Alignments of quasar axes with large-scale structures

D. Hutsemékers (hutsemekers@astro.ulg.ac.be), L. Braibant, V. Pelgrims, D. Sluse
Institut d'Astrophysique et de Géophysique, Université de Liège, Belgium

Based on measurements of optical linear polarization of quasars belonging to large groups at redshift z ~ 1.3, we found that quasar spin axes are likely parallel to their host large-scale structures (Hutsemékers et al. 2014). These observations can constrain models of the co-evolution of AGN, galaxies and large-scale structures.

Introduction – Models of co-evolution of galaxies with the large-scale structures in which they are embedded predict alignments or anti-alignments of galaxy axes with filaments depending on halo mass, redshift and AGN feedback (e.g., Dubois et al. 2014b and references therein). Quasars allow us to test these models at moderate to high redshifts. Since quasar polarization is often related to the object's geometry, we have measured the polarization of quasars belonging to the large quasar groups Huge-LQG and CC-LQG described in Clowes et al. (2013). These quasar structures extend over Gpc scales at redshift z ~ 1.3.

Observations and polarization measurements – Observations were carried out at the European Southern Observatory, Paranal, using the Very Large Telescope equipped with FORS2 in its imaging polarimetry mode. All observations were obtained in the V filter. The linear polarization of all 73 quasars of the Huge-LQG and of 20 out of the 34 quasars of the CC-LQG has been obtained, i.e., for a total of 93 quasars. The error on the polarization degree is between 0.06% and 0.23%, with a mean value of 0.12%. In this region of the sky, the interstellar polarization is around 0.1%. We consider that polarization is essentially intrinsic to the quasar when $p \geq 0.6\%$. 19 quasars out of 93 are significantly polarized with $p \geq 0.6\%$. For these 19 polarized quasars, the error on the polarization angle is smaller than 10° with a mean value of 3°.

Analysis of polarization measurements – In order to compare the quasar polarization angles to the direction of the local structures, we consider four sub-structures for which we determine a mean orientation (Fig 1). We then estimate the acute angle Δθ between the quasar polarization vectors and the PA of the structures to which they belong. The distribution of Δθ is illustrated in Fig. 2. It shows a bimodal distribution, with both alignments (Δθ ~ 0°) and anti-alignments (Δθ ~ 90°). This shows that quasar polarization vectors are either parallel or perpendicular to the large-scale structures to which they belong. A bimodal distribution of Δθ is exactly what we expect if the quasar morphological axes are related to the orientation of the host large-scale structures. Indeed, the polarization of type 1 AGN is usually either parallel or perpendicular to the AGN accretion disk axis depending on the inclination with respect the line of sight (Smith et al. 2004). In Fig. 3, the quasar polarization angles modified according to θ = mod(θ, 90°) + 90° are plotted over the LQG structure, unveiling a remarkable correlation. The probability that these results can be attributed to a random distribution of polarization angles is on the order of 1%. We stress that such a behavior cannot be due to contamination by interstellar polarization which would align all polarizations similarly.

Interpretation – Since the width of low-ionization emission lines (Hβ , MgII) observed in quasar spectra correlates with the object's inclination with respect to the line of sight (Wills & Brown 1986), we plot in Fig. 4 the angle Δθ as a function of the quasar MgII emission line width. We see that most objects with polarization perpendicular to the host structure (Δθ > 45°) have large emission line widths while all objects with polarization parallel to the host structure (Δθ < 45°) have small emission line widths. Quasars seen at higher inclinations (face-on: i=0°, edge-on: i=90°) generally show broader low-ionization emission lines, in agreement with line formation in a rotating disk (Wills & Brown 1986). This supports our hypothesis that the polarization of quasars is either parallel or perpendicular to the host structure depending on their inclination. When rotating by 90° the polarization angles of objects with MgII emission line widths larger than 4300 km/s, a stronger alignment is seen (Fig. 5). On the other hand, it should be emphasized that the emission line width does not only depend on inclination but also on the mass of the central black hole if the rotating disk is virialized. Quasars with lower black hole mass will have narrower emission lines whatever their inclination so that some of them may still appear anti-aligned in Fig. 4. Since objects seen at higher inclinations preferentially show polarization perpendicular to their axes (Smith et al. 2004), we finally infer that quasar spin axes should be predominantly parallel to the orientation of the structures to which they belong.

