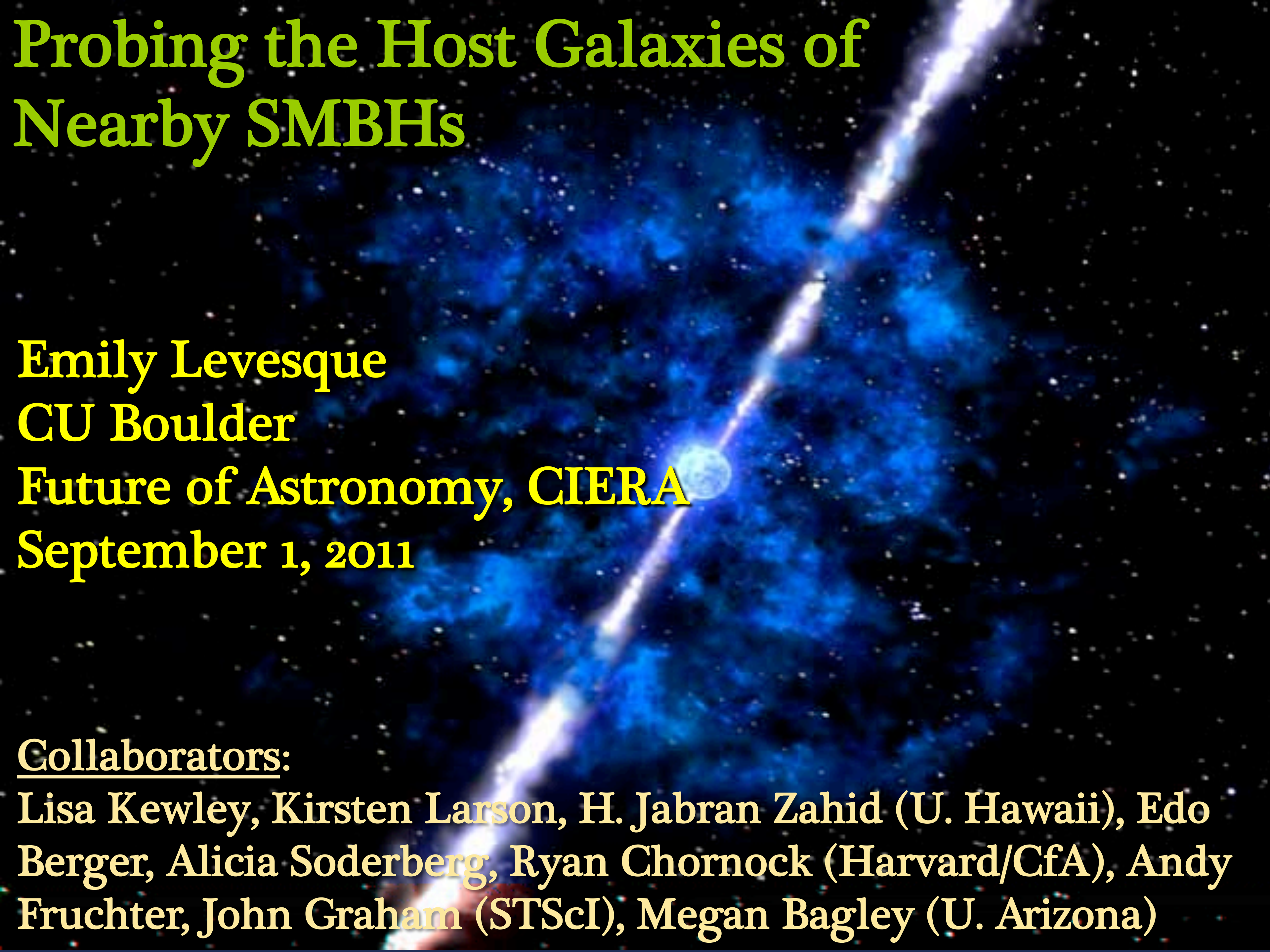


Probing the Host Galaxies of Nearby SMBHs

Emily Levesque
CU Boulder

Future of Astronomy, CIERA
September 1, 2011

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

Probing the Host Galaxies of Nearby ~~SMBHs~~ (Long-Duration GRBs)

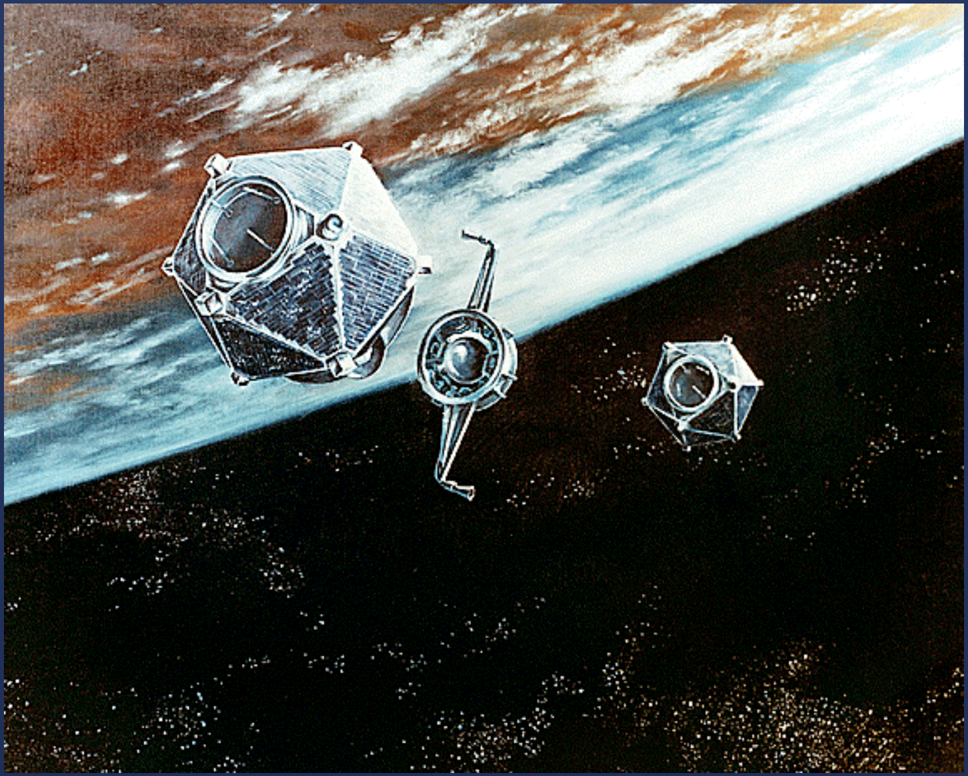
Emily Levesque
CU Boulder
Future of Astronomy, CIERA
September 1, 2011

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

Gamma-ray bursts (GRBs) are the signatures of extraordinarily high-energy events occurring in our universe.

Originally discovered in the late 1960's by the Vela satellites (Klebasedel et al. 1973)

We have since learned that these events originate in distant galaxies, stretching back to the early universe.

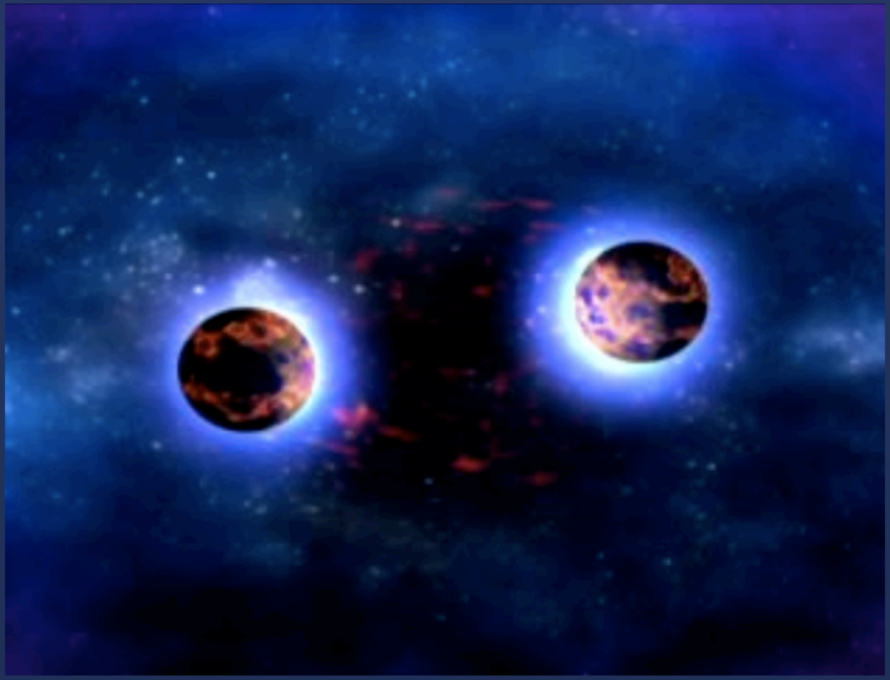


- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

GRBs have been split into two broad classifications: long and short GRBs (Kouveliotou et al. 1993)

SGRB: < 2 s; compact object coalescence?

