Complete Metallicity Measurements of Long GRB Host Galaxies at Low-Redshifts

GRB Workshop 2015 in RIKEN

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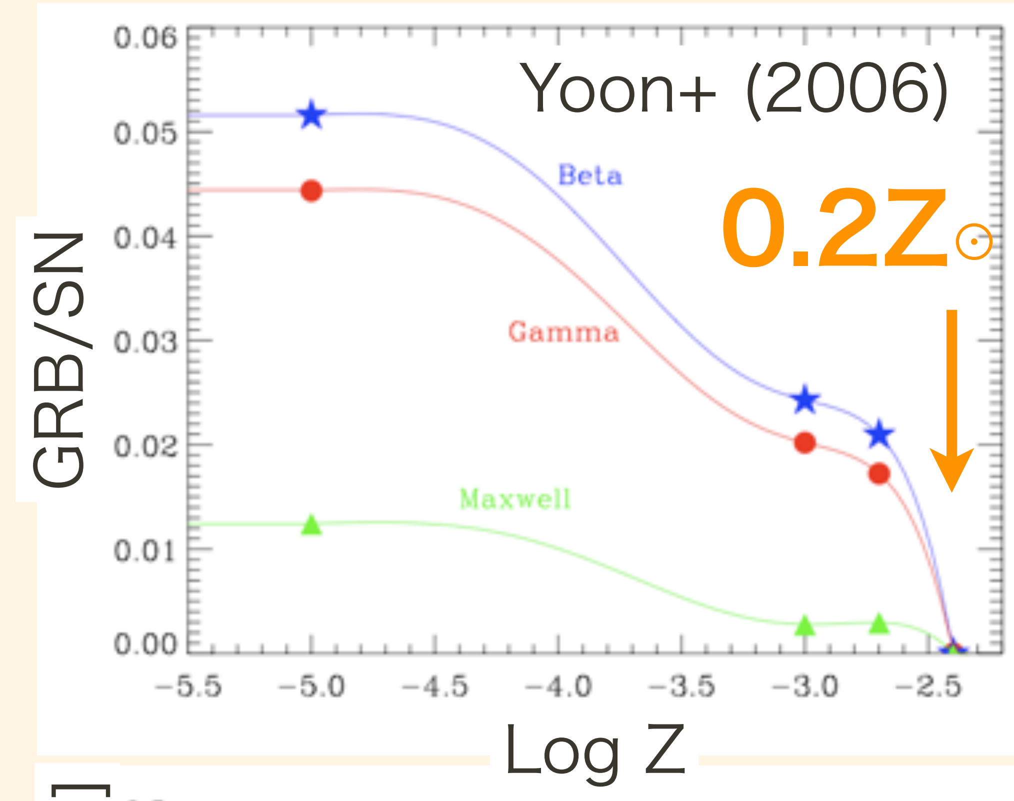
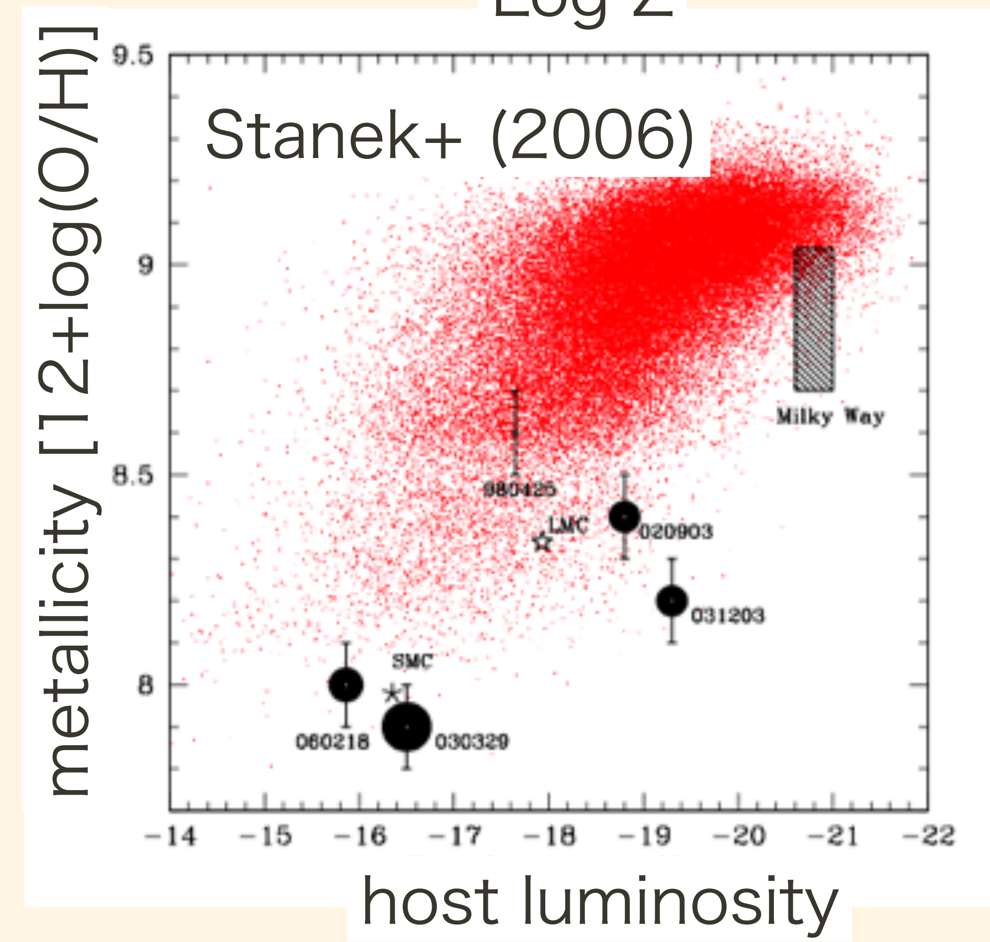
Introduction

Long GRB Occurrence & Metallicity

- Stellar evolution theory:
  - Only a low-metallicity star can maintain rotation to form a GRB central engine.
- Host galaxy observations:
  - Long GRBs preferentially occur in low-metallicity galaxies.
  - A few host galaxies have high-metallicity.
- Metallicity determines the relation between SFR & R_{GRB}.
  - How? Not known quantitatively.





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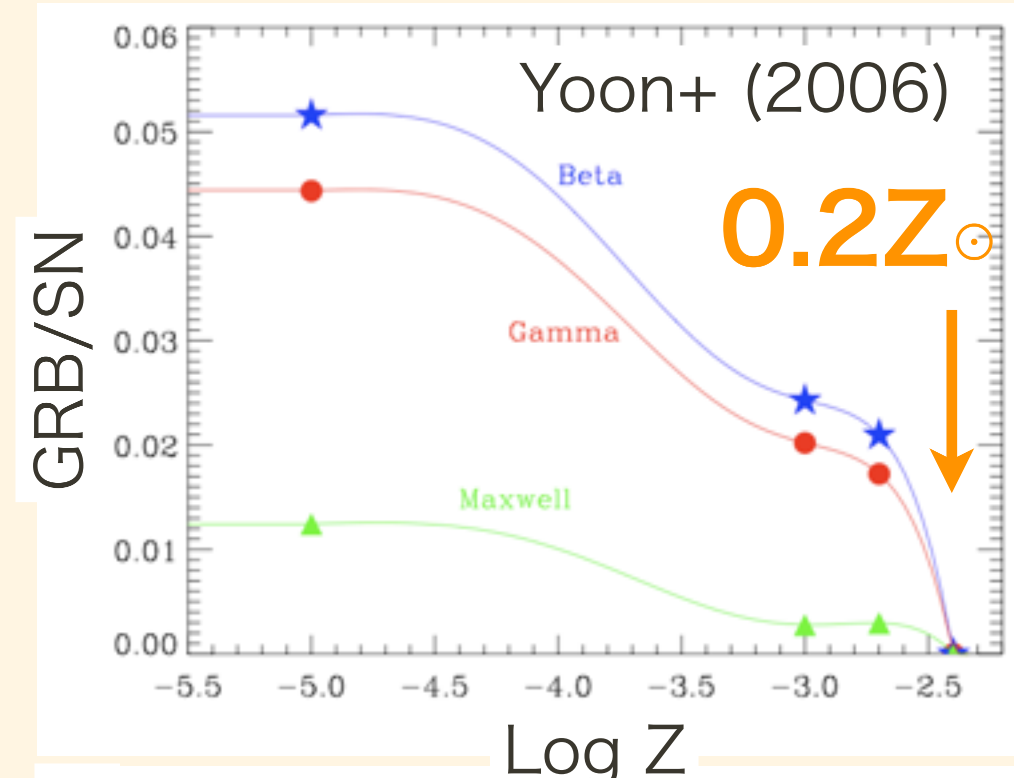
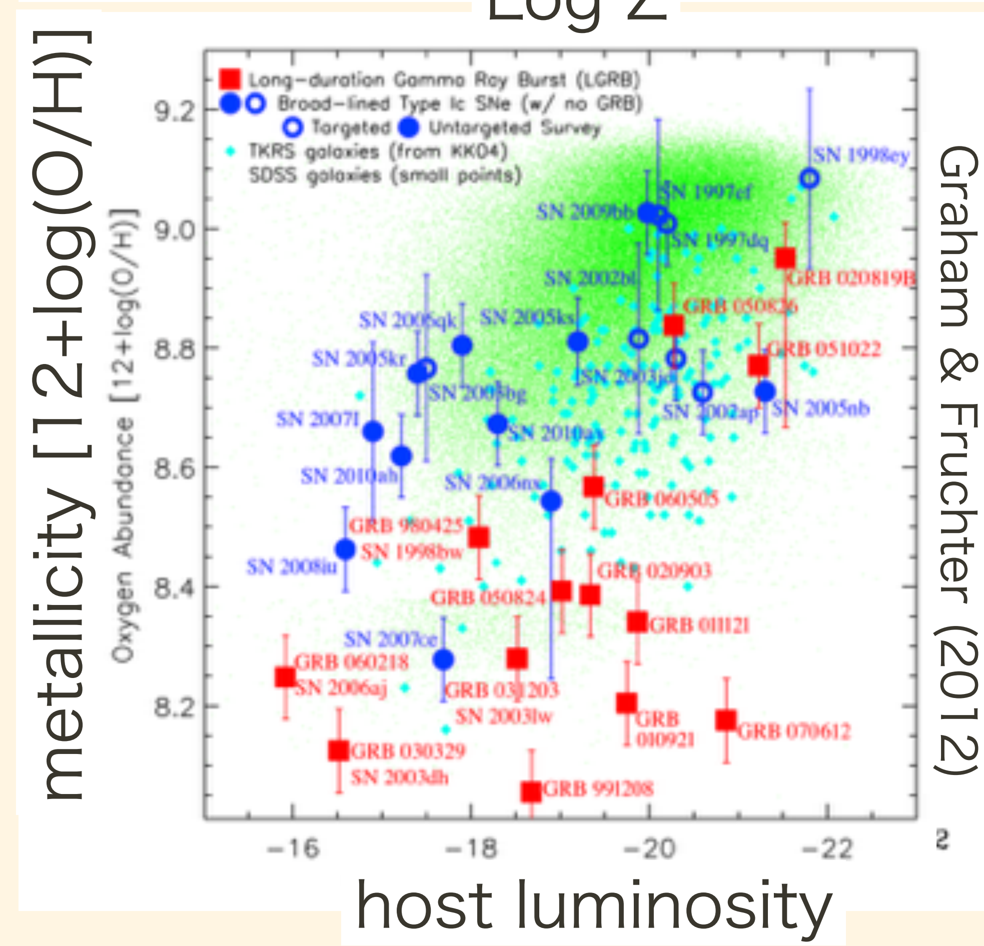




