A Hallmark of Science

A scientific model must make **testable** predictions about natural phenomena that would force us to **revise or abandon the model** if the predictions do not agree with observations.

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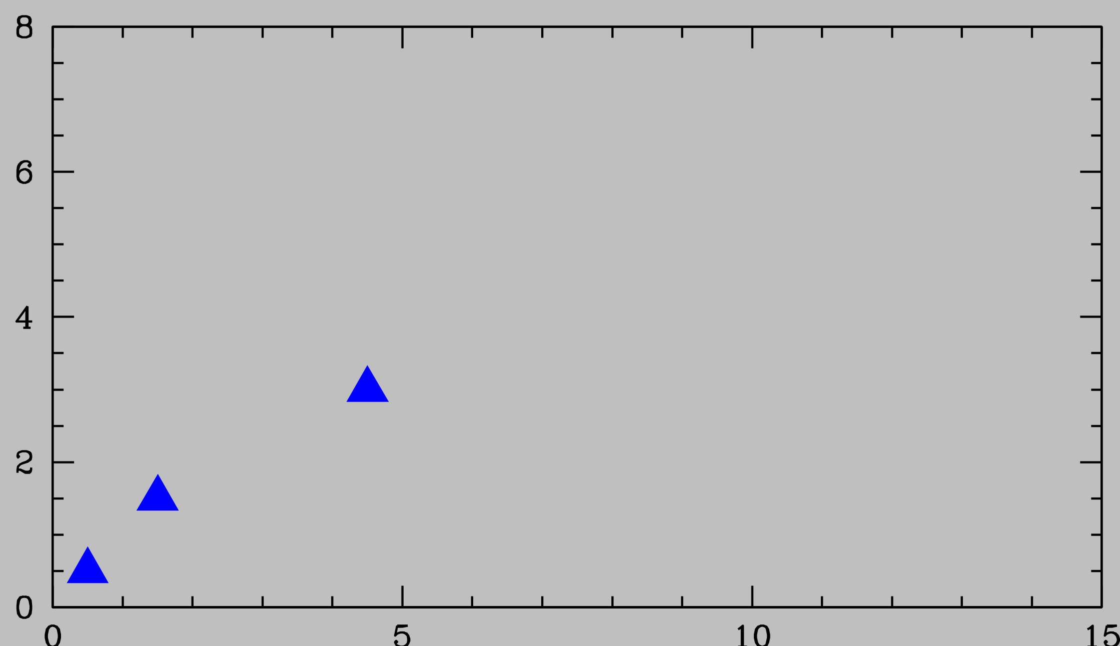

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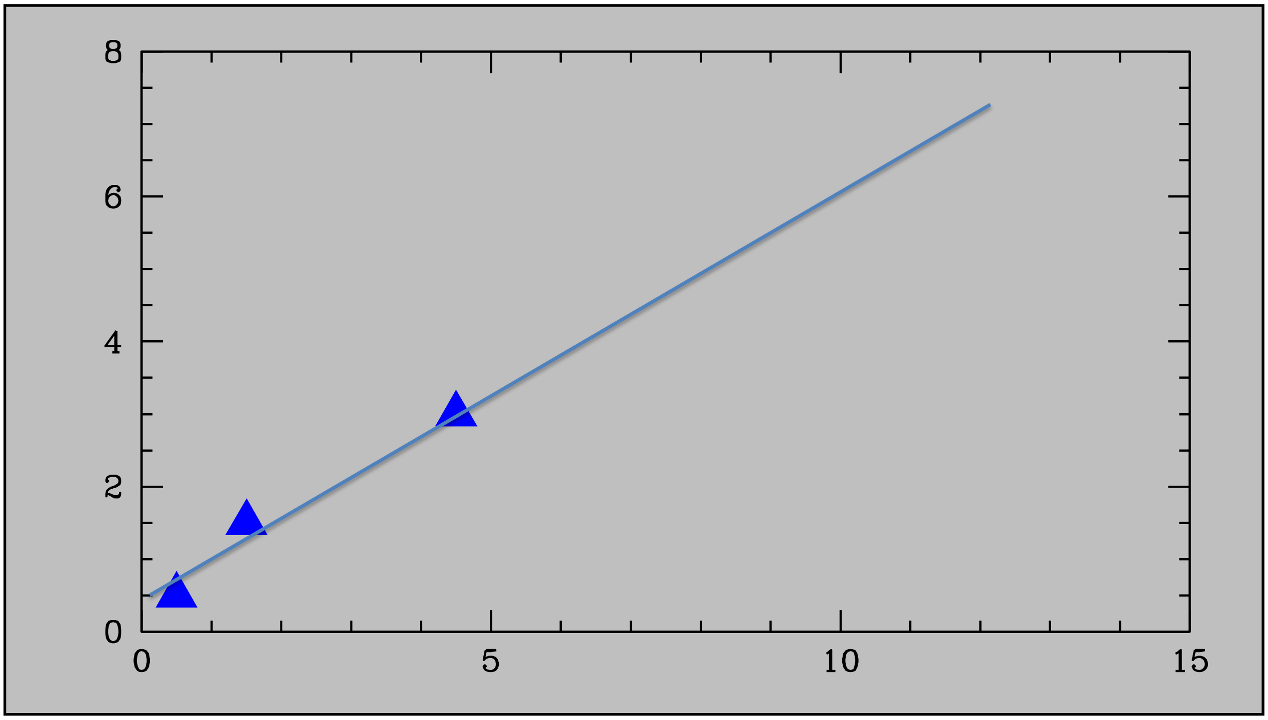

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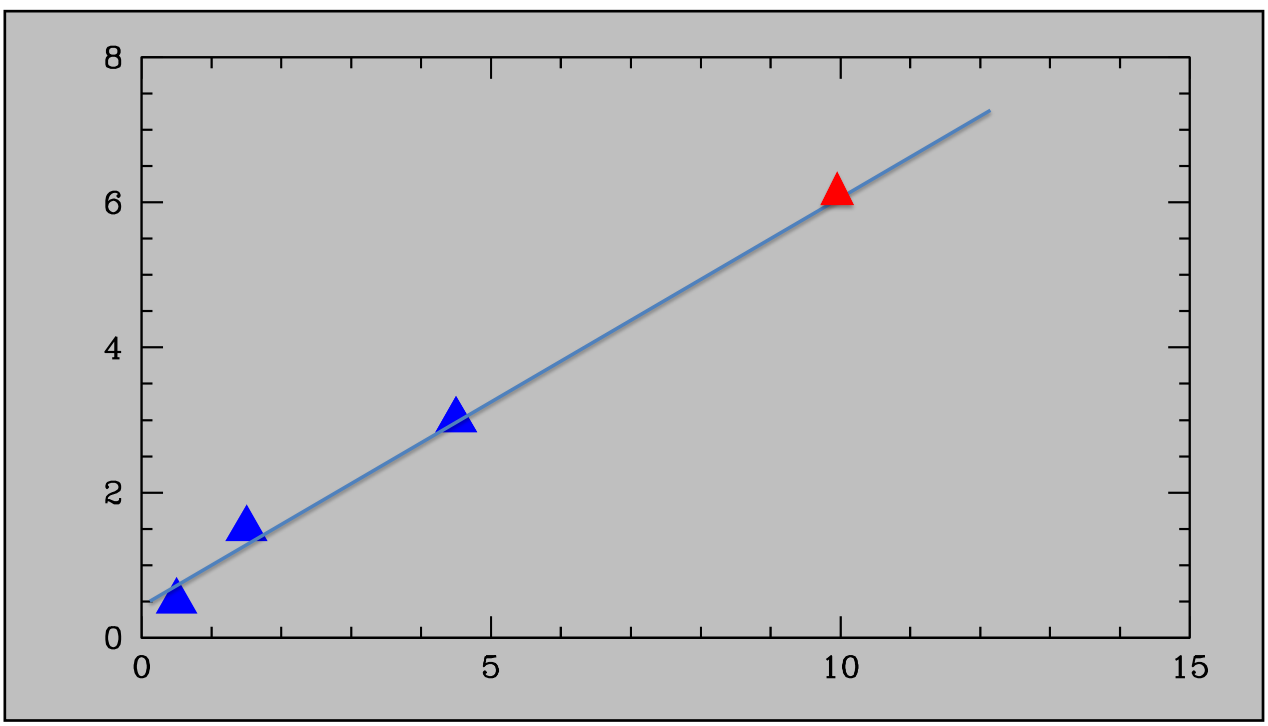

