Short Gamma-Ray Burst Afterglows

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special thanks to:
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B. Ashley Zauderer
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Derek Fox
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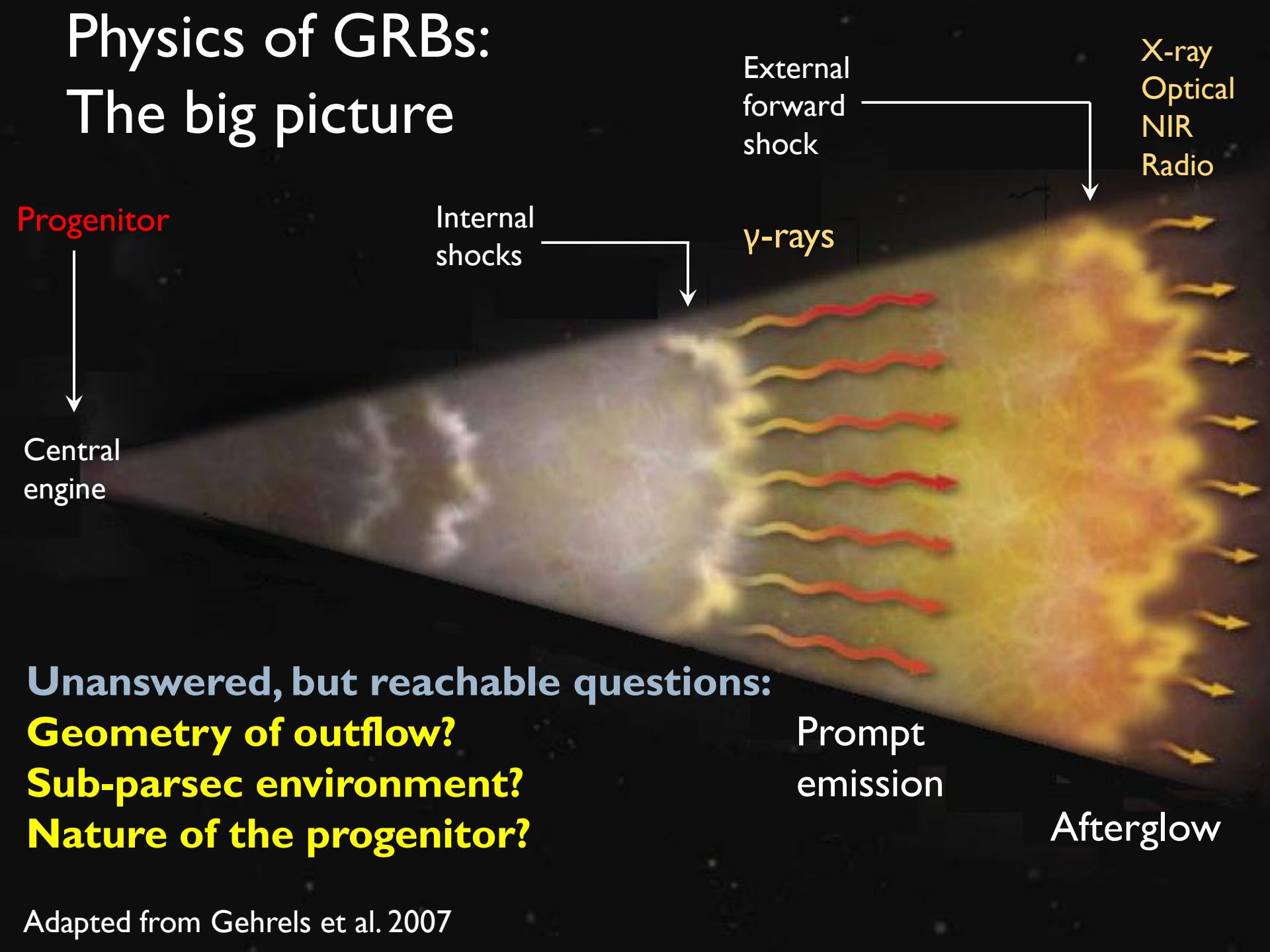
Physics of GRBs: The big picture



Unanswered, but reachable questions:

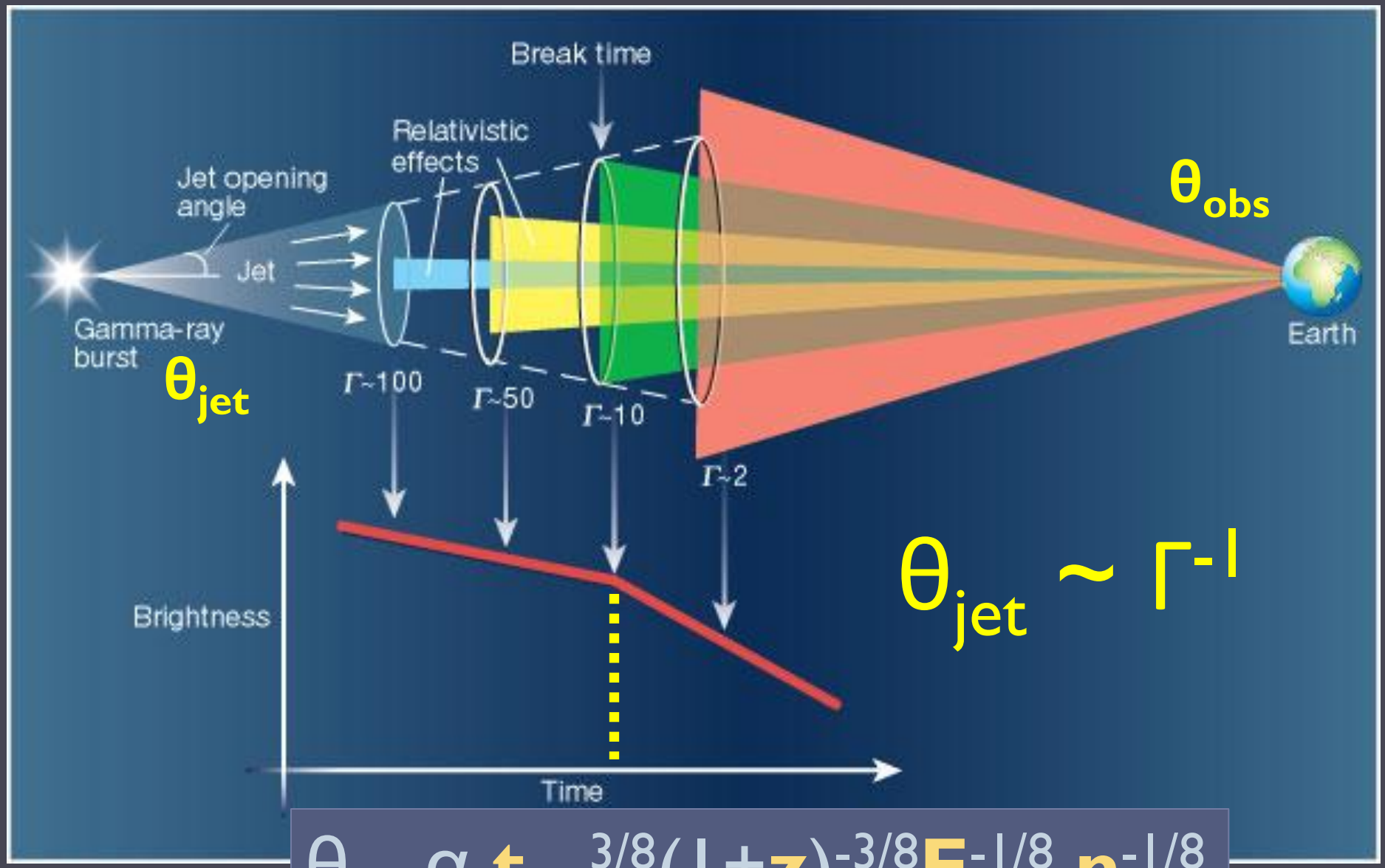
Geometry of outflow?

Sub-parsec environment?

Nature of the progenitor?

