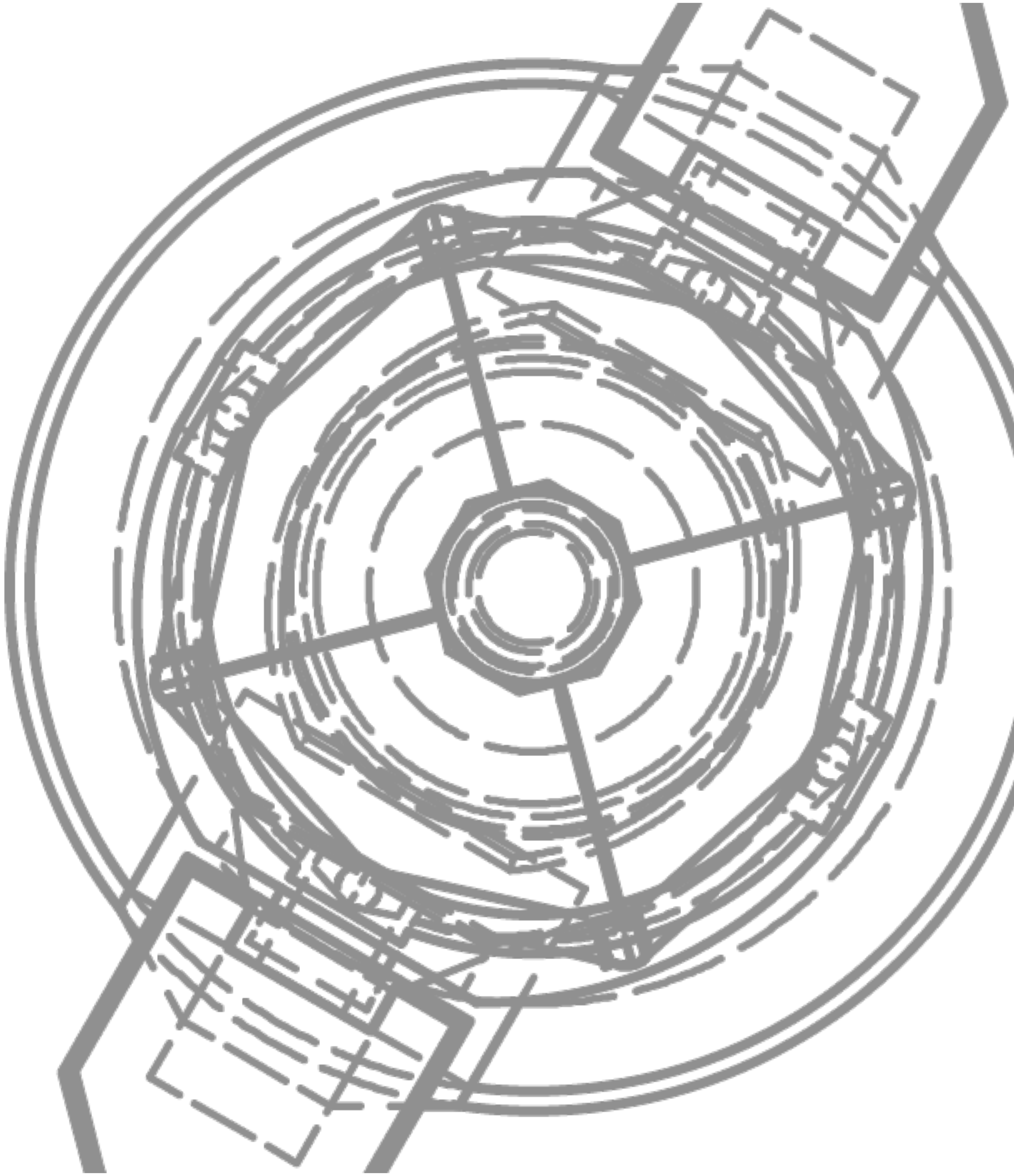
New Robotic Telescope

in the context of EM Detectors and future prospects
for multi-messenger science



A. Melandri - INAF/OAR

Third Gravi-Gamma Workshop: The multi-messenger view of the black hole life cycle

Volterra - 2022

Robotic Telescope

- Robotic is not Remote
- A system that makes obs without being operated by humans
- Humans initiate the schedule at the beginning of the night
- Reliability of controlling system and software and are the key
- Sets of predefined observational sequences (triggered by alerts)
- This approach works very well for all transients sources!!

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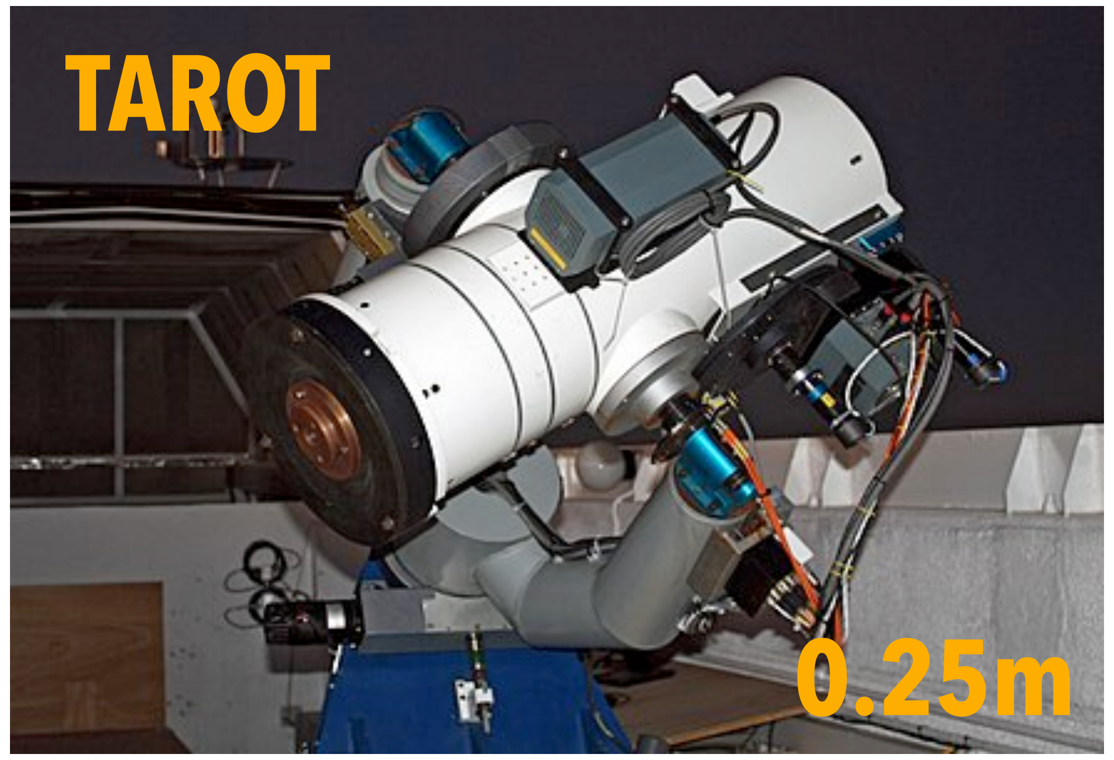
Available Robotic Telescopes

Size < 0.5m (network of small apertures)



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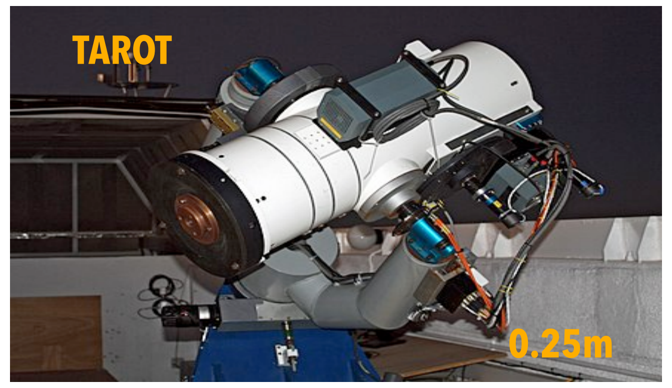
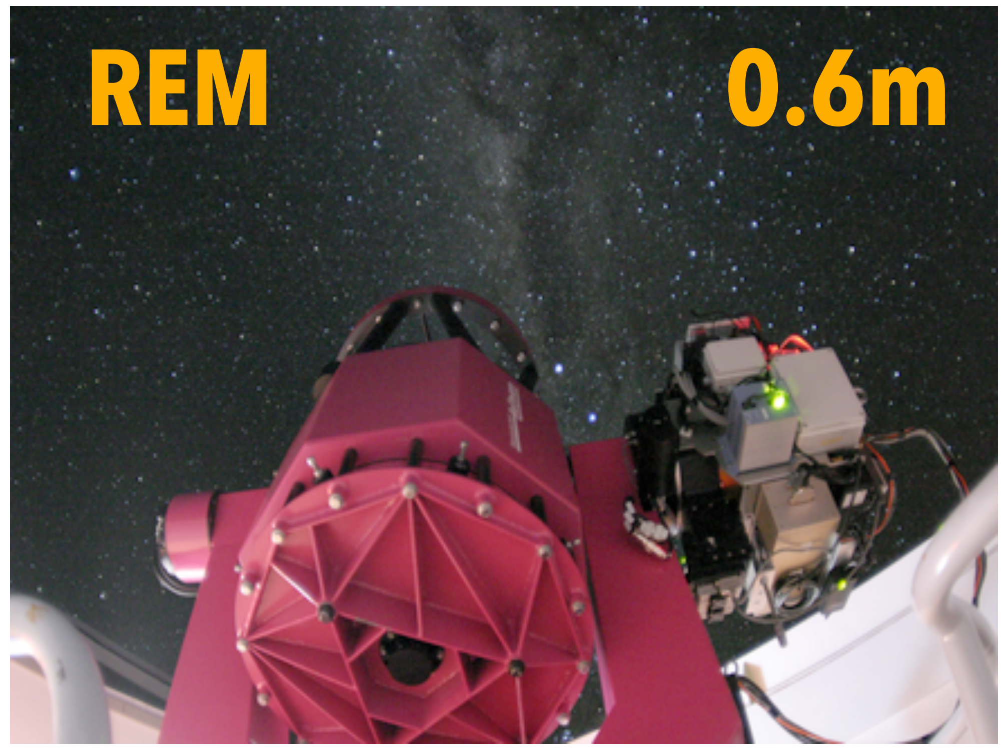
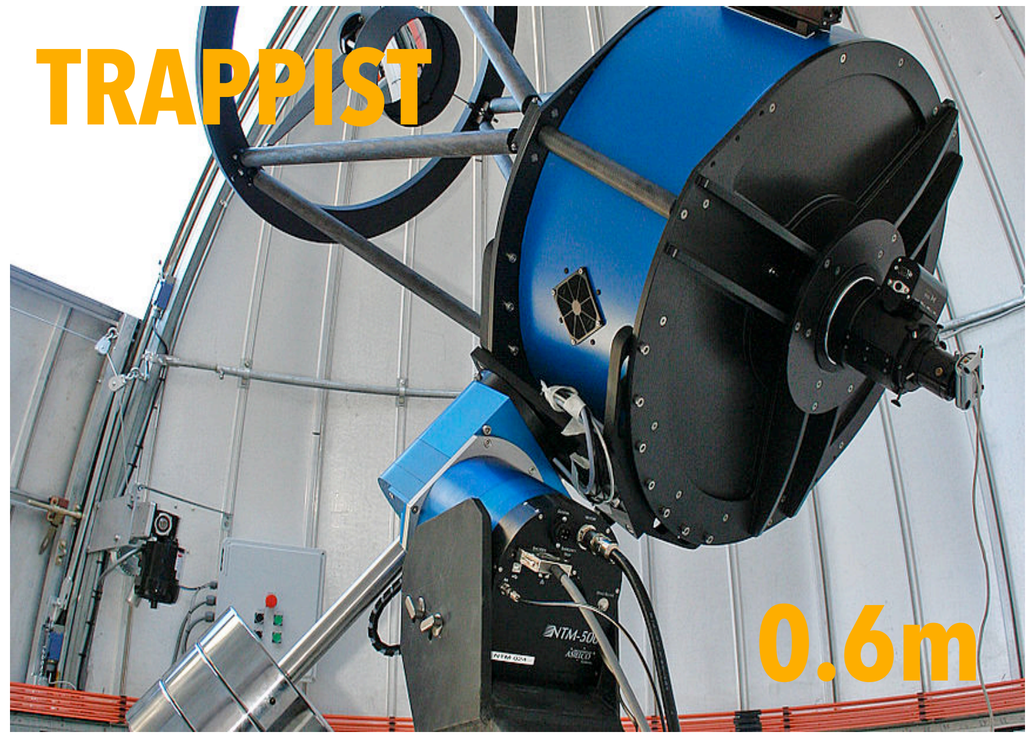
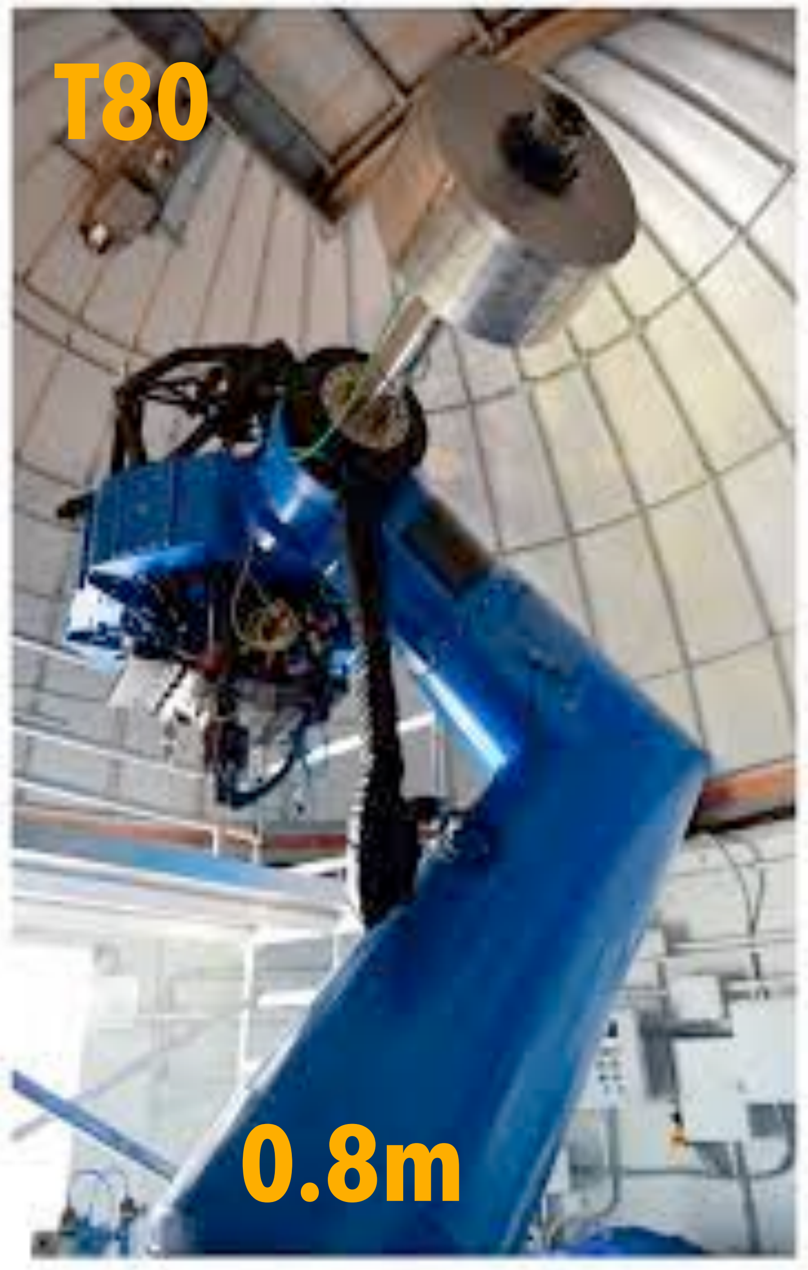


0.5m < Size < 1m







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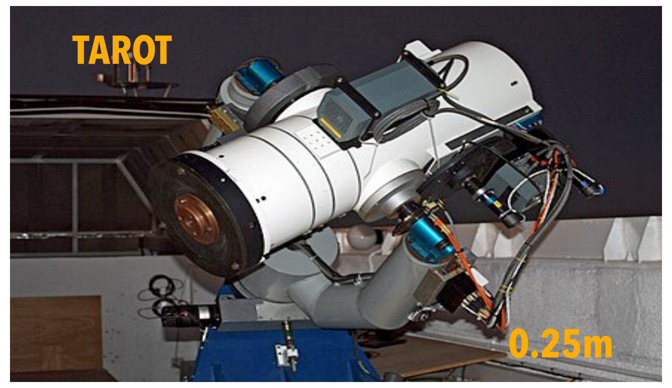

