Exploring the Host Environments of Long-Duration GRBs

Emily Levesque, CU Boulder

Gamma-Ray Bursts 2010

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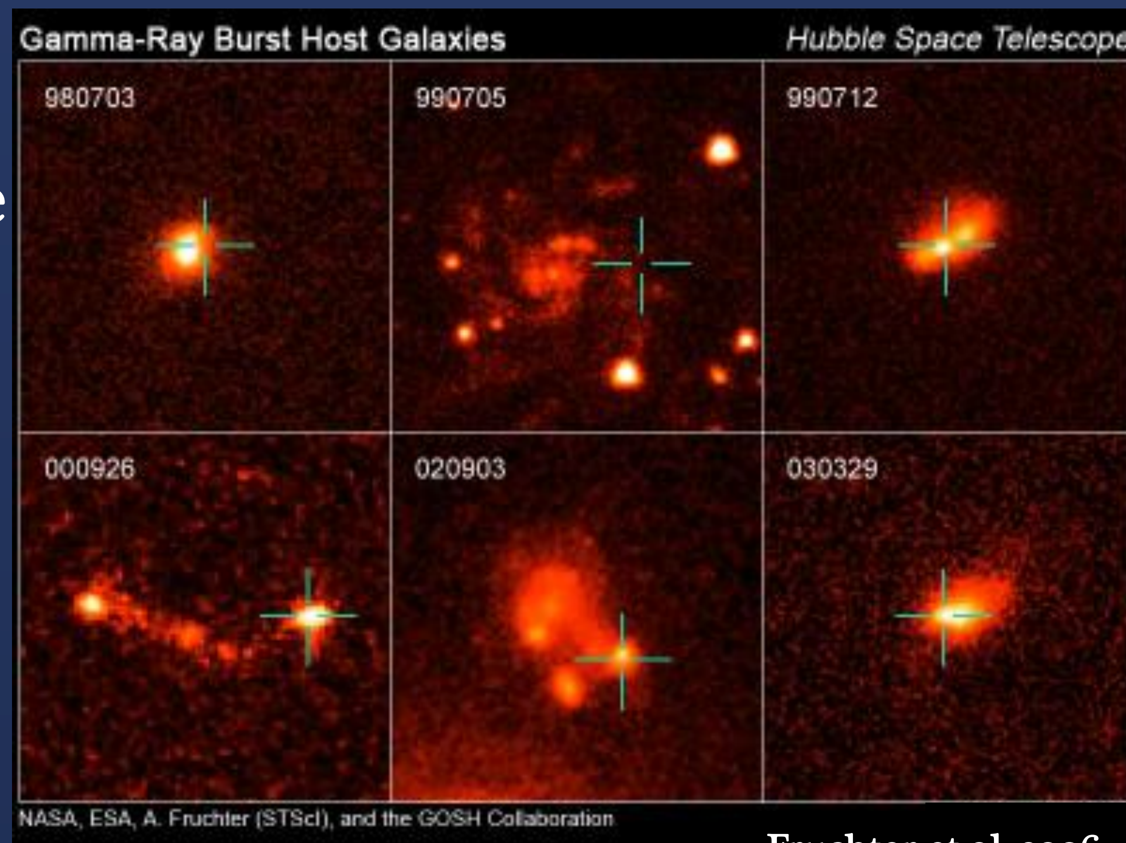
Collaborators:
Lisa Kewley, Kirsten Larson, H. Jabran Zahid (U. Hawaii), Edo Berger, Alicia Soderberg (Harvard/CfA), Andy Fruchter, John Graham (STScI), Megan Bagley (U. Wyoming)

- Motivation
- LGRB Survey
  - observations
  - comparisons
  - ISM properties
- Metallicity
  - L-Z and M-Z
  - high-Z events
  - energetics
- New Questions

LGRBs are often cited as unbiased tracers of star formation (e.g., Wijers et al. 1998; Bloom et al. 2002; Fynbo et al. 2007, Savaglio et al. 2009)

For this to be true, their ISM environments need to be typical of the general galaxy population…

In recent years, several studies have found evidence that LGRBs occur in low-Z environments (e.g., Stanek et al. 2006, Fruchter et al. 2006, Kewley et al. 2007 Modjaz et al. 2008, Kocevski et al. 2009)



Fruchter et al. 2006

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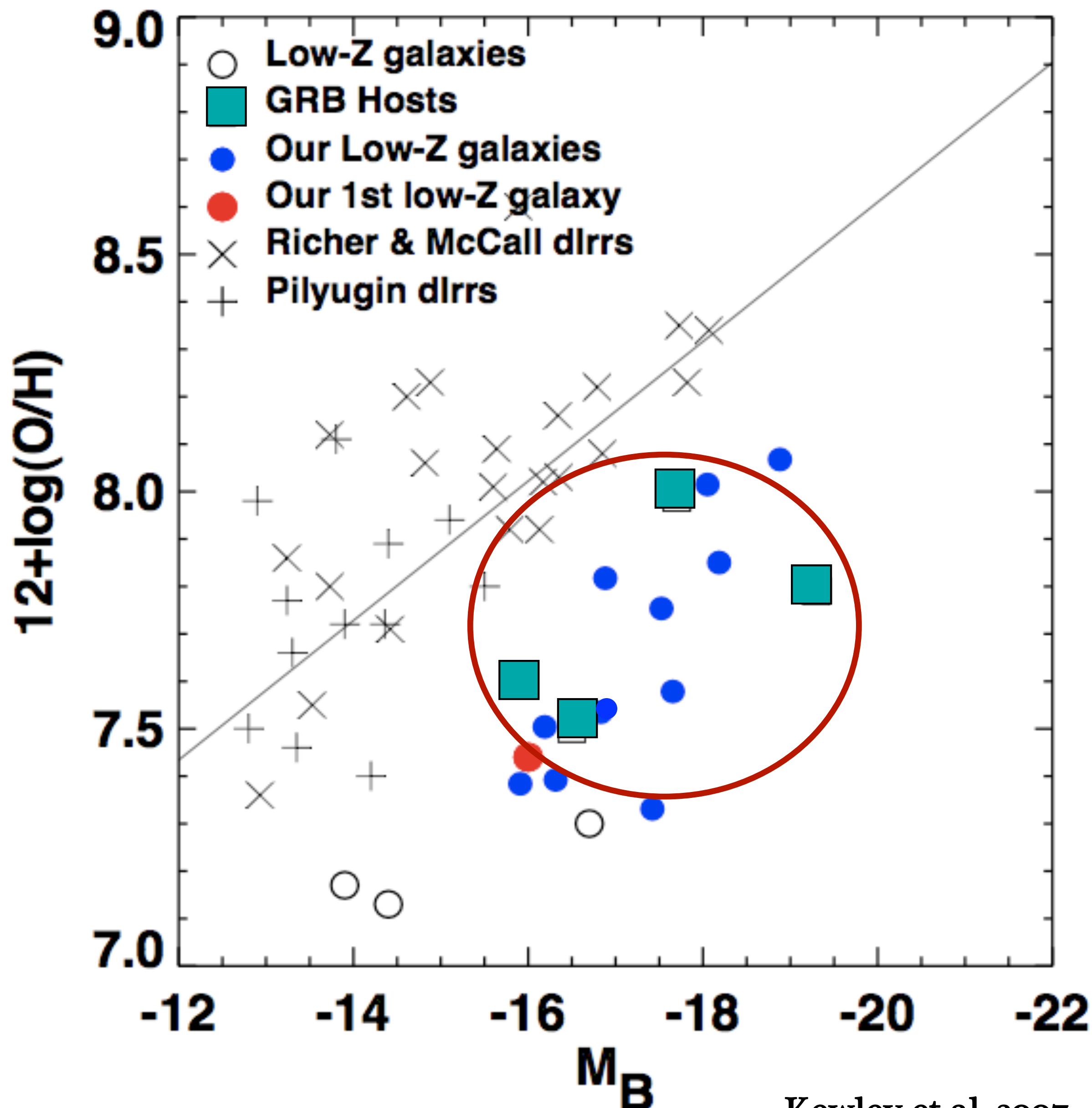

