Multi-Wavelength Transients with CTA

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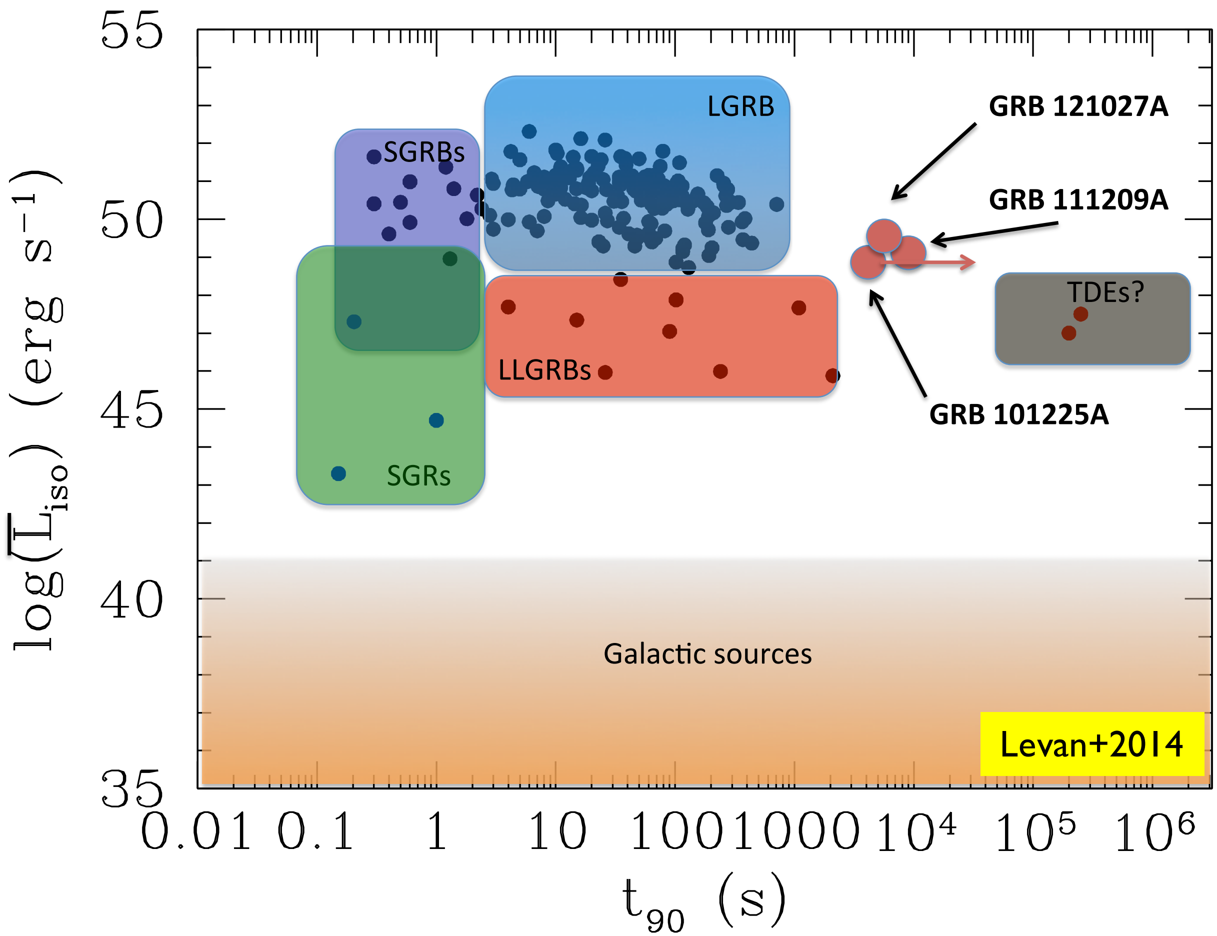
(UC Berkeley, NASA Einstein fellow)

Diversity of GRB



Low-Luminosity GRBs

- Much dimmer

$$E_{LL}^{iso} \sim 10^{50} \text{ erg} \sim 10^{-3} E_{HL}^{iso}$$

- Nearby (ex. 060218@140Mpc)
- More frequent

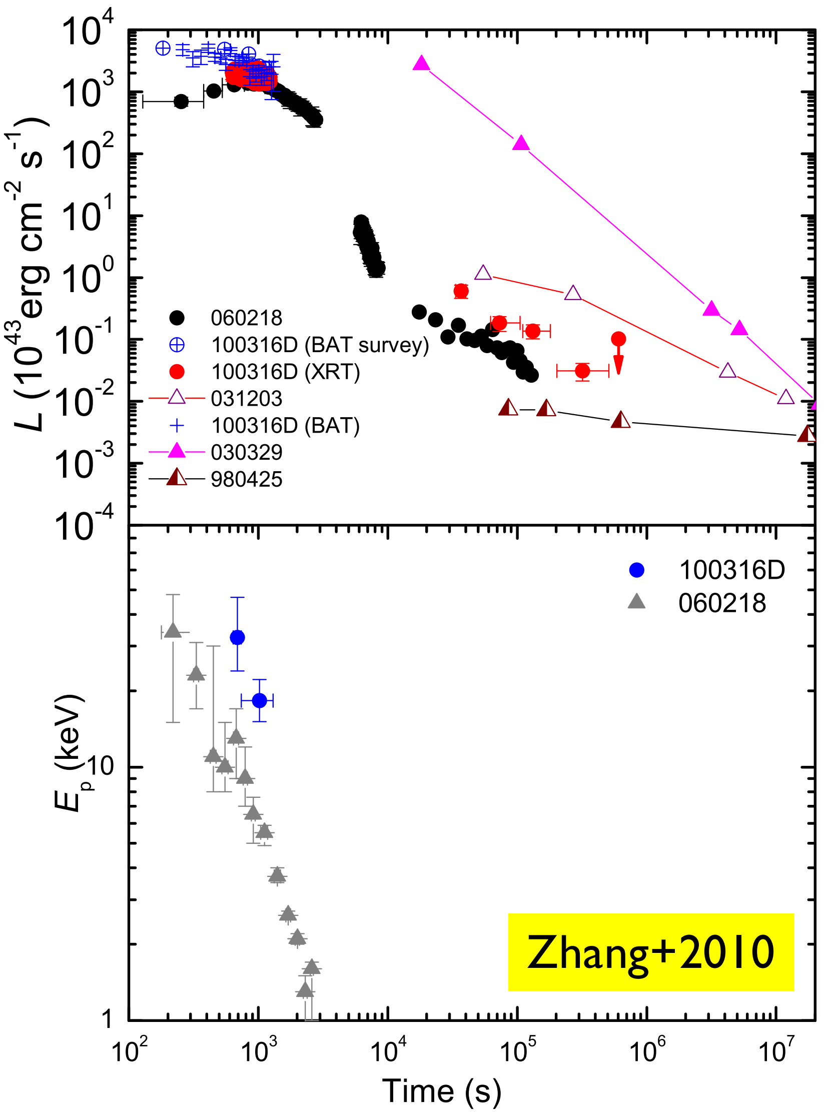
$$\rho_{LL} \sim 10^{2\text{-}3} \text{Gpc}^{-3} \text{yr}^{-1} \gtrsim 10^3 \rho_{HL}$$

