Scitags: Summary and Outlook

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on behalf of the **RNT Working Group** and **Scitags project**

LHCOPN/LHCONE 2026, Naples, Italy

Scitags and Other Network Visibility Projects

WAN / PATHS / BGP

perfSONAR

Network Measurements

Target: Network Performance & End-to-End Paths

- Active end-to-end probing (ps_trace, owamp, iperf3 metrics)
- Detects ASN-path anomalies, route changes, & WAN bottlenecks

TCP / DATA TRANSFERS

Scitags

Flow & Packet Marking

Target: Transfer Context & Packet-Level Visibility

- **TCP/Data Level:** UDP Fireflies signal exp/activity IDs
- **Packet Level Insertion:** IPv6 Flow Labels & Extension Headers for per-packet visibility

FLOWS (NETFLOW/SFLOW)

MetrANOVA

Flow & Telemetry Stack

Target: High-Cardinality Flow Records

- Open-source architecture optimized for sharing data
- Leverages ClickHouse datastore for fast NetFlow/sFlow ingestion

PACKETS / FRAMES

ESnet High-Touch

FPGA / Hardware Telemetry

Target: Packet Headers & Real-time Trajectory

- Per-packet line-rate inspection via FPGA/P4 programmable data planes
- Precision timestamps to analyze loss, jitter & goodput per flow

Path Probing (perfSONAR) | Contextual Tagging & Packet Marking (Scitags) | Flow Ingestion (MetrANOVA) | Hardware Telemetry (ESnet)

Firefly Collectors

Infrastructure & Production Collectors

Focused on building up collection and processing infrastructure for fireflies.

Production Deployments:
Active at **ESnet** and **GÉANT**

Internet2 Support: GeoIP DNS service

- collector.scitags.org resolves to the nearest collector

ESnet Message Bus: Production active

- Exchanging live data between GÉANT and ESnet

Global Expansion: Seeking partners to run production collectors in the Asia/Pacific region

Capitalizing on synergies with other projects presents an **opportunity to stand up set of telemetry hubs**, synthesizing multi-source data to achieve global visibility.

Experiment Collectors & Analytics

Message Bus Subscription

Experiments can directly subscribe to the message bus to receive real-time firefly streams.

Production Usage

ATLAS uses stream data to perform analytics on a common dataset integrated with **Scitags**, **FTS**, and **perfSONAR**.

Part of an initiative to test **AIOps** during the WLCG Data Challenge in 2027.

Current Status: Software Support

Full support for fireflies now available across the entire WLCG DDM tool chain

Distributed Data Management (DDM):

- Rucio (from 32.4.0) and FTS/gfal2 from 3.2.10/2.21.0
- DIRAC - (from 9.0.8) - works with FTS the same way as Rucio
- ALICE O2 - supported since xrootd 5.0+

Storage:

- XRootD includes a Scitags implementation (from 5.0+)
- EOS includes Scitags support from 5.2.19+
- StoRM includes Scitags support from 1.4.3+
- dCache supports fireflies since 11.2.3
  - includes storage statistics (read/write latency to/from disk)

Beyond WLCG we now also have support in **Pelican** (core OSG DDM)
Globus ?

Current Status: Experiments Readiness and Adoption

All WLCG experiments now ready

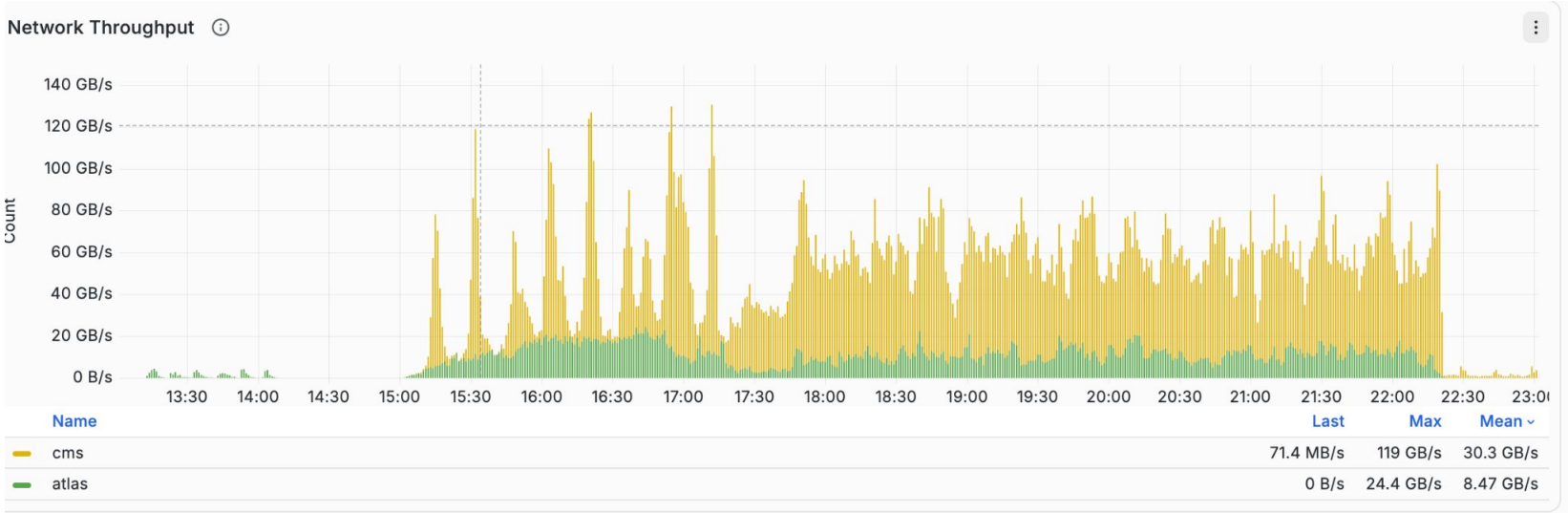
- Fireflies enabled in production for every DDM in WLCG
  - Rucio, FTS, DIRAC, Alice O2
- Progressive deployment on storages at various sites

Validations and Capability Data Challenges have been discussed with all WLCG experiments.

