



Shaping the Future of Time-Domain and Multi-Messenger Astronomy with HWO

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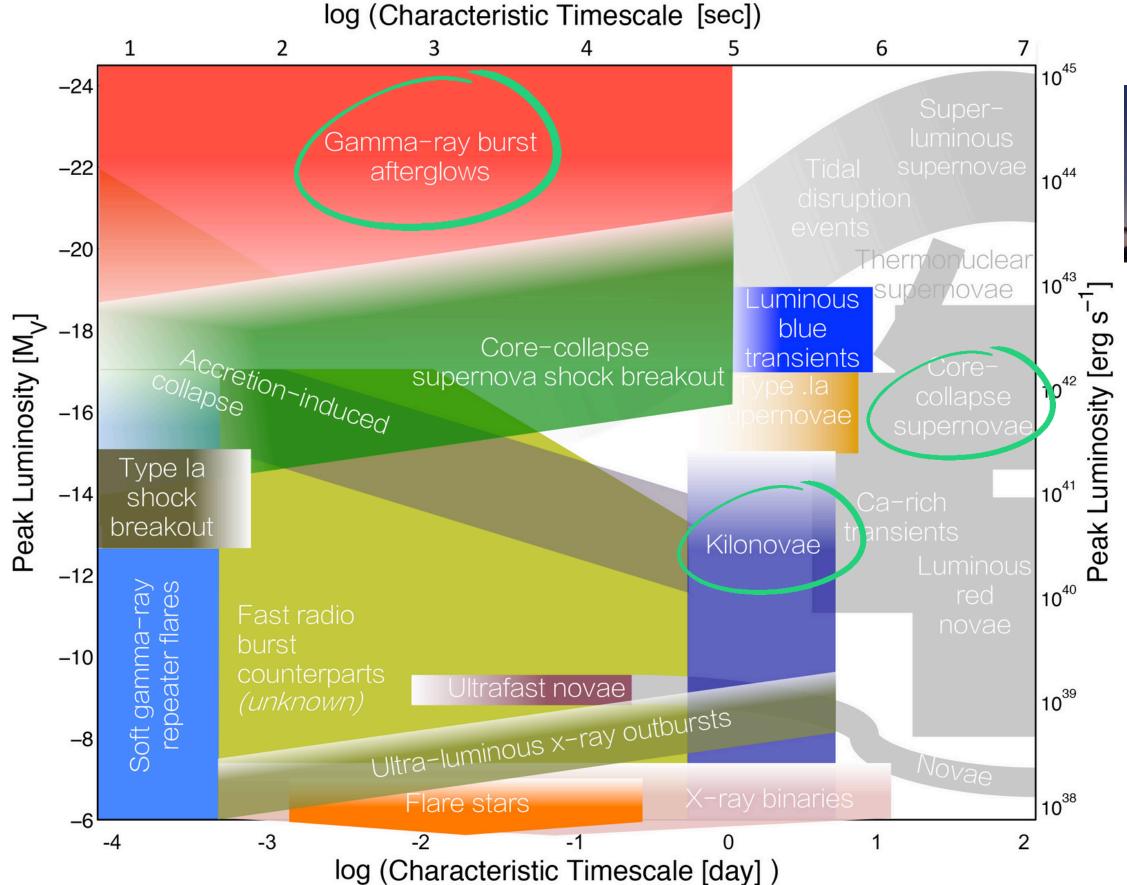
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GW



Neutrinos

THE TRANSIENT SKY WITH MMA







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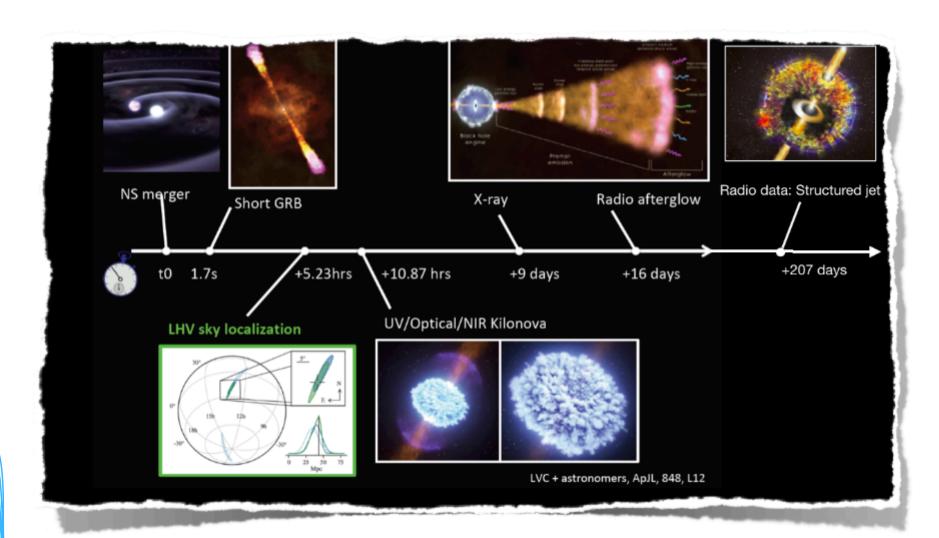
EM facilities



