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Constraints on PBH with dense-cadence HSC observation of M31

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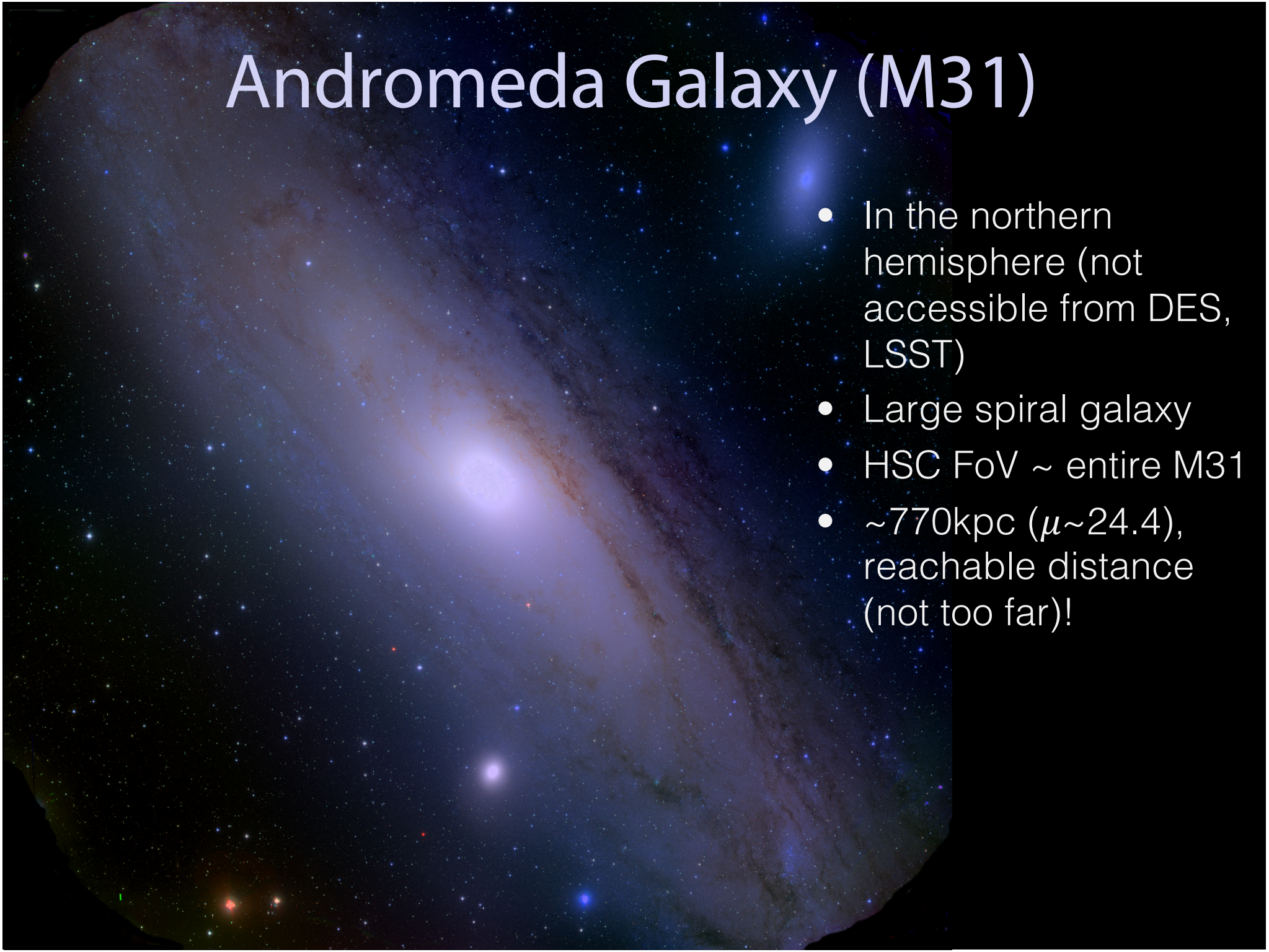
wpi

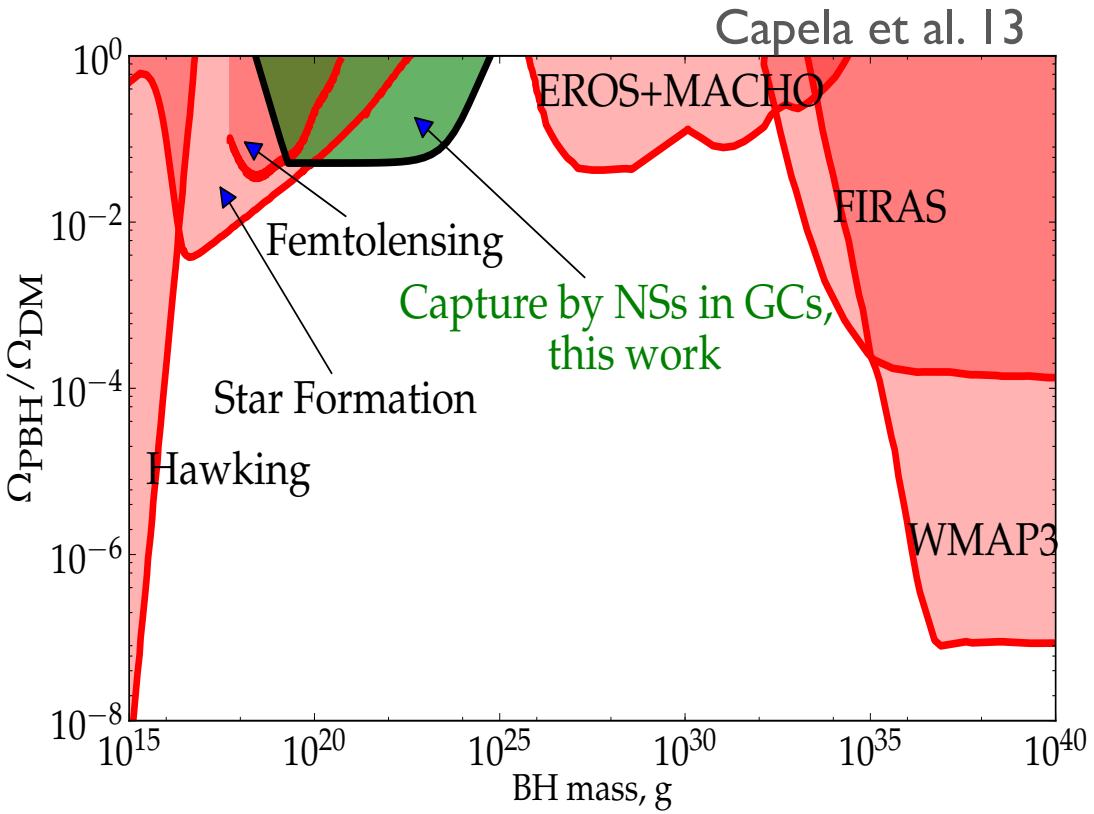
Andromeda Galaxy (M31)

