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Astronomy

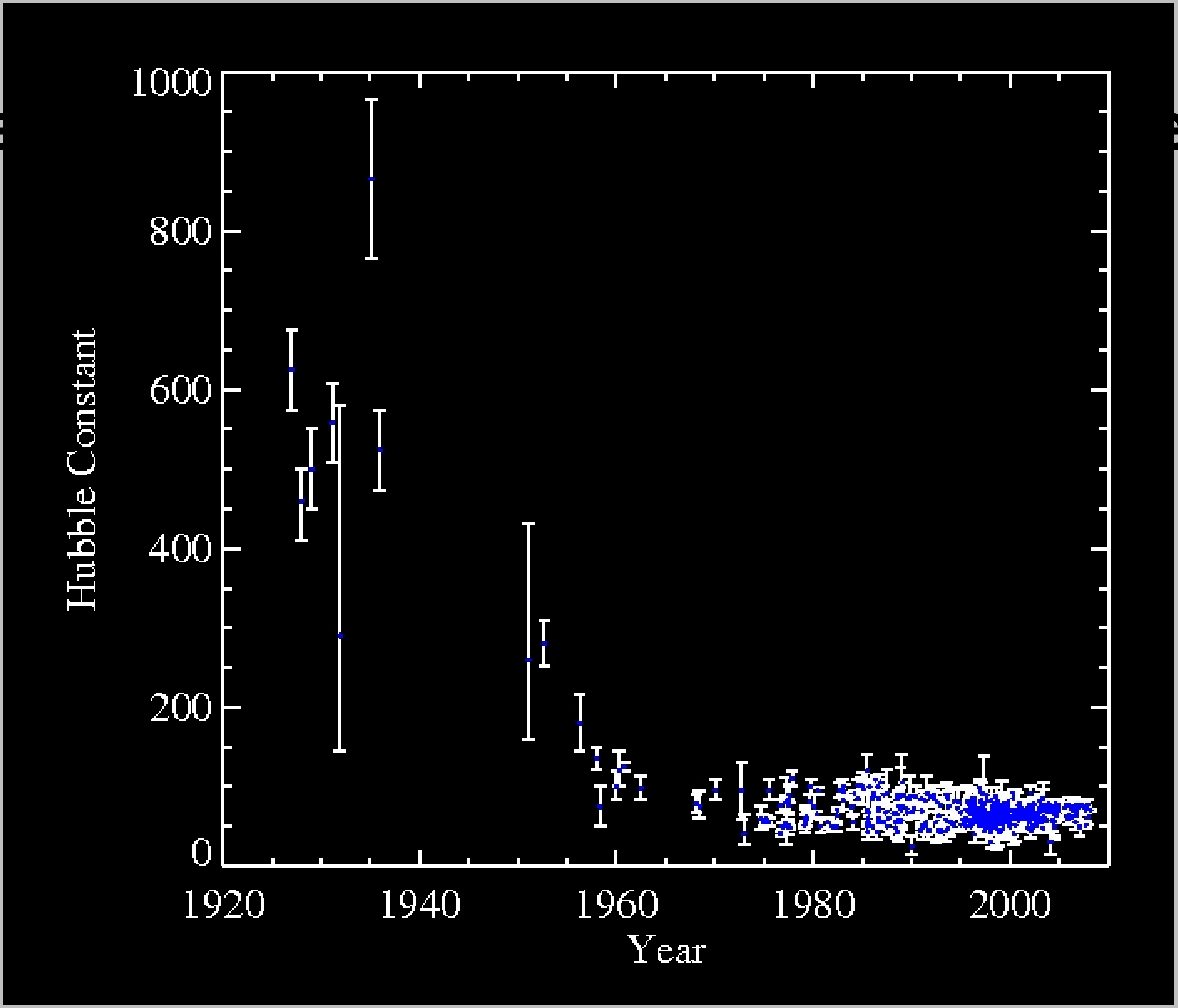
Computational, Statistical, and Mathematical Challenges in Astronomy

The Challenges

- **The Demand for Higher Precision Science**
  - The Hubble Constant

The Challenges

- **The De** ... **ence**
  - The



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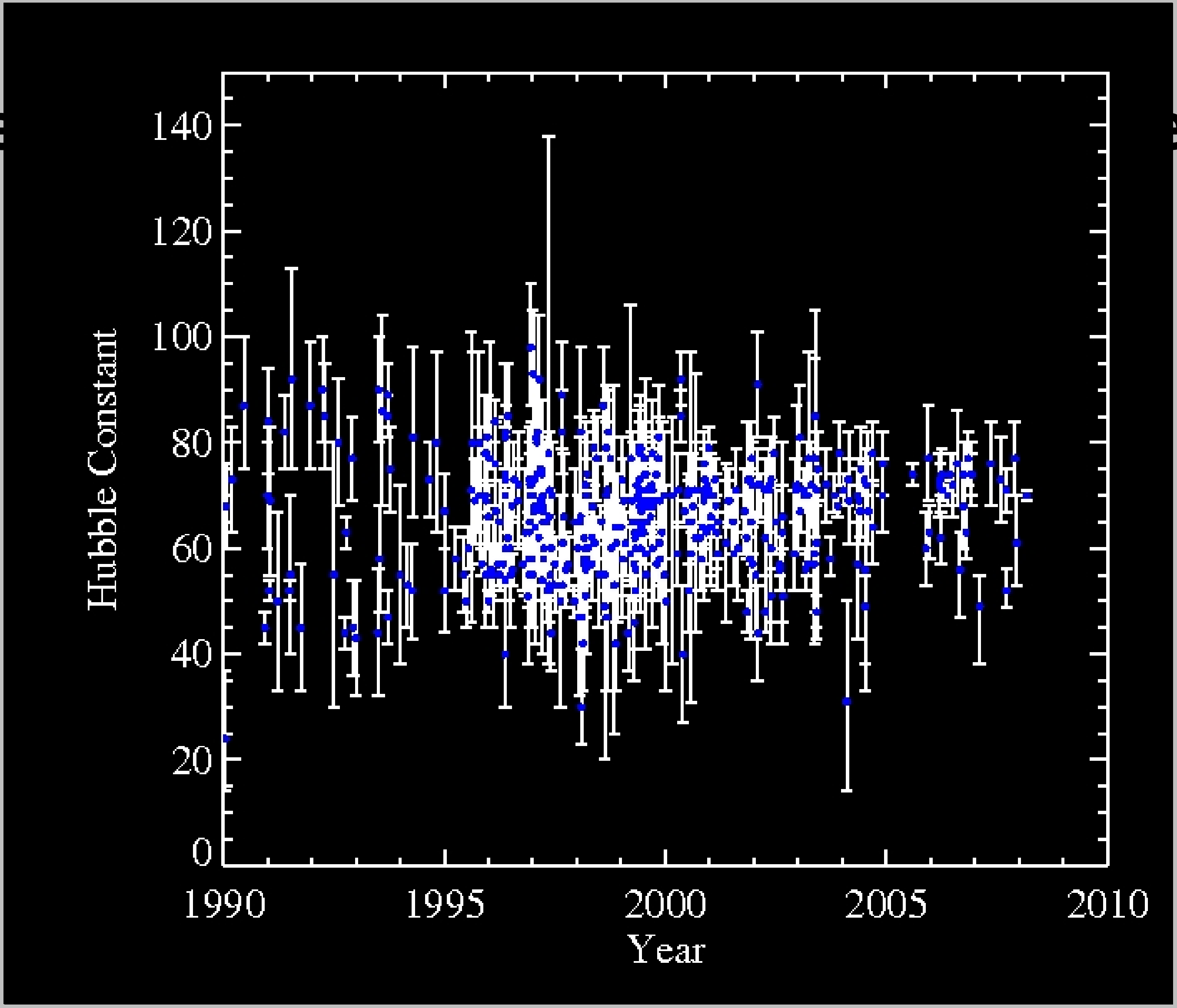

