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Concluding remarks

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We select several highlights from the past week of lectures and discussions to provocatively illustrate a few points of general interest: i) The origin of the high energy neutrinos: either a nearby source, radio galaxies pointed at us at medium redshift, or activity of the earliest stellar or super-massive black holes. ii) The origin of the ultra-high energy cosmic ray particles: For nuclei the radio galaxy Cen A is the best bet, and for protons we may see the local 100 Mpc volume, only limited by magnetic fields. iii) The duty cycle of an AGN: There are several arguments that suggest that active galactic nuclei have a small duty cycle, and relativistic jets may have an extremely short duty cycle. iv) The prevalence of echoes, both in photons and in particles: We now routinely detect echoes from transient beams of ultra-violet light, and we ought to also detect the effects of transient particle beams. v) The propagation of photons and protons from relativistic jets pointed at Earth: There is a possibility that the magnetic fields in intergalactic space are either extremely weak, or extremely structured, so as to allow near-straight-line propagation of very energetic protons, producing gamma photons in interaction with the extragalactic radiation field; these gamma photons may contribute to the emission of high redshift relativistic jets pointed at us. And finally vi) What we might detect of the early universe: with the most challenging the discovery of the formation of the first generation of super-massive black holes, in as yet unseen gigantic explosions at high redshift.

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1. Selected Highlights

- 1 Where do High Energy (HE) neutrinos come from ? Sofar we have near isotropy of the arriving events, with a very uncertain possible cluster of events in the general region of the Galactic Center, prompting some to propose a theory just for events originating in the central part of the Galactic plane, certainly the most active star forming area in the Galaxy (e.g. Bykov et al. 2015). On the other hand, in analogy to compact flat spectrum radio sources, GeV and TeV emitters, all of which can be understood as relativistic jets pointed at Earth, it seems very plausible, that all other high energy particle emitters will also a member of this class of sources. However, if so, the identification of the first such source ought to be possible soon. The polarized high frequency sources detected by Planck could be an interesting database for such a search, just as the list of all compact flat spectrum radio sources detected at frequencies of 5 GHz or higher.

- 2 Where do Ultra High Energy Cosmic Ray (UHECR) particles come from ? The Auger array seems to detect a clustering of events near the radio galaxy Cen A, long predicted as a major candidate for high energy cosmic particles. The Telescope Array (TA) sees a hot spot not very far from the starburst galaxy M82, one of the best candidates to have a recent invisible Gamma Ray Burst (GRB), and so a possible emitter of UHECR particles.

- 3 What is the duty cycle of jet AGN ? The spatial structure of radio galaxies strongly suggests that the powering of the relativistic jets is highly intermittent: the observations of the radio galaxy Her A look as if energy had been deposited in various points at the of an activity episode of the jet, pointing in slightly different directions. Are radio galaxies really just a sequence of bursts, so better described as Bursting Radio Galaxies (BRGs)?

- 4 Echoes in photons and particles ? We see light echoes in many places, and they do support the view-point that the on-times of these ultra-violet beams emanating from the invisible center of a galaxy are very brief, of order down to 10^4 yrs. Similarly, energetic particles might be ejected only in bursts (such as by a GRBs) and have consequences, such as the decay of the neutrons in a beam.

- 5 High z blazars ? TeV consequences ? The spectrum and photon energies detected from high redshift blazars (powerful relativistic jets pointed at Earth) are just about compatible with the far-infrared (FIR) radiation field deduced from galaxy counts. However, if we were to detect even even higher energy gamma-ray photons from the same high redshift blazars, or from blazars at even higher redshift, the consequences would present a serious challenge. A possible alternative explanation (Essey & Kusenko 2010, 2014, Essey et al. 2010, 2011a, b) could be that protons already at EeV energies travel nearly straight, interact with the ambient radiation field, and so produce the observed gamma rays as secondary emission. The requirement on intergalactic magnetic field would be extreme, either in strength or in structure.

- 6 Final: do we see the very early universe ? What is the possibly strongest manifestation of the very early universe? I posit that the formation of the first generation of Super-Massive

PoS(MULTIF15)076

Black Holes (SMBHs) could be the most likely discovery, gigantic explosions, with much more energy than a GRB, but also much slower. We cannot say at this time, whether these formation events would immediately be accompanied also by relativistic jets, only some of which may point at Earth. The event ought to be a transient, and its redshift might be detectable via absorption lines of molecular neutral or ionized HD.