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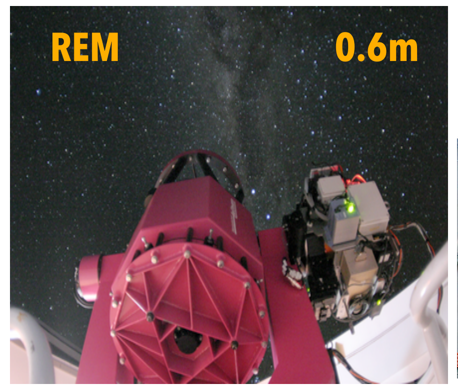
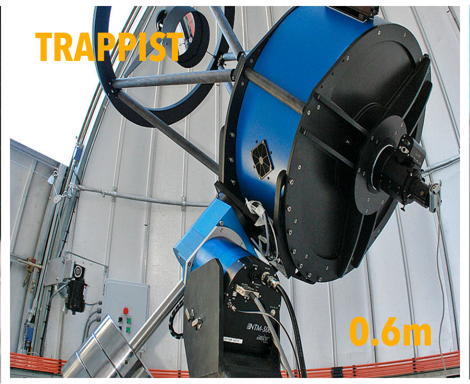
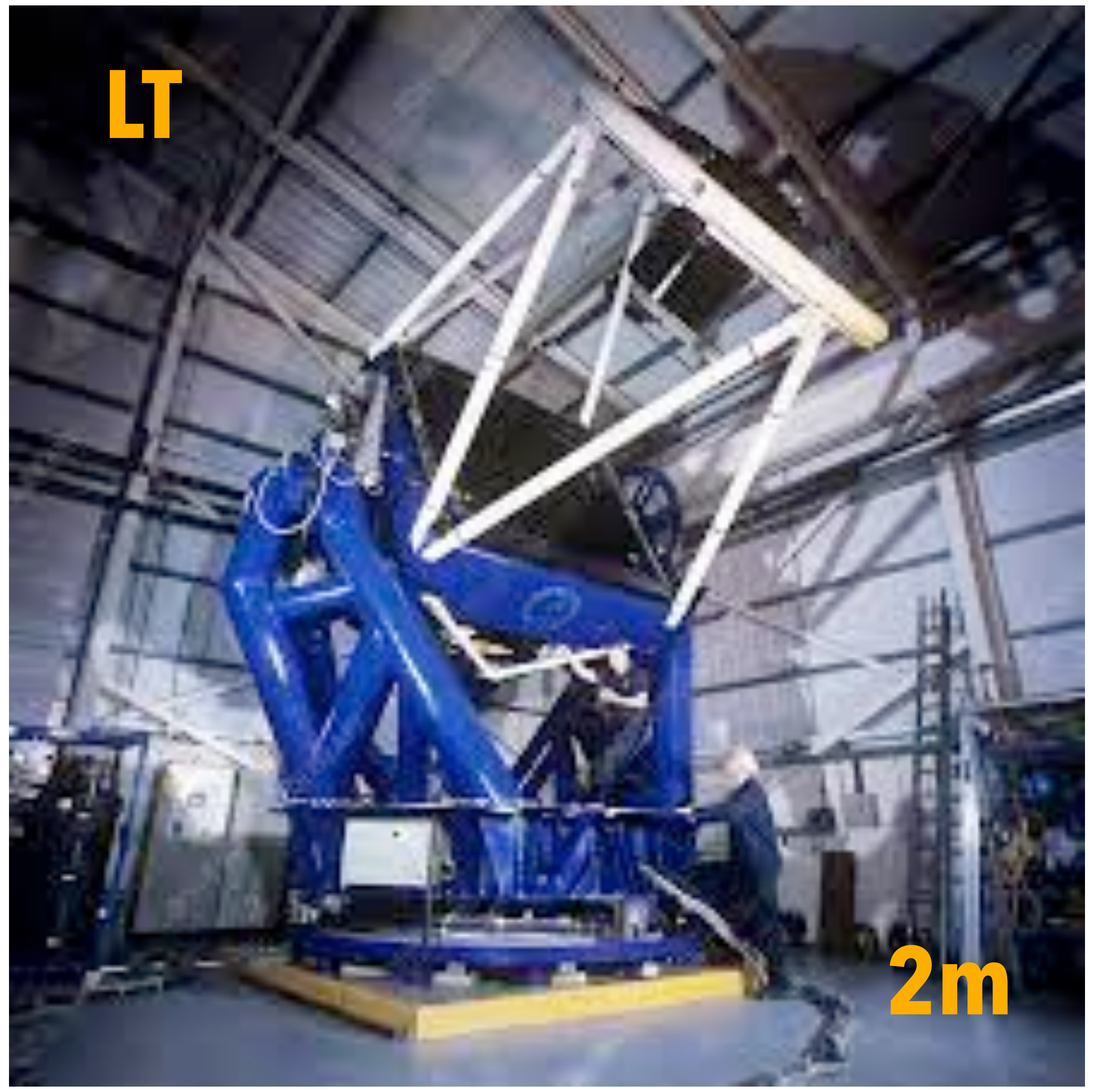
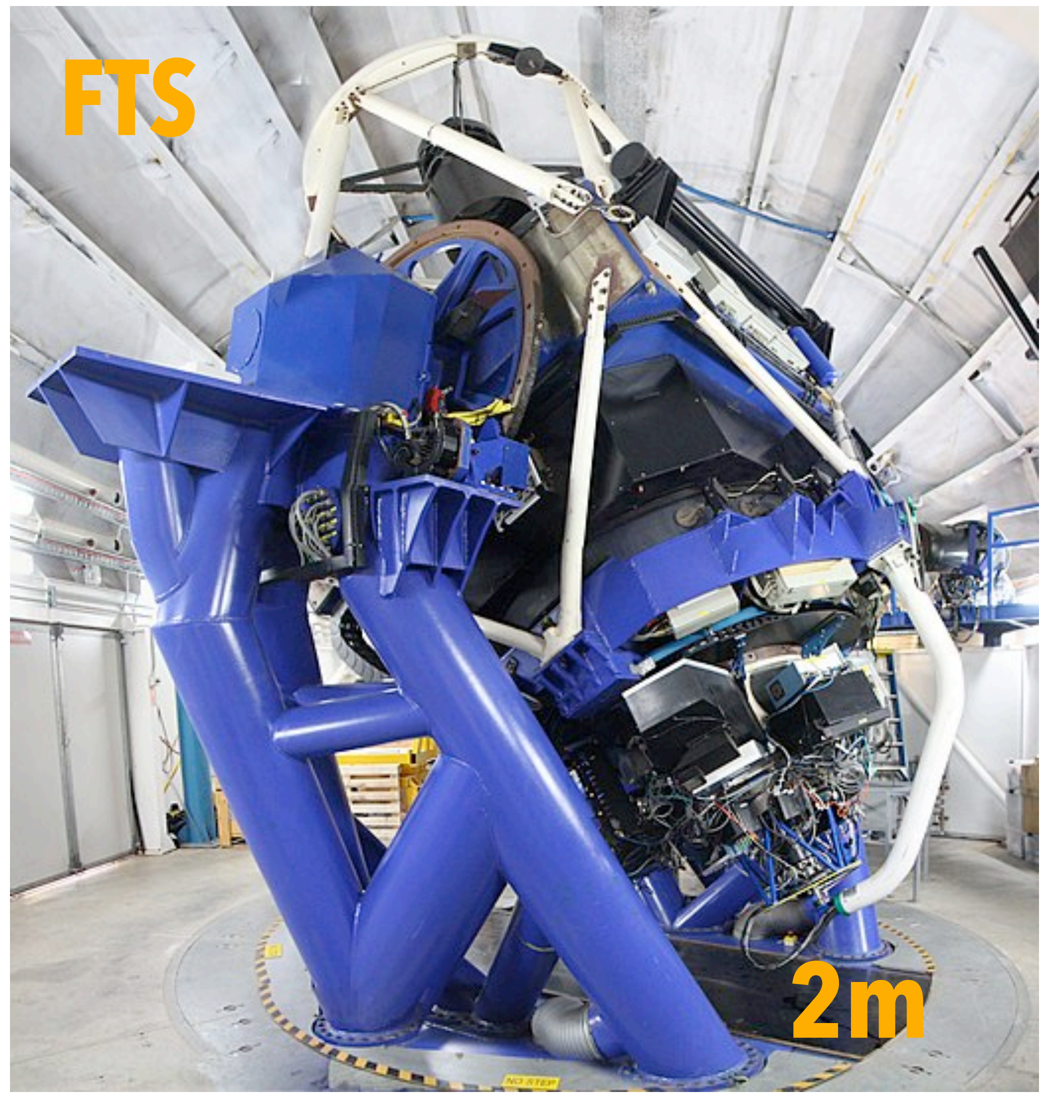




1m < Size < 3m





Available Robotic Telescopes

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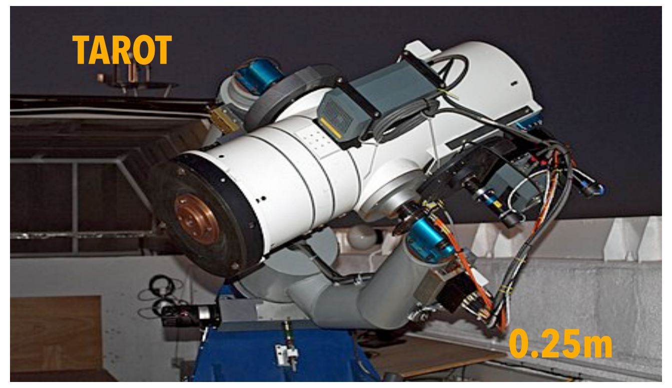

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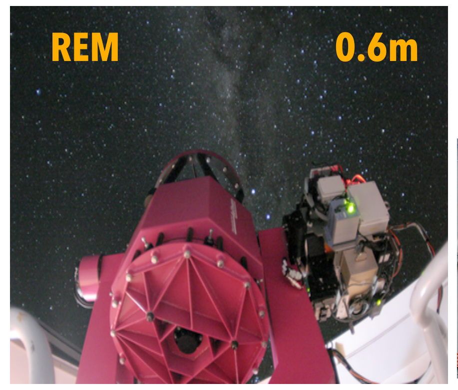
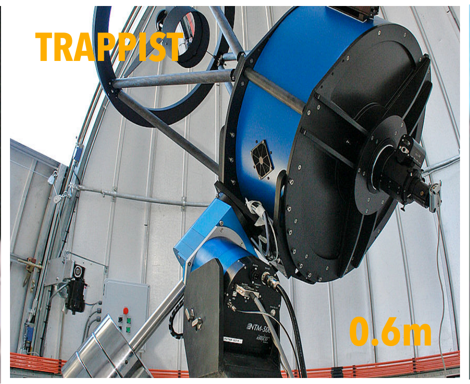
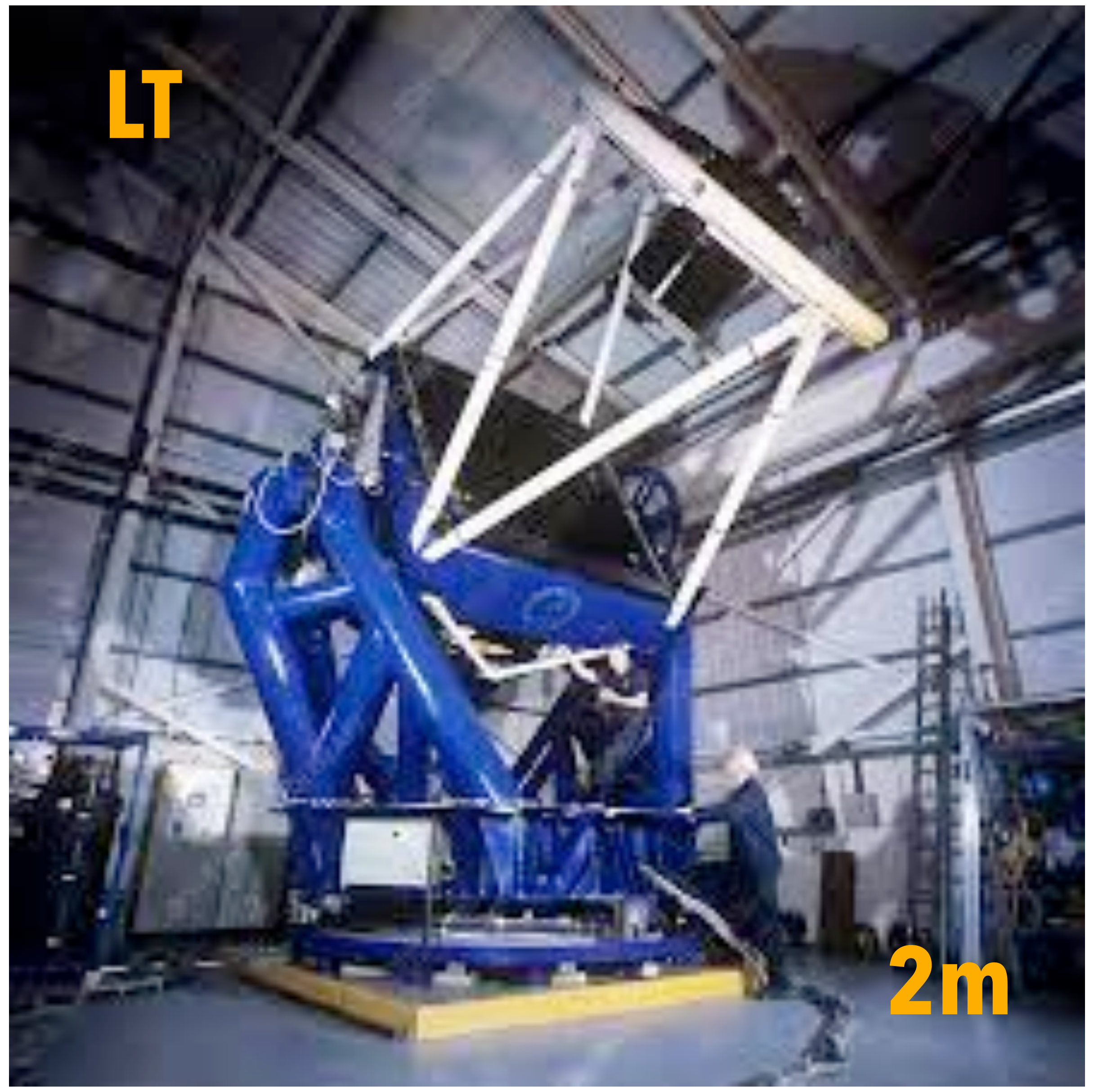
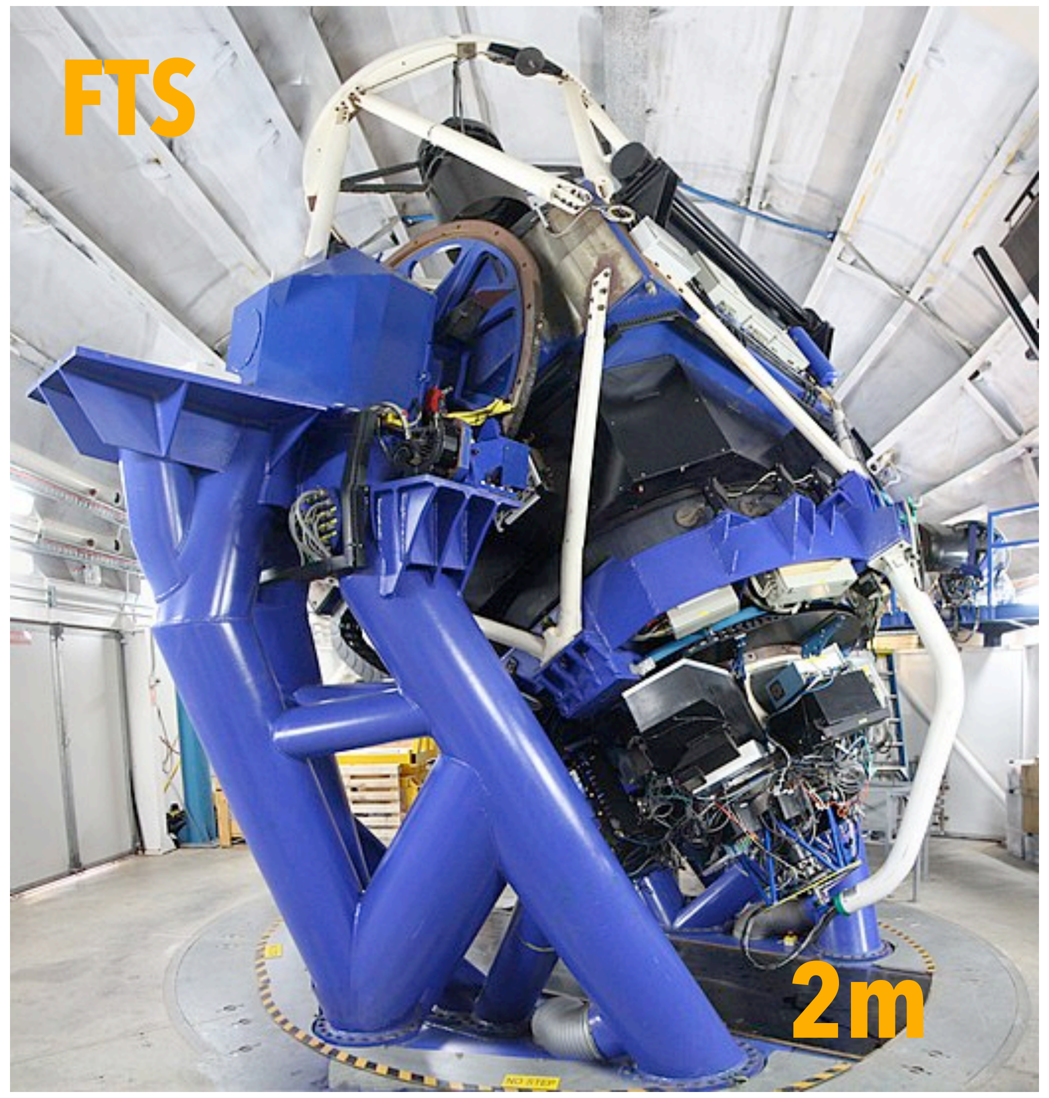




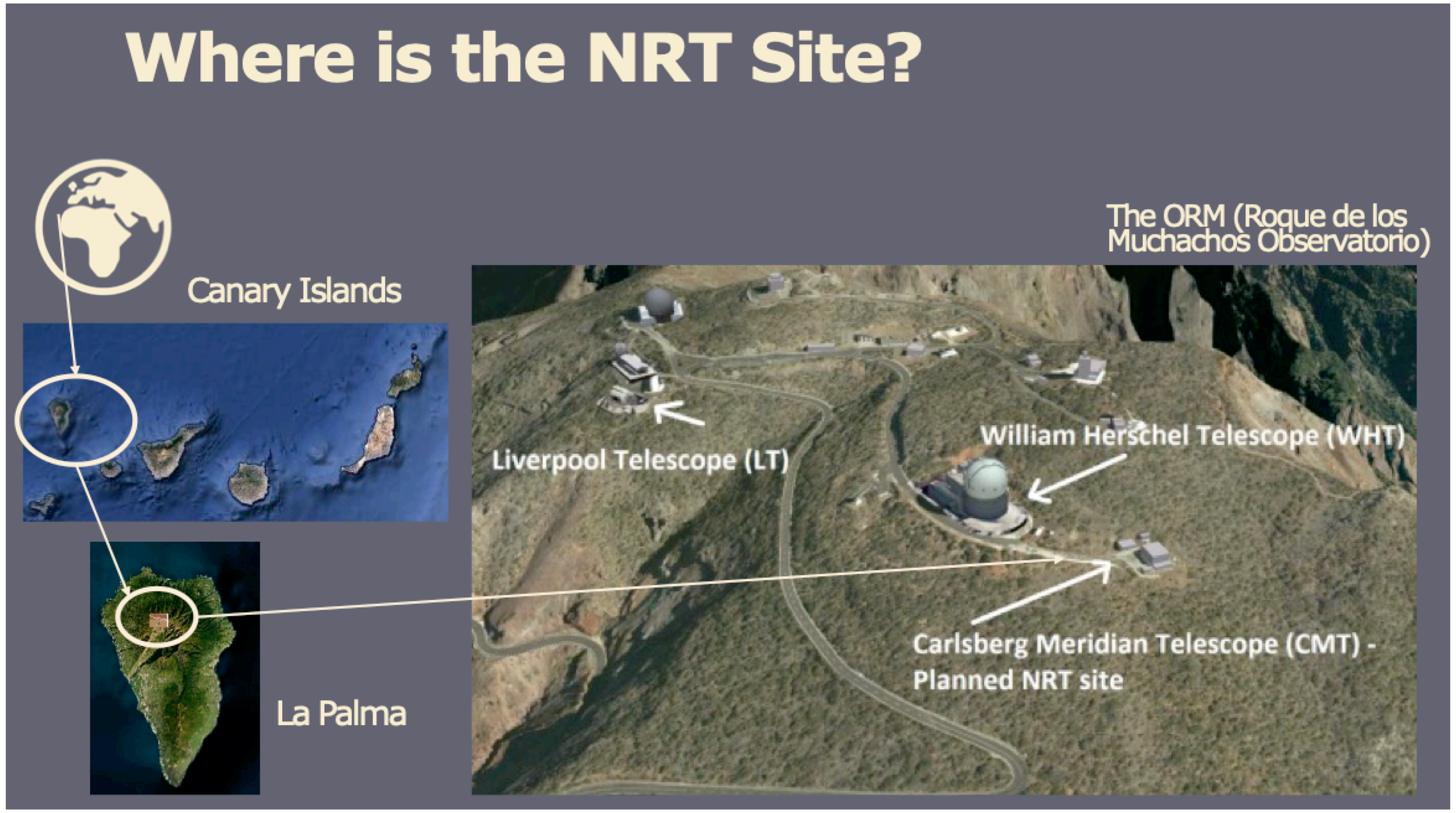




Why not bigger?

