Gamma-Ray Burst Host Galaxies as Probes of Galaxy Formation and Evolution

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University of Colorado at Boulder

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2008

- Prompt Emission
- Afterglows
- High-energy Emission
- SGRBs
- Gravity Waves, Neutrinos, and Cosmic Rays
- Host Galaxies
- SN and GRB progenitors
- High-z GRBs
- Magnetars
- GRB cosmology

2008

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- High-z GRBs
- SNe and LGRB
  Progenitors
- Magnetars
- SGRB Obs
- SGRB Theory
- High-energy
  Emission
- Outflows and Jets
- Multi-Messenger
- Host Galaxies
- Poster prize talks

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- GRB cosmology
- LGRB progenitors
- SGRB progenitors
- Central Engine
  Physics
- Instrumentation
- Gravity Waves,
  Neutrinos, Cosmic
  Rays, and UHEE
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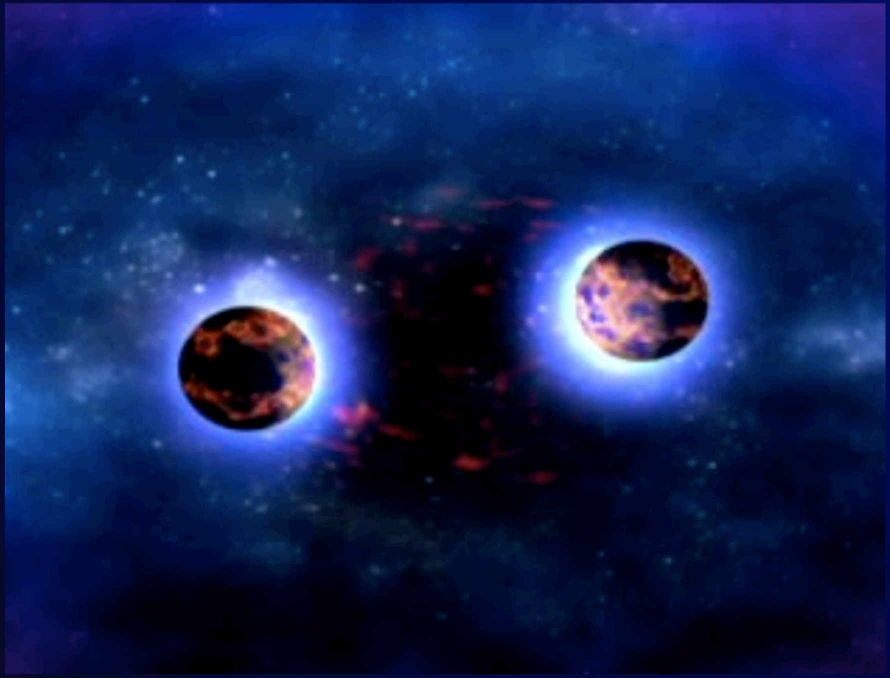
2014
- Host Galaxies!
- etc…
- etc…
- etc…

SGRB hosts: late-type OR star-forming galaxies, generally large offsets for the SGRB positions
-- parent stellar populations, progenitor ages, progenitor scenarios



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  - populations
  - high-z utility
  - biases?
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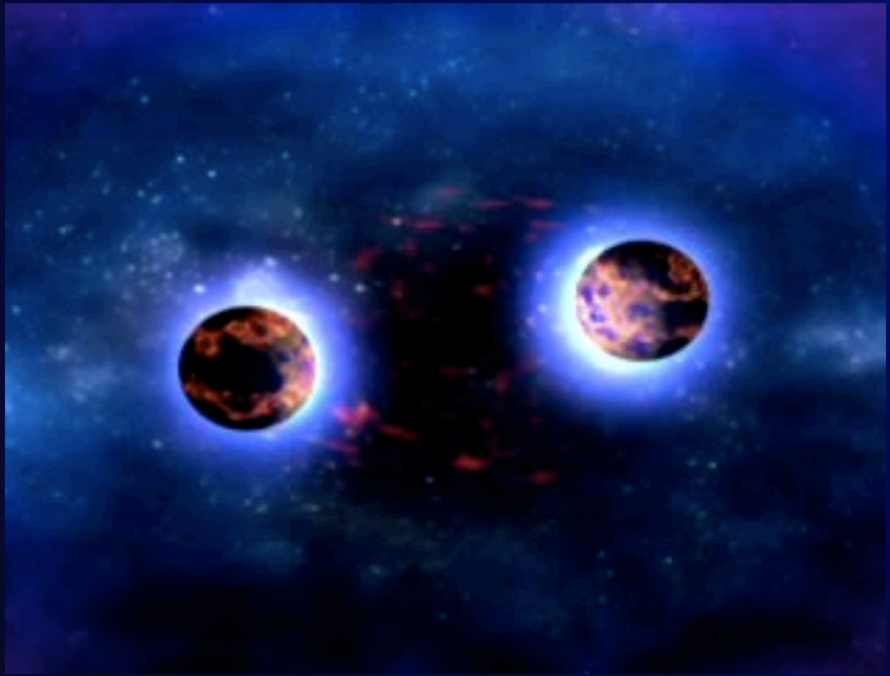
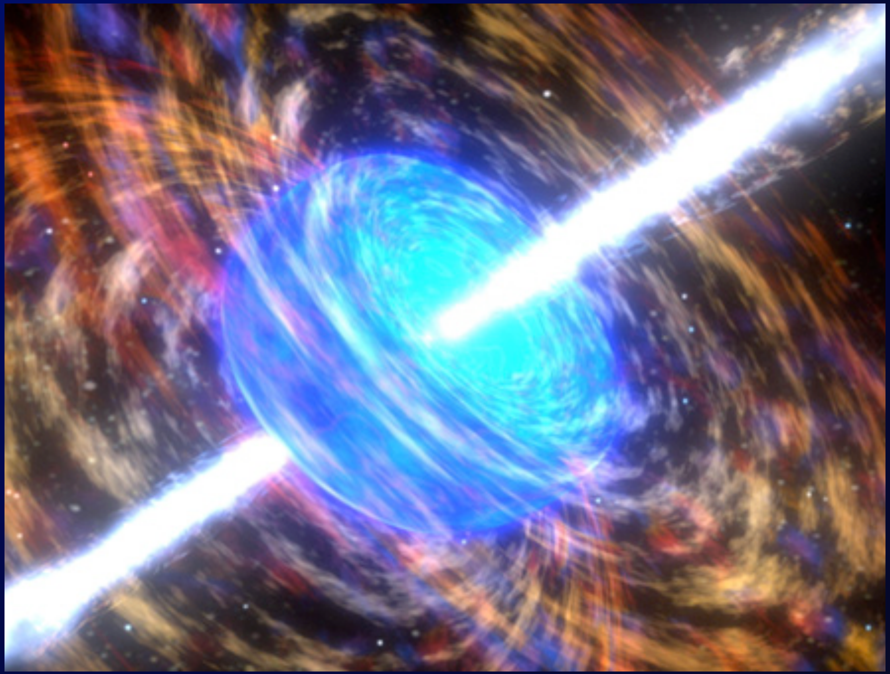
LGRB hosts: young star-forming galaxies, LGRBs concentrated in bluest regions
--progenitor ages, conditions for progenitor evolution, probes of early star formation





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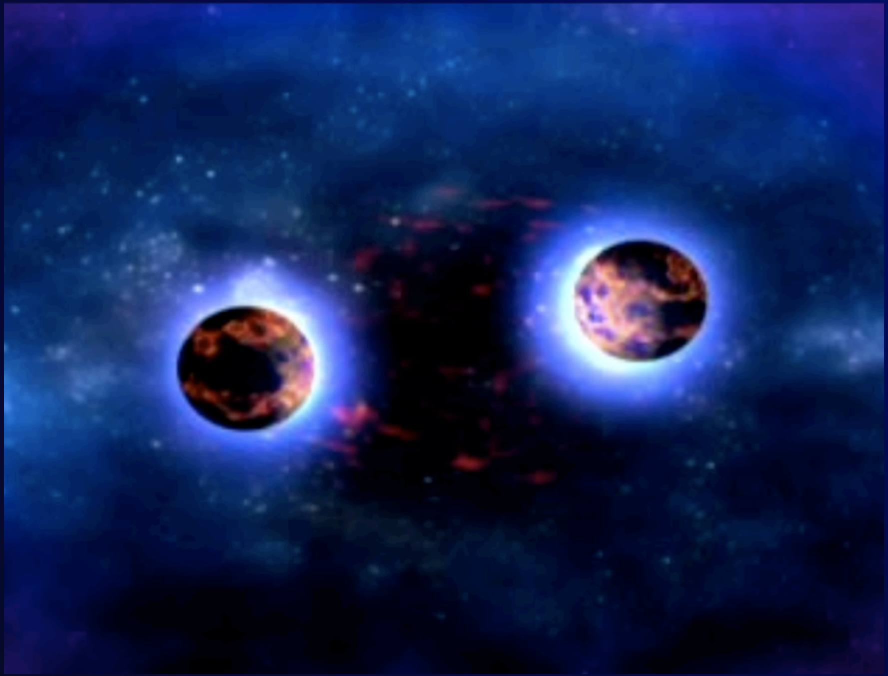

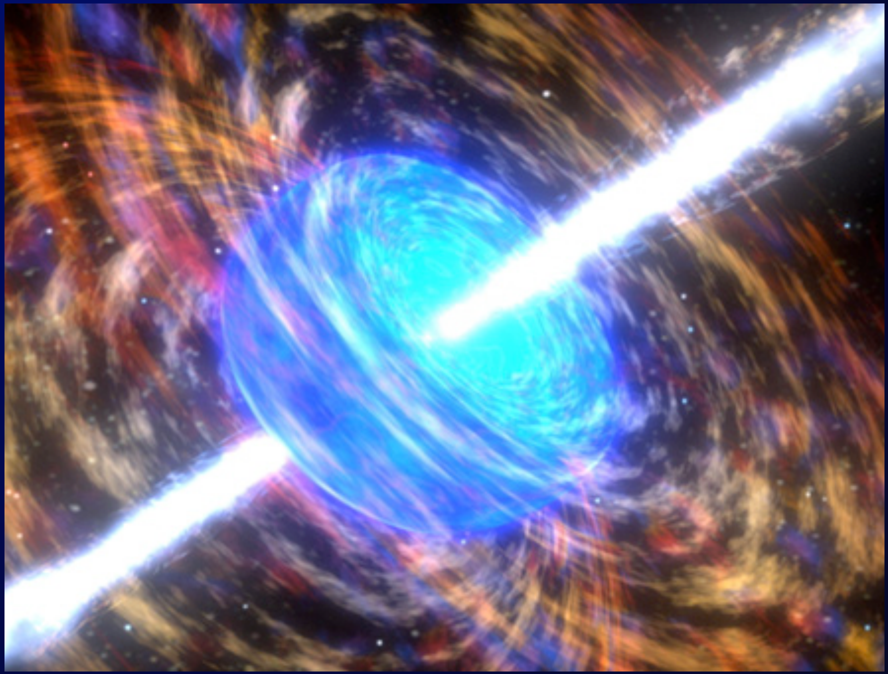

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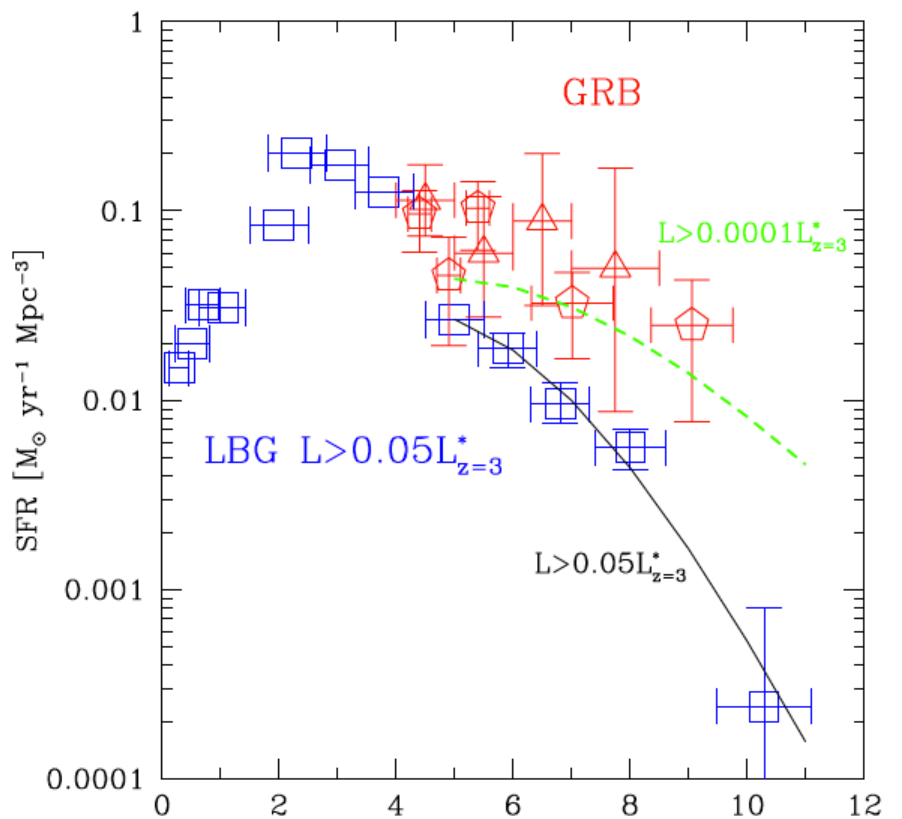
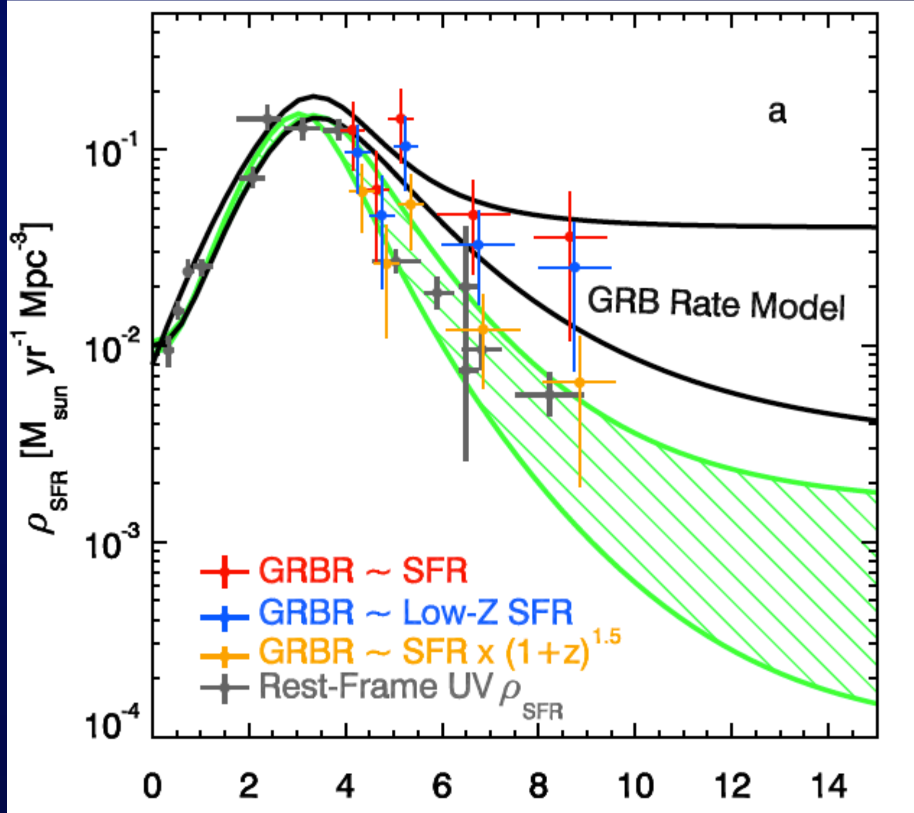
LGRBs are often cited as potentially powerful tracers of star formation out to high redshifts.

