

Inhomogeneous structure formation may alleviate need for accelerating universe

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Abstract

When taking the real, inhomogeneous and anisotropic matter distribution in the semi-local universe into account, there may be no need to postulate an accelerating expansion of the universe despite recent type Ia supernova data. Local curvatures must be integrated (over all space) to obtain the global curvature of the universe, which seems to be very close to zero from cosmic microwave background data. As gravitational structure formation creates bound regions of positive curvature, the regions in between become negatively curved in order to comply with a vanishing global curvature. Furthermore, this negative curvature will increase as a function of time as structure formation proceeds, which mimics the effect of “dark energy” with negative pressure. Hence, the “acceleration” may be merely a mirage.

Measurements since the late 1990s on type Ia supernovae (SN) [1],[2] surprisingly seemed to indicate that the universe accelerates its expansion at the present epoch, instead of the retardation expected if gravity is universally attractive. This finding has resulted in an interpretation where the present universe is believed to be dominated by “dark energy” with negative pressure. However, when taking the observed inhomogeneous structure of the universe into account, and considering the real geodesic paths of observed SN light, such a hypothesis might be superfluous.

In general relativity, all gravitationally bound systems have a positive curvature. At the same time we know that the global geometry of the universe is most probably flat from measurements of the cosmological microwave background radiation (CMBR)[3],[4]. This means that the curvature between gravitationally bound systems (solar systems, galaxies, galaxy clusters, etc) must be, on the average, negative. This conclusion applies to all globally flat universes with (semi-)localized gravitationally bound systems.

Thus, we can get an arbitrarily large negative curvature effect in an expanding universe by “dumping” matter into localized, gravitationally bound objects/systems. If we further assume that luminous matter (and by necessity gas, dust and plasma for star formation) is good “tracer” of regions of higher than average density, almost all photons from distant objects that reach us on earth must have traversed regions with little or no matter with which it can interact electromagnetically. This can be a crucial consideration for type Ia supernova data. We must consider how the evolving matter distribution between us and the source has affected the light reaching us now.

For an exact description, we would need to know the energy-momentum tensor ($T_{\mu\nu}$) at each point between us and the SN, which is physically impossible. Even if we had such perfect information, it would still be mathematically impossible to solve the Einstein equations,

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \kappa T_{\mu\nu}, \quad (1)$$

to deduce the local curvature at each point in terms of the Riemann curvature tensor, due to the complexity of the equations.

Our only hope is that an approximate model can be used to determine an “effective” curvature for bound systems and for the space in between. We then define a semi-local mean curvature parameter, k , for the regions *bound/between*. (This parameter is related to the scalar curvature $R = R^\mu_\mu$, averaged over the region, $\langle R \rangle$.)

As

$$k_{global} = 0, \quad (2)$$

from CMBR data, and

$$k_{bound} = +1, \quad (3)$$

this means that

$$k_{between} = -1. \quad (4)$$

In terms of $\Omega = \rho/\rho_{crit}$ (where ρ_{crit} is the density required for flatness):

$$\Omega_{global} = 1, \quad (5)$$

$$\Omega_{bound} > 1, \quad (6)$$

$$\Omega_{between} < 1. \quad (7)$$

(Or, stated in terms of the mass-energy density: $\rho_{global} = \rho_{crit}$, $\rho_{bound} > \rho_{crit}$, $\rho_{between} < \rho_{crit}$.)

Assuming that matter preferentially clumps in well localized objects (stars, etc), the majority of the photons that reach us travel mainly in “under-dense” (negatively curved) $\Omega < 1$ space. By observing *light* we are thus automatically biased to measure an “apparent” curvature which is less than the actual global curvature of the universe.¹ Light from a SN source will, in a universe which exhibits gravitational clumping/structure formation, always be switched towards a seemingly more negatively curved universe. For a universe with zero global curvature, the SN light will thus approach the curve for an *open* universe, see Fig. 1.

Another compelling property is that the negative curvature effect will automatically mimic a very small cosmological constant, beginning to “dominate” at an epoch when a significant amount of structure has evolved. Before structure formation through gravitational condensation becomes effective ($1100 \gg z > 4$), all space will have roughly the same curvature ($k \simeq 0$). However, structure formation will produce bound systems with increasing Ω_{bound} , which means that $\Omega_{between}$ will be a decreasing function of time. Hence, the space in between bound systems will asymptotically approach $\Omega = 0$ as time increases (density being diluted by expansion), simulating an accelerated expansion by means of cosmological constant/quintessence.

We end with some related comments:

- The considerations of this paper is not the same as gravitational lensing of the SN sources, previously studied by others. Gravitational lensing is a (local) transverse curvature effect, while we consider the (semi-global, integrated) longitudinal curvature effect accumulated along the geodesic followed by observed SN photons. So, although the effect locally is largest for $z \rightarrow 0$ (much structure) it also affects higher z -data as the effect is cumulative along the line of sight.

¹Neutrinos and gravitational waves should show less bias as they can travel unhindered through huge amounts of matter without interacting appreciably. This means that both negative and positive curvature effects contribute, which reduces the bias.

