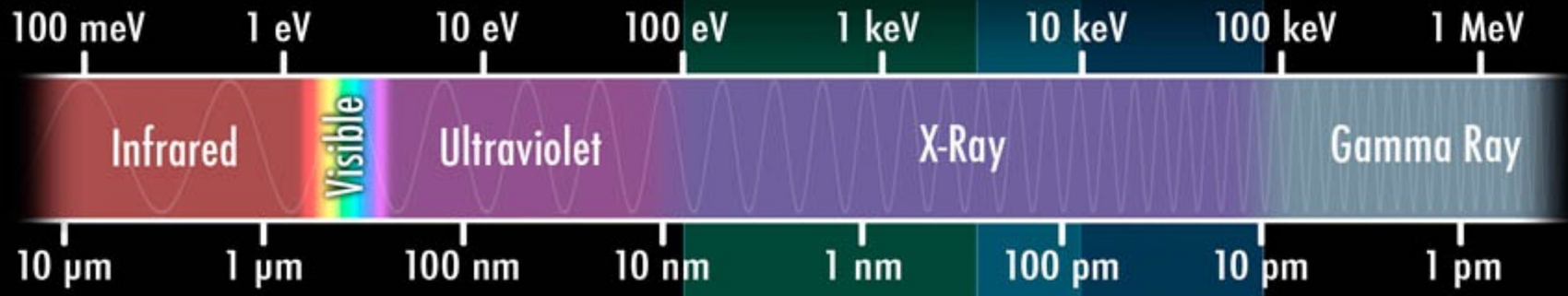
NuSTAR Status Update

2023 Summer APAC Meeting

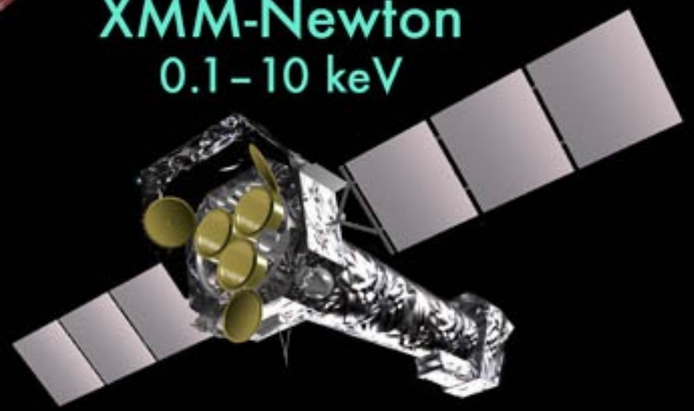
Brian Grefenstette, Caltech
***NuSTAR* Principal Mission Scientist, for the *NuSTAR* Team**

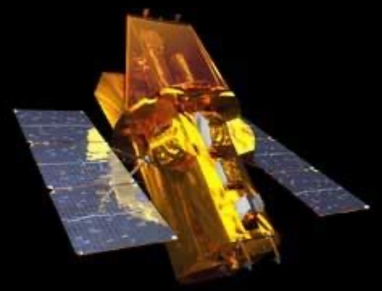
X-Ray Telescopes & the Electromagnetic Spectrum

NICER
0.2-12 keV

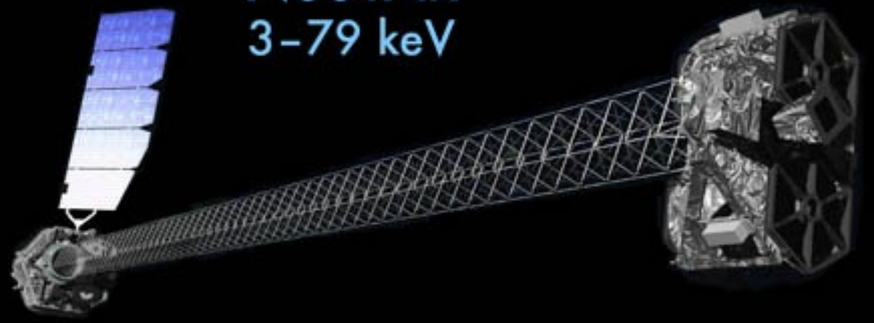


Chandra & Swift-XRT &
XMM-Newton
0.1–10 keV





NuSTAR
3–79 keV



NuSTAR by the Numbers

Launch Date: June 13, 2012

Time in space: >4,000 days (>60,000 orbits)

