Time dilation and space-time curvature

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Abstract

Correlation between relativistic time dilation and space-time curvature is presented aiming to explain the observed galactic rotational curves without introducing hidden parameters, such as dark matter. The relation is supported with measured data from five spiral galaxies of various sizes and rotational velocities. Correlations are also provided for a galaxy cluster and for the Solar System.

Introduction

Discrepancies between the observed mass and velocities of our galaxy had been reported as early as 1904 by Lord Kelvin. This issue attracted more attention after publications related to other galaxies, such as the one made by Rubin & Ford (1970). It became clear that the velocities of the spiral galactic members do not decay with distance in a Newtonian way unless there is hidden mass. The equations of the general relativity (GR), on the other hand, are nearly impossible to apply to a large array of bodies. Nevertheless, the rotational velocities in the galaxies are considered to be too low to justify the GR approach.

The objective of this manuscript is to propose a way to resolve the discrepancies without introducing hidden parameters, and possibly without the need to modify the GR laws. According to GR, time dilation relates to space-time curvature. Let's presume that it is the time lag causing space-time curvature and see where it leads. This approach should not result in significant changes in the predictions of relatively slow orbital velocities found in the Solar System or in some ultra-diffuse galaxies. There would be, however, differences in the predictions of the higher orbital velocities in the spiral galaxies, for example. This is due to the fact that for higher orbital velocities the kinematic time dilation dominates the gravitational time dilation far from the galactic core, especially in the galactic fringe area. The correlations made in this manuscript will show that the orbital velocities are approximately inversely proportional to the total time dilation, without introducing any hidden parameters, such as dark matter.

Correlation between time dilation and space-time curvature

According to the theory of relativity, there are relativistic delays due to mass and motion; see Misner et al 2017. The time dilation in all figures represents the delay that an observer staying still relative to the center of a galaxy, and situated outside the gravity well, will witness while looking at the moving members of the galaxy. The observer can be also placed at the center of the galaxy, providing it is not occupied by a stellar object. The gravitational time dilation ratio ***GTD(r)*** is computed based on the Schwarzschild metric, describing space-time near a spherically symmetric object. Note that this formula may be not very accurate for spiral galactic shapes:

$$GTD\ (r) = \sqrt{1 - \frac{2\ GM(r)}{rc^2}} \tag{1}$$

Here ***r*** is the distance to the galactic center, ***G*** is the gravitational constant, ***c*** is the speed of light, and ***M(r)*** is the mass (in solar mass units) residing in a sphere with radius ***r***:

$$M\ (r) = \ 2\pi \int_0^r R\, S_b(R) dR \tag{2}$$

where $S_b(R)$ is the surface brightness measured by Courteau (1996, 1997) in units of the solar luminosity normalized by surface area, and r-band corrected for inclination and dust extinction.

The velocity time dilation ratio ***VTD(r)*** is computed based on the special relativity formula:

$$VTD\ (r) = \sqrt{1 - \frac{v^2(r)}{c^2}} \tag{3}$$

where ***v(r)*** is the rotational velocity measured by Courteau (1996, 1997) at a distance r from the galactic center. Figuratively speaking, the contribution of this term to the space-time curvature is as follows: an observer would accelerate down into the gravity well because the inertial mass underneath the observer is always late to reach the point where it should be from observer's point of view.

The data used to compute time dilation was summarized in an atlas by Sofue (2017) and available for download at the University of Tokyo website (http://www.ioa.s.u-tokyo.ac.jp/~sofue/smd2018/).

The total (combined) time dilation ***TTD(r)*** is computed similar to the way used for the Global Positioning System (GPS) corrections; see Ashbey (2002):

$$TTD\ (r)\ = \sqrt{1 - \frac{2\ GM(r)}{rc^2} - \frac{v^2(r)}{c^2}} \tag{4}$$

Figures 1-3 show and correlate the computed time dilation based on measured velocities and optical photometry in r-band produced by Courteau (1996, 1997). The results show good agreement for mass derived from optical photometry in r-band, denoted as "C-sample" in Sofue (2014). The correlation, however, was not good for mass estimated from mid-infrared photometry, denoted as "P-sample" in Sofue

(2014). The gravitational dilation component appears to dominate heavily the velocity dilation component in N-galaxies from the “P-sample”.

