RUHR-UNIVERSITÄT BOCHUM

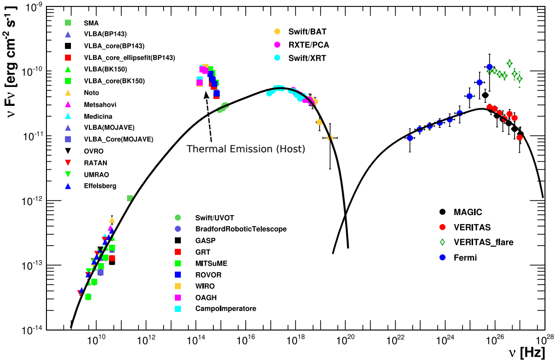
Hadronic Modeling of AGN Variability

Matthias Weidinger[1] **Felix Spanier**[2]
[1]Theoretische Physik IV: Weltraum- und Astrophysik
[2]ITPA, Universität Würzburg

Granada 2013-06-13

The Emission of Blazars

Markarian 501 multifrequency campaign 2009[1]:

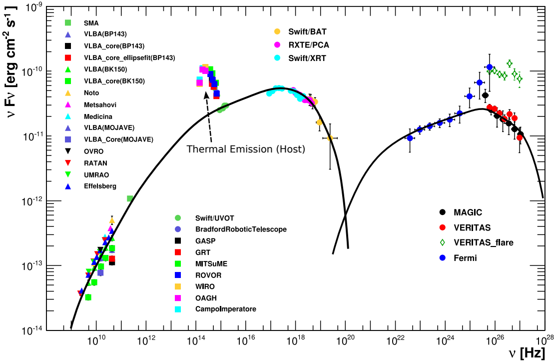


- typical double hump structure
- from radio to gamma-rays
- peak frequencies and flux levels vary

[1] from Abdo et al. 2011

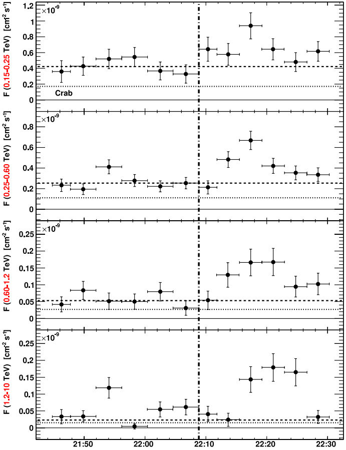
The Emission of Blazars

Markarian 501 multifrequency campaign 2009[1]:



- typical double hump structure
- from radio to gamma-rays
- peak frequencies and flux levels vary

MAGIC observations 2007[2]:

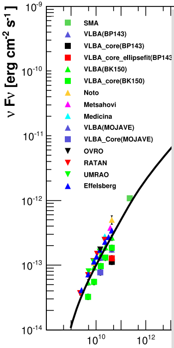


- short-time variability

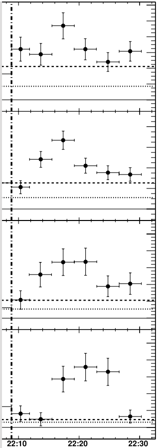
[1]from Abdo et al. 2011, [2]from Albert et al. 2007

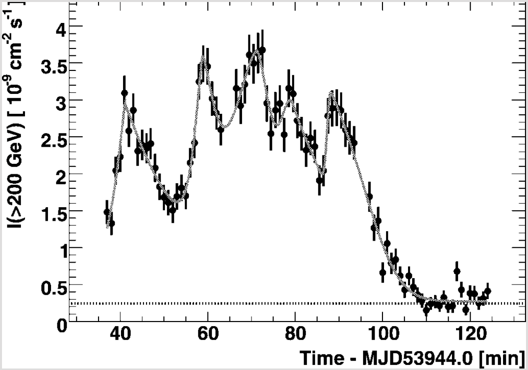
The Emission of Blazars

Markarian 501 multifrequency campaign 2009[1]:



MAGIC observations 2007[2]:





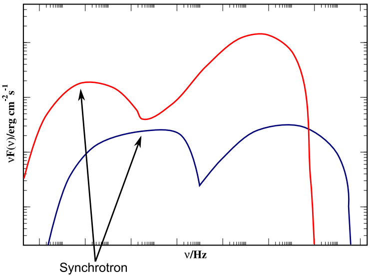
PKS 2155-304 [Aharonian et al., ApJL 664 (2006)]

- typical do
- from radi
- peak frequencies and flux levels vary

- short-time variability

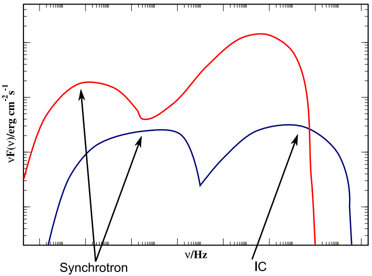
[1]from Abdo et al. 2011, [2]from Albert et al. 2007

Mechanism Underlying the Second Peak



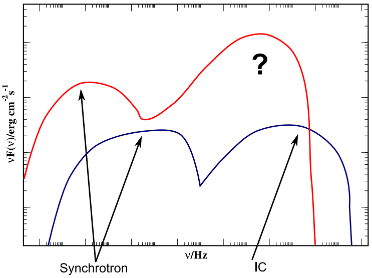
- optical to hard X-Ray peak:
  doppler enhanced synchrotron radiation

Mechanism Underlying the Second Peak



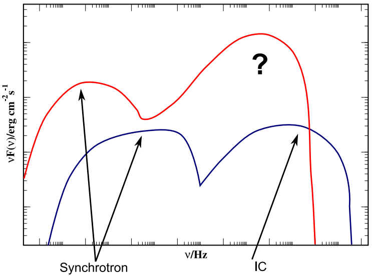
- optical to hard X-Ray peak: doppler enhanced synchrotron radiation
- Low luminosity blazars (mostly BL Lacs): well described by the Synchrotron Self-Compton mechanism

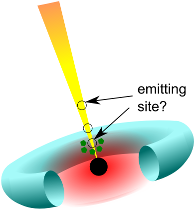
Mechanism Underlying the Second Peak



- optical to hard X-Ray peak: doppler enhanced synchrotron radiation
- Low luminosity blazars (mostly BL Lacs): well described by the Synchrotron Self-Compton mechanism
- High luminosity blazars (e.g. FSRQs): simple SSC fails, require:
  - compton upscattering of **external** photons
  - **hadronic** synchrotron radiation and subsequent cascades

Mechanism Underlying the Second Peak





- optical to hard X-Ray peak: doppler enhanced synchrotron radiation
- Low luminosity blazars (mostly BL Lacs): well described by the Synchrotron Self-Compton mechanism
- High luminosity blazars (e.g. FSRQs): simple SSC fails, require:
  - compton upscattering of **external** photons
  - **hadronic** synchrotron radiation and subsequent cascades
- strongly dependent on the emitting site within the jet (within the broad line region or beyond)

Demands on the Model

Unbiased hybrid emission model

- allow for non-thermal leptons **and** hadrons - if $r_l(B)$ confined - to be relevant emitters in the jet
- determine dominating species during the modeling

Introduce as few parameters as possible

- linking observational evidence to microphysics (additional parameter checks for sensibility)

Demands on the Model

Unbiased hybrid emission model

- allow for non-thermal leptons **and** hadrons - if $r_l(B)$ confined - to be relevant emitters in the jet
- determine dominating species during the modeling

