Conference Summary

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Abstract. This conference on "Multi-wavelength AGN Surveys and Studies" has provided a detailed look at the explosive growth over the past decade, of available astronomical data from a growing list of large scale sky surveys, from radio-to-gamma rays. We are entering an era were multi-epoch (months to weeks) surveys of the entire sky, and near-instantaneous follow-up observations of variable sources, are elevating time-domain astronomy to where it is becoming a major contributor to our understanding of Active Galactic Nuclei (AGN). While we can marvel at the range of extragalactic phenomena dispayed by sources discovered in the original "Markarian Survey" – the first large-scale objective prism survey of the Northern Sky carried out at the Byurakan Astronomical Observtory almost a half-century ago – it is clear from the talks and posters presented at this meeting that the data to be be obtained over the next decade will be needed if we are to finally understand which phase of galaxy evolution each Markarian Galaxy represents.

Keywords. AGNs: surveys, multi-wavelength

1. Introduction

On behalf of the Scientific Organizing Committee (SOC) I would like to sincerely thank the Local Organizing Committee (LOC) and its Chair, Areg Mickaelian, along with the LOC supporting students who worked extremely hard in preparing for this IAU Symposium, for their gracious hospitality in hosting this week's conference in Yerevan. This meeting has been a fitting tribute not only to the memory of Beniamin Markarian, but also to the work carried out over the years by the entire staff of the Byurakan Astrophysical Observatory (BAO), in the successful planning and excution of the pioneering "Markarian Survey". I would also like to thank all of the speakers and poster presenters for their collective effort in making this meeting a great success. Each of the meeting sessions has been well attended, and the large number of oral and poster presentations have provoked lively discussion. In the five days of talks we have managed to thoroughly cover the full wavelength spectrum of AGN Surveys – past, present and future – and to provide a comprehensive picture of the wide variety of AGN phenomena.

2. Retrospective and Highlights

The invited and contributed talks given during Days 1–5 of this meeting were designed to cover all aspects of AGN observations – from the identification and cataloging of AGN in large scale sky surveys at various wavelengths, to more detailed multi-wavelength studies of smaller AGN samples. Both types of studies are obviously necessary to understand the origin and evolution of AGN, the relationship of AGN to their host galaxies and the impact of AGN on their intergalactic environment. The talks were arranged in ten Sessions (S1 ... S10), corresponding roughly to the Morning and Afternoon meeting times on

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each day of the conference. Day 1 (S1) set the stage by providing a reminder of what was learned from the early "Historical Surveys" of AGN, while the meeting concluded on Day 5 (S10) with a look at future surveys planned to begin during the next ten years. Sessions 2–9 were each introduced by 2-3 Invited presentations that were designed to provide an overview of specific AGN phenomena, followed by 4-5 Contributed talks focused on more detailed studies of individual objects of classes of objects. There was ample time during coffee breaks for viewing the sixty-three poster presentations on display throughout the meeting.

In trying to judge the current state of AGN Surveys and our overall understanding of AGN phenomena, I found it very helpful to review the Proceedings of the last two AGN conferences held in Armenia – *AGN and Related Phenomena* – IAUS194, (Terzian, Weedman & Khachikian 1999), and *AGN Surveys* – IAUC184, (Green, Khachikian & Sanders 2001). Most of the "future surveys" discussed at these earlier meetings have since come to fruition, and it is clear that analyses of AGN phenomena have moved beyond studies of relatively small samples of objects at a few wavelengths, to studies that more often than not cover AGN samples containing hundreds to thousands of objects, where the available data can span the full range from radio to X-ray wavelengths, thus providing detailed spectral energy distributions (SEDs) that were only dreamed of as little as a decade ago.

The Invited Talks at the beginning of each Session of the conference provide excellent overviews of the current state of AGN research, including detailed references to the latest results. The following subsections are meant to simply capture the overall themes of each Day of the meeting, including a few highlights that punctuate some of the important results that were likely new to the majority of the meeting participants.

