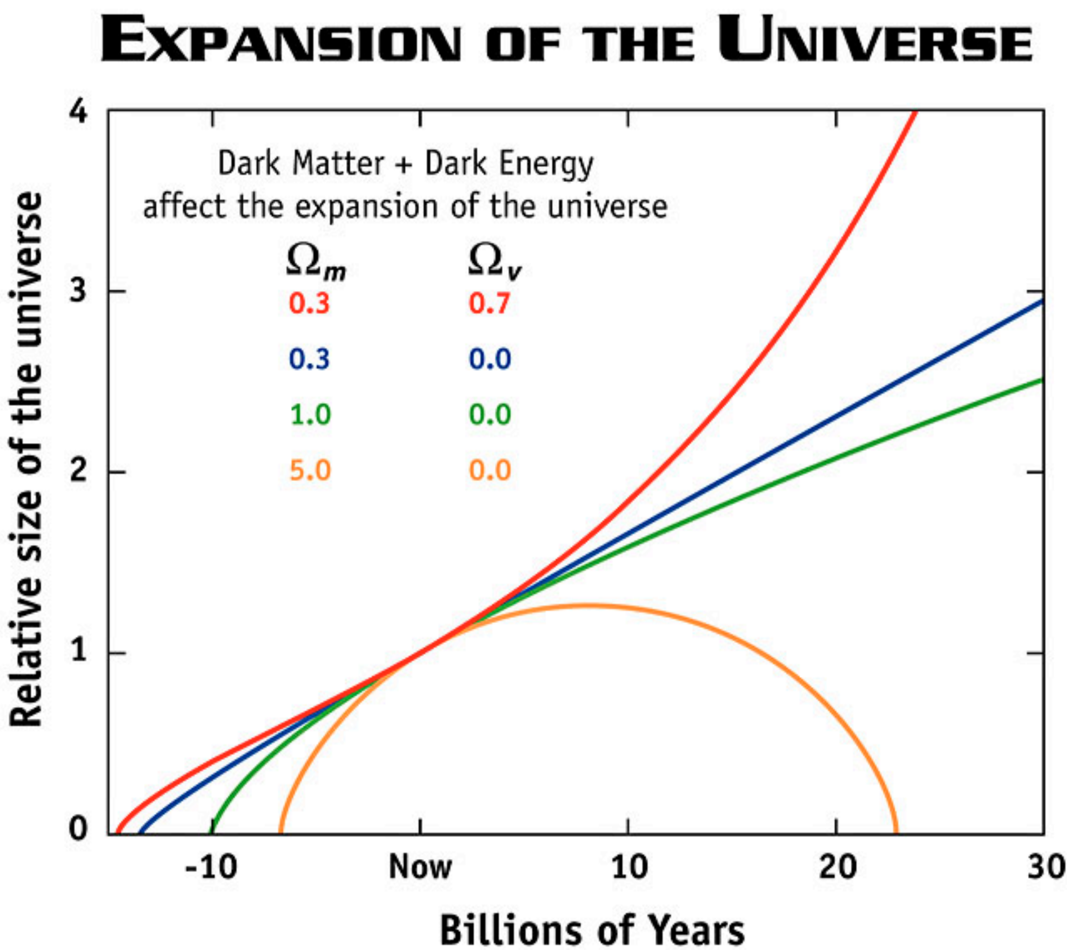
How My Students Determined the Fate of the Universe

One Way to Overcome the Math Barrier with Non-STEM



Steve Cederbloom
University of Mount Union

Outline

- The challenge
- A framework for meeting the challenge
- My solution
- New explorations

The challenge

- A course for the "Integrative Core" – "Einstein's Universe: The Big Bang, Black Holes, and Beyond"
- Cosmology is an *observational* science, not an *experimental* science
- How do I get students to DO cosmology?

Authentic science practice in the classroom (Edelson, 1997)

- Attitudes
- **<u>Tools and techniques</u>**
- Social interactions

Why is Inquiry Inherently Difficult?

- "The Getting on Board Problem" (Meyer and Avery, 2010)
  - Observations generate the need to describe, organize, and explain
  - The resulting paradigm suggests new observations to make

