

Concluding Remarks - II

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I summarise the concluding remarks I gave at the Multifrequency Behaviour of High Energy Cosmic Sources - XIII Workshop. That was *not* a summary talk and was meant to be provocative. I first give what I think the main message of the workshop was, then provide some (biased) highlights, touch upon the upcoming new facilities and the issues of “quantity vs. quality” and productivity in astronomy, and finally conclude with a look to the future. Astronomers who did not attend the workshop might still find the first two topics appealing and the last two thought-provoking.

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*Speaker.

1. The end of an era

If I had to summarise in one sentence this workshop, I would say this: *It marked the end of an era and the beginning of a new one.* People have a tendency to think that their epoch is somewhat special compared to previous ones but in our case, it really is! In the last couple of years we have witnessed the birth of (non-stellar) multi-messenger astrophysics¹. First, there was the detection of the first gravitational wave (GW) event by LIGO in 2016 [1] [Gondek-Rosinka, Poggiani²], followed by the association in 2017 between a LIGO/Virgo event (GW170817) and electromagnetic emission from a binary neutron star merger (GRB 170817A) in the galaxy NGC 4993 at $z = 0.01$ [3] [D’Avanzo]. Then there was the first association of high-energy IceCube neutrinos with a blazar at $z = 0.3365$, TXS 0506+056, in July 2018 [15, 16, 24] [Righi, Paredes, Padovani]. And, as a bonus, this year we also had the first image of the “shadow” of a black hole (BH) [10] [De Laurentis]. What an amazing time to be an astronomer!

While the astrophysical relevance of the GW170817/GRB 170817A event has been discussed at length in the literature, I feel this is not the case for the neutrino result. This has a number of astrophysical implications [24]: 1. with neutrinos we are now exploring an energy range (\sim PeV $= 10^{15}$ eV) which is, and will always be, inaccessible with photons at this (or any!) redshift. That is because these very high-energy photons collide with IR/mm photons (the so-called extragalactic background light [Costamante, Paredes]) and are annihilated with the resulting production of electron – positron pairs. Neutrinos provide us then with a new and unique window on blazar physics; 2. the spectral energy distribution of at least one blazar has to be modelled using protons (the so-called lepto-hadronic scenario), laying to rest a debate (leptons or hadrons?), which has been around for decades; 3. the number of known neutrino sources has jumped by 50% from two (the Sun and SN 1987A) to three. And we have identified the first non-stellar neutrino source; 4. the *first* cosmic ray (CR) source has been identified. The IceCube results, in fact, imply the existence of protons with energies $\gtrsim 1$ PeV, around the so-called “knee” of the CR flux distribution [Caccianiga], in the blazar TXS 0506+056. And as it often happens when new, ground-breaking observations are available, theorists have some difficulty in explaining in a coherent way the electromagnetic and neutrino emission in TXS 0506+056 (e.g. [18, 32]) [Righi].

2. Selected topics at this workshop

The advent of this “new era” is also apparent in the topics discussed at the workshop, which are shown in Fig. 1: a conservative estimate shows that 21% of the talks dealt with multi-messenger (i.e., non “photon-based”) astronomy. This is a considerable fraction, which reflects also the fact that this was the first Frascati Workshop after the LIGO/Virgo and IceCube results. I now touch upon some selected (and biased) topics, which were discussed at the workshop.

2.1 Peak luminosities of Gravitational Wave events

The GW events reach extraordinary values of peak luminosity, so far all but one above 10^{56}

¹This birth happened actually in 1968 with the discovery of solar neutrinos and then (again) with the detection of neutrinos from SN 1987A. Hence the addition of “non-stellar”.

²I include the names of the speakers who dealt with the topic at hand during the Workshop.

