ULTRASAT: A Wide-Field UV Space Telescope

Revolutionizing our view of the transient Universe

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System Engineer: Y. Yaniv (WIS)
Contracts/Finance: O. Alkaslasy (WIS)
SOC infrastructure: L. Ayubi (WIS)
SOC Software: C. Tishler (WIS)
Outreach: D. Polishook (WIS)
Admin: R. Baram (WIS)
Fin/Admin oversight: H. Atsits (WIS)

Funding partners
- ISA
- WIS
- DESY
- NASA

Industry partners
- IAI
- Ellop
- Tower
The study of Transient Cosmic Phenomena is taking Center Stage

An exciting frontier, many fundamental open questions

<table>
<thead>
<tr>
<th>Sources</th>
<th>Open questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collisions and mergers of stars</td>
<td>- Where did the heavy elements, from Iron to Gold and Uranium, form?</td>
</tr>
<tr>
<td></td>
<td>- How do black holes form?</td>
</tr>
<tr>
<td></td>
<td>- What is the current expansion rate of the Universe?</td>
</tr>
<tr>
<td>Explosive deaths of massive stars</td>
<td>- How do massive stars explode and affect their environment?</td>
</tr>
<tr>
<td>Tidal disruption of stars by super-massive black holes (SMBH)</td>
<td>- What is the SMBH “demographics”?</td>
</tr>
<tr>
<td></td>
<td>- How do they affect their environment?</td>
</tr>
<tr>
<td></td>
<td>- How is mass accreted onto BH?</td>
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<td>...</td>
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</table>
Why now?

Technology enables telescopes with very large fields of view, allowing a systematic study of transient events.
ULTRASAT will be unique and superior to all other missions

- ULTRASAT’s Unique capabilities
  - Very large (200 deg²) field of view
  - High UV (220-280nm) sensitivity: $f = 1.5 \times 10^{-3} \text{ ph/cm}^2 \text{ s} \ (900\text{s}, 5\sigma)$
    $[m = -2.5 \log_{10}(f/f_0) = 22.4]$  
  - Geo-stationary orbit

- UV advantages
  - Low sky background
  - Strong signals from hot sources
  - Unique information

- Transient detection rates of leading surveys

- Monitor an unprecedentedly large volume of the Universe
- New window in wavelength (NUV) and in cadence (min - mon).
- Real-time alerts to ground/space-based telescopes, initiate world-wide follow-ups.
## ULTRASAT: Science highlights

<table>
<thead>
<tr>
<th>Source Type</th>
<th># Events per 3 yr mission</th>
<th>Science Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supernovae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shock break-out and Early (shock cooling) of core collapse SNe</td>
<td>&gt;40 &gt;500</td>
<td>Understand the explosive death of massive stars</td>
</tr>
<tr>
<td>Superluminous SNe</td>
<td>&gt;250</td>
<td>Early evolution, shock cooling emission</td>
</tr>
<tr>
<td>Type Ia SNe</td>
<td>&gt;40</td>
<td>Discriminate between SD and DD progenitors</td>
</tr>
<tr>
<td>Compact Object Transients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emission from Gravitational Wave events: NS-NS and NS-BH</td>
<td>~25</td>
<td>Constrain the physics of the sources of gravitational waves</td>
</tr>
<tr>
<td>Cataclysmic variables</td>
<td>&gt;25</td>
<td>Accretion and outburst physics</td>
</tr>
<tr>
<td>Tidal disruption of stars by black holes</td>
<td>&gt;250</td>
<td>Accretion physics, black hole demographics</td>
</tr>
<tr>
<td>Quasars and Active Galactic Nuclei</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous UV lightcurves</td>
<td>&gt;7500</td>
<td>Accretion physics, BLR Reverberation mapping</td>
</tr>
<tr>
<td>Stars</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M star flares</td>
<td>&gt;4×10^5</td>
<td>Planet habitability, magnetospheres</td>
</tr>
<tr>
<td>RR Lyrae</td>
<td>&gt;1000</td>
<td>Pulsation physics</td>
</tr>
<tr>
<td>Nonradial hot pulsators, e.g., α Cyg, δ Scuti, SX Phe, β Cep etc. types</td>
<td>&gt;250</td>
<td>Asteroseismology</td>
</tr>
<tr>
<td>Eclipsing binaries</td>
<td>&gt;400</td>
<td>Chromosphere and eclipse mapping</td>
</tr>
<tr>
<td>Galaxies and Clusters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Sky Survey – galaxies</td>
<td>&gt;10^8</td>
<td>Galaxy Evolution, star formation rate</td>
</tr>
</tbody>
</table>
Key Science Goal 1: Mergers of Neutron Stars
The evolution of Massive stars: Some open questions

