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A multi-wavelength view of Active Galactic Nuclei with an emphasis on γ-rays

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Active Galactic Nuclei (AGN) are remarkable astronomical sources emitting over the whole electromagnetic spectrum, with different bands providing unique windows on distinct sub-structures and their related physics. AGN come in a large number of types only partially related to intrinsic differences. I highlight here the most important AGN classes, namely jetted and non-jetted, radiatively efficient and inefficient, and face-on and edge-on, the source types selected by different bands together with the most important selection effects and biases, and the underlying emission processes, emphasising the γ-ray band. I then conclude with a look at some open issues in AGN research and at the main new astronomical facilities, which will provide us with new data to tackle them.

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1. Active Galactic Nuclei

There are about 2 trillion galaxies in the Universe [1]. Although most of them are believed to have a supermassive ($\gtrsim 10^6\ M_\odot$) black hole (SMBH) at their centres, in the majority ($\gtrsim 99\%$) of cases the SMBH is inactive [2]. A small minority of galaxies, however, become active, with their nuclei being much more powerful than the nuclei of normal galaxies. These "active galactic nuclei" therefore have an "additional" component, which is now universally accepted to be due to the actively accreting central SMBH. Namely, matter falls onto it and in the regions close to the SMBH converts part of its gravitational energy into radiation. This leads to a number of fascinating properties, which include [see 2, for a review]: 1. very high luminosities (up to $L_{\rm bol} \approx 10^{48}$ erg s^{-1}), which make AGN the most powerful non-transient sources in the Universe, hence visible up to large redshifts [currently $z = 7.642$: 3]; 2. small emitting regions in most bands (down to milliparsec scales), which imply very large energy densities; 3. strong evolution of the luminosity functions, in the sense that the number density and/or typical power of AGN increase with redshift, with a peak at $z \approx 2$; 4. broad-band emission covering the entire electromagnetic spectrum from the radio to the γ-ray band over almost twenty orders of magnitude in frequency.

This latter property means that AGN have been, and are being, discovered in *all* spectral bands, by employing a variety of methods and selection techniques. The crucial point is that *different wavelengths provide different windows* on AGN physics. Namely, as discussed extensively in [2], the infrared (IR) band is mostly sensitive to obscuring material and dust, the optical/ultraviolet (UV) band is related to emission from the accretion disk (the so-called "big blue bump"), while the X-ray band traces Comptonized emission from a hot corona. γ-ray and (high flux density) radio samples, instead, preferentially select AGN emitting strong non-thermal radiation coming from relativistic jets (see Fig. 1 and Sect. 2.1).

The way AGN have been selected have led, almost unavoidably, to an explosion of classes and sub-classes, which can be very confusing, as can be seen in Tab. 1 of [2]. A small sample includes quasars, Seyfert Is and IIs, blazars, Fanaroff-Riley type Is and IIs, broad absorption line quasars, core-dominated quasars, lobe-dominated quasars, Compton-tick AGN, flat and steep spectrum radio quasars, and X-ray-bright optically normal galaxies. Reality, however, is much simpler, with most, if not all, of these apparently different classes being due to changes in a small number of parameters. Which leads me to the most relevant AGN classes.

2. The most relevant AGN classes

2.1 Jetted vs. non-jetted AGN

Soon after the discovery of the first quasar, 3C 273, a very strong radio source ($S_{1.4\rm GHz} \sim 50$ Jy), it was realised that there were many more similar sources, which were undetected by the radio telescopes of the time: they were "radio-quiet" (RQ) [6].[1] These sources were later understood to be only "radio-faint", as for the same optical power their radio powers were ≈ 3 orders of magnitude smaller than their "radio-loud" (RL) counterparts, but the name stuck.

[1] Most of these so-called "quasi-stellar galaxies" turned out to be stars; but the concept of radio-quiet quasars, i.e., the existence of quasars with much weaker radio emission, proved to be correct.