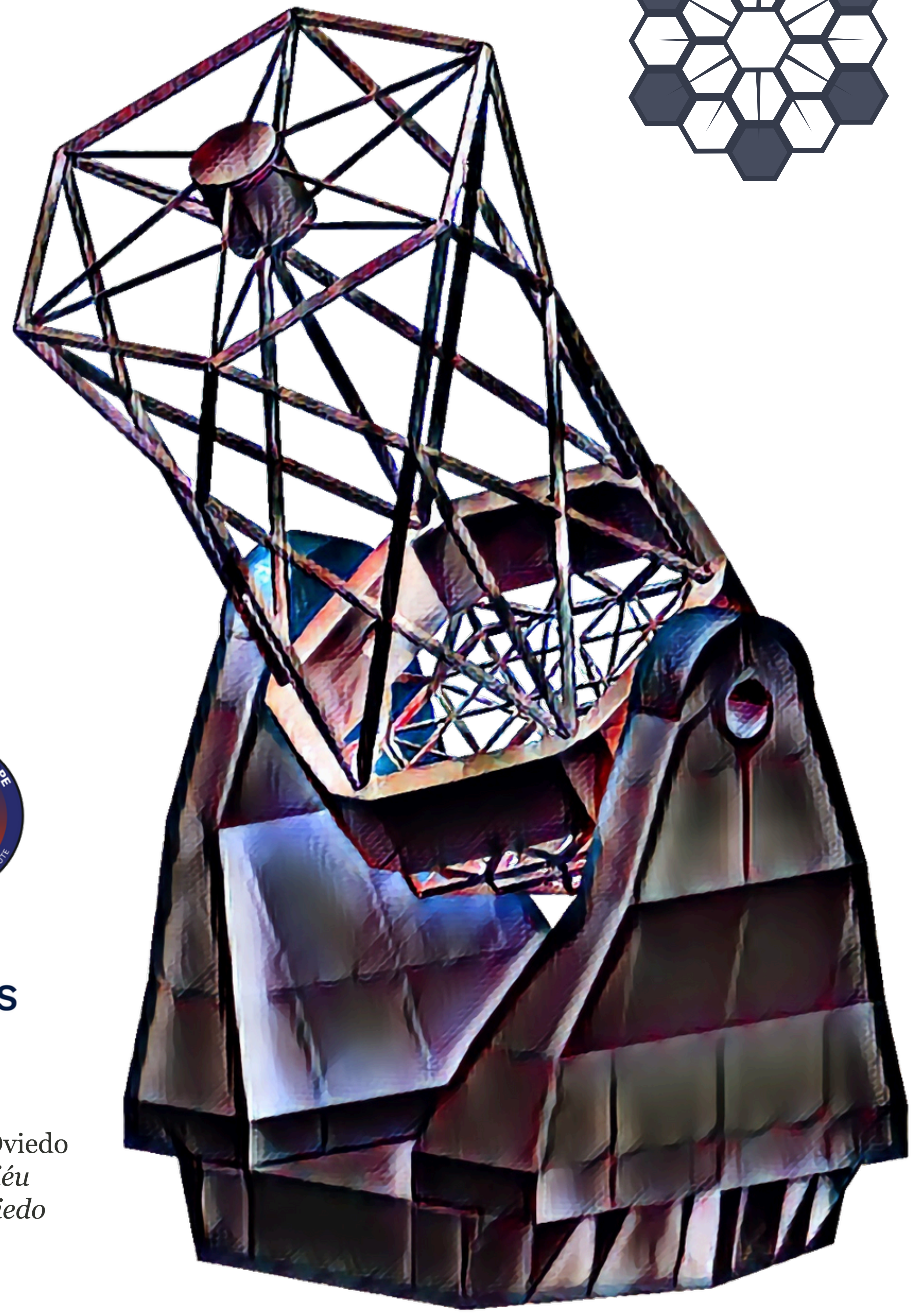
New Robotic Telescope

- Largest robotic telescope !!
- Located on La Palma at the ORM; site approved
- 4.2 metre clear aperture, F/10.8
- Clamshell enclosure: efficient, no dome seeing



LIVERPOOL JOHN MOORES UNIVERSITY

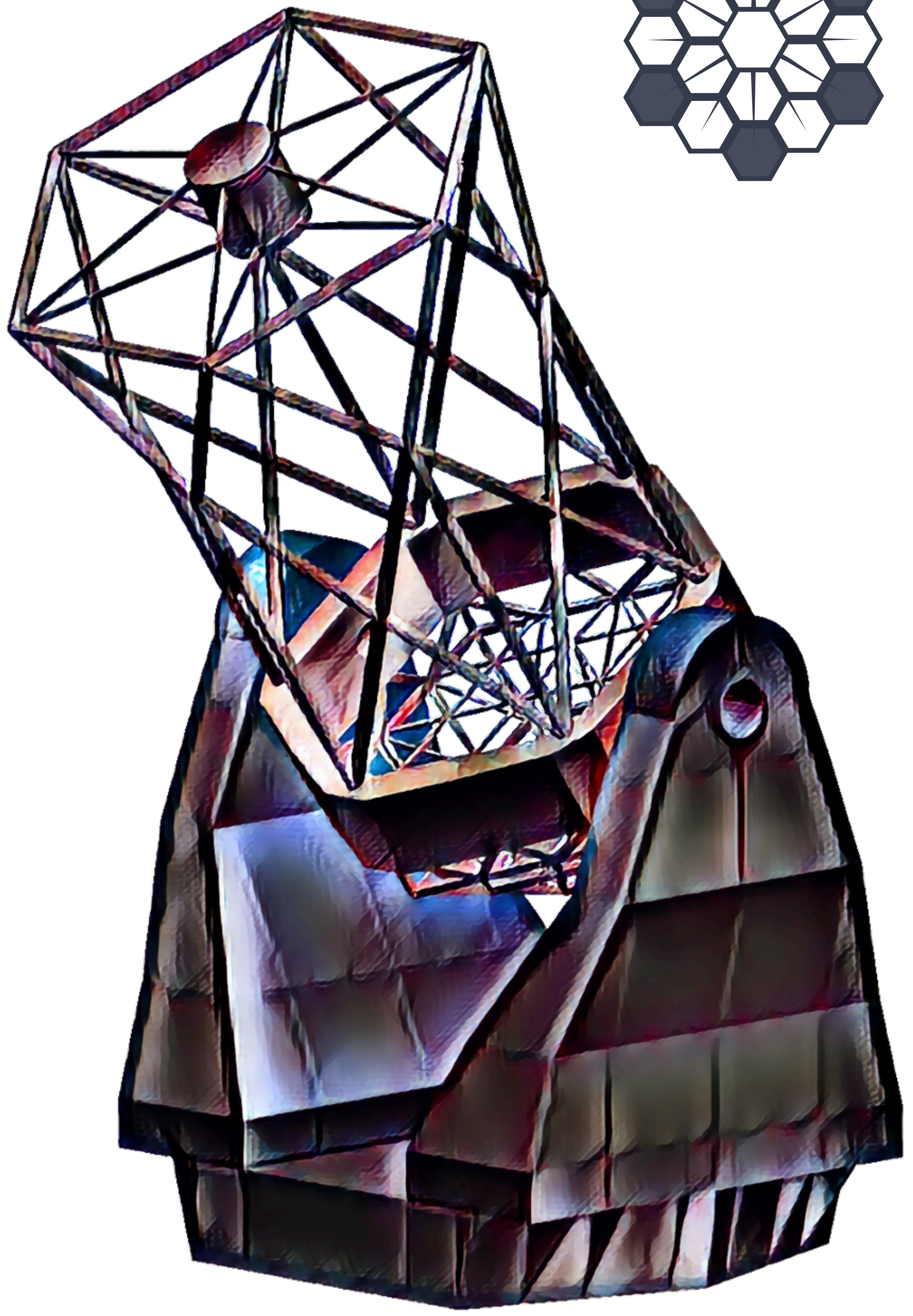
Universidad de Oviedo
Universidá d'Uviéu
University of Oviedo



Courtesy of H. Jenmak

New Robotic Telescope

- First on target, fast slewing
- Autonomous, robotic operation: unstaffed facility
- Intelligent scheduler with 'look-ahead capabilities'
- Will not replace LT: combined facility



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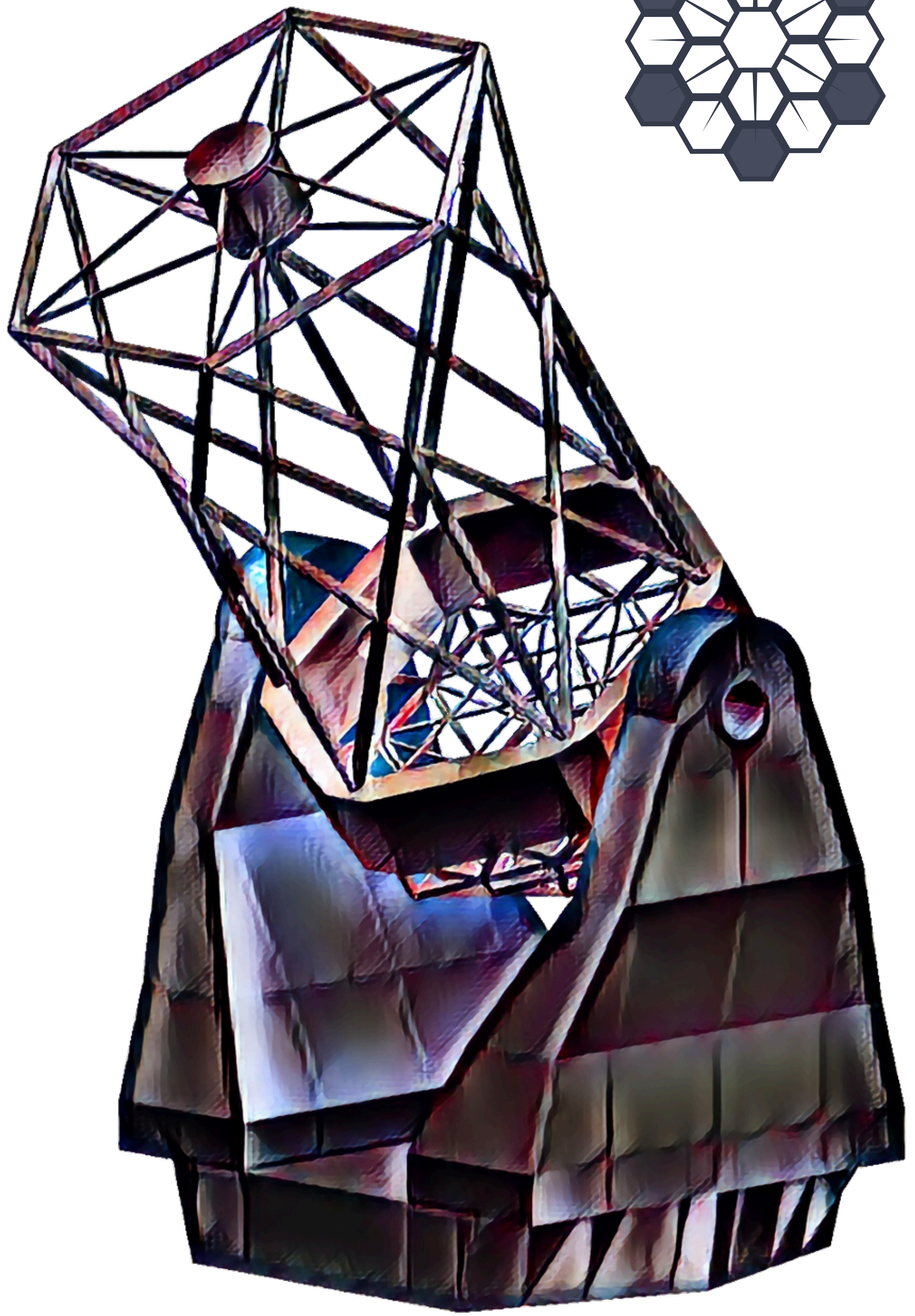
Sensitive. Rapid. Efficient.

(repointing in ~30 s)



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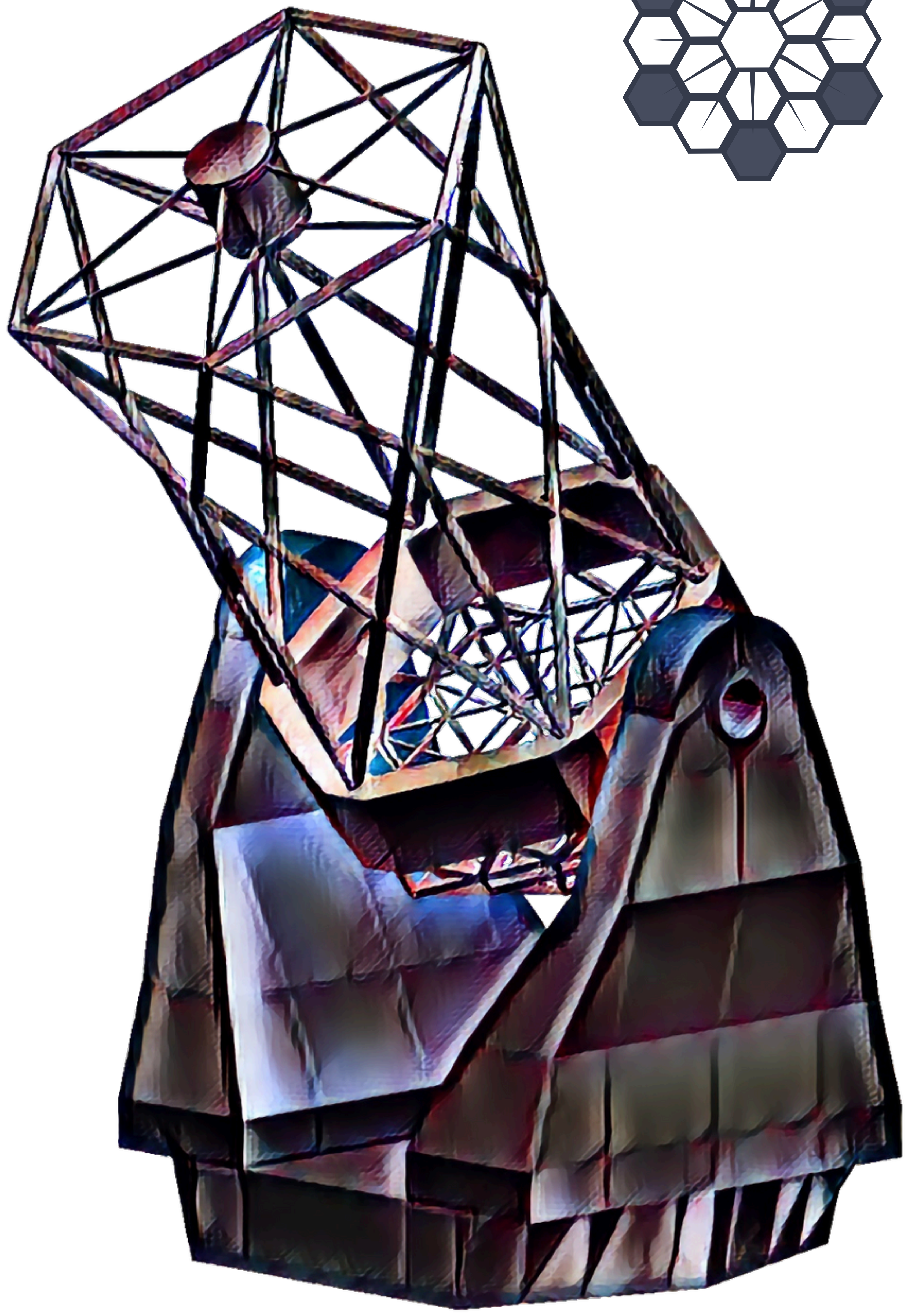
Time Domain Astronomy



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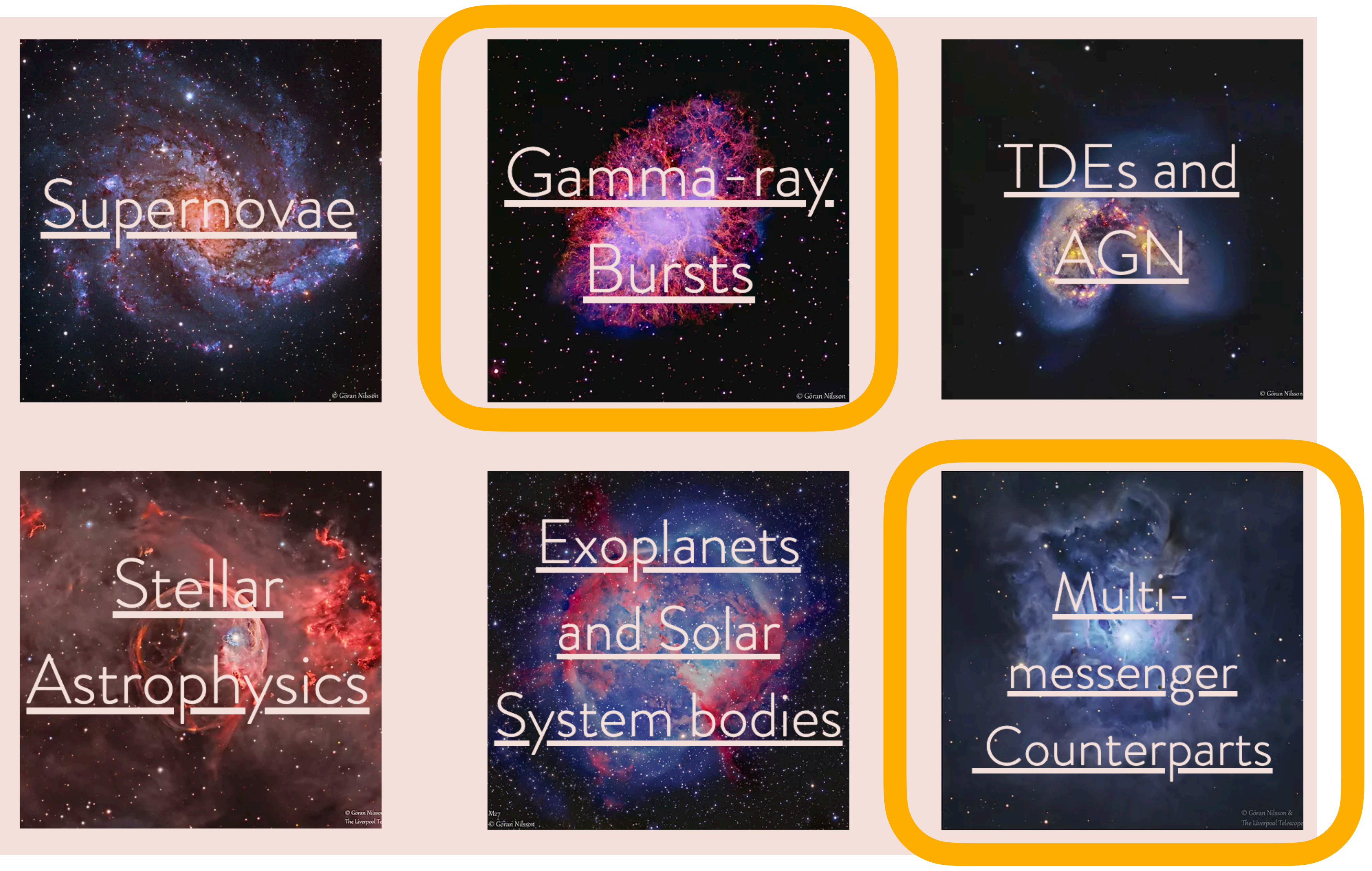
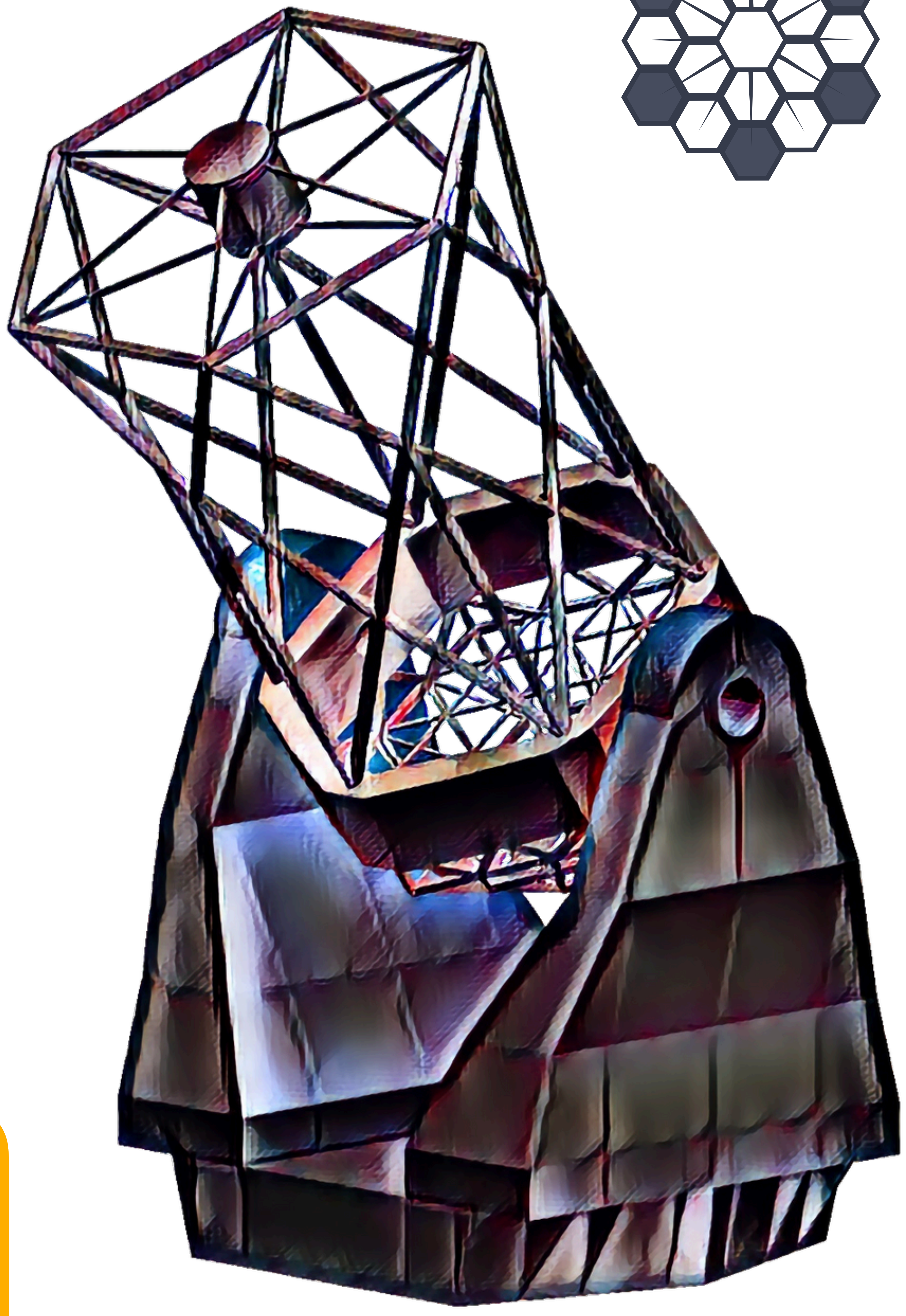


