiyama

Primordial black hole (PBH)

black hole



dark matter

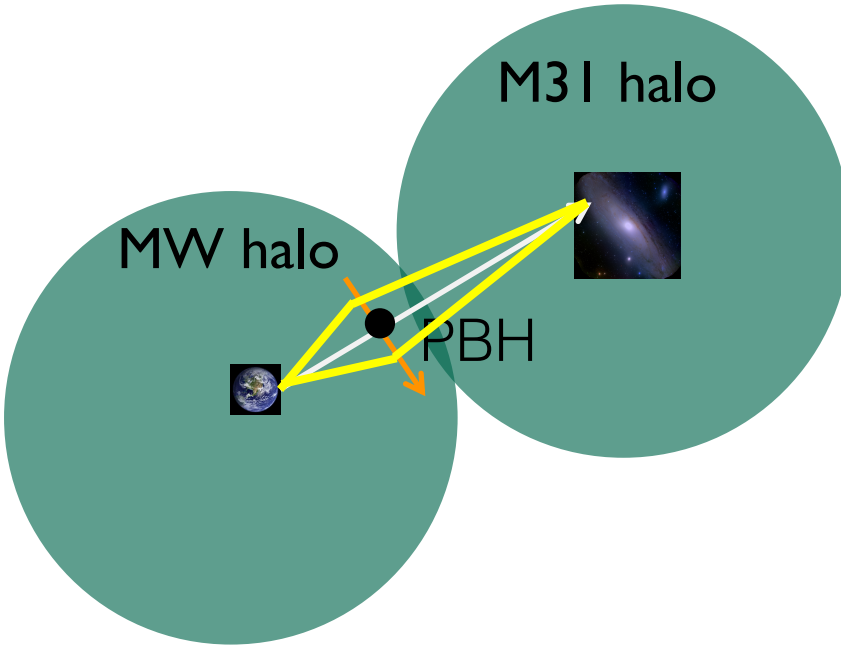
PBH

- Black holes can be formed in the early universe (Hawking)
- PBH, if formed, acts as a collision-less dark matter (so can explain all DM)
- If we find any black hole with ~1Msun, it is a direct evidence of PBH!
- HSC microlensing is very powerful to search for PBHs (already ~140 citations of Niikura et al. 2019)

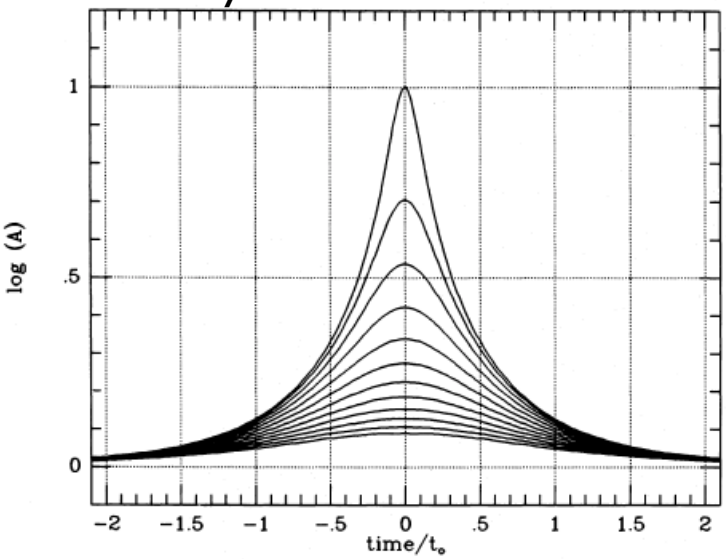
H. Niikura
(PhD 2019)

PBH microlensing on M31 star

- PBH = a viable dark matter candidate
- Lensed images can't be resolved with optical resolution (~10^{-8} arcsec) ⇒ only light curve is a signal
- Huge volume
- MW/M31 halo ~ 10^{12}Msun (we assumed NFW models)
- PBH has a peculiar velocity of ~200km/s
- Need to monitor brightness of the same star as a function of "time" (time domain astronomy)



