A Wide-Field Search for Massive PopIII Stars in High-z Universe in the Subaru Deep Field

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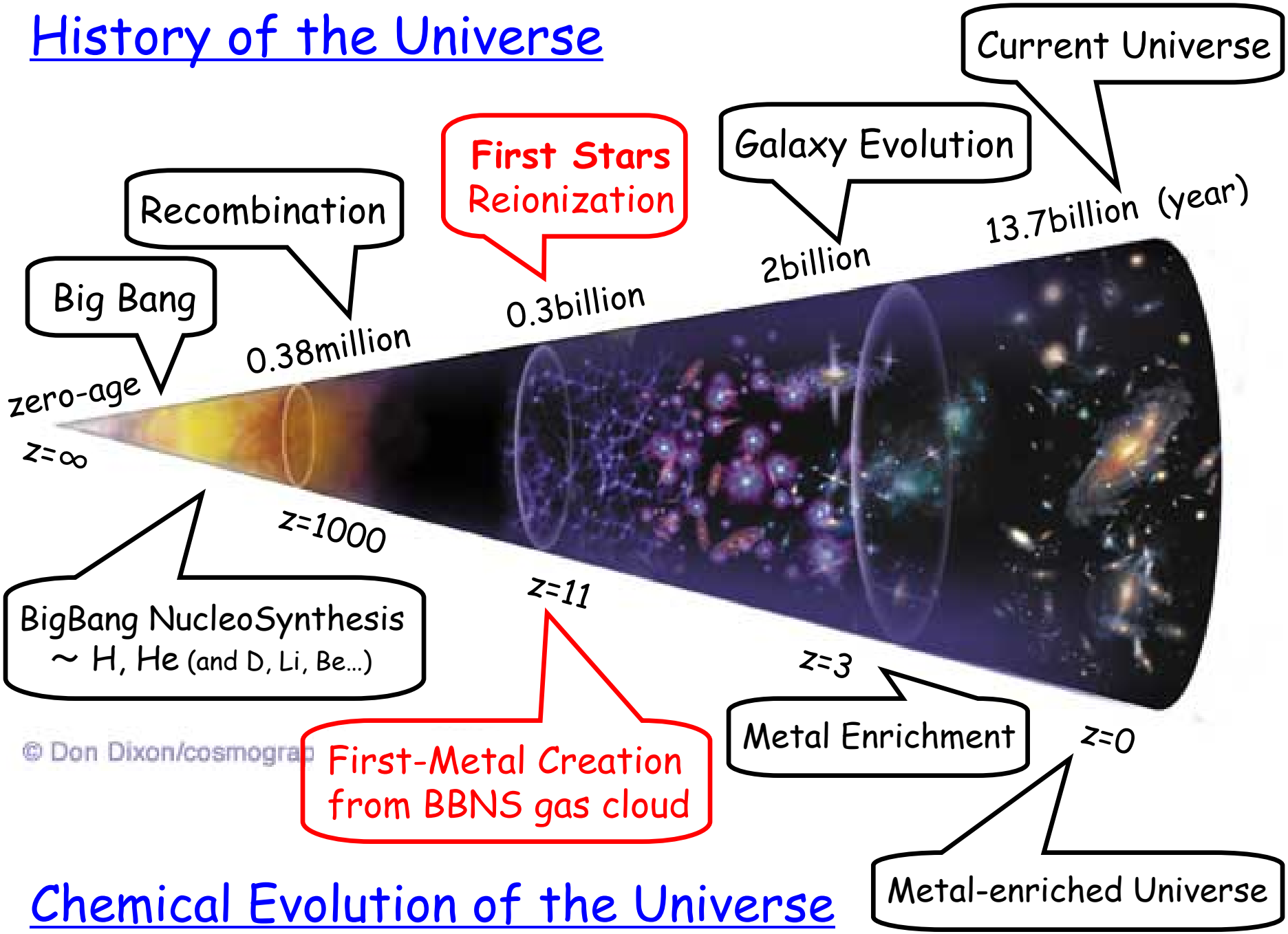
(see Nagao et al. 2008, ApJ, 680, 100 for more details!)