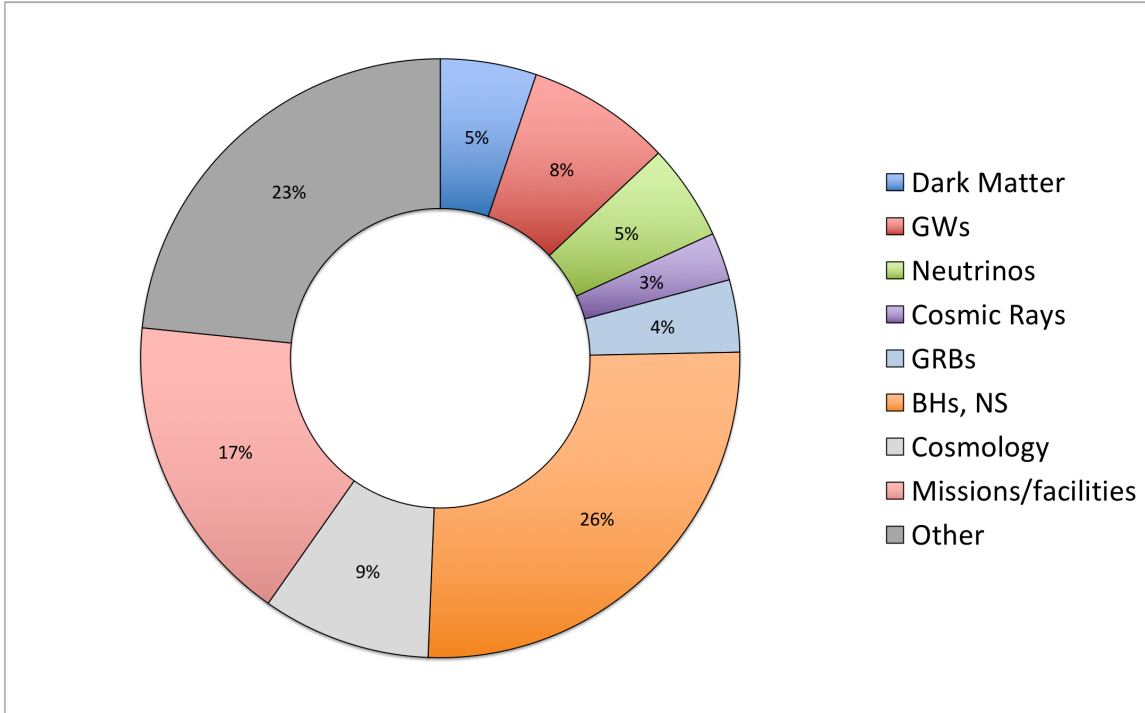


Figure 1: The distribution of talks at the workshop grouped by topics: 21% of the talks dealt with multi-messenger astronomy.

erg s^{-1} (Tab. III of [4]), albeit over a very short time (\approx a few ms) [Gondek-Rosinka, Poggiani]. These can be compared to the powers of Active Galactic Nuclei (AGN), with $L \lesssim 3 \times 10^{48} \text{ erg s}^{-1}$ over more than tens of millions of years, and γ -ray bursts, with $L \lesssim 5 \times 10^{54} \text{ erg s}^{-1}$ over a few seconds. Amazingly enough, the GW luminosities are even larger than the power emitted by all the stars in the Universe! An upper limit to this value can be roughly calculated by multiplying the luminosity of the Milky Way ($\sim 8 \times 10^{43} \text{ erg s}^{-1}$) by the number of galaxies in the Universe ($\approx 10^{12}$: [8]), which gives $L_{\text{all stars}} < 8 \times 10^{55} \text{ erg s}^{-1}$ (as most galaxies are less luminous than the Milky Way).

These powers are also quite close to the *maximum* luminosity of any physical system, which is sometimes called the Planck luminosity L_{Planck} [27, 2]. This can be derived by dividing the rest mass energy of a body (Mc^2) by the crossing time of its event horizon ($\sim [2GM/c^2]/c$), which yields $L_{\text{Planck}}/2$, where $L_{\text{Planck}} = c^5/G = 3.63 \times 10^{59} \text{ erg s}^{-1}$.

