Observations of Short GRBs: Beaming, Energetics & Environments

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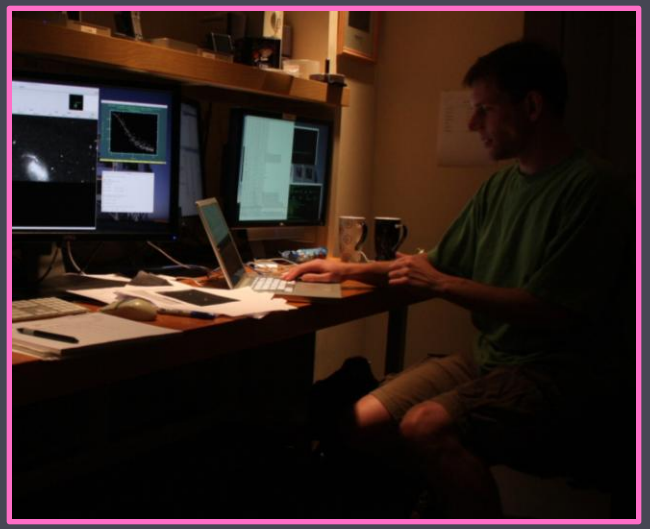
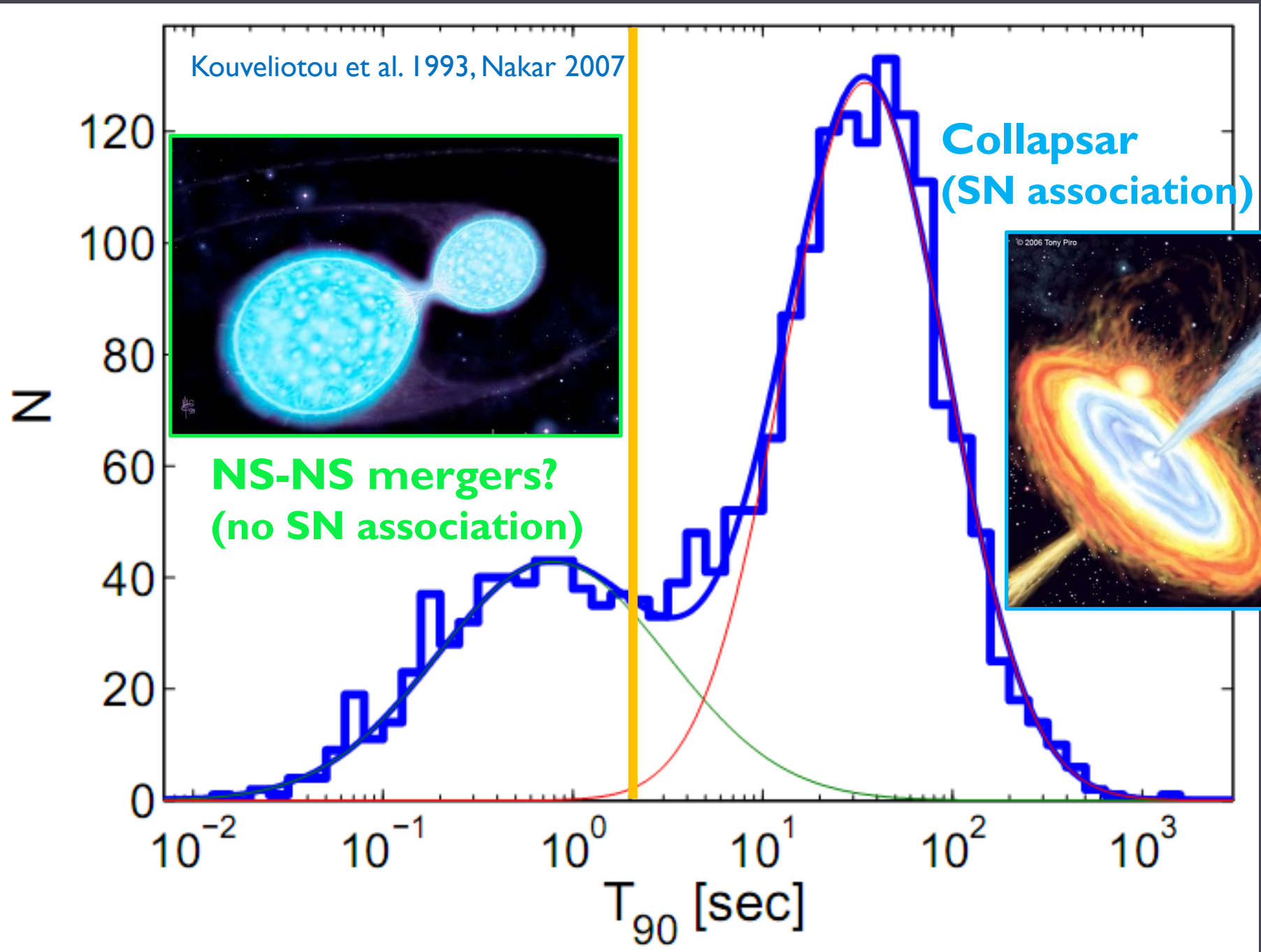
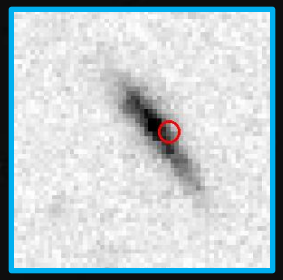


Rattle & Shine, KITP, 08.01.2012


Kouveliotou et al. 1993, Nakar 2007
Collapsar
(SN association)
NS-NS mergers?
(no SN association)
© 2006 Tony Piro
N
120
100
80
60
40
20
0
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
T_{90} [sec]

Physics of GRBs: The Big Picture



Progenitor

Central engine

Internal shocks

γ-rays

External forward shock

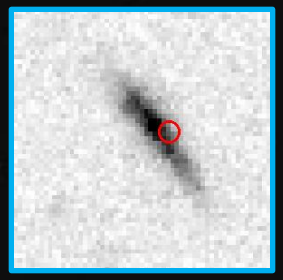
X-ray
Optical
NIR
Radio

Prompt emission

Afterglow

Adapted from Gehrels et al. 2007

Physics of GRBs: Open Questions



Progenitor

?

Central engine

Internal shocks

γ-rays

External forward shock

X-ray
Optical
NIR
Radio

θ?

-Geometry of outflow
-Energies and densities
-Nature of the progenitor

E_γ?

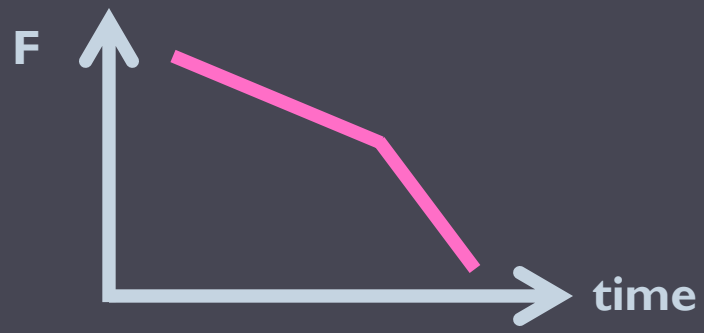
E_K?

n?

Adapted from Gehrels et al. 2007

What can we learn from observations?

1. Geometry of outflow

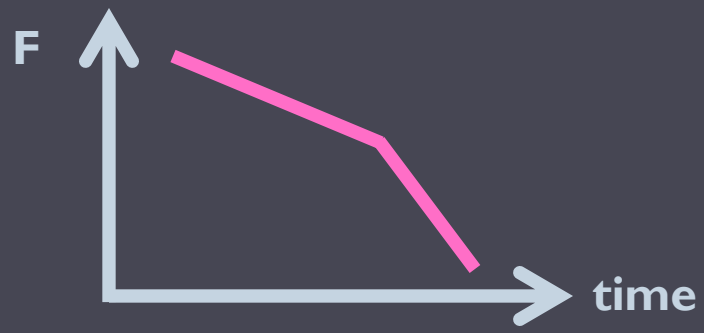


True energy scale

Rates

What can we learn from observations?

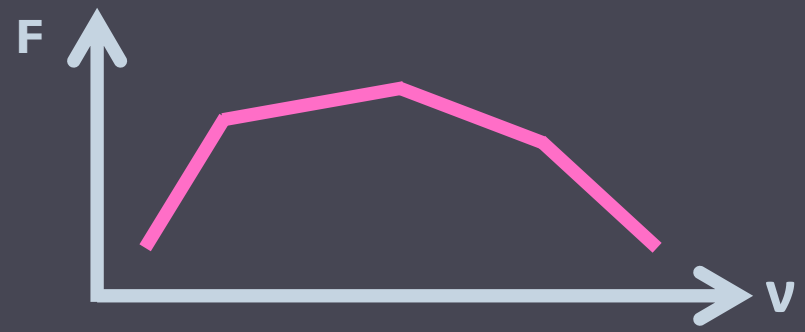
1. Geometry of outflow



True energy scale

Rates

2. Energies and densities



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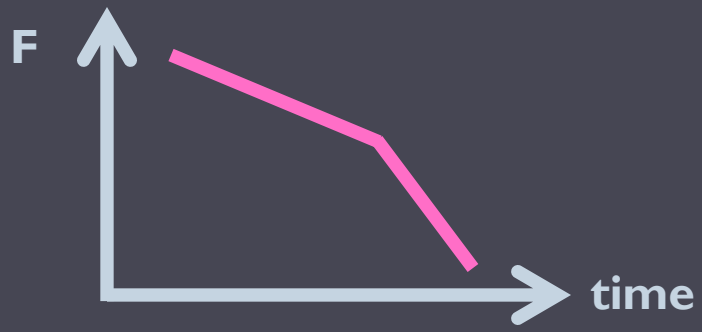
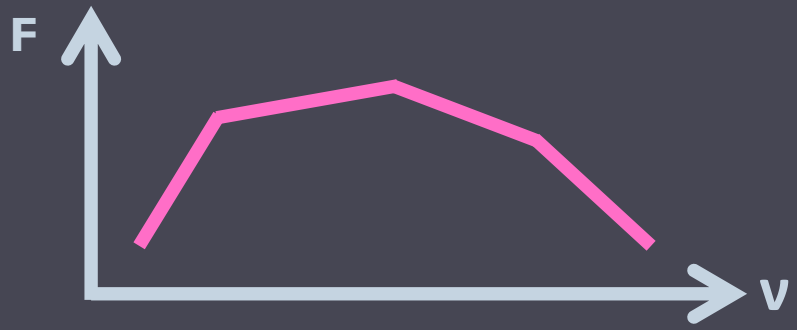
1. Geometry of outflow



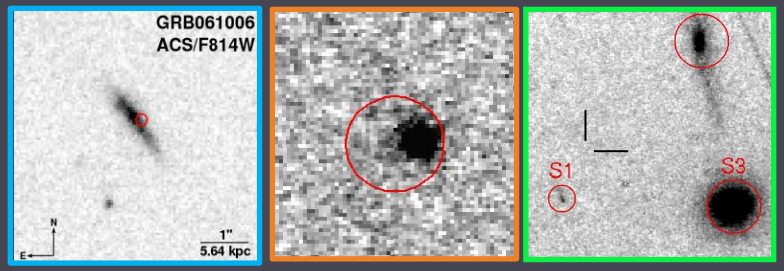
True energy scale

Rates

2. Energies and densities



3. Nature of the progenitor



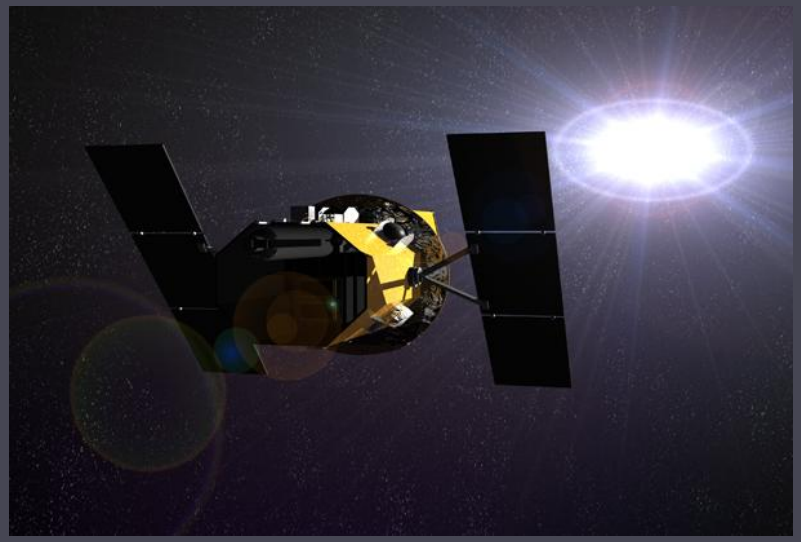
Demographics

Stellar pop. characteristics

Burst locations (kicks?)

The multi-wavelength Target-of-Opportunity afterglow chase

Swift discovers a burst…



Magellan (Chile)

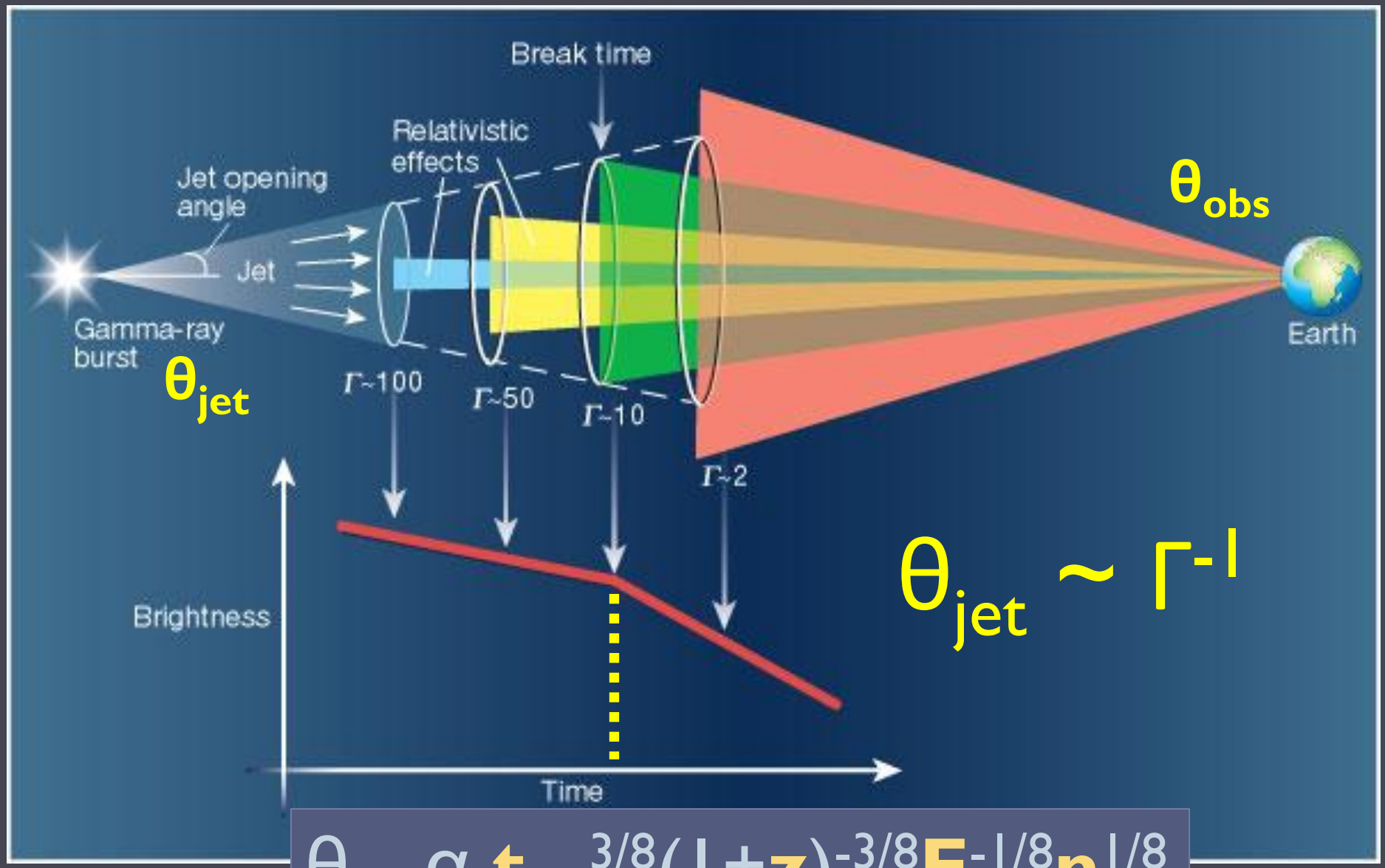
Chandra

Gemini-North (HI) and South (Chile)

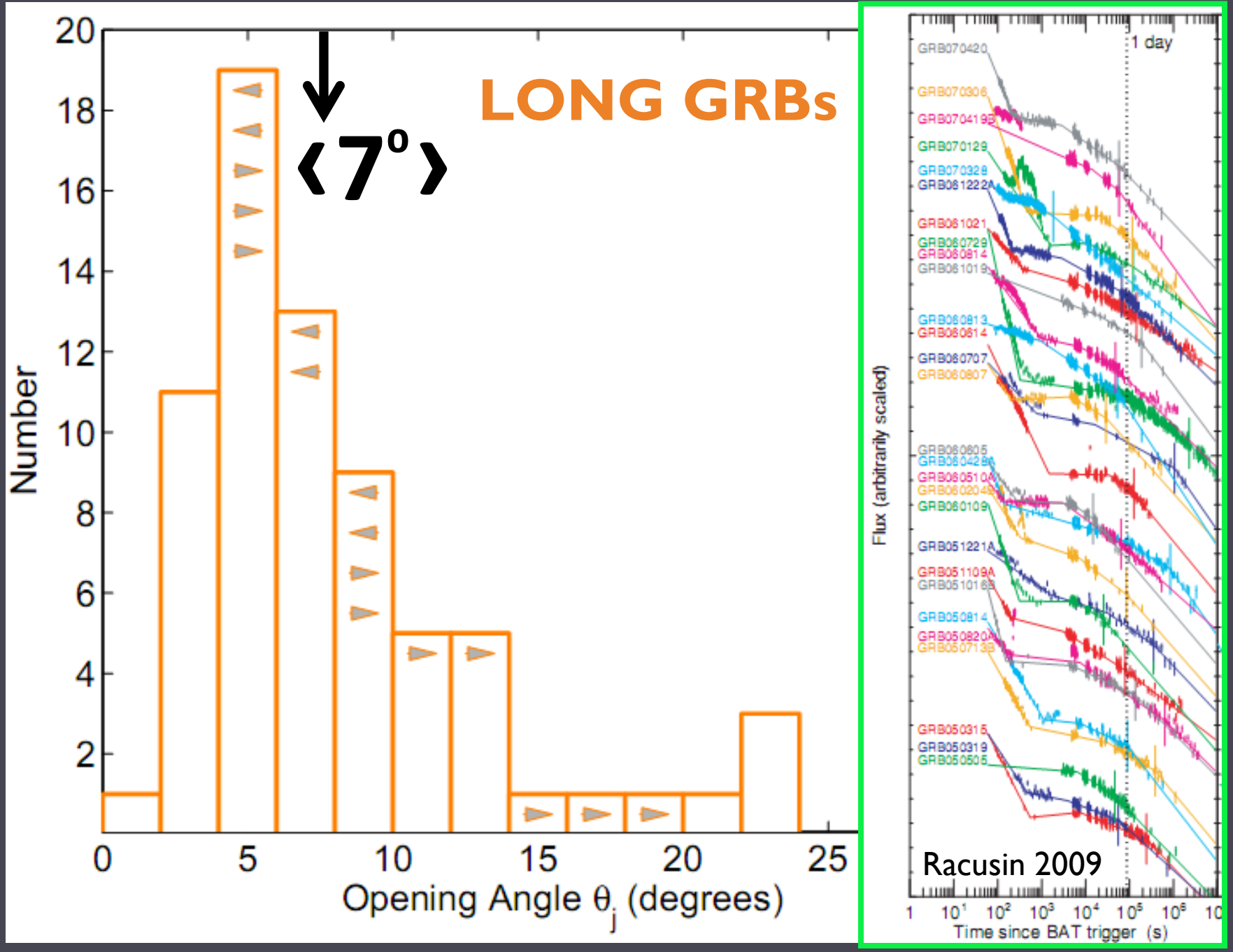
EVLA (New Mexico)

…and we diligently chase the afterglow (and eventually host)!