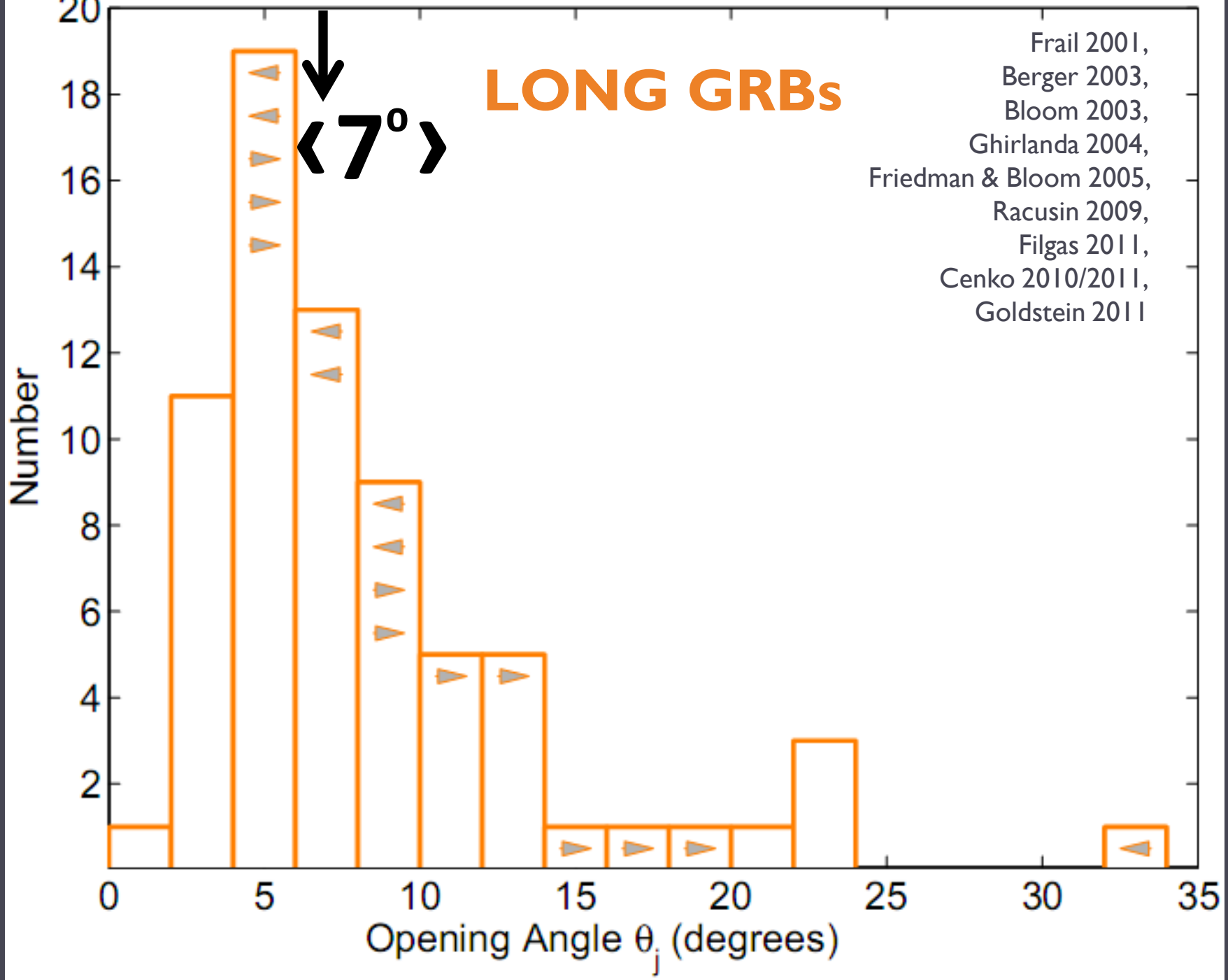
Adapted from Gehrels et al. 2007

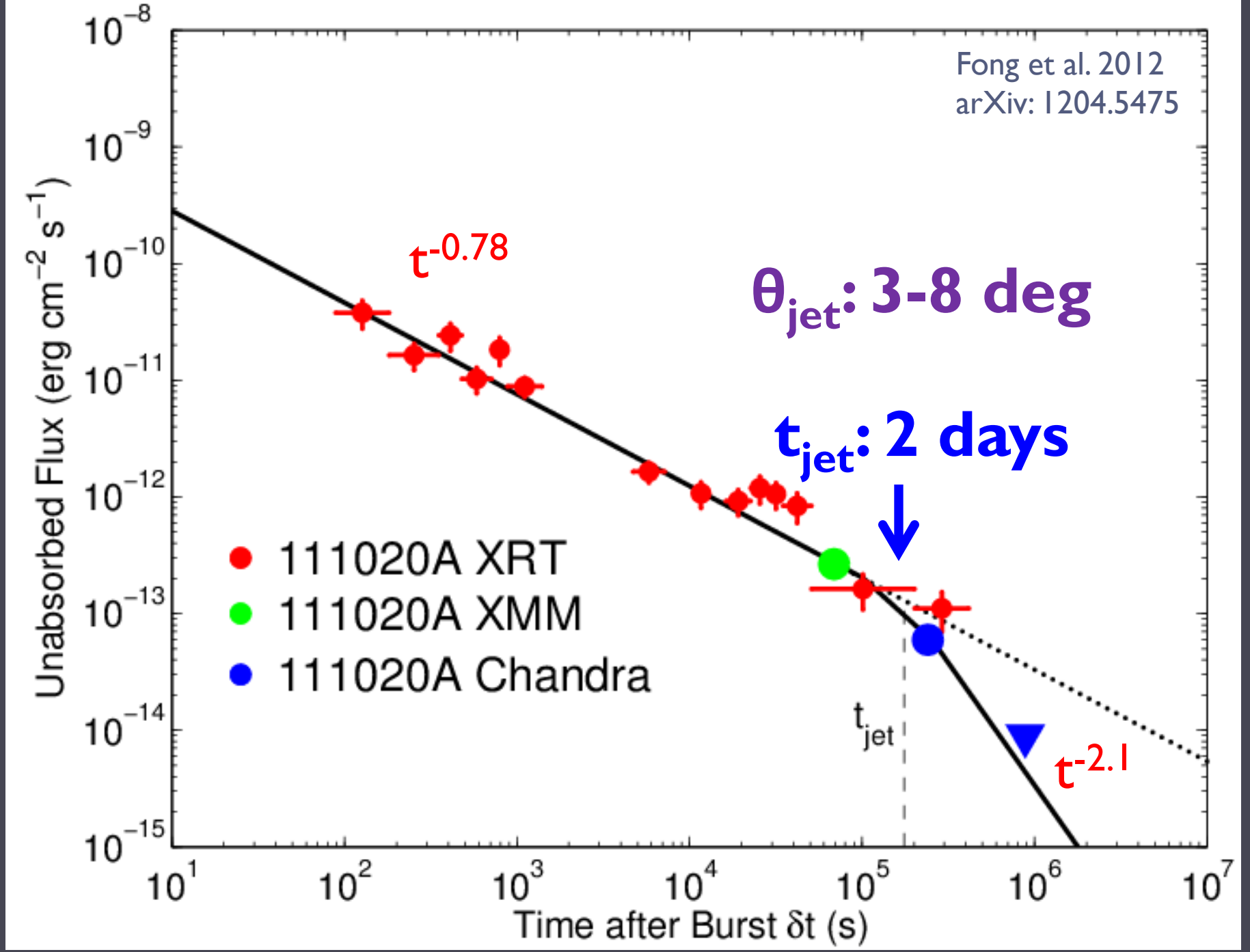
Geometry of outflow? Jet Breaks

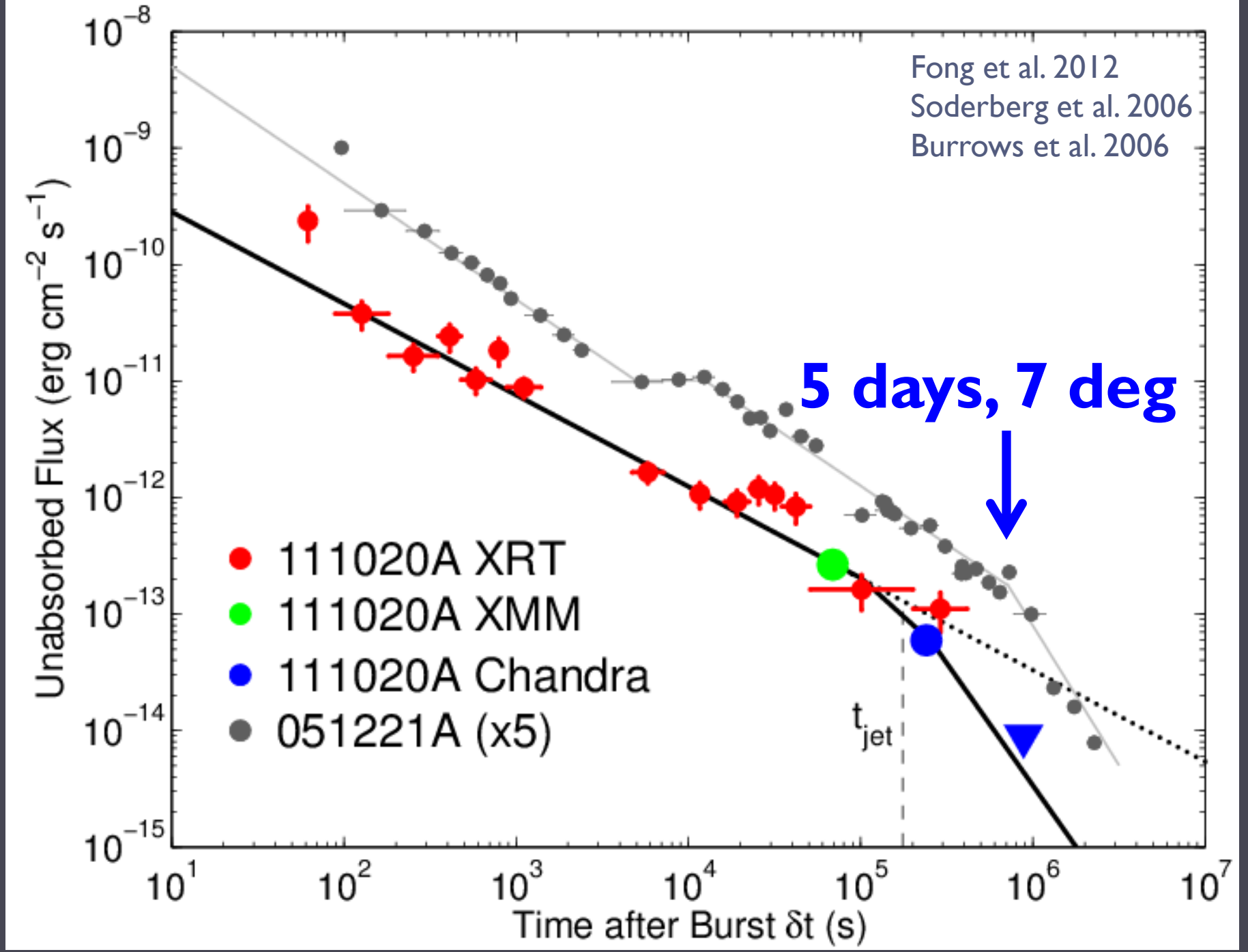


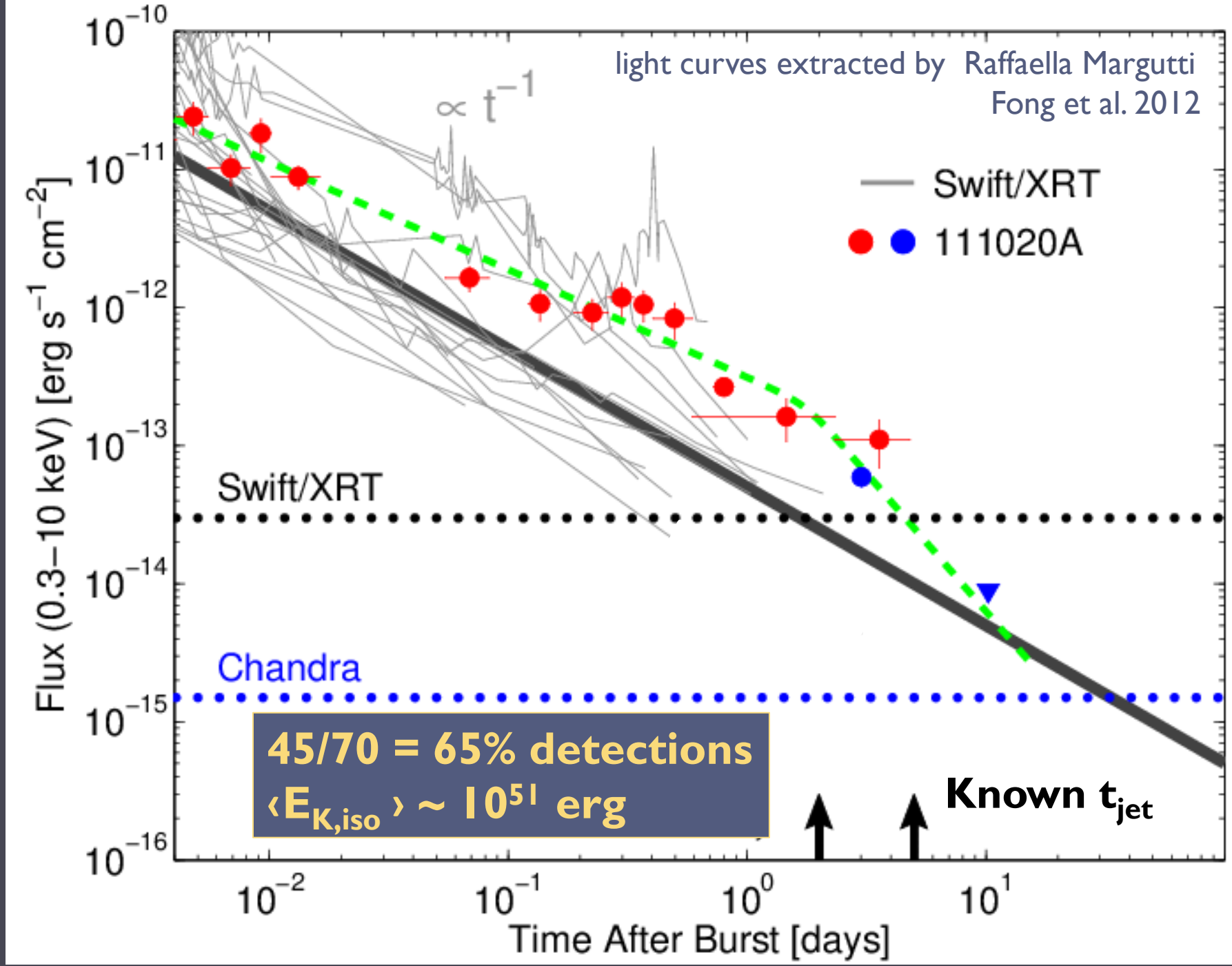
$\theta_{jet} \sim \Gamma^{-1}$

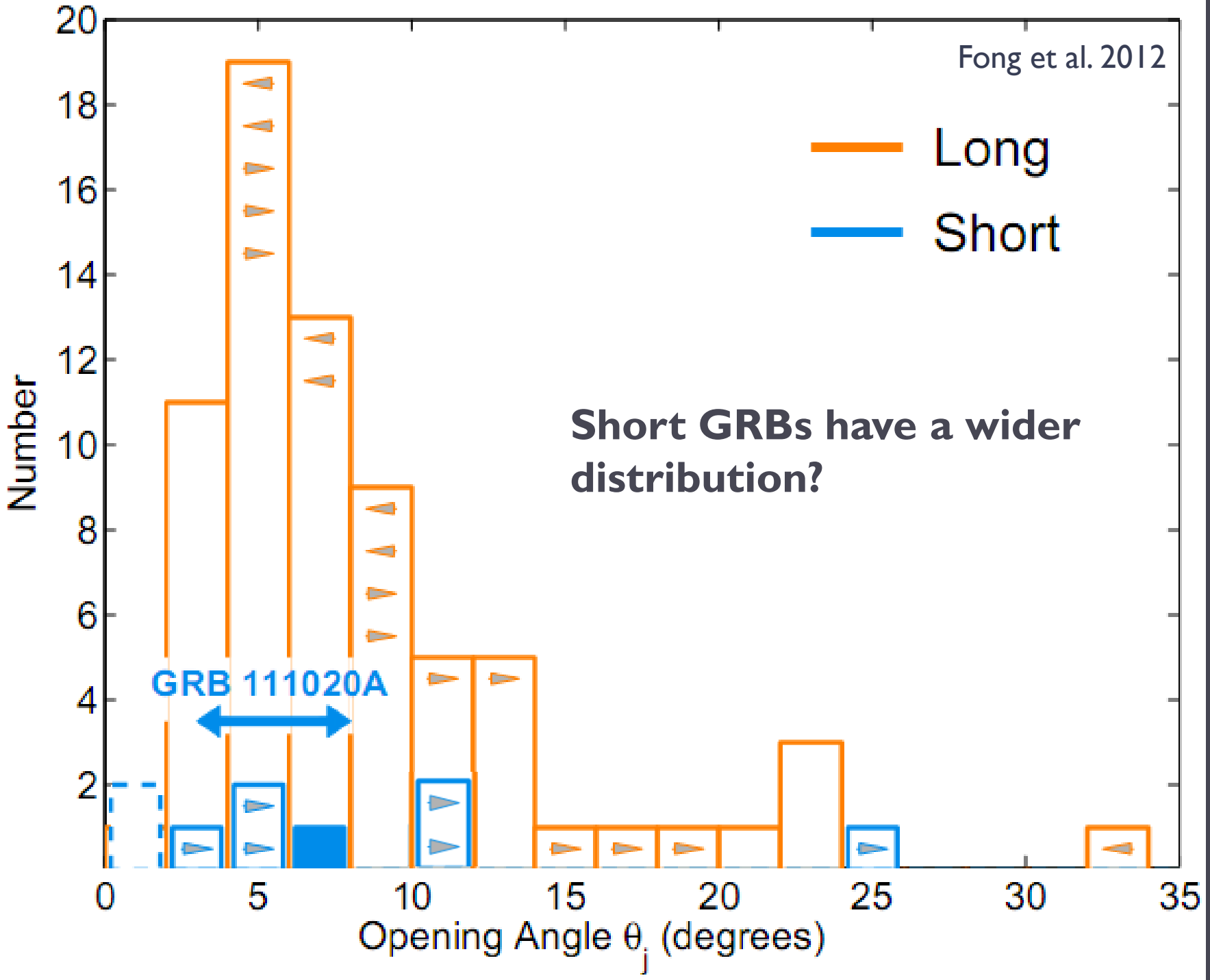
$\theta_{jet} \alpha t_{jet}^{3/8}(1+z)^{-3/8} E^{-1/8} n^{-1/8}$


LONG GRBs
⟨7°⟩
Frail 2001,
Berger 2003,
Bloom 2003,
Ghirlanda 2004,
Friedman & Bloom 2005,
Racusin 2009,
Filgas 2011,
Cenko 2010/2011,
Goldstein 2011
Number
Opening Angle θj (degrees)
0
5
10
15
20
25
30
35
2
4
6
8
10
12
14
16
18
20


Fong et al. 2012
arXiv: 1204.5475
$t^{-0.78}$
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}


light curves extracted by Raffaella Margutti
Fong et al. 2012
$\propto t^{-1}$
Swift/XRT
111020A
Swift/XRT
Chandra
45/70 = 65% detections
‹E$_{K,iso}$ › ~ 10^{51} erg
Known t$_{jet}$
Flux (0.3–10 keV) [erg s^{-1} cm^{-2}]
Time After Burst [days]
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-2}
10^{-1}
10^{0}
10^{1}