2.1. *Day 1*

The Symposium appropriately began with a review by Areg Mickaelian of "Historical AGN Surveys", starting with the First Byurakan Survey (FBS). The FBS is perhaps best known for producing the twenty-five "Lists of UV-excess galaxies" (e.g. Markarian 1967), [or simply "Markarian Galaxies" (Khachikian 1968)], and for the spectroscopic data analyses which led to the identification of different AGN spectral types (e.g. Weedman & Khachikian 1968). AGN data from the Sloan Digital Sky Survey (SDSS) were then summarized, along with AGN data from other surveys, including surveys at low-frequency radio wavelengths to high energy γ-Rays.

Highlights from Day 1 included:

- The Digitized FBS (Mickaelian *et al.* 2007) $\rightarrow$ ($\sim 2 \times 10^6$ objects; $\sim 4 \times 10^6$ spectra)
- New SDSS color-selected Quasar Catalogs ($\sim 2 \times 10^5$ quasars)
- The largest sample of dwarf galaxies ($\sim 2.5 \times 10^4$ objects) hosting MBH

2.2. *Day 2*

Day 2 continued a theme of summarizing recent results from large AGN surveys, but with a specific focus on the smallest angular scales. Monitoring results from the VLBA (10×25m stations, and 9000km baselines), and EVN were presented revealing rapid variability, very compact, and high doppler factor jets in Blazars. It was announced that RadioNet3, which includes 27 European coordinating partners, was recently approved for funding (2013-15). The Space-VLBI project, RadioAstron (10m diameter), launched in 2011, is currently operating with links to all of the world's largest radio telescopes (tracking from Russia, Green Bank, South Africa), providing $\sim 300,000$km baselines (!)

capable of resolutions of $\sim 7\mu$as at $\lambda = 1.3$cm. Initial results suggest that AGN have compact cores with $T_{\rm b}$ higher than the the predicted limit due to inverse Compton scattering. LOFAR was reported to be operational, with the Netherlands antenna network connected to eight European Stations providing 8mas resolution at $\sim$150MHz.

At the other end of the wavelength spectrum, very high energy γ-Rays have been detected by VERITAS, and 145 sources detected by TeVCAT are providing new insight into the "family" of BLAZARS and Radio Galaxies. Detections by SWIFT-BAT/IBIS suggest that high-luminosity AGN are less obscured than low-luminosity AGN, and surveys by Fermi-LAT suggest that the known extragalactic γ-Ray background is dominated by BLAZARS. Deep X-Ray surveys have now made it possible to construct X-Ray luminosity functions as a function of redshift, and to estimate the contribution of heavily obscured (i.e. CT AGN) to the total AGN population.

Highlights from Day 2 included:

- VLBI (sub-)parsec scale "movies" reveal complex jet structure in RLAGN
- Early AGN results from Radio-Astron - AGN cores with higher than predicted $T_{\rm b}$
- The LOFAR Network (NL + 8 European Stations) is operational
- The fraction of heavily obscured AGN increases with redshift as $\sim (1+z)^{0.5-0.6}$

2.3. _Day 3_

Day 3 continued with a discussion of the X-Ray background (XRB), presenting new results on the relative importance of secular processes and mergers in the triggering of AGN, and speculation on the contribution of AGN during the epoch of re-ionization. The indentifcation of new AGN from Mid-IR surveys (e.g. WISE and NeoWISE) was also presented. Vahe Petrosian then gave a thoughtful presentation warning of observational selection effects in dealing with multiwariate luminosity functions; he then proceeded to show that there is no sign of bi-modality in the intrinsic radio loudness distribution of AGN, but there is strong positive luminosity evolution with redshift in the radio power of AGN.

An overview of results from the Cosmic Evolution Survey (COSMOS) provided a detailed look at the large-scale structure (LSS) environment of AGN. Deep X-Ray coverage of the full 2-deg^2 COSMOS Field with _Chandra_ and XMM, along with extensive multiwavelenth coverage of the field from radio-to-UV wavelengths and follow-up spectroscopy with large optical telescopes, now provides detailed SEDs and redshifts for tens of thousands of AGN, and the ability to study AGN within the context of their LSS environment. Clustering analysis suggests that more luminous AGN live in more massive halos.