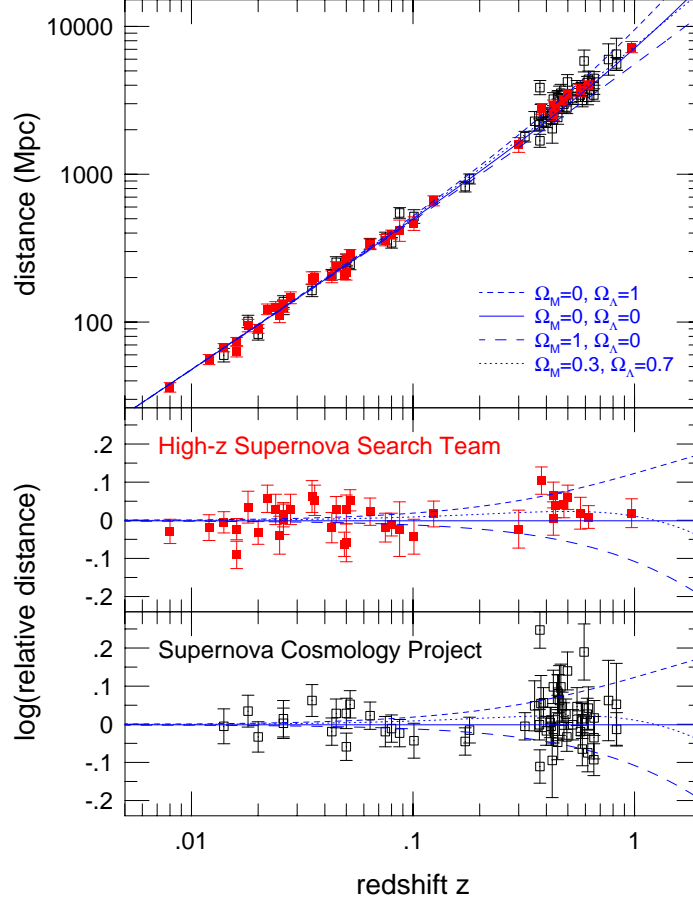


Figure 1: Shown [5] are the original data points of the *High-z Supernova team* (filled squares)[1], and the *Supernova Cosmology Project* (open squares)[2]. The dashed line is the theoretical prediction for a homogeneous and isotropic (FRW) universe which is flat and without cosmological constant ($\Omega_M = 1$, $\Omega_\Lambda = 0$). The solid line is the corresponding prediction for an empty (open) universe ($\Omega_M = 0$, $\Omega_\Lambda = 0$). The dotted line is the solution currently favored for the SN Ia data by both experimental groups ($\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$) put in for comparison. Also shown (short dashes) is the theoretical prediction for a flat universe with only a dark component ($\Omega_M = 0$, $\Omega_\Lambda = 1$). We see that the open universe solution is well within the statistical uncertainty of the data, and that it actually almost coincides with the favored (dotted) solution for the whole observed region. For $z > 1$, where unfortunately also observational measurements become increasingly difficult, it starts to deviate towards the ($\Omega_M = 1$, $\Omega_\Lambda = 0$) line. Observed SN photons within a globally flat universe will always tend towards the line for the open universe, due to inhomogeneous structure formation (assuming $\Omega_\Lambda = 0$).

- SN Ia data probe the semi-local neighborhood ($z \leq 1.2$). Homogeneity and isotropy is valid only on scales significantly larger (orders of magnitude) than the cosmological “voids” [6, 7], *i.e.*, at distances $\gg 120$ Mpc (corresponding roughly to $z \sim 0.03$). Neither can one *a priori* rule out clumping on even grander scales. Hence, the “cosmological principle” of homogeneity and isotropy, which the FRW-metric is based upon, might not apply. Instead full consideration of the inhomogeneities must be taken, up to the distance scale where homogeneity and isotropy can be considered as a valid approximation. (For distances one order of magnitude greater than the voids, 1200 Mpc, this corresponds to $z \sim 0.2$.)
- The CMBR almost certainly probes the overall geometry/curvature of the universe ($z \sim 1100$), as no gravitational structure could form/grow before photon decoupling. The statistical weight of the (low/medium) z -range where appreciable structure has formed is negligible compared to the higher z -range which thus dominates the integrated effect for the CMBR. For very high redshift the photons accordingly behave “as expected” in a flat universe. Also, the CMBR is “everywhere” while SN photons travel from a pointlike source to us along a sharp geodesic “ray”. This means that, due to the anisotropy at small to medium scales, constraints from SN and CMBR do not “carry over” trivially to one another. A simplified analogy might clarify the problem: trying to measure the curvature of the earth’s surface (positive) by making semi-localized measurements in a mountain pass “saddle” (negative curvature), or in the Himalayas (highly irregular mixture of positive and negative curvatures) would be futile.
- In a universe with a cosmological constant it is just a strange cosmic coincidence that $\Omega_M \sim \Omega_\Lambda$ *now* ($\Omega_M \gg \Omega_\Lambda$ earlier and $\Omega_M \ll \Omega_\Lambda$ later). However, in our scenario it is an automatic bonus, as an appreciable amount of structure must form before intelligent life can evolve to observe it. It is thus natural that we live in an epoch when the apparent “acceleration” becomes observable.

In conclusion, we have noted that by regarding the real inhomogeneous matter distribution arising from time-dependent gravitational structure formation, it might be possible to avoid the conclusion that the expansion of the universe accelerates, normally drawn from high- z SN Ia data. This would

alleviate the need to postulate that the present universe at large is dominated by an exotic “dark energy” with a somewhat mysterious negative pressure.

A detailed numerical study of this geometrical “mirage” effect, utilizing realistic matter distributions currently used in studies of gravitational lensing, is underway [8].

References

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