Kewley et al. 2007

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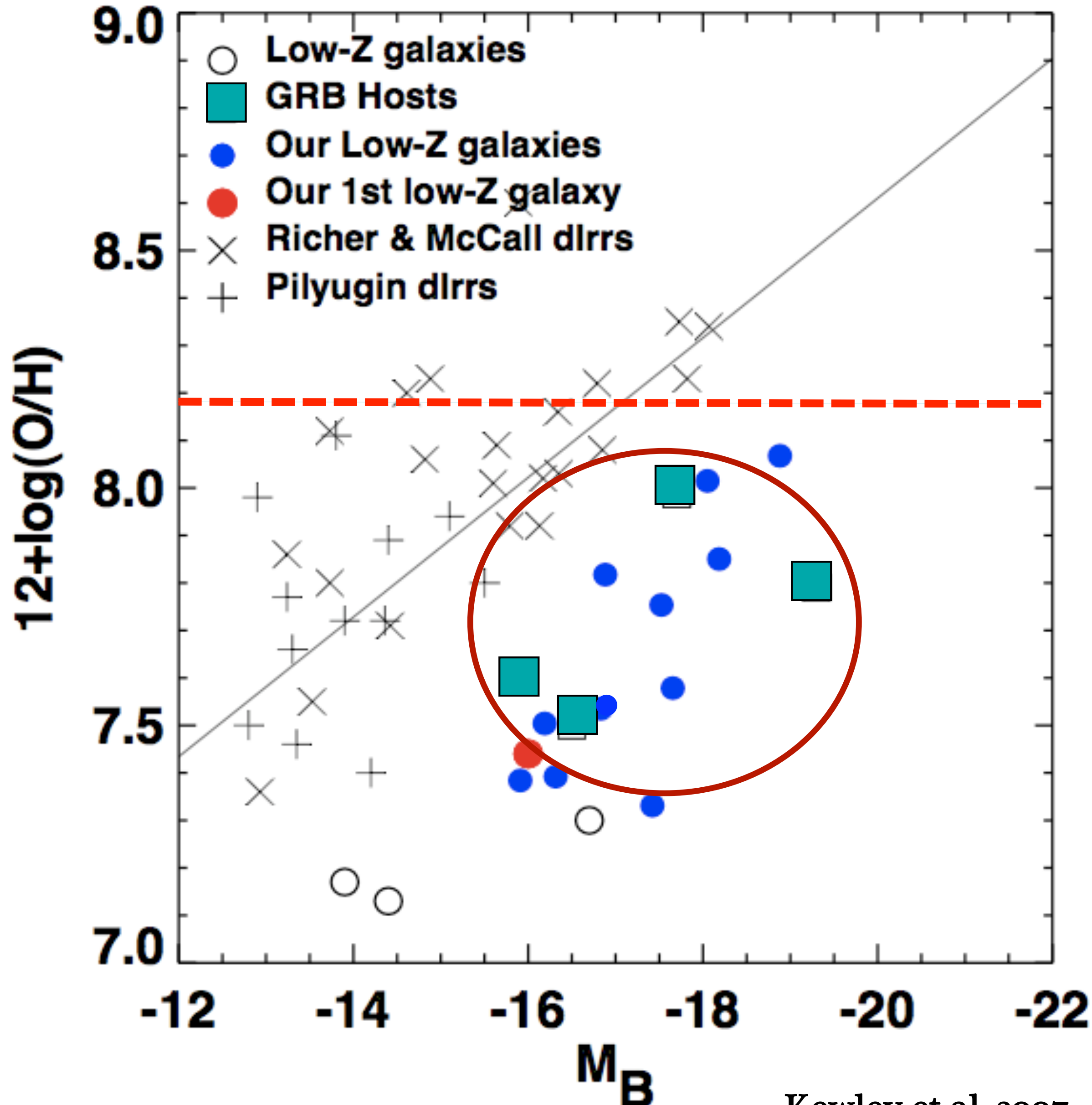
A low-metallicity requirement is supported by the *collapsar* model…



Kewley et al. 2007

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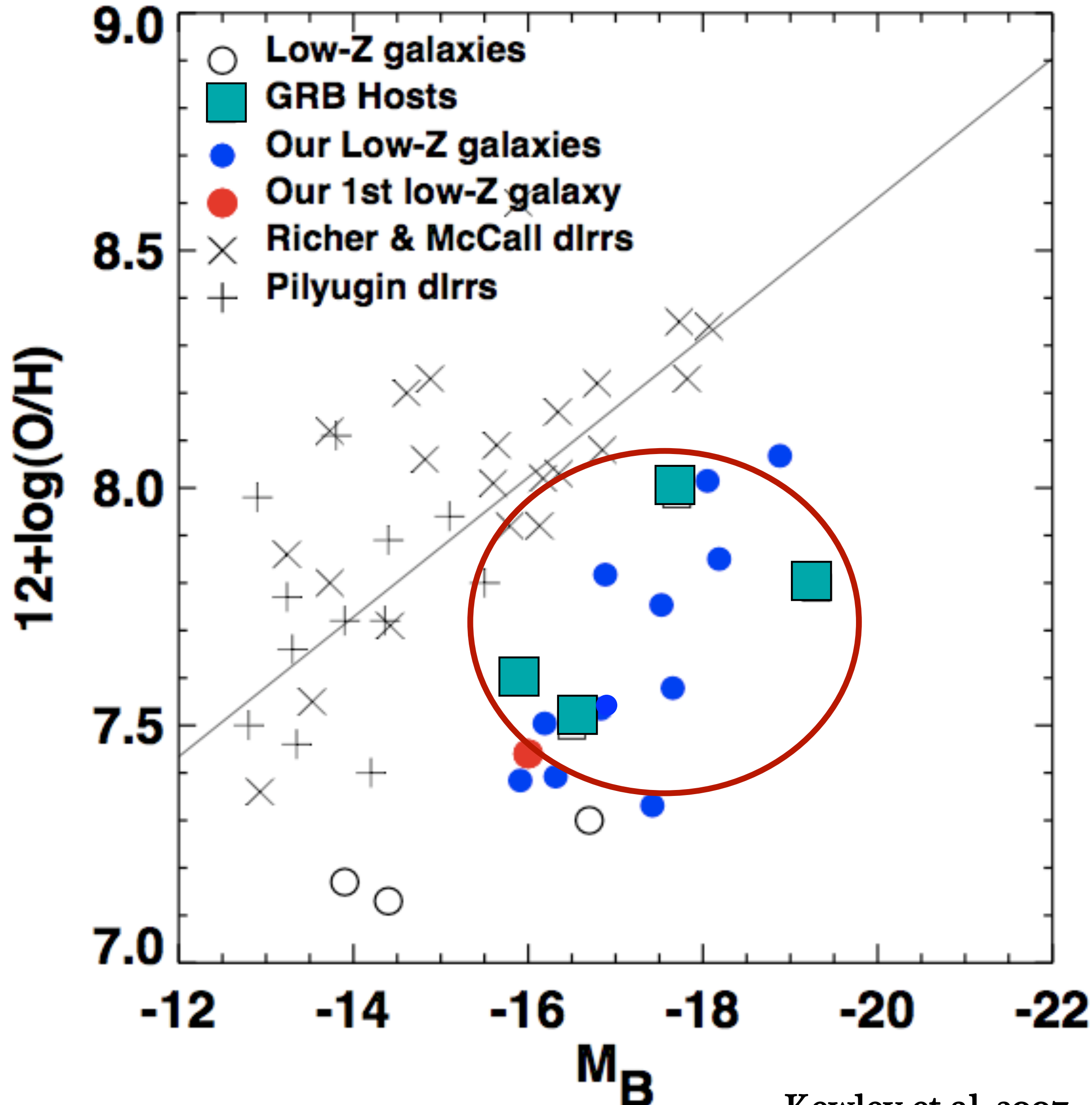
A low-metallicity requirement is supported by the *collapsar* model…

…but this could also be an artifact of some other bias, such as young progenitor age.



Kewley et al. 2007

Investigating this requires a large number of LGRB host spectra, that can be combined with emission line diagnostics to determine ISM properties.

However, previous spectra weren't enough…

- insufficient S/N
- insufficient wavelength range

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…uniform rest-frame optical survey of LGRB host galaxies

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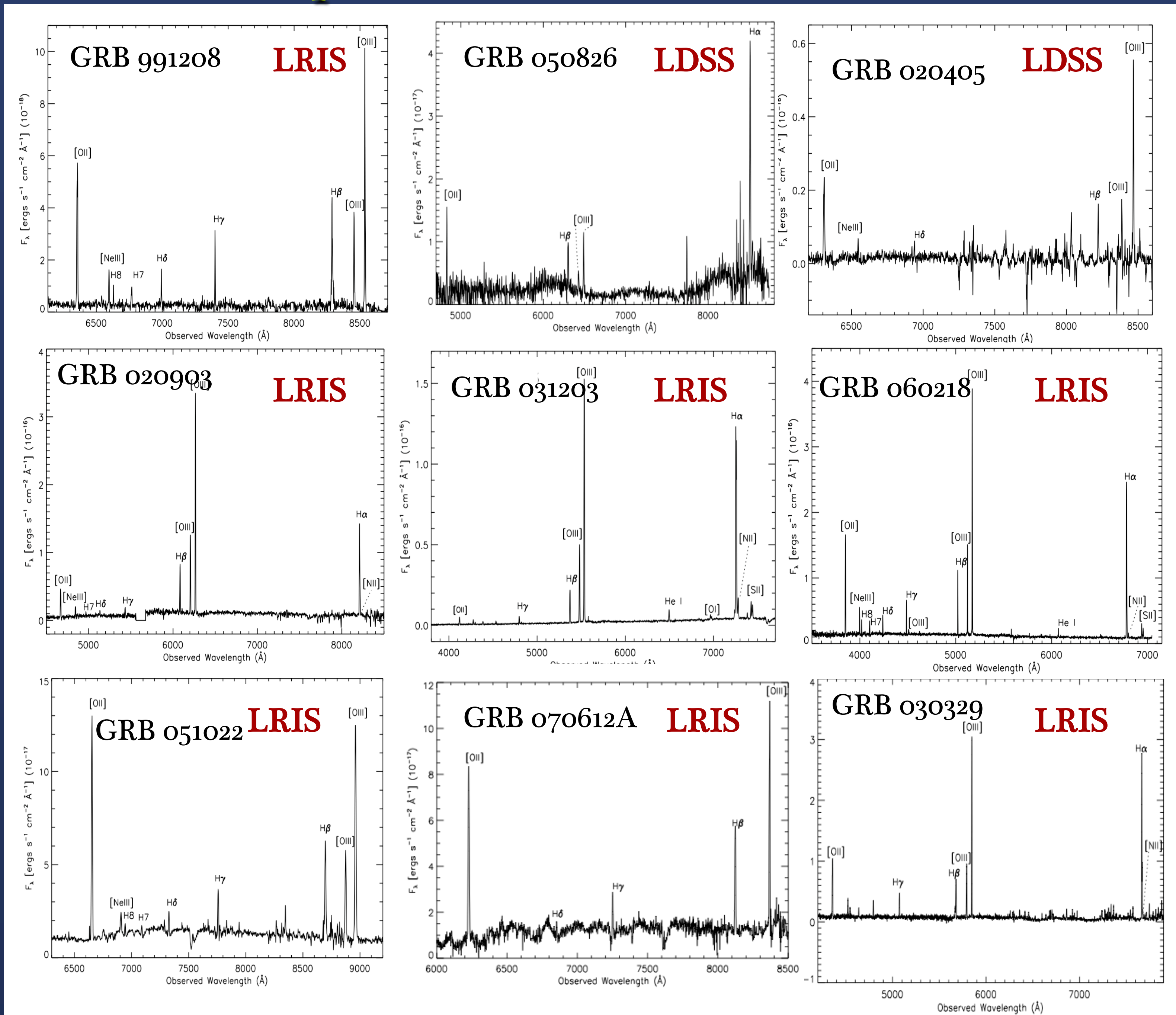
LGRB Host Spectra