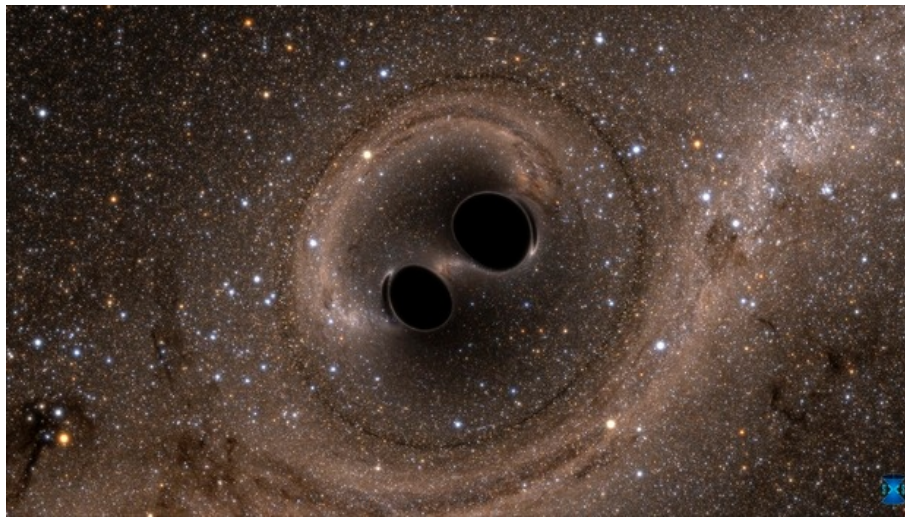


- In the northern hemisphere (not accessible from DES, LSST)
- Large spiral galaxy
- HSC FoV ~ entire M31
- ~770kpc (μ~24.4), reachable distance (not too far)!

Primordial Black Hole (PBH)

- Dark matter needed
- Can be formed in the early universe
- One of viable candidates of CDM (based on a minimum assumption, from Standard Model particles in principle)
- Progenitor of LIGO GW binary BHs? (Sasaki, Suyama, Tanaka & Yokoyama, PRL 2016; Bird te al. 16)