Paczynski 86

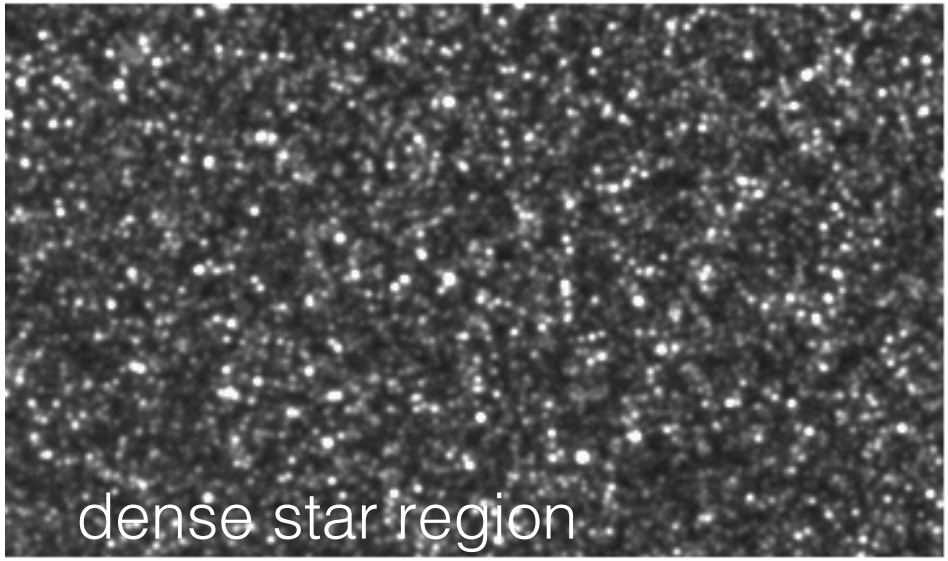


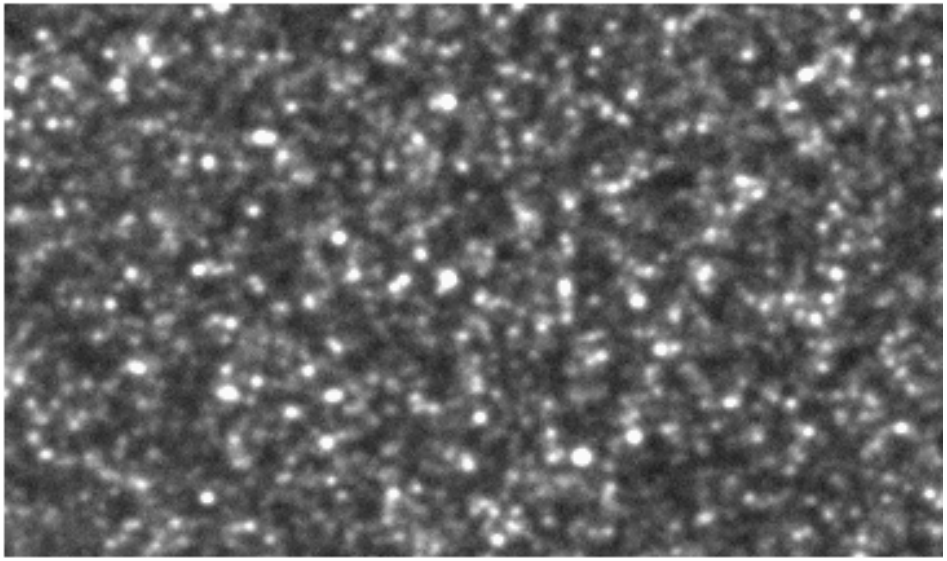
$$R_E = \sqrt{\frac{4\pi G M_{\rm PBH} d(1-d/d_s)}{c^2}}$$

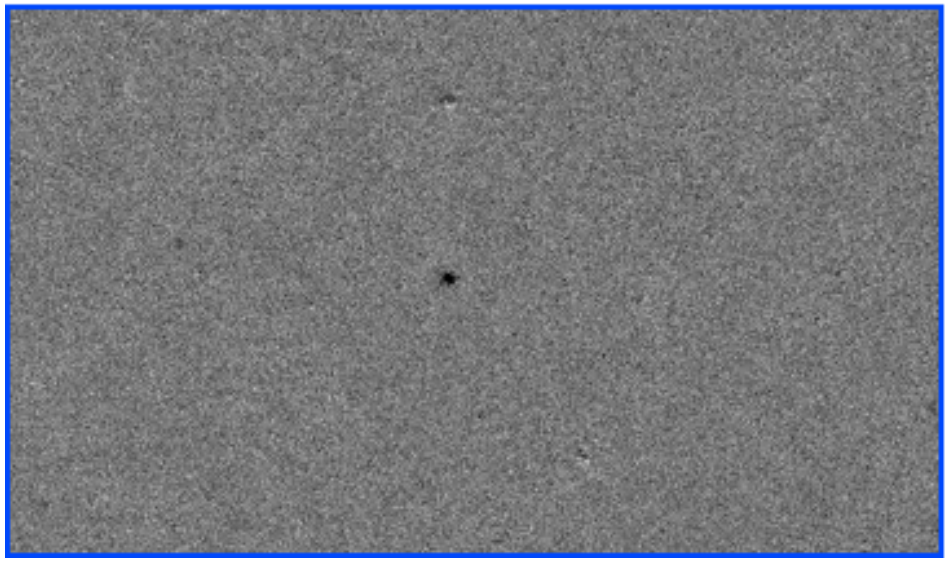
Pixel lensing: analysis pipeline already developed

