ULTRA HIGH ENERGY PARTICLES AND COSMIC RAY ELECTRONS/POSITRONS: FROM MASSIVE STAR EXPLOSIONS

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Cosmic ray electrons and positrons: new data

- Pamela: 0810.4995: positron fraction increasing with energy

- ATIC: Nature **456**, 362 (2008): “flat” feature in cosmic ray electrons

- H.E.S.S.: 0811.3894: “steep” feature in cosmic ray electrons

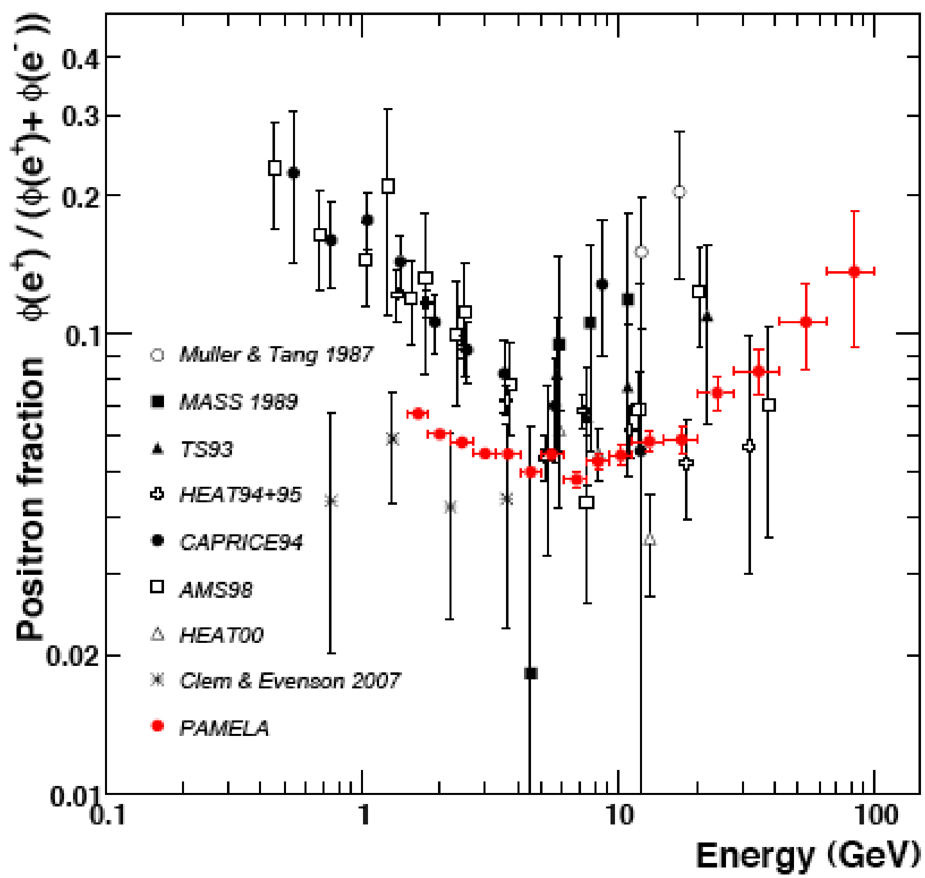

FIG. 3: **PAMELA positron fraction with other experimental data.** The positron fraction measured by the PAMELA experiment compared with other recent experimental data[24, 29, 30, 31, 32, 33, 34, 35]. One standard deviation error bars are shown. If not visible, they lie inside the data points.

Figure 1 Pamela data on positron fraction, 2008

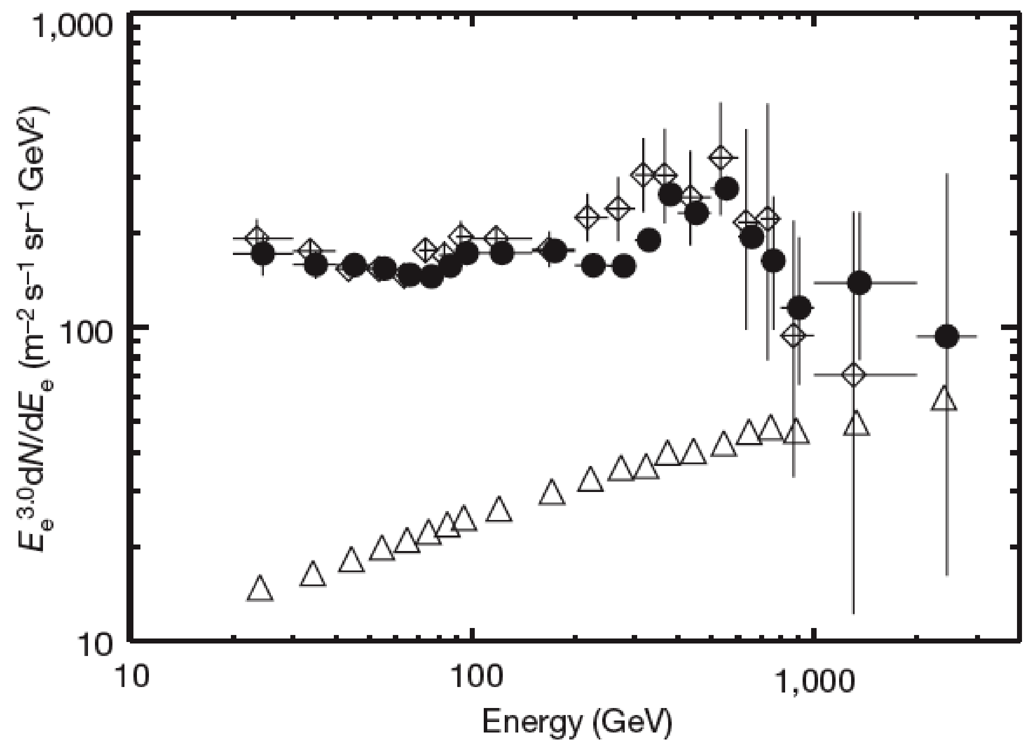

Figure 2 | ATIC-1 and ATIC-2 spectra at balloon altitude, showing good agreement with each other. The measured primary electron flux (scaled by E^3) at flight altitude is shown for ATIC-1 (open squares) and ATIC-2 (filled circles). The errors are one standard deviation. Both balloon flights were from McMurdo, Antarctica, and circumnavigated that continent. ATIC-1 was a test flight in 2000–01 and the usable data correspond to an exposure of 0.61 m^2 sr days. ATIC-2 was a science flight in 2002–03 with an exposure of 2.47 m^2 sr days. To eliminate edge effects, we restrict the incident zenith angle to be less than $\sim 37^\circ$ ($\cos\theta \geq 0.8$), use only the central 80% of the SiM

Figure 2 ATIC data on cosmic ray electrons, 2008; open triangles background

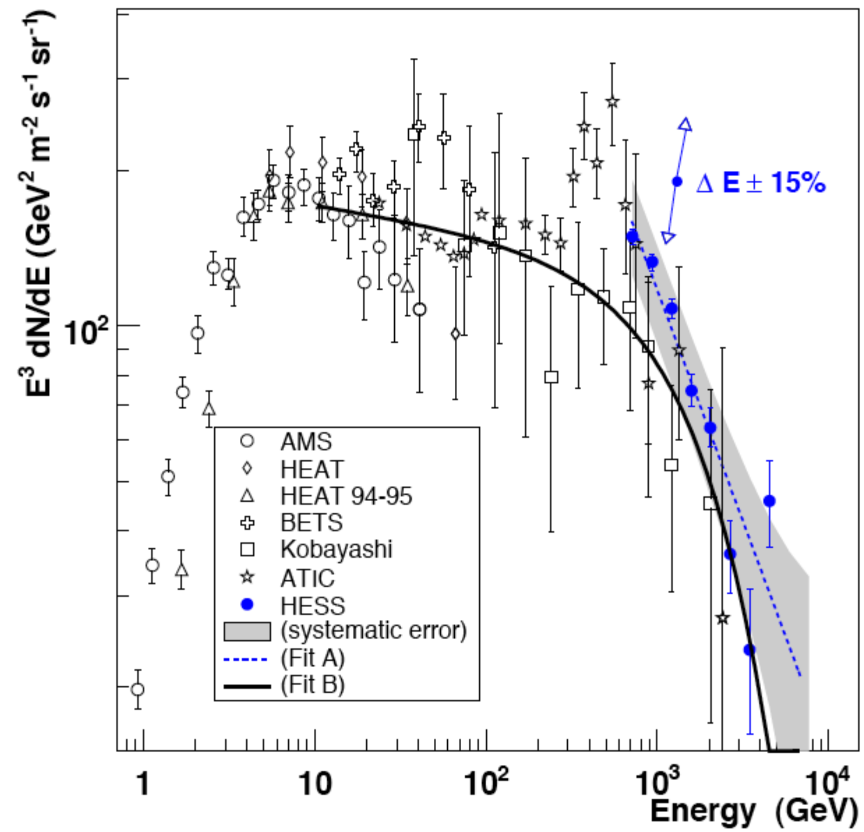

FIG. 3: The energy spectrum E^3 dN/dE of CR electrons as measured by H.E.S.S. in comparison with previous measurements. The H.E.S.S. data are shown as solid points. The two fit functions (A and B) are described in the main text. Upper limits are given for a confidence level of 95%. The shaded band indicates the approximate systematic error arising from uncertainties in the modeling of hadronic interactions and in the atmospheric model. The double arrow indicates the ef-

Figure 3 H.E.S.S. data on cosmic ray electrons, 2008

Some suggestions

- L. Bergström et al., 0808.3725: Positrons from SUSY dark matter
- V. Barger et al., 0809.0162: Dark matter lighter than the top quark
- J.H. Huh et al, 0809.2601, 2008: Two DM components and MSSM
- Yüksel et al., 0810.2784: TeV gamma rays from Geminga...

Massive stars

- Stars between 8 and 15 $M_{\odot}$ Zero Age Main Sequence mass(ZAMS) explode into the ISM
- Stars above 15 $M_{\odot}$ explode into their own stellar wind
- Both, the ISM and stellar winds, are magnetized
- Explosions into the ISM give $E^{-2.42}$, the predicted injection limit
- Diffusive losses add factor $E^{-1/3}$, so a spectrum of $E^{-2.75}$, the diffusion limit
- Excellent fit to data in other galaxies, and all across disk galaxies
- Theory error bars typically ± 0.04 in the spectrum

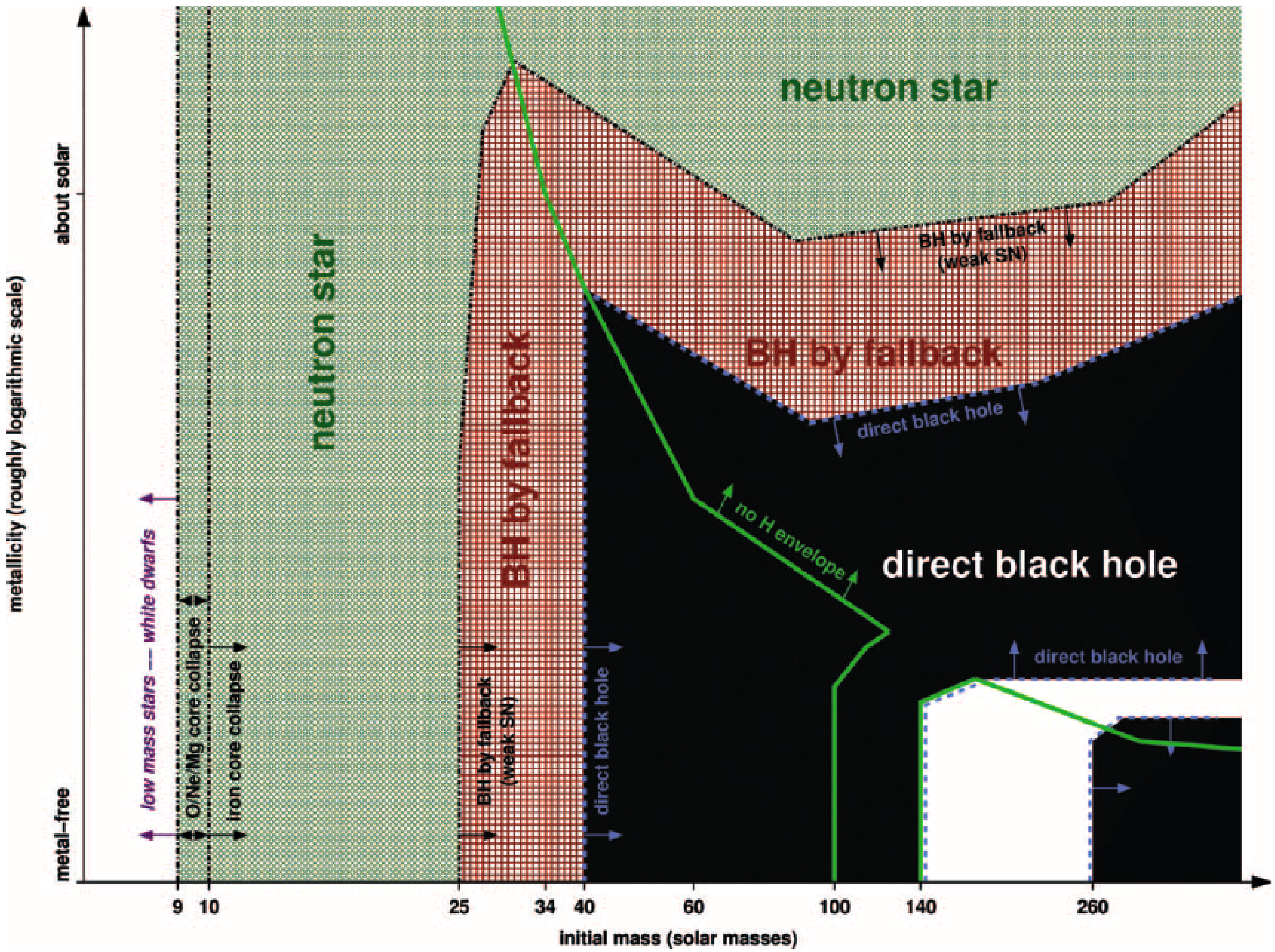

FIG. 1.—Remnants of massive single stars as a function of initial metallicity (*y-axis*; qualitatively) and initial mass (*x-axis*). The thick green line separates the regimes where the stars keep their hydrogen envelope (left and lower right) from those where the hydrogen envelope is lost (upper right and small strip at the bottom between 100 and 140 $M_{\odot}$). The dashed blue line indicates the border of the regime of direct black hole formation (*black*). This domain is interrupted by a strip of pair-instability supernovae that leave no remnant (*white*). Outside the direct black hole regime, at lower mass and higher metallicity, follows the regime of BH formation by fallback (*red cross-hatching and bordered by a black dot-dashed line*). Outside of this, green cross-hatching indicates the formation of neutron stars. The lowest mass neutron stars may be made by O/Ne/Mg core collapse instead of iron core collapse (*vertical dot-dashed lines at the left*). At even lower mass, the cores do not collapse and only white dwarfs are made (*white strip at the very left*).