The final session of the day brought attention to the exciting new results being obtained from integral field unit (IFU) observations of AGN host galaxies. New line-diagnostic diagrams were presented that may be of use in spectral-type classification, particularly at higher redshifts where the widely-used "BPT diagram" often fails due to the shift of diagnostic lines outside the optical window or to inaccurate radiative transfer models. Also discussed was a new "Cosmic BPT Diagram" that accounts for the change of metallicity and ISM conditions (e.g. UV hardness) with redshift. New IFU observations were presented, illustrating the power of spatially resolved spectroscopy to disentangle AGN from starbursts and shocks in galaxy disks. Particularly impressive was the ability to clearly distinguish spatially distinct features such as AGN jets, circumnuclear starburst rings, and galaxy-wide starburst winds.

Highlights from Day 3 included:

- ∼90% of AGN (low-lum) triggered by secular processes → contribute 40% of XRB
- ∼10% of AGN (high-lum) triggered by mergers → contribute 60% of XRB
- X-Ray selected BLAGN live in more massive halos
- A new "Cosmic BPT Diagram" for studying high redshift AGN
- New IFU data separates AGN nuclei, starburst rings, galaxy-scale winds/shocks

2.4. *Day 4*

Day 4 continued the discussion of AGN-Starburst diagnostic diagrams, with the introduction of several new empirical relationships: the Tourille-Barger-Tremonti ("TBT Diagnostic") diagram for use at $z < 1.4$, which adds the [NeIII] and [OII] emission lines to the standard BPT lines; the Color(U-B)-[OIII]/Hβ ("CEX Diagnostic") diagram and $M_{\rm galaxy}$ - [OIII]/Hβ ("MEx Diagnostic") diagram, both of which are useful up to $z < 1$.

Several presentations discussed the power of AGN monitoring campaigns to reveal the deatiled properties of radio cores, torii, and jets. The remainder of the Day focused on the important role of AGN feedback - including the effects of feedback on the host galaxy as well as the larger effect of AGN feedback on the intergalactic medium. We were reminded that theoretical simulations of galaxy formation require significant feedback to reproduce the shape of the observed galaxy luminosity function. Compelling new evidence from *Herschel* was presented, showing the ubiquity of massive molecular outflows from the nuclei of ULIRGs. New VLT-KMOS observations also suggests that galaxy-wide outflows are common in $z \sim 2$ (U)LIRGs. An analysis of the kinematic trends with $L_{\rm AGN}$ suggests that the AGN plays a dominant role in all ULIRGs. Finally, results from line-of-sight spectroscopy toward "QSO pairs" were presented showing evidence for very high ($\sim 60\%$) covering fractions of metal-rich gas within a virial radius ($\sim 160{\rm kpc}$), stongly suggesting that QSO outflows are responsible for producing the large masses ($\sim 10^{10} M_\odot$), of $T \sim 10^4{\rm K}$ gas observed to be present.

Highlights from Day 4 included:

- Development of new empirical emission line diagnostics: TBT, CEx, MEx
- Observational evidence for powerful mulecular outflows in nearby AGN
- Herschel discovers ubiquitous and massive molecular outflows in the nuclei of ULIRGs
- AGN are the driver of molecular outflows above $L_{\rm AGN}^{\rm break} = 10^{11.8 \pm 0.3} L_\odot \sim L_{\rm min}({\rm quasar})$

2.5. *Day 5*

Day 5 began with a review of "binary AGN" discovered in multi-wavelength observations of the complete sample of (U)LIRGs in the Great Observatories All-Sky LIRGs Survey. We were also reminded of the wealth of cataloged extragalactic observational data, including overlays of multi-wavelength images, that are available on-line via such services as the NASA Extragalactic Database (NED). The detailed information available for nearby objects was illustrated by showing multi-wavelength maps of the spectacular object NGC5256 (= Mrk266), which contains what appear to be precessing radio jets, as well as powerful outflows associated with the MBH in each nucleus, both of which are heavily obscured by enormous nuclear reservoirs of molecular gas and dust. Several presentations then focused on the use of varability studies to discover AGN at high redshift, and in particular on using variability in the mid-IR to detect heavily obscured AGN.

