Radio galaxies in Very-High Energy Gamma-rays

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Overview

AGN and Jets

Supermassive black holes (SMBHs) in Galaxies

- SMBHs at centre of almost all known galaxies
- a few percent of these BHs are "active"
- "active" $\rightarrow$ luminous centres

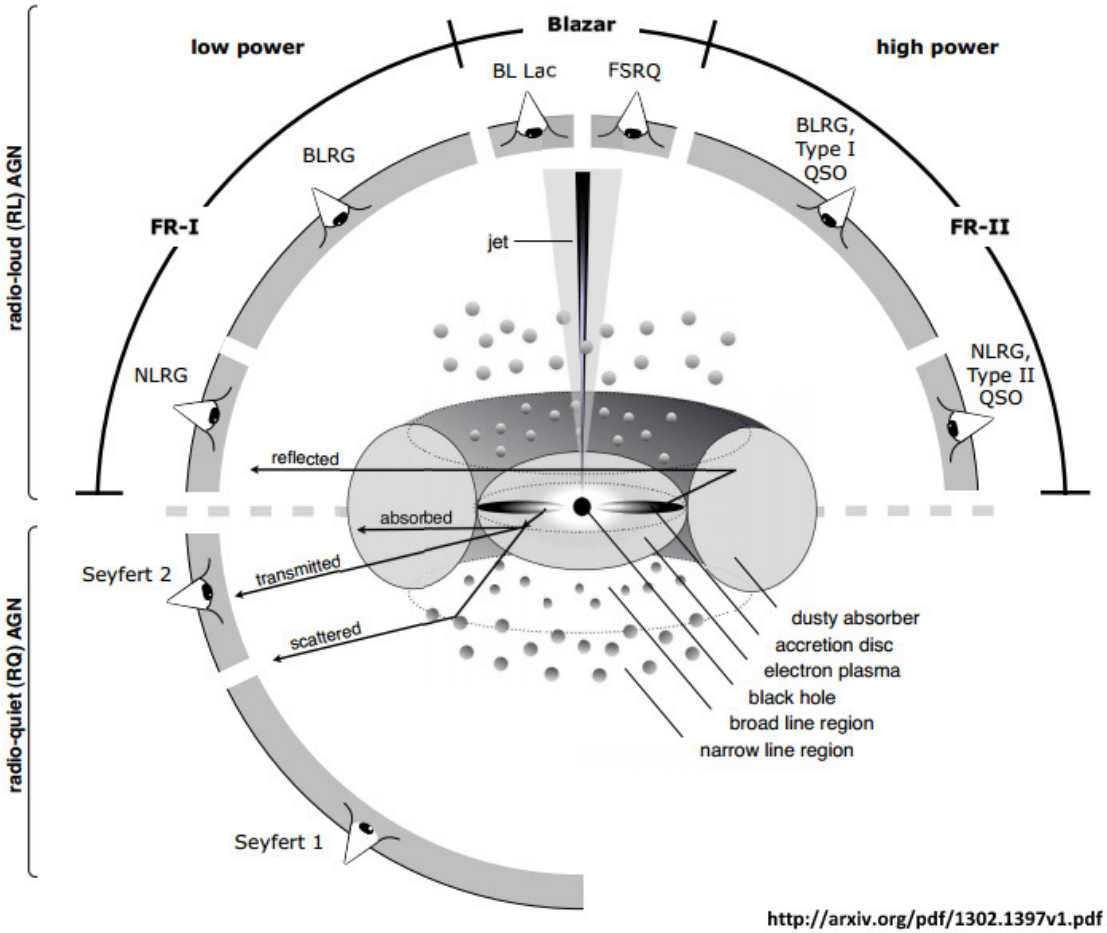
Jets from AGN

- a few percent of AGN eject radio-emitting jets
- jets with relativistic charged particles