Figure 4 Heger et al. ApJ 591, 288 (2003), Fig. 1: Massive stars' fate as function of metallicity and ZAMS mass

Red Supergiant and Wolf Rayet star environments

- Stars $\gtrsim 15\, M_\odot$ ZAMS explode as red super-giant stars, short RSG stars, with magnetic winds
- Stars $\gtrsim 25\, M_\odot$ ZAMS explode as blue super-giant stars, Wolf Rayet (WR) stars, massive magnetic winds
- The first stellar wind was discovered 1950. The magnetic field structure was described 1958:
- $B_\phi \sim \{\sin\theta\}/r$, and $B_r \sim 1/r^2$, so polar cap radial field dominates, most of 4π tangential field dominates
- Explosions into the wind give predicted $E^{-7/3}$, with diffusion limit $E^{-8/3}$; up to knee, then steeper beyond
- Theory error bars typically -0.02 ± 0.02 in the spectrum, asymmetric error distribution

A massive star and its magnetic field

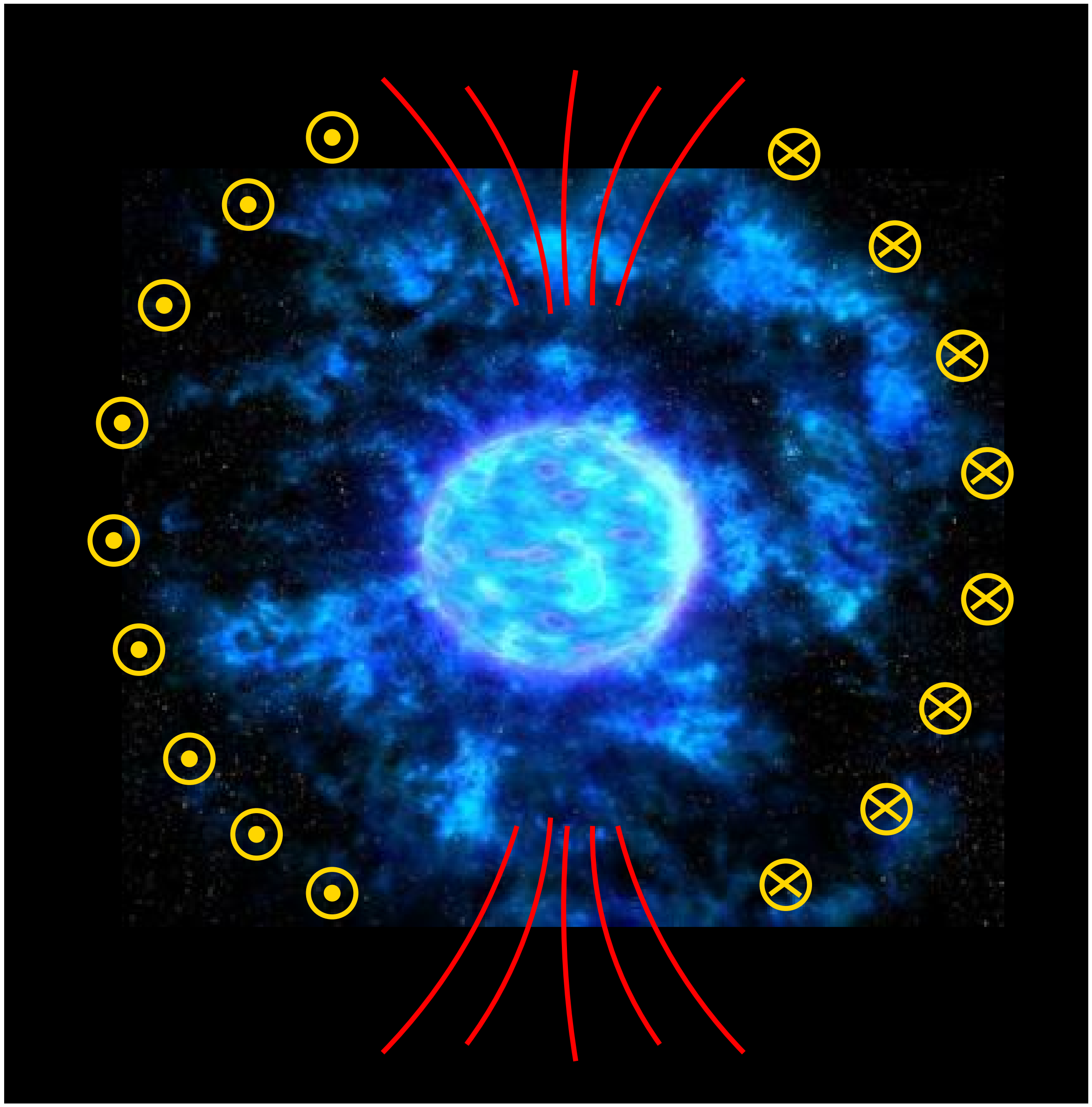

Figure 5 Magnetic field topology around a massive star in its wind: Graph following Parker 1958; central graph NASA, Wolf Rayet star WR124

The polar cap component

- Polar cap magnetic field parallel to shock normal, standard shock acceleration
- So polar cap cosmic ray component $E^{-2.00}$, right up to knee (about $Z\,10^{15}$ eV)
- at injection energies some percent of total CR power
- Electrons beyond about 20 GeV in loss limit (Kardashev 1962): so spectrum $E^{-3.00}$
- Electrons injected from about 30 MeV (Protheroe & Biermann 1996)
- Therefore cosmic ray electron polar cap component appears earlier in particle energy by the ratio of the mass, say, of Fe, and the 30 MeV, so about a factor of 4000 lower in energy, in the hundreds of GeV

Cosmic ray knee: paper CR-IV, 1993

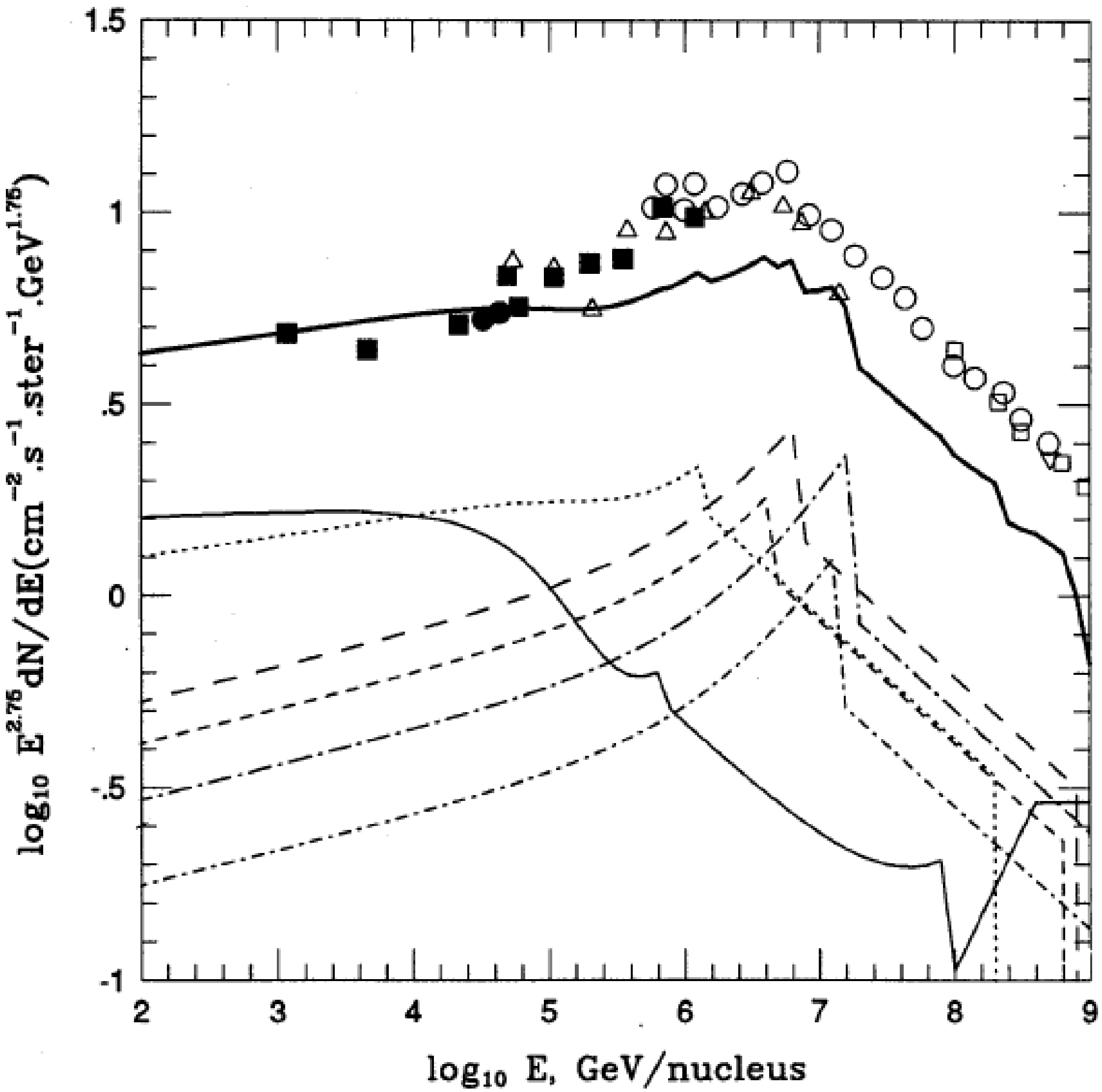

Figure 6 Spectral and chemical structure at the knee, to be repeated at high energy? Element groups are H, He, CNO, Ne-S, Cl-Mn, and Fe. Here the spectra are in the diffusion limit, and we may need the injection limit; this implies multiplying all curves by $(A/Z)^{1/3} \simeq 10^{0.1}$. Source: Stanev et al., paper CR-IV 1993

Cosmic ray electrons and positrons: some of our contributions

- Biermann, P.L., *Astron. & Astroph.* **271**, 649 (1993); paper CR-I
- Stanev, T., Biermann, P.L., & Gaisser, T.K., *Astron. & Astroph.* **274**, 902 (1993); CR-IV
- Biermann, P.L., review lecture at the Nuclear Astrophysics meeting at Hirschegg, in Proc., GSI, Darmstadt, p. 211 - 222 (1998)
- Biermann, P.L., Langer, N., Seo, E.-S., & Stanev, T., *Astron. & Astroph.* **369**, 269 - 277 (2001); CR-IX
- Biermann, P. L., Becker, J. K., Meli, A., Rhode, W., Seo, E.- S., Stanev, T., in press *Phys. Rev. Letters* (2009); arXiv:0903.4048

