

ACTIVE GALACTIC NUCLEI: SOURCES FOR ULTRA HIGH ENERGY COSMIC RAYS

Peter L. Biermann^{1,2,3,4,5}, with Julia Becker^{6,7},
Laurențiu Caramete^{1,8}, Alex Curuțiu¹, Ioana Duțan¹,
Ralph Engel⁵, Heino Falcke⁹, Laszlo Gergely^{10,11}, P.
Gina Isar^{5,8}, Ioana C. Mariș⁵, Athina Meli¹²,
Karl-Heinz Kampert¹³, Faustin Munyaneza¹, Todor
Stanev¹⁴, Oana Tașcău¹³, & Christian Zier^{1,15}

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¹ MPI for Radioastronomy, Bonn, Germany

² Dept. of Phys. & Astron., Univ. of Bonn, Germany

³ Dept. of Phys. & Astr., Univ. of Alabama, Tuscaloosa,
AL, USA

⁴ Dept. of Phys., Univ. of Alabama at Huntsville, AL,
USA

⁵ Inst. Nucl. Phys. FZ, Karlsruhe Inst. of Techn. (KIT),
Germany

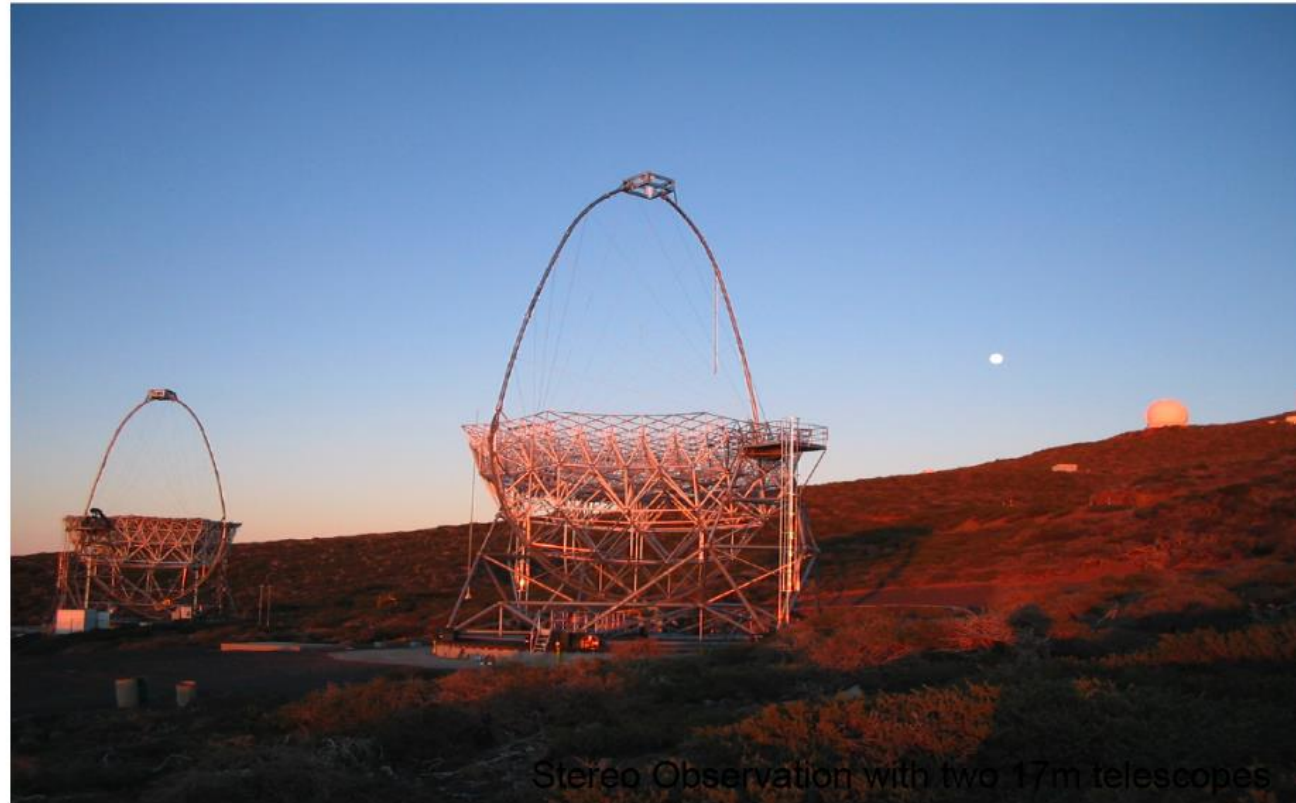
- ⁶ Institution för Fysik, Göteborgs Univ., Sweden
- ⁷ Dept. of Phys., Univ. Dortmund, Dortmund, Germany
- ⁸ Institute for Space Studies, Bucharest, Romania
- ⁹ Dept. of Astrophys., IMAP, Radboud Univ., Nijmegen,
Netherlands
- ¹⁰ Dept. Appl. Sci., London South Bank University, UK
- ¹¹ Phys. Dept., Univ. of Szeged, Szeged, Hungary
- ¹² Physik. Inst. Univ. Erlangen-Nürnberg, Germany
- ¹³ Phys. Dept., Univ. Wuppertal, Germany
- ¹⁴ Bartol Research Inst., Univ. of Delaware, Newark,
DE, USA
- ¹⁵ Raman Res. Inst., Bangalore, India

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What is matter, and how do we find out?

- Almost all matter in the Universe is Hydrogen, and almost all energetic cosmic ray particles are Hydrogen nuclei - protons; at 50 Joule per particle still true?
- The ultimate accelerator, and ultimate beam-dump:
- Super-massive black holes, eject relativistic jets, have shock-waves, which accelerate ultra high energy particles
- Supermassive black holes grow by merging: merger leads to spin-flip: spin-flips lead to newly directed jets hitting molecular clouds
- We observe the very high energy photons (HESS; MAGIC; Veritas), the very high energy neutrinos (IceCube), and the ultra high energy cosmic rays (AUGER, TA),

MAGIC-I and MAGIC-II



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Figure 1 Both MAGIC TeV photon telescopes in La Palma; source Teshima

