ON THE FLARING GAMMA-RAY ACTIVITY OF QUASAR 3C 279

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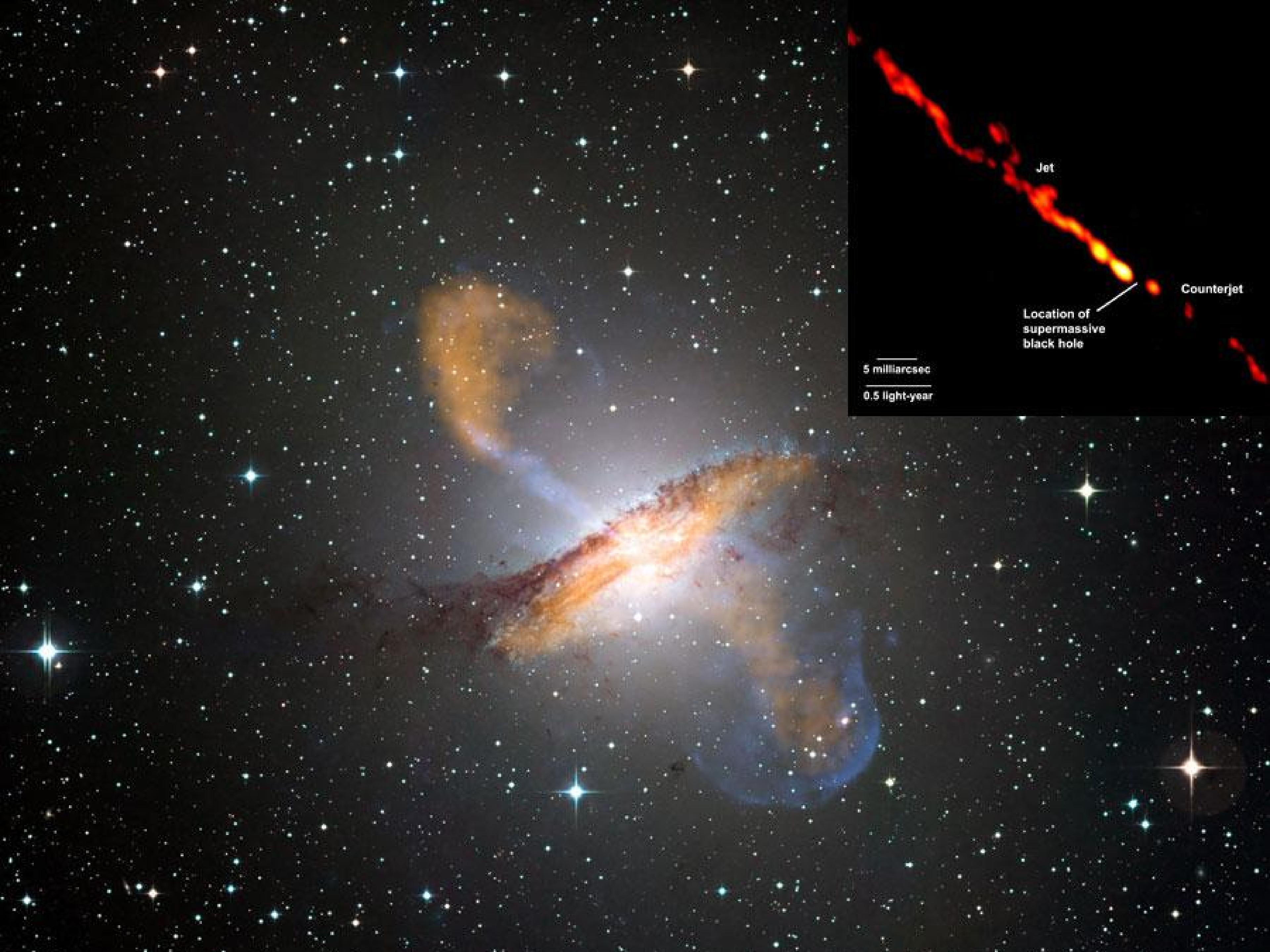
TALK OUTLINE

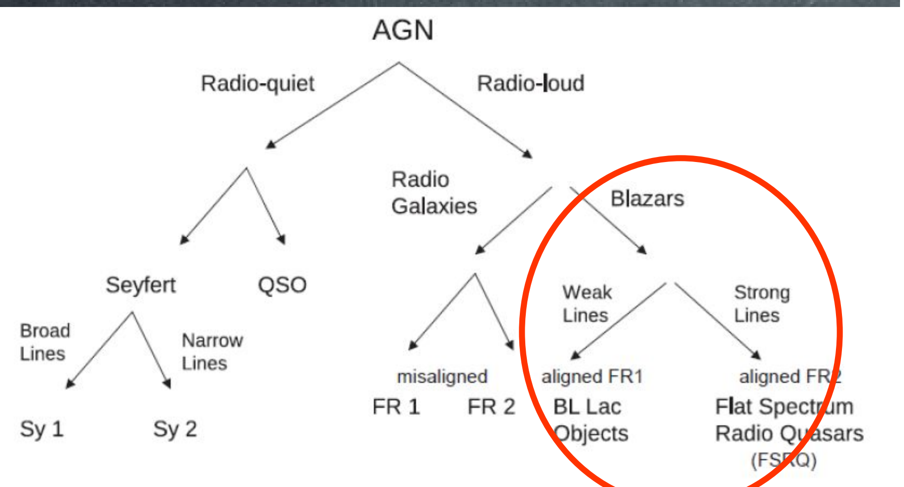
- Active Galactic Nuclei → Blazars
- Models for Multiwavelength emission
- 3C 279: The ‘extreme’ flare of June 2015

