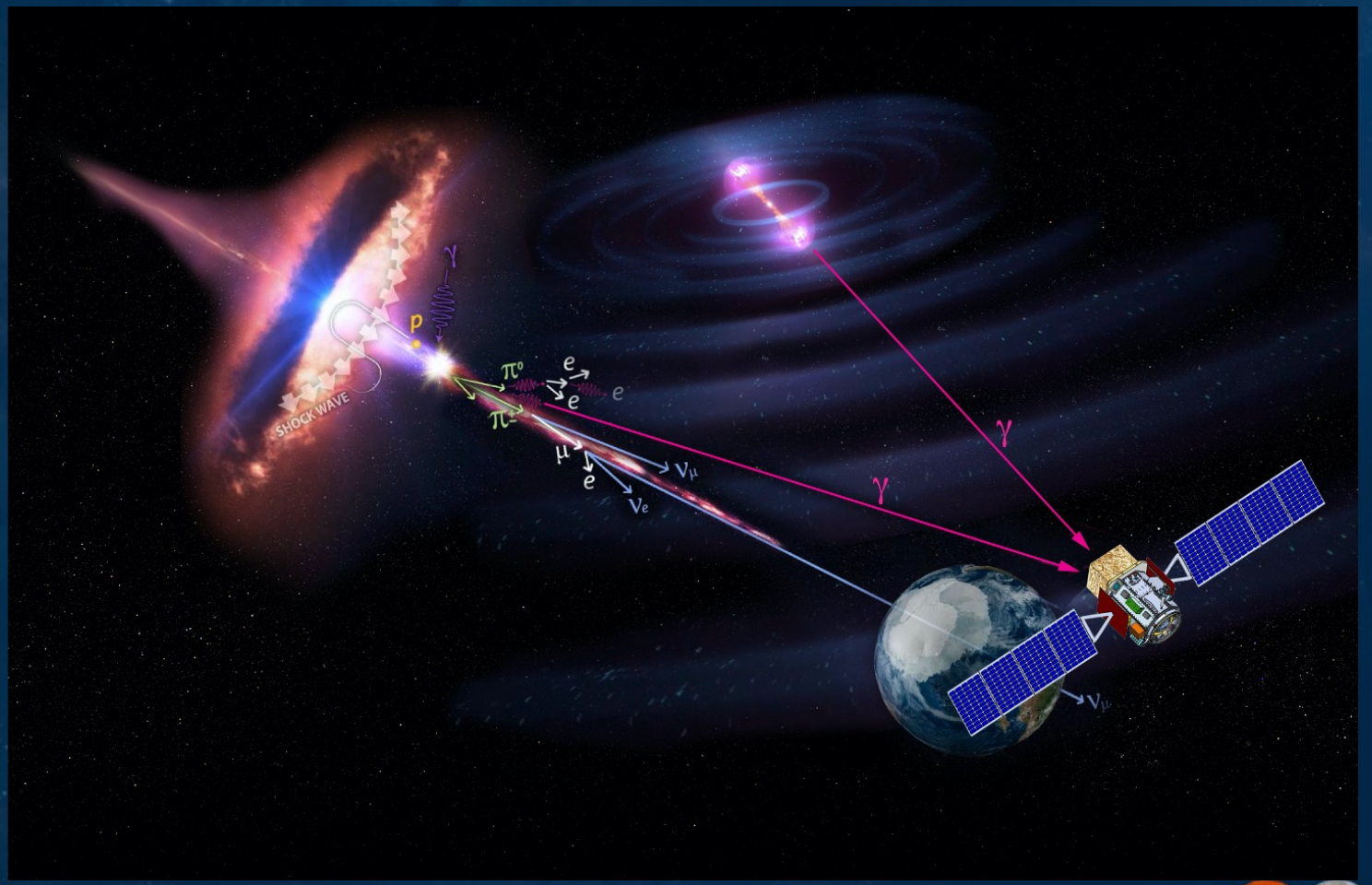
NASA's capabilities for Multimessenger and Time Domain Astrophysics

Rita Sambruna (she/hers)
NASA/GSFC

EGO
October 11, 2022



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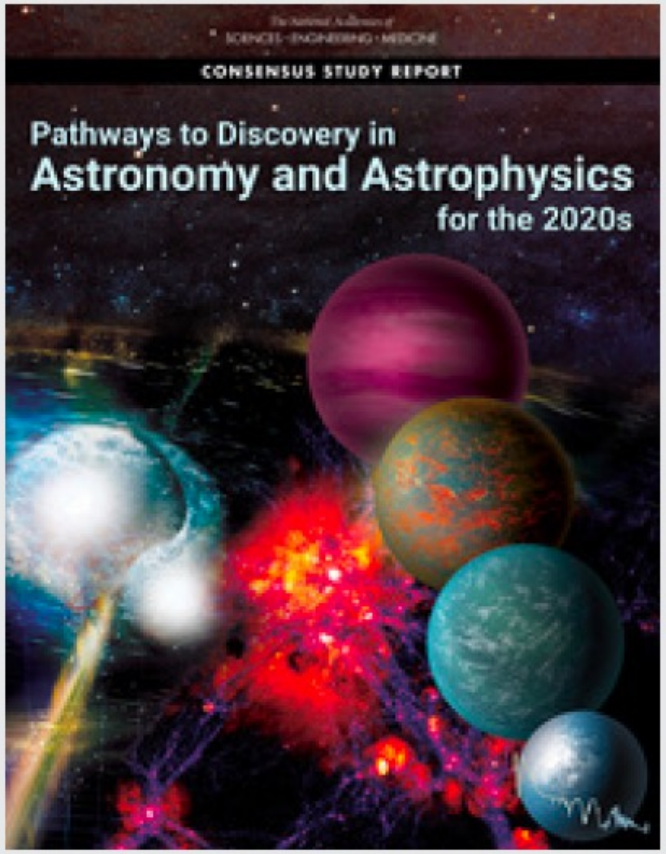
The 2020 Astrophysics Decadal

- *"The New Messengers and New Physics theme embodies the dual revolutions brought about by the marriage of observations of light with those from gravitational waves and elementary particles (multi-messenger astrophysics) along with the expansion of measurements of the sky over time (time-domain)"*



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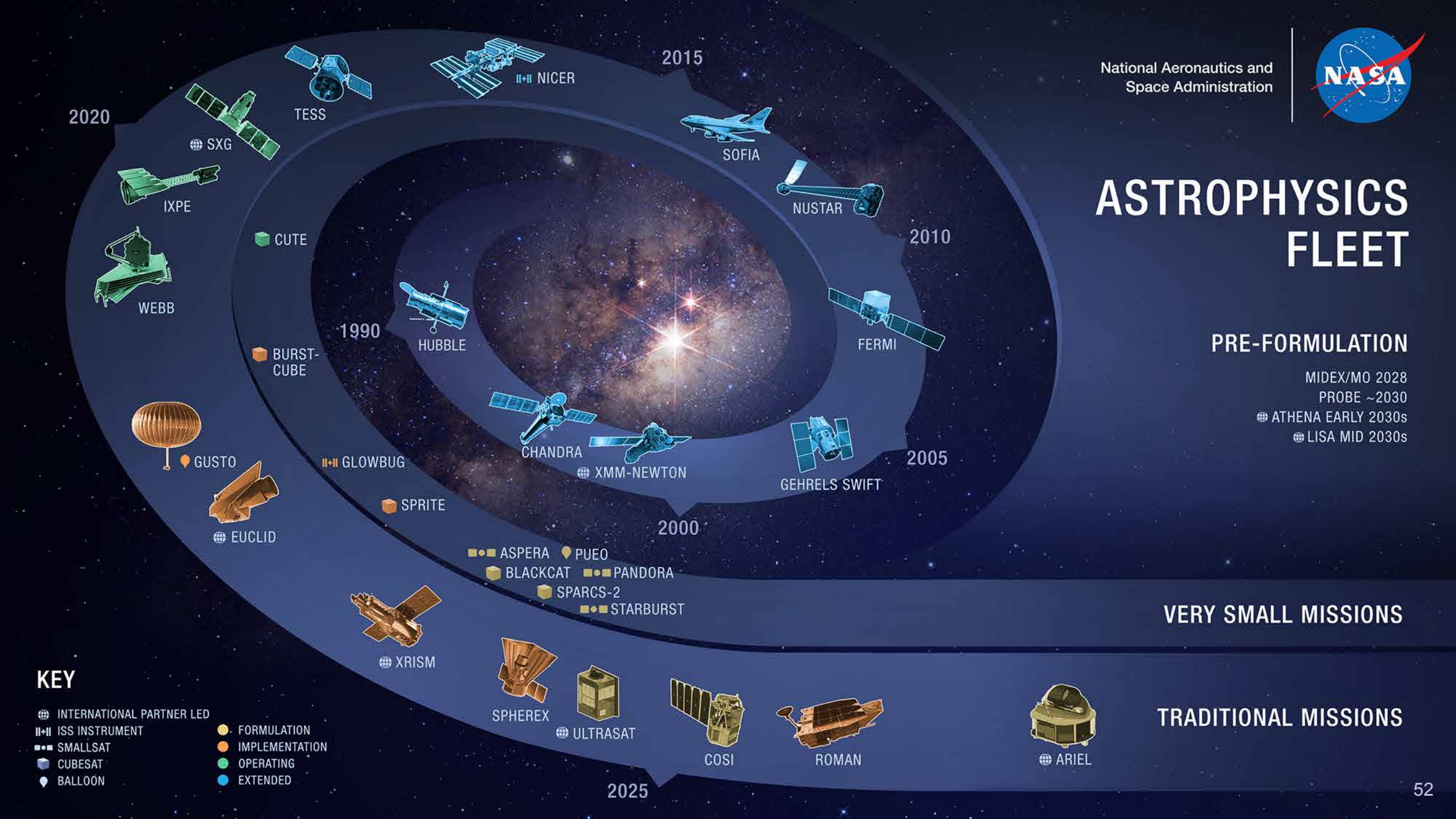
What is NASA doing for MMA/TDA?

