AGN Physics with the Sloan Digital Sky Survey
*ASP Conference Series, Vol. **VOLUME***, 2004*
G.T. Richards and P.B. Hall

Long Term Profile Variability of Double-Peaked Emission Lines in AGNs

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Abstract. An increasing number of AGNs exhibit broad, double-peaked Balmer emission lines, which are thought to arise from the outer regions of the accretion disk which fuels the AGN. The line profiles are observed to vary on a characteristic timescales of 5-10 years. The variability is not a reverberation effect; it is a manifestation of physical changes in the disk. Our group has monitored a set of 20 double-peaked emitters for the past 8 years (longer for some objects). Here, we characterize the variability of the double-peaked Hα line profiles in five objects from our sample. By experimenting with simple models, we find that disks with a single precessing spiral arm are able to reproduce many of the variability trends that are seen in the data.

1. Introduction

An increasing number of AGNs are known to exhibit broad, double-peaked, Balmer emission lines. Approximately 20% of Broad-Line Radio Galaxies (BLRGs) are double-peaked emitters (Eracleous et al. 1994). Recently, over 100 double-peaked emitters were discovered in the SDSS (Strateva et al. 2003). Double-peaked emission lines have also appeared in objects which did not previously exhibit them, most notably in the LINER NGC 1097 (Storchi-Bergmann et al. 1993). The lines are thought to originate in the outer portions of the accretion disk (R $\sim$ 100s -1000s r_g, where $r_g = GM_\bullet/c^2$). The *profiles* of the double-peaked emission lines are observed to vary on timescales of 5-10 yrs. These variations are *not* a result of reverberation, which occurs on the much shorter light-crossing timescale. The profile variability is a manifestation of *physical* changes in the outer disk. Therefore, detailed studies of the double-peaked emitters are important, not only because they are part of an intriguing (and growing) class of objects, but also because they are an important tool which can be used to test models for the outer accretion disk. They may also provide clues for the origin of the photometric variability of all AGNs.

A simple axisymmetric disk can reproduce many of the individual double-peaked profiles, but cannot explain the variability or the commonly observed profiles in which the red peak is stronger than the blue peak. The simplest extensions are axisymmetric disks with emissivity perturbations, disks with precessing spiral arms, or precessing elliptical disks. These models predict variability over several different physical timescales, the dynamical, thermal, and sound crossing times, which are set by the black hole mass ($\mathrm{M}_\bullet$) and given by: $\tau_{dyn} \sim 6\ \mathrm{M}_8\ \xi_3^{3/2}$ months; $\tau_{th} \sim \tau_{dyn}/\alpha$; and $\tau_s \sim 70\ \mathrm{M}_8\ \xi_3\ \mathrm{T}_5^{-1/2}$ years, where $\mathrm{M}_8 = \mathrm{M}_\bullet/10^8\ \mathrm{M}_\odot$, $\xi_3 = \mathrm{R}/10^3\mathrm{R_g}$, $\mathrm{T}_5 = \mathrm{T}/10^5$ K, and $\alpha(\sim 0.1)$ is the Shakura-Sunyaev viscosity parameter (Shakura & Sunyaev 1973). Matter embedded in the disk will orbit on the dynamical timescale, thermal instabilities will dissipate over a thermal timescale, while density perturbations will precess on timescales from a few τ_{dyn} – few τ_s. Any of the above families of models predict variability timescales that are roughly consistent with those observed. In order to observe profile variability over the different possible timescales, our group has been monitoring a set of 20 double-peaked emitters over the last decade. About half of the objects are observed two or three times a year; others are accessible only once each year. For a subset of these objects, the available data span a longer baseline.