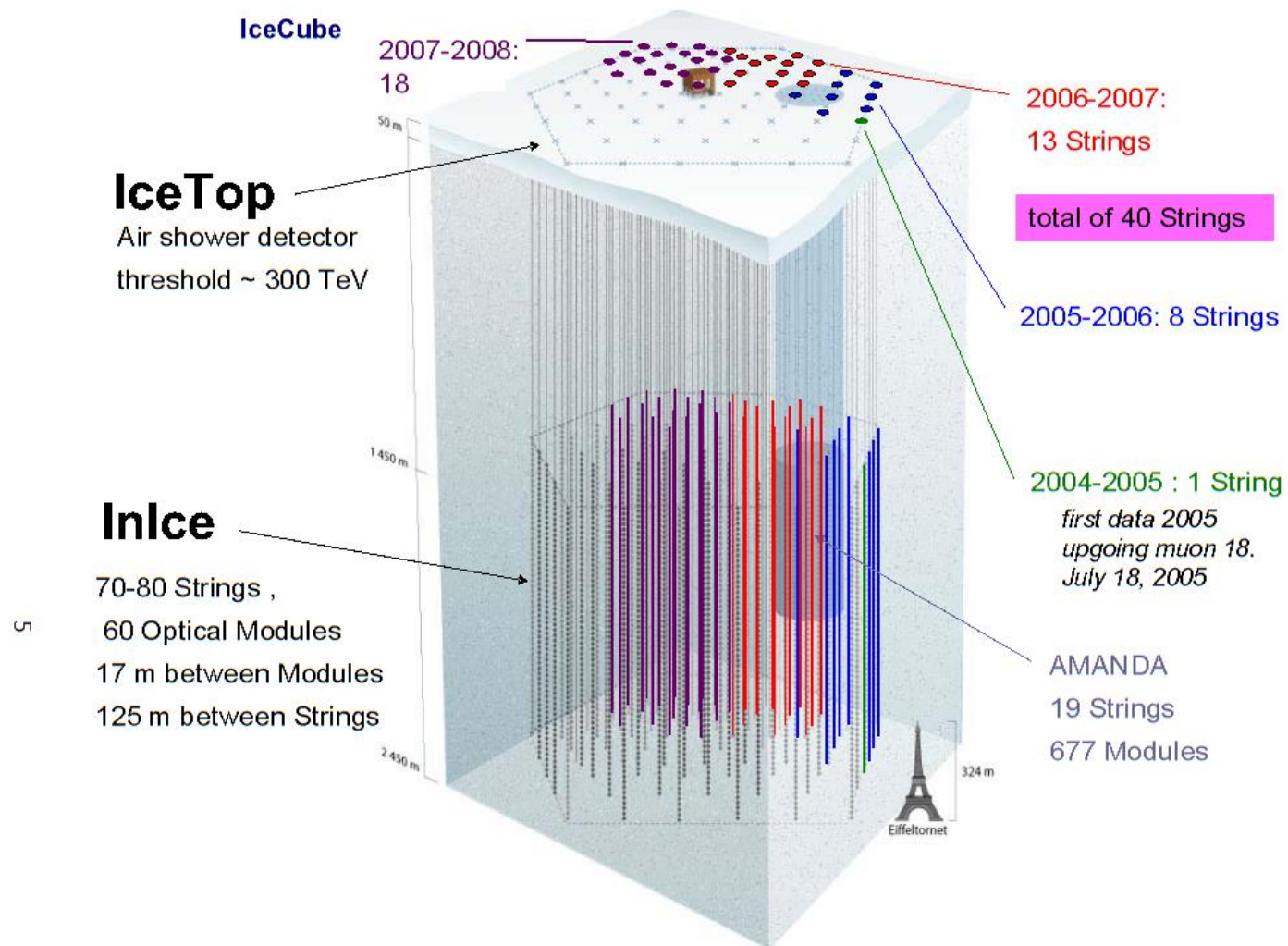


Figure 2 IceCube Neutrino telescope at the south pole

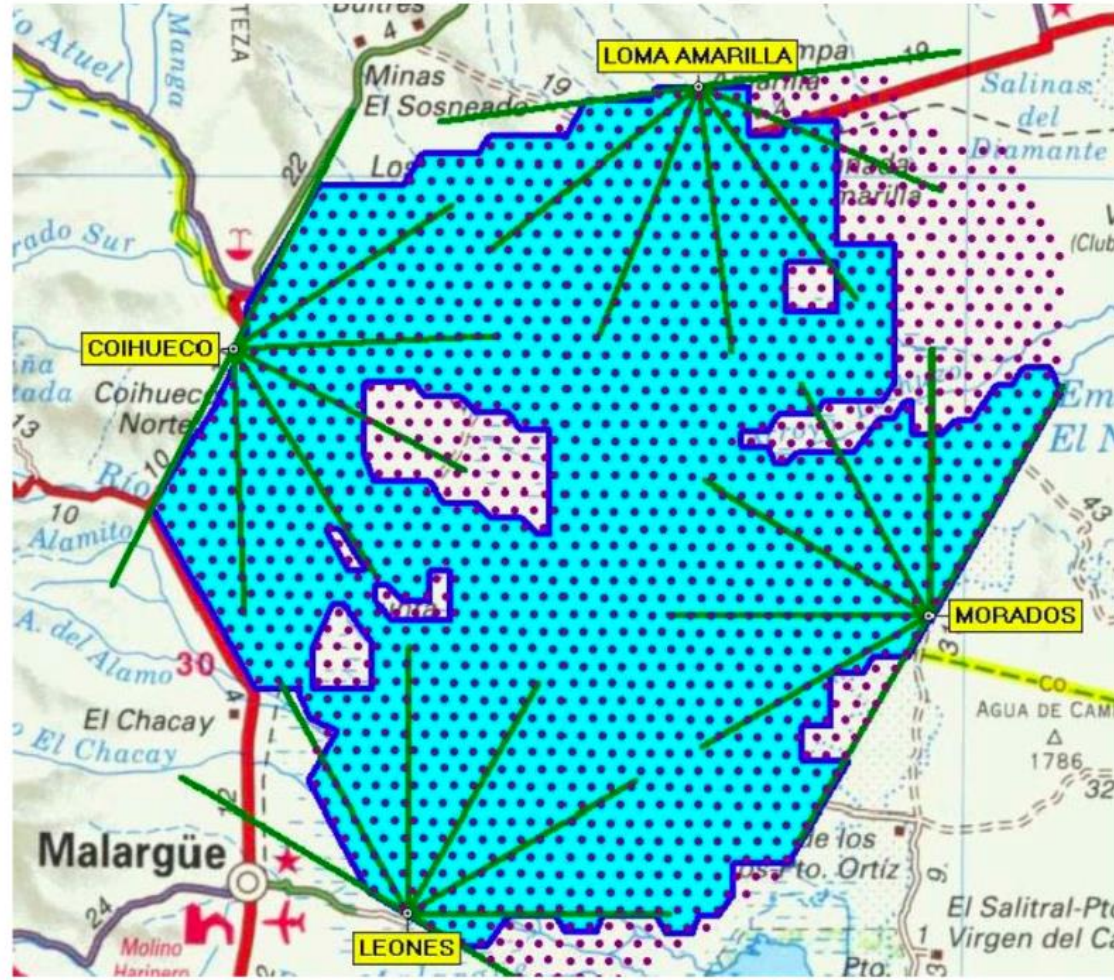


Figure 3 Auger array in Malargüe, Argentina

Discovery and Prediction 1: The GZK-cutoff

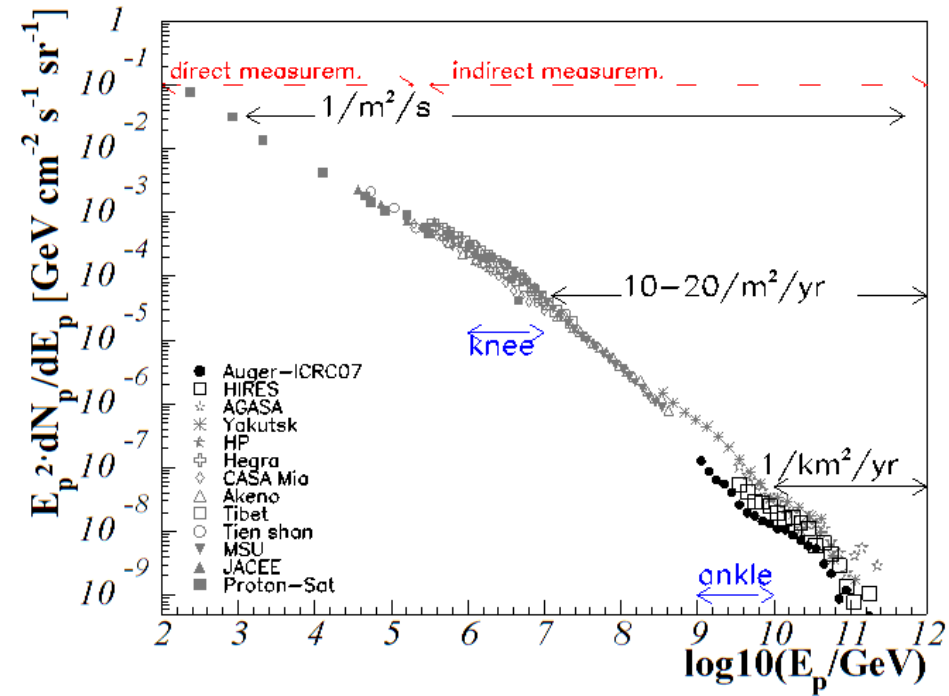


Figure 4 All-particle cosmic ray spectrum from many earlier experiments. Filled circles at the highest energies are recent results from Auger (ICRC 2007), clearly showing the Greisen-Zatsepin-Kuzmin cutoff, which is due to the interaction with the cosmic microwave background. Clearly the particle energies require revision and rescaling. This is the spectrum to explain, and the strongest radio galaxies can provide an explanation.

- Linsley (1963): Detection of first event $\gtrsim 10^{20}$ eV - uncontainable in magnetic field of Galaxy
- Nearby candidates (Ginzburg & Syrovatskii 1963 *Astron. Zh.*; before discovery of UHECRs): Radio galaxies Cen A (= NGC 5128), Vir A (= M87 = NGC 4486) For A (= NGC 1316)
- Prediction (1966) of GZK-turnoff near 5×10^{19} eV due to interaction with the cosmic microwave background (MWBG: Greisen, Zatsepin & Kuzmin; sometimes called GZK-cutoff).
- Now many events near and beyond 5×10^{19} eV – nearly isotropic (Stanev et al. *Phys. Rev. Letters* 1995)
- Turnoff seen by HiRes (2005, 2008) and AUGER (ICRC 2007, Mexico, 2008), and so prediction confirmed

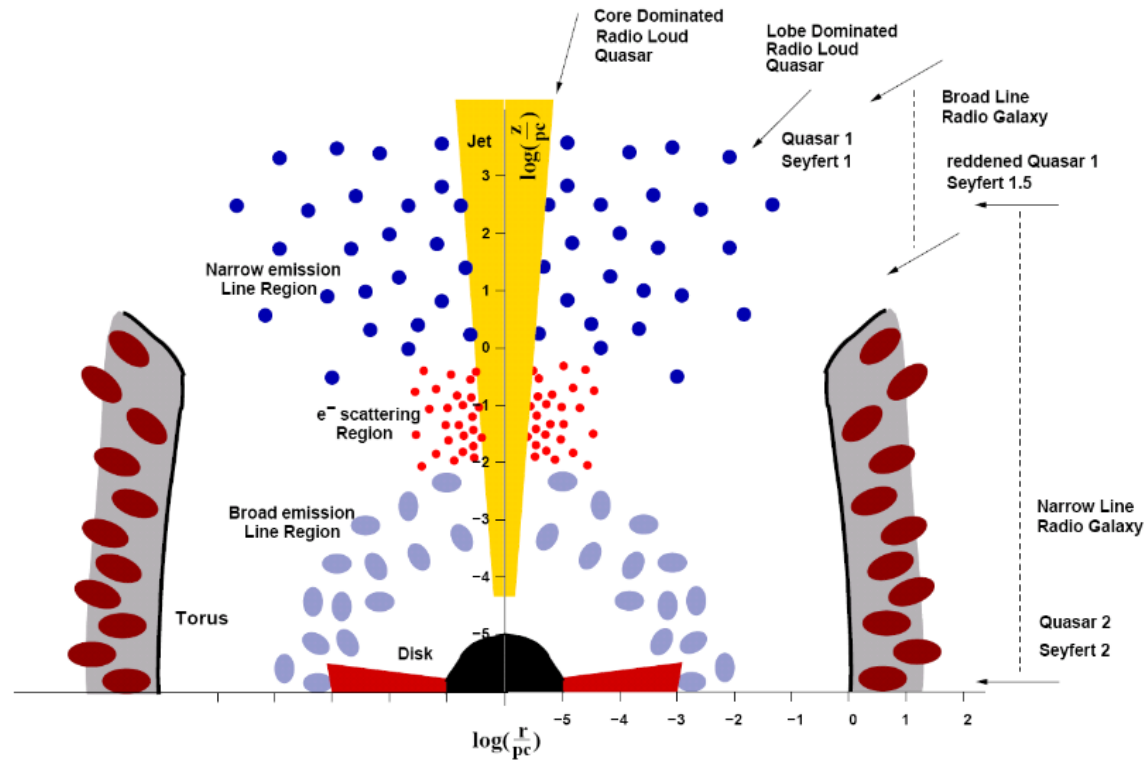


Figure 5 A sketch of the cylindrically symmetric AGN. The cut shows the r - z -plane, both axes logarithmically scaled to 1 pc, with the black hole at the center providing the symmetry. The basic constituents are the central BH with a surrounding accretion disk, the jet perpendicular to the disk and the torus encircling this configuration. The dark patches in the torus indicate the clouds, made up by stellar winds in the concept proposed (Zier & Biermann 2001, 2002).