Possible Bias & the Unbiased Surveys

- 2000's: many groups independently observe their target of interest.
  - possible bias:
    - redshift & host galaxy identification
    - human interest
- 2010's: unbiased surveys
  - selection only by γ-ray properties & observing condition
  - unbiased population of GRB host galaxies
  - maybe not the best for constraining the progenitors
    - spanning wide range of redshift (~ 0–6)
    - without complete spectroscopy

How can we constrain the metallicity effect?

- Low redshift GRBs are the clue.
  - The metallicity effect would appear most significantly.
  - A wealth of control sample (e.g. SDSS @ $z \lesssim 0.3$).
- Low redshift sub-samples in the unbiased surveys are too small (2–3 long GRBs @ $z \lesssim 0.3$).
- Complete spectroscopy of low redshifts long GRB host galaxies is needed.
  - possible bias: redshift identification
    - less strong at lower redshifts

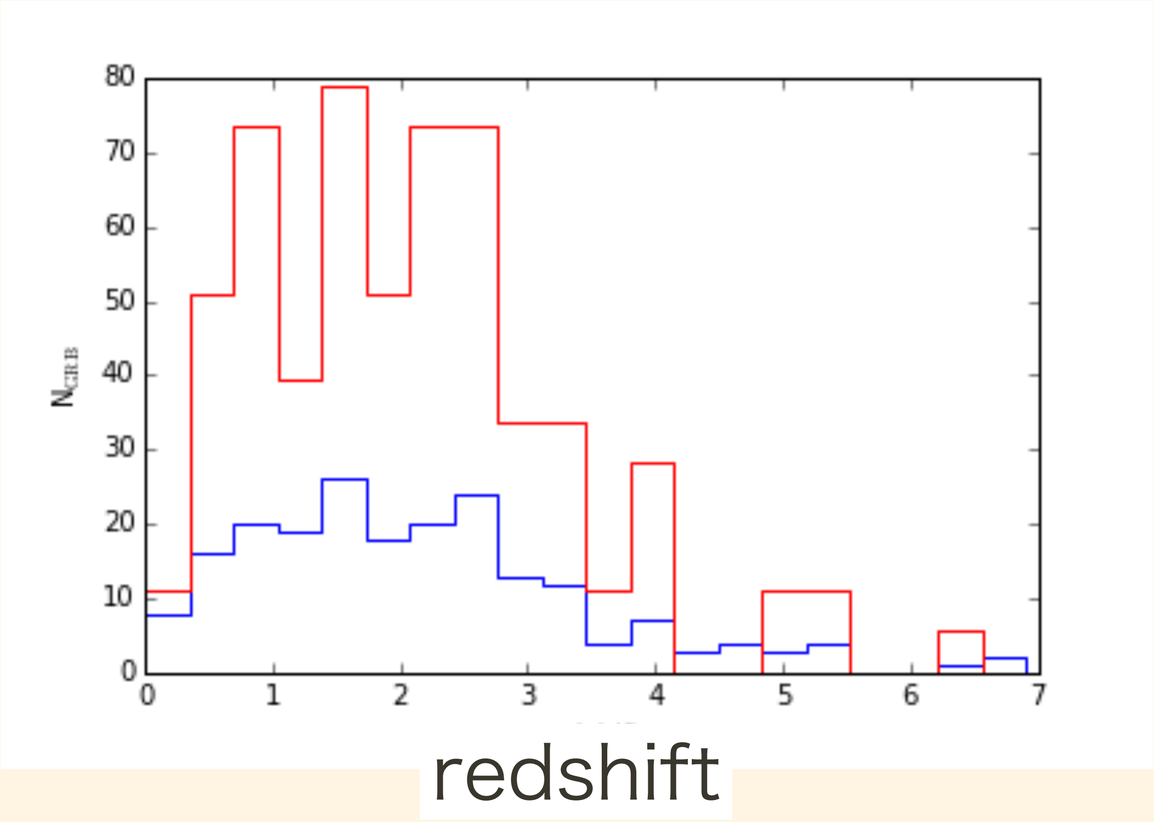
Observations

Target Selection

- all long GRBs known @ $z \leq 0.345$ (telescope time limited) until Mar. 2014
  - 11 GRBs
    - 7 with significant limit on metallicity
    - 3 without sufficient spectroscopy
      - GRB 060614, 090417B, 130427A
    - 1 with archival spectra obtained irrelevantly to the GRB

Redshift Determination Bias

- The SHOALS unbiased sumple
  - Swift GRBs between 041217 & 120308A
  - spec. redshift 103/119
  - 2 @ z ≤ 0.345
- All GRBs in the same epoch
  - 587 (204 known redshifts)
  - assuming the SHOALS z-dist.: 11.4 @ z ≤ 0.345
  - 8 known @ z ≤ 0.345
    - ~ 70% success?