On a separate note, although the LIGO/Virgo data are not sensitive to the signal of binary supermassive black hole (SMBH), GW data have already been used in this context: [17] have excluded the presence of a binary SMBH in 3C 66B, a radio galaxy at $z = 0.02$, using pulsar timing [Possenti]. Were this binary BH there, in fact, as had been suggested by radio observations, it would have been apparent in the 7 yr of timing data from the radio pulsar PSR B1855+09.

In general, accreting systems, ranging from white dwarf binaries to cataclysmic variables to X-ray binaries to AGN, are potential gravitational wave emitters at different scales [Poggiani]. The spectrum of GWs from these systems is very broad and their detection requires ground based interferometry, space based interferometry, and pulsar timing.

2.2 Getting really close to black holes

The Event Horizon Telescope (EHT) has given us the first ever images of the “shadow” of the BH at the centre of M 87 [10] [De Laurentis], which has allowed the EHT collaboration to determine its mass ($6.5 \pm 0.7 \times 10^9 M_{\odot}$). The diameter of the shadow is ~ 5.5 times the Schwarzschild radius of the SMBH. It is estimated that these images have been seen by about three billion people (H. Falcke, p.c.), which would make these the most popular images of all times. With a jet inclination angle $\sim 17^{\circ}$ [31] M 87 is *almost* a blazar of the BL Lac type [29] (see also Sect. 2.5).

GRAVITY at the ESO/VLT is also getting very close to the BH at the centre of the Milky Way by studying flares at distances $\sim 3 - 5$ times the Schwarzschild radius, with significant and continuous positional changes of the emission centroid corresponding to $\sim 30\%$ the speed of light [14] [Borkar]. The Extremely Large Telescope³, which in 2025 will be the largest optical-near-IR telescope in the world with a diameter of 39m [Padovani], will be able to detect a $10^6 M_{\odot}$ BH up to ~ 30 Mpc and a $10^9 M_{\odot}$ one up to ~ 1 Gpc. This will provide an increase in the distances reachable with current 8-10m telescopes of a factor ≈ 5 . The ELT, thanks to its much better resolution, will also be able to get even closer to BHs than currently possible.

2.3 Black hole spins

We have also heard about BH spins [Aschenbach, Bambi]. The mantra in the AGN community has been for years that jetted AGN [22] (also called, I think misleadingly, “radio-loud”) are powered by a rotating BH while non-jetted AGN are not [23]. X-ray reflection spectroscopy is currently the only available method to measure the spin of SMBHs and 70% of AGN have very high a_* (> 0.9 , where $a_* = cJ/GM^2$ is the dimensionless BH spin parameter and J is the angular momentum) [Bambi]. But most of these are non-jetted AGN, which should be non-rotating. However, these spin measurements have to be taken carefully, as they may be affected by systematics related to the model employed to infer them [7].

M 87 is a classical jetted AGN. I would have then expected the EHT collaboration (Sect. 2.2) to find a relatively high value of a_* . However, the M 87 papers just say that “compact 1.3 mm emission in M87 arises within a few r_g of a Kerr BH” [11]. So we know that the BH at the centre of M 87 is rotating but more data are needed before a specific value of a_* can be provided. This reflects the fact that the size of the shadow of a Kerr BH depends only weakly on spin (and inclination) [25].

The LIGO/Virgo GW data can also constrain spins [Gondek-Rosinka, Poggiani], in this case of stellar BHs. Table III of [4] provides values of χ_{eff} , which is a mass-weighted linear combination of the spins of the two merging BHs projected onto the Newtonian angular momentum. Only in 2/11 cases can $\chi_{\text{eff}} = 0$ be excluded at $> 90\%$ confidence, which means that the data disfavour scenarios in which most BH merge with large spins aligned with the binary’s orbital angular momentum.