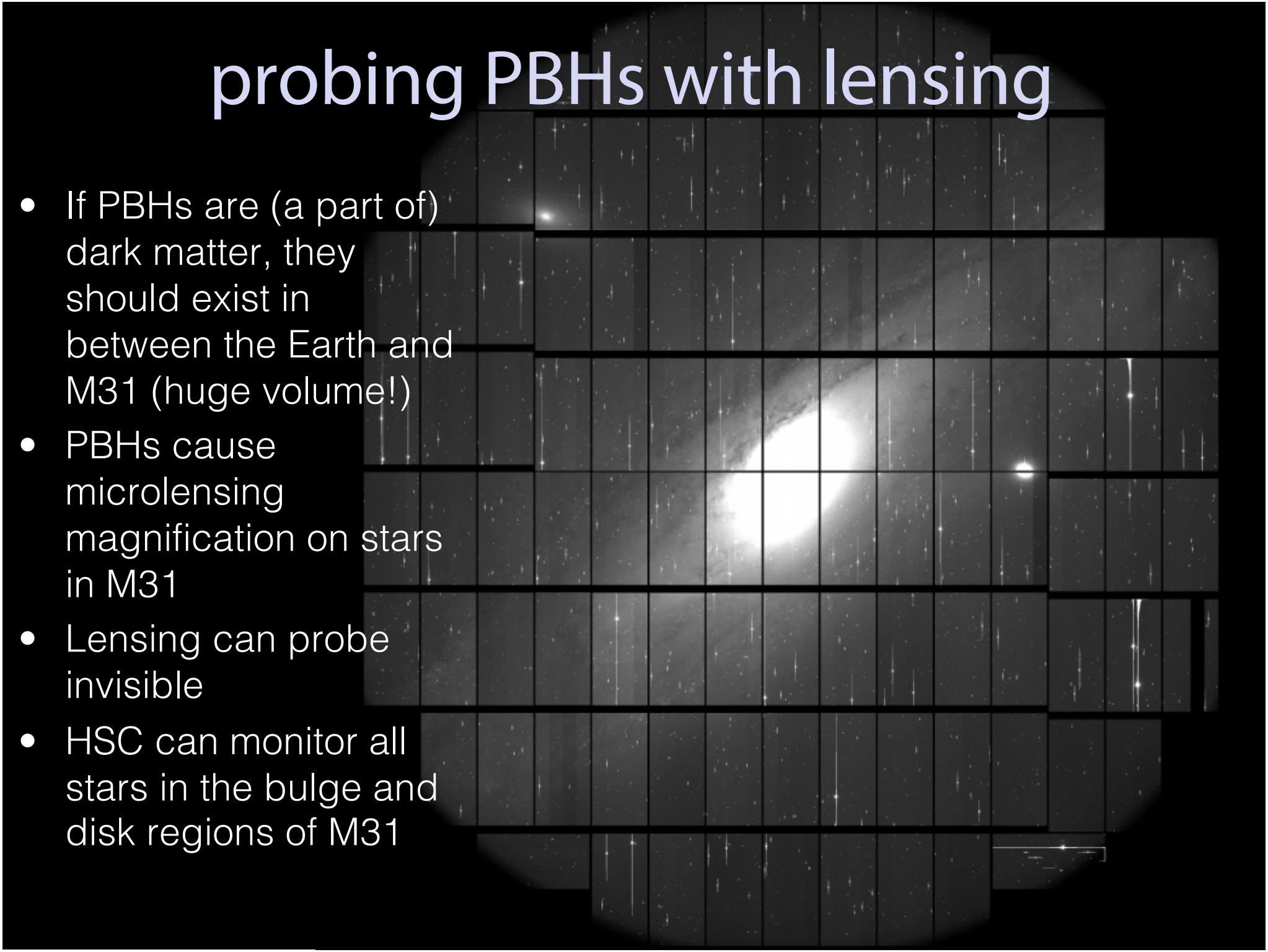




$M_{\rm PBH} \sim 10^{24}{\rm g} \sim M_H \ @ \ T \sim 10^{10}$ GeV

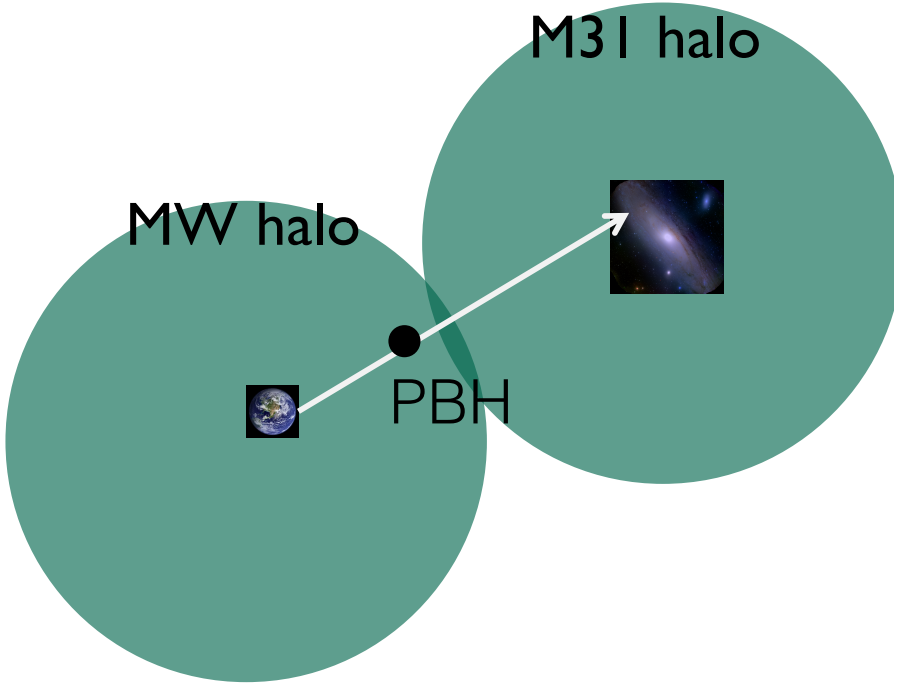
probing PBHs with lensing

- If PBHs are (a part of) dark matter, they should exist in between the Earth and M31 (huge volume!)
- PBHs cause microlensing magnification on stars in M31
- Lensing can probe invisible
- HSC can monitor all stars in the bulge and disk regions of M31

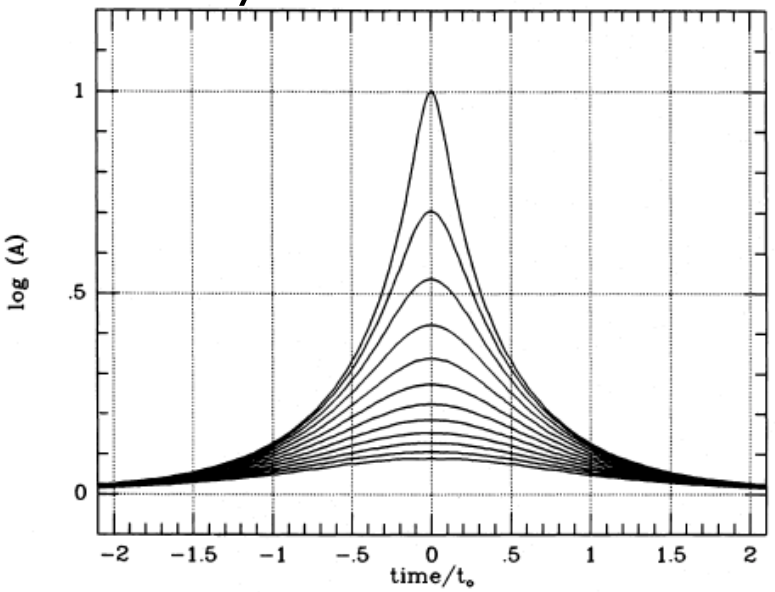


PBH microlensing on M31 star

- Lensed image can't be resolved with optical resolution (~10^{-8} arcsec) ⇒ only light curve is a signal
- So huge volume
- MW/M31 halo ~ 10^{12}Msun (we assumed NFW models)
- PBH has a peculiar velocity of ~200km/s

