Systematic Observation of Long GRB Host Galaxies in the Subaru/Gemini Time Exchange Program

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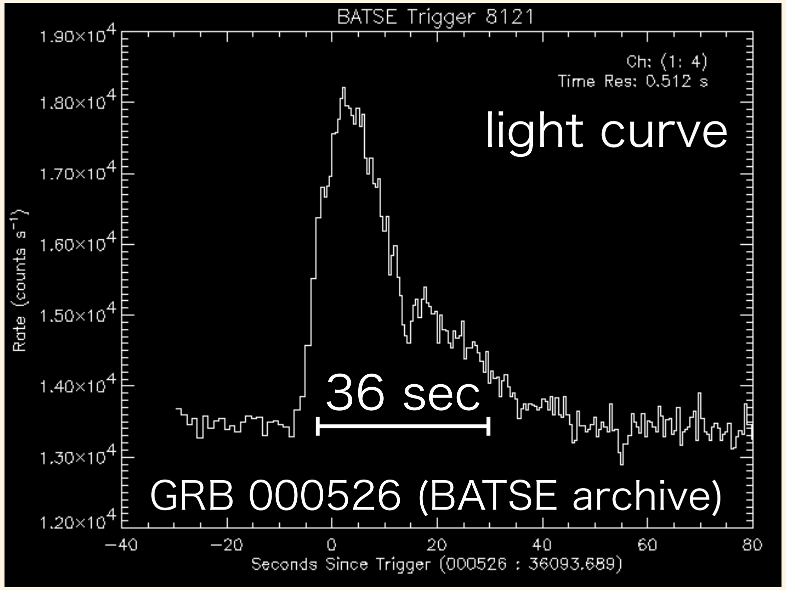
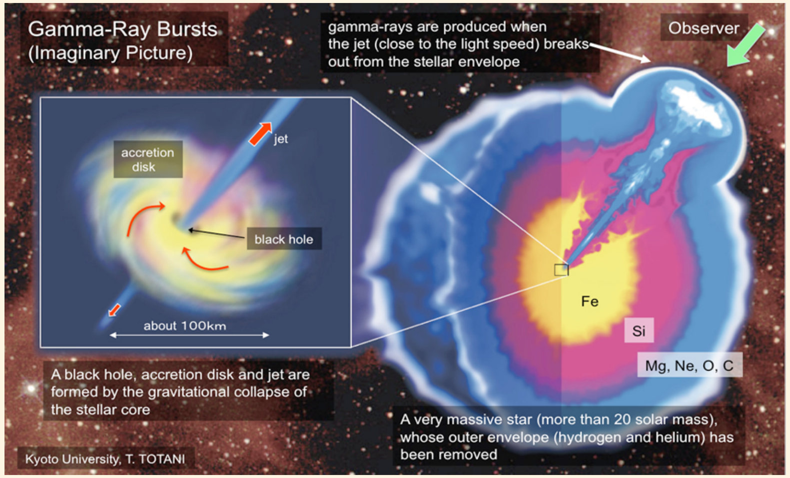
Introduction

Long Gamma-Ray Bursts (GRBs)

- Transient events in soft γ-ray/hard X-ray
  - accompanied by afterglows in X-ray—radio
- duration ~ 2-1000 sec
  - afterglows last hrs—days
- very bright
  - highest GRB spec-z: 8.2
- associated with core-collapse events of massive stars
  - relativistic jets erupted from newly born BH accretion disk/magnetars.

