Observational Study on the Chemical Evolution of Galaxies

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Cosmic Chemical Evolution

Big Bang

0 yr

0.38 Myr

Recombination

Dark Age

0.3 Gyr

Population III & Reionization

2.0 Gyr

Galaxy Evolution

13.7 Gyr

Current Universe

Big Bang Nucleosynthesis

~ first hydrogen
~ first helium

First Heavy Elements

~ first stars, first supernovae
~ second generations
~ third, fourth, ...

Chemical Evolution

~ earth-like planets
~ life, human, & you

WHEN? WHERE? HOW MUCH?

0 yr

0.38 Myr

z=1100

z=11

z=3

z=0

z=∞
Contents of This Presentation

(1) Metallicity Evolution of Galaxies
   ~ Luminosity-metallicity & mass-metallicity relations
   ~ Toward high-z universe up to z=3
   ~ Comparison with model predictions

(2) Search for “Population III” Galaxies
   ~ Population III at z < 10 !?
   ~ Expected “observational” properties of PopIII
   ~ Subaru searches for PopIII galaxies

(3) Future Prospects
   ~ Metallicity at z > 3 (by focusing on AGNs?)
   ~ Searching for PopIII galaxies with... ??
   ~ My personal interests
Lequeux et al. (1979)
Metallicity Measurements of Galaxies

focusing on “O/H”

\[
\frac{O}{H} = \frac{(O^0 + O^+ + O^{2+} + \ldots)}{H^+} = \frac{(O^0 + O^+ + O^{2+})}{H^+}
\]

We need to know emission-line fluxes and gas temperature.

\[
F(H^+) = \int N_p N_e h\nu \alpha(T) \, dV
\]
\[
F(O^0) = \int N_{O^0} N_e h\nu q_{O^0}(T) \, dV
\]
\[
F(O^+) = \int N_{O^+} N_e h\nu q_{O^+}(T) \, dV
\]
\[
F(O^{2+}) = \int N_{O^{2+}} N_e h\nu q_{O^{2+}}(T) \, dV
\]
Accurate Metallicity Measurements

$O^{2+}$ Grotrian diagram

$T_e$-sensitive emission-line flux ratio

$[O\text{III}]4363$ is available only in nearby galaxies...
Convenient Metallicity Measurements

Using only strong lines ("strong-line methods") → applicable to faint targets

McGaugh (1991)
Calibrating Strong-Line Methods

Kewley & Ellison (2008)

Nagao et al. (2006c)
Metallicity of Galaxies at $z=0.1$

"Luminosity-Metallicity Relation"  
"Mass-Metallicity Relation"

Tremonti et al. (2004)
Metallicity of Galaxies at $z=0.1$ (cont.)

Assuming "closed box":
$Z = y \ln(\mu_{\text{gas}}^{-1}) \Rightarrow \text{"yeff"}$

Lee et al. (2006)

M-Z relation for 6 decades in stellar mass

Tremonti et al. (2004)
Metallicity of Galaxies at $z=0.7$

Evolving L-Z relation!!

M-dependent M-Z evolution!!
Metallicity of Galaxies at $z=2$

Erb et al. (2007)
Metallicity of Galaxies at $z=3$

Maiolino, Nagao, et al. (2008)

Calibration: Nagao et al. (2006c)
M-Z Relation: Observational Result

“Down-sizing chemical evolution”

M–Z Relation: Observations vs. Models

Simulation: Kobayashi et al. 2007
Toward Zero-Metallicity: PopIII

Scannapieco et al. (2003)
Tornatore et al. (2007)
Yoshida et al. (2003)
Expected Properties of PopIII

Tumlinson et al. (2003)

\[ \text{Yoshida et al. (2003)} \]

\[ \text{Tumlinson} \rightarrow \text{He}^+ \rightarrow \text{He}^{2+} \]

\[ \text{He}^0 \rightarrow \text{He}^+ \]

\[ \text{H}^0 \rightarrow \text{H}^+ \]

\[ 54.4 \quad 24.6 \quad 13.6 \quad \text{(eV)} \]
The earliest phase (with PopIII) of the galaxy evolution is characterized by strong H I and He II emission lines!

Schaerer (2002)

Yoshida et al. (2003)
Searching PopIII Galaxies

Nagao et al. (2004)

SDF i-drop with huge EW Ly $\alpha$

Nagao et al. (2005b)

Subaru/OHS J-band spectroscopy
54 ksec (3 nights) integration (!!!)
$\rightarrow$ no detection...

SDF i-drop with huge EW Ly $\alpha$:
see also Nagao et al. (2005a, 2007)
Stacking Analysis

811 LBGs at z=3
(Shapley et al. 2003)

**He II emission !?**

Evidence of PopIII !?
(Jimenez & Haiman 2006)

Just a stellar feature?
(mentioned by Shapley+03)

...let’s see LAEs, instead of LBGs...
36 LAEs at z=3.1
31 LAEs at z=3.7
(Ouchi et al. 2008)
No He II emission...

11 LAEs at z=4.5
(Dawson et al. 2004)
No He II emission...
Deep NB816/921 data in SDF
~ HeII emitters @z=4.0/z=4.6?
~ They should show Ly\(\alpha\) also...

No candidates found...

Nagao et al. (2008)
PopIII Galaxies: Observations vs. Models

SFRD model: Tornatore+2007
Observational limit: Nagao+2008
Future Prospects...?? (1)


Going beyond $z=3$ !?

- Is it really interesting !?
- Is it really feasible !?
Future Prospects...?? (1)


**Going beyond z=3 !?**

- Is it really interesting !?
- Is it really feasible !?
- Let’s try with TMT
- Or, focusing AGNs !?
- Or, waiting for JWST !?
Future Prospects...?? (2)


Still search for PopIII !?

- Let’s wait for HSC
- Follow-up with JWST

Z=0 (Zero Metallicity)
Future Prospects...?? (3)

Maiolino, Nagao, et al. (2008)

Extremely Metal-Poor Gals

- Now Surveys on Going...
- Studying Earliest Phase of Chemical Evolution
- through “Relative” element abundance ratios

Z=0 (Zero Metallicity)

Koblunicky & Skillkman (1998)
Summary

(1) Metallicity Measurements of Galaxies
   ~ Downsizing evolution of the M-Z relation @ z<3
   ~ Inconsistent with Theoretical Models

(2) Observational Study to Search for PopIII
   ~ Possibly interesting even at z<10
   ~ He II emission is the most powerful diagnostic line
   ~ Multi-NB imaging $\rightarrow$ Meaningful limit on SFRD$_{\text{PopIII}}$

(3) Open Issues
   ~ Metallicity @ z>3: [Ne III] method, AGNs, or JWST
   ~ HSC may find PopIII candidates $\rightarrow$ JWST
   ~ Relative element abundance ratios (especially in XMPGs)
Collaborators

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- Alessandro Marconi (Florence Univ.)
- Matt Malkan (UCLA)
- Ly Chun (UCLA)
- Daniel Schaerer (Geneve Observatory)
- Kentaro Motohara (Tokyo Univ.)
- Nobunari Kashikawa (NAOJ)
- Yoshiaki Taniguchi (Ehime Univ.)
- Takashi Murayama (Tohoku Univ.)

The AMAZE collaboration
Subaru Deep Field project

and much more...