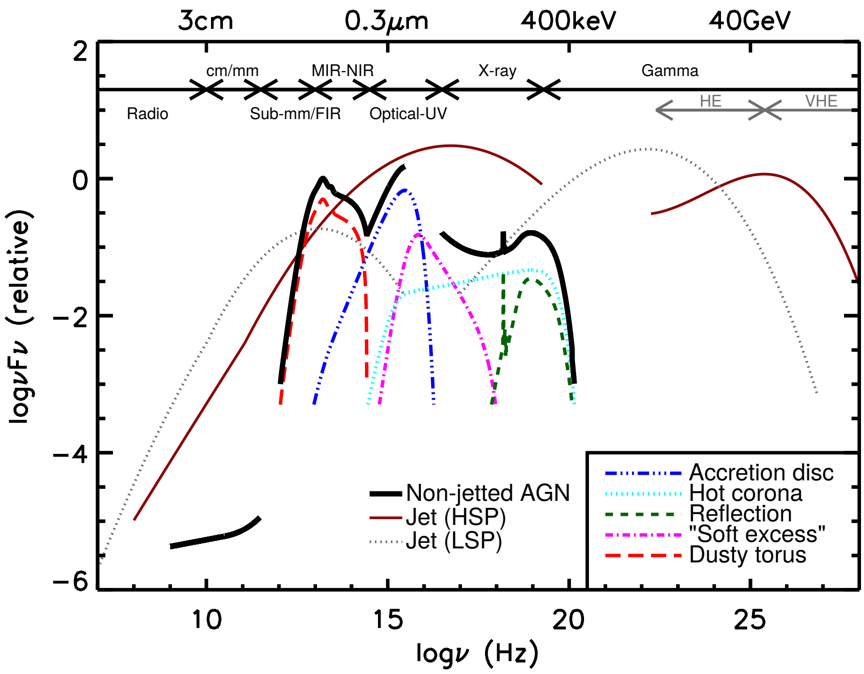

Figure 1: A schematic representation of the spectral energy distribution (SED) of radiatively efficient AGN, loosely based on the observed SEDs of non-jetted quasars [e.g. 4, 5]. The black solid curve represents the total emission and the various coloured curves (shifted down for clarity) represent the individual components. The jet SED is also shown for a high-energy synchrotron peaked blazar (HSP; based on the SED of Mrk 421) and a low-energy synchrotron peaked blazar (LSP; based on the SED of 3C 454.3: see text). Reproduced from [2], Fig. 1, with permission, adapted from a figure by C. M. Harrison.

The properties of the two AGN classes in various bands have been compared innumerable times to try to understand their inherent differences. As it turned out, the distinction between the two types is not simply a matter of semantics but instead they represent intrinsically different objects, with RL AGN emitting a large fraction of their energy non-thermally and in association with strong, relativistic jets, i.e. structures in which matter is expelled close to the speed of light. The multi-wavelength emission of RQ AGN is instead dominated by thermal emission, directly or indirectly related to the accretion disk. I then prefer to refer to the former as "jetted AGN", which I find much more physical than the old, but unfortunately still widespread, RL denomination [7]. Note that non-jetted AGN might still have small, weak, and slow jets, which are however of a different kind than those present in the jetted AGN type (see also [8]).

Only jetted AGN are γ-ray emitters, which is one of the main messages of Fig. 1 for the purpose of this symposium, which makes them particularly relevant in this context ([9] and Sect. 3.5). Strong, relativistic jets are the exception, not the norm, as only (much) less than $\sim$ 10% of all AGN [e.g. 10, 11] are jetted. Jetted AGN pointing towards us (within, say, 10 – 15°) are called blazars [2, 12], which include only roughly one galaxy out of 100,000. Despite their rarity, *blazars dominate the γ-ray sky* (Sect. 3.5).

Blazars are sub-divided from an SED point of view based on the rest-frame frequency of their low-energy (synchrotron) hump ($\nu^S_{\rm peak}$) into low- (LSP: $\nu^S_{\rm peak} < 10^{14}$ Hz), intermediate- (ISP:

10^{14} Hz $< \nu^S_{\rm peak} < 10^{15}$ Hz), and high-energy (HSP: $\nu^S_{\rm peak} > 10^{15}$ Hz) peaked sources [13, 14] (see Fig. 1). This is quite relevant for the γ-ray band (Sect. 3.5). Blazars come into two main flavours, i.e. flat-spectrum radio quasars (FSRQs) and BL Lac objects. FSRQs display broad, quasar-like emission lines while BL Lacs exhibit only weak, if any, absorption and emission lines [12]. Again, this is not only semantics, as these two classes are physically different, as detailed in the following Section.

