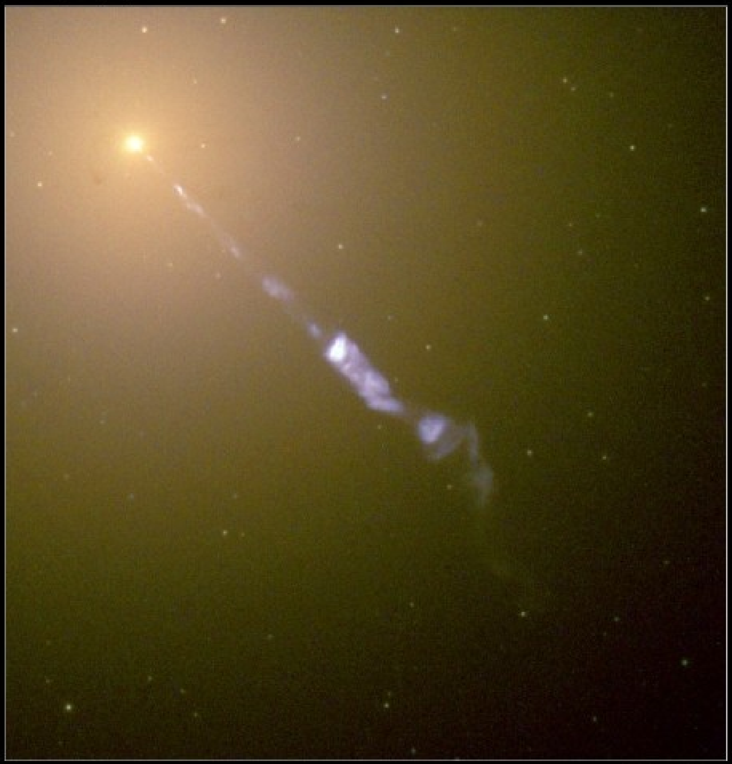
Time Variability of Active Galactic Nuclei : Why, How and Some Recent Results

Ritaban Chatterjee,
Boston University.
IIA colloquium,
June 12th, 2008.

The M87 Jet

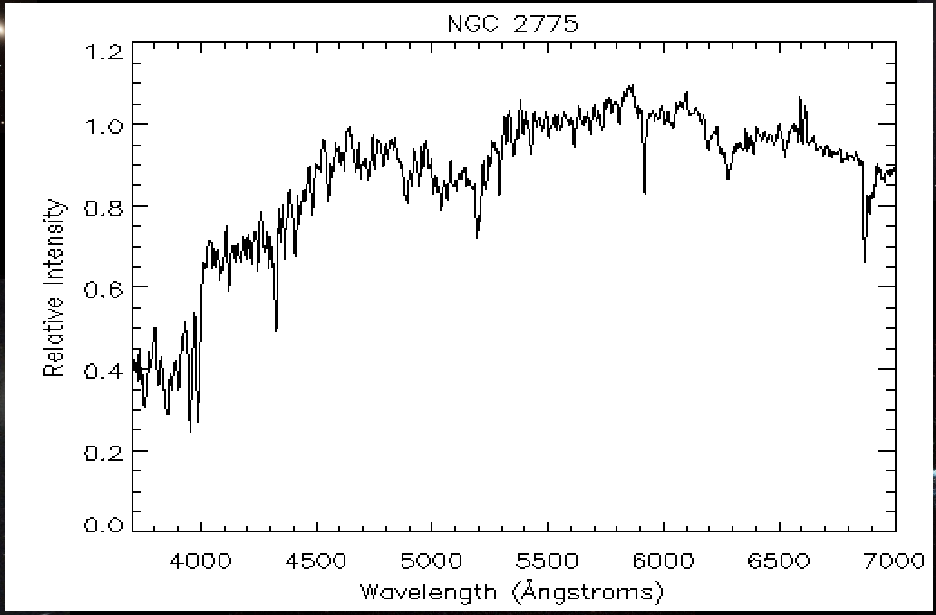


PRC00-20 • Space Telescope Science Institute • NASA and The Hubble Heritage Team (STScI/AURA)

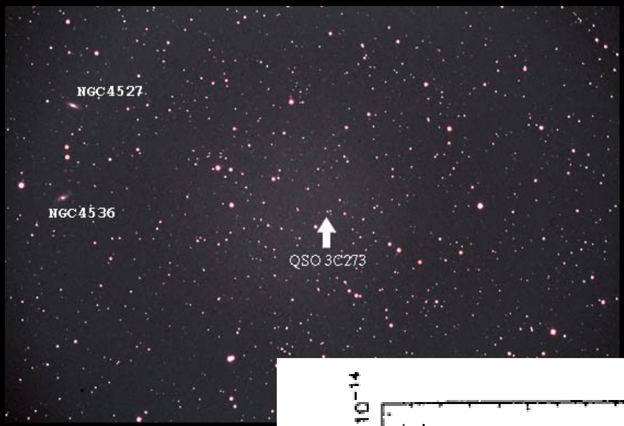
"An **active galactic nucleus** (**AGN**) is a compact region at the centre of a galaxy which has a much higher than normal luminosity over some or all of the electromagnetic spectrum. The radiation from AGN is believed to be a result of accretion on to the super-massive black hole at the centre of the host galaxy."