Massive Stars
\[ M \sim 10 \times M_{\text{sun}} \]

Burn H $\rightarrow$ He $\rightarrow$ C/O $\rightarrow$ Si $\rightarrow$ Fe

- Once nuclear energy source exhausted, collapse and explode as Supernova- How?
- Where were the elements beyond Fe produced?

Nuclear binding energy

“Dead” remnants of massive stars

- Neutron Star
  - \[ 1 \ M_{\text{sun}} \]
  - 10 km
  - \[ 10^{14} \text{g/cc} \]

- Black Hole
  - \[ 1 \ M_{\text{sun}} \]
  - 3 km
Merging Binary Neutron Stars / Black Holes

- Most stars “live” in binaries

- Massive star binaries may lead to the formation of binary Neutron Star / Black Hole systems

- “Tight” NS/BH binaries, separation < 1 Million km, can merge by emitting Gravitational Waves (GW).

- GW Detection- A fundamental test of GR (1916)
- 2016: LIGO detects a 2x 30 solar mass BH binary merger. Distance ~ 1 Billion light years
Detecting GW and light from NS-NS/BH mergers

- Nuclear density radioactive material torn and ejected at close to light speed. May be the source of heavy, “rapid neutron capture”, elements beyond Iron.

- Detecting light from radioactive material following GW is (one of) the major goals of astronomy in the coming decade:
  - Identify the origin of heavy elements
  - Study the properties of material at nuclear density
  - Accurately localize the merger, identify host galaxy → Measure the current expansion rate $H_0$ of the Universe
  - Identify environment → Constrain progenitor system
ULTRASAT Key Science Goal 1: GW sources

- Starting early 2025, GW detectors will improve detection horizon to ~ 1 Billion light years, provide ~ 10 NS-NS merger events per year, with ~100 squared degree error box. (Until then - a few in total.)

- EM detection- ULTRASAT:
  - Instantaneous >50% of sky in <15 min. (8 times better than ground based).
  - GW error box in a single image.
  - Sensitive out to ~ 1 Billion light years.

- EM detection in other bands-challenging:
  - X-rays: likely 1:100 (beamed).
  - Radio: ~1yr delay

Bright, Early (hr) UV emission expected
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Must be in space by 2025
First detection of GW from a NS merger [2017]

- Very nearby, 120 M light-yrs. Light detected after 0.5 day, Very UV bright

- ULTRASAT is far superior to other searches:
  - GW error box covered in single image, vs search over ~$10^3$ galaxies at 1B light-yrs.
  - EM detection in other bands-challenging. X, γ: GW170817 NOT detectable 200M l-yrs.
  - IR, Radio: Challenging and late detection.

- Heavy elements beyond Iron – produced.
  - How heavy (Germanium or Gold) – uncertain.
  - More detections, with earlier light detection, are required.
  - Early UV has unique discriminating power.
First detection of GW from a NS merger [2017]

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  - Early UV has unique discriminating power.

Strong support to ULTRASAT
Key science goal 2: Deaths of Massive stars

- Supernova mechanism not understood.
- Key to progress:
  - Identify the “initial conditions”, which stars explode as which SNe?
  - So far- a handful of associations: pre- vs post- explosion high-res. galaxy images

- An alternative- Early, <1d, UV emission carries unique signatures of the progenitor (“erased” at later time):
  - Progenitor type (size, envelope composition),
  - Explosion properties,
  - Pre-explosion evolution.
SN explosions: ULTRASAT’s uniqueness

ULTRASAT
- High quality early UV data,
  Rapid alerts for follow-ups.
- Determine progenitor and environment
  properties for all, including rare, SN types.

