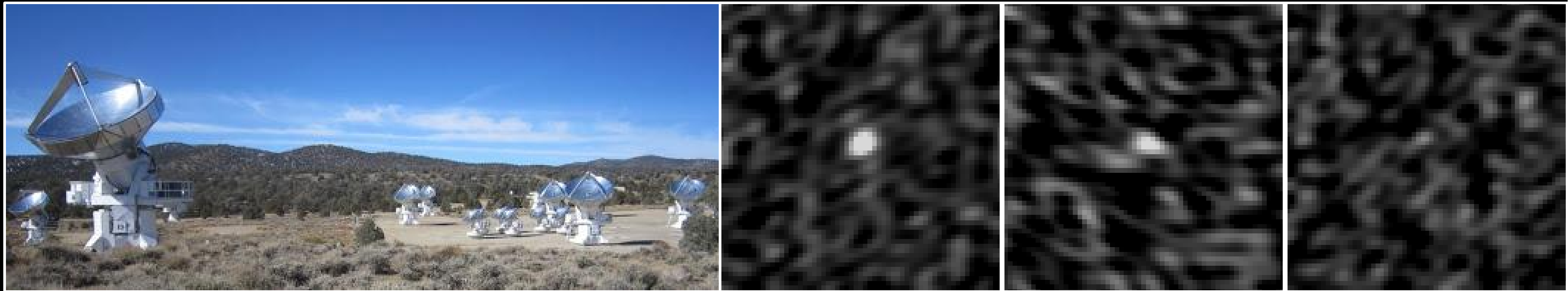


Millimeter-Wave Observations of GRB Afterglows

Daniel Perley (Caltech)
+ Alessandra Corsi, Assaf Horesh, Bradley Cenko,
Dale Frail and many others

Outline

Background Overview

- Gamma-ray bursts
- Synchrotron afterglow

What millimeter-wave data contributes

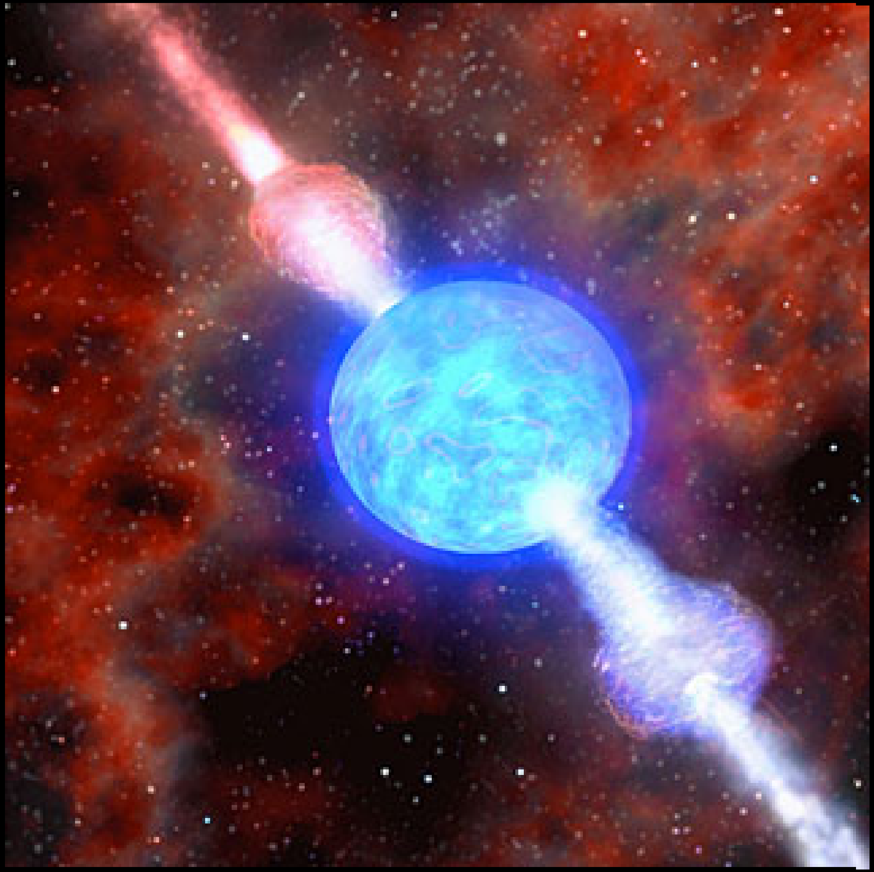
- Energies, densities, testing models
- Early-time observations and reverse shock

CARMA Results

- Remarkable CARMA GRBs past/present
- Diversity of environments / shock physics

Long-Duration Gamma-Ray Bursts

Relativistic (Γ = ~100), collimated ($\theta \sim 10°$) explosions launched by massive stars in the moments following core-collapse.



Extremely powerful (10^{51} erg) but extremely rare (~1/galaxy/10^6 years) and last only a few (~10) seconds.

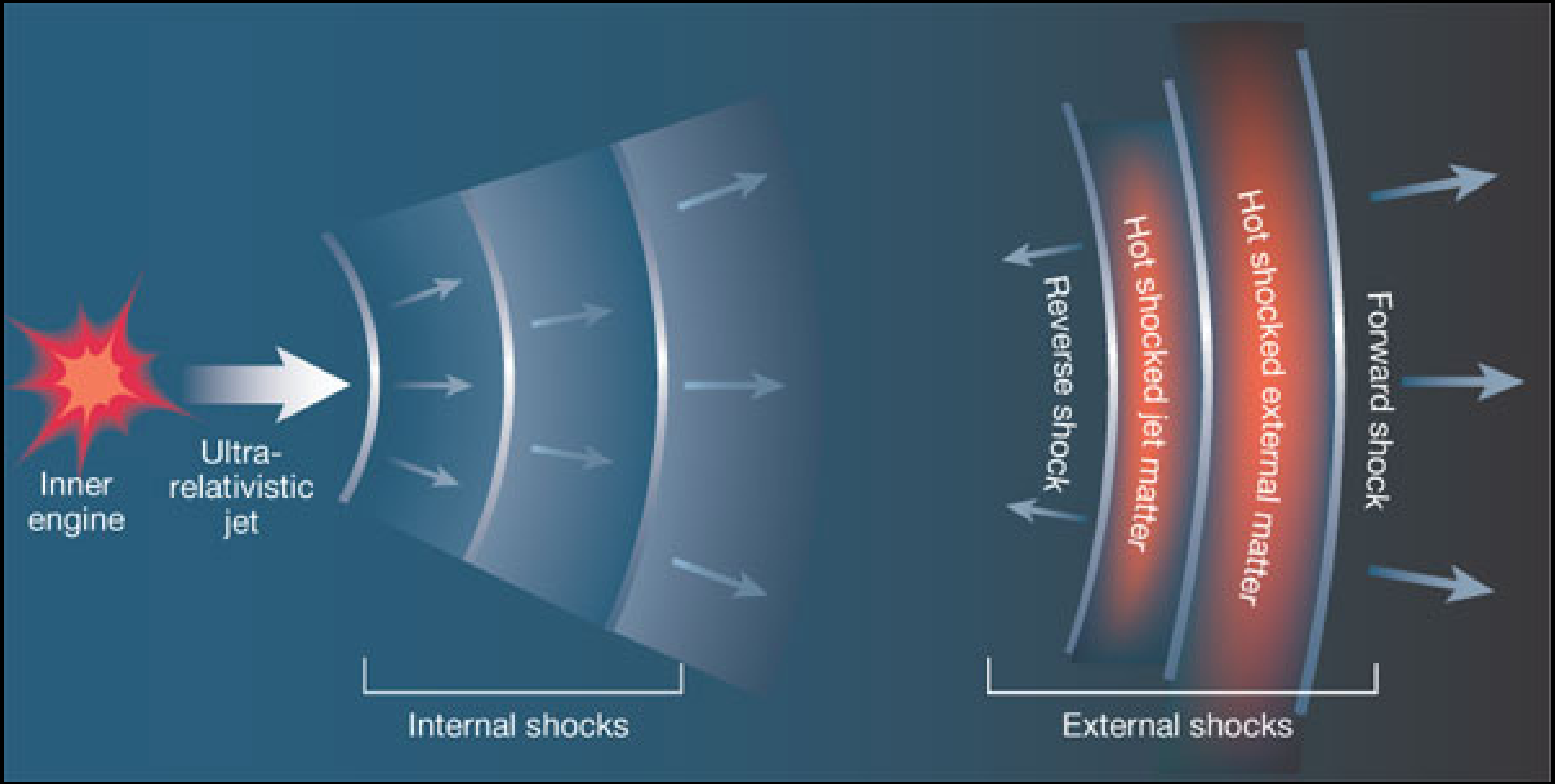
Open questions:

- What is the progenitor?
  - (Ultra-massive WR, binary, etc.)
- How is radiation generated?

- What can they teach us?
  - (About locations of star-formation, fundamental physics, etc.)

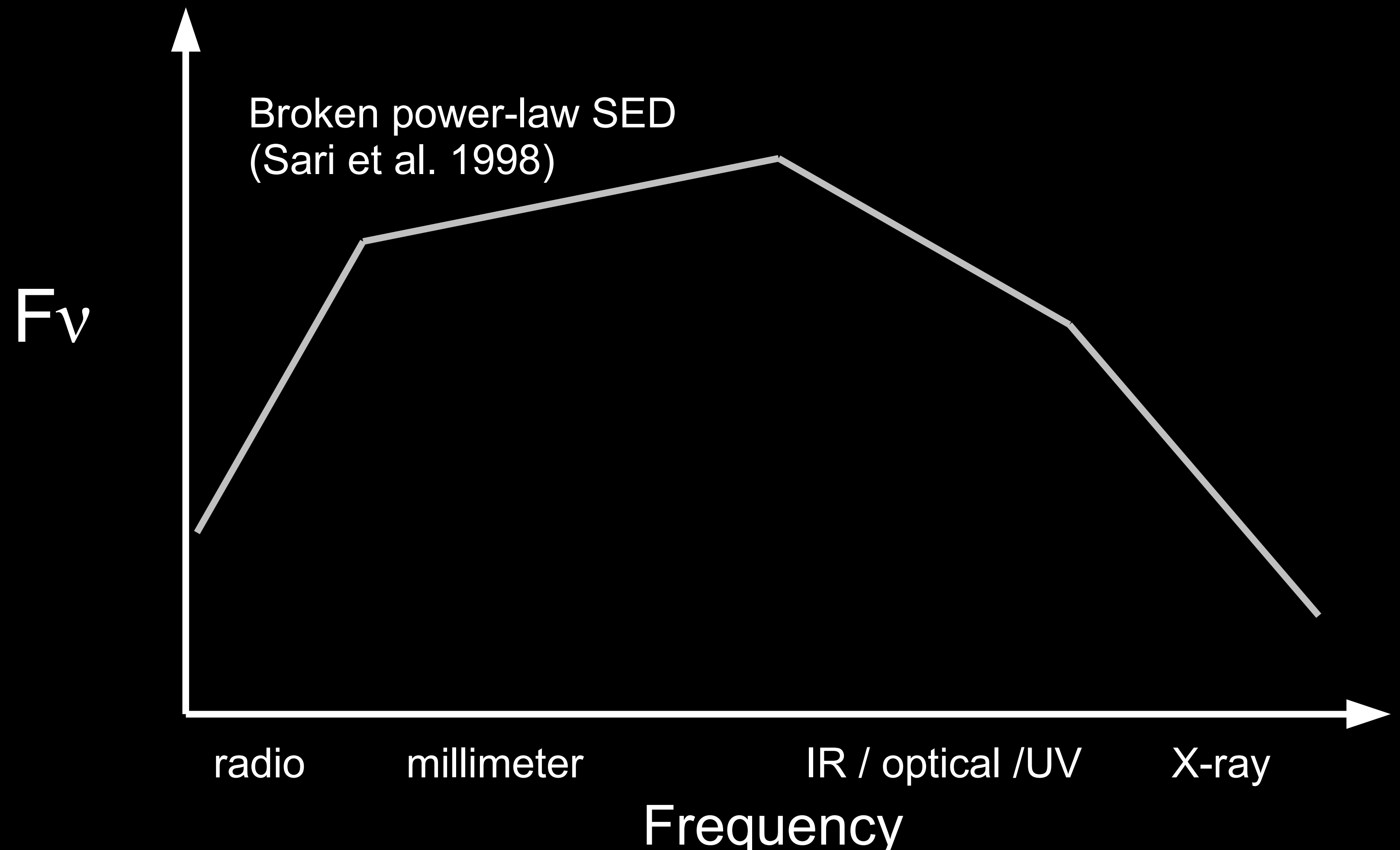
Afterglows

Relativistic ejecta plows into circumstellar medium, producing a **relativistic shock wave**



