Implications of GW observations for short GRBs

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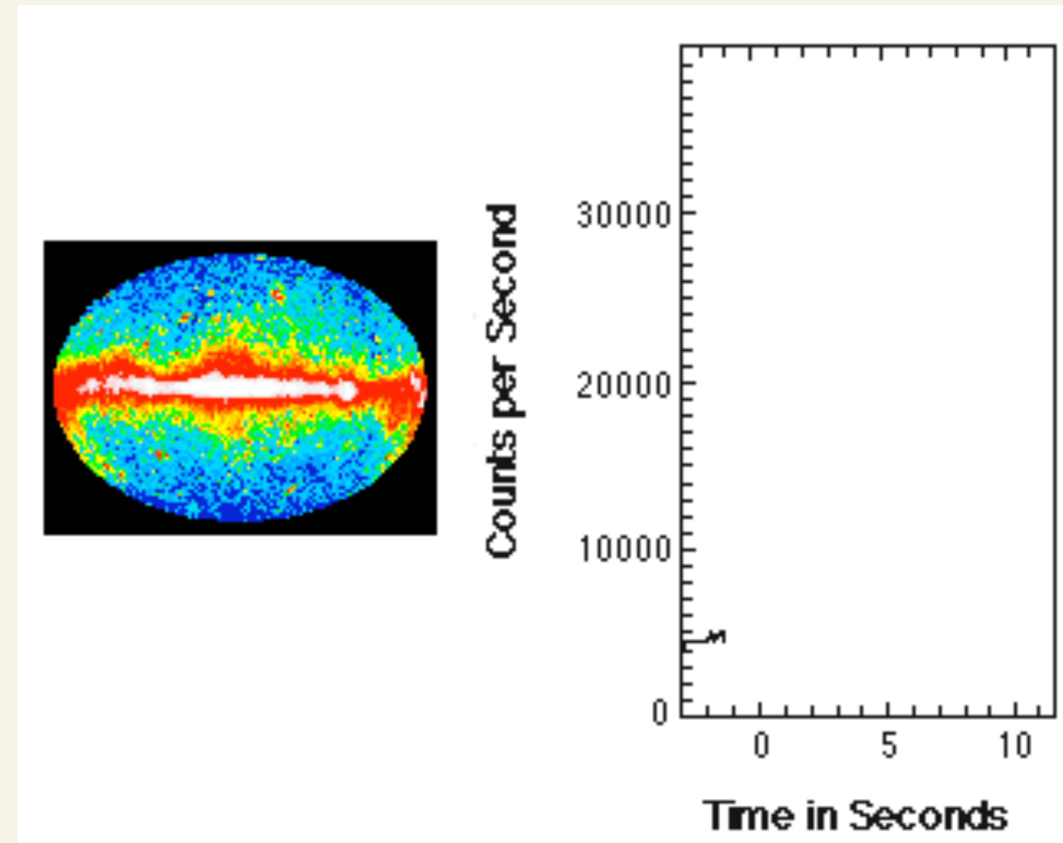
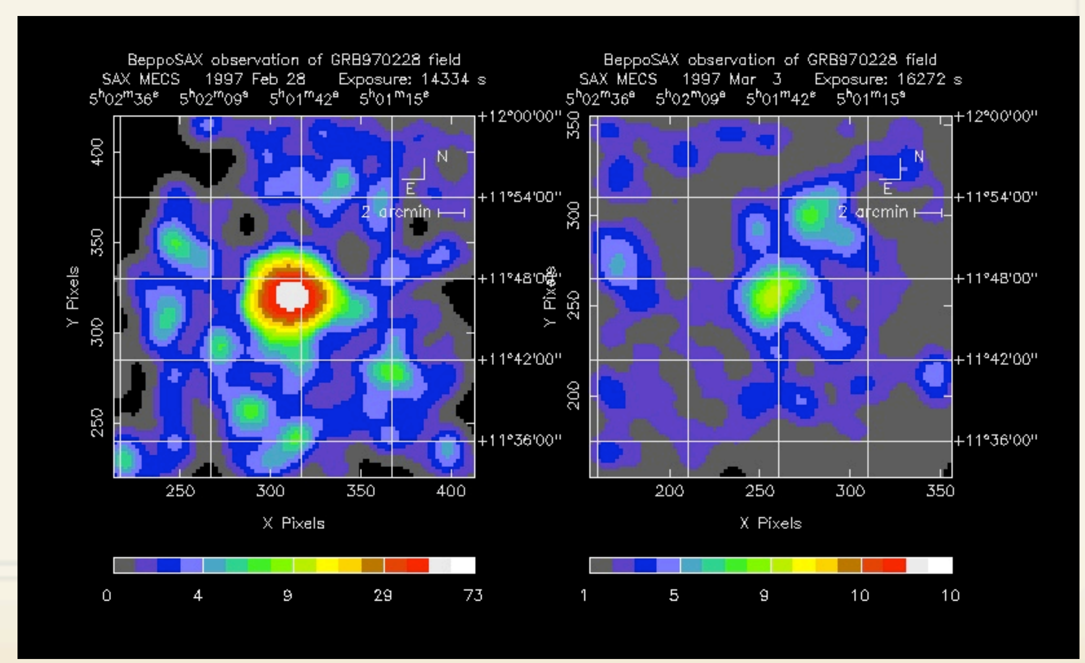
- What are Gamma Ray Bursts?
- What are short GRBs?
- Open Questions :
  - Central engine of sGRBs
  - Progenitors of sGRBs
- GW diagnosis can seal the debate

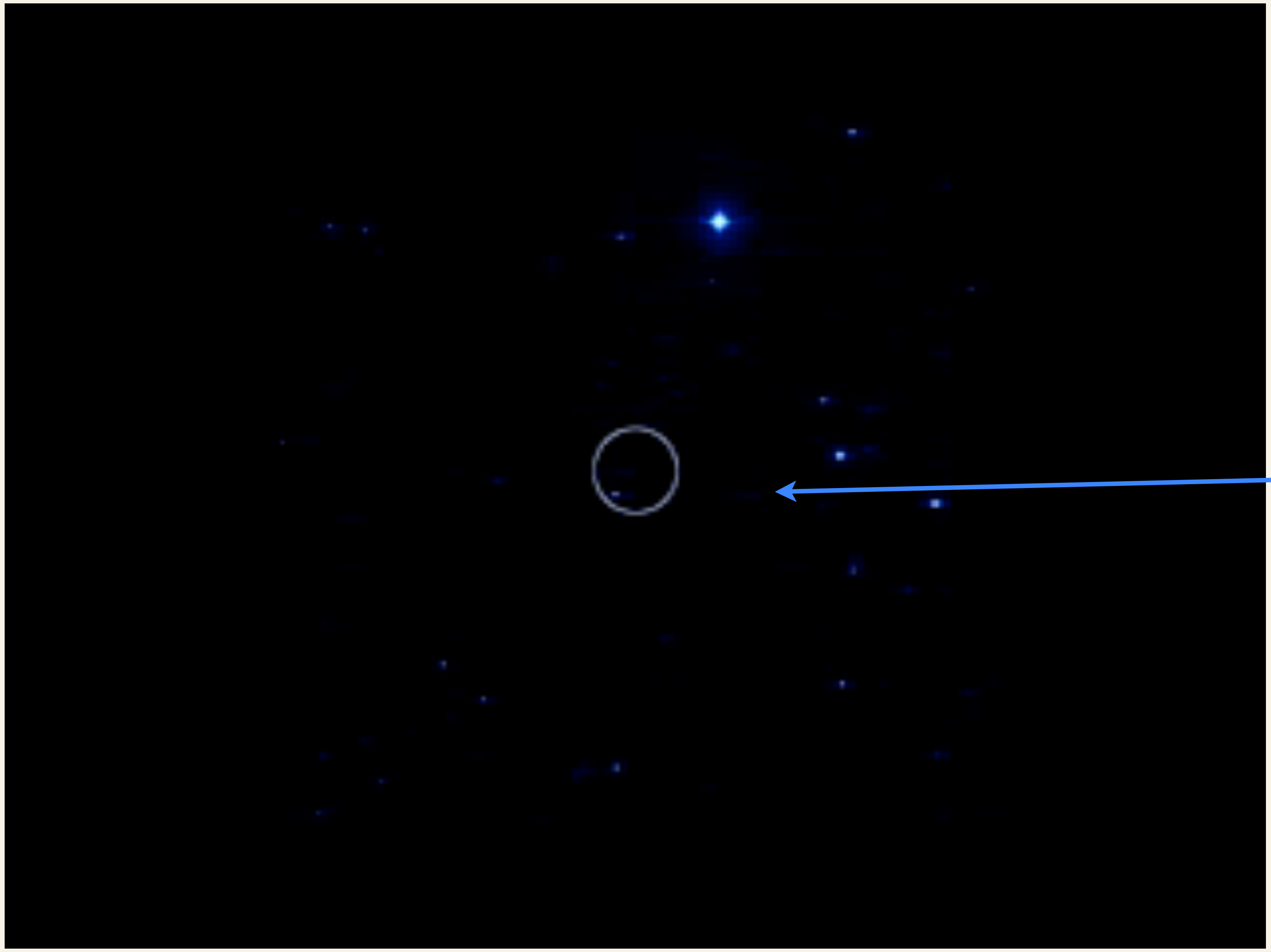
Gamma Ray Bursts

- Short (a few seconds) flashes of γ-rays (~ MeV)
- Typical energy release ~ 10^{48} -10^{52} ergs
- Non-repetitive, from random directions in the sky
- 1 event/day (on an average)
- Extra-galactic, Cosmological (0.0085 - z - 9.4)
- Longer lasting low-frequency counterparts