Introduce as few parameters as possible

- linking observational evidence to microphysics (additional parameter checks for sensibility)

Selfconsistency

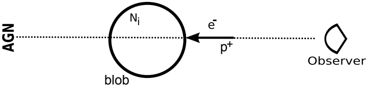
- particle spectra should arise from acceleration and cooling
- radiative output highly dependent on input p^+ spectral shape (cf A. Mastichiadis)

Timedependency

- exploit the full information we get from blazar-emission

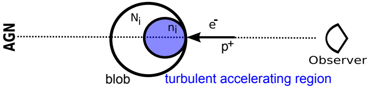
The Model I

Assume spherical emitting region, containing isotropic particle distributions and random B, moving towards the observer at Γ:



The Model I

Assume spherical emitting and acceleration region, containing isotropic particle distributions and and random B, moving towards the observer at Γ:



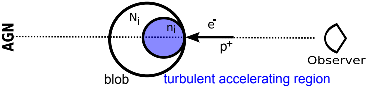
Kinetic equation: acceleration zone

$$\partial_t n_i = \partial_\gamma \left[(\beta_{s,i}\gamma^2 - t_{\mathrm{acc},i}^{-1}\gamma) \cdot n_i \right] + \partial_\gamma \left[[(a+2)t_{\mathrm{acc},i}]^{-1} \gamma^2 \partial_\gamma n_i \right] + Q_{0,i} - t_{\mathrm{esc},i}^{-1} n_i$$

see M. Weidinger et al. 2010 for details

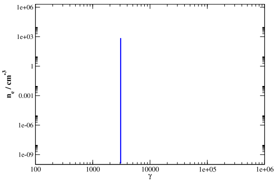
The Model I

Assume spherical emitting and acceleration region, containing isotropic particle distributions and and random B, moving towards the observer at Γ:

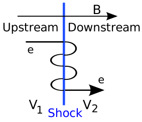


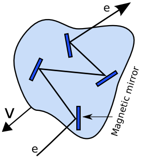
Kinetic equation: acceleration zone

$$\partial_t n_i = \partial_\gamma \left[(\beta_{s,i}\gamma^2 - t_{\mathrm{acc},i}^{-1}\gamma) \cdot n_i \right] + \partial_\gamma \left[[(a+2)t_{\mathrm{acc},i}]^{-1}\gamma^2 \partial_\gamma n_i \right] + Q_{0,i} - t_{\mathrm{esc},i}^{-1} n_i$$

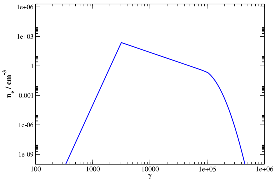


+





=



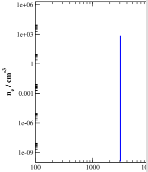
see M. Weidinger et al. 2010 for details

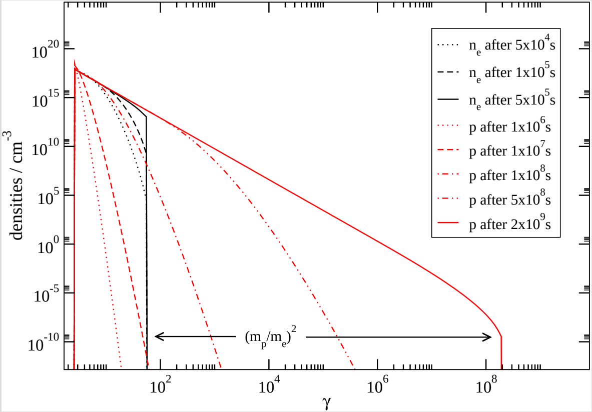
The Model I

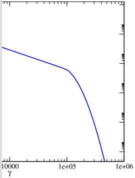
Assume spherical emitting and acceleration region, containing isotropic particle distribution

Kinetic equ

$$\partial_t n_i = \partial_\gamma \quad \ldots \quad - t_{\mathrm{esc},i}^{-1} n_i$$





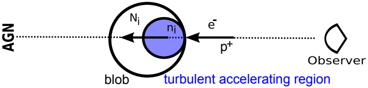


$\beta_{s,i} \propto m_i^{-3}$, $t_{\mathrm{acc},i} \propto m_i$

for details

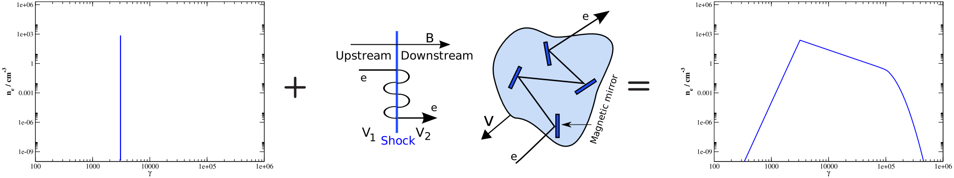
The Model I

Eventually all particles may escape the highly turbulent region to enter the radiation zone.



Kinetic equation: acceleration zone

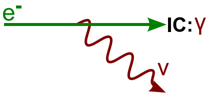
$$\partial_t n_i = \partial_\gamma \left[(\beta_{s,i}\gamma^2 - t_{\mathrm{acc},i}^{-1}\gamma) \cdot n_i \right] + \partial_\gamma \left[[(a+2)t_{\mathrm{acc},i}]^{-1}\gamma^2 \partial_\gamma n_i \right] + Q_{0,i} - t_{\mathrm{esc},i}^{-1} n_i$$



see M. Weidinger et al. 2010 for details

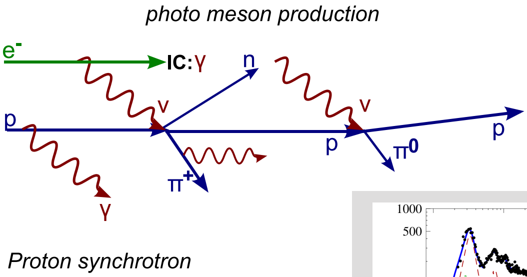
Radiation Mechanisms

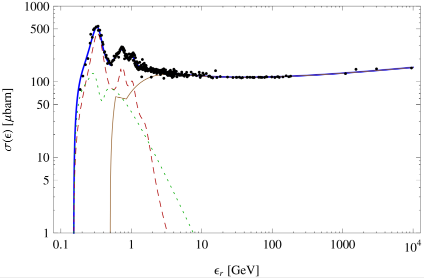
Unlike e^-, p^+ are not elementary particles $\Rightarrow$ many interaction branches besides synchrotron (and IC) from primary e^- and p^+.



Radiation Mechanisms

Unlike e^-, p^+ are not elementary particles ⇒ many interaction branches besides synchrotron (and IC) from primary e^- and p^+.

