Kostelecky and Mewes have recently shown that sensitive constraints can be placed on some aspects of Lorentz symmetry violation using certain astronomical data on high-redshift sources. Here, I introduce that data in its astronomical context, making it clear that these data are robust and accurate for their purpose. In particular, I explain that spatially extended scattered light from obscured quasars leads to a centrosymmetric scattering polarization, with polarization position angle independent of wavelength. Evidently, these relationships aren’t spoiled by propagation effects as the photons cross the universe.

1 Introduction

Many astronomical objects are hidden from direct view by clouds of gas accompanied by small solid particles called dust by astronomers. If scattering particles are also present, a halo of scattered light is observable, with tangential position angles in a centro-symmetric pattern around the direction on the sky of the hidden object. For example, during a total solar eclipse, a beautiful outer atmosphere becomes visible (the “corona”) and much of this light is simply Thomson-scattered from the unseen bright solar photosphere. For Thomson scattering, spectral features are broadened somewhat because of the electrons’ thermal motions.

A radio galaxy is a galaxy with powerful radio emission, typically from two “lobes” on $10^6$ light year scales, symmetrically placed about the galaxy. The detected continuum, which is spatially resolved on the sky, is mostly starlight from the host galaxies. By contrast, a quasar is a pointlike optical continuum source with a similar radio manifestation. This powerful and variable continuum source may be thermal emission from gas heated as it falls toward the event horizon of a supermassive black hole.

The quasar pointlike optical sources are surrounded by fuzzy light, which is in fact mostly starlight from its host galaxy. It is now known that the powerful distant radio galaxies and quasars differ only in orientation with respect to the line of sight! In particular the powerful radio galaxies contain quasars hidden from direct view by dust clouds. We detect the hidden quasars via their halos of scattered light, just as in the case of the solar corona. The observed
perfect tangential and centrosymmetric polarization patterns are evidently unaffected by the long traverse through the universe.

Data on the material in this review are analyzed quantitatively by Wardle et al. (1997).

2 The Unified Model

Let’s look closely at the optical spectra of radio galaxies and quasars. Figure 1 shows a spectrum of the typical powerful radio galaxy Cygnus A, with a modest redshift of 0.07: the continuum light is mostly starlight. The emission lines however must come from clouds of ionized gas. The emission lines are due to recombination or collisional excitation of species photoionized by the quasar continuum. The spectrum is quite different from that of laboratory gases: the transitions which violate electric dipole selection rules are quite strong. This indicates a very low density gas. In such a gas, every time an excited state is populated, whether or not it’s metastable, a photon results from the subsequent spontaneous radiative de-excitation. The Einstein “A” coefficient, which is many orders of magnitude smaller for the forbidden transitions than for the permitted ones, makes no difference. Every excitation results in a “bankable” photon, whether the decay time is very long or very short.

The finite spectral width of both kinds of emission lines comes from bulk motions of the ionized gas clouds, and indicate internal motions within the emitting region of $\sim 1,000$ km/sec.
Figure 2: Optical spectrum of the quasar (or “broad line radio galaxy”) 3C 382, from Osterbrock, Koski and Phillips, Ap J 206, 898

Figure 2 shows the spectrum of the quasar (or “broad line radio galaxy,” for any astronomers reading this) called 3C382. It consists of some starlight, the same type of low-density emission lines seen in the radio galaxy Cygnus A above, plus two more components. One is a mysterious continuum component, which is powerful and variable and may come from thermal radiation by optically thick matter accreting onto a supermassive black hole; and the other is the broad bases on the permitted lines only. These must come from a family of ionized gas clouds with a \( \sim 10,000 \) km/sec velocity dispersion, and a relatively high density so that the permitted lines are much much stronger than the forbidden lines. At these densities the gas is like that in the laboratory: the excited states are well populated for both permitted and forbidden transitions, so their ratio is determined by the Einstein A’s in this case.

During the 1980’s it was deduced from polarimetry and other data that the latter two components, the variable (and thus extremely compact) continuum source and the broad-emission-line region, are in fact present in powerful radio galaxies as well as in quasars, and can be detected via scattered polarized light. The electric vectors are always perpendicular to the radio source symmetry axes, and thus the photons’ last flights before being scattered into the line of sight were along the radio axes. From the point of view of the nuclear light, the other directions are blocked by a torus-shape collection of dusty (neutral)
gas clouds. Figure 3 shows a cartoon.

The scattered light around a radio galaxy manifests as a bipolar reflection region (Fig. 4) and a polarized light spectrum identical to the total-flux spectra of quasars, complete with the nuclear continuum and the broad wings on the permitted emission lines.

The Unified Model for active galactic nuclei and quasars is reviewed in Antonucci 1993.

3 Implications for Particle Physicists

These scattering regions are visible at redshifts up to $> 2$, though the data aren’t as pretty as for the nearby case shown here. The scatterers are sometimes small dust particles and sometimes free electrons, or a combination of the two. The point is, the electric vectors are all exactly perpendicular to the direction to a single point, where the hidden quasar lies. Any propagation effects that would spoil this perpendicular relationship are tightly constrained in size. One example is foreground gravitational lensing, which rotates the radius vectors due to shear, but leaves the electric vectors of the scattered light unchanged. Another is the hypothetical Lorentz-symmetry-violating effect discussed by Kostelecky and Mewes. (Their constraint depends on the ratio of the wavelength of observation to the source distance, so will become several orders of magnitude more powerful when X-ray polarization can be used.)

Finally let me apprise you of a related effect which can sometimes be used for the same purpose. It is less accurate and robust. Consider the radio maps themselves. The radio photons are also polarized, but by a different effect: here the photons are intrinsically polarized because they derive from the synchrotron process. Since the double-lobed radio sources are axisymmetric to zeroth order, the net radio polarization integrated over the entire source tends to be either parallel or perpendicular to the structural axis. This just follows from the overall approximate axisymmetry of the radio morphology. Its polarization is not trivially understood from first principles as for the scattered optical light. And because it depends on the detailed “gastrophysics” or environmental “weather,” it isn’t precise; for some objects the polarization angle isn’t related to the symmetry axis at all. However, statistically we can compare the radio structural axes with the integrated radio polarization electric vector position angles, and limit deviations in a statistical sense: clearly if all the polarization angles (or all of the structural axes) were rotated by over a radian by some propagation effect, the statistical correlation with the radio axes would be destroyed.
Figure 3: Cartoon showing the obscuring torus, polar scattering regions, and radio jets, from Urry and Padovani 1995 Pub ASP 107, 803
Figure 4: Polarization image of the Cygnus A radio galaxy, showing the bipolar reflection nebula. From Ogle et al 1997 Ap J 482, L37
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References
