Observability of low mass Pop III survivors in the Milky Way and dwarf galaxies

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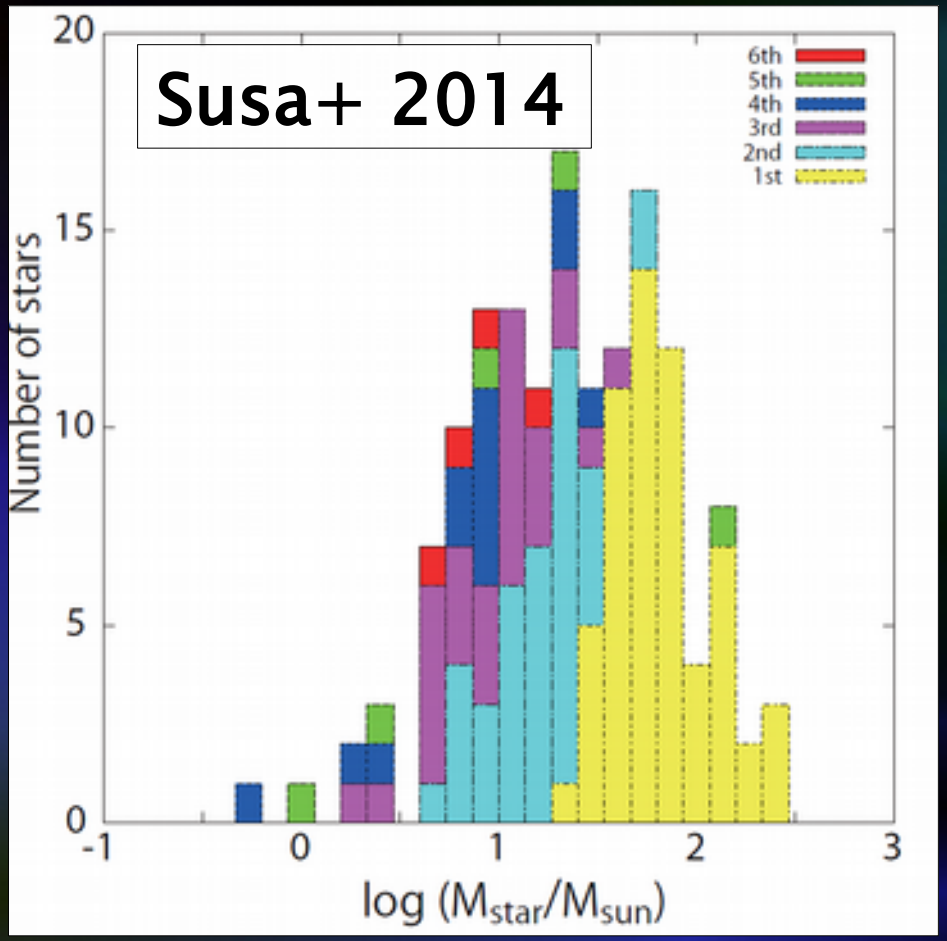
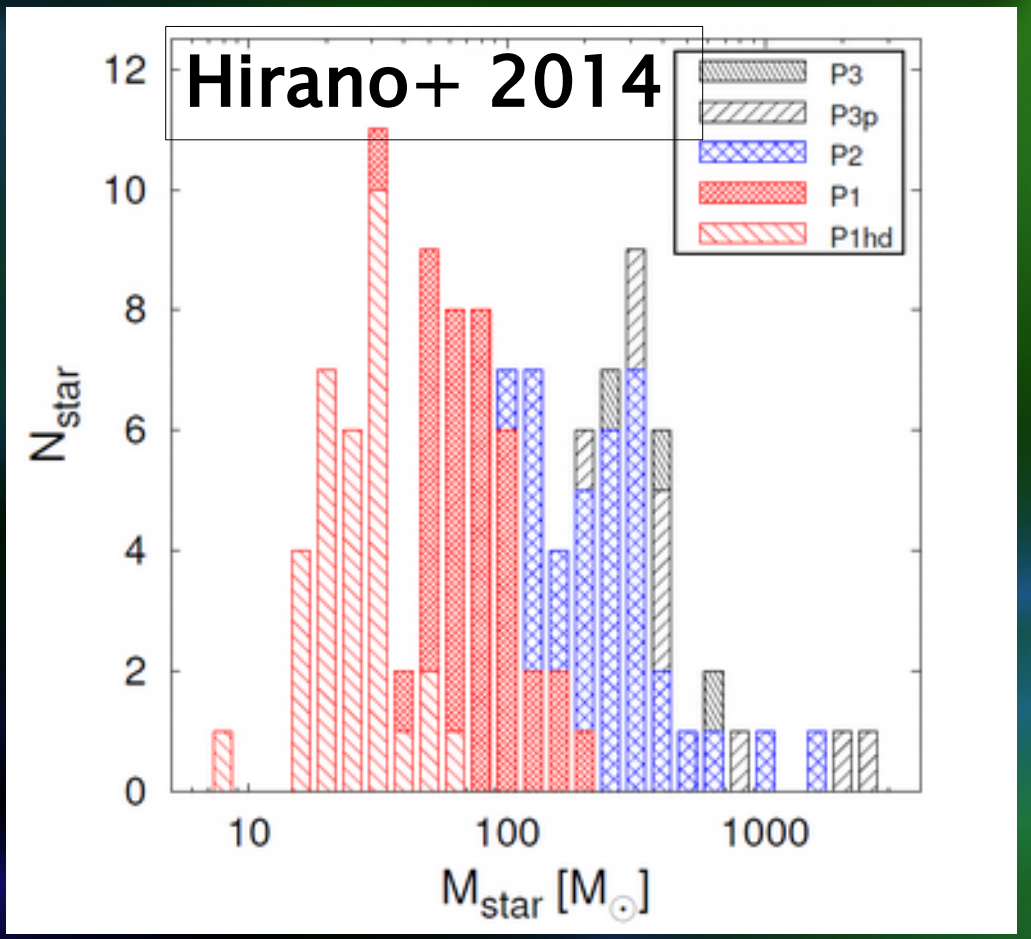
Ishiyama et al., ApJ, 2016, 826, 9 (arXiv:1602:00465)