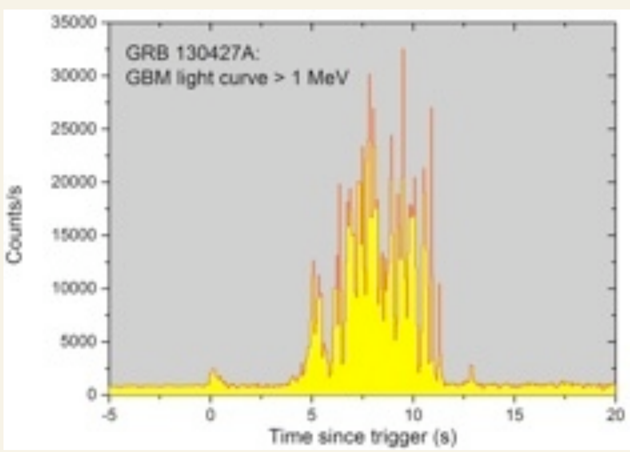
Zooming into a GRB location



Host Galaxy

Relativistic jets in GRBs

Large optical depth to pair production ⟷ But non-thermal spectrum



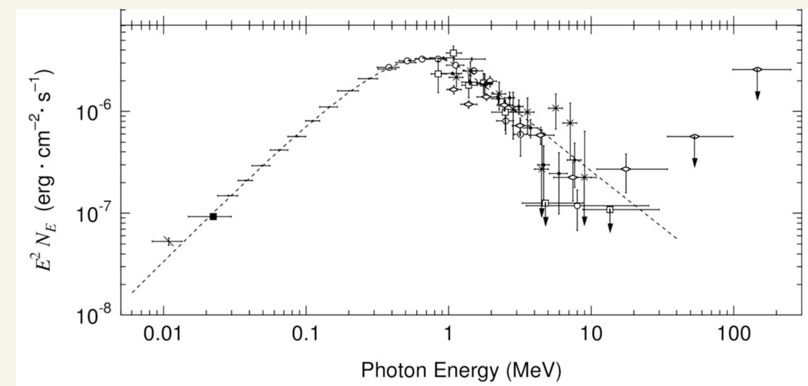
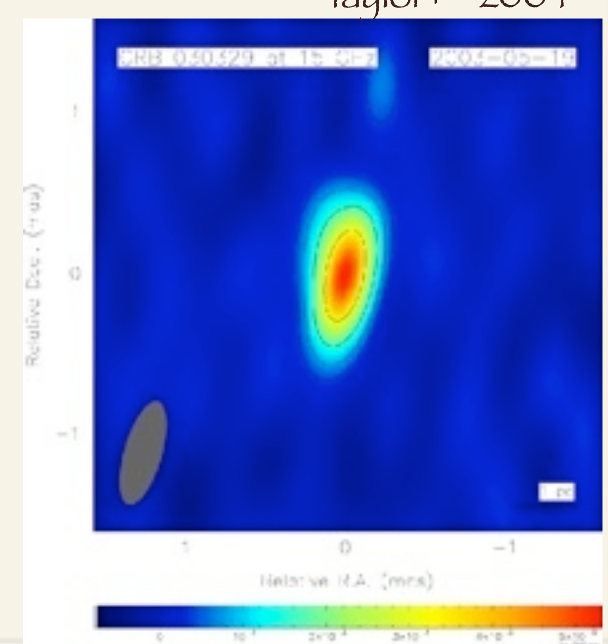


Fig. 23. A typical Band-function spectrum of GRB 990123. From Briggs et al. (1999).

