The Transparency of the Universe Limited by $Ly - \alpha$ Clouds

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ABSTRACT

The brightnesses of supernovae are commonly understood to indicate that cosmological expansion is accelerating due to dark energy. However the entire discussion presumes a perfectly transparent universe because no effects of reddening associated with the interstellar extinction law are seen. We note that with two kinds of dark matter (baryonic and non-baryonic) strongly dominating the known mass of the universe, it is seriously premature to assume that these dark matter components have not reduced the transmission of the universe for cosmological sources.

We show that the long-known $Lyman - \alpha$ clouds, if nucleated by the population of baryonic dark matter primordial planetoids indicated by quasar microlensing, would act as spherical lenses and achromatically fade cosmologically distant sources. We attempt to estimate the amount of this cosmological fading, but ultimately the calculation is limited by lack of a satisfactory model for the tenuous outer parts of a primordial planetoid. We also consider the effects of such cosmological fading on the light of quasars.

Subject headings: Galaxy: halo – baryonic dark matter: Dark Energy: Lyman-alpha Clouds

1. Introduction

Fundamental to our understanding of the nature of our universe from observations of brightnesses of cosmologically distant objects is the assumption that the universe is basically transparent, with any departures from total transparency signaled by a reddening effect
caused by scattering of light by dust. However, with almost all of the matter in the universe in 2 unknown dark matter forms, there is the possibility that additional processes may be limiting the transparency. In the following, we propose that achromatic refraction by the \( \text{Ly} - \alpha \) clouds long known to pervade intergalactic space may cause an effective reduction of the transparency.

The properties of the network of \( \text{Ly} - \alpha \) clouds have been recently reviewed by Rauch (1998). We remind here that the earliest investigations of the clouds produced the conclusion that they must dissipate on a short time scale by simple diffusion/evaporation, and that therefore there must be some hot inter-cloud medium pervading all space to confine them. Subsequent observations showed that the hot intercloud medium does not exist, leaving the confinement of the clouds a mystery.

Recent developments suggest another possibility; the clouds do indeed evaporate continuously but are continually refreshed by the planet-mass primordial baryonic dark matter objects discovered in quasar microlensing (Schild, 1996; 2004a,b). Such objects would produce a new perspective on the transparency of the universe, because any centrally condensed spherical object becomes a refracting lens, which would necessarily refract light out of the beam of a cosmologically distant background source. Because of the simple molecular and atomic structure of hydrogen gas, the refraction would be nearly achromatic, thus leaving no observable color signature.

In the remarks to follow, we offer two calculations of the refractive properties expected for the cloud population. In section 2 we examine the process of refraction applied to the \( \text{Ly} - \alpha \) clouds if they are nucleated by a compact object, and we check this calculation in section 3 with known properties of the terrestrial atmosphere. Here we notice that dark objects of approximately this outer density and mass have been observed elsewhere in the astronomical zoo, which gives us the size of the dark matter object without any complicating model calculation. Thus in section 4 we can easily determine the cosmological loss of transmission due to this cloud population and in section 5 we suggest falsifiable predictions implied by the mechanism. We conclude in section 6 that the light of quasars should also be affected.

2. The refracting layer density from the lens-maker’s equation

We adopt the simple picture of the \( \text{Ly} - \alpha \) cloud (hereinafter Cloud) as a spherically symmetrical object with an unknown density gradient and a total mass of approximately \( 10^{-6} M_\odot \), after the quasar microlensing results of Schild (1996). It will become apparent that the refraction occurs in tenuously held outer layers of the object, which does not concern us.
The index of refraction of hydrogen at S.T.P. is 1.000132, and the pressure and density dependence has been reported by Ruoff and Ghandehari (1993) and by Stewart (1964) for the relevant temperature range 24 - 33 K. The refractivity, \((n-1)\), remains linear to very low densities measured.

The lensmakers equation can then be used to make an estimate of the focal length of the lens, from which we determine the refracted angle. We use the simplified version of the lensmaker’s equation, also called the simple lens equation, which is applicable because the refracted angle is extremely small and the thickness of the Cloud, 2R, is small compared to the cosmological distances involved. We treat the source as at infinite distance and compute the focal length of the lens f as:

\[
f = \frac{R}{2(n - 1)}
\]

Here we have adopted the radius of the cloud as R. The most comparable object in the astronomical zoo to our hypothetical Cloud is the knot found abundantly in the Helix Nebula (Gibson, 2003). These objects have direct determinations of mass, radius, and density from Meaburn et al (1998) and Huggins et al (1992) from direct CO detection, and although they have been explained away as Rayleigh-Taylor instabilities in the expanding gas shell, the measured density enhancement is much greater than can be possible for such an instability. The fact that they probably do not show the expansion of the nebular shell (O’Dell and Handron, 1996), suggests that they are our primordial baryonic dark matter objects. For S.T.P, (Standard Temperature and Pressure) the focal length of the Cloud computed for the \(H_2\) index of refraction is \(2 \times 10^{10} \text{km}\), and the refracted ray is at an angle of approximately an arc minute.

