U.S. DEPARTMENT of ENERGY

BERKELEY LAB

ESnet
ENERGY SCIENCES NETWORK

Rucio/SENSE Productization for LHC CMS and ATLAS



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Pilots & Prototypes

Group Lead, ESnet

Rucio Community Workshop 2026

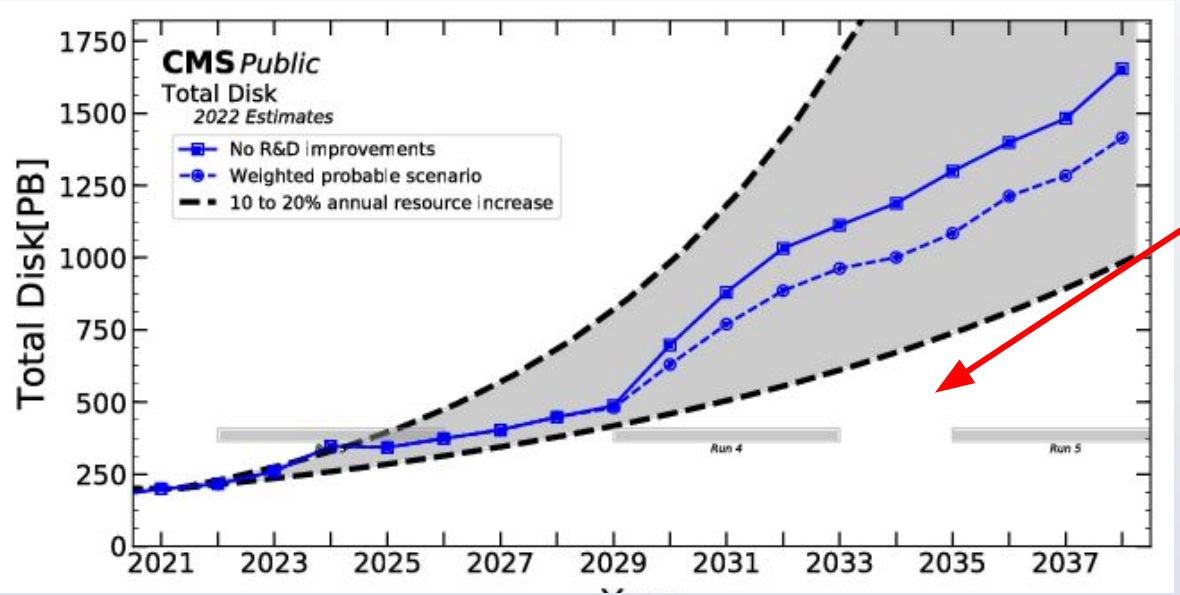
Lyon, France

October 27, 2026

What Makes SENSE - The User Story

Bandwidth Management Problem: Not enough end-to-end throughput for all data at all times.

Performance Engineering Problem: How to prioritize select data flows at any given time?



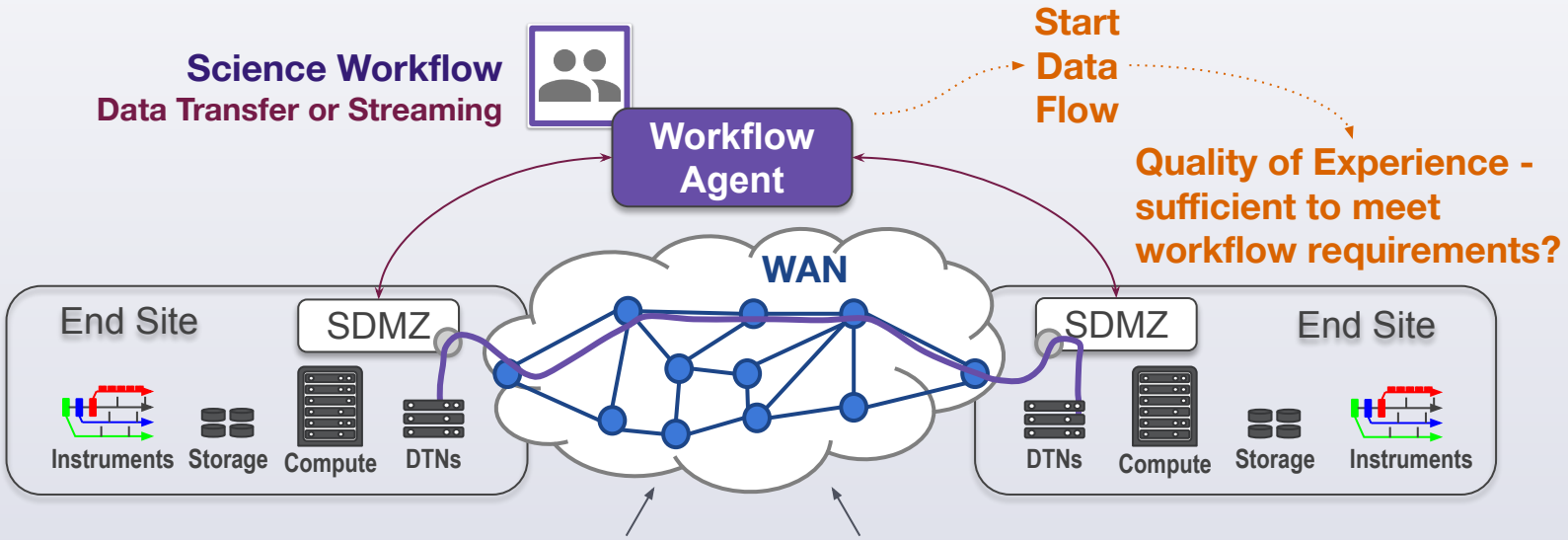
2025 Worldwide LHC Computing Grid (WLCG) predictions point more into the lower band and below…

Looks like we will be tight on disk by the time of High Luminosity.