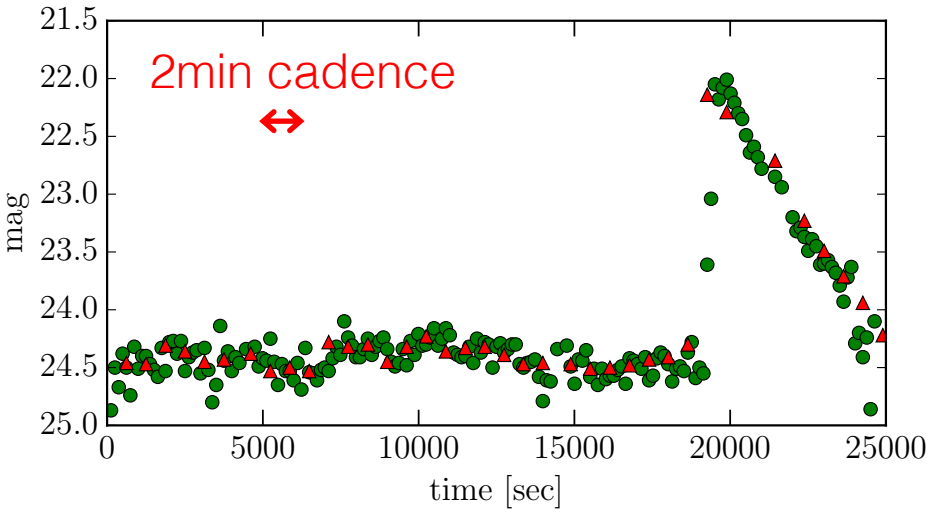
Niikura + in press

Fluxes from multiple stars are overlapped at each position

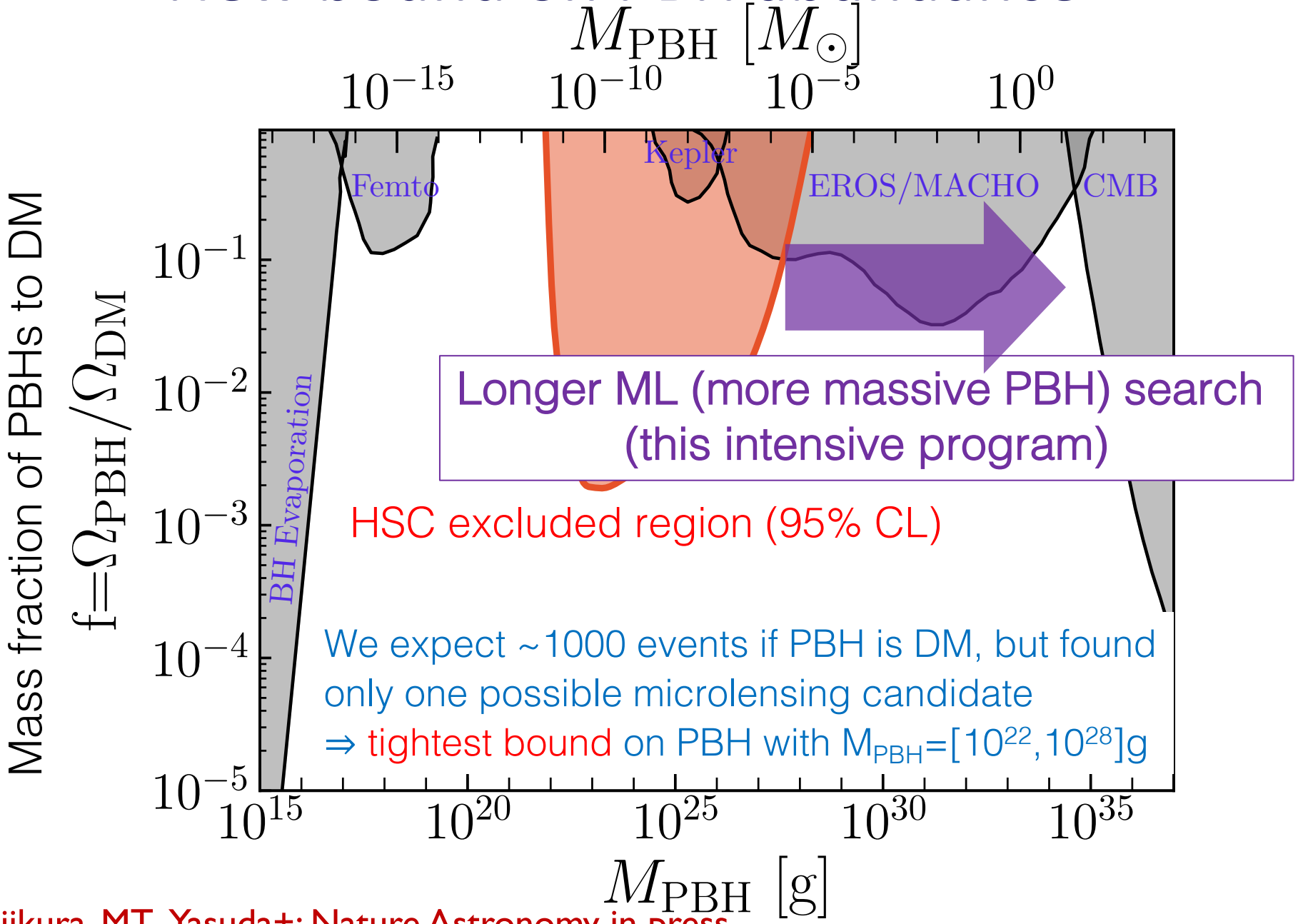








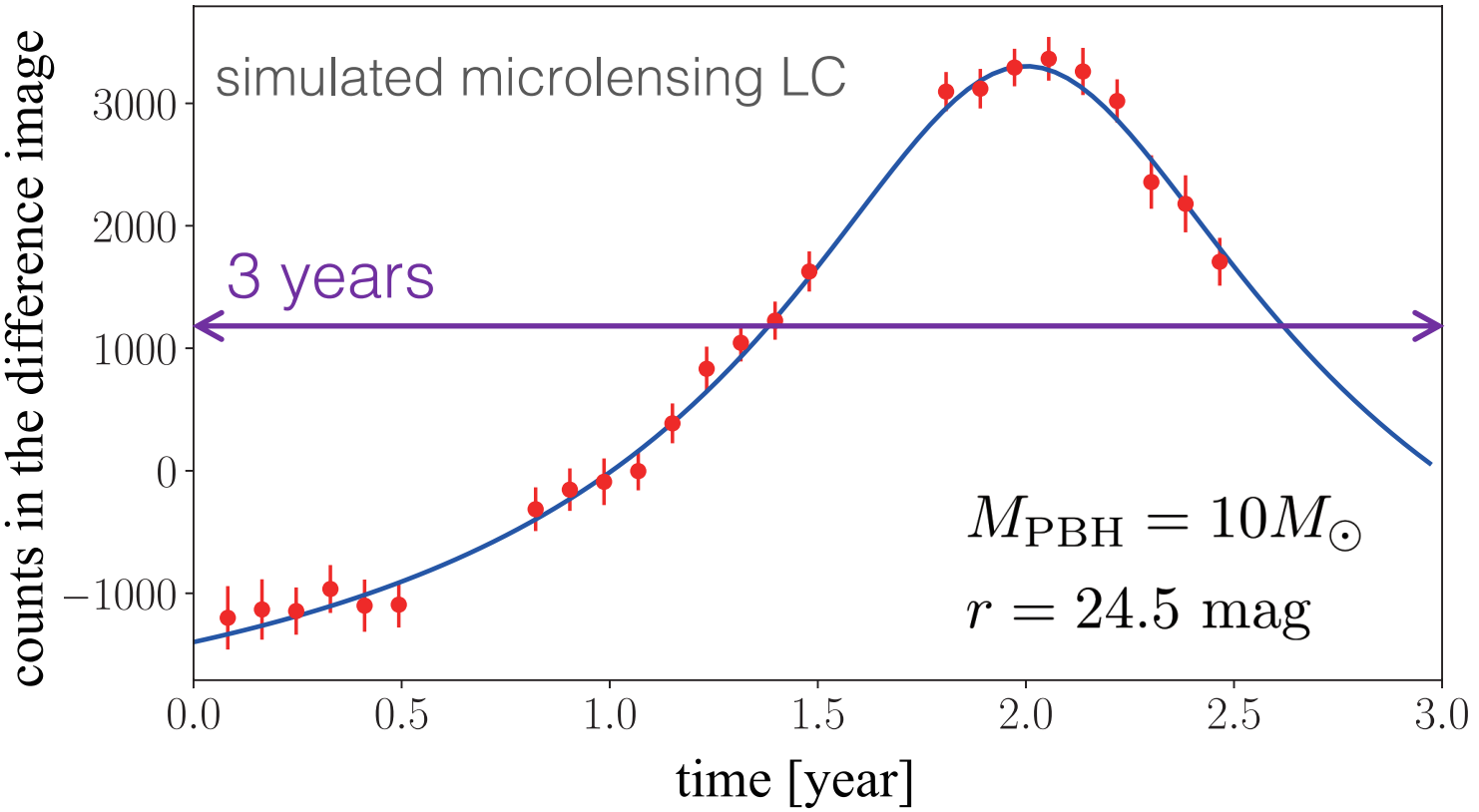
New bound on PBH abundance



Niikura, MT, Yasuda+; Nature Astronomy in press

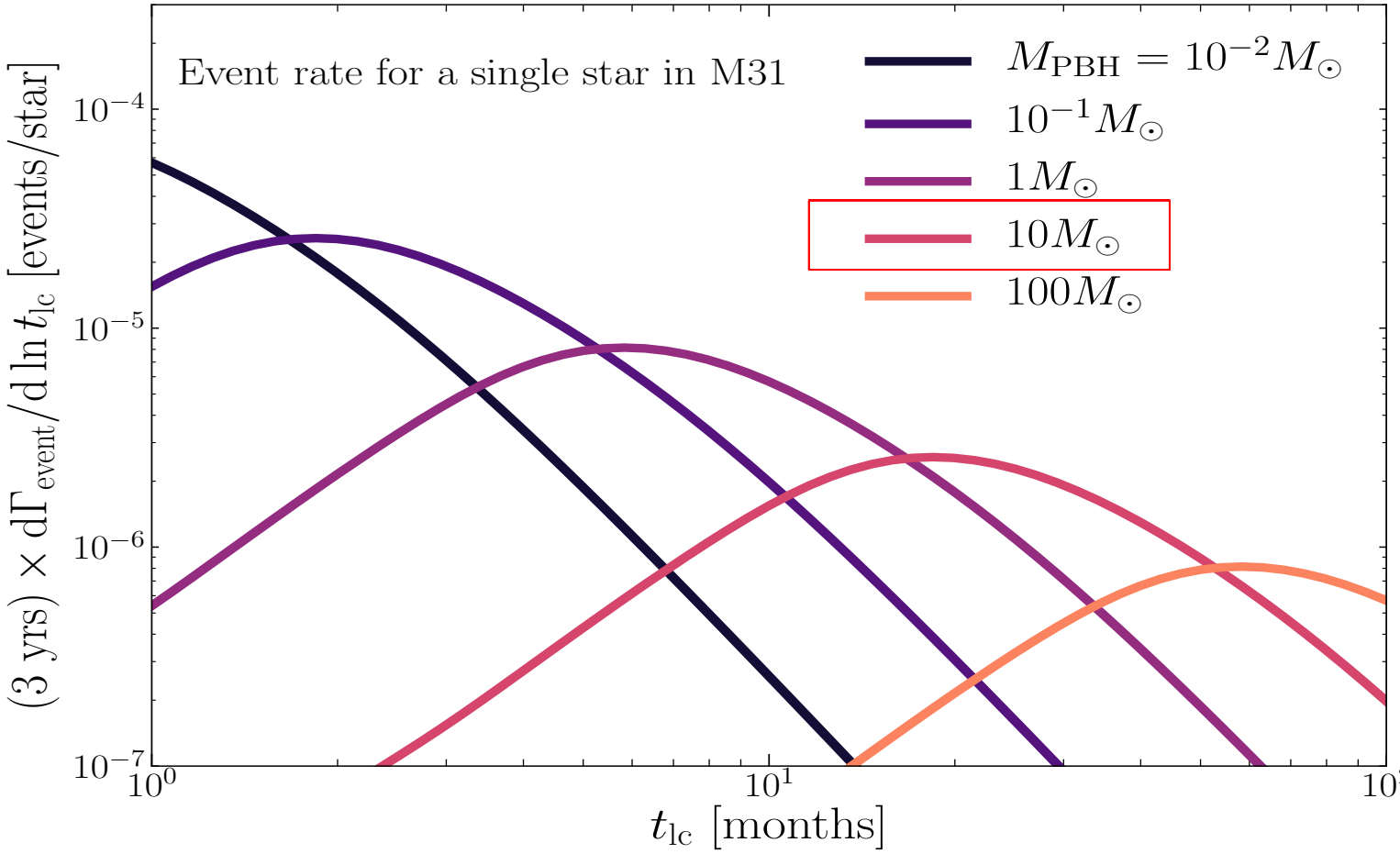
S18-093I: Observation strategy

- ~5 × 90 sec exposures in each HSC run of June – Feb each year, both g and r bands (g, r bands needed for testing achromatic nature of microlensing)
- Monitoring HSC obs. of M31 over 3 years (lost some months in S18B semester due to the earthquake/power outage)
- Request <5 nights (S18B – S21B) in total (incl. weather factor)