Afterglows

Electrons excited to relativistic speeds by the shock wave gyrate along magnetic field lines and release **synchrotron radiation:**



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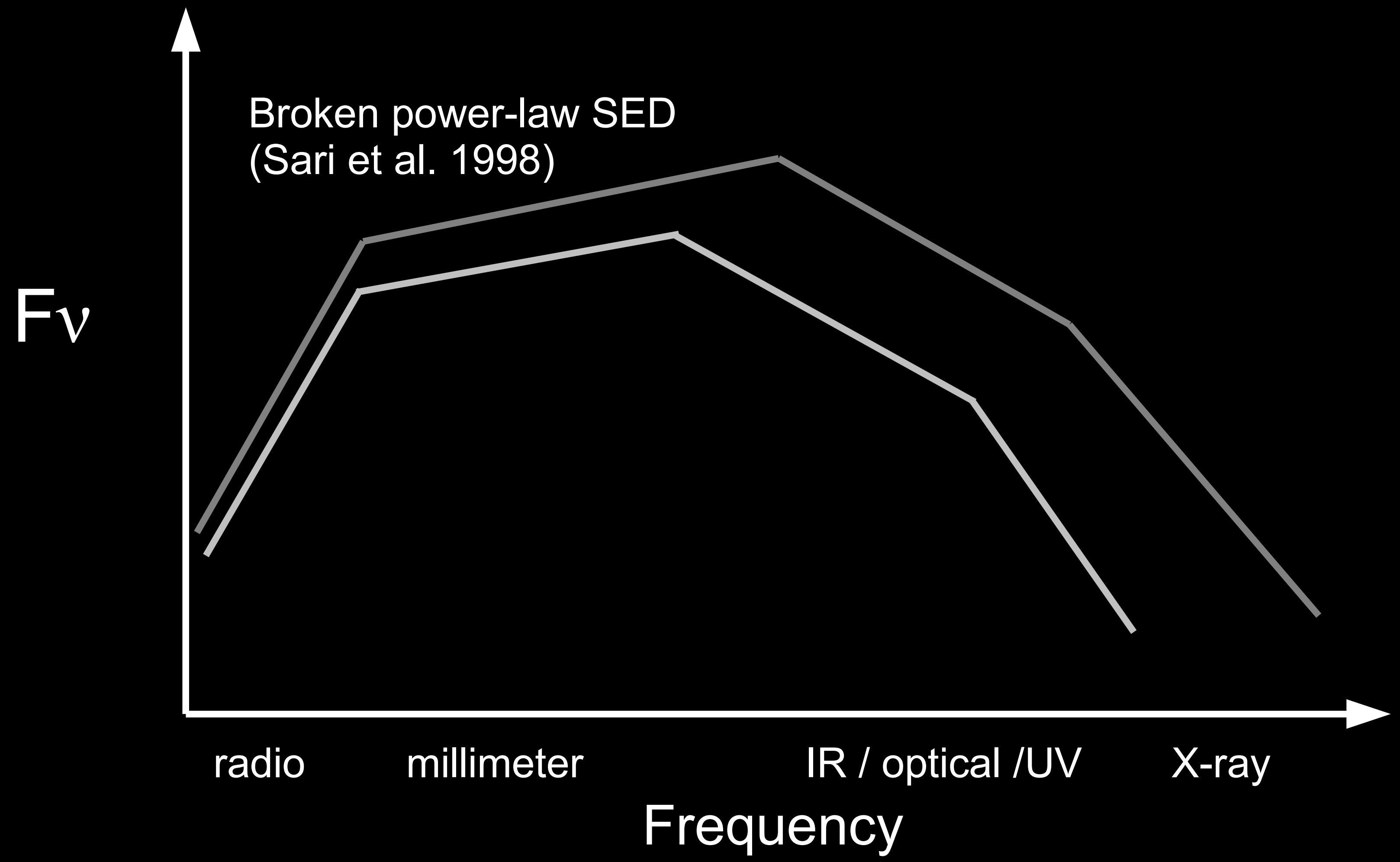

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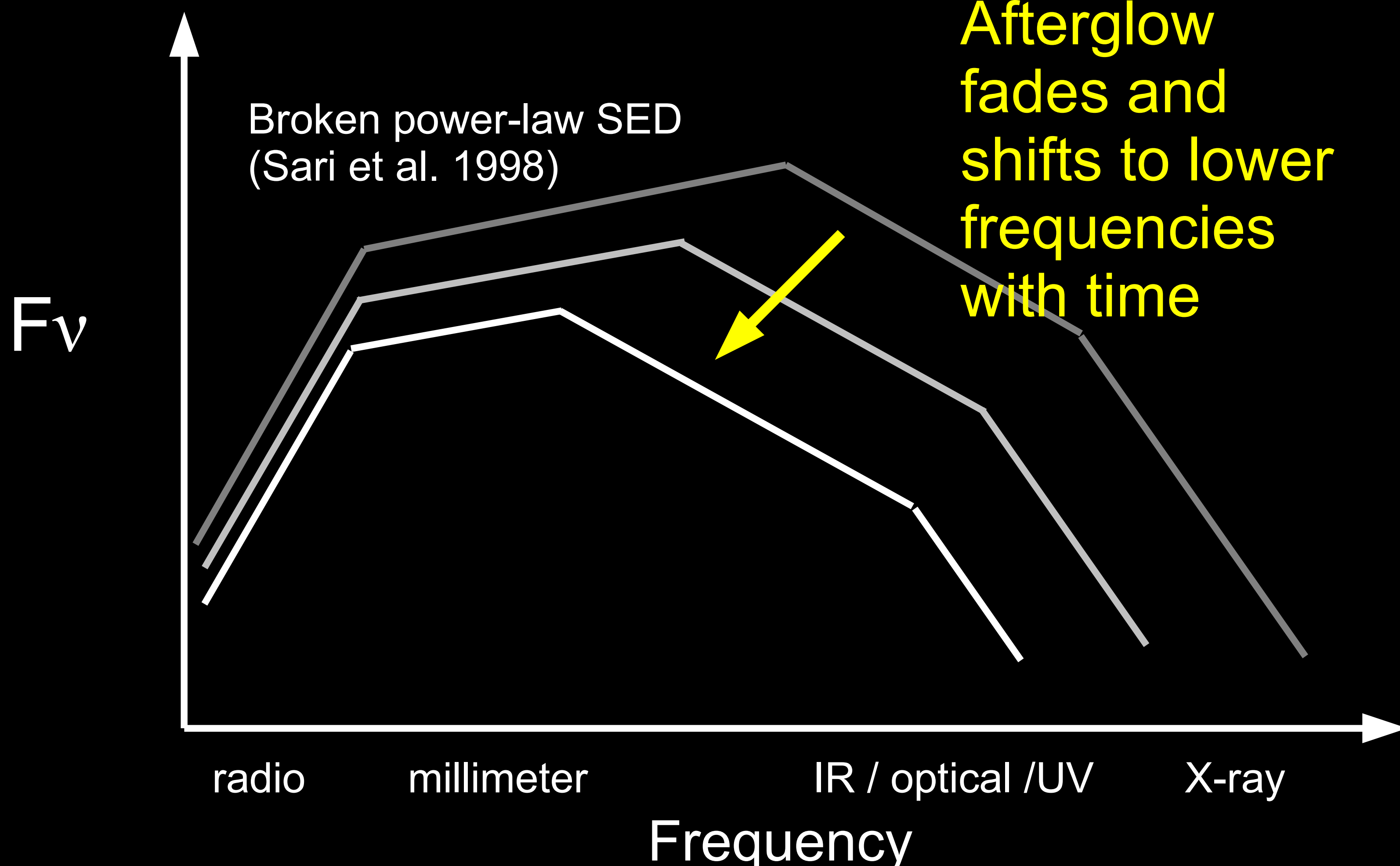


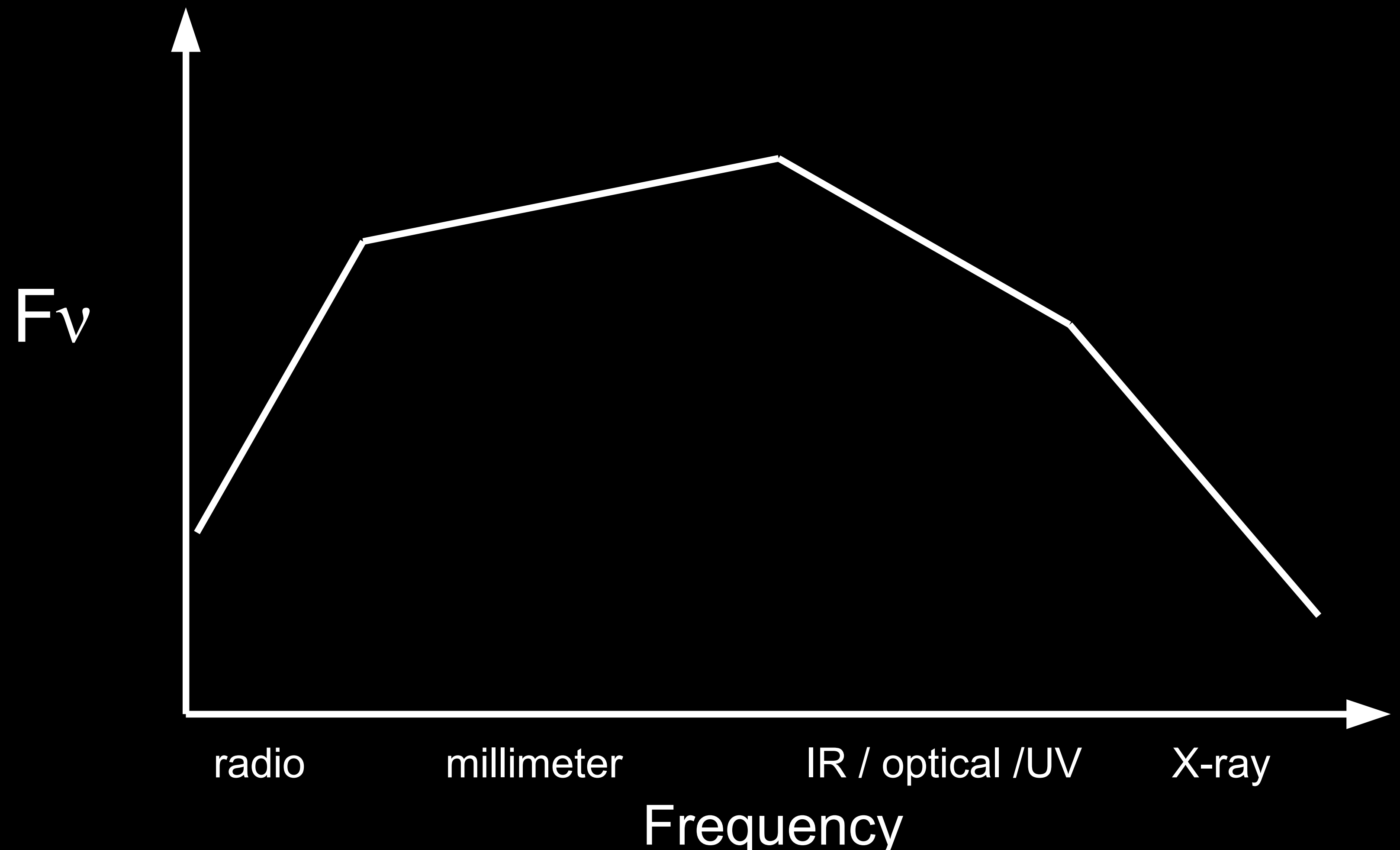
Why millimeter?

At late times...
Unique, critical region of synchrotron SED – necessary to constrain burst's *environment* and total *energetics*.

At early times...
Ideal band for observing the *reverse shock*, a basic prediction of standard models.