2. Characterizing the Profile Variability

Finding an appropriate model which can self-consistently reproduce a sequence of profiles is a time-consuming process. Even within a family of models, the parameter space to explore is large. As a *first step*, to aid us in selecting suitable models, we have begun characterizing the profile variability of the objects in our sample by reducing each profile to a set of easily measured quantities whose variability patterns can be quickly compared with those of a set of model profiles. These parameters are: the velocities of the red and blue peaks; the blue-to-red peak flux ratio; the full widths at half and quarter maximum (FWHM and FWQM); and the velocity shifts of the FWHM and FWQM centroids. Thus, for a given family of models we can efficiently select the regions of parameter space that should be used for detailed modeling for each object in our group.

Here, we compare the observed profile variability with that expected from a circular disk with a single, precessing, spiral arm. Chakrabarti and Wiita (1994) first suggested that spiral shocks in AGN accretion disks might explain the observed line profile variability in Arp 102B and 3C 390.0. This is an attractive model to test first for several reasons. (1) Spiral arms have been used very successfully in detailed modeling of sequences of profiles by Gilbert et al. (1999; 3C 390.3 and 3C 332) and Storchi-Bergman et al. (2003; NGC 1097). (2) Spiral arms are present in other astrophysical disks (i.e. galaxies and some cataclysmic variables). (3) A spiral arm provides a mechanism for removing angular momentum from the disk. If the profile variability is caused by the precession of a spiral arm, detailed modeling could give us important information about how the matter in the outer accretion disk sheds its angular momentum - something which is not yet well understood!

