Gamma Ray Burst Spectral properties

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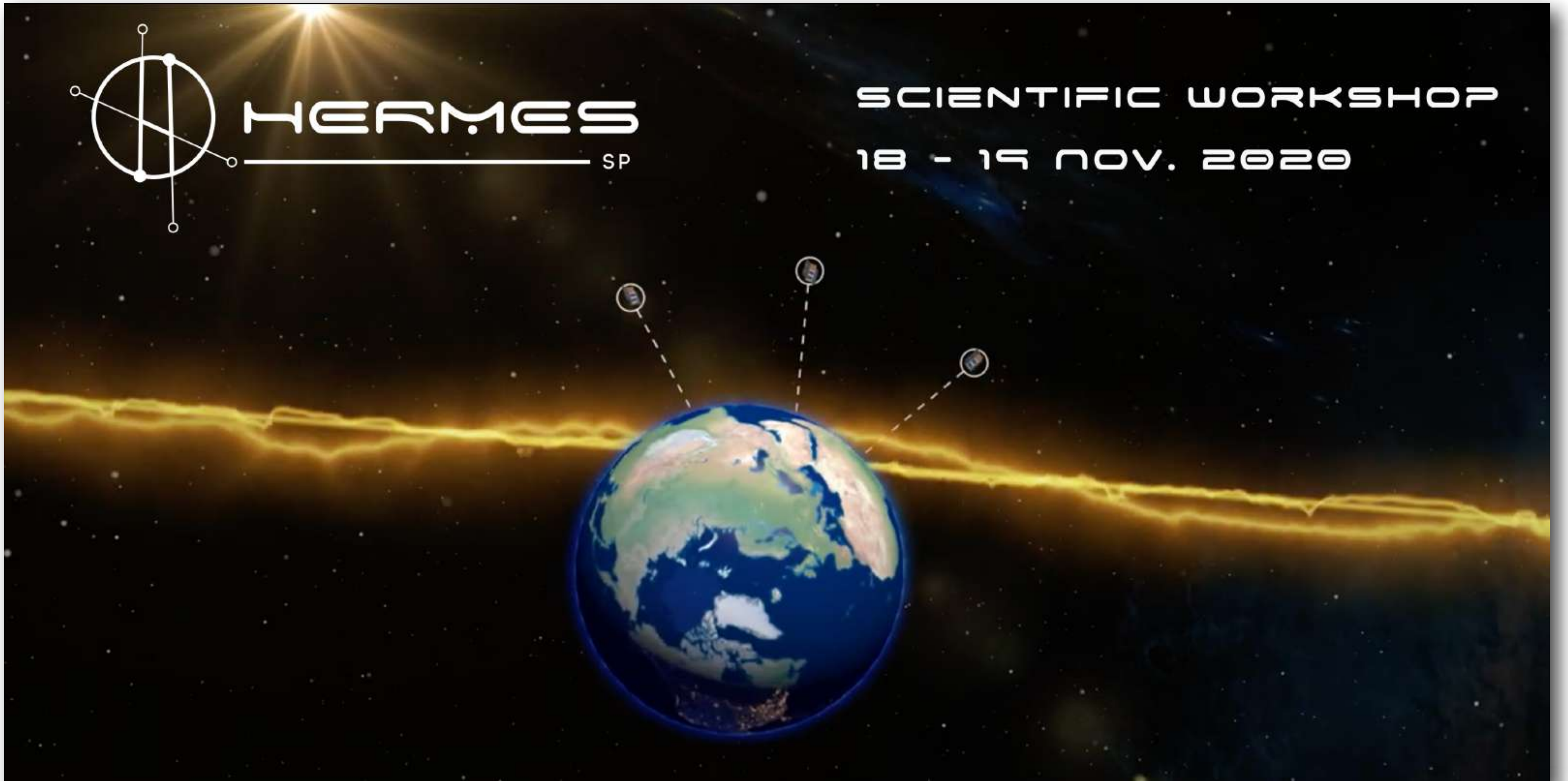
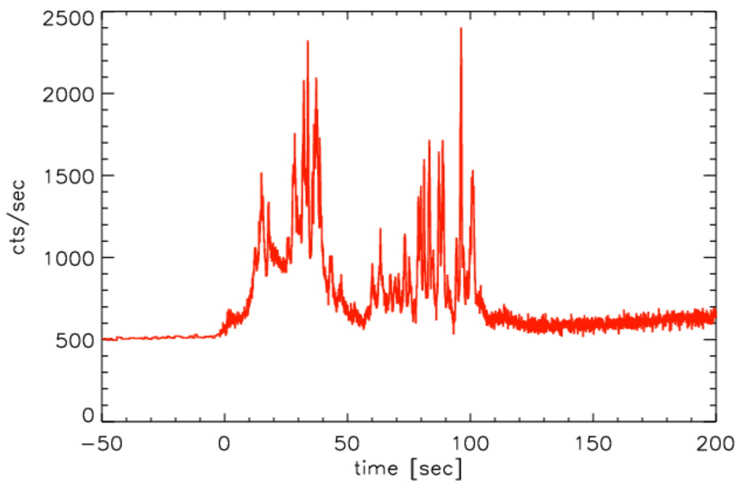
1. GRB introduction
2. Spectral properties and interpretation
3. Hermes (in coll. with L. Nava)