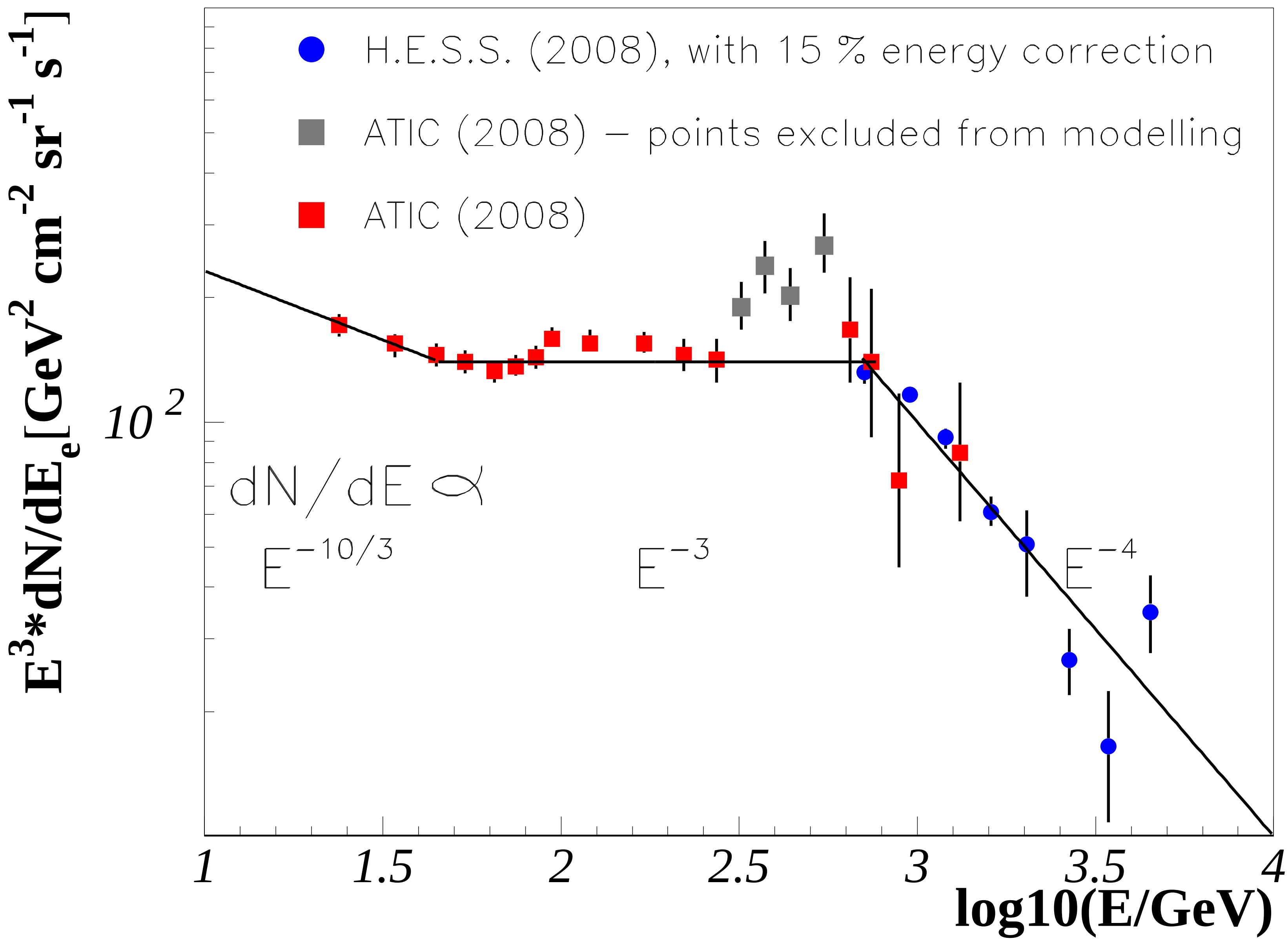

Figure 7 Model prediction with ATIC and H.E.S.S data for cosmic ray electrons: $E^{-10/3}$, E^{-3}, and E^{-4}

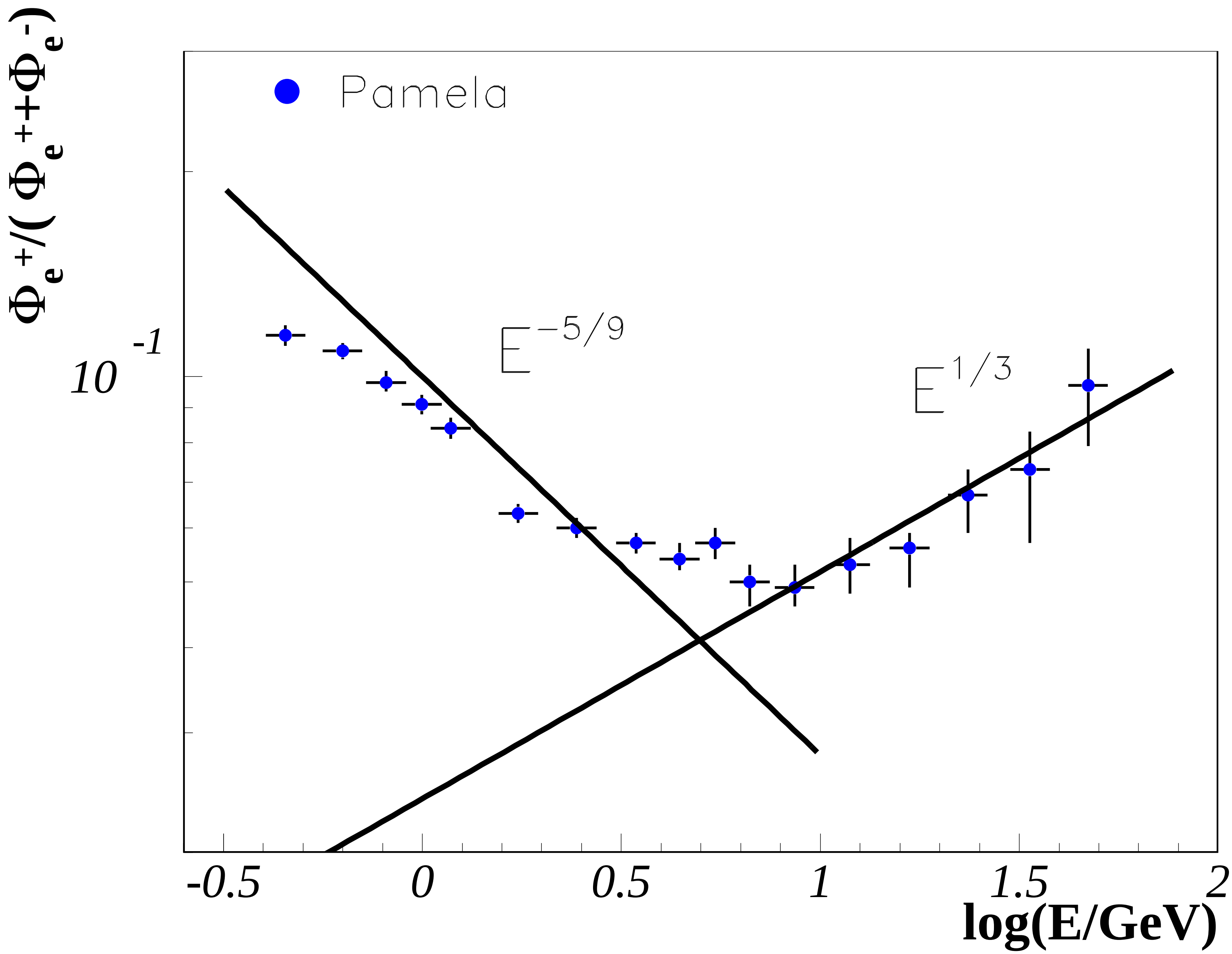

Figure 8 Model prediction with Pamela data for cosmic ray positrons, matching $E^{-5/9}$ at lower energy, and $E^{+1/3}$ at higher energy.

Confirmation?

Our paper submitted as arXiv:0903.4048, on March 24, 2009; now in press in *Phys. Rev. Letters*

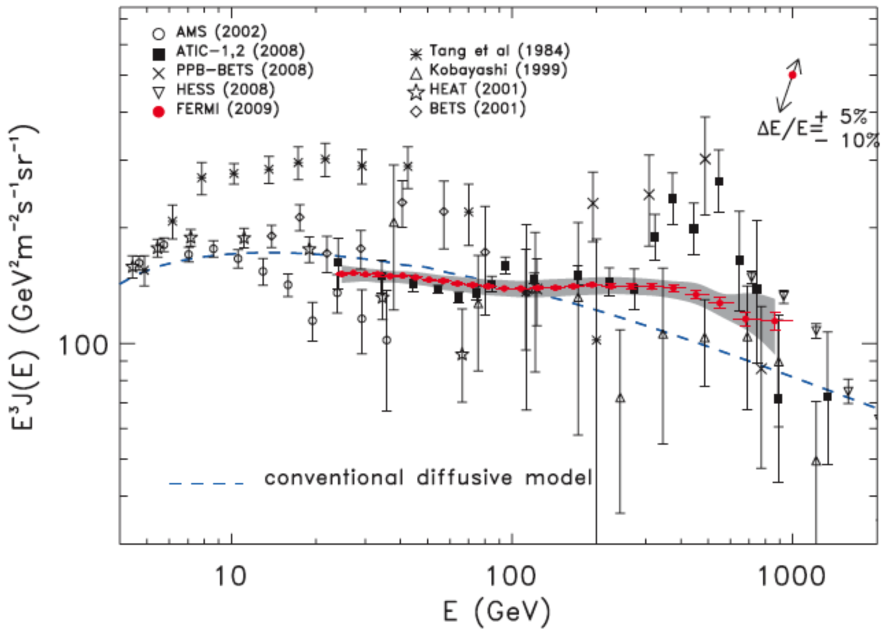

FIG. 3 (color). The Fermi LAT CR electron spectrum (red filled circles). Systematic errors are shown by the gray band. The two-headed arrow in the top-right corner of the figure gives size and direction of the rigid shift of the spectrum implied by a shift of $^{+5\%}_{-10\%}$ of the absolute energy, corresponding to the present estimate of the uncertainty of the LAT energy scale. Other high-energy measurements and a conventional diffusive model [1] are shown.

Figure 9 Latest Fermi data confirming the spectrum proposed (09050025, April 30, 2009).

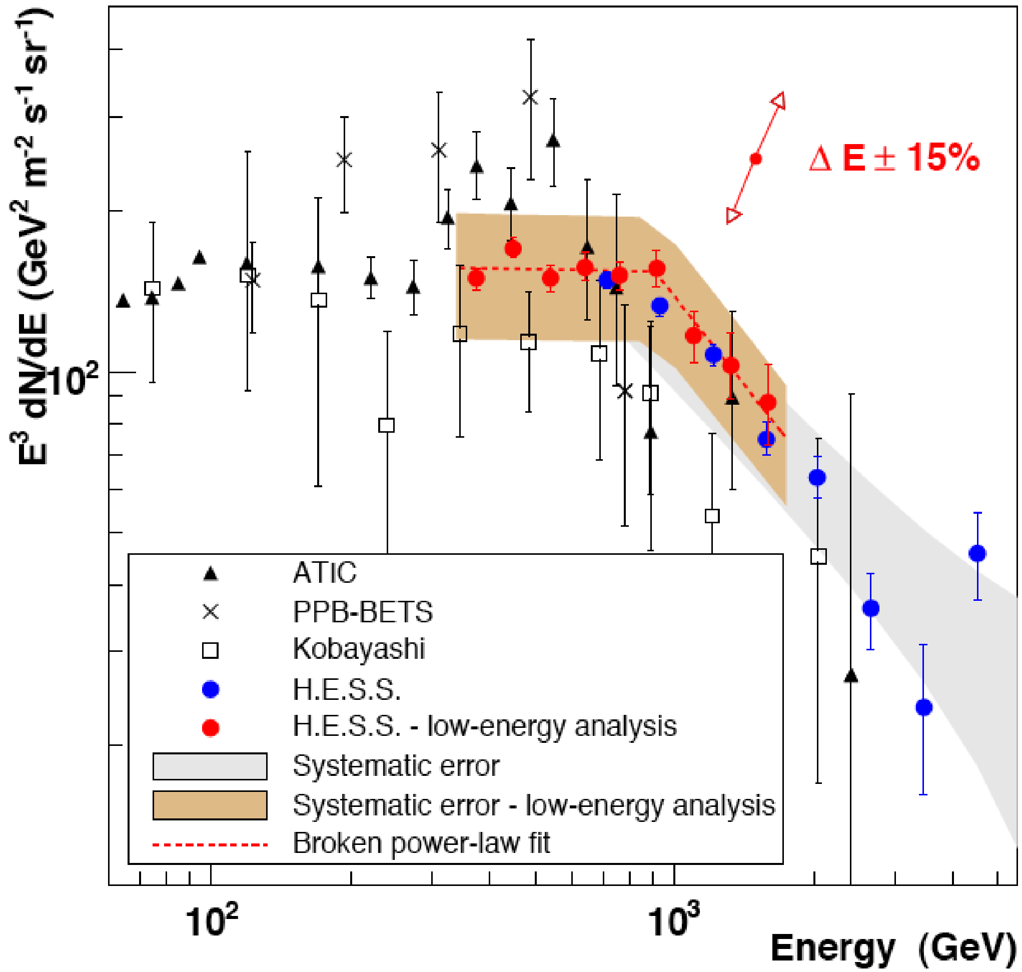

FIG. 2: The energy spectrum E^3 dN/dE of cosmic-ray electrons as measured by ATIC [4], PPB-BETS [12], emulsion chamber experiments [3] and H.E.S.S. Previous H.E.S.S. data [8] are shown as blue points, the result of the low-energy analysis presented here as red points. The shaded bands in-

Figure 10 Latest H.E.S.S. data confirming the spectrum proposed (09050105, May 1, 2009).