2. Where do HE neutrinos come from ?

IceCube has published a number of papers since 2013 on the spectrum and sky distribution of high energy neutrino events (Abbasi et al., IceCube-Coll., 2012; Aartsen et al., IceCube-Coll. 2013, 2014, and 2015). As yet there is no clearly identified source. The sky distribution is consistent with isotropy; a difficulty is that some events have an error circle on the sky of radius about 10 degrees, and others of about 1 degree. The spectrum is somewhat steeper than E^{-2}, but the error bars are still large; the spectrum is consistent with a single power-law with no certain cut-off apparent.

The possible sources - assuming that at the current number of events there is only one source class - could be quite close, like most starburst and active galaxies from about redshift 1 to 2, or like all activity connected to a very low metal abundance, at very high redshift. In the first two cases we do have a chance to identify the sources, despite confusion.

If the sources were really close, then they surely would have been identified already: However, since most events have a large directional error circle, many possibilities remain; in fact, several events are consistent with one region in the inner Galaxy, and if processes in this region allow acceleration to far beyond PeV (10^{15} eV), so as to produce PeV neutrinos in interaction, it could be a viable explanation just for these events, making them a special case. To do this would require that in this region, probably exemplary for others, cosmic ray (CR) sources exist with a very different spectrum than what appears to be normal in the Solar neighborhood: The injection spectrum deduced for the explosion of very massive stars is $E^{-2.33}$, compatible with what IceCube sees. However, the turn-over called the *knee* at about a few PeV in particle energy, would have to be shifted to much higher energy, at least about 100 PeV to explain the data. It is remarkable that in the observed CRs the knee is a very well defined feature, as if all explosions contributing adhere to the same energy/charge ratio. This is not suggestive of a wide distribution of this critical energy across the Galaxy; we do sample quite a large local region in these CRs. For such a proposal to be viable, it would be an odd coincidence, that the sky distribution is well approximated by isotropy. The interaction length for CRs in different directions is vastly different (as is clear from γ-ray data), making isotropy hard to understand, unless the distance from which we see the freshly produced neutrinos is well contained within the thick CR disk, contradicting the CR data. So a tantalizing but very speculative possibility.

Next let us consider galaxies, starburst galaxies and Active Galactic Nuclei (AGN):

Let us use the Olbers' integral for the background, expressed as energy flux per solid angle in the low redshift limit, ignoring the spectral behavior, since the spectrum is nearly flat:

$$F_{\nu} \sim \int N_z \, z^2 \, \frac{L}{z^2} \, dz \sim \Delta z,$$

Almost all normal sources obey approximately $N_z \sim (1+z)^3$, up to about some critical redshift between 1 and 2, in the comoving frame. This means that in such an integral $z_{sources} \sim 2$ will dominate strongly, just as found for the far-infra red (FIR) radiation field (Lagache et al. 2005; Dole et al. 2006; Costamante 2013). This is true for galaxies, starburst galaxies, as well as Active Galactic Nuclei (AGN). Relativistic jets pointed at Earth, have very strong selection effects due to relativistic boosting (Gregorini et al. 1984), and show a somewhat different evolution, not quite as straight-forward to quantify including high redshifts.

For some possible source classes N_z runs inversely with heavy element abundance mass fraction Z, so let us consider the Olbers' integral in the high redshift limit:

$$F_\nu \sim \int N_z \frac{L}{(1+z)^{7/2}} dz \sim \int \frac{N_z L dt}{(1+z)},$$

For Δt given as a fixed lifetime $\Delta z \sim (1+z)^{5/2} \Delta t$ we obtain a stronger contribution at very high redshift, for $N_z \sim (1+z)^{1+\varepsilon}$ for $\varepsilon > 0$ allowing for low heavy elements to produce more active sources; assuming the energy output to be fixed implies $\int L dt$ given as a constant, and so the redshift of the dominant population is large $z_{sources} >> 2$:

But are neutrino sources actually visible at very high redshift ?

Redshifts of z up to 100 are possible for first star formation (Biermann & Kusenko 2006), where the key is H_2 formation stimulated by DM-decay (assuming DM to be a sterile neutrino) and cooling; this cooling can be extreme, and would be especially strong in the shockwaves due to supersonic flow between baryonic and dark matter (DM) (Tseliakhovich & Hirata 2010, O'Leary & McQuinn 2012, Visbal et al. 2012, Fialkov 2014). These shocks might attain the cooling limit, and so allow baryonic density jumps of order 10, at an epoch when the DM has fluctuations still extremely weak, far below unity in relative density fluctuations.