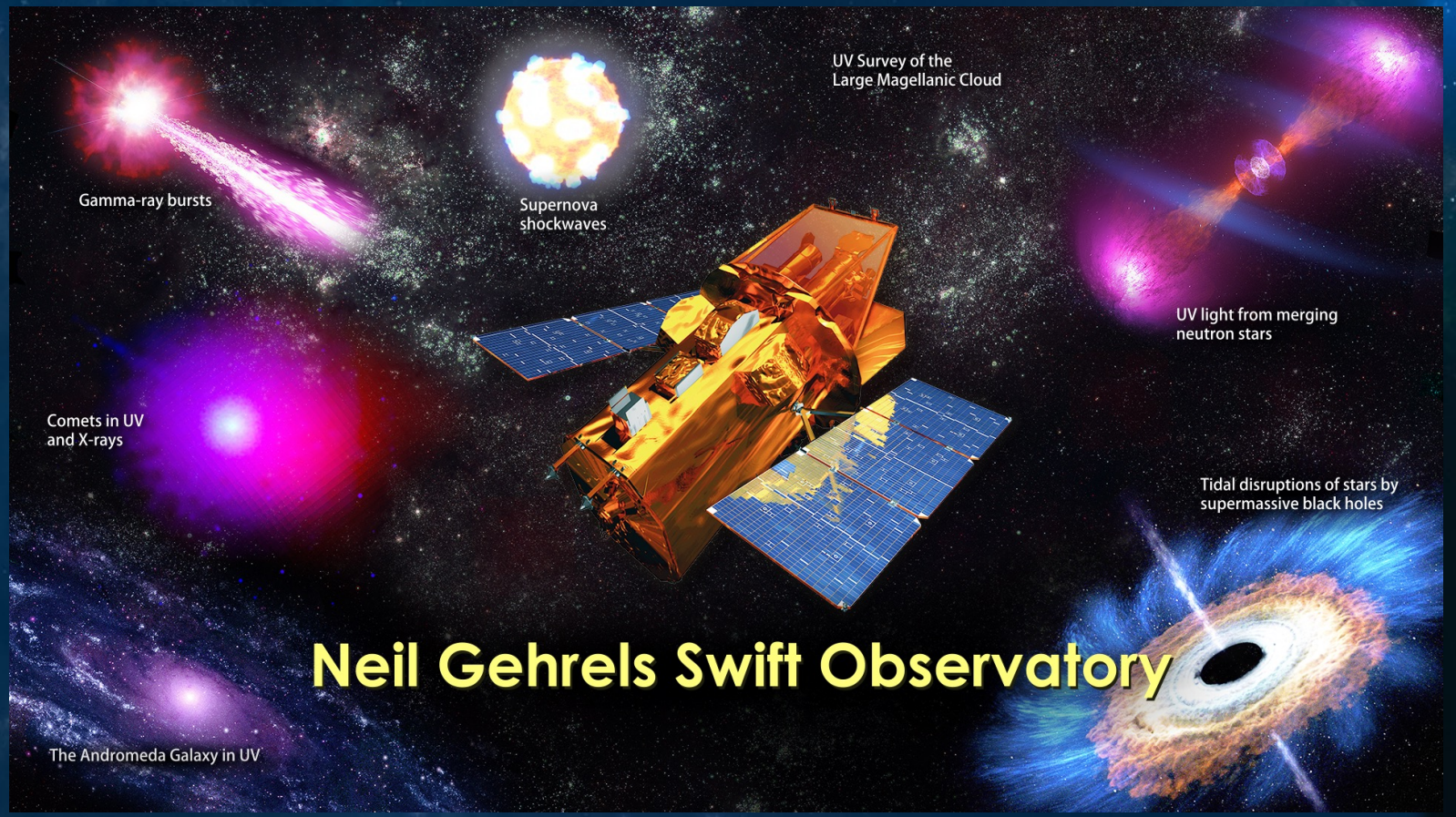
- Missions
  - Currently operating fleet
  - In development
- Infrastructure
  - TDAMM Workshop
  - A study for TDAMM Program
  - TDAMM International
- Grassroot efforts
  - MOSSAIC

Missions


National Aeronautics and Space Administration
NASA
ASTROPHYSICS FLEET
PRE-FORMULATION
MIDEX/MO 2028
PROBE ~2030
ATHENA EARLY 2030s
LISA MID 2030s
2015
2020
2010
1990
2005
2000
2025
NICER
TESS
SXG
SOFIA
IXPE
NUSTAR
CUTE
WEBB
HUBBLE
FERMI
BURST-CUBE
CHANDRA
XMM-NEWTON
GEHRELS SWIFT
GUSTO
GLOWBUG
SPRITE
EUCLID
ASPERA
PUEO
BLACKCAT
PANDORA
SPARCS-2
STARBURST
VERY SMALL MISSIONS
XRISM
SPHEREX
ULTRASAT
COSI
ROMAN
ARIEL
TRADITIONAL MISSIONS
KEY
INTERNATIONAL PARTNER LED
ISS INSTRUMENT
SMALLSAT
CUBESAT
BALLOON
FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED

Workhorse 1: Swift Time-Domain and Multi-Messenger Science

- UV kilonova from binary neutron star merger detected in gravitational waves (GW170817)
- Constraining emission models from flaring blazar detected in high-energy neutrinos (IC-170922A)
- > 1500 GRBs, ranging from nearby galaxies to the early universe
- Supernova shock breakout following core collapse of a massive star (SN2008D)
- Relativistic jet launched following the tidal disruption of a star by a super-massive black hole (Sw J1644+57)
- Best is yet to come! (GW and neutrino upgrades, Rubin, etc.)



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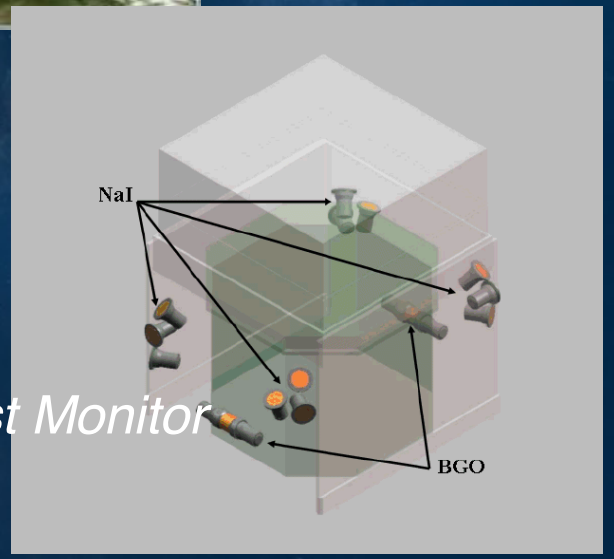
Workhorse 2: Fermi