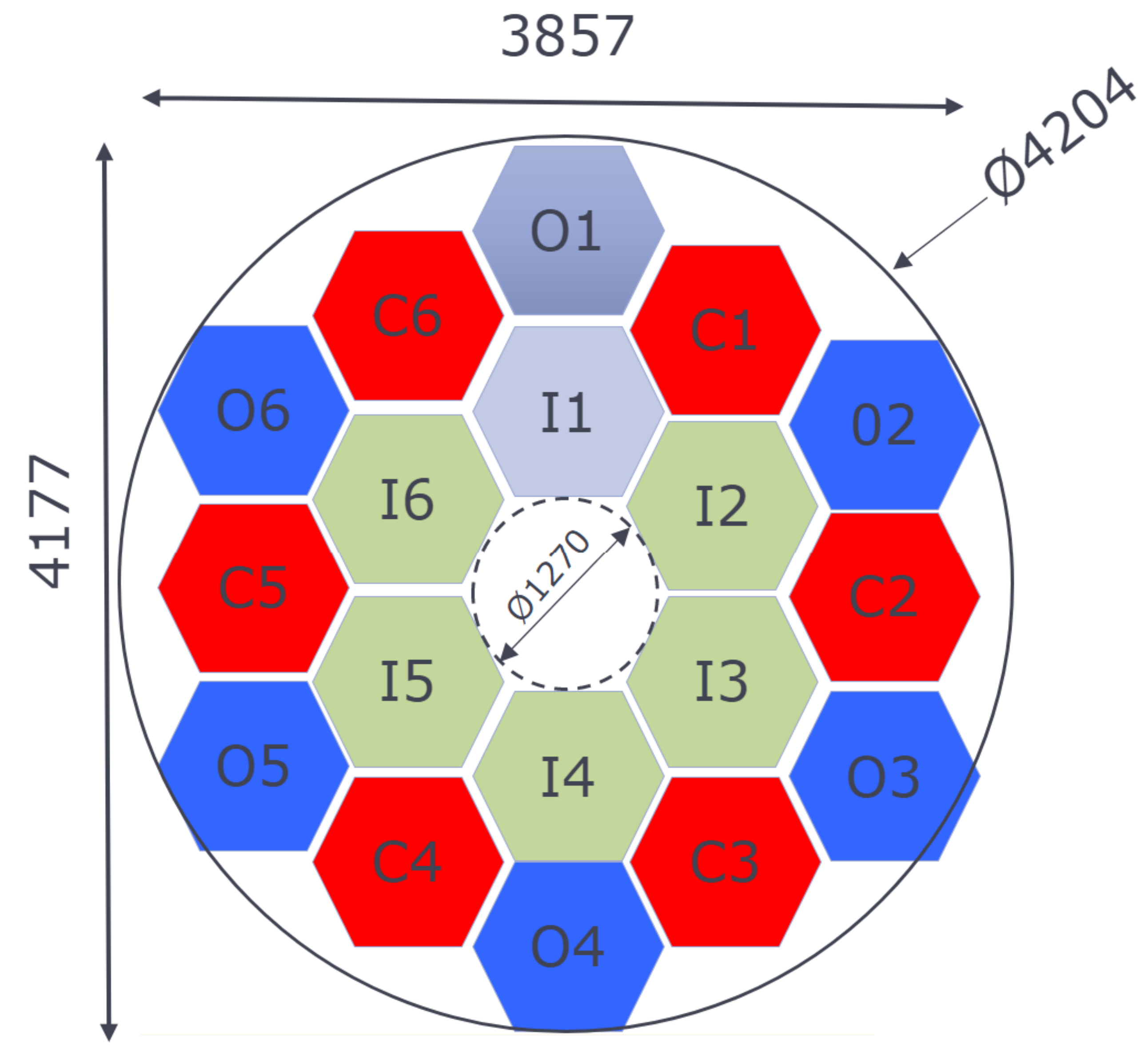


Courtesy of H. Jenmak

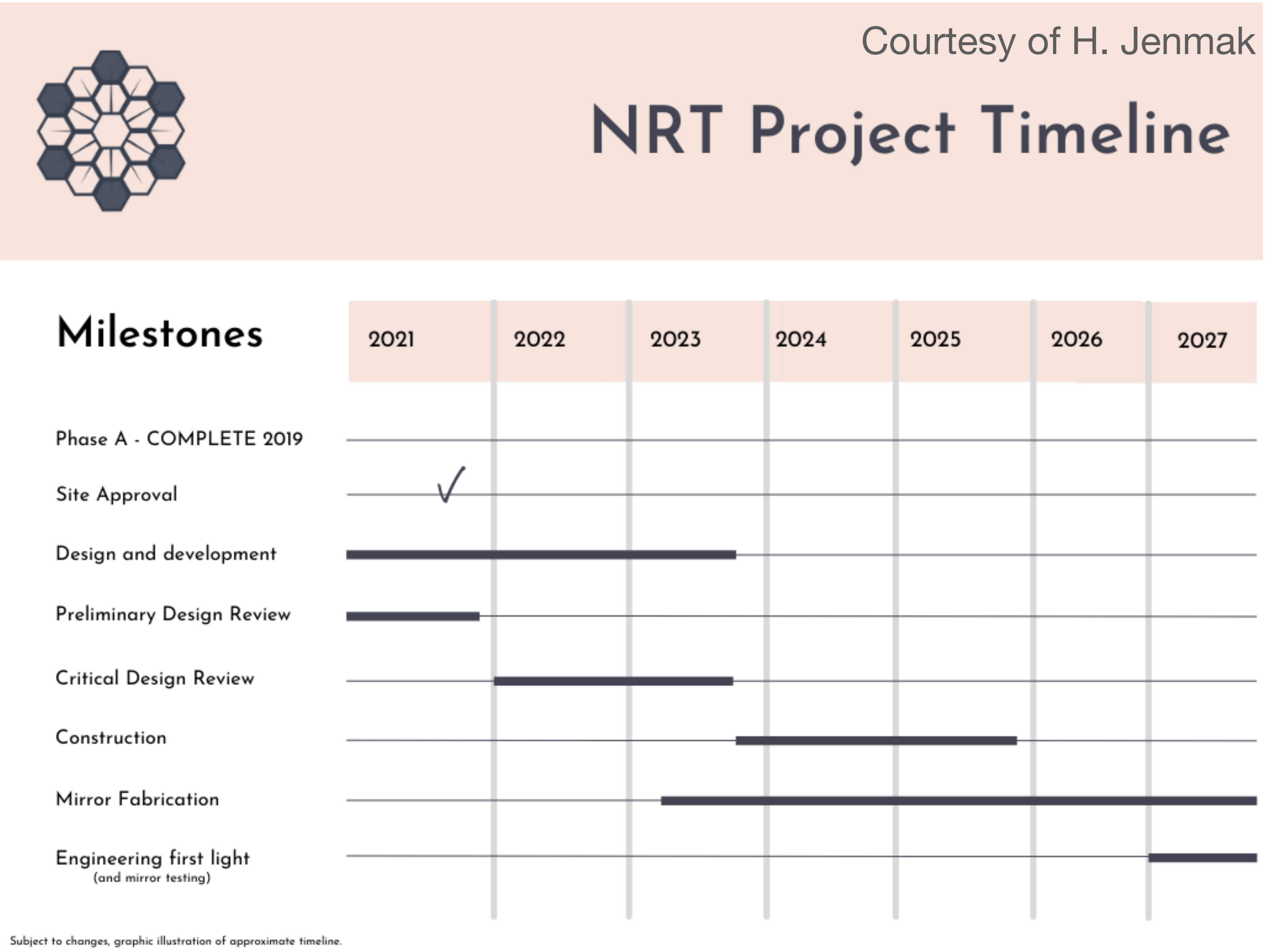
New Robotic Telescope

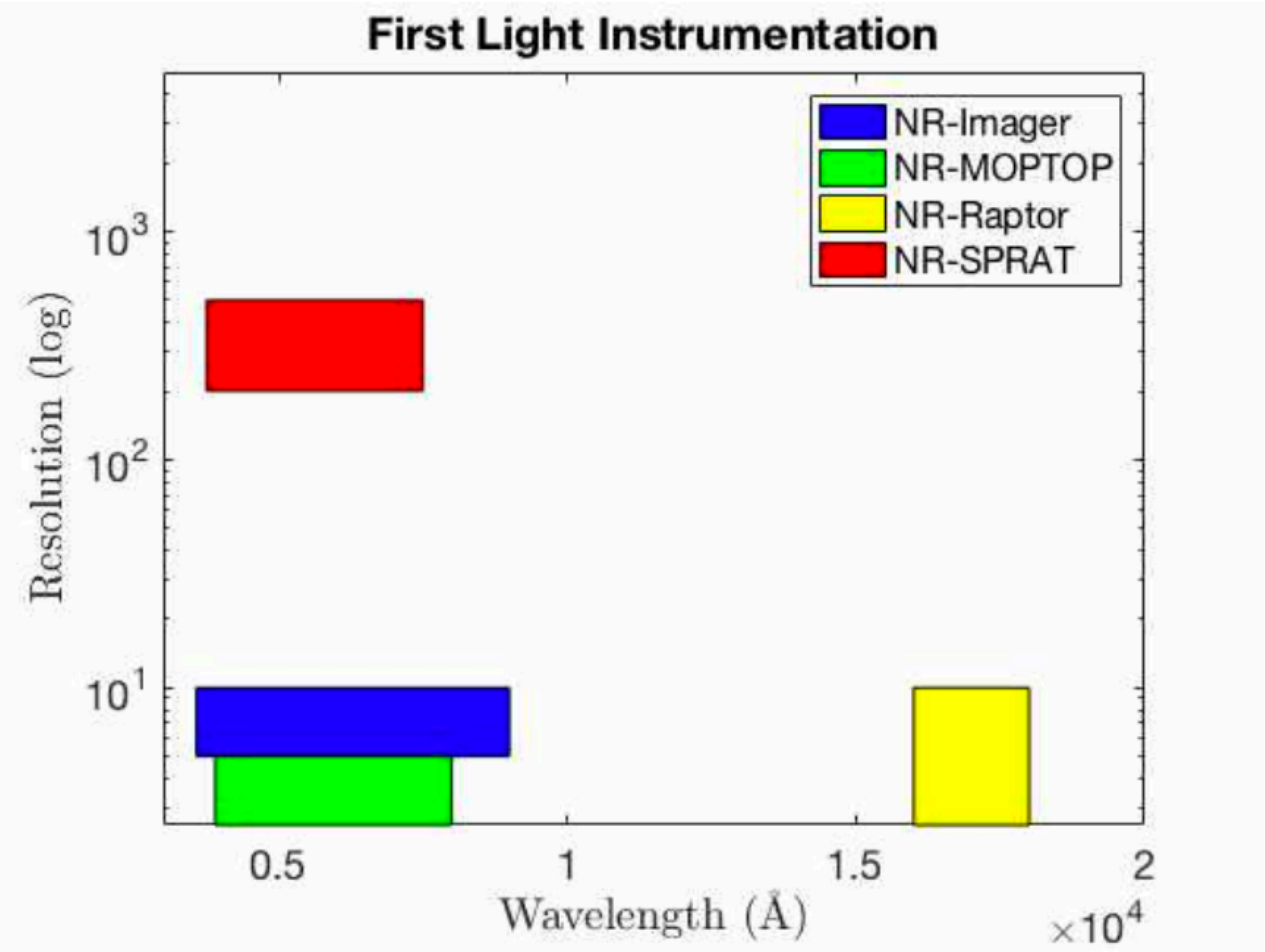
- Cassegrain focal station with 7 instrument ports
- FoV 14 (side) and 30 arcmins (straight through)
- Polarimetric capabilities
- Segmented (18 hexagons) primary mirror
  - Lightweight
  - Easier to fabricate and for operations and maintenance

INSTRUMENT	Wavelength	Field Of View	Notes	Science Cases
NR-SPRAT	3750 - 7500 Å	12 x 12 arcsec	IFU Spectrograph R=360	Type Ia SNe, Type II SNe, unknown transients (e.g. AT2018cow), strongly lensed SNe, GW counterparts, TDEs, exoplanets, solar system bodies
NR-IMAGER	3500 - 10000 Å	7.5 x 7.5 arcmin	*ugriz* filter set	Superluminous SNe, strongly lensed SNe, exoplanet transits
NR-MOPTOP	4000 - 8000 Å	5 x 5 arcmin	Polarimeter BVRI filter set	GRBs, blazars, unknown transients, CTA follow-up, GW counterparts
NR-RAPTOR	1.6 - 1.8 μm	3.2 x 2.6 arcmin	H band filter	Type Ia SNe, GW counterparts, faint red transients, dust forming novae

