

Electro-magnetic transient surveys: A key to progress in High Energy ν astronomy

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IceCube's extra-Galactic ν 's: What we have learned

~ 50 TeV – ~ 3 PeV

- The energy production rate density in the local universe in ~ 100 TeV ν 's and in $>10^{10}$ GeV CRs is similar: $\sim 10^{44}$ erg/Mpc³yr ($\Phi \approx \Phi_{\text{WB}}$):
Suggests that
 - ν 's and HE CRs produced by the same sources;
 - HE CR sources reside in “calorimetric” environments, most likely star-forming galaxies, where 1(E/Z) PeV CRs lose all their energy to pion]

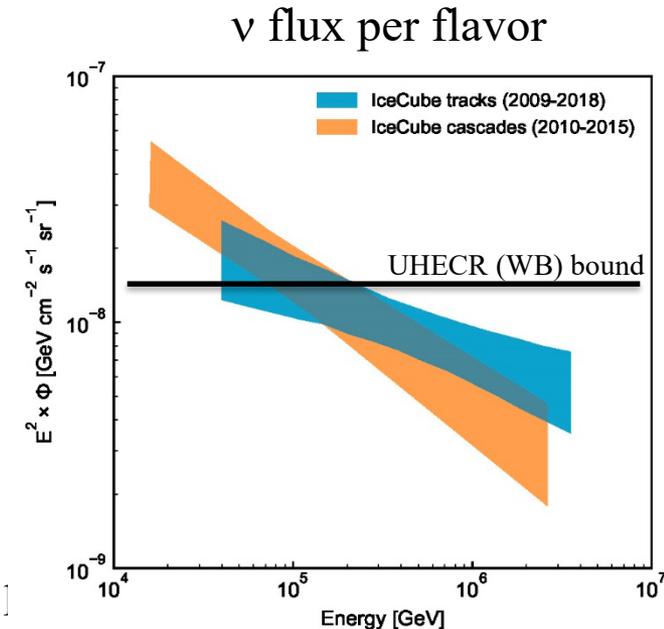
- No “point sources” (multiple event sources) identified.

Flux dominated by many weak sources: $n_s > 10^{-7}/\text{Mpc}^3$, $L_\nu < 10^{42.5}$ erg/s.

~ 20 TeV

- $\Phi \approx 2\Phi_{\text{WB}}$ and is in tension with the 100 GeV γ background.

Suggests the existence of “hidden sources”, from which only (mainly) ν 's escape.



The key goals of HE ν astronomy

- Identify the sources of (very) HE cosmic-rays,
- Provide unique constraints on models of HE astrophysical sources,
- Possibly: Study ν /fundamental physics.

The detection of high energy (HE) extra-Galactic neutrinos by IceCube demonstrates the potential for achieving these goals.

Fulfilling the potential relies on the electromagnetic identification of the neutrino sources.

Extra-Galactic ν 's: What we are missing

10 TeV – 10 PeV

- The sources have not been identified.
 - Indication ($<3\sigma$) for an association with one blazar, and one SFR/AGN galaxy.
[Blazar association (Buson et al.)- some caveats & inconsistencies remaining.]
 - Blazars may contribute to, but cannot dominate, the flux.
- The spectrum measurement is crude.
 - A single power-law or multiple “breaks”?
- The flavor ratio measurement is crude.
 - Consistent with 1:1:1.

$10^8 - 10^{10}$ GeV

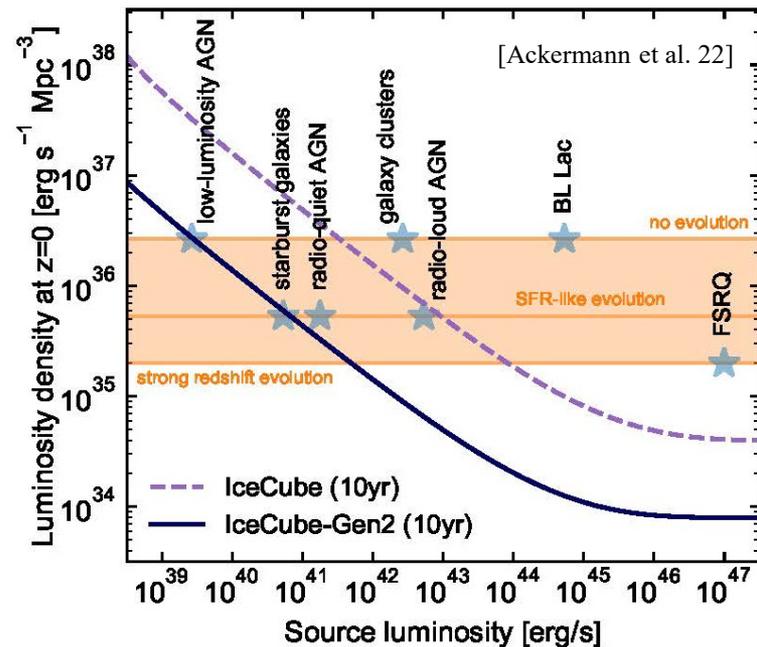
- A flux measurement (10^{-9} GeV/cm²s sr) will constrain the UHE CR composition.