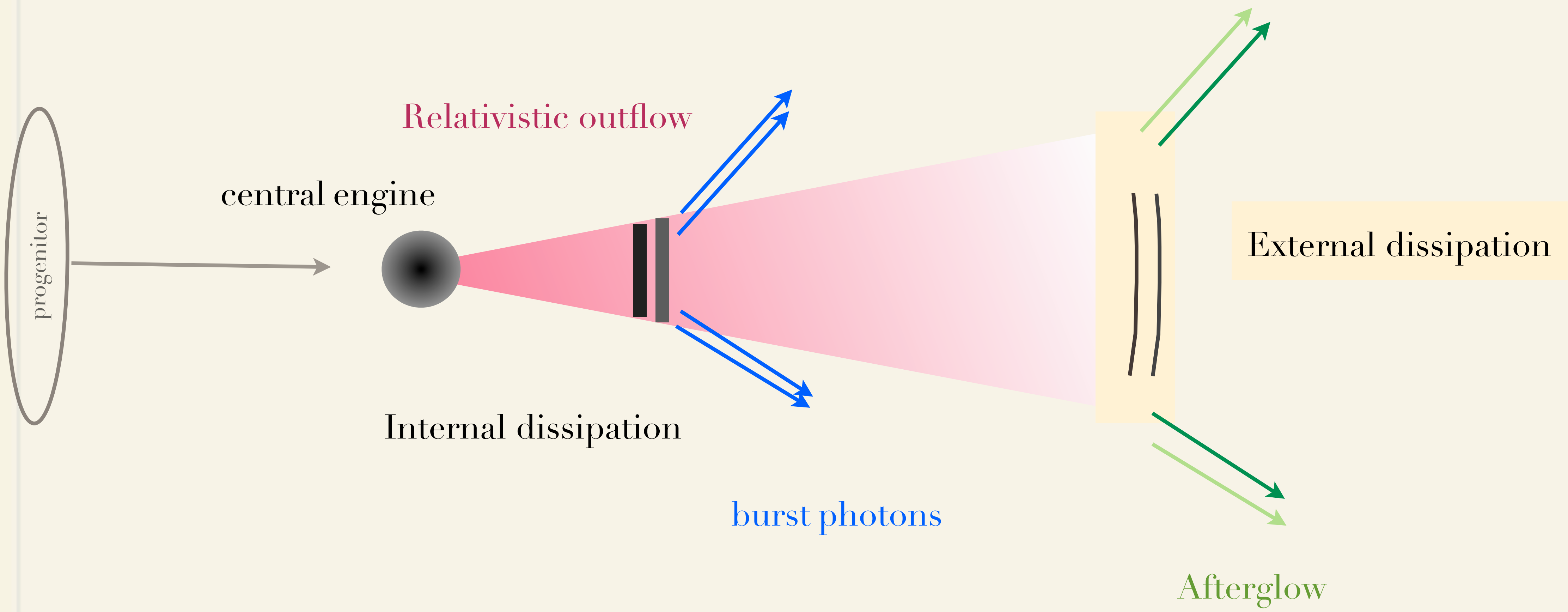
Taylor+ 2004



Relativistic bulk motion

Most conclusive : VLBI image of resolved GRB jet

Fireball Model

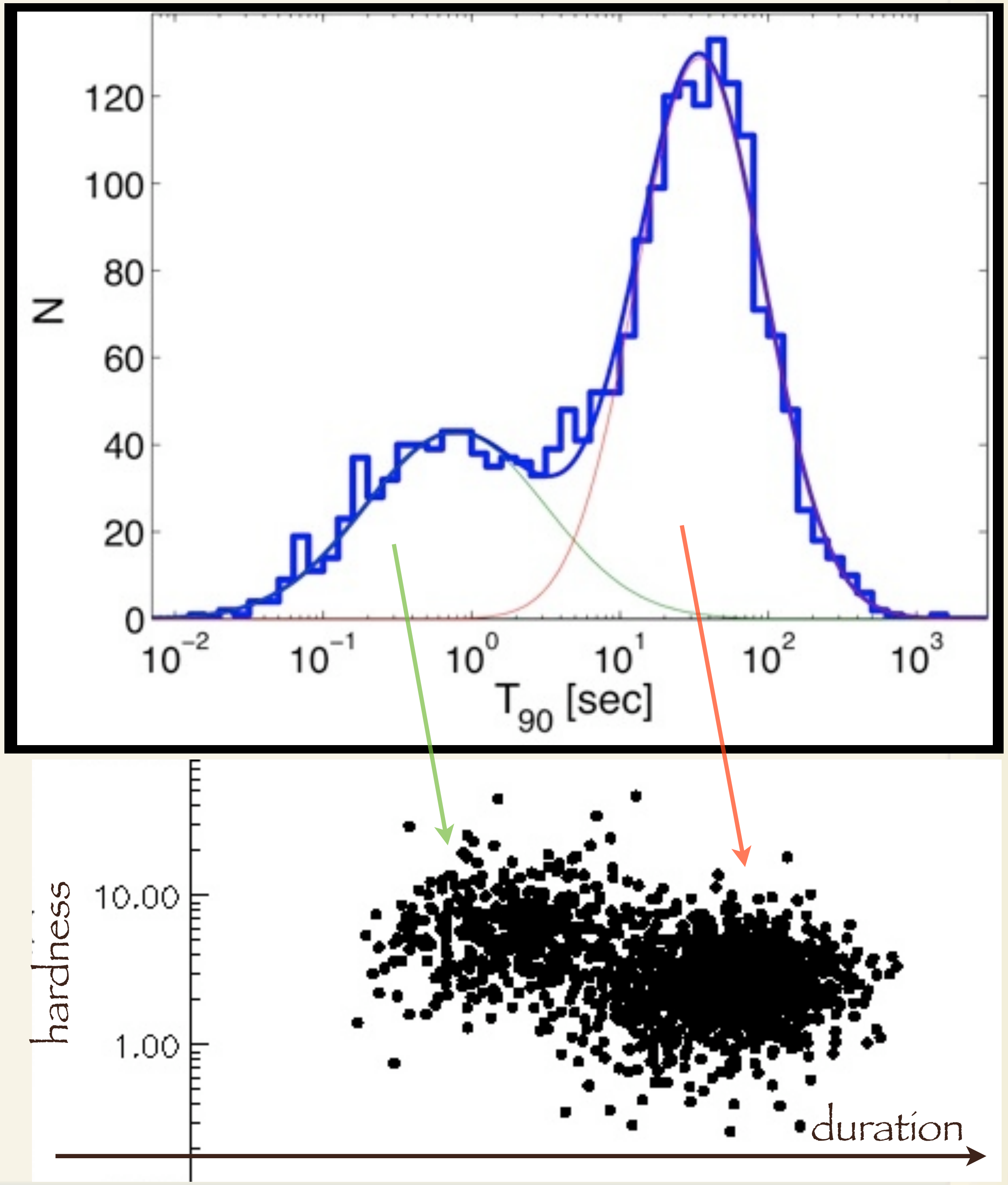


Short GRBs

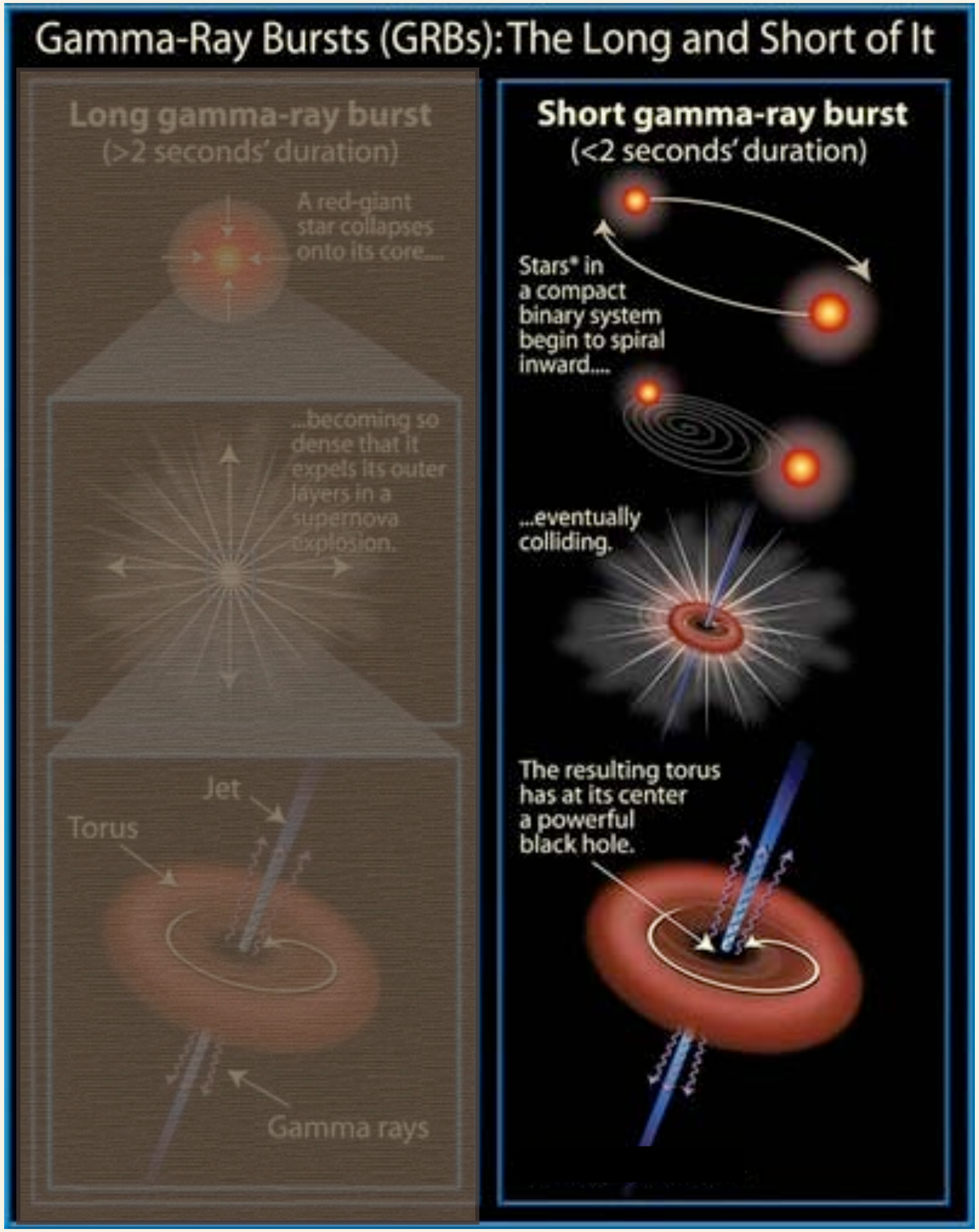
- Predominantly two classes of GRBs
- Short Hard & Long soft

T <~ 2s

T >~ 2s

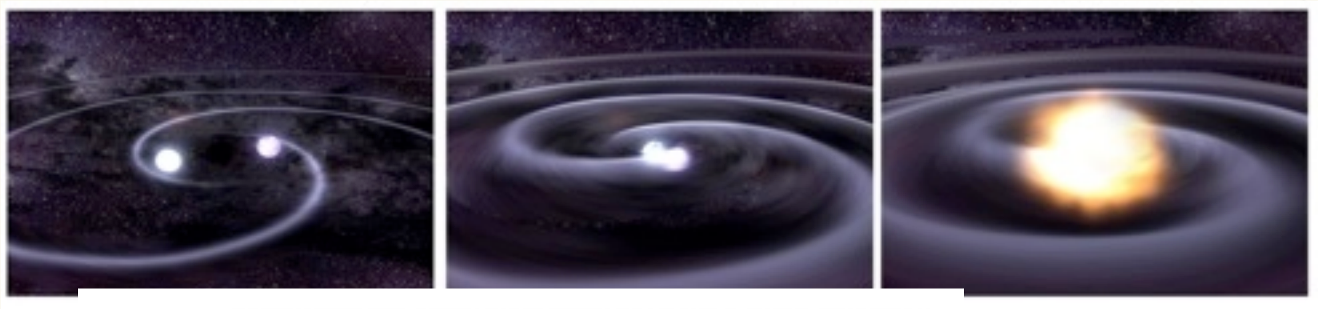


Progenitor Types

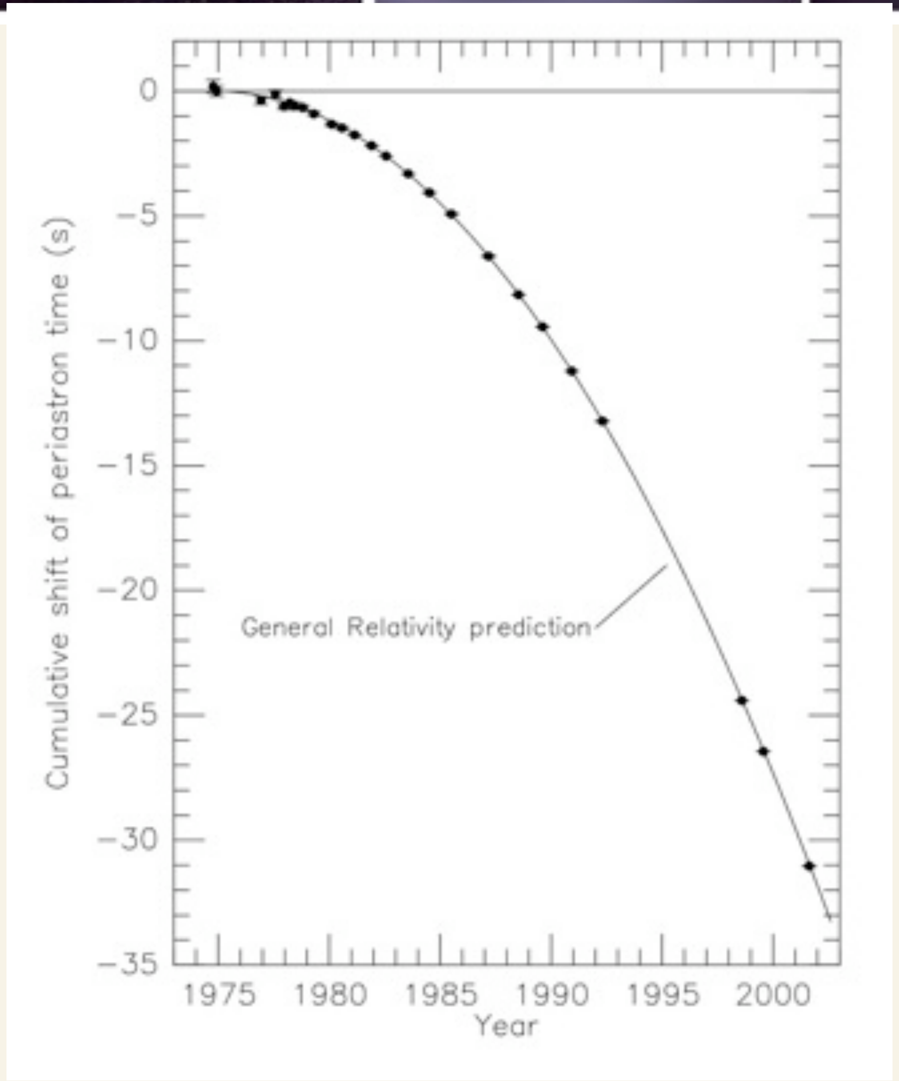


- In the torus : 0.01 - 0.1 $M_\odot$
- Accretion ends within a few seconds (disk ends & collapses into the BH)