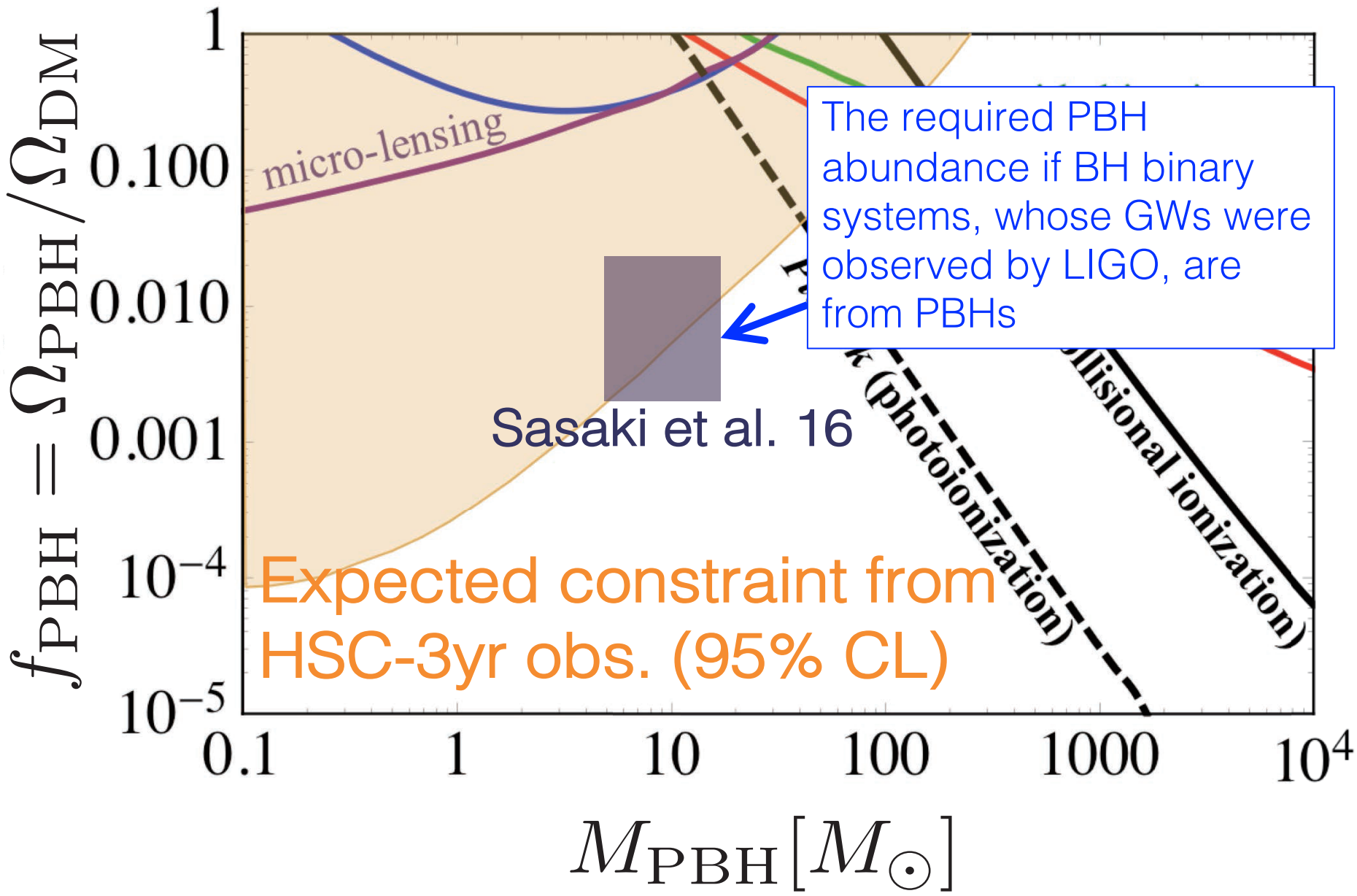
Event rates of microlensing

$$t_{\rm lc} \simeq \frac{R_{\rm E}}{v} \simeq 25\ {\rm months} \left(\frac{M_{\rm PBH}}{10 M_\odot}\right)^{1/2} \left(\frac{D}{100\ {\rm kpc}}\right)^{1/2} \left(\frac{v}{200\ {\rm km/s}}\right)^{-1}$$



Event rate per **3yr-obs. time** and per **a single star** in M31 for **a given timescale of light curve** (we monitor **~10^8 stars** in M31 thanks to FoV and depth of HSC/Subaru)

Expected PBH constraint



Summary

- The coming semesters (S19A/B) are critical
- Request to carry out our observation in each of June 2019 – Feb 2020 runs
  - So far Nov/Dec in 2018 and May, June & Sep in 2019 observations
  - Just received the S19A Sep data (thank you)
  - We are now working on the data
- A discovery potential (if we find PBH microlensing, it is a big discovery)
- Legacy value of this dataset
  - Deliver a catalog of variable star candidates in M31 (nova, RR-Lyrae, RCB-type stars, …)

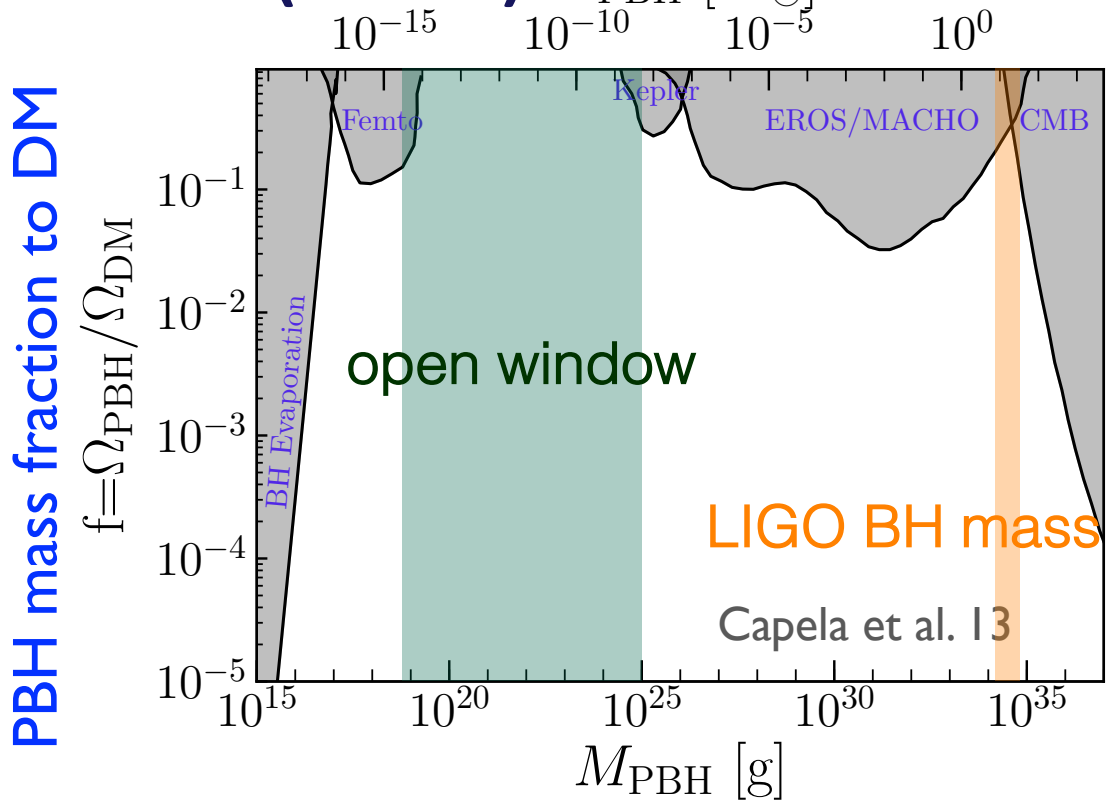
Exploring **primordial black holes** with HSC observation of Andromeda Galaxy (M31)

