GRBs

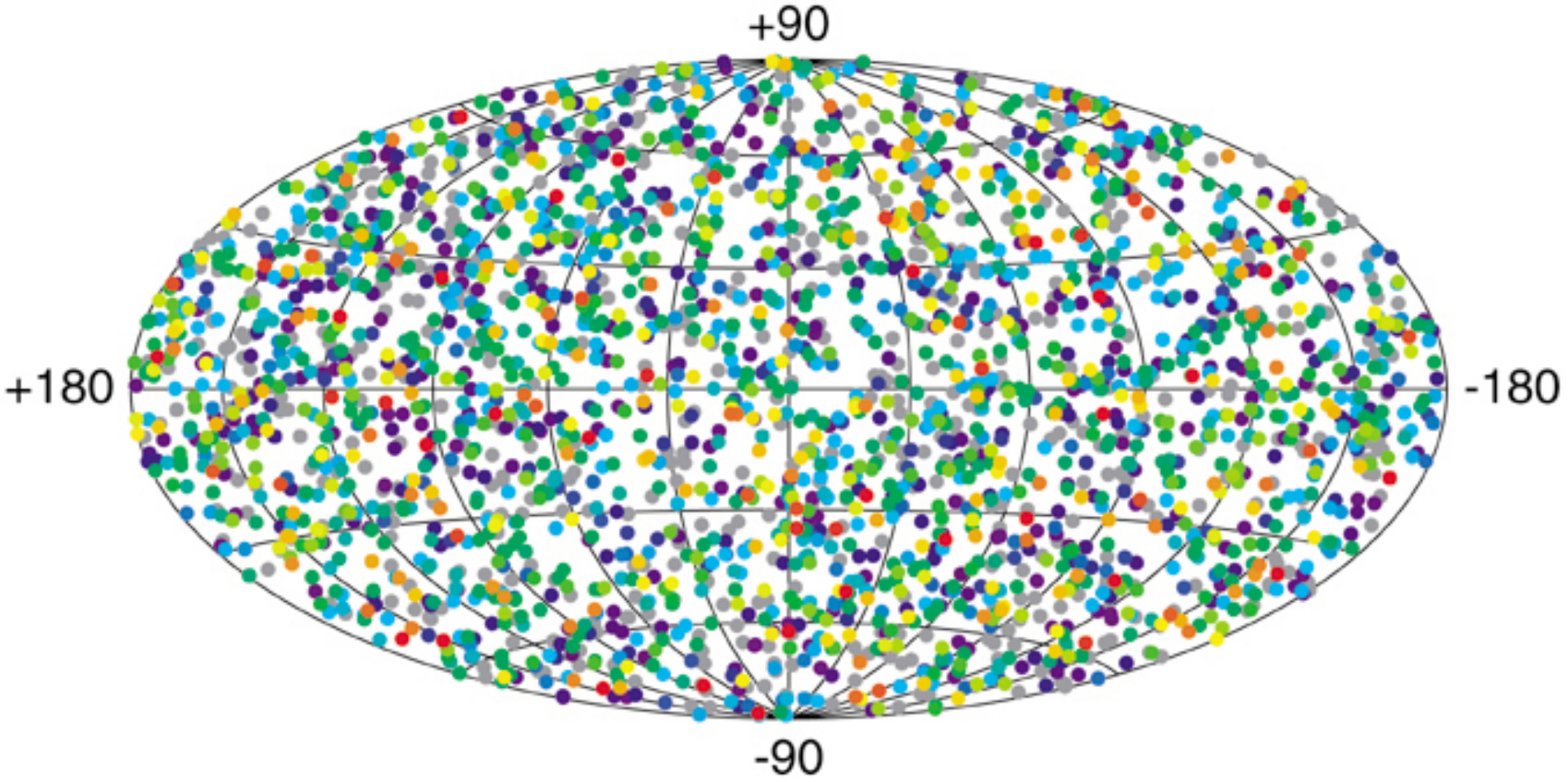
Astrophysical Dynamics

Mohammadtaher Safarzadeh

GRBs: The Very Brief Version

- Humble Beginnings: A Bomb or Not a Bomb?
  - ⇨ Vela Program
- A few hundred events, a few hundred theories
- Finally, science to the rescue
  - ⇨ Compton Gamma Ray Observatory
  - ⇨ BeppoSAX/ROTSE/HST/ (and a host of others)

