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Accretion of gaseous disks at high redshifts and the depolarization asymmetry of radio-loud quasars

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Abstract. A new scenario is explored to understand the striking depolarization asymmtery observed between the two lobes of powerful radio sources exhibiting one-sided jets. According to this tight correlation, commonly known as the Laing-Garrington effect, the lobe on the counter-jet side is found to depolarize more rapidly at longer radio wavelengths, compared to the opposite lobe. Conventionally, this is explained by postulating that distant radio sources are embedded within large halos of dense magneto-ionic plasma, with typical dimensions of the core of intra-cluster medium (ICM). Pointing out potential problems with this scheme, we argue that the depolarization asymmetry, instead of arising from the putative ICM cores at high redshifts, could occur more commonly due to extended disks of dusty magneto-ionic medium surrounding elliptical galaxies hosting quasars. Differring radically in their physical origin from the postulated ICM haloes, such disks are likely to have been acquired in the events of capture of gas-rich galaxies, or their progenitors, by massive radio-loud ellipticals. Radio and optical evidences for such disks are summarized and some aspects of their evolution are briefly discussed.

Key words: galaxies: active – galaxies: ellipticals – galaxies: interactions – galaxies: ISM – galaxies: jets – radio continuum: galaxies

1. Introduction

Although the two radio lobes of powerful double radio sources are broadly similar in many ways, a number of significant and striking differences between them have been revealed by high quality radio/optical observations. Some of the well known types of asymmetries involve observed properties such as the jet's brightness, optical line-emission from the lobes, radio spectral index and spectral curvature, as well as the radio depolarization of the lobes (as summarized recently, e.g., by Komberg 1994 and by Gopal-Krishna & Wiita 1996). The jet asymmetry, which is now generally regarded as being primarily an illusion arising from the jet's bulk relativistic motion and the consequent Doppler boosting of its radiation, provides a useful framework for gaining insight into the origin of the various other types of asymmetry (e.g., Scheuer 1995; Bridle et al. 1994; Saikia 1981).

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Laing (1988) and Garrington et al. (1988) first reported a striking correlation which involves the depolarization asymmetry of the radio lobe pair (see, also, Garrington et al. 1991). For a sample of double-lobed radio sources showing one-sided jet (i.e., mostly quasars), they demostrated a very strong tendency for the lobe on the jet's side to depolarize less rapidly with increasing wavelength, as compared to the opposite lobe. This correlation, commonly known as the Laing-Garrington (L-G) effect, is now regarded as a fairly general property of quasars and constitutes a key evidence for the relativistic motion of the jets persisting out to kiloparsec-scale (e.g., Scheuer 1987).

According to the currently popular explanation for the L-G effect, the host galaxies of radio-loud quasars (as well as distant radio galaxies) are supposed to be embedded within $\approx$ 100 kpc diameter hot gaseous haloes, similar to the core of the intra-cluster medium (ICM) of nearby clusters of galaxies, such that the haloes are similar in size to the associated double radio sources. The observed rapid depolarization of the radio lobe associated with the counter-jet is then attributed to the fact that the lobe is seen through a substantially longer depth of magneto-ionic medium, as compared to the lobe on the jet's side which lies on our side and hence, largely in the foreground of the ambient ICM core (cf. Laing 1988; Garrington et al. 1988; Garrington & Conway 1991; Tribble 1992; also, Slysh 1966). Note that this explanation predicts a weaker depolarization asymmetry for radio galaxies since, according to the currently popular unified scheme, they are believed to be the parent population of quasars, so that their radio axes are oriented at large angles from the line-of-sight (Barthel 1989; Antonucci 1989; Urry & Padovani 1995; Gopal-Krishna 1995, 1996). Consistent with this picture, it has been argued that any depolarization asymmetry in radio galaxies is mainly due to a combination of an asymmetric extension of the two lobes from the nucleus and the radially declining density of the hot gaseous coronae associated with the parent galaxies themselves (e.g., Garrington & Conway 1991; Tribble 1992; Strom & Jägers 1988).

