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Active galaxies and their importance: results from imaging them in the UV

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Abstract. The current phenomenology of active galaxies is briefly outlined. Their significance in the larger context of galaxy formation and evolution is described. Recent ultraviolet imaging results are then summarized in the context of exploring the potential of TAUVEX in furthering AGN investigations.

Keywords : galaxies: active – galaxies: general – galaxies: evolution

1. Introduction

A small fraction of all galaxies was historically called "active" because their nuclei (the AGN) were seen to produce very powerful emission at all wavelengths observed from radio to gamma-rays, often peaking in the rest-frame ultraviolet, which could not be explained by stellar processes alone. This non-stellar emission from AGN has been understood as due to accretion of matter onto a supermassive blackhole, *i.e.*, a blackhole of mass about a million solar masses or more.

2. Observed manifestations of the AGN phenomenon

The AGN phenomenon manifests itself in many different ways, with each exhibiting a wide range in degree when the whole population of active galaxies is considered.

Considering the nature of host galaxies that harbours the AGN, their morphology, luminosity, colours and distribution of starlight in the galaxy and other features, are not necessarily strikingly different from those of non-active galaxies. However, when the

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nucleus is very luminous relative to its host galaxy, the light from the nucleus can blind us to the point that the host galaxy is buried within the point-spread function and the object appears point-like (like a star) rather than a galaxy, especially at large redshifts, *viz.*, in the quasars. Further, it is often seen, especially at higher redshifts, that the host galaxies that *are* visible, especially as imaged by HST, show evidence for highly disturbed morphology of the starlight. But by and large, the host galaxy does not have any features that can be said to be characteristic signatures of an active galaxy.

On the other hand, on this same spatial scale if these objects are imaged in the commonly seen emission line such as the Hβ or [OIII]λ5007 line, large areas of ionised emission are visible (e.g. Wilson 1996), which are filamentary but highly elongated. The elongation is often parallel to the radio structure and thus already reflects the axisymmetry of the accreting supermassive blackhole on these scales (of $\sim$ kpc). As one gets closer to the nucleus, one cannot resolve the gaseous filaments or clouds spatially, but the spectra bear very clear footprints (in the form of the Broad Emission Lines) of much denser clouds in much faster motion, with implied velocity dispersion of up to 30,000 km s^{-1}or even greater.

When imaged at radio wavelengths, evidence for bipolar outflow of plasma emerging from the nucleus is seen. This outflow in most cases is confined to within the host galaxy (the so-called radio-quiet AGN), but in a minority of active galaxies (the radio-loud AGN), the outflow reaches well-outside the host galaxy, up to scales of even a Mpc. These jets are visible due to the synchrotron emission that they emit, which is most readily seen at radio wavelengths but is also visible at optical UV and more often at X-ray wavelengths. Multi-epoch radio-imaging has resulted in measurements of the proper motion of synchrotron-emitting components in the nuclear part of the jets, which has demonstrated that the jets are certainly outflow. Moreover from the observed phenomenon of "super-luminal" (apparent speeds greater than the speed of light) motion, we know that the jets are highly relativistic. A corollary is that when this jet is directed close to the line-of-sight, then the synchrotron emission from the jet overwhelms any other emission due to the fact that it is relativistically Doppler-enhanced.

Even when the synchrotron component does not dominate, the very high temperatures of the accretion disc leads to emission at high energies, and thus X-ray emission is in fact a defining signature of an active galaxy.

Both the direction of the synchrotron jet and the accretion tend to be unstable, leading to variability that is observed on all scales from these objects, and this is another of defining characteristic of AGN.

Another interesting bit of the anatomy of an active galaxy is relatively cold material, consisting of molecular gas and dust, that surrounds the central regions in a non-isotropic fashion, and thus obscures these regions when the active nucleus is viewed from certain lines of sight; this notion is based on the observation that, several active galaxies do not show evidence for gas clouds at the high velocities of ∼10,000 km s^{-1}mentioned earlier, *i.e.*, the Broad Emission Lines; a good number of such objects, however, do show the presence of Broad Emission Lines in *polarised* light (Antonucci & Miller 1985; Moran et al. 2000) or infrared light (Veilleux et al. 1997). The best explanation for these results has been that, a direct view of the Broad Emission Lines in these objects is hidden from our line-of-sight by obscuring material that surrounds the AGN in the rough morphology of a torus; but in polarised light we are able to see these emission lines scattered into our line-of-sight; and similarly, the obscuring material is transparent to infrared light, and therefore the infrared spectroscopy reveals the presence of Broad Emission Lines.

