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Meeting Summary: A 2017 View of Active Galactic Nuclei

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The topics covered in this summary review reflect the major areas discussed in the Padova meeting, in April 2017. They are divided into general categories: those areas where large progress has been made leading to a real new understanding (what we are doing "right"), and those where we are still in the dark (what we are doing "wrong"). The division reflects the status of the field as well as my subjective opinion.

Keywords: black holes, star formation, host galaxies, cosmology, accretion disks, reverberation mapping, AGN-feedback

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1. INTRODUCTION: "RIGHT" AND "WRONG" IN AGN STUDY

The topics covered in this meeting are very broad: from the central black hole (BH) and the accretion disk (AD), to the observations and physics of the broad line region (BLR), narrow line region (NLR), AGN-tori, AGN winds and feedback, the various types of AGN, the connection to the host galaxy and its star forming (SF) regions, and even AGN in a cosmological context. To summarize this huge area (usually divided into sub-areas and discussed in more specialized meetings) I chose to assess the quality of the observations presented here, and the complexity and reality of the associated models, by assigning to each one of the categories one of two "quality flags," either "right," or "wrong." These should not be understood in their every-day meaning. Rather, they reflect my personal view of where we have made big progress, and are starting to understand the big picture, and where we are probably missing some essential points, and hence may be proceeding in the wrong direction. Thus, the meaning of "we must be doing something wrong" used often in this review, means that in my opinion, we are missing some important ingredients either because we misunderstand the objects or phenomena we are studying, or because the work necessary to reach a real understanding is so complicated, or time-consuming, that it has not yet been done. Obviously there is no way to refer to all the talks and posters presented in the meeting, many of which represent excellent work. I only chose a small number of those that seem to represent the topics where "right" or "wrong," as defined here, are more clearly separable.

2. THE AGN FAMILY: NEW MULTI-WAVELENGTH OBSERVATIONS

2.1. Something Right: Systematic Study of LINERS, Seyferts, High Luminosity AGN and Objects Containing Disk-Like BLRs

There is rapid progress in obtaining improved observations of large and small AGN samples. The SDSS is leading this field because of the very large number of sources observed spectroscopically in this survey. However, smaller samples, especially those that are carefully selected in one wavelength band and then studied in others, provide valuable information in terms of being more complete. The COSMOS sample is one such sample, alongside with the older PG-Quasar sample, the new BAT sample, and more. Examples of this type were provided by Márquez et al. (2017, LINERs and Seyfert 2s) and Richards (2017, type-I AGN in the SDSS sample combined with a new division into eigenvector groups), (Lusso and Risaliti, 2018) who provided a fresh look at X-ray sources and even some GAIA results that are going to contribute their part to the field in the near future (Angello, 2017). A somewhat different example, presented by Storchi-Bergmann et al. (2017), demonstrated the great advantage of looking at the rare group of double-hump broad line sources where studying a large sample in a very systematic way, leads to a new insight.

2.2. Something Wrong: A Complete Picture of Radio AGN

The clear and comprehensive review by Padovani (2017), as well as several talks on Blazars, only helped to demonstrate that we are still far from understanding many of these sources, their physics, variability and, most importantly, the connection (if any) between radio and optical-UV properties of many radio loud AGN. The Blazar field is perhaps the least understood and the new big observatories which help to extend their study to very high energies, and help to follow their variations in more detailed ways, seems to provide only incremental improvements over what was known 10 and 20 years ago. We must be doing something wrong in this area.

3. MAPPING AND MODELING THE BLR AND MEASURING BH MASS

3.1. Something Right: Reverberation Mapping in One and Two Dimensions

A giant leap forward in terms of 2D (location and kinematics) reverberation mapping (RM) of the BLR is the recent (2013–2014) study of NGC 5548 by HST and a host of ground-based telescopes. Despite being only one source, that may not be typical with respect to its very high X-ray luminosity compared with the optical-UV luminosity, this is a superb example of the power of well planned spectroscopic observations. The light-curves of different emission lines at various gas velocities are text-book examples which will likely provide the tool to solve some of the issues related to the physics of the BLR. The new information about time-dependent broad and narrow absorption lines, and the accretion disk itself, is equally exciting. Some examples of this were shown by Horne (2015) and Fausnaugh et al. (2017). The same group, now with the help of many others, is making plans to carry out a similar study of other AGN.

3.2. Something Right: The R-L Relationship and Single-Epoch Mass Measurements

Related to this is the impressive collection of sources (more than 70) where the emissivity weighted radius of the broad Hβ line has been measured through the correlated line and continuum variations, and variability may even be related to eigenvector 1 (Ilić et al., 2017; Bon et al., 2018). In some of the mapped sources, the Hβ line can be divided into several velocity bins allowing one to answer a simpler question of whether the BLR motion is mostly outflow, inflow, or closer to a bound rotational motion (Pancoast et al., 2014). Surprisingly, there is no single canonical dynamical pattern. Other important new results connect the Hβ emission region size to the Eddington ratio of the accreting BH.