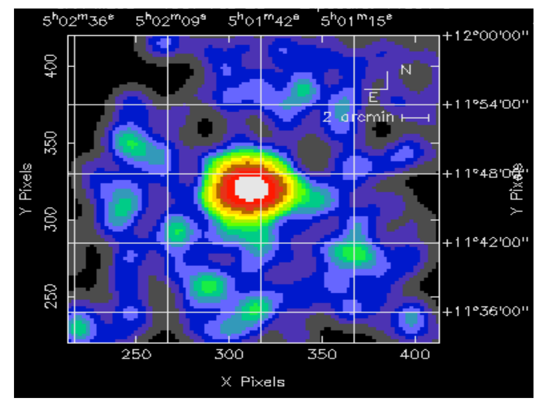


>1973
Short flashes of keV photons
PROMPT
γ-ray

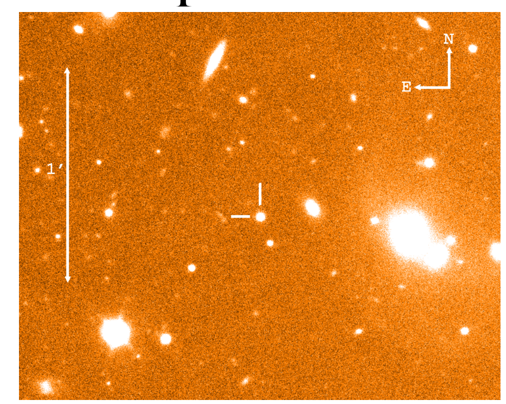


>1997
Accompained by emission at lower frequencies
AFTERGLOW

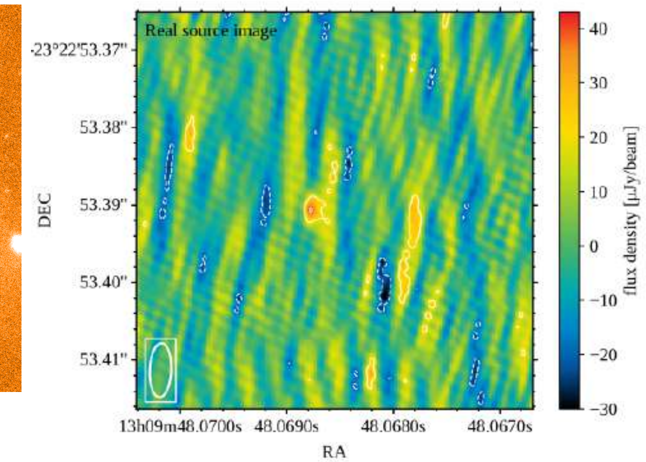
X-ray

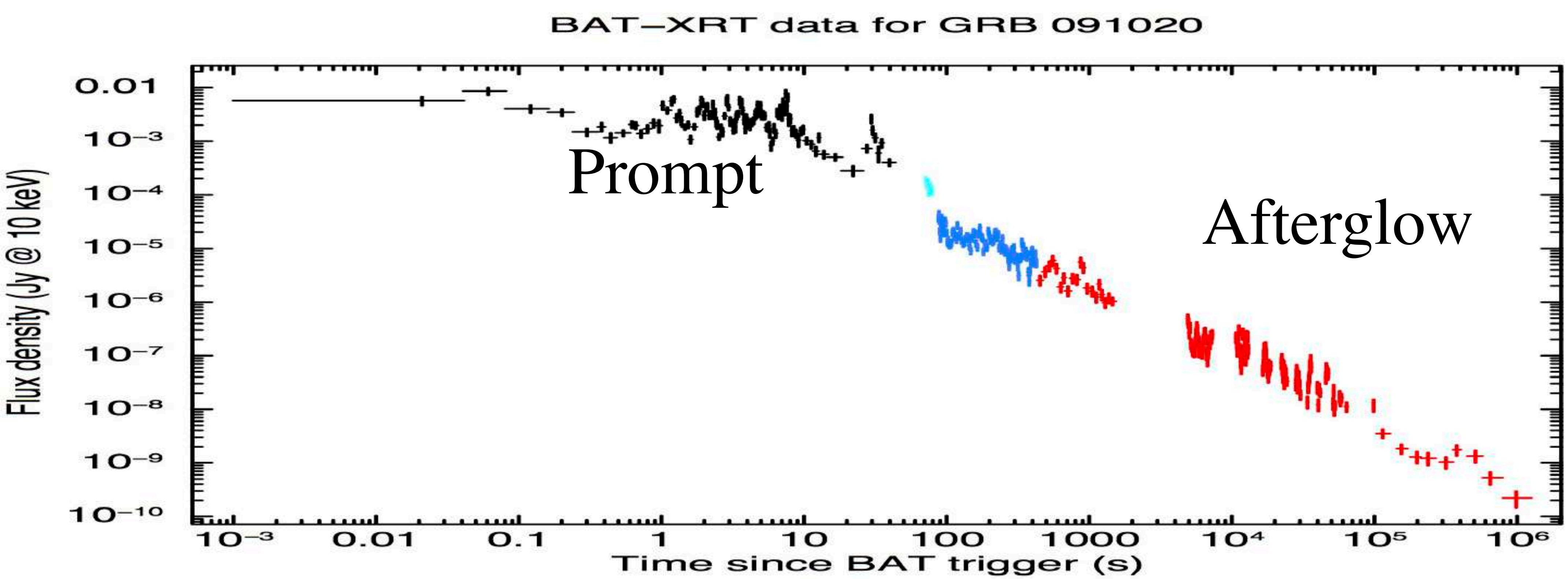


Optical

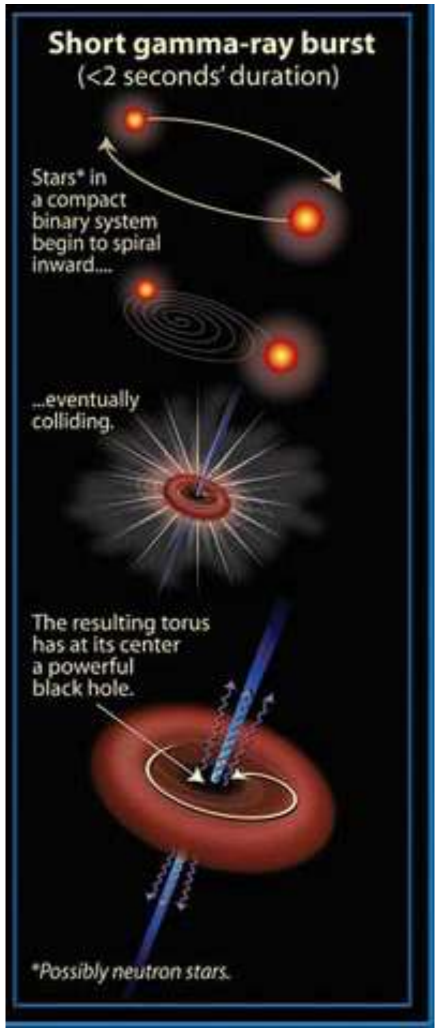


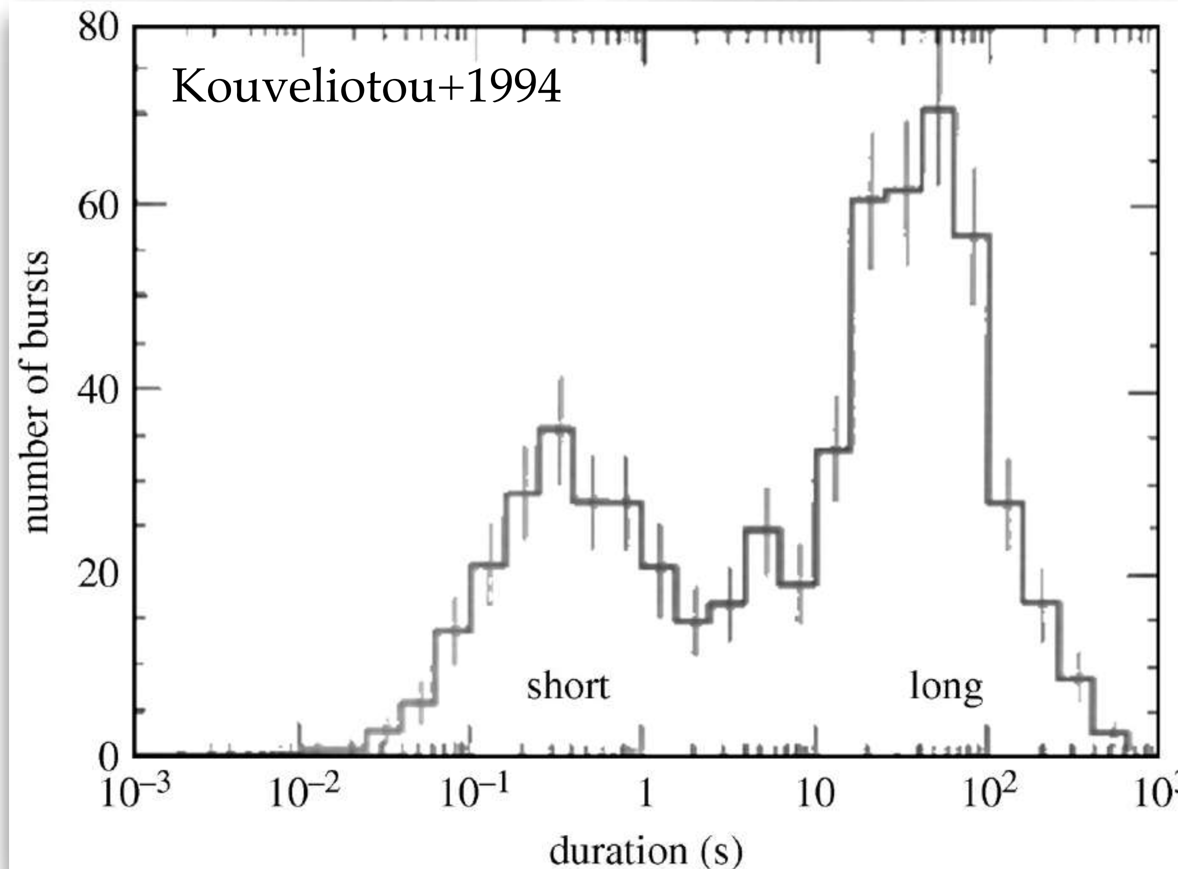
Radio

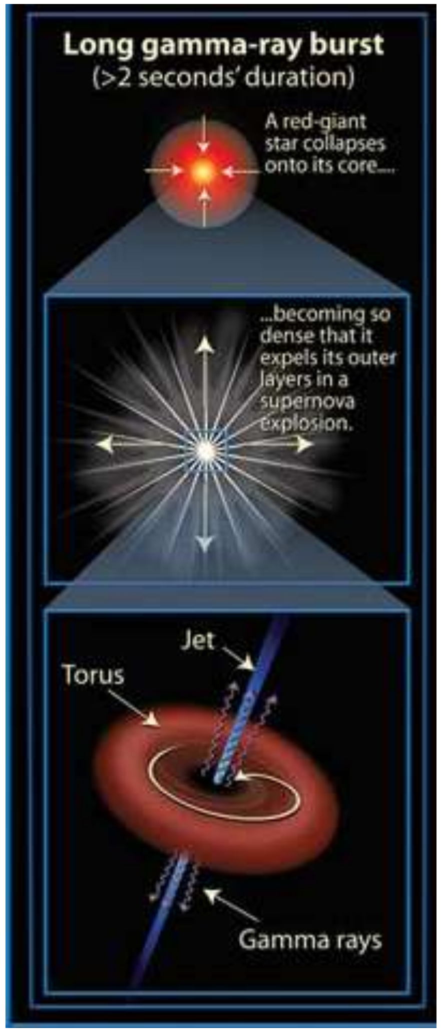


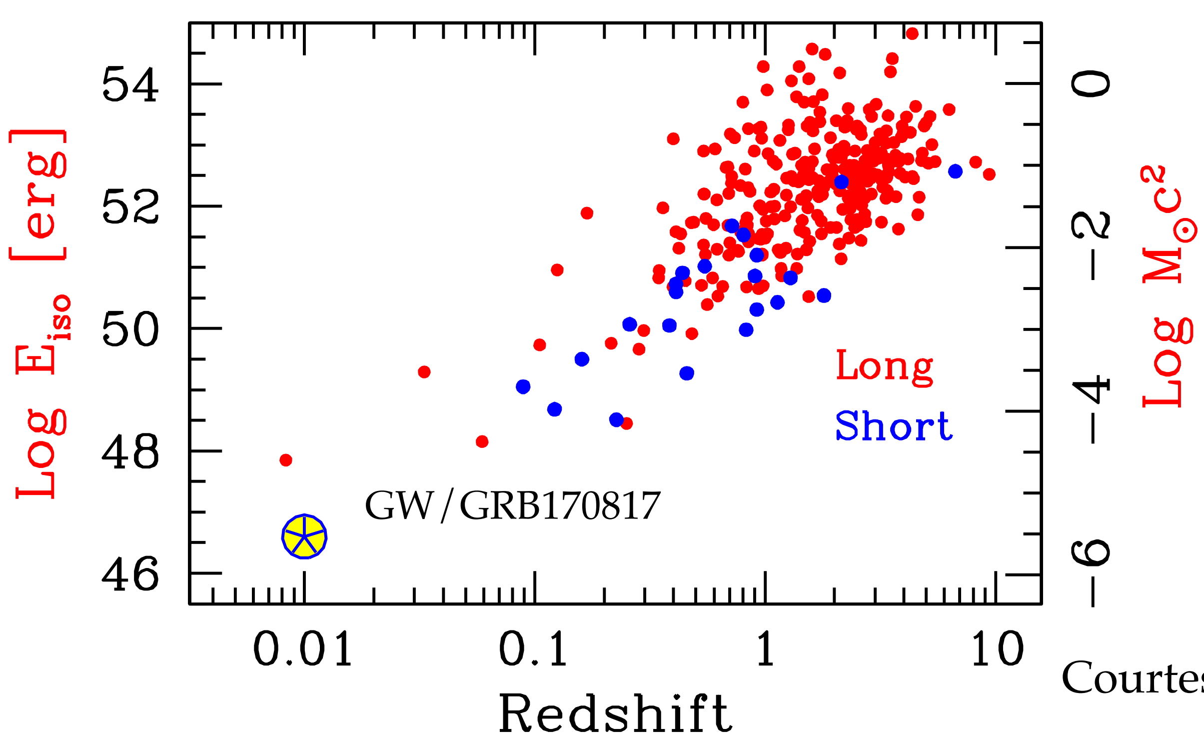


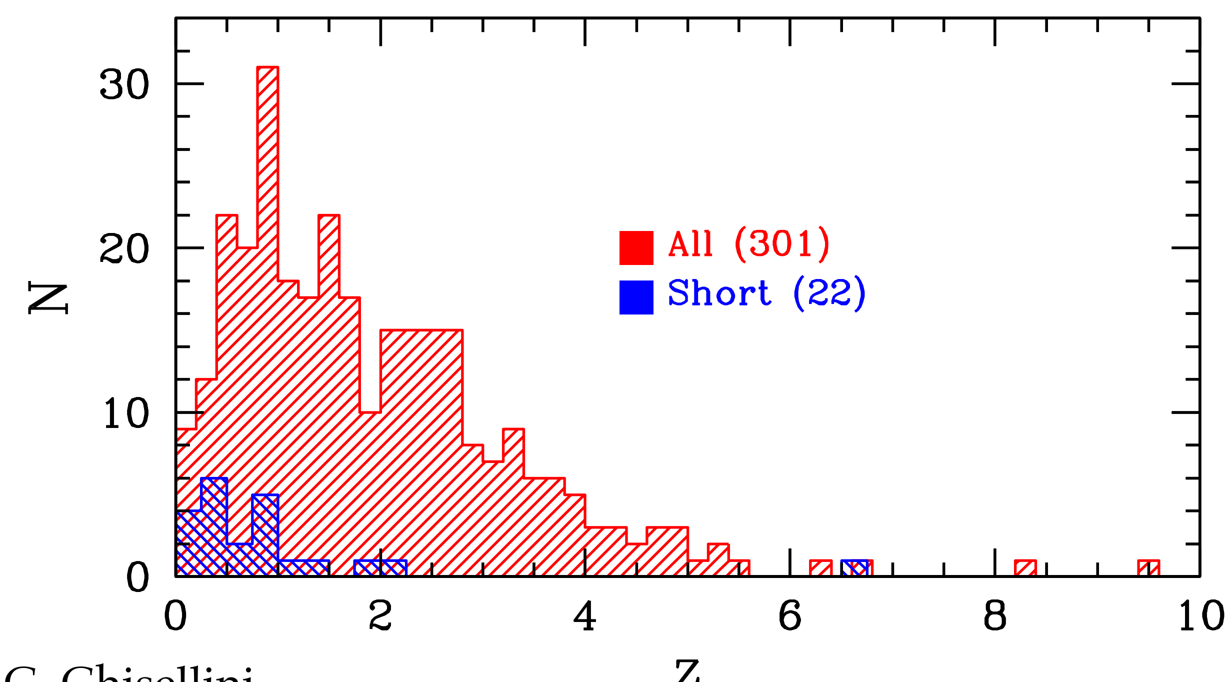
Gamma Ray Bursts: two populations





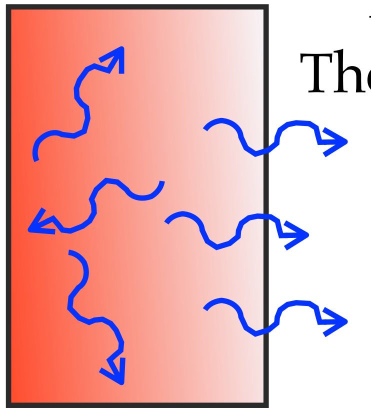




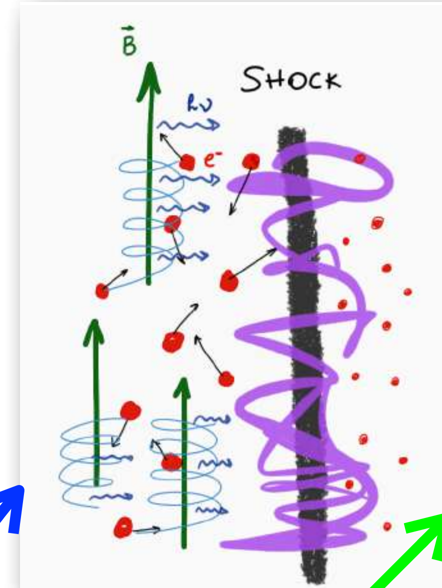


Courtesy of G. Ghisellini

The Machinery