Discussion – Galaxy spin axes are known to align with large-scale structures such as cosmic filaments (e.g., Tempel & Libeskind 2013; Zhang et al. 2013). Till now, such alignments are detected up to redshift z ~ 0.6 at scales < 100 Mpc. We have found that quasar accretion disk axes are likely parallel to the large-scale structures to which they belong over Gpc scales at redshift z ~ 1.3, i.e., one order of magnitude bigger than currently known galaxy alignments. Although the scales involved are much larger, we may assume that similar mechanisms can explain alignments of quasar and galaxy axes with their host large-scale structure. Models of galaxy evolution show that there exists a transition mass below which their axes are parallel to the large-scale structure filaments and above which they are perpendicular. AGN feedback and merging play a key role in the (mis)alignment mechanism. The transition mass of the dark matter halo is thought to be around $\log (M_H / M_\odot) \sim 12$ (e.g., Aragon-Calvo et al. 2007, Codis et al. 2012). On the other hand, due to feedback, quasar activity apparently occurs in low-mass halos with $\log (M_H / M_\odot) < 12$ (Fanidakis et al. 2013, Cen et al. 2015). Since at redshift z ~ 1.5, super massive black holes are still aligned with their host galaxy / halo (Dubois et al. 2014a), quasar axes are expected to be predominantly parallel to their host large-scale structures. This is in agreement with our observations.

References

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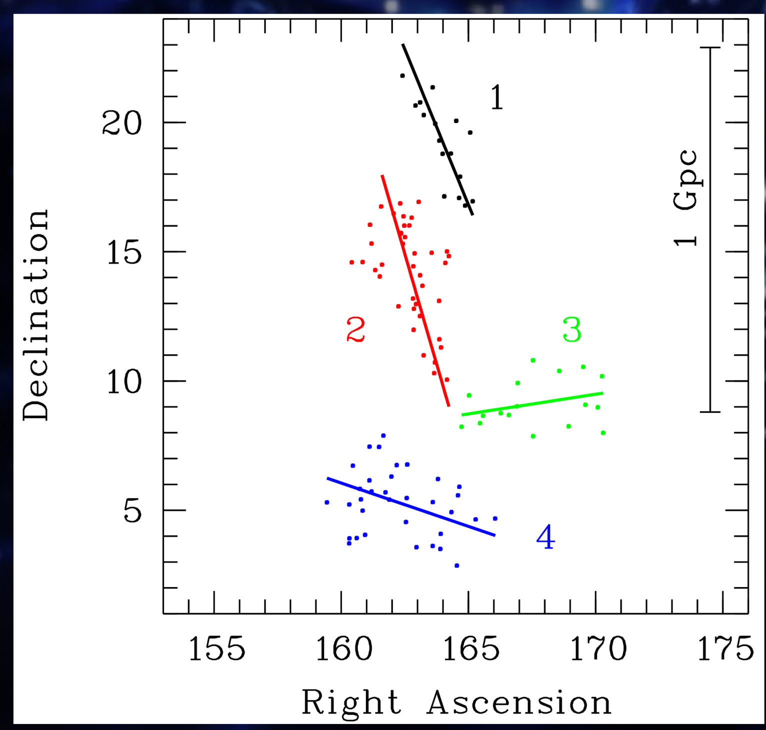


Fig. 1. The large quasar groups and their orientations on the sky. The superimposed lines illustrate the orientations of the four groups labeled 1, 2, 3, 4. The comoving distance scale at redshift z = 1.3 is indicated.