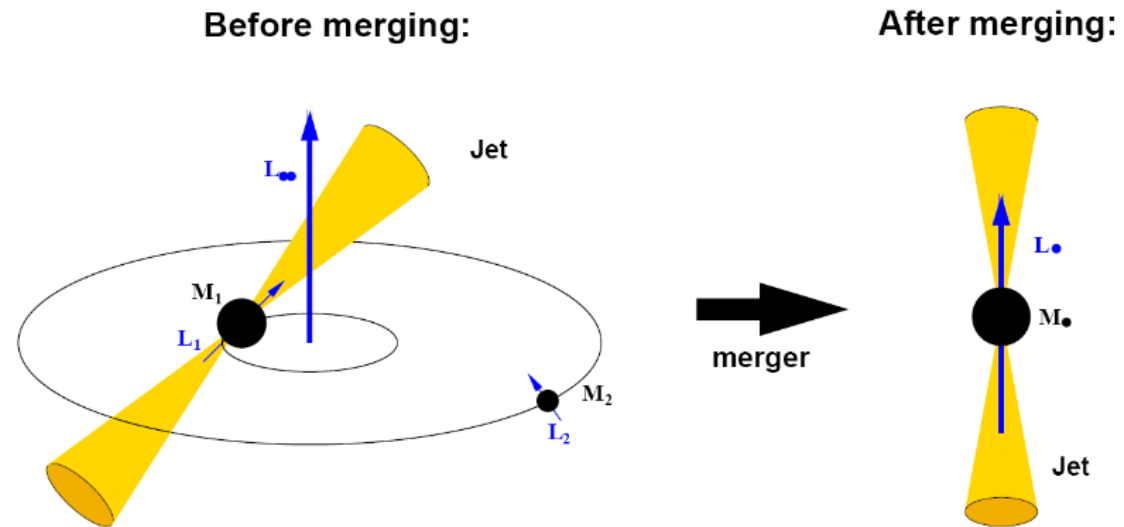
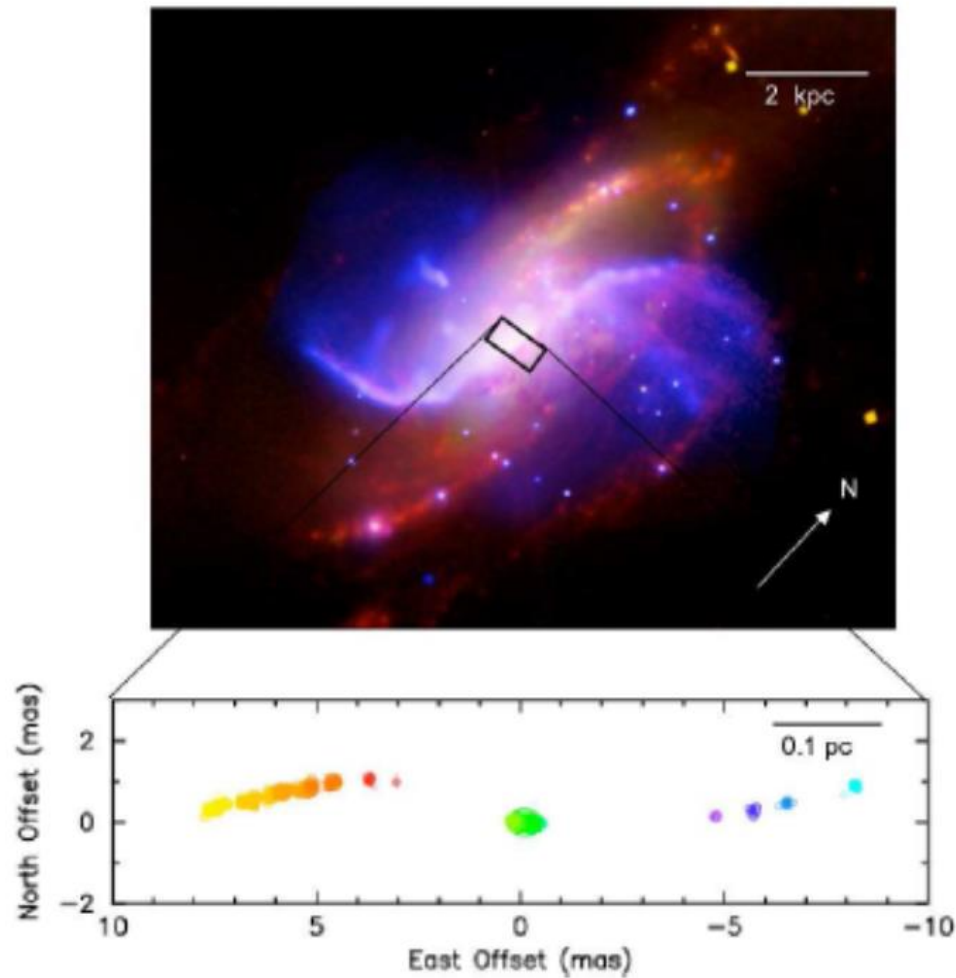


Figure 6 This figure illustrates the change of the direction of the spin of the BH, induced by the merger of 2 massive BHs, and consequently the change of the direction of the jet. Basically the orbital spin wins over the two intrinsic spins. The left panel shows the situation before the merger, when the jet is aligned with the individual spin of the primary black hole of the binary system (Zier & Biermann 2001, 2002).



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Figure 1. Top: A multiwavelength image (X-ray, $H\alpha$, 1.4 GHz radio) from Yang et al. (2007) of the inner part of the galaxy NGC 4258, also known as M106. Unfortunately, this black-and-white rendition of the color image does not serve to distinguish the various wavelength regimes very well. The so-called anomalous arms, seen by their synchrotron emission, have position angles of about -45 and 135 degrees and exhibit sharp bends about 2 kpc from the nucleus. A large angle between the position angle of the accretion disk and the galaxy was assumed by Holm (1982). Bottom: Image of the maser emission from the central accretion disk of the galaxy from VLBA observations. Note that the overplotting of many maser emission spots makes the disk look much fatter than it actually is. From Argon et al. (2007)

- Warped disk (rainbow) and sprinkler-like jets (blue)

Physics of active galactic nuclei

- Almost all galaxies have
- a central super-massive black hole,
- a compact accretion disk (not always radiating),
and
- a relativistic jet
- Activity episodic, driven by minor (other galaxy without a central black hole) and major mergers (other galaxy, also with a central black hole)
- Merging activity began early, far beyond redshift 6.4 (800 million years in the concordance cosmology): already then black holes with $> 10^9 M_{\odot}$; after redshift 1.5 - 2 merging activity rapidly decreases
- Orbital spin change prior to black hole merger? Question on final spin of merged supermassive black hole

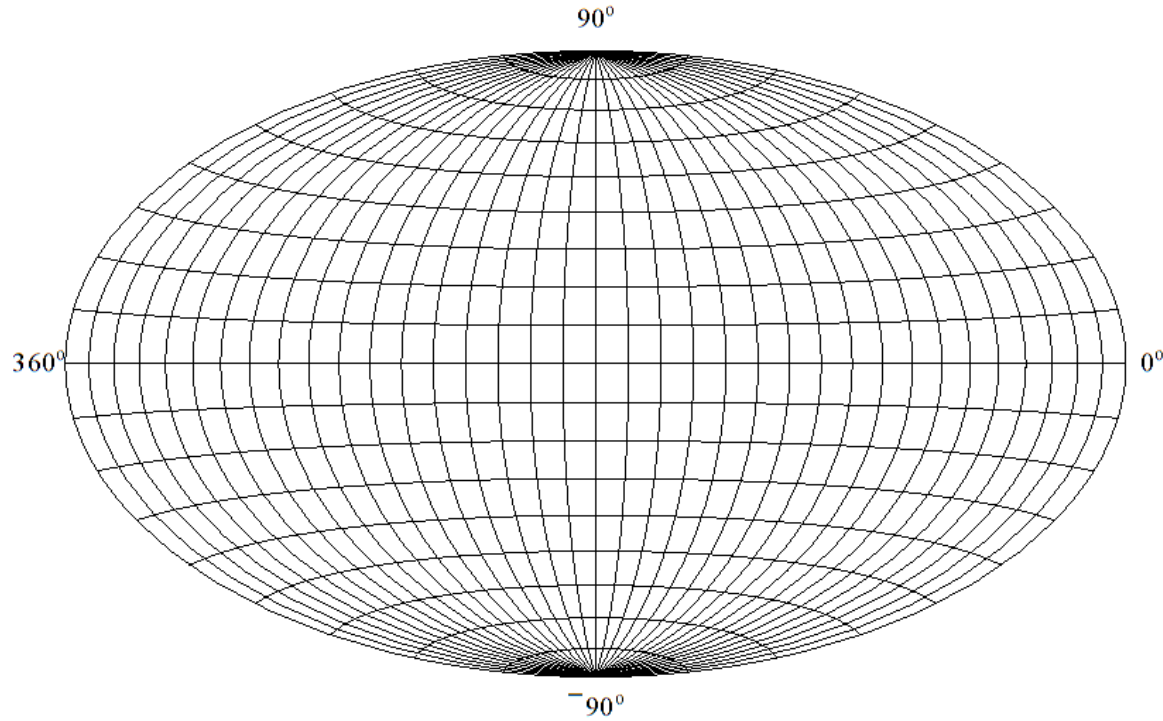


Figure 8 The sky in black holes, $\geq 10^7 M_{\odot}$: Aitoff projection in galactic coordinates of 5,978 candidate sources in the case of a complete sub sample (the Galactic plane remains obscured). The choice was made from a complete sample of 10,284 candidate brighter than 0.03 Jy at 2 micron, and selected at $z < 0.025$; this uses the 2 micron all sky survey, limited in a 20 degree band in the Galactic plane. Normal and starburst galaxies were counter-selected using color and FIR/radio ratio (Biermann & Fricke 1977, Kronberg et al. 1985, Chini et al. 1989, and other work). These candidate sources are probably all black holes, with masses near to or above 10^7 solar masses; the black hole mass was determined with the black hole versus mass spheroidal stellar population correlation, and tested. The color code is Black, Blue, Green, Orange, Red corresponding to redshifts between 0, 0.005, 0.01, 0.015, 0.02, 0.025: Caramete et al. 2008

Discovery and Prediction 2: Particles in radio galaxies

- Cutoff in nonthermal spectrum $\nu^?$ observed in many radio galaxies since 1976 (Rieke et al. 1976+ Nature ; Bregman et al. 1981 Nature ; Stocke et al. 1981 Nature ; Meisenheimer & Röser 1986+ Nature): feature of acceleration of protons to 10^{21} eV, shown by Biermann & Strittmatter (1987 Astrophys. J.):
- Protons get accelerated in shock, reach loss limit, establish wave field of irregularities in magnetic plasma, non-linear cascading
- Electrons get accelerated in shock, scatter in given wave field, go to loss limit, produce cut-off in non-thermal emission spectrum, so maximal frequency.