DCO binaries



- 8 confirmed DNS systems in our Galaxy
- Rate : 6 - 100 Myr^{-1}
- No NS-BH system known till now



Duration : The iceberg's Tip

Long GRBs

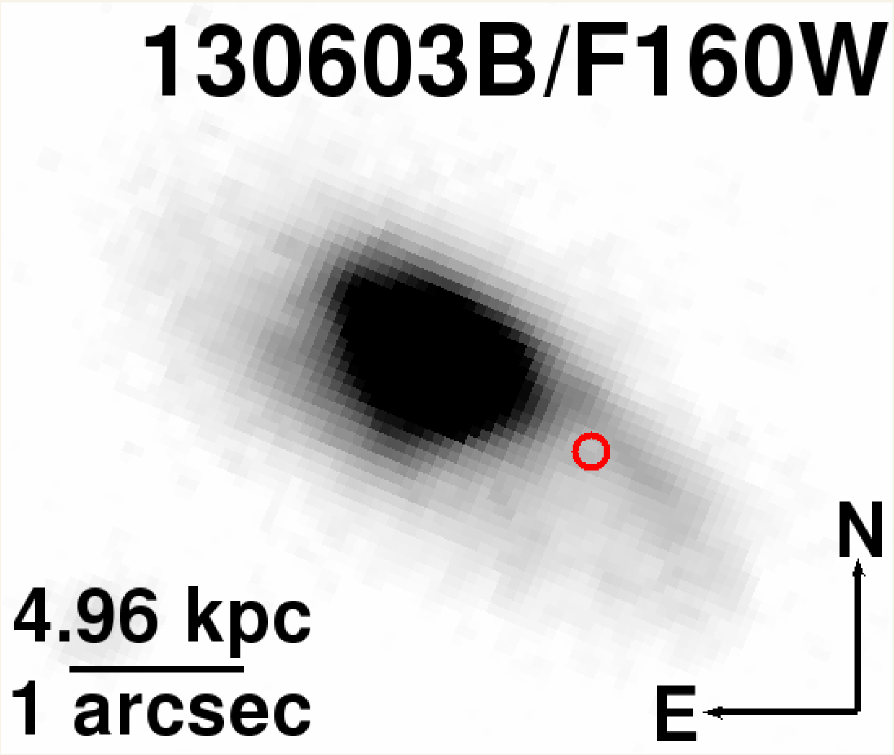
- Association with supernovae
- Origin in star forming galaxies
- Close to the bright UV regions of host

Short GRBs

- No confirmed SN association so far
- Occurs in both in late & early type
- Relatively larger <u>offsets</u>

Burst Offset

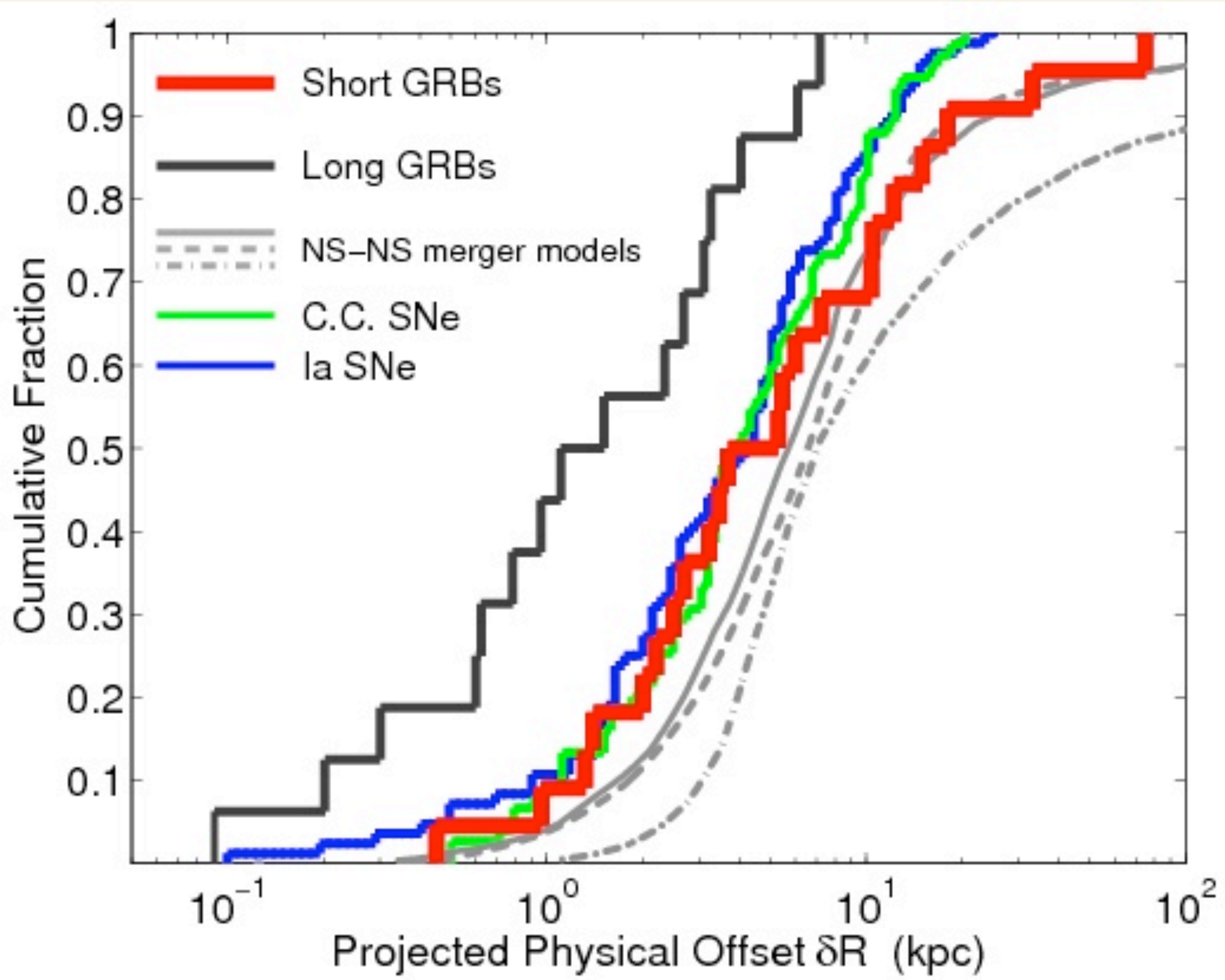
- In DCO model
  - The NS/BH receives a kick due to SN explosion
  - Translates to binary linear momentum (Podsiadlowski+95)
  - Binary wanders in the galactic potential
  - Till it merges (τ_{gw})



Fong+ 2011

Bloom + 1999, Behroozi + 2014,
Also Arun, Ajith, Resmi, Misra (In preprn)

