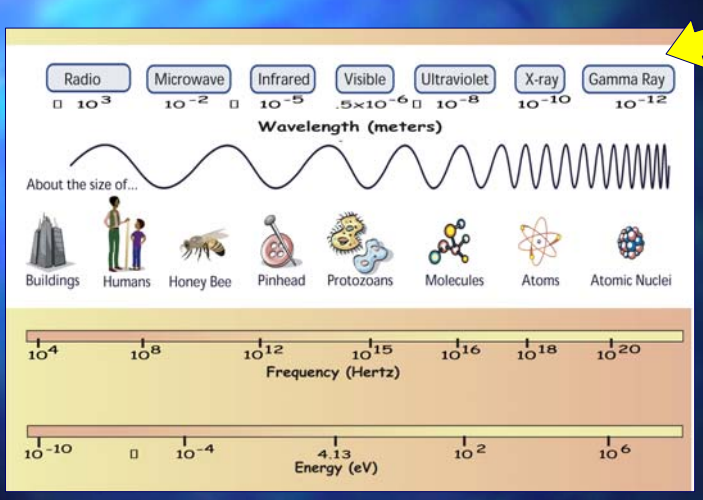
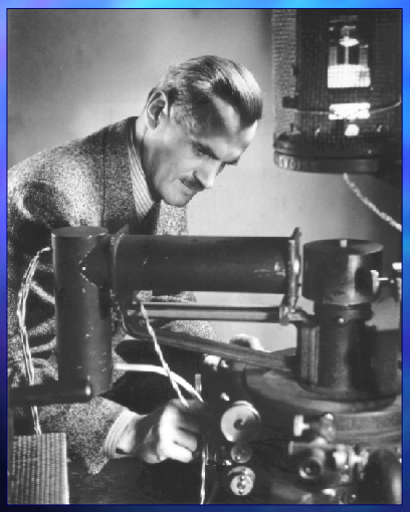
Gamma-Ray Bursts

A Detective Story

Invisible Astronomy



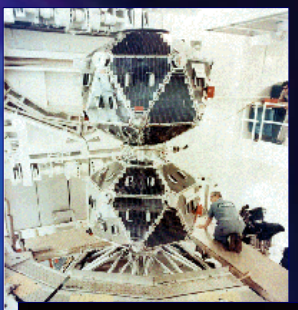
Arthur Holly Compton



- Nobel proze in 1927 for the measurements of photon-electron interaction (Compton effect)
- First experimental evidence of the photon's wave-particle behaviour

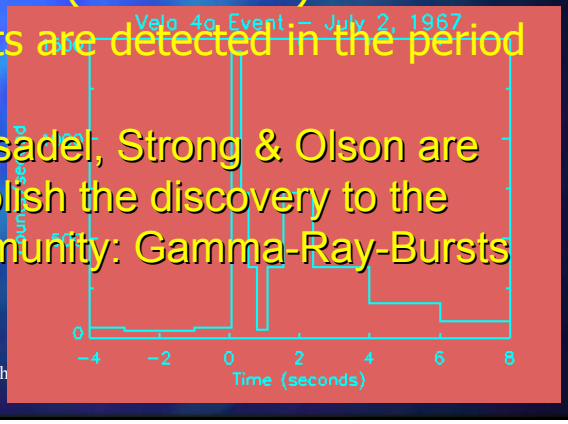
VELA satellites

- In 1960 a US fleet of satellites is put into orbit in the framework of nuclear test controls
- Multiple satellites to register coincidences in the gamma ray band
- Poor accuracy in orbit reconstruction



First bursts

- In 1969 data of a 1967 detection of a few seconds non-terrestrial burst of gamma rays are released (declassified)
- Other 16 bursts are detected in the period 1969 - 1972
- In 1973 Klebesadel, Strong & Olson are allowed to publish the discovery to the scientific community: Gamma-Ray-Bursts (GRB)

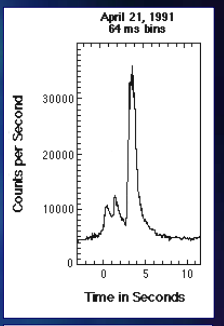


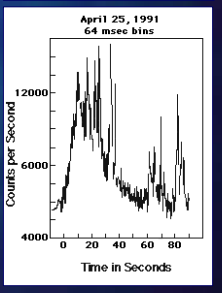
What are they ?