Science Observations: >5,000

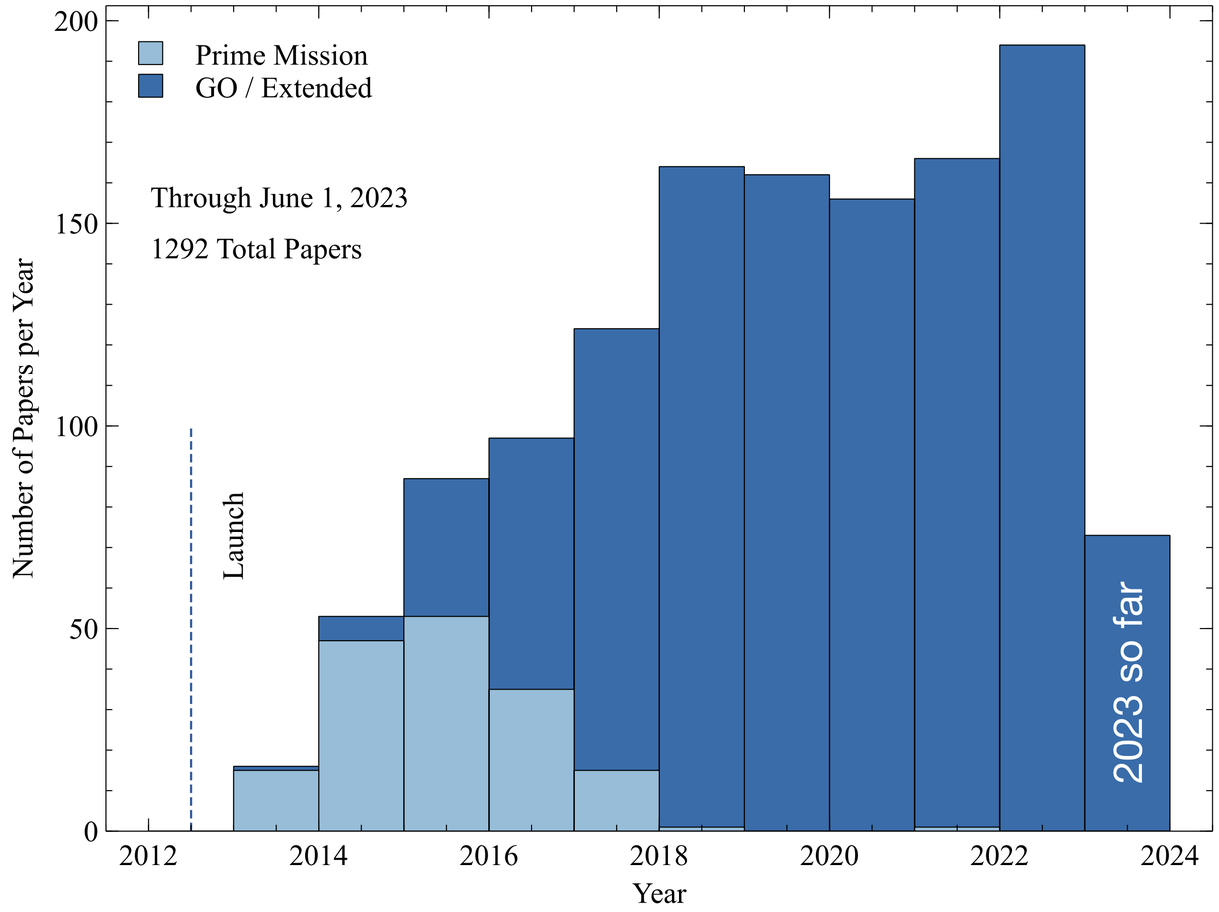
First Light: June 28, 2012

Baseline science mission: July 2012 - April 2015

Currently in Guest Observer Cycle 09

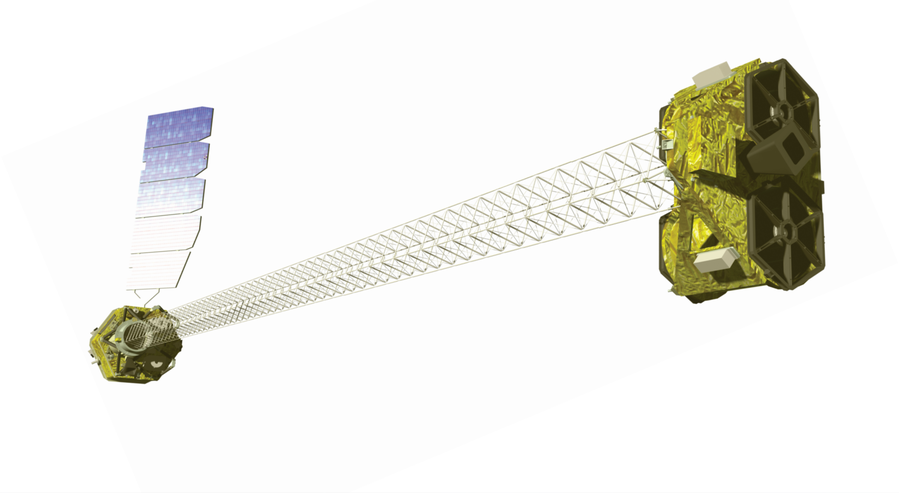
NuSTAR Scientific Productivity

- Total 1292 papers to date
  - “h-index” > 70
- Since 2018, avg ~160 papers per year
  - 2022 “Covid Bump”?
  - 2023 on-pace to match 2021/2022 numbers

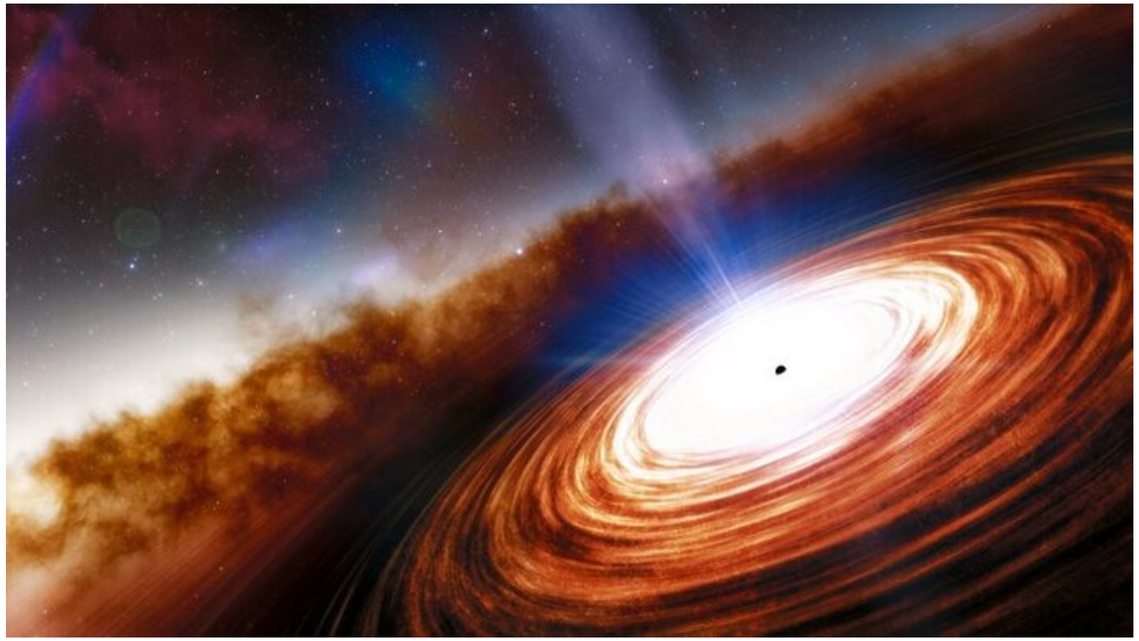


NuSTAR and TDAMM

Time Domain in the X-ray



- The X-ray sky is incredibly dynamic: time domain science “baked in” to X-ray observations
  - X-rays are produced by the most energetic sources in the Universe
  - X-rays probe extreme events that are highly variable
  - No “standard candles” in the X-ray sky