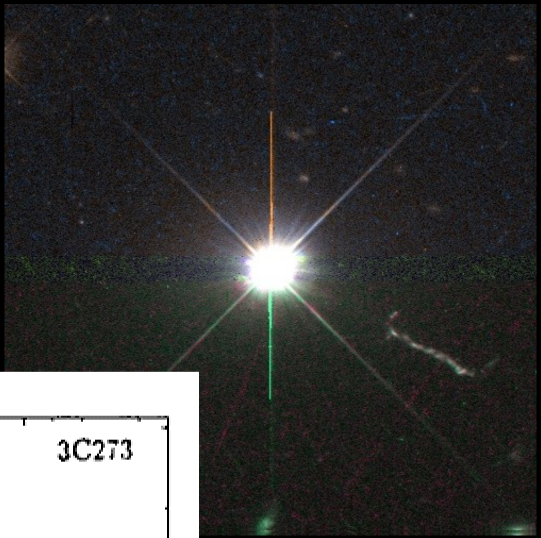
-Wikipedia

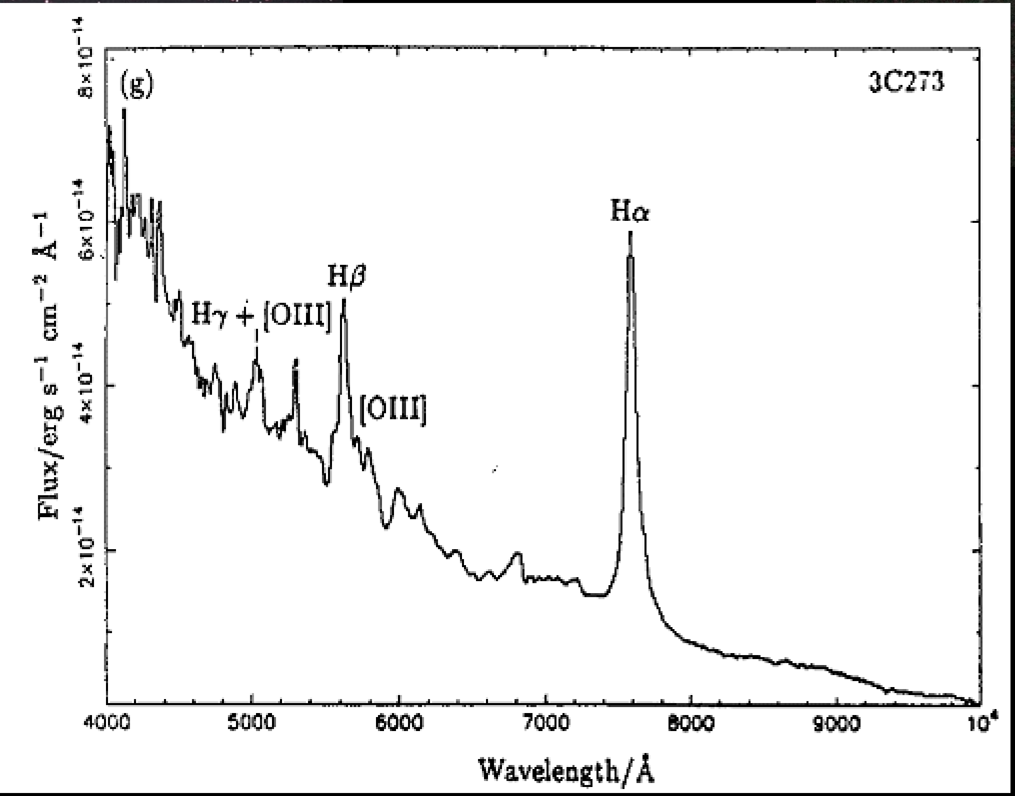
Typical Galaxy Spectrum

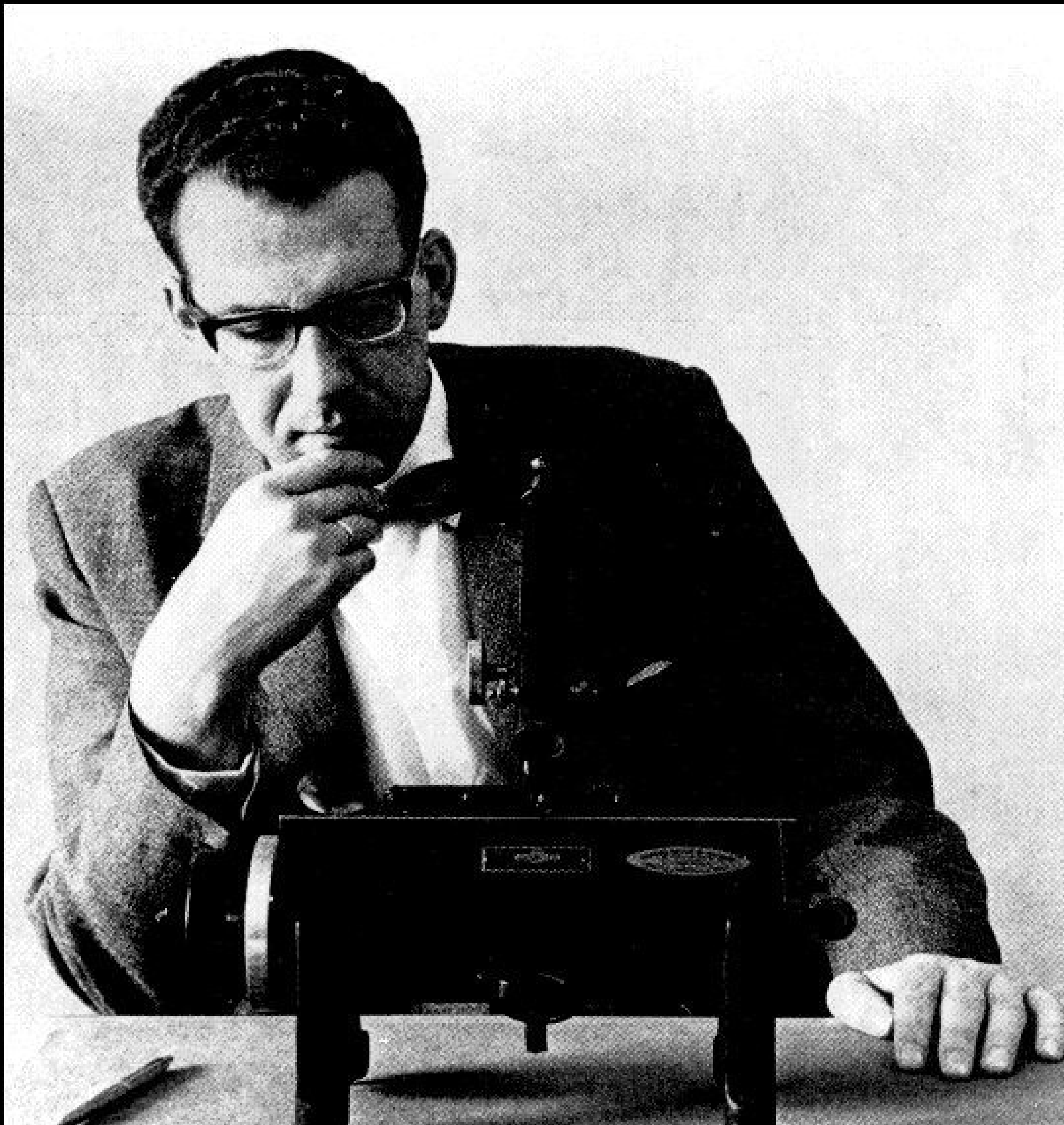


1963 : Spectrum of 3C 273



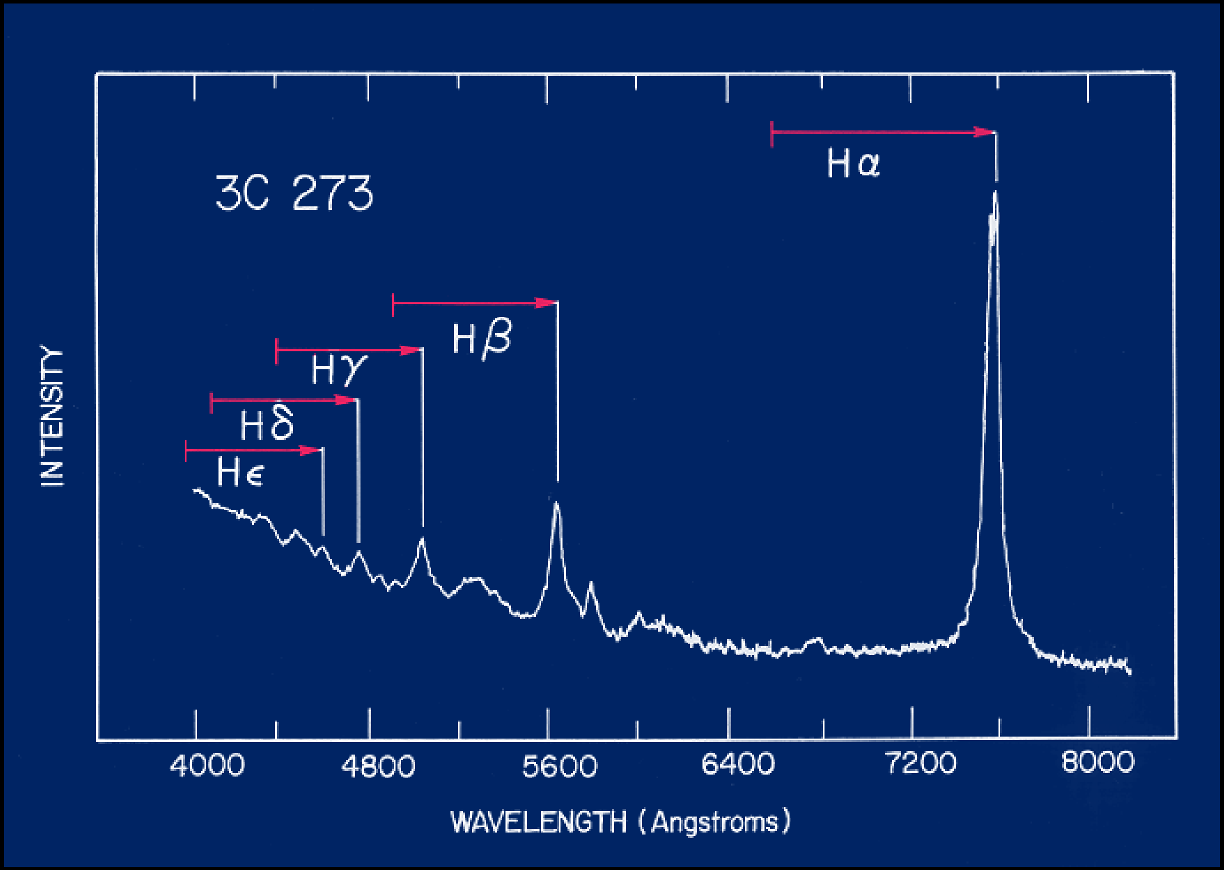






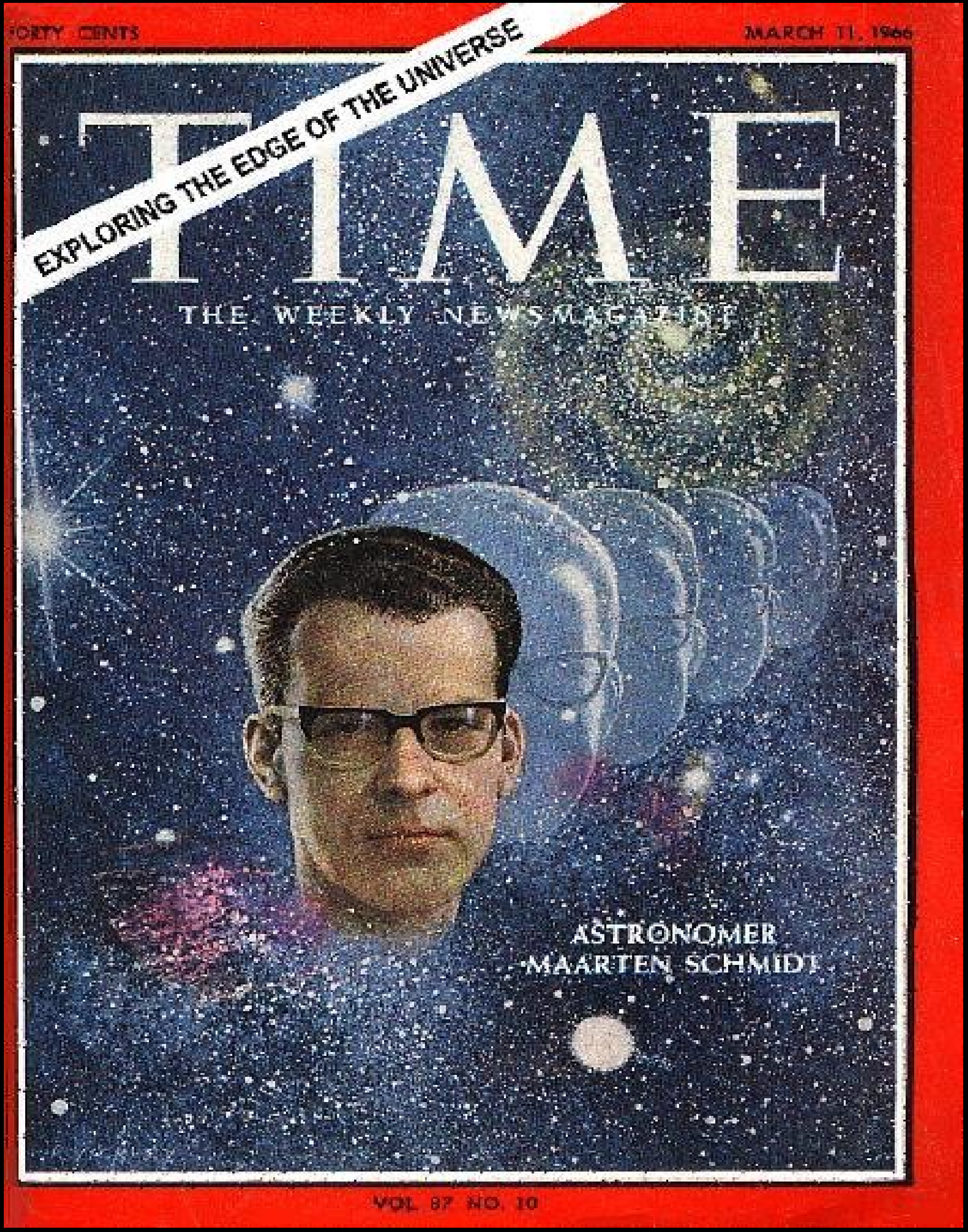
"Wait a minute, I know what's going on!"
-Maarten Schmidt (1963)

Spectrum of 3C 273 : Redshifted Hydrogen Balmer Series



z = 0.158
=> Distance
~ 1900 light years
=>Visual luminosity
~ 10^{46} ergs/sec

Extreme values of luminosity and distance (at that time)!!


FORTY CENTS
MARCH 11, 1966
EXPLORING THE EDGE OF THE UNIVERSE
TIME
THE WEEKLY NEWSMAGAZINE
ASTRONOMER
MAARTEN SCHMIDT
VOL. 87 NO. 10

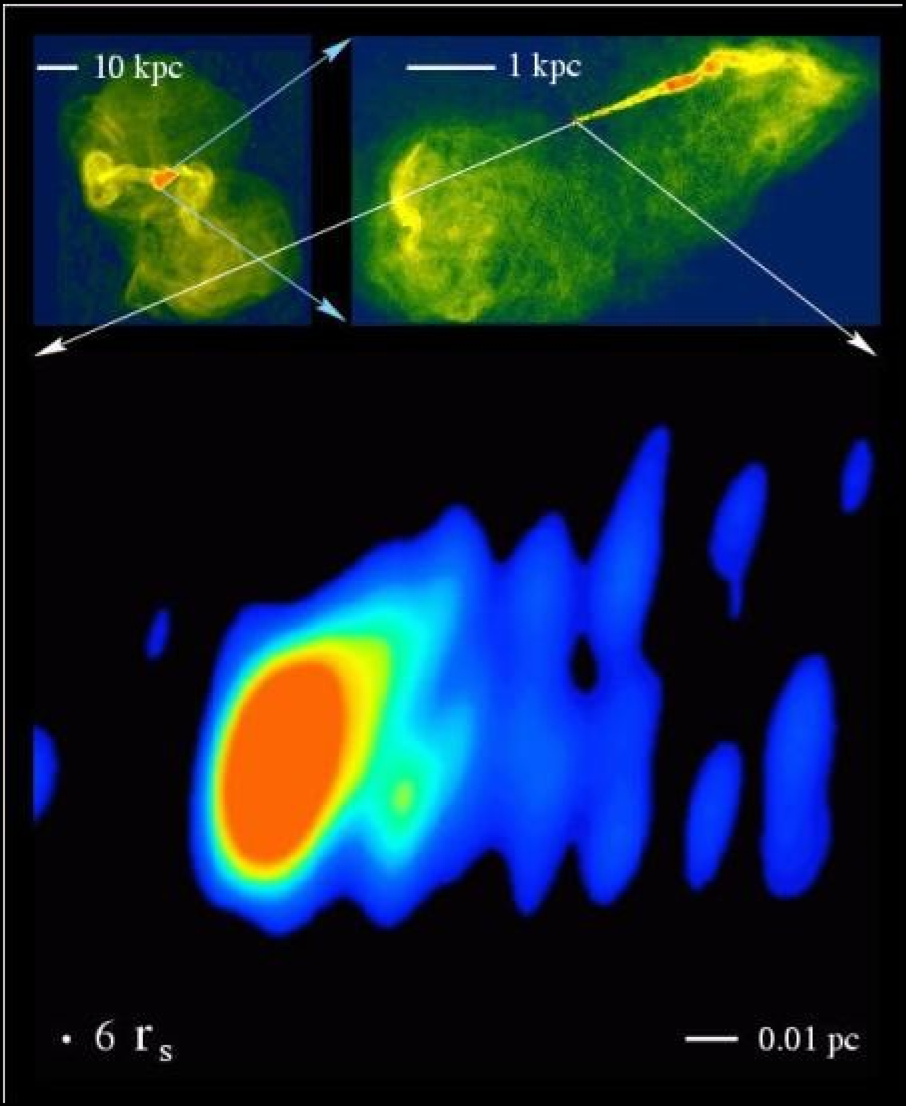
VLA : maximum baseline 36 k.m (resolution 0.5 arcsec)

VLA as seen from the north

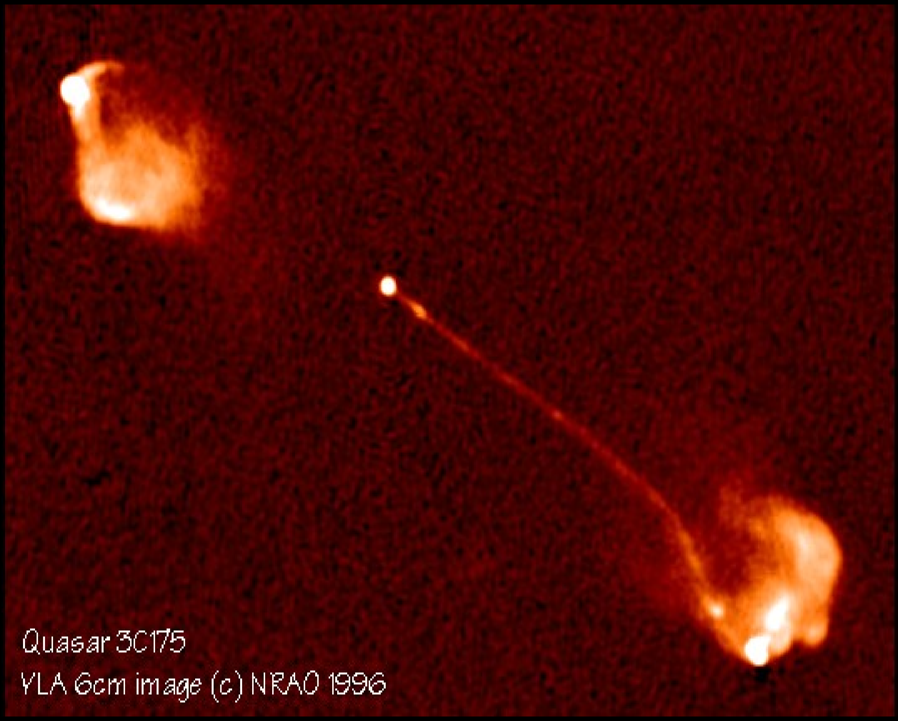
Close-up of one dish

VLBA : Maximum baseline 8611 k.m (sub-miliarcsecond resolution)

Observations with Radio Interferrometry

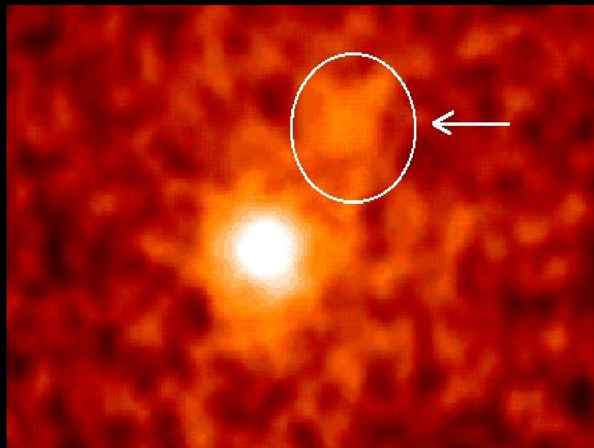


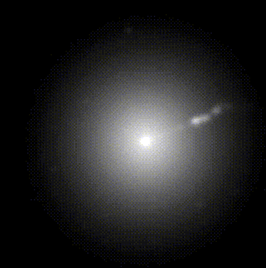
Courtesy, NRAO

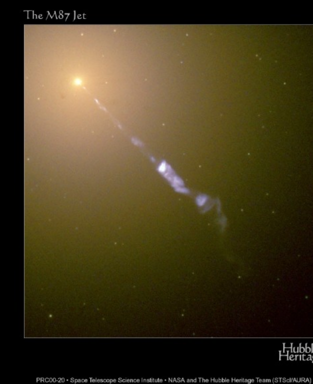


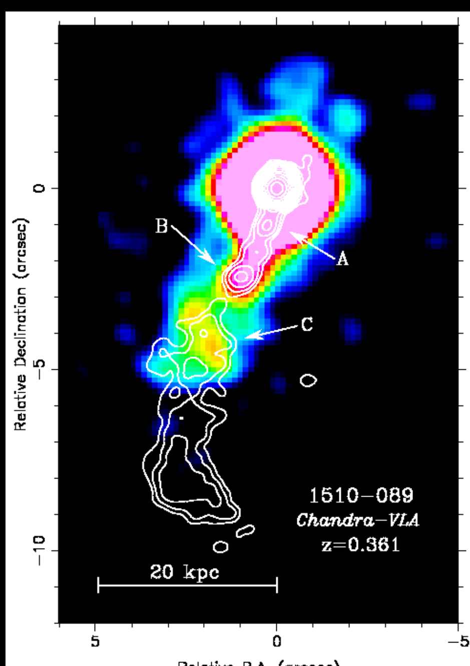
Space Based Observatories

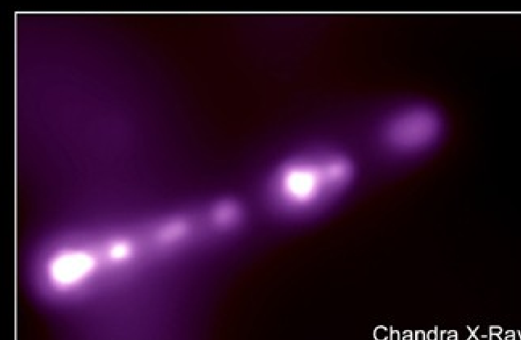
Space Based Optical, X-ray and Gamma ray Observations

