The SVOM Mission: Perspectives for Multi-Messenger Astronomy

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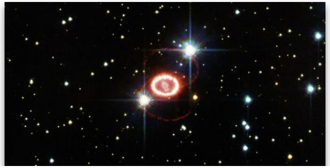
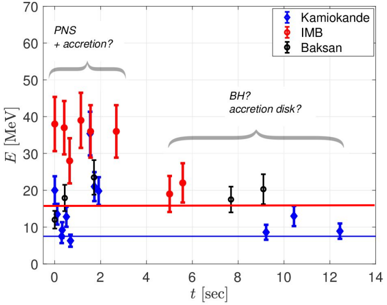
Seventeenth Marcel Grossman Meeting | 9 July 2024

Multi-Messenger Astronomy

the observation of an astrophysical phenomenon in more than one cosmic "messenger"

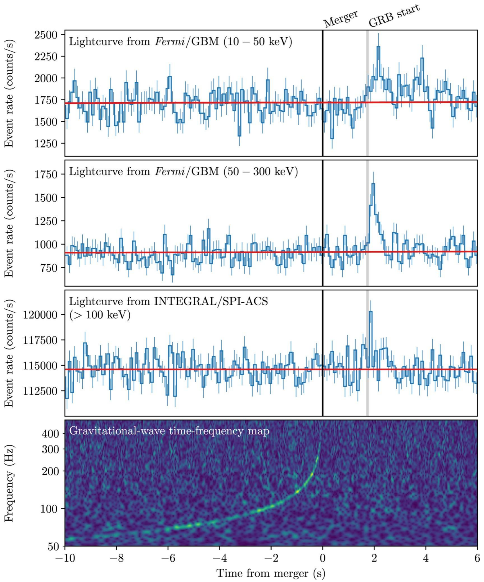
SN 1987A





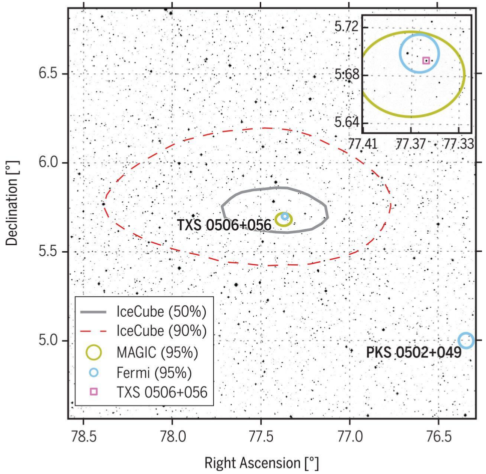
NASA Hubble | Bar et al 2020

GW170817 / GRB 170817A



Abbott et al 2017, ApJ 848 L13

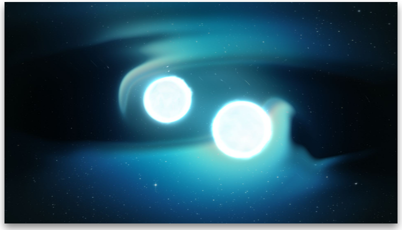
TXS 0506+056 / IceCube 170922A