Levesque et al. 2010a,b

Summary

- 16 $z < 1$ LGRB host galaxies
- 12 hosts in survey, 4 with high-quality literature data
- 6 *nearby* ($z < 0.3$) hosts; 10 *intermediate* ($0.3 < z < 1$) hosts

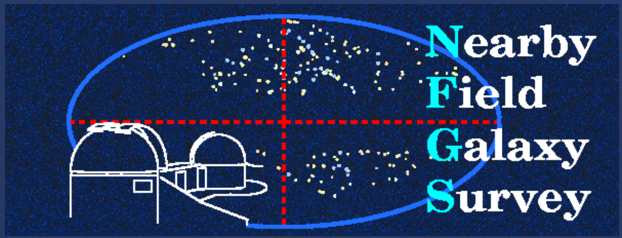
The Comparison Sample

z < 0.3

SDSS (Kewley et al. 2006)

- 60,920 star-forming galaxies
- $0.04 < z < 0.1$

NFGS (Jansen et al. 2000a, 2000b)



- 95 star-forming galaxies
- median $z = 0.01$

Blue compact galaxies (Kong & Cheng 2002)

Nearby metal-poor galaxies (Brown et al. 2008)

- 10 galaxies, $z < 0.1$
- direct Z comparison

Nearby SN-Ic host galaxies (Modjaz et al. 2008)

- 8 galaxies, $z < 0.1$
- direct progenitor environment comparison

0.3 < z < 1

TKRS (Kobulnicky & Kewley 2004)

- 204 galaxies at $0.3 < z < 1$

DEEP2 (Zahid et al. 2010)

- 1330 galaxies at $0.75 < z < 0.82$

Environmental Properties

Metallicity - defined here as log(O/H) + 12 (R_{23}, PP04, and T_e diagnostics)

Ionization parameter - velocity of ionizing front driven by the local radiation field ([OIII] and [OII])

Extinction - total reddening due to interstellar dust in the direction of the galaxy (Balmer emission features)

Young stellar population - age of the most recently formed stars in the galaxy (Hβ)

Star formation rate - rate at which a galaxy is forming new stars (Hα and [OII])

Stellar mass - mass in a galaxy contain in stars as opposed to gas or dark matter (multiband photometry, synthesis models)

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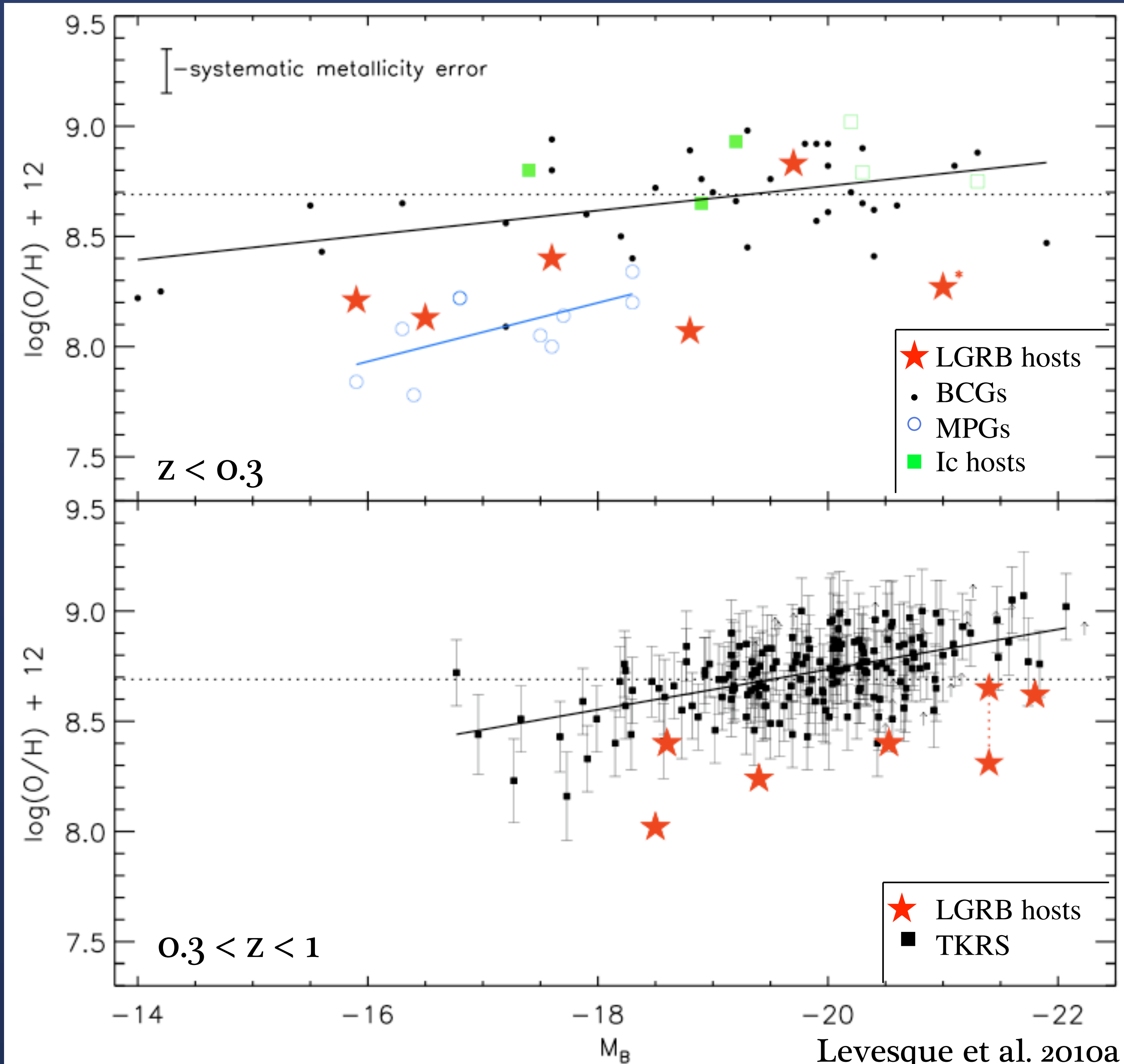
LZ relation shows *general* trend towards low metallicity out to z ~ 1…