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  - One of dozens of Cosmological Parameter

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  - There is more to astronomy than cosmology
    - Galaxies have mass and stellar populations with ages, metallicities, star formation histories

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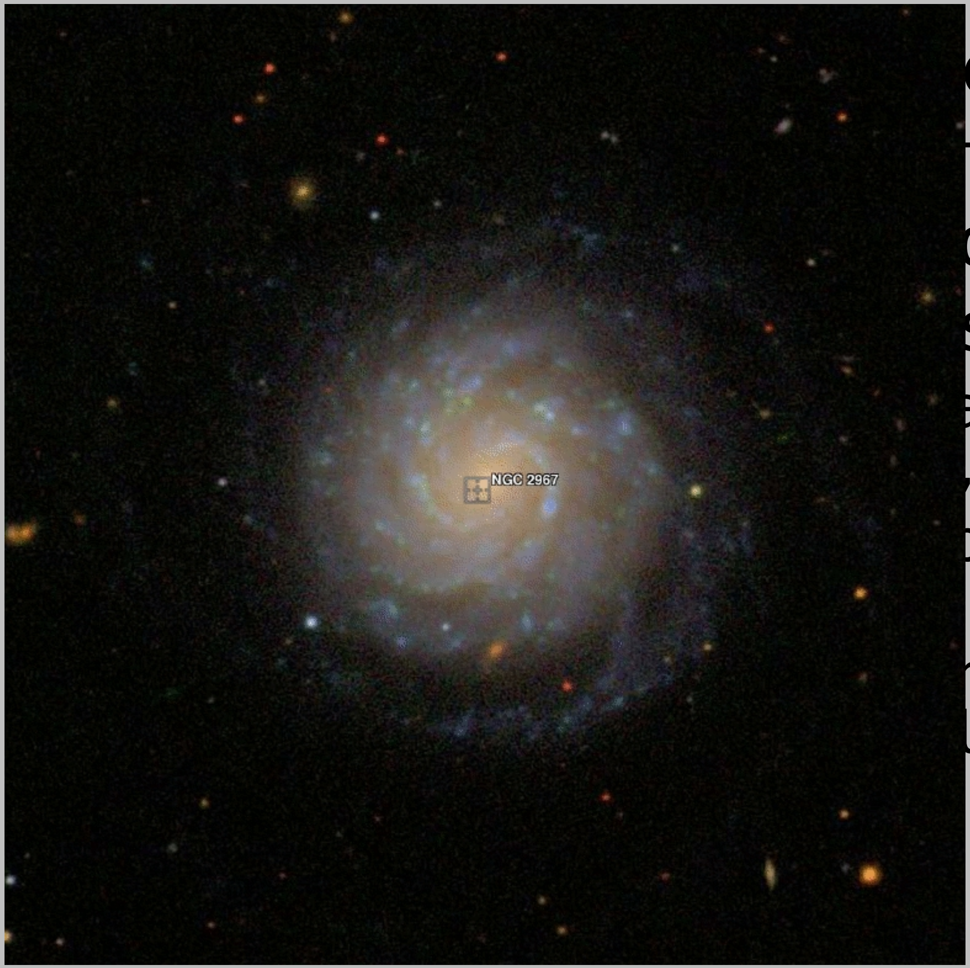