Aartsen et al 2018, Science, 361, 3698

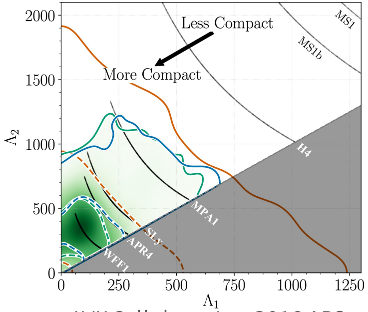
...with Light and Gravitational Waves

Compact Object Evolution



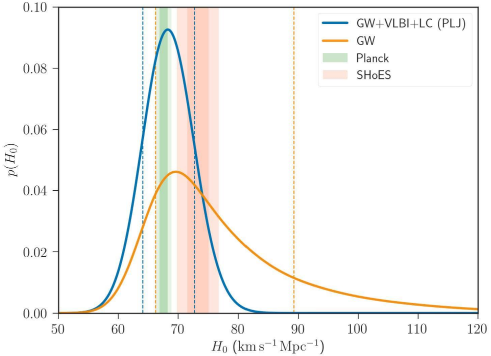
NASA/Goddard

NS Equation of State



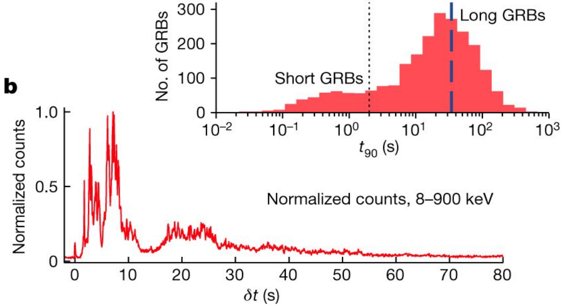
LVK Collaboration 2018 APS

Cosmology



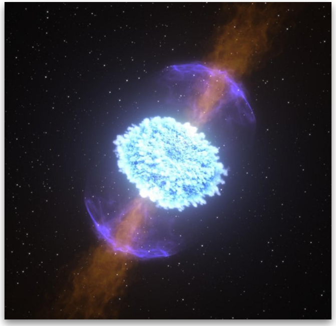
Hotokezaka et al 2019

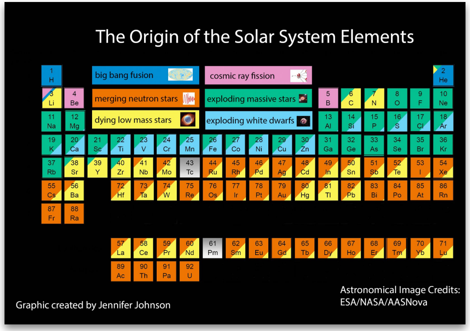
Merger Remnant and GRBs Physics



Rastinejad et al 2022

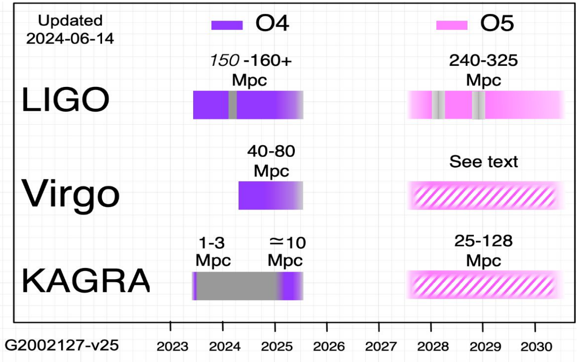
Heavy Element Production





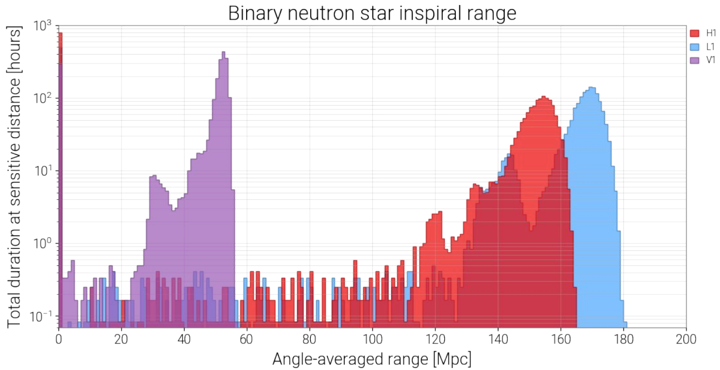
LIGO/Virgo/Kagra O4 Run

Extended to **9th June 2025**!