- Quasi-thermal soft spectrum

$$\varepsilon_{peak,LL} \sim 1\text{-}10 \text{ keV} \sim 10^{-2} \varepsilon_{peak,HL}$$

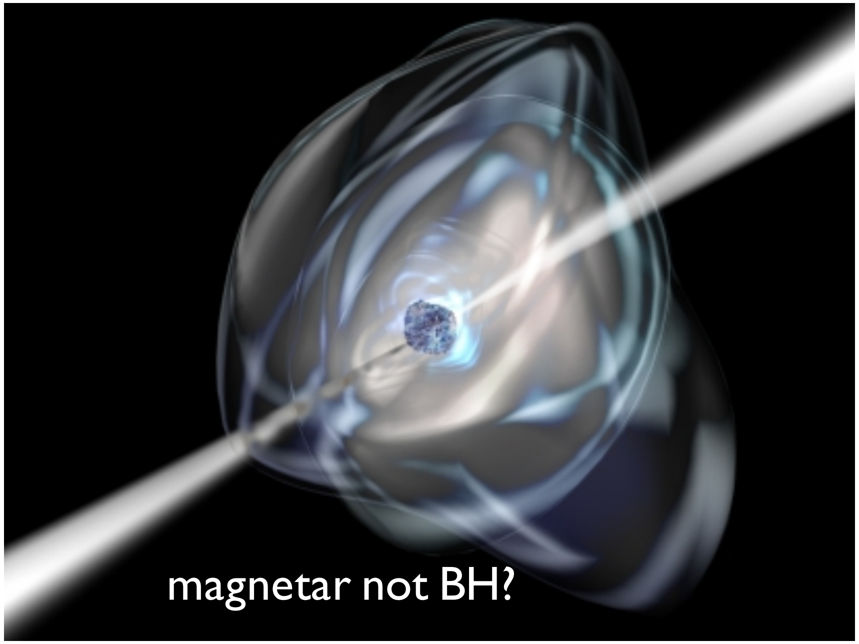
- Associate broad line type Ic SN

  → Walf-Rayet star



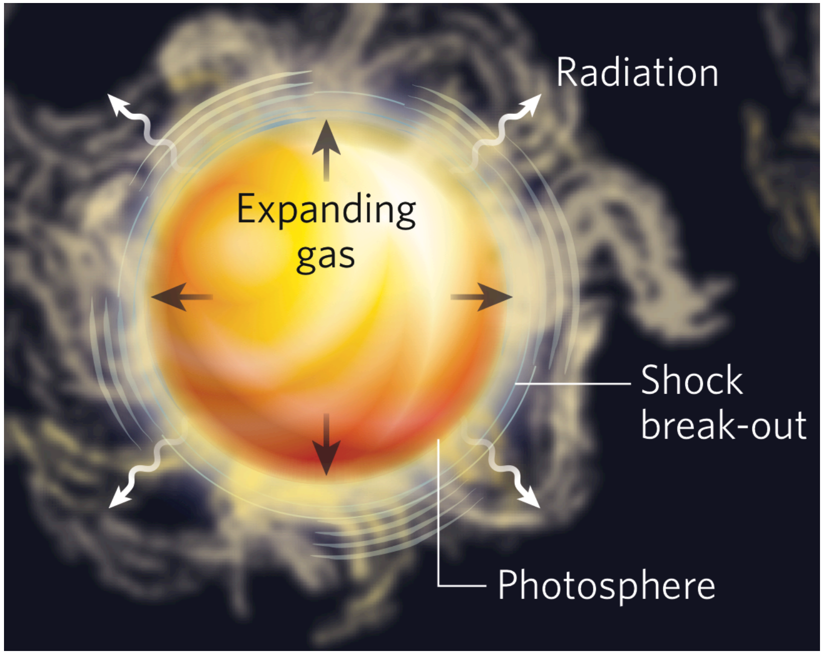
Two Competing Scenarios

Low-power relativistic jet



vs

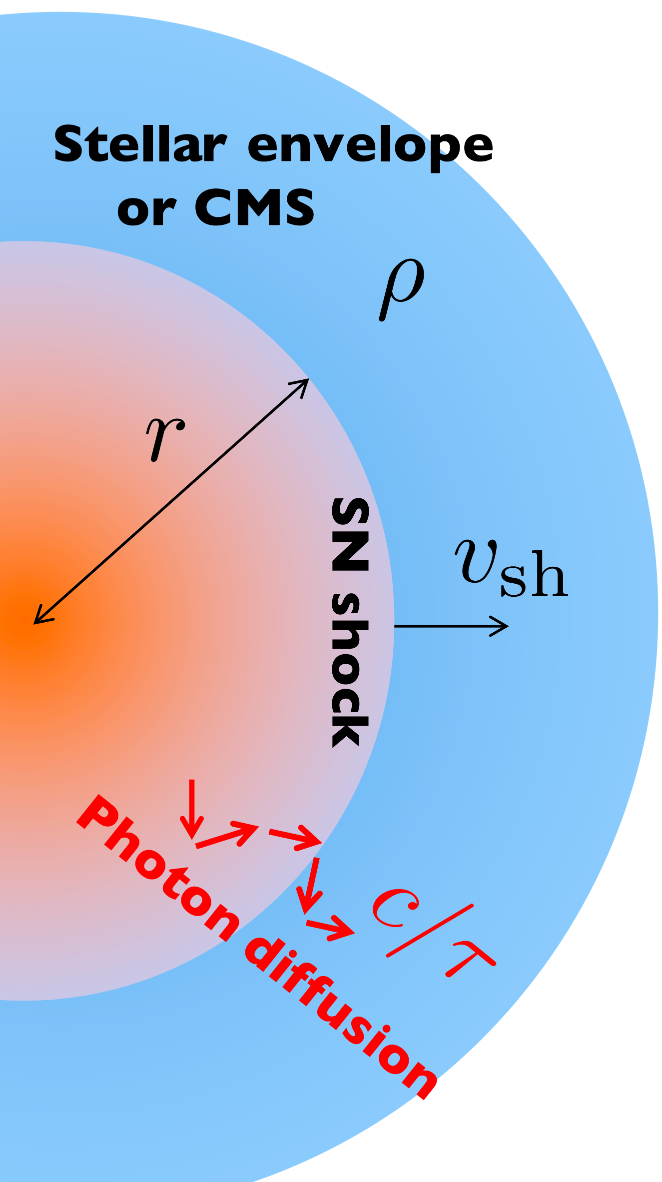
Trans-relativistic shock breakout from optically-thick wind



Toma+2007
Fan+2010

Waxman+2010
Nakar & Sari 2012

Shock Breakout



- ✓ The shock downstream is radiation-dominated.

$$P_{\rm rad} \gtrsim P_{\rm gas}$$

- ✓ The shock is initially inside optically-thick media.