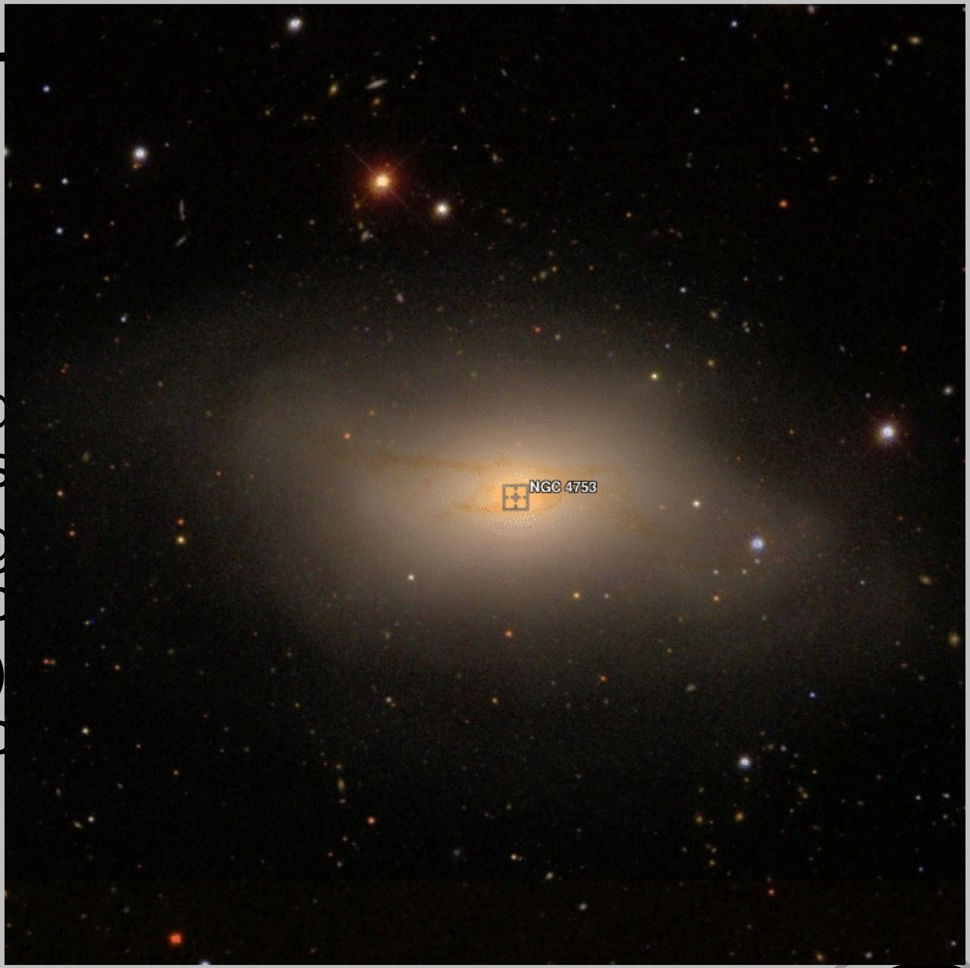

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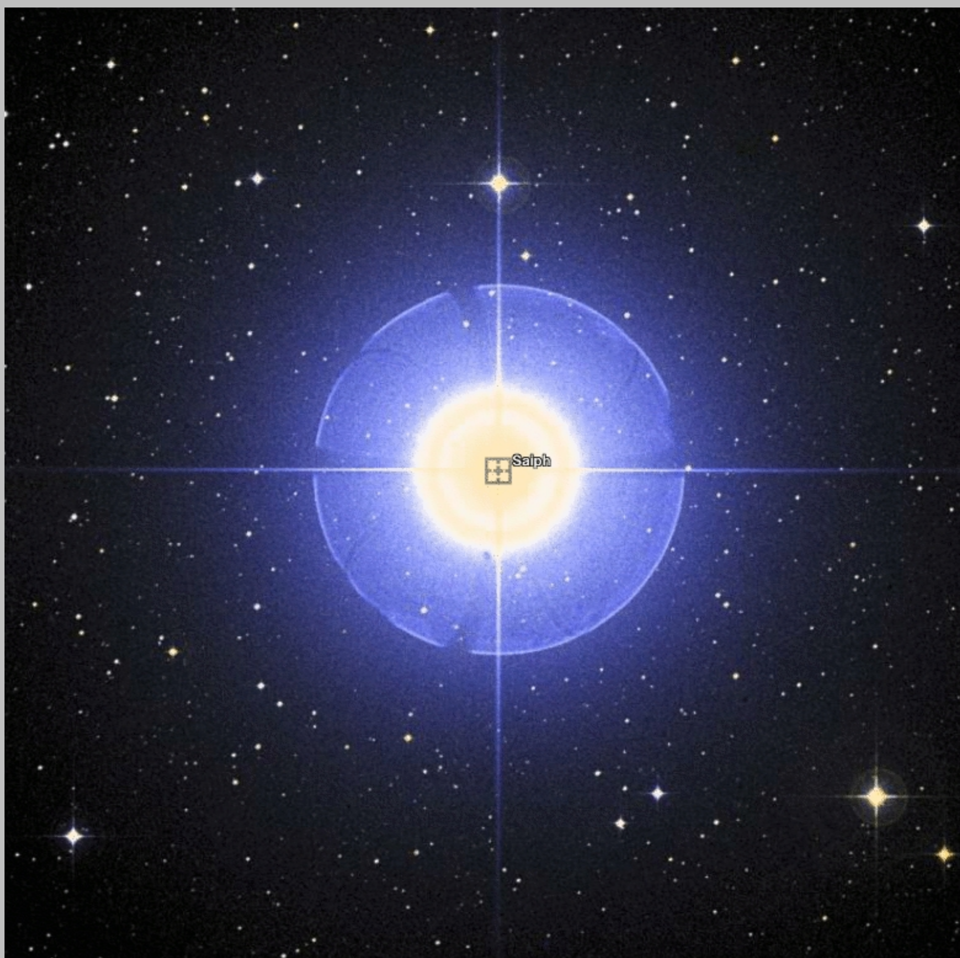

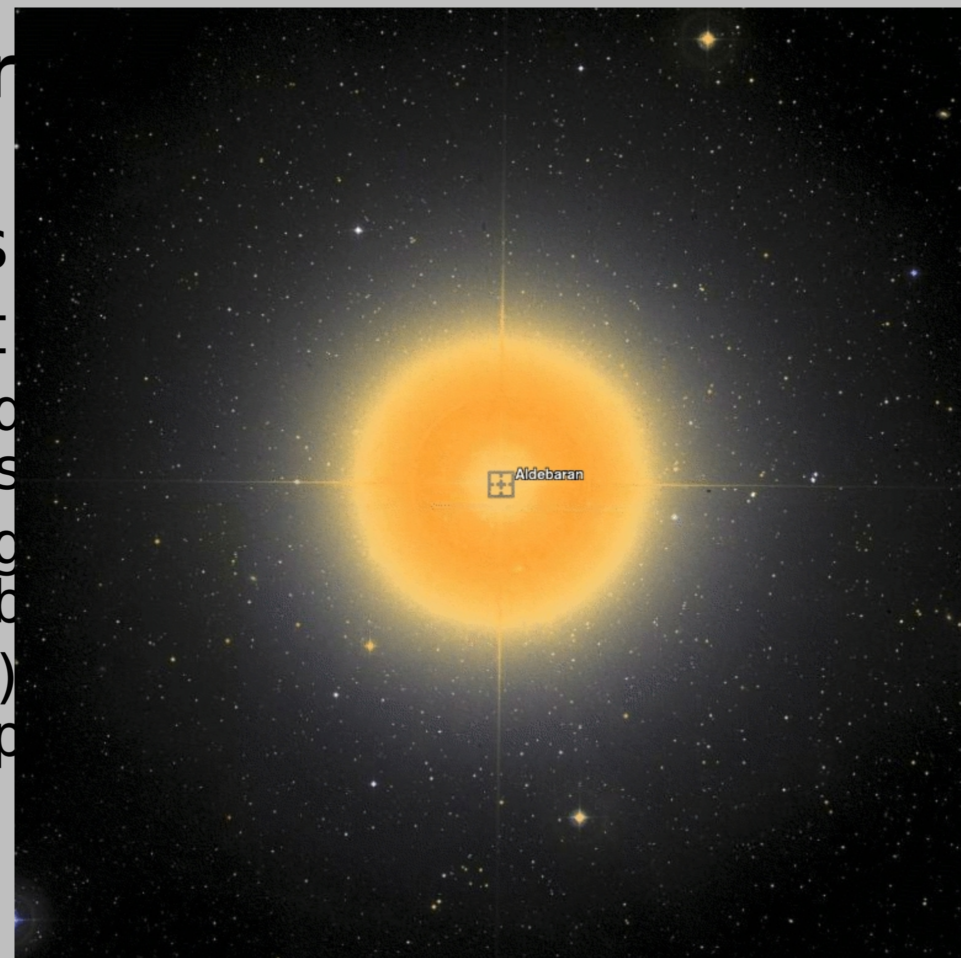

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    - Planets (around stars) have masses, compositions, atmospheres, orbital parameters