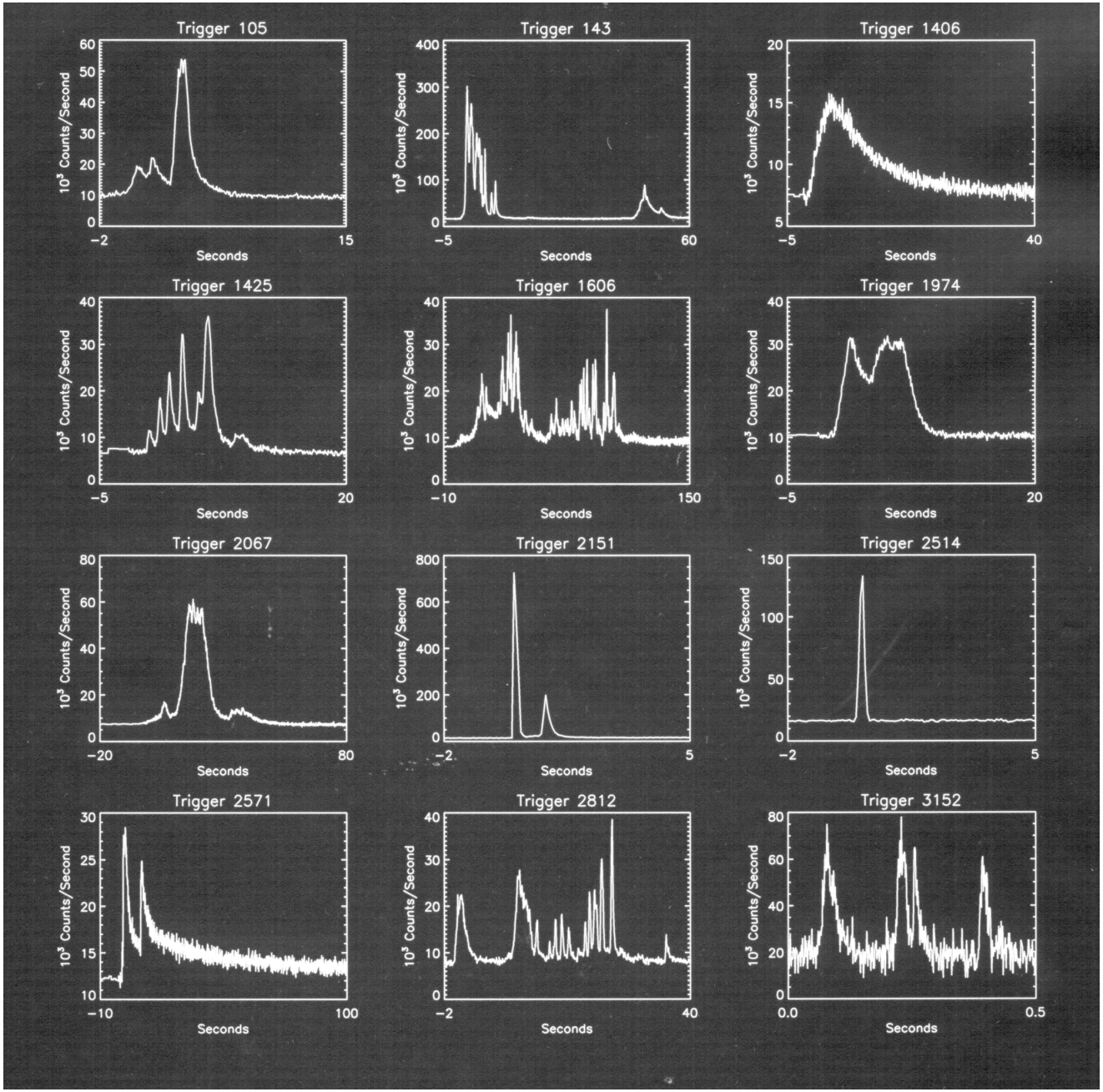
2704 BATSE Gamma-Ray Bursts



Great debate: 1967-1997

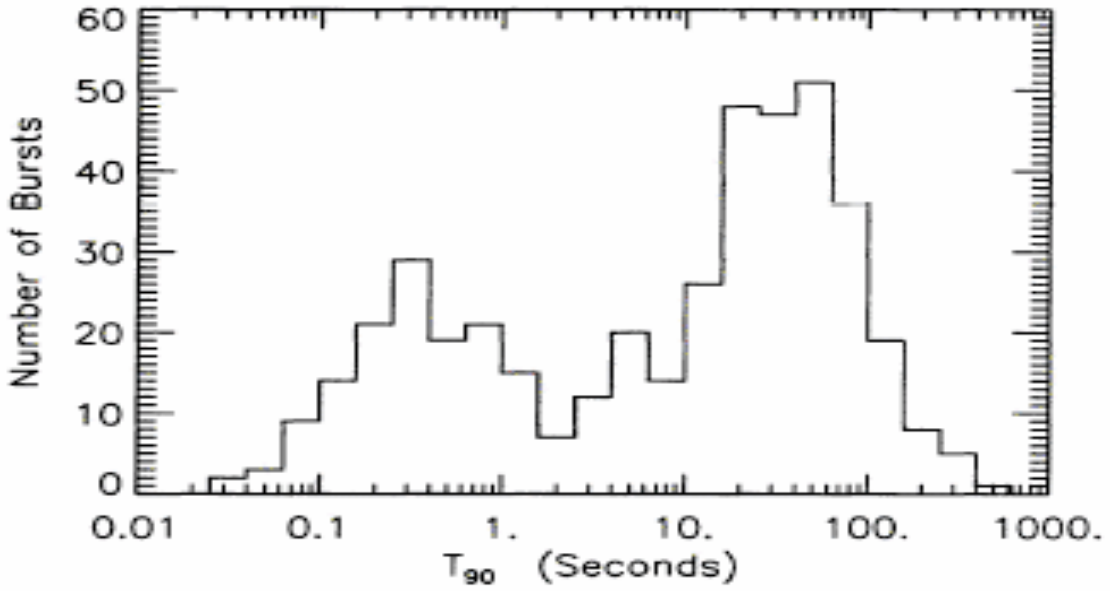
Summary of the Observations of Long GRBs

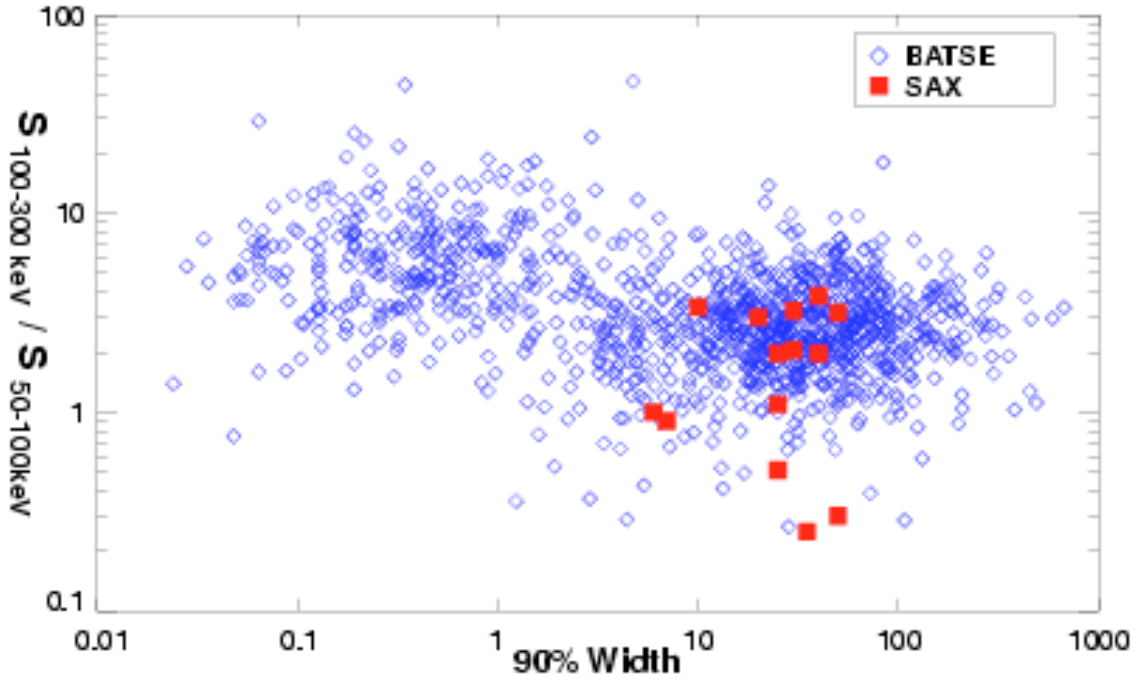
- A “typical” long-duration GRB lasts 20 s in γ-rays from keV to MeV energies
- It takes place in star-forming (spiral or dwarf irregular) galaxies, but not in ellipticals
- It takes place in a galaxy at z ~ 1
- About 10^{51} – 10^{54} ergs of (apparent isotropic) energy are emitted and (apparent isotropic) powers of ~ 10^{50} – 10^{52} ergs/s
- It is followed by long-lived X-ray, optical, and radio afterglow emission