SENSE = Software-defined networking for End-to-end Networked Science at the Exascale

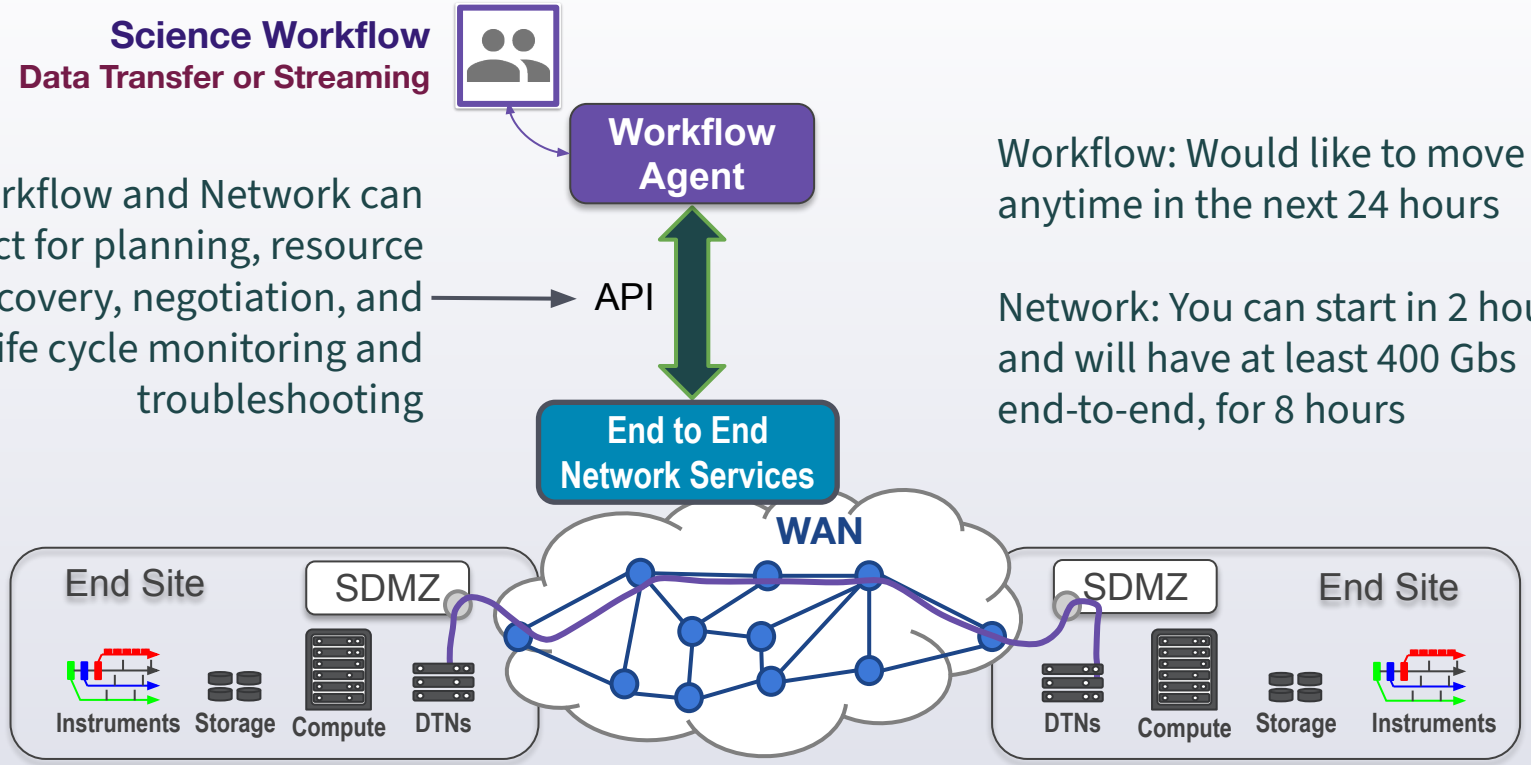
Current Workflows - Networks as "Opaque Infrastructure"

- Workflow agents must start data flow, and hope for the best
- No real-time per flow data available for planning or monitoring
- No "deterministic" network services available



- Good visibility into historical, aggregated network utilization
- No workflow accessible real-time data for their specific data flows

SENSE - Networks as a 1st Class Resource



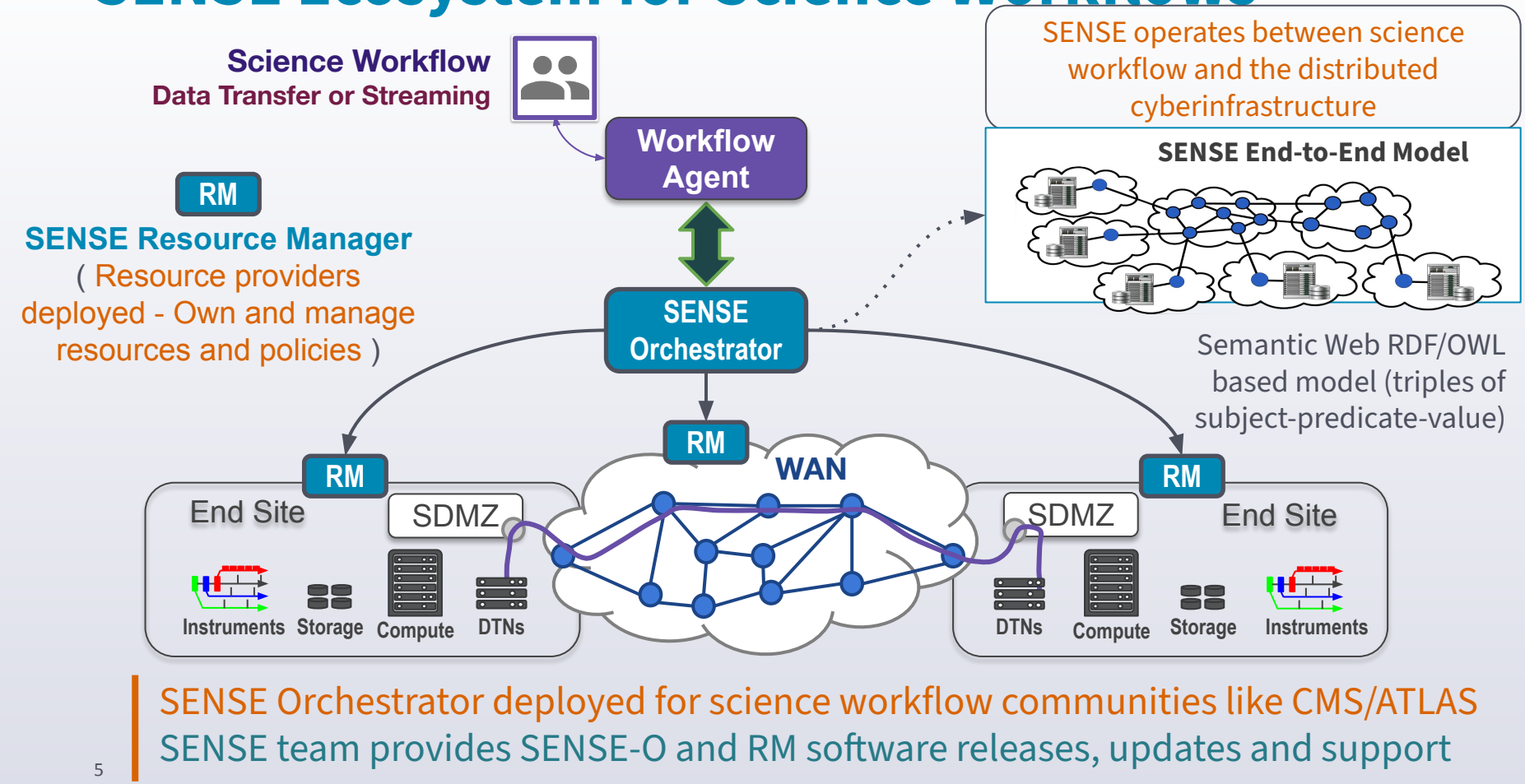
Workflow and Network can interact for planning, resource discovery, negotiation, and full life cycle monitoring and troubleshooting

