Engaging astronomy students online with scientific reasoning about real data

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PICUP Virtual Conference – June 26, 2020

Why engage students with real data?

- Everyone is a natural-born scientist but starting from a different place:

  "I've learned about astronomy before and want to know more!"

  vs.

  "I'm really curious about space!" BUT

  "I'm just not a science/math person."

- "Doing science" vs. "being told science"

Examples:

- Hubble's law / discover dark energy (main focus due to time)

  See https://arxiv.org/abs/2002.02439 - to appear in TPT

- Online "test" – discover the properties of a star

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At this point in the course…

- Students have learned some basics of cosmology, in particular have seen that:

  - Homogeneous/isotropic expansion → Hubble's Law, $v = H\ d$
  - Value of H → age of universe

- Students have already used Jupyter notebooks for a few other homework problems.

hubble_data

Clone 180 Star 0

Status: Stopped

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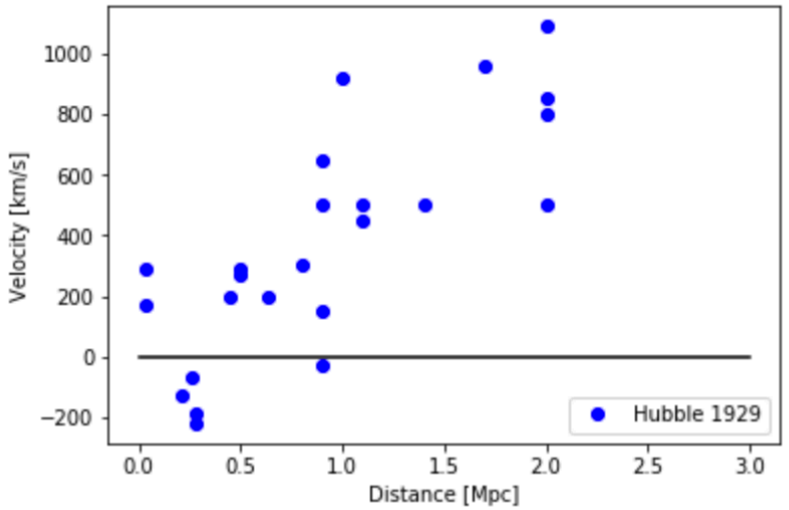
	Name	File Type	Modified On	Created On
	ct_data.dat	DAT	Dec 4, 2019	
	hubble1929.dat	DAT	Dec 4, 2019	
	hubble_key_cepheids.dat	DAT	Dec 4, 2019	
	hubble_key_snia.dat	DAT	Dec 4, 2019	
	parameter_fitting.ipynb	Notebook	Jun 26, 2020	
	snc_data.dat	DAT	Dec 4, 2019	

Showing 6 search results (1 hidden)

```
# Create a line to show Hubble's Law for some choice of Hubble constant H
D=sp.linspace(0,3,100) # creates array of distances (start of fit line, end of fit line, number of points in between)
                       #                                                  distance over which you
H=0 # Hubble parameter
v=H*D # Hubble's law

# Plot all of this stuff
plt.plot(D,v,color='black') # Plots the fit line for Hubble's Law, using your value of H
plt.plot(disthubble,velhubble,'o',color='b',label='Hubble 1929') # Plots Hubble's 1929 data
#plt.plot(distkeyc,velkeyc,'x',color='g',label='Hubble Key Project Cepheids') # Plots Hubble Key Project Cepheids data
plt.legend(loc='lower right') # Puts the legend in a nice spot
plt.xlabel('Distance [Mpc]') # Labels the axes!
plt.ylabel('Velocity [km/s]')
```

Students change the value of H to approximately fit the data.

