**Exponential Energy Loss and Observational Deviation from the Hubble Law**

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## Abstract:

*In this work we plot the observational measurements of 240 SNIA events in standard astronomical Hubble fashion. We demonstrate that there is a greater than 98% correlation to an exponential loss of energy with distance.*

## Introduction:

For the roughly three-quarters of a century between about 1920 and 1995, the apparently linear correlation of redshift to distance for extra-galactic objects was noted and became a cosmological paradigm. In these models, redshift is always interpreted as a measure of the speed of recession. A minority view throughout the period was that light lost energy with distance traveled. In general, such a theory is generally discounted in cosmology on the basis that there is no accepted theoretical mechanism for it.

Beginning in the 1990's, observations of supernovae deviated from the accepted Hubble relationship. Cosmologists required a change to the model to include a "dark energy" in what became the current "lambda cold dark matter" (ΛCDM) model. By this time, cosmologists were tweaking many different big bang models, and were focused on variations of theoretical parameters between the minor variations – no longer questioning the underlying paradigm. This paper plots the raw supernovae data in the original non-cosmological Hubble layout. The resulting curve is found to be undeniably exponential – in full accord with an energy loss model.

## Background History:

In the 1920's it was noticed that there as objects increased with distance, the spectrum of the absorption lines found in stellar emissions shifted more toward the red end of the spectrum (the red shift). This shift was originally interpreted as a Doppler shift due to motion. The shift is now interpreted as a stretching of wavelengths due to expansion of space itself during the time light travels between emission and observations in our solar system. In both interpretations, distance between objects is increasing with time.

The physical measure for the vertical axis is the change in wavelength ($\Delta\lambda$) divided by the original wavelength ($\lambda$). This ratio is often provided as **z**.[1] This is a general relationship of the apparent distance of a galaxy/object when plotted against its redshift.

[1] Without multiplying by the speed of light: $\mathbf{z} = (\Delta\lambda / \lambda)$ (Rowland, 2020)

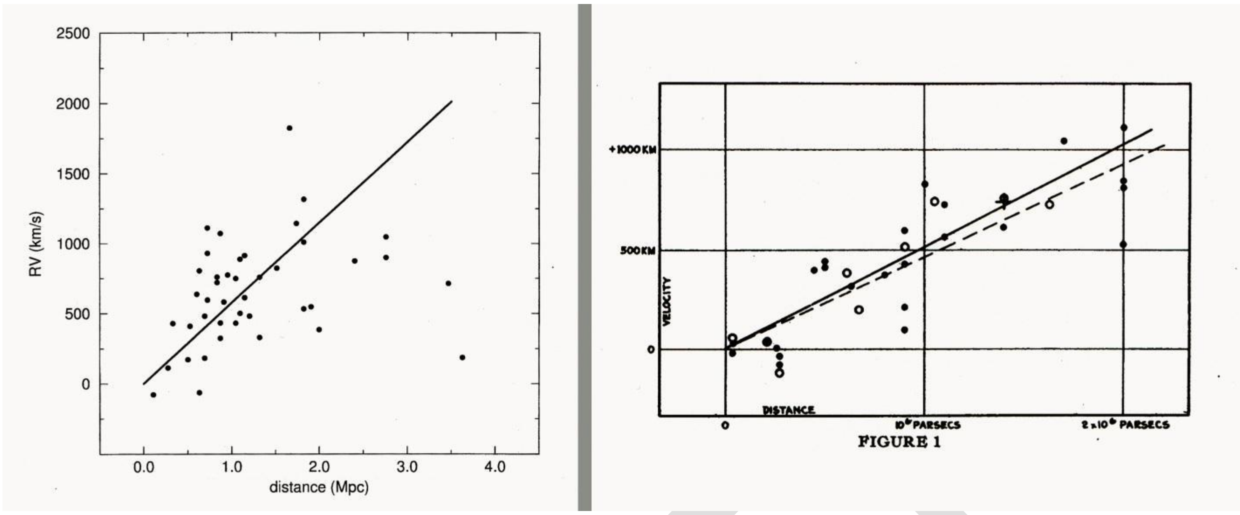


*Figure 1- Redshift versus distance, Lemaitre 1927 & Hubble 1929*

It is telling that from the very first graphs in 1927 (above)[2], the redshift-distance relations have always been presented with vertical axis converted to a theoretical Doppler speed by multiplying the redshift by the speed of light (**c**)[3]. [i] *"(T)he predominant tradition in relativistic cosmology was heavily oriented towards mathematics and had little contact with either physics or observational astronomy*." (Kragh, Cosmology and Controversy, 1996), p 42. Although Hubble himself usually used the term "apparent velocity," the philosophical preference was ingrained from the start as a "recessional velocity" caused by the radial Doppler Effect[4]. The impressed straight-line relation was later named "Hubble law" and is given by the simple equation; **v = Hr**, where **H** is the linear slope, and is called the Hubble constant[5], **v** is the recessional velocity of the galaxy, and **r** is the distance to the galaxy.

The assumption that the red shift was caused solely by motion was not universally accepted by many early astronomers. The most well-known of these was Fritz Zwicky, who proposed in 1929 that light lost energy as it traveled cosmic distances. According to Fred Hoyle, Zwicky's proposal was "*generally ignored, as is inevitably the case when the establishment has made up its mind, as it had by around 1930*." (Fred Hoyle, 2000). Correspondingly, Zwicky's proposal as such is not even referenced in many standard cosmological histories such as Peebles' "*Principals of Physical Cosmology*" and Misner, Thorne, and Wheeler's "*Gravitation*."

Currently we can safely state that there is no *accepted* proposal for light to lose energy while traveling cosmological distances. Such loss of energy with distance is sometimes described as "***Tired Light***." Zwicky's initial proposals were primarily dismissed as *ad hoc*. (Kragh, Is the Universe Expanding? Fritz Zwicky and Early Tired Light Hypotheses, 2017) Misner, Thorne, and Wheeler summarize the establishment view that "*(n)o one has ever put forward a satisfactory explanation for the cosmological redshift other than the expansion of the universe.*" (Misner, 1970) (see p. 775).

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[2] Similar relations were obtained by Carl Wirtz (1924), Lemaître (1927), and Slipher(1917)**Invalid source specified.Invalid source specified.**

[3] The Doppler speed for light waves is given by $\mathbf{v = c}$ $(\Delta\lambda/\ \lambda)$.

[4] The Doppler effect has been replaced by spatial expansion in later models.

[5] The accepted modern value is approximately 70 kps per Mpc.

**The Dimming of the Standard Candles (1998).**

In 1998, measurements of 42 distant supernovae (Perlmutter, 1999) were found to deviate from the straight-line prediction of the Hubble Law for the ΛCDM models.

