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The Tilt between Acretion Disk and Stellar Disk

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Abstract. The orientations of the accretion disk of active galactic nuclei (AGN) and the stellar disk of its host galaxy are both determined by the angular momentum of their forming gas, but on very different physical environments and spatial scales. Here we show the evidence that the orientation of the stellar disk is correlated with the accretion disk by comparing the inclinations of the stellar disks of a large sample of Type 2 AGNs selected from Sloan Digital Sky Survey (SDSS, York *et al.* 2000) to a control galaxy sample. Given that the Type 2 AGN fraction is in the range of 70–90 percent for low luminosity AGNs as *a priori*, we find that the mean tilt between the accretion disk and stellar disk is ~ 30 degrees (Shen *et al.* 2010).

Key words. Galaxies: statistics—galaxies: Seyfert—galaxies: nuclei—galaxies: spiral.

1. Introduction

In the unified AGN model, a Type 2 AGN is seen from an angle close to the plane of the central accretion disk. On this plane, the accretion disk and the broad line regions are obscured by an outer molecular torus, while a bi-polar jet emanating from the nucleus is perpendicular to the plane (Antonucci *et al.* 1993). The Type 1 AGNs are then objects that we are able to see directly into the central regions.

Several studies have revealed that the angle between the orientation of the kiloparsec-scale jet and the normal to the host galaxy plane has a wide/random distribution based on the samples of dozens of radio galaxies (Gallimore *et al.* 2006). This leads to a conclusion that the internal gas fuelling the black hole may not be co-aligned with the outer gas forming the stellar disk.

If the orientations of the accretion disk and the stellar disk were completely uncorrelated with each other, we would expect that the inclination of the stellar disks would be independent of the AGN phenomena. On the contrary, if the stellar disks of AGN hosts have preferred inclinations, e.g., a deficiency of edge-on galaxies in Type 1 AGNs found in an earlier study (Keel 1980) and recently confirmed by Lagos *et al.* (2010), an intrinsic correlation between the alignment of the stellar disk and the accretion disk could be expected.

2. Axis ratio of spiral hosts of Type 2 AGNs

We have selected a sample of Type 2 AGNs from the complete spectroscopic galaxy sample of the data release 7 of SDSS using the empirical relation between the emission line ratios proposed by Kauffmann *et al.* (2003). We then use the criteria $fracDev < 0.5$ to select the AGNs hosted by disk galaxies (Abazajian *et al.* 2004).

For a realistic triaxial ellipsoid model of spiral galaxies, the observed b/a is dependent on two parameters, the disk height $\gamma \equiv C/A$ and the disk ellipticity $\epsilon \equiv (1 - B/A)$, where A, B, C are the major, middle and minor axes of the ellipsoid respectively (Binney 1985). The galaxies with different physical properties (e.g., mass and size) are shown to follow different intrinsic (γ, ϵ) distributions (Padilla & Strauss 2008). Therefore, to quantify the inclinations of the disks of our AGN hosts, their physical properties and sample selection criteria must be well-defined or controlled.

The AGN host galaxies are known to have distinctive physical properties (Kauffmann *et al.* 2003). For our sample of AGNs hosted by disk galaxies, we find that their hosts are biased towards these objects with large bulge component, high concentration and old stellar population. To quantify the sample properties of our AGN hosts, we built a control sample of galaxies (without AGN phenomena) from the same galaxy catalogue of SDSS, which are selected to have same sample size, stellar properties and selection effects (e.g., red-shift distribution) as the AGN hosts. We then compare b/a distributions of these two samples. The AGN sample has systematically more number of galaxies than the control galaxy sample in small b/a bins. We show the number ratios of AGNs to the control galaxies ($N_{\rm AGN}/N_{\rm GAL}$) in different b/a bins in Fig. 1. As we can see, this ratio decreases with the increasing of b/a systemtically. Since the galaxy sample have already been controlled to have the same physical properties and selection effects as the AGN hosts, the systemical bias in b/a distribution of the AGN hosts could only be stemmed from their preferred (non-random) viewing angles.

3. The shape of the AGN host spiral galaxies

To quantify the preferred inclinations of our Type 2 AGN hosts, we need to know the shape of their host galaxies, i.e., the γ and ϵ distributions, which can be obtained from the Monte-Carlo fitting of the b/a distribution of the control sample of galaxies since their viewing angles are random.

For the disk galaxies in general, it is found that the γ distribution can be approximated by a normal function whereas ϵ follows a normal or log-normal distribution (Ryden 2004). However, for our control sample of galaxies, the sample selection is not well-defined and the goodness of the fit is also bad when only single Gaussian distributions are assumed for γ and $\epsilon/\ln\epsilon$ as *a priori*. As an alternative, the sample of our control galaxies can be viewed as a combination of sub-samples of galaxies, where the γ and ϵ distributions both follow Gaussian distributions for each sub-sample. We then use the non-negative least square linear regression technique to fit the observed b/a distribution of the control galaxies to get the fraction of each subset. With (γ, ϵ) distributions known for control galaxies, so also for AGN hosts, we then model the viewing angles of the AGN hosts from their *b/a* distribution.