Workflow: Would like to move 1PB anytime in the next 24 hours

Network: You can start in 2 hours, and will have at least 400 Gbs end-to-end, for 8 hours

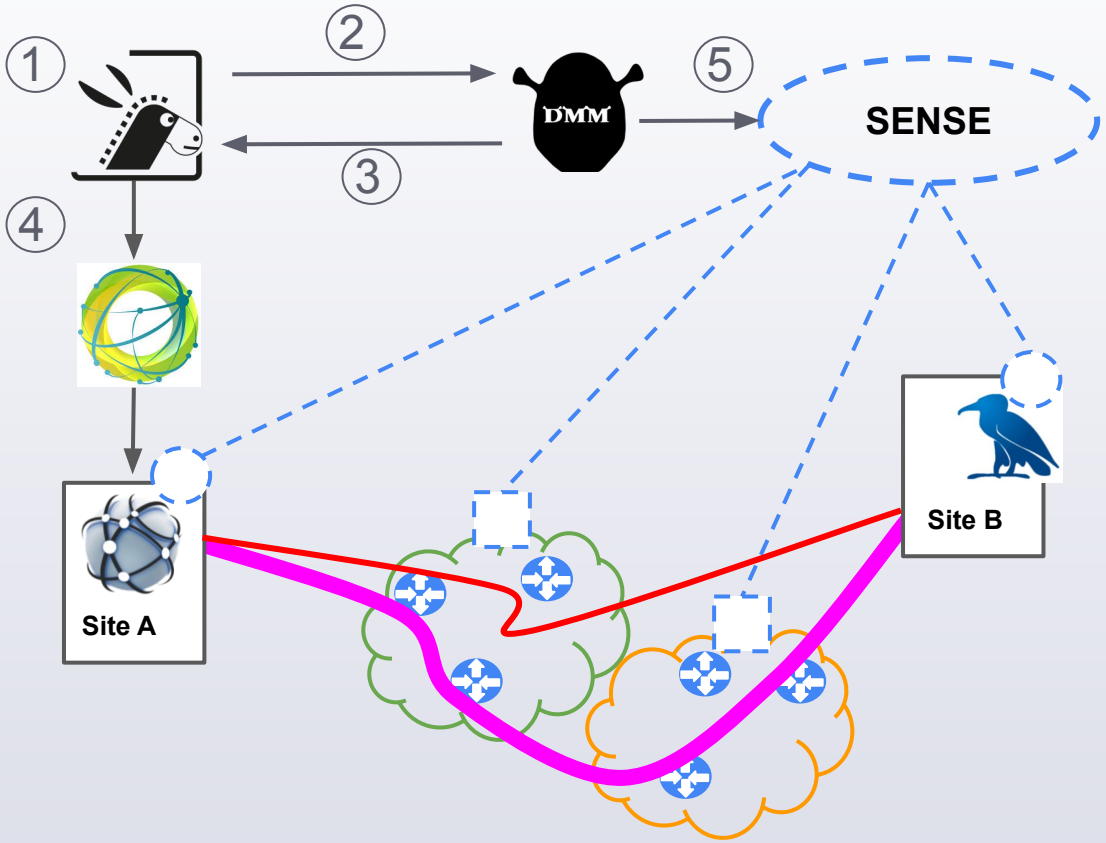
Allow workflows to view network resources as a first-class resource similar how they view compute, storage, instruments now

SENSE Ecosystem for Science Workflows



SENSE Orchestrator deployed for science workflow communities like CMS/ATLAS
SENSE team provides SENSE-O and RM software releases, updates and support

Rucio/SENSE Workflow - End-to-End Orchestration



1. A user creates a Rucio rule with the ***SENSE*** flag (“I want priority path”).

2. Rucio contacts *Data Movement Manager* to get new pair of **endpoints**.

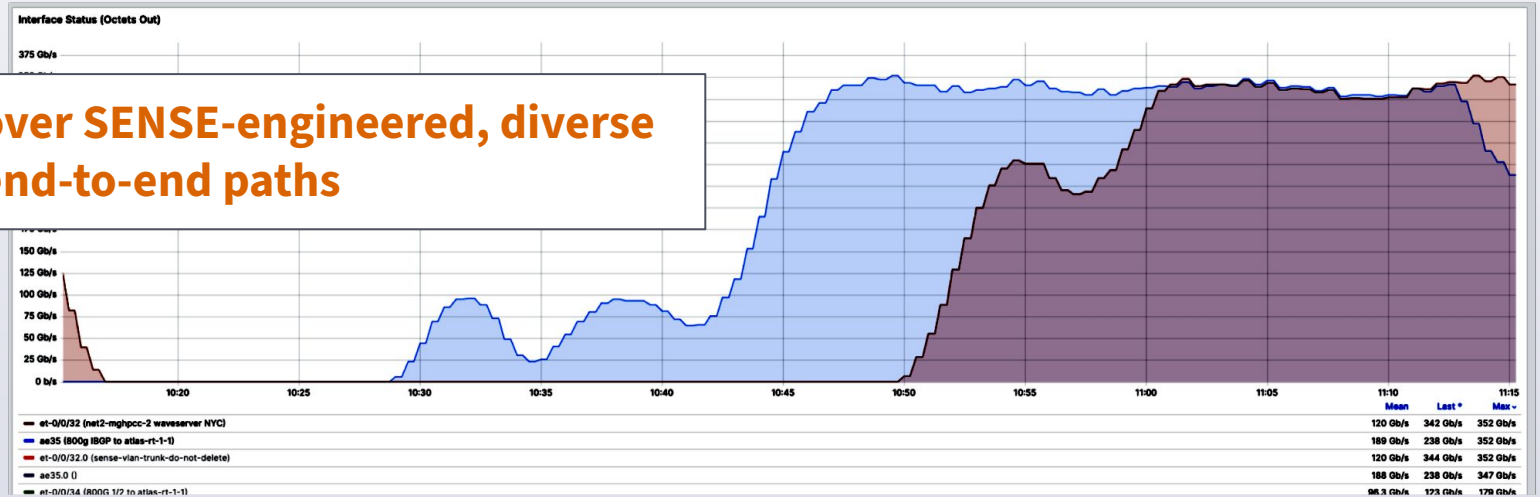
3. These are the **SENSE network touchpoints** on the **same sites** but in **special IPv6 subnets**.