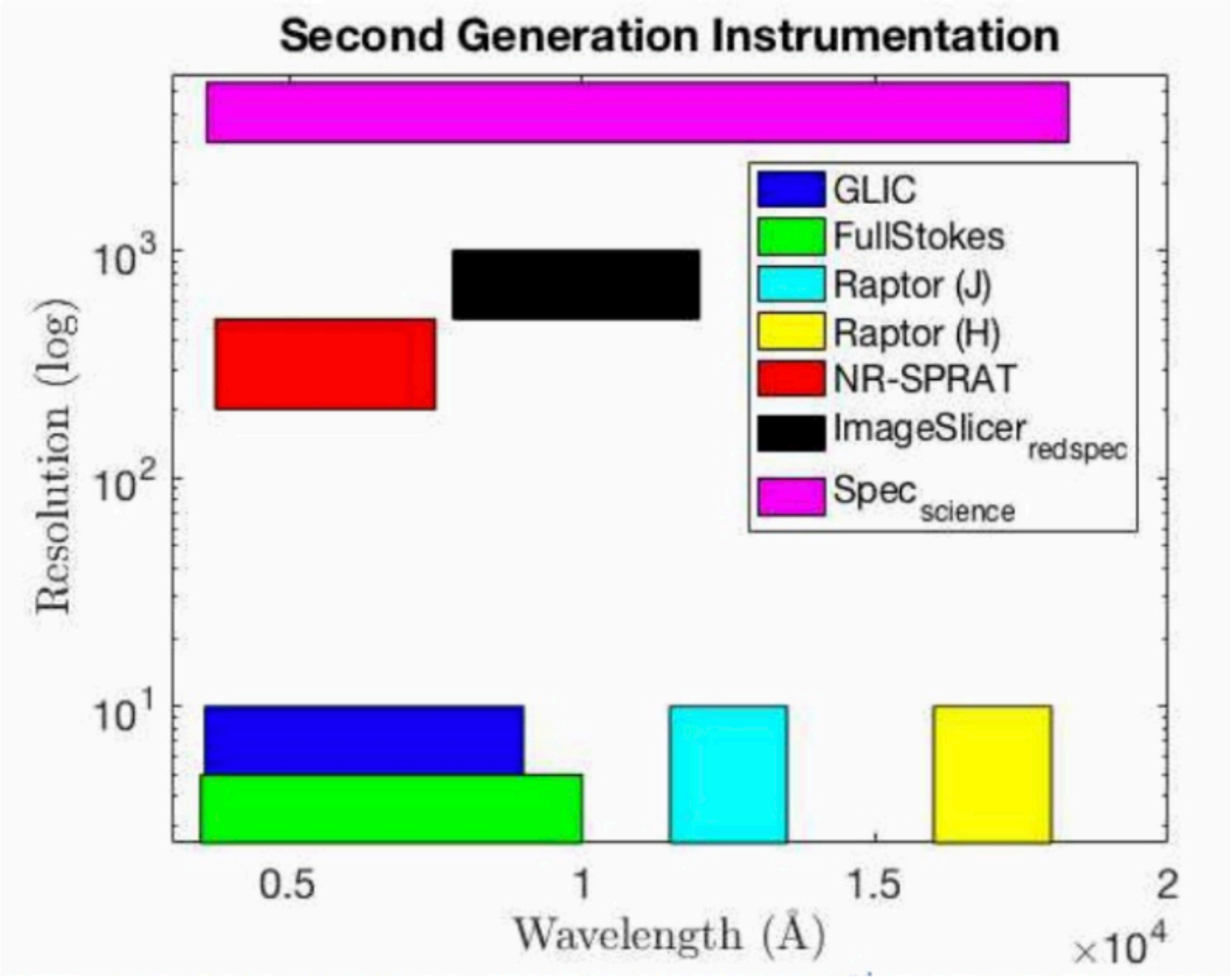


Primary Mirror Segment Identification



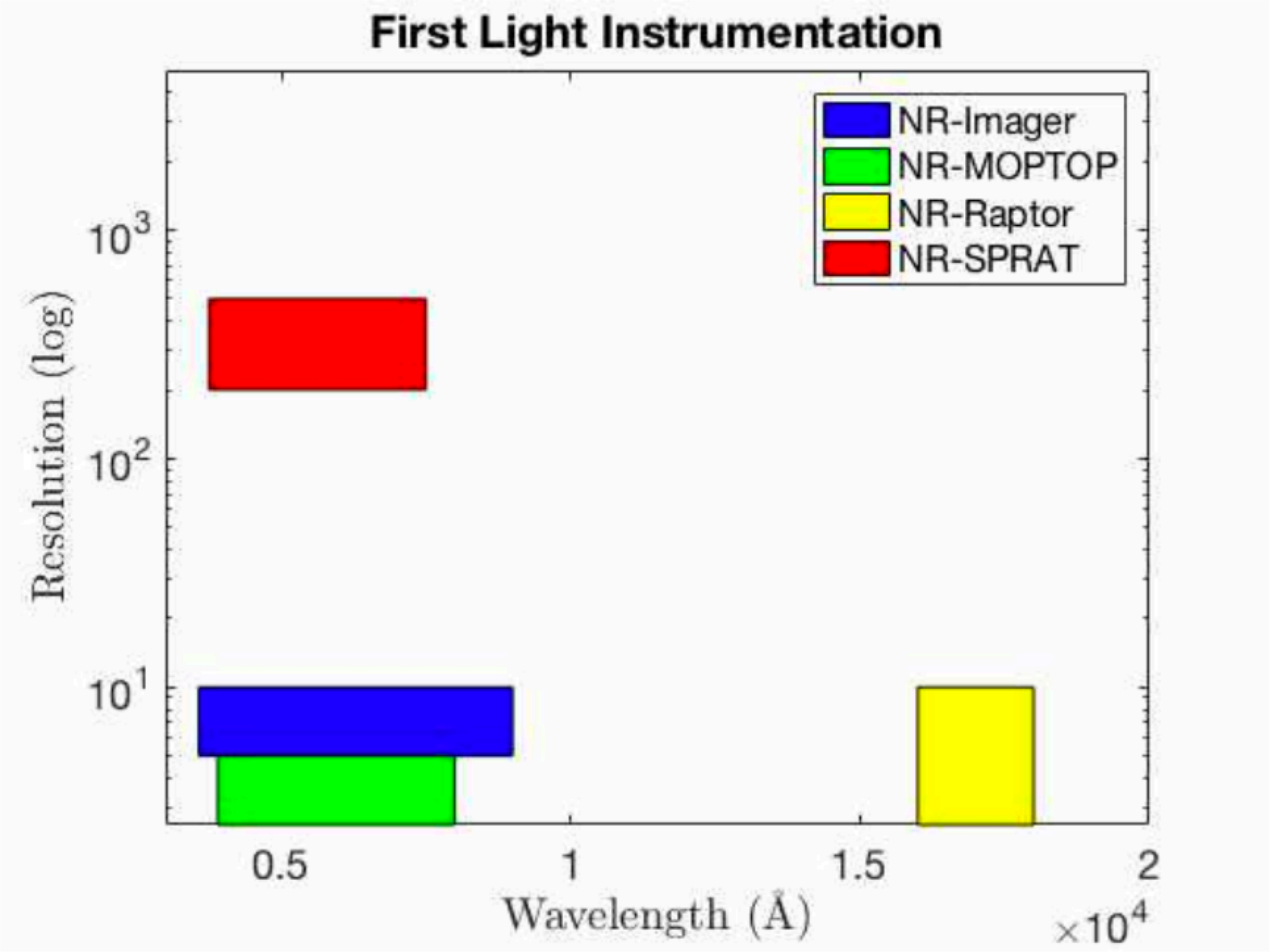


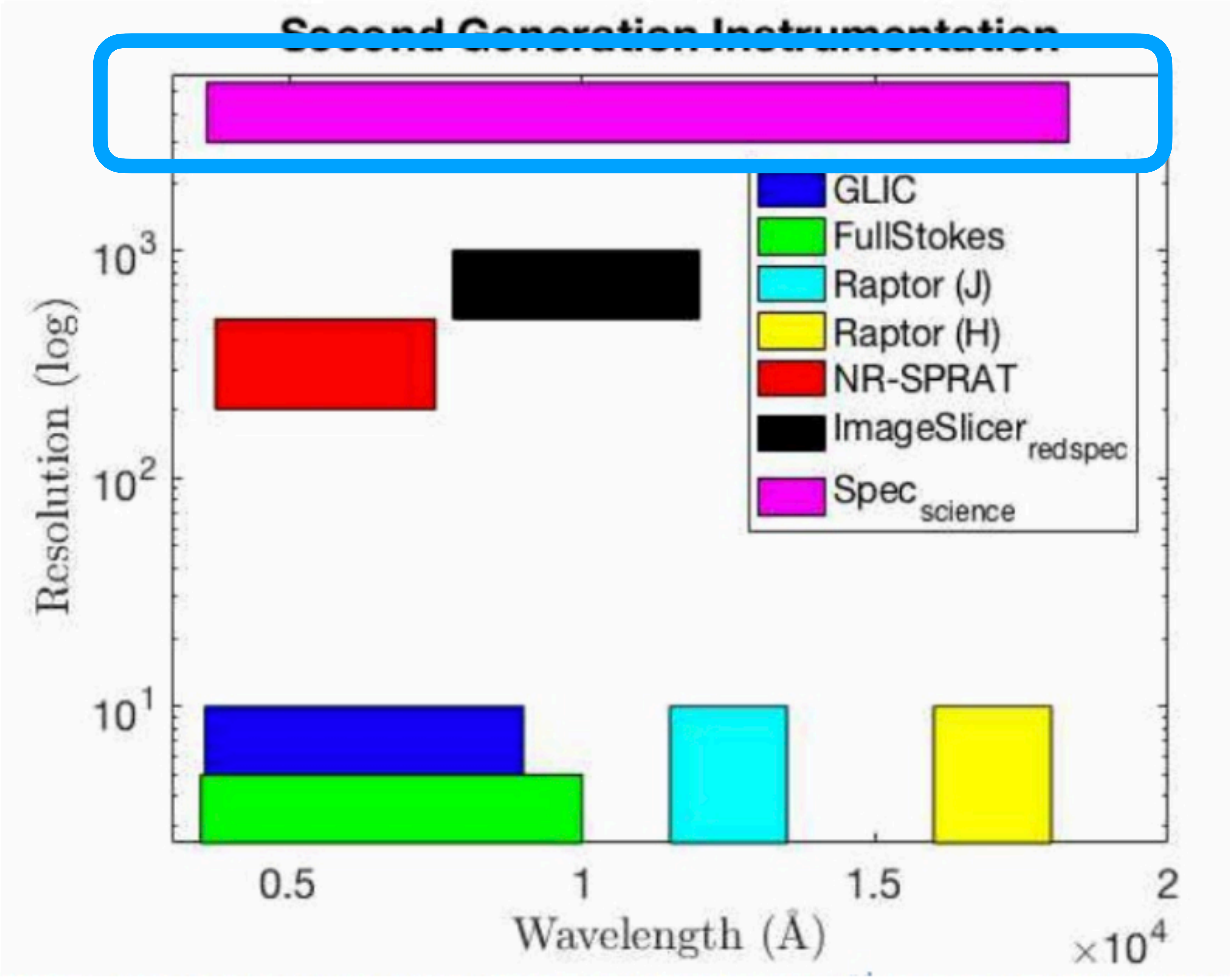
First Light Instrumentation
NR-Imager
NR-MOPTOP
NR-Raptor
NR-SPRAT
Resolution (log)
10^3
10^2
10^1
0.5
1
1.5
2
Wavelength (Å)
$\times 10^4$



Second Generation Instrumentation
GLIC
FullStokes
Raptor (J)
Raptor (H)
NR-SPRAT
ImageSlicer$_{redspec}$
Spec$_{science}$
Resolution (log)
10^3
10^2
10^1
0.5
1
1.5
2
Wavelength (Å)
$\times 10^4$

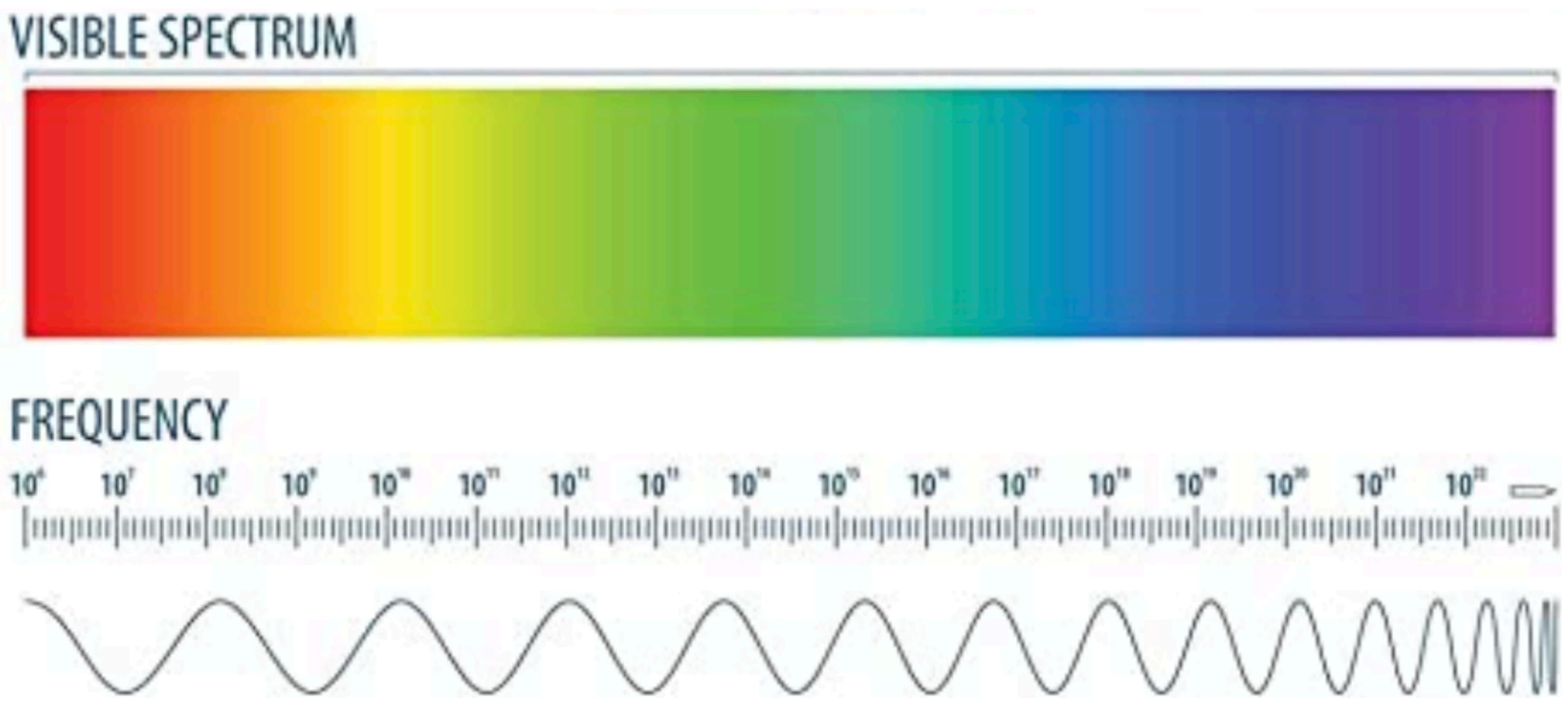
Key instrument: SOXS-like intermediate resolution spectrograph





Time Domain Landscape

why now?



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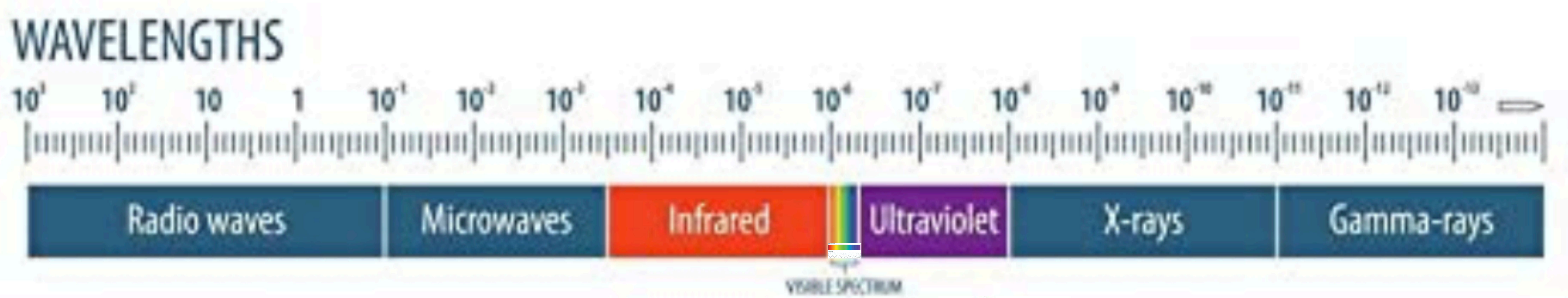

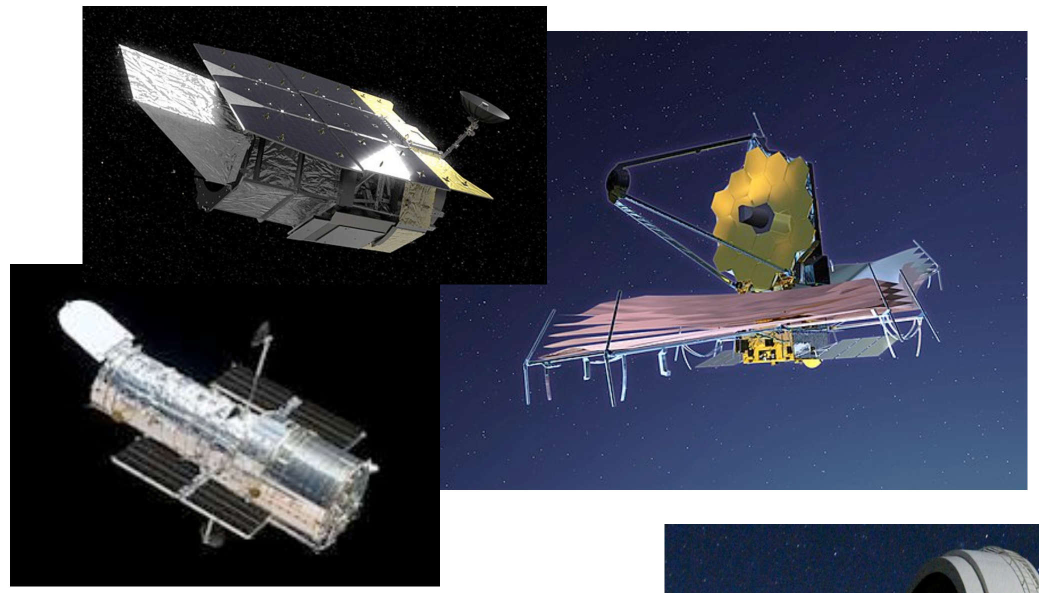

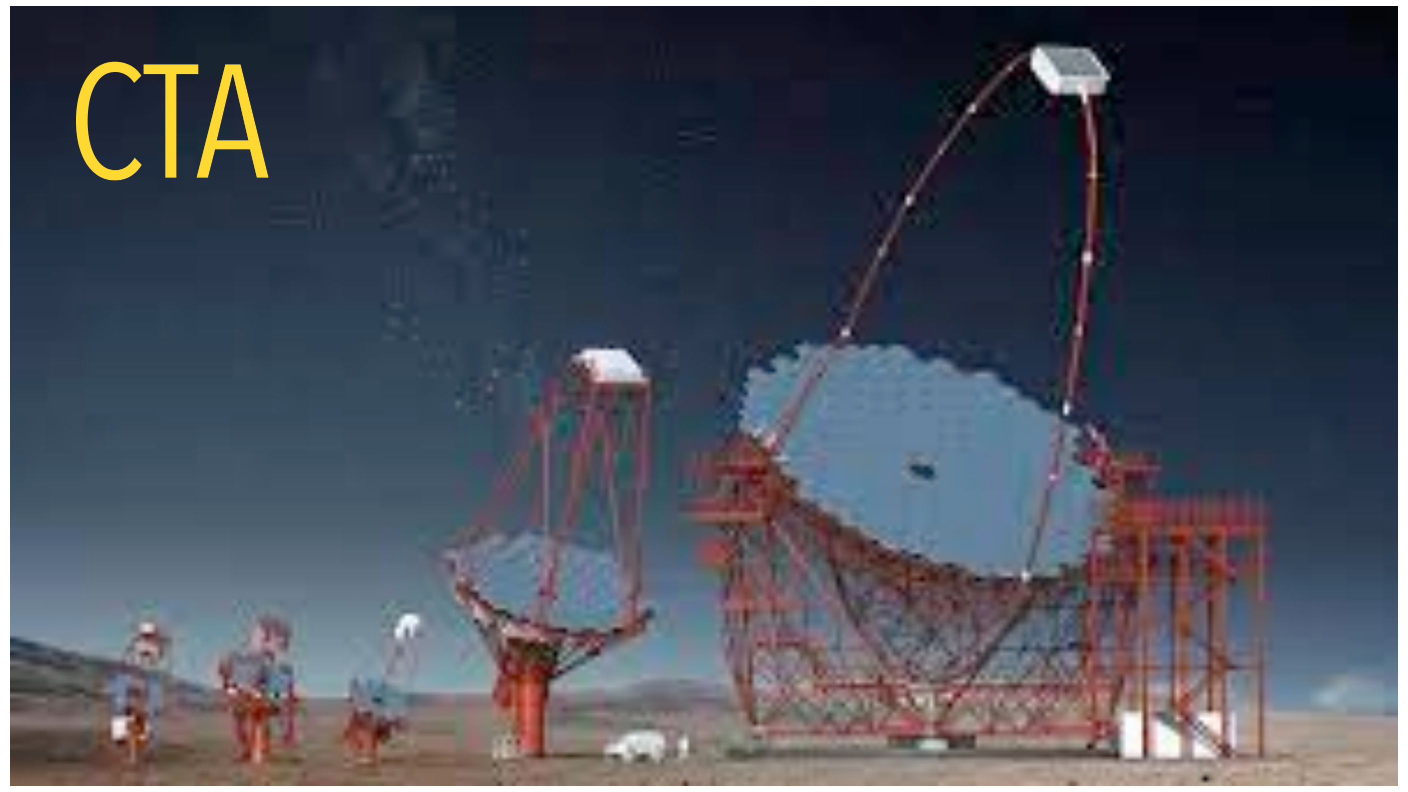

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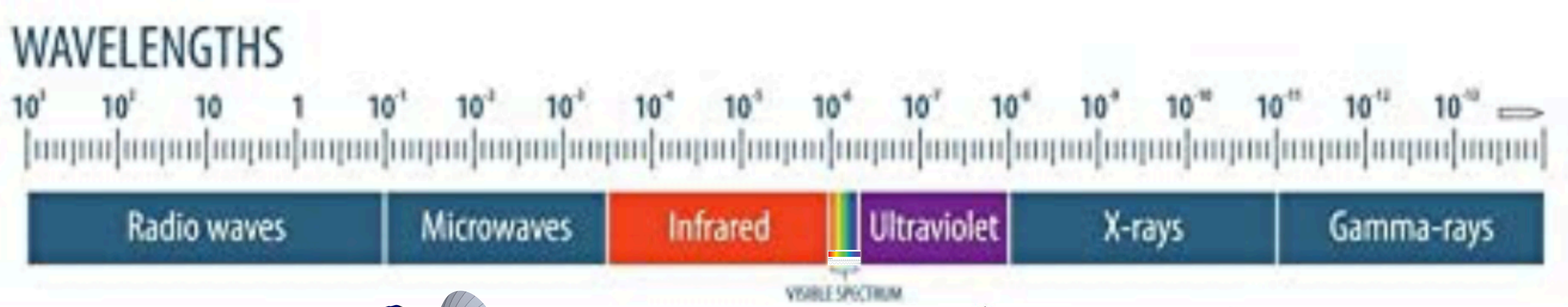
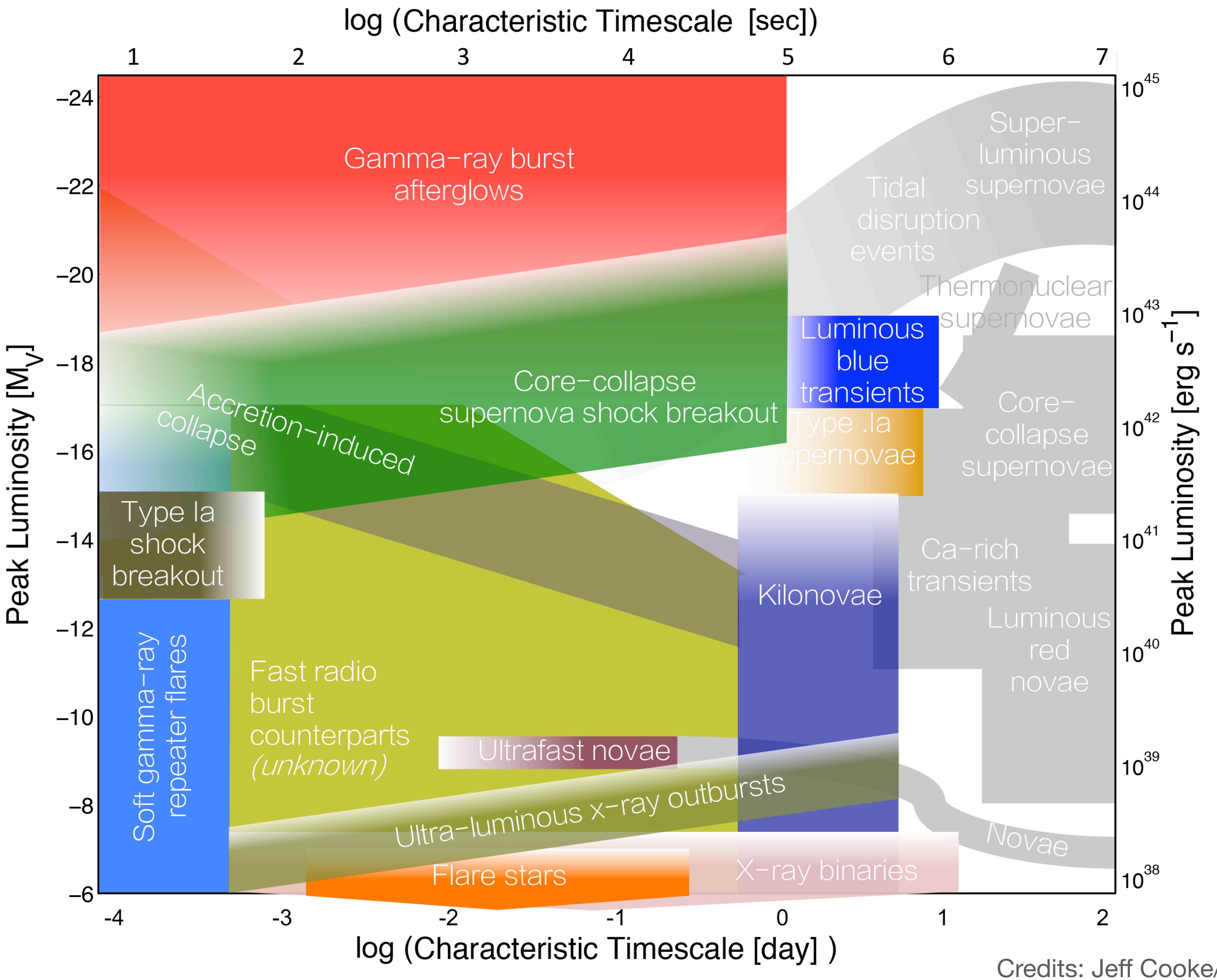


Time Domain Landscape



Credits: Jeff Cooke/Swinburne University of Technology

Time Domain Landscape

why now?