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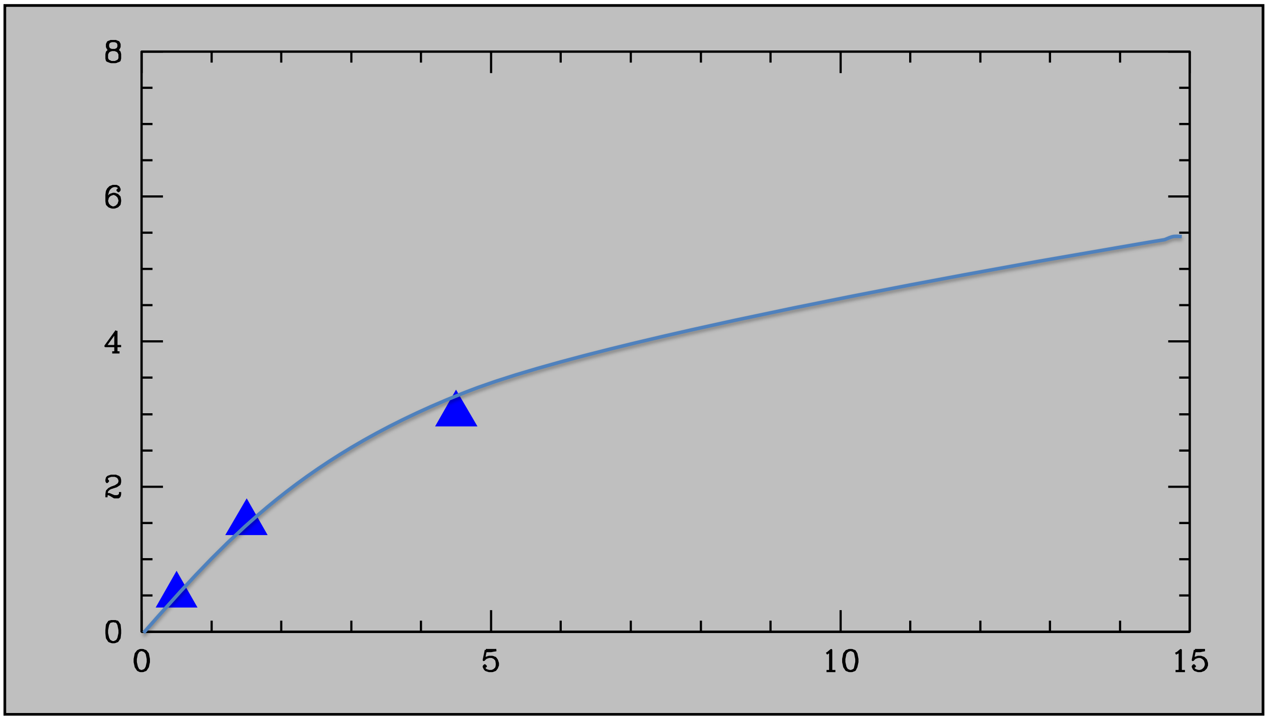

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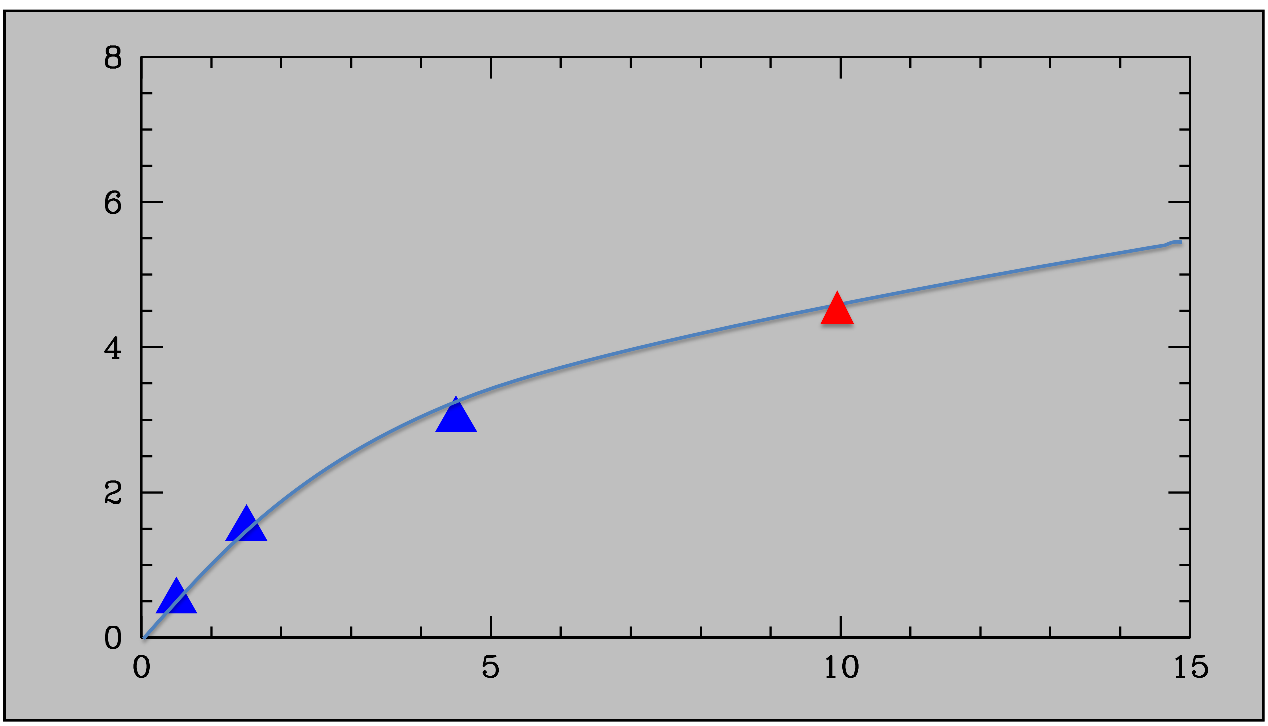

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So how should we fit this?

8

So how should we fit this?

