ELSEVIER

Astroparticle Physics 6 (1997) 387-394

Astroparticle Physics

High energy radiation from the center of the local supercluster

H.C. Arp [a], J.V. Narlikar [b], H.-D. Radecke [c]

[a] *Ungererstrasse 19, 80802 Munich, Germany*

[b] *Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India*

[c] *Max-Planck Institut für Extraterrestrische Physik, 85740 Garching, Germany*

Received 19 September 1996; accepted 9 November 1996

Abstract

Evidence in X-rays, gamma rays and ultra high energy cosmic rays (UHCR) suggests the existence of active centers in extragalactic space which eject high energy particles and quanta. A concentration of these highest energy sources in the direction of the Local Supercluster indicates that the brightest apparent magnitude AGN's such as 3C274 (M87), 3C273, 3C279 and Markarian 421 are the only candidate sources for this radiation. A theoretical model of mass creation in the Local Supercluster based on a Machian theory of gravitation is described as a possible mechanism for production of the high energy while at the same time allowing the AGN's to be at the relatively close distance of the Supercluster. The fact that infrared photons fill intergalactic space limits the distance to the UHCR sources at a little over twice the distance to the center of the Local Supercluster strongly localizing the highest energy radiation to this relatively close distance.

Keywords: Quasars and active galactic nuclei; High energy radiation sources; Matter creation

1. Introduction

Three different high energy bands have recently shown the strongest outpouring of energy to come from the supergalactic plane with particular concentration toward the center of the Local Supercluster. X-rays from the ROSAT survey, three independent instruments on the gamma ray satellite and numerous ground based measurements of ultra high energy cosmic rays agree on the general direction from which this radiation comes.

Optical and radio observations have long marked this region as containing the largest aggregation of galaxies and active objects. The highest energy cosmic rays are indicated to be not able to travel more than about 30 Mpc through the microwave background. Since the Virgo Cluster, at the center of the Local Supercluster, is at a distance of 16–20 Mpc. It represents the natural, and apparently only, candidate source for this radiation.

While attempts are usually made to understand active galactic nuclei (AGN) and related phenomena through interaction of massive black holes with the surroundings, there are a number of observational difficulties [1,2]. We here consider a theoretical explanation for such phenomena based on the hypothesis that these active centers pour out newly created matter in the form of particles of Planck energy which quickly decay into a horde of hadrons and leptons as well as photons of high energy. The former are created with zero rest mass but their inertia increases with time. Thus in a typical creation event we have a group

PII S0927-6505(96)00072-2

of low mass particles which travels outwards at high speeds but slows down as the mass of a typical particle grows. This hypothesis is based on a Machian theory of gravitation. Before considering the theoretical aspects we first review the evidence.

2. Observational evidence

2.1. X-rays

The Local Supercluster is the largest aggregate of bright apparent magnitude galaxies in the sky. Its center is in the Virgo Cluster about 17 Mpc distant. There is a concentration of bright radio sources in the direction of the Virgo Cluster [3]. There is a concentration of quasars in this same direction [4-7]. The most active, bright radio galaxy in the sky (M87 = 3C274) and the brightest quasar (3C273) are aligned exactly across the brightest galaxy in the Virgo Cluster (M49 = NGC4472) as shown in Fig. 1. All three of these objects are strong X-ray emitters as shown in Fig. 2.

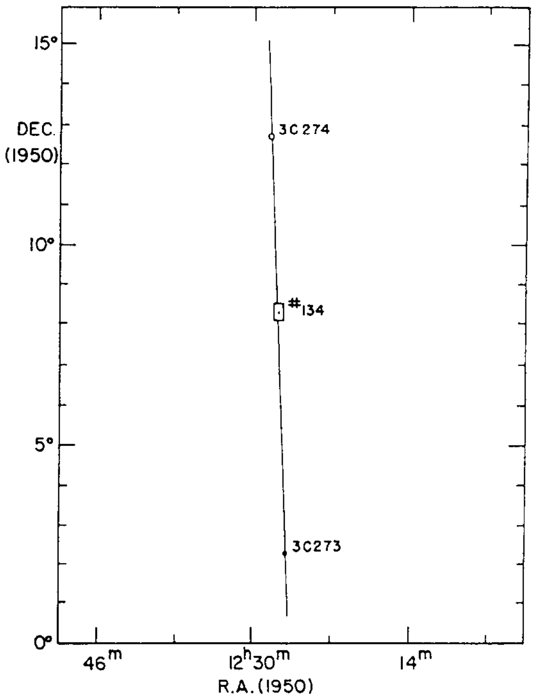

Fig. 1. The brightest apparent magnitude quasar in the sky, 3C273, and the brightest jet radio galaxy, 3C274 (M87), are aligned exactly across the brightest galaxy in the center of the Virgo Cluster, M49. (No. 134 from Atlas of Peculiar Galaxies is M49).