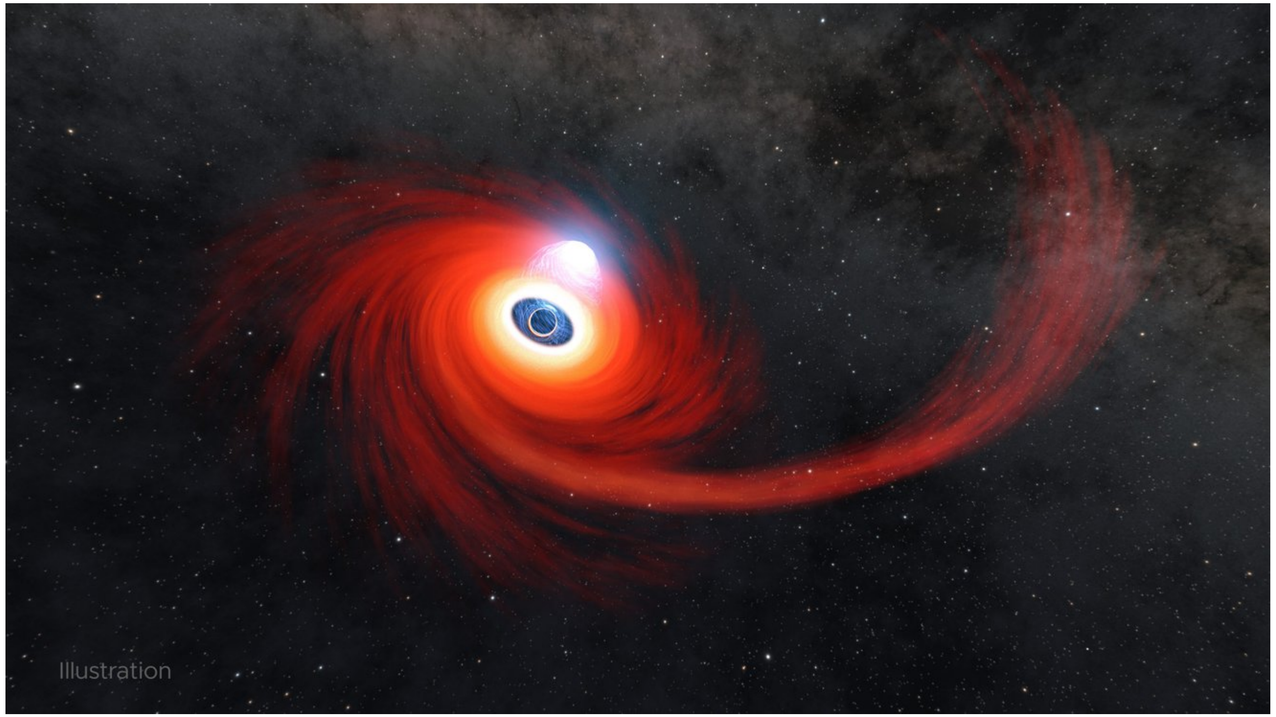


Artist’s impression of a quasar Credit: NOIRLab/NSF/AURA/J. da Silva

Science Highlights from 2022/2023

“NASA Gets Unusually Close Glimpse of Black Hole Snacking on Star”

- Original discovery of a tidal disruption event (TDE) by the Zwicky Transient Factory led to multiple NASA telescopes observing a massive black hole tearing apart a star that got too close to the black hole.
- *NuSTAR* hard X-ray observations provided an unprecedented view of the formation and evolution of the black hole’s corona.
- Media coverage:
  - Number 1 story on JPL the week of release.
    - Top 10 at JPL from December 2022 - April 2023
  - Number 1 feature on nasa.gov



A disk of hot gas swirls around a black hole in this illustration. The stream of gas stretching to the right is what remains of a star that was pulled apart by the black hole. A cloud of hot plasma (gas atoms with their electrons stripped away) above the black hole is known as a corona. Credits: NASA/JPL-Caltech

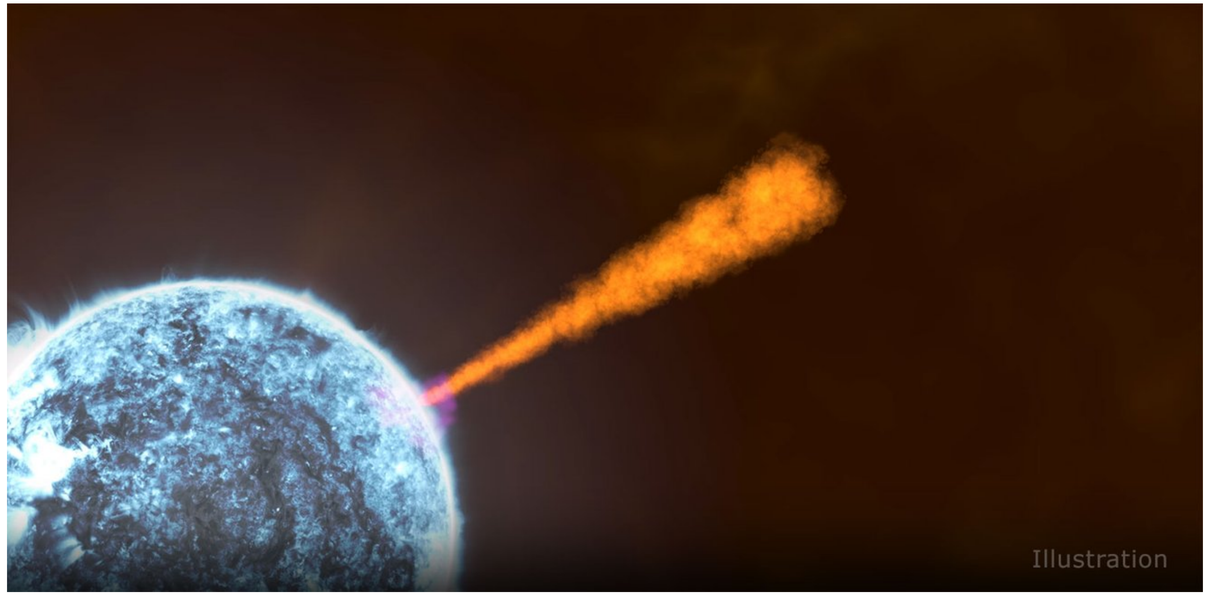
https://www.jpl.nasa.gov/news/nasa-gets-unusually-close-glimpse-of-black-hole-snacking-on-star

Science Highlights from 2022/2023

“Brightest Cosmic Explosion Ever Detected Had Other Unique Features”

- *NuSTAR* observed the afterglow of gamma-ray burst GRB 22109A (the “Brightest of All Time”) along with *NICER*, *Swift*, and *XMM-Newton* to help constrain the jet geometry.