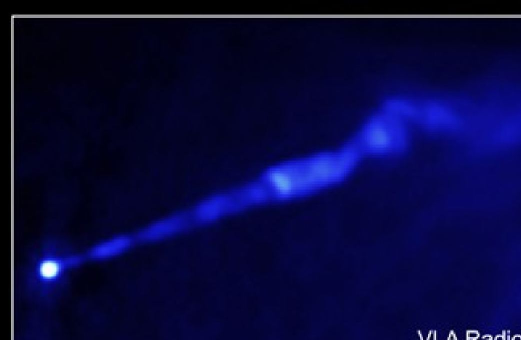


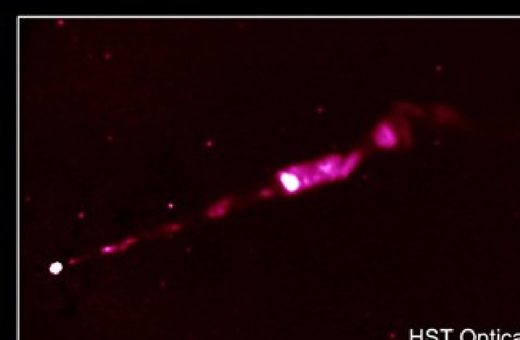




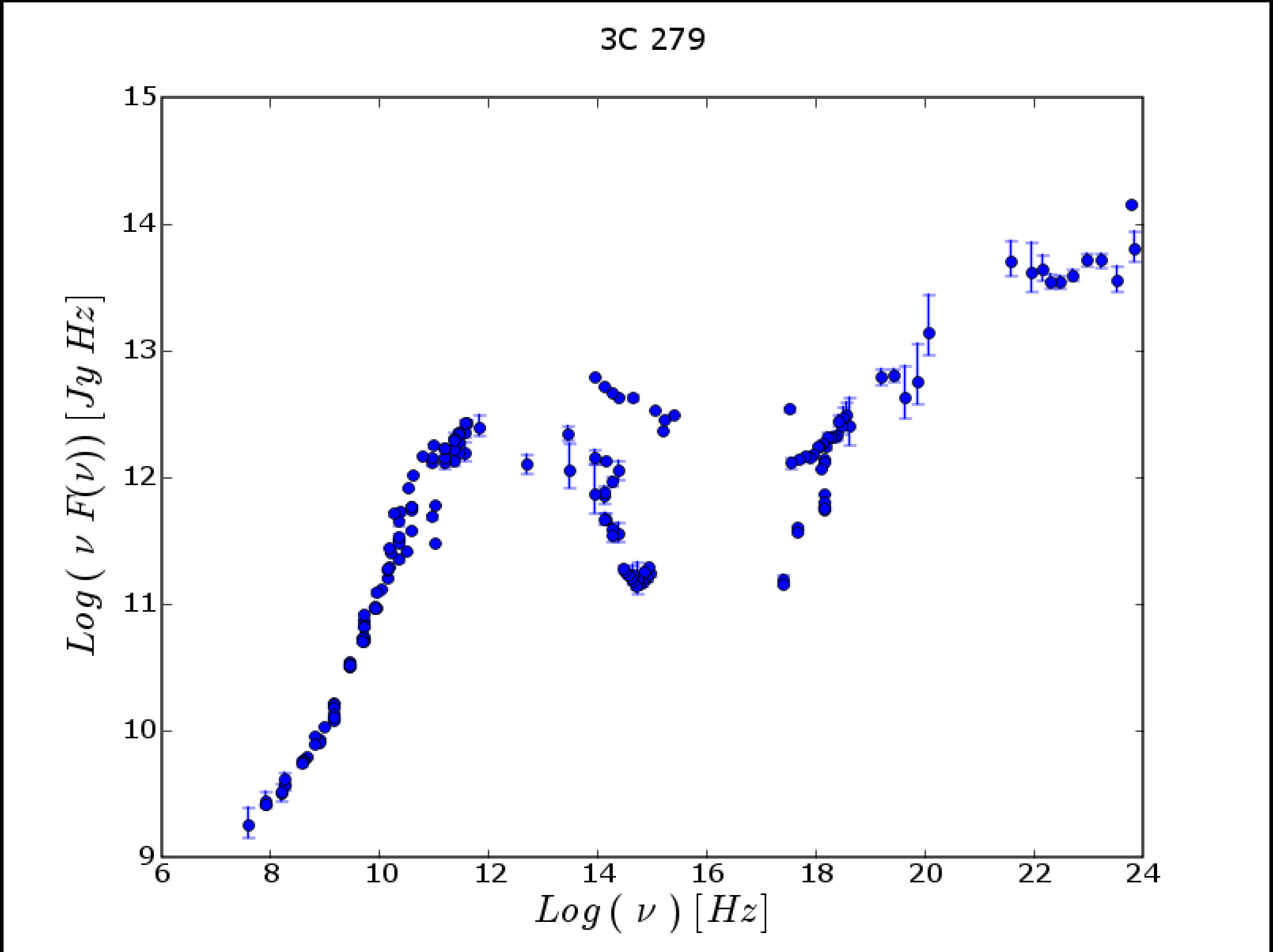






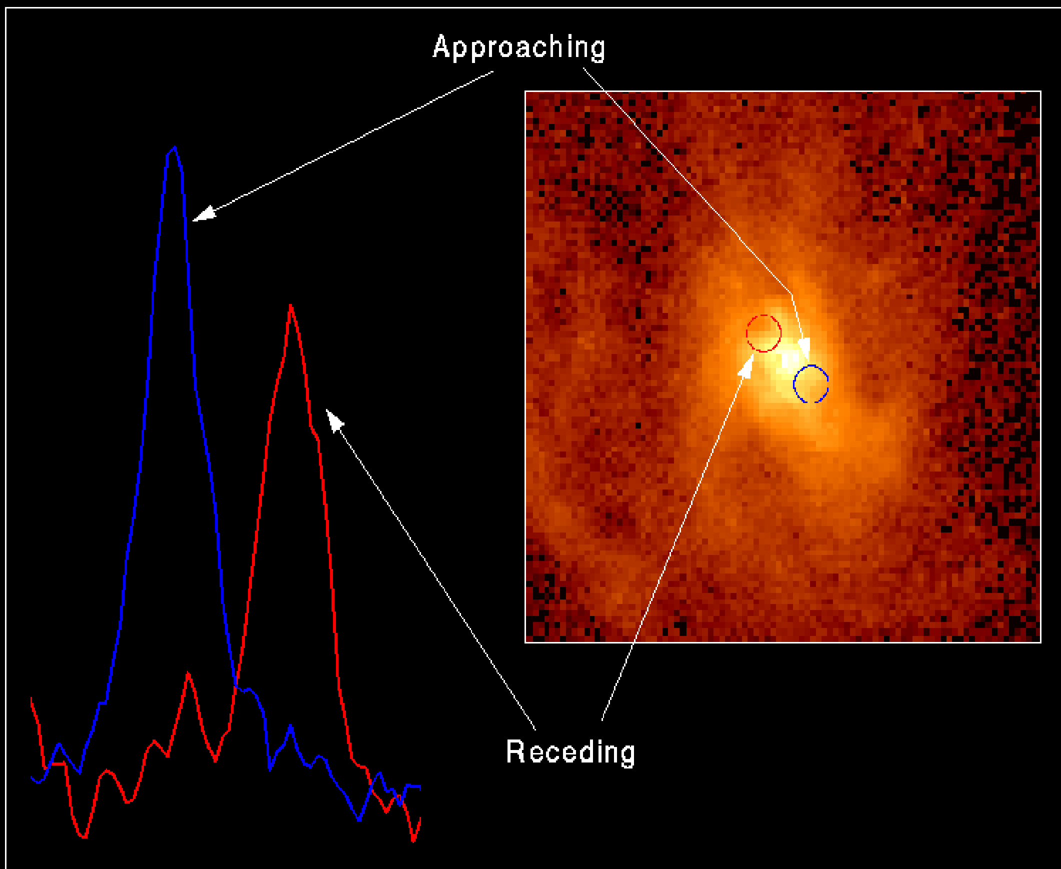


Spectral Energy Distribution of 3C 279 : Spanning 16 decades of Frequency



Proof of Super-massive Black Hole

Spectrum of Gas Disk in Active Galaxy M87



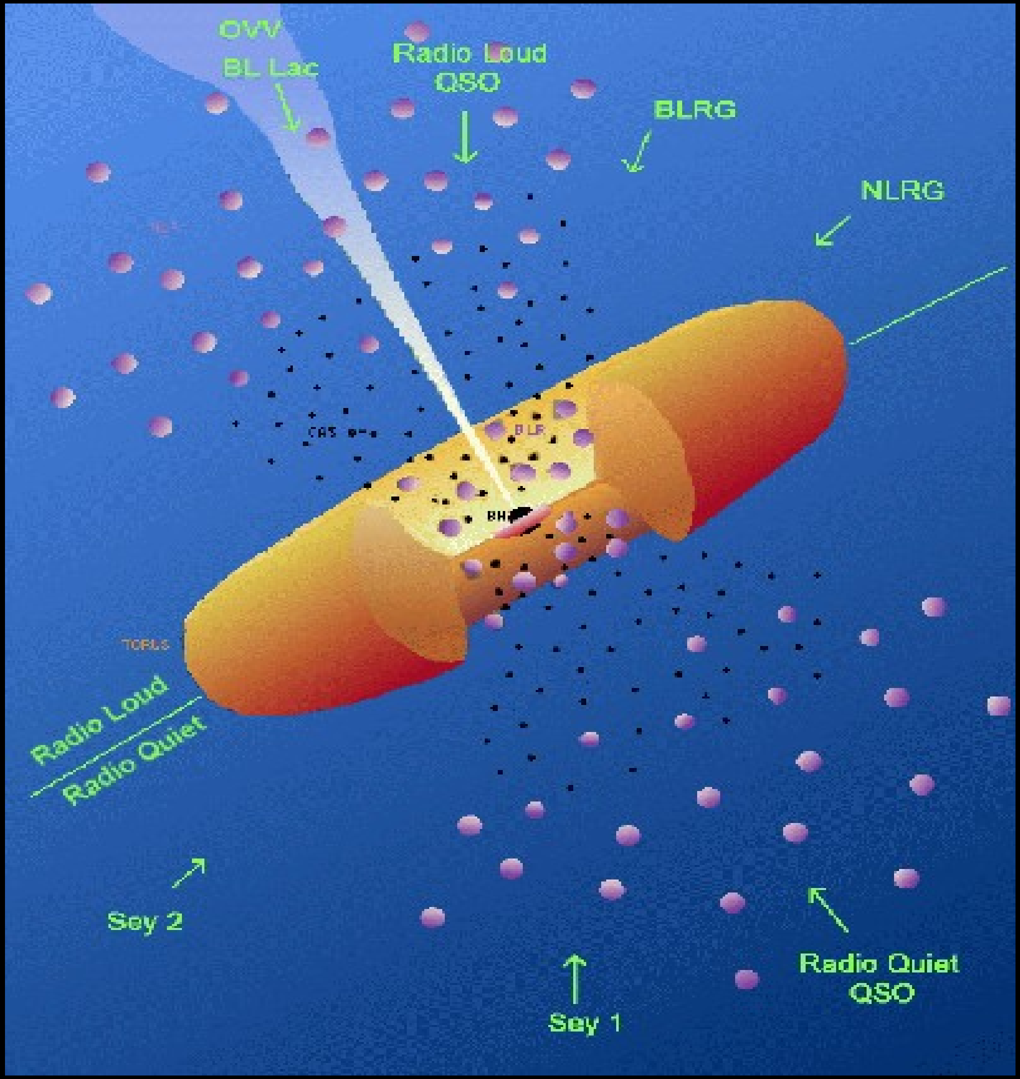
Hubble Space Telescope • Faint Object Spectrograph

- Red/Blue Shift = 7 A^0 for 5007 A^0 line of Oxygen
- V = (7/5007)*c = 419 km/s
- R = $1.1X10^{15}$ k.m.
- M = v^2R/G

=> $1.5X10^9$ Solar Mass

SPACE TELESCOPE SCIENCE INSTITUTE

AGN : Unified Picture



Where We Stand

1. High luminosity from small size.
2. Large line-width => high velocity

   Super-massive black hole (10^6 – 10^9 solar mass) => strong gravitational potential well => accretion disk => large amount of radiation.
3. Broad spectral energy distribution

   Thermal and non-thermal processes involved => Black body, Synchrotron, Inverse-Compton radiation.
4. Unification : Does same physical mechanism govern different kinds of AGNs

   In some cases, we are sure. The rest . . . may be.

Where We Stand (contd.)

5. Jets

a) Production : Twisted magnetic field, spinning black hole, Angular momentum?

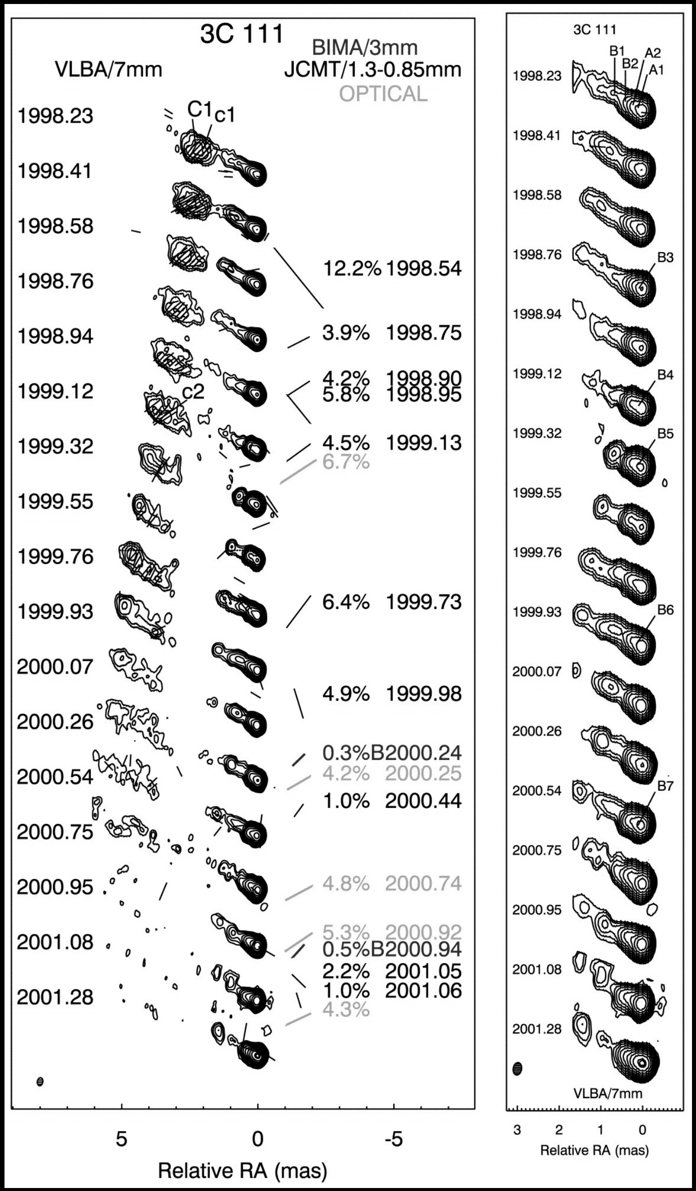
b) Content : Electron-proton, electron-positron plasma?

c) Particle acceleration : Shock, turbulence?

d) Emission mechanism : Synchrotron, synchrotron self-Compton, external Compton?

e) Emission location : Accretion disk, jet?