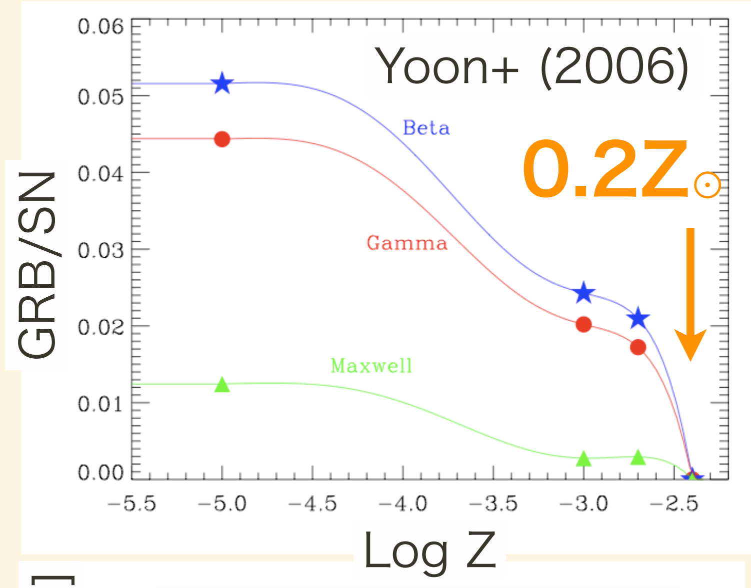


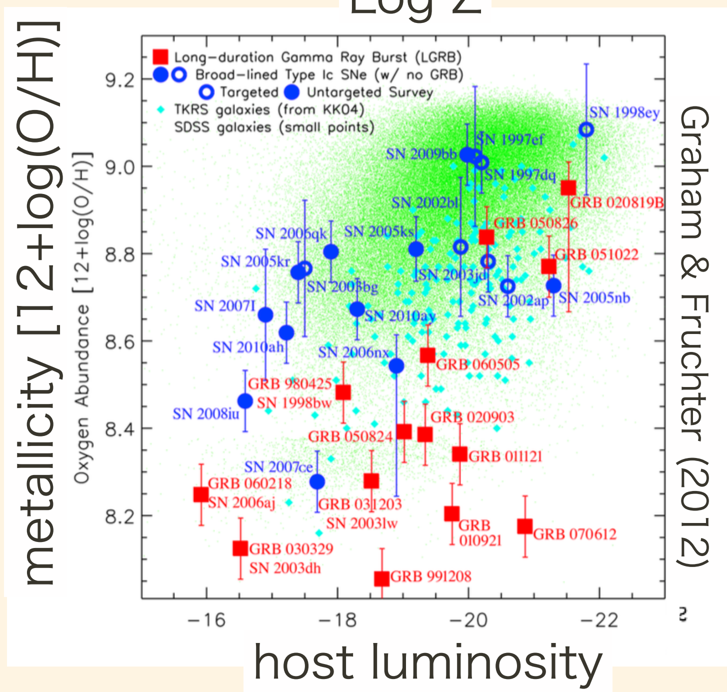


Credit: T. Totani

Long GRB Occurrence & Metallicity

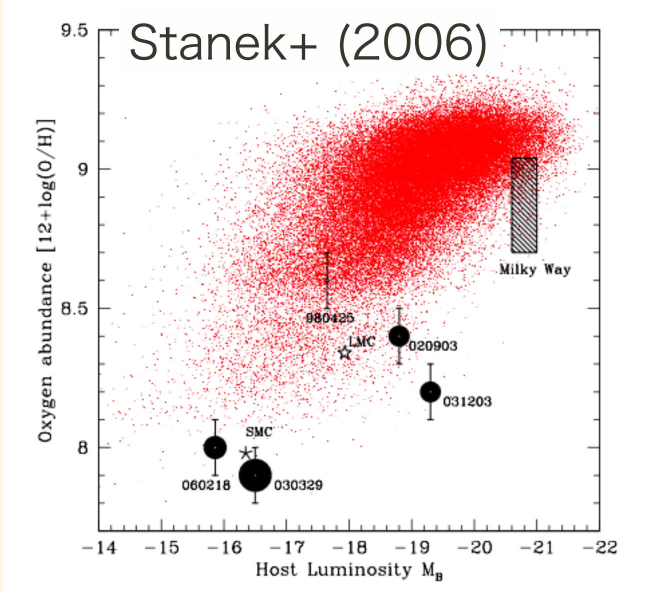
- GRB/core-collapse ~ 1/1000
- Stellar evolution theory:
  - Only a low-metallicity star can maintain rotation to form a GRB central engine.
- Host galaxy observations:
  - Long GRBs preferentially occur in low-metallicity galaxies.
  - A few host galaxies have high-metallicity.
- Metallicity determines the relation between SFR (core-collapse) & R_{GRB}.
  - Quantitative constraint is poor.

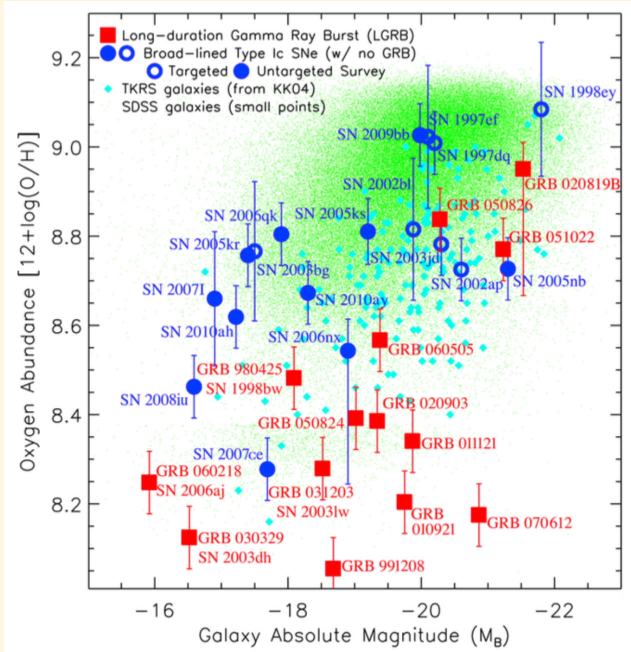




Previous Studies of GRB Hosts (1)

