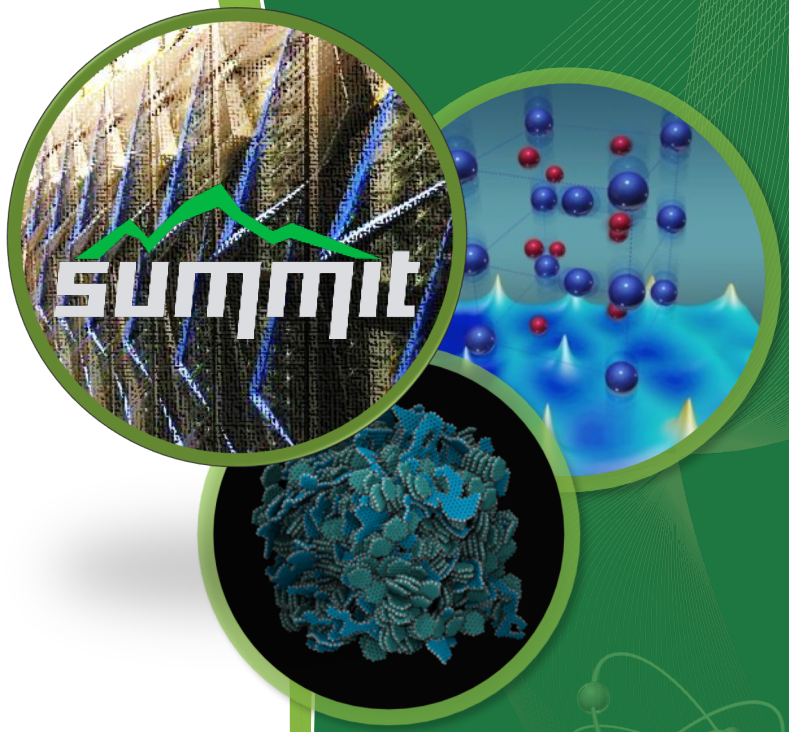
OLCF Facility Update

2019 OLCF User Meeting



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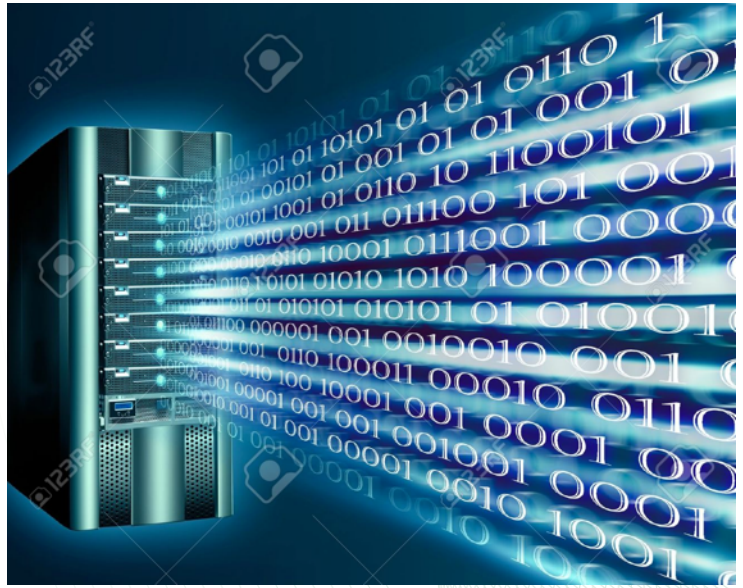
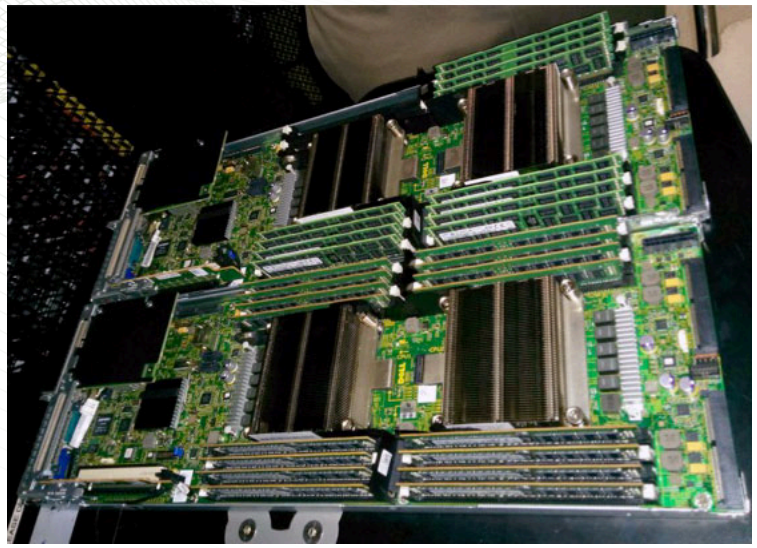
OLCF Upcoming System Changes

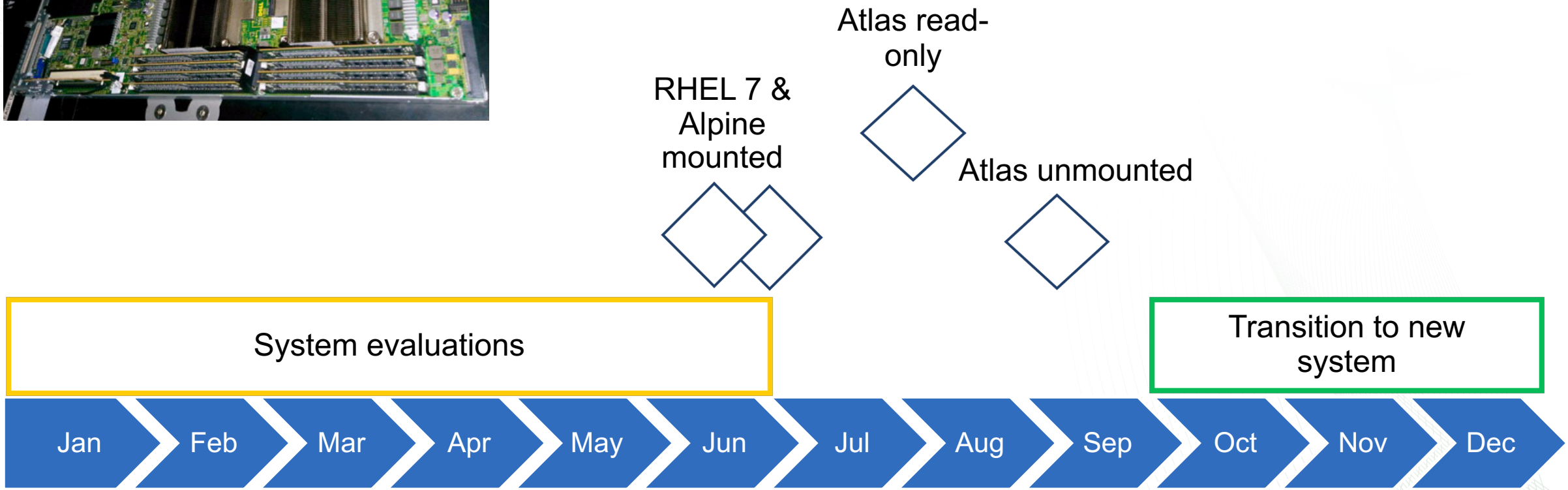
- OLCF System Decommissions and Notable Changes
  - Rhea transitions from Atlas Lustre to Alpine GPFS filesystem (more on next slide)
  - Last day to submit jobs to Titan and Eos: **June 30**
  - Atlas filesystem becomes read-only **August 1**
  - Titan and Eos will be decommissioned **August 1**
  - Atlas decommissioned **August 15**

- Transfer your data NOW!
  - More information on this later…



Rhea Transition Timeline





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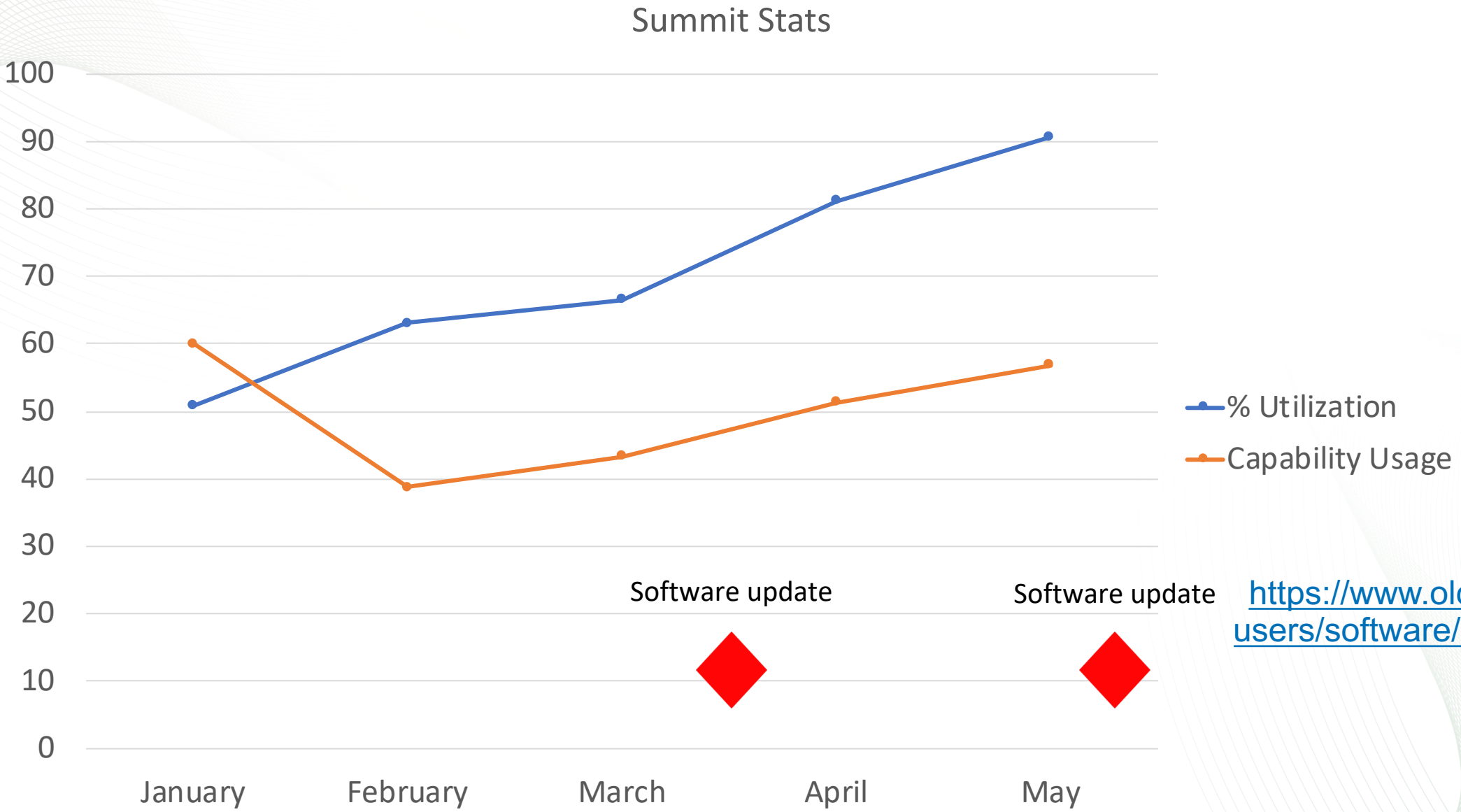
Summit Updates/Stats



https://www.olcf.ornl.gov/for-users/software/software-news/

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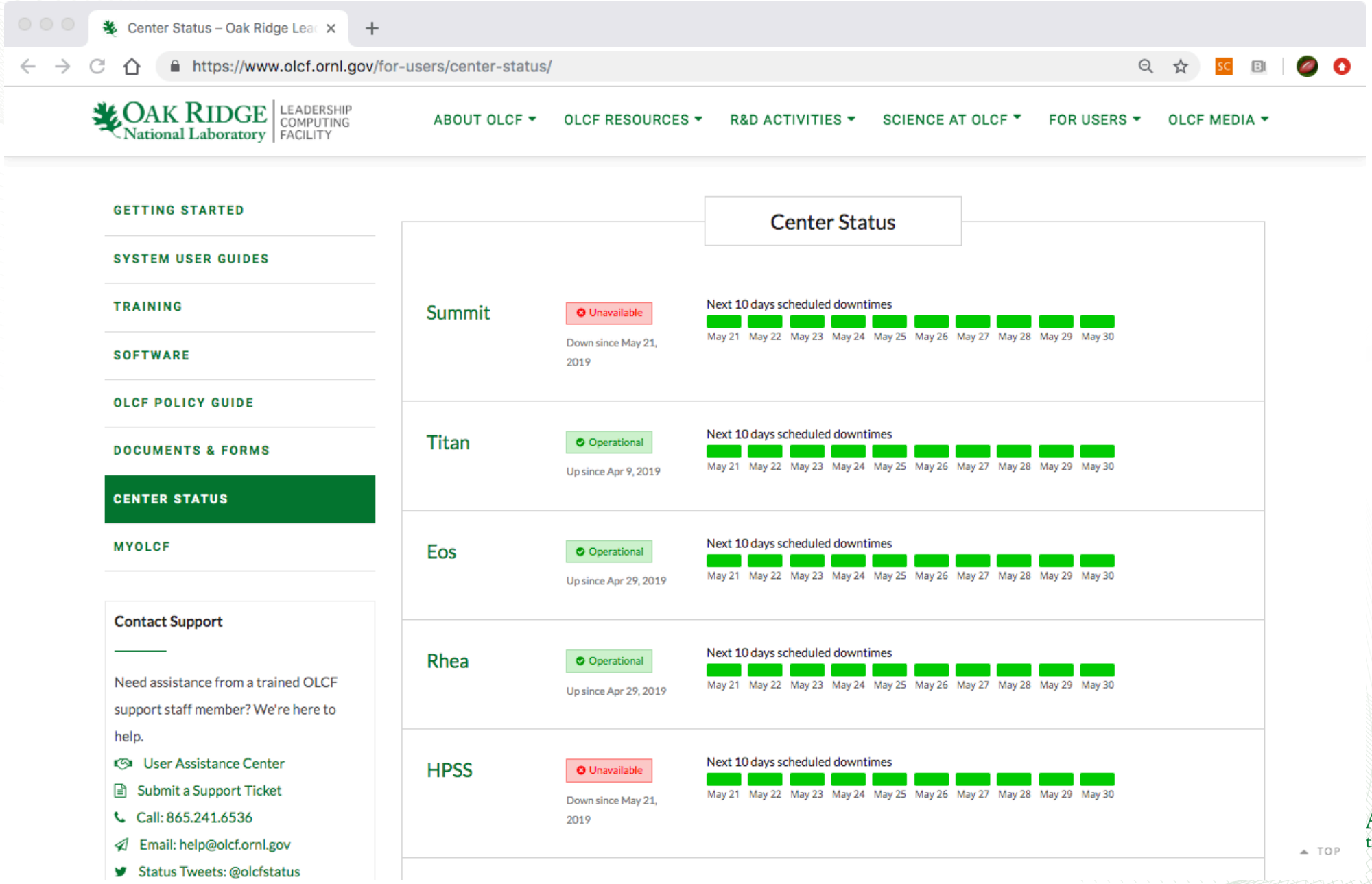
Center Status



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Innovative and Novel Computational Impact on Theory and Experiment (INCITE) Program for 2020

- Access to the fastest open science supercomputers in the nation
- Call for proposals opened April 15, 2019. Proposals due June 21, 2019.
- Proposals must:
  - Be high-impact, computationally and/or data intensive
  - Take advantage of unique HPC architectures
  - Be research that cannot be performed anywhere else.
- Broad array of science, engineering and computer science domains welcome to apply
- For more information visit http://www.doeleadershipcomputing.org/