History of the Universe



Chemical Evolution of the Universe

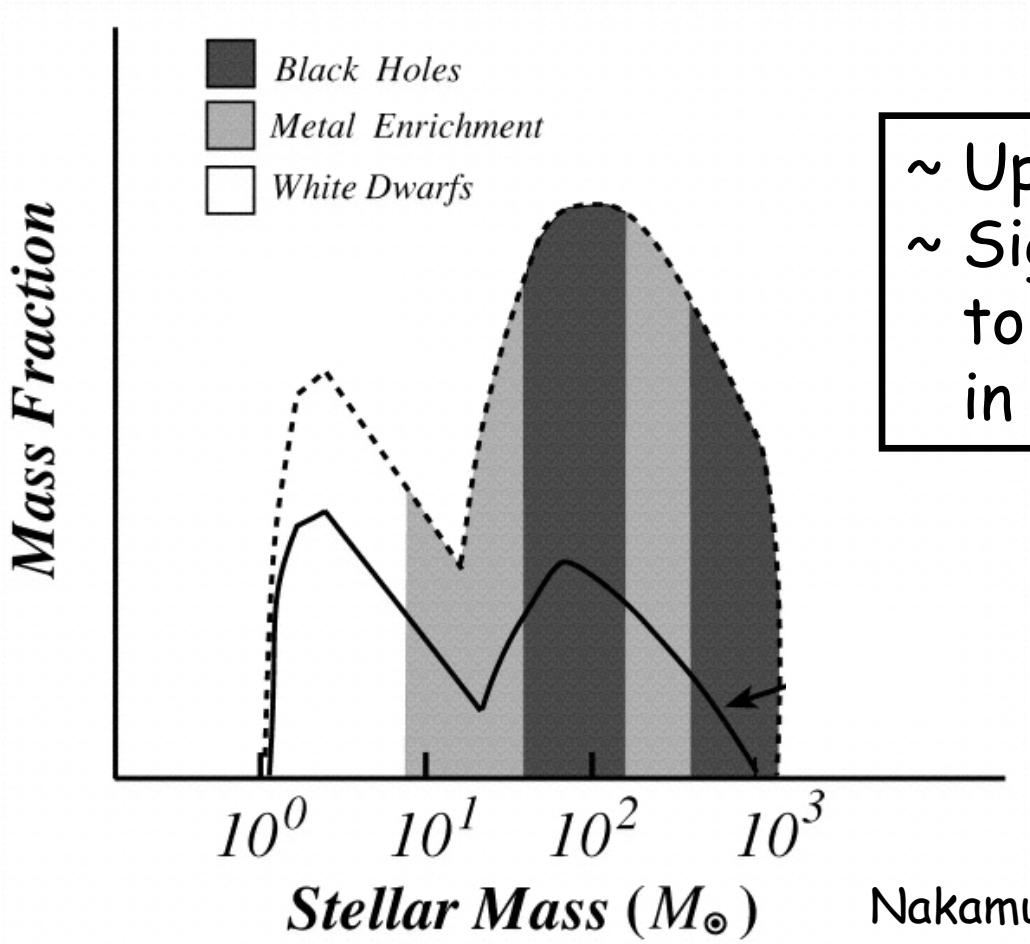
What is PopIII? …Massive Stars.

PopIII: First-Generation Stars

— Created from BBNS (or "Zero-Metal") Gas Clouds

Formation of Very Massive PopIII

— Insufficient Cooling → Suppressed Fragmentation



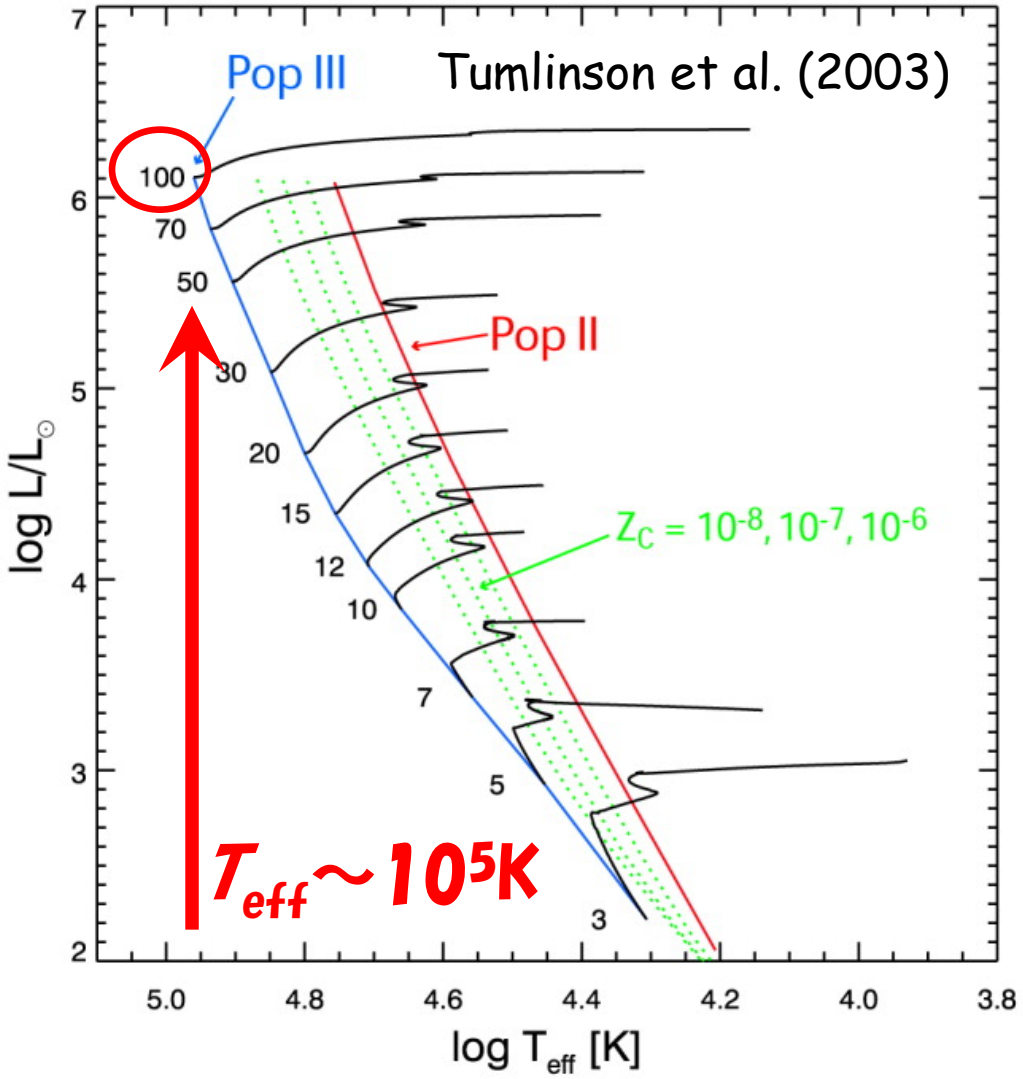
~ Up to a few 10^2—10^3 M_{sun}
~ Significant contribution to chemical enrichment in the early unverse

Nakamura & Umemura (2001)

What is PopIII? …Hot Stars.