[Image]

Current data

ULTRASAT data
(simulated)

[Graphs and diagrams]

[Ganot et al. 16]

[Rubin et al. 16]
Science goal: Planet habitability

- UV flares and Coronal Mass ejections around prime candidate stars for terrestrial planet searches (M-dwarfs/young Solar analogues)
  - Severely limit habitability,
  - May allow prebiotic chemistry,
  - May produce false positive biomarker signatures
    \( \text{(O}_3 \text{ from photo-dissociation of H}_2\text{O & CO}_2) \).

- Flares dominate UV output. Flare rates unknown.

- ULTRASAT will monitor \(~10^6\) stars
  - Determine NUV flare frequency and luminosity distribution
    as functions of both spectral subclass and stellar rotation period,
  - Determine best habitable planet candidates (e.g., from TESS)
    for expensive spectroscopic bio-marker searches, e.g. by JWST.
ULTRASAT: Implementation & Collaboration

Spacecraft: IAI

Telescope: Elop/Elbit

Hosted launch to GEO (GTO): NASA
Launch Q4 2024, >3 year science mission

Dimentions: 1.5 x 1.1 x 3.0 (m³)
Power: 300 W
Mass: 400 + 500 (Prop) kg

Focal Plane Array ("Camera"): DESY/Helmholtz
Sensor: Tower

Ø 670 mm
~ 1600 mm
ULTRASAT: Mission profile

- **ALL SKY SURVEY**
  - 3hr/day during the first 6 months
  - 7x deeper than state-of-the art (GALEX) (23 AB limiting mag @ |b|>30°)

- **LONG STARES**
  - 2 directions near the Ecliptic poles, minimize Galactic extinction and zodiac bgnd
  - Real-time data download and analysis
  - Alerts within 15min of observations

- **Targets of Opportunity (ToO’s)**
  - Instantaneous >50% of the sky in <15 min for >3 h
  - No limit on ToO number, except for max 75 with negative power balance (~15%)
  - Continuous transmission to the ground
Spacecraft & Telescope
S/C Configuration

S/C Overview

- Sun Sensors
- Telescope
- Solar Panel
- Propulsion System
- LHP Radiator
- BUS Structure
- Helium Tank
- Payload Structure
- Star Trackers
- Baffle + TCD
- OMNI Tx and Rx (X2)
- APM1
- APM2
Telescope & Camera Requirements

- 220-280nm Sensitivity 1.5x10^{-3} ph/cm^2s (900s, 5\sigma)
  Over a field of view of 170 deg^2

- Translates to requirements* on
  Optics - FOV 170 deg^2
  - PSF (Point Spread Function) < 15”
  - Out-of-band suppression <4x10^{-3}
  Detector - QE 70%
  - Dark current < 0.03 e^-/s (cool to 200 °K)
  - Read noise < 3.5 e^- 
  Baffle - Stray light suppression < 2 \times 10^{-11}
  - Cosmic-ray e^- suppression (Cerenkov) < 0.15

*Partial list
Telescope: Main Components

- Baffle
- Schmidt Corrector
  - Reduce Spherical aberration
  - 33 cm clear aperture
  - Fused Silica & CaF$_2$ (tandem)
- Mirror
  - 50 cm
- Field Flattener lens
  - Reduces Field Curvature
- Detector Assembly

- Added after PDR
  - Out-of-band filter at FF
  - Focus mechanism at FF
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1st CaF$_2$ Blank

Hellma Materials
Effective PSF (model): Meets requirements

Source: Blackbody T=20,000 [K]
Optics coatings & Filters (Measured): Meets out-of-band attenuation requirements
Focal Plane array: Main characteristics