- In the 1970 gamma ray astronomy was still young
- The distance problem: were these bursts emitted by nearby or by far-away sources ?
- No way to establish distances
- The poor accuracy in defining the arrival direction of arriving signals did not allow a clear-cut association of GRBs with known astrophysical objects
- The short duration of bursts did not allow follow-ups in other spectral bands

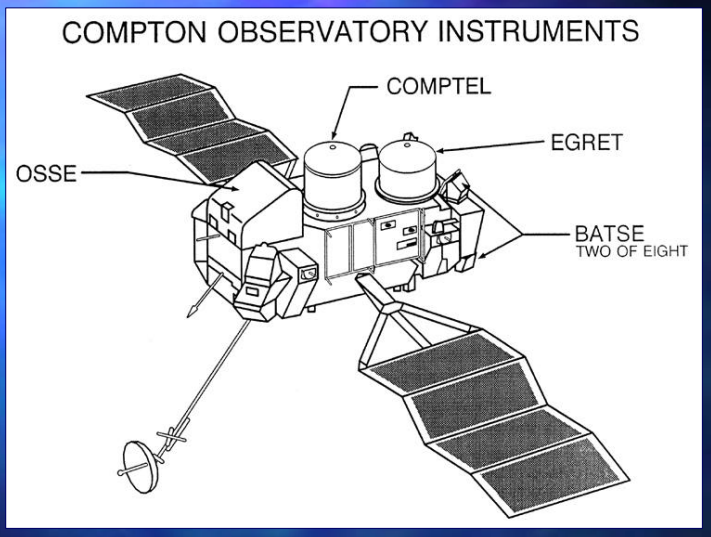
Mistery deepens

- Classes of bursts:
  - Single, regular bursts
  - Complex multi-peaked bursts
  - Short-duration, narrow bursts followed by secondary longer bursts
  - Time scales from 30 msec to 1000 sec

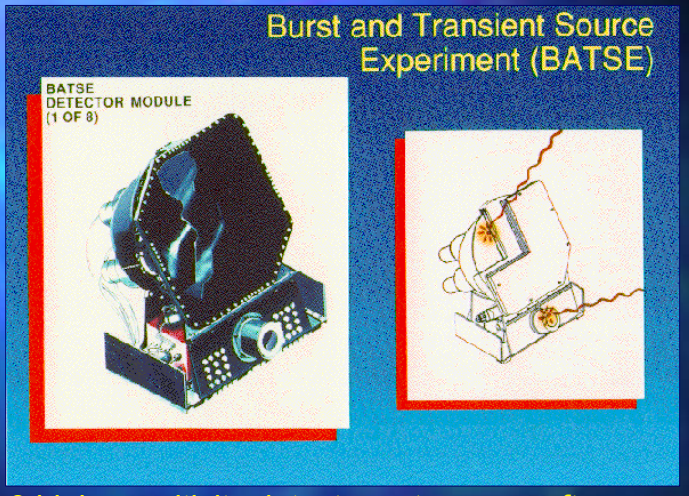




Compton Gamma Ray Observatory CGRO (1991-2000)