The formal presentations concluded with a look toward future surveys and what we might expect to gain in our understanding of AGN. The launch of eROSITA and the new

SKA radio facilities will add new data in the X-ray and radio, respectively. The ability to routinely explore the time domain using new multi-epoch, large scale optical sky surveys (e.g. LSST), will be particularly useful for studying variable phenomena typically associated with AGN.

Highlights from Day 5 included:

- Binary AGN revealed in the GOALS Survey of (U)LIRGs
- Mid-IR variability studies predict X-Ray surveys miss many highly obscured AGN
- Prediction that 10^7 quasars will be identified with LSST
- Machine Learning + Data Mining tools for studying AGN in future 4D Surveys

3. Questions for Discussion

One common theme running through all of the presentations at this conference is that the wealth of new multi-wavelength sky survey data currently available for studying the properties of all extragalactic sources, is allowing us to place AGN firmly in the overall context of galactic evolution, rather than as isolated, exotic phenomena. What still caught me a bit by surprise was the enormous wealth of new survey data that now exist on-line in searchable databases that are readily accessible to all astronomers, and how quickly one is able to gain new insight by studying the multi-wavelength properties of tens of thousands of sources as opposed to the much slower pace when only a few objects with restricted wavelength coverage were available for study. And this is only the beginning of what will surely continue to be an exciting new era of AGN studies as the new 4-D surveys (e.g. PanSTARRS, SKYMAPPER, LSST, ...) begin to routinely provide time-domain data that will be particularly useful for studying the wealth of variable phenomena associated with AGN.

The final few minutes of the conference were devoted to a short discussion of seven broad questions/comments that were raised during the week-long meeting. These questions (plus short responses) are simply presented here as an addendum to the talks, and to remind us of what the future holds for AGN research.

Q1. <u>Definitions and Terminology for AGN ?</u>
We were often reminded of the confusion caused by use of terms like "narrow-line Sy1" and "broad-line Sy2", but it is clear that AGN will continue to be described and classified by their multi-wavelength properties. There will likely be numerous additions to the current dictionary of acronyms (e.g. LLRGs, PRGs, IRQSOs, BLAZARS, ...).

Q2. <u>Have all AGN types been discovered ?</u>
No, but one suspects that most major phases of AGN evolution have already been observed. It is also clear that heavily obscured AGN and low-luminosity AGN will continue to be difficult to detect.

Q3. <u>AGN growth, structure versus time ?</u>
Disentangling the importance of secular versus merger driven accretion will enhance our understanding of AGN growth.

Q4. <u>AGN spectral energy distribuitons versus time ?</u>
The increasing depth and breadth of large scale multi-wavelength sky surveys will provide uniformly sampled SEDs for large numbers of AGN, but our ability to correlate

SED shapes with other properties, in particular with galaxy morphology and environment will be extremely important.

Q5. <u>The importance of AGN feedback ?</u>

Although there is little doubt that AGN feedback exists (jets, winds, outflows, ...), its overall importance has not been firmly established. However, there seems to be increasingly strong evidence that AGN feedback in the most luminous sources (e.g. QSOs, ULIRGs) is having a profound effect of both the host galaxy as well as the surrounding intergalactic environment.

Q6. <u>AGN seeds in the early universe ?</u>

The relative importance of AGN in re-ionization is not firmly established. A better understanding of the AGN luminosity function at high-z is required.

Q7. <u>Future AGN surveys, data mining ?</u>

The future is bright for AGN research, given the 4D all-sky coverage that will be provided by future surveys (e.g. LSST). But it is also clear that future extragalactic research will require an ability to use sophisticated data mining tools in order to make maximum use of the extremely large volumes of data that will be accessible within the next 10–20 years.

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