The International AGN Watch: Past, Present, and Future

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Abstract. The International AGN Watch is an informal consortium of astronomers who acquire multiwavelength monitoring data to study the inner structure of active galactic nuclei. We briefly summarize the projects undertaken by the AGN Watch over the last decade, and discuss the future of multiwavelength monitoring.

1. Origin of the International AGN Watch

By the late 1980s, it had become apparent from both space-based (with the *International Ultraviolet Explorer [IUE])* and ground-based emission-line variability studies (e.g., Ulrich et al. 1985; Peterson et al. 1985) that reverberation mapping (Blandford & McKee 1982) would work — that given enough suitable monitoring data, one could determine the structure and kinematics of the broad-line region (BLR). The problem, of course, was how to *get* the necessary data.

In response to this problem, the International AGN Watch[1] was conceived at a meeting on AGN variability in Segovia, Spain, in the fall of 1987. It was generally recognized that the only way that AGN monitoring would be done right was by concentrating the efforts of the entire community on a single target. For a variety of reasons, including accessibility to *IUE* (in terms of both apparent brightness and position) and well-documented history of suitable variability (e.g., Peterson 1987; Wamsteker et al. 1990), NGC 5548 was an obvious choice as the target. Two important points quickly became apparent:

1. The amount of *IUE* time required was so large that a proposal would have to involve all three *IUE* agencies (NASA, ESA, and SERC [since replaced by PPARC in the UK]), and the proposal would have to be scientifically excellent and demonstrate broad community support.

2. The scientific return on the project would be greatly enhanced by a concurrent ground-based program of photometry and spectroscopy.

[1] A more complete history of the AGN Watch is available on the AGN Watch World-Wide Web site at URL http://www.astronomy.ohio-state.edu/∼agnwatch/. All AGN Watch data and results are also available at this site.

Both of these considerations pointed to a large consortium. Additional project participants were thus recruited privately and by open invitation at later AGN meetings in Atlanta and Santa Cruz.

This program was eventually approved and was begun in 1988 December. The *IUE* program consisted of four hours of observation once every four days for an eight-month period (Clavel et al. 1991). The concurrent ground-based program involved more than 20 observatories, yielding an average sampling rate of about one observation every 2.4 days (Peterson et al. 1991). The program was enormously successful. Important results were:

1. The BLR is compact and "thick", i.e., the outer radius of the BLR is at least 10 times larger than the inner radius.

2. There is evidence for ionization stratification of the BLR. The higher ionization lines respond to continuum variations with shorter lags than the lower ionization lines.

3. The UV and optical continuum variations appear to be closely coupled in time.

Following the original NGC 5548 monitoring program, similar coordinated UV and optical programs were undertaken on NGC 3783 (Reichert et al. 1994; Stirpe et al. 1994), Fairall 9 (Rodríguez-Pascual et al. 1997; Santos-Lleó et al. 1997), and 3C 390.3 (O'Brien et al. 1998; Dietrich et al. 1998). The results of the later experiments were generally consistent with the NGC 5548 results, except that in the case of 3C 390.3, the only broad-line radio galaxy in the sample, the high-ionization UV lines have longer lags than the Balmer lines, in contrast to the usual pattern.

Other projects were built on the foundation provided by the AGN Watch UV/optical monitoring programs. These include:

1. Continuing ground-based monitoring of NGC 5548 (Peterson et al. 1992, 1994, 1998a; Dietrich et al. 1993; Maoz et al. 1993; Korista et al. 1995; Romanishin et al. 1995). This is now in its tenth year.

2. An intensive *HST* UV monitoring program on NGC 5548 was undertaken to address questions raised by the original *IUE* campaign, but which required better time sampling and higher signal-to-noise ratios (Korista et al. 1995). Extreme-UV monitoring with *EUVE* was carried out at the same time (Marshall et al. 1997).

3. X-ray monitoring of 3C 390.3 with *ROSAT* led to the first well-sampled simultaneous X-ray/UV light curve for an AGN (Leighly et al. 1996).