Pop III IMF





- Very massive as a first approximation
- Unstable circumstellar disks fragment into small pieces, which could end up as low mass Pop III stars (e.g., Greif+12, Machida and Doi 2013, Susa 2013, Susa+ 2014)

This work

- Low mass Pop III stars are possible
  - Their lifetimes are longer than the age of the Universe, If they are less massive than ~0.8 Msun
  - Average number per minihalo is unknown

To constrain the low mass Pop III IMF by observations

- We predict the distribution of Pop III survivors by using numerical model based on
  - hierarchical formation of dark matter minihalos and Milky Way halos taken from single cosmological simulation
  - recepie for the formation of Pop III in H_2 cooling minihalos
- Assuming an IMF of low mass Pop III, we constrain the models in reverse by past/ongoing/planning observations

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Cosmological N-body simulation

z=0

- 2048^3 particles
- 8Mpc/h Box
- $m=5.13\times10^3$ Msun/h
- softening 120 pc/h
- Planck Cosmology
- z=127 to 0

- GreeM TreePM code (Ishiyama+ 2009, 2012)
- Aterui@NAOJ

Model for the formation of Pop III stars

- Identify halos by friends-of-friends method and generate merger tree
  - Minimum halo mass is 1.64×10^5 Msun/h (32 particles)
  - four Milky Way sized halos @z=0

- The condition of minihalos where Pop III can form

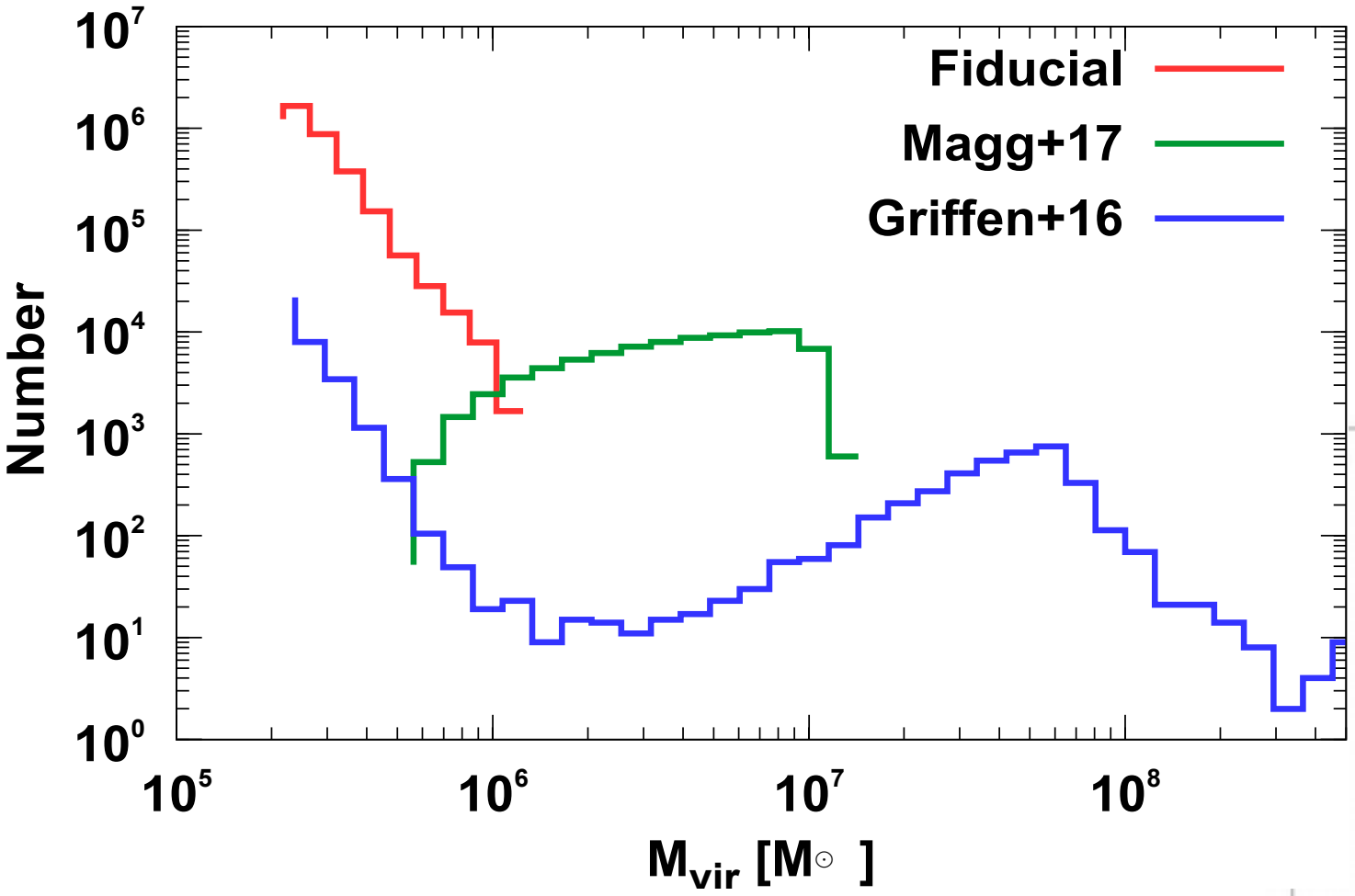
$$\left(\frac{T_{\rm vir}^{\rm crit}}{1000}\right) \approx 0.36\left[(\Omega_b h^2)^{-1}\left(\frac{F_{\rm LW}}{10^{-21}}\right)\left(\frac{1+z}{20}\right)^{3/2}\right]^{0.22}$$