LGRB: > 2 s; core-collapse (Type Ic SN) of a young massive star

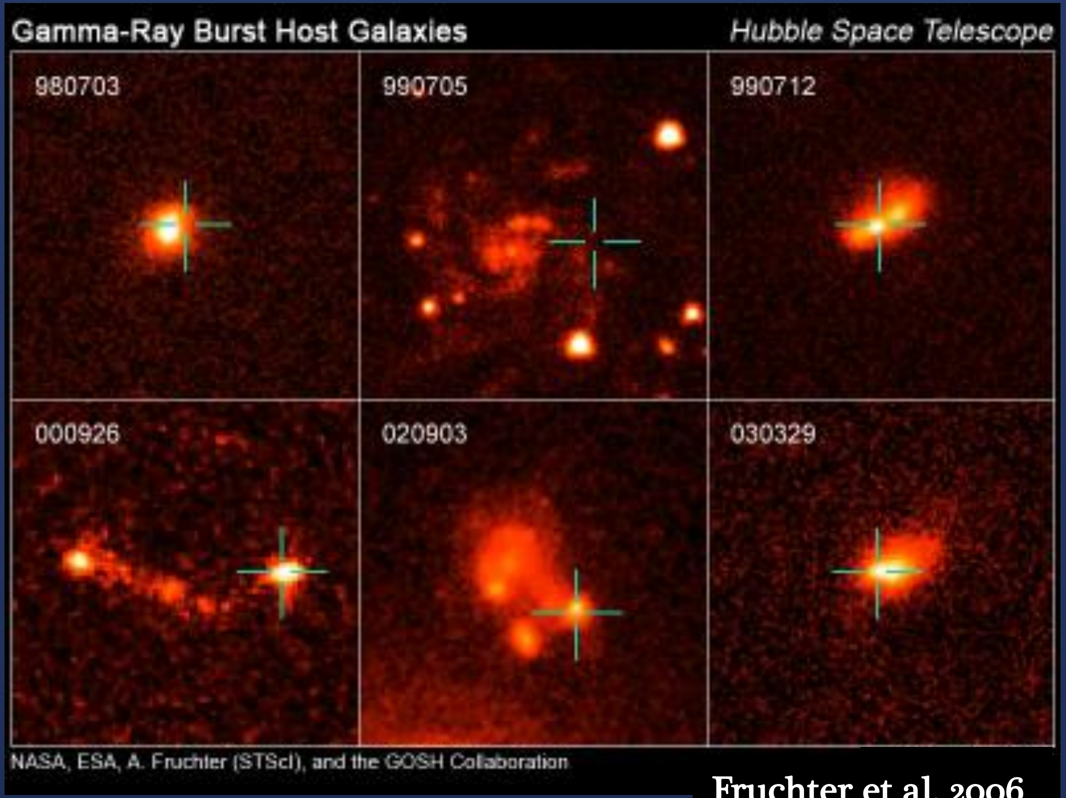


- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

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

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

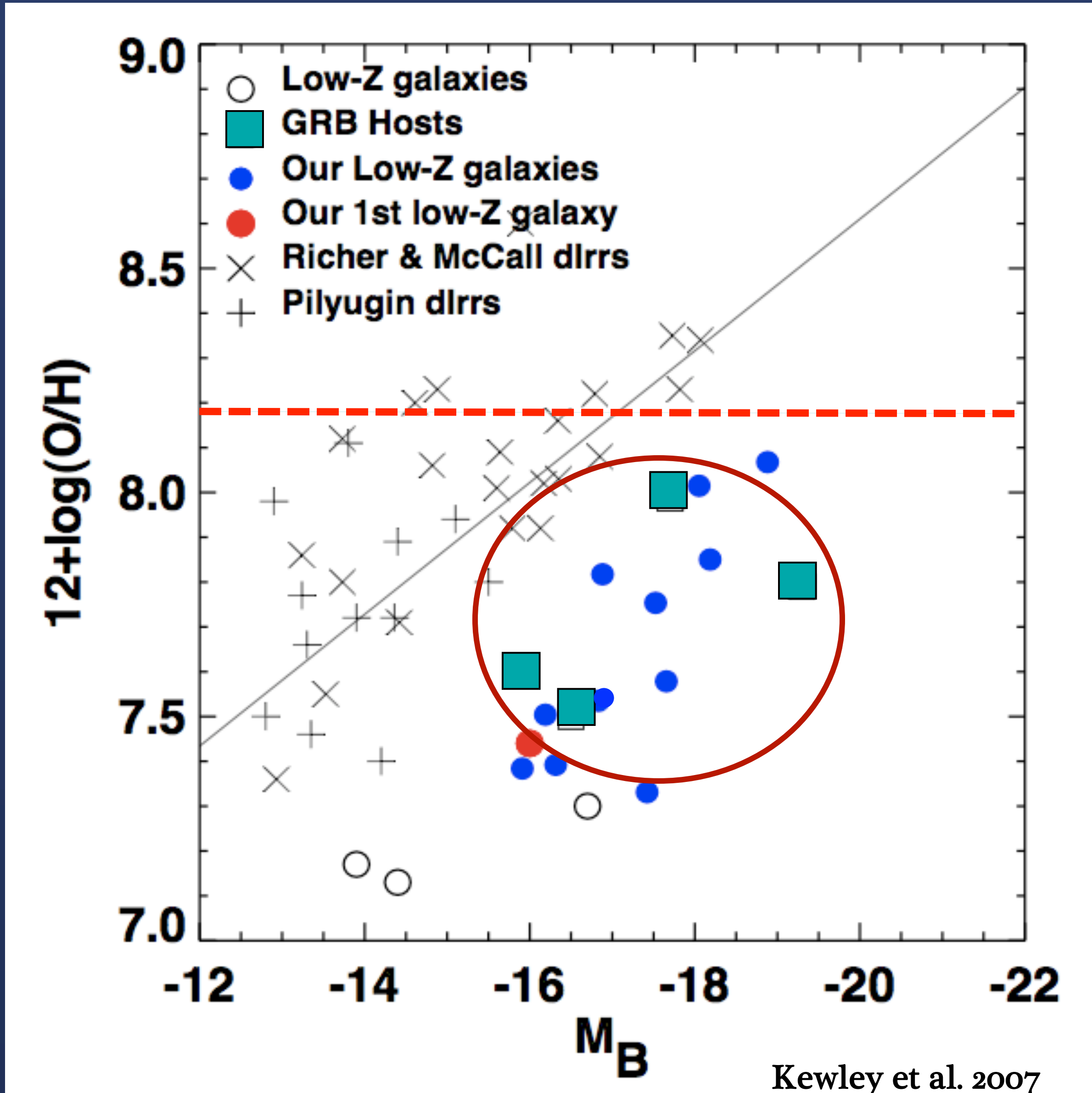
In recent years, several studies found evidence that LGRBs occur in low-Z environments (e.g., Stanek et al. 2006, Fruchter et al. 2006, Kewley et al. 2007 Modjaz et al. 2008, Kocevski et al. 2009)



Fruchter et al. 2006

• Motivation
• LGRB survey
- host sample
- the M-Z relation
• Metallicity?
- energetics
- host vs. site
• New Questions

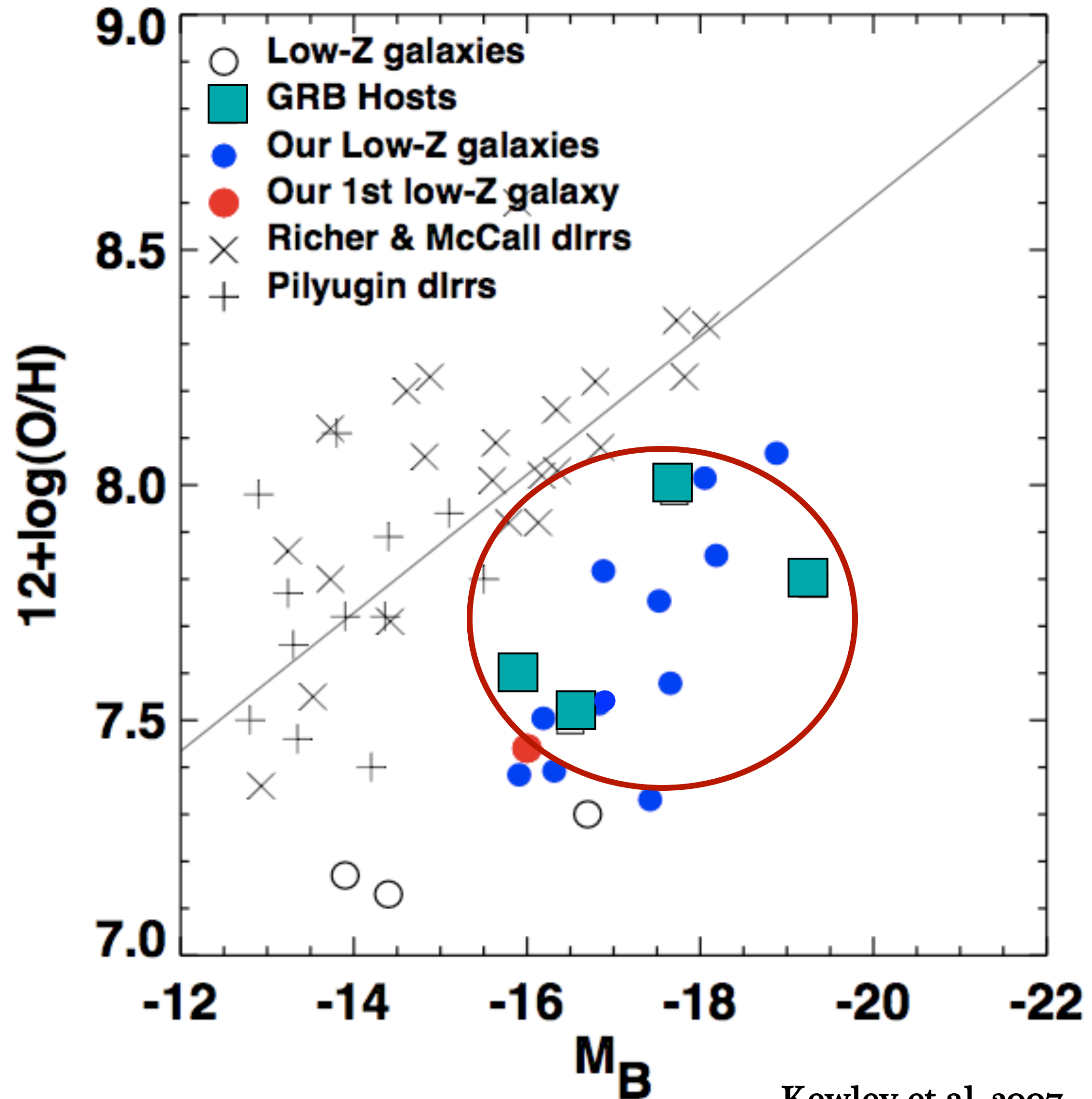
A low-metallicity bias is supported by stellar evolutionary theory under the *collapsar* model…



Kewley et al. 2007

A low-metallicity bias is supported by stellar evolutionary theory under the *collapsar* model…

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



Kewley et al. 2007

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

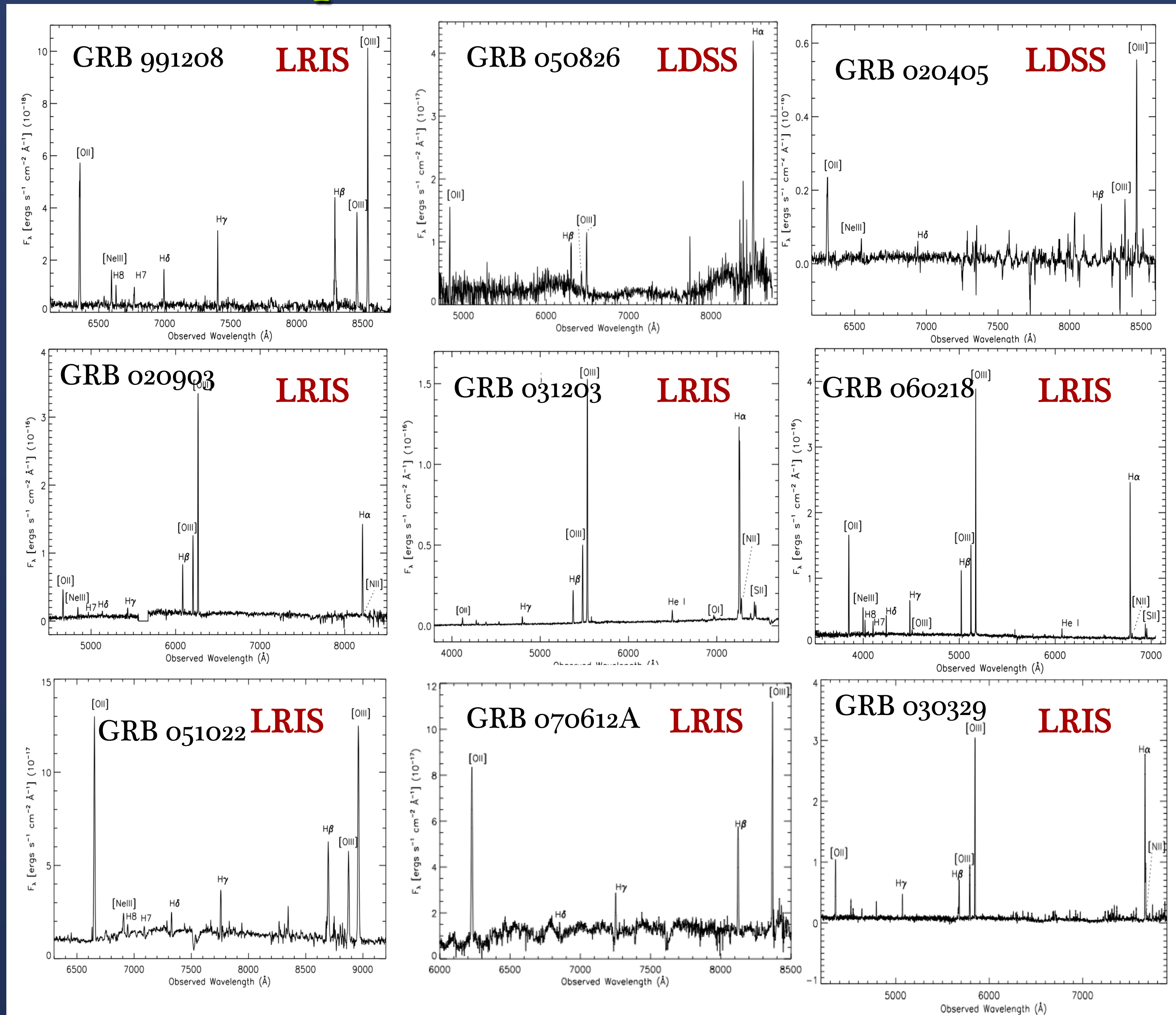
Exploring the complex connection between LGRBs and their host galaxy metallicities requires a large sample of high-quality LGRB host spectra that can be used to determine ISM properties.