Summary of massive star physics: cosmic ray electrons and positrons

- Cosmic ray electrons at low energies sum of $E^{-2.75}$ and $E^{-8/3}$
- The cosmic ray electron spectrum $E^{-10/3}$ at moderate energies, E^{-3} at higher energy,
- and at the highest energies E^{-4}
- The cosmic ray positron/electron ratio will approach a $E^{-5/9}$ at lower relativistic energy for the wind component; mixing with CR-e from ISM-SNe will give $E^{-0.47}$,
- and $E^{+1/3}$ at higher energy

Ultrahigh energy particles

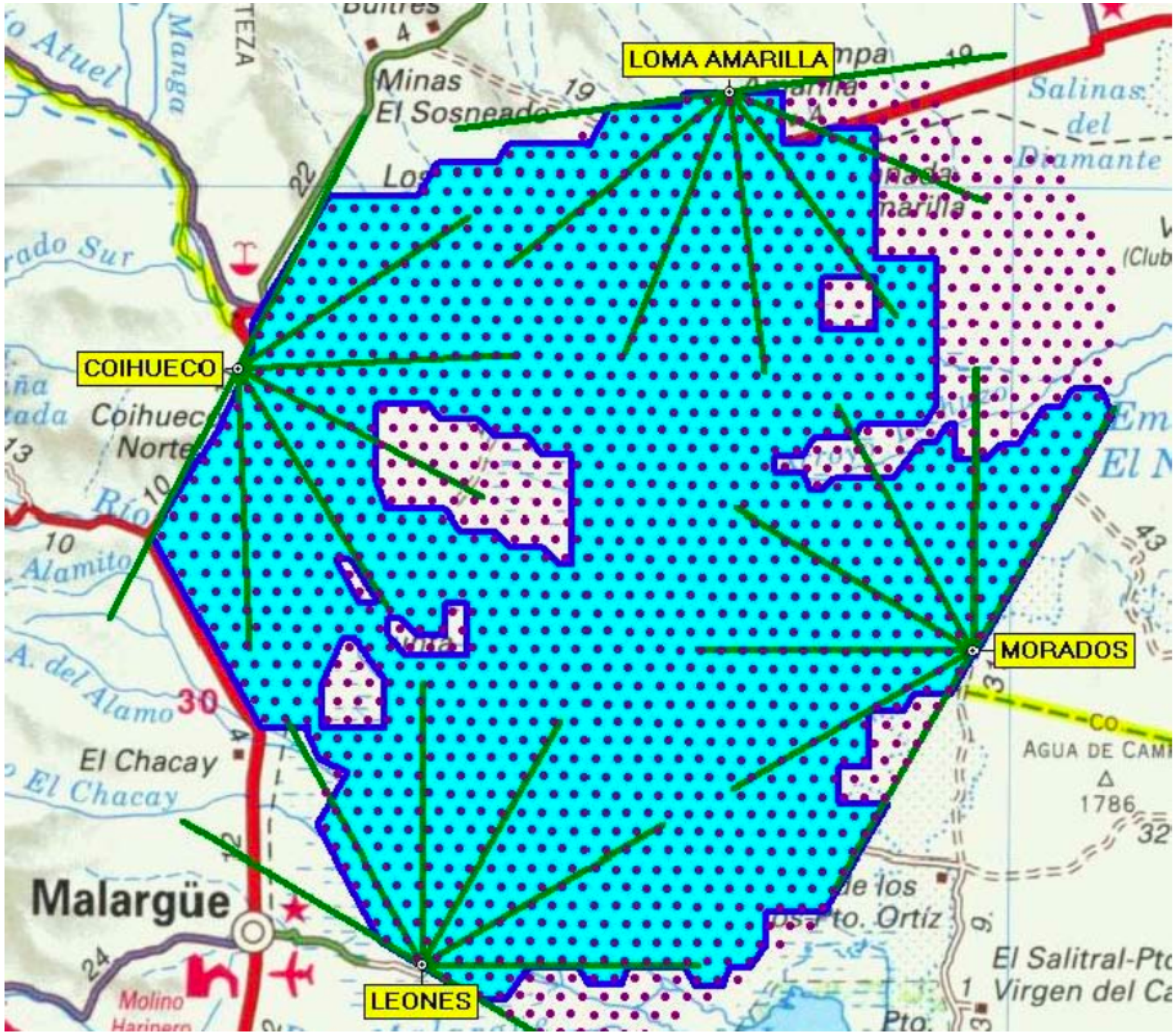

Figure 11 **Auger** array in Malargue, Argentina

Discovery and Prediction: The GZK-turn-off

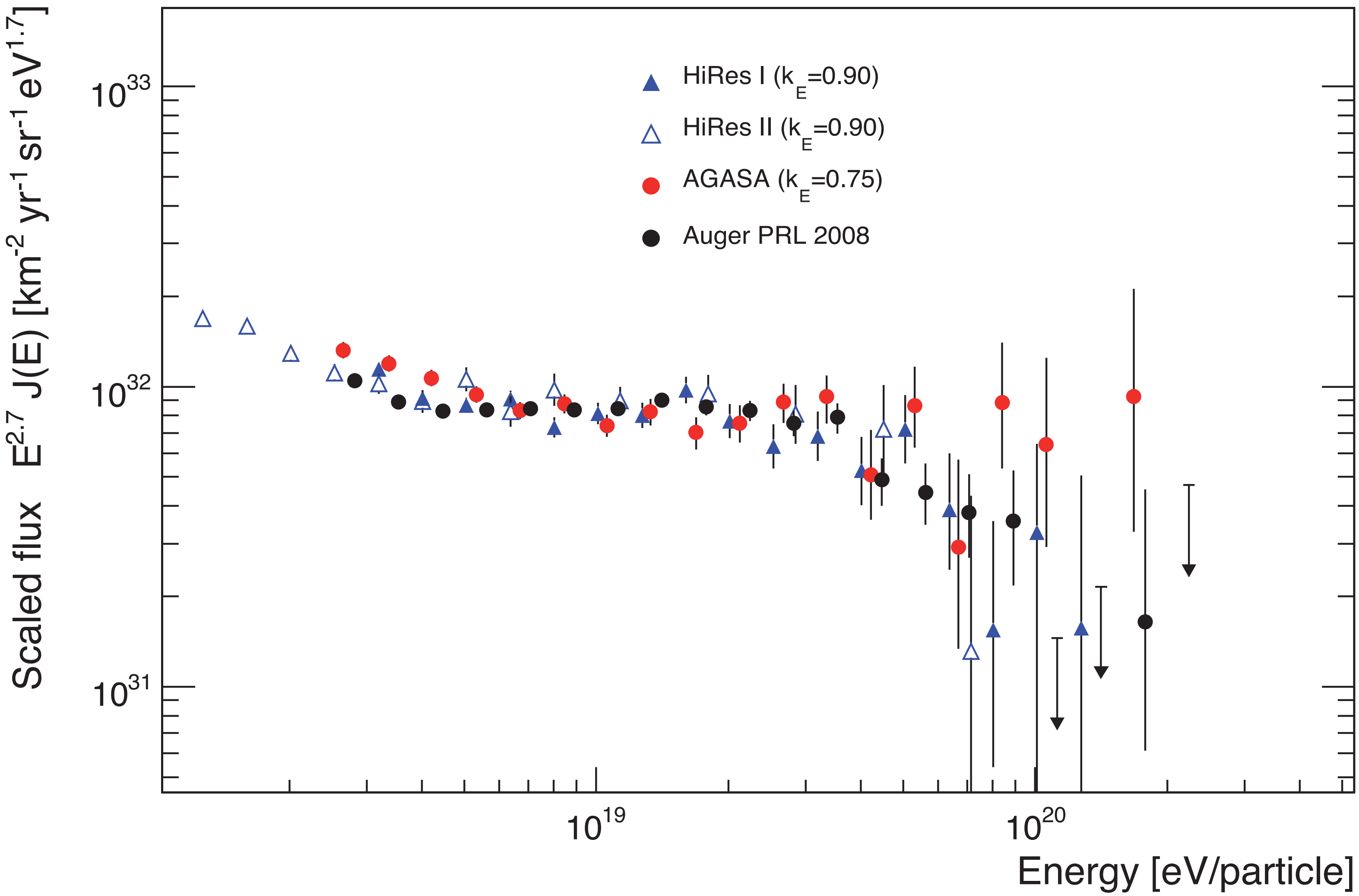

Figure 12 All-particle cosmic ray spectrum from many earlier experiments. Filled circles at the highest energies are recent results from Auger (PRL 2008), clearly showing a cutoff, which may be the Greisen-Zatsepin-Kuzmin cutoff due to the interaction with the cosmic microwave background. This is the spectrum to explain, and the strongest radio galaxies can provide an explanation. Sources HiRes and Auger Coll. and papers

Particle physics to 10^{21} eV

Observe particles at these energies directly! At 10^{12} GeV, >> LHC at CERN, even in center of mass frame.

- Linsley (1963): **Detection of first event** $\gtrsim 10^{20}$ eV = 100 EeV - 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 50 EeV due to interaction with the cosmic microwave background (Greisen; Zatsepin & Kuzmin; a.k.a. GZK-cutoff): turn-off established, but physical reason?
- Now many events near and beyond 50 EeV – **anisotropy subtle** (Stanev et al. *Phys. Rev. Letters* 1995)

Basic physics of active galactic nuclei

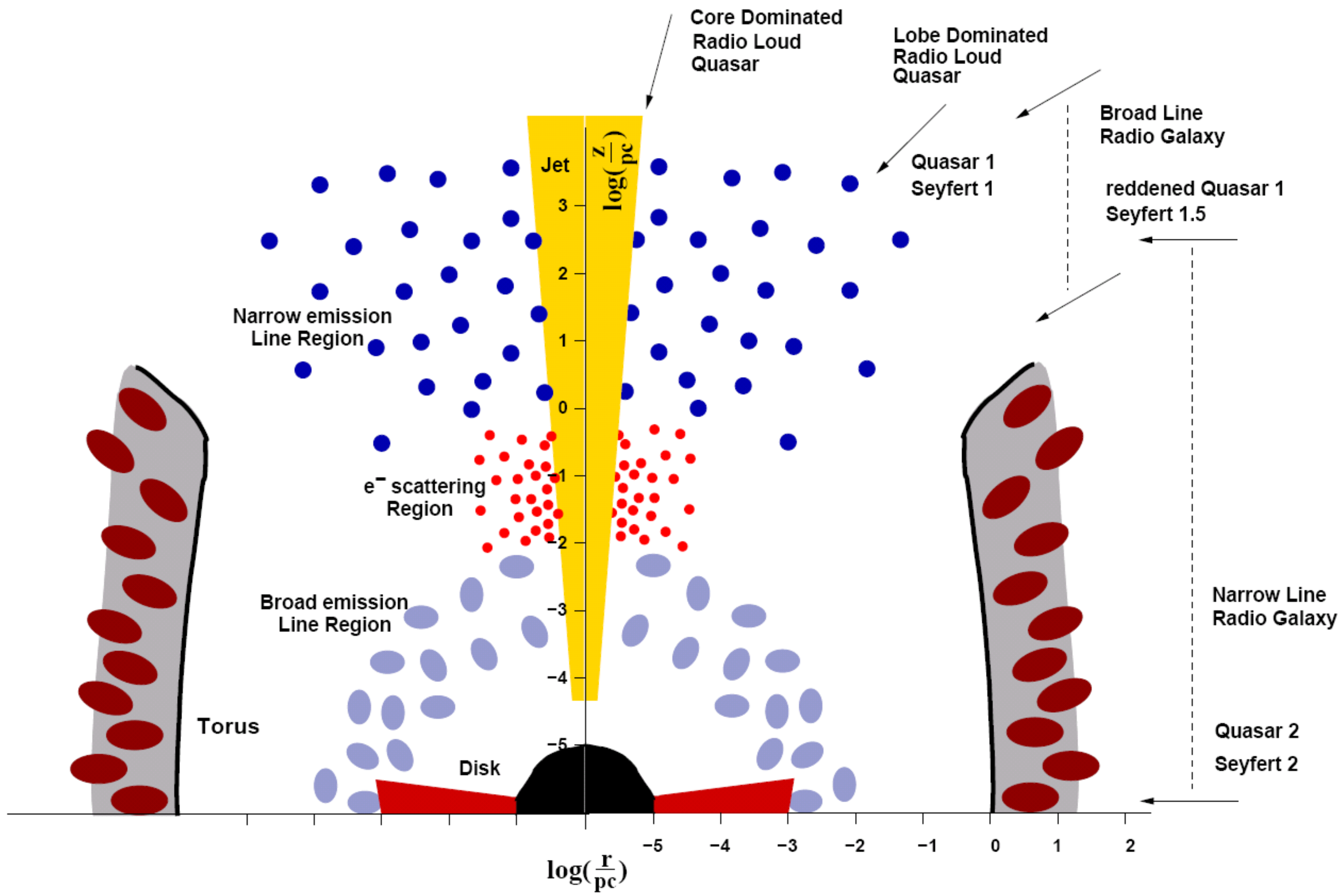

Figure 13 A sketch of the cylindrically symmetric AGN. The cut shows the r - z-plane, both axes logarithmically scaled to 1 pc, with the black hole at the center providing the symmetry; the geometry is tweaked to improve the understanding. The basic constituents are the central BH with a surrounding accretion disk, the jet perpendicular to the disk and the torus encircling this configuration. There is a lower identical half not shown, of this rotationally symmetric graph. The dark patches in the torus indicate the clouds, made up by stellar winds in the concept proposed (Zier & Biermann 2001, 2002).