Recent observations with the X-ray telescope ROSAT have shown this central region of the Virgo Cluster to be filled in with extended X-ray emission, running from the central M49 north to M87 and south to 3C273 (see Fig. 2). The strong radio galaxy 3C270 is encountered along this line as well as a quasar of $z = 0.334$ [8]. This radiation runs roughly along the line of the supergalactic equator which, proceeding toward the south galactic hemisphere, eventually runs through the radio/Seyfert galaxy (CenA = NGC5128) which is 53 degrees further along in supergalactic longitude.

2.2. Gamma rays

The X-rays which delineate the spine of the Virgo Cluster are in the 0.1 to 2.4 keV range. But if we consult observations from the gamma ray observatory (GRO) in the 0.7 to 30 MeV range (COMPTEL) we see extensions SSE from 3C273 to 3C279 and northward toward M49 and M87 (see Fig. 3)

The quasar 3C279 is violently variable and was, from Harvard patrol camera records in the early 1900's once one of the brightest apparent magnitude quasars in the sky. Like 3C273 then, it is reasonable that it would be associated with the largest aggregate of bright galaxies and radio sources in the sky. It is classified as a 'blazar' and is one of the brightest gamma ray AGN's in the sky. Lower energy gamma rays are also observed by the separate GRO instrument OSSE in this Virgo region but the map has not yet been released.

In the higher energy gamma rays from the entirely independent instrument EGRET, Fig. 4 shows indications of extended radiation from the center of the Virgo Cluster (declination $\delta = 8$ deg) to the north toward M87 ($\delta = 12$ deg) to the south to 3C273 ($\delta = 2$ deg) and then most strongly to 3C279 ($\delta = -5.5$ deg). This is in the > 100 MeV energy range and the same general extension is seen in the > 1000 MeV range [9].

The point is that the optical galaxies, the radio sources, the X-rays and the gamma rays all define the same locus at the center of the Local Super Cluster. Since 3C279 emits much higher energy gamma rays than 3C273 it is also apparent that as we move generally southward in the Virgo Cluster the energy hardens as we approach the higher redshift, higher energy