Which Model is correct?

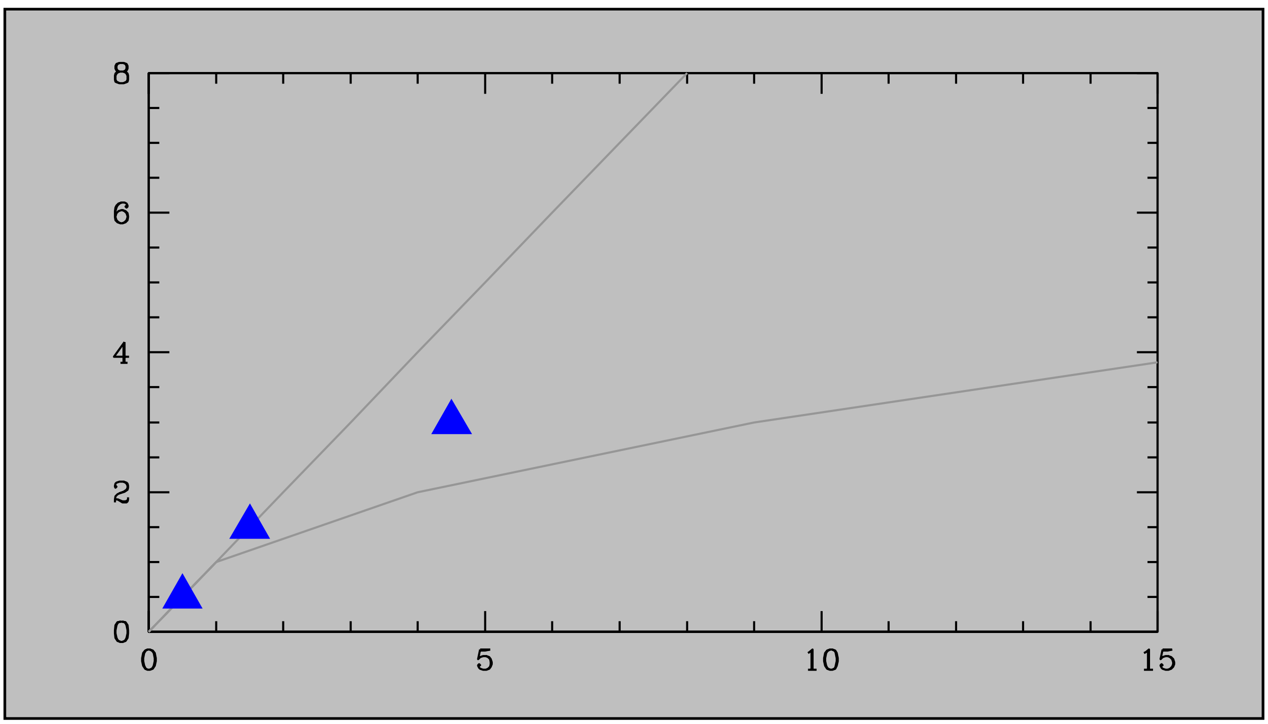
9

So how should we fit this?

Which Model is correct?

Are these actually Models?

10



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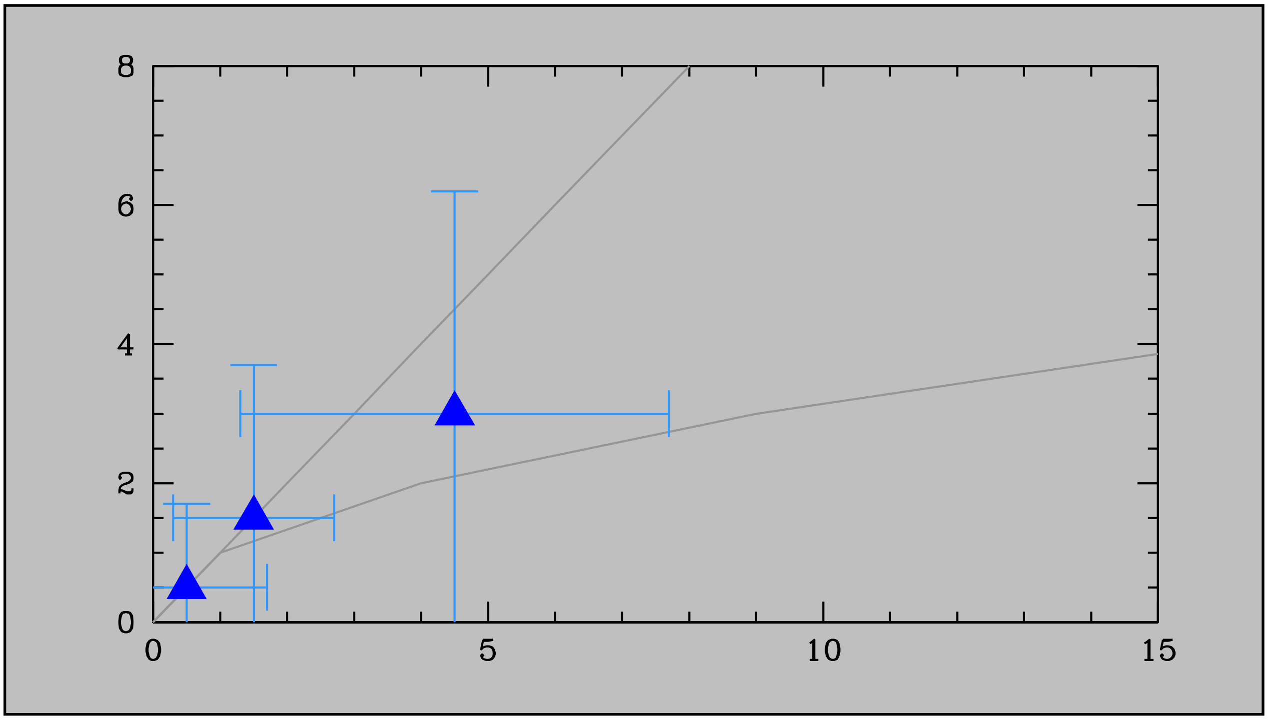