Large Area Telescope

20% sky at once
full sky 3 hours



Gamma-ray Burst Monitor

full unocculted sky continuous coverage

All data is publicly available 24 hours after it's taken

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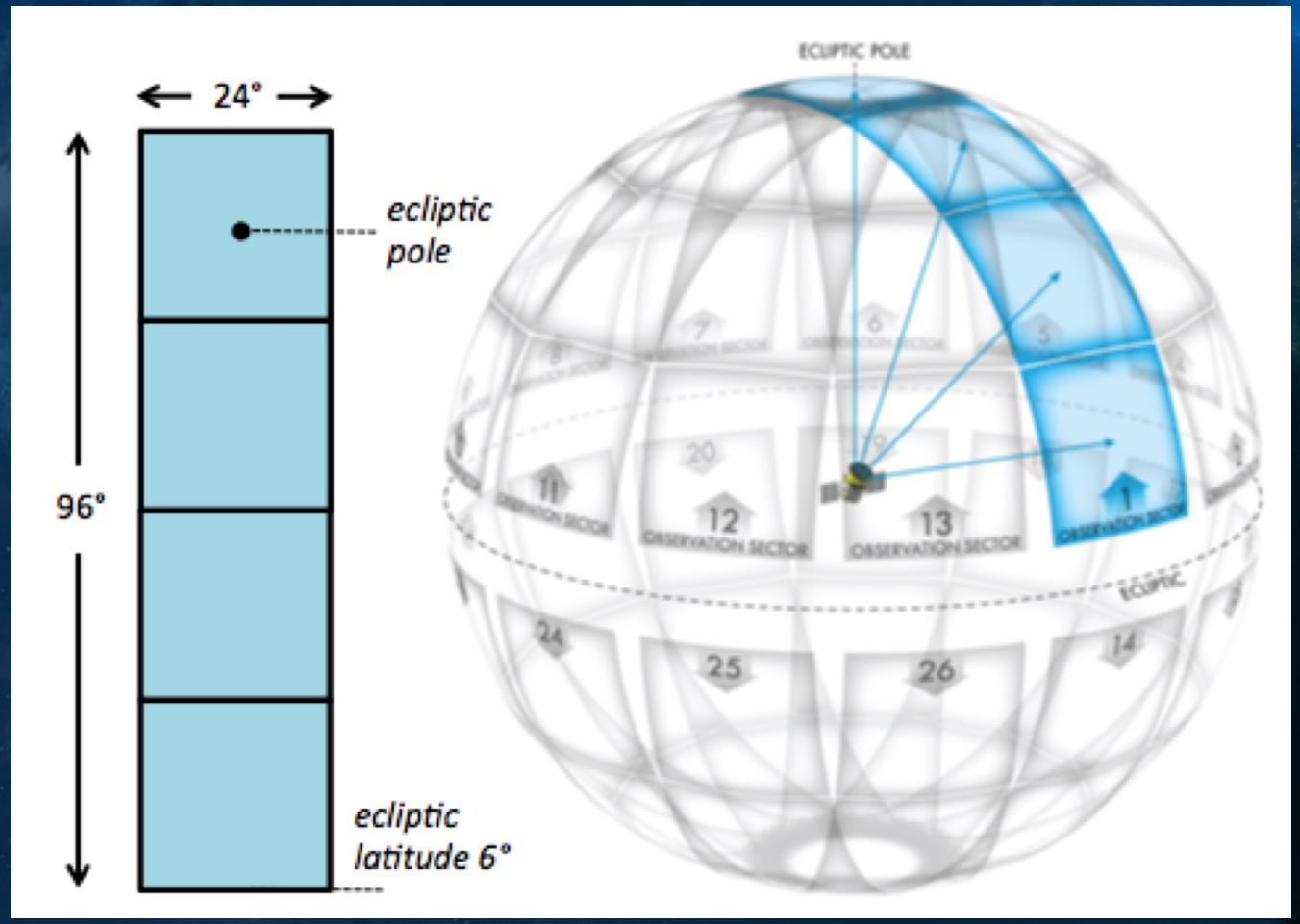
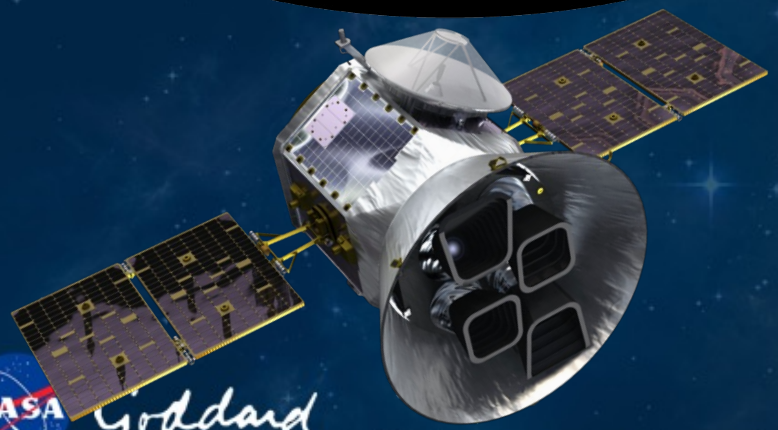
Workhorse 3??

Courtesy K. Smith 2022

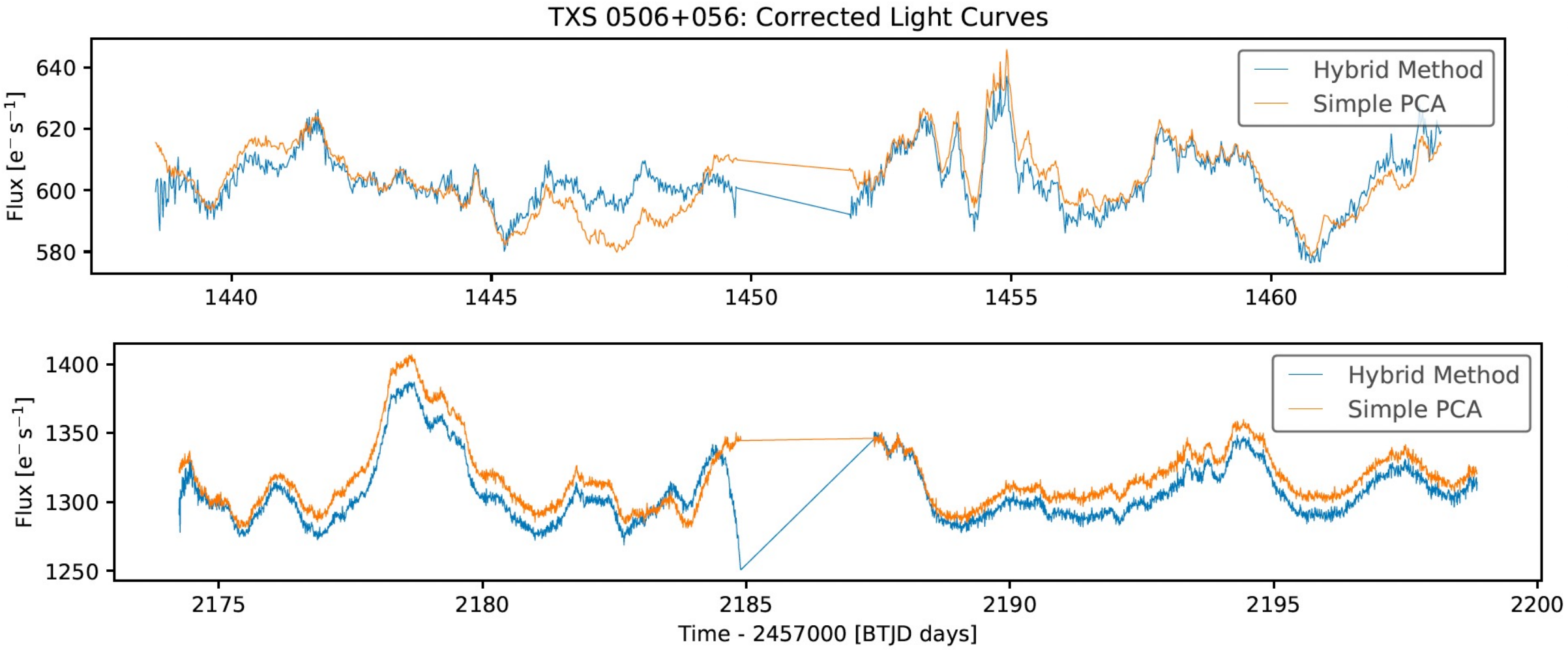




Ricker et al. (2014), Sullivan et al. (2015)

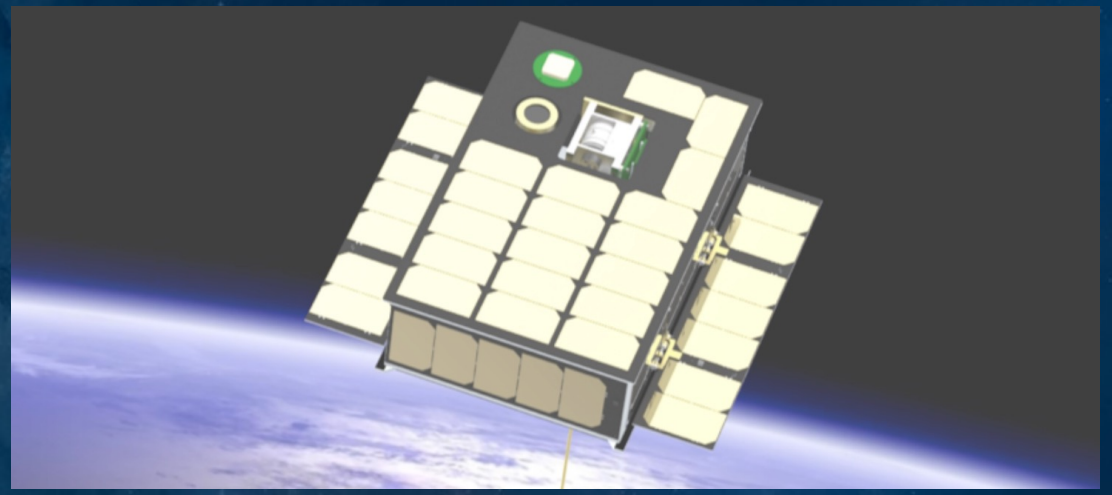
TESS Light Curves (from Quaver)