- Media coverage:
  - Hot off the press (Released June 6th)

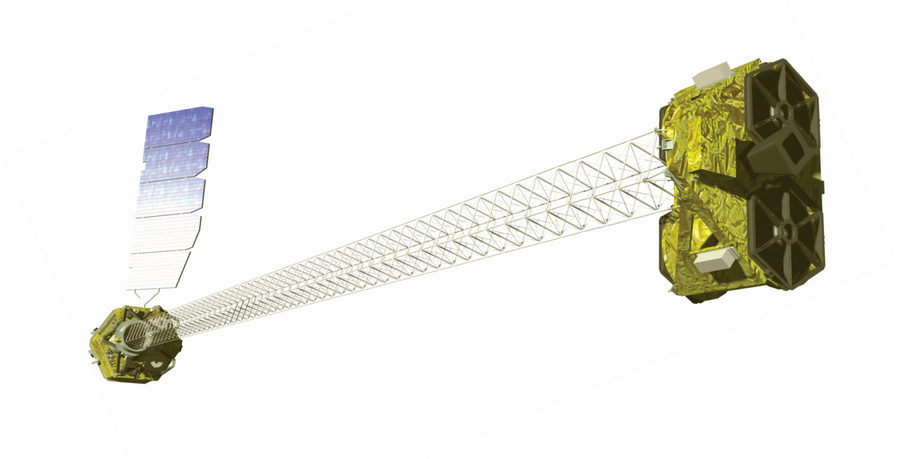


A jet of particles pierces a star as it collapses into a black hole during a typical gamma-ray burst, as depicted in this artist’s concept. The jet created by gamma-ray burst 221009A had some unique features. Credit: NASA’s Goddard Space Flight Center

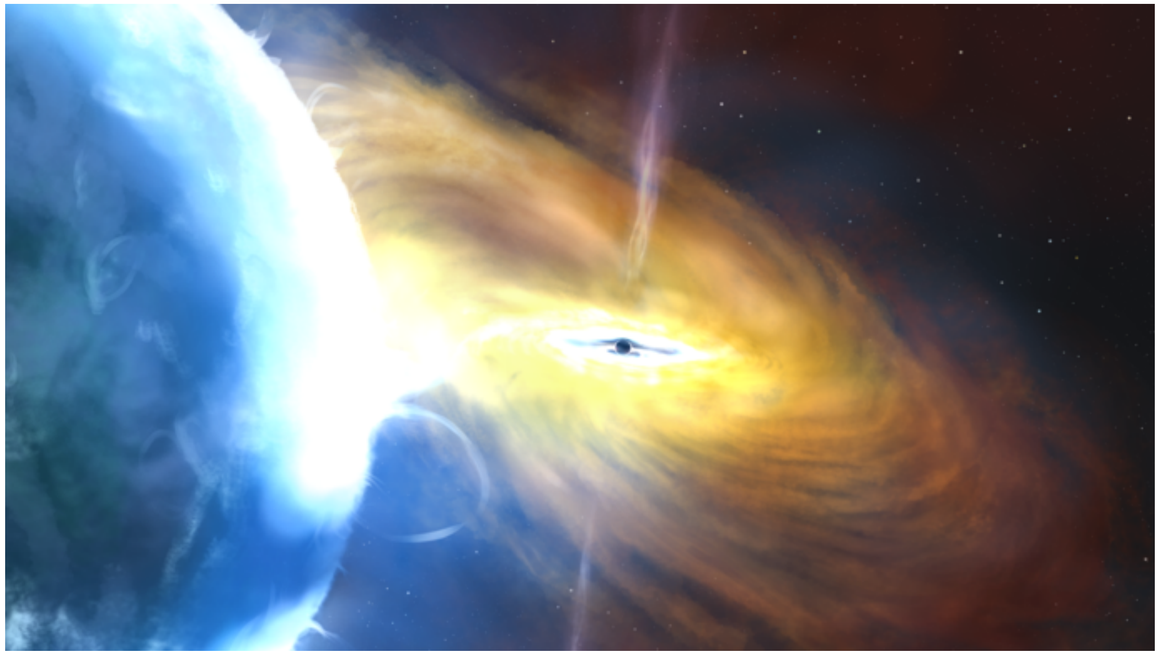
https://www.jpl.nasa.gov/news/brightest-cosmic-explosion-ever-detected-had-other-unique-features

NuSTAR and TDAMM

Time Domain



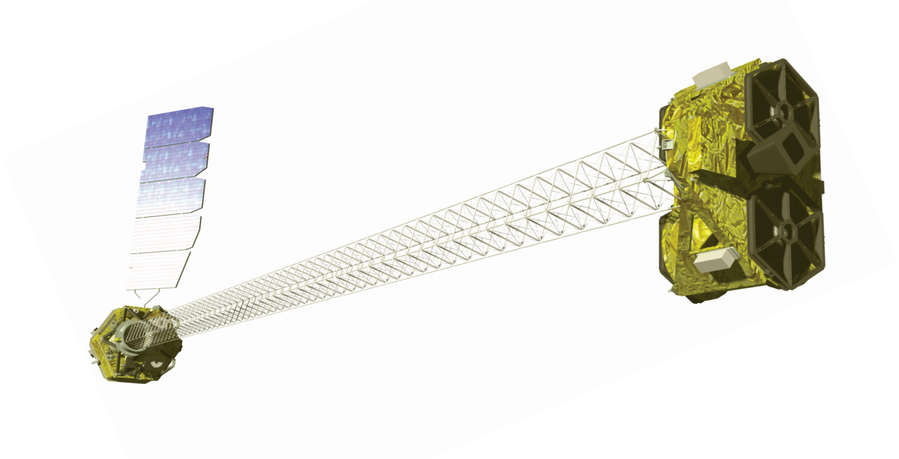
- *NuSTAR* remains incredibly flexible both in schedule and field of regard
  - Example: GO program to follow-up transient sources near the Sun
  - No hard limits on observing direction due to thermal constraints