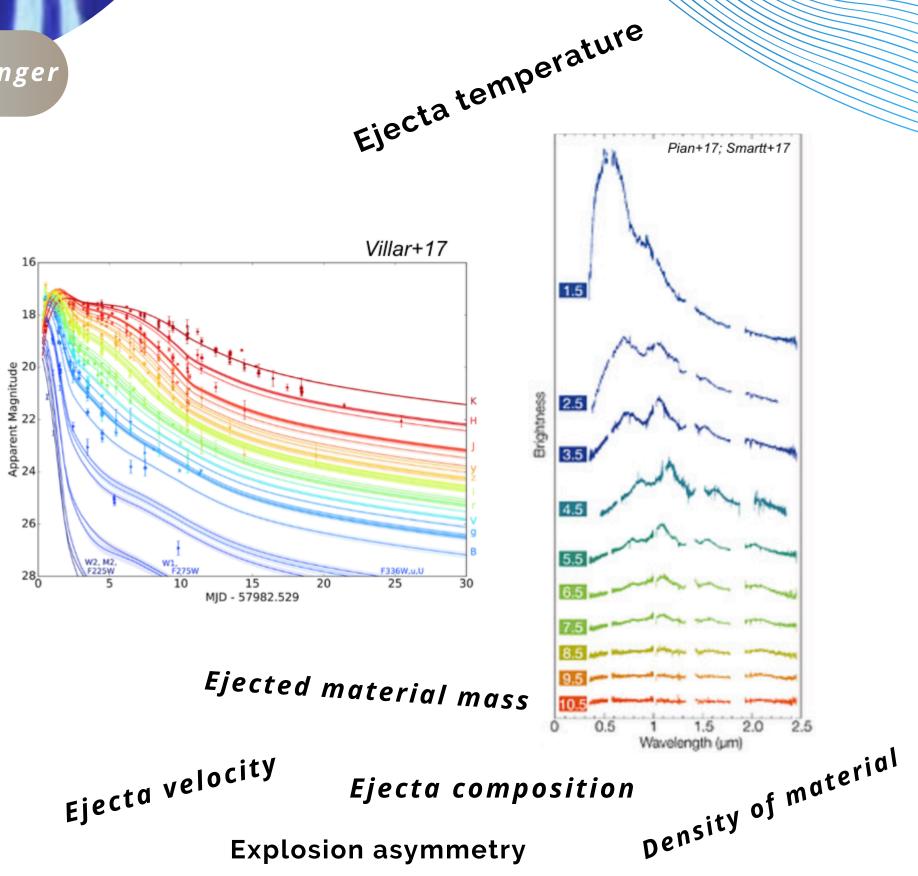
KILONOVAE what we saw/know







Abbott et al. 2017



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ISTITUTO NAZION
DI ASTROFISICA

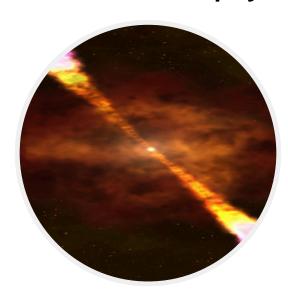
Explosion asymmetry

The Down of MultiMessenger era (after SN1987A)

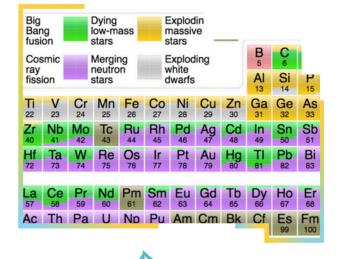
Radioactively powered transients





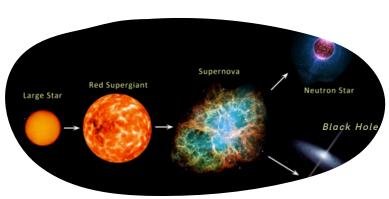


Nucleosynthesis and enrichment of the Universe

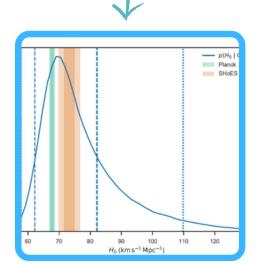




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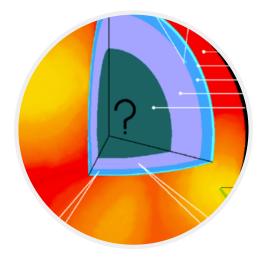






Cosmology





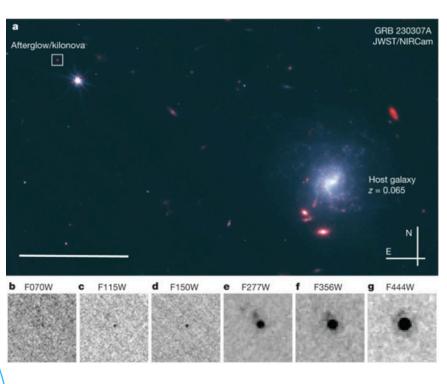
KILONOVAE what we saw/know

not only GW170817 - GRB170817

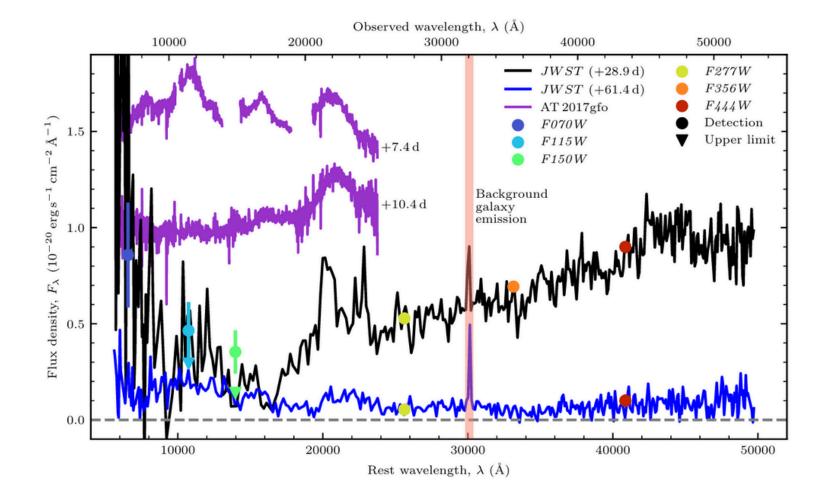


constraining r-process elemental production

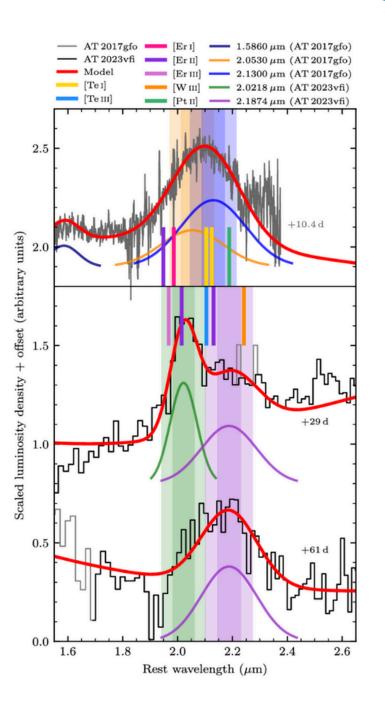
KN AT2023vfi (aka GRB230307A) @300Mpc with JWST