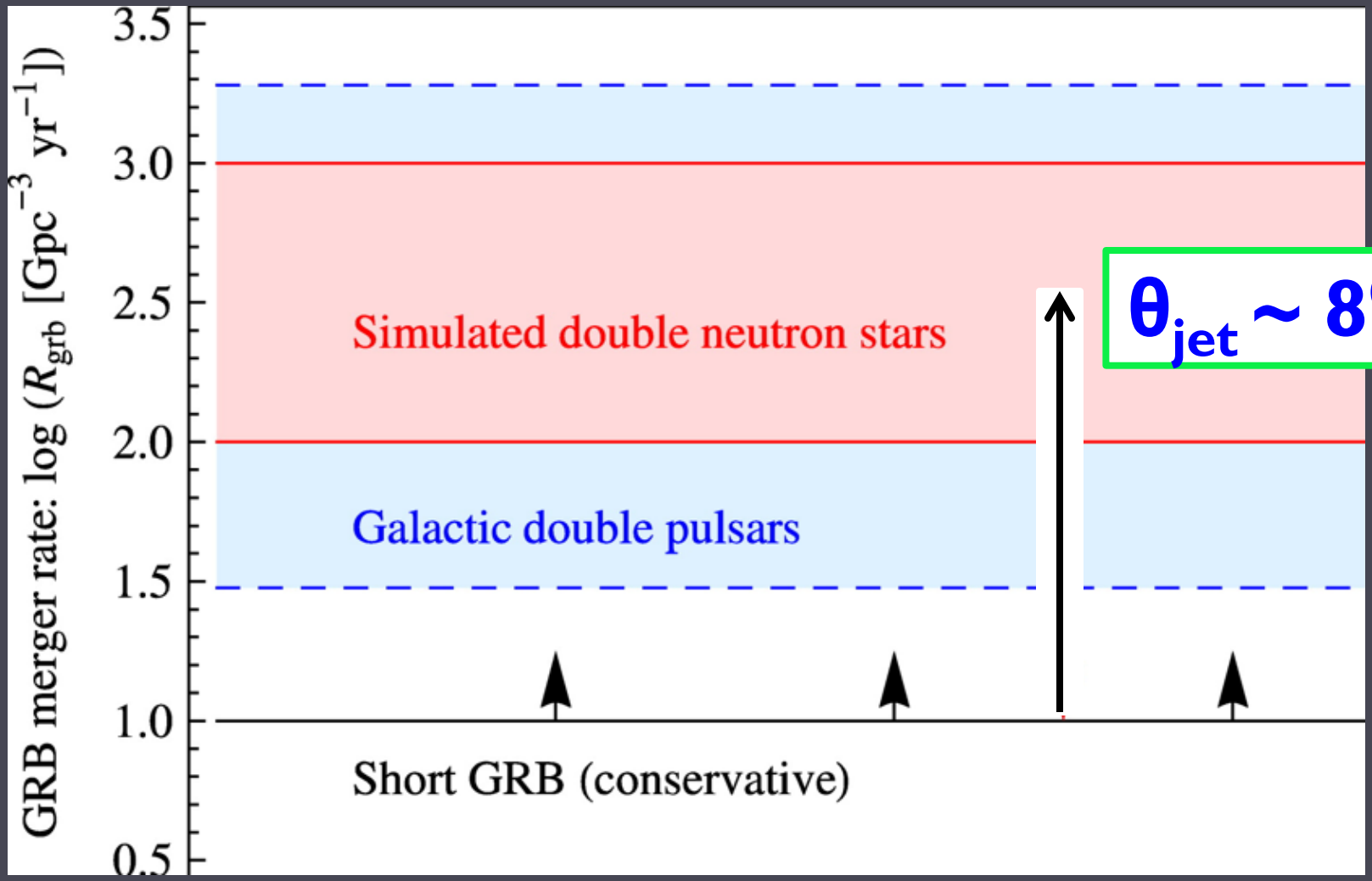

Fong et al. 2012
Long
Short
Short GRBs have a wider distribution?
GRB 111020A
Number
Opening Angle θj (degrees)
0
5
10
15
20
25
30
35
2
4
6
8
10
12
14
16
18
20

Implications: Energy Scale

- isotropic-equivalent energy $E_{iso} \sim 10^{51}$ erg
- beaming-corrected true energies ~ **10^{49} erg**
- mechanism of energy extraction predictions:
  - neutrino-antineutrino annihilation ~ 10^{48}-10^{49} erg
  - MHD processes, magnetically-dom. jet ~ >10^{49} erg

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

Implications: Rates

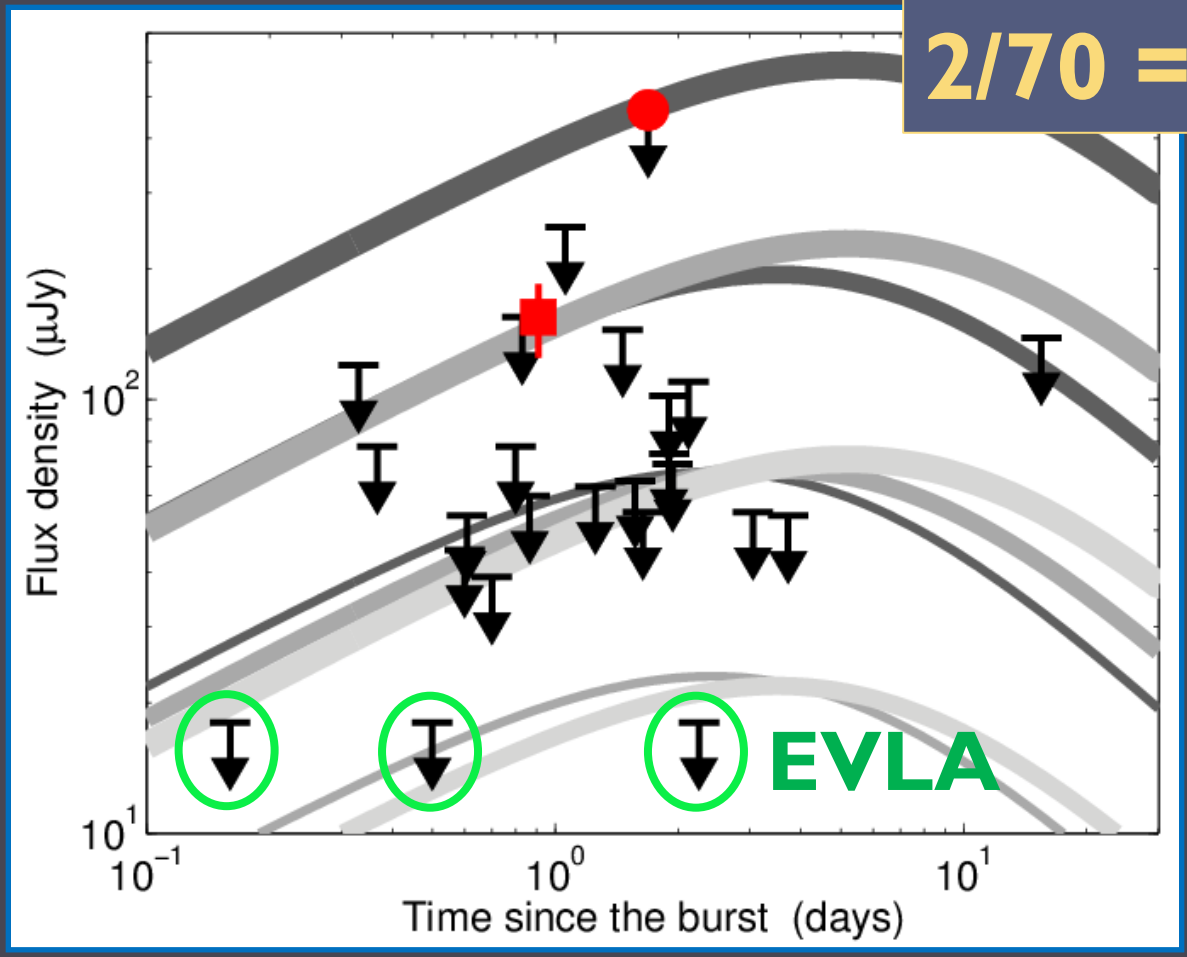


observed short GRB rate of 10 Gpc^{-3} yr^{-1} → 100-1000 Gpc^{-3} yr^{-1}

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

Sub-pc environment: Radio afterglows

2/70 = 3% detections



Fong in prep. 2012

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

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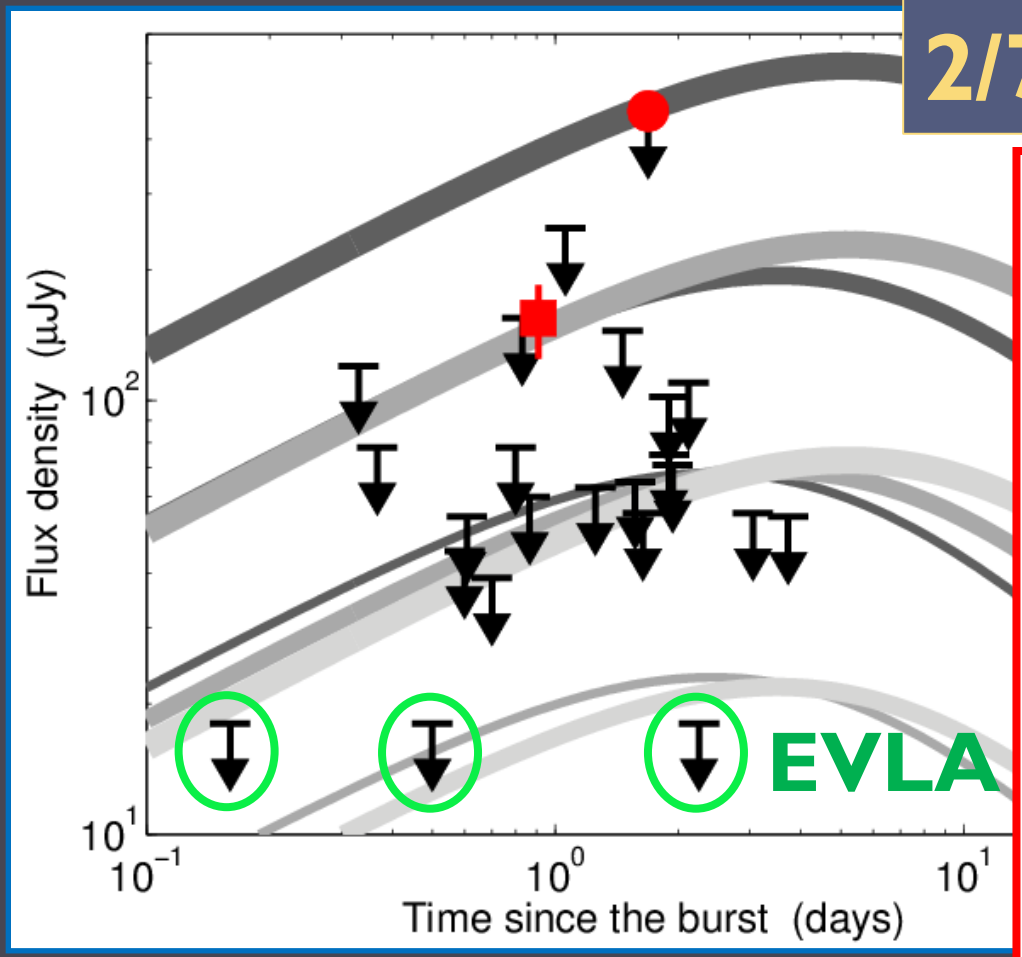
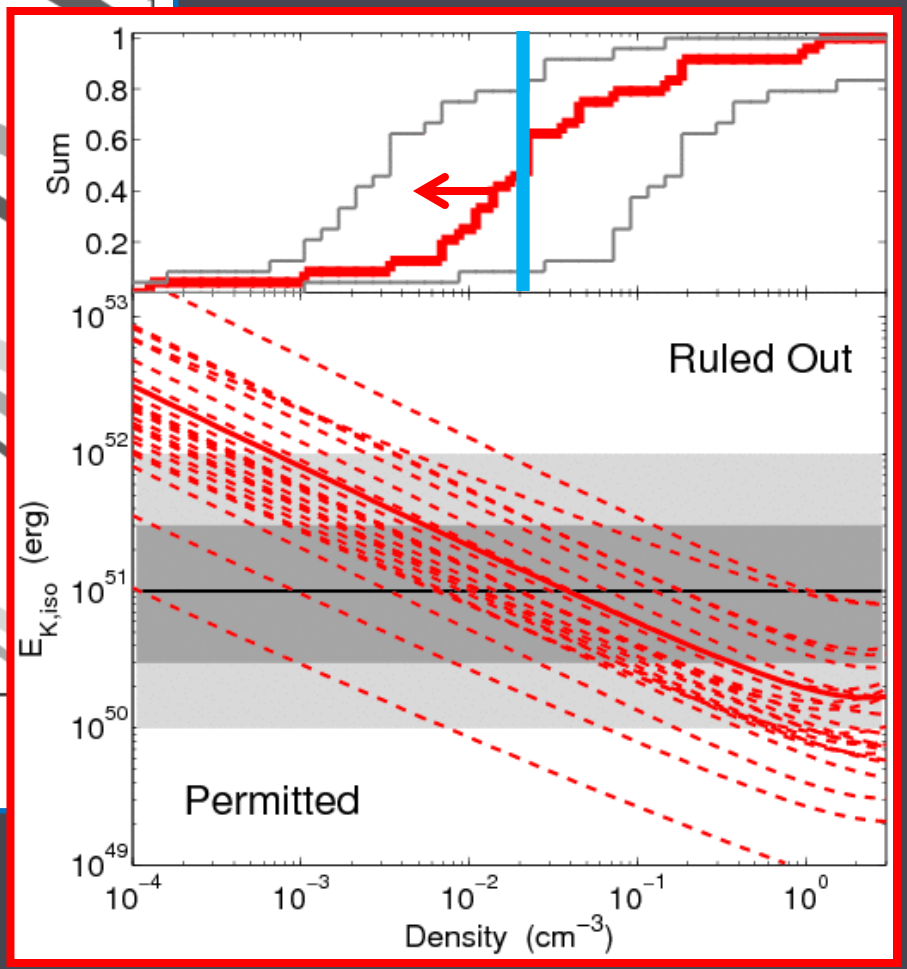


