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Simulation of Content-Driven Cosmic Expansion

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Abstract: The standard cosmic expansion model, in which gravity acts to decelerate the expansion, has its problems. This paper explores an alternative model, which has a content-driven mechanism, and in which gravity does not play a role in the overall expansion. Cosmic expansion was simulated with a three-step iterative algorithm, three fundamental parameters, and Planck-scale initial conditions. Model characteristics include self-regulated expansion, causal mechanisms for the Big Bang and Inflation, non-zero and non-fundamental time (t), parametric Ht (the product of t and the Hubble parameter (H)), a dynamic deceleration parameter (q), Ht lagging $(1+q)^{-1}$, and attractors in the q-Ht phase diagram. Simulation results support refinement of the standard model and open the door for similarly exploring and comparing other cosmic expansion models.

Keywords: cosmology, modeling, simulation, complex systems

1 Introduction

Proponents of the most generally accepted cosmic expansion model (the standard model) posit that gravity has acted to decelerate the expansion since the Universe burst forth from a singularity at time zero (Shu 1982). The expansion metric is the scale factor (R), which has units of length. The metric for the deceleration is the dimensionless deceleration parameter ($q \equiv -a \cdot \ddot{a}/\dot{a}^2$, where $a=R/R_{now}$).

The standard model has its issues, including singularity-generated infinities at time zero, its false premise (Gimenez 2009) that gravity plays a role in the overall expansion, and its lack of causal mechanisms for the Big Bang and Inflation. Also, accelerated expansion, as indicated by supernovae observations (Riess et al. 1998, Perlmutter et al. 1999), cannot be found in the standard model. Saul Perlmutter (2003), referring to fine tuning coincidences and the mysterious substances of dark energy and dark matter, writes that it seems likely that we are missing some fundamental physics and one is tempted to speculate that these ingredients are add-ons, like the Ptolemaic epicycles, to preserve an incomplete theory.

This paper explores a content-driven approach to cosmic expansion and argues that indications of current acceleration are in error. An iterative algorithm, which focuses on Mach's Principle, the past lightcone, and an hypothesis that the increasing content on our past lightcone provides the causal mechanism for cosmic expansion, is constructed to numerically simulate cosmic expansion. The Big Bang is simulated at Planck time and Inflation is found in the Matter Era.

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2 The Model and Simulations

2.1 Ansatz

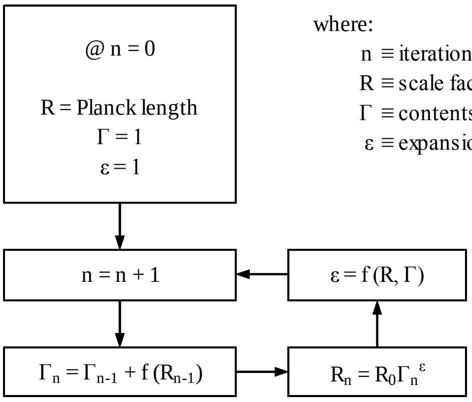
The guiding principles in this effort to simulate cosmic expansion were to keep the algorithm simple and use only assumptions and mechanisms that reflect fundamental realities. This was done in part by using natural c=1 units and adhering to Mach's Principle and Einstein's Locality Principle, which in turn placed the focus on local time and the past lightcone.

Einstein coined the term Mach's Principle (MP) and, although he attempted to incorporate MP into General Relativity (GR), his attempt is believed by some theorists to have failed. This lack of a consensus is due in part to the lack of a widely accepted definition for MP. As used here, MP is a take on Mach's reference to the 'fixed stars': The content on our past lightcone defines our inertial reference frame, and that content is finite and increasing with time.

Einstein wrote 'Space without material object is inconceivable' (Jammer 1953), and Gottfried Leibniz before him wrote 'Where there is no matter, there is no space' (Harrison 2000). With MP and the past lightcone in mind, this space-content connection is extrapolated into an hypothesis that cosmic expansion is connected to the increasing amount of content (Γ) on our past lightcone, yielding $R=R_0\cdot\Gamma^{\varepsilon}$, where ε is an expansion exponent.