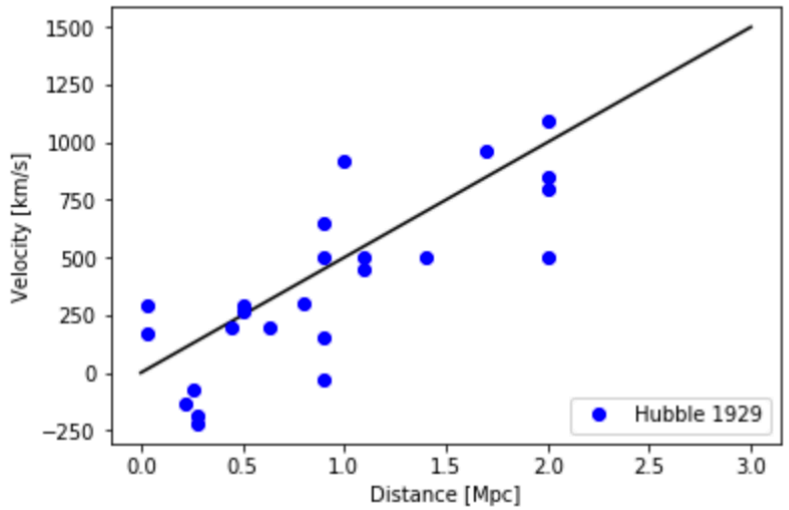
Out[2]: Text(0,0.5,'Velocity [km/s]')



```
# Create a line to show Hubble's Law for some choice of Hubble constant H
D=sp.linspace(0,3,100) # creates array of distances (start of fit line, end of fit line, number of points in between)
                       #                                                  distance over which you
H=500 # Hubble parameter
v=H*D # Hubble's law

# Plot all of this stuff
plt.plot(D,v,color='black') # Plots the fit line for Hubble's Law, using your value of H
plt.plot(disthubble,velhubble,'o',color='b',label='Hubble 1929') # Plots Hubble's 1929 data
#plt.plot(distkeyc,velkeyc,'x',color='g',label='Hubble Key Project Cepheids') # Plots Hubble Key Project Cepheids data
plt.legend(loc='lower right') # Puts the legend in a nice spot
plt.xlabel('Distance [Mpc]') # Labels the axes!
plt.ylabel('Velocity [km/s]')
```

H = 500 km/s/Mpc … implies the universe is just a few billion years old. (Less than Earth!)

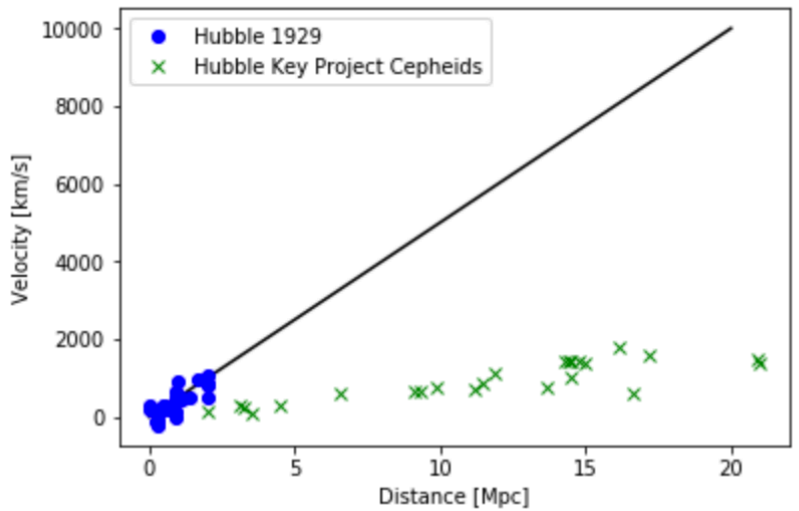
Out[3]: Text(0,0.5,'Velocity [km/s]')



```
# Create a line to show Hubble's Law for some choice of Hubble constant H
D=sp.linspace(0,20,100) # [illegible] line, end of fit line, number of points in between)
                        # [illegible] distance over which you
H=500 # Hubble parameter
v=H*D # Hubble's law

# Plot all of this stuff
plt.plot(D,v,color='black') # Plots the fit line for Hubble's Law, using your value of H
plt.plot(disthubble,velhubble,'o',color='b',label='Hubble 1929') # Plots Hubble's 1929 data
plt.plot(distkeyc,velkeyc,'x',color='g',label='Hubble Key Project Cepheids') # Plots Hubble Key Project Cepheids data
plt.legend(loc='upper left') # Puts the legend in a nice spot
plt.xlabel('Distance [Mpc]') # Labels the axes!
plt.ylabel('Velocity [km/s]')
```

Whoa! A new data set doesn't agree with that. Which is right?