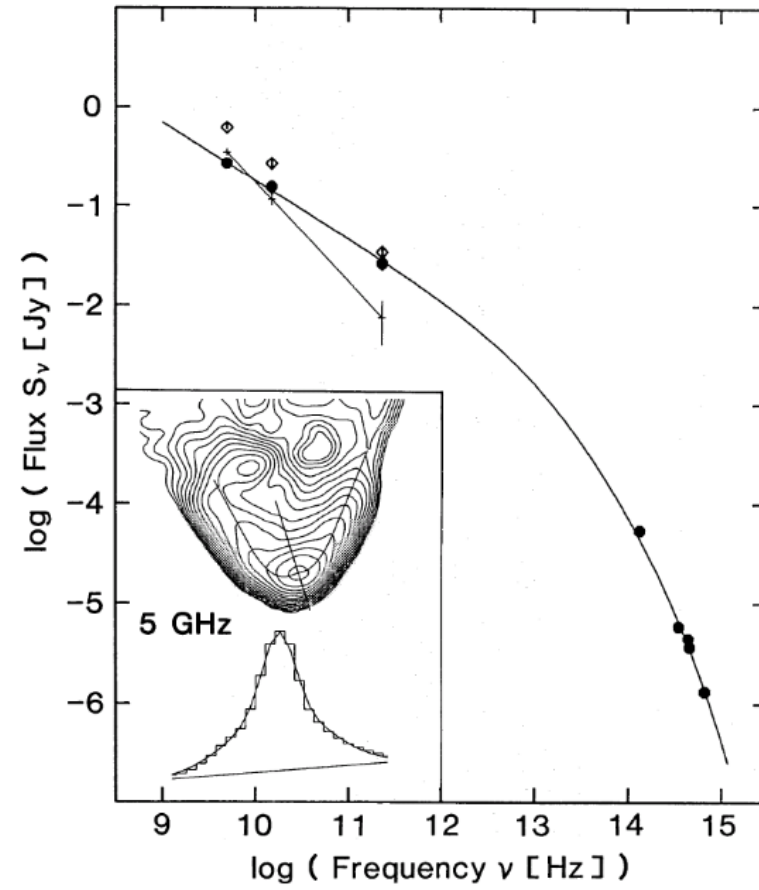


Figure 9 Decomposition of the observed spectrum of 3C 33 south. (K. Meisenheimer et al., *Astron. & Astroph.* 1989)

- Electron emission maximal frequency:

$$\nu^? \rightarrow 3 \times 10^{14} \text{ Hz} \quad (1)$$

- Loss limit and spatial limit combined give

$$E_{p,\text{max}} \rightarrow 1.4 \times 10^{21} \text{ eV} \quad (2)$$

- Independent of intensity of the turbulence, shock speed, etc.; dependence via magnetic field on parameters with the 1/14-power
- Prediction: Lower energy jet-sources: gamma ray bursts, microquasars, jet-supernovae. Gamma ray bursts (GRBs) possibly source of ultra high energy neutrons
- Prediction: Radiogalaxies sources at $> 10^{20}$ eV!

The Poynting flux limit

- The Poynting flux, lower limit to energy flow, can be written as (Lovelace 1976)

$$L_P = \frac{B^2}{4\pi} \pi \theta^2 z^2 c \quad (3)$$

Observer frame; in comoving frame $B_{\text{jet}} \sim 1/\gamma_j$.

- The helical path limit across the jet

$$E_{\text{max}} = eB\theta z \quad (4)$$

$$L_P = \frac{c}{4\pi} \frac{E_{\text{max}}^2}{e} \quad (5)$$

$$L_P = 10^{47} \text{ erg/s} \frac{E_{\text{max}}^2}{10^{21} \text{ eV}} \quad (6)$$

- The radio galaxies M87 and Cen A have at most 10^{45} erg/s, and 10^{43} erg/s (Whysong & Antonucci 2003): Problem
- Way out: In the comoving frame a shock gives an extra factor of γ_s (Gallant & Achterberg 1999), so

$$E_{\max} = eB\theta z\gamma_s \quad (7)$$

- The steady flow has Lorentz factor γ_j , shock faster in observer frame. Transforming the magnetic field and the particle energy to observer frame:

$$L_p = \frac{c}{4\pi} \frac{E_{\max}^2}{e} \frac{1}{\gamma_s^2} \quad (8)$$

- Conclusion: Weak radio galaxies (FR-I) can also accelerate particles to ultra energies. Shock in observer frame $\gamma_\Sigma = 2\gamma_j \times 2\gamma_s$.

The Polarization limit

An argument using the radio polarization data from jets
(Bridle & Perley 1984)

- The radio polarization data show that the magnetic fields are parallel to the jet axis near to the black hole, and perpendicular far from the black hole
- This is fully consistent with the radial magnetic field component running as $1/z^2$, so dropping out in competition with the perpendicular component running as z^{-1} ,
- Such a transition is visible in the standard Solar wind MHD wind theory (Parker 1958)
- At the black hole the magnetic field is limited by equipartition from the accretion flow to about 10^4 Gauß (Shakura & Sunyaev 1973)

- Going with z^{-2} to 5000 gravitational radii only, and then switching cuts down the available magnetic field for confinement by a factor of 5000, so as to limit the maximal particle energy to 10^{16} eV
- Therefore radio galaxies cannot accelerate particles to 10^{21} eV
- Way out: The radio polarization is observed in regions of enhanced emission, so almost certainly shocks: Highly oblique bi-conical shock structures are expected, and they enhance the magnetic field components parallel to the shock surface. In BL Lac there is observational evidence (Marscher et al. 2008) for such shock structures.
- Conclusion: Ultra high energy particles allowed (Becker & Biermann 2008)

The spectrum limit

- We need the energy at 10^{20} eV; and yet, most spectral models suggest a spectrum of $E^{-2.2}$ or so, suggesting a weakening of luminosity by a factor of 160, $10^{0.2 \times 11}$.
- Chemical potential? Photon spectra can be starved. Can cosmic ray spectra be starved?
- Given a number of energetic particles, their spectrum, and their energy content independently, there is a contradiction. In Comptonization solved by starving the low energy tail of the spectrum.
- Suggestion: Starved ultra high energy cosmic ray spectra, therefore a weakened low energy tail, so satisfying energy and number content.

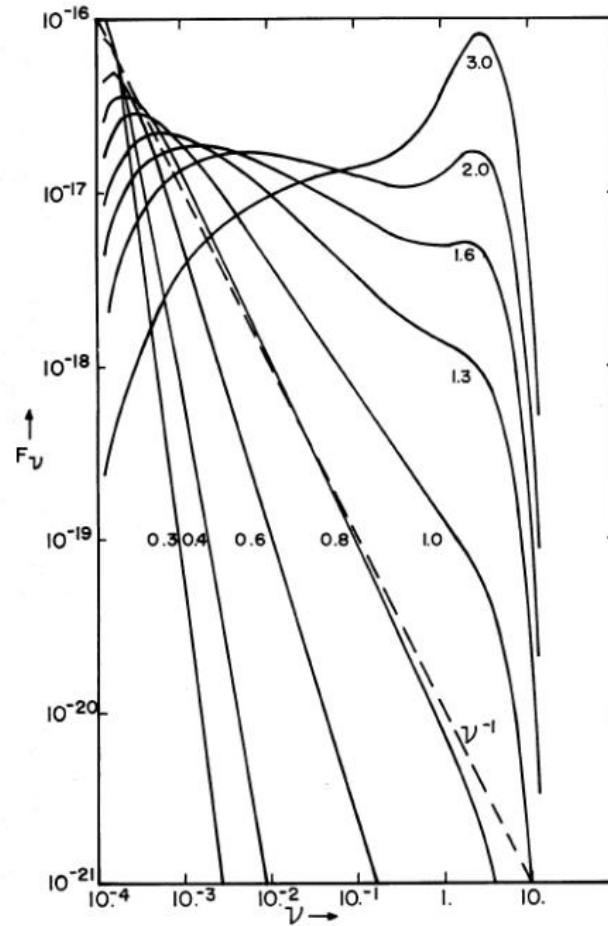
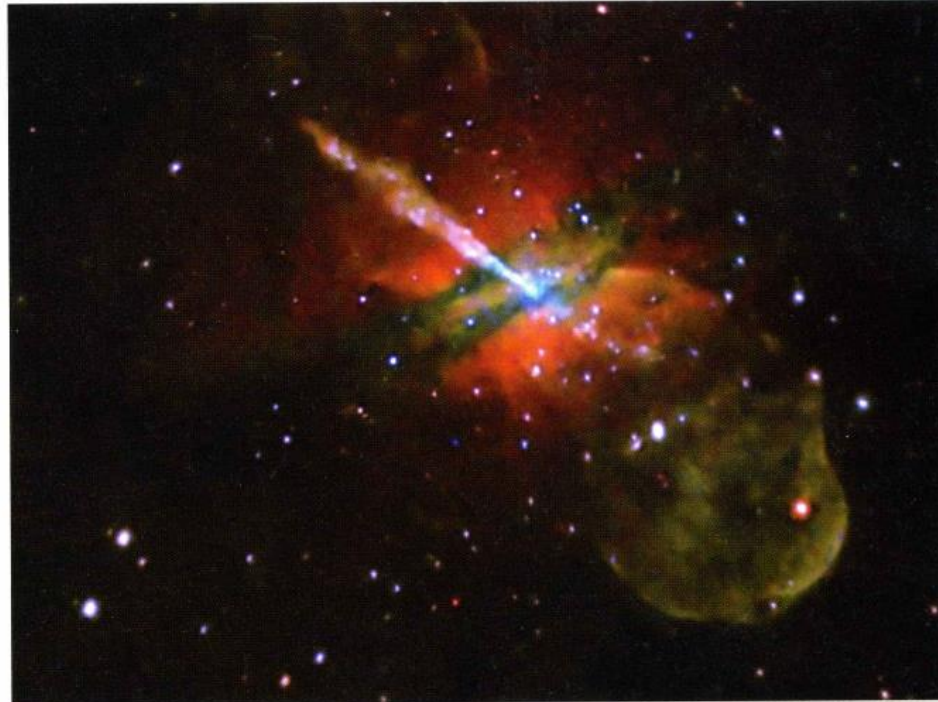


FIG. 2.—Emergent steady-state radiation spectra from a finite sphere with a central soft photon source. Parameters and units are as Fig. 1, except that curves are labeled by sphere radius in units of criticality radius $(\pi/2)(mc^2/3\kappa T)^{1/2}$.