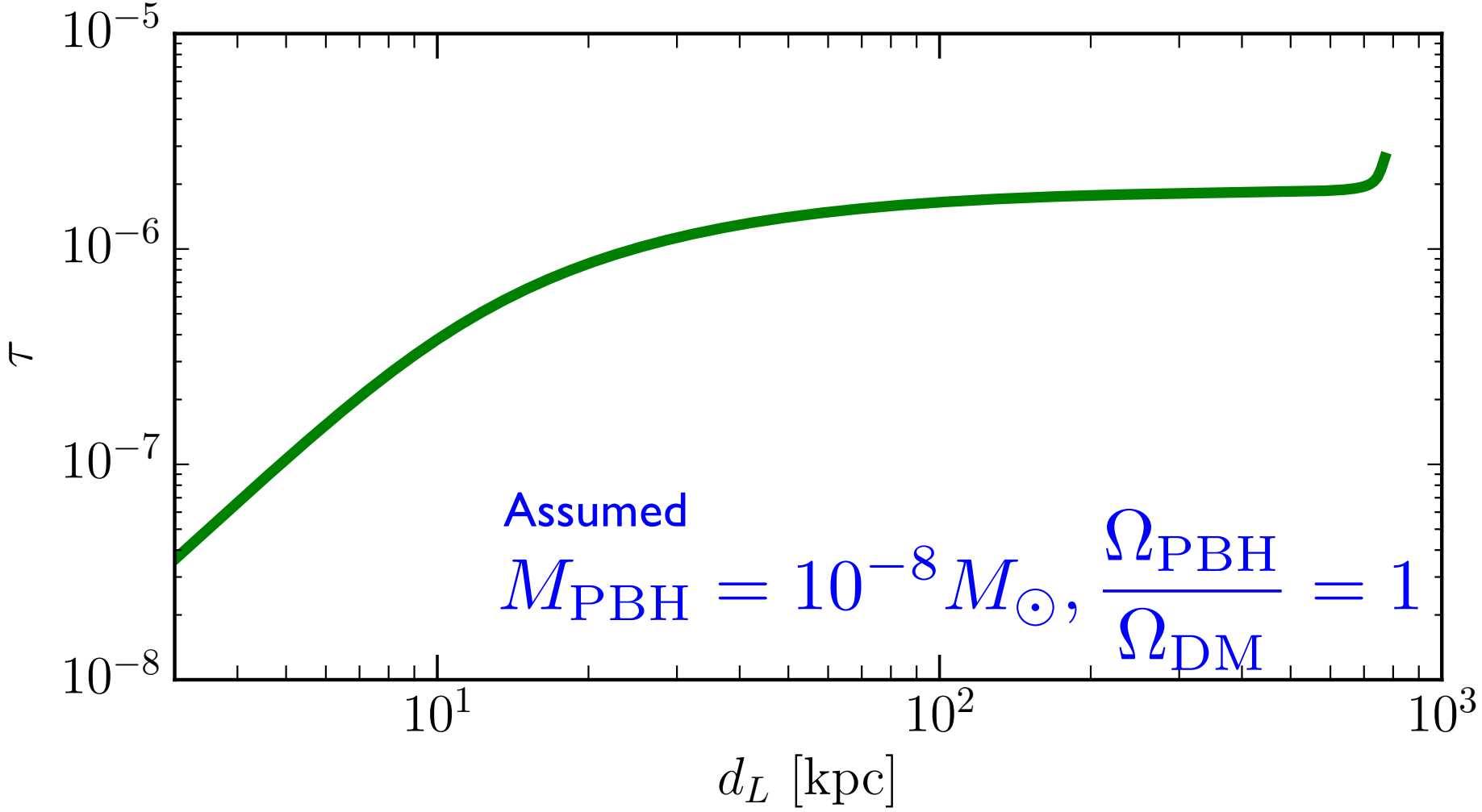


Paczynski 86



PBH microlensing on M31 star

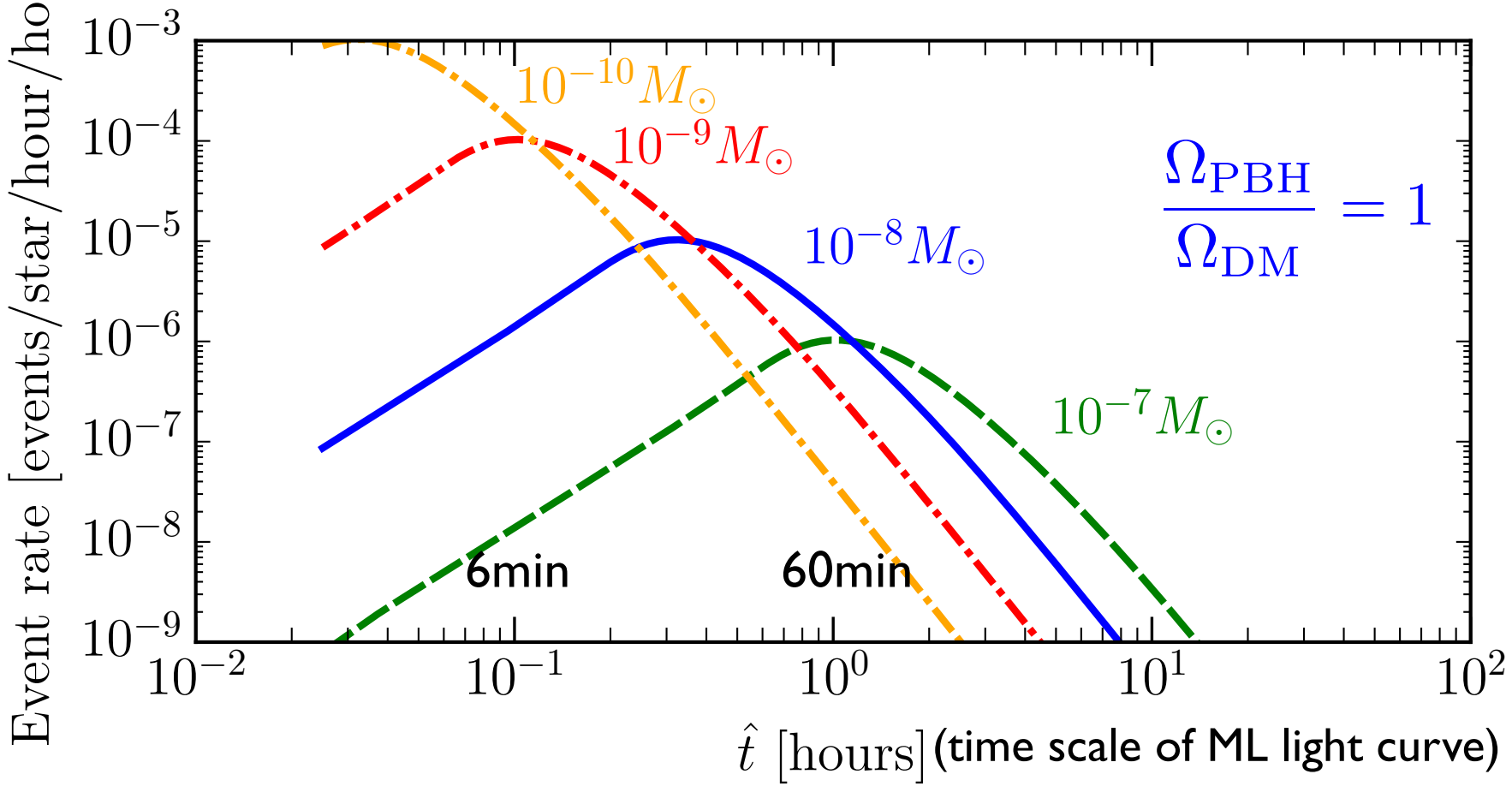
Cumulative optical depth of PBH microlensing for a **single** star in M31