However, their utility can be strongly impacted by environmental biases…



Trenti et al. (2012)



Robertson & Ellis (2012)

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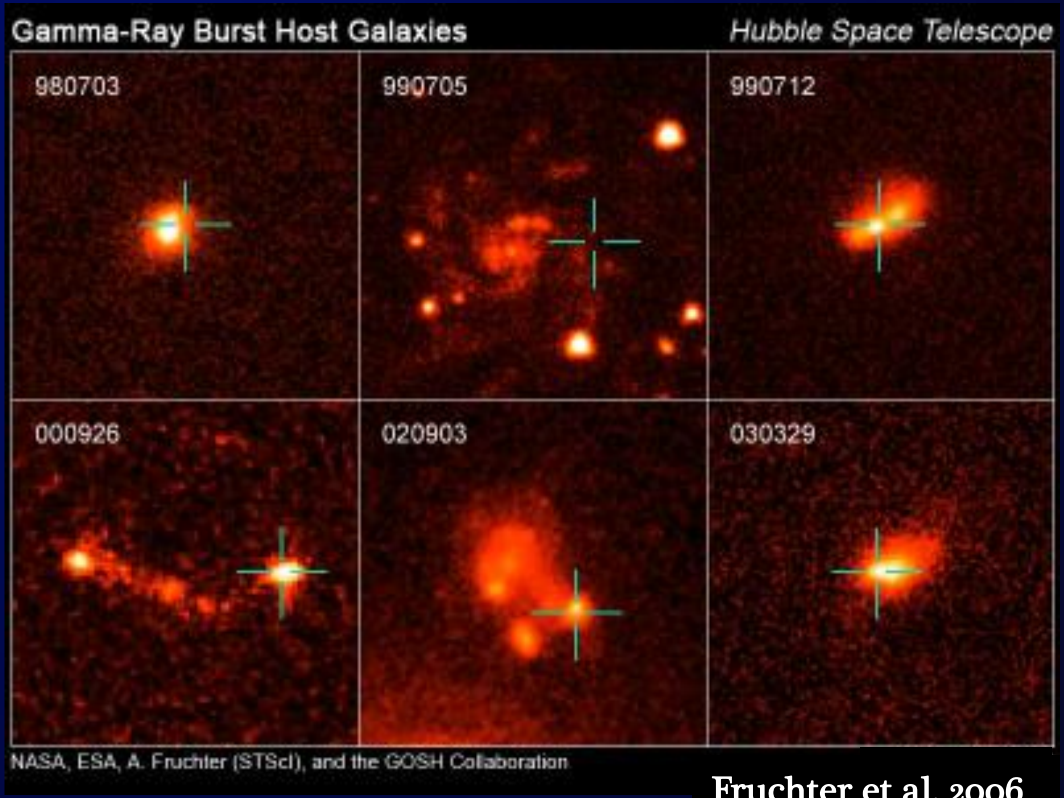
However, their utility can be strongly impacted by environmental biases…

In recent years, several studies found evidence that LGRBs occured 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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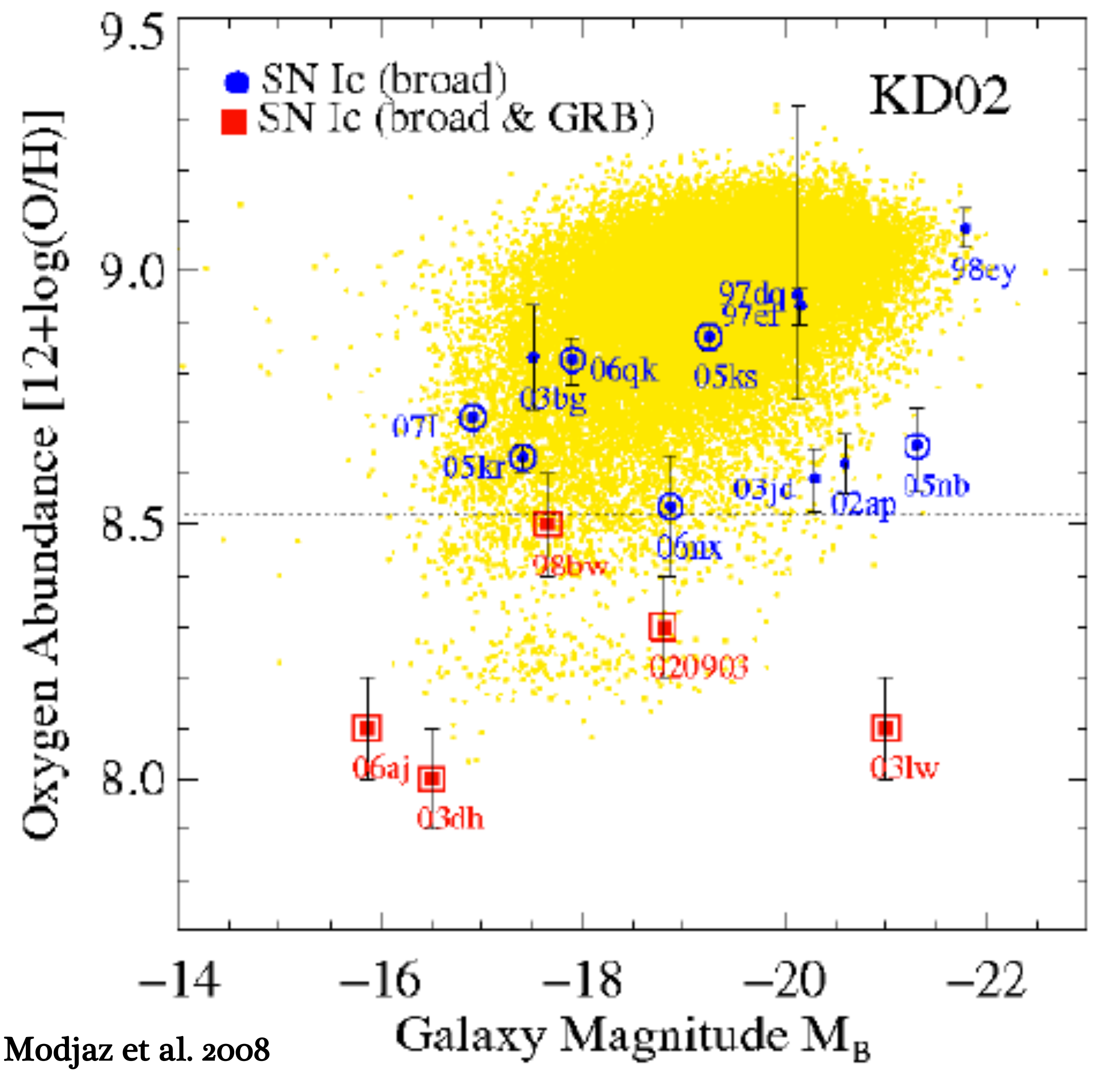

Modjaz et al. 2008

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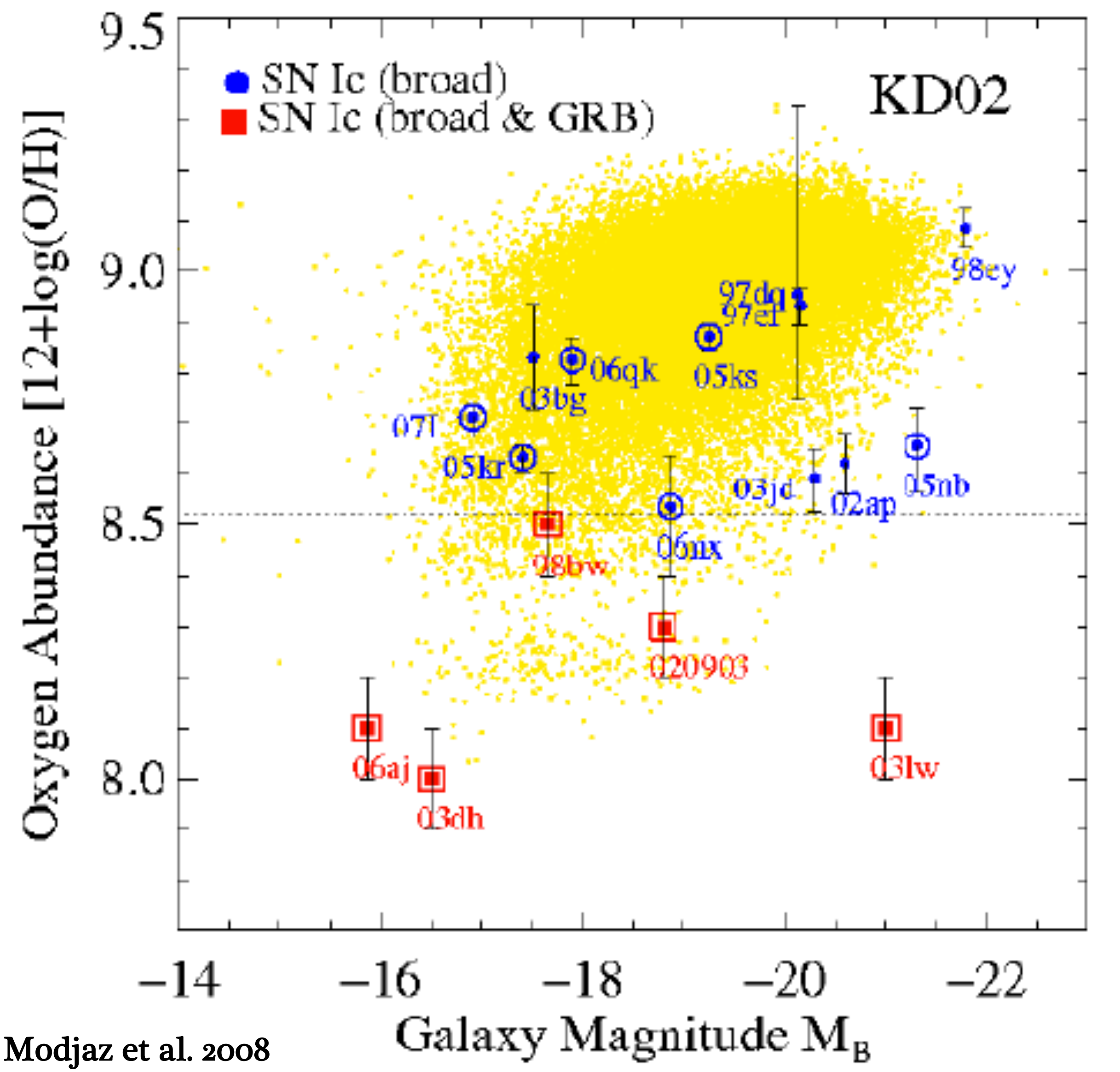
A low-metallicity bias is supported by stellar evolutionary theory under the *collapsar* model…



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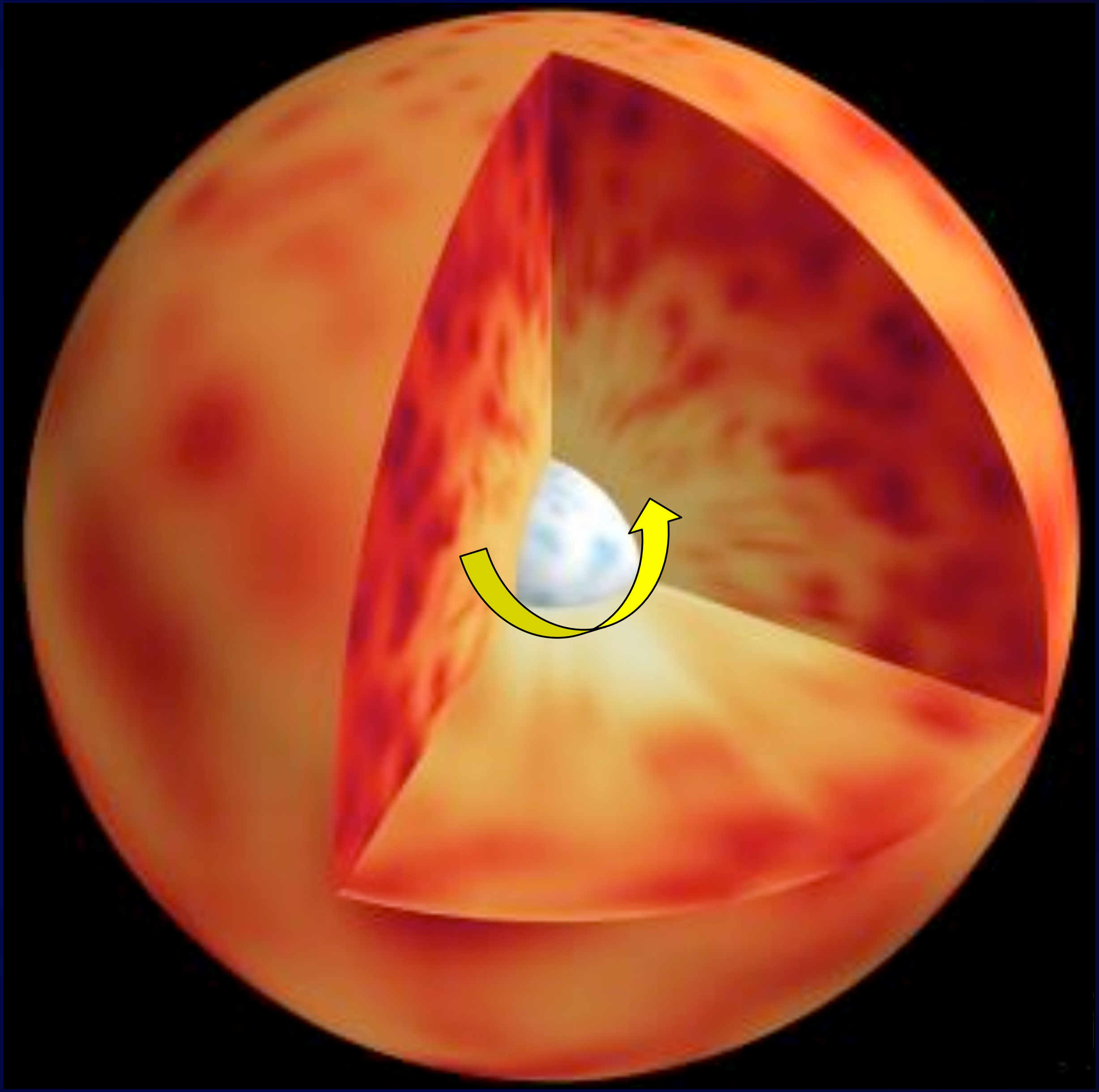

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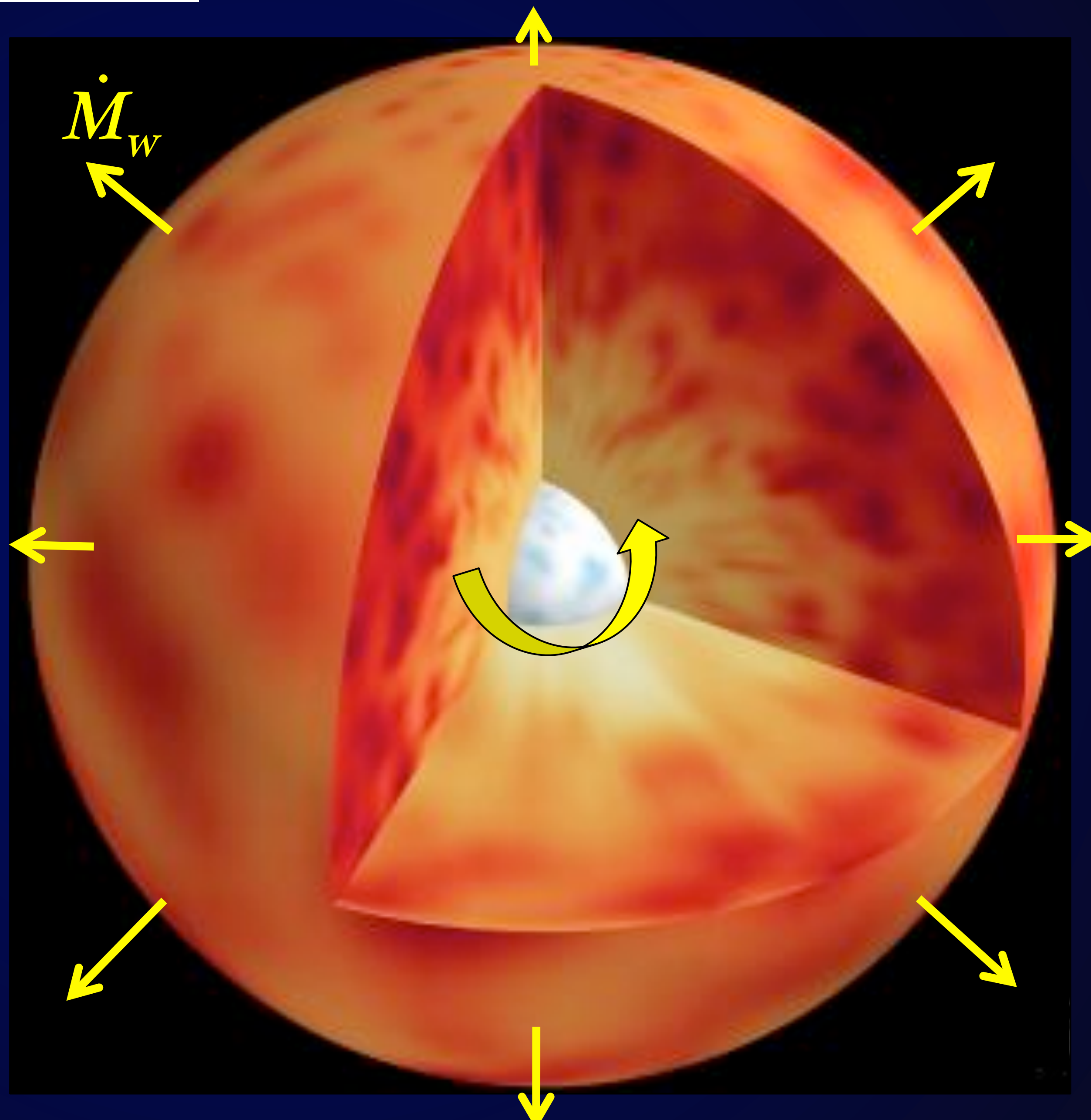
$$\dot{M}_w \propto Z^{0.7}$$ (Vink et al. 2001)

…stronger winds at higher Z lead to more angular momentum loss.