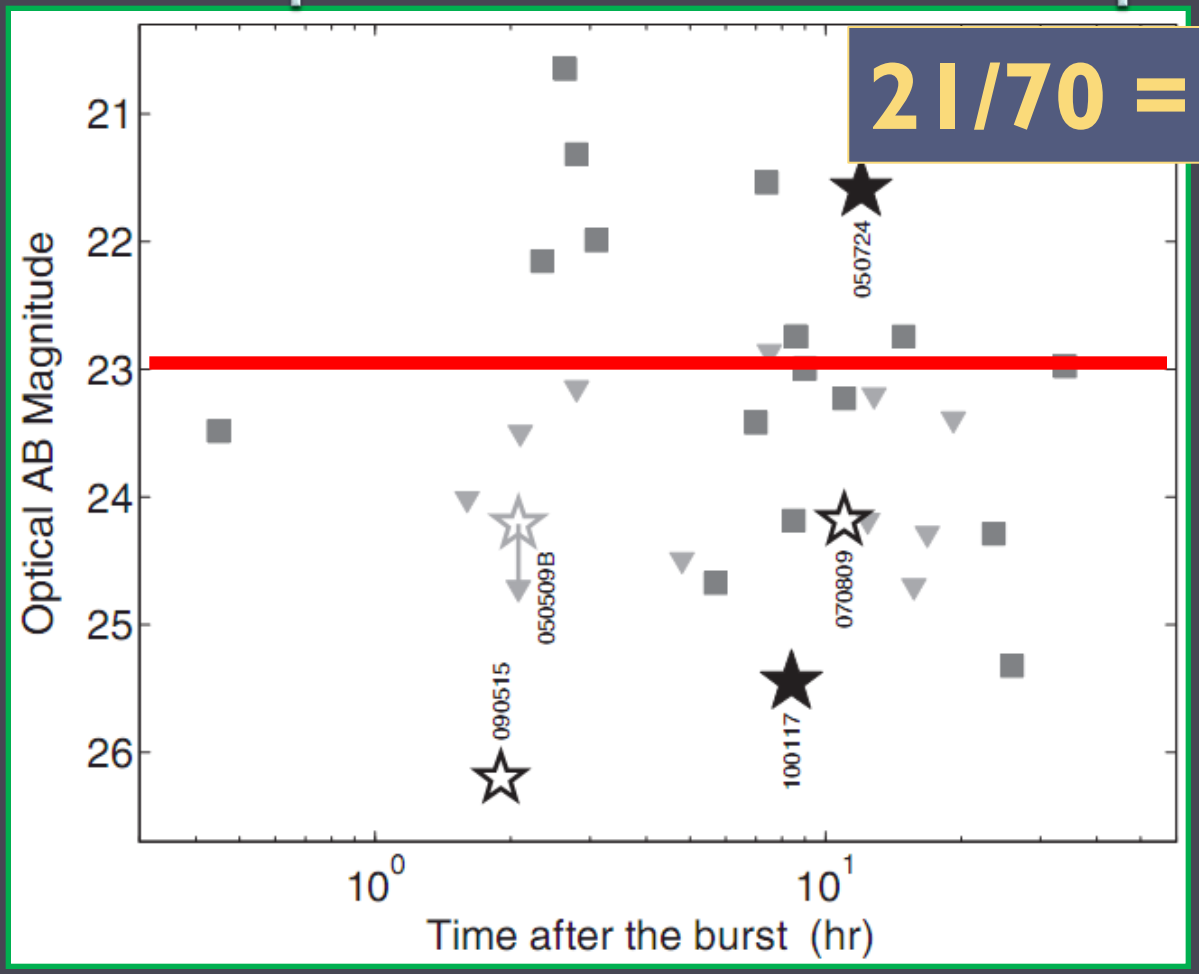


Fong in prep. 2012

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

from UL and detections: ⟨n⟩ ≤ 0.02 cm^{-3}

Sub-pc environment: Optical afterglows

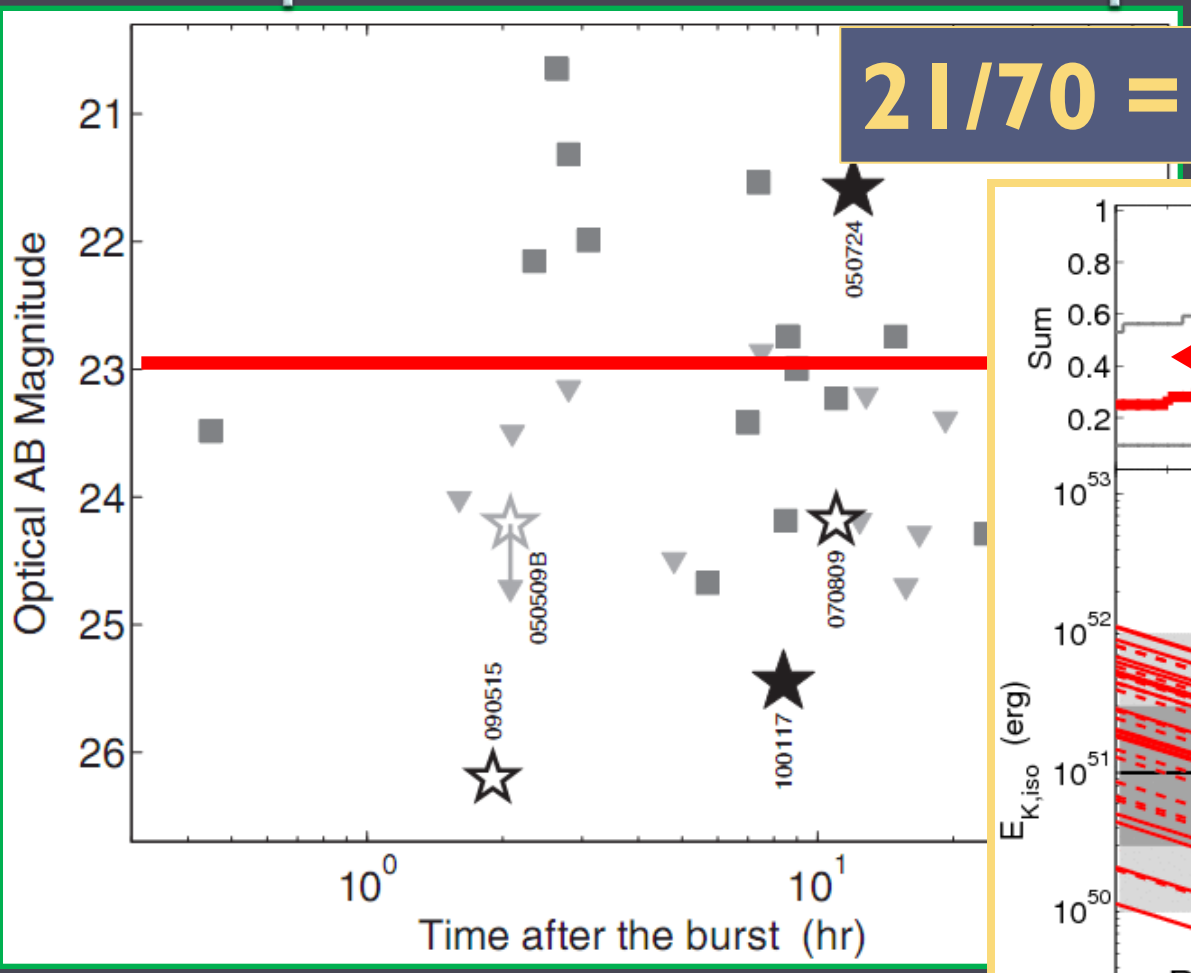


21/70 = 30% detections

Berger 2010, Fong et al. 2011

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

Sub-pc environment: Optical afterglows



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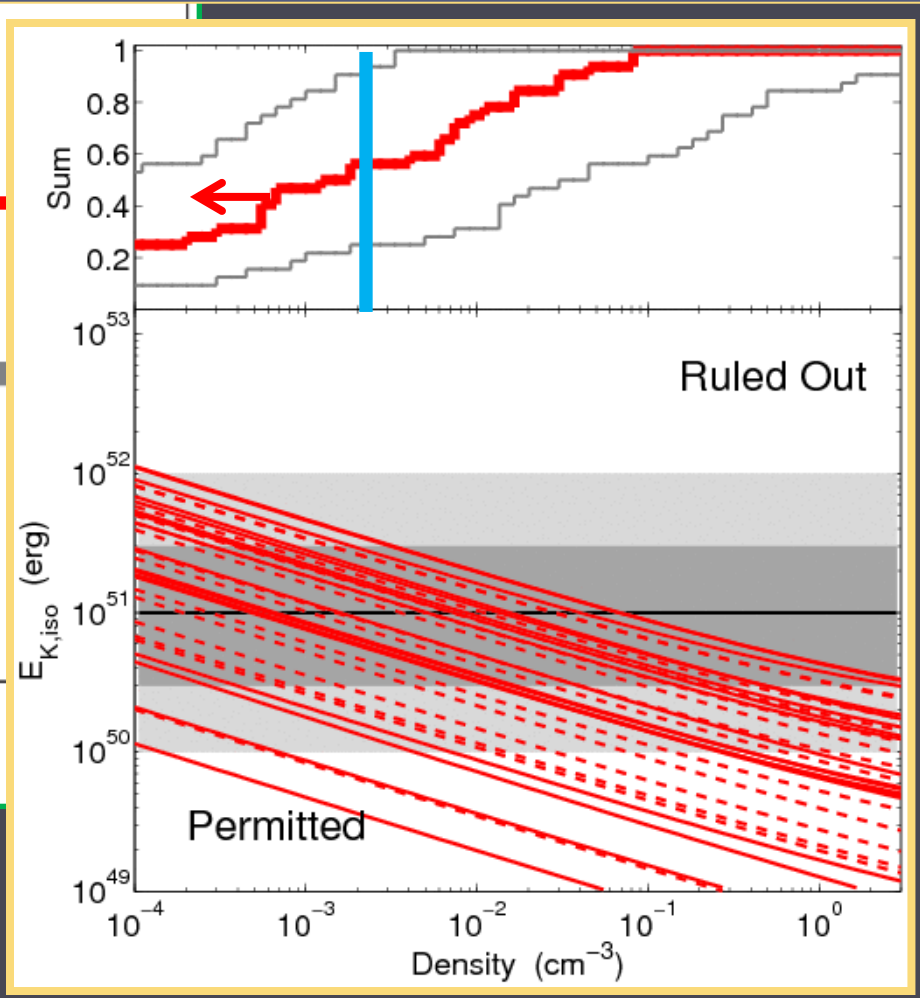