- pre-Swift era (< 2004)
  - small number of GRBs with redshift measurements
  - the host galaxies were intensely studied once the redshift is known to be low (≲ 0.3)
- Swift era
  - many GRB redshifts
    - but still < 50%
    - maybe biased against dusty event
  - various groups independently observe their target of interest.
    - more spectra but with uncontrolled sampling

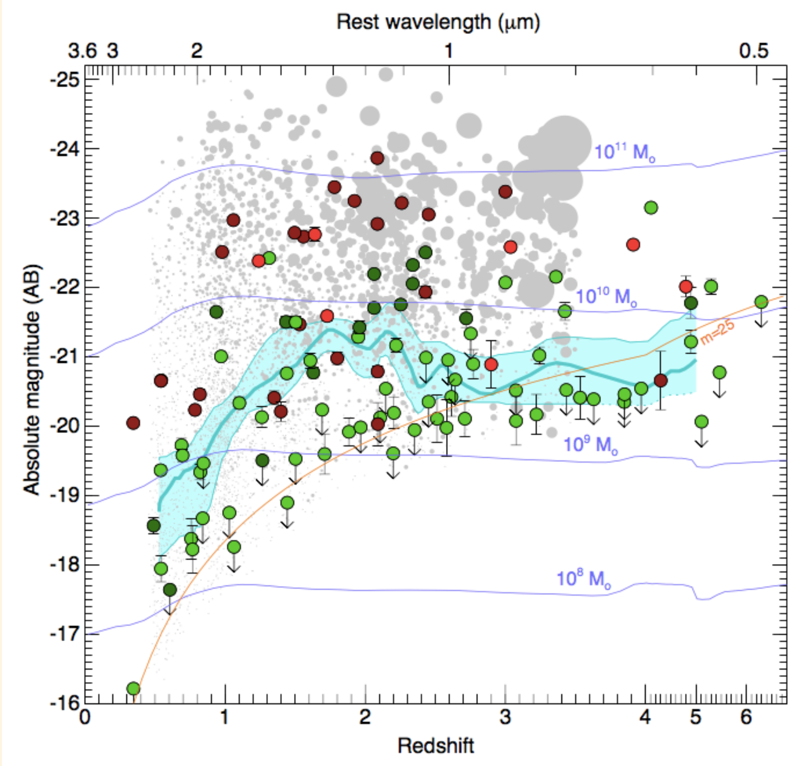




Graham & Fruchter (2012)

Previous Studies of GRB Hosts (2)

- 2010's: unbiased surveys
  - selection only by γ-ray/X-ray properties & observing condition
  - observe all objects that fulfill the selection criteria
- difficulties in studying progenitor properties with these samples
  - spanning wide range of redshift (~ 0–6)
  - mainly photometric



Perley+ (2015)