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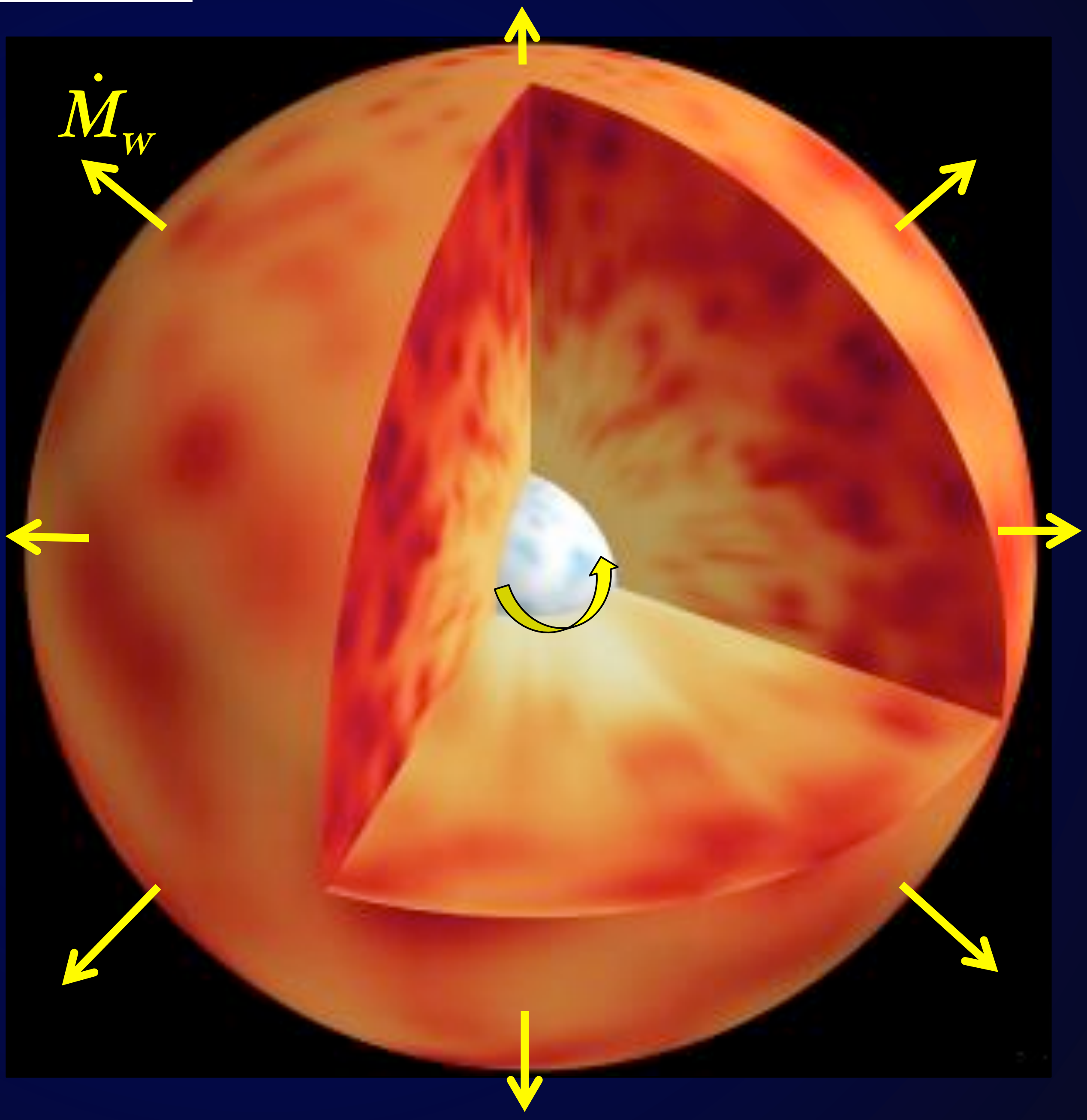

…stronger winds at higher Z lead to more angular momentum loss.

Diminished core rotation should **prevent LGRB production in high-Z hosts.**

Maximum host Z?

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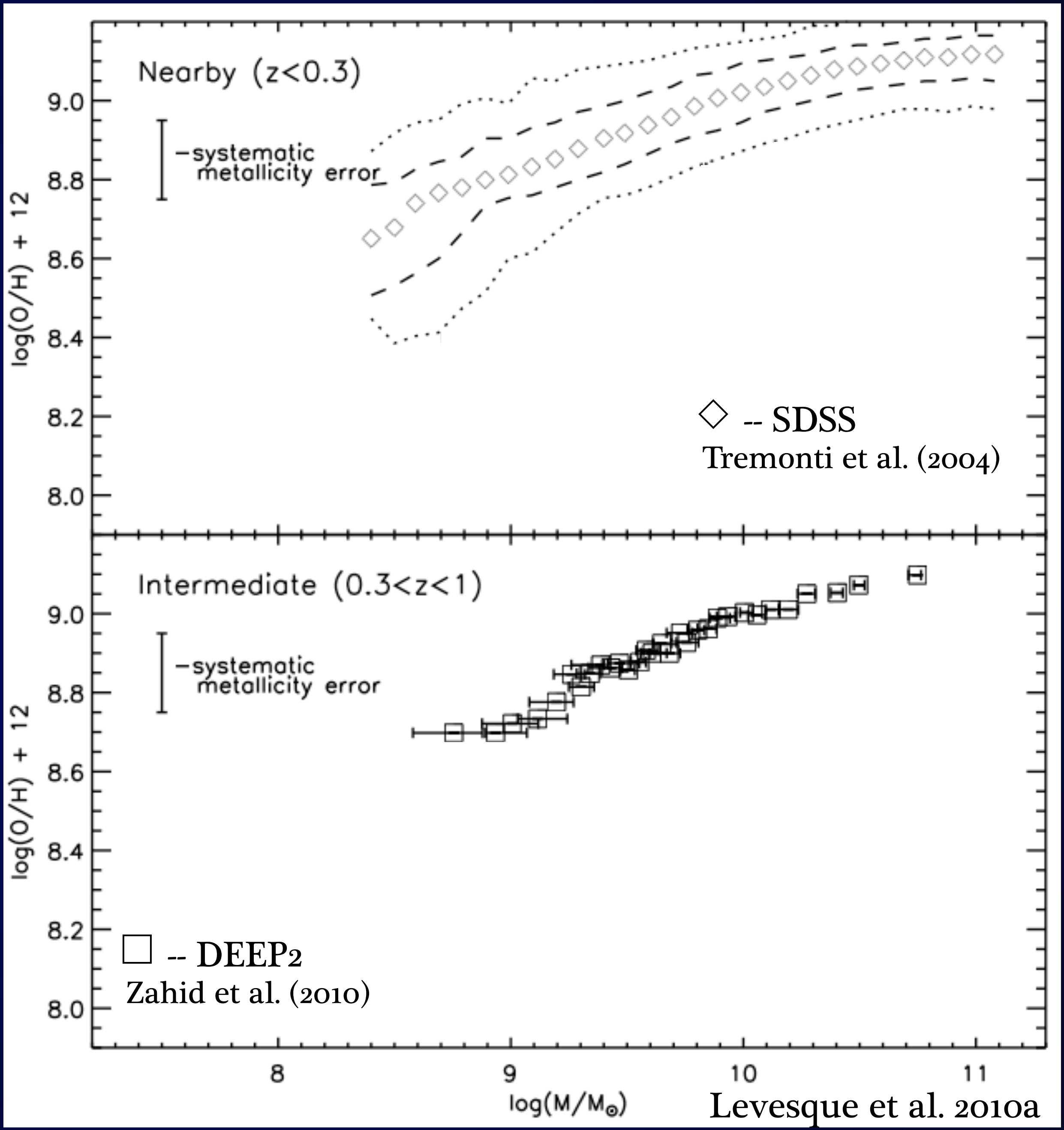

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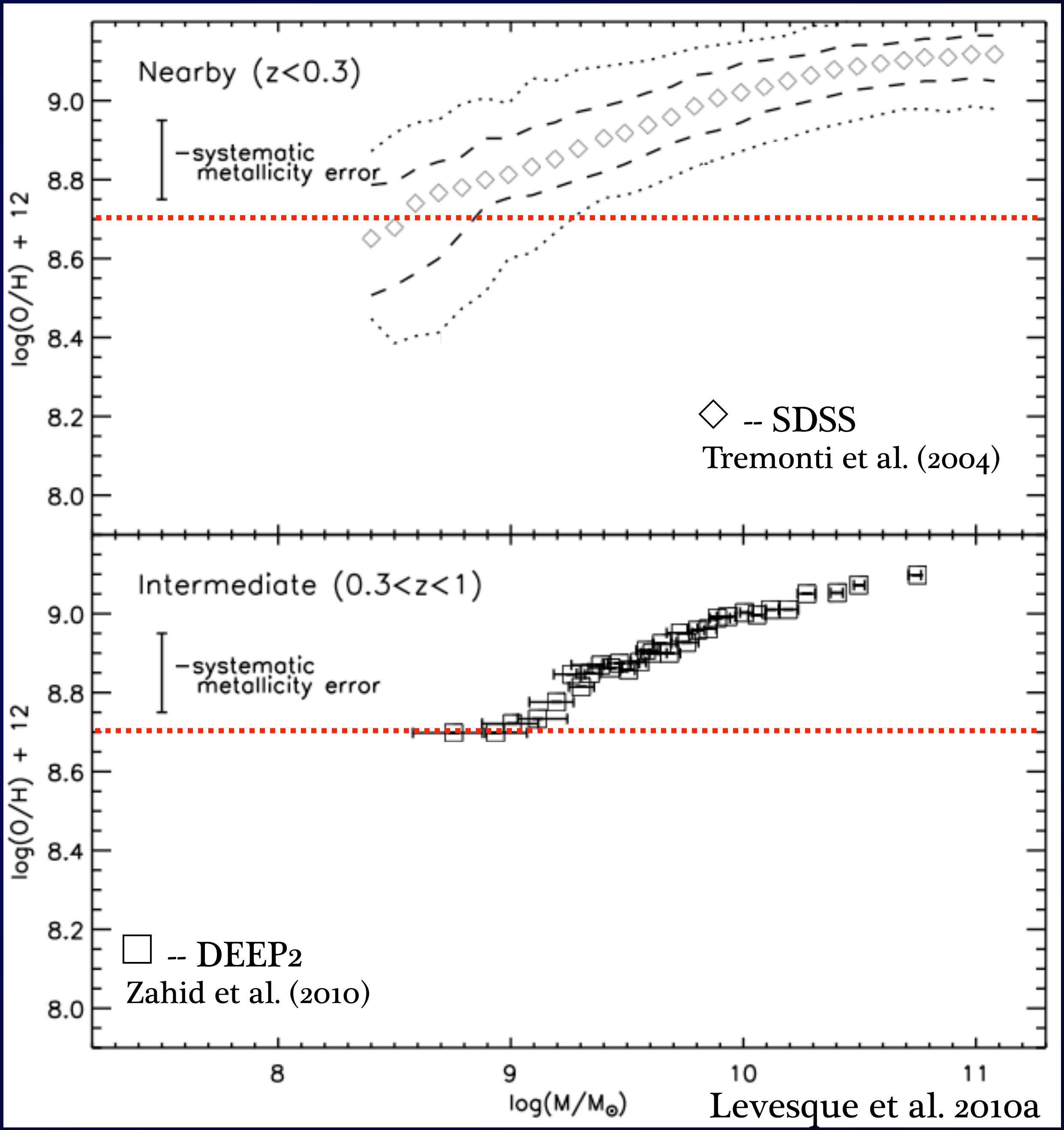
The simplest collapsar model predicts a cutoff metallicity.



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Instead the hosts:
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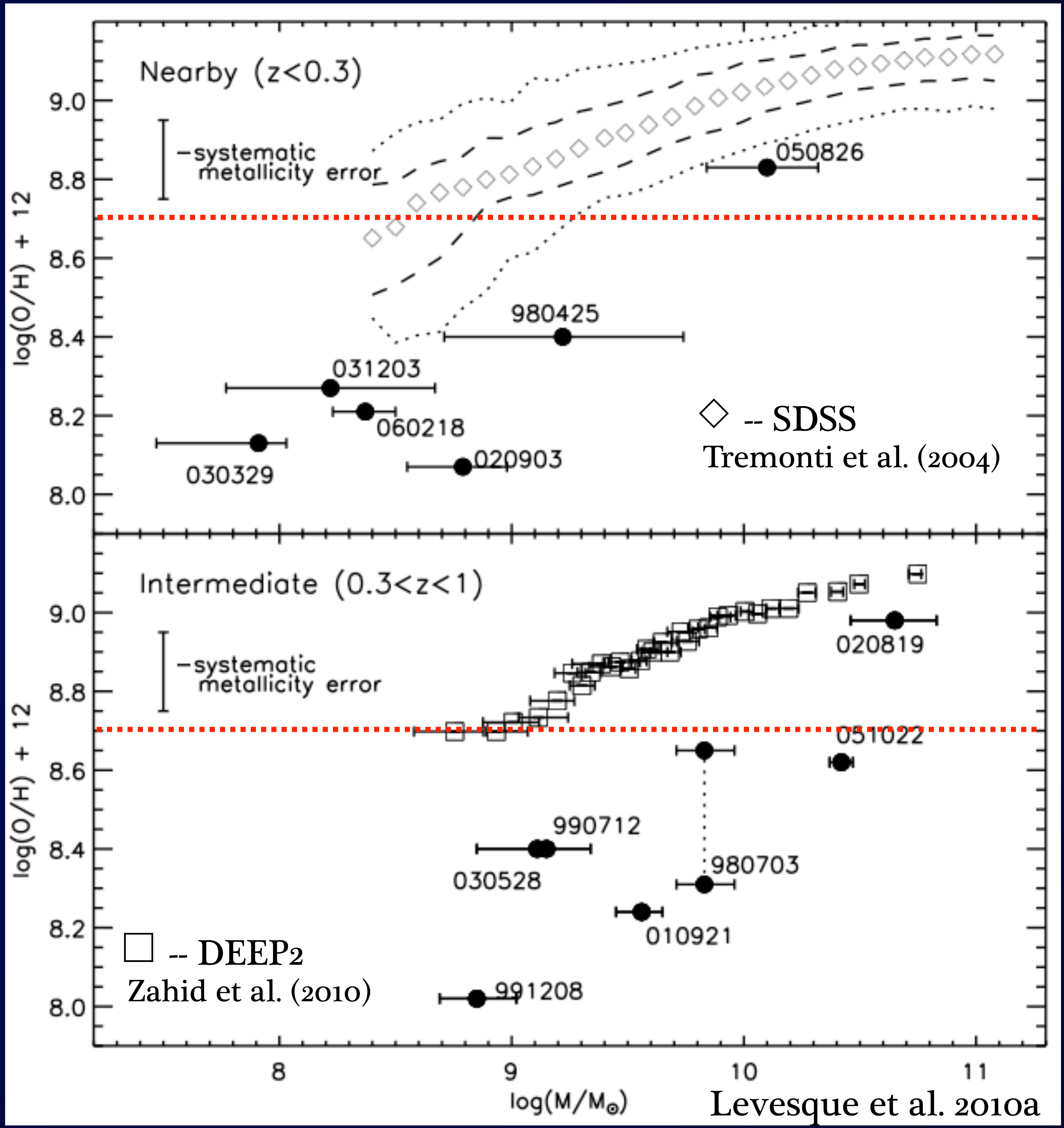

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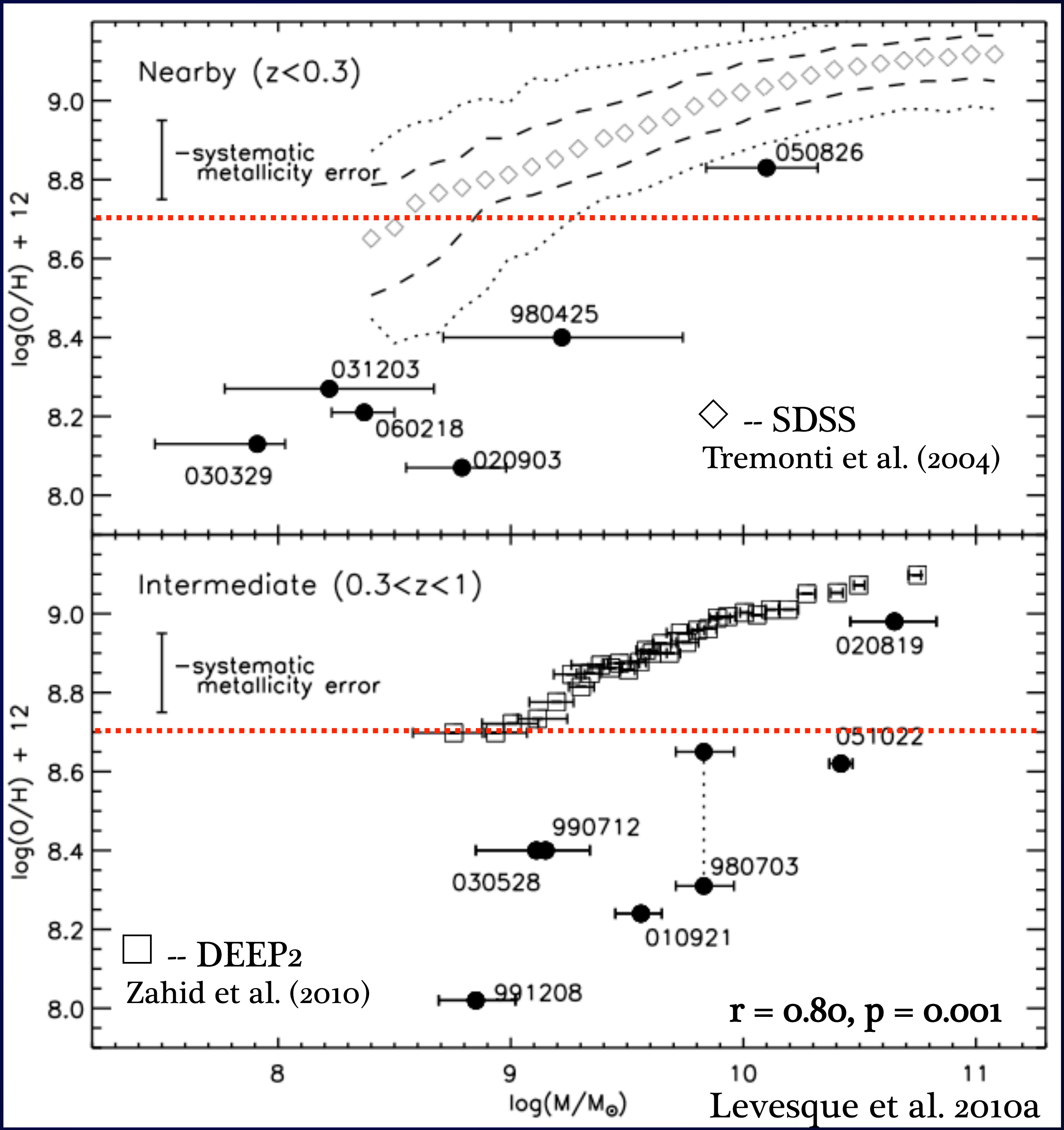
Maximum host Z?