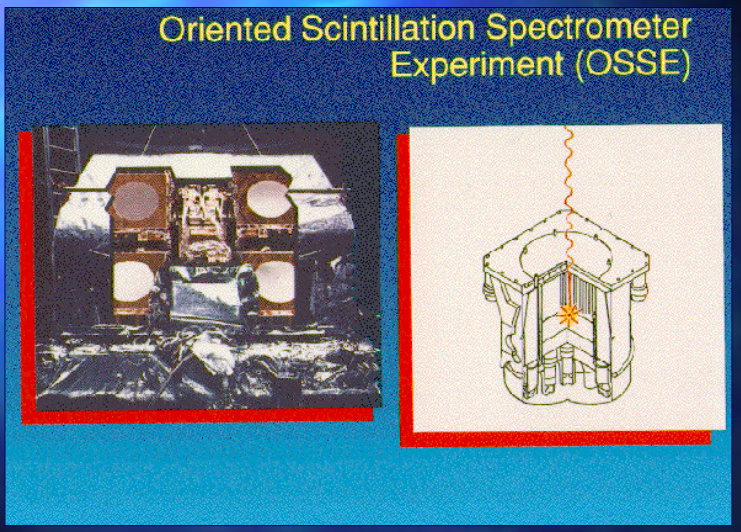


BATSE

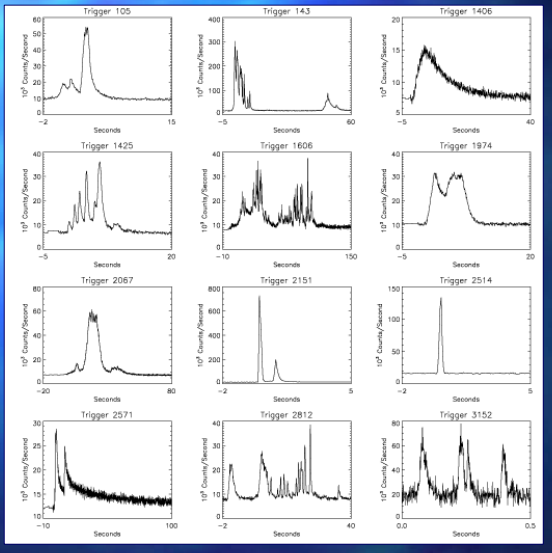


8 high-sensitivity detectors at spacecraft corners with energy resolution and directional response

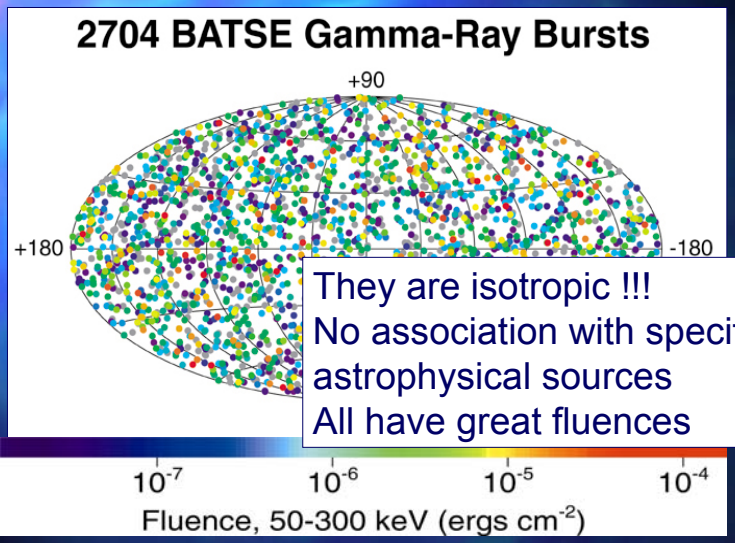
OSSE



The GRB "zoo"



Spatial distribution



They are isotropic !!!
No association with specific astrophysical sources
All have great fluences

Close-by or far-away ?

- Implications of isotropic distribution
  1. In the Solar neighborhood, within the Galaxy:
     - Which sources have an isotropic distribution ?
     - Why no weak bursts ?
     - A nearby origin would require a small energy release: even an asteroid falling onto a netron star would suffice
  2. Far-away, ar cosmological distances:
     - Isotropy would be easily understood
     - Large energies would be required !