2.2 Algorithm.

The algorithm for content-driven expansion (figure 1) is iterative and discreet and does not require Nature to understand complex math or perform massive computations. Time (t), which was neither in the iterative loop nor one of the three fundamental parameters, was progressed using $\Delta t=R/c$, where R is the cosmic scale factor and c is the speed of light.



where:

$n \equiv$ iteration number

$R \equiv$ scale factor

$\Gamma \equiv$ contents factor

$\varepsilon \equiv$ expansion exponent

Nonfundamental calculations

$t_n = t_{n-1} + R_n/c$

$H_n = \dot{R}_n/R_n = \dot{a}_n/a_n$

$q_n = -a_n\cdot\ddot{a}_n/\dot{a}_n^2$

where:

$t \equiv$ cosmic time

$H \equiv$ Hubble parameter

$q \equiv$ deceleration parameter

$a \equiv R/R_{now}$

Figure 1. Iterative expansion algorithm. The three fundamental parameters (R, Γ, and ε) are in the three-step iterative loop. With R_0 set to Planck length, t_0=Planck time, $\dot{R}_0=c$, $H_0=1/t_0$, $Ht_0=1$, $\ddot{a}_0=0$, and $q_0=0$.

2.3 Progressing time with $\Delta t=R/c$

R/c is the time for light to traverse the distance R. With R_{now}=~20Mly, Δt_{now} (today's tick of the clock) is ~20My ($\Delta t=R/c$). Midway through the development of the simulation, $\Delta t=R/c$ was replaced when a more supportable method was found in $\Delta t=\Delta R/R/H$, which follows from $H\equiv\dot{R}/R$. Surprisingly, replacing $\Delta t=R/c$ with $\Delta t=\Delta R/R/H$ had no impact on the simulation, and the simpler $\Delta t=R/c$ was reinstated.

For an object with velocity (v), relavistic $\Delta t=R\cdot(1-(v/c)^2)^{0.5}/c$ would be more accurate. If v for the Solar System were 630km·s^{-1} (Jones 2004) relative to the microwave background radiation, using the relavistic Δt in place of $\Delta t=R/c$ would not have significantly altered the simulation's results.

2.4 Expansion exponent

To calculate ε, the local ε (ε_{local}) was first progressed from 1 to infinity using:

$\varepsilon_{local}(R)=10\text{^}((\ln(R/R_0))^3/(17000+(\ln(R/R_0))^{2.95})$

A content-allocated average of past values of ε_{local} was then calculated using:

$\varepsilon_n=(\varepsilon_{n-1}\cdot\Gamma_{n-1}+\varepsilon_{local})/\Gamma_n$

2.5 Asymptotic q_∞ *and* Ht_∞

Theory-connected asymptotic q_∞ and Ht_∞ were in sync with GR (figure 2). At radiation-dominated Planck time, $q_\infty=1$ and $Ht_\infty=½$. For matter-dominated expansion, $q_\infty=½$ and $Ht_\infty=⅔$. In the distant future, q_∞ approached 0 and Ht_∞ approached 1 (vacuum-dominated).