U.S. DEPARTMENT OF ENERGY
INCITE
LEADERSHIP COMPUTING

U.S. DEPARTMENT OF ENERGY | Office of Science

OAK RIDGE National Laboratory | LEADERSHIP COMPUTING FACILITY

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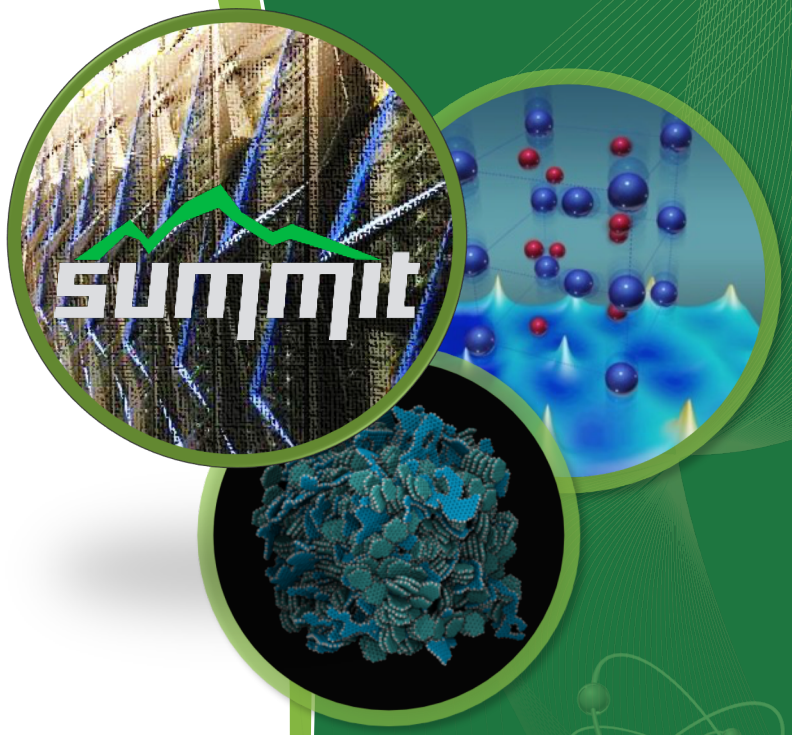
Introduction to Frontier

2019 OLCF User Meeting
(Public information)



Justin Whitt

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U.S. Department of Energy and Cray to Deliver Record-Setting Frontier Supercomputer at ORNL

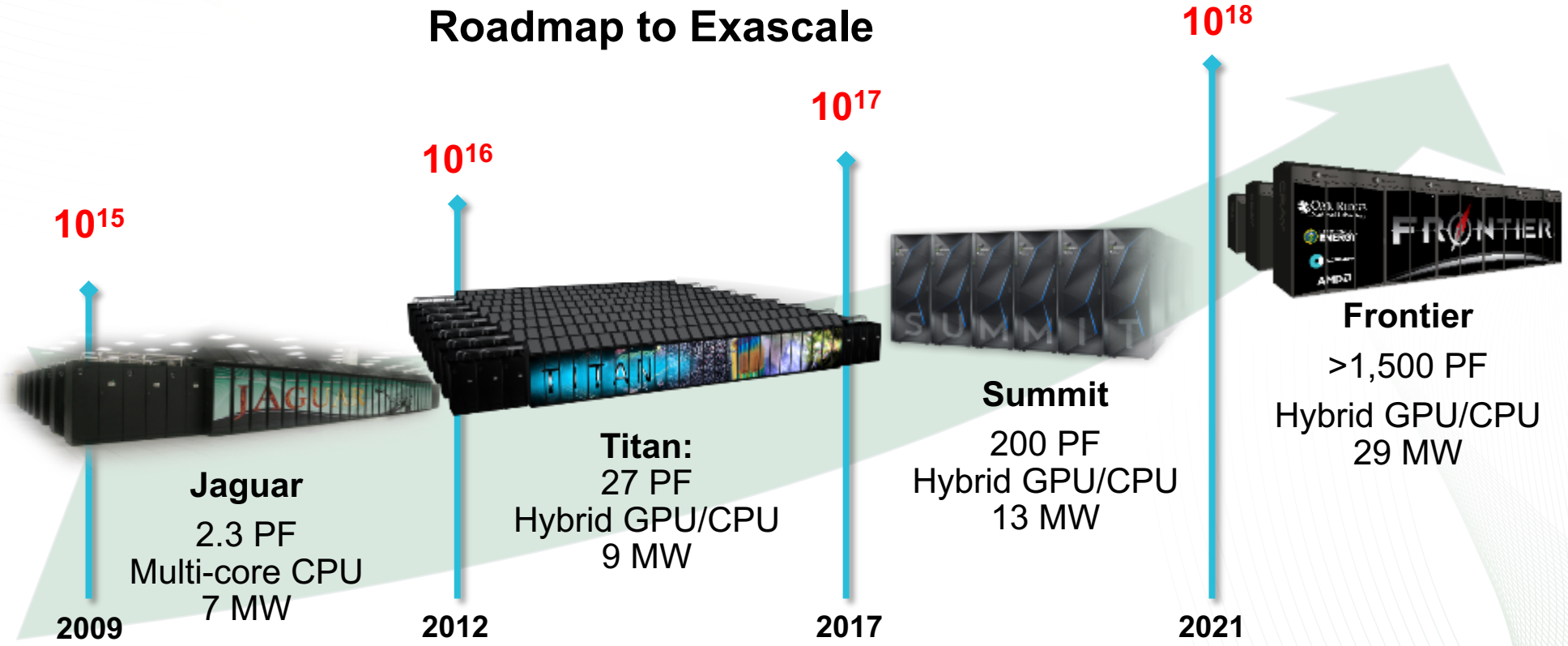
Exascale system expected to be world's most powerful computer for science and innovation

- With Secretary of Energy Rick Perry and other DOE, industry and community leaders at ORNL for InnovationXLab, DOE announced on May 7 a contract with Cray Inc. to build an exascale supercomputer at the Lab.
- When it debuts in 2021 performing at more than 1.5 exaflops, Frontier is anticipated to calculate up to five times faster than Summit, which currently holds the top world ranking, and 50 times faster than Titan, which remains in the top ten (TOP500).
- The contract, including system and technology development, is valued at $600 million, which is a record in itself for such a procurement.

Oak Ridge Leadership Computing Facility – a DOE Office of Science User Facility

Mission: Providing world-class computational resources and specialized services for the most computationally intensive global challenges	Vision: Deliver transforming discoveries in energy technologies, materials, biology, environment, health, etc.

Roadmap to Exascale



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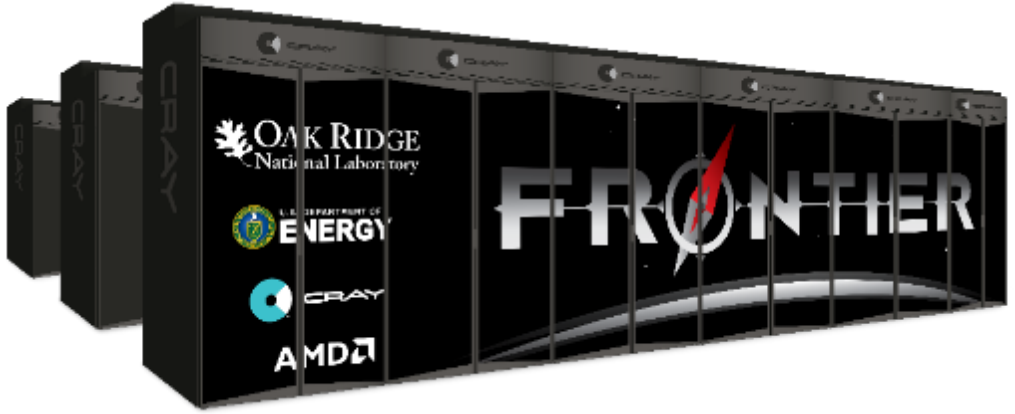
Frontier Overview



Partnership between ORNL, Cray, and AMD

The Frontier system will be delivered in 2021

Peak Performance greater than 1.5 EF

Composed of more than 100 Cray Shasta cabinets

- Connected by Slingshot™ interconnect with adaptive routing, congestion control, and quality of service

Node Architecture:

- An AMD EPYC™ processor and four Radeon Instinct™ GPU accelerators purpose-built for exascale computing
- Fully connected with high speed AMD Infinity Fabric links
- Coherent memory across the node
- 100 GB/s injection bandwidth
- Near-node NVM storage

Comparison of Titan, Summit, and Frontier Systems

System Specs	Titan	Summit	Frontier
Peak	27 PF	200 PF	~1.5 EF
# cabinets	200	256	Similar foot print
Node	1 AMD Opteron CPU 1 NVIDIA K20X Kepler GPU	2 IBM POWER9™ CPUs 6 NVIDIA Volta GPUs	1 AMD EPYC CPU (HPC and AI Optimized) 4 AMD Radeon Instinct GPUs
On-node interconnect	PCI Gen2 No coherence across the node	NVIDIA NVLINK Coherent memory across the node	AMD Infinity Fabric Coherent memory across the node
System Interconnect	Cray Gemini network 6.4 GB/s	Mellanox Dual-port EDR IB network 25 GB/s	Cray four-port Slingshot network 100 GB/s
Topology	3D Torus	Non-blocking Fat Tree	Dragonfly
Storage	32 PB, 1 TB/s, Lustre Filesystem	250 PB, 2.5 TB/s, IBM Spectrum Scale™ with GPFS™	2-4x performance and capacity of Summit's I/O subsystem.
Near-node NVM (storage)	No	Yes	Yes

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Frontier Programming Environment

- To aid in moving applications from Titan and Summit to Frontier, ORNL, Cray, and AMD will partner to co-design and develop enhanced GPU programming tools designed for performance, productivity and portability.
- This will include new capabilities in the Cray Programming Environment and AMD's ROCm open compute platform that will be integrated together into the Cray Shasta software stack for Frontier
- In addition, Frontier will support many of the same compilers, programming models, and tools that have been available to OLCF users on both the Titan and Summit supercomputers

Summit is a premier development platform for Frontier

Frontier Portable Programming with HIP

HIP (Heterogeneous-compute Interface for Portability) is an API developed by AMD that allows developers to write portable code to run on AMD or NVIDIA GPUs. It is a wrapper that uses the underlying CUDA™ or ROCm platform that is installed on the system

The API is very similar to CUDA so transitioning existing codes from CUDA to HIP is fairly straightforward.

AMD has developed a “hipify” tool that automatically converts source from CUDA to HIP.

Developers can specialize for the platform to tune for performance or handle unique cases

OLCF plans to make HIP available on Summit so that users can begin using it prior to its availability on Frontier

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Artificial Intelligence and Machine Learning on Frontier

Closely integrating artificial intelligence with data analytics and modeling and simulation will drastically reduce the time to discovery by automatically recognizing patterns in data and guiding simulations beyond the limits of traditional approaches.

Frontier will have a fully optimized, scalable data science suite in addition to the Cray Programming Environment Deep-learning plugin that provides support for Apache Spark, GraphX, MLib, Alchemist frameworks, and pbdR.

Like Summit, Frontier will be fine tuned to run AI workloads

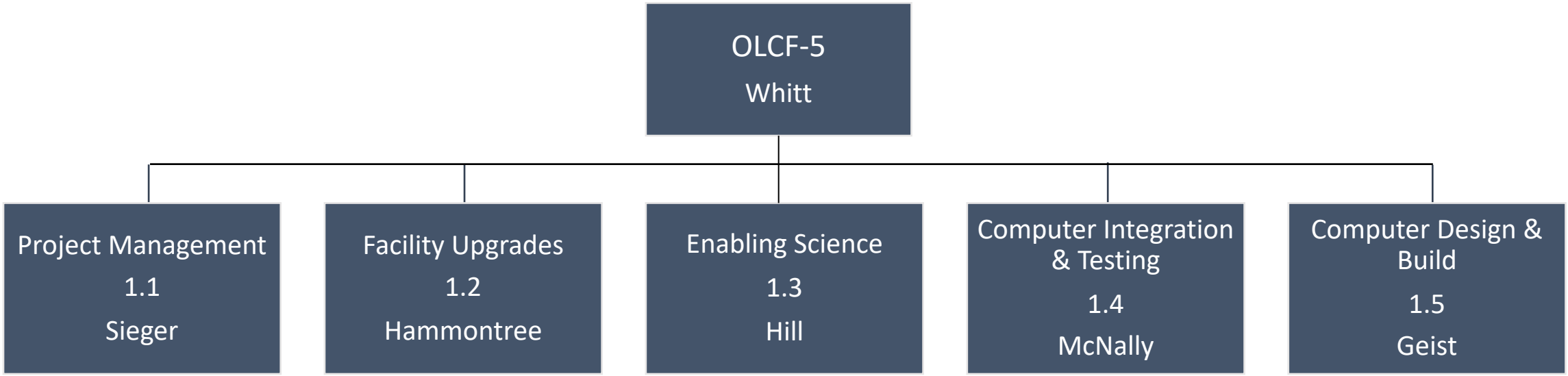
CAAR Accepting Application Team Proposals for Frontier System

Submissions being accepted now through June 8

The OLCF is seeking partnerships with select applications teams to develop scientific applications for highly effective use on the Frontier system.

- Through its Center for Accelerated Application Readiness (CAAR), the OLCF will partner with simulation, data-intensive, and machine learning application teams consisting of application core developers and OLCF staff members.
- The teams will receive technical support from Cray and AMD—Frontier's primary vendors—and have access to multiple early-generation hardware platforms in the run up to the system's 2021 delivery.
- Leading up to the delivery of Frontier, the CAAR application teams will redesign, port and optimize their software to the system's architecture and demonstrate the effectiveness of their applications through a scientific grand-challenge project.
- CAAR partnership project proposals, accepted now through June 8, will be evaluated by a computational and scientific review conducted by the OLCF. In addition to gauging the scientific merit and acceleration plan of each proposal, the committee will strive to select a mix of computational algorithms and programming approaches representing a broad range of scientific disciplines.