However, we need to remember that neutrinos do interact ! At very high redshift the observed PeV neutrinos will be at correspondingly even higher energy locally, and so interact even more. The 2015 Planck results give for the baryonic density relative to the critical density $\Omega_b = 0.04860 \pm 0.00031$ (Ade et al., Planck-Coll. 2015). As the density runs as $\rho_{bar} \sim (1+z)^3$, the interaction probability steeply rises with redshift. Interactions with photons could become even more important, as their energy density increases as $\rho_{rad}\,(1+z)^4$, and the photon energy as $(1+z)$. Work by Todor Stanev (priv.comm.) suggests that for observed PeV neutrinos the limit is a redshift of about 18.

So, if highest energy νs arise, with a straight unbroken power-law spectrum to the observed PeV energies, from first generation of SMBH, then this must have originated at a redshift below this limit ! If the highest observed neutrino energies are even higher, with a straight spectrum, the cutoff redshift is even lower. On the other hand, if we were to find a strong cut-off at some energy, this would immediately suggest a critical redshift with most of the sources at higher redshift. so an analogon to the famous GZK-cut-off (Greisen 1966, Zatsepin & Kuzmin 1966).

The same argument sets limits on any interaction with DM, whatever its nature. If, as some argue, the DM particle is a keV sterile neutrino (Hogan & Dalcanton 2000, Dalcanton & Hogan 2001, Biermann & Kusenko 2006, de Vega et al. 2014, and others) then the question is especially interesting, although it may limit only pre-star formation processes.

PoS(MULTIF15)076

3. Where do UHECR particles come from ?

The Auger array has published a sky distributions and a spectrum (Aab et al., Auger-Coll., 2014a, 2014b, 2015a, 2015b), showing a power-law below the ankle (at around 3 EeV (= $3 \cdot 10^{18}$ eV), a distinctly flatter short power-law segment at higher energies, and then a cut-off. It is not clear whether this cut-off is due to interaction of the particles with the intergalactic radiation field, or due to energy limit in the source(s). It is interesting to note, that the UHECR-spectrum may be quite consistent with the typical spectrum of radio galaxies not pointed at Earth of $E^{-2.64 \pm 0.08}$ (Gregorini et al. 1984).

The sky distribution is suggestive of a clustering around the nearest radio galaxy Cen A (Kotera & Olinto 2011, Aab et al., Auger-Coll., 2015b), as predicted more than fifty years ago by Ginzburg & Syrovatskij (1963). If the chemical composition of elements heavier than Helium is confirmed finally, then Cen A may be the only viable source. Gopal-Krishna et al. (2010), Biermann & de Souza (2012), and Todero Peixeto et al. (2015) have shown how a normal CR population can be used to explain the spectral, abundance and directional data, using the single-kick limit of the mechanism of Achterberg (Gallant & Achterberg 1999, Achterberg et al. 2001); in this mechanism a relativistic shock emanating from the central super-massive black hole (SMBH) in an activity episode can shift the pre-existing CR-spectrum up by a constant factor, preserving the shape of the spectrum. The near-isotropy of all the UHECR events is due in such a picture to scattering in the halo-wind of our Galaxy, sure to be there using the criteria of Rossa & Dettmar (2003), and the analysis of Everett et al. (2008, 2012), Uhlig et al. (2012), and Sarkar et al. (2015). In such a picture, the sum of all radio galaxies, most of which most accelerate protons and some Helium, might explain the lower energy extragalactic component predicted in Rachen et al. (1993), and now detected. Alternate pictures also using the radio galaxy Cen A have been worked out by several other groups (e.g., Kachelrieß et al. 2009; Yüksel et al 2012; Wykes et al. 2013, 2014, 2015; Keivani et al. 2015; Unger et al. 2015; Farrar & Piran 2010, 2014; Müller et al. 2015), all following Ginzburg & Syrovatskij (1963).

The Telescope Array (TA) has also published (Abbasi et al., TA-Coll., 2012, 2014, 2015) its spectrum and sky distribution; it sees what it calls a hot spot, so a possible cluster of arrival directions of the events, not very far from the starburst galaxy M82 (Fargion et al. 2014). From this galaxy the most plausible possible source of UHECRs would be GRBs; for this explanation to be viable, and under the assumption, that this hot spot is real, the orbits need to be bent slightly to allow a relation to M82.

