TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
et en physique des particules

The Scientific Method

Modeling How the Universe Works
Since 1609

Overview: the cycle


Observations
Predictions
Models
Simplicity
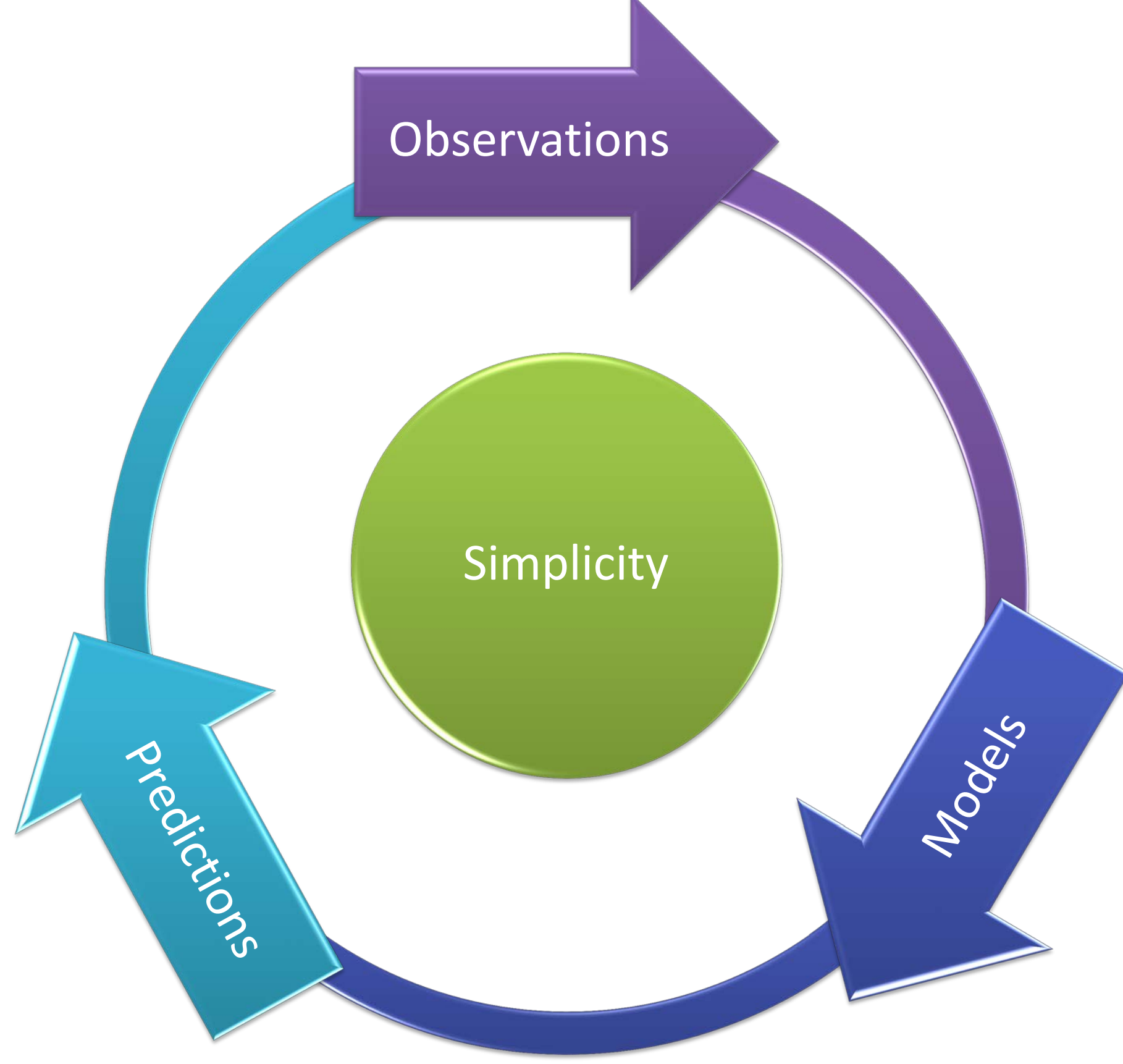
- Begin with a set of observations.
- Create a model to explain the observations.
- Make testable predictions using the model.
- Compare the predictions to new observations.
- Use the comparison to assess and modify the model.
- Repeat as required.

Simplicity selects one preferred model from the many possible models that describe any set of observations.