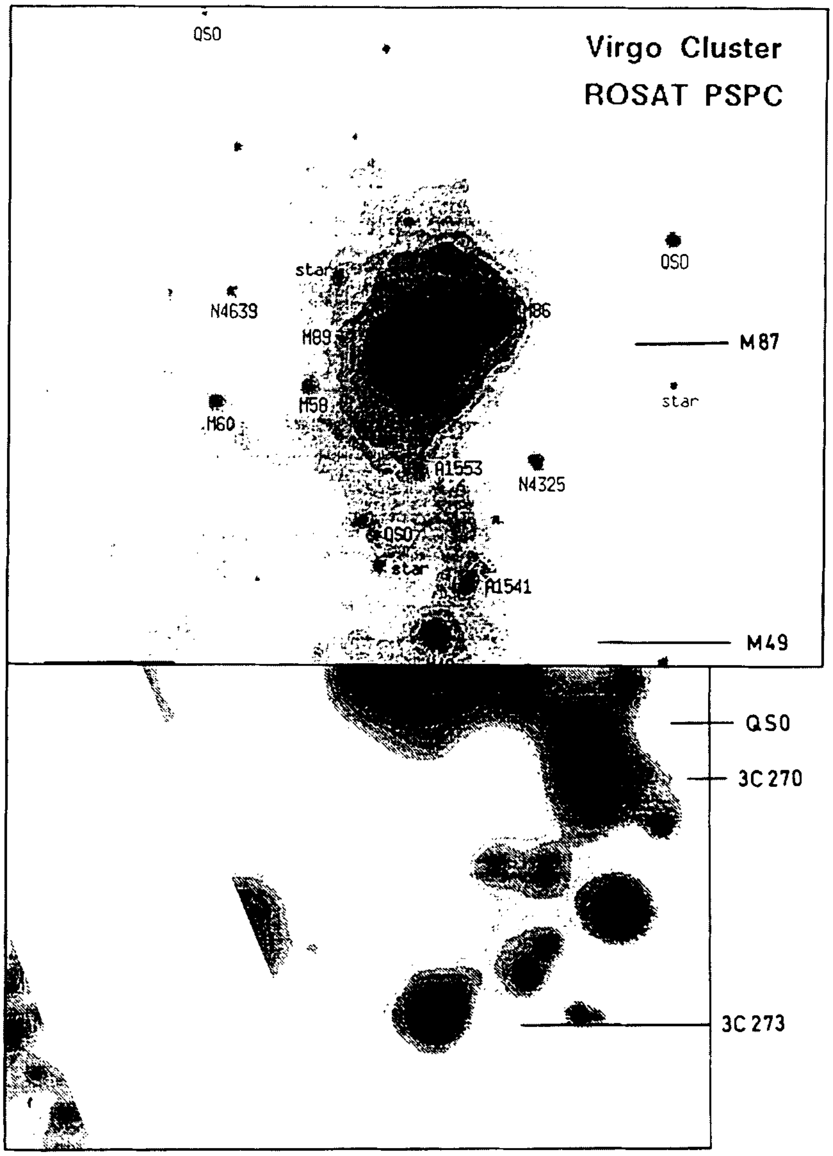

Fig. 2. Low surface brightness X-rays connect M49 to M87 in the north and 3C273 in the south. Upper integration from ROSAT Sky Survey by Böhringer et al. [33], lower by Arp [8] from the same survey.

density quasars [10]. It would seem necessary to conclude that these quasars and associated activity in this region are responsible for the extremely high energy gamma rays observed. In addition it is now becoming clear that the highest energy radiation known, cosmic rays of $> 10^{19}$ eV are also coming from this same region of space.

2.3. Ultra high energy cosmic rays (UHCR)

Recently the most energetic particles have been identified as coming from the approximate direction of the Local Supercluster and Supergalactic plane [11,35]. Above $10^{18.5}$ eV there appears to be a transition from the heavy atomic nuclei like Fe to light (protons) with increasing energy [12,13]. Analy-

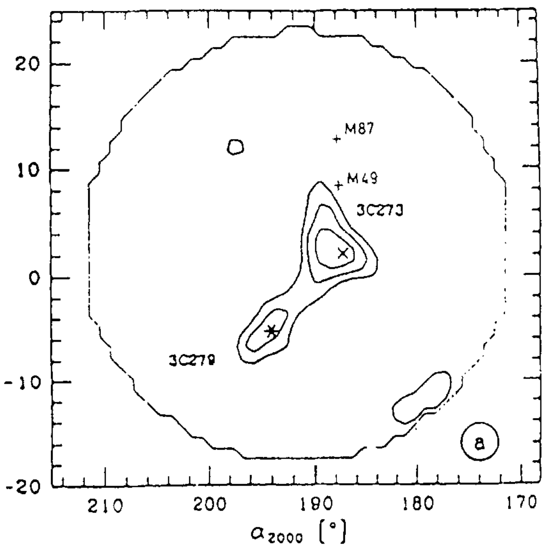

Fig. 3. Observations of 3C273 and 3C279 in low energy gamma rays (0.75 to 30MeV) [34] from COMPTEL instrument aboard the Gamma Ray Observatory (GRO).

sis by Norman, Melrose and Achterberg [14] and Norman [15] concluded this component was "accelerated from primordial material". Identification with the Local Supercluster is further strengthened by the argument that origin at greater distances than 30-50 Mpc would be precluded by UHCR scattering off microwave background photons (Phys. Today 1995, Vol. 48, No. 12, p. 11). Recently a possible gap in the spectrum of the highest energy cosmic rays has led Sigl et al. [16] and Sigl, Schramm and Lee [17] to question the conventional Fermi acceleration mechanism for this range of cosmic rays. The authors suggest the possibility of such particles representing phase transitions from spontaneous symmetry breaking of primeval GUT's.