Offset & DCO model

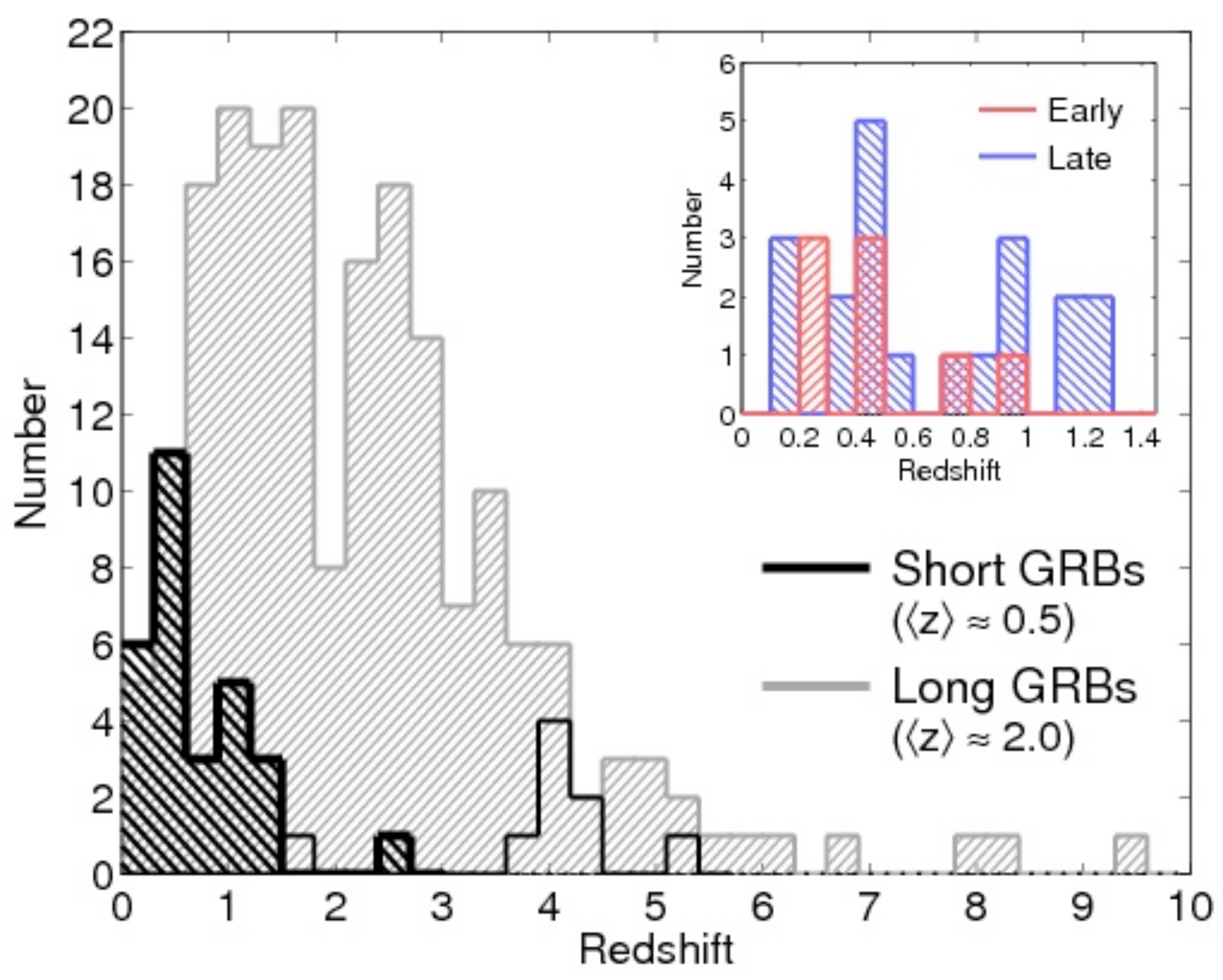


Fong+ 2011

1. Delay times ($\tau_{GW} \propto a^4/\mu M^2$): span a wide range → Possible in both Spirals & Ellipticals
2. Natal kicks & delay time → high offsets

Others

Redshift distribution

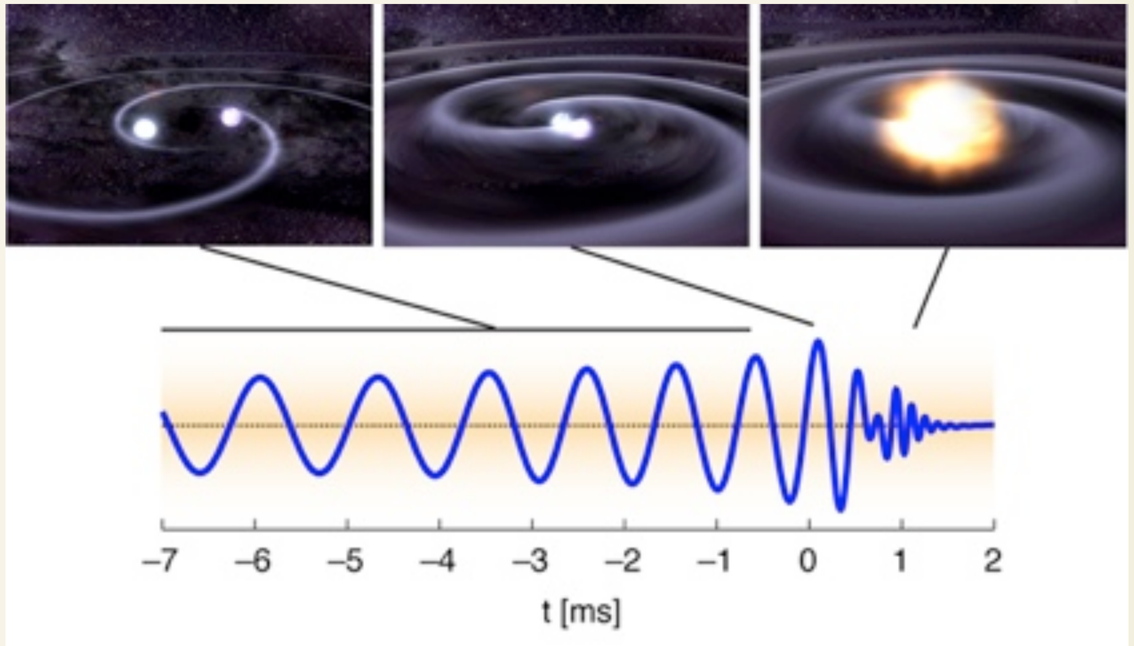


- Redshift distribution
- E_{bol} ~(1/100) of lGRBs
- Systematically lower AG flux compared to lGRBs

Background

1. Distinct bimodality in GRB population ⇒ Two different progenitor classes.
2. Existence of DCO systems in our Galaxy.
3. Conjecture : DNS or NS-BH binary coalescence due to energy & angular momentum loss to GW.
4. A stellar mass BH + (short lived) Torus system ⇒ short GRB

sGRB : GW source



Shibata+

Important Questions

1. What are the central engines of short GRBs?
2. Are **all** short GRBs from binary compact object mergers?

short GRB central engine

- Should launch an
  - energetic (10^{48}-10^{51} erg),
  - clean ($E/N_b >> m_p c^2$) jet
- Be active for the burst duration

sub second duration ⇒ formation of prompt BH

short GRB central engine

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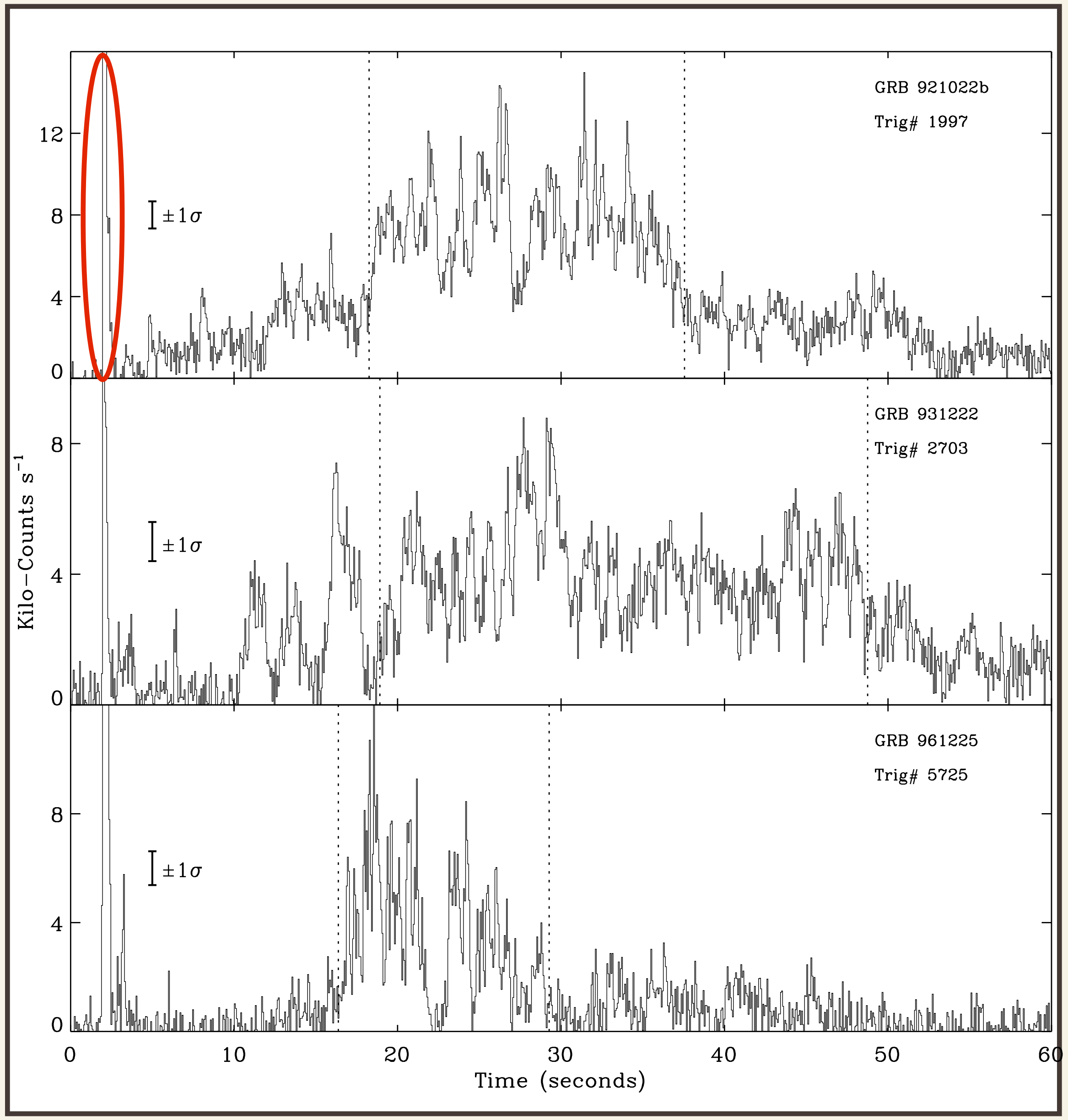
Continued central engine activity