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

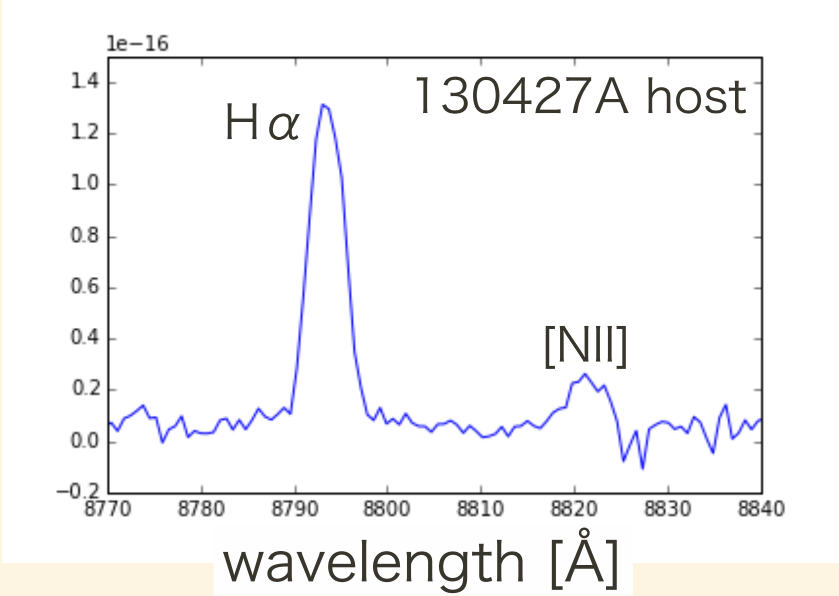
Observations

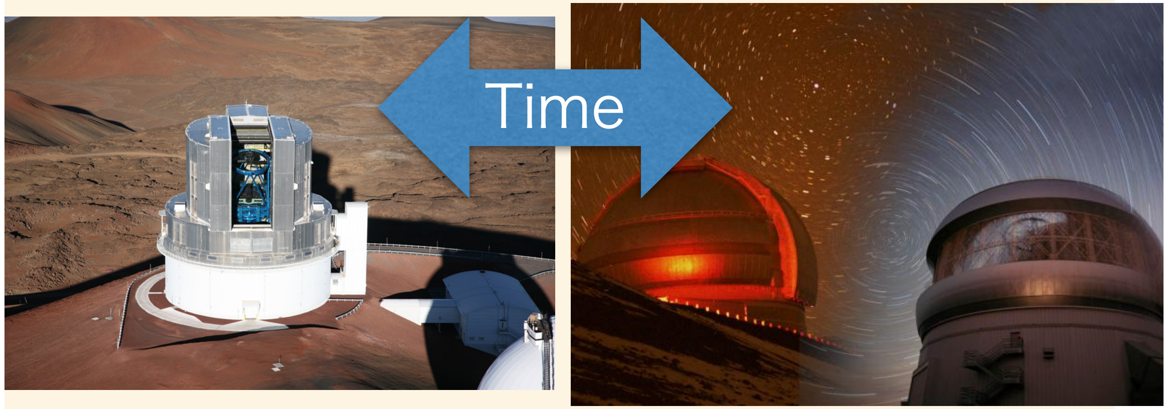
Target Selection

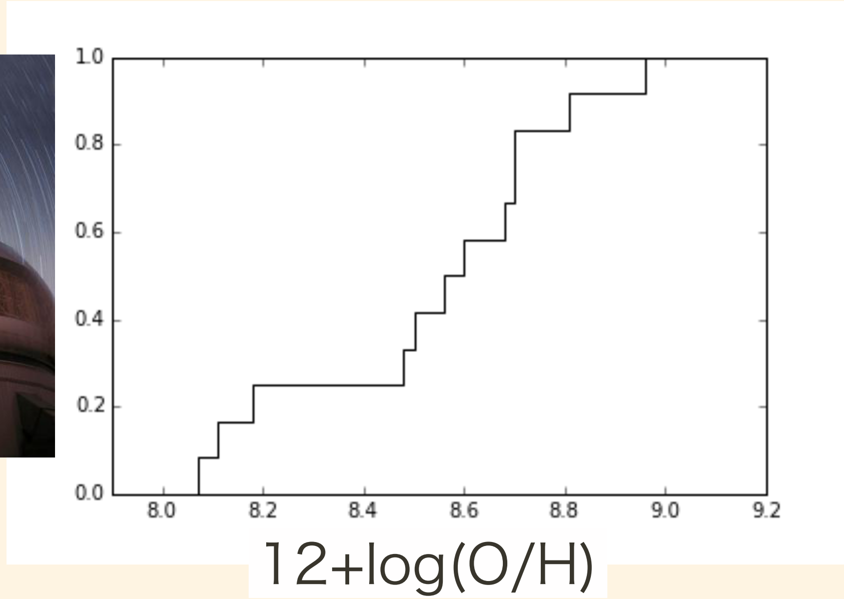
- all long GRBs known @ $z \leq 0.41$ (telescope time limited) until Mar. 2014
  - 12 GRBs (excluding XRFs)
    - 7 with known metallicity
    - 5 without sufficient spectroscopy
      - we observe 3 of them ($z < 0.35$)
      - 2 spectra were published recently (Krühler+ 2015)

Gemini/GMOS Spectroscopy

- The targets are widely spread over RA & DEC.
  - Queue mode capability in the northern & southern hemisphere is essential.
- The Subaru–Gemini time exchange.
  - queue mode with GMOS–N/S
- Theoretical metallicity calibration by Kobulnicky & Kewley (2004, KK04), using [OII], Hβ, [OIII], Hα & [NII]