$$\tau \approx \rho \kappa_{\rm T} r \gg 1$$

⇩

Radiation-mediated shock

Shock acc is suppressed. e.g., Weaver 1976

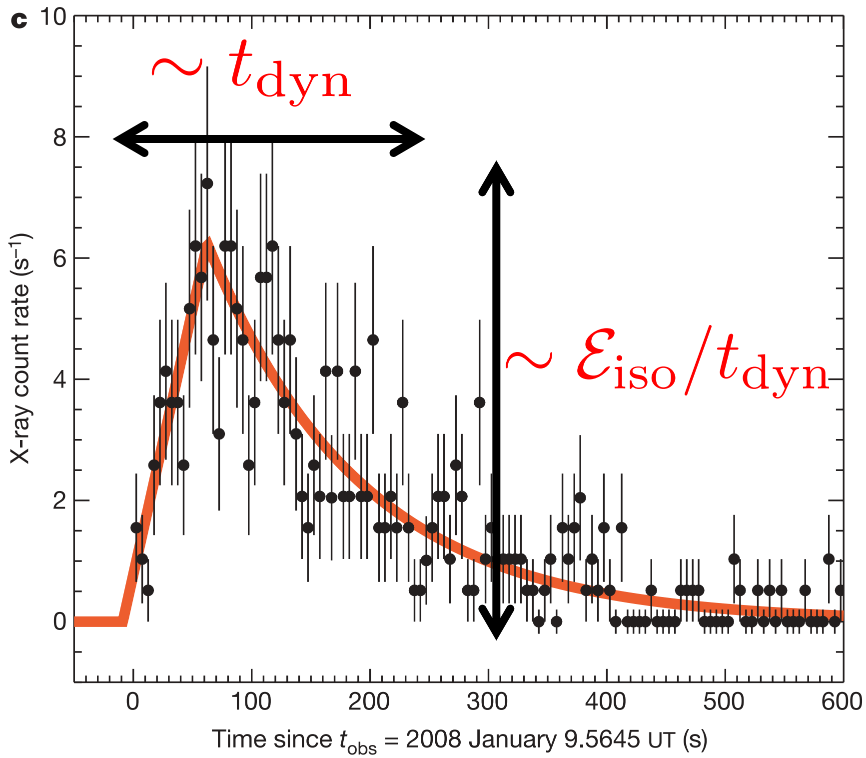
Shock breakout @ $r = r_{\rm sb}$
where $c/\tau \approx v_{\rm sh}$

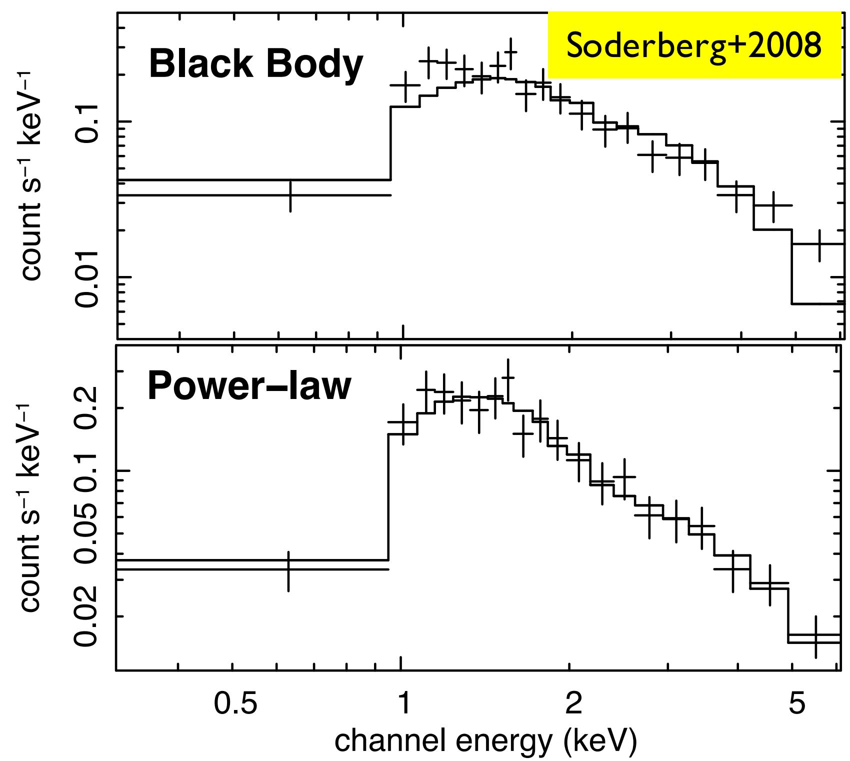
⇩

The downstream photons begin to escape.

- ✓ Shock breakout emission → LL GRB?
- ✓ No longer radiation-mediated
  → Shock acc starts → CR, γ, ν?

What Shock Breakouts Tell Us





$$t_{\rm dyn} \sim r_{\rm sb}/c\beta_{\rm sh}$$

$$\mathcal{E}_{\rm iso} \sim 2\pi\rho {r_{\rm sb}}^3 {\beta_{\rm sh}}^2 c^2$$

$$\rho \sim 1/\kappa_{\rm T} r_{\rm sb}\beta_{\rm sh}$$

Light curve $\longrightarrow$ $r_{\rm sb}$, $\beta_{\rm sh}$

Spectrum: quasi-thermal

The temperature and the power low tail depends on the details of plasma.

($e^{\pm}$ Is relevant for $\beta_{\rm sh} \gtrsim 0.1$.)

Shock Breakout Scenario for LL GRB

$E_{\gamma,iso} \sim 10^{50}$ erg $\quad t_\gamma \sim 3000$ s

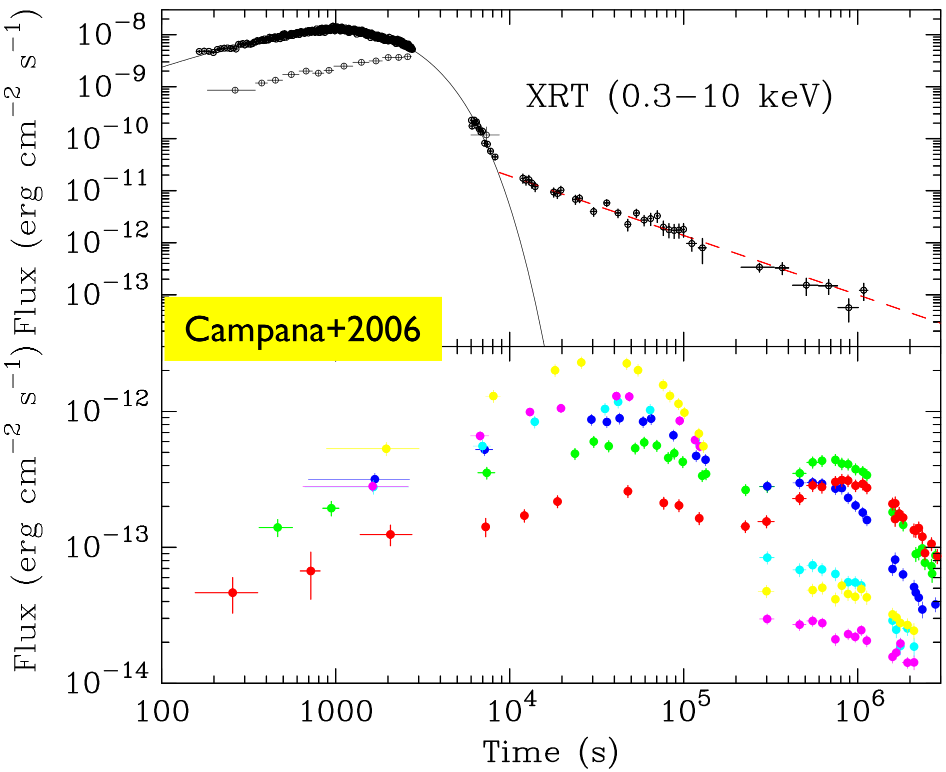
$\Downarrow$

$\beta_{sh} \sim 1 \quad r_{sb} \sim 9 \times 10^{13}$ cm

(Too large for a C-O WR $\sim 10^{11}$ cm)

$\rho(r_{sb}) \sim 10^{-14}$ g cm^{-3}

$\longrightarrow \dot{M} \sim 0.1\ M_\odot$ yr^{-1}



A trans-relativistic shock breakout from an optically-thick envelope formed by a strong wind.