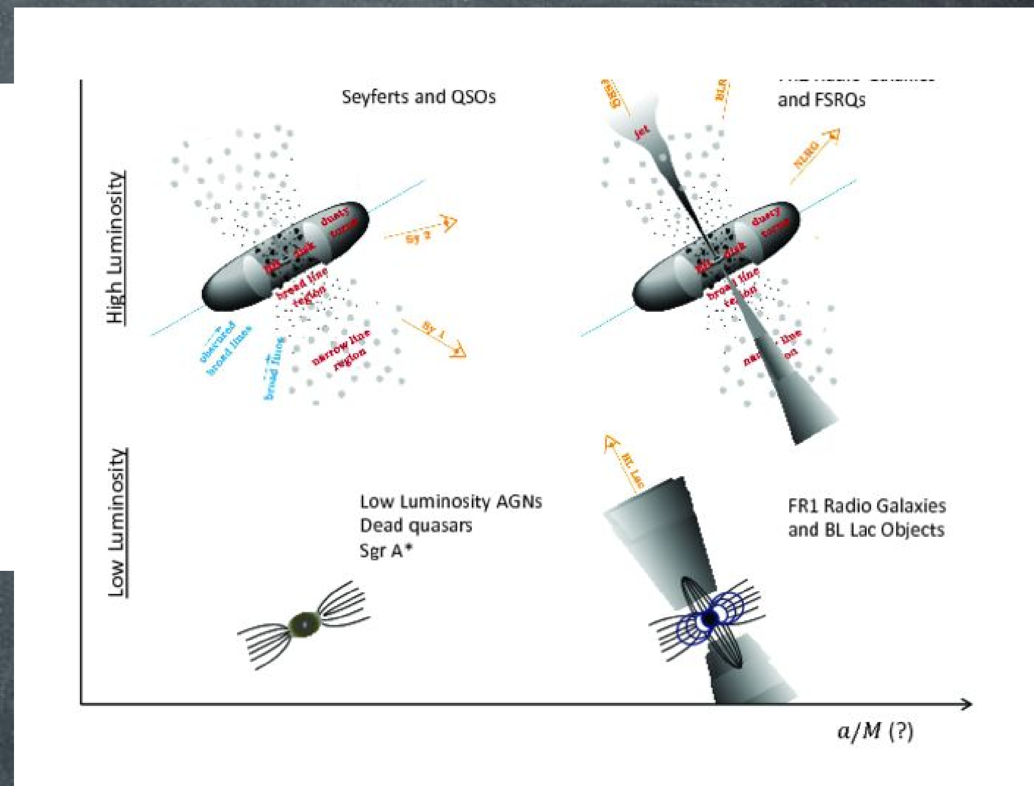
In collaboration with

- Maria Petropoulou – *Purdue University*
- Ioulia Florou – *NKUA*


Jet
Counterjet
Location of supermassive black hole
5 milliarcsec
0.5 light-year

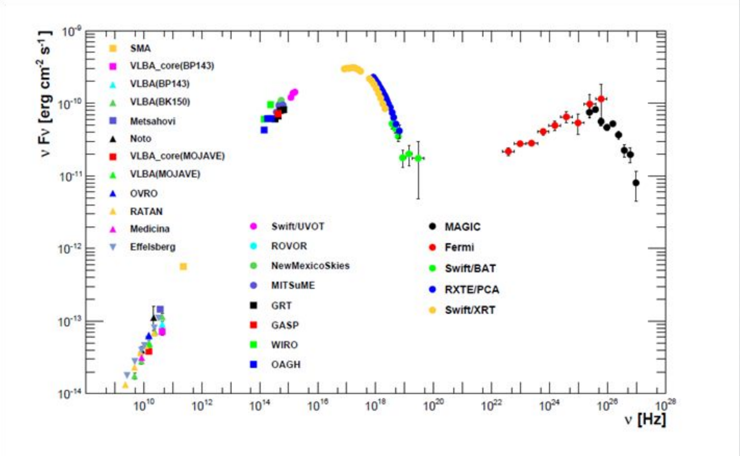
AGN TAXONOMY

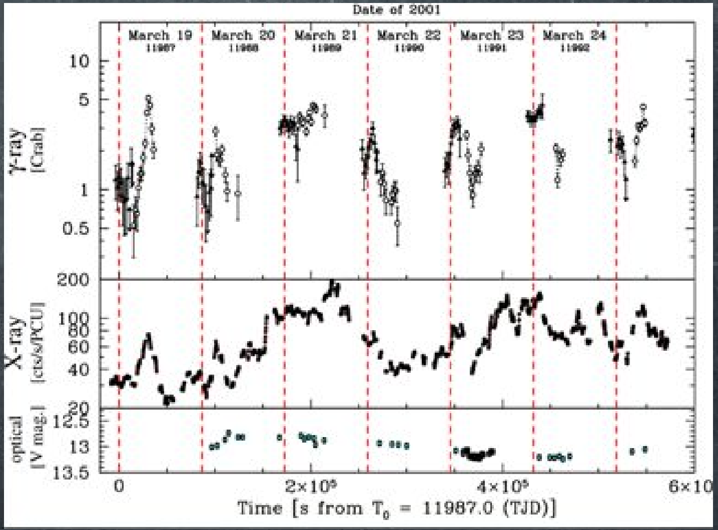




BLAZARS

- Few (~5% of all AGN)
- Compact , flat spectrum radio sources
- Broad (radio-gamma) non-thermal continuum : 'Double hump' spectrum
- Variable at all energies: short – large amplitude variability + correlations
- Superluminal motion





SPECTRAL FORMATION

Three observational facts

- MW Spectrum → Particle acceleration to high energies + non-thermal radiation mechanisms
- Fast + correlated variability → emission from a localized region
- Superluminal motion → emission from inside the jet → relativistic beaming

Radiation transfer problem: theoretical questions

(1) Geometry of emitting region

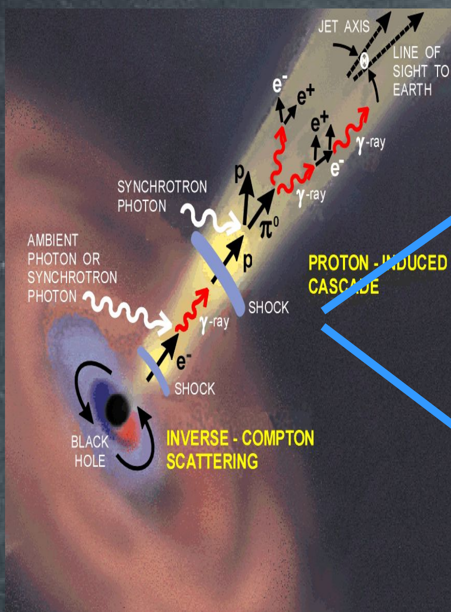
(2) Photon emission + absorption mechanisms

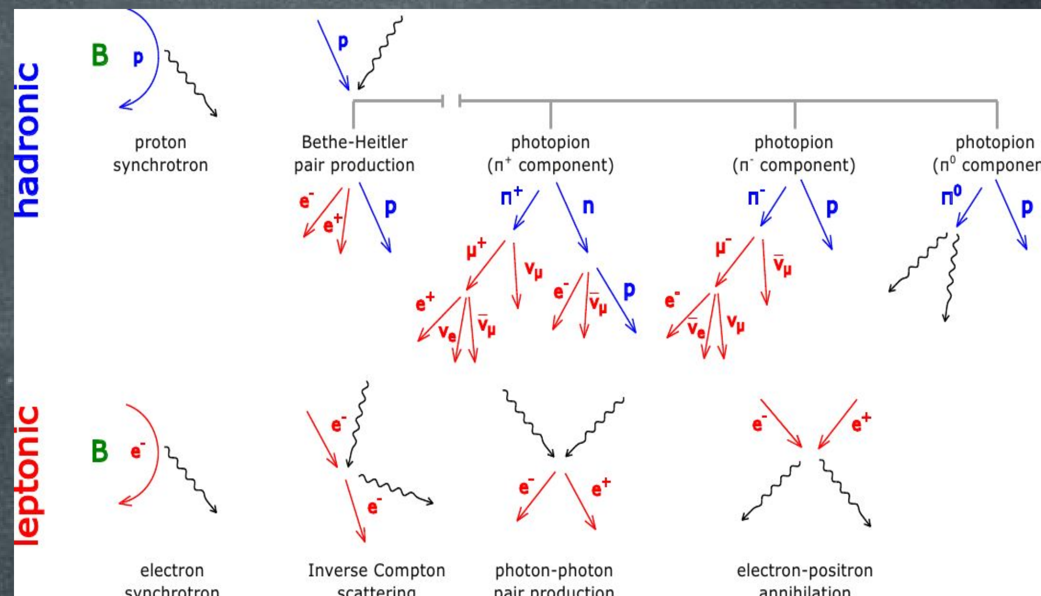
(3) Particle energization/acceleration

(4) Species of radiating particles

(5) Location of ‘active’ region

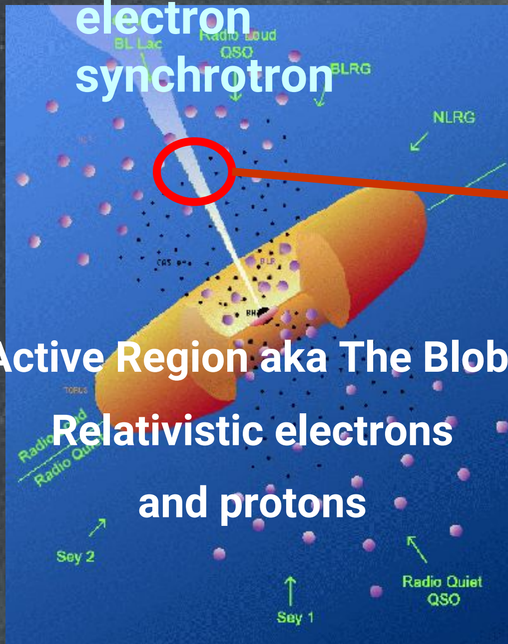
RADIATION MECHANISMS





MODELS FOR BLAZAR EMISSION

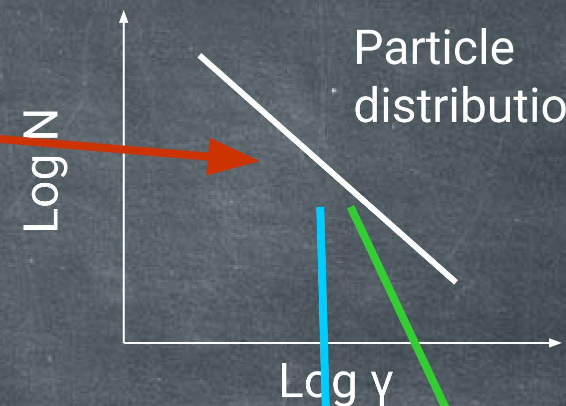
electron synchrotron



Active Region aka The Blob:

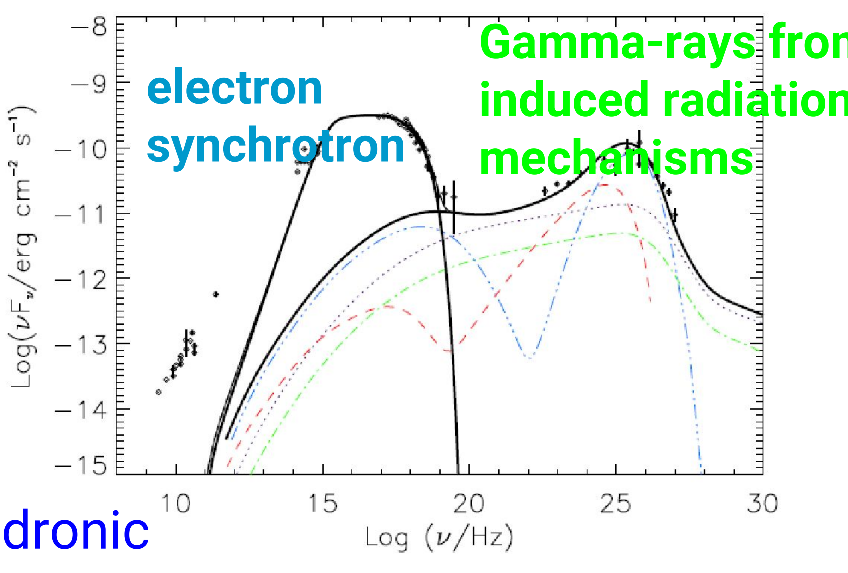
Relativistic electrons and protons

Estimation of B, R_b, δ + specifics of radiating particles



B-field

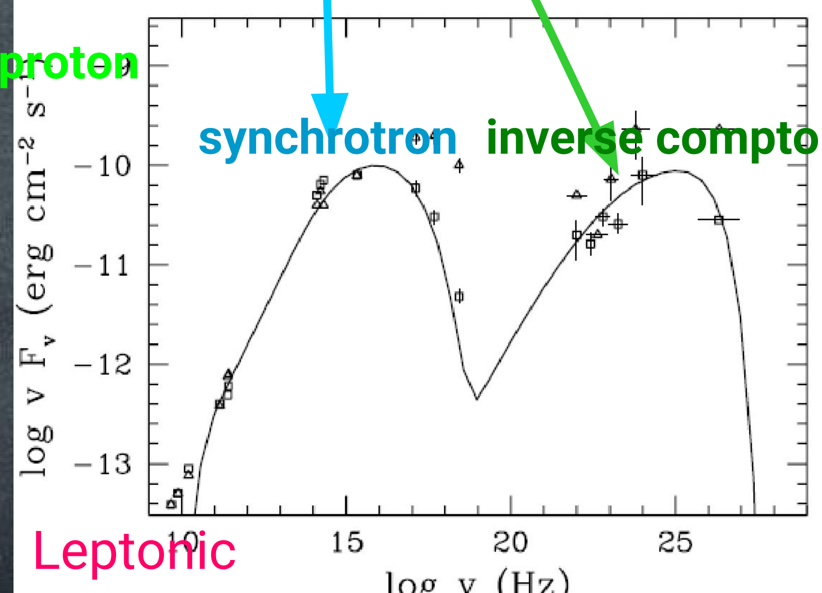
soft photons



electron synchrotron

Gamma-rays from proton induced radiation mechanisms

Hadronic

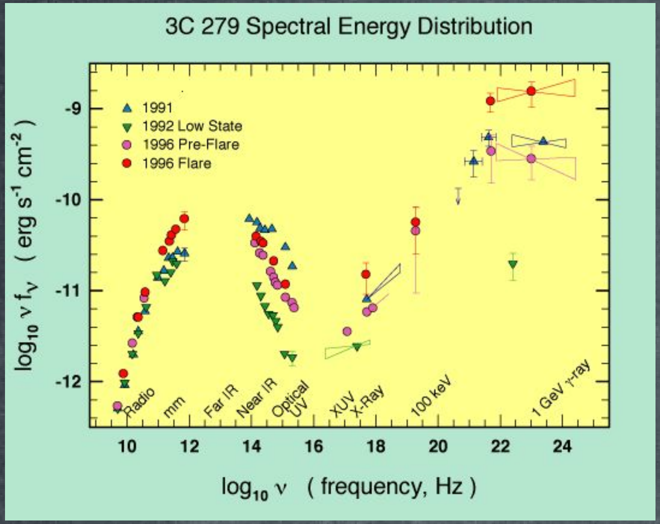


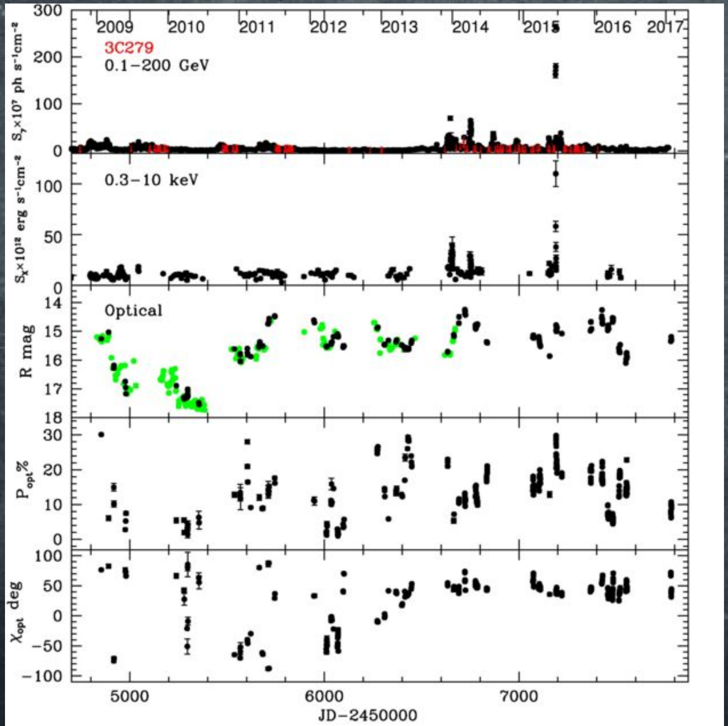
synchrotron

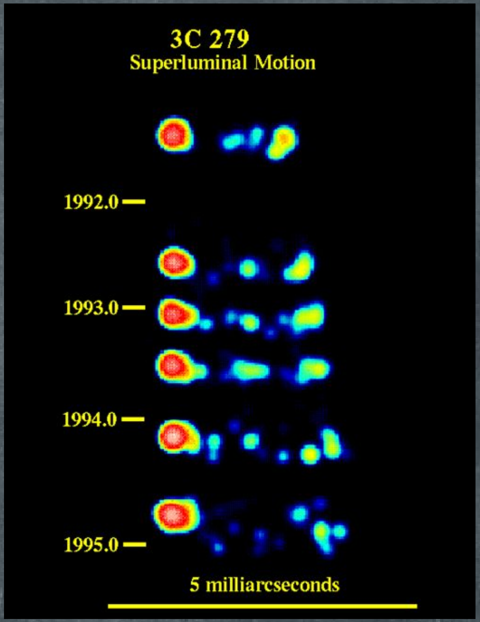
inverse compton

Leptonic

QUASAR 3C 279



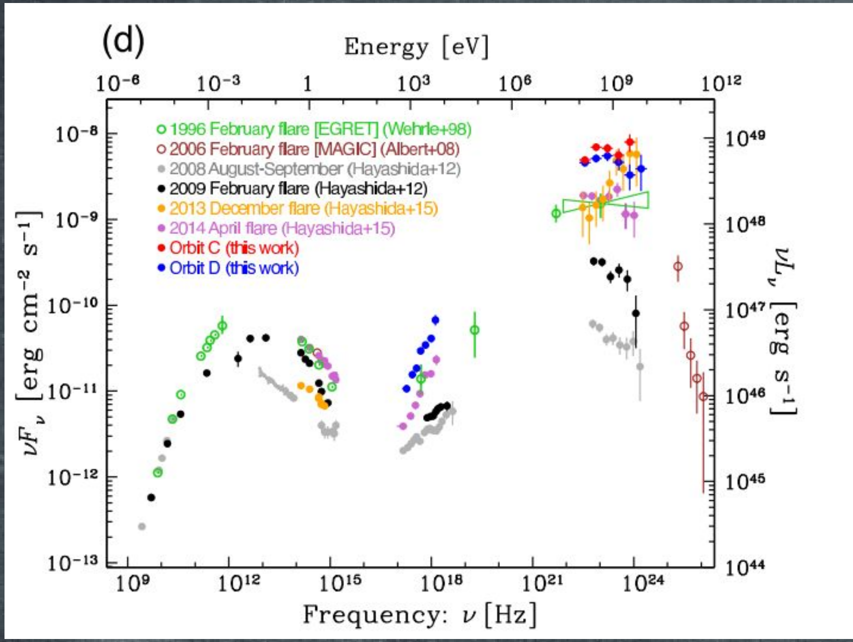


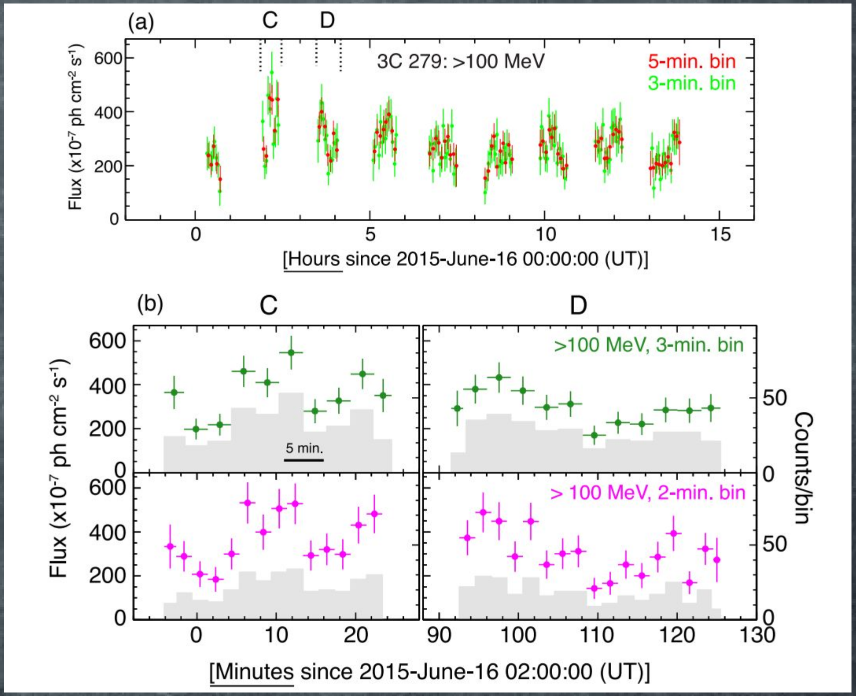


Luminosity ~1.e48 erg/sec

Black hole mass ~ 5.e8 M_{sun}

THE JUNE 2015 GAMMA-RAY FLARE





Giant flare $L_\gamma \sim 1.e49$ erg/sec

Subflares as fast as $t_{var} \sim 5$ min (first ever for Fermi)

A very unique and extreme case for ALL models

Ackermann et al 2016

THE COMPACTNESS PROBLEM

- Absorption mechanism for gamma-rays on soft photons