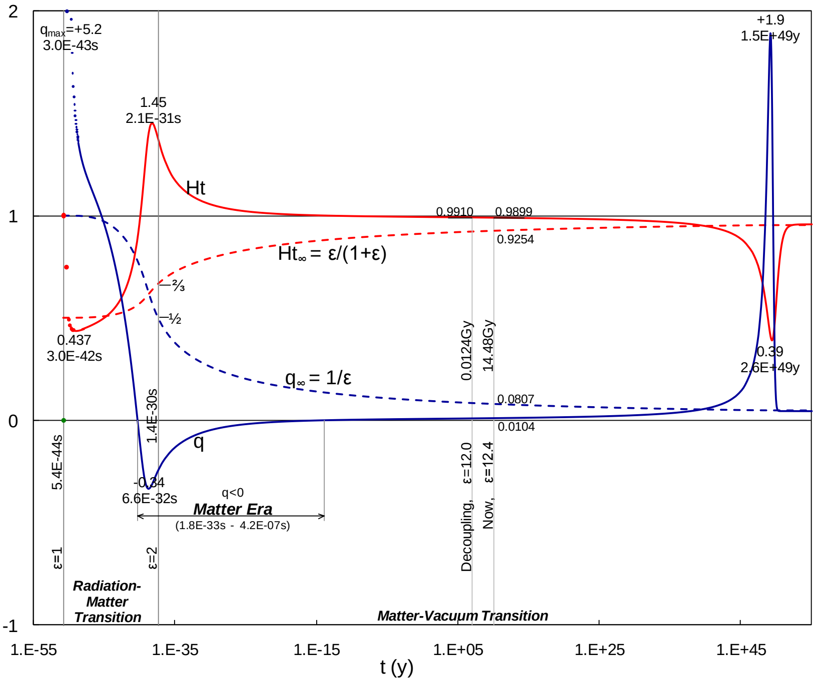


Figure 2. q(t), Ht(t), $q_\infty(t)$, and $Ht_\infty(t)$. Negative q defines the Matter Era. ε=2 delineates the Radiation-Matter Transition and Matter-Vacuum Transition.

2.6 Dynamic q and Ht

Distinct from theory-connected q_∞ and Ht_∞, q and Ht projected a dynamic expansion (figure 2). From the non-zero Planck-scale beginning of time, q cycles from 0 to more than 5 to –0.34 to +1.9 and back to 0, and Ht cycles from 1 to 0.437 to 1.45 to 0.39 and back to 1. In all cases, Ht_{max} lagged q_{min} and Ht_{min} lagged q_{max}. In contrast to past and future expansion, in the current epoch – defined here as the time since Decoupling at redshift z=1090.88 (Hinshaw et al. 2009) – the expansion was effectively ‘coasting’ with q=~0 and Ht=~1.

2.7 Inflation, the Matter Era, and era transitions

The Matter Era was initially defined as beginning with $Ht_\infty=0.583$ (midway between 1/2 and 2/3) and ending with $Ht_\infty=0.833$ (midway between 2/3 and 1). When a definitive time was found for $\varepsilon=2$ (associated with the Matter Era’s $Ht_\infty=2/3$), a line of demarcation between the Radiation-Matter Transition and the Matter-Vacuum Transition was established, and the three eras were abandoned. Later came the finding that when q was negative, Ht_∞ rose from 0.562 to 0.881 – roughly the same values previously used to define the Matter Era. Linking the Matter Era to Inflation, the three eras were reinstated.

2.8 Time of Decoupling

The simulation found the time of Decoupling (t_D) to be 12.4My by setting redshift (z) to zero at $t_{now}=14.48$Gy and using $z_D=1090.88$ (Hinshaw et al. 2009) and $z_D+1=R_{now}/R_D$, where z_D and R_D are the redshift and scale factor at Decoupling. 12.4My is in relative agreement with a coasting model’s $t_D=13$My (Gimenez 2009). The current literature typically places $t_D=0.377$My (Hinshaw et al. 2009), which appears to be based on $z_D+1=(t_{now}/t_D)^{Ht}$, $t_{now}=13.72$Gy, and Ht=2/3. Hinshaw’s $H_{now}=70.5\mathrm{km}\cdot\mathrm{s}^{-1}\cdot\mathrm{Mpc}^{-1}$ (1/13.87Gy) and $t_{now}=13.72$Gy, however, produce $Ht_{now}=0.9892$, which is inconsistent with Ht=2/3.

2.9 q-Ht phase diagram

Dynamic q-Ht fluctuations appeared in the q-Ht phase diagram (figure 3) as large lobes that roughly took on the shape of the attractor rail – a line of attractors that q-Ht would gravitate to if ε were constant. Paralleling the finding that Ht_{max} lagged q_{min} and Ht_{min} lagged q_{max}, with the q-Ht trace orbiting clockwise around a moving attractor on the attractor rail, Ht lagged $(1+q)^{-1}$. Four exceptions to the Ht-Lag rule occurred when Lag=0.

Lag was found to be $\beta\cdot t^2\cdot d^2Ht/dt^2$, with Lag_{now} and Lag_D near zero and virtually unchanged (0.000177 versus 0.000165), $t^2\cdot d^2Ht/dt^2$ changed only modestly (0.00042 versus 0.00036), and $\beta_{now}=0.421$ and $\beta_D=0.458$. As evidenced by the large lobes in the Radiation and Vacuum eras, early-Radiation and late-Vacuum Lag is more dynamic.