The Radio Galaxy 3C 111 (z=0.0485)



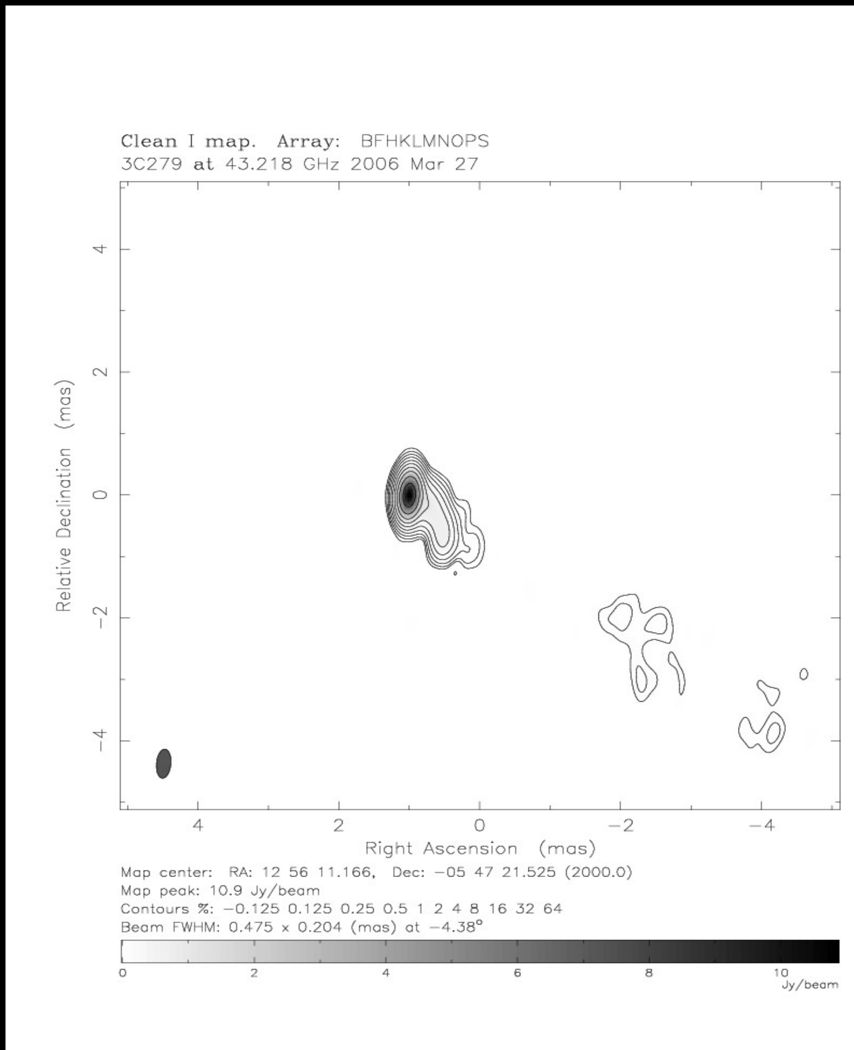
One-sided jet structure with superluminal apparent motion of 5c (1.5 milliarcsec/yr)

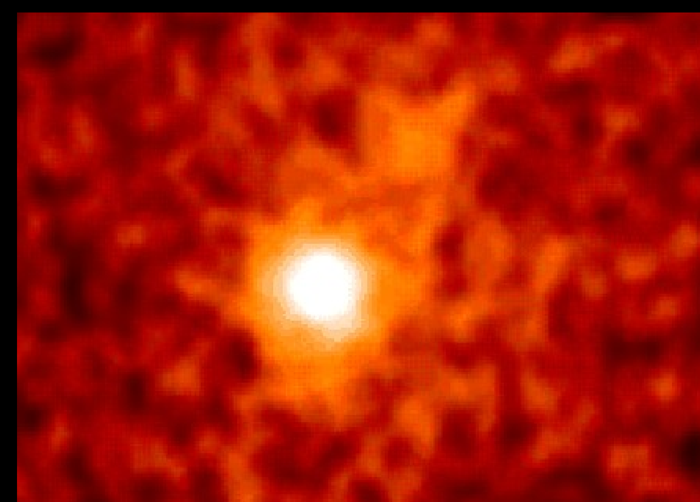
Jet propagates through galaxy and into intergalactic space, where it feeds giant twin radio "lobes"

Scale: 1 mas = 0.92 pc

Observations made at 43 GHz with the VLBA of the National Radio Astronomy Observatory

Time Variability : WHY?

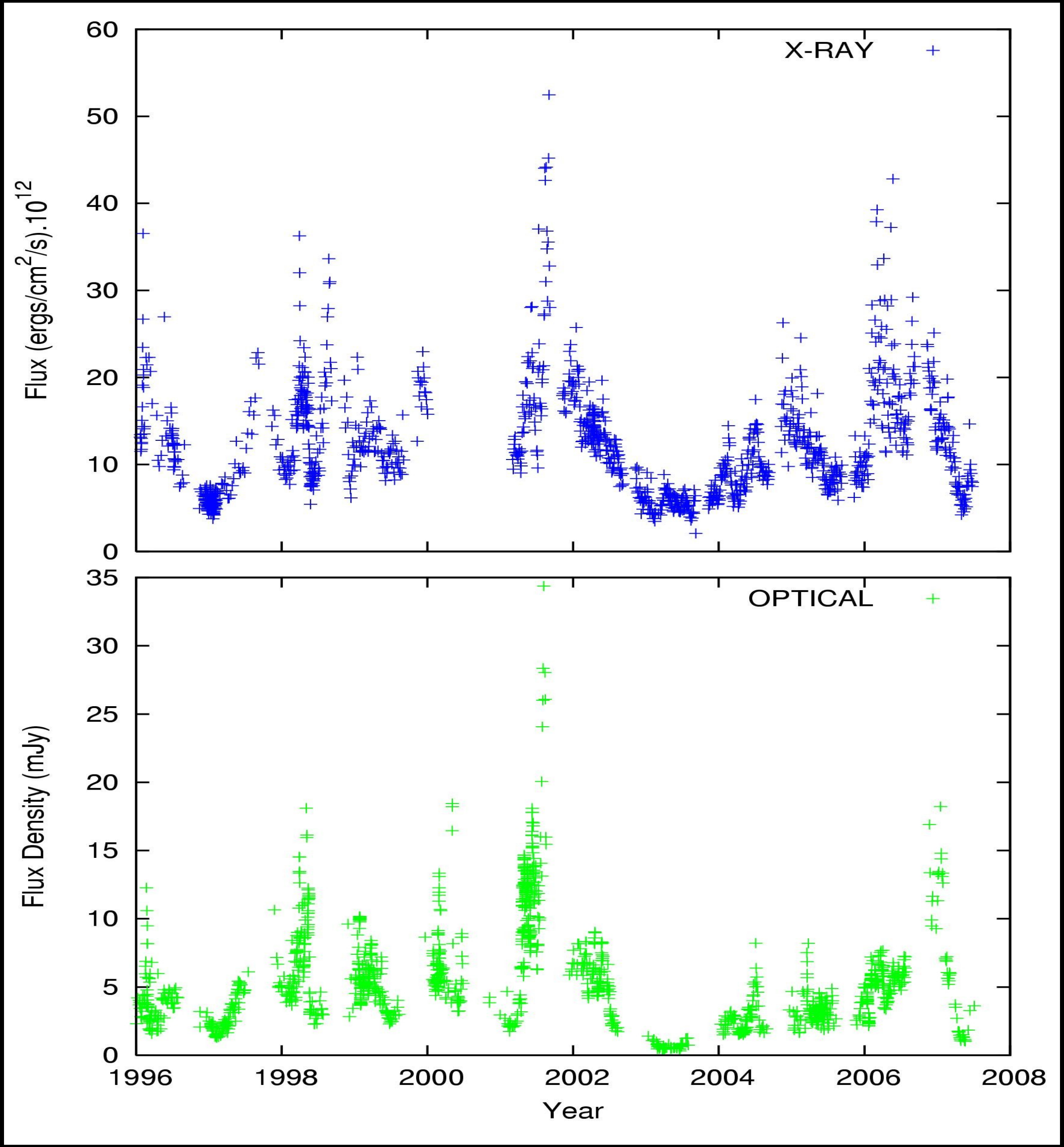




3C 279 (Z=0.536), 1 mas = 6.3 pc

Time Variability : HOW?

- Long-term monitoring in multiple wavelengths and VLBA
- Power spectral density (PSD)
- Comparison of fluxes at different wavelengths : Correlation
- Simulation of time variable non-thermal radiation
- Polarization in radio and optical

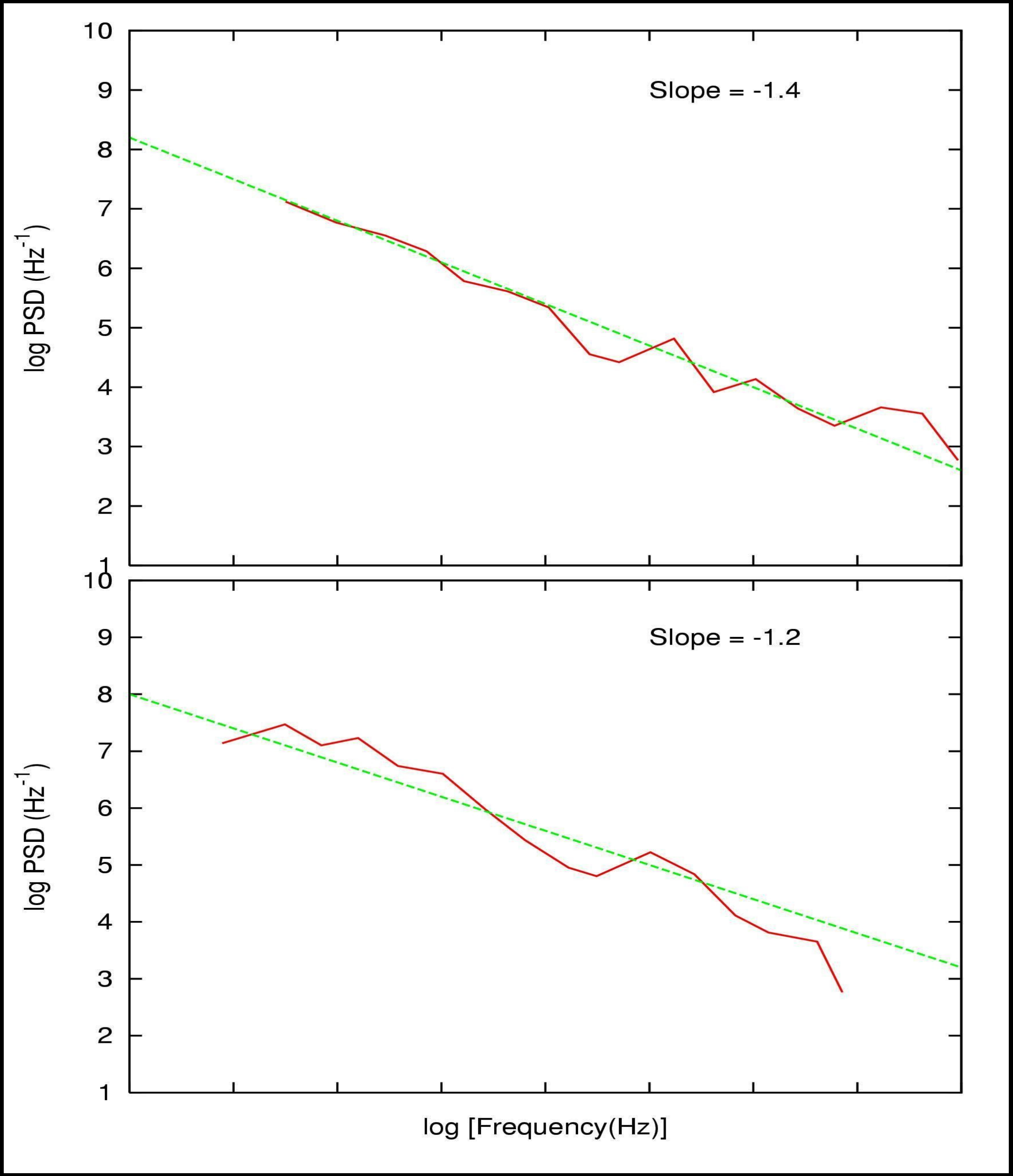


X-RAY

3C 279
Z=0.536

OPTICAL

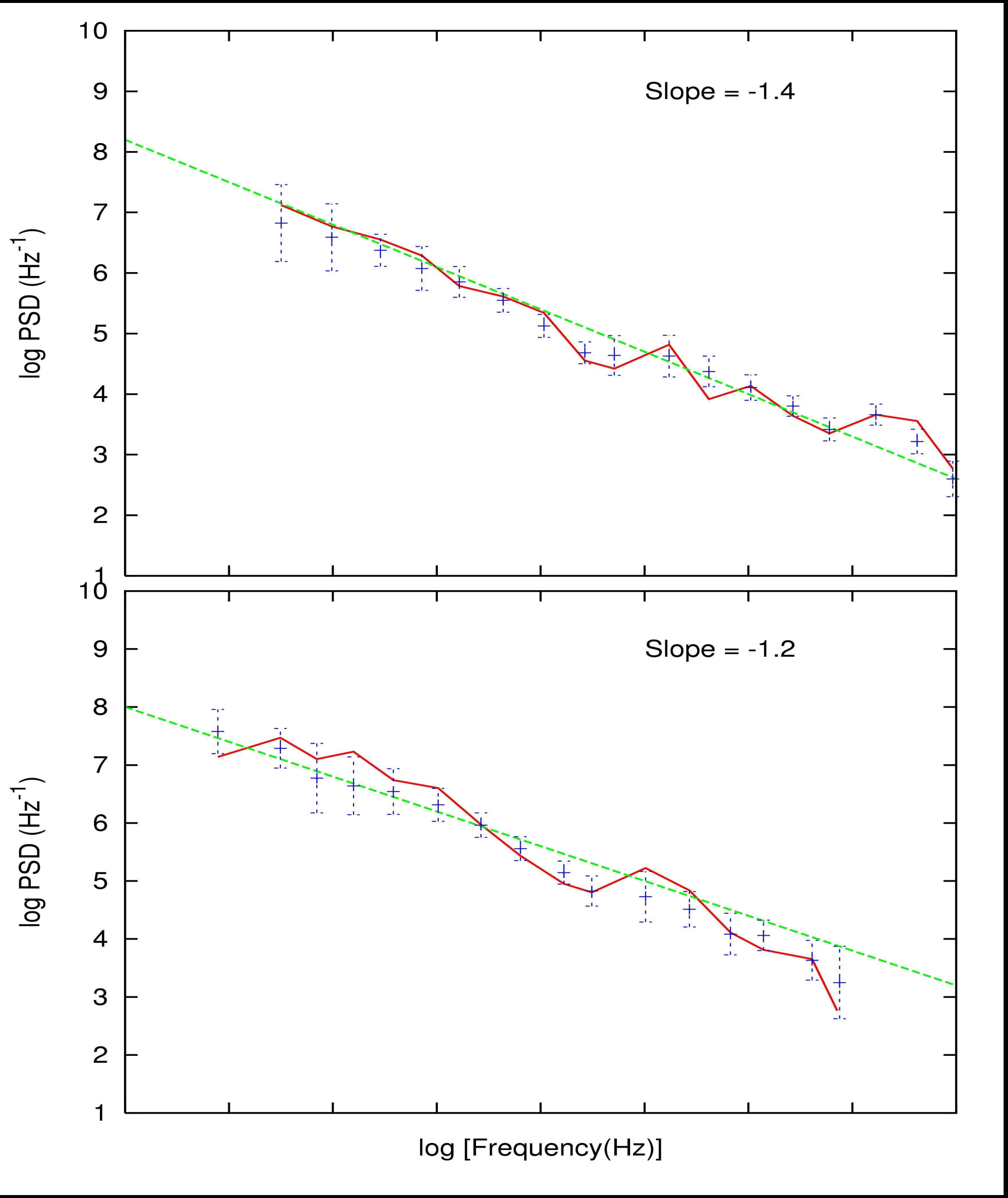
PSD



- First PSD of nonthermal radiation from AGN jets

Chatterjee et al. (submitted to ApJ)