4. Rucio-FTS transfers now **bind to** the SENSE priority path by replacing the old endpoints with the new ones.

5. Behind the curtain, *DMM* requests the creation of the SENSE path.

** SENSE error? Transfer remains on or fails back to default path **transparently.***

SC25 Results - Bandwidth Management

- **MGHPCC Prod (35 servers) to FNAL Testbed (4 Servers)**
  - FDT: 350 Gbps
  - gfal: 240 Gbps
- **MGHPCC Prod to UCSD/SDSC NRP (2 servers)**
  - FDT: 350 Gbps
  - gfal: 260 Gbps
- 

over SENSE-engineered, diverse end-to-end paths

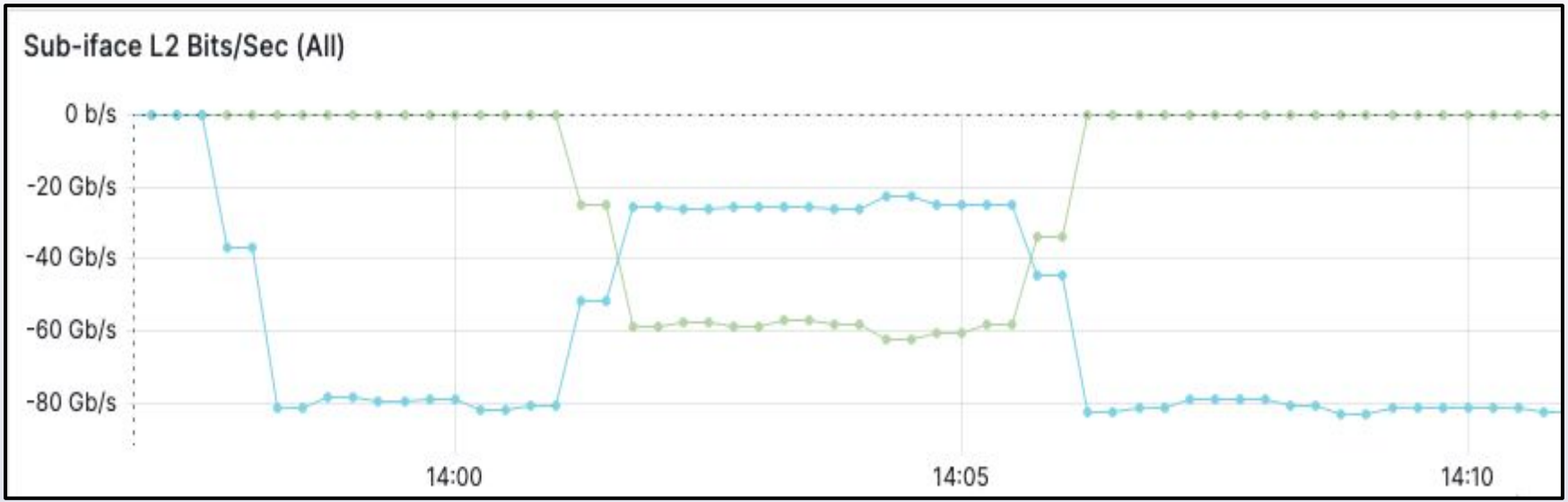
SC25 Results: Performance Engineering

- **MGHPCC Prod to UCSD/SDSC (2 servers)**
  - Best Effort (default) **Red** used full capacity when no competition.
  - SENSE Priority traffic **Blue** took over the capacity when requested.