The Challenges

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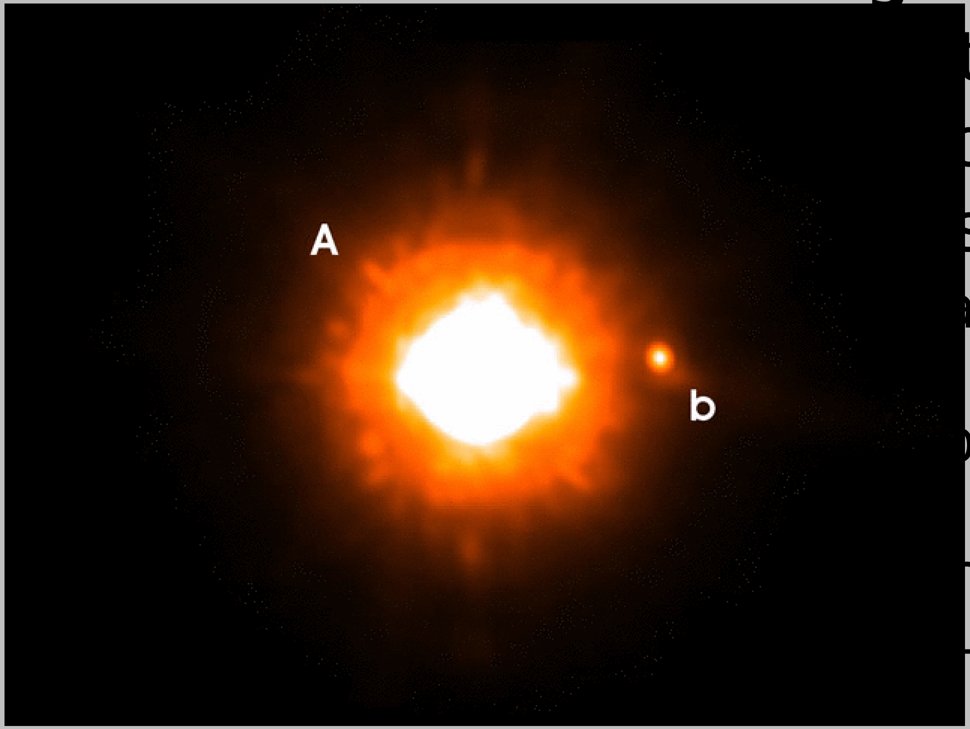
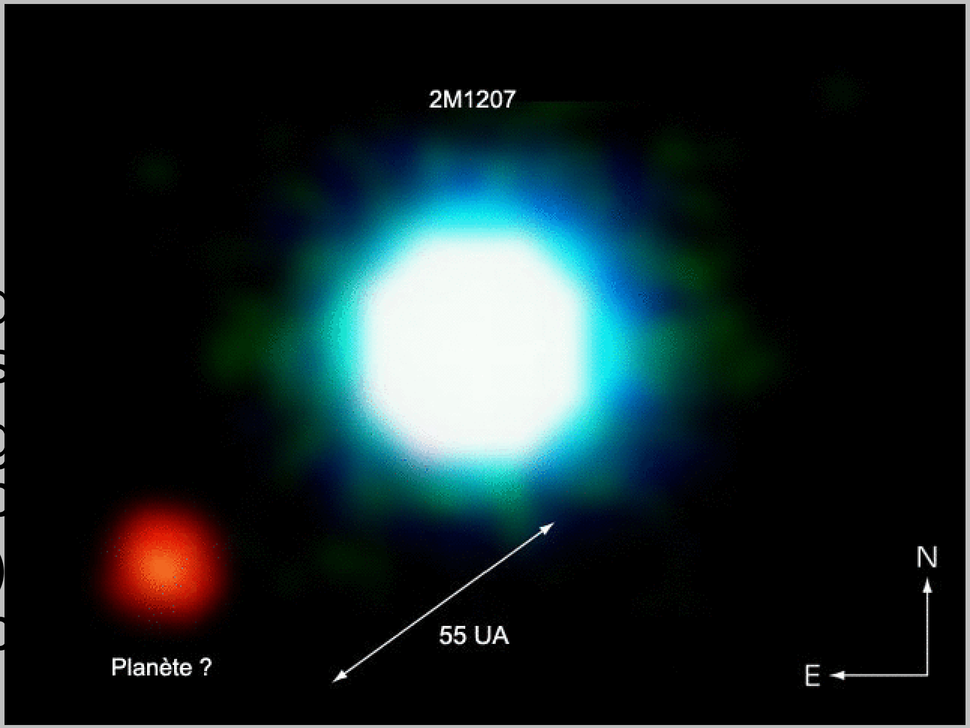
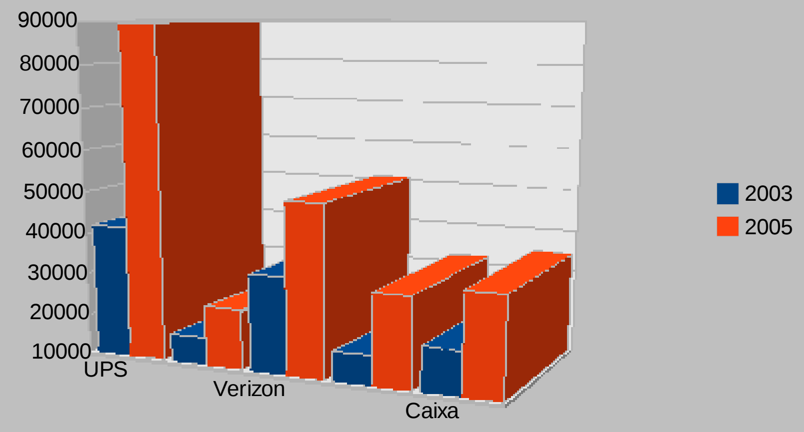




The Challenges

- **The “Data Flood”**
  - Astronomical catalogs today contain about 1.5 billion objects (SDSS is ~300 million, IRSA is ~1 billion).
    - A factor of 20 smaller than the largest commercial DBs
  - LSST (~2020) will have ~50 billion objects
    - Large by today's standards. But average (or even small) by 2015
  - Astronomy has “Real World” DB challenges



Data volumes grow as well.....20 times increase from 2003-2005

The Challenges

- Astronomy Data is Distributed

The Challenges

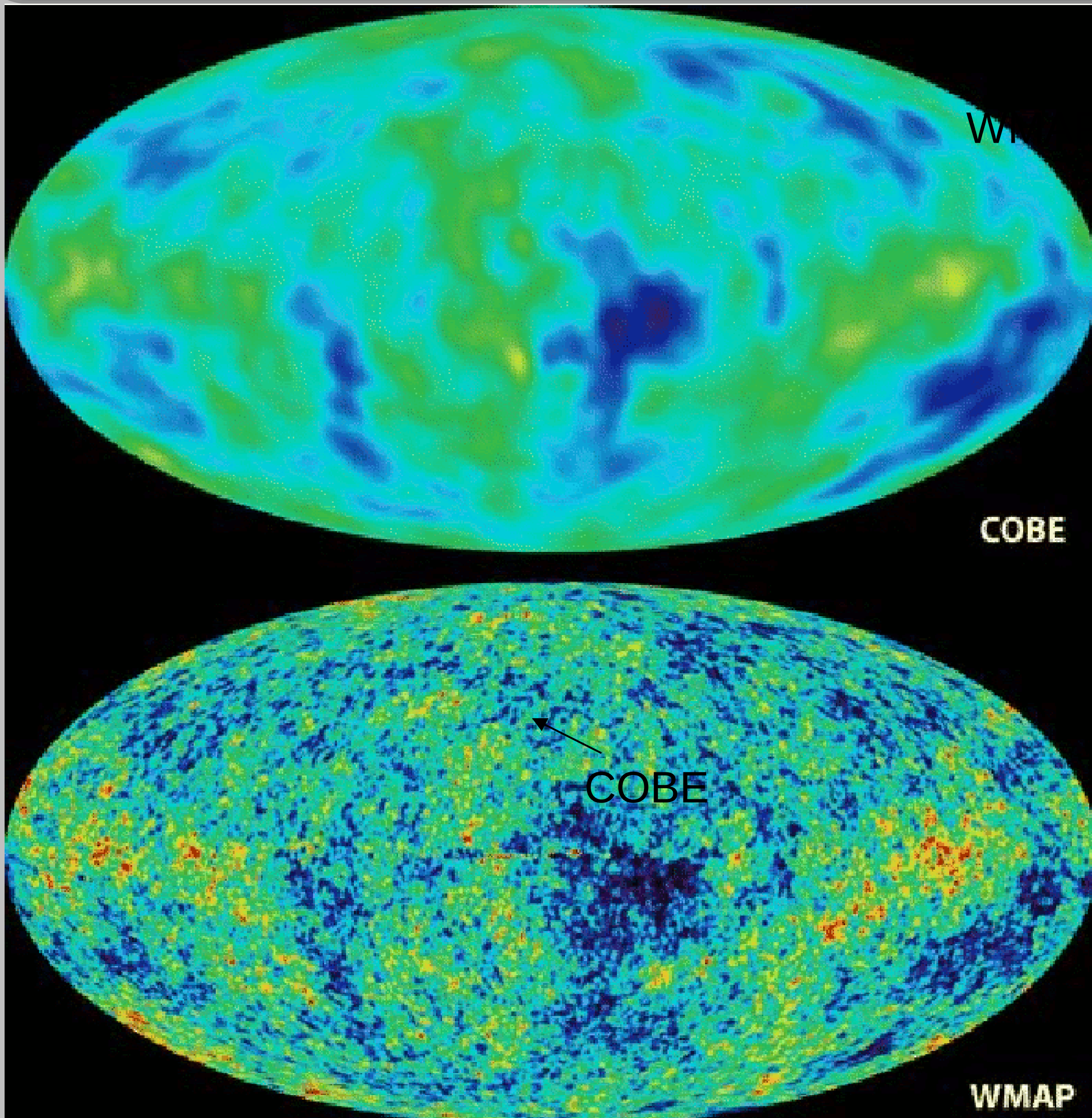
The Solutions

- Astronomical data creates opportunities for Computer Science, Information Technologies, and Statistics
  - Astronomy provides the (interesting) datasets, the distributed network, and the scientific questions
  - IT connects the network
  - CS handles the datasets and algorithms
  - MATHEMATICS and STATISTICS quantifies the answers