- BSI CMOS from TowerJazz (4 tiles aligned to < 50 μm)
- High UV QE using high-K dielectric coating, optimized anti-reflection coating
- Ramon Space support for space qualified design (e.g., radiation hardness)

<table>
<thead>
<tr>
<th>Sensor main Specs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosensitive surface</td>
</tr>
<tr>
<td>Pixel size</td>
</tr>
<tr>
<td>Operation waveband</td>
</tr>
<tr>
<td>Mean QE in Operation band</td>
</tr>
<tr>
<td>Operation temperature</td>
</tr>
<tr>
<td>Dark current @ 200 °K</td>
</tr>
<tr>
<td>Readout mode</td>
</tr>
<tr>
<td>Readout time</td>
</tr>
<tr>
<td>Readout noise @ High-gain</td>
</tr>
<tr>
<td>Electronic cross-Talk</td>
</tr>
<tr>
<td>Pixel sampling scheme</td>
</tr>
<tr>
<td>Low-gain Well capacity</td>
</tr>
<tr>
<td>High-gain Well capacity</td>
</tr>
<tr>
<td>Bits per Pixel – total (data only)</td>
</tr>
</tbody>
</table>
“Scouts” QE (Measured): Meets requirements
Sensitivity: Meets requirements

$\mathcal{f} = 1.5 \times 10^{-3} \text{ ph/cm}^2 \text{ s} \ (900\text{s}, \ 5\sigma)$

$m = -2.5 \log_{10}(\mathcal{f}/\mathcal{f}_0) = 22.4$

- Optics: Model
  Will be measured on ground

- Coatings, filters, QE: Measured
  (samples & scouts)
Ground station
and
Science Operation Center (SOC)
Purpose:
➢ The ULTRASAT Science Operation Center (SOC) will support all scientific aspects of the ULTRASAT mission

Objectives:
➢ Observation operations (Plan and schedule, ToOs, Decontamination)
➢ Interface to IAI Ground Control Segment
➢ Image and Data processing
➢ Scientific Data Products archiving
➢ Ultrasat Alerts generation
➢ Data Accessibility (multiple products, access methods and permissions, WEB)
➢ External Interface to DESY/LSST/NASA etc.
SOC Architecture
Science Operation Center

Location:
- The SOC will be located at WIS
  - Start operations in the current building
  - New building: Dedicated area, including visiting auditorium
- Planning and development phase initiated

SOC development project:
- Top-level requirements and development plan were defined
- Image processing development on-going
Supporting the ULTRASAT Mission
WIS ground-based optical follow up programs
Supporting the ULTRASAT Mission
WIS Observatory in Neot Semadar

LAST - The Large Array Survey
Telescopes: Photometry

<table>
<thead>
<tr>
<th># of Telescopes x Aperture</th>
<th>48 x 11”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optration Band</td>
<td>Visible: 400 – 850nm</td>
</tr>
<tr>
<td>FoV – Aperture:</td>
<td>7.4 sq. degrees / 1.5m</td>
</tr>
<tr>
<td>Narrow Field of View</td>
<td></td>
</tr>
<tr>
<td>FoV – Aperture:</td>
<td>~355 sq. degrees / 28cm</td>
</tr>
<tr>
<td>Max Field of View</td>
<td></td>
</tr>
<tr>
<td>Exposure Time</td>
<td>15sec</td>
</tr>
</tbody>
</table>

LAST Spec: Spectroscopy

<table>
<thead>
<tr>
<th># of Telescopes x Aperture</th>
<th>18 x 24”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optration Band</td>
<td>Visible: 400 – 850nm</td>
</tr>
<tr>
<td>Effective Aperture</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Low Spectral Resolution</td>
<td>( \Delta \lambda = 20\text{Å} ) ( (1000 \text{ km s}^{-1}) )</td>
</tr>
<tr>
<td>High Spectral Resolution</td>
<td>( \Delta \lambda = 0.25\text{Å} ) ( (15 \text{ km s}^{-1}) )</td>
</tr>
</tbody>
</table>
Supporting the ULTRASAT Mission
Spectroscopy @ Chile