The great debate (1995)

Cosmological or Galactic ?

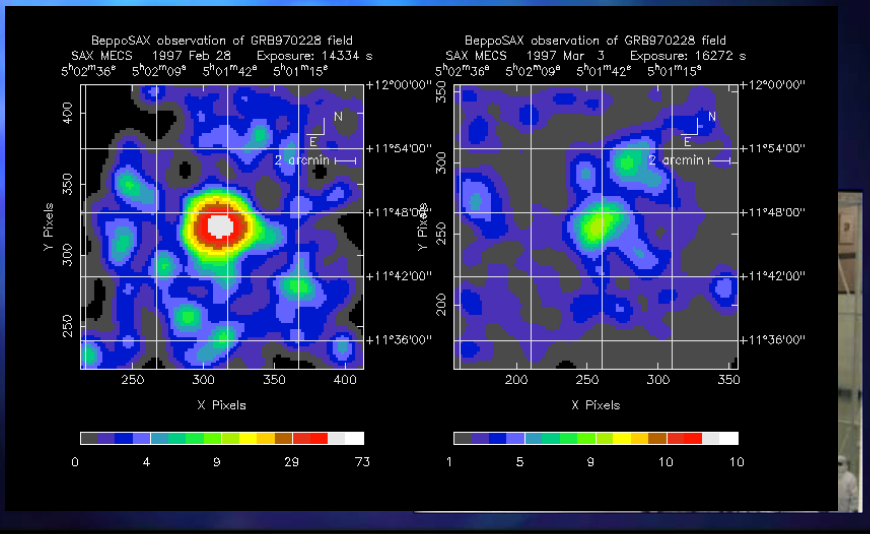
Fluence:
10^{-7} erg cm^{-2} s^{-1}

Distance: 1 Gpc
Energy:10^{51} erg

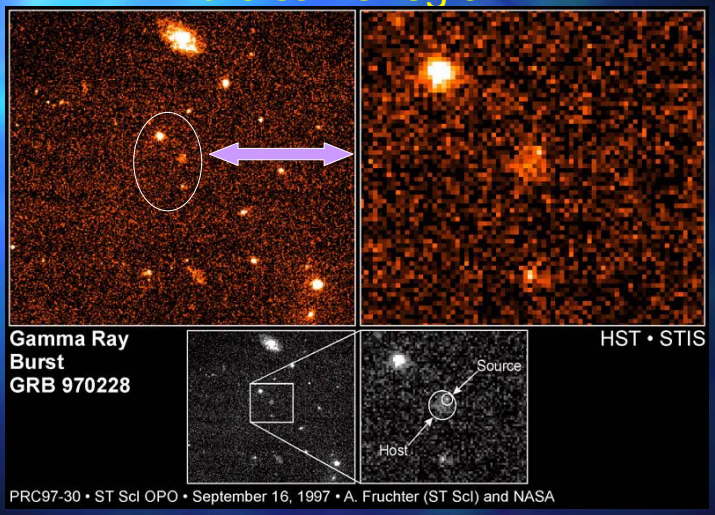
Distance: 100 kpc
Energy: 10^{43} erg

Observations of new type are required

Towards a solution: BeppoSAX and HST



7 months later the Hubble Space Telescope detects optical emission from the same region



- 990123: the first optical afterglow detected by HST immediately after a GRB
- 990123 reaches the 9.0 magnitude
- The GRB is associated with a far galaxy
- The cosmological origin wins !
- Detectable by a small binocular !