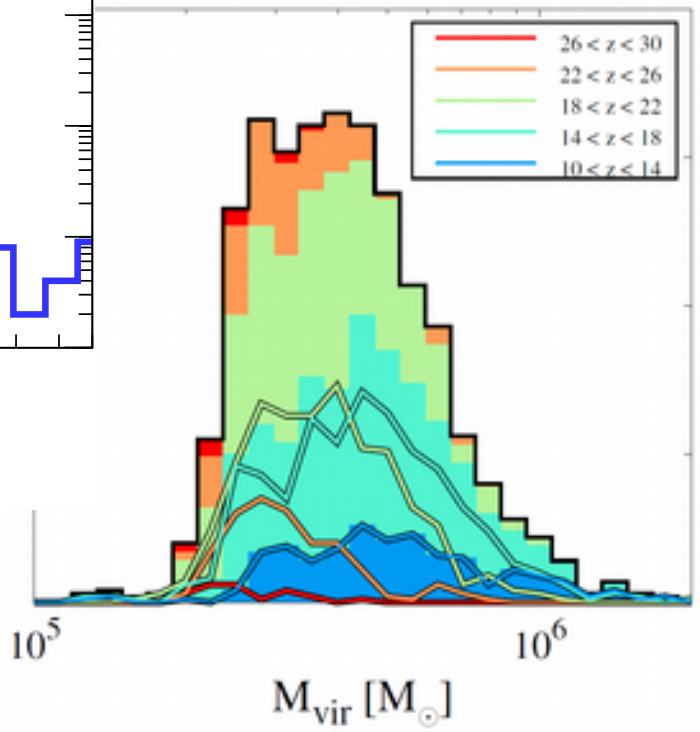
Machacek+2001

  - **T^{crit}_{vir} < Virial temperature < 2000K**
    - Efficient H_2 cooling under Lyman-Werner Background
    - $F_{LW}(z)$ is taken from a simulation result
      (Ahn+2012, spatially uniform, redshift dependent)

1. **Do not have progenitors that satisfy the condition 1**
   - Metal free
2. **collapse at z>10**
   - Before reionization