Powering source

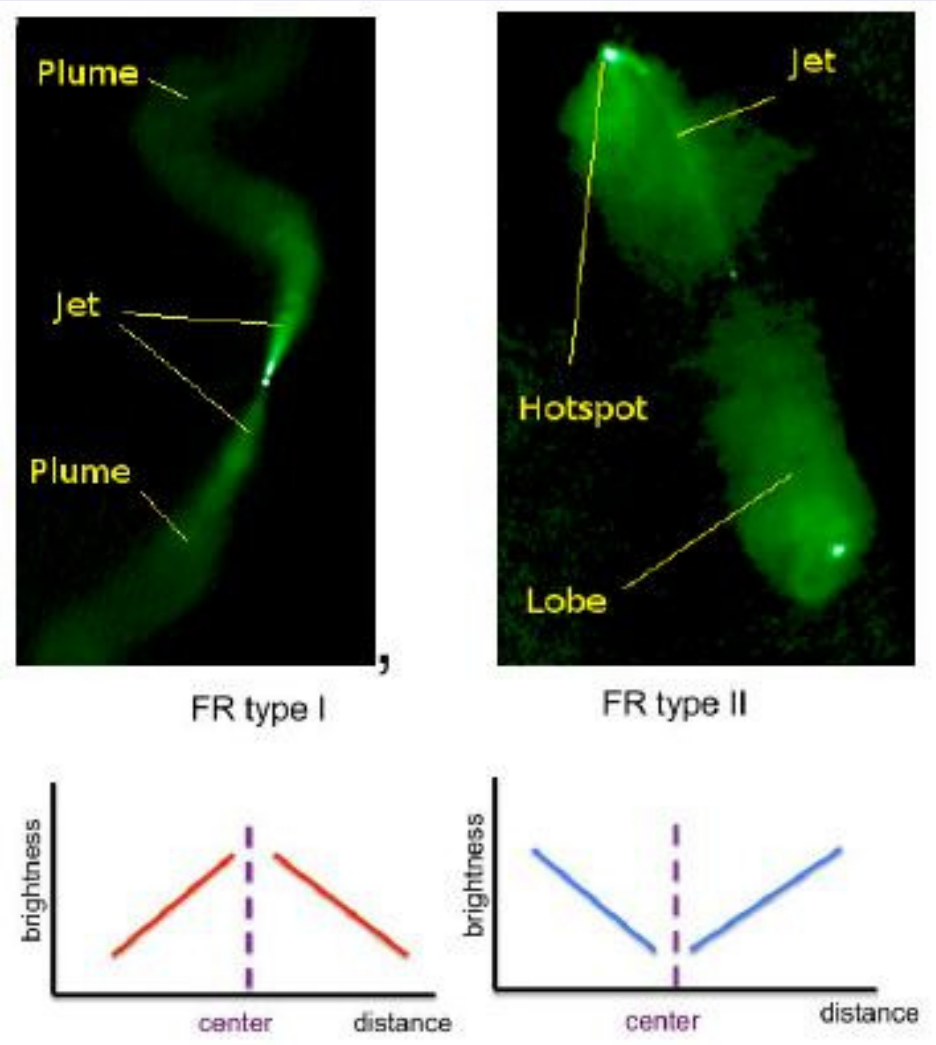
- BH & accretion $\rightarrow$ rotation & accretion-disk $\rightarrow$ radiation