1. Extended emission
2. Flares
3. Plateau phase

1. Extended Emission

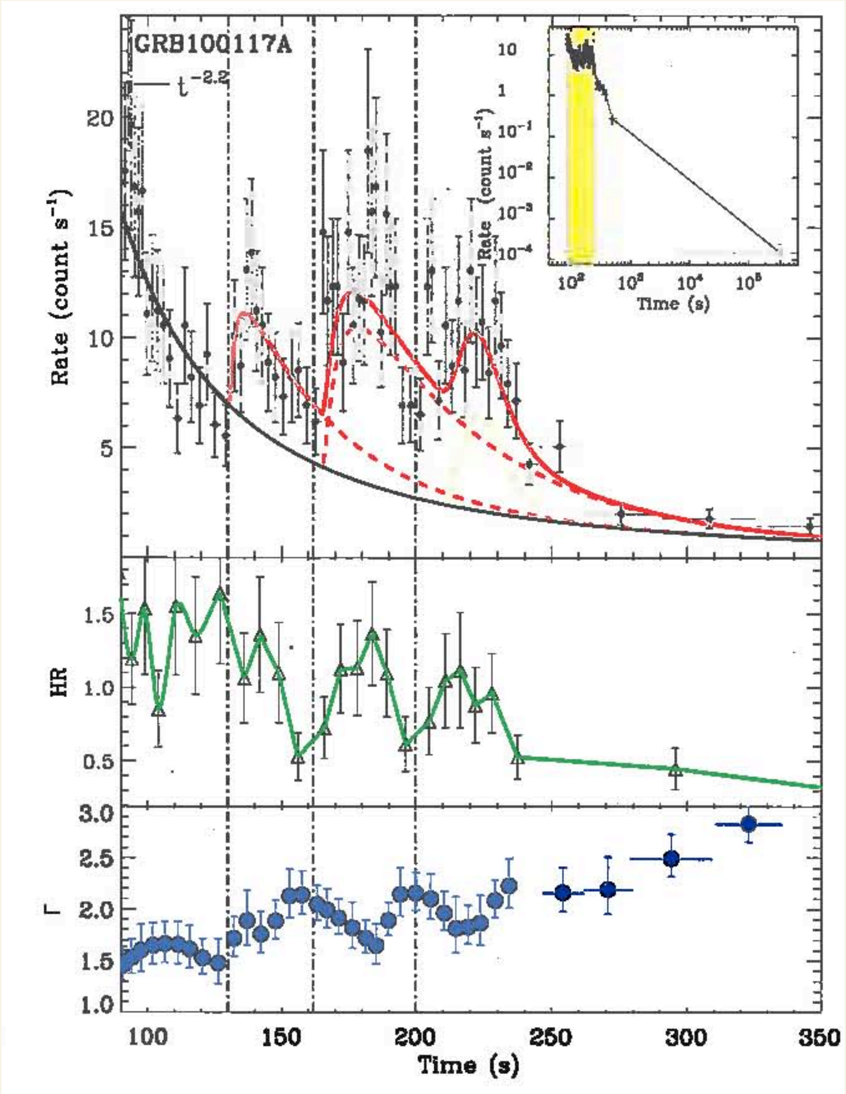
- 25 % has short EE ~ 100s (Fong + 2013)
- Energies equal to or larger (~30 times) than initial spike (Sakamoto+ 2011, Perley+ 2009)



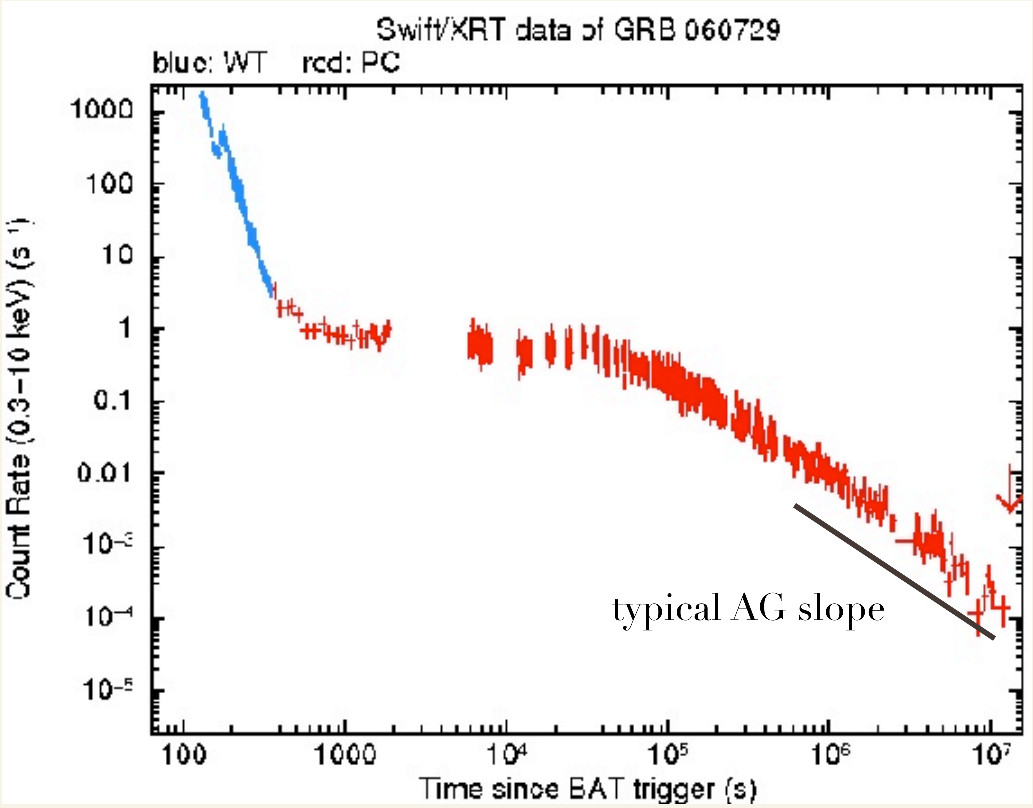
Norris & Bonnell 2006

2. X-ray Flares

- Flares similar to γ-ray burst (spectral & temporal)
- SGRBs show weaker (2 orders of mag. dimmer) ones compared to LGRBs
- But similar Flare/Prompt intensity

