

How (Not) to Give a Talk

Prof. Eric Gawiser

Rutgers University

Department of Physics & Astronomy

Be organized

- Make sure your talk flows logically
- Start with an outline (or conclusions!), then introduction, method, results, conclusions
- Remind audience visually and/or orally when you move on to the next phase
- Give each slide a punchline in title or footer
- Leave conclusions slide up during questions

Use phrases instead of complete sentences

- The nice thing about using phrases is that people can read them much faster and then concentrate on what you're saying rather than trying to process both audio and visual information at the same time.
- If you just read out the full sentences you wrote on the slide word for word that makes it easy to process the information, but it gets boring quickly.
- Seriously, phrases help

Keep text in a readable size font (preferably Sans-Serif, not yellow, and with a simple slide background)

- It's critical that everyone, especially those in the back of the room, can read what you put on the board
- Small fonts are pointless since they would only be needed if your slide has too much text anyhow
- This is 12pt, I always use **at least 20pt** except for references down to 16pt
- If you can read this, you don't need glasses
- All work and no play makes Jack a dull cosmologist
- All work and no play makes Jack a dull astronomer
- All work and no play makes Jack a dull physicist
- All work and no play makes Jack a dull astrophysicist
- All work and no play makes Jack a dull cosmetologist
- All work and no play makes Jack a dull observer
- All work and no play makes Jack a dull theorist
- All work and no play makes Jack a dull simulator
- All work and no play makes Jack a dull experimentalist
- All work and no play makes Jack a dull telescope operator
- All work and no play makes Jack a dull department chair
- All work and no play makes Jack a dull observatory director
- All work and no play makes Sir Martin a dull Astronomer Royal

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Leave slide onscreen long enough to be read

- Even if there is not a lot of text and figures, rushing through it helps nobody

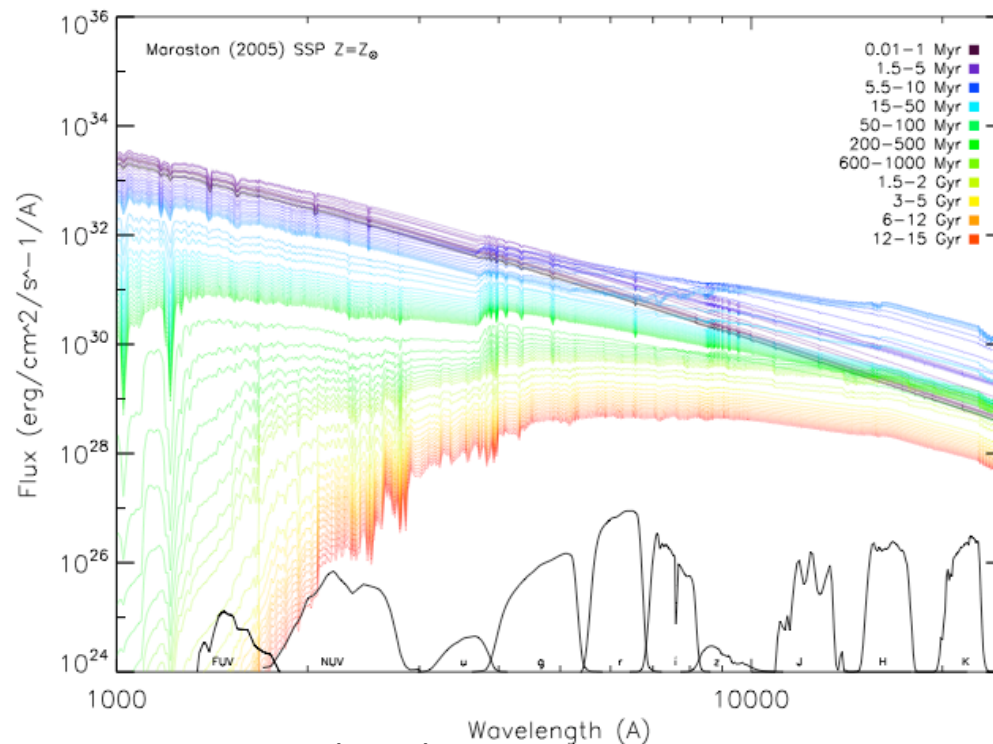
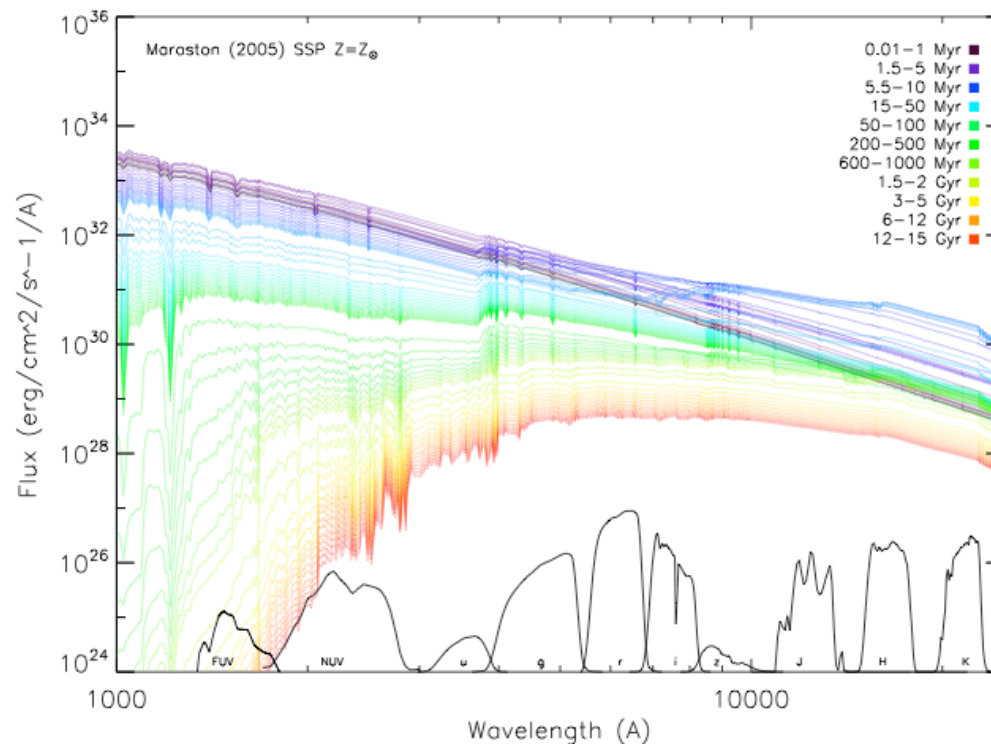