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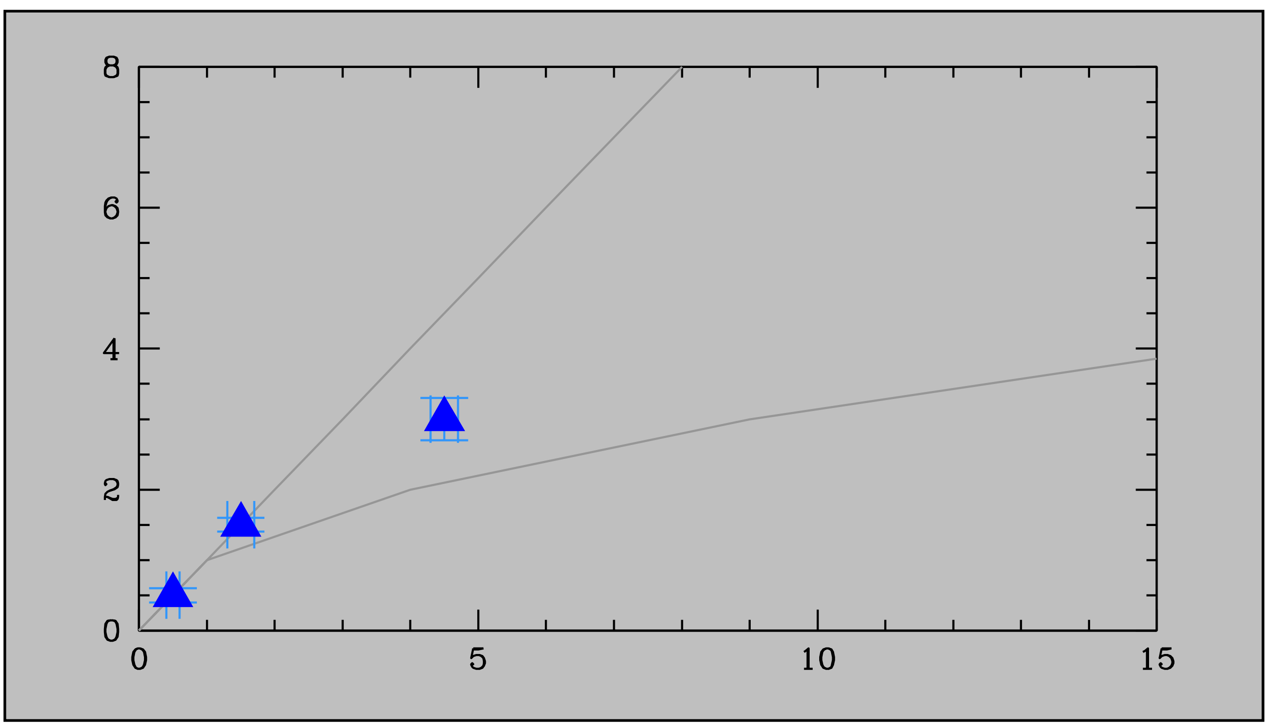

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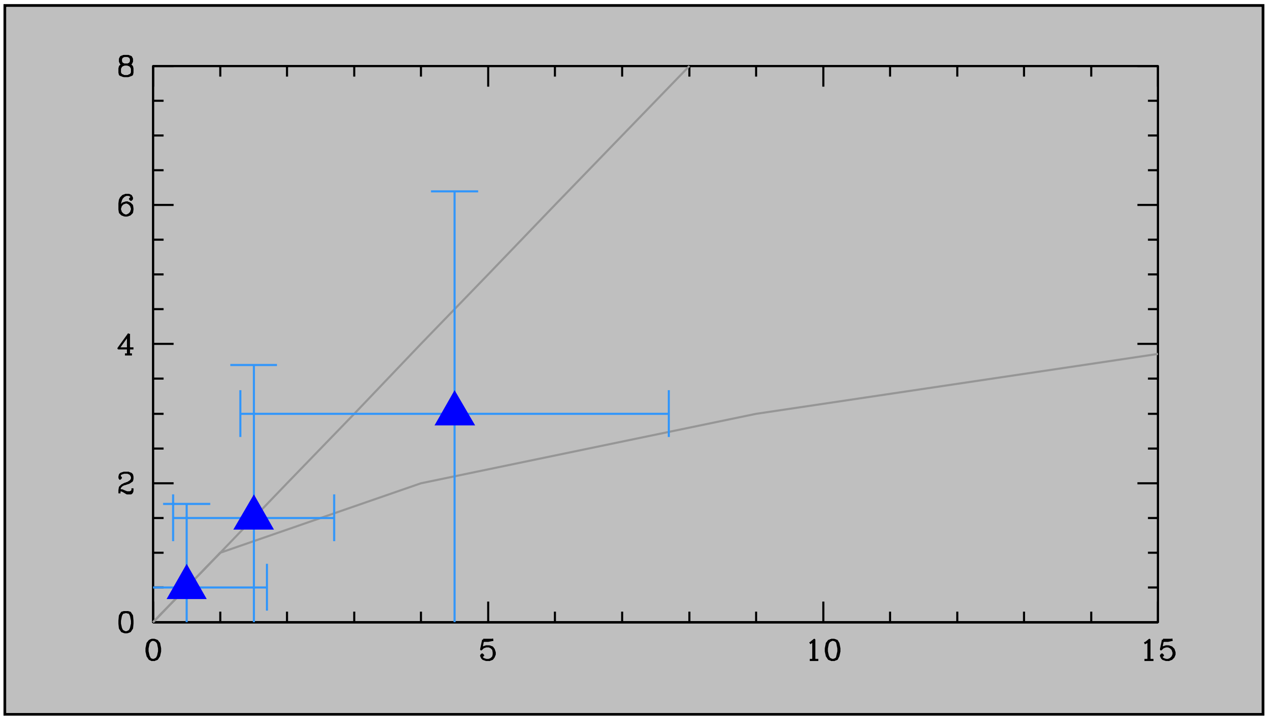

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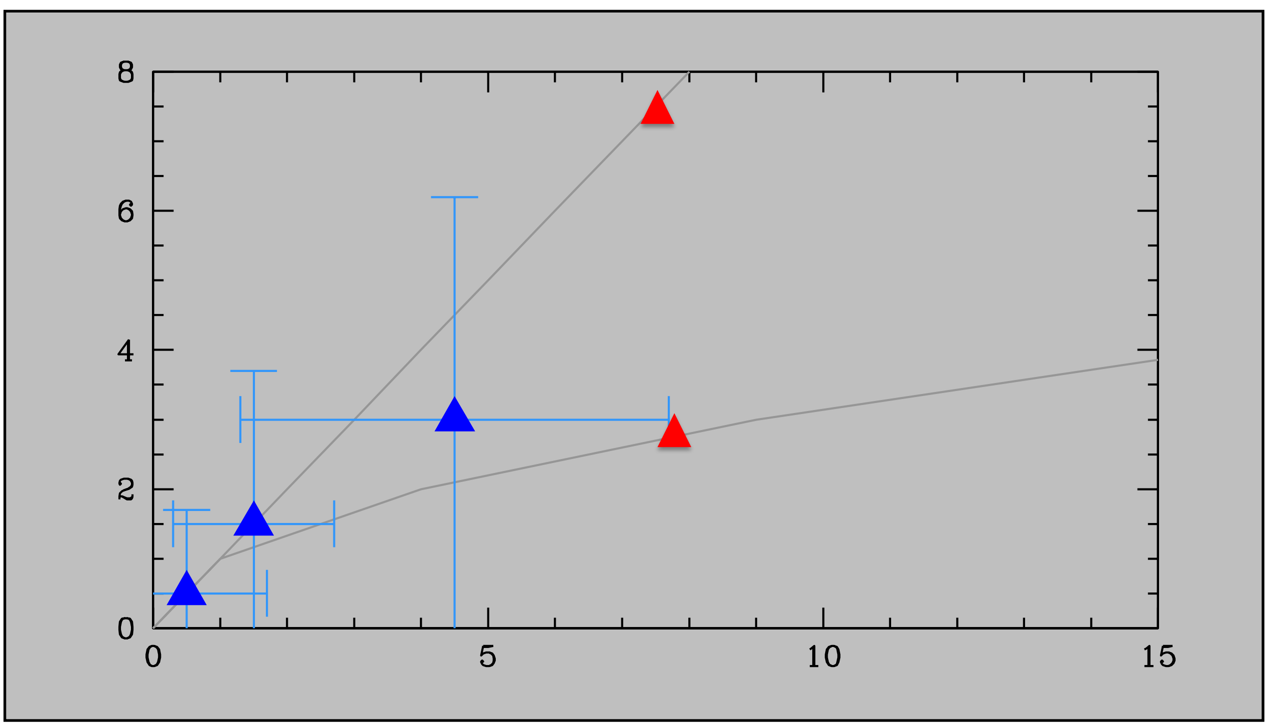