2.4 Magnetars

I really enjoyed learning about magnetars [Mereghetti, Nakagawa, Dainotti, D’Avanzo, Ferrazzoli]; see also [21]. A magnetar is a type of neutron star having a huge external magnetic field $\sim 10^{13} - 10^{15}$ G, i.e., up to $\sim 1,000$ above the average. This is the main source of energy, instead of

³<http://www.eso.org/sci/facilities/eelt/>

the rotation, accretion, nuclear reactions, or cooling, which power the more normal neutron stars. What are now called magnetars were initially split into two separate classes of sources, soft γ -ray repeaters and anomalous X-ray pulsars. The main properties of the two dozen magnetars known in the galaxy and the Magellanic Clouds are their slow rotation periods ($P \sim 2 - 12$ s), persistent X-ray powers ($L_X \approx 10^{34} - 10^{36}$ erg s $^{-1}$), faint optical/NIR counterparts ($K \sim 20$), and strong variability, with powerful short bursts in the X-rays and soft γ -rays, often reaching super-Eddington luminosities. Three *giant* flares have also been observed with huge peak powers. The most powerful one ($\approx 10^{47}$ erg s $^{-1}$) came from SGR 1806–20 on December 27, 2004 and was mind-boggling: more than 20 satellites recorded this exceptional event, which started with a hard pulse so intense that it saturated most detectors and significantly ionised the Earth’s upper atmosphere [20]. The flare was brighter than anything ever detected from beyond our Solar System with a fluence ~ 2 erg cm $^{-2}$ ($E > 80$ keV) and lasted over a tenth of a second. Magnetars are also possible GW sources both through their fast rotation, which leads to deformations, and their impulsive activity.

2.5 Blazars

Blazars are AGN hosting a relativistic jet oriented at a small angle ($\lesssim 15 - 20^\circ$) w.r.t. the line of sight [29, 22]. This translates into very interesting and somewhat extreme properties, including relativistic beaming, which makes blazars appear orders of magnitude more powerful than they really are, superluminal motion, and strong, non-thermal emission over the entire electromagnetic spectrum and beyond, i.e., into neutrino territory. At the meeting we heard the latest news about blazars [Costamante, Böttcher, Pittori]. These include the image of the “shadow” of the BH at the centre of M 87, which is “almost” a blazar (Sect. 2.2) and the first association of high-energy IceCube neutrinos with a blazar of the BL Lac type at $z = 0.3365$, TXS 0506+056 (Sect. 1). Apparently Nature loves disks and jets, as they seem to be present in a variety of astronomical objects ranging from stars and planetary systems, X-ray binaries, and AGN, including blazars of the “flat spectrum radio quasar” (FSRQ) type. In the latter, however, it looks like the power of relativistic jets is larger than the luminosity of their accretion disks [13]. γ -ray emission in FSRQs is generally explained as inverse Compton radiation of relativistic electrons in the jet scattering optical-UV photons from the broad-line region (BLR), the so-called BLR external Compton (EC) scenario. However, [9] have found no evidence for the expected BLR absorption, with only 1 object out of 10 being compatible with substantial attenuation, which essentially rules out the EC mechanism and implies that γ -ray emission originates predominantly outside the BLR. This has important implications for the theoretical interpretation of the spectral energy distributions of blazars and it also means that CTA should see many more FSRQs than previously thought. Finally, the Astro-rivelatore Gamma a Immagini Leggero (AGILE) satellite, has found three transient γ -ray sources ($E > 100$ MeV) temporally and spatially coincident with recent high-energy neutrino IceCube events [19]. The post-trial chance probability for this to happen is $\sim 4.7\sigma$. One of the objects is the already known neutrino source TXS 0506+056 (Sect. 1). For the other two there are no obvious counterparts, although one of the most interesting sources is (again) a blazar of the BL Lac type (3FGL J0627.9–1517).