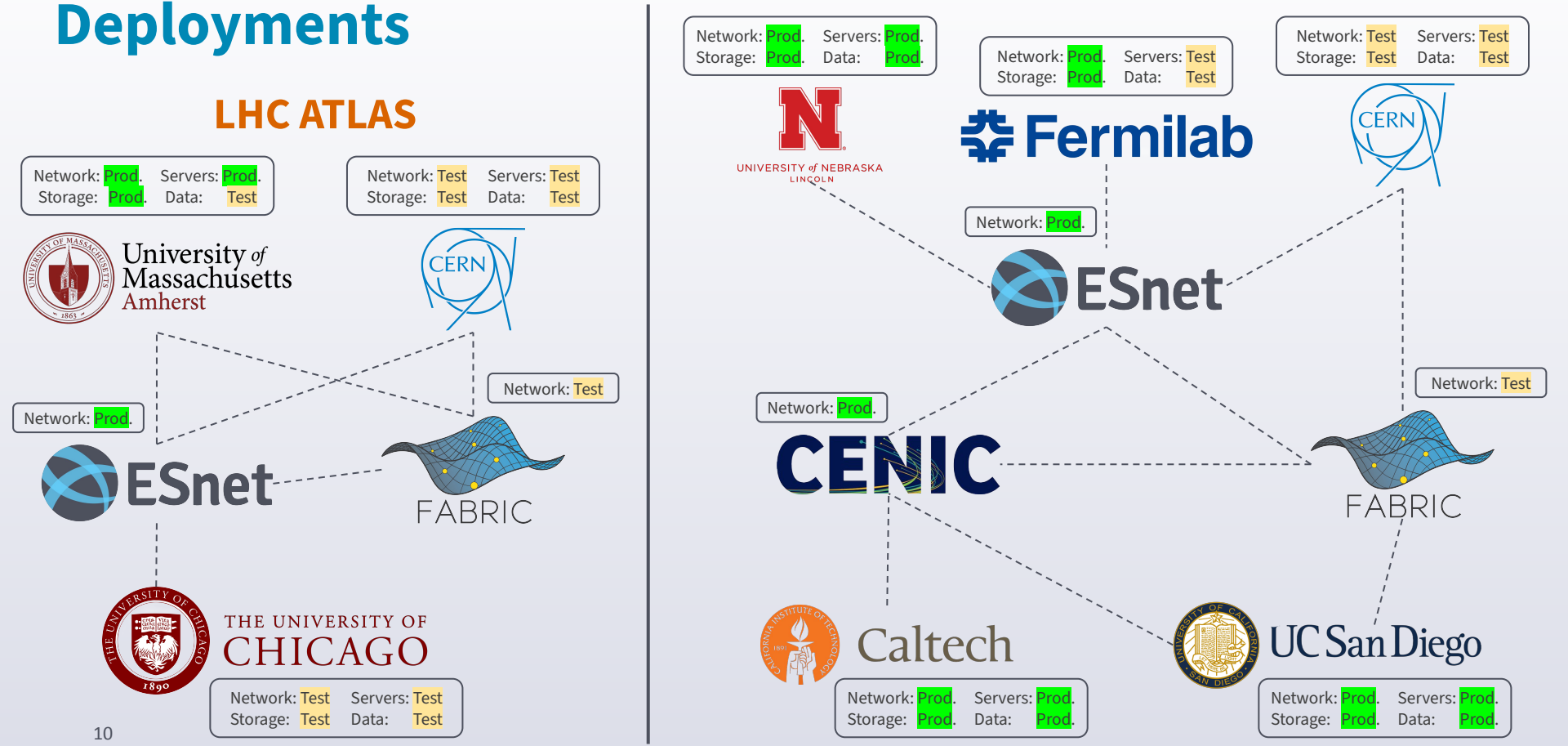


WLGC 2026 Capability Mini-Challenge Tests

- **100Gbps SENSE managed data flows between UChicago and UMass**



SENSE and Rucio/FTS/XRootD Deployments



Source: D. Davila, "Rucio/SENSE Integration update on the path to production", FTS/XRootD Workshop, Sep 2026

Phased Rucio/SENSE Productization Plan

Aug 31, 2026

Pre-Production
- Caltech, UNL, UCSD, FNAL

Prototype
- UWISC, UFlorida, CERN, UChicago AF, MGHPCC/NET2

Nov 15, 2026

Production-Phase 1
- Caltech, UNL, UCSD

Pre-Production
- FNAL, UWISC, UFlorida, CERN, UChicago AF, MGHPCC/NET2

Prototype
- Vanderbilt, Purdue, MIT

Feb 1, 2027

Production-Final
- Caltech, UNL, UCSD

Production-Phase 1
- UWISC, UFlorida, CERN, MGHPCC/NET2, Vanderbilt, Purdue, MIT

Pre-Production
- FNAL, Vanderbilt, Purdue, MIT

Apr 30, 2027

Production-Final

All Sites Operational:
- Caltech, UNL, UCSD, FNAL
- UWISC, UFlorida, CERN, MGHPCC/NET2
- Vanderbilt, Purdue, MIT

Prototype
- **Rucio/DMM:** Project Specific
- **Storage:** Local / Standalone
- **Site Net & WAN:** Prototype

Pre-Production
- **Rucio/DMM:** Project Specific
- **Storage:** Prod Storage (Test Data)
- **Site Net & WAN:** Prototype

Production-Phase 1
- **Rucio/DMM:** Integration Instance
- **Storage:** Integration Datasets
- **Site Net & WAN:** Production

Production-Final
- **Rucio/DMM:** Operational System
- **Storage:** Full Production Data
- **Site Net & WAN:** Production

DC27 Goal: Production-Ready Integration for CMS

System stability has improved, and three production CMS sites are now supporting SENSE, positioning us to transition SENSE into the live CMS Rucio environment.

Proposed Deployment Path*:

1. **Establish CMS-Rucio ownership** - Deploy a DMM instance under CMS-Rucio team control
2. **Enable Integration** - Patch the CMS Rucio-Integration instance by year end
3. **Validate Readiness** - Demonstrate successful SENSE integration in the pre-production environment
4. **Transition to Production** - Patch the CMS Rucio-Production instance in late January 2027

**NB: This represents the proposed path from the Rucio/SENSE team. Timing and sequencing remain subject to alignment with the CMS-Rucio team.*

Data Movement Manager (DMM) Update

Core Role & Functions

- Interface between Rucio, SENSE, and FTS
- Map rule (datasets) to site network endpoint (IPv6 subnets)
- Decision making for per-rule network bandwidth allocation
- Workflow coordination through data transfer and network service lifecycles