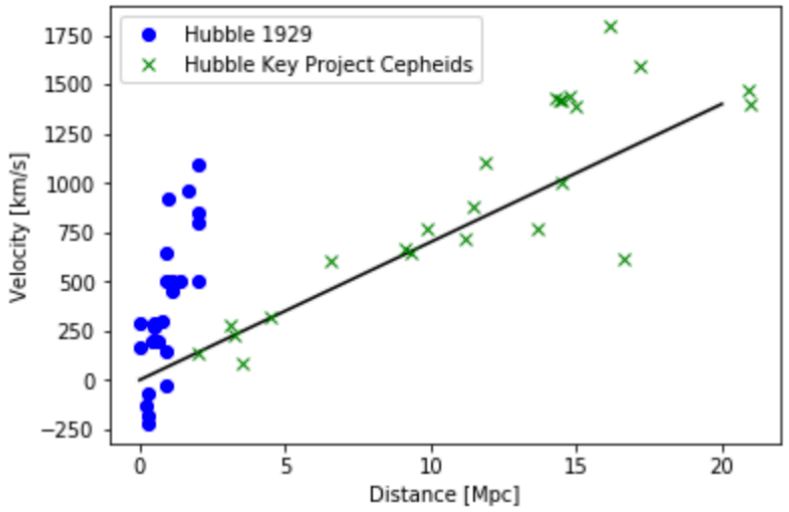
Out[6]: Text(0,0.5,'Velocity [km/s]')



```
# Create a line to show Hubble's Law for some choice of Hubble constant H
D=sp.linspace(0,20,100) #                    line, end of fit line, number of points in between)
                        #                    distance over which you
H=70 # Hubble parameter
v=H*D # Hubble's law

# Plot all of this stuff
plt.plot(D,v,color='black') # Plots the fit line for Hubble's Law, using your value of H
plt.plot(disthubble,velhubble,'o',color='b',label='Hubble 1929') # Plots Hubble's 1929 data
plt.plot(distkeyc,velkeyc,'x',color='g',label='Hubble Key Project Cepheids') # Plots Hubble Key Project Cepheids data
plt.legend(loc='upper left') # Puts the legend in a nice spot
plt.xlabel('Distance [Mpc]') # Labels the axes!
plt.ylabel('Velocity [km/s]')
```

This value of H implies an older universe… hmm…

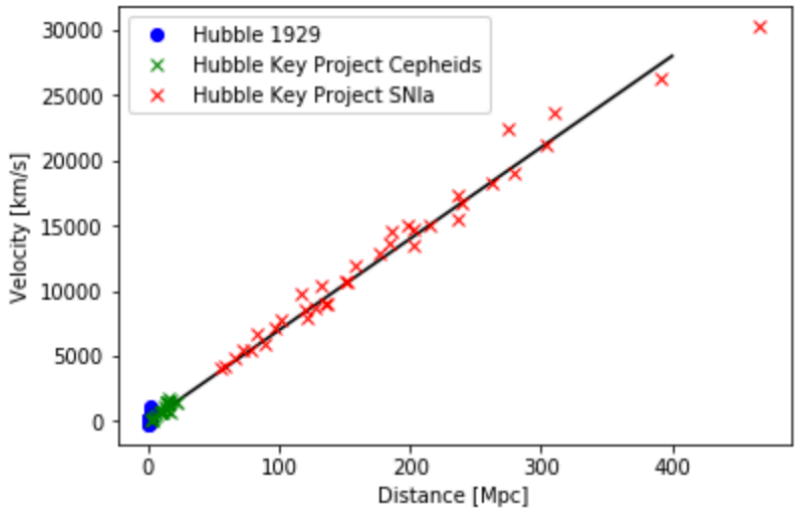
Out[8]: Text(0,0.5,'Velocity [km/s]')