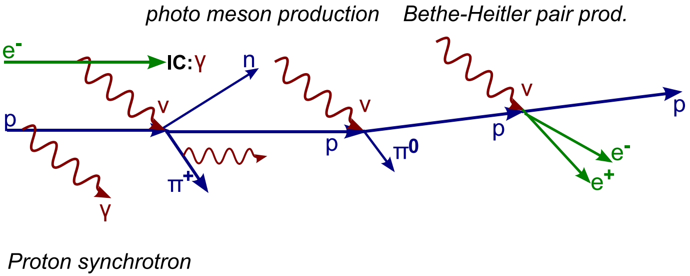




$p\gamma$ cs [Hümmer et al., ApJ 721 (2010)]

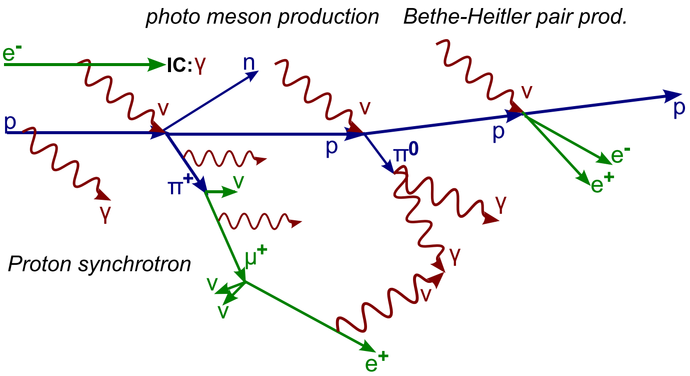
Radiation Mechanisms

Unlike e^-, p^+ are not elementary particles $\Rightarrow$ many interaction branches besides synchrotron (and IC) from primary e^- and p^+.



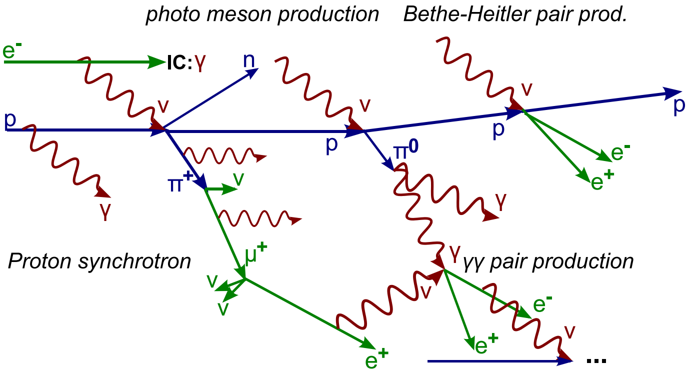
Radiation Mechanisms

Unlike e^-, p^+ are not elementary particles $\Rightarrow$ many interaction branches besides synchrotron (and IC) from primary e^- and p^+.



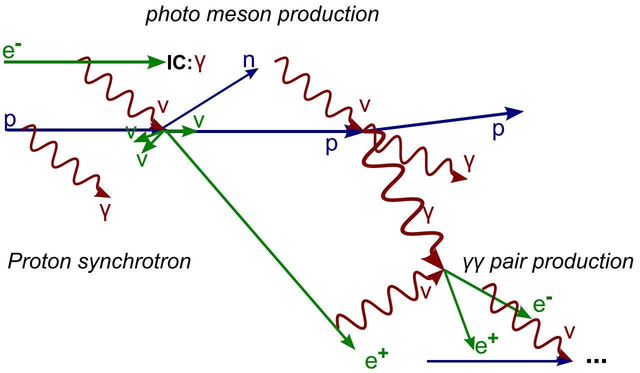
Radiation Mechanisms

Unlike e^-, p^+ are not elementary particles $\Rightarrow$ many interaction branches besides synchrotron (and IC) from primary e^- and p^+.



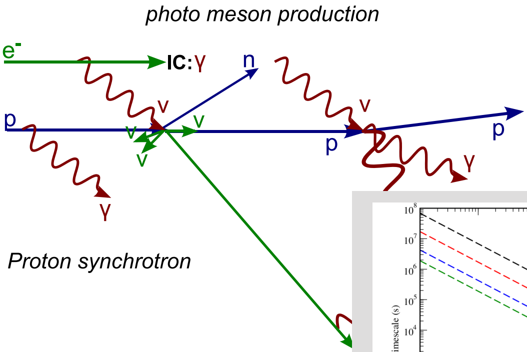
Radiation Mechanisms

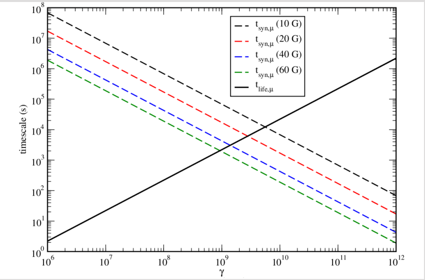
Unlike e^-, p^+ are not elementary particles ⇒ many interaction branches besides synchrotron (and IC) from primary e^- and p^+.



Radiation Mechanisms

Unlike e^-, p^+ are not elementary particles $\Rightarrow$ many interaction branches besides synchrotron (and IC) from primary e^- and p^+.





Muon lifetime

RUB

The Model II

We end up with 4 **non-linear coupled** equations in the radiation zone:

Kinetic equations: radiation zone

$$\partial_t N_{p^+} = \partial_\gamma \left[\left(\beta_p \gamma^2 + P_{p\gamma} \right) \cdot N_{p^+} \right] + b^3 t^{-1}_{\mathrm{esc,p}} n_{p^+} - t^{-1}_{\mathrm{esc,p,N}} N_{p^+}$$

$$\partial_t N_{e^-} = \partial_\gamma \left[\left(\beta_e \gamma^2 + \dot{\gamma}_{\mathrm{IC}} \right) \cdot N_{e^-} \right] + b^3 t^{-1}_{\mathrm{esc,e}} n_{e^-} + Q_{\mathrm{pp}} + Q_{\mathrm{p}\gamma^-} - t^{-1}_{\mathrm{esc,e,N}} N_{e^-}$$

$$\partial_t N_{e^+} = \partial_\gamma \left[\left(\beta_e \gamma^2 + \dot{\gamma}_{\mathrm{IC}} \right) \cdot N_{e^+} \right] + Q_{\mathrm{pp}} + Q_{\mathrm{p}\gamma^+} - t^{-1}_{\mathrm{esc,e,N}} N_{e^+}$$

Photon distribution

$$\partial_t N_{\mathrm{ph}} = R_{\mathrm{syn}} + R_{\mathrm{IC}} + R_{\pi^0} - c \left(\alpha_{\mathrm{SSA}} + \alpha_{\mathrm{pp}} \right) N_{\mathrm{ph}} - t^{-1}_{\mathrm{esc,ph}} N_{\mathrm{ph}}$$

- Kelner Aharonian parameterization of the SOPHIA Monte Carlo results is used to calculate $Q_{p\gamma^-}$, $Q_{p\gamma^+}$, R_{π^0}

RUB

The Model II

We end up with 4 **non-linear coupled** equations in the radiation zone:

Kinetic equations: radiation zone

$$\partial_t N_{p^+} = \partial_\gamma \left[(\beta_p \gamma^2 + P_{p\gamma}) \cdot N_{p^+} \right] + b^3 t_{\mathrm{esc,p}}^{-1} n_{p^+} - t_{\mathrm{esc,p,N}}^{-1} N_{p^+}$$

$$\partial_t N_{e^-} = \partial_\gamma \left[(\beta_e \gamma^2 + \dot{\gamma}_{\mathrm{IC}}) \cdot N_{e^-} \right] + b^3 t_{\mathrm{esc,e}}^{-1} n_{e^-} + Q_{\mathrm{pp}} + Q_{\mathrm{p}\gamma^-} - t_{\mathrm{esc,e,N}}^{-1} N_{e^-}$$

$$\partial_t N_{e^+} = \partial_\gamma \left[(\beta_e \gamma^2 + \dot{\gamma}_{\mathrm{IC}}) \cdot N_{e^+} \right] + Q_{\mathrm{pp}} + Q_{\mathrm{p}\gamma^+} - t_{\mathrm{esc,e,N}}^{-1} N_{e^+}$$

