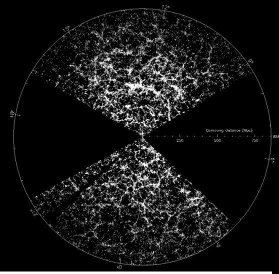
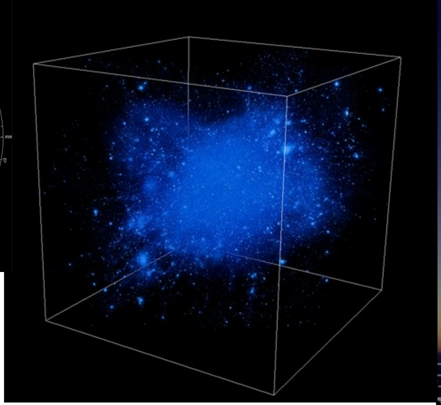
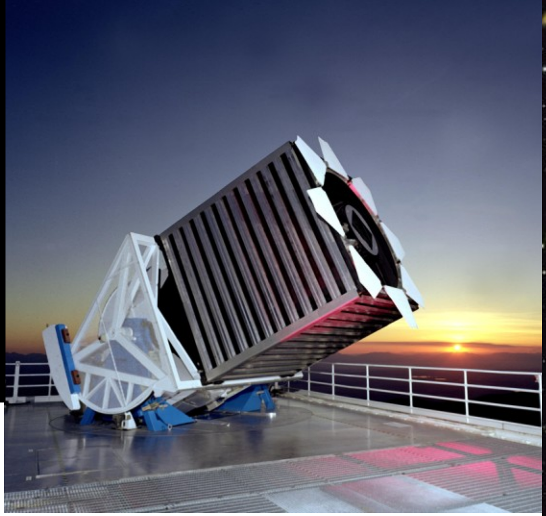
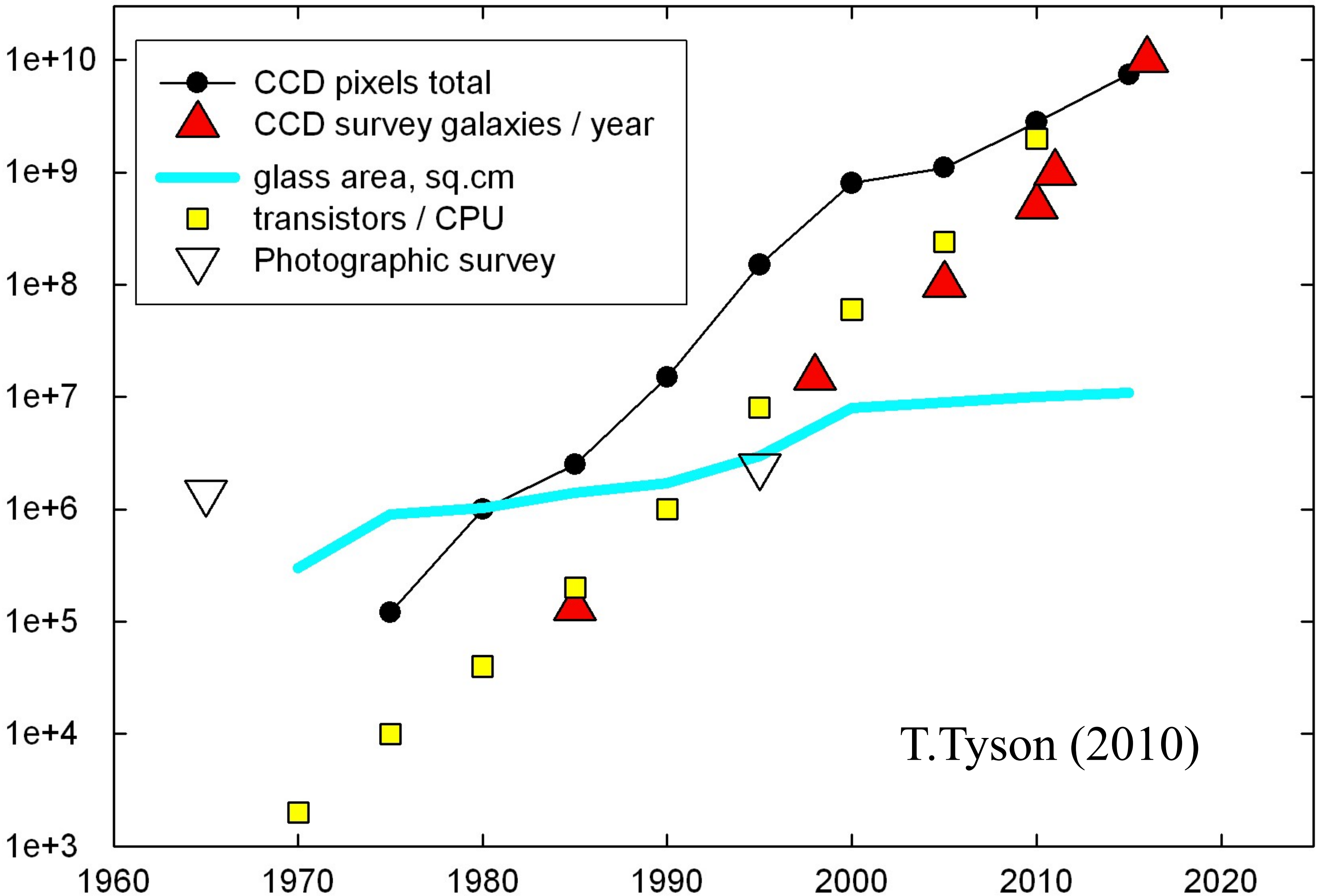