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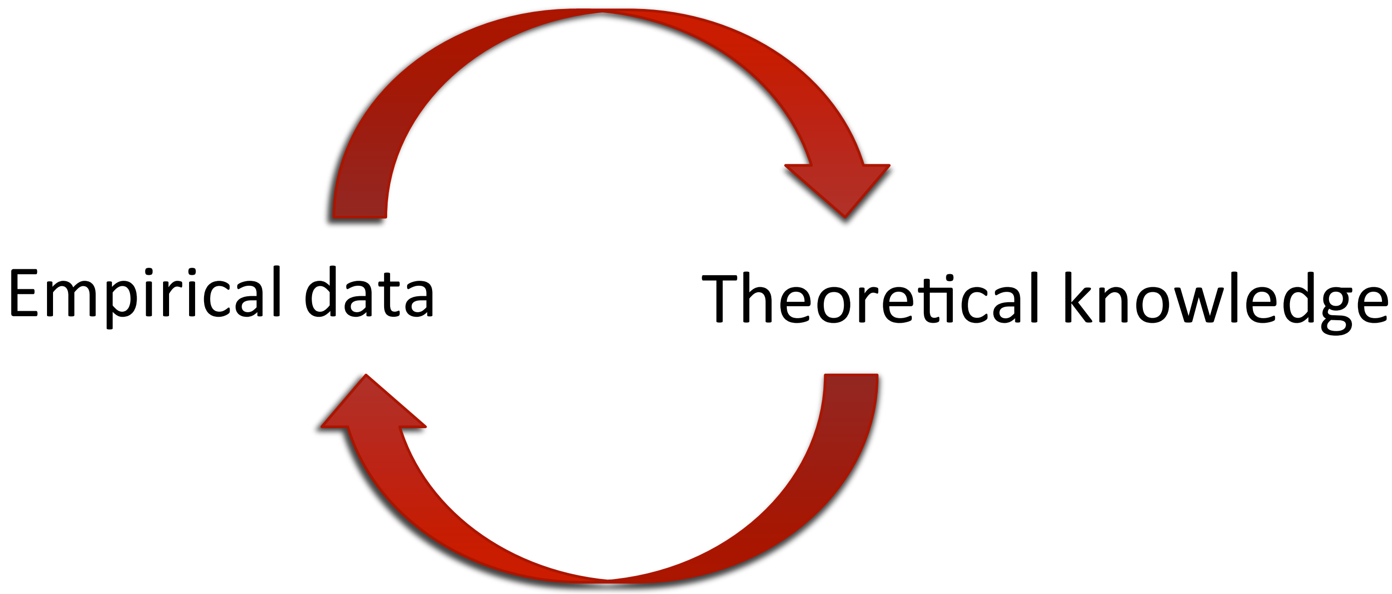


Why is Inquiry Inherently Difficult?

- “The Getting on Board Problem” (Meyer and Avery, 2010)
  - Observations generate the need to describe, organize, and explain
  - The resulting paradigm suggests new observations to make
- How do you break into this cycle?
  - New Ph.D students start by joining ongoing work of mentors

A framework for meeting the challenge

- Choose a topic for the students to explore
  - The expansion of the universe
- Choose the tools to use
  - Euler's method
  - Excel
- Backwards design - scaffolding

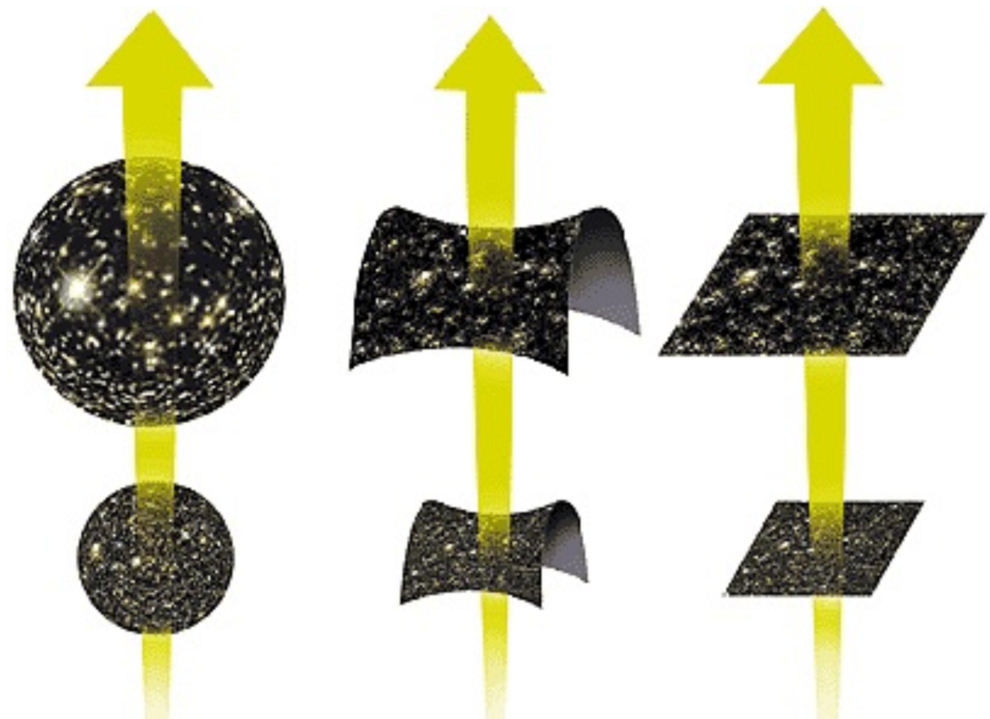
Scaffolding

- Making a graph
  - Using only data at first
  - Using equations also
- Equations in Excel
  - Cell addresses
  - Copy and drag
  - Setting up constants
- Trendlines and slopes