However, previous spectra weren't enough…

- insufficient S/N
- insufficient wavelength range

LGRB Host Spectra

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions



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

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

Host Sample Properties

Metallicity - defined here as log(O/H) + 12

Ionization parameter - velocity of ionizing front driven by the local radiation field

Extinction - total reddening due to interstellar dust in the direction of the galaxy

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

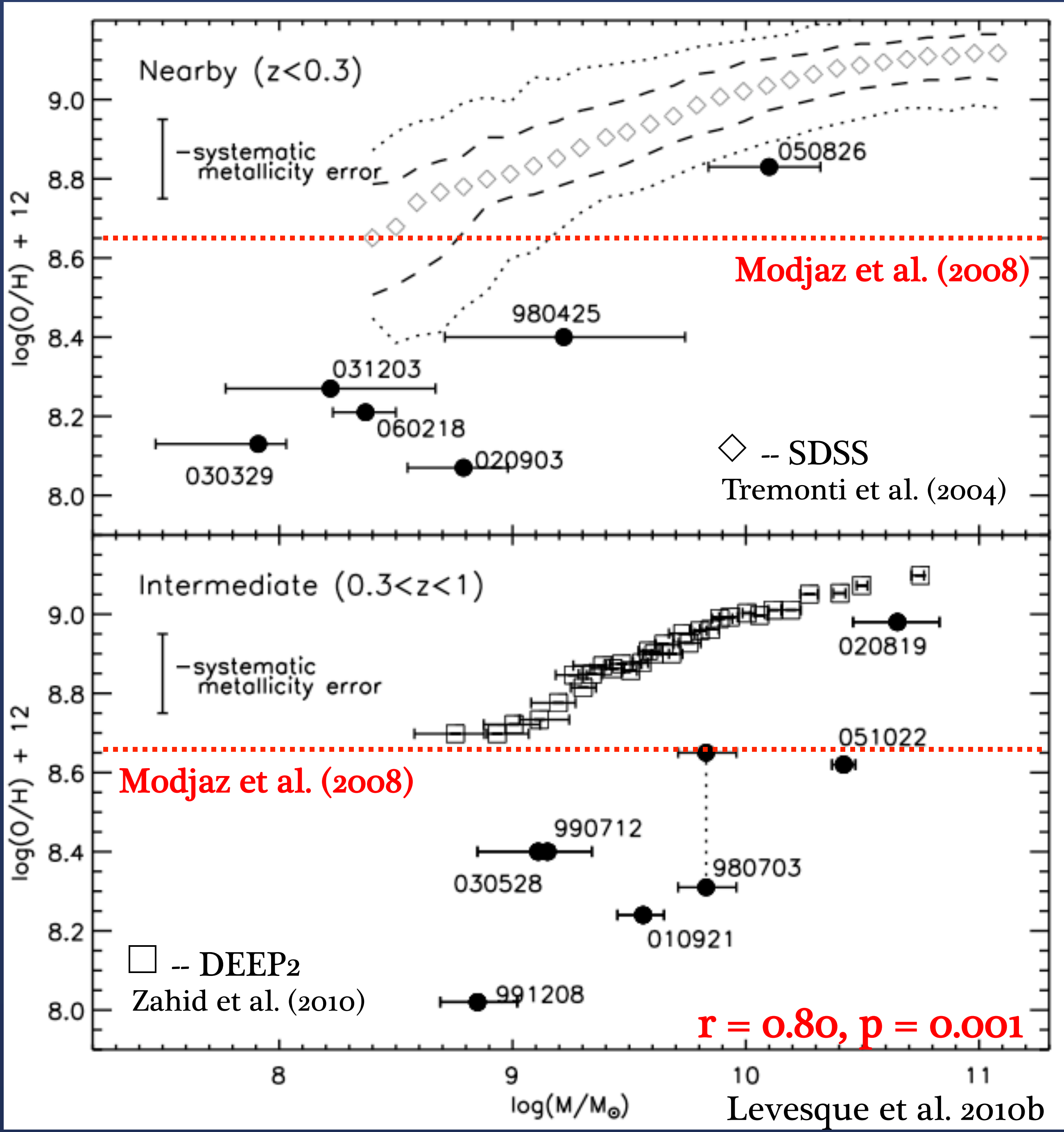
SFR and SFH - star-forming behavior of galaxy

Stellar mass - galaxy mass contained in stars

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

LGRB hosts fall below general MZ relation (average offset of -0.50 ± 0.19 dex)

However, there is NO clear cutoff metallicity for LGRB hosts.

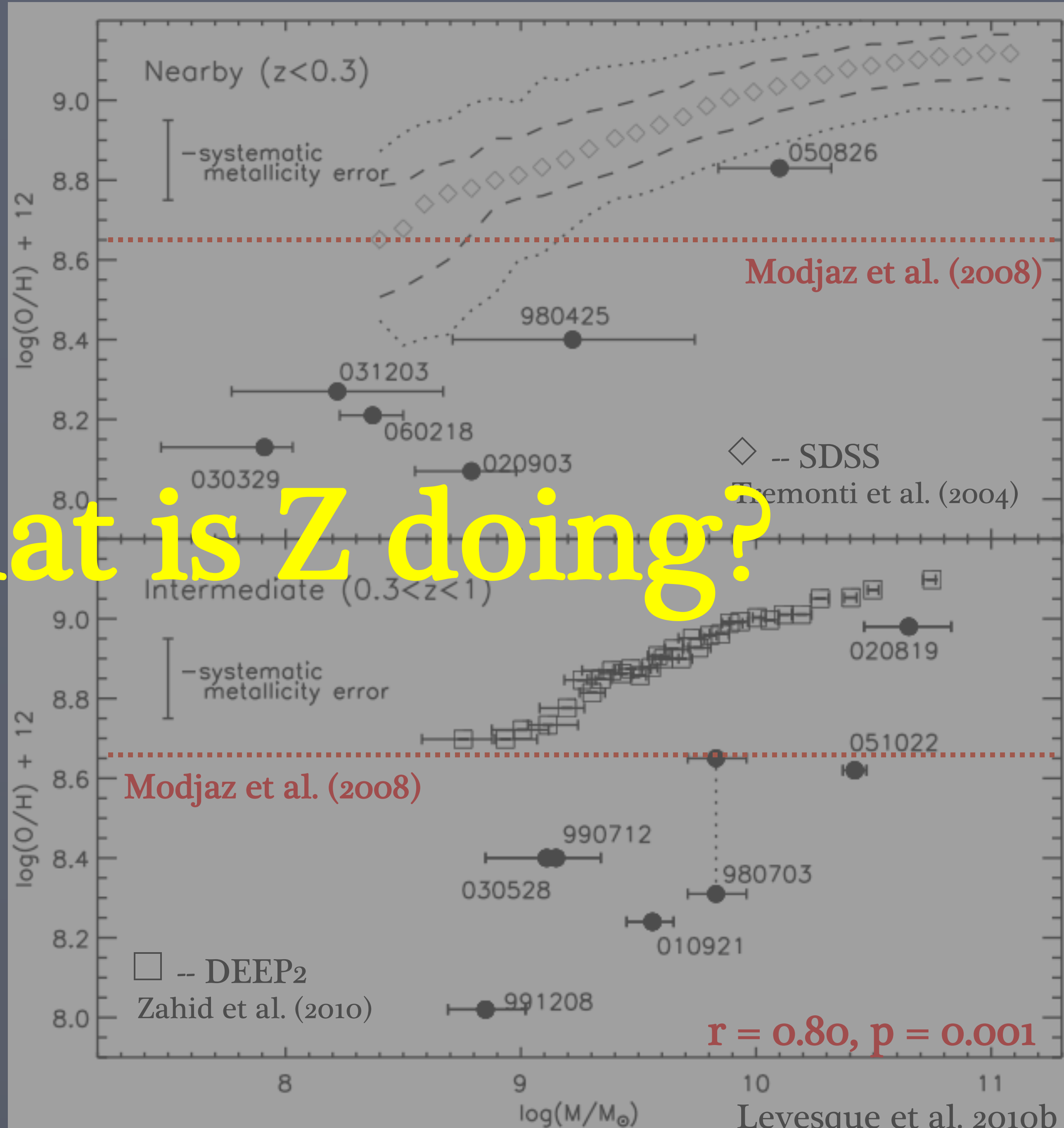


- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

What is Z doing?

LGRB hosts fall below general MZ relation (average offset of -0.50 ± 0.19 dex)

However, there is NO clear cutoff metallicity for LGRB hosts.



- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

Could metallicity be directly affecting the explosive properties of LGRBs?

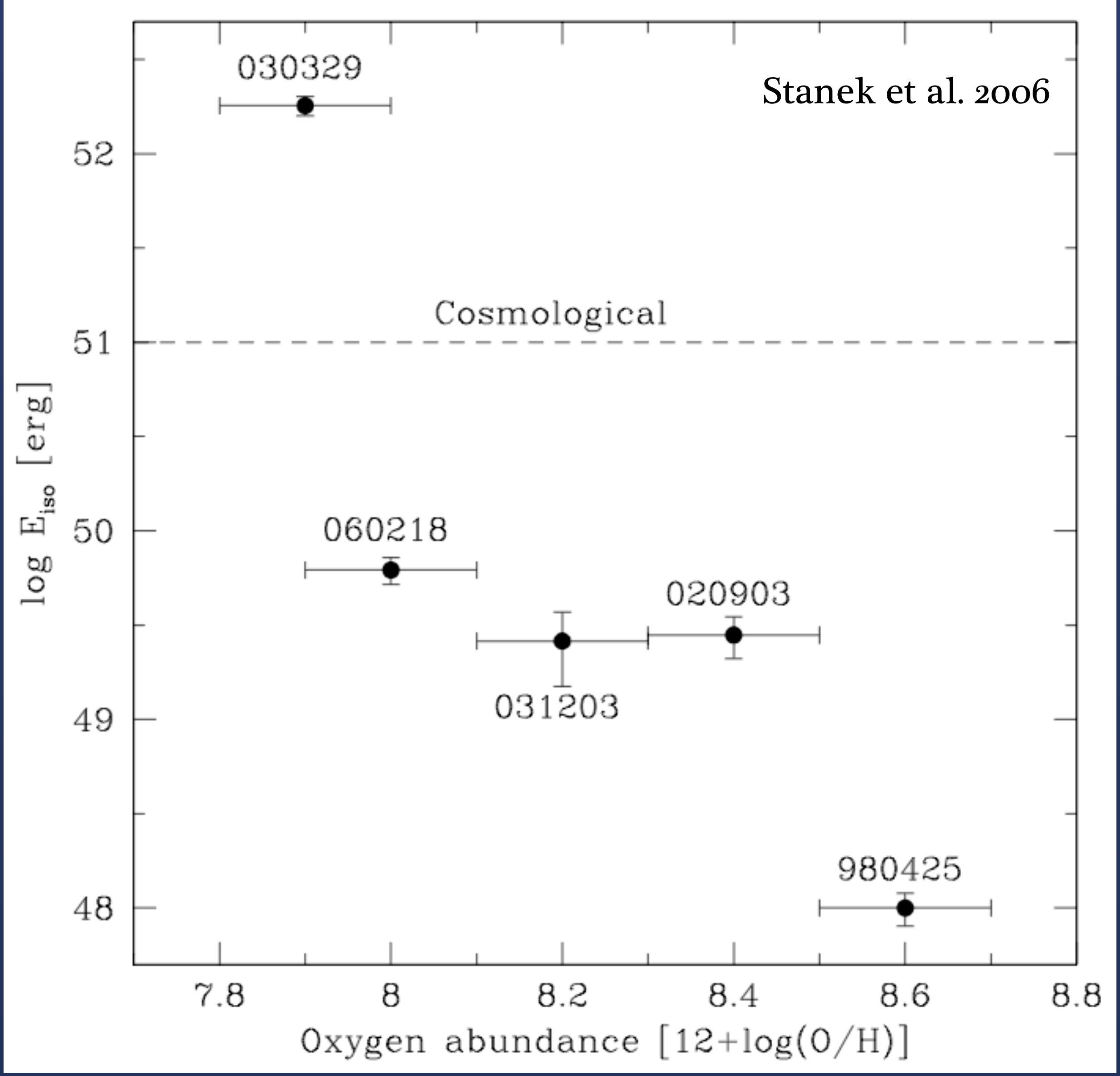
$E_{\gamma,iso}$ = assumes a quasi-spherical burst