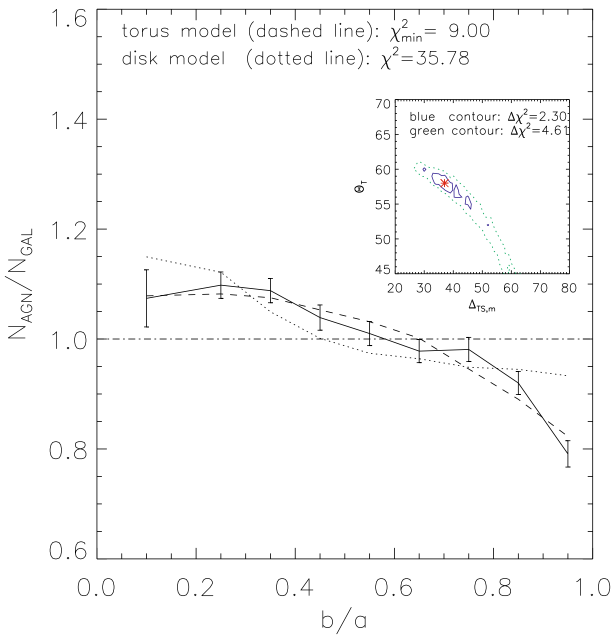

Figure 1. The ratio of the numbers of the AGNs to the control galaxies in different b/a bins. The solid line with error-bars shows the observational results from the SDSS. The dashed curve shows the best model fitting from the aligned torus model (section 4) while the dotted curve shows the model prediction from the stellar dust model (section 5).

4. Result: The tilt between the accretion disk and stellar disk

We parameterize the inclinations of the accretion disk as θ_A, where θ_A ($0° \leq \theta_A \leq 90°$) is the angle between the normal line of the accretion disk plane and the line-of-sight. Correspondingly, the inclination of the stellar disk is denoted as θ_S. The tilt angle between the accretion disk and stellar disk is then denoted as Δ_{TS}. As in the unified AGN model, we assume that the obscuring torus lies on the plane of the accretion disk and with opening angle $2\Theta_T$. Obviously, a Type 2 AGN satisfies the criteria $90° - \theta_A < \Theta_T$.

In this model, there are only two free parameters, the torus opening angle Θ_T and the tilt angle Δ_{TS}. Θ_T could be constrained from the Type 2 AGN fraction f_2 since $f_2 = \sin(\Theta_T)$. For tilt angle Δ_{TS}, it is a reasonable assumption that the most probable orientation of the torus plane is to be the same as the stellar disk, i.e., $P_{max}(i_S) = P(\Delta_{TS} = 0)$, but with significant scatters on Δ_{TS}. On the other hand, $\cos(\Delta_{TS})$ would follow a uniform distribution between 0 and 1 if the orientations of the torus plane and the stellar disk were independent. Thus, we further assume that $\cos(\Delta_{TS})$ follows a Gaussian distribution which peaks at $\Delta_{TS} = 0$ and has a scatter $\cos(\Delta_{TS,m})$. Under this assumption, $\Delta_{TS,m}$ could be viewed as an effective tilt angle, which 68% of the Δ_{TS} are distributed.

With Θ_T and $\Delta_{TS,m}$ assigned, we make Monte-Carlo simulations to predict the number ratios N_{GAL}/N_{GAL} in different b/a bins. We use the least square routine to search the best model parameters of Θ_T and $\Delta_{TS,m}$ by fitting the observed N_{AGN}/N_{GAL} in different b/a bins. The best model fitting is shown as dashed line in Fig. 1, which has the minimum $\chi^2_{min} \approx 9$, comparable to the number of data points (9 b/a bins), indicating an excellent goodness of fit. The best model parameters are $\Theta_T = 58°$ and $\Delta_{TS,m} = 37°$, respectively. $\Theta_T = 58°$ corresponds to a Type 2 AGN fraction of $f_2 = 0.85$, in excellent agreement with the results quoted in literature for low luminosity AGNs (Simpson 2005). *For the tilt angle between stellar disk and accretion disk, the effective tilt angle $\Delta_{TS,m} = 37°$ corresponds to a mean tilt angle $\bar{\Delta}_{TS} \approx 30°$.*

5. Discussion: Could the stellar disk be the nuclei obscurer?

When a stellar disk is viewed as edge-on, the extinction is quite large (Shao *et al.* 2007). Therefore, it is also possible that the over-density of the edge-on Type 2 AGNs is caused by the stellar dust layer.

To test this scenario, we now no more assume that the nuclei obscuring torus (accretion disk) is correlated with the stellar disk, but consider it being randomly orientated. However, we consider that when a stellar disk is viewed as edge-on ($\theta_S < \gamma$), the stellar dust layer will obscure the nuclei and make it a Type 2 AGN. The prediction from this stellar dust model is shown as dashed line in Fig. 1. As we can see, the stellar obscurer indeed predicts over-density of the low axis ratio galaxies ($b/a < 0.4$). However, for the galaxies with $b/a > 0.4$, the predicted N_{AGN}/N_{GAL} is roughly a constant, whereas the observation show continuous decreasing of Type 2 AGNs in more round galaxies.

However, we would mention that there is no tunable parameter in this stellar dust model, whereas the aligned torus model (in section 4) has two free parameters, and we assume that the stellar dust layer following the same shape of the stars might be too simplistic. A more sophisticated treatment of the distribution of the stellar dust might help, but it is out of range of the current study.

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