Distribution of Pop III forming minihalo mass

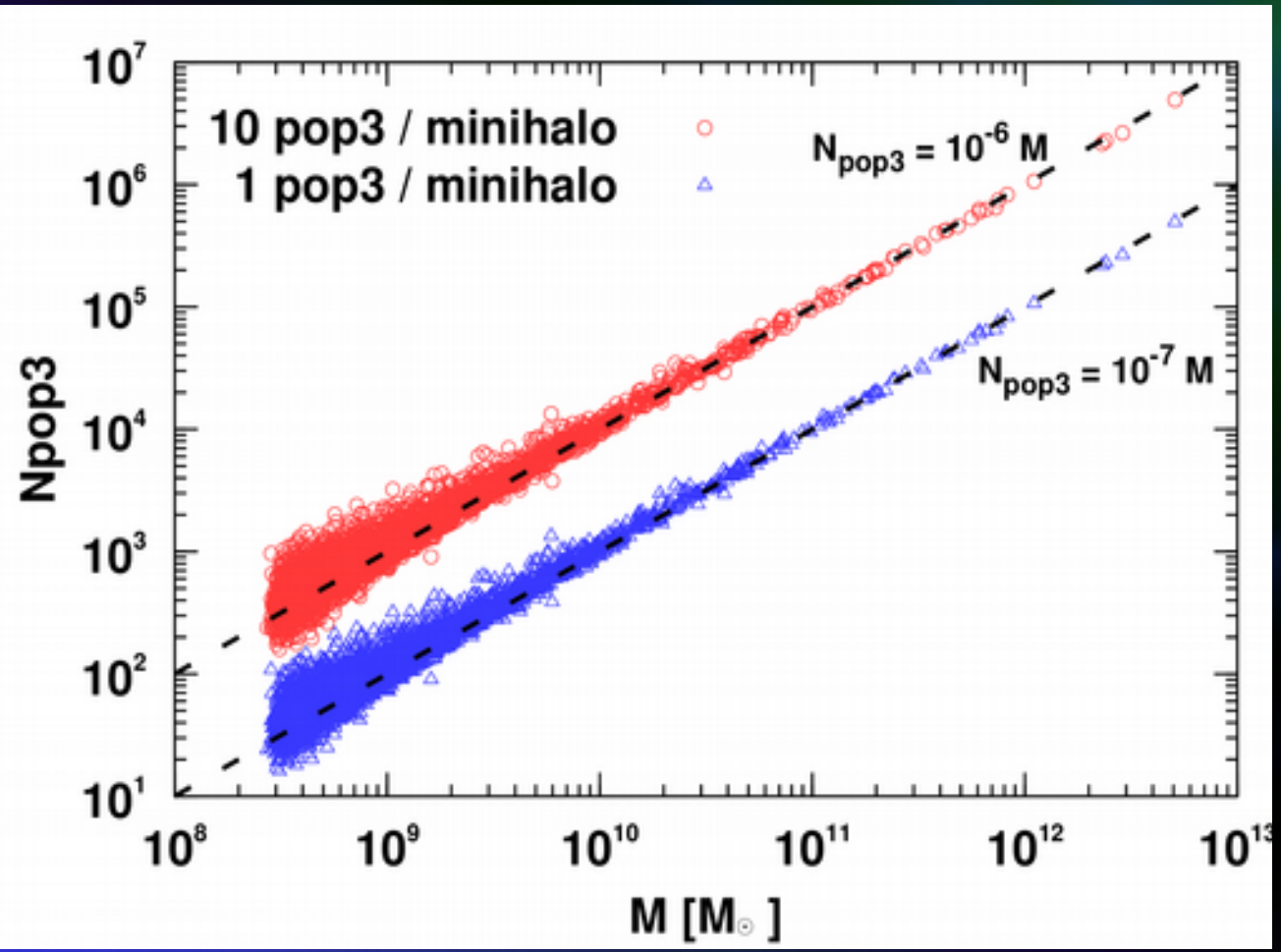




Hirano+ 2015

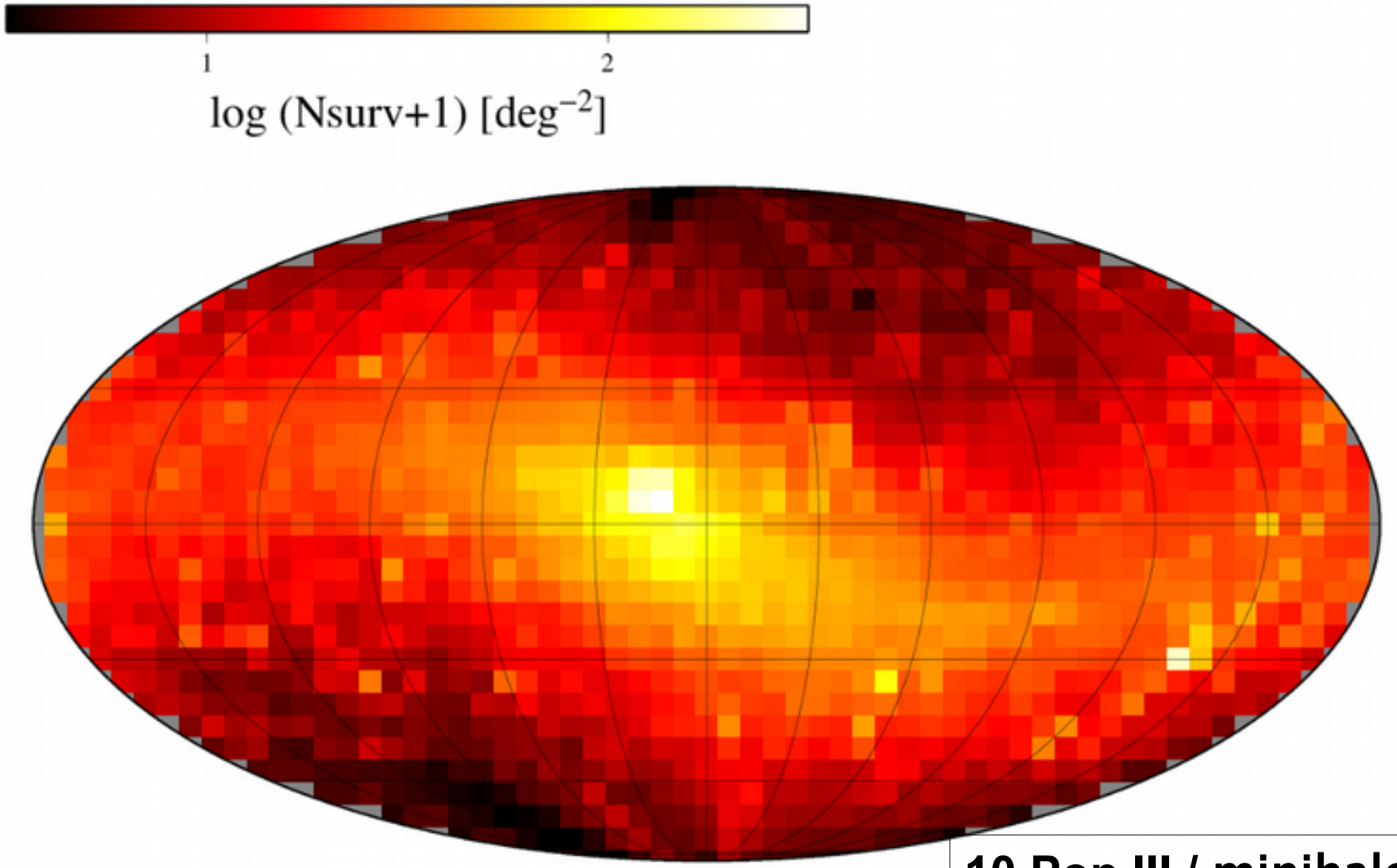
Number of Pop III survivors / minihalo at z=0

1. Assuming 10 (1) low mass Pop III stars born per minihalo
   - Kroupa IMF, 0.15 ~ 1.0 Msun
2. Randomly select 10 (1) DM particles of minihalos as tracers of Pop III
3. Use an isochrone model to calculate magnitudes of various bands



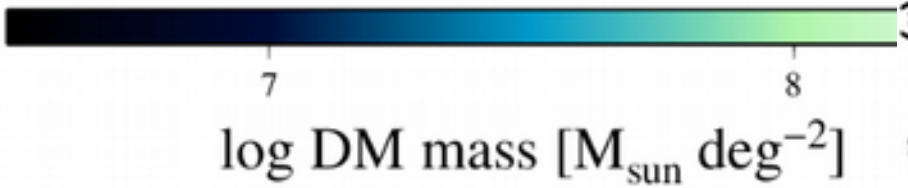
- Number of Pop III / halo @z=0 is proportional to
  - halo mass
  - assuming number of Pop III / minihalo

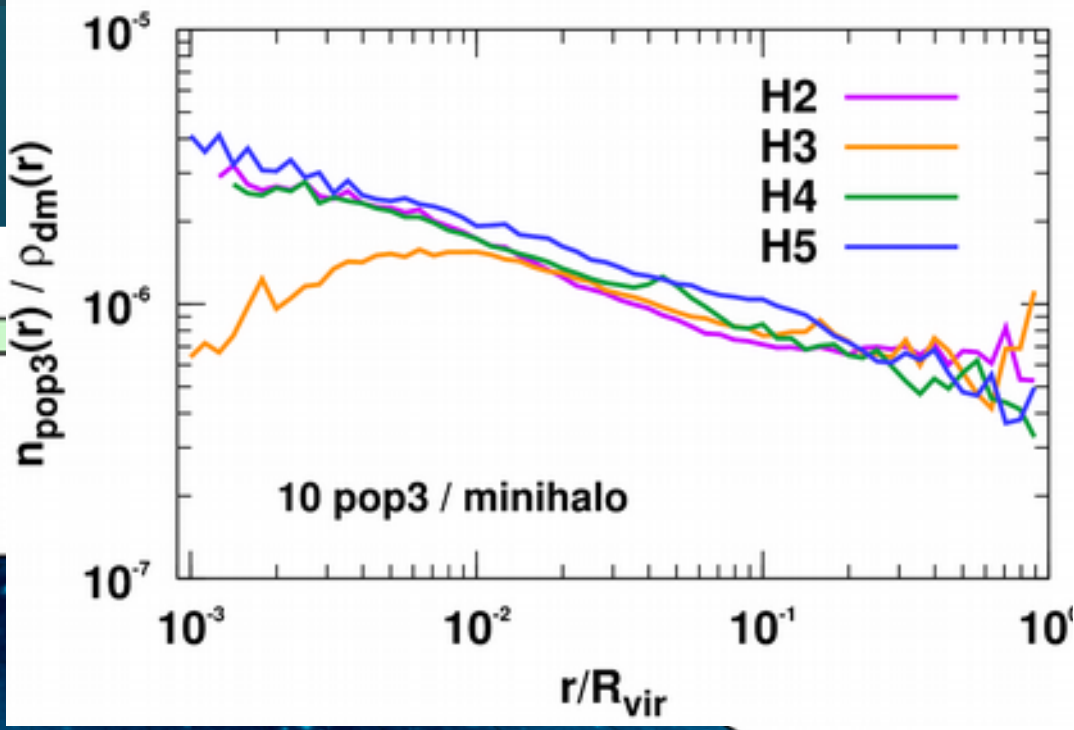
Projected number density of all Pop III survivors, observed from Sun's position in a MW halo @z=0