- **Survey Era**: capacity to follow-up these targets has been massively outpaced

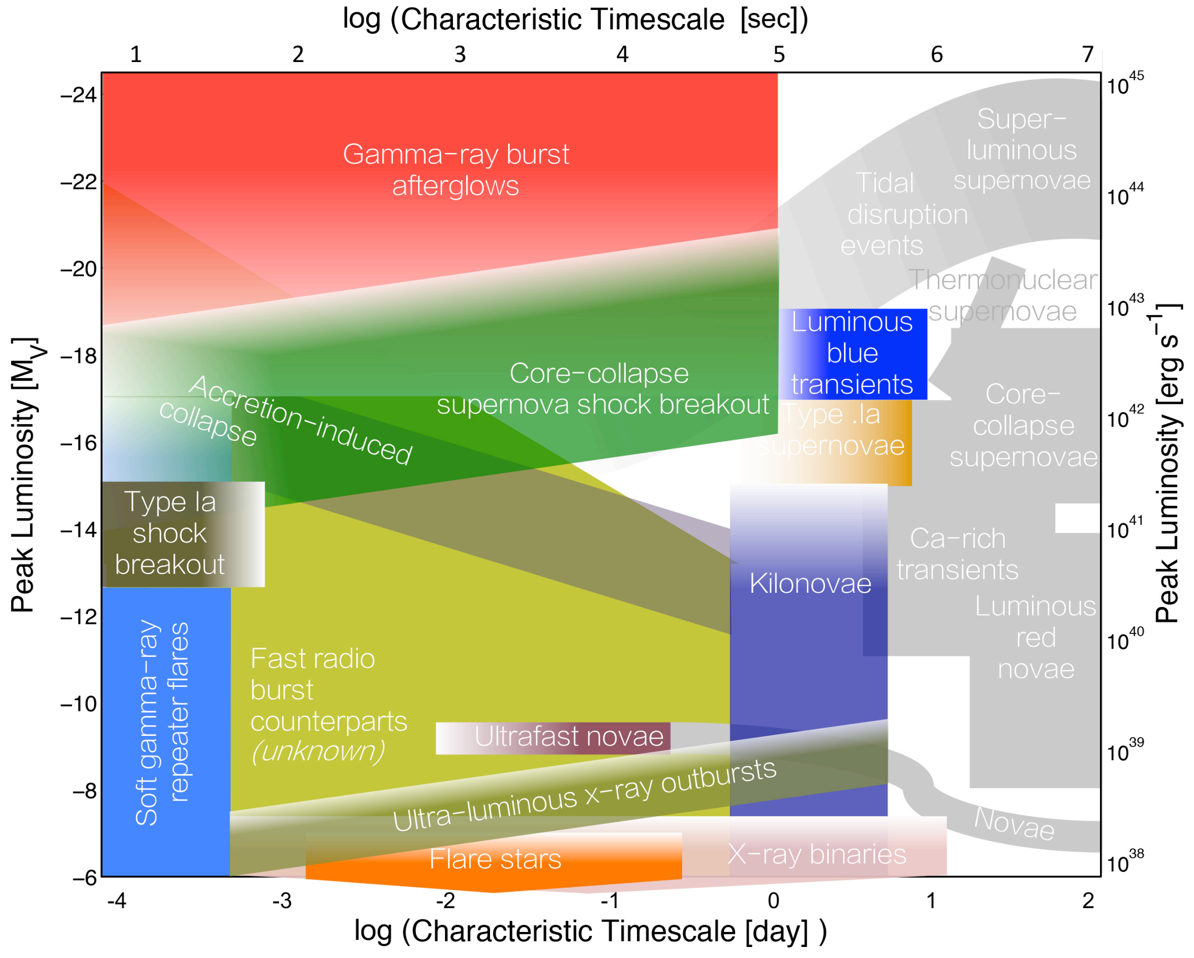
  (only 10-20% of transients get a spectroscopic classification)

- Explore new parameter space for known transients

  (e.g. pre-SN burst, shock breakout, rising emission or precursors, etc…)

- Discover new types of transients

  (SLSNs, fast rising transients, etc…)



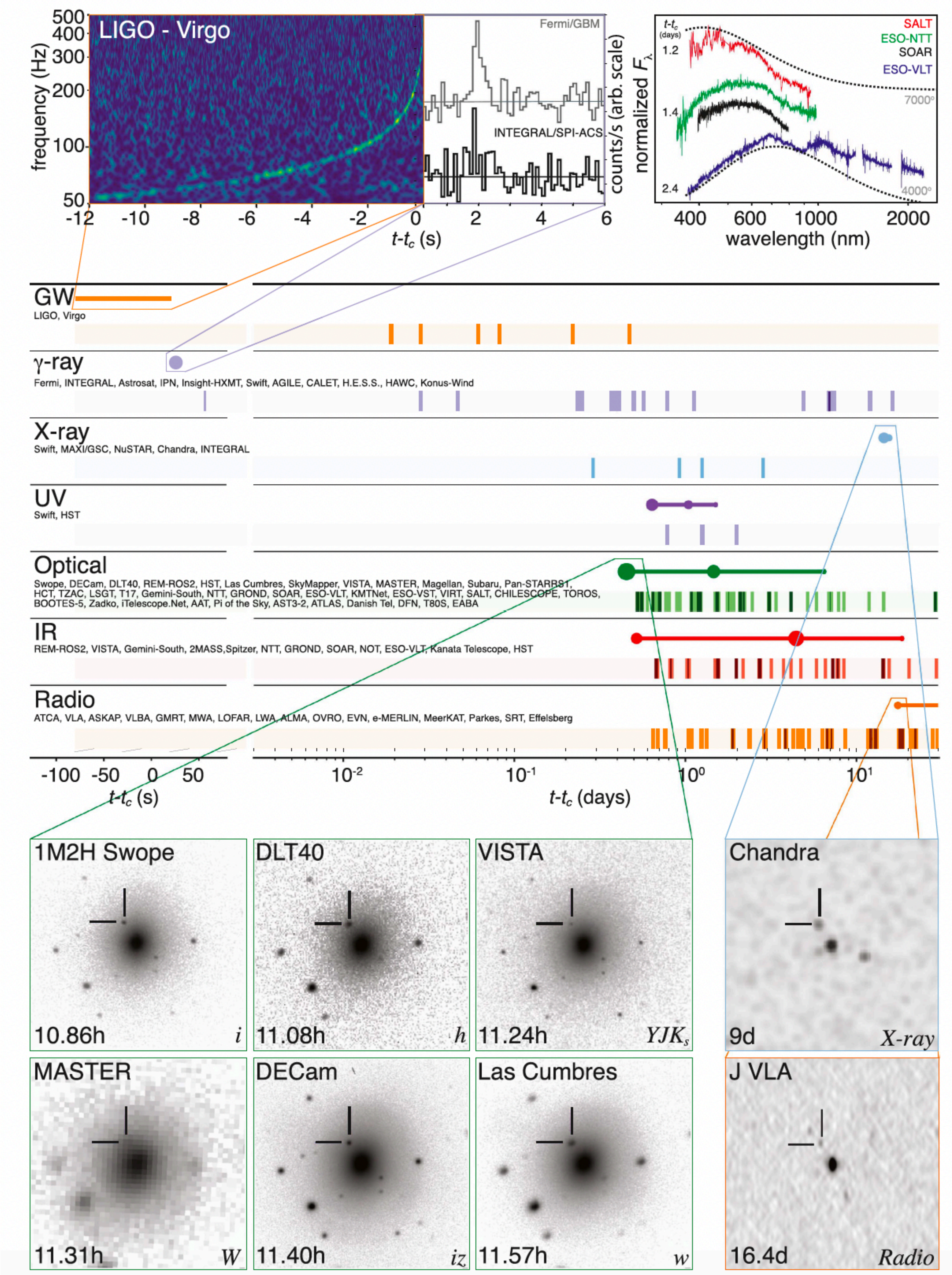
Multi-wavelengths Astrophysics

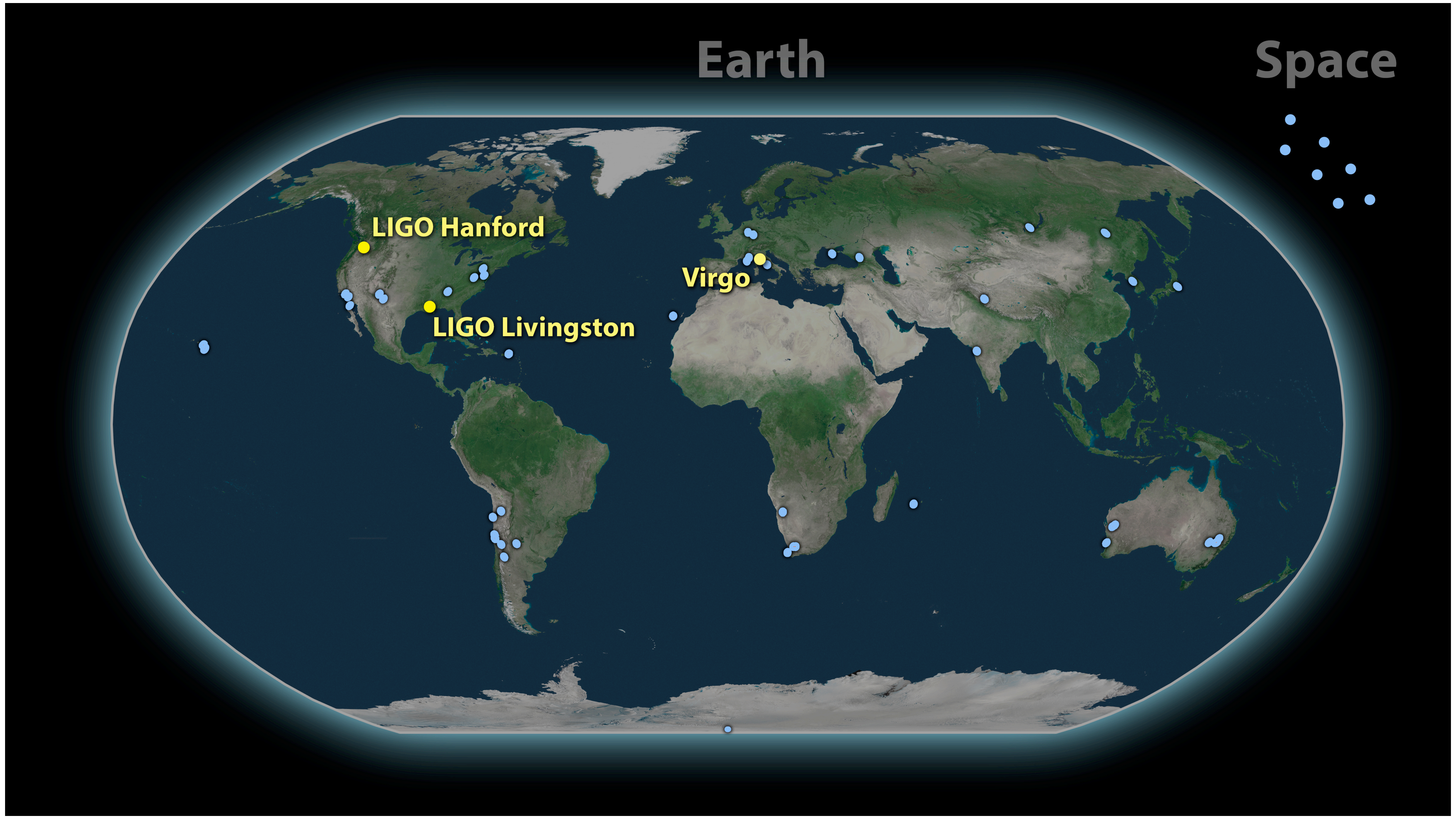
(from radio to gamma)

Multi-messenger Astrophysics

(EM, neutrinos, GW)

