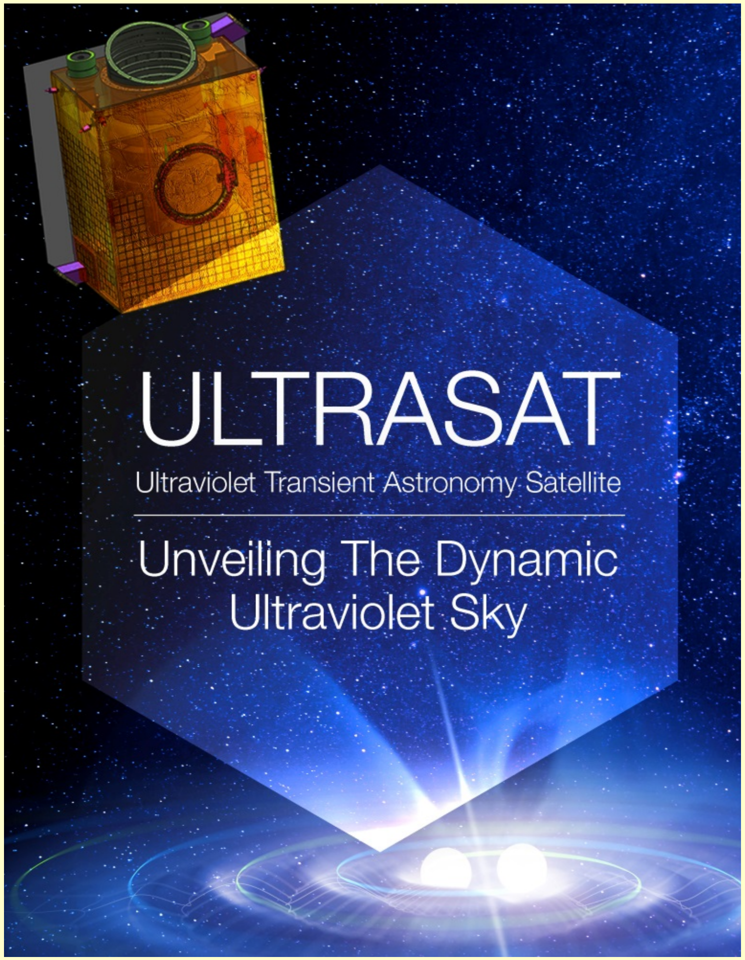
ULTRASAT: A Wide-Field UV Space Telescope



ULTRASAT will

Revolutionize our view of the transient Universe

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Funding partners
ISA
WIS
DESY
NASA
ESA

Industry partners
IAI
Elop
Tower

Transient Astronomy is taking center stage

- An exciting frontier, Many fundamental open questions

Sources	**Open questions**
NS-NS/BH mergers	Where in the Universe are the heavy elements produced? What are the properties of matter at nuclear density? What is the evolution path of massive binary stars? What is the current expansion rate of the Universe?
Supernova explosions	How do massive stars explode and affect their environment? What is the pre-explosion evolution & mass loss?
Tidal disruption of stars by super-massive BH	What is the SMBH "demographics"? How do they affect their environment? How is mass accreted onto BH?
…	…

Transient Astronomy is taking center stage

- Technology developments enable

- Wide Field of View surveys:
  Optical (LSST), Radio (LOFAR, SKA),
  X/γ-ray (Fermi, AstroSat, SVOM; HAWC, CTA, LHAASO).

- Non-EM ("Multi-Messenger Astronomy") detectors:
  GW (LIGO, Virgo)
  ν (IceCube, KM3NeT)

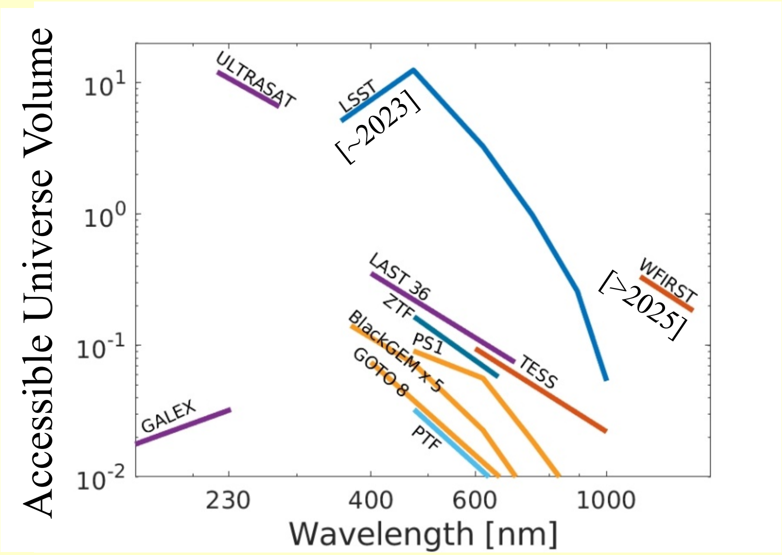
- Open questions + WFOV & MMA
  "Time domain astronomy" is an "area of unusual discovery potential" (Decadal Survey)