Table 1 Properties of the selection in passband 6cm (5 GHz), redshift $z \leq 0.018$ and $z \leq 0.0125$ flux density brighter than 0.5 Jy, steep spectrum and no starburst, sample of 21 and 14 candidate sources. The FIR/radio ratio can readily distinguish radio galaxies from normal galaxies and starbursts

Name	Morphological type	Redsh.	Dist. Mpc	M_{BH} $10^8 M_{\odot}$	Core flux density mJy	B-V mag	FIR/Radio ratio
NGC 5128	S0 pec Sy2	0.001825	3.4	2	133361	0.88	3.39
NGC 4651	SA(rs)c LINER	0.002685	18.3	0.4	700	0.51	8
MESSIER 084	E1;LERG;LINER Sy2	0.003536	16	10	2094.18	0.94	0.17
MESSIER 087	E+0-1 pec;NLRG Sy	0.00436	16	31	9480.75	0.93	0.01
NGC 1399	cD;E1 pec	0.004753	15.9	3	342	0.95	0.04
NGC 1316	(R')SAB(s)00 LINER	0.005871	22.6	9.2	5651.61		0.06
NGC 2663	E	0.007012	32.5	6.1	628.56		0.08
NGC 4261	E2-3;LINER Sy3	0.007465	16.5	5.2	2662.69	0.97	0.02
NGC 4696	BCG;E+1 pec LINER	0.009867	44.4	3	518.28		0.08
NGC 3801	S0/a	0.011064	50	2.2	300.25	0.9	0.3
IC 5063	SA(s)0+: Sy2	0.011348	44.9	2	321.14	0.93	11.08
NGC 5090	E2	0.011411	50.4	7.4	488.13	..	0.1
NGC 5793	Sb: sp Sy2	0.011645	50.8	1.4	51.5	0.79	12.76
IC 4296	BCG;E;Radio Galaxy	0.012465	54.9	10	442.22	0.95	0.08
NGC 0193	SAB(s)0-:	0.014657	55.5	2	285.93	0.98	0.76
VV 201	Double galaxy	0.015	66.2	1	450.09		0.05
UGC 11294	E0?;HSB	0.016144	63.6	2.9	254.52		0.33
NGC 1167	SA0-;LINER Sy2	0.016495	65.2	4.6	393.09		0.13
CGCG 114-025	SA0-	0.016885	67.4	1.9	443.39		0.01
NGC 0383	BCG;SA0-: LERG	0.017005	65.8	5.5	414.25		0.21
ARP 308	Double galaxy WLRG	0.018	69.7	1	88.54		0.09



X-raying a galactic jet set

Jets of energetic particles shoot out from a supermassive black hole in the deepest X-ray image ever taken of the galaxy Centaurus A, 11 million light-years from Earth. In this 199-hour portrait, recorded with NASA's Chandra X-ray Observatory, red denotes the lowest-energy X rays, blue the highest. The image shows new details within a 13,000 light-year-long jet (pointing to the upper left) and a shorter, oppositely directed counterpart. The X rays come from electrons whipping around strong magnetic fields, but the emissions would fade if the electrons were not continually reenergized. Clumps in the inner parts of the jets may mark places where the jets plow into gas clouds or stars, generating shock waves that reboost the electrons. Many of the pointlike X-ray sources are small, stellar-mass black holes that feed off normal companion stars. Gregory Sivakoff of the Ohio State University in Columbus and his colleagues reported their work in Austin, Texas, at a meeting of the American Astronomical Society. —RON COWEN

Figure 11 The gas jets of Centaurus A galaxy. Clumps in the inner parts of the jets may

- Our active neighbor (3.5 Mpc): Radio galaxy Cen A: the jet bores through molecular clouds

Particle energy and particle flux predictions

Complete samples (Caramete et al., 2008).

Spin-down powered jets (Blandford & Znajek 1977, Duřan et al., 2005, 2008):

$$E_{\max} \sim M_{\text{BH}}^{1/2} \quad (9)$$

$$F_{\text{CR}} \sim S_{\text{rad}}^{6/5} D_{\text{L}}^{2/5} M_{\text{BH}}^{-7/10} \quad (10)$$

25 Accretion powered jets (Falcke et al. 1995, Tařcău, M.Sc. thesis 2003, Tařcău et al., 2008):

$$E_{\max}^{\dagger} \sim S_{\text{rad}}^{1/3} D_{\text{L}}^{2/3} M_{\text{BH}} \quad (11)$$

$$F_{\text{CR}}^{\dagger} \sim S_{\text{rad}}^{2/3} D_{\text{L}}^{-2/3} \quad (12)$$

For distances < 50 Mpc usually NGC5128, possibly NGC1316 and a group around M87 dominate in predicted UHECR flux (Syrovatskii & Ginzburg 1963).

Table 2 Using core flux-density at 5 GHz for the complete sample of 29 steep spectrum sources. Col. 4: (*) Core flux density estimated from the total flux density by using $\log(P_{\text{core}}) = 11.01 + 0.47 \log(P_{\text{tot}})$, cf. Giovannini 1988; Col. 5 & 6: Relative values of the particles maximum energy and UHECR flux by using spin-down (I. Duřan). Col. 7 & 8: (†) Relative values of the particles maximum energy and UHECR flux by using accretion, (O. Taşcău).

Source	D (Mpc)	M_{BH} ($\times 10^9 M_{\odot}$)	$S_{5\text{GHz}}$ (mJy)	$E_{\text{max}}/E_{\text{max}}^{\text{M87}}$	$F_{\text{CR}}/F_{\text{CR}}^{\text{M87}}$	$E_{\text{max}}/E_{\text{max}}^{\text{M87}\dagger}$	$F_{\text{CR}}/F_{\text{CR}}^{\text{M87}\dagger}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ARP 308	69.7	0.1	88.53*	0.18	0.31	0.03	0.04
CGCG 114-025	67.4	0.19	2260	0.25	9.37	0.15	0.33
ESO 137-G006	76.2	0.92	631.32*	0.54	0.71	0.51	0.13
IC 4296	54.9	1	214	0.57	0.16	0.31	0.08
IC 5063	44.9	0.2	321.15*	0.25	0.75	0.06	0.12
NGC 0193	55.5	0.2	285.93*	0.25	0.71	0.07	0.09
NGC 0383	65.8	0.55	414.25*	0.42	0.58	0.24	0.11
NGC 1128	92.2	0.2	280.2*	0.25	0.84	0.1	0.07
NGC 1167	65.2	0.46	393.1*	0.39	0.61	0.2	0.1
NGC 1316	22.6	0.92	26	0.54	0.01	0.08	0.03
NGC 1399	15.9	0.3	10	0.31	0.01	0.01	0.02
NGC 2663	32.5	0.61	160	0.44	0.13	0.12	0.09
NGC 3801	50	0.22	635	0.26	1.66	0.09	0.17
NGC 3862	93.7	0.44	1674	0.38	4.15	0.39	0.21
NGC 4261	16.5	0.52	390	0.41	0.32	0.09	0.26
NGC 4374	16	1	168.7	0.57	0.07	0.13	0.15
NGC 4486	16	3.1	2875.1	1	1	1	1
NGC 4651	18.3	0.04	15	0.12	0.04	0	0.03
NGC 4696	44.4	0.3	55	0.31	0.07	0.05	0.04
NGC 5090	50.4	0.74	268	0.49	0.25	0.23	0.1
NGC 5128	3.4	0.2	6984	0.25	13	0.04	3.63
NGC 5532	104.8	1.08	194.58*	0.59	0.18	0.5	0.05
NGC 5793	50.8	0.14	95.38*	0.21	0.23	0.03	0.05
NGC 7075	72.7	0.25	20	0.28	0.03	0.04	0.01
UGC 01841	84.4	0.1	365.46*	0.18	1.81	0.05	0.08
UGC 02783	82.6	0.42	541	0.37	1.06	0.23	0.11
UGC 11294	63.6	0.29	314	0.31	0.64	0.11	0.09
VV 201	66.2	0.1	450.1*	0.18	2.11	0.04	0.11
WEIN 045	84.6	0.27	321.6*	0.29	0.78	0.13	0.08