It has also been recently argued that gamma ray bursts (GRBs) and UHCR may have a common origin [18] and one GRB has been identified as coming from the direction of 3C273 [19] and that GRB's in general are identified with bright Abell clusters of galaxies [20].

3. The working hypothesis

The above line of evidence is clearly similar to the earlier evidence from optical and radio astronomy and tends to corroborate the earlier interpretation of ejection. Here we briefly outline a possible theoretical model that may shed light on these phenomena which otherwise cannot be accommodated within the usual solutions of the equations of general relativity.

The main problem of the conventional framework is how to account for the energy source of such high energy particles and photons. It is also not easy to see how, in the popular massive black hole accretion disc paradigm matter and energy are ultimately ejected *outward* against the prevailing strong gravitational field. A black hole naturally attracts (not ejects) surrounding matter, yet there is more evidence for outgoing rather than infalling matter while, at the same time the observed ejection remains unexplained.

The problem was dealt with in a different way by Hoyle, Burbidge and Narlikar [21-24] in their new cosmology, the so-called quasi-steady state cosmology (QSSC). The QSSC envisages a universe without a beginning, without an end in which matter creation goes on in bursts near collapsed massive objects. The process of creation is not singular as in big bang cosmology but is the consequence of the interaction of a massless scalar field C with negative stress-energy tensor. We will outline this theory briefly as it provides the germ of an explanation of the above phenomena.

The conservation of energy-momentum at creation of a mass m is guaranteed by the equation

$$C_i = p_i, \quad i = 0, 1, 2, 3 \tag{1}$$

where C_i is the gradient of C with respect to space-time coordinates x^i and p_i is the 4-momentum vector of the created particle. Thus we need

$$C_i C^i = m^2 \tag{2}$$

at the point of creation. (We are using conventional general covariance of relativity with a signature $(+, -, -, -)$ for the metric.)

It will happen that the general background level of $C_i C^i$ will be lower than m^2, thus precluding any creation at an arbitrary space-time point. Near a collapsed massive object, the level rises, however, and close to (but outside) the theoretical event horizon, it