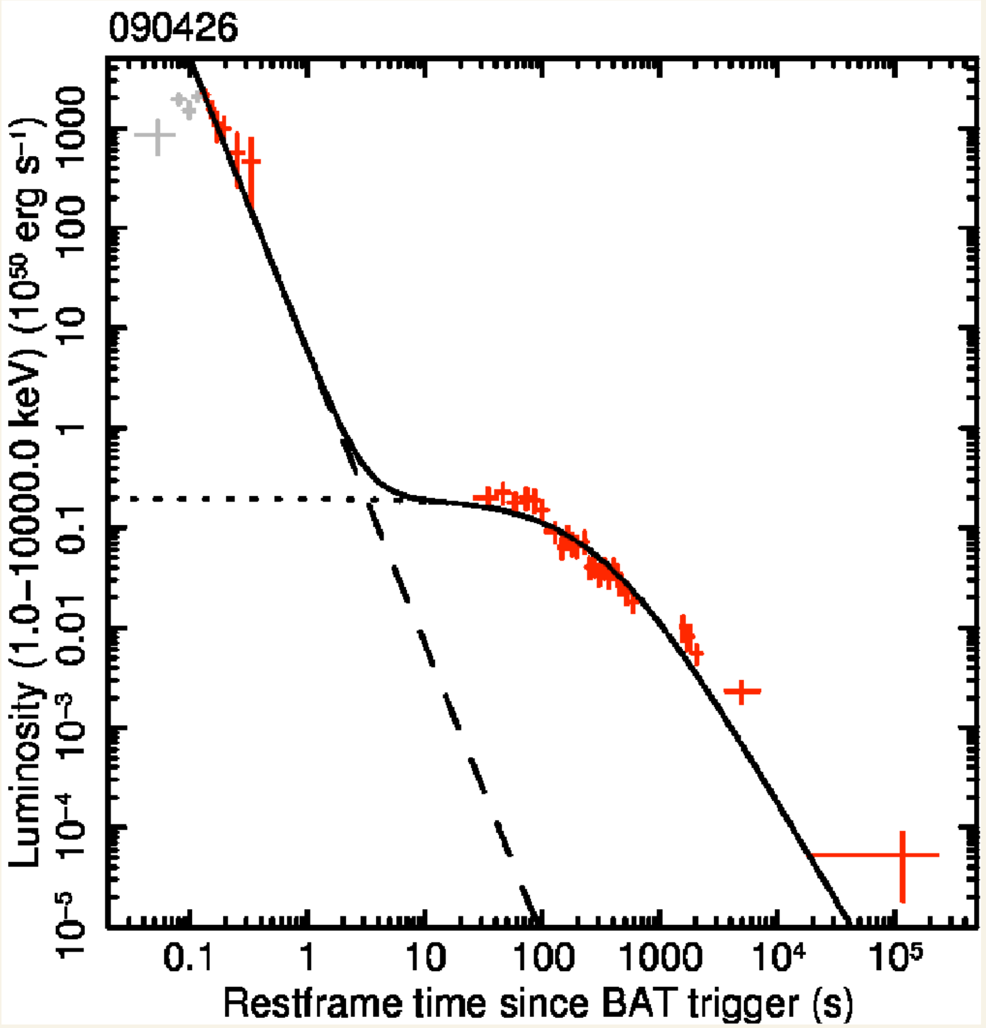


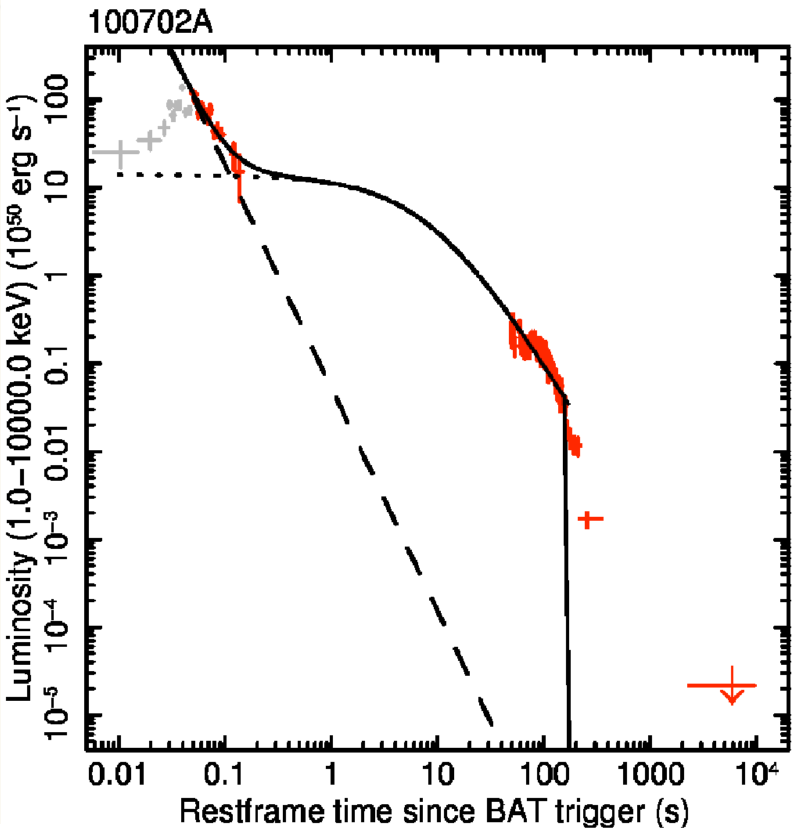
3. Plateaus

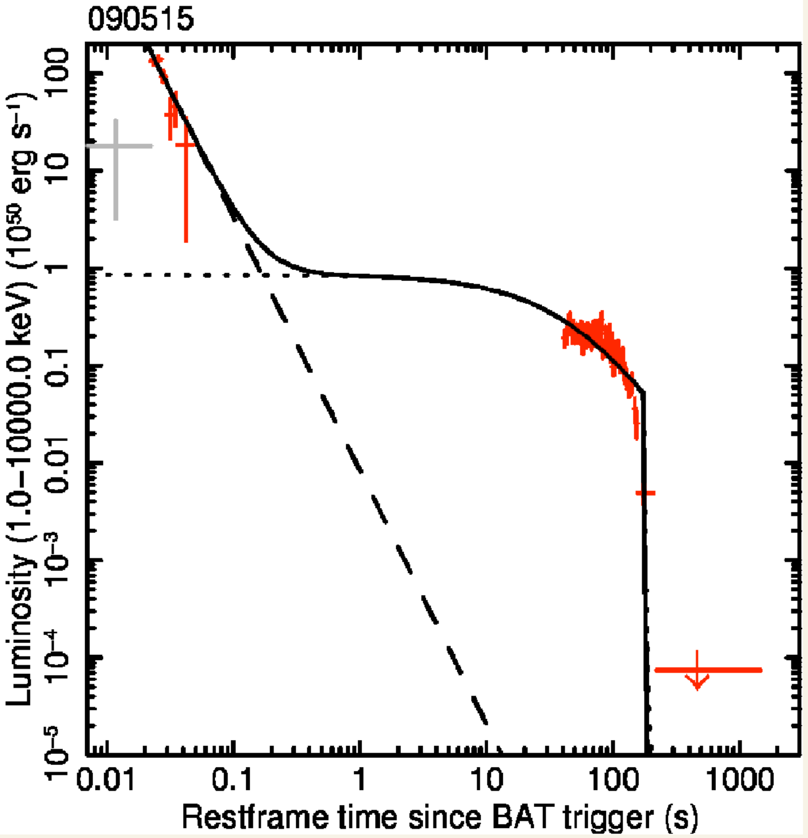


Long GRB, swift XRT repository

3. Plateaus







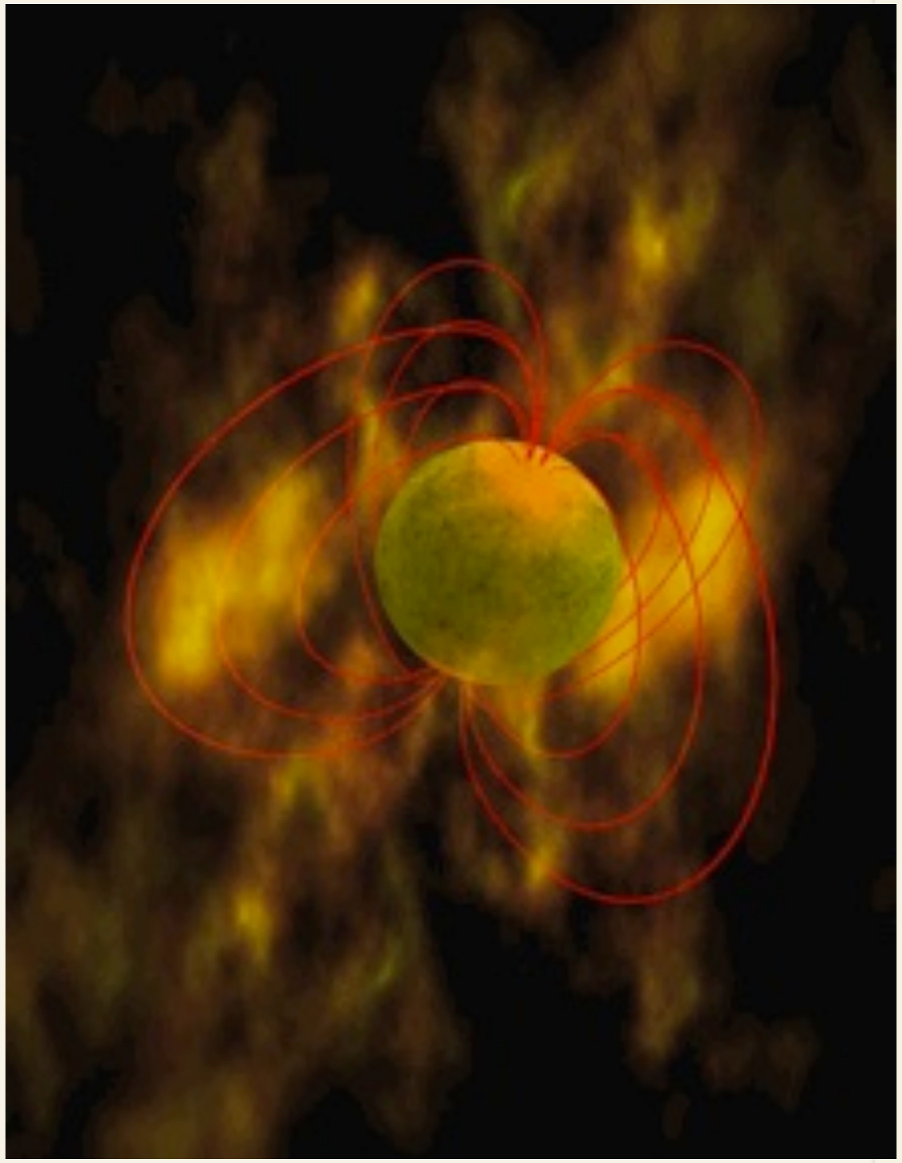
sGRB Rowlinson+2013

Central engine : prompt-BH

- Accretion timescale too less for EE, flares, plateaus
- For BH-NS merger, tidal disruption of NS throws matter out to highly eccentric orbits [Rosswog 2007]
- This material falls back : EE?, Flares?