- Threshold: if

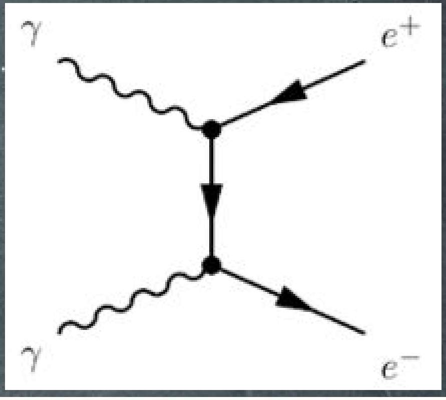
$$x_\gamma = \frac{h\nu_\gamma}{m_e c^2}$$ then $$x_{soft} \geq x_{thr} = \frac{2}{x_\gamma}$$

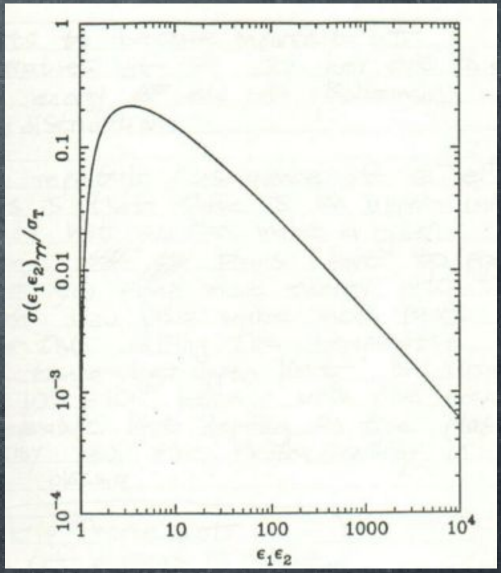
- Optical depth $$\tau_{\gamma\gamma} \approx \sigma_{\gamma\gamma} n_s R_b$$
- Fast variability → small source (or large δ)

$$R_b \sim \delta\, t_{\mathrm{var}}\, c$$

- Target photon density $$n_s = \frac{L}{4\pi R_b^2 c h \nu_{soft}}$$

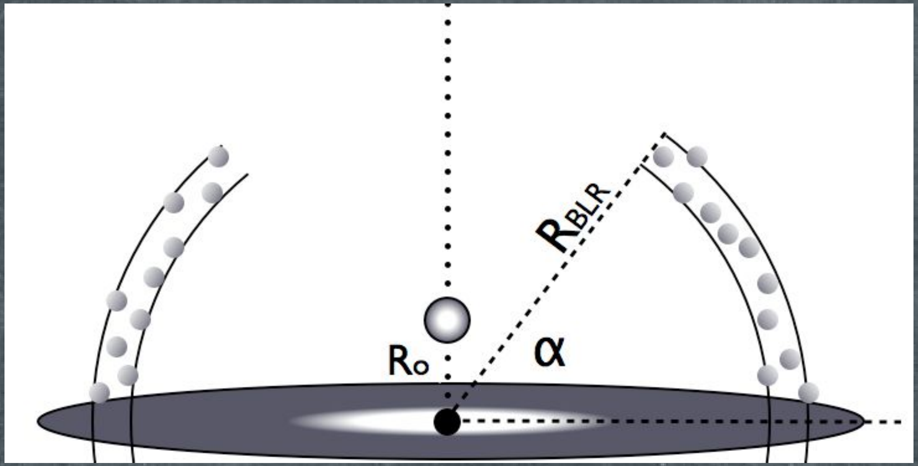
therefore $$\tau_{\gamma\gamma} \sim L/R_b$$ (compactness)





If compactness high, $\tau_{\gamma\gamma}$>>1 → efficient gamma ray absorption

EXTERNAL γγ ABSORPTION

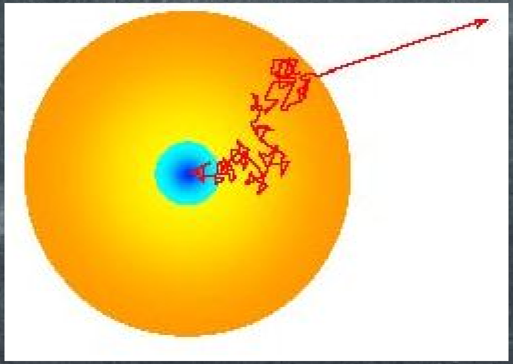


- FSRQs have strong Broad Lines → high densities of soft (target) photons
- If $z_0 < R_{BLR}$ → $\tau_{\gamma\gamma}$ can be high ("external" absorption)
- Site of radiation zone is crucial for FSRQs