1.1. Potential caveats with the canonical explanation

Although, the above explanation for the L-G effect in quasars, invoking an ICM-core like ambient medium, has gained wide popularity, a few potential difficulties seem to question its robustness. In particular, the viability of the model rests on the tacit assumption that in every case, the surrounding ICM core is somehow able to maintain a diameter pretty close to the steadily growing size of the radio source. Even a factor of two difference between the two sizes would erode the L-G correlation seriously (cf. Garrington & Conway 1991). No regulatory mechanism has been proposed, however, that would ensure the needed tight coupling between the two sizes. Secondly, the L-G effect is found to become stronger at higher redshifts (Garrington & Conway 1991) and, while deep optical imaging observations do reveal a clear tendency for radio galaxies and quasars at higher redshifts to occur in cluster environments (e.g., Hill & Lilly 1991; Yates et al. 1989; Yee & Green 1987), the hot intracluster medium (ICM) itself appears to actually thin out towards higher redshifts (Castender et al. 1995). Due to this, the basic assumption of the canonical model, namely, the existence of a dense ICM core ($n \gtrsim 10^{-2}\ cm^{-3}$) around $z \gtrsim 1$ quasars (cf. Garrington & Conway 1991), is fraught with some uncertainty (though, clearly, at least a low-density gas envelope must exist even around distant radio sources). In any event, the origin of the presumed microgauss magnetic field in the ICM, which must, moreover, be ordered on the scale of a few kiloparsecs already by $z \gtrsim 2$, remains to be explained in a convincing manner.

2. An alternative proposal for the origin of the depolarization asymmetry

Considering the above, it seems desirable to explore an alternative scenario to account for the L-G effect. Here we examine the possibility whereby the required Faraday screen contributing the extra rotation measure (RM) in the foreground of the farther radio lobe is associated not with any putative ICM core around the radio source, but, instead, with a large *disk* of magneto-ionic medium surrounding the host galaxy and oriented roughly perpendicular to the radio source axis. Prominent tracers of such gaseous disks are the extended dust-lanes seen across many massive nearby elliptical galaxies, including our radio-loud neighbour Centaurus A, as well as 3C 270 (Mahabal et al. 1996) (Sect. 3). It is well known that the dust-lanes tend to align perpendicular to the jets (Kotanyi & Ekers 1979; Moellenhoff et al. 1992). Being often decoupled – kinematically as well as morphologically – from the stars in the associated elliptical galaxy, the disks are generally believed to be of an external origin, probably acquired through merger of a gas-rich galaxy (e.g., Goudfrooij & de Jong 1995). According to recent models, dust-lanes begin to form through dissipative processes after making a few orbits around the accreting galaxy, i.e., $\approx 10^9$ years after the capture (e.g., Steinman-Cameron 1991; Quinn 1991; Rix & Katz 1991). Indeed, according to a long-standing view based on a variety of observational evidence, capture of gas-rich disks by massive ellipticals at $z \simeq 2-3$ is probably responsible for the intense quasar activity witnessed at those early epochs, including the great abundance of powerful double radio sources (e.g., Fukugita et al. 1996; Lynden-Bell 1996; also, Wilson & Colbert 1995). It has been argued that the process of galaxy capture may be accelerated due to the ram-pressure breaking applied by the gaseous coronae of the accreting ellipticals (Sofue & Wakamatsu 1992). Conceivably, the captured objects could even be damped Lyman-alpha clouds; they are thought to be progenitors of the massive spirals and more abundant at higher redshifts (Wolfe et al. 1995).

3. Evidence for dust-lanes/gaseous disks around massive ellipticals

3.1. The optical evidence

As mentioned above, since galaxy interactions/mergers seem to be frequently involved in the genesis of the quasar phenomenon, gaseous disks are expected to be a common feature of massive ellipticals hosting a quasar nucleus. CCD imaging surveys of nearby elliptical galaxies have frequently revealed absorption features identified as dust-lanes extended across them (e.g., Goudfrooij & de Jong 1995; Zeilinger et al. 1990). Inspite of the difficulty in detecting dust-lanes, unless viewed almost edge-on, they have been observed in 40 $\%\ to$ 50% of bright ellipticals (e.g., Sadler & Gerhard 1985; Jura et al. 1987; Ebneter et al. 1988; Goudfrooij & de Jong 1995; Zeilinger et al. 1990). At large redshifts ($z \gtrsim 2$), evidence for such disks of dusty gaseous material surrounding radio-loud galaxies and quasars comes from the apparent suppression of $L_y - \alpha$ emission from the region of the radio lobe located on the far side of the parent galaxy, both in cases of radio galaxies (Gopal-Krishna et al. 1995) and quasars (Heckman et al. 1991). Many authors have linked the onset of nuclear activity in galaxies to the formation of dust lanes around them, due to accretion of a gas-rich galaxy (e.g., Colina & de Juan 1995; Ellingson et al. 1991; Sparks et al. 1989; Sect. 2).