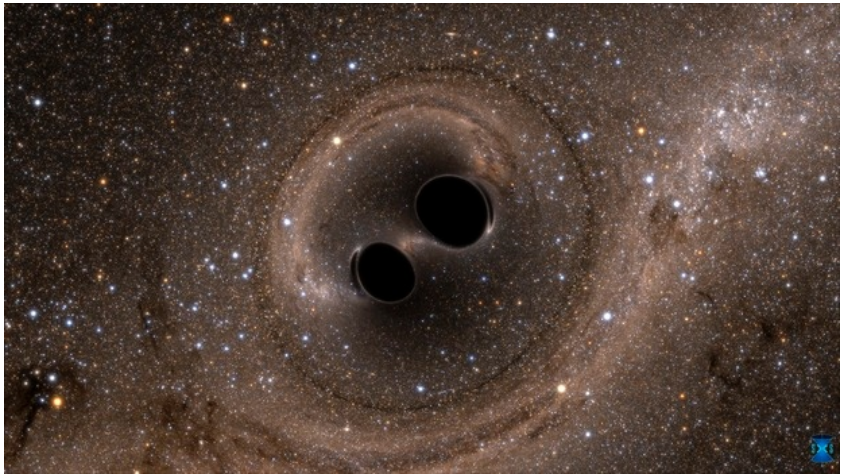
Initiated by MT's daily conversation with Hitoshi and Masahiro (Kawasaki)

- In the northern hemisphere (not accessible from VST, DES, LSST)
- Large spiral galaxy
- HSC FoV ~ entire M31
- ~770kpc (μ~24.4), reachable distance (not too far)!

Primordial Black Hole (PBH)

- Can be formed in the early universe (Zel'dovich & Novikov67; Hawking1971); not from any astrophysical processes
- A viable candidate of (cold) DM
- Progenitor of LIGO GW binary BHs? (Sasaki, Suyama, Tanaka & Yokoyama, PRL 2016)