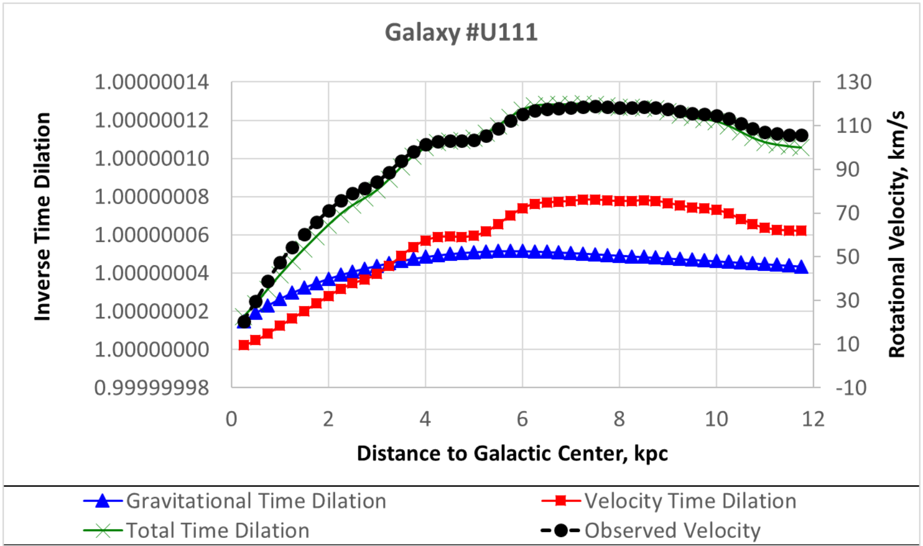

Figure 1: Correlation between combined time dilation and measured rotational velocities for # U111

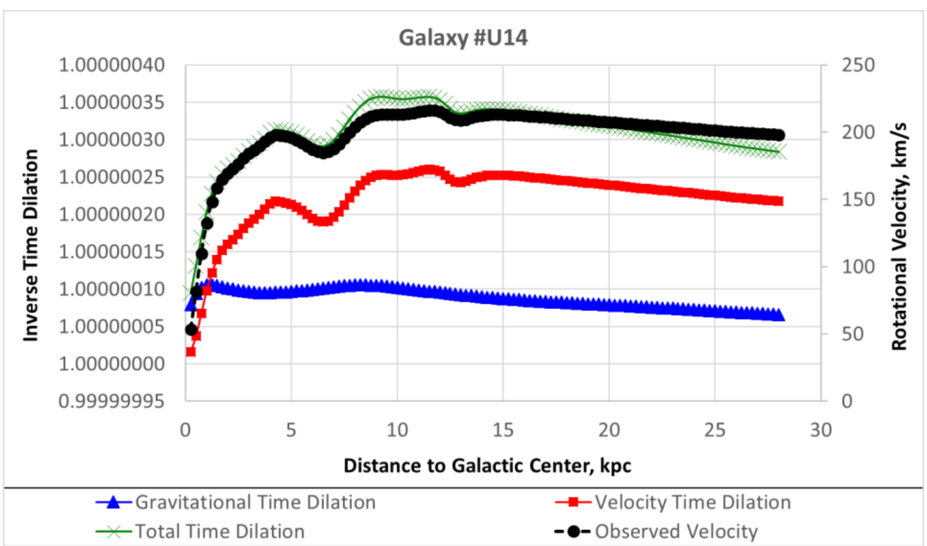

Figure 2: Correlation between combined time dilation and measured rotational velocities for # U14