RADIATIVE TRANSFER: AN ANALOGY

STELLAR ASTROPHYSICS

- Stellar core emits hard photons ε_γ (nuclear lines)
- Energy is degraded as photons diffuse on stellar envelope
- Surface emits $\varepsilon_\nu \sim \kappa T \ll \varepsilon_\gamma$



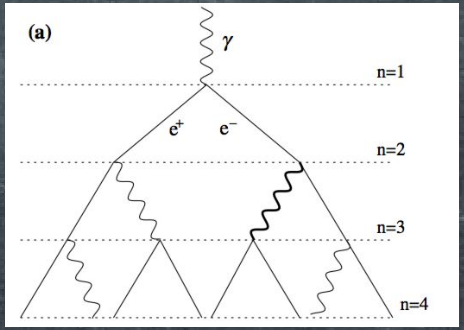
HIGH ENERGY ASTROPHYSICS

- Blob emits gamma-rays
- If absorbed → creation of secondary ee pairs
- Pairs emit more gamma rays

→ photon energy is degraded

(initial energy is shared by many)

→ electromagnetic cascade



Luminosity is conserved **but** photon energy is downgraded

Protons:

$$\frac{\partial n_{\rm p}}{\partial t} + L_{\rm p}^{\rm BH} + L_{\rm p}^{\rm photopion} + L_{p}^{\rm psyn} + \frac{n_{\rm p}}{t_{\rm p,esc}} = Q_{\rm p}^{\rm inj} + Q_{\rm p}^{\rm photopion}$$

Electrons:

$$\frac{\partial n_{\rm e}}{\partial t} + L_{\rm e}^{\rm syn} + L_{\rm e}^{\rm ics} + L_{\rm e}^{\rm ann} + L_{\rm e}^{\rm tpp} + \frac{n_{\rm e}}{t_{\rm e,esc}} = Q_{\rm e}^{\rm ext} + Q_{\rm e}^{\rm BH} + Q_{\rm e}^{\gamma\gamma} + Q_{\rm e}^{\rm photopion} + Q_{\rm e}^{\rm tpp}$$

Photons:

$$\frac{\partial n_{\gamma}}{\partial t} + \frac{n_{\gamma}}{t_{\gamma,\rm esc}} + L_{\gamma}^{\gamma\gamma} + L_{\gamma}^{\rm ssa} = Q_{\gamma}^{\rm syn} + Q_{\gamma}^{\rm psyn} + Q_{\gamma}^{\rm ics} + Q_{\gamma}^{\rm ann} + Q_{\gamma}^{\rm photopion}$$

Neutrinos:

$$\frac{\partial n_{\nu}}{\partial t} + \frac{n_{\nu}}{t_{\rm esc}} = Q_{\nu}^{\rm photopion}$$

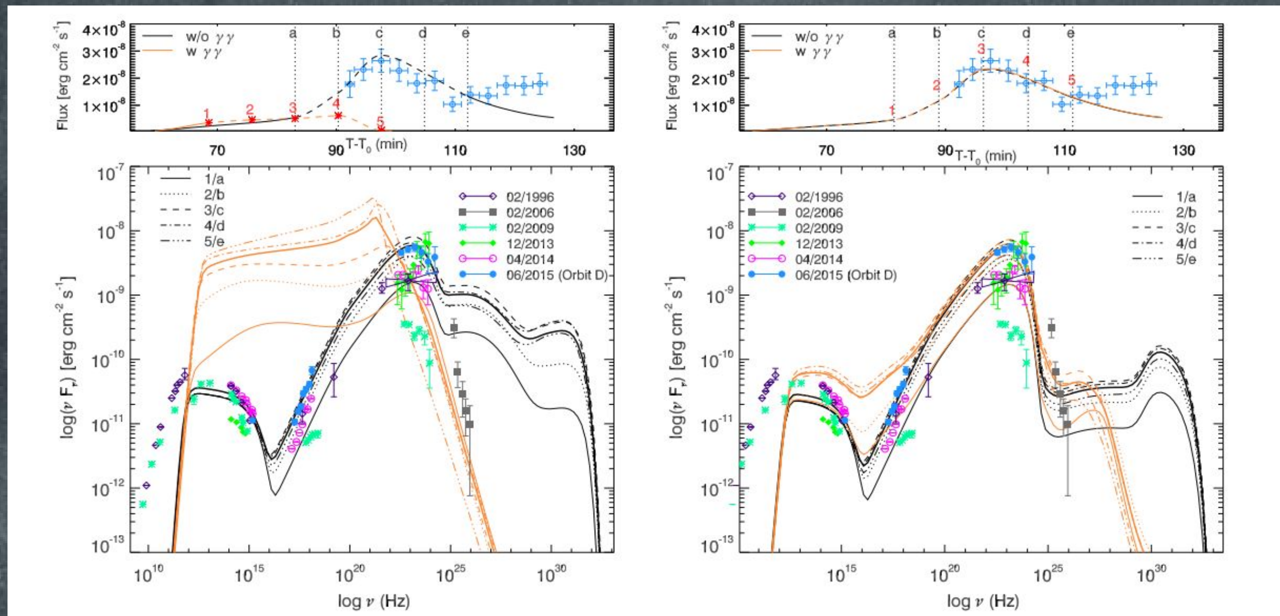
Neutrons:

$$\frac{\partial n_{n}}{\partial t} + L_{n}^{\rm photopion} + \frac{n_{n}}{t_{\rm esc}} = Q_{n}^{\rm photopion}$$

- **Energy conserving scheme**
- **Pion, muon & kaon decay is modeled using results of MC code SOPHIA (Muecke et al. 2000)**
- **Synchrotron cooling of secondaries is also included.**

Dimitrakoudis et al. 2012

HADRONIC ‘FITS’ TO THE 3C 279 FLARE



Role of γγ absorption crucial

Symbol	Parameter	Case A	Case B
δ	Doppler factor	19.5	50
Γ	Bulk Lorentz factor	9.9	25
B' (kG)	Magnetic field strength	2.2	0.8
$r'_{\rm b}$ (cm)	Source radius	1.7×10^{14}	4.4×10^{14}
$P_{\rm j}$ (erg s^{-1})	Absolute total jet power	8.3×10^{47}	10^{48}
$u'_{\rm p}$ (erg cm^{-3})	Proton energy density	2.6×10^5	7×10^3
$u'_{\rm B}$ (erg cm^{-3})	Magnetic energy density	2×10^5	2.6×10^4
$E'_{\rm p,max}$ (eV)	Max. proton energy	5.2×10^{16}	4.8×10^{16}
$z_{\rm diss}$ (cm)	Dissipation distance	1.7×10^{16}	1.1×10^{17}