θ_j = opening angle of the GRB jet

$E_\gamma = E_{\gamma,iso} \times (1-\cos(\theta_j))$

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- **Metallicity?**
  - **energetics**
  - host vs. site
- New Questions

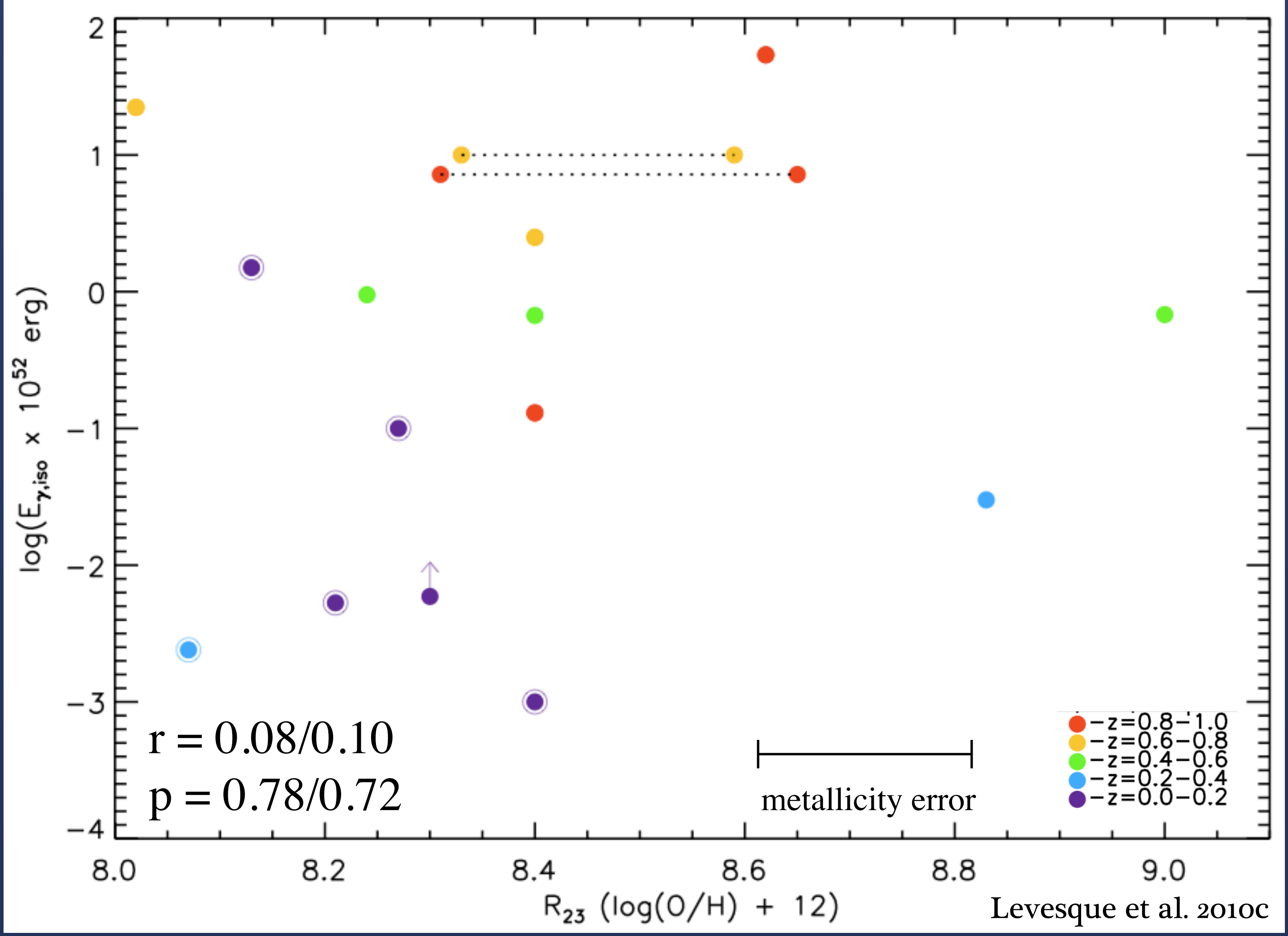
We should also consider the energetic properties of LGRBs.



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

• Motivation
• LGRB survey
- host sample
- the M-Z relation
• **Metallicity?**
- **energetics**
- host vs. site
• New Questions

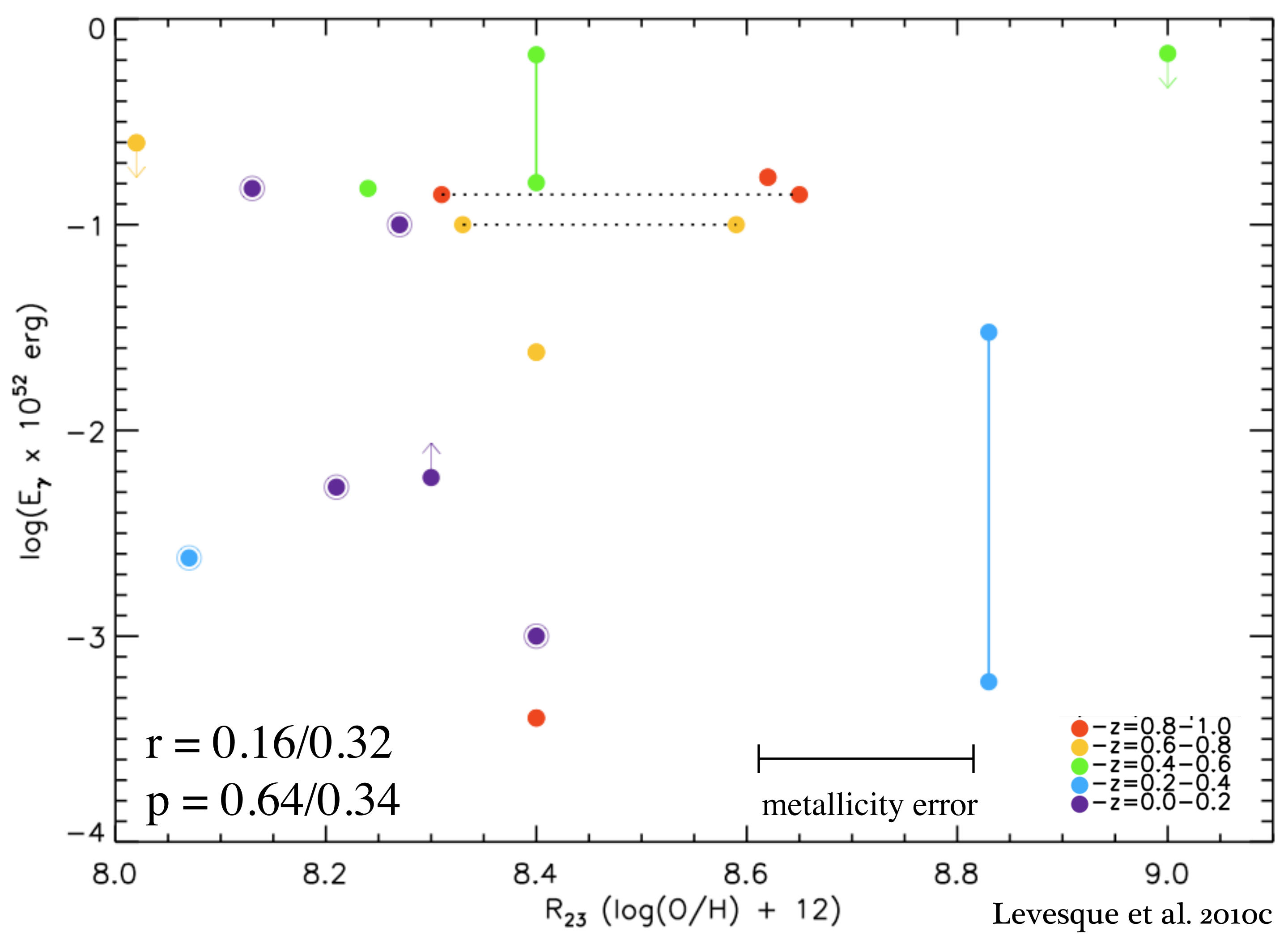
We should also consider the energetic properties of LGRBs.



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

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

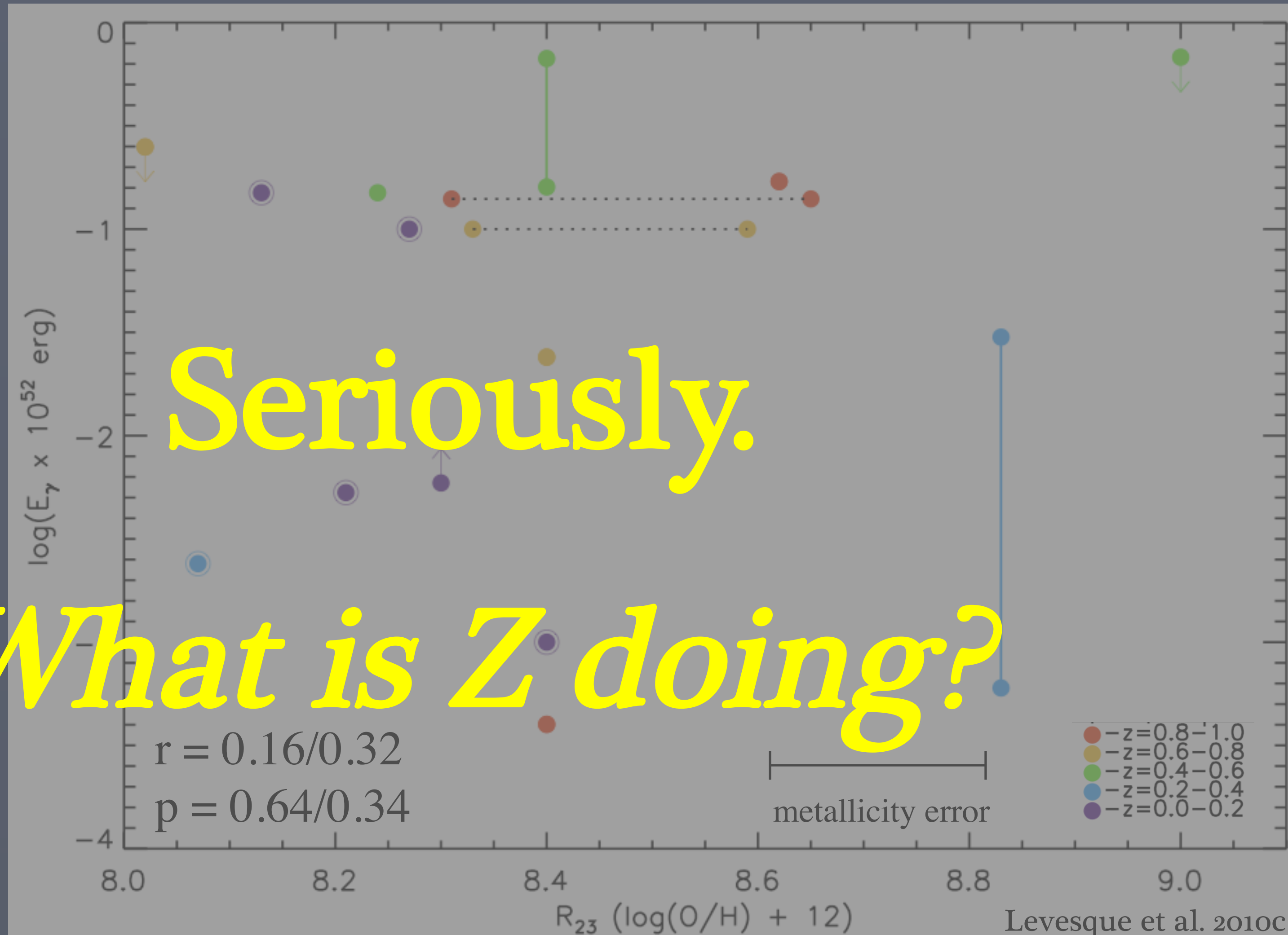
We should also consider the energetic properties of LGRBs.