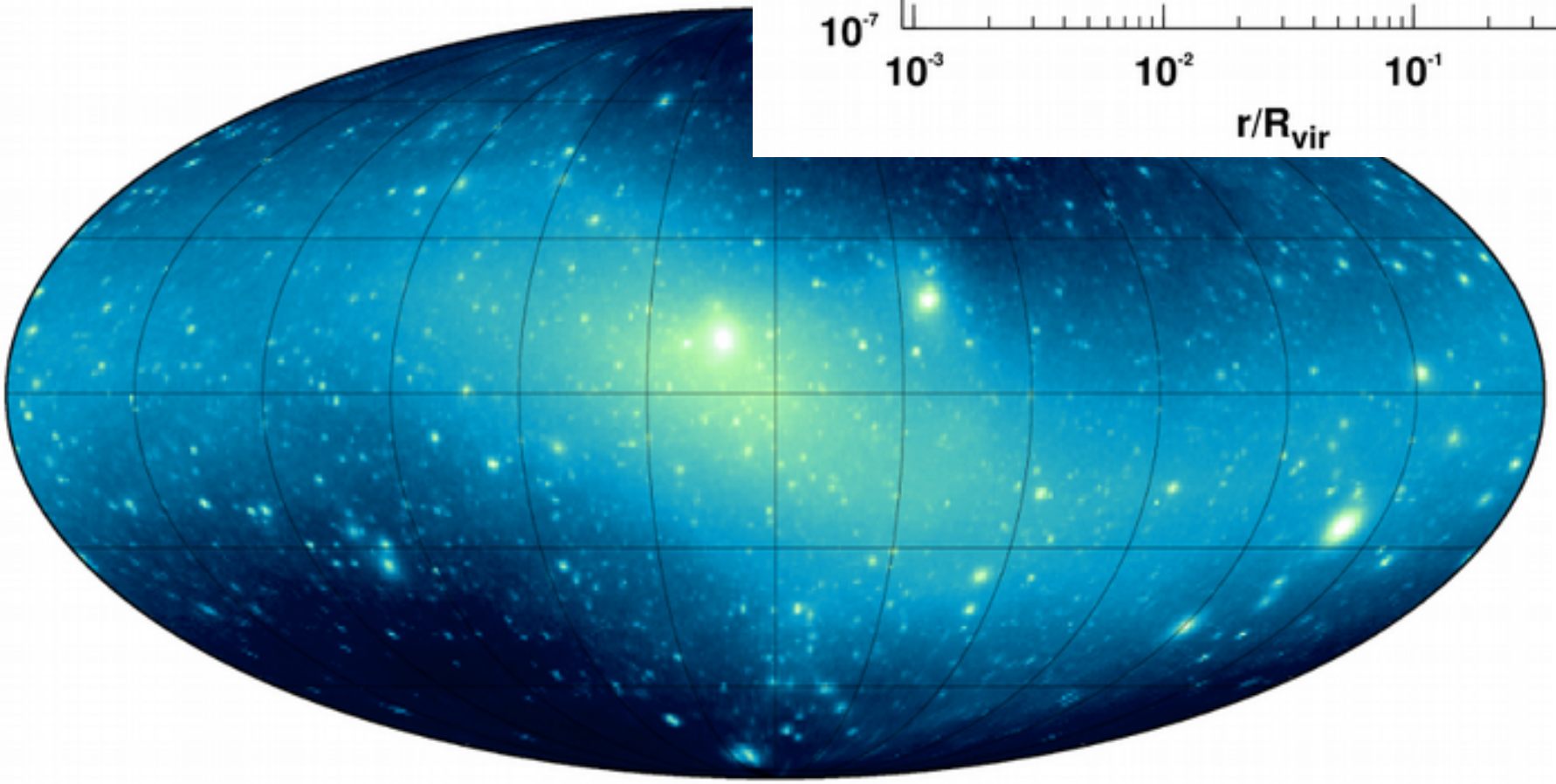


10 Pop III / minihalo

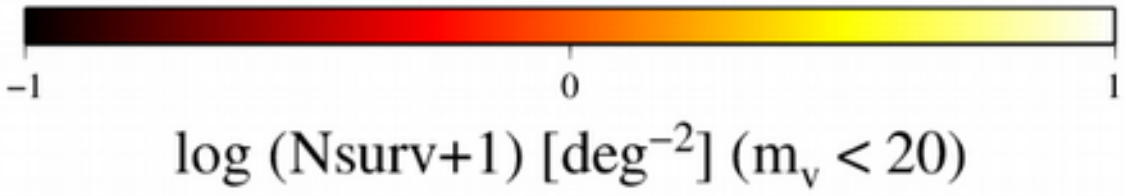
Projected DM density



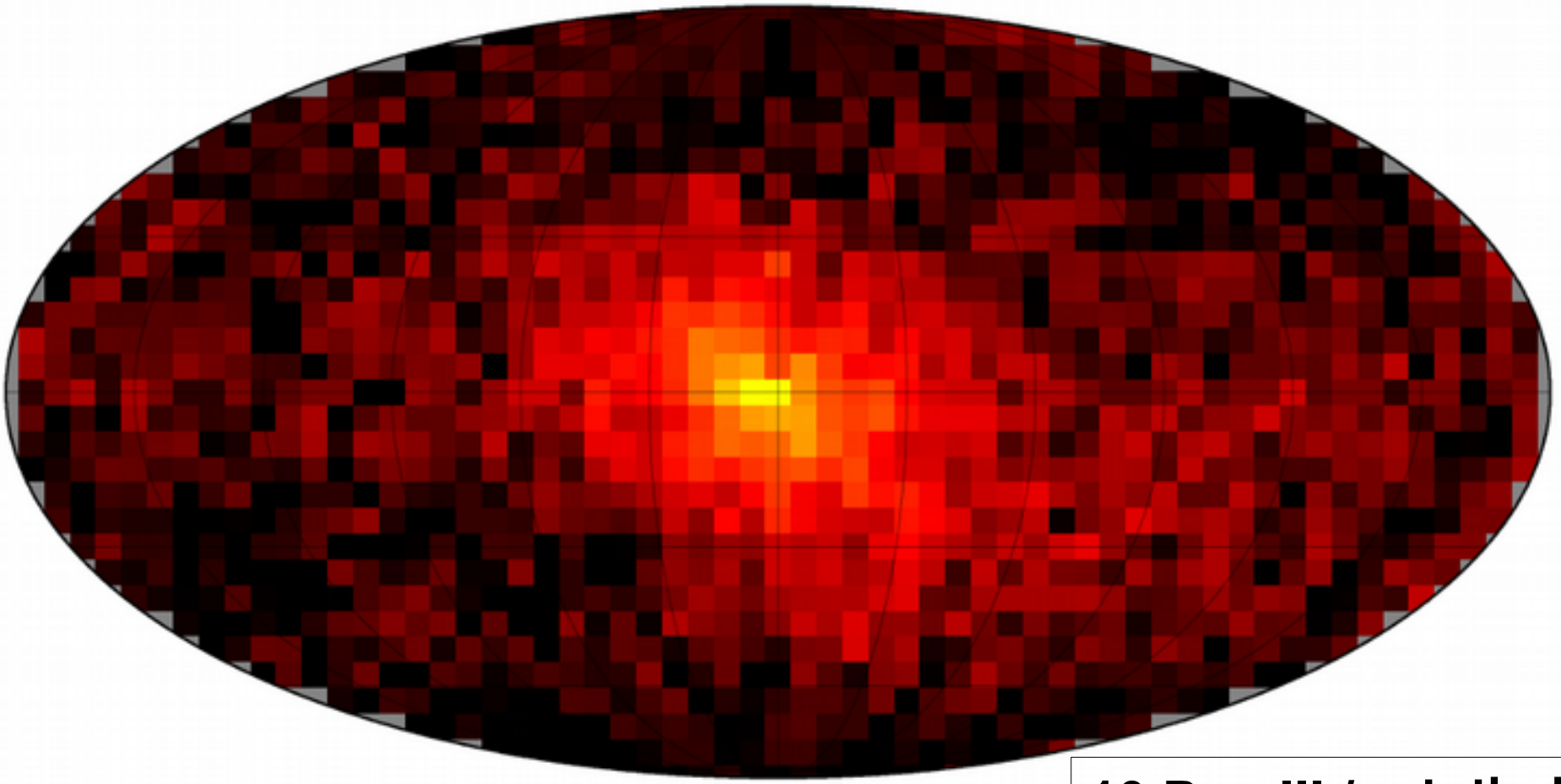




Projected number density of Pop III survivors with $m_v < 20.0$

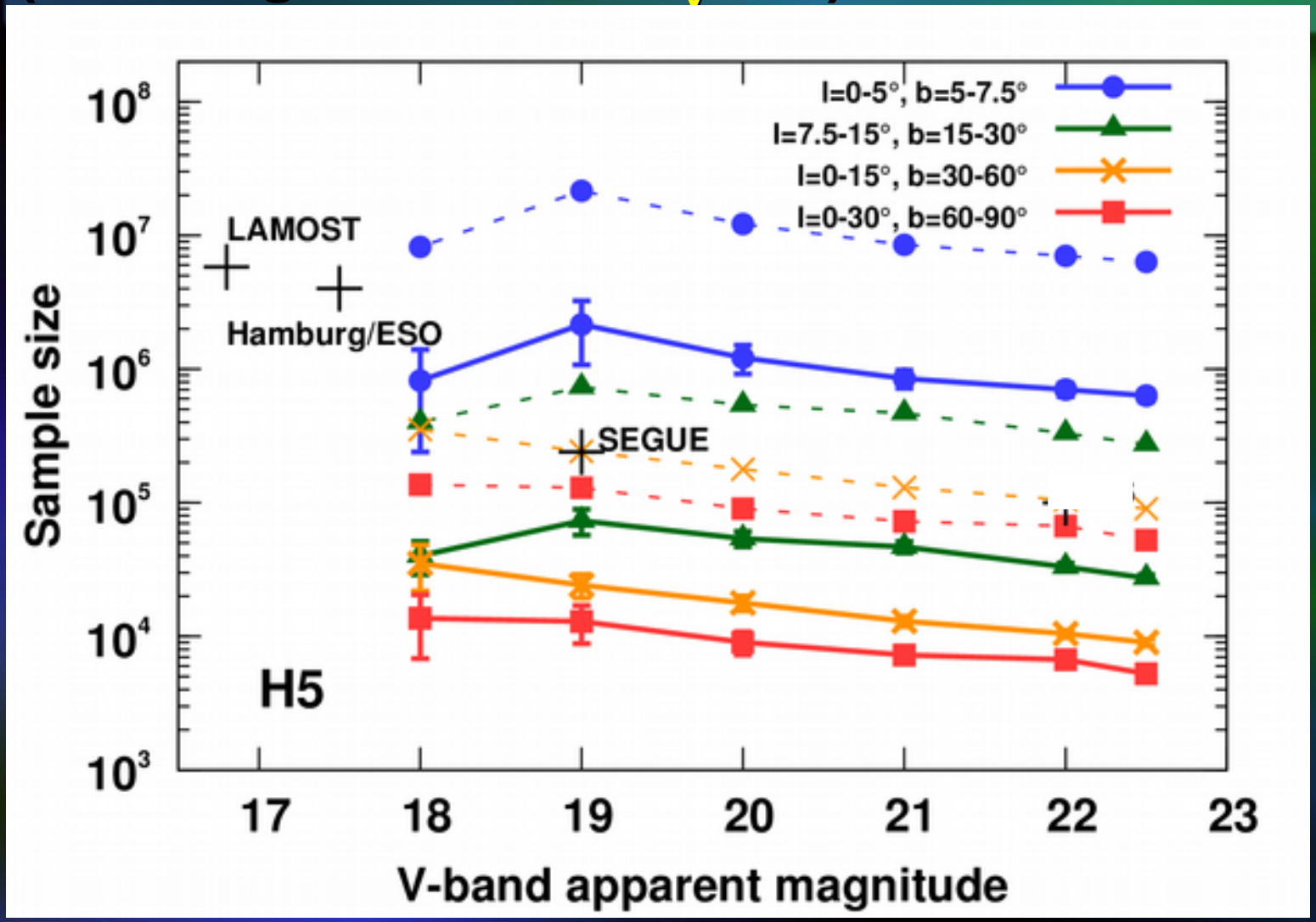