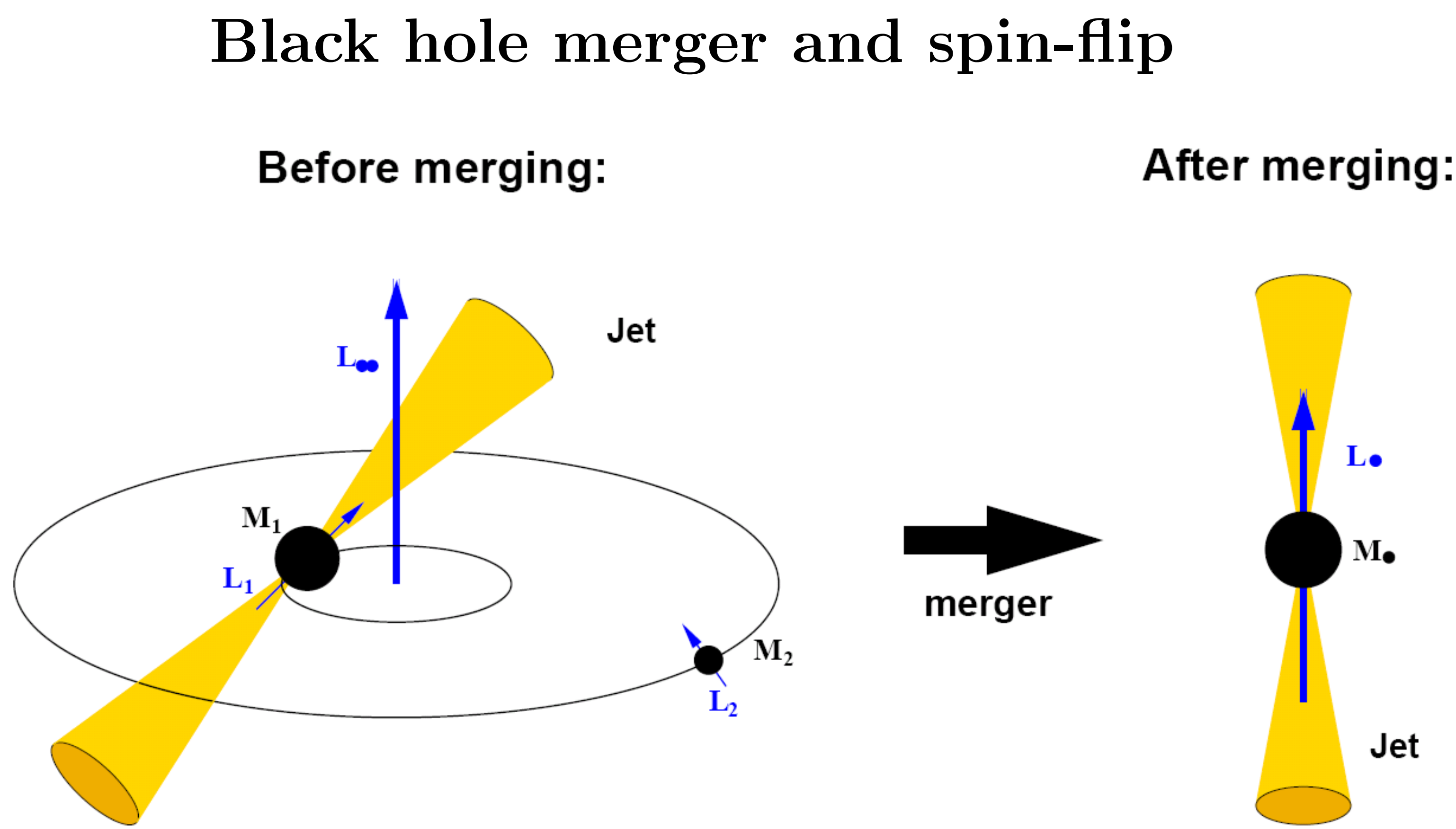

Figure 14 This figure illustrates the change of the direction of the spin of the BH, induced by the merger of two massive BHs, and consequently the change of the direction of the jet. Basically the orbital spin wins over the two intrinsic spins. The left panel shows the situation before the merger, when the jet is aligned with the individual spin of the primary black hole of the binary system (Zier & Biermann 2001, 2002). We have proposed the super-wind radio galaxies (Gopal-Krishna et al. 2006, 2007) to be the radio galaxies just before the spin-flip, due to the merger of two black holes, during the stage of violent precession of the jet (Gergely & Biermann 2008).

Warped compact disk and sprinkler-like jets

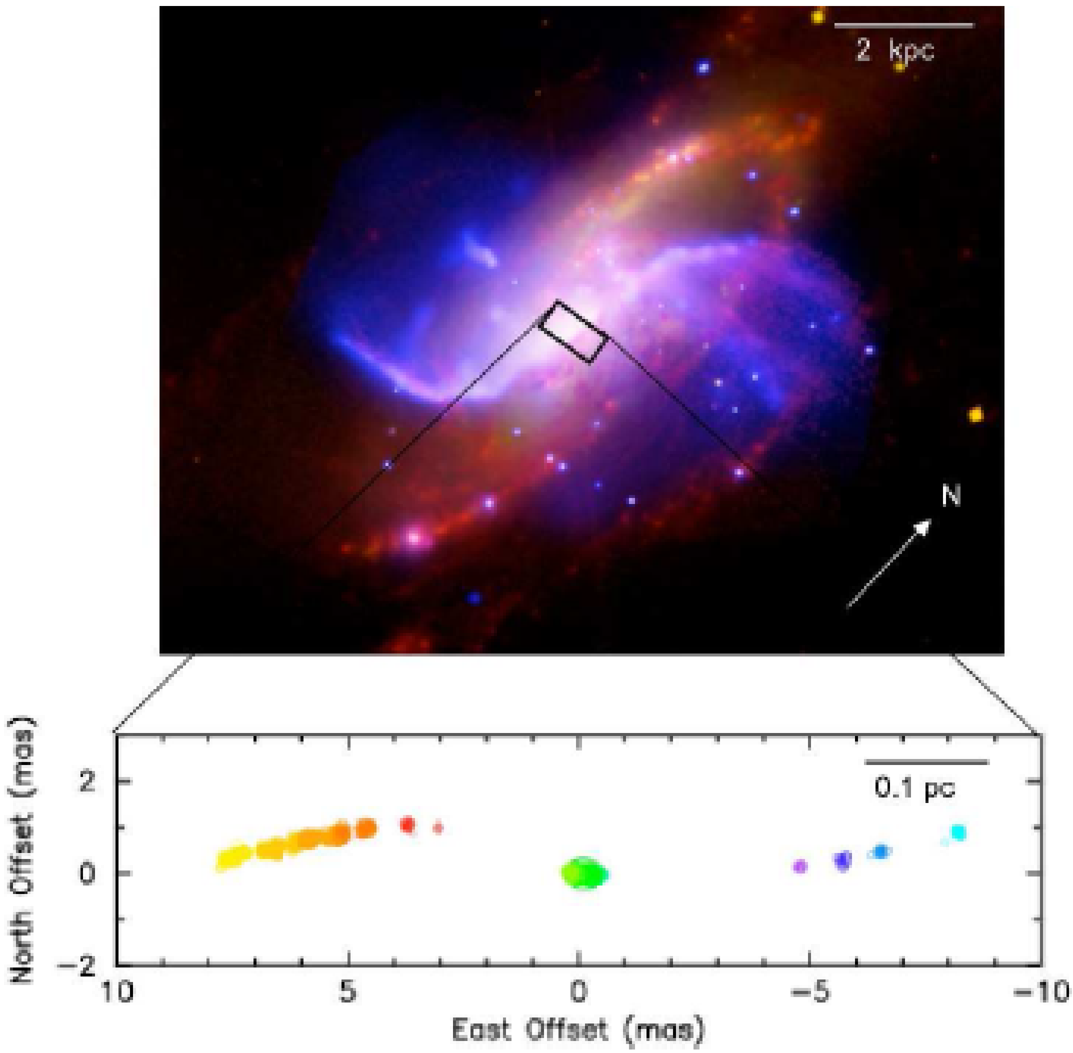

Figure 1. **Top: A multiwavelength image (X-ray, Hα, 1.4 GHz radio) from**

Figure 15 What a galaxy looks like after a spin-flip; the accretion disk is still warped: The normal and anomalous arms and the compact disk in NGC 4258 (− > Moran 2008)

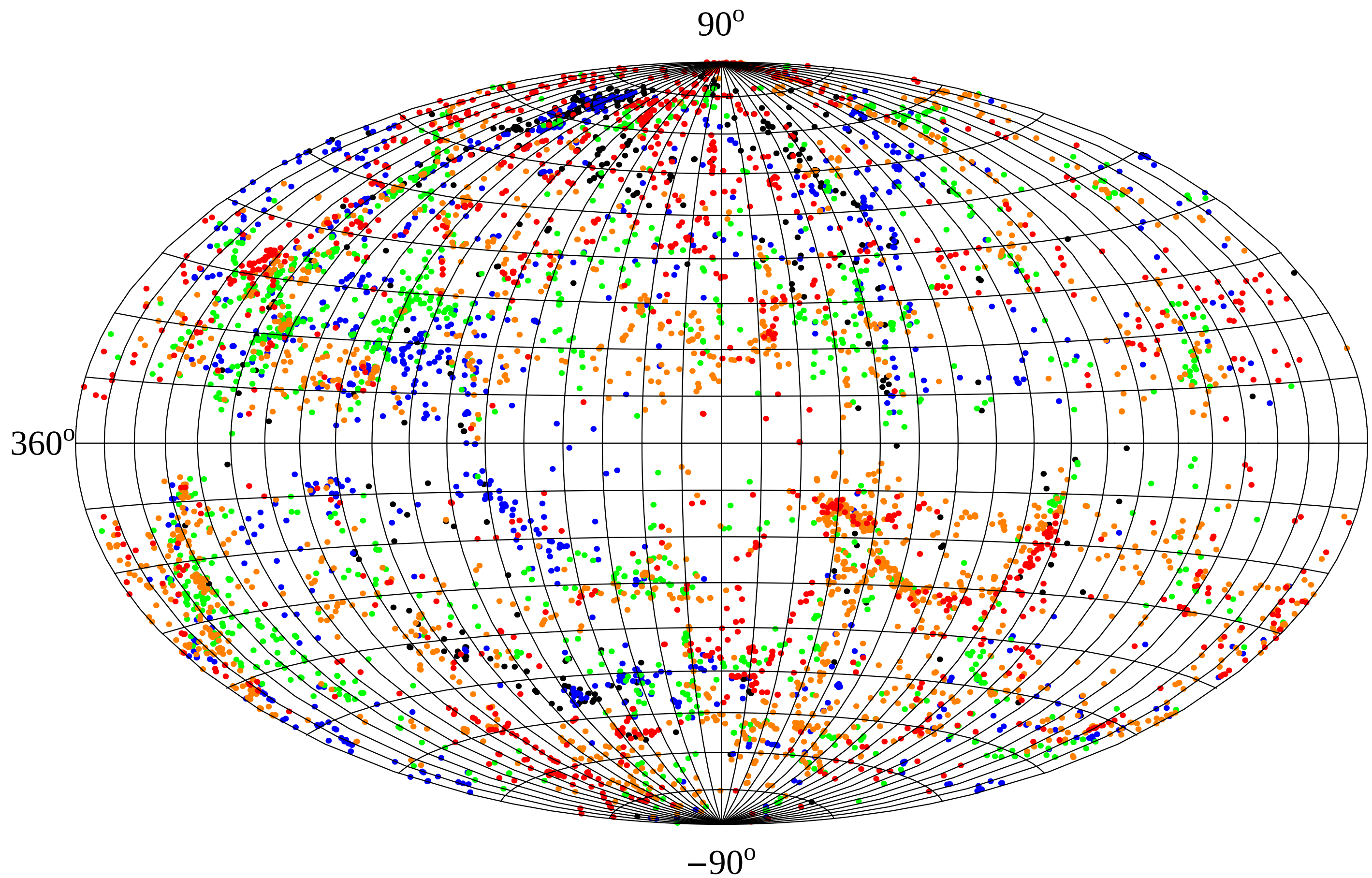

Figure 16 **The sky in black holes**, $\gtrsim 10^7\ M_\odot$: Aitoff projection in galactic coordinates of 5,978 candidate sources in the case of a complete sub sample (the Galactic plane remains obscured). The choice was made from a complete sample of 10,284 candidate brighter than 0.03 Jy at 2 micron, 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 curved feature near NGC315 (Enßlin et al. 2001) - almost a half-circle, with very tight redshift distribution - may be explainable in some models of WDM (Gao & Theuns 2007). The sample is complete to full distance only above $10^8\ M_\odot$. The color code is Black, Blue, Green, Orange, Red corresponding to redshifts betwen 0, 0.005, 0.01, 0.015, 0.02, 0.025: Caramete et al. 2008

Prediction: Particles in radio galaxies

- **Cutoff in nonthermal spectrum** $\nu^{\star}$ 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:

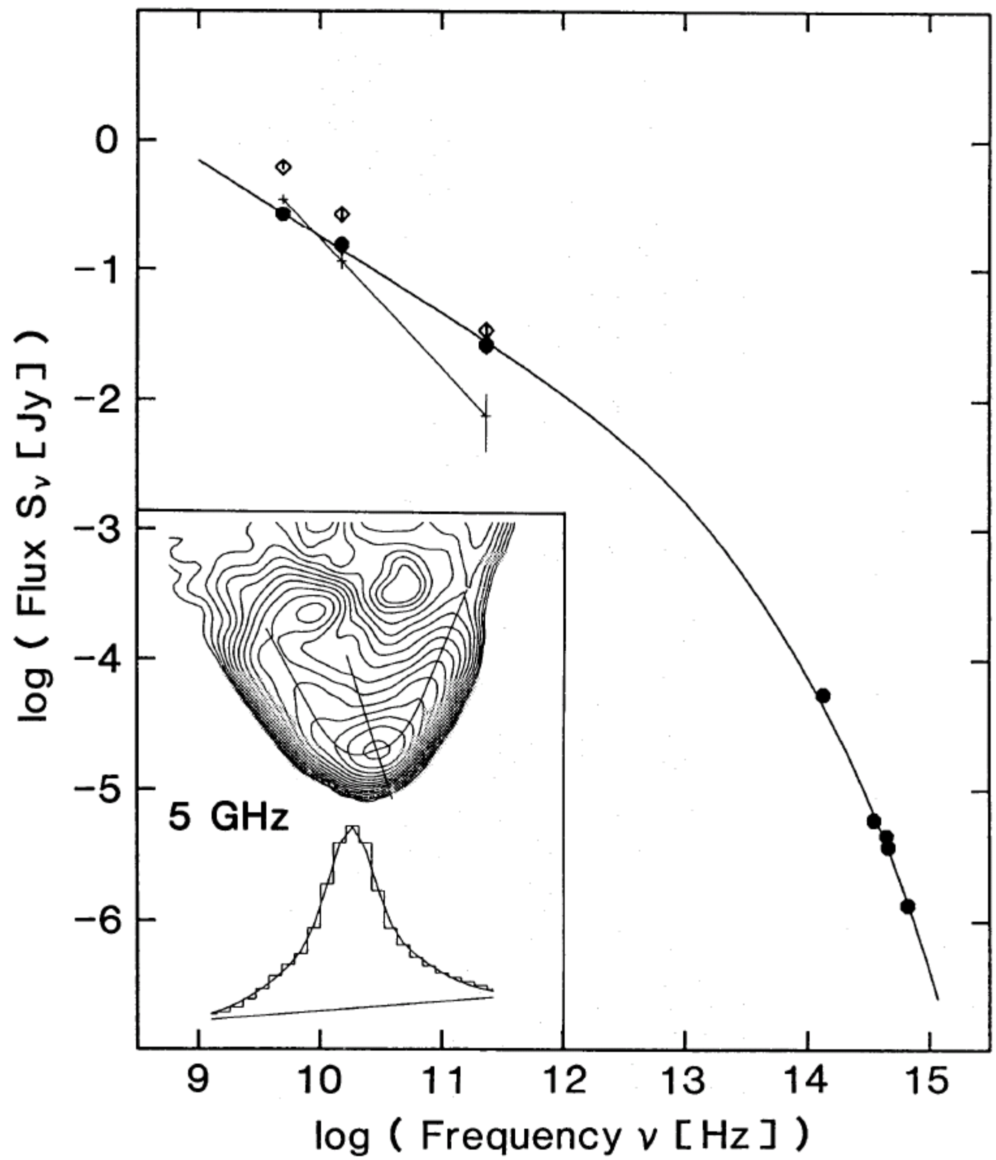

Figure 17 Decomposition of the observed spectrum of 3C 33 south. (K. Meisenheimer et al., *Astron. & Astroph.* 1989)

- **Electron emission** maximal frequency $\{c/r_{\rm o}\times(m_e/m_p)^2\}$:

$$\nu^\star \simeq 3 \times 10^{14}\,\mathrm{Hz} \tag{1}$$

- **Loss limit and spatial limit** combined give

$$E_{p,max} \simeq 1.4 \times 10^{21}\mathrm{eV} \tag{2}$$

- **Independent** of intensity of the turbulence, shock speed, etc.; dependence via magnetic field on observed and assumed parameters with the exponent 1/14

- 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 in protons!

The Poynting flux limit

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

$$L_P = \frac{B^2}{4\pi}\pi\theta^2 z^2 c \quad \text{and} \quad E_{max} = ZeB\theta z \qquad (3)$$

$$L_P = 10^{47}\,\mathrm{erg/s}\left(\frac{E_{max}}{Z\,10^{21}\,\mathrm{eV}}\right)^2 \qquad (4)$$

- M87 and Cen A $< 10^{45}$ erg/s, $< 10^{43}$ erg/s (Whysong & Antonucci 2003): **Problem** for $Z = 1$. Way out: shock in upstream flow γ_{sh} (Gallant & Achterberg 1999)

$$L_P = \frac{c}{4\pi} f_{flar}\left(\frac{E_{max}}{e\,Z\,\gamma_{sh}}\right)^2 \qquad (5)$$

- $Z >> 1$, $\gamma_{sh} > 1$, and $f_{flar} < 1$ perhaps all required.

Intermittency: the radio galaxy Her A

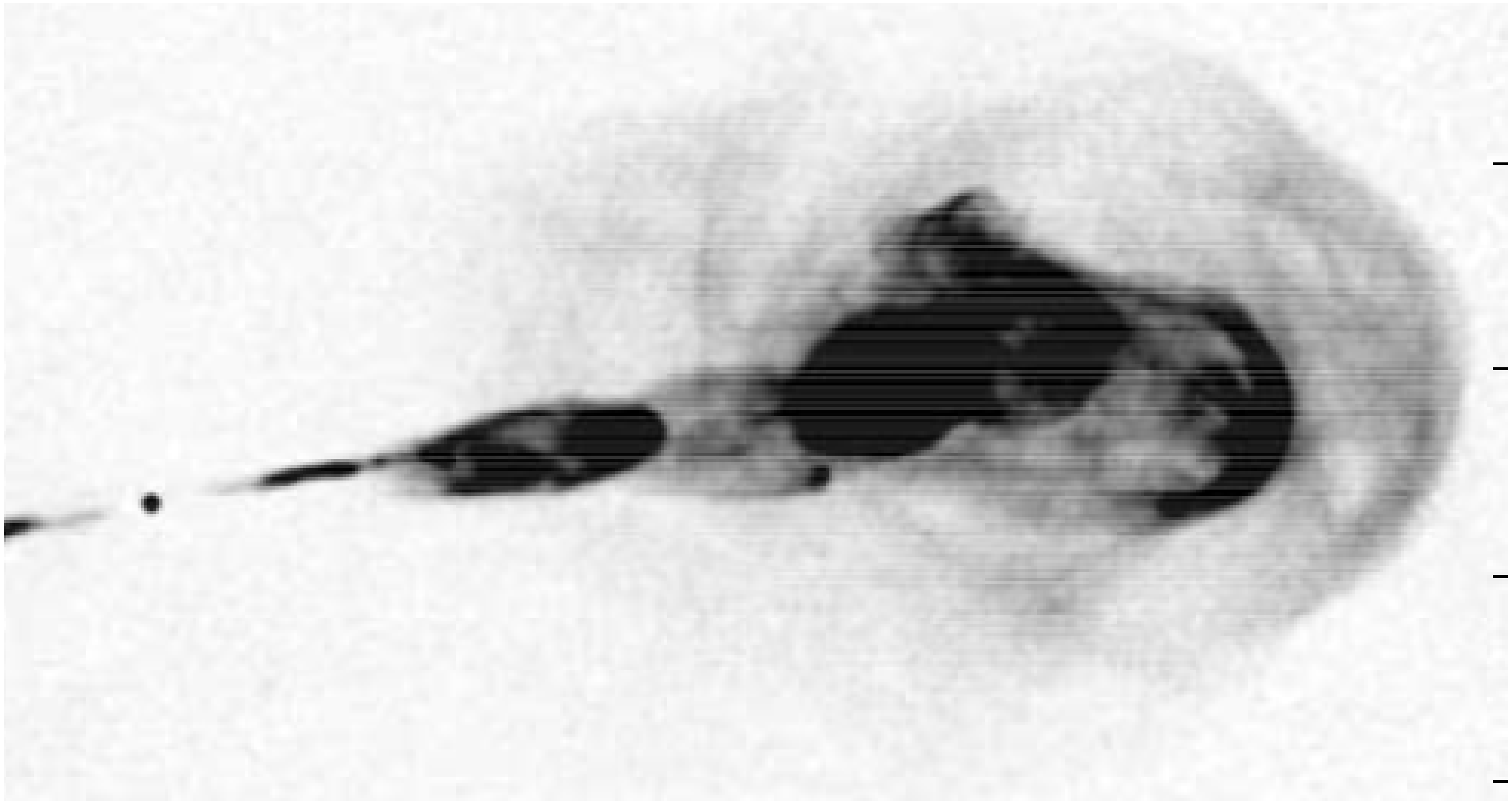

Figure 18 The radio galaxy Her A, showing intermittency: Source Gizani & Leahy 2003. Her A deposits an enormous amount of energy in its surrounding cluster: The age of the outburst is $\sim 5.9 \cdot 10^7$ yr, its energy $\sim 3 \cdot 10^{61}$ ergs, and its mean power $\sim 1.6 \cdot 10^{46}$ ergs/s (Nulsen et al. 2005)

Particle energy and particle flux predictions

Complete samples (Caramete et al., 2008).

Spin-down powered jets (Blandford & Znajek 1977, Ensslin et al. 1997):

$$E_{max} \sim D_L\, S_{2.7,tot}^{1/2} \tag{6}$$

$$F_{CR} \sim S_{2.7,tot} \tag{7}$$

Accretion powered jets (Falcke et al. 1995, Taşcău 2003, Taşcău et al. 2008):

$$E^{\dagger}_{max} \sim S_{rad}^{1/3}\, D_L^{2/3}\, M_{BH} \tag{8}$$

$$F_{CR}{}^{\dagger} \sim S_{rad}^{2/3}\, D_L^{-2/3} \tag{9}$$

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

UHECR predictions:

- 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 $\log(P_{core}) = 11.01 + 0.47 \log(P_{tot})$, cf. Giovannini 1988;
- Col. 5 & 6: Relative values of the particles maximum energy and UHECR flux by using spin-down (equations above).
- Col. 7 & 8: (†) Relative values of the particles maximum energy and UHECR flux by using accretion (O. Taşcău).
- No losses, just spatial limit, flux reduction with distance squared. Energies with an asterisk starburst.

Table 1 UHECR predictions:

Source (1)	D (Mpc) (2)	M_{BH} ($\times 10^9 M_\odot$) (3)	S_{5GHz} (mJy) (4)	E_{max}/E_{max}^{M87} (5)	F_{CR}/F_{CR}^{M87} (6)	$E_{max}/E_{max}^{M87\dagger}$ (7)	$F_{CR}/F_{CR}^{M87\dagger}$ (8)
ARP 308	69.7	0.1	88.53*	0.8	0.025	0.03	0.04
CGCG 114-025	67.4	0.19	2260	0.8	0.03	0.15	0.33
ESO 137-G006	76.2	0.92	631.32*	1.8	0.13	0.51	0.13
IC 4296	54.9	1	214	0.6	0.025	0.31	0.08
IC 5063	44.9	0.2	321.15*	0.22 *	0.0075	0.06	0.12
NGC 0193	55.5	0.2	285.93*	0.45	0.01	0.07	0.09
NGC 0383	65.8	0.55	414.25*	0.7	0.025	0.24	0.11
NGC 1128	92.2	0.2	280.2*	1.1	0.03	0.1	0.07
NGC 1167	65.2	0.46	393.1*	0.5	0.011	0.2	0.1
NGC 1316	22.6	0.92	26	1.3	0.8	0.08	0.03
NGC 1399	15.9	0.3	10	0.1	0.012	0.01	0.02
NGC 2663	32.5	0.61	160	0.22	0.012	0.12	0.09
NGC 3801	50	0.22	635	0.23	0.007	0.09	0.17
NGC 4261	16.5	0.52	390	0.3	0.1	0.09	0.26
NGC 4374	16	1	168.7	0.2	0.03	0.13	0.15
NGC 4486	16	3.1	2875.1	1	1	1	1
NGC 4651	18.3	0.04	15	0.1 *	0.012	0	0.03
NGC 4696	44.4	0.3	55	0.35	0.018	0.05	0.04
NGC 5090	50.4	0.74	268	0.5	0.025	0.23	0.1
NGC 5128	3.4	0.2	6984	0.4 *	4.0	0.04	3.63
NGC 5793	50.8	0.14	95.38*	0.25 *	0.008	0.03	0.05
NGC 7075	72.7	0.25	20	0.45	0.0055	0.04	0.01
UGC 01841	84.4	0.1	365.46*	0.5	0.055	0.05	0.08
UGC 02783	82.6	0.42	541	0.5	0.006	0.23	0.11
UGC 11294/4	63.6	0.29	314	0.45	0.007	0.11	0.09
VV 201	66.2	0.1	450.1*	0.8	0.04	0.04	0.11
WEIN 045	84.6	0.27	321.6*	1.0	0.03	0.13	0.08

Cosmic magnetic fields

- Cosmos full of magnetic fields
- **Galactic magnetic winds** exist (Westmeier et al.; Everett et al.; Breitschwerdt; Chyży et al.)
- Galactic magnetic winds important ingredient of **magnetic dynamo mechanism** to strengthen and order galactic magnetic fields (Parker; Hanasz et al.)
- Kronberg et al. intergalactic medium **observations**
- Ingredient: Black hole activity intergalactic medium **feedback** to enhance intergalactic magnetic fields: Enßlin et al.; Kronberg et al.; Gopal-Krishna & Wiita.
- Ryu et al. **cosmological MHD simulations**, self-consistent turbulent dynamo