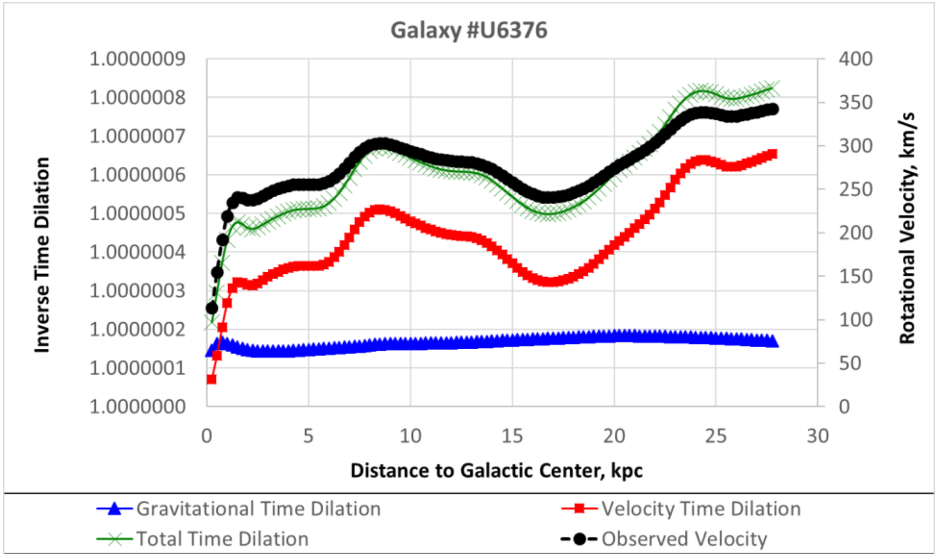

Figure 3: Correlation between combined time dilation and measured rotational velocities for # U6376

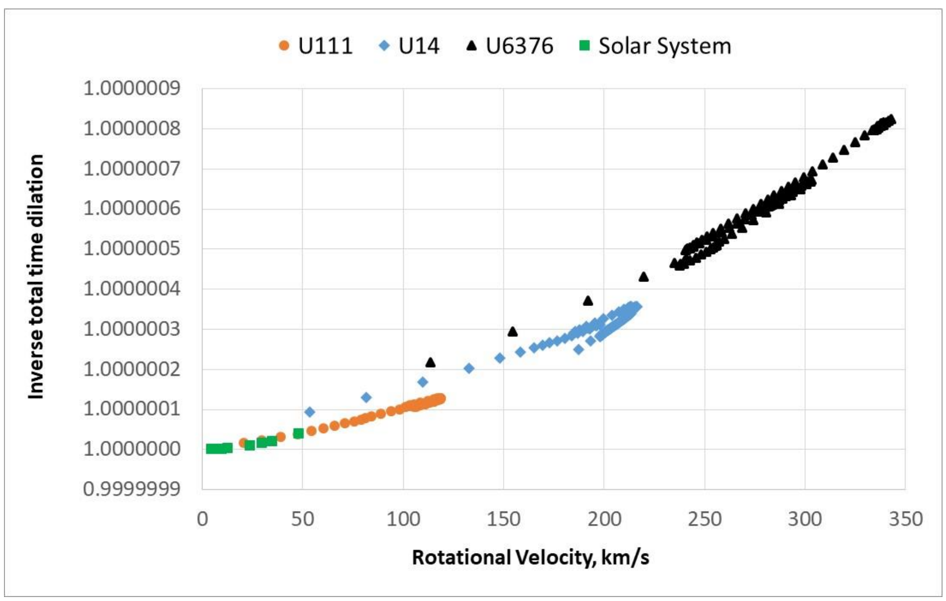

Figure 4: Distance-independent correlation between combined time dilation and rotational velocities for the three galaxies. The Solar System is also included for reference.