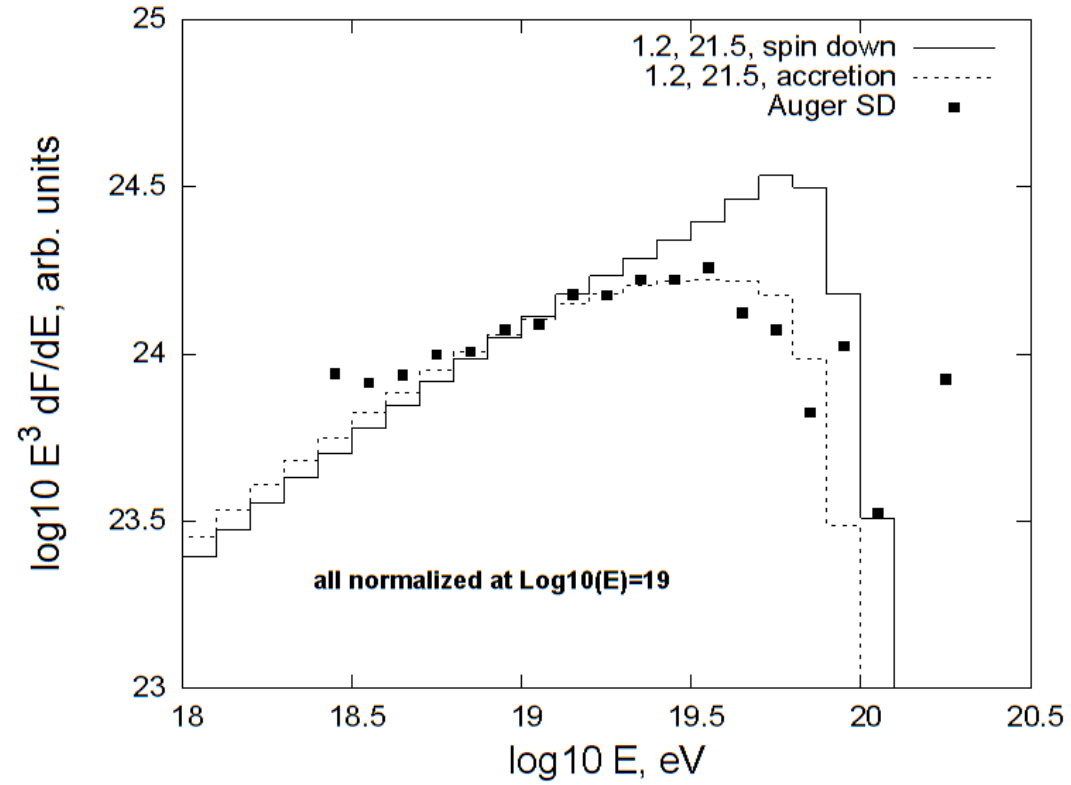


Figure 12 The results after propagation for maximum energy (exponential cutoff) at 10^{21} eV and acceleration spectral index $\gamma=1.2$, $\log_{10}(E_{\max}) = 21.5$, spin down and accretion. No delay times used. Both models normalized to the Auger experimental value at 10^{19} eV. T. Stanev

Discovery and Prediction 3: Cosmic magnetic fields

- Events are not isotropic:
- However, very few radio galaxies are viable
- All black holes in our cosmic neighborhood extremely anisotropic in their distribution: no known and identified sub-class of sources (low power radio galaxies, Seyfert galaxies, Liners, ..) , which would explain the arrival distribution of the events on the sky
- Therefore, bending of orbital path required for consistency, nearby cosmos and galactic magnetic wind
- What is the distribution of bending angles θ (A. Curuțiu 2008, Das et al. 2008)?

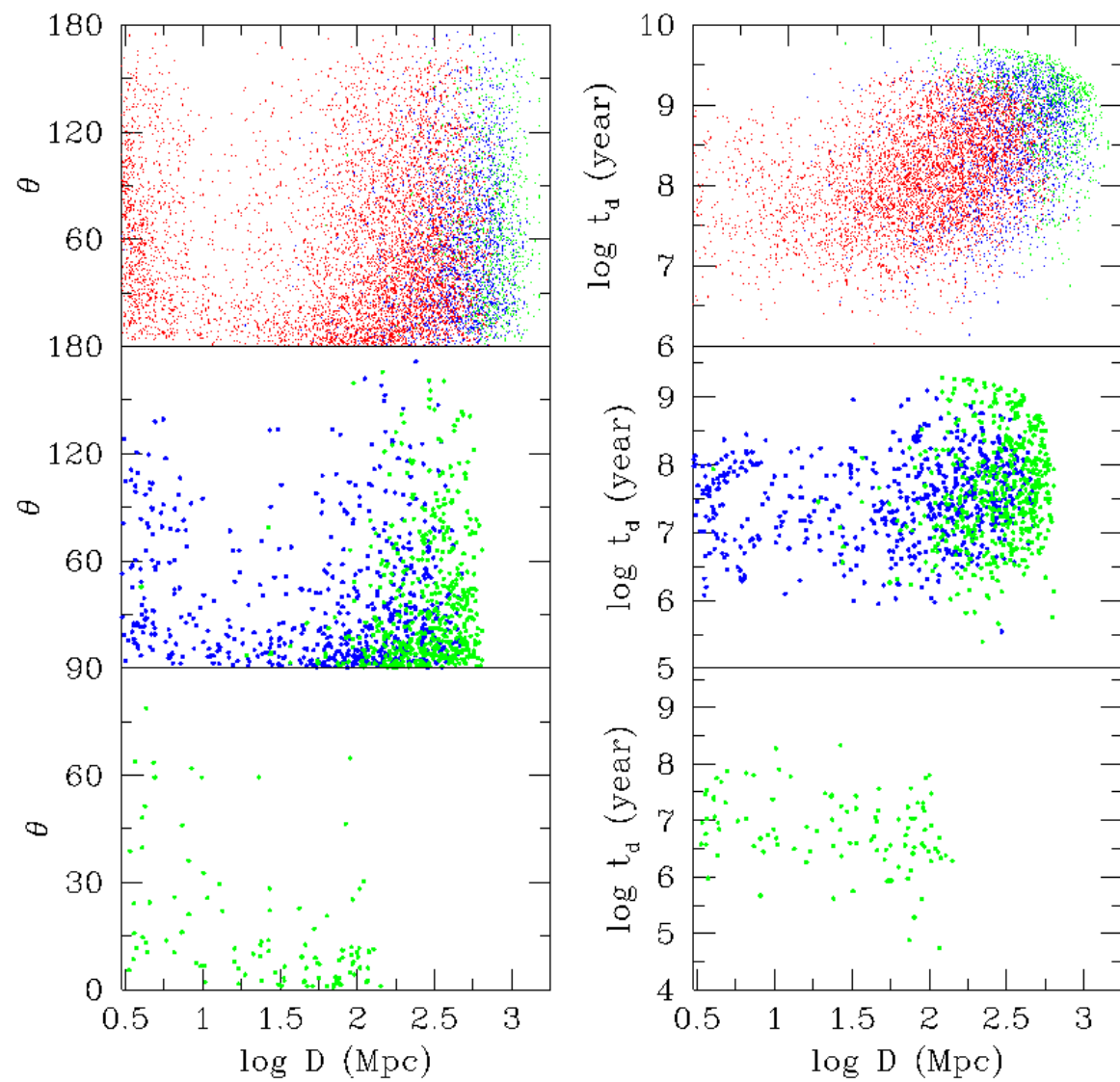


Figure 13 Angle distribution and time distribution: Das et al 2008 Fig. 5: Top panels 10 - 30 EeV, center panels 30 - 60 EeV, and bottom panels > 60 EeV

Simulation of correlations

- Test in Auger paper was to identify with active galactic nuclei from the Véron-Cetty & Véron (VCV) catalogue.
- Using a Monte-Carlo approach we can repeat the exercise with a) a source list (L. Caramete), b) a flux prediction (I. Duțan), and c) a scattering model (A. Curuțiu, Das).
- We can then also differentiate between the Auger sky and the HiRes sky.
- Result favors radio galaxies, selected at 5 GHz and with steep spectrum, using their compact components for estimating the power in ultra high energy cosmic rays, and adopting the point of view, that spin-down (I. Duțan) or accretion mode (O. Tașcău) are key to understanding the powering of the jet, hot spots and cosmic ray acceleration.

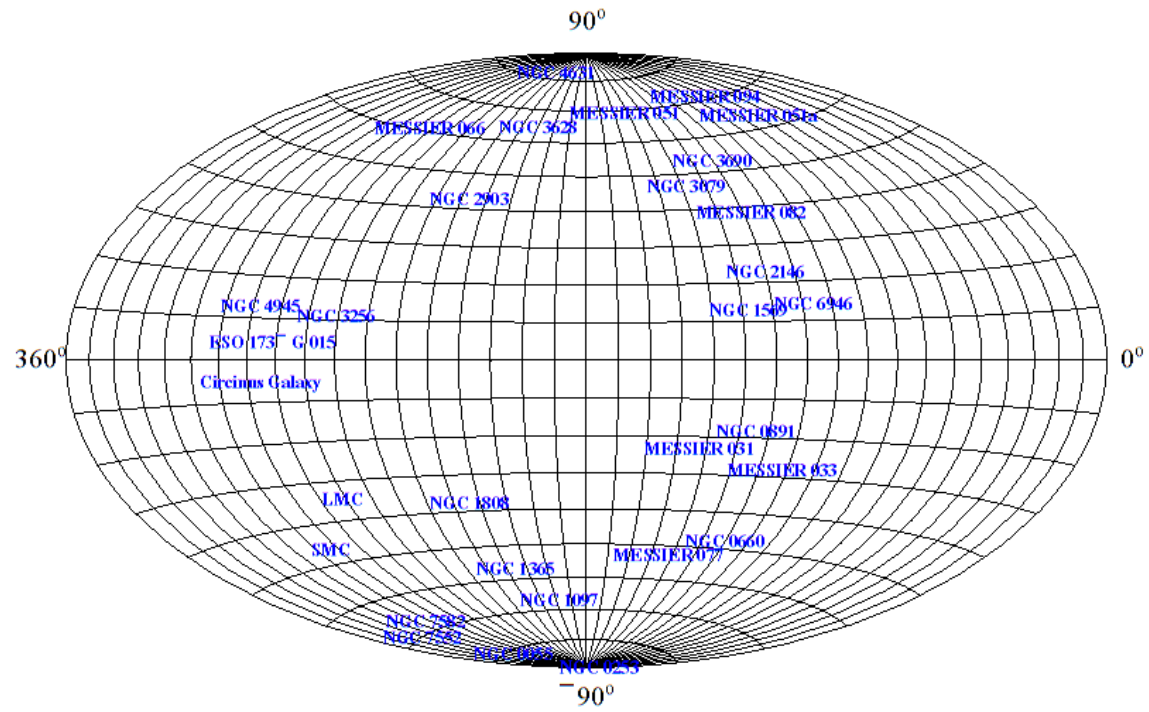


Figure 14 Aitoff projection in galactic coordinates of the selection from NED in $60\mu\text{m}$, redshift $z \leq 0.0125$, flux density brighter than 50 Jy , starburst selected, sample of 32 candidate sources and 100 virtual events from this sources and weighted contribution. Double Monte-Carlo to simulate the intermittent nature of Gamma Ray Bursts

Table 3 The fraction of the 100 virtual events from sources at redshift $z \leq 0.0125$ for Auger and HiRES sky coverage and the correlation with the Véron-Cetty & Véron catalogue (2006). We test radio galaxies, normal and starburst galaxies assuming that Gamma Ray Bursts are the sources, and simple isotropy. Here with $z < 0.0125$

