Summary of Extragalactic News and Progress

Markus Böttcher

Ohio University
Athens, OH
USA
Outline

1. AGN
   a. Blazars
   b. Non-Blazar AGN
2. Other sources
3. EBL and EGMF
Apologies...

90 extragalactic contributions
40 minutes
=> 26.7 sec/contrib.
AGN: Two main categories

1. Dominated by (mostly) thermal emission from accretion disk -
   Radio quiet AGN (>~90 %)

1. Dominated by Non-Thermal radiation –
   Jet dominated AGN (< 10%)

When $\Theta < \theta_{\text{blazar}}$ → Blazar

(P. Giommi)

Most (over 1000) extragalactic Fermi sources are blazars; over 50 VHE gamma-ray blazars detected.
### Blazar Classification

**Quasars:**
Low-frequency component from radio to optical/UV,
\[ v_{sy} \leq 10^{14} \text{ Hz} \]
High-frequency component from X-rays to \( \gamma \)-rays, often dominating total power

**Low-frequency peaked / Intermediate BL Lacs (LBLs/IBLs):**
Peak frequencies at IR/Optical and GeV gamma-rays,
\[ 10^{14} \text{ Hz} < v_{sy} \leq 10^{15} \text{ Hz} \]
Intermediate overall luminosity
Sometimes \( \gamma \)-ray dominated

**High-frequency peaked BL Lacs (HBLs):**
Low-frequency component from radio to UV/X-rays,
\[ v_{sy} > 10^{15} \text{ Hz} \]
often dominating the total power
High-frequency component from hard X-rays to high-energy gamma-rays
The Blazar Sequence (?)

[adapted from Fossati et al 1998]

(E. Meyer)
The Blazar Sequence (?)

$\nu_{\text{peak}}$ vs photon index

- FSRQs
- LSP-BL Lacs
- ISP-BL Lacs
- HSP-BL Lacs

(D. Gasparetini)
The Blazar Sequence (?)

Mostly Selection Effects (+ missing redshifts of powerful high-z blazars)

(P. Giommi)
The Blazar Sequence (?)

- Two Branches:
  (A) Strong (not decelerating) jets
  (B) Weak (decelerating) jets

(E. Meyer)
### Newly/Recently Discovered VHE Blazars

<table>
<thead>
<tr>
<th>Object Name</th>
<th>Instrum.</th>
<th>Type</th>
<th>Redshift</th>
<th>Model</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ES 0033+595</td>
<td>MAGIC</td>
<td>HBL</td>
<td>???</td>
<td>SSC</td>
<td>Uellenbeck</td>
</tr>
<tr>
<td>RGB J0521.8+2112</td>
<td>VERITAS</td>
<td>HBL</td>
<td>???</td>
<td>SSC</td>
<td>Galante</td>
</tr>
<tr>
<td>1ES 0502+576</td>
<td>VERITAS</td>
<td>HBL</td>
<td>???</td>
<td>SSC</td>
<td>Galante</td>
</tr>
<tr>
<td>1ES 1727+502</td>
<td>MAGIC</td>
<td>HBL</td>
<td>0.055</td>
<td>SSC</td>
<td>De Caneva</td>
</tr>
<tr>
<td>SHBL J001355.9-185406</td>
<td>H.E.S.S.</td>
<td>HBL</td>
<td>0.095</td>
<td>SSC</td>
<td>Sanchez</td>
</tr>
<tr>
<td>1ES 1312-423</td>
<td>H.E.S.S.</td>
<td>HBL</td>
<td>0.105</td>
<td>SSC</td>
<td>Biteau</td>
</tr>
<tr>
<td>1ES 1215+303</td>
<td>MAGIC</td>
<td>HBL</td>
<td>0.130</td>
<td>SSC</td>
<td>Sitarek</td>
</tr>
<tr>
<td>RX J0648.7+1516</td>
<td>VERITAS</td>
<td>HBL</td>
<td>0.179</td>
<td>SSC+EC / hadr.</td>
<td>Benbow</td>
</tr>
<tr>
<td>RBS 0413</td>
<td>VERITAS</td>
<td>HBL?</td>
<td>0.190</td>
<td>SSC+EC / hadr.</td>
<td>Benbow</td>
</tr>
<tr>
<td>PKS 0301-243</td>
<td>MAGIC</td>
<td>HBL</td>
<td>0.26</td>
<td>?</td>
<td>Wouters</td>
</tr>
<tr>
<td>RGB J0136+3905</td>
<td>MAGIC</td>
<td>HBL</td>
<td>&gt;0.4</td>
<td>?</td>
<td>Mazin</td>
</tr>
<tr>
<td>KUV 00311-1938</td>
<td>H.E.S.S.</td>
<td>HBL</td>
<td>&gt;0.51 (0.61?)</td>
<td>?</td>
<td>Becherini</td>
</tr>
</tbody>
</table>