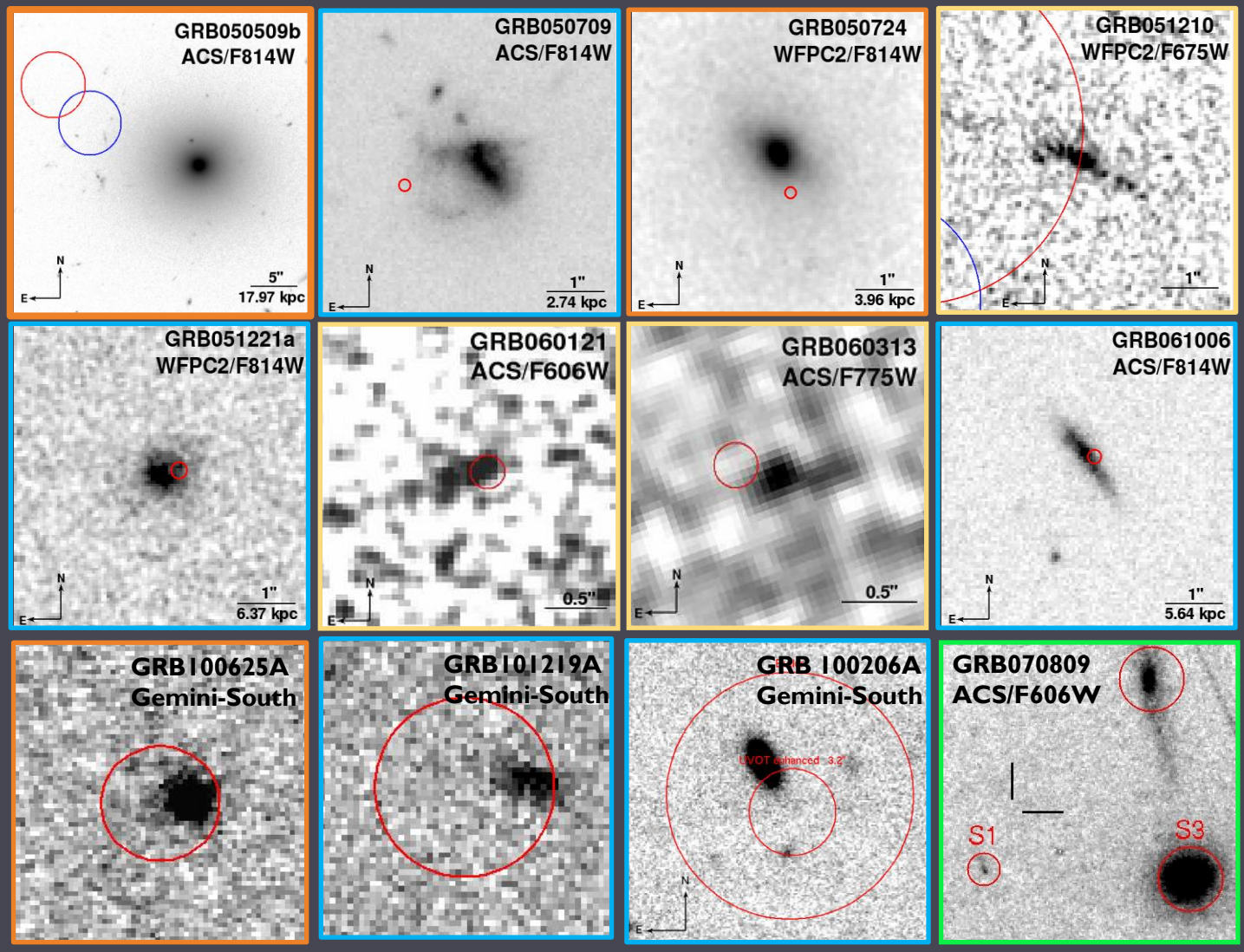
Berger 2010, Fong et al. 2011

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

from UL and detections: ⟨n⟩ ≤ 0.002 cm^{-3}

Nature of the progenitor? Galactic-scale environments

See posters:
D. Perley,
T.Sakamoto



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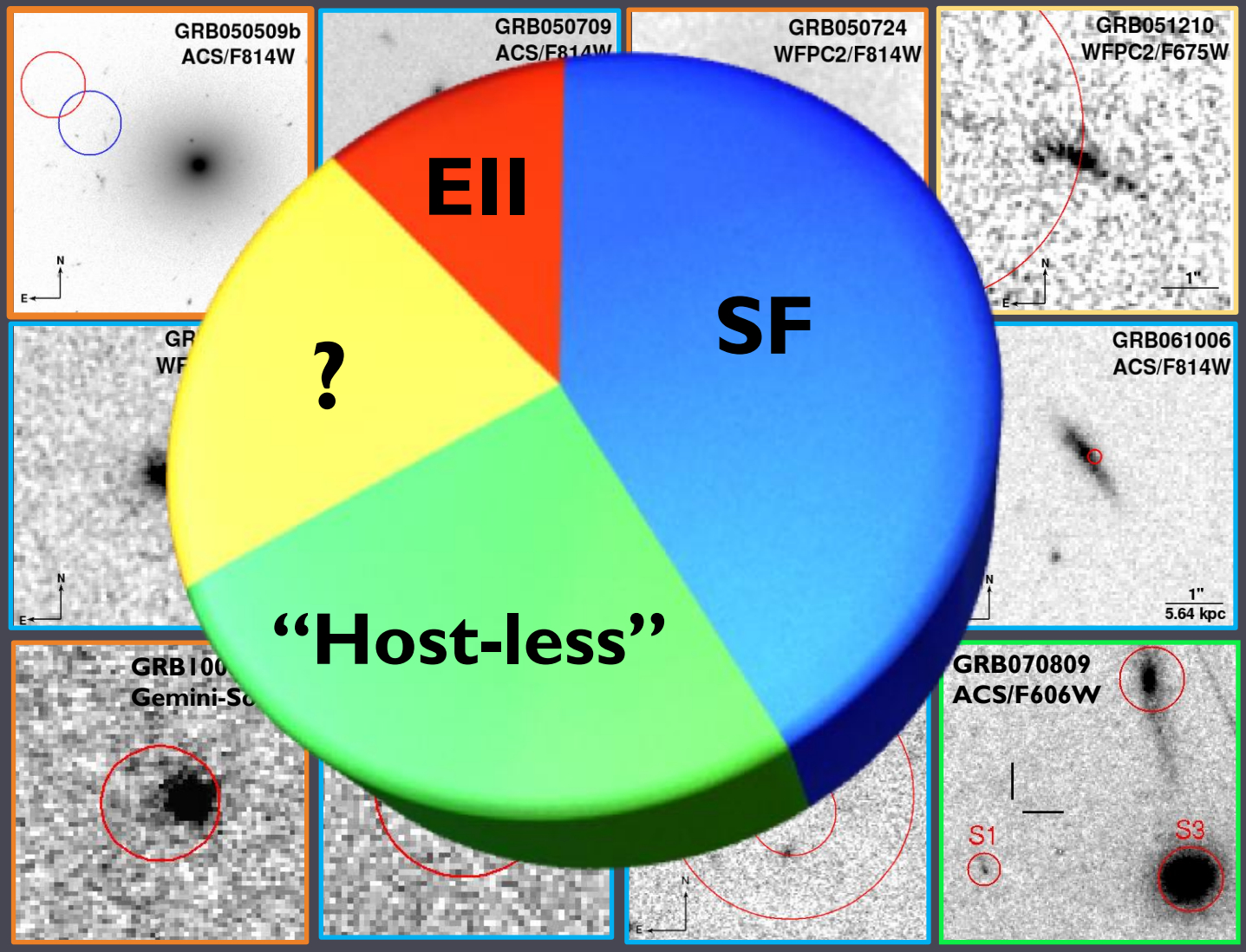
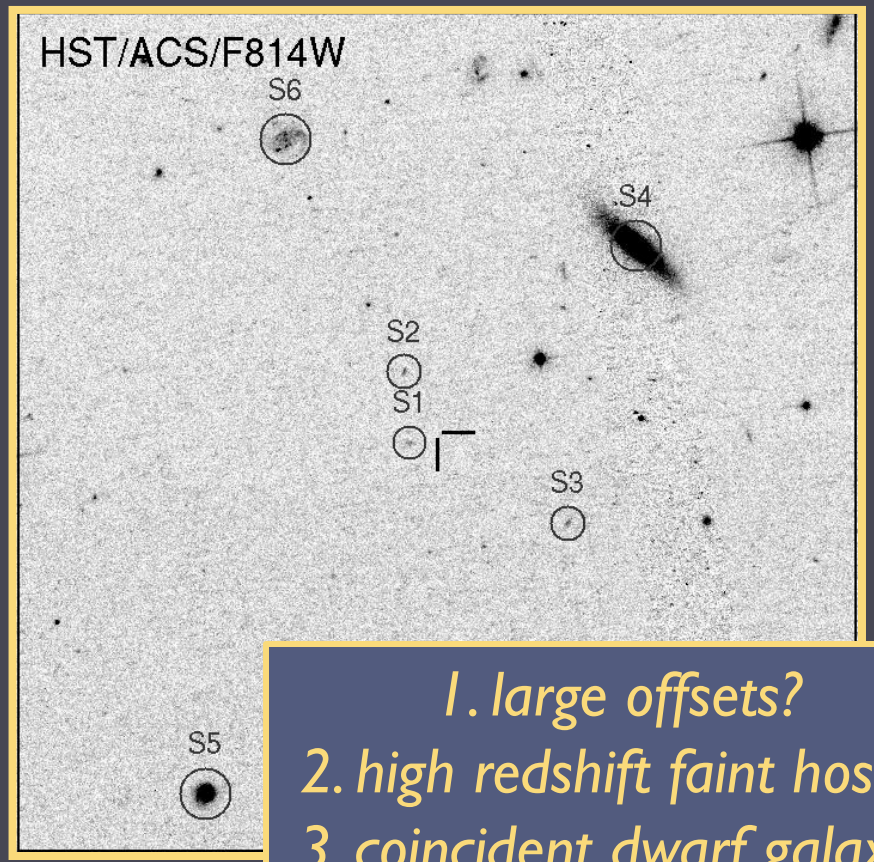