The Solutions

- Possible Detection of Baryonic Fluctuations in the Large-Scale Structure Power Spectrum: Miller, Nichol, Batuski 2001, ApJ
- Acoustic Oscillations in the Early Universe and Today: Miller, Nichol, Batuski 2001, Science
- Controlling the False Discovery Rate in Astrophysical Data Analysis: Miller, Genovese, Nichol, Wasserman, Connolly Reichart, Hopkins, Schneider, Moore, 2001 AJ
- A new source detection algorithm using FDR Hopkins, Miller, Connolly, Genovese, Nichol, Wasserman, 2002 AJ
- A non-parametric analyss of the CMB Power Spectrum Miller, Genovese, Nichol Wasserman, ApJ
- Non–parametric Inference in Astrophysics, Wasserman, Miller, Nichol, Genovese, Jang, Connolly, Moore, Schneider, 2002
- Detecting the Baryons in Matter Power Spectra Miler, Nichol, Chen 2002 ApJ
- Galaxy ecology: groups and low-density environments in the SDSS and 2dFGRS Balogh, Eke, Miller, Gray et al. 2002, MNRAS
- The Clustering of AGN in the SDSS Wake, Miller, Di Matteo, Nichol, Pope, Szalay, Gray, Schnieder, York 2004 ApJ
- Nonparametric Inference for the Cosmic Microwave Background Genovese, Miller, Nichol, Arjunwadkar, Wasserman. 2004 Annals of Statistics
- The C4 Clustering Algorithm: Clusters of Galaxies in the SDSS Miller et al. 2005 AJ
- The Effect of Large-Scale Structure on the SDSS Galaxy Three–Point Correlation Function Nichol et al. 2006, MNRAS
- Mapping the Cosmological Confidence Ball Surface Bryan, Schneider, Miller, Nichol, Genovese, Wasserman, 2007 ApJ
- Inference for the Dark Energy Equation of State Using Type Ia SN data Genovese, Freeman, Wasserman, Nichol, Miller 2008, Annals of Statistics

Example: Non-parametric fits of the CMB



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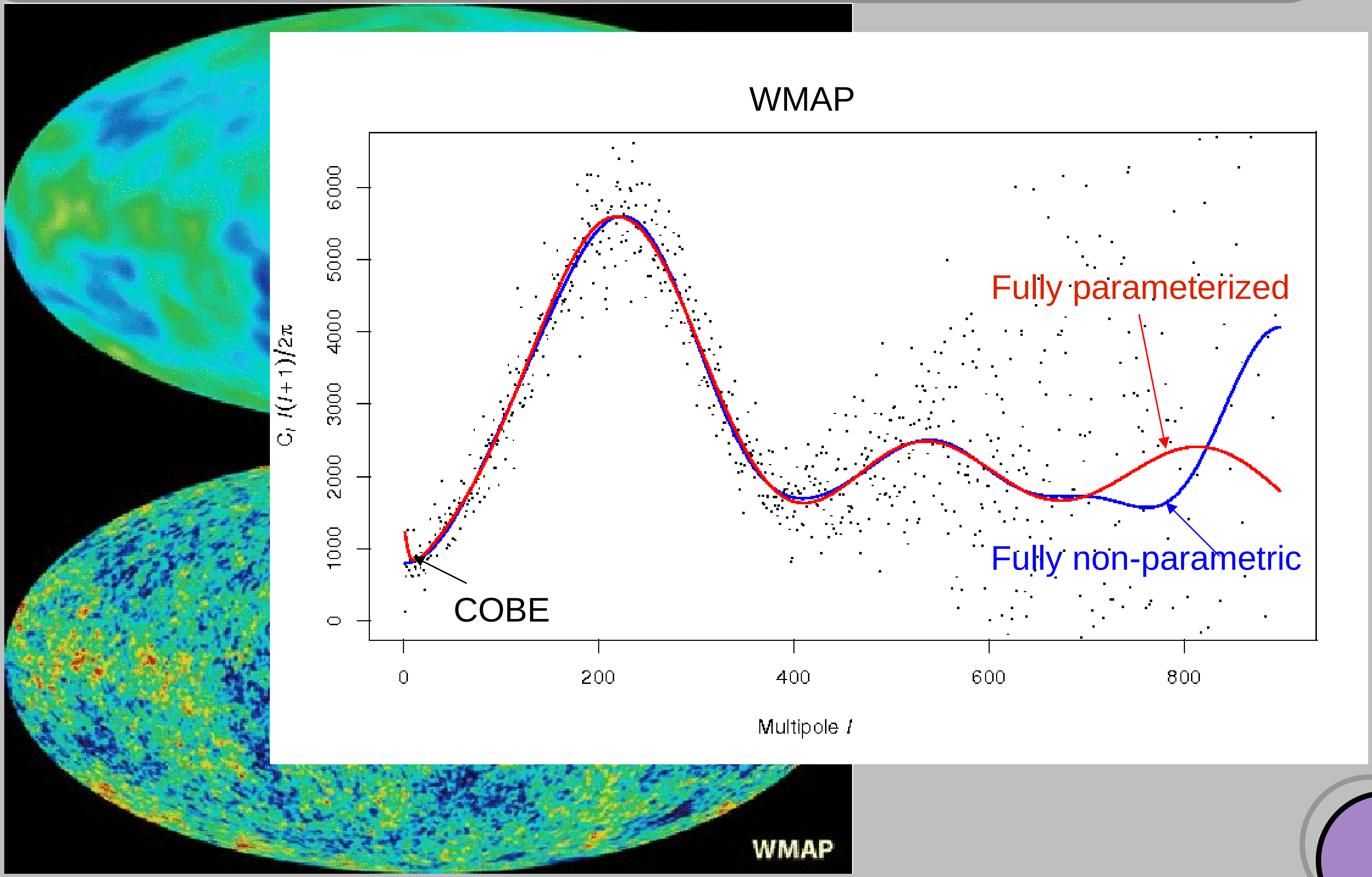
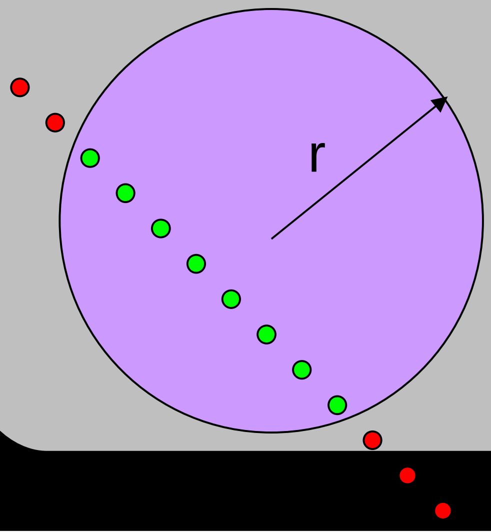
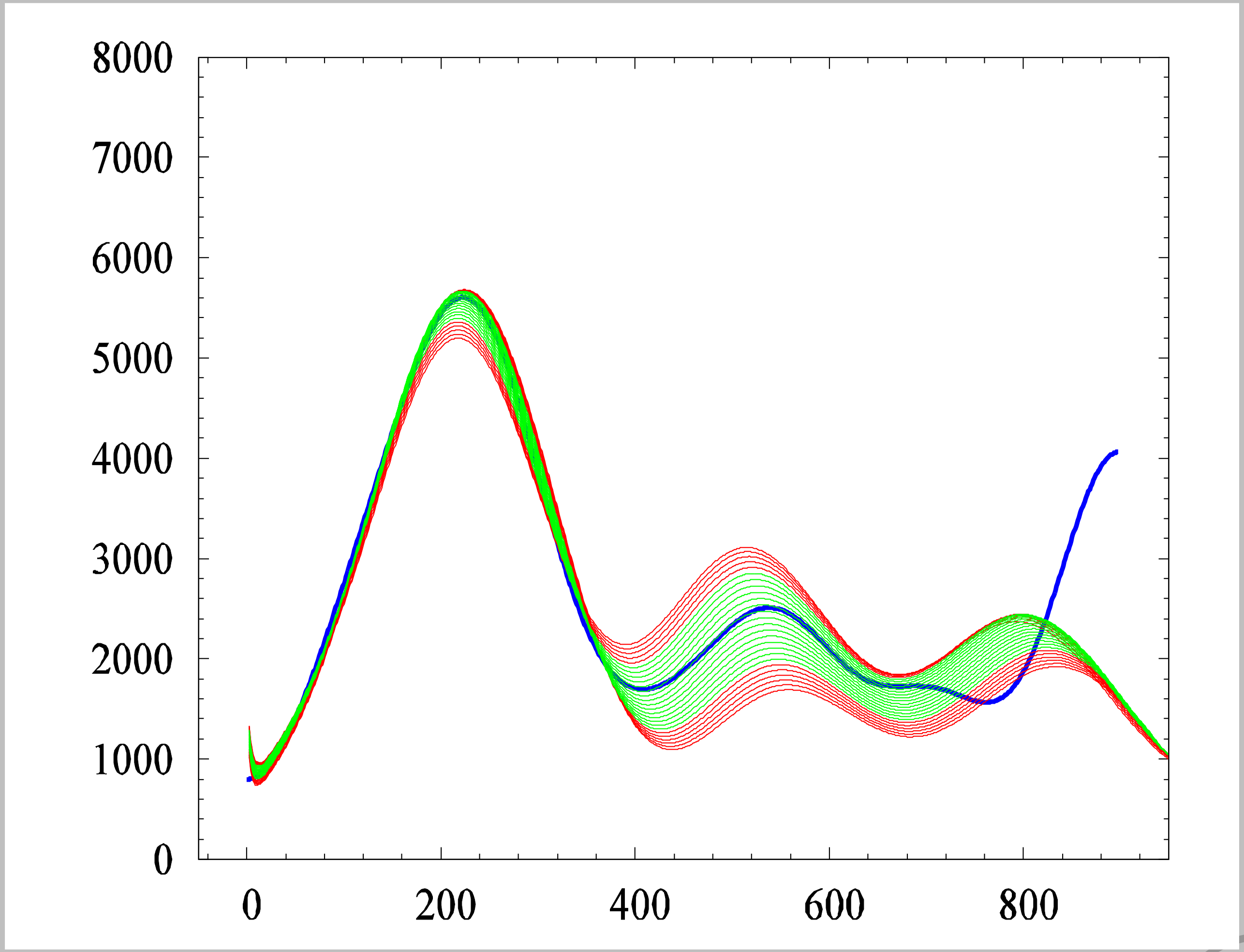