Levan+24



Gillanders+23 - Levan+24



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Gillanders +25

GW follow-up is not the only way to discover kilonovae

KILONOVAE what we saw/know





GRB170817 & GRB230307 weren't a canonical short-duration GRB

Revisiting GRB Classification? Insights from Kilonovae

the game changer

Observed extended emission

(short hard spike of gamma-ray emission followed by a longer, softer component of 10s) in GRBs/KN (Magnetized central engine? Fallback accretion, especially in NS-BH mergers? NS-WD mergers?)

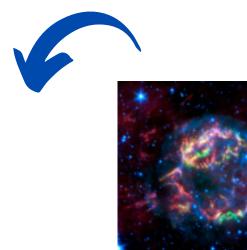


From "short" or "long" GRBs to

"Merger" GRBs (e.g., from NS-NS or NS-BH systems)

AND

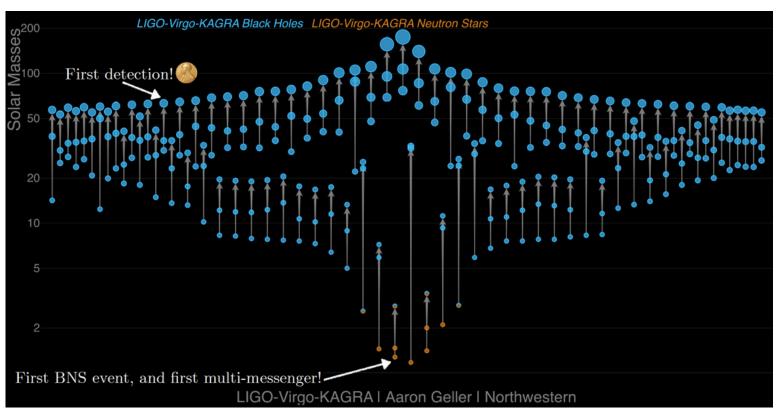
"Collapsar" GRBs (e.g., from massive star collapse)

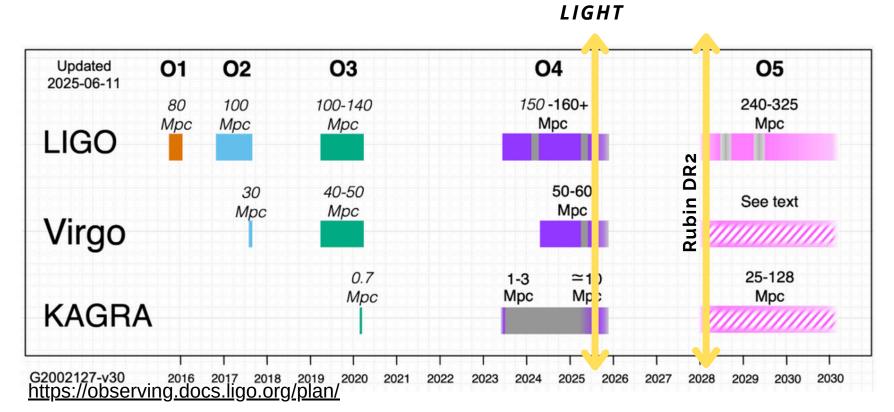


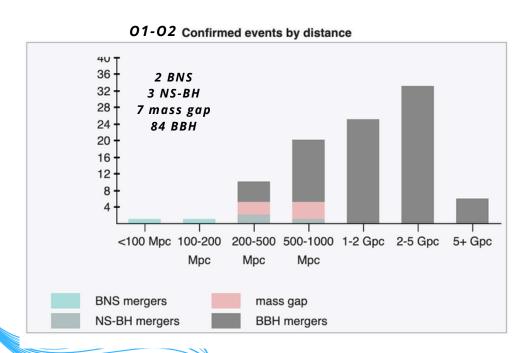


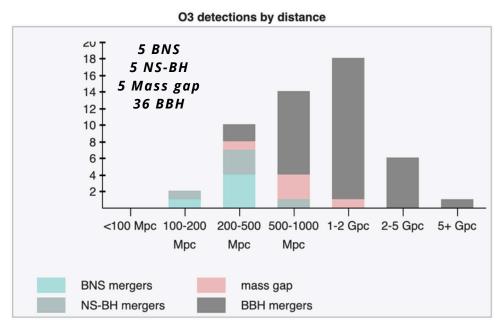
GW data as of TODAY









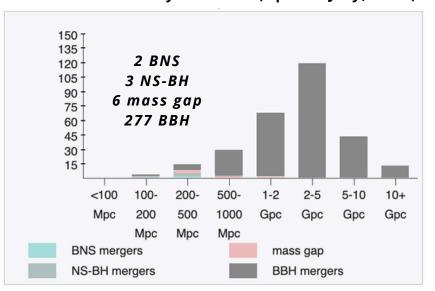


O4 detections by distance (up to 5 July, 2025)

