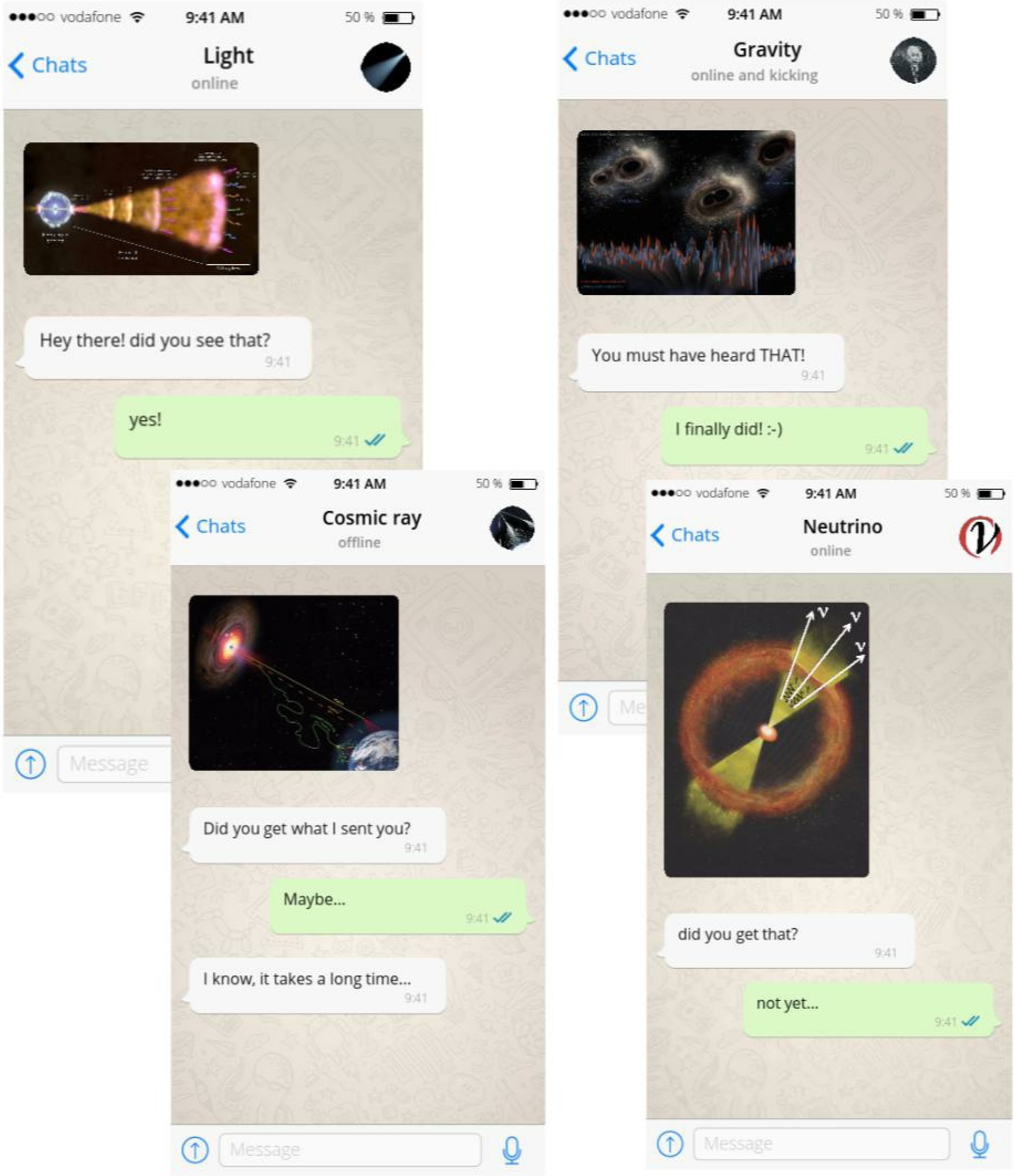
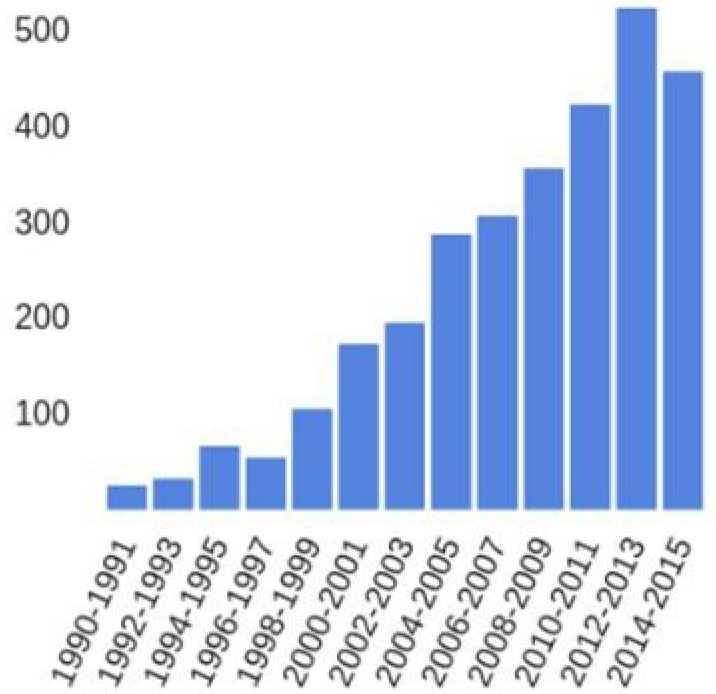
GRBS AS MULTI-MESSENGER SOURCES

G. Vianello (Stanford University)



PRIME M-M SOURCES

- publications talking about GRBs and either:
    - GW
    - neutrino
    - cosmic rays



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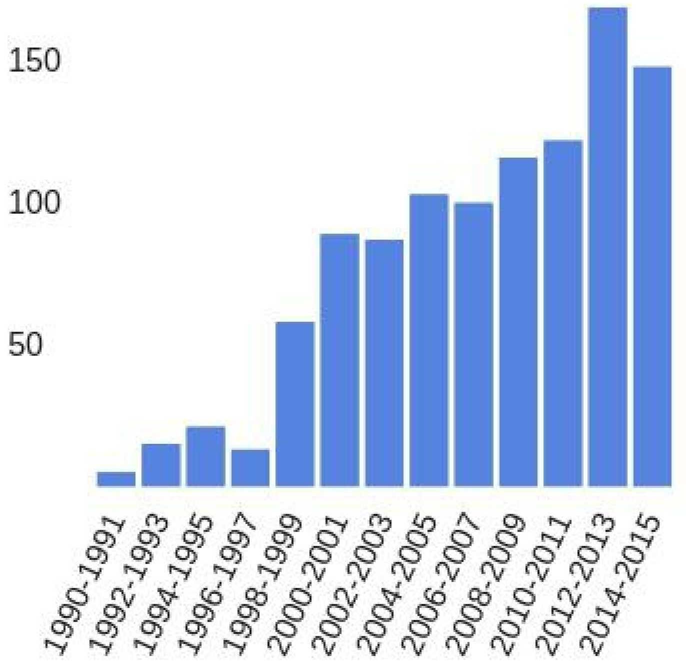