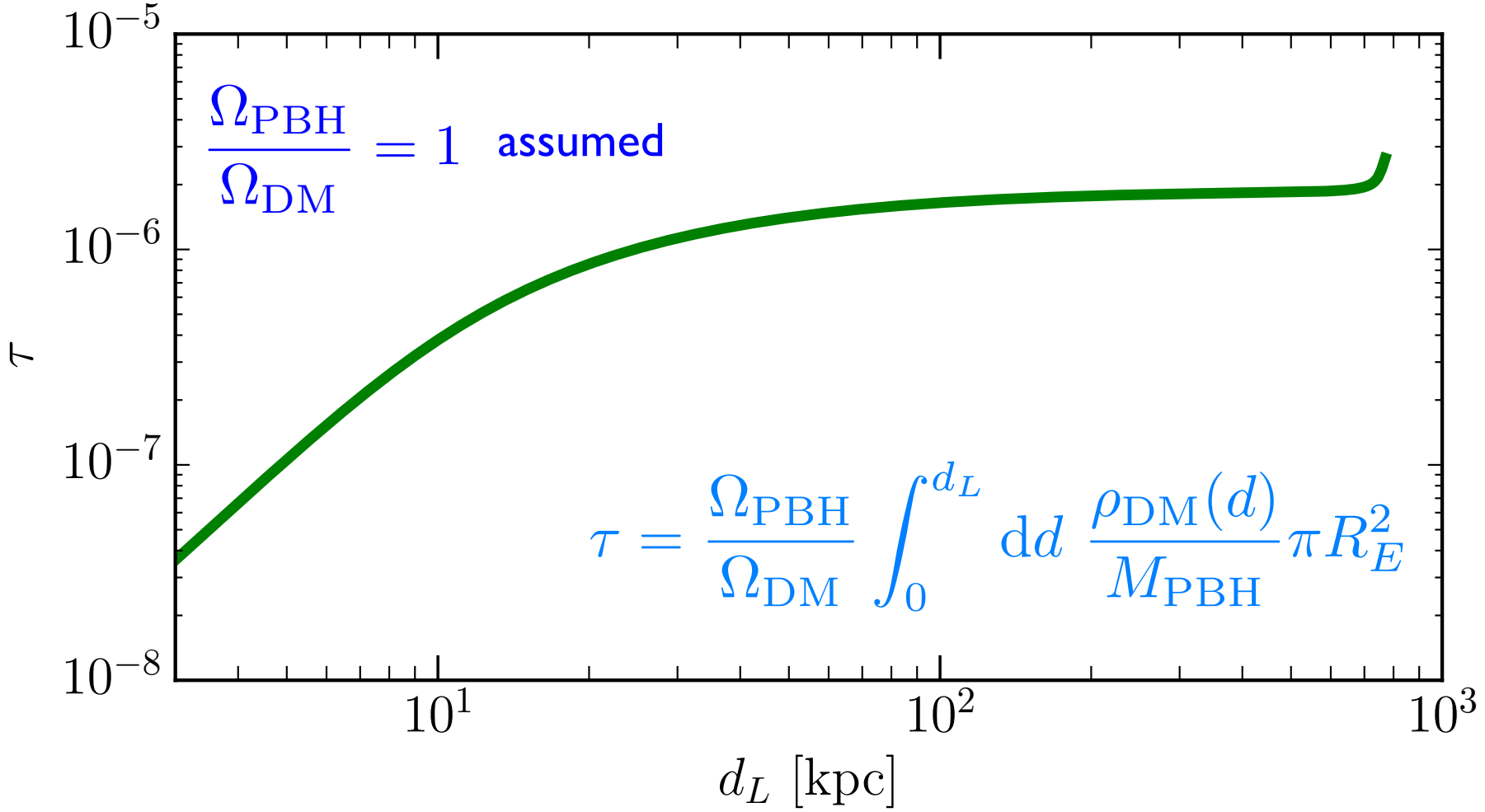




$M_{\rm PBH} \sim 10^{24}{\rm g} \sim M_H \ @\ T \sim 10\ {\rm TeV}$

PBH microlensing on M31 star

Cumulative optical depth of PBH microlensing for a **single** star in M31

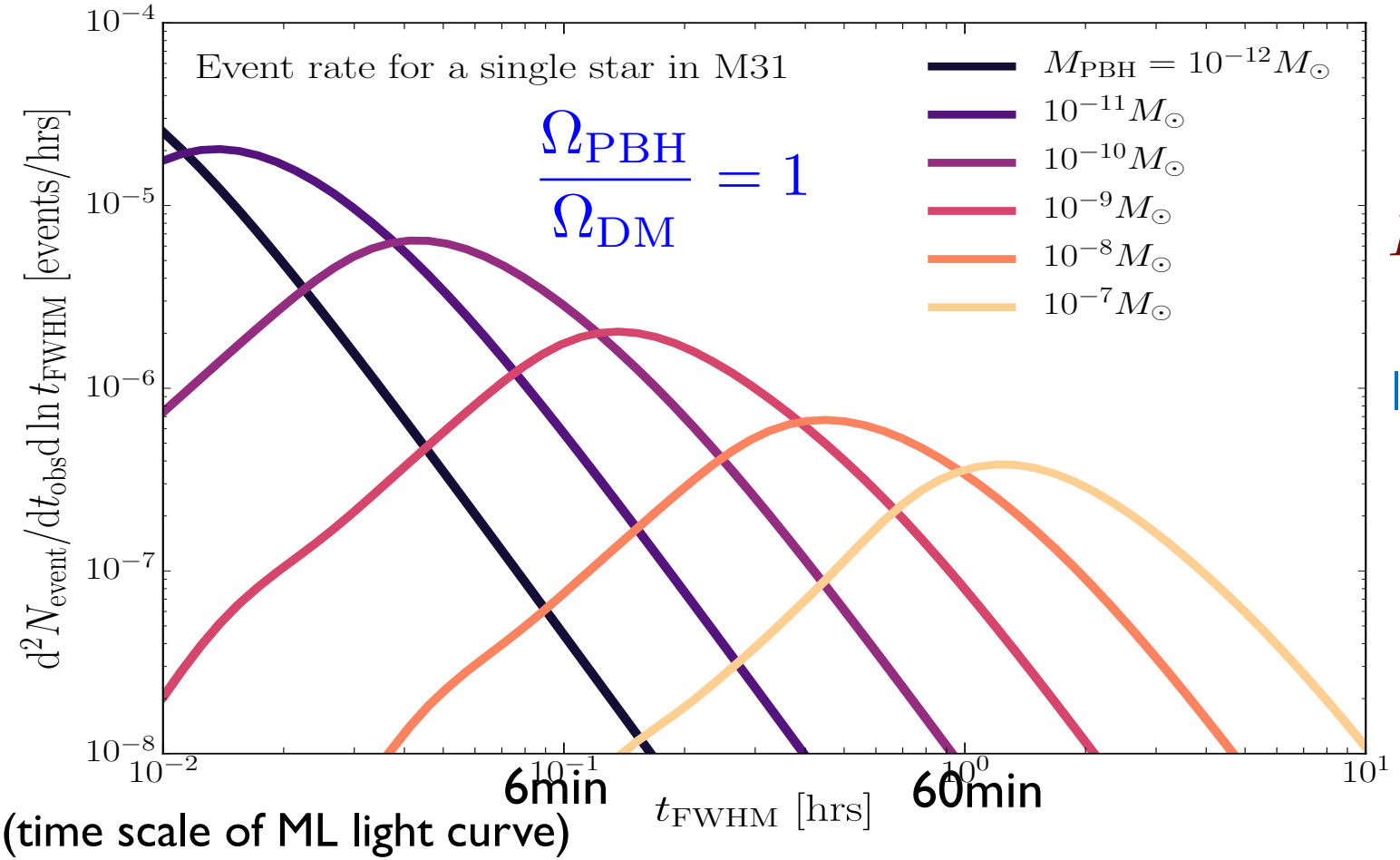


If we observe ~10^6 **stars** at one time, **one star at leas**
should be micro-lensed if PBHs are DM

PBH microlensing event rate

source star

$$t_E \sim \frac{d_L \theta_E}{v_{\rm PBH}} \sim 34\ {\rm min} \left(\frac{M_{\rm PBH}}{10^{-8} M_\odot}\right)^{1/2} \left(\frac{d_L}{100\ {\rm kpc}}\right) \left(\frac{v_{\rm PBH}}{200\ {\rm km/s}}\right)^{-1}$$



(time scale of ML light curve)

$R_E \propto M_{\rm PBH}^{1/2}$

lens (PBH)

observer

Event rate per **unit obs. time** and per **a single star** in M31 for **a given timescale of light curve (we monitored ~10^8 stars)**

One real candidate of microlensing …?