Figure 4 shows nonlinearity, which is governed by the last (kinematic time dilation) term in formula (4). The nonlinearity is also based on the simple summation (4) used for combined time dilations. Since every galaxy maintains its radial size because of the velocities (squared) of its members, the kinematic (velocity) dilation may be contributing to the space-time curvature differently than the gravitational time dilation. For example, the following formula (5) gives more "weight" to the kinematic time dilation component than (4).

$$TTD2\ (r) = \sqrt{1 - \frac{2\,GM(r)}{rc^2} - \frac{v^2(r)}{c^2}} \tag{5}$$

Figure 5 shows a comparison between the total time dilation computed based on formulas 4 and 5 for the same as in Figure 1 galaxy #U111

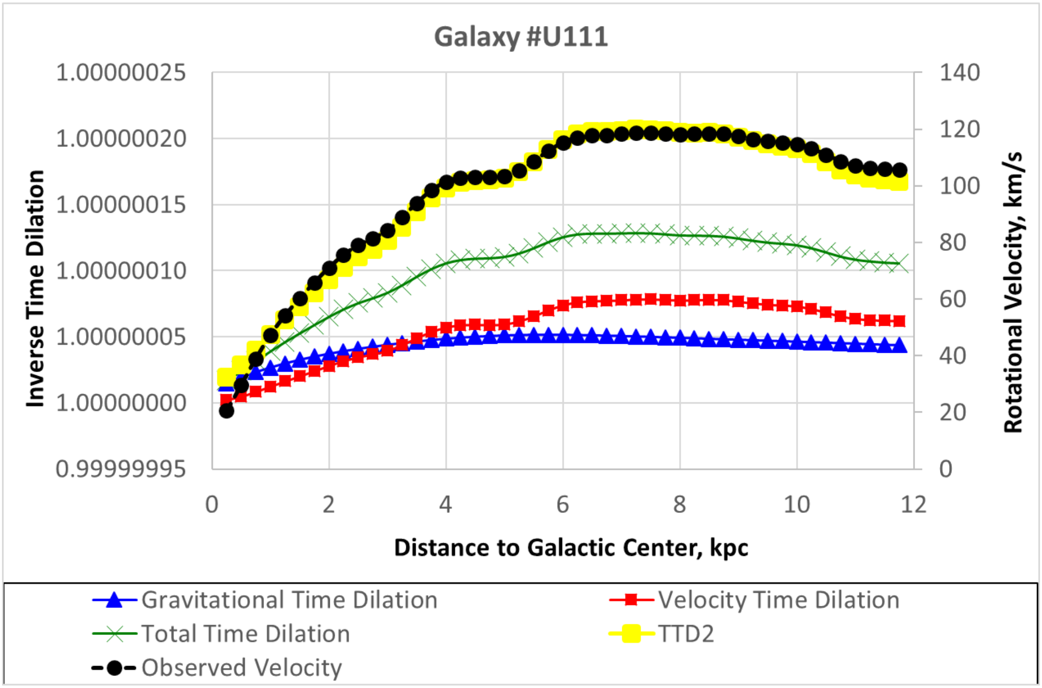

Figure 5: Comparison between the total time dilation based on formulas 4 and 5

Figures 6-8 use formula (5) for the total time dilation computed from velocities observed by McGaugh et al. (2001). In this case, the baryonic mass had to be back-calculated from the given velocity components for gas, disk, and bulge, because brightness data was not found in the 2001 source. Based on the orbital speed relation:

$$v(r) = \sqrt{\frac{GM(r)}{r}} \tag{6}$$

and formula (1), the gravitational time dilation ratio becomes:

$$GTD\ (r) = \sqrt{1 - 2\left(\frac{V_{gas}^2(r) + V_{disk}^2(r) + V_{bulge}^2(r)}{c^2}\right)} \tag{7}$$