AGN Classification Scheme



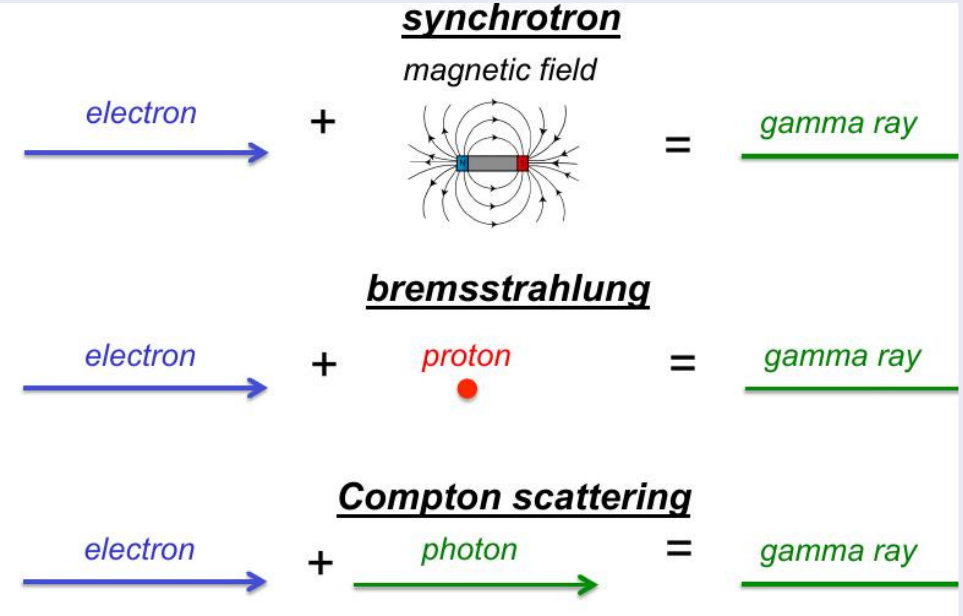
http://arxiv.org/pdf/1302.1397v1.pdf

Radio Galaxy Classification Scheme

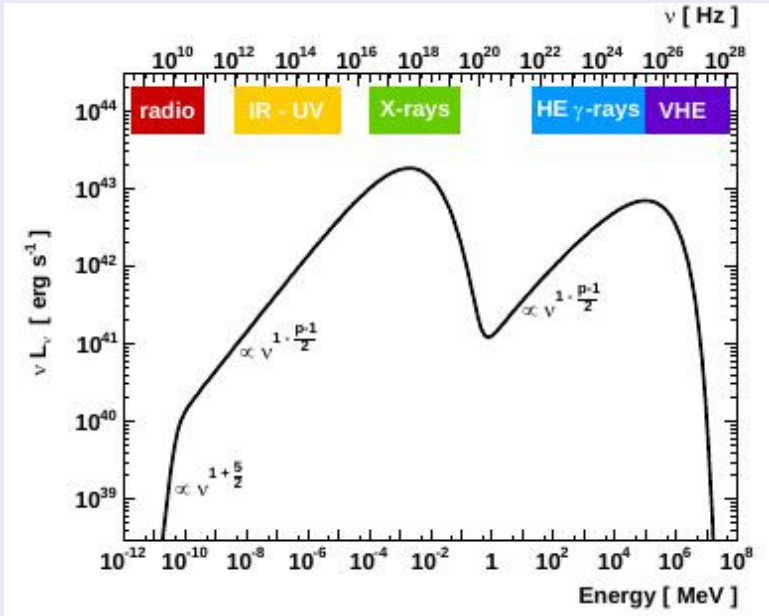


- morphology of double structure
- jets, lobes and hotspots
- by Fanaroff & Riley in 1974
- FR I often steeper spectra
- FR I e.g. Centaurus A
- FR II often giant elliptical hosts
- FR II e.g. 3C 47