Very High Effective Temperature

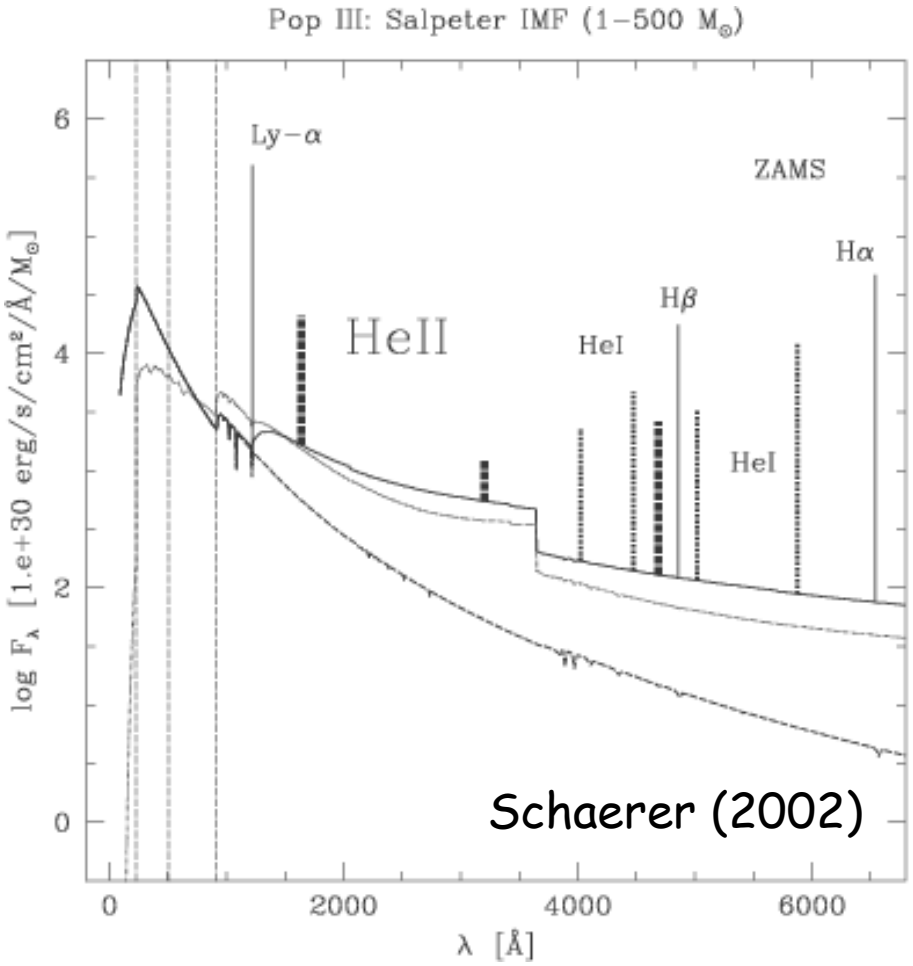
— No Metals in Atmosphere → Low Opacity

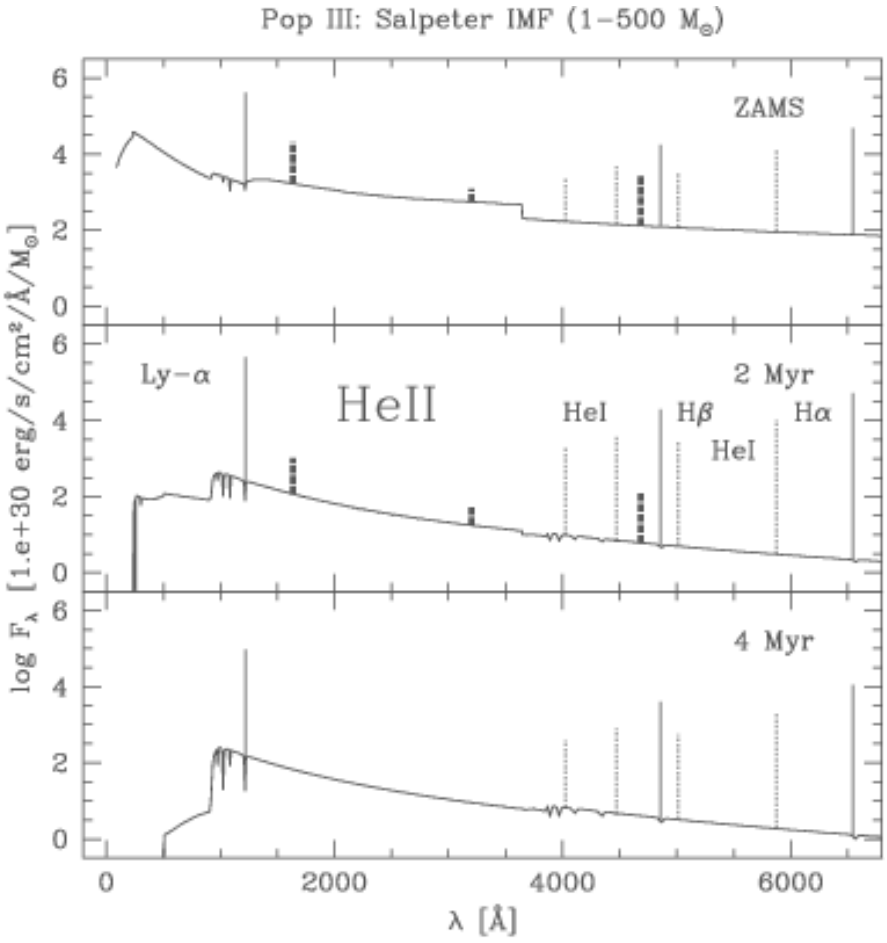


~ SED: characterized by very high T_{eff}
~ Emitting huge number of UV photons
~ Significant contribution to cosmic re-ionization in the early unverse

