Lecture 20 – High-Energy Astronomy

- HEA intro
- X-ray astrophysics – a *very* brief run through.
- Swift & GRBs
- 6.4 keV Fe line and the Kerr metric

Tut 5 remarks

- Generally much better. However:
  - Beam area.
  - T_{inst} vs T_{zenith}
  - Is V significant?
  - arctan(4.04/-1.16)
  - Faraday rotation

High-Energy Astronomy

- Means x-rays and gamma rays.
- It's convenient at this end of the spectrum to concentrate on the particle part of the quantum wave-particle duality.
  - So we usually talk about the energy of the photons which make up the radiation, rather than their wavelength or frequency.
  - A convenient energy unit is the electron volt (eV).
  - Confusingly, x-ray fluxes are often cited in ergs.
    - 1 eV ~ 1.6 $\times 10^{-19}$ joules ~ 1.6 $\times 10^{-12}$ ergs.
  - From $E=h\nu$, 1 eV ~ 2.42 $\times 10^{14}$ Hz.

High-Energy Astronomy

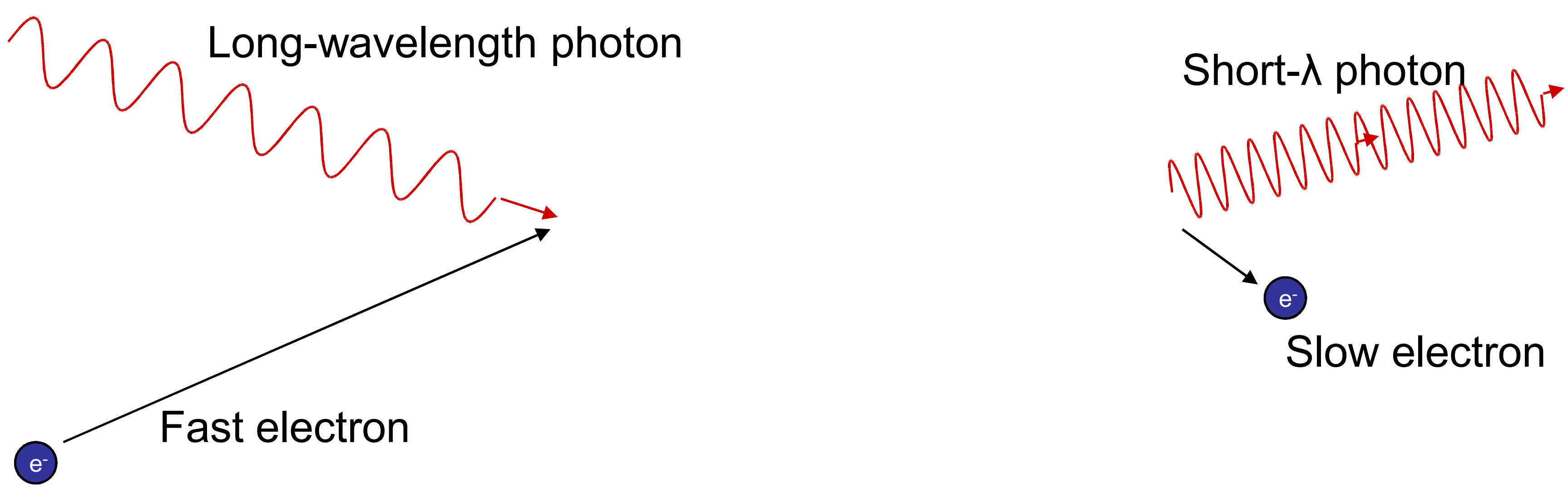
- X-rays: roughly speaking, from ~100 to ~10^5 eV.
  - We speak of hard (= high energy) vs soft x-rays.
- Gamma: anything higher.
- Physical sources: as the name ‘high energy’ implies, very energetic events tend to generate x-rays and gamma rays.
  - Thermal radiation if the temperature is >10^6 K – eg:
    - the sun’s corona (➔ soft x-rays)
    - Black Hole accretion disk (➔ hard x-rays)
  - Nuclear fusion (➔ soft x-rays)
  - Matter falling into a gravity well.
    - Supernova (➔ hard x-rays, gammas)
    - GRB (?) (➔ gamma rays)
- It is interesting that radio and x-ray images often follow similar brightness distributions.
  - Because hot plasma ➔ relativistic synchrotron emission.

X-ray astrophysics

- Most sources appear to be compact – previously it was thought that there was diffuse emission both from the Milky Way and from much greater distances; however recent, more sensitive telescopes have resolved most of this into sources.
  - Accretion disks
    - X-ray binaries – small, nearby
    - AGN – large, far away
  - Compact ➔ variable on short time scales.
- Resolved (ie extended, non-compact) sources:
  - mostly clusters – x-rays from hot intergalactic gas.

Emission processes

- Thermal – must have *T* ~ millions of kelvin.
  - Bremsstrahlung from optically thin gas, or
  - Black-body radiation from optically thick gas.
- Synchrotron – ultra-relativistic electrons needed to get synchrotron at x-ray wavelengths.
- Fluorescence (hence narrow spectral lines)
- Inverse Compton scattering:



X-ray spectra:

- Thermal: exponential decrease with *E*.
- Synchrotron, inverse Compton: power-law decrease with *E*.
- All measured spectra show a fall-off at low *E*
  - This is due to photoelectric absorption by gas in the line of sight – mostly H.
  - Depends on the column density N_H in atoms cm^{-2}.
  - Cutoff energy is (very roughly) ~ $3 \times 10^{-9} \times N_H^{0.4}$ keV.

Some spectral lore: (1) Hardness ratios.

- This is a term you will encounter often in the high-energy world.
  - Add up the counts within energy band 1 ➔ C_1;
  - add up the counts in band 2 ➔ C_2;
  - the hardness ratio is defined as

$$\mathrm{HR} = \frac{C_2 - C_1}{C_2 + C_1}$$

- Clearly confined to the interval [-1,1].
- It is a crude but ready measure of the spectral properties of the source.
- Uncertainties are often tricky to calculate.

Some spectral lore: (2) Photon index.