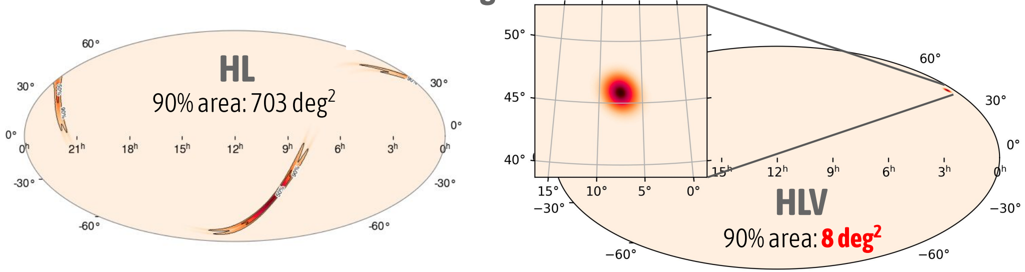
IGWN Public Alerts User Guide

Current LIGO BNS range: 140-180 Mpc



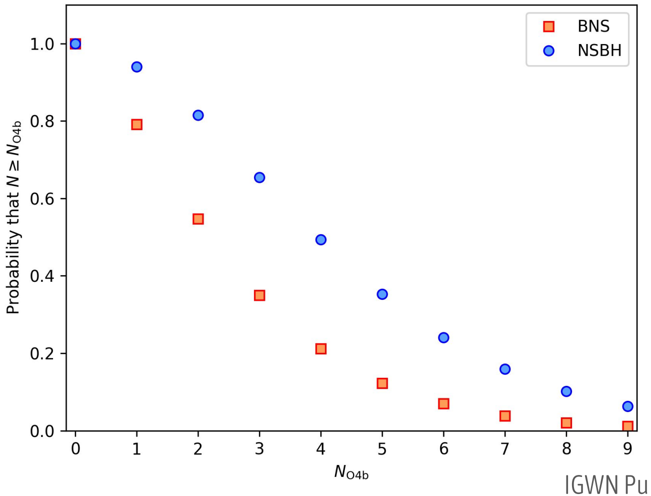
Virgo used in parameter estimation, notably reducing localizations

S240615dg



Expected GW Rates

- **O4b:**
  - 1 significant NS merger (GW230529) but no detected EM emission
  - 79% probability for at least 1 significant BNS merger
- **O5**: possible increase by factor of 10 in BNS public reporting rate



		BNS		
Annual number of public alerts (log-normal merger rate uncertainty × Poisson counting uncertainty)				
O4	HKLV	36^{+49}_{-22}	6^{+11}_{-5}	260^{+330}_{-150}
O5	HKLV	180^{+220}_{-100}	31^{+42}_{-20}	870^{+1100}_{-480}
Median luminosity distance (Mpc, Monte Carlo uncertainty)				
O4	HKLV	398^{+15}_{-14}	770^{+67}_{-70}	2685^{+53}_{-40}
O5	HKLV	738^{+30}_{-25}	1318^{+71}_{-100}	4607^{+77}_{-82}