- Missing: UV.

Transient Astronomy is taking center stage

Field of View	200 deg^2
Band	220-280 nm
Cadence	900 (3x300) s
Limiting mag	22.3 (5σ, 900s)
PSF, pixel #	<13", 100Mpxl
Alert distribution	<20 min
ToO	>50% of sky in <15min for >3hr

Transient detection rates of leading surveys



- New window in wavelength (NUV) and in cadence (min).
- Drive vigorous ground-based follow-up programs.
- Potential serendipitous discoveries.

ULTRASAT: Science highlights

Source Type		# Events	Science Impact
Supernovae			
	Shock break-out and Early (shock cooling) of core collapse SNe	>30 >400	Understand the explosive death of massive stars
	Superluminous SNe	>200	Early evolution, shock cooling emission
	Type Ia SNe	>30	Discriminate between SD and DD progenitors
Compact Object Transients			
	Emission from Gravitational Wave events: NS-NS and NS-BH	~20	Constrain the physics of the sources of gravitational waves
	Cataclysmic variables	>20	Accretion and outburst physics
	Tidal disruption of stars by black holes	>200	Accretion physics, black hole demographics
Quasars and Active Galactic Nuclei			
	Continuous UV lightcurves	>6000	Accretion physics, BLR Reverberation mapping
Stars			
	M star flares	$>3\times10^5$	Planet habitability, magnetospheres
	RR Lyrae	>800	Pulsation physics
	Nonradial hot pulsators, e.g., α Cyg, δ Scuti, SX Phe, β Cep etc. types	>200	Asteroseismology
	Eclipsing binaries	>300	Chromosphere and eclipse mapping
Galaxies and Clusters			
	All Sky Survey – galaxies	$>10^8$	Galaxy Evolution, star formation rate

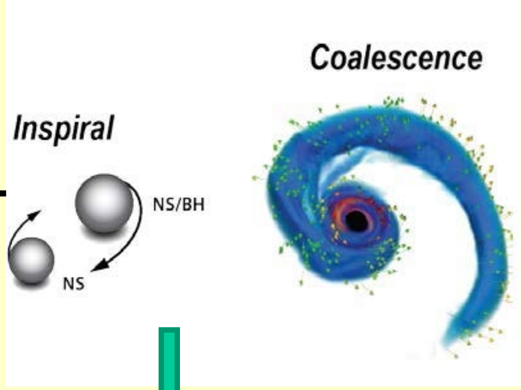
Binary Neutron Star mergers

- Emit detectable Gravitational Waves, allowing tests of General Relativity
- Eject neutron rich material, possible sources of the heaviest elements
- Enable tests of matter properties at nuclear density

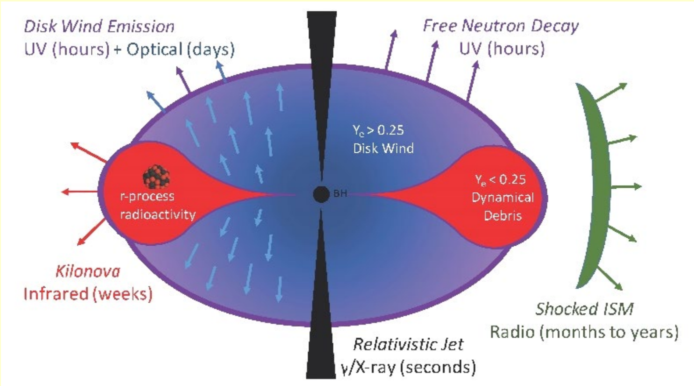
- Detection of Electro-Magnetic "afterglows" is crucial to:
  - Identify heavy elements,
  - Determine matter properties,
  - Identify the host galaxy and measure the Universe expansion rate,
  - Identify the environment and constrain progenitors paths.