For cosmological distances, refraction at a much smaller angle suffices to remove light from the supernova or quasar image. A standard supernova or luminous quasar accretion disc radius of \(10^{15} \text{cm}\) (Schmidt and Wambsganss 2001) and the simple assumption that the refracting lens is half-way to the cosmological source means that a refraction angle of approximately a nano-arcsec will displace the beam away from the observer. This can be easily seen by imagining an observer at the quasar looking at the Earth. If light beams are directed toward earth at angles with subtense larger than the resolved quasar image, the light will not reach the observer.

A more careful calculation shows that the deflection needs to be more than 30 nano-arcsec for a luminous supernova shell of \(R = 10^{15} \text{cm}\), or for a quasar at the \(z=1.9\) peak of the quasar redshift distribution.

Clearly the refraction angle needed to significantly fade the image of a distant supernova or quasar is much smaller than that of our Cloud, imagined above to be at S.T.P. If we take
Cloud radii as above and a refracting angle of 30 nano-arcsec and compute the density correction implied by the refractivity required for our lens, we easily compute a density of only $2 \times 10^{-14} \text{g/cm}^{-3}$ for the refracting layer in a spherical Cloud lens of radius $2 \times 10^{10} \text{km}$.

3. The refracting layer density from scaled terrestrial refraction

Another well-studied reference point for the refractive properties of a gas cloud is the refraction of the setting Sun. It is a well known result that the apparent horizon Sun is refracted 34 arcminutes from its astronomical direction, for a terrestrial atmosphere at S.T.P. (Thomas and Joseph, 1996). The theory of refraction in a nearly isothermal atmosphere has been given by Lepetit and Lempel (2004) and Sloup (2003) and discussed exhaustively by Garfinkel (1967). Thus it is easy to scale to lower densities for the much smaller 30 nano-arcsec deflection required here. Adopting an S.T.P. density of air of $0.0013 \text{g/cm}^3$ and noting that the index of refraction of hydrogen is half that of air (Essen 1953) we easily scale the density of a hydrogen atmosphere refracting by 30 nano-arcsec to have density $5 \times 10^{-14} \text{g/cm}^3$. This is comfortably close to the value surmised by a more standard Section 2 calculation.

We finally take the atmospheric density required to produce a refraction effect large enough to remove the light from a supernova or quasar beam, $2 \times 10^{-14} \text{g/cm}^3$, and ask what would be the radius of a Cloud to this density value. In the absence of a model of a primordial hydrogen cloud (brown dwarf) that has cooled for the entire life of the universe, we again refer to the observations of such clouds in the Helix Nebula. Total masses for the clouds, called cometary knots when ablated by the central star’s radiation pressure, have been investigated by direct CO mass measurement (Huggins et al, 1992) and from an ablation theory applied to the best resolved objects (Meaburn et al 1998). The estimated mass in both methods is $10^{-5} M_\odot$, in near agreement with the value estimated from quasar microlensing ($10^{-6} M_\odot$; Schild, 1996).

The density computed above for our Cloud to have significant refraction is approximately $10^{-14} \text{g/cm}^3$. From Avagadro’s number, this is equivalent to $10^{10} \text{molecules/cm}^3$. This will be an important number to match to the density profile of a primordial brown dwarf object to estimate the size of such an object to this density. However we caution that at such low densities, the atmosphere will be loosely bound to the planetoid and probably irregular in structure.

We also note in caution that the measured diameter and total mass of the clouds have been combined in the cited references to estimate the mean Helix knot density to be only $10^6 \text{particles/cm}^3$, but these estimates will be dominated by the mass of the dense central
region (presumably having the density and pressure of the earth’s core). Thus, lacking a real model of such a primordial planetoid, our safest recourse is to simply observe that the Helix Nebula knots are opaque to a diameter of $2 \times 10^{15} \text{cm}$ (Meaburn, 1996; O’Dell and Handron, 1996) at all optical wavelengths. This is the diameter we take for our calculation of the transparency of the universe in the following section. Note that the size of a Cloud is comparable to the size of a supernova or quasar optical disc ($10^{15} \text{cm}$).

4. The Transparency of the Universe limited by Baryonic Dark Matter Objects

We now take the above estimates of the radius and mass of the dark matter objects and compute their probable limits on the transparency of the universe. We presume that any light incident upon the back side of an object to the critical radius for refraction more than 30 nano-arcsec is lost to the beam and eventually is absorbed or contributes to the cosmological background light. We assume that along the line of sight to a cosmologically distant object at redshift 2, a Milky Way type galaxy with a mass including its Baryonic dark matter halo of $10^{12} M_\odot$ (Allen’s Astrophysical Quantities, 4’th edition, p571) and a size of 50 kpc (distance to the Magellanic clouds) will be encountered. For our toy calculation, we assume that the refracting objects are uniformly distributed in a cube $10^5 \text{pc}$ on a side, and the mass of each planetoid is $10^{-6} M_\odot$. Then the surface area covered by the planetoid objects will be $10^{49} \text{cm}^2$ and the projected total area of the Galaxy Halo will be $10^{50} \text{cm}^2$. Thus the refracting halos cover 10 percent of the light path through the Galaxy Halo, and several galaxy halos along the line of sight would refract a significant fraction of the light of a cosmological source.