Gaisser et al. (2013) have given an analysis of all CR experiments focussing on the chemical composition using the parameter of the average atomic weight in the form $< \ln A >$ plotted vs energy E per particle. In this plot two lows and two highs are apparent, with the chemical composition steadily rising from GeV energies towards about 100 PeV, then rapidly dropping again, to rise again from around 3 EeV towards the unknown, but certainly much heavier than simply Helium. So it appears as if the rise in chemical composition is repeated at high energy; the explanation offered in Gopal-Krishna et al. (2010) is in fact, that this is the same rise, just shifted up in energy by a relativistic shock (Gallant & Achterberg 1999, Achterberg et al. 2001); in the single kick limit mechanism the shape of the spectrum is preserved. This is the scenario outlined above.

PoS(MULTIF15)076

4. What is the duty cycle of jet AGN ?

There is much evidence that the activity of AGN is intermittent:

The optical light echoes discussed below show variability time-scales of down to 10^4 years, while the overall time-scale, the envelope of many episodes perhaps is usually estimated to be of order millions of years.

The radio picture of the radio galaxy Her A (Gizani & Leahy 2003) suggests, that the jet aims in slightly different directions, and basically deposits a lot of energy in a very confined region, making Her A appear as a series of shells, which look naively just like Super-Nova Remnants (SNRs). Clearly, a strong rise in jet-power for a brief period of time, and a rapid decay afterwards might be a viable explanation for this observation.

For the radio galaxy M87 there are very different estimates of what maximal particle energy is allowed just by the Larmor motion (the Hillas 1984 criterion), at kpc scale energies beyond 10^{20} eV are allowed (Biermann & Strittmatter 1987), for sub-parsec scales only very much less seems allowed (Kino et al. 2015), less than about 10^{19} eV. Again, variability seems to be a viable explanation.

Now, Zdziarski & Böttcher (2015) have again looked the possible hadronic processes in jet AGN, and have argued that the duty cycle has to be extremely small. While one may quibble with their choice of the assumed parameters in the hadronic model, they attempt to shoot down, the essential argument remains: The source has to be extremely intermittent to be viable as a hadronic source. Is this analogous to the activity loops which we observe in active stars (Walg et al. 2014)?

I agree, my conclusion is indeed: AGN are extremely intermittent. And it would certainly help explain the highest particle energies observed, if the normal radio galaxies, for which we observe some long time integral of activity in their radio emission, were in fact intermittently very much more powerful than the observations suggest. That would allow much higher particle energies, and then the sum of the nearby radio galaxies would easily suffice to explain the flux and spectrum observed by TA and Auger. In such a concept the observed radio galaxies show the time integral of the many very brief episodes of jet activity.

5. Echoes in photons and particles ?

Light echoes are known in astronomy for more than a hundred years (Kapteyn 1901), although the correct interpretation was only done by Couderc (1939), using observations of 1901 and 1902. Echoes were again invoked for SN 1987A (Schaefer 1987), and other SNe (e.g., Krause et al. 2005, Dwek & Arendt 2008).

Echoes have been invoked as well in the center of our Galaxy, to explain certain features in X-rays and γ-rays (e.g., Neronov et al. 2010).

Now many light echoes have been discovered, from episodic activity emanating from the compact regions in the center of galaxies, such as a SMBH (Keel et al. 2012, 2015; Gagne et al. 2014). A burst of ultraviolet light emitted in a direction almost sideways to the line of sight, and coming from a central region of the galaxy often obscured to view, excites an echo in ionized Oxygen (O^{++}). The fact, that the echo is visible, while the central activity is surely all gone, allows a time scale to be estimated, and this sometimes on time scales as short as 10^4 yrs.

One might so expect that GRBs also give rise to echoes, both in their photon emission, after all reaching γ-ray energies, as well as in particles. An especially interesting speculation could be if in the acceleration and interaction of ultra high energy particles many very high energy neutrons are also produced (Rachen & Mészáros 1998, Biermann et al. 2004). A beam of energetic neutrons has the interesting properties, that they decay back to protons at a distance commensurate with their energy, due to relativistic time dilation, and so these resulting protons then may interact along a line as seen from Earth. What we might observe is then the result of these secondary interactions. There is no such confirmed observation yet.

Similarly, the ionizing radiation of a GRBs could produce a thin double-cone of gas, that may remain ionized for long at sufficiently low density, and so make it appear just as the string of bubbles along the path of an ionizing particle in a bubble chamber in a science museum. One might speculate, that each star forming galaxies might be traversed by quite a few such thin cones, if we could only figure out how to detect them.

It seems obvious, that the potential of echo observations both in photons as well as in particles is not exhausted.