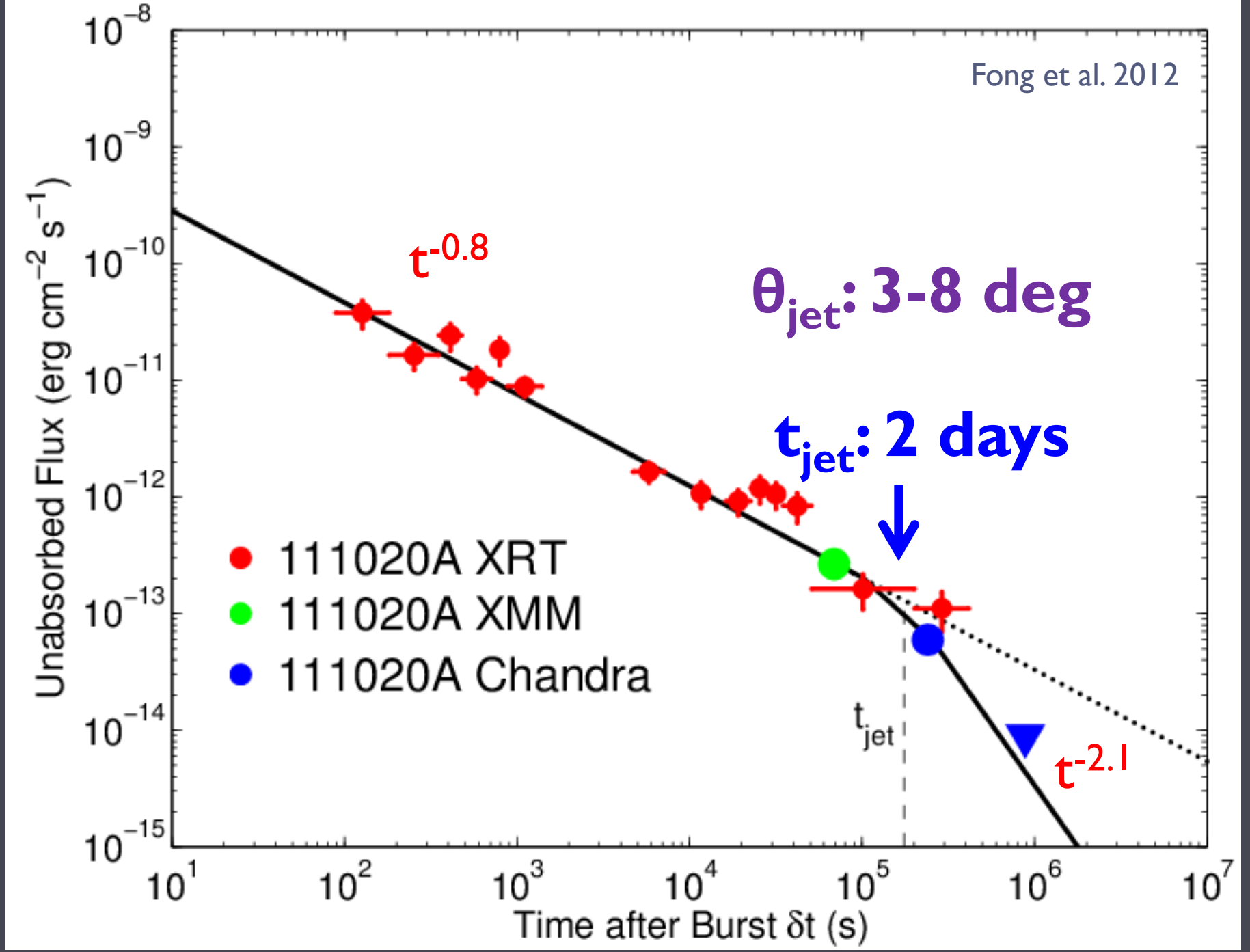
1. Geometry of outflow

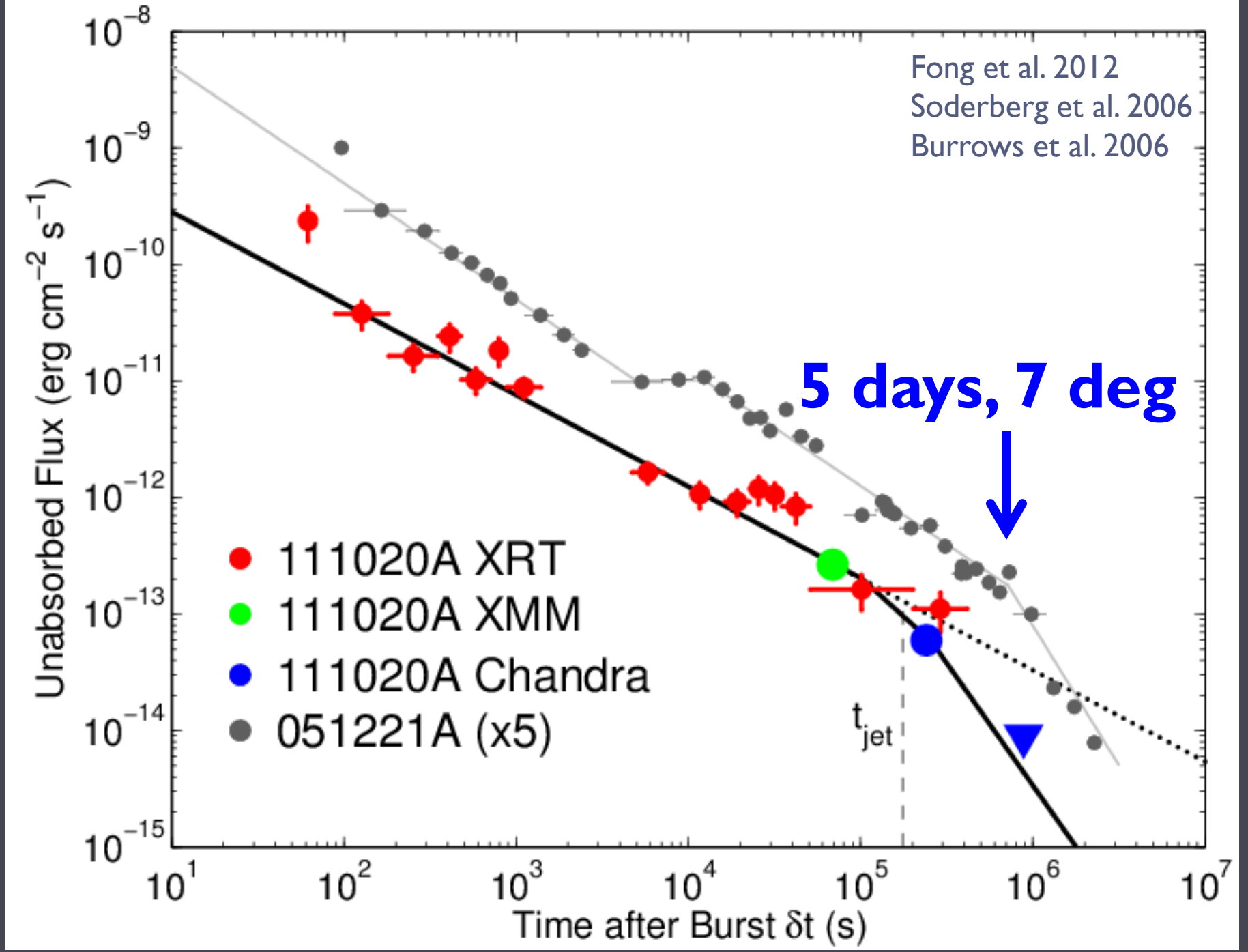


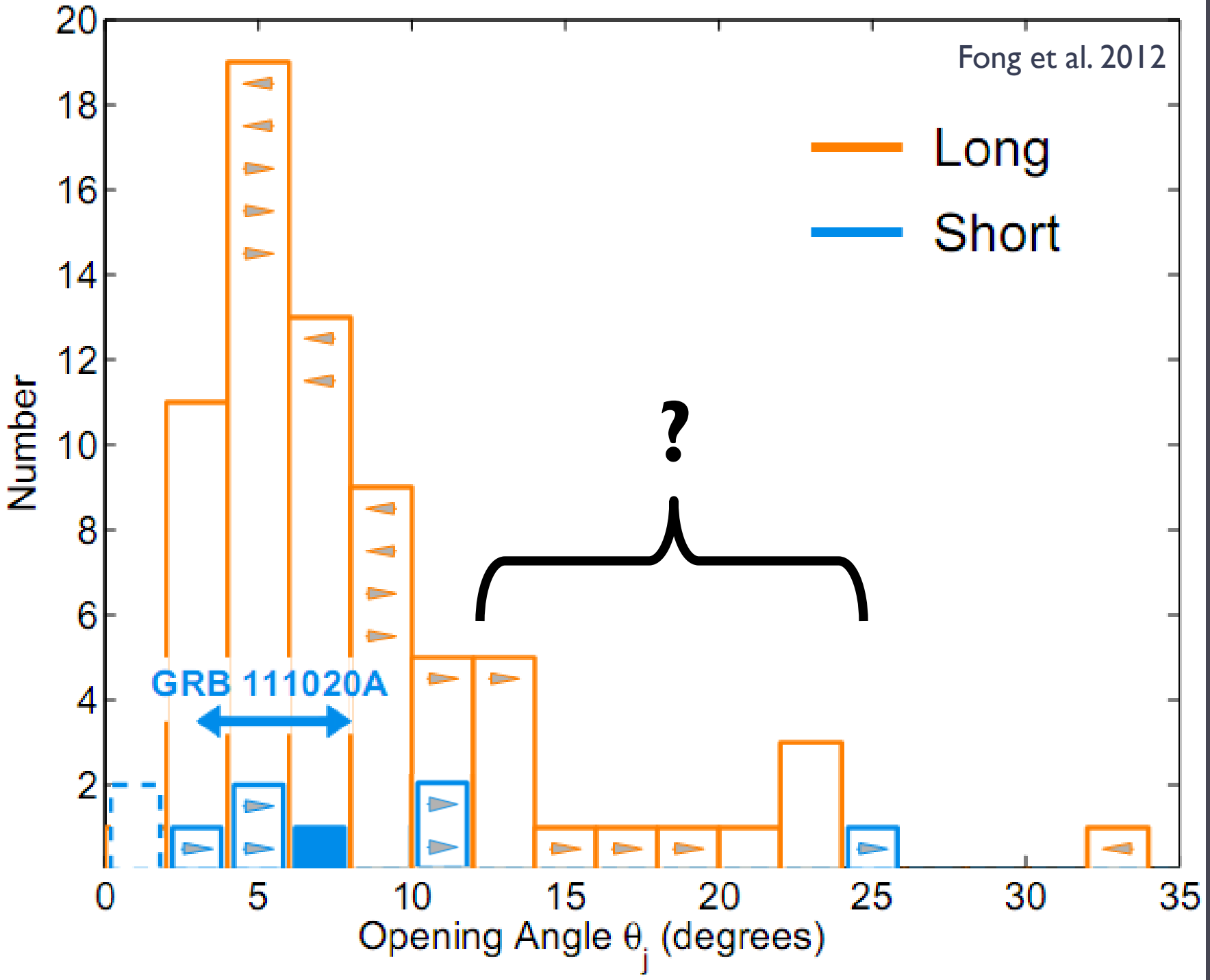
$$\theta_{jet} \propto t_{jet}^{3/8}(1+z)^{-3/8}E^{-1/8}n^{1/8}$$



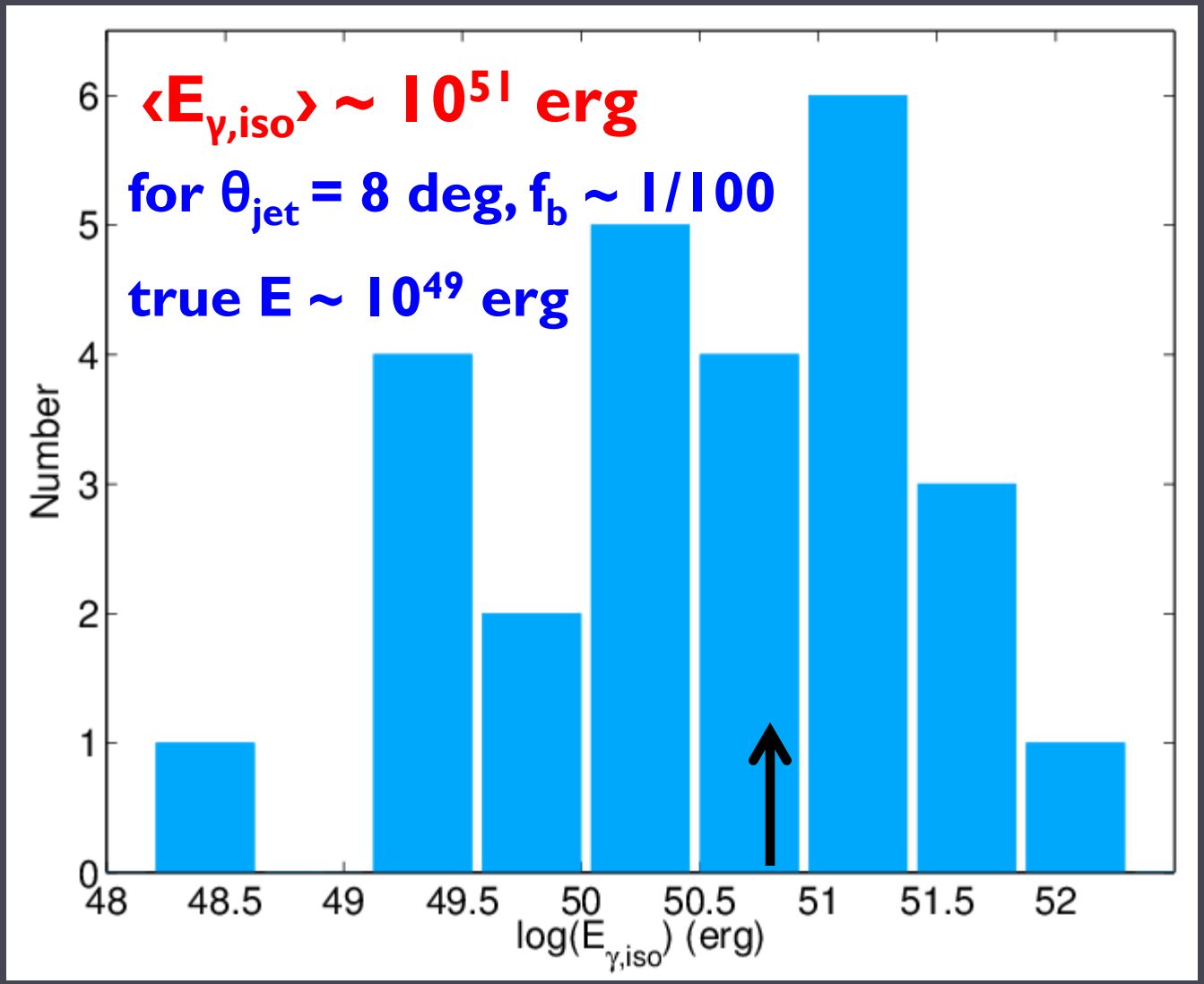
Frail 2001, Berger 2003, Bloom 2003, Ghirlanda 2004,Friedman & Bloom 2005, Racusin 2009, Filgas 2011, Cenko 2010/2011, Goldstein 2011


Fong et al. 2012
$t^{-0.8}$
θ_{jet}: 3-8 deg
t_{jet}: 2 days
111020A XRT
111020A XMM
111020A Chandra
t_{jet}
$t^{-2.1}$
Unabsorbed Flux (erg cm^{-2} s^{-1})
Time after Burst δt (s)
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}


Fong et al. 2012
Soderberg et al. 2006
Burrows et al. 2006
5 days, 7 deg
111020A XRT
111020A XMM
111020A Chandra
051221A (x5)
t_{jet}
Unabsorbed Flux (erg cm^{-2} s^{-1})
Time after Burst δt (s)
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}


Fong et al. 2012
Long
Short
?
GRB 111020A
Number
Opening Angle θj (degrees)
0
5
10
15
20
25
30
35
2
4
6
8
10
12
14
16
18
20

Implications: Energy Scale



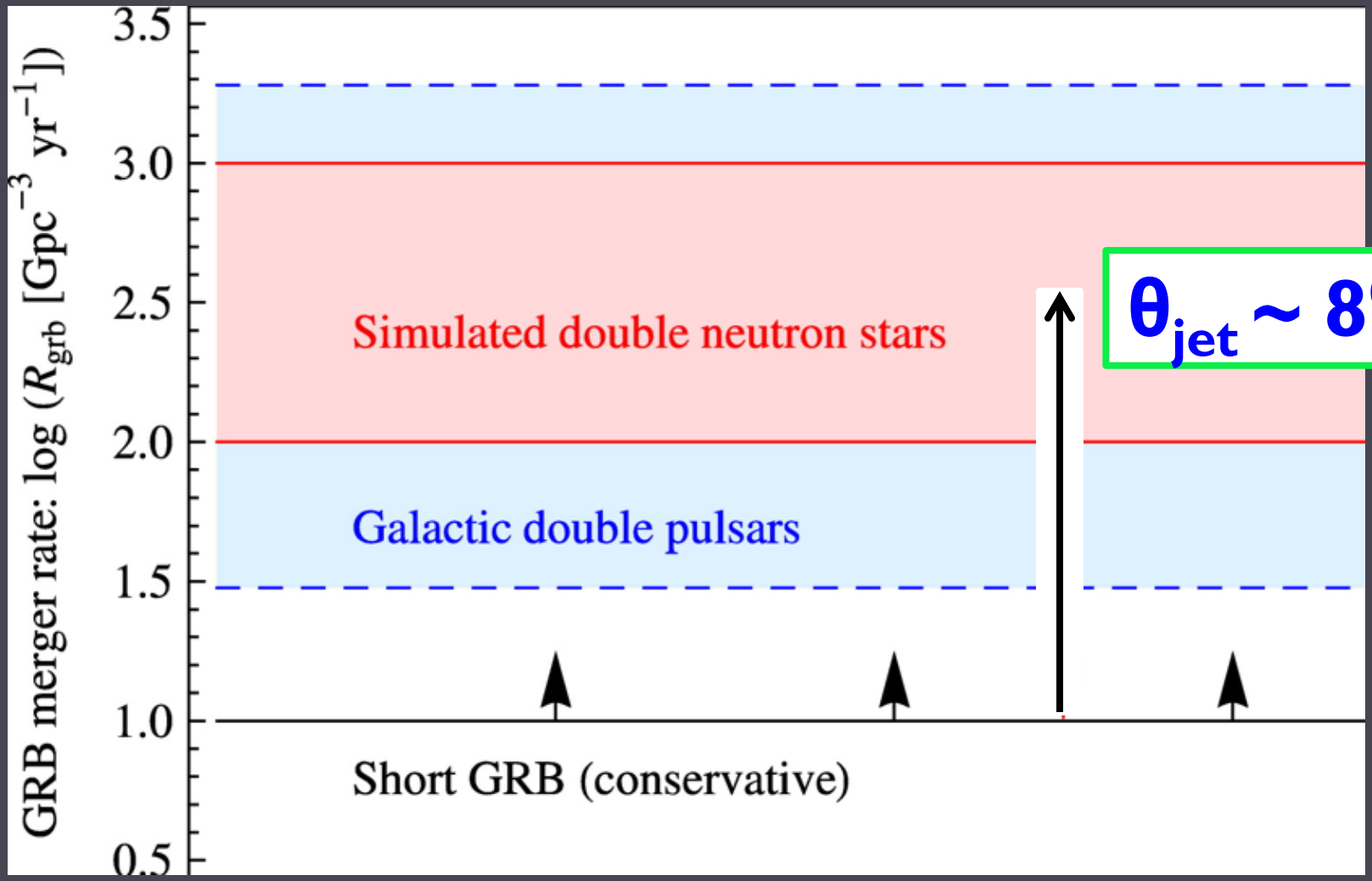
E extraction predictions:

$\bar{\nu}\nu$: 10^{48}-10^{49} erg

MHD: >10^{49} erg

Rosswog et al. 2003, Rosswog 2005, Birkl et al. 2007, Lee & Ramirez-Ruiz 2007

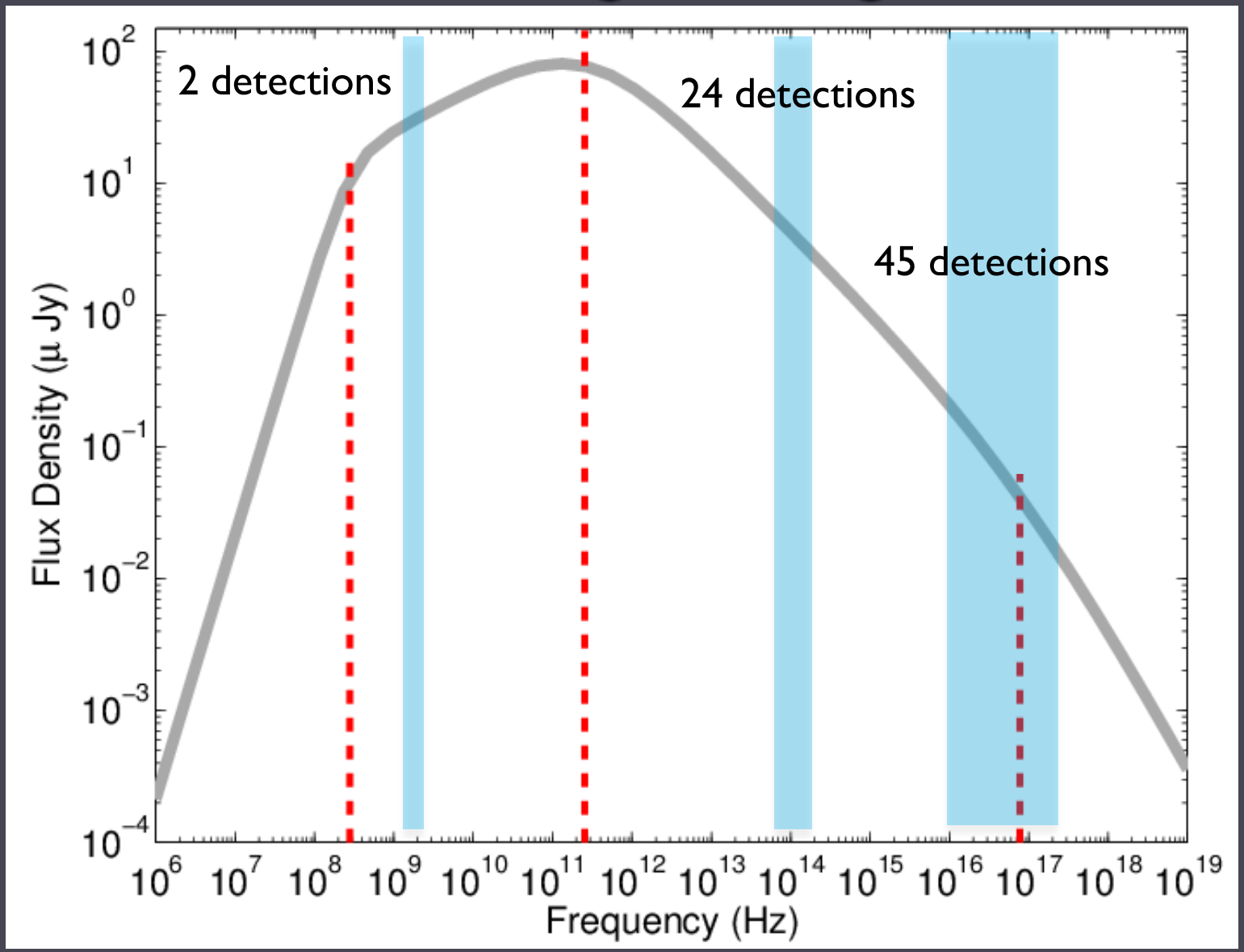
Implications: Rates



observed short GRB rate of 10 Gpc^{-3} yr^{-1} → 100-1000 Gpc^{-3} yr^{-1}

Kalogera et al. 2004, Belczynski et al. 2007, Nakar 2007

2. Energies & Densities: Multi-wavelength Afterglows



created using models from Granot & Sari 2002

2. Energies & Densities: Multi-wavelength Afterglows

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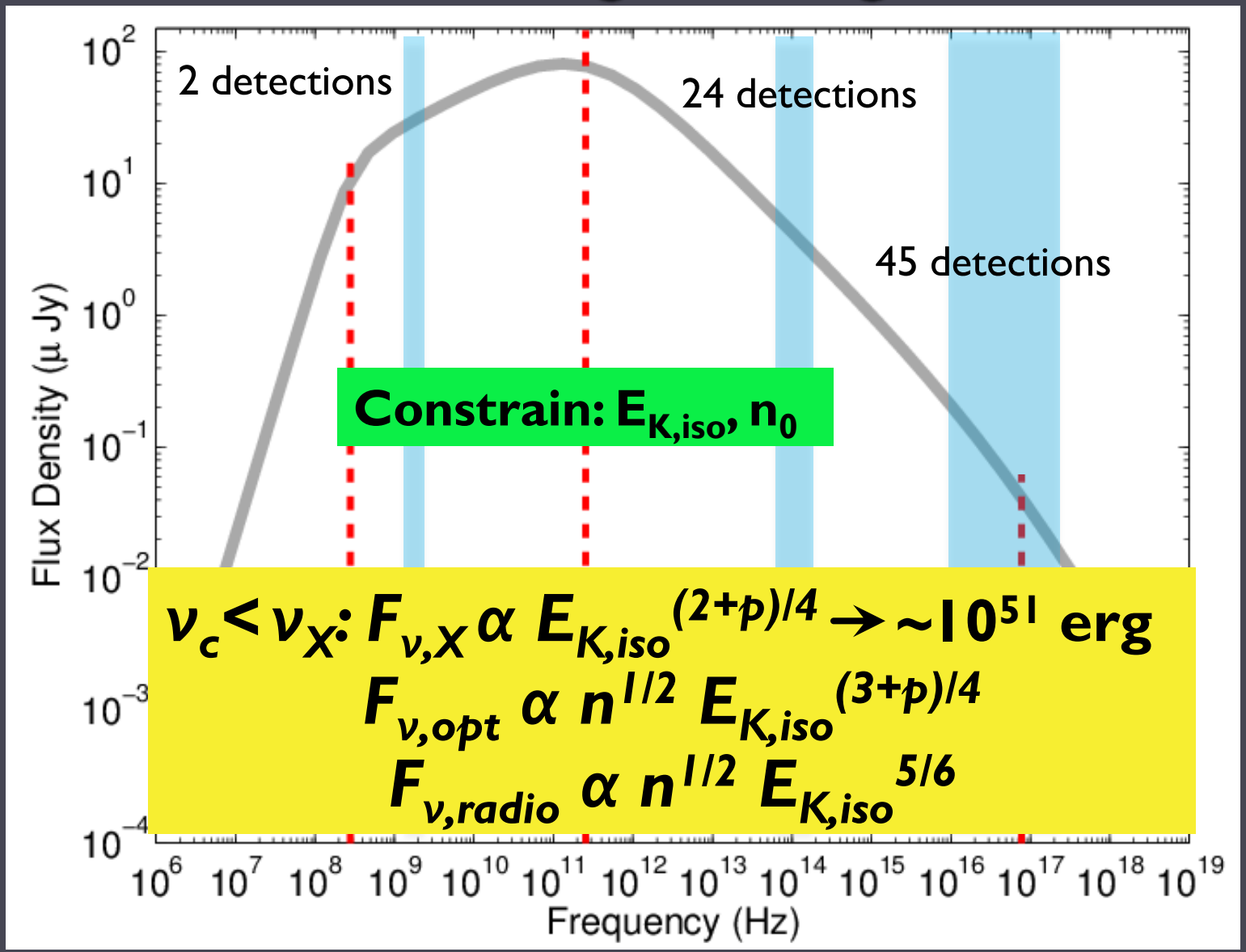
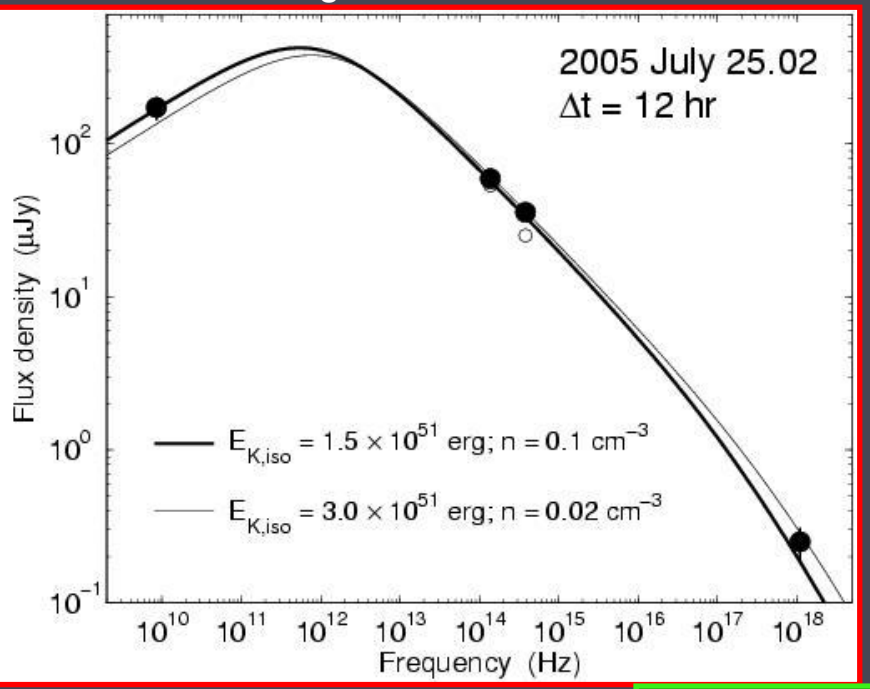


Golden examples: GRBs 050724 and 051221A

GRB 050724A; Berger et al. 2005



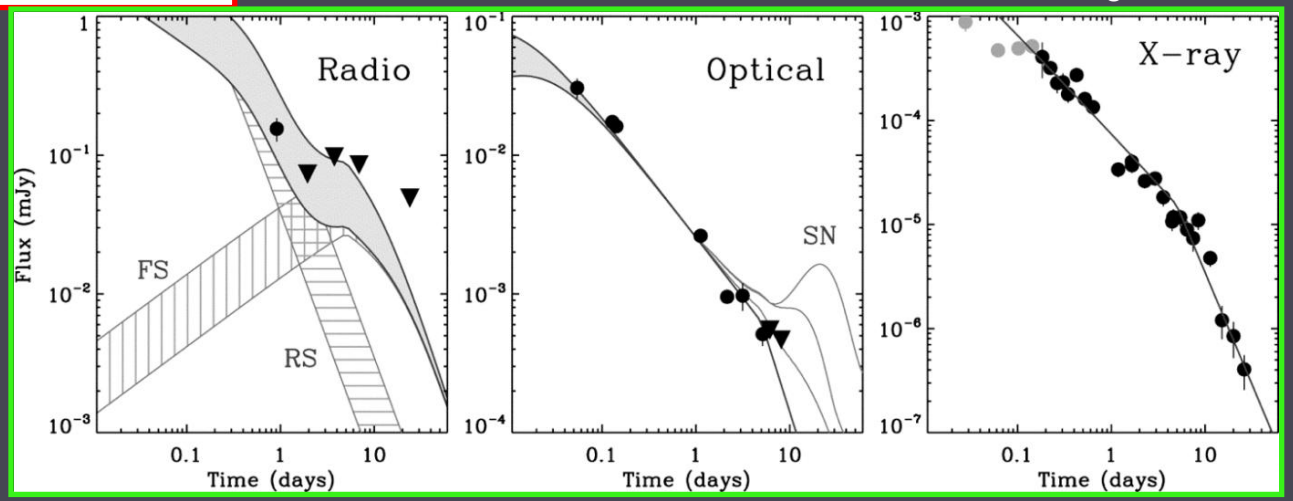
$\theta_j > 25$ deg

$E_{\gamma,iso} \approx 4 \times 10^{50}$ erg

$E_{K,iso} \approx (2\text{-}3) \times 10^{51}$ erg

$n \approx 0.01\text{-}0.1$ cm^{-3}

GRB 051221A; Soderberg et al. 2006



$\theta_j \approx 7$ deg

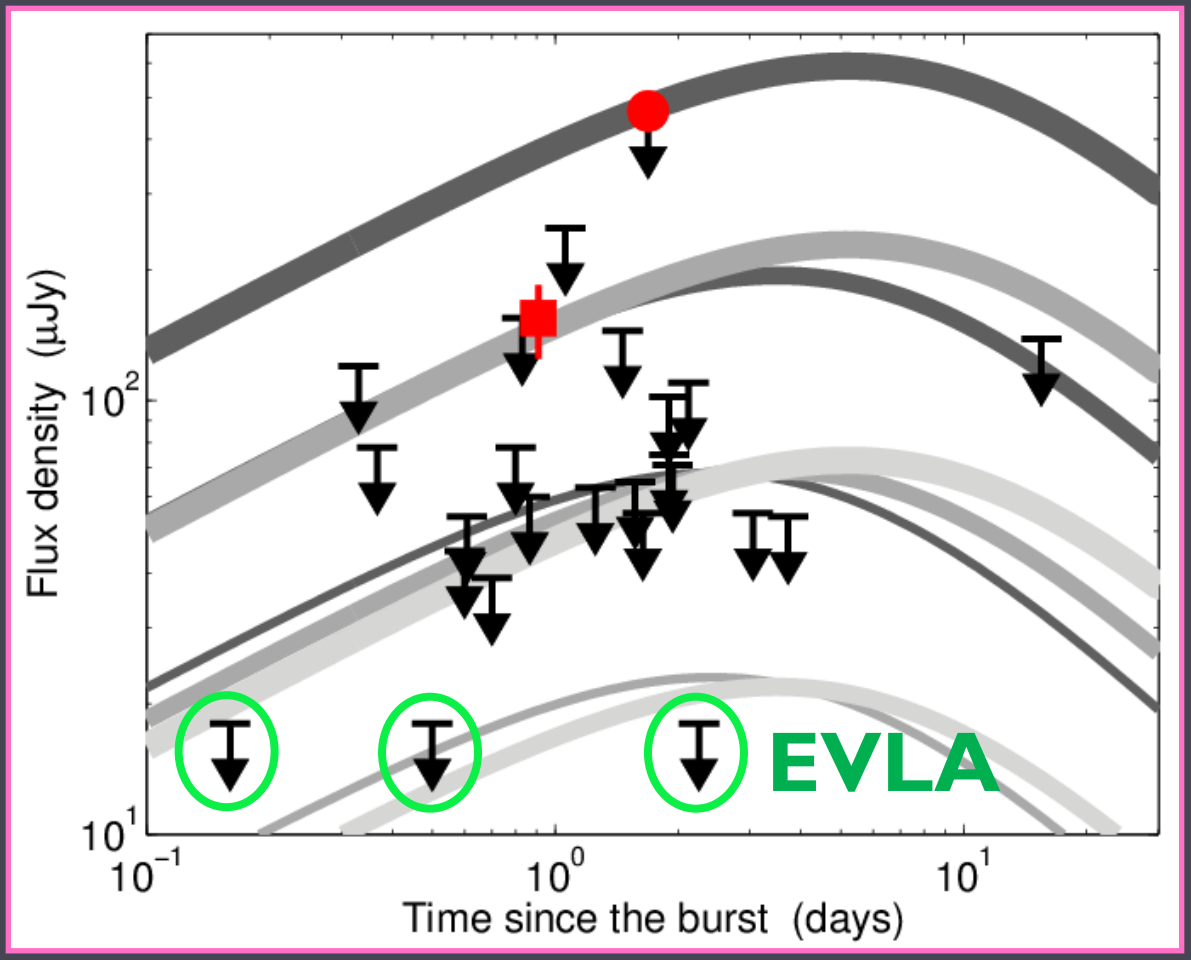
$E_\gamma \approx 1.5 \times 10^{49}$ erg