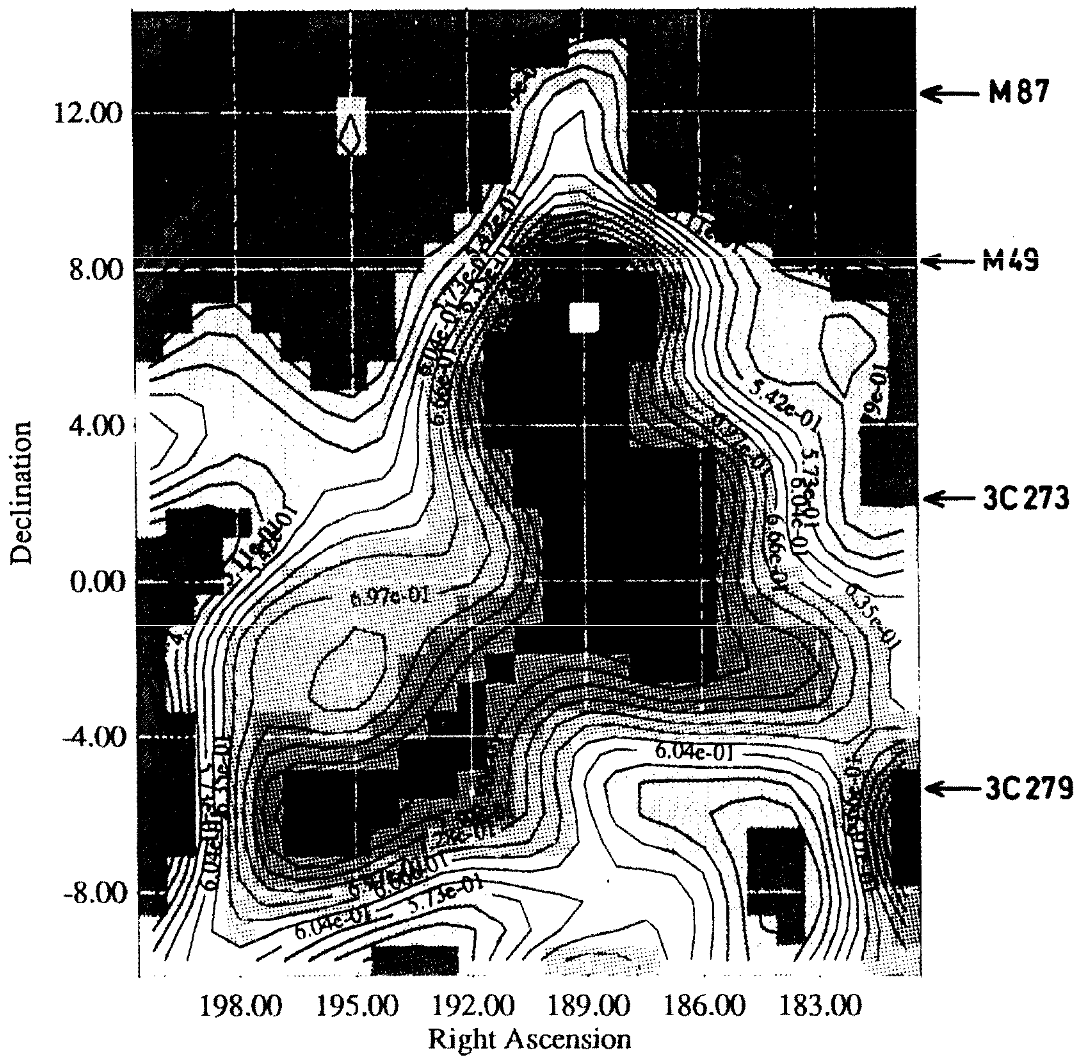

Fig. 4. Contoured EGRET counts sky map of Phase 2 observations of the Virgo region for the energy range > 100 MeV. Declination of M87 is about 12 deg., M49 8 deg, 3C273 2 deg and 3C279 −6 deg.

will reach m^2. This starts off the creation of particles of mass m along with the C-field. The latter, however, escapes (with the speed of light) but, because of its negative stresses, temporarily creates a repulsion prone environment near the massive object. The impact on space–time thus is to expand rapidly, carrying the created particles outwards.

We thus have creation of new matter and its ejection outwards, both achieved by standard relativistic dynamics. If the massive object is spinning (as is very likely), the Kerr-type geometry promotes ejection outside the ergosphere, preferably along the axis of rotation.

We can, in this way understand not only the ejection process but also the possible alignment of the ejecta along the axis. The question, however, still remains about the source of high energy radiation. The QSSC provides a solution in this way.

The mass m in the theory is none other than the Planck Mass $(\hbar c/G)^{1/2} \simeq 10^{19}$ GeV/c^2. This is highly unstable and decays within a short time scale $\sim 10^{-43}$ s. The decay products include hadrons and

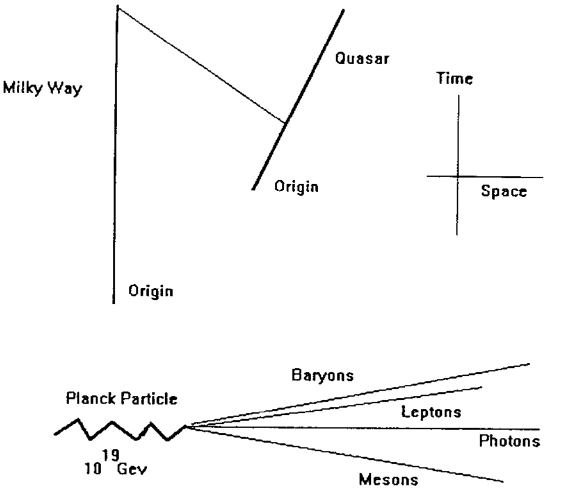

Fig. 5. A schematic representation of a newly created Planck particle breaking subsequently into sub particles in succeeding eras. Top sketch represents our Milky Way observing a quasar more recently created on a separate world line.

radiation at very high energies. For example, a 'Planck particle' may decay into $\sim 10^{18}$ baryons and mesons as well as high energy photons. In addition, to descend from 10^{19} GeV to 10^{19} eV of UHCR, it may produce 10^9 such high energy particles. This is schematically depicted in Fig. 5. It is thus a source of high energy particles which may in turn supply energy to other particles through compton scattering, and synchrotron radiation (if magnetic fields are present).