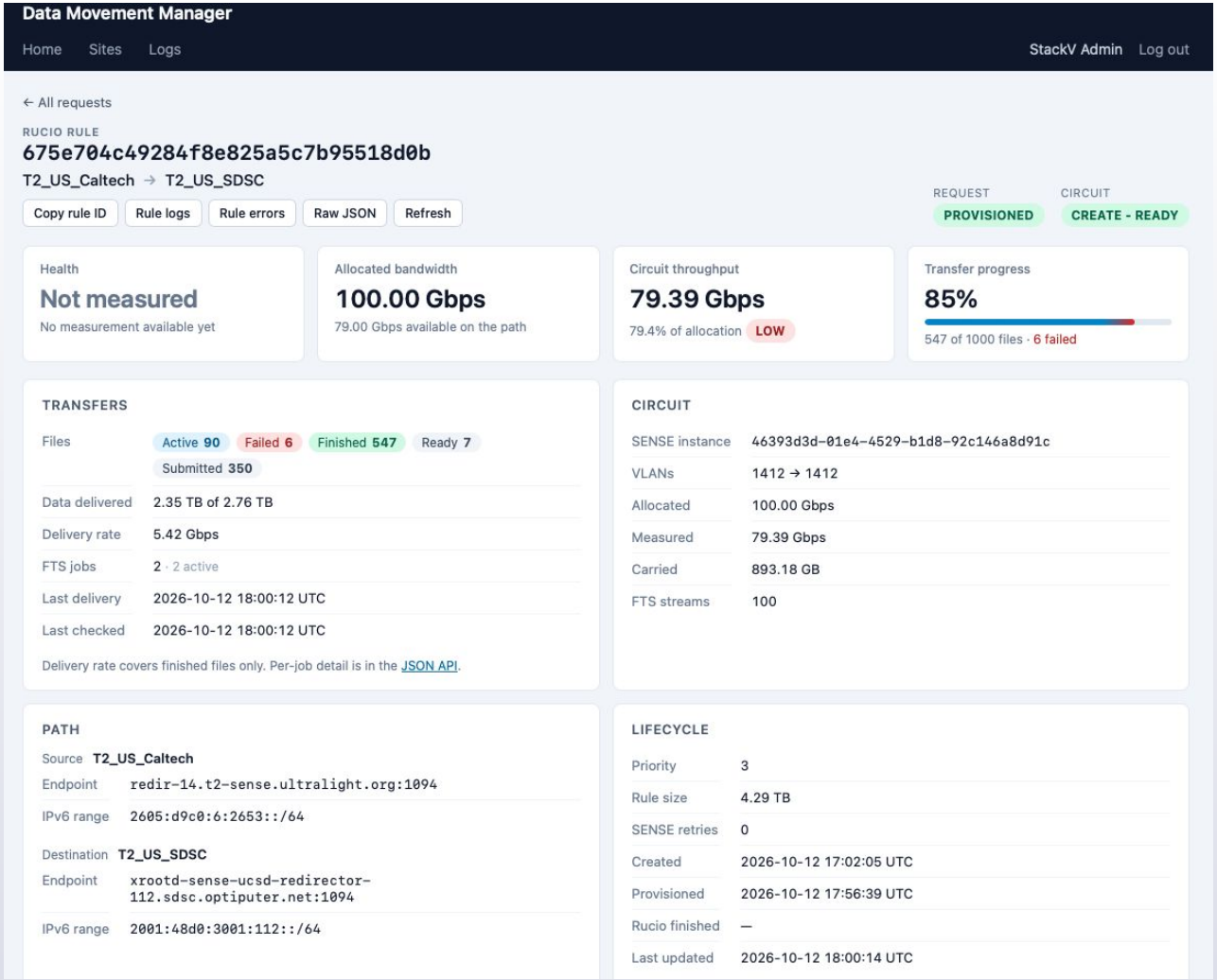
Recent Enhancements

- Improved workflow error handling, recovery, and retry for network failures
- Improved portal UI/UX and monitoring
- Support “logical site”—allowing use cases to work with segregated enclave of “servers and networks” on same physical site

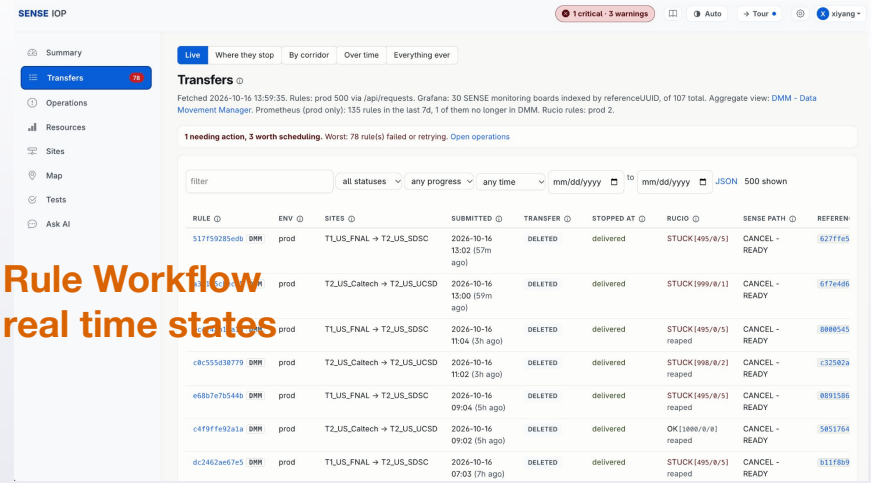
https://github.com/rucio/sense-dmm

DMM Portal

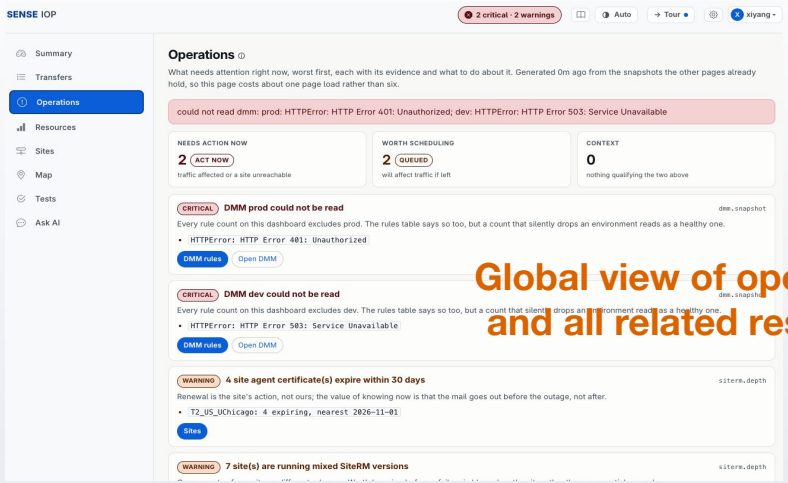
- **New UI: Rucio Rule -> DMM -> SENSE Workflow Details**



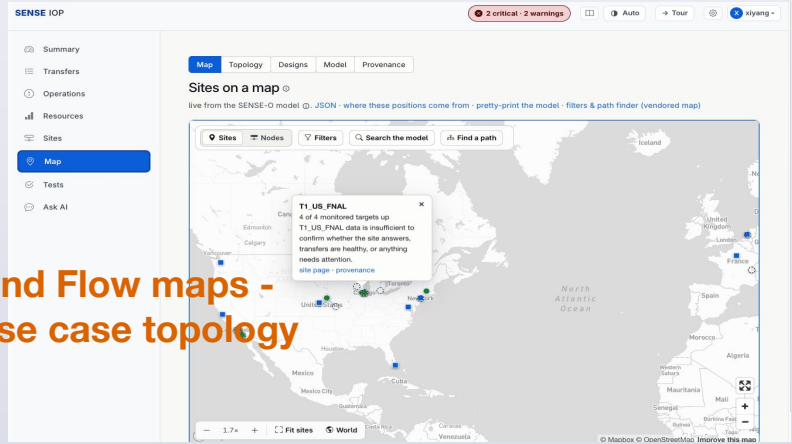
SENSE/Rucio Integrated Operations Portal (IOP)