Levesque et al. 2010a

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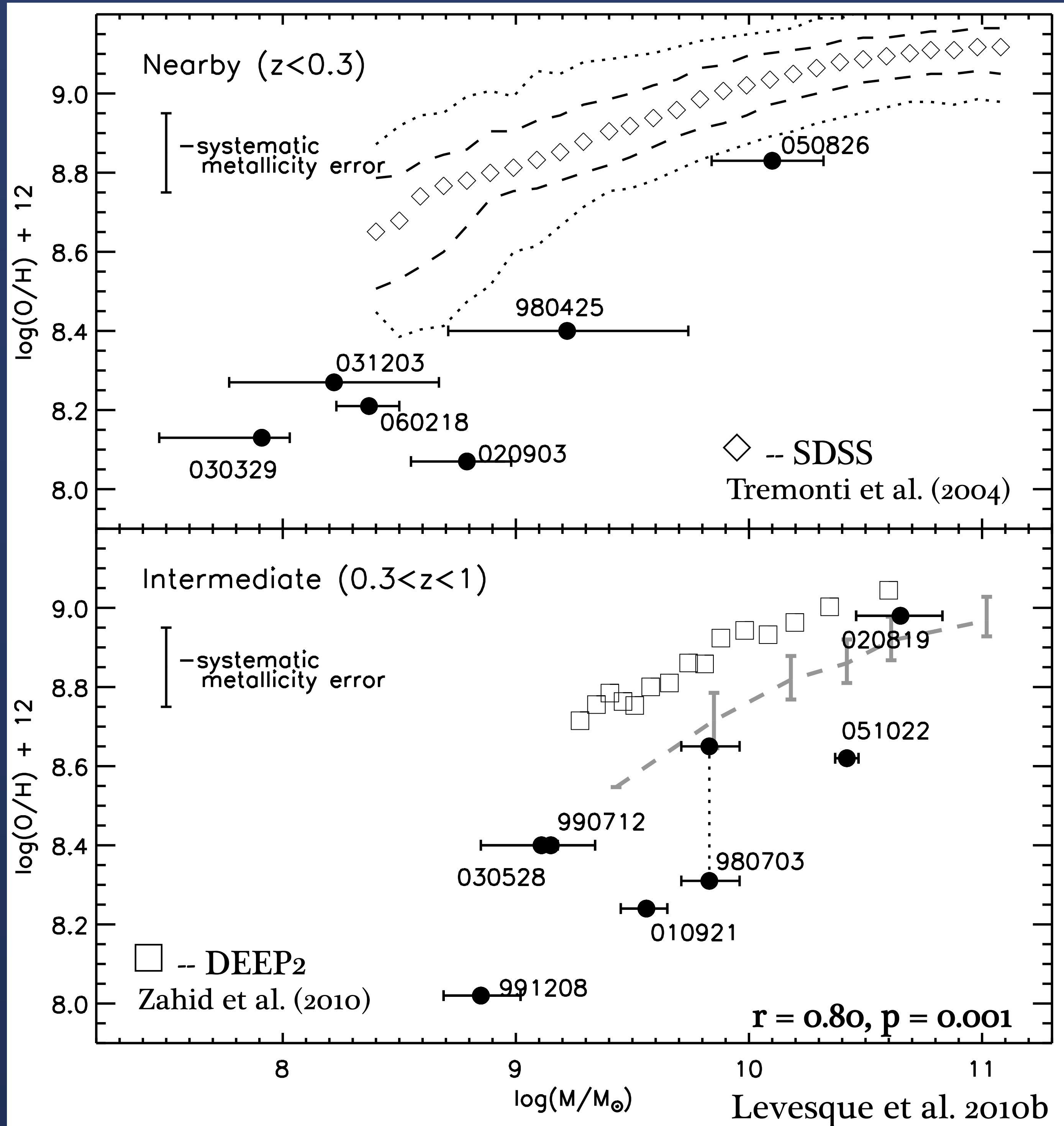
LGRB hosts fall below general MZ relation (average offset of **-0.50 ± 0.19 dex**), and follow a statistically robust MZ relation themselves.



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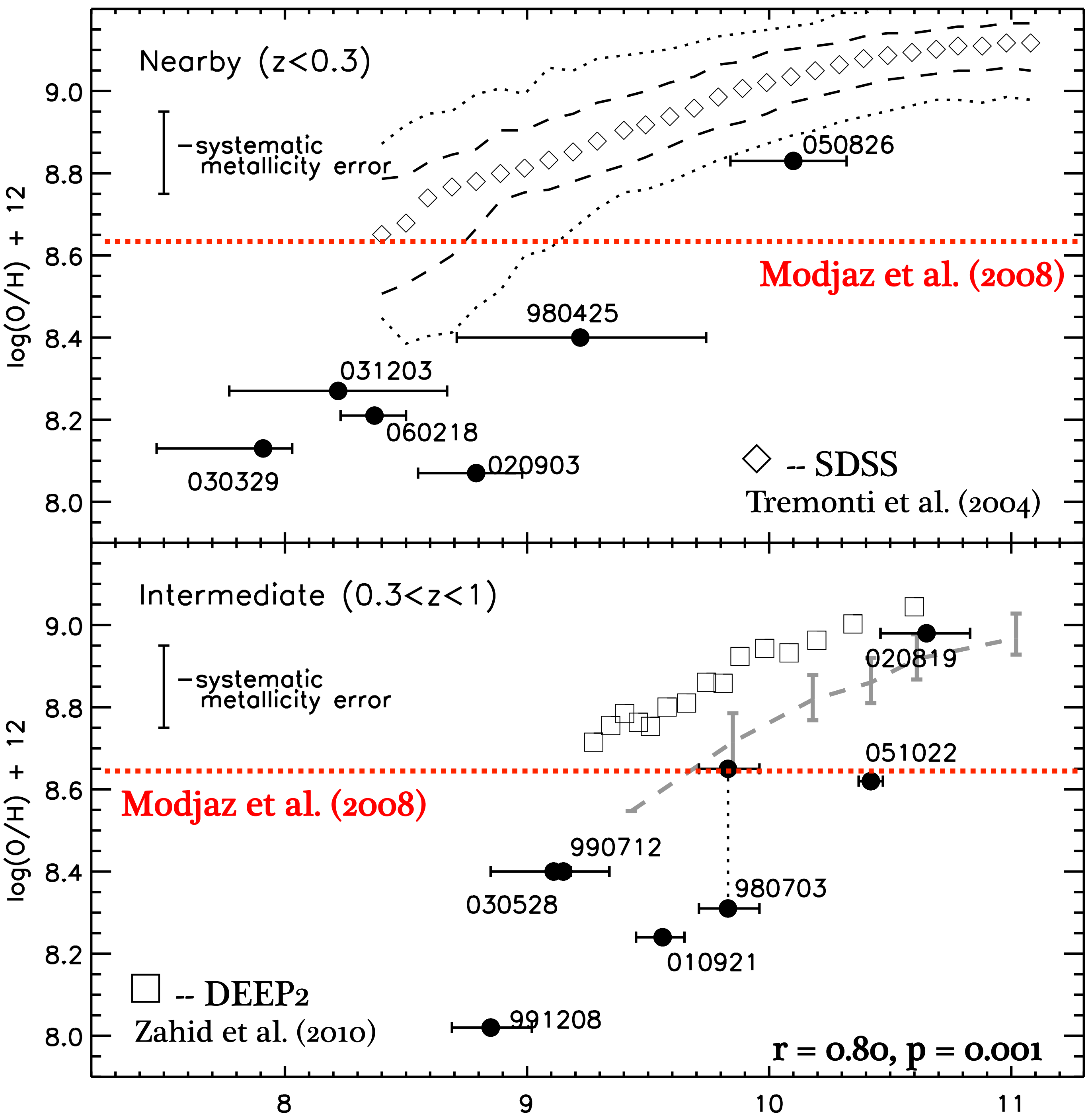
There appears to be NO clear cutoff metallicity for LGRB hosts.



Levesque et al. 2010b

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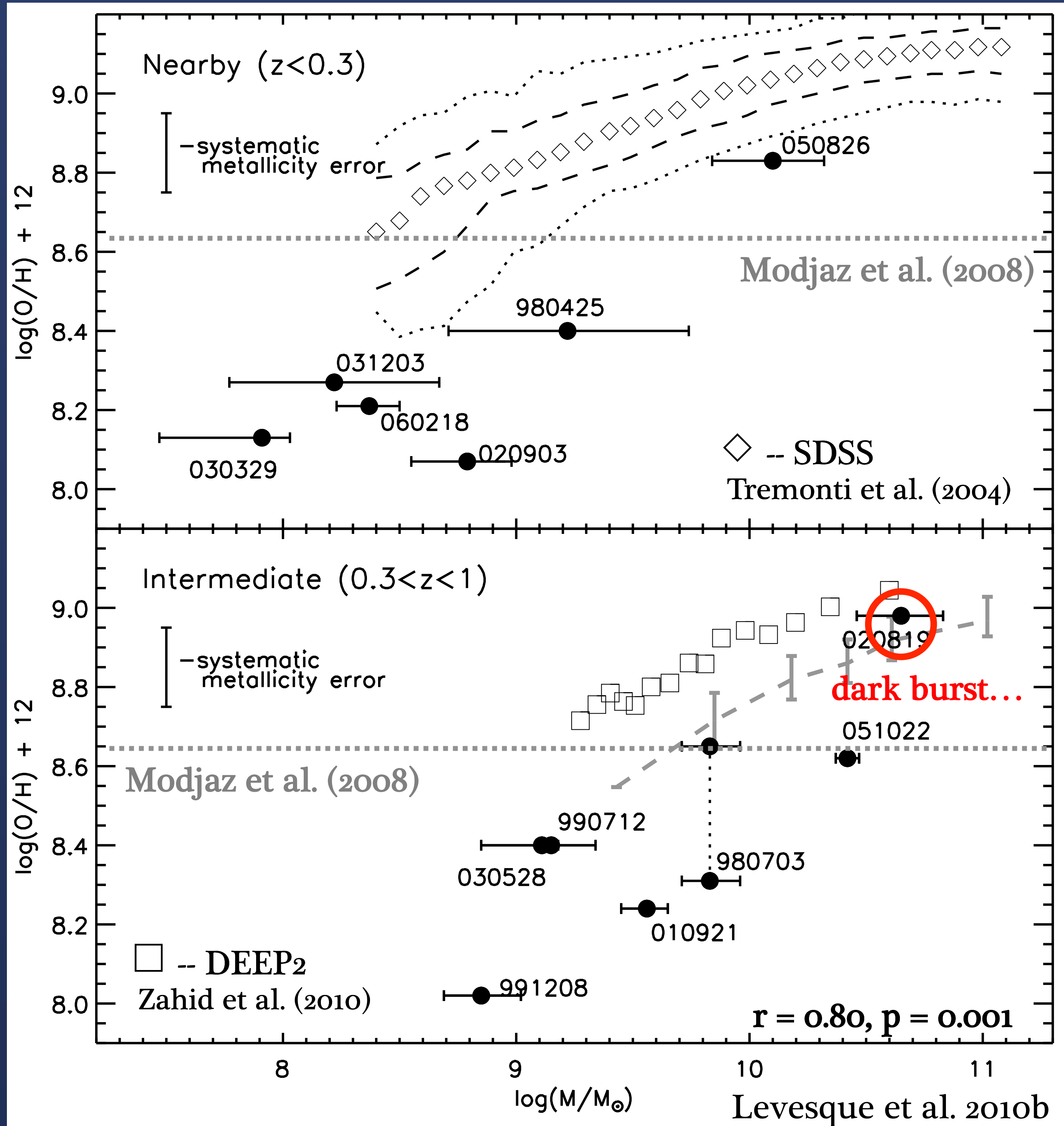