NS-NS/BH merger

GW ←



Neutron rich radioactive ejecta



HE γ's, ν's ?

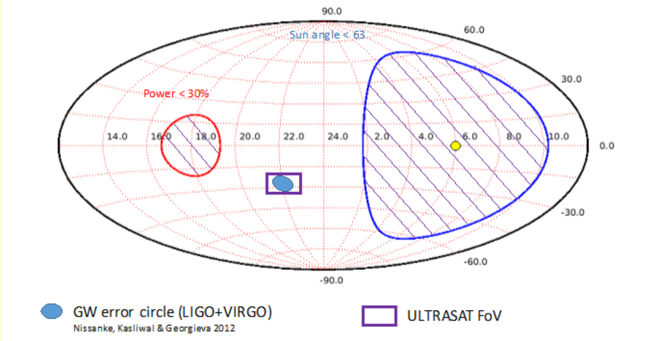
ULTRASAT Key Science Goal 1: GW sources

- NS-NS merger GW triggers expected
  <~2023 (O4):
  a few, 150 deg^2 error box, d ~ 150 Mpc
  >~2024 (O5):
  ~10/yr 100 deg^2 error box, d ~ 300 Mpc.

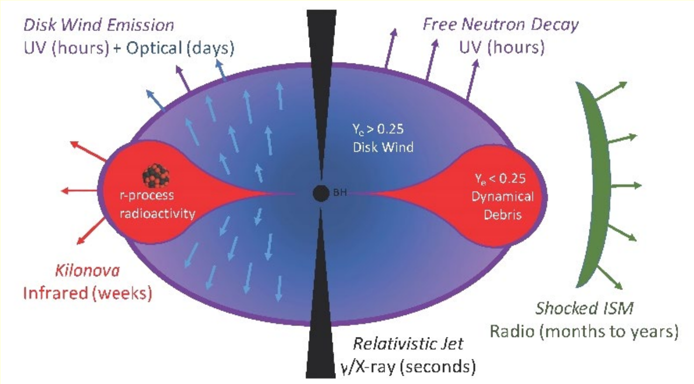
- EM detection- ULTRASAT:
  - Instantaneous >50% of sky in <5 min.
    (8 times better than ground based).
  - GW error box in a single image.
  - Sensitive out to ~300 Mpc

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

ULTRSAT's ToO access



Bright, Early (hr) UV emission expected



Must be in space by 2024

GW 170817: NS merger at 40 Mpc, Provides strong support to ULTRASAT

- Bright UV, T(0.5 day) = 10,000 K
  ULTRASAT's horizon: >300 Mpc.

- ULTRASAT is far superior to other searches:
  - Identifying EM by searching over all galaxies within GW error volume- prohibitive, ~10^3 galaxies at 200 Mpc.
  - EM detection in other bands-challenging.
    X, γ: GW170817 NOT detectable >60 Mpc.
    IR, Radio: Challenging and late detection.

- The inferred ejecta structure & composition are uncertain.
  - Early UV measurements crucial for discriminating between ejecta models.

PRL 119, 161101 (2017) PHYSICAL REV

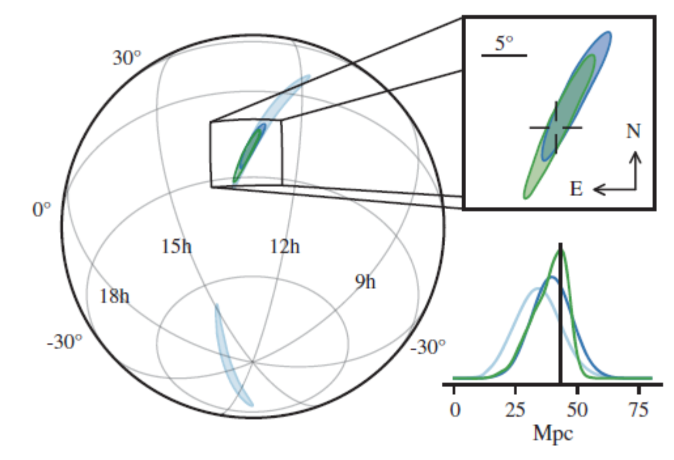
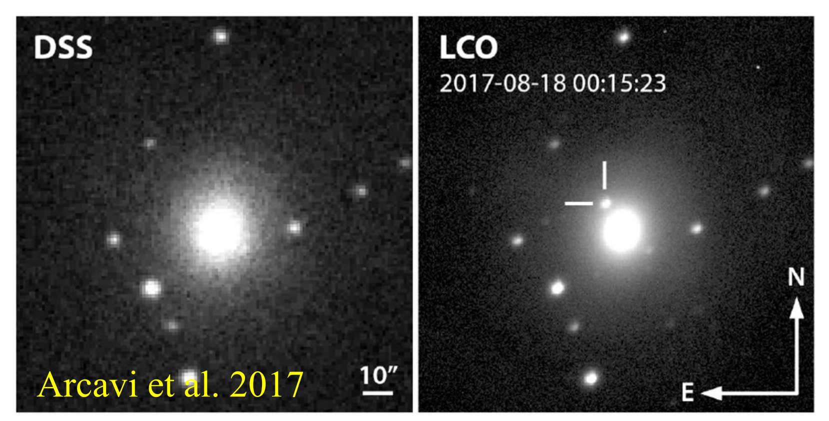