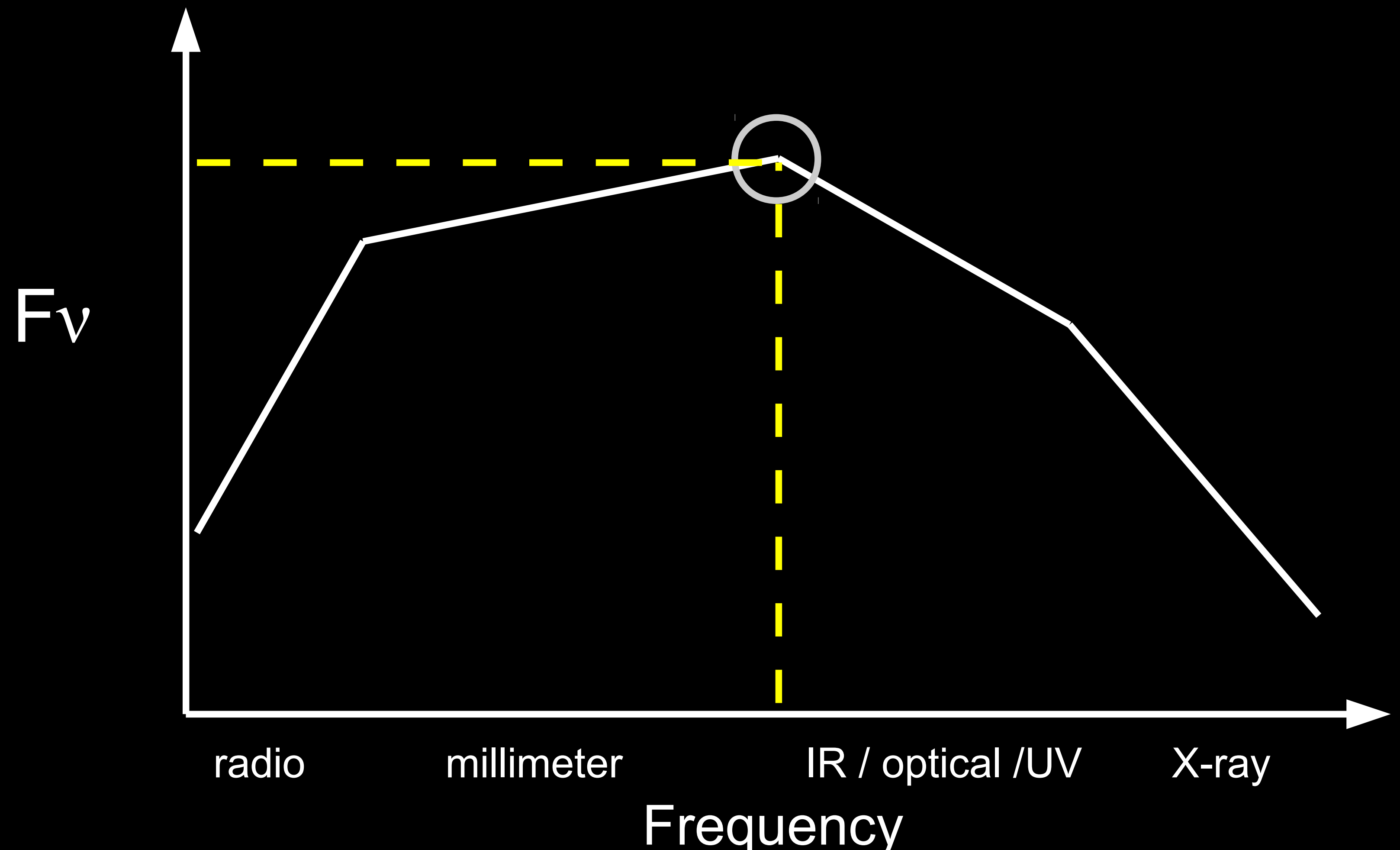
At any time...
Unaffected by gas and dust; can uncover GRBs from *dust-obscured* environments.

Afterglow Parameters



Afterglow Parameters

Peak flux and frequency set by density of environment and energy (per Ω) of shock.



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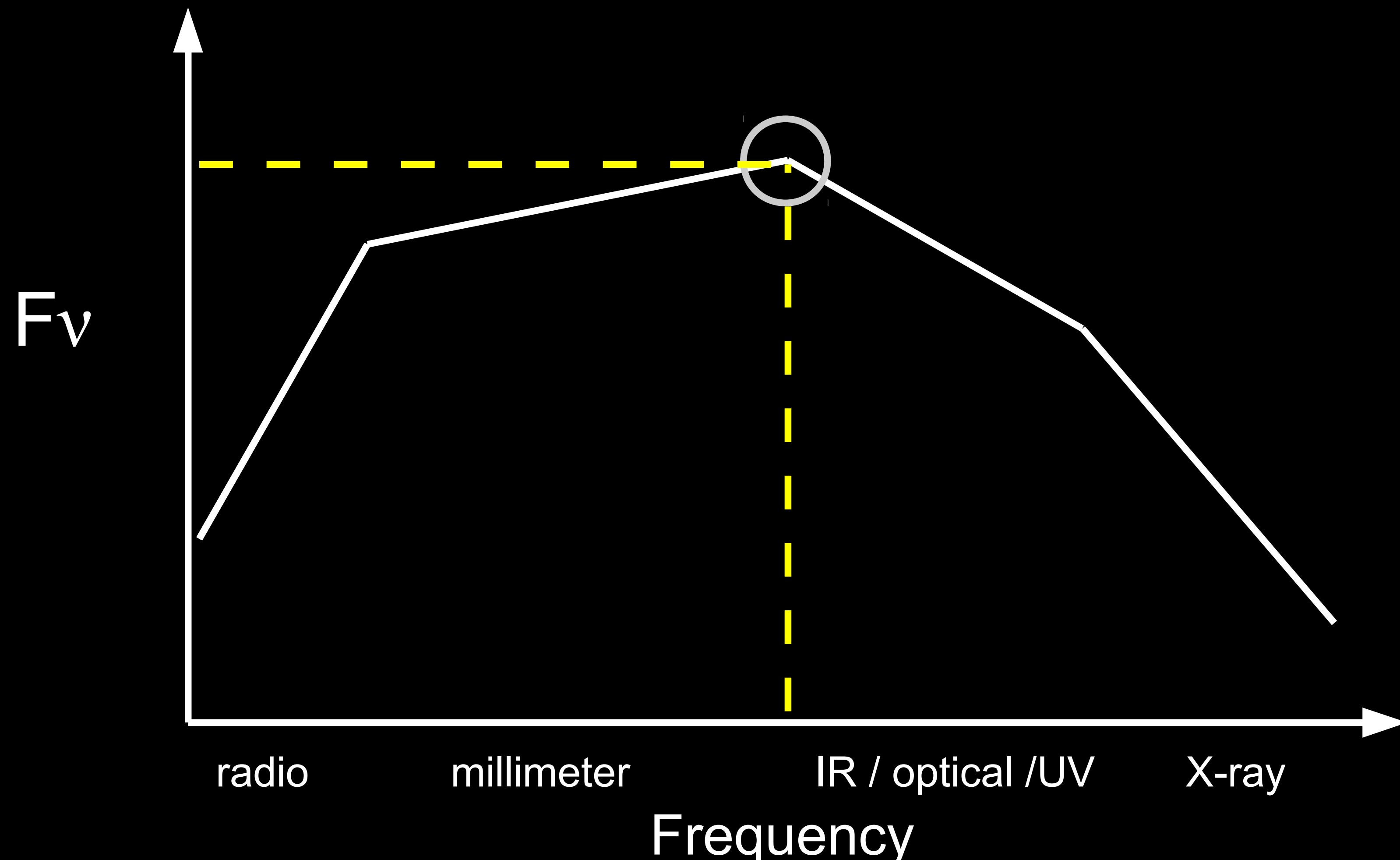
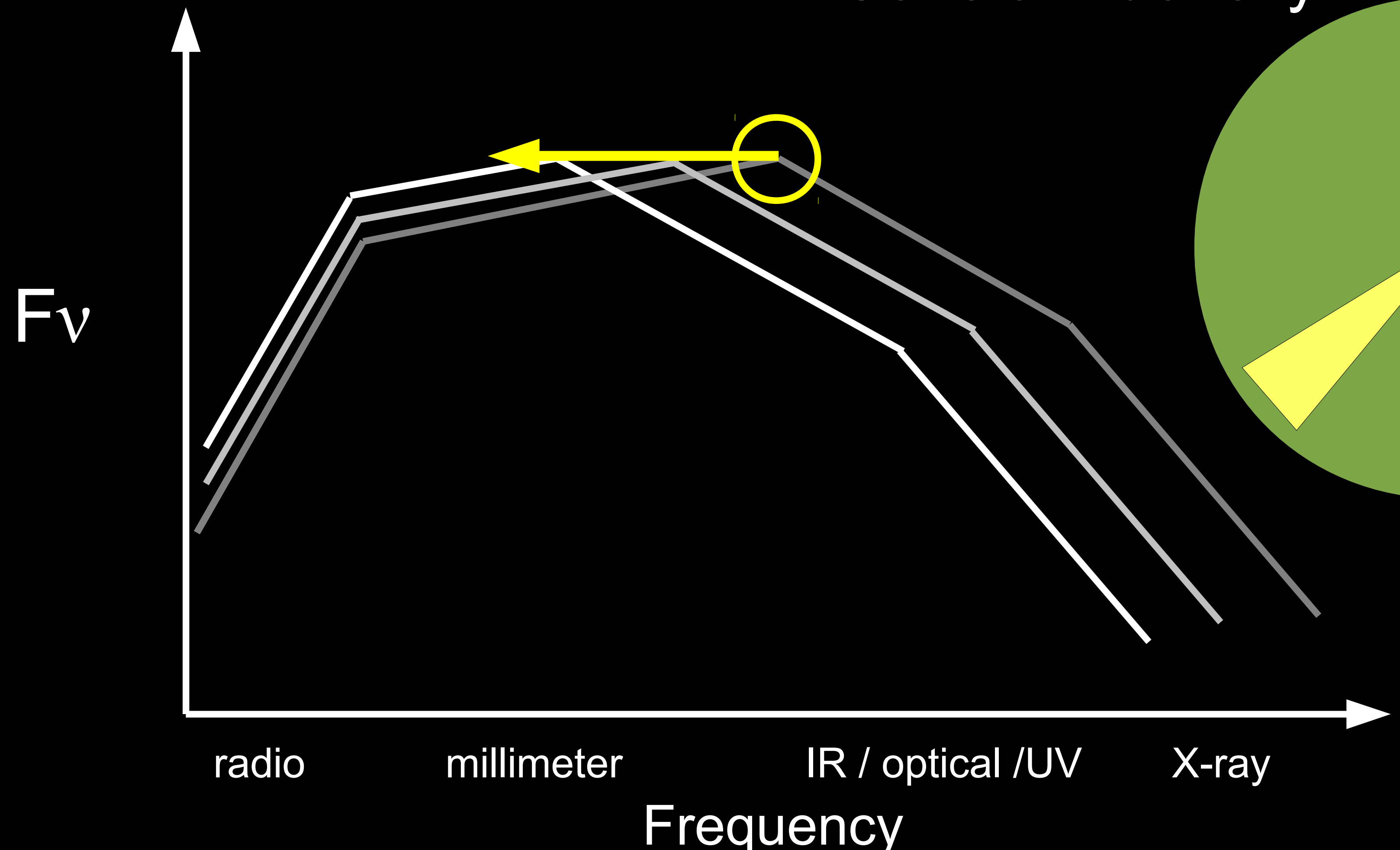
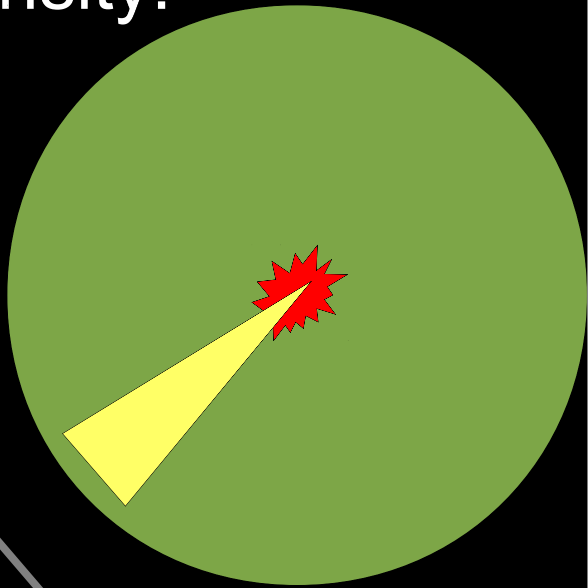