Observations: the ultimate authority

- ❖ Direct observations by any of the five senses
- ❖ Observations enhanced by aids such as a telescope
- ❖ Controlled experiments
- ❖ Measurements with fancy apparatus like the ATLAS detector at the Large Hadron Collier
- ❖ Need a model of how the detector works even in simple cases like the telescope

But even the simplest observations need interpretation. The cougar may be obvious but is that a rabbit or a duck?
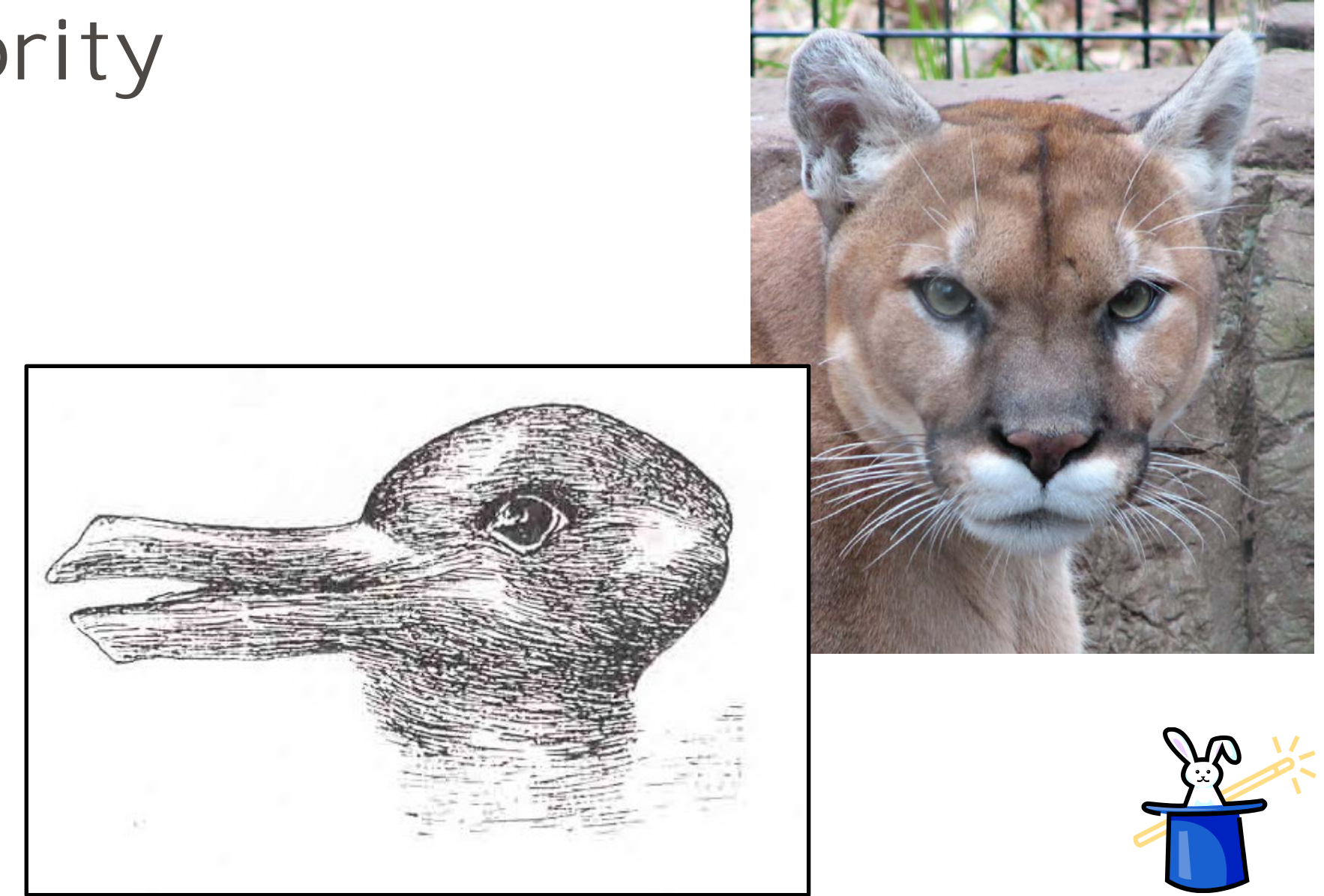
## Predictions: the demarcation criteria for science

Useless prediction:

The two greatest ones of Asia and of Africa,
From the Rhine and Lower Danube they will be said to have come,
Cries, tears at Malta and the Ligurian side.
(Nostradamus)

Cannot be tested. Cannot say with any certainty if it is correct.