Data Analysis and Access in Astrophysics

Alex Szalay
The Johns Hopkins University

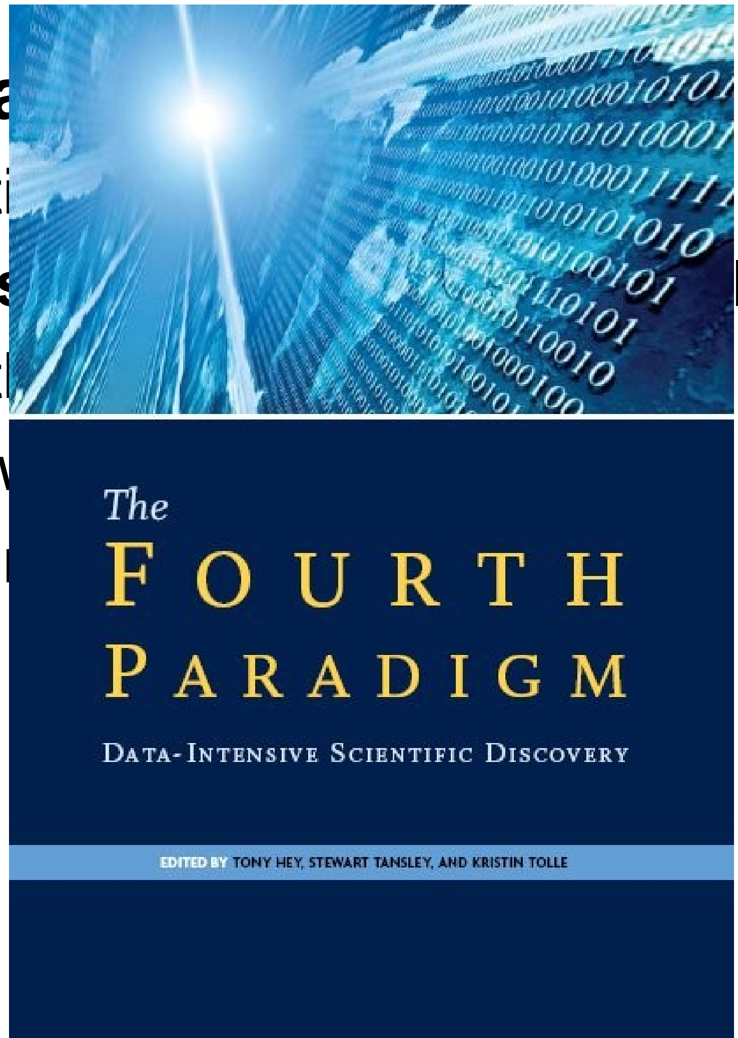
Survey Trends



Gray's Laws of Data Engineering

Jim Gra

- Scienti around **data**
- Need **s** lysis
- Take t
- Start w
- Go fro

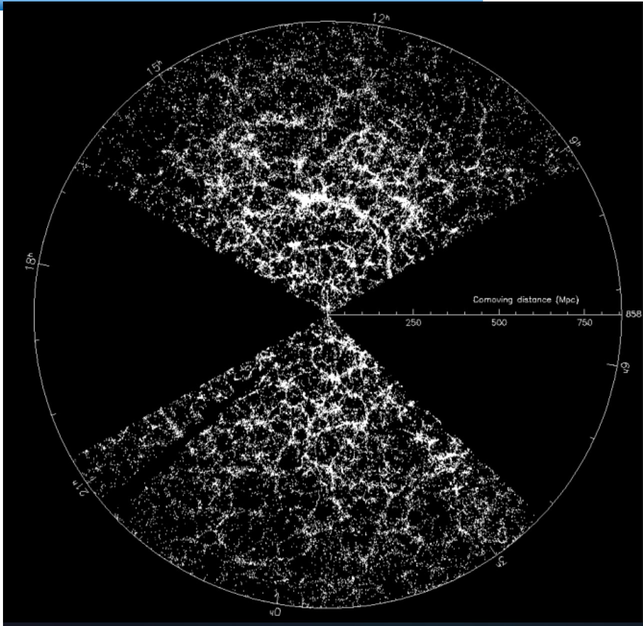


Technical Challenges

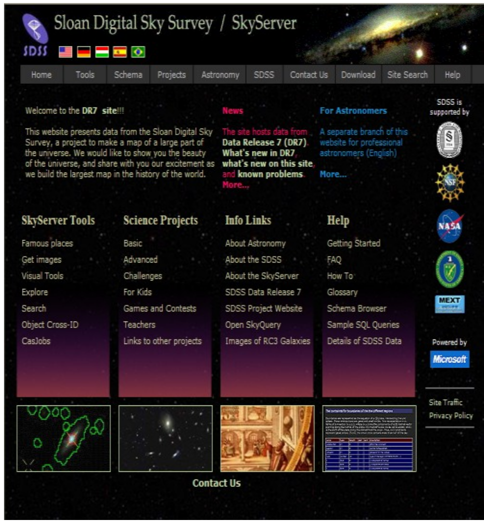
- **Data Access**:
  - *Data sets have a power law distribution*
  - *Move analysis to the data*
  - *Locality is the key*
- **Discovery**:
  - *Shannon ⇔ new dimensions*
  - *Federation still requires data movement*
- **Analysis**:
  - *Only max* NlogN *algorithms possible*

Sloan Digital Sky Survey

- **“The Cosmic Genome Project”**
- Two surveys in one
  - Photometric survey in 5 bands
  - Spectroscopic redshift survey
- Data is public
  - 2.5 Terapixels of images => 5 Tpx
  - 10 TB of raw data => 120TB processed
  - 0.5 TB catalogs => 35TB in the end
- Started in 1992, finished in 2008
- Database and spectrograph built at JHU (SkyServer)



SkyServer



- Prototype in 21st Century data access
  - *847 million web hits in 10 years*
  - *The world's most used astronomy facility today*
  - *1,000,000 distinct users vs. 10,000 astronomers*
  - *The emergence of the "Internet scientist"*
- GalaxyZoo (Lintott et al)
  - *40 million visual galaxy classifications by the public*
  - *Enormous publicity (CNN, Times, Washington Post, BBC)*
  - *300,000 people participating, blogs, poems…*
  - *Amazing original discoveries (Voorwerp, Green Peas)*

Impact of Sky Surveys

Astronomy

Sloan Digital Sky Survey tops astronomy citation list

NASA's Sloan Digital Sky Survey (SDSS) is the most significant astronomical facility, according to an analysis of the 200 most cited papers in astronomy published in 2006. The survey, carried out by Juan Madrid from McMaster University in Canada and Duccio Macchetto from the Space Telescope Science Institute in Baltimore, puts NASA's Swift satellite in second place, with the Hubble Space Telescope in third (arXiv:0901.4552).

Madrid and Macchetto carried out their analysis by looking at the top 200 papers using NASA's Astrophysics Data System (ADS), which charts how many times each paper has been cited by other research papers. If a paper contains data taken only from one observatory or satellite, then that facility is awarded all the citations given to that article. However, if a paper is judged to contain data from different facilities – say half from SDSS and half from Swift – then both facilities are given 50% of the citations that paper received.