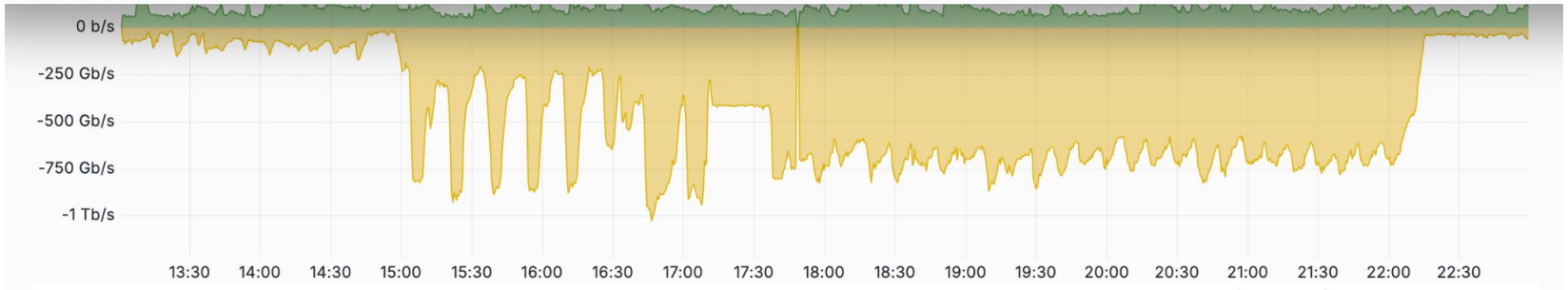
Beyond WLCG: SKA, Belle II, Vera Rubin, DUNE, Auger, etc.

- Most of these communities share the same tooling (Rucio/FTS) and could adopt the technology “relatively easily”
- Looking for opportunities to get involved – feel free to contact us