FIG. 3. Sky location reconstructed for GW170817 by a rapid



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. host galaxy images).

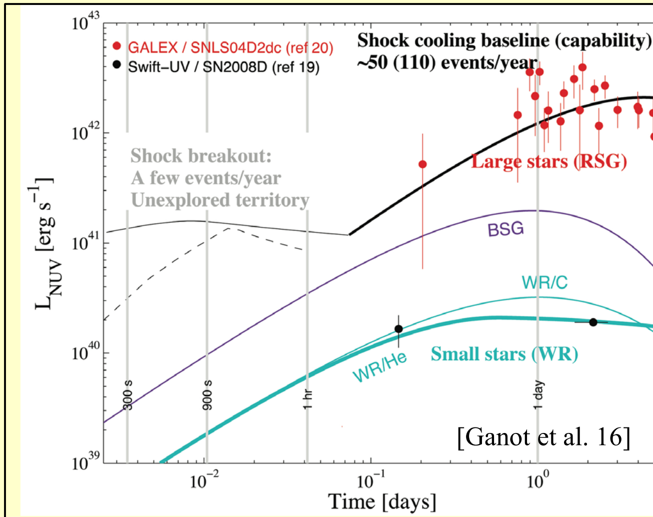
- An alternative- Early, <1d, UV emission
  carries unique signatures of the progenitor ("erased" at later time):
  Progenitor type (size, envelope composition),
  Explosion properties,
  Pre-explosion evolution.

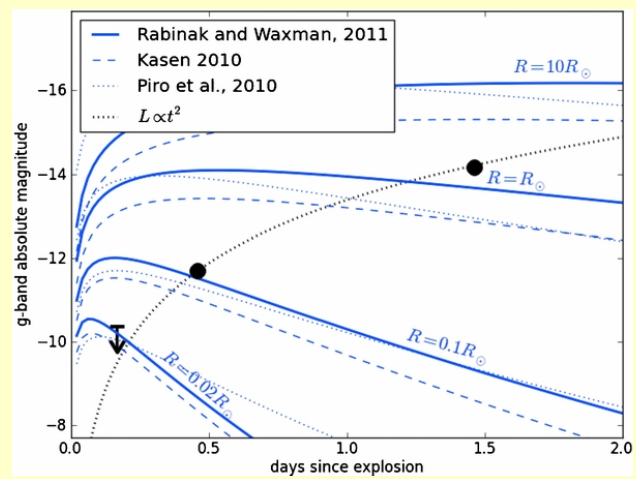
Key science goal 2: Deaths of Massive stars

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

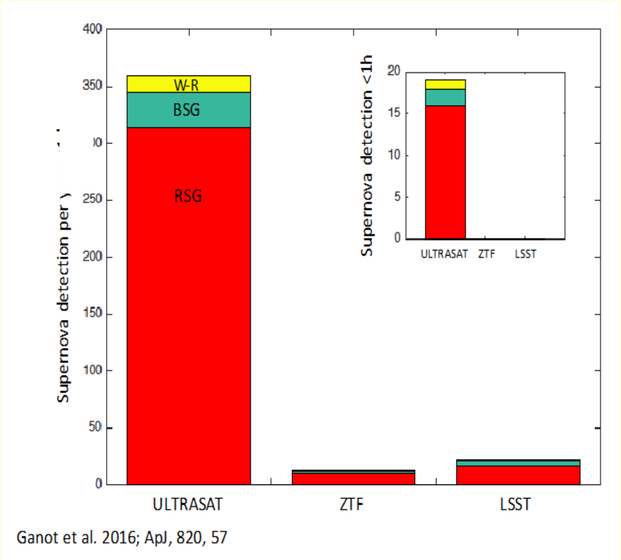




[Bloom et al. 11, Maoz et al. 14]