3.2. The radio evidence

The evidence for large gaseous disks is further bolstered by the detection of millimetric continuum radiation from high-z radio sources, which is interpreted to arise mainly from massive dusty disks (e.g., Dunlop et al., 1994; Chini & Krügel 1994; Ivison 1995; Andreani et al. 1993). For the z = 3.8 radio galaxy 4C41.17 (Chambers et al. 1990), the gas mass associated with the dusty disk is estimated to be enormous ($\gtrsim 10^{11}\ M_{\odot}$) (see, Chini & Krügel 1994; Dunlop et al. 1994), albeit, consistent with the inference made from the far-infrared emission of powerful radio sources (Sect. 4).

A key evidence for fat and highly extended gaseous disks around the elliptical galaxy hosts of powerful double radio sources comes from the detection of sharp and often quasi-linear inner boundaries of the radio lobes, as highlighted recently by Gopal-Krishna & Wiita (1996). These sharp inner edges of the lobes (on the side facing the parent galaxy), give rise to strip-like central gaps in the radio bridges. Their detection requires not only maps with high sensitivity and dynamic range, but also a favourable orientation of the lobe axis, i.e., close to the plane of the sky. Despite these difficult demands, clear examples of the sharp inner boundaries of radio lobes have been observed in a number of powerful double radio galaxies. A few examples are: 3C34 (Johnson et al. 1995); 3C192 (Leahy et al. 1997); 3C227 (Black et al. 1992); 0828+32 (Capetti et al. 1993) and 3C16, 3C33, 3C61.1, 3C184.1, 3C341, 3C381, 4C14.11 and 4C14.27 (Leahy & Perley 1991). In the nearby radio galaxy M87, a recent interferometric map at 90 GHz has revealed a linear feature which is likely to be an enormously massive ($\gtrsim 10^{12} M_{\odot}$) disk-like structure of very cold atomic gas, oriented perpendicular to the jet (Despringre et al. 1996).

The sharply bounded emission gaps seen near the middle portions of radio bridges are commonly attributed to a blocking of the 'back-flowing' radio plasma of the lobes by a denser thermal plasma (ISM) associated with the parent elliptical galaxy (Leahy & Williams 1984; Black et al., 1992; Gopal-Krishna & Wiita 1996). The detection of quasi-linear inner boundaries of the radio lobes is strongly indicative of a disk-like geometry for the thermal ISM *blocking* the radio plasma of the lobes. Very large *minimum* values for the disk diameter are thus inferred from the fact that the strip-like radio emission gaps are seen to extend across the radio bridges to great distances. From the radio maps of the 12 relatively nearby ($z_{median} \sim 0.2$) radio galaxies cited above, we infer a median value of $\approx 75\ kpc$ for the disk diameter (clearly a lower limit). Likewise, the median value for disk thickness is found to be $l_{disk} \approx 25\ kpc$. In the following discussion about high-z radio sources, these estimates will be taken as representative values.

Further, it may be noted that the appreciable offset of the active nucleus from the mid-point of the radio emission gap, as witnessed in several of these sources, probably arises from the motion of the parent galaxy. Recently, some interesting implications of this possibility have been discussed by Gopal-Krishna & Wiita (1996) who have argued that the correlated radio-optical asymmetry of powerful double radio sources (McCarthy et al. 1991) can be more readily understood in terms of an asymmetric disposition of the obscuring dusty ISM of the parent elliptical galaxy, resulting from the motion of the galaxy (instead of the widely discussed explanation invoking a large-scale density asymmetry of the circum-galactic medium). Here we explore the nature and some likely consequences of the disky thermal ISM, in particular the possibility that it could account for the L-G effect, thus obviating the need to postulate clusters with a dense ICM at high redshifts, with dimensions fairly closely matched to the radio source size (Sect. 1).