Trigger 105
60
50
40
30
20
10
0
10^3 Counts/Second
−2
15
Seconds
Trigger 143
400
300
200
100
0
10^3 Counts/Second
−5
60
Seconds
Trigger 1406
20
15
10
5
10^3 Counts/Second
−5
40
Seconds
Trigger 1425
40
30
20
10
0
10^3 Counts/Second
−5
20
Seconds
Trigger 1606
40
30
20
10
0
10^3 Counts/Second
−10
150
Seconds
Trigger 1974
40
30
20
10
0
10^3 Counts/Second
−5
20
Seconds
Trigger 2067
80
60
40
20
0
10^3 Counts/Second
−20
80
Seconds
Trigger 2151
800
600
400
200
0
10^3 Counts/Second
−2
5
Seconds
Trigger 2514
150
100
50
0
10^3 Counts/Second
−2
5
Seconds
Trigger 2571
30
25
20
15
10
10^3 Counts/Second
−10
100
Seconds
Trigger 2812
40
30
20
10
0
10^3 Counts/Second
−2
40
Seconds
Trigger 3152
80
60
40
20
0
10^3 Counts/Second
0.0
0.5
Seconds

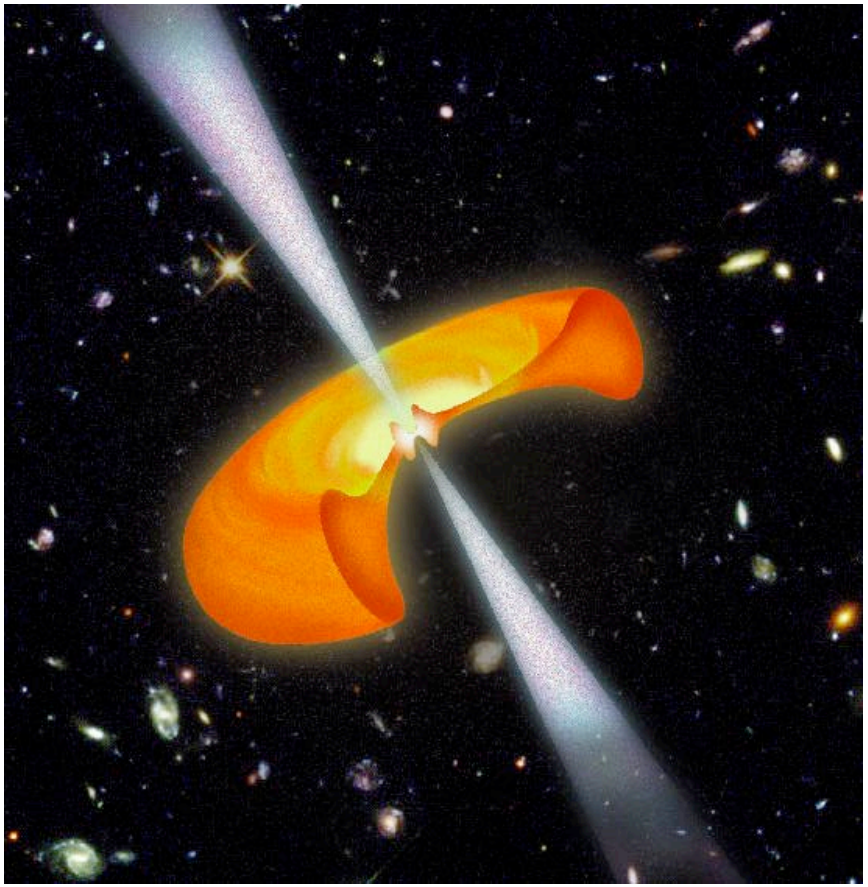
Durations

- Two classes:
  1. Short: T_{90}< 2 s, harder
  2. Long: T_{90}> 2 s, softer

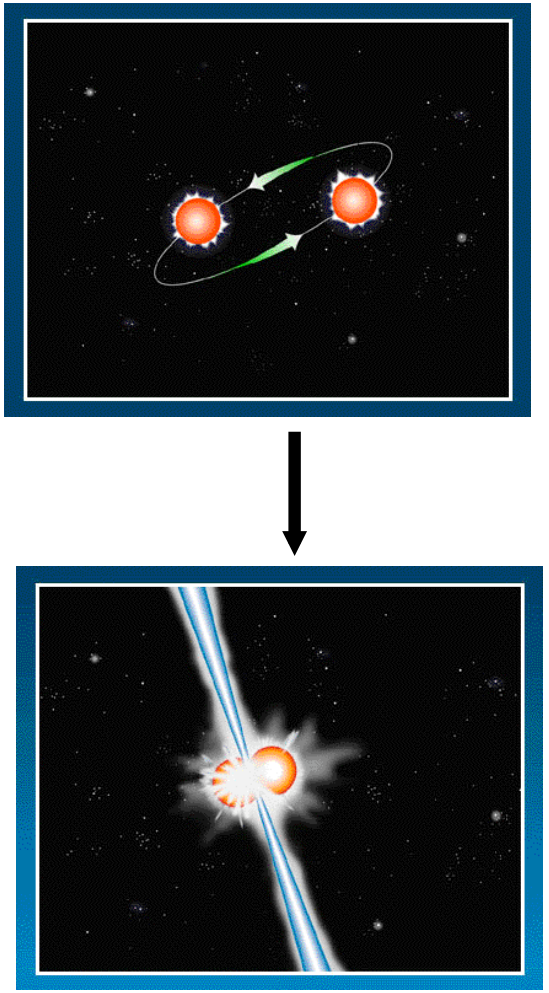




Models for GRBs



Hypernova



Merging Neutron Stars

Core collapse vs. Mergers

HYPERNOVAE

- Collapse of a >30 $M_{\odot}$ star
- Massive stars like these are born with low velocities and live for only ~10^6 y
- When they explode, they are still in their host galaxy, in dusty, star-forming regions