**SOXs**

Spectroscopy at Magellan: G-CLEF

<table>
<thead>
<tr>
<th>Telescope</th>
<th>ESO 3.8m</th>
<th>6.5 m Magellan Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New Technology Telescope</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Operation Band</strong></td>
<td>VIS-NIR: 360nm − 2.1µm</td>
<td>VIS-NIR: 350nm − 950nm</td>
</tr>
<tr>
<td><strong>Spectral Resolution</strong></td>
<td>Δλ = 20Å (1000 km s⁻¹)</td>
<td>Δλ = 0.04Å (2.2 km s⁻¹)</td>
</tr>
</tbody>
</table>
Program management
Implementation Organization

(*) Steering committee: ISA, WIS, HH/DESY, PI

Science Board
Mission PI
Working groups 1-12

Outreach Program

Science Operation Center

Executive board
ISA, WIS, DESY
Program Office
Manager- Udi Netzer

DESY
Elbit/ELOP
IAI/Mabat
Launch NASA (TBD)

TowerJazz

(*) All future Agencies providing substantial support will be part of the Steering Committee.
<table>
<thead>
<tr>
<th>Topic</th>
<th>Subsystem</th>
<th>When</th>
</tr>
</thead>
<tbody>
<tr>
<td>TowerJazz - Detector supplier</td>
<td>Camera</td>
<td>March 2020</td>
</tr>
<tr>
<td>Focus mechanism</td>
<td>Telescope</td>
<td>March 2020</td>
</tr>
<tr>
<td><strong>Direct to GEO → GTO</strong></td>
<td><strong>Spacecraft / Launcher</strong></td>
<td><strong>July 2020</strong></td>
</tr>
<tr>
<td>CaF2 lenses</td>
<td>Telescope</td>
<td>October 2020</td>
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<tr>
<td>G5 optical model</td>
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<tr>
<td>Propulsion system</td>
<td>Spacecraft</td>
<td>November 2020</td>
</tr>
<tr>
<td>UV ARC selection</td>
<td>Camera</td>
<td>February 2021</td>
</tr>
<tr>
<td>Model plan (EM, EQM, PFM)</td>
<td>Camera/Telescope/Spacecraft</td>
<td>February 2021</td>
</tr>
<tr>
<td>Wafer post processing and die packaging</td>
<td>Camera</td>
<td>February 2021</td>
</tr>
<tr>
<td>Filter addition</td>
<td>Telescope</td>
<td>June 2021</td>
</tr>
</tbody>
</table>
Major Project Decisions Since Kickoff (Sep 19)

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<tr>
<td>packaging</td>
<td>Telescope</td>
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</table>

Budget & Timeline impact

- **Direct to GEO → GTO**
  - Cost increase (propulsion system & re-design). Risk identified, partners committed to extra-cost at kickoff.
  - 6 Month launch delay- does not affect arrival time at GEO slot.

- **Filter addition**
  - Approx. 2 mon delay.
# Program Timeline

<table>
<thead>
<tr>
<th>Mile Stone</th>
<th>ARO + Month</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kick off</td>
<td>0 (23 September 2019)</td>
<td>“Q4” 2019</td>
</tr>
<tr>
<td>SRR</td>
<td>3</td>
<td>Q1 2020</td>
</tr>
<tr>
<td>SDR</td>
<td>6</td>
<td>Q2 2020</td>
</tr>
<tr>
<td>PDR</td>
<td>16</td>
<td>Q1 2021</td>
</tr>
<tr>
<td>CDR</td>
<td>27</td>
<td>Q4 2021</td>
</tr>
<tr>
<td>Supply of Camera</td>
<td>39</td>
<td>Q4 2022</td>
</tr>
<tr>
<td>Supply of Payload</td>
<td>49</td>
<td>Q4 2023</td>
</tr>
<tr>
<td>DRB</td>
<td>59</td>
<td>Q3 2024</td>
</tr>
<tr>
<td>Launch</td>
<td>63</td>
<td>Q4 2024</td>
</tr>
</tbody>
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Financing Principles