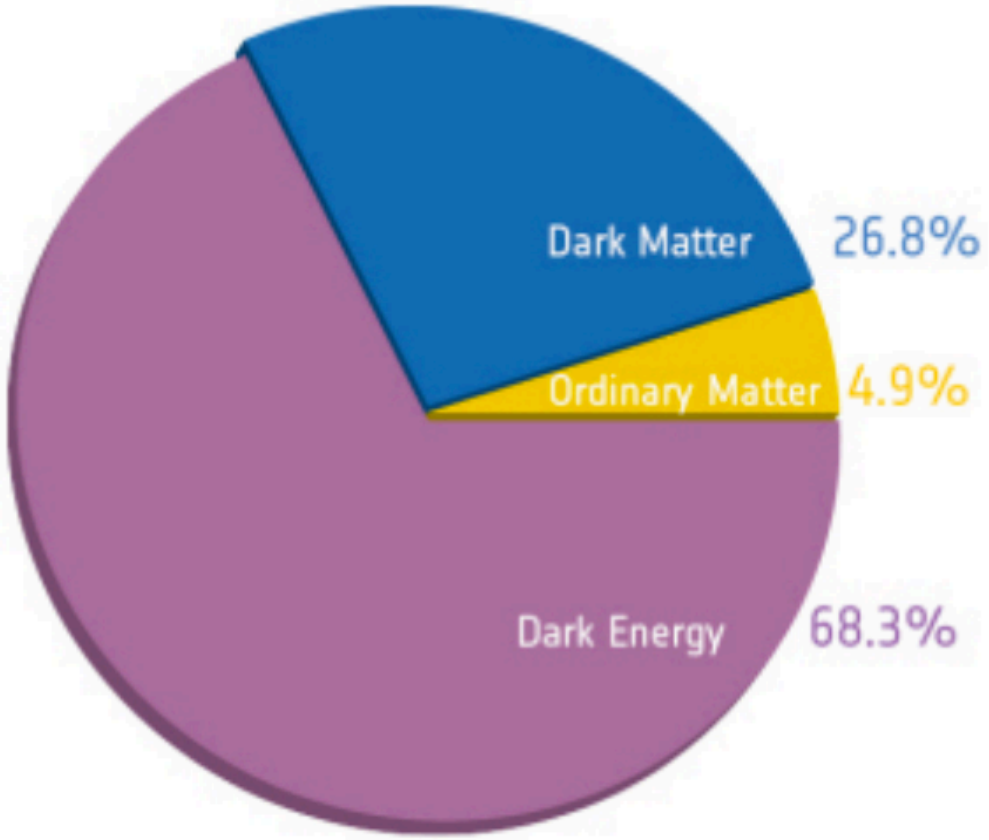
```
# Create a line to show Hubble's Law for some choice of Hubble constant H
D=sp.linspace(0,400,100) # creates array of distances (start of fit line, end of fit line, number of points in between)
                         # distance over which you
H=70 # Hubble parameter
v=H*D # Hubble's law

# Plot all of this stuff
plt.plot(D,v,color='black                                    using your value of H
plt.plot(disthubble,velhubble,'o',color='b',label='Hubble 1929') # Plots Hubble's 1929 data
plt.plot(distkeyc,velkeyc,'x',color='g',label='Hubble Key Project Cepheids') # Plots Hubble Key Project Cepheids data
plt.plot(distkeysn,velkeysn,'x',color='r',label='Hubble Key Project SNIa')
plt.legend(loc='upper left') # Puts the legend in a nice spot
plt.xlabel('Distance [Mpc]') # Labels the axes!
plt.ylabel('Velocity [km/s]')
```

And it's consistent with H found from a different standard candle (distance measure).