Afterglow Parameters

Evolution is set by density profile:

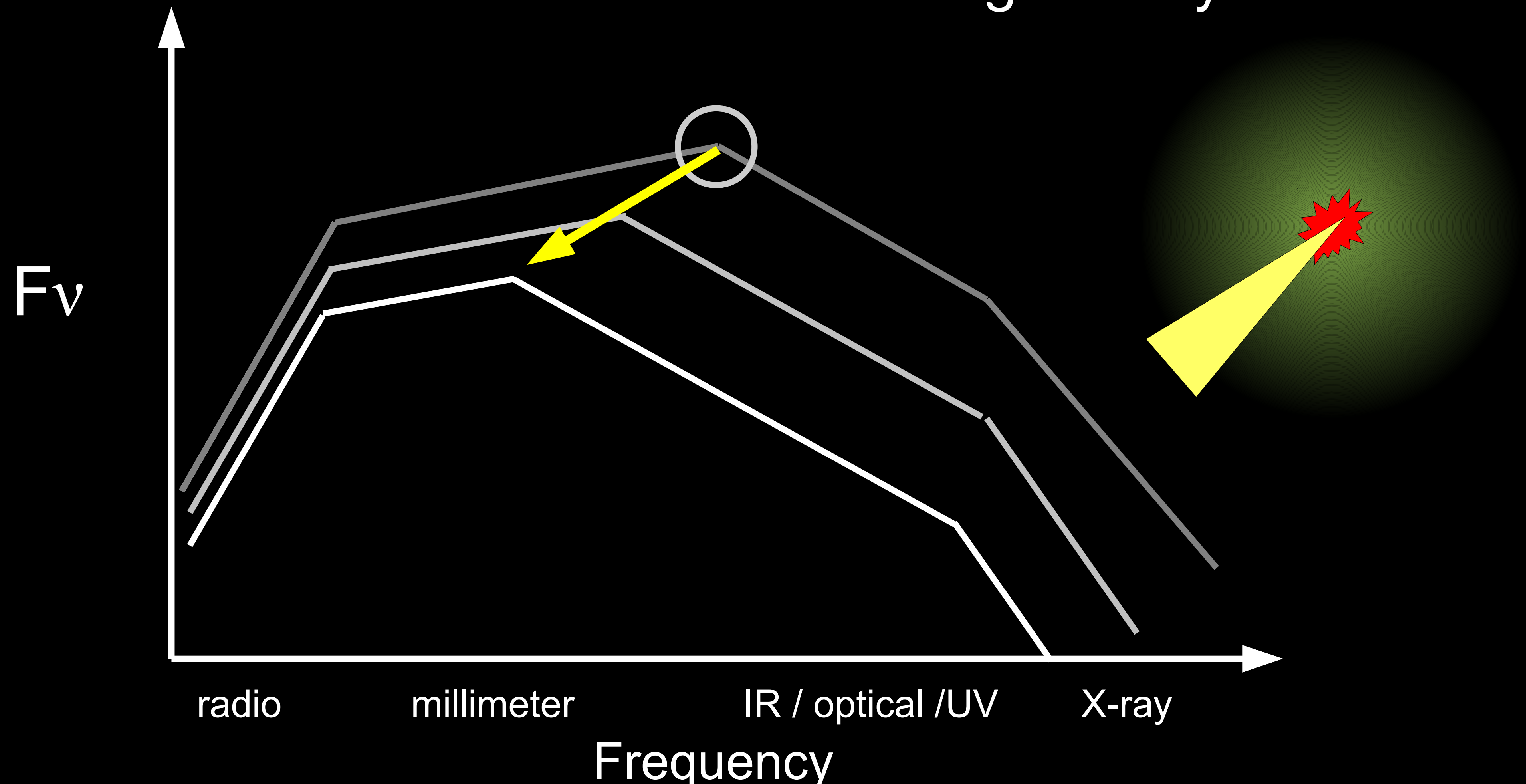
Constant density:





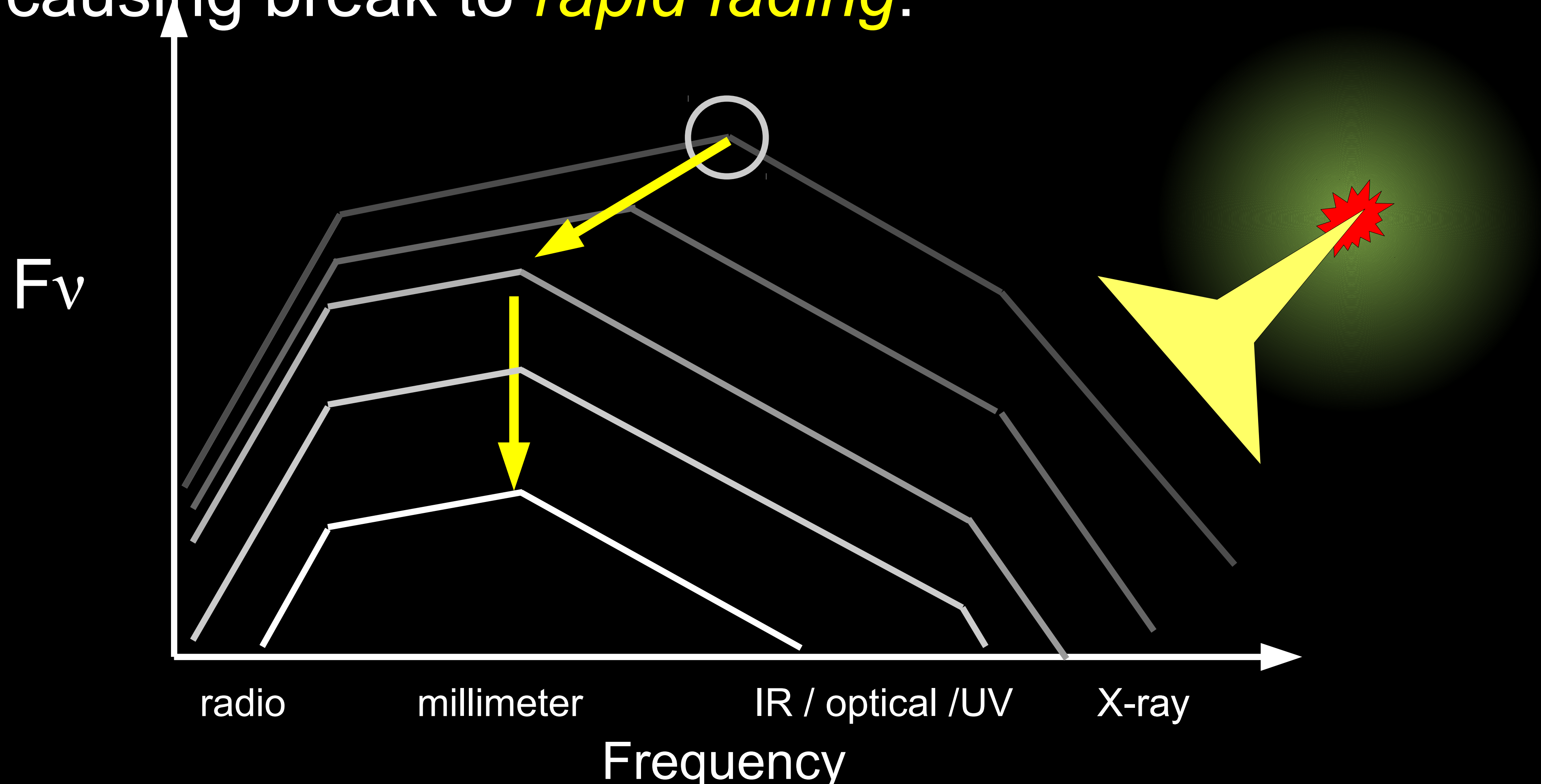
Evolution is set by density profile:

Declining density:



Afterglow Parameters

Jet eventually (depending on beaming angle) becomes non-relativistic and spreads, causing break to *rapid fading*:



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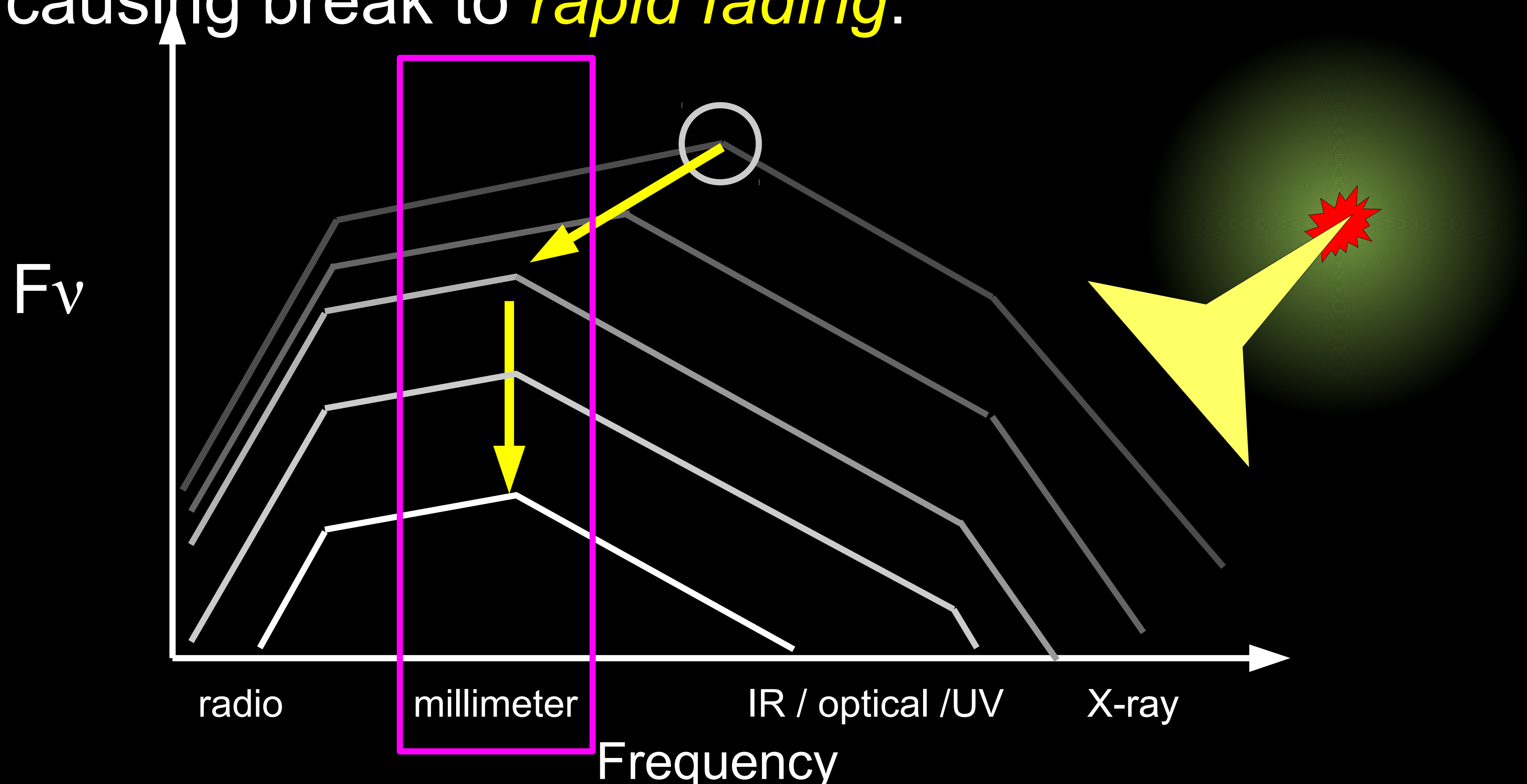


Objectives of Millimeter Observations

Circumburst environment

Wind-driven profile or not? Density/velocity?
Progenitor? (WR, LBV, binary, something else, multiple types?)