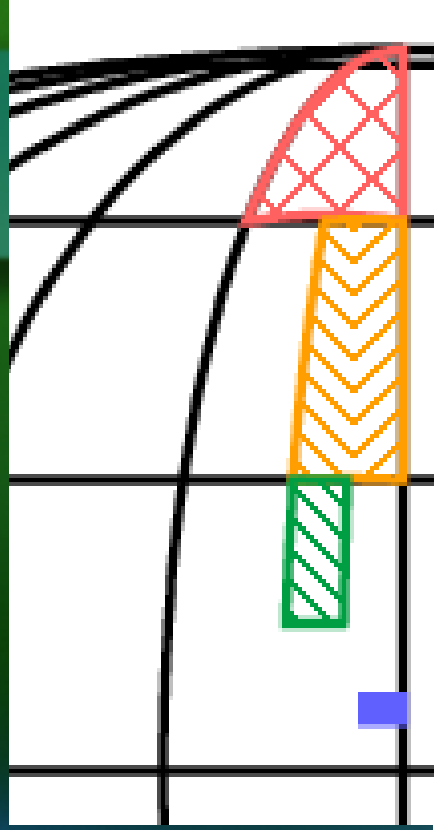
The distribution of survivors with V-band apparent magnitude brighter than 20.0 are pretty different from that of all survivors.



10 Pop III / minihalo

#All stars / #Pop III survivors (counting stars with m_v >17)