The researchers then totted up all the citations and produced a top 10 ranking (see table). Way out in front with 1892 citations is the SDSS, which has been running since 2000 and uses the 2.5 m telescope at Apache Point in New Mexico to obtain images of more than a quarter of the sky. NASA's Swift satellite, which studies gamma-ray bursts, is second with 1523 citations, while the Hubble Space Telescope (1078 citations) is third.

Although the 200 most cited papers make up only 0.2% of the references indexed by the ADS for papers published in 2006, those 200 papers account for 9.5% of the citations. Madrid and Macchetto also ignored theory papers on the basis that they do not directly use any telescope data. A similar study of papers published in 2004 also puts SDSS top with 1843 citations. This time, though, the European Southern Observatory, which has telescopes in Chile, comes second with 1365 citations and the Hubble Space Telescope takes third spot with 1124 citations.

Michael Banks

Top 10 telescopes

Rank	Telescope	Citations	Ranking in 2004
1	Sloan Digital Sky Survey	1892	1
2	Swift	1523	N/A
3	Hubble Space Telescope	1078	3
4	European Southern Observatory	813	2
5	Keck	572	5
6	Canada–France–Hawaii Telescope	521	N/A
7	Spitzer	469	N/A
8	Chandra	381	7
9	Boomerang	376	N/A
10	High Energy Stereoscopic System	297	N/A

Virtual Observatory

- Started with NSF ITR project, “Building the Framework for the National Virtual Observatory”, collaboration of 20 groups
  - *Astronomy data centers*
  - *National observatories*
  - *Supercomputer centers*
  - *University departments*
  - *Computer science/information technology specialists*
- Similar projects now in 15 countries world-wide

⇒ International Virtual Observatory Alliance

NSF+NASA=>

VO Challenges

- Most challenges are sociological, not technical
- Trust: scientists want trustworthy, calibrated data with occasional access to low-level raw data
- Career rewards for young people still not there
- Threshold for publishing data is still too high
- Robust applications are hard to build (factor of 3…)
- Archives (and data) on all scales, all over the world

- Astronomy has successfully passed the first hurdles!

