Observational Searches for High-z Galaxies Hosting PopIII Stars

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Deciphering the Ancient Universe with Gamma-Ray Bursts

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Yonetoku+04

GRBs decipher star-formation activities in the cosmic dark age

...and PopIII stars!?
Deciphering the Ancient Universe with Gamma-Ray Bursts

Kawai+05

z = 6.3

...but PopIII at z < 10 ?

Tanvir+09

z = 8.2

9-23, 2010
Some cosmological simulations predict PopIII formation even at $5 < z < 10$!!

... but how discriminate??
How discriminating PopIII stars?

- Very high $T_{\text{eff}}$ due to low opacity even below $M=100M_{\odot}$
- Very hard SED especially at FUV

...could be diagnostics for PopIII stars!?
SED of PopIII stellar clusters (= PopIII galaxies)

Huge number of H & He ionizing photons !!

Color info are NOT useful

Tumlinson+00
Expected Spectrum of PopIII Galaxies

- Strong H I and He II discriminating from PopI
- Especially He II 1640 accessible even at high-z; no resonance effects
- No metal lines discriminating from AGN

Schaerer 02
Expected Strength of Emission Lines

Schaerer 03

Possible strategy for PopIII searches:
1) search for strong “Lyα emitters”
2) identifying He II line among them
Our Search for "Lya–HeII Dual Emitters"

- Spectroscopy? ...not a bad idea, but too expensive
  ~ faint HeII emission at NIR (or red part in Opt)
  ~ low number density of targets → longslit obs.

A deep NIR spectroscopy for a Ly$\alpha$ emitter at $z=6.3$ with Subaru/OHS

**Nagao+04**

Upper limit on SFR(PopIII):
- $13.2 \, M_{\odot}/yr$ if IMF $1<M/\, M_{\odot}<500$
- $1.8 \, M_{\odot}/yr$ if IMF $50<M/\, M_{\odot}<1000$

**Nagao+05**

42 ksec exposure for only ONE target → no He II detection...
“Stacked” Spectra

Stacked 811 LBGs at $z=3$ (Shapley+03)

...He II emission !?

Evidence of PopIII !? (Jimenez+06)

Just a stellar feature ? (Shapley+03)
36 LAEs at $z=3.1$
31 LAEs at $z=3.7$
(Ouchi+08)

No He II emission...

11 LAEs at $z=4.5$
(Dawson+04)

No He II emission...
Our Search for “Lyα-Hell Dual Emitters”

- Spectroscopy? ...not a bad idea, but too expensive
  ~ faint Hell emission at NIR (or red part in Opt)  
  ~ low number density of targets  -->  longslit obs.

- Narrow-Band Imaging?
  ~ requiring “well-matched” combination of filters
  ~ requiring huge FOV to search “rare” objects

For both
Lyα @\(\lambda_{\text{rest}} = 1216\text{A}\) &  
Hell @\(\lambda_{\text{rest}} = 1640\text{A}\)

Subaru/Suprime-Cam + custom filter set

very wide FOV  
(27’x34’’)

National Astronomical Observatory of Japan
Observation

- $z=4.0$
  - HeII@8200A: “NB816”
  - Lyα @6080A: “IA598”

- $z=4.6$
  - HeII@9180A: “NB921”
  - Lyα @6810A: “IA679”

- NB816 & NB921
  ~ originally for Lyα emitters at $z = 5.7, 6.5$

- IA598 & IA679
  ~ wide bandwidth ($\Delta\lambda \sim 300\text{A}$): sensitive only to large-EW
  ... no problem for us, because our targets are PopIII!!
Selection of “IA598-NB816 Dual Emitters” \((z=4.0)\)

- Cont. – IA598 > 0.3 mag \(\Leftrightarrow\) \(EW_{obs} > 114\)A
- (133 objects)
Selection of “IA598-NB816 Dual Emitters”\( (z=4.6) \)

- Cont. – IA679 > 0.3 mag

\( \iff \)

\( EW_{obs} > 145 \text{A} \)

(234 objects)
Results: Discovery of “Dual Emitters” !?

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

... candidates of PopIII !?

Galaxies at $z > 4$ should show “red” $B-V$ colors ($B-V > 1.5$)

All IA-NB dual emitters show “blue” $B-V$ colors ($B-V < 1.0$)

IA-NB dual emitters:
consistent to

$[OII]$ & $[OIII]$ at $z=0.6/z=0.8$
$H\beta$ & $H\alpha+[NII]$ at $z=0.2/z=0.4$

$\Rightarrow$ No “Ly$\alpha$-HeII dual emitters” found...
Upper Limit on the PopIII SFR Density (SFRD)

- **Our survey sensitivity on \( SFR_{\text{PopIII}} \)**
  
  \[ L(\text{HeII}) = f_{1640} \times SFR_{\text{PopIII}} \]

  \( \sim f_{1640} \): depends on model parameters, e.g., IMF
  
  \( \sim \) adopting \( f_{1640} \) reported by Schaerer (2003)

  [assuming Salpeter IMF with \( 50 < M_{\text{PopIII}}/M_{\odot} < 500 \)]

  \[ [SFR_{\text{PopIII}}]_{\text{lim}} \sim 2 \, M_{\odot}/\text{yr} \]

- **Upper limit on the PopIII SFR density (\( SFRD_{\text{PopIII}} \))**

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

  \( \sim \) no galaxies with \( SFR_{\text{PopIII}} > 2 \, M_{\odot}/\text{yr} \) were found

  \( \sim \) assuming no PopIII formation with low \( SFR_{\text{PopIII}} \)

  \( \sim [SFRD_{\text{PopIII}}]_{\text{lim}} = [SFR_{\text{PopIII}}]_{\text{lim}} / V_{\text{survey}} \)

  \( SFRD_{\text{PopIII}} < 5 \times 10^{-6} \, M_{\odot}/\text{yr}/\text{Mpc}^3 \)
SFRD(PopIII): Comparison with Theoretical Work

SFRD model: Tornatore+07

Observational limit: Nagao+08

![Graph showing SFRD (M_{sun} yr^{-1} Mpc^{-3}) vs Redshift]
What’s Next? ...“Hyper Suprime-Cam’’ !!

New Optical Imager on Subaru
Tremendous FOV and Red-Sensitive Detectors

PopIII survey with HSC
~ much deeper and x10 wider survey
~ multiple narrow-band $\rightarrow$ Ly$\alpha +$ He II

First Light in 2012 (quite soooon!!)

figures: courtesy by Miyazaki-san (HSC PI)
Summary

Diagnostics for high-z PopIII galaxies

- Focusing on hard SED of massive PopIII stars
- Hard SED → Very strong Ly$\alpha$ and detectable He II
- Rest-UV He II $\lambda$1640 is especially useful

Observational strategies to search for PopIII

- NIR spectroscopy constrains $SFR_{\text{PopIII}}$ for EACH galaxy
- Multi-narrowband search constrains $SFRD_{\text{PopIII}}$ at $z=4-5$
- Current limit on $SFRD_{\text{PopIII}}$ seems close to predictions

High-z PopIII surveys in (very-near) future

- Subaru’s HSC will start its observations in 2012
- HSC surveys: much deeper and wider than SCam surveys
- Multiple narrowband HSC survey → discovery of PopIII (!?)
Main Collaborators (only a part of the whole collaboration)

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The Subaru Deep Field collaboration
The HSC Survey collaboration