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Journal

GAMMA-RAY BURSTS - SECOND WORKSHOP

ISSN

0094-243X

Author

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Publication Date

1994

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Peer reviewed

BURSTERS AND THE QUEST FOR "COSMOLOGICAL EFFECTS"

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ABSTRACT

From Hubble's time to the present, astronomers have sought observational discriminants for and between Friedmann-Robinson-Walker models of the universe. None has been unambiguously successful, so that confirmation of the constellation of redshift effects (low count rates, long duration, soft spectrum) in gamma ray burst events would have philosophical importance beyond its role in constraining the nature of burst sources.

1. INTRODUCTION: CONFIRMED EFFECTS

An approximation to the $1/R^2$ law for received flux was presumably known to whichever paleolithic tribe that first carried its campfires from place to place. That we look back in time when we look out in space was discovered in 1675 by the Dane Ole Romer (who also built the first meridian transit telescope). He explained irregularities in the timing of eclipses of Jovian satellites by finite light travel speed, putting the earth 11 light minutes from the sun. Since he assumed Cassini's 1672 value of 9.5" for solar parallax, this corresponds to a velocity of about 210,000 km/s, though Romer, working in pre-Revolutionary Paris, must have used different units. Finally, the first third of this century saw the gradual realization that redshifts of spiral nebulae are correlated with their distances, either quadratically (according to Lundmark, 1925; Wirtz, 1925; Stromberg, 1925; and a very few modern disciples like I. Segal) or linearly (according to Hubble [1929] and many others).

And there we come to a screeching halt. In no other case is what we observe about any astronomical phenomenon or object dominated by the large scale structure of the universe, as opposed to astrophysical evolution of intrinsic properties of the objects and/or difficulties with the observations themselves. Direct evidence telling us that we live in some kind of Friedmann-Robertson-Walker universe (that is, that the redshifts are indeed due to the expansion of space-time rather than to tired light, the de Sitter [1933] effect, or something else) or telling us which of the FRW metrics is the best description of the real cosmic four-geometry remains sparse, ambiguous, or worse.

2. THE CLASSICAL TESTS

The redshift-apparent-magnitude diagram at large z would be a relatively pure test for q_0 , the deceleration parameter, if galaxies were standard candles

(see Sandage, 1988 for thorough discussion of all the classical tests). Unfortunately they are not. Though the light of brightest cluster member elliptical galaxies is dominated by red giants, whose increasing number partly compensates for smaller individual brightness as the main sequence erodes away, evolution nevertheless wins. An important implication of B.M. Tinsley's thesis and later work (Tinsley 1972) is that the luminosity of galaxies with different possible histories diverge from each other with increasing z as fast or faster than the luminosities of galaxies with any one history but in universes with q differing by 0.5.

Counting objects as a function of flux received also goes back to Hubble, who, not surprisingly, found no evidence for deviations from Euclidean space. The application to radio sources (e.g. Ryle 1961) was more disconcerting. Redshift should cause any plot of $\log N$ vs. $\log S$ to droop below the Euclidean -1.5 power law line, by different amounts for different geometries, including steady state. But the data clearly traced out a slope of -1.8 for moderately bright sources. In any evolutionary universe, you can explain this by saying that there were more sources ("density evolution") or brighter sources ("luminosity evolution") in the past. Steady state was allowed no such out, and $\log N$ - $\log S$ was its death knell in many minds. The two forms of evolution are not distinguishable with only a single power-law slope to go by, but currently popular cosmological models of gamma bursters would make density evolution the more likely.

Counting galaxies as a function of redshift sounds, at first hearing, less likely to be done in by evolution. Loh and Spillar (1986) made the attempt, claiming $\Omega \approx 1$ (though the test is really primarily sensitive to geometry, K/a^2 , not to density. In any case, further analysis (Bahcall & Tremaine 1988) revealed that evolution strikes again and models from empty to closed could not be ruled out.

The observed angular diameter of an object of known physical size and redshift also probes geometry or radius of curvature, K/a^2 , of the universe. The optical case has long been recognized as fairly hopeless (e.g. Djorgovski & Spinrad 1981), but radio hope springs eternal. The trouble is that, when you plot authentic raw data in $\log \theta$ vs. $\log z$, you always seem to trace out $\theta \propto 1/z$ (flat, static space), even steady state's $\theta \propto \ln(1+z)^{-1}$ turning up too sharply (e.g. Milsson et al., 1993). Ah, you conclude, the sources were smaller in the past, and, given the redshifts, we can correct for that. Yes, but you must assume a model to do it. And (Milsson et al.), if you assume $q = \frac{1}{2}$ (and $\Lambda = 0$), your corrected data happily trace out the $q = \frac{1}{2}$ theoretical curve; while if you assume $q = 0$, the differently corrected data equally happily trace out its curve. Once again, evolution one, cosmology zero. Kellermann (1993) has tried using more compact radio sources which might be less affected by secular changes in environment. He too finds $q = \frac{1}{2}$, but