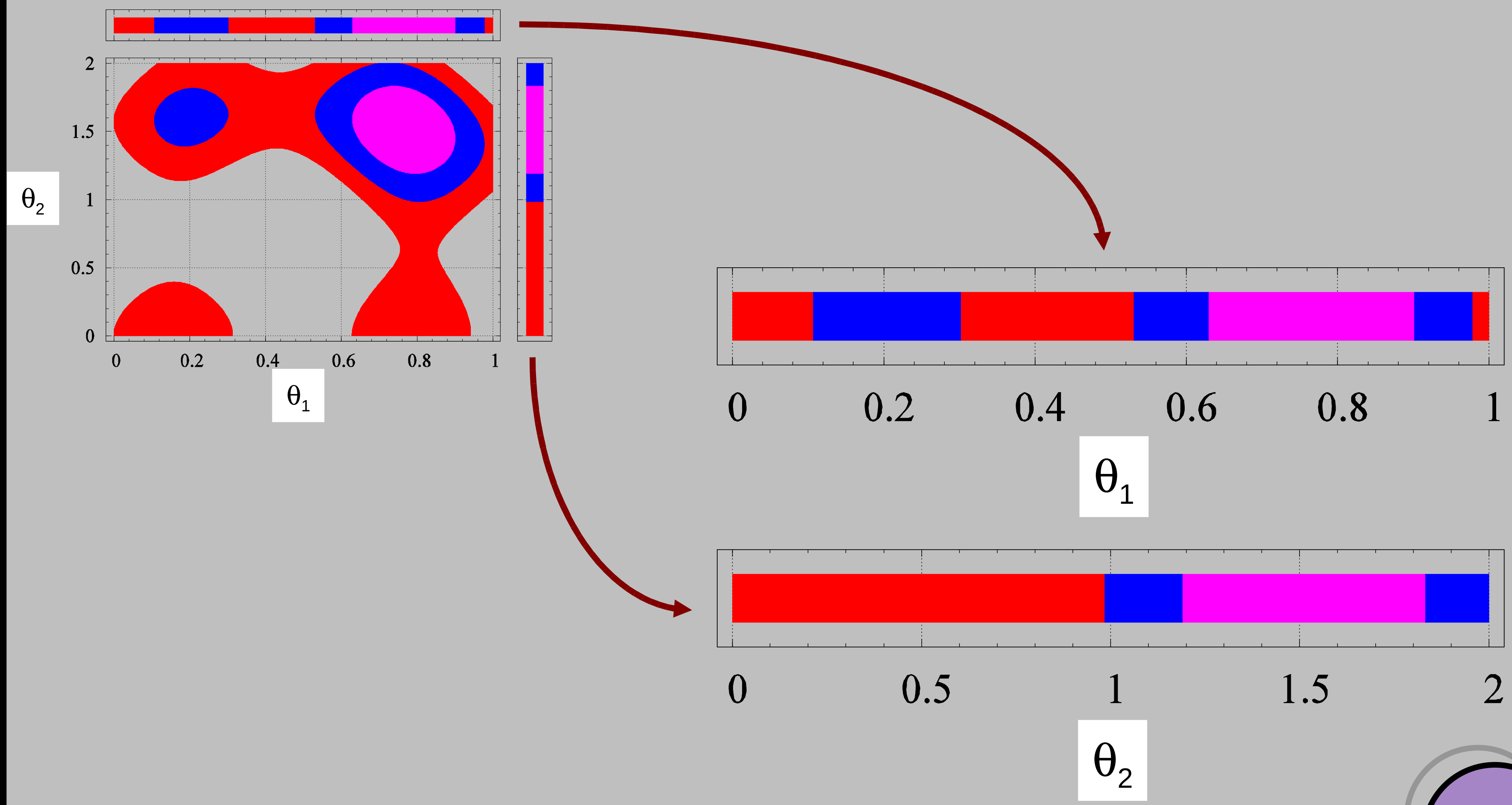
Confidence Balls: Pictorially

1. obtain experimental data
2. compute non-parametric fit
3. compute confidence ball
4. Iterate through parameters to determine confidence.