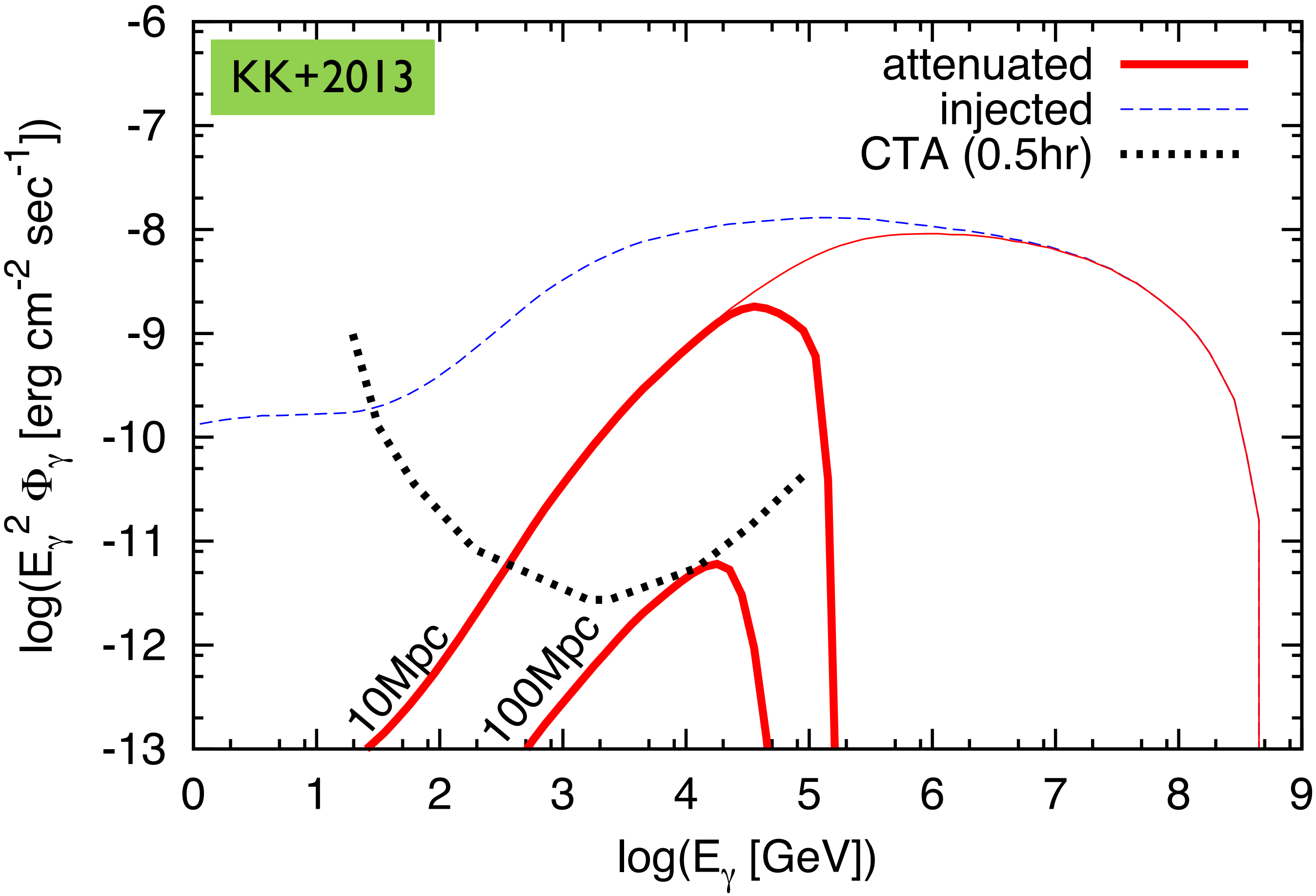
TeV Gamma Rays Counterpart

proton acc. @ collisionless sh. + s.b.o ph. → $p\gamma$ int.

Including the effect of

$$\gamma\gamma \rightarrow e^{\pm}$$

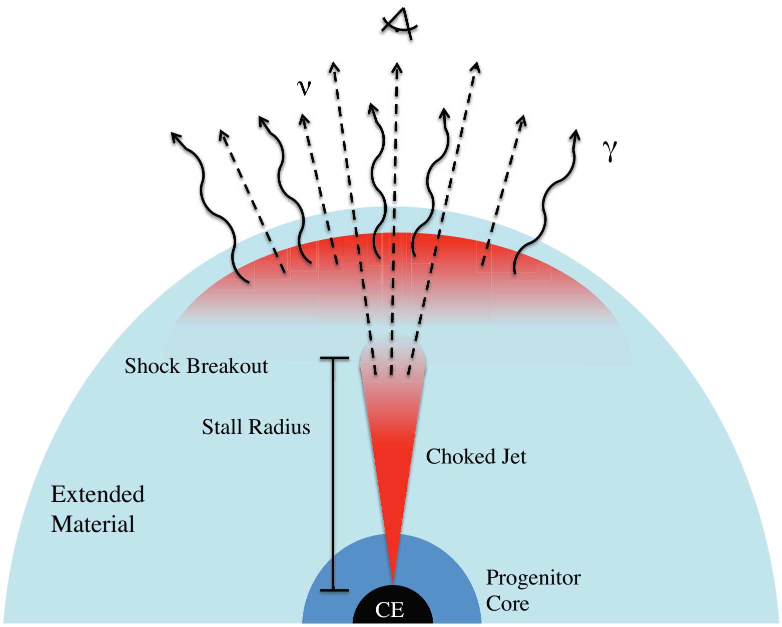
within the source and during propagation