IGWN Public Alerts User Guide

The SVOM Mission

Prompt

ECLAIRs

Coded-mask imager

4-120 keV

~12 arcmin localization

Full photon data

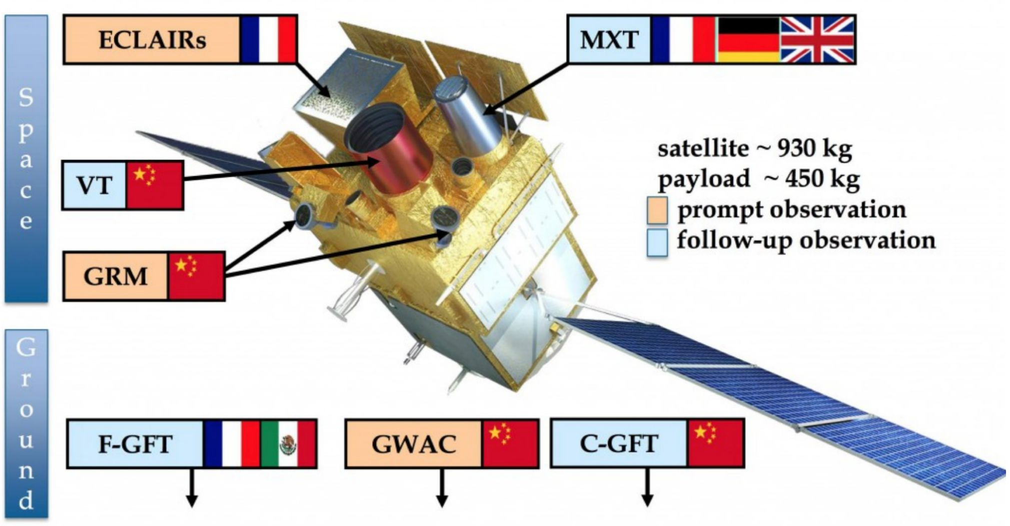
GRM

3 scintillation detectors

15 keV-5 MeV

~10 deg localization

~20 microsec resolution



Follow-Up

MXT

Lobster-eye optics

0.2-10 keV

<1 arcmin localization

VT

40-cm mirror

Red filter (650-1000 nm)

~arcsec localization

23 mag (300 s)

Prompt GRB Detection

1. Ideal Scenario: If ECLAIRs promptly detects GRB, then spacecraft can automatically slew to best location

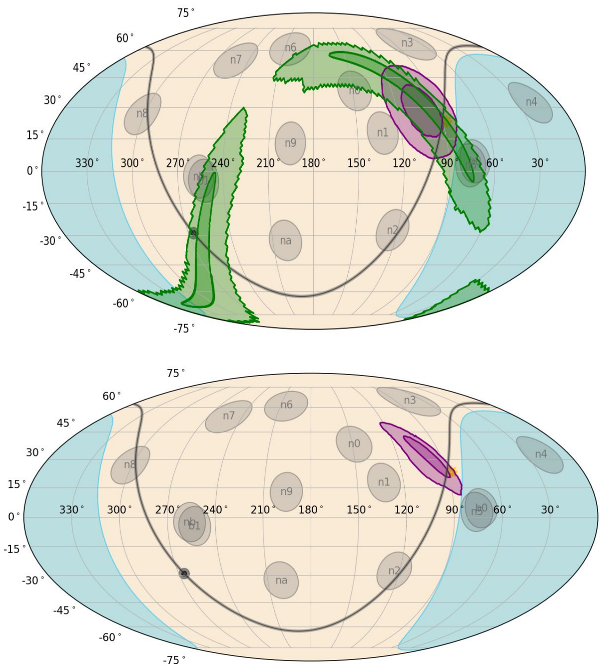
- GRB notices automatically sent to GCN – less than 30 s
- MXT and VT counterpart detection – minutes
- Scientific products will be publicly accessible - minutes

2. RAVEN: LVK receives SVOM notice and publishes **Potential Coincidence** alert to GCN (if passes reporting threshold)

- Joint FAR and combined Healpix skymap (Ashton et al 2018)

Coincidence FAR: $$FAR_c = FAR_{gw} \frac{R_{ext}\Delta t}{I_\Omega}$$ x trials factor

S230619bd (GCN 34054)



ECLAIRs Ground Searches (in development)

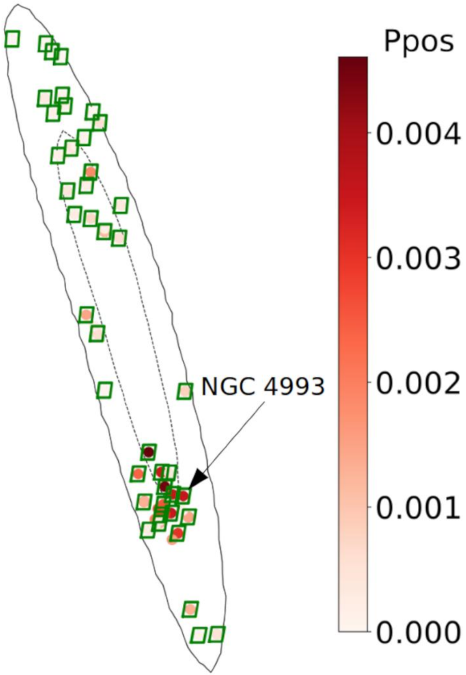
Full photon data (X-Band) available to perform sensitive searches for gamma-ray transients