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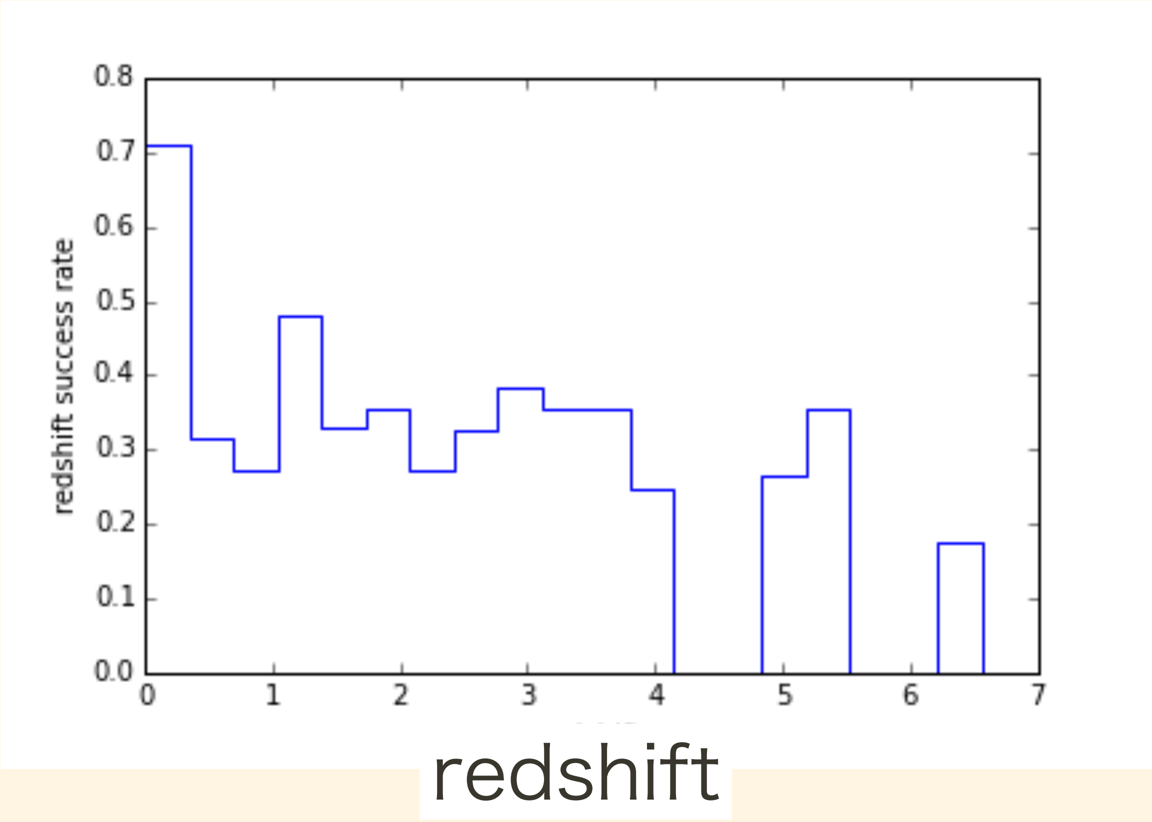
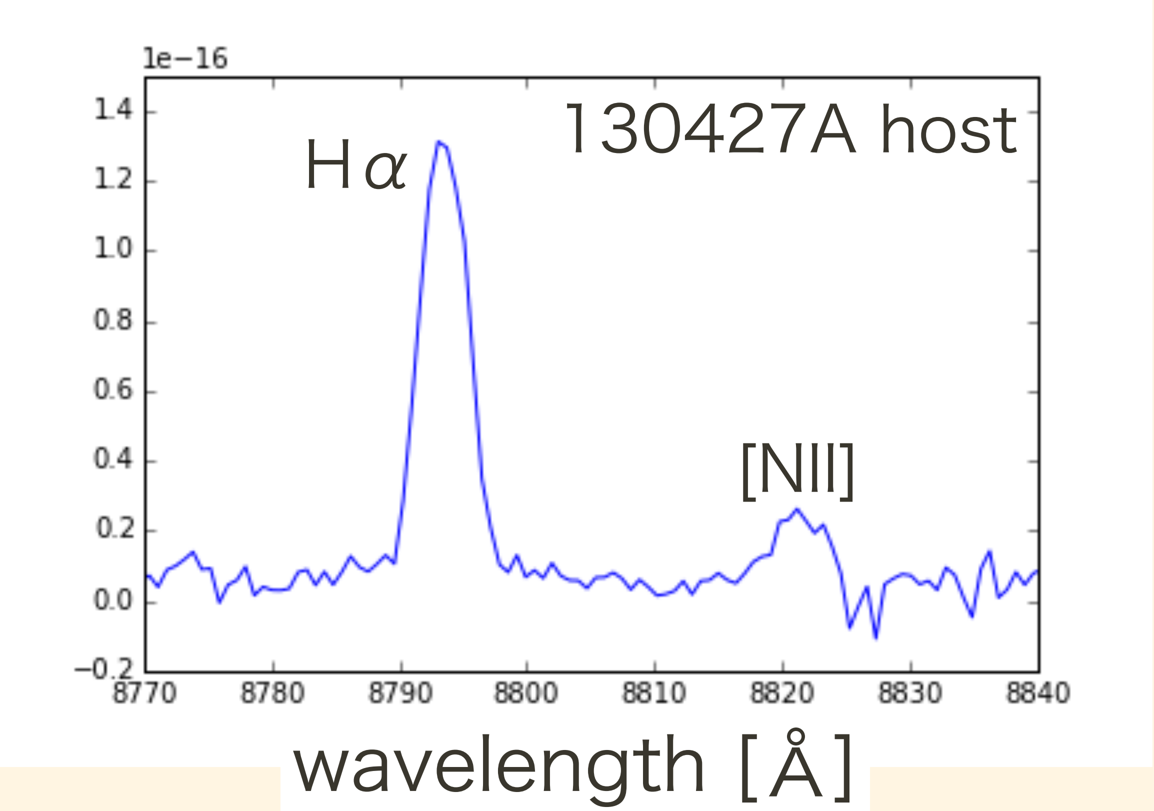
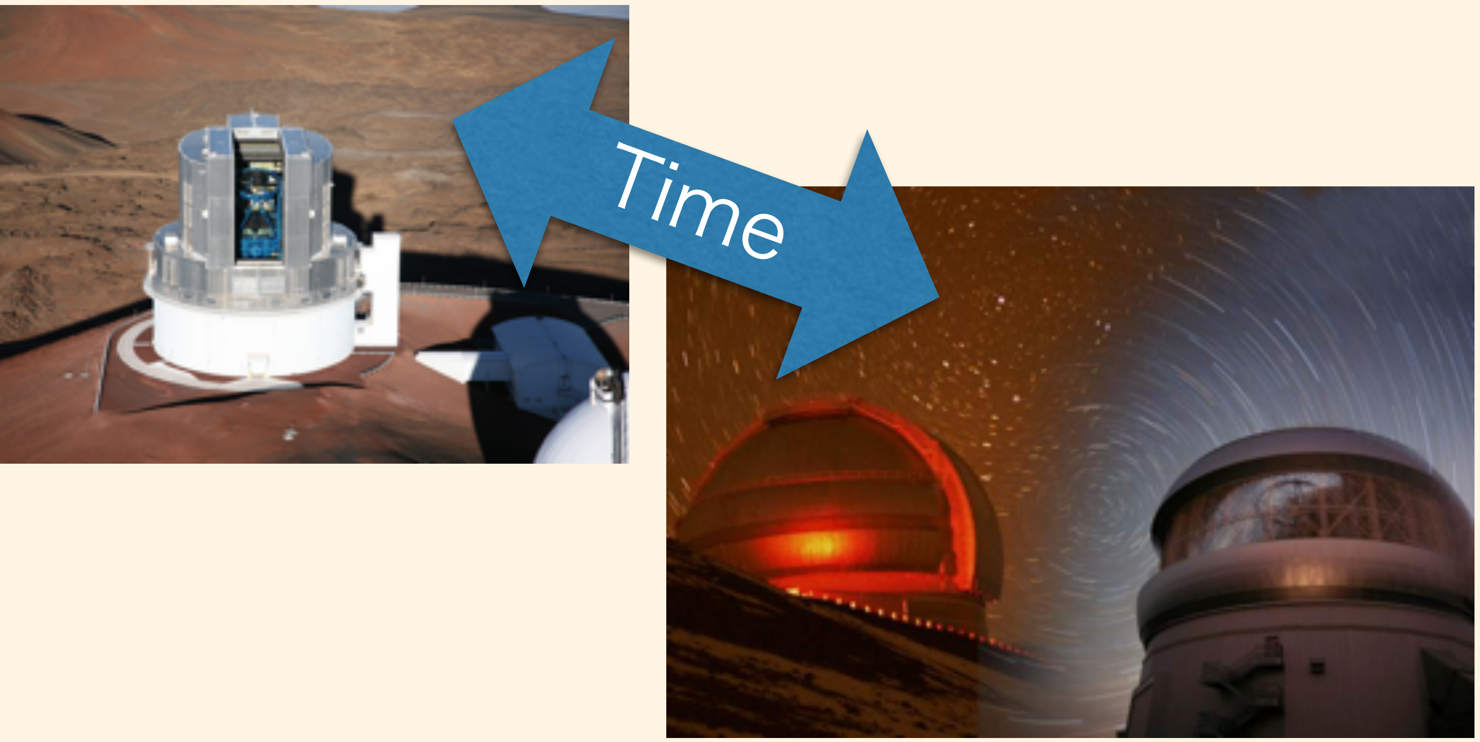
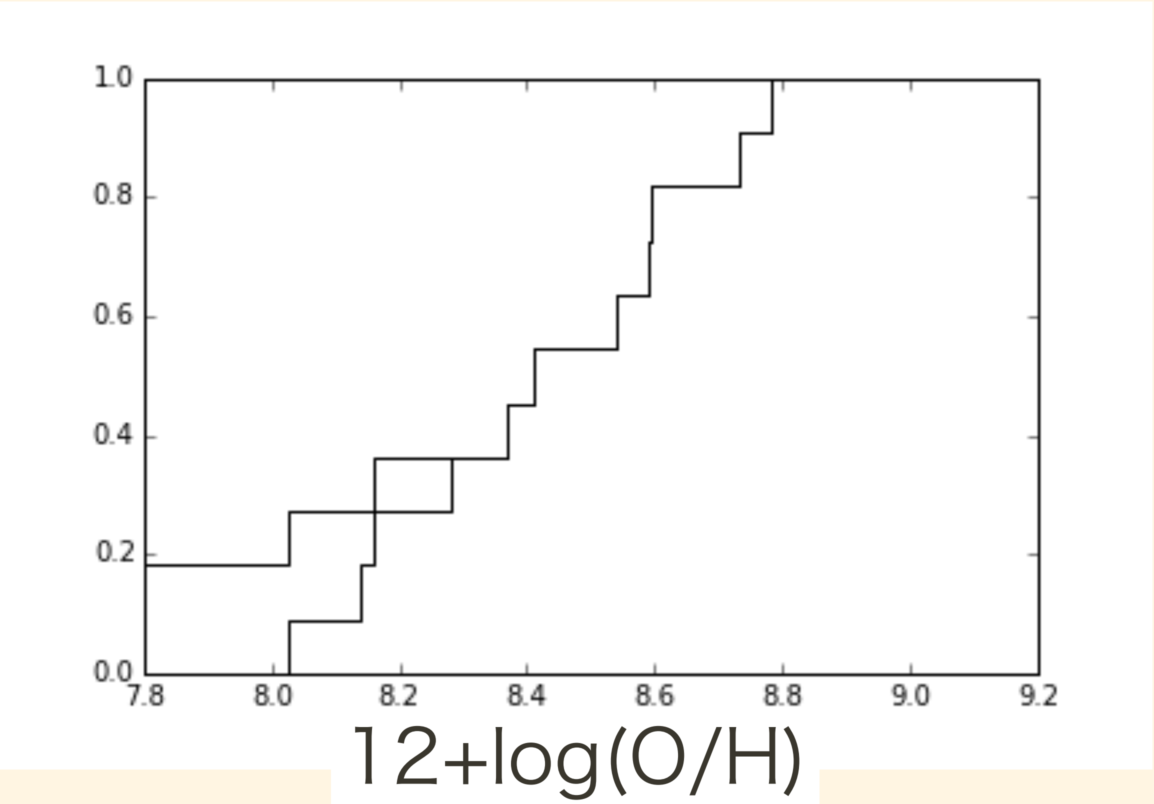