4. A ground-based optical monitoring program was carried out on Mrk 509 (Carone et al. 1996). Long-term monitoring of this source turned out to be essential on account of the long emission-line lags (of order 80 days for Hβ) for this source.

5. In conjunction with the NGC 3783 monitoring program, a simultaneous multiwavelength snapshot, from γ-rays to radio, was obtained (Alloin et al. 1995).

6. An intensive 10-day multiwavelength monitoring program on NGC 4151 explored the relationship between continuum variations over a broad range (Edelson et al. 1996). This program, which involved *IUE* (Crenshaw et al. 1996), *ROSAT*, *ASCA*, and *CGRO* (Warwick et al. 1996) and ground-based telescopes (Kaspi et al. 1996a), found virtually zero time delay between the continuum variations in these various wave bands.

We refer the reader to more detailed reviews by Peterson (1993) and Netzer & Peterson (1997). Additional information about the International AGN Watch, including light curves, spectra, and recent papers, can be found on the AGN Watch World-Wide Web site.

2. Current AGN Watch Projects

The AGN Watch recently completed an intensive multiwavelength study of NGC 7469. The core of this program was 48 days of *continuous* monitoring with *IUE* (Wanders et al. 1997). Ground-based observations were obtained at several observatories (Collier et al. 1998), and 30 days of nearly continuous *RXTE* observations were made at the same time (Nandra et al. 1998). This program produced some potentially very important results on the continuum:

1. Across the UV/optical continuum, the variations at longer wavelengths follow those at shorter wavelengths. The lag between the shortest (1315 Å) and longest (6962 Å) wavelength continuum bands measured amounts to about 1.8 ± 0.9 days, and the effect seems to be significant at a level of confidence higher than 95% (Peterson et al. 1998b).

2. In contrast to what has been observed in other well-studied AGNs, the X-ray continuum variations do not appear to be well correlated with the UV/optical continuum variations.

These two results seem to be completely at odds with one another. The UV/optical wavelength-dependent continuum lags suggest that the accretion disk is reprocessing some variability signal that propagates at the speed of light. Indeed, the wavelength dependence of the continuum lags is consistent with the $\tau \propto \lambda^{4/3}$ dependence that would be expected for an X-ray irradiated accretion disk (Collier et al. 1998). On the other hand, direct observation of the 2–10 keV X-rays does not support the hypothesis that the X-rays drive the longer-wavelength variations. Previous monitoring experiments, notably the AGN Watch programs on NGC 4151 (Edelson et al. 1996) and 3C 390.3 (Leighly et al. 1997; Dietrich et al. 1998; O'Brien et al. 1998) indicate that the high-energy variations are closely coupled to the UV/optical variations.

At this time, these results remain unexplained theoretically; the observational results seem significant, but not overwhelmingly. UV/optical wavelength-dependent continuum lags have not been detected in any other AGN (though there is a *hint* of the effect in the NGC 4151 data), although the time sampling was probably inadequate to see this effect in other sources (Peterson et al. 1998b). In the case of the X-rays, the time series was too short to determine if there is any correlation between the light curve at any lag. Obviously better, longer time series will be needed to provide convincing evidence one way or the other.

At the present time, the AGN Watch is also working on coordinated *ISO* and ground-based observations of Mrk 279.

3. Future of the AGN Watch

Nearly all the AGN Watch programs have been built around *IUE* projects. Now that *IUE* has been turned off, what is the future of the AGN Watch?

Firstly, the observers involved have decided to maintain the optical monitoring program on NGC 5548 indefinitely. No other radio-quiet AGN has such a long, well-sampled light curve, and the people involved agree that it is important to keep this program going so that we have at least *one* such data set. Potential areas of interest concern the long-term continuum behavior (specifically considering issues such as characteristic frequencies or where the turn-over in the low-frequency power spectrum occurs), the possible evolution of the BLR on dynamical time scales, and the probably related question of what causes emission-line profile variations (see Peterson, Pogge, & Wanders, this volume).