- ISA: 2/3 of S/C and Payload, Operational costs, outreach program
- WIS: 1/3 of S/C and Payload, Scientific mission, Data Center, Program Management, outreach, education program
- DESY: Camera, Scientific participation
- NASA: Launcher, Scientific participation

- Program overall cost approx. $105M
Risks

• Challenging time line
• Complex Interfaces
• Contamination prevention and control
Outreach & Education
High-school physics students:
• In collaboration with Schwartz/Reisman Science Education Center
• A dedicated “30% program” for matriculation exams in physics:
  ➢ “hands-on” work with data - understanding and explaining the observed universe
  ➢ Science questions studied by ULTRASAT (e.g., the Universe expansion rate)
• Two pilot programs - fall semester of 2021

Public outreach - young students and general public (jointly with ISA):
• In collaboration with Davidson Institute of Science Education as a “flagship project”
• Preliminary program includes, e.g.:
  ➢ Visits at the Science Operation Center
  ➢ Scientists on-line, teaching the teachers, “theater” productions-podcasts, Youtube short videos
  ➢ Small scale traveling exhibition to be presented in malls/schools/community centers
A Science Driven Collaboration

- 12 Science Working Groups - WG members receive real time data access
  Open to all (and already including most) Israeli astronomers

- NASA Launch contribution-
  Science return: 8 US PIs (NASA funded) in WG’s

- DESY Camera contribution-
  Science return: 3 DESY PIs in WG’s

- LSST collaboration – advanced negotiations
  - Joint LSST/ULTRASAT alerts
  - Real time access to LSST data for Israeli astronomers
    Science return: US PIs in WG’s
ULTRASAT: Impact

- Provide groundbreaking high profile science with a small, affordable satellite.

- Put Israel at the forefront of Observational Astrophysics.

- Put Israeli industry at the forefront of a global movement to explore the Universe with small, affordable satellites.

- Enhance international collaborations with leading Agencies and Industries. NASA are joining an Israeli led Science project.

- Draw Israeli students to science and technology studies. Education & Outreach program in construction.
Backup
Why now?

Technology enables telescopes with very large fields of view, allowing a systematic study of transient events.

- Optical (LSST), Radio (LOFAR, SKA)
- X/γ-ray (Fermi, AstroSat, SVOM; HAWC, CTA, LHAASO)
- Gravitational Waves (LIGO, Virgo)
- ν (IceCube, KM3NeT)

• Missing: UV
Gravitational Waves

Electro-Magnetic Transmitter
Accelerating electric charge (dipole) \( \rightarrow \) EM Wave

Receiver
Accelerating electric charge

Gravitational “Transmitter”
Accelerating mass (Quadrupole) \( \rightarrow \) GW

Gravitational Antenna
Accelerating mass
Detecting Gravitational Waves: The Challenge

- Predicted by Einstein’s theory of gravity in 1916
- Challenge: \( \frac{dL}{L} = 10^{-21} \)
First direct detection of Gravitational Waves [2016]

• 2016:
  LIGO detects a 2x 30 solar mass BH binary merger.
  Distance ~ 1 Billion light years
  \[ h = \frac{dL}{L} \approx \frac{R_s}{d} = 10^{-21} \frac{M/10M_{Sun}}{d/1G \text{ light-yr}} \]
  \[ f \approx \frac{c}{2\pi R_s} = 1 \frac{1}{M/10M_{Sun}} \text{ kHz} \]

• 2017 Physics Nobel Prize (Weiss, Barish, Thorne).
GW detector network timeline

LIGO
- O1: 80 Mpc
- O2: 100 Mpc
- O3: 105-130 Mpc
- O4: 160-190 Mpc
- O5: Target 330 Mpc

Virgo
- O1: 30 Mpc
- O2: 50 Mpc
- O3: 90-120 Mpc
- O4: 150-260 Mpc

KAGRA
- O1: 8-25 Mpc
- O2: 25-130 Mpc
- O3: 130+ Mpc

LIGO-India
- O5: Target 330 Mpc
Key science goal 2: Deaths of Massive stars

• Early UV/opt.: status.
  - A handful of (late, low-quality) RSG explosions.
  - Space UV (lucky) detection of 1 SN Ib: R=10^{11}\text{cm}; \text{He} + \text{C/O} \text{envelope}; \text{E/M}
  - A handful of type Ia non detections: R_* < 4\times10^{9}\text{cm} \rightarrow \text{White Dwarfs.}

• Current data
  - Validate models,
  - Direct constraints on compact progenitors,
  - Demonstrate potential.