$E_K \approx 0.8 \times 10^{49}$ erg

$n \approx 1.5 \times 10^{-3}$ cm^{-3}

Radio afterglows

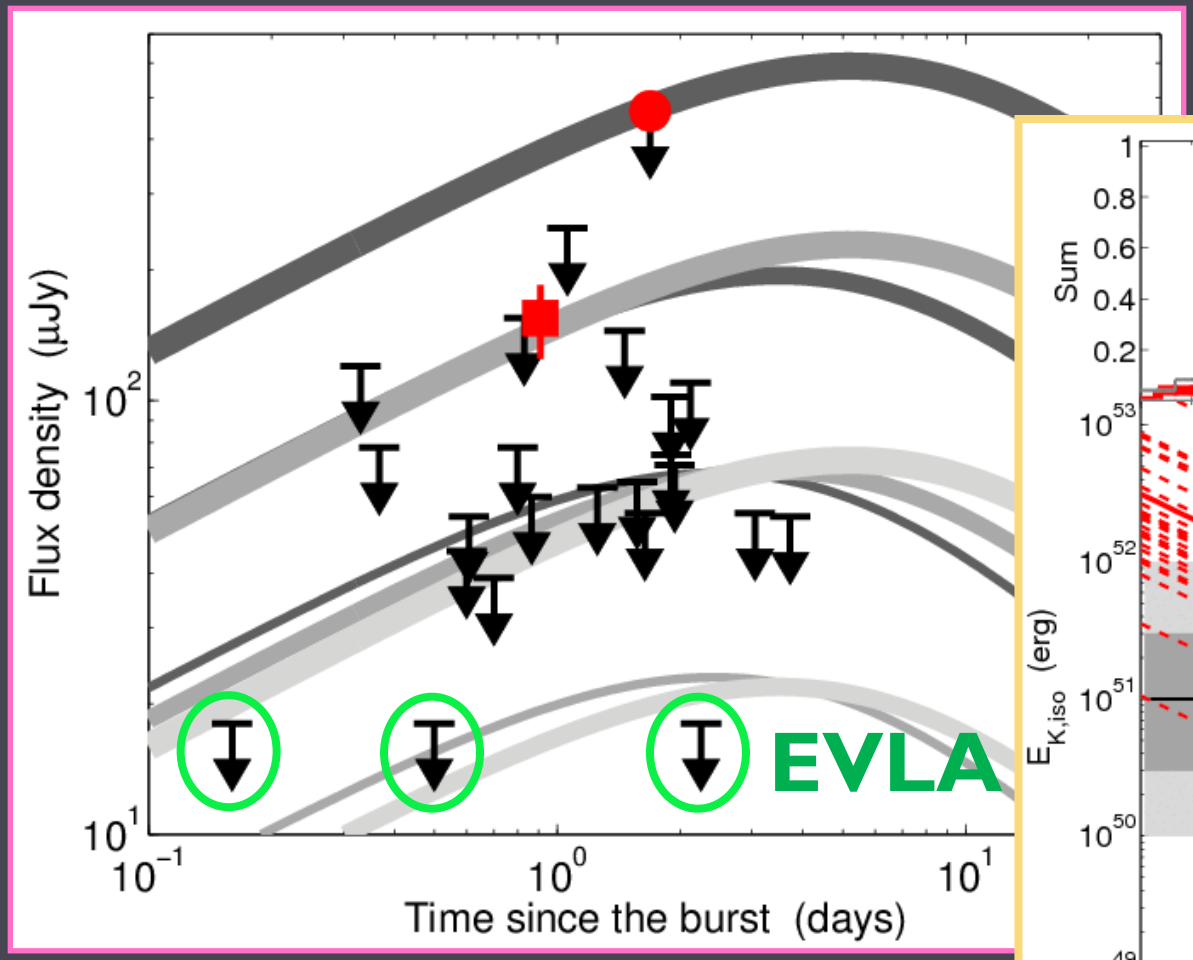
Fong+ in prep

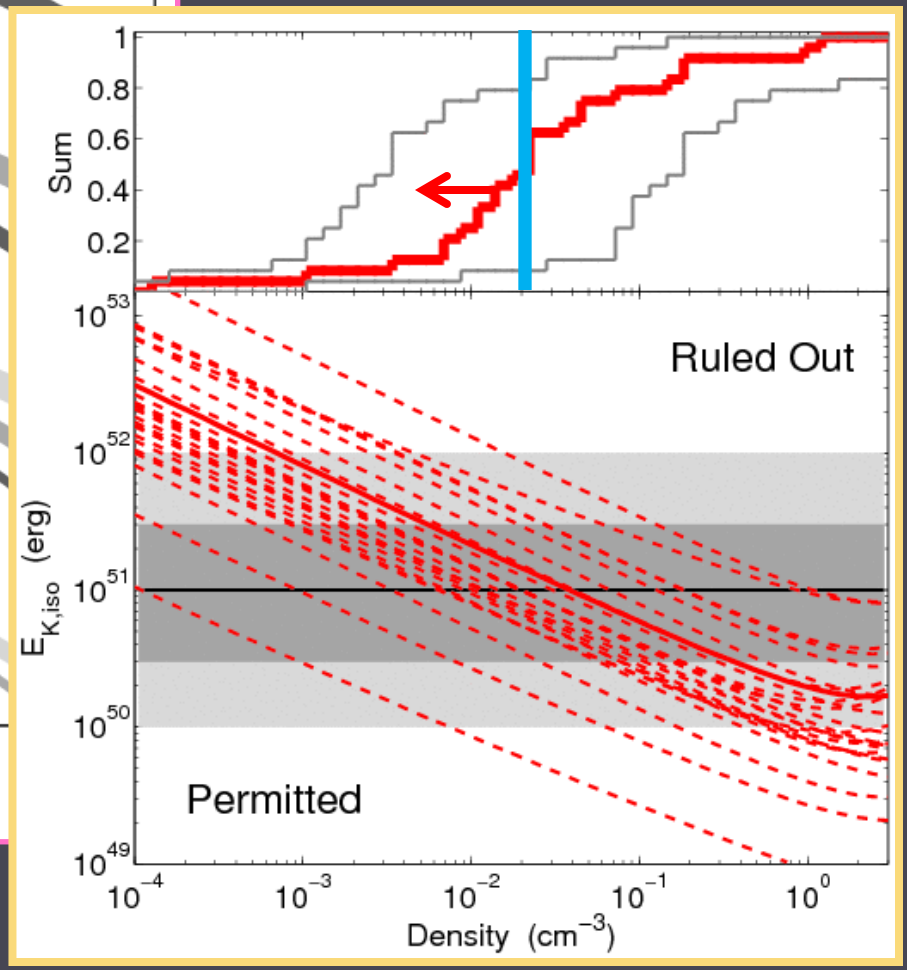


$$F_{\nu,\,radio} \propto n^{1/2} E_{K,iso}^{5/6}$$

Radio afterglows

Fong+ in prep



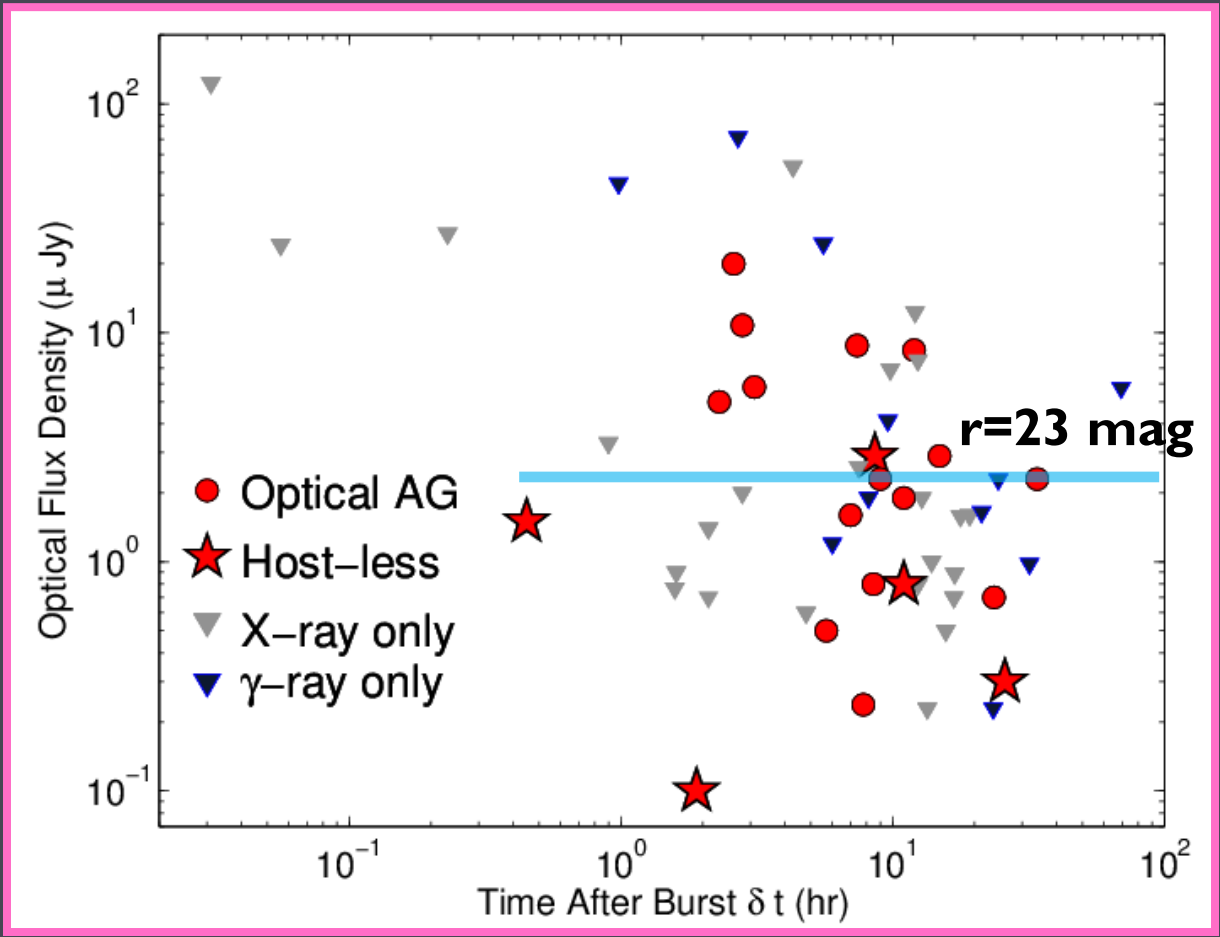


$F_{\nu,\,radio} \propto n^{1/2} E_{K,iso}^{5/6}$

from UL and detections: $\langle n \rangle \leq 0.02\ cm^{-3}$

Optical afterglows

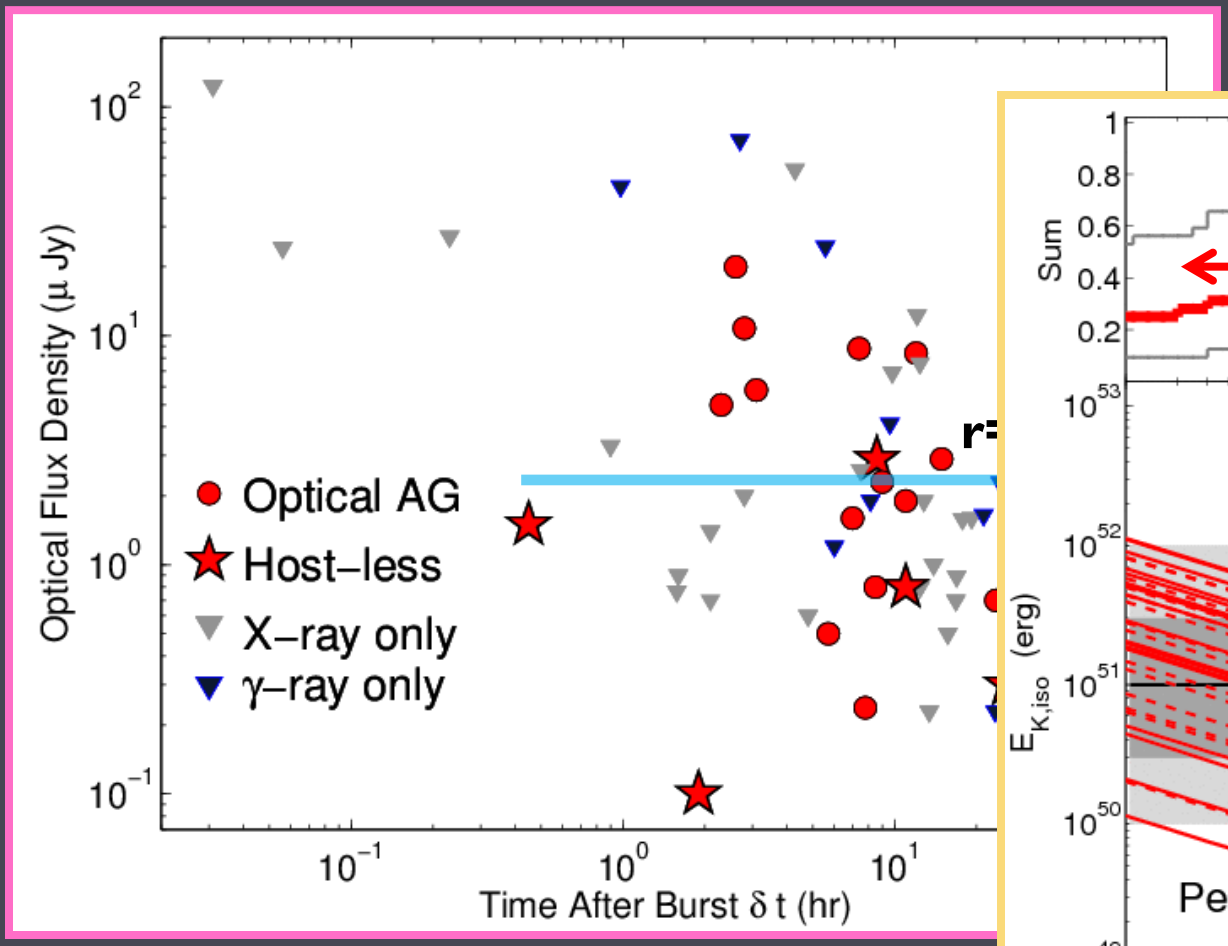
Fong+ in prep

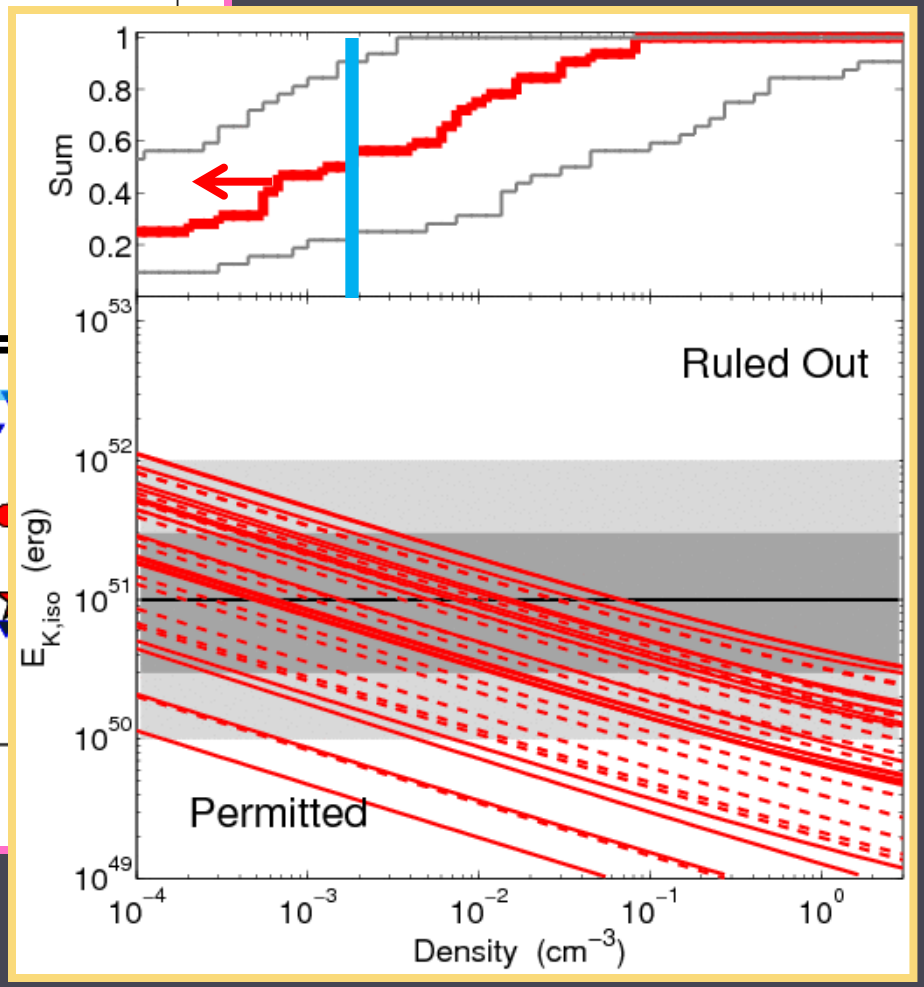


$$F_{\nu,opt} \propto n^{1/2} E_{K,iso}^{(3+p)/4}$$

Optical afterglows

Fong+ in prep





$F_{\nu,opt} \propto n^{1/2} E_{K,iso}^{(3+p)/4}$

from UL and detections: $\langle n \rangle \leq 0.002\ cm^{-3}$

[pause] Afterglows

Fraction are collimated

$\theta_{jet} \sim 8$ deg ($f_b = 1/100$)

Isotropic-equivalent energies:

$E_{iso,tot} \sim 10^{51}$ erg (10^{48}-10^{52} erg)

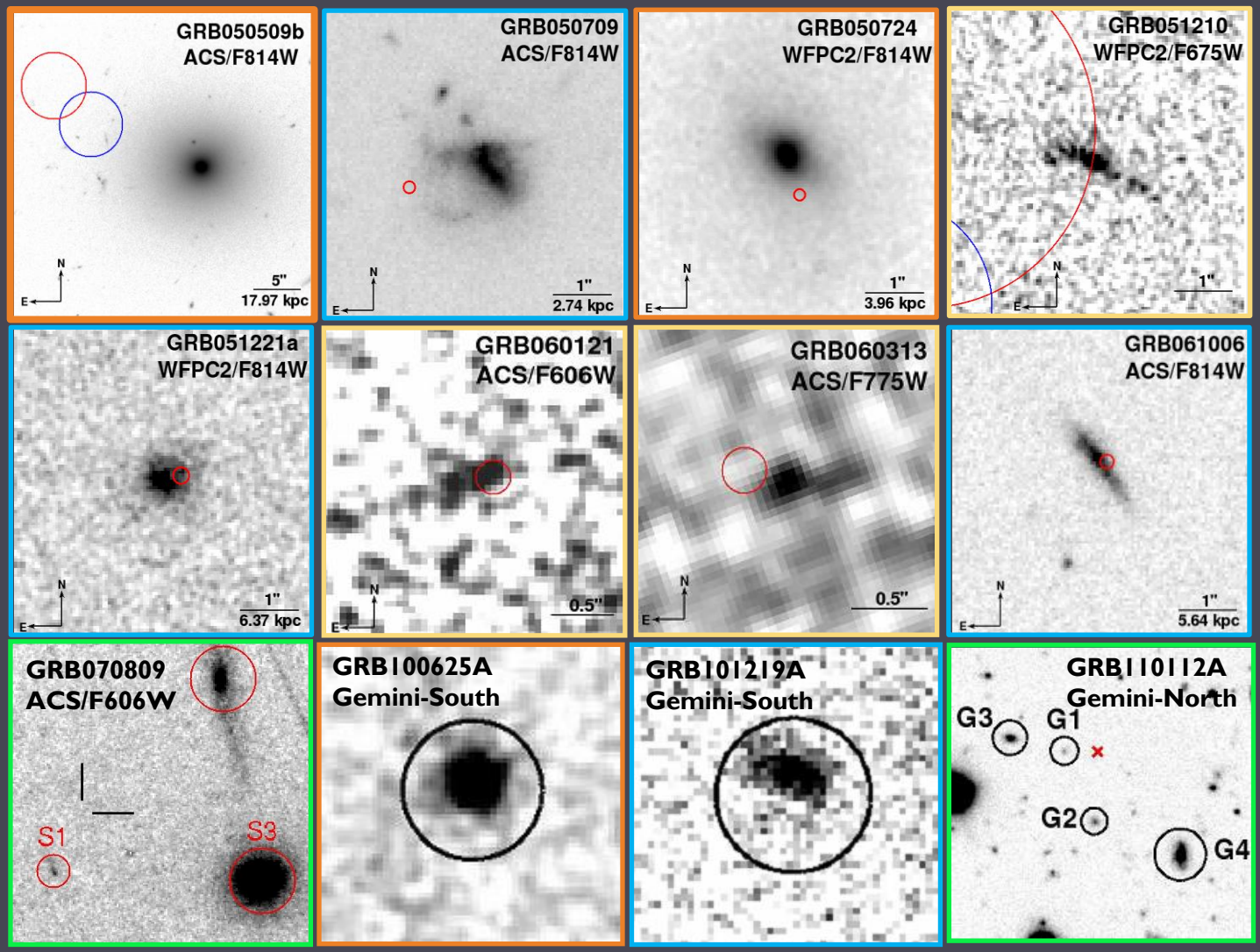
Beaming-corrected energies:

$E_{tot} \sim 10^{49}$ erg

Rates 100-1000 Gpc^{-3} yr^{-1}

Typical density is low: $\langle n_0 \rangle \leq 10^{-2}$-$10^{-3} cm^{-3}$

3. Nature of the progenitor
Galactic-scale environments



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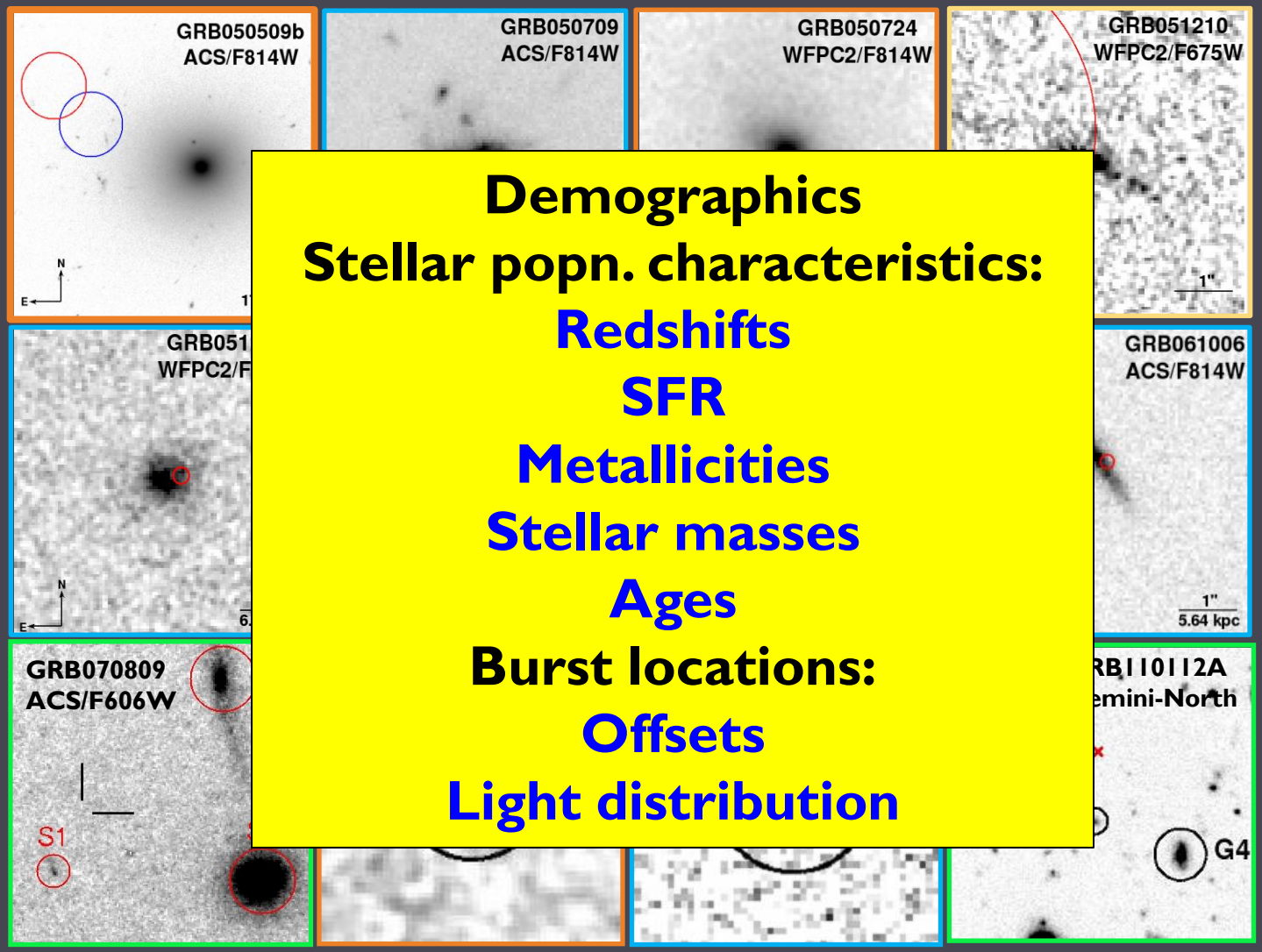