Identifying the sources: An order of magnitude increase in the detected ν number is required

- Measured flux implies a ($z=0$) luminosity density $n_s L_\nu \approx 10^{43.5} \text{erg/Mpc}^3 \text{yr} = 10^{36} \text{erg/Mpc}^3 \text{s}$.
- $$N(\text{multiple tracks}) = 1 \left(\frac{\zeta}{3}\right)^{-\frac{3}{2}} \left(\frac{n_s}{10^{-7} \text{Mpc}^{-3}}\right)^{-\frac{1}{2}} \left(\frac{A}{1 \text{km}^2}\right)^{\frac{3}{2}}$$

$$\Rightarrow n_s > \frac{10^{-7}}{\text{Mpc}^3} \left(\frac{A}{1 \text{km}^2}\right)^3, \quad L_\nu < 10^{42.5} \text{erg/s},$$

$$N(\text{all sky}) > 10^6.$$
- Rare bright sources (eg “blazars”)- Ruled out as the dominant sources.



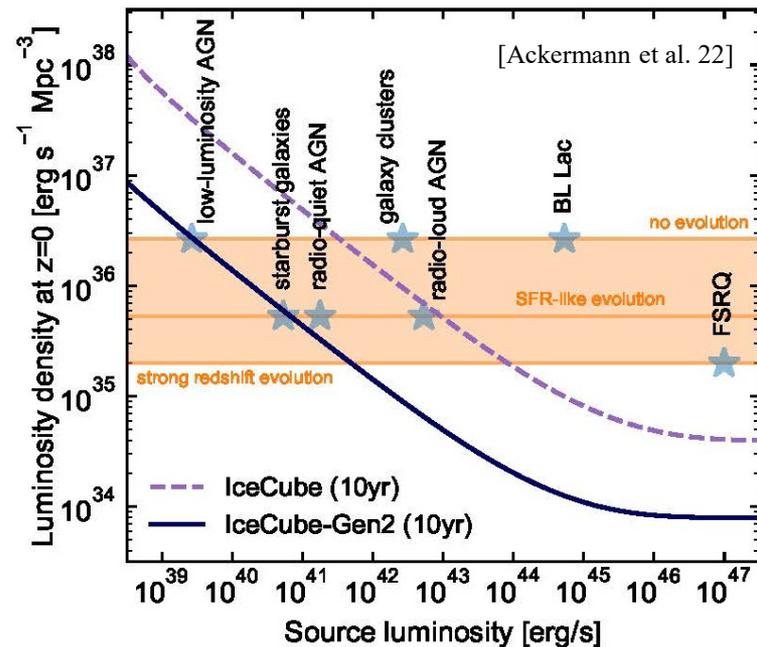
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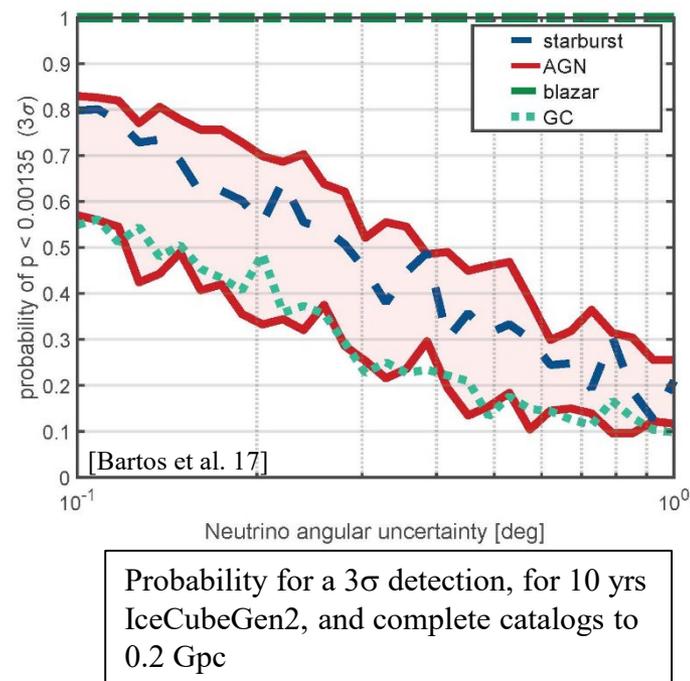


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Can we make progress towards source identification before this is achieved (in ~2040)?

Source identification by angular correlation with EM source catalogs: Unlikely.

- ν track direction uncertainty ~ 1 deg,
50% of ν 's produced beyond $z \approx 1$, $d_L \approx 5$ Gpc,
 $\gg 1$ sources/deg².
- Can we look only at nearby sources, with lower angular sky density?
 - $\approx 5\%$ of ν 's produced by sources at $d < 0.5$ Gpc
→ Only a handful of track events from $d < 0.5$ Gpc sources.
 - Catalogs are highly incomplete already at 0.2 Gpc.



Can the sources be identified by temporal correlation with X/ γ -ray flares?