Data Sharing/Publishing

- What is the business model (reward/career benefit)?
- Three tiers (power law!!!)
    - *(a) big projects*
    - *(b) value added, refereed products*
    - *(c) ad-hoc data, on-line sensors, images, outreach info*
- We have largely done (a), mandated by NSF/NASA
- Need “Journal for Data” to solve (b)
- Need “VO-Flickr” (a simple interface) for (c)
- Mashups are emerging (GalaxyZoo)
- New public interfaces to astro data (Google Sky, WWT)
- Integrated environment for
  ‘*virtual excursions*’ for education (C. Wong)

‘Journal of Data’ in Astronomy

Create new paradigm in publishing scientific data

- *Team up with the main journals in astronomy*
- *On-line supplement for data related to journal articles*
- *Easy submission process for authors*
- *Data replicated among university libraries*
- *Data guaranteed to exist for 20 years*
- *Uses Fedora Commons*
- *Curation, curation, curation!!!*

with S. Choudhury, T. DeLauro (JHU Eisenhower Lib), R. Hanisch (Space Telescope), E. Vishniac (McMaster), C. Lagoze (Cornell)

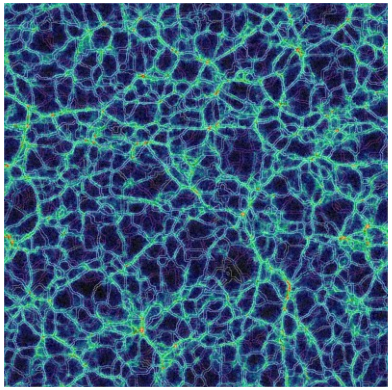
Capture Communications

- No ‘Einstein letters’ today… very little paper trail
- Proposals and papers archived
- Most large projects communicate through email exploders and phonecons
- Often reaching back to the Internet Archive
- Some technical info on WIKI pages
- Science oriented blogs are appearing
- Collaborative workbenches emerging
- More instant messaging, especially next generation
- What can we and what should we capture?
- What will science historians do in 50 years?

Continuing Growth

How long does the data growth continue?

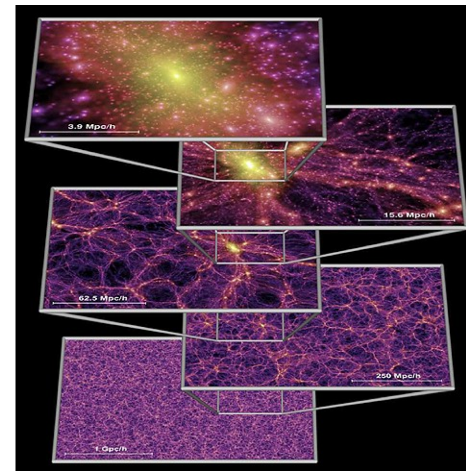
- High end always linear
- Exponential comes from technology + economics
  - *rapidly changing generations*
  - *like CCD's replacing plates, and become ever cheaper*
- How many generations of instruments are left?
- Are there new growth areas emerging?
- **Software is becoming a new kind of instrument**
  - *Value added data*
  - *Hierarchical data replication*
  - ***Large and complex simulations***



Cosmological Simulations

In 2000 cosmological simulations had 10^9 particles and produced over 30TB of data (Millennium)

- Build up dark matter halos
- Track merging history of halos
- Use it to assign star formation history
- Combination with spectral synthesis
- Realistic distribution of galaxy types

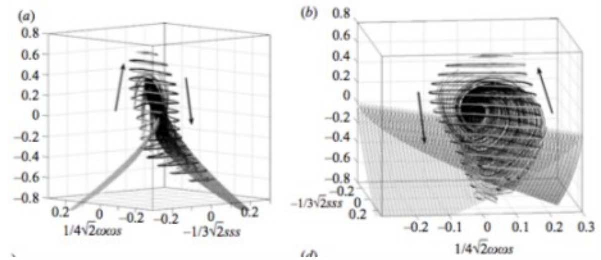


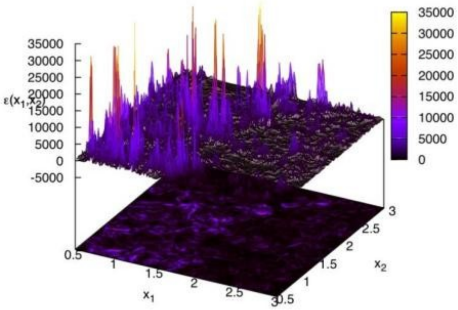
- Today: simulations with 10^{12} particles and PB of output are under way (MillenniumXXL, Exascale-Sky, etc)
- Hard to analyze the data afterwards -> need DB
- What is the best way to compare to real data?