Out[11]: Text(0,0.5,'Velocity [km/s]')



Dark Energy!

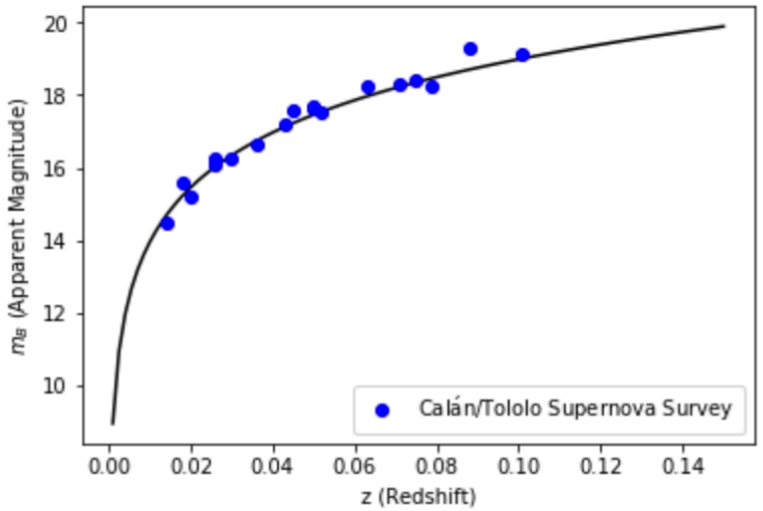


https://sci.esa.int/web/planck/-/51557-planck-new-cosmic-recipe

```
const=24.00 # This is the overall parameter that accounts for the luminosity of Type Ia supernovae.

# Create a fit cu
z=sp.linspace(0.0
decel=OmegaRadiat
m=const-5*sp.log1(

# Plot fit curve and data on same axes
plt.plot(z,m,color='black')
plt.plot(redshiftct,magct,'o',color='b',label=r"""Cal$\'{\rm a}$n/Tololo Supernova Survey""")
#plt.plot(redshiftsnc,magsnc,'x',color='g',label='Supernova Cosmology Project')
plt.legend(loc='lower right')
plt.xlabel('z (Redshift)')
plt.ylabel('$m_B$ (Apparent Magnitude)')
```

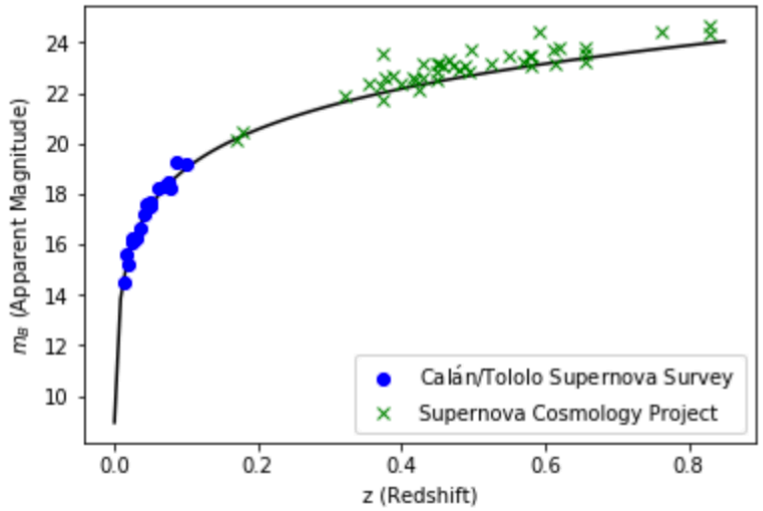
A constant related to the absolute magnitude of the standard candles is used to fit a curve to the first data set.