The simplest collapsar model predicts a cutoff metallicity.

Instead the hosts:
- show no cutoff
- follow their own robust M-Z relation



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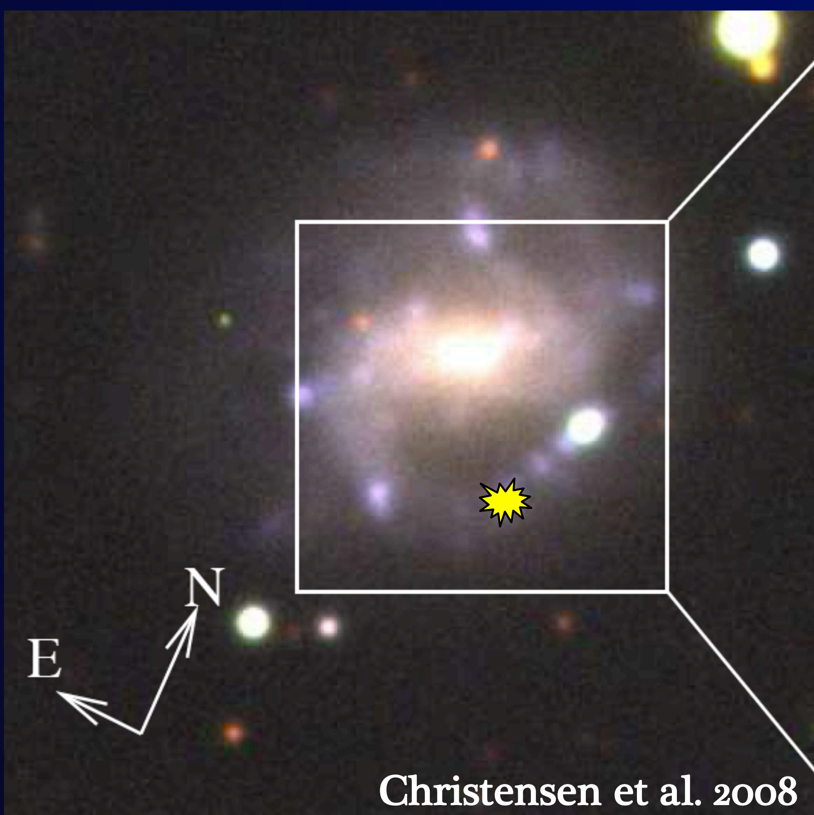
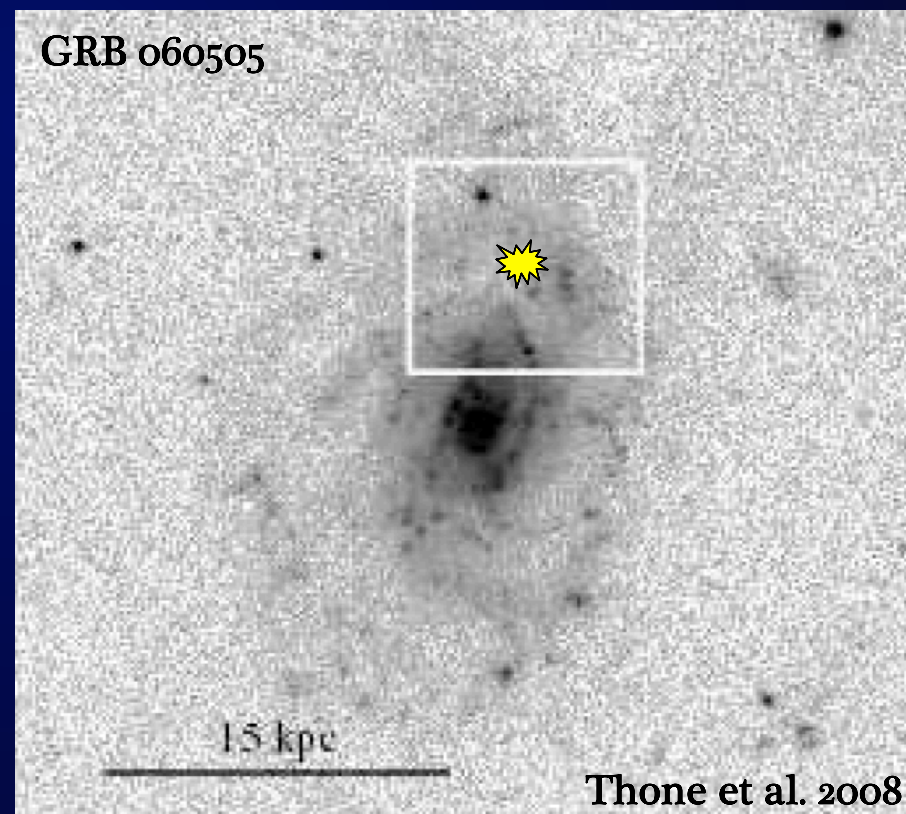
~~Maximum host Z?~~ Low local Z?

- are these "global" metallicities accurate estimates?

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





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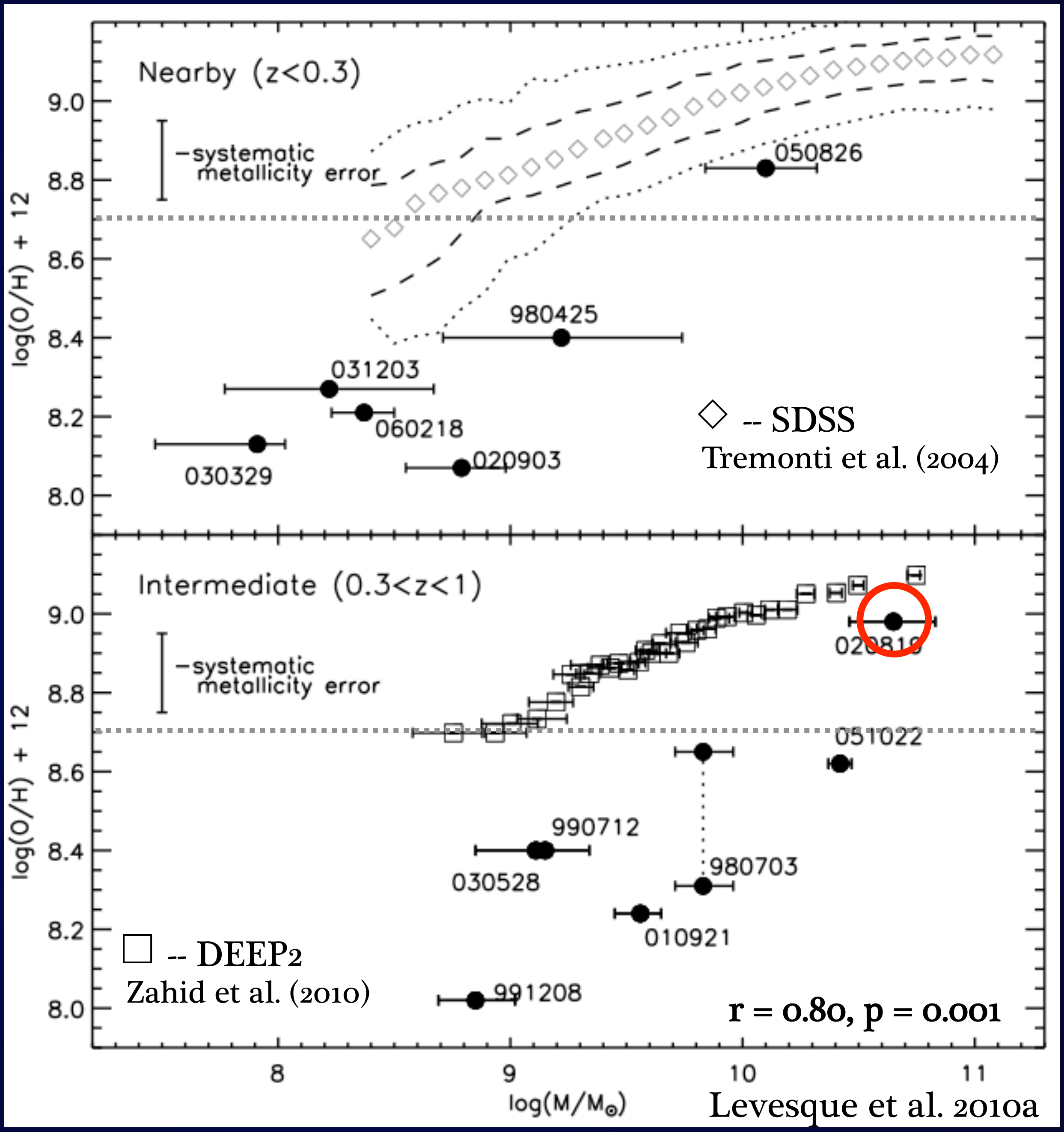

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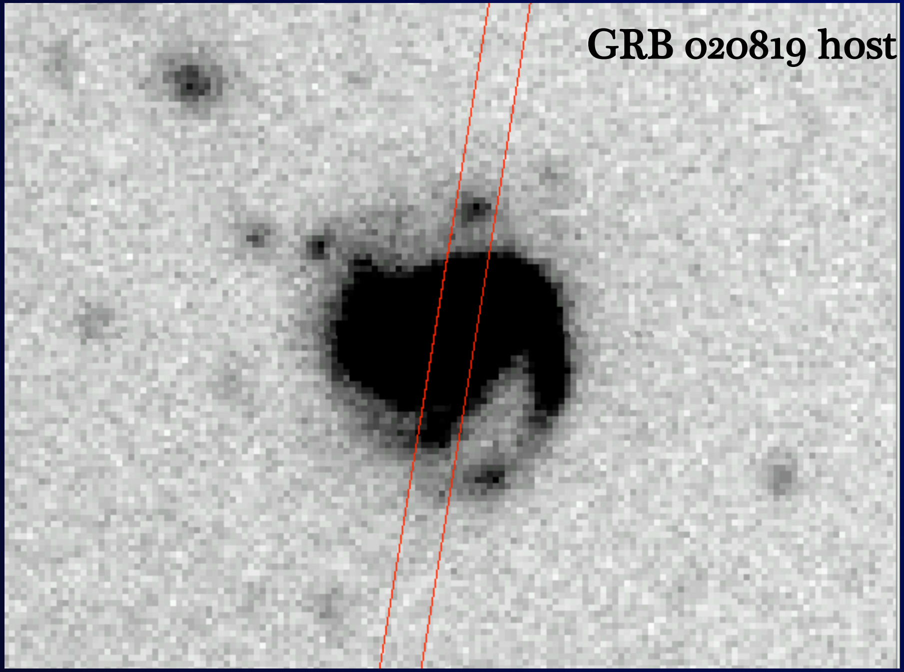
Observed GRB 020819 host galaxy nucleus AND explosion site:



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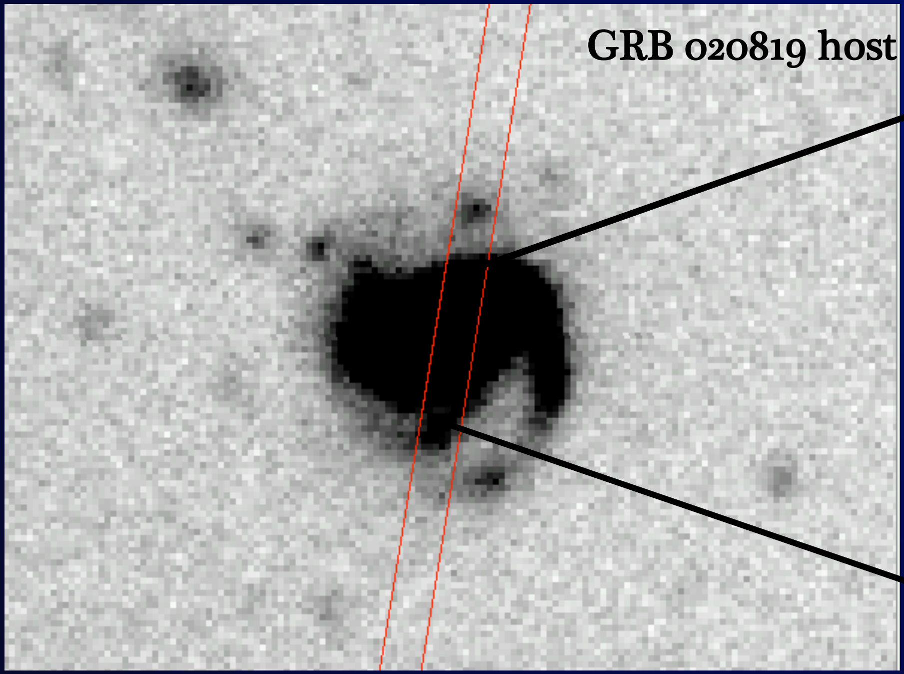

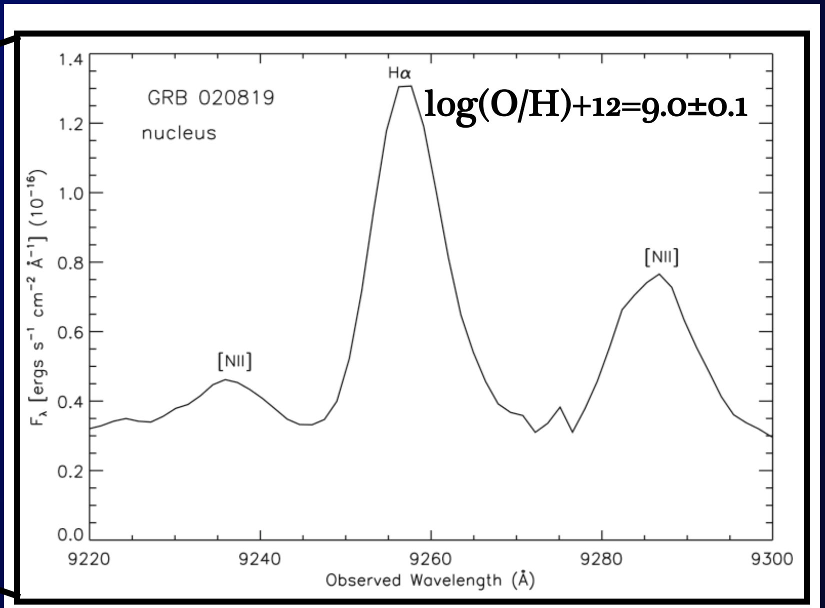

Levesque et al. 2010b

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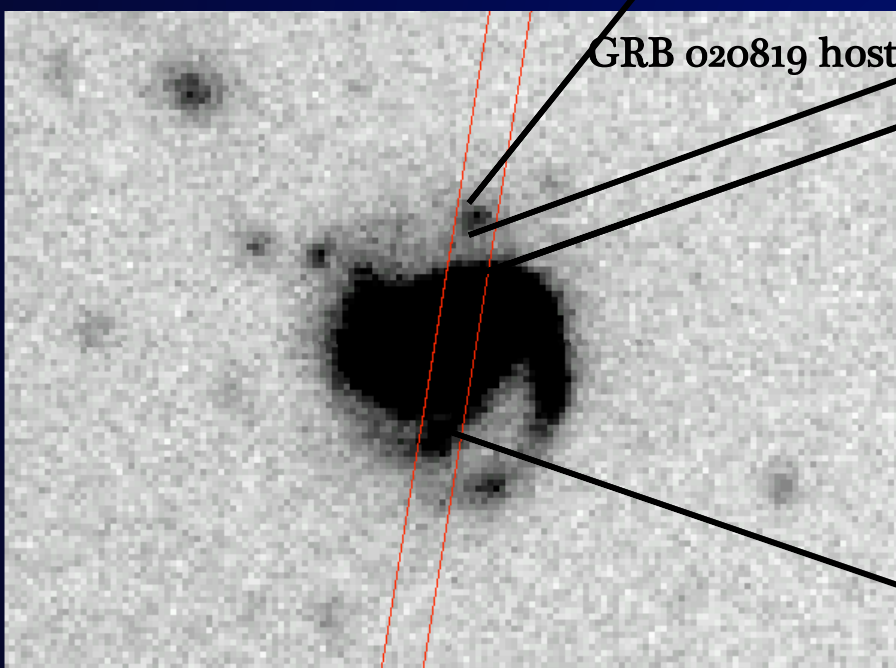