~ Strong Ly alpha and He II emission lines

Spectrum of HII Regions around PopIII Galaxies

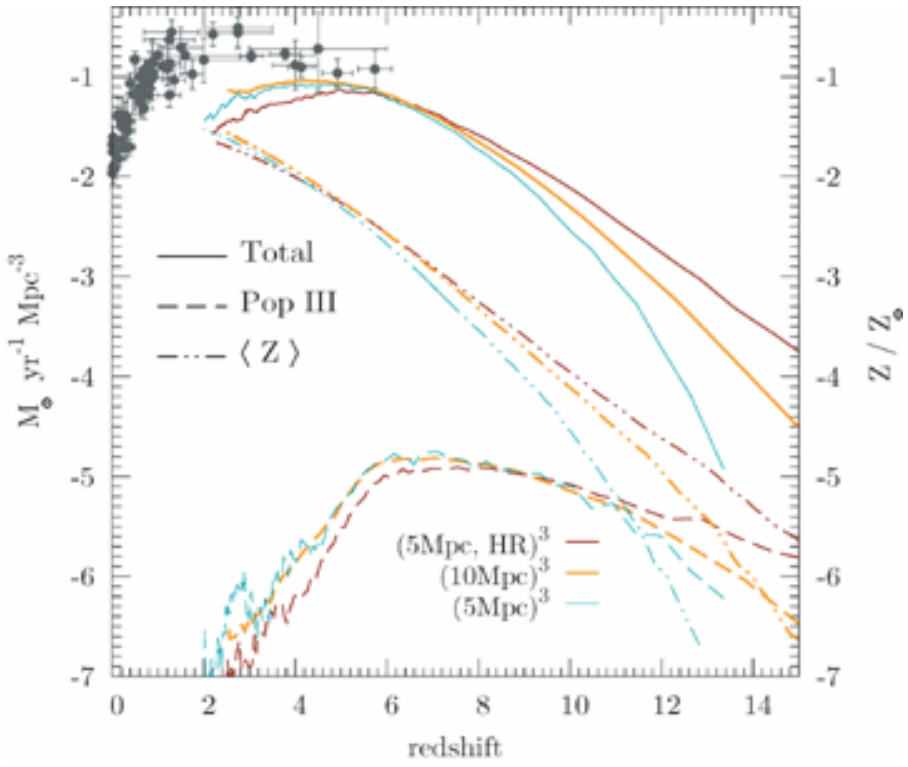




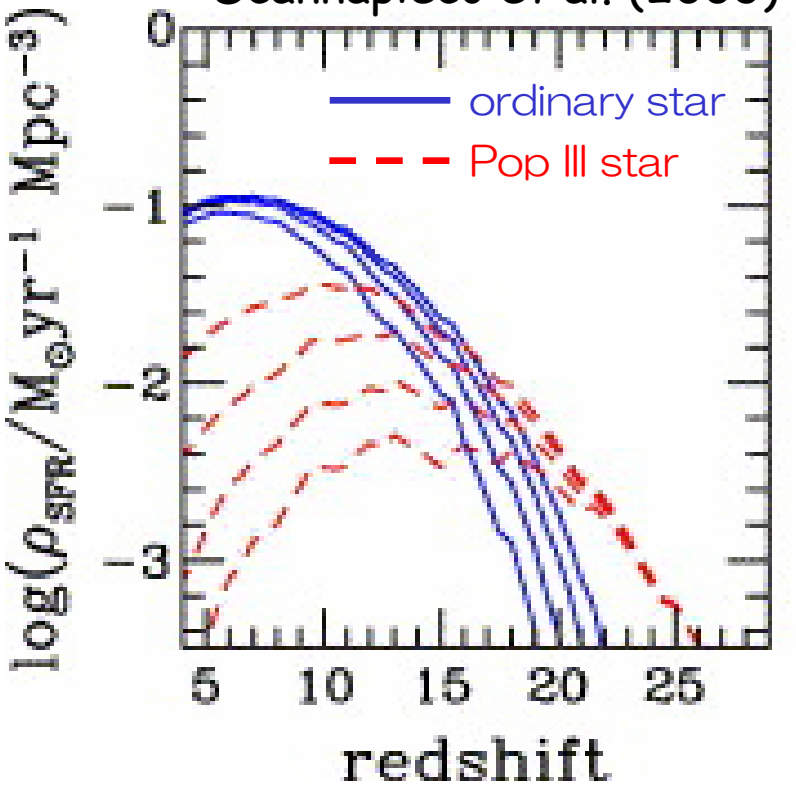
Characterized by strong H I and He II emission lines at the earliest phase (~ a few Myr) of the galaxy evolution

Where (When) do PopIII Stars Exist ?