Demographics

Stellar popn. characteristics:

Redshifts

SFR

Metallicities

Stellar masses

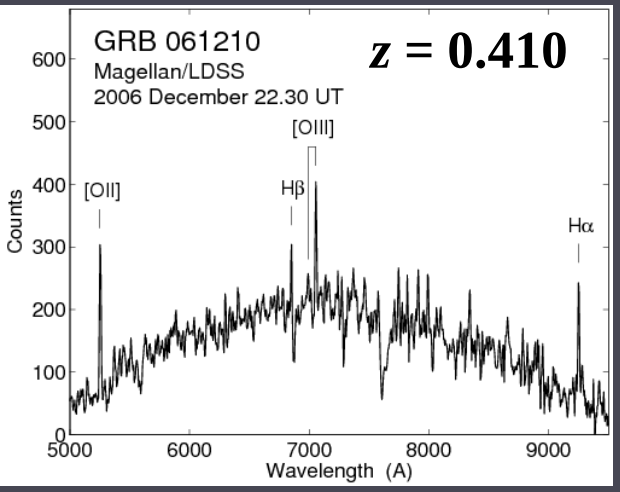
Ages

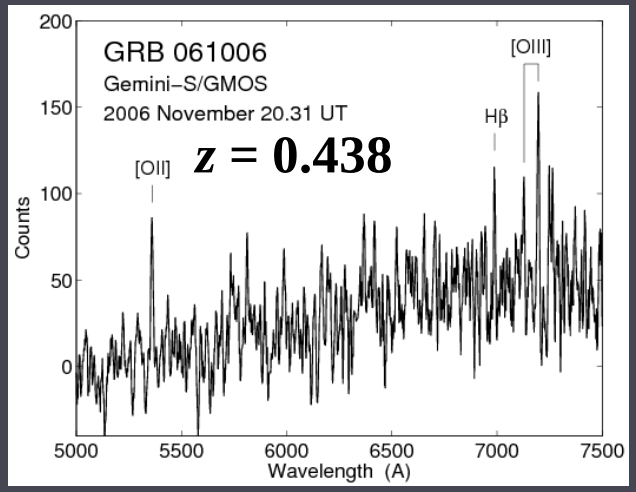
Burst locations:

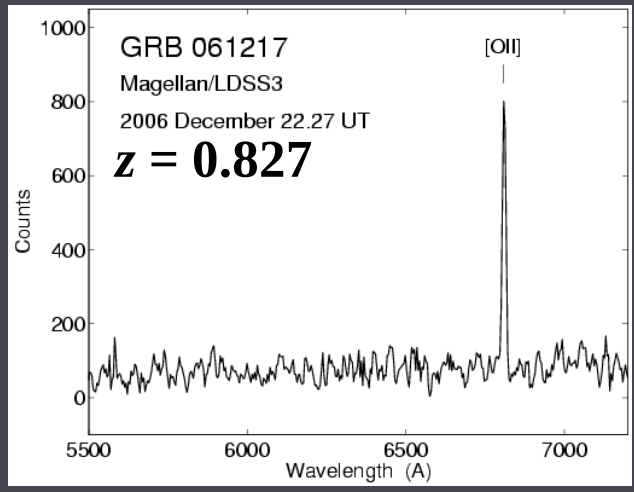
Offsets

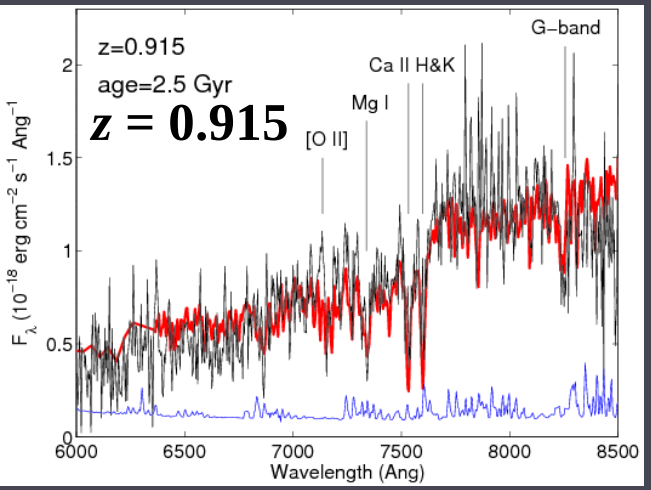
Light distribution

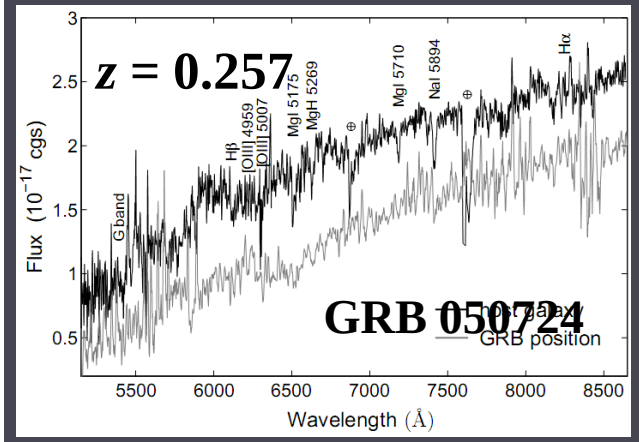
Short GRB redshifts *exclusively* determined from association with a host galaxy

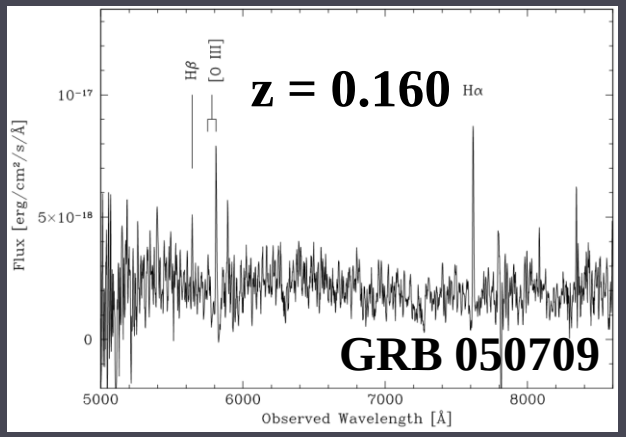




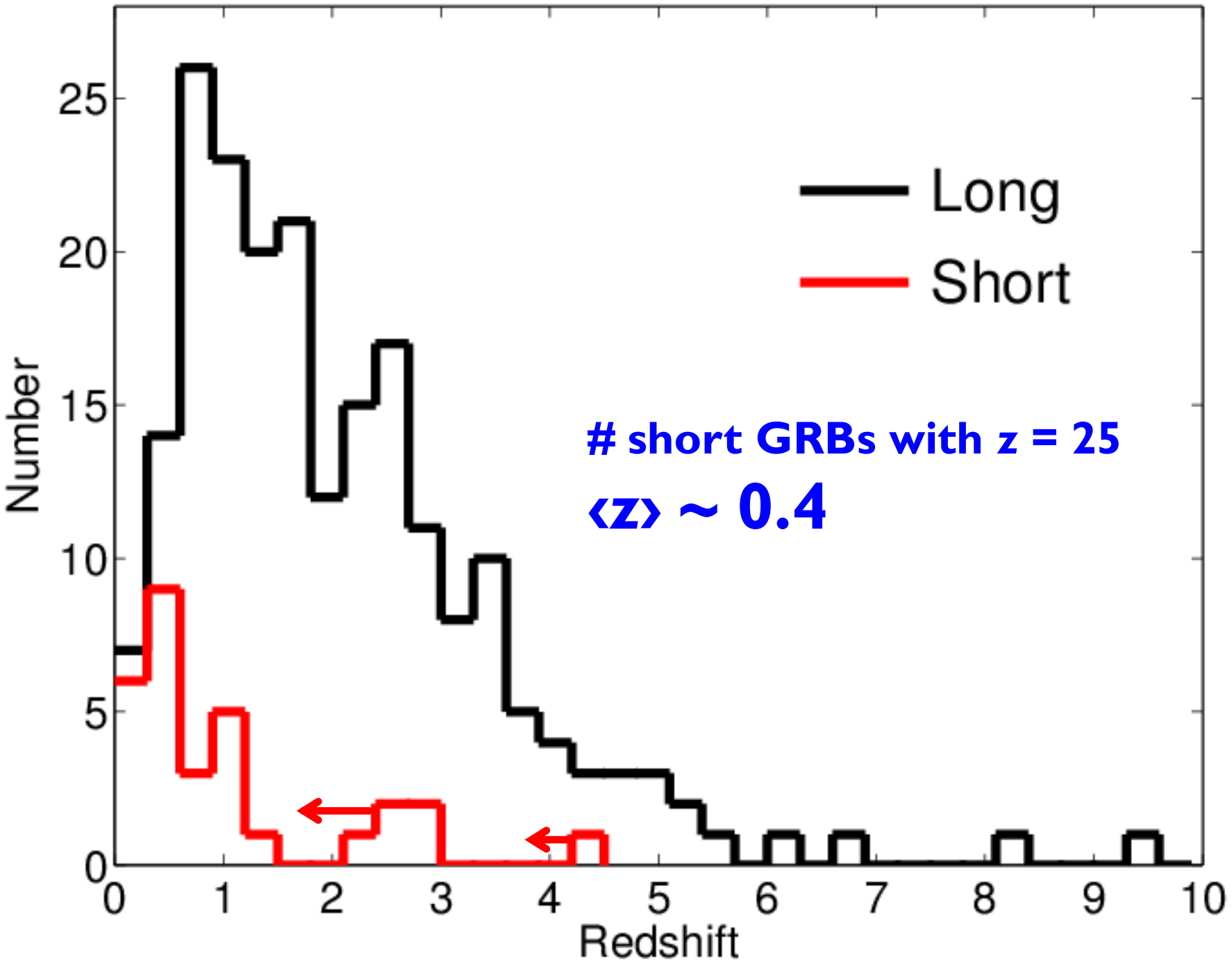




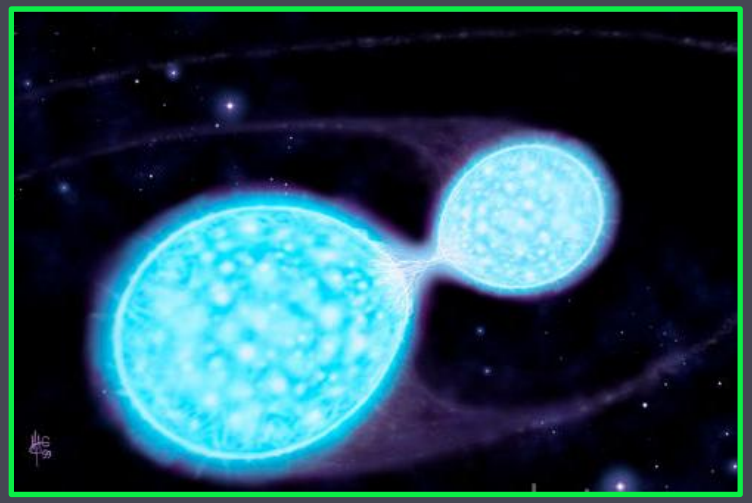




Berger et al. 2005; Fox et al. 2005; Berger et al. 2007; Berger 2009; Fong et al. 2011; Berger 2010


Long
Short
short GRBs with z = 25
‹z› ~ 0.4
Number
Redshift
0
5
10
15
20
25
0
1
2
3
4
5
6
7
8
9
10

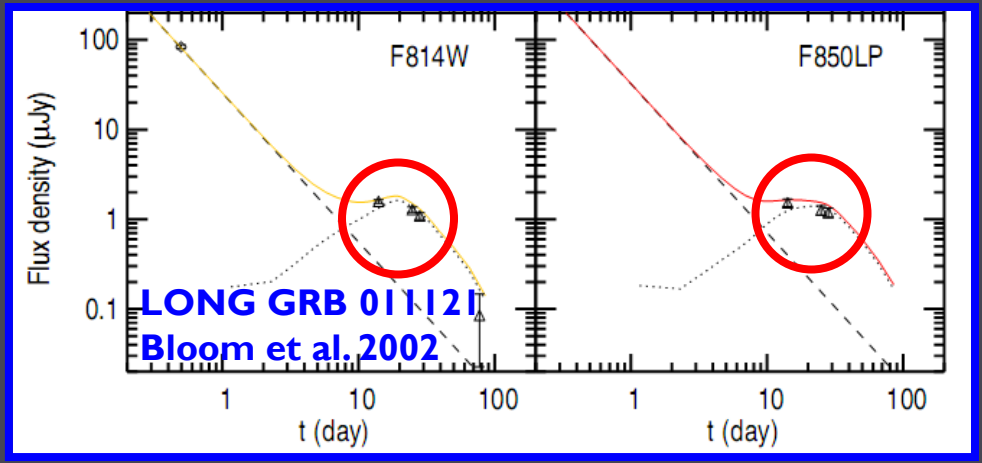
Expectations

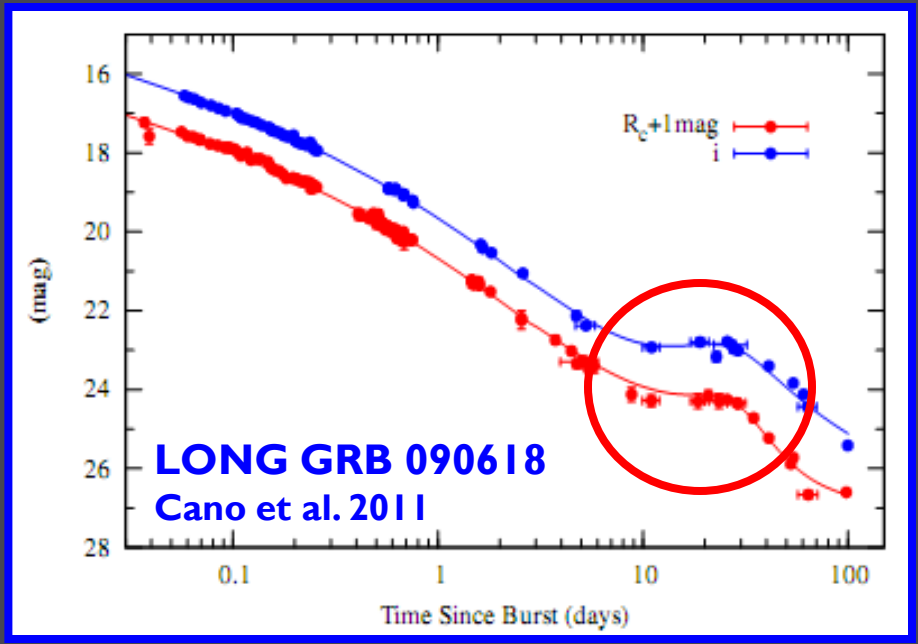


Neutron Star-Neutron Star merger / Neutron Star-Black Hole merger	Massive Stars
• No association with SNe	• Association with SNe
• Little correlation with star formation	• High correlation with star formation
• Occur in older stellar populations	•Occur in younger stellar populations
• Substantial offsets (potential kicks)	•Small or moderate offsets (no kicks)

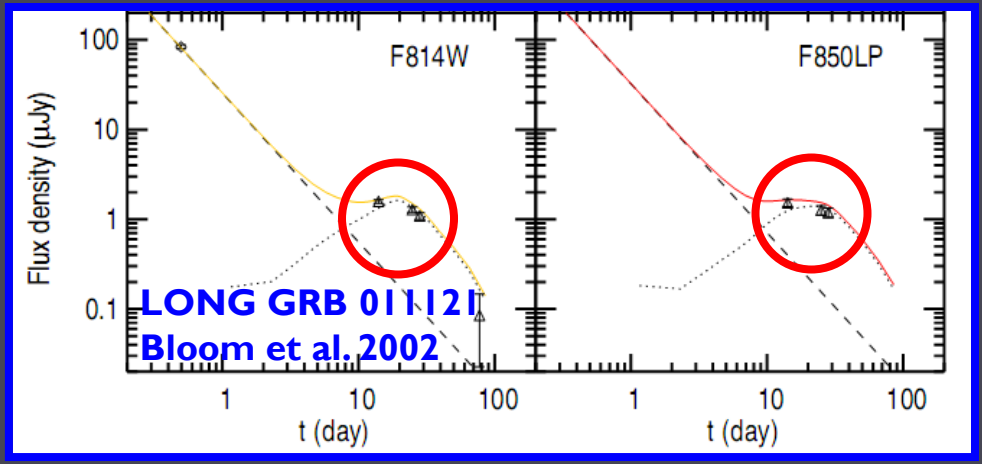
Environments are key to understanding the progenitor