K. Smith 2022

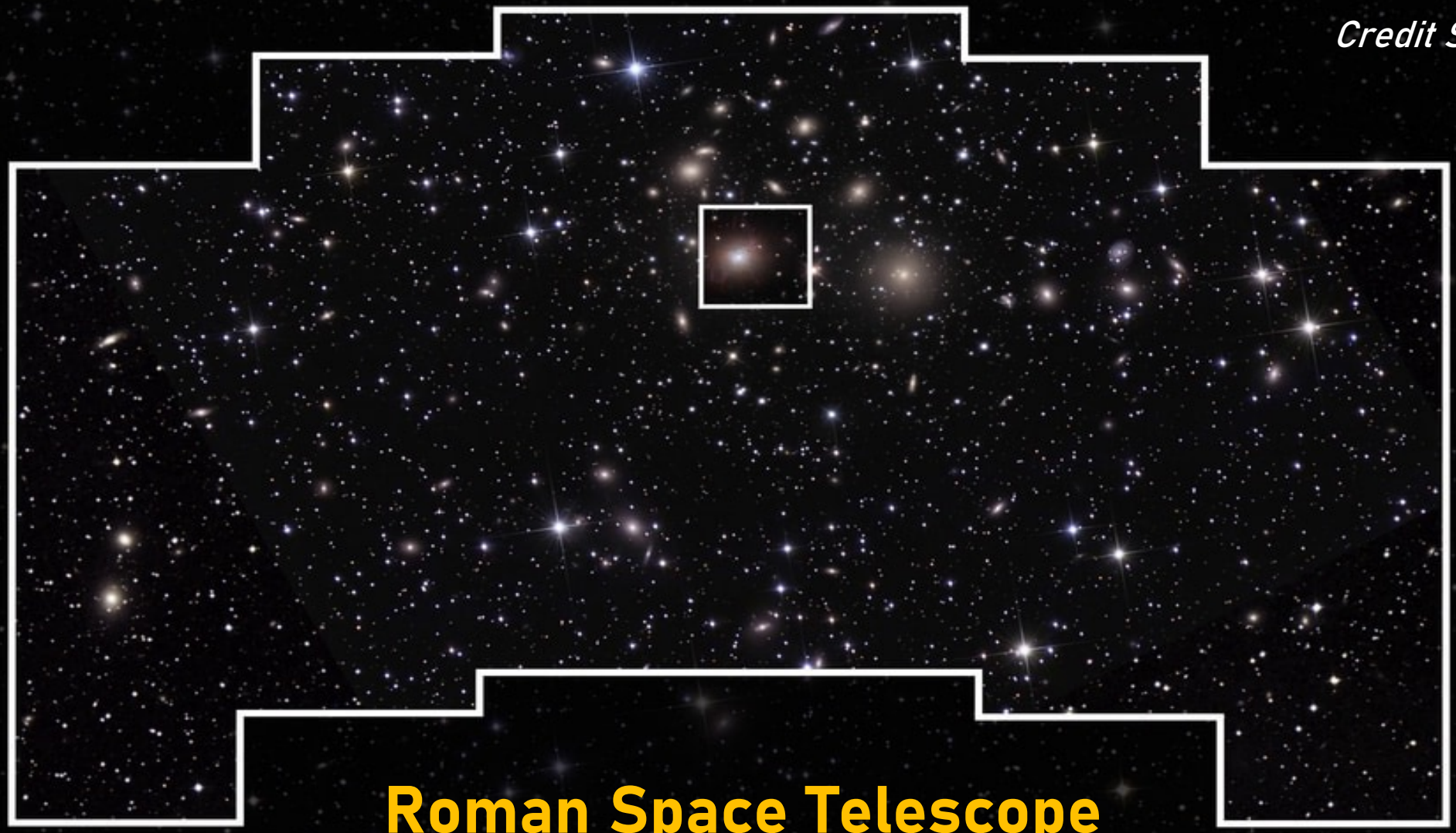


SmallSATs

- CubeSATs, Pioneers, etc. provide an agile platform for rapid identification of GW/neutrino sources
- Training of next gen of PIs
- E.g., BurstCUBE (PI: J. Perkins, GSFC)
  - 4 scintillators, 6U CubeS
  - Short GRBs detection alerts
  - Launch early 2023



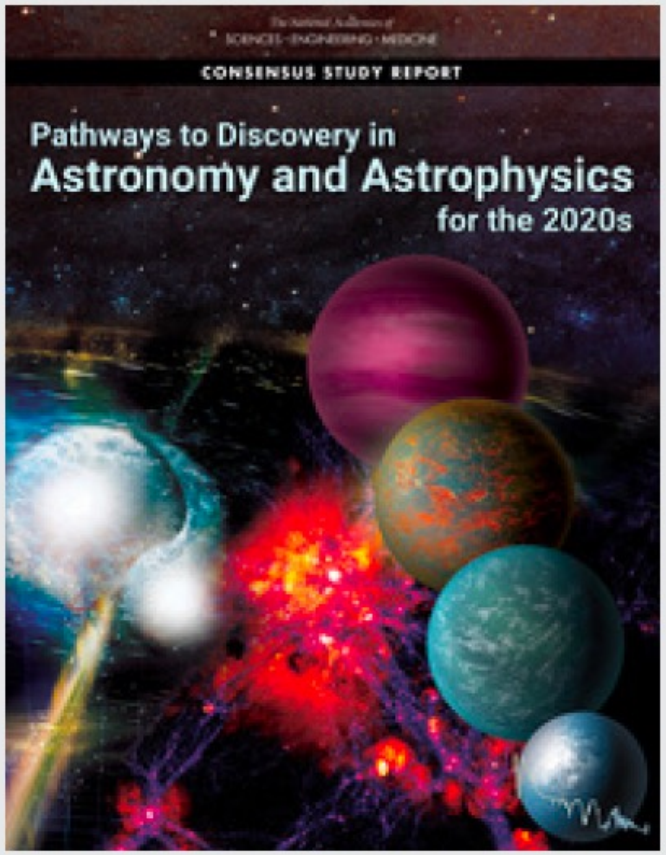
Many others: Glowbug, PUEO, Starburst, MoonShine, TIGERISS, etc. at other NASA Centers and Universities



Roman Space Telescope

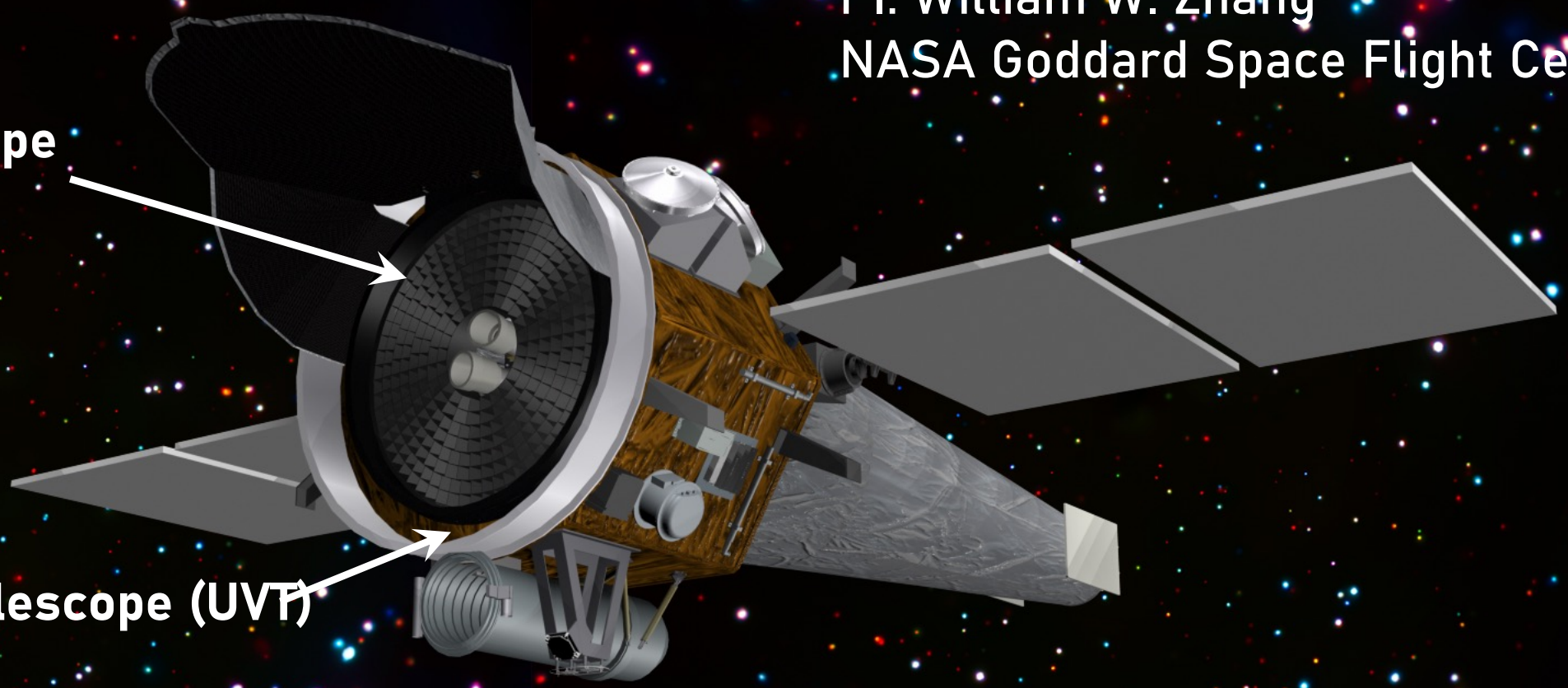
Back to the Astrophysics Decadal

- *"Exploring the cosmos in the multi-messenger and time domains is a key scientific priority for the coming decade… To advance this science, it is essential to maintain and expand space-based time-domain and follow up facilities in space. Many of the necessary observational capabilities can be realized on Explorer-scale platforms, or possibly somewhat larger."*



