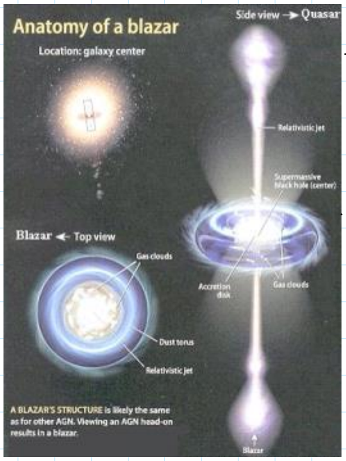
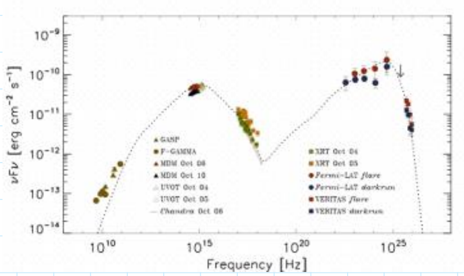
5) γ-ray emission from Blazars





γ-rays can collide w/ each other (or X-rays) to produce e^+/e^- pairs. Thus, observing high-energy gamma-rays set limits on source size/luminosity.

Consider, e.g. γ-rays at the threshold for pair production
$\epsilon \sim m_e c^2$

The m.f.p. for $\gamma\gamma$ collisions is $\lambda = \dfrac{1}{N_\gamma \sigma_{\gamma\gamma}}$ where N_γ is the # density of photons w/ energies of ϵ ; $\sigma_{\gamma\gamma} \simeq 0.2\sigma_T \sim \sigma_T$

If the source has luminosity L_γ ; size D,

$$N_\gamma = \frac{L_\gamma}{4\pi D^2 c \epsilon}$$

$\left(\text{Flux} = \dfrac{L_\gamma}{4\pi D^2} , \quad \#\text{Flux} = \dfrac{L_\gamma}{4\pi D^2 \epsilon} \right.$

$\left. \#\text{Flux} = \#\text{density} \times c \right)$

∴ For the source to be opaque to pair production: $D \simeq \lambda$

ie, $D \simeq \dfrac{4\pi D^2 c\epsilon}{L_\gamma \sigma_T}$ or $\dfrac{L_\gamma \sigma_T}{4\pi D c^3 m_e} \simeq 1$

The quantity $C = \dfrac{L_\gamma \sigma_T}{[4\pi] m_e c^3 D}$ is called the Compactness

If $C > 1$, then would not expect a long-lived γ-ray source

For blazars, $L_\gamma \sim 10^{48}$ erg/s ; $D \sim$ light-day $\rightarrow C \sim 10^3$!

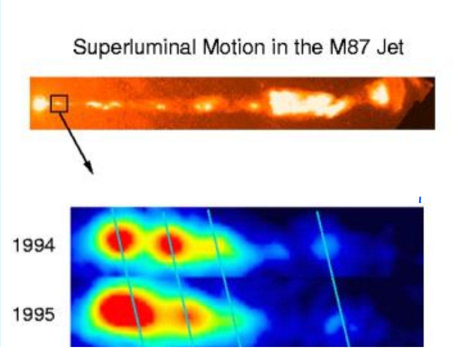
Relativistic beaming solves this:

First, the actual luminosity is a factor δ^4 smaller than the observed L where $\delta = \dfrac{\gamma_{lorentz}}{(1-\beta\cos\theta)}$;

Second, time interval of emission is smaller in emitted frame so D is a factor of δ smaller

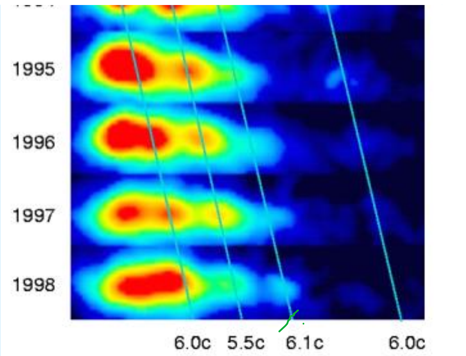
so, $C = \dfrac{\delta^5 L' \sigma_T}{4\pi m_e c^3 D'}$ thus $C < 1$ if $\delta \gtrsim 4$

6) Apparent Superluminal Motion at relativistic speeds



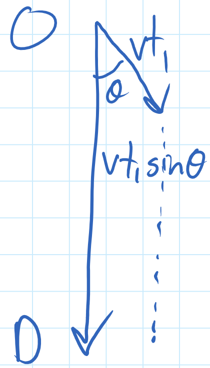
The observer is located at a distance D from the source.

The source comp/blob is ejected from the origin O



ejected from the origin O at some time t_0 & the observer detects this at time $t = \frac{D}{c}$ later

After some time t_1 :



The component/blob is now located at a distance vt_1 from O & is observed at a projected distance $vt_1 \sin\theta$ according to the observer.

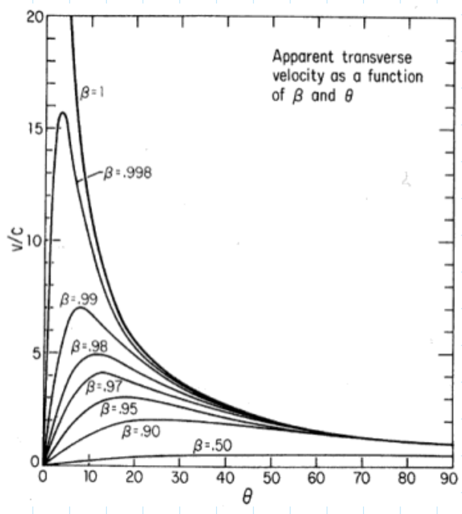
The light-signal from the blob arrives at the observer at a time $t_2 = t_1 + \left(\frac{D}{c} - \frac{vt_1\cos\theta}{c}\right)$

$\therefore$ According to the distant observer the transverse speed of the blob is

$$V_\perp = \frac{vt_1 \sin\theta}{t_2 - t} = \frac{vt_1 \sin\theta}{t_1 + \left(\frac{D}{c} - \frac{vt_1\cos\theta}{c}\right) - \frac{D}{c}} = \frac{vt_1 \sin\theta}{t_1 - \frac{vt_1\cos\theta}{c}} = \frac{v\sin\theta}{1 - \frac{v\cos\theta}{c}}$$

The max. observed $V_\perp$ occurs at an angle $\cos\theta = \frac{v}{c}$ & is $V_\perp^{max} = \gamma v$. Thus, provided the blob moves w/ $v \lesssim c$

$V_\perp > c$, e.g. if $v = 0.98c$, $V_\perp \leq 5c$


Apparent transverse
velocity as a function
of β and θ
β=1
β=.998
β=.99
β=.98
β=.97
β=.95
β=.90
β=.50
v/c
θ
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90