- Coincident transient ν /EM detection increases the significance of an angular association, for transient duration $\Delta t \ll T \sim 1\text{yr}$. ($\Delta t \sim$ months- minor improvement.)
- The absence of neutrino point sources:

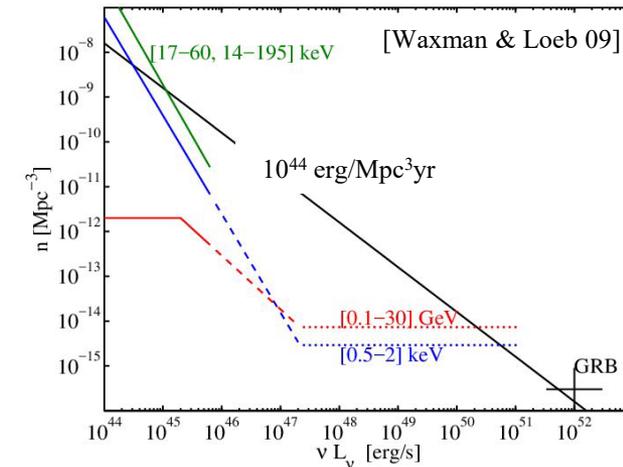
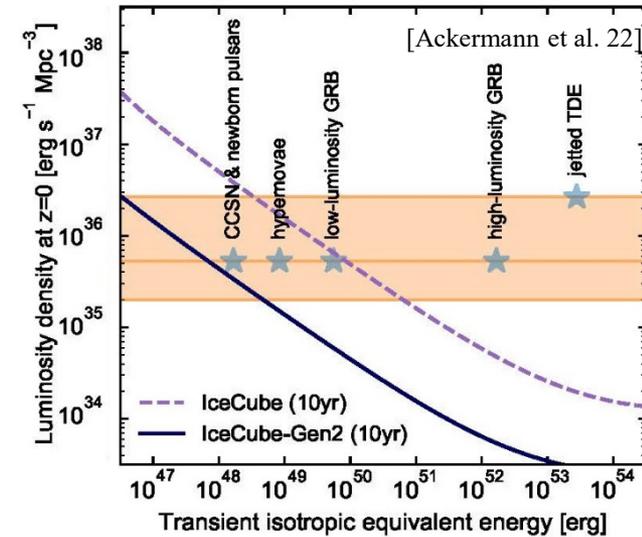
$$\dot{n}_S = \frac{n_S}{T} > \frac{10^{-7}}{\text{Mpc}^3\text{yr}}, \quad E_\nu = L_\nu T < 10^{50}\text{erg}.$$

The number of active X/ γ -ray flares:

$$L_\gamma < 10^{45}\text{erg/s} \quad (\text{assuming } L_\nu \leq L_\gamma).$$

The required sensitivity:

$$f_\gamma < \frac{10^{44}\text{erg/s}}{4\pi(1\text{Gpc})^2} = 10^{-12}\text{erg/cm}^2\text{s}.$$



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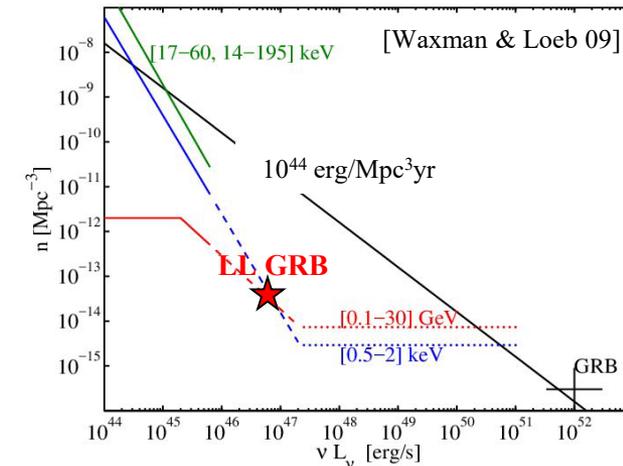
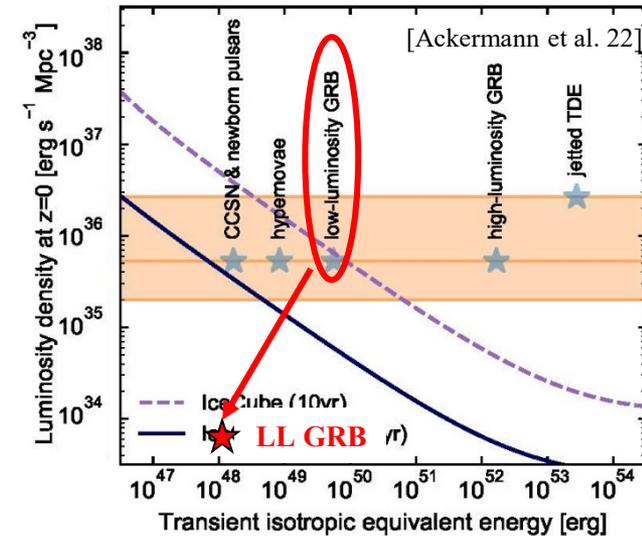
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For LL GRBs to produce the observed ν flux, they need to produced 100 times more energy in ν's than in γ's.

This is not supported by any observation.