Non-thermal Radiation Process & Spectra

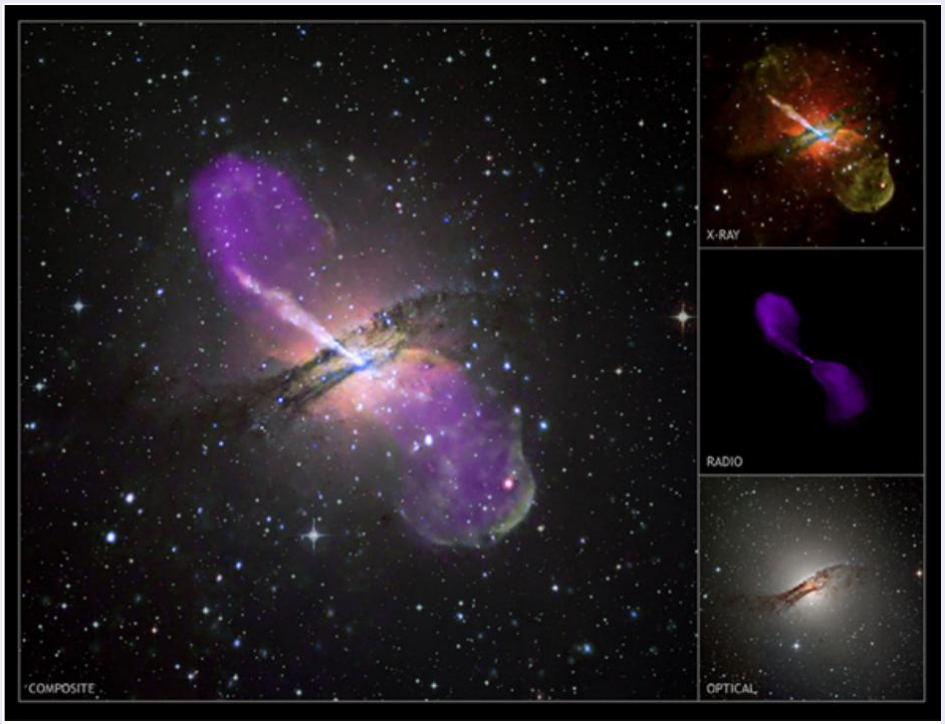


Seed photon population $\dashrightarrow$



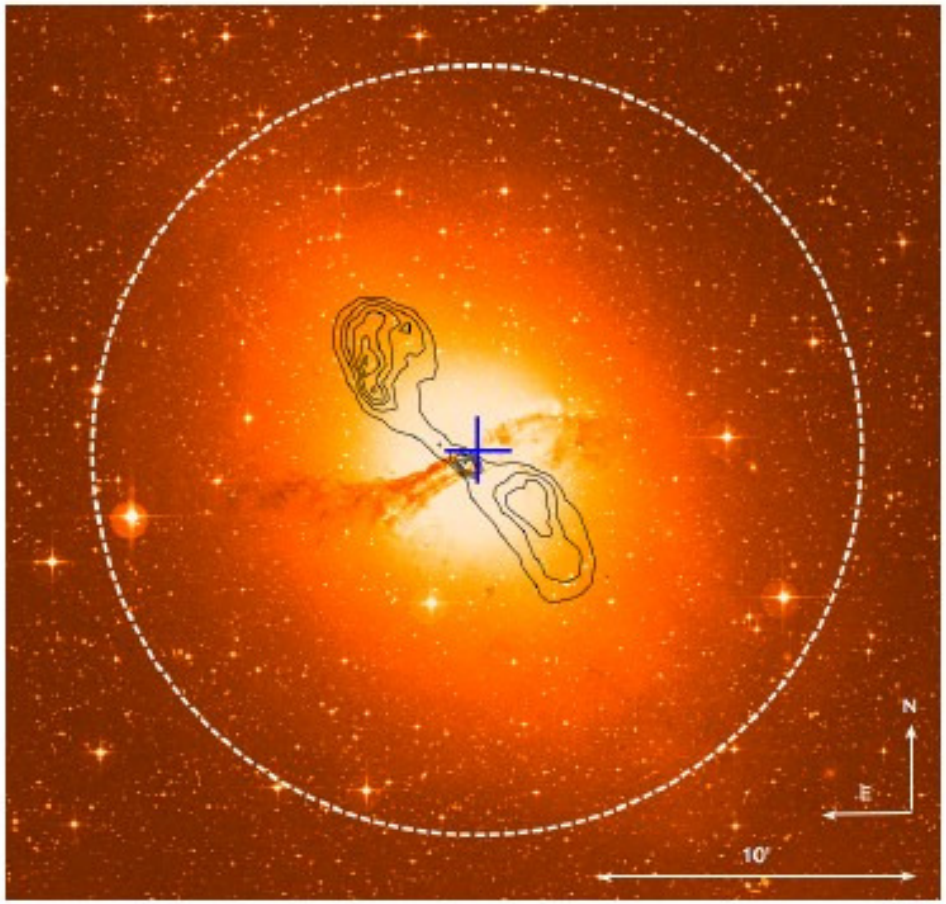
"external inverse-Compton" or "synchrotron self-Compton"

Cen A: Typical Radio Galaxy (NGC 5128)



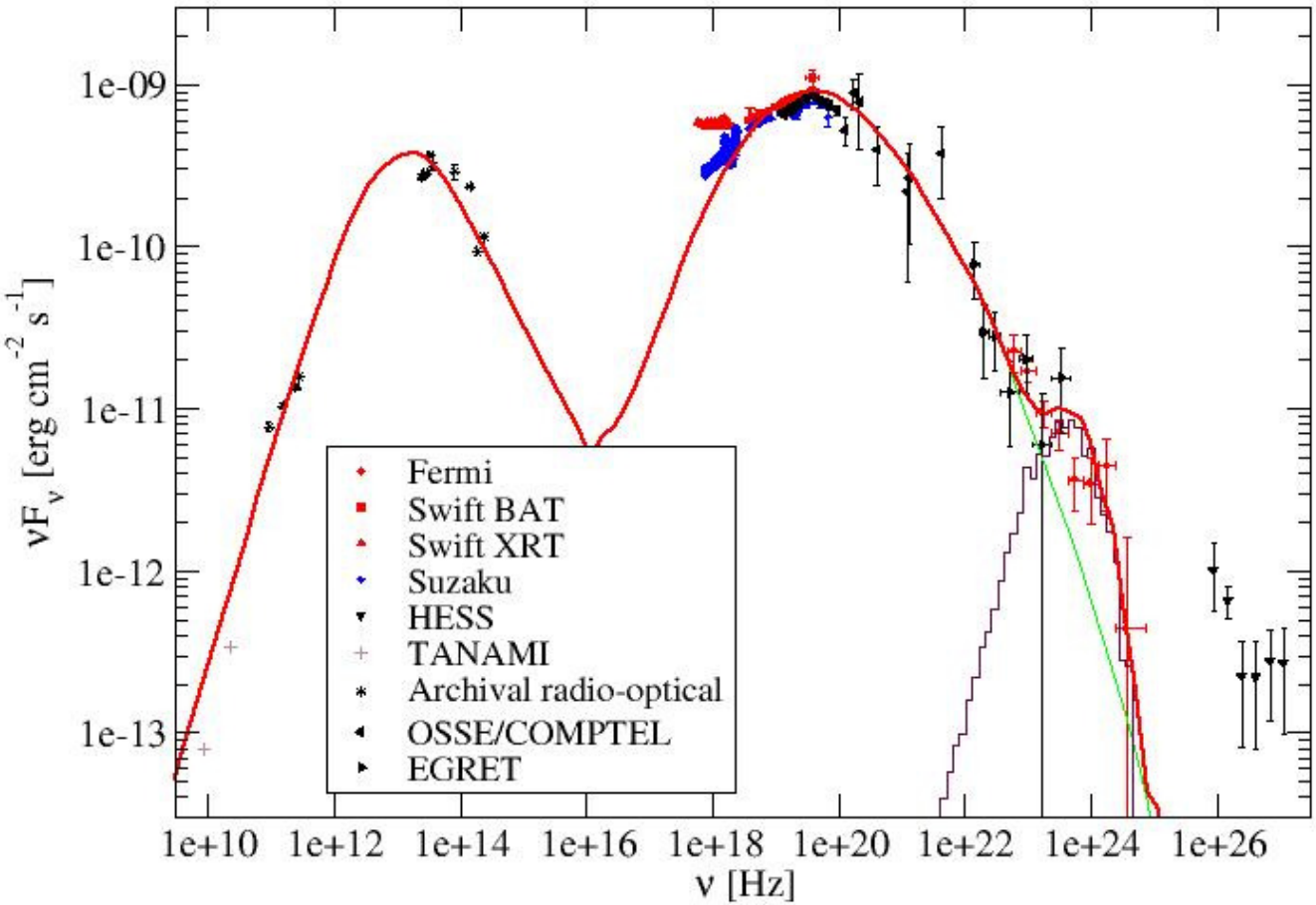
- giant elliptical host galaxy
- FR I type radio galaxy
- closest AGN to us, 10 to 16 million light years only
- harbouring 55 million solar mass black hole
- jets million light-years in length
- seen in VHE γ-rays