Out[14]: Text(0,0.5,'m_B (Apparent Magnitude)')



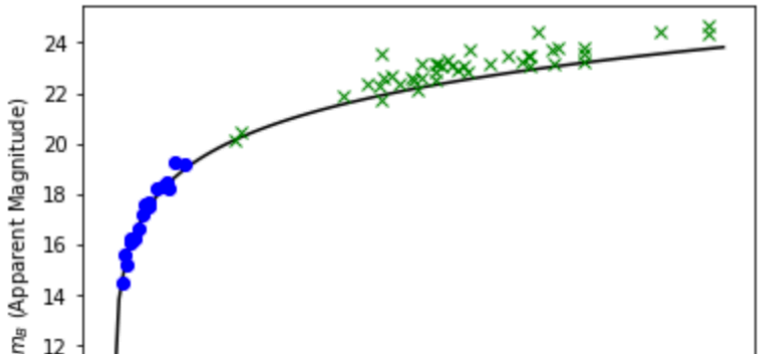
```
const=24.00 # This is the overall parameter that accounts for the luminosity of Type Ia supernovae.

# Create a fit curve based on model parameters
z=sp.linspace(0.001,0.85,100)
decel=OmegaRadiation+0.5*OmegaMatter-OmegaLambda
m=const-5*sp.log10(H0/68)+5*sp.log10(z)+1.086*(1-decel)*z

# Plot fit curve and data on same axes
plt.plot(z,m,color='black')
plt.plot(redshiftct,magct,'o',color='b',label=r"""Cal$\'{\rm a}$n/Tololo Supernova Survey""")
plt.plot(redshiftsnc,magsnc,'x',color='g',label='Supernova Cosmology Project')
plt.legend(loc='lower right')
plt.xlabel('z (Redshift)')
plt.ylabel('$m_B$ (Apparent Magnitude)')
```

Out[18]: Text(0,0.5,'m_B (Apparent Magnitude)')



```
# Set model parameters to compare with data
OmegaRadiation=0.5
OmegaMatter=0.5
OmegaLambda=0.0 # In a flat universe, the Omega's have to add up to 1.
H0=70 # Present-day value of Hubble constant
const=24.00 # This is the overall parameter that accounts for the luminosity of Type Ia supernovae.

# Create a fit curve based on model parameters
z=sp.linspace(0.001,0.85,100)
decel=OmegaRadiation+0.5*OmegaMatter-OmegaLambda
m=const-5*sp.log10(H0/68)+5*sp.log10(z)+1.086*(1-decel)*z

# Plot fit curve and data on same axes
plt.plot(z,m,color='black')
plt.plot(redshiftct,magct,'o',color='b',label=r"""Cal$\'{\rm a}$n/Tololo Supernova Survey""")
plt.plot(redshiftsnc,magsnc,'x',color='g',label='Supernova Cosmology Project')
plt.legend(loc='lower right')
plt.xlabel('z (Redshift)')
plt.ylabel('$m_B$ (Apparent Magnitude)')
```