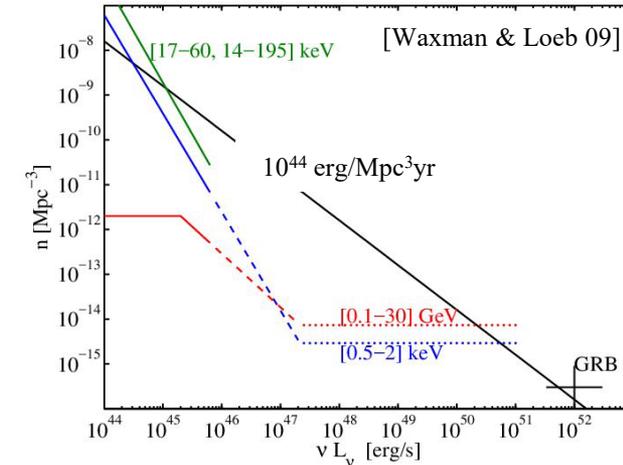
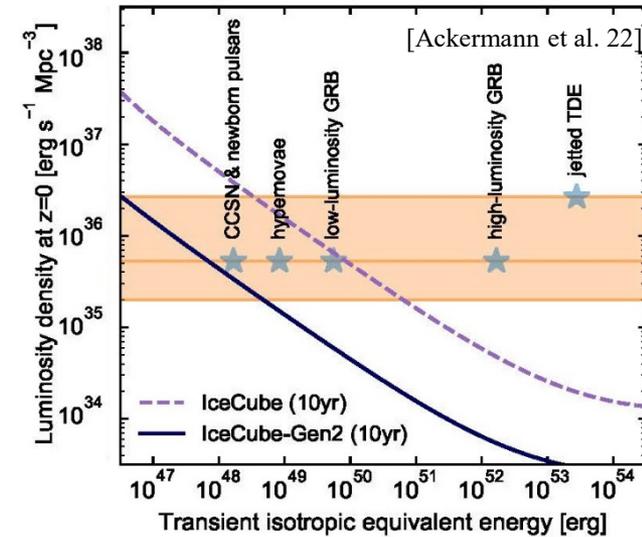
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- $\Delta t < 1 \text{ min}$ – Requires very wide FOV EM detectors for simultaneous observations.
 - BAT/GBM $\sim 1\text{MeV}$ sensitivity $\sim 10^{-8.5} \text{ erg/cm}^2\text{s}$, corresponding to 10^{48}erg/s at 1 Gpc.
 - Far from required sensitivity.
 - Fermi LAT $\sim 1\text{GeV}$ sensitivity $\sim 10^{-12} \text{ erg/cm}^2\text{s}$ for 1yr integration.
 - LHAASO sub TeV ($\tau_{\gamma\gamma}=1$ for 0.3 TeV @ 1Gpc) sensitivity $\sim 10^{-11} \text{ erg/cm}^2\text{s}$ for 1yr integration.
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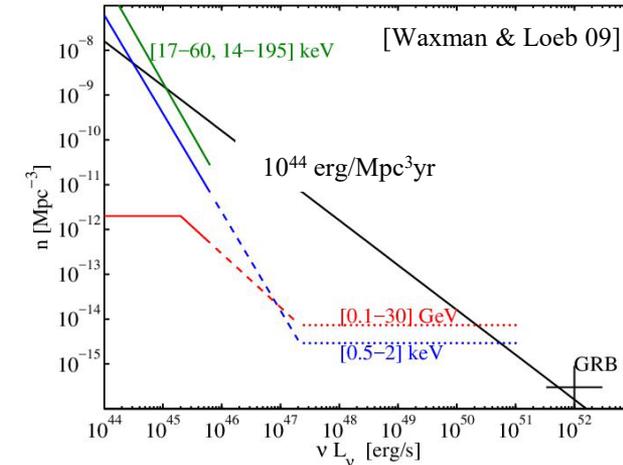
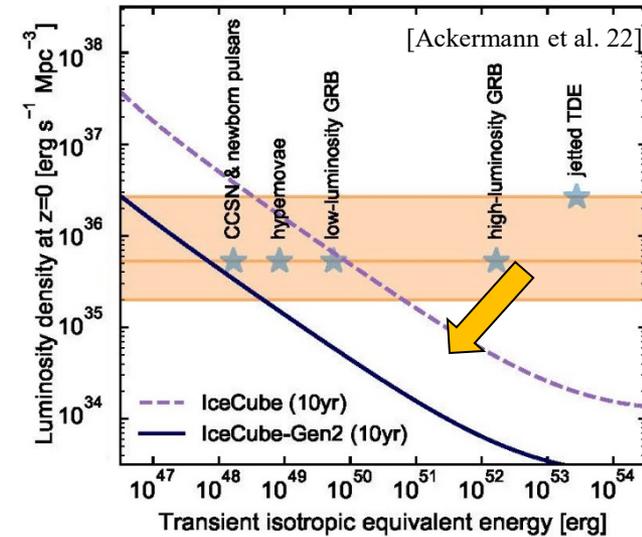
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- Very bright transients, GRBs/TDE-jets, may be detectable. However, they contribute up to $\sim 1\%$ of the flux, i.e., up to $\sim 1 \nu$.



The number density of active X/ γ -ray flares

Can the sources be identified by temporal correlation with X/ γ -ray flares? Possibly in X-rays, if bright.