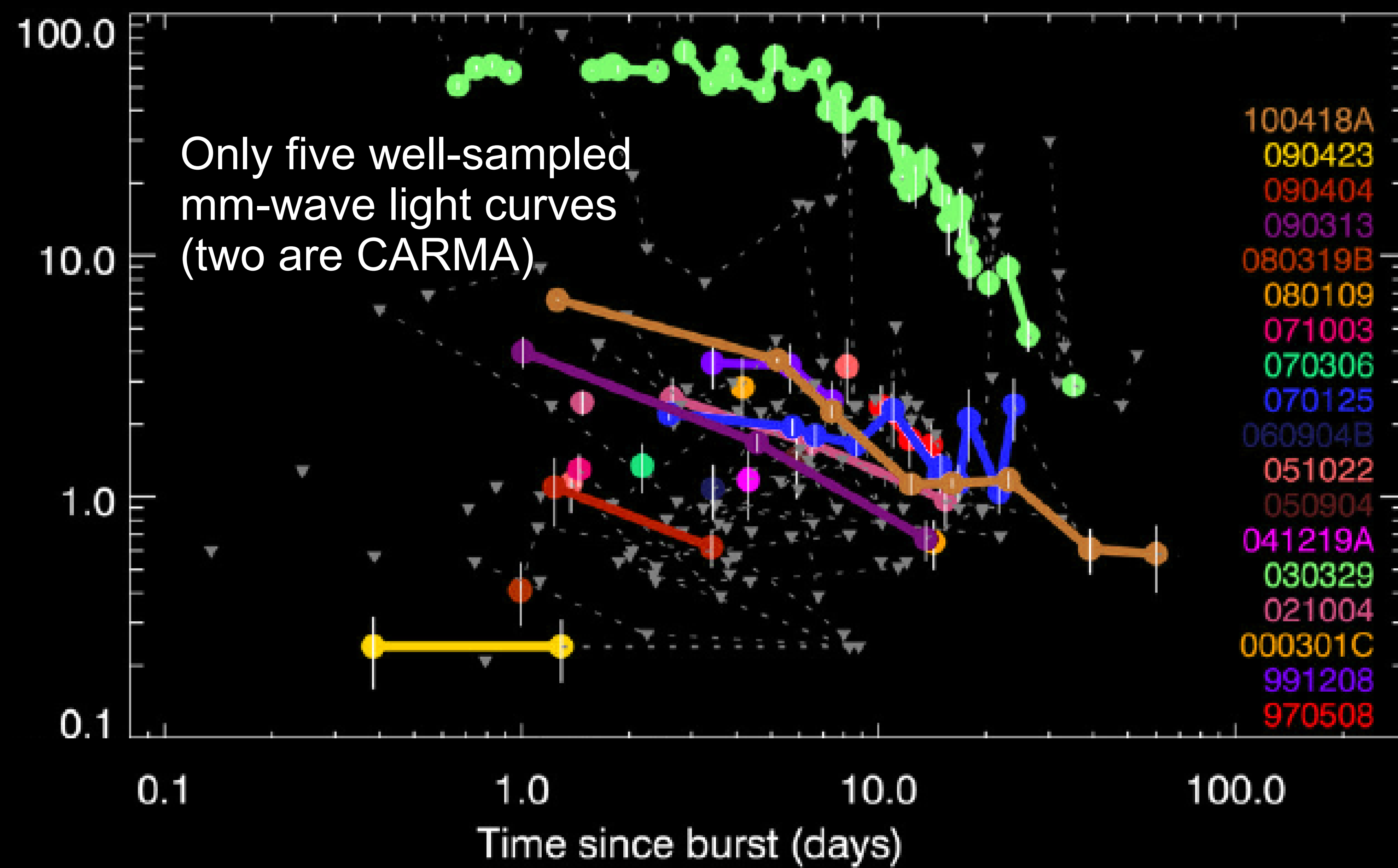
Energetics of shock and burst

$E_{shockwave}$ vs $E_{gamma-rays}$: *efficiency*
GRB radiation mechanism?
How much material is ejected and how fast?
Beaming angle / true energy scale

Test of standard afterglow models

X-ray – density independent; cooling timescale; central-engine flaring
Optical – Difficult to gather at late times (runs into SN/host), cooling timescale, dust
Radio – Self-absorption, interstellar scintillation

All 3mm Light Curves as of 2010

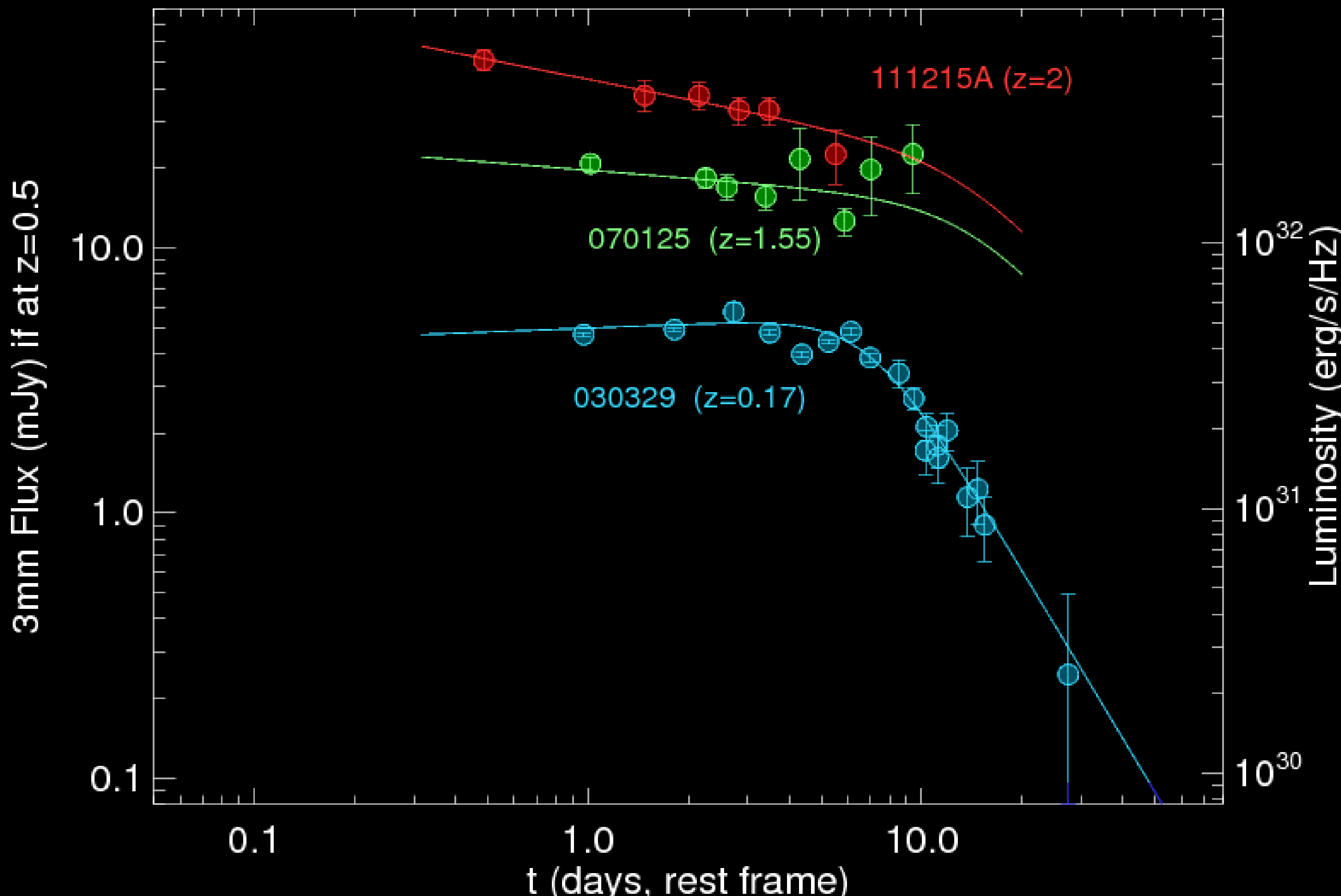


CARMA vs. The World

	CARMA	Everyone else
2006	0	1
2007	1	3
2008	1	3
2009	1	2
2010	0	2
2011	1	1
2012	2	3
2013	5	0