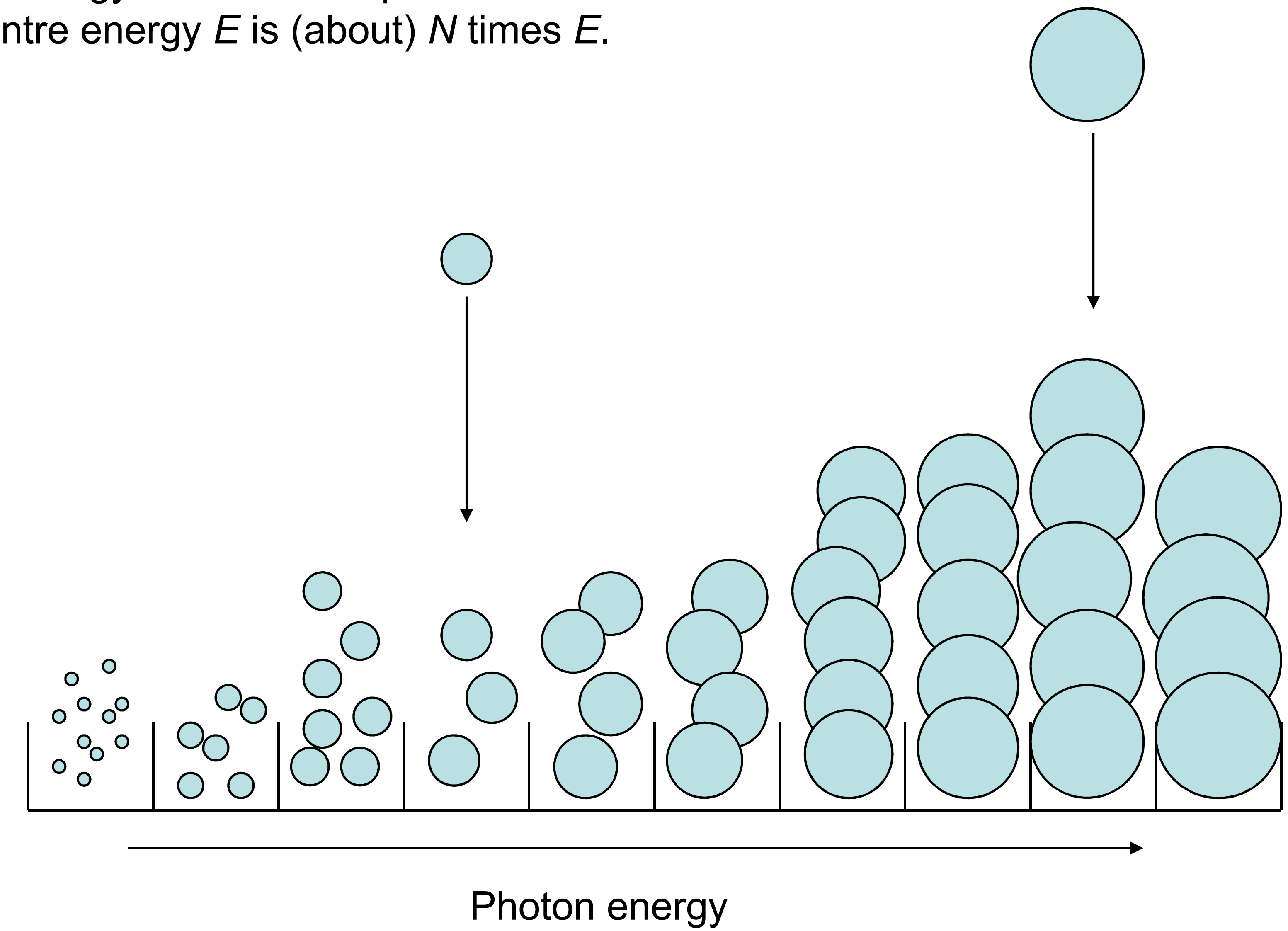
- Suppose a source has a power spectrum, ie

$$S(E) = S_0 E^{\alpha}$$

- As we know, α is called the spectral index. If we plot log(S) against log(E), we get a straight line of slope α.
- But! Think how we measure a spectrum. We have to count photons and construct a frequency histogram – so many within energy bin foo, etc.

Photon frequency histogram

Total energy *S* of all the *N* photons in a bin of centre energy *E* is (about) *N* times *E*.



Photon index.

- Thus the energy spectrum *S*(*E*) and the photon spectrum *N*(*E*) are related by