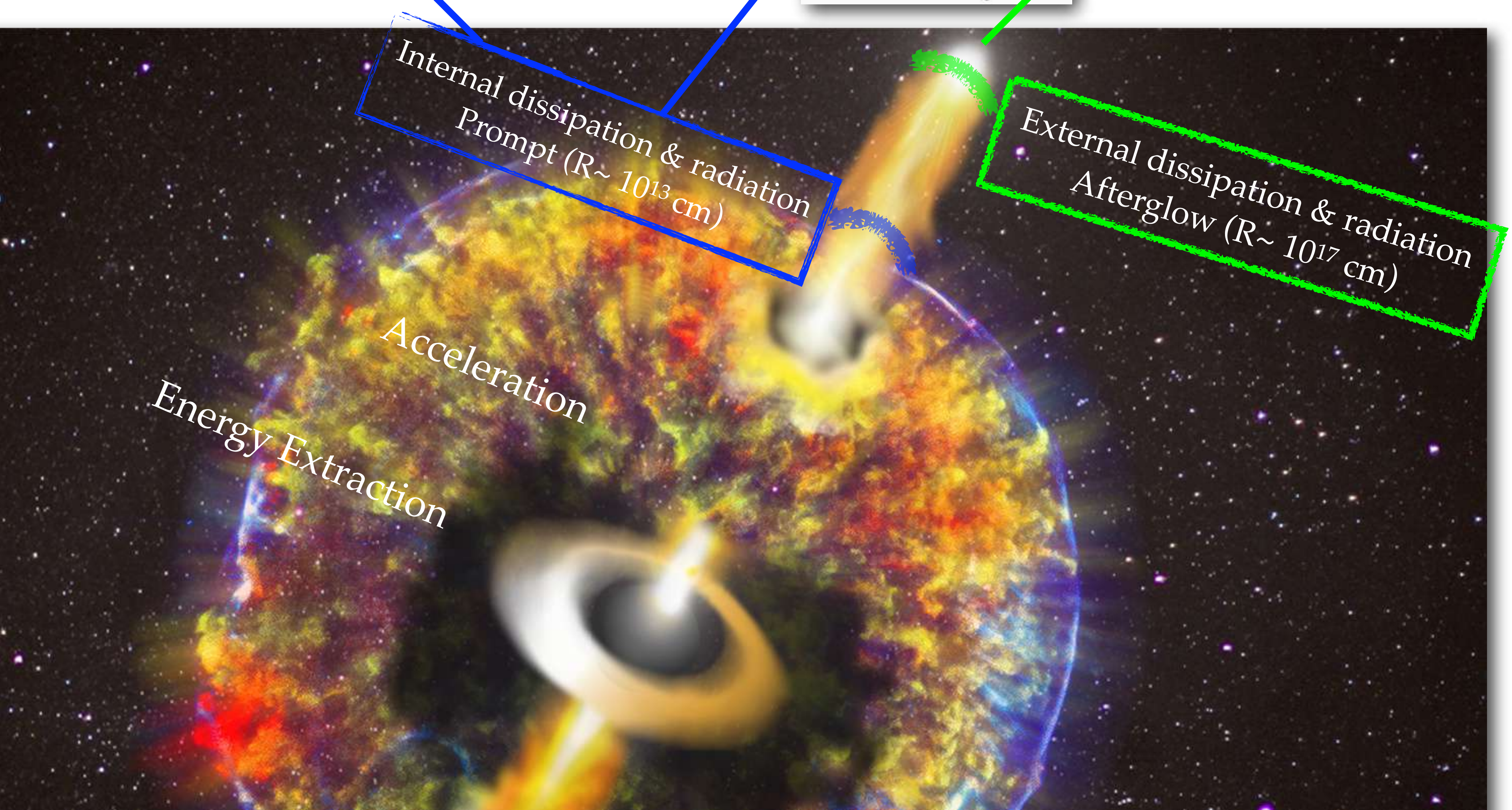


Transparency
Thermal spectrum

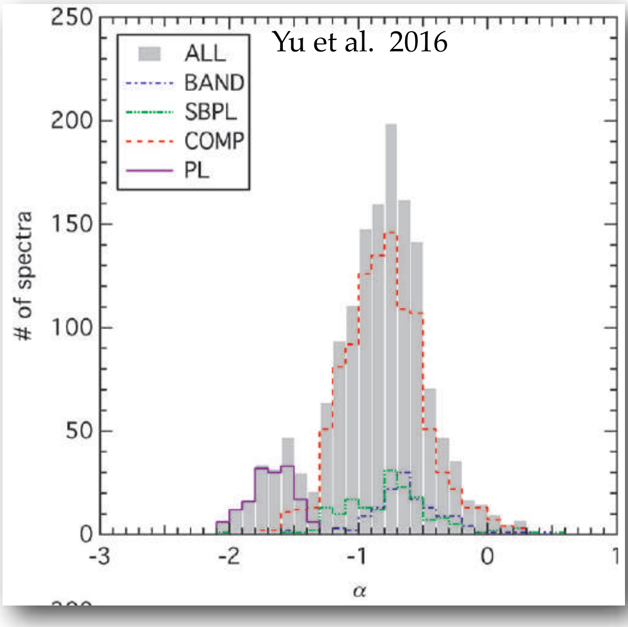


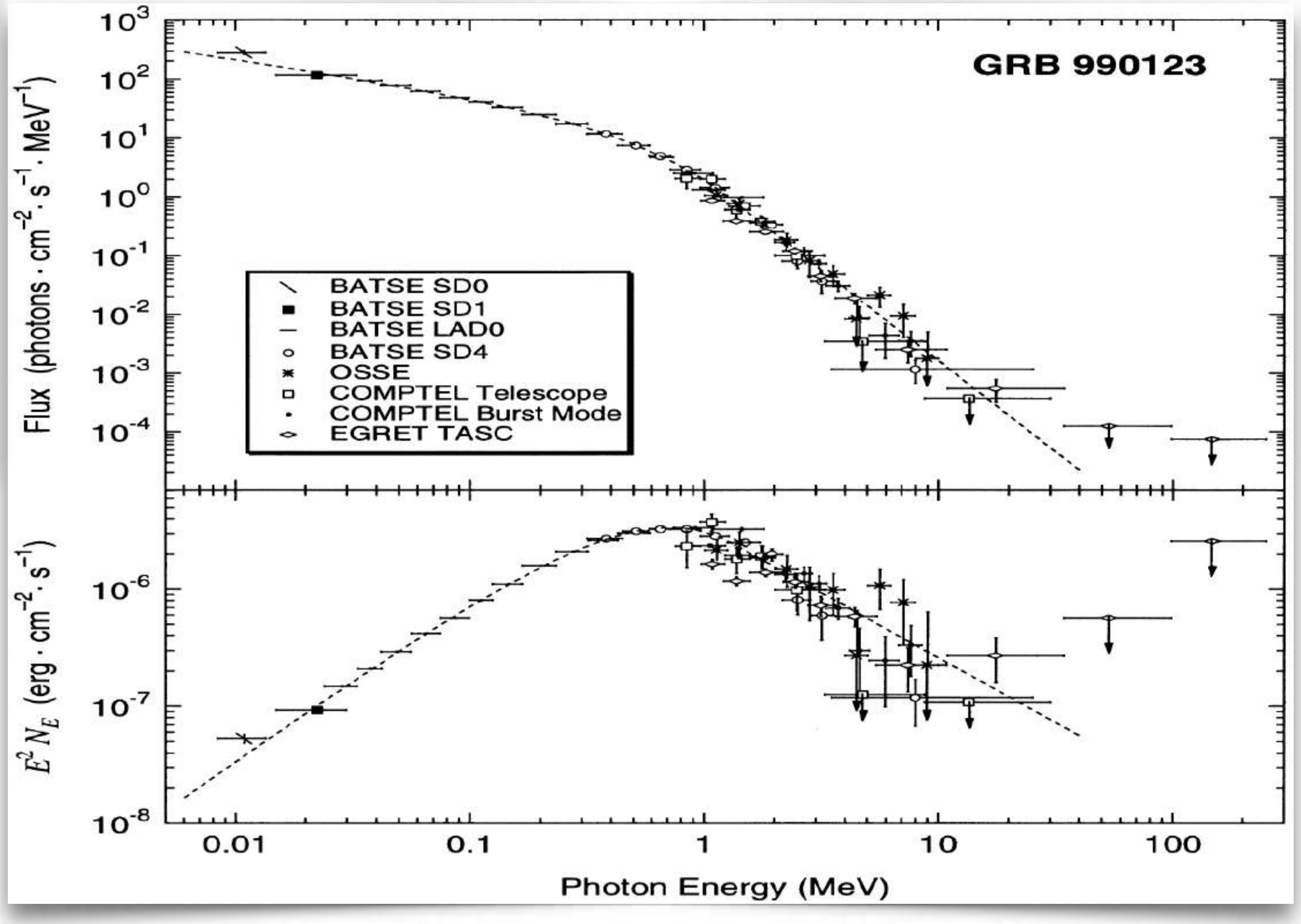
- Particle acceleration
- B field

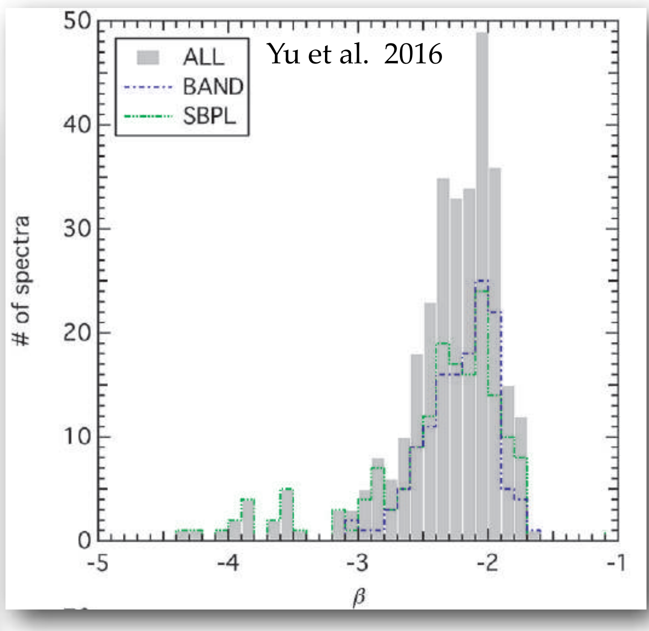
Synchrotron

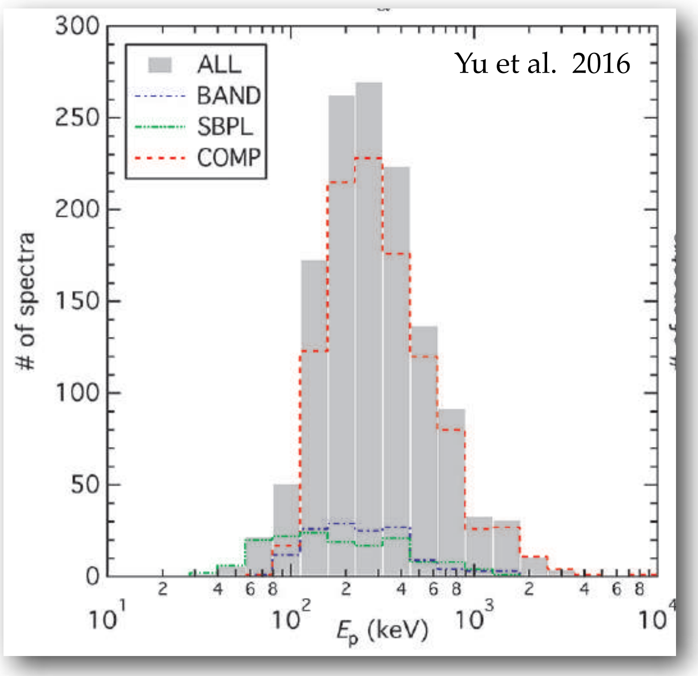


PROMPT EMISSION SPECTRAL SHAPE



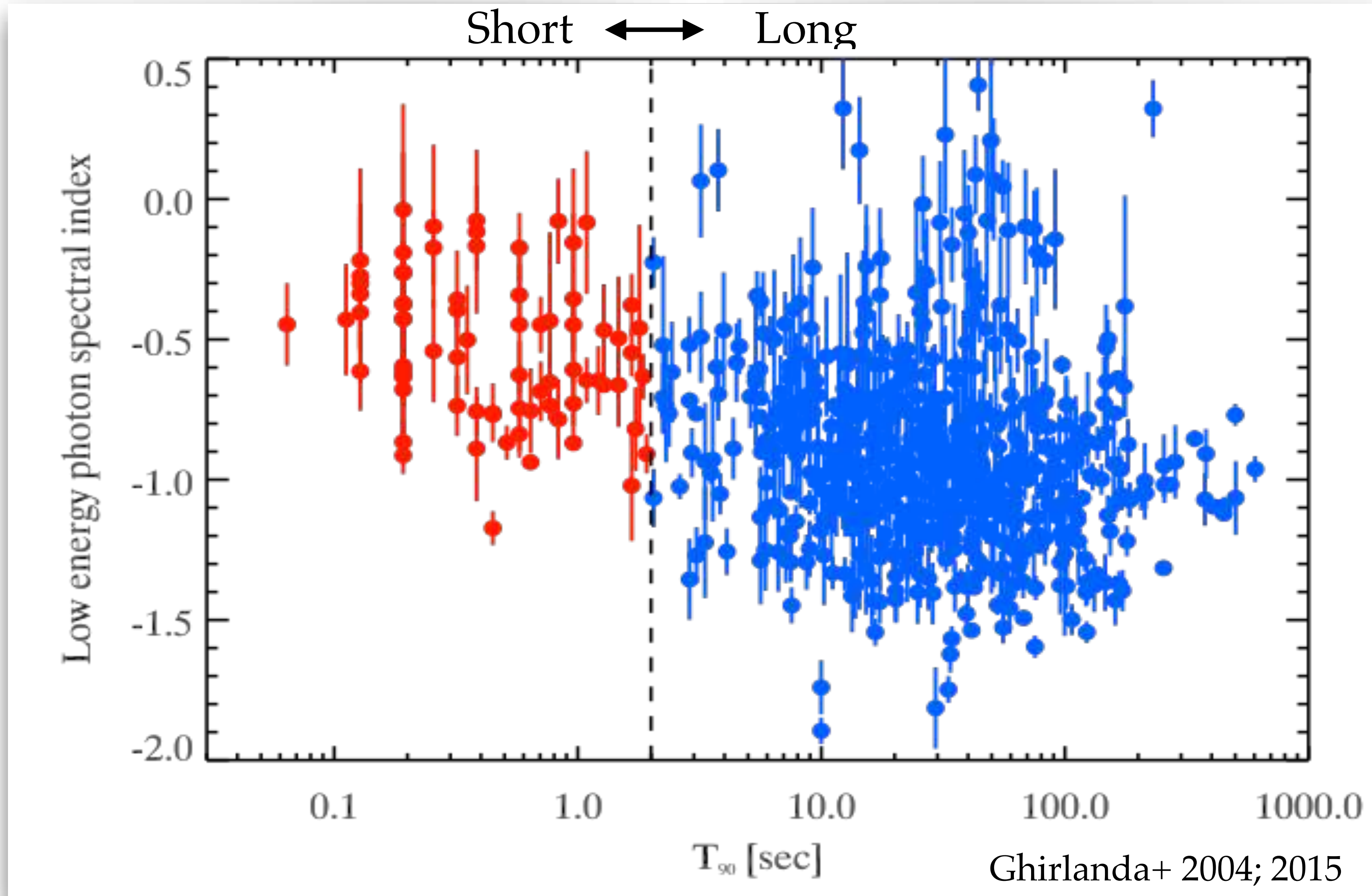


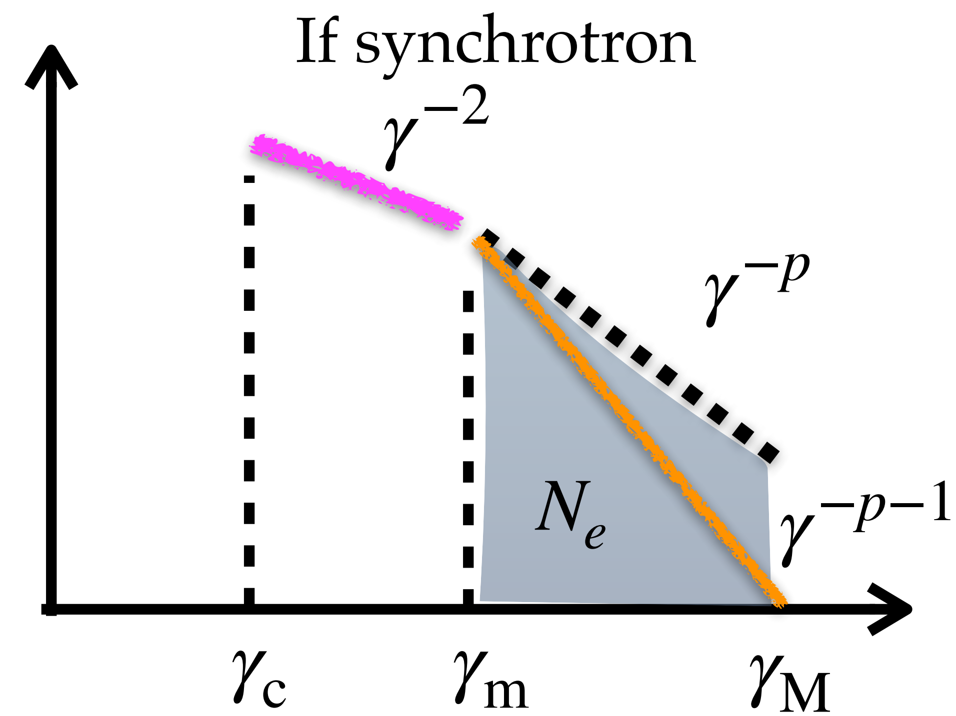




Kaneko+2006 (CGRO)
Nava et al. 2011 (Fermi)
Sakamoto et al. 2011 (Swift)
Goldstein+2012(Fermi)
…

PROMPT SPECTRUM: THE SYNCHROTRON PROBLEM

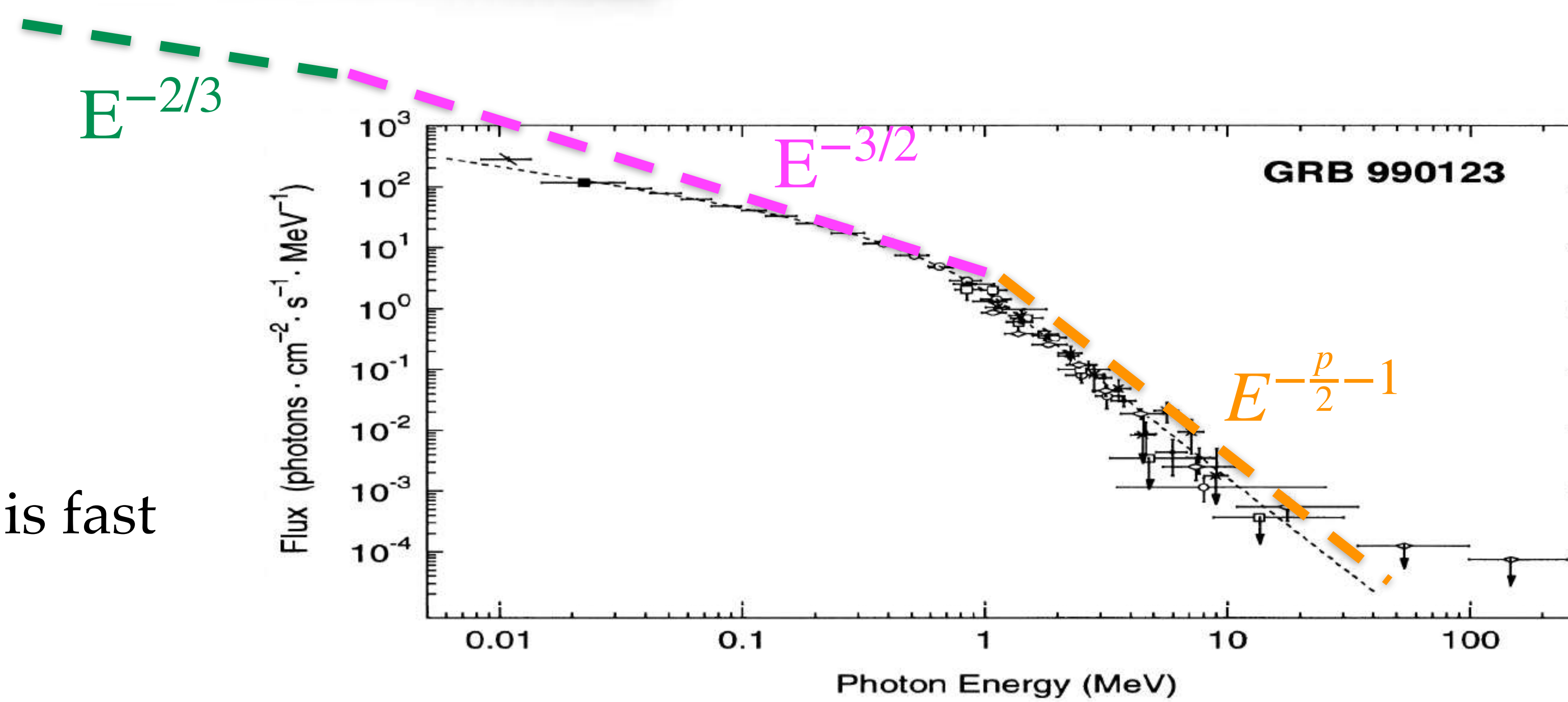




Ghisellini & Celotti 1999

$$t'_{\rm cool} = \frac{\gamma}{P_{rad}} \simeq \frac{3m_e c^2}{4\sigma_T c\gamma[U'_B + \xi U'_r]}$$