SN explosions: ULTRASAT's uniqueness

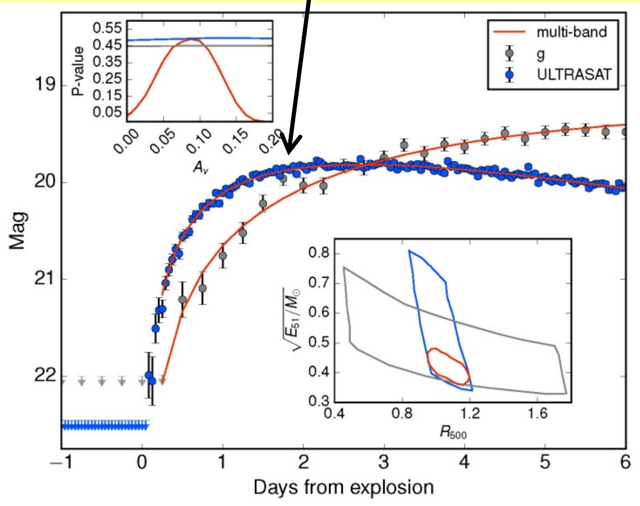
ULTRASAT is an order of magnitude more powerful discovery machine than any other survey



ULTRASAT will map all (including rare) SN types

Why UV?

t (T=1 eV) → R_*



[Rubin et al. 16]

Recombination at T < 1 eV

→ no optical peak, structure degeneracy

Additional science goal: Planet habitability

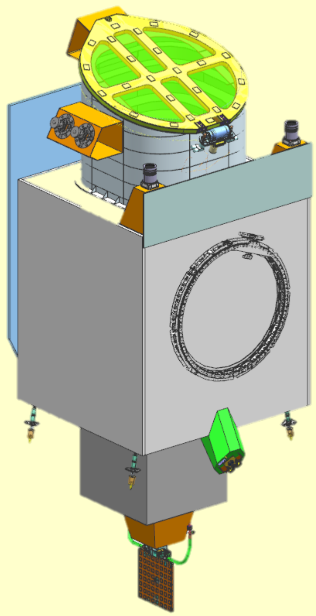
- UV flares and Coronal Mass ejections around M-dwarfs/young Solar analogues
  - Severely limit habitability,
  - May allow prebiotic chemistry
  - May produce false positive biomarker signatures (O_3 from photo-dissociation of H_2O & CO_2).

- Flare rates unknown.

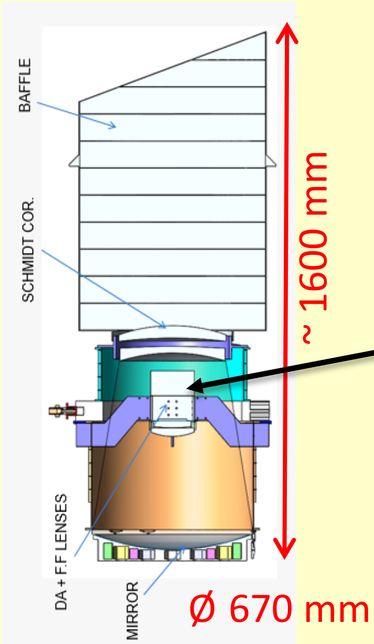
- ULTRASAT will monitor ~10^6 stars,
  - Determine NUV flare frequency and luminosity distribution as functions of both spectral subclass and stellar rotation period,
  - Determine best habitable planet candidates (e.g., from TESS) for expensive spectroscopic bio-marker searches, e.g. by JWST.