Frontier Project Scope



Frontier Project Staff

Thomas Zacharia
Laboratory Director
ORNL

Matt Sieger
Deputy Project Director

Justin Whitt
Project Director

Buddy Bland
Program Director

Jim Hack
NCCS Division Director

Jeff Nichols
Associate
Laboratory Director
Computing &
Computational Sciences

Lewis
Galyon
PMO

Bart
Hammontree
Facilities

Judy
Hill
NCCS

Al Geist
CSMD

Stephen
McNally
NCCS

Ashley
Barker
NCCS

Kevin
Thach
NCCS

David
Bernholdt
CSMD

Willy
Besancenez
Contracts

Bronson
Messer
NCCS

Tjerk
Straatsma
NCCS

Veronica
Melesse
Vergara
NCCS

Scott
Atchley
NCCS

Jim
Rogers
NCCS

Paul
Newman
NCCS

Sudarshan
Vazhkudai
NCCS

Dustin
Leverman
NCCS

Michael
Brim
CSMD

Sarp
Oral
NCCS

Matt
Ezell
NCCS

Ryan
Adamson
NCCS

John
Sanseverino
MIA

Chris
Fuson
NCCS

Rick
Griffin
Facilities

Paul
Abston
NCCS

Denise
Hoomes
PMO

Oscar
Hernandez
CSMD

Jesse
Hanley
NCCS

David
Grant
Facilities

Chris
Tavino
Facilities

Jason
Hill
NCCS

Reuben
Budiardja
NCCS

Scott
Koch
NCCS

Darren
Norris
Facilities

Thomas
Papatheodore
NCCS

Jonathan
Neuman
Facilities

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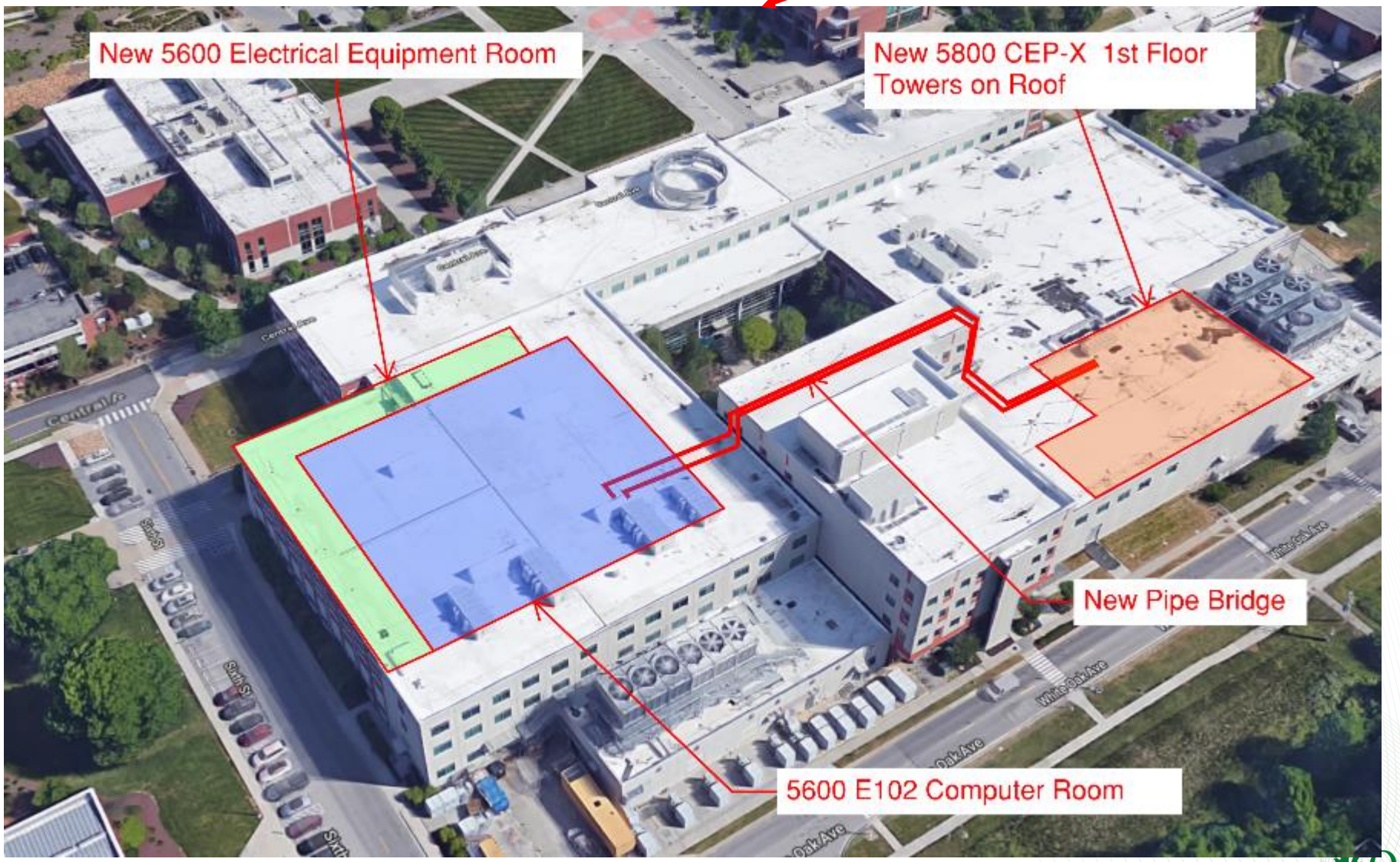
Required Power and Cooling Upgrades



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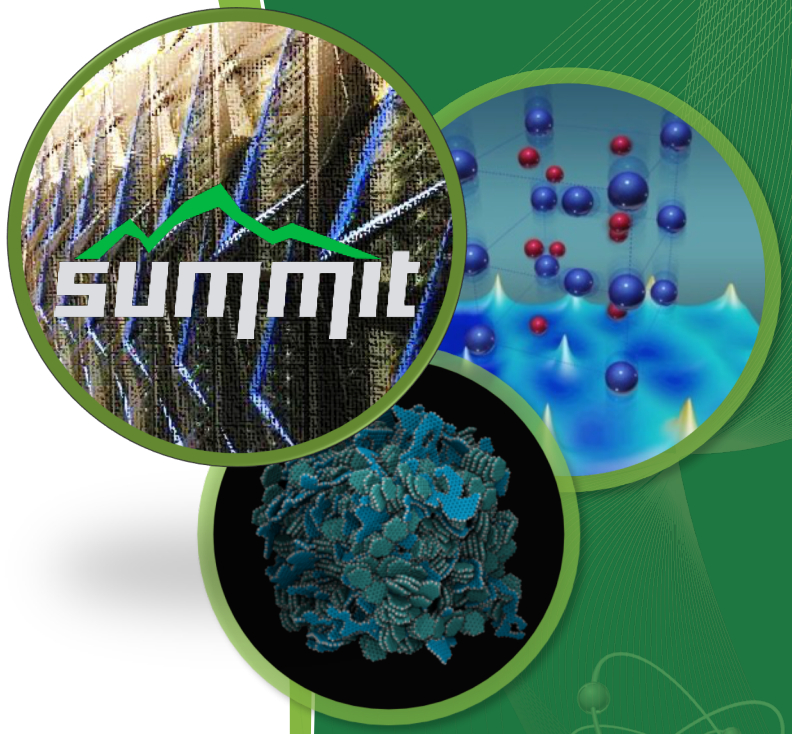

OLCF Research Data Program

Implementation plans

The OLCF Data Working Group

Kevin Bivens, Michael Brim, Stefan Ceballos, Jamison Daniel, Pete Eby, Markus Eisenbach, Dustin Leverman, Ross Miller, Byung Park, Ryan Prout, William Renaud, Suhas Somnath, Matthew Wolf, Jason Hill, Valentine Anantharaj, Jack Wells, and Stephen McNally

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Motivation

- ASCR and OLCF are guided by science needs that are increasingly a community effort.
- We are generating and accumulating data at unprecedented scales, both from observations and simulations.
- Scientific needs include real-time modeling & simulations and learning applications during experiments, requiring exascale computational and data infrastructure & resources.
- Increasing complexity in everything - computing, data, workflows and management.
- Users require continuity across projects and programs, and expect multi-year commitments from facilities, like OLCF.

A set of common requirements

- Large-scale data analysis, longer-term data storage, and community reuse.
- Integrated experimental, simulation and learning workflows.
- Tools for effective data management solutions: support for data life cycle management activities, including archiving and curation.
- Sharing of data and provisioning remote access to data.
- Efficient and fast data transfer mechanisms.
- Facilitate reuse of data, methods and techniques.
- Support for community protocols and standards.

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Current status

- Increasing user needs and requests to retain data at OLCF for continued analysis and future projects.
- Requests for data services and tools to exploit data for science deliverables.
- The few data-only projects are *ad hoc*
  - Evaluated on their own merit and requirements.
  - Resource utilization varies vastly.
  - We are in the process of developing consistent policies for long-term storage, publication and data management.
  - We are developing & deploying tools and services to support longer term projects.

Toward implementing the new data user program

- *Short-term data repository projects.*
  - *Continuity* for ongoing projects.
  - Need more time to complete analysis and publish.
  - Opportunity to prepare for follow-on projects.
- *Computational data analytics and learning projects.*
  - Enable *discovery science* via analytics and learning applications.
  - *Containerization* and supported *data stack*.
- *Data services projects* to engage and serve user communities.
  - Data collections that benefit the *broader domain science community*.
  - Initialization and parameter data; validation data; reference data.
  - Utilize the OLCF *Slate* services.
  - Data publication and utilize DOI as a service.
  - Reproducible science.

Elements of the new data user program

- Complementary to existing user programs: INCITE, ALCC & DD.
- *Short-term data repository projects.*
  - Awarded for 1 year initially with the possibility of extension for one year.
  - No computational allocation.
- *Computational data analytics and learning projects.*
  - Computational and storage allocation for 2 years with no extension.
  - Computational and data readiness required.
- *Data services projects* to engage and serve user communities.
  - Initial allocation for 3 years.
  - Data collections that benefit the *broader domain science community*.
  - Data services include portals, databases, data catalogs & publication (DOI services), data transfer and other.
  - Need a well-defined data curation & lifecycle management process.

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Proposal elements

- Scientific impacts
  - DOE SC mission: *“deliver scientific discoveries … to transform our understanding of nature …”*
- Ownership of data and access considerations.
- Target community and consumers and mode of usage.
- File size distribution, type, volume, etc.
- Metadata and provenance.
- Software and tools.
- Availability (disk, tape) and access requirements.
- Data lifecycle management plan.
- Plans for disposition of data upon completion.

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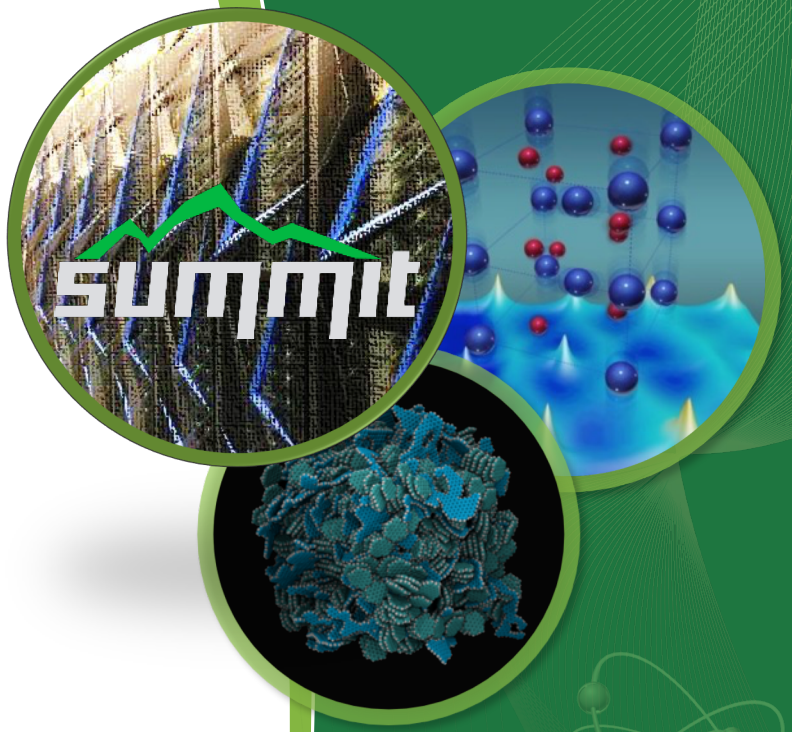
Spectral

Christopher Zimmer



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Summit Storage Options

- Parallel File System
  - Spider-3 center-wide GPFS
  - 250 PB @ 2.5 TB/s
  - ~540 MB/s write performance per node when all nodes are writing

- Burst Buffer
  - 4,608 nodes with NVMe SSDs (Samsung PM1725a)
  - 7.3 PB Total
  - 9.67 TB/s aggregate write 27 TB/s aggregate read performance when using all nodes

What's a Burst Buffer?

- Originally: A combination of **software** and **hardware** to accelerate phased periodic I/O
  - E.g. Applications checkpointing hourly
- Why it helps
  - The aggregate Summit NVMe's have ~4X more write bandwidth than the PFS and a larger factor more meta-data create performance.
  - Goal: shrinking a 5 minute hourly I/O phase for a 24 hour job to 2 minutes
    - Reduces I/O from 8% of application runtime to 3%
      - In early testing the meta-data performance improvement is even greater

Spectral

- On node copy agent
  - Runs on isolated cores as system agent
- Application Interface Transparent
  - No code modifications (LD_PRELOAD)
    - Changes limited job scripts
  - Application only reasons about a single namespace
- Preserves portability with single namespace
- Non-shared files

Lammps Example

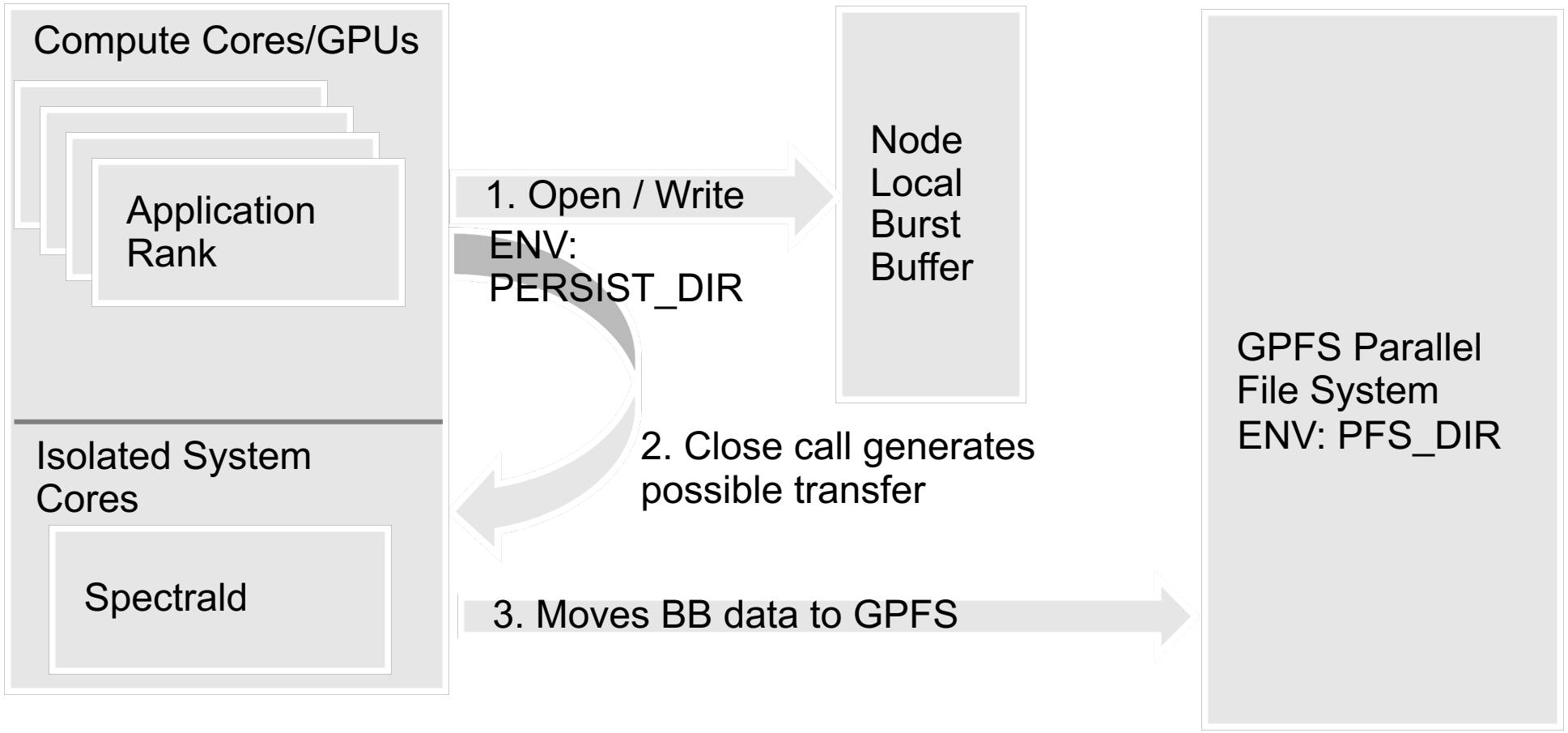
```
#BSUB -alloc_flags spectral
module load spectral
export PERSIST_DIR=${BBPATH}
export PFS_DIR=$PWD/restart/


echo >&3 "Start of lammps run: $(date)"
jsrun --nrs 16 --rs_per_host 1 --tasks_per_rs 6 ${BINARY} -v number_of_atoms ${natoms} -v output_dir ${PERSIST_DIR} < ${LAMMPS_INPUT_FILE}
echo >&3 "End of lammps run: $(date)"

spectral_wait.py
```

- When spectrald detects a write into PERSIST_DIR, the data is moved to PFS_DIR outside of the application
- Spectral_wait.py
  - Transaction log of file movement states (Used to determine when finished at end of job or after application run)