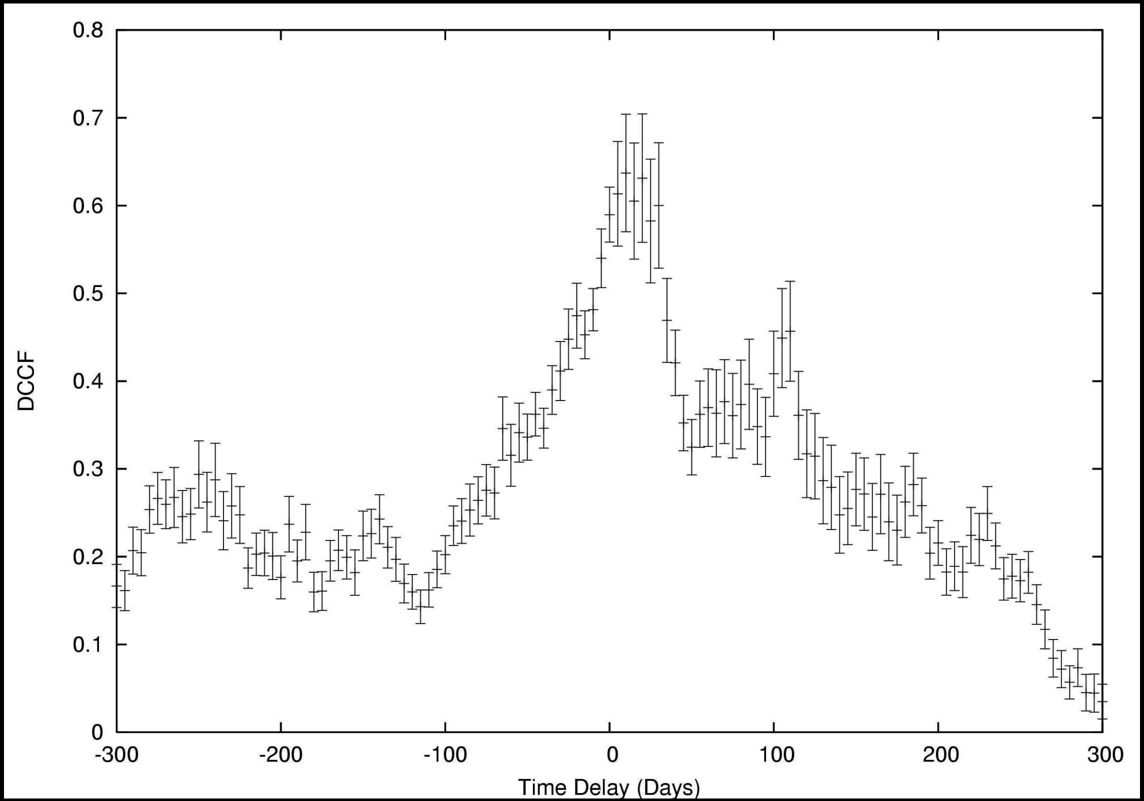
PSD



- First PSD of nonthermal radiation from AGN jets

Chatterjee et al. (submitted to ApJ)

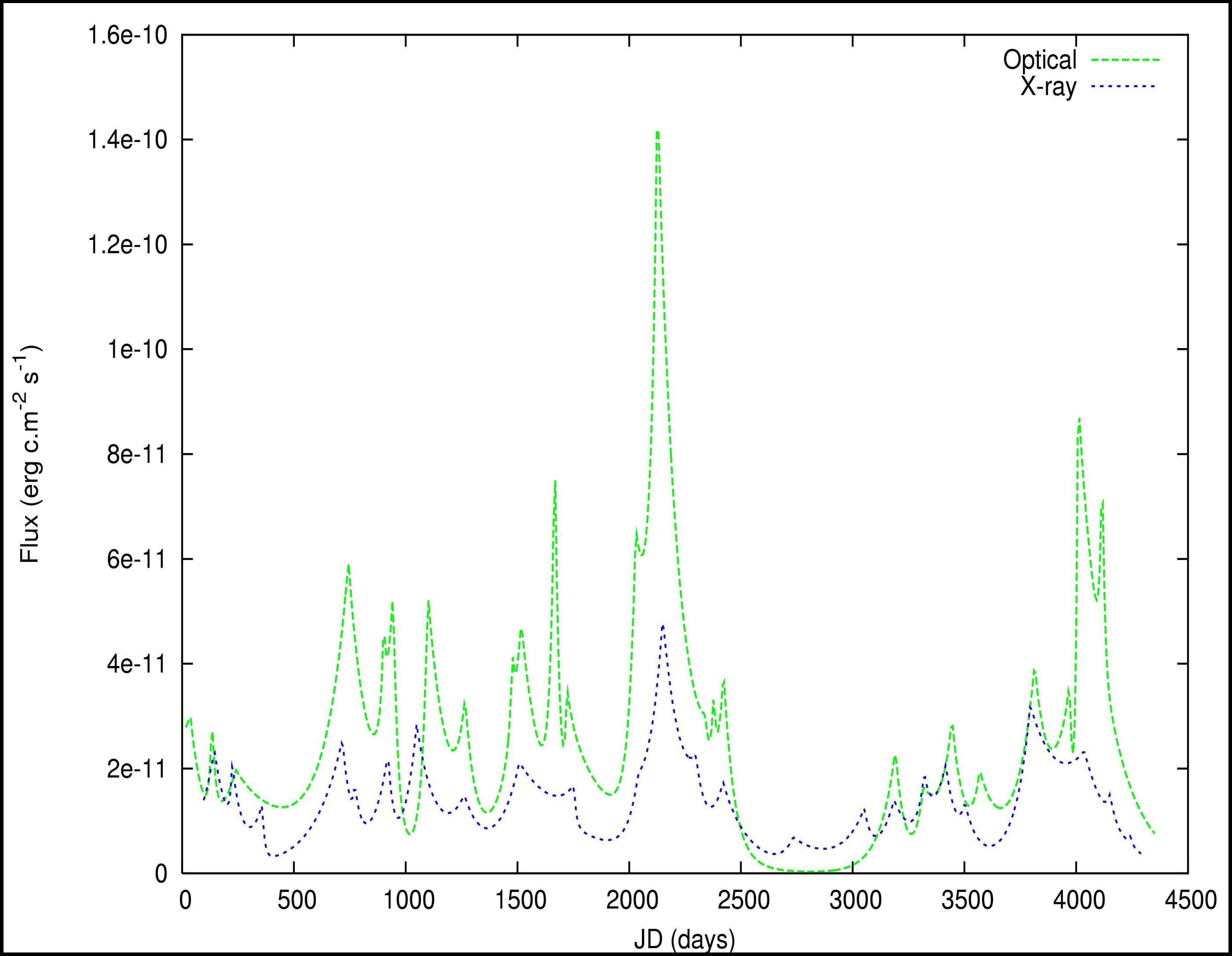
3C 279 : X-ray-optical Cross-Correlation



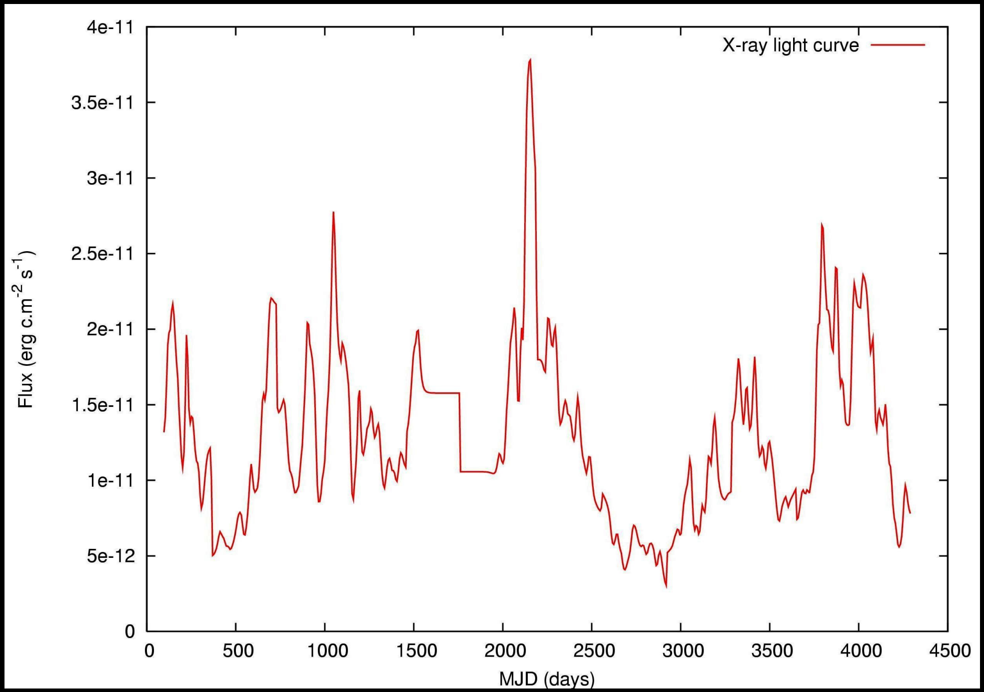
Chatterjee et al. (submitted to ApJ)

- Optical leads X-ray by ~ 19 Days

X-ray and Optical : Superposed

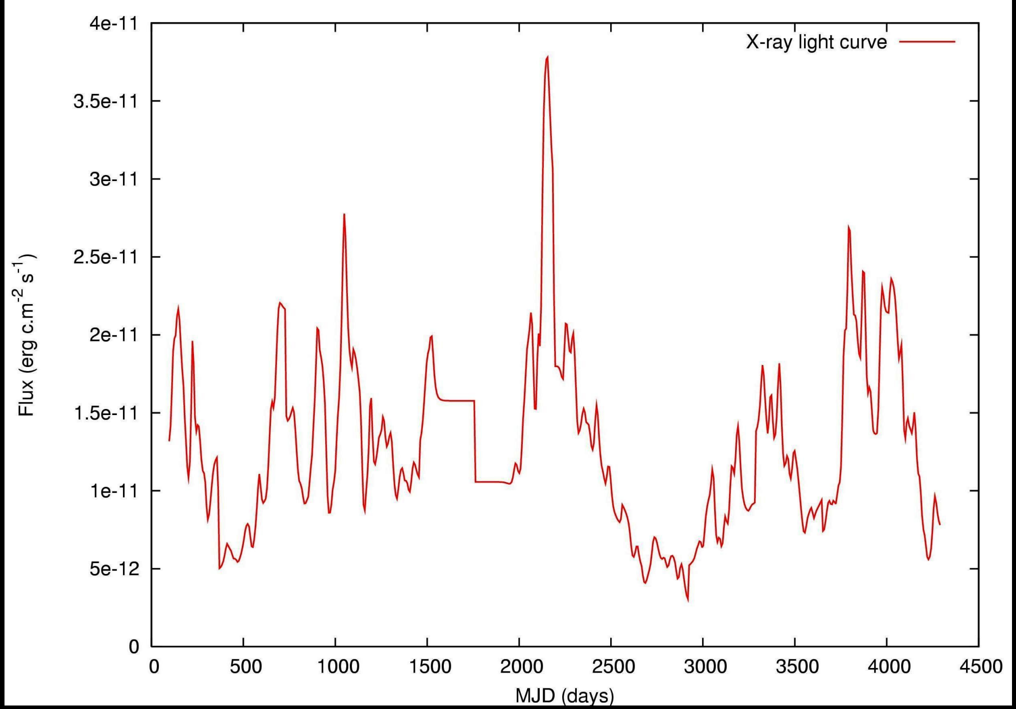


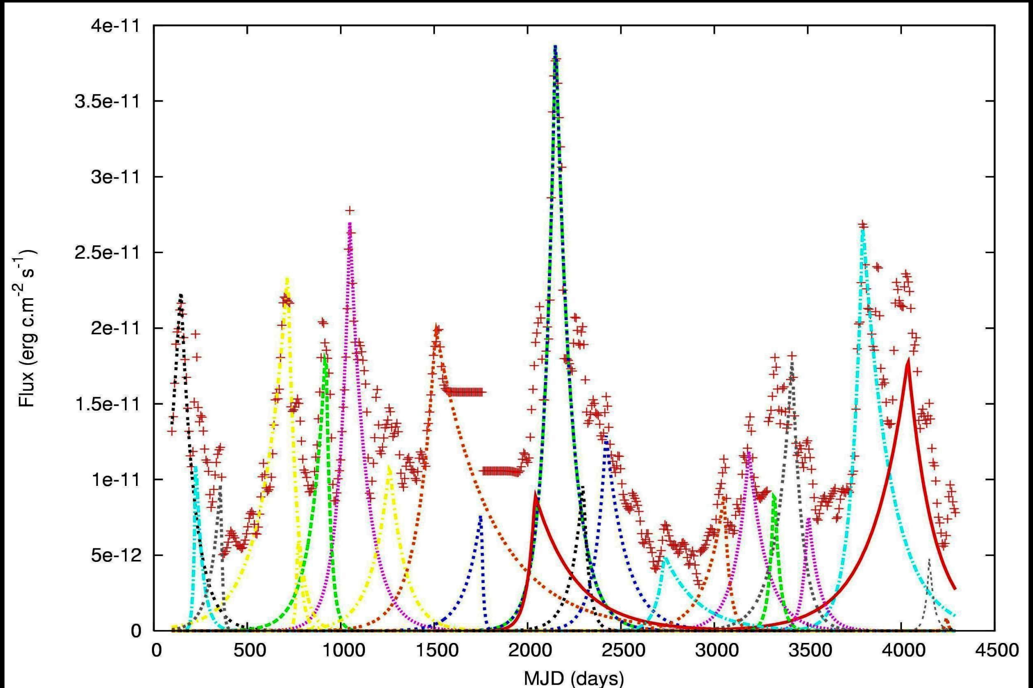
Comparison of flares between different wavelengths