ULTRASAT: Implementation & Partners

Spacecraft: IAI



Telescope: Elop/Elbit



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

Sensor: Tower

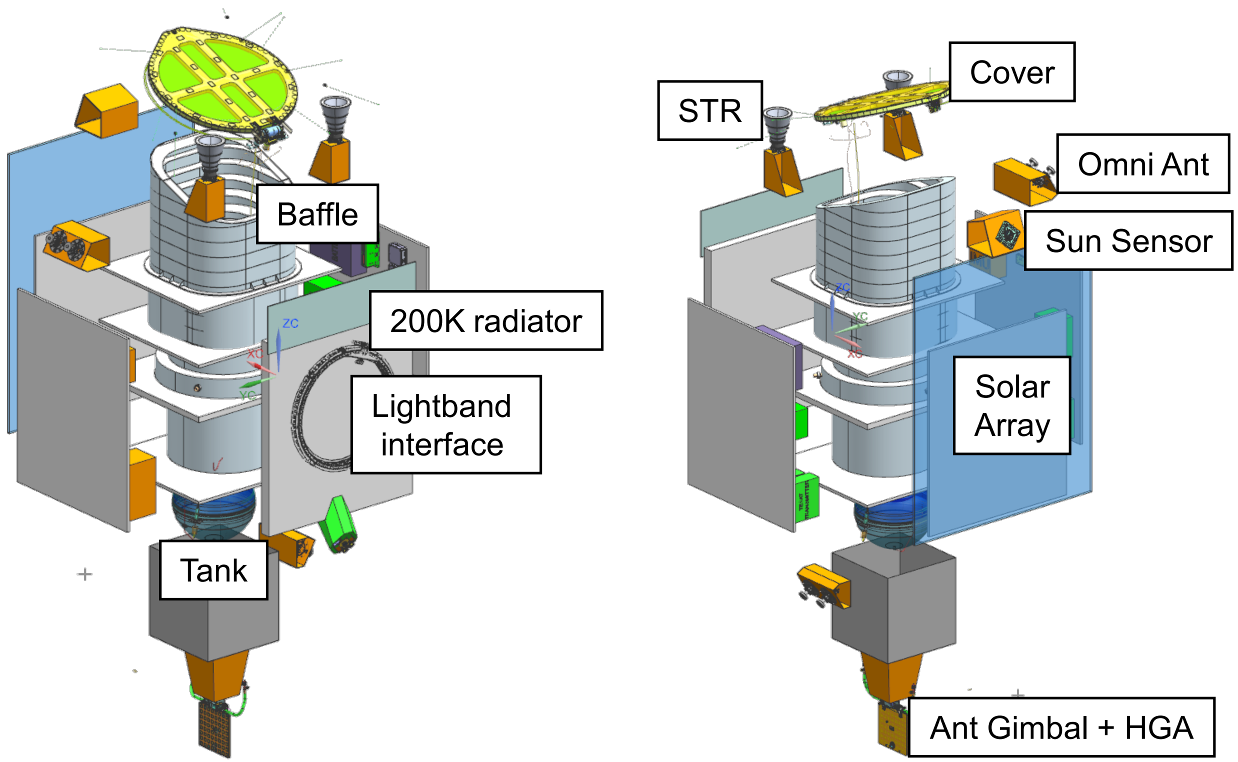
Components contribution: ESA

Hosted launch to GEO(/GTO): NASA

Launch Q2 2024, >3 year science mission

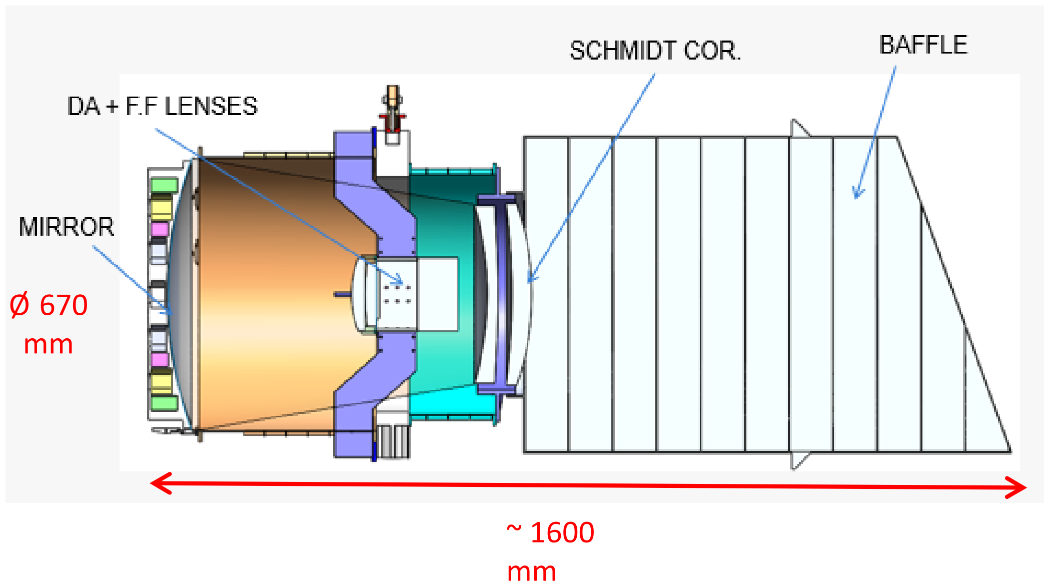
Dimentions: 1 x 1 x 1.7 (m^3)
Power: <300 W
Mass: <300 kg