2.10 Age of the Universe

The Simon-Verde-Jimenez (SVJ) data points (Simon et al. 2005) were used to establish the age of the Universe (t_{now}). While $t_{now}=13.72$Gy (Hinshaw et al. 2009) is more widely accepted, $t_{now}=14.48$Gy is a better fit with the SVJ data points (figure 4). $1/H_{now}=14.63$Gy (from $t_{now}=14.48$Gy and $Ht_{now}=0.9899$) is within the literature’s range of 13.4Gy (Riess et al. 2005) to 15.7Gy (Sandage et al. 2006). As with calculating t_D, z was calculated here using $z=R_{now}/R-1$.

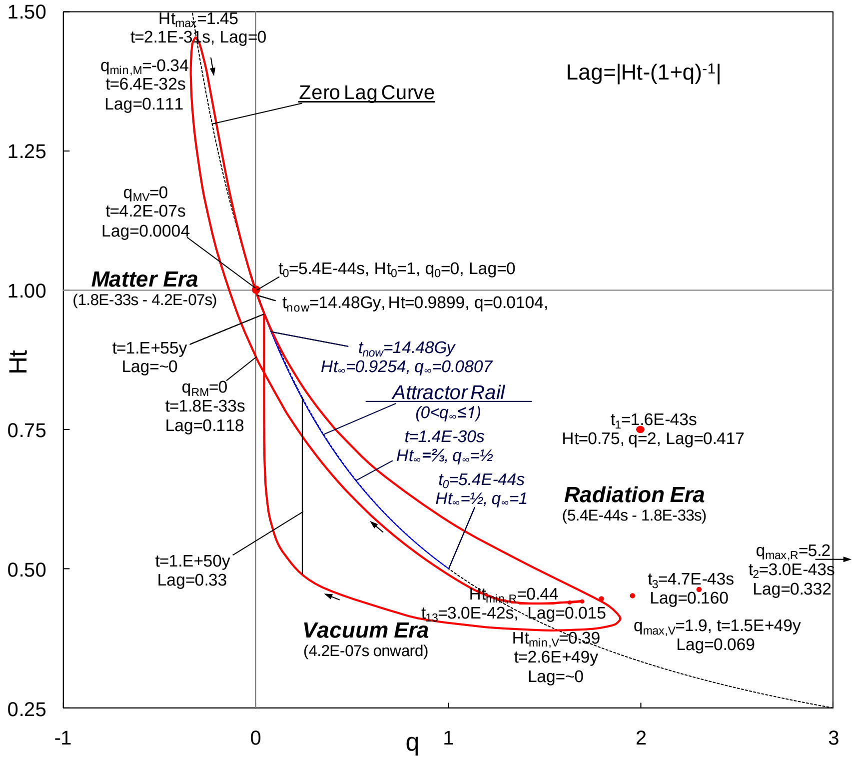
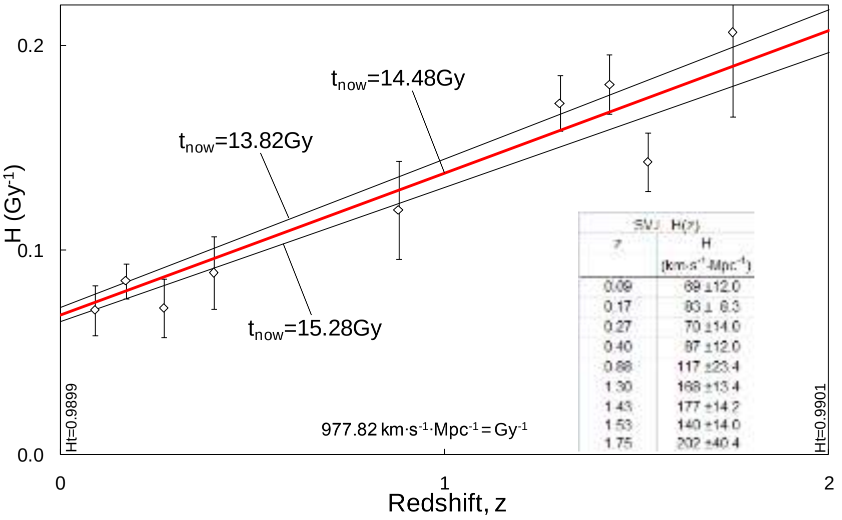


Figure 3. q-Ht phase diagram.