Levesque et al. 2010c

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

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions



Seriously.

What is Z doing?

We should also consider the energetic properties of LGRBs.

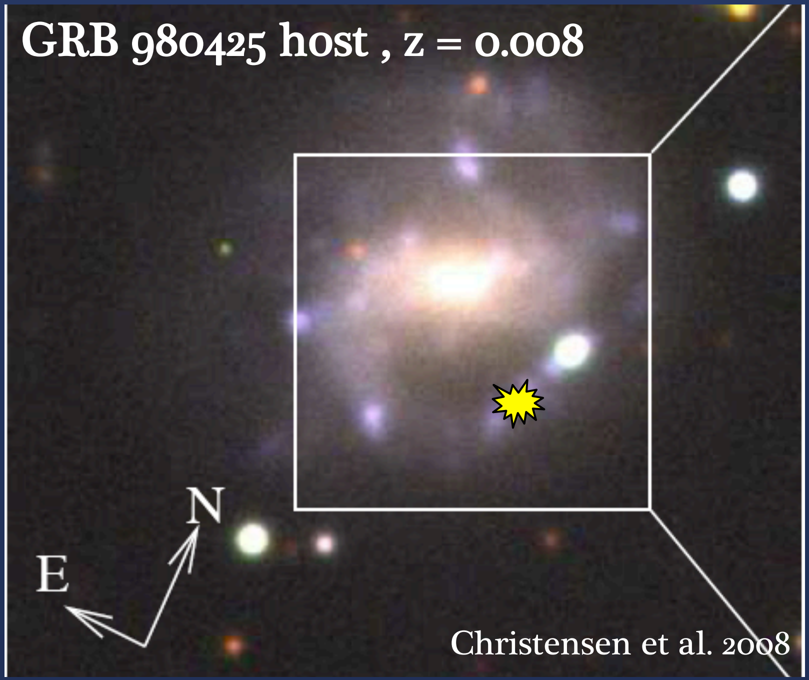
However, we find no statistically significant correlation between host galaxy metallicity and $E_{\gamma,iso}$ *or* E_γ.

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

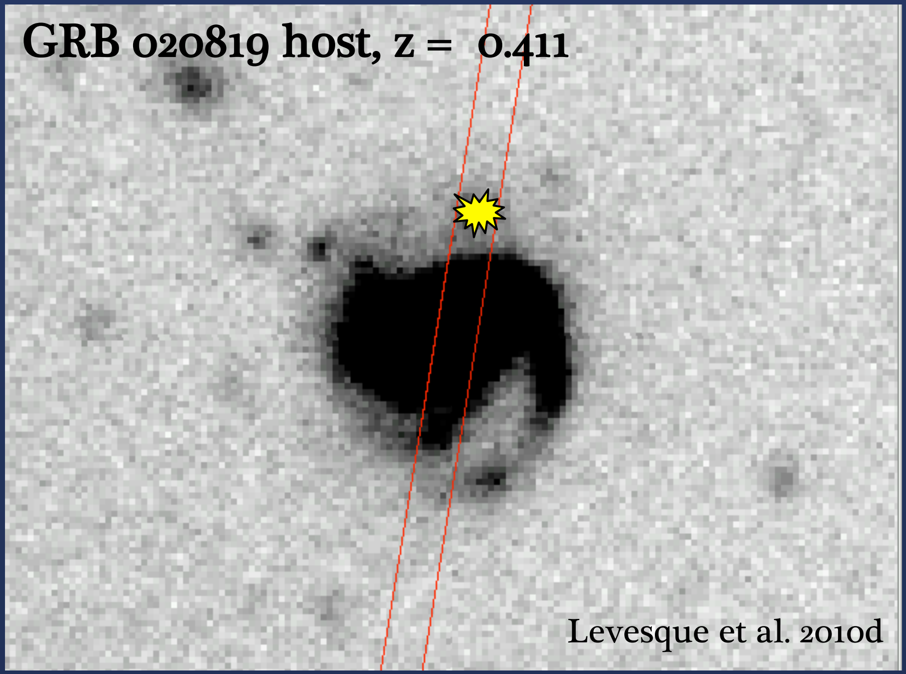
"Host" vs. "Site" metallicities…

- are these "global" metallicities accurate estimates?

- how does the explosion site environment compare to the galaxy as a whole?



Global: log(O/H) + 12 = 8.4 ± 1
GRB site: log(O/H + 12 = 8.3 ± 1



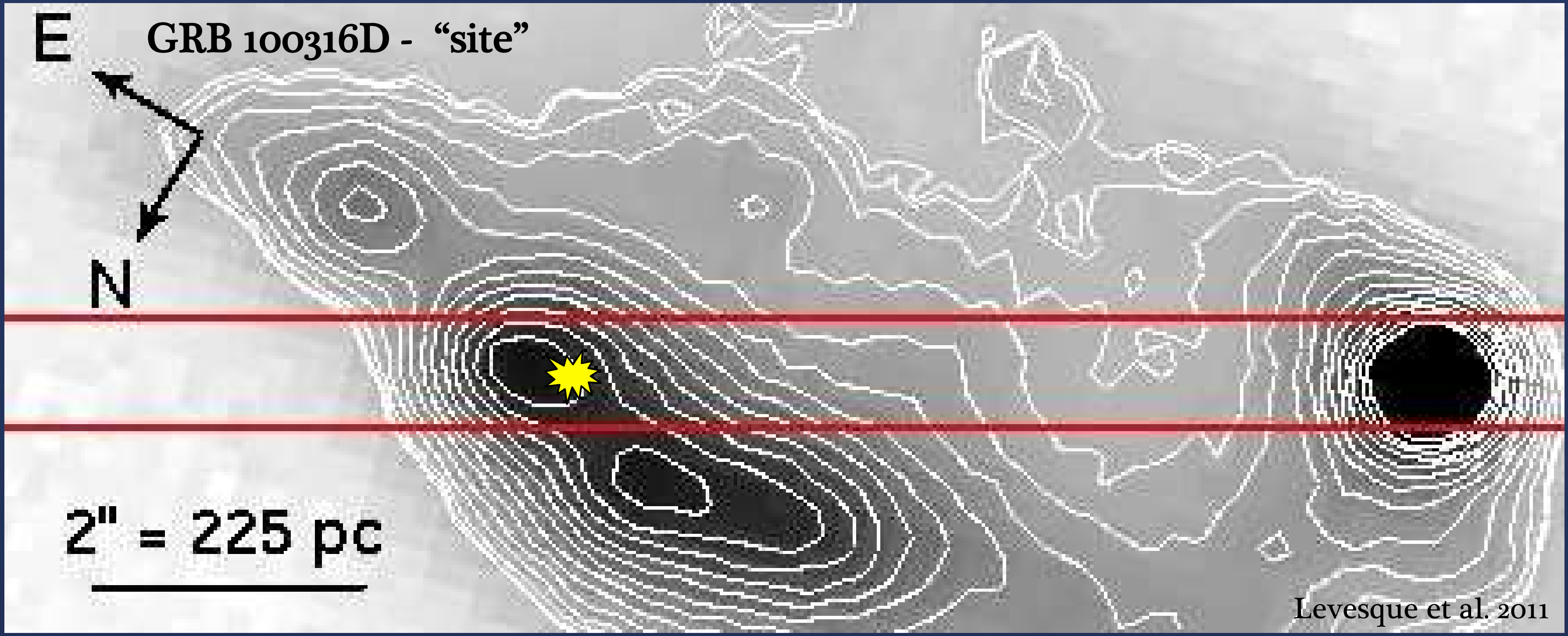
Nucleus: log(O/H) + 12 = 9.0 ± 1
GRB site: log(O/H + 12 = 9.0 ± 1

• Motivation
• LGRB survey
- host sample
- the M-Z relation
• Metallicity?
- energetics
- host vs. site
• New Questions

"Host" vs. "Site" metallicities…

- are these "global" metallicities accurate estimates?

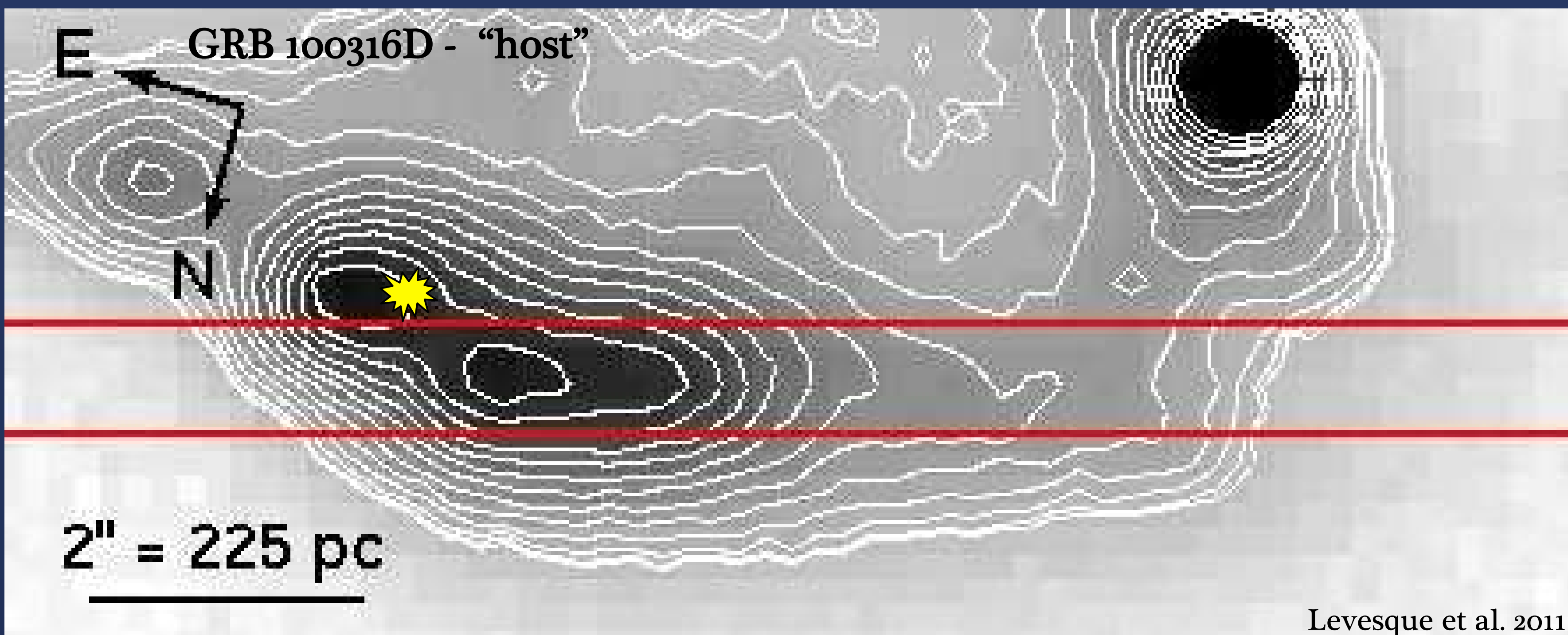
- how does the explosion site environment compare to the galaxy as a whole?