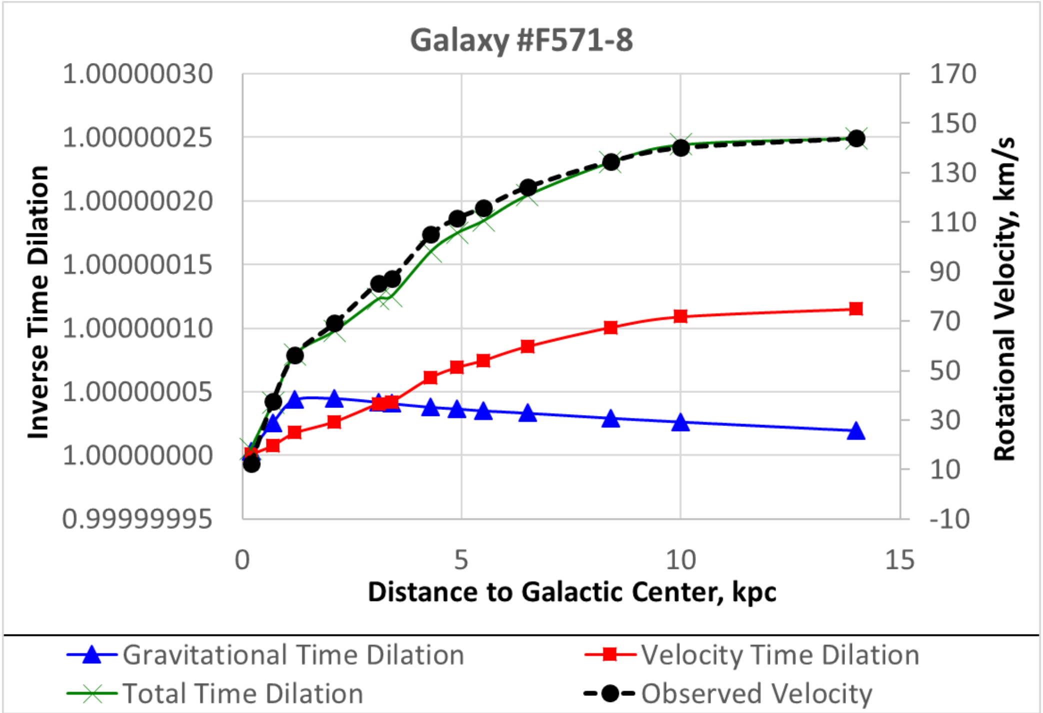

Figure 6: Correlation between combined time dilation (5) and measured rotational velocities for # F571-8

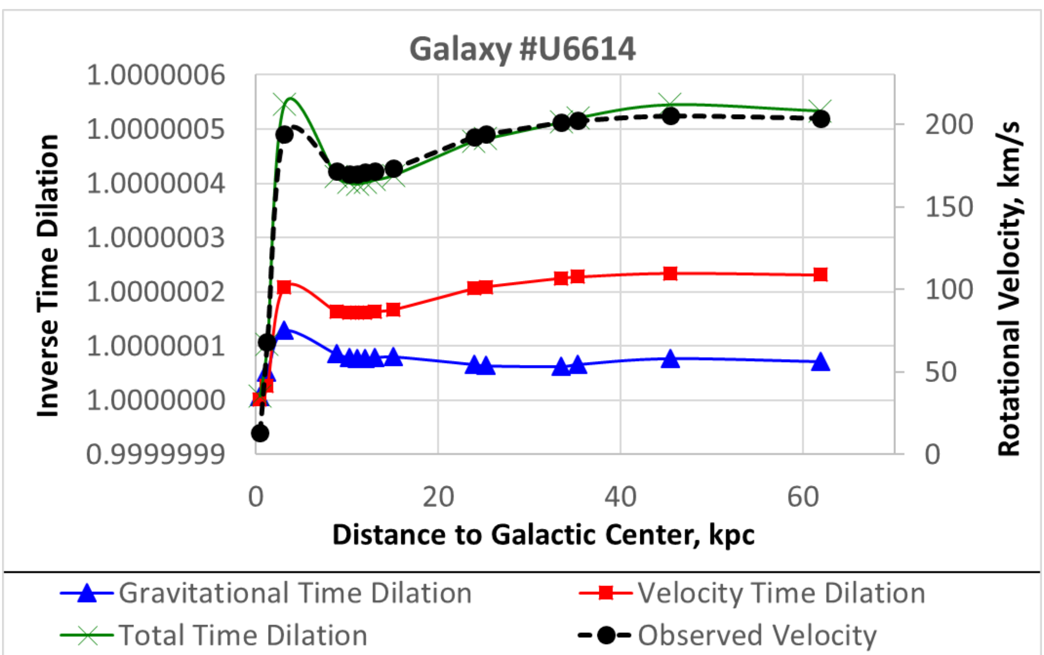

Figure 7: Correlation between combined time dilation (5) and measured rotational velocities for # U6614