4. Mass estimates for the gaseous disks of distant radio galaxies

As mentioned in Sect. 3.2, the $z = 3.8$ radio galaxy 4C41.17 exhibits a dusty disk also detected in the millimetric continuum, whose total gas content is estimated to be $\sim 10^{11}\ M_{\odot}$, assuming the galactic gas-to-dust ratio of 500. Even down to moderate redshifts, $z \simeq 1$, it is now evident from sensitive spectroscopy of optically selected field galaxies that star formation continued to remain very active in large disk galaxies and, hence, much of their mass had yet not condensed into stars (Cowie et al. 1996). Independent evidence for occurence of such massive gaseous disks obtains from studies of radio-loud quasars; they are found to emit a few times more of the far-infrared radiation compared to the disks of radio galaxies of matched radio lobe power (Heckman et al. 1992). Attributing this excess to the difference in the disk orientation for the two classes of sources and to the implied high far-infrared opacity of the dust in the disk, these authors have estimated a *minimum* gas content of $\sim 10^{11} M_{\odot}$ in a kiloparsec-scale disk component, assuming the far-infrared radiation to be thermal, as argued earlier by Sanders et al. (1989), Phinney (1989) and Antonucci et al. (1990). Allowing for the possibility that even in lobe-dominated quasars, a fraction of the far-infrared emission can be the beamed nonthermal continuum of the nucleus (Hes et al. 1995), we shall adopt $\sim\ 10^{10} - 10^{11} M_{\odot}$ as a representative value for the *total* gas content of the disks/dust-lanes associated with intermediate to high redshift radio sources (see, also, Eales & Edmonds 1996).

5. Composition and heating of the gaseous disks

As mentioned above, the gaseous disks seen as dust-lanes across elliptical galaxies are believed to be the remnants of gas-rich galaxies captured by the massive ellipticals. In order to understand the physical composition of the disks, it is therefore important to recapitulate the current knowledge about the warm and cool ISM of well studied spiral galaxies. Most of the information on the warm ionized medium (WIM) at $T \simeq 10^4 K$ comes from the studies of our Galaxy within the solar neighbourhood. It is estimated that the WIM fills roughly 20% of the total disk volume, and has a typical electron density of $n \sim 0.2\ cm^{-3}$ with a vertical height of $\sim 1\ kpc$ (e.g., Walterbos & Braun 1996). Most of the mass of the ISM is, however, contained in the neutral HI phase whose properties are best determined from the observations of face-on spirals, such as the Sc galaxy M 101. The clumpy and the diffuse cool ($T \lesssim 100K$) components of the ISM in this galaxy are estimated to contribute comparable amounts of HI line emission, though the clumped HI gas is essentially confined to within the optically luminous part of the galactic disk (Walterbos & Braun 1996).

When, following its capture, such a gaseous disk would begin to settle around the massive elliptical, the various components of its ISM would respond differently to the surrounding hot corona associated with the elliptical. The thermal pressure within the corona typically corresponds to $nT \sim 10^3 - 10^5\ K.cm^{-3}$. Such a high ambient pressure would compress the larger gas clumps further to densities of $\simeq 10^2 - 10^4\ cm^{-3}$ which are typical of molecular clouds capable of shielding the embedded dust particles against sputtering by the hot coronal gas (e.g., Sparks et al., 1989; de Jong et al. 1990). On the other hand, the diffuse component and the smaller clumps of the cool ISM inside the disk would get rapidly depleted *via* a heat transfer from the hot ambient gas (and join the existing warm medium:

WIM), following a turbulent mixing of the two phases. The thus augmented warm ISM of the disk will be the subject of focus in the present work. Since the details of the heating/evaporation process are highly model dependent (e.g., Sparks 1992; de Jong et al. 1990; Sparks et al. 1989), our attempt here is only to check broad consistency of our proposed scenario with the available observations.