Most distant VHE BL Lac object (even most distant VHE blazar?) ever detected!
HBL at $z > 0.51$ (possibly $z = 0.61$). Most distant VHE BL Lac object ever detected

Extrapolation of Fermi spectrum after EBL absorption consistent with H.E.S.S. spectrum for $z = 0.61$. 

(Y. Becherini)
PKS 0447-439

Claimed redshift of $z > 1.246$ incorrect!

Ca II H&K and Na I D lines indicate $z = 0.273$.

(Pita et al.)
News on Known VHE Blazars

• VHE + GeV Flare of BL Lacertae (Galante)

• Variability seen in 1ES 0806+524 (Schultz)

• High State of PG 1553+113 (Becerra-Gonzalez)

• MAGIC detects PKS 1510-089, no re-detection of 3C279 (de Caneva)

• IBLs (3C66A, W Comae) detected in low state (Fortson)

• VERITAS detects 1ES 1215+303 (Prokoph)

• Minute-scale variability in Mrk 421 (Galante)
News on AGN Population Studies

• Comparing BL Lac beaming statistics to the FRI population -> Complex jet structure is required (Gerard)

• Fermi FSRQs have systematically smaller $M_{BH} \Leftrightarrow$ higher $L/L_{Edd}$ than optically selected quasars (Shaw)

• Fermi spectral break in many FSRQs variable in time (magnitude and break energy!) -> not consistent with double-absorber model (Harris)

• “Weak jets” seem to prefer rich cluster environments (Willett)
Leptonic Blazar Models

Relativistic jet outflow with $\Gamma \approx 10$

Injection, acceleration of ultrarelativistic electrons

Radiative cooling $\leftrightarrow$ escape $\Rightarrow$

Seed photons:

Synchrotron (within same region [SSC] or slower/faster earlier/later emission regions [decel. jet]), Accr. Disk, BLR, dust torus (EC)

\[ \gamma_b : \tau_{\text{cool}}(\gamma_b) = \tau_{\text{esc}} \]

(Fossati, Georganopoulos, Lefa, Menzler, Prandini, Sun, Tammi, Tramacere, Villaume, Zacharias)
Hadronic Blazar Models

Injection, acceleration of ultrarelativistic electrons and protons

Relativistic jet outflow with $\Gamma \approx 10$

Proton-induced radiation mechanisms:

- Proton synchrotron
  - $p\gamma \rightarrow p\pi^0$
  - $\pi^0 \rightarrow 2\gamma$
- $p\gamma \rightarrow n\pi^+$; $\pi^+ \rightarrow \mu^+\nu_\mu$
- $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$
  - $\rightarrow$ secondary $\mu$-, e-synchrotron
- Cascades ...

