Data Transmission Needs for Emerging Missions:

Findings of Time Domain and Multi-Messenger Astrophysics Communications Science Analysis Group (TDAMM CommSAG)

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On behalf of the SAG

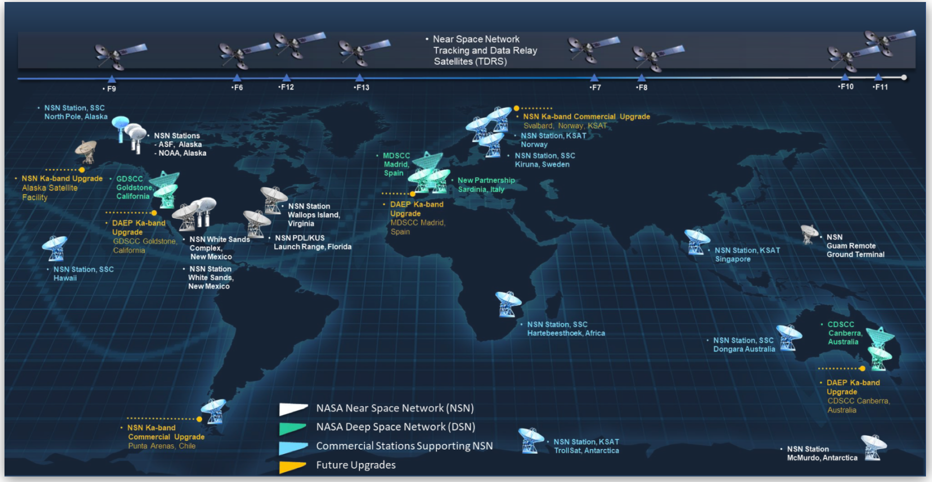
CAA

TDAMM Comm SAG

- Why TDAMM? - Rapidly time-variable and transient phenomena motivate the most stringent requirements on communications.
- Specifically if improve infrastructure to meet TDAMM needs, everyone benefits.
- SAG membership recruited by invitation for current missions and missions in development, communications experts, and open community call (~30 participants).
- Defined TOR, and met monthly from July 2023 - March 2024 to discuss each Topic in TOR.
- Compiled report with case studies and findings.
- Presented to APAC in July 2024
- **Final Report: https://arxiv.org/abs/2410.03980**

Current NASA Communications Services

- Near Space Network
  - Supporting missions <1M miles from Earth
  - Space Relay (TDRS)
    - Spacecraft initiated demand access
    - Low-latency commanding
    - High data rate, high coverage
    - Example usage: Hubble, Fermi, Swift, ISS
  - Direct to Earth (DTE) ground stations
  - Commercial Stations Supporting NSN
- Deep Space Network (DSN)
  - Supporting missions typically >1M miles from Earth
  - Example usage: TESS, JWST, Chandra, planetary missions



https://ntrs.nasa.gov/api/citations/20210020202/downloads/NASACommercialStrategy_WidebandandStds_KaBand2021_R8921.pdf

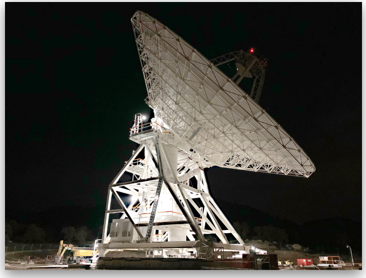
Future Challenges with NASA Communications Services

Space Relay - TDRS

- NASA is not planning to replace TDRS satellites, but continuing to operate fleet into the 2030's
    - Last TDRS launch in 2017 (TDRS-13)
    - Services are already degraded - TDRS-9 decommissioned January 2023
    - Guam ground station damaged after Typhoon in May 2023, service to TDRS-275 restored in June 2024
        - Caused ~10 minute gap in continuous coverage for >1 year
    - Only missions in development (COSI, StarBurst) allowed to use TDRS, but only guaranteed in prime mission
    - Hubble and ISS are the major users - future of TDRS uncertain beyond their operation

Ground Network - DTE & DSN

- DTE provides access to NASA and some commercial ground stations
    - Limited access to Ka-band stations
    - Adopting use of additional commercial ground stations will help alleviate congestion
    - On-the-fly comms requires modernization of scheduling interfaces
- DSN utilizes 3 capable antennas
    - Oversubscription is limiting utilization by missions
    - Advance scheduling makes it not ideal for TDAMM



Communications Services Project (CSP)

- Study of commercial space relay replacements for the TDRS system
- Six Funded Space Act Agreements (FSAA) to commercial industry partners with the objective of demonstrating end-to-end services to meet multiple NASA mission use case
- Developing portfolio of validated commercial services that will be ready for adoption and acquisition by NASA missions no later than 2030
- Ultimately RfP process open to all commercial service providers
- TDAMM Comm SAG co-chairs participating in Commercial Services Users Group (CSUG)