Trans-Atlantic Mini Data Challenge

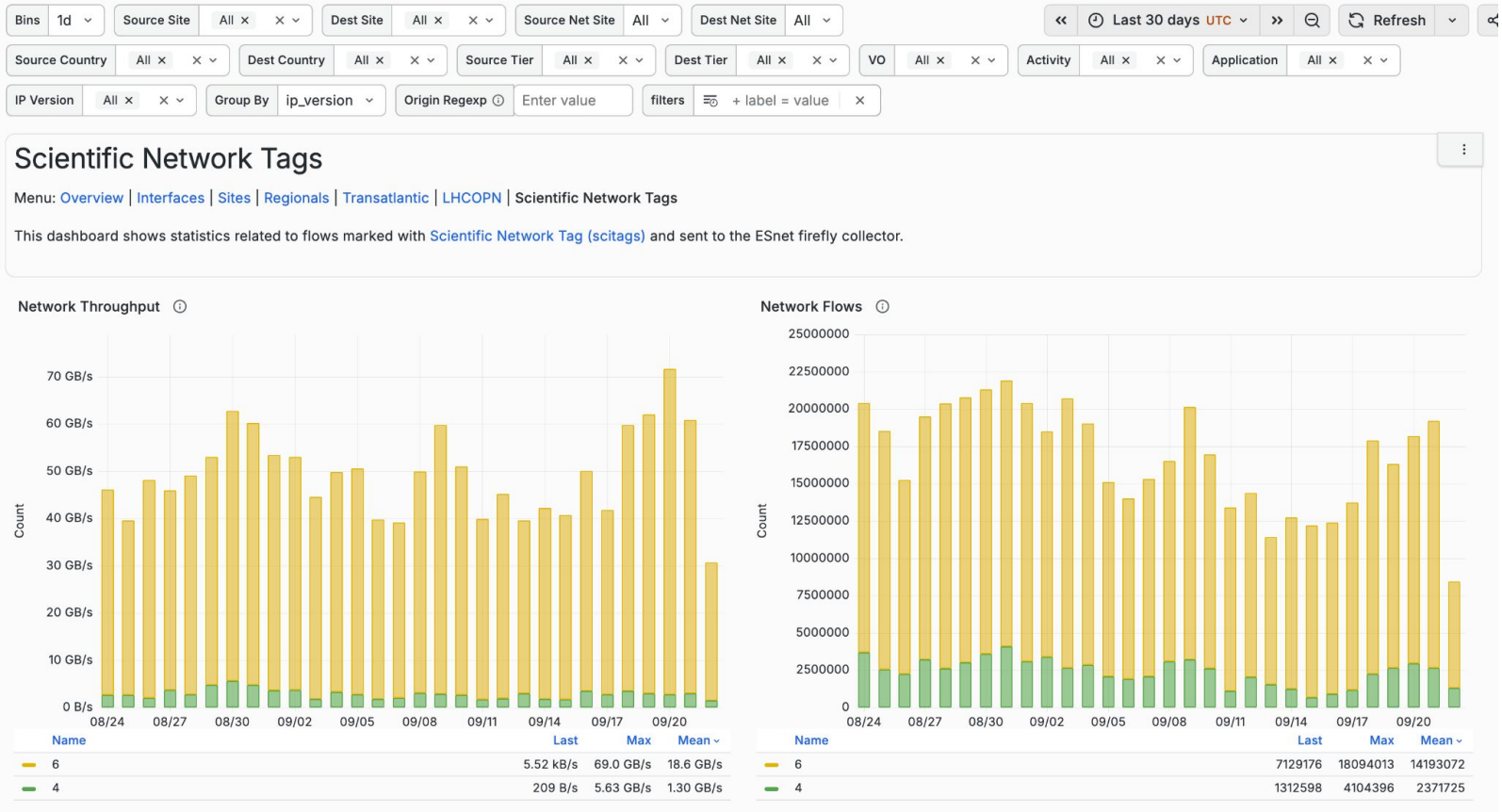


Link



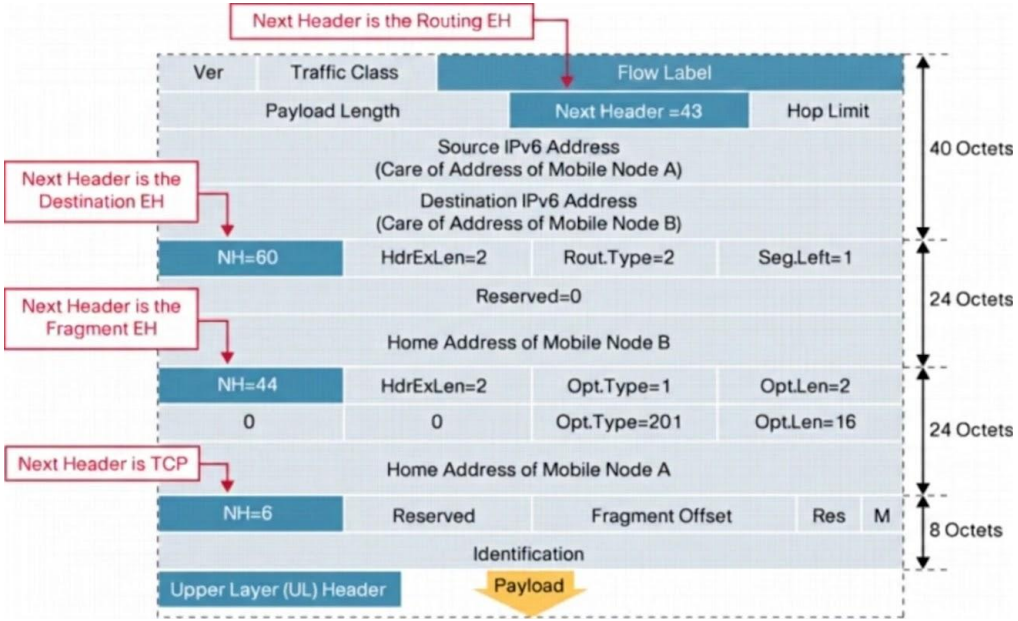
Link

Scitags Insights: IPv6/IPv4 usage



R&D: Packet Marking in IPv6

Based on feedback from IETF v6ops community
Started exploring Destination Option (DO) and Hop-by-Hop Option (HbH) as alternatives (eBPF-PDM, eBPF-extHeaders) to flow label.



We have demonstrated packet marking at scale at SC25 using both Flow Label and Destination Option

Prototype implementation developed as part of **flowd-go** service

Flowd-go: perfSONAR Integration

1. Automated Traffic Marking

Integrate **flowd-go** with **perfSONAR** to automatically mark all network test traffic packets.

- **iperf3 Throughput Tests:** Attach custom IPv6 Flow Labels and/or Extension Headers to high-bandwidth streams.
- **OWAMP Tests:** Attach custom IPv6 Flow Labels and/or Extension Headers to UDP packets of the One-Way Active Measurement Protocol (OWAMP) latency probes.

2. Primary Use Case: IPv6 EH Reachability

Initial focus centered on evaluating network behavior across global infrastructure:

- Study the **reachability and behaviour** of IPv6 Extension Headers (EH) across R&E networks.
- Compare delivery rates and performance impacts between **Flow Label** marking and **Extension Headers** (Hop-by-Hop / Destination Options).

3. Next-Gen In-Band Network Measurements (Potential R&D Spin-Off)

Combining **Scitags technology (flowd-go)** and **perfSONAR** unlocks novel telemetry capabilities:

- **In-Packet Metric Encoding:** Create a new class of measurements or implement modern IPv6 diagnostic protocols where telemetry metrics are encoded directly into packet headers.
- **Deep TCP Insights:** Leverage full, real-time access to kernel TCP statistics via eBPF/netlink to enrich active measurement streams.
- **Future Collaborative R&D:** Serves as a foundation for new projects targeting advanced network transparency and flow-level tracking.

Summary

- **Scitags is ready and in production**
  - Open platform to collect, process and visualize network flows
  - Pioneering project spanning multiple domains (Experiments, DDMs, Storages, NRENs, Sites/Platforms)
  - The platform already shows network and storage data
  - Significant progress has been made in enabling flow labelling within the LHC experiments (CMS, ATLAS, ALICE, LHCb)

- We're **open to collaboration with other science domains** and R&E networks - please contact us if you have specific use cases/tools, etc.
- We plan to demonstrate new and existing capabilities during WLCG mini-challenges, SC26 and DC27

Finding More Information: https://scitags.org

Code

Technical Spec

Howto guide

Scientific network tags (scitags) is an initiative promoting identification of the science domains and their high-level activities at the network level.

It provides an open system using open source technologies that helps *Research and Education (R&E) providers* in understanding how their networks are being utilised while at the same time providing feedback to the *scientific community* on what network flows and patterns are critical for their computing.

Our approach is based on a network tagging mechanism that marks network packets and/or network flows using the science domain and activity fields. These tags can then be captured by the *R&E providers* and correlated with their existing netflow data to better understand existing network patterns, estimate network usage and track activities.

The initiative offers an **open collaboration on the research and development of the packet and flow marking prototypes** and works in close collaboration with the scientific storage and transfer providers to enable the marking capability. The project is currently in the prototyping phase and is open for participation from any science domain that require or anticipate to require high throughput computing as well as any interested *R&E providers*.

Participants

Publications

- Identifying and Understanding Scientific Network Flows, CHEP2023, EPJ Web Conf. to appear (2024, pdf)
- Use of the IPv6 Flow Label for WLCG Packet Marking, IETF Draft
- Scitags: A Standardized Framework for Traffic Identification and Network Visibility in Data-Intensive Research Infrastructures, CHEP2025, EPJ Web Conf. to appear (2025, pdf)

Recent papers and talks

Mini Data Challenge Co-located with SC26

Scitags Mini Data Challenge

Objectives:
Ramp Up Deployment: Accelerate deployment of fireflies across all participating sites to ensure full coverage.