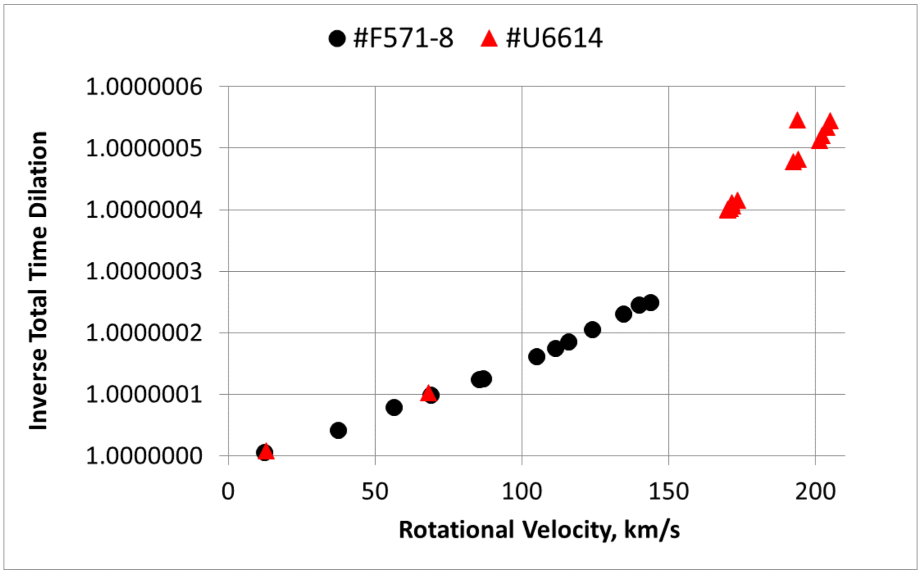

Figure 8: Distance-independent correlation between combined time dilation (5) and rotational velocities for two galaxies