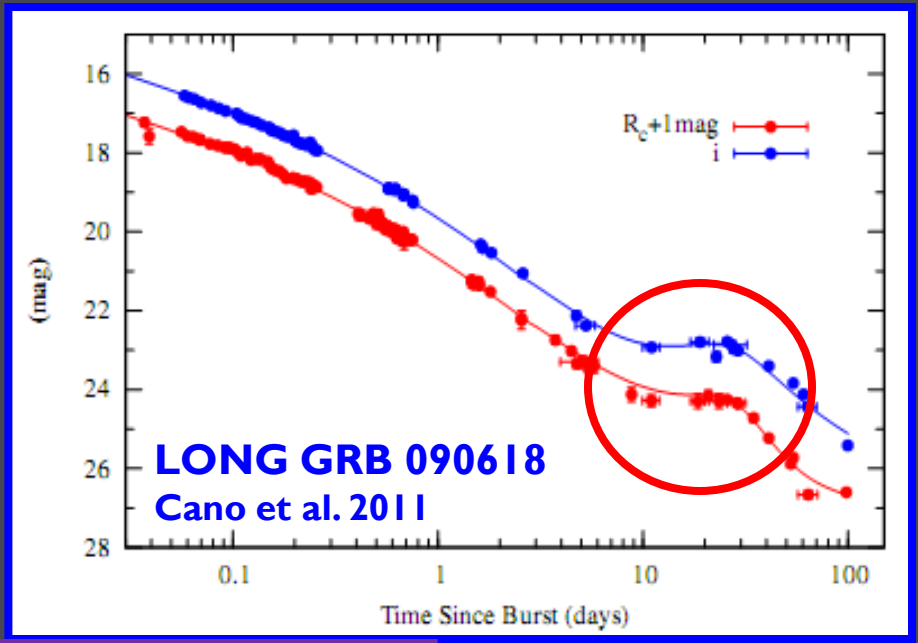
Long GRBs have associated SNe…

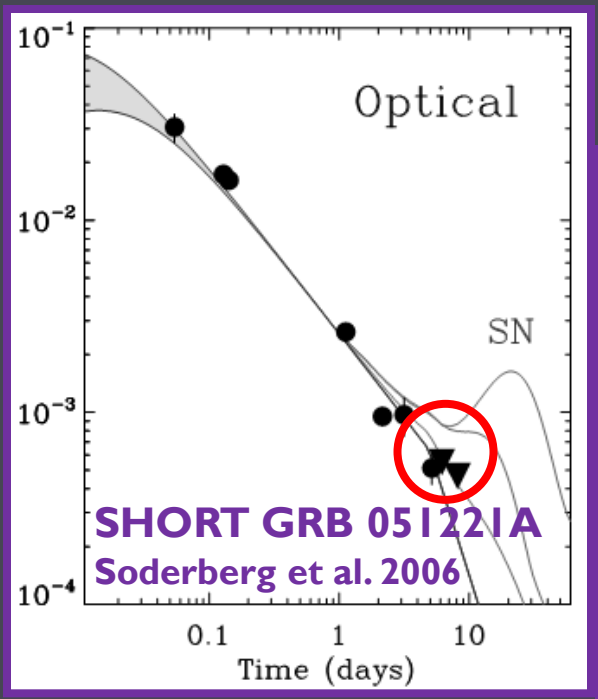


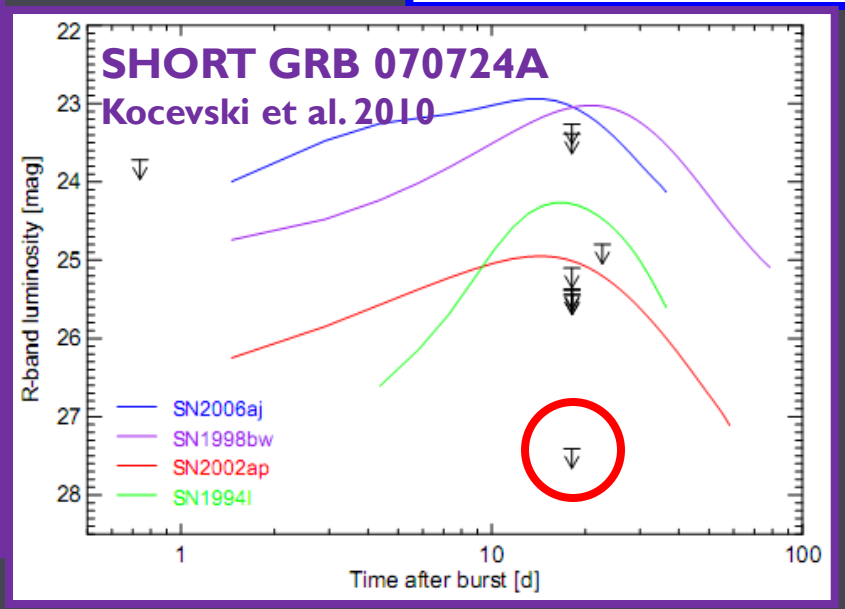


Long GRBs have associated SNe…



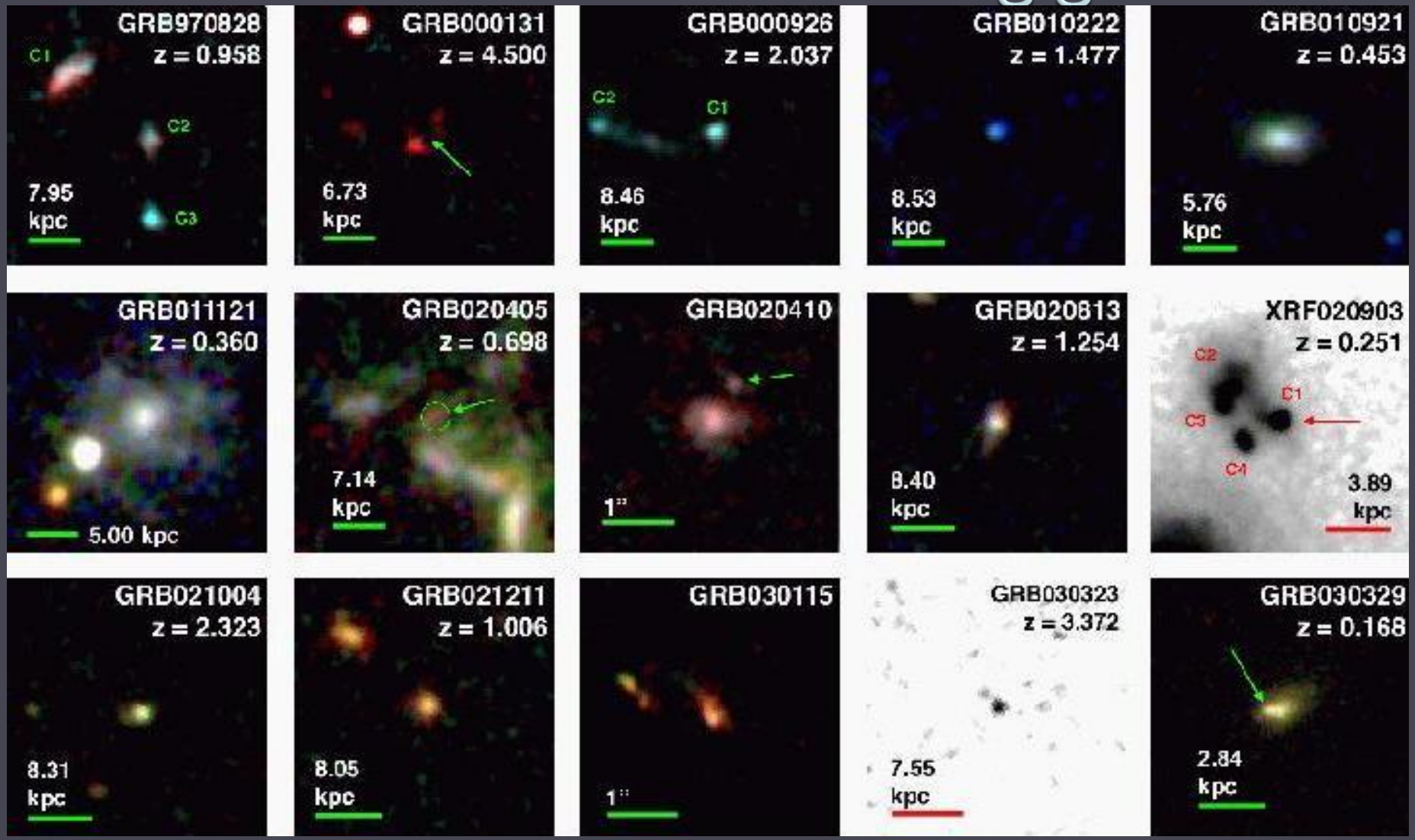






…observed short GRBs do not

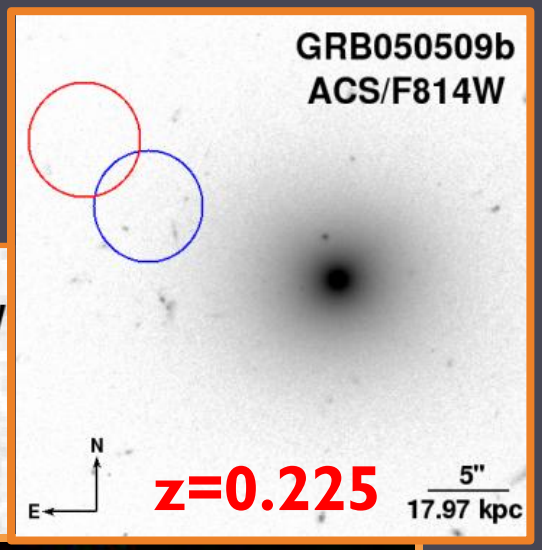
Morphology: Long GRBs exclusively associated with star-forming galaxies



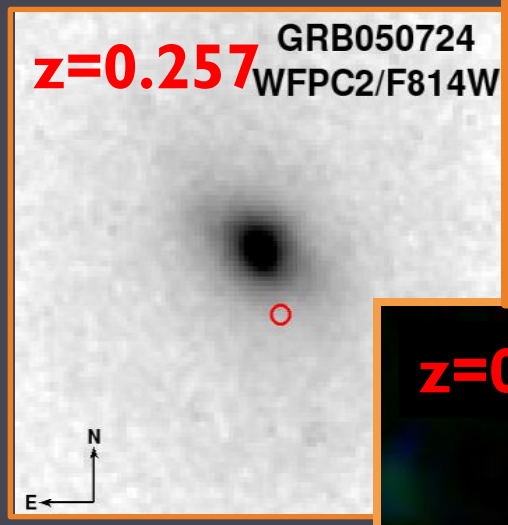
Wainwright et al. 2007; Fruchter et al. 2006

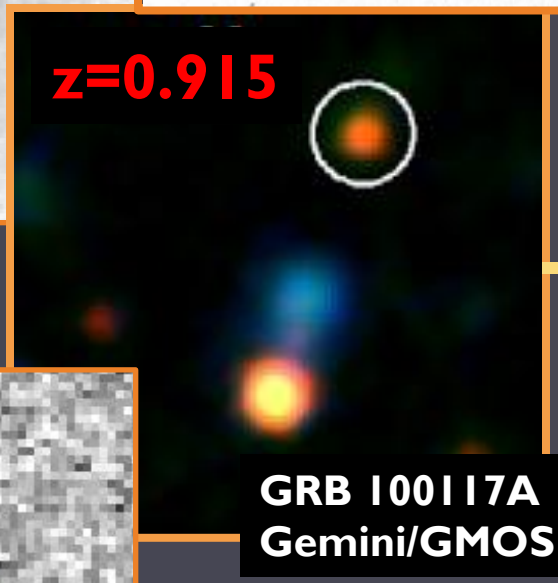
Short GRBs: A few elliptical hosts

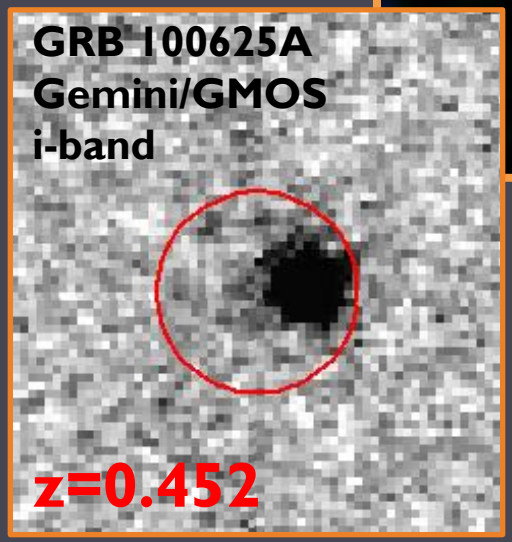
Bloom et al. 2006



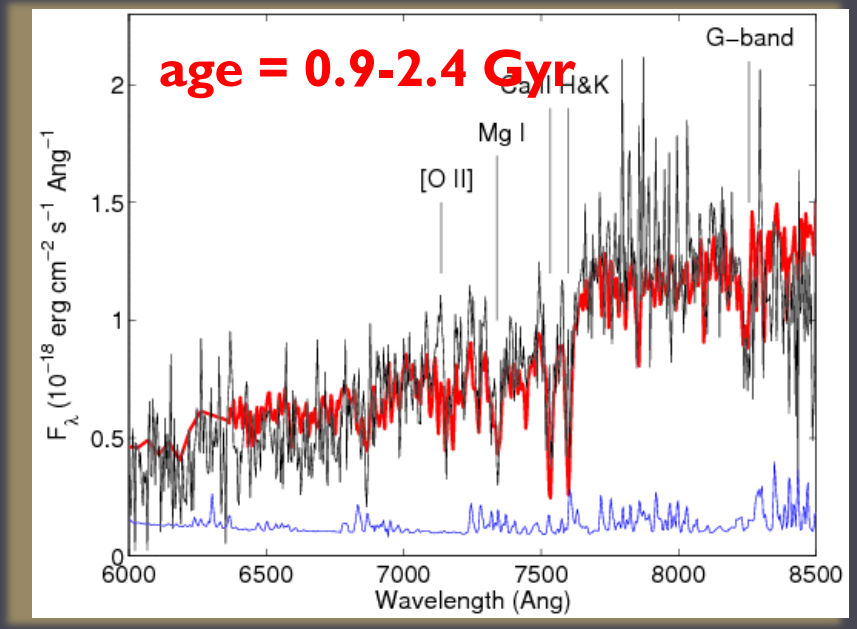
Berger et al. 2005







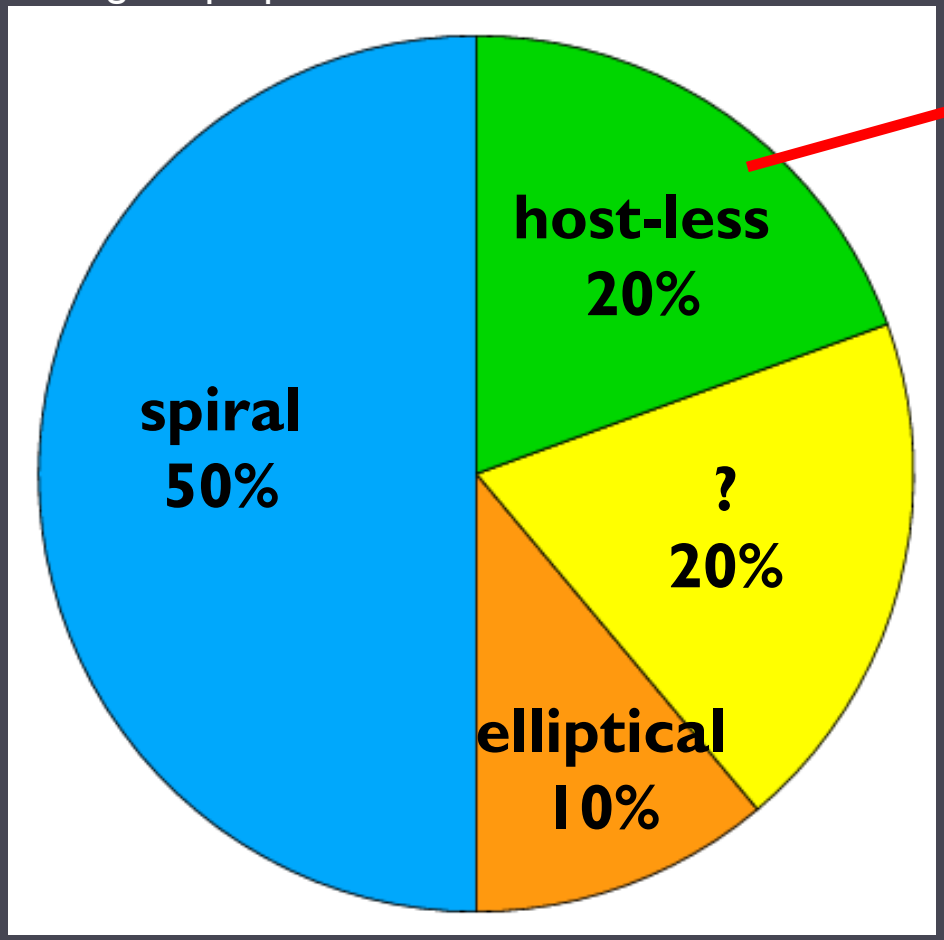
Fong et al. 2011



Distinct environments from those of long GRBs

Morphology: Short GRBs found in *elliptical and spiral* galaxies

Fong+ in prep. 2012



1 spiral
2 elliptical
3 faint/inconclusive

Sample: 36

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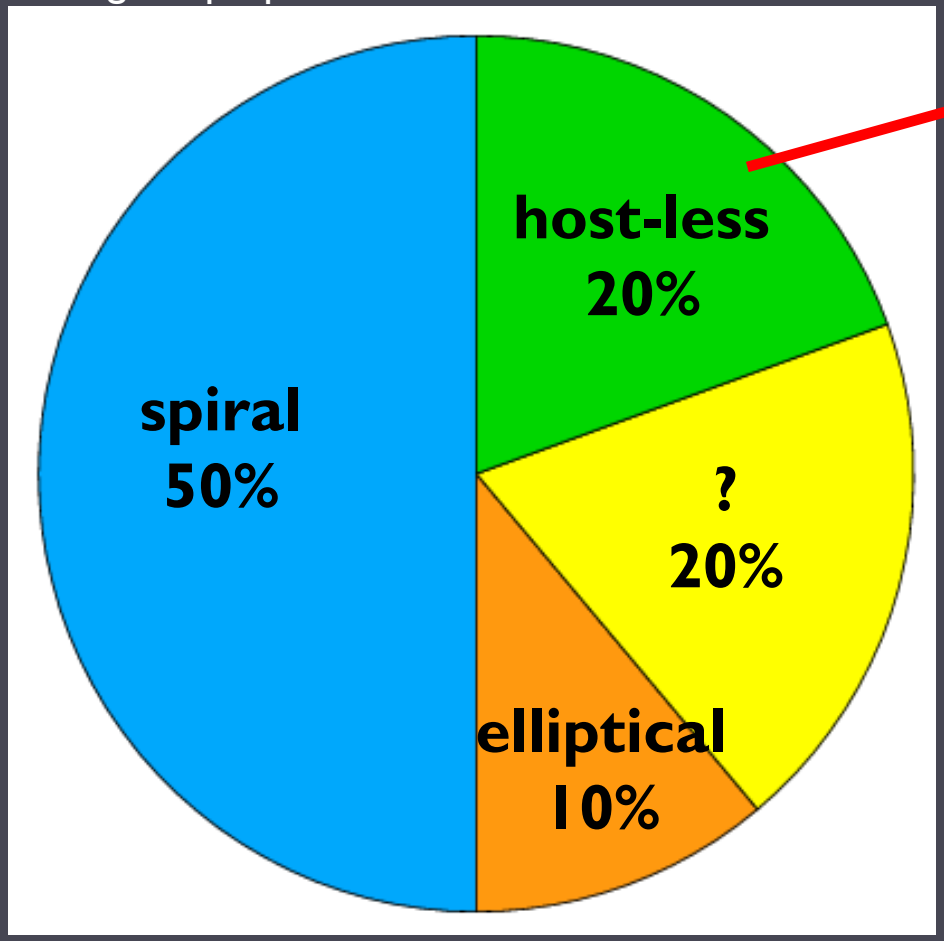

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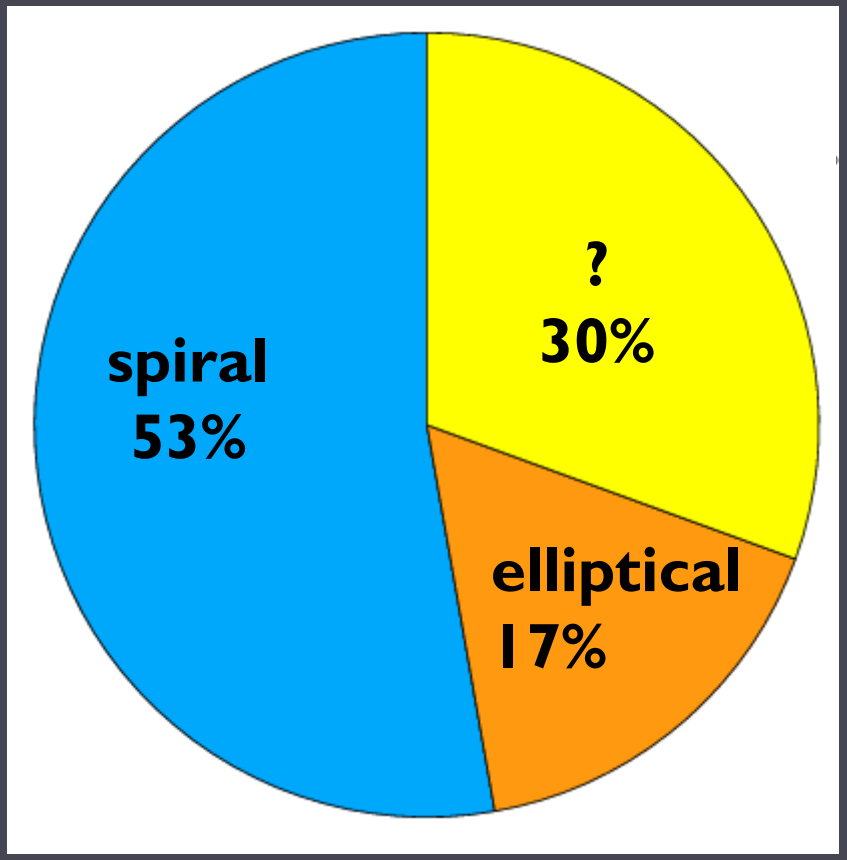
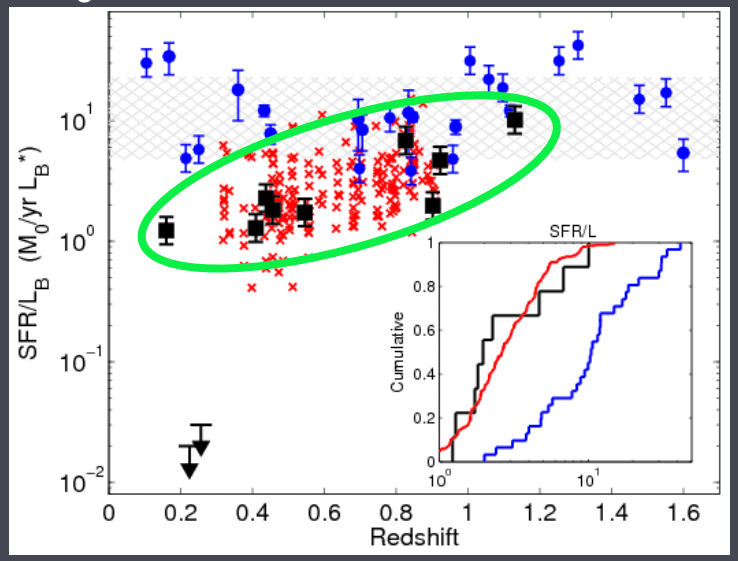