(Cerutti, Dimitrakoudis, Mastichiadis, Petropoulou, Reimer)
Spectral modeling results along the Blazar Sequence: Leptonic Models

High-frequency peaked BL Lac (HBL):

- Low B fields (\( \sim 0.1 \) G);
- High electron energies (up to TeV);
- Large bulk Lorentz factors (\( \Gamma > 10 \))

The “classical” picture

- No dense circumnuclear material \( \rightarrow \) No strong external photon field

RGB J0710+591

- Synchrotron
- SSC
Spectral modeling results along the Blazar Sequence: Leptonic Models

Radio Quasar (FSRQ)

High magnetic fields (∼ a few G);
Lower electron energies (up to GeV);
Lower bulk Lorentz factors (Γ ∼ 10)

Plenty of circumnuclear material → Strong external photon field
Challenges to One-Zone Models

- Uncorrelated X-ray / $\gamma$-ray variability
  - Mrk 421: Fortson
  - Mrk 501: Nowak – VHE high state correlated with optical polarization

- 1ES 1959+650: Two-component GeV – TeV spectrum: not well fit by SSC + EC or hadronic or $\gamma\gamma$-absorption (Backes)

- Modeling of PKS 1424+240 not consistent with one-zone models (Prandinini)

Mrk 421 (L. Fortson)

![Graphs showing variability and spectral data for Mrk 421 and 1ES 1959+650]
New Model Ideas and Developments

• Hadronic models: Need to include self-consistent proton cooling on secondary-particle synchrotron emission! (Mastichiadis)

• Beware of photon quenching by $\gamma\gamma$-absorption in hadronic models (Petropolou)

  -> Lower limit on Doppler factor $\delta \sim 20$ for 3C279.

![Graph showing the subcritical and supercritical regimes with PPS Loop and quenching reaction cascade](image)

• Hadronic Models become time-dependent (Dimitrakondis, Reimer)

  -> Uncorrelated X-ray / $\gamma$-ray variability possible!
New Model Ideas and Developments

- From beaming: Powerful jets are EC dominated;
- From energy dependence of cooling times: Distinguish between EC on IR (torus) and optical/UV lines (BLR) (Georganopoulos)
Time-dependent SSC + EC Monte-Carlo simulations: PKS 1510-089 (Fossati, Chen)
New Model Ideas and Developments

- High-energy emission and variability from jet-star interactions.
  - 3C454.3 flare reproduced with $L_j \sim 10^{49}$ erg/s; $\delta \sim 60$ (Barkov).
  - Jet-stellar wind interaction produces double bow shock (Araudo)

- Log-parabolic spectra are the natural result of stochastic particle acceleration: Curvature related to momentum diffusion coefficient (Tramacere).
  - Quasi-Maxwellian electron distribution -> Hard VHE $\gamma$-ray spectra in several VHE blazars (Lefa)

- SSC-dominated compact emission regions can produce FSRQ-like blazar SEDs
  - non-linear electron cooling (Zacharias)

- Consider high-energy (X-/\gamma-ray) polarization in blazar models (Menzler).

- Magnetic reconnection (Cerutti) or shear flows (MB, Liang) may produce anisotropic particle distributions, ordered magnetic fields -> overcome Doppler factor crisis.
New Model Ideas and Developments

The Big Blue Bump:

• Bulk Compton? Self-consistent shock-acceleration simulations to find thermal vs. non-thermal populations. (MB, M. Baring)

• Synchrotron emission from VHE γ-ray induced pair cascades? (P. Roustazadeh)
## Non-Blazar AGN Radio Galaxies