Rubin

FIRST

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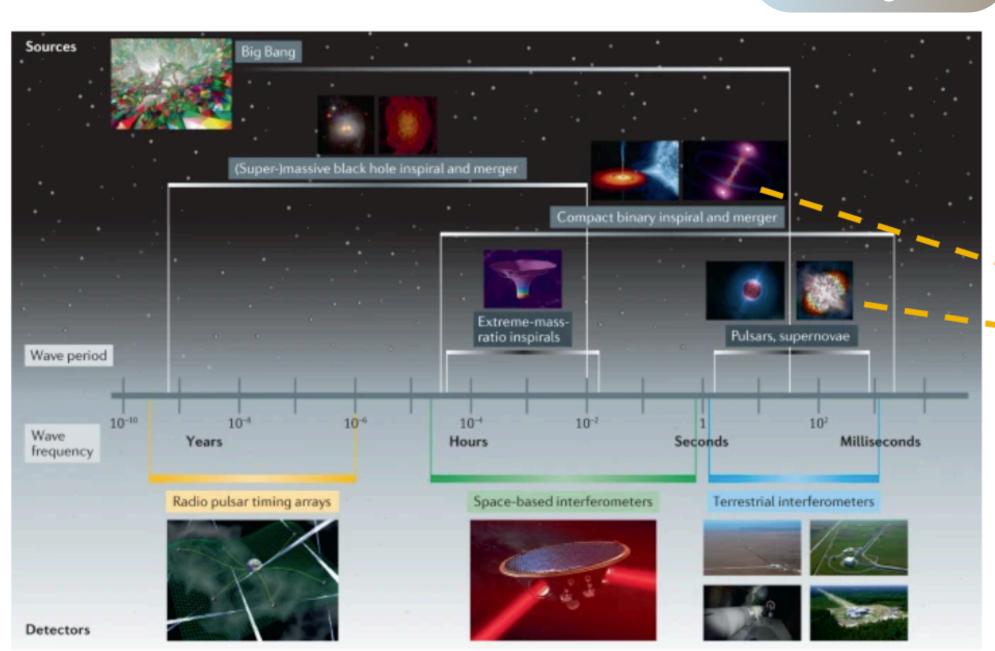




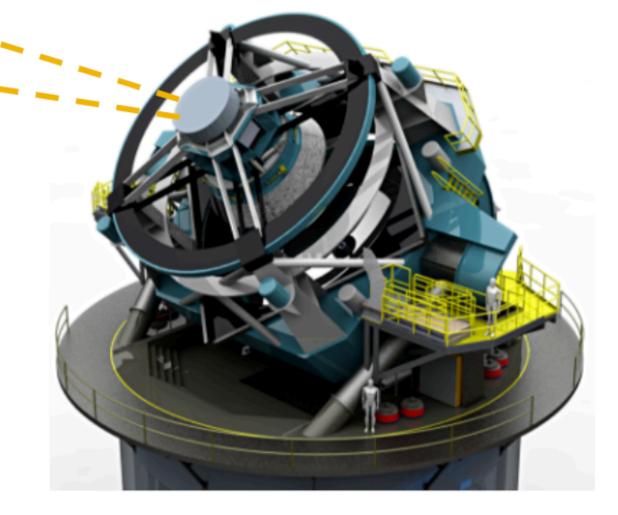


RUBIN, a game changer?

Rubin FIRST LIGHT: JUNE 2025!



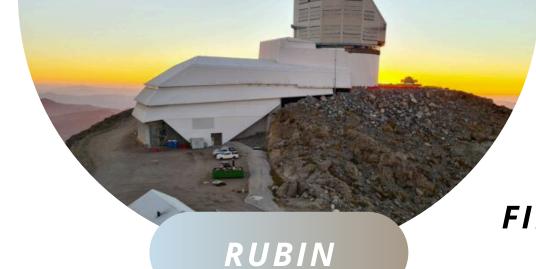
- Rubin as a (ToO) follow-up machine -> sources from GW detectors
- Rubin as a discovery machine -> follow-up from other facilities



Gravitational-wave physics and astronomy in the 2020s and 2030s, Nature

Reviews Physics

up to 10^5 alerts per day!



FIRST LIGHT: JUNE 2025!

The Vera C. Rubin Observatory and EM counterparts Discovery

- ~18,000 deg² of the Southern sky over 10 years
 9.6 deg² wide-field camera, reaching r ~24 mag in 30s exposures
- Will build a deep time-resolved map of the optical sky (u-g-r-i-z-y filters)
- Useful for:
 - --> Filtering out contaminating transients in multi-messenger searches
 - --> Enabling statistical studies of faint, fast-evolving sources like kilonovae







up to 10^5 alerts per day!



The Vera C. Rubin Observatory and Kilonova Discovery

Target-of-Opportunity (ToO) Follow-up for GW Events

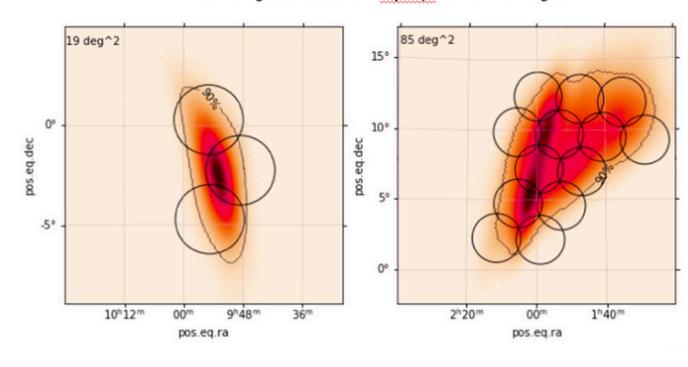
- Rubin has a built-in system to interrupt regular survey for ToO observations
- Up to 3% of total observing time may be used for ToOs, including GW follow-up
- Estimated detection rate in O5: ~6 BNS and up to 2 NSBH events/year (well-localized and observable)

Proposed follow-up strategies:

- Well-localized events: g+r+i on first night, then 2-band monitoring (e.g. r+z)
- **Poorly localized events**: g+z or g+i for wide area coverage and color identification
- Option to re-weight survey cadence around the GW localization (ZTF-style strategy)

Goal: detect fast-evolving, red or reddening optical counterparts and probe early blue components



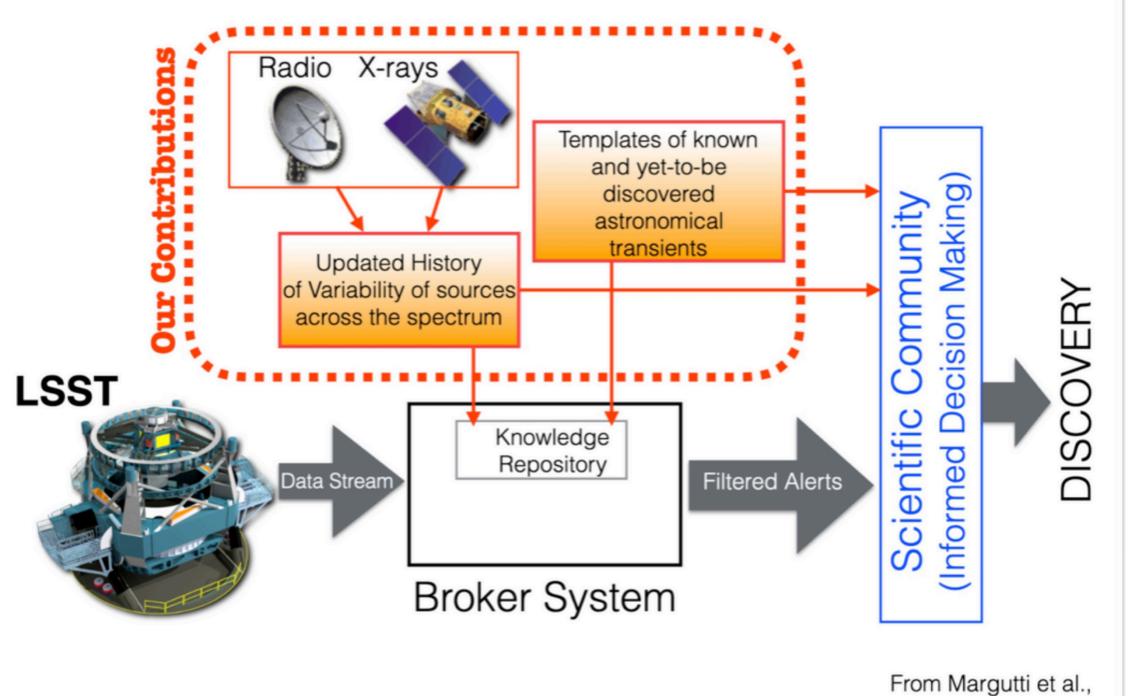


Andreoni+22

Rubin-LSST =
DISCOVERY
machine





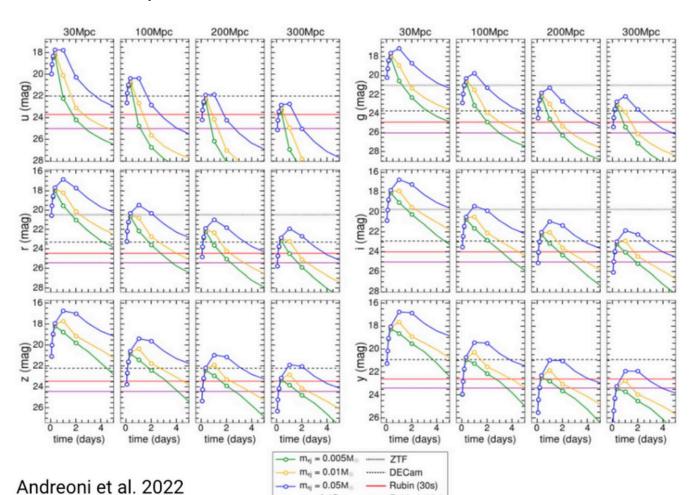


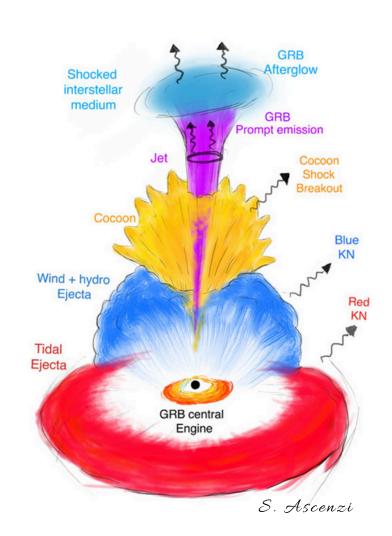
LSST Science Support Proposal



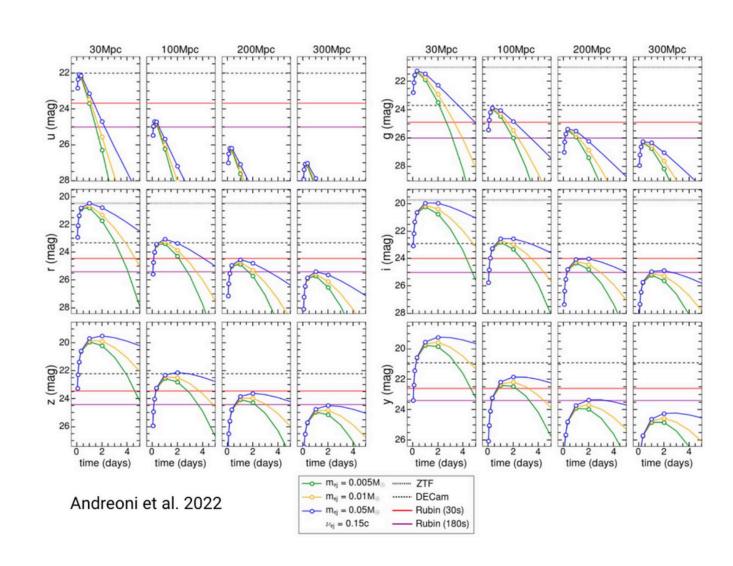
Justification for the use of Rubin

Blue Kilonovae with Rubin
--> 1 mag deeper to see
rapid fade and reduce false
positive