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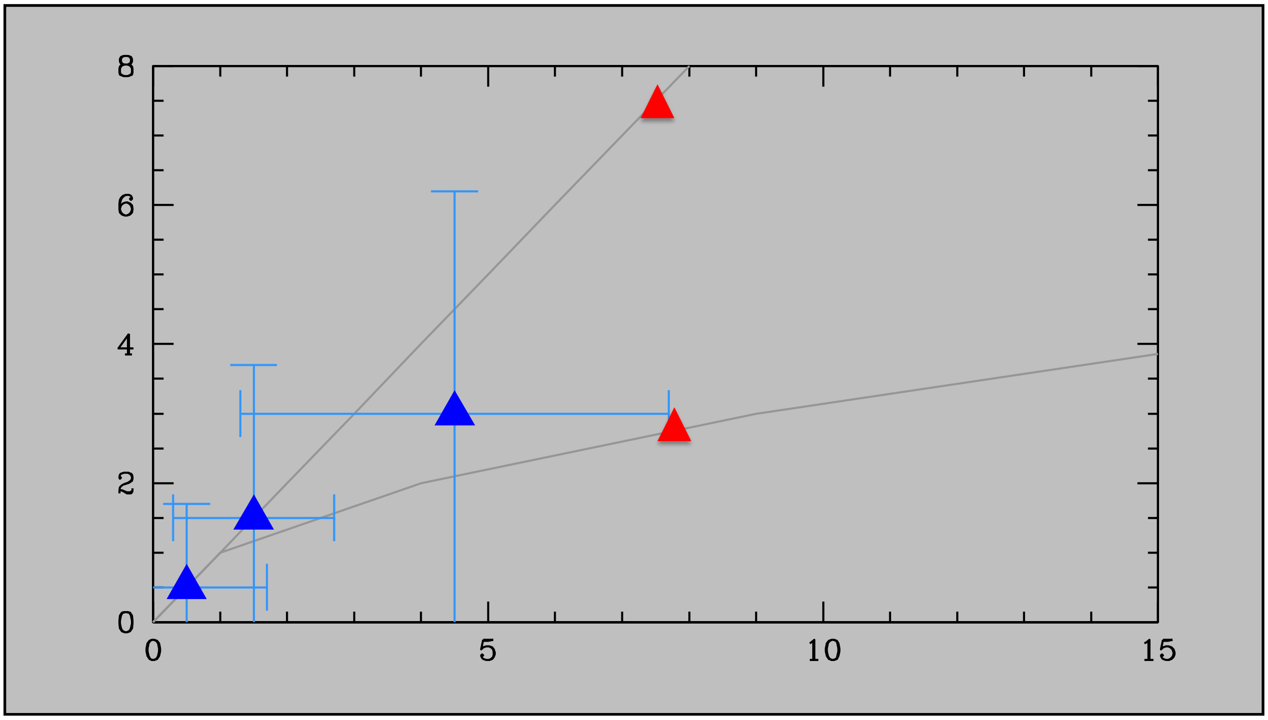

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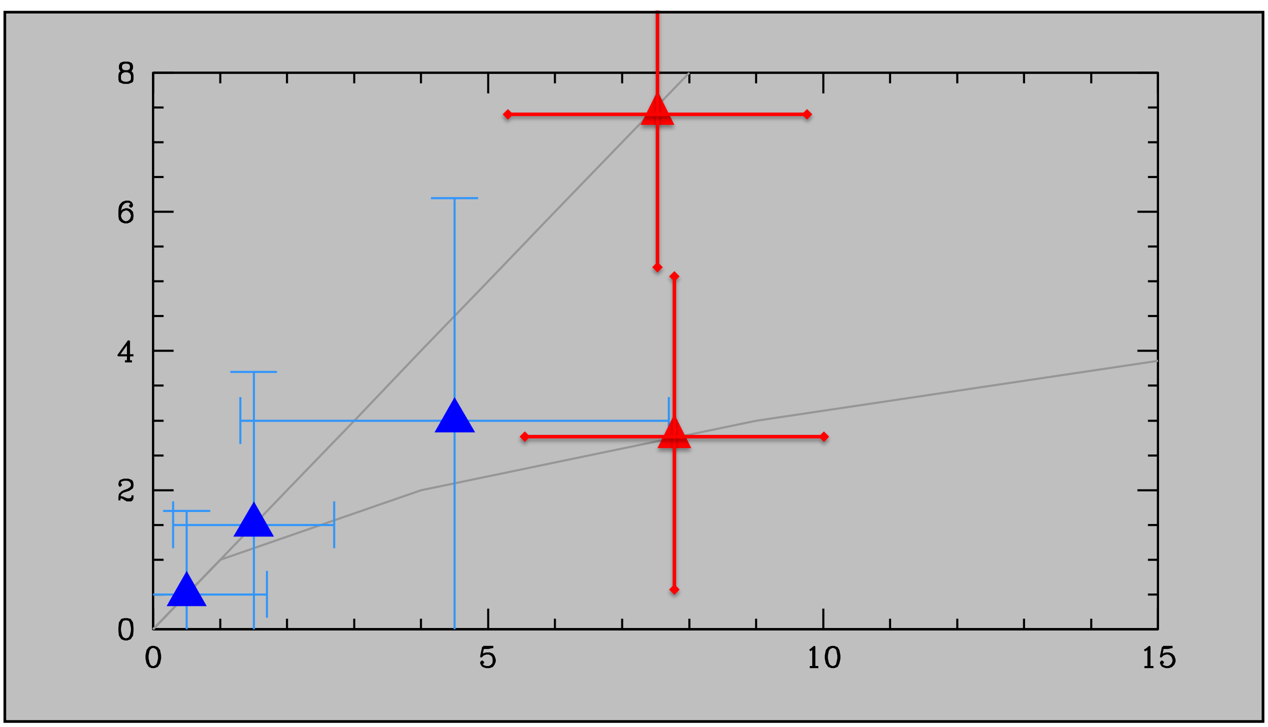