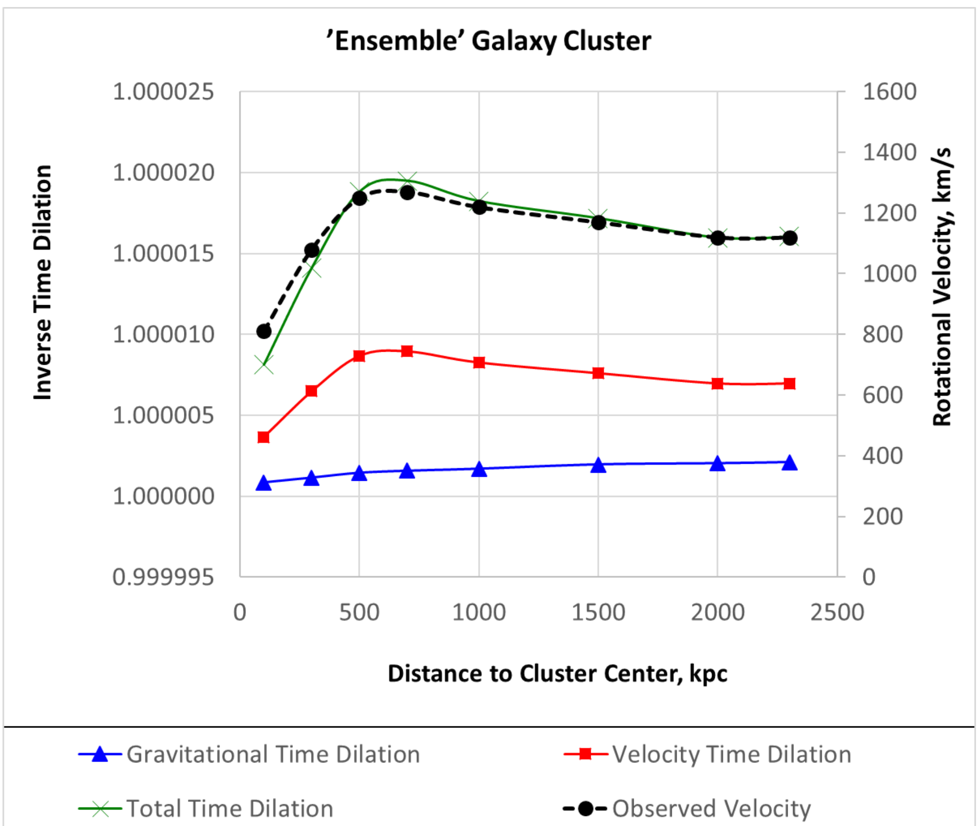

Figure 9: Correlation between combined time dilation (5) and measured rotational velocities in a galaxy cluster

Figure 9 shows how the total time dilation correlates with the rotational velocities in an ‘ensemble’-type cluster, which was built from the combined data from 59 clusters by Biviano & Salucci (2005). As expected, the kinematic time dilation component dominates the gravitational dilation for the entire radial range.

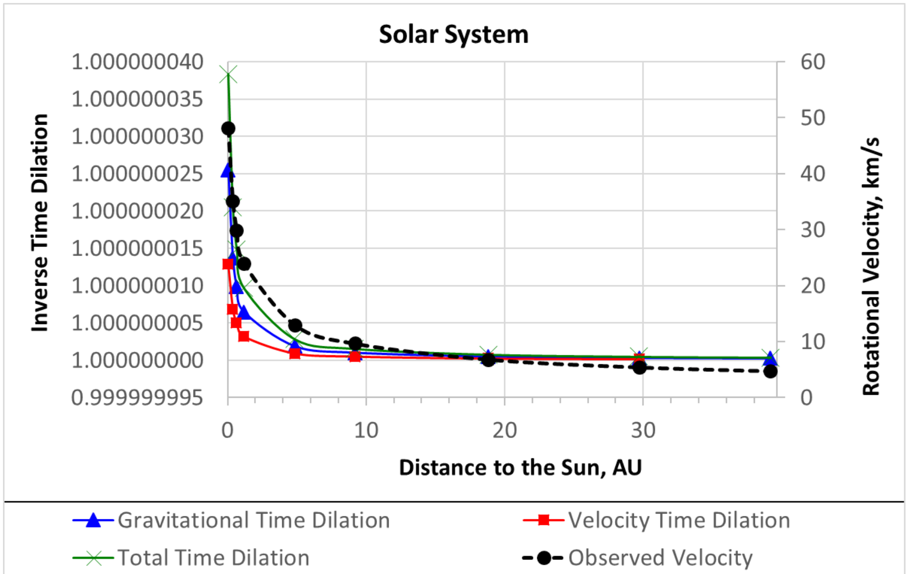

Figure 10: Correlation between combined time dilation and measured rotational velocities for the planets in the Solar System