figure by Kevin Schawinski (Yale)

Be sure to reference general research ideas and specific figures

(see handout on "Effective Oral Presentations" by JL Consulting, and the figure below)



Use 1 (or at most 2 related) figure(s) per slide

Time Dependence of Scale Factor, Hubble Parameter and Energy Density for Six Cosmological Models

Jean P. Walker¹, Amruta Deshpande¹

Rutgers University
Department of Physics and Astronomy
136 Frelinghuysen Rd.
Piscataway, NJ 08854

jwalker@physics.rutgers.edu, amrejd@physics.rutgers.edu

ABSTRACT

As part of the first assignment, this document explores the time evolution of various properties of the universe, as determined by six different models of the universe. The properties examined include scale factor, energy density, and the Hubble's constant. We also look at the age and fate of the universe as suggested by each model. These models differ in the attributes that they assign the universe like curvature, presence or absence of dark energy, and the behaviour of dark energy in time. The Einstein-de Sitter model is a flat matter dominated universe, with no dark energy. The next two models also have no dark energy, but one is a closed universe, while the other is an open universe. We test the Λ CDM model along with models where the dark energy equation of state has parameter w on either side of -1 . Radiation energy density is not included in these models and we briefly investigate how including radiation would alter the universe.

1. Introduction

The main goal of cosmology has been to calculate the time evolution of the expansion of the universe in the form of the scale factor. The derivation that follows comes from Dodelson (2003) and derives the first Friedmann equation in flat space. General Relativity determines the time dependence of the scale factor and the energy density by using the Einstein equations:

$$G_{\mu\nu} \equiv R_{\mu\nu} - \frac{g_{\mu\nu}R}{2} = 8\pi GT_{\mu\nu} \quad (1)$$