Spectral Data Flow



Spectral Open Redirection

- Optional Limited mode
  - Spectral intercepts **open** calls for files in PFS_DIR and redirects to NVMe
    - export PRELOAD_OPEN=1
  - Open –
    - Passed in : /gpfs/arete/cjzimmer/gtc/restart_dir1/restart0.dat
    - Returns : /mnt/bb/cjzimmer/restart_dir1/restart0.dat
  - Spectral transfers to terminal destination upon close

Spectral Limitations

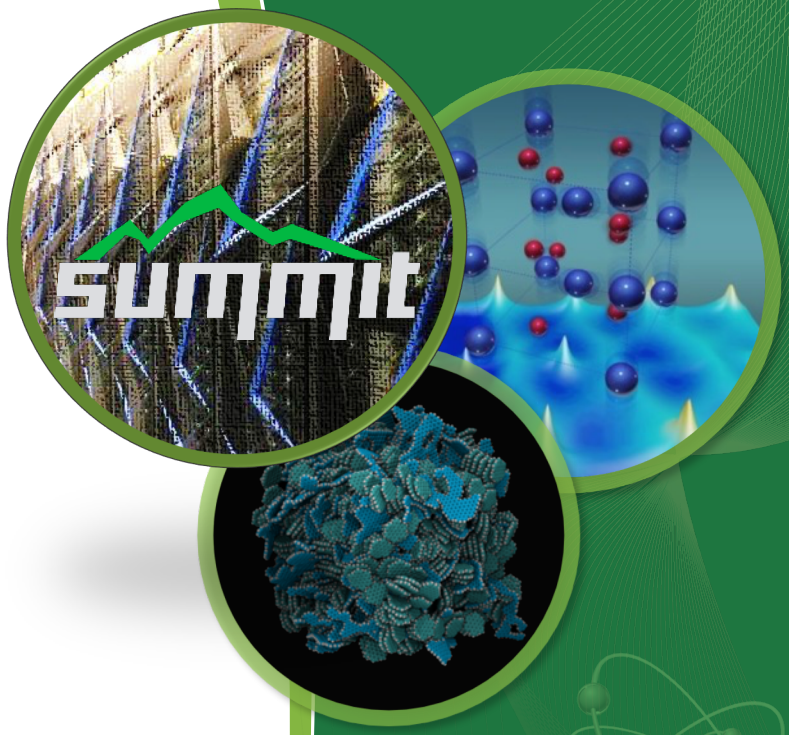
- No shared file support
- Using PRELOAD_OPEN option PFS_DIR must be for output files only
  - Today: For performance Spectral does not check access flags
    - This may be updated in a future release
    - A file opened for read in these directories will be redirected to a non-existant file

Questions/Interest in early access?

- Spectral - zimmercj@ornl.gov

Globus on HPSS

George S. Markomanolis,



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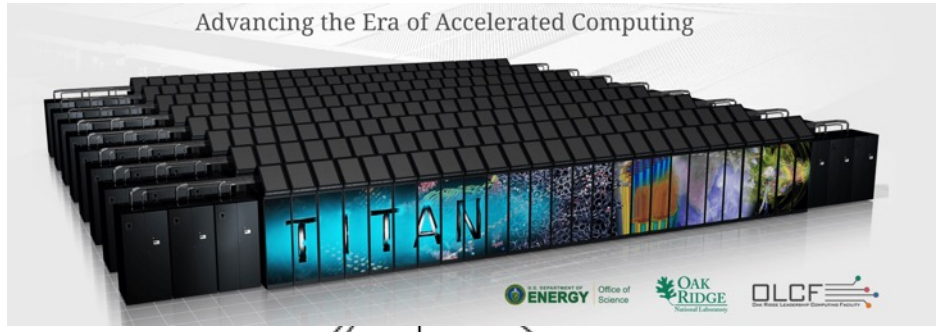
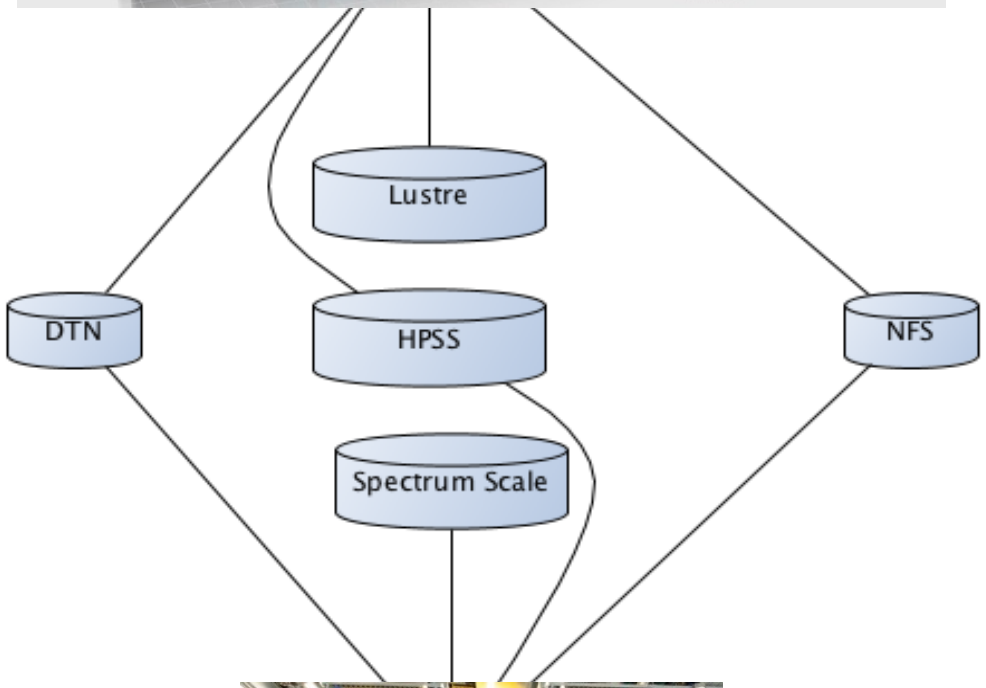
Data Transfer

Data Transfer Nodes (DTN) improve the performance by reducing the load on the login and service nodes of the HPC facilities. Moreover, transfer data outside the HPC facility.





High Performance Storage System (HPSS)

- User archive: /home/$USER
- Project archive: /proj/[projid]
- **Long-term** storage for large amount of general data under home or related to project under proj.
- **Quota** of 2 TB and 100 TB for user and project archive respectively.
- **Not purged**
- User archive is user-centric

Storage policy

Name	Path	Type	Permissions	Backups	Purged	Quota	Mounted on Compute nodes
User Home	`$HOME`	NFS	User Set	yes	no	50GB	Read-only
User Archive	`/home/$USER`	HPSS	User Set	no	no	2TB	No
Project Home	`/ccs/proj/[projid]`	NFS	770	yes	no	50GB	Read-only
Member Work	`/gpfs/alpine/scratch/[userid]/[projid]/`	Spectrum Scale	700	no	90 days	50TB	Yes
Project Work	`/gpfs/alpine/proj-shared/[projid]`	Spectrum Scale	770	no	90 days	50TB	Yes
World Work	`/gpfs/alpine/world-shared/[projid]`	Spectrum Scale	775	no	90 days	50TB	Yes
Project Archive	`/proj/[projid]`	HPSS	770	no	no	100TB	No

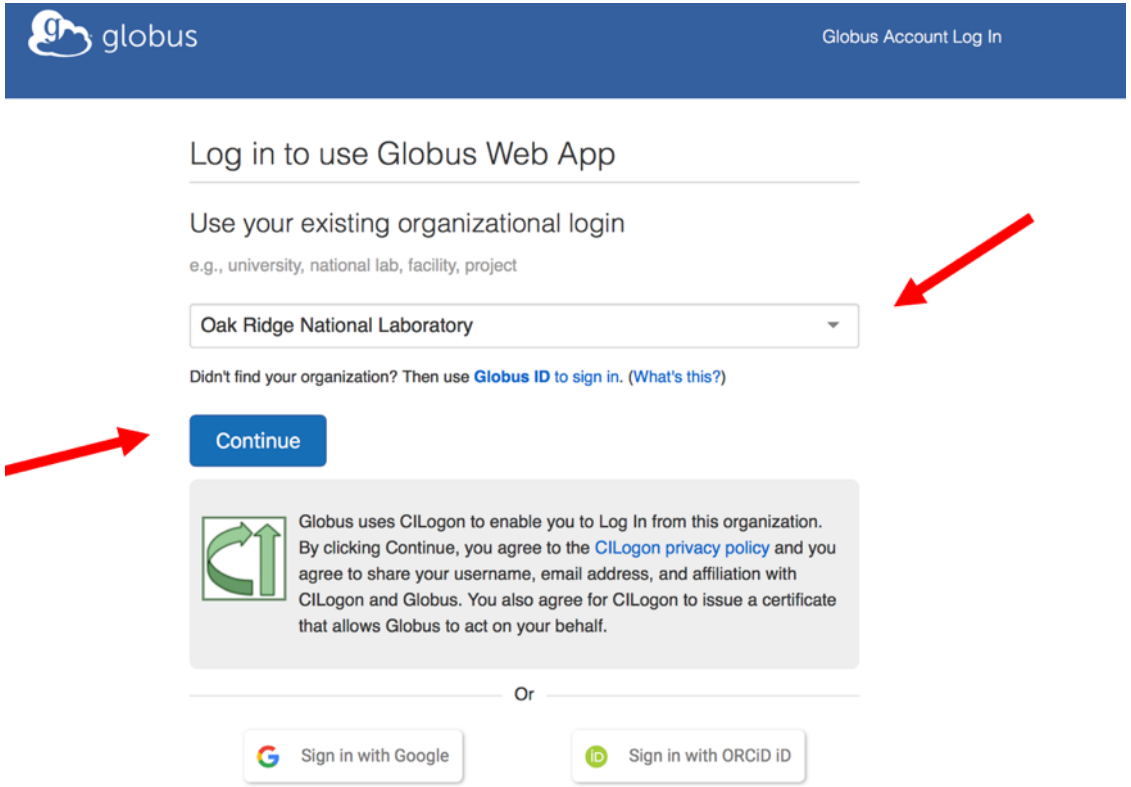
Globus

- Globus transfers fast, parallel and reliable files between two endpoints
- Endpoints are different locations where data can be moved using the Globus transfer
- Visit www.globus.org to register and/or login
- You can find the **OLCF DTN** endpoint to access the data on Lustre/GPFS and **OLCF HPSS** to access the data on HPSS.