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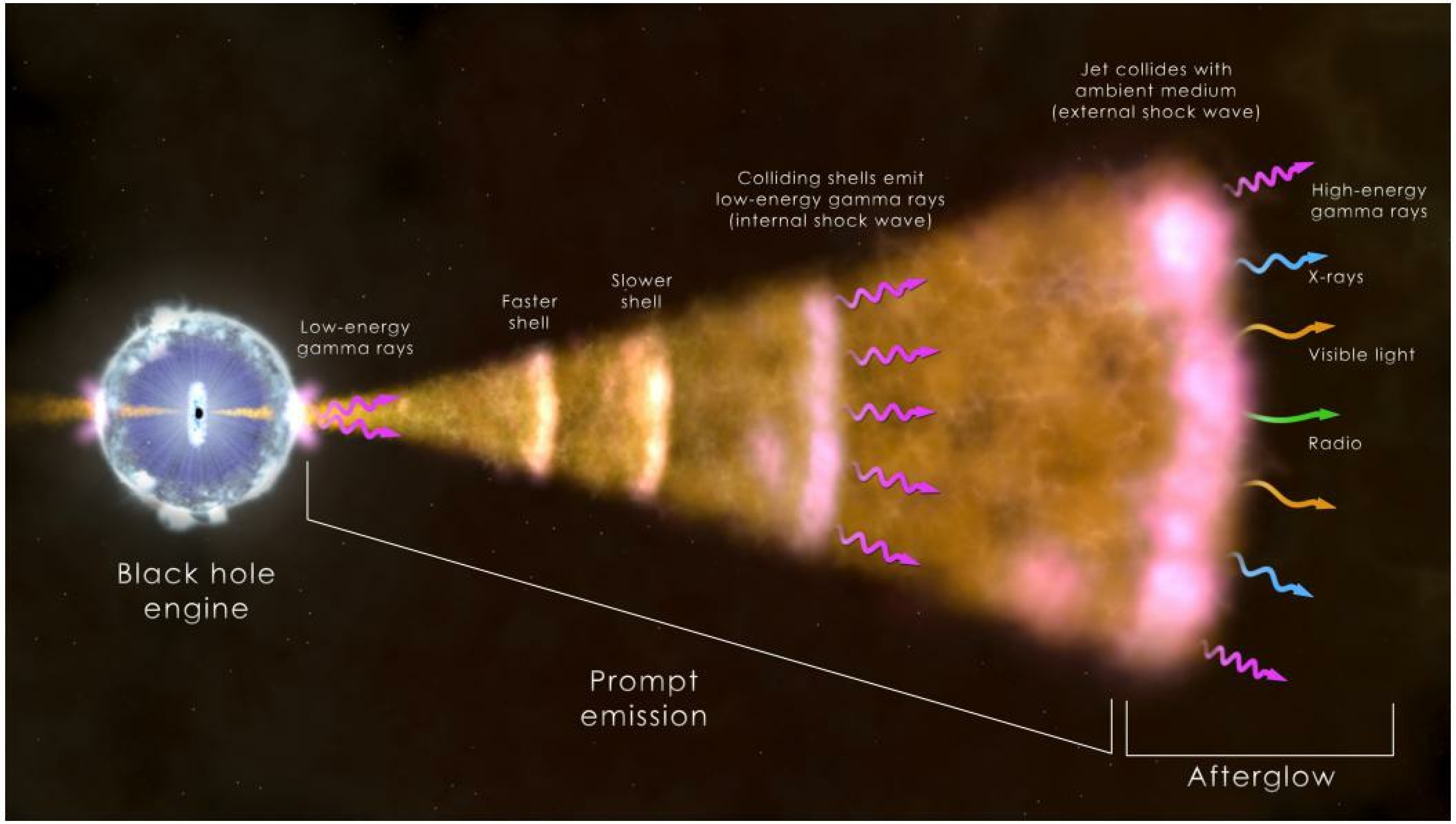
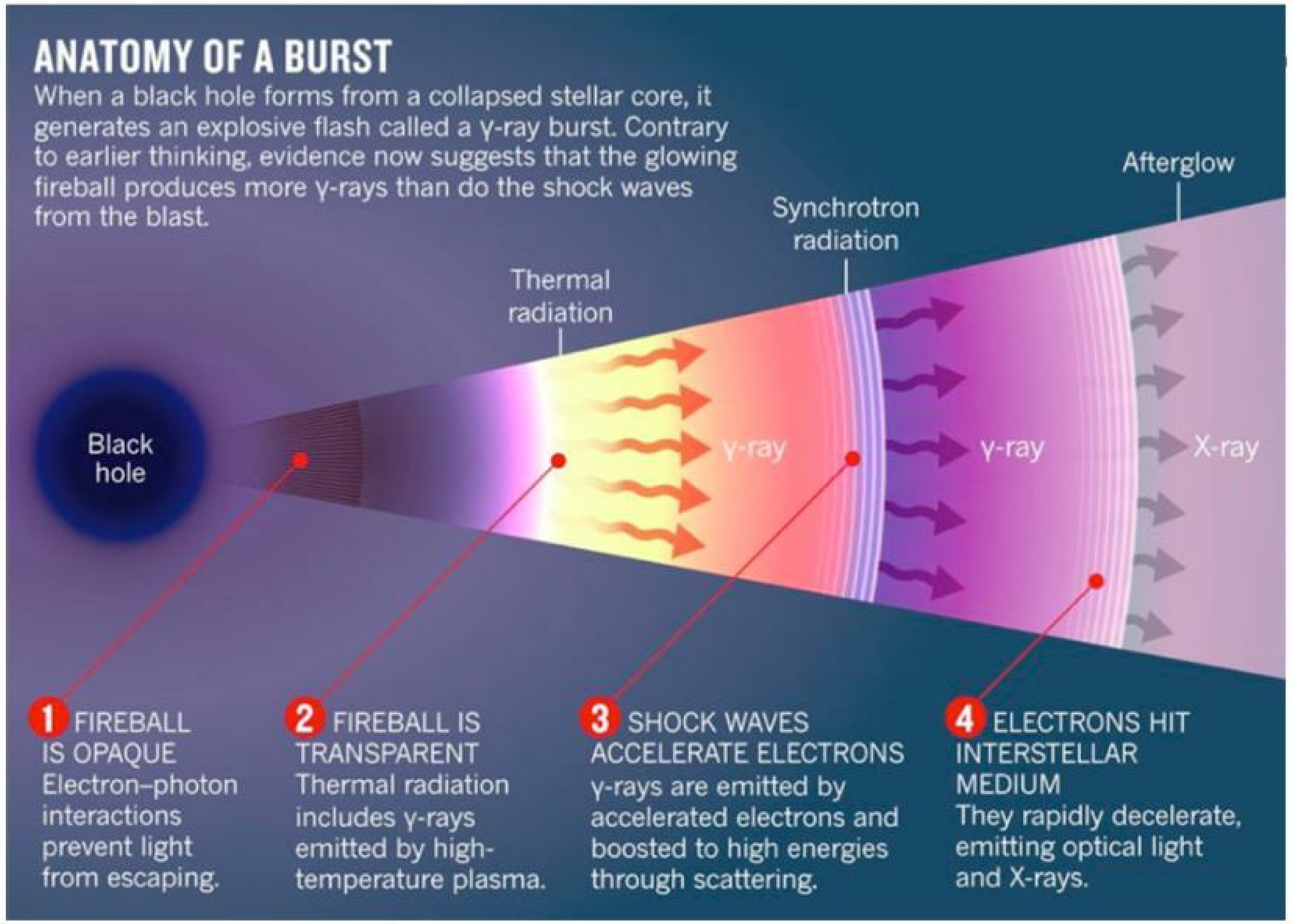
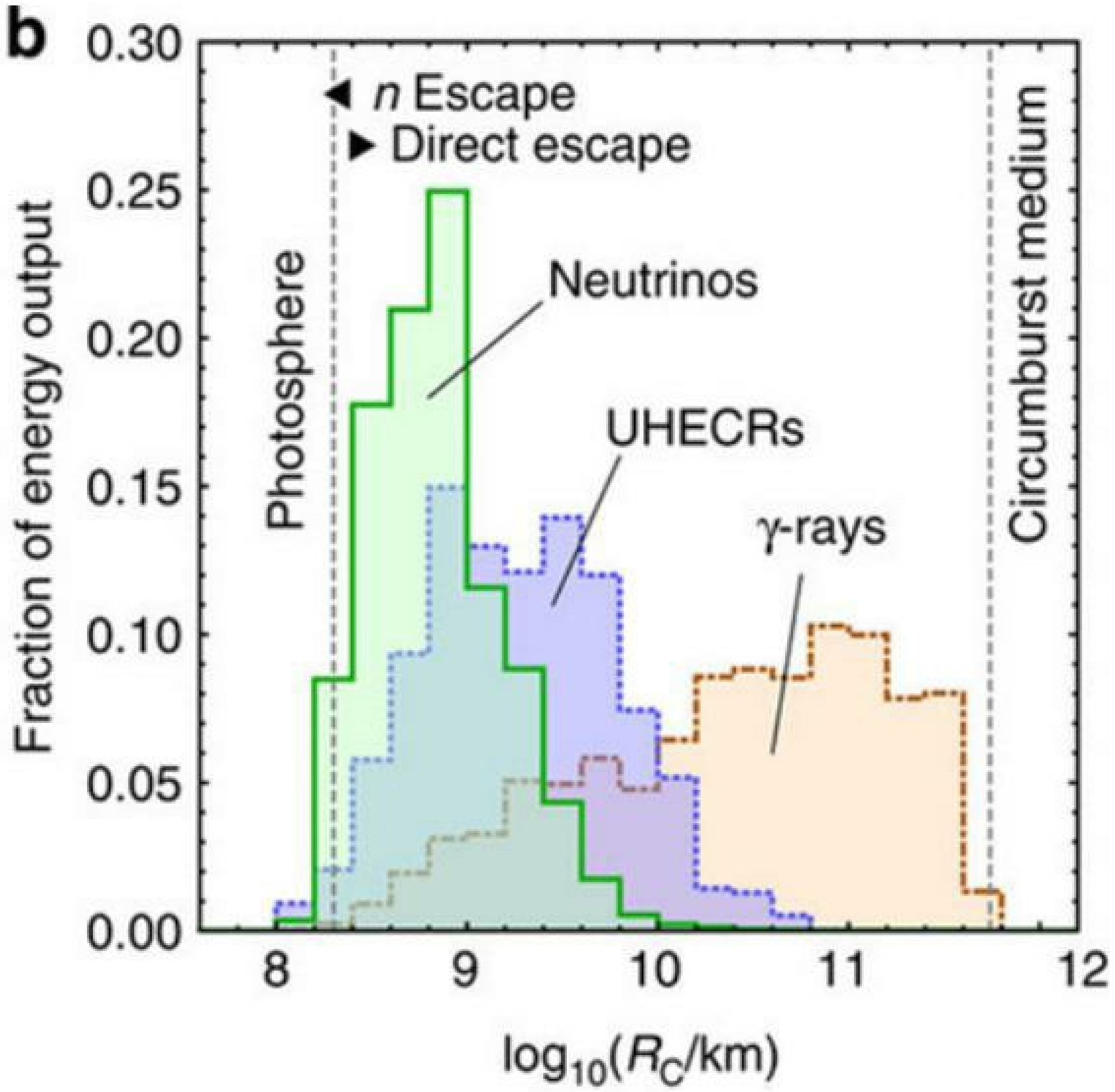
CURRENT MODELS