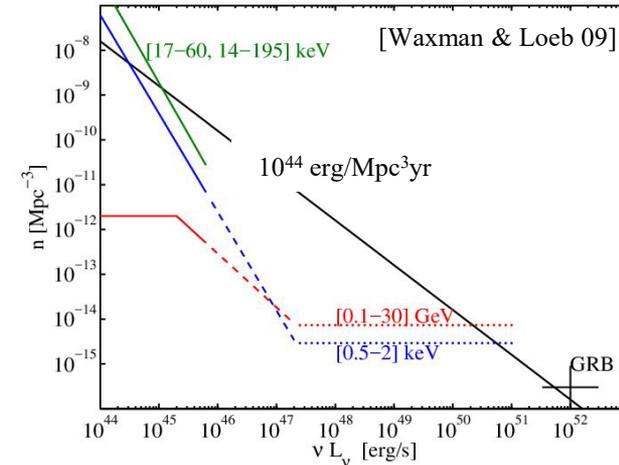
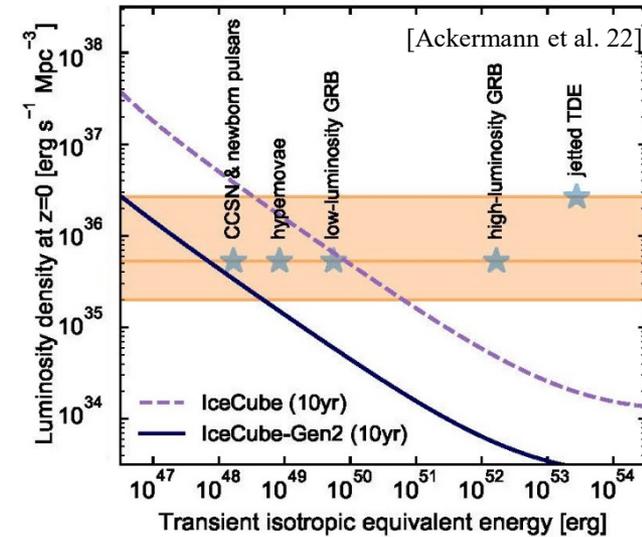
- The required sensitivity:

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- $\Delta t \sim 1 \text{ hr} - 1 \text{ d}$: Allows slewing $\sim 1\text{deg}$ FOV detectors.

- XRT $\sim 1\text{keV}$ 3hr sensitivity $\sim 10^{-13} \text{ erg/cm}^2\text{s}$,
 \rightarrow A few transients may be detected, if bright enough.
 (NuStar FOV 10').

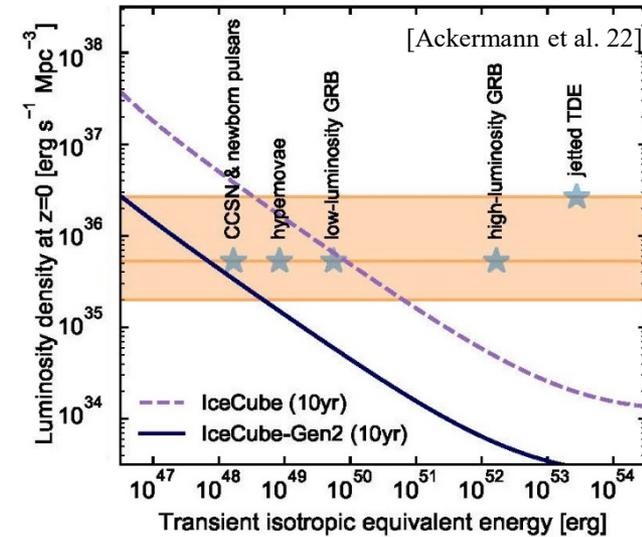
- CTA (sub-TeV) 50 hr sensitivity $\sim 10^{-12} \text{ erg/cm}^2\text{s}$,
 \rightarrow Marginal.
 (HESS/MAGIC less sensitive).



The number density of active X/ γ -ray flares

Can UV/Optical transient surveys help identify the sources? Possibly.

- $\Delta t < 1$ min – Requires very wide FOV EM detectors.
Not sensitive enough.
- $\Delta t \sim 1$ hr -1 d: Allows slewing.
Requirements:
 - FOV > 1 deg²,
 - Sensitivity much better than 10^{-13} erg/cm²s.SWIFT UVOT – 0.1 deg², 5×10^{-15} erg/cm²s (10⁴s).



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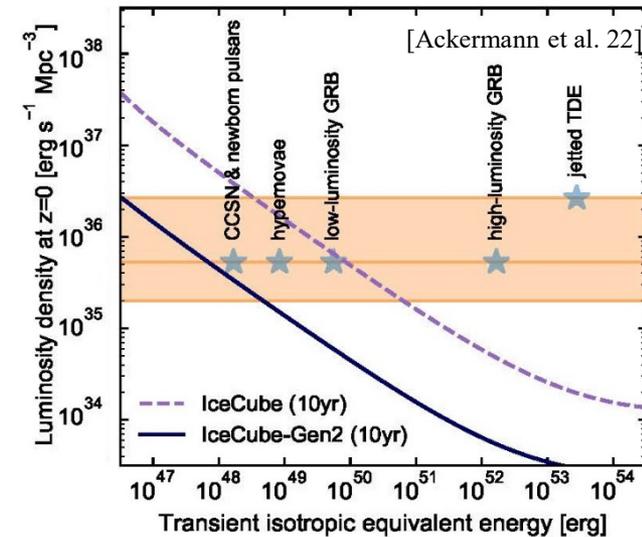
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- Many candidate sources are expected to be UV bright.
 - Supernovae: Jet driven explosions,
(LL GRBs),
Ejecta – Circumstellar Medium interaction,
 - Tidal disruption events.