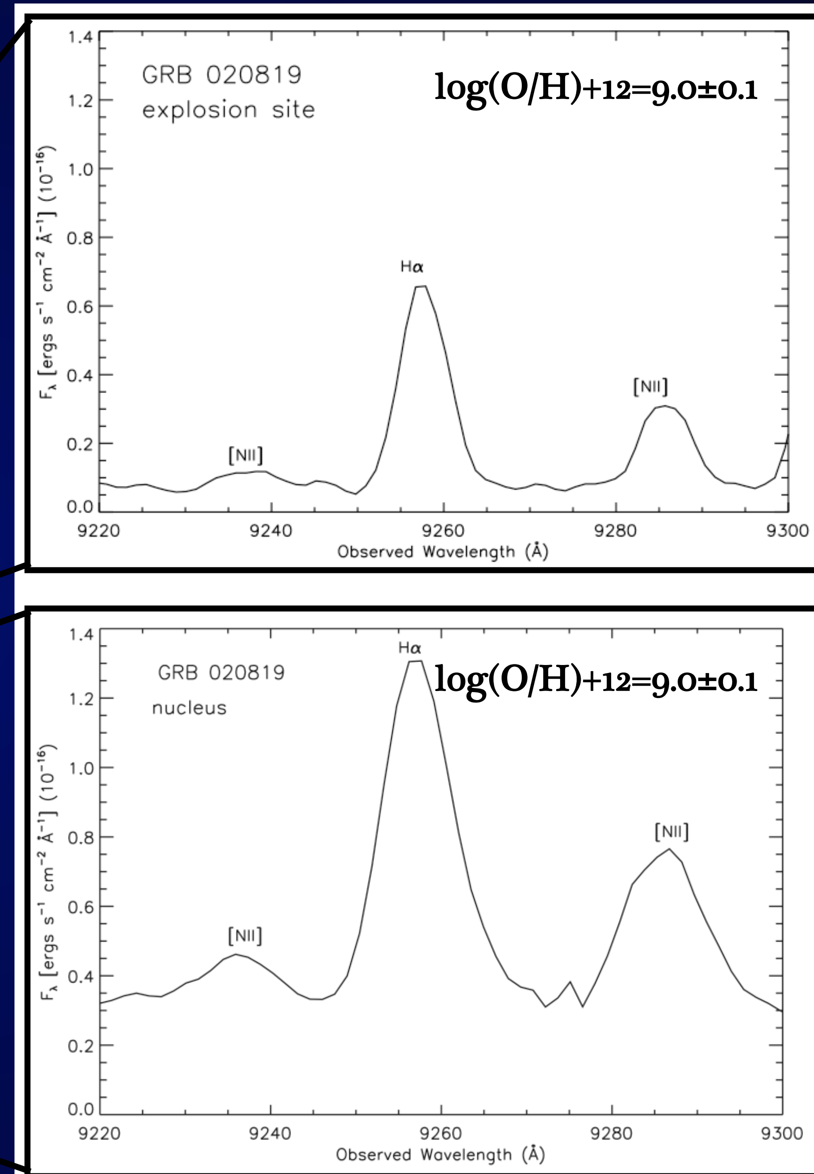

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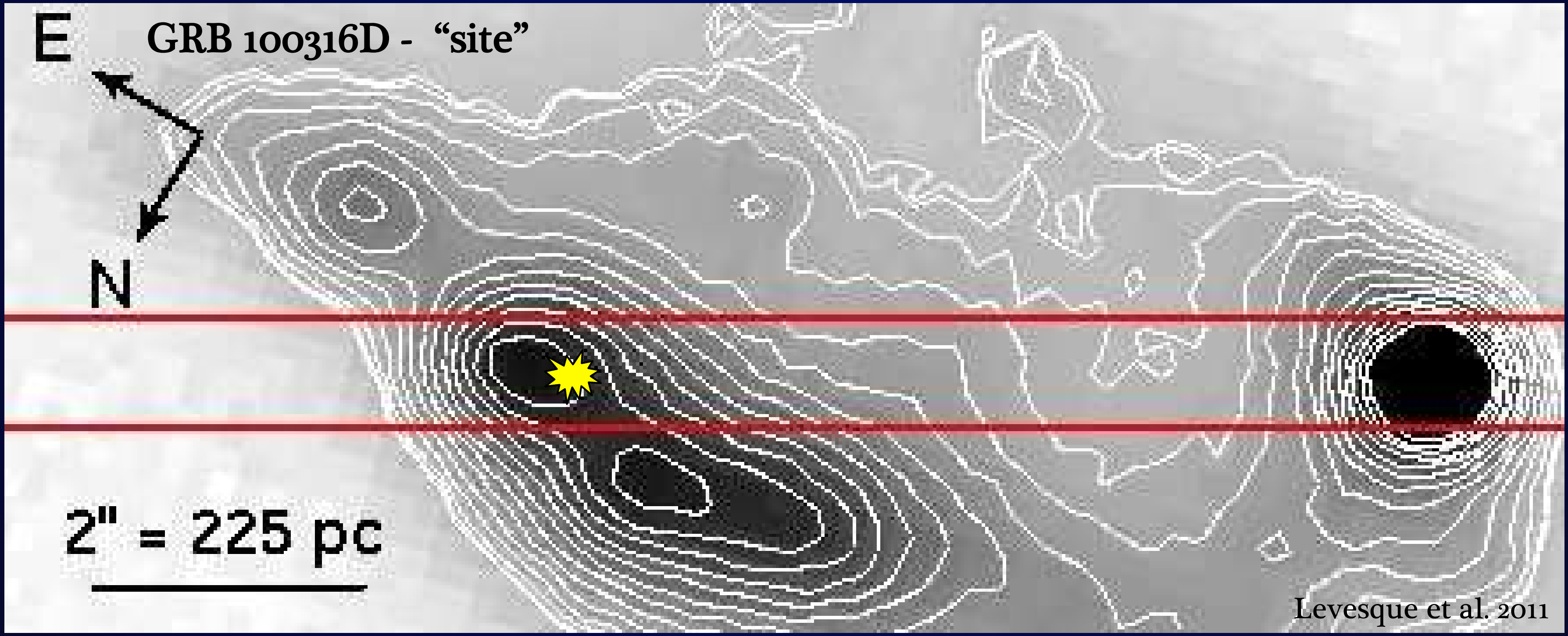
GRB 100316D: very nearby (z = 0.06) GRB/SN

Two longslit spectra across the host complex, centered on the *explosion site*



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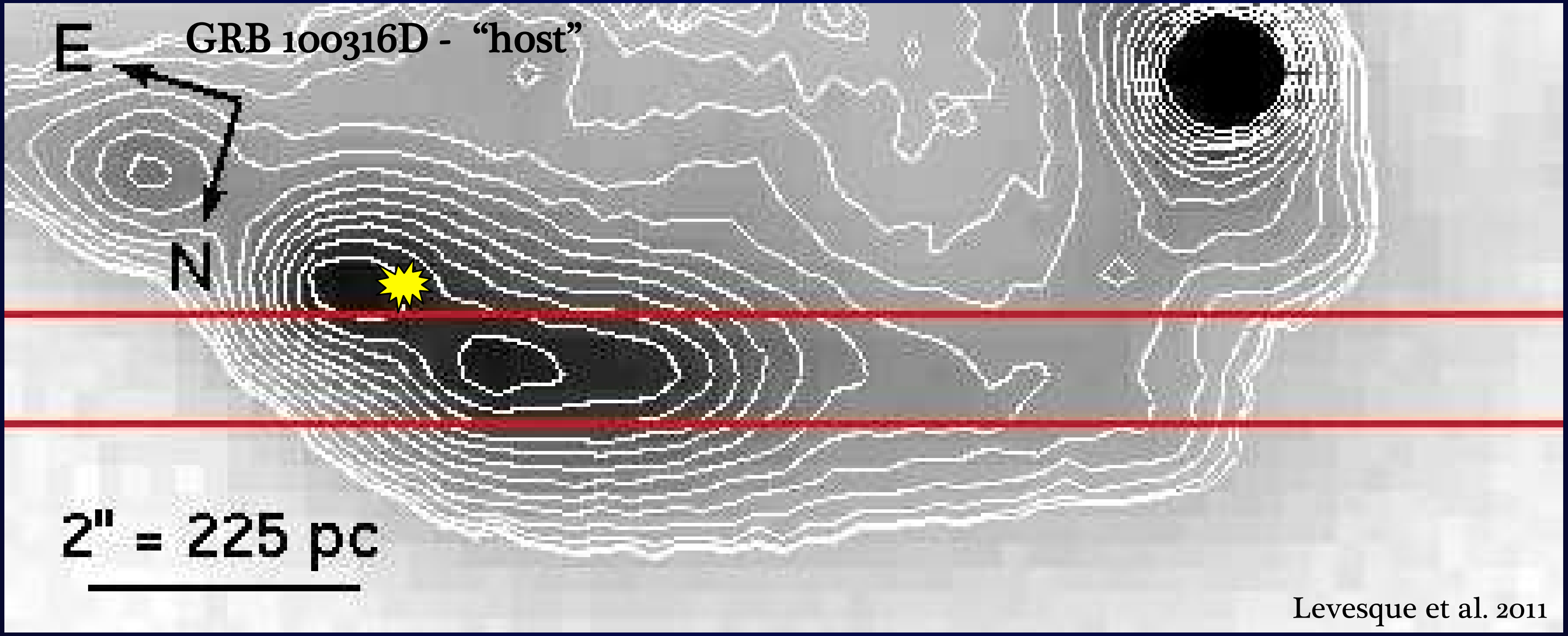
GRB 100316D: very nearby (z = 0.06) GRB/SN

Two longslit spectra across the host complex, centered on the *explosion site* and the *extended host emission*.



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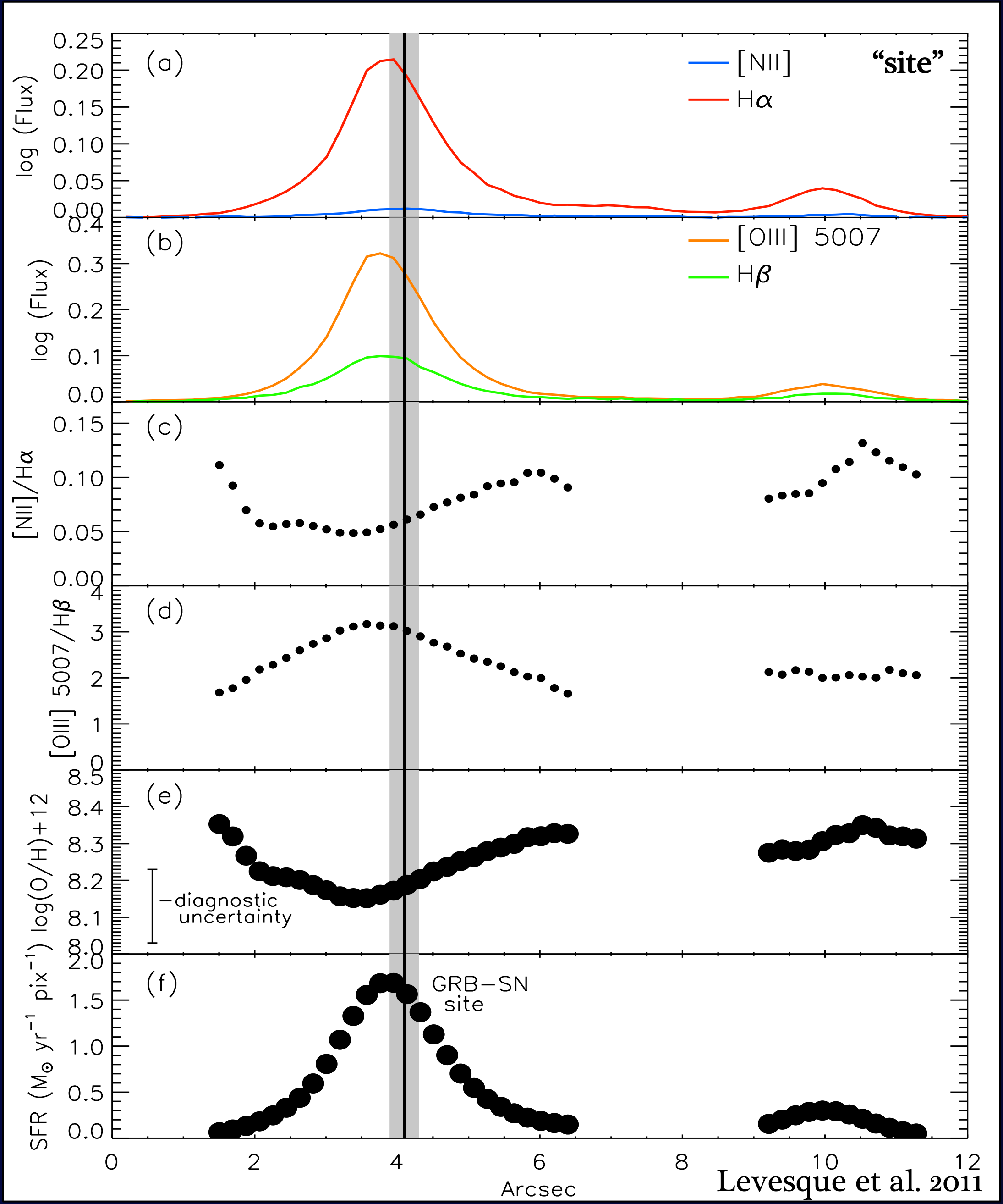
- GRB occurred near Z minimum and SFR maximum



Levesque et al. 2011

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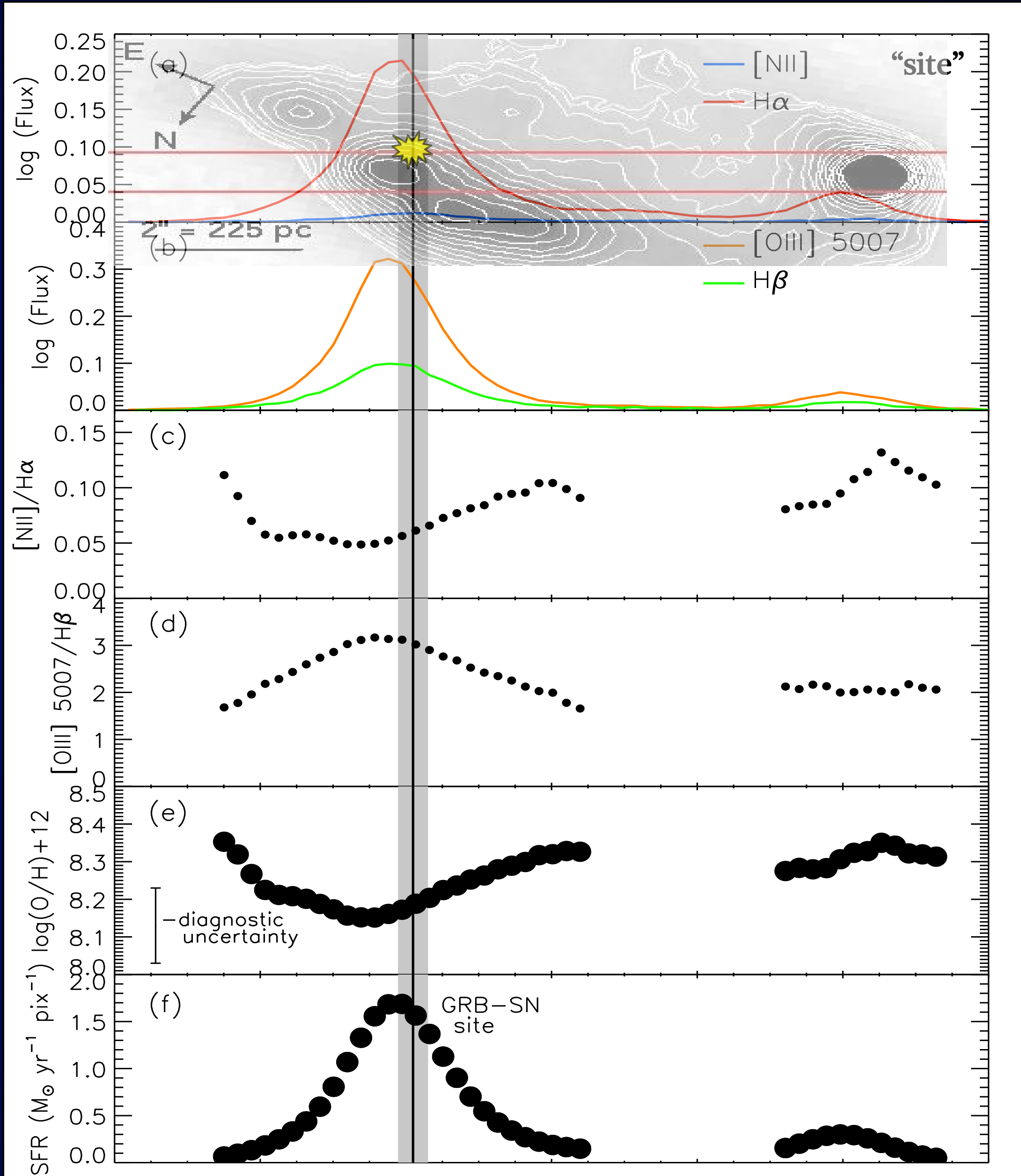