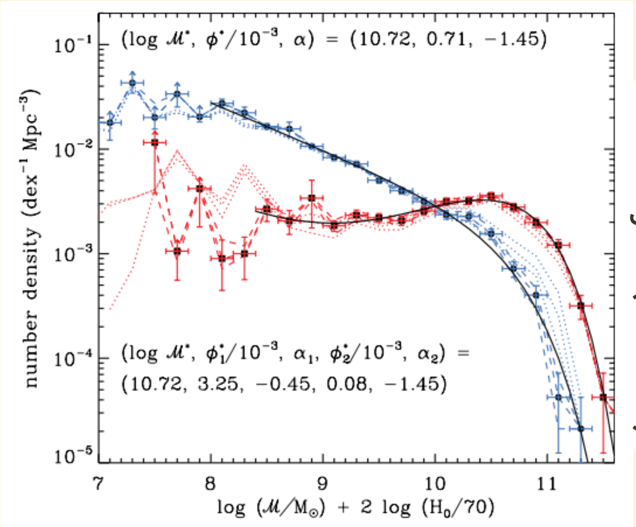




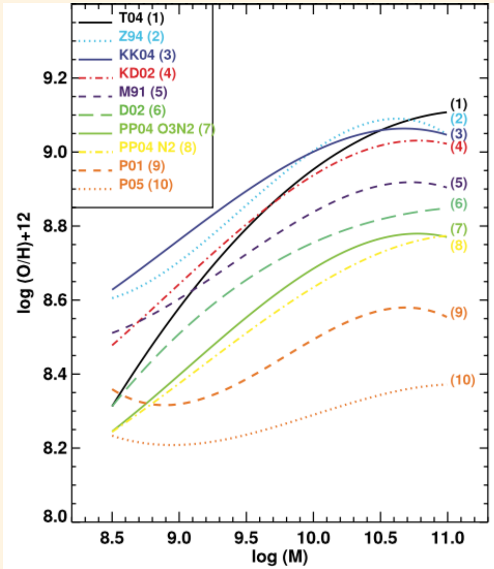


Comparison to General Star Forming Galaxies

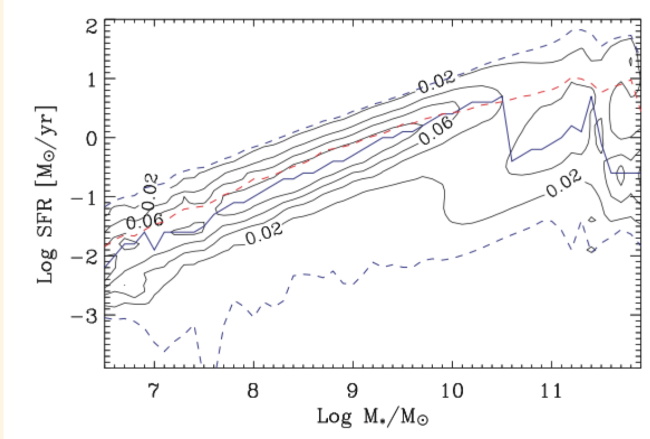
M★, SFR, Metallicity of Galaxies



Baldry+ (2012)

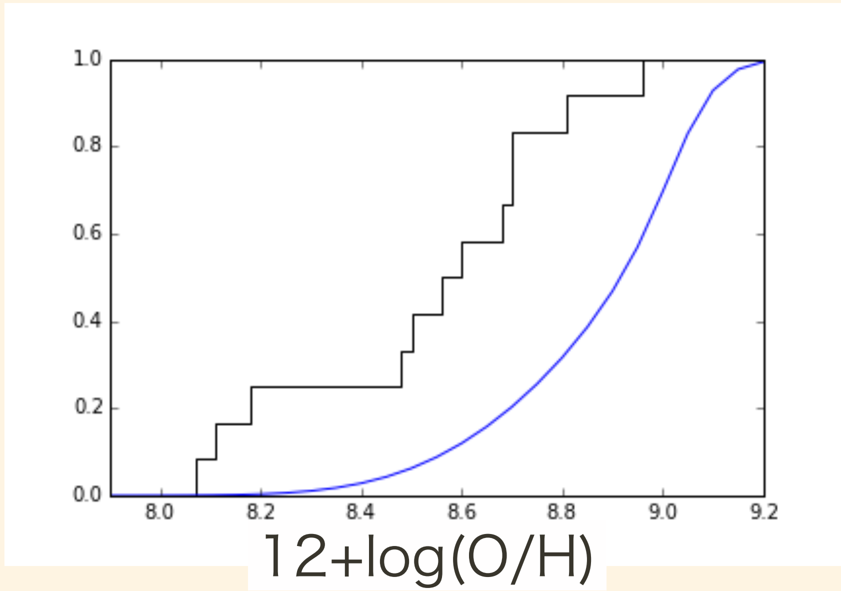


Kewley & Ellison (2008)