Immersive Turbulence

"… the last unsolved problem of classical physics…" Feynman

- **Understand the nature of turbulence**
  - *Consecutive snapshots of a large simulation of turbulence: now 30 Terabytes*
  - *Treat it as an experiment, **play** with the database!*
  - ***Shoot test particles** (sensors) from your laptop into the simulation, like in the movie Twister*
  - *Next: 70TB MHD simulation*



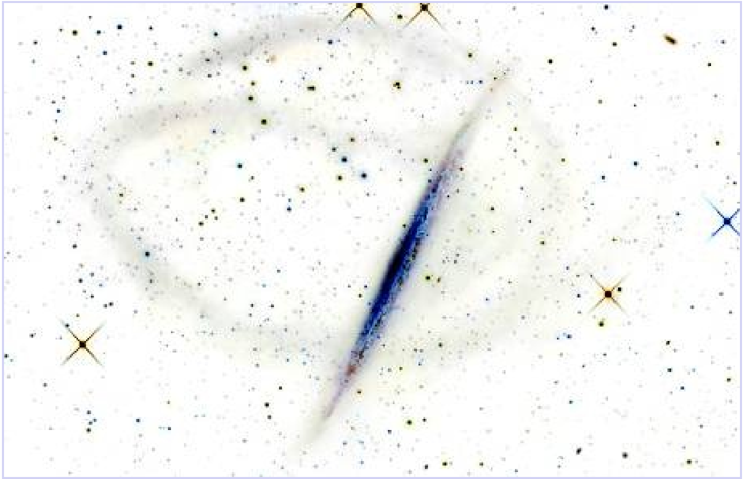


- **New paradigm** for analyzing simulations!

with C. Meneveau, S. Chen (Mech. E), G. Eyink (Applied Math), R. Burns (CS)

The Milky Way Laboratory

- Use cosmology simulations as an immersive laboratory for general users
- Via Lactea-II (20TB) as prototype, then Silver River (50B particles) as production (15M CPU hours)
- 800+ hi-rez snapshots (2.6PB) => 800TB in DB
- Users can insert test particles (dwarf galaxies) into system and follow trajectories in pre-computed simulation
- Users interact remotely with a PB in ‘real time’

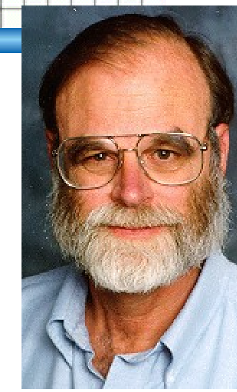


Stadel, Moore, Madau, Kuehlen
Szalay, Wyse, Silk, Lemson, Westermann, Blakeley

JHU Efforts in Data Archiving

- JHU is the lead on the **Data Conservancy**, one of the first NSF DataNet projects (5+5 years)
  - *PI: Sayeed Choudhury*
  - *Goal: understand long term archival and **curation** of scientific data*
  - *Testbeds: SDSS data, sensors, environmental, genomics*
- Institute for Data Intensive Engineering and Science (IDIES: pronounced as “ideas”)
  - *50 faculty involved, 3 schools, soon medicine and public health joining*
- Substantial hardware facilities
  - *by Aug 2011 about 8PBytes of storage and analysis*

Petascale Computing at JHU



- Distributed SQL Server cluster/cloud w.
- 50 Dell servers, 1PB disk, 500 CPU
- Connected with 20 Gbit/sec Infiniband
- 10Gbit lambda uplink to UIC
- Funded by Moore Foundation, Microsoft and Pan-STARRS
- Dedicated to eScience, provide public access through services
- Linked to 1000 core compute cluster
- Room contains >100 of wireless temperature sensors