Gemini/GMOS Spectroscopy

- The targets are widely spread over the sky.
    - Queue mode capability in the northern & southern hemisphere is essential.
- S15A Subaru-Gemini time exchange:
    - 7.5 hrs in total
- Metallicity indicator: [NII]/Hα
    - analysis of oxygen lines underway

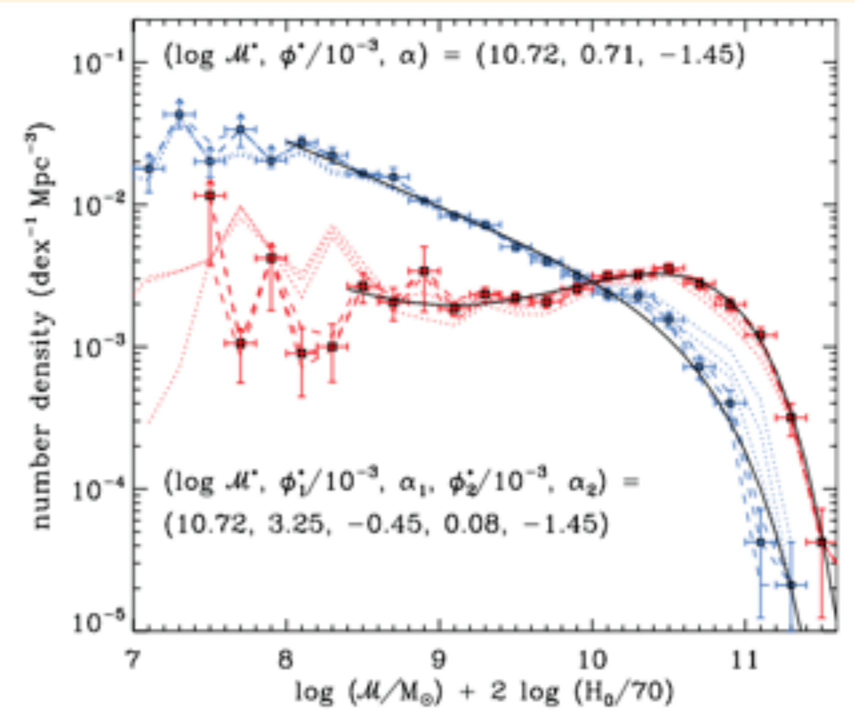




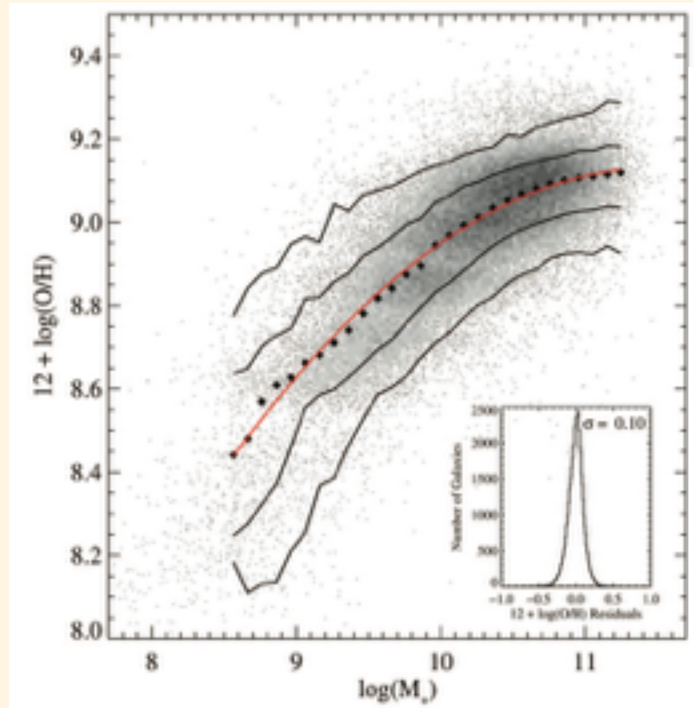


Comparison to General Star Forming Galaxies

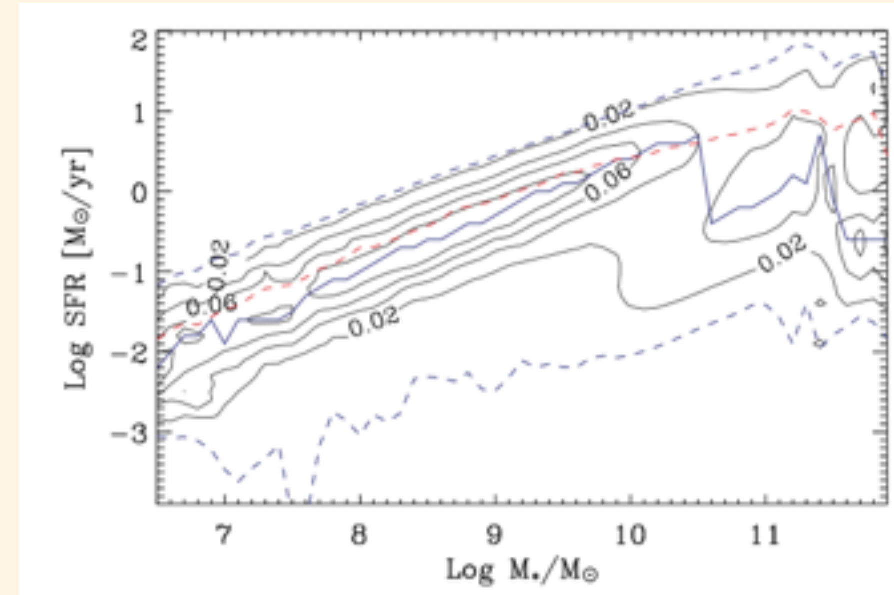
$M_\star$, SFR, Metallicity of Galaxies



Baldry+ (2012)

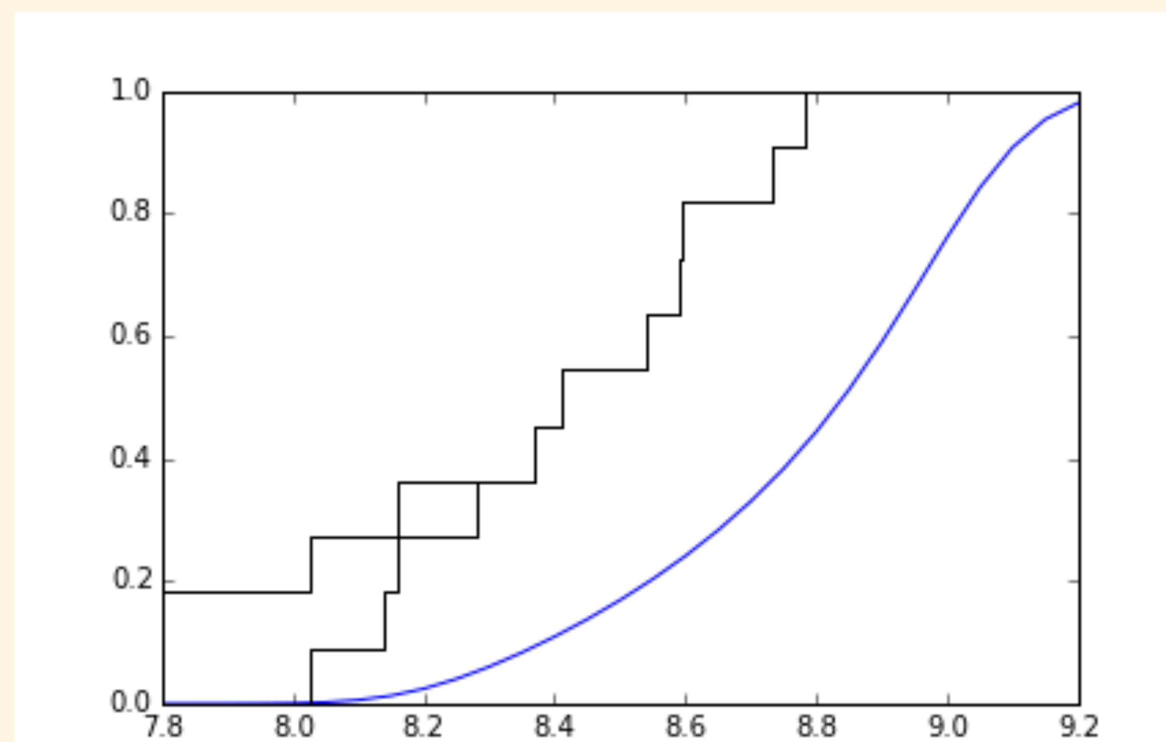


Tremonti+ (2004)