The topic

The universe is expanding

The curvature is linked to its history & destiny



The “scale factor” of the Universe, ***R***, is governed by the Friedmann equation:

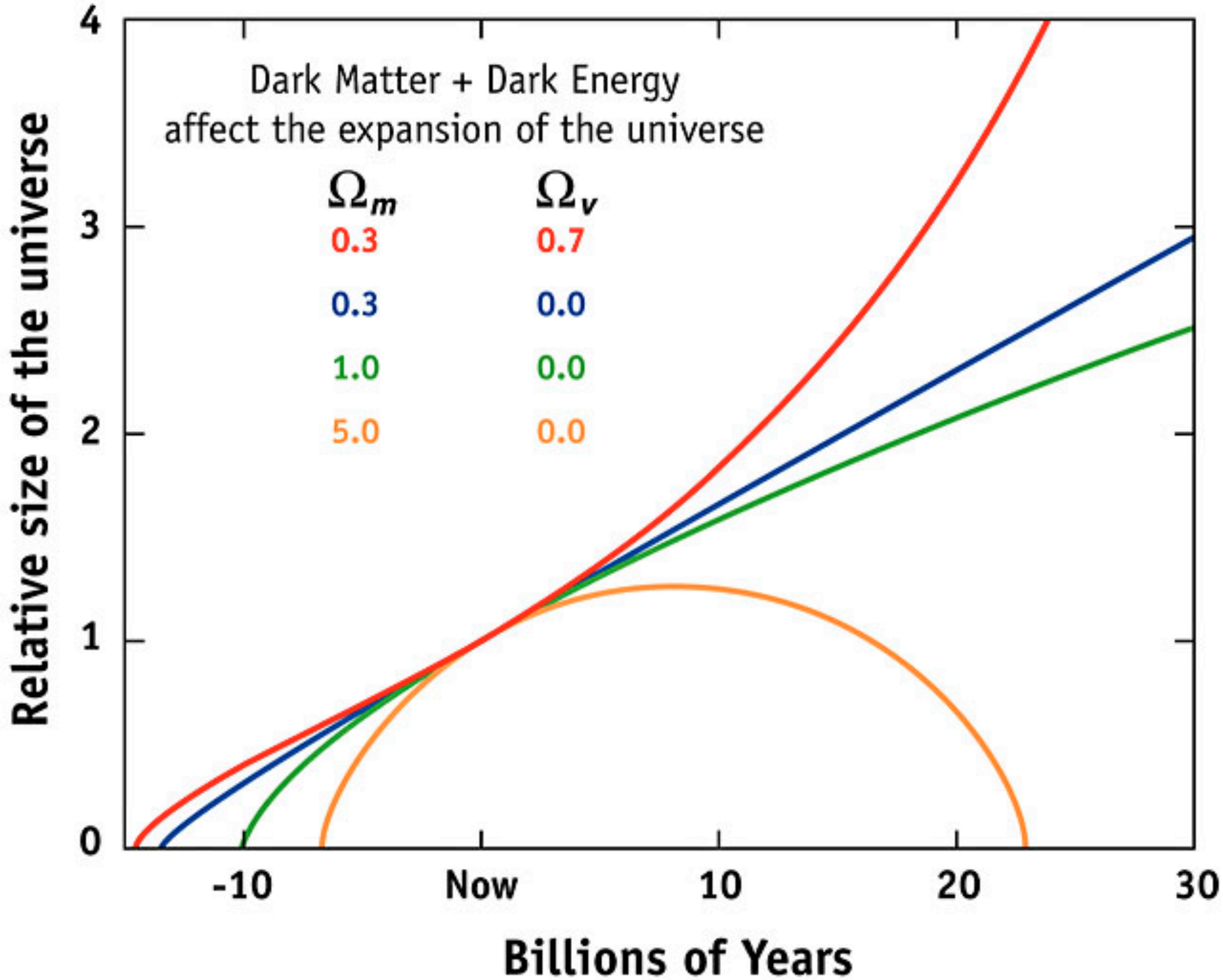
$$\left(\frac{1}{R}\frac{dR}{dt}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{R^2} + \frac{\Lambda}{3}$$

$$\rho = mass\ density\ of\ Universe$$
$$k = curvature\ constant$$
$$\Lambda = cosmological\ constant$$

Solutions tell us the possible history of the Universe

- Depend on amounts of matter, radiation, dark matter, & dark energy

Expansion of the Universe



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ρ changes according to conservation laws

Start with *V* and change to slope:

$$\left(\frac{1}{R}V\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{R^2} + \frac{\Lambda}{3}$$

$$\left(\frac{1}{R}\frac{\Delta R}{\Delta t}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{R^2} + \frac{\Lambda}{3}$$