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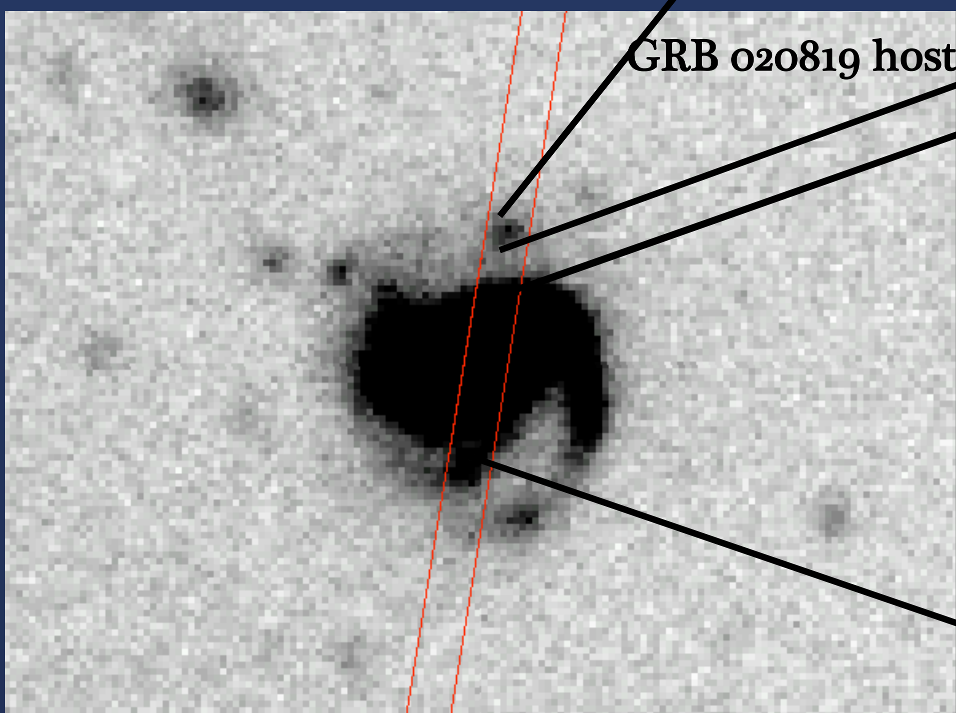
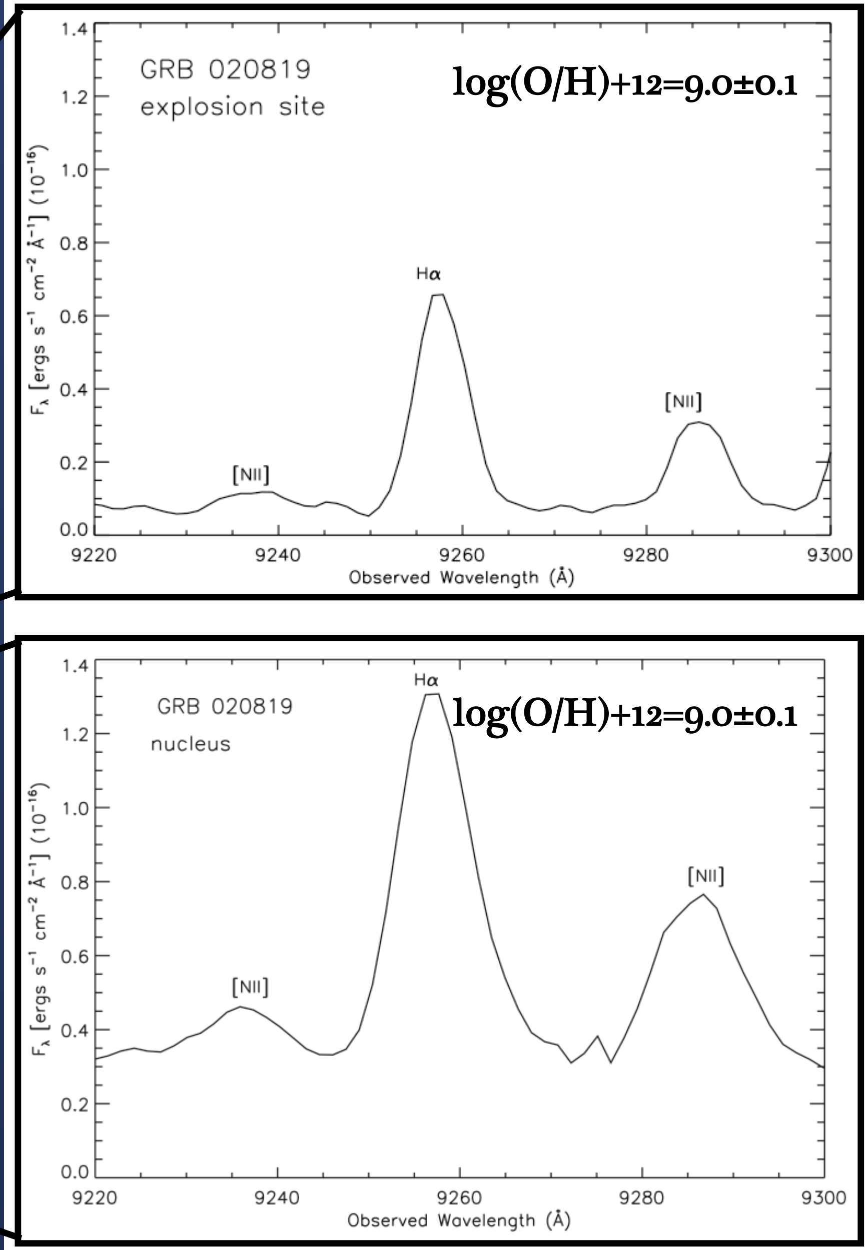
GRB 020819: well-localized by radio afterglow

Observed GRB 020819 host galaxy nucleus AND explosion site:





Levesque et al. 2010c

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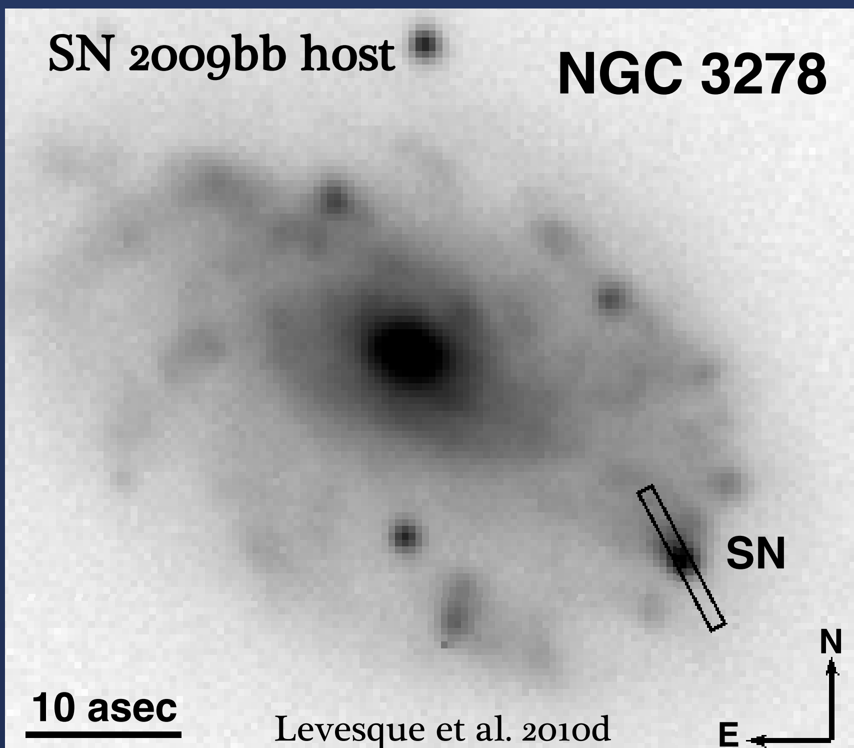
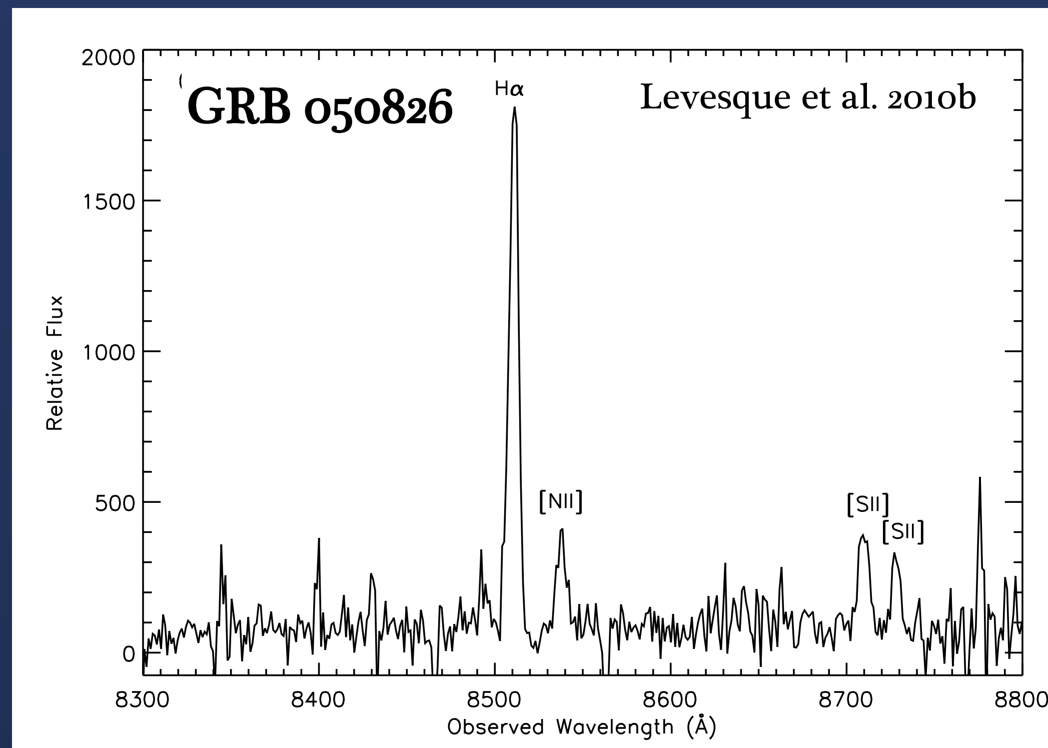
Other high-Z relativistic explosions...