2.6 Supernovae (in the optical band)

Last but not least, I wanted to mention two examples of synergy between supernovae in the

optical band and cosmology. We learnt that extinction in starburst clusters is temporarily altered by type II SNe for $\sim 50 - 100$ Myr after the star formation episode, which has important implications for extinction corrections in the early Universe [De Marchi]. And also that SNe Ia are dimmer in ellipticals and brighter in spirals, which implies that the supernova properties depend on their environment. Said differently, one needs to include a host galaxy term into the Hubble diagram fit, which is used to constrain the shape of the Universe [Pruzhinskaya].

3. New facilities and the era of “even bigger data”

We have also heard about some of the new facilities, which will come online in the next few years (or have been recently starting taking data) and will be very relevant for the topics discussed at the workshop. These include, without any claim to completeness (and in rough chronological order within a band):

- Radio: ASKAP, MeerKAT, e-MERLIN, APERTIF, SKA
- IR: JWST, Tokyo Atacama Observatory, Euclid, WFIRST, SPICA
- Optical/near-IR: Zwicky Transient Facility, LSST, ELT, GMT, TMT
- X-ray: eROSITA, IXPE, SVOM, eXTP, XIPE, Athena, Theseus, FORCE, XRISM, Colibrì
- γ -ray: Large High Altitude Air Shower Observatory, CTA

... and certainly more, including CubeSats [Bernardini, Caiazzo, Ferrazzoli, Hudec, Ishida, Mori, Padovani]. These are going to move us from the “big data” era into the “even bigger data” era. For example, while the volume of the Sloan Digital Sky Survey was around 40 Terabytes, the LSST will reach 200 Petabytes, while the SKA will get into Exabyte territory [33].

3.1 Quantity vs. quality

More data might mean more papers. Can we see signs of increasing astronomical output also in terms of published papers? Yes, as shown in Fig. 2 (red line). After a slow rise the numbers have started to pick up after around 1960. Is this a good sign? Well, about 50% of all science papers have ≤ 1 citations, based on a study of about 58 million papers published since 1900 [30]. And the percentage of papers published in 2009 with no citations other than self-citations after 5 years, based on 120 million academic papers, is 72.1%, down from even higher values in previous years [12].

The case for astronomy looks much better, although the studies I found were old and/or limited in numbers: 3.3% of papers (283/7724) published in 2001 and 2002 in 20 journals are never cited during the three calendar years after the one in which they were published [28]; and 6.1% of papers (20/326) published in 1961 in American journals are never cited during the 18 years after publication [5]. To get some better statistics I picked two random contiguous years (2000 and 2001) and used the Astrophysics Data System. Out of the 39,972 astronomical refereed papers published in that time period 15.8% (6327) gathered zero citations to date. Most of these are in (many) minor



Figure 2: The number of astronomical papers (red line) and publishing astronomers (blue line) per year vs. year. Note the logarithmic scale on the y-axis. Courtesy of Robert Simpson: see <https://orbitingfrog.com/2012/08/04/authorship-in-astronomy/>.

journals. If I consider only AAS journals, A&A and A&AS, MNRAS, PASP, and PASJ the fraction of never cited papers gets much smaller, i.e., 1.3% (159/12568).

But is quantity correlated with quality? Or is there actually an inverse correlation? A “destructive feedback between the production of poor-quality science, the responsibility to cite previous work and the compulsion to publish” has been pointed out [26] (see also Franco Giovannelli’s introductory remarks at this workshop). The same paper talks also about the fact that “Current trajectories threaten science with drowning in the noise of its own rising productivity ... Avoiding this destiny will, in part, require much more selective publication. Rising quality can thus emerge from declining scientific efficiency and productivity. We can start by publishing less, and less often”. Granted, this paper deals with biology but some of these points apply to astronomy as well. Whose fault is it? At least partly ours. We as referees, together with the journal editors, allow way too many papers to get published⁴. Moreover, I have the feeling that the system, to which we all belong, tends to give way too much importance to quantity, which is easier to evaluate, and less to quality.