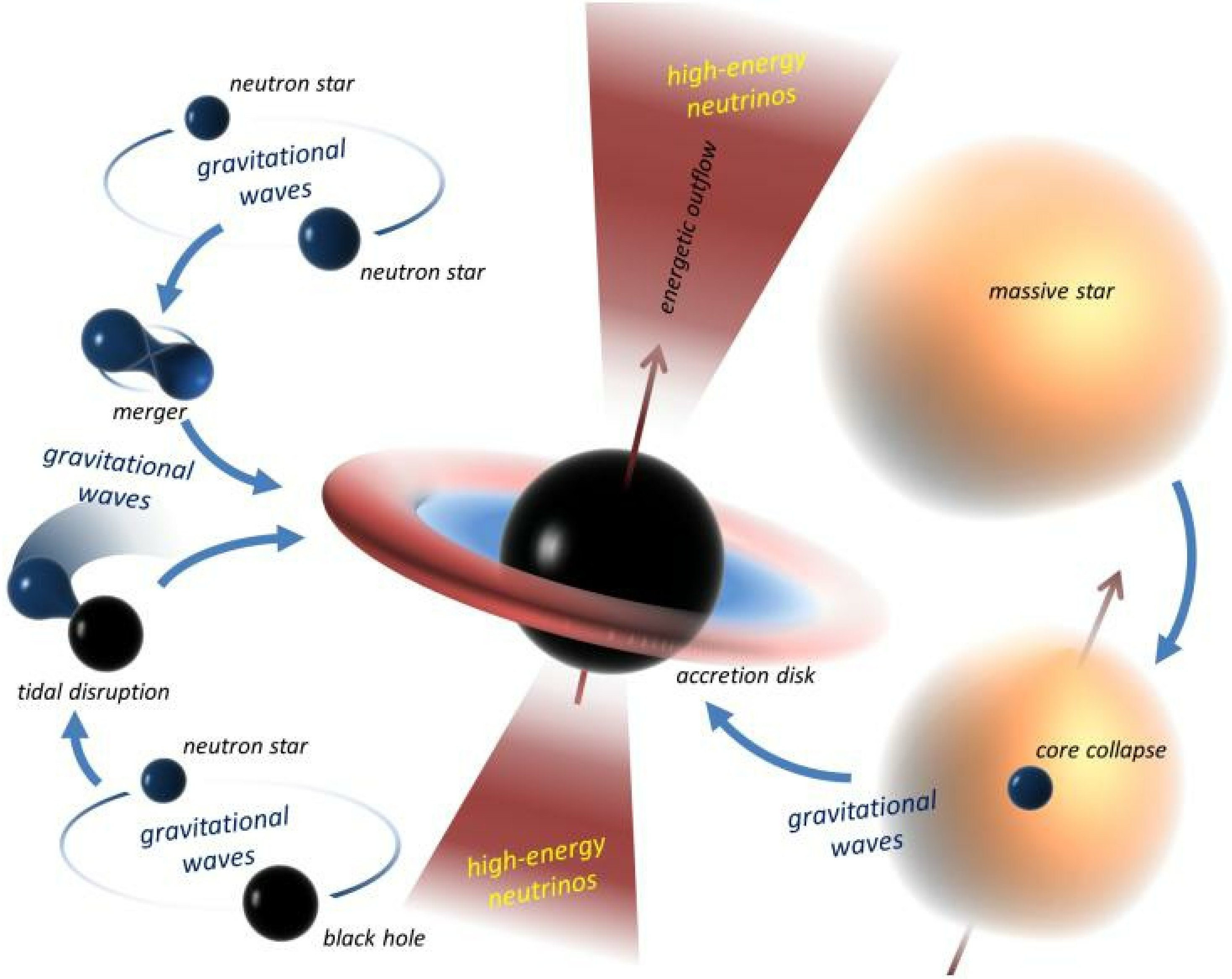




- Classical Internal-external shock model:
  - well studies/understood
  - good description of general phenomenology
  - efficiency of IS is a long-standing problem
- Photospheric models:
  - many variations, very active research
  - support from observations not firmly estabilished