6. High z blazars ? TeV consequences ?

Nowadays we can detect blazars such as 3C279 at TeV photon energies coming from a redshift of 0.5. Many years ago, using the FIR background models available then, the maximal redshift to detect TeV energies in γ-photons was argued to be of order 0.1 (Mannheim et al. 1996). Is this a crisis? Some believe, that the recent high redshift detections are a problem. However, using strictly only the source counts of FIR galaxies, all observed spectra can still be explained (Costamante 2013).

But as already speculated in Mannheim et al. (1996) if we were even more successful in detecting high redshift blazars at near TeV photon energies, we may get into a problem. Then we may require that near EeV protons go nearly along a straight path to Earth, and produce the observed TeV-γ-rays through interaction with the intergalactic radiation field (see also Kneiske & Dole 2010, Abramowski et al., H.E.S.S.-Coll. 2013). This has been thoroughly discussed by Essey & Kusenko (2010, 2014), Essey et al. (2010, 2001a, 2011b).

On the other hand, the extremely low magnetic fields implied in such an argument violate self-consistent simulations of cosmic magnetic fields as well as the observations (Ryu et al. 2008, 2010; and Kronberg et al. 2007, 2008). Can we reconcile these two vastly discrepant lines of reasoning?

One aspect is striking and that is in all these cosmic simulations the energy input from AGN, and especially radio galaxies is completely missing; and yet, their energy output might be equivalent, if not even stronger than all the other sources of energy for the magnetic field. Radio galaxies can reach Mpc distances, reach far outside of groups and clusters (e.g., Gopal-Krishna & Wiita 2001, Colafrancesco et al. 2014); the winds of starburst galaxies may still be enough to reach out to scales of the order of 100 kpc or more. All this is neglected in the simulations, that are already in conflict with the hypothesis of a straight-line propagation of protons, and AGN, especially radio galaxies, and it would add even more energy.

Radio galaxies visibly push gas around (see, e.g., the Perseus and Virgo clusters in combined X-ray and radio images), and so possibly produce thin transition layers, shocked regions, where

PoS(MULTIF15)076

the magnetic field is very high, but only in a thin sheet-like geometry. If all the energy put into magnetic fields in simulations such as (Ryu et al. 2008) were not distributed smoothly, but all pushed into thin highly convoluted sheets, might this allow a net propagation of near EeV protons that is almost straight? If so, should we be able to identify these radio galaxies and blazars directly from Auger observations (Aab et al., Auger-Coll., 2014b)?

If so, proton initiated cascades might contribute to the observed TeV γ-ray photons.

7. Final: do we see the very early universe ?

What can we expect to detect from the very early universe? The first zero-heavy element stars, and their explosions, distributing the first heavy elements and dust, the first possibly super-massive stars, and their explosions, possibly leading to the very first generation of SMBHs?

A very first step would be to verify the origin of the high energy neutrinos and UHECRs, so as to understand, what processes might produce such particles in the very early universe, detectable directly perhaps via UHECR interactions producing energetic neutrinos.

In this quest we will possibly also learn, whether the observed neutrinos come from nearby, from the epoch around redshift 1 to 2, or from a very much higher redshift.

Matching the observed UHECR particles at energies both below and above the ankle, at 3 EeV, to their possible sources will allow to comprehend the role of intergalactic magnetic fields, limiting the reach of these particles, and confining them.

We need to verify the non-thermal radio background detected by Fixsen et al., Kogut et al., and Seiffert et al. (all 2011), and identify the sources; taken in conjunction with the source counts (Condon et al. 2012) surely extended and probably overlapping.

Going to yet higher redshift ought to allow us to verify that big disk galaxies never merged, and were large from early on. Combining Spitzer and Gaia results may already help.

If SMBHs formed early in a first generation, possibly all with a mass of the same order of magnitude as the Galactic Center BH, then their formation and merger surely produced a GW background, that may be detectable with the satellite mission Gaia, as well as with pulsar timing. The giant SMBHs observed today quite possibly formed by merging at an early epoch, beyond today's observations. The gravitational wave background formed during the formation and merging ought to be there, and give strong clues to when this all happened.

To check on the redshifts in the very early universe, absorption lines of neutral and ionized HD ought to be the best candidate.

But the main goal must be the detection of the explosive events leading to the formation of the first generation of SMBHs. This epoch ought to be detectable in all avenues available today or in the foreseeable future to observation, such as radio, low energy γ-photons, neutrinos and gravitational waves (Mignard & Klioner 2012, Klioner 2014, Taylor et al. 2015). A detection of gravitational waves will surely start to open up a path to today's holy grail of physics, the unification of gravity with quantum physics.

Thank you!

PoS(MULTIF15)076

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