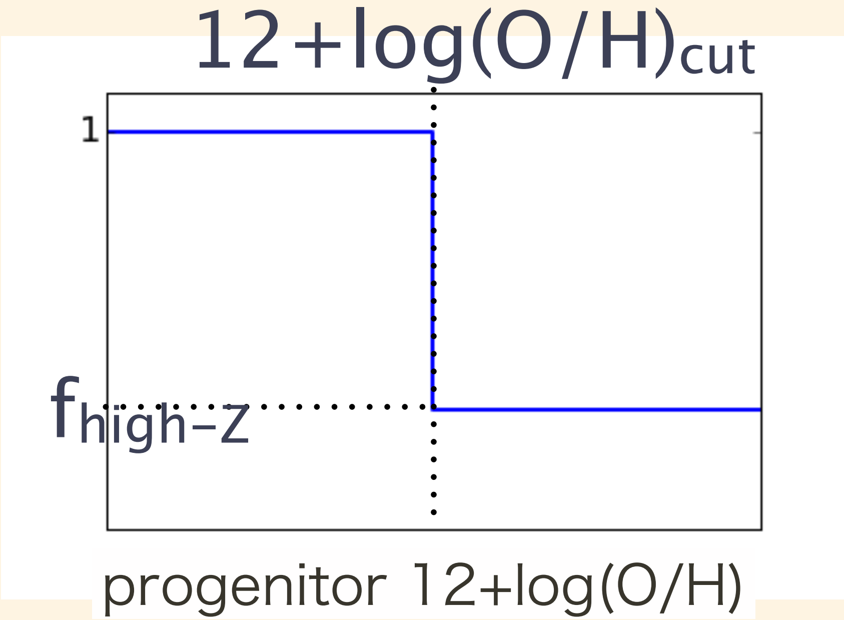
Brinchmann+ (2004), Salim+ (2007)

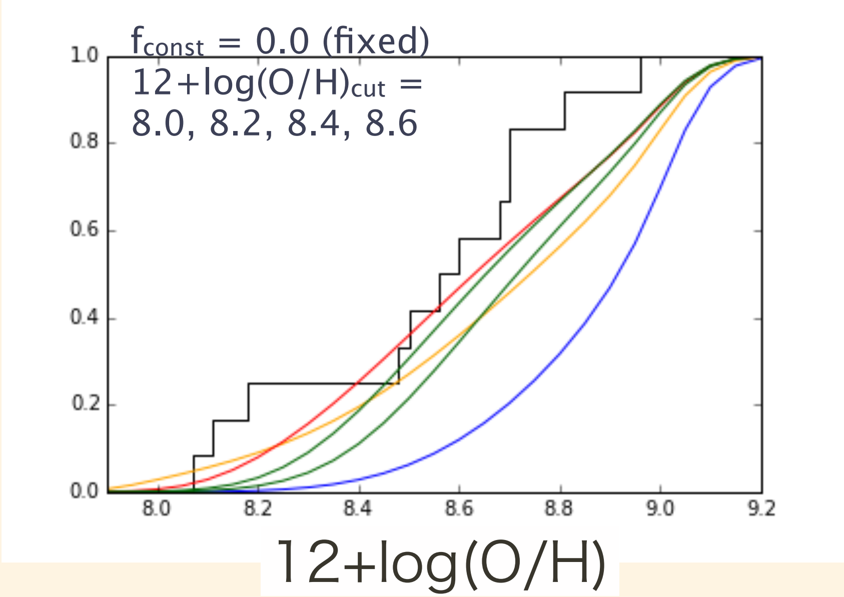
- SFR weighted log(O/H) dist. of general star forming galaxies of local galaxies
  - assuming M★ function, M★–Z relation, & M★–SFR (main sequence) relation
- inconsistent with the GRB host galaxies
  - in agreement with the previous results with smaller/incomplete sample