¹Rutgers University

Fig. 1.— Scale factor evolution with time in all six models

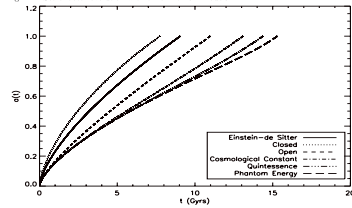


Fig. 2.— Total energy density evolution with time in all six models

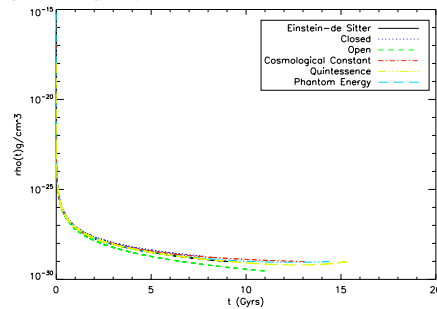


Fig. 3.— Hubble constant evolution with time in all models

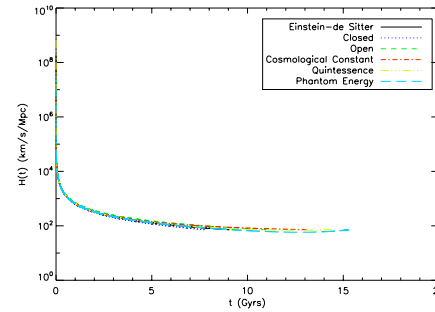
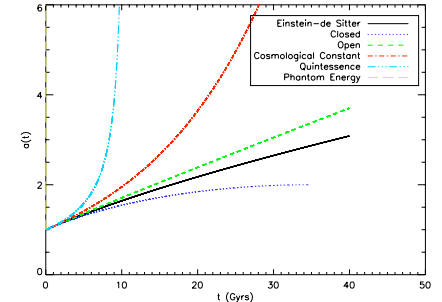


Fig. 4.— The future of the six models



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$$R_{\mu\nu} = \Gamma_{\mu,\alpha}^{\alpha} \Gamma_{\nu,\beta}^{\beta} - \Gamma_{\mu,\alpha}^{\alpha} \Gamma_{\nu,\beta}^{\beta} + \Gamma_{\mu,\alpha}^{\alpha} \Gamma_{\nu,\beta}^{\beta} - \Gamma_{\mu,\alpha}^{\alpha} \Gamma_{\nu,\beta}^{\beta} \quad (2)$$

$$R = g^{\mu\nu} R_{\mu\nu} \quad (3)$$

The metric utilized was the Friedmann-Robertson-Walker (FRW) metric and an energy-momentum metric for a perfect isotropic fluid.

$$g_{\mu\nu} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & a^2(t) & 0 & 0 \\ 0 & 0 & a^2(t) & 0 \\ 0 & 0 & 0 & a^2(t) \end{pmatrix}, \quad T_{\mu\nu}^{\nu} = \begin{pmatrix} -\rho & 0 & 0 & 0 \\ 0 & P & 0 & 0 \\ 0 & 0 & P & 0 \\ 0 & 0 & 0 & P \end{pmatrix} \quad (4)$$

Considering the time-time component we then have the second and fourth term surviving in the Ricci tensor $R_{\mu\nu} = R_{00} = -\Gamma_{0,\alpha}^{\alpha} \Gamma_{0,\beta}^{\beta} = -3\frac{\dot{a}}{a}$ and the space-space component is $R_{ij} = \delta_{ij} [2\dot{a}^2 + a\ddot{a}]$. The Ricci scalar is

$$R = g^{\mu\nu} R_{\mu\nu} \quad (5)$$

$$= -R_{00} + \frac{R_{ij}}{a^2} \quad (6)$$

$$= 6 \left[\frac{\dot{a}}{a} + \left(\frac{\dot{a}}{a} \right)^2 \right] \quad (7)$$

Finally, combining the elements together we attain the first Friedmann equation for flat space:

$$R_{00} - \frac{g_{00}R}{2} = \frac{8\pi G T_{00}}{2} \quad (8)$$

$$\left(\frac{\dot{a}}{a} \right)^2 = \frac{8\pi G}{3} \rho \quad (9)$$

When the equation is generalized to any space, we then have (H_0 is the Hubble parameter at present time):

$$\left(\frac{\dot{a}(t)}{a(t)} \right)^2 = \frac{8\pi G}{3} \left[\rho(t) - \frac{K}{a^2(t)} \right] \quad (10)$$

$$K = -(\rho - \rho_c), \quad \rho_c = \frac{3H_0^2}{8\pi G} \quad (11)$$

The second equation that describes the time dependence of the energy density is derived from the vanishing covariant derivative of the energy-momentum tensor $\nu = 0$ component.

$$T_{0\nu}^{\nu} \equiv \frac{\partial T_{0\nu}^{\nu}}{\partial x^{\nu}} + \Gamma_{0\nu}^{\alpha} T_{\alpha}^{\nu} - \Gamma_{0\nu}^{\alpha} T_{\alpha}^{\nu} = 0 \quad (12)$$

$$\frac{\partial \rho}{\partial t} + \frac{\dot{a}}{a} [3\rho + 3P] = 0 \quad (13)$$