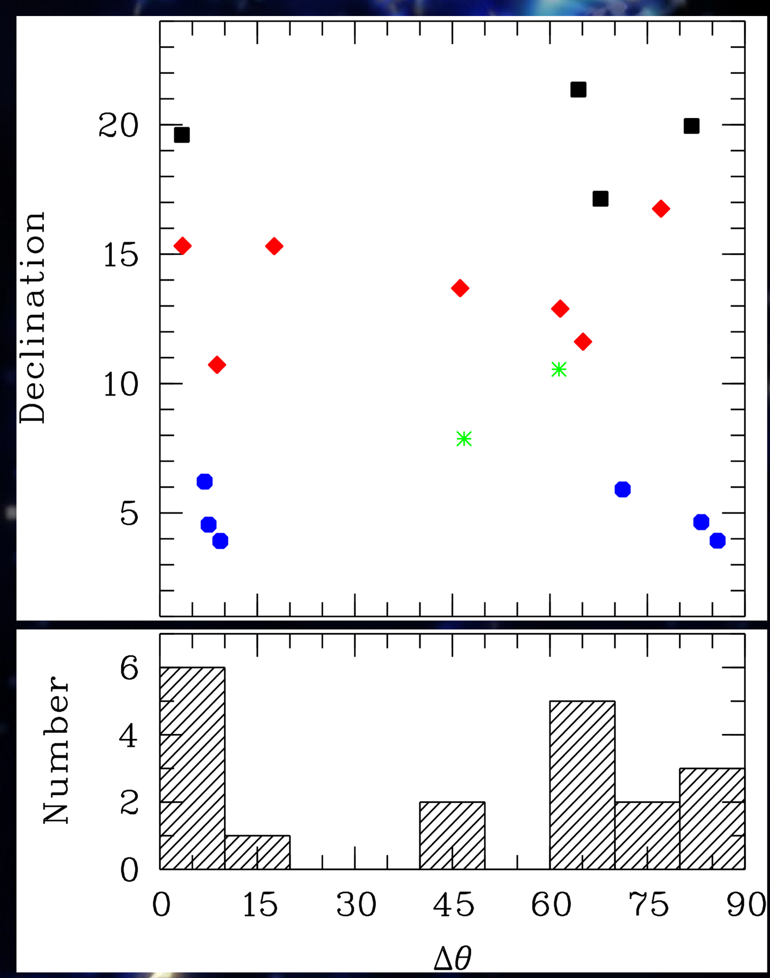


Fig. 2. Bottom: distribution of the acute angle Δθ (in degree) between quasar polarizations and the orientation of their host large-scale structure. The bimodal distribution shows that quasar polarization vectors are either parallel or perpendicular to the large-scale structures to which they belong. Top: Δθ is plotted against the object's declination to illustrate the behavior of the different quasar groups (colors as in Fig. 1).