Cen A in Optical and Radio



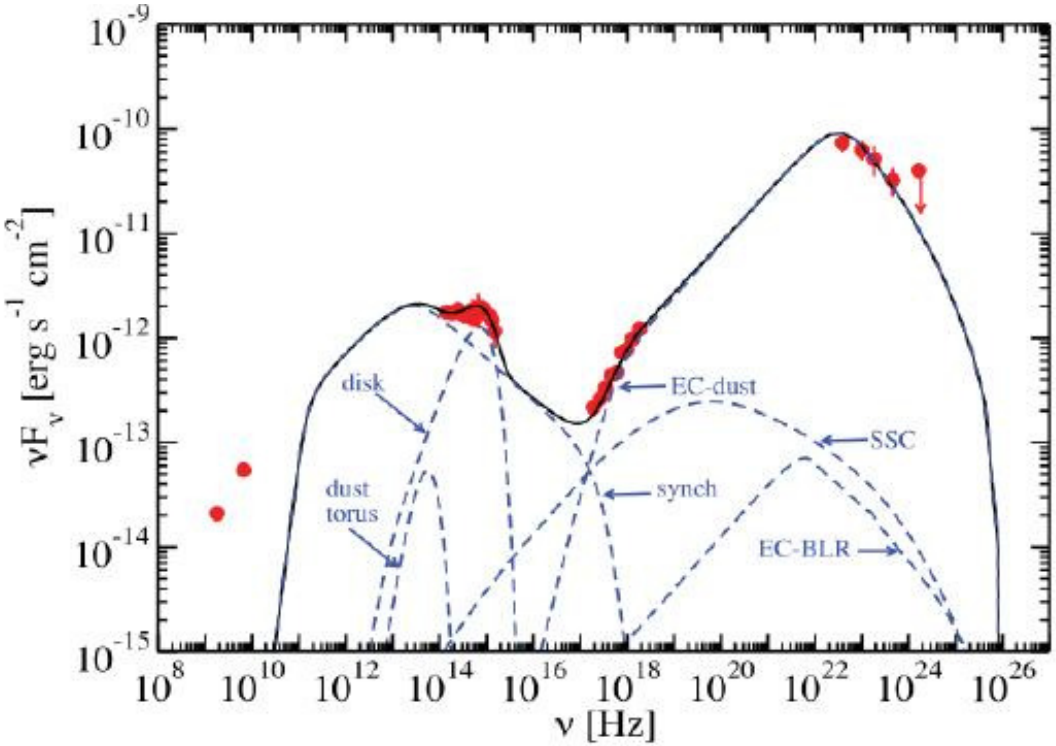
H.E.S.S. collaboration, F. Aharonian et al., Astrophysical Journal Letters, 695 (2009) L40-L44

Multi-λ Observated Emission from Cen A



Roustazadeh & Böttcher, Astrophysical Journal, 728, 134 (2011)