For typical parameters cooling is fast



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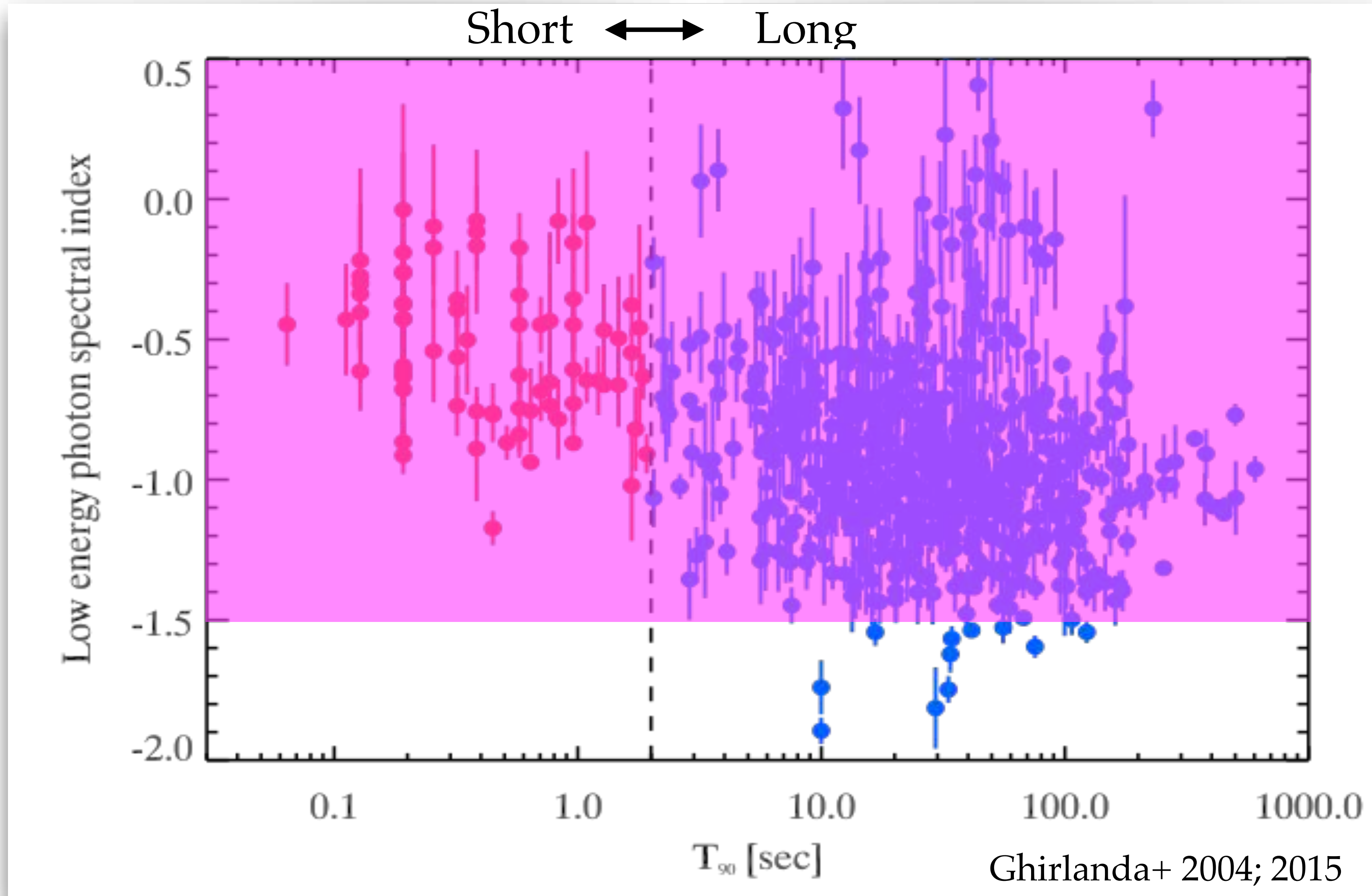

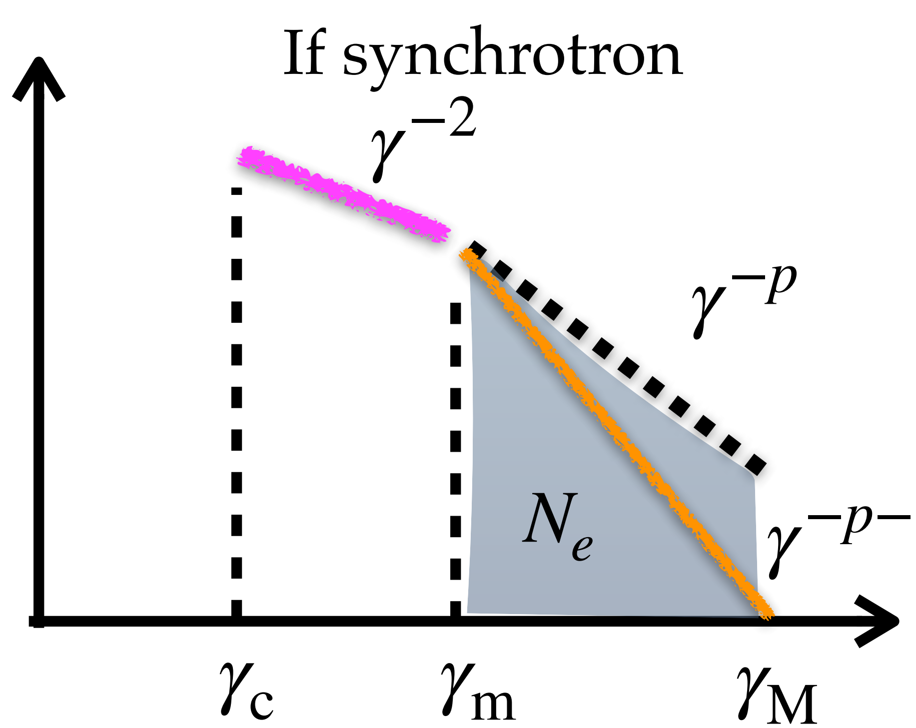

Inconsistency of observed low energy spectral slope

[Preece et al. 1998; Ghirlanda et al. 2002; Kaneko et al. 2006; Frontera et al. 2006; Vianello et al. 2008; Gruber et al. 2014 …]

Ghisellini & Celotti 1999

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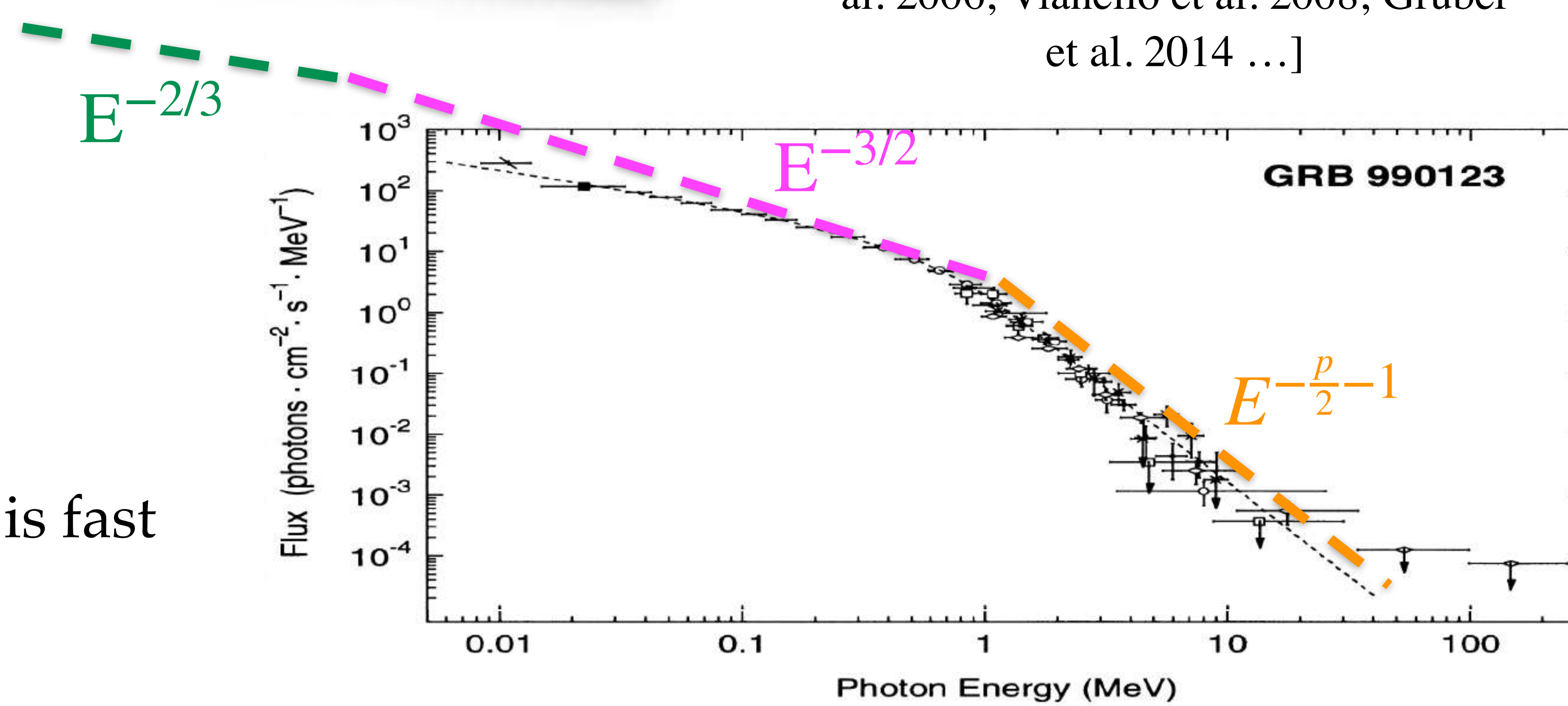
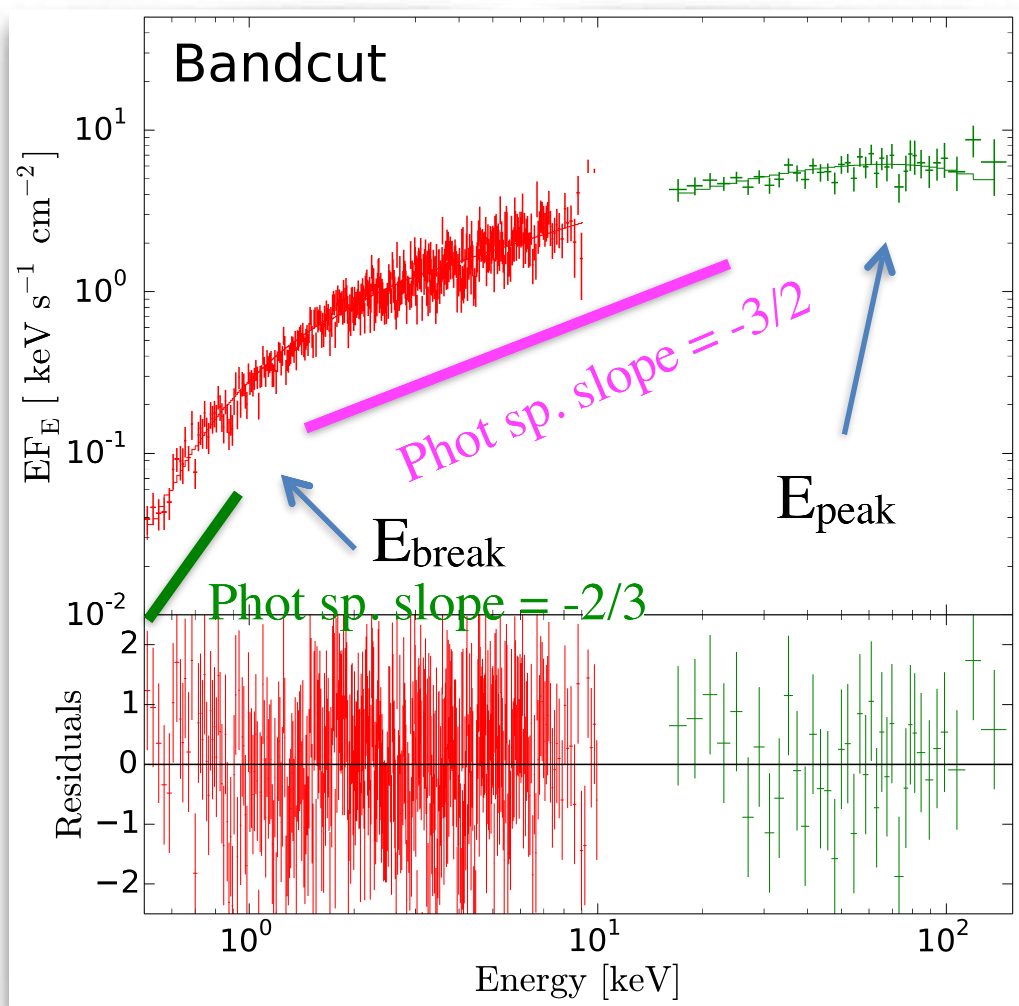


Prompt emission: discovery of an additional break … and more

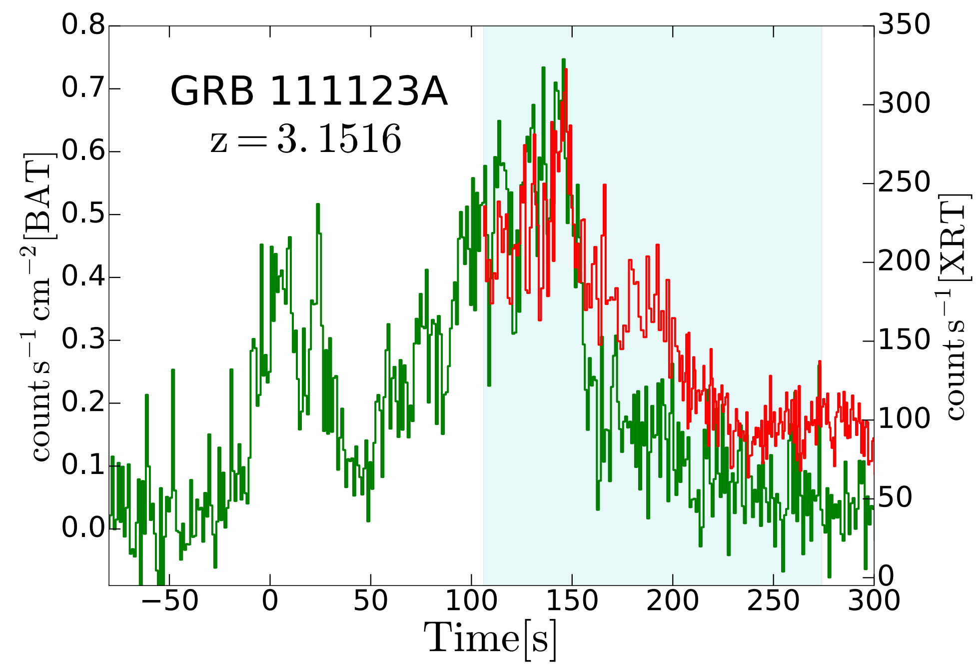
Oganesyan Gor (former Sissa PhD now @ GSSI) et al. 2017:
14 bright GRBs detected by Swift