Reported detections: **11** **14**

Some prominent CARMA GRBs

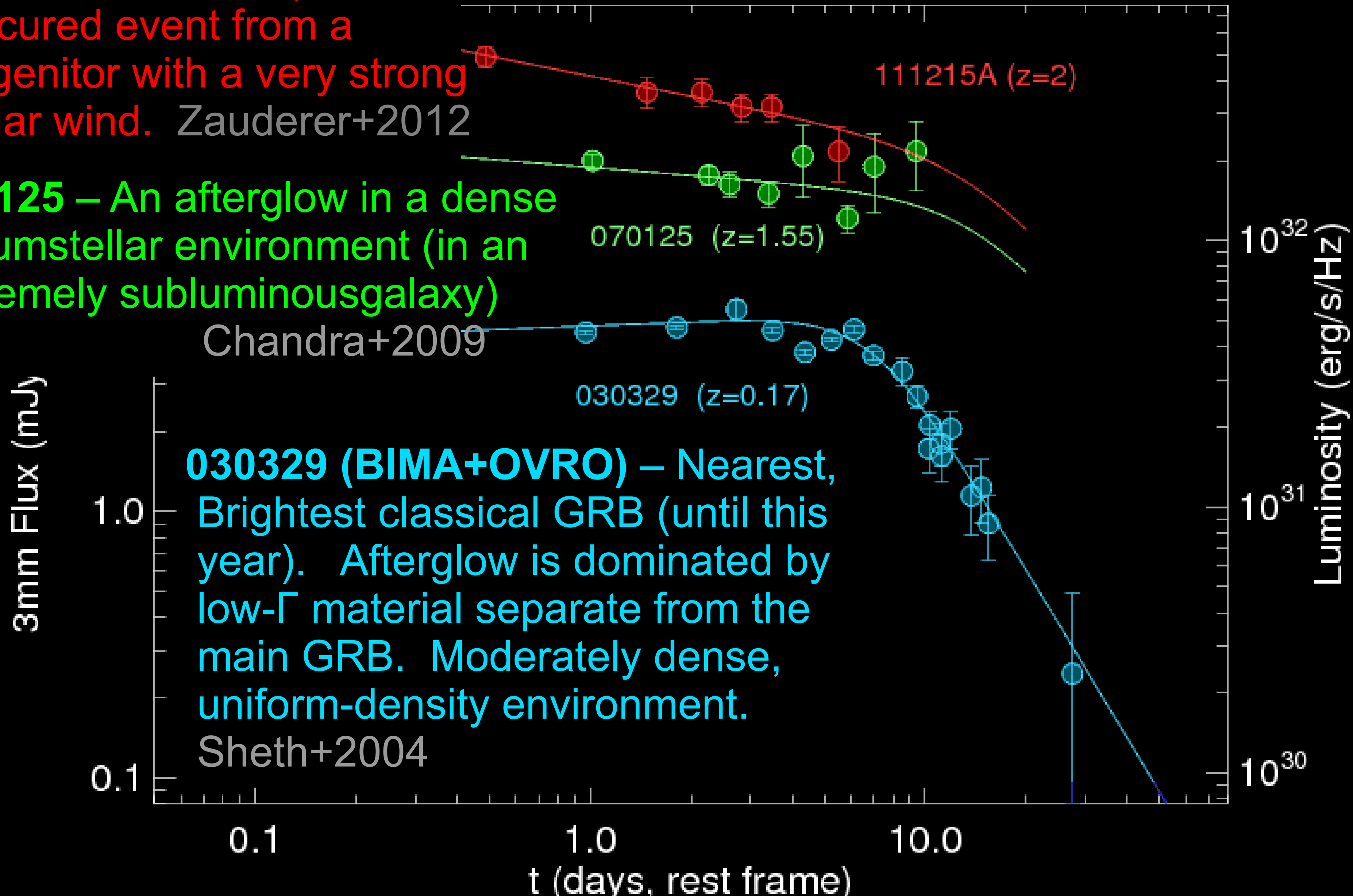


Some prominent CARMA GRBs

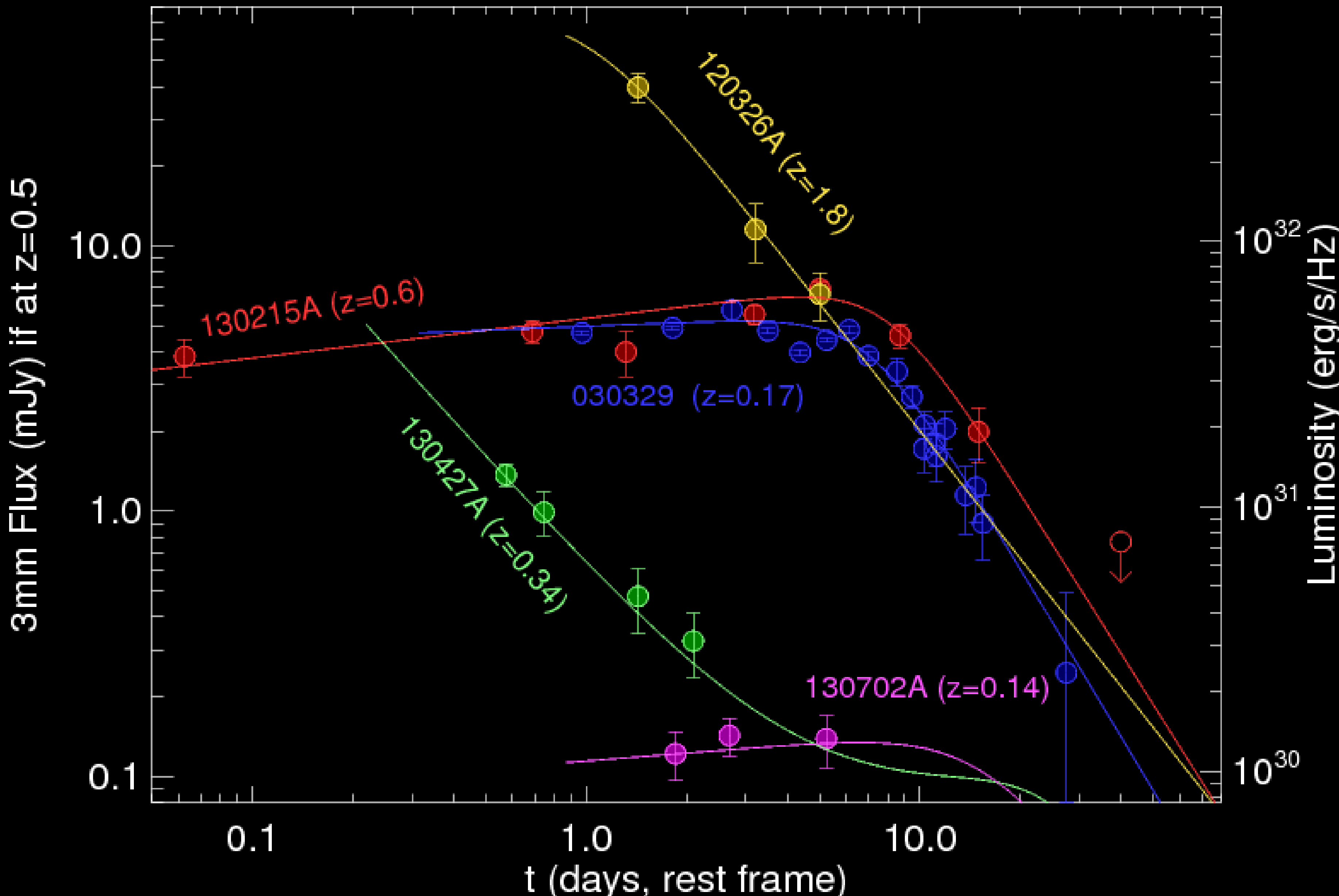
111215A – A heavily dust-obscured event from a progenitor with a very strong stellar wind. Zauderer+2012

070125 – An afterglow in a dense circumstellar environment (in an extremely subluminousgalaxy) Chandra+2009

030329 (BIMA+OVRO) – Nearest, Brightest classical GRB (until this year). Afterglow is dominated by low-Γ material separate from the main GRB. Moderately dense, uniform-density environment. Sheth+2004



Recent CARMA GRBs



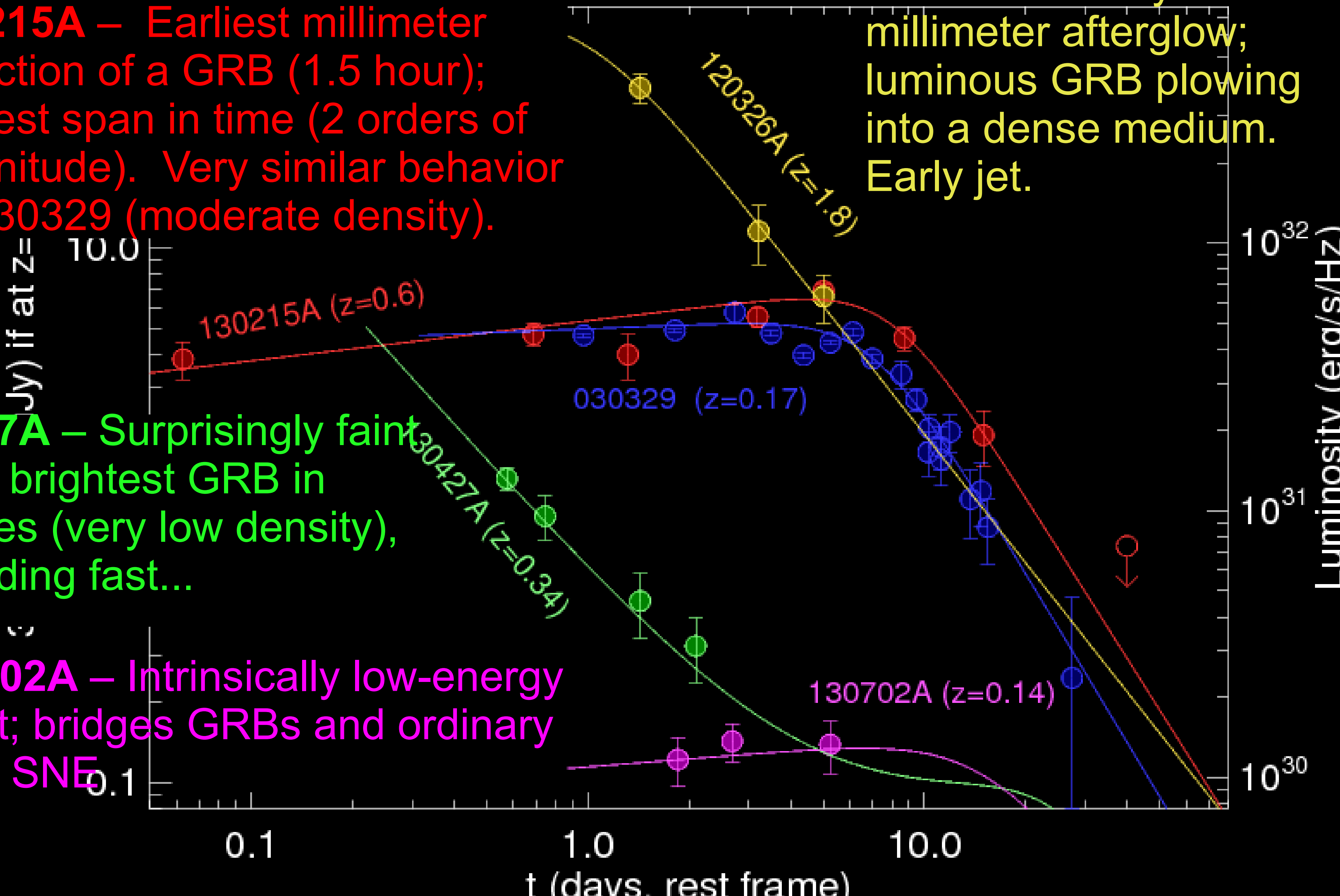
Recent CARMA GRBs

130215A – Earliest millimeter detection of a GRB (1.5 hour); longest span in time (2 orders of magnitude). Very similar behavior as 030329 (moderate density).

120326A – Very luminous millimeter afterglow; luminous GRB plowing into a dense medium. Early jet.

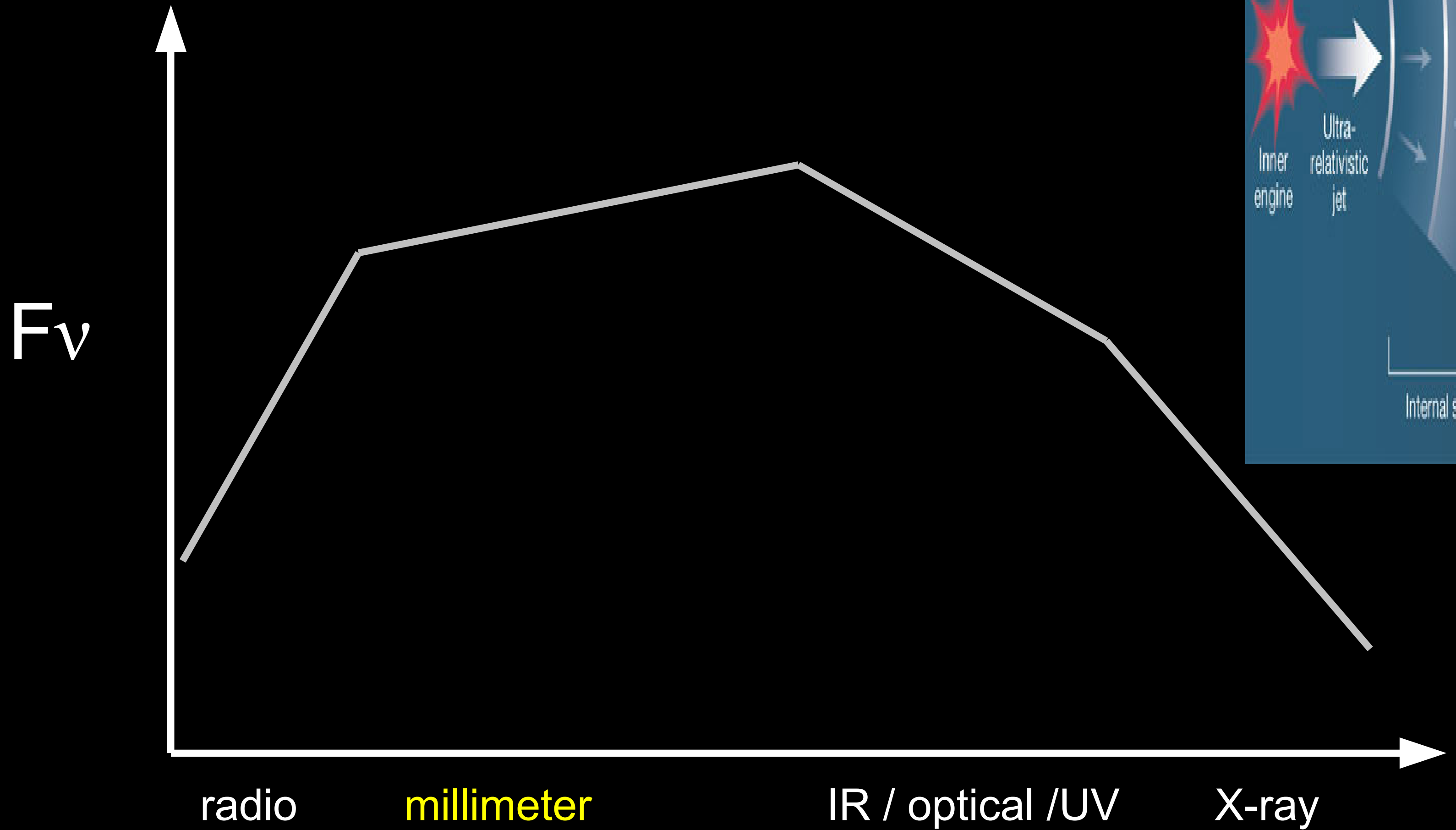
130427A – Surprisingly faint for the brightest GRB in decades (very low density), and fading fast...