SN 2009bb: relativistic Type Ic SN with a high-metallicity explosion site and no detected LGRB

GRB 050826: a disconcertingly normal LGRB at z = 0.296





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What is the role of metallicity in LGRB production?

- Is high metallicity connected to dark LGRBs?

- Is a selection effect in place that prevents detection of high-metallicity LGRBs?

- Does metallicity directly affect the explosive properties of LGRBs?

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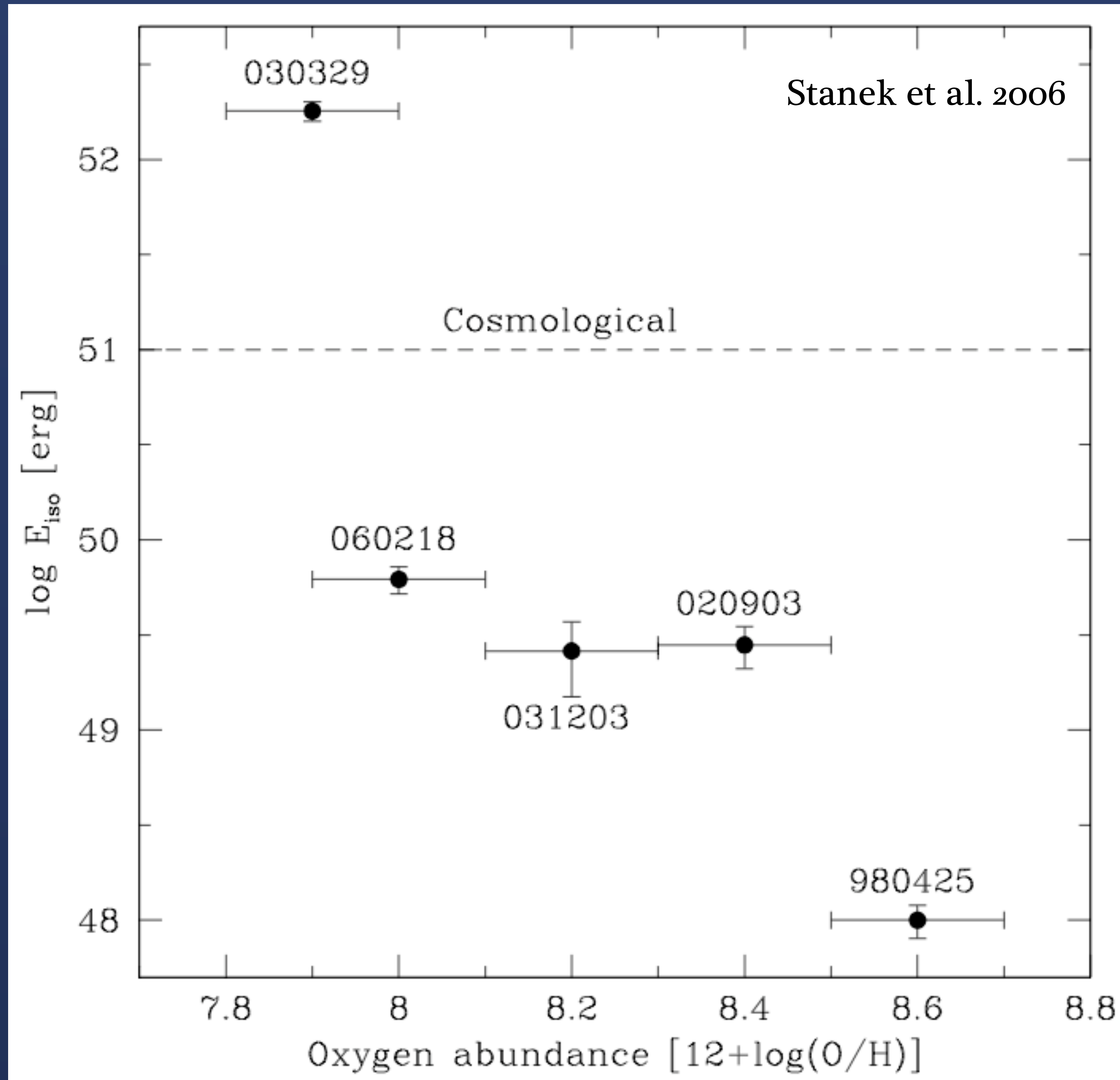
From anticipated metallicity effects on massive stars, LGRBs at higher metallicity SHOULD have lower $E_{\gamma,iso}$ and/or E_{γ}.



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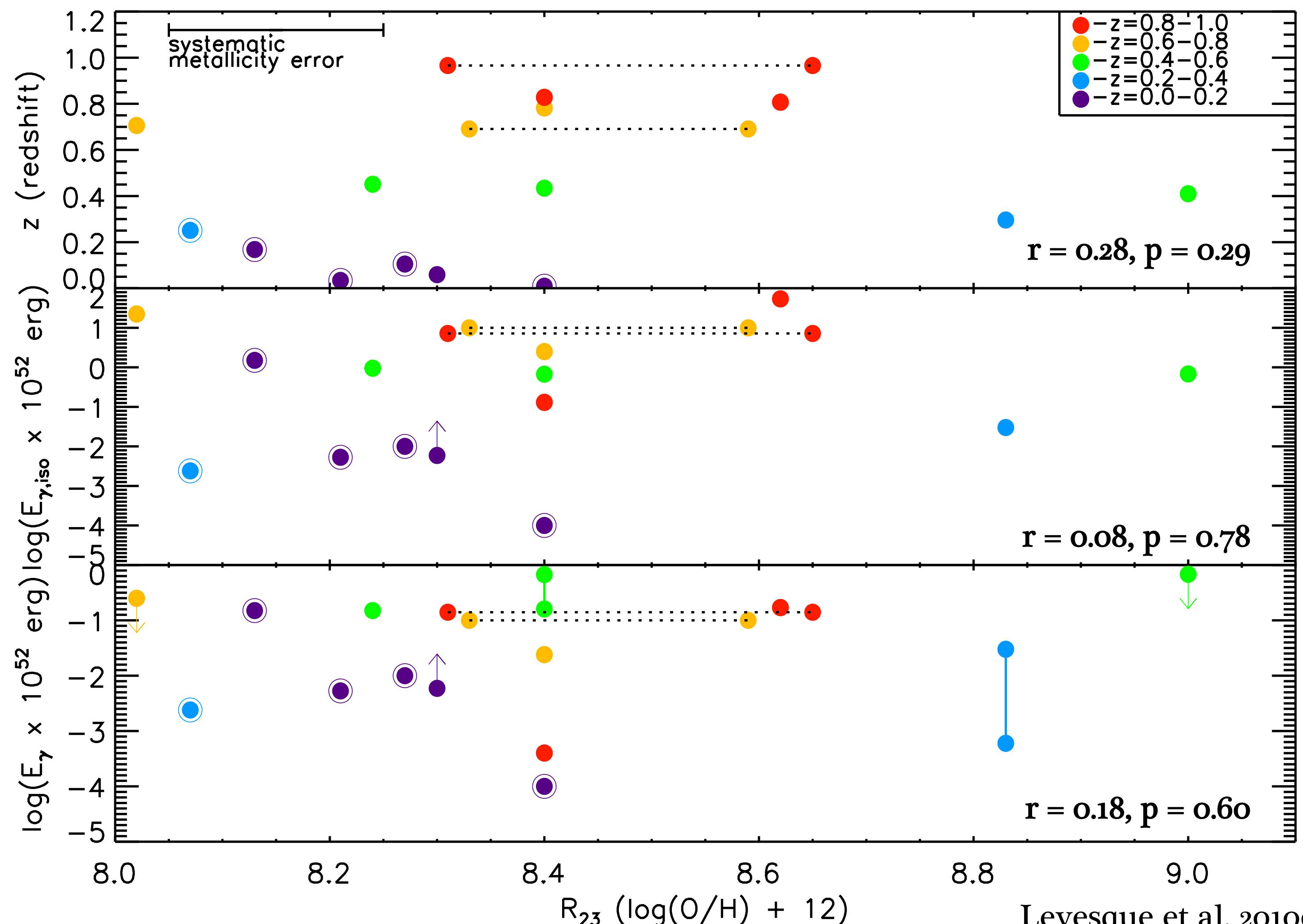

Levesque et al. 2010e

However, we find no statistically significant correlation between host galaxy metallicity and $E_{\gamma,iso}$ or E_γ.