Euler's method

$$\frac{\Delta R}{\Delta t} = \frac{R_2 - R_1}{t_2 - t_1}$$

$$R_2 = R_1 + \frac{\Delta R}{\Delta t}\left(t_2 - t_1\right)$$

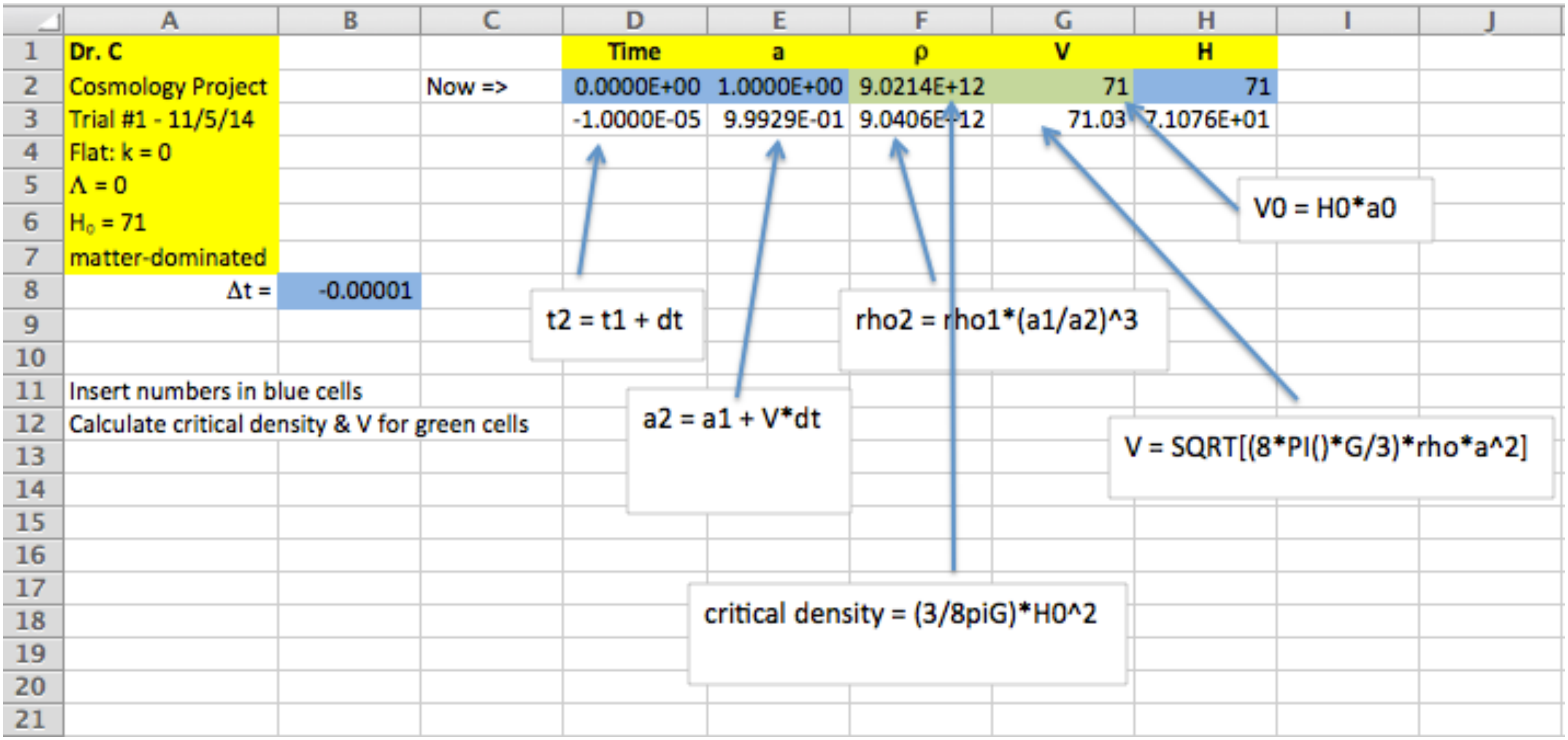
Start with "Now"

	A	B	C	D	E	F	G	H
1	**Dr. C**			**Time**	**R**	**ρ**	**V**	**H**
2	Cosmology Project		Now =>	**0.0000E+00**	**1.0000E+00**	9.0214E+12	71	**71**
3	Trial #1 - 11/5/14							
4	Flat: k = 0							
5	Λ = 0							
6	H_0 = 71							
7	matter-dominated							