→ high δ

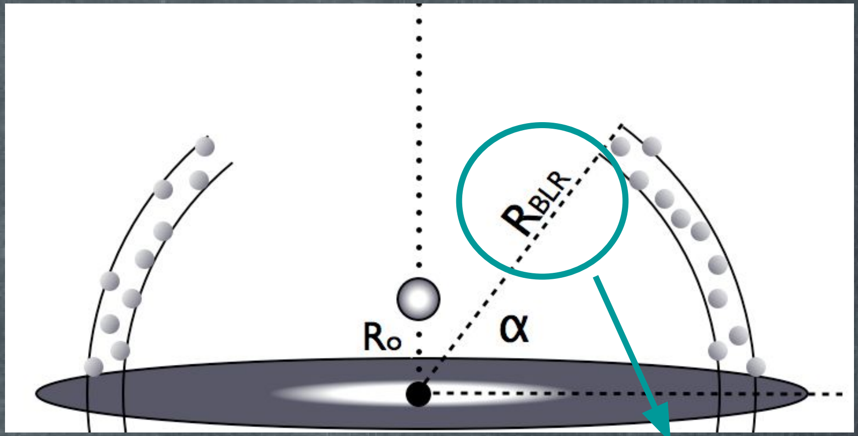
→ small source

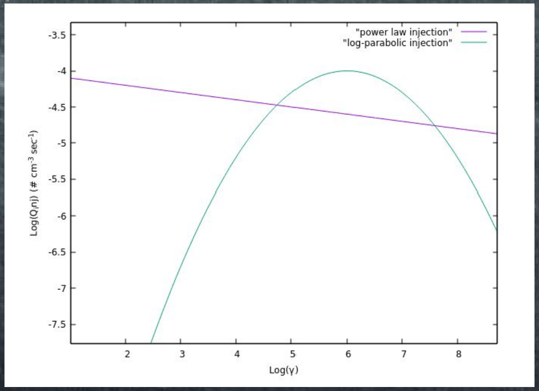
→ $10L_{Edd}$

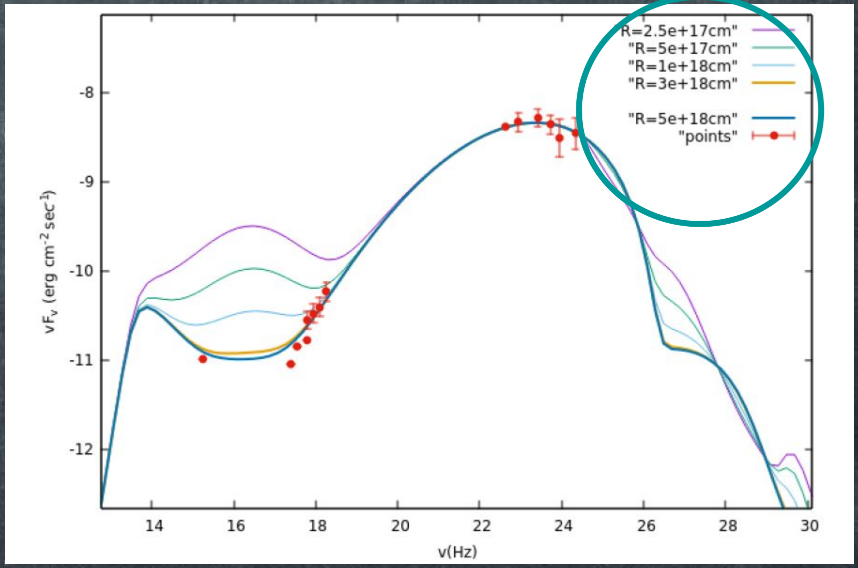
Petropoulou et al 2017

ANOTHER EFFORT

- Change power-law proton injection to log parabolic (more economic)
- Use R_{BLR} as a free (?) parameter → minimize external absorption



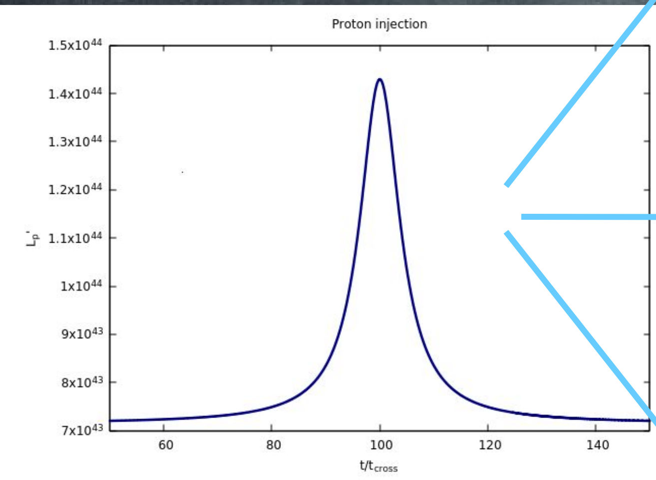


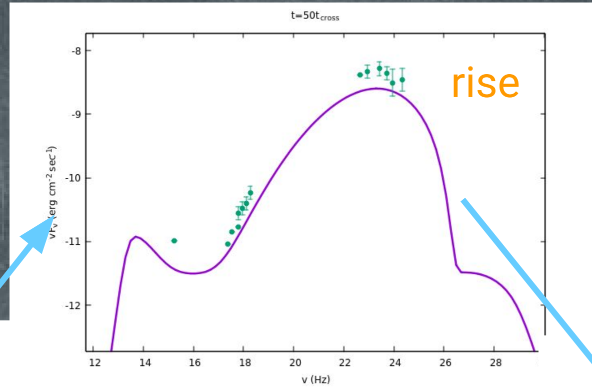


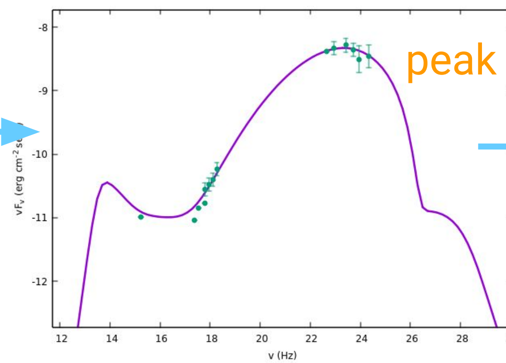
See Ioulia Florou's poster

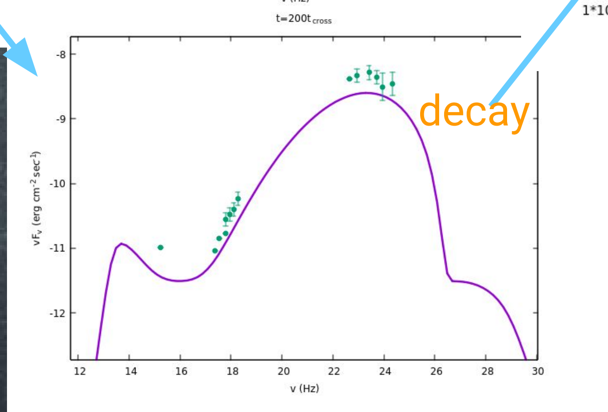
MODELING THE 5 min FLARE

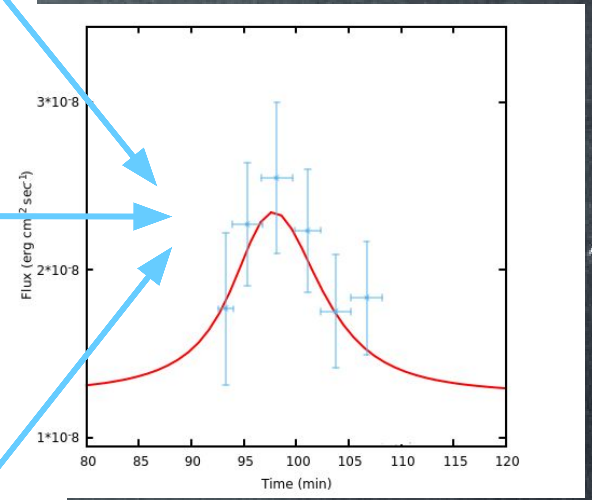
$P_{jet} \sim 5 L_{Edd}$











Lorentzian injection
of relativistic protons

Gamma-ray lightcurve

See Ioulia Florou's poster

MW photon specta

CONCLUSIONS

- The one-zone hadronic model can reproduce (rather) successfully the ‘extreme’ 5 min gamma-ray flare of 3C 279 of June 2015
- Extreme events require extreme conditions:
  - High δ factors (> 50) – compactness problem!
  - Super Eddington jet power (~10) – log-parabolic distributions more economic by a factor of 2.
  - ‘Active’ region of small size (~1.e14 cm) and outside the BLR (z>0.1 pc) – external $\gamma\gamma$ absorption
- Leptonic models?
- Time for a new approach? Maybe more examples needed (it’s only a flare, not some steady state)
- Any new model has to treat correctly the radiative transfer for gamma-rays!