$$S(E) = E \times N(E)$$

- Hence, if

$$S(E) \propto E^{\alpha}$$

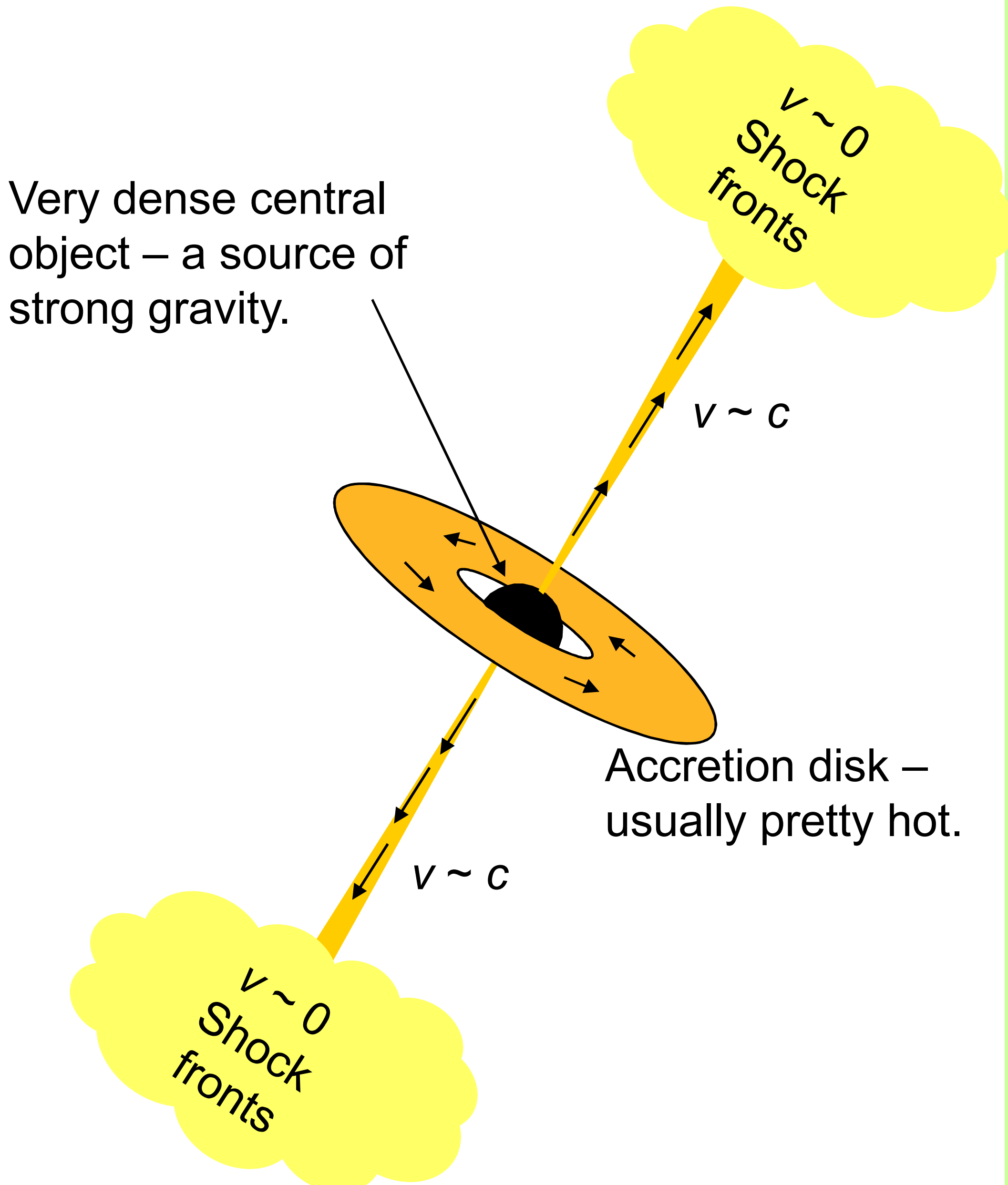
then

$$N(E) \propto E^{\alpha-1}$$

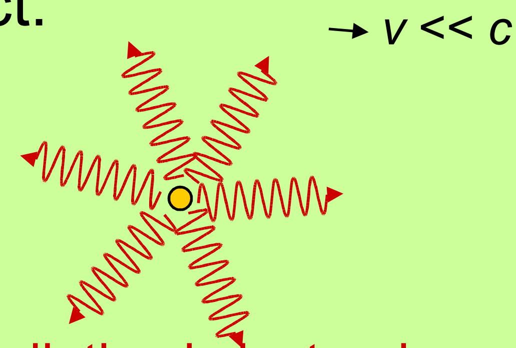
Matters aren't helped by the habit to use eV for the photon energy but ergs for the total energy!

- ➔ photon index is always 1 less than the spectral index.

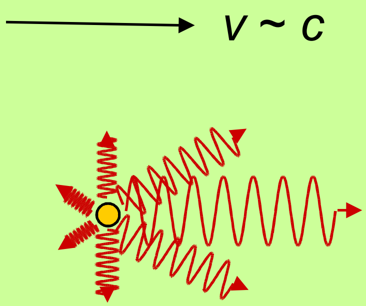
Relativistic jets – x-ray and radio aspects.



- Slowly moving bright object:



  - Radiation is isotropic.
  - 'Normal' Doppler shift.
- Object moving at relativistic speeds:



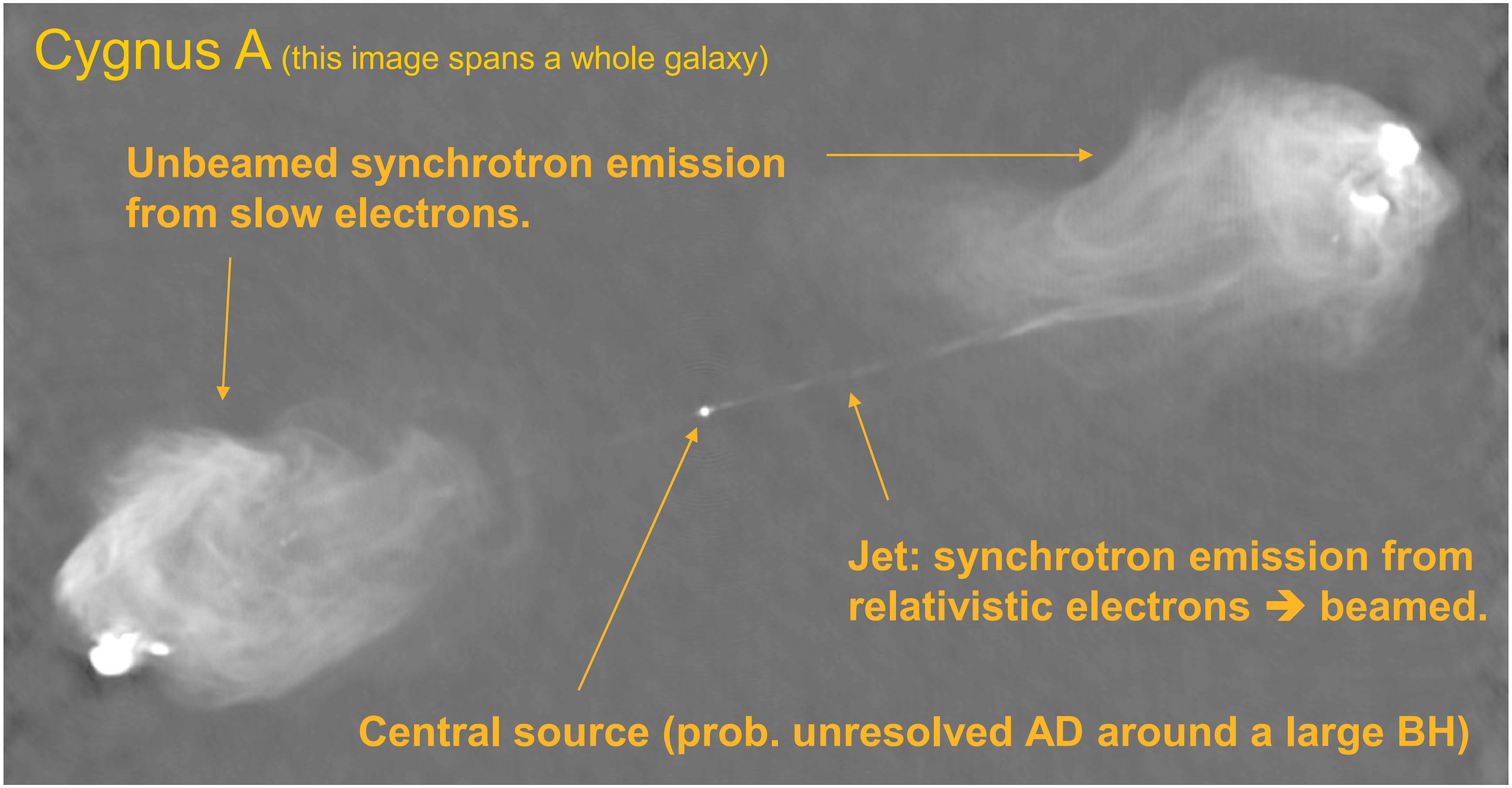
  - Radiation is beamed.
  - + sidewards Doppler.