- Long GRBs are indeed found close to the centers of their host galaxies
- ISM density allows shock formation
- Host galaxies are still forming stars

MERGING NEUTRON STARS

- A binary neutron star system may be born with a high kick velocity, > 200 km/s
- The system loses orbital energy by gravitational radiation
- Merger takes place in 10^8 – 10^9 y
- By then, the system may be outside the galaxy where it was born
- The tenuous medium might not allow strong shock formation, and therefore the production of intense afterglows
- The host galaxy might not be forming stars at a high rate any more

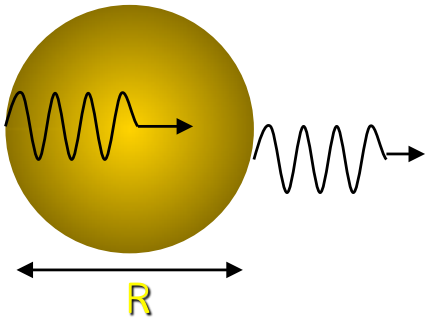
Beaming of GRB Emission

- Beaming into a cone of 5-10° decreases the gamma-ray energies by two orders of magnitude, to ~10^{51} erg
- It also increases the total burst rate by the same factor, but this does not contradict anything we know about star formation and evolution
- How to obtain large energy releases, large luminosities, short variability time scales?
- How does the kinetic energy of the ejecta get converted to electromagnetic radiation?
- Fireball/blast wave model

Compactness problem

- $\delta T \leq .1$ sec $\Rightarrow$ maximum size of the source $R \leq c\delta T = 3\ 10^9$ cm.

- $E \cong 10^{51}$ ergs.