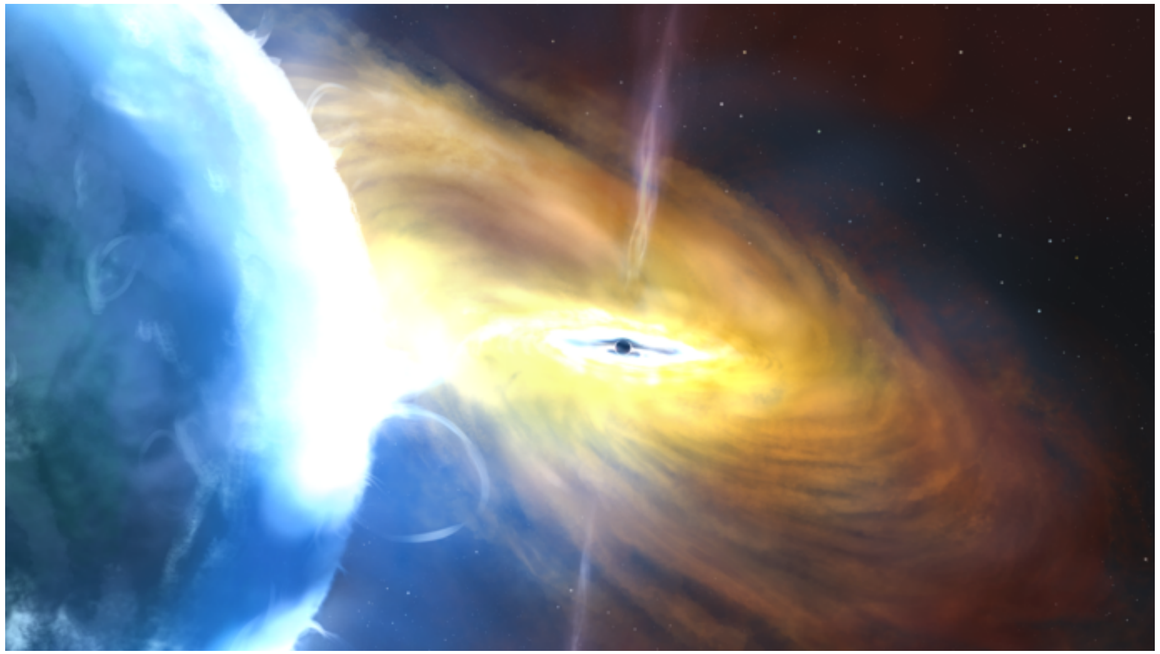
This illustration shows the Cygnus X-1 system, located more than 6,000 light-years from Earth. The black hole is shown at the center and its companion star is depicted on the left. The immense gravity of the black hole pulls material off the star, forming a disk called an “accretion disk” around the black hole. Credits: John Paice

NuSTAR and TDAMM

Time Domain



- NuSTAR has responded to community demand for time domain observations.
- >25% of *NuSTAR* observations are in response to ToO requests
- Includes the GO programs and community-driven ToOs
  - GO programs routinely have rapid response <2-days
  - Community-driven ToOs ~few days to 1-week



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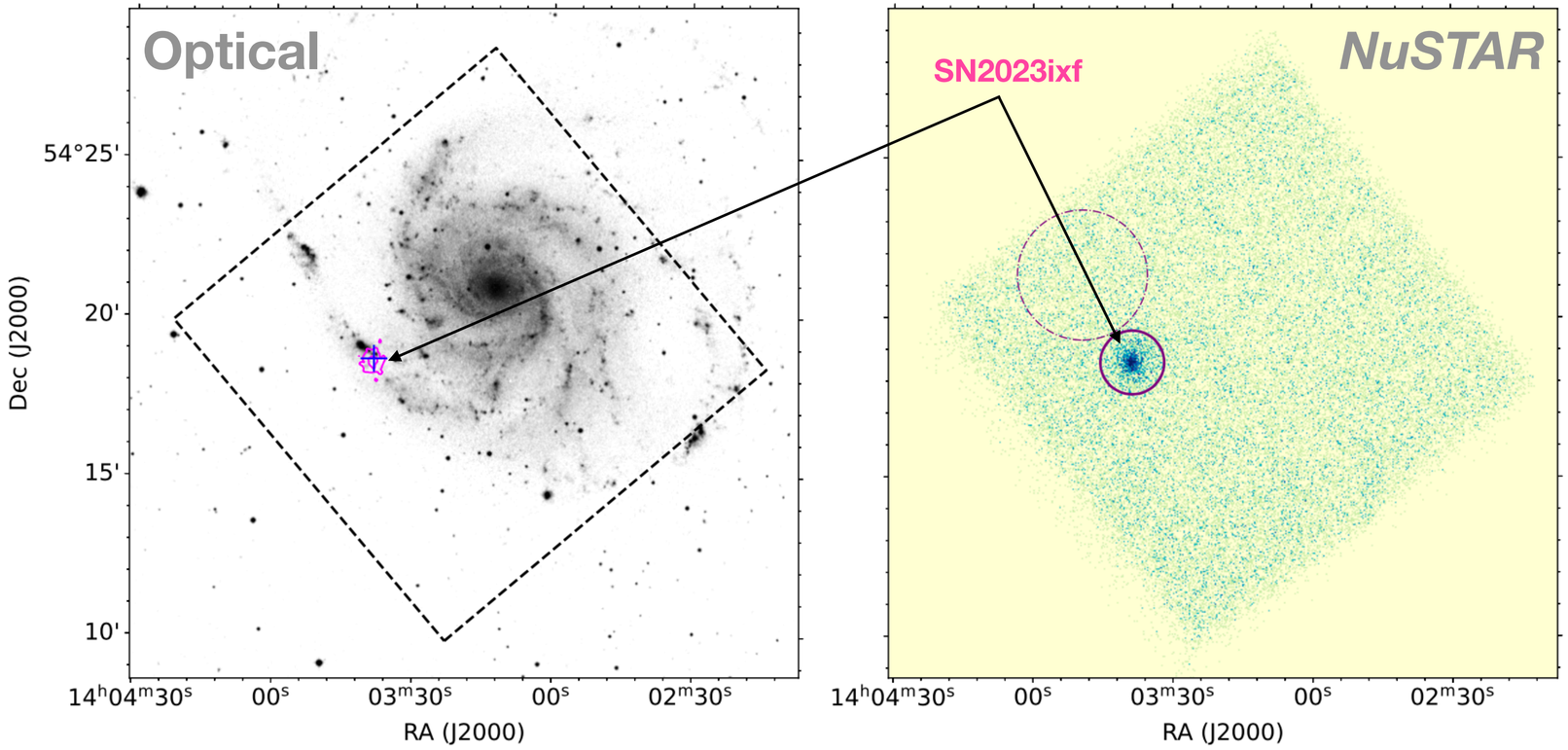
NuSTAR and TDAMM