S/C Configuration



Telescope Main Components

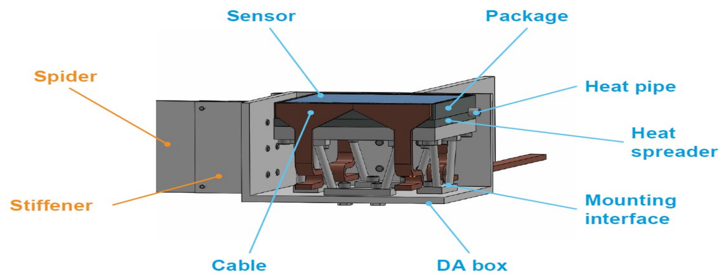
- Baffle
  - Reduce stray light
  - Cerenkov Radiation Suppression
- Schmidt Corrector
  - Reduce Spherical aberration
  - 33 cm clear aperture
  - Fused Silica & CaF_2
- Detector Assembly
  - Developed By DESY
- Field Flattener lens
  - Reduces Field Curvature
- Mirror
  - 50 cm



Overview

- Developed and supplied by DESY
- BSI CMOS from TowerJazz
  - 4 quarters ("graceful degradation")

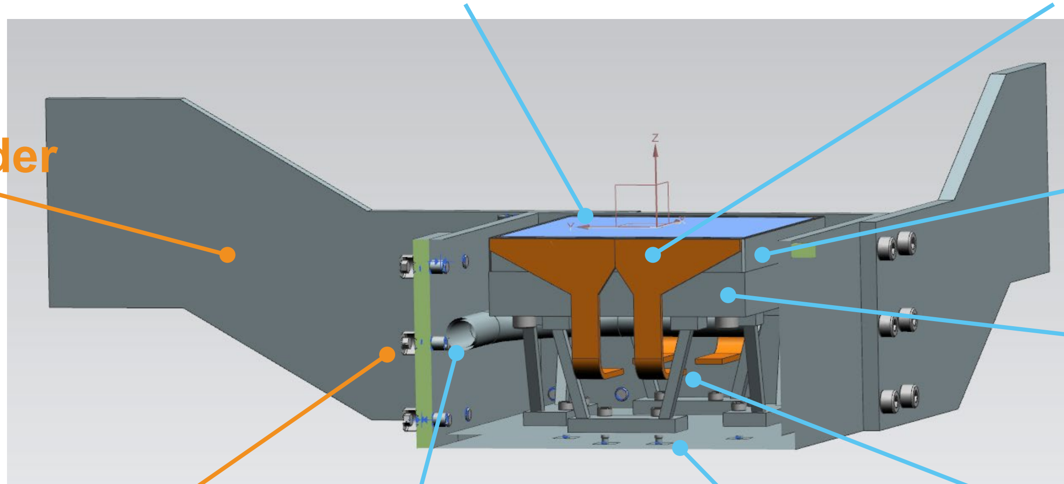
    OR
  - Single die, two-halves electronically
- Optimized UV QE using high-K dielectric coating
- Ramon Space support for space qualified design (e.g., radiation hardness)



Sensor main Spec.

Photosensitive surface	90x90 mm
Pixel size	9.5 µm
Operation waveband	220-280nm
Mean QE in Operation band	>70%
Operation temperature	200±5 °K
Dark current @ 200 °K	<0.03 e^-/sec
Readout mode	Rolling shutter
Readout time	<25 sec
Readout noise @ High-gain	<3.5 e^-/pixel
Electronic cross-Talk	<0.01%
Pixel sampling scheme	HDR capability
Low-gain Well capacity	140-155 Ke^-
High-gain Well capacity	16-21 Ke^-
Bits per Pixel – total (data only)	14 (13)