Useful prediction:

It will be raining tomorrow at 2:00 pm in Vancouver BC..

Can be tested. Can say with some certainly if it is correct.

TRIUMF in the rain
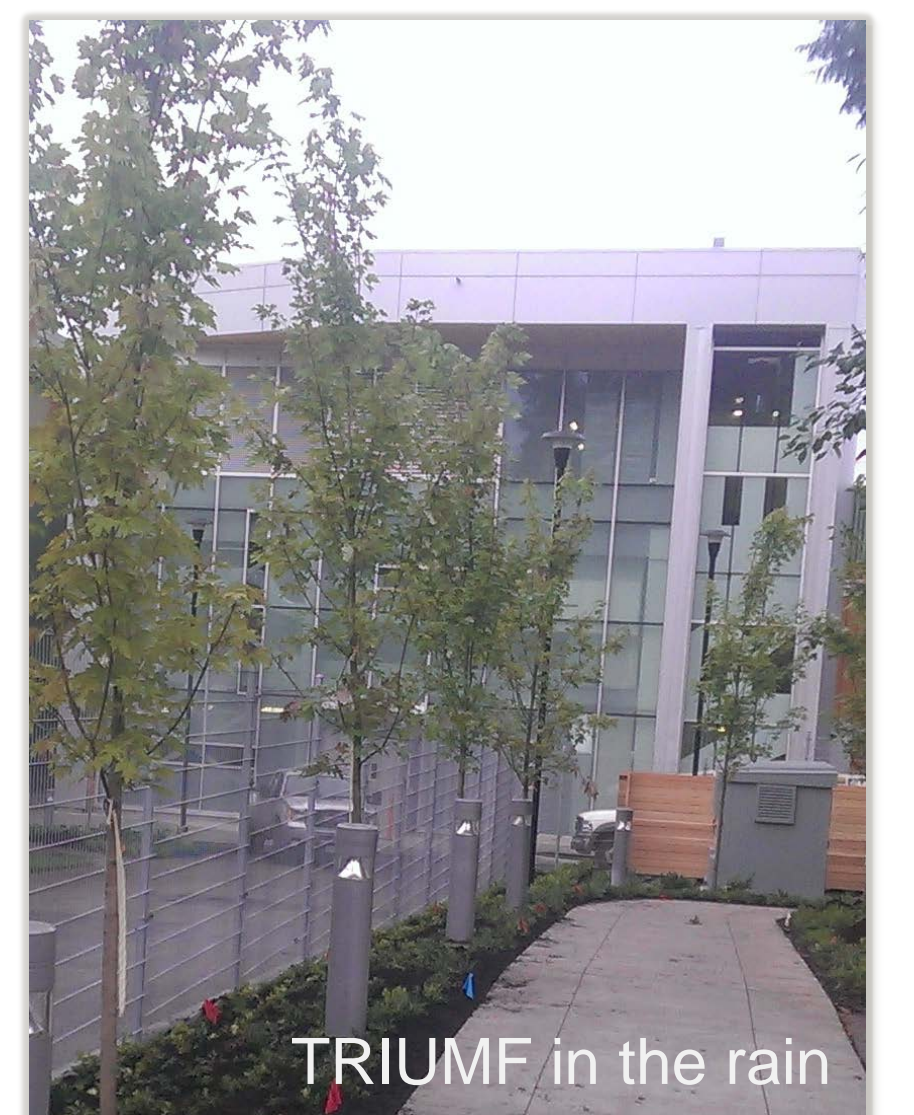
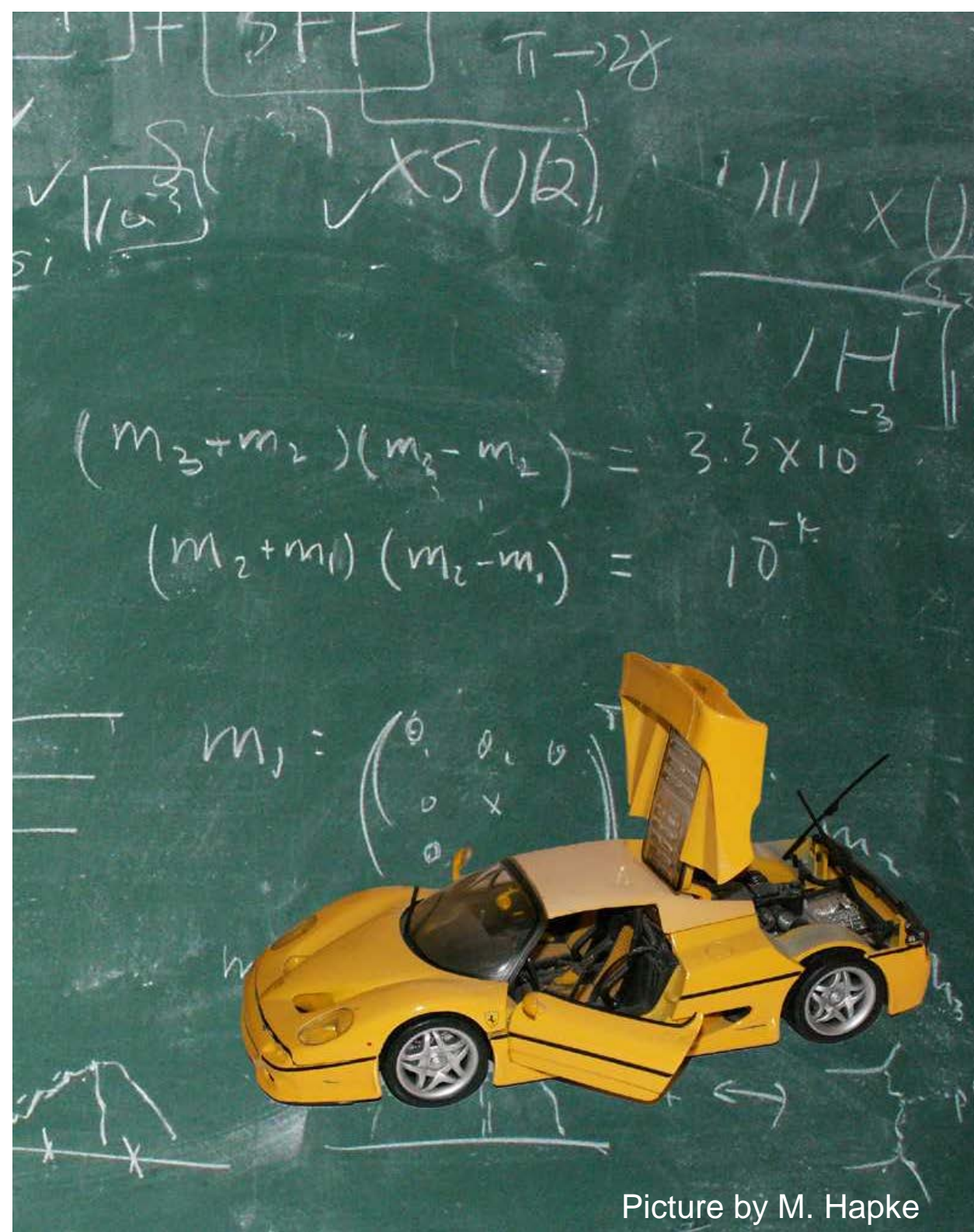**If your model does not make testable predictions it is not science.**