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Conclusions:

1. LGRBs occur preferentially in galaxies with low metallicities relative to their luminosity and mass.

2. There is no apparent cut-off metallicity above which LGRBs cannot form.

3. We find no correlation between the host galaxy metallicities and gamma-ray energy release of LGRBs.

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Some new metallicity questions…

How do these results fit with predictions of the collapsar model?

- high-Z collapsars?
- physical process driving MZ offset?
- further progenitor sub-classes? (subluminous, dark, relativistic SNe…)

Some new metallicity questions…

1. LGRBs occur in low metallicity environments
2. LGRBs originate from C or O Wolf-Rayet stars

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Some new metallicity ~~questions~~ problems…

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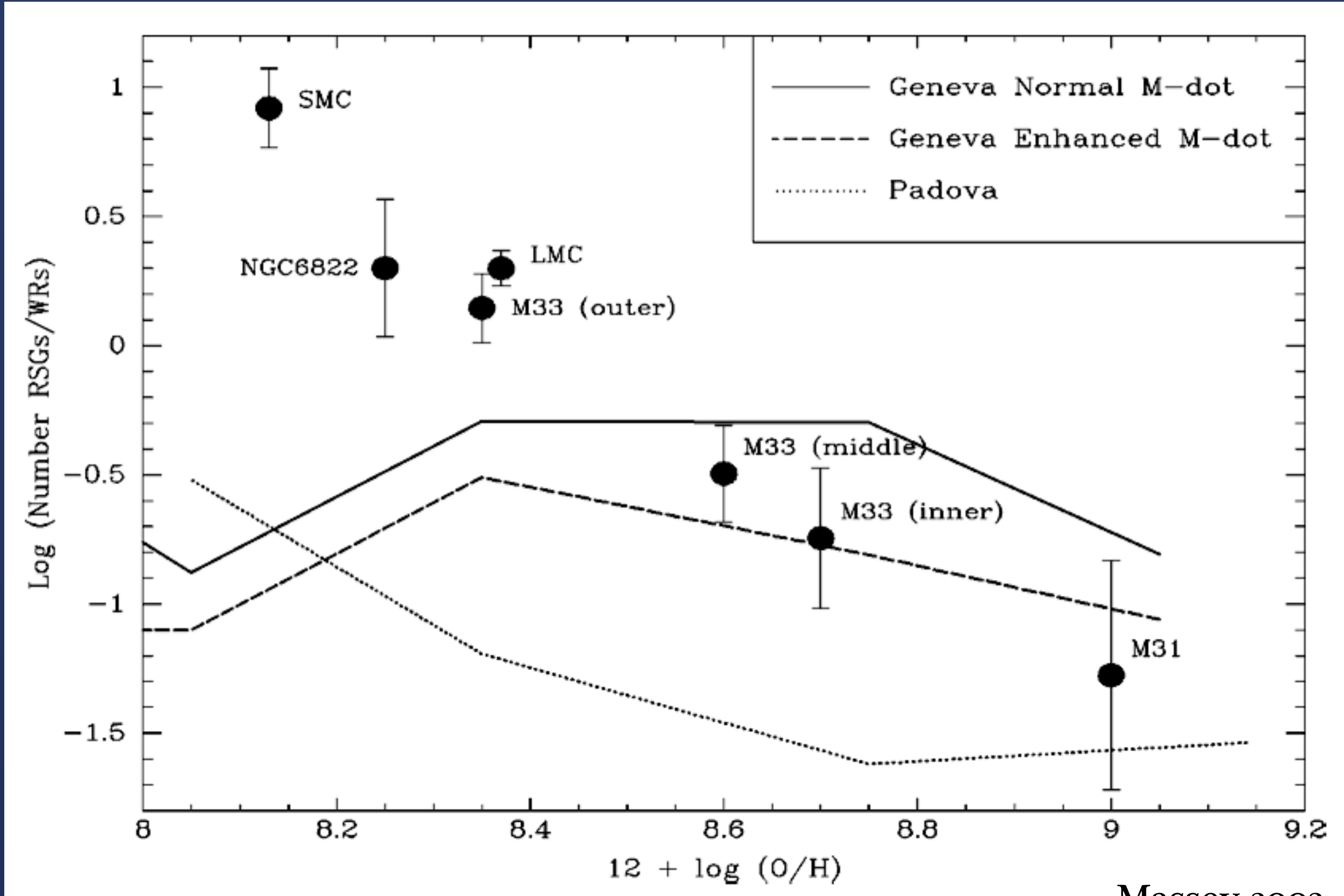

Massey 2003

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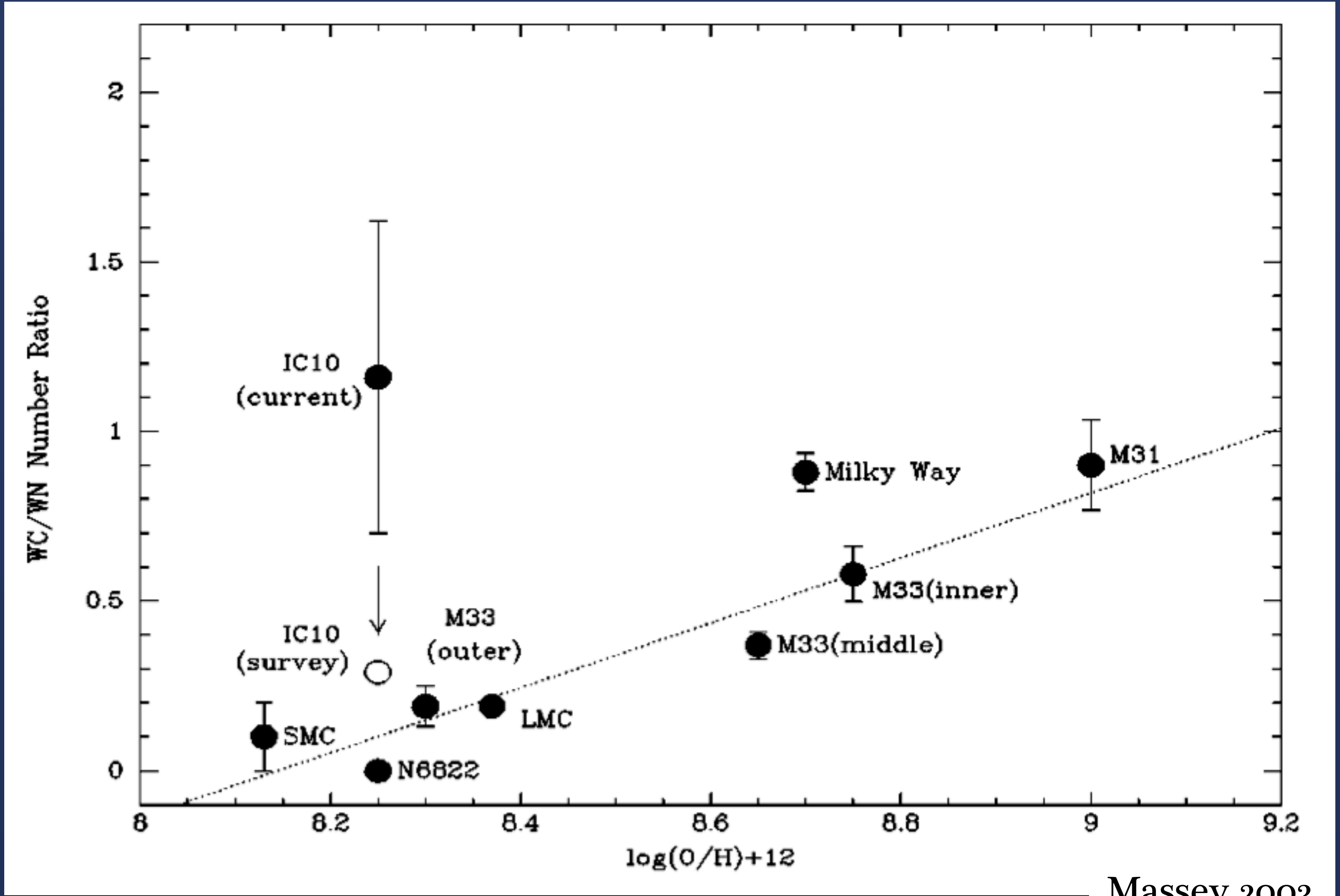
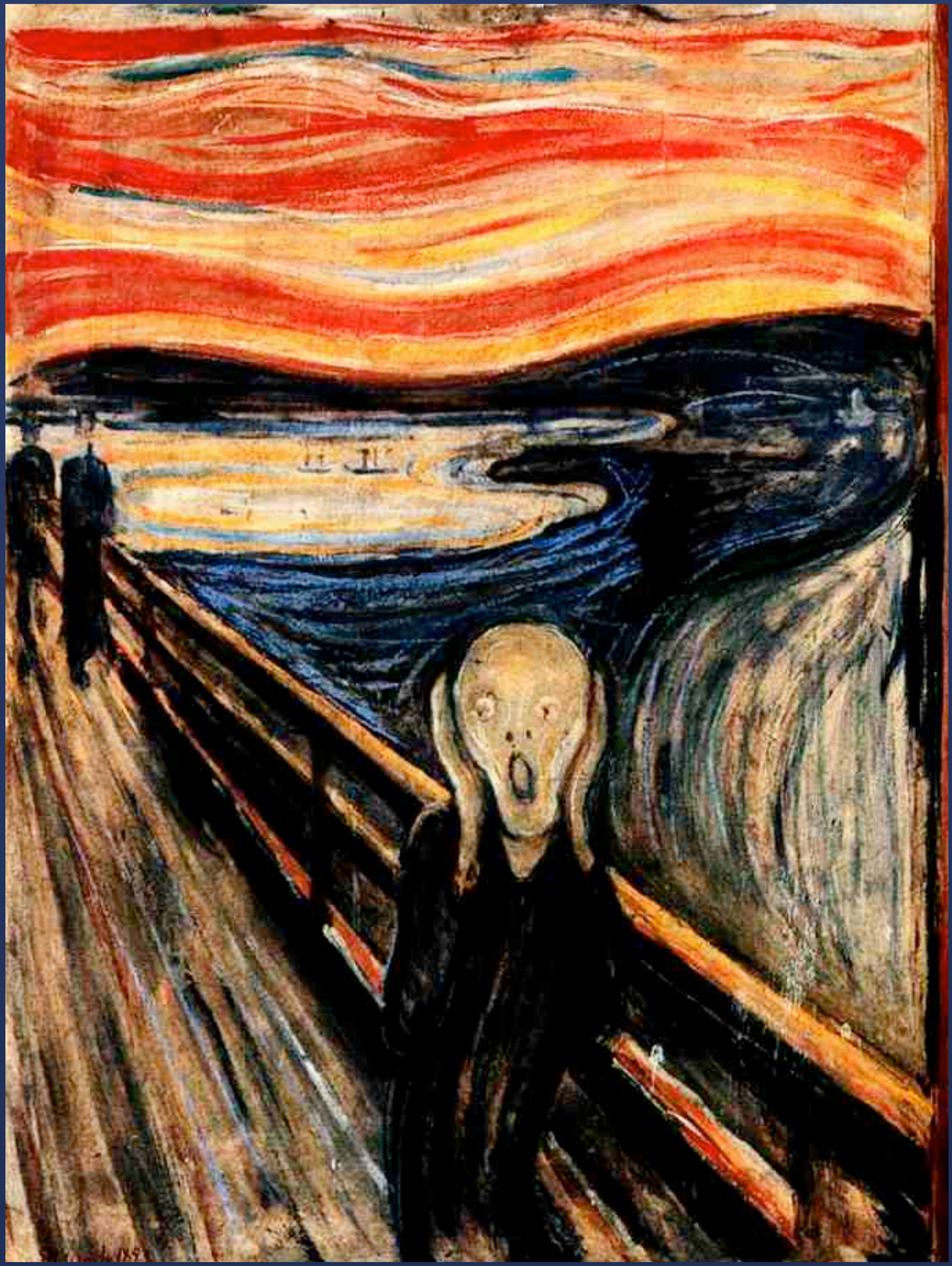