Brinchmann+ (2004), Salim+ (2007)

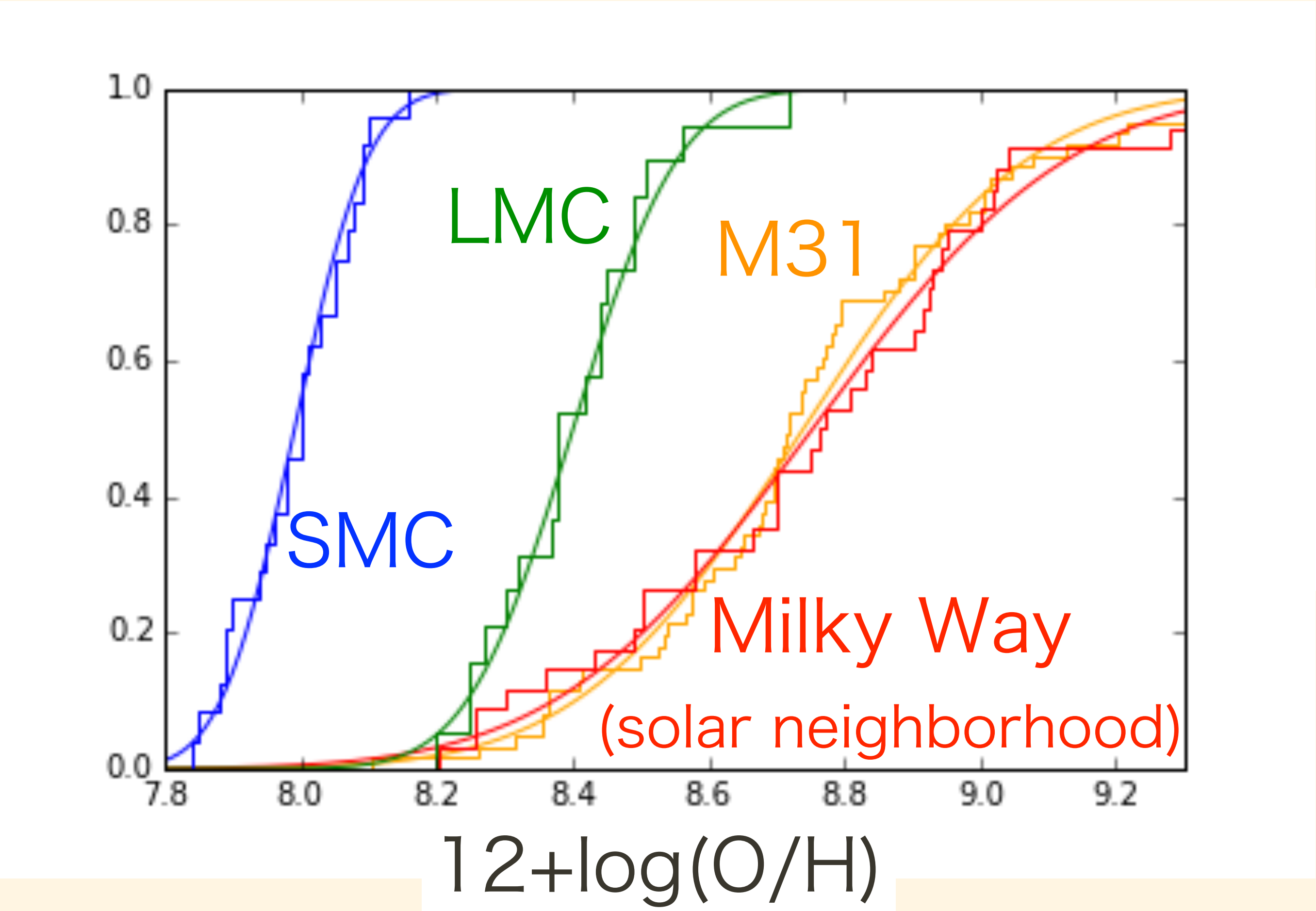
- SFR weighted log(O/H) dist. of general star forming galaxies
  - assuming $M_\star$ function, $M_\star$-Z relation, & $M_\star$-SFR (main sequence) relation of local galaxies
- inconsistent with the GRB host galaxies
  - in agreement with the previous results with smaller sample

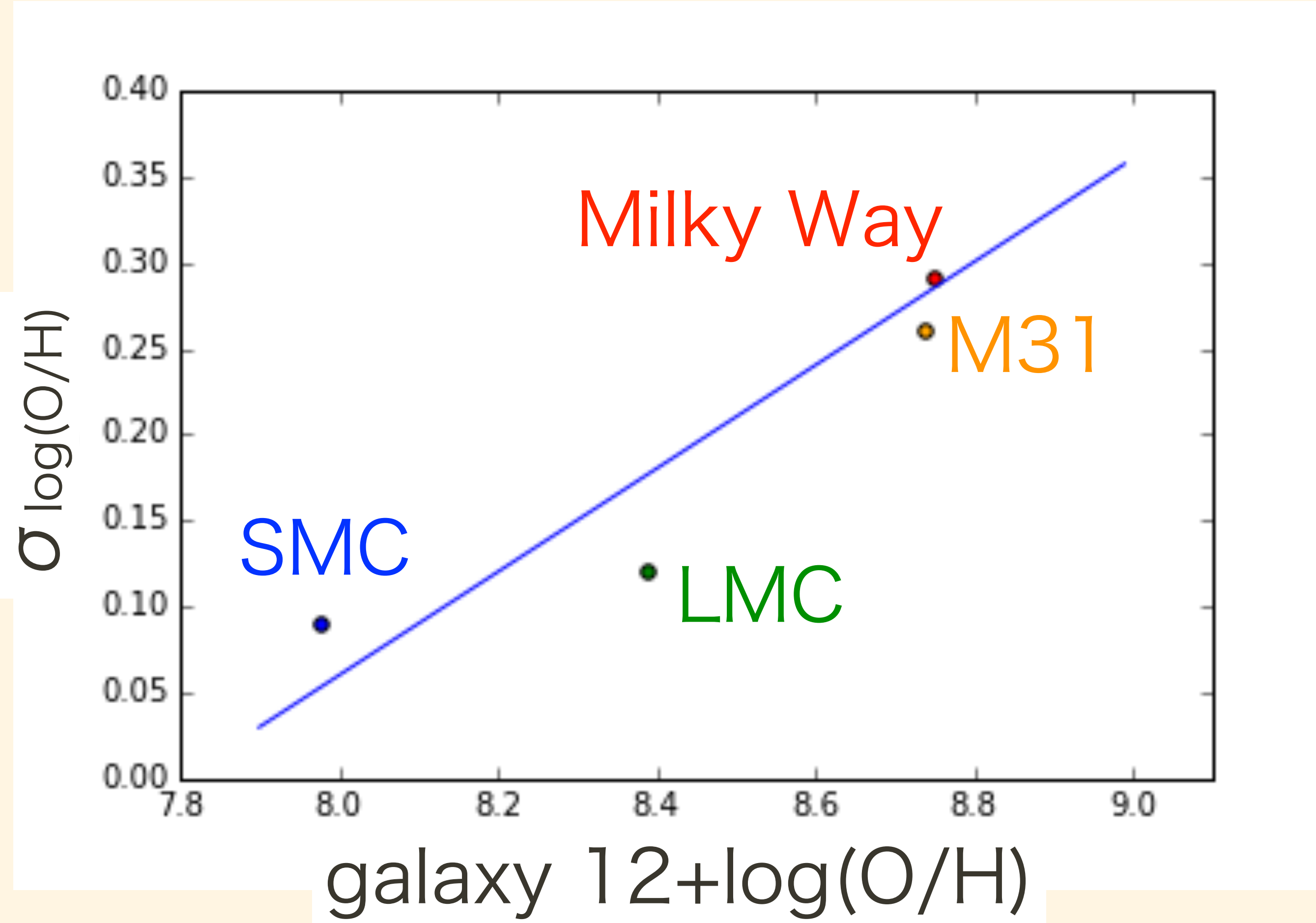


12+log(O/H)

Internal O/H Variation

- what we observe: host galaxy metallicity
- what determines GRB occurrence: progenitor metallicity
  - can be different





MW: Afflerbach+ (1997), LMC/SMC: Pagel+ (1978), M31: Sanders+ (2012)