2.2 Radiatively efficient vs. radiatively inefficient AGN

The idea that not all AGN have the same central engine goes back to at least the late 70's, when it was shown that 3CR radio galaxies could be grouped into two spectral types, i.e. galaxies with strong [O II] 3727 and sometimes also [O III] 5007 and [Ne III] 3869 emission lines and galaxies with only the absorption line spectra typical of giant elliptical galaxies or else very weak [O II] 3727 lines [15].

In 1980 Heckman defined "a class of Low Ionization Nuclear Emission-line Regions (LINERs) which have optical spectra dominated by emission-lines from low ionization species" [16]. Namely, compared to Seyferts, LINERs had stronger [O II] 3727, [O I] 6300, [N II] 6584 and weaker [O III] 5007 and [Ne III] 3869 lines. Since then other different excitation-based definitions have appeared in the literature but there is agreement that low-excitation AGN are less luminous than high-excitation ones. Nowadays, the consensus is that these two classes resort to fundamentally different ways of producing energy and a distinction is made between radiatively efficient and inefficient AGN, which are associated with a switch between a standard accretion, i.e. a geometrically thin (but optically thick) and a geometrically thick (but optically thin) accretion flow [e.g. 2, 17, and references therein]. This gets reflected into different Eddington ratios, i.e. the ratio between bolometric and the Eddington luminosity, $L_{\rm Edd} = 1.3 \times 10^{46}$ $(M/10^8 {\rm M}_\odot)$ erg s^{-1}, with radiatively inefficient and efficient AGN having $L/L_{\rm Edd} \lesssim 0.01$ and $\gtrsim 0.01$ respectively [e.g. 18]. In other words, the latter class produces more power at a given black hole mass. The radiatively efficient class includes all broad-lined and narrow-lined AGN, namely quasars and Seyferts (of all orientations: Sect. 2.3). The two blazar flavours reflect this dichotomy, with FSRQs being radiatively efficient and BL Lacs being inefficient (with the slight complication that "masquerading" BL Lacs, which are in reality FSRQs whose emission lines are washed out by a very bright, Doppler-boosted jet continuum, are therefore radiatively efficient: see, e.g., [19] and references therein).

Radiatively efficient AGN are the exception, which is consistent with the fact that they are more powerful than their inefficient version [e.g. 18], so inefficiency is the norm as far as AGN are concerned (not much of a surprise there ...).

2.3 Face-on vs. edge-on AGN

Orientation plays a very big role in AGN. The seminal work by [20] made this very clear, as it showed that NGC 1068, the prototypical Seyfert II galaxy, displayed narrow lines in total light but broad lines, like Seyfert Is, in polarised light. The authors suggested that "the continuum source and broad line clouds are located inside a thick disk, with electrons above and below the disk scattering continuum and broad-line photons into the line of sight". In other words, Seyfert Is and IIs are intrinsically the same objects oriented at different angles w.r.t. the line of sight. The presence of obscuring material in a doughnut-like configuration, the so-called "dusty torus", surrounding the accretion disk on scales larger than that of the region emitting the broad lines, implies that in Seyfert IIs the central nucleus and close-by material are obscured by the dust and only narrow lines, emitted by more distant clouds, are visible in their optical spectra, while in the case of Seyfert Is we have an unimpeded view of the accreting SMBH. This marked the birth of AGN unified schemes [e.g. 12, 21]. According to these, broad-lined AGN (i.e., quasars and Seyfert Is) are the face-on version of narrow-lined AGN (type 2 quasars and Seyfert IIs).