"Host" vs. "Site" metallicities…

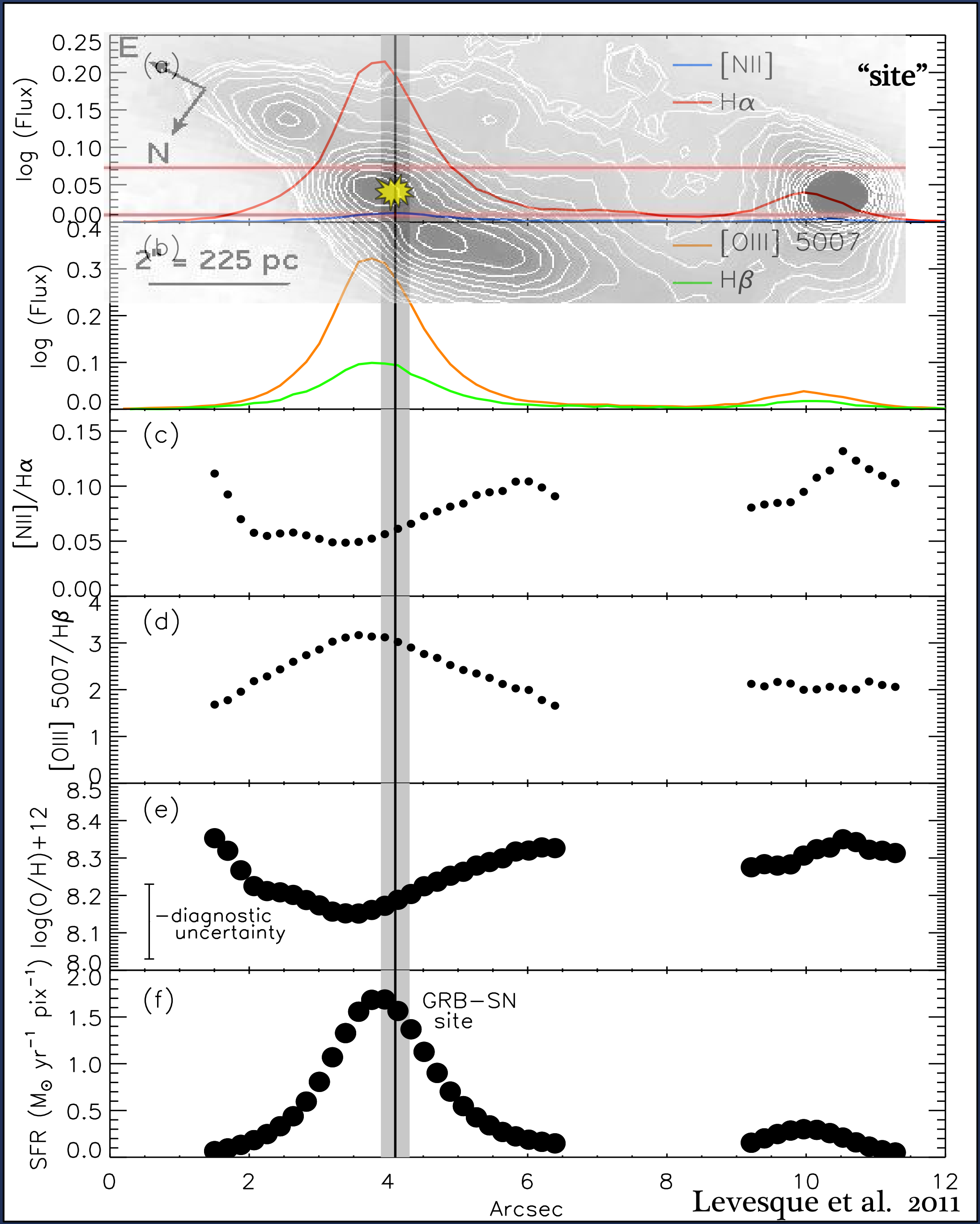
- are these "global" metallicities accurate estimates?

- how does the explosion site environment compare to the galaxy as a whole?



- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

- GRB occurred near Z minimum and SFR maximum

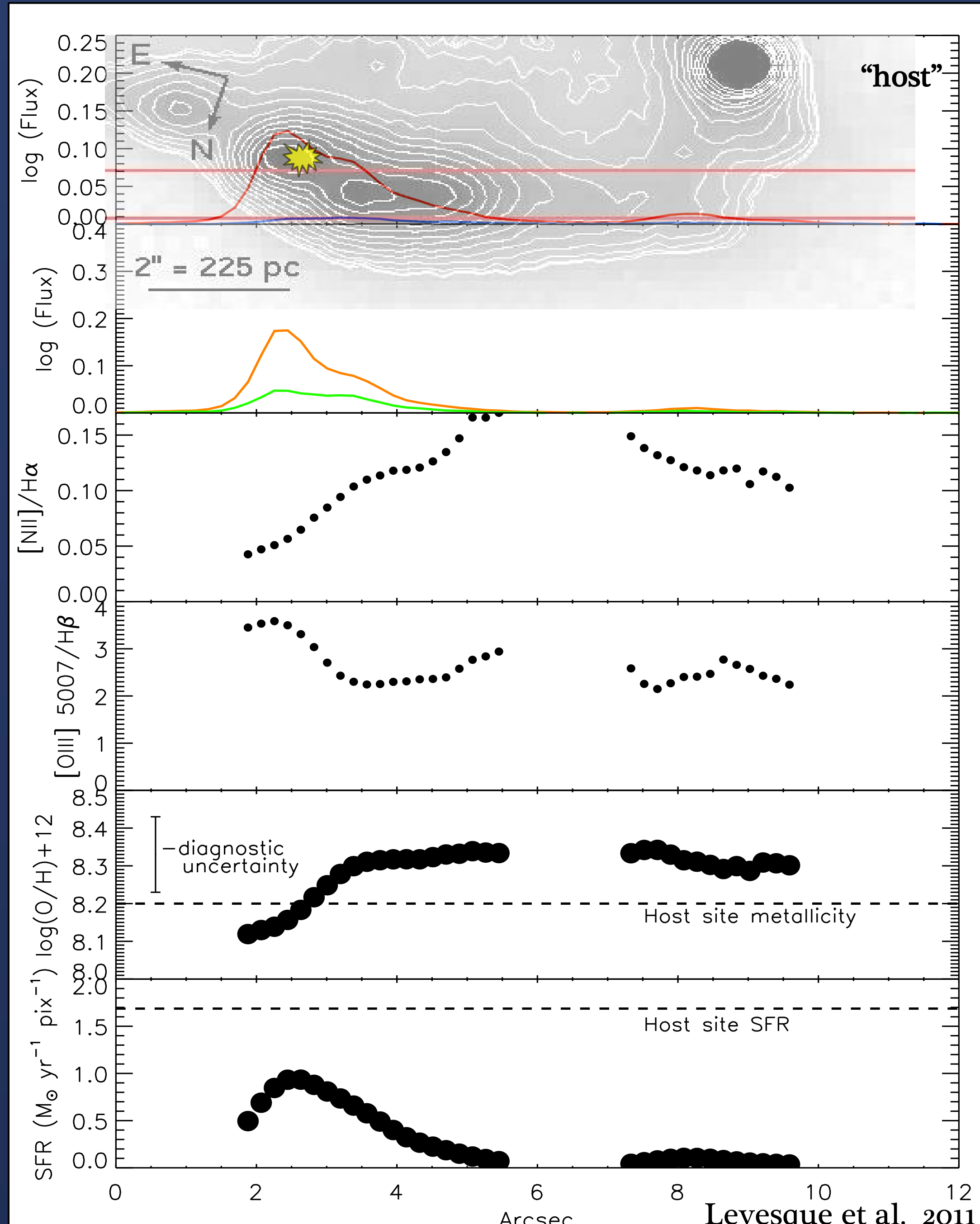


• Motivation
• LGRB survey
- host sample
- the M-Z relation
• **Metallicity?**
- energetics
- **host vs. site**
• New Questions

- GRB occurred near Z minimum and SFR maximum

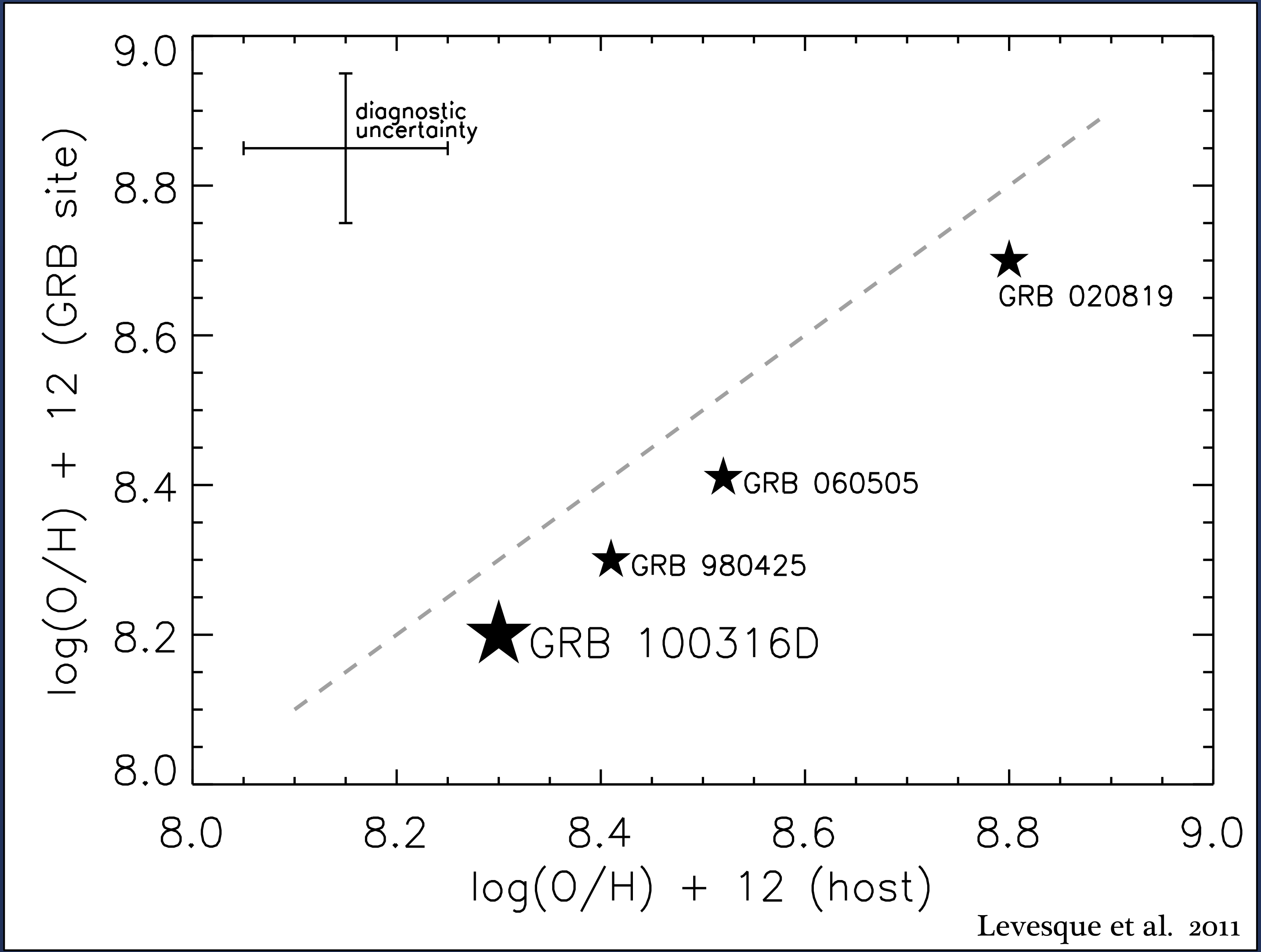
- Z gradient across entire galaxy is very low

- what can this tell us?