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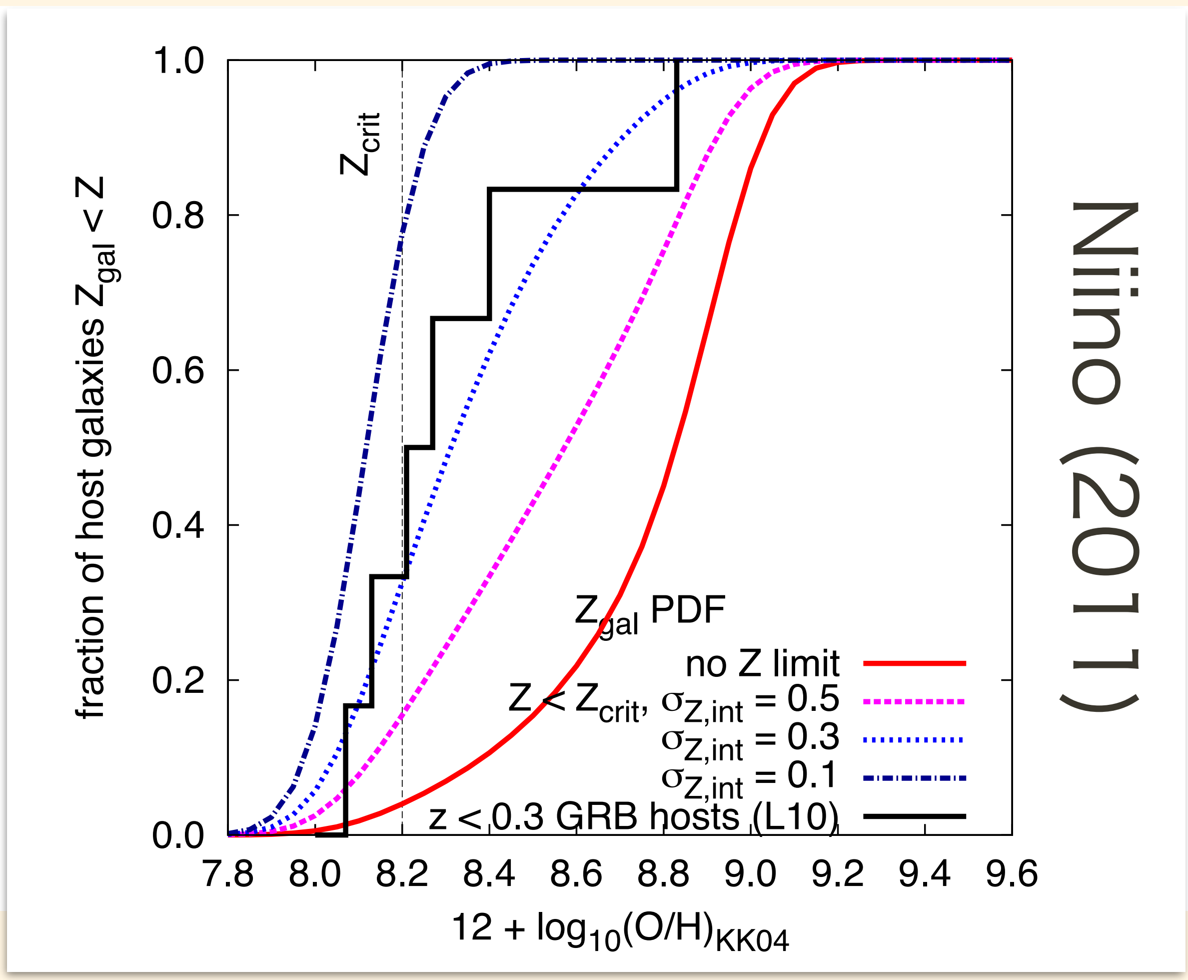
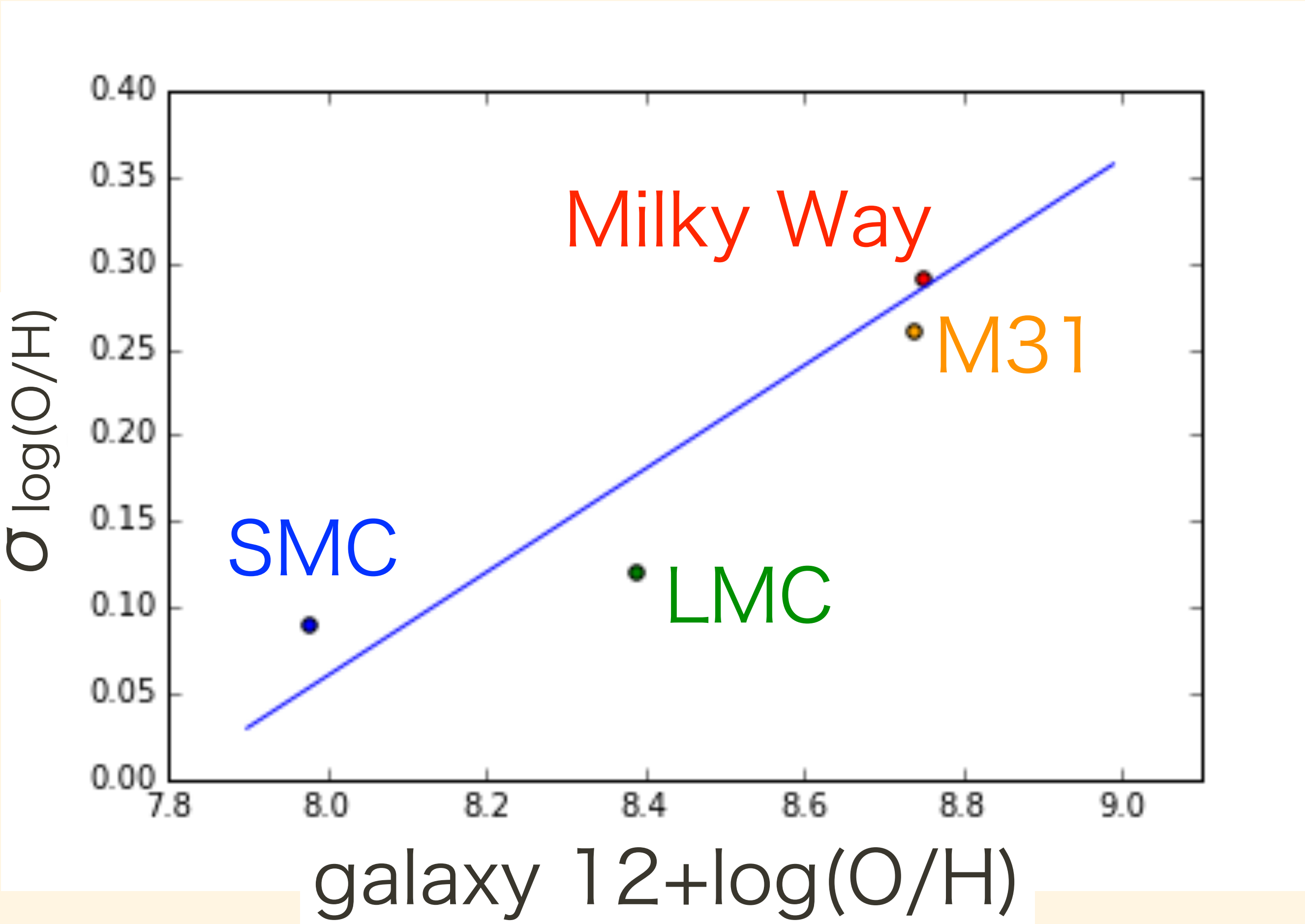


Niino (2011)