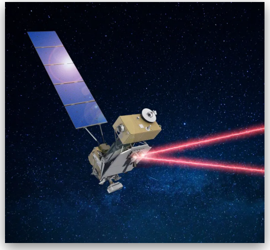
FSAA Partner	Architecture	Mission Partners	Demo Complete
amazon | project kuiper	Optical LEO Network	Amazon mission & Blue Canyon	Q3 FY25 Q1 FY26
SPACEX	Optical LEO Network	Commercial Crew	Q1FY26
Viasat	GEO commercial Ka-band	Maxwell & Loft Orbital	Q1 FY26 Q2 FY26
inmarsat	GEO L-band	Blue Origin & Maxwell	Q4 FY25 Q2 FY26
SES GOVERNMENT SOLUTIONS	GEO C-band and MEO commercial Ka-band	Planet	Q4 FY25
TELESAT	GEO C-band and LEO commercial Ka-band	Planet	Q1 FY27

https://www.nasa.gov/directorates/somd/space-communications-navigation-program/communications-services-project/

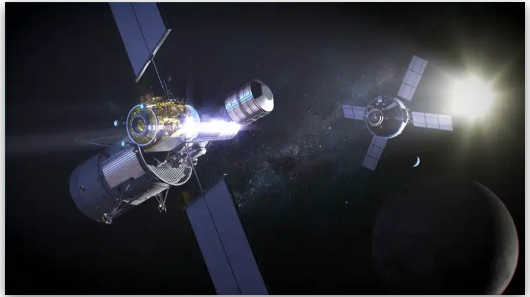
Other Future Capabilities

- Commercial ground stations
  - Commercial providers such as KSAT, AWS, and Azure offer Ground Stations as a Service (GSaaS)
  - Growing capability
- Laser Comms
  - Laser Communications Relay Demonstration (LCRD)
  - Deep Space Optical Communications (DSOC) - used for Psyche mission.
  - Commercial Laser Comms - e.g. Starlink Space-to-Space comms.
- Lunar Relay
  - Direct-to earth communication and navigation services for missions operating from 36,000 km in the GEO to cis Lunar and other orbits out to 2 Million km
  - S-band, X-band, Ka-band
  - Program in development

https://spacenews.com/aws-completes-six-ground-stations-changes-rollout-strategy/



https://www.nasa.gov/directorates/stmd/tech-demo-missions-program/laser-communications-relay-demonstration-lcrd-overview/



https://explorers.larc.nasa.gov/2023APPROBE/pdf_files/Prog05d.%20LEGS%20Brochure%20r20.pdf

TDAMM Driven Communications Capabilities

- A broad range of comms capabilities are needed at both predictable and unpredictable times.
- While existing NASA resources can meet these needs, they do not necessarily provide adequate flexibility, availability, and cost effectiveness.
- Upcoming replacement commercial services should improve upon current capabilities and maximize the science potential of NASA's future fleet.

Communication Capability	**Usage**	**Technical Challenges**	**Examples**
Continuous Contact	Forward - commanding Return - alerts	Spacecraft Power Availability, Geographical Coverage, Network Congestion, Complexity (pointing, handovers, etc.)	Space-to-Space Laser Comms Scheduling frequent passes on TDRS-MA, DTE, or commercial systems
Demand Access	Return - small alerts (e.g. GRB notice). Spacecraft initiated contact.	Availability, Geographical Coverage, Complexity, Additional Hardware	TDRS-DAS, Commercial space communications
Low-Latency Data Downlinking	Frequent pre-scheduled passes. On-the-Fly scheduling of passes with low latency	Availability, Geographical Coverage, Automation. Flexibility.	KSAT-lite and other GSaaS providers.
High-Latency Data Downlinking	Download bulk data	Latency	DSN, DTE, TDRS-SA

Science Drivers

Science Topics defined by [2022 NASA-NSF TDAMM Workshop White Paper]

- TDAMM science cases drive latency and data volume
- TDAMM drives the need for
  - Rapid alerting
  - Rapid commanding
  - Rapid downlinking for ground searches