Thus according to this simple optical refraction model, the baryonic dark matter objects discovered in quasar microlensing reduce the brightnesses of distant cosmological sources.

Of course the simple picture needs refinement, but little improvement will be possible until a primordial brown-dwarf type object with $10^{-6} M_\odot$ is modeled to see what its effective diameter is for refractive attenuation of cosmologically distant background sources. For the present we only claim that there is the possibility that refractive opacity to cosmologically distant sources must be considered before concluding that supernova brightness curves strongly indicate a second inflation event (Dark Energy) in the universe.
5. Some Falsifiable Predictions

A universal population of refracting clouds has already been implied by $Ly-\alpha$ absorption clouds long seen in quasar spectra. The present interpretation of their refractive properties has two immediate implications for observable side effects:

1. cosmologically distant sources should be surrounded by faint halos caused by refracted light

2. since some fraction of the refracted light is not absorbed, it should contribute to a cosmological background light.

Both effects have been seen.

With respect to item 1, it might be argued that in a linear process about as much light gets scattered into the quasar/supernova image as is scattered away. However, observations of occultations of stars by solar system planets show peaks in their brightness curves that indicate that even for tightly held planetary atmospheres in the Solar System, layered structures exist that make the refraction process complex and non-linear (Hubbard et al, 1972; Veverka et al, 1974).

At the same time, halos are ordinarily seen around quasars, where the underlying fuzz is interpreted to be the resolved image of the host galaxy, also present. The study of the faint fuzz is complicated by the bright quasar emission and the usual instrumental problems due to light scattering in the spectrograph and telescope optics. However the fiber optic bundle field resolving spectrograph applied by Mediavilla et al (1998, and further related references) shows a halo in AGN MKN 509 out to a distance of 8 kpc from the galaxy center in the light of the broad emission lines originating in the nucleus. The authors concluded that the broad emission line cloud could not be 16 kpc in diameter and attributed the observation to light scattering, but a process of refraction was not considered. Thus such small halos around distant stellar sources are observed, and whether caused by refraction or scattering they will reduce the measured brightness of cosmologically distant sources.

Halos around supernova are unsurprising because supernovae are often associated with clustered stars, particularly the Type 2 variants. The profile fitting used to measure the supernova brightness is insensitive to the existence of faint fuzz in the low S/N region surrounding the bright stellar component.

The issue of cosmological background light has been controversial because while its detection has been claimed, it is just a faint residual seen against a bright foreground caused by the zodiacal light. Nevertheless in a recent report, Dwek et al (2005) conclude that the detected radiation is too bright to be understood by a hypothetical Pop III sky background.
Our refraction model predicts that the Extragalactic Background Light should be comparable to, or slightly less than, the average background light of all resolved sources.

A weak prediction comes from calculation of the neutral hydrogen optical path length through the lensing Cloud. The above numbers for the density and size of our cloud suggest that the optical path through the cloud would produce a surface mass density of approximately $10^{22} \text{particles/cm}^2$, which is the surface mass density of the so-called damped Lyman-alpha systems. It would be interesting to see whether cosmological sources with such damped Lyman-alpha profiles in their ultraviolet spectra are slightly fainter (about 0.1 magnitudes per damped profile) than otherwise.

6. Transmission of the Universe to the Light of Quasars and Supernovae

The study of quasars has long ago produced a puzzling observation that is probably relevant. The number of quasars peaks at a redshift around $z = 1.9$. This means that if we consider all directions of space and ask how many quasars are contained as a function of redshift, that function will peak at $z = 1.9$.

There is presently no accepted theory of the formation of quasars, and this peak in the number distribution is unexplained. However it can be easily understood as resulting from the reduced transparency of the universe also seen in the supernovae, and the simplest assumption that quasar intrinsic luminosities have not changed to $z = 5$. Recall that the supernova brightness-redshift relation purported to demonstrate dark energy shows about a 1.4 magnitude deficit for the quasar peak at $z = 1.9$. In other words, the dark matter cosmology curve is fainter than the standard cosmology curve at the quasar density peak by 1.4 magnitudes. This means that the transmission losses by the dark matter are becoming significant at these redshifts, and the proposal is that both the supernova brightness deficit and the quasar brightness peak can reasonably be understood as resulting from reduced transmission of the universe due to the baryonic dark matter.

Moreover, the exact form of the reduced transmission law exactly fits the supernova observations. It has long been known (Zuo and Lu, 1993) that the density of $L_y - \alpha$ clouds increases with redshift as $(1 + z)^{2.8}$. It has also been noticed by Goobar et al (2002) that an absorption law scaling as $(1 + z)^3$ and constant beyond $z = .5$, can explain the supernova brightness-redshift relationship of Riess et al (2004). Thus it is easy to understand how the known $L_y - \alpha$ clouds can exactly describe the supernova brightness anomaly presently ascribed to dark energy.
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