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

PBH microlensing event rate

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



Event rate per **unit obs. time** and per **a given timescale of light curve** for **a single star** in M31

Hiroko Niikura

HSC dense-cadence observation of M31 (PI Takada)

Got this idea from conversation with Hitoshi and Masahiro Kawasaki

90sec exposure each (r-band)

~35sec readout

~190 exposures

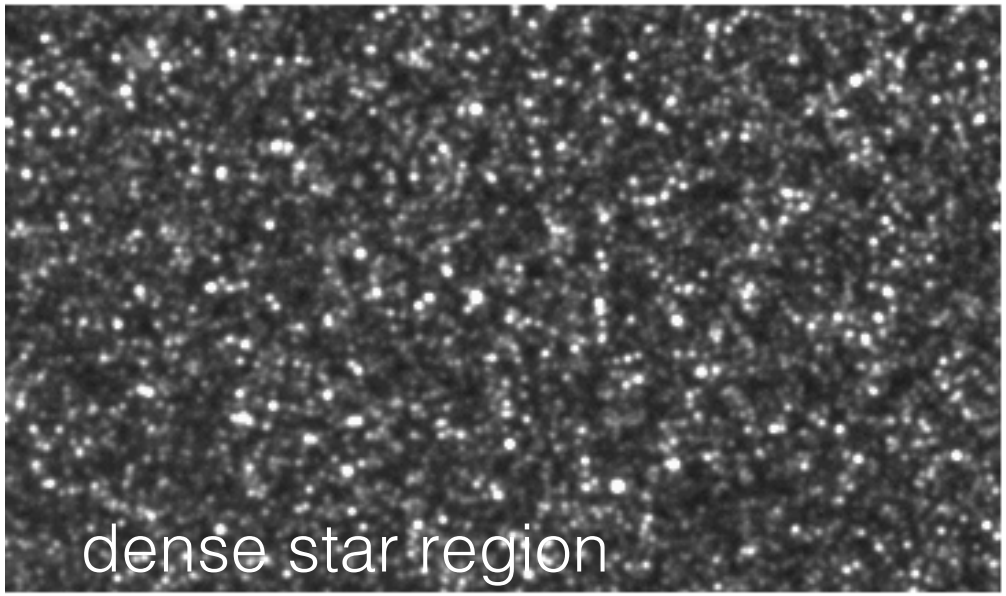
No dithering

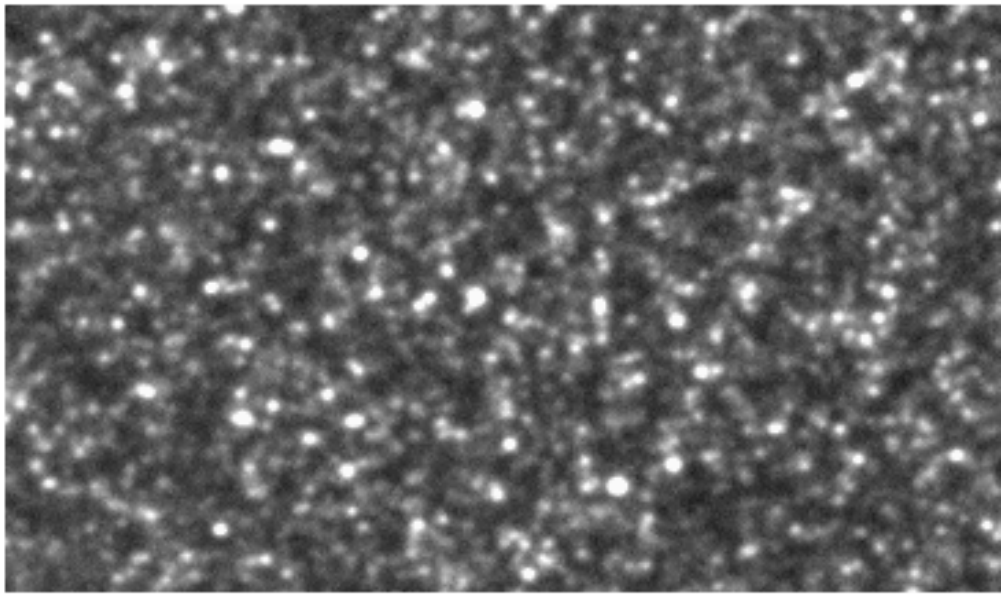
one clear night (seeing~0.5-0.6'')