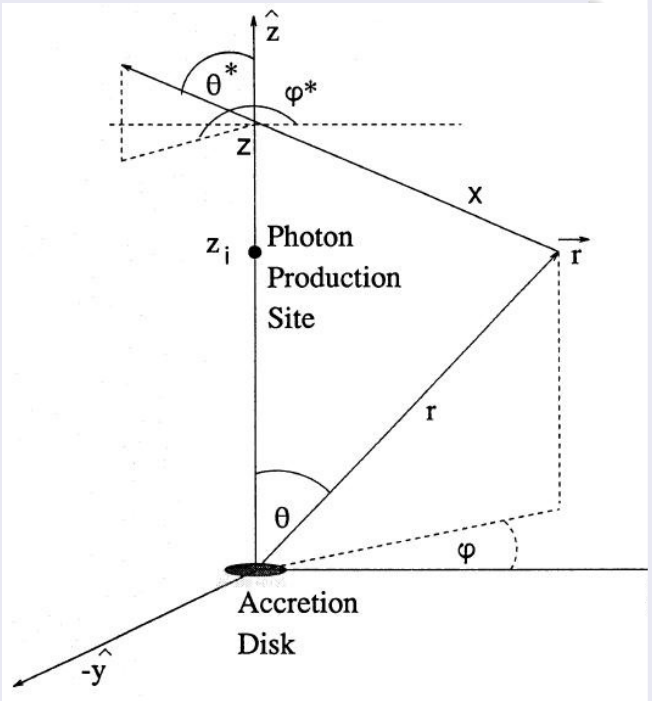
Numerical Models of Emission from AGN



In the models

- set **B**, $n_{\rm ph}$, $n_{\pm {\rm e}}$, R, etc.
- leptonic and or hadronic models
- angle-dependency

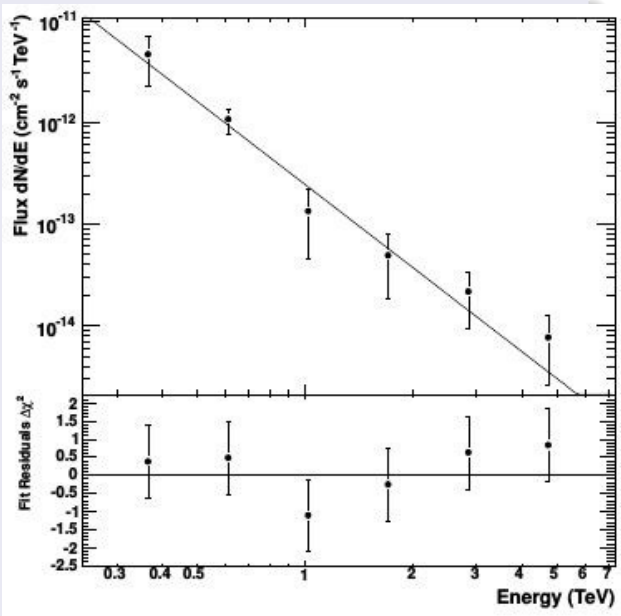
Reverberation Mapping of Broad Line Region



- "hinted" in 1995 by Böttcher & Dermer for BL Lacs
- if flare in disk, soft photon into BLR
- upscattering by electrons in BLR
- intercept jet photons
- temporal difference in X-ray and γ-rays observed
- infer location and density of γ-ray production sites

Böttcher & Dermer, 1995, Reveberation Mapping of AGN

Cen A Spectrum — H.E.S.S. — 2009



- detected in TeV at $\sim 4\sigma$ by HESS up to 2009
- $\frac{dN}{dE} \propto E^{-\Gamma}$ with $\Gamma = 2.73 \pm 0.45_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}$
- $\Phi(E > 250\ \mathrm{GeV}) = 1.56 \times 10^{-12}\mathrm{cm}^{-12}\mathrm{s}^{-1}$
- no significant variation in 28 minute scale

H.E.S.S. collaboration, F. Aharonian et al., Astrophysical Journal Letters, 695 (2009) L40-L44

HESS Phase II Telescopes

$$\mathrm{CT}_5 \neq \mathrm{CT}_1,\ \mathrm{CT}_2,\ ,\mathrm{CT}_3,\mathrm{CT}_4$$