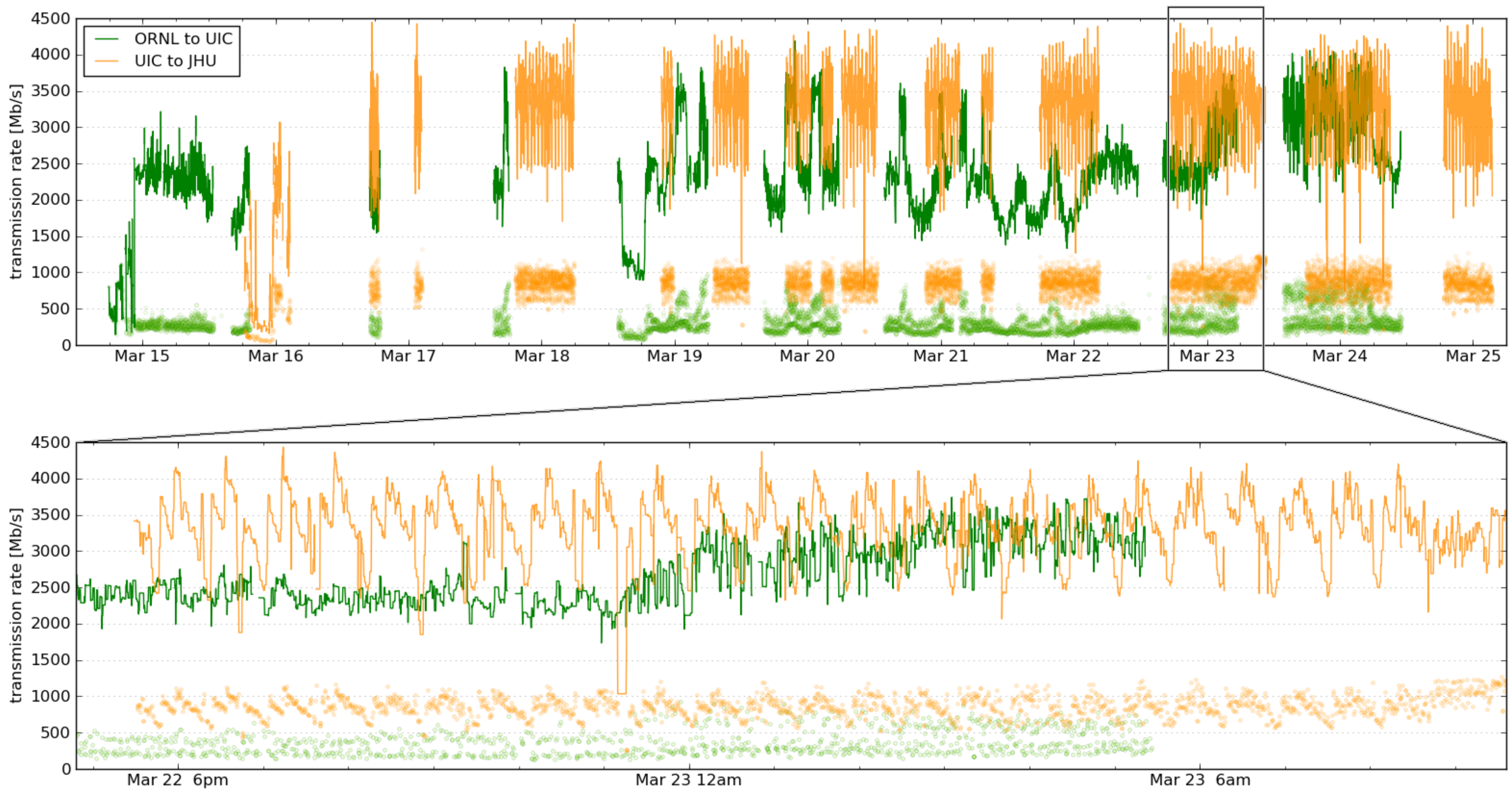
graywulf

DISC Needs Today

- Disk space, disk space, disk space!!!!
- Current problems not on Google scale yet:
  - *10-30TB easy, 100TB doable, 300TB really hard*
  - *For detailed analysis we need to park data for several months*
- Sequential IO bandwidth
  - *If not sequential for large data set, we cannot do it*
- How do can move 100TB within a University?
  - *1Gbps 10 days*
  - *10 Gbps 1 day (but need to share backbone)*
  - *100 lbs box few hours*
- From outside?
  - *Dedicated 10Gbps or FedEx*

Silver River Transfer

- 150TB in less than 10 days from Oak Ridge to JHU using a dedicated 10G connection



Tradeoffs Today

"Extreme computing is about tradeoffs"