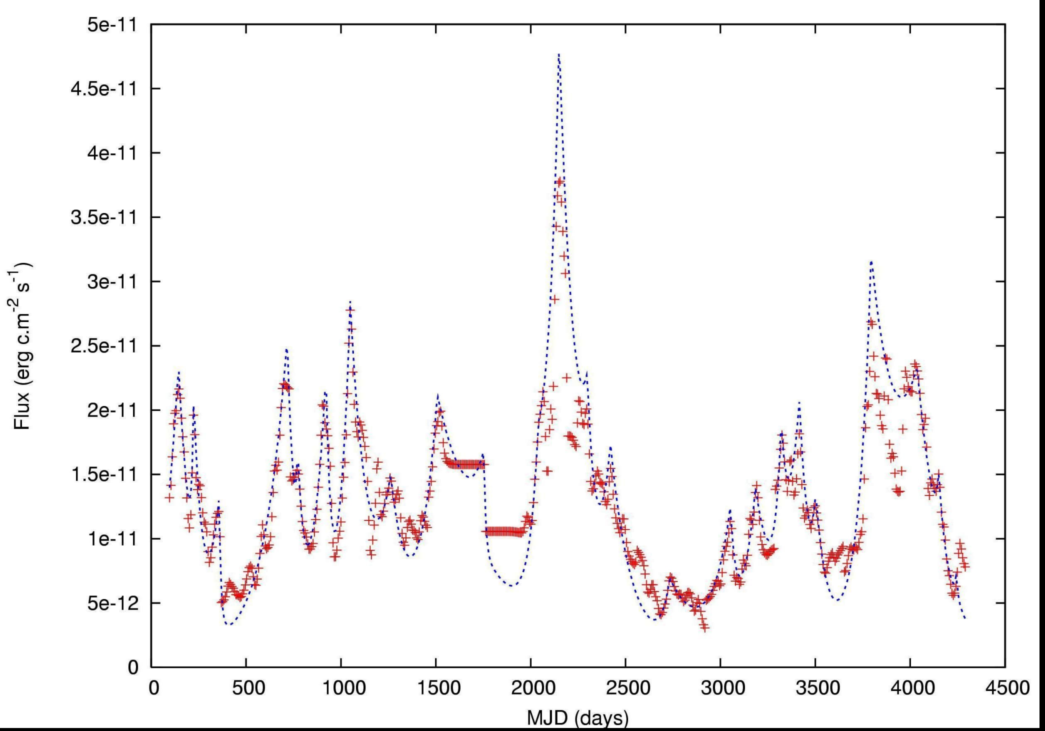


X-ray light curve : 10-day Gaussian smoothing applied

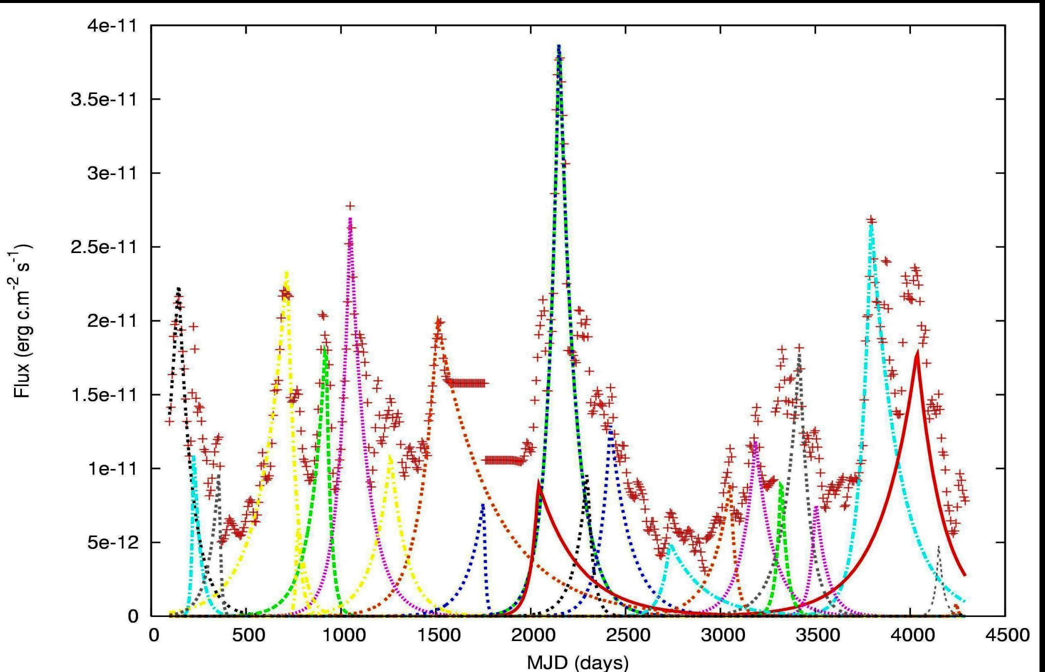
X-ray light curve : Decomposition into flares



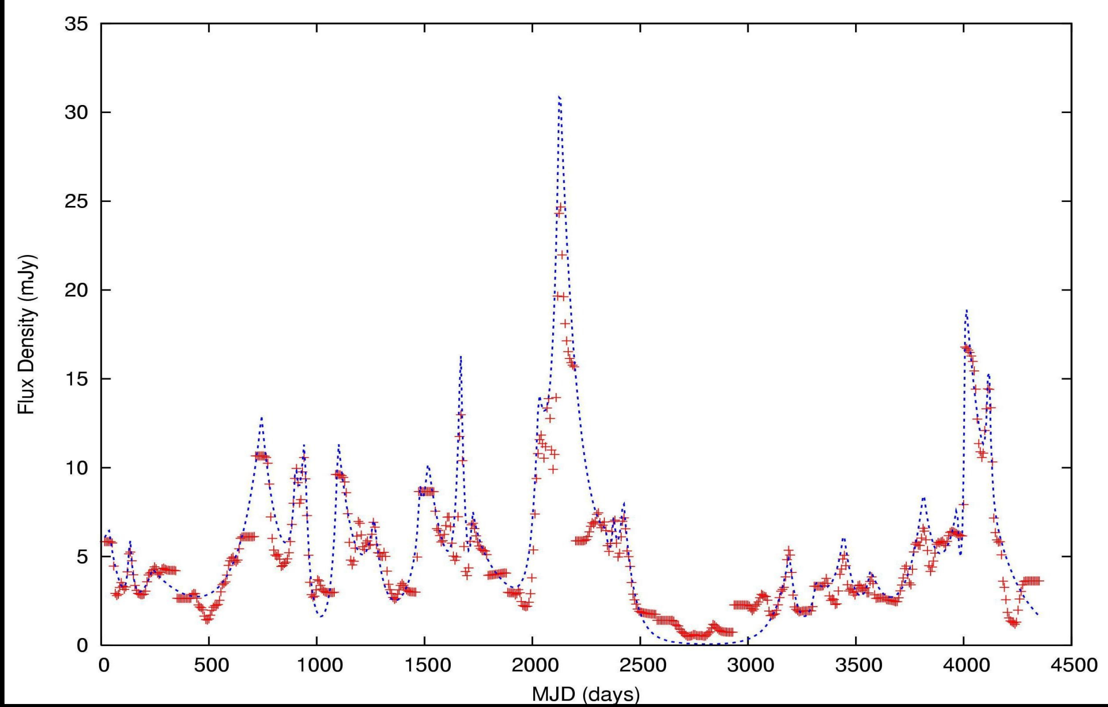


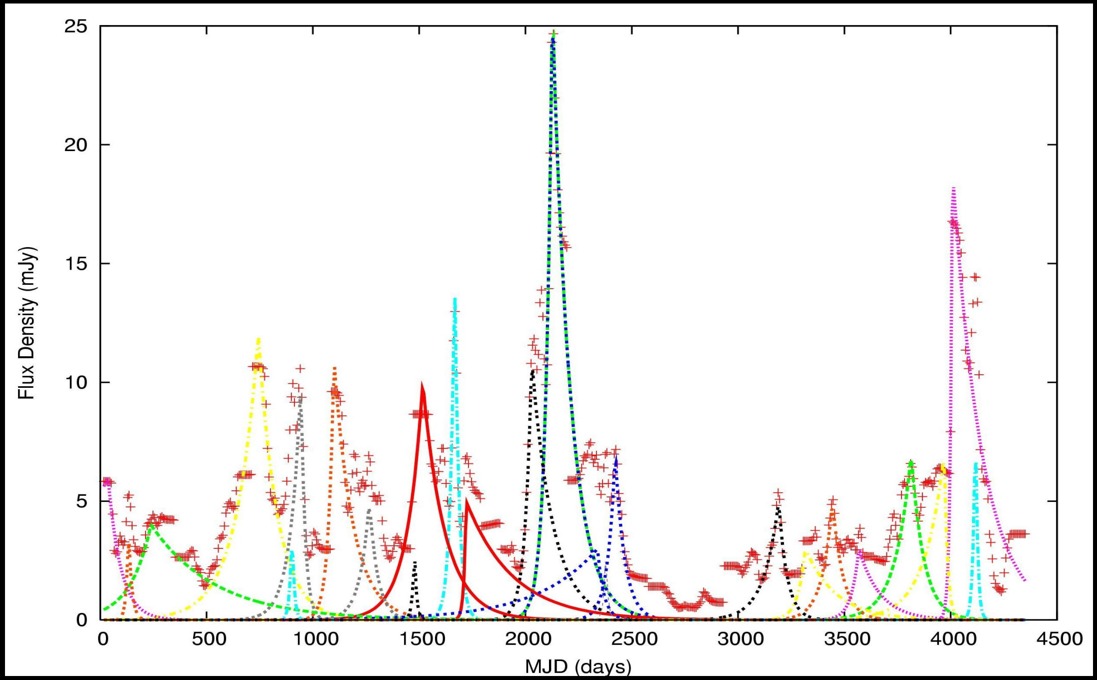


X-ray light curve : Sum of model flares & real data



Chatterjee et al. (submitted to ApJ)

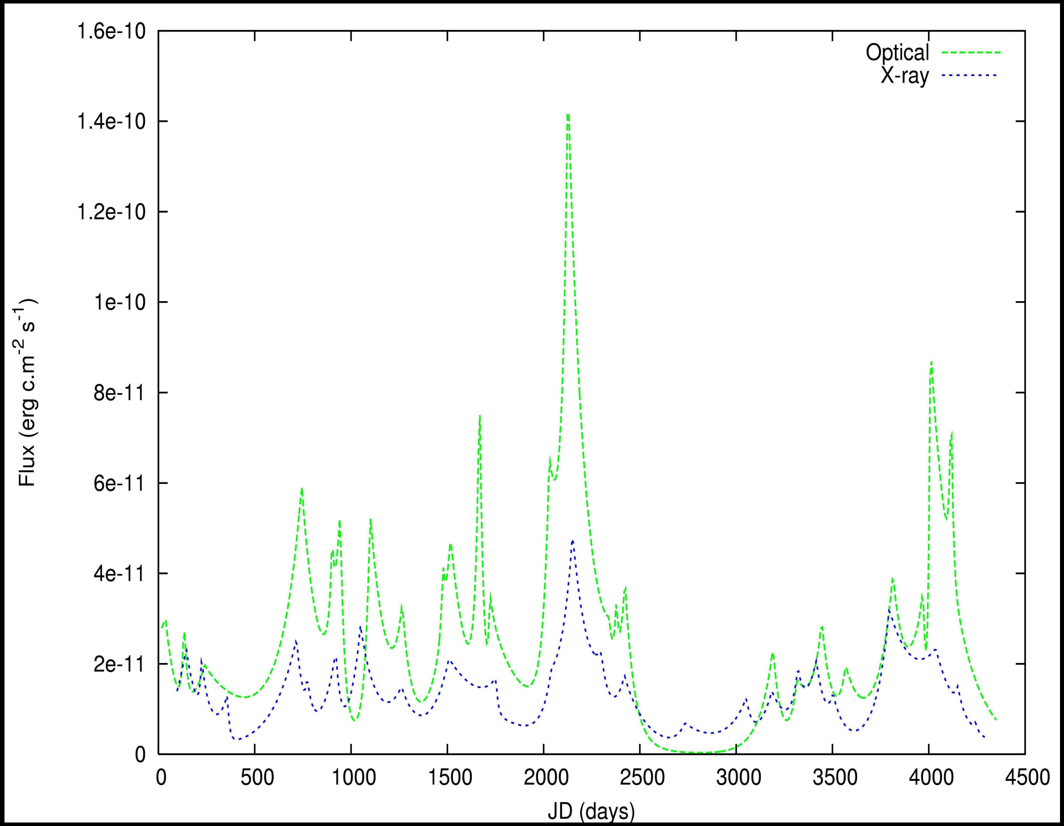




Optical light curve : Sum of model flares & real data

Chatterjee et al. (submitted to ApJ)

X-ray and Optical : Superposed



1. Time lag between peaks
3. Energy output of flares :
   Area under the curve

	Time Delay (Days)	X/Op Ratio
1.	-27	0.4
2.	-24	0.62
3.	-15	0.44
4.	-28	1.09
5.	-22	1.4
6.	16	0.18
7.	25	0.38
8.	27	0.3
9.	-3	0.95
10.	-8	0.98
11.	-3	0.87
12.	-6	0.88

Larger time delay, Smaller ratio (rows 1–8)

Smaller time delay, Ratio ~1 (rows 9–12)

- 6 out of 12 optical flares have more power than the related X-ray flare.
- Optical => Synchrotron
- X-ray=> Synchrotron self-Compton (SSC)
- SSC/Synch < 1 => Puzzling!
- When x/op ~1, time delay is very small.

- ***Modeling*** *of synchrotron (optical) and synchrotron self-Compton (X-ray) flares*
- $B \sim r^{-b}$, $N_0 \sim r^{-n}$, $R \sim r$

The Synchrotron emission coefficient :

$$j_\nu(\nu) = \frac{\nu N_0}{k\prime} \int_{\gamma_{min}}^{\gamma_{max}} \gamma^{-s}(1-\gamma kt)^{s-2}\, d\gamma \ \int_{\frac{\nu}{k\prime\gamma^2}}^{+\infty} K_{\frac{5}{3}}(\xi)\, d\xi$$

Power-law electron energy distribution : $N(\gamma) = N_0\gamma^{-s}$.

s=2.5

Critical frequency : $\nu_c = k\prime\gamma^2$.

Synchrotron energy loss : $\frac{dE}{dt} = -k\gamma^2$

$K_{\frac{5}{3}}$: Modified Bessel function of the second kind of order $\frac{5}{3}$.