Validate at Scale: Confirm that the monitoring infrastructure works reliably under production-level workloads.

Co-located with SC26 (Nov 15-20): Showcase a live, fully functional production setup running directly in real-world scenarios during the conference.

Explore support for agents, develop/test MCP access to scitags and potentially integrate with ESnet's High-Touch Service to be able to track network flows all the way to the individual packets.

SC26 Scitags R&D Experiments

High-Fidelity Packet Marking: Conduct collaborative, real-time testing and performance impact measurements on the showfloor.

Focused on packet marking at high throughput.
We plan to have 1.6Tbps btw. two HP Gen6 servers each with 2x800Gbps (Univ of Victoria and Starlight), with CERN at 1.2 Tbps (DTN Gen5 3x400Gbps).

Key Contributing Partners:

- **University of Victoria**
- **Fermilab (FNAL)**
- **CERN**
- **StarLight**

Packet Marking at 1.6 Tbps

- **SC26 Goal:** Showcase Scitags for high-fidelity network visibility
- **Area 1: Global 1.2/2.8 Tbps Packet Marking**
  - 1.2 Tbps end-to-end (3x400G DTNs); potential 1.6 Tbps (2x800G) in addition
  - Sites: UVic, CERN, StarLight, FNAL, & SC26 booth
  - CERN will have 3x400Gbps (1.2 Tbps) capability
  - Tests: Memory/disk tests (iperf3, xRootd, dCache) and performance impact
- **Area 2: Production Demo of Fireflies (US/ATLAS & US/CMS)**
  - Working with WLCG to showcase our current production deployment
  - Scitags visibility in active HEP production
- Integration with **ESnet high-touch** for packet-level drill-down and **NRP** for DTN deployment

Thank you - questions?

Finding More Information: https://scitags.org

The following table summarizes the main component classes in the Scitags framework architecture

Component Class	Role within the SciTags Topography	Prominent Implementations
Central Registry	Maintains the globally authoritative mapping of Virtual Organization (VO) names and specific computational activities to standardized numerical SciTag IDs.	Scitags API
Data Management Systems (Orchestrators)	The origin point of the data transfer intent. These distributed systems possess the required contextual knowledge of exactly why a file is being moved. They formulate the initial SciTag and pass it to the transfer scheduling services.	Rucio, DIRAC, ALICE O2
Transfer Services	Intermediary scheduling brokers that manage the execution queues. They receive the job from the orchestrator and actively push the SciTag metadata to the physical storage nodes during protocol negotiation.	FTS (File Transfer Service), gfal2
Storage Systems (Data Transfer Agents)	The physical server nodes executing the high-throughput disk-to-network input/output operations. They accept the SciTag from the transfer service and must inject it into the network layer via flow services or directly by sending fireflies to collectors.	XRootD (pmark), dCache, EOS, StoRM
Flow Service	Lightweight node-level agents that monitor kernel sockets to emit UDP Fireflies, and optionally, can perform packet marking. This service is optional and focuses mainly on R&D.	flowd-go
Collectors	Distributed, big-data aggregation pipelines that collect, parse, store and calculate base metrics from the incoming global firefly/telemetry stream.	firefly-collector
Dashboards	Dashboards showing a global view based on the fireflies collected	ESnet Dashboard

Acknowledgements

We would like to thank the **WLCG**, **HEPiX**, **perfSONAR** and **OSG** organizations for their work on the topics presented.

In addition we want to explicitly acknowledge the support of the **National Science Foundation** which supported this work via:

- OSG: NSF MPS-1148698
- IRIS-HEP: NSF OAC-1836650

Finding More Information: https://scitags.org

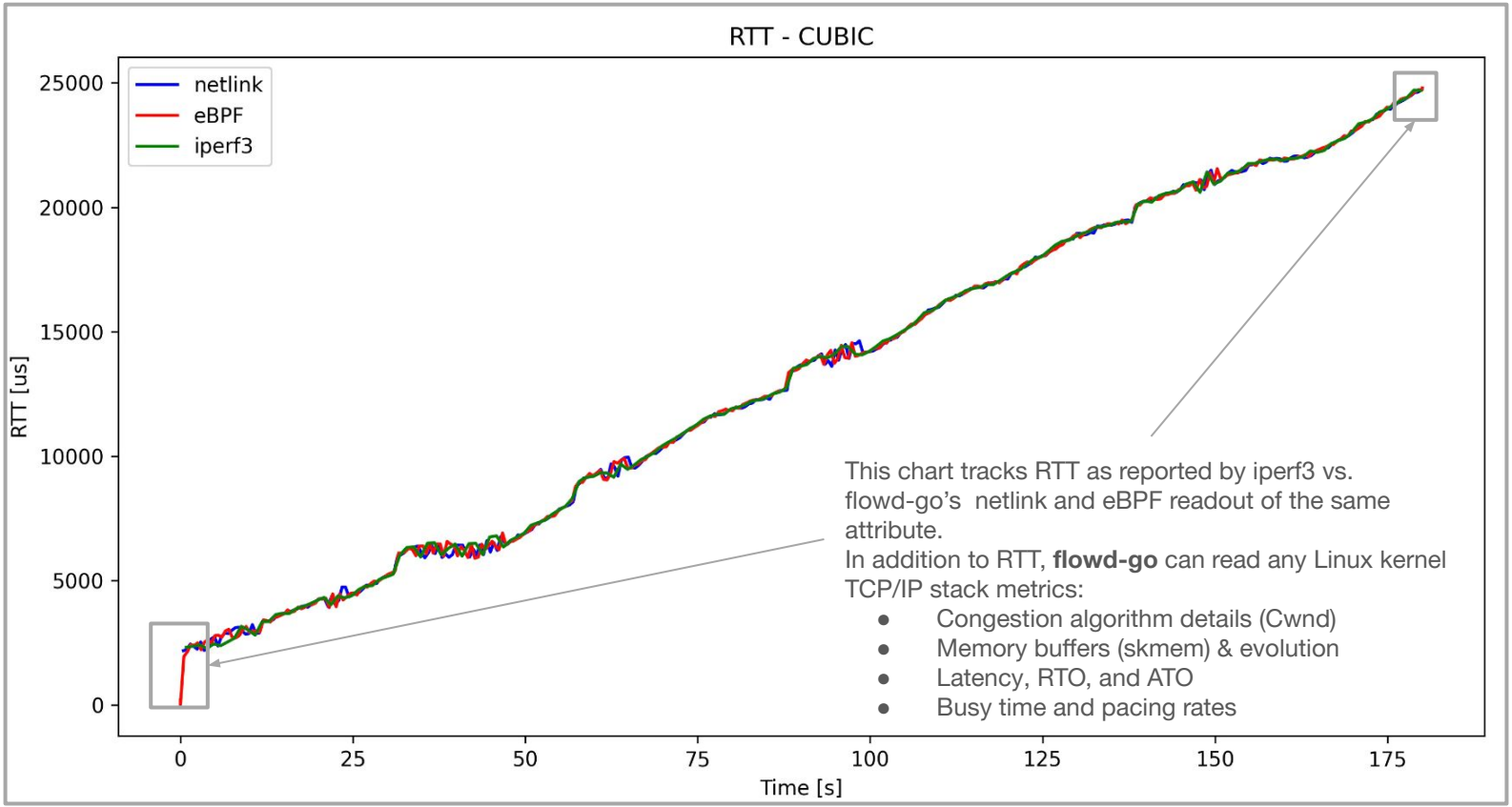
Code

Technical Spec

Mailing List

Presentations

Flowd-go: Linux kernel TCP/IP stack readout !

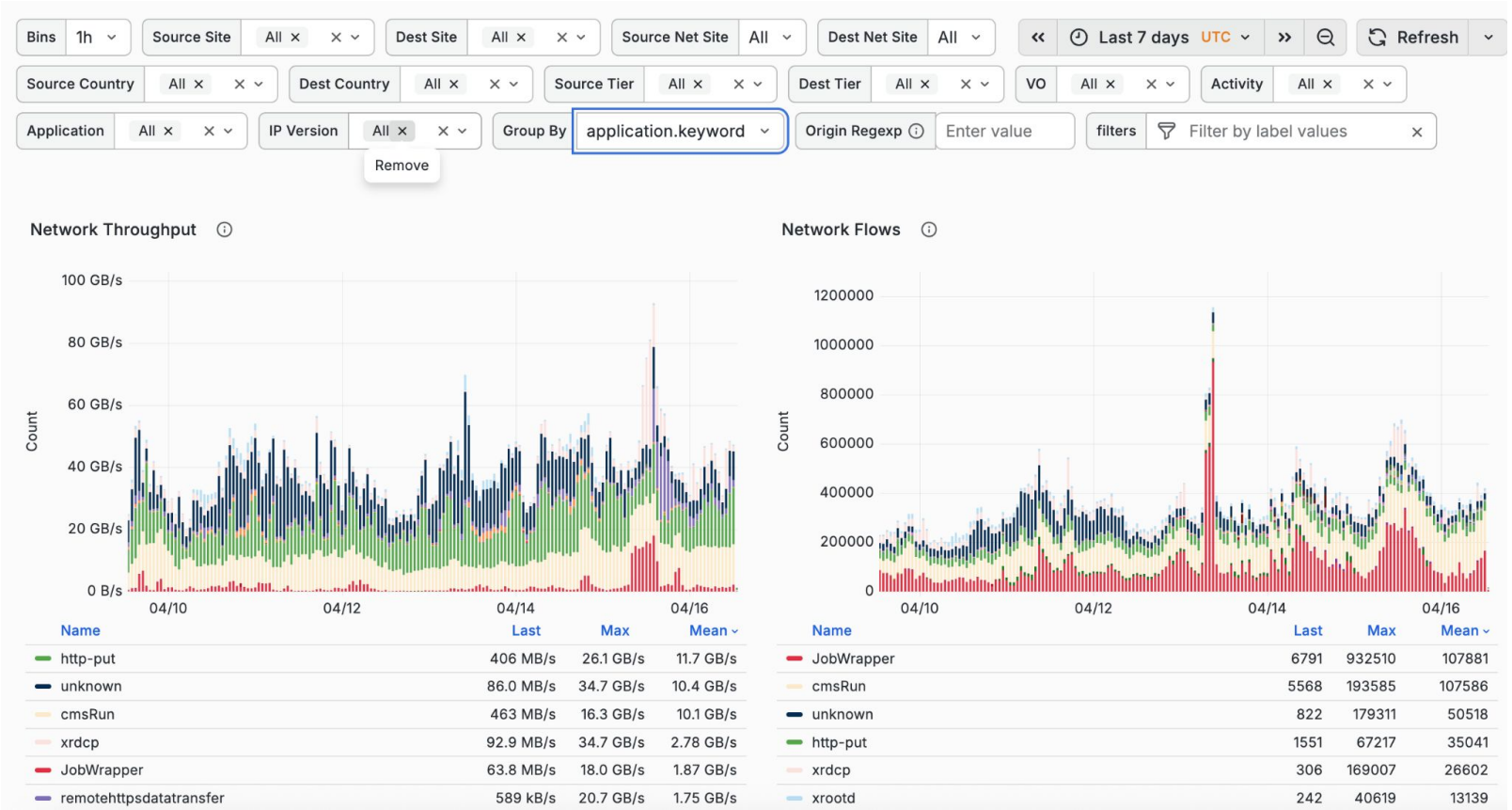


This chart tracks RTT as reported by iperf3 vs. flowd-go's netlink and eBPF readout of the same attribute.