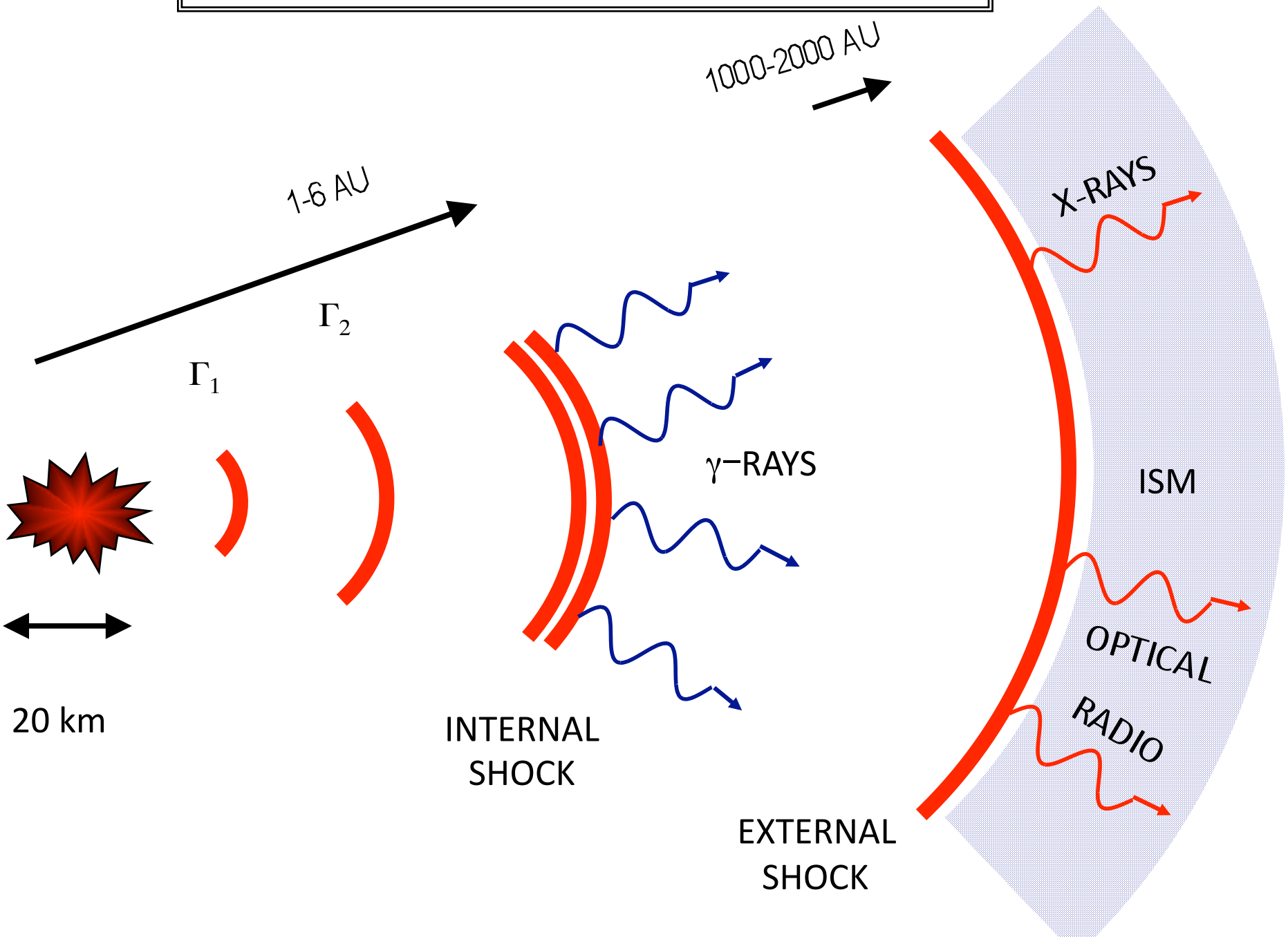


Due to the large photon density and energy $\gamma\gamma \rightarrow e^+e^-$

Expected thermal spectrum and no high energy photons

? ?

Fireball/Blast Wave Model



What are the X-Ray Flashes?

- If XRFs are another manifestation of long GRBs, then are they

1. GRBs at high redshift?
2. GRBs observed away from the jet axis?
3. Explosions with less relativistic ejecta?

- We have fairly complete data on one XRF (XRF020903, z=0.251); in this case, the answer is compatible with 3 (Soderberg et al. 2004)

- Amati relation gives evidence that XRFs and GRBs are part of the same family

GRB/Supernovae Rates and Energetics

	GRBs	SUPERNOVAE
UNIVERSE-WIDE RATE	100 - >1000/day	100000/day (all types) 1000-10000/day (Ic)
RATE PER GALAXY	$1/10^5$ years	1/50-100 years
ENERGY	10^{51-52} erg	10^{51-52} erg