5.1. Heating of the accreted disk material by the ambient hot corona

In order to sketch the thermal and dynamical evolution of the volume-filling warm ISM (WIM) of the captured disk, we shall make a few simplifying, plausible assumptions. As a first clue, recall that the estimated mass of the diffuse ionized gas in the disk of our Galaxy is $M_{gas} \sim 10^9$ M$_\odot$, taking a scale height of $\sim$ 1 kpc, a radius of $\sim$ 15 kpc, and a filling factor $f \sim 0.2$, corresponding to a volume-averaged density of $\sim$ 0.04 cm^{-3}, as estimated from the dispersion measures of pulsars and faint optical emission from the WIM (e.g., Kulkarni & Heiles 1988; Reynolds 1989). Based on Sect. 4, we shall assume that the gaseous disks around the hosts of high$-z$ quasars and radio galaxies contained an order-of-magnitude more ionized gas (*i.e.*, 10^{10} M$_\odot$) than our Galaxy. This is also consistent with the evidence for intense star-formation activity occuring in the large disk galaxies at those early epochs (Sect. 4), and their additional heating/ionization after the capture, as discussed below.

The tidal shearing of the captured disk by a massive elliptical is expected to stretch the disk, as the accretion progresses. To make a rough allowance for this and also paying attention to the observational evidence (Sect. 3.2), we adopt for the accreted disk a radius of $\sim$ 30 kpc and an initial thickness $l_{disk} \sim 1$ kpc. The implied volume, together with the above mentioned gas content $M_{gas} \sim 10^{10}$ M$_\odot$ yields an initial mean electron density $n \sim 0.3$ cm^{-3}. At $T \sim 10^4$ K, this warm disk medium would be in pressure equilibrium with the ambient hot gas ($T_{ext} \sim 10^{7.5}$ K) at a typical density $n_{ext} \sim 10^{-4}$ cm^{-3} in the outskirts of the corona, as inferred for nearby massive ellipticals (e.g., Fabbiano 1987; Sarazin 1990). Note that our adopted value of T_{ext} is on the higher side of the range established for the coronae of nearby massive ellipticals, consistent with the prevailing notion that a deep gravitational potential is condusive to the formation of powerful radio sources.

We next consider the thermal evolution of the warm ISM of the captured disk at $T_{disk} \sim 10^4$ K as it gravitates towards the inner regions of the hot corona of the elliptical. Assuming a uniform gas density within the disk (see below), the net heating rate, Q, of the disk ISM due to thermal conduction through both surfaces of the disk, is given by (Spitzer 1962):

$$Q \approx 3 \times 10^{-49} (T_{ext} - T_{disk}) T_{ext}^{2.5} l_{kpc}^{-2} \quad \mathrm{erg\,s^{-1}\,cm^{-3}}$$
$$\approx 5 \times 10^{-23} \mathrm{erg\,s^{-1}\,cm^{-3}} . \quad (1)$$

Expecting a low metallicity (Z $\sim 0.1 Z_\odot$) to characterize disk ISM at high redshifts, the *peak* cooling rate of the gas would be $\sim$ 2×10^{-22} n^2 erg s^{-1} cm^{-3} at $T_{disk} \sim 10^5$ K (Fall & Rees 1985). This peak value being comparable to the heating rate (cf. Eq. 1), even for the above estimated *initial* density, $n \sim 0.3$ cm^{-3} of the disk ISM (Eq. 1), the ISM would continue to tap heat from the massive ambient corona and its temperature would rise along the range $T_{disk} \sim 10^4 - 10^5 K$. The heating would simultaneously cause the disk to expand, thereby maintaining pressure equilibrium with the ambient corona. In view of the cylindrical geometry of the disk we assume that, to a first order, its expansion occurs mainly along the axial direction, thus conserving the ISM column density ($\Sigma \sim 300$ $pc.cm^{-3}$), while broadening the disk from $\approx$ 1 kpc to $\approx$ 10 kpc in 10^8–10^9 yr at the local sound speed of $\sqrt{(\frac{\gamma k_B T}{\mu m_H})} \sim 40$ km s^{-1}. Such a width of the disk would be consistent with the extent of the emission gaps observed in the radio bridges (Sect. 3.2). Note that moving towards a temperature of $\approx$ 10^5 K, the disk ISM would primarily cool *via* hydrogen line emission in the blue/UV region, which is likely to be absorbed by the dust within the disk and re-emitted in the far-infrared. It may be recalled that far-infrared is the energetically dominant spectral region for powerful radio galaxies, with $L_{FIR} \sim 10^{12}$ $L_\odot$ (Heckman et al. 1992).