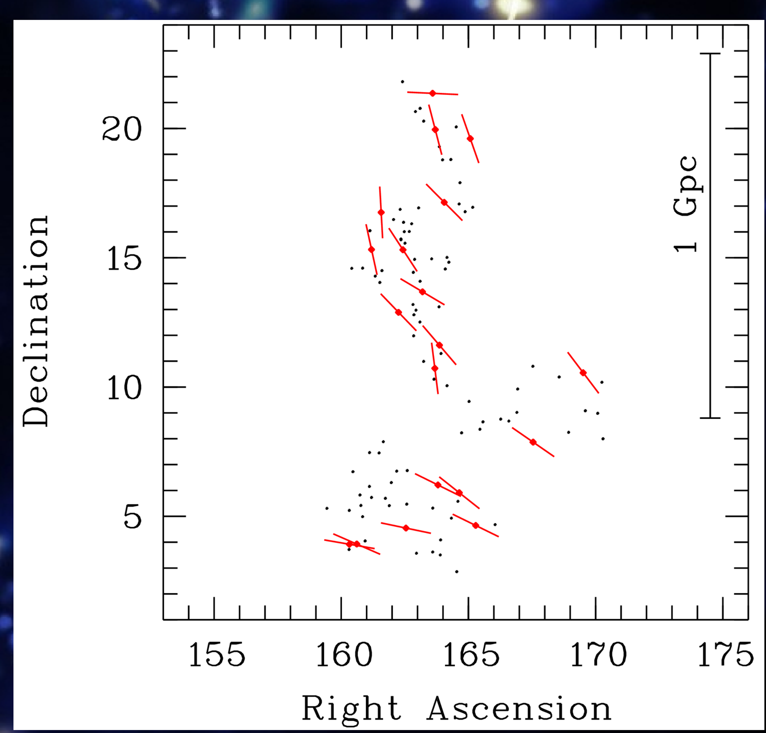
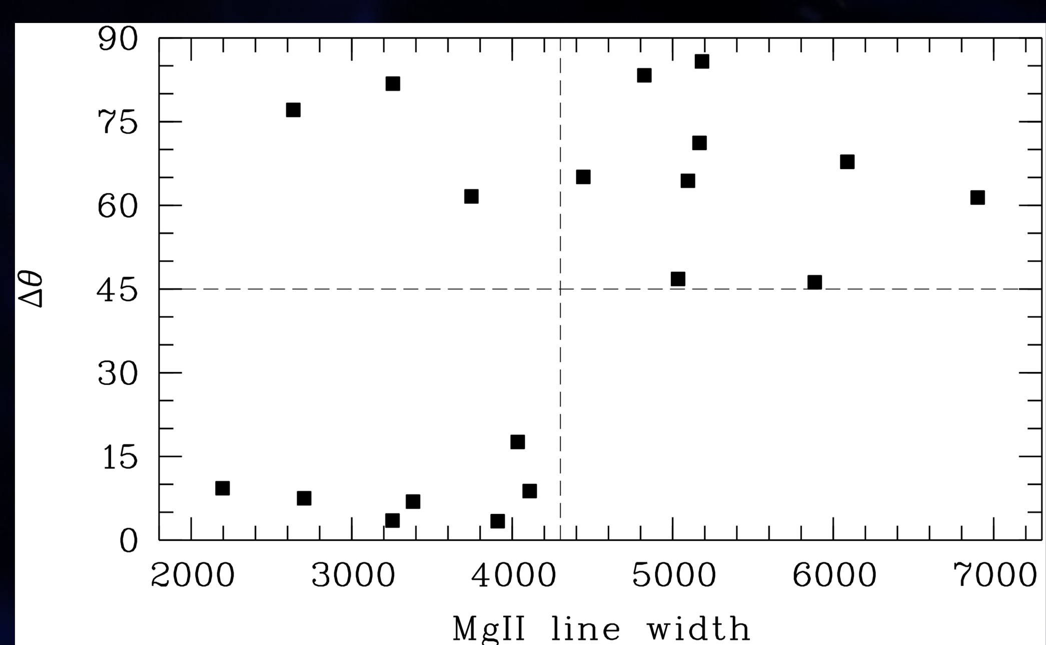


Fig. 3. The polarization vectors of the 19 quasars with p ≥ 0.6% are superimposed on the large-scale structure after rotation of the polarization angles according to θ = mod(θ, 90°) + 90°. A clear correlation is seen. [We nevertheless caution against exaggerated visual impression since polarization angles are now in the range 90°–180°].

Fig. 4. The acute angle Δθ between quasar polarizations and the orientation of their host large-scale structures as a function of the MgII emission line width (FWHM in km/s). Quasars seen at higher inclinations show broader emission lines, suggesting that polarization is either parallel or perpendicular to the large-scale structure depending on the object's inclination.



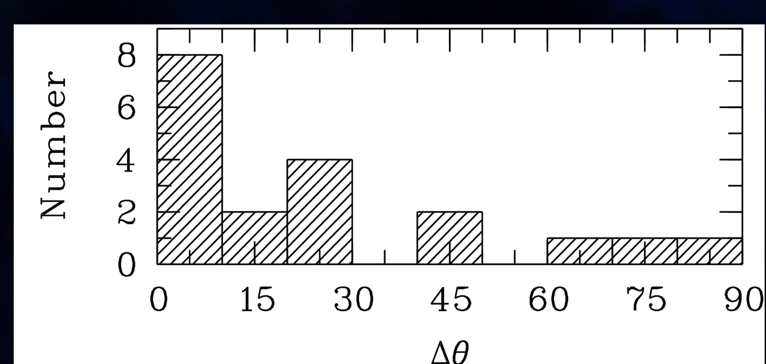


Fig. 5. Distribution of the acute angle Δθ between quasar polarizations and the orientation of their host large-scale structure after rotating by 90° the polarization angles of objects with MgII emission line widths larger than 4300 km/s.

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