But are we really publishing more? No: per capita we are publishing less! Fig. 3 shows that while in 1960 astronomers were publishing about 1 paper each per year, we are now getting close to 1 paper every three years. Every colleague I show this figure to is shocked, as we are all under the impression that we are publishing a lot. But the number of papers has not caught up with the increasing number of astronomers, which means we are getting less efficient. My interpretation of this result has to do with the increasing size of astronomical collaborations: while a group of 2 – 4 astronomers might easily publish 2 – 4 papers per year, a large collaboration of, say, 100 people, is *not* going to publish 100 papers per year. One might however argue that papers in 1960 were shorter [6] and therefore easier to write, although I am not sure this effect by itself can explain the trend shown in Fig. 3.

⁴I am doing my best to go against the tide: in the past four years I have rejected 73% of the papers I have refereed. I simply require that papers add something *substantially new* to our understanding of the topic at hand.

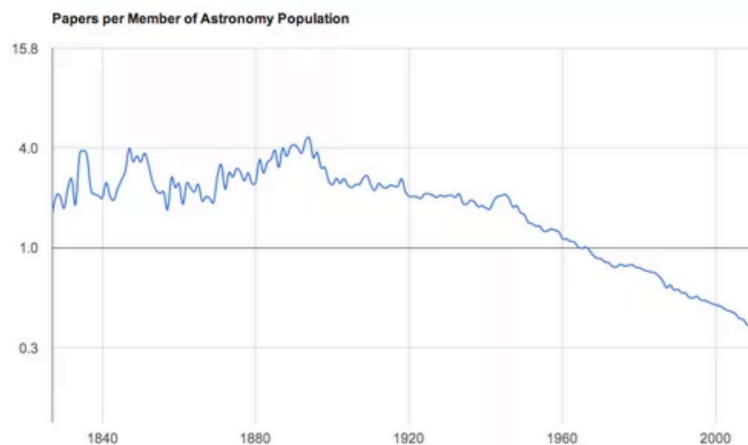


Figure 3: The number of astronomical papers per capita per year vs. year. This is the ratio of the red and blue lines in Fig. 2. Note the logarithmic scale on the y-axis. Courtesy of Robert Simpson: see <https://orbitingfrog.com/2012/08/04/authorship-in-astronomy/>.

4. Getting ready

Let us look at the bright side: we will soon be (even more) flooded with data relevant to the topics discussed at this workshop. And we need to be ready for that. What follows is some advice (mostly for the younger members of the astronomical community):

- Think out of the box: even now there are lots of data but very few new ideas. Spend less time running around writing papers and more time thinking about the important open issues.
- Ask the right questions: doing that is the toughest part of solving problems.
- Change topic every once in a while. I love this quote from Pablo Picasso: “Success is dangerous. One begins to copy oneself, and to copy oneself is more dangerous than to copy others. It leads to sterility.” Astronomy is great also because one can change band and topic relatively easily. It takes some courage and humility, as you need to start from scratch in a new field, but it is very rewarding.
- Learn the right tools. Be they “data mining”, “virtual observatory”, “neural networks”, “artificial intelligence”, whatever. It is clear that we cannot handle the huge amount of data we will soon get without changing the way we deal with them. As a first step, have a look at the presentations given at the Workshop on “Artificial Intelligence in Astronomy” held at ESO in June 2019 (<https://www.eso.org/sci/meetings/2019/AIA2019.html>).
- Have fun! This is the most important advice. If you do not enjoy what you are doing you will be much less productive and also less happy.

I want to conclude with a plea to Franco Giovannelli to change the workshop name to *Multi-messenger Behaviour of High Energy Cosmic Sources!*

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