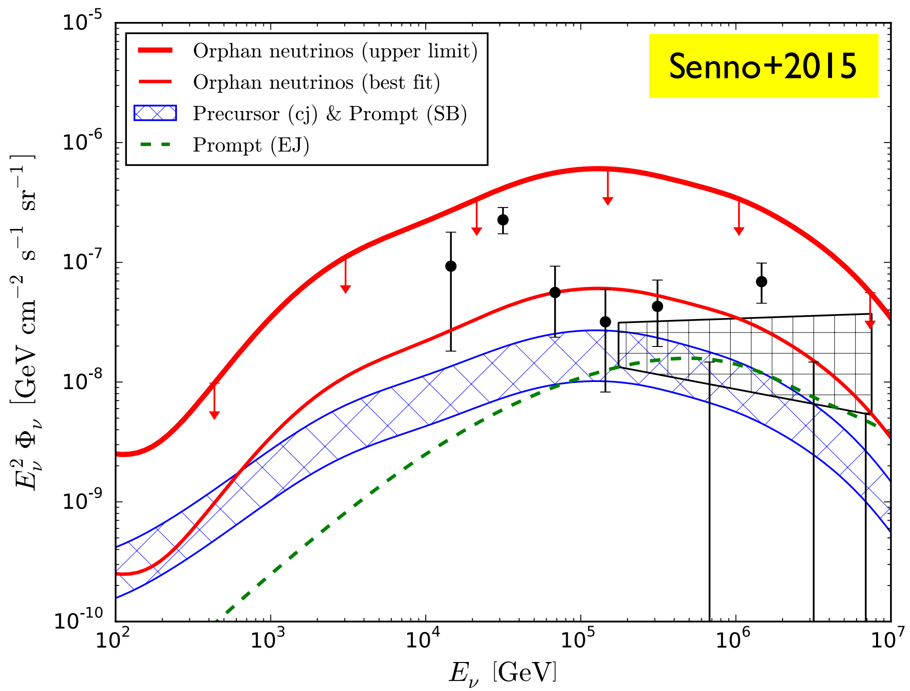


Detectable even from 100 Mpc away by CTA.

Nakar 2015

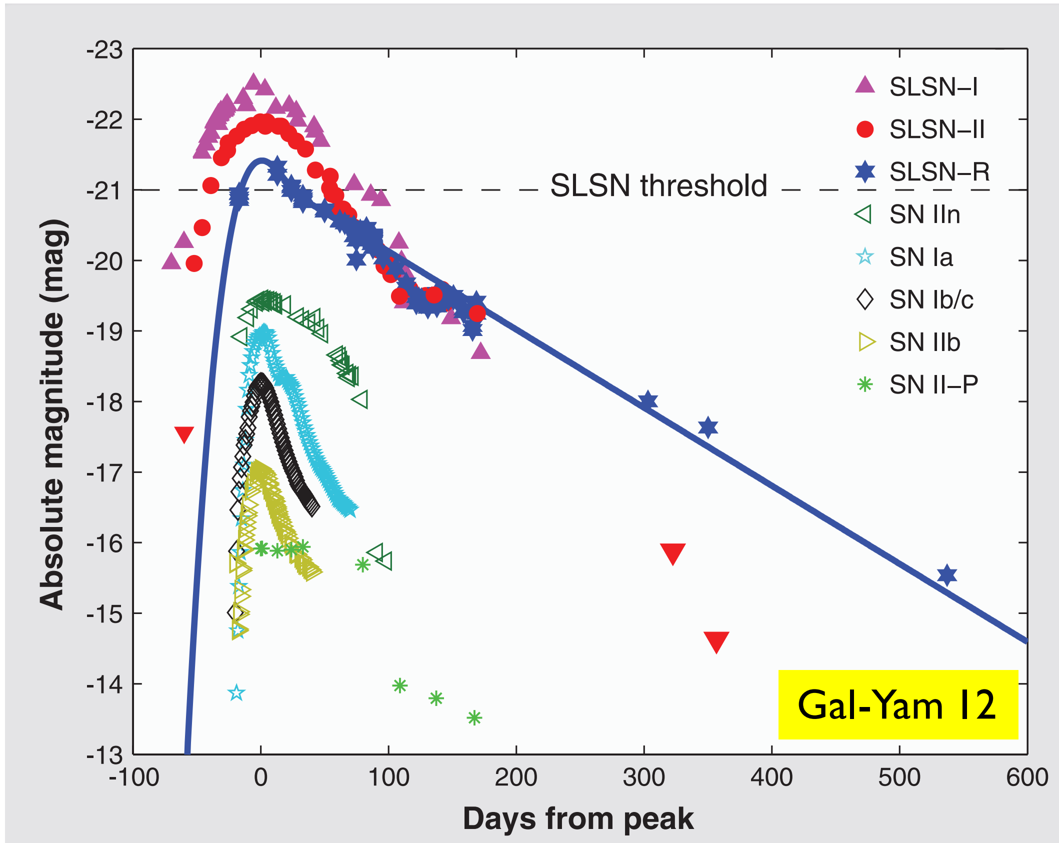
If the rela s.b.o is driven by a chocked jet, …





- ✓ **The diffuse neutrino flux from LL GRBs may be compatible with the IceCube data (~10-100 TeV) without contradicting the limits on classical GRBs.**
- ✓ **Such events do not contribute significantly to the Fermi b.g..**

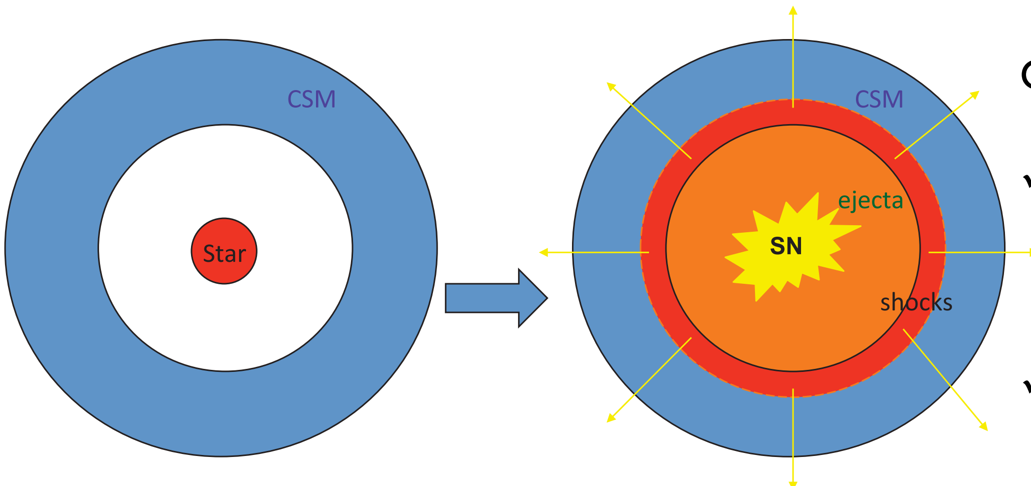
Diversity of Supernova



- ✓ Some classes of SNe cannot be explained by classical 56Ni decay model.
- ✓ Need additional energy source → circum-stellar shock (e.g., IIn) or pulsar wind (e.g., Ibc)

Non-Ni-decay-powered Supernovae

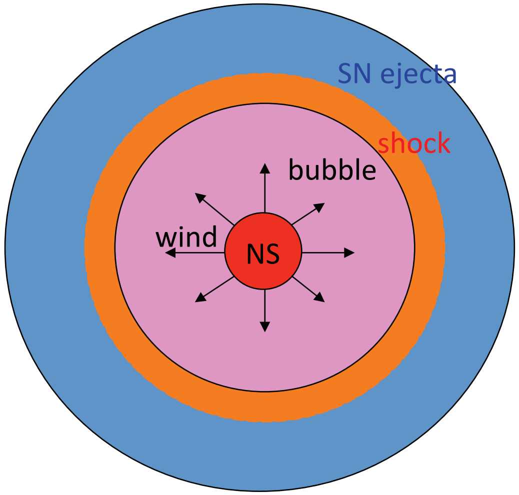
Interaction-powered



Obs. tell us …

- ✓ pre-collapse mass ejection from massive stars
- ✓ early shock acc.