critical density = (3/8πG)*H0^2

V0 = H0*R0

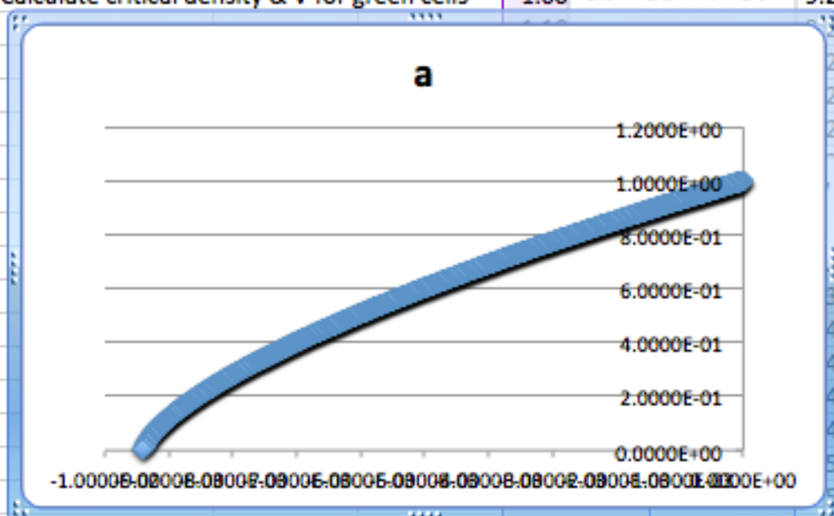
Type in equations for one time step



	A	B	C	D	E	F	G	H	I	J
1	**Dr. C**			**Time**	**a**	**ρ**	**V**	**H**		
2	Cosmology Project		Now =>	0.0000E+00	1.0000E+00	9.0214E+12	71	71		
3	Trial #1 - 11/5/14			-1.0000E-05	9.9929E-01	9.0406E+12	71.03	7.1076E+01		
4	Flat: k = 0									
5	Λ = 0									
6	H_0 = 71									
7	matter-dominated									
8	Δt =	-0.00001								
9										
10										
11	Insert numbers in blue cells									
12	Calculate critical density & V for green cells									
13										
14										
15										
16										
17										
18										
19										
20										
21										

The past

	A	B	C	D	E	F	G	H
1	Dr. C			Time	a	ρ	V	H
2	Cosmology Project		Now =>	0.0000E+00	1.0000E+00	9.0214E+12	71	71
3	Trial #1 - 11/5/14			-1.0000E-05	9.9929E-01	9.0406E+12	71.03	7.1076E+01
4	Flat: k = 0			-2.0000E-05	[illegible]	[illegible]	71.05	7.1152E+01
5	Λ = 0			-3.0000E-05	9.9787E-01	9.0793E+12	71.08	[illegible]
6	H_0 = 71			-4.0000E-05	9.9716E-01	9.0987E+12	71.10	[illegible]
7	matter-dominated			-5.0000E-05	9.9645E-01	9.1182E+12	71.13	7.1380E+01
8	Δt =	-0.00001		[illegible]	9.9574E-01	[illegible]	[illegible]	7.1457E+01
9				[illegible]	9.9502E-01	[illegible]	[illegible]	[illegible]
10				[illegible]	9.9431E-01	[illegible]	[illegible]	[illegible]
11	Insert numbers in blue cells			[illegible]	[illegible]	9.1968E+12	71.23	7.1687E+01
12	Calculate critical density & V for green cells			[illegible]	[illegible]	9.2166E+12	[illegible]	[illegible]
13				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15				[illegible]	[illegible]	[illegible]	71.33	7.1997E+01
16				[illegible]	[illegible]	[illegible]	71.36	7.2074E+01
17				[illegible]	[illegible]	[illegible]	[illegible]	7.2152E+01
18				[illegible]	[illegible]	[illegible]	[illegible]	7.2231E+01
19				[illegible]	[illegible]	[illegible]	[illegible]	7.2309E+01
20				[illegible]	[illegible]	[illegible]	[illegible]	7.2387E+01
21				[illegible]	[illegible]	[illegible]	71.49	7.2466E+01
22				[illegible]	[illegible]	[illegible]	71.51	7.2545E+01
23				[illegible]	[illegible]	[illegible]	71.54	7.2624E+01
24				[illegible]	[illegible]	[illegible]	71.56	7.2703E+01
25				[illegible]	[illegible]	[illegible]	71.59	7.2782E+01
26				[illegible]	[illegible]	[illegible]	71.62	7.2862E+01
27				[illegible]	[illegible]	[illegible]	71.64	7.2942E+01
28				-2.6000E-04	9.8146E-01	9.5424E+12	71.67	7.3022E+01