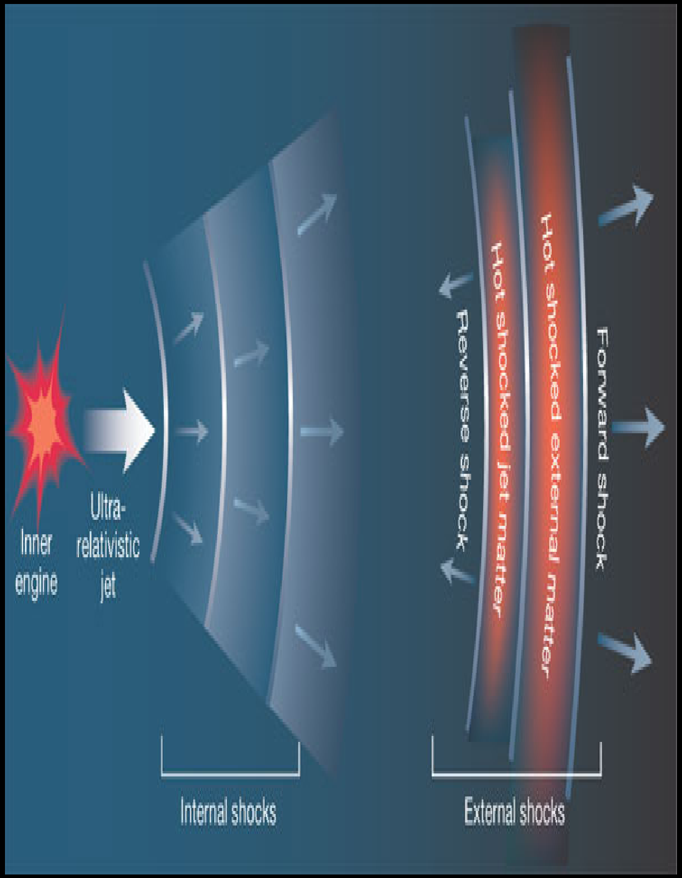
130702A – Intrinsically low-energy event; bridges GRBs and ordinary radio SNE.



The Reverse Shock

A second, even brighter shock is also present!





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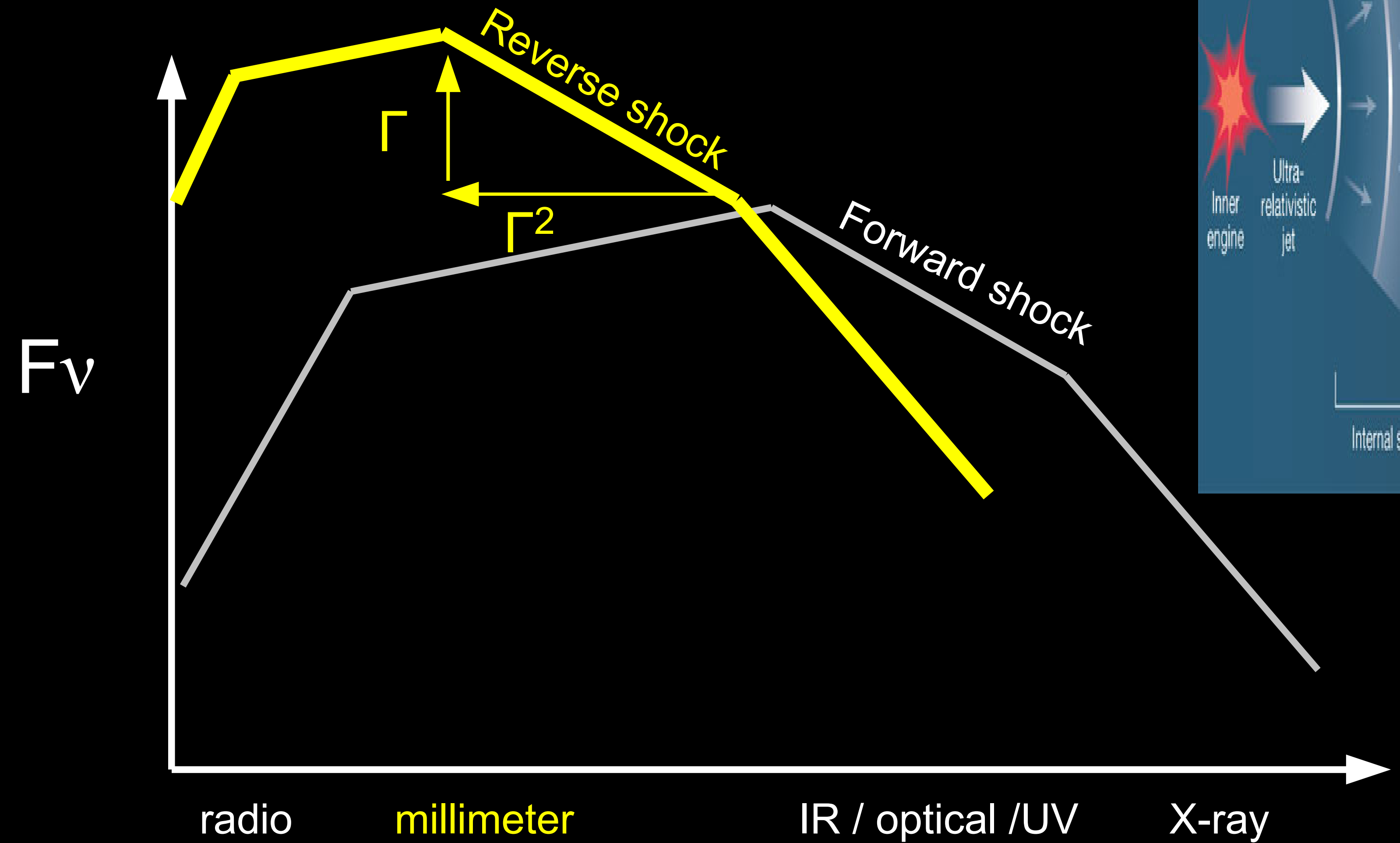