- Online search for count rate excesses below on-board triggering threshold (S. Schanne)
- SNR search of image data triggered by external alerts (M. Llamas Lanza)
- Counts-based search triggered by external alerts (R. Hamburg)
- Blind, wavelet algorithm (S. Mate, N. Dagoneau)
- ML-based anomaly detection algorithm (B. Arcier)

GW Follow-up with MXT and VT

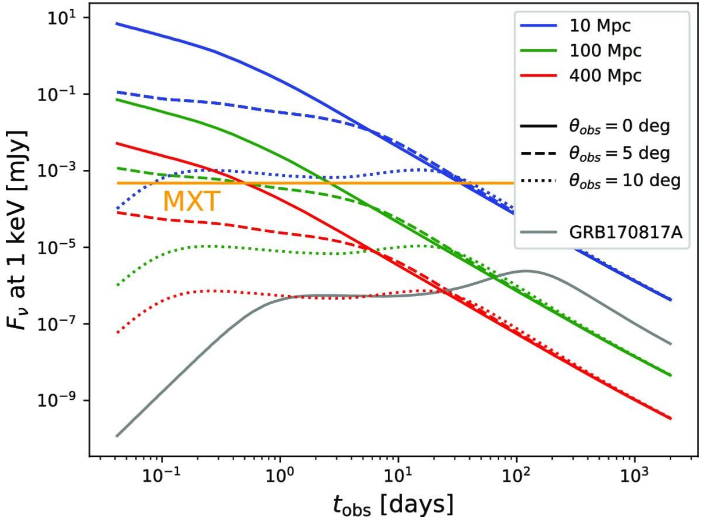
Likely scenario: receive GW alert and SVOM pipeline composes **galaxy tiling** strategy (Ducoin et al 2020, 2023)

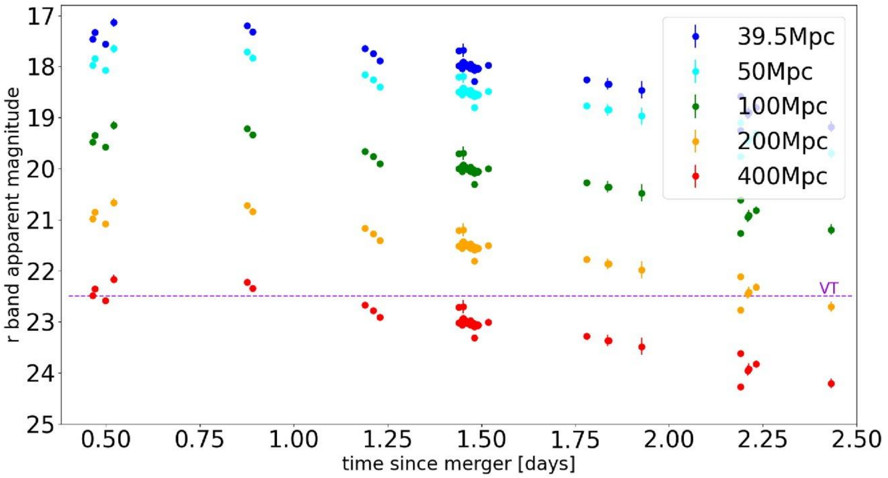
1. Built off *gwemopt* (Coughlin et al 2019)
2. Select galaxies from MANGROVE catalog (up to 400 Mpc)
   - 90% GW localization probability
   - 3σ GW distance posterior
3. Weight tile probability by stellar mass
4. Apply observing constraints
   - Anti-solar pointing (<90 deg)
   - Minimize slews > 5 deg
5. Optimization
   - Reduce tile overlap
   - 1+ galaxy in VT FOV