Tornatore et al. (2007)



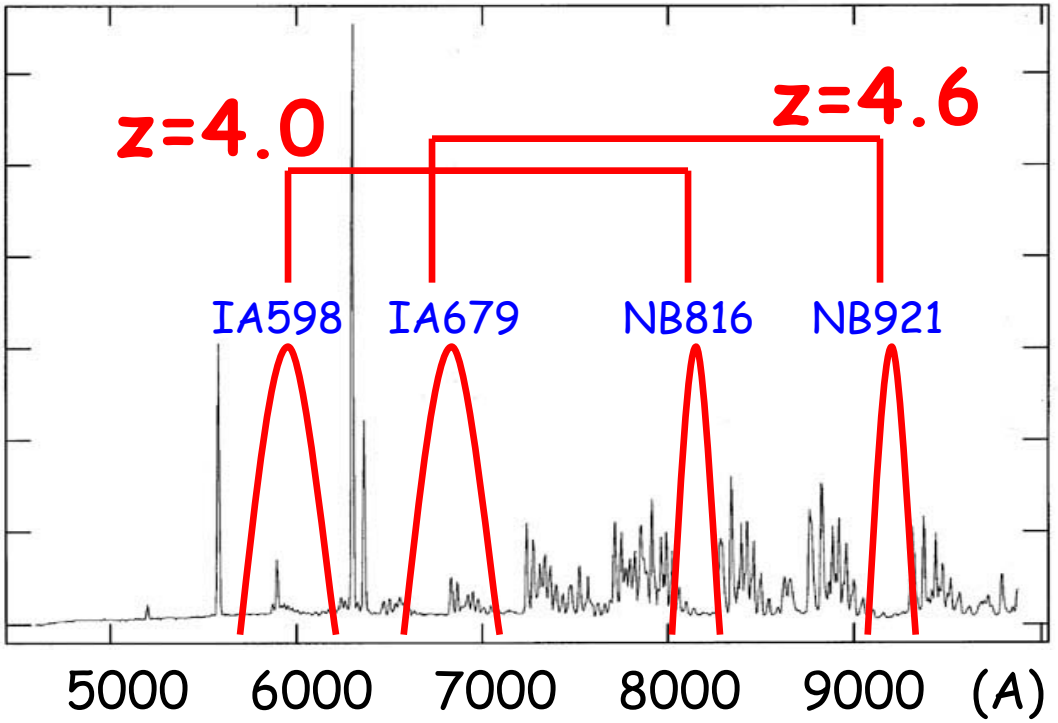
Scannapieco et al. (2003)



PopIII possibly existed even at z~4-7 ← currently accessible !!
Let's search for "Lyα-HeII dual emitters" as PopIII candidates
↓ ~ requiring "well-matched" combination of filters
~ requiring very wide FOV to find "rare" objects
Why not use **Subaru/Suprime-Cam + Custom Filter Set** !!

Observations

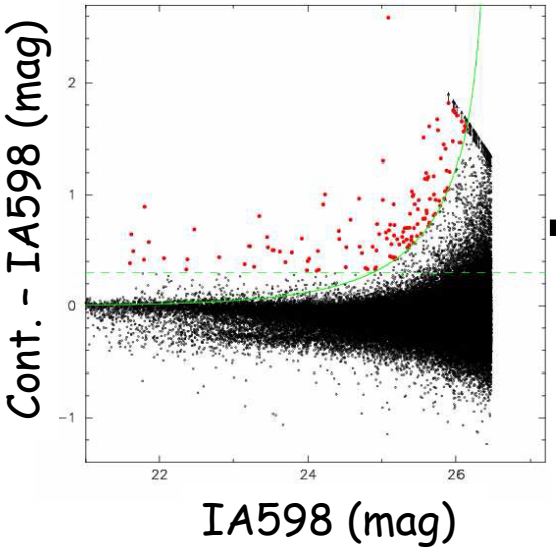
- z=4.0
  - ~ HeII@8200A: **"NB816"**
  - ~ Lya @6080A: **"IA598"**
- z=4.6
  - ~ HeII@9180A: **"NB921"**
  - ~ Lya @6810A: **"IA679"**

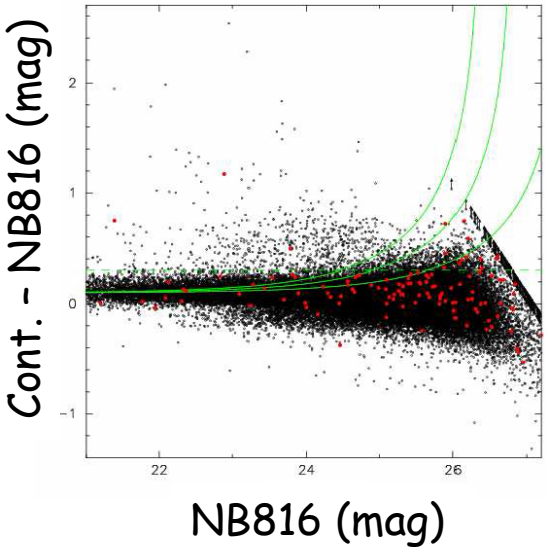


- NB816 & NB921: Existing deep data@Subaru Deep Field (SDF)
  - ~ originally for Lya emitters at z = 5.7, 6.5 (Taniguchi+05, Kashikawa+06)

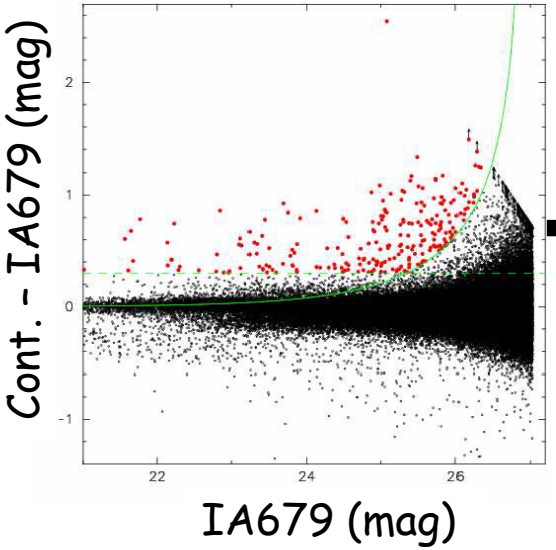
- IA598 & IA679: Additionally obtained in April 2007 @ SDF
  - … m_{lim}(IA598) = 26.52 (**111min**), m_{lim}(IA679) = 27.07 (**231min**)
  - ~ wider bandwidth ($\Delta\lambda$~300A): sensitive only to large-EW
    - … no problem for us, because our targets are PopIII !!