GRB Efficiency Model

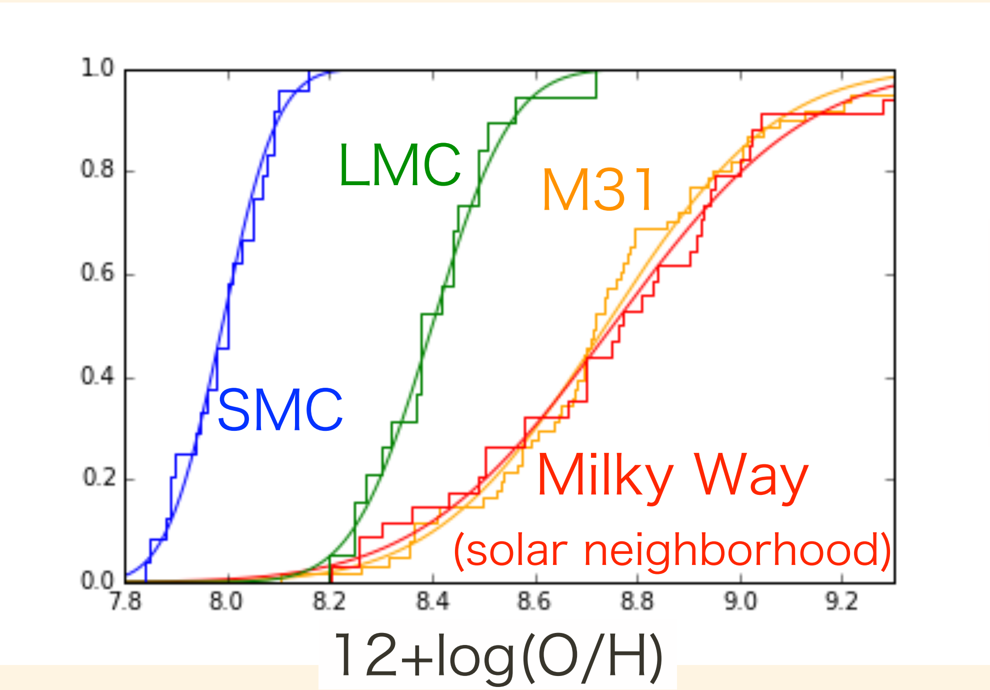
- GRB efficiency
  - $\varepsilon_{GRB} = R_{GRB}/SFR$
- assumptions:
  - a step function of "progenitor" metallicity
    - ≠ "host" metallicity
  - 2 parameters:
    - $12+\log(O/H)_{cut}$
    - $f_{high\text{-}Z}$

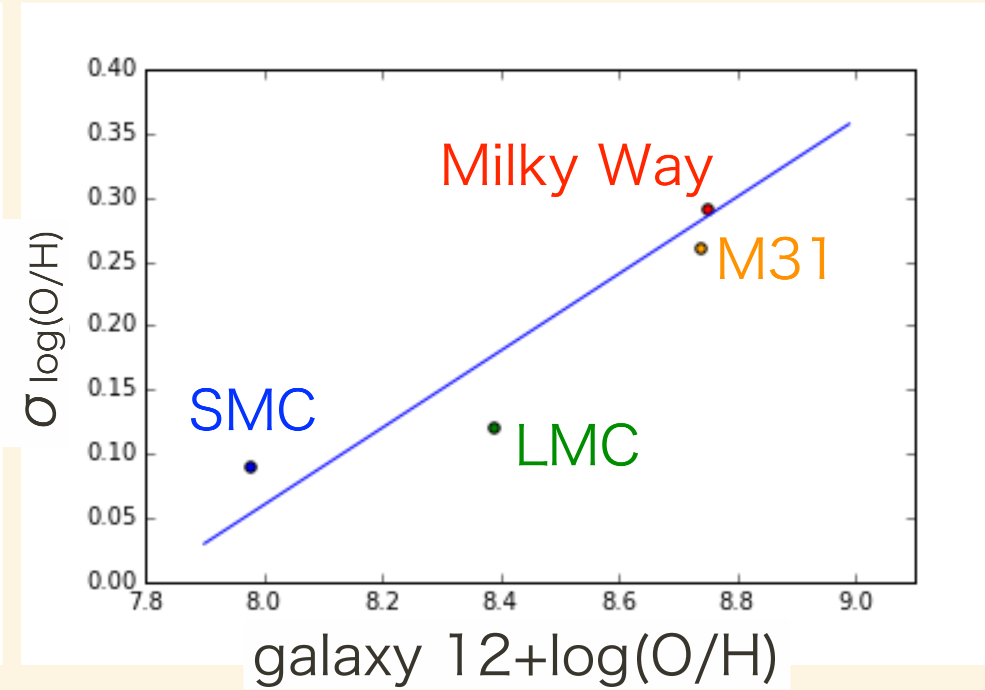




Internal O/H Variation

- what we observe: host galaxy metallicity
- $12+\log(O/H)_{cut}$: progenitor metallicity
- We need to know metallicity distribution of young stars in each galaxy.
    - Not well understood