Along the same vein, FSRQs are face-on radiatively efficient or high-excitation radio galaxies (HERGs), while BL Lacs are the face-on version of radiatively inefficient or low-excitation radio galaxies (LERGs). In both cases the jet is pointing towards us (Sect. 2.1) but no dust is involved in the latter. In fact, it now looks like dust and the broad line region (BLR) are only present at high powers ($\gtrsim 10^{42}$ erg s^{-1})/high Eddington ratios [$L/L_{\rm Edd} \gtrsim 0.01$; see discussion in 2], which implies that dust-driven unification breaks down below these values, i.e. for radiatively inefficient AGN.

Over the last decades it has become clear that dust distribution in AGN is more complex than initially envisioned, in the sense that multiple absorbers, on different physical scales, have to be taken into account to paint a complete view of AGN obscuration. Namely: 1. X-ray variability gives evidence of absorbing gas within the so-called sublimation radius, i.e. on scales smaller than the "dusty torus"; 2. mid-infrared interferometry has suggested a two-component structure of the torus, which includes an equatorial thin disk and an extended feature along the polar direction possibly due to a dusty wind; 3. increased obscuration with redshift might also occur on host galaxy scales ($\lesssim$ kpc), especially for massive ($M_* > 10^{10} M_\odot$) galaxies [e.g. 22–24, and references therein].

Fig. 4 of [22] shows how the main AGN classes can be explained by just the three parameters discussed above: radiative efficiency, relativistic jet presence (or absence), and orientation.

3. A multi-wavelength view of AGN

I now discuss how different AGN classes are detected in the various electromagnetic bands, always with an eye to the γ-rays.

3.1 The radio band

The bright ($f \gtrsim 1$ mJy) GHz radio sky includes mostly jetted AGN, mainly blazars and radio galaxies. For example, all but two of the 527 sources with $f_{\rm 5GHz} > 1$ Jy and Galactic latitude $|b_{\rm II}| \geq 10°$ are radio galaxies, radio quasars, or blazars, the latter making up $\sim 51\%$ of the classified sources [25]. AGN selection is very easy, as one just needs to observe the high Galactic latitude sky. The only bias is that we are only sampling the minority jetted AGN population. Radio emission probes the jet and is due to synchrotron radiation (ultra-relativistic electrons moving in a magnetic field). Basically all *Fermi*-detected AGN have relatively high radio flux densities so the bright radio and γ-ray skies are very similar, being both populated by non-thermal sources (Sect. 3.5).

When one moves to lower flux densities ($f \lesssim 1$ mJy) non-jetted sources become the predominant AGN type, as they are intrinsically fainter radio emitters, while star-forming galaxies (SFGs) become the majority population [e.g. 9, and references therein]. Once one can overcome the non-trivial separation between non-jetted AGN and SFGs, one can reach the most common AGN with no obscuration bias (see later on). Radio emission at these flux density levels probes a variety of emission processes in AGN, i.e. those related to star-formation in the host galaxy, the corona, outflows, and jets, but the relative importance of these is still not clear [26].

3.2 The IR band

As discussed in Sect. 2.3, there is dust around many AGN outside the accretion disk and on scales larger than those of the BLR with $T \sim 100 - 1,000$ K, located at a minimum distance determined by the sublimation temperature of the dust grains [e.g. 2, and references therein]. UV/optical emission from the accretion disk is absorbed by it and re-emitted in the infrared (IR) band where it dominates the AGN SED at $\lambda \gtrsim 1$ μm up to a few tens of micron (Fig. 1).

AGN selected in the IR band include by definition almost only radiatively efficient AGN, mostly of the non-jetted type with some FSRQs, as the radiatively inefficient ones have no dust (Sect. 2.3). The IR is sensitive to both obscured and unobscured AGN, providing an almost isotropic selection, in particular to extremely obscured AGN (missed by optical and soft X-ray surveys: see below). Selection is done by typically using IR colours with the aim of separating AGN from SFGs [e.g., Sect. 3.2 in 2, and specifically Fig. 5 and Table 2].

3.3 The optical/UV band

Optical/UV emission in AGN comes from the accretion disk and the BLR. Because of the presence of dust (Sect. 2.3), and the fact that extinction opacity is pretty large in the optical/UV band, this emission is detected only in unobscured sources. The optical/UV band, therefore, provides a very biased view of the AGN phenomenon, although it was also thanks to their strong optical/UV emission that AGN were mostly discovered in the past.

