Did Zhao & Qin Solve the Apparent Conflict Beween Gravitational Lens Time Delays, Dark Matter and the Hubble Constant?

C. S. Kochanek
Harvard-Smithsonian Center for Astrophysics
60 Garden Street
Cambridge, MA 02138
ckochanek@cfa.harvard.edu

ABSTRACT

The solution proposed by Zhao & Qin to the apparent conflict between gravitational lens time delays, local estimates of the Hubble constant and current expectations for the structure of CDM halos is discussed. Two essential points emerge. First, the degeneracy is exactly the same as the local surface density degeneracy previously discussed in the literature. Second, the proposed mass distribution is inconsistent with CDM halo models. The Hubble constant is raised by making the dark matter far less centrally concentrated than predicted for CDM halos, much like the changes suggested for reconciling CDM halos with the rotation curves of dwarf and LSB galaxies. Thus, while galaxies still have dark matter, the Zhao & Qin solution to the time delay problem requires fundamental changes in the CDM paradigm for halo structure.

1. Discussion

In a series of papers (Kochanek [astro-ph/0204043], [astro-ph/0205319], [astro-ph/0206006]) we have been exploring the relationship between recently measured gravitational lens time delays, the expected properties of CDM halos, and local estimates of the Hubble constant. At least at present, there seems to be a problem because reconciling the time delays with the local estimates of the Hubble constant seems to require constant $M/L$ distributions in which the mass traces the light, quite different from our theoretical expectations and other evidence against constant $M/L$ on the relevant scales. While no position was taken on the solution to the problem, one suspects it is a combination of problems in all three elements.

Unfortunately, we cannot determine the dark matter distributions of the time delay lenses given the available model constraints, so it is relatively easy to propose alternate mass distributions for these lenses. In particular, we demonstrated in Kochanek (2002, [astro-ph/0205319]) that the time delays of gravitational lenses are controlled by the projected surface density of the lens in the annulus between the images for which the delay is measured. Zhao & Qin ([astro-ph/0209191], [astro-ph/0209304]) use this degeneracy to create mass distributions with high Hubble constants and massive dark matter halos. In essence, they use a constant $M/L$ model for the lens out to
the radius of the outer lensed image. Since this model has a low surface density in the annulus between the images it allows a high Hubble constant. They then attach a dark halo with a flat rotation curve onto the mass distribution starting at the outer most lensed image. Essentially by Gauss’ law, the halo affects neither the lens model constraints nor the high Hubble constant estimate permitted by the constant M/L central regions of the model.

Two simple points have been lost in generating the models.

First, it is not a new degeneracy. It is exactly the same degeneracy we discussed in Kochanek (2002, astro-ph/0205319) and was partially discussed by Saha (2000), Gorenstein et al. (1988) and Falco et al. (1985). The value of the Hubble constant found for a given time delay is (basically) proportional to $1 - \langle \kappa \rangle$ where $\langle \kappa \rangle$ is the average surface density in units of the critical surface density for lensing in the annulus between the images for which the delay is measured. The Key Project value of 70km/s/Mpc requires $0.1 < \langle \kappa \rangle < 0.2$ given the delays in the 4 simplest time delay lenses. The observed lens geometry constrains the mass enclosed by the Einstein ring, for a fixed Hubble constant the time delay constrains the surface density near the ring, and you can then attach whatever exterior (monopole) mass distribution you desire without affecting any observable properties of the lens. Zhao & Qin simply produce a particular realization of such a model.

Second, while the Zhao & Qin mass model has an infinitely massive dark matter halo, it is not a model consistent with the expectations of CDM. CDM predicts not only the existence but also the structure of the dark halos surrounding galaxies. The Zhao & Qin model can be thought of as a model in which the central cusp of the dark matter distribution has been destroyed and replaced by a finite core radius at least as large as the Einstein ring of the lens. In Kochanek (2002, astro-ph/0206006) we illustrated how CDM halo models are related to time delays and the Hubble constant, and demonstrated that the two can be reconciled provided the mass fraction represented by the visible lens galaxy is large. Given the globally small baryonic mass fraction of halos, standard CDM halo models have difficulty reducing the amount of dark matter in the central regions enough to allow a large Hubble constant. The Zhao & Qin model solves this problem by giving the dark matter a distribution which avoids the central regions of the halo. It is not, however, a standard CDM halo.

In fact, the Zhao & Qin model is very similar to the solutions proposed for the rotation curves of dwarf galaxies (see van den Bosch & Swaters astro-ph/0006048 or McGaugh astro-ph/0107490 and references therein). The rotation curves of some dwarf and low surface brightness galaxies seem to be inconsistent with the relatively high central dark matter densities implied by the NFW or Moore profiles, suggesting to some that the cusp must somehow be converted into a large finite core radius (e.g. the Burkert (1995, ApJL 447 25) profile). There is, however, considerable debate about the existence and significance of the conflict between CDM halo models and dwarf/LSB rotation curves. The Zhao & Qin model represents the same class of solution – keep a massive dark matter halo but greatly reduce its central concentration compared to the cuspy CDM halo.
models. Just as in the dwarf/LSB galaxies, this allows the central mass distribution to follow the stellar distribution, and constant M/L mass distributions for the time delay lenses lead to values of the Hubble constant large enough to agree with local estimates.

While it is certainly correct that the present data on the time delay lenses cannot exclude the Zhao & Qin mass distribution, it is probably ruled out as a general distribution from other observations. In particular, where lenses do constrain the shape of the rotation curve directly, they almost always favor an essentially flat rotation curve inside the Einstein ring rather than the more Keplerian form of the Zhao & Qin model. The most interesting recent demonstrations of this have come from Koopmans & Treu ([astro-ph/0202342], [astro-ph/0205281]) who combine lensing constraints with measurement of the velocity dispersions of the lens galaxy to show that the two lenses MG2016+112 and 0047-281 have mass distributions corresponding to flat rotation curves. These mass distributions imply $\langle \kappa \rangle \sim 0.5$ on the corresponding scales of the time delay lenses and are consistent with $\rho \sim r^{-1}$ central cusps in the dark matter. While it is always possible that some time delay lenses have peculiar halo properties, it seems unlikely that all 4 of the (apparently) simple delay lenses have peculiar halo properties.

In summary, Zhao & Qin are using the known degeneracy between surface density and gravitational lens time delays to invent a dark matter distribution which allows for a high Hubble constant. The solution is to change the structure of CDM halos so they are significantly less centrally concentrated (cuspy) than present theories. While this may well be an element of the solution to the problem, it is important to recognize the implications of the proposal – galaxies can still have dark matter halos, but CDM theory has failed to accurately predict their structure.