3. Evidence for supermassive blackholes in AGN

Many of the manifestations of AGN described in the previous section are circumstantial evidence for AGN being driven by accretion around a supermassive blackhole. More direct evidence is also available, however. HST spectroscopic studies of the AGN M87 measured the line-of-sight velocity difference between spatially resolved line-emitting regions, which, if assumed to be Keplerian yielded a blackhole mass of $\sim 10^9 M_\odot$(Harms et al. 1994). In the AGN NGC4258, multi-epoch imaging of the spatially resolved water maser spots yielded $3.6 \times 10^7 M_\odot$within a region less than 0.13 pc as the the driving central mass, *i.e.*, the putative supermassive blackhole (Miyoshi et al. 1995). The profile of the X-ray emission line from ionised Fe in the nucleus of several AGN is observed to be highly asymmetric, consistent with the predicted gravitational redshift that would be expected as the line emerges from the vicinity of the supermassive blackhole (e.g. Tanaka et al. 1995). The technique of reverberation-mapping, which measures the time-lag between the variation in the emission lines and the nuclear continuum that drives the line-variations, and thereby infers the distance of the line-emitting clouds from the driving central mass (the supermassive blackhole) has been done for several AGN (e.g. Ferrarese et al. 2001).

4. AGN, non-active galaxies and supermassive blackholes

Are supermassive blackholes the prerogative of active galaxies alone? The answer is an astounding "no". Starting with our own Milky Way, every galaxy with a bulge whose stellar velocity dispersion in the nucleus has been measured shows evidence for the presence of a supermassive blackhole (e.g. Gebhardt et al. 2000). Clearly, therefore, if these currently dormant supermassive blackholes were supplied with material to accrete, they would shine. Thus AGN practitioners have emerged out of the "pathologist angst": the active galaxy phenomenon is not a pathological one but appears to be a phase in the evolution of every galaxy with a bulge.

Not only does every galaxy with a bulge appear to harbour a supermassive blackhole; the mass of the blackhole correlates with the mass of the bulge, and even more strongly with its stellar velocity dispersion—the "$M - \sigma$" relationship (e.g. Ferrarese & Merritt

2000). This correlation holds for both active and non-active galaxies and the correlation parameters are similar for the two classes (Ferrarese et al. 2001). The correlation clearly means that growth of the blackhole and the growth of the galaxy bulge must go hand in hand. The nuclear supermassive blackholes grow both when the AGNs shine (due to accretion of matter) and when galaxies with blackholes merge (so that the blackholes also merge). Thus there must operate a feedback mechanism between the evolution of the two. A consensus on such a mechanism is yet to emerge. Numerical simulations do show, however, that while galaxy-galaxy collisions on the one hand produce gas inflows that feed the merged supermassive blackhole, the energy released by the shining blackhole system expels sufficient gas to quench both circum-nuclear star formation and further black hole growth (di Matteo et al. 2005).

5. The importance of imaging AGN in the ultraviolet: potential of TAUVEX

TAUVEX will be able to image several areas of the sky to unprecedented depths in the ultraviolet. This imaging capability has the potential to take forward our understanding of AGNs and their role in galaxy evolution in several different ways.

AGN are powerful emitters at ultraviolet wavelengths, with contributions from both the accretion disc and the synchrotron emission from the jet. In addition, several AGN show evidence for associated cirucum-nuclear star formation and also jet-induced star formation. These phenomena are clearly demonstrated by the GALEXimage of the radio-powerful galaxy Centaurus A (Neff et al. 2003; Brookes et al. 2006). Star formation is best delineated in the ultraviolet because the star-forming regions stand out in high contrast from the older stellar population, as has been amply demostrated by innumerable GALEXimages.

In order to understand the physics of the variability of AGN, the temporal structure of the variability, as well as the chromaticity of this structure needs to be determined, which requires simultaneous multiwavelength observations including the ultraviolet (e.g. Raiteri et al. 2005).

Furthermore, deep ultraviolet imaging and imaging surveys are important to understand the systematics of the connection between AGN activity and star-forming galaxies. For example, Heckman et al. (2005) have found from GALEXsurveys that there exist a significant number of "compact ultraviolet-luminous galaxies" in the nearby universe which are the analogs of the Lyman-Break galaxies. They are thus "living fossils", in which physical processes similar to those in the Lyman-Break galaxies can be studied. Galaxy evolution is synonymous with its star formation history, and thus ultraviolet imaging is essential both to improve our understanding of the connection between the nature and evolution of the host galaxy and its AGN, and to determine the mechanisms of feedback between the blackhole growth and evolution of the galaxy. Indeed, Schawinski et al. (2006) argue from their ultraviolet images of early-type galaxies obtained from GALEX, that AGN feedback is the most likely mechanism by which the available gas is heated and expelled in massive early-type galaxies. Also, extending the extinction curves into the ultraviolet in order to study the diversity of dust properties of active galaxies (e.g. Gaskell & Benker 2005) is an important line of investigation that can be persued with TAUVEX.

6. Conclusions

The importance of imaging active galaxies in the ultraviolet with telescopes such as TAUVEX is two-fold: (a) to image the AGNs in conjunction with ground-based multi-wavelength observations to investigate both their spatial and temporal structure, and, (b) to image the host galaxies of AGN, in order to investigate the connection between the AGN and nature of their host galaxies, and to statistically investigate feed-back mechanisms between AGN and host galaxy evolution.

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