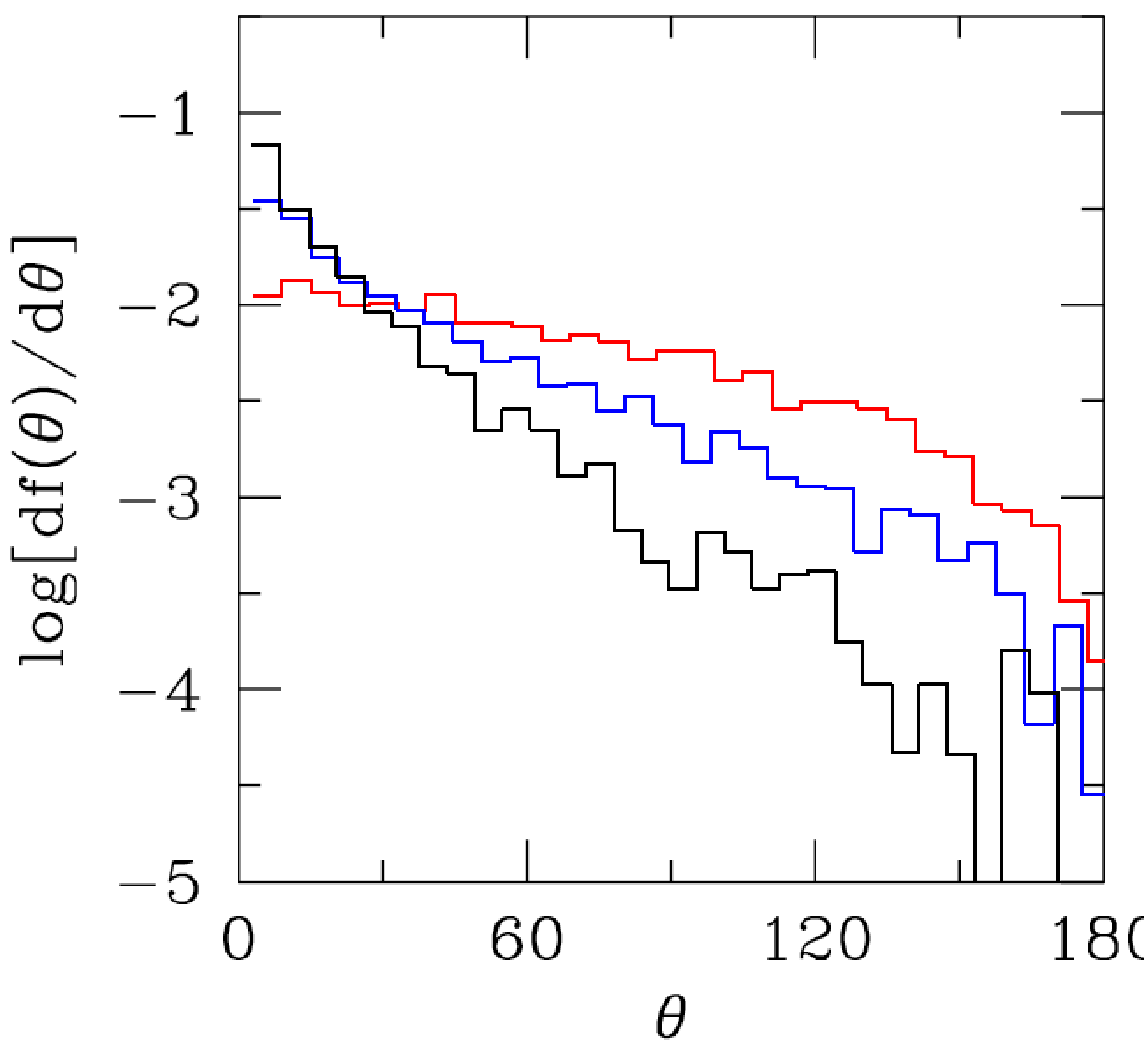

Figure 19 Angle distribution: Das et al 2008 Fig. 7, left panel. $>$ 60 EeV red, 30 - 60 EeV blue, 10 - 30 EeV black. Scattering to large angles for protons, but effect of galactic disk not included. At $>$ 60 EeV power-law with approximately θ^{-2}

Gamma ray bursts? Starburst galaxies, selected at 60 μ

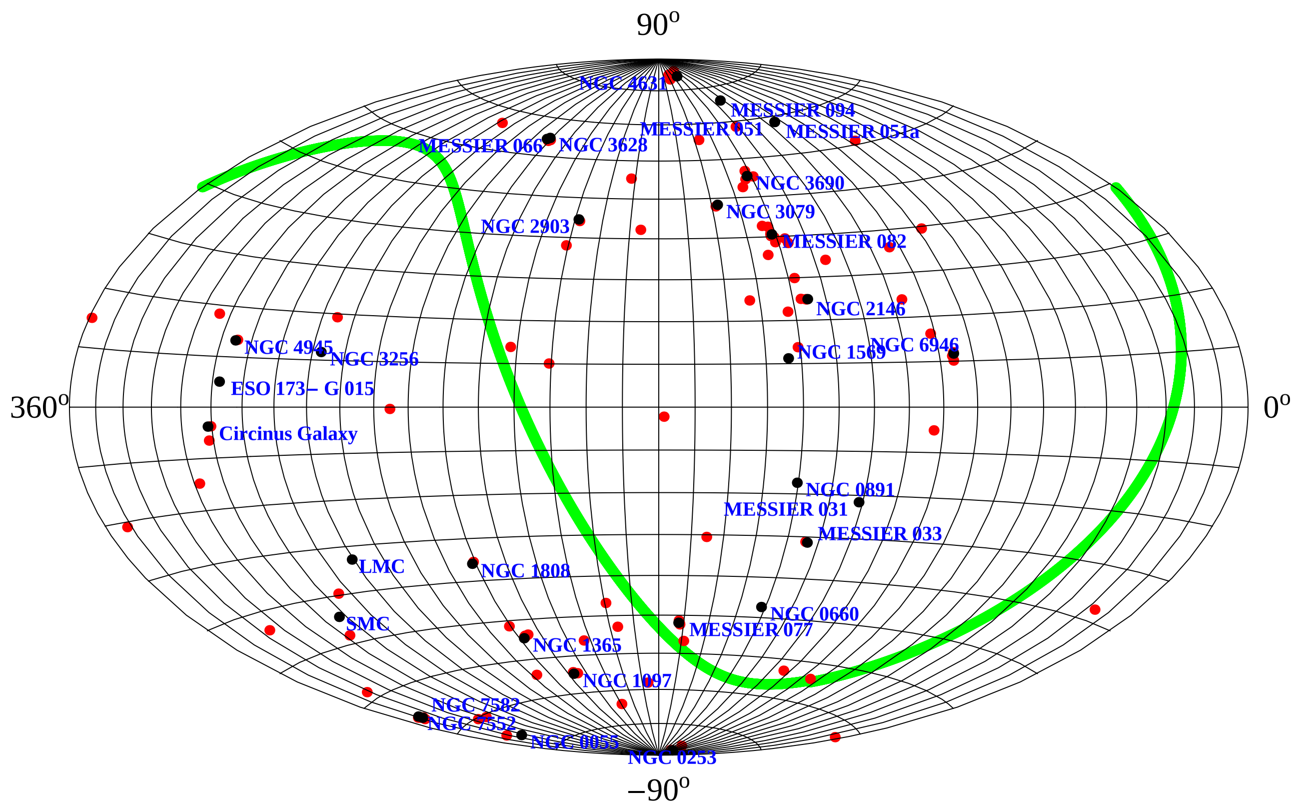

Figure 20 Alternative: Aitoff projection in galactic coordinates of the selection from NED in 60μm, redshift $z \leq 0.0125$, flux density brighter than 50 Jy, starburst selected, sample of 32 candidate sources and 100 virtual events from this sources and weighted contribution. Double Monte-Carlo to simulate the intermittent nature of gamma ray bursts

UHECR abundances?

- Episode: Merger, starburst, spinflip, bare AGN, decay
- Acceleration to high energy: from sea of galactic CRs, **injection from PeV** (Gallant & Achterberg 1999)? Entrainment in jet boundary (Ostrowski 2000+)?
- Energies jump by $\Gamma_{sh}^2 2^n$, and so the spectral pattern at the knee will be repeated at high energy. **Sequence in edges He, CNO, ...** suggests $\Gamma_{sh} \simeq 50$, $n = 0$.
- Polar cap component sharpens the edges ?
- If injection from **gamma ray bursts** (Rachen & Mészáros 1998), then maximal energy in neutrons (No Helium), so pure protons predicted! Heavy nuclei ?
- Later in life injection from **intergalactic medium**, diluted cosmic abundances. Abundances and spectra different for M87 (North) and Cen A (South)!

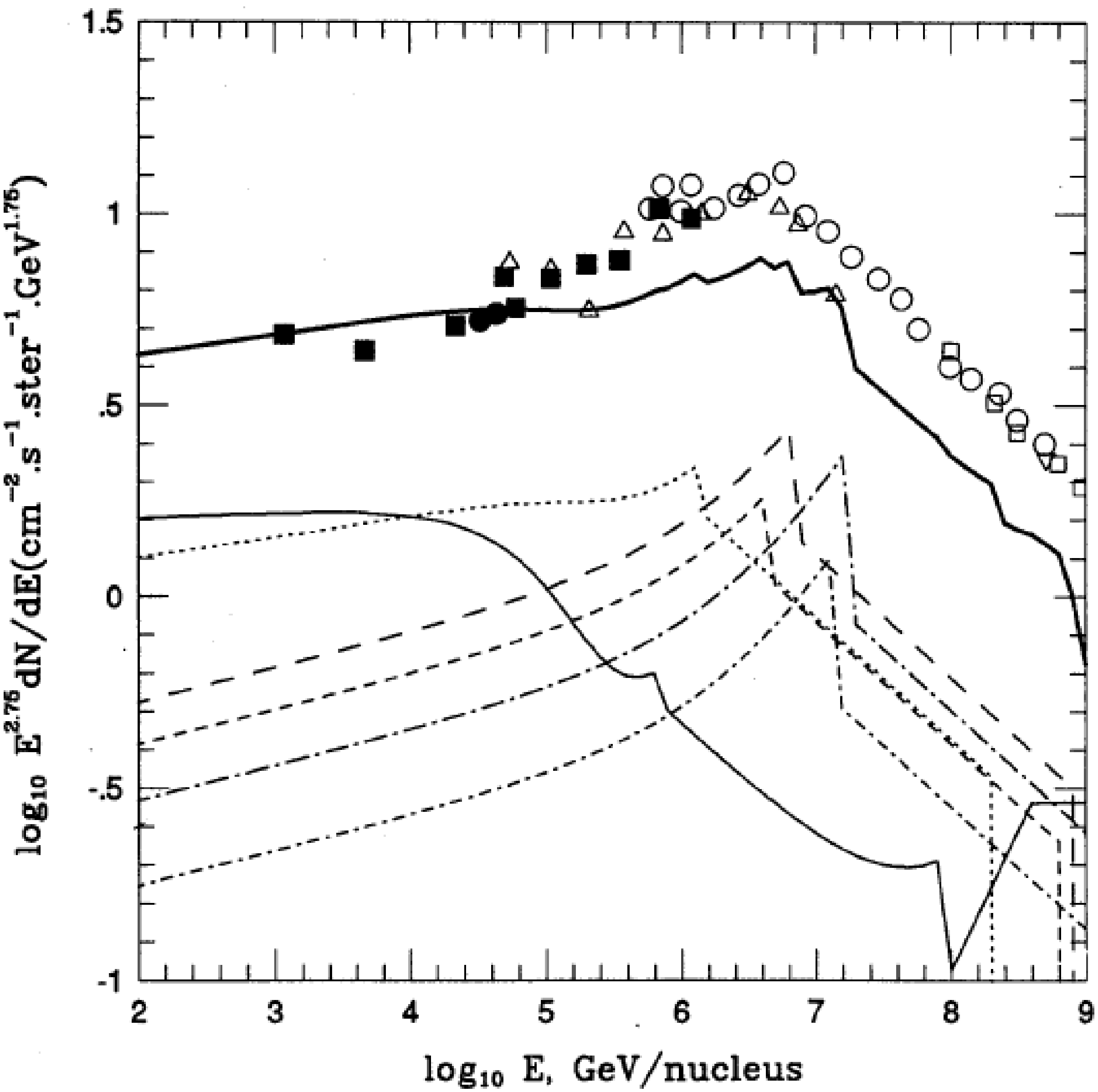

Figure 21 Spectral and chemical structure at the knee, to be repeated at high energy? Element groups are H, He, CNO, Ne-S, Cl-Mn, and Fe. Here the spectra are in the diffusion limit, and we may need the injection limit; this implies multiplying all curves by $(A/Z)^{1/3} \simeq 10^{0.1}$. Source: Stanev et al., paper CR-IV 1993