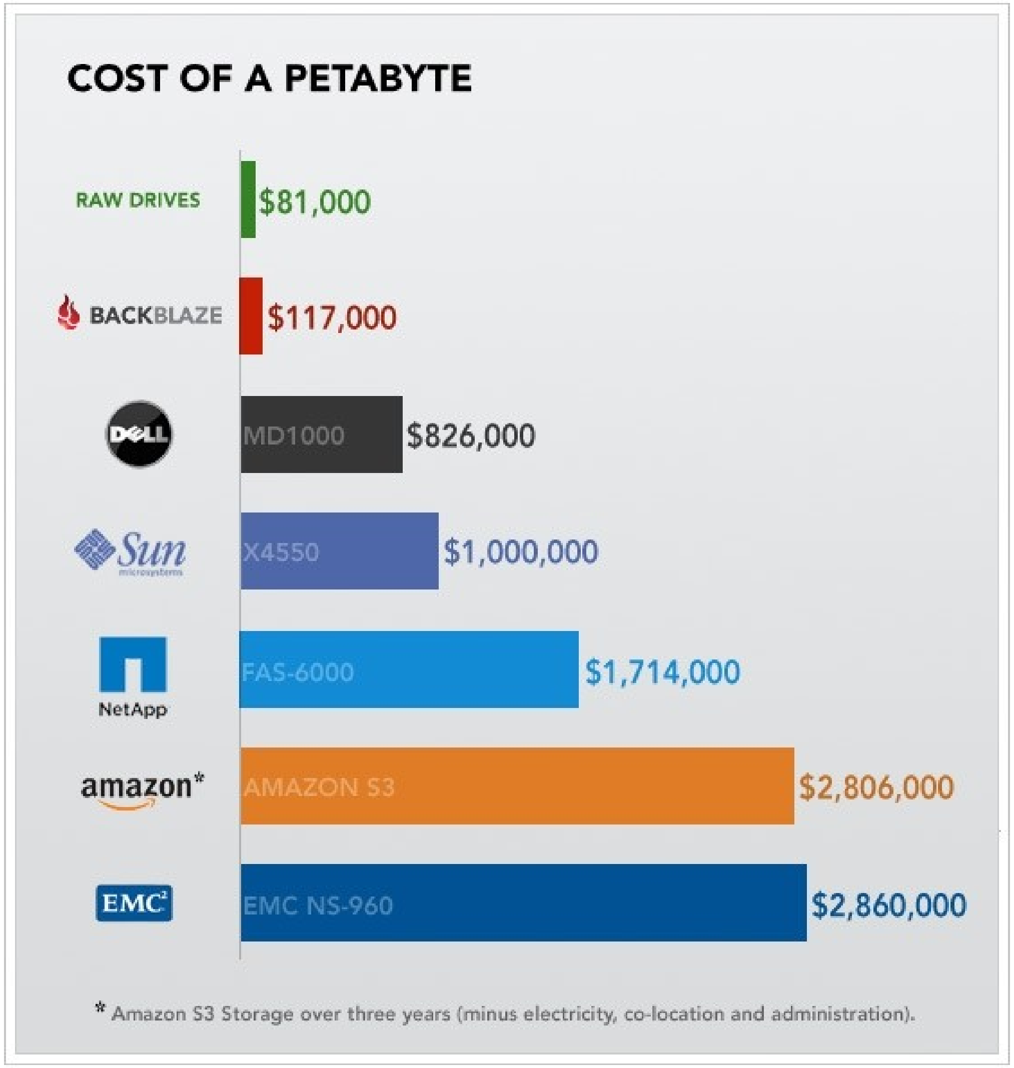
Stu Feldman (Google)

Ordered priorities for data-intensive scientific computing

1. *Total storage (-> low redundancy)*
2. *Cost (-> total cost vs price of raw disks)*
3. *Sequential IO (-> locally attached disks, fast ctrl)*
4. *Fast stream processing (->GPUs inside server)*
5. *Low power (-> slow normal CPUs, lots of disks/mobo)*

The order will be different in a few years...and scalability may appear as well

Cost of a Petabyte



From backblaze.com
Aug 2009

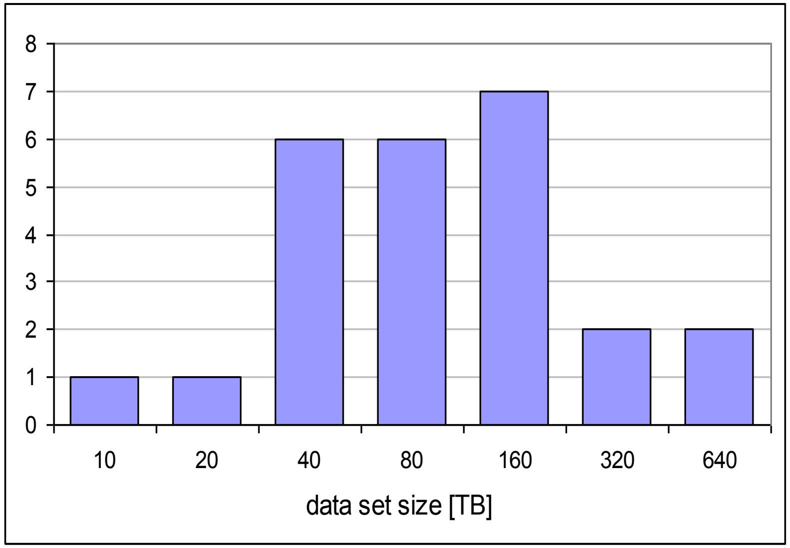
JHU Data-Scope

- Funded by NSF MRI to build a new 'instrument' to look at data
- Goal: 102 servers for $1M + about $200K switches+racks
- Two-tier: performance (P) and storage (S)
- Large (5PB) + cheap + fast (400+GBps), but …
  . ..a special purpose instrument