AGN selected in the optical/UV band, therefore, include unobscured sources mostly of the non-jetted type (as only a small fraction of jetted AGN, the radiatively efficient kind, also have a standard accretion disk and a BLR); in short, broad-lined AGN. This band misses the obscured AGN (the type 2's), although many of them are still selected through their narrow emission lines, and even the moderately obscured ones. Other biases are against low-luminosity AGN (where the host galaxy light swamps the AGN) and also AGN close to stellar loci (as stars are also strong optical/UV emitters) especially at $z \sim 2.6$ and 3.5. The optical/UV band, however, compensates for these shortcomings on two levels: 1. by providing detailed spectra, vital to study AGN physics, e.g., the accretion disk, and the AGN spectral diversity, and to estimate the mass of the central SMBH through "reverberation mapping"; 2. by supplying us with huge optical catalogues. More details on these issues can be found in Sect. 4 of [2].

3.4 The X-ray band

X-ray emission appears to be one of the defining features of AGN and therefore the X-ray band has been crucial for AGN studies. X-rays are supposed to be due to inverse Compton scattering of the accretion-disk photons by an atmosphere above the disk (referred to as the "corona" and whose geometry is still unknown). These X-rays then interact with matter by being reflected, scattered, and absorbed by the accretion disk, the dust, and even the host galaxy (Sect. 2.3). X-ray spectra are sensitive to all of these components and, in particular, to the amount of absorbing material, which means they can be also used to classify sources into absorbed (type 2) and unabsorbed (type 1) [e.g.

22, and references therein]. Low energy X-rays, in fact, are more easily absorbed than higher energy ones and so the spectrum shape depends on the column density $N_{\rm H}$. When $N_{\rm H} > 1.5 \times 10^{24}$ cm^{-2} (in so-called Compton-thick [CT] sources) the source looks completely absorbed in the X-ray band. In jetted AGN the X-rays can have a major contribution from the jet as well.

X-ray selected AGN, then, include in theory all AGN. However, sources with progressively larger $N_{\rm H}$ will be systematically missed below an increasingly higher energy, until the CT value is reached when all AGN are undetectable in the X-ray band. Low-luminosity AGN with $L_{\rm x} \lesssim 10^{42}$ erg s^{-1} are also biased against as this is the power associated with host galaxy emission. LERGs are also mostly missed since their X-ray jet emission is not very strong and they lack an accretion disk. More details on these topics can be found in Sect. 5 of [2].

3.5 The γ-ray band and the multi-messenger link

Only jetted AGN, almost all of the blazar type, reach the γ-ray ($E \gtrsim 1$ MeV) regime, as non-jetted AGN are not detected by *Fermi*[2]. In fact, blazars make up > 55% (and likely up to ≈ 90% if most unclassified sources, as very likely, will turn out to be blazars) of the *Fermi* (50 MeV – 1 TeV) sky [e.g. 27]. Moreover, ∼ 90% of all extragalactic sources with $E > 1$ TeV are also blazars[3], studied with Imaging Atmospheric Cherenkov Telescopes (IACTs) such as MAGIC[4], H.E.S.S.[5], and VERITAS[6]. Therefore, the γ-ray sky is similar to the bright radio sky, as they are both dominated by blazars (Sect. 3.1). This is also due to the fact that blazars are relativistically beamed, that is, Doppler boosted, which leads to an enormous increase in their observed power [12], giving them a huge advantage over their edge-on version, namely radio galaxies. The very high-energy ($E \gtrsim 100$ GeV) γ-ray sky is mostly populated by a specific blazar sub-class, namely HSPs[3], as their SEDs are shifted overall to higher frequencies (see Fig. 1).