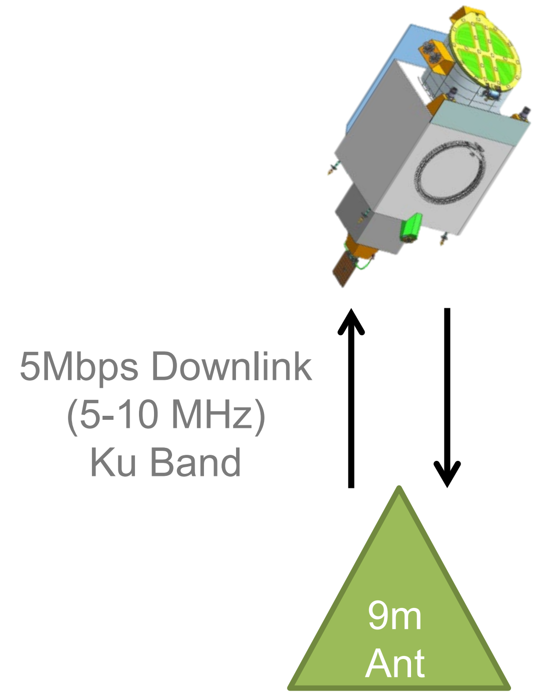
Camera components



ELOP
DESY

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



ULTRASAT: Mission profile

- ALL SKY SURVEY

  3hr/day during the first 6 months

  23 AB limiting mag (|b|>30°), 7x deeper than the GALEX

- LONG STARES

  2 directions near the Ecliptic poles, minimize Galactic extinction and zodiac bgnd

- ToO's

  Instantaneous >50% of the sky in <5 min for >2.5 h

  No limit on ToO number, except for max 75 with Sun angle > 144° (13%)

  Continuous transmission to the ground , except for 13% of ToOs

  (Sun angle <85°; data storage followed by repointing and downlink)

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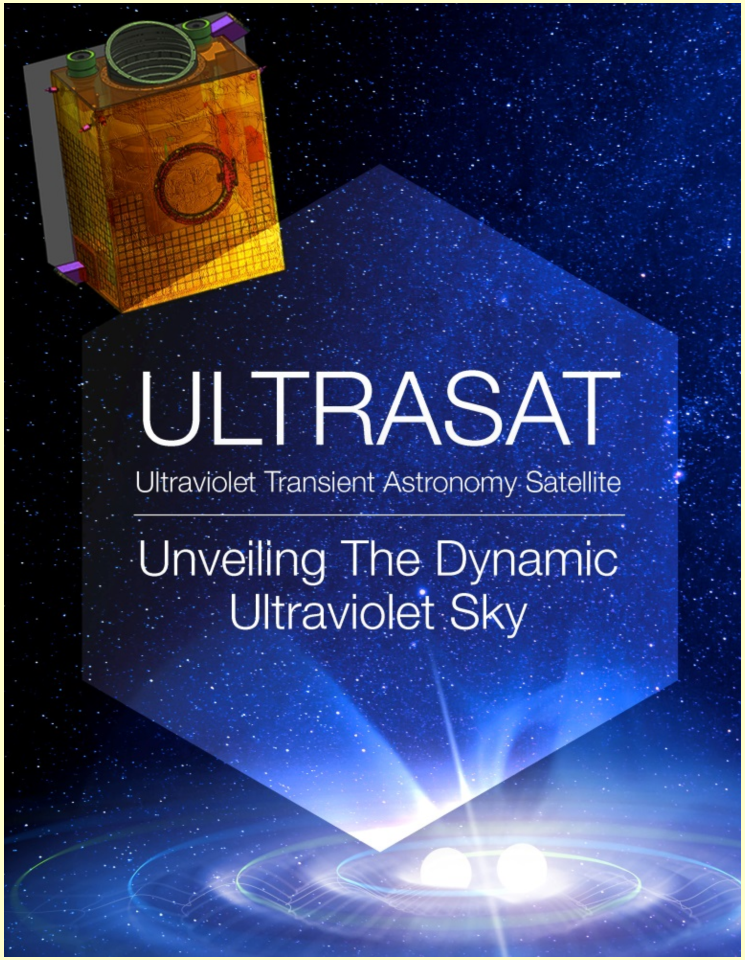

ULTRASAT will

- **Revolutionize our view of the transient Universe**
- **Have a broad science impact across**
  - **Gravitational Wave sources**
  - **Explosions of massive stars**
  - **Stellar disruptions by black holes**
  - **Planet habitability**
- **Lead the study of some of the most important astrophysics questions of the coming decade**