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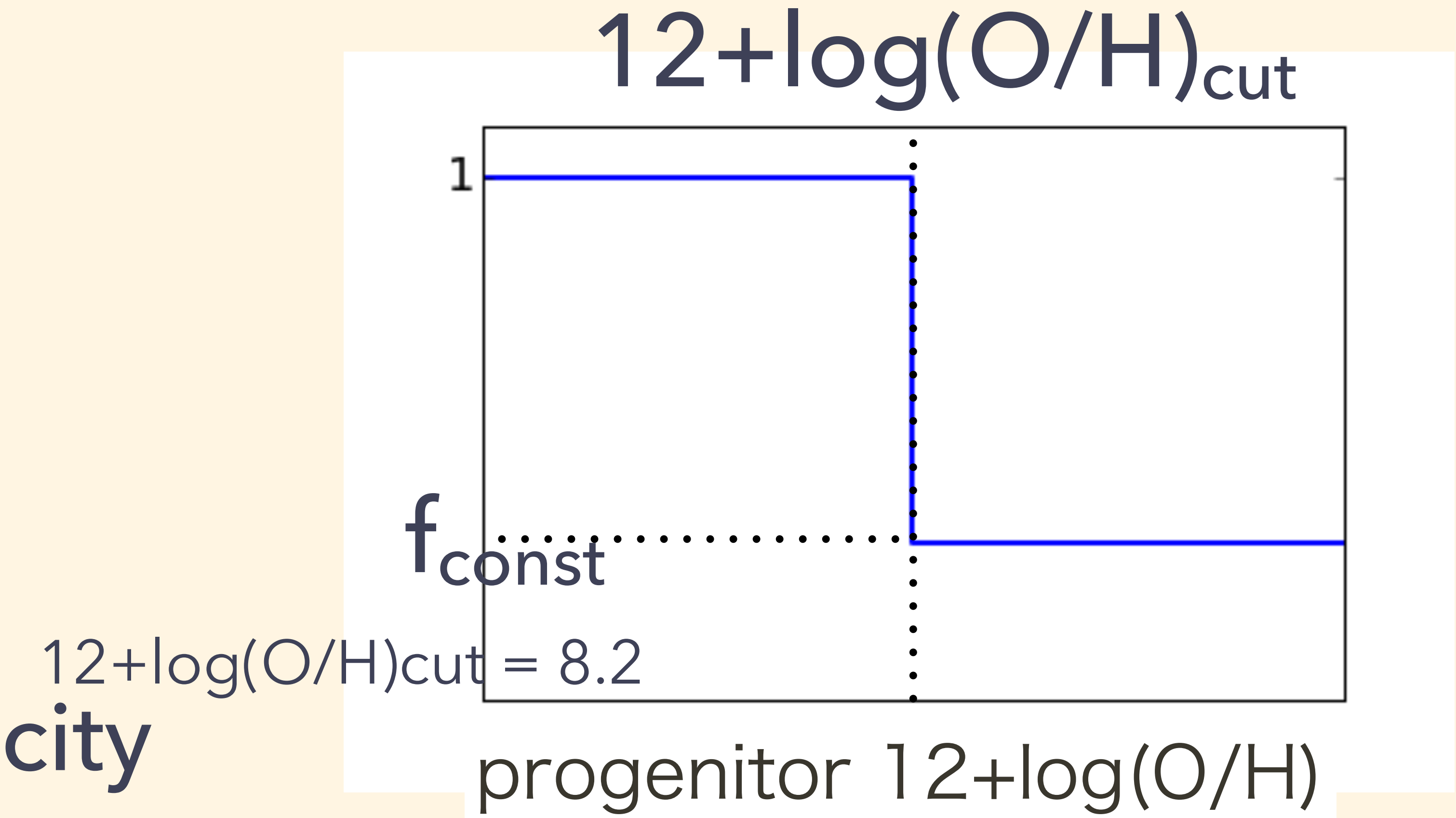
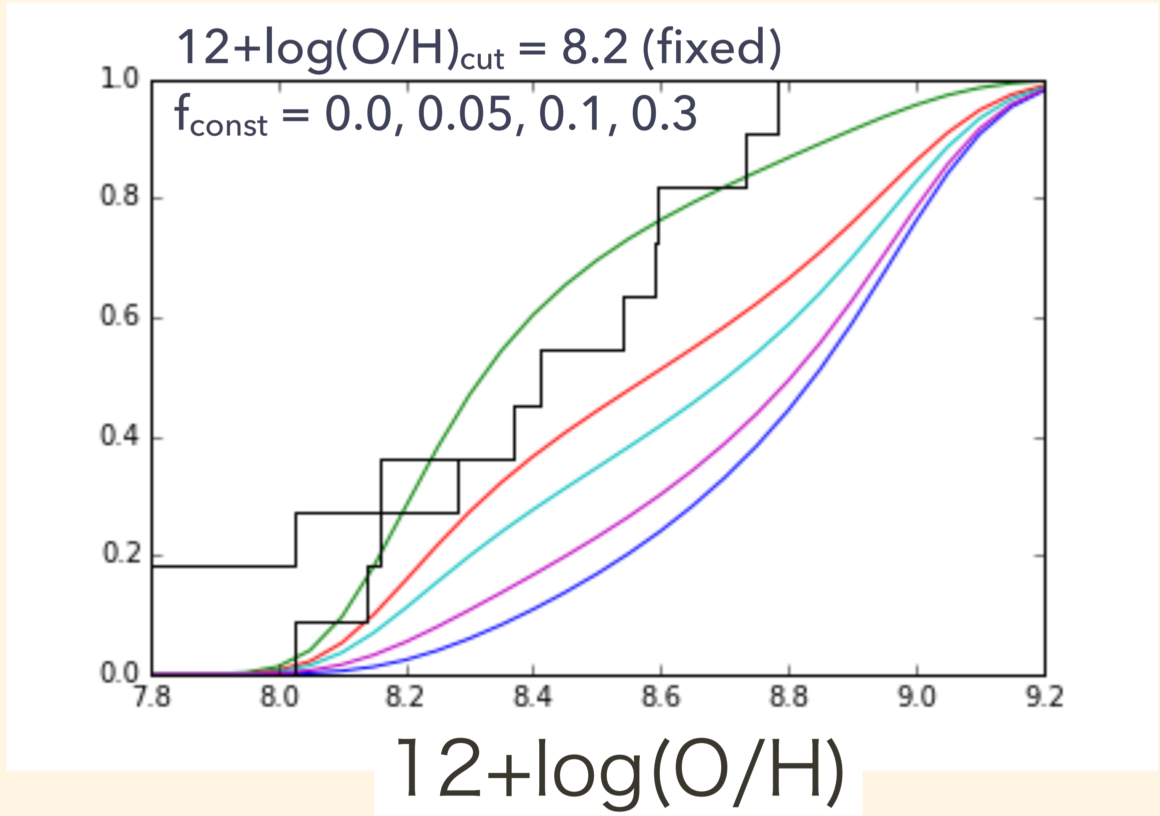
GRB Efficiency Model

- GRB efficiency
  - $\varepsilon_{GRB} = R_{GRB}/SFR$
- assumptions:
  - a step function of progenitor metallicity
    - not host galaxy metallicity
  - 2 parameters:
    - $12+\log(O/H)_{cut}$
    - f_{const}