Models 1: what is a model?

The term 'model' can replace:
- ❖ Theory
- ❖ Hypothesis
- ❖ Scientific
  - ➤ Law
  - ➤ Rule
- ❖ Paradigm
- ❖ Controlling Narrative

Model: any construct that helps make predictions. In science it is frequently, but not necessarily, mathematical.

**Model creation is a creative not an algorithmic activity.**

Two Types of models: Mathematical (from a scientist's working blackboard) or a toy.

Picture by M. Hapke

Simplicity: omnipresent

- ❖ Frequently overlooked.
- ❖ More important than fitting the data. The theoretical curve never goes through all the data points.
- ❖ Selects the Standard Model of particle physics from numerous viable alternatives.

Curve misses data points so the curve can be simple
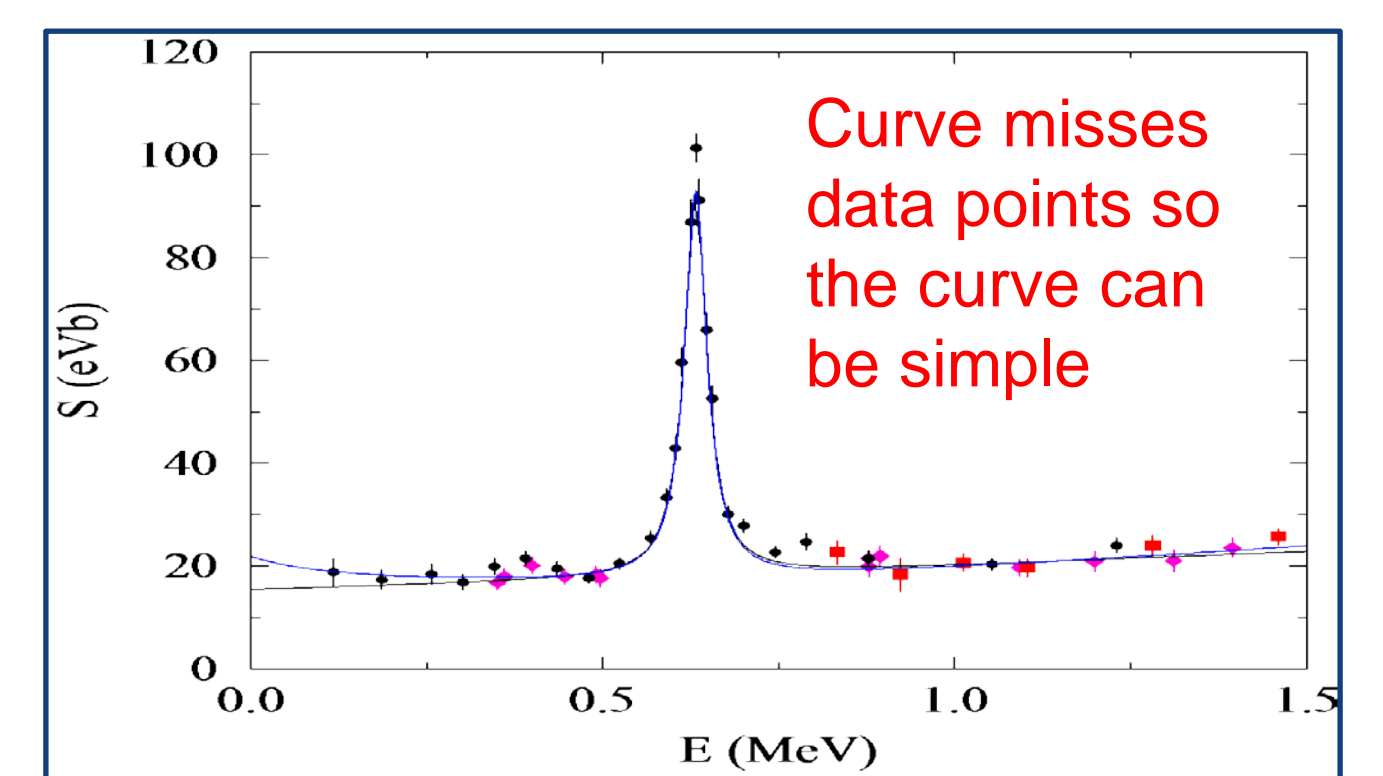
Invisible pink unicorns are eliminated because they do not help make more accurate predictions and add complexity.

Concepts: some clarify and some obscure

Clarify:
- Observation
- Model
- Prediction
- Simplicity

Obscure:
- Realism
- Naturalism
- Fact
- Truth™

Concentrate on the what clarifies. Ignore what obscures.

But is it natural?

Models 2: the meaning is in the model

The human perceptual apparatus creates a model that we mistake for reality. It was honed by evolution and gives meaning to our surroundings; meanings like: *that tawny colored blob in the top right-hand column is a cougar.*

Similarly, scientists create models that we often mistake for reality. However they do give meaning to experiments. Experiments at the Large Hadron Collider are given meaning by the standard model of particle physics.

While the meaning given to observations is model dependent the observations themselves tend not to be.

Neither the models of perception nor the models of science should be confused with reality. In the end, they are only models, useful models that give meaning, but still only models.

Diagram from Wikipedia

The location of the chess pieces only has meaning in the context of a model for how the game is played.

Reductionism versus emergence

Reductionism: resolving the details at shorter scales.

Emergence: hiding the details of shorter scales in a few parameters.

Longer Scales
Shorter Scales

Emergence and reductionism are flip sides of the same coin.

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