Photon distribution

$$\partial_t N_{\mathrm{ph}} = R_{\mathrm{syn}} + R_{\mathrm{IC}} + R_{\pi^0} - c\,(\alpha_{\mathrm{SSA}} + \alpha_{\mathrm{pp}})\, N_{\mathrm{ph}} - t_{\mathrm{esc,ph}}^{-1} N_{\mathrm{ph}}$$

- Kelner Aharonian parameterization of the SOPHIA Monte Carlo results is used to calculate $Q_{p\gamma^-}$, $Q_{p\gamma^+}$, R_{π^0}
- Cascades will emerge in the optically thick regime $> 10^{28}$ Hz

The Model II

We end up with 4 **non-linear coupled** equations in the radiation zone:

Kinetic equations: radiation zone

$$\partial_t N_{p^+} = \partial_\gamma \left[(\beta_p \gamma^2 + P_{p\gamma}) \cdot N_{p^+} \right] + b^3 t^{-1}_{\mathrm{esc,p}} n_{p^+} - t^{-1}_{\mathrm{esc,p,N}} N_{p^+}$$

$$\partial_t N_{e^-} = \partial_\gamma \left[(\beta_e \gamma^2 + \dot{\gamma}_{\mathrm{IC}}) \cdot N_{e^-} \right] + b^3 t^{-1}_{\mathrm{esc,e}} n_{e^-} + Q_{\mathrm{pp}} + Q_{\mathrm{p}\gamma^-} - t^{-1}_{\mathrm{esc,e,N}} N_{e^-}$$

$$\partial_t N_{e^+} = \partial_\gamma \left[(\beta_e \gamma^2 + \dot{\gamma}_{\mathrm{IC}}) \cdot N_{e^+} \right] + Q_{\mathrm{pp}} + Q_{\mathrm{p}\gamma^+} - t^{-1}_{\mathrm{esc,e,N}} N_{e^+}$$

Photon distribution

$$\partial_t N_{\mathrm{ph}} = R_{\mathrm{syn}} + R_{\mathrm{IC}} + R_{\pi^0} - c \left(\alpha_{\mathrm{SSA}} + \alpha_{\mathrm{pp}} \right) N_{\mathrm{ph}} - t^{-1}_{\mathrm{esc,ph}} N_{\mathrm{ph}}$$

- Kelner Aharonian parameterization of the SOPHIA Monte Carlo results is used to calculate $Q_{p\gamma^-}$, $Q_{p\gamma^+}$, R_{π^0}
- Cascades will emerge in the optically thick regime $> 10^{28}$ Hz
- $P_{p\gamma}$ neglectable in most cases; adiabatic losses @ low γ_p (cf M. Böttcher)

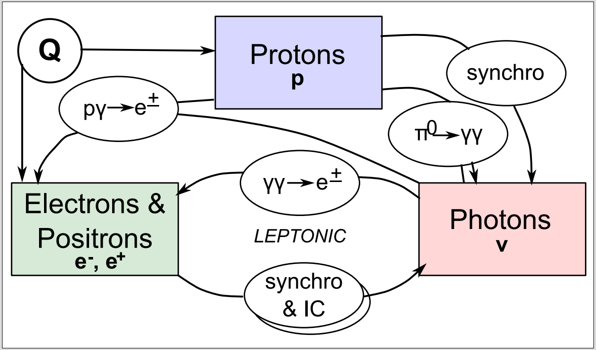
The Model II

We end up with 4 **non-linear coupled** equations in the radiation zone:

Kinetic equ

$\partial_t N_{e^-}$ … ,N N_{e^-}

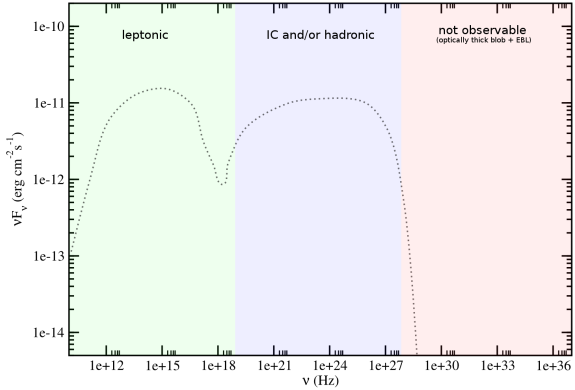
Photon dist



Non-linearities

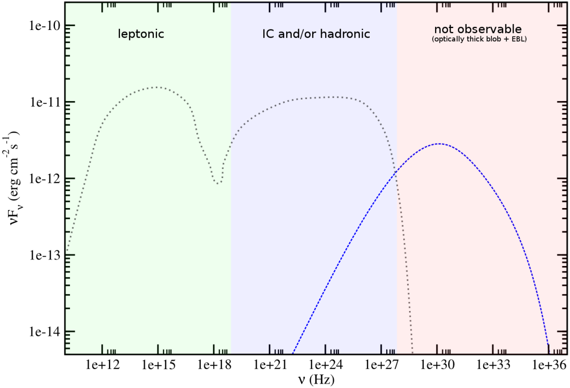
- Kelne… sults is used t…
- Casca…
- $P_{p\gamma}$ neglectable in most cases; adiabatic losses @ low γ_p (cf M. Böttcher)

Principle SED



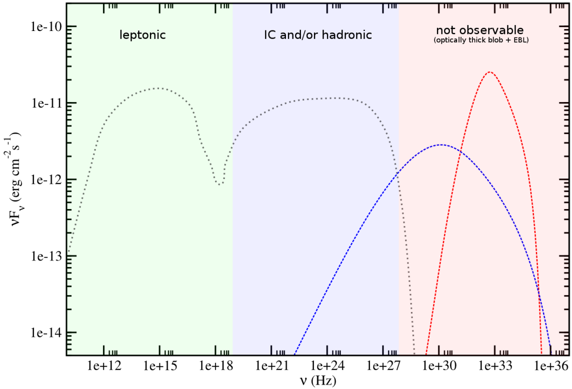
Principle SED

- $e^{\pm}$-synchrotron
  $\pi^{\pm} \to \mu^{\pm} + \nu_\mu/\bar{\nu}_\mu \to$
  $e^{\pm} + \nu_e/\bar{\nu}_e + \bar{\nu}_\mu/\nu_\mu$



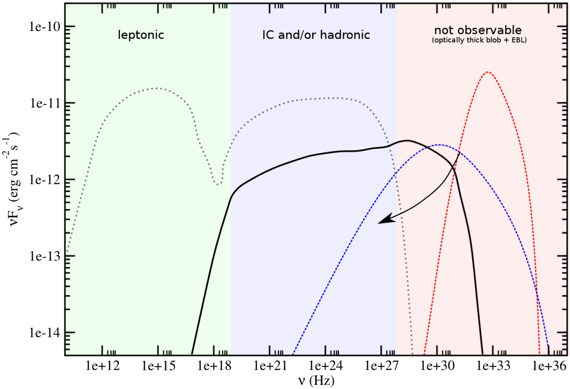
Principle SED

- $e^{\pm}$-synchrotron
  $\pi^{\pm} \rightarrow \mu^{\pm} + \nu_\mu/\bar{\nu}_\mu \rightarrow$
  $e^{\pm} + \nu_e/\bar{\nu}_e + \bar{\nu}_\mu/\nu_\mu$
- $\pi^0 \rightarrow \gamma + \gamma$ contribution