• ULTRASAT:
  - >100/yr, <1d, high quality UV,
    Map all (including rare) SN types.
  - Rapid alerts for follow-ups.

[Bloom et al. 11, Maoz et al. 14]

[Ganot et al. 16]

[Bloom et al. 11, Maoz et al. 14]
SN explosions: ULTRASAT’s uniqueness

ULTRASAT is an order of magnitude more powerful discovery machine than any other survey

ULTRASAT will map all (including rare) SN types

Why UV?

$\text{t} \ (T=1 \ eV) \rightarrow R_*$

Recombination at $T < 1 \ eV$

$\rightarrow$ no optical peak, structure degeneracy

[Rubin et al. 16]
S/C Configuration

- Baffle
- 200K radiator
- Lightband interface
- Tank

- Cover
- Omni Ant
- Sun Sensor
- Solar Array
- Ant Gimbal + HGA
ULTRASAT Optical Design Guidelines

• Challenges:
  o Limited materials with high transmission in the UV, namely CaF₂, Fused Silica and Sapphire.
  o High slope of dispersion curve at shorter wavelengths.

• A modified Schmidt telescope:
  o CaF₂ and Fused silica work in tandem to minimize chromatic aberrations.
  o Meniscus corrector plates before telescope pupil to balance aberrations across the FoV.
  o A Field Flattener pair to correct primary mirror focal plane curvature.

• Sapphire Filter
  o High rejection of out-of-band wavelength requires >1000 layers.
  o Requires a stiff substrate to avoid stresses (i.e., localized changes in the wavefront).
  o Use of high index of refraction sub-micron layers of HfO₂ annealed at high temperatures.
  o Unique cut along the crystal to minimize Birefringence takes into account the telescope fast beam.
Design Considerations

• Short Focal Depth
  o A theoretical 20 um
  o High Stability needed

• Thermal Gradients
  o First lens exposed to outer space
  o Thermal analysis accuracy

• Focus Mechanism
  o FF vs Mirror

• Contamination
  o Particular and molecular
  o High absorption coefficient
Camera components

- Sensor
- Flex cables
- Package
- Heat spreader
- Mounting interface
- Spider
- Bolts
- Heat pipe
- DA box

ULTRASAT
Ultraviolet Transient Astronomy Satellite

6/17/2021 Project Status Overview
Camera time line

- **11/2018**: ‘Can DESY do a UV space camera?’
- **07/2019**: ‘Yes we can!’ – budget secured
- **09/2019**: Program Kick off
- **01/2020**: System Requirements Review
- **03/2020**: System Design Review
- **12/2020**: Preliminary Design Review
- **01/2021**: Prototypes characterized (ARC selection), sensor designed and in production.

- Team of 11 FTE in full swing
- Space expertise build-up with new hires, DLR cooperation, external international advisory board
- Time line in particular in Corona times the single most challenging aspect!

Test sensor at the optical-lab
Anti-reflection coatings (ARC) for QE optimization
Chromatic PSF
Effective PSF
Ground Station

- Terminal @ IAI/MBT GEO Ground Station
  - Command & Control, Telemetry Processing
  - Immediate ToO tasking
  - Receive imagery data, deliver to WIS (SOC)
- High-rate Ku communication
- Perform ranging for orbit determination

5Mbps Downlink (5-10 MHz) Ku Band

Mission Planning

Telemetry

Image Reception

Comm

Downlink data

CMD

Raw Image

Tasking

SOC