Oganesyan G. et al. 2018: 34 GRBs detected by Swift

XRT+BAT+(GBM) spectra: 0.3 keV to 1 MeV



XRT + BAT

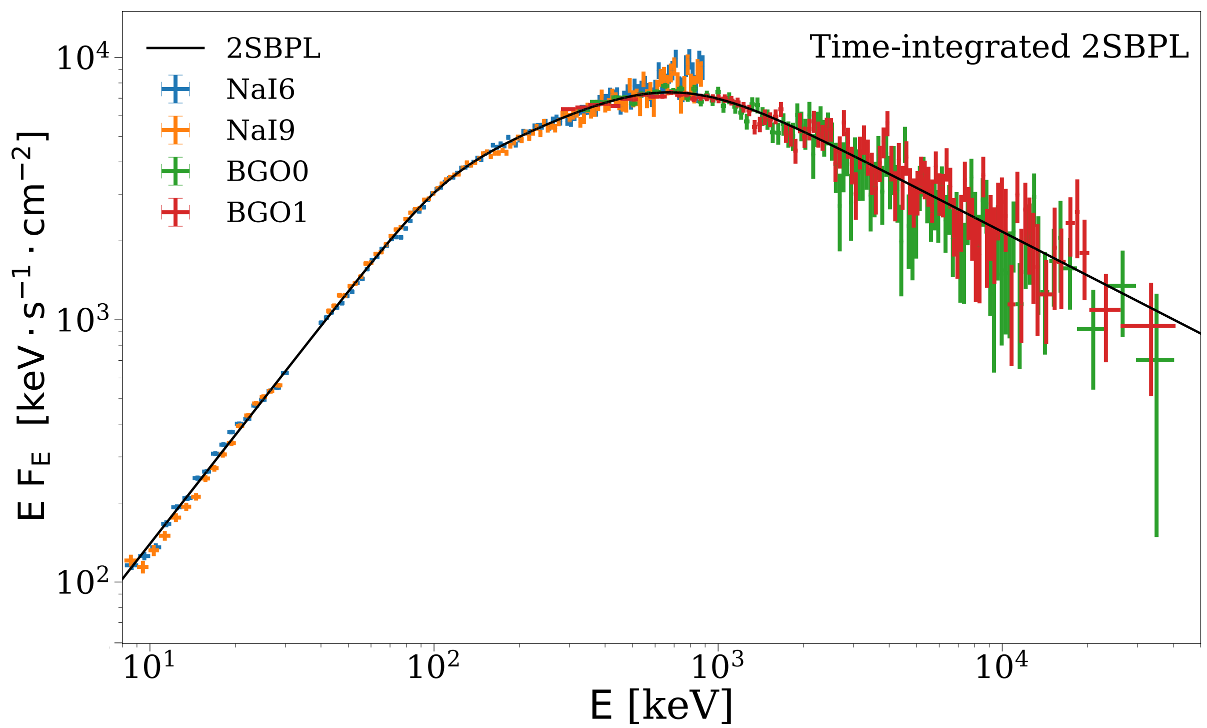


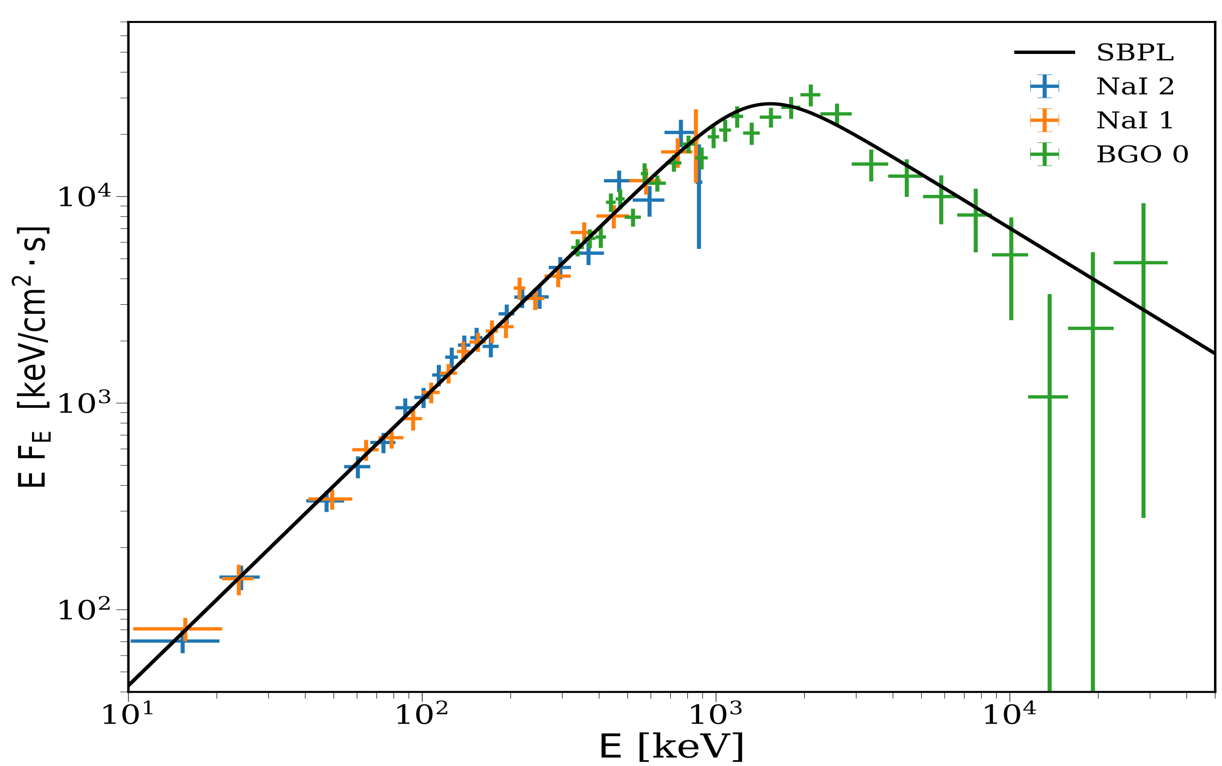
62% of GRBs

- ✓ Show two spectral breaks (new: low energy break 3-20 keV) which significantly improves the fit sigma
- ✓ The average photon indices below and above the break are -2/3 and -3/2
- ✓ $E_{peak}/E_{break} \sim 30$

PROMPT EMISSION: BREAK AND MORE … ALSO IN FERMI/GBM

Fermi/GBM → Ravasio M. (PhD Univ. Bicocca) et al. 2018, 2019: 10 brightest Long and Short





Long GRBs

- E_{break}
- $E_{break}/E_{peak} \sim 1/10$
- α_1 and α_2 ~ synchrotron values

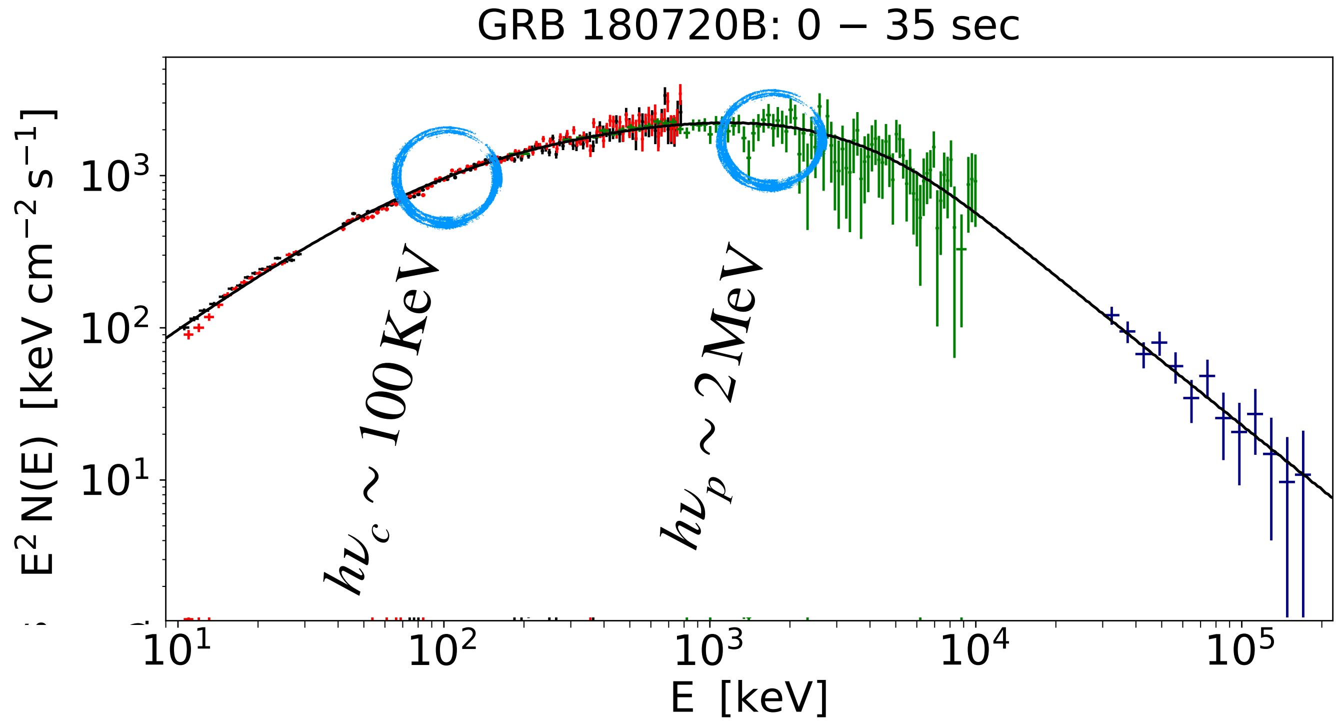
Short GRBs

- no E_{break}
- $\alpha_1 \sim -2/3$ (i.e. $E_{break} \sim E_{peak}$)

SYNCHROTRON: OBSERVABLES —> PHYSICAL PARAMETERS

Fit of observed spectra with physical synchrotron model: Oganesyan+2019; Burgess+2019; Ronchi+2020

GRB 170820B: Ronchi M. (Master Univ. Bicocca now @ ISS Barcelona) et al. 2020



Prompt: GBM+LAT(LLE) synchrotron fit

Resulting physical parameters:

- $h\nu_{\rm cool} \sim 100$ keV
- $h\nu_{\rm max} \sim 2$ MeV
- $p \sim 4.3$

SYNCHROTRON: OBSERVABLES —> PHYSICAL PARAMETERS

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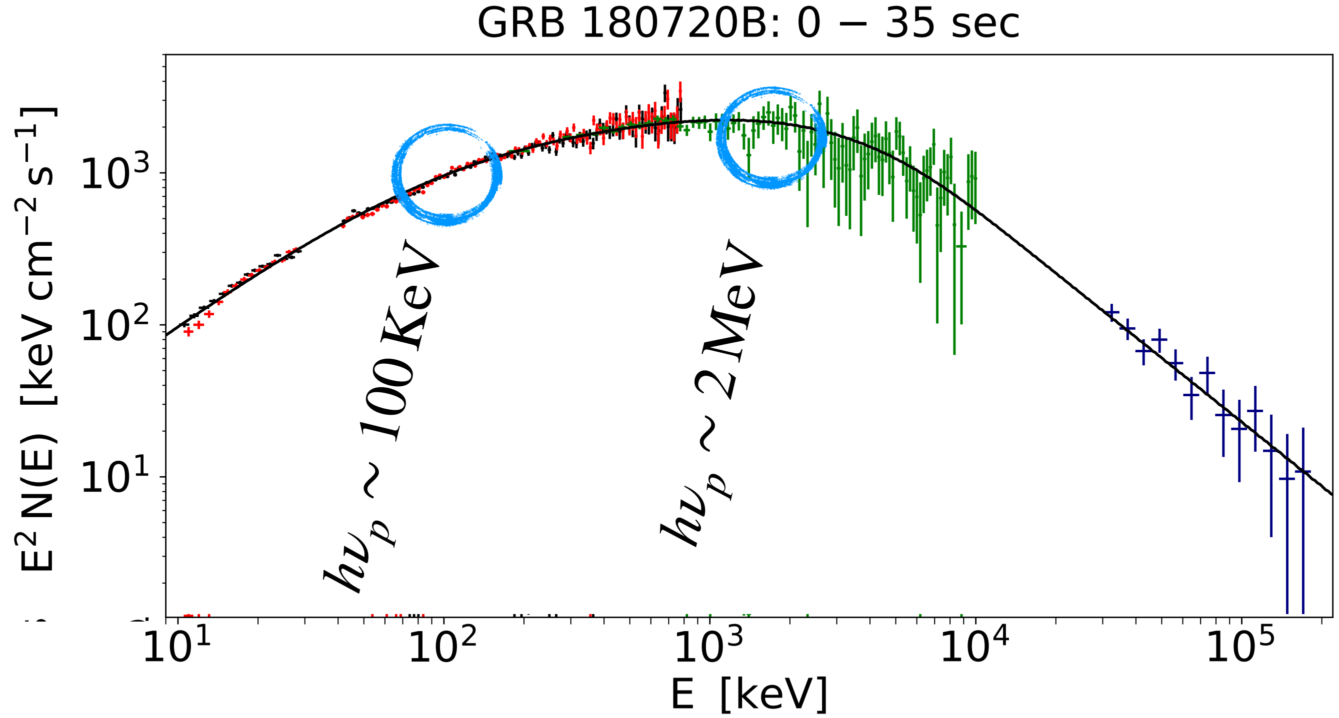

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Most of analysed GRBs

$$\nu_{\rm cool} \leq \nu_{\rm max}$$

Oganesyan et al. 2019

$$10^4 < \gamma_{\rm m} < 10^5$$

$$10^{48} < N_{\rm e} < 10^{50}$$

$$5\,{\rm G} < B' < 30\,{\rm G}$$

$$10^{16}\ {\rm cm} < R_{\rm diss} < 10^{17}\ {\rm cm}$$

$$P_{rad} = P_{\rm syn} + P_{\rm IC} \propto U'_B + \xi U'_r$$

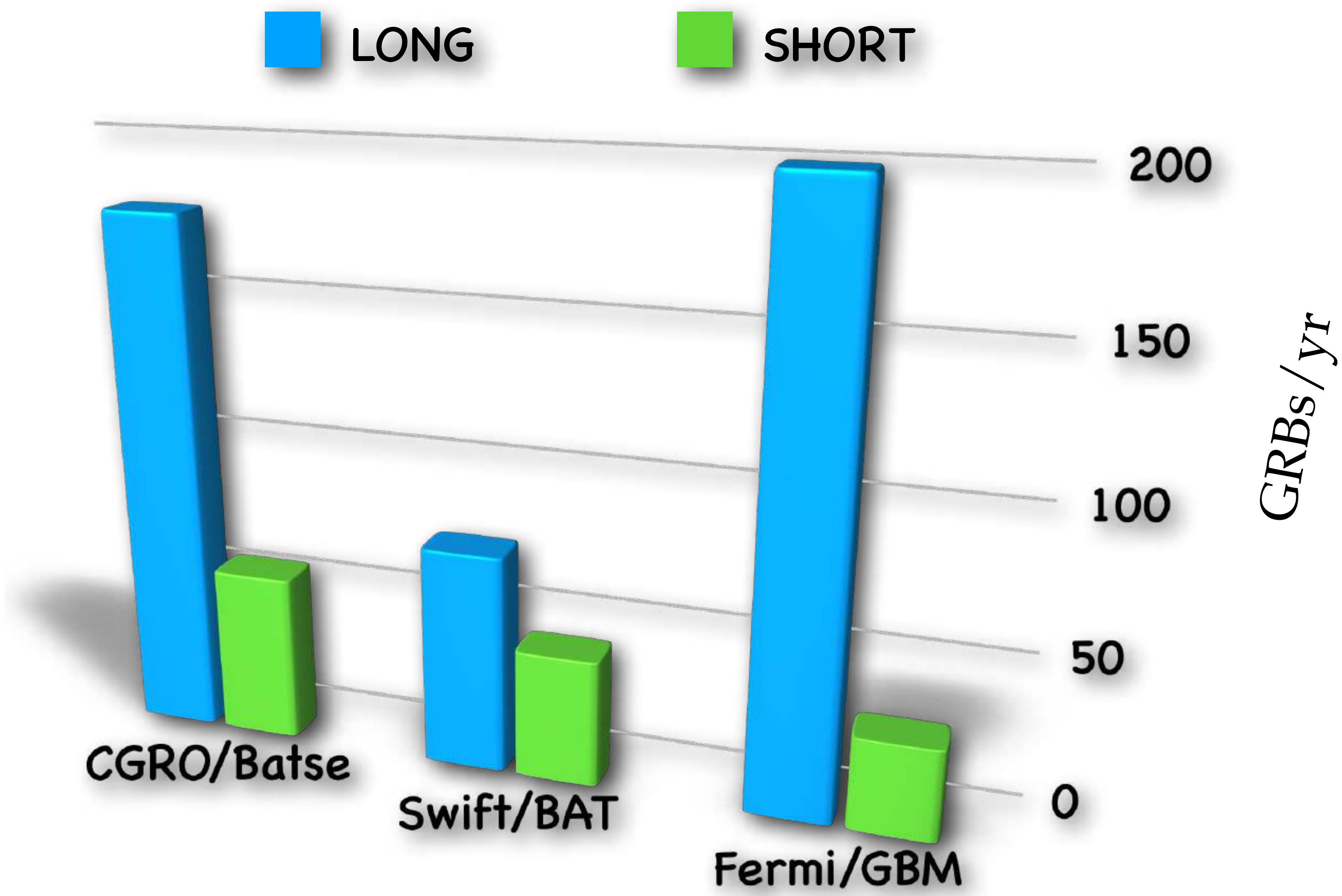
$U'_B \to B'^2$, $U'_r \to 1/R^2$

$$t'_{\rm cool} = \frac{\gamma}{P_{rad}} \simeq \frac{3 m_e c^2}{4\sigma_T c \gamma [U'_B + \xi U'_r]}$$