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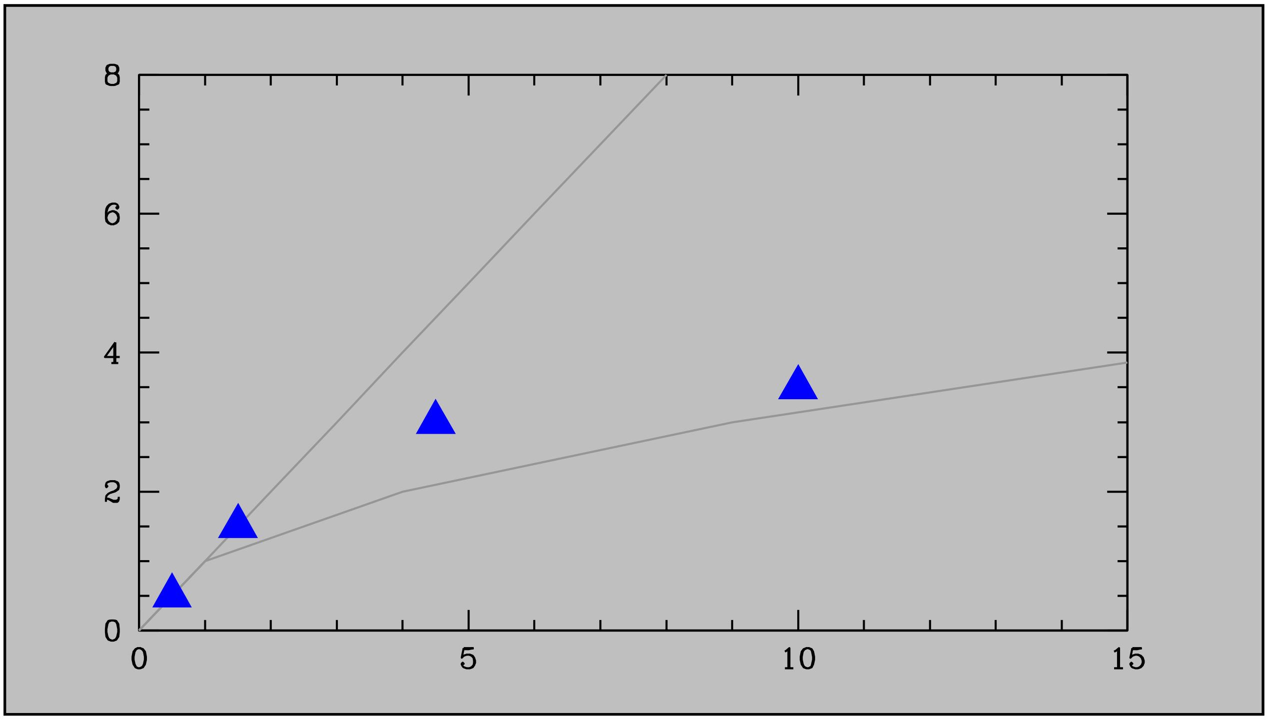

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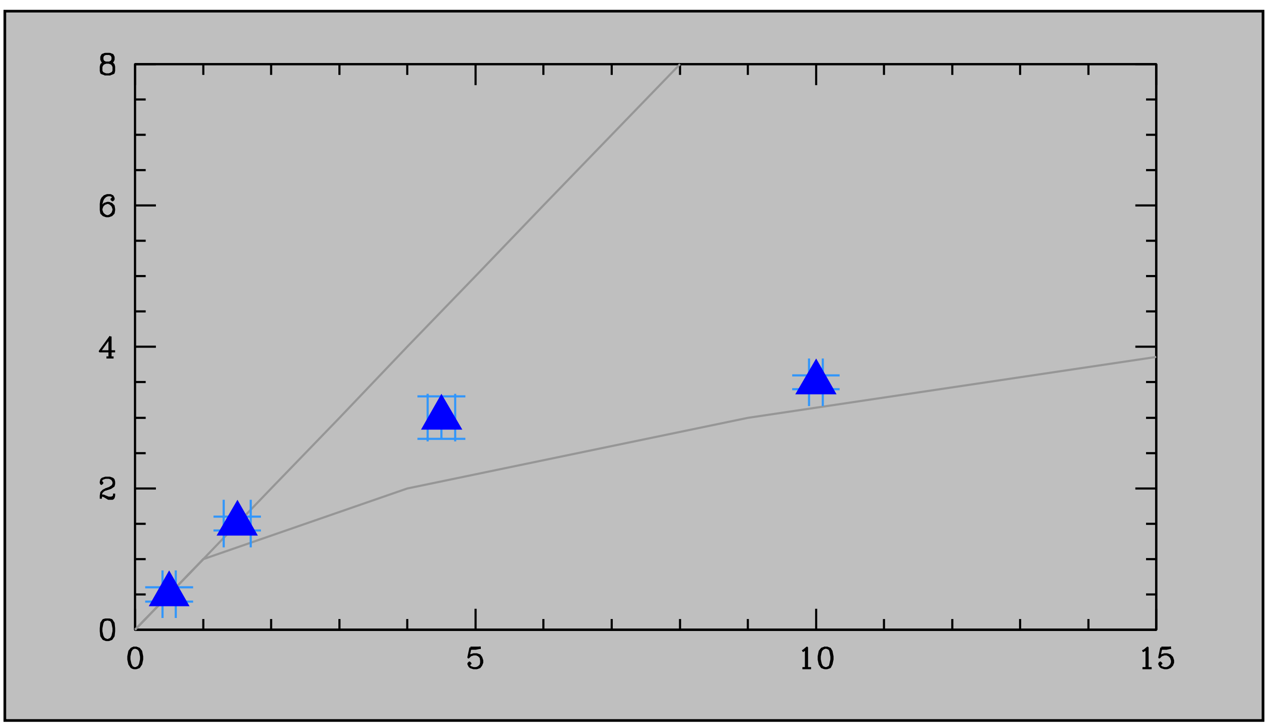

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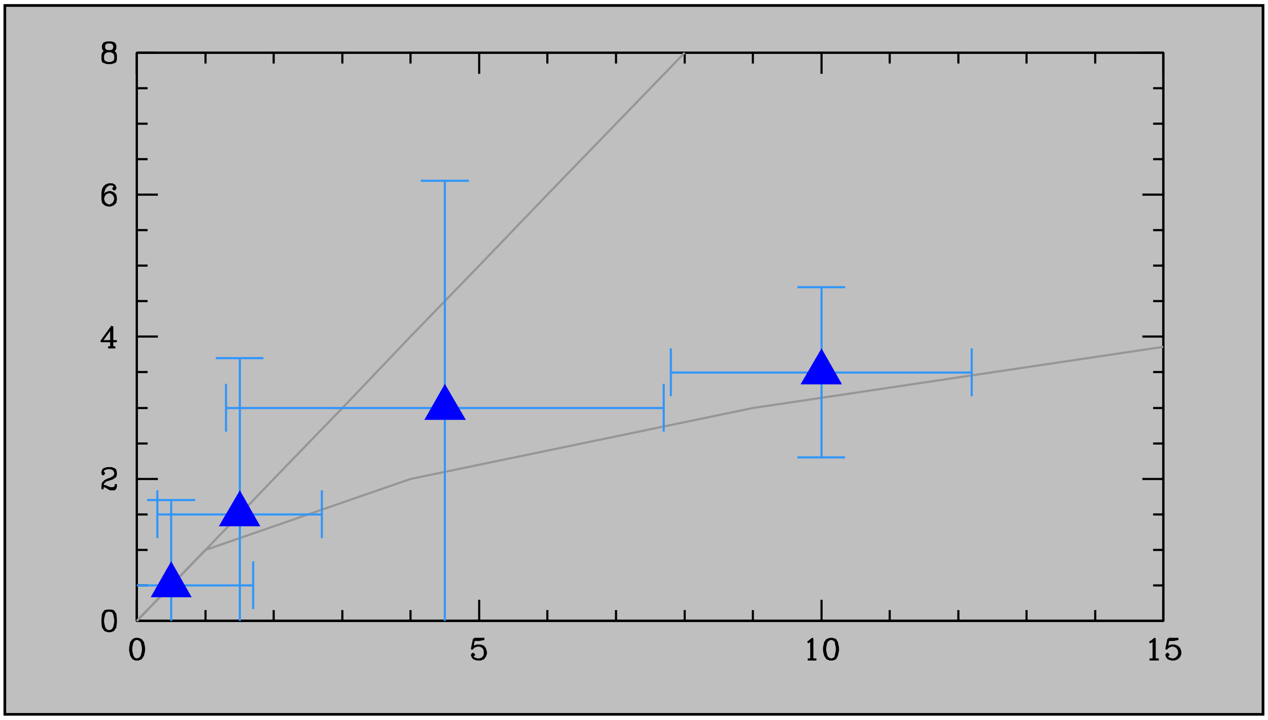

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Models need data to test against.
Data need to test models

Uncertainties KEY to matching!