Out[19]: Text(0,0.5,'m_B (Apparent Magnitude)')



```
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OmegaRadiation=0.0
OmegaMatter=0.5
OmegaLambda=0.5 # In a flat universe, the Omega's have to add up to 1.
H0=70 # Present-day value of Hubble constant
const=24.00 # This is the overall parameter that accounts for the luminosity of Type Ia supernovae.

# Create a fit curve based on model parameters
z=sp.linspace(0.001,0.85,100)
decel=OmegaRadiation+0.5*OmegaMatter-OmegaLambda
m=const-5*sp.log10(H0/68)+5*sp.log10(z)+1.086*(1-decel)*z

# Plot fit curve and data on same axes
plt.plot(z,m,color='black')
plt.plot(redshiftct,magct,'o',color='b',label=r"""Cal$\'{\rm a}$n/Tololo Supernova Survey""")
plt.plot(redshiftsnc,magsnc,'x',color='g',label='Supernova Cosmology Project')
plt.legend(loc='lower right')
plt.xlabel('z (Redshift)')
plt.ylabel('$m_B$ (Apparent Magnitude)')
```
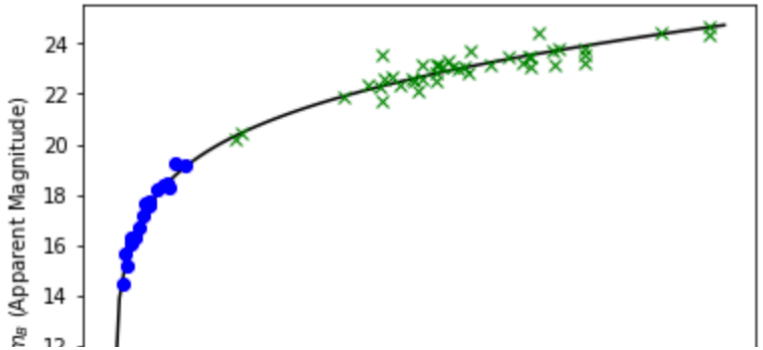
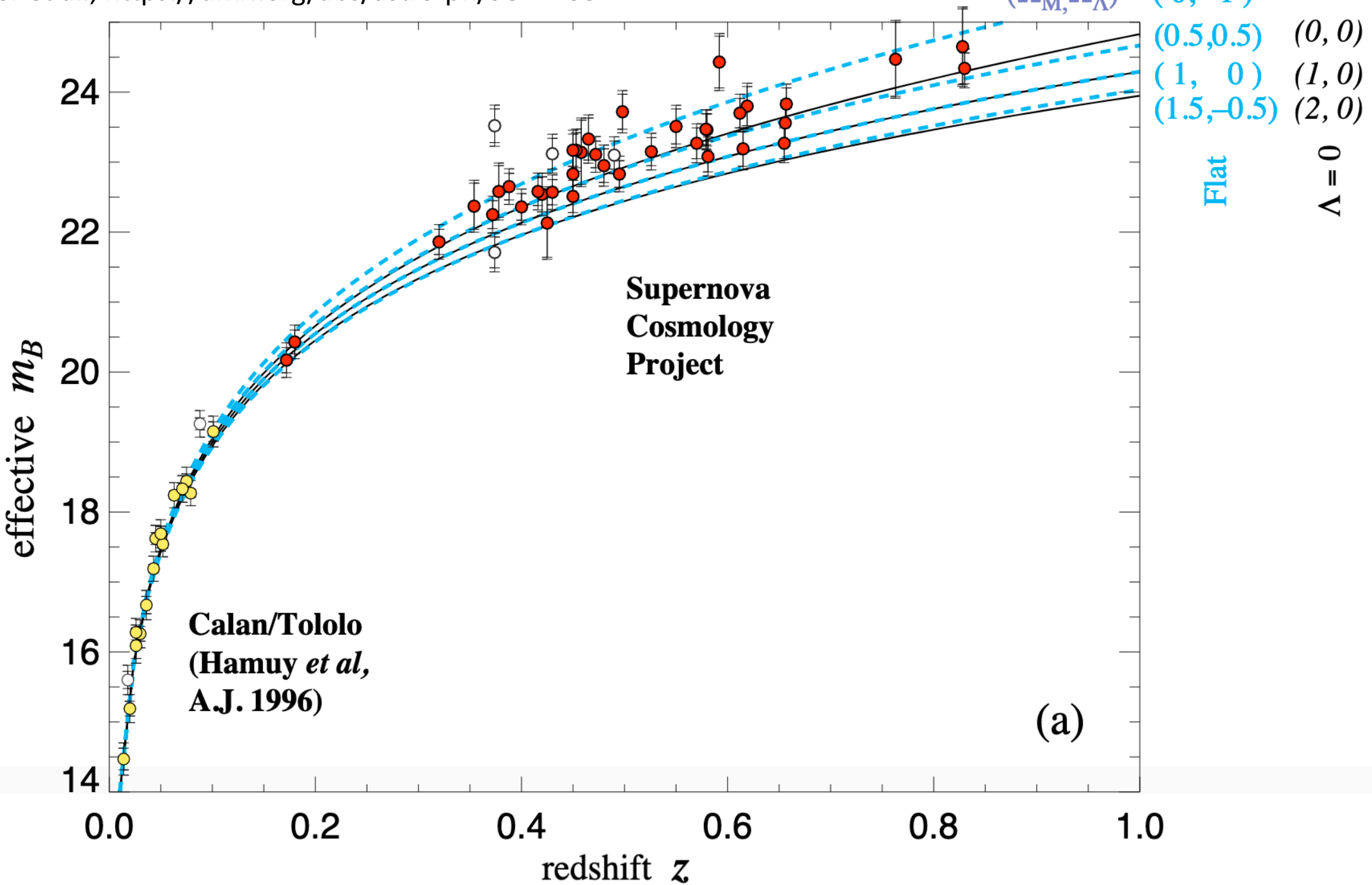