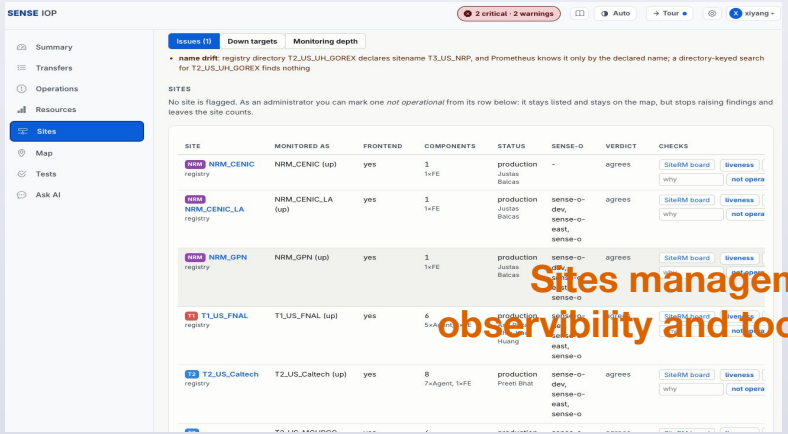
Rule Workflow real time states



Global view of operations and all related resources



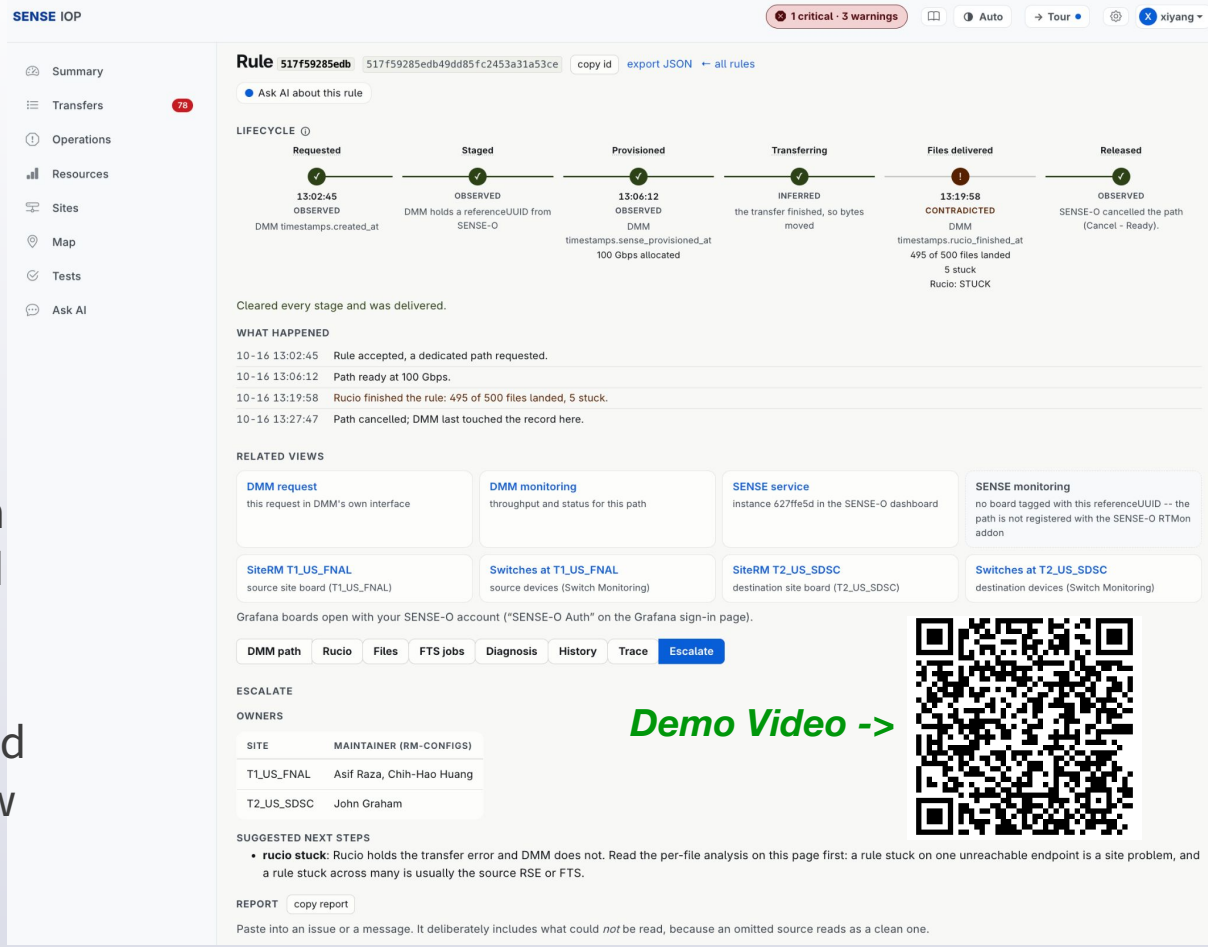
Site and Flow maps - per-use case topology