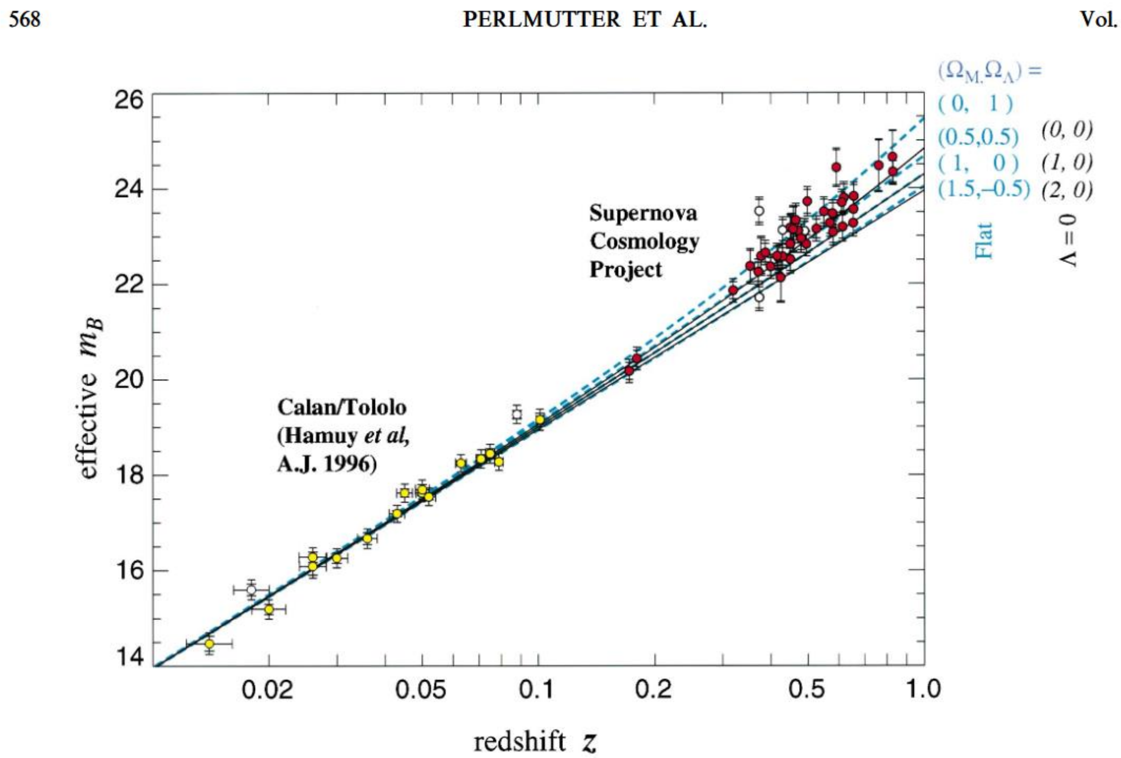


*Figure 2*

Perlmutter et al presented the above (*figure 2*[6]) as the "Hubble diagram." For their own purposes they have swapped the graph's axes. Redshift is presented along the bottom. "Effective magnitude" is brought in as a rough indicator of distance[7]. Deviations from the linear trend are interpreted as showing an accelerating expansion ("*dark energy*"[8]) from what is often called anomalous dimming. Cosmologists interpret this deviation as indicating that the universal expansion is accelerating via a sort of negative gravity called the cosmological constant (Λ)[9] . *No one has put forward a satisfactory explanation* for the source or creation of this energy from nothing.

**Swapping the point-of-view:**

One often learns unexpected lessons from changing one's point of view. Perlmutter's graph for ΛCDM dark energy can be converted back into a "standard" Hubble diagram by assuming that the visual

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[6] Presented as the "Hubble diagram" in Figure 1 in (Perlmutter, 1999).
[7] Apparent brightness ($m_B$) drops off with distance. The astronomical scale for brightness gets dimmer as the magnitude number increases. (A 1st magnitude star is 2.5 times brighter than a 2nd magnitude star, and so on.)
[8] The term dark energy is derived as an extension from the earlier term dark matter.
[9] The "Λ" in the ΛCDM name.

absolute magnitude of Type Ia supernovae is Mv[10] = −19.3 (Hillebrandt & Niemeyer, 2000). See Appendix A-1 for the supporting table.[11] A reversion to non-cosmological point-of-view gives figure 3:

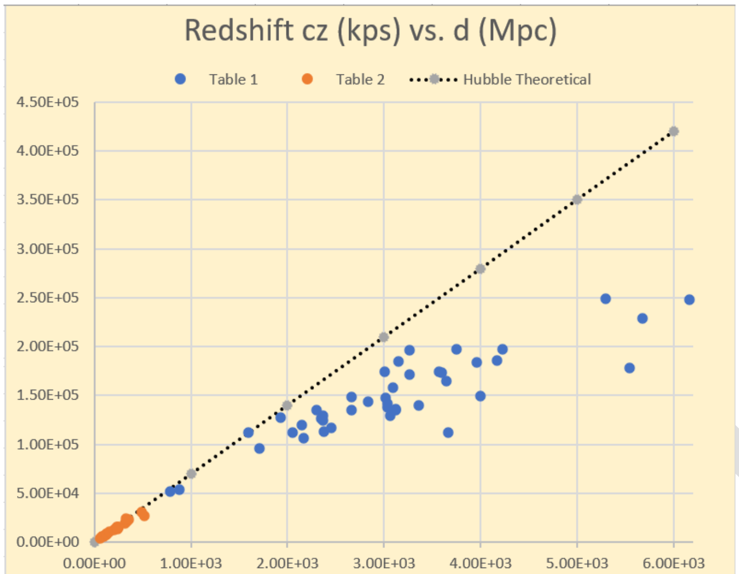


Figure 3

The dotted line is the theoretical standard value of $H_0$ = 70 kps/Mpc. This plot includes the 61 supernovae in Perlmutter (from two data tables).

The apparent reduction in universal expansion rate ($H_0$) is the evidence used for existence of "dark energy. In the past (at higher distances and z values), the universal expansion rate appears significantly lower than the current value of 70 kps/Mpc. This is interpreted as universal expansion increasing with time.

Instead of being presented as "anomalous dimming," this point-of-view shows an increasing indicated ***distance*** beyond the expected linear Hubble prediction when normal astronomical standard candle calculations are used. The above plot shows a clear and accelerating deviation from the currently presumed linear Hubble slope value as distances exceed 600 Mpc. The departure from the straight line appears to profile an exponential process.

**Wave Energy Loss as the Cause of the Redshift:**

The data supports an exponential variant of the "tired light" hypothesis[12]. Tired light has been proposed several times over the past 90 years by theorists dissatisfied by various aspects of the ΛCDM model.[13] Tired Light is in general described as the concept that light ***naturally*** loses energy as it travels astronomical distances through space[14]. One can consider this postulate to be ad hoc (*hypothesis non fingo*). However, every other instance of wave propagation known to science has an innate loss of

[10] There are differences between the visual-filter magnitude ($M_V$) and the blue-filter magnitude ($M_B$). These are minor variances in the current analysis.
[11] Later presentations of more extensive data indicate hundreds of measured SN Ia supernovae. These papers do not present the data in an accessible, tabular form. They cover the same range and conform to the overall trend.
[12] In general. Not necessarily Zwicky's specific theoretical cause.
[13] For a modern review, see (Ming-Hui Shao, 2018, Dec 7th)
[14] In other words, light need not interact with matter (i.e., electrons or dust) to lose energy.

energy with distance traveled as an observed physical property. The lack of such loss for light (*electromagnetic waves*) would make it the only known exception to this otherwise universal rule.[ii]

While there is no currently-accepted model for light-wave energy loss, light is experimentally seen to lose energy exponentially with distance as it passes through matter. This is true for both high-energy light[15] and solar radiation passing through water.

