Detecting the Unexpected
Discovery in the Era of Astronomically Big Data

Insights from Space Telescope Science Institute’s first Big Data conference

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"Big Data" is a term borrowed from industry, which collects data on large scale from users and sensors, and is typically used to serve advertisements with a higher return on investment than would otherwise be possible.

Our definition:

• Data whose raw form is so large that we must qualitatively change the way in which we reduce, store, and access it.

• Data whose reduced form is so large that we must qualitatively change the way in which we interact with and explore it.

• Data whose structure is so complex that our current tools cannot efficiently extract the scientific information we seek.
Our conference was not concerned with \textit{data volume} so much as \textit{the scientific method}.

Technology growth outpaces astro imaging.
Serendipitous discovery is a foundation of astronomy. Is that foundation secure in the era of Big Data? What do we need to do technically and culturally to continue to detect the unexpected?
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Themes

Machine Learning: Have a computer look at it

Citizen Science: Have a lot of people look at it

Visualization: Look at it better
Machine Learning
(non-parametric classification of high-D data)

• Many outlier detection methods were discussed: DEMUD, RF methods
tSNE, various eigenbasis methods
• Many finds including galaxies and stars with unexplained spectra
• Often outliers are “close” in these spaces; extreme outliers are known/artifacts
• Classifiers are becoming portable from theory to data, and from data to data
• Models (theory) can quantify the expected look for unexpected in residuals
Deep Learning (data classification directly from pixel data)

• Deep Learning / Artificial Neural Net are seeing a fast expansion in astronomy, especially Convolutional Neural Nets (CNNs)
• CNNs are mostly used for classification, but can also be used to hone intuition
• Topics include strong lenses, galaxy morphology, dark matter, dark energy
• Deep Learning requires astronomers to think about their models as big data, which is a wholly new skill set
Citizen Science
(contributions from laypeople over web)

• Zooniverse is the dominant platform for citizen science, with many big unexpected discoveries to date (Boyajian’s star, Hanny’s voorwerp, green peas, etc.)
• CS can be used in synergy with machines in the big data era: different weaknesses
• Building CS tools is extremely easy — a presenter built one during her 15 minute talk
• CS requires a new skill set for astronomers to use it effectively: community management
Visualization

- Multidimensional visualization is key for understanding and exploring big data
- Hackable interfaces allow users to explore data easily but also deeply
- Fast visualization of very large data sets is a real engineering challenge
- Federation of big data systems will be needed if we expect to visualize them with a range of tools
Philosophy & Culture

• If we want junior people doing high risk data exploration we need better ways to protect them in case of failure
• Our culture needs to think more clearly about the term “fishing expedition”
• We need to reaffirm our commitment to software as “soft instrumentation”
• Detecting the Unexpected requires teamwork between domain specialists and methods experts, which requires breaking the lone genius myth
Detecting the Unexpected: Data and Methods Bazaar

Session 1 (4:55-5:15 / 5:15-5:35):

• (1) Graham: "Letting data describe itself"

• (2) Snyder: "Observing Virtual Universes: Synthetic HST & JWST Images from the Illustris Project"

• (3) Teuben: "ALMA Data Mining Toolkit (or Astro Data Mining Toolkit)"

• (4) Price-Whelan: “A custom Monte Carlo sampler for sparse or noisy radial velocity data: how to sample from highly multi-modal distributions over Keplerian orbital parameters”

• (CafeCon) Bot/Bosh: "Building Hierarchical Progressive Surveys (HIPS) from a set of images and using Multi Order Coverage maps (MOC) to explore large catalogs"

Session 2 (5:35-5:55 / 5:55-6:15):

• (1) Gordon: "The Unexpected BEAST?: PHAT catalogs of stellar and dust extinction properties of millions of stars in M31"

• (2) Sanderson: "Galaxia on FIRE: Mock surveys of high-resolution cosmological, hydrodynamic Milky Way simulations"

• (3) Loredo: "CUDAHM: A C++ framework for GPU-accelerated hierarchical Bayesian inference with simple graphical models"

• (CafeCon) Weaver/Olsen: "Exploring Large Datasets with the NOAO Data Lab"
Hack Day Projects

- Exploiting variation in survey filters to find extreme emission lines
- Developing new outlier detection methods based on topology/homology
- Deploying a citizen science tool on very complex ISM data
- Convolutional Neural Nets for merger classification and spectral typing
- Developing a database of outlier detection methods
- Developing new tech for serving histograms of big data over networks
- Extreme Deconvolution on stellar density catalogs
- Using DEMUD to determine how computers and human find outlier supernovae differently