t2 = t1 + dt

a2 = a1 + V*dt

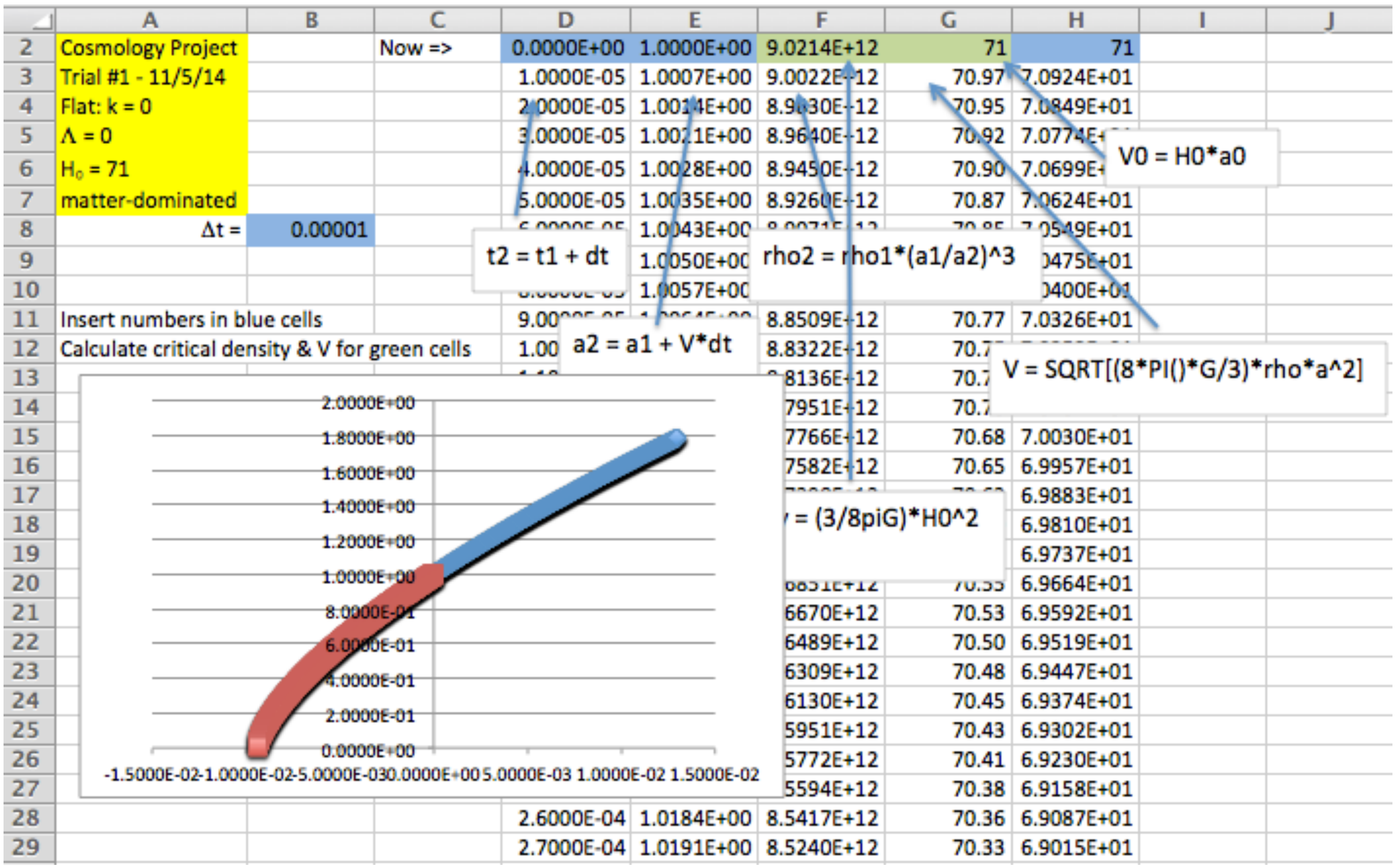
rho2 = rho1*(a1/a2)^3

V0 = H0*a0

V = SQRT[(8*PI()*G/3)*rho*a^2]