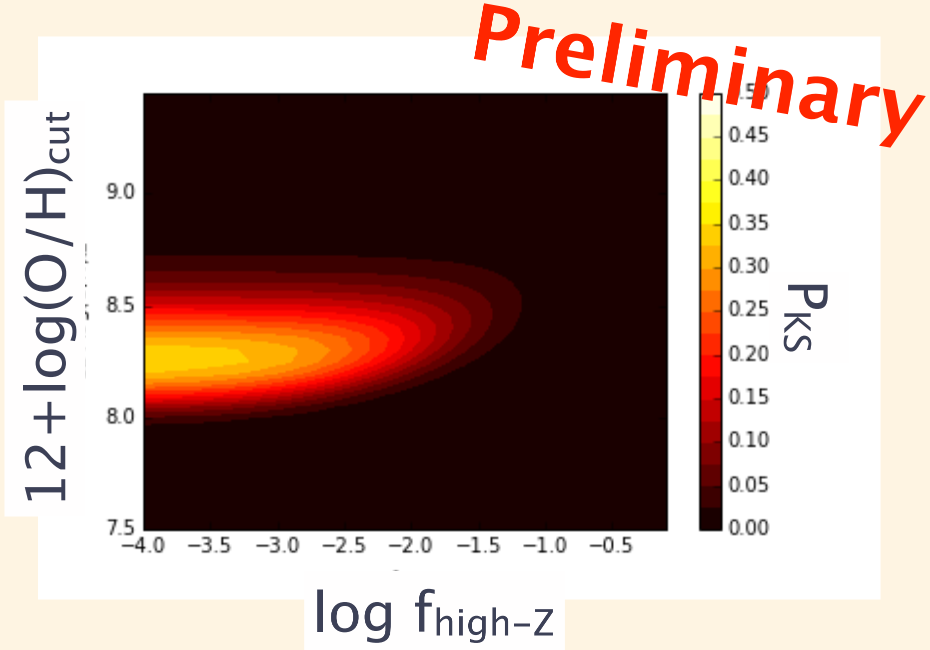


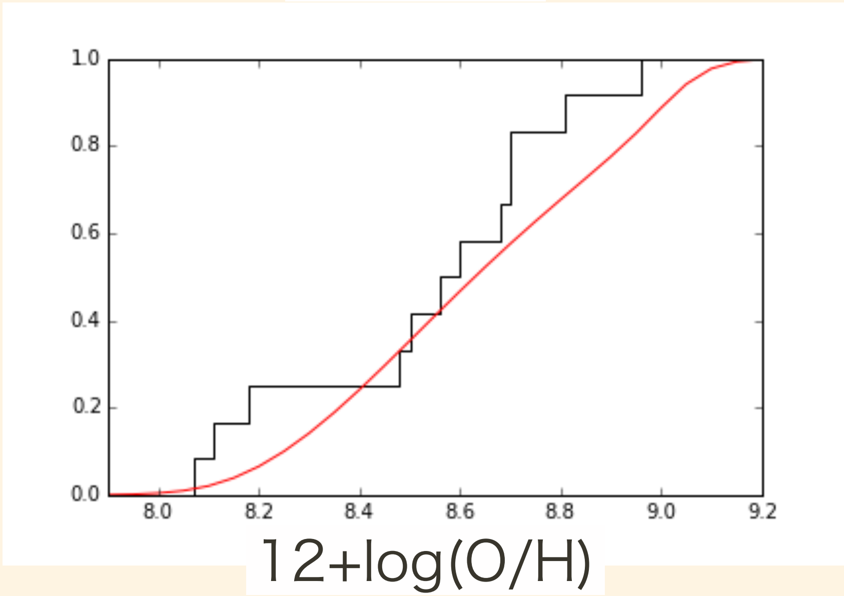


MW: Afflerbach+ (1997), LMC/SMC: Pagel+ (1978), M31: Sanders+ (2012)

Results & Discussion

- Preliminary results suggest:
  - $12+\log(O/H)_{cut}$ = 8.1—8.4
    - ~ 0.3—0.5$Z_\odot$
  - $f_{high\text{-}z}$ < 3% (0 is the best)
- The power-law ε_{GRB} also prefer steep slope index < -4.
- There might be sub-populations among the low-z long GRBs.
  - The sample is too small to discuss the sub-populations.
    - wider redshift range, more recent objects, XRFs





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 with sharp cut at ~ 0.3—0.5$Z_{\odot}$ & no high-metallicity GRB production.