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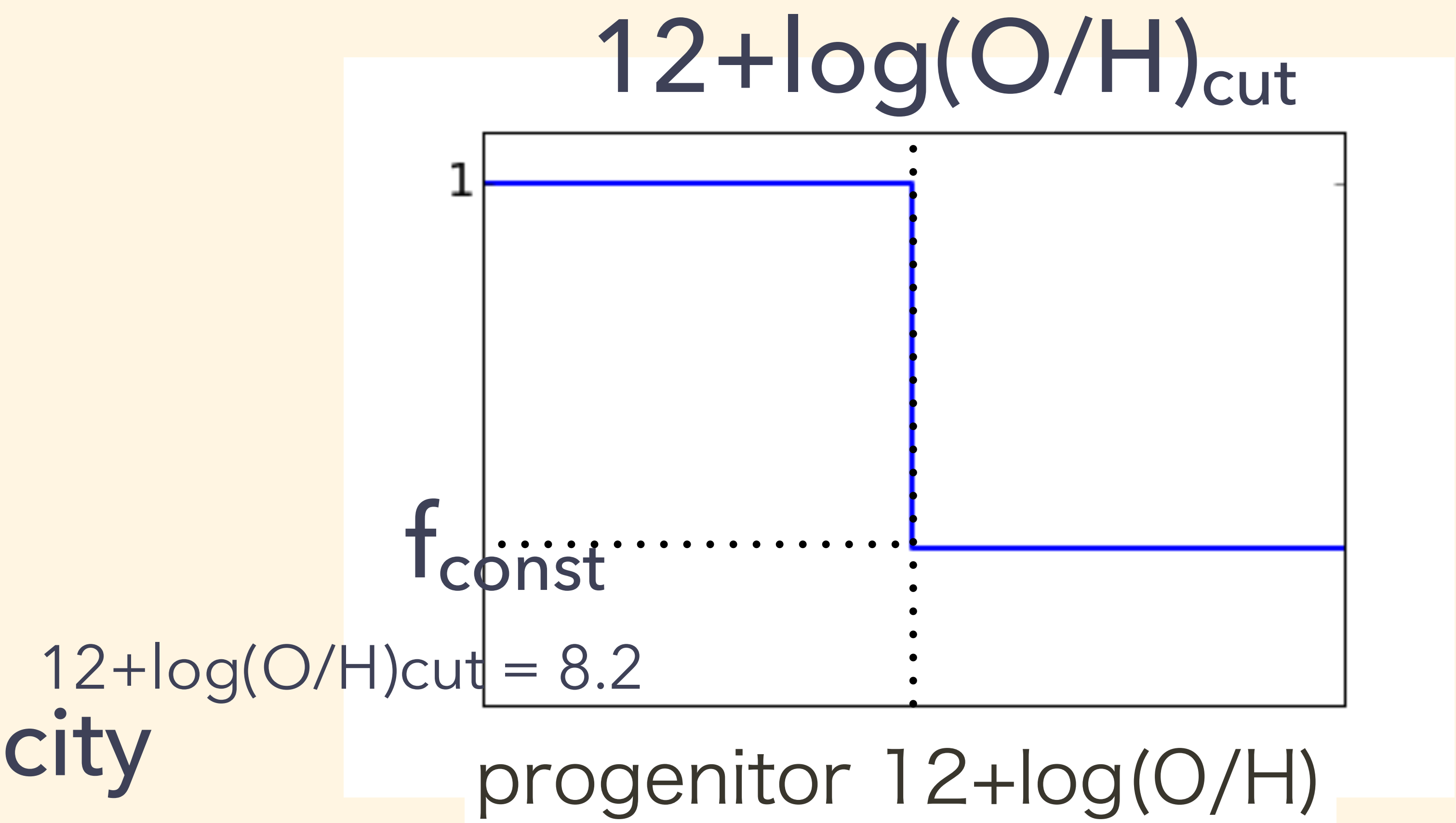
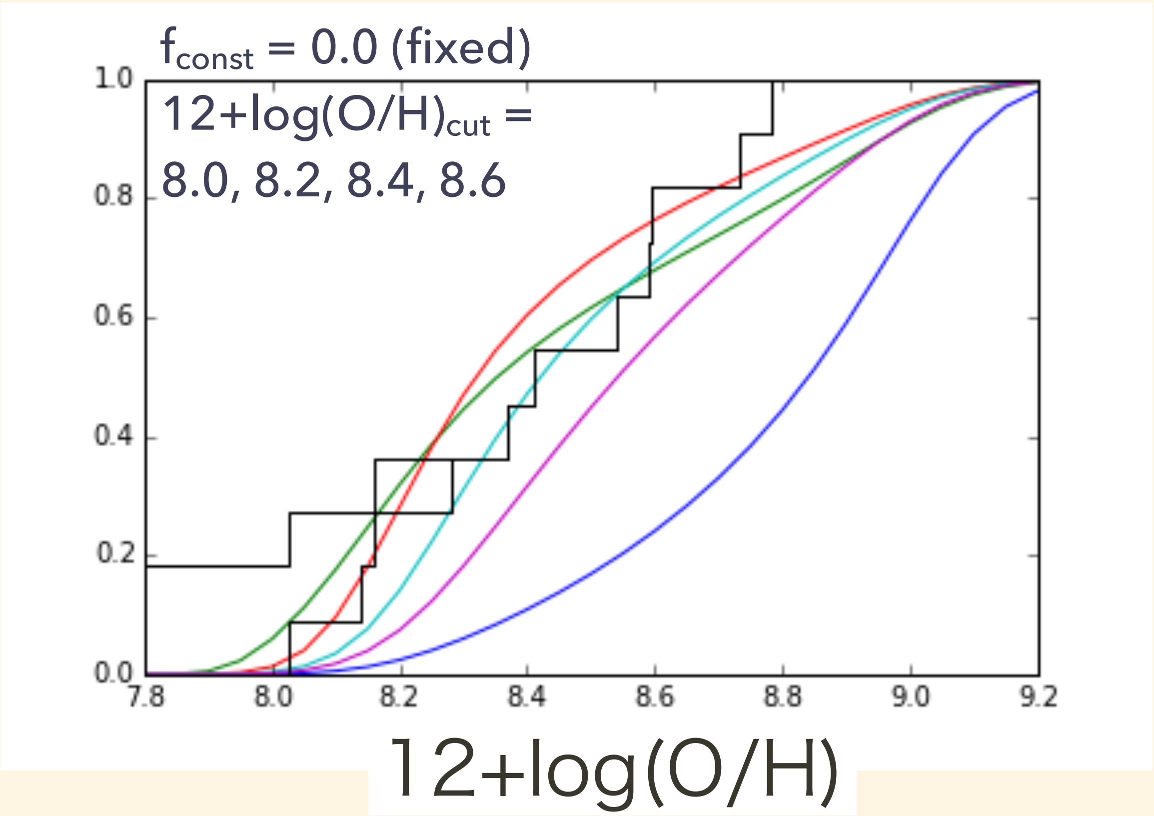
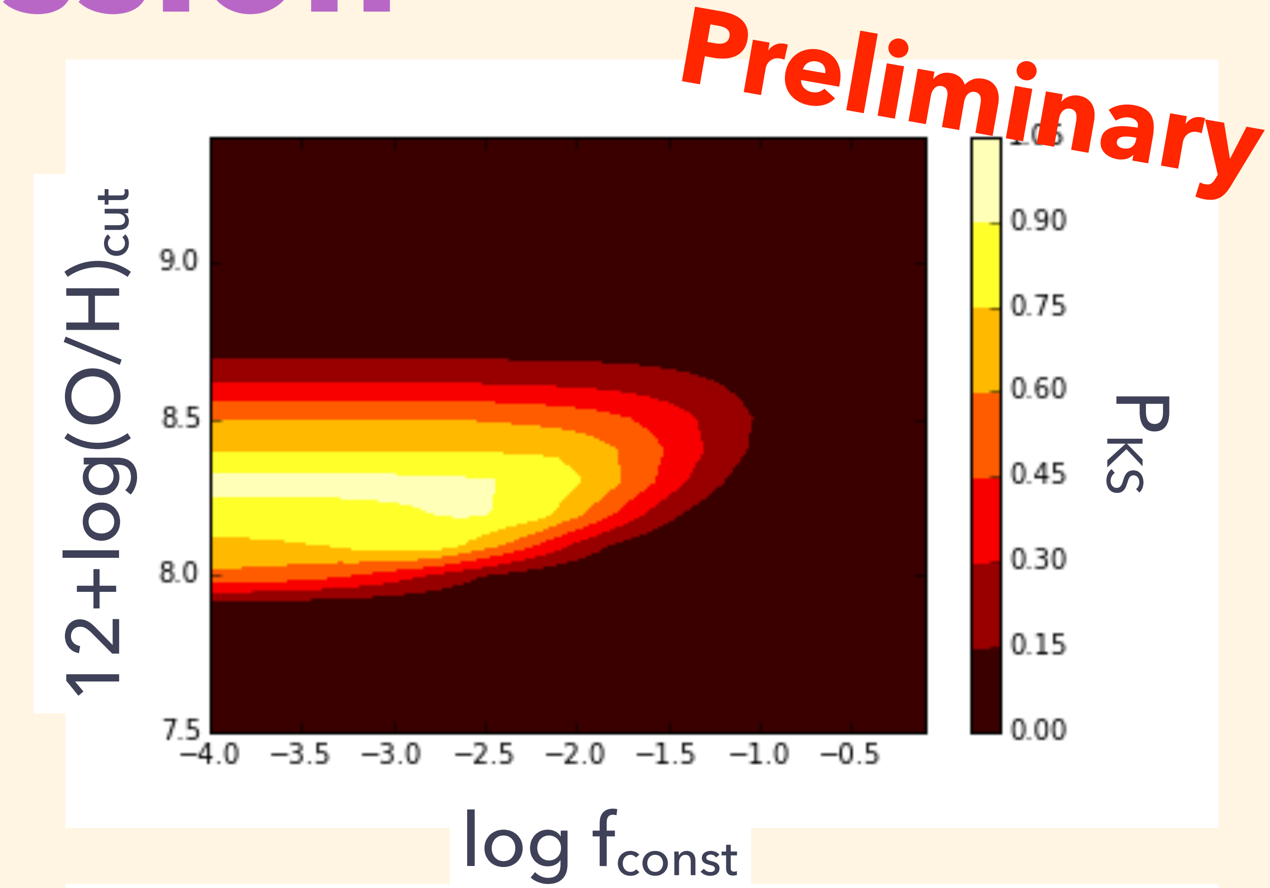
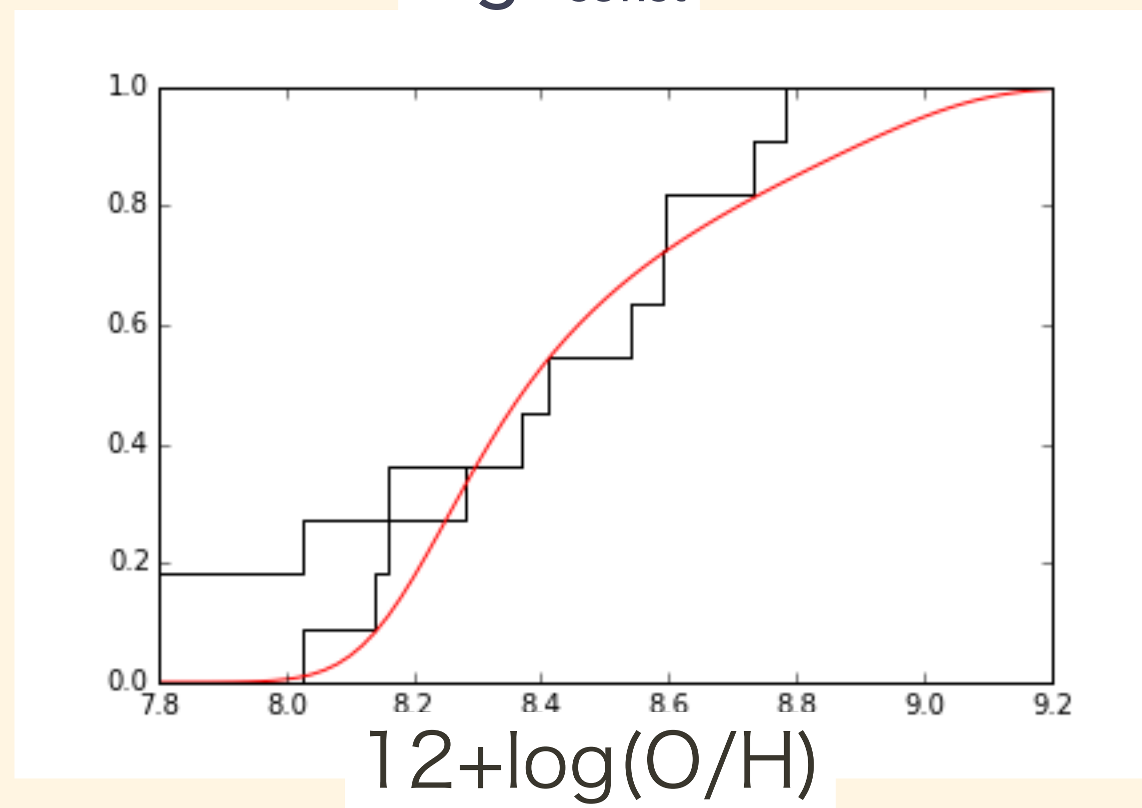




Results & Discussion

- $\log(O/H)_{cut}$ and f_{const} are determined almost independently.
- Preliminary results suggest:
  - $12+\log(O/H)_{cut} = 8.1–8.4$
  - $f_{const} < 3\%$ (0.0 is the best)
- The host galaxy metallicity distribution prefers single low-metallicity channel.





Summary

- Unbiased and redshift selected studies of GRB host galaxies works complementarily to unveil the nature of long GRB progenitors.
  - Redshift selected: constrain progenitor models
  - Unbiased: clarify sampling the bias effects
- Current data prefer progenitor models without high-metallicity GRB production.
- Internal metallicity variation within each galaxy maybe a major source of uncertainties.