Example Timeline: SN2023ixf

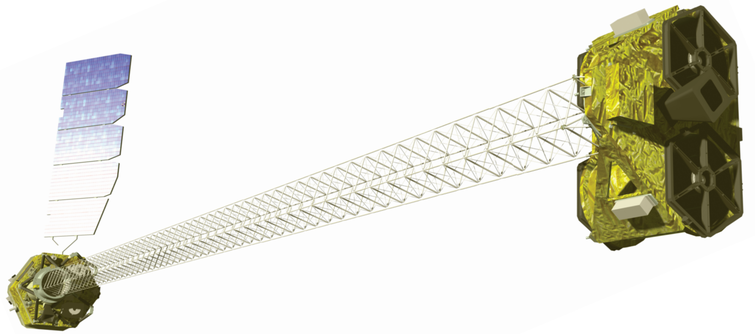


Left is the Digital Sky Survey optical image of M101. The blue cross shows the location of SN2023ixf. Right side is the *NuSTAR* hard X-ray image of the galaxy showing the X-ray discovery image of the SN2023ix. Figure taken from Grefenstette et al, ApJL (2023, accepted).

- Supernova discovered on 2023-05-19 17:30 (by K. Itagaki)
- Community ToO Request submitted 2023-05-20 01:30 (Friday evening)
- ToO request approved 2023-05-20 16:30 (Saturday morning)
- First observation NuSTAR epoch obtained 2023-05-22 17:56 (Monday)
  - Only 3.6 days post-explosion
  - Not detected by *Swift*-XRT in soft X-rays due to circumstellar obscuration
  - Hard X-rays detected by *NuSTAR* pass through this material, and allow scientists to study the material ejected by the supernova pre-explosion

NuSTAR and TDAMM

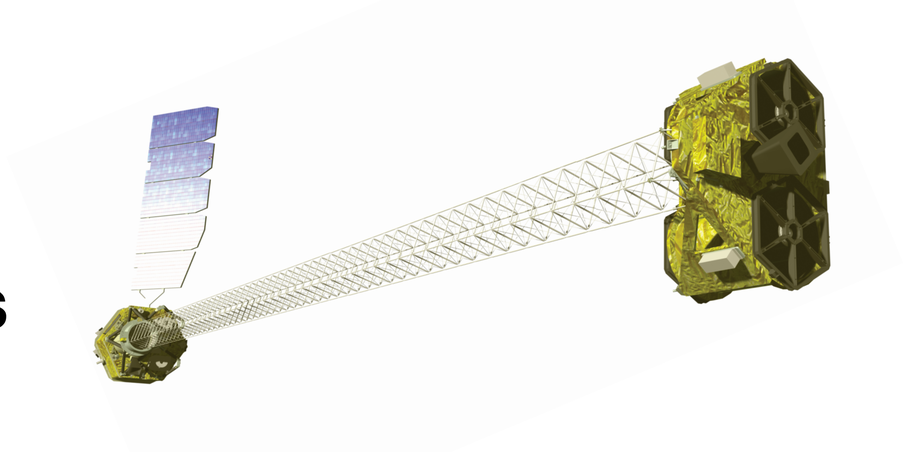
Time Domain - Programmatic Changes



- Project increased allocated observing time to ToOs programs from 500-ks to 1000-ks
  - Demand has risen to match
  - ToO’s consistently the most over-subscribed program
    - Current oversubscription rate is 7x (overall is 4x)

NuSTAR and TDAMM

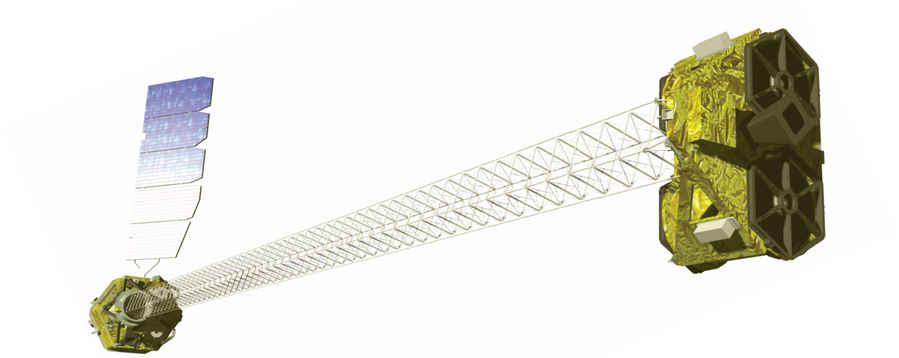
Time Domain - Programmatic Changes



- On-going upgrades proposed in 2022 Senior Review to the Science Operations Center / Mission Operations Center to enable even faster ToO response
  - Work is in progress, will primarily affect on-target time for GO programs
  - Community-driven ToOs typically will not interrupt on-going observations, so have to wait for an available window in the schedule (not intended to be fast-turnaround).
- Only concern for TD science is increase in coordinated observations over time

NuSTAR and TDAMM

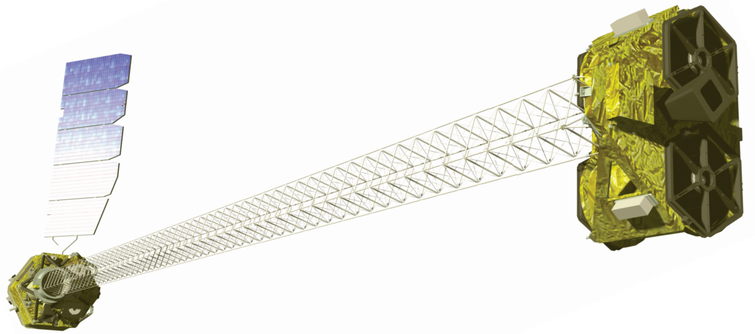
Multi-messenger science



- Primarily addressed through the GO program(s):
  - Existing NS-NS GW counterpart searches approved through *NuSTAR*, *XMM-Newton*, *INTEGRAL*, and *Chandra* GO programs.
    - Ready for O4 trigger!
  - Follow-up of ICECUBE triggers also approved through *NuSTAR* GO program
  - *In-situ* multi-messenger observations approved through *NuSTAR* GO program:
    - Coordinated observations of the Sun with *Parker Solar Probe* perihelion passes
    - Coordinated observations of Jupiter with *Juno* observations