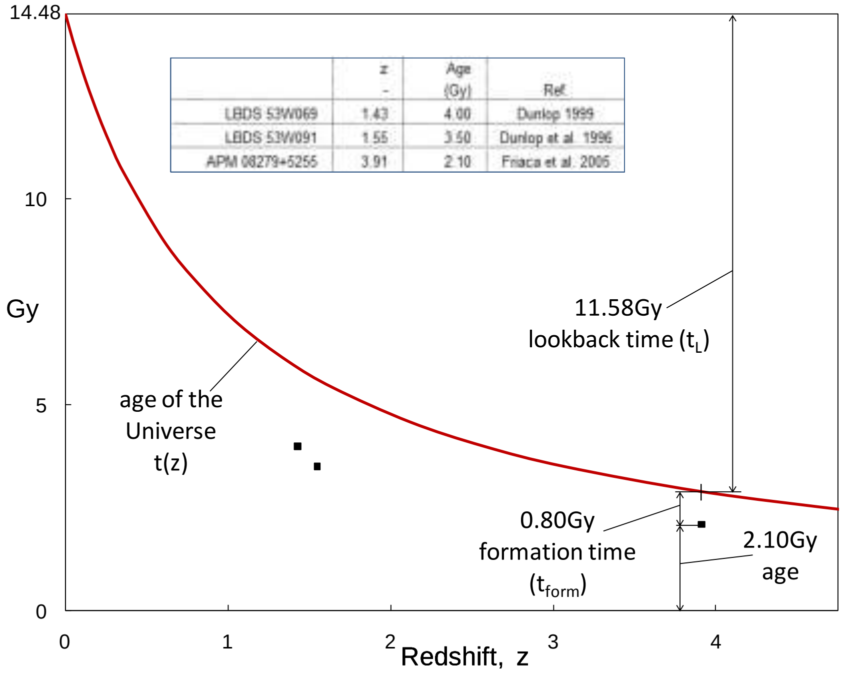


SVJ	H(z)
z	H ($km\cdot s^{-1}\cdot Mpc^{-1}$)
0.09	69 ±12.0
0.17	83 ± 8.3
0.27	70 ±14.0
0.40	87 ±12.0
0.88	117 ±23.4
1.30	168 ±13.4
1.43	177 ±14.2
1.53	140 ±14.0
1.75	202 ±40.4

Figure 4. H(z) for high-z radiogalaxy SVJ data points with σ=1 error bars and curves for t_{now} of 13.82Gy, 14.48Gy, and 15.28Gy.

2.11 Age-Redshift Test

The simulation passes the age-redshift test (figure 5) with a 0.80Gy formation time (t_{form}) for the worst case APM 08279+5255 at z=3.91. For t_{now}=13.7Gy, t_{form}=0.66Gy.



	z -	Age (Gy)	Ref.
LBDS 53W069	1.43	4.00	Dunlop 1999
LBDS 53W091	1.55	3.50	Dunlop et al. 1996
APM 08279+5255	3.91	2.10	Friaca et al. 2005

Figure 5. t(z) with age(z) for three old celestial objects.

2.12 t_L, t, t_{now}, z, and H

During work on figure 5, the following relationships were uncovered between time (t), current age of the Universe (t_{now}), Hubble parameter (H), and redshift (z) and between lookback time (t_L), current age of the Universe (t_{now}), and the Hubble parameter (H), time (t), and redshift (z).

$$(t/t_{now})^{Ht} = 1/(1+z)$$

$$(t_L/t_{now})^{Ht} = z/(1+z)$$

A search of the literature has not found anything resembling these two equations.

3 Discussions

3.1 No current acceleration

This effort to numerically simulate cosmic expansion began with the belief that any indication of a current accelerated expansion ($q_{now}<0$) was in error. The Cosmos was not expanding out of control, and a Big Rip was not forecast. We believed in self-regulating expansion. Not too surprisingly, we found just that.

