How (Not) to Give a Tlak

Eric Gawiser

P&A 346, Spring 2021

Know the audience

- Know what level of background information you need to give
- Use only the jargon they are comfortable with
- Backwards faded scaffolding
- Use consistent language
- Define and then speak out acronyms (like SOA)

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
- Have an appropriate number of slides (1-2 minutes per slide)
- 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

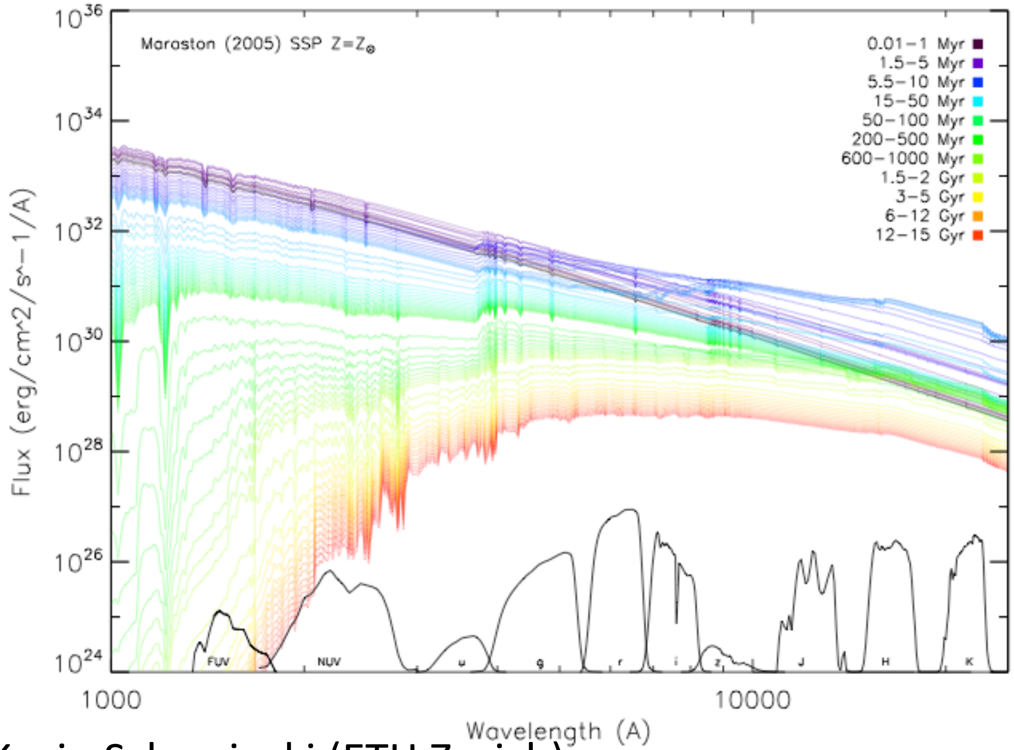
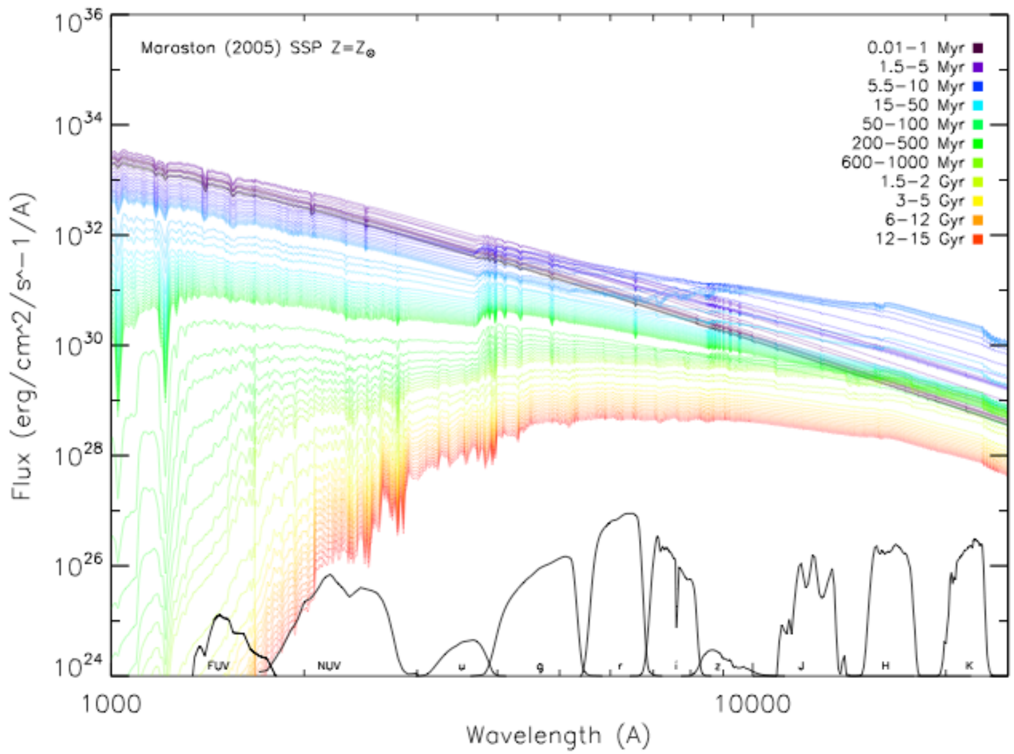


figure by Kevin Schawinski (ETH Zurich)