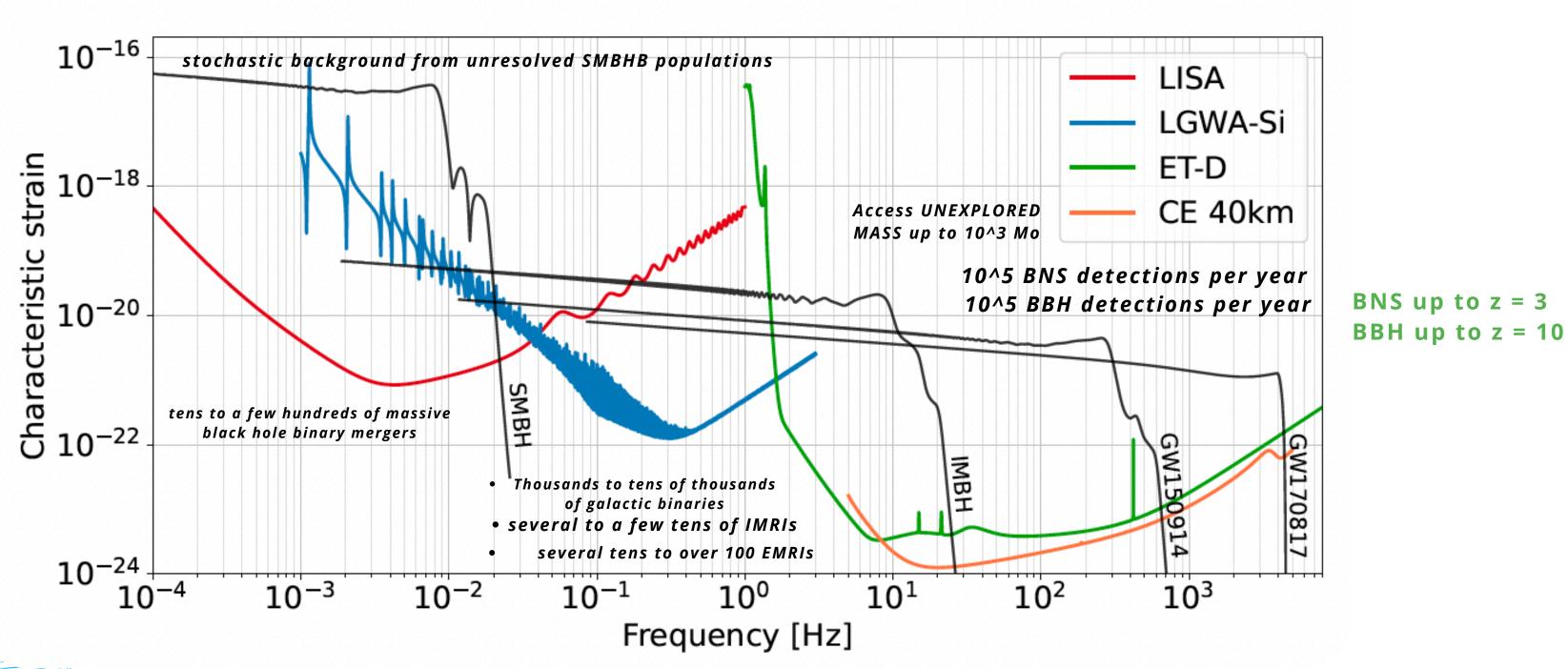


"Red" and faint kilonovae Impossible with any other facility than Rubin



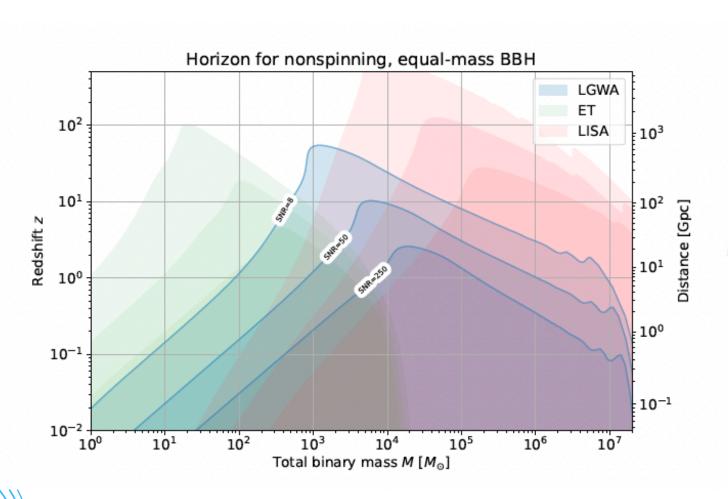


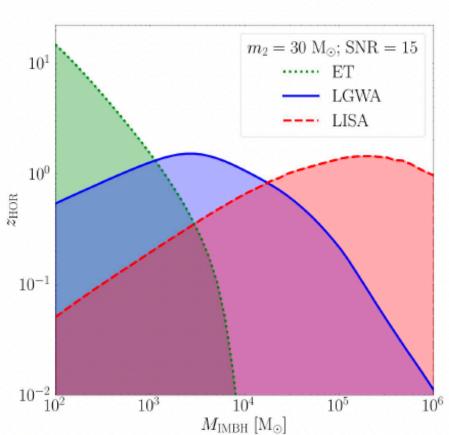












LGWA - WDNS (10 yr)
---- LGWA - DWD (10 yr)
---- LISA - DWD (3 yr)
---- LISA - DWD (3 yr)
---- LISA - DWD (3 yr)
---- Frequency, max-cutoff [Hz]

horizon for equal-mass black hole binaries, comparing Einstein Telescope, LGWA and LISA.