New, long expected RM results applied to the most luminous AGN, at high redshift, were presented by Kaspi et al. (2017) and Lira et al. (2018). They show that the CIVλ1549 and Lyα emitting regions are much closer to the central BH compared with the Hβ emitting region, by a factor of $\sim$ 3. The two RM campaigns that finally answered this question took 10–15 years (!!) to complete—a good example showing what science can reveal when managing to convince large telescope TACs that some problems require more than a decade of observations. The other very good news in this area is the completion of VLT/GRAVITY that is capable of measuring, directly, BLR sizes in a small number of nearby type-I AGN.

Another idea, which is clearly becoming more visible due to the fact that more and more type-I AGN are studied, spectroscopically, in more and more detail, is the suggestion, by Marziani et al. (2018) that different locations in the eigenvector 1 plane hint to fundamentally different physics.

3.3. Something Wrong: Phase-Space Modeling of the BLR

Despite the impressive 2D RM maps of NGC 5548 presented in the meeting, and lower quality ones available for other sources, there is little if any progress in constructing consistent spatially and dynamically connected maps for the best studied source. We seem to be facing the same questions that were asked some 20 years ago, after the analysis of the very first optical-UV RM study of the same sources with ground based telescopes and the IUE satellite. This field is eagerly waiting for a more detailed models which will justify the huge resources invested in it.

Some good news in this area, not directly related to the mapping of the BLR, is a new model presented by Czerny et al. (2017), where the origin (and hence location) of the BLR clouds is the dusty outer parts of the central accretion disk. This and similar models can be tested by next generation 2D BLR models. Some other ideas that were proposed but never tested properly are related to the commonly assumed relationship $R_{BLR} \propto L^{\alpha}$ where R_{BLR} is the BLR radius estimated from RM campaign, L the monochromatic continuum at a chosen wavelength, and $\alpha = 0.5 \pm 0.1$. Is it possible, in view of the dependence on the Eddington ratio discovered recently, and hence the role of radiation pressure force, that an alternative approximation of the type $R_{BLR} = c_1 L^{\alpha} + c_2(L/M)$ will provide better BH mass estimates?

3.4. Better Calibration of BH Masses

While the commonly used single-epoch (SE) BH mass measurements is a substantial step forward, which is well recognized by the community, the field is still looking for a way to improve the calibration of these measurements, i.e., the factor f_{BLR} in the expression $M_{BH} = f_{BLR} R_{BLR} V_{BLR}^2/G$. The way used by most researchers is based on the well known $M_{BH} - \sigma *$ relationship which provides the calibration of f_{BLR} in the local universe, i.e., mostly for low luminosity AGN. A new promising method was presented by Mejía-Restrepo et al. (2018, paper presented by Lira). In this method, applied so far to high luminosity, high redshift ($z \sim 1.5$) AGN, the observed FWHM of the broad lines can provide the desired calibration, i.e., $f_{BLR} \propto 1/FWHM(line)$.

4. ACCRETION DISKS AND DISK WINDS

4.1. Something Right: Thin Accretion Disk Models and the Optical-UV SED

After years of study it is now apparent that the optical-UV continuum of at lease some AGN, those with large BH mass ($10^8 - 10^9$ M_{sun}) and not too large Eddington ratio, can be adequately fitted by the canonical spectrum of a thin accretion disk. Apparently, the previous failure of such attempts was probably due to the lack of simultaneous observations that cover a large enough wavelength range.

4.2. Something Wrong: The Spectrum and Properties of Slim Accretion Disks

Despite heroic observational and theoretical efforts, slim accretion disks, those with an Eddingto ratio exceeding about 0.3, are not yet understood. The SED beyond the Lyman limit is not known observationally and there are clear discrepancies between theoretical predictions and the observed luminosity ratios of their NIR, extreme UV and X-ray radiation (Castelló-Mor et al., 2017).

4.3. Disk Winds: Right and Wrong

All theoretical slim disk models, as well as present-day (rather simplified) numerical simulations, show that strong disk winds must be present, especially close to the central BH. The amount of accreted energy carried out in such winds, and hence not by radiation, is not known and the geometry and velocity fields can only be guessed. On a slightly larger scale, there was a lot of discussion about dusty and dust-free winds as presented by Elitzur (e.g., Elitzur and Netzer, 2016). In fact, it is hard to imagine a disk with a strong magnetic field that does not show this component. One claim is that the outflowing BLR clouds, and even the dusty torus, are also related to such flows.

Unfortunately, so far we do not have a clear and convincing observational evidence for such winds. The dynamical studies of the BLR gas only show the signature of outflows in a hand-full of sources and other observations show exactly the opposite. There are however a couple of new observations that can be interpreted as a signature of a wind. The first is the "polar dust" found in a couple of sources studied with various interferometers (Hönig, 2016). The second, which I consider to be one of the most amazing results presented in the meeting, is the study of a source which is microlensed by a foreground star (Hutsemékers et al., 2017). Reconstructing the lens magnification map, allows one to combine location and velocity in the lensed BLR. It shows that the Hα line profile is produced by a flat, rotating BLR while the CIVλ1549 line is probably produced in an outflowing polar gas. This way of probing the dynamics is extremely accurate but, unfortunately, can only be applied to a handful of lensed sources.