Be sure to reference general research ideas and specific figures

(see 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

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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 unvierse, 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 ΛCDM 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:

$$G_{\mu\nu} \equiv R_{\mu\nu} - \frac{g_{\mu\nu}R}{2} = 8\pi G T_{\mu\nu} \tag{1}$$

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$$R_{\mu\nu} = \Gamma^{\alpha}_{\mu\nu,\alpha} - \Gamma^{\alpha}_{\mu\alpha,\nu} + \Gamma^{\alpha}_{\beta\alpha}\Gamma^{\beta}_{\mu\nu} - \Gamma^{\alpha}_{\beta\nu}\Gamma^{\beta}_{\mu\alpha} \tag{2}$$

$$R = g^{\mu\nu}R_{\mu\nu}. \tag{3}$$

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

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

Considering the time-time component we then have the second and fourth term surviving in the Ricci tensor $R_{\mu\nu} = R_{00} = -\Gamma^{i}_{0i,0} - \Gamma^{i}_{j0}\Gamma^{j}_{0i} = -3\frac{\ddot{a}}{a}$ and the space-space component is $R_{ij} = \delta_{ij}\left[2\dot{a}^2 + a\ddot{a}\right]$. The Ricci scalar is

$$\begin{aligned} R &\equiv g^{\mu\nu}R_{\mu\nu} & (5)\\ &= -R_{00} + \frac{R_{ii}}{a^2} & (6)\\ &= 6\left[\frac{\ddot{a}}{a} + \left(\frac{\dot{a}}{a}\right)^2\right]. & (7) \end{aligned}$$

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

$$\begin{aligned} R_{00} - \frac{g_{00}R}{2} &= 8\pi G T_{00} & (8)\\ \left(\frac{\dot{a}}{a}\right)^2 &= \frac{8\pi G}{3}\rho & (9) \end{aligned}$$

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

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

$$K = -(\rho_c - \rho_0) \quad , \quad \rho_c = \frac{3H_0^2}{8\pi G}. \tag{11}$$

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

$$T^{\mu}_{0;\mu} \equiv \frac{\partial T^{\mu}_{0}}{\partial x^{\mu}} + \Gamma^{\mu}_{\alpha\mu}T^{\alpha}_{0} - \Gamma^{\alpha}_{0\mu}T^{\mu}_{\alpha} = 0 \tag{12}$$

$$\frac{\partial\rho}{\partial t} + \frac{\dot{a}}{a}\left[3\rho + 3P\right] = 0 \tag{13}$$

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 $H_0 = 2.3 \times 10^{-18}$ s^{-1} and $\rho_c = 9.8 \times 10^{-30}$ 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 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 $\rho \rightarrow \rho_\Lambda(t)$ 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:

$$a(0) = 1 \qquad \dot{a}(0) = -H_0$$
$$\rho_\Lambda(0) = \Omega_\Lambda\rho_c \quad \dot{\rho}(0) = 3H_0\Omega_\Lambda\rho_c\left[1 + w\right].$$

3. Results and Disccussion

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	ΛCDM	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 $\pm$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 ΛCDM models could be consistent within statistical uncertainty.

In calculating the ages, and all the plots, ρ_r, the energy density of radiation was excluded. The effect of including this quantity in $\rho(t)$ is to increase the age of the unvierse. This 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. ΛCDM 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 exibiting 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 unvierse 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 LaTeX macros v5.2.