STAR-X: Survey and Time-domain Astrophysical Explorer

PI: William W. Zhang
NASA Goddard Space Flight Center

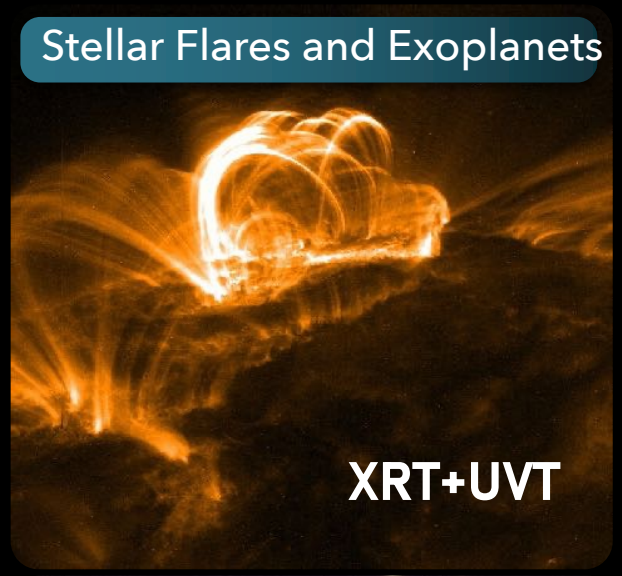


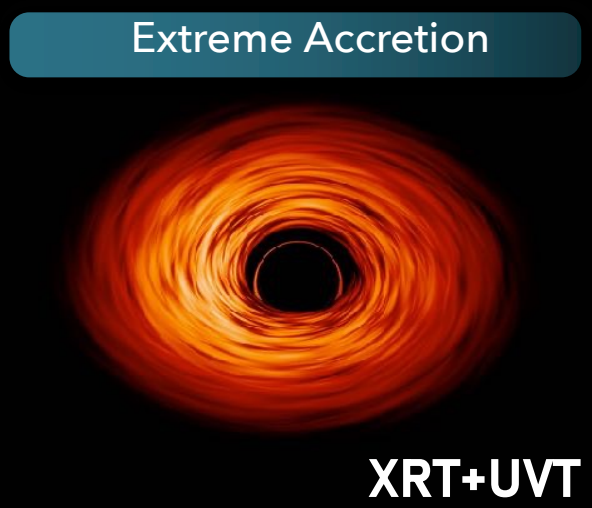
NASA Goddard Space Flight Center | Ball | MIT Kavli Institute | CU LASP Laboratory for Atmospheric and Space Physics, University of Colorado Boulder

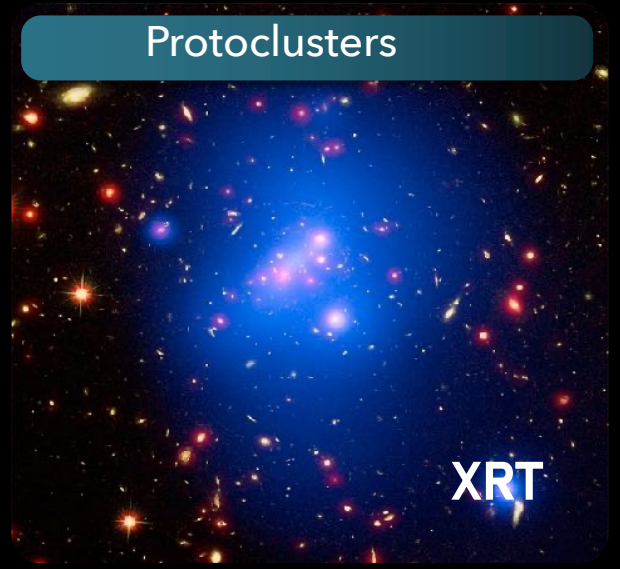
Salient Features of STAR-X

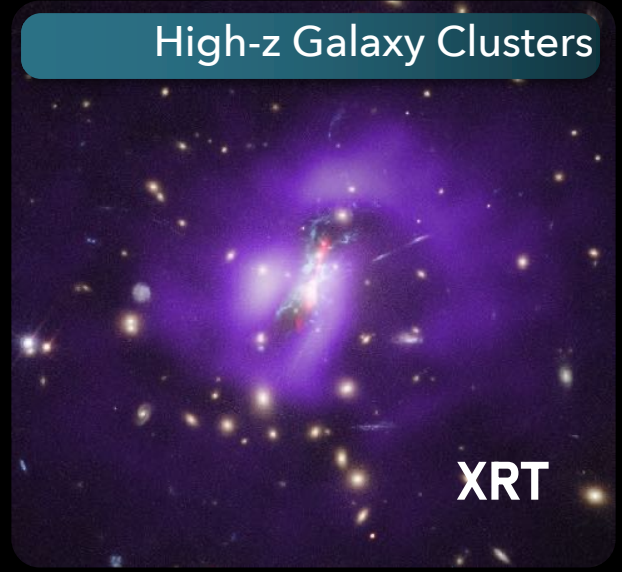
- Simultaneous coverage in X-ray and UV bands.
- Excellent PSF: 2.5” in X-ray; 4” in UV.
- Large field of view: 1 deg^2 in both X-ray and UV.
- Fast response to targets of opportunity:
  On target in <120 mins 90% of the time.
- High observing efficiency: >70%.
- Low detector background for high sensitivity.
- No consumable → Long mission life.

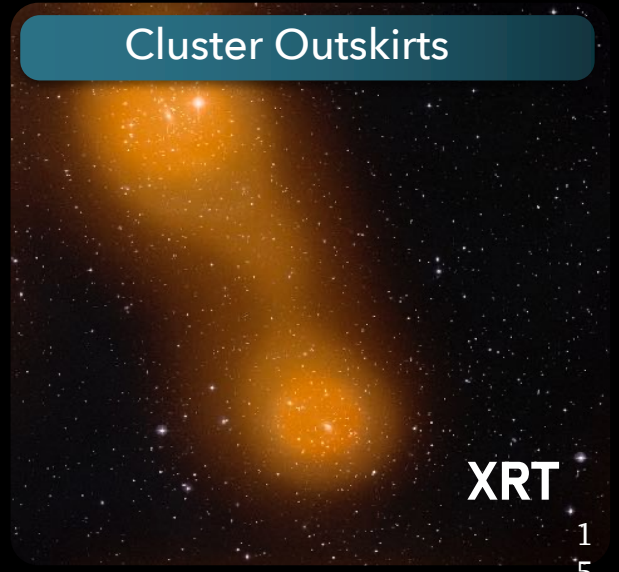
STAR-X Science Objectives









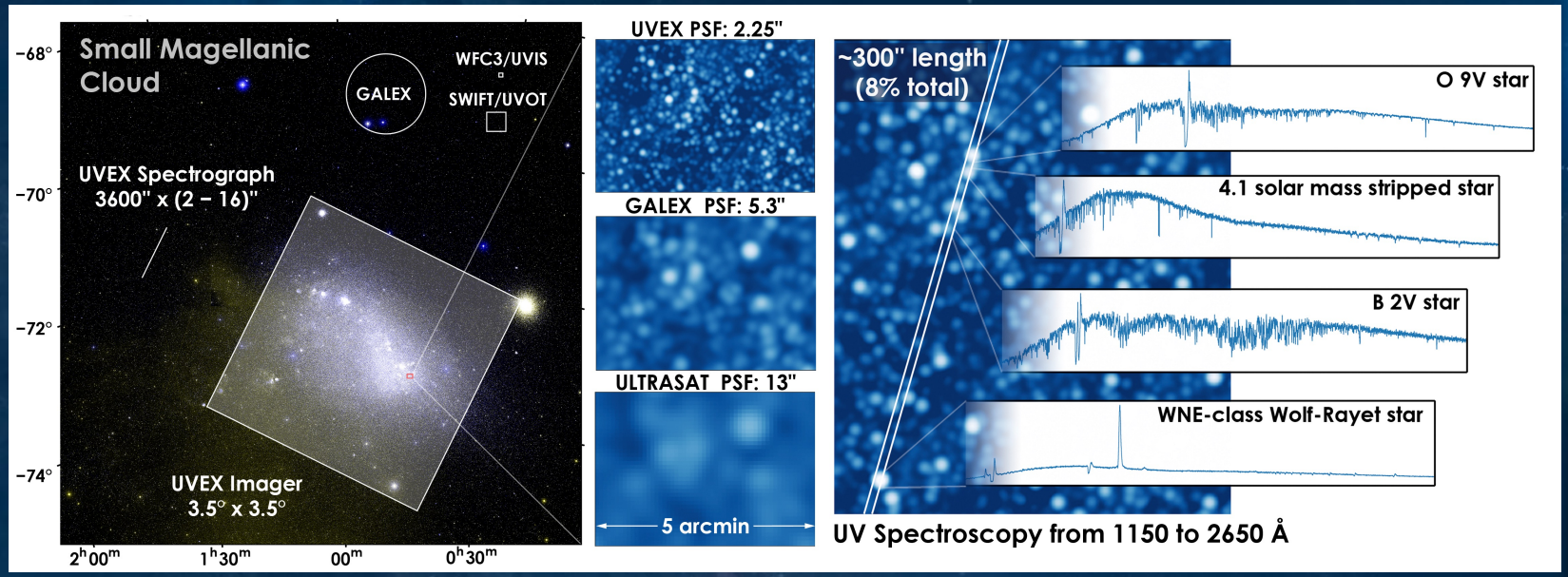


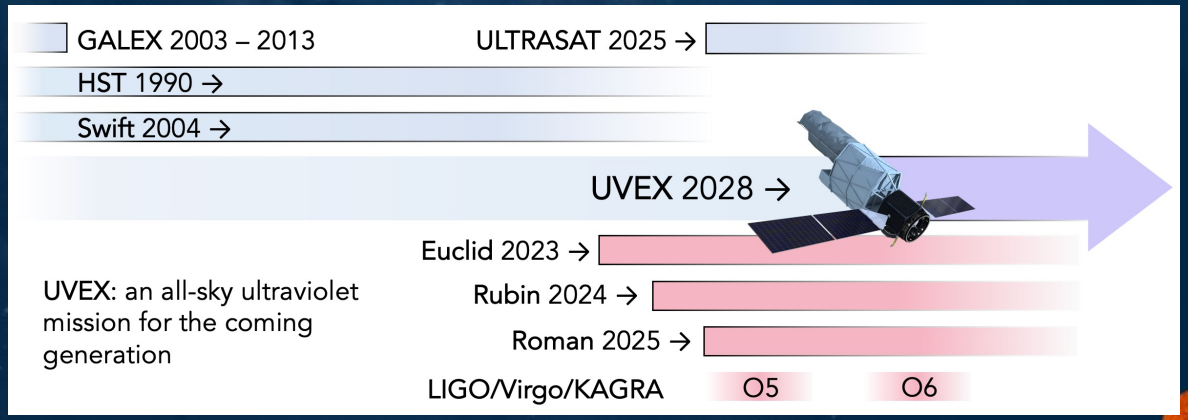
UVEX Capabilities

PI: Fiona Harrison, Caltech

UVEX INSTRUMENT

- Simultaneous FUV and NUV imaging with large FOV (3.5° × 3.5°) and high dynamic range
- Long-slit spectrograph (length 1°) with multiple slit widths (2″ – 16″)
- Pixel size: 10 × 10 micron (1″ × 1″)
- PSF (HPD): ≤2.25″ (field-averaged)
- Large field of regard (≥70% sky accessibility)
- High QE CMOS detectors without bright source constraints
- High efficiency coatings