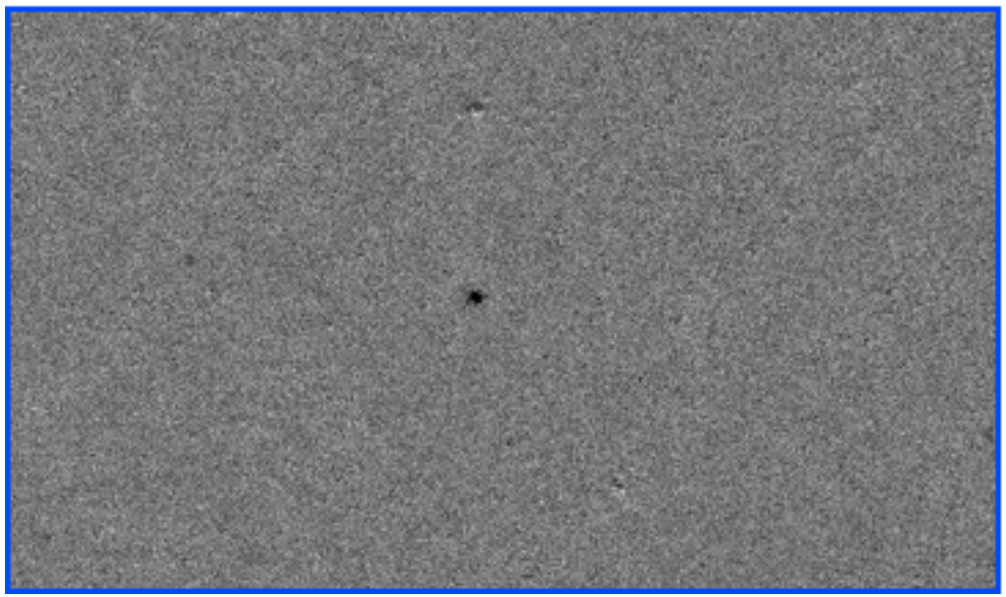
Also used g-data (from

Challenges: Pixel lensing

Fluxes from multiple stars are overlapped at each position

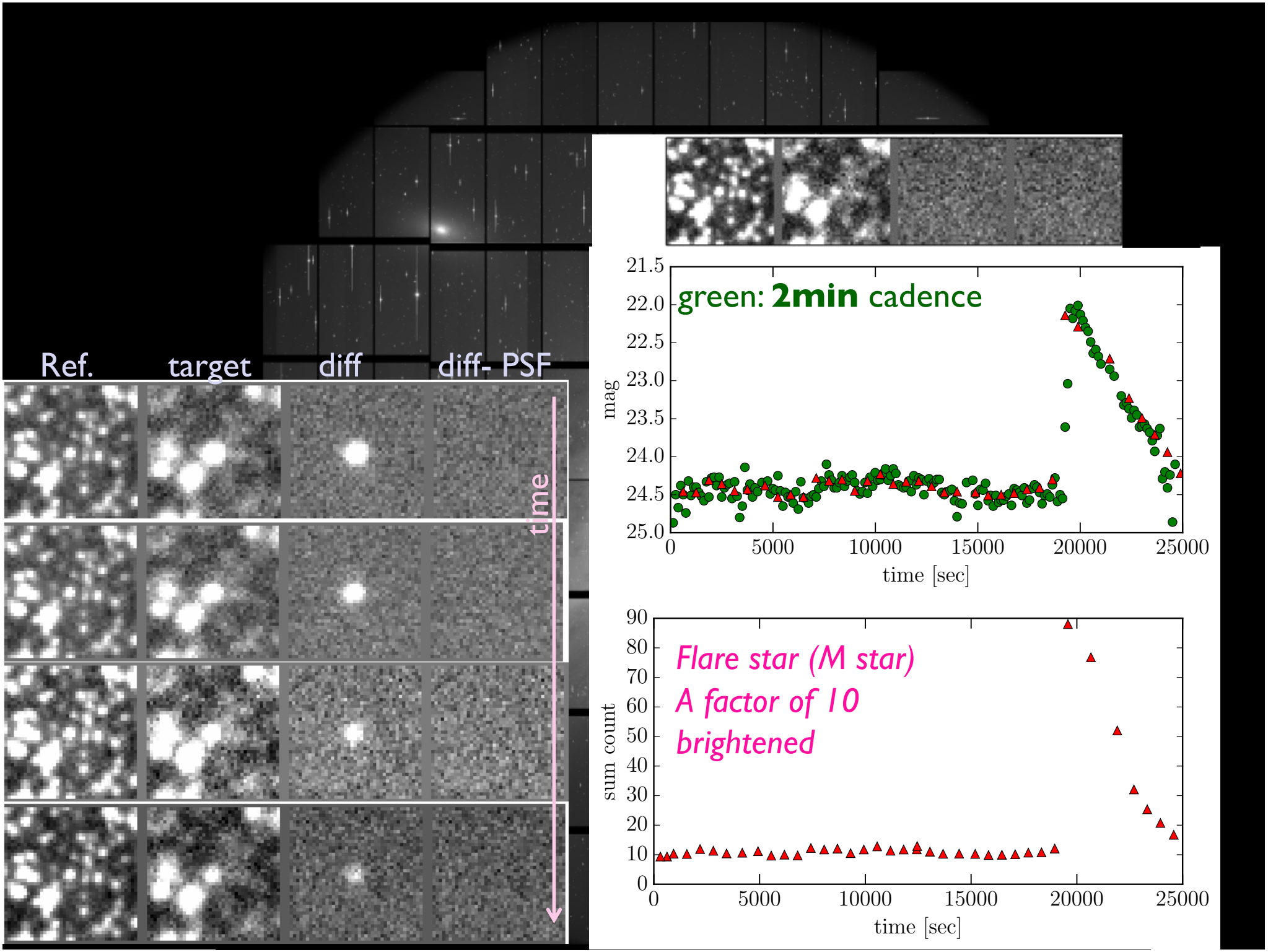


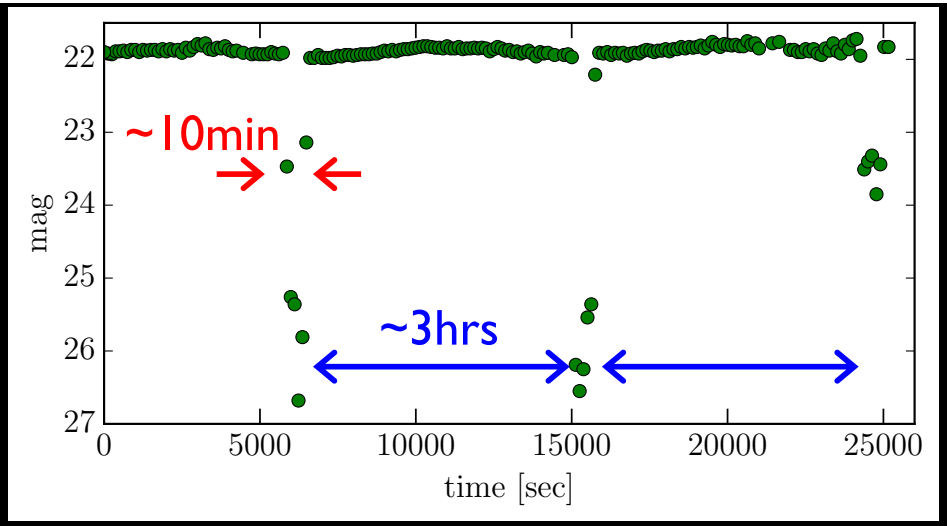




Upper left: reference image (0.5'')
Upper right: target image (0.8'')
Lower: difference image

Accurate PSF and astrometry measurements needed.
HSC pipeline works!