Relativity?

- The special theory of relativity:
  - – effects of motion.
    - Beaming
    - Sidewards Doppler shift
- The general theory of relativity:
  - – effects of gravity.
    - Gravitational red shift
    - Time dilation

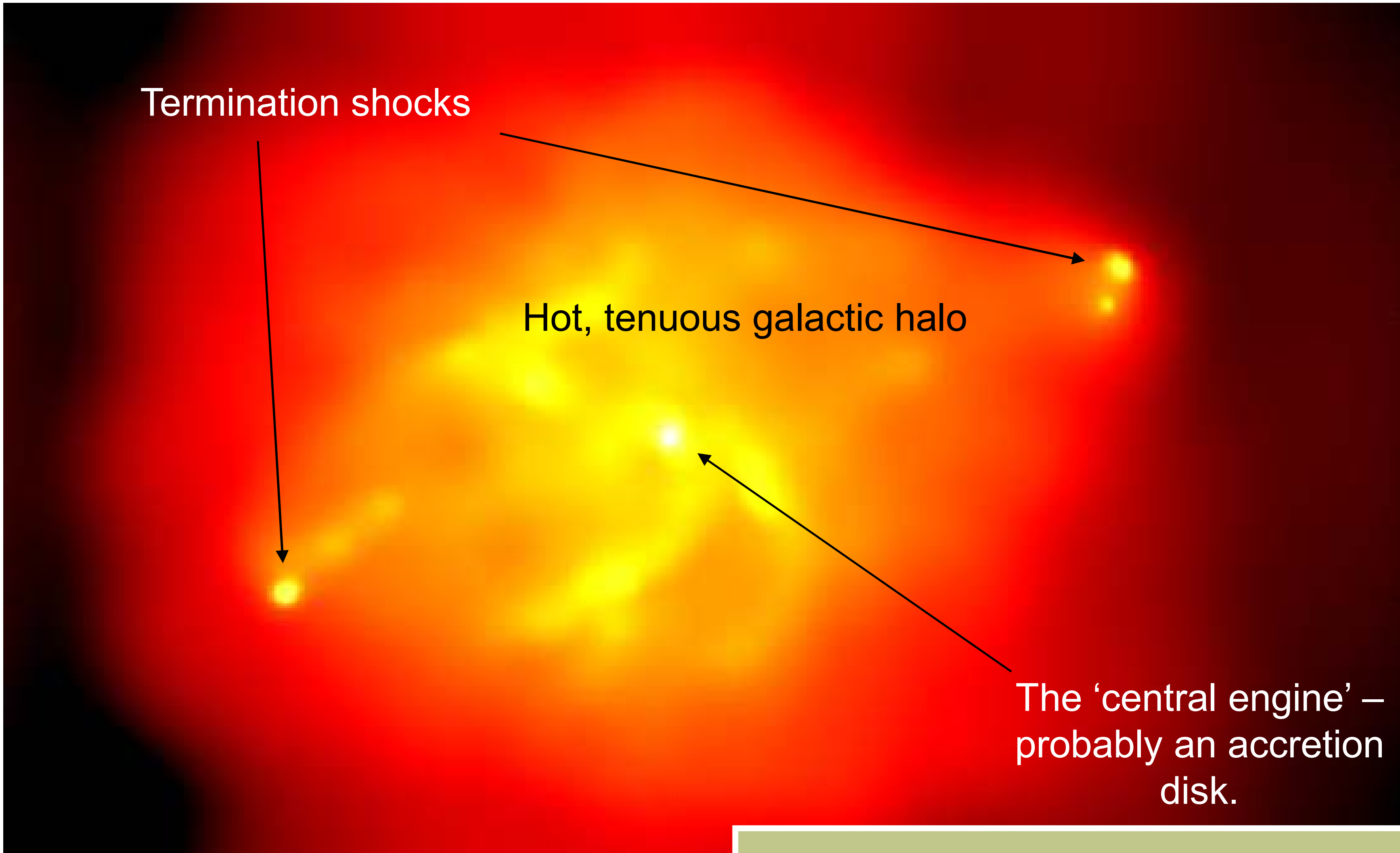
Jet radio emission

Jets are (at least, we think) always symmetrical; but because of relativistic beaming, we only see the jet which is directed towards us (unless both go sideways).