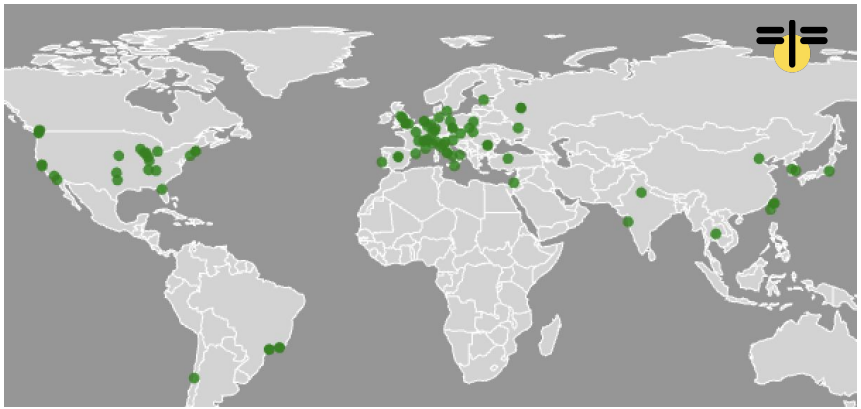
In addition to RTT, **flowd-go** can read any Linux kernel TCP/IP stack metrics:

- Congestion algorithm details (Cwnd)
- Memory buffers (skmem) & evolution
- Latency, RTO, and ATO
- Busy time and pacing rates

ESNet: production Scitags firefly dashboard



Fireflies Deployment



Global Monitoring Coverage

Our coverage likely exceeds WLCG FTS as we also see WN transfers and XRootD traffic across all active deployment sites.

FLOW VOLUME

20M fireflies / day

vs. **8-12M** transfers/day seen in WLCG FTS

capturing end-to-end data transfer orchestration and job-level storage access

dCache 11.2 Integration Status

Major T1s and T2s are being added as they update to dCache 11.2:

DONE **CERN, US CMS inc. FNAL, AGLT2, MWT2, KISTI**

TBD **BNL, PIC, KIT, TRIUMF**

Scitags: Bridging Four Distinct Domains

Scitags provides a shared platform that integrates expertise across specialized segments of the infrastructure stack to address global network visibility challenges.

NETWORK PROVIDERS

Manage high-capacity R&E backbones and deploy telemetry collectors to correlate scientific traffic:

GÉANT • ESnet • Internet2 • Jisc

SCIENCE DOMAINS

Data-intensive international research collaborations:

LHC Experiments (ALICE, ATLAS, CMS, LHCb) • DUNE

DATA MANAGEMENT TECHNOLOGIES

Orchestration, transfer, and storage solutions:

Rucio • DIRAC • FTS

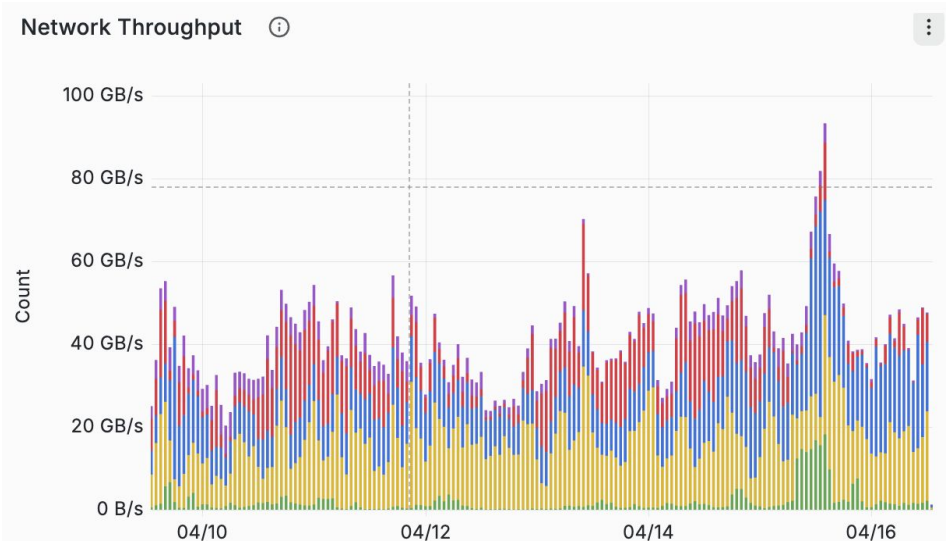
Storage: **XRootD, EOS, dCache, StoRM**

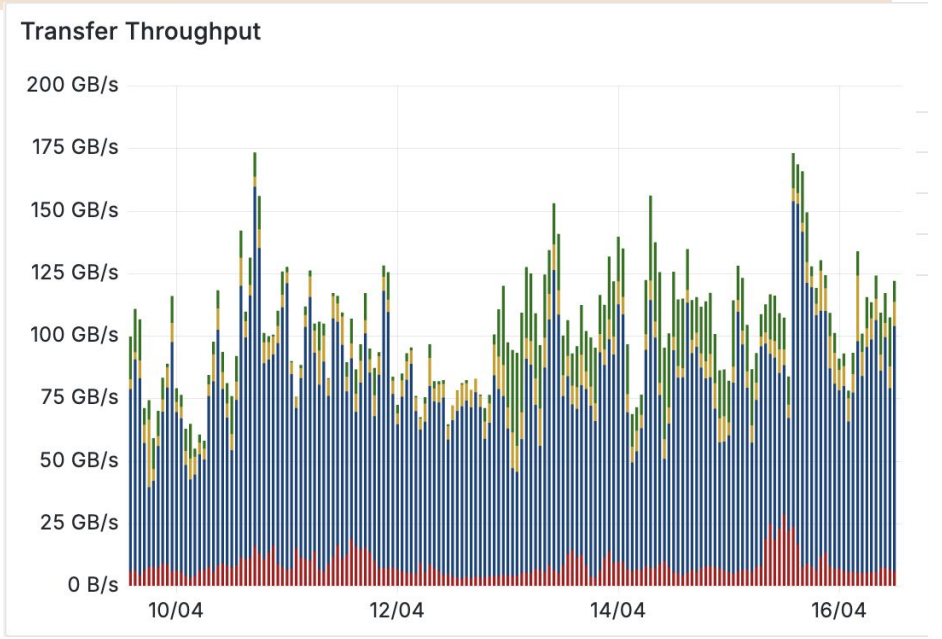
PLATFORMS & SITES

Key contributing institutions and compute sites:

CERN • FNAL • RAL • CNAF • Univ. of Victoria
Univ. of Michigan • UCSD • Univ. of Nebraska
National Research Platform and many others

ESNet: production Scitags firefly dashboard





Comparing Scitags dashboard (left) with WLCG Transfers dashboard (right)

- Shows throughput calculated from network flows vs throughput from transfers

What is needed to use Scitags? Howto ?

See our draft howto guide

Site-level requirements:

- Run one of the supported storages (XRootD, EOS, StoRM, dCache)
- Engage to determine the Scitag collector(s) to use (NREN / global)
- Configure and test Scitags on their storage (see howto guide for details)

Experiment-level requirements:

- Run one of the supported data management systems
  - Rucio, FTS, DIRAC, Pelican
- Engage to ensure experiment ID and activity IDs are added to the Registry where needed

NRENs:

- An NREN **may** run a collector to gather Scitag data for its sites, and share the data to the global collector(s) via Kafka

Registry of experiment and activity IDs

We have standardised the Experiment and Activity fields we use for both flow marking and packet marking.

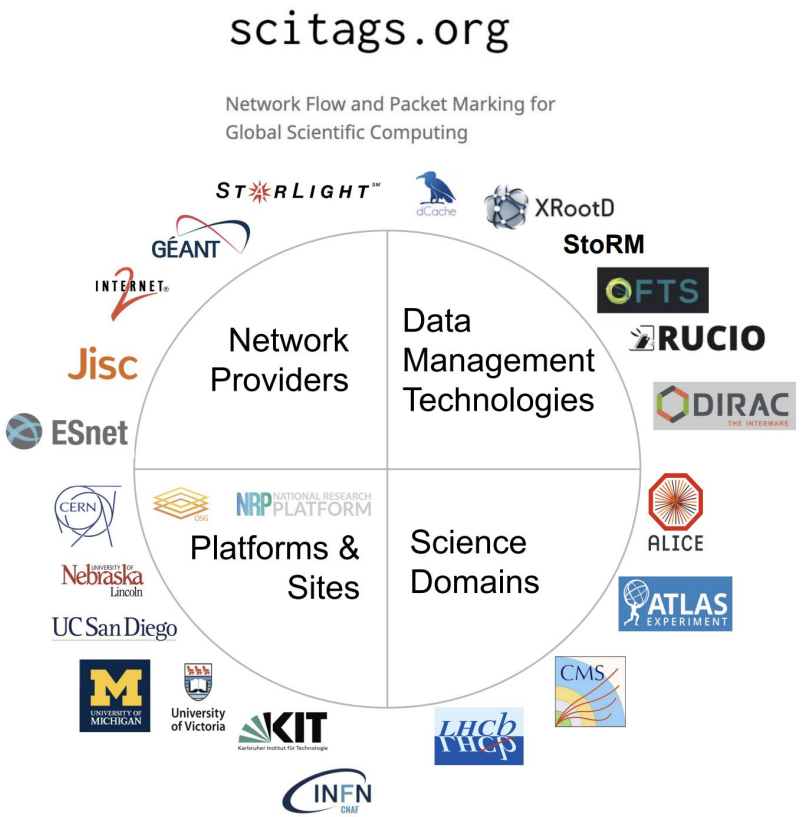
The **scitags.org** domain provides an API that can be consulted to get the registered values: https://api.scitags.org or https://www.scitags.org/api.json

The underlying source of truth is a set of Google sheets that are maintained and writeable by a few stewards.

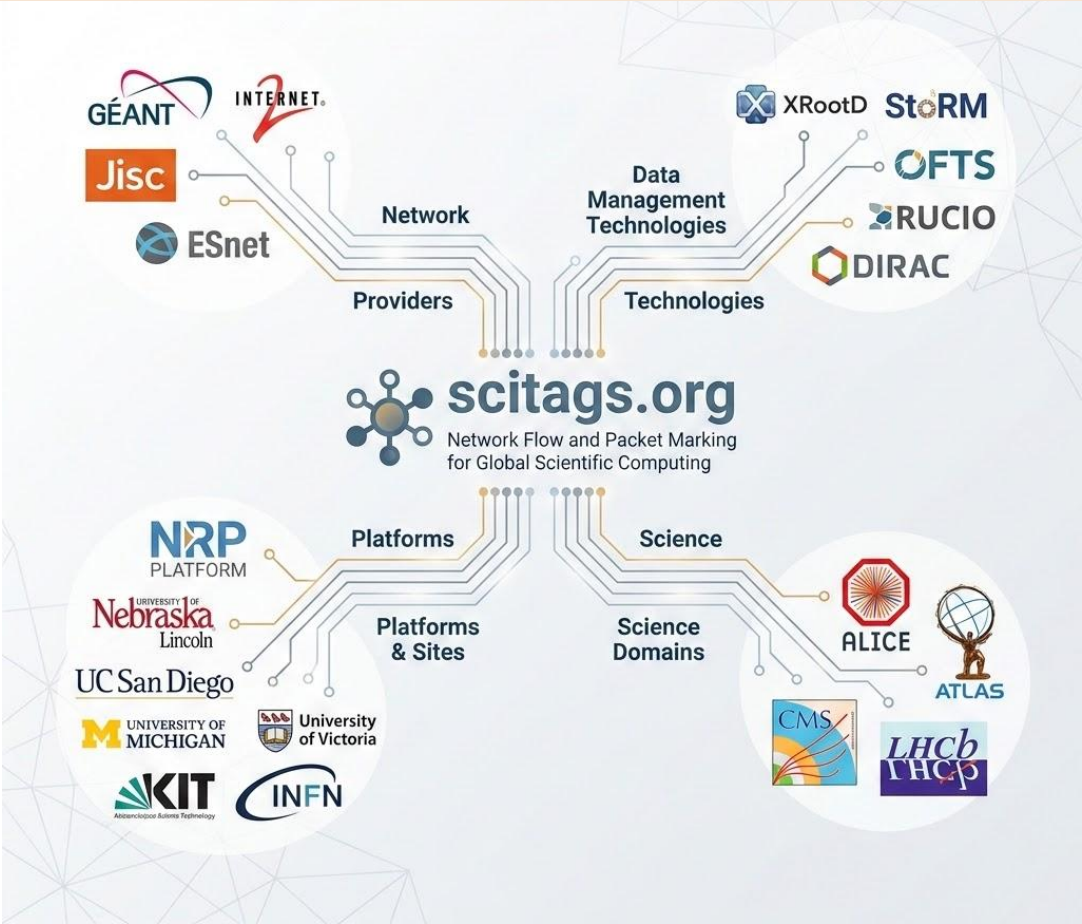
Note: the API provides the defined values **but** how the values are used is specified in our Google sheets

