Morphology and Dynamics of High Z Radio Galaxies and Quasars

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Abstract. The continuum morphologies of high redshift radio galaxies and quasars can be modeled as enormous bipolar reflection nebulae from shells of dust swept up by bipolar outflows. If the observed shape of a particular object is fit with an analytic function, then the velocity of the shell is specified by the equations of motion. The predicted kinematics can be compared with the observed emission line velocity field, and the resulting fit is excellent. The implications for massive galaxies at high redshift include the requirement of an initial epoch of star formation that creates dust distributed throughout a very large, diffuse, nearly virialized halo.

PHYSICAL MODEL OF THE ALIGNMENT EFFECT

High redshift radio galaxies have peculiar spatially extended optical and infrared morphologies that are generally aligned along the axis of their powerful radio sources [1,2]. This phenomena is called the “alignment effect” [3]. Dozens of distinct mechanisms for this phenomena have been proposed in the literature, but there has been no general consensus on the nature of the emission mechanisms. Among the various proposals for an optical alignment effect is the idea that the surrounding medium scatters a narrow anisotropic beam of light (e.g. a blazar) from an AGN and this beam appears as a visible pencil of light, like a searchlight beam scattered by fog [4–7]. Tadhunter et al. [4] argued that if the scattering medium had an optical depth $\tau \sim 0.1$, then the scattered intensity would be consistent with the brightest known blazars. This idea is inextricably mixed with proposals for the unification of radio sources [8]. In the unified scheme, radio galaxies are the unbeamed parent population of QSRs: a radio galaxy observed within 45° of the axis would have the appearance of a QSR.

Optical polarization has been detected in a number of HZRGs [7,9,10]. Spectropolarimetry has found specific QSR features in the polarized component of the spectra of HZRGs [11–13]. Furthermore, broad band optical and infrared polarimetry show the polarization properties are consistent with the characteristics of scat-

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tering by silicate-graphite dust grains rather than electron scattering [14]. The
discovery of polarization in HZRGs in the infrared [15] is crucial because it shows
that the light redward of the 4000 Å break can be dominated by dust scattering.
This is an important step forward in understanding the infrared alignments seen in
HZRGs [16–18].

Manzini & di Serego Alighieri [19] proposed a specific model for dust scattering
in high redshift radio galaxies where a diffuse spherical halo of dust was illuminated
by a 45 degree bi-conical beam of quasar light, rather than a narrow blazar beam.
Either model has a fundamental problem if the scattering medium is dust. They
assume a unified scenario where radio galaxies are the parent population of the
radio quasars, but if this assumption is true, these models would predict the radio
quasars would be reddened when observed near the axis. This is not observed.

A solution to the problem can be found if the dust is distributed in an expanding
bipolar shell of dust with an evacuated interior [20]. If the outward opening shell is
illuminated by the active nucleus, then we can recover a self-consistent unification
scheme. Although this is an oversimplification, I postulate that the morphologies
and polarization properties are due to giant bi-polar dust nebulae [21]. For the
high redshift radio galaxies, this hypothesis can account for an extraordinarily wide
range of phenomena including: the alignment effect, the various features of quasar
nebulousity, the presence of quasar spectral features in the spectropolarimetry of
of high redshift radio galaxies, and the unification of quasars and radio galaxies
without requiring reddening of quasars observed on axis.

In order to investigate this proposal further, I have modeled the morphology and
dynamics of expanding bipolar dust shells illuminated from a central source [20]. By
assuming an analytical form for an axisymmetric density distribution \( \rho = Q(\theta) r^{-2} \),
and bipolar wind force \( P(\theta) \), the shape of a swept-up shell can be determined by
quadrature [22,20]. If \( P(\theta) \) and \( Q(\theta) \) and the orientation \( i \) are chosen such that
the resulting shell matches the observed morphology, then the model predicts the
dynamics of the shell. The predicted velocity field can be compared with long slit
spectroscopy.

An example of this kind of model is shown in Figure 1. The model has an inclina-
tion of 20 degrees from the plane of the sky and dust with a Henyey-Greenstein
phase function. The functions \( P(\theta) \) and \( Q(\theta) \) were chosen to fit the morphology of
the high redshift radio galaxy 3C265 [23]. The model spectrum has four compo-
nents, two from the isotropic insitu photoionized emission line gas from the front
and back surfaces of the shell, and two from the nuclear line emission scattered by
dust grains swept up in the expanding shells. The model gives a remarkably good
fit to the complex data set [24].

This model is the first physically self-consistent explanation of both the morphol-
ogy and dynamics of high redshift radio galaxies [20]. Any alternative model for the
complex emission line spectrum, e.g. entrainment in the jet, triggered star forma-
tion, or mergers, would be unlikely to reproduce these features seen in the velocity
field data without introducing excessively ad-hoc components. Alternative scattering
mechanisms for the polarization such as electron scattering or inverse Compton
are similarly excluded. A prediction of the model is that the two scattered emission line components will be partially polarized, whereas the two isotropic emission line components will not be polarized. Furthermore the scattered components should contain the high ionization lines of the broad line region. The continuum emission should show the same partial polarization as the scattered components (which will not be the same as the total line emission since some fraction is insitu and some fraction is isotropic).

**IMPLICATIONS FOR GALAXY FORMATION**

The strong evolutionary “turn on” of the alignment effect at $z \sim 1$ together with the ubiquity of the phenomena up to at least $z \sim 5$ has not been addressed in standard cosmogonies. This aspect of the alignment effect is particularly noteworthy given the success of the dynamical model discussed above. The model is largely dependent on the assumption of dust distributed throughout a very large halo with an ambient density distribution roughly proportional to $1/r^2$. This implies a large, nearly virialized halo diffused with dust from a previous star formation episode. In particular, the halo cannot be very “lumpy” as one would expect from the merging of subgalactic units, or the dynamics and morphologies would be far more disorganized than they are. The presence of aligned structures out to redshifts $z > 4$ indicates that large halos were well organized at the time of the first major epoch of starformation [20].

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FIGURE 1. Dynamical model of the extended emission in high redshift radio galaxies as an expanding bipolar dust shell which scatters light from a quasar core (Chambers 1999). The functions $P(\theta)$ and $Q(\theta)$ were chosen to fit the morphology of the high redshift radio galaxy 3C265. A simulated narrow band image is constructed from the isotropic line emission (a), and a simulated broad band image is constructed from the scattered continuum (b). The model long slit spectrum has four components, two from the isotropic insitu photoionized emission line gas in the front and back shells, and two from the nuclear line emission scattered by dust grains swept up in the expanding shells. The predicted long slit spectrum (c) is compared with the observed $[OIII]$ velocity field of Tadhunter (1991) shown in boxes. The lumpiness of the model spectrum is an artifact of the course grid required by computing resources; the average surface brightness is representative. A falsifiable prediction of the model is that the scattered spectral components will be partially polarized and show the high ionization line ratios of the BLR whereas the isotropic components will not be polarized and will have low ionization line ratios.

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