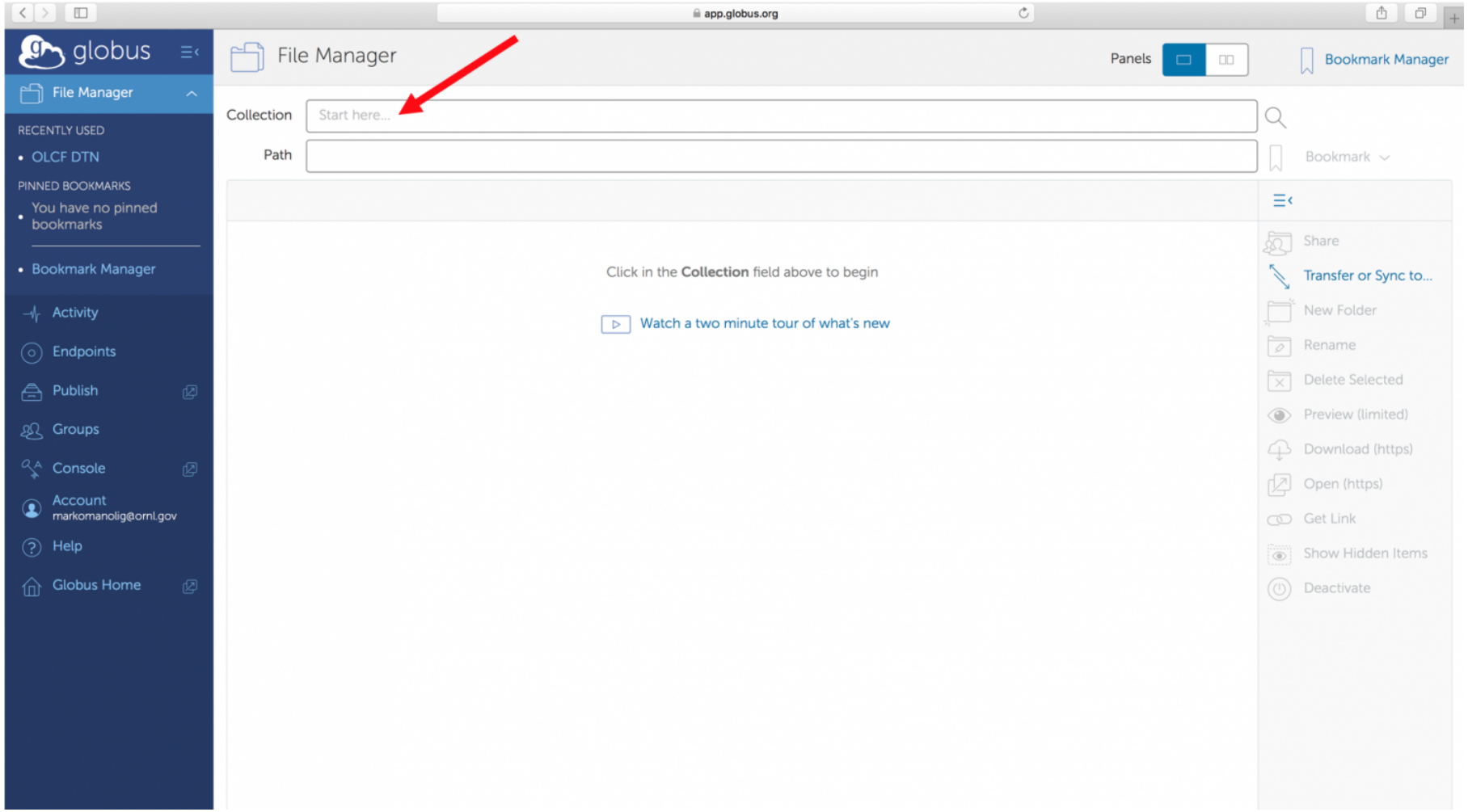
Globus - Login

www.globus.org

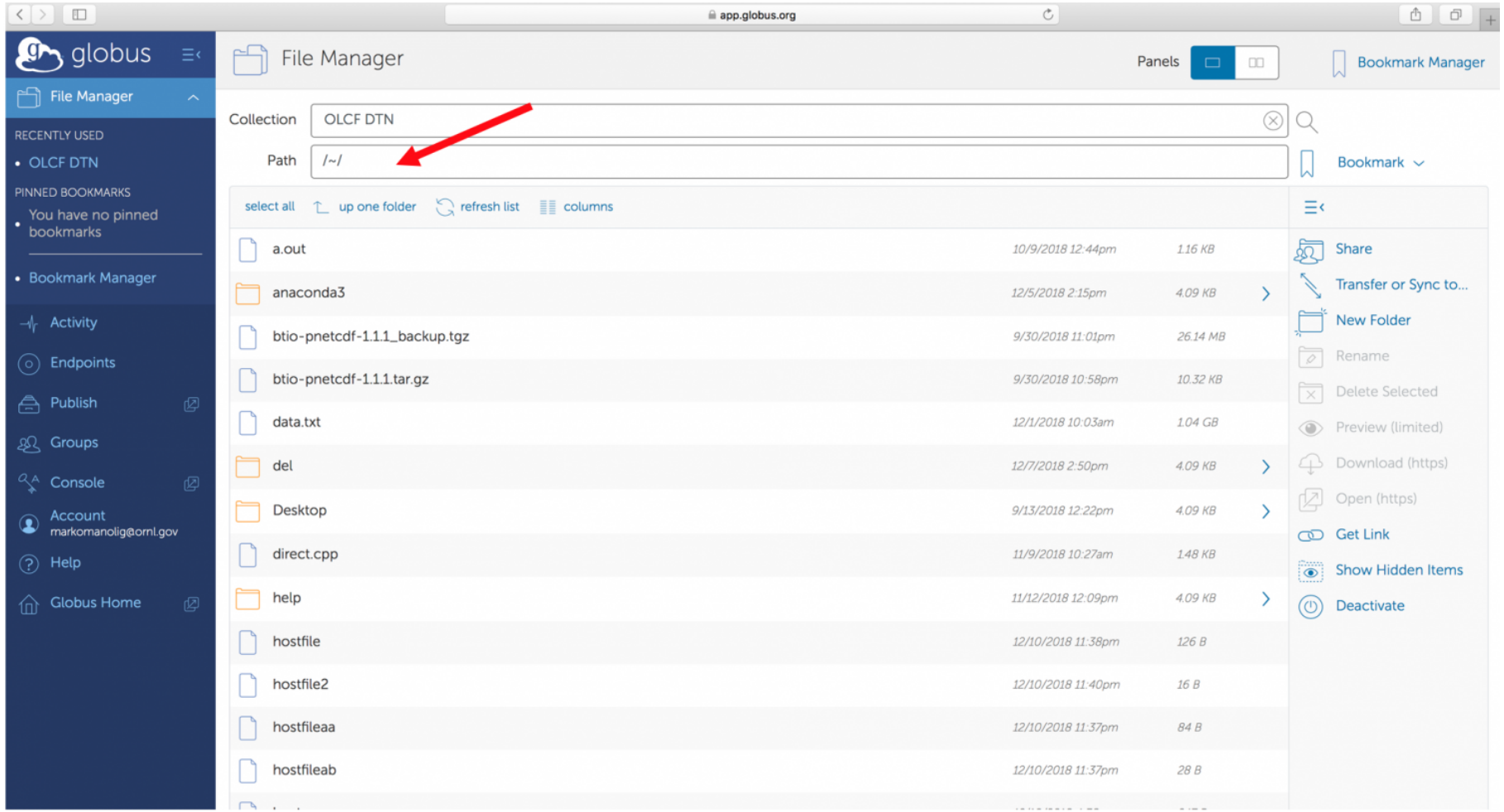
Globus - Organization



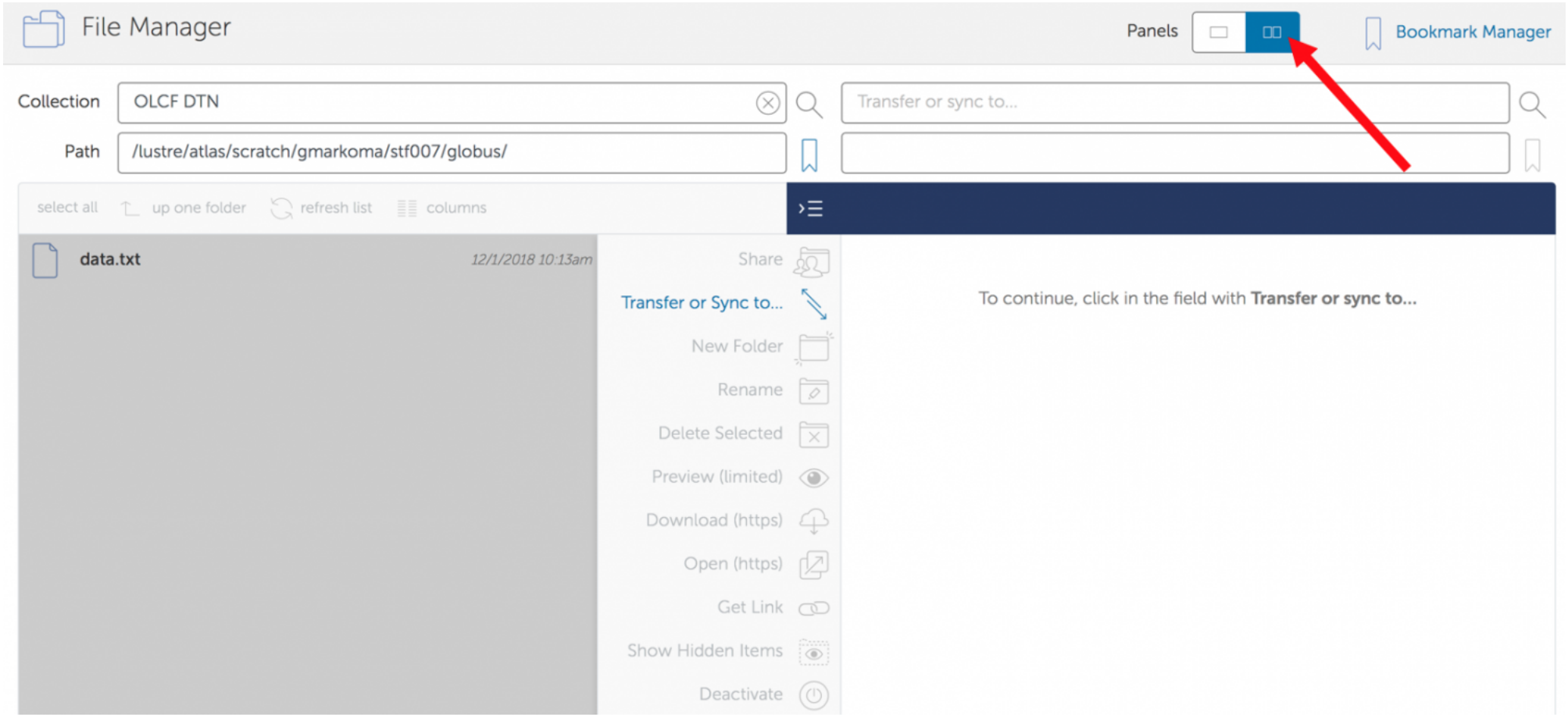
Globus – Endpoint and path



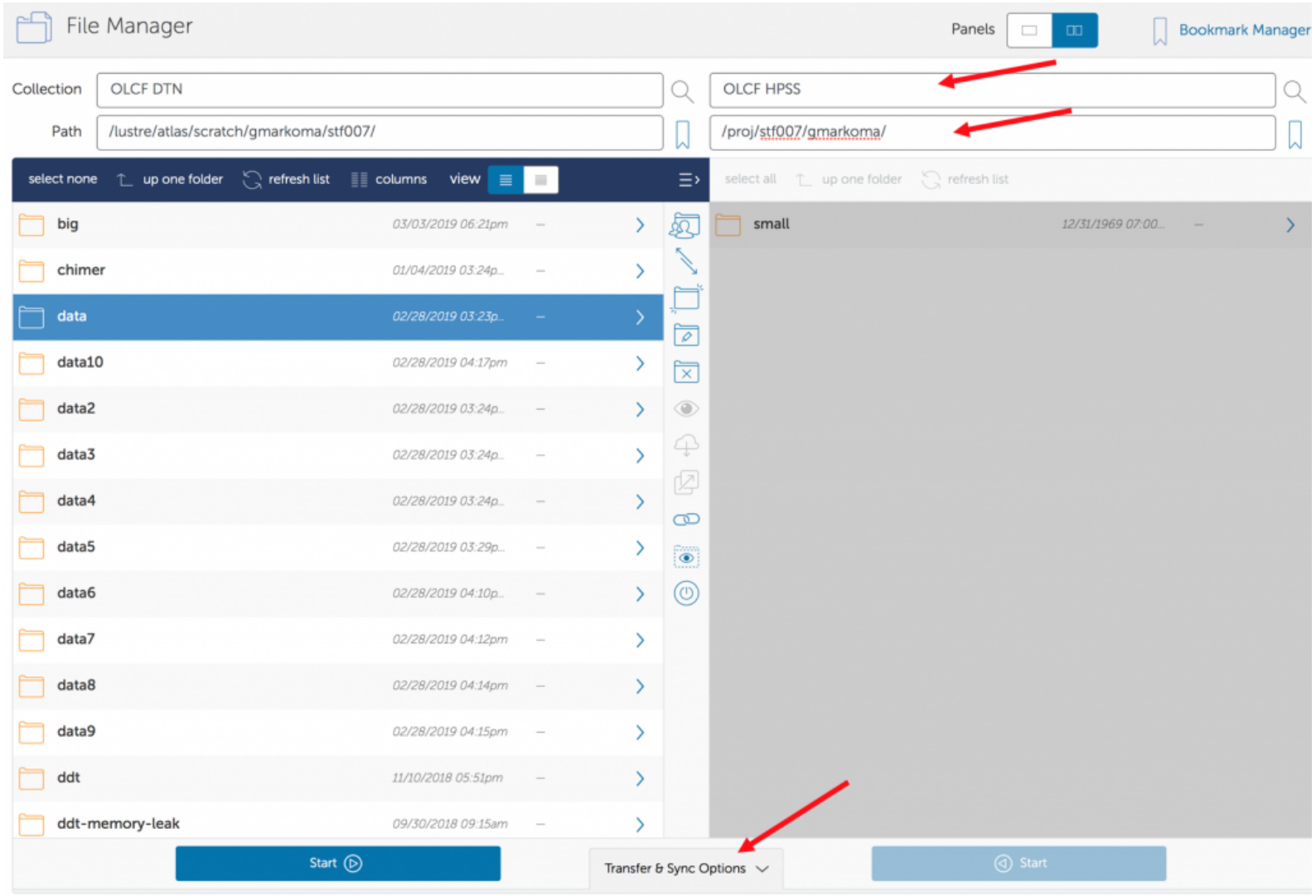
Globus – Endpoint and path



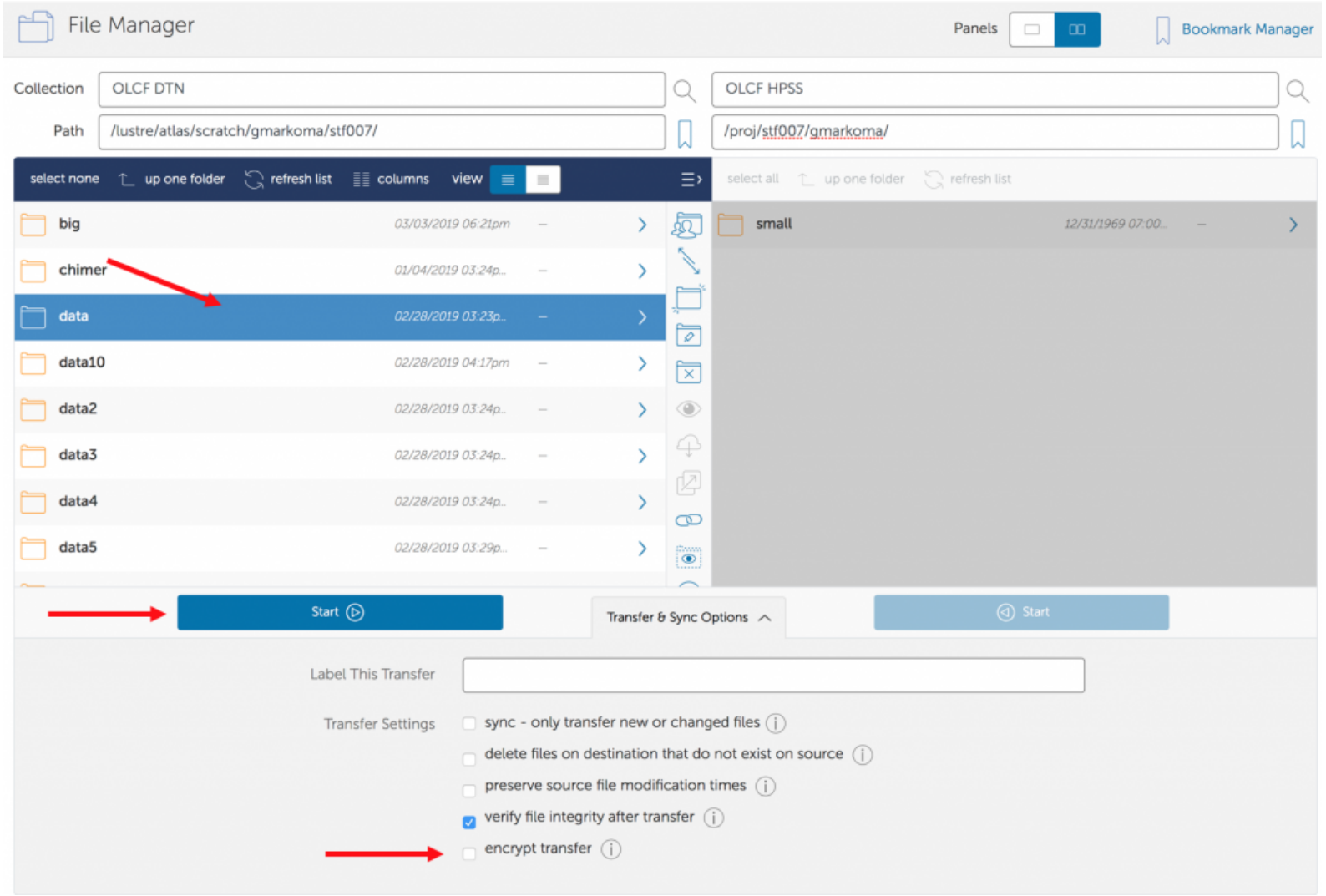
Globus - Panels



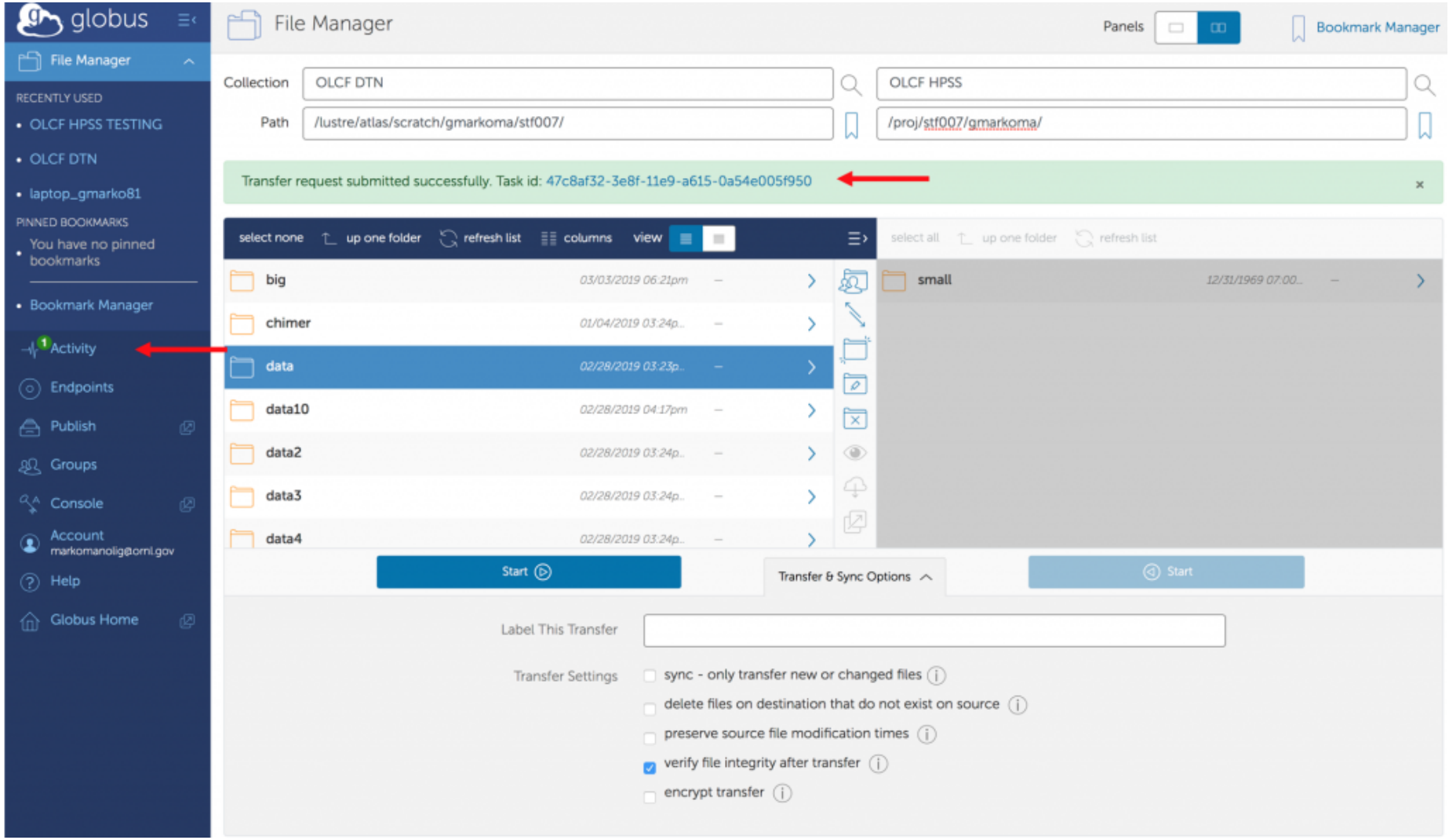
Globus - HPSS


File Manager
Panels
Bookmark Manager
Collection
OLCF DTN
OLCF HPSS
Path
/lustre/atlas/scratch/gmarkoma/stf007/
/proj/stf007/gmarkoma/
select none
up one folder
refresh list
columns
view
select all
up one folder
refresh list
big 03/03/2019 06:21pm
chimer 01/04/2019 03:24p...
data 02/28/2019 03:23p...
data10 02/28/2019 04:17pm
data2 02/28/2019 03:24p...
data3 02/28/2019 03:24p...
data4 02/28/2019 03:24p...
data5 02/28/2019 03:29p...
data6 02/28/2019 04:10p...
data7 02/28/2019 04:12pm
data8 02/28/2019 04:14pm
data9 02/28/2019 04:15pm
ddt 11/10/2018 05:51pm
ddt-memory-leak 09/30/2018 09:15am
small 12/31/1969 07:00...
Start
Transfer & Sync Options
Start