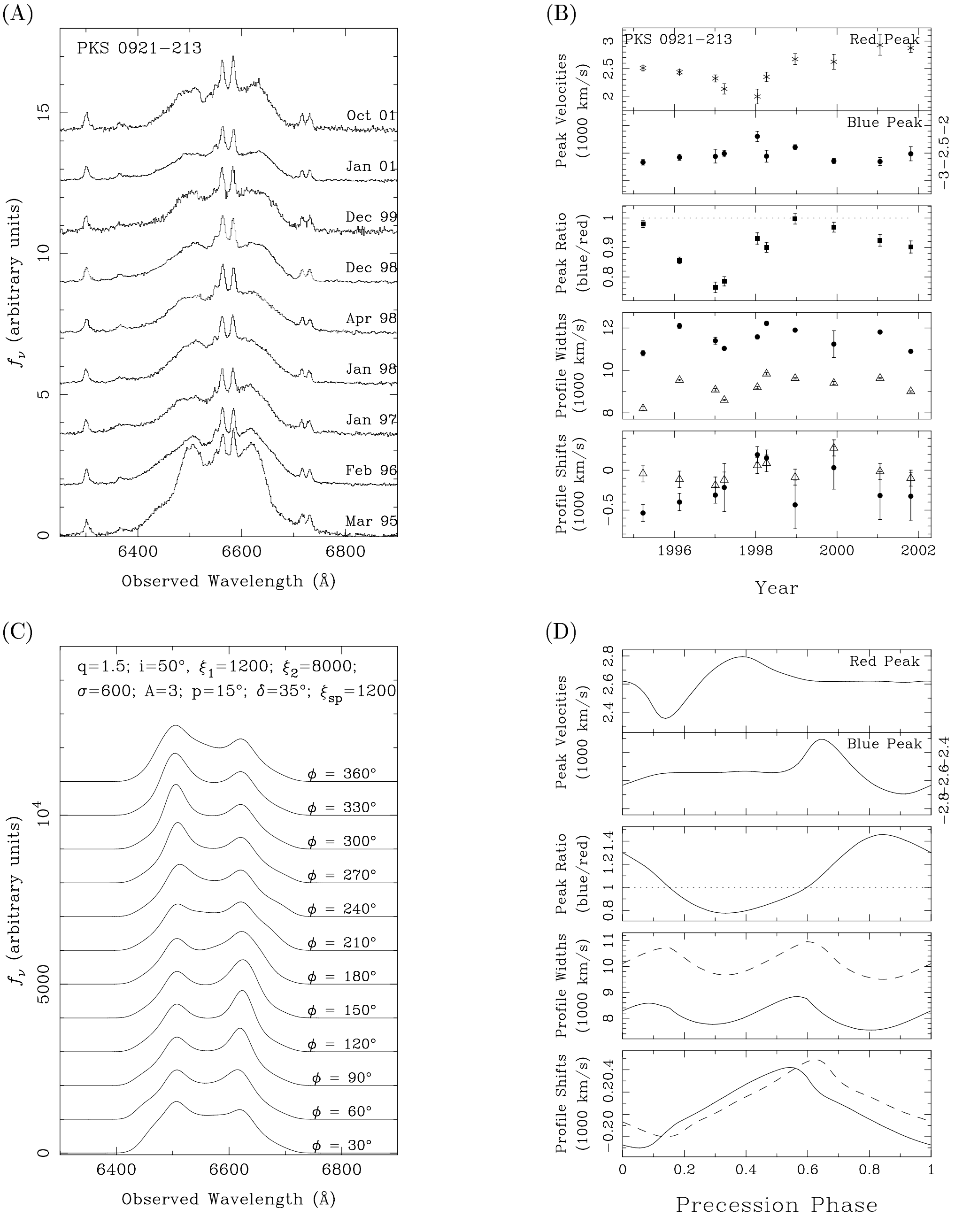

Figure 1. *PKS 0921–213 data* (A) Time sequence of profiles for PKS 0921-213. The variation in the relative fluxes of the red and blue peaks is quite clear. (B) Variability of the profile properties with time. The FWHM is denoted with triangles, while the FWQM is shown with filled circles. Observations taken within 1 month of each other have been averaged together. The most striking variation is the reversal in the blue to red peak flux ratio. *One-Armed Spiral Model* (C) Example set of model profiles. The disk parameters (see text for the definitions) have been tuned to fit the profile of PKS 0921–213 while the spiral arm model parameters were chosen merely to serve as an illustration. (D) The corresponding variability in the model profile properties. The FWQM is shown with a dashed line.

The underlying axisymmetric disk has the following parameters: the inner and outer radii, ξ_1 and ξ_2 (in units of $GM_\bullet/c^2$); the inclination angle, i; a broadening parameter, σ; and the slope of the axisymmetric emissivity law, q ($\epsilon \propto \xi^{-q}$). The one-armed spiral is modeled as a perturbation in the emissivity pattern, introducing the following extra parameters: the amplitude, A, of the spiral arm (i.e. the contrast relative to the underlying disk); the pitch angle, p; the angular width of the arm, δ; the inner radius of the arm, ξ_{sp}; and the phase angle, ϕ (see Storchi-Bergmann et al. 2003 for the full description). Profile sequences are produced by varying ϕ.

3. Results

Thus far, we have characterized the variability of five of the 20 objects in our sample (PKS 0921–213, CBS 74, PKS 1020–103, PKS 1739+184, and 3C 59). Each object is unique, but there are some common trends which are exemplified in PKS 0921–213 (Fig. 1). (1) The most striking variation is in the peak flux ratio. In some cases a complete peak reversal is seen, *demanding* some kind of azimuthal asymmetry in the disk. (2) The peak velocities show more moderate modulations than the peak flux ratio. (3) The FWHM and FWQM vary synchronously and by the same magnitude while the shifts of the FWHM and FWQM centroids often vary at different times and by different magnitudes.

The one-armed spiral models reproduce a wide range of variability patterns. But as a class, the spiral-arm models exhibit common trends, some of which bear a striking resemblance to the data. An example is shown in Figure 1. (1) Peak reversals are a ubiquitous feature of the model profiles. (2) The blue and red peaks vary at different times, but by the same magnitude. (3) The profile widths change in-sync and by the same magnitude, as seen in the data. Although not well demonstrated in Figure 1, in many models, the shifts of the FWHM and FWQM centroids do not always vary synchronously.

This preliminary variability characterization suggests that a spiral arm model is certainly capable of reproducing many of the variability patterns that are observed. Additionally, this model has been used quite successfully to model *sequences* of profiles. Therefore, this model is likely to be an excellent candidate for detailed modeling of these objects, and likely many more in our sample.

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