NuSTAR and TDAMM

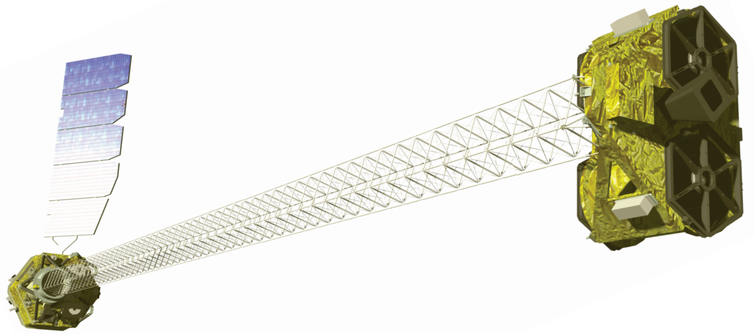
Future challenges (into the 2030/2040s)



- *NuSTAR* currently operating well, no degradation to overall sensitivity or operational capabilities.
- Biggest threat is atmospheric drag during current solar maximum
  - Currently at 590-km, slowly decaying
    - Note: No on-board propellant or boost capability
  - Likely to survive to at least the next solar maximum
    - Pending one-off issues (space debris, impacts, etc)

NuSTAR and TDAMM

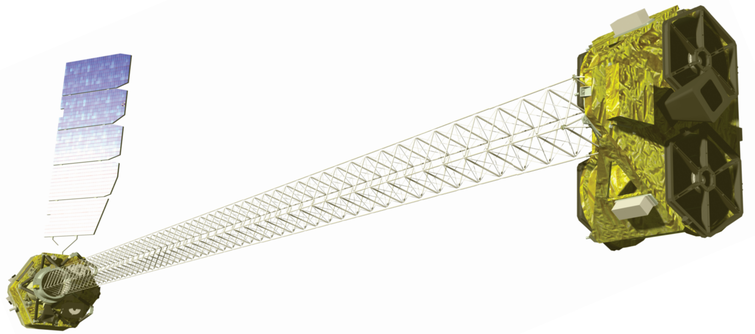
Future challenges (into the 2030/2040s)



- *NuSTAR* is a SMEX that is operating well, but well beyond its design lifetime
- No other currently funded sensitive hard X-ray focusing missions*
  - Loss of *NuSTAR* implies a loss of capabilities for sensitive, broadband X-ray coverage
  - *with data available to the community (only other telescope is the ART-XC on the Russian *Spektr-RG* mission)

NuSTAR and TDAMM

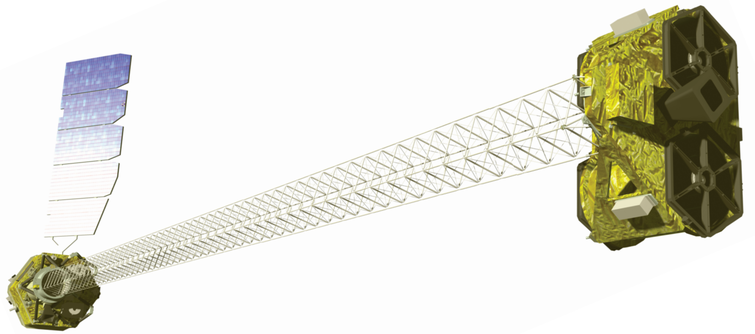
Future challenges (into the 2030/2040s)



- Asks for APAC:
  - *NuSTAR* is currently responding to community demand for time domain and multi-messenger observations
  - Outside of turning down the solar cycle, no outstanding asks for *NuSTAR* from the APAC
  - Communications concerns / improvements to be addressed via the TDAMM Communications SAG

NuSTAR and IDEA

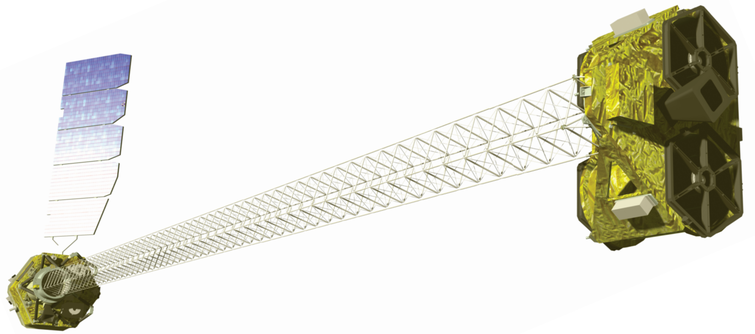
Inclusion, Diversity, Equity, and Accessibility



- Engagement with NuSTAR data, both through archival analysis and through new observing proposals, introduces a barrier to scientists at institutions without a strong tradition of *NuSTAR* and X-ray data analysis.
- The Project team at Caltech makes a strong commitment to mentoring students with diverse backgrounds:
  - Racial
  - Socioeconomic
  - Neurodiverse
- The *NuSTAR* Project also funds workshops and mentorship opportunities focused at minority serving institutions.