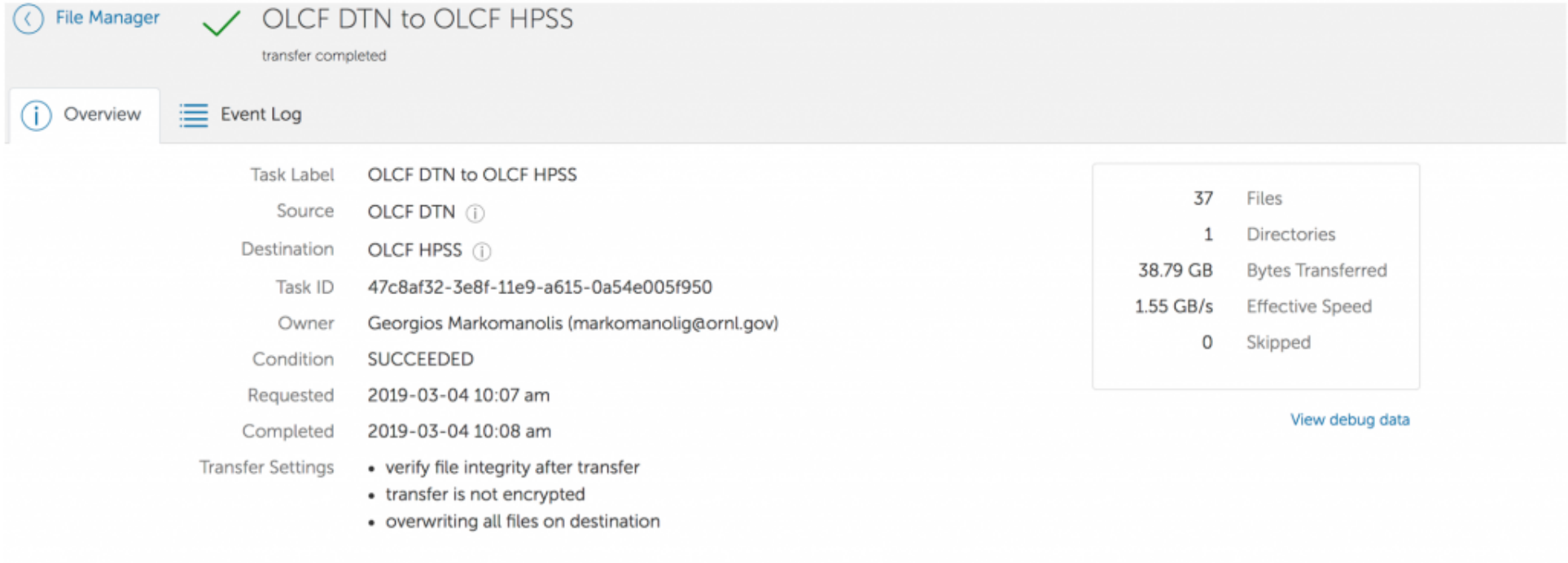
Globus – Start transfer



Globus - Activity



Globus(cont.)

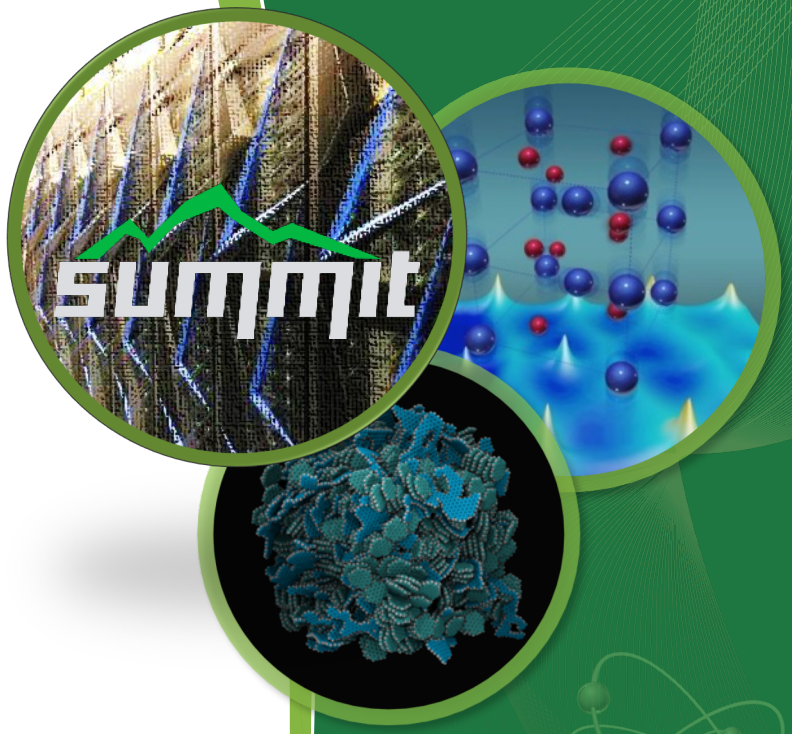

File Manager
OLCF DTN to OLCF HPSS
transfer completed
Overview
Event Log
Task Label
OLCF DTN to OLCF HPSS
Source
OLCF DTN
Destination
OLCF HPSS
Task ID
47c8af32-3e8f-11e9-a615-0a54e005f950
Owner
Georgios Markomanolis (markomanolig@ornl.gov)
Condition
SUCCEEDED
Requested
2019-03-04 10:07 am
Completed
2019-03-04 10:08 am
Transfer Settings
verify file integrity after transfer
transfer is not encrypted
overwriting all files on destination
37
Files
1
Directories
38.79 GB
Bytes Transferred
1.55 GB/s
Effective Speed
0
Skipped
View debug data

Conclusions

- Globus is easy to be used, no need to remember any specific commands
- It is even more efficient when we have many large files
- You can start a file transfer and shut down your computer, no need to have an active connection
- You will receive an email when the transfer finishes

Upcoming Training Opportunities

Tom Papatheodore



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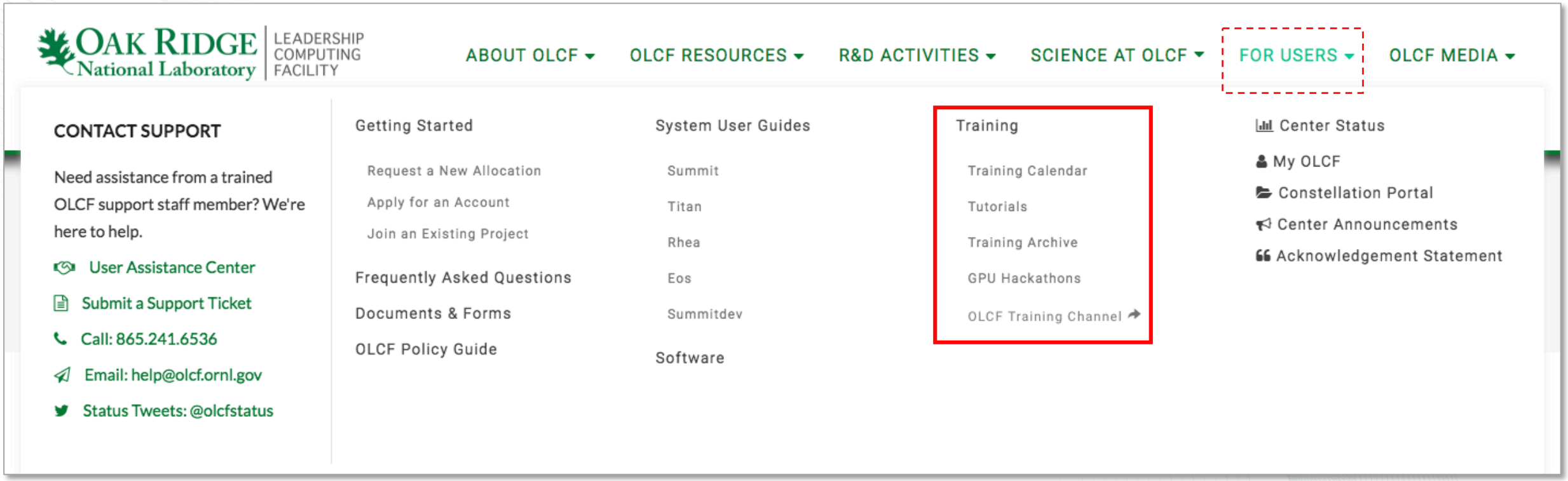
OAK RIDGE
National Laboratory

OLCF Training Resources

OAK RIDGE National Laboratory

OLCF Training Resources

www.olcf.ornl.gov

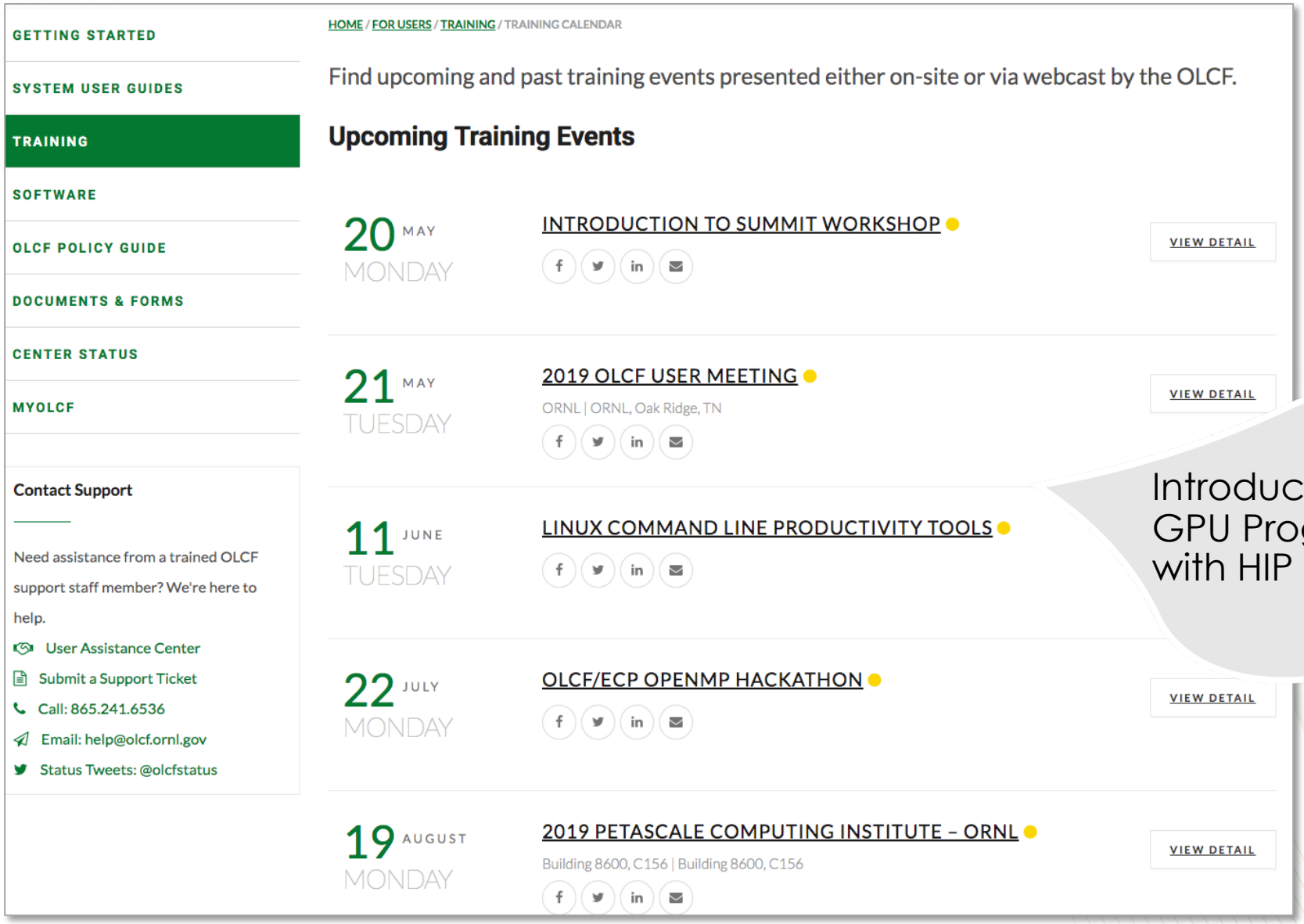


<OR>

https://www.olcf.ornl.gov/for-users/training/

Training Calendar

www.olcf.ornl.gov/for-users/training/training-calendar/



Introduction to AMD GPU Programming with HIP (June 7)

Training Archive

www.olcf.ornl.gov/for-users/training/training-archive/

HOME / FOR USERS / TRAINING / TRAINING ARCHIVE

Training Archive

Below you will find links to the slides and recordings of presentations given at prior OLCF training events.