Model for CR contribution	Auger Sky Coverage	Possible HiRES Sky Coverage	Extreme HiRES Sky Coverage
5GHz, steep spectrum weighted contribution from I. Duřan spin-down model	92 with 62 correlation	28 with 15 correlation	41 with 19 correlation
5GHz, steep spectrum weighted contribution from O. Tařcău accretion model	94 with 53 correlation	34 with 20 correlation	58 with 24 correlation
5GHz, steep spectrum uniform contribution	93 with 60 correlation	41 with 20 correlation	56 with 28 correlation
For estimated core flux			
5GHz, steep spectrum weighted contribution from I. Duřan spin-down model	89 with 67 correlation	15 with 8 correlation	28 with 13 correlation
5GHz, steep spectrum weighted contribution from O. Tařcău accretion model	92 with 63 correlation	20 with 9 correlation	38 with 16 correlation
60micron, starburst selected uniform contribution double Monte-Carlo for GRBs	67 with 30 correlation	46 with 30 correlation	67 with 37 correlation
60micron, starburst selected weighted contribution double Monte-Carlo for GRBs	58 with 33 correlation	55 with 32 correlation	70 with 39 correlation
100 random events across the sky	73 with 20 correlation	53 with 19 correlation	76 with 23 correlation

Auger versus HiRes

- Virtual events: 1,000,000; scattering -2 power-law, core 3 degree, cut on 90 degrees.
- I. Duțan: spin-down, Auger / HiRes ratio: 8.71
- O. Tașcău: accretion, Auger / HiRes ratio: 6.03
- Only the GRBs even give a clearly higher flux for HiRes than Auger, but nowhere near such a factor.
- In almost all models the predicted flux and spectrum of UHECRs in the North and South different. So spectra should not match at high energy!
- Energy scale different between Auger and HiRes!
- At lower energy more scattering from magnetic fields, reduced correlations with large scale structure, so also fewer AGN from the VCV catalogue.

Prediction 4: Test on source spectra

- All sky samples of radio sources, active galactic nuclei
- Using jet-disk symbiosis concept (Falcke et al. 1995 +) or spin-down model (Blandford & Znajek 1976 +; Duřan et al. 2005) to predict maximal particle energy, and maximal flux of ultra high energy cosmic rays
- Take each event and rank plausible sources with predicted UHECR-flux divided by angular distance squared, and then take the top as "source" – uses probability
- So check on scattering distribution; allow for extended source, central shift, and temporal variability
- Check on source spectrum vs prediction

Prediction 5: Question on abundances

- Stages of an active galactic nucleus episode:
- Merger of galaxies
- Starburst, lots of high energy cosmic rays, population of Oxygen, Carbon, Iron etc nuclei
- Orbital spin-change, merger of black holes, and spin-flip
- Acceleration to high energy: from sea of galactic cosmic rays? Entrainment?
- With dilution increasing with time fewer nuclei, more Hydrogen nuclei (protons)? Abundances different for M87 and Cen A?

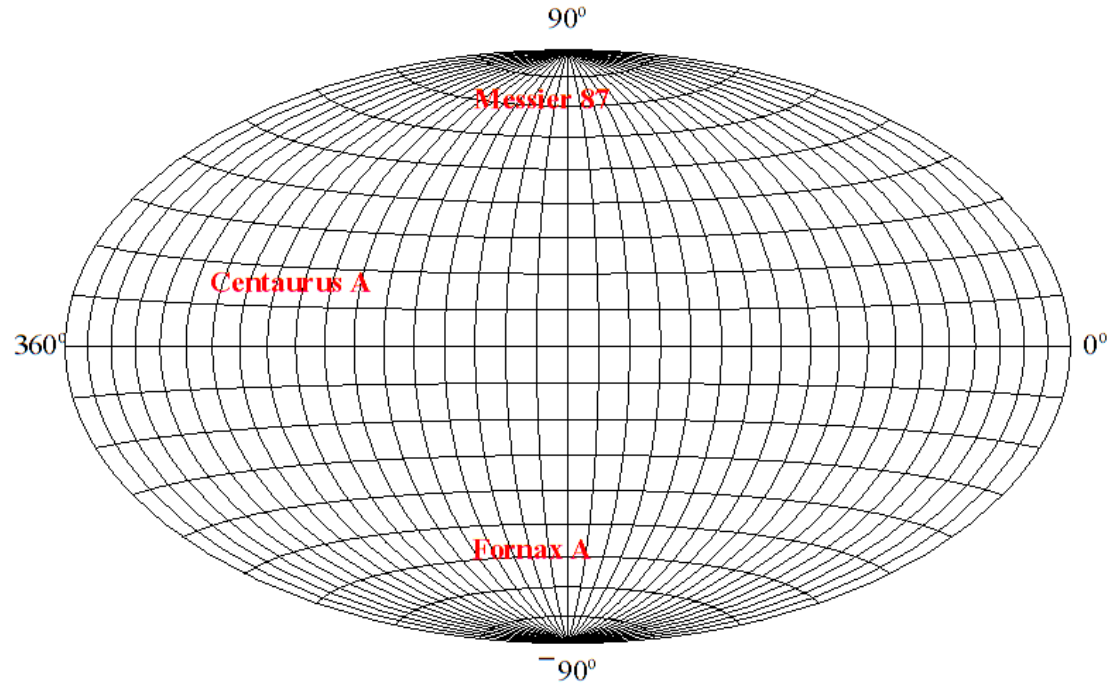


Figure 15 Aitoff projection in galactic coordinates of the three strongest radio sources in the sky and the arrival directions of the 27 cosmic rays with the highest energy $\geq 6 \cdot 10^{19}$ eV detected by the Pierre Auger Observatory

Key Concepts

- Radio galaxies able to produce particles to 10^{21} eV, also low power radio galaxies nearby like Cen A and M87:
- Cosmic magnetic fields: Scattering to large angles!
- Correlation with active galactic nuclei and galaxies
- Neutrino emission beamed from first shock in jet near black hole
- Neutrino emission and energetic particle abundances from recently merged black holes with spin-flip?

Future

The sites of acceleration and interaction

physics laboratory to understand the

**fundamental physics of the structure of
matter (almost all Hydrogen)**

at the highest energies, so at the deepest level

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References

- [1] Beck, R., Brandenburg, A., Moss, D., Shukurov, A., & Sokoloff, D., *Annual Rev. of Astron. & Astrophys.* 34, 155 - 206 (1996).
- [2] Biermann, L., *Z. f. Naturf.* 5a, 65 - 71 (1950)
- [3] Biermann, L., Schlüter, A., *Phys. Rev.* 82, 863 - 868 (1951)
- [4] Biermann, P.L., *Astron. & Astroph.* 271, 649 (1993), astro-ph/9301008
- [5] Biermann, P.L., in *Proc. Erice Meeting Dec. 2000*, Eds. H.J. de Vega et al., *Phase transitions in the early Universe: Theory and Observations*, p. 543 - 557 (2001)

- [6] Birk, G. T., Wiechen, H., Lesch, H. & Kronberg, P. P., 2000, *Astron. & Astroph.* 353, 108 - 116 (2000)
- [7] Blasi, P., Burles, Sc., Olinto, A.V., *Astrophys. J.* 514, 79 (1999), astro-ph/9812487
- [8] Blasi, P., Olinto, A.V., *Phys. Rev. D* 59, ms. 023001 (1999), astro-ph/9806264
- [9] Clarke, T., Kronberg, P.P., Böhringer, H., in *Diffuse thermal and relativistic plasma in galaxy clusters*, Ringberg Conference, Eds. H. Böhringer et al., Max-Planck-Institut für Extraterrestrische Physik, p. 82 (1999)
- [10] Clarke, T., Kronberg, P.P., Böhringer, H., *Astrophys. J. Letters* 547, L111 - L114 (2001), astro-ph/0011281
- [11] Cowling, T.G., *Solar Electrodynamics*, 1953, in *The Sun*, Ed. Kuiper, G.P., Univ. of Chicago Press, Chicago

- [12] Duschl, W.J., Strittmatter, P.A., & Biermann, P.L., *Astron. & Astroph.* 357, 1123 - 1132 (2000), astro-ph/0004076
- [13] Enßlin, T.A., Biermann, P.L., Kronberg, P.P., & Wu, X.-P. , *Astrophys. J.* 477, 560, (1997), astro-ph/9609190
- [14] Galea, C., M.Sc. thesis, University of Bucuresti (2002)
- 41 [15] Ultra-high-energy cosmic ray acceleration by relativistic blast waves, Gallant, Y- A., Achterberg, A., *Month. Not. Roy. Astr. Soc.* 305, L6 - L10 (1999)
- [16] Ginzburg, V. L., Syrovatskii, S. I., *Astron. Zh.* 40, 466 - 476 (1963); transl. in *Sov. Astron. A.J.* 7, 357 - 364 (1963)
- [17] Ginzburg, V.L. & Syrovatskii, S.I., *The origin of cosmic rays*, Pergamon Press, Oxford (1964), Russian edition (1963)

- [18] Han, J.L., Qiao, G.J., *Astron. & Astroph.* 288, 759 (1994)
- [19] Han, J.L., Manchester, R.N., Berkhuijsen, E.M., Beck, R., *Astron. & Astroph.* 322, 98 (1997)
- [20] Han, J.L., Manchester, R.N., Qiao, G.J., *Month. Not. Roy. Astr. Soc.* 306, 371 (1999)
- [21] Kaneda, H., et al. *Astrophys. J.* 491, 638 (1997)
- [22] Khanna, R., & Camenzind, M., *Astrophys. J. Letters* 435, L129 - L132 (1994)
- [23] Kim, K.T., et al., *Nature* 341, 720 - 723 (1989)
- [24] Krause, F., Steenbeck, M., *Z. f. Naturf.* 22a, 671 - 675, (1967), translated in NCAR-TN/IA-60 *The turbulent dynamo*, edited by P.H. Roberts, M. Stix, 1971, p. 81
- [25] Krause, F., *Habilitationsschrift*, Univ. of Jena, 1967, translated in NCAR-TN/IA-60 *The turbulent dy-*