Levesque et al. 2011

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- **Metallicity?**
  - energetics
  - **host vs. site**
- New Questions



- From current sample, "host" and "site" metallicities are comparable, with "site" metallicities slightly lower

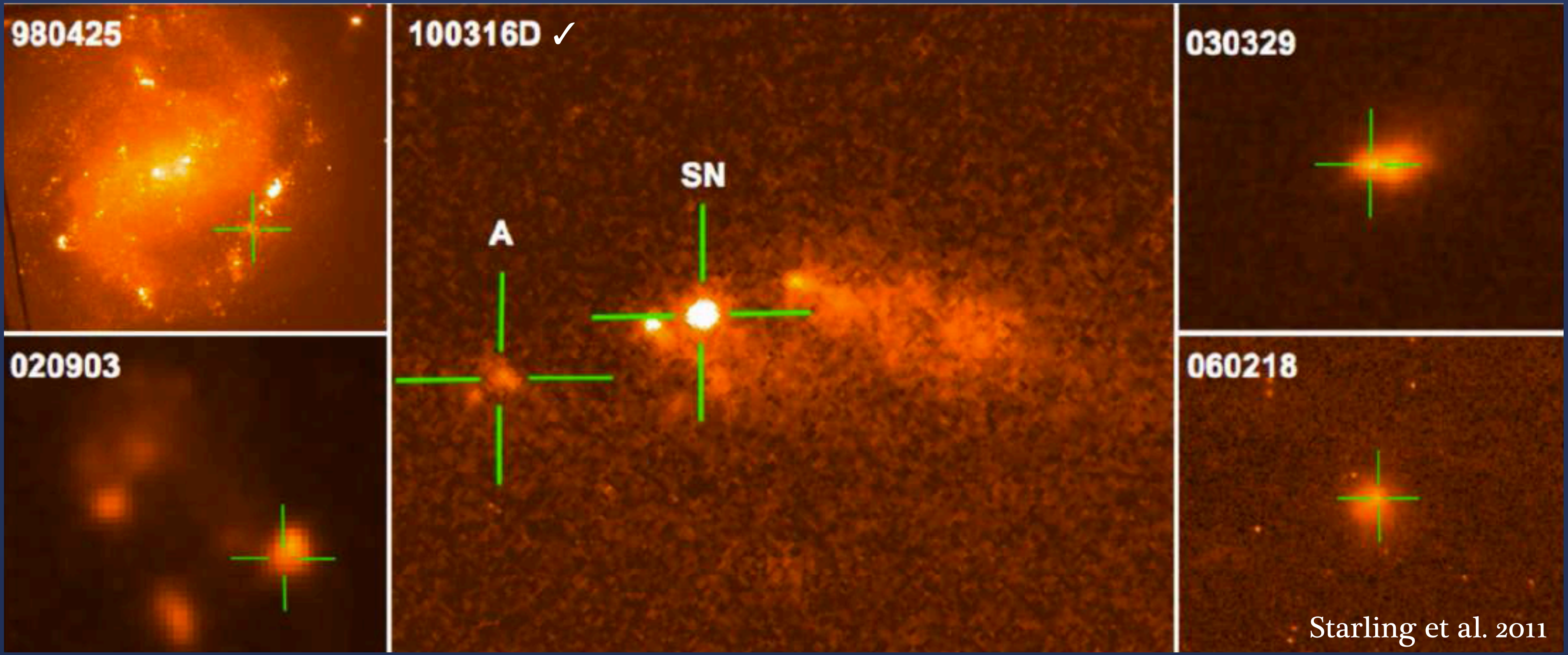
- What does this mean for larger host studies?

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

"Host" vs. "Site" metallicities…

- More studies of LGRB and GRB/SN explosions sites are required

- The nearby sample offers an excellent unexplored opportunity for study…



Starling et al. 2011

• Motivation
• LGRB survey
- host sample
- the M-Z relation
• Metallicity?
- energetics
- host vs. site
• New Questions

Some new metallicity questions…

How do these results fit with predictions of the collapsar model?
- high-Z LGRBs?
- physical process driving MZ offset?
- lack of a correlation with burst properties?