Fast-spinning-newborn-pulsar-powered



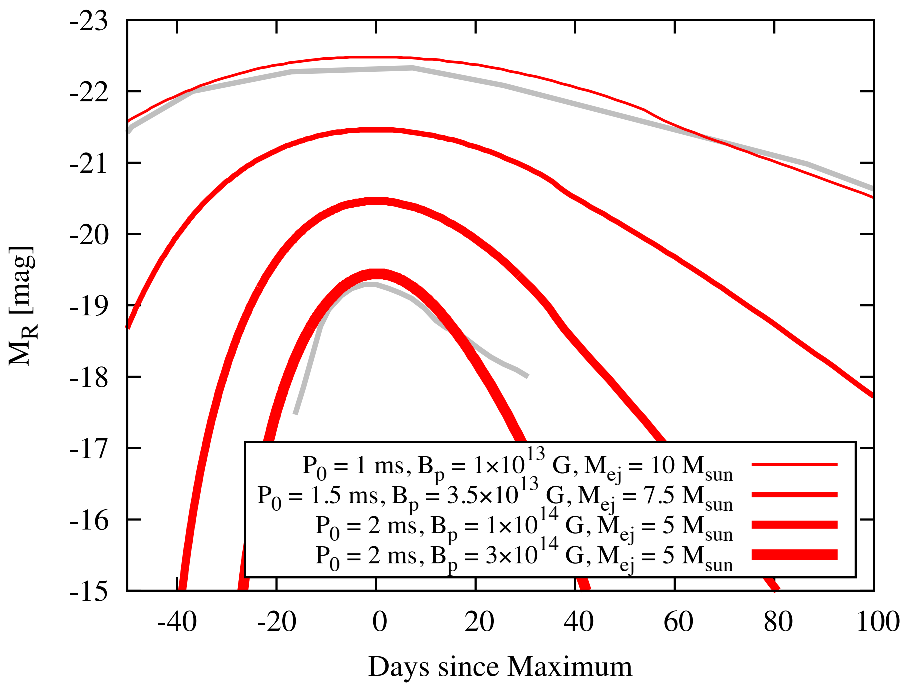
Obs. tell us …

- ✓ Physical para. of newborn pulsars "How magnetars born?"
- ✓ Particle acc. in young PWNe

Constraints from SN light curve

e.g., in the case of the pulsar-powered scenario

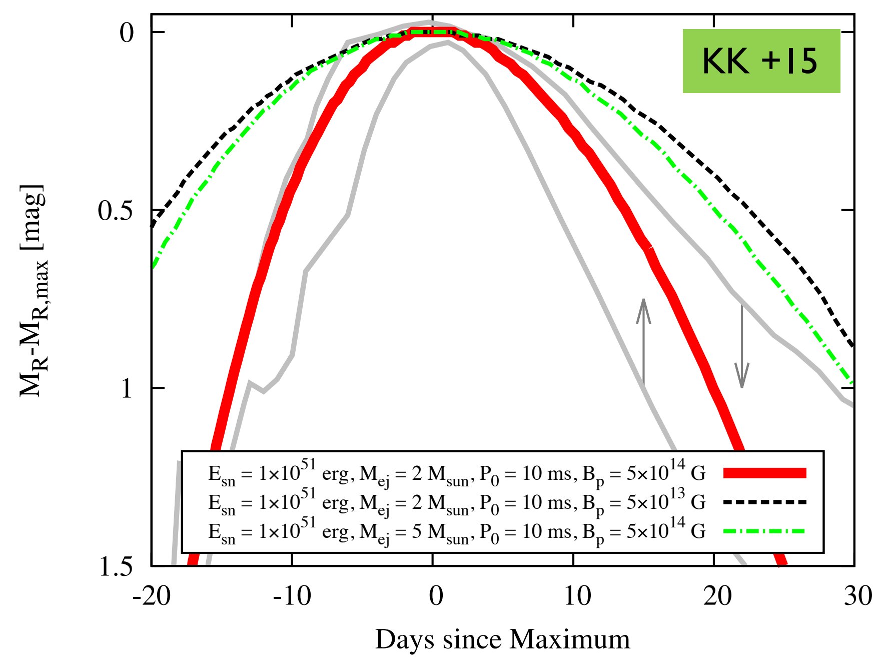
"Height"



For a given P_0 ,
SN becomes the brightest if

$$t_{\rm sd} \sim t_{\rm dif}$$

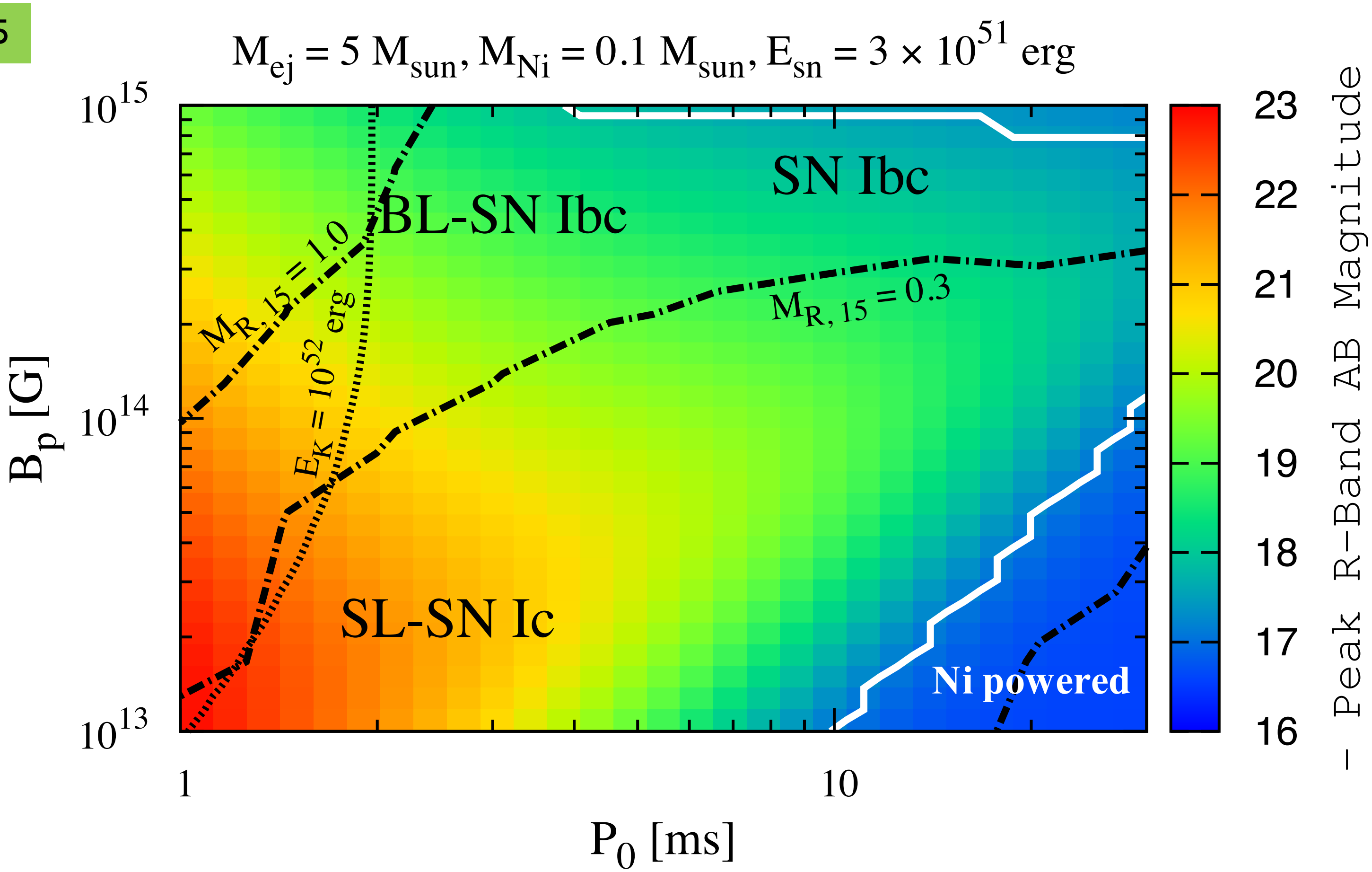
"Width"