The standard loss equation for such a process is given by:

$$\mathbf{E_x = E_o e^{-\mu x}} \quad \textit{Eq 1}$$

Where x is the distance traveled, $\mu$ is the linear attenuation coefficient and E is the energy of the photon. In material systems the energy term E is replaced by A, the amplitude of the wave with other terms remaining unchanged. This energy loss is physically expressed as a reduction in the wave's intensity with the original wave-length/frequency remaining unchanged. For EM radiation energy is defined by the equation E = hυ. Given that Planck's term h is constant, losses must be physically manifested as a reduction in frequency (υ) and a corresponding increase in wave length ($\lambda$). Therefore, for the above equation, energy E can be replaced by frequency υ. It will be a postulate in this work that the current Hubble Term (**H**) represents the measured value of the linear first order value of $\mu$ in the exponential $e^{-\mu x}$ when the $\mu x$ is much less than unity. When H is converted from (km/sec-MPC) to inverse meters the value of $\mu$ becomes approximately ***7.548E-27***. The magnitude of this value far too small to exhibit any observable effects except at very great distances such as Hubble's measurements. This damping process exhibits a distinctive non-linear profile starting at distances where $\mu x$ becomes nontrivial ($> \sim 0.02$) and would clearly be falsified if redshift / distance measurements followed a strictly linear profile at all visible ranges. It is the exponential decay profile which is a unique property of the tired light process. No other cosmological model can ***naturally*** incorporate this profile.

Although *Figure 3* has an undeniable exponential trend, we next added data from Tonry, et al (2003). Tonry's data has some apparent discrepancies.[16] This data drives a larger scatter than indicated by Perlmutter. Tonry includes data from 189 additional supernovae. (Tonry, 2003) spanning distances from z = 0.002 to z = 0.830. This results in a total 240 observed SN1A with 167 having z greater than or equal to 0.02 putting them in the divergent from linearity region. Once the data was plotted we used Excel's standard *Trendline* function to generate a 'best fit' curve of these values. The results are shown in *Figure 4* below:

[15] Gamma rays

[16] Tonry presents distances as a function of the Hubble constant in Table 15. The only raw distance data provided is for six usable supernovae in table 13. Of these six, we could only duplicate the distance moduli for two, from the other data provided in Tonry. The other four supernovae in Table 13 vary, sometimes substantially. There is an apparent additional undefined modification within Tonry that results in a higher scatter of data. Whether this is an oversight in Tonry or a misunderstanding on our part, the results are consistent – if more scattered.

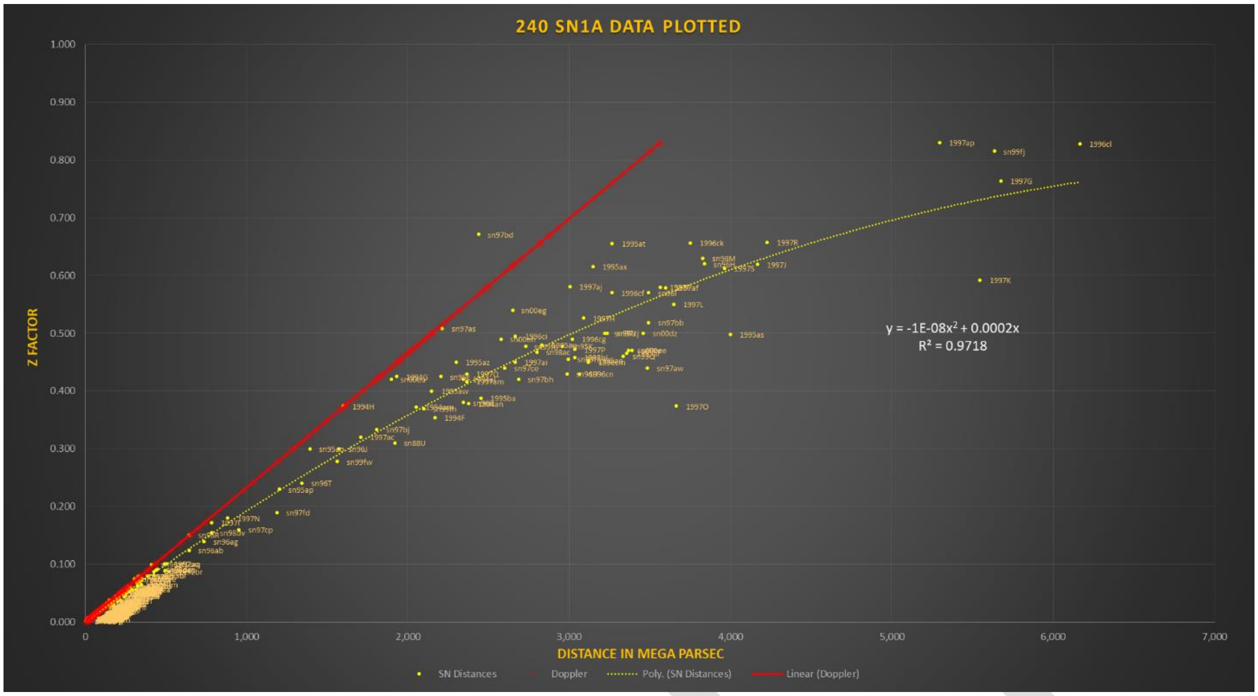


*Figure 4*

The result clearly shows the exponential non-linearity in the measured distances. The red line is the ideal linear Hubble redshift-distance plot. The curve fit correlation (r) is 0.9859 showing that the data correlates extremely well to the resulting computed regression curve.

We then superimpose the calculated ideal exponential energy loss calculation using as an initial value the Hubble constant of 70 kps/Mpc (*equation 1 above*). This gives the green line shown in *Figure 5* below.