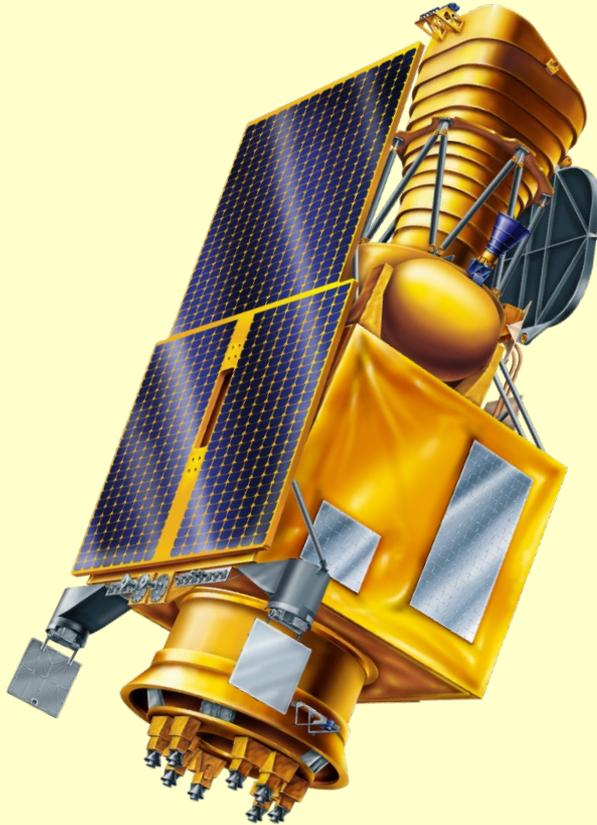


A handful of ν - γ associations for the nearest, yet quite distant – 0.5 Gpc, sources, will not enable a systematic detection and study of the transient sources.

Sensitive wide FOV UV/Optical surveys are key for systematic study and understanding.

ULTRASAT: A Wide-Field UV Space Telescope

Revolutionize our understanding of the hot transient Universe



PI	E. Waxman (WIS)
Program Manager	U. Netzer (ISA/WIS)
Deputy PI	A. Gal-Yam (WIS)
Camera PI	D. Berge (DESY)
Project Scientist	Y. Shvartzvald (WIS)
Science Lead	E. Ofek (WIS)
Payload Lead	S. Ben-Ami (WIS)
Technology Lead	O. Lapid (WIS)

Funding partners	Industry partners
ISA	IAI
WIS	Elop
NASA	Tower
DESY	

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ULTRASAT's uniqueness

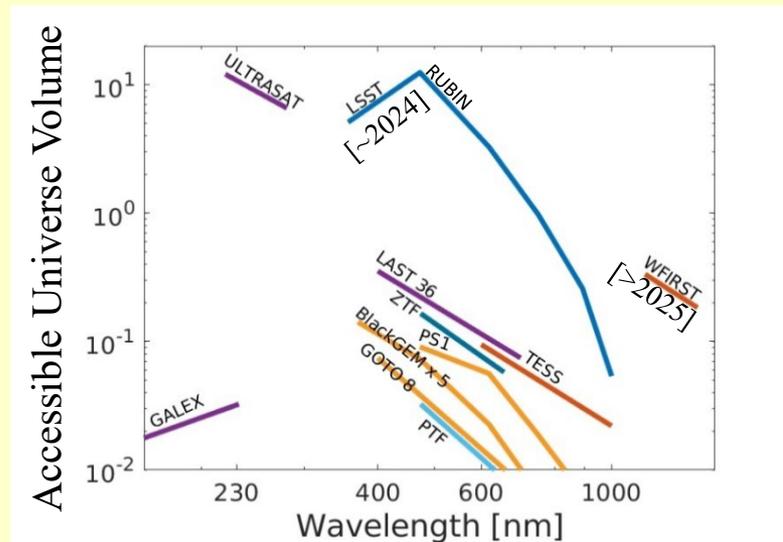
Key Properties

- Very large, 200 deg², field of view.
- High UV (230-290nm) sensitivity:
 1.5×10^{-3} ph/cm² s (900s, 5 σ)
[m = 22.4],
 3×10^{-15} erg/cm² s (10⁴s).

Key Capabilities

- Monitor an unprecedentedly large volume of the Universe.
- New window in wavelength (NUV) and in cadence (minutes - months).
- Real-time alerts to ground/space-based telescopes (GEO orbit), initiate world-wide follow-ups.
- ToO: Instantaneous >50% of the sky in <15 min for >3 hr.