VLA 6 cm radio image.
(Courtesy Dept of Astron, U Colorado)

Cygnus A in x-rays:



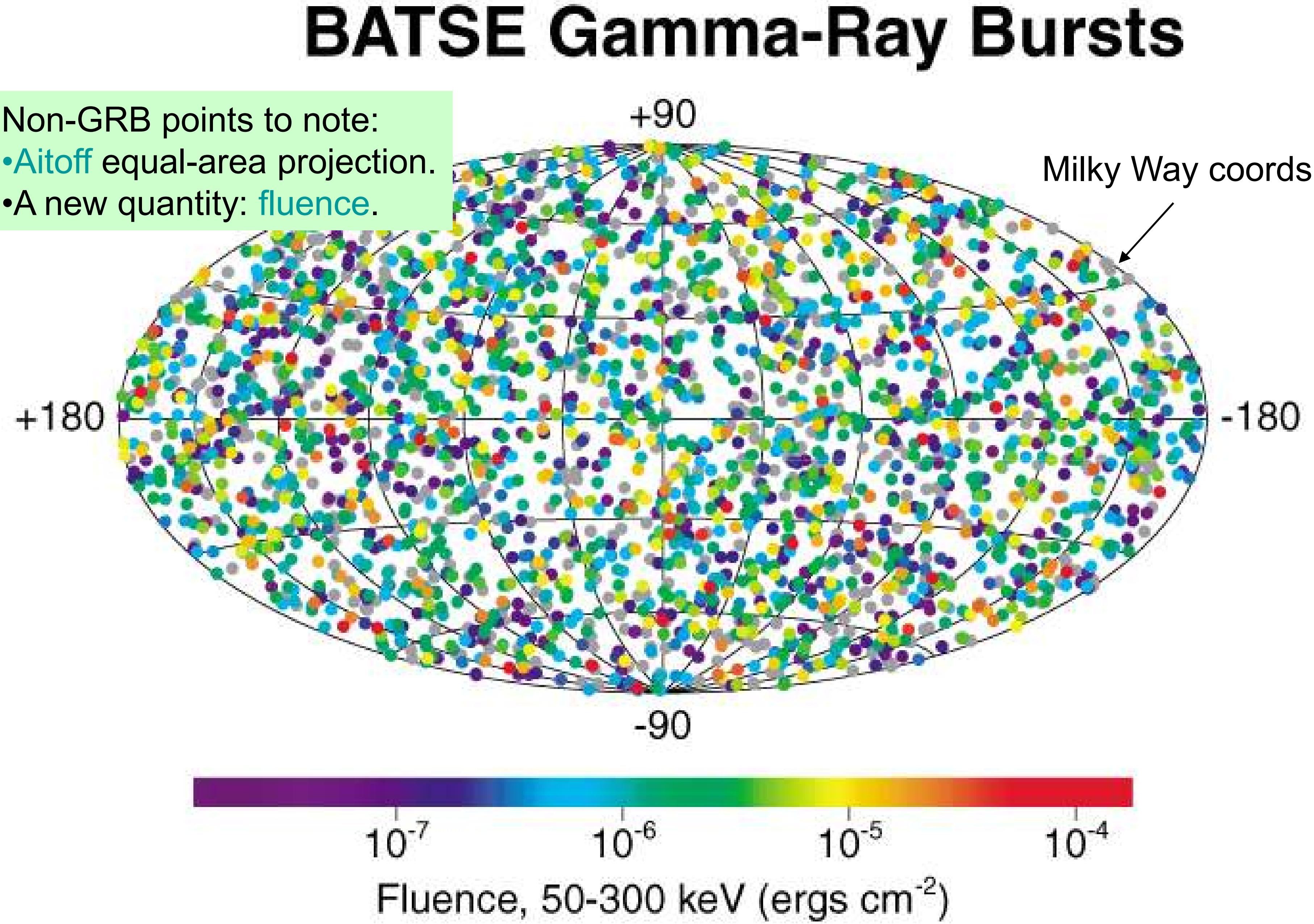
Credit: NASA/UMD/A Wilson et al.

GRBs (Huge thanks to Paul O'Brien for many pictures.)

- History:
  - 1963: VELA satellites launched – intended to monitor nuclear blasts.
  - 1972: VELA archival data on 'non-Earth' detections was examined. ➔ serendipitous discovery of cosmic gamma ray bursts.
    - Indications that burst flux could vary on timescales < 1s ➔ source must be small – must be time for a physical change to propagate across the detector.
  - 1991: BATSE detector of Compton/GRO.
    - Showed that sources were isotropic – NOT what was expected.
      - This means they are either very near by or very far away.

Non-GRB points to note:

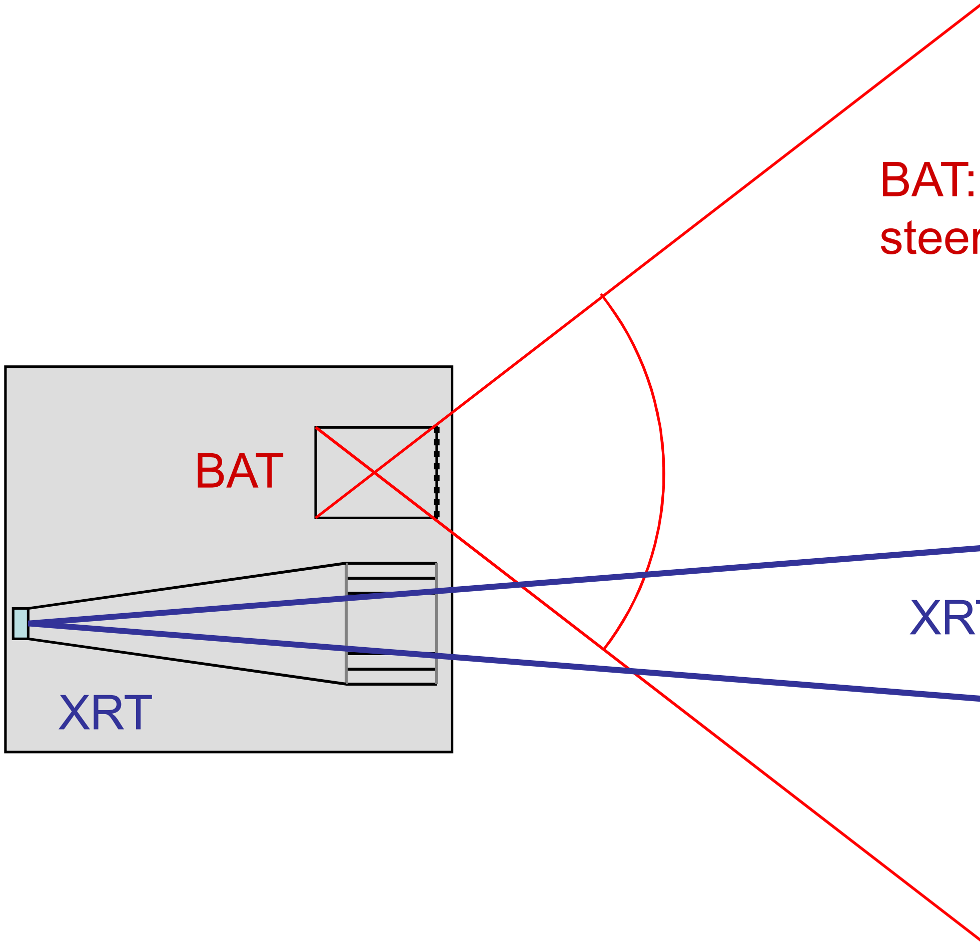
- Aitoff equal-area projection.
- A new quantity: fluence.