5. STAR FORMATION GALACTIC-SCALE WINDS MERGERS AND FEEDBACK

5.1. Something Right: Observational Evidence for Outflow and Mergers

In terms of new observations, and on-going effort, this topic is, arguably, the place where most observational effort has been made over the last few years. We have been presented with superb quality velocity maps, in different objects, showing large scale outward motion of ionized and molecular gas. The outflow can be associated with the vicinity of the BH (mostly X-ray outflows), the narrow line region, or even further away in the galaxy. Evidence comes from low redshift sources just "around the corner" and for redshift as large as 3–6. The available velocity maps are already of high quality and the coming new-generation IFU instruments, on JWST and several large ground-based telescopes, will no doubt provide even more detailed observations. ALMA is likely to play a role in proving, or disproving, the suggestion that many of the ionized outflow are associated with high mass-outflow rate molecular gas.

5.2. Something Wrong: Interpreting Outflow and Feedback

We are still in the dark regarding accurate measurements of mass outflow rates and hence the importance of AGN-feedback in quenching SF and in shaping the structure and evolution of the host galaxy. In ionized outflow, the main uncertainties are in those terms combining gas density and gas filling factor. The difficulty is due to poor observations (lack of outflow signature in several lines, not just the strongest ones) and the difficult estimate of the outflow filling factor. Molecular outflows are easier to model but questions about the production of CO lines in outflowing material still remain.

Present day feedback models are still not advanced enough to make clear and specific predictions about the galactic scale influence of the process. In particular, it is not very clear whether energy-conserved outflows, or momentum conserved outflows, are more important. One of them is associated with radiation pressure force mostly on dust grains. The other, with galactic scale shocked gas. Here, again, theory lags the observations, or perhaps more precisely, numerical simulations of galactic-scale shocks, and feedback, have a long way to go. The larger scale, cluster-size feedback, associated with powerful radio jets and X-ray cavities, is perhaps better understood (Morganti, 2017).

Related questions are the correlation of SF and AGN luminosity in low and high redshift sources. Here, again, we heard some conflicting results reflecting the large uncertainties in measuring SF rates, mostly in the FIR, and in correlating it with optical and X-ray observations. Thus Ichikawa et al. (2017) showed several samples where L(AGN)$\propto$L(SF) while according to Stanley et al. (2015), such a correlation does not exist in any redshift.

The presence of near companions can be interpreted as indication for merger that can trigger SF and speed up the evolution of the system. The beautiful results presented by Fogasy et al. (2017), Kimball et al. (2015) and Trakhtenbrot et al. (2018) are quite amazing, given the redshift, size and brightness of the sources. However, they do not seem to be in agreement with each other, e.g., in relation to the question of which one is more FIR luminous, the AGN-host or the companion.

6. COSMOLOGY WITH AGN

6.1. Something Wrong: All AGN-Based Methods

Efforts to identify reliable tools based on AGN physics, that can help map the universe, and its expansion, at high redshift, and improve on the accuracy of present day measurements based on Type-Ia SNs, have not yet produced meaningful results. Some of these ideas have been mentioned in the meeting, e.g., the use of the observed luminosity of super-Eddington AGN, dust RM and its comparison with accurate IR interferometry (Hönig, 2016), the scaling of BLR density and ionization parameter (Negrete et al., 2017), or the relationship between X-ray and UV observations of type-I AGN (Lusso and Risaliti, 2018). Unfortunately, systematic uncertainties in all the methods, combined with a lack of understanding of some of the involved processes, prevent us from reducing the uncertainties of such methods to a trustable and useful level. We must be missing something very important in all these methods or, perhaps, AGN are simply not the tool to advance precision cosmology.

7. OPTIMISTIC SUMMARY

The approach followed in this summary review, of comparing things we understand ("we must be doing something right") with those we do not yet understand ("we must be doing something wrong") is useful since it allows us to produce an itemized list of topics, and hence specific goals, for future projects and meetings. Under the "right" header in this review I included: detailed and accurate new observations, larger and more complete samples, wider wavelength coverage, better spatial resolution, better time sampling, and more. The "wrong" category includes, in my opinion (and correct to 2017) topics like: understanding BH and galaxy evolution, simulating large scale baryonic processes like feedback, measuring mass outflow rates, understanding slim accretion disks and disk winds, proper modeling of the BLRs and dusty disk winds, and more. The common denominator is evident: We are making large and significant steps forward on the observational front but the theory, and the numerical simulations, lag behind. The optimistic view is that doing "wrong" is the first step for success. A nice summary of this idea is a clever quote from the writing of the late Susan Jeffers, a well known American psychologist and author, who once said: "If you haven't made any mistakes lately, you must be doing something wrong."

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