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2. Methodology

We created a numerical solver which used Runge-Kutta method, with a timestep of 3×10^4 years, to plot the time dependence of $a(t)$, $H(t)$ and $\rho(t)$ from equations (10) and (13). The values for $H_0 = 2.3 \times 10^{-18} \text{ s}^{-1}$ and $\rho_c = 9.8 \times 10^{-30} \text{ gcm}^{-3}$. In our solver $t = 0$ represents present-day, and $t > 0$ represents the past. Our plots however start with $t = 0$ as the Big Bang and $t > 0$ continues to present-day. The components of the energy density and present day values are:

$$\rho_m(t) = \frac{\Omega_m \rho_c}{a^3(t)}, \quad \rho_{m,0} = \Omega_m \rho_c$$

$$\rho_{\Lambda,0} = \Omega_{\Lambda} \rho_c$$

The dark energy density at each time step is determined from (13) where $\rho = \rho_{\Lambda}(t)$ and $P = w\rho_{\Lambda}(t)$. We did not include an energy density for radiation in our code. Equation (10) then determines the time dependence of $a(t)$. Our initial conditions for $a(t)$ and $\rho(t)$ are:

$$a(0) = 1, \quad \dot{a}(0) = -H_0$$

$$\rho_{\Lambda}(0) = \Omega_{\Lambda} \rho_c, \quad \dot{\rho}(0) = 3H_0 \Omega_{\Lambda} \rho_c [1 + w].$$

3. Results and Discussion

We've plotted $a(t)$, $\rho(t)$, and $H(t)$ for each of the models in figures 1, 2 and 3 in the appendix. The time range in each plot is the age of the universe, and is tabulated below for each model.

Table 1: Age of Universe According to Each Model (Gyrs)

Einstein-de Sitter	Closed	Open	Λ CDM	Quintessence	Phantom Energy
9.1	7.8	11	13	14	15

The Einstein-de Sitter model age is 2σ away and the closed universe age is 2.5σ away from the measured age of globular clusters (13 ± 2 Gyrs). Their deviation significantly suggests that the universe is neither closed nor flat and matter dominated. The phantom energy model gives an age that is 1σ away from the globular cluster age. And the rest of the models predict ages that are within one standard deviation. The quintessence and phantom energy models are definitely consistent with the age of globular clusters, while the open universe and Λ CDM models could be consistent within statistical uncertainty.

In calculating the ages, and all the plots, ρ_c , the energy density of radiation was excluded. The effect of including this quantity in $\rho(t)$ is to increase the age of the universe. This

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quantity dominates the early universe, and causes the the scale factor to vary as $a(t) \propto t^{1/2}$ lengthening the time, as is shown on page 3 of Dodelson (2003). Including radiation would make the models more consistent with the age of globular clusters.

What should happen in the future? We propagated our code forward in time, setting $t=0$ at present-day (Figure 4). It seems that the universe will expand forever in the Einstein-de Sitter, and the open universe models. At $a = 2$, according to the closed universe model, the scale factor stops changing. But we're not sure how to propagate the code beyond this value of a since the Hubble parameter becomes imaginary for higher values of a . Λ CDM exhibits inflation, and the remaining two dark energy models accelerate much faster, and seem to approach a vertical line (the big rip). The phantom energy model exhibits an extremely accelerated increase in scale factor (almost discontinuously).

If we chose a different value of the scale factor for today, then we would essentially find rescaled plots exhibiting the same trends. In order to have some absolute, or scaled measurement of the scale factor, we'd have to have distances for the same 2 objects in the past, and now, which we cannot do. Either this or we need an analogy of the SN1 standard candle for distances (standard rulers).

Using $1/H$ as an estimate of the age of the universe is apparently already getting problematic. In our plots, as time approaches present day, H has a very shallow slope. This indicates that the estimate form H could be considerably far away from the actual age of the universe for large times. In the phantom energy model the same value of H would give 2 different estimates for the age of the universe since H has a local minimum near present day.