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UVEX Science

THE LOW-MASS GALAXY FRONTIER

NEW VIEWS OF THE DYNAMIC UNIVERSE

A LEGACY OF DEEP, SYNOPTIC IMAGING AND SPECTROSCOPIC DATA

UVEX opens a window onto the lowest mass, lowest metallicity galaxies, and their unique cosmic ecosystems

Finding the local low-mass galaxies

Physical processes in very low-metallicity environments

LMC/SMC as low-metallicity laboratory

UVEX captures the early UV emission of transient events, testing models and probing mass loss in the years before stellar collapse

Afterglow of merging compact objects

Core collapse supernovae

Community-driven follow-up programs

UVEX leaves a large all-sky legacy dataset, enabling a wide range of scientific studies

Variability across multiple timescales

Mapping of dust and Galactic diffuse emission

The life cycles of hot stars

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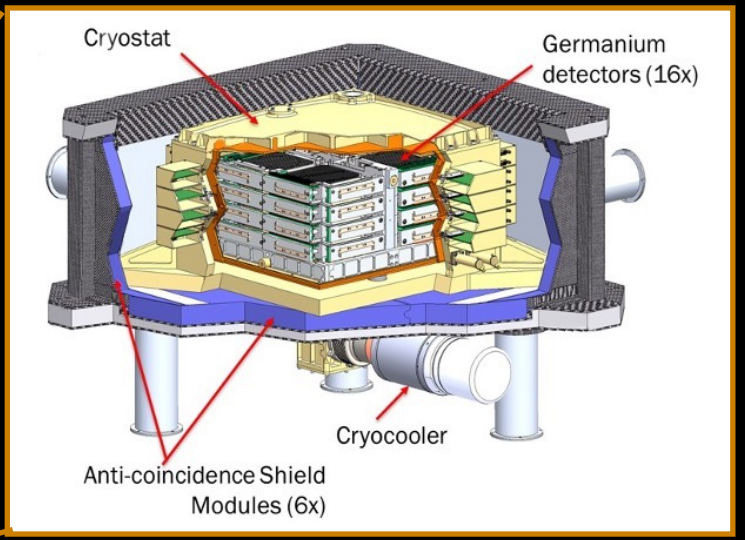
COSI Small Explorer

COSI is a wide FOV soft γ-ray telescope that will revolutionize our understanding of the creation and destruction of matter in our Galaxy.

PI: John Tomsick (UCB/SSL)

Four main science goals:

1. Reveal Galactic element formation
2. Uncover the origin of Galactic positrons
3. Gain insight into extreme environments with polarization
4. Probe the physics of multimessenger events



To be launched in 2026 to LEO providing daily full-sky coverage of the MeV sky

COSI is a single instrument:

- 16 germanium detectors image γ-rays
- BGO anti-coincidence shield to reduce background

Infrastructure

Before the 2020 Decadal

- First NASA look at MMA/TDA infrastructure:

  2019 GW-EM taskforce

  https://asd.gsfc.nasa.gov/mossaic/docs/GW-EM_Report_02102020.pdf

- Tasked with looking at NASA capabilities for the GW era
  - Performed a survey of MMA community
  - Provided several key findings for missions, archives, R&A, etc.

2019 GW-EM Taskforce

- Selected Key Findings:
  - Communication between missions and the broader astronomical community would be improved if all NASA missions implemented common standards for reporting on planned and executed observations, and the detection of transient sources. These standards should be identical to those adopted by NSF-funded (e.g., LSST) and internationally funded (e.g., SKA) facilities. […]
  - As gravitational wave detectors improve in sensitivity and event rates correspondingly increase, archival searches will become an increasingly important tool in multi-messenger astronomy. […]
  - For GW-EM science, the community strongly favors shorter (≤ 1 month) proprietary periods, as this was believed to significantly benefit scientific discovery potential, as well as career development and recognition of the contributions of early career researchers. At a minimum, missions should allow proposers to decrease the default proprietary ti

NASA's activities vs. Grassroot Activities

- NASA HQ sponsoring:
  - Alerts (since the 1990s), General Coordinate Network
  - TDAMM Workshop August 2022
  - Study for a TDAMM Program and Program Office
  - International Steering Board

- Grassroots are efforts in the community with partial or no funding from NASA or other Agencies
  - Because the Universe does not wait

The TDAMM Workshop

Annapolis, MD
August 22-24, 2022
Attended by ~300 scientists

https://pcos.gsfc.nasa.gov/TDAMM/

Deliverable	Responsible party	Due date
Individual report sections	The co-chairs , SOC	October 14
First draft report	The Co-chairs, SOC	November 4
Draft report posted for community input	Community	November 30
Report finalized	Co-chairs, SOC	December 16
Report submitted to HQ	Co-chairs	December 20

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Workshop Findings (selected)

1. Invest more in theory for modeling and precursor iscience
2. Better coordination btw ground and space, including mission/project planning
3. One-stop shop for proposals
4. Archives are all different and it is taxing to collect data from multiple ones
5. TDAMM Guest Observer Facility: coordination of NASA's current suite of missions, to optimize capabilities, including coordination of ground-based facilities. Avoid being flagged "high risk" for coordination with a ground-based project.
6. Infrastructure: coordination/collation of alert streams, international
7. Invest into data science and data scientists
8. Open science: data available asap including ground-base
9. Using MMA as an opportunity for training students, postdocs, in a multi-disciplinary field, inclusive and diverse community
10. Time domain includes many more phenomena not mentioned here (stellar flares, exoplanets, astrometric variations, …)

NASA study for a TDAMM program

- A pool of reserved time on operating missions for MMA/TDA proposals from community
- Managed by a central General Observer Facility (GOF)
  - Proposals review and selection
  - Grant management
  - Tools for proposers and data analysis
- Timeline of the Study
  - Team selected and oriented no later than 14 October 2022
  - Draft findings to be completed by 31 January 2023
  - Review to be completed and study report delivered by 30 April 2023
  - Study Review Team findings delivered by 31 July 2023
  - Final recommendation of plans for GOF implementation delivered to NASA by 31 August 2023

TDAMM International

- The Decadal recommended establishing an international Steering Board to coordinate missions with other Agencies
- NASA held talks with the ESA, JAXA, CSA, and more counterparts at the TDAMM workshop

- There is no doubt that international collaboration is key to the science

Many undergoing grassroot efforts

- ScIMMA (NSF)
- Treasuremap
- AMON

.....