= (3/8piG)*H0^2

The future and the past

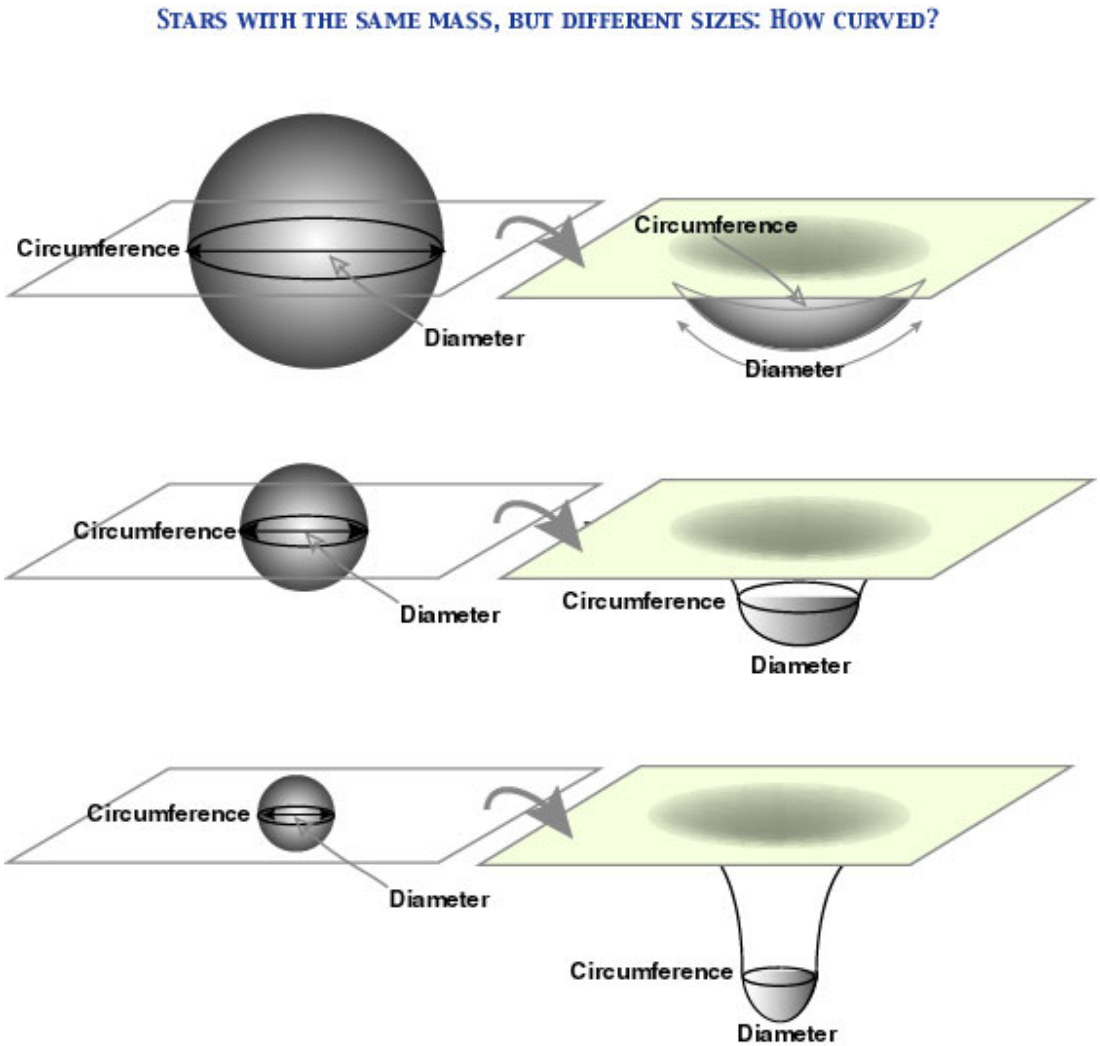


New explorations – two dimensions

- Can these histories lead the students to new questions?

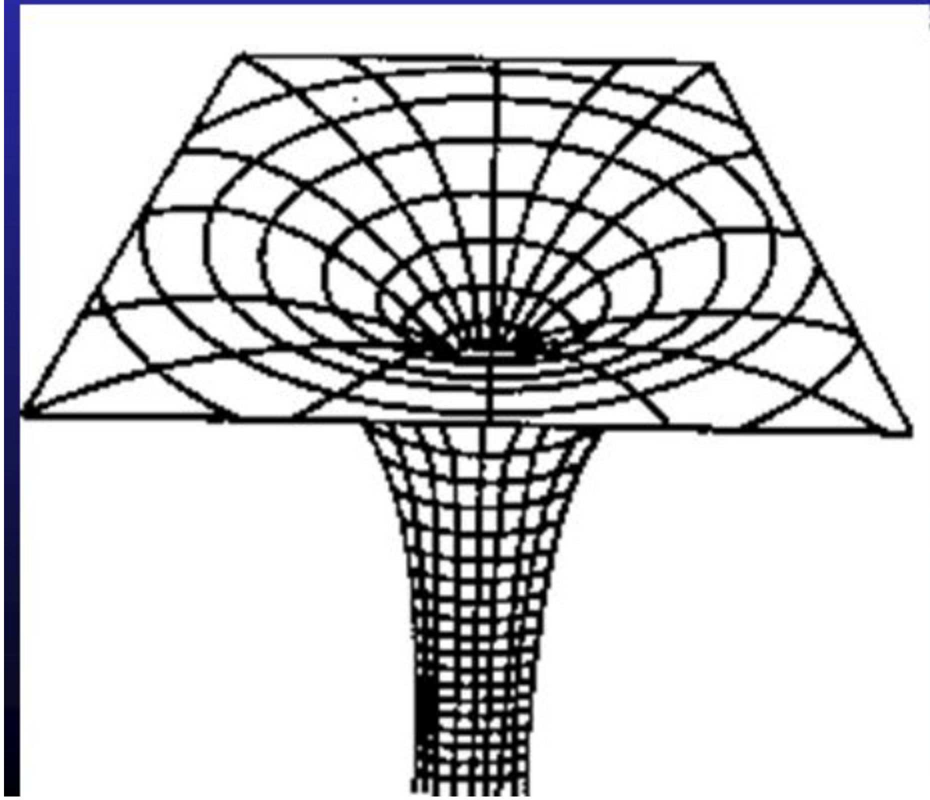
- Are there other questions that students could investigate with these tools and techniques?