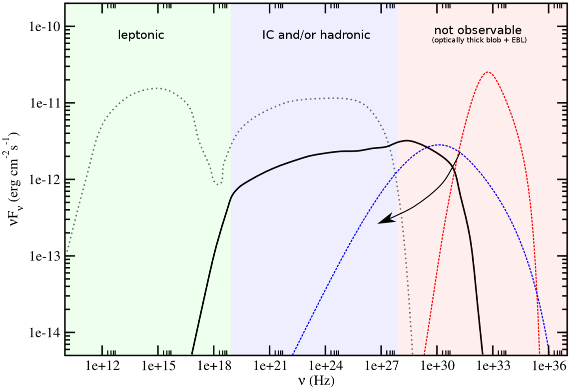
Principle SED

- $e^{\pm}$-synchrotron
  $\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}/\bar{\nu}_{\mu} \rightarrow$
  $e^{\pm} + \nu_e/\bar{\nu}_e + \bar{\nu}_{\mu}/\nu_{\mu}$
- $\pi^0 \rightarrow \gamma + \gamma$ contribution
- Pair cascades with low ν photons
  $\gamma + \gamma \rightarrow e^+ + e^-$
  ($e^{\pm}$-Synchrotronstr.)



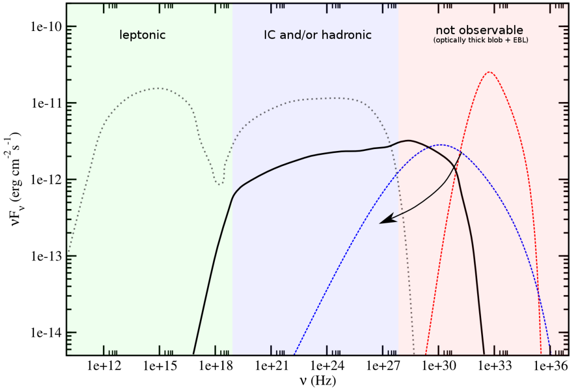
Principle SED

- $e^{\pm}$-synchrotron
  $\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}/\bar{\nu}_{\mu} \rightarrow$
  $e^{\pm} + \nu_e/\bar{\nu}_e + \bar{\nu}_{\mu}/\nu_{\mu}$
- $\pi^0 \rightarrow \gamma + \gamma$ contribution
- Pair cascades with low ν photons
  $\gamma + \gamma \rightarrow e^+ + e^-$
  ($e^{\pm}$-Synchrotronstr.)
- Proton synchrotron emission must be relevant



Principle SED

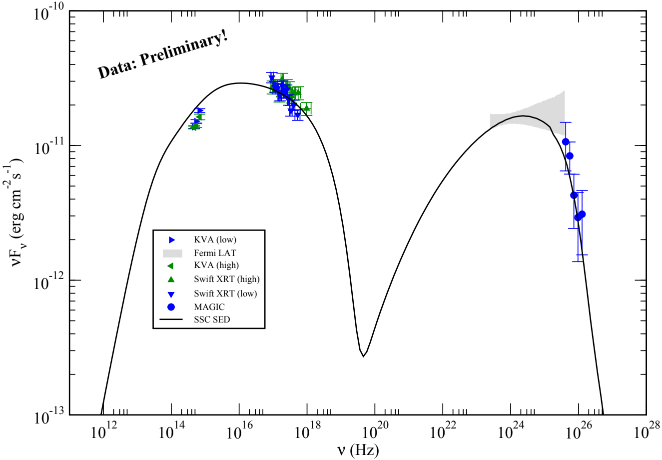
- $e^{\pm}$-synchrotron
  $\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}/\bar{\nu}_{\mu} \rightarrow$
  $e^{\pm} + \nu_e/\bar{\nu}_e + \bar{\nu}_{\mu}/\nu_{\mu}$
- $\pi^0 \rightarrow \gamma + \gamma$ contribution
- Pair cascades with low ν photons
  $\gamma + \gamma \rightarrow e^+ + e^-$
  ($e^{\pm}$-Synchrotronstr.)
- Proton synchrotron emission must be relevant



Requires p^+ with $\gamma > \Delta^+/E_{\text{photons}} \approx 10^7 - 10^9$ to be present in the jet.

1 ES 1011

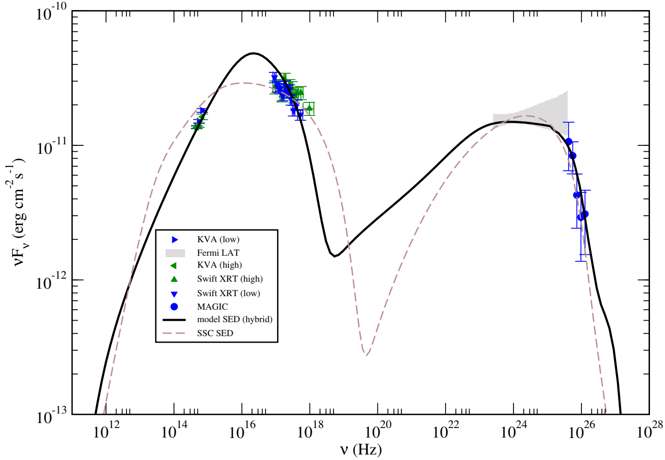
Intermediate frequency peaked BL Lac object @ $z = 0.212$



$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	t_a/t_e	δ	γ_0
$7.50 \cdot 10^4$	0.18	$8.0 \cdot 10^{15}$	1.2	44	868

1 ES 1011

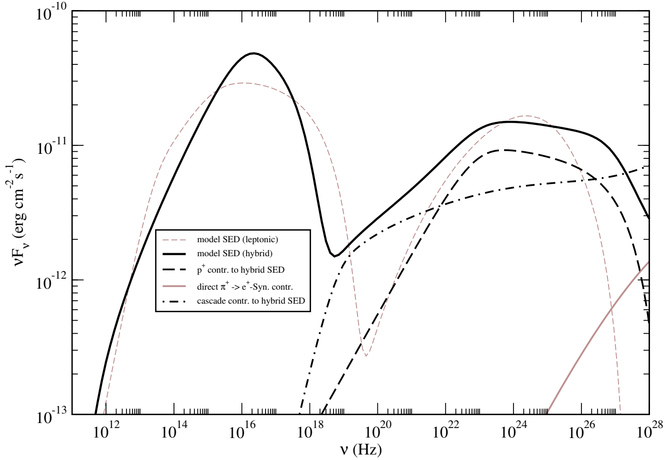
Intermediate frequency peaked BL Lac object @ $z = 0.212$



$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	t_a/t_e	δ	γ_0	$Q_p(\mathrm{cm}^{-3})$	γ_{0p}
$1.55 \cdot 10^8$	8.0	$1.8 \cdot 10^{15}$	1.3	36	3400	$3.8 \cdot 10^7$	600

1 ES 1011

Intermediate frequency peaked BL Lac object @ z = 0.212



$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	t_a/t_e	δ	γ_0	$Q_p(\mathrm{cm}^{-3})$	γ_{0p}
$1.55 \cdot 10^8$	8.0	$1.8 \cdot 10^{15}$	1.3	36	3400	$3.8 \cdot 10^7$	600