Sample: 36

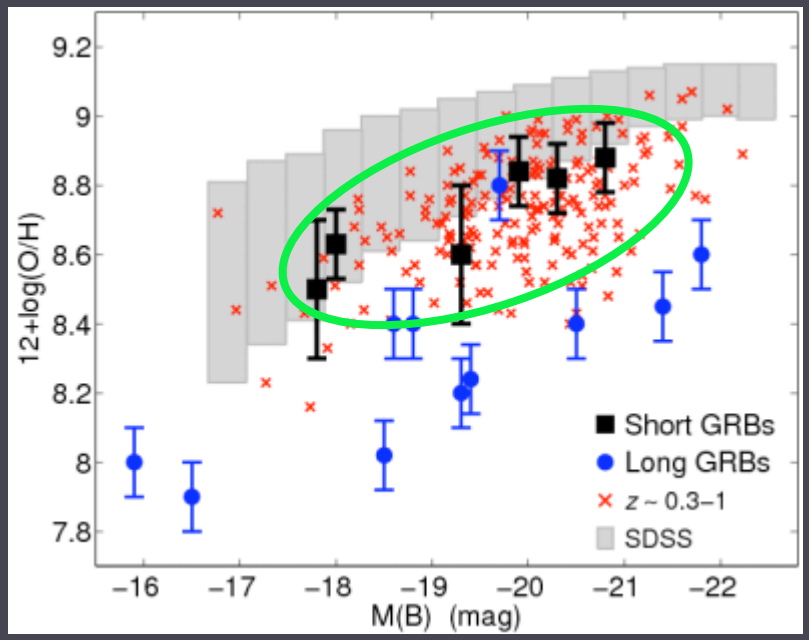
Stellar population characteristics

Berger et al. 2009



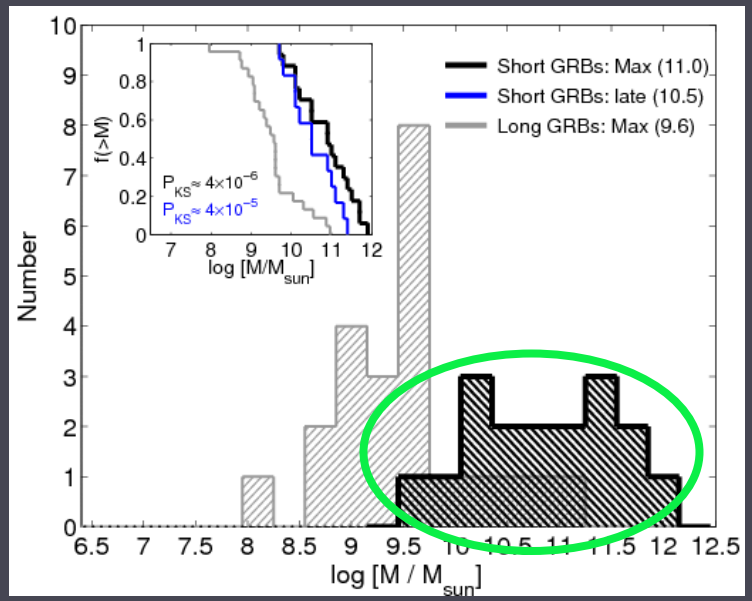
Lower specific star-forming rates…

Higher metallicities…



Berger et al. 2009

Higher stellar masses….

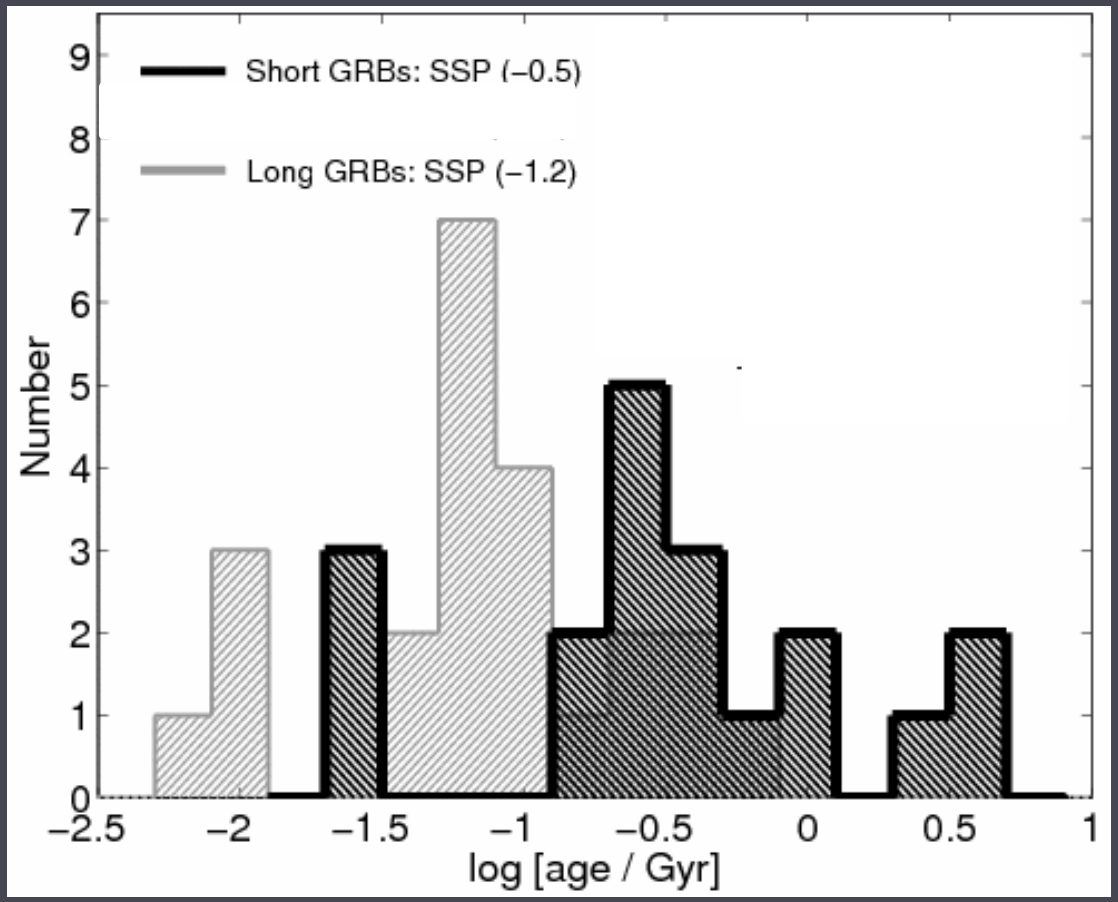


Leibler & Berger 2010

All point to a <u>different</u> origin!

Stellar population ages

Leibler & Berger 2010



$\tau_{short,SF}$ ~ 0.3 Gyr

$\tau_{short,E}$ ~ 3 Gyr

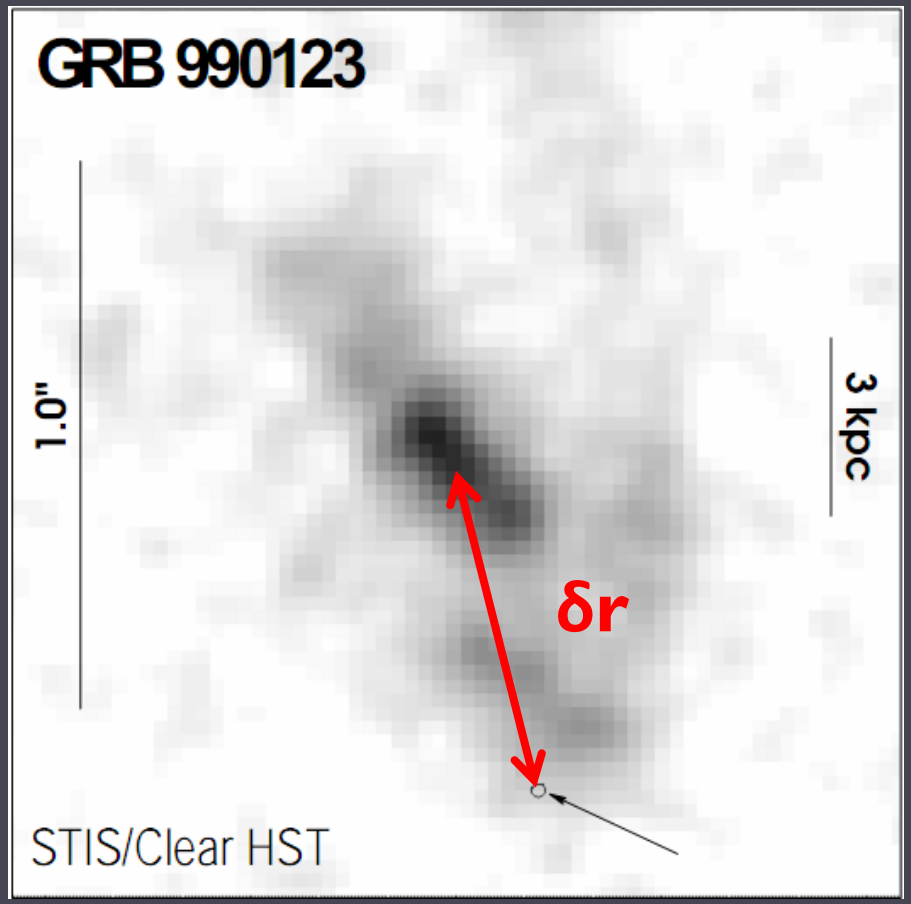
τ_{long} ~ 60 Myr

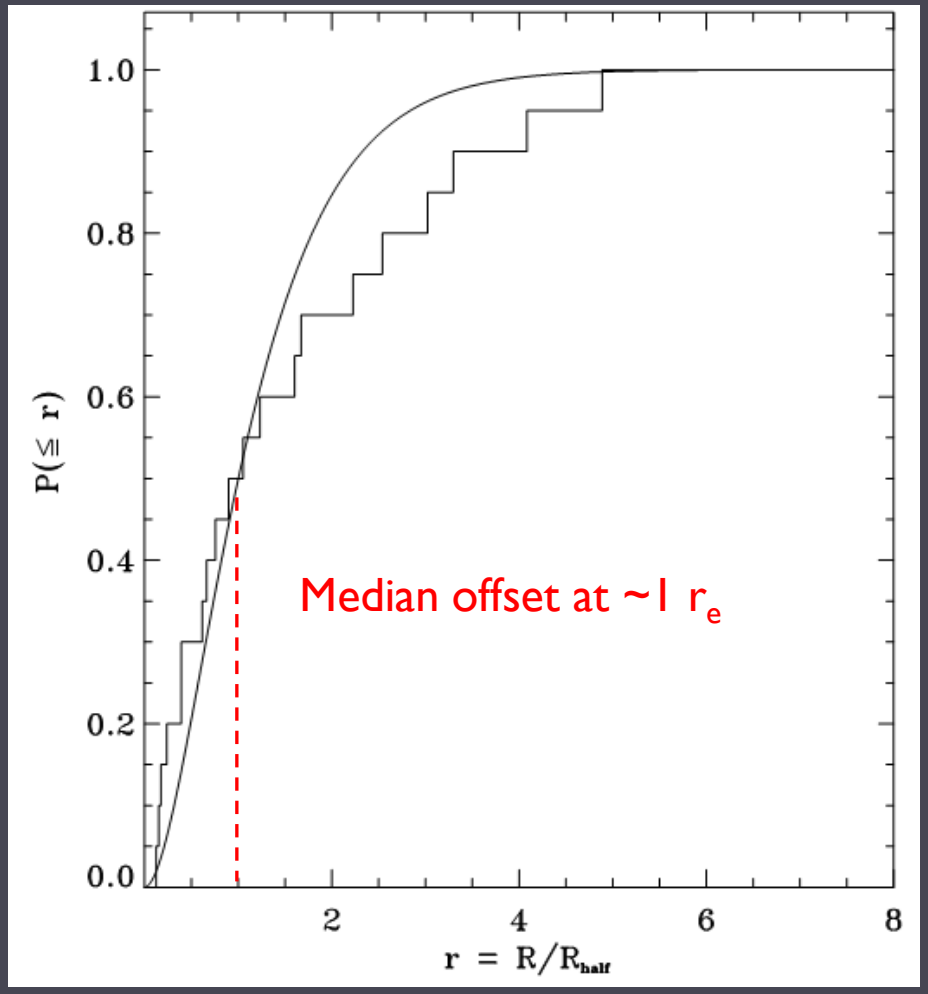
estimate of merger timescale

Short GRB progenitors have older ages than long GRBs.

Long GRB locations: Consistent with a massive star origin

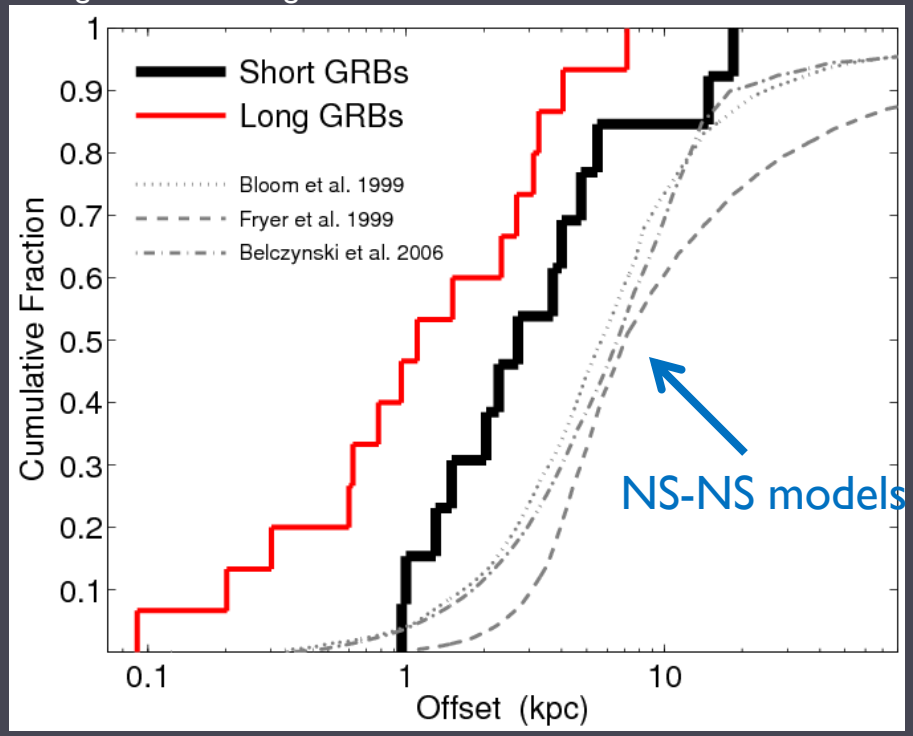
Bloom et al. 2002





Locations: Offset and Light Distributions

Fong et al. 2010; long GRBs from Bloom et al. 2002



Short GRB offset ~ 5 kpc
Long GRB offset ~ 1 kpc

Locations: Offset and Light Distributions

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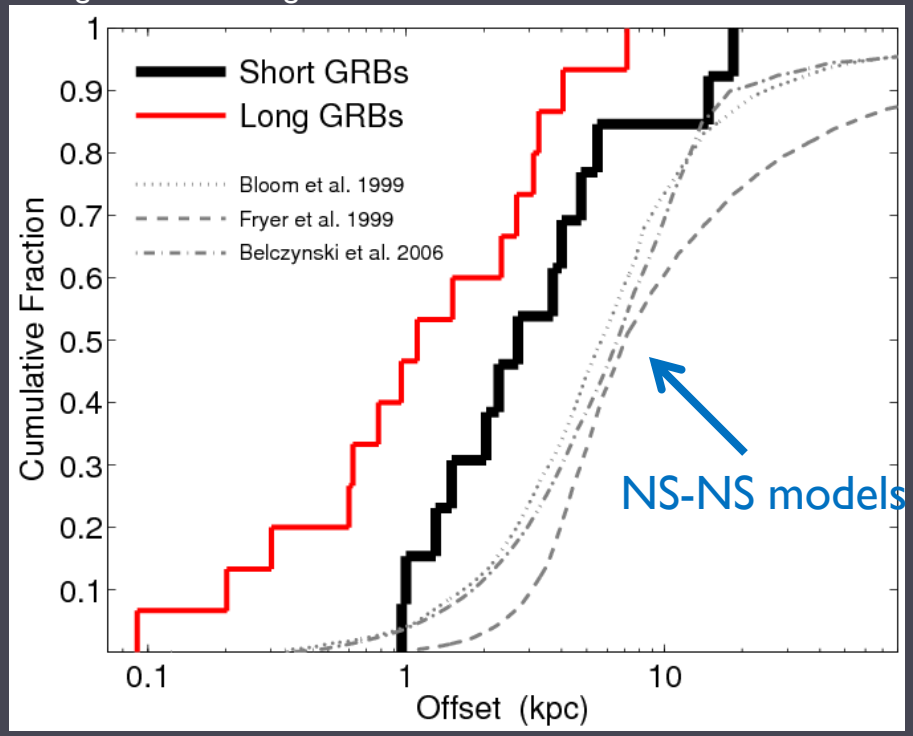
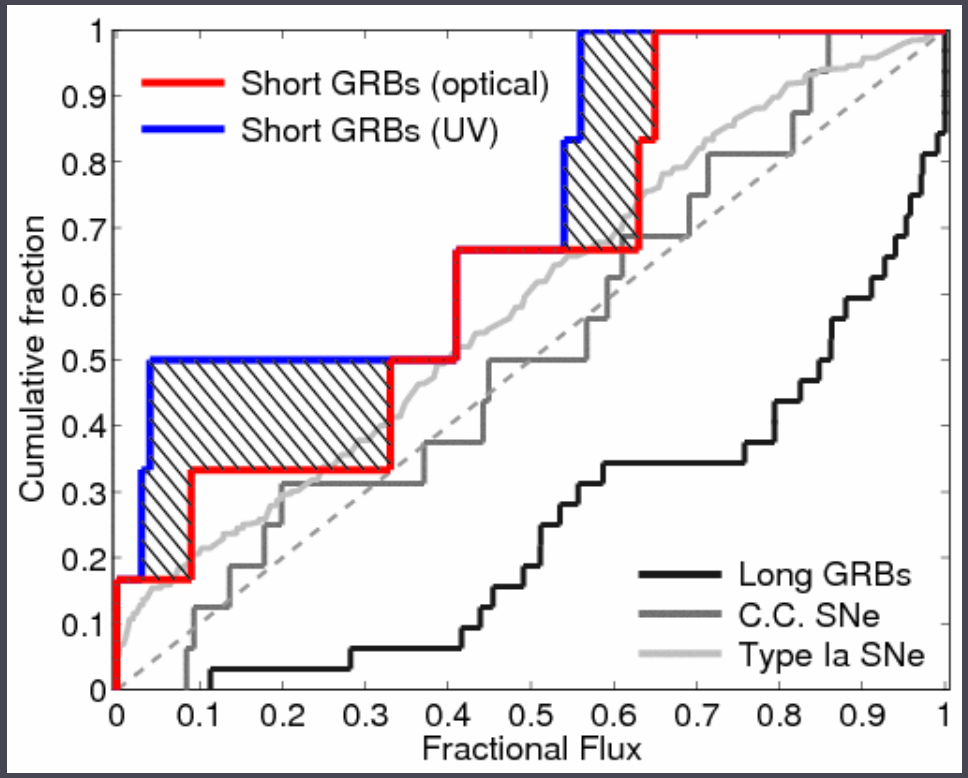


Short GRBs correlated with diffuse UV regions (no ongoing star formation)