MULTI-MESSENGER SIGNAL IN GRBS

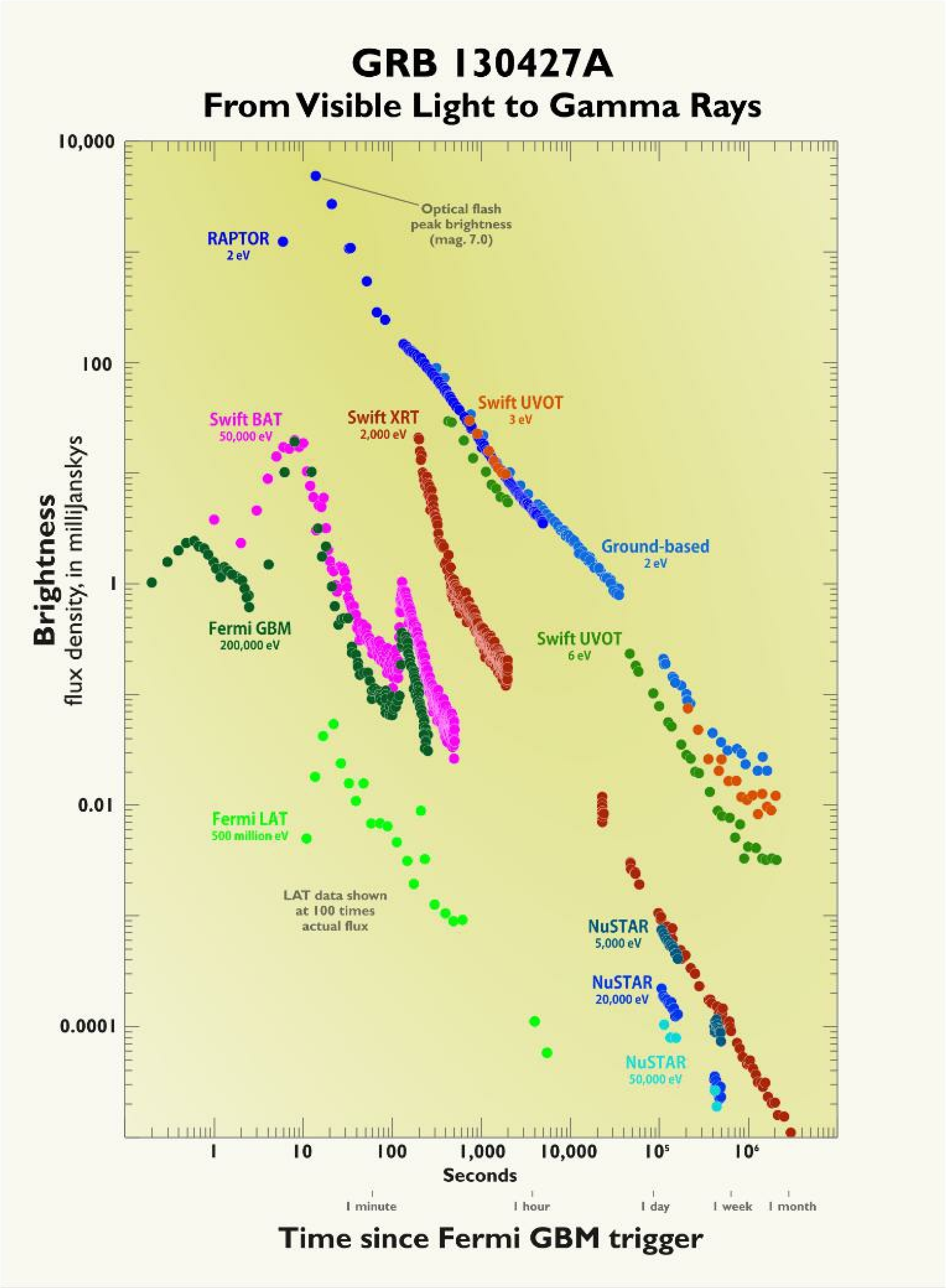




Bustamante et al. 2015

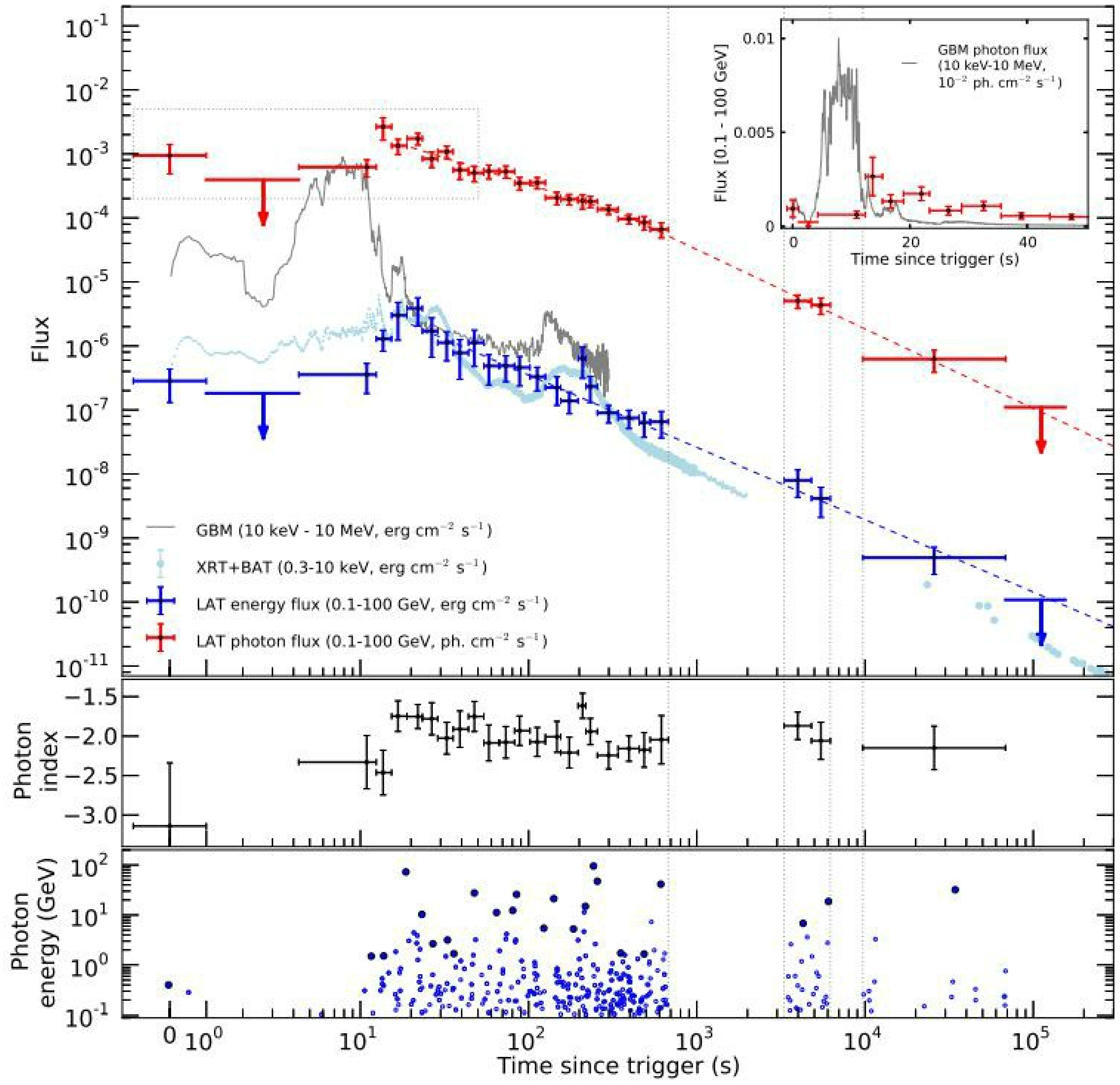
GRB e.m. phenomenology

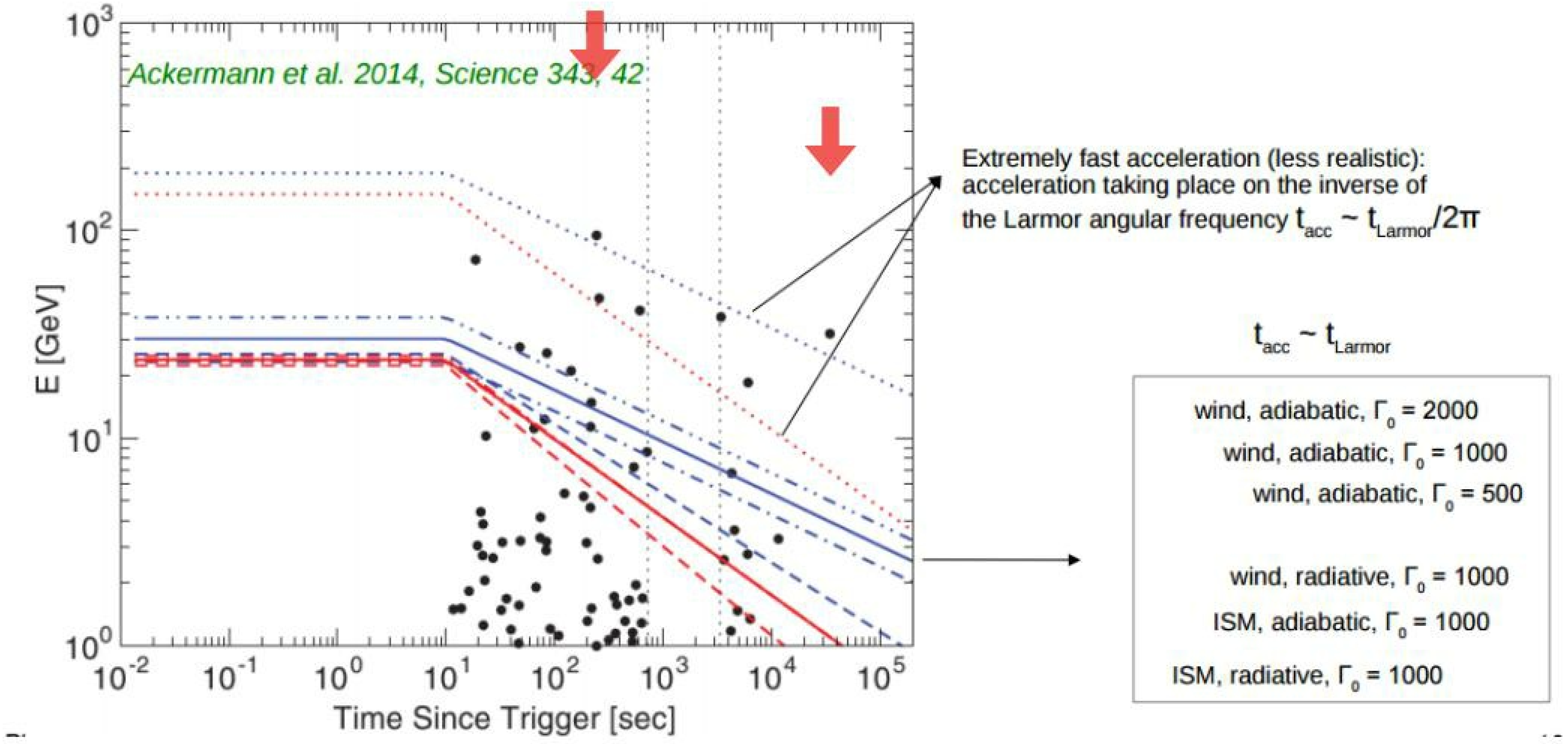
- Spiky prompt emission (gamma, x, optical)
- Smoother afterglow emission (radio, HE gamma, optical, x-ray)



High-energy photons: a challenge

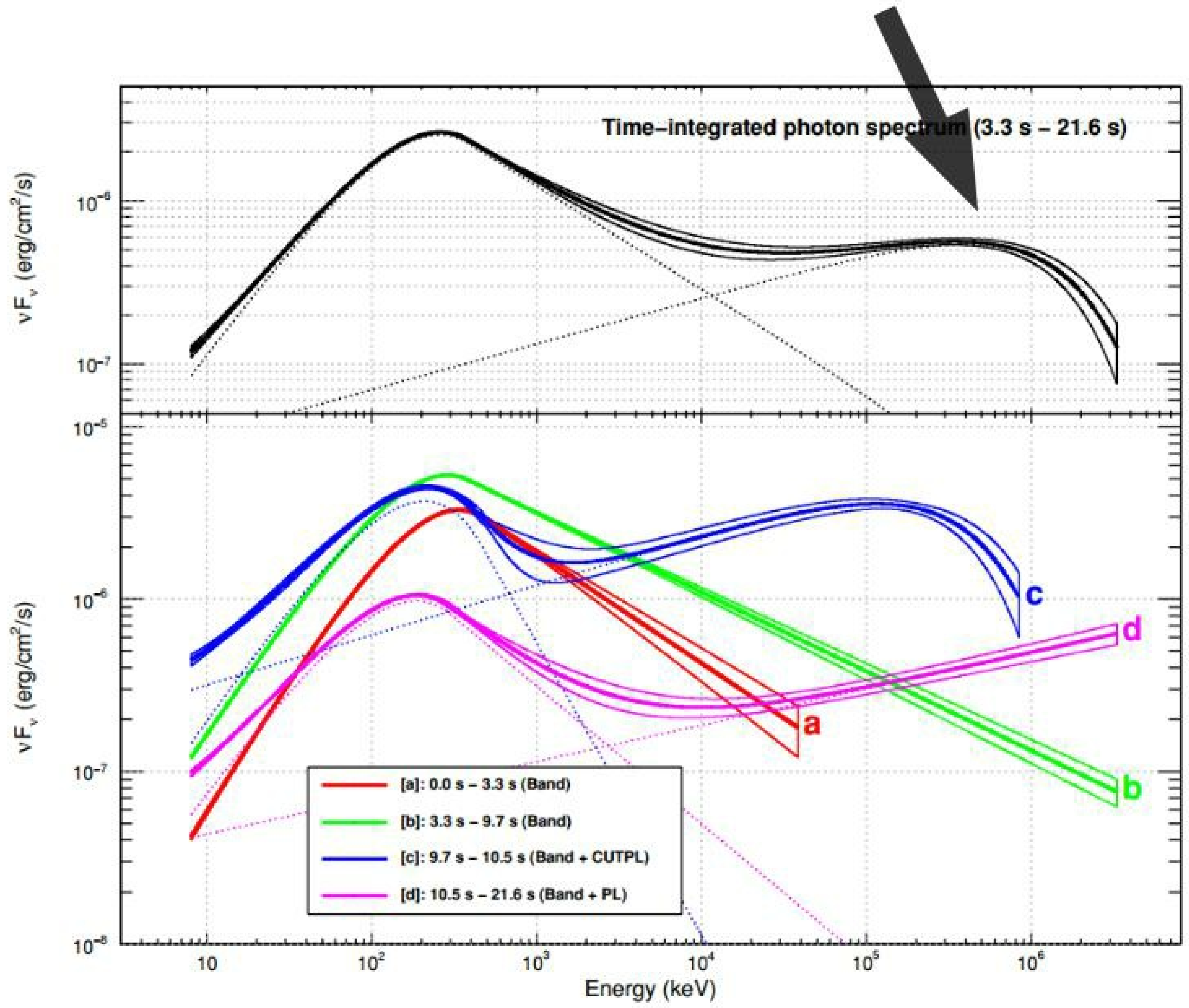
Synch. emission very problematic
IC would predict spectral evolution





Link to m-m

GRB 090926A: spectral cutoff intrepreted as g-g opacity -> Gamma ~ 220 - 700 (modeling uncertainties)



- High-energy photons (> 10 GeV) are particularly interesting for m-m observations:
  - show that GRBs are very good particle accelerator
  - + variability -> constrain Lorentz factor
  - GRBs can accelerate CR up to 10^20 eV (Dermer et al. 2010)