Blazars have also recently become multi-messenger sources thanks to IceCube[7], the largest neutrino detector in the world, which has been operating from the South Pole for about 10 years and has detected hundreds of astrophysical neutrinos with energies in some cases extending beyond 1 PeV (10^{15} eV). A high-energy neutrino event ($E \sim 290$ TeV) observed on September 22, 2017, in fact, was found to be in spatial coincidence with the known ("masquerading") ISP BL Lac TXS 0506+056 at $z = 0.3365$ undergoing a period of enhanced γ-ray emission, first observed by the *Fermi* satellite and later by the MAGIC telescopes. The chance coincidence of the neutrino alert with the flaring γ-ray source is at the level of $3 - 3.5\sigma$ [29]. Furthermore, an archival analysis revealed that during the September 2014 to March 2015 time period TXS 0506+056 showed a prolonged outburst when it emitted 13 ± 5 neutrinos. A chance correlation of this type of neutrino outburst can be excluded at a confidence level of 3.5σ [30]. This association, together with a growing body of evidence, links at least some blazars to IceCube neutrinos [e.g. 31–33, and references therein], although it is also clear that only a minority of such sources can be IceCube neutrino emitters [e.g. 34]. This ties in with the $4.2\,\sigma$ neutrino excess recently reported from the

[2]A handful of Seyferts, including NGC 1068 and NGC 4945, are listed in the *Fermi*-4FGL-DR3 catalogue [27] but their γ-ray emission is thought to be related to starburst emission in their host galaxy and not to their SMBH [28].

[3]http://tevcat.uchicago.edu/

[4]https://magic.mpp.mpg.de/

[5]https://www.mpi-hd.mpg.de/hfm/HESS/

[6]https://veritas.sao.arizona.edu/

[7]http://icecube.wisc.edu

direction of the local ($z = 0.004$) Seyfert 2 galaxy NGC 1068 [35], an astrophysical source, which is very different from TXS 0506+056.

This multi-messenger connection is extremely relevant for γ-ray emitting blazars. First, it has vital implications for the nature of γ-ray emission in blazars, which is still debated, as the two alternative interpretations at present are not experimentally distinguishable [e.g. 36, and references therein] (but the Cherenkov Telescope Array [CTA] should help in this respect: e.g., [37]). In the first scenario, so-called leptonic, γ-ray emission is due to inverse Compton scattering between the electrons in the jet and their own synchrotron emission (synchrotron self-Compton) or an external photon field, such as the accretion disk, the broad line region, or the torus (external inverse Compton) [e.g. 38]. Based on the discussion above, the latter applies only to FSRQs, which means that within this framework the details of the dust distribution (Sect. 2.3) will have an effect on their γ-ray emission and spectrum. In the second scenario, the hadronic one, γ-rays are instead thought to originate from high-energy protons either loosing energy through synchrotron emission or through the photo-meson process [e.g. 39]. The latter is the production of neutral and charged mesons (π^0, π^+ and π^-), which then decay into neutrinos, γ-rays, and other particles. Photo-meson production has one fundamental property: neutrinos and γ-rays (of roughly similar energy and flux) are produced simultaneously. Neutrino detection from a blazar is the smoking gun that relativistic protons, i.e. hadronic processes, are at work. Moreover, while γ-rays are absorbed by pair-production interactions with the extragalactic background light (EBL) at $E \gtrsim 100$ GeV [e.g. 40, and references therein], neutrinos can travel cosmological distances basically unaffected by matter and magnetic fields (unlike cosmic rays) and are the only "messengers", which can provide information on the very high-energy physical processes that generated them. Said differently, since the extragalactic photon sky is almost completely dark at the energies sampled by IceCube ($\gtrsim 60$ TeV), neutrinos are our only hope to probe these energies. Finally, the presence of PeV neutrinos implies the existence of protons up to energies $\gtrsim 10^{17}$ eV. This has huge implications for the study of high-energy emission processes in astronomical sources.

Note that, even compared to, e.g., IACTs, neutrino experiments still have a somewhat limited angular resolution ($\sim 0.2-0.3$ deg 95% error radius in the case of NGC 1068 [35]), making joined multi-messenger efforts desirable.

AGN outflows, i.e. large-scale winds of matter driven by the central SMBH, have also recently entered the γ-ray arena, as they have been detected in sources with ultra-fast outflows (UFOs) through a stacking analysis at the 5.1σ level by *Fermi* [41]. These were predicted to be (faint) γ-ray sources, as their semi-relativistic speeds (up to $\sim 50{,}000$ km s^{-1}) can drive a shock that accelerates and sweeps up matter [e.g. 42]. The protons accelerated by these shocks can then generate low-level γ-ray emission via collisions with protons in the interstellar medium through proton - proton interaction followed by the meson decay described above.