Central engine : magnetar

- Highly magnetized (10^{10}-10^{11} T) neutron star
- Proposed to explain SGRs and AXPs in our galaxy
- Like pulsars, relativistic wind of charged particles



Central engine : magnetar

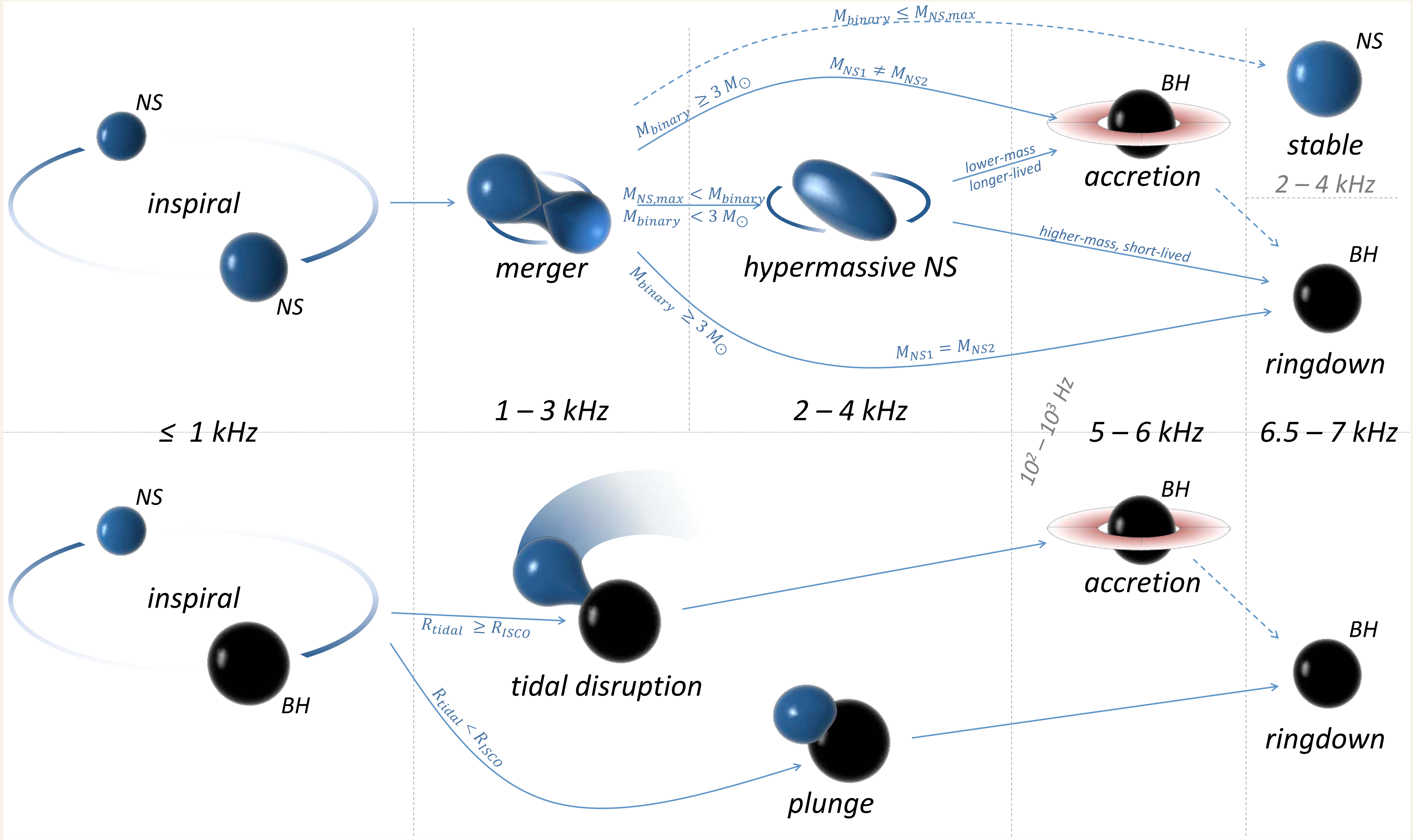
- ✦ A millisec proto-magnetar is formed [Metzger + 2007]
  - ➡ AIC of WD
  - ➡ Merger : WD-NS
  - ➡ Merger : NS-NS
- ✦ Prompt spike : Accretion onto magnetar
- ✦ Flares : late magnetar activity (Metzger; Giannios 2006)
- ✦ EE : powered by relativistic wind from magnetar
- ✦ Plateau : powered by spin down of magnetar (Zhang & Meszaros, 2001, Rowlinson+ 2013)

Magnetar : Difficult to produce jets

Feasibility of magnetar formation after merger

- DNS merger can result in an NS (Shibata+ 2006, Morrison + 2004)
  - Depends on EOS, total mass of binary, rotation
- Discovery of 1.97 M_{sun} NS (Demorest 2010) : high mass NS are possible

GW diagnosis



Bartos + 2012

GW diagnosis

- Detection of GW chirp signal
- Different between prompt-BH & magnetar
- “ring down” signal
- extended GW due to secular bar-mode instability
- (Baiotti+ 2008)

Progenitor of sGRB

- Magnetar model $\Rightarrow$ AIC of WD can also form a sGRB
- Merger time delay distribution from theory $\nRightarrow$ fit to all sGRB data (Virgili+ 2011)

Summary

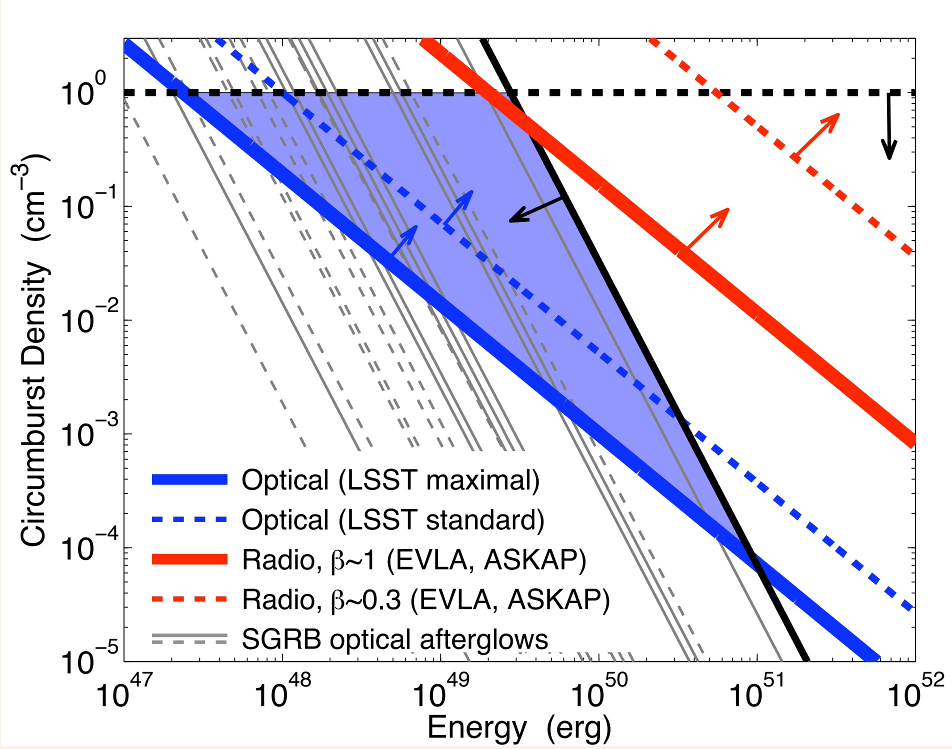
- Short duration GRBs were conventionally believed to be DCO mergers
- Model can explain (i) burst nature (ii) host population (iii) offset, but difficulty reproducing central engine longevity (plateau, Flares & EEs)
- Magnetar CE proposed to explain continuous powering of CE. But has difficulties producing collimated jets
- GW signal can conclude the debate
- sGRB population may have massive star candidates? Again GW signal can be conclusive
- Inclination angle measurement (Arun+ 2014) & orphan AGs

Additional slides

Magnetar-nova

- Interaction of e+/e- wind with the merger remnants
- Brighter than kilonova
- Metzger 2014, Zhang 2012

Orphan AGs



Metzger, Berger 2011

- LSST
- SKA
- Inclination angle measurement (Arun+ 2014) : angle btn angular mom. axis and l.o.s

Central engine

- Should launch an
  - energetic (10^{49}-10^{55} erg),
  - clean ($E/N_b >> m_p c^2$) jet
- Should be intermittent

☑ Hyper-accreting stellar mass BH

☑ Rapidly spinning magnetar

$$L_{GRB} = \zeta \dot{m} c^2 = 1.8 \times 10^{51} \text{ erg/s} \quad \zeta_{-3} \quad [\dot{m}/(M_\odot\, s^{-1})]$$

$$E_{rot} = (1/2)\, I\, \Omega^2 = 2 \times 10^{52} \text{ erg } [M/1.4M_\odot]\, [R/10\text{km}]^2\, [P/1\text{ms}]^{-2}$$