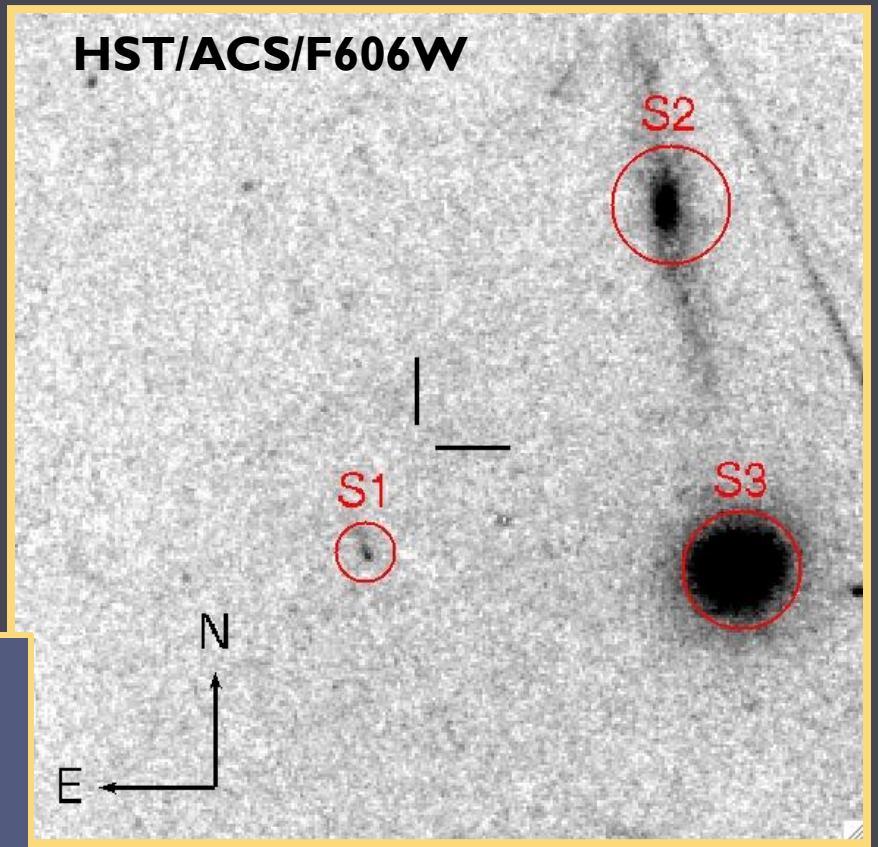


Evidence for kicks? Six "host-less" bursts

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



GRB 070809



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

What is the probability of chance coincidence?
(What is the likelihood of finding an unrelated galaxy?)

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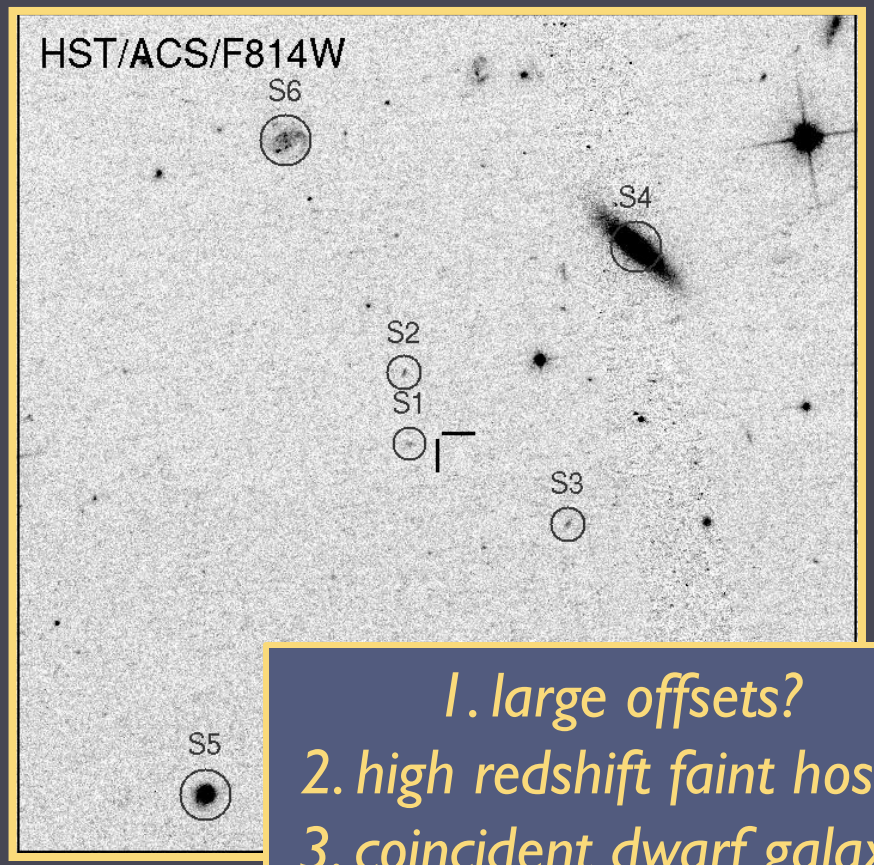