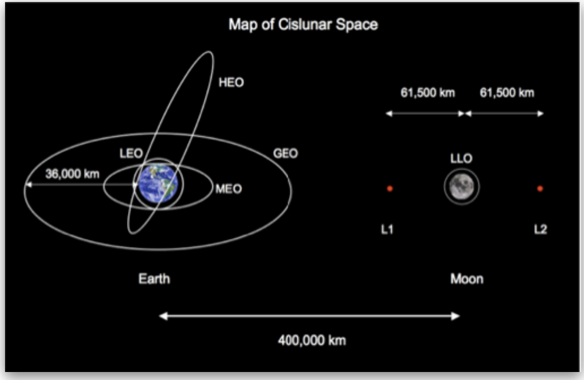
Capability	Science Examples	Onboard Alert Latency	Ground Search Latency	Follow-up Latency	Data Volume
Rapid Discovery and Reporting	GRB prompt emission	seconds	minutes	–	small
	SGRs	seconds	–	days	medium
	Magnetar Giant Flares	seconds	–	minutes	medium
	Type 1 X-ray Bursts	seconds	hours	days	small
	Supergiant Fast X-ray Transients	seconds	days	days	medium
Rapid Follow Up	GRB afterglows	–	–	minutes	small
	Neutron Star Mergers (GW trigger)	–	minutes	seconds	small
	Nearby CCSNe (ν trigger)	–	–	minutes	small
	Fast Optical Transients	–	–	hours	small
	Kilonova	–	–	hours	medium
	Novae	–	hours	days	medium
	SN Ia	–	hours	days	small
	CCSNe (γ-ray lines)	–	hours	days	medium
Ground Searches of Large Datasets	X-ray binaries	–	days	hours	large
	Orphan GRB Afterglows	–	hours	hours	medium
Variable Sources in Outburst	Blazars	minutes	hours	hours	large
	Non-jetted TDEs	–	hours	hours	large
	Jetted TDEs	minutes	hours	minutes	large

small - kB to MB, medium - 10’s of MB, large - 100’s of MB to GB

Non-LEO Orbits Offer Advantages to TDAMM Missions

Finding #1: Developing services to provide high-bandwidth, low-latency communications to non-LEO orbits is essential to enable future TDAMM missions.

Finding #2: Investment in developing new technologies that can provide spacecraft initiated demand access service or continuous communication links to non-LEO orbits is essential to enable future TDAMM missions.



https://ntrs.nasa.gov/api/citations/20120009459/downloads/20120009459.pdf

Bandwidth, Latency, and Coverage Limit TDAMM ConOps

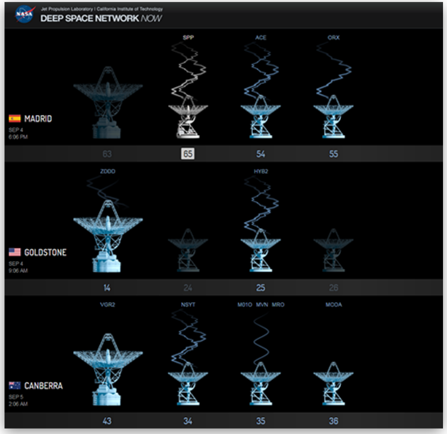
Finding #3: To support TDAMM Science, future communications solutions should look to ensure that low latency, high bandwidth and high coverage is available for all missions profiles.

Update: CSP assessing vendors on science alert capability

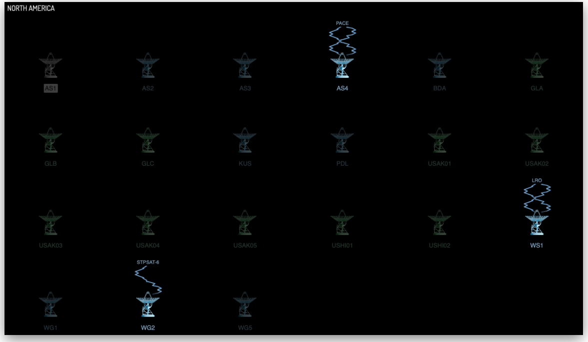
Finding #4: The flexibility of TDRS has enabled TDAMM science, therefore access to similar solutions with commercial services in the future will be crucial.

Finding #5: Due to the limitations of onboard computing, some missions require rapid or high cadence downlinks of large datasets to detect and characterize transients - a function that is not currently possible.