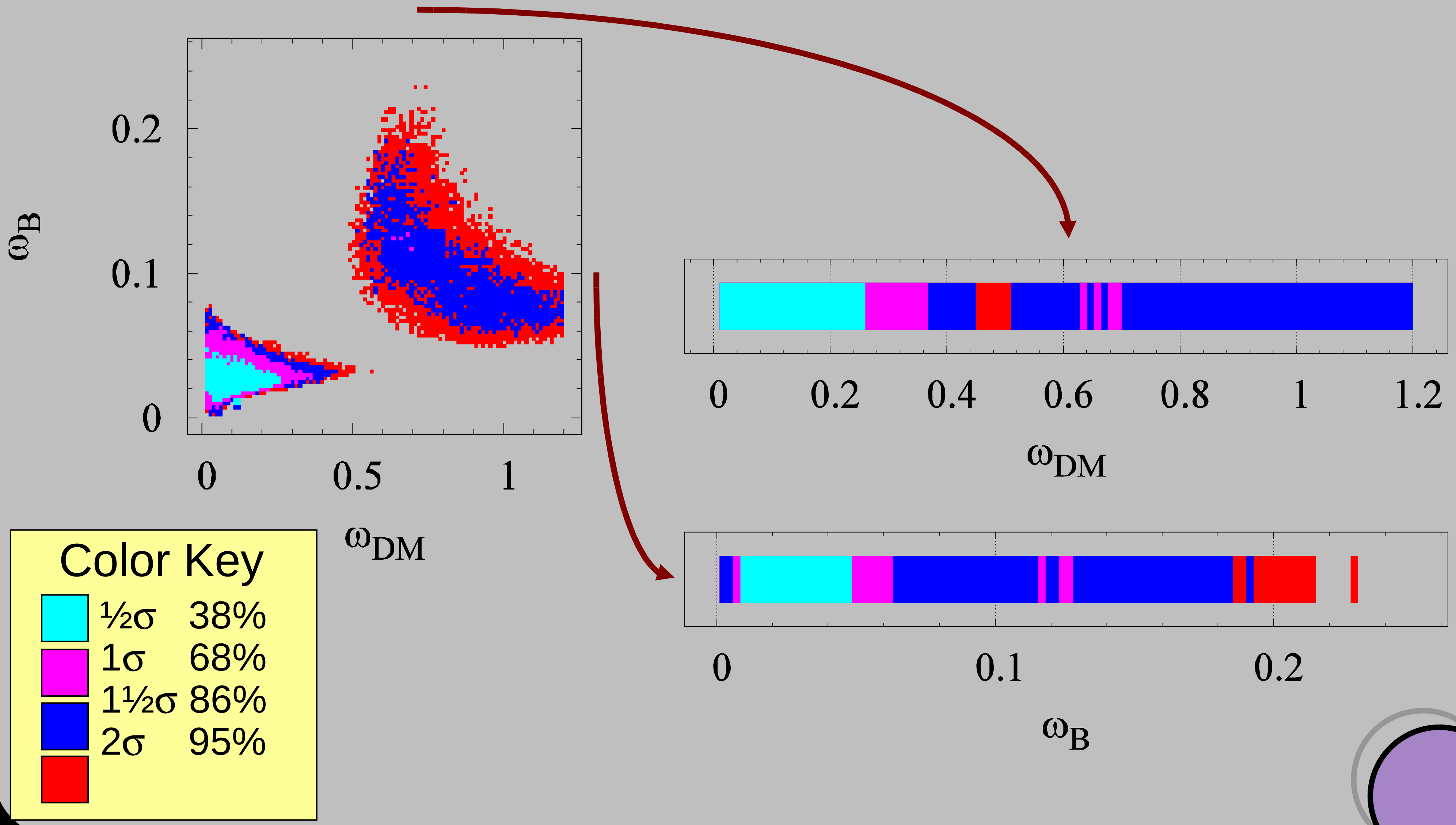




Deriving Confidence Intervals

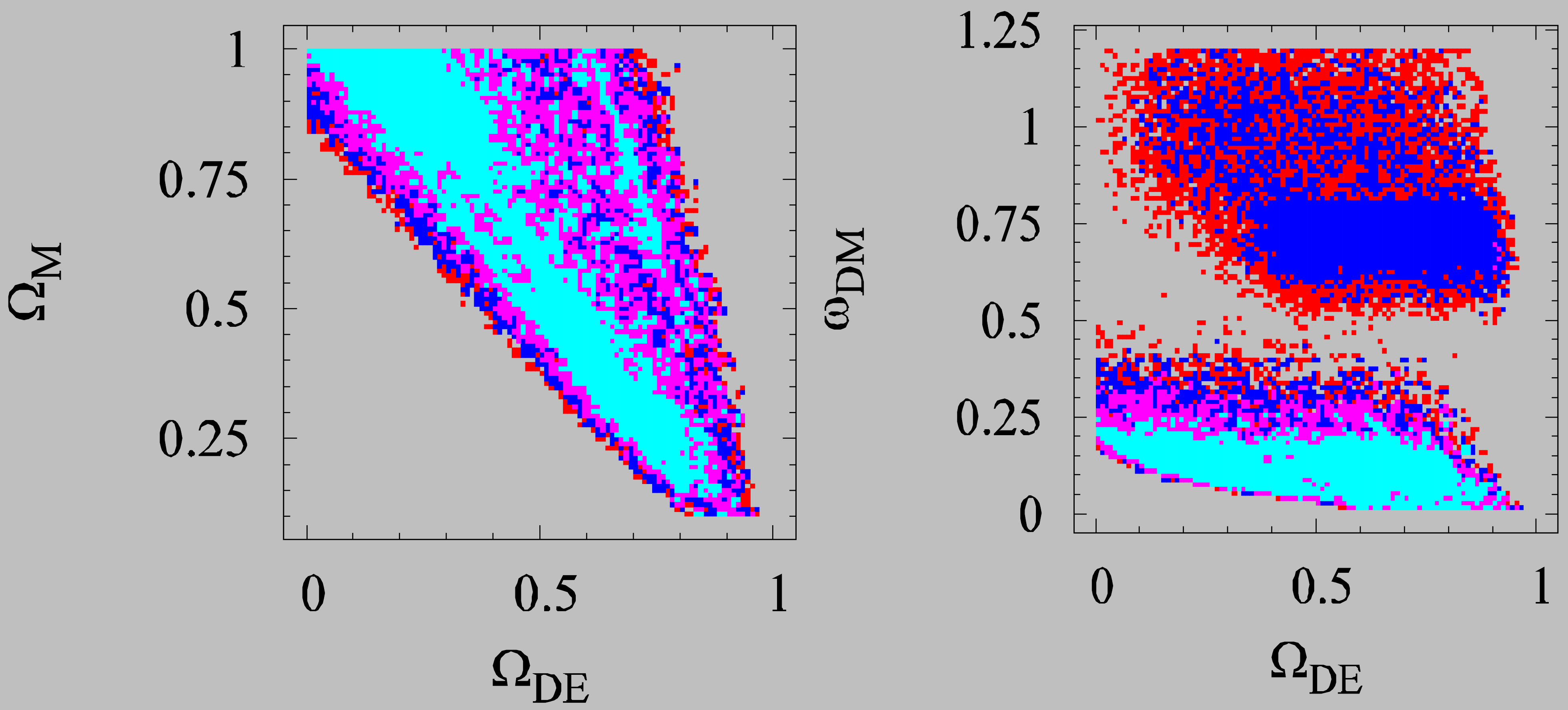


Cosmological Confidence Intervals



Including Assumptions

(Bryan et al., ApJ 2007)