History continued

  - If bursts are close, one should eventually be able to detect a bias in the fainter tail. As time went on, the ‘nearby’ hypothesis came to seem less and less likely.
  - But, if the bursts are far enough away that they large-scale structure is smeared out, energy production must be gigantic!
- 1996: BeppoSAX launched.
  - Sees about 1 GRB per day.
  - X-ray afterglows also seen.
  - First redshifts measured: average about 1.
- 2004: Swift launched.
  - BAT: wide-angle gamma detector, to detect bursts;
  - XRT: narrow-angle, x-rays, more sensitive.

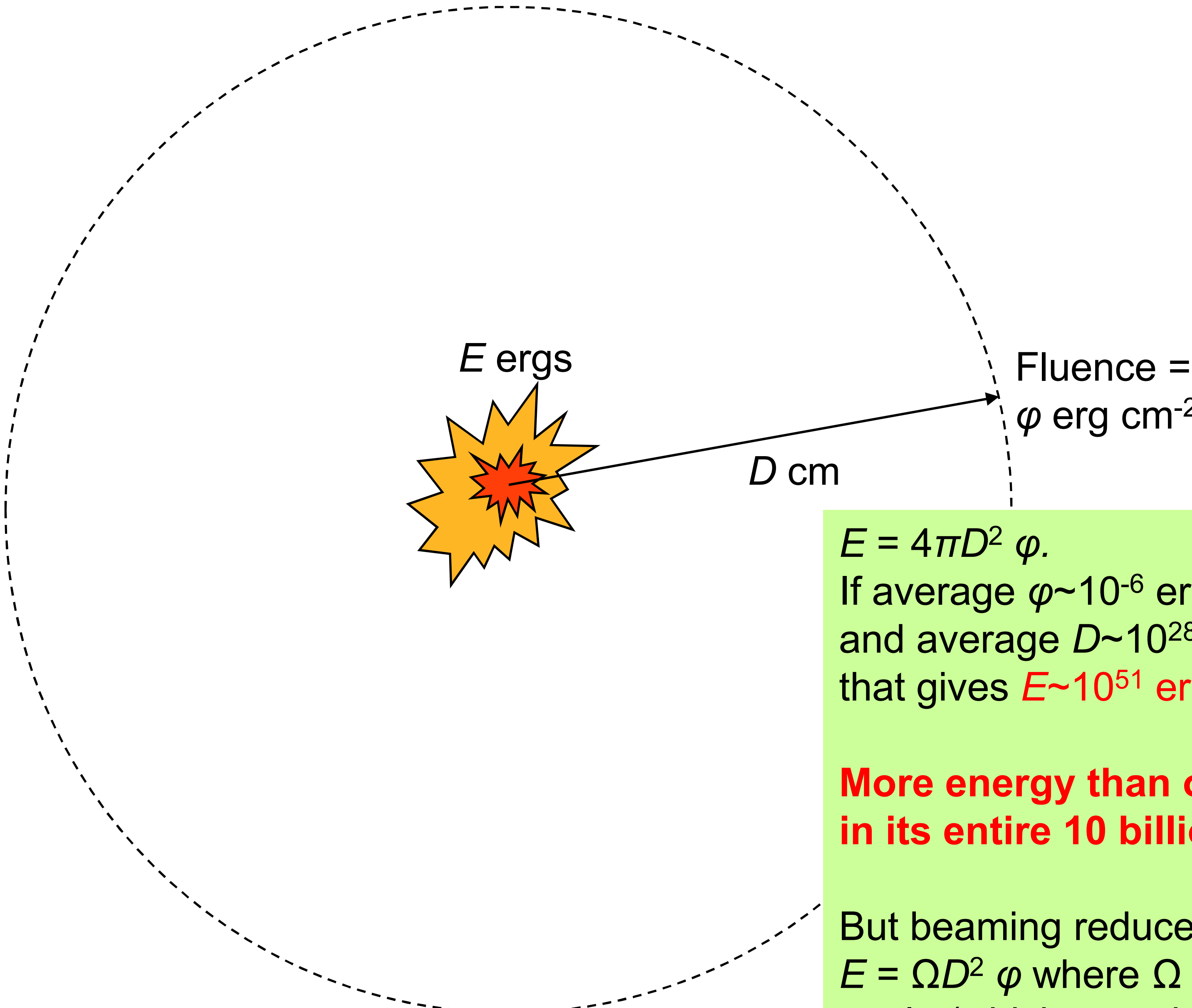
Swift instrumentation



BAT: Wide-angle, detects burst, spacecraft steers to point XRT at the location.

XRT: high-res, narrow field, high sensitivity.

How much energy in a GRB?