For a given P_0 ,
SN becomes slower
for a smaller B_p

Constraints from SN light curve

KK +15



Unified pulsar-powered scenario for stripped-envelope SNe

$$P_0 \sim \text{ms},\ B_p \gtrsim 10^{13}\ \text{G} \ \rightarrow \text{SL-SNe Ic}$$

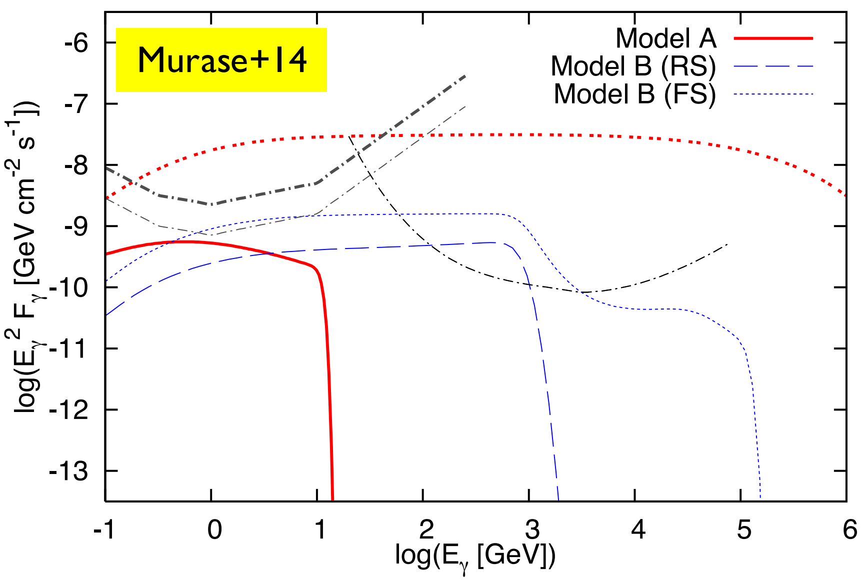
$$P_0 \sim \text{ms},\ B_p \gtrsim 5 \times 10^{14}\ \text{G} \ \rightarrow \text{BL-SNe Ibc}$$

$$P_0 \sim 10\ \text{ms},\ B_p \gtrsim 5 \times 10^{14}\ \text{G} \ \rightarrow \text{SNe Ibc}$$

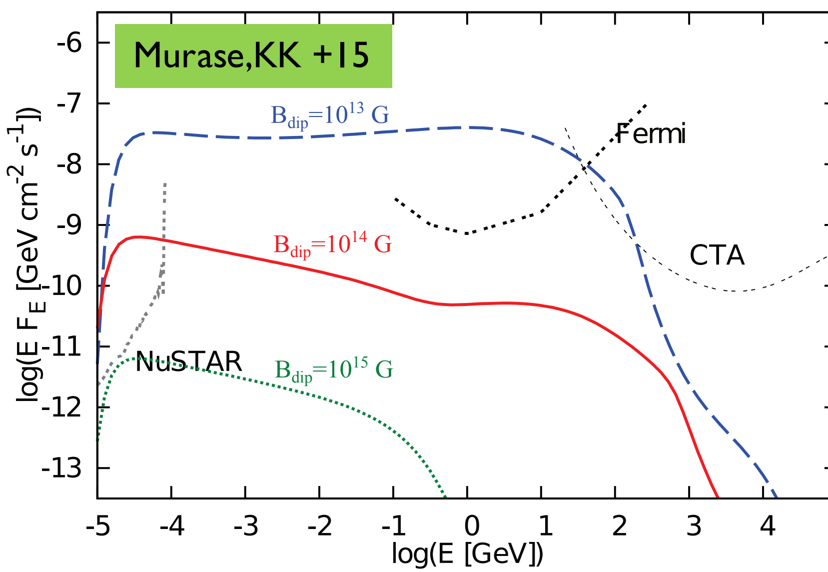
Gamma-ray counterparts

1. detect supernovae with high cadence SN surveys (e.g., PTF, Pan-STARRS, Hyper-Supreme Cam)
2. theoretically constraint on the model parameters, select good candidates for gamma-ray followup

Interaction-powered (SNe IIn, SLSN-II)



Pulsar-powered (SNe Ibc, SLSN-I)