Realistically, the ISM of the captured disk is expected have a substantial density structure, due to which the external heating would give rise to a range of temperature, even extending beyond 10^5 K. Conceivably, the hotter, more rapidly expanding phases of the ISM would determine the width of the disk. Another potential contributor to the widening of the disk is the stripping of its ISM due to external ram-pressure generated by the motion of the elliptical galaxy itself, as inferred from the frequently observed positional offsets of the active nucleus from the midplane of the radio emission gap (Sect. 3.2).

While the present treatment of the disk heating is very approximate, we note that observational evidence is already available to support the basic picture of depletion of the cool diffuse ISM of the disk embedded within a massive elliptical bulge component having a hot corona. This is seen on a recent HI map of the Sa type galaxy NGC1291 in which ROSAT PSPC observations have revealed a corona of X-ray emitting gas centred on the bulge component (Bregman et al. 1995). This hot corona is similar to the coronae of other nearby massive early-type galaxies, with central densities in the range $0.01 - 0.1$ cm^{-3} (e.g., Sarazin 1990). Interestingly, the large HI mass of $\sim 3.10^9 M_\odot$ in NGC1291 is found to be concentrated within an annular portion of the disk; at 10 kpc radius inside which HI emission becomes undetectable, the hot gas becomes detectable in X-rays and attains a pressure given by $nT \sim 10^4 K.cm^{-3}$, before rising by two orders of magnitude near the centre (Bregman et al. 1995). This spatial anti-correlation between the cool and hot gaseous components shows that if any significant neutral gas is at all present within the portion of the disk coinciding with bulge, it must be in the form of molecular clumps. The lack of HI in the bulge region can be understood as a consequence of thermal interaction between the cool and hot gas phases through turbulent mixing and conduction, leading to a heating/depletion of the HI within the inner disk. This finding lends strong support to the scenario we have sketched above for the heating of the captured gaseous disk by the hot coronal gas of the captor elliptical galaxy. Note that the possibility of dust-lanes receiving heat input from the hot ambient corona, via grain-gas collisions, and then re-radiating it in the far-infrared has also been considered by Sparks & Collier-Cameron (1988) in a different context.

To summarize our basic picture, the capture of a gas-rich galactic/proto-galactic disk by a massive elliptical with a hot corona would, in addition to an occasional triggering of radio jets, also lead to the formation of an extended disk filled with diffuse ionized gas and dense, dusty clumps of molecular gas embedded in it. We have estimated that over the formation time-scale of the dust lane (typically $\simeq 10^9$ yrs) the heated portion of the accreted disk would have steadily expanded in width to $\gtrsim 10\ kpc$, thus accounting for the large, sharply bounded central emission gaps which have been detected in the middle portions of the radio bridges. The other possible signatures of such fat disks, e.g., soft X-rays, have not yet been picked up in imaging observations, for which several plausible reasons exist. Firstly, the radiation from the putative disk component could easily be outshined by the coronal X-rays of the powerful radio galaxies and quasars. Moreover, conceivably, the captured disk may only attain a temperature which is substantially lower than that of the ambient corona ($T \approx 10^7 K$), in which case the PSPC images would not be sensitive to the disk emission. In any event, X-ray images are not available presently even for moderately distant ellipticals, let alone the distant ones being discussed here in the context of the L-G effect.

5.2. The gaseous superdisk as a Faraday screen

Quasars at $z \gtrsim 1$ typically have apparent radio sizes of ~ 60 to 70 kpc (taking $H_o = 75\ km.s^{-1}.Mpc^{-1}$ and $q_o = 0.5$) (e.g., Kapahi 1990; Singal 1993), and their radio axes are inclined, on average, at an angle of $\approx 30^o$ from the line-of-sight (Barthel 1989). Hence, the radio lobes on the far side could well be hidden behind the large magneto-ionic disks discussed above, which are oriented roughly perpendicular to the radio axis (Sect. 3.2). Conceivably, such disks could provide a significant coverage even to the lobes of radio galaxies (despite their axes being oriented closer to the sky plane), because the disks are expected to be often appreciably warped in their outer parts (see, Sanders et al. 1989; Phinney 1989).