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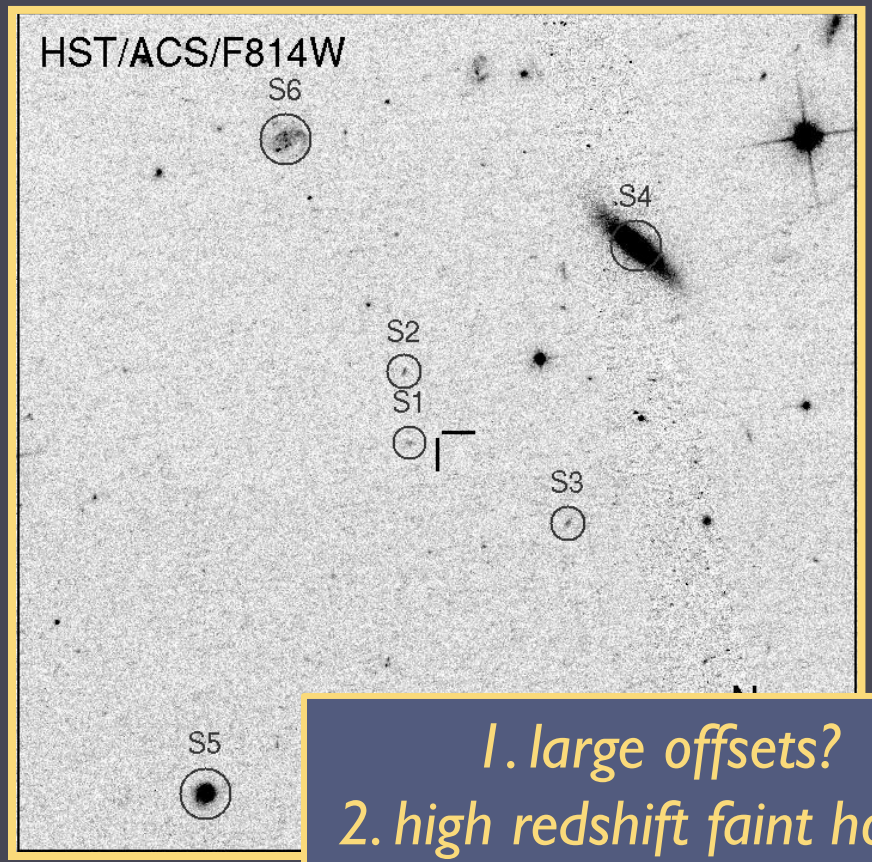
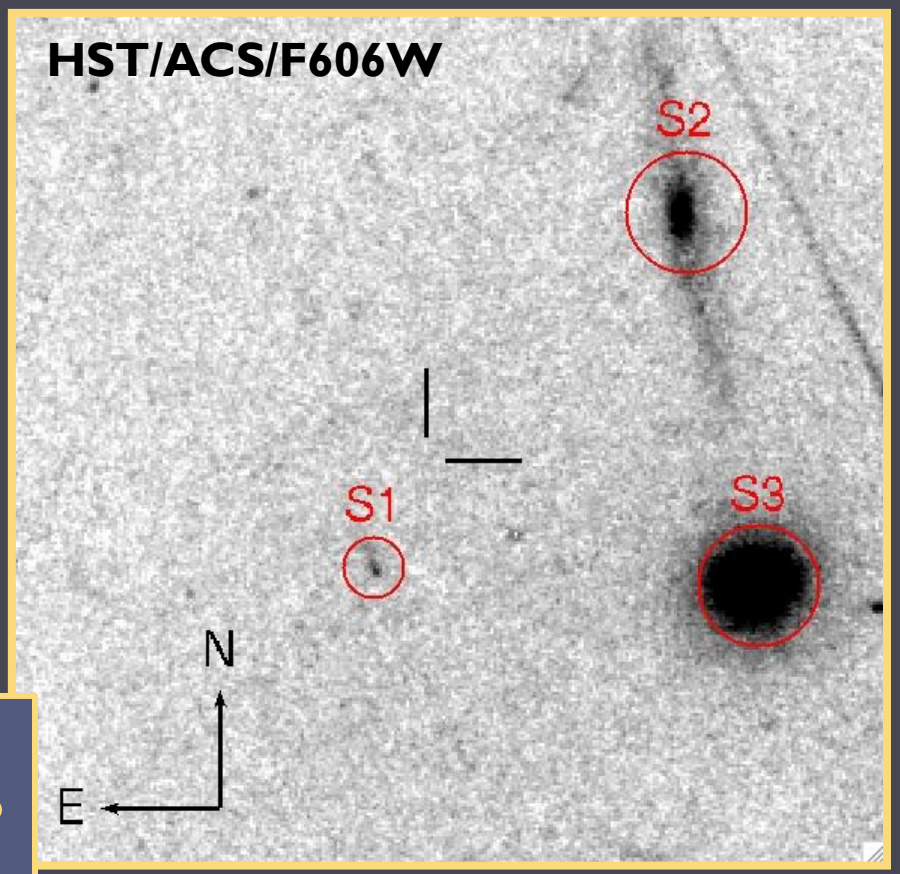
Evidence for kicks? "Host-less" bursts

GRB 061201 Berger 2010; Stratta et al. 2006; Fong et al. 2010



1. large offsets?
2. high redshift faint hosts?
3. coincident dwarf galaxy?

GRB 070809



What is the likelihood of finding an unrelated galaxy?

Evidence for kicks? "Host-less" bursts

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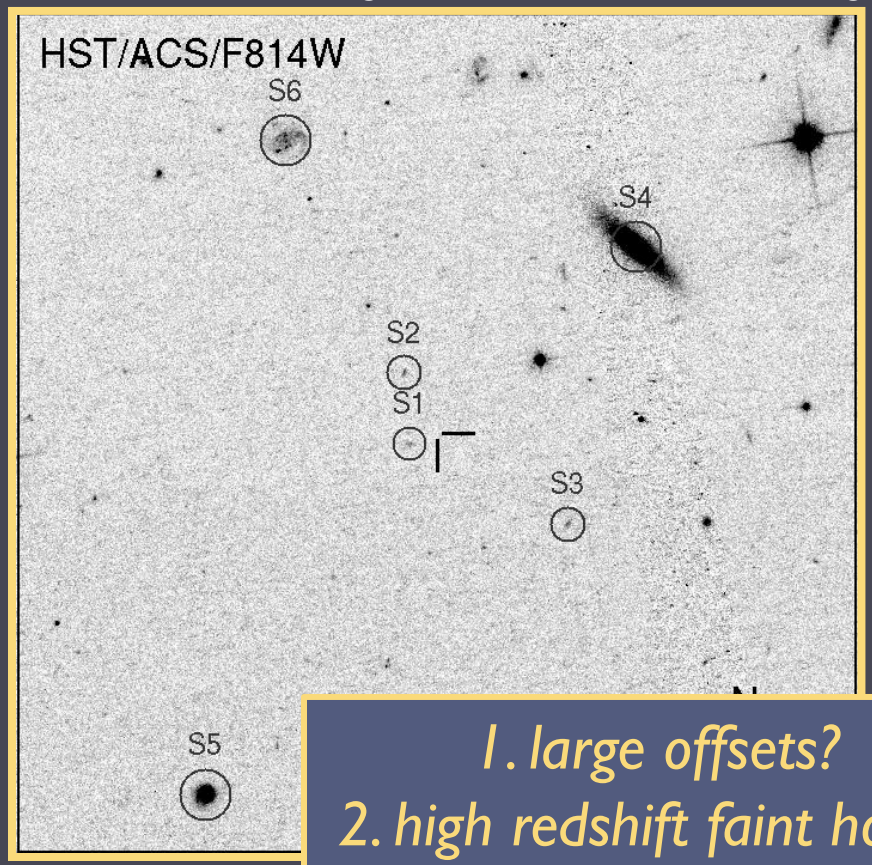

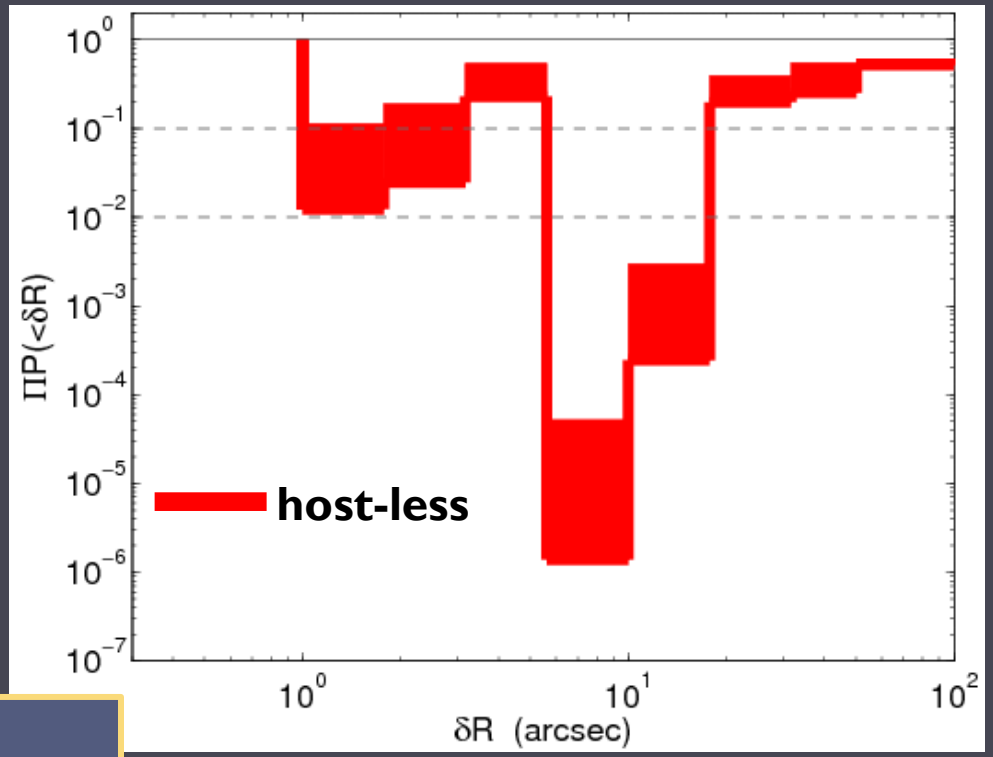

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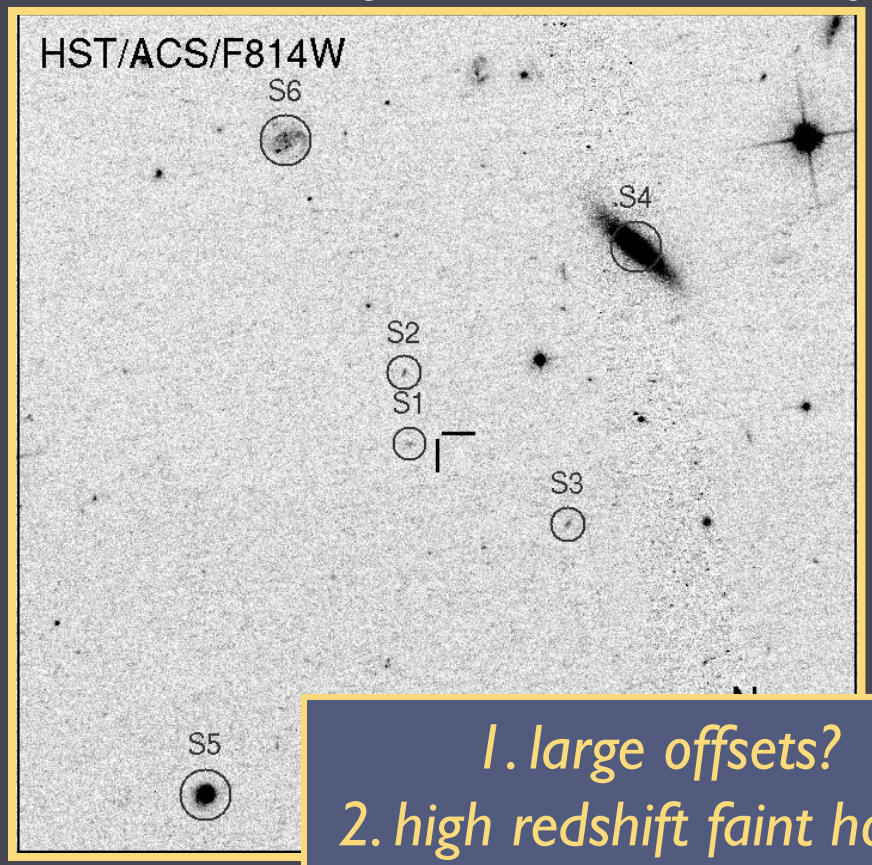

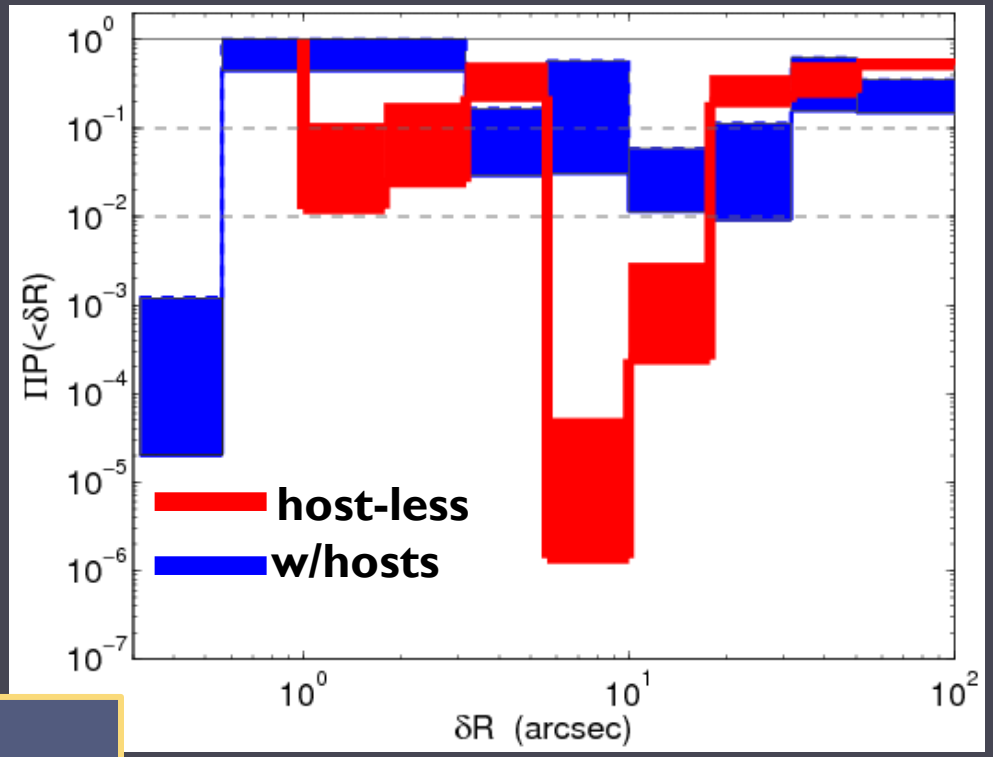

1. large offsets?
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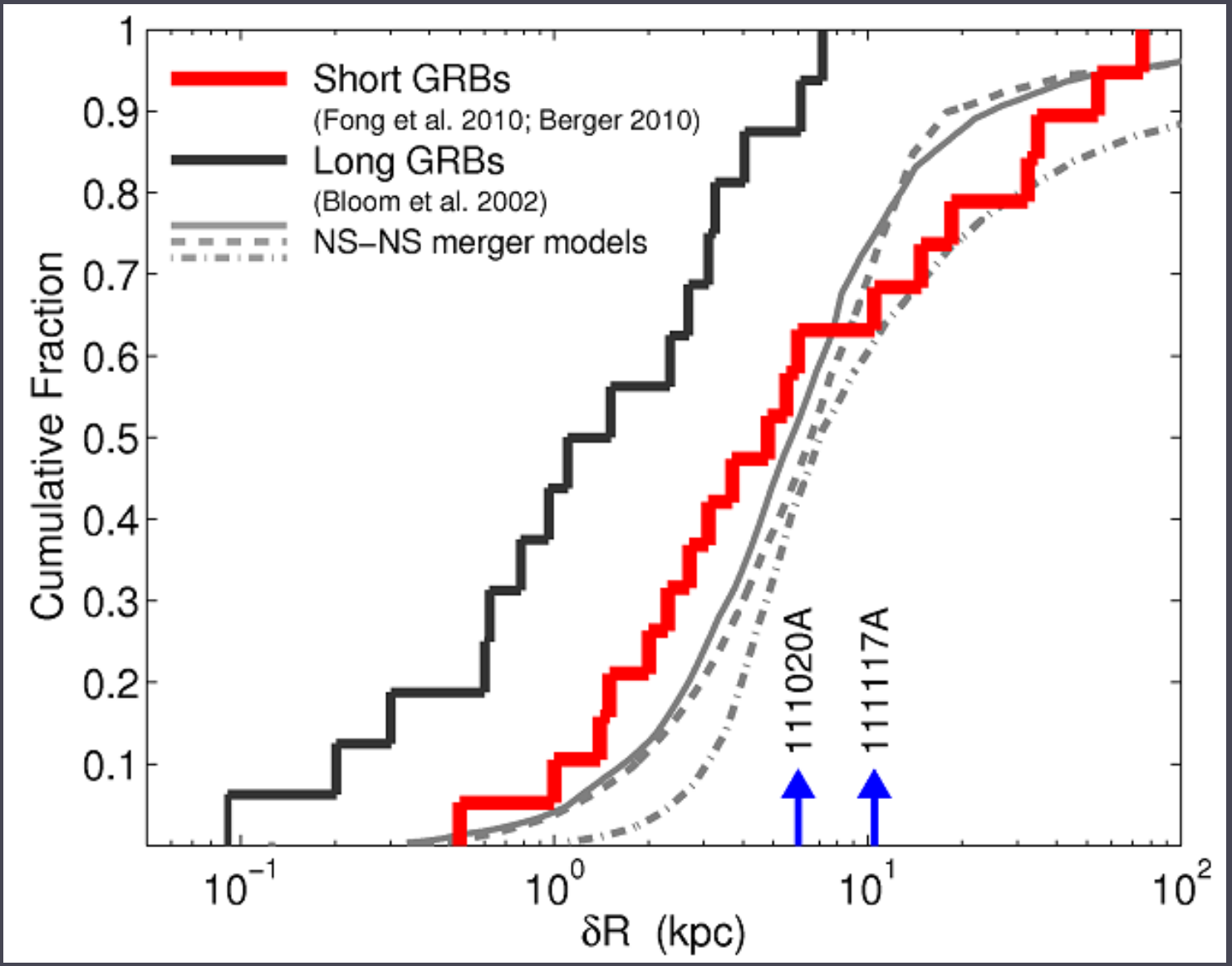
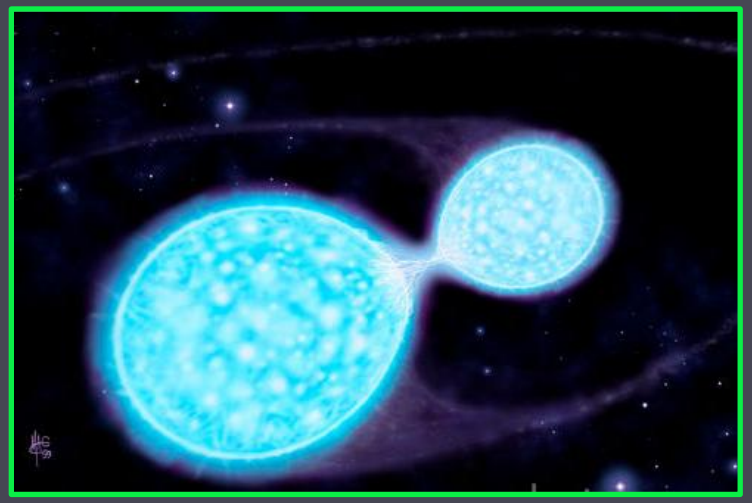
Strong evidence for a highly-kicked progenitor system?



Margutti, Berger, Fong+ 2012; models: Fryer/Bloom 1999, Belczynski et al. 2006

Provide best agreement with NS-NS models to date

Revisiting the expectations



Neutron Star-Neutron Star merger / Neutron Star-Black Hole merger	Massive Stars
• No association with SNe • Little correlation with star formation • Occur in older stellar populations • Substantial offsets (potential kicks)	• Association with SNe • High correlation with star formation • Occur in younger stellar populations • Small or moderate offsets (no kicks)

SHORT

LONG

The Story So far: Nature of the progenitor

Short GRBs reside in…

50% spiral galaxies, 20% host-less,
10% elliptical, 20% inconclusive

Compared to long GRBs, short GRBs have…

lower specific SFRs
higher metallicities
higher stellar masses

Ages ~ merger timescale? **0.3-3 Gyr**

Offsets with hosts: **~5 kpc**
Offsets of host-less: **30-70 kpc**