Ref.
target
diff
diff- PSF
time
green: 2min cadence
mag
time [sec]
Flare star (M star)
A factor of 10
brightened
sum count
time [sec]

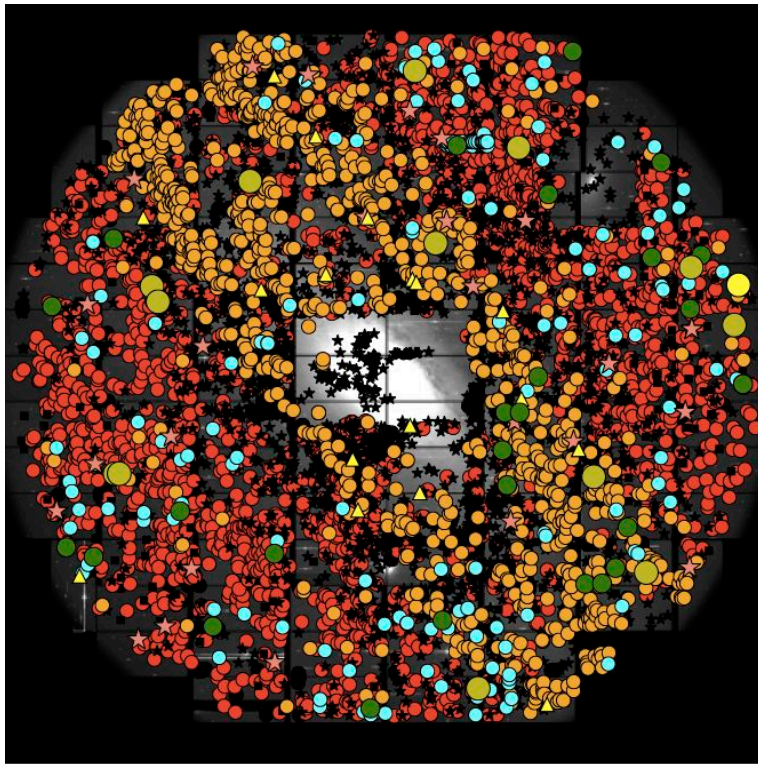


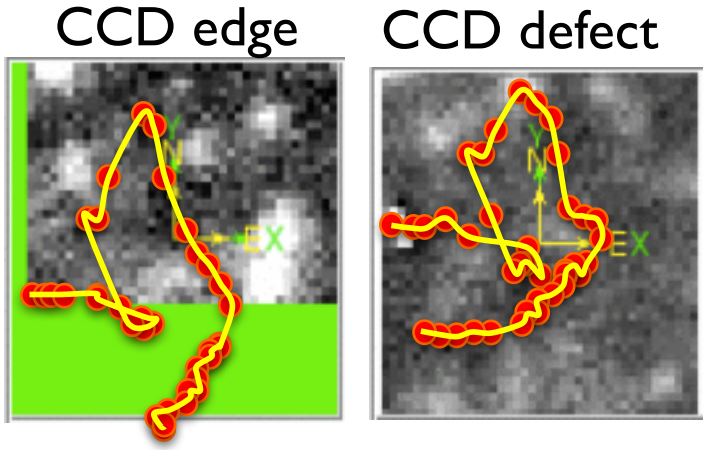
An entire star disappears for ~10min, with a 3hrs interval