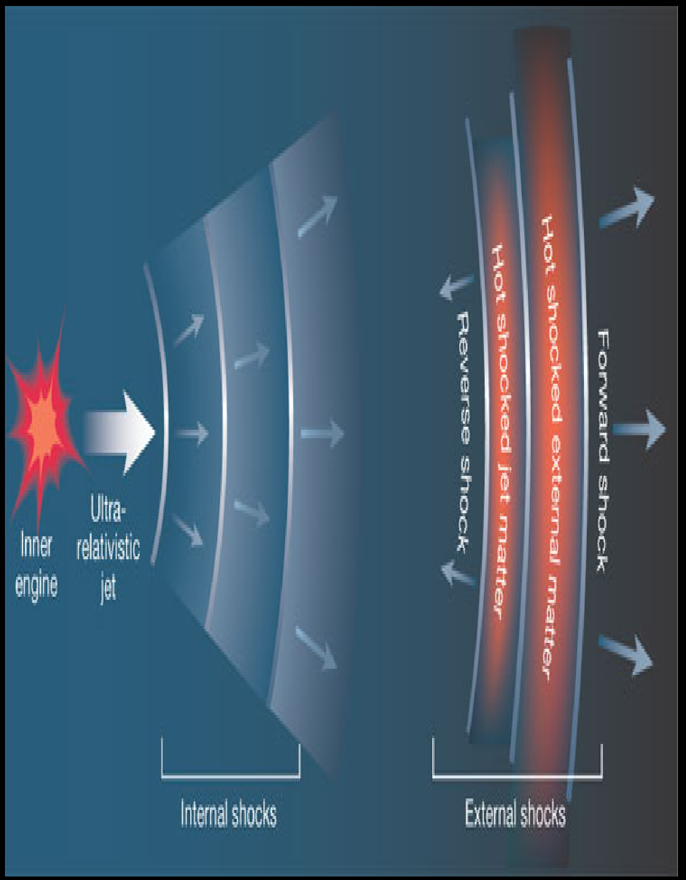

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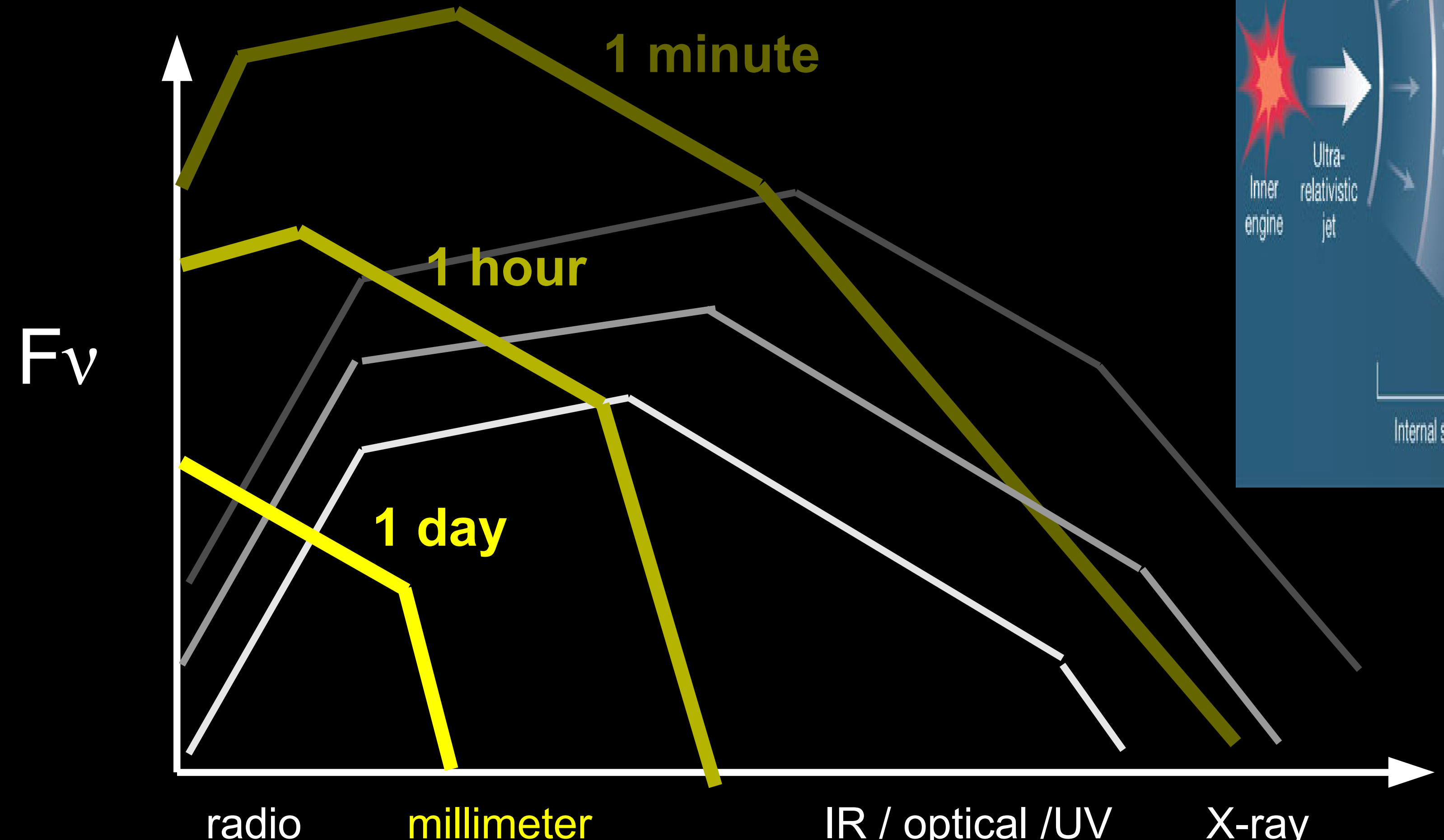
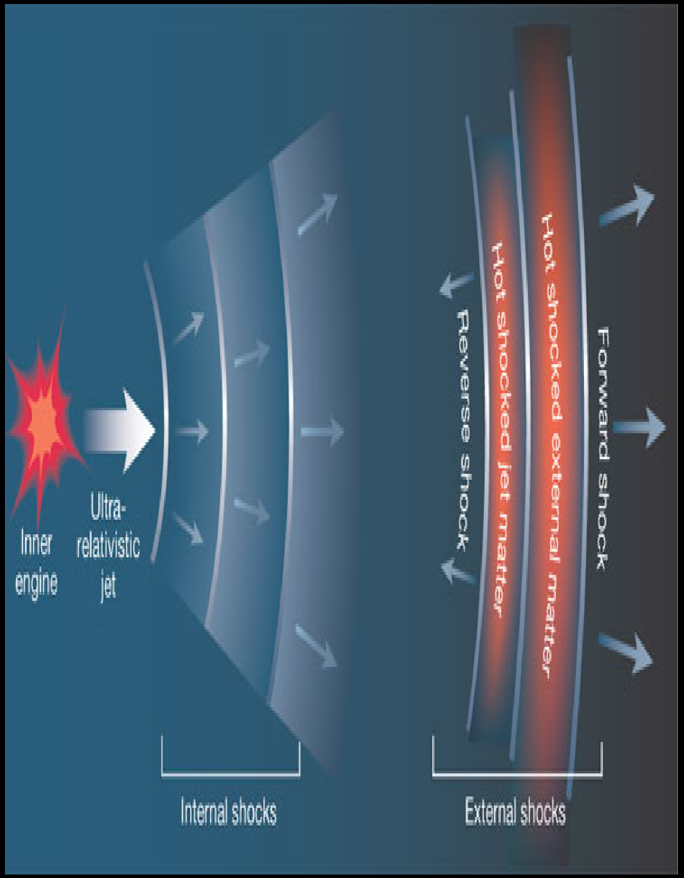
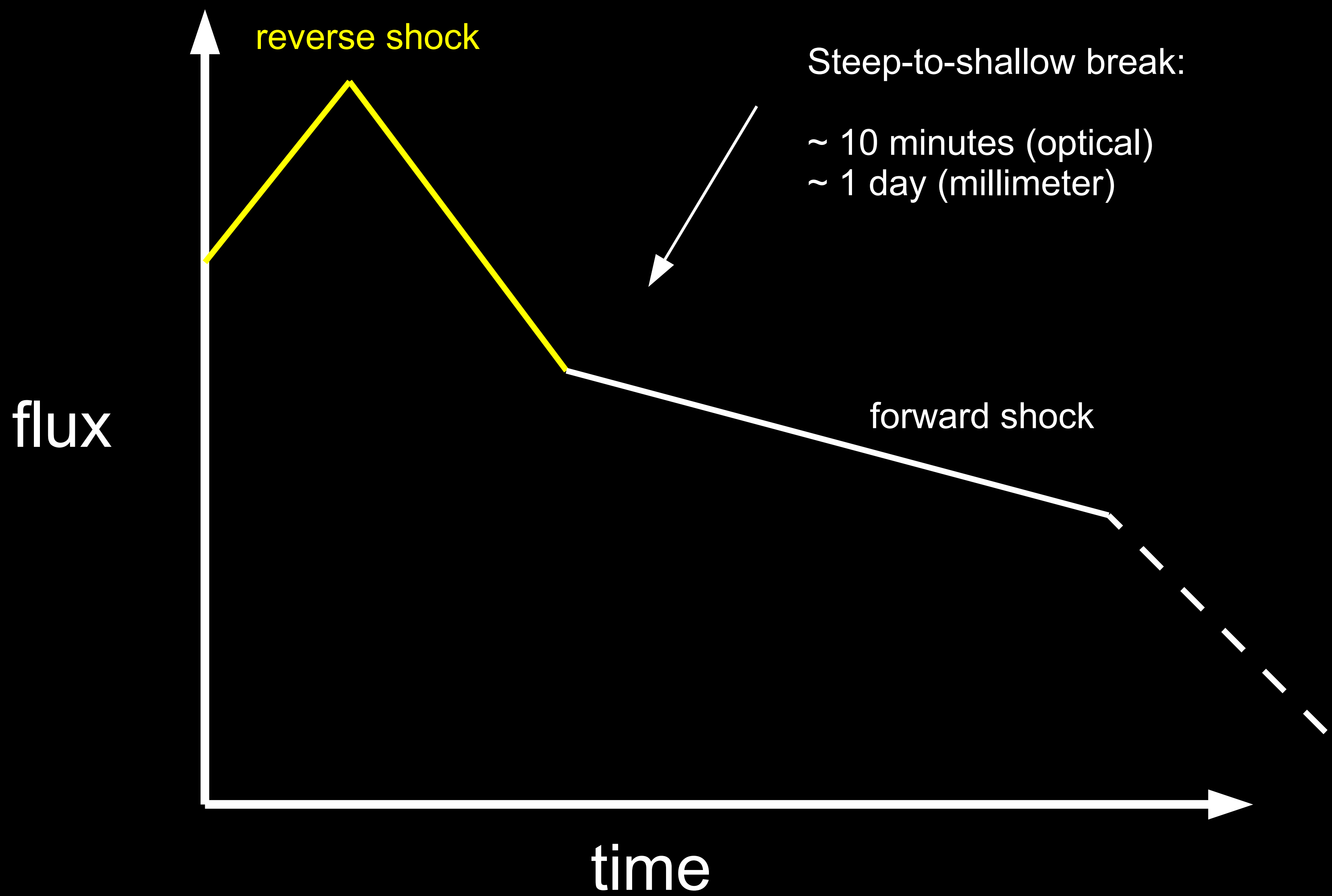
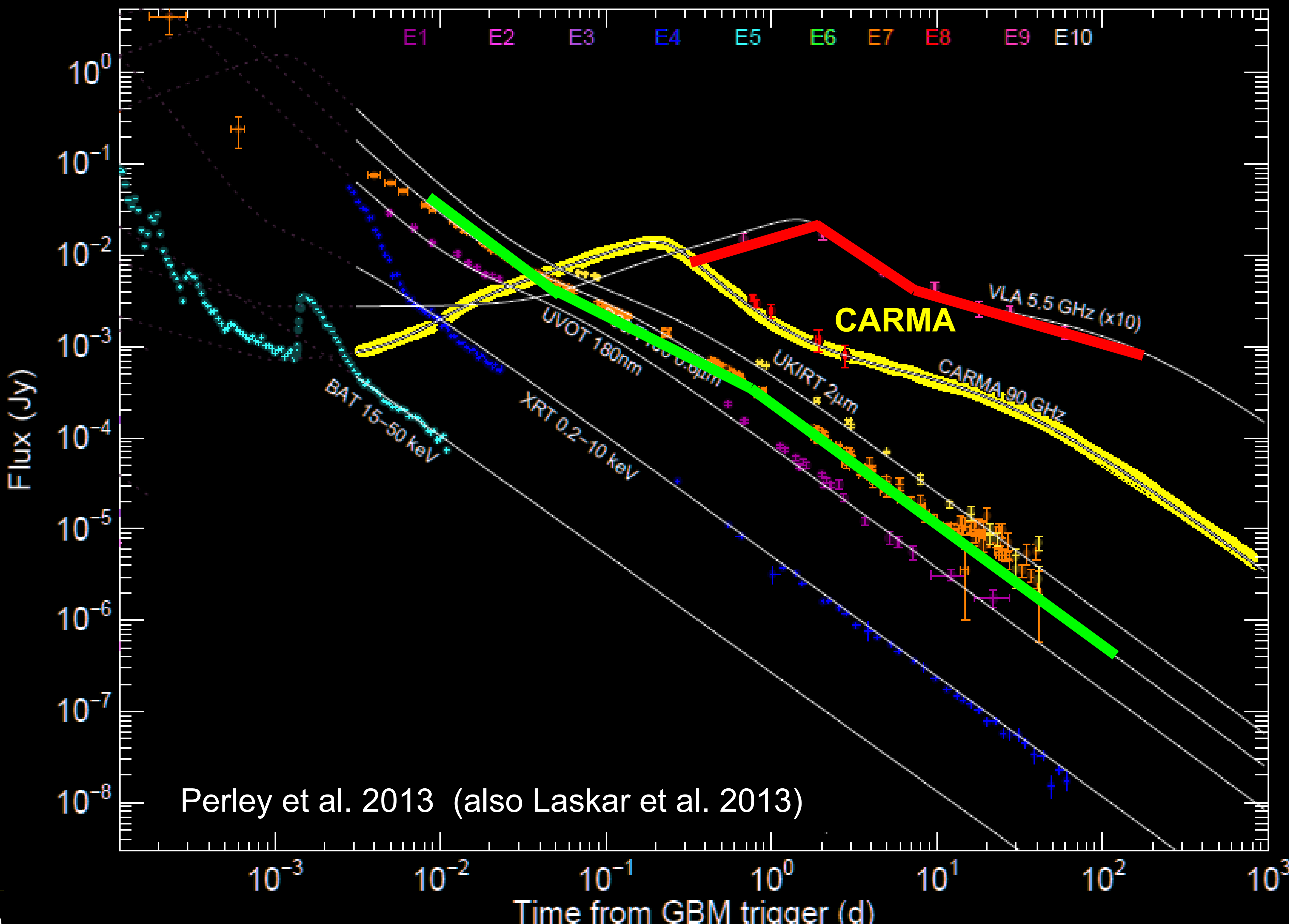




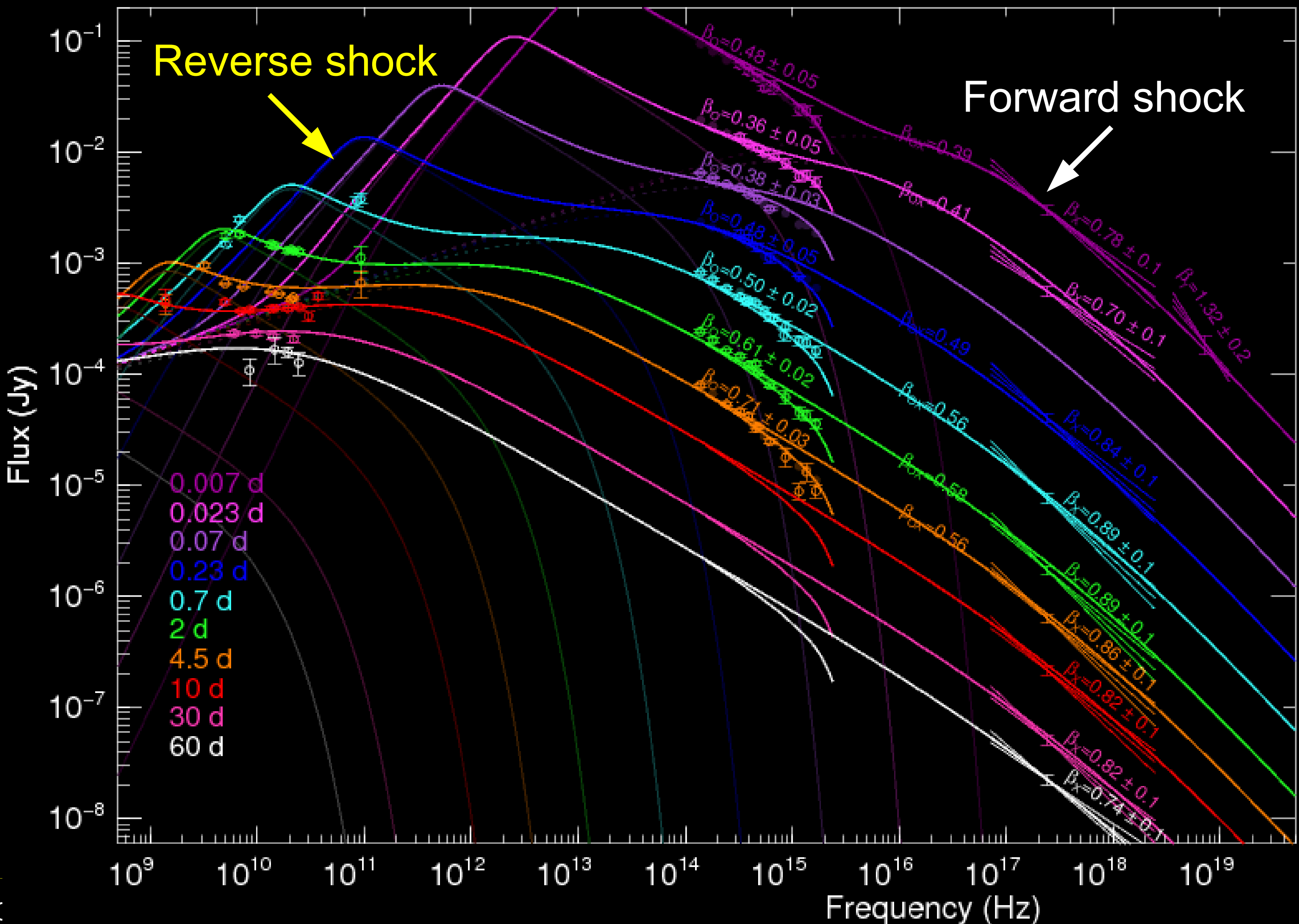
Predicted Light Curve



Light Curves



Time-Evolving Spectral Energy Distribution



Conclusions

Millimeter observations are critical for determining the burst **environment** and **energetics**.

Improved samples of *all types of bursts* (bright, faint, nearby, dust-obscured) are giving a better picture of GRB **demographics**. GRBs are diverse: progenitor can produce strong and weak winds, “slow” ejecta as well as fast ejecta; diversity of explosion energy scales.

Clearest-ever detection of a **reverse shock** in GRB130427A.