Redshift threshold for detection (SNR 15) for an IMRI (Intermediate Mass Ratio Inspirals) with primary mass M(IMBH) and secondary mass of $30M_{\odot}$

LGWA (LISA) detection horizons for DWD and WD/NS inspiral signals observed over 10 years or 3 years and with SNR threshold as indicated in the plot.





THINK LIKE THERE IS

NO BOX



from nHz to kHz

PTA - now

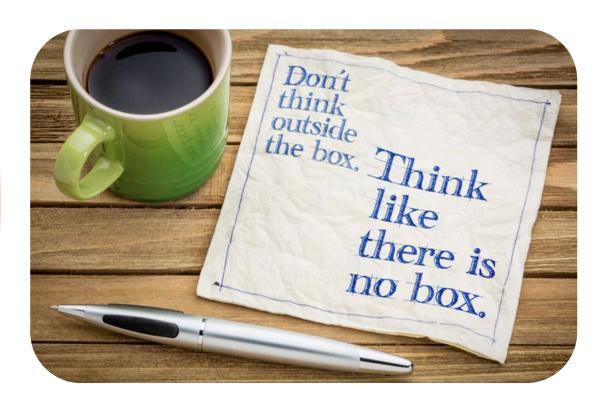
LISA - 2035

DECIGO - 2030

LGWA - 2040

EINSTEIN TELESCOPE - 2035

COSMIC EXPLORER - 2035





WST ? - 2040

TDT? - 2040

CUBES@VLT - 2030

ELT - 2028

--> Di Marcantonio's

talk

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4MOST - 2026

UVEX - 2030?

HERMES - 2027

Rubin - now

SOXS@NTT - now

EUCLID - now

JWST - now

HST - now

DESI-TAIPAN....

TOGETHER WITH NEXT
RADIO & (SUB)MM &
HighEnergy & VHE
facilities (e.g.
SKA&ATlast&Theseus&
NewAthena&CTA...

NEUTRINOS

ICECUBE KM3NET









Compact Binaries (BH-BH, NS-NS, BH-NS)

Magnetars

Fast Radio Bursts (FRBs)

White Dwarf Mergers

astronomical objects
observable via
multimessenger
astronomy

Supernovae core-collapse

Supermassive Black Hole Binaries

Active Galactic Nuclei (AGN) / Blazars

Early Universe / Stochastic Background

Pulsars / Continuous GW sources

Dark matter, primordial black holes, new particles



FUNDAMENTAL PHYSICS AND COSMOLOGY

Black hole properties

Neutron star properties

The nature of compact objects

Dark matter

Galaxies growth





ASTROPHYSICS

WHAT WE WILL KNOW from a MM point of view

(with 2 or 3 messengers together)

Expansion of the universe

General relativity and gravity test

Production of heavy elements

Jet physics, cosmic rays

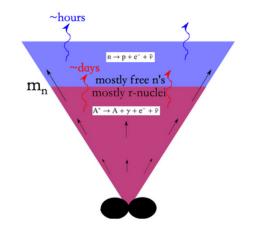




KILONOVAE what we (don't) KNOW

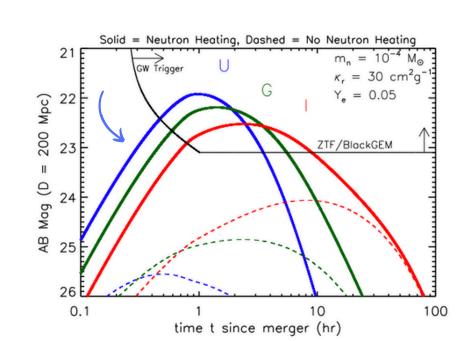
CHALLENGES

KN neutron precursor



Matter originates from the **shock-heated interface** between the merging NSs.

Metzger+14

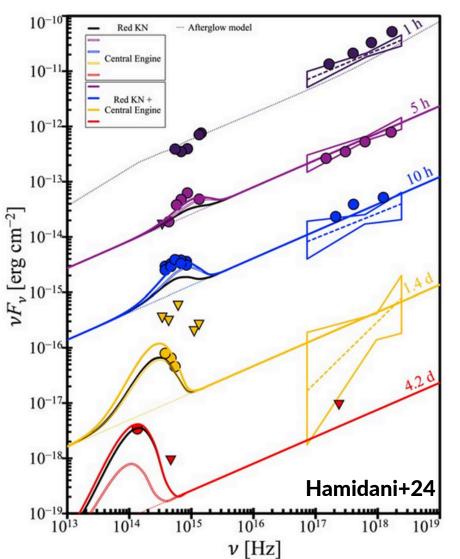


β-decay of these **free neutrons** in the outermost ejecta could power a '**precursor**' to the main kilonova emission?

What is the origin of the blue component?



GRB 211211A



r-process
heating alone
cannot
explain the
entire light
curve and SED

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A centralenginepowered KN?

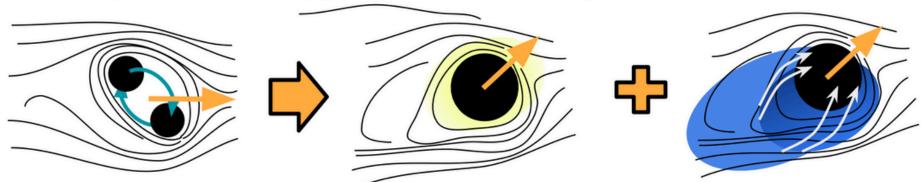
A low-power jet launched by late engine activity interacts with the lanthanide-rich ejecta

BBH Emission?