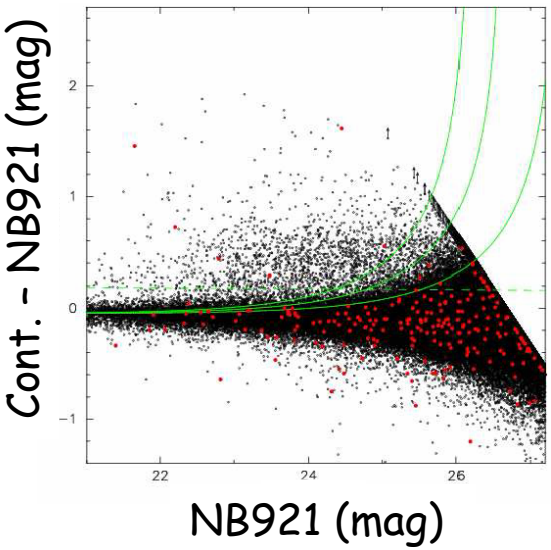
Selection of Lyα-HeII Dual Emitters





- for z=4.0
  - ~ using IA598 & NB816
  - ~ Cont – IA598 > 0.3 mag
  - ~ EW_{obs} > 114A
  - ~ 113 guys show IA excess
  - ~ 4 guys show NB excess