Levesque et al. 2011

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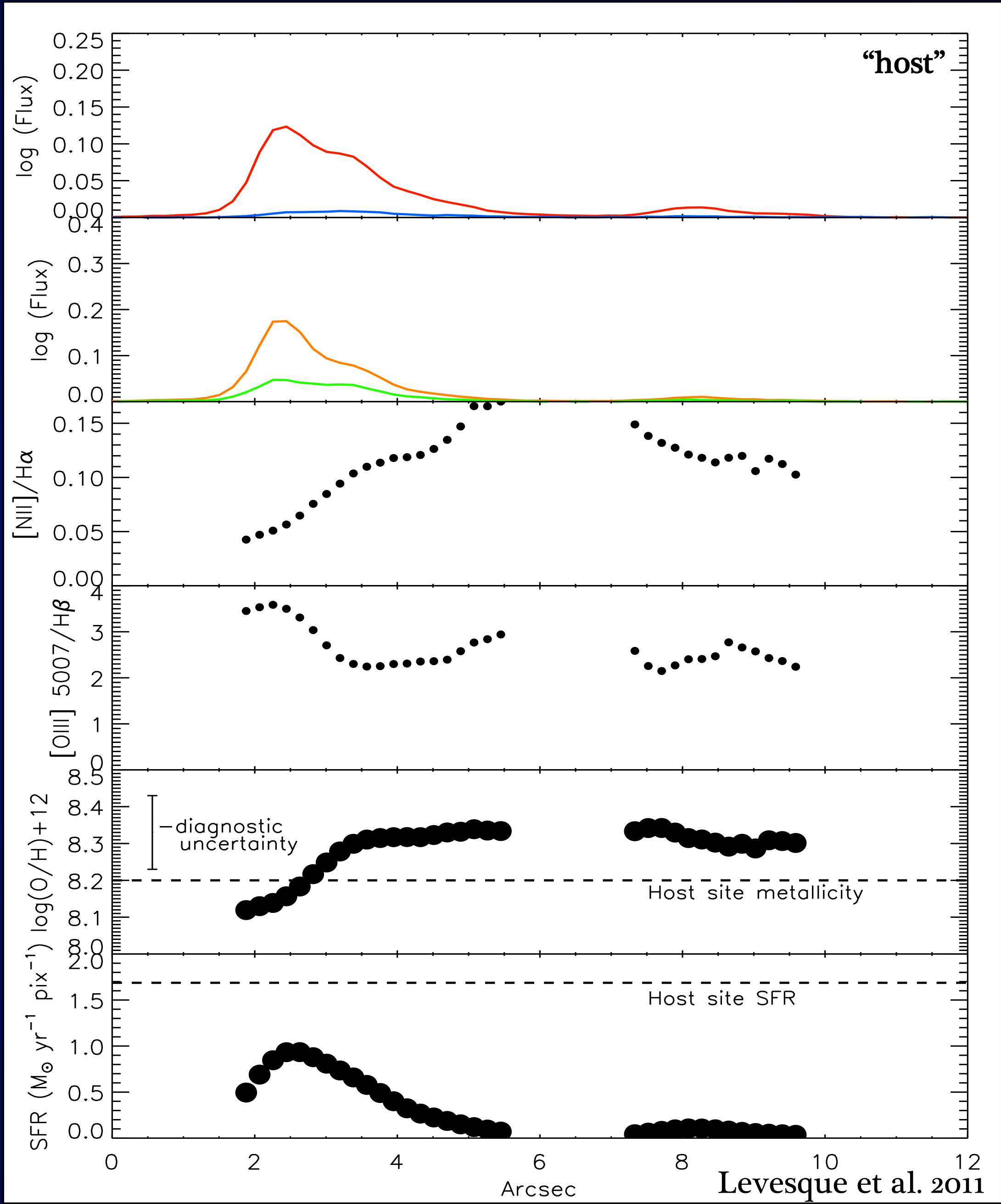
- Z gradient across entire galaxy is very low



Levesque et al. 2011

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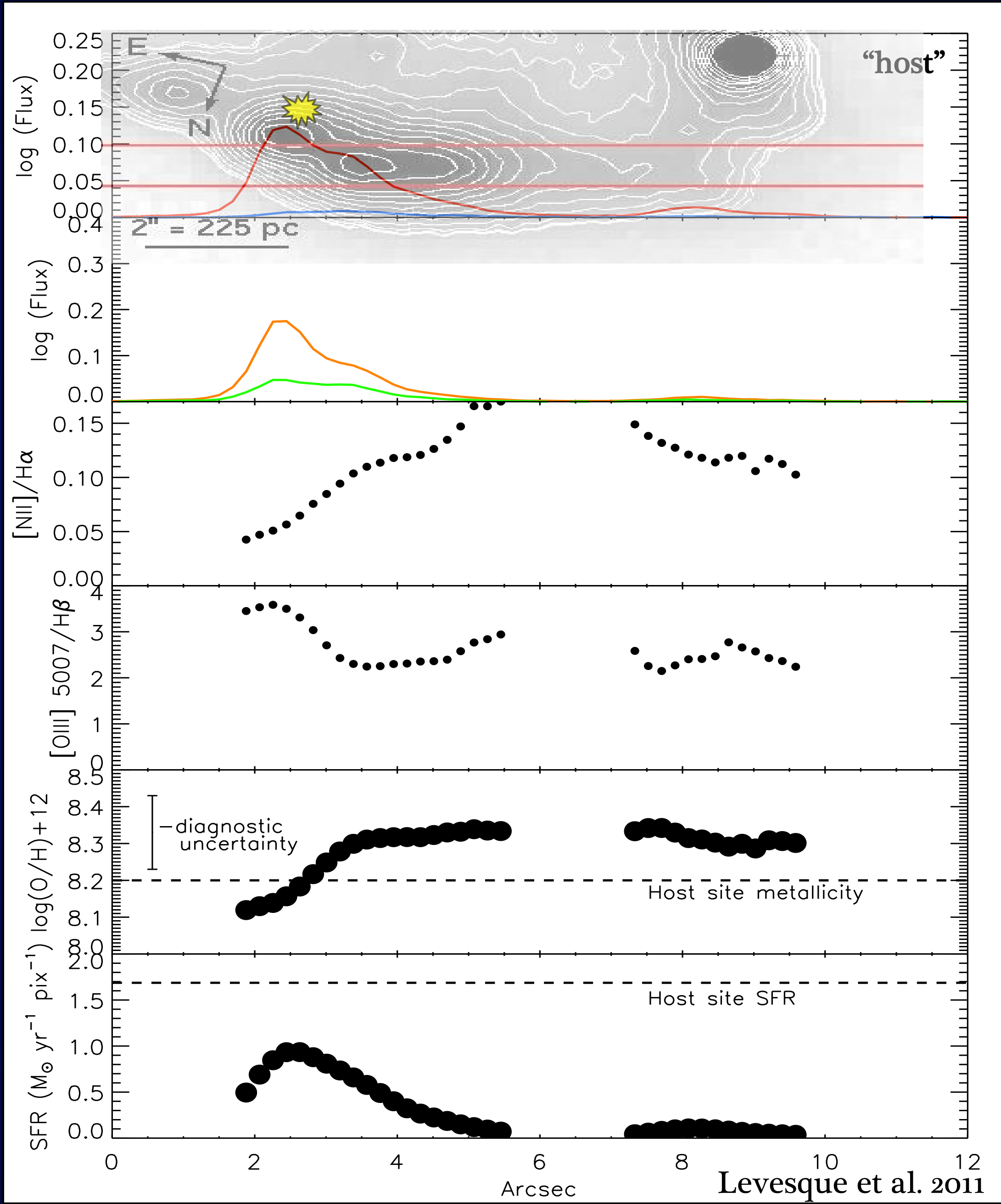

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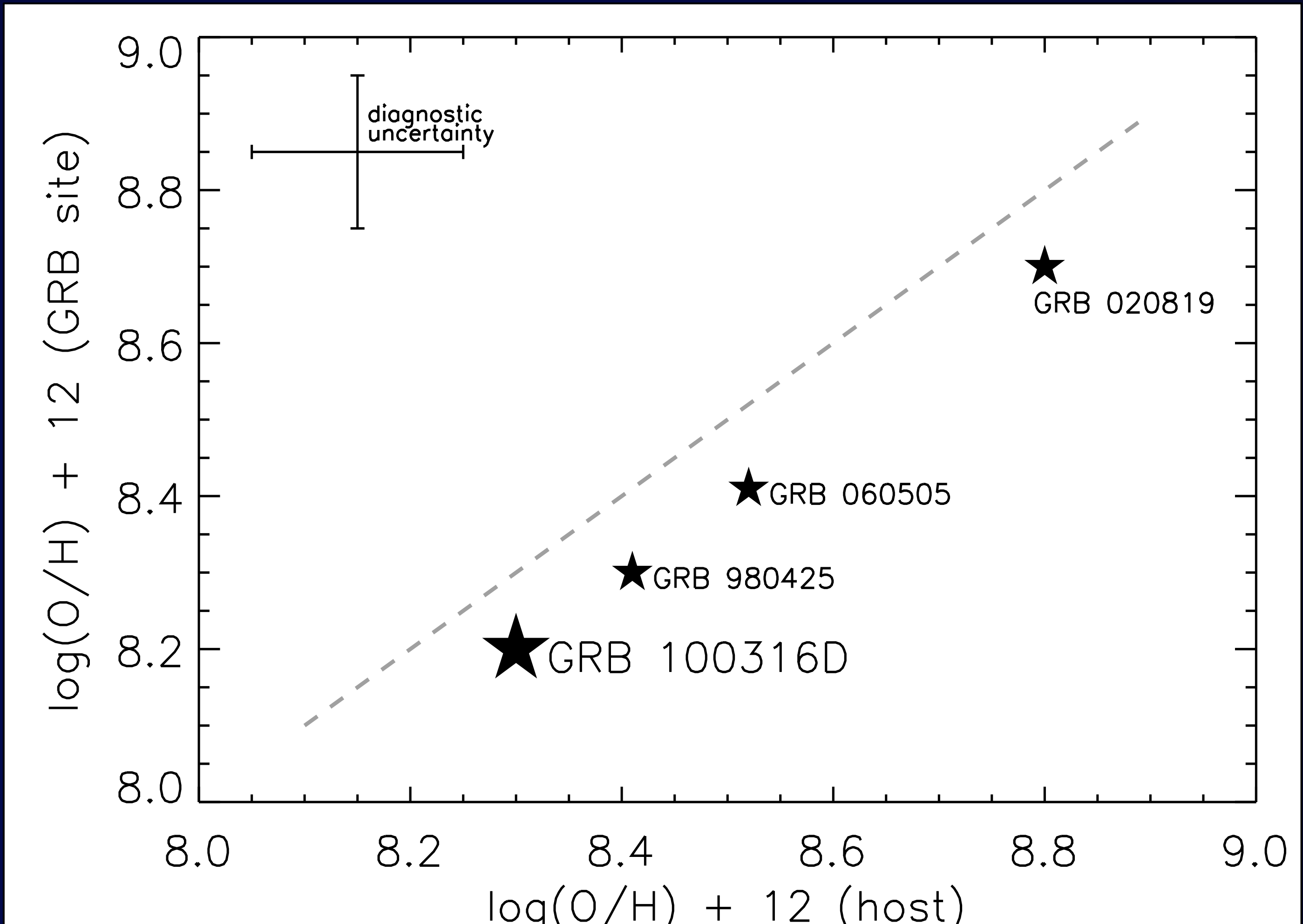

Levesque et al. 2011

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

- What does this mean for larger host studies?

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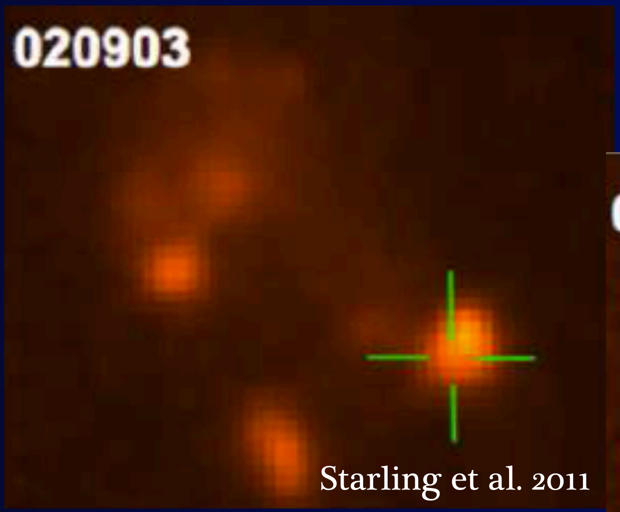
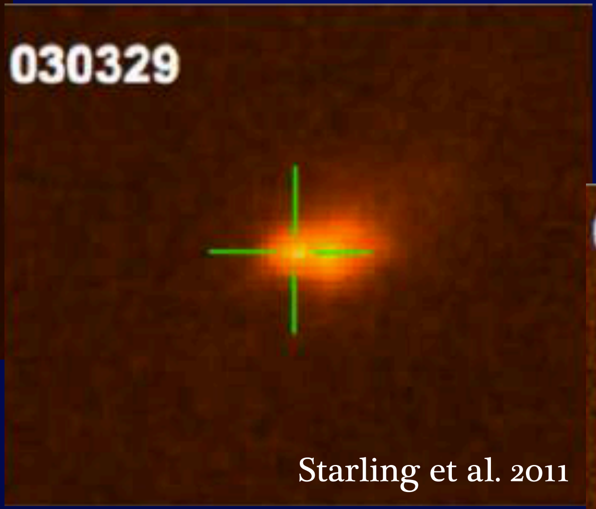
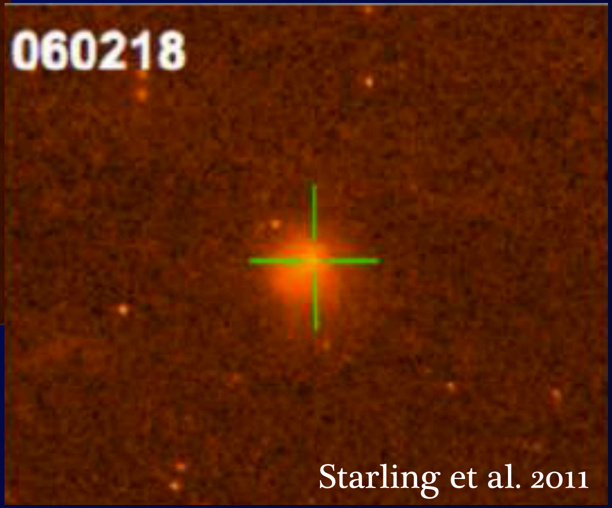
- More studies of LGRB and GRB/SN explosions sites are required

- Three more nearby galaxies offer excellent opportunities for future study…







~~Maximum host Z?~~ ~~Low local Z?~~ Effect on energetics?

We should also consider the energetic properties of LGRBs.

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

θ_j = opening angle of the GRB jet

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

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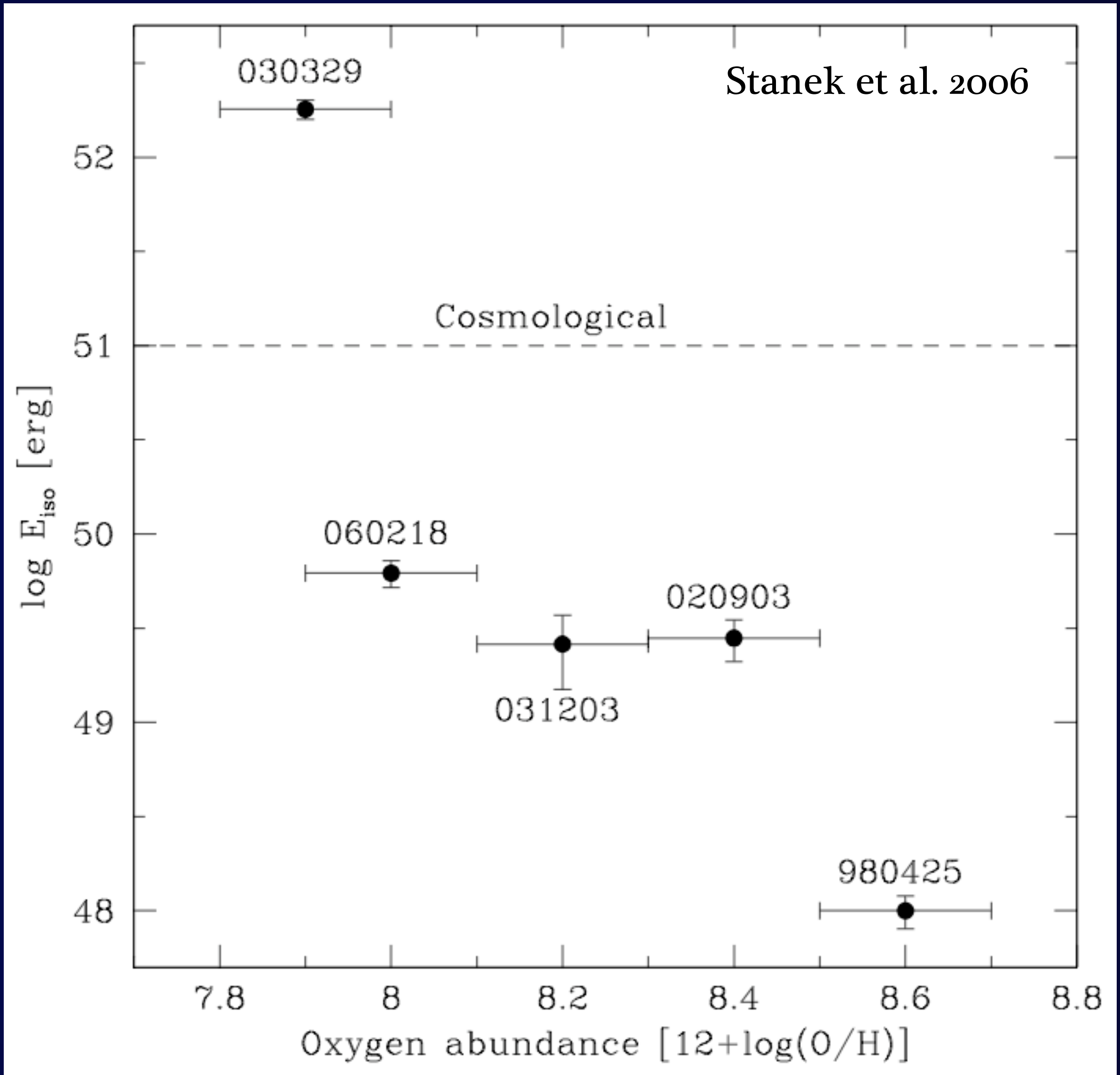