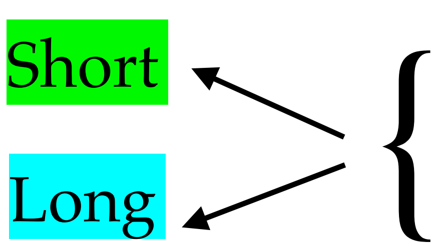
Cooling is "moderate" [e.g. Daigne 2011; Beniamini & Piran 2013]

A new challenge: see Ghisellini et al. 2020 for a possible solution and discussion of alternatives

Gamma Ray Bursts detection rates



Detection rate depends:

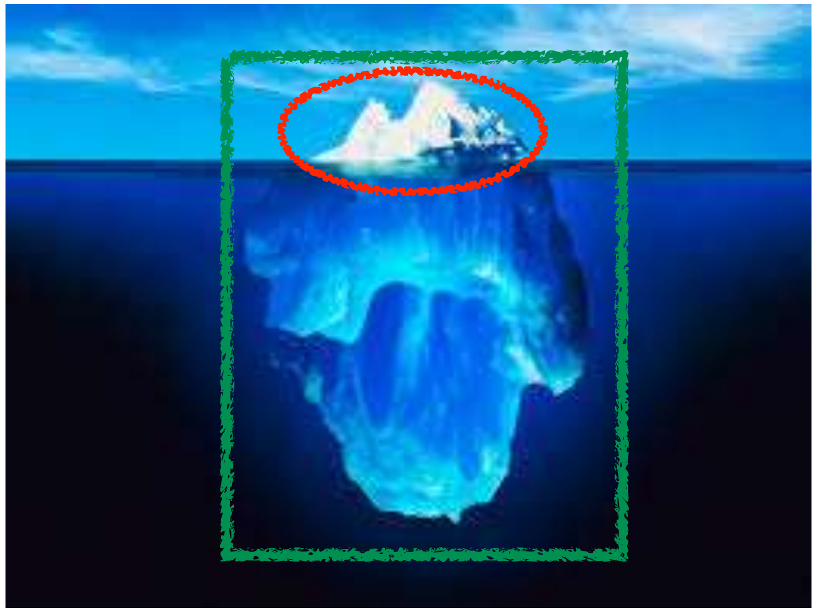


GRB intrinsic properties
- Luminosity distribution
- Redshift distribution
- SED
- Duration

Instrumental properties
- Energy range
- Background
- Field of view
- Duty cycle

HERMES GRB DETECTION RATES

In collaboration with L. Nava



Population Based

- Ghirlanda et al. 2015 (long GRBs)
- Ghirlanda et al. 2016 (short GRBs)

Population intrinsic properties:

1. Luminosity/energy function $\phi(L)$

2. Cosmic rate distribution $\Psi(z)$

↔ Reproduce GRB samples (Batse, Swift, Fermi …)

↓

Hermes instrumental parameters → Hermes GRB detection rates

Adv.

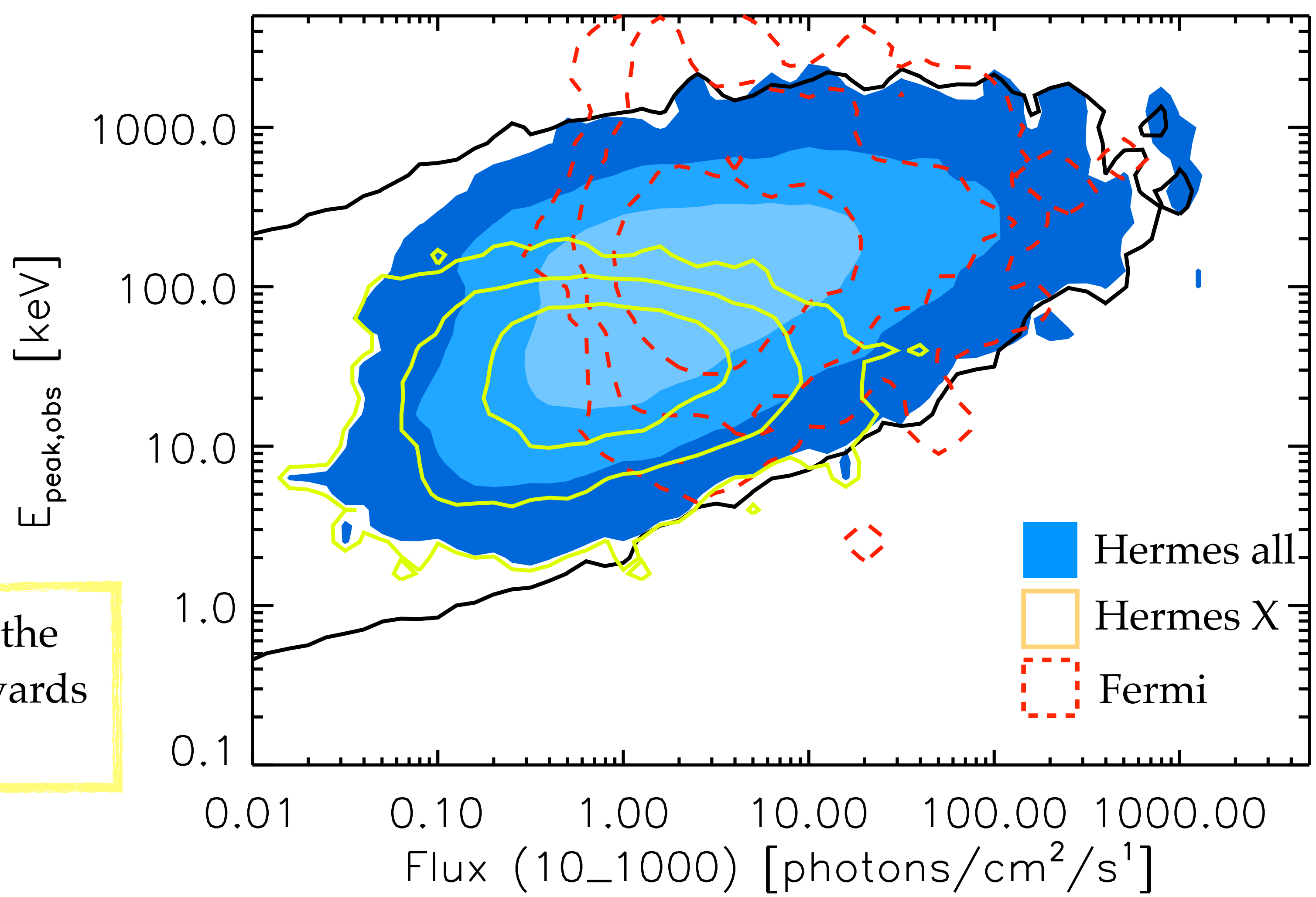
1) Control of selection biases (wrt sample based estimates)
2) Multi-observable constraints
3) Used for different missions/telescopes (e.g. CTA, Theseus …) —> explore synergies

HERMES GRB DETECTION RATES

- S (50-300 keV); 80 deg
- X (3-20 keV); 60 deg
- Aeff(ϑ)
- Detect >5σ
- duty cycle=0.5
- Fluence or Peak flux

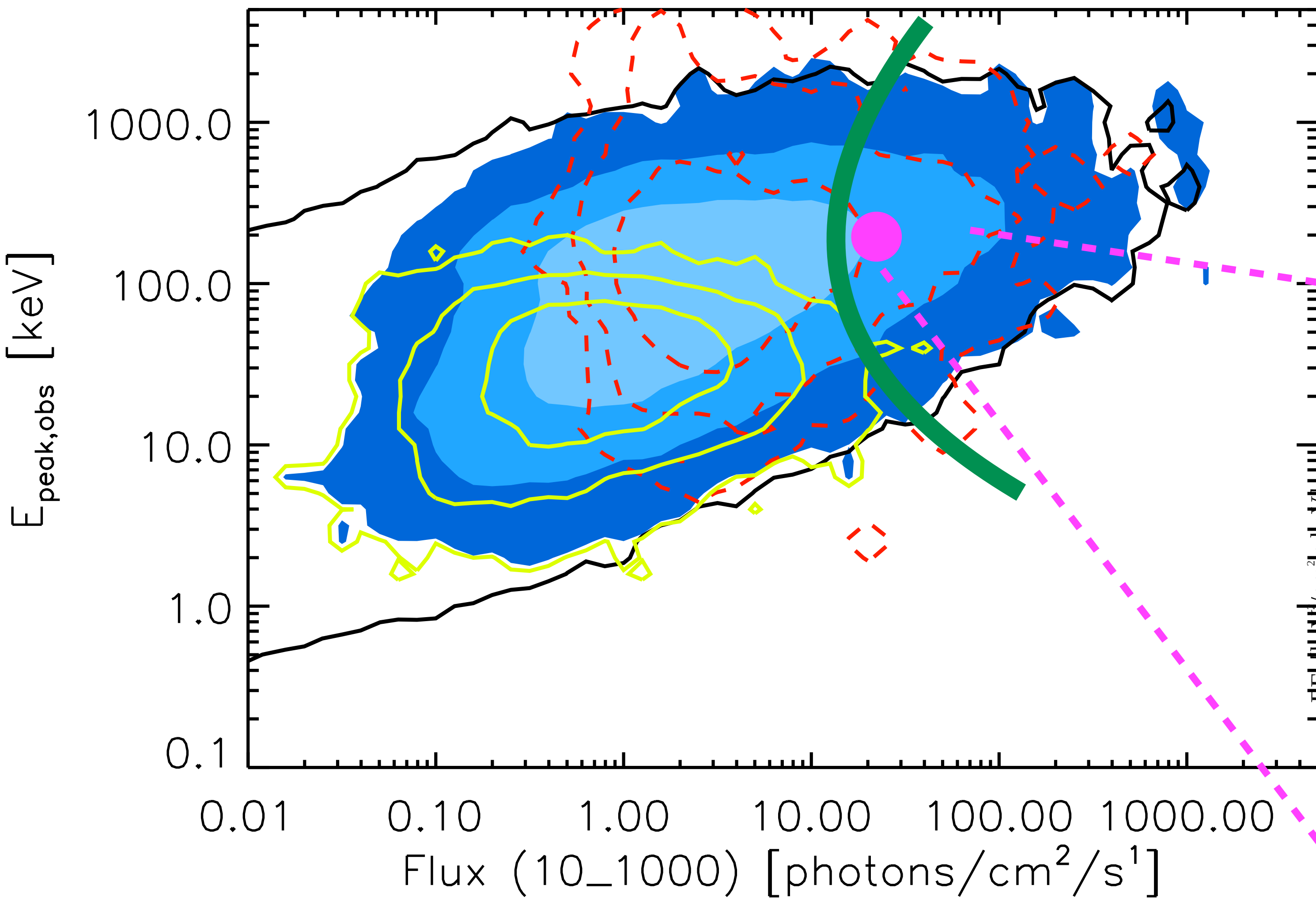
Type	Total [yr^{-1}]	S [yr^{-1}]	X [yr^{-1}]
Long GRBs	50-150	40-106	34-110
Short GRBs	14	13	9

G. Dilillo & F. Fiore now testing different triggers on real light curves

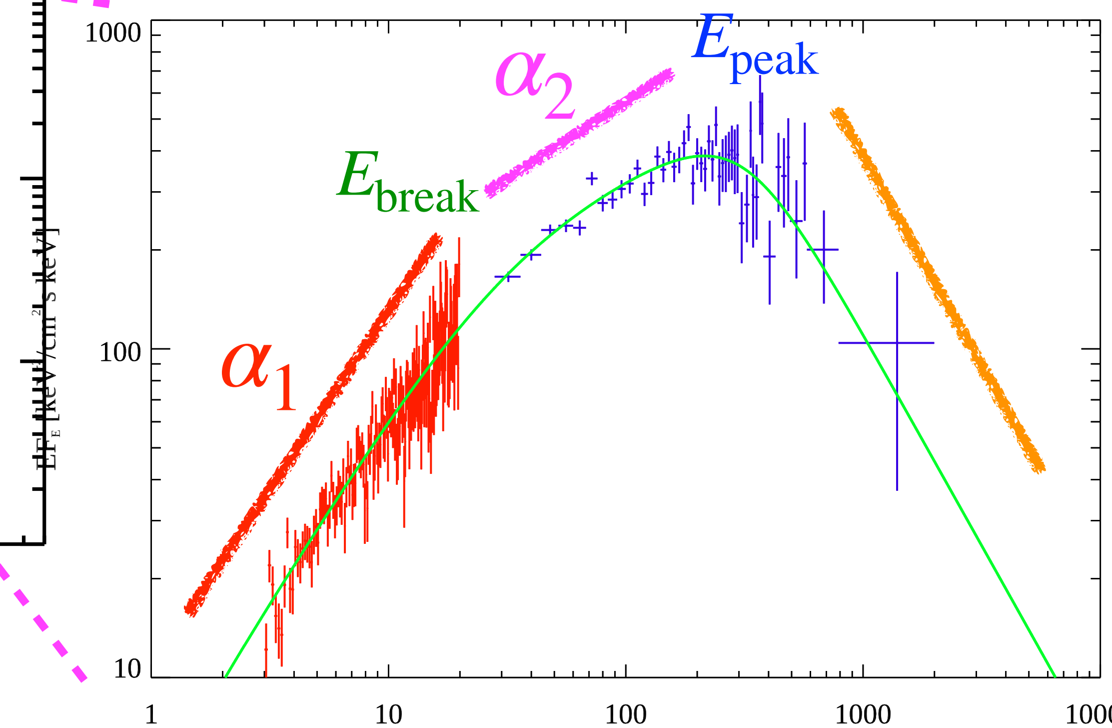


X detector will extend the detected population towards softer events

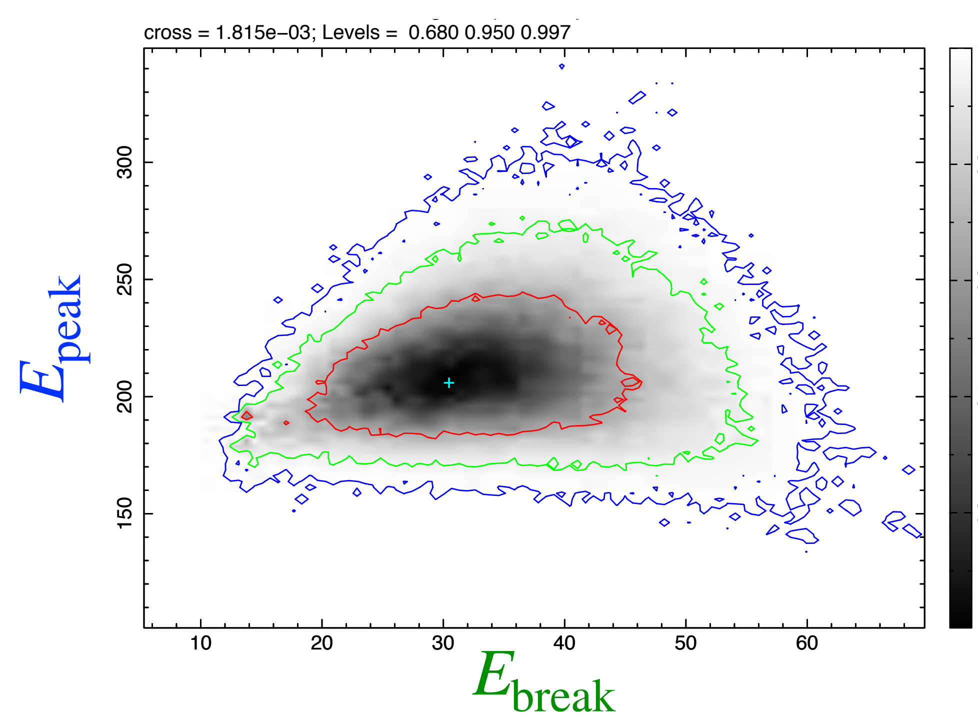
HERMES VIEW OF GRB SPECTRA (I)