Depolarization due to a magneto-ionic screen can arise from multiple patches of varying rotation measure present within the beam. A quantitative estimation of this would require the knowledge of several parameters, such as the detailed geometry of the screen and the distribution of the electron density, as well as the magnetic field within the disk. Lacking this information, we shall only attempt to make a gross estimate of the Faraday effects, with the objective of checking the basic viability of the proposed new model for the L-G effect. Taking a typical value of 1 μG for the ordered component of the disk magnetic field along the line-of-sight and an electron column density $\Sigma \simeq 300\ pc.cm^{-3}$ (Sect. 5.1), the average rotation measure across the disk $< RM > = 8 \times 10^5\ B\ \Sigma$ would be $\approx 240\ rad.m^{-2}$. This translates to an average Faraday rotation angle of $\approx 2 - 3\ rad$ at an emission wavelength $\lambda \sim 10\ cm$ where the L-G effect has been observed (see, Garrington et al. 1991). Plausibly, such a magnitude of Faraday rotation can fulfil the basic requirement for depolarization of a background source, assuming that significant irregularities exist in the Faraday screen on a scale $d \simeq 1\ kpc$, creating several patches of varying rotation measure within the beam (as found by Garrington & Conway 1991, in their analysis of the L-G effect). To a first order, the Faraday dispersion parameter $\Delta \sim < n^2 B^2 >^{1/2} (l_{disk})^{1/2}$ would amount to $\Delta \gtrsim 10^2\ cm^{-3}.\mu G.pc$, for the disk parameters estimated above. Such values are consistent with those inferred from the analysis of the radio depolarization maps of quasars (cf. Table 1 of Garrington & Conway 1991). It may also be noted that the uniform magnetic field component of $1 \mu G$ assumed here for the fat disk considered here is well within the corresponding value of $\sim 5\ \mu G$ for our Galaxy (Wielebinski 1988) and also modest compared to the typical field strength of $\sim 8\ \mu G$ estimated by Krause (1990) for a set of 11 nearby disk galaxies.

6. Summary: the canonical versus the present model

A comparison of the conventional explanation with the model explored here for the depolarization asymmetry of quasars, i.e., the cluster-size ICM core *v/s* the fat gaseous disk, posits several advantages in favour of the latter proposition. Firstly, even though the ionized portion of the captured disk is likely to grow in the radial direction (due to an ongoing heat input from the ambient corona of the elliptical), our model does not require the growth to be *in tandom* with the expansion of the radio source. This is unlike the conventional explanation which demands the ICM halo to somehow maintain a size close to the extent of the expanding radio source (Sect. 1). The present model only requires that the disk is large enough to occult the far-side radio lobe. For instance, even if a large disk has already formed while the radio source is just born and hence small in size, our explanation would still be viable. Secondly, in contrast to the observationally inferred decline in the abundance of clusters with dense ICM cores at higher redshifts ($z \geq 0.5$), there is a growing evidence for massive disks of dust and gas around radio galaxies and quasars, particularly at high redshifts (Sect. 1 & 3), where the depolarization asymmetry is found to be strong (Garrington & Conway 1991). Finally, the required ordering of the magnetic field on the kiloparsec scale within the Faraday screen proposed here, namely the gaseous superdisk, could arise in a fairly natural way; basically, the field inherited from the captured disk galaxy would probably get partially ordered as the disk material performs orbital motion around the accreting elliptical galaxy and, simultaneously, undergoes lateral expansion due to heating.

It may further be emphasized that the difference between the present and the conventional explanation for the depolarization asymmetry is not merely in the geometries of the depolarizing media; the two media have very different physical origin. In the near future, considerable progress in understanding the role of the gaseous superdisks invoked here should be possible by making detailed maps of the radio bridges, especially at metre wavelengths, as well as by sensitive imaging of the region of the radio continuum 'gaps' in the HI line, and also in the far-infrared region using the recently launched ISO.

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