Update: CSP looking into this as a use case



DSN Real Time Status: https://eyes.nasa.gov/dsn/dsn.html

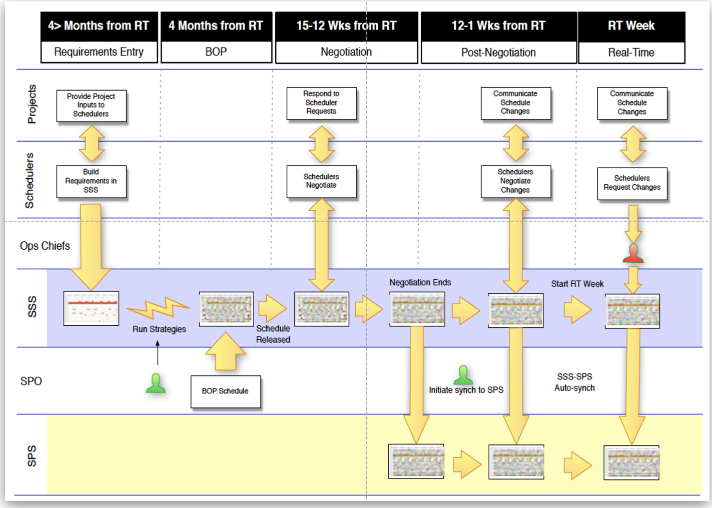


NSN Real Time Status: https://scan-now.gsfc.nasa.gov/dte

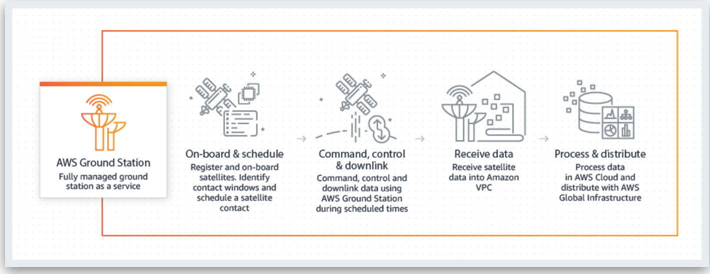
Availability and Scheduling Flexibility are Needed to Enable TDAMM Observations

Finding #6: High availability of communication networks on short notice is essential for TDAMM missions to rapidly schedule communications assets to both respond to target of opportunity (ToOs) follow-up observations and prioritize downlinking of data around events of interest.

Finding #7: The use of efficient modern commercial scheduling interfaces (e.g APIs) will enable TDAMM observations, and are more efficient than existing SCaN interfaces. APIs provide realtime view of availability and eliminate back and forward interactions with human schedulers.



Deep Space Network Mid-Range Scheduling Process



https://aws.amazon.com/ground-station/

High Comms Cost Disadvantages TDAMM Proposals

Finding #8: In order to ensure that reliable and timely cost estimation by proposal teams is possible, teams need easy access to up-to-date documentation or tools to allow an accurate self assessment of projected communications costs.

Finding #9: Pursuing direct relationships with commercial communications providers allows proposal teams to realize potential cost savings.

Finding #10: Removing communications costs from PI Managed Mission Costs would ensure TDAMM missions are not disadvantaged compared to other missions with less burdensome communications requirements, and ensure communications needs are scientifically motivated, rather than cost-driven.

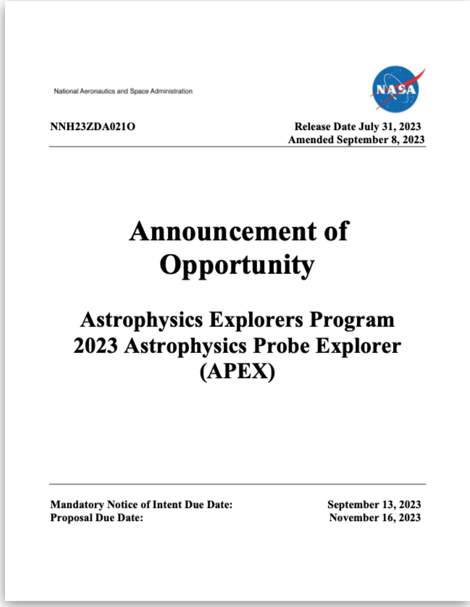
Update: HQ APD has "has taken this under advisement and is looking into what might be possible" (Clampin APAC presentation Nov 2024)

Lack of Transition Planning and AO Consistency Threatens Future TDAMM Capabilities

Finding #11: A smooth transition between communications services in the future ensures that AOs do not disadvantage missions whose science case depends on a service which is in transition.

Finding #12: Consistent communications requirements and costing across all NASA SMD AOs would ensure more accurate proposal development and evaluation.

Finding #13: Access to multiple providers through a common interface has potential to provide affordability and long-term stability to missions via bulk investment by SCaN.



National Aeronautics and Space Administration

NNH23ZDA021O

Release Date July 31, 2023
Amended September 8, 2023

Announcement of Opportunity

Astrophysics Explorers Program
2023 Astrophysics Probe Explorer (APEX)

Mandatory Notice of Intent Due Date:	September 13, 2023
Proposal Due Date:	November 16, 2023

Conclusions

- Commercial providers have great potential to enable TDAMM missions in Earth orbit, if implemented correctly (e.g. allow GSaaS scheduling APIs, transition planning and affordability).
- Non-LEO orbit solutions, which lack commercial development, provide an opportunity for NASA to invest in the future.
- Removing comms costs from AOs would ensure TDAMM Missions can compete on a level playing field with other mission types.
- APAC acknowledged the findings of this report and are particularly concerned about transition planning
- SCaN/CSP and APD are engaged in addressing these findings