Out[20]: Text(0,0.5,'m_B (Apparent Magnitude)')

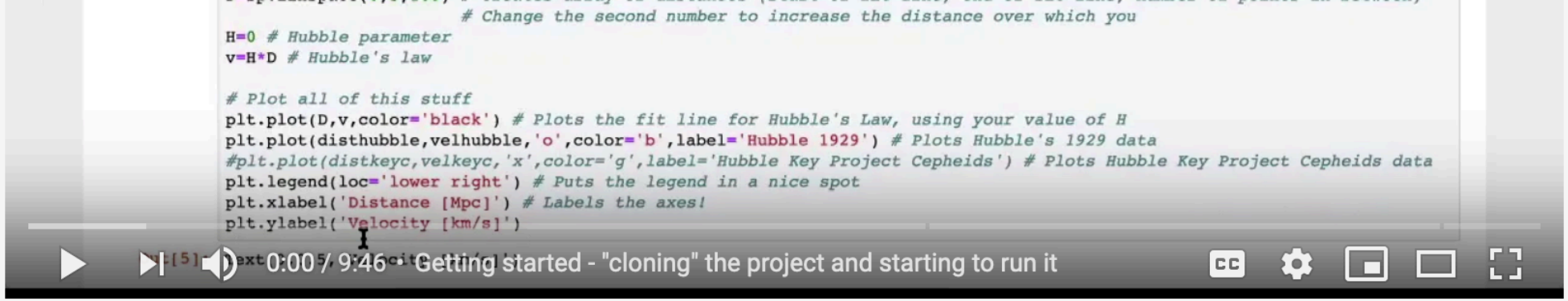


Some Issues to Consider

- “I know this is the right number because I looked it up just to check.”
- Problems / questions about running code.
- Follow-up after the assignment.

Perlmutter et al., https://arxiv.org/abs/astro-ph/9812133





Overview of Hubble Data Code

Unlisted

43 views • May 3, 2020

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Jeff Hyde
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This overview shows you how to get started and points out some important features. The video mentions some of the things that you'll do for this problem, but the assignment PDF (on Blackboard) does that in much more detail.

Clarification at 0:33: you can run the code in your cloned version, but not when you are viewing mine.

0:00 - Getting started - "cloning" the project and starting to run it
1:27 - Overview of part one - adding data to plot, changing fit line
5:49 - Overview of part two
9:09 - One last tip - if you have trouble getting this to work *after* the code has already been running

Examples:

- Hubble's law / discover dark energy (main focus due to time)

  See https://arxiv.org/abs/2002.02439 - to appear in TPT

- Online "test" – discover the properties of a star

Examples:

- Hubble's law / discover dark energy (main focus due to time)

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- Online "test" – discover the properties of a star

How could I test students on “doing science?”

- Given observed properties of a star (parallax angle, apparent magnitude, spectrum, …)

- How far away is it? How big is it? How hot? What is its fate?

Thank you!

- Resources: https://drive.google.com/drive/folders/1ZNFMX0IK3nSYpjp_sSAygGdTgewSP84e?usp=sharing

- Contact info: jhyde@bowdoin.edu