Transient detection rates of leading surveys



ULTRASAT: A broad science impact

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

ULTRASAT: Key Science Goals

EM counterparts to GW sources

Starting (late) 2025: GW detectors will identify

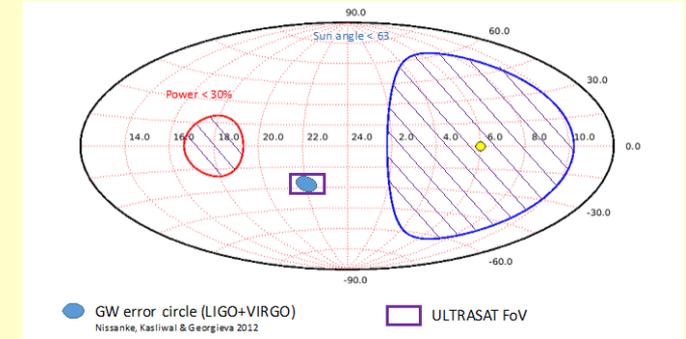
~10 NS-NS events/yr, ~100 deg² error box.

- Fast localization of NS-NS/BH mergers:
Rapid, <15min, access to >50% of sky,
Cover GW error box in a single image.
- Localize mergers to their host galaxies.
- Provide UV light curves to measure ejecta properties.

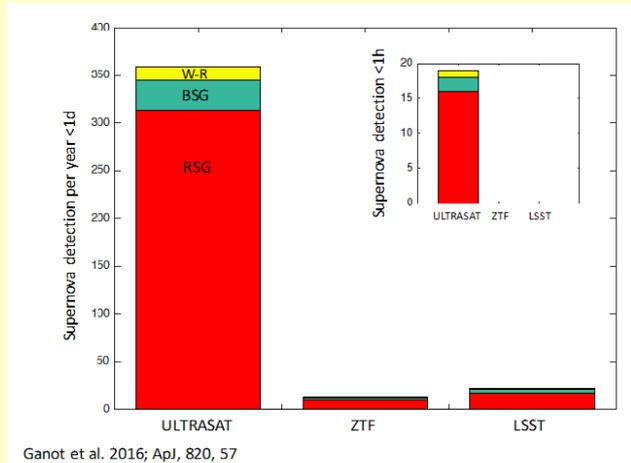
Deaths of massive stars

- High quality early high cadence UV data,
Rapid alerts for follow-ups,
100's of SNe including rare types.
- Measure properties of supernova progenitors.
- Map progenitors to supernova types.
- Reveal pre-explosion evolution and mass loss.

ULTRASAT's ToO access



Rates of early detections of SNe

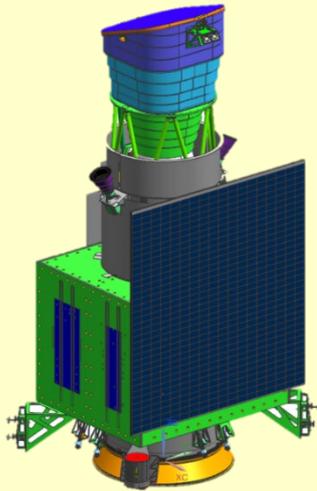


Science goal: Planet habitability

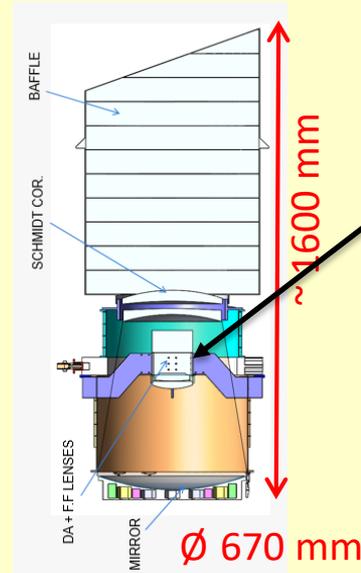
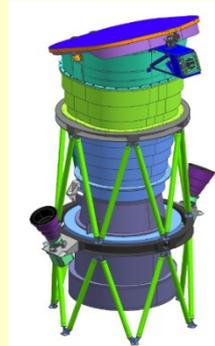
- UV flares and Coronal Mass ejections around prime candidate stars for terrestrial planet searches (M-dwarfs/young Solar analogues)
 - Severely limit habitability,
 - May allow prebiotic chemistry,
 - May produce false positive biomarker signatures (O₃ from photo-dissociation of H₂O & CO₂).
 - Flares dominate UV output. Flare rates unknown.
 - ULTRASAT will monitor $\sim 10^6$ 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 (extended).
-

ULTRASAT: Implementation & Collaboration

Spacecraft: IAI



Telescope: Elop/Elbit



Focal Plane Array
DESY/Helmholtz
(Germany)

Sensor: Tower
(Israel)

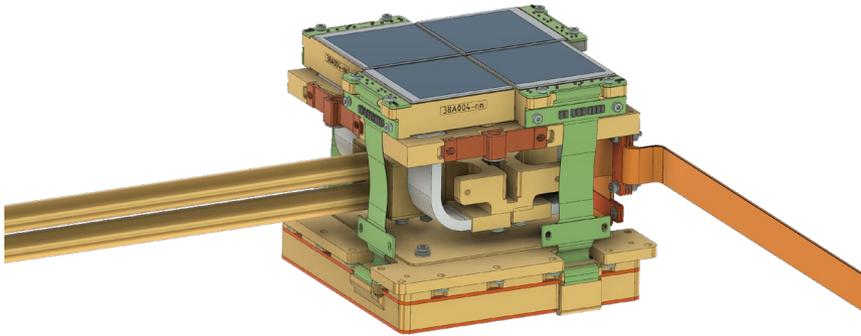
Hosted launch to GTO: NASA
(MoU negotiations near final stage)