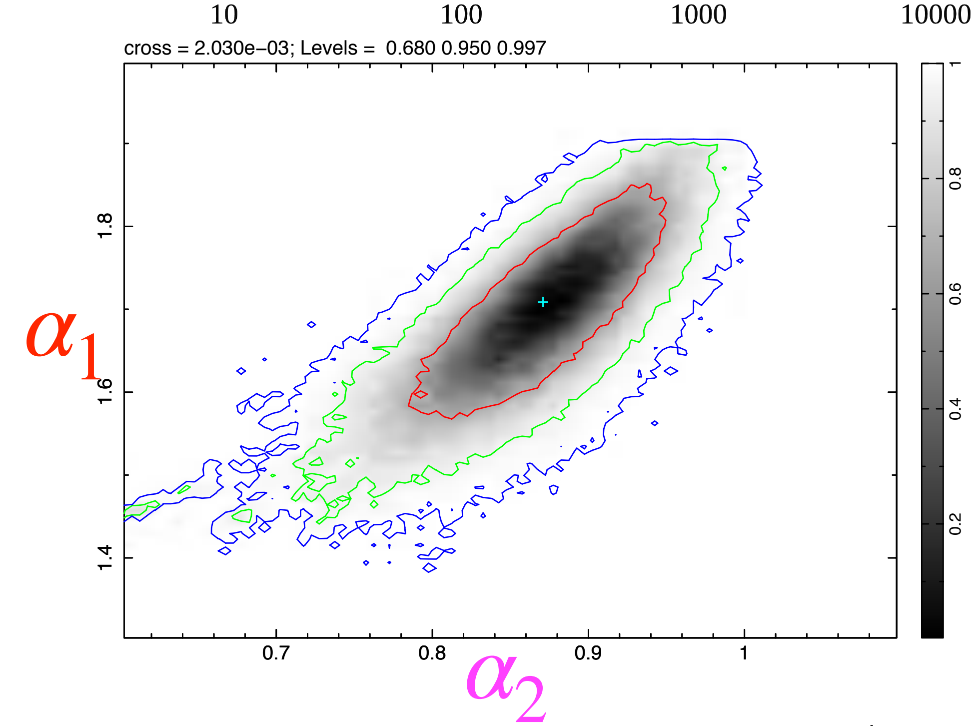


Green: limiting flux for significant identification of the break



+Hermes:
Ebreak(t); Epeak(t)



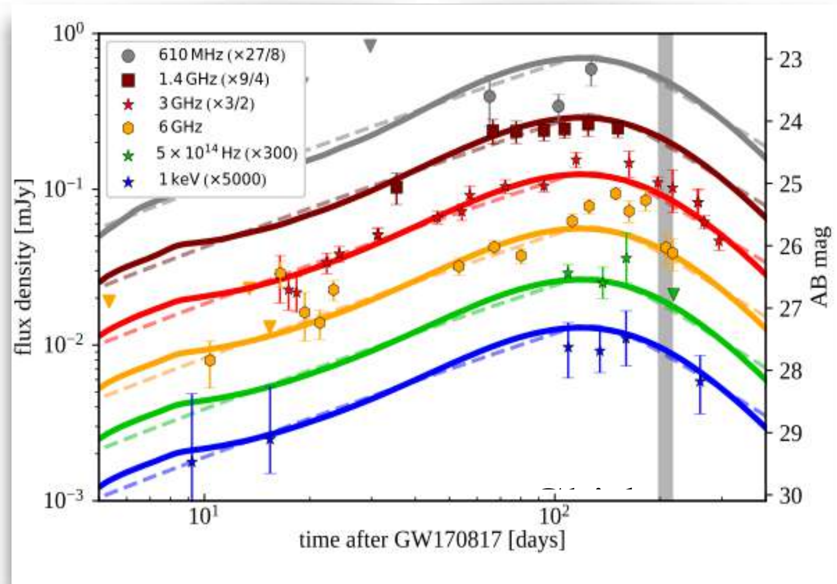


Hermes and Gravitational Waves counterparts

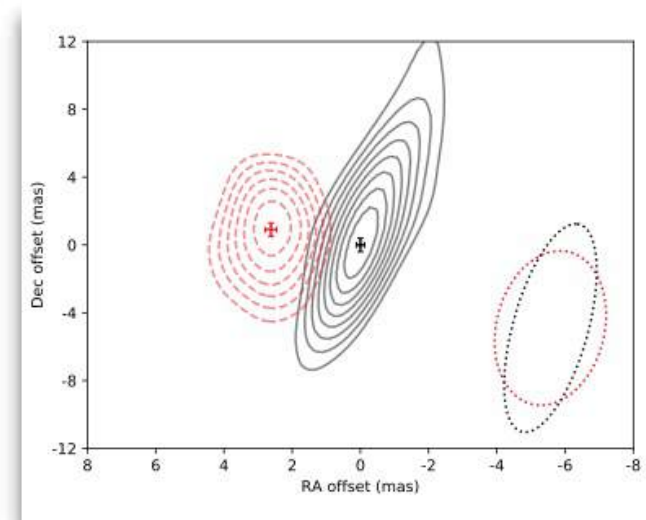
GW170817 [Abbott+2017]

GRB170817 [Abbott+2017a]

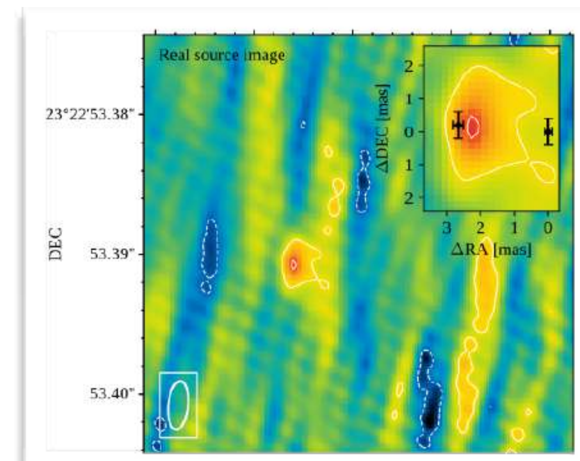
KN AT2017gfo
[Coultier+2017; Pian+2017 …]



Afterglow temporal evolution
[Margutti+2018; D'Avanzo+2018 …]

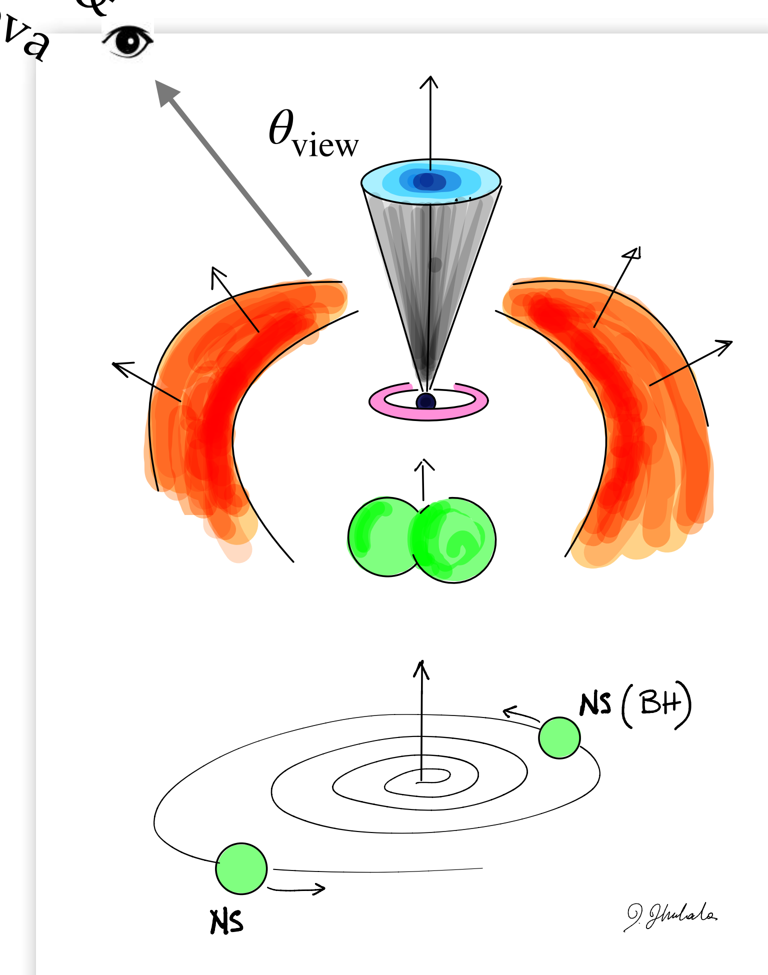


Source proper motion
(Mooley+2018)



Source size constraints
(Ghirlanda, Salafia+2019)

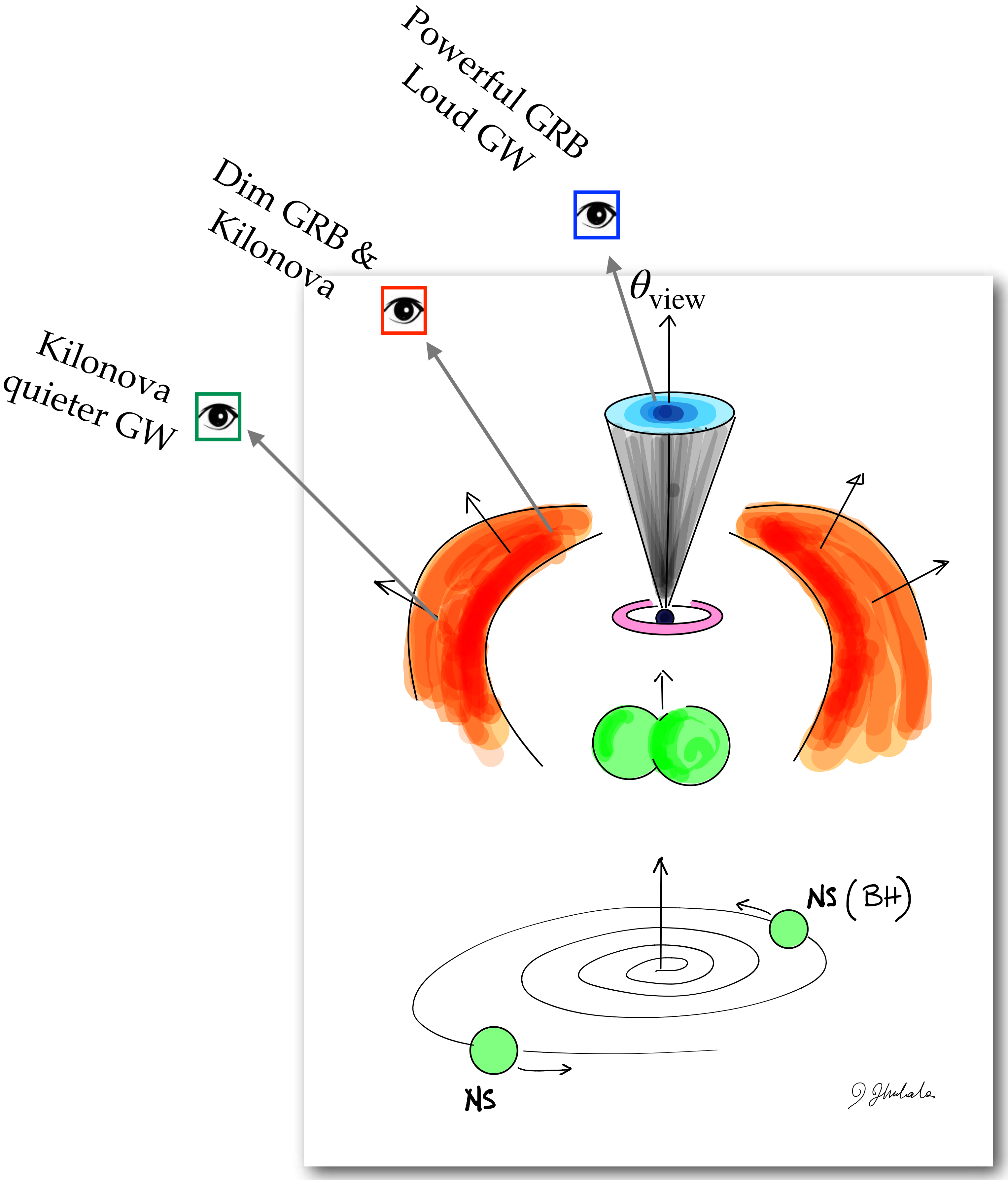
Dim GRB & Kilonova

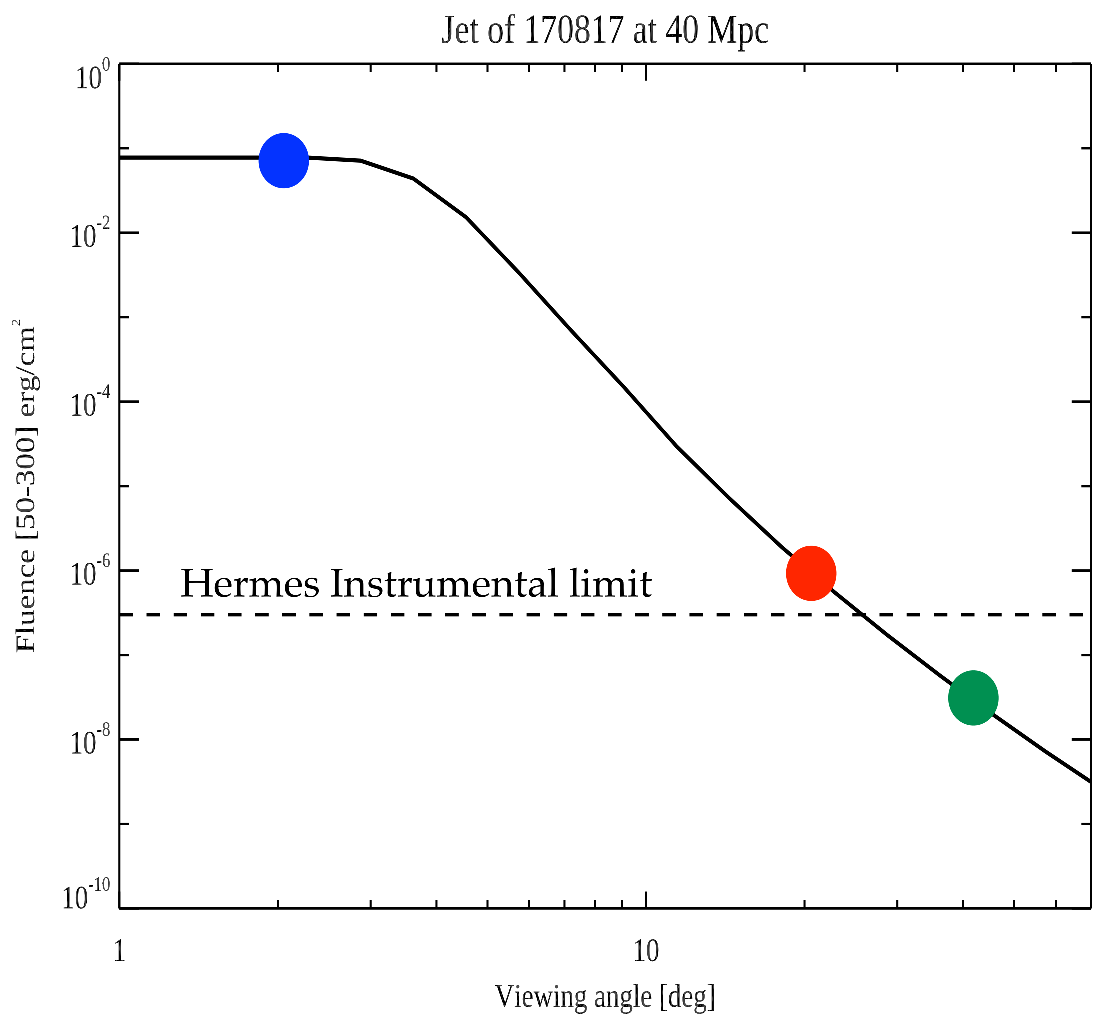


A jet with an angular structure of:

- Energy
- Bulk Lorentz factor

WHEN ORIENTATION MATTERS





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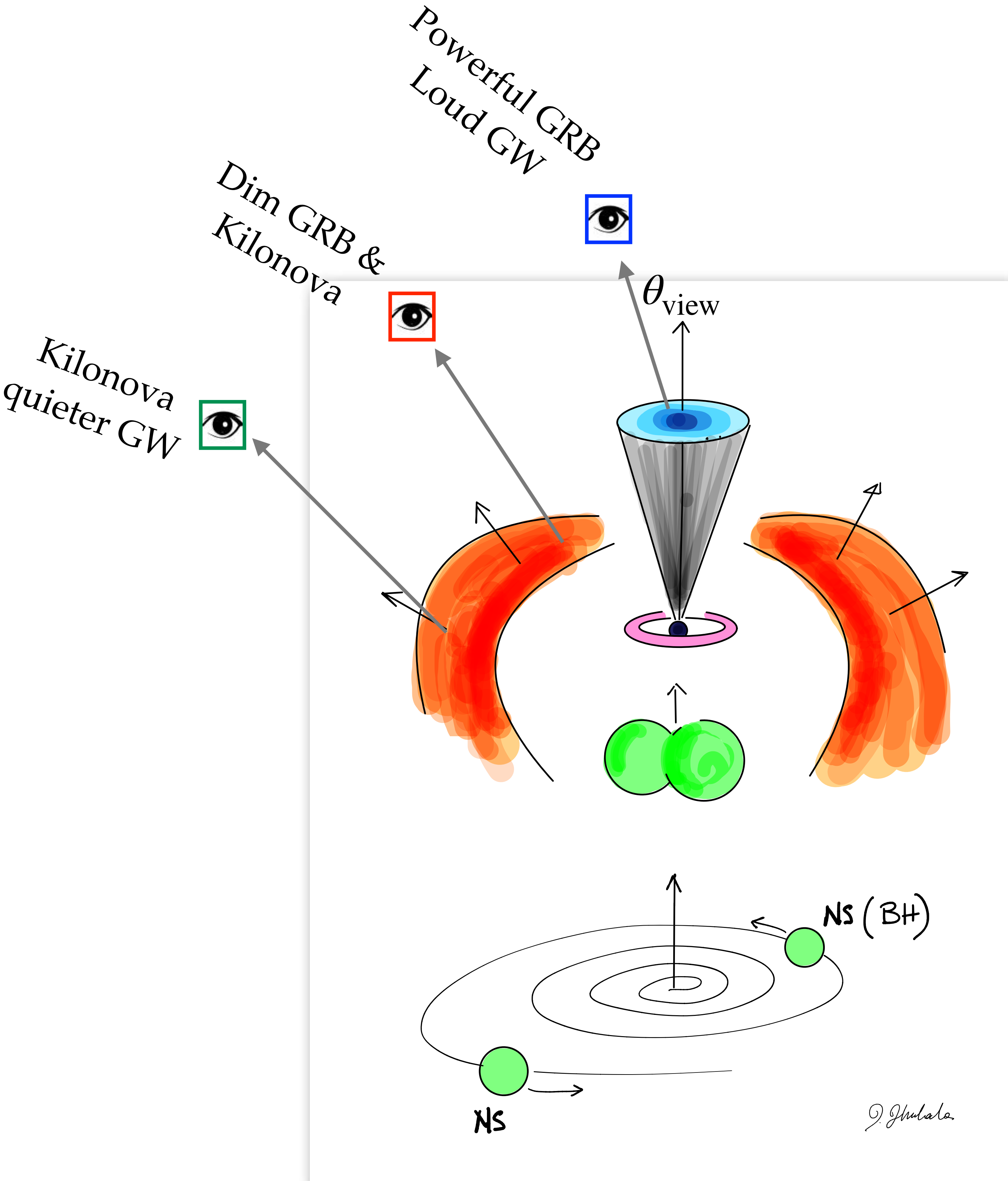
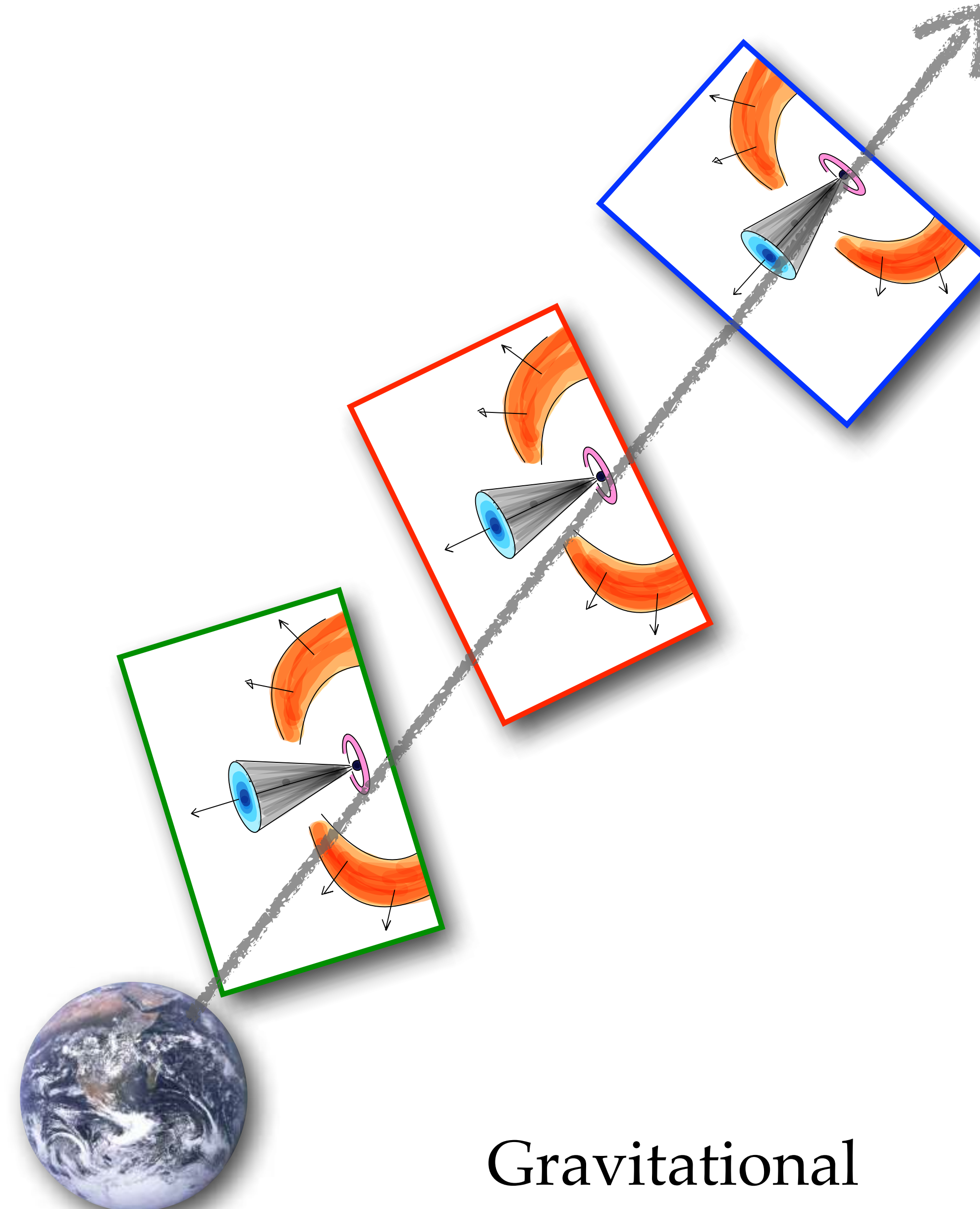
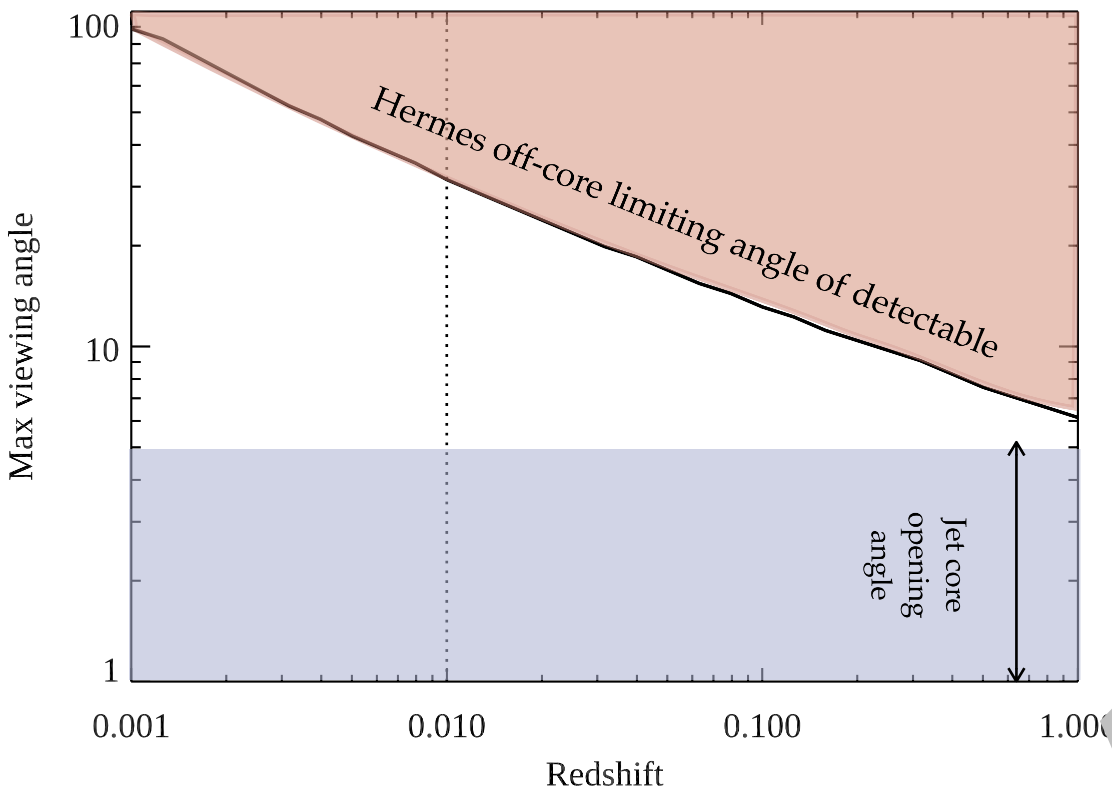


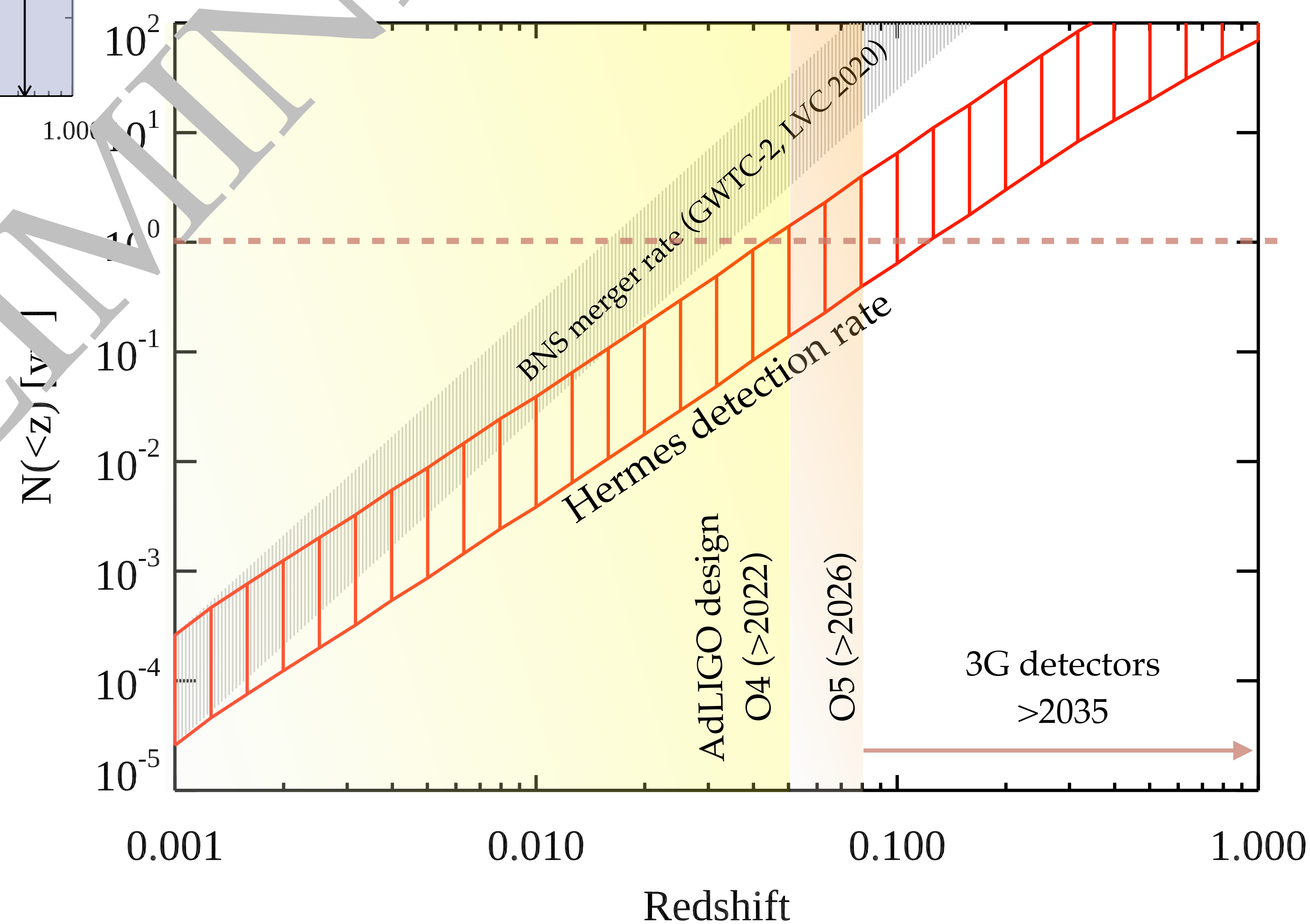


Gravitational
&
Electromagnetic
ranges

Hermes: BNS-EM counterpart detection rate



Assuming E(ϑ) and Γ(ϑ) of 170817 (from Ghirlanda, Salfia+2019)



Preliminary estimates adopting

1) Early Hermes detector response files etc.
2) BNS —> succesful jet
3) Should account for jet structure post.

Conclusions

GRB prompt emission: discovery of a low energy break and typical slopes

- Prompt emission seems synchrotron (both empirical and physical model fits)
- Cooling break ≲ injection break in long GRBs (~ for short GRBs)
  - ✳Requires small magnetic field and large emission radii … but maybe protons

Hermes: GRB detection and study

- ~100 yr^{-1} Long & ~15 yr^{-1} Short
- Can identify E_{break} (tnx low energy threshold ~ 3 keV)
- Can constrain thermal emission components
- Can detect GW/GRB counterparts (LV design and 3G)