GRB 170817A-like GRBs

- MXT sensitive to nearby, on-axis afterglow at early times from weak GRBs (Pellouin & Daigne 2024, in press)
- VT can catch early kilonova emission out to ~400 Mpc





Ducoin et al 2023

ToO Program

15% nominal (40% extended) mission dedicated to unplanned observations

ToO Nominal

Standard GRB follow-up or source observation

- Rate: 1 / day
- Time: 1 orbit (~45 min)
- Latency: 24-48 hr

ToO MM

GW or neutrino follow-up

- Rate: 1 / week
- Time: 1-14 orbits (24 hr max)
- Latency: 12 hr (S-band) / 4 hr (Beidou)

ToO Exceptional

Special GRB, GW, neutrino follow-up

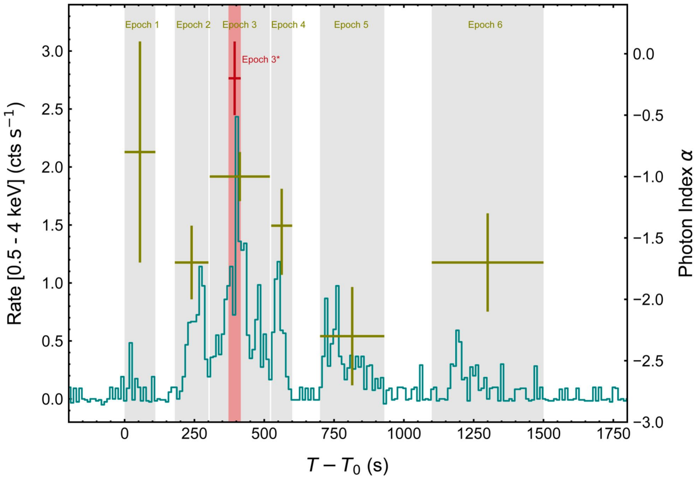
- Rate: 1 / month
- Time: 7-14 orbits (24hr max)
- Latency: 12 hr (S-band) / 4 hr (Beidou)

ToO submission will be open to all and science products will be delivered to community as soon as possible

Synergy with Einstein Probe

Can coordinate observations for faster tiling of GW localization skymap

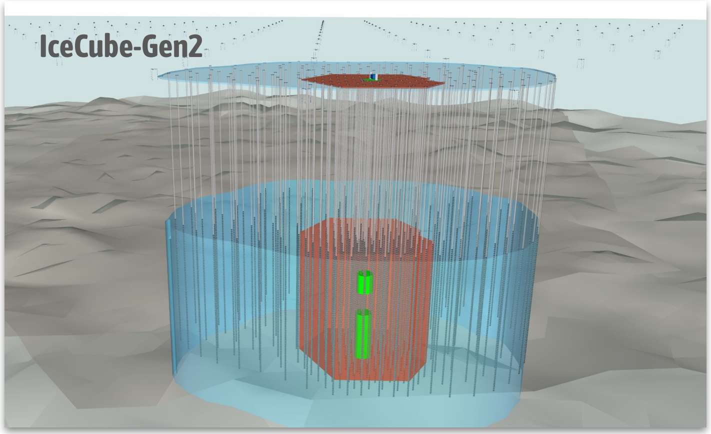
- EP already detecting GRBs and X-ray transients (e.g., EP 240315A, z = 4.859, GCN)
- SVOM and EP share data centers, Co-Is, and can provide multi-band coverage