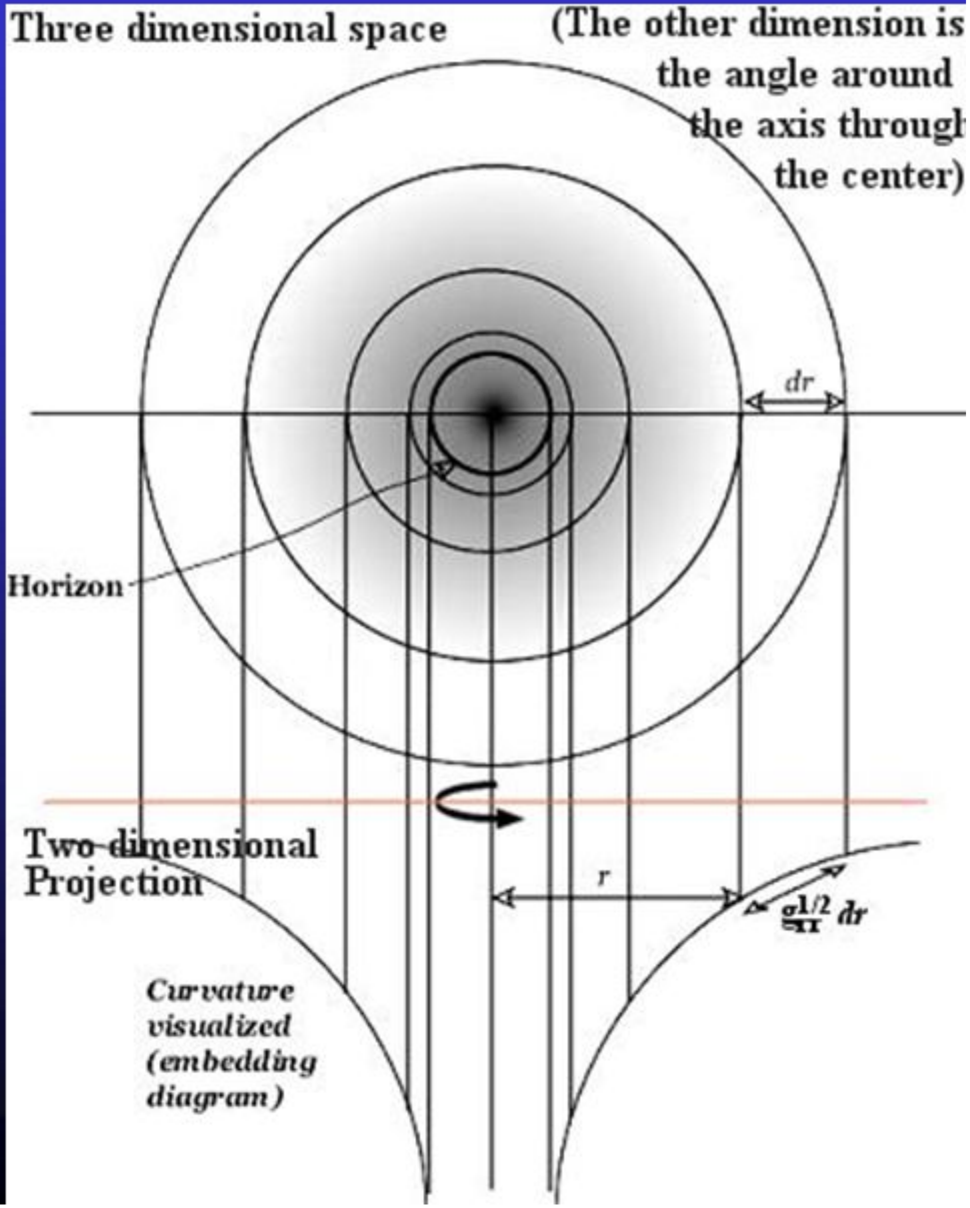
Embedding diagrams



Embedding diagram

- $dR = (1-2GM/c2r)^{-1/2}$ dr
- go dr in radius but proper length dR so tilt
- $dR > dr \rightarrow \infty$ as $r \rightarrow 2GM/c^2$





References

- Edelson, Daniel C. (1997). Realising Authentic Science Learning Through the Adaption of Scienctific Practice. In K. Tobin & B. Fraser (Eds.), *International Handbook of Science Education*. Kluwer, Dordrecht, NL.

- Meyer, Daniel Z. & Avery, Leanne M. (2010). Why Inquiry is Inherently Difficult…and Some Ways to Make it Easier. *Science Educator, 19(1*), 26-32.