The Inverse Compton emission (SSC in this case) coefficient :

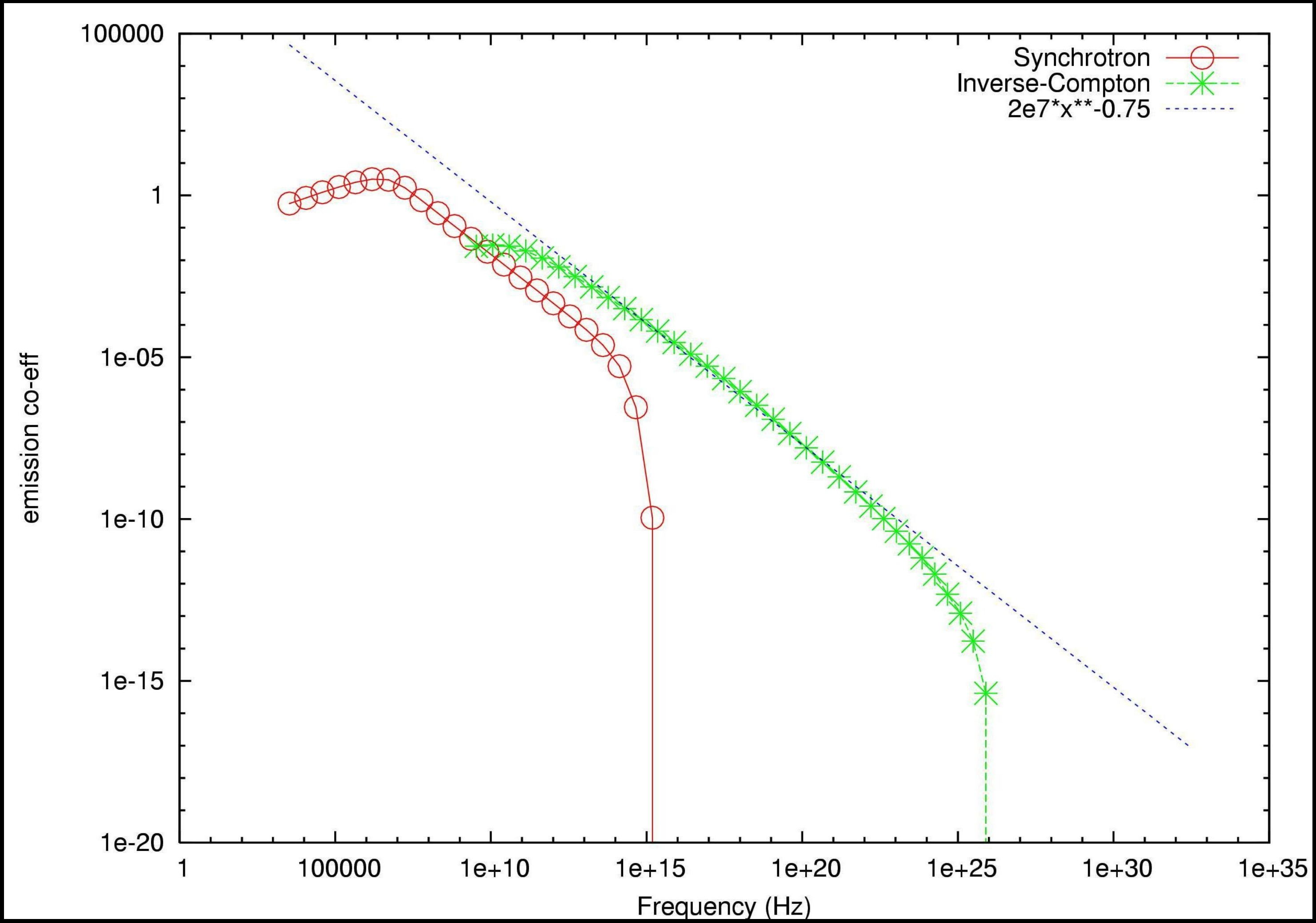
$$j_\nu^C = \int_\nu \int_\gamma \frac{\nu_f}{\nu_i} j_\nu(\nu_i) R\sigma(\epsilon_i, \epsilon_f, \gamma) N(\gamma)\, d\gamma d\nu_i$$

The Compton cross section :

$$\sigma(\epsilon_i, \epsilon_f, \gamma) = \frac{3}{32}\sigma_T \frac{1}{\epsilon_i\gamma^2}(8 + 2x - x^2 + 4x ln(\frac{x}{4})),$$

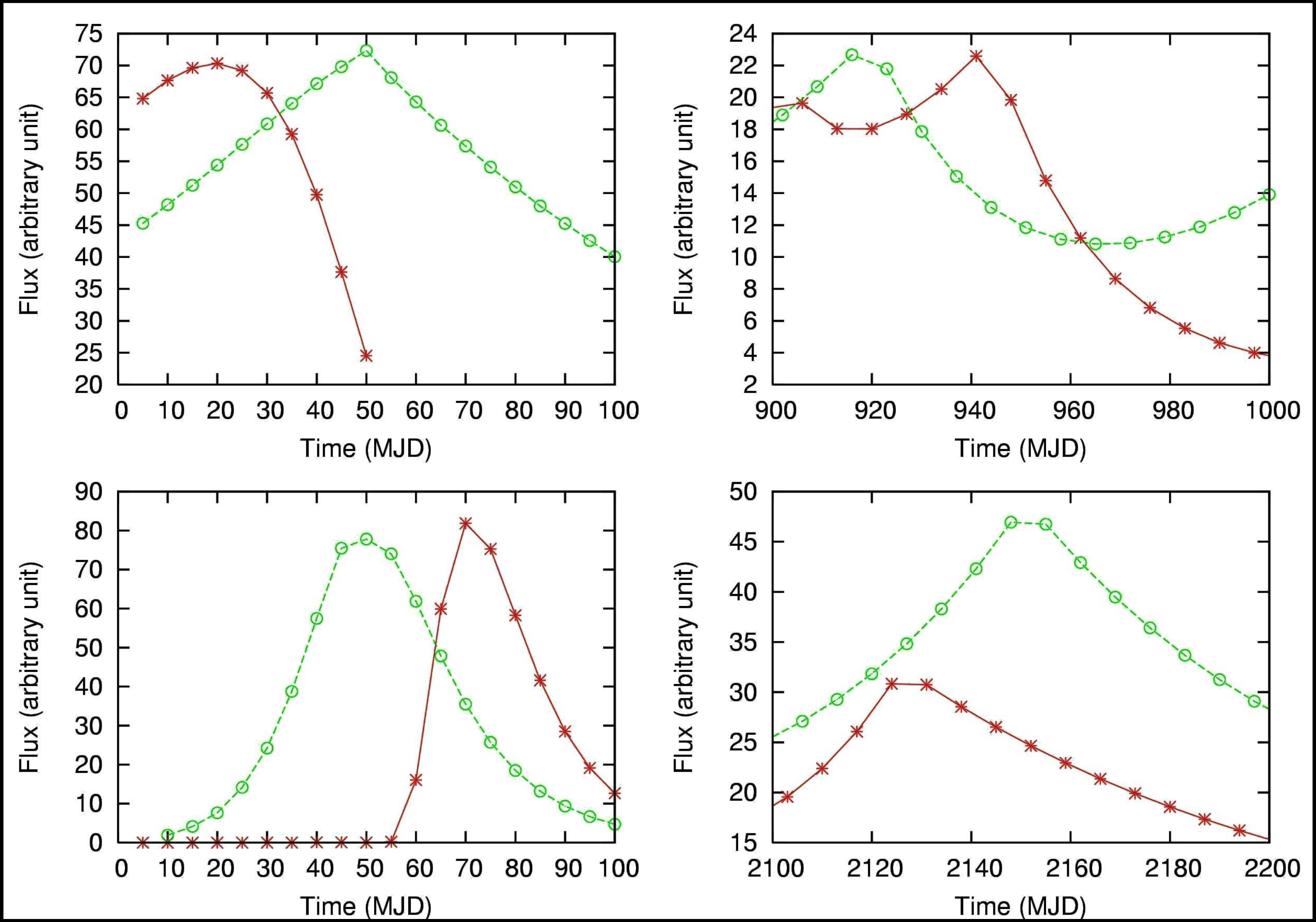
$$x = \frac{\epsilon_f}{\epsilon_i\gamma^2}$$

Spectrum for Sanity Check



Real and Simulated Light Curves

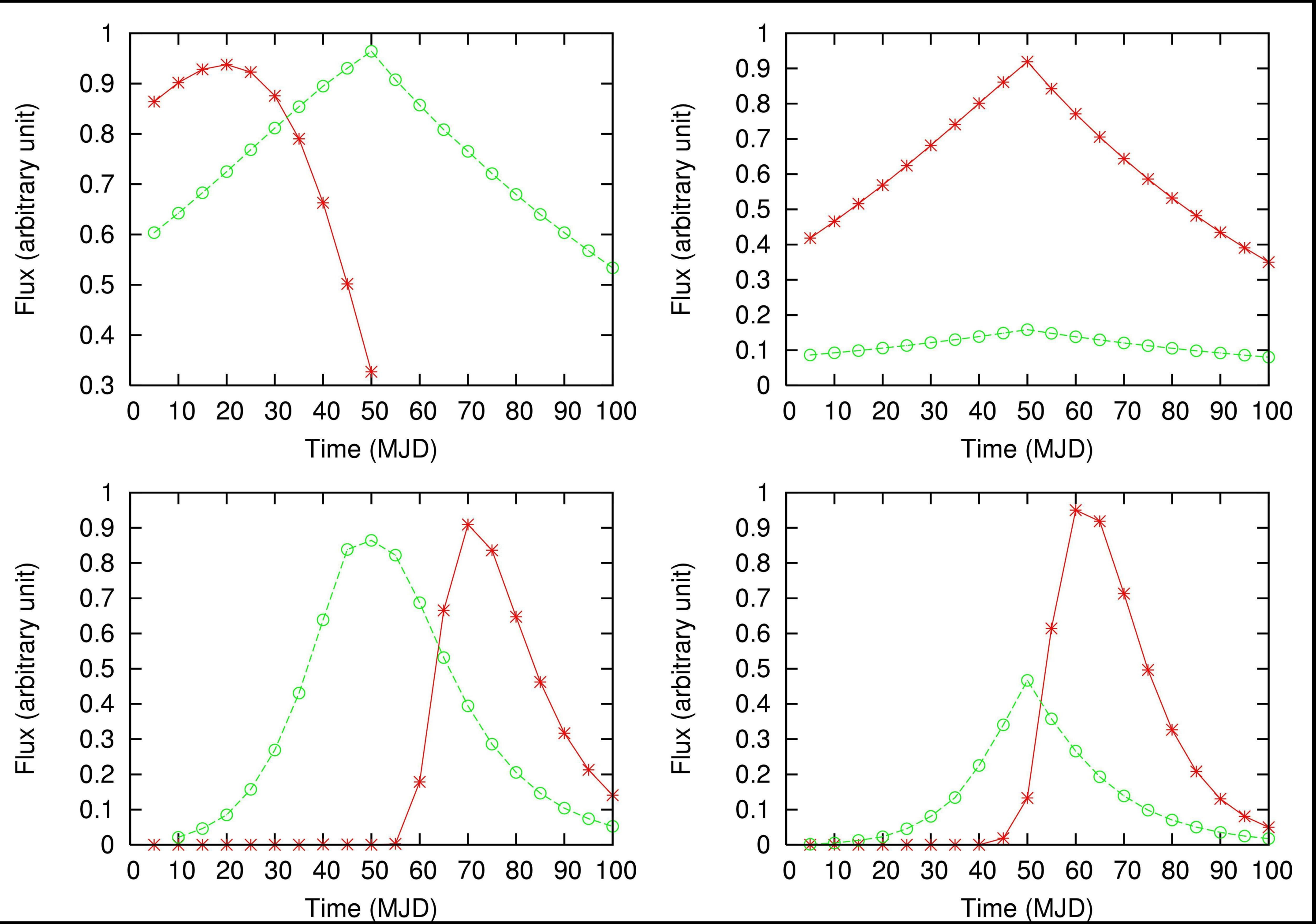
SIMULATED **REAL**



Chatterjee et al. (submitted to ApJ)

Downstream SSC (Green) maybe smaller than Synchrotron (Red)

UPSTREAM **DOWNSTREAM**

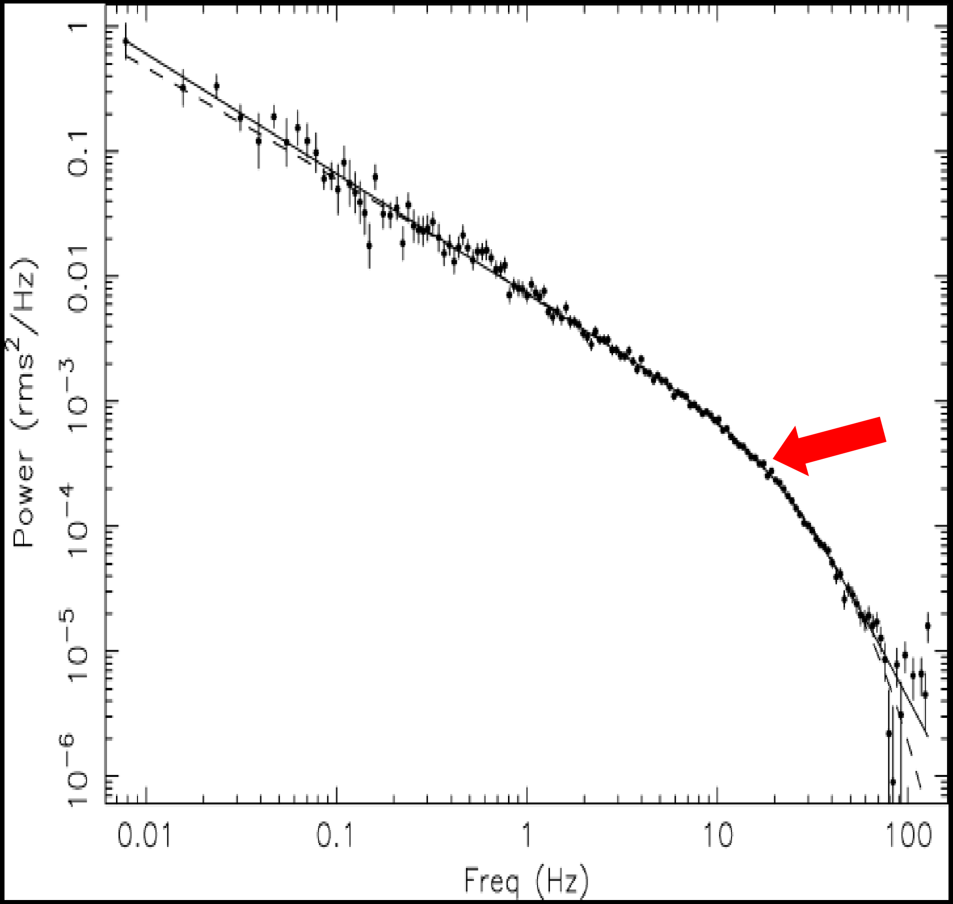


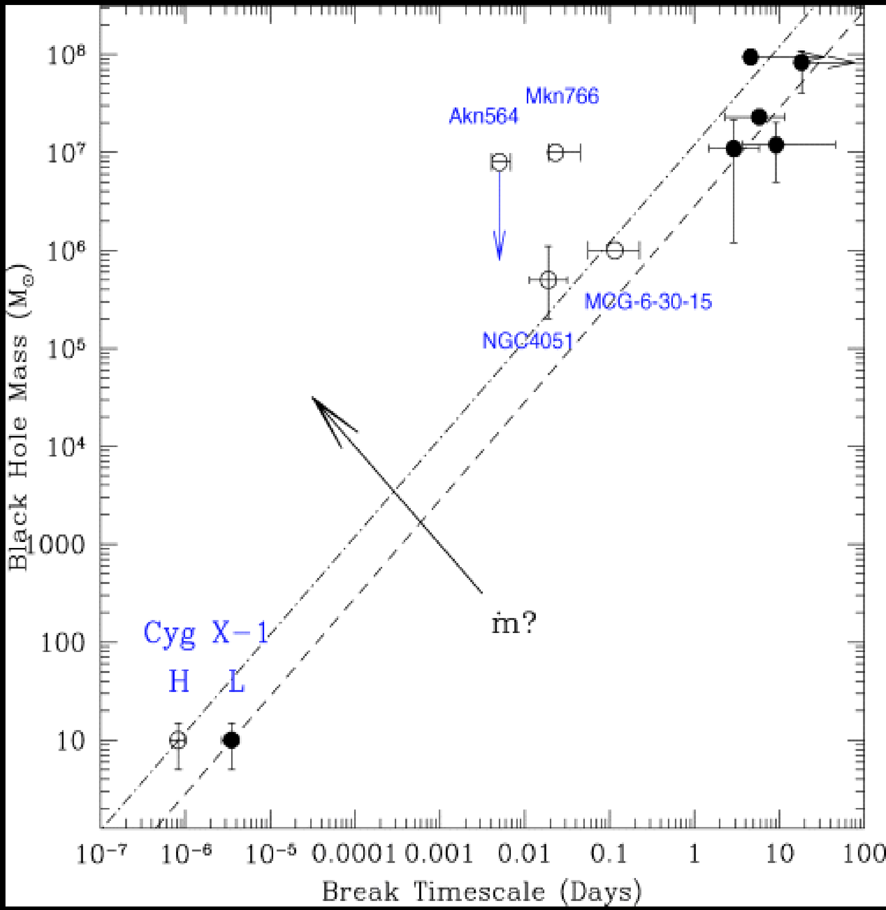
Chatterjee et al. (submitted to ApJ)

WORK IN PROGRESS

- PSD of 3C 120 : Break?