I refer to Table 3 of [2] for a multi-wavelength overview of AGN highlighting the different selection biases (weaknesses) and key capabilities (strengths) of the various bands.

4. Open issues and the near future

We have learnt a lot about AGN since the discovery of the first quasar in 1963. However, there are still many open questions in AGN research, some of them quite important, a comprehensive

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list of which is given in Sect. 8.4 of [2] (see also [43] for a critical examination of what we still do not know). The topics most relevant to this conference include: 1. why do only a minority of AGN have jets (Sect. 2.1)? 2. what is (are) the acceleration process(es) in AGN jets? 3. why are only some blazars neutrino emitters (Sect. 3.5)? And what is this telling us about γ-ray emission processes in blazar jets? 4. what is the composition, geometry, and morphology of the obscuring dust (Sect. 2.3)? And what is its relation to external inverse Compton emission in FSRQs?

We will soon have even more data than we had so far to tackle these and other open issues. I list here some of the main relatively new and future facilities, sorted by band. More (still not too out-of-date) details and relevant hyperlinks can be found in [2].

- Radio: ASKAP (Australia), MeerKAT (South Africa), e-MERLIN (UK), WSRT - Apertif (The Netherlands), and finally the Square Kilometre Array;
- IR: JWST (NASA/ESA), Tokyo Atacama Observatory (Japan), Euclid (ESA/NASA), Nancy Grace Roman Space Telescope (previously known as WFIRST; NASA);
- Optical/NIR: Zwicky Transient Facility (USA), Vera C. Rubin Observatory (previously known as LSST), and the extremely large telescopes namely GMT, TMT, and the ELT;
- X-ray: eROSITA (Germany/Russia), IXPE (NASA/ASI/+), SVOM (China/France), and eXTP (China);
- γ-ray: the Large High Altitude Air Shower Observatory (China) and the Cherenkov Telescope Array; plus the missions discussed at this conference.

Just to give a sense of how these facilities will open up entire new regions of parameter space, especially with regard to sensitivity and number of sources, the Evolutionary Map of the Universe, one of the ASKAP surveys, will detect approximately 30 million AGN in the radio band, Euclid will provide NIR spectra for $\approx$ 1 million AGN, the Vera C. Rubin Observatory will select more than 10 million AGN, eROSITA will provide X-ray data for $\approx$ 3 million AGN, while the Cherenkov Telescope Array will detect $\sim$ 10 times more blazars than are currently known at TeV energies.

In short, the future of AGN studies is very bright and we will soon be flooded with amazing new data. To take full advantage of them we will need to ask the right questions and use suitable and efficient tools.

5. Conclusions

The main points of this paper can be thus summarised:

1. Most of the apparently different AGN classes can be explained by three features of their central black hole: 1. the accretion disk, which can be either radiatively efficient (the exception) or not (the norm) ($L/L_{\rm Edd} \gtrsim 0.01$ or $\lesssim 0.01$); 2. a strong, relativistic jet, which can either be there (the exception) or not (the norm); 3. orientation of the jet and the obscuring dust, for jetted and radiatively efficient AGN respectively.

2. Different bands give us very different perspectives on the relevant physics and distinct AGN types. One needs to be very aware of selection effects.

3. Jetted AGN are rare but (almost) the only γ-ray emitters; blazars rule the γ-ray and (the bright radio) sky because of Doppler boosting. HSPs dominate above $\sim$ 100 GeV as a result of their SEDs.

4. AGN (actually, blazars) have gone multi-messenger: TXS 0506+056, a blazar at z = 0.3365, has been associated with IceCube neutrinos. There is growing evidence that at least some blazar classes are neutrino sources. This is very relevant for the issue of γ-ray emission processes in blazars.

5. In the next few years we will be flooded with (even more) AGN data. Hopefully they will help us to sort out a number of open issues in AGN research.

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