NuSTAR and IDEA

Community Engagement



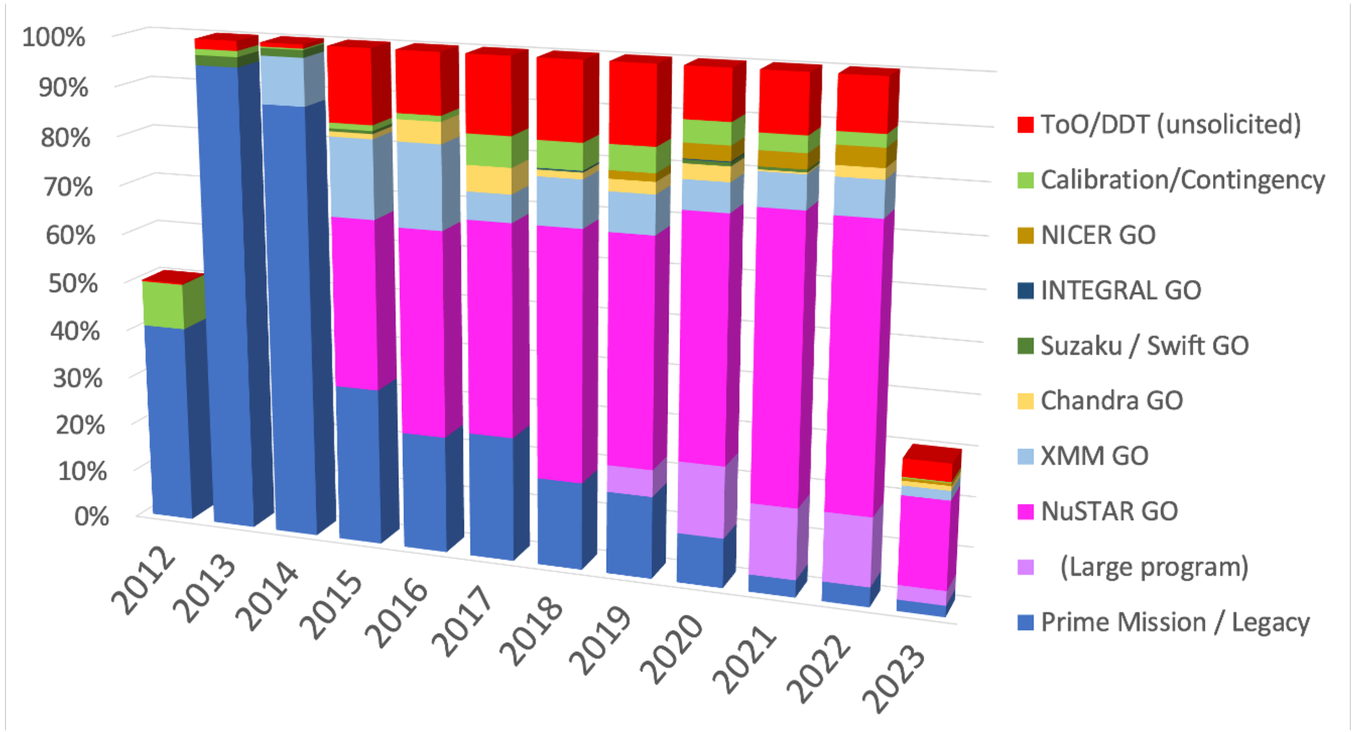
- *NuSTAR* regularly engages in activities to expand our user community:
  - Booths at conferences e.g., AAS, HEAD.
  - In April 2023, we had a special session at the APS, which is a new venue for the mission, to further expand the user community.
  - Regular public talks and community outreach activities.
  - Quickstart guides / tutorials for observers at institutions without a history of X-ray data analysis
- The *NuSTAR* group at Caltech hosts Summer Students through the SURF and WAVE programs for undergraduates and Summer Research Connections for high school students.
- Dual-Anonymous Peer Review (DAPR)
  - DAPR has been shown to expand the user community by removing unconscious bias from the review process.

Backup slides

NuSTAR Guest Observer Program

NuSTAR is a community observatory

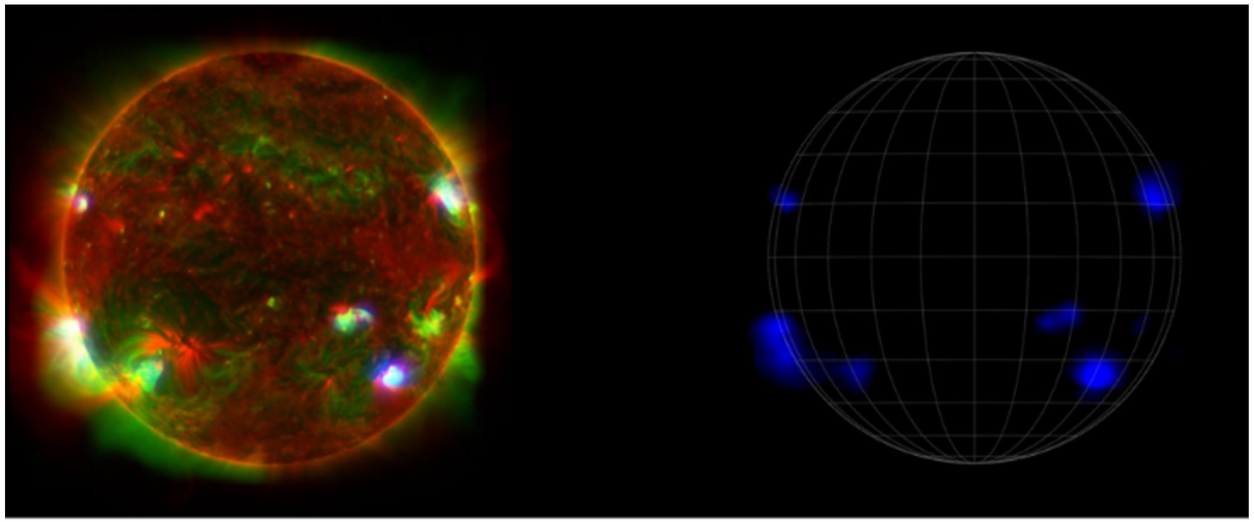
- Formal joint observing programs with *XMM-Newton, Chandra, NICER, Swift,* and *INTEGRAL*
- Best-effort joint programs with *IXPE*, *XRISM*, *JWST, HST,* and ground-based observatories including gamma-ray observatories and the Event Horizon Telescope.
- Currently over 50% of *NuSTAR* observations are coordinated with other observatories
- Over 25% of *NuSTAR* observations are in response to ToO triggers



Science Highlights from 2022/2023

“NASA’s NuSTAR Telescope Reveals Hidden Light Shows on the Sun”

- *NuSTAR* currently the only focusing hard X-ray observatory capable of imaging the Sun
- Complements dedicated solar observatories to extend study up to the hottest material in the solar corona
- Media coverage:
  - Number 1 story on JPL the week of release.
  - Accuweather interview on why a black hole machine is looking at the Sun



The Sun appears different depending on who’s looking. Wavelengths of light from three space observatories are overlapped to provide a unique view of the Sun in the image at left. The high-energy X-ray light detected by NASA’s NuSTAR is seen isolated at right; a grid was added to indicate the Sun’s surface. Credit: NASA/JPL-Caltech/JAXA

https://www.jpl.nasa.gov/news/nasas-nustar-telescope-reveals-hidden-light-shows-on-the-sun