3. Follow-up observation of nearby (~ 10 Mpc) SNe ~ months to ~ yr after the explosion

Fast Radio Bursts

~ 1.4 GHz

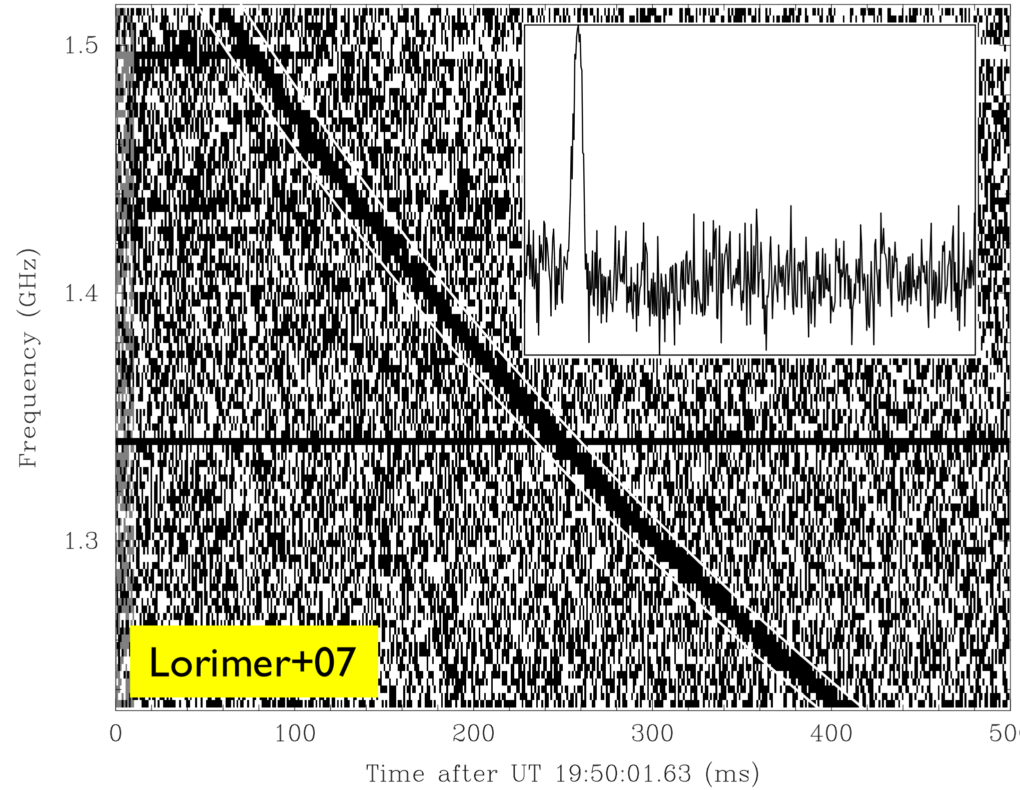
$\sim$ ms

$\sim$ Jy

$\sim 10^{3-4}$ day^{-1} sky^{-1}

$\approx \nu^{-2}$ arrival time pulse sweep

radio dispersion in cold ionized medium



$DM \sim$ 500-1100 cm^{-3} pc $\gg DM_{\rm mw}$

- ✓ Cosmological distance (z ~ 1) !? → very high effective temperature → coherent emission
- ✓ Can be an unique probe of cosmology and new physics??

Models

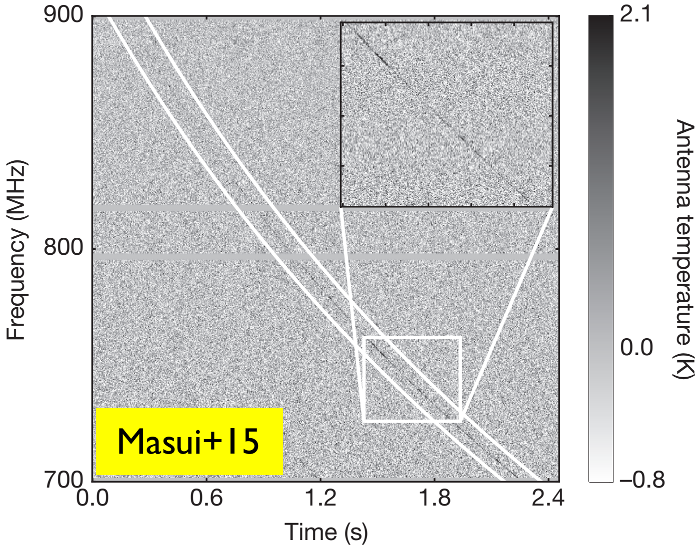
- Galactic
  - Rotating radio transients
  - Flaring stars — Loeb+13
- Extragalactic
  - Giant pulse from young pulsars
  - Magnetar giant flares — Popov&Postnov 08, Thornton+13, Lyubarsky+14
  - Supernovae into nearby stars — Calgate+71,75, Egorov&Postnov 08
  - Core-collapses of hypermassive NSs — Falcke&Rezzolla 13, Zhang 13
  - Binary NS mergers — Hansen&Lyutikov+01, Totani 13
  - Binary WD mergers — KK, Ioka, Meszaros 13
  - Evaporations of BHs — Rees 77, Blandford 77, Kavic+08, Keane+12
  - Superconducting cosmic strings — Cai+12

and more…

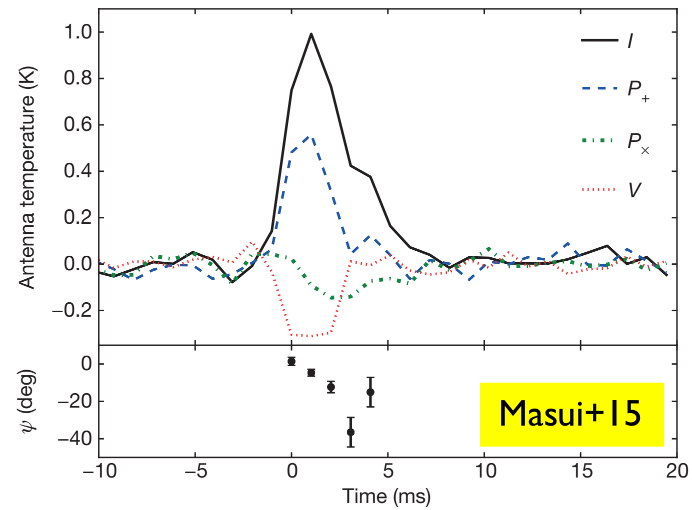
No counterpart detection so far.

Recent advances

✓ at lower frequencies (GBT)



✓ liner and circular polarization



✓ large scattering and rotation measure

→ sufficient plasma density and magnetic field surrounding the source?

→ star forming region?

→ Magnetar giant flare is the most promising?

Kulkani+15, Masu+15

In a magnetar model, TeV gamma rays are detectable up to ~ 100 Mpc with CTA.

Lyubarsky+14

If ~10^4 per day per sky up to ~ Gpc, ~3 per 5deg x 5deg per yr up to ~ 100 Mpc…

They repeat!

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Localizing the Unique Repeating Fast Radio Burst FRB 121102

Proposal Code:	VLA/15B-378
Principal Investigator:	Shami Chatterjee
Co-Investigators:	Paul Demorest, Scott Ransom, James Cordes, Jason Hessels, Laura Spitler, Robert Wharton, Victoria Kaspi, Paul Scholz, Joeri van Leeuwen
Science Category:	Energetic Transients and Pulsars
Proposal Type:	Director's Discretionary Time
Approved Hours:	10.0
Abstract:	The Fast Radio Burst 121102, discovered at Arecibo by the PALFA survey, was the first non-Parkes FRB. We have recently identified ten more bursts from the source of FRB 121102 in a follow-up observation campaign in May/June 2015. These bursts have the same anomalously large pulse dispersion measure, suggestive of an extragalactic origin, and a tentative underlying periodicity of 8.1 seconds, tantalizingly similar to the typical periods of magnetars. Here we request Target of Opportunity fast-dump observations of the unique repeating FRB 121102 with the VLA in its current compact configuration, distributed over ten 1 hour sessions and triggered by a confirmation that the FRB source is still in a sporadically active state. A detection with the VLA will begin the process of localizing the source and identifying a multiwavelength counterpart or host galaxy, thus elucidating the nature of FRBs.
Submitted:	2015-11-12T22:03:54Z

More hopes for just waiting!?

Summary and Discussion

- Three approaches to multi-wavelength transients
  1. "Need to harry!" (20 sec < t_γ < day)
     - e.g., low-luminosity GRBs
       - ✓ TeV gamma ray is the smoking gun signal of the shock breakout model.
       - ✓ also may give an important hint on the origin of IceCube neutrino.
  2. "Need not too much harry" (day < t_γ < year)
     - e.g., non-Ni-powered SNe
       - ✓ Follow up obs. from months to year after the explosion is enough.
       - ✓ Gamma rays can test supernova models, probe newborn pulsars, etc
  3. "Just wait" (t_γ < 20 sec)
     - e.g., FRBs
       - ✓ In a magnetar model, a few times per CTA FoV per yr
       - ✓ Some of them do repeat! → targeted observation is also feasible