How well you know the measurement uncertainty is MORE important than the specific value you measure!

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ERROR ANALYSIS: RANDOM AND SYSTEMATIC ERRORS

REFERENCE: L. Lyons, *A Practical Guide to Data Analysis for Physical Science Students*, Chapter 1, pp.1-15.

What is error analysis? Why do it?

- We rarely find "truth" by performing an experiment once.
- Repeat experiments with refined techniques and methods --> Approach truth asymptotically (or at least we have confidence that we do).
- "ERROR" = Difference between calculated / observed value and truth value.
- Of course, we do not usually know "truth" (or there would be no reason to do experiment).
- So we need to come up with ways to determine from the data themselves how much confidence to have in the results (reliability).

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- This is the subject of **Error Analysis:**.
  - Error analysis is a required -- ***and very important*** -- part of scientific research.
  - It's not enough to give the results of an experiment
    -- We have also to give some assessment of the reliability of the result you give.
  - This alerts the user of the information about how much trust one should put in the result.
  - We often do this by actually giving an estimate of the level of *unreliability* in the experiment. This is done by quantifying an *uncertainty* in the result.
  - This expected part of your stated results is the only way to assess whether theory proven/expectations met.

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- We typically give a quantitative assessment of the result of an experiment as a number appended with a "**+/-**" value that accounts for the uncertainty on the result (*in the same units*):

e.g., in the form ***y +/-ε*** , where **ε** is the uncertainty.

Sometimes we see the form:

$$\boldsymbol{y \pm \varepsilon \pm \delta}$$

Where,
ε is the contribution to the uncertainty from ***random errors*** and
δ is the contribution from ***systematic errors*.**

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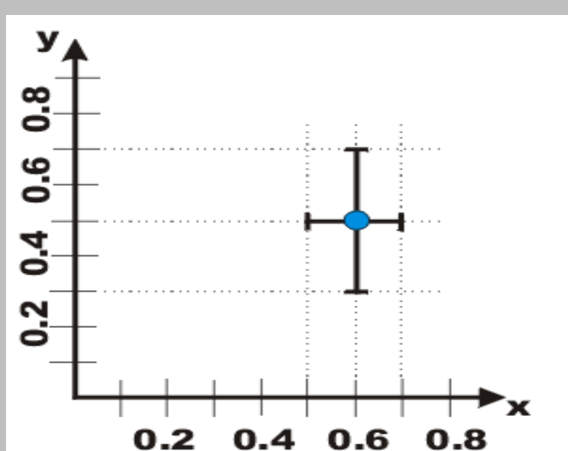
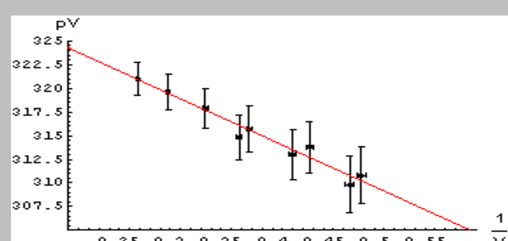
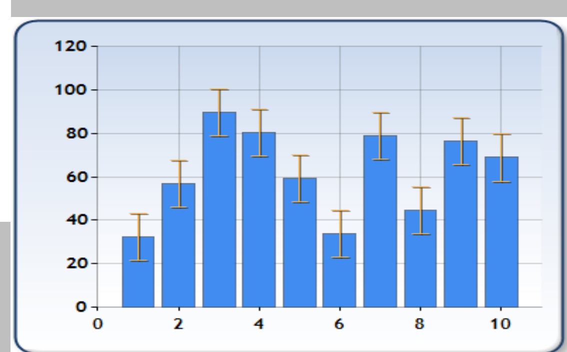
We also display errors graphically with use of *error bars* in plots showing our data:







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Example:
You do an experiment to measure the acceleration due to gravity and find

$$\boldsymbol{g = 9.70\ m/s^2\ +/-\ 0.15\ m/s^2}$$

Here you are stating that the uncertainty in your result: **0.15 m/s²**

Now, the actual known value of *g* found after numerous experiments over the centuries, is

$$\boldsymbol{g = 9.81\ m/s^2}$$

What do we make of the discrepancy between these values?

26

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What do we make of the discrepancy between these values?
Consider three possibilities:

1. Since we said that our uncertainty in our experiment was $0.15\ m/s^2$, the two values of g are actually in agreement, given the quoted reliability (uncertainty) in our experiment.
   $g = 9.70\ m/s^2$ +/- $0.15\ m/s^2$ **is** consistent with $9.81\ m/s^2$.

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2. However, if our quoted uncertainty had been **+/-0.01 m/s²**, then our measured result would be greatly at odds (*by 11 times the quoted uncertainty in our experiment*) with the accepted value.

   g **= 9.70 m/s² +/-0.01 m/s²** is NOT consistent with **9.81 m/s²**.

   In this case, one of several things might be going on:

   1. We have greatly underestimated the real uncertainty in our experiment.
   2. We have estimated the uncertainty of our experiment properly, but somehow our experiment was *biased* with an unexpected ***systematic error*** to give a value offset from the norm (see description of systematic errors below).
   3. We have estimated the uncertainties properly and our experimental is giving a proper value; hence we have made a discovery with a significance of 11 times the uncertainty in our experiment (which is quite large).
      (*Perhaps the gravity we measured locally has been skewed by local geology beneath the test apparatus or as a result of our altitude.*)

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3. Let's say that we had evaluated the true uncertainty in our experiment to be **+/-5 m/s²**.

   Our result is now consistent with the true value of *g*, but the accuracy of our measurement is so poor that it is incapable of really distinguishing even significant differences between what we measure and the real value of *g*, and our experiment is not really very useful.

   g **= 9.70 m/s² +/- 5 m/s²** is consistent **with 9.81 m/s²**,
   but is consistent with a huge range of other possible values as well.

   In this case, that we got as close to 9.81 m/s² would have been a case of good luck, because we might well have also measured 7.1 or 13.9 m/s².

As this example demonstrates, how we evaluate our experiment greatly depends on the numerical estimate of the uncertainty (accuracy) of our results.

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Now consider the above three cases where the quoted uncertainties had been correctly determined
(i.e. **+/-0.15**, **+/-0.01** and **+/-5 m/s^2**, respectively),
but we never cited those uncertainty values!

NO ONE would be able to judge the meaning/significance of your experimental result!