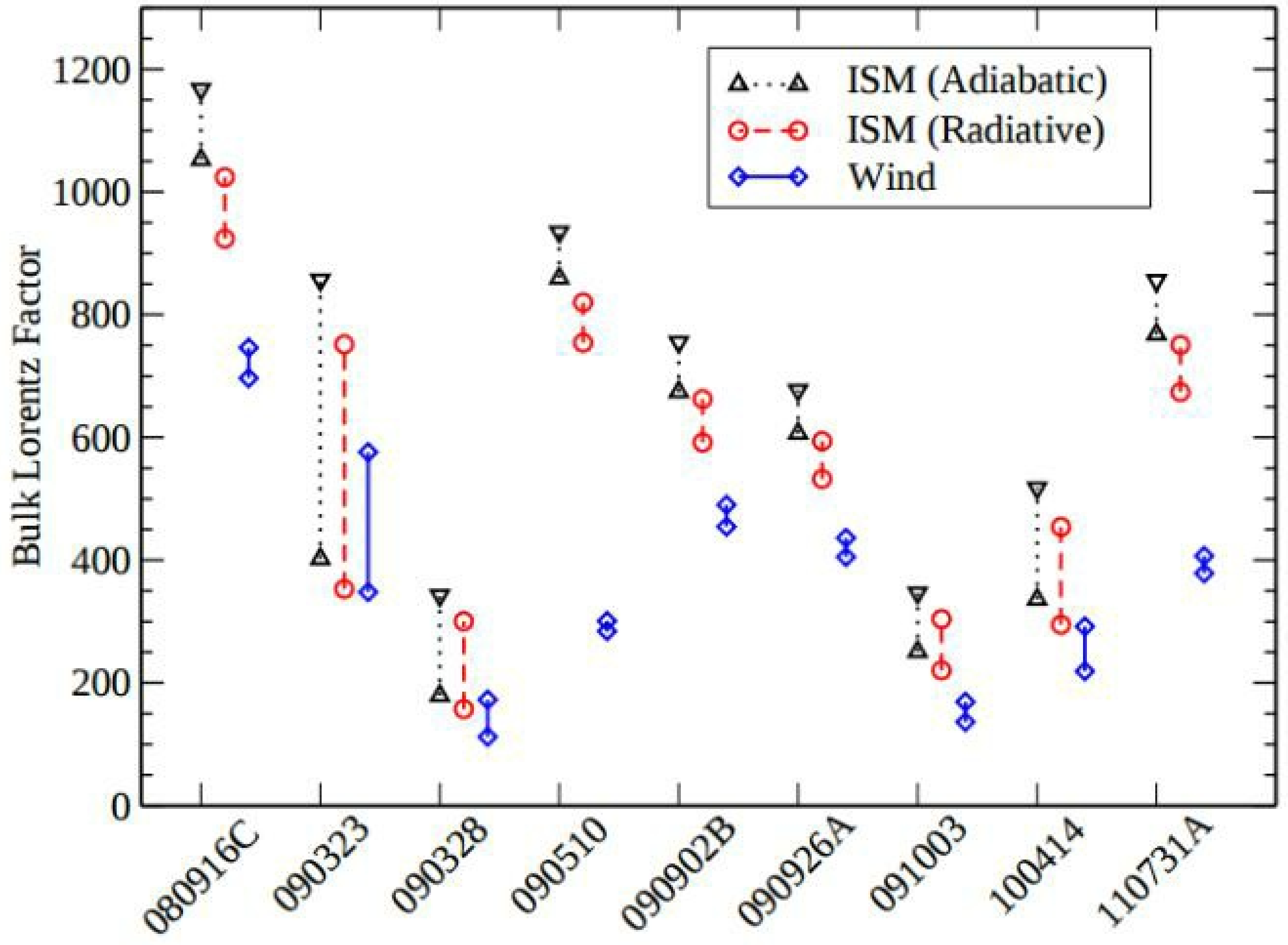
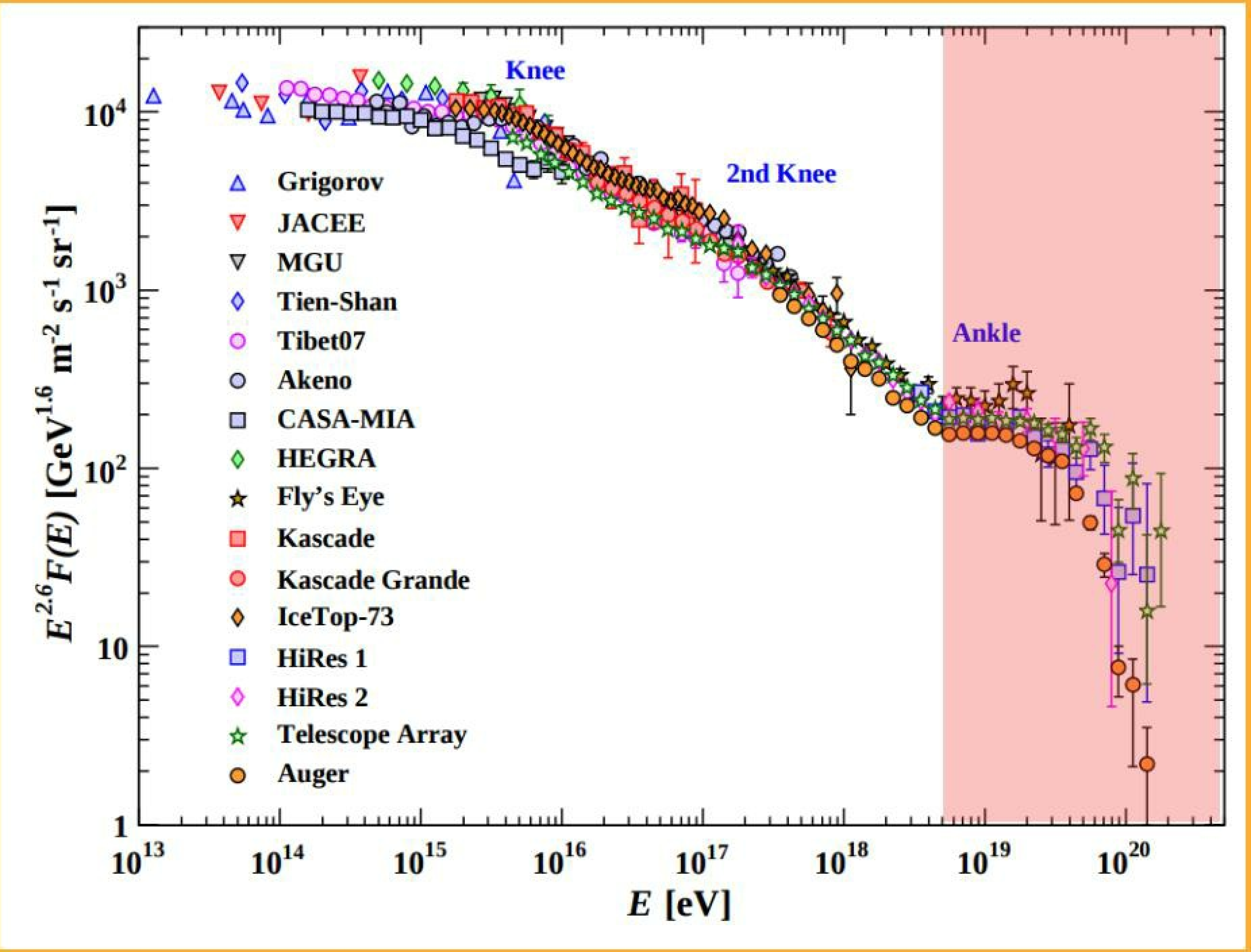


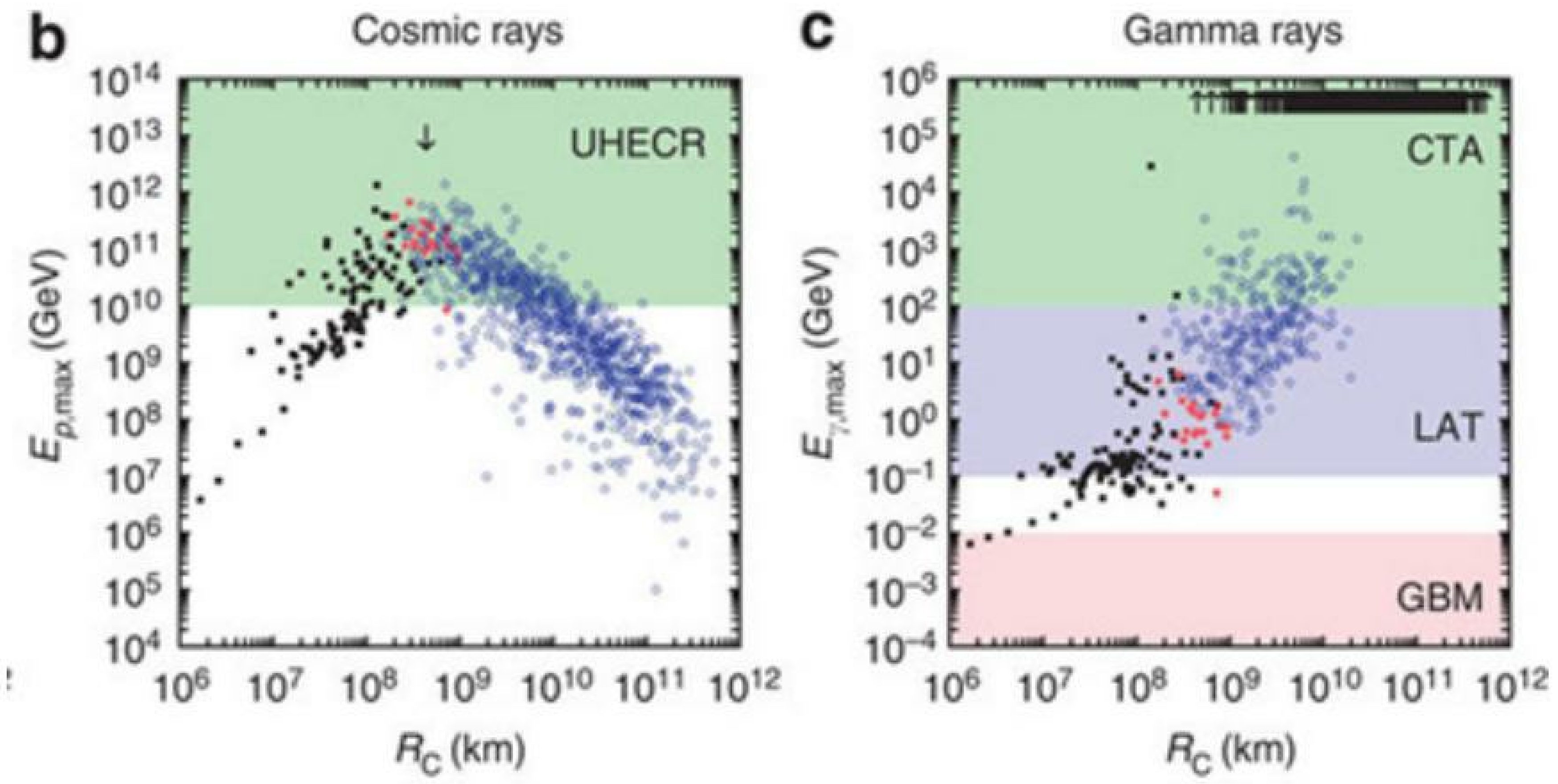
Fig. 32.— Bulk Lorentz factors of the LAT bursts derived on the assumption that the peak flux time in the LAT (Fig. 14) represents the fireball-deceleration time through Eqs. (7) and (8). We also assumed a constant ISM density of $n = 1$ cm^{-3}, a wind parameter with $A_\star = 0.1$ and a kinetic energy four times the γ-ray energy, $E_{k,\rm iso} = 4 \times E_{\gamma,\rm iso}$, for this illustrative plot. The range of Γ_0 in each case represents the 1σ error on $t_{\rm peak}$.