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Distance</th>
<th>MeV/GeV detection</th>
<th>VHE</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cen A</td>
<td>FR 1</td>
<td>3.7 Mpc</td>
<td>EGRET, LAT 2010</td>
<td>✓</td>
<td>Fermi: Core/lobes</td>
</tr>
<tr>
<td>M87</td>
<td>FR 1</td>
<td>16 Mpc</td>
<td>LAT 2009</td>
<td>✓</td>
<td>TeV 1d-variability</td>
</tr>
<tr>
<td>Fornax A</td>
<td>FR 1</td>
<td>18 Mpc</td>
<td>LAT 2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cen B</td>
<td>FR 1</td>
<td>56 Mpc</td>
<td>LAT 2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 1275</td>
<td>FR 1</td>
<td>75 Mpc</td>
<td>LAT 2009</td>
<td>✓</td>
<td><strong>; jet precession; LAT days-variability</strong>*</td>
</tr>
<tr>
<td>IC 310</td>
<td>FR 1 head-tail</td>
<td>80 Mpc</td>
<td>LAT 2010</td>
<td>✓</td>
<td>Neronov+2010; VHE yr-variability</td>
</tr>
<tr>
<td>NGC 6251</td>
<td>FR 1</td>
<td>106 Mpc</td>
<td>EGRET, LAT 2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3C 78</td>
<td>FR 1</td>
<td>124 Mpc</td>
<td>LAT 2010*</td>
<td></td>
<td>BLRG</td>
</tr>
<tr>
<td>3C 120</td>
<td>FR 1</td>
<td>142 Mpc</td>
<td>LAT 2010*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3C 111</td>
<td>FR 2</td>
<td>213 Mpc</td>
<td>EGRET, LAT 2010*</td>
<td></td>
<td>BLRG</td>
</tr>
<tr>
<td>PKS 0943-76</td>
<td>FR 2</td>
<td>1360 Mpc</td>
<td>LAT 2010</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Rieger)
Non-Blazar AGN Radio Galaxies

M 87

Extensive MWL campaign over several years:
VHE: VERITAS, MAGIC, HESS
HE: Fermi
X-ray: Chandra
Optical: HST, Liverpool Telescope
Radio: VLBA, VLA, EVN, Mojave (VLBA)

3 flaring episodes (maybe 4)

(Beilicke, Galante)
Radio Galaxies

M 87

TeV-only flare poses challenges to one-zone (SSC) models

Possible models:
• Magnetic reconnection
• Jet-Star interaction
• BH Magnetospheric acceleration

(Rieger)
Radio Galaxies

IC 310

Originally classified as head-tail radio galaxy.
Rapid variability + VLBA structure suggest blazar-like properties!

(D. Eisenacher, P. Colin)
Radio Galaxies

Cen A

γ-ray emission from IC on CMB, EBL and galaxy light =>
Good fits with $B \sim 0.1 \text{ nT}$; giant lobes close to equipartition!

“Gamma-Ray Galaxies” (Hardcastle)
Radio Galaxies
Cen A

Model constraints on viewing angle

(Hardcastle)
Radio Galaxies

Cen A

Fermi Lobes are 3 times larger than radio lobes!
NLSy1

- 5 high-confidence (+ 3 low-confidence) Fermi detections
  Also: LINER/Sy1 @ z = 0.12 PMN J0710-3850 identified as the counterpart of EGRET UID 3EG J0706-3837 (Meintjes).
- PMN 0948+0022 shows radio polarization swings simultaneous with γ-ray flare
Comparison with Blandford-Znajek

Calculated according to Ghosh & Abramowicz 97

Hydromagnetic wind contribution?
(winds in RG, Tombesi+ 2010)

Scenario Cavaliere & D’Elia (2002):
BZ as backbone + hybridization as accretion increases

(Foschini)
Starburst Galaxies

VHE $\gamma$-ray emission

- Point-like emission, coincident with the SB nuclei
- Limit on extension (3$\sigma$, 2.4$'$) comparable to size of $^{12}$CO emission (0.5$'$ x 1.0$'$) for NGC 253
- Supports picture of CRs interacting with gas in the SB nucleus, producing VHE $\gamma$ rays
- HE $\gamma$-ray emission?

(S. Ohm)

Sakamoto et al. 2011

Acero et al., 2009
Starburst Galaxies

Sample of $\gamma$-ray galaxies is increasing:

- NGC 4945 & 1068 ($\gamma$-rays from AGN?)
- Hint for emission from NGC 2146 & M83

Up to 10 galaxies in 10 years of Fermi (?)  
(S. Ohm)
Starburst Galaxies

- Gamma-ray dominance
  - Evidence for CR-induced $\pi$-production and decay
    (neutrino fluxes probably too low for detection)
- $u_{CR} \sim u_B \sim u_{FIR}$
- Lack of IC emission $\Rightarrow$ Limit on B-field