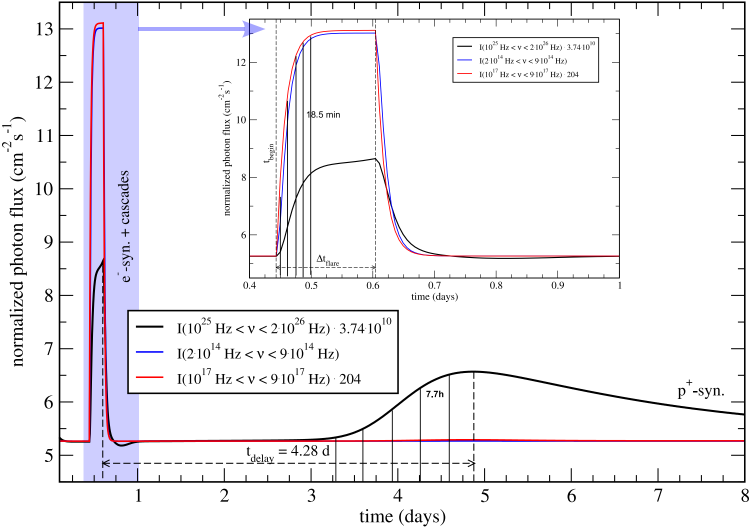
1 ES 1011

Intermediate frequency peaked BL Lac object @ z = 0.212

$Q_0(\text{cm}^{-3})$	$B(\text{G})$	$R_{\text{blob}}(\text{cm})$	t_a/t_e	δ	γ_0	$Q_p(\text{cm}^{-3})$	γ_{0p}
$1.55 \cdot 10^8$	8.0	$1.8 \cdot 10^{15}$	1.3	36	3400	$3.8 \cdot 10^7$	600

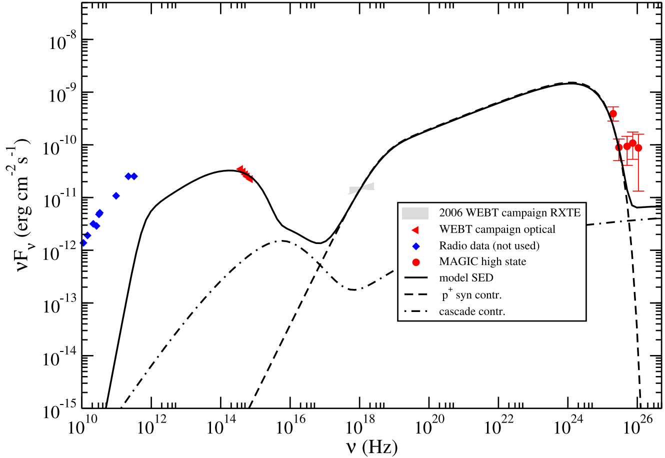
Outburst of 1 ES 1011

Injection of more primary e^- and p^+ for $\Delta t \approx 4$ h.



3C 279

Flat Spectrum Raido Quasar @ z = 0.536



$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	t_a/t_e	δ	γ_0	$Q_p(\mathrm{cm}^{-3})$	γ_{0p}
$2.0 \cdot 10^{10}$	34	$3.0 \cdot 10^{16}$	0.5	20	125	$4 \cdot 10^6$	$2 \cdot 10^6$

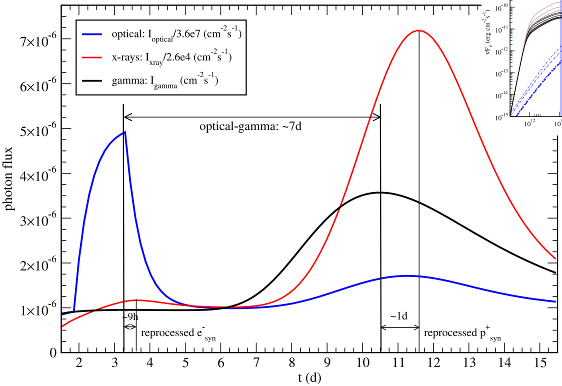
3C 279

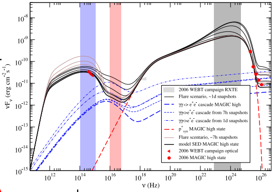
Flat Spectrum Raido Quasar @ $z = 0.536$

$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	$t_{\mathrm{a}}/t_{\mathrm{e}}$	δ	γ_0	$Q_p(\mathrm{cm}^{-3})$	γ_{0p}
$2.0 \cdot 10^{10}$	34	$3.0 \cdot 10^{16}$	0.5	20	125	$4 \cdot 10^6$	$2 \cdot 10^6$

3C 279

Flat Spectrum Raido Quasar @ $z = 0.536$

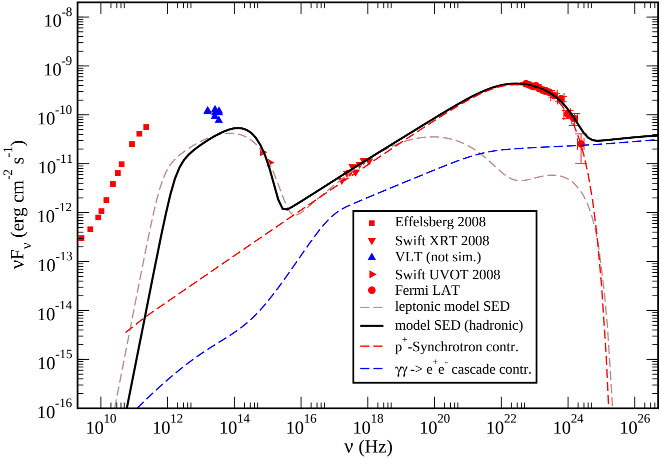




$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	t_a/t_e	δ	γ_0	$Q_p(\mathrm{cm}^{-3})$	γ_{0p}
$2.0 \cdot 10^{10}$	34	$3.0 \cdot 10^{16}$	0.5	20	125	$4 \cdot 10^{6}$	$2 \cdot 10^{6}$

3C 454.3

Flat Spectrum Radio Quasar @ $z = 0.859$



$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	t_a/t_e	δ	γ_0	$Q_p(\mathrm{cm}^{-3})$	γ_{0p}
$3.8 \cdot 10^7$	10.2	$5 \cdot 10^{15}$	1.1	43	580	$4.2 \cdot 10^8$	300

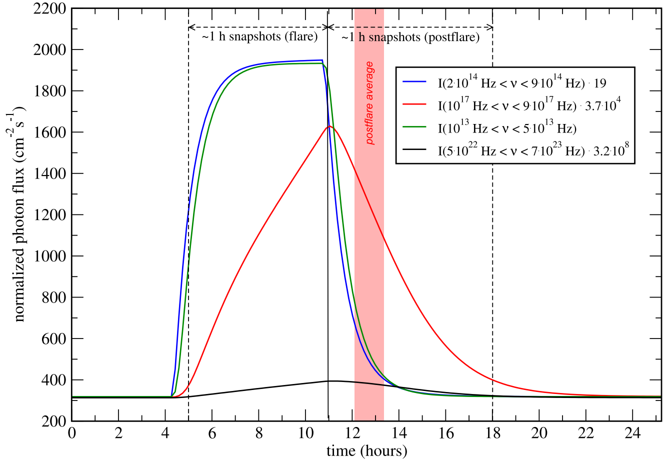
3C 454.3

Flat Spectrum Radio Quasar @ $z = 0.859$

$Q_0(\text{cm}^{-3})$	$B(\text{G})$	$R_{\text{blob}}(\text{cm})$	t_a/t_e	δ	γ_0	$Q_p(\text{cm}^{-3})$	γ_{0p}
$3.8 \cdot 10^7$	10.2	$5 \cdot 10^{15}$	1.1	43	580	$4.2 \cdot 10^8$	300