	1P	*1S*	*90P*	*12S*	*Full*	
servers	1	1	90	12	102	
rack units	4	12	360	144	504	
capacity	24	252	2160	3024	5184	TB
price	8.5	22.8	766	274	1040	$K
power	1	1.9	94	23	116	kW
GPU	3	0	270	0	270	TF
seq IO	4.6	3.8	414	45	459	GBps
netwk bw	10	20	900	240	1140	Gbps

Proposed Projects at JHU

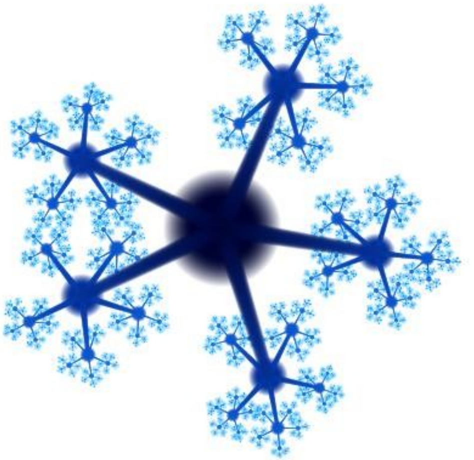
Discipline	data [TB]
Astrophysics	930
HEP/Material Sci.	394
CFD	425
BioInformatics	414
Environmental	660
Total	2823



19 projects total proposed for the Data-Scope, more coming, data lifetimes between 3 mo and 3 yrs

Fractal Vision

- The Data-Scope created a lot of excitement but also a lot of fear at JHU…
  - *Pro: Solve problems that exceed group scale, collaborate*
  - *Con: Are we back to centralized research computing?*
- Clear impedance mismatch between monolithic large systems and individual users
- e-Science needs different tradeoffs from eCommerce
- Larger systems are more efficient
- Smaller systems have more agility
- How to make it all play nicely together?



Increased Diversification

One shoe does not fit all!

- Diversity grows naturally, no matter what
- Evolutionary pressures help
  - *Large floating point calculations move to GPUs*
  - *Large data moves into the cloud*
  - *RandomIO moves to Solid State Disks*
  - *Stream processing emerging (SKA…)*
  - *noSQL vs databases vs column store vs SciDB …*
- Individual groups want subtle specializations

At the same time

- What remains in the middle (common denominator)?
- Boutique systems dead, commodity rules
- We are still building our own…

Collaborative Trends

- Science is aggregating into ever larger projects
- Collection of data **increasingly separated** from subsequent analysis
- Connection is through the data archives
- Natural size for close collaborations is small
- May be the only way to do **'small science'** in 2020

The VO is inevitable

- It is a disruptive technology
- It is a new way of doing science
- Present on every physical scale today (VAO, LHC,
  Human Genome, NEON, EOS, …)

DISC Sociology

- What happens to a discipline after the world's largest instrument is built?
  - *We should not take for granted that there will be a next*
  - *There is a lot of data to be analyzed*
- Broad sociological changes
  - *Data collection in ever larger collaborations (VO)*
  - *Analysis decoupled, on archived data by smaller groups*
- The impact of power laws
  - *we need to look at problems in octaves*
  - *Pareto rule (90% of the people only look at 10% of data)*
  - *the scientists may only be the tail of our users*
  - *there is never a discrete end or a sharp edge (except for our funding)*

DISC Economics

- What is the price of **software**?
  - *30% from SDSS, more for LSST*
  - *Repurpose for other disciplines, do not reinvent the wheel*
- What is the price of **hardware**?
  - *Moore's Law comes to the rescue…*
    we could build the LSST HW today, no problem in 10 years
  - *Extreme computing is about extreme tradeoffs….*
- What is the price (value) of **data**?
  - *$100,000 /paper (Ray Norris)*
- The cost of total ownership and business model contrasted with level budgets

Summary

- Science is increasingly driven by large data sets
- Large data sets are here, COTS solutions are not
  - *100TB is the current practical limit*
- We need a new instrument: a “microscope” and “telescope” for data=> a **Data-Scope**!
- Increasing diversification over commodity HW
- Changing sociology:
  - *Data collection in large collaborations (VO)*
  - *Analysis done on the archived data, possible (and attractive) for individuals*
- A new, Fourth Paradigm of Science is emerging…

but it is not incremental….

"If I had asked my customers what they wanted, they would have said faster horses…"

Henry Ford

From a recent book by Eric Haseltine:
"Long Fuse and Big Bang"