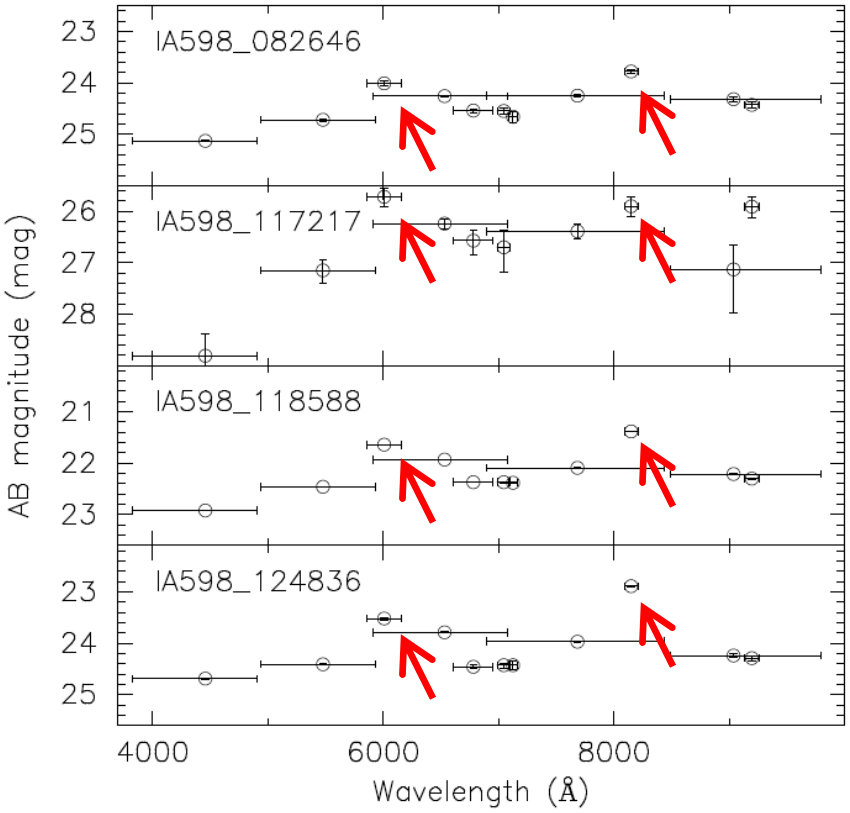


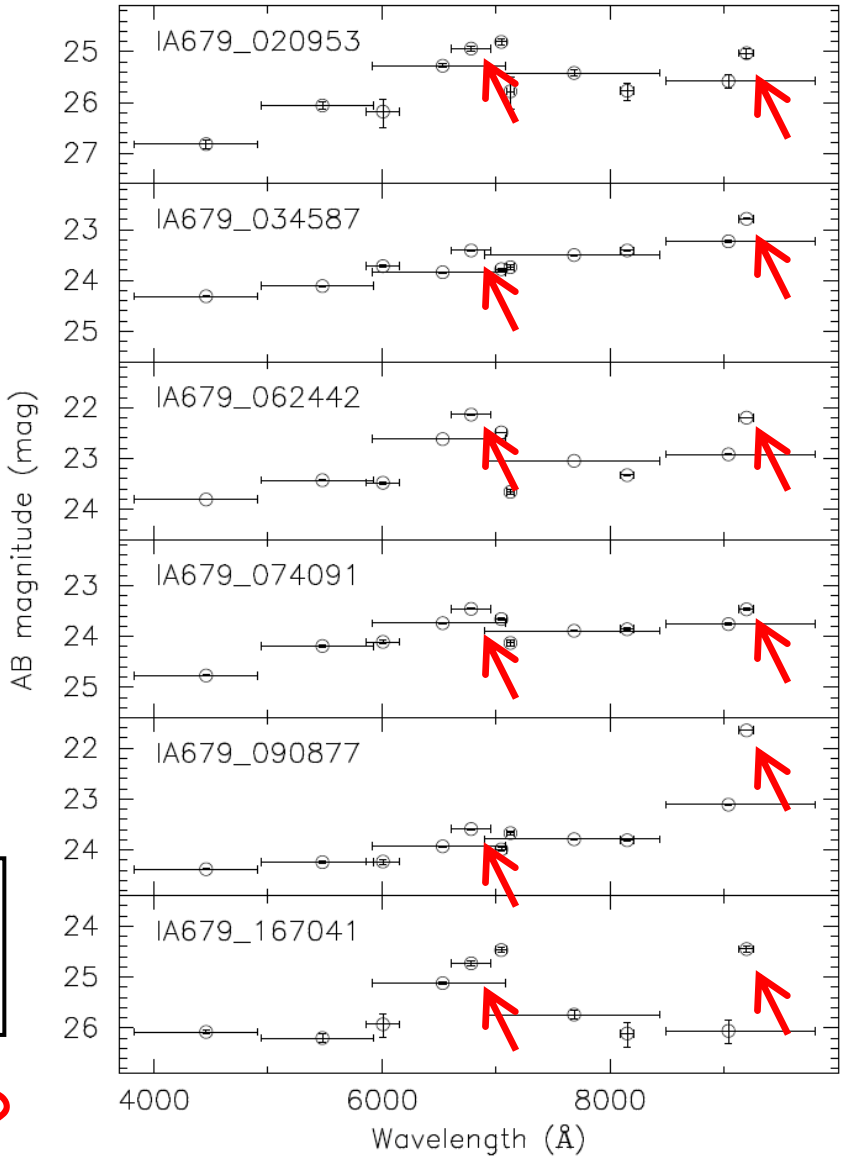


- for z=4.6
  - ~ using IA679 & NB921
  - ~ Cont – IA679 > 0.3 mag
  - ~ EW_{obs} > 143A
  - ~ 234 guys show IA excess
  - ~ 6 guys show NB excess

Results: Discovery of "Dual Emitters" !?

Nagao et al. (2008)

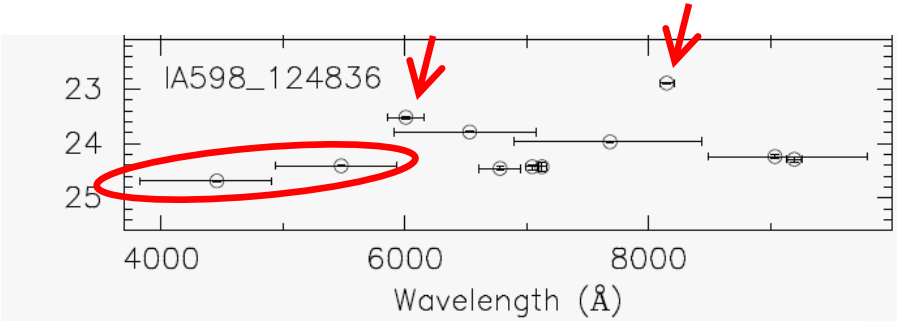




4 IA598-NB816 dual emitters
6 IA679-NB921 dual emitters

... candidates for PopIII !?

Results: No "Lya-HeII Dual Emitters" Found…



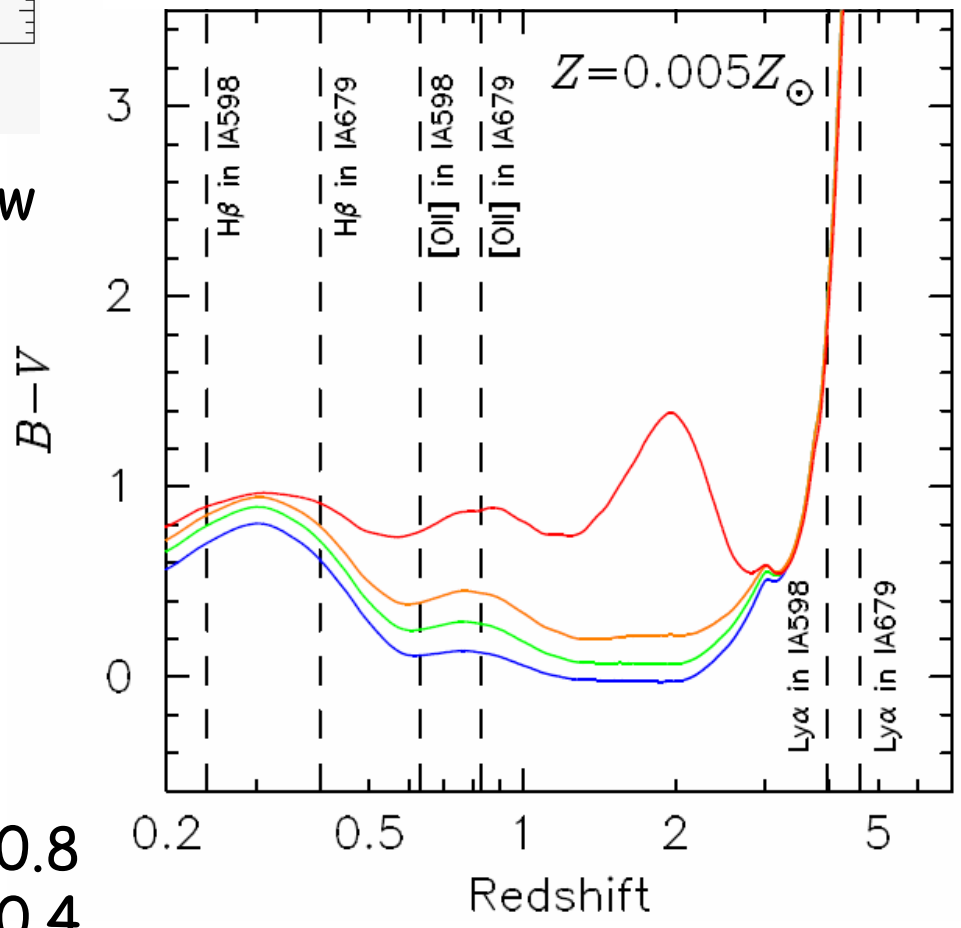
All of IA-NB dual emitters show "blue" B-V colors (B-V < 1.0)