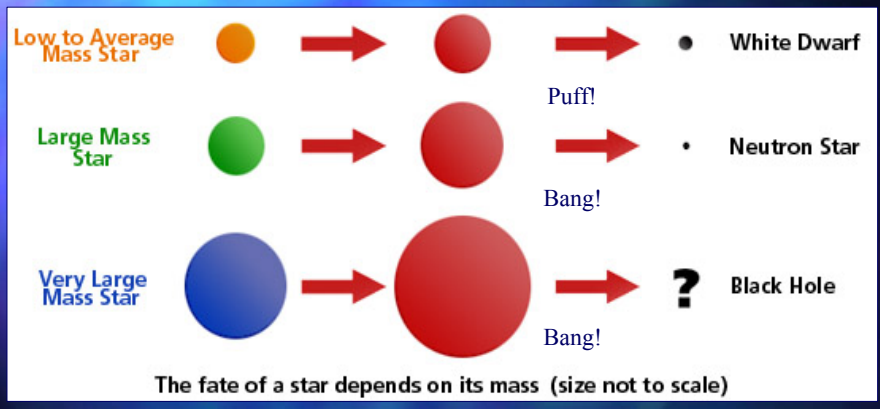
The energy problem

- Where does all that energy in such a short time come from ?
- Models: gravitational energy release

Ipernova
Supranova

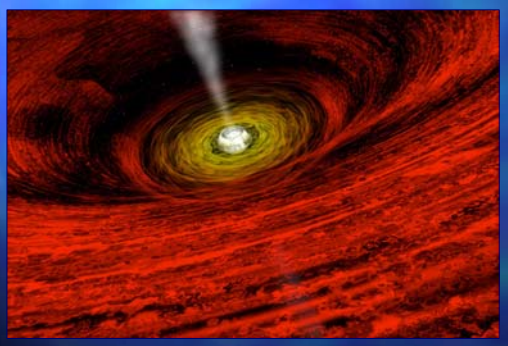
Coalescing neutron stars

Stellar evolution in brief



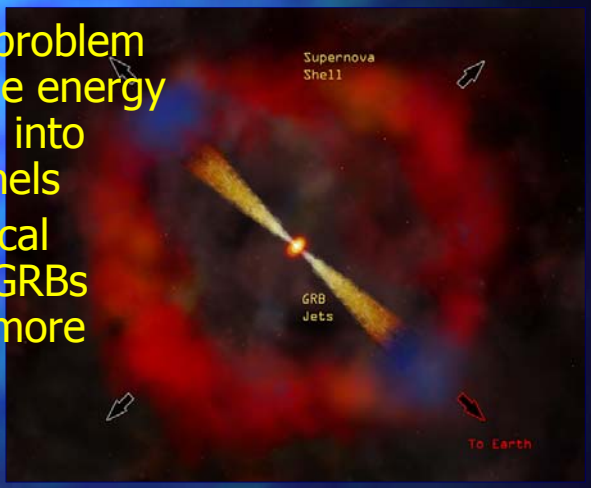
How to make visible black holes

- Accretion disks, gravitational vortices
- Infalling matter releases up to 40% of mass energy: $E \sim 0.4\ mc^2$