Massey 2003

Some new metallicity questions…

Contemplating binary scenarios…



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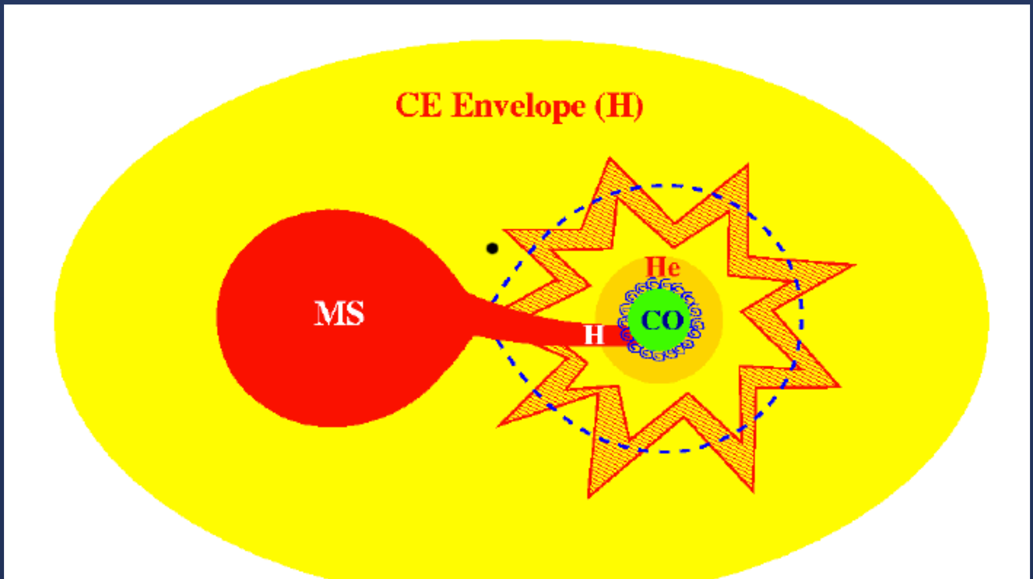
Some new metallicity questions…

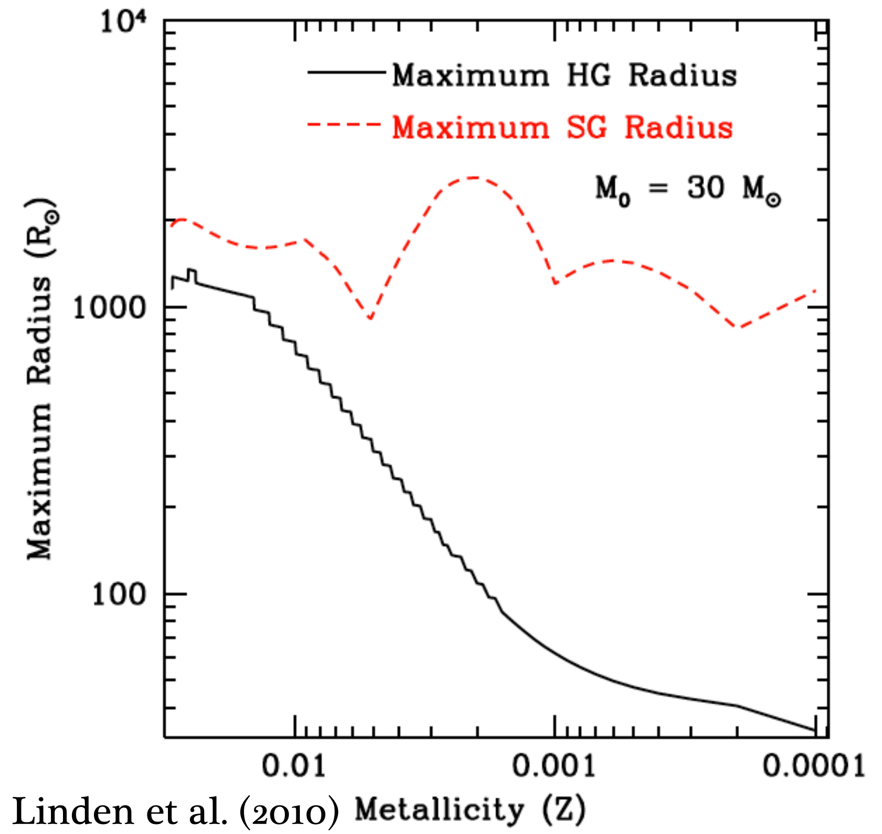
Considering binary scenarios…

<u>terminal CE phase</u>: higher rate at low Z due to stellar wind effects (Podsiadlowski et al. 2010)

<u>interim CE phase/RLO</u>: higher rate at low Z due to wider range of permissible Roche lobe radii (Linden et al. 2010)



Podsiadlowski et al. (2010)



Linden et al. (2010)

Some new metallicity questions…

Considering binary scenarios…

terminal CE phase: higher rate at low Z due to stellar wind effects (Podsiadlowski et al. 2010)

interim CE phase/RLO: higher rate at low Z due to wider range of permissible Roche lobe radii (Linden et al. 2010)

- ☑ more common at low Z
- ☑ not impossible at high Z
- ☑ models suggest that Z has no effect on terminal physical properties (purely a statistical effect)

Conclusions:

1. LGRBs occur preferentially in galaxies with low metallicities relative to their luminosity and mass.

2. There is no apparent cut-off metallicity above which LGRBs cannot form.

3. We find no correlation between the host galaxy metallicities and gamma-ray energy release of LGRBs.

New Questions:

1. What is metallicity's role in LGRB production? How can we explain a low-Z trend without a low-Z cutoff?

2. What are the implications for LGRB progenitor scenarios?

3. What are the implications for the utility of LGRBs as star formation tracers?