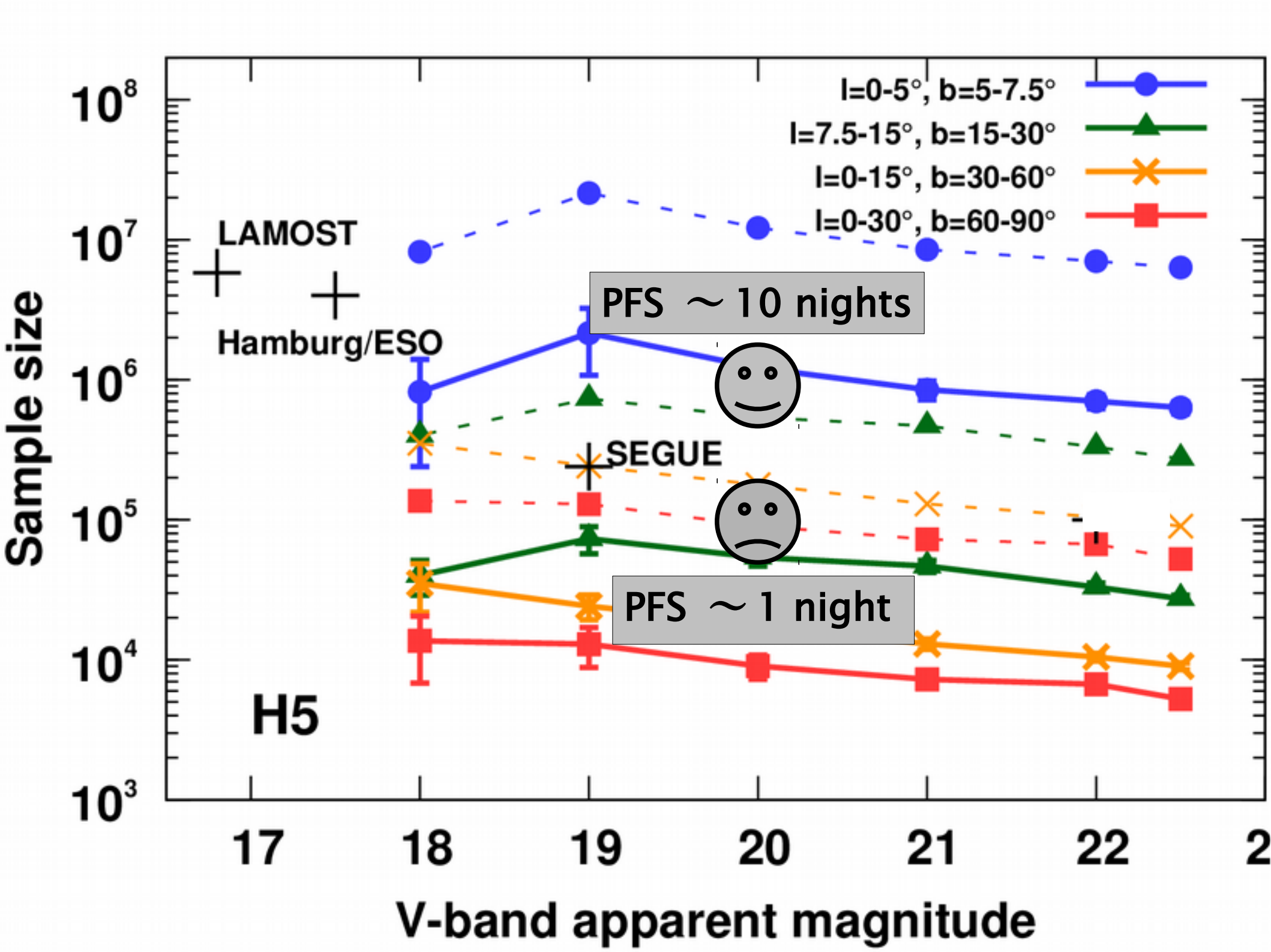


solid :
10 pop3/
minihalo

dotted:
multiplied by 10

If available observations have not detected any survivors, the formation models of low-mass Pop III stars with > 10 stars/minihalo are already excluded.