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

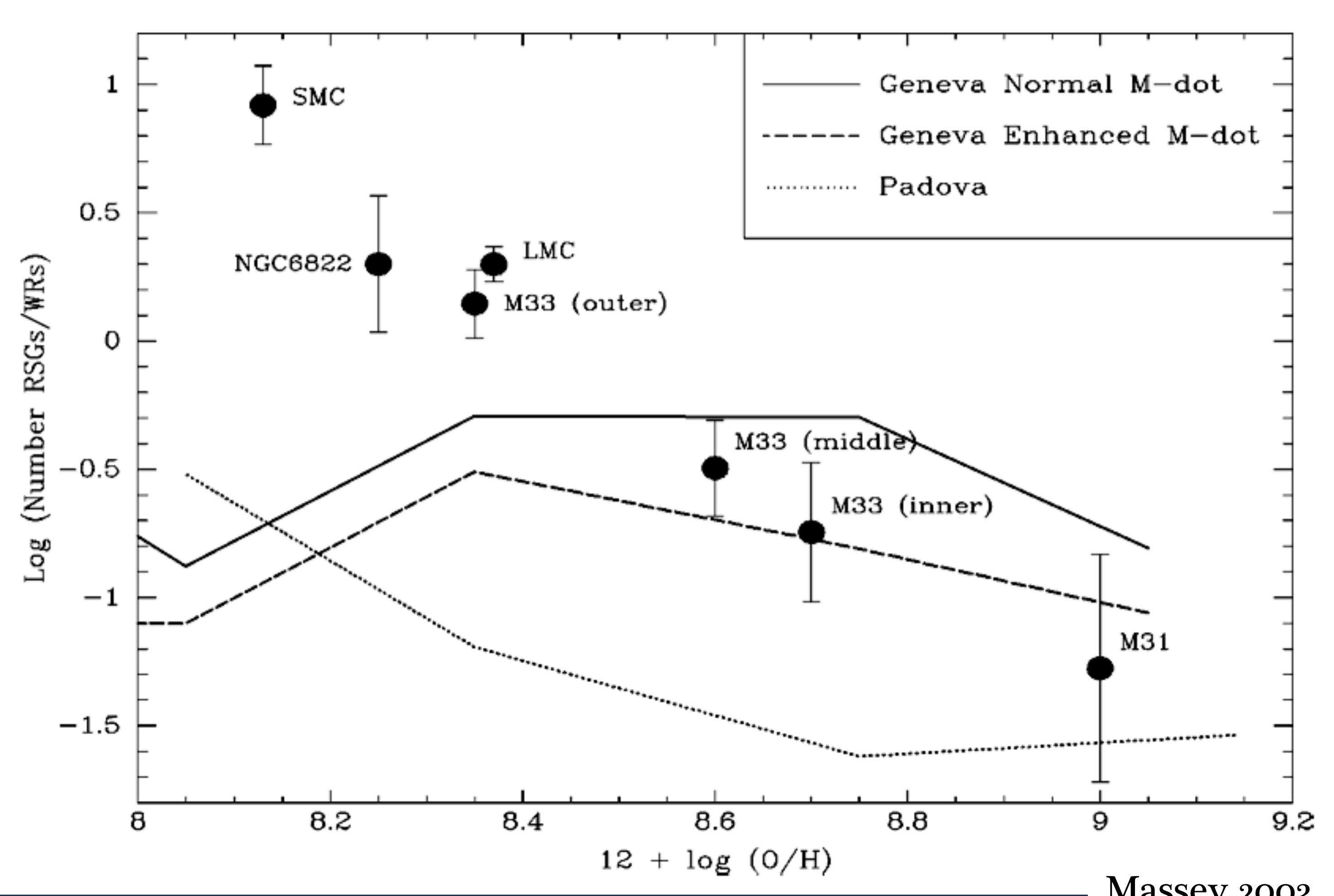
Some new metallicity questions…

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

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- **New Questions**

Some new metallicity ~~questions~~ problems…

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

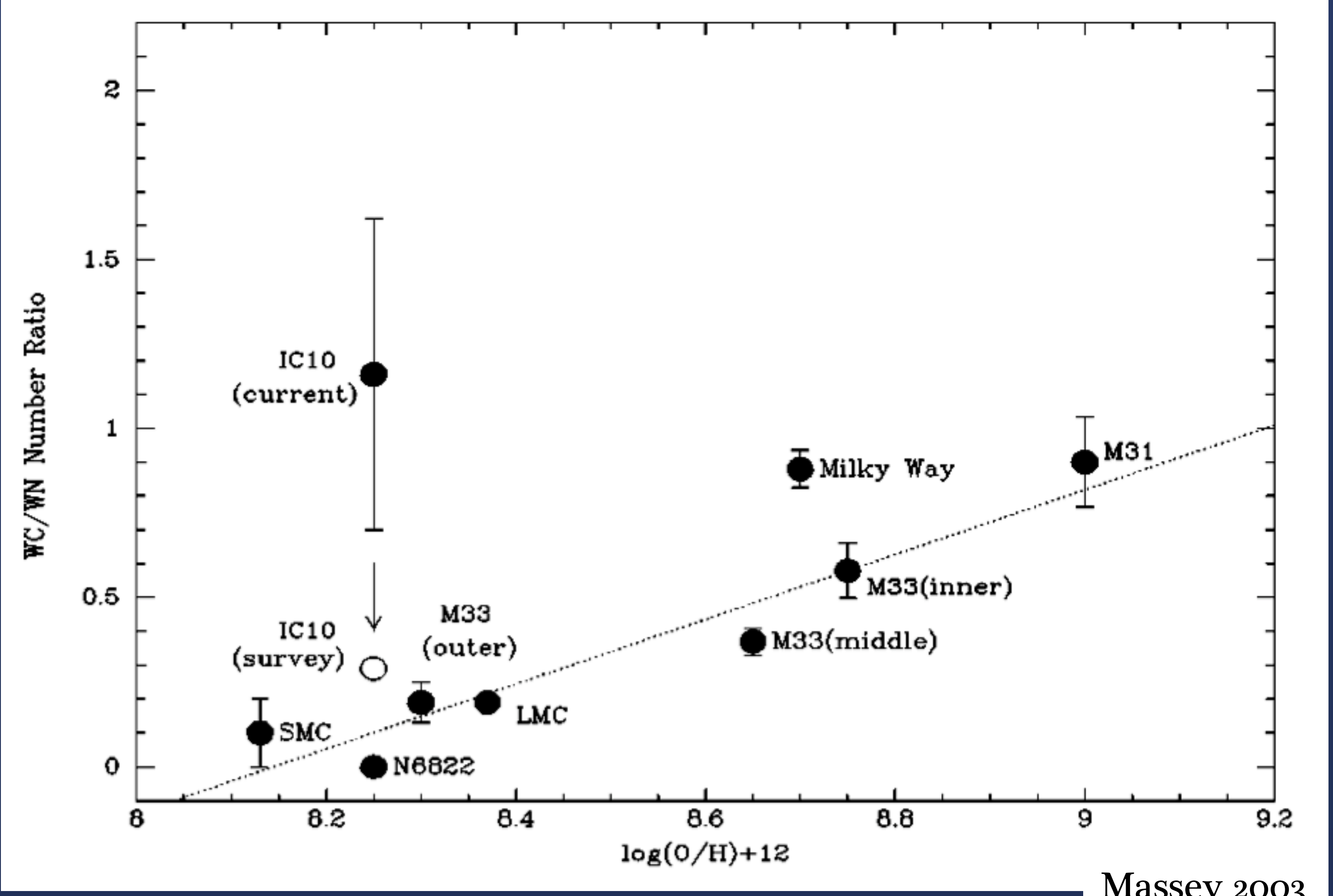


Massey 2003

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- **New Questions**

Some new metallicity ~~questions~~ problems…

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

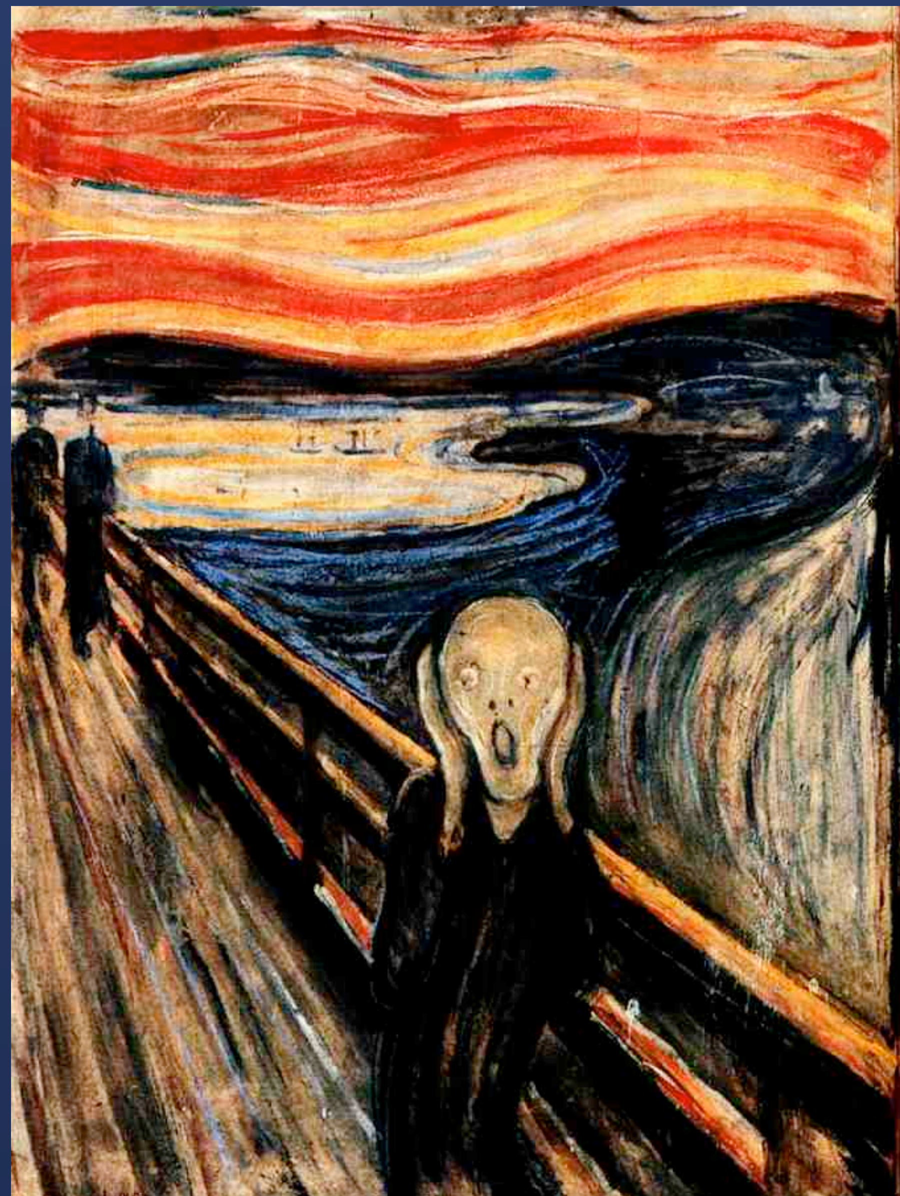


Massey 2003

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- **New Questions**

Some new metallicity solutions?

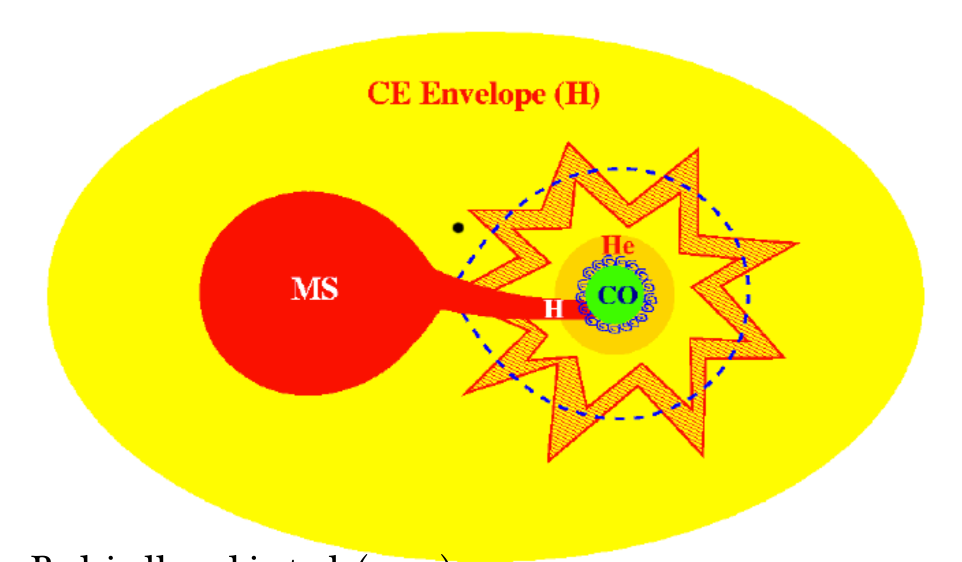
Contemplating binary scenarios…



Some new metallicity solutions?

Contemplating binary scenarios…

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



Podsiadlowski et al. (2010)

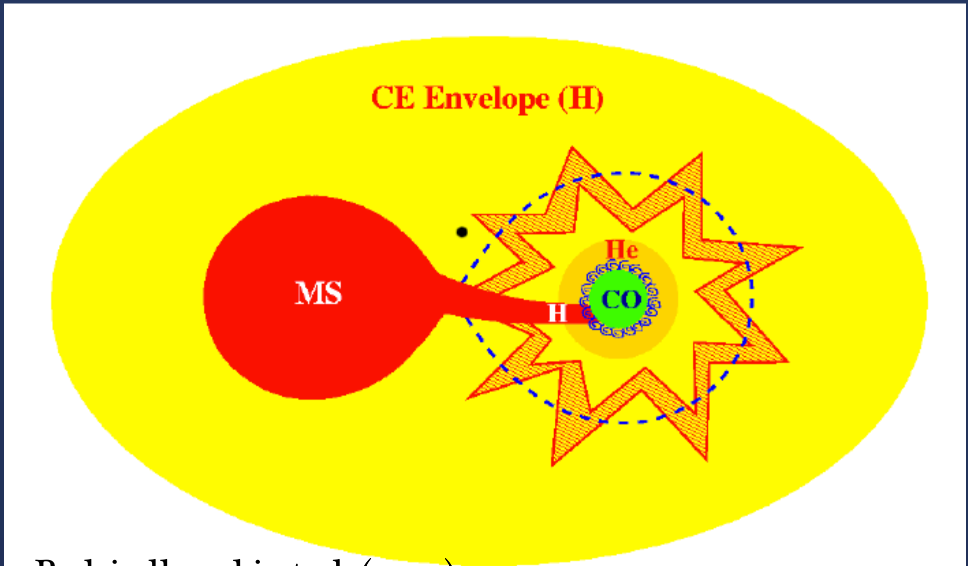
- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- **New Questions**

Some new metallicity solutions?

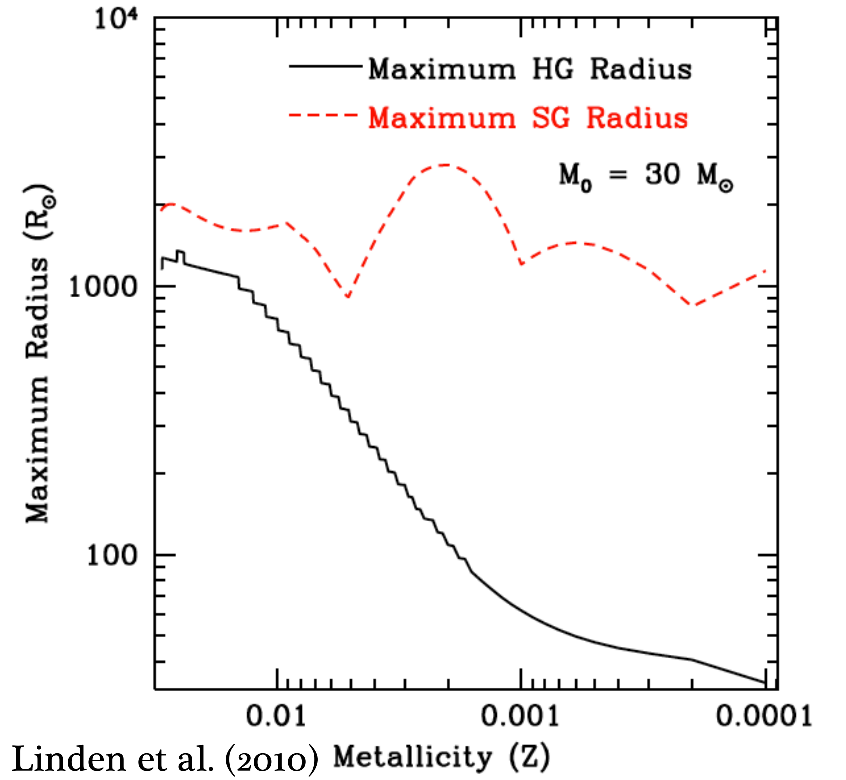
Contemplating binary scenarios…

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)



Podsiadlowski et al. (2010)



Linden et al. (2010)

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- **New Questions**

Some new metallicity solutions?

Contemplating 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)

The Evolution of Massive Stars and Progenitors of Gamma-Ray Bursts

June 17 - July 1 2012
Aspen Center for Physics

More information at http://casa.colorado.edu/~emle6425/aspen/

A two-week workshop bringing together experts in the two complementary areas of massive stellar evolution and LGRB studies.

- Motivation
- LGRB survey
  - host sample
  - the M-Z relation
- Metallicity?
  - energetics
  - host vs. site
- New Questions

Conclusions:

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

Questions for the future:

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?