The results of this simulation indicate that q_{now}=+0.0104. If current evidence of a negative q_{now} were to be confirmed, the results of this simulation would be refuted. It is highly doubtful, however, that q_{now} is negative, since the best estimates for H_{now} and t_{now} place Ht_{now}=0.9892 (Hinshaw et al. 2009). If Lag_{now}=~0 (as indicated by this simulation) and $Ht_{now}=(1+q_{now})^{-1}$, Ht_{now}=0.9892 would force q_{now} positive and a negative q_{now} would force Ht_{now} greater than one. If, instead, Hinshaw's Ht_{now}=0.9892 were coupled with q_{now}=–0.6 (Shapiro et al. 2005) and $Lag=|Ht-(1+q)^{-1}|$, Lag would be greater than 1.5, which would be indicative of an implausibly wild dynamic that was not seen in this simulation (Lag never exceeded 0.011 in the current epoch).

3.2 Refining values for H, t, q, t_{now}, z, and t_L

Errors in observational data – especially evident in deriving distances – have been the bane of astronomy since before the time of Hubble. The SVJ data points (figure 4) demonstrate the significance of the error and how underestimated that error typically is. As seen in section 3.1, with Lag_{now}=~0 in the current epoch (z=0 to z=1091), $Ht=(1+q)^{-1}$ can be used to good approximation to refine values for H, t, and q. Similarly, $(t/t_{now})^{Ht} = 1/(1+z)$ and $(t_L/t_{now})^{Ht} = z/(1+z)$ can be used to refine values for t, t_{now}, H, z, and t_L.

3.3 Unexpected findings

Aside from the above-mentioned bias towards a self-regulated expansion, the findings of this paper did not come from prescient expectations or deliberate attempts to address specific issues. The findings came from the computer-generated output of the simulation, where dynamic q and Ht – distinct from theory-connected q_∞ and Ht_∞ – emerged. From these findings came answers to some significant questions that confront science today.

3.4 Inflation

Perhaps first amongst these questions concern Inflation. During the simulation's initial development, with an unchanging ε, there was no Inflation. Allowing ε to increase with time created a dynamic q that turned negative (Inflation) in the Matter Era. The mechanism for both Inflation and the demise of Inflation was found in an ever-increasing ε. Helping to further explain the dynamics of Inflation, a book-balancing deflationary Ht trough and peak q occur in the Vacuum Era. One clear indicator that Inflation did occur is that Ht_{now}>0.93 – without Inflation, Ht_{now} would be less than Ht_∞ (0.93).

3.5 The inflaton

Particle physics has no place for the inflaton and this simulation has no need for it. Simplicity dictates that the inflaton does not exist.

3.6 Before Planck time

When cosmologists attempt to extrapolate cosmic expansion back to a time before Planck time, they see physics breaking down and singularities developing. Both quantum mechanics (QM) and the results of this simulation would say that there is no time before Planck time. Given our QM-based Ansatz (R_0=Planck length and t_0=Planck time), the simulation's consistency with QM is more input than output.

3.7 Nonfundamental time

This simulation does not treat time as a fundamental parameter. Like the t_0 consistency with QM discussed above, the nonfundamental nature of time is more input than output. The robustness of the simulation's results without a fundamental time, however, attests to the nonfundamental stature of time.

3.8 Entropy and the arrow of time

The low-to-high direction for both entropy and time would imply a connection. $\Delta t=R/c$ says that the tick of the cosmic clock is proportional to R. Given that R and c are both positive, $\Delta t=R/c$ does not allow for the reversibility of time. Entropy, in contrast, while generally having the same unidirectional nature as time, is related to information and thus Γ. The connection between entropy and the arrow of time is thus the connection between Γ and R.

4 Conclusions

Using a content-driven iterative algorithm that had three fundamental parameters and a three-step iterative loop, complexity arose from simplicity. The algorithm generated a forward-progressing, multifaceted representation of cosmic expansion that is self-consistent, concordant with observation, and consistent with SR, QM, and GR.

Dynamic q and Ht emerge, a book-balancing payback for Inflation is found late in the Vacuum Era, a causal mechanism is found for the Big Bang and Inflation, and a discrete and self-regulated expansion is seen. The expansion's discreteness resonates with black-hole thermodynamics, string theory, and spin networks. The expansion's emerging complexity and self-regulation hint at self-organization.

With the model's unmatched simplicity, depth and breadth of findings, and resolution of cosmological issues, the simulation of content-driven expansion supports refinement of the standard model and opens the door for exploring and comparing other cosmic expansion models.

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