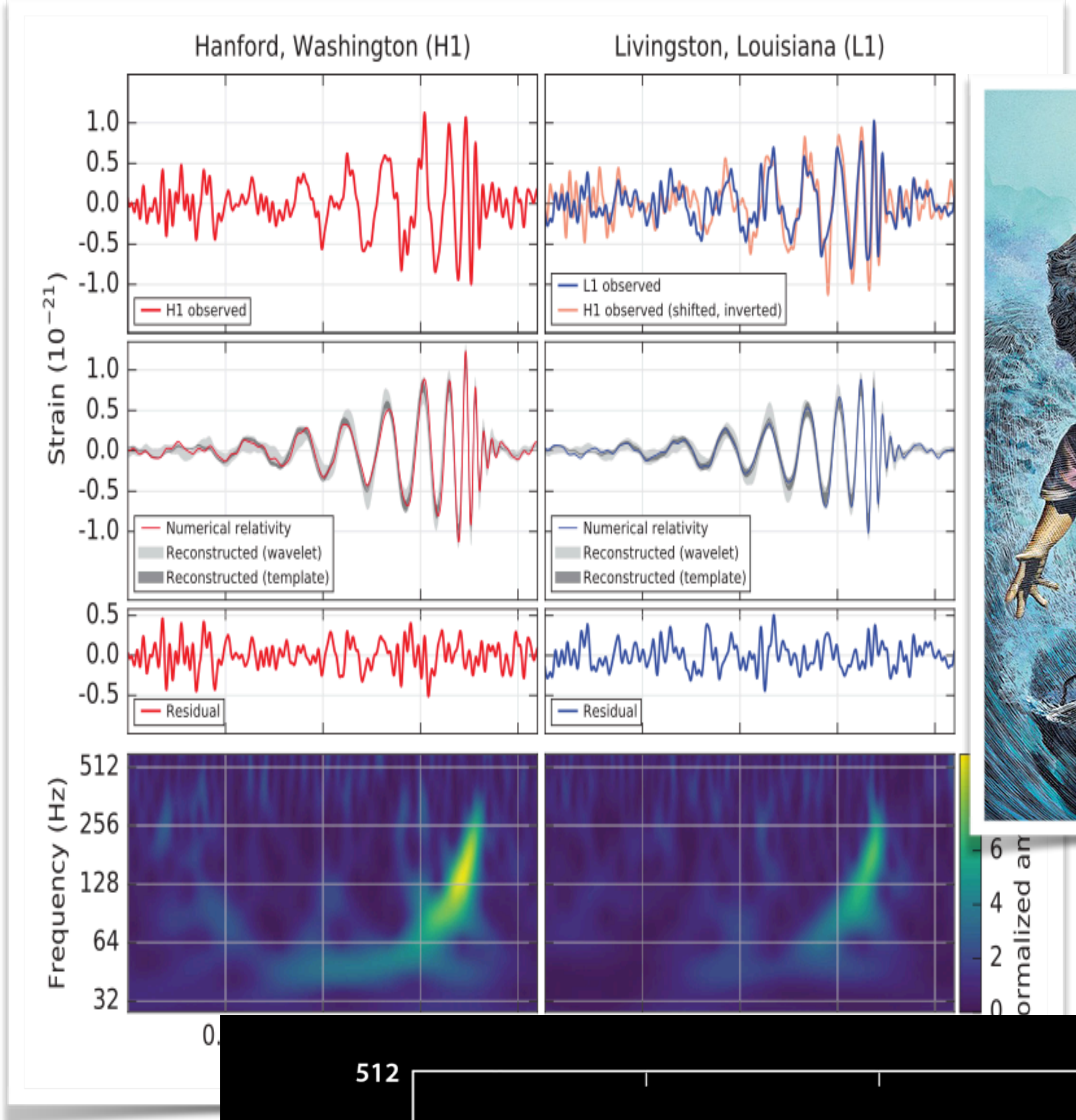
No photon left behind

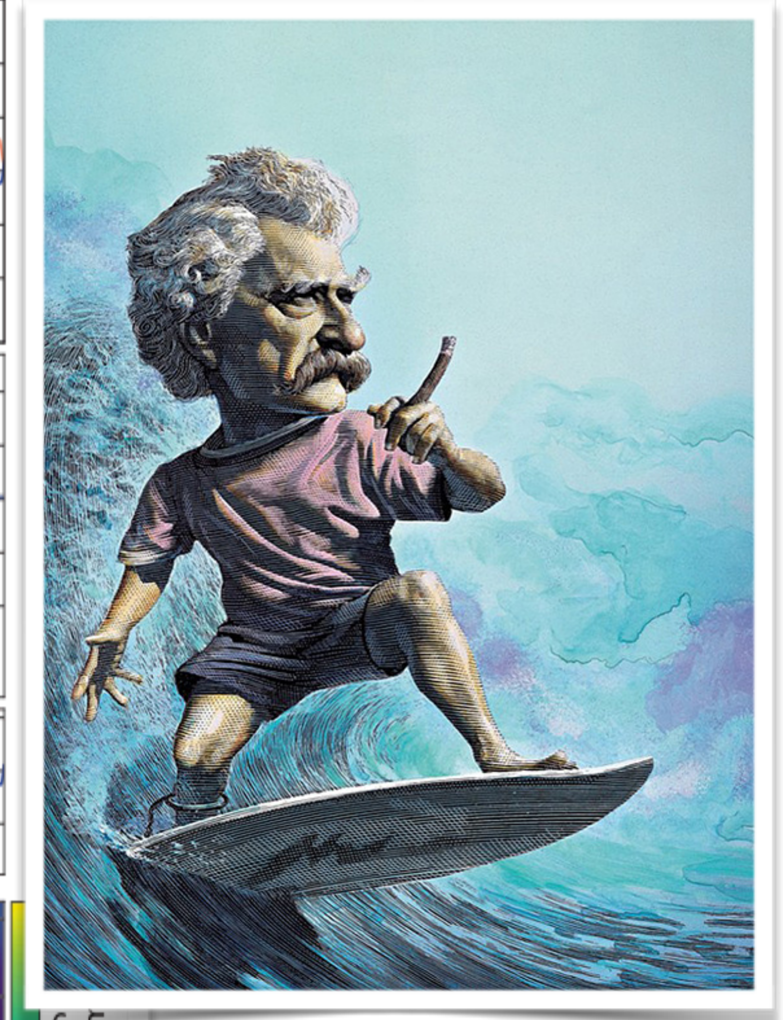


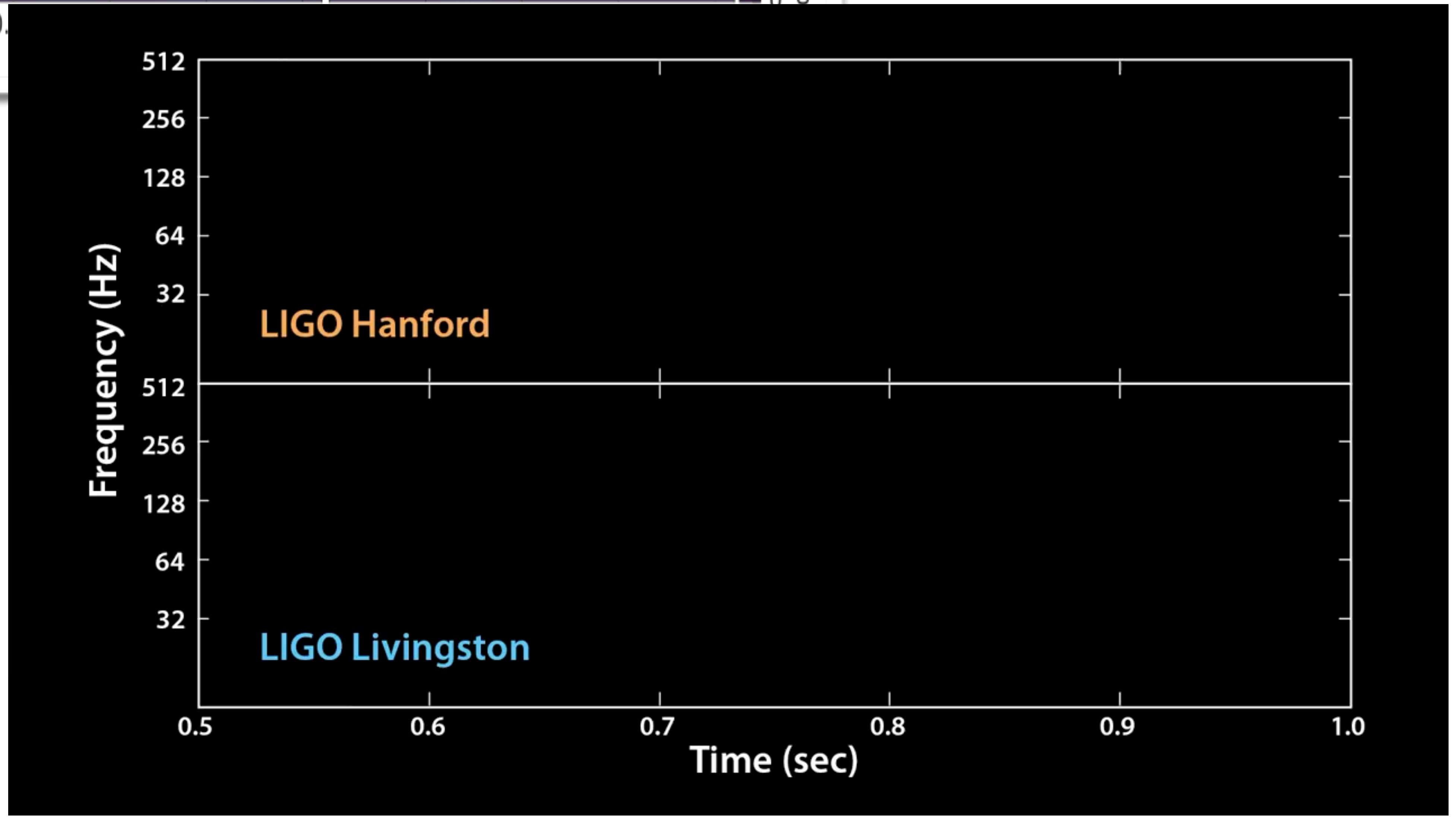


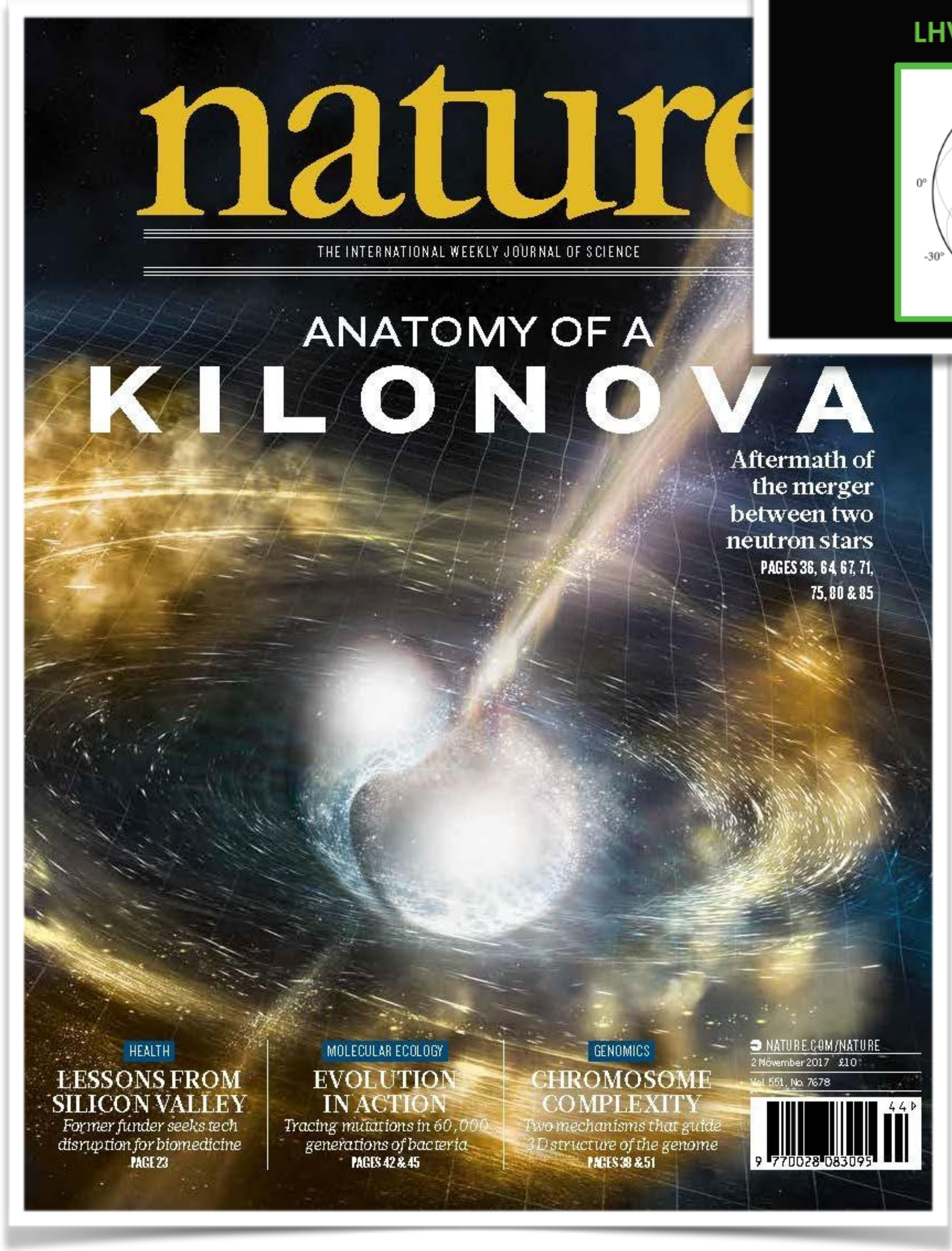
GW150914 (first ever GW, BBH)