Mostly focused on ground-based observations

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

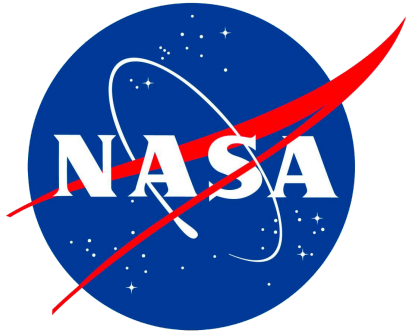
LSU

MOSSAIC

Multimessenger Operational Science Support and Astrophysics Collaboration

http://asd.gsfc.nasa.gov/mossaic

GSFC
MSFC

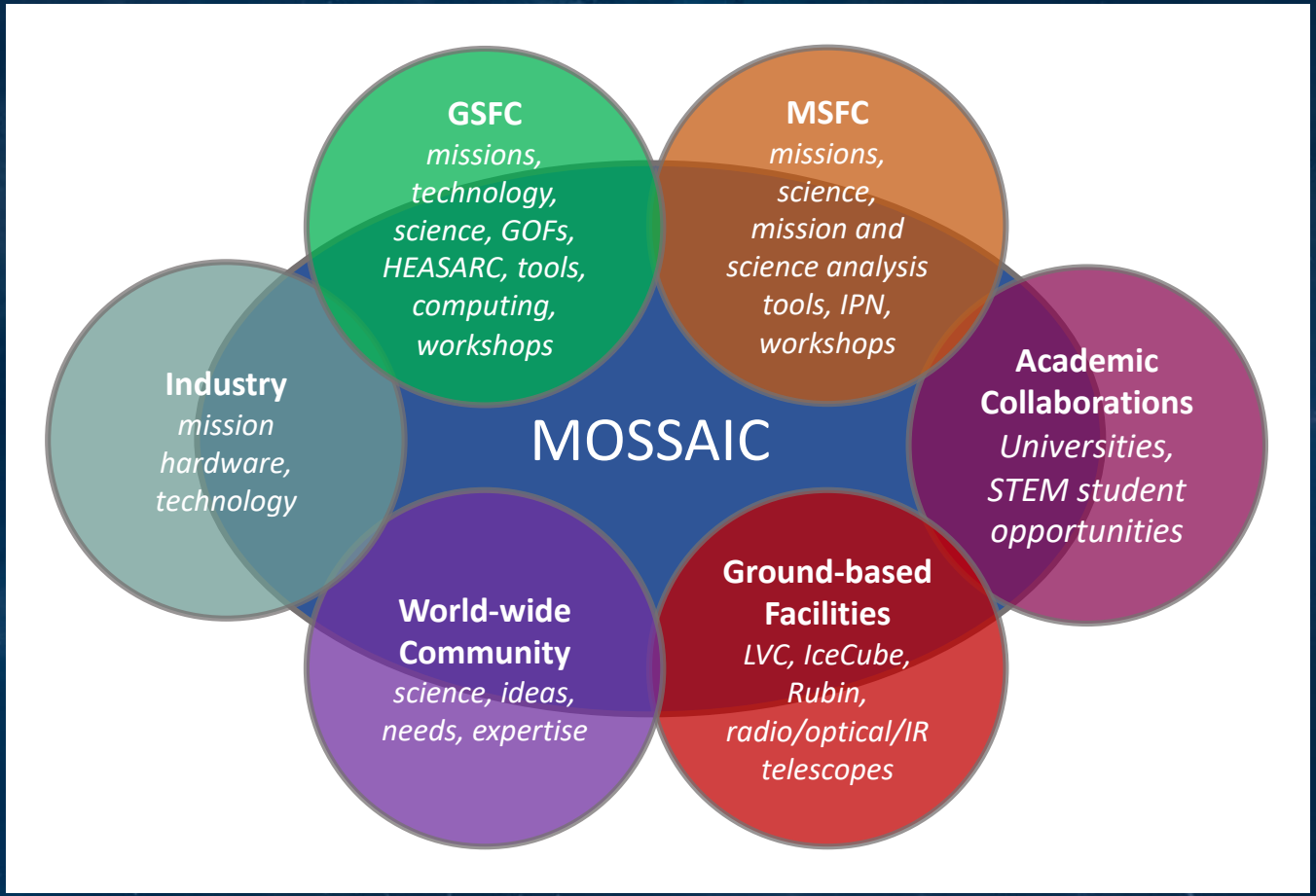


https://doi.org/10.1016/j.ascom.2022.100582

What is MOSSAIC?

- Multimessenger Operational Science Support and Astrophysical Information Collaboration
- Based on the 3Cs: Communicate (often and regularly), Coordinate (plan and execute together), and Collaborate (share ideas and tools)
- Primarily intended as a service to the community, to facilitate connections between ground- and space-based observers, theorists, computing and data scientists from the astronomy and physics fields.

Who is MOSSAIC?



What does MOSSAIC do? *See also Backup Slides*

MOSSAIC provides the MMA/TDA community with:

- Expertise in observations, data analysis, and interpretation
- Connection ground- and space-based observers for joint planning and executing
- Tools for observers and proposers for NASA missions
- Alerts (GCN, GCN modernization)
- Mission Development Support (Design Labs, STM development)
- Computing, AI/ML, and Theoretical modeling
- Mission Data Archive and analysis software (HEASARC)
- Space Communications capabilities and expertise (TDRS, DSN)
- STEM education and training
- Community Development (brainstorming sessions, workshops, internships)

Inclusion, Accessibility, and Open Science

- Multimessenger Astrophysics requires many brains
  - To optimize the science goals
  - To coordinate various parties
  - To figure out innovative solutions to problems
- MOSSAIC's tenet is to facilitate community connection and sharing of data and analysis tools
  - Allow access to the field by non-traditional communities
  - Talent comes in many shapes and from many backgrounds
  - Satisfies Open Science requirement (SPD-41a)
    - Public data and public software

MOSSAIC Future Events

- Winter 2023 AAS
  - Special session: “Preparing for Multimessenger and Time Domain Astrophysics in the 2020 Decadal era”,
    Seattle, WA,
    Jan 23, 2-3:30pm
- MOSSAIC Team meeting in February 2023, location TBD on East Coast of US

Conclusions

- The 2020 Astrophysics Decadal recommended MMA and TDA as top science priority
- NASA is taking the first steps to implement the Decadal recommendations
  - TDAMM Workshop
  - TDAMM program study
  - International Steering Board
- Grassroots activities are ongoing in parallel: MOSSAIC https://asd.gsfc.nasa.gov/mossaic

THANK YOU!

Description of MOSSAIC Tasks

Community Access Portal (CAP)

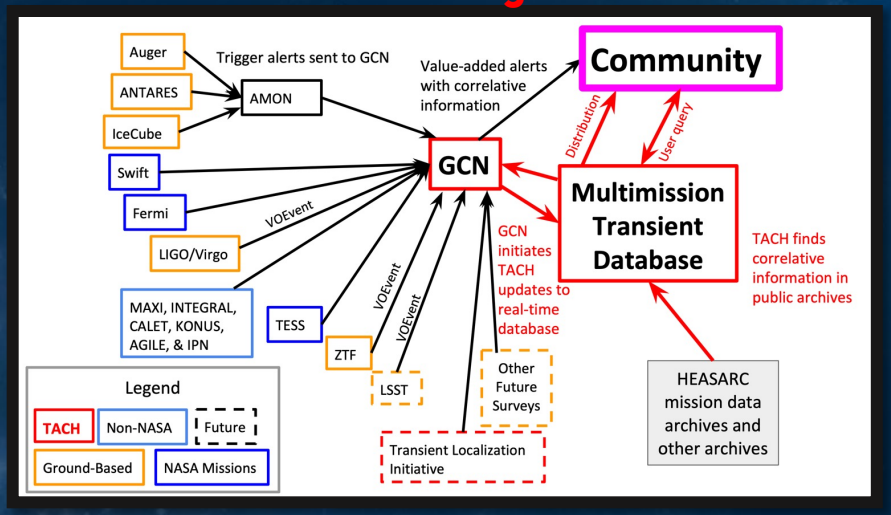
- One-stop-shop for community access to MOSSAIC services and functions
  - Primary website to find alerts, data, and tools services, seek support, and access MMA news and updates
  - Real-time community forum for instant communication
  - Access to HelpDesk
  - Events planning and calendar

- Ideally hosted and co-run by a Uni. partner because of NASA IT restrictions

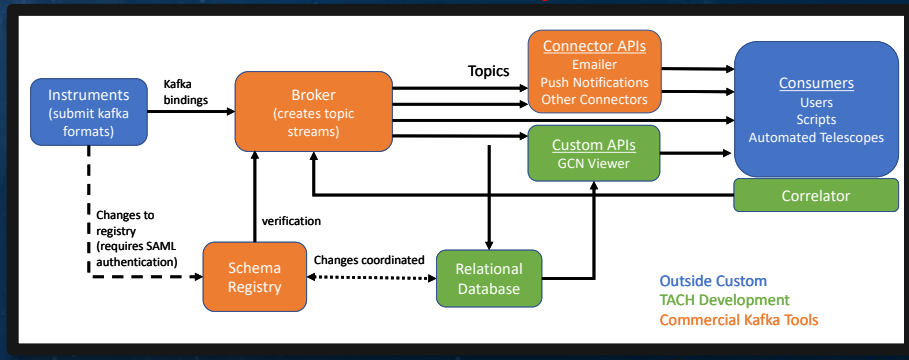
TACH/GCN Kafka Alert System

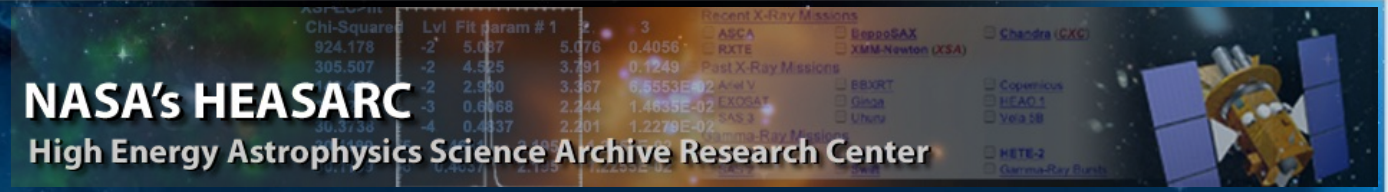
- ISFM TACH (Time-domain Astronomy Coordination Hub; FY19-FY22)
  - Proposed Tasks
    - Upgrades to Gamma-ray Coordinates Network (GCN)
    - Realtime Transient Database
    - Transient localization infrastructure
  - Extension of scope – due to change in landscape and solution to implementation of original goals
    - GRB Name Server (working with TNS)
    - Initial implementation of Kafka (alert protocol) system for GCN users/missions, compatible with other community transient alerts (in partnership with Code 710, 730, & Confluent)
- (FY23+)
  - Maintenance of TACH systems
  - New development of applications for Kafka system
  - Expanded scope of alerts, aggregation, correlation, and coordination with others (e.g. LIGO, Rubin, IceCube, SCiMMA)

TACH Program



New Alert System





HEASARC

- NASA's primary archive for high energy astrophysics and CMB data, curating active and legacy holdings from 50+ HEA and CMB missions.
- The GCN was permanently integrated into the HEASARC effective Oct 1, 2016
- The HEASARC is a central component of TACH, providing the GCN Viewer and Transient DB.
- For MOSSAIC, the HEASARC will:
  - Provide the primary archive for the many and varied types of MMA data: catalogs, light curves, SEDs, images, calibrations, custom datasets, appropriate calibrations, and documentation, in formats conducive to cross-dialog with other archives and compliant with Virtual Observatory protocols.
    - Includes new data holdings from non-NASA observatories -- IceCube
  - Provide analysis tools to the community, within the established HEASoft framework, for the analysis of multimessenger datasets
  - Provide tutorials for data analysis
  - Broad benefit to world-wide MMA community

GOF-Like Services

How can MMA scientists rapidly identify and utilize the best NASA observing resources to maximize their science?