Cherenkov Light Pool

History & Facts

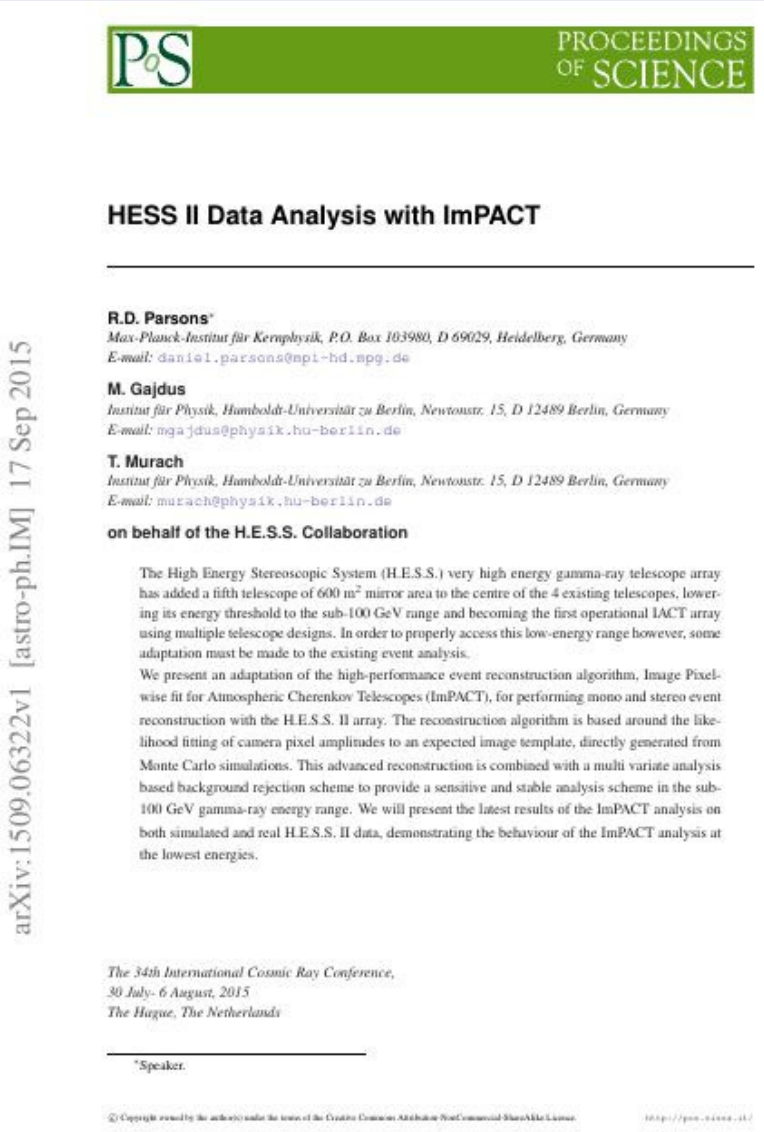
The particles keeping the directional information are the neutral ones:

- NEUTRONS (too short lifetime)
- NEUTRINOS (extreme low cross-section → very large detectors)
- PHOTONS

GAMMA RAYS → *trace back to the origin of their generator, carry energy information about it and preserve the time structure of the emission signal*

- $\sim$ 89% protons (hadronic)
- $\sim$ 9% α particles
- $\sim$ 1% ionized heavier elements
- $\sim$ 1% electrons
- ONLY $\sim$ 0.9% are photons
- stolen from: Fabio Zandanel (20xx)

Heidelberg ImPACT Data Analysis



PROCEEDINGS OF SCIENCE

HESS II Data Analysis with ImPACT

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on behalf of the H.E.S.S. Collaboration

The High Energy Stereoscopic System (H.E.S.S.) very high energy gamma-ray telescope array has added a fifth telescope of 600 m^2 mirror area to the centre of the 4 existing telescopes, lowering its energy threshold to the sub-100 GeV range and becoming the first operational IACT array using multiple telescope designs. In order to properly access this low-energy range however, some adaptation must be made to the existing event analysis.

We present an adaptation of the high-performance event reconstruction algorithm, Image Pixel-wise fit for Atmospheric Cherenkov Telescopes (ImPACT), for performing mono and stereo event reconstruction with the H.E.S.S. II array. The reconstruction algorithm is based around the likelihood fitting of camera pixel amplitudes to an expected image template, directly generated from Monte Carlo simulations. This advanced reconstruction is combined with a multi variate analysis based background rejection scheme to provide a sensitive and stable analysis scheme in the sub-100 GeV gamma-ray energy range. We will present the latest results of the ImPACT analysis on both simulated and real H.E.S.S. II data, demonstrating the behaviour of the ImPACT analysis at the lowest energies.

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The Hague, The Netherlands

*Speaker.