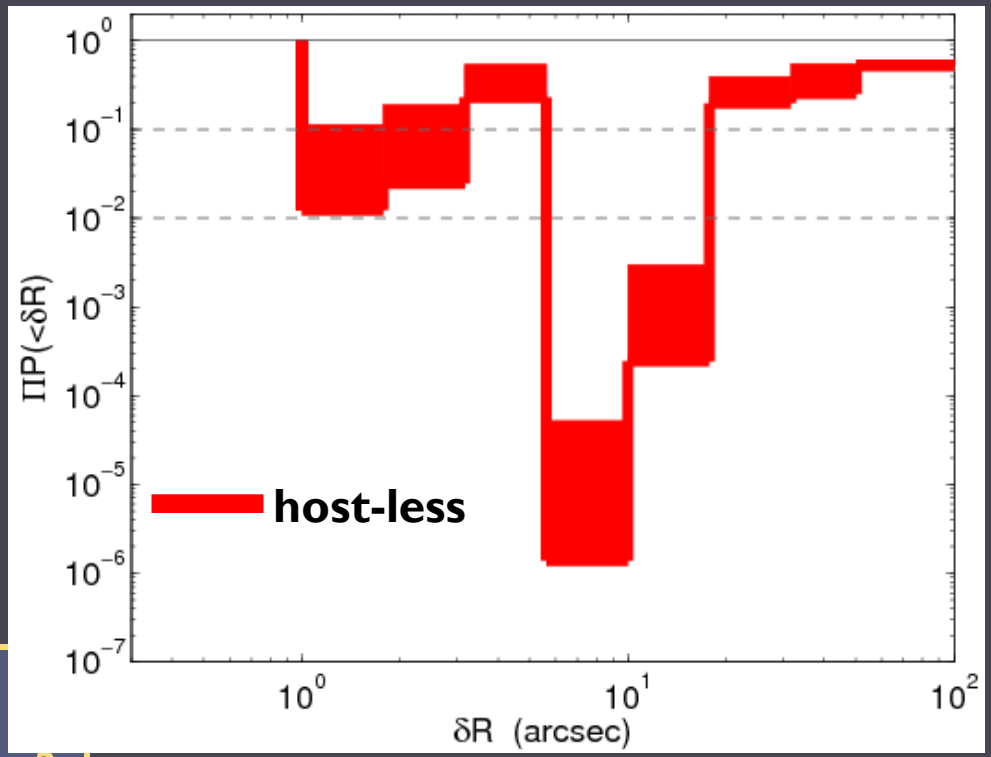

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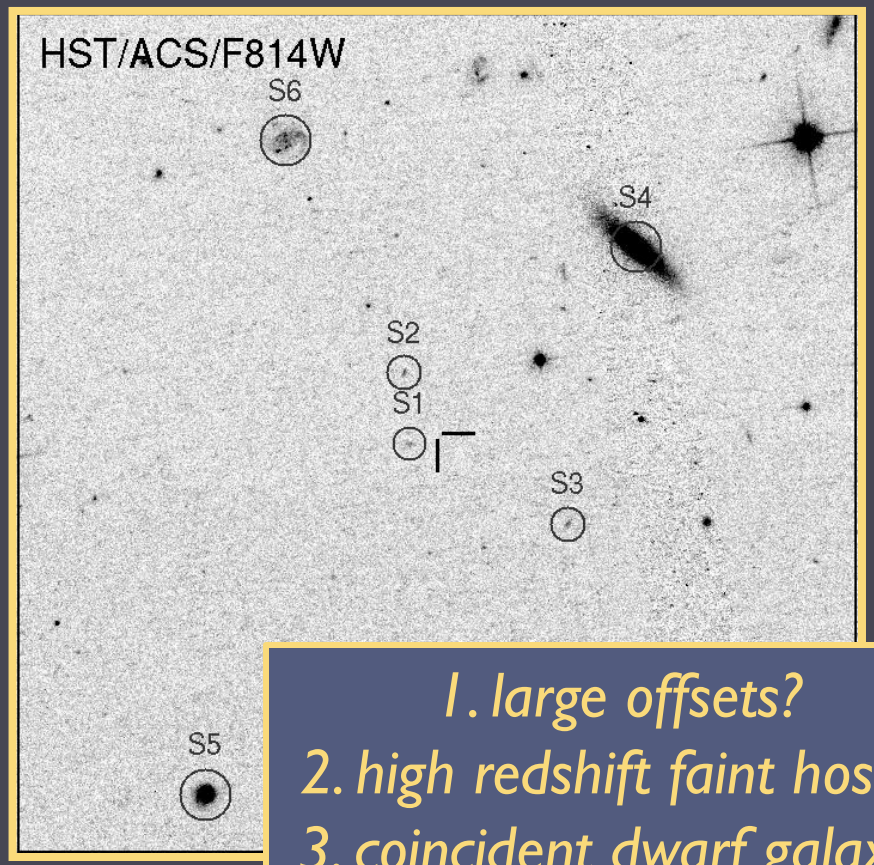

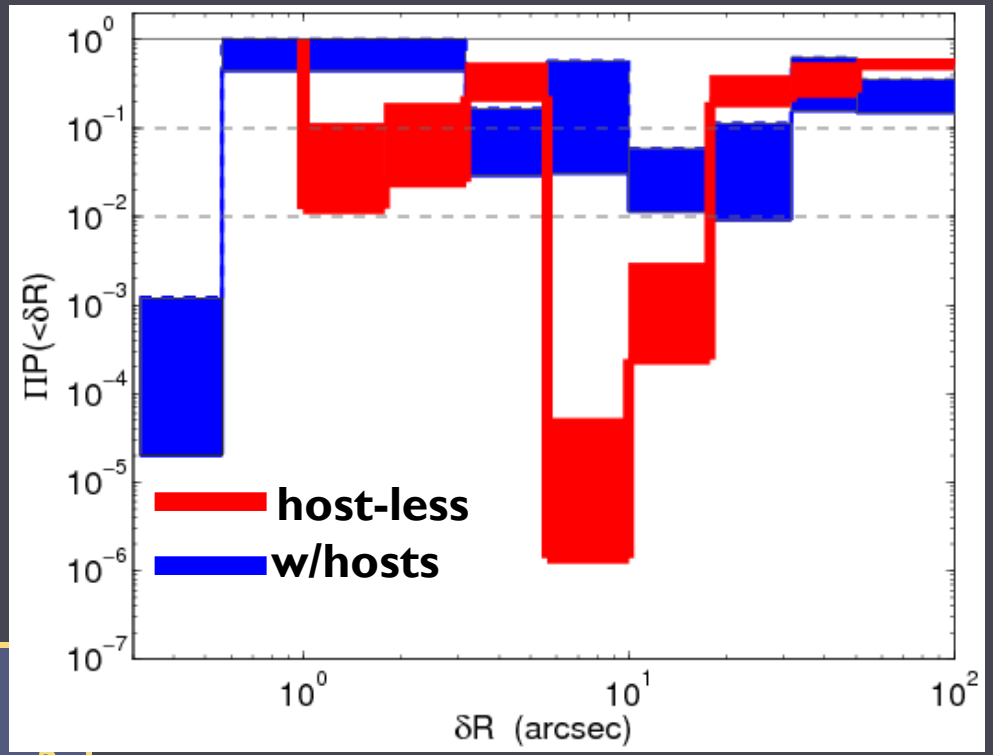

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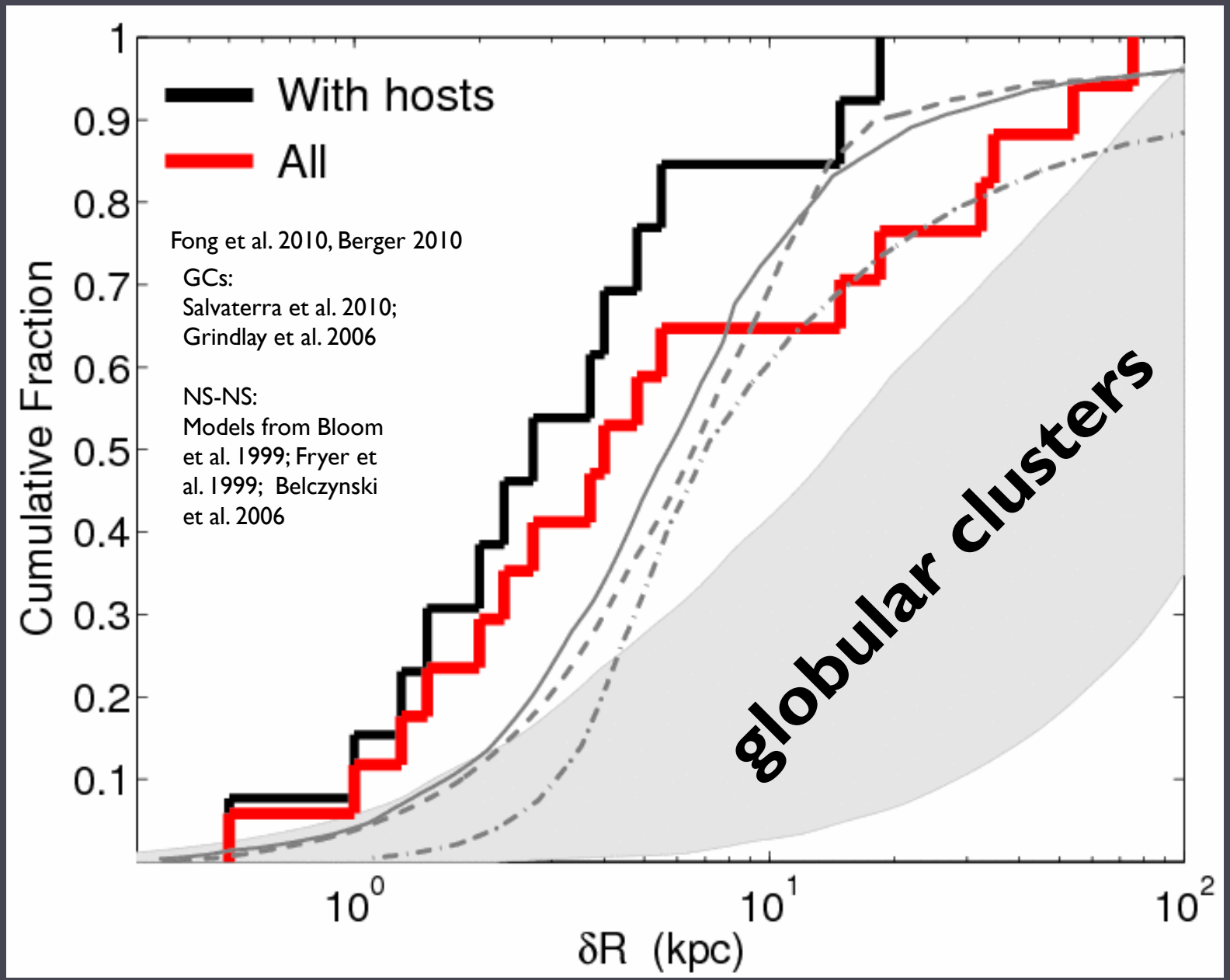
Strong evidence for a highly-kicked progenitor system?

Short GRB offsets



The story so far…

- **Geometry of outflow?**
  - Fraction are highly collimated
  - Rates may be comparable with NS-NS predictions
- **Sub-parsec environment?**
  - LOW densities, $\sim 10^{-2}$-10^{-3} cm^{-3}
  - Median energy scale of 10^{51} erg
- **Nature of the progenitor?**
  - Offsets provide best agreement with DNS models to date