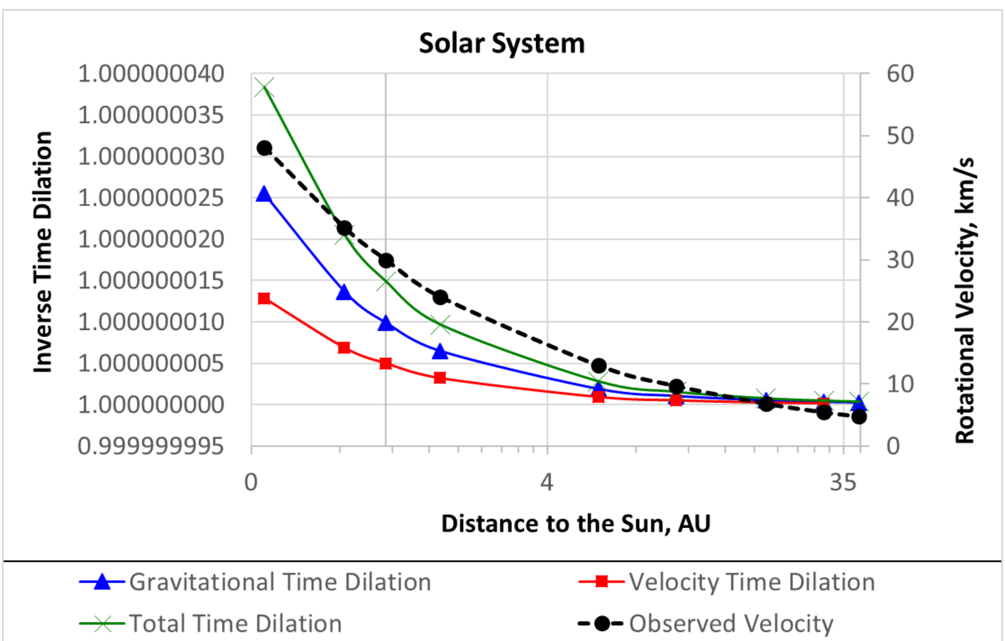

Figure 11: Same as Figure 10 but AU given in a logarithmic scale

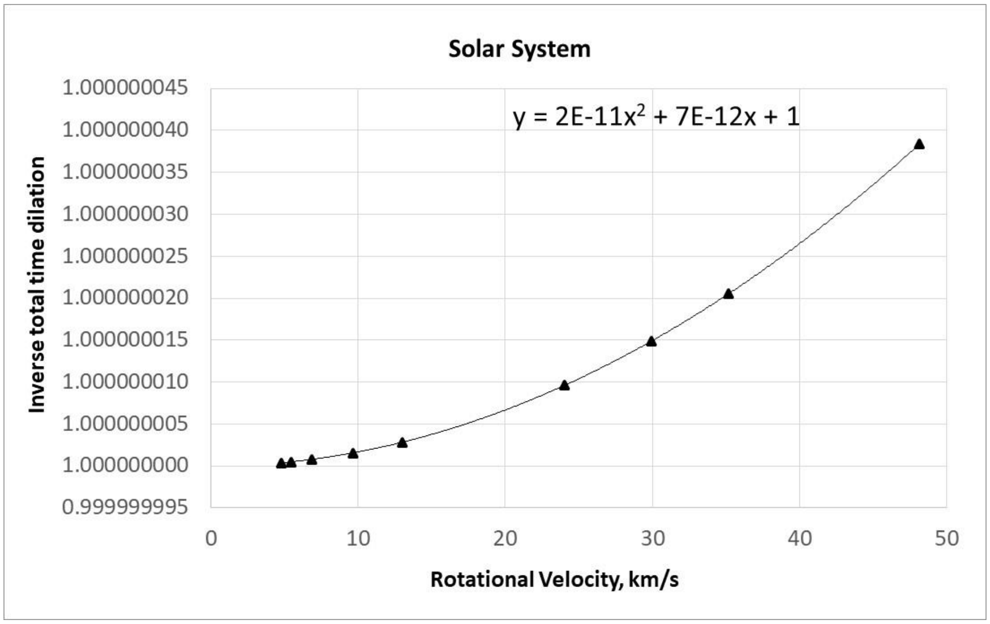

Figure 12: Distance-independent correlation between combined time dilation and rotational velocities for the planets in the Solar System

The last three figures show correlations from the solar system. Here, the gravitational time dilation dominates the kinematic one. The velocities trend with distance is reversed in comparison with the galaxies due to the lower amount of mass and the high concentration of mass in a single central star.

Conclusions

The presented results for different size spiral galaxies, one galaxy cluster, and the Solar System imply that the space-time curvature within large arrays of bodies may be due to known relativistic sources of time lag, and not due to dark matter.

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