Flash5 and Adventures with the Cosmological Friedmann Equation

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What is the Friedmann Equation?

- Describes universe expansion in Einstein's General Relativity
- Derived in 1922 by Alexander Friedmann
- Assumes universe has a given uniform density and pressure
- A standard assumption in theoretical cosmology today

Know Your Speaker (R. J. Nemiroff)

- Involved in APOD
  - http://apod.nasa.gov/
  - Basis of talk tomorrow at SCAM
- Involved in the Night Sky Live project
  - http://NightSkyLive.net/
- Created popular web site on what it looks like to go near a black hole
  - http://antwrp.gsfc.nasa.gov/htmltest/rjn_bht.html
  - Based on American Journal of Physics article

Know Your Speaker (R. J. Nemiroff)

- Recent refereed papers:
  - Software design for panoramic astronomical pipeline processing (MNRAS 2006)
  - All-Sky Relative Opacity Mapping Using Nighttime Panoramic Images (PASP 2005)
  - Can a Gravitational Lens Magnify Gravity? A Possible Solar System Test (ApJ 2005)
  - PHOTZIP: A Lossy FITS Image Compression Algorithm That Protects User-defined Levels of Photometric Integrity (AJ 2005)
- Other possibly notable papers:
  - Limits on the cosmological abundance of supermassive compact objects from a millilensing search in gamma-ray burst data (PRL 2001)
  - Finite source sizes and the information content of macho-type lens search light curves (ApJ 1994)

This is a “Test” Talk

- I have never spoken about this topic before
- I am writing a paper on the topic and testing out the ideas here today
- Constructive criticism is solicited
- In the event of a real talk you will be properly instructed

Plain Vanilla Friedmann Equation

$$H^2 = \frac{8\pi G}{3}\rho + \frac{\Lambda}{3} - \frac{k}{R^2},$$

- Most common form found in books
- H: Hubble parameter (km/sec/Mpc)
  - Will change with redshift z
- G: Gravitational constant
  - Will NOT change with redshift z
- ρ: form of energy
  - Can be mass, radiation, etc.
- Λ: form of energy ("cosmological constant")
- k: curvature (0 = flat will be typical)
- R: Scale factor of the universe
  - think: average distance between galaxies

H: Hubble Parameter

- Present value of H: Hubble constant
  - $H(z=0) = H_o \sim 70$ km/sec/Mpc
- $H = (da/dt)(1/a)$
  - $a = R/Ro$ = dimensionless scale factor of the universe
- Therefore, H tells how fast the universe is expanding

Generalizing the Friedmann Equation

- Write density in every possible way explicitly:

$$\rho = \rho_0 + \frac{\rho_1}{a} + \frac{\rho_2}{a^2} + \ldots,$$

- Unsubscripted density ρ evolves with a
- Subscripted densities ρ_n fixed at a=1

Generalizing the Friedmann Equation

- Define critical density:

$$\rho_c = 3H^2/(8\pi G)$$

- Define all density in terms of the present value of this critical density:

$$\Omega = \frac{8\pi G\rho}{3H_o^2} = \frac{8\pi G\rho_0}{3H_o^2 a^0} + \frac{8\pi G\rho_1}{3H_o^2 a^1} + \frac{8\pi G\rho_2}{3H_o^2 a^3} + \ldots,$$

Generalizing the Friedmann Equation

- Friedmann Equation becomes:

$$(H/H_o)^2 = \sum_{-\infty}^{\infty} \Omega_n \, (a)^{-n}.$$

- Define a = 1/(1+z). Then

$$(H/H_o)^2 = \sum_{-\infty}^{\infty} \Omega_n \, (1+z)^{n}.$$

General Friedmann Equation is …

$$
\begin{aligned}
(H/H_o)^2 \sim & \quad \Omega_{\text{phantom energy}}\,(1+z)^{<0} + \Omega_{\text{dark energy}}\,(1+z)^{0} + \Omega_{\text{domain walls}}\,(1+z)^{1} \\
+ & \quad \Omega_{\text{cosmic strings}}\,(1+z)^{2} + \Omega_{\text{matter}}\,(1+z)^{3} + \Omega_{\text{radiation}}\,(1+z)^{4} + \Omega_{\text{flash}}\,(1+z)^{>4} \\
+ & \quad (\Omega_{\text{total}} - 1)\,(1+z)^{2}.
\end{aligned}
$$

n<0: Phantom Energy

- n<0 & w < -1
- Energy grows as the universe expands
- Universe will end in a Big Rip
- Might violate GR energy conditions
- Might create "cascading universes" if phantom energy decays
- Formal Friedmann solution when dominates:

$$a = \left[\frac{1}{1-(-n/2)t}\right]^{2/(-n)} .$$

What is w?