3C 454.3

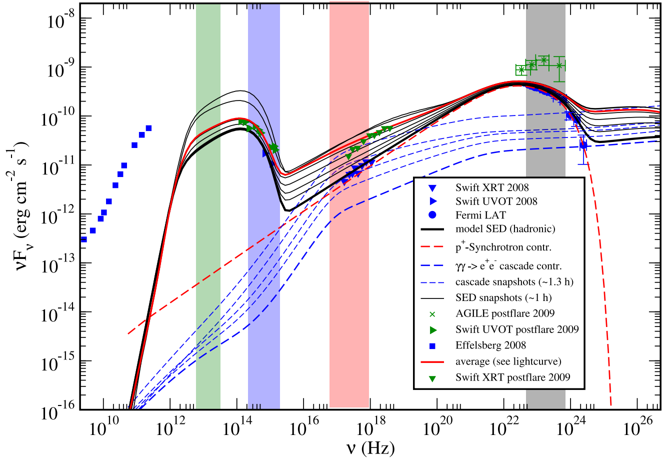
Flat Spectrum Radio Quasar @ $z = 0.859$



$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	t_a/t_e	δ	γ_0	$Q_p(\mathrm{cm}^{-3})$	γ_{0p}
$3.8 \cdot 10^7$	10.2	$5 \cdot 10^{15}$	1.1	43	580	$4.2 \cdot 10^8$	300

3C 454.3

Flat Spectrum Radio Quasar @ $z = 0.859$



$Q_0(\mathrm{cm}^{-3})$	$B(\mathrm{G})$	$R_{\mathrm{blob}}(\mathrm{cm})$	t_a/t_e	δ	γ_0	$Q_p(\mathrm{cm}^{-3})$	γ_{0p}
$3.8 \cdot 10^7$	10.2	$5 \cdot 10^{15}$	1.1	43	580	$4.2 \cdot 10^8$	300

RUB

Blazar Sequence

- Systematic blazar modeling reveals both, leptonic and hadronic dominated jets.
- B as important parameter.

Blazar Sequence

- Systematic blazar modeling reveals both, leptonic and hadronic dominated jets.
- B as important parameter.

Blazar Sequence (Fossati et al. 1998):

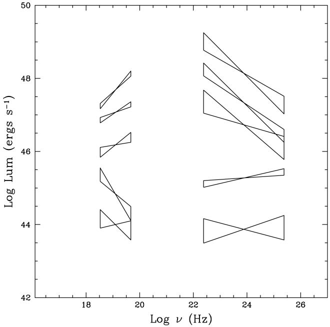
- high luminosity, low ν_{syn}
- low luminosity, high ν_{syn}

$\Rightarrow$ synchrotron losses and emissivity

Dichotomy in AGN

- Radio: FR I and FR II
- MHD: poynting and kinetic dominated jets

$\Rightarrow$ different dominating particle species (revealed by their radiative signature?)



from Sambruna et al. 2010

Blazar Sequence

- Systematic blazar modeling reveals both, leptonic and hadronic dominated jets.
- B as important parameter.

Blazar Sequence (Fossati et al. 1998):

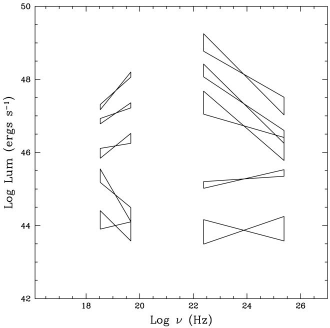
- high luminosity, low ν_{syn}
- low luminosity, high ν_{syn}

$\Rightarrow$ synchrotron losses and emissivity

Dichotomy in AGN

- Radio: FR I and FR II
- MHD: poynting and kinetic dominated jets

$\Rightarrow$ different dominating particle species (revealed by their radiative signature?)



from Sambruna et al. 2010

B and p^+ confinement will introduce a dichotomy across blazar flavors (i.e. in the "blazar sequence")

Blazar Sequence

- Systematic blazar modeling reveals both leptonic and hadronic dominated j
- B as import

Blazar Sequence (

- high luminosit
- low luminosity

⇒ synchrotron loss

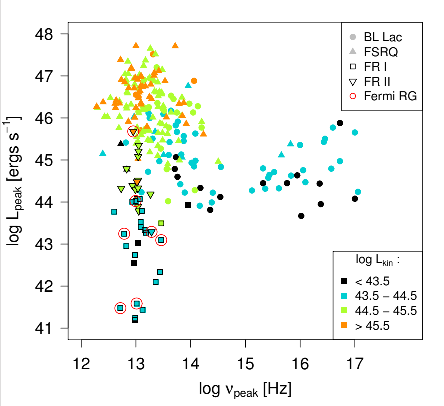
Dichotomy in AGN

- Radio: FR I ar
- MHD: poyntir

⇒ different domina
(revealed by the

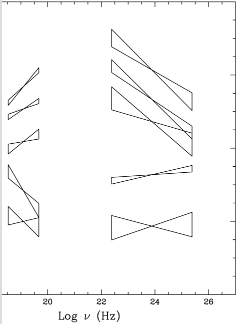
B and p^+ confin … ss blazar flavors
(i.e. in the "blazar sequence")

p^+ confinement may be important:



Envelope structure of the blazar sequence

[Credit: E. Meyer et al. 2011]



rom Sambruna et al. 2010

Conlusions and Outlook

- Fully selfconsistent hybrid emission model for blazars
- including the non-linear feedback.
- Injected p^+/e^- energy density (and γ_{0p}/γ_{0e}) as free parameters

Conlusions and Outlook

- Fully selfconsistent hybrid emission model for blazars
- including the non-linear feedback.
- Injected p^+/e^- energy density (and γ_{0p}/γ_{0e}) as free parameters
- Short-term variability as most important distinguishing feature.
- Time-dependent SEDs inevetible when comparing different ν-collecting times of instruments in MWL campaigns.
- Systematic modeling brings new insight to the long-term variation in blazar spectra.

Conlusions and Outlook

- Fully selfconsistent hybrid emission model for blazars
- including the non-linear feedback.
- Injected p^+/e^- energy density (and γ_{0p}/γ_{0e}) as free parameters

- Short-term variability as most important distinguishing feature.
- Time-dependent SEDs inevetible when comparing different ν-collecting times of instruments in MWL campaigns.
- Systematic modeling brings new insight to the long-term variation in blazar spectra.

- Some blazars as possible production sites of UHECRs
- of course highly dependent on acceleration mechanism.
- Systematic modeling might reveal physical reason for blazar sequence.

Conlusions and Outlook

- Fully selfconsistent hybrid emission model for blazars
- including the non-linear feedback.
- Injected p^+/e^- energy density (and γ_{0p}/γ_{0e}) as free parameters

- Short-term variability as most important distinguishing feature.
- Time-dependent SEDs inevetible when comparing different ν-collecting times of instruments in MWL campaigns.
- Systematic modeling brings new insight to the long-term variation in blazar spectra.

- Some blazars as possible production sites of UHECRs
- of course highly dependent on acceleration mechanism.
- Systematic modeling might reveal physical reason for blazar sequence.