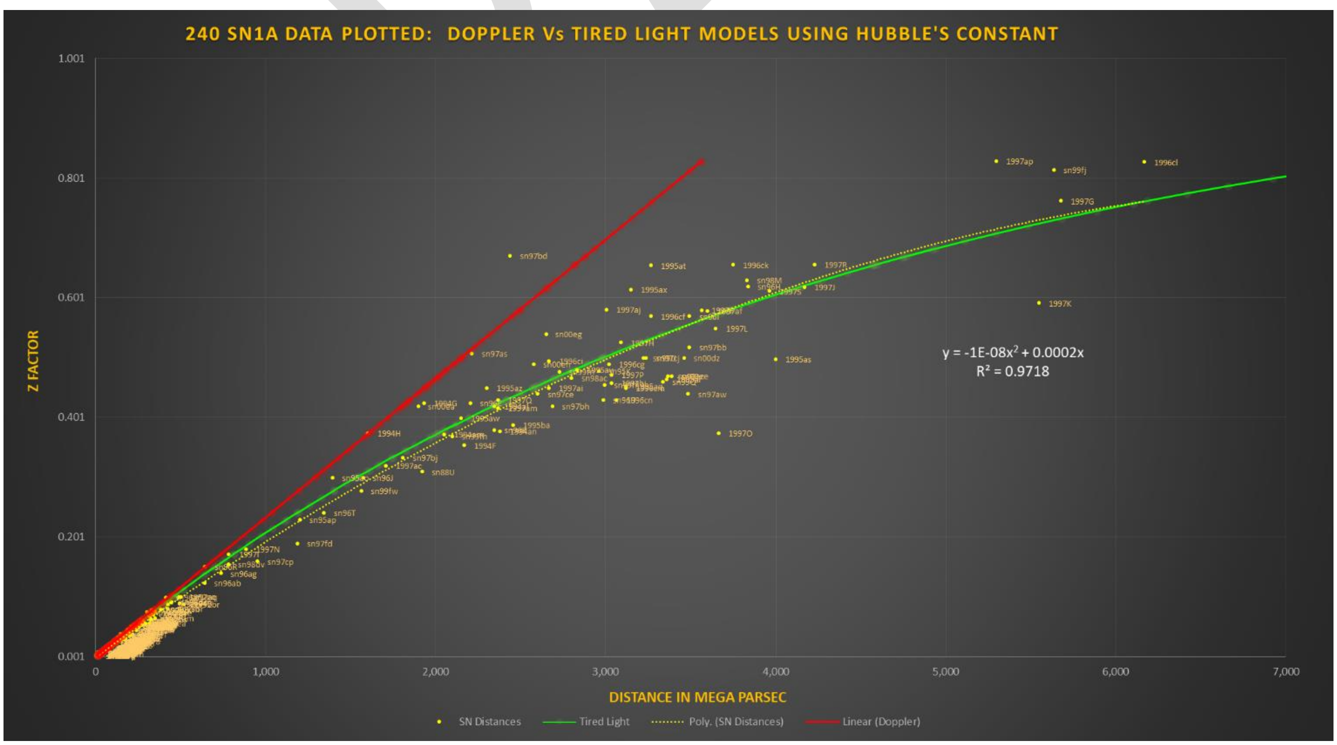


*Figure 5*

As can be seen, the fitted curve almost perfectly matches the standard exponential energy loss profile.

The deviation from the linear Hubble profile is not predicted by the Big Bang model –nor is the point at which this deviation would begin. The addition of "dark energy" – an ad hoc unphysical anti-gravity force of arbitrary strength – is necessary to account for these observations.

**Conclusions:**

The observed curve fits a standard wave damping 'tired light' process extremely well. There is no need for any additional ad hoc postulates.

Using this the published observations fit its predictive curve almost perfectly. The results speak for themselves.

With wave damping there is simply no unique data that could define the origin and evolution of the universe. This will certainly disappoint many who desire to be certain of the beginnings and endings of all things. It will disappoint cosmologists – who would lose the underpinnings of $\Lambda$CDM that generate most cosmological research papers.

But there will be no lack of work for astronomers, astrophysicists, and cosmologists. The remoter rungs of the cosmological distance ladder which are currently tied to the linear Hubble law and the velocity/redshift assumptions must be re-evaluated. All distances to extragalactic objects will need to be reevaluated. Apparent anomalies such as quasar redshifts and distances could be examined anew.

And best of all, physicists could begin searching for the physical foundational process of this Energy loss. One that would be acceptable to a large number of newly-disappointed theorists.

# Appendix A-1

## Conversion of Perlmutter et al, Tables 1 and 2 to standard Hubble law diagram format:

**Sorted by redshift (z) within each table.  Columns 1, 2, 3 from Perlmutter.**

| SN | redshift factor z | $m_B^{eff}$ | Distance modulus*[17] | Distance (Mpc)[18] | Apparent velocity cz (kps) | Indicated H0 (kps/Mpc) |
|---|---|---|---|---|---|---|
| 1997I | 0.172 | 20.17 | 39.47 | 7.83E+02 | 5.16E+04 | 65.9 |
| 1997N | 0.180 | 20.43 | 39.73 | 8.83E+02 | 5.40E+04 | 61.1 |
| 1997ac | 0.320 | 21.86 | 41.16 | 1.71E+03 | 9.60E+04 | 56.3 |
| 1994F | 0.354 | 22.38 | 41.68 | 2.17E+03 | 1.06E+05 | 49.0 |
| 1994am | 0.372 | 22.26 | 41.56 | 2.05E+03 | 1.12E+05 | 54.4 |
| 1994H | 0.374 | 21.72 | 41.02 | 1.60E+03 | 1.12E+05 | 70.1 |
| 1997O | 0.374 | 23.52 | 42.82 | 3.66E+03 | 1.12E+05 | 30.6 |
| 1994an | 0.378 | 22.58 | 41.88 | 2.38E+03 | 1.13E+05 | 47.7 |
| 1995ba | 0.388 | 22.65 | 41.95 | 2.45E+03 | 1.16E+05 | 47.4 |
| 1995aw | 0.400 | 22.36 | 41.66 | 2.15E+03 | 1.20E+05 | 55.9 |
| 1997am | 0.416 | 22.57 | 41.87 | 2.37E+03 | 1.25E+05 | 52.7 |
| 1994al | 0.420 | 22.55 | 41.85 | 2.34E+03 | 1.26E+05 | 53.7 |
| 1994G | 0.425 | 22.13 | 41.43 | 1.93E+03 | 1.28E+05 | 66.0 |
| 1996cn | 0.430 | 23.13 | 42.43 | 3.06E+03 | 1.29E+05 | 42.1 |
| 1997Q | 0.430 | 22.57 | 41.87 | 2.37E+03 | 1.29E+05 | 54.5 |
| 1995az | 0.450 | 22.51 | 41.81 | 2.30E+03 | 1.35E+05 | 58.7 |
| 1996cm | 0.450 | 23.17 | 42.47 | 3.12E+03 | 1.35E+05 | 43.3 |
| 1997ai | 0.450 | 22.83 | 42.13 | 2.67E+03 | 1.35E+05 | 50.6 |
| 1995aq | 0.453 | 23.17 | 42.47 | 3.12E+03 | 1.36E+05 | 43.6 |
| 1992bi | 0.458 | 23.11 | 42.41 | 3.03E+03 | 1.37E+05 | 45.3 |
| 1995ar | 0.465 | 23.33 | 42.63 | 3.36E+03 | 1.40E+05 | 41.6 |
| 1997P | 0.472 | 23.11 | 42.41 | 3.03E+03 | 1.42E+05 | 46.7 |
| 1995ay | 0.480 | 22.96 | 42.26 | 2.83E+03 | 1.44E+05 | 50.9 |
| 1996cg | 0.490 | 23.10 | 42.40 | 3.02E+03 | 1.47E+05 | 48.7 |
| 1996ci | 0.495 | 22.83 | 42.13 | 2.67E+03 | 1.49E+05 | 55.7 |
| 1995as | 0.498 | 23.71 | 43.01 | 4.00E+03 | 1.49E+05 | 37.4 |
| 1997H | 0.526 | 23.15 | 42.45 | 3.09E+03 | 1.58E+05 | 51.1 |
| 1997L | 0.550 | 23.51 | 42.81 | 3.65E+03 | 1.65E+05 | 45.2 |
| 1996cf | 0.570 | 23.27 | 42.57 | 3.27E+03 | 1.71E+05 | 52.4 |
| 1997af | 0.579 | 23.48 | 42.78 | 3.60E+03 | 1.74E+05 | 48.3 |
| 1997F | 0.580 | 23.46 | 42.76 | 3.56E+03 | 1.74E+05 | 48.8 |
| 1997aj | 0.581 | 23.09 | 42.39 | 3.01E+03 | 1.74E+05 | 58.0 |
| 1997K | 0.592 | 24.42 | 43.72 | 5.55E+03 | 1.78E+05 | 32.0 |
| 1997S | 0.612 | 23.69 | 42.99 | 3.96E+03 | 1.84E+05 | 46.3 |
| 1995ax | 0.615 | 23.19 | 42.49 | 3.15E+03 | 1.85E+05 | 58.6 |