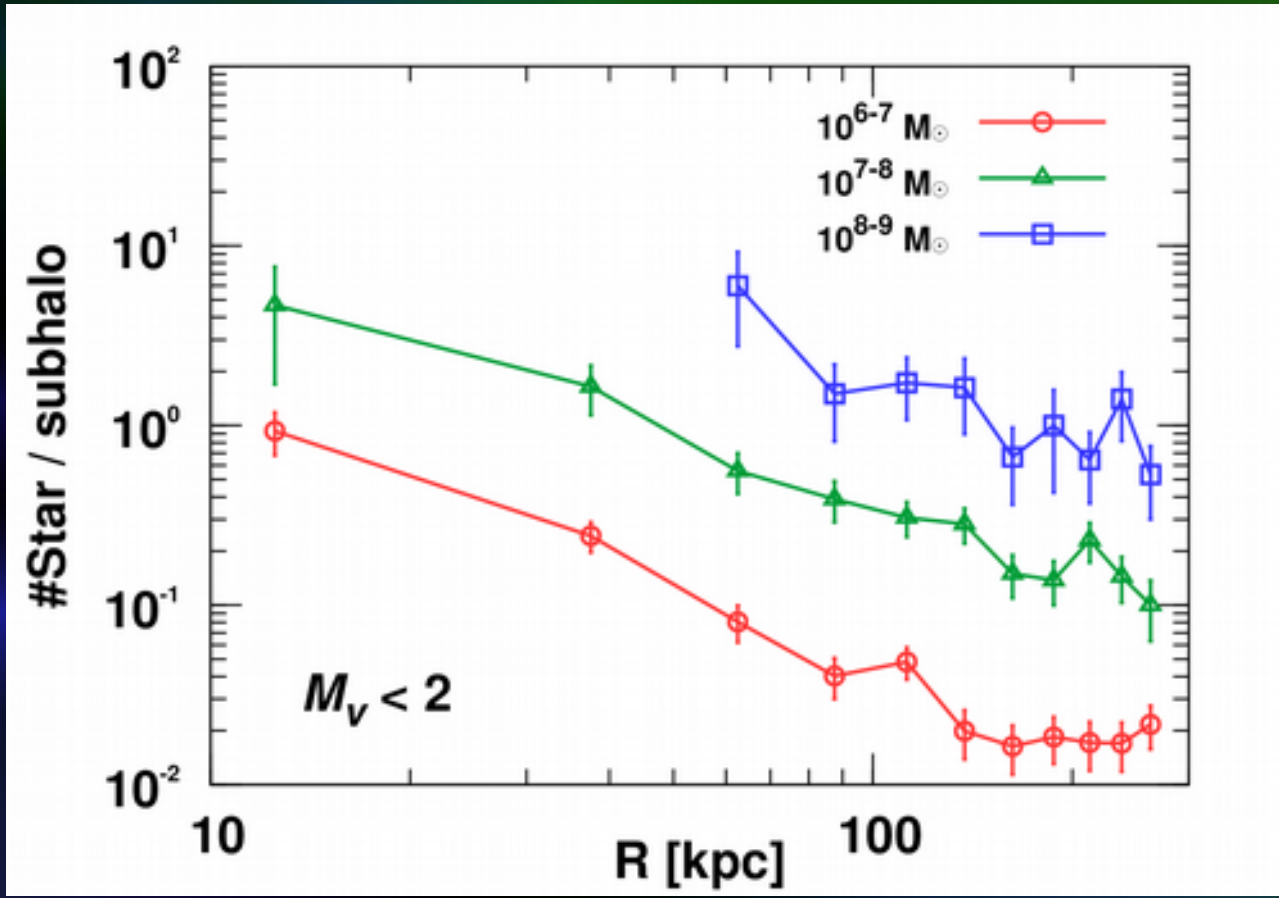
Stellar component is generated by Besancon (http://model.obs-besancon.fr/)


l=0-5°, b=5-7.5°
l=7.5-15°, b=15-30°
l=0-15°, b=30-60°
l=0-30°, b=60-90°
LAMOST
Hamburg/ESO
SEGUE
PFS ～10 nights
PFS ～1 night
H5
Sample size
V-band apparent magnitude
10^8
10^7
10^6
10^5
10^4
10^3
17
18
19
20
21
22

Dwarf Galaxies

- If the dwarf galaxies have a common mass of 10^7 Msun, the required number of dwarf galaxies to find one Pop III survivor is less than 10 at < 100kpc for the tip of red giant stars (M_v~2, m_v~20)

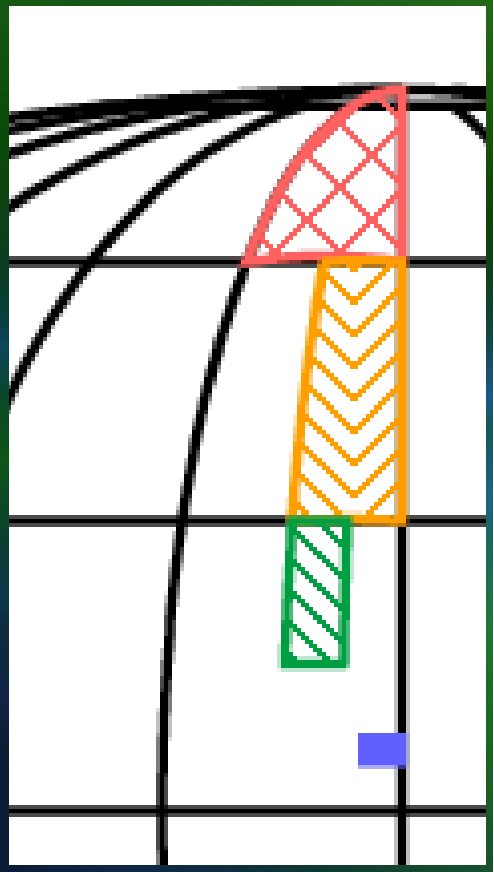
- Currently ~50 dwarf galaxies are discovered. But no Pop III survivor has been detected
  →
  disfavor 10 Pop III / minihalo, but is consistent with 1 Pop III / minihalo



10 Pop III / minihalo

Photometry + Spectroscopy

- The higher latitude fields require lower sample sizes because of the high number density of stars in the galactic disk
- But the number of survivors itself is small



- If we assume that photometric classification with optimized narrow-band filters could exclude 95% of stars with [Fe/H]>-1.5, the sample sizes can be reduced by factors of
  - 2.8 (high)
  - 3.8 (middle)
  - 7.8 (low)
  - 17 (central)

→ comparable sample sizes in the high- and middle- lattitude

→ Enhance the efficiency of follow-up spectroscopy

Summary

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- The number density of low mass Pop III survivors is higher in the galactic center. But higher latitude field is suitable to detect Pop III survivors since other stellar component is too many

- From available observations of MW and dwarf galaxies, the formation models of low-mass Pop III stars with > 10 stars/minihalo are already excluded

- **Strong constraint of low-mass Pop III IMF by PFS + HSC @ Subaru**