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

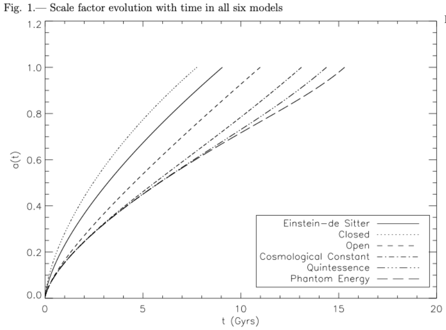


Fig. 2.— Total energy density evolution with time in all six models

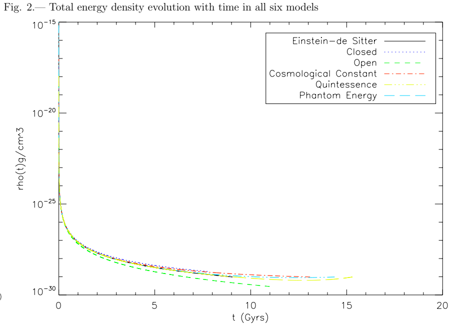


Fig. 3.— Hubble constant evolution with time in all models

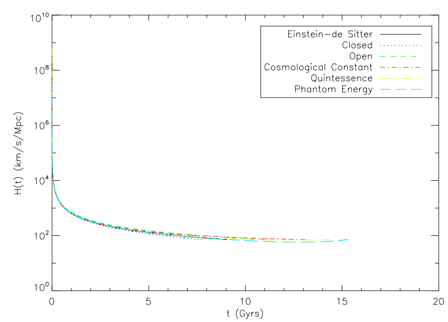
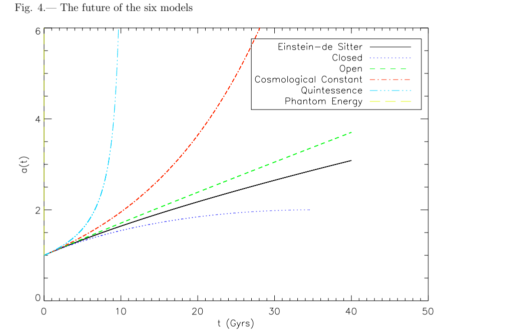
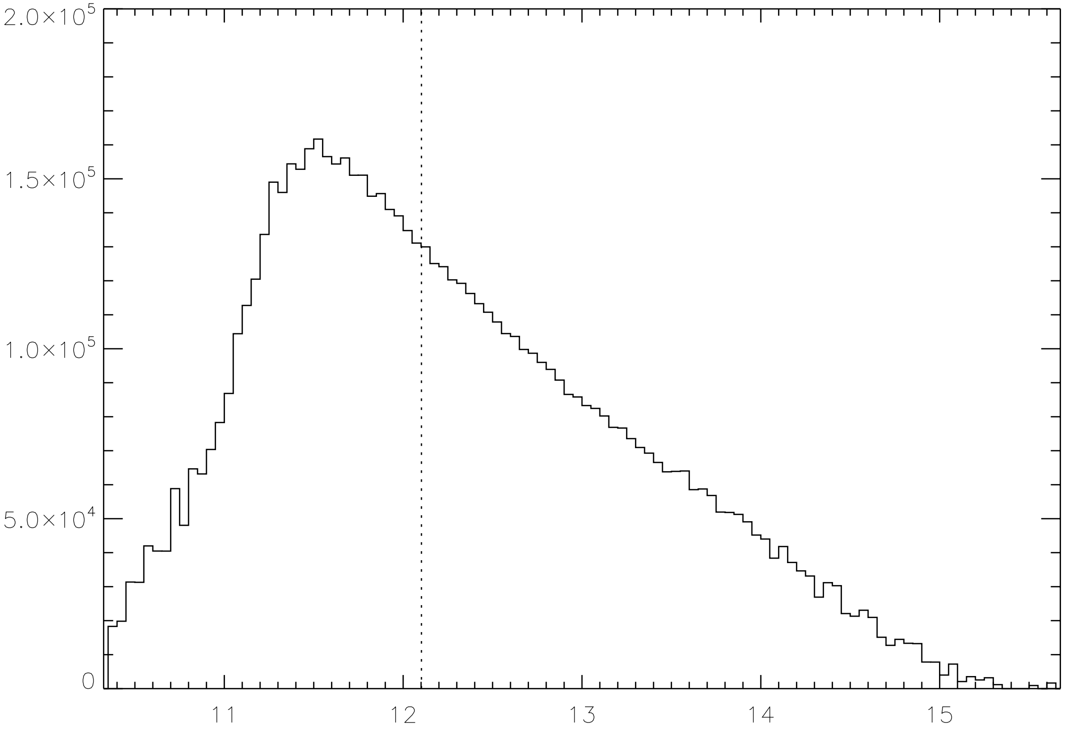


Fig. 4.— The future of the six models



Format figures carefully

- Use thick lines on plots
- Use distinctly different colors or different types of lines
- Always explain the axes!



State the main point of each figure in a "punchline" like this.

Deliver your message clearly

- Make eye contact
- Practice your talk, but don't let it ***sound*** memorized
- Knowing the slide transitions makes the talk more polished
- 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.

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 mic if offered unless there's feedback
- Use a remote for extra-smooth presentations
- Adding new media format in middle of talk is good, but make sure it works
- Don't overdo it with too much fancy Powerpoint

Summary

- Know the audience (and SOA)
- Be organized
- Use phrases instead of complete sentences
- Keep text in a readable font size & color with simple background
- Leave slide onscreen long enough to be read
- Reference research ideas, results, and figures
- Use 1 (or at most 2 related) figure(s) per slide, with "punchlines"
- Format figures carefully
- Deliver your message clearly
- Present yourself with confidence
- With technology, "trust but verify"