[17] Distance Modulus defined as: m - M = 5 log d – 5.  Using Maximum Absolute Visual Magnitude for SN Ia of -19.3 (Hillebrandt & Niemeyer, 2000)

[18] Standard-candle distance as determined from distance modulus.

| | | | | | | |
|---|---|---|---|---|---|---|
| 1997J | 0.619 | 23.80 | 43.10 | 4.17E+03 | 1.86E+05 | 44.5 |
| 1995at | 0.655 | 23.27 | 42.57 | 3.27E+03 | 1.97E+05 | 60.2 |
| 1996ck | 0.656 | 23.57 | 42.87 | 3.75E+03 | 1.97E+05 | 52.5 |
| 1997R | 0.657 | 23.83 | 43.13 | 4.23E+03 | 1.97E+05 | 46.6 |
| 1997G | 0.763 | 24.47 | 43.77 | 5.68E+03 | 2.29E+05 | 40.3 |
| 1996cl | 0.828 | 24.65 | 43.95 | 6.17E+03 | 2.48E+05 | 40.3 |
| 1997ap | 0.830 | 24.32 | 43.62 | 5.30E+03 | 2.49E+05 | 47.0 |
| 1990O | 0.030 | 14.47 | 33.77 | 5.68E+01 | 4.20E+03 | 74.0 |
| 1990af | 0.050 | 15.61 | 34.91 | 9.59E+01 | 5.40E+03 | 56.3 |
| 1992P | 0.026 | 15.18 | 34.48 | 7.87E+01 | 6.00E+03 | 76.2 |
| 1992ae | 0.075 | 16.08 | 35.38 | 1.19E+02 | 7.80E+03 | 65.5 |
| 1992ag | 0.026 | 16.28 | 35.58 | 1.31E+02 | 7.80E+03 | 59.7 |
| 1992al | 0.014 | 16.26 | 35.56 | 1.29E+02 | 9.00E+03 | 69.5 |
| 1992aq | 0.101 | 16.66 | 35.96 | 1.56E+02 | 1.08E+04 | 69.4 |
| 1992bc | 0.020 | 17.19 | 36.49 | 1.99E+02 | 1.29E+04 | 65.0 |
| 1992bg | 0.036 | 17.61 | 36.91 | 2.41E+02 | 1.35E+04 | 56.0 |
| 1992bh | 0.045 | 17.63 | 36.93 | 2.43E+02 | 1.50E+04 | 61.7 |
| 1992bl | 0.043 | 17.69 | 36.99 | 2.50E+02 | 1.50E+04 | 60.0 |
| 1992bo | 0.018 | 17.54 | 36.84 | 2.33E+02 | 1.56E+04 | 66.9 |
| 1992bp | 0.079 | 18.24 | 37.54 | 3.22E+02 | 1.89E+04 | 58.7 |
| 1992br | 0.088 | 18.33 | 37.63 | 3.36E+02 | 2.13E+04 | 63.4 |
| 1992bs | 0.063 | 18.43 | 37.73 | 3.52E+02 | 2.25E+04 | 64.0 |
| 1993B | 0.071 | 18.27 | 37.57 | 3.27E+02 | 2.37E+04 | 72.6 |
| 1993O | 0.052 | 19.28 | 38.58 | 5.20E+02 | 2.64E+04 | 50.8 |
| 1993ag | 0.050 | 19.16 | 38.46 | 4.92E+02 | 3.03E+04 | 61.6 |

# Appendix A-2

## Conversion of Tonry et al, Tables 15 and 13 to standard Hubble law diagram format:

**Sorted by redshift (z) within each table. Columns 2, 4, 5 from Tonry.**

| SN | redshift factor z | log(dH0)[19] | Distance (Mpc)[20] | Apparent velocity cz (kps) | Indicated H0 (kps/Mpc) |
|---|---|---|---|---|---|
| sn72E | 0.002 | 2.399 | 3.86E+00 | 6.90E+02 | 179.0 |
| sn86G | 0.003 | 2.440 | 4.24E+00 | 8.10E+02 | 191.2 |
| sn94D | 0.003 | 3.003 | 1.55E+01 | 8.10E+02 | 52.3 |
| sn99by | 0.003 | 3.067 | 1.80E+01 | 8.10E+02 | 45.1 |
| sn89B | 0.004 | 2.844 | 1.07E+01 | 1.08E+03 | 100.5 |
| sn98aq | 0.004 | 3.181 | 2.33E+01 | 1.11E+03 | 47.6 |
| sn96ai | 0.004 | 3.109 | 1.98E+01 | 1.23E+03 | 62.2 |
| sn91bg | 0.004 | 3.064 | 1.78E+01 | 1.26E+03 | 70.7 |
| sn98bu | 0.004 | 2.912 | 1.26E+01 | 1.29E+03 | 102.7 |
| sn90N | 0.004 | 3.204 | 2.46E+01 | 1.32E+03 | 53.6 |
| sn94ae | 0.005 | 3.295 | 3.03E+01 | 1.62E+03 | 53.4 |
| sn98dm | 0.005 | 3.498 | 4.84E+01 | 1.62E+03 | 33.5 |
| sn81D | 0.006 | 3.044 | 1.70E+01 | 1.68E+03 | 98.7 |
| sn80N | 0.006 | 3.140 | 2.12E+01 | 1.68E+03 | 79.1 |
| sn94U | 0.006 | 3.149 | 2.17E+01 | 1.68E+03 | 77.5 |
| sn92A | 0.006 | 3.124 | 2.05E+01 | 1.74E+03 | 85.0 |
| sn95al | 0.006 | 3.328 | 3.27E+01 | 1.80E+03 | 55.0 |
| sn97dt | 0.006 | 3.375 | 3.65E+01 | 1.83E+03 | 50.2 |
| sn92G | 0.006 | 3.286 | 2.97E+01 | 1.86E+03 | 62.6 |
| sn91T | 0.007 | 2.961 | 1.41E+01 | 2.10E+03 | 149.3 |
| sn00cx | 0.007 | 3.320 | 3.21E+01 | 2.10E+03 | 65.3 |
| sn81B | 0.007 | 3.077 | 1.84E+01 | 2.16E+03 | 117.6 |
| sn96bk | 0.007 | 3.298 | 3.06E+01 | 2.16E+03 | 70.7 |
| sn91M | 0.008 | 3.397 | 3.84E+01 | 2.28E+03 | 59.4 |
| sn98dh | 0.008 | 3.403 | 3.89E+01 | 2.28E+03 | 58.6 |
| sn95D | 0.008 | 3.373 | 3.63E+01 | 2.31E+03 | 63.6 |
| sn96X | 0.008 | 3.266 | 2.84E+01 | 2.34E+03 | 82.4 |
| sn97br | 0.008 | 3.282 | 2.95E+01 | 2.40E+03 | 81.5 |
| sn99cl | 0.008 | 3.009 | 1.57E+01 | 2.46E+03 | 156.6 |
| sn96Z | 0.009 | 3.387 | 3.75E+01 | 2.61E+03 | 69.6 |
| sn99gh | 0.009 | 3.356 | 3.49E+01 | 2.64E+03 | 75.6 |
| sn97bp | 0.010 | 3.416 | 4.01E+01 | 2.85E+03 | 71.1 |
| sn98es | 0.010 | 3.438 | 4.22E+01 | 2.85E+03 | 67.6 |
| sn97bq | 0.010 | 3.484 | 4.69E+01 | 2.88E+03 | 61.4 |
| sn99ac | 0.010 | 3.478 | 4.62E+01 | 2.97E+03 | 64.2 |