ULTRA HIGH-ENERGY COSMIC RAYS

- The ankle is interpreted as the onset of extra-galactic component
- the cutoff is interpreted as GZK effect (interaction of CR with CMB)
    - if E > 10^20, then d < 100 Mpc
- What can accelerate CRs up to 10^20 eV?
    - GRBs
    - blazars (not covered)



UHECR AND GRBS



Bustamante et al. 2014

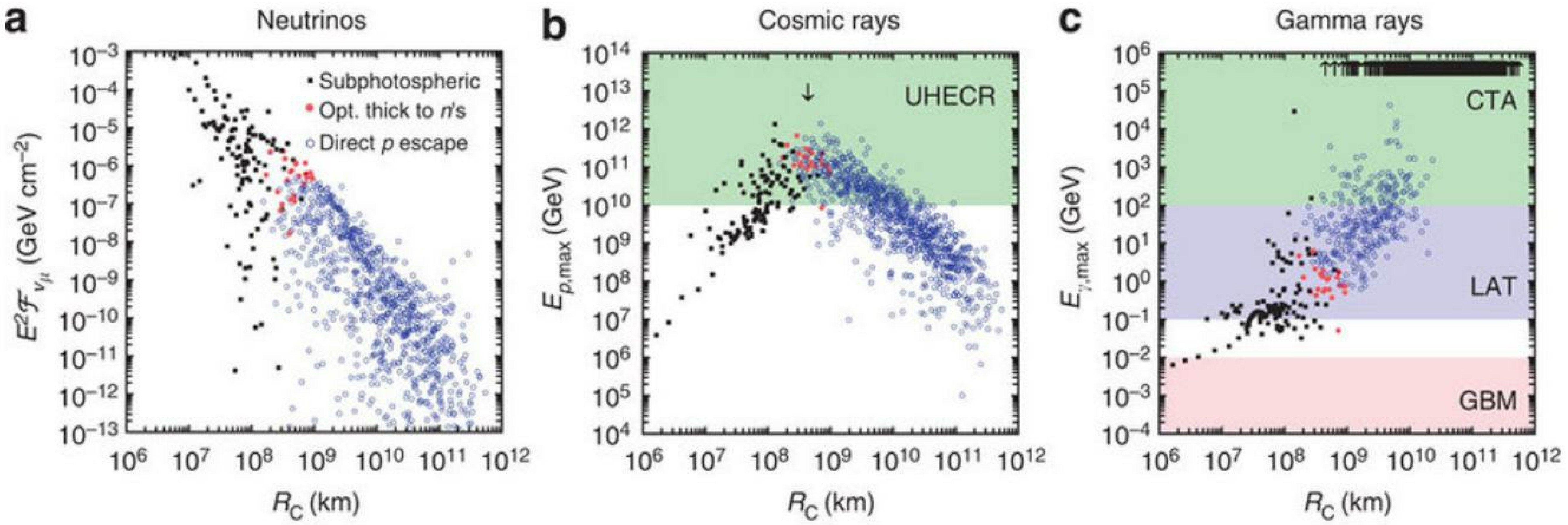
- In the internal shock model protons are expected to be accelerated as well
- Efficiency of p acceleration depends on the collision radius:

$$R_c = \Gamma^2 \, c \, \delta t_v / (1 + z)$$

- For GRB 090926A, Rc ~ 4 x 10^8 km -> UHECR
- GRBs might be too rare within the GZK radius to explain the very end of the spectrum:
  - estimates depend on Intergalactic Magnetic Field, beaming factor, GRB rate...

THE NEUTRINO CONNECTION

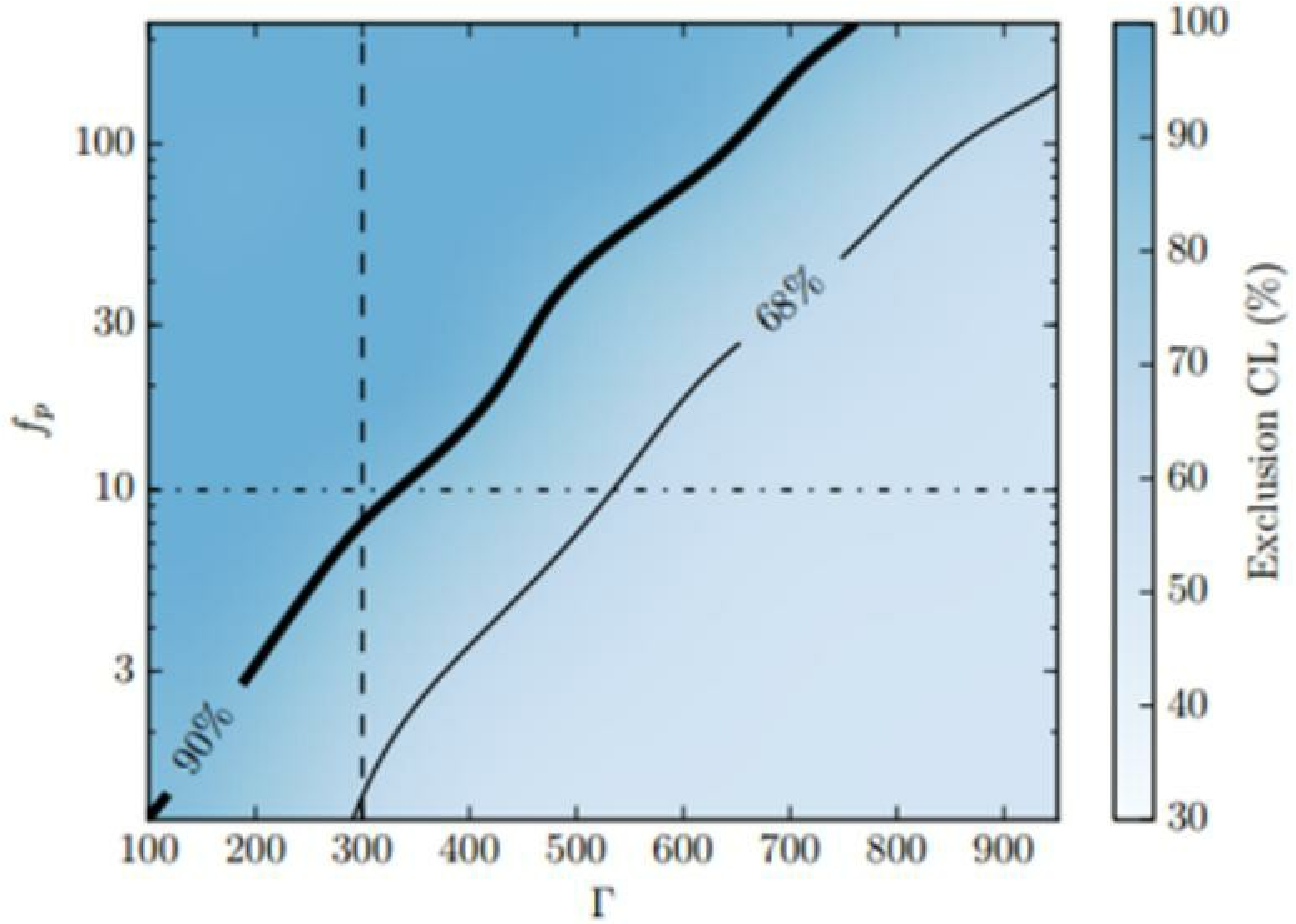
- Different proton escape regimes in internal shocks:
  - protons are confined, but photoadronic interactions -> neutrons + neutrinos which escape (1 neutrino per neutron with 1:1:1 ratio)
  - protons escape from the side of the jet ("direct escape") -> very few neutrinos
  - all hadrons are confined due to many photoadronic interactions -> many neutrinos, no CRs



Bustamante et al. 2015

ICECUBE LIMITS

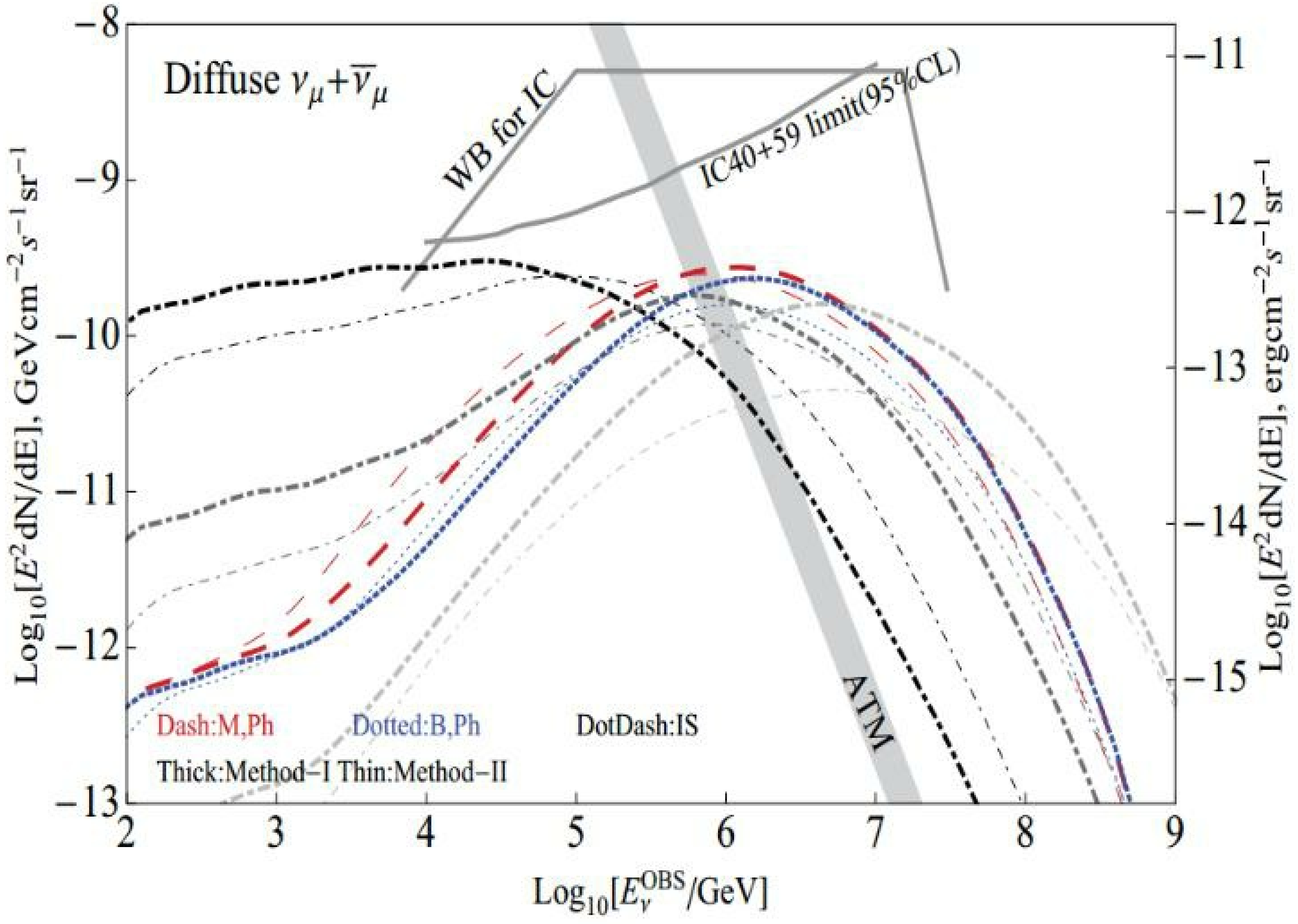
- searches for coincidences between GRBs and neutrino did not return any significant result
- constraints on simple 1-CR-1-neutrino model for IS is constraining, assuming same zone for CR and gamma production