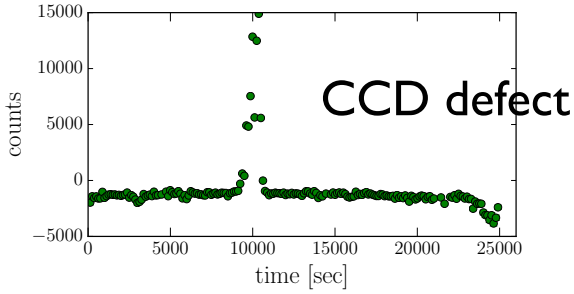
WD – brown dwarf binary

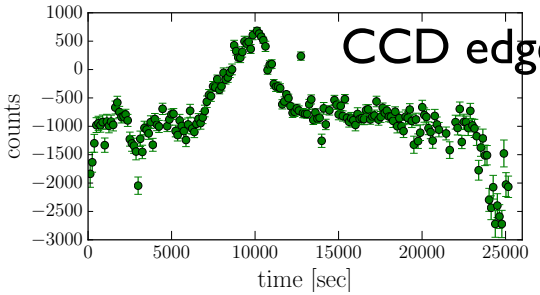
time

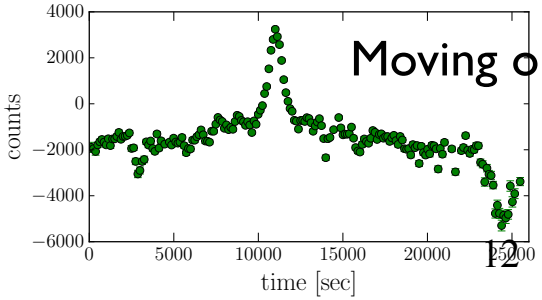
So far… no promising candidate :<







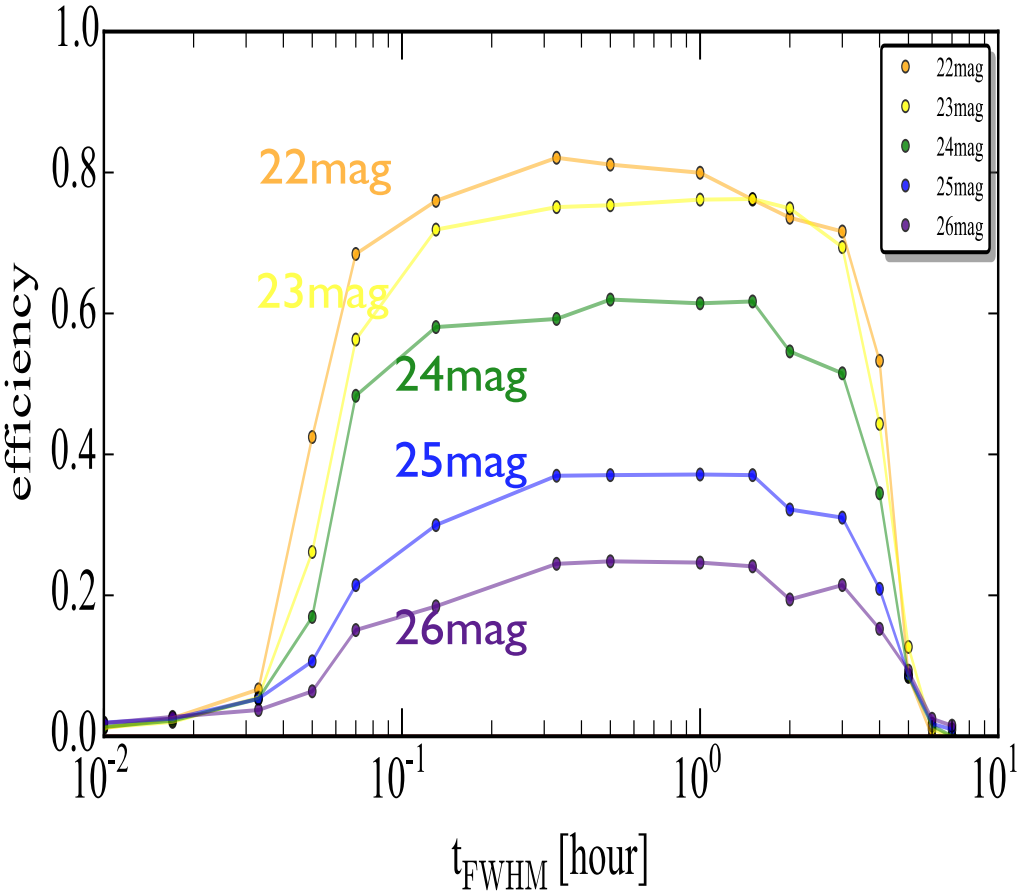


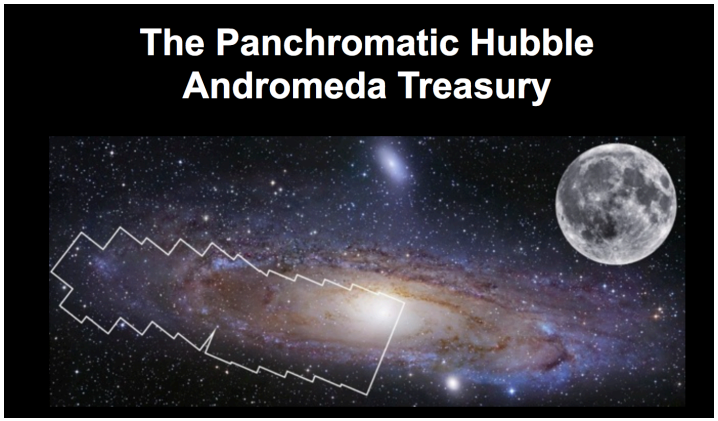


- ~10,000 candidates
- In the end, based on visual inspection
- Impose the conditions (fitting to a model microlensing light curve, …)
- No secure candidate of PBH lensing
- PS: no contact binary of OB stars

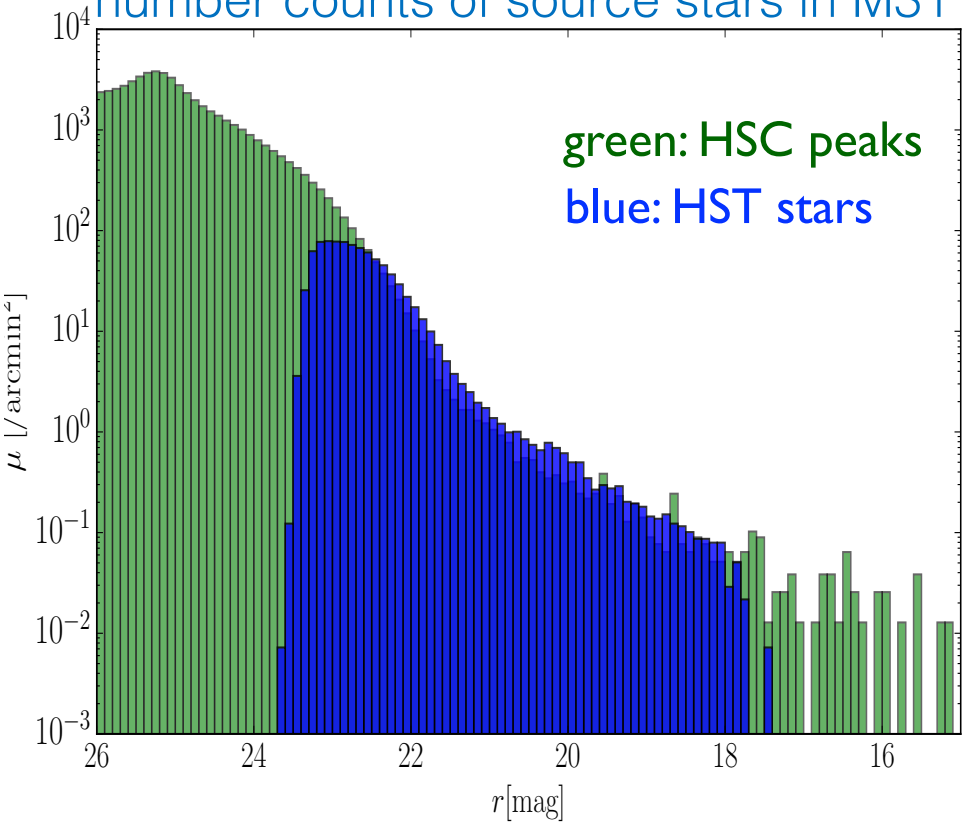
Constraint on the PBH abundance

efficiency of detecting microlensing of a star in a given magnitude under our observation conditions; estimated using the simulated microlensing light curves





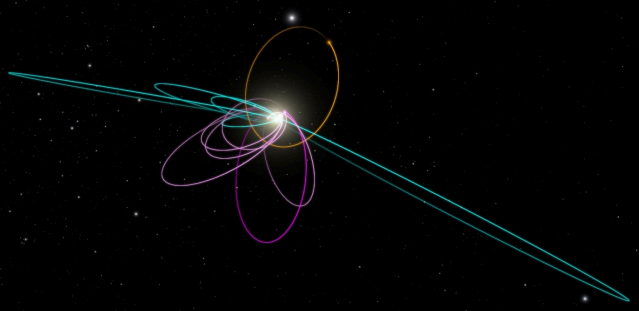
number counts of source stars in M31



summary

- HSC is very powerful: ~1min exposure reaches 25-26mag depth for a point source
- Image difference technique (already integrated in the standard HSC pipeline)
- Tightest upper bound on the PBH abundance: tighter than Kepler 2yrs data & now no allowed window of PBH mass
- New opportunity for time-domain astronomy with HSC before LSST: GW counterpart, supernovae, ….

HSC hunt of Planet Nine



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