BACK UP SLIDES

OVERALL ENERGETICS

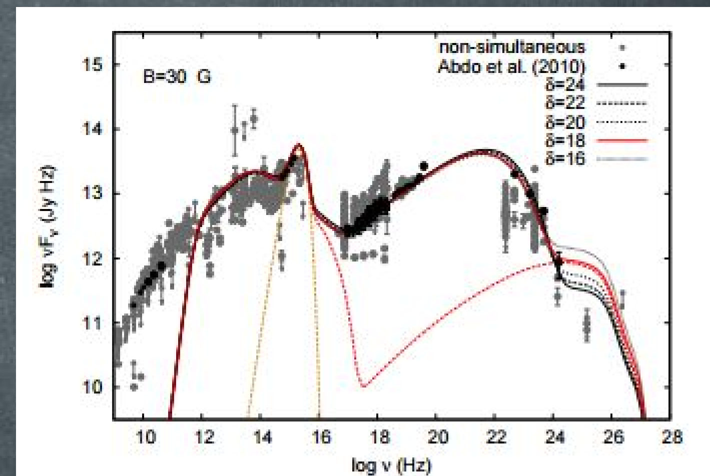
- Simple one-zone synchrotron hadronic fits can be degenerate → different sets of parameters give same fits.
- Minimize the power (similar to equipartition arguments in radio sources with gamma-rays replacing radio and protons replacing electrons) (*Petropoulou & AM 2012*)

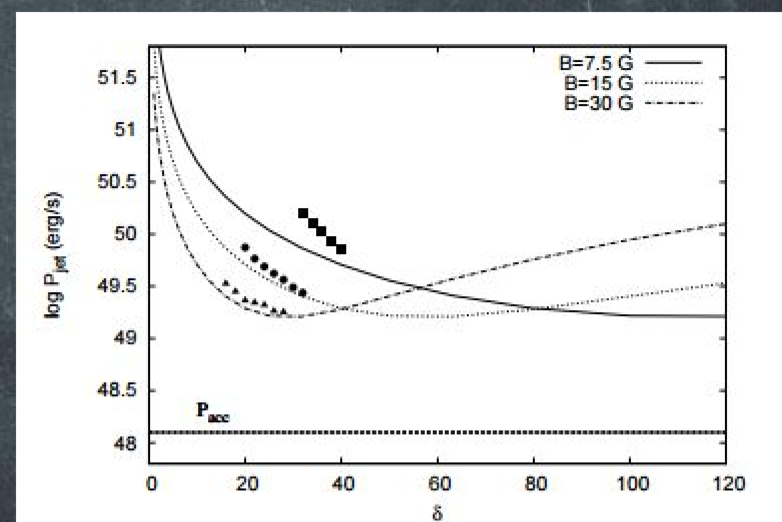
$$P_{jet} \approx \pi R^2 \Gamma^2 c(u_p + u_B)$$

$$P_{jet} \approx \pi R^2 c \left[A(\delta.B)^{-3/2} + \frac{(\delta.B)^2}{8\pi} \right]$$

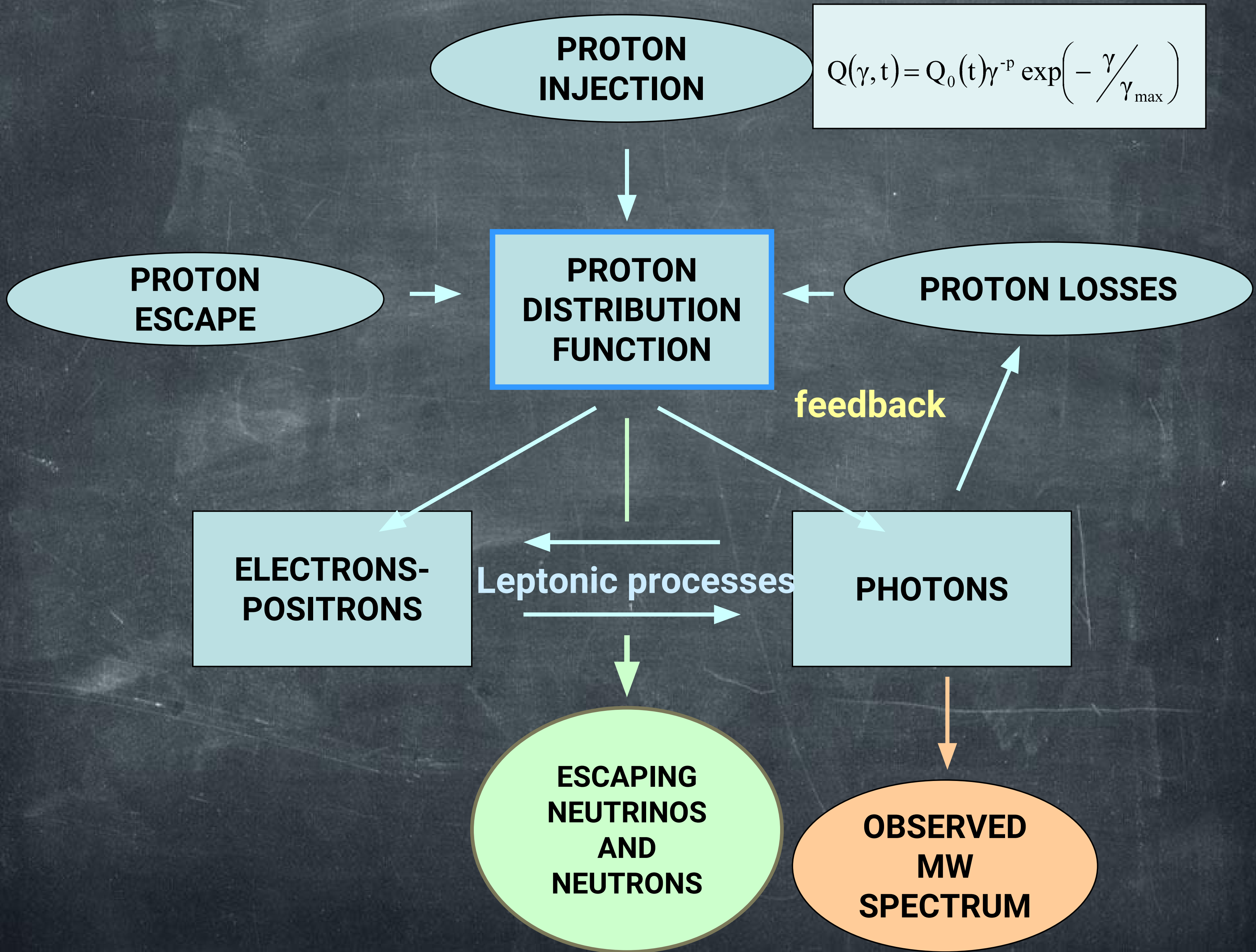
$$\frac{dP_{jet}}{dB} = 0 \Rightarrow P_{jet,min} \text{ for } \delta.B = C$$

3C273





Petropoulou & Dimitrakoudis 2015



PROTON INJECTION
$Q(\gamma, t) = Q_0(t)\gamma^{-p} \exp\left(-\gamma/\gamma_{max}\right)$
PROTON ESCAPE
PROTON DISTRIBUTION FUNCTION
PROTON LOSSES
feedback
ELECTRONS-POSITRONS
Leptonic processes
PHOTONS
ESCAPING NEUTRINOS AND NEUTRONS
OBSERVED MW SPECTRUM

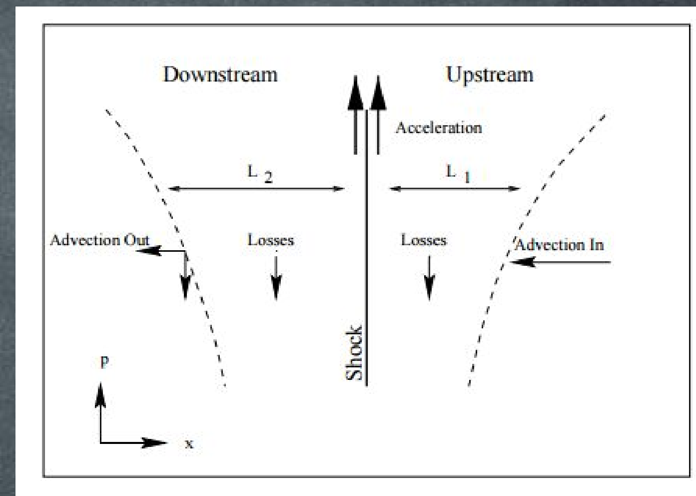
A PARADIGM: BOX-MODEL FOR PARTICLE ACCELERATION