The process is self regulatory in the sense that if the creation activity becomes too large, its impact on the expansion of space-time is also large and expansion by a linear scale S leads to a diminution of the C-field strength $C_i C^i$ as S^{-4}. This makes the creation process more and more difficult as it becomes harder for any creation centre to satisfy Eq. (2). Hence creation is switched off temporarily, leading to a slowing down of expansion and to an eventual contraction. With decrease of S, the C-field strength grows once again and creation is resumed.

The field equations of QSSC are derived from the Machian conformally invariant theory of gravity of Hoyle and Narlikar [25]. A variation on the same basic theory by Narlikar [26] explains the observed anomalous redshifts.

This variation allows for newly created matter to start off with zero rest mass and pick up inertia as it gets older. Thus, the Planck particle would have the energy 10^{19} GeV but zero rest mass. It starts off with the speed of light but slows down as its rest mass grows. The decay products (e.g., baryons, electrons etc.) will show a similar behaviour. Thus coherent lumps of matter like quasars formed from such matter would have masses growing with time. As discussed by Narlikar and Das [27] and later by Narlikar and Arp [28], such objects show an excess redshift over that of old matter, an excess which decreases with time.

Thus, quasars recently ejected from an old galaxy would show an anomalous redshift that would tell us how 'young' the matter in those quasars is. As the ejected matter gets older, the extent of 'anomalousness' will decrease. Thus, companion galaxies showing excess redshift of a few thousand kilometers per second must have been ejected from their parent galaxies long ago.

4. Summary of theory

The model just outlined connects together the following salient observations:

(i) It identifies the strongest high energy radiation in the sky, which comes from the direction of the Local Supercluster, as originating in that unique aggregate of active objects.

(ii) It attributes the energy production to ongoing matter creation, a process which replenishes the unavoidably rapid decay of radiation of such high frequency over a very short (compared to cosmic) time scale.

(iii) Since the newly injected matter has initially high intrinsic redshift, the younger, higher energy density quasars and radio galaxies are allowed to be in their apparent location in the Virgo Cluster and naturally identified as the principal contributors to the high energy radiation in the Local Supercluster.

(iv) The extended distribution of the X-ray, and particularly the gamma ray radiation, in Virgo would be a natural consequence of the ejection of new energy into the intercluster medium.

The observations do not presently have enough resolution to show whether the highest frequency radiation is coming directly from the most active objects or whether it is coming from secondary or tertiary or diffused creation points which are ejected into the intergalactic medium from the conspicuous jets which emerge from such well known active nuclei in the region such as 3C274 (M87), 3C273, 3C270 and 3C279. The creation-ejection process can also be further elucidated by studies of the quasars and active companion galaxies associated with Seyfert galaxies [29-32].

5. Independent distance checks on proposed supercluster AGN's

The alignments (Fig. 1) and the luminous connections in X-rays and gamma rays (Figs. 2, 3 and 4) between the brightest active members of the Virgo Cluster, M87 and M49, and the brightest AGN's, 3C273 and 3C279, are the most direct evidence that the latter are members of the Local Supercluster. This is now supported by its suggested identification as the source of the UHCR which cannot travel much further than the distance to the Local Supercluster.

The recent strong outburst of TeV gamma rays from Markarian 421 (about 30 degrees north of the Virgo Cluster and about 10 degrees from the supergalactic plane) cannot be used to estimate distance because of the uncertainty in the density of intervening infrared photons. So far estimates of this density assume the infrared photons are emitted by a homogeneous distribution of galaxies in space [36]. If, however, the large concentration of galaxies in the Local Supercluster is taken into account we can see that the absorption of high energy radiation will be smaller in the outskirts or center than for objects behind the Supercluster. Markarian 421, however, at an apparent magnitude of $V = 12.9$ mag. matches closely the apparent brightness of galaxies in the Virgo Cluster and, if in the outskirts would suffer very litle absorption at TeV wavelengths. Moreover, if it is at the distance of the Supercluster rather than its redshift distance, the luminosity it needs to radiate from a volume only 1-10 light hours in diameter [37] would be reduced by a factor of 100.

On the other hand, if the strong gamma ray source 3C279 were a source of UHCR radiation at its redshift distance, it would be clearly out of the question for it to be able to shine through this very large distance and the Virgo cluster as well. Probably detection at even TeV wavelengths would have something important to say about the distance to this very well known quasar [36].