- w is the Equation of State of the universe
- w = pressure / density = P/ρ
- $n = 3(1+w)$ for perfect fluid universes

What is pressure?

- Gravitational pressure P in GR has no Newtonian analog
- Acts sort of like density but can go negative (w < 0) and hence make gravity repulsive
- In weak field GR limit:

$$\nabla^2\phi = 4\pi G(\rho + 3P/c^2),$$

n=0: Cosmological Constant

- Dark energy form where n=0 & w=-1
- Keeps constant as universe evolves
- First postulated by Einstein to keep universe from collapsing
- Might be related to vacuum energy fluctuations of some quantum field
- Formal Friedmann solution when dominates:

$$a = k\ e^{\Omega_0^{1/2}\ t},$$

n=1: Domain Walls

- Dark energy where n=1 & w = -2/3
- Gravitationally repulsive (near field)
- Dilutes geometrically as universe expands
- Possibly sheets of trapped “cosmological constant” energy
- Domain “Balls” would act as normal n=3 matter
- Formal Friedmann solution when dominates:

$$a = \left(\frac{n}{2}\right)^{2/n} \Omega_n^{1/n} \ t^{2/n}.$$

n=2: Cosmic Strings

- Dark energy where n=2 & w=-1/3
- Gravitationally neutral (near field)
- Dilutes geometrically as universe expands
- Possibly strings of trapped “cosmological constant” energy
- Small loops would act as normal n=3 matter
- Formal Friedmann solution when dominates:

$$a = \left(\frac{n}{2}\right)^{2/n} \Omega_n^{1/n} t^{2/n}.$$

n=3: Normal matter

- Familiar energy type with n=3 & w=0
- Not dark energy but could be dark matter
- No pressure: familiar $F=GMm/r^2$ gravitational attraction
- Dilutes geometrically as universe expands
- Could be type of confined exotic matter
- Used to dominate universe a few billion years ago
- Formal Friedmann solution when dominates:

$$a = \left(\frac{n}{2}\right)^{2/n} \Omega_n^{1/n} t^{2/n}.$$

n=4: Radiation

- Familiar energy type with n=4 & w=1/3
- Not dark energy and not dark matter
- Positive pressure: very attractive gravitationally
- Dilutes geometrically as universe expands
- Dilutes energetically as universe expands
- Once dominated the universe
- Formal Friedmann solution when dominates:

$$a = \left(\frac{n}{2}\right)^{2/n} \Omega_n^{1/n} \, t^{2/n}.$$

n>4: Flash

- Never before postulated energy type with n>4 & w>1/3
- Flash5 would have n=5, w=2/3
- Flash5 dilutes geometrically [by 3 factors of (1+z)] and energetically [by 2 factors of (1+z)] as the universe expands
- Might have once dominated the universe but now diluted below detection
- Formal Friedmann solution when dominates:

$$a = \left(\frac{n}{2}\right)^{2/n} \ \Omega_n^{1/n} \ t^{2/n}.$$

n=4 radiation can become n=3 matter

- Any moving n=3 matter will appear to slow as the universe expands
- Any relativistically moving n=3 matter acts cosmologically like n=4 radiation
- For relativisticly moving n=3 matter, this cosmological “slowing” gives the extra (1+z) energy dilution of radiation
- No matter has n=3 exactly: our Galaxy has n = 3 – (2×10^{-6}), for example
- Does any radiation have n=4 exactly?
  - No: future of all n=4 radiation is n=3 matter

What is flash?

- Is it excluded by any theoretical arguments?
- Could one form be misclassified as some type of radiation presently?
- Could sound waves in the early universe act like flash?
- Could extra spatial dimensions (like those postulated in string theory) make normal matter into flash?

History of the Universe in terms of n transitions

- n tends toward integers
  - An "Integer Energy Conjecture"
  - Why? Geometry only?
- n tends to 3 as the universe expands
  - An "Energy Entropy Conjecture"
  - Why? Statistical grounds only?

History of the universe in terms of n transitions

- In early universe n=0 dominated (inflation) and then decayed into primarily n=4 energy
- Later n=4 energy diluted faster than n=3 energy so that n=3 energy dominated
- Small n=0 term remained that did not dilute and now dominates the universe, causing an accelerated expansion
- Is dark energy stable?
- Are there any small n<0 terms that are growing?
- Was there ever a flash epoch of the universe?

Educational References

- Book: “Cosmological Physics” by Peacock
- Online Living Review: “The Cosmological Constant” by Carroll