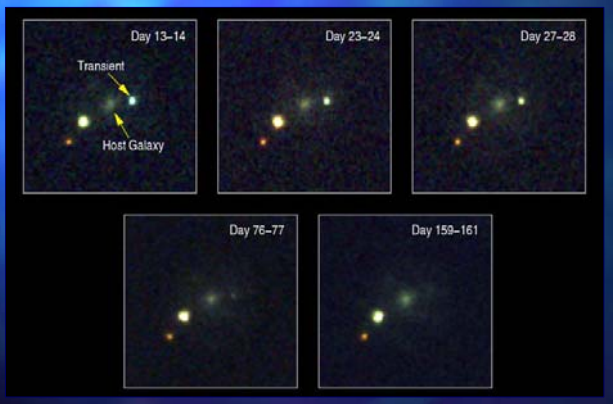
1 candy = 10 kilotons

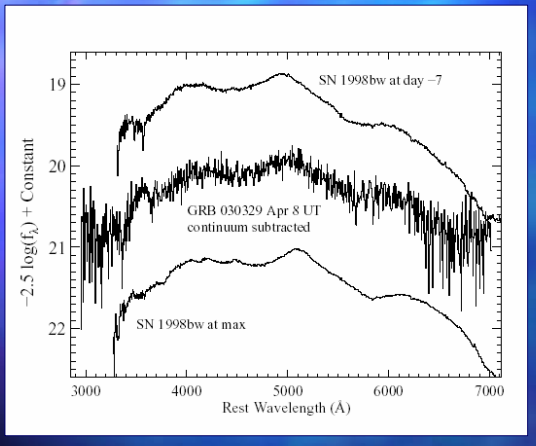
- A supernova ending into a neutron star or a black hole is a GRB candidate
- The energetic problem is reduced if the energy ejection comes into collimated funnels
- But, for statistical reasons, then GRBs must be even more numerous



The Supernova Connection GRB011121

- The optical afterglow shows a decay consistent with a supernova light curve

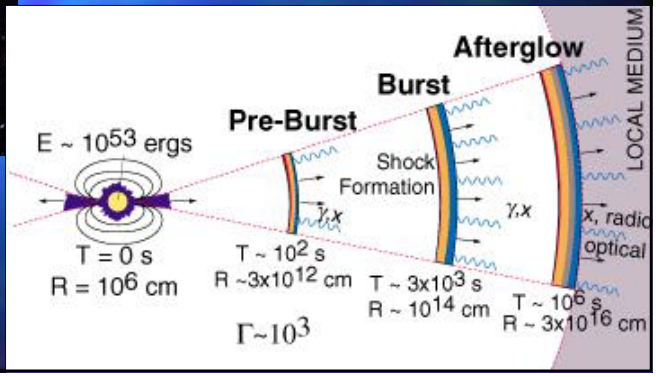




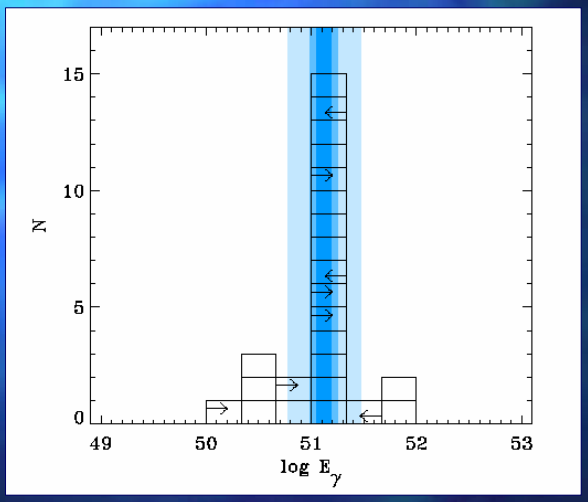
- Some GRB afterglows, after decaying, make the supernova light to emerge

- These observations favor the ipernova model with respect to coalescence
- But more classes of GRBs exist
- Recently fast GRBs appear to be more consistent with neutron star coalescence
- Both classes are associated with violent phenomena in far galaxies leading to the formation of black holes
- The presence of jets and their orientation must be taken into account for estimating the energetics: "relativistic beaming"

Ipernova with jets and shocks



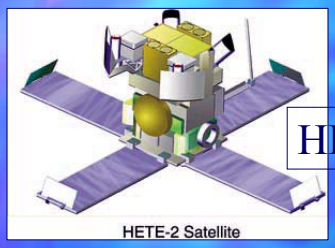
Uniform energetics after correcting for jet beaming



GRBs and cosmology?

- GRBs would be standard candles
- Same energetics: Type IA supernovae and coalescence of neutron stars release Mc^2 ➡ $0.42 \times 2 \times 10^{54}$ ergs
- Distance estimates
- Observations of first stars
- SWIFT, AGILE, GLAST missions

Hunting GRBs



HETE-2

Swift

GLAST

AGILE