MOSSAIC provides tools and services, in coordination with observatory operations teams, to enable rapid follow-ups.

Target Visibility Planner

- One-stop visibility analysis for all participating observatories
- Both future and historical events
- Joint, tiled, temporal cadence constraints, and sky visualizations

Follow-Up Hub

- Curate observatory data and tech documentation
- Streamline ToO requests, for speed and accuracy
- Broker ToO requests to observatories where feasible

Multi-Mission, Multi-Messenger Optimization Toolkit

How can MMA scientists make the best use of ground-based telescopes in coordination with space telescopes?

MOSSAIC will develop new algorithms and a software toolkit to optimally plan and coordinate observations in space and on the ground.

Multi-Mission Observer Toolkit

- An open source community framework for target of opportunity and time-domain survey planning
- Builds on Goddard experience with GW follow-up from space (Swift, Dorado) and with ground-based telescopes (Zwicky Transient Facility, Palomar Observatory)

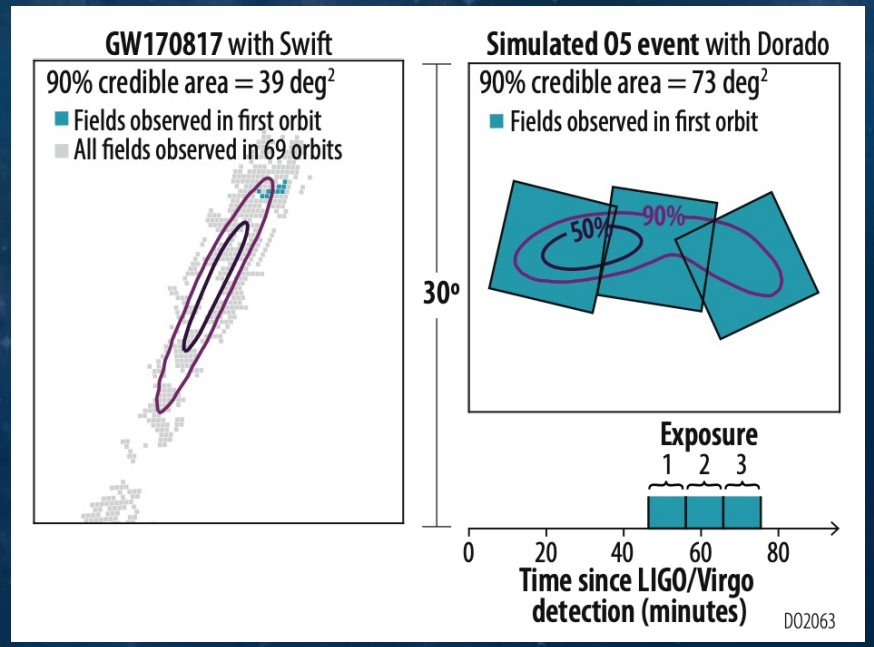


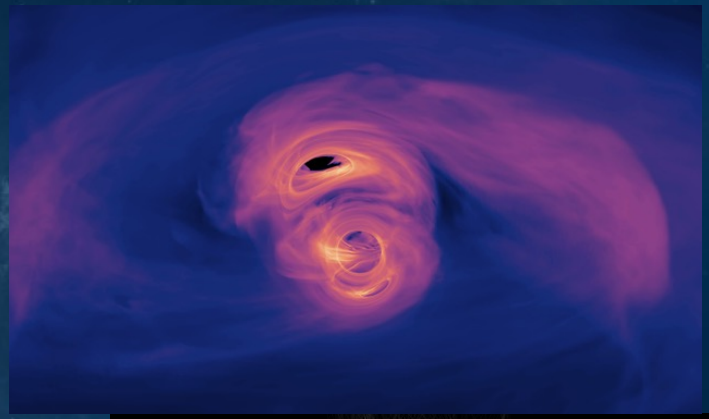
Image: Dorado CSR

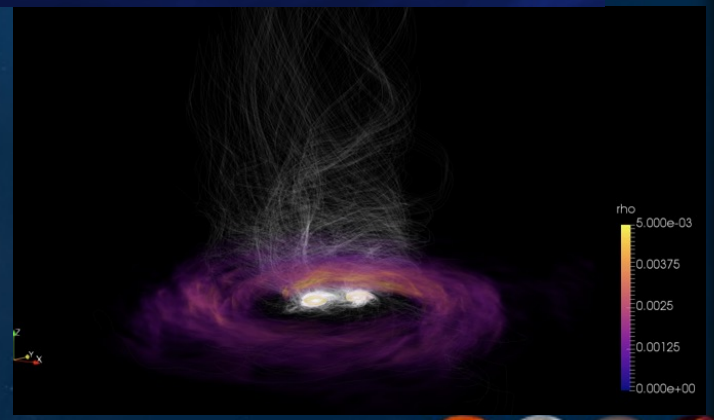
Science feasibility and return for MMA Facilities

MOSSAIC provides expertise for the external community in informing science feasibility of MMA mission concepts

through a variety of modeling and data interpretation services:

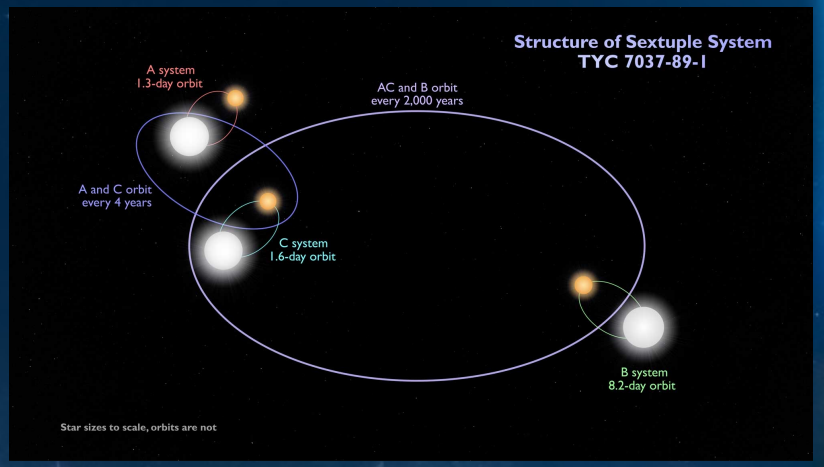
- Computational modeling of multimessenger signals to identify target observations for future missions.
- Modeling support for science definition for proposals and future mission concepts.
- Evaluating multi-mission and multi-dataset analysis and interpretation.



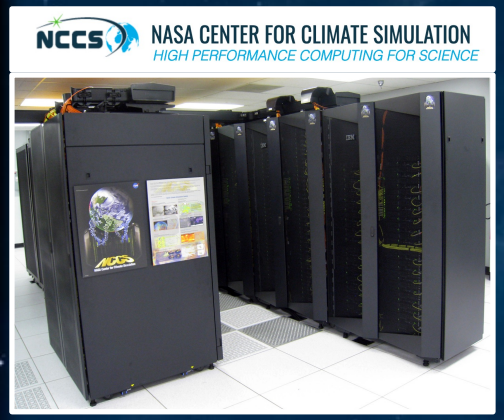


AI/ML Enhancement

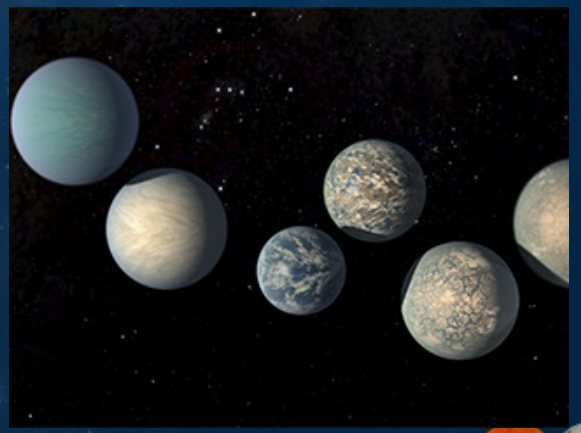
- In order to truly leverage the power of MMA, algorithmic methodologies must be employed to properly characterize and analyze the data
- MOSSAIC is poised to provide a platform for future AI/ML analysis of astrophysical data



AI/ML already in use at GSFC, using neural networks to discover exoplanets, eclipsing binaries, and multiple star systems (including sextuple!)



NCCS CPU and GPU resources supporting the effort, allowing for fast AI/ML analyses



Space Communications & Navigation

- MMA mission concepts present several challenges for C&N
  - Event-triggered, time-sensitive data from, to & among observatories
  - Synchronized timing, navigation & control of MMA space observatories
- MOSSAIC ensures MMA community will fully leverage C&N capabilities in autonomy, interoperability, networking, optical technologies and commercial services