[19] Tonry's cosmological distance value

[20] Conversion of Tonry's dH0 to d, based on Tonry's value of H of 65 kpc/Mpc

| | | | | | |
|---|---|---|---|---|---|
| sn98bp | 0.010 | 3.475 | 4.59E+01 | 3.12E+03 | 67.9 |
| sn99cp | 0.010 | 3.525 | 5.15E+01 | 3.12E+03 | 60.5 |
| sn97do | 0.010 | 3.545 | 5.40E+01 | 3.12E+03 | 57.8 |
| sn92K | 0.011 | 3.432 | 4.16E+01 | 3.36E+03 | 80.8 |
| sn99cw | 0.011 | 3.469 | 4.53E+01 | 3.36E+03 | 74.2 |
| sn95E | 0.012 | 3.559 | 5.57E+01 | 3.48E+03 | 62.4 |
| sn98dk | 0.012 | 3.571 | 5.73E+01 | 3.60E+03 | 62.8 |
| sn99da | 0.012 | 3.623 | 6.46E+01 | 3.63E+03 | 56.2 |
| sn99ej | 0.013 | 3.684 | 7.43E+01 | 3.81E+03 | 51.3 |
| sn98D | 0.013 | 3.605 | 6.20E+01 | 3.96E+03 | 63.9 |
| sn97E | 0.013 | 3.624 | 6.47E+01 | 3.96E+03 | 61.2 |
| sn99dq | 0.014 | 3.548 | 5.43E+01 | 4.08E+03 | 75.1 |
| sn91ag | 0.014 | 3.626 | 6.50E+01 | 4.23E+03 | 65.1 |
| sn92al | 0.014 | 3.636 | 6.65E+01 | 4.23E+03 | 63.6 |
| sn99dk | 0.014 | 3.686 | 7.47E+01 | 4.23E+03 | 56.7 |
| sn95bd | 0.015 | 3.648 | 6.84E+01 | 4.56E+03 | 66.7 |
| sn99aa | 0.016 | 3.684 | 7.43E+01 | 4.71E+03 | 63.4 |
| sn98de | 0.016 | 3.727 | 8.21E+01 | 4.71E+03 | 57.4 |
| sn94S | 0.016 | 3.693 | 7.59E+01 | 4.83E+03 | 63.7 |
| sn01V | 0.016 | 3.662 | 7.06E+01 | 4.86E+03 | 68.8 |
| sn97cw | 0.016 | 3.674 | 7.26E+01 | 4.92E+03 | 67.7 |
| sn00dk | 0.016 | 3.677 | 7.31E+01 | 4.92E+03 | 67.3 |
| sn96bo | 0.017 | 3.653 | 6.92E+01 | 4.95E+03 | 71.5 |
| sn00ce | 0.017 | 3.705 | 7.80E+01 | 4.95E+03 | 63.5 |
| sn97Y | 0.017 | 3.730 | 8.26E+01 | 4.98E+03 | 60.3 |
| sn96bv | 0.017 | 3.663 | 7.08E+01 | 5.01E+03 | 70.8 |
| sn98ef | 0.017 | 3.650 | 6.87E+01 | 5.10E+03 | 74.2 |
| sn98V | 0.017 | 3.686 | 7.47E+01 | 5.10E+03 | 68.3 |
| sn98co | 0.017 | 3.729 | 8.24E+01 | 5.13E+03 | 62.2 |
| sn97cn | 0.018 | 3.730 | 8.26E+01 | 5.25E+03 | 63.5 |
| sn99ek | 0.018 | 3.687 | 7.48E+01 | 5.28E+03 | 70.6 |
| sn92bo | 0.018 | 3.745 | 8.55E+01 | 5.34E+03 | 62.4 |
| sn93ae | 0.018 | 3.684 | 7.43E+01 | 5.40E+03 | 72.7 |
| sn92bc | 0.019 | 3.777 | 9.21E+01 | 5.58E+03 | 60.6 |
| sn99gd | 0.019 | 3.779 | 9.25E+01 | 5.70E+03 | 61.6 |
| sn00B | 0.019 | 3.740 | 8.45E+01 | 5.79E+03 | 68.5 |
| sn98ec | 0.020 | 3.801 | 9.73E+01 | 6.00E+03 | 61.7 |
| sn00fa | 0.022 | 3.837 | 1.06E+02 | 6.54E+03 | 61.9 |
| sn95ak | 0.022 | 3.772 | 9.10E+01 | 6.57E+03 | 72.2 |
| sn00cn | 0.023 | 3.847 | 1.08E+02 | 6.99E+03 | 64.6 |
| sn98eg | 0.023 | 3.897 | 1.21E+02 | 7.02E+03 | 57.8 |
| sn94M | 0.024 | 3.835 | 1.05E+02 | 7.32E+03 | 69.6 |
| sn96V | 0.025 | 3.871 | 1.14E+02 | 7.50E+03 | 65.6 |
| sn93H | 0.025 | 3.845 | 1.08E+02 | 7.53E+03 | 69.9 |