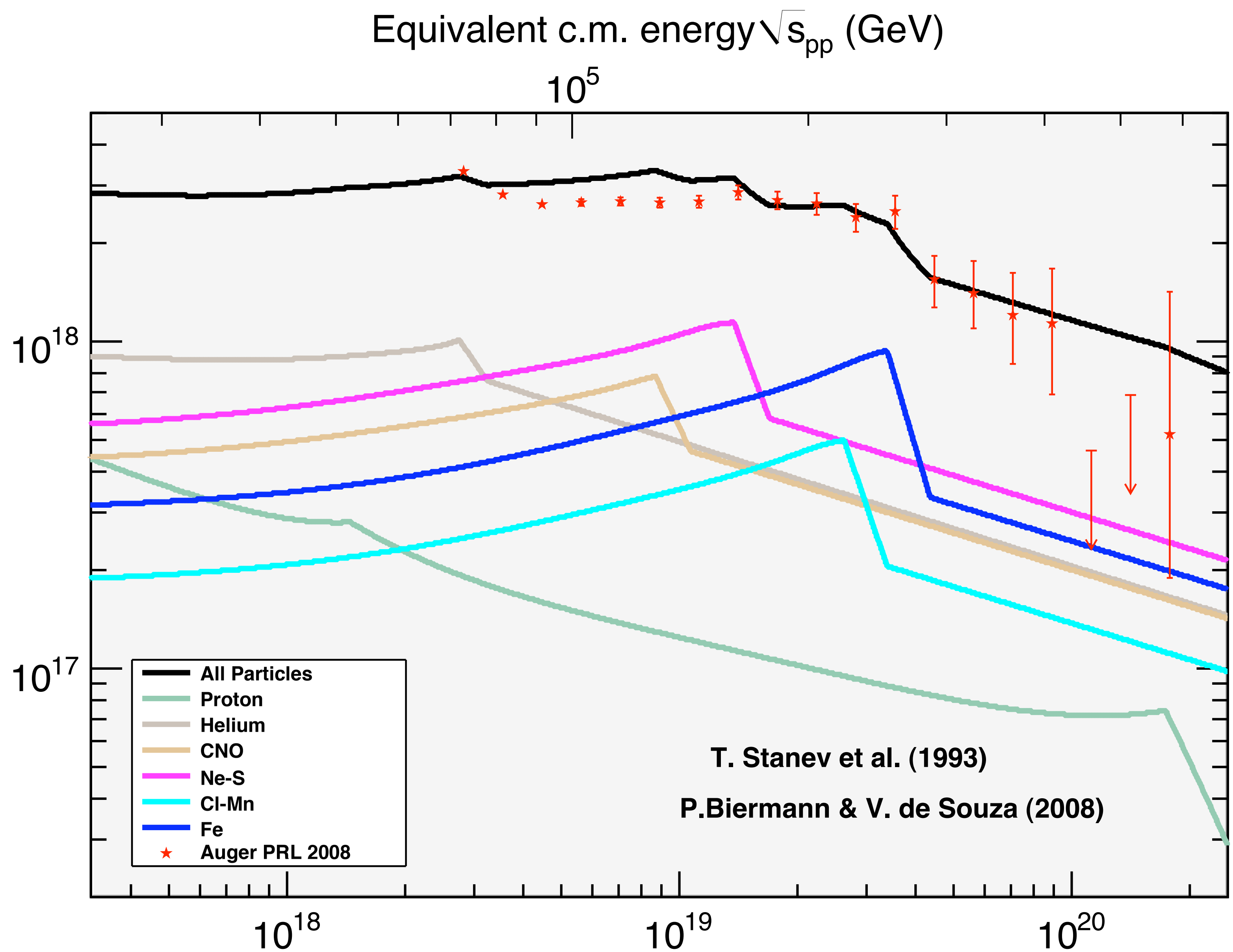

Figure 22 Testing the spectrum in paper CR-IV with Auger data, with all six element groups unmodified.

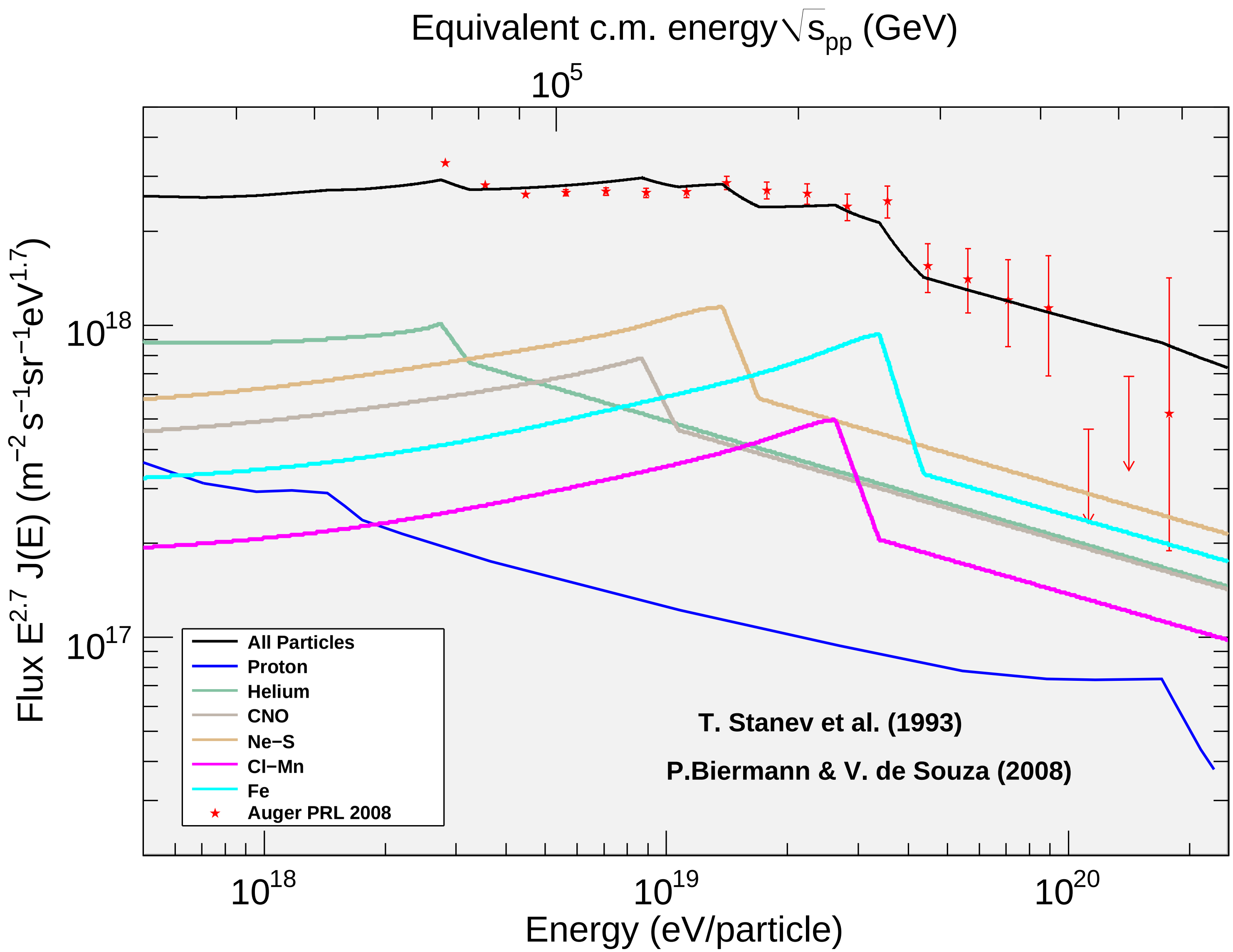

Figure 23 Testing the shift of the spectrum in paper CR-IV with Auger data, with Ne-S and the Cl-Mn flux 20% down: Note, that the turn-off here is due to the MHD structure of massive star winds, pushed to EeV energies by a highly relativistic shock; there is a final complete cutoff due to spatial confinement in the front shock of the jet

Ultra high energy neutrinos and photons

- The largest interaction for ultra high energy **protons and ions** is at the first strong shock, near about 3000 r_g
- Ion-γ leads to single nucleons, second stage p-γ: Luminosity scales with $\tau_{ion\,\gamma} \times \tau_{p\,\gamma}$, so accentuates **flaring**!
- Charged pion decay also leads to very energetic electrons and positrons, that themselves also emit photons, covering a different photon energy range
- The resulting flux should scale with the **square** of the photon field. One could imagine a third stage, with IC on the resulting leptons, so third power possible
- In fact, all strong GeV and TeV sources are flat spectrum radio sources: all **highly variable**

Flat spectrum radio sources

predicted to be strong flaring neutrino emitters

Ultra high energy neutrino source candidates

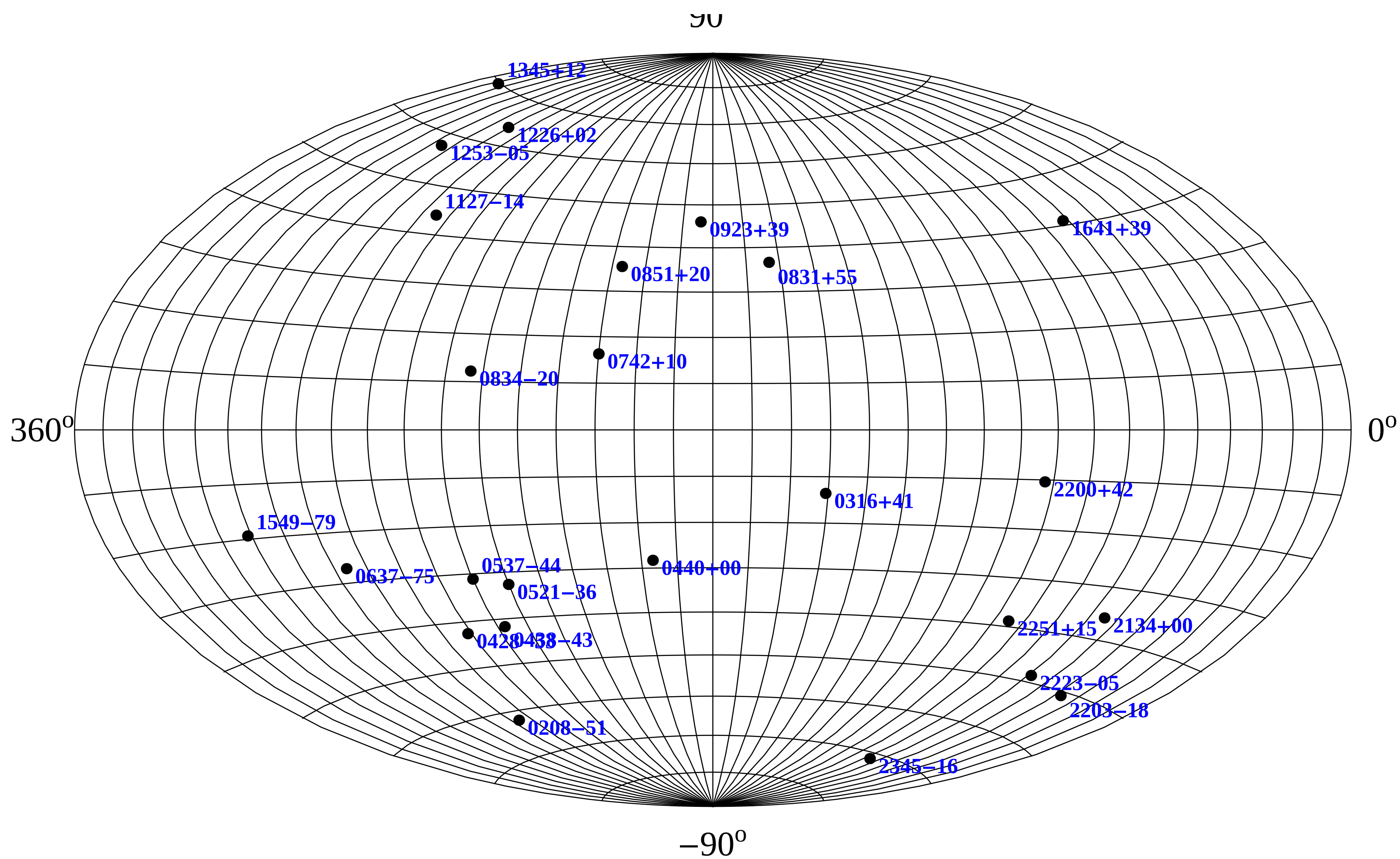

Figure 24 Aitoff projection in galactic coordinates of the 25 flat and inverted radio spectrum sources highest in flux density at 2.7 GHz. These sources are prime candidates to be ultra high energy neutrino and photon sources. 3C279 = 1253-05, see Mannheim et al. 1992

Ultra high energy cosmic ray particles: some of our contributions

- Synchrotron emission from shockwaves in active galactic nuclei, Biermann, P.L., Strittmatter, P.A., *Astrophys. J.* **322**, 643 (1987)
- Cosmic rays: origin and acceleration - what can we learn from radio astronomy, Peter L. Biermann; plenary lecture at 23rd International Conference on Cosmic Rays, 1993, in Proc. "Invited, Rapporteur and Highlight papers"; Eds. D. A. Leahy et al., World Scientific, Singapore, 1994, p. 45
- Active Galactic Nuclei with Starbursts: Sources for ultra high energy cosmic rays?, P.L. Biermann, et al., review for "High-Energy Gamma-rays and Neutrinos from Extra-Galactic Sources", Heidelberg Jan 2009, (in press) 2009; arXiv:0904.1507

Key Concepts UHECRs

- Radio galaxies able to produce particles to $> 10^{20}$ eV, also low power radio galaxies nearby like Cen A and M87 - **spin-down power**
- Three classes of AGN activity: i) Energetic particles from **Wolf-Rayet star SN (so C, O, Mn, Fe,...)**, ii) ISM and IGM, or iii) gamma ray bursts (GRBs) (neutrons $->$ protons)
- BHs grow by **mergers**: mergers lead to **spin-flips**: so new jet bores through starburst
- Cosmic magnetic fields: Scattering to **large angles** possible! Significant delay times! Magnetic field extremely inhomogeneous - 4π view necessary!
- Neutrino emission from **flat radio spectrum AGN**
- **Simple: Cen A, heavy elements, large angles!**

The origin of cosmic rays

- Massive stars, **Red Super Giant (RSG) Stars, and Wolf Rayet (WR) Stars**: explode into winds
- Magnetic winds, in polar cap component: flatter spectrum, enhanced interaction: **cosmic ray e^- and e^+**
- Shocks in RSG and WR winds explain **cosmic ray knee structure**: H, He, CNO, Ne-S, Cl-Mn, and Fe
- Relativistic jet, re-orientated after spin-flip, pushes shock through starburst region, with RSG and WR stars
- Cosmic ray knee structure pushed up in energy by about $\Gamma_{jet}^2 \simeq 3000$, heavy nuclei
- Cosmic magnetic fields: Scattering to **large angles** !
- **Radio galaxies with starburst injection** produce particles to $> 10^{20}$ eV, such as Cen A:
- **Simple: UHE nuclei, beam dump, physics**

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