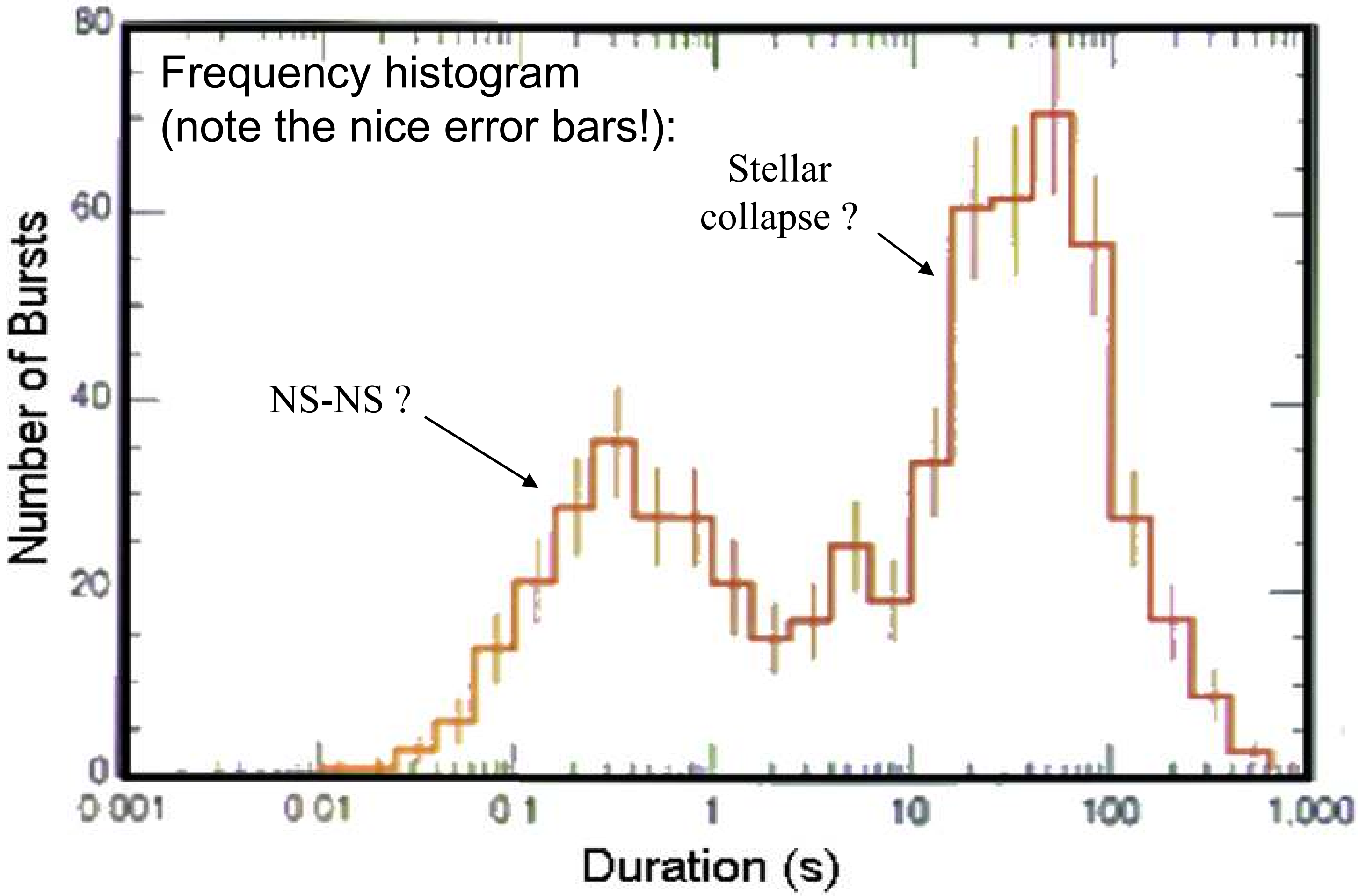
$E = 4\pi D^2\ \varphi$.
If average $\varphi \sim 10^{-6}$ erg cm^{-2},
and average $D \sim 10^{28}$ cm,
that gives $E \sim 10^{51}$ ergs.

More energy than our Sun will emit in its entire 10 billion year lifetime!

But beaming reduces this to
$E = \Omega D^2\ \varphi$ where Ω is the beam solid angle (which must be <= 4π).

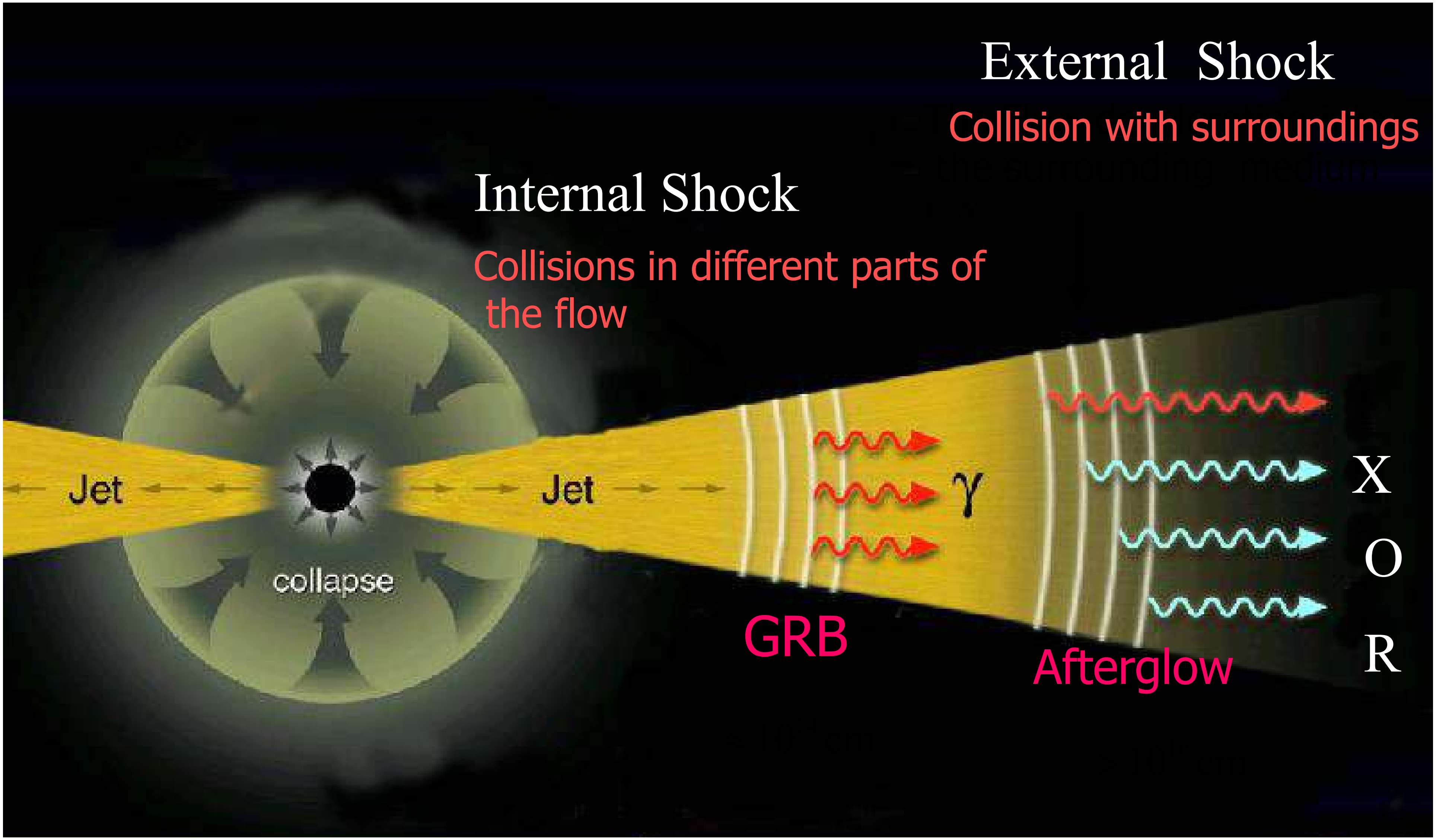
What are GRBs? There seem to be 2 sorts:

1. Short, faint, hard bursts
2. Long, bright, soft bursts



Long-burst GRBs: fireball-shock model

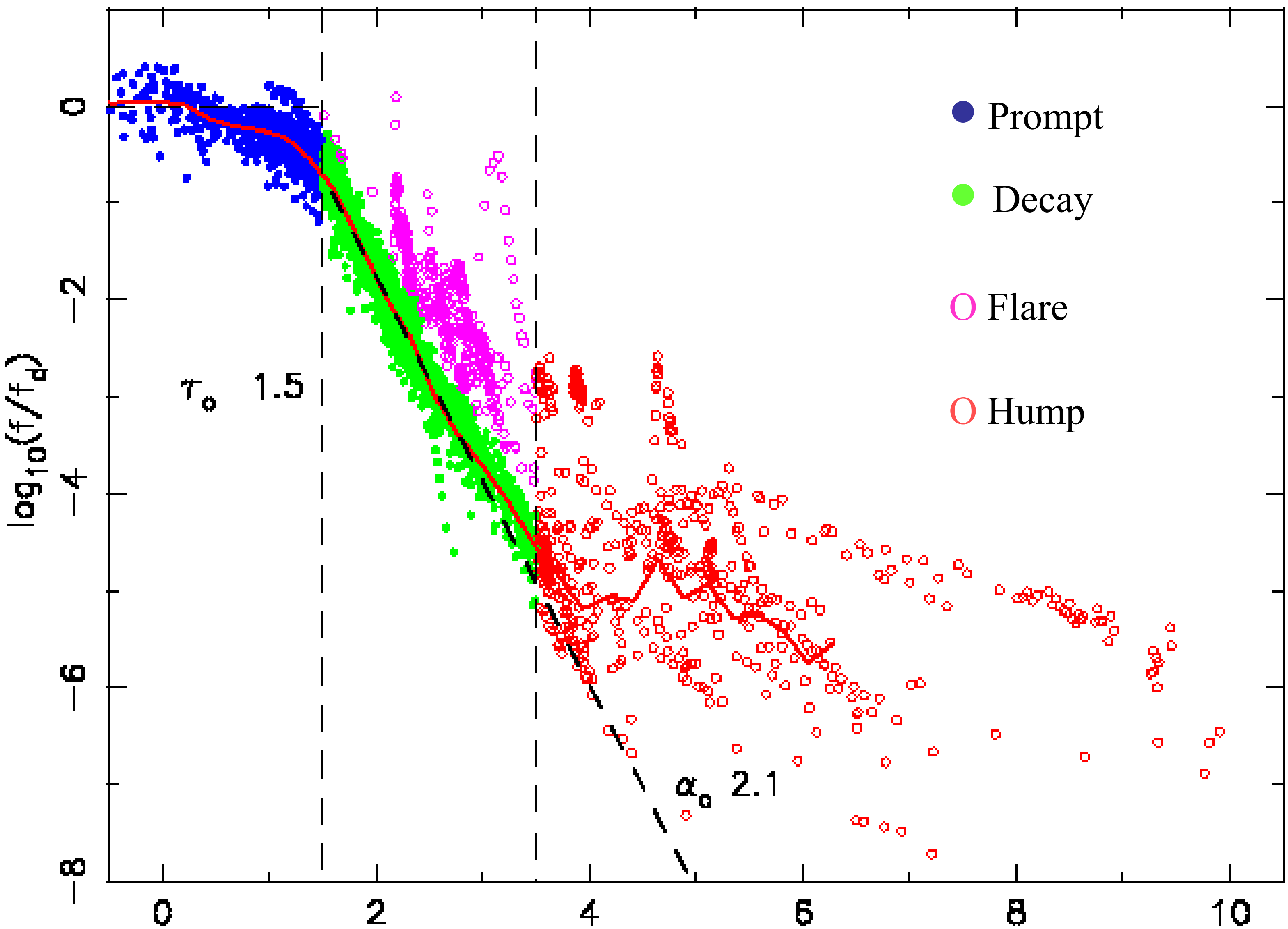
Jet is so fast that the synchrotron is blue-shifted to gamma!



Latest GRB history:

- GRB 090423: redshift 8.2 – that's *huge*. This breaks the record for the most distant object observed from Earth.
  - Only infrared afterglow seen for this GRB: all the visible light has been absorbed by the thin hydrogen haze between the galaxies.
- Another recent (rather clever) discovery:
  - 'Long' GRBs seem to have very varied light curves.
  - But! There is a transform which brings them all into a common pattern.

Transformed light curves:



Cheering news, because a common pattern implies common physics.