Batch Schedulers & Job Launchers

Summit

Summit Scheduler & Job Launcher (Chris Fuson, OLCF): (**slides** | **video**)

Titan

Intro to Batch Scheduler & Job Launcher (Chris Fuson): slides, recording

Debugging and Profiling

Arm Forge Tools – DDT and MAP (Nick Forrington): slides, recording (part 1), recording (part 2), recording (part 3)

Debugging (Arm DDT) (Nick Forrington, ARM): (**video**)

Arm MAP/Performance Reports (Nick Forrington, ARM): (**video**)

Score-P / Vampir (Ronny Brendel): slides, recording

• • •

• • •

Intro to vim (Jack Morrison): slides, recording

UNIX

Intro to UNIX (Bill Renaud): slides, recording

Advanced UNIX & Shell Scripting (Bill Renaud): slides (same slides as Intro to UNIX), recording

Version Control

Intro to git (Jack Morrison and James Wynne): slides, recording

Previous Training Events (source of presentations above)

Introduction to NVIDIA Profilers on Summit

Summit Training Workshop

Programming Methods for Summit's Multi-GPU Nodes

Arm Debugging and Performance Analysis Workshop

Score-P / Vampir Workshop

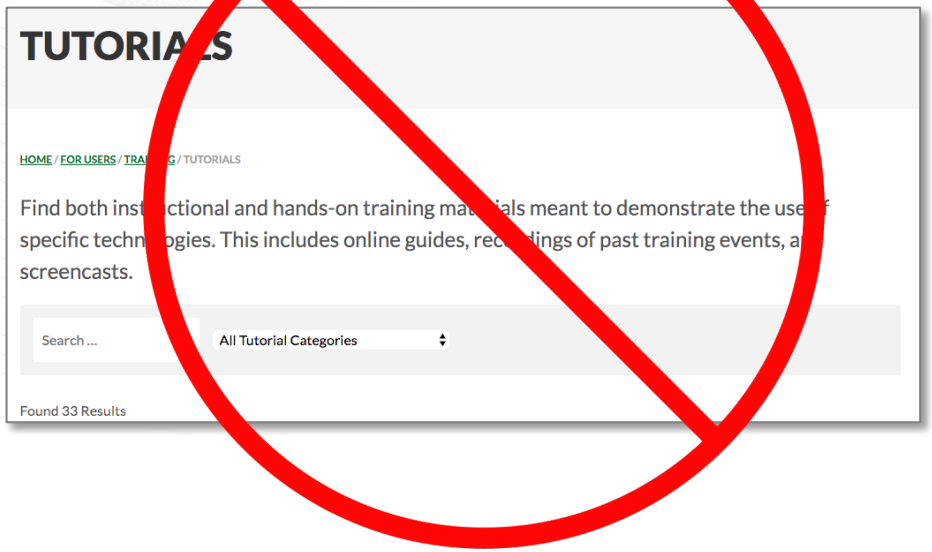
Introduction to HPC

Introduction to Summit Webinar

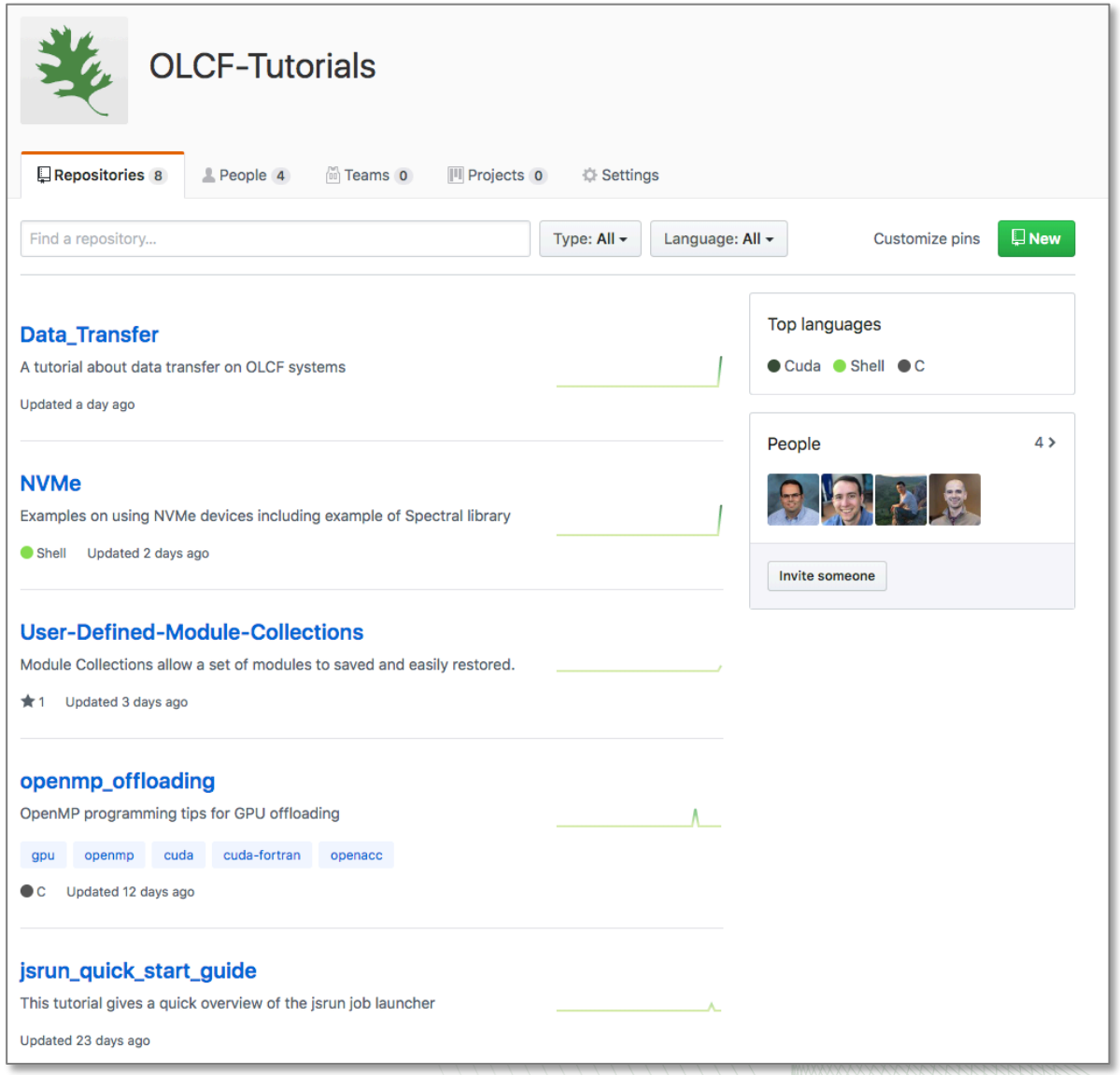
Also make sure to visit the OLCF Training Calendar for past and upcoming events!

Tutorials

www.olcf.ornl.gov/for-users/training/tutorials



www.github.com/olcf-tutorials



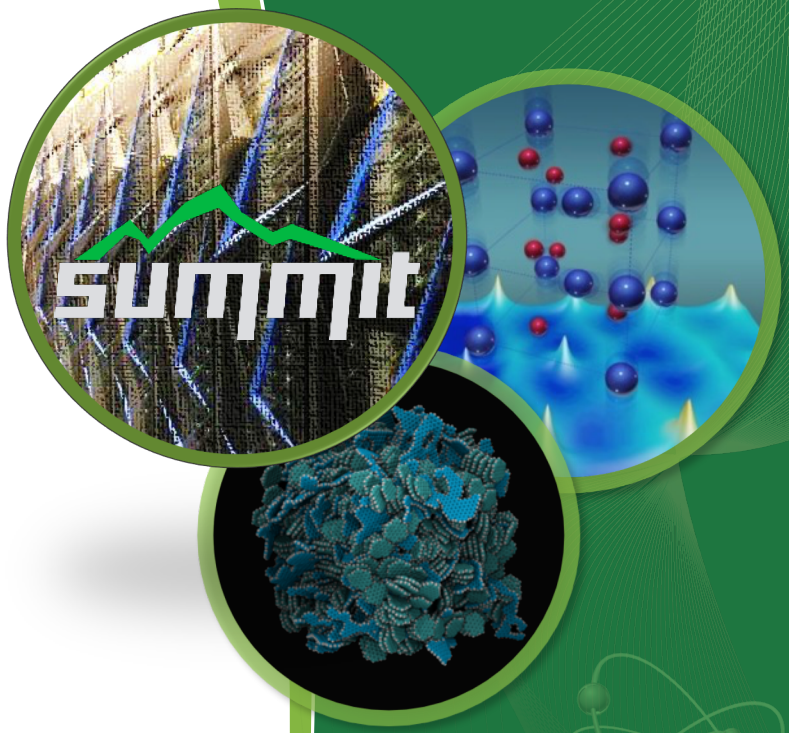
Currently in the process of moving our OLCF tutorials entirely to GitHub.

GPU Hackathons

www.olcf.ornl.gov/gpu-hackathons

Location	Call for Proposals Opens	Call for Proposals Closes	Event
KISTI – Seoul, South Korea	November 12	January 25	February 18-22
Pawsey SC – Perth, Australia	December 19	February 14	March 25-29
Helmholtz – Jülich, Germany	November 16	February 4	April 8-12
JGI – Walnut Creek, CA (focus on bioinformatics community)	January 10	March 31	May 6-10
MIT – Cambridge, MA	February 22	April 14	June 3-7
Princeton – Princeton, NJ	January 31	April 26	June 24-28
NERSC – Oakland, CA	March 25	May 15	July 15-19
Sheffield – United Kingdom	April 1	June 16	August 19-23
Brookhaven – Upton, NY	March 4	June 30	September 23-27
CSCS – Lugano, Switzerland	March 20	July 7	September 30 – October 4
OLCF – Knoxville, TN	February 22	August 16	October 21-25

Goodbye to Titan



Katie Bethea
Communications Team Lead
Oak Ridge Leadership Computing Facility
National Center for Computational Sciences

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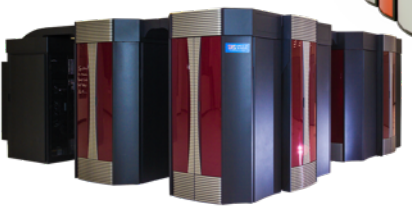
OAK RIDGE National Laboratory


TITAN

Titan carried on a strong legacy in leadership computing



OLCF-1

OLCF-2

OLCF-3

18.5 TF
2004
Cray X1E
Phoenix

25 TF
2005
Cray XT3
Jaguar

54 TF
2006
Cray XT3
Jaguar

62 TF
2007
Cray XT4
Jaguar

263 TF
2008
Cray XT4
Jaguar

1 PF
2008
Cray XT5
Jaguar

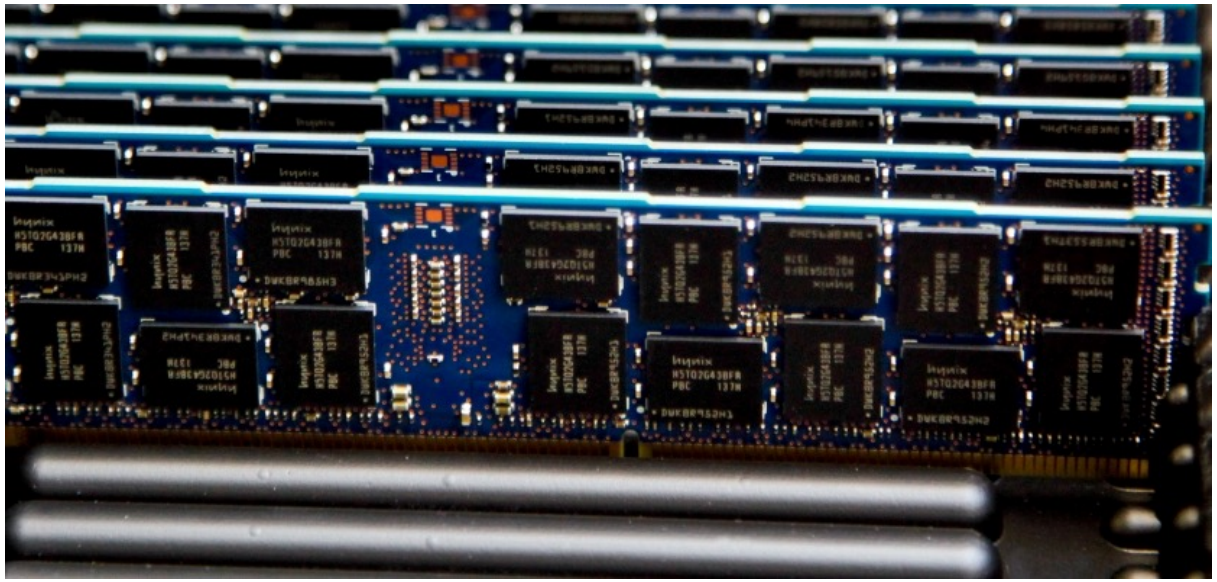
2.5 PF
2009
Cray XT5
Jaguar

1000-fold improvement in 8 years

27 PF
2012
Cray XK7
Titan

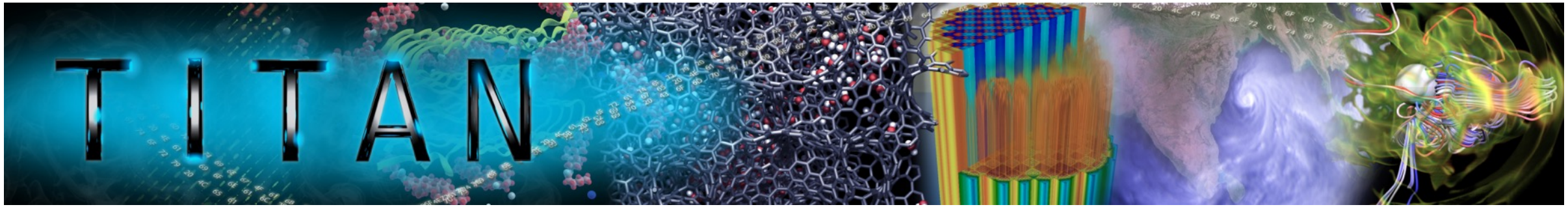
Titan, six years old in October 2018, continues to deliver world-class science research in support of our user community. We will operate Titan through July 2019 when it will be decommissioned.

2012: Transition from Jaguar to Titan



2012: Transition from Jaguar to Titan

2012: Titan Debuts at No. 1 on the TOP500



- The combination of 16-core CPUs and GPUs marked the birth of Titan, a hybrid machine that took parallelism to the next level.
- With a theoretical peak of 27 petaflops, Titan realized 10 times the performance of Jaguar with only a 20 percent increase in electricity usage.


TOP500 CERTIFICATE

Titan, a Cray XK7 System at the U.S. Department of Energy/SC/Oak Ridge National Laboratory, TN, USA

is ranked

No. 1

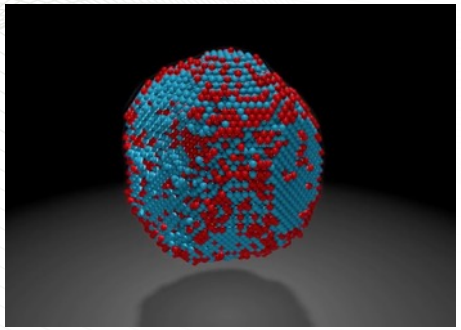
among the World's TOP500 Supercomputers with 17.59 PFlop/s Linpack Performance on the TOP500 List published at the SC12 Conference, November 13, 2012

Congratulations from the TOP500 Editors

Hans Meuer, University of Mannheim; Erich Strohmaier, NERSC/Berkeley Lab; Jack Dongarra, University of Tennessee; Horst Simon, NERSC/Berkeley Lab

Titan Enables Breakthrough Science

Materials Science



Markus Eisenbach
ORNL

Eisenbach and team modeled the properties of strongly magnetic regions of an FePt nanoparticle. The researchers used the LSMS code on Titan to further determine the magnetic anisotropy of more than 1,300 atoms from regions of the nanoparticle.

Y. Yang, et al. 2017. Nature. **542**.

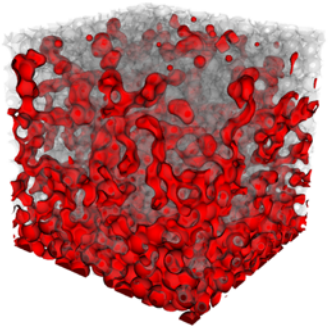
Engineering

Peter Vincent
Imperial College

Vincent's team is tackling unsteady airflow patterns in jet engines and providing engineers with an unprecedented tool to solve long-standing design problems.

P. Vincent, et al. 2016 Proc. of the Int'l. Conf. for HPC, Net., Storage and Analysis.

Geosciences

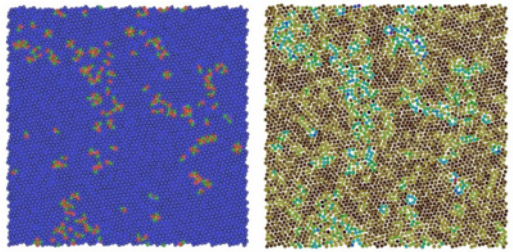


James McClure
Virginia Tech

McClure's team created a computational framework to study complex subsurface interactions, incorporating micro-CT imaging data to directly visualize the movement of fluids in underground reservoir rocks and other geologic materials.