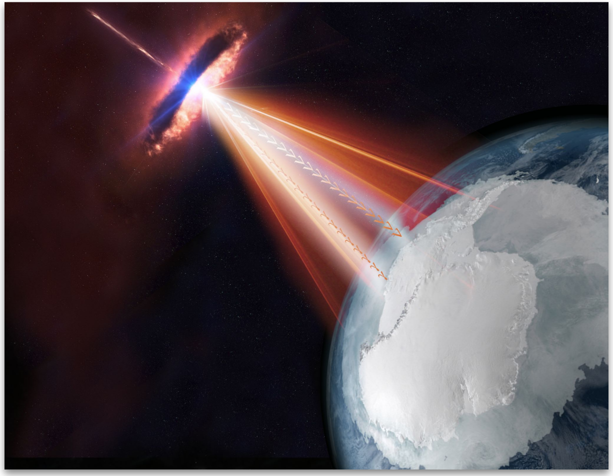
Liu et al 2024

Neutrino Follow-Up

- Observations in the keV band can be important for multi-messenger studies of blazars (Keivani et al 2018)
- SVOM pipeline being built for automatic follow-up of neutrino alerts from IceCube, SNEWS, and (upcoming) KM3NeT



Credit: IceCube Collaboration



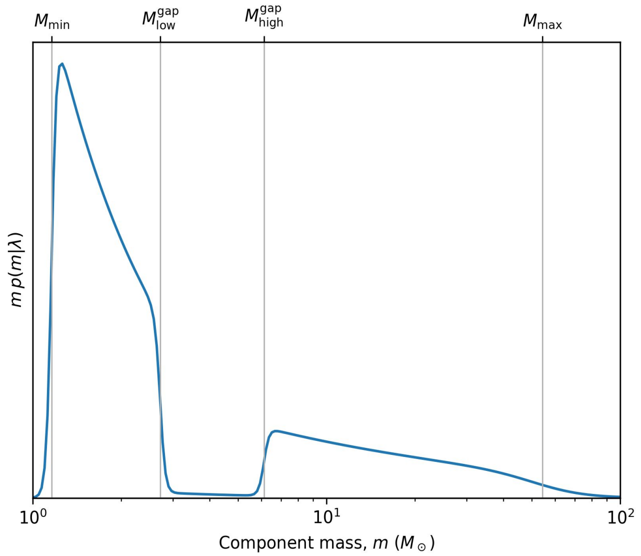
Conclusions

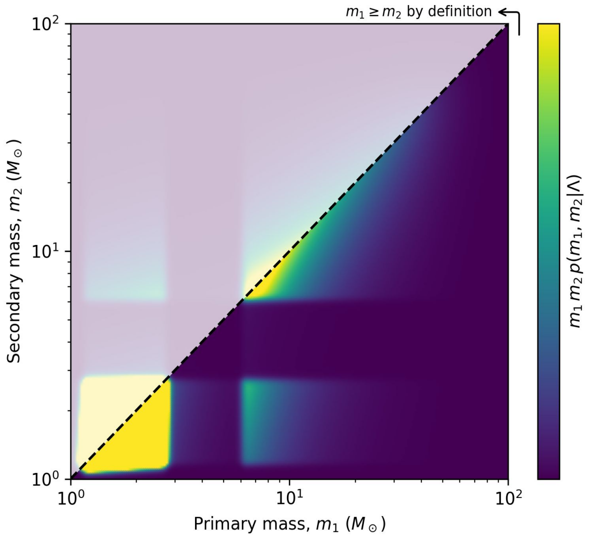
- SVOM will be a powerful instrument for multi-messenger astronomy in the coming years!
- With O4 extension, still looking forward to GW/EM detection!
- Combined efforts with Einstein Probe could reduce GW localization tiling time
- Look out for more SVOM GRBs!

Back-Up

O5 Expected Detection Rates

- O3 global fit to mass distribution
- High end of BNS range for all detectors except Virgo
- 70% duty cycle for each detector





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$$P_{\rm pos} = P_{dV} = \frac{P_{\rm pixel}}{\rm Pixel\ area} N_{\rm pixel}\, e^{-\frac{1}{2}\left(\frac{D_{\rm galaxy}-\mu_{\rm pixel}}{\sigma_{\rm pixel}}\right)^2}$$

$$G_{\rm mass} = \frac{M_{*,\rm galaxy}}{\sum M_{*,\rm galaxy}}$$