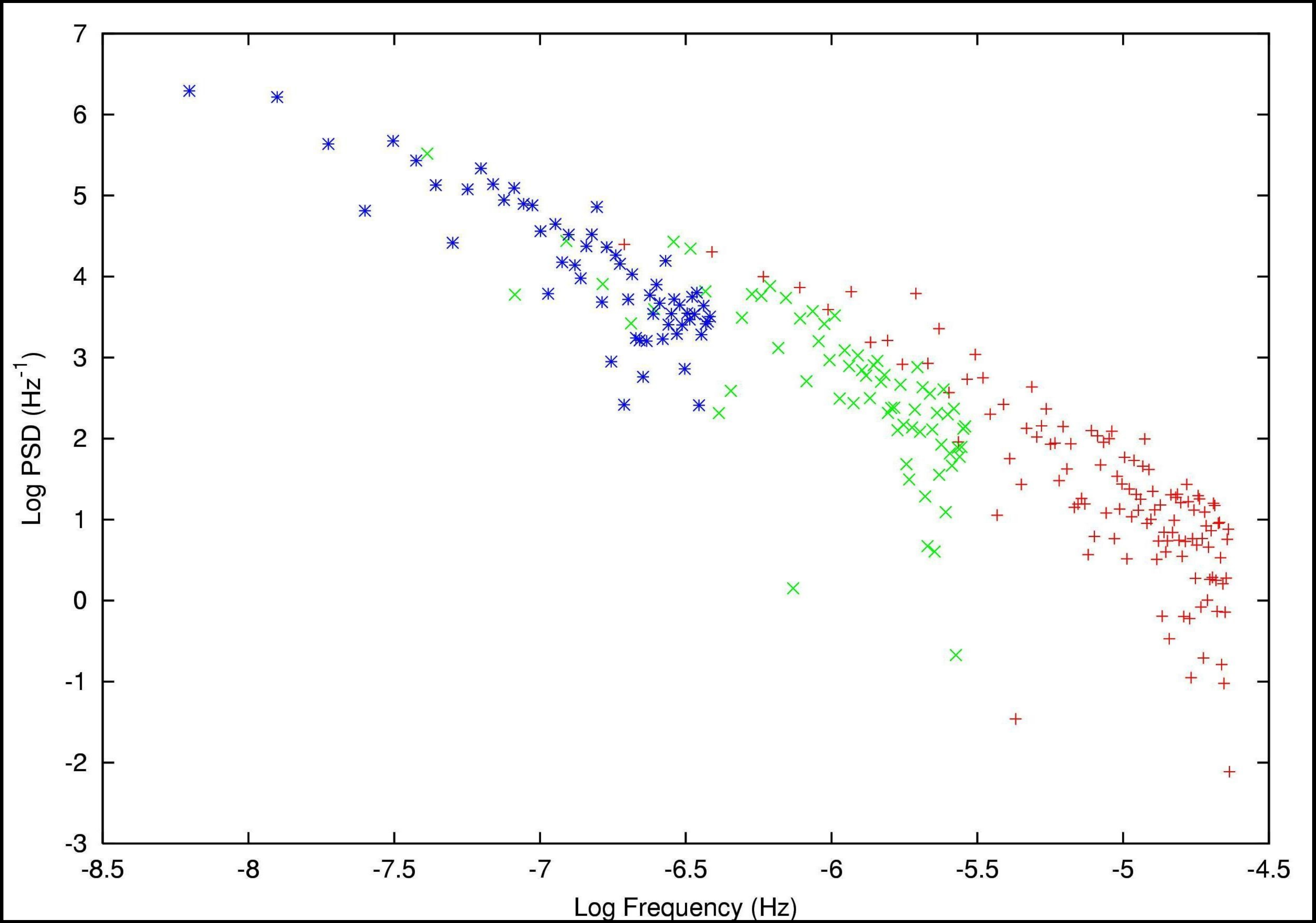
PSD of Cygnus X-1 : Break Frequency



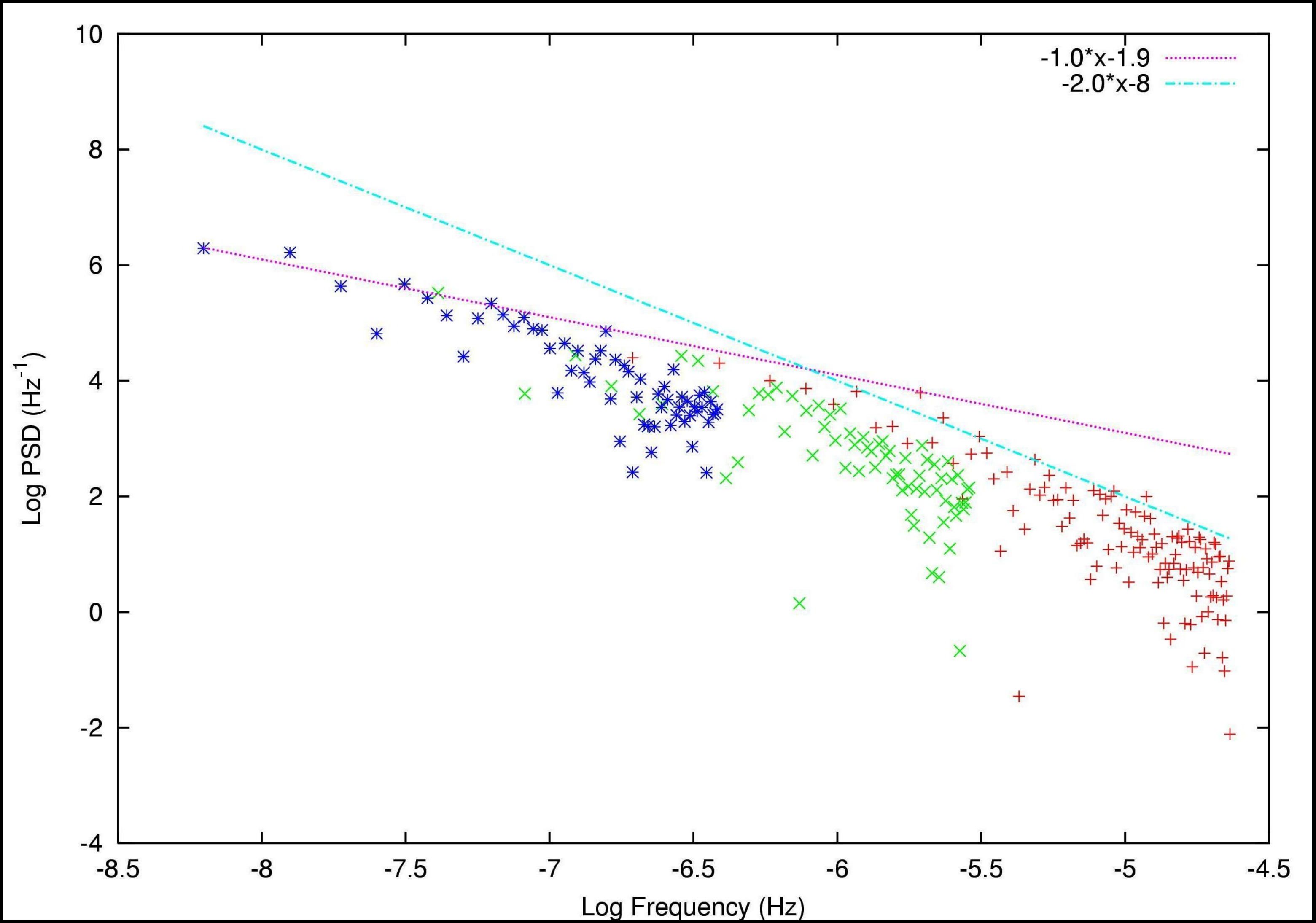


Credit : Uttley et al. (2004)

3C 120 : Broken Power-Law?



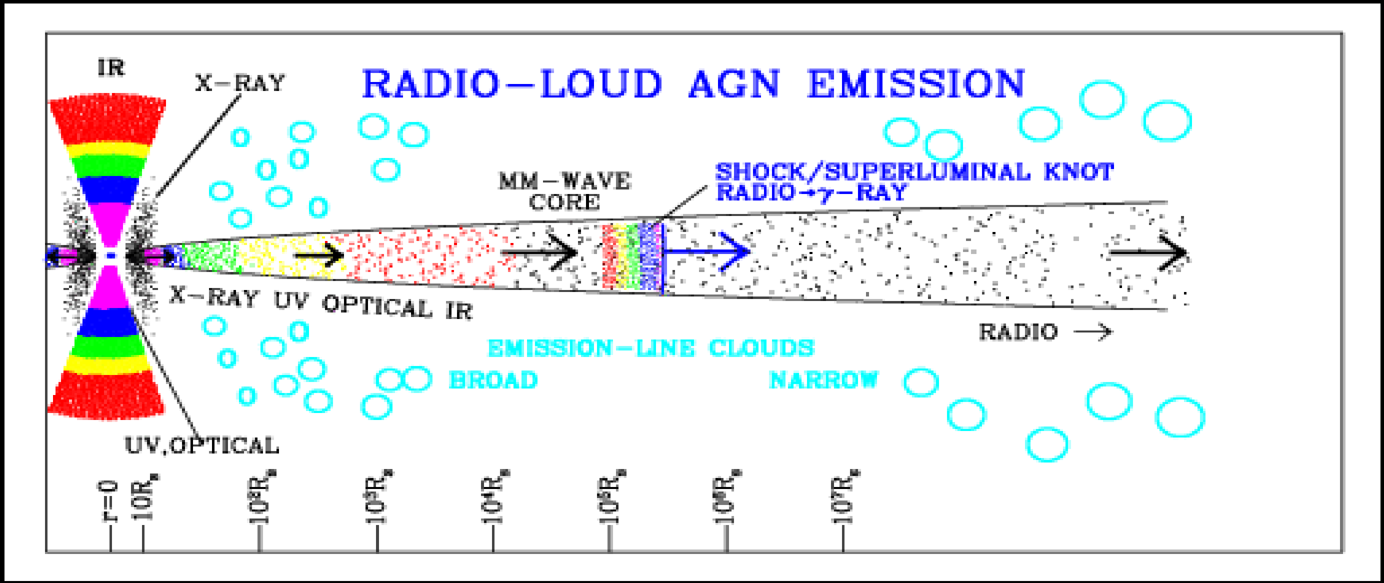
3C 120 : Broken Power-Law?



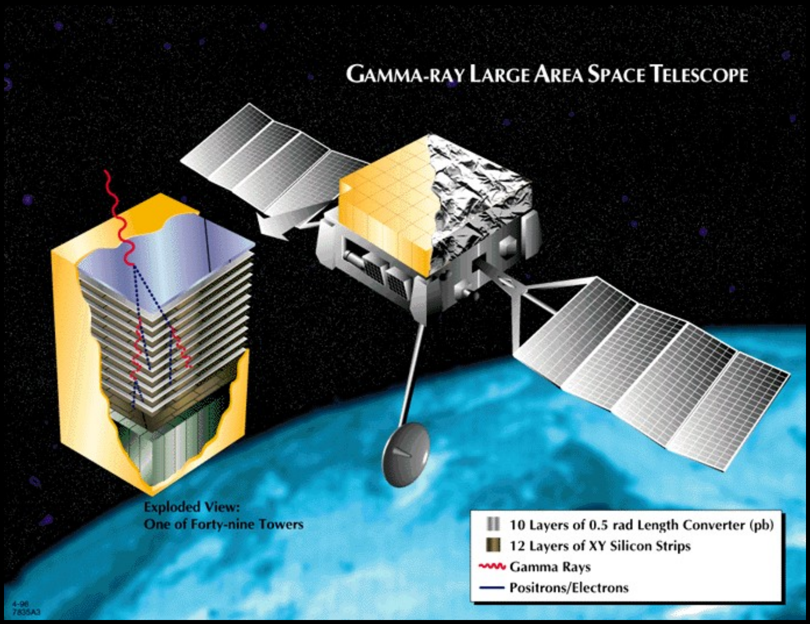
Marshal, K et al. (in preparation)

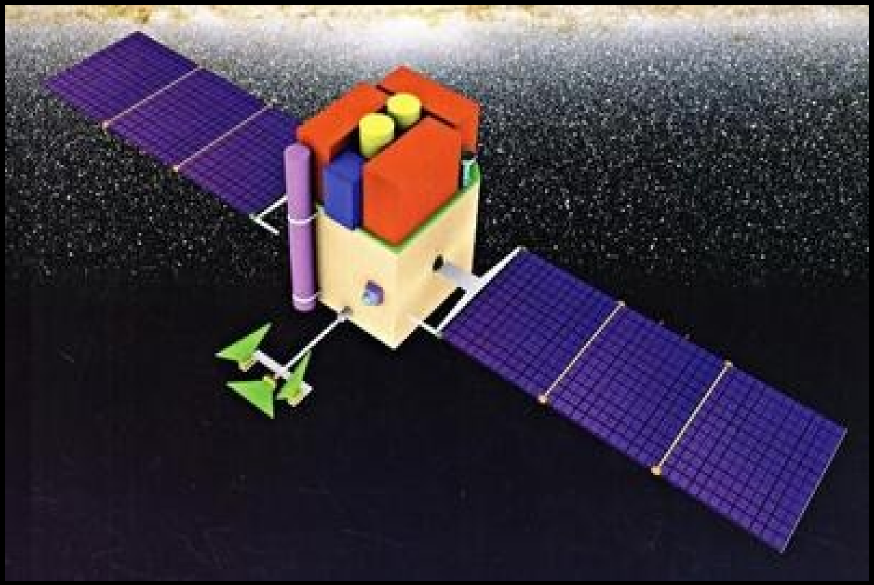
Theoretical Work in Progress

- Calculations of the variability of Synchrotron and Synchrotron self-Compton emission in the jet in the presence of turbulent magnetic field and a moving shock front.



GLAST and ASTROSAT





Golden age of high energy time variability study

THE END