Secondly, there is also a wide-spread feeling that these hard-won monitoring data have been under-used. Certainly some of the cream has been skimmed off the top, but there are a number of other important issues that can be addressed with these data. In order to promote more use of these data, the AGN Watch has organized all of the data on a publicly accessible World-Wide Web site, as noted earlier. Furthermore, the AGN Watch hopes to sponsor a workshop on monitoring data in the near future, probably in the summer of 1999.

Thirdly, the AGN Watch remains available to support on an *ad hoc* basis AGN monitoring programs that may be carried out on other spacecraft, including *HST*, *AXAF*, *FUSE*, and *XMM*. I will return to this topic below.

4. The Future of Reverberation Mapping

A related question, of course, is what is the future of reverberation mapping? A significant qualitative improvement in reverberation mapping studies will require time series that are both longer and better sampled than previous light curves. Given this, it is unlikely that we will see an improvement over the NGC 5548 *HST* ultraviolet data at any time in the near future. Similarly an improvement in the optical ground-based data will be hard to manage; high time resolution requires multiple telescopes, and our experience has been that this will impose much more stringent data requirements than have been applied currently, since systematic differences between data sets now limit the quality of the light curves (indeed, in the NGC 4151 and NGC 7469 experiments, many of the submitted optical data had to be rejected on quality grounds).

On the other hand, the sampling requirements can be relaxed by carrying out monitoring programs on higher luminosity (and thus higher redshift) sources; intrinsically slower variations, longer emission-line lags, and $1+z$ time dilation suggest that this frontier is more amenable to AGN Watch-type monitoring. It is not clear, however, that large consortia are either necessary or desirable for this work; limited collaborations are already making progress in this area (e.g., Kaspi et al. 1996b). In any case, the number of collaborators in spectroscopic observations of high-redshift sources is likely to be limited to observers with access to larger telescopes.

In my opinion, significant improvements in monitoring of bright Seyfert galaxies for reverberation mapping or for continuum studies will depend on dedicated telescopes, either in space or on the ground. Such facilities are necessary not only for AGN programs, but other types of synoptic studies. For this reason, we should explore collaborations with astronomers working in other science areas to develop common facilities that can be used for long-term monitoring projects. It is extremely important, however, that the goals of such a program remain limited and well-focused; there is a natural tendency in astronomy to parcel resources thinly, and this has been much to the detriment of monitoring projects. In the case of the AGN Watch, both the NGC 4151 and NGC 7469 projects were cut back significantly by the *IUE* time allocation committees, and the scientific results of both programs were highly compromised as a result — the NGC 4151 program was so short that it produced virtually no useful information on the emission lines, and the NGC 7469 program, cut back to 65% of the original request, left us with ambiguities in the continuum behavior that we are not likely to have resolved at any time in the near future.

5. What Can the AGN Watch Do For You?

As mentioned above, the AGN Watch is always willing to consider supporting observations of compelling monitoring programs undertaken on existing or future spacecraft, or participating in purely ground-based efforts. Basically the things to keep in mind are:

- The AGN Watch is an informal consortium; members choose to participate in projects on their own. They will expect appropriate credit (usually a co-authorship on the first data paper) for participation in a project. The AGN Watch web site contains an explanation of AGN Watch policies on data, and this should give you a good idea of how to deal with all these observers.

- If you want to get the full value of ground-based participation by the AGN Watch, contact us early, preferably *before* you submit your observing proposal. There are two reasons for this: (a) if your project will really benefit from ground-based support, participation by the AGN Watch will lend credibility to your proposal; and (b) ground-based observations also take time to arrange. Proposals need to be submitted, and planning needs to take place. A year's lead time is not unreasonable. A ground-based support program that is thrown together in a couple of months is not likely to provide the data that you need.

- You are under no obligation to use every datum submitted to you; by far, the best strategy is to indicate quality specifications in advance. Data that do not meet these requirements do not have to be used.

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