From anticipated metallicity effects on massive stars, LGRBs at higher metallicity SHOULD have lower $E_{\gamma,iso}$ and/or E_{γ}

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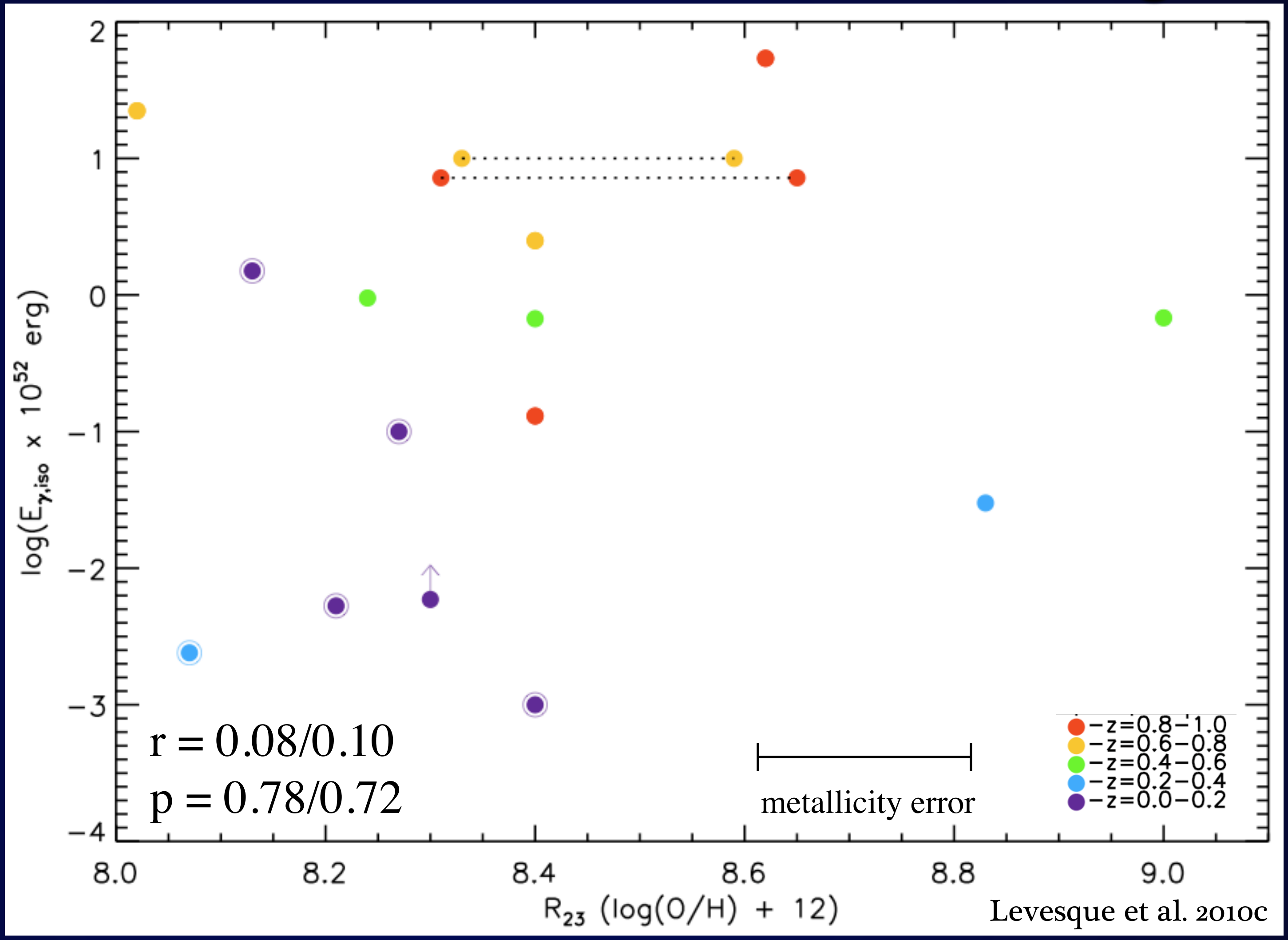

However, we find **no statistically significant correlation** between host galaxy metallicity and $E_{\gamma,iso}$

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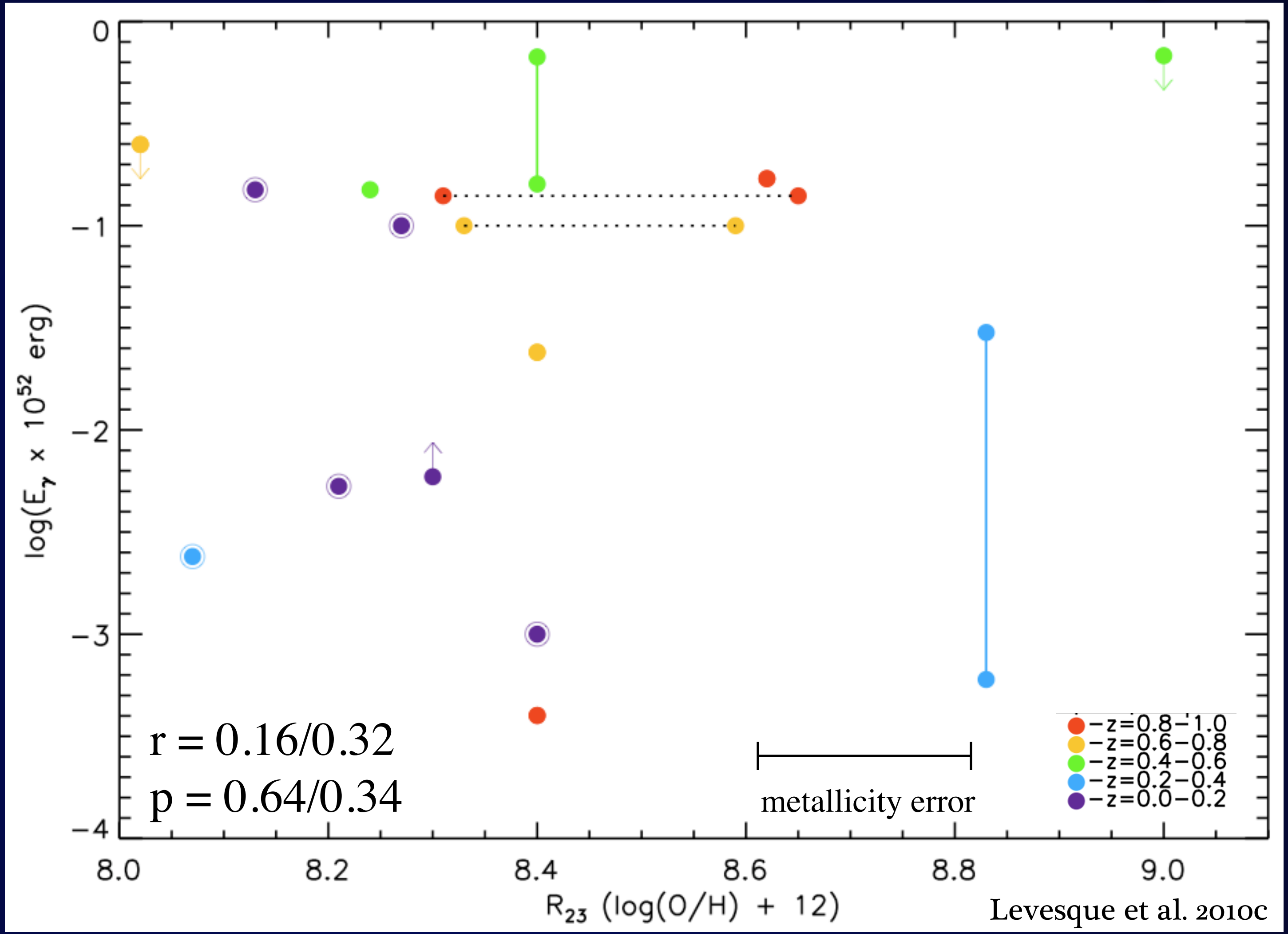

However, we find no statistically significant correlation between host galaxy metallicity and $E_{\gamma,iso}$, *or* E_{γ}.

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~~Maximum host Z?~~ ~~Low local Z?~~ ~~Effect on energetics?~~
So what DOES metallicity do?...

~~Maximum host Z?~~ ~~Low local Z?~~ ~~Effect on energetics?~~

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The modern LGRB progenitor model must:

1. be more common at low metallicity
2. still be present at high metallicity
3. *not* directly connect metallicity and E_γ

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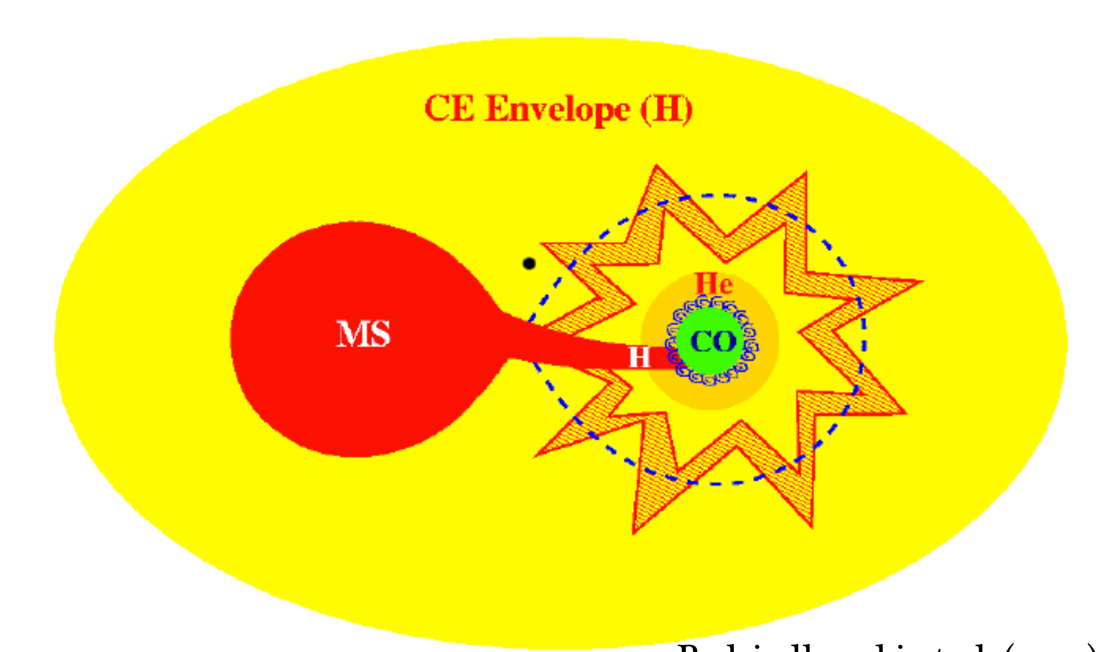

Podsiadlowski et al. (2010)

- GRB Hosts
  - populations
  - high-z utility
  - biases?
- Metallicity
  - cutoff?
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- Looking Ahead

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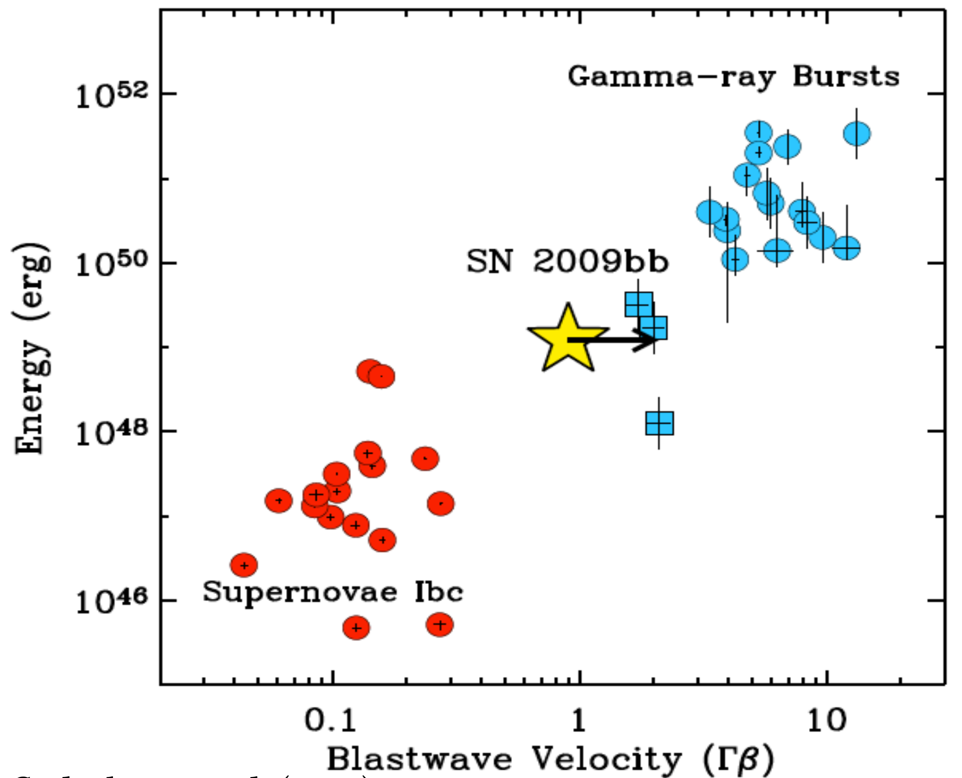

Soderberg et al. (2010)

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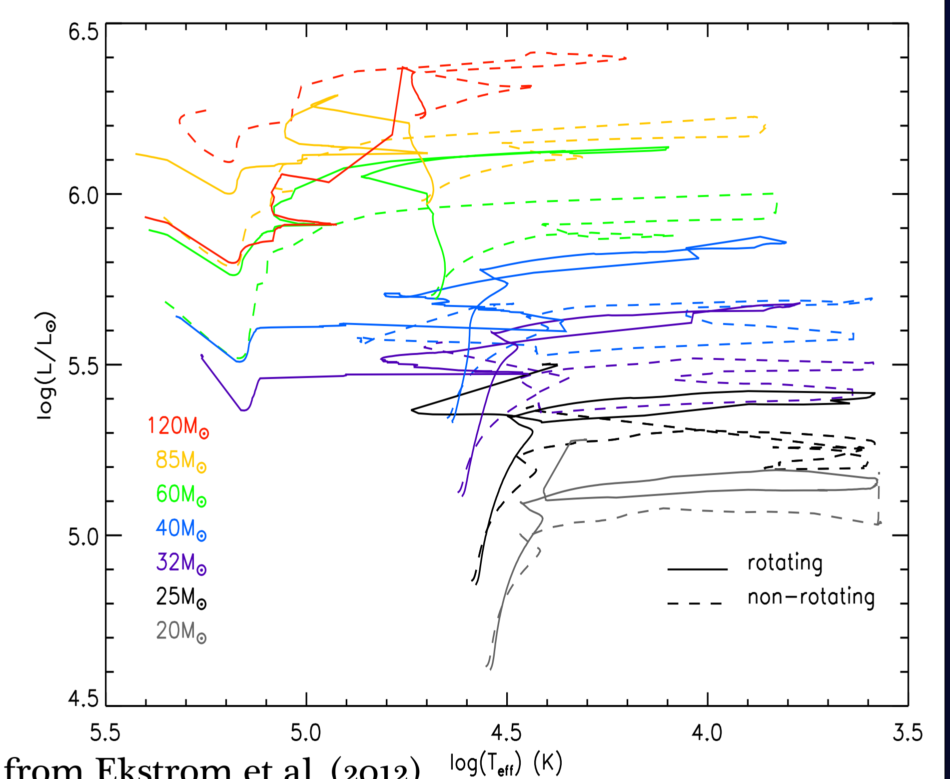

from Ekstrom et al. (2012)

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Looking ahead…

Effects of rotation:

Longer MS lifetimes

Larger post-MS masses

Larger WR mass range

Broader range of WR ages

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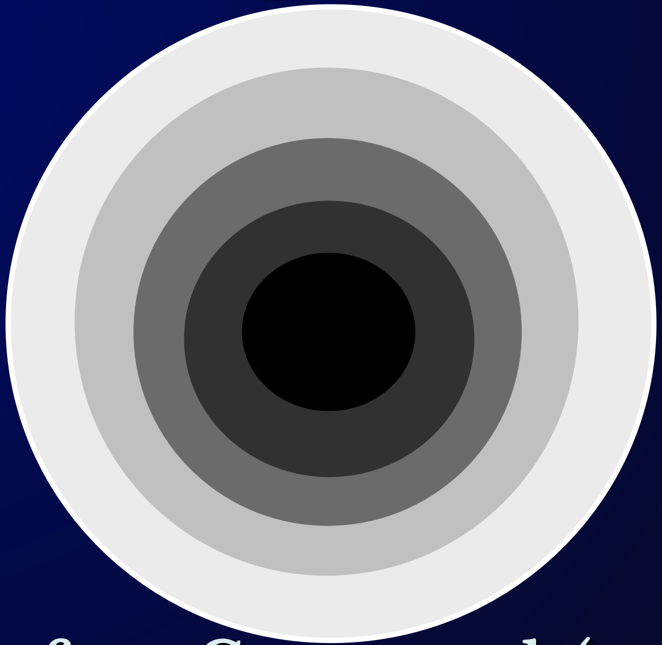
Newest models consider $Z=Z_{\odot}$ stars with $v_{ini} = 0.4v_{crit}$ (Ekstrom et al. 2012)

• perfect differential rotation *over*-predicts the LGRB rate!

decoupled interior



from Georgy et al. (2012)

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from Georgy et al. (2012)

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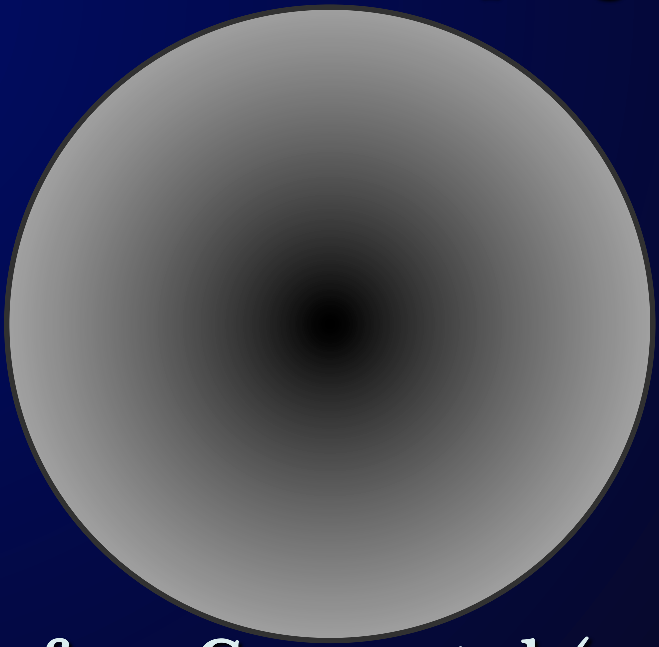
- a strong interior B-field (imposing solid body rotation) over-restricts it
- reality suggests internal differential rotation with moderate coupling

moderate coupling



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Looking ahead…

Effects of rotation:

→ Harder ionizing spectrum

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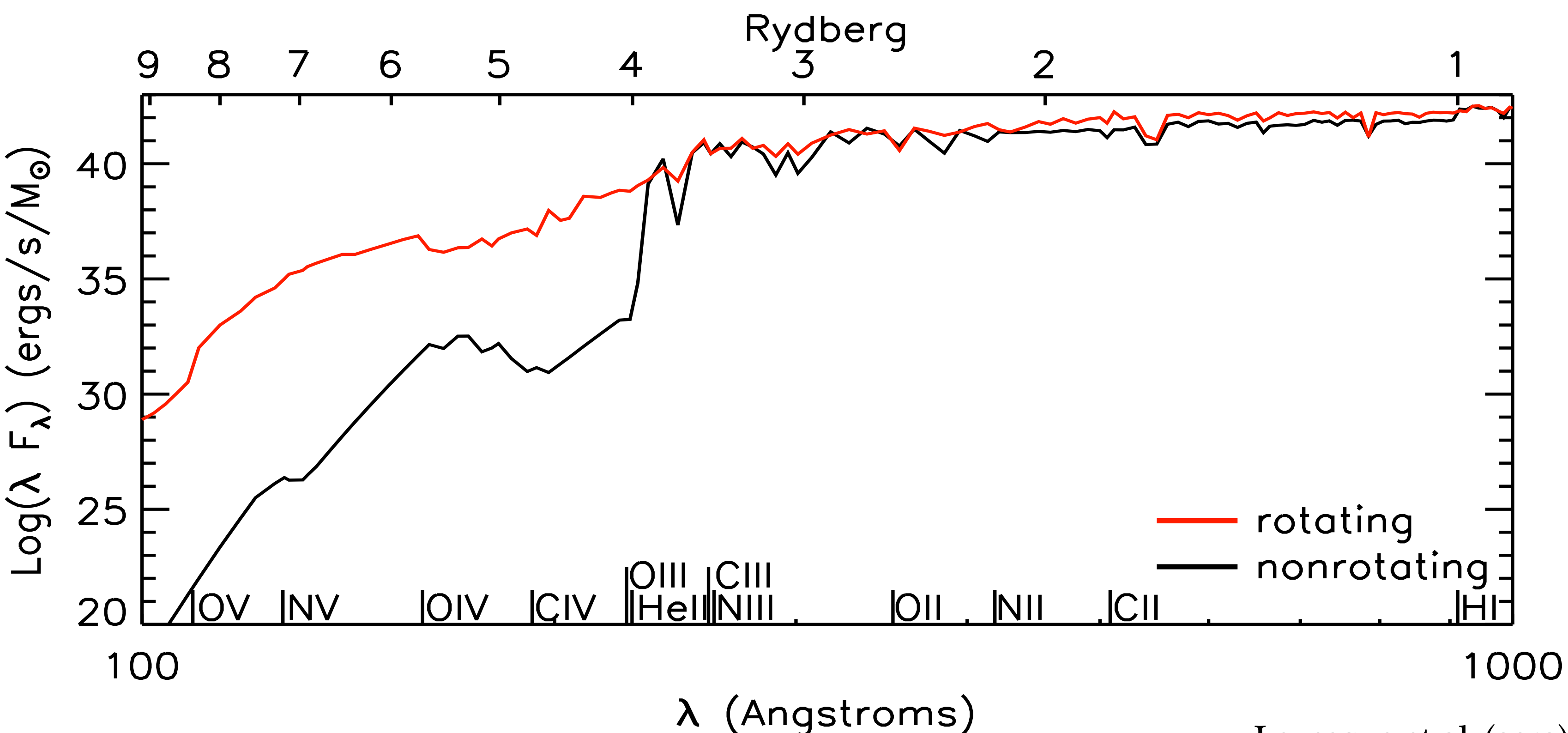

Levesque et al. (2012)

Looking ahead…

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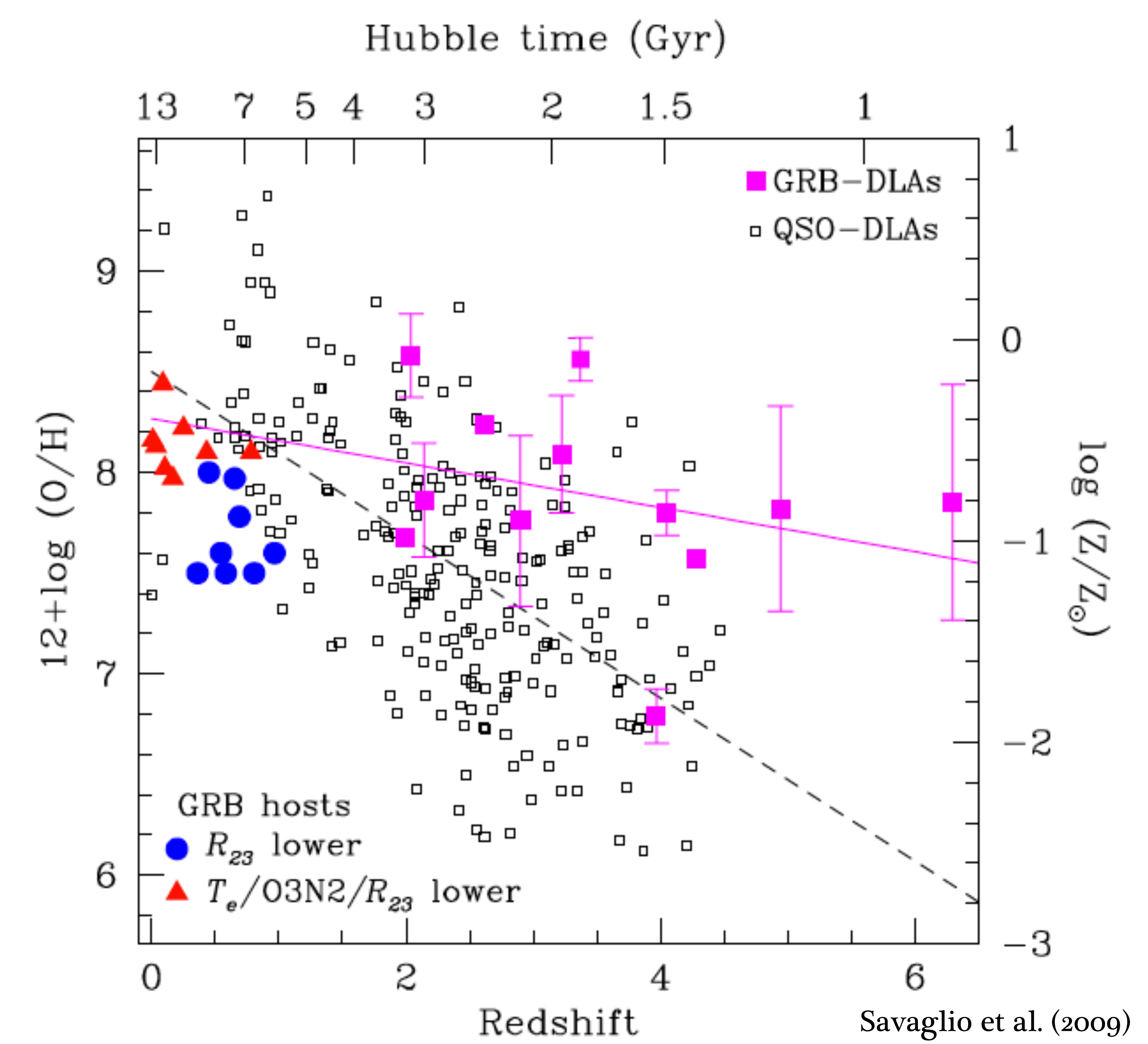

Savaglio et al. (2009)

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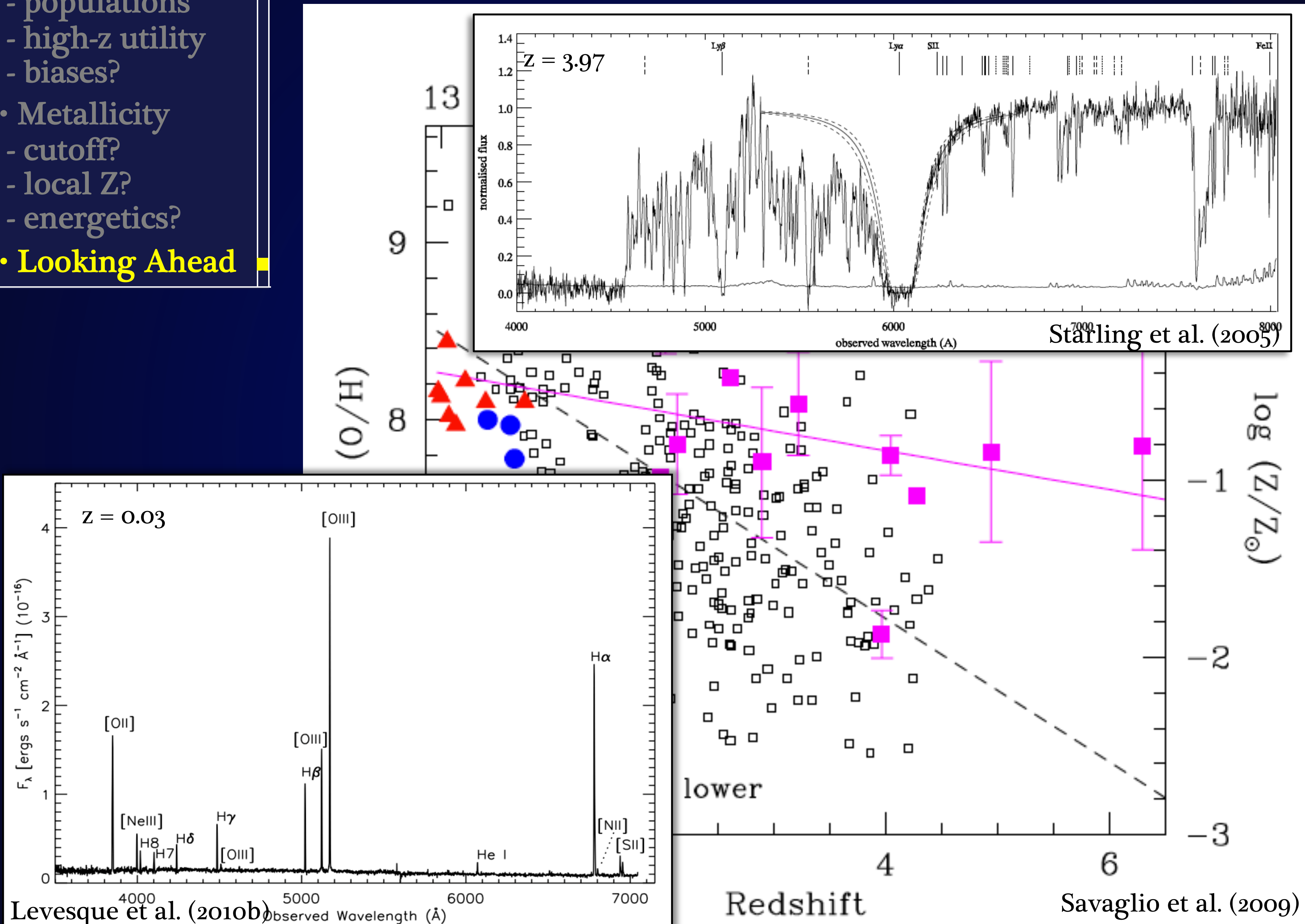

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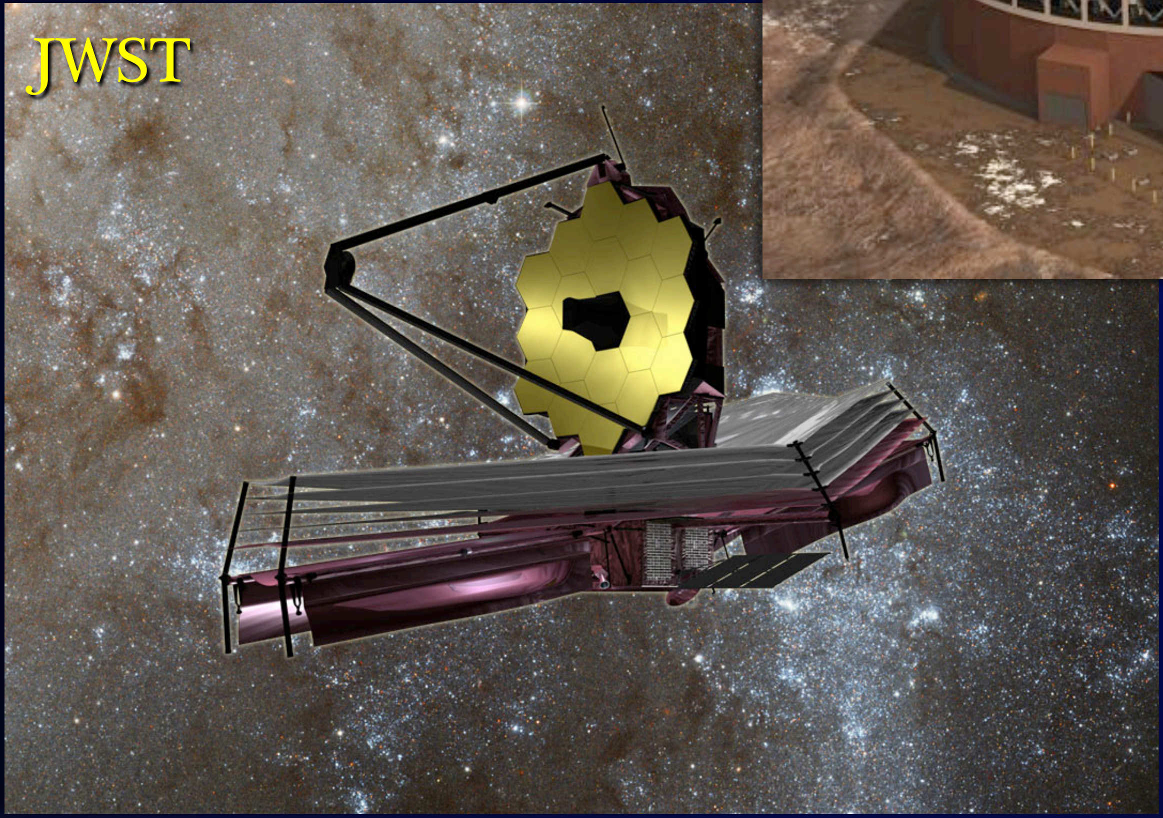

Looking ahead…

1. What are the progenitors of LGRBs?

2. How does the nature of these progenitors impact the host galaxies selected by LGRB detections?

3. How does the nature of LGRB progenitors impact their use as star formation probes out to high redshift?

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