Launch Q2/3 2025
>3.5 year science mission (6 year fuel)

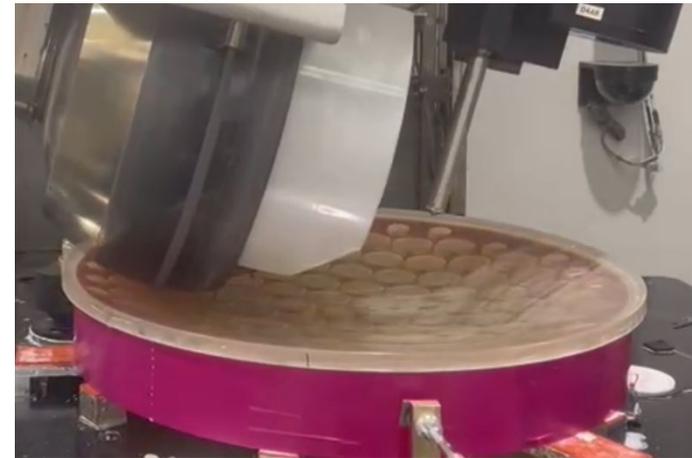
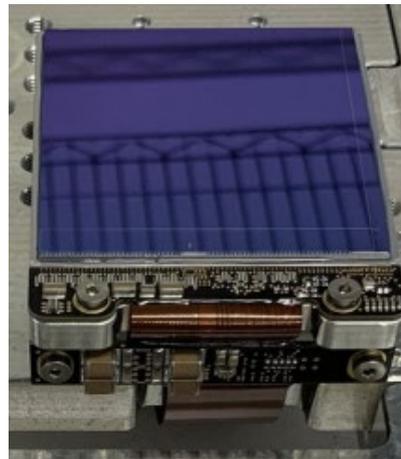
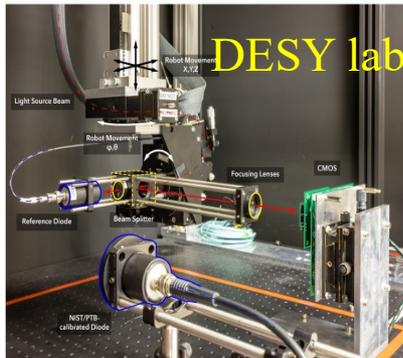
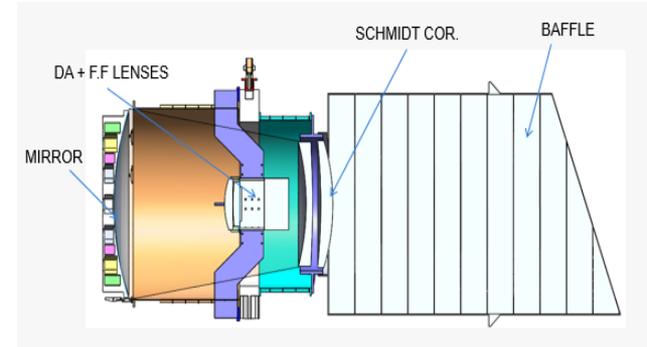
Dimensions: 1.5 x 1.7 x 3.4 (m³)
Power: 500 W
Mass: 500 + 630 (Prop) kg

Long lead items (LLI)

Sensors manufactured, tested,
now being integrated



Mirror Production at Elop



ULTRASAT: Science Collaboration

- 13 Science Working Groups - WG members receive real time data access.
Open to all (and already including most) Israeli astronomers.
 - NASA Launch contribution- MoU negotiations at final stage,
Science return: US PIs (NASA funded) will join WG's,
NASA project scientist: J. Rhoads.
 - DESY Camera contribution-
Science return: 3 DESY PIs in WG's.
 - Rubin (LSST) collaboration- advanced negotiations.
-

Summary

- HE ν astronomy has the potential to
 - Provide unique constraints on models of HE astrophysical sources, and
 - Identify the sources of (very) HE cosmic-rays.
- Fulfilling the potential relies on the EM identification of the neutrino sources.
- $M_{\text{eff}} \sim 10 \text{ Gton} @ 10^5 - 10^8 \text{ GeV}$ (IceCube Gen2 + KM3NeT/GVD/P1) is required to
 - Detect multiple events from few nearby sources (eg starbursts),
 - Possibly detect luminous transients (GRB/TDE-jet) contributing $\sim 1\%$ of the flux,
 - Obtain accurate ν spectrum, angular distribution and flavor content.
- EM follow-up observations may identify hour-day long transient sources, Crucial for a systematic study of the sources.
EM detector requirements: $\text{FOV} > 1 \text{ deg}^2$, Sensitivity better than $10^{-13} \text{ erg/cm}^2\text{s}$.
 - May be possible at X-ray (XRT), UV/O.
 - Very challenging at sub-TeV (CTA).
- $10^8 - 10^{10} \text{ GeV}$: A flux measurement ($10^{-9} \text{ GeV/cm}^2\text{s sr}$) will constrain the UHE CR composition (Radio).