150 $\mu$G model for M82

(B. Lacki)
Newly Still-Not-Detected

**Swift 1644+57**

- Triggered BAT multiple times
- Extended X-ray afterglow without significant decay
- Stringent historical X-ray flux upper limits
- $z=0.354$, source in the center of galaxy
- Minimum variability $\sim 100$ s
- **Suggested to be the tidal disruption of a star by a $10^6$ M$_{\odot}$ black hole**

---

Lack of gamma-ray detection (Fermi, VERITAS) - now confirmed by MAGIC (Lombardi) - possibly due to $\gamma\gamma$ absorption.
Newly Still-Not-Detected

ULXs

Search for GeV emission (Fermi) from ULX in 18 nearby galaxies – no detection.
Upper limits consistent with extrapolation from X-rays.

Galaxy Clusters

- Still no GeV – TeV emission from clusters of galaxies, but detection of several BCGs (NGC 1275, ...)

(Lombardi)
Newly Still-Not-Detected
Dark-Matter Annihilation Signatures from Dwarf Spheroidals and Galaxy Clusters

(Fermi, VERITAS, H.E.S.S.):
No detection
(not as much excitement as Galactic center!)

(Cholis, Conrad, Galante, Grube, van Eldik)
EBL and Extragalactic Magnetic Fields

The EBL

- EBL constrained to be within ~ factor 2 of lower limits from galaxy counts (Meyer) – $\alpha = 1.27$ (Biteau)
- Can be used to constrain star-formation history (Raue)

EBL absorption effect clearly reflected in GeV – TeV breaks (Sanchez; Biteau; Gasparrini)

EBL absorption effect seen in Fermi blazar spectra (Ajello)
Intergalactic Cascading and Magnetic Fields

• (Deflected) IC cascades may fill in GeV emission, lead to extended halos -> Limits on B-field
Intergalactic Cascading and Magnetic Fields

New exclusion regions from Blazar measurements

Andrew Taylor
Intergalactic Cascading and Magnetic Fields

T. Arlen: $B = 0$ can NOT be excluded!

A. Kusenko: Cosmic-Ray Induced $\gamma$-rays produce universal VHE $\gamma$-ray spectra, almost independent of EBL!
Intergalactic Cascading and Magnetic Fields

Secondary pairs may lose energy in plasma instabilities
⇒ No B-fields needed!
⇒ Substantial influence on thermal history of the IGM.
⇒ Substantial influence on cosmological structure formation.

(C. Pfommer)
Central Problems

- Origin of high-energy emission in blazars (leptonic/hadronic – location of the emission region)
- Origin of the blazar sequence (if real)
- Composition of jets and lobes – pressure balance?
- Origin of $\gamma$-ray emission in radio galaxies
- Connection between star formation activity and gamma-ray emission (→ CRs)
- EBL absorption relevant? Signatures of IGMF?
A Word from the Shameless Commerce Department

Written by a carefully selected consortium of researchers working in the field, this book provides an up-to-date summary of the current observational and theoretical understanding of relativistic jets, focusing on jets from active galactic nuclei. As such, this monograph includes a history and theory refresher, an overview of observational results from all wavelengths, from radio to gamma-rays, analytical and numerical theoretical results, and a description of current research topics.

From the contents:
- Introduction and Historical Perspective
- Special Relativity of Jets
- Radiation Processes
- Central Engines, Acceleration, Collimation and Confinement of Jets
- Observational Details: Radio
- Optical, Infrared and UV Observations
- Observational Details: X-rays
- Unresolved Emission from the Core: Observations and Models
- Particle Acceleration in Turbulent Magneto-hydrodynamic Shocks
- Simulations of Jets from Active Galactic Nuclei and Gamma-ray Bursts
- Jet Structure, Collimation and Stability – Recent Results from Analytical Methods and Simulations
- Jets and AGN Feedback

Edited by M. Boettcher, D. E. Harris, and H. Krawczynski

Relativistic Jets from Active Galactic Nuclei