Simple IS model

IceCube coll. 2016

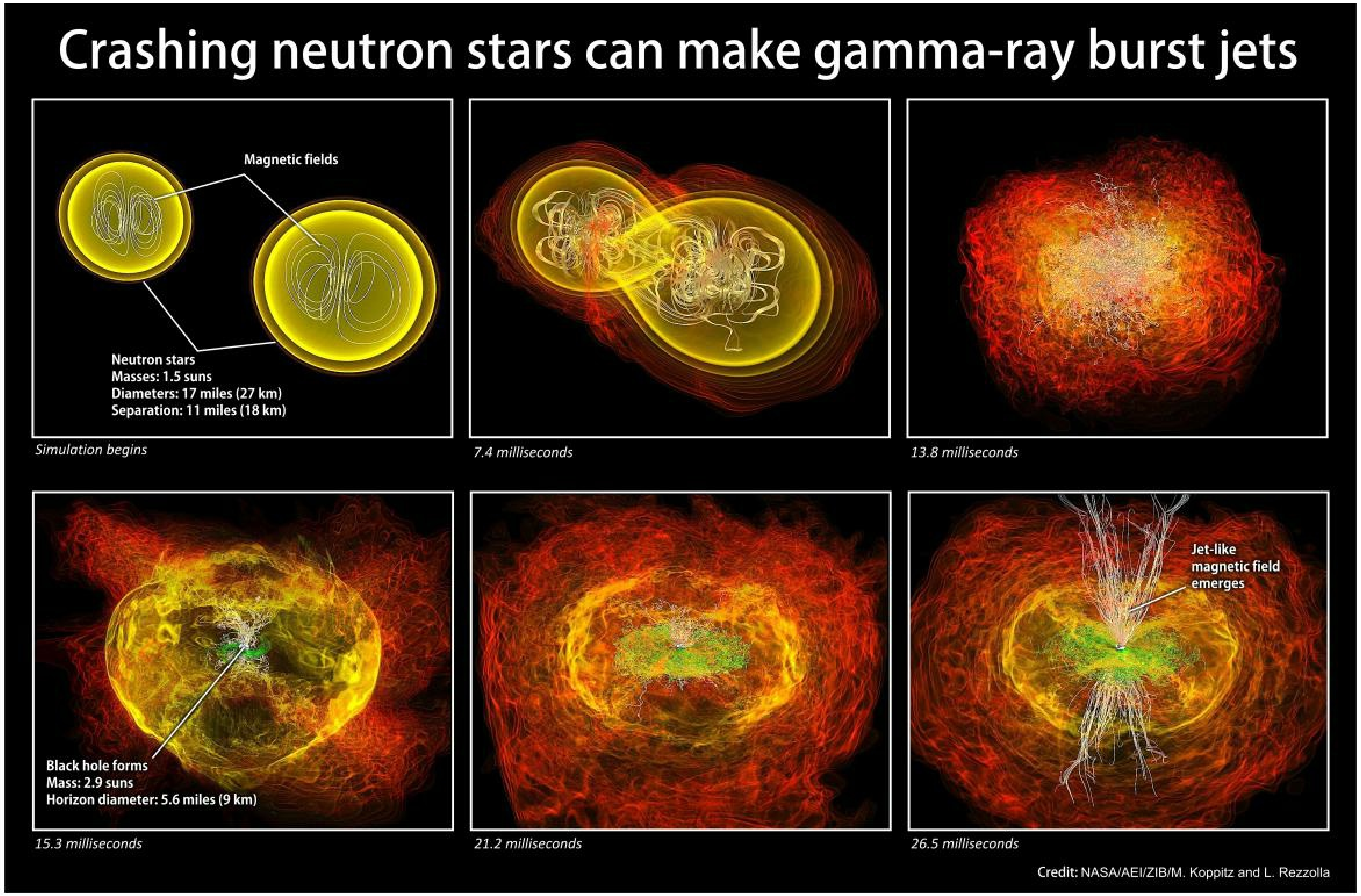
Meszaros 2015



blue and red: two photospheric models
black: internal shocks with different variability times

BOTH GRB MODELS FAMILIES SURVIVE

- IceCube limits constrain simple versions of the GRB models
- Both photospheric model and IS model survive in more refined versions
- 10 yr of IceCube should reduce limits by ~an order of magnitude
  - very important constraints