- [26] Krause, F., Monatsb. Dt. Akad. Wiss. 11, 188 - 194, (1969), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 313
- [27] Krause, F. & Beck, R., Astron. & Astroph. 335, 789 (1998)
- [28] Kronberg, P.P., Rep. Prog. Phys., 57, 325 - 382 (1994)
- [29] Kronberg, P.P., Lesch, H., Hopp, U., Astrophys. J. 511, 56 - 64 (1999)
- [30] Kronberg, P.P. in The Origins of Galactic Magnetic Fields, 24th meeting of the IAU, Joint Discussion 14, August 2000, Manchester, England.
- [31] Kronberg, P.P. in High Energy Gamma-Ray Astronomy, International Symposium held 26-30 June, 2000, in Heidelberg, Germany. AIP) Proc., vol. 558, 451 (2001)

- [32] Kulsrud, R.M., Cen, R., Ostriker, J.P., Ryu, D., *Astrophys. J.* 480, 481 (1997)
- [33] Kulsrud, R.M., *Annual Rev. of Astron. & Astrophys.* 37, 37 (1999).
- [34] Lerche, I. & Parker, E. N., *Astrophys. J.* 168, 231 (1971)
- [35] Lerche, I. & Parker, E. N., *Astrophys. J.* 176, 213 (1972)
- ⁴⁴ [36] Krause, F., Radler, K. H. & Rüdiger, G., *The cosmic dynamo: proceedings of the 157th Symposium of the International Astronomical Union held in Potsdam, F.R.G., September 7-11, 1992, publ. 1993*
- [37] Lin, C. C., Yuan, C., & Shu, Frank H., *Astrophys. J.* 155, 721 (1969); Erratum in *Astrophys. J.* 156, 797 (1969)
- [38] Lynden-Bell, D., Pringle, J. E., *Month. Not. Roy.*

- [39] Mestel, L., Roxburgh, I.W., *Astrophys. J.* 136, 615 - 626 (1962)
- [40] Parker, E. N., *Astrophys. J.* 157, 1129 (1969)
- [41] Parker, E. N., *Annual Rev. of Astron. & Astrophys.* 8, 1 (1970)
- [42] Parker, E. N., *Astrophys. J.* 160, 383 (1970)
- [43] Parker, E. N., *Astrophys. J.* 162, 665 (1970)
- [44] Parker, E. N., *Astrophys. J.* 163, 255 (1971)
- [45] Parker, E. N., *Astrophys. J.* 163, 279 (1971)
- [46] Parker, E. N., *Astrophys. J.* 164, 491 (1971)
- [47] Parker, E. N., *Astrophys. J.* 165, 139 (1971)
- [48] Parker, E. N., *Astrophys. J.* 166, 295 (1971)
- [49] Parker, E. N., *Astrophys. J.* 168, 239 (1971)
- [50] Parker, E. N., *Astrophys. Sp. Sc.* 22, 279 (1973)

- [52] Parker, E. N., New York Academy Sciences Annals, 257, 141 - 155, (1975)
- [53] Rädler, K.-H., Z. f. Naturf. 23a, 1841 - 1851 (1968), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 247
- [54] Rädler, K.-H., Z. f. Naturf. 23a, 1851 - 1860 (1968), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 267
- [55] Rädler, K.-H., Monatsb. Dt. Akad. Wiss. 11, 194 - 201, (1969), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 291
- [56] Rädler, K.-H., Monatsb. Dt. Akad. Wiss. 11, 272 - 279, (1969), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 301
- [57] Rädler, K.-H., Monatsb. Dt. Akad. Wiss. 12, 468

turbulent dynamo, edited by P.H. Roberts, M. Stix,
1971, p. 309

[58] Rybicki, G.B., Lightman, A.P., Radiative processes
in astrophysics, Wiley Interscience, New York, 1979

[59] Ryu, D., Kang, H., Biermann, P.L., *Astron. & As-
troph.* 335, 19 - 25 (1998), astro-ph/9803275

[60] Seemann, H. & Biermann, P.L., *Astron. & Astroph.*
327, 273 (1997), astro-ph/9706117

47

[61] Shu, F. H., *Astrophys. J.* 160, 89 (1970)

[62] Shu, F. H., *Astrophys. J.* 160, 99 (1970)

[63] Shu, F. H., et al., *Astrophys. J.* 172, 557 (1972)

[64] Simard-Normandin, M. & Kronberg, P.P., *Astro-
phys. J.* 242, 74 - 94 (1980)

[65] Snowden, S.L., et al., *Astrophys. J.* 485, 125
(1997).

- [66] Spitzer Jr., L. , Physics of fully ionized gases, 1962, 2nd ed., Wiley Interscience, New York.
- [67] Spitzer Jr., L. , Diffuse matter in space, 1968, Wiley Interscience, New York.
- [68] Steenbeck, M., Krause, F., Monatsb. Dt. Akad. Wiss. 7, 335 - 340, (1965), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 21
- [69] Steenbeck, M., Krause, F., Rädler, K.-H., Z. f. Naturf. 21a, 369 - 376, (1966), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 29
- [70] Steenbeck, M., Krause, F., Z. f. Naturf. 21a, 1285 - 1296 (1966), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 49
- [71] Steenbeck, M., et al. Monatsb. Dt. Akad. Wiss. 9,

The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 97

[72] Steenbeck, M., Krause, F., *Astron. Nach.* 291, 49 - 84 (1969), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 147

[73] Steenbeck, M., Krause, F., *Astron. Nach.* 291, 271 - 286 (1969), translated in NCAR-TN/IA-60 The turbulent dynamo, edited by P.H. Roberts, M. Stix, 1971, p. 221

[74] Valinia, A., Marshall, F. E., *Astrophys. J.* 505, 134 - 147 (1998).

[75] Vallée, J.P., *Astron. J.* 99, 459 (1990).

[76] Völk, H.J. & Atoyan, A.M., *Astrophys. J.* 541, 88 - 94 (2000).

- [77] “Superluminal non-ballistic jet swing in the quasar NRAO150 revealed by mm-VLBI”, Agudo, I., et al., *Astron. & Astroph. Letters* 476, L17 (2007)
- [78] “Correlation of the highest energy cosmic rays with nearby extragalactic objects”, AUGER-collaboration, *Science* 318, 939 - 943 (9 November 2007); arXiv:0711.2256
- [79] “Correlation of the highest-energy cosmic rays with the positions of nearby active galactic nuclei”, AUGER-collaboration, *Astropart. Phys.* 29, 188 - 204 (2008); arXiv:0712.2834
- [80] “Neutrinos from active black holes, sources of ultra high energy cosmic rays”, Becker, J.K., & Biermann, P.L., submitted to *Astropart. Phys.* (2008); arXiv:0805.1498
- [81] “The active jet in NGC4258 and its associated shocks”, Cecil, G., et al., *Astrophys. J.* 536, 675

- [82] “The smallest AGN host galaxies”, Greene, J.E., Barth, A.J., & Ho, L.C., *New Astron. Rev.* 50, 739 - 742 (2006); astro-ph/0511810
- [83] “VLBA continuum observations of NGC4258: Constraints on an advection-dominated accretion flow”, Herrnstein, J.R. et al., *Astrophys. J. Letters* 497, L69 (1998)
- [84] “The inner jet of an active galactic nucleus as revealed by a radio-to- γ -ray outburst”, Marscher, A.P. et al., *Nature* 452, 966 - 969 (2008)
- [85] “The black hole accretion disk in NGC4258: One of Nature’s most beautiful dynamical systems”, Moran, J., *AIP Conf.* in press (2008); arXiv: 0804.1063
- [86] “Fast Growth of supermassive black holes in Galaxies”, Munyaneza, F., & Biermann, P.L., *Astron. & Astroph.* 436, 805 - 815 (2005); astro-ph/0403511
- [87] “Degenerate sterile neutrino dark matters in the

Astron. & Astroph. Letters 458, L9 - L12 (2006);
astro-ph/0609388

[88] “A search for CO in Markarian and Seyfert galaxies”,
Wilson, T. L.; Biermann, P.; Fricke, K. J., Astron.
& Astroph. 79, 245 - 246 (1979)

[89] “Superluminal non-ballistic jet swing in the quasar
NRAO150 revealed by mm-VLBI”, Agudo, I., et al.,
Astron. & Astroph. Letters 476, L17 (2007)

52 [90] “Correlation of the highest energy cosmic rays
with nearby extragalactic objects”, AUGER-
collaboration, Science 318, 939 - 943 (9 November
2007); arXiv:0711.2256

[91] “Correlation of the highest-energy cosmic rays with
the positions of nearby active galactic nuclei”,
AUGER-collaboration, Astropart. Phys. 29, 188 -
204 (2008); arXiv:0712.2834

[92] “Neutrinos from active black holes, sources of ul-

mann, P.L., submitted to *Astropart. Phys.* (2008);
arXiv:0805.1498

[93] “The active jet in NGC4258 and its associated shocks”, Cecil, G., et al., *Astrophys. J.* 536, 675 (2000)

[94] “The smallest AGN host galaxies”, Greene, J.E., Barth, A.J., & Ho, L.C., *New Astron. Rev.* 50, 739 - 742 (2006); astro-ph/0511810

53

[95] “VLBA continuum observations of NGC4258: Constraints on an advection-dominated accretion flow”, Herrnstein, J.R. et al., *Astrophys. J. Letters* 497, L69 (1998)

[96] “The inner jet of an active galactic nucleus as revealed by a radio-to- γ -ray outburst”, Marscher, A.P. et al., *Nature* 452, 966 - 969 (2008)

[97] “The black hole accretion disk in NGC4258: One of Nature’s most beautiful dynamical systems”, Moran,

- [98] “Fast Growth of supermassive black holes in Galaxies”, Munyaneza, F., & Biermann, P.L., *Astron. & Astroph.* 436, 805 - 815 (2005); astro-ph/0403511
- [99] “Degenerate sterile neutrino dark matters in the cores of galaxies”, Munyaneza, F., & Biermann, P.L., *Astron. & Astroph. Letters* 458, L9 - L12 (2006); astro-ph/0609388
- [100] “A search for CO in Markarian and Seyfert galaxies”, Wilson, T. L.; Biermann, P.; Fricke, K. J., *Astron. & Astroph.* 79, 245 - 246 (1979)