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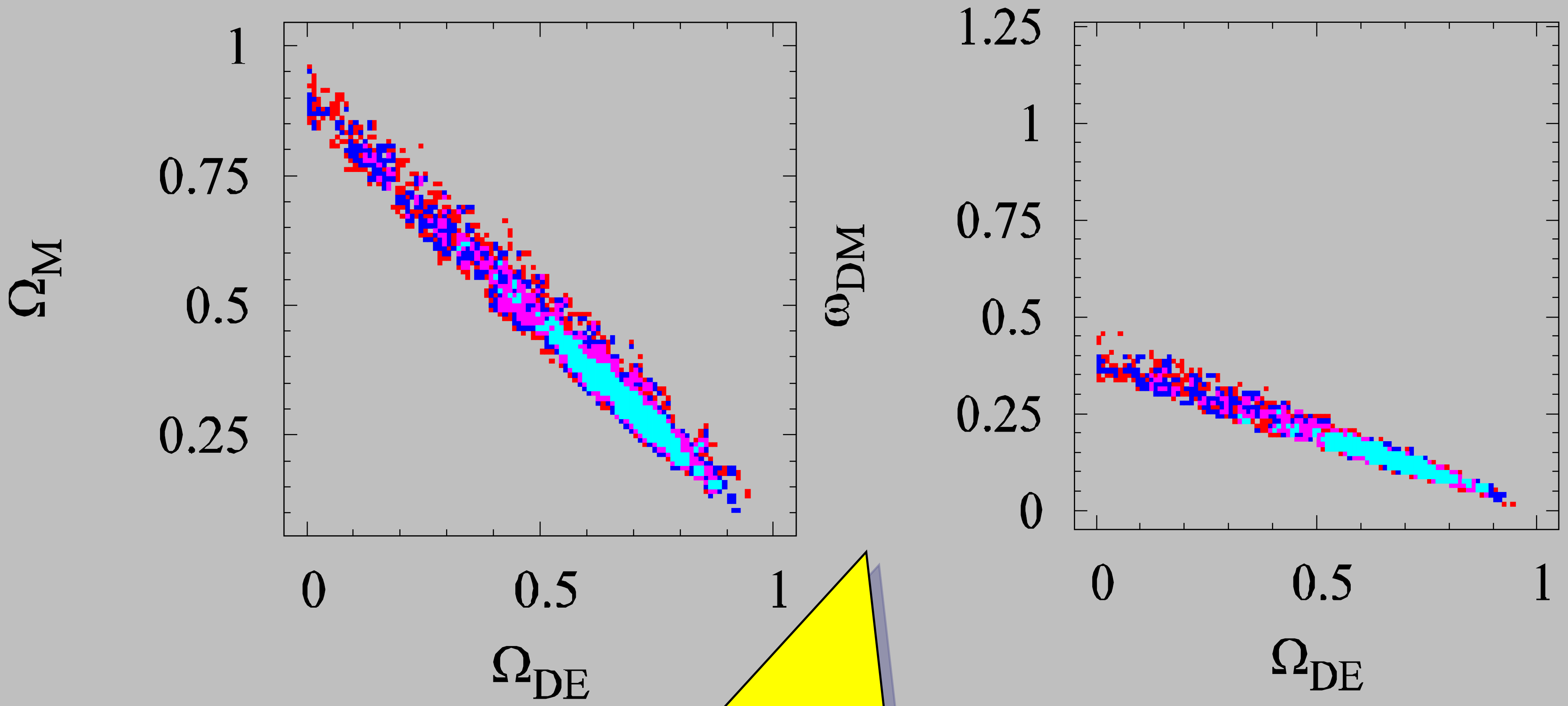
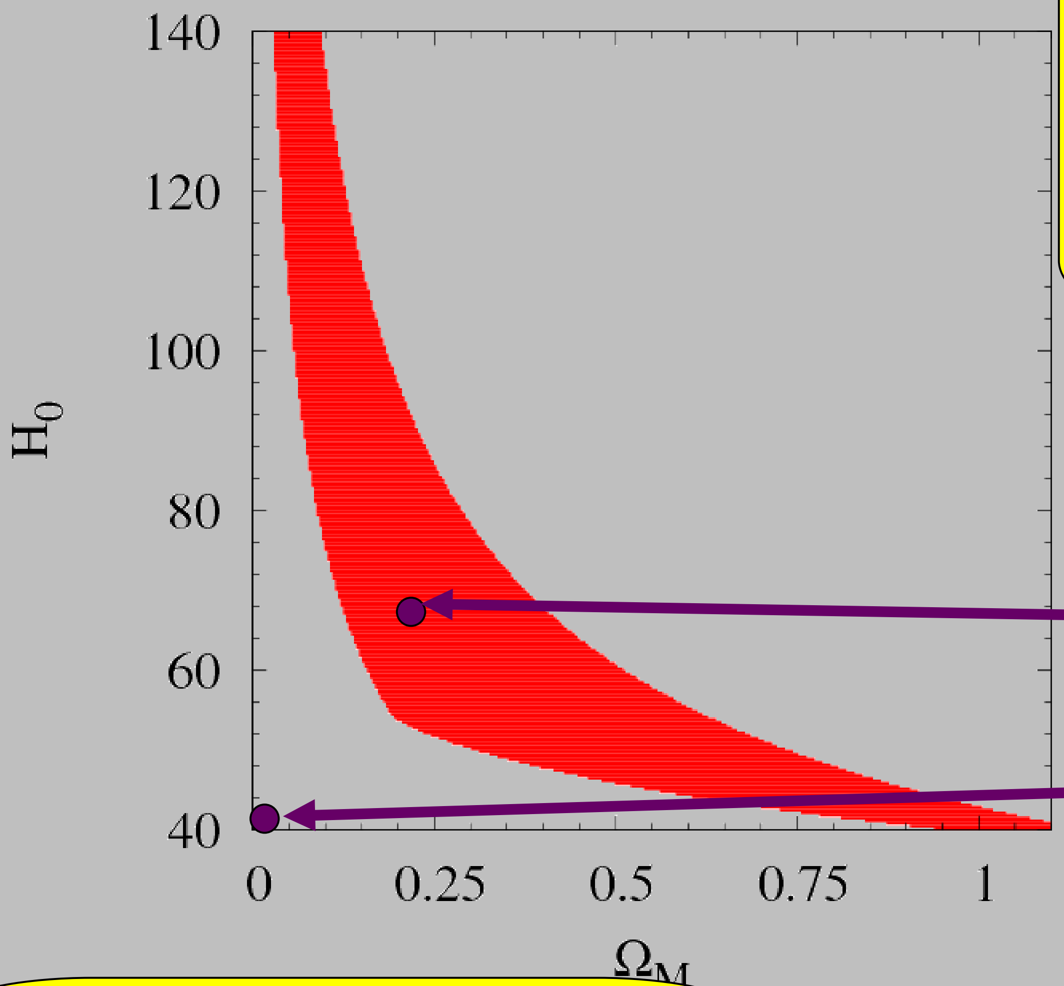


Assumes $60 \leq H_0 \leq 75$ (km/s)/Mpc

What Does “Convergence” Mean?

To prove p_1 is within the confidence region:
$\exists\ \Omega_\Lambda$ such that $m(\theta)$ is accepted



- $\theta = \{H_0, \Omega_M, \Omega_\Lambda\}$
- $p_1 = \{65, 0.23, ?\}$
- $p_2 = \{0.02, 42, ?\}$

can’t check all Ω_Λ

s from based

To prove p is not within the region:
$\forall\ \Omega_\Lambda$, $m(\theta)$ is rejected

A Summary of the INCA Group Activities in Astronomy

- Originated at Carnegie Mellon University and the University of Pittsburgh (PiCA Group).
  - Membership expanded and members moved so that we changed the name to the INternational Computational Astrostatistics Group).
- A loose group of committed researchers (no formal structure)
- Astronomy provides the data and drives the science
  - Real work is done in developing, proving, and applying novel statistical methods and computational algorithms to astronomical datasets
  - Success is shared equally amongst the domains
- What are we interested in?

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- What are we interested in?
  - Parametrics
    - Dis-entangling multiple -components via Expectation Maximization
  - Nonparametrics
    - Reducing the size of the error ellipse
  - Non-linear SVM-like spaces
    - Focusing the available model space
  - High-dimensional searches and surface fitting
    - Constraining (as opposed to finding) the truth