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial E}\left(r_{acc} E N - \alpha_s E^2 N\right) = Q - r_{esc} N$$

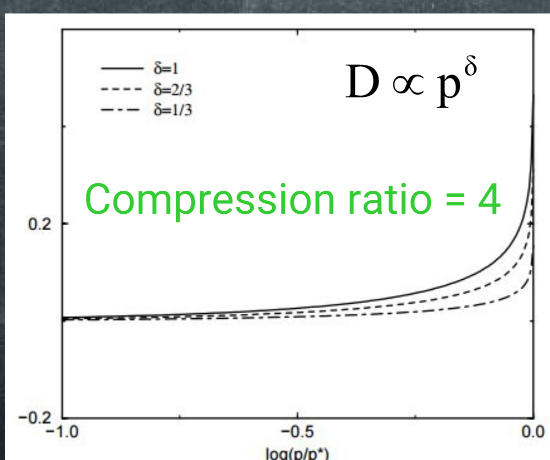
acceleration — energy loss — particle injection at low momenta — escape

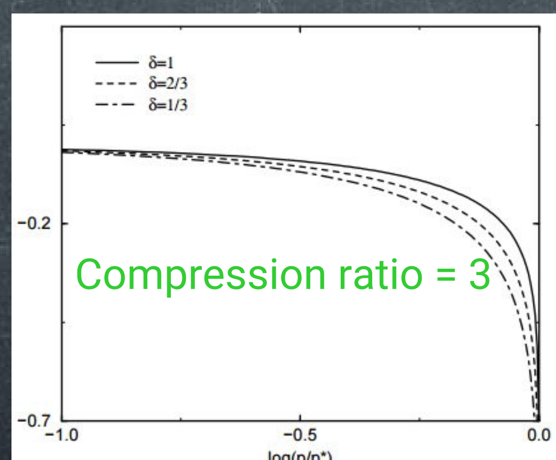
$$r_{acc} = \frac{\vec{n}\cdot(\vec{\upsilon}_1 - \vec{\upsilon}_2)}{3L}$$

$$r_{esc} = \frac{\vec{n}\cdot\vec{\upsilon}_2}{L}$$



Drury et al. 1999





Particle distribution up to a max energy where Tacc=Tloss. Shape of cutoff not *a-priori* assumed (obtained shape non-trivial, *e.g.* pile-ups)

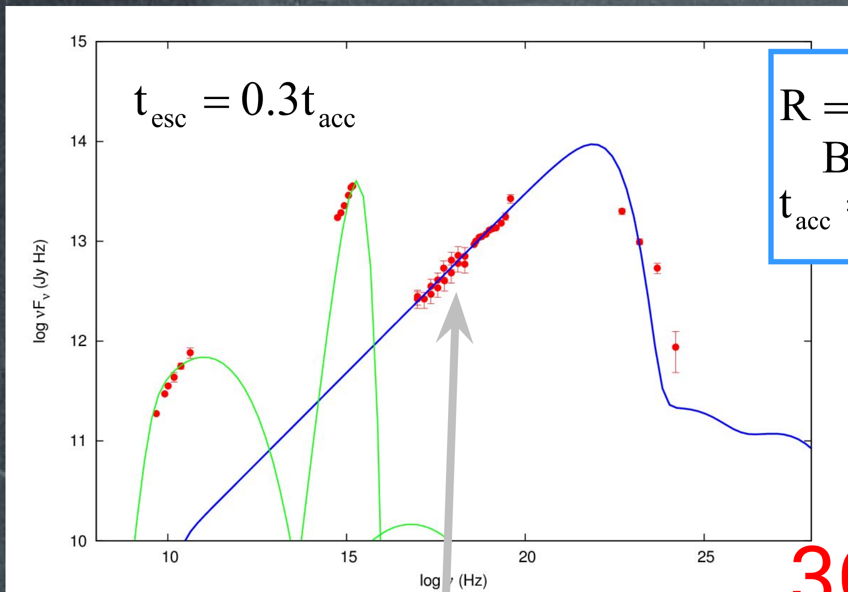
Standard box model

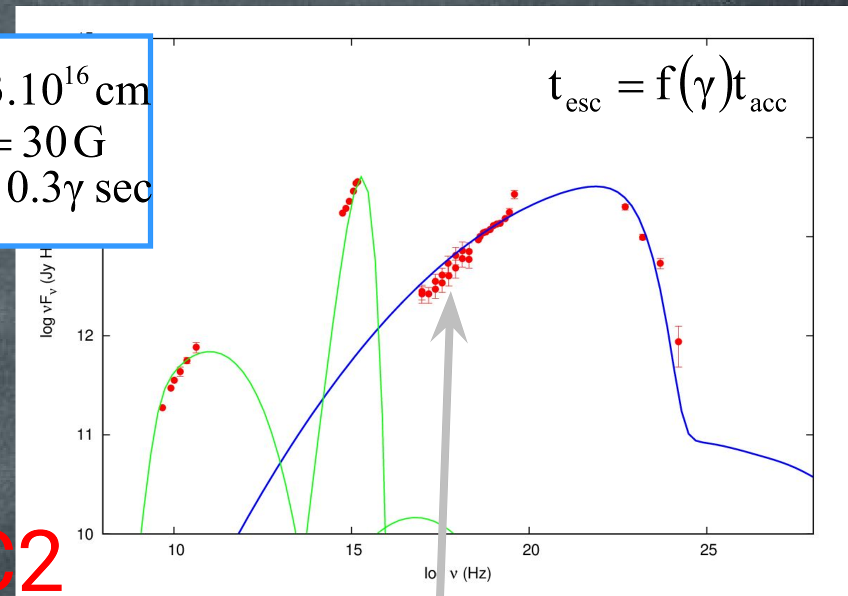
Modified box model

$R = 3.10^{16}\,cm$

$B = 30\,G$

$t_{acc} = 0.3\gamma\ sec$





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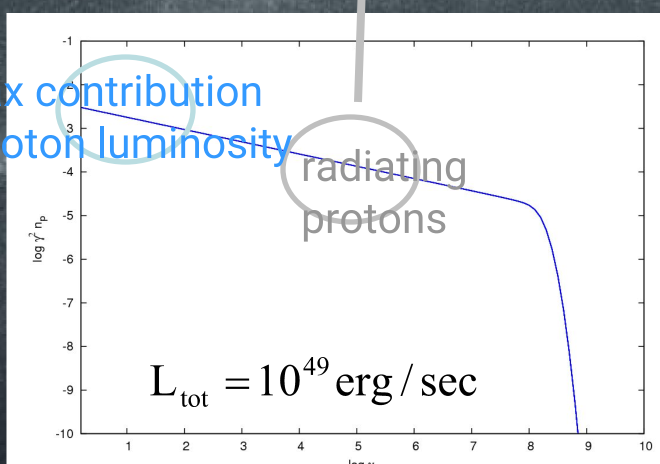

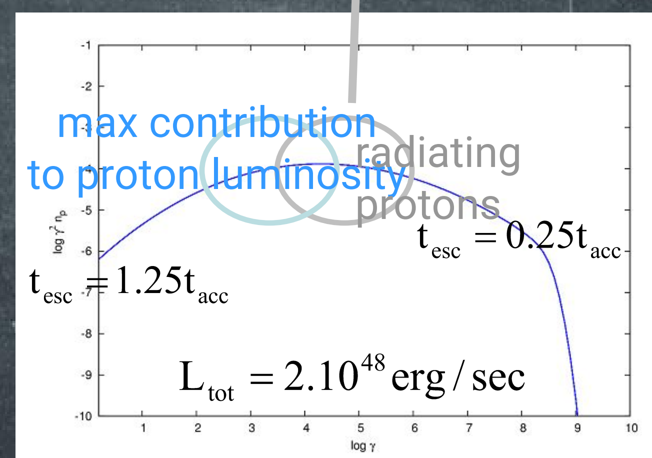

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial E}\left(r_{acc} E N\right) = Q - r_{esc} N$$