R. T. Armstrong, et al. 2016. Phys. Rev. E. **94**.

Materials Science

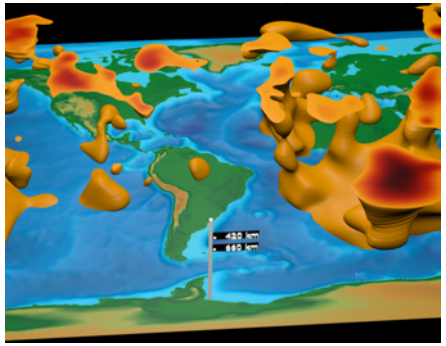


Sharon Glotzer
University of Michigan

Glotzer's team ran a series of hard particle simulations to study melting in 2-D systems, exploring how particle shape affects the physics of a 2-D solid-to-fluid melting transition.

J. A. Anderson, et al. 2016. Computer Physics Comm. **204.**

Geosciences

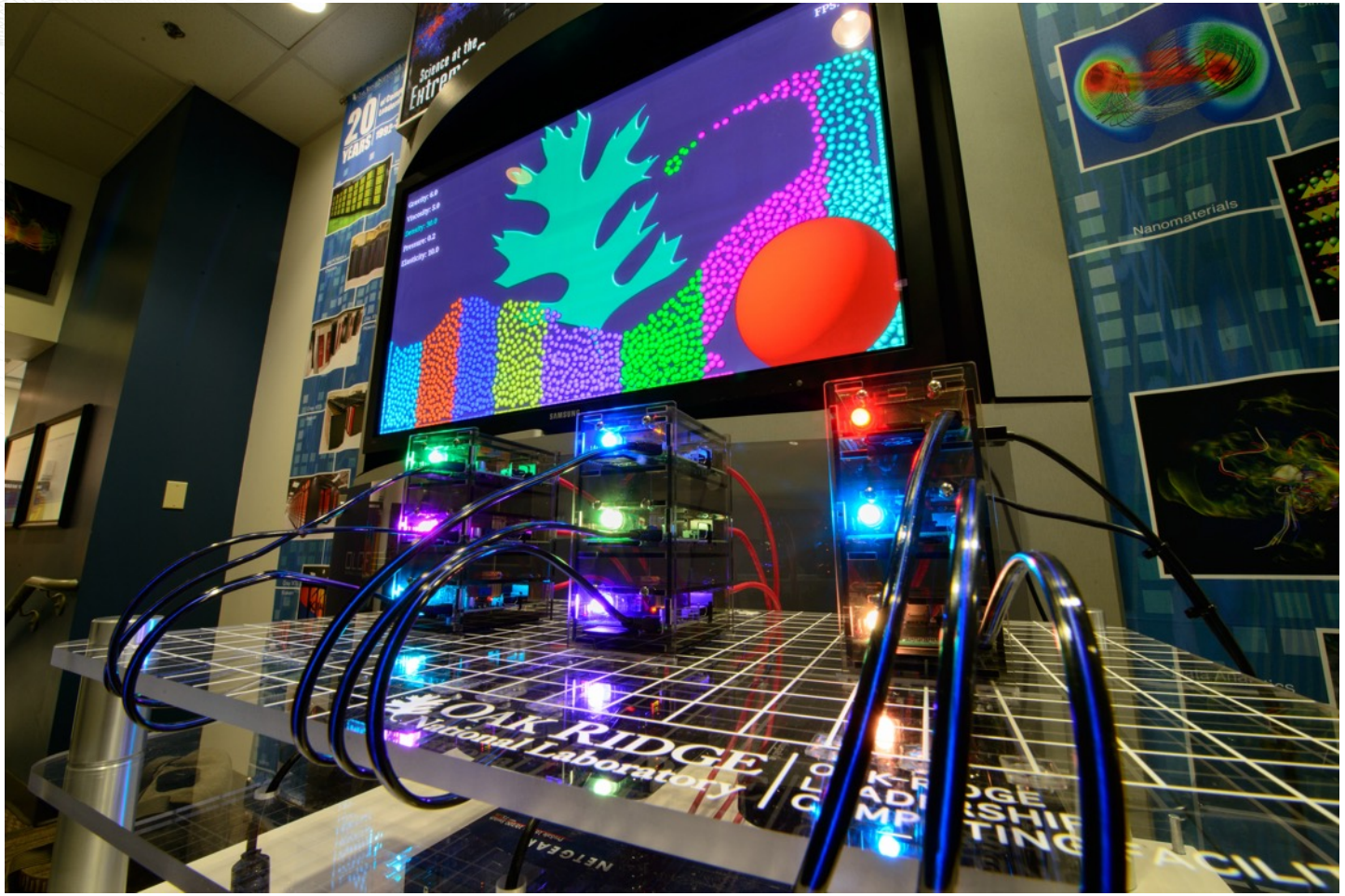


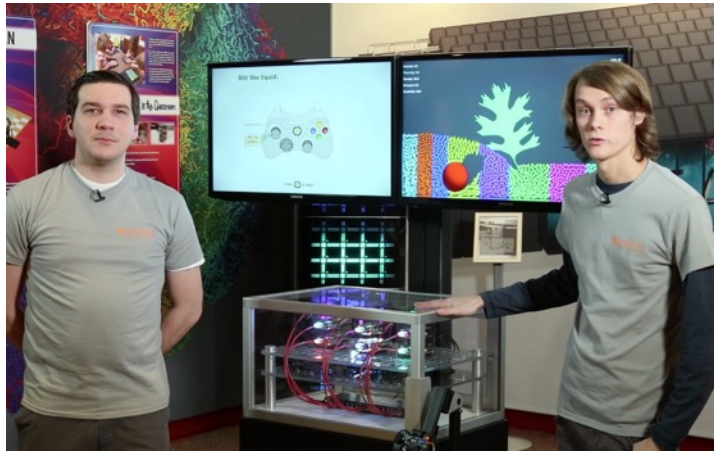
Jeoren Tromp
Princeton University

Tromp and his team modeled Earth's interior using Titan. This 3-D map shows shear wavespeed perturbations calculated using data from 253 earthquakes.

E. Bozdağ, et al. 2016. Geophysical J. Int'l. **207**.

Public Outreach: Tiny Titan and the Science Fair Trailer



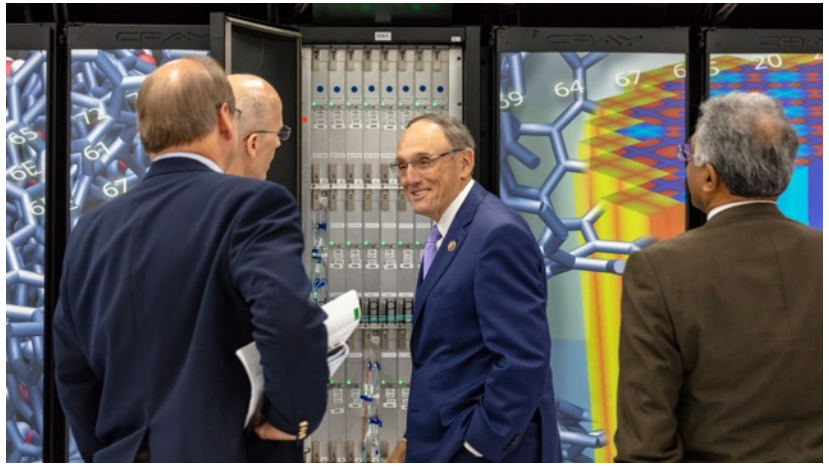


Titan has hosted countless special guests over the years

- Nobel Laureates and distinguished lecturers
- Senators and Members of Congress
- Secretaries, Deputy Secretaries, and Under Secretaries of Energy
- Make-A-Wish® Grantees
- UT basketball coach, Tour de France champion
- Countless students, scouts, and interns

Nobel Laureates and distinguished lecturers

Senators and Members of Congress

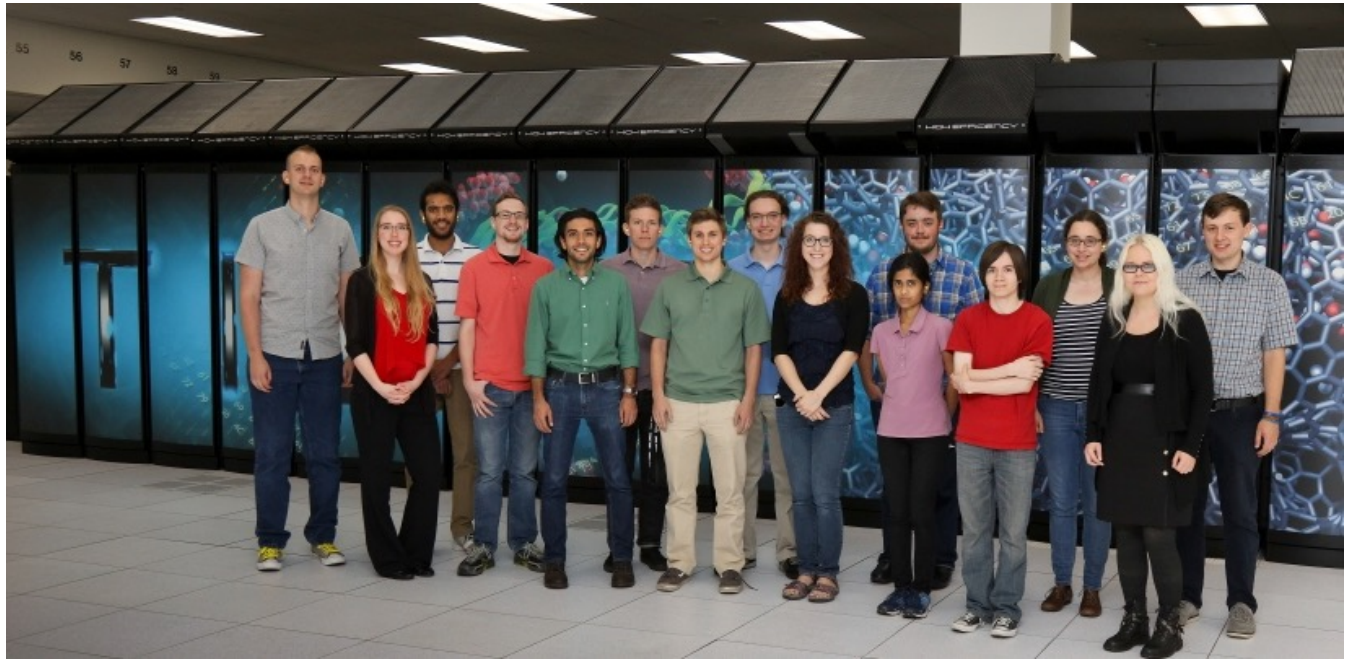


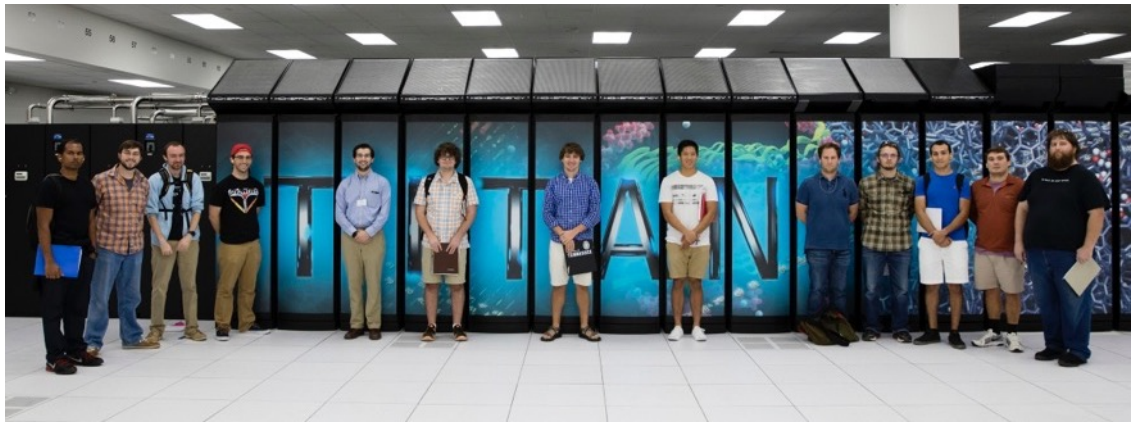
Secretaries, Deputy Secretaries, and Under Secretaries of Energy

Make-A-Wish® Grantees

UT basketball coach, Tour de France champion

Countless students, scouts, and interns

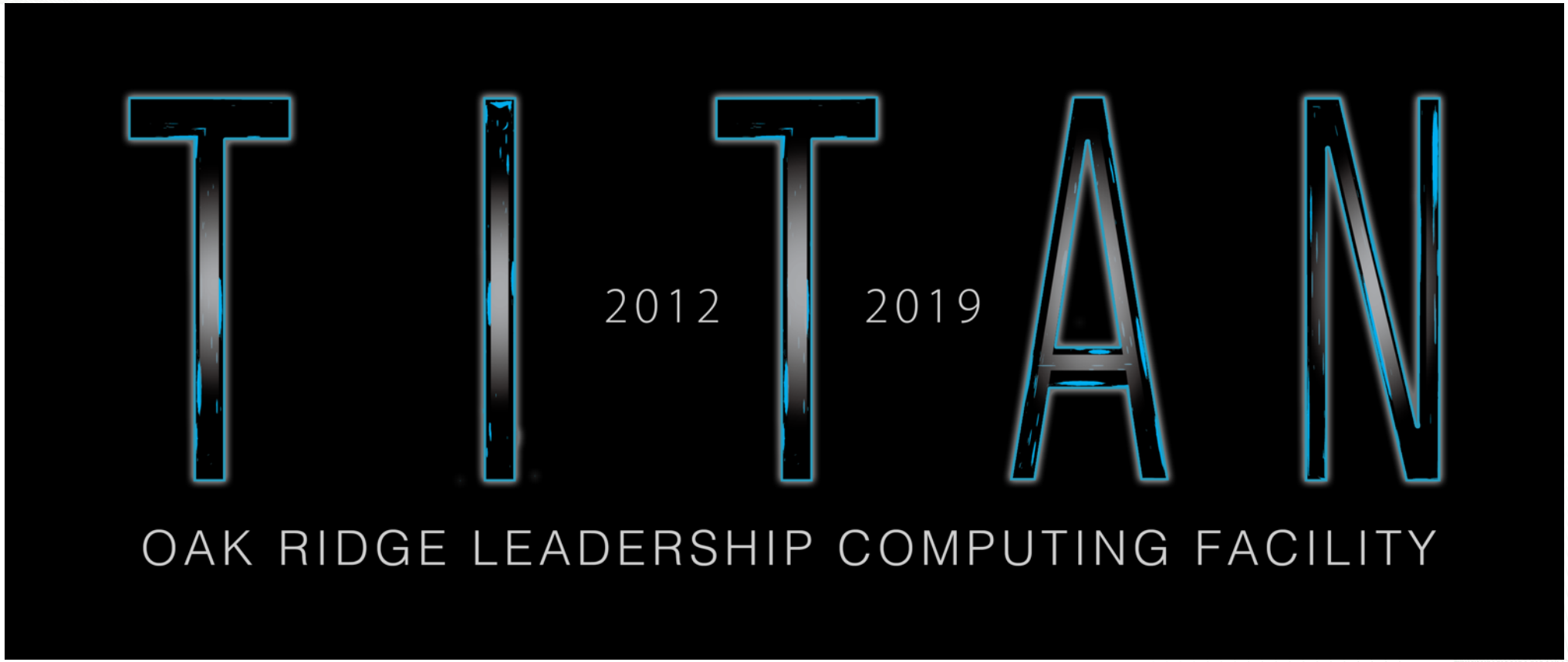




Now it's your turn!
Photo opportunity at Titan

- If you'd like your photo with Titan, please participate in the tour following the group photo (3:30pm).
- All User Meeting participants can get their photo taken (including ORNL staff).
- We will collect your names and send you the photos next week.

OAK RIDGE National Laboratory


TITAN
2012
2019
OAK RIDGE LEADERSHIP COMPUTING FACILITY

Questions?

OAK RIDGE National Laboratory