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|---|---|---|---|---|---|
| sn99X | 0.026 | 3.888 | 1.19E+02 | 7.71E+03 | 64.9 |
| sn99gp | 0.026 | 3.933 | 1.32E+02 | 7.80E+03 | 59.2 |
| sn92ag | 0.026 | 3.864 | 1.12E+02 | 7.86E+03 | 69.9 |
| sn92P | 0.027 | 3.939 | 1.34E+02 | 7.95E+03 | 59.5 |
| sn00bk | 0.027 | 3.911 | 1.25E+02 | 7.98E+03 | 63.7 |
| sn96C | 0.028 | 3.989 | 1.50E+02 | 8.28E+03 | 55.2 |
| sn98ab | 0.028 | 3.876 | 1.16E+02 | 8.34E+03 | 72.1 |
| sn93ah | 0.029 | 3.933 | 1.32E+02 | 8.58E+03 | 65.1 |
| sn94Q | 0.029 | 3.955 | 1.39E+02 | 8.70E+03 | 62.7 |
| sn97dg | 0.030 | 4.033 | 1.66E+02 | 8.91E+03 | 53.7 |
| sn90O | 0.031 | 3.977 | 1.46E+02 | 9.21E+03 | 63.1 |
| sn97bz | 0.031 | 4.060 | 1.77E+02 | 9.39E+03 | 53.2 |
| sn99cc | 0.032 | 3.983 | 1.48E+02 | 9.48E+03 | 64.1 |
| sn98cs | 0.033 | 3.956 | 1.39E+02 | 9.81E+03 | 70.6 |
| sn91U | 0.033 | 3.938 | 1.33E+02 | 9.93E+03 | 74.4 |
| sn96bl | 0.035 | 4.033 | 1.66E+02 | 1.04E+04 | 62.9 |
| sn94T | 0.036 | 4.014 | 1.59E+02 | 1.08E+04 | 68.0 |
| sn92bg | 0.036 | 4.036 | 1.67E+02 | 1.08E+04 | 64.6 |
| sn00cf | 0.036 | 4.112 | 1.99E+02 | 1.08E+04 | 54.2 |
| sn99ef | 0.038 | 4.147 | 2.16E+02 | 1.14E+04 | 52.8 |
| sn90Y | 0.039 | 3.985 | 1.49E+02 | 1.17E+04 | 78.7 |
| sn90T | 0.040 | 4.101 | 1.94E+02 | 1.20E+04 | 61.8 |
| sn92bl | 0.043 | 4.095 | 1.91E+02 | 1.29E+04 | 67.4 |
| sn97by | 0.045 | 4.084 | 1.87E+02 | 1.35E+04 | 72.3 |
| sn92bh | 0.045 | 4.191 | 2.39E+02 | 1.35E+04 | 56.5 |
| sn92J | 0.046 | 4.099 | 1.93E+02 | 1.38E+04 | 71.4 |
| sn95ac | 0.049 | 4.160 | 2.22E+02 | 1.47E+04 | 66.1 |
| sn93ac | 0.049 | 4.206 | 2.47E+02 | 1.47E+04 | 59.5 |
| sn98dw | 0.049 | 4.208 | 2.48E+02 | 1.47E+04 | 59.2 |
| sn90af | 0.050 | 4.149 | 2.17E+02 | 1.50E+04 | 69.2 |
| sn93ag | 0.050 | 4.209 | 2.49E+02 | 1.50E+04 | 60.3 |
| sn94C | 0.051 | 4.139 | 2.12E+02 | 1.53E+04 | 72.2 |
| sn93O | 0.052 | 4.231 | 2.62E+02 | 1.56E+04 | 59.6 |
| sn95M | 0.053 | 4.243 | 2.69E+02 | 1.59E+04 | 59.1 |
| sn97fb | 0.053 | 4.254 | 2.76E+02 | 1.59E+04 | 57.6 |
| sn98dx | 0.054 | 4.175 | 2.30E+02 | 1.61E+04 | 70.1 |
| sn97fc | 0.054 | 4.230 | 2.61E+02 | 1.62E+04 | 62.0 |
| sn99ao | 0.055 | 4.242 | 2.69E+02 | 1.65E+04 | 61.4 |
| sn91S | 0.056 | 4.283 | 2.95E+02 | 1.68E+04 | 56.9 |
| sn98ea | 0.057 | 4.314 | 3.17E+02 | 1.71E+04 | 53.9 |
| sn92bk | 0.058 | 4.222 | 2.56E+02 | 1.74E+04 | 67.8 |
| sn96ao | 0.058 | 4.240 | 2.67E+02 | 1.74E+04 | 65.1 |
| sn96bx | 0.058 | 4.256 | 2.77E+02 | 1.74E+04 | 62.7 |
| sn98fb | 0.060 | 4.262 | 2.81E+02 | 1.80E+04 | 64.0 |

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|---|---|---|---|---|---|
| sn92au | 0.061 | 4.252 | 2.75E+02 | 1.83E+04 | 66.6 |
| sn97cu | 0.062 | 4.240 | 2.67E+02 | 1.86E+04 | 69.6 |
| sn92bs | 0.063 | 4.327 | 3.27E+02 | 1.89E+04 | 57.9 |
| sn96am | 0.065 | 4.356 | 3.49E+02 | 1.95E+04 | 55.8 |
| sn95ae | 0.068 | 4.315 | 3.18E+02 | 2.04E+04 | 64.2 |
| sn93B | 0.071 | 4.345 | 3.40E+02 | 2.13E+04 | 62.6 |
| sn97dr | 0.075 | 4.296 | 3.04E+02 | 2.25E+04 | 74.0 |
| sn92ae | 0.075 | 4.359 | 3.52E+02 | 2.25E+04 | 64.0 |
| sn92bp | 0.079 | 4.336 | 3.33E+02 | 2.37E+04 | 71.1 |
| sn98cm | 0.080 | 4.398 | 3.85E+02 | 2.40E+04 | 62.4 |
| sn98br | 0.081 | 4.442 | 4.26E+02 | 2.43E+04 | 57.1 |
| sn92br | 0.088 | 4.441 | 4.25E+02 | 2.64E+04 | 62.2 |
| sn94B | 0.090 | 4.507 | 4.94E+02 | 2.70E+04 | 54.6 |
| sn98dz | 0.091 | 4.458 | 4.42E+02 | 2.73E+04 | 61.8 |
| sn98do | 0.092 | 4.462 | 4.46E+02 | 2.76E+04 | 61.9 |
| sn96af | 0.100 | 4.428 | 4.12E+02 | 3.00E+04 | 72.8 |
| sn92aq | 0.101 | 4.513 | 5.01E+02 | 3.03E+04 | 60.4 |
| sn96ab | 0.124 | 4.621 | 6.43E+02 | 3.72E+04 | 57.9 |
| sn96ag | 0.140 | 4.680 | 7.36E+02 | 4.20E+04 | 57.0 |
| sn96R | 0.151 | 4.621 | 6.43E+02 | 4.53E+04 | 70.5 |
| sn98dv | 0.155 | 4.706 | 7.82E+02 | 4.65E+04 | 59.5 |
| sn97cp | 0.160 | 4.792 | 9.53E+02 | 4.80E+04 | 50.4 |
| sn97I | 0.172 | 4.713 | 7.94E+02 | 5.16E+04 | 64.9 |
| sn97N | 0.180 | 4.765 | 8.96E+02 | 5.40E+04 | 60.3 |
| sn97fd | 0.190 | 4.888 | 1.19E+03 | 5.70E+04 | 47.9 |
| sn95ap | 0.230 | 4.893 | 1.20E+03 | 6.90E+04 | 57.4 |
| sn96T | 0.241 | 4.941 | 1.34E+03 | 7.23E+04 | 53.8 |
| sn99fw | 0.278 | 5.007 | 1.56E+03 | 8.34E+04 | 53.3 |
| sn95ao | 0.300 | 4.957 | 1.39E+03 | 9.00E+04 | 64.6 |
| sn96J | 0.300 | 5.010 | 1.57E+03 | 9.00E+04 | 57.2 |
| sn88U | 0.310 | 5.096 | 1.92E+03 | 9.30E+04 | 48.5 |
| sn97ac | 0.320 | 5.051 | 1.73E+03 | 9.60E+04 | 55.5 |
| sn97bj | 0.334 | 5.070 | 1.81E+03 | 1.00E+05 | 55.4 |
| sn94F | 0.354 | 5.155 | 2.20E+03 | 1.06E+05 | 48.3 |
| sn99fh | 0.369 | 5.135 | 2.10E+03 | 1.11E+05 | 52.7 |
| sn94am | 0.372 | 5.131 | 2.08E+03 | 1.12E+05 | 53.7 |
| sn94H | 0.374 | 5.023 | 1.62E+03 | 1.12E+05 | 69.2 |
| sn97O | 0.374 | 5.383 | 3.72E+03 | 1.12E+05 | 30.2 |
| sn94an | 0.378 | 5.195 | 2.41E+03 | 1.13E+05 | 47.0 |
| sn96K | 0.380 | 5.183 | 2.34E+03 | 1.14E+05 | 48.6 |
| sn95ba | 0.388 | 5.209 | 2.49E+03 | 1.16E+05 | 46.8 |
| sn95aw | 0.400 | 5.151 | 2.18E+03 | 1.20E+05 | 55.1 |
| sn97am | 0.416 | 5.193 | 2.40E+03 | 1.25E+05 | 52.0 |
| sn00ea | 0.420 | 5.091 | 1.90E+03 | 1.26E+05 | 66.4 |