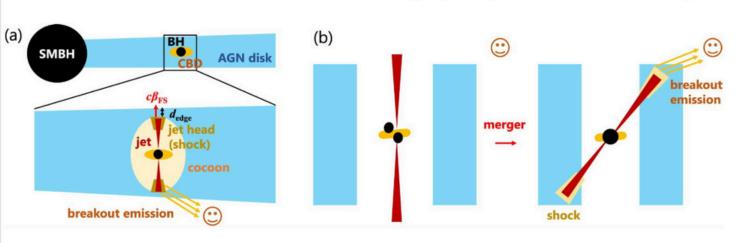


BBH mergers embedded in AGN disks can produce EM emission?

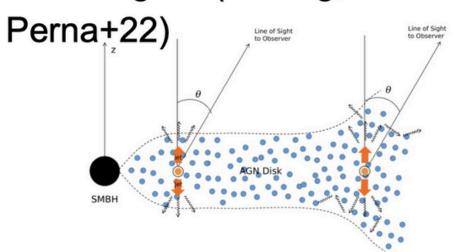
Ram-pressure stripping + Bondi tail (McKernan+19, Antoni+19)



Jet breakout, shock cooling (Tagawa+23, 24)



Jet afterglow (~Wang, Lazzati &

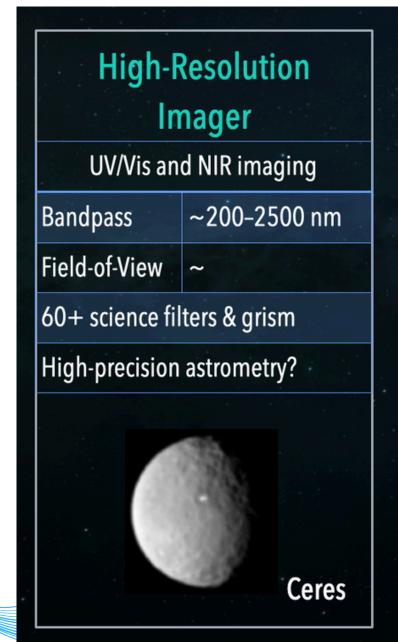


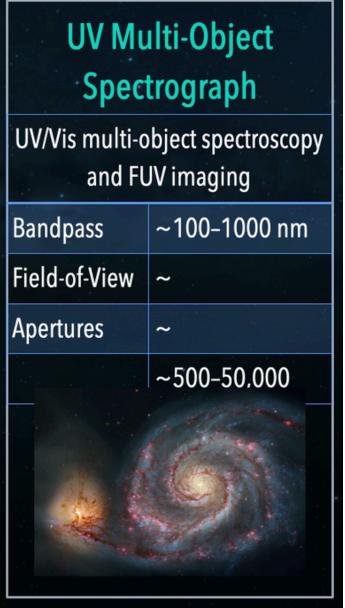
Models predict flare timescales of days to weeks.

These prompt, luminous UV flares (up to 10⁴¹–10⁴² erg/s) can outshine the AGN.





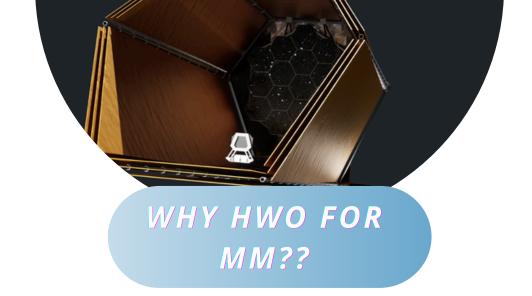




this wavelength range is crucial to study the **KN early emission** as well as the environment and host galaxy information



could be a game-changer for detecting and understanding **UV flares** from stellar-mass black hole **(BBH) mergers** in active galactic nucleus (AGN) disks







Unprecedented Spectral Coverage: filling the post-HST UV gap and exceeding the sensitivity of JWST and UVEX in the UV



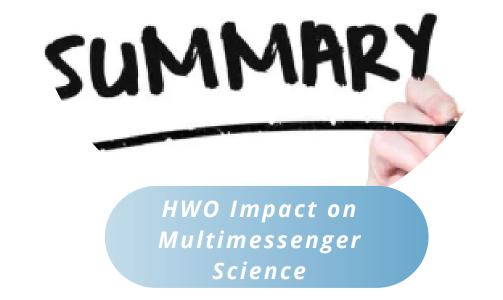
High Sensitivity and Resolution: enable detection and detailed study of faint, distant, or confused multimessenger sources—crucial for localizing and physically characterizing electromagnetic counterparts of GW sources

Multi-object Spectroscopy and Imaging: vital for rapid follow-up of transient-rich multimessenger events (e.g., kilonovae, BBH mergers in AGN disks, shock breakouts)

Continuous, atmosphere-free monitoring for precise photometry and spectroscopy, with the ability to respond quickly to external triggers from GW or neutrino observatories



enable the localization and physical characterization of electromagnetic counterparts to GW and neutrino events, even in crowded or faint host environments.





Far-UV sensitivity is essential for capturing the earliest, most diagnostic emission from kilonovae, supernovae, and black hole mergers—often missed by optical/NIR-only facilities.

Synergy with Other Facilities: HWO will be the definitive platform for detailed follow-up and physical characterization of sources discovered by Rubin, WST, ELT, UVEX, and future GW/neutrino detectors, maximizing the scientific return of the multimessenger era.





UV spectroscopy uniquely probes the chemical composition, star formation, and physical conditions of host galaxies, key for understanding the environments of multimessenger events.





New Bento Box - focused on science questions

what is the mass of the dark matter particle? how does star formation propagate within galaxies?

why do massive galaxies stop forming stars?

how are heavy elements recycled by galaxies?

how many black holes are in the Milky Way?

where are the smallest galaxies?



answering transformative astrophysics questions

how do the most chemically primitive stars live and die?



YOUR IDEA HERE!

detectors, maximizing the scientific return of the

are there habitable icy worlds in the outer solar system?

how do the most massive black holes form?



in 2040s!!