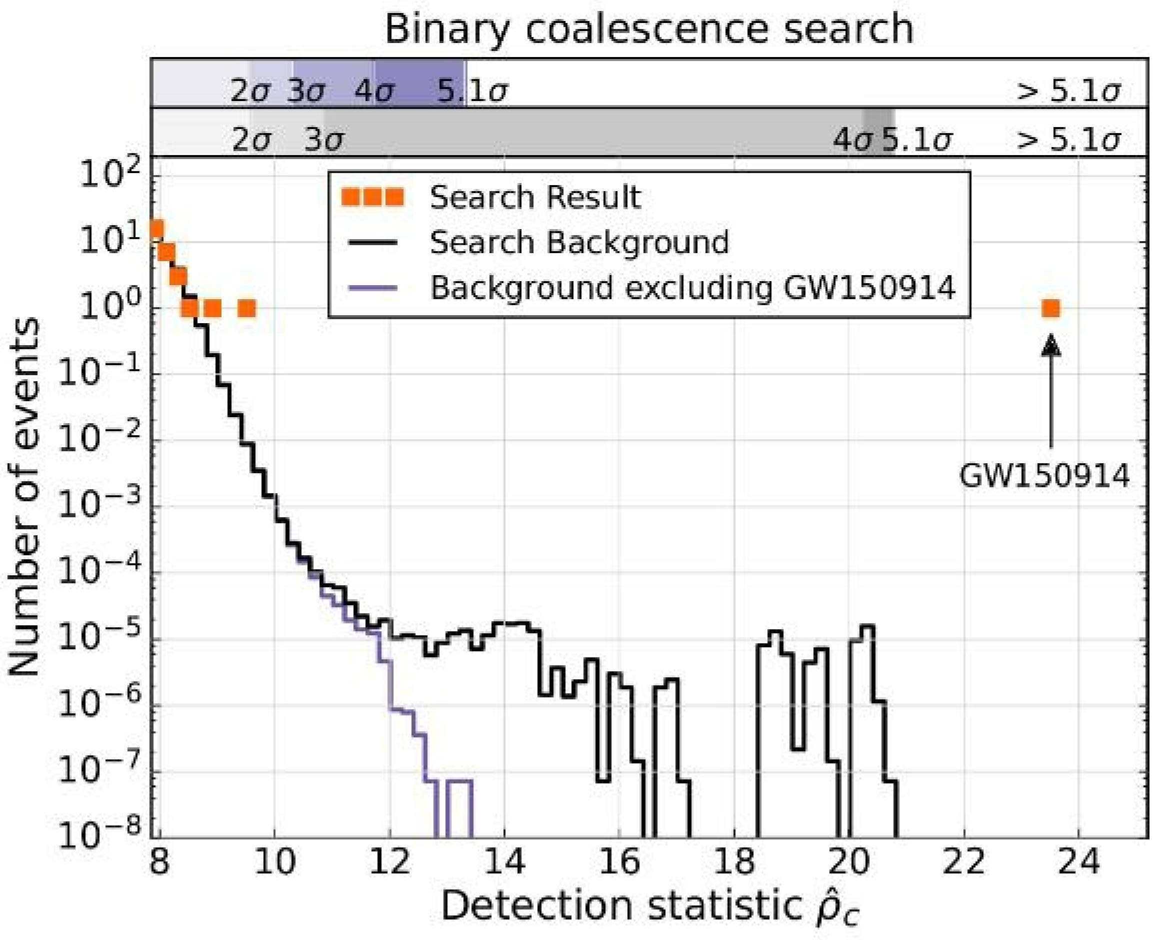
Rezzolla 2011

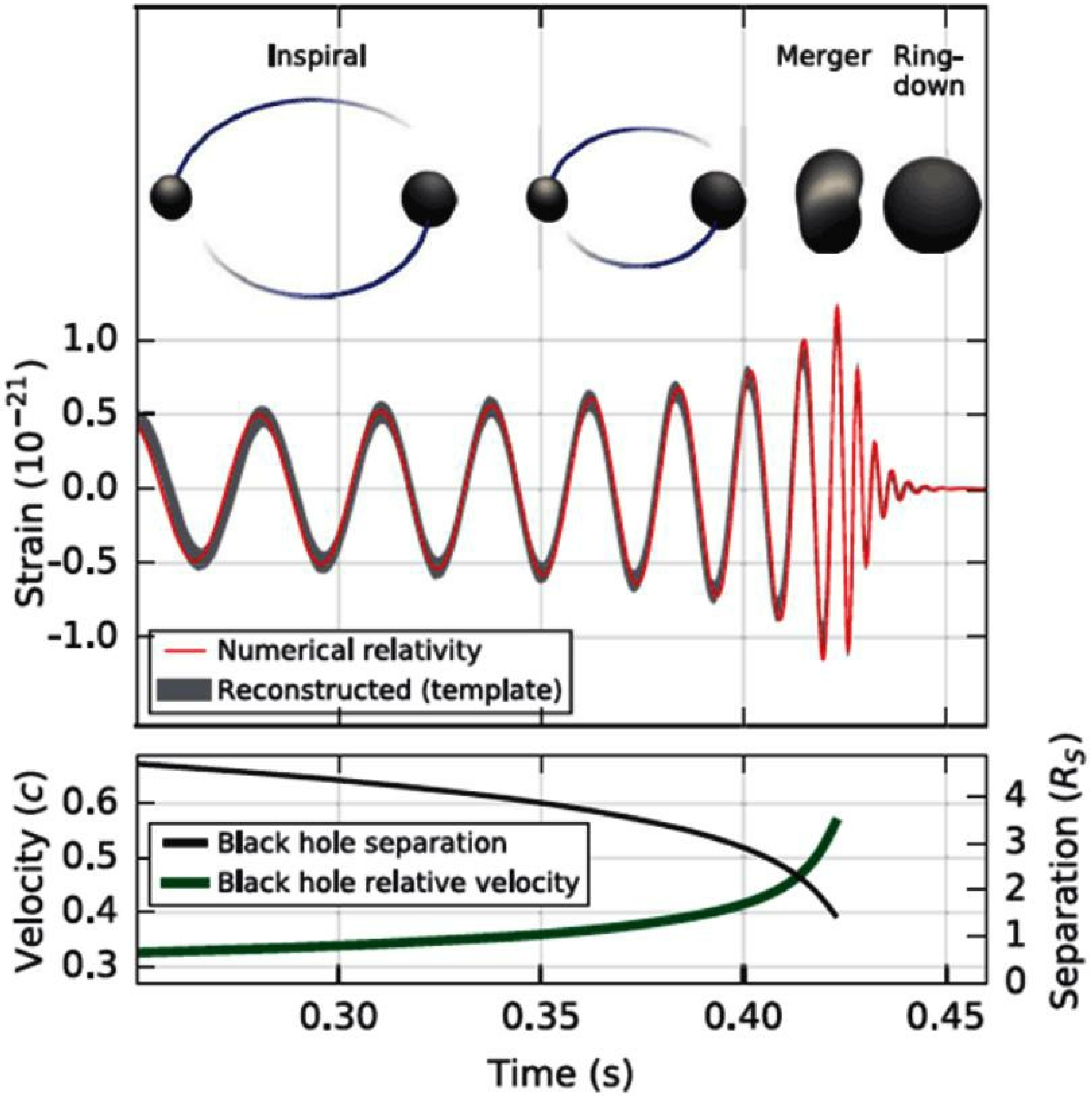
GRBS AND GW

- GRBs are divided in short / long
- Short GRBs are thought to come from NS-NS or BH-NS mergers
  - strong emitters of
- See Nicola's presentation on Tue as well as many presentations on Wednesday

GRAVITATIONAL WAVES

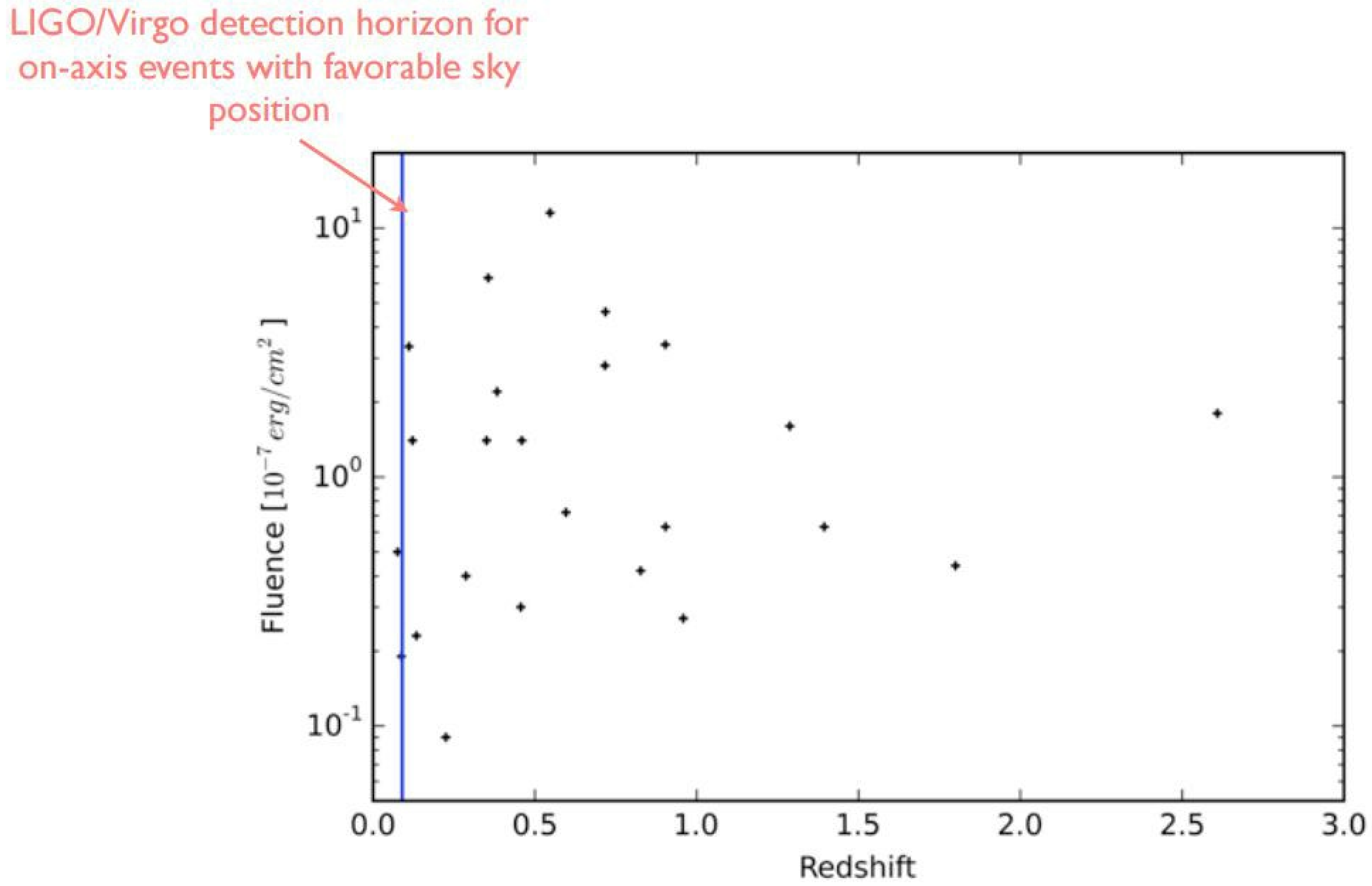
- The LIGO detection of 3 BH-BH mergers opened up the GW era



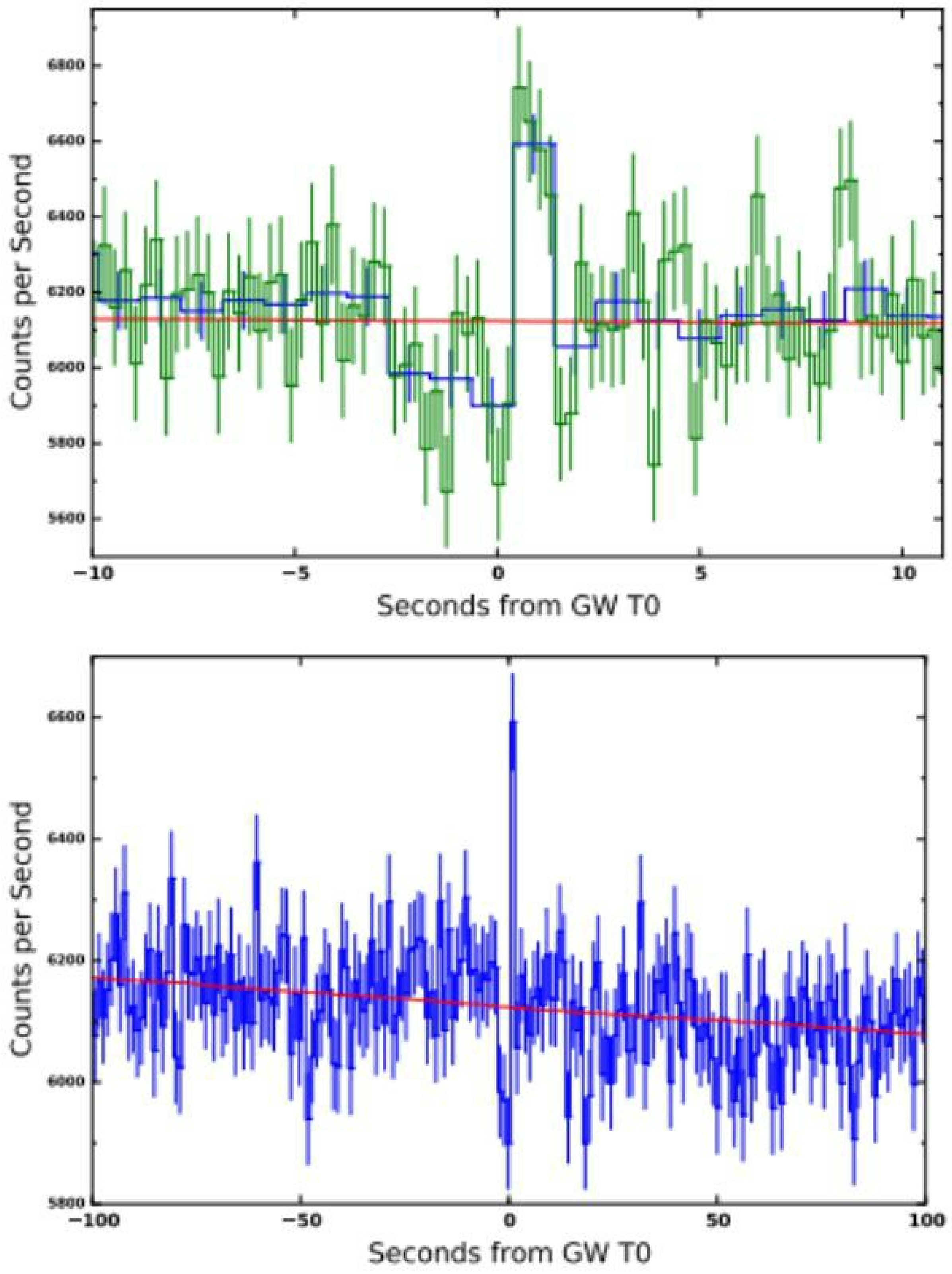


Rate prediction

- GW detection of NS-NS or NS-BH merger:
  - 0.08 - 30 per year (nominal LIGO/VIRGO configuration)
- simultaneous GW - EM detection with GBM:
  - 0.01 - 2 per year



Credits: V. Connaughton, Fermi Symposium 2015



SURPRISE?

- BH-BH mergers are not expected to produce e.m. signal, as they are "clean" systems
- Fermi/GBM saw a blip 0.4 s after the GW event
    - significance is low (2.9 sigma)
    - tension with INTEGRAL/ACS non-detection
    - Greiner et al. found a lower significance using different detector selections and different methods
- The next LIGO/VIRGO runs should clear out this tension, either with a stronger detection or with a null detection

A TRULY MULTI-MESSENGER TALE

- GRB models start to be constrained by all messengers together
- A truly multi-messenger problem