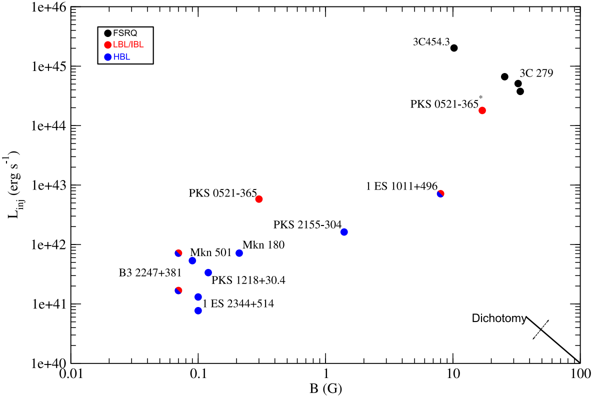
Consistent treatment of different blazars allows for multi-messenger interpretation of diffuse phenomena (e.g. neutrinos, CRs, envelope)

Alhambra, June 10

Thank You for the Attention

Overview

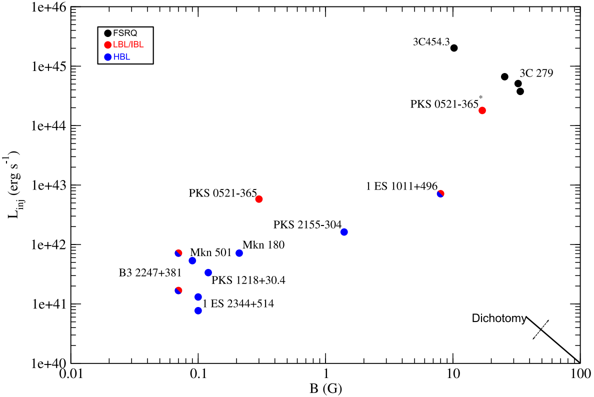
Compute jet power $L_{inj} = \frac{4}{3}\pi R_{\text{acc}}^3 m_i c^2 \frac{\delta}{2} \int d\gamma \gamma Q_{0,\text{i}}(\gamma)$ over B:



- rising trend $L(B)$, even across different regimes of the model
- Proton confinemend via r_{gyr} naturally leads to a dichotomy
- non-thermal protons only can exist in high B-Field jets

Overview

Compute jet power $L_{inj} = \frac{4}{3}\pi R_{\mathrm{acc}}^3 m_i c^2 \frac{\delta}{2} \int d\gamma \gamma Q_{0,\mathrm{i}}(\gamma)$ over B:



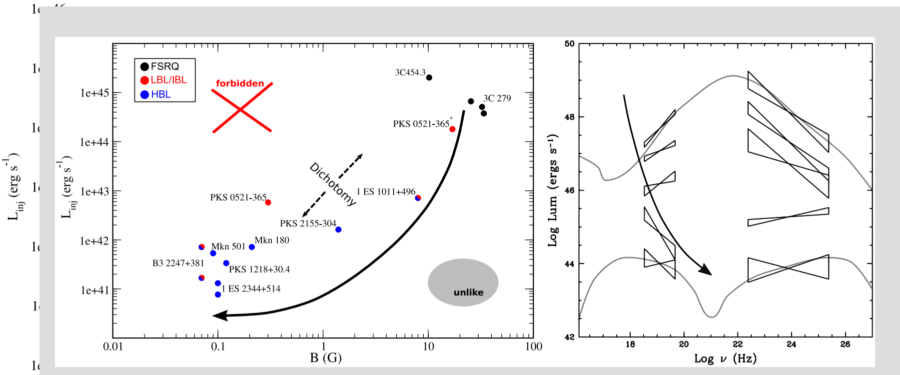
- rising trend $L(B)$, even across different regimes of the model
- Proton confinemend via r_{gyr} naturally leads to a dichotomy
- non-thermal protons only can exist in high B-Field jets

Other AGN manifestations also show that dichotomy: FR-I/FR-II radio galaxies

[Details see: M.Weidinger et al. 2010, M. Weidinger & F. Spanier 2010(I)(II), M. Weidinger & F.Spanier 2011, F. Spanier & M. Weidinger 2012, MAGIC Collaboration & M. Weidinger 2012]

Overview

Compute jet power $L_{inj} = \frac{4}{3}\pi R_{\rm acc}^3 m_i c^2 \frac{\delta}{2} \int d\gamma \gamma Q_{0,\rm i}(\gamma)$ over B:



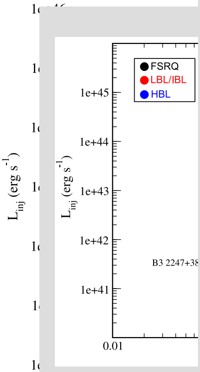
Interpretation of the sequence

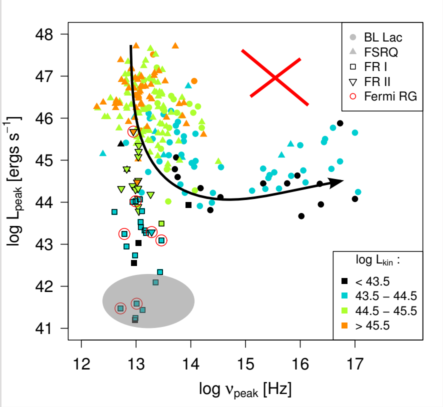
Other AGN manifestations also show that dichotomy: FR-I/FR-II radio galaxies

[Details see: M.Weidinger et al. 2010, M. Weidinger & F. Spanier 2010(I)(II), M. Weidinger & F.Spanier 2011, F. Spanier & M. Weidinger 2012, MAGIC Collaboration & M. Weidinger 2012]

Overview

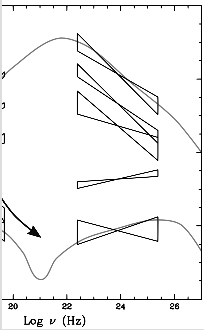
Compute jet power $L_{inj} = \frac{4}{3}\pi R^3_{acc} m_i c^2 \frac{\delta}{2} \int d\gamma\gamma Q_{0,i}(\gamma)$ over B:





Envelope structure of the blazar sequence

[Credit: E. Meyer et al. 2011]



en

nes

ls

n

etation of the sequence

Other AGN mani /FR-II radio galaxies

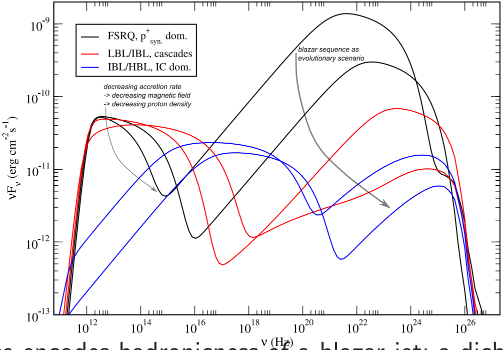
[Details s), M. Weidinger & F.Spanier 2011,

ollaboration & M. Weidinger 2012]

Blazar-Sequence and evolution II

Assume a "standard" blazar @ $z = 0.2$ in 2% equipartition (E_B/E_{kin})
(partially) self-generated B as only relevant parameter:

- reduce $Q_p(\gamma_{0,p})$ maintaining 2% equiparition $\Rightarrow$ B scales with Q_p
- until $r_{\rm gyr} \approx R_{\rm rad}$ and protons are no longer confined
- equipartition for e^- becomes relevant at low B fields (at ≈ 0.25 G)



$\Rightarrow$ Blazar-Sequence encodes hadronicness of a blazar-jet; a dichotomy arises
Reason for high-mass loading (e.g. spin, acretion, shocks) see DM, AT, ...?