H.E.S.S. observations of radio galaxies
Very High Energy Gamma-Ray Astronomy

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Outline

- About Active Galaxies and Jets
- Radiation Process
- AGN Classification
- Some Radio Galaxies with HESS
- Outlook
“not-so-active” Galaxies
Active Galaxies

- Given a **supermassive black hole** (SMBH) at galaxy center
- most galaxies have quiet centers
- a few accrete mass and emit radio to gamma
- latter said to be **Active Galactic Nuclei** (AGN)
Astrophysical Jets

- jets are **common** in the Universe
- jets from: pulsars, X-ray binaries, AGN, GRBs
- in AGN: jets due to accretion onto SMBH
- carry particles, energy, B-field
- should be powered by central SMBH

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Jet Physics — Superluminal Motion

- apparent $v > c$, hence “superluminal”
- only a geometric effect
- arrival time of later pulses enhanced by source motion
- apparent transverse speed

$$v_{\perp \text{app}} \leq c \sqrt{\Gamma^2 - 1}$$

with typical blazars with $\Gamma \sim 10$
Jet Physics — Relativistic Beaming

- radiating blob along jet
- blob moves at relativistic speed
- blob radiation beamed into forward direction
- result: Lorentz boosted headlight effect

\[
F_{\nu}^{\text{obs}} = \delta_D^3 F_{\nu}^{\text{em}}
\]

where \( \delta_D = \frac{1}{\Gamma(1 - \beta \cos \theta)} \)
Radiation Processes

Non-thermal process involving electrons

- Flux depends on electron energies, $B$, volume, photon density, etc.
- Inverse-compton upscattering of low-energy photons
- Syn. Self-Compt. (SSC): seed photons from synchrotron
- External Compt. (EC): seed photons from CMB, disk, etc.

\[ \nu_{\text{Compt}} \sim \nu_0 \gamma^2 \]
Radiated Spectra

- Synchrotron peak in lower energies up to X-rays
- Inverse-compton peak in $\gamma$-rays

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Modelling the VHE Spectra

- leptonic or hadronic
- gamma-gama pair production
- Spine-sheath model: two flow in jet
- Multi-blob SSC models

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Classifying AGN by Viewing Angle

- Viewing angle $\theta_{\text{view}}$ b/w LoS and jet direction
- for small $\theta_{\text{view}}$: blazar
- for large $\theta_{\text{view}}$: radio galaxy
- can be radio-loud or radio-quiet
- can have broad/narrow line emission
- **BL Lacs** have a narrower than **FSRQs**
Classifying Blazars by Synchrotron Peak

Blazer

Blazar

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Classifying Blazars by Synchrotron Peak

- check frequency at which “Synchrotron Peaks” (SP)
  - LSP (Low): $\nu < 10^{14} \text{ Hz}$
  - ISP (Intermediate): $10^{14} \text{ Hz} < \nu < 10^{15} \text{ Hz}$
  - HSP (High): $\nu > 10^{15} \text{ Hz}$

From Low to High-energy peaked Blazars:
FSRQ - LBL - IBL - HBL - Extreme BL
Classifying Radio Galaxies by Morphology

- study morphology of extended **double** radio structures
- classify by **structural features**: jets, lobes & hotspots
- 1974: Fanaroff & Riley proposed FR I and FR II types
  - FR I e.g. Cen A | FR II e.g. 3C 47
  - FR I: spectra steeper, aged radiating particles
  - FR II: often giant elliptical host

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The broader picture

Active Galactic Nuclei
(A few % of all galaxies)

- Radio-quiet
  - (85% – 95%)
  - Spirals
    - The most common class of AGN
    - Seyfert 1
      - Have both broad lines (Balmer Hα, Hβ, etc.) and narrow lines of ionized metals
    - Seyfert 2
      - Show only narrow lines of Hα in spectra

- Radio-loud
  - (5% – 15%)
  - Ellipticals
  - Quasi-Stellar Objects

Blazars
(5% of all AGNs)

FSRQs
- Flat spectrum
- Low radio luminosity
- High quasar luminosity
- Low, intermediate & high synchrotron peaked

BL Lacs
- Featureless optical spectrum

identified as few sources
Centaurus A

- giant elliptical host galaxy NGC 5128
- FR I and closest AGN to Earth at $\sim 13 \times 10^6$ light years
- SMBH $\sim 55 \times 10^6 M_\odot$
- large viewing angle $\sim 70^\circ$ ⇒ weak/no relativistic boosting
- hence not expected as up to TeV emitter
- HESS obs.: seen in TeV ⇒ “puzzle”
Spectrum: Centaurus A with H.E.S.S.

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Current TeV AGN Sky

AGN seen at TeV

- H.E.S.S.
- VERITAS
- MAGIC
- All AGNs

http://tevcat.uchicago.edu

- 60 AGNs are currently detected at TeV
- Large dominance of HBLs (75%)

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Other Radio Galaxies with HESS

- M 87 in Virgo cluster — extensively studied since start of HESS
- supergiant NGC 6251 in constellation Ursa Minor — far too north (dec +82°)
- 3C 236 an FR II — also a northern source
- 3C 111 – Seyfert 1 Galaxy
- 3C 320 – A broad line radio galaxy
- radio galaxies are handful at...
Currently: analyzing 3C 120, PKS 1510-089 with HESS tools

Performing FERMI analysis — Pass 8 one week old in public

revisit Cen A VHE spectra and do hard-X-ray analysis (Swift)

In general: Looking forward to CTA regime: next-generation VHE-γ-ray Observatory