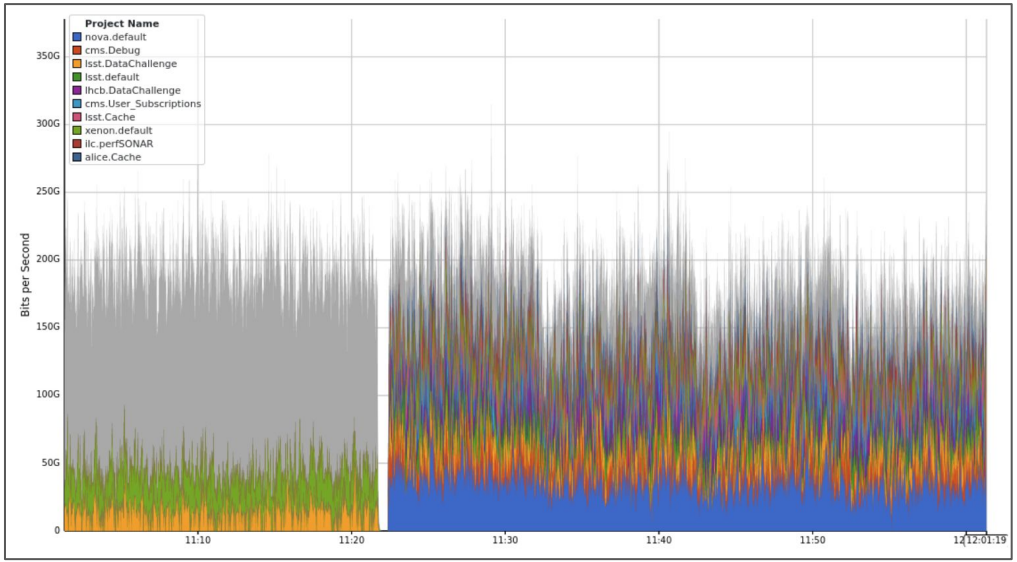
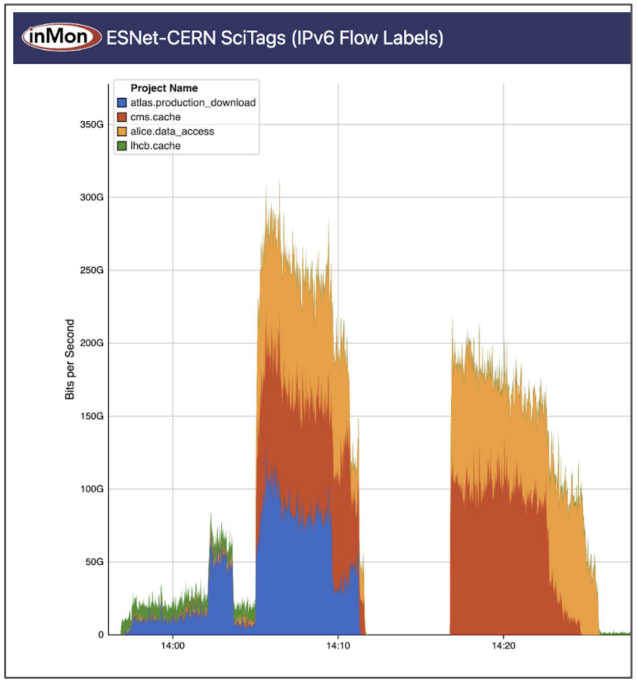

```
{
  - experiments: [
    - {
        expName: "default",
        expId: 1,
      - activities: [
        - {
            activityName: "default",
            activityId: 1
          }
        ]
      },
    - {
        expName: "atlas",
        expId: 2,
      - activities: [
        - {
            activityName: "perfsonar",
            activityId: 2
          },
        - {
            activityName: "cache",
            activityId: 3
          },
        - {
            activityName: "datachallenge",
            activityId: 4
          },
        - {
            activityName: "default",
            activityId: 8
          },
        - {
            activityName: "analysis download",
            activityId: 9
          },
        - {
            activityName: "analysis download direct io",
            activityId: 10
```

Scitags Project - who?



Scitags Project - who?



Packet and Flow Marking Demos

- We plan to demonstrate packet marking at 1.2 Tbps (3x400Gbps DTNs)
- Using flowd-go - both with flow labels and extension headers (DO) via eBPF
- We will report on the results – previous testing at SC24 was encouraging