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Analysis & Modeling

- E.g. how to talk to computers to help you solve Physics problems, present data, and do basic statistics.

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Analysis & Modeling

- E.g. how to talk to computers to help you solve Physics problems, present data, and do basic statistics.
- Rule #1:
  - Computers do **exactly** what you tell them to do!!
  - (Not necessarily what you **want** them to do!)

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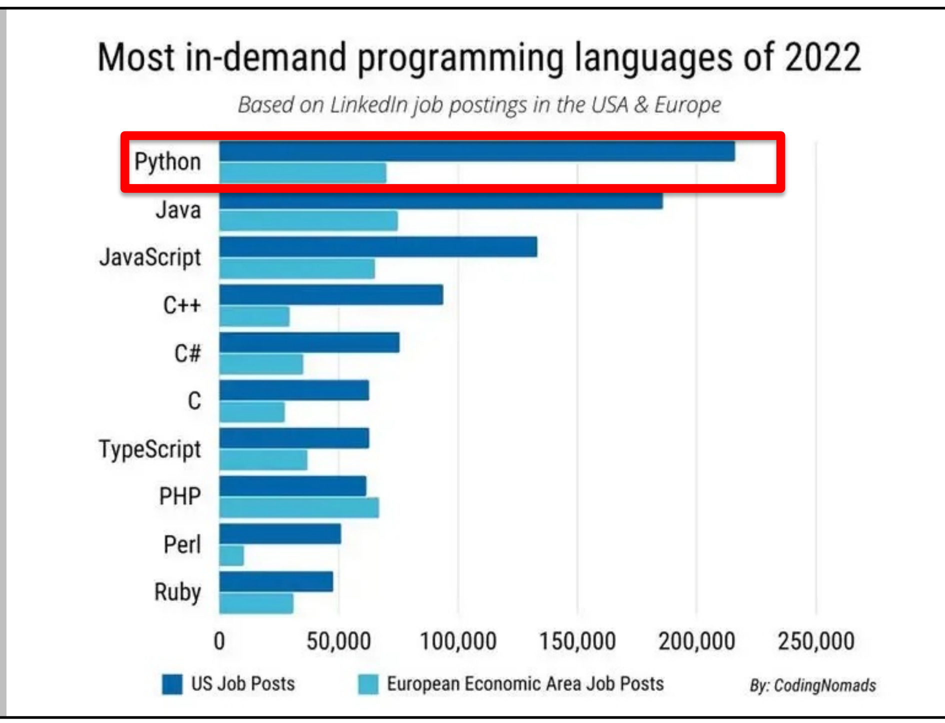

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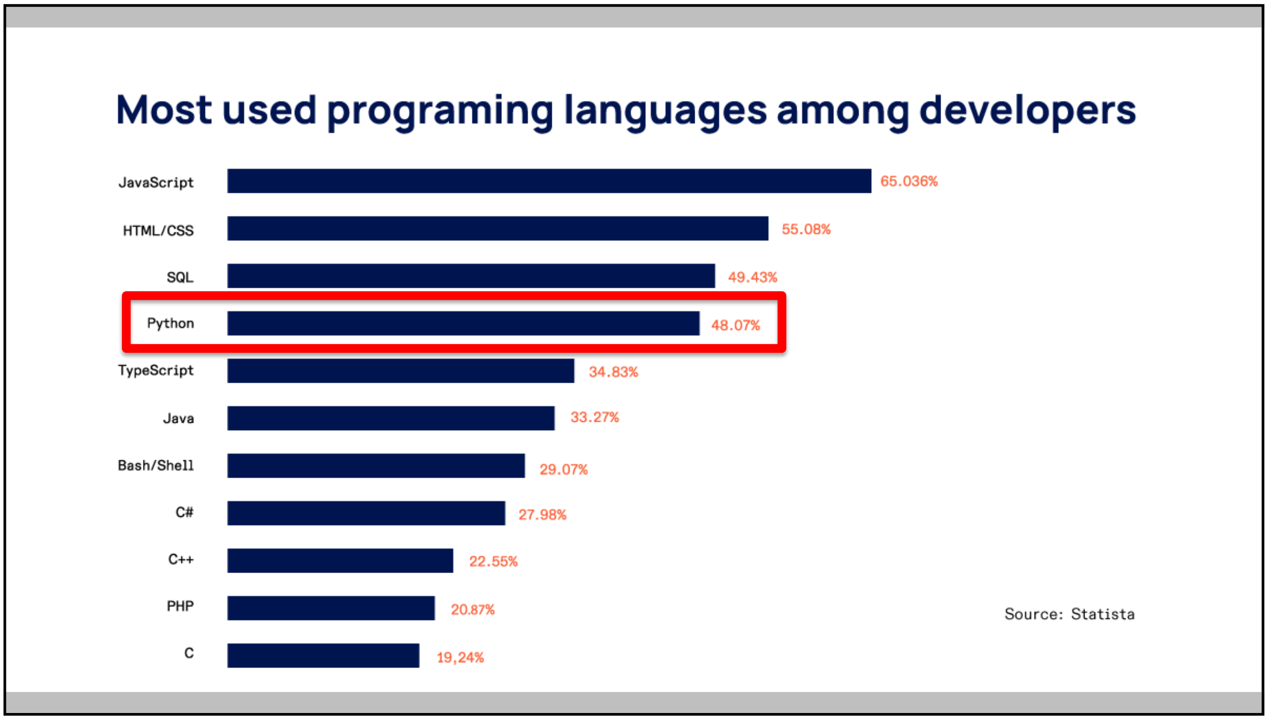

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Python is a general purpose programming language that was named after the Monty Python (so you know it's fun to work with)!

Python is simple and incredibly readable since closely resembles the English language. It's a great language for beginners, all the way up to seasoned professionals.

Python recently bumped Java as the language of choice in introductory programming courses with eight of the top 10 computer science departments now using Python to teach coding, as well as 27 of the top 39 schools.

Because of Python's use in the educational realm, there are a lot of libraries created for Python related to mathematics, physics and natural processing. PBS, NASA and Reddit use Python for their websites.

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Python

- Primary Language used in this class
- Broad usage
  - Simple small codes
  - Large parallel supercomputing codes
  - Becoming a standard in both Academia AND Industry

- But not only language!!! (Fortran, C, IDL, etc.)

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Python

- Strengths
  - Wide usage
  - FREE!!
  - Large User/Library for functionality (and growing)
  - Built-in Plotting
  - ***Available for all platforms for free***

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Syllabus and Class Organization

- Course Assignments
  - Start with assignment Grads additional project
- Class meetings:
  - MONDAY & WEDNESDAY:
    - Lecture (20-40 min)
    - Working time (20-40 min)

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Textbook(?)

- COMPUTATIONAL PHYSICS
  - Mark Newman
    - Chapter 2-5 available online
    - http://www-personal.umich.edu/~mejn/cp/

- Jupyter Python Notebooks

- Which Flavor of Python?
    - Anaconda Python

  http://continuum.io/downloads

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Computer(?)

- Which Flavor of Python?
  - Anaconda Python

  http://continuum.io/downloads

1. CAN USE YOUR OWN – IF YOU WANT
2. ALL COMPUTERS IN SWR 360 – HAVE IT INSTALLED

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