Sites management observability and tooling

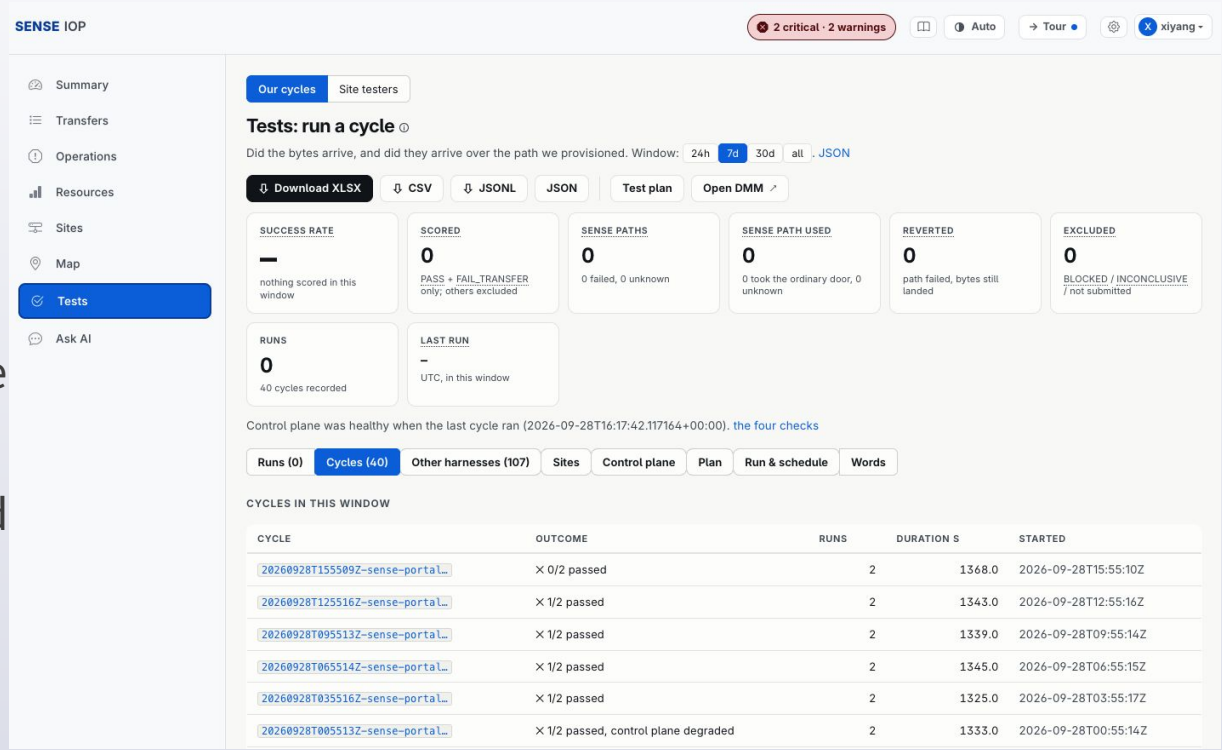
Rucio - SENSE - Sites Co-Operations

- Single pane of glass for total observability
- Confluence of operations metadata for rucio /dmm /sense /sites /xroot /data etc. elements
- Communication hub with normalized language and contact & escalation
- AI assisted monitoring and troubleshooting workflow and chat bot



SENSE Automated Full-Stack Tests

- In order to increase the stability of the overall system we started running periodic automated tests across the site in the CMS testbed
- Every 2 hrs a set of short-lived Rucio rules are injected requesting “SENSE” treatment
- These tests have help us find bugs across the whole infrastructure
- The same is being planned for ATLAS testbed



Co-authors: Tom Lehman, Justas Balcas, Chin Guok, Inder Monga, Mohammad Sada, Frank Würthwein, Diego Davila, Aashay Arora, John Graham, Thomas Hutton, Harvey Newman, Preeti Bhat, Andres Moya, Oliver Gutsche, Phil Demar, Asif Shah, Dmitry Litvintsev, Garhan Attebury, Rafael Coelho, Eduardo Bach, Jessa Westclark, John Remy Steele, Robert Gardner, Fengping Hu, Lincoln Bryant

More SENSE Information

SENSE in Practice: Quantifying the End-to-End Benefits of Intent-Based Bandwidth Reservation for Exascale Science Workflows https://doi.org/10.1145/3731599.3767454

SENSE Tutorial Video

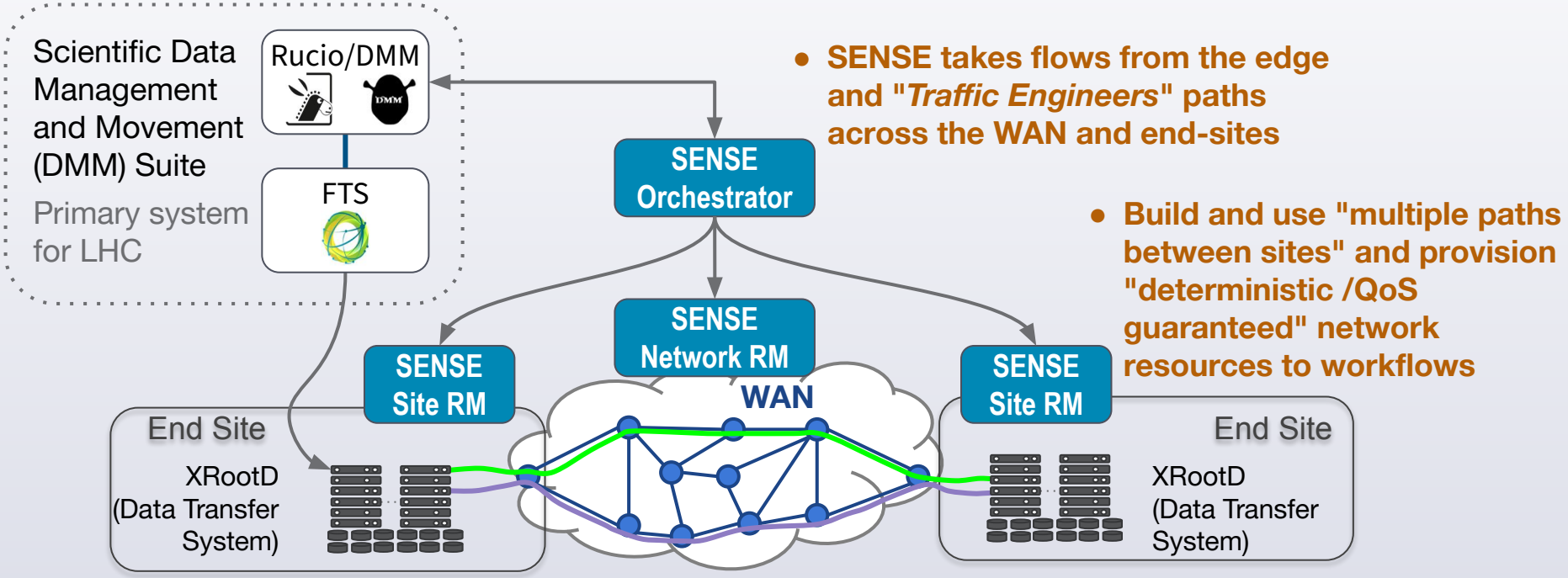
SENSE Information: sense-info@es.net

SENSE Website: sense.es.net

Extra Slides

Example - SENSE and Rucio/FTS/XRootD Interoperation

- **Rucio identifies groups of data flows (replication rules) which are "high priority"**
- **Rucio DMM leverages the SENSE orchestration to drive workflow decisions**



- **SENSE takes flows from the edge and "*Traffic Engineers*" paths across the WAN and end-sites**
- **Build and use "multiple paths between sites" and provision "deterministic /QoS guaranteed" network resources to workflows**

Science Workflows and Infrastructure – Big Changes on Immediate Horizon

- Increased workflow dependency on real-time integration of multiple distributed resources
- Artificial Intelligence driven processes and innovations
- Result will be "adaptive workflows" -> steps may not be precisely known before runtime
- Infrastructures will need to support seamless access in the context of the increased degree of resource distribution

Networks will need to provide predictable services and support real-time workflow driven adjustments