References

[1] H. Arp, Quasars, Redshifts and Controversies (Interstellar Media, Berkeley, 1987).

[2] G. Burbidge, A. Hewitt, J.V. Narlikar and P. Das Gupta, Ap. J. Supp. 74 (1990) 675.

[3] C. Kotanyi, ESO Workshop on the Virgo Cluster, September 1984, eds. O.-G. Richter and B. Binggeli (1985), p. 13.

[4] H. Arp, J. Astrophys. Astr. (India) 7 (1986) 77.

[5] H. Arp, Phys. Lett. A 129 (1988) 135.

[6] J.W. Sulentic, Phys. Lett. A 131 (1986) 227.

[7] X. Zhu and Y. Chu, Chinese Astron. Astrophys. 19 (2) (1995) 129.

[8] H. Arp, Phys. Lett. A 203 (1995) 161.

[9] H.-D. Radecke, Evidence for Extended Gamma Ray Structure, Astrophys. Space Sci., submitted (1996).

[10] H. Arp, in: Frontiers of Fundamental Physics, eds., M. Barone and F. Selleri (Plenum Press, 1993), p. 1.

[11] T. Stanev, P.L. Biermann, P.L.J. Loyd-Evans, J.P. Rachen and A.A. Watson Phys. Rev. Lett. 75 (1995) 3056.

[12] T. Gaisser et al., Phys. Rev. D 47 (1993) 1919.

[13] D.J. Bird et al. Phys. Rev. Lett. 21 (1993) 3401.

[14] C.A. Norman, D.B. Melrose and A. Achterberg, Ap. J. 454 (1995) 60.

[15] C.A. Norman, IAU Symposium 175, to be published (1996).

[16] G. Sigl, S. Lee, D.S. Schramm and P. Bhattacharjee, Science 270 (1995) 1977.

[17] G. Sigl, D.N. Schramm and S. Lee, FERMILAB-Pub-96/121-A (1996).

[18] J. Miralda-Escudé and E. Waxman, preprint astr-ph 9601012 (1996), ApJ Lett., submitted.

[19] J.N. Hewitt et al., preprint astr-ph 9601046 (1996).

[20] T. Kolatt and T. Piran, preprint astro-ph 9605025 (1996).

[21] F. Hoyle, G. Burbidge and J.V. Narlikar, Ap. J. 410 (1993) 437.

[22] F. Hoyle, G. Burbidge and J.V. Narlikar, M.N.R.A.S. 267 (1994) 1007.

[23] F. Hoyle, G. Burbidge and J.V. Narlikar, A & A 289 (1994) 729.

[24] F. Hoyle, G. Burbidge and J.V. Narlikar , Proc. R. Soc. A 448 (1995) 191.

[25] F. Hoyle and J.V. Narlikar, Proc. R. Soc. A 282 (1964) 191.

[26] J.V. Narlikar, Ann. Phys. 107 (1977) 325.

[27] J.V. Narlikar and P.K. Das, Ap. J. 240 (1980) 401.

[28] J.V. Narlikar and H. Arp, Ap. J. 405 (1993) 51.

[29] W. Pietsch et al., A & A 284 (1994) 386.

[30] E.M. Burbidge, A & A 298 (1995) L1.

[31] H.-D. Radecke, X-ray Sources $< 1^\circ$ from Seyfert Galaxies, A & A, in press (1996).

[32] H. Arp, Identification of X-ray Sources $< 1^\circ$ from Seyfert Galaxies, A & A (1996) in press.

[33] H. Böhringer, U.G. Briel, R.A. Schwarz, W. Voges, G. Hartner and J. Trümper, 368 (1994) 828.

[34] W. Hermsen, H.J.M. Aarts, K. Bernnet et al., Astron. Astrophys. Supp. 97 (1993) 97.

[35] N. Hayashida, K. Honda, M. Honda, et al., Phys. Rev. Lett. 77 (1996) 1000.

[36] F.W. Stecker, O.C. De Jager and M.H. Salaman, Ap. J. 390 (1992) L49.

[37] J.A. Gaidos, C.W. Akerlof, P.J. Boyle et al., Nature 383 (1996) 319.