The test using surface brightness of galaxies vs. redshift straddles the classical and modern periods. Surface brightness within a given metric diameter differs from one FRW model to another. But surface brightness within a given isophotal diameter, which is what can usually be measured, scales as $(1+z)^{-4}$ in any FRW universe. That this should be so feels slightly mysterious (though

Sandage 1988 explains it clearly as the ratio of well-known formulae for received flux and apparent angular diameter. Why then try the test at all? Because non-expansion causes of redshift lead to different exponents on $(1+z)$. The “4” is made up of one power from energy per photon, one from photon arrival rate, and two from an aberration effect on (θ^2) or surface area. Tired light has only the first of these, so $SB \propto (1+z)$. Newtonian expansion has the first and second effects and $SB \propto (1+z)^2$. Surface brightness vs. redshift can, therefore, tell us whether we actually live in a FRW universe.

The most recent application is that of Sandage and Perelmuter (1991). Using their own data out to $z = 0.1$, they find (not surprisingly) that scatter, both observational and real, strews the observed points across all possible SB vs. $(1+z)$ curves, even when the data are normalized to represent galaxies of a standard total brightness ($M_v = -24$) and size. In order to get to larger redshifts where cosmological effects will outweigh the scatter, they apply similar normalization to the data of Djorgovski and Spinrad (1981), extending out to $z = 0.58$ (but ignoring a couple of galaxies at still larger z). They conclude that the normalized data (while not distinguishing one value of q_0 from another) clearly point to a $(1+z)^{-4}$ relation, ruling out tired light and other non-expanding causes of redshift. The original observers, however, feel that the data are not sufficiently robust to support the weight they are being asked to carry (G. Djorgovski, 1993, pr. comm., phrased somewhat more forcefully). The possibility of additional confounding from evolutionary changes in SB remains to be explored.

3. MORE RECENT TESTS

A universe with a positive cosmological constant goes through a “coasting phase” in which a good deal of time is spent at nearly constant expansion parameter. Thus, looking backward, we expect to see many objects with redshift corresponding to that coasting era. This was invoked some years ago as a potential explanation for the apparent pile-up of qso’s at redshifts near 1.95. More recently, the numbers of gravitationally-lensed qso’s and the redshift distributions of the sources and lenses have been analyzed to look for evidence of such a coasting phase. Turner (1990) concluded that the dimensionless value of λ could not be more than 0.9. Maoz and Rix (1993) have pushed this further down to 0.7, at which point the coasting phase would not last long enough to increase the age of an Ω (total) = 1 universe above that of the oldest globular clusters (the main purpose of non-zero Λ in most people’s minds). If the limit is correct then $\Lambda \neq 0$ universes cease to be interesting. Krauss and Schramm (1993) point out, however, that the current samples are essentially magnitude-limited ones, so that evolutionary changes both in the intrinsic brightness of the sources and in the masses and mass distributions of the lenses may permit a wider range of λ , including interesting values for the age problem. Once again, cosmological effects probably do not dominate what we observe.

Finally, an attempt has been made to look directly for time dilation (that is, expansion vs. tired light or de Sitter effect) in the light curves of Type Ia

supernovae. The raw data for the one at largest redshift (SN 1992bi, $z = 0.45$, Pennypacker et al., 1992) have not yet been published. But Nørgaard-Nielsen et al. (1988) show their measured magnitudes and dates for SN 1988U at $z = 0.31$. The points fit well onto a standard SN Ia light curve when time dilation is allowed for. Unfortunately, they did not catch the event at peak light, and the distance modulus to the host galaxy has all the usual uncertainty from $H = 50$ or 85 to 100. Thus the points can, to a certain extent, be slid both vertically and horizontally, permitting at least plausible fits also without time dilation. More events are needed!

The SN Ia case is the one most closely resembling that of the gamma-ray bursters. A light curve from $z \approx 0$ is used as a template, and the high- z light curve undilated to fit it. If Ia supernovae at $z = 0.3$ (or more) were physically different from those here and now, then we will be, at least, misled. The burst case is slightly more difficult, because the template itself must be extracted from the data base that is to be tested for time dilation effects, and because there is no direct, independent measurement of redshifts.

If the very persuasive correlations shown by J. Norris and others at this meeting are indeed the results of large distances and expansion acting on the count rates, time scales, and spectral hardness of otherwise very similar photon bursts, then we have not only a piece of the solution to the gamma-ray burst problem, but also the first astronomical entities in which cosmological effects win out over evolution and observational difficulties. Which of these you think is the more important probably depends on whether the first astronomy book you ever read was written by Fred Hoyle!

4. ACKNOWLEDGEMENTS

The one small idea contained herein is surely not original, but I am not sure from whom I first heard it (the culprit, if he or she confesses, is entitled to a free drink at the next CGRO symposium). The truism that evolution always wins dawned on me very gradually beginning with Caltech graduate lectures by Maarten Schmidt and Peter Scheuer, and continuing with a few months in the early 70's of sharing an office at University of Maryland with the late Beatrice M. Tinsley.

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