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|---|---|---|---|---|---|
| sn94al | 0.420 | 5.189 | 2.38E+03 | 1.26E+05 | 53.0 |
| sn97bh | 0.420 | 5.242 | 2.69E+03 | 1.26E+05 | 46.9 |
| sn94G | 0.425 | 5.105 | 1.96E+03 | 1.28E+05 | 65.1 |
| sn96E | 0.425 | 5.156 | 2.20E+03 | 1.28E+05 | 57.9 |
| sn97Q | 0.430 | 5.193 | 2.40E+03 | 1.29E+05 | 53.8 |
| sn96U | 0.430 | 5.288 | 2.99E+03 | 1.29E+05 | 43.2 |
| sn96cn | 0.430 | 5.305 | 3.11E+03 | 1.29E+05 | 41.5 |
| sn97ce | 0.440 | 5.228 | 2.60E+03 | 1.32E+05 | 50.8 |
| sn97aw | 0.440 | 5.355 | 3.48E+03 | 1.32E+05 | 37.9 |
| sn95az | 0.450 | 5.181 | 2.33E+03 | 1.35E+05 | 57.8 |
| sn97ai | 0.450 | 5.245 | 2.70E+03 | 1.35E+05 | 49.9 |
| sn96cm | 0.450 | 5.313 | 3.16E+03 | 1.35E+05 | 42.7 |
| sn95aq | 0.453 | 5.313 | 3.16E+03 | 1.36E+05 | 43.0 |
| sn99ff | 0.455 | 5.289 | 2.99E+03 | 1.37E+05 | 45.6 |
| sn92bi | 0.458 | 5.301 | 3.08E+03 | 1.37E+05 | 44.7 |
| sn99Q | 0.460 | 5.336 | 3.33E+03 | 1.38E+05 | 41.4 |
| sn95ar | 0.465 | 5.345 | 3.40E+03 | 1.40E+05 | 41.0 |
| sn98ac | 0.467 | 5.260 | 2.80E+03 | 1.40E+05 | 50.0 |
| sn00ec | 0.470 | 5.340 | 3.37E+03 | 1.41E+05 | 41.9 |
| sn00ee | 0.470 | 5.343 | 3.39E+03 | 1.41E+05 | 41.6 |
| sn97P | 0.472 | 5.301 | 3.08E+03 | 1.42E+05 | 46.0 |
| sn99fn | 0.477 | 5.249 | 2.73E+03 | 1.43E+05 | 52.4 |
| sn95K | 0.478 | 5.284 | 2.96E+03 | 1.43E+05 | 48.5 |
| sn95ay | 0.480 | 5.271 | 2.87E+03 | 1.44E+05 | 50.2 |
| sn00eh | 0.490 | 5.224 | 2.58E+03 | 1.47E+05 | 57.0 |
| sn96cg | 0.490 | 5.299 | 3.06E+03 | 1.47E+05 | 48.0 |
| sn96ci | 0.495 | 5.245 | 2.70E+03 | 1.49E+05 | 54.9 |
| sn95as | 0.498 | 5.421 | 4.06E+03 | 1.49E+05 | 36.8 |
| sn99U | 0.500 | 5.321 | 3.22E+03 | 1.50E+05 | 46.6 |
| sn97cj | 0.500 | 5.323 | 3.24E+03 | 1.50E+05 | 46.3 |
| sn00dz | 0.500 | 5.352 | 3.46E+03 | 1.50E+05 | 43.4 |
| sn97as | 0.508 | 5.158 | 2.21E+03 | 1.52E+05 | 68.8 |
| sn97bb | 0.518 | 5.356 | 3.49E+03 | 1.55E+05 | 44.5 |
| sn97H | 0.526 | 5.309 | 3.13E+03 | 1.58E+05 | 50.4 |
| sn00eg | 0.540 | 5.236 | 2.65E+03 | 1.62E+05 | 61.2 |
| sn97L | 0.550 | 5.381 | 3.70E+03 | 1.65E+05 | 44.6 |
| sn96cf | 0.570 | 5.333 | 3.31E+03 | 1.71E+05 | 51.6 |
| sn96I | 0.570 | 5.356 | 3.49E+03 | 1.71E+05 | 49.0 |
| sn97af | 0.579 | 5.375 | 3.65E+03 | 1.74E+05 | 47.6 |
| sn97F | 0.580 | 5.371 | 3.61E+03 | 1.74E+05 | 48.1 |
| sn97aj | 0.581 | 5.297 | 3.05E+03 | 1.74E+05 | 57.2 |
| sn97K | 0.592 | 5.563 | 5.62E+03 | 1.78E+05 | 31.6 |
| sn97S | 0.612 | 5.417 | 4.02E+03 | 1.84E+05 | 45.7 |
| sn95ax | 0.615 | 5.317 | 3.19E+03 | 1.85E+05 | 57.8 |

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|---|---|---|---|---|---|
| sn97J | 0.619 | 5.439 | 4.23E+03 | 1.86E+05 | 43.9 |
| sn96H | 0.620 | 5.397 | 3.84E+03 | 1.86E+05 | 48.5 |
| sn98M | 0.630 | 5.396 | 3.83E+03 | 1.89E+05 | 49.4 |
| sn95at | 0.655 | 5.333 | 3.31E+03 | 1.97E+05 | 59.3 |
| sn96ck | 0.656 | 5.393 | 3.80E+03 | 1.97E+05 | 51.8 |
| sn97R | 0.657 | 5.445 | 4.29E+03 | 1.97E+05 | 46.0 |
| sn97bd | 0.671 | 5.200 | 2.44E+03 | 2.01E+05 | 82.6 |
| sn97G | 0.762 | 5.573 | 5.76E+03 | 2.29E+05 | 39.7 |
| sn99fj | 0.815 | 5.564 | 5.64E+03 | 2.45E+05 | 43.4 |
| sn96cl | 0.827 | 5.609 | 6.25E+03 | 2.48E+05 | 39.7 |
| sn97ap | 0.829 | 5.543 | 5.37E+03 | 2.49E+05 | 46.3 |
| sn98J | 0.833 | 5.615 | 6.34E+03 | 2.50E+05 | 39.4 |
| sn98aj | 0.860 | 5.698 | 7.68E+03 | 2.58E+05 | 33.6 |
| sn98I | 0.887 | 5.575 | 5.78E+03 | 2.66E+05 | 46.0 |
| sn99fm | 0.949 | 5.580 | 5.85E+03 | 2.85E+05 | 48.7 |
| sn97ck | 0.970 | 5.638 | 6.68E+03 | 2.91E+05 | 43.5 |
| sn99fk | 1.056 | 5.659 | 7.02E+03 | 3.17E+05 | 45.2 |
| sn99fv | 1.199 | 5.651 | 6.89E+03 | 3.60E+05 | 52.2 |
| sn97ff | 1.755 | 5.905 | 1.24E+04 | 5.27E+05 | 42.6 |

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