Galaxies at z > 4 should show "red" B-V colors (B-V > 1.5)

IA-NB dual emitters : consistent to
[OII] & [OIII] at z=0.6 or z=0.8
Hβ & Hα+[NII] at z=0.2 or z=0.4

➔ ***No "Lya-HeII dual emitters" found…***

Models: Bruzual & Charlot (2003)



Upper Limit on the PopIII SFR Density (SFRD)

- Our survey sensitivity on SFR_{PopIII}

$L(HeII) = f_{1640} \times SFR_{PopIII}$

↓

~ f_{1640} : depends on model parameters, e.g., IMF
~ adopting f_{1640} reported by Schaerer (2003)
[assuming Salpeter IMF with $50 < M_{PopIII}/M_{sun} < 500$]

$[SFR_{PopIII}]_{lim} \sim 2\ M_{sun}/yr$

- Upper limit on the PopIII SFR density ($SFRD_{PopIII}$)

$V_{survey} = 4.03 \times 10^5\ Mpc^3$ (3.93<z<4.01 & 4.57<z<4.65)

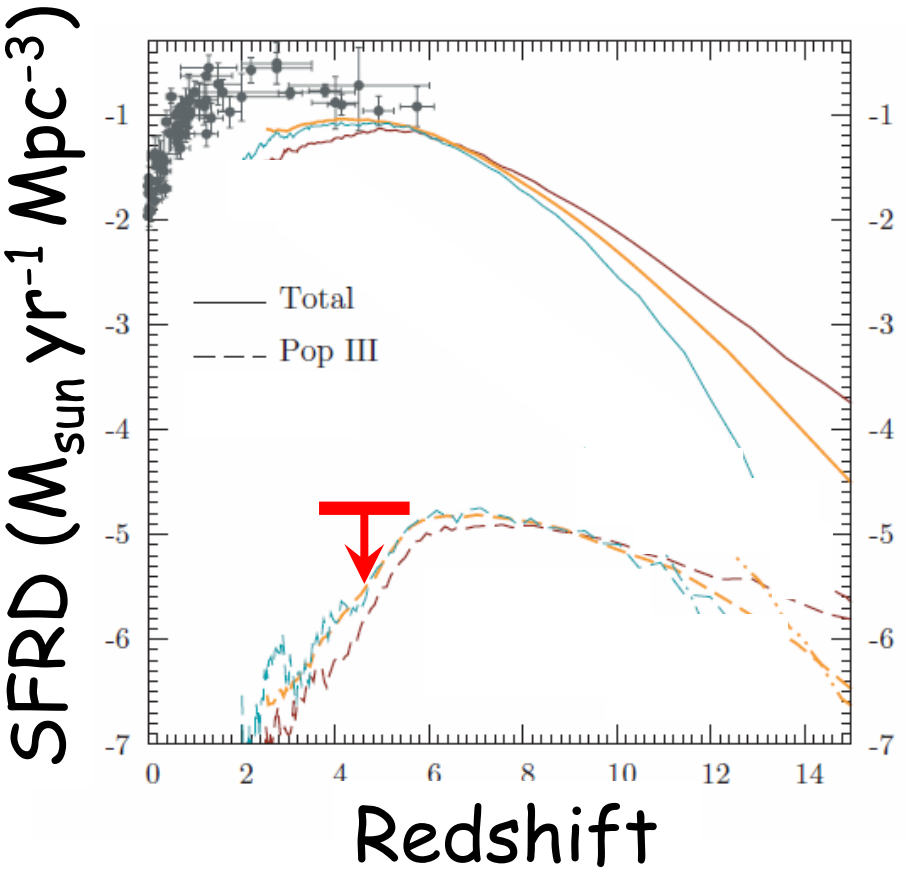
↓

~ no galaxies with $SFR_{PopIII} > 2\ M_{sun}/yr$ were found
~ assuming no PopIII formation with low SFR_{PopIII}
~ $[SFRD_{PopIII}]_{lim} = [SFR_{PopIII}]_{lim} / V_{survey}$

$SFRD_{PopIII} < 5 \times 10^{-6}\ M_{sun}/yr/Mpc^3$

SFRD(PopIII): Comparison with a Theoretical Work

- Expected PopIII fraction is lower at lower redshift
- Expected $SFRD_{PopIII}$ shows a "peak" at rather low-z (~6)
- Our upper limit on $SFRD_{PopIII}$ is higher than model prediction, but not so discrepant !!
- Further observational limits will give interesting constraints on PopIII theoretical works !!



SFRD model:
Tornatore et al. (2007)

Observational limit:
Nagao et al. (2008)

Summary

- Our new survey for "Lya-HeII dual emitters"
  - ~ a new strategy to search for PopIII in high-z galaxies
  - ~ selecting PopIII candidates by combining NB filters

- No candidates found
  - ~ [OII]-[OIII] dual emitters are detected
  - ~ sensitivity: $[SFR_{PopIII}]_{lim}$ = 2 M_{sun}/yr
  - ~ $[SFRD_{PopIII}]_{lim}$ = 5 x 10^{-6} M_{sun}/yr/Mpc^3
  - ~ very close to theoretical predictions

- Our future plan
  - ~ "Hyper S-Cam" : FOV = 1.5 deg^2
    (Subaru next-generation camera [2011-(?)])
  - ~ x10 deeper limits on $SFRD_{PopIII}$
    at 4 < z < 5 → constraints on models