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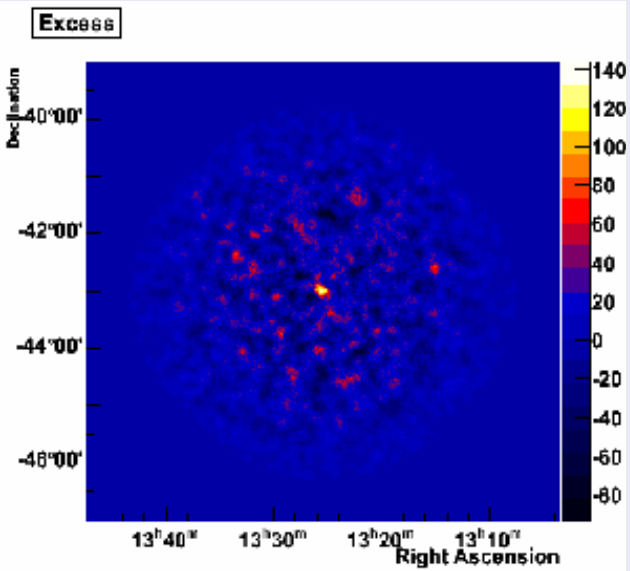
- event reconstruction & background rejection
- improvement to traditional Hillas analysis
- adaption for sub-100 GeV range for H.E.S.S. II
- ImPACT "Image Pixel-wise fit for ACTs"
- likelihood fitting of camera pixel amplitudes to image templates
- library of template created from Monte Carlo simulations
- multivariate analysis for background rejection
- improvements particularly in lowerly energies

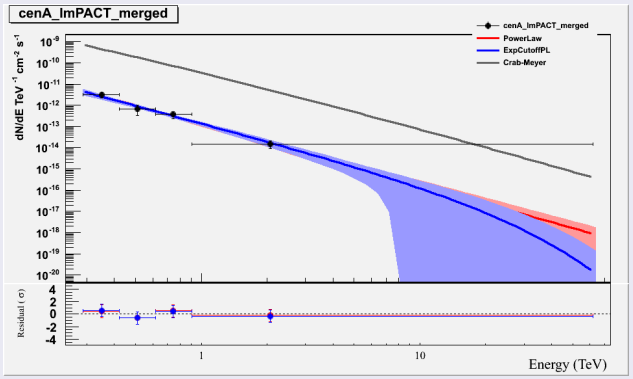
Example: ImPACT output on Cen A 2008 data

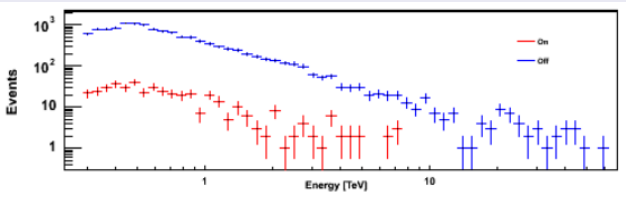
Example (ImPACT Analysis Statistics)

```
[BgStats_RingBgMaker_Merged]
        NumOn          = 155 runs
        NumSkippedOn   = 0 runs
        NumBadOn       = 0 runs
        NumOff         = 155 runs
        NumSkippedOff  = 0 runs
        NumBadOff      = 0 runs
        Skipped        = false
        Bad            = false
        ConfigName     = std_ImPACT
        ObservationPos= (13h21m38.22s, -43d1'9'')[System:
        [RADecJ2000System]]
        MeanZenithOn   = 22.7366 deg
        MeanZenithOff  = 22.7407 deg
        MeanOffsetOn   = 0.700848 deg
        MeanOffsetOff  = 0.796545 deg
        MeanAzimuthOn  = 183.447 deg
        MeanAzimuthOff= 183.448 deg
        StartTime      = (Sun Mar  9 00:53:28 2008)
        EndTime        = (Thu Jul  3 18:10:55 2008)
        N_on           = 424
        N_off          = 12209
        Exposure_on    = 319.472
        Exposure_off   = 12365.7
        Alpha          = 0.0258354
        Excess         = 108.576
        Significance   = 5.72374
        Livetime       = 65.4177 hrs
        Rate           = 0.0276622 +/- 0.0048329 1/min
        Sig/sqrt(hr)   = 0.707672
```

Example: ImPACT output on Cen A 2008 data







- we reach $\sim 5\sigma$ detection in TeV
- power law spectrum
- $\frac{dN}{dE} \propto E^{-\Gamma}$ with $\Gamma = 2.8815 \pm 0.2744_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}$
- "OFF" events $>$ "ON" events
- refine analysis parameters
- template fitting: ImPACT time consuming
- this is 2008 data ONLY — sample

The TO-DO List

H.E.S.S. Analysis

- analyze both HESS I and HESS II data with ImPACT
- confirm usefulness of ImPACT for radio galaxies in TeV

Reverberation mapping of Broad Line Region of Cen A

- obtain long-term TeV γ-ray lightcurve
- obtain long-term X-ray lightcurve (e.g. Swift-BAT)
- if flares exist: attempt to constrain the BLR with reverberation mapping

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and in particular Idan Shilon for valuable comments