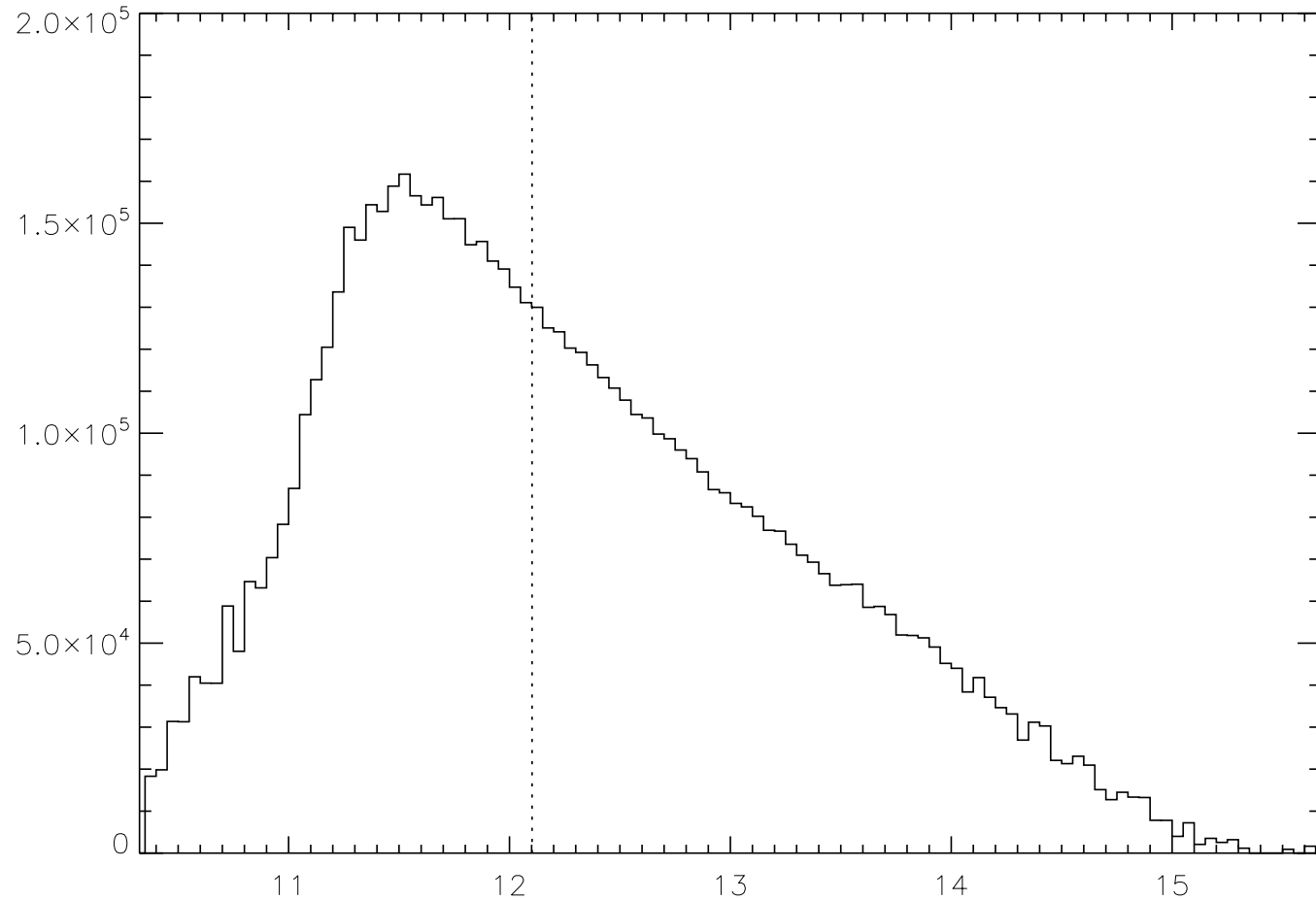
REFERENCES

Dodelson, S. 2003, Modern Cosmology, ed. J. Hayhurst (Elsevier)

This preprint was prepared with the AAS L^AT_EX macros v5.2.

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Make sure figures have readable lines
and that axes are explained



Deliver your message clearly

- Speak loudly without shouting
- Speak slowly and vary your pitch and rhythm
- Silence is golden! Use it instead of "um" or "uh". A second's pause feels like forever to the speaker but actually helps get the attention of the audience.
- Practice your talk, but don't let it ***sound*** memorized

Present yourself with confidence

- The speaker is in charge!
- Dress appropriately – avoid distractions
- Avoid pacing/rocking/dancing – move only during transitions
- Don't attack anything (or anyone) with the pointer

With technology, "trust but verify"

- Practice with a new projector by setting up early enough to trouble-shoot
- Use a body mike if offered unless there's feedback
- Use a remote for extra-smooth presentations
- Don't overdo it with too much fancy Powerpoint

Summary

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