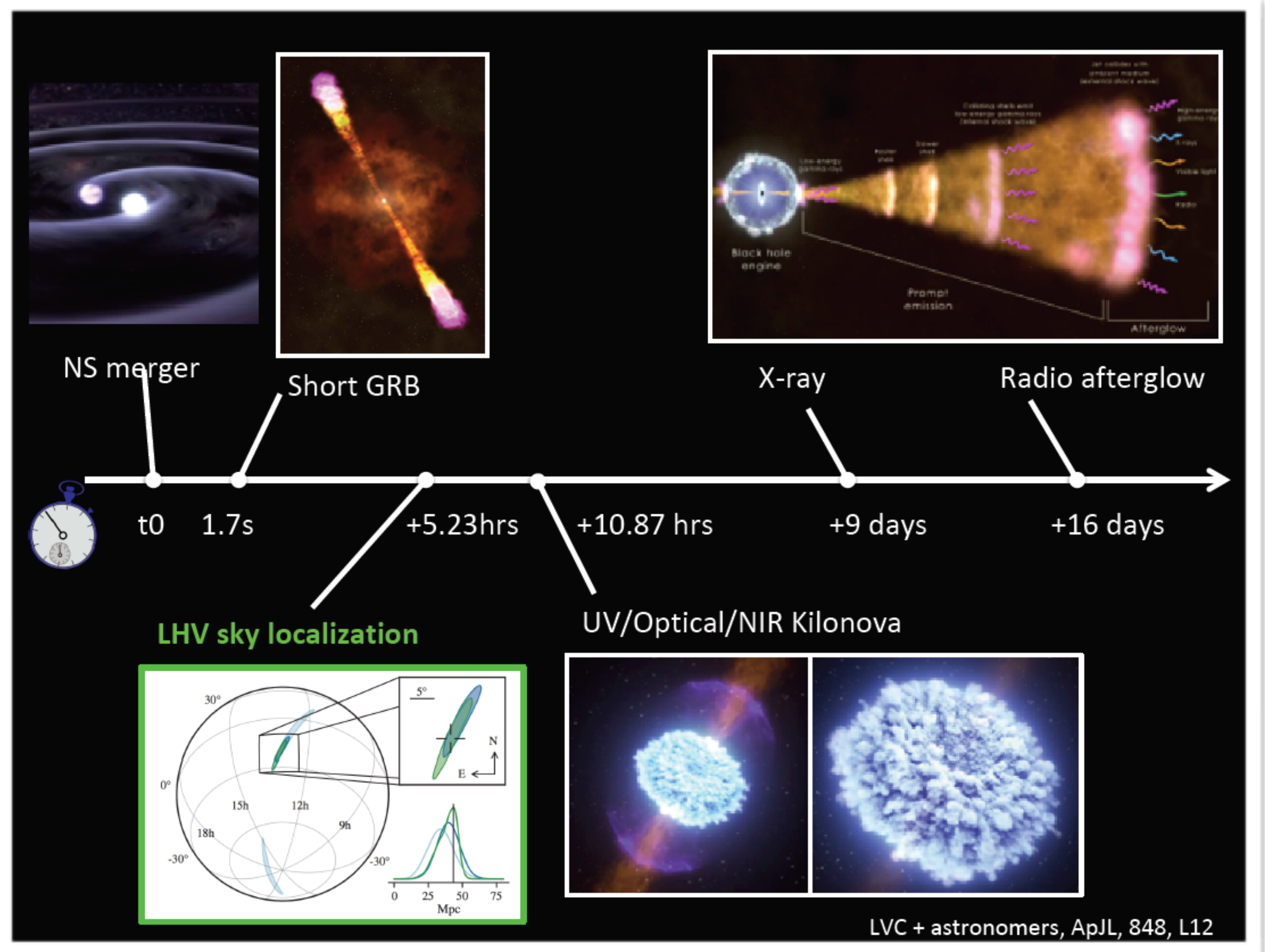
(first counterpart EM, BNS) GW170817

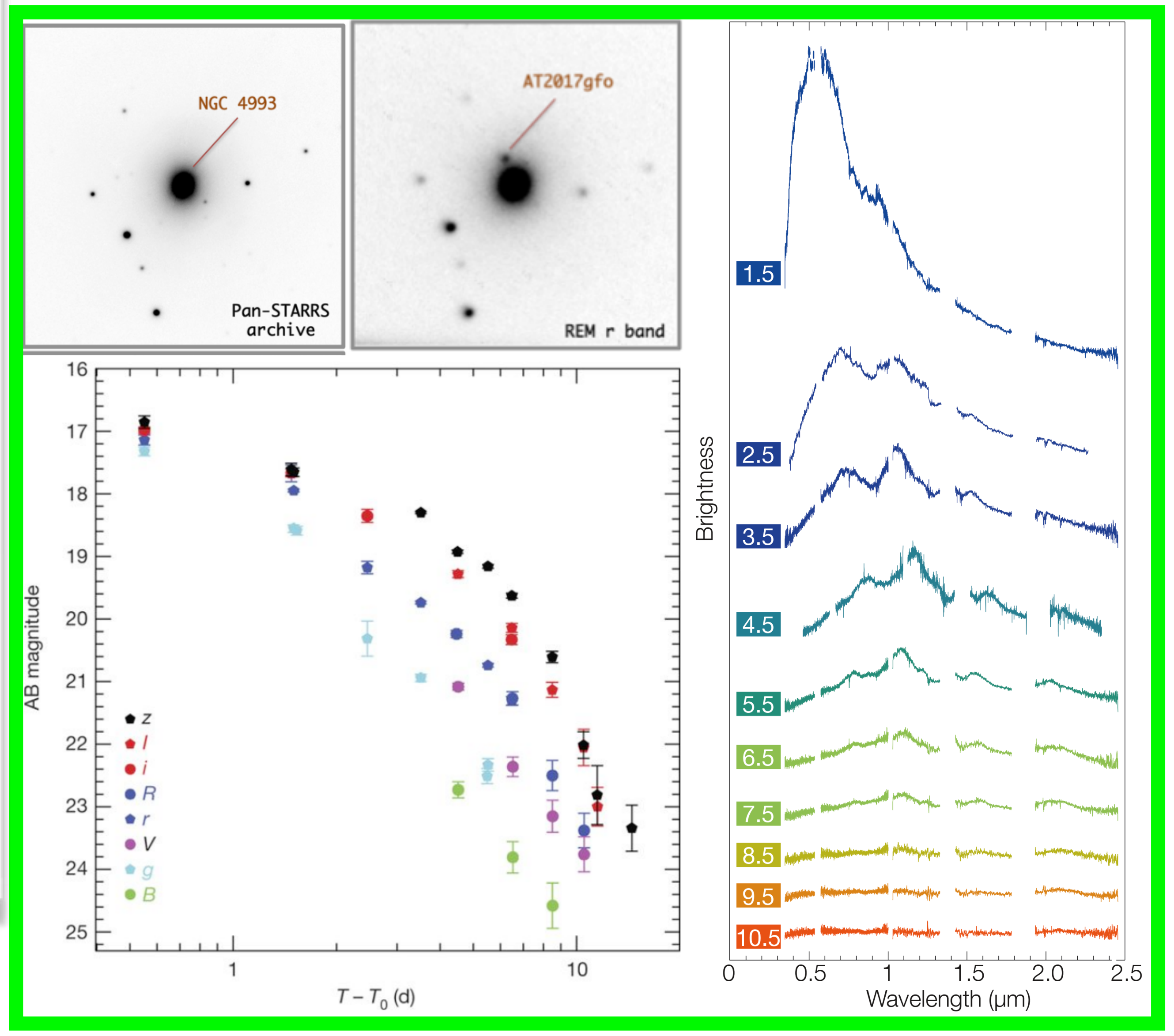












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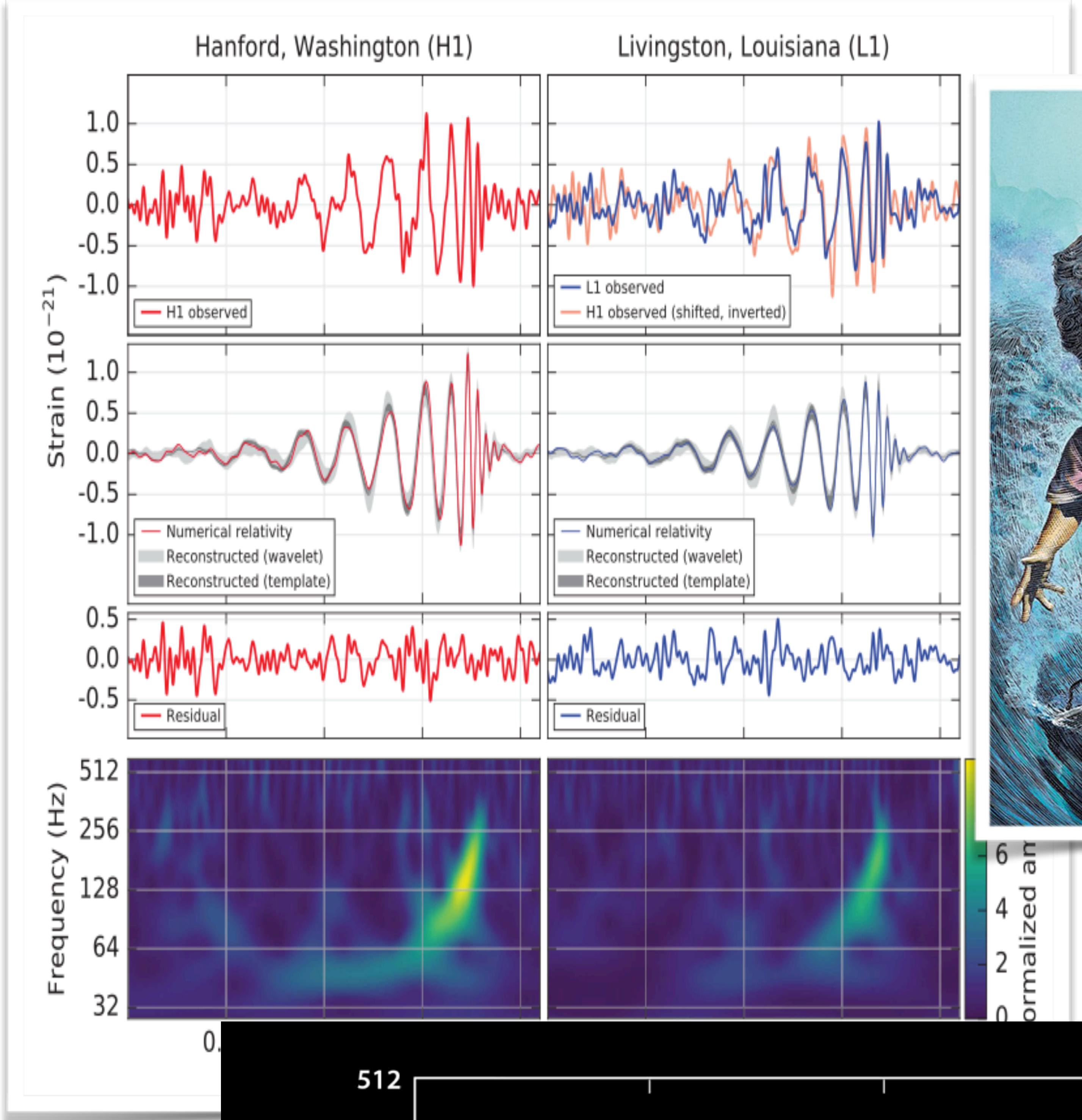
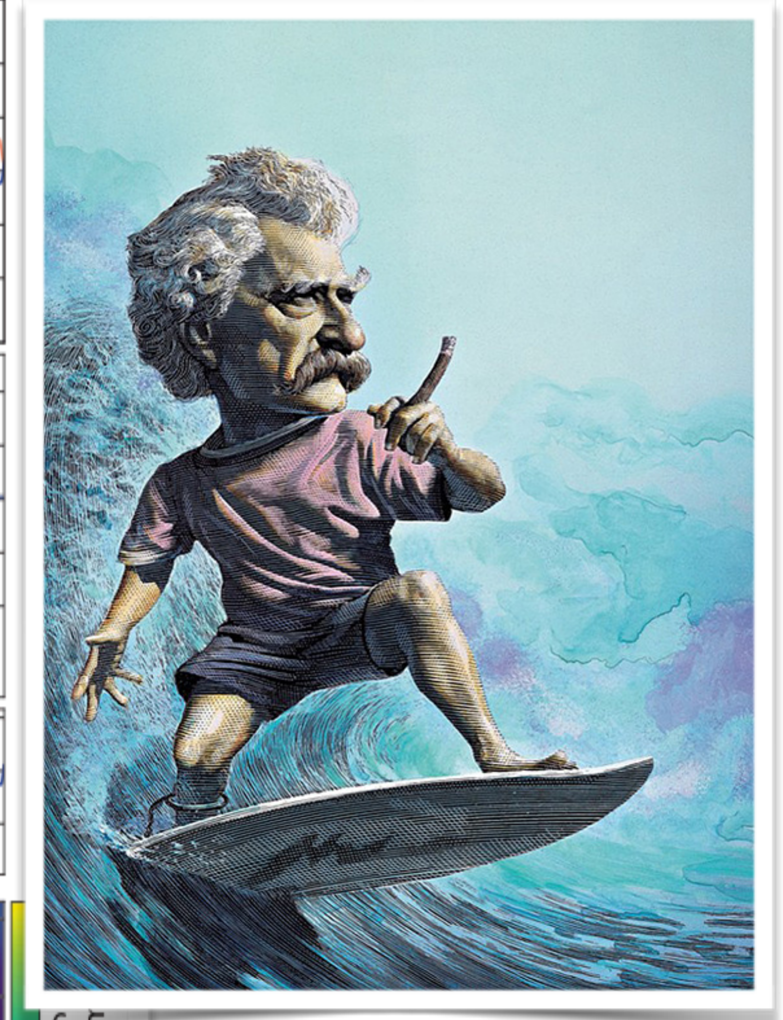
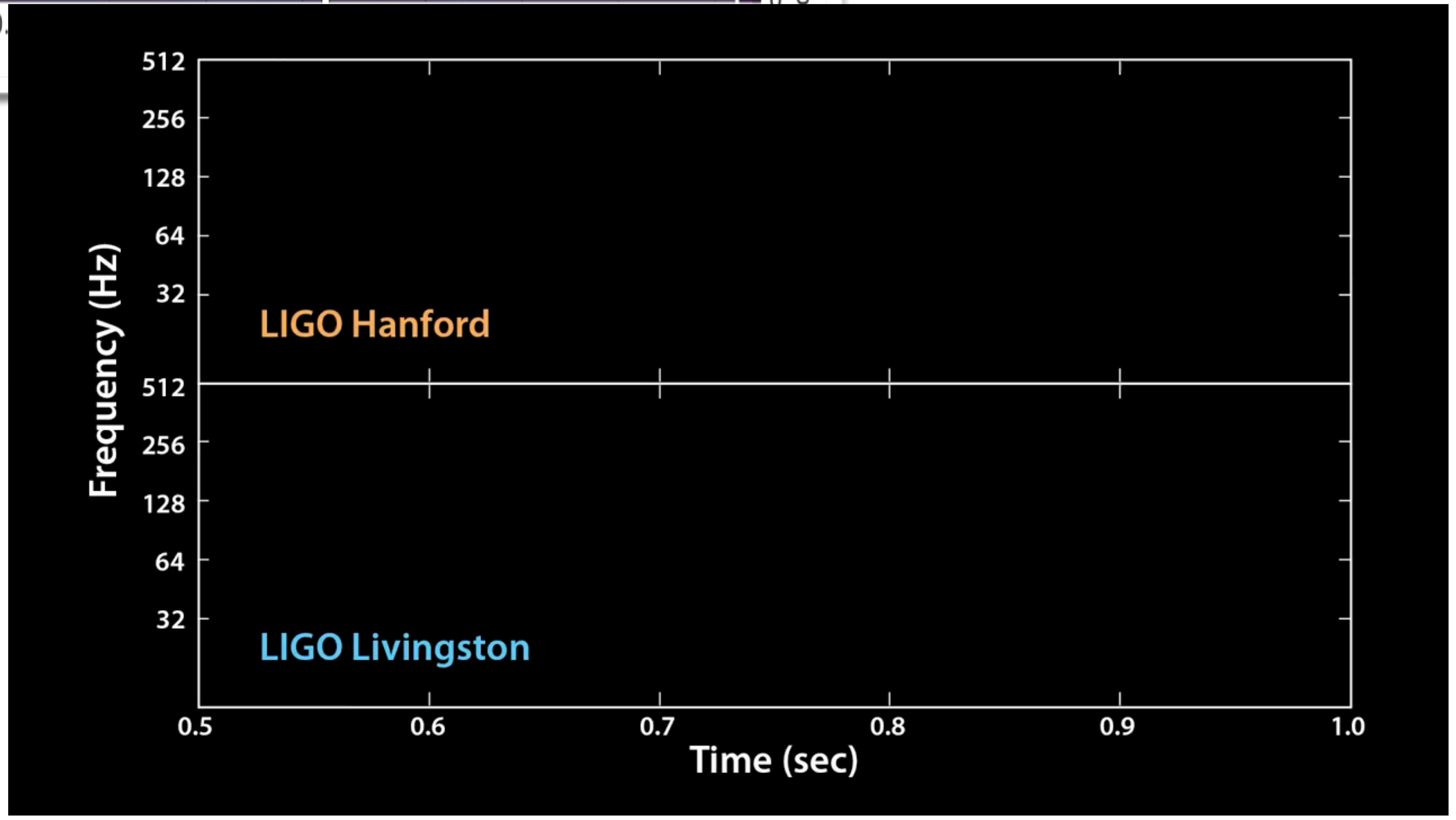
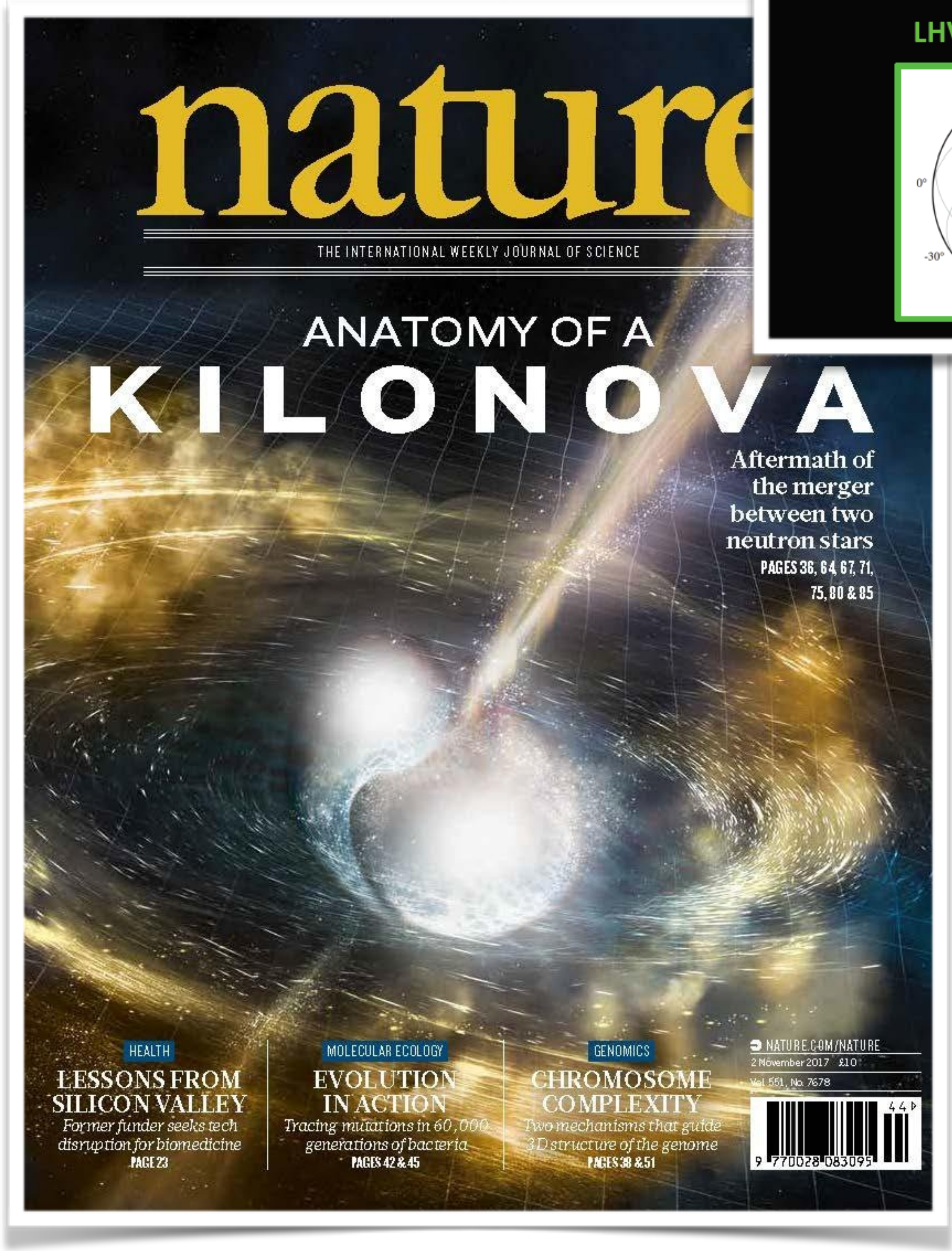
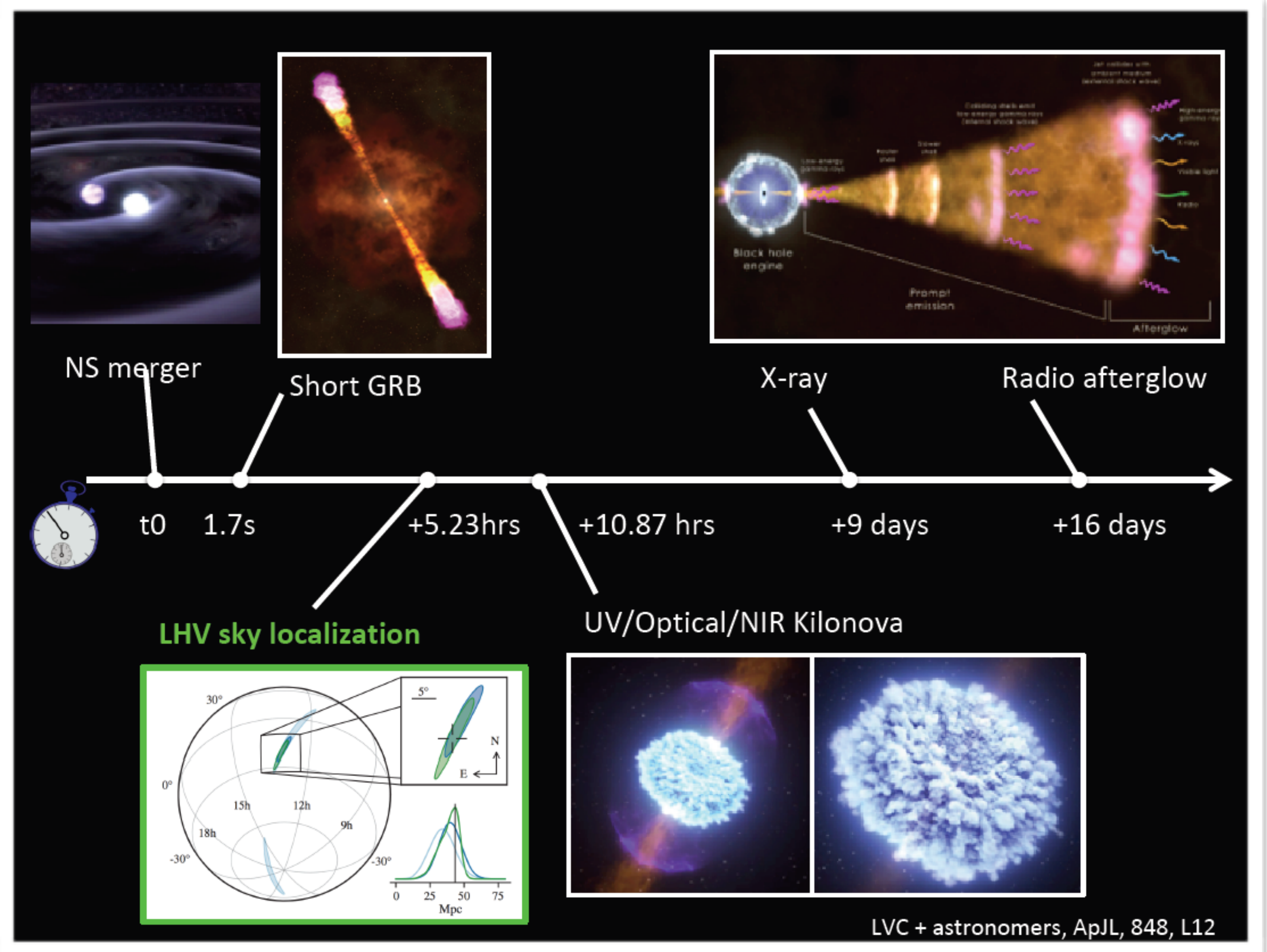
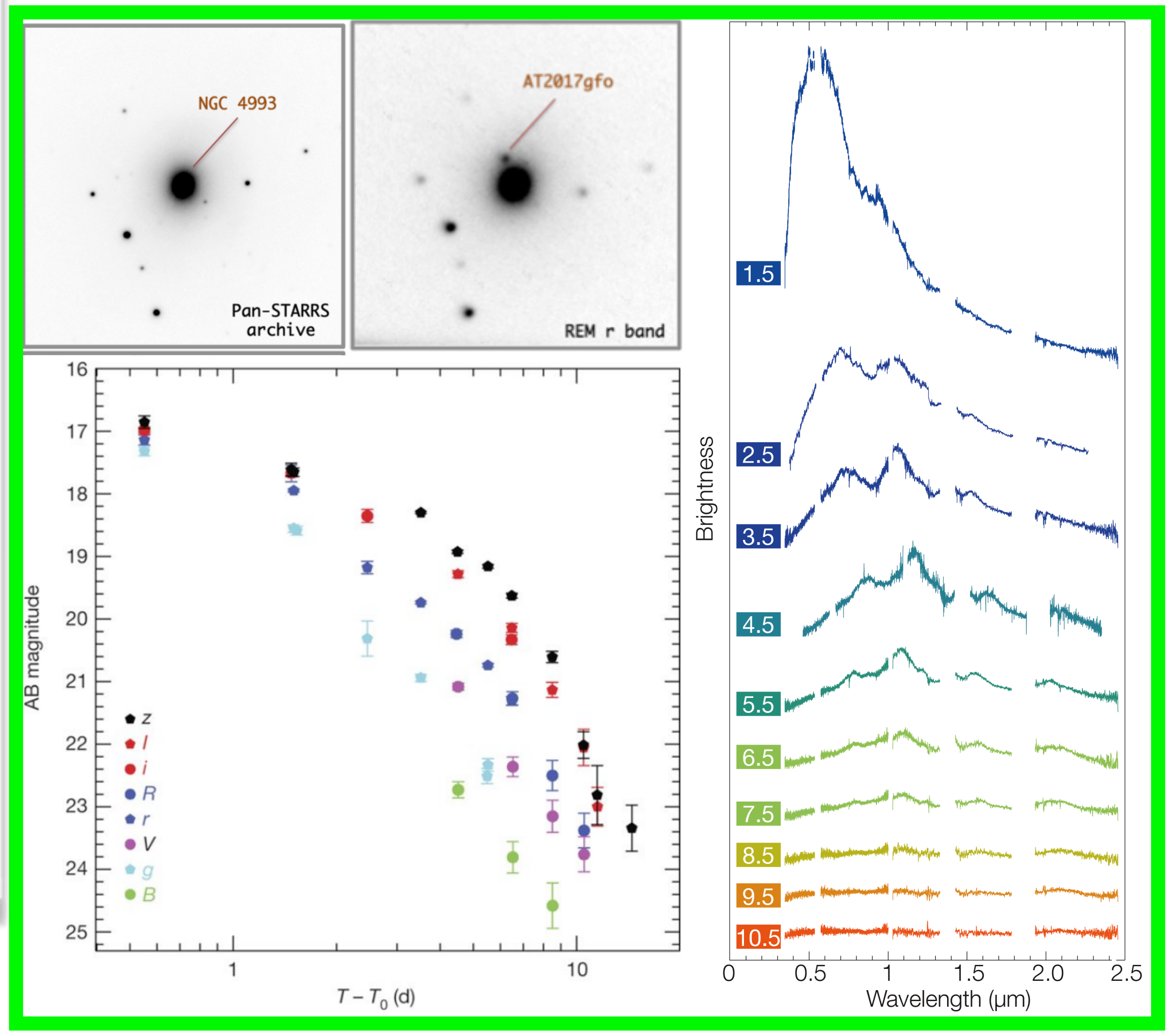












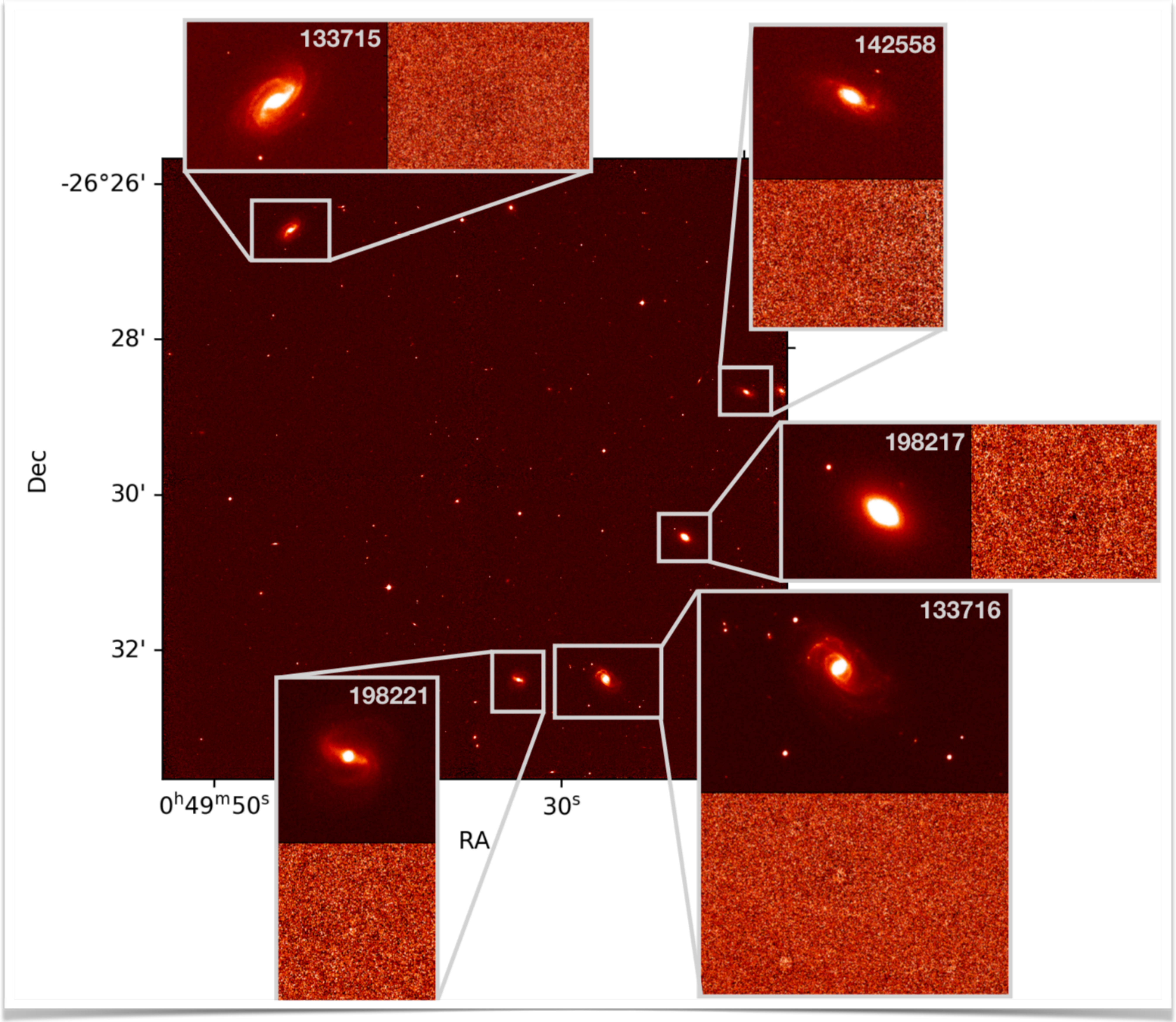
GW190814

(Lighter BH ever observed?)

- **During O1 (~4 months)**:
  - 3 confident BBHs
- **During O2 (~8 months)**:
  - 7 confident BBHs
  - 1 confident BNS
- **During O3a (~6 months)**:
  - 1 consistent with BNS masses (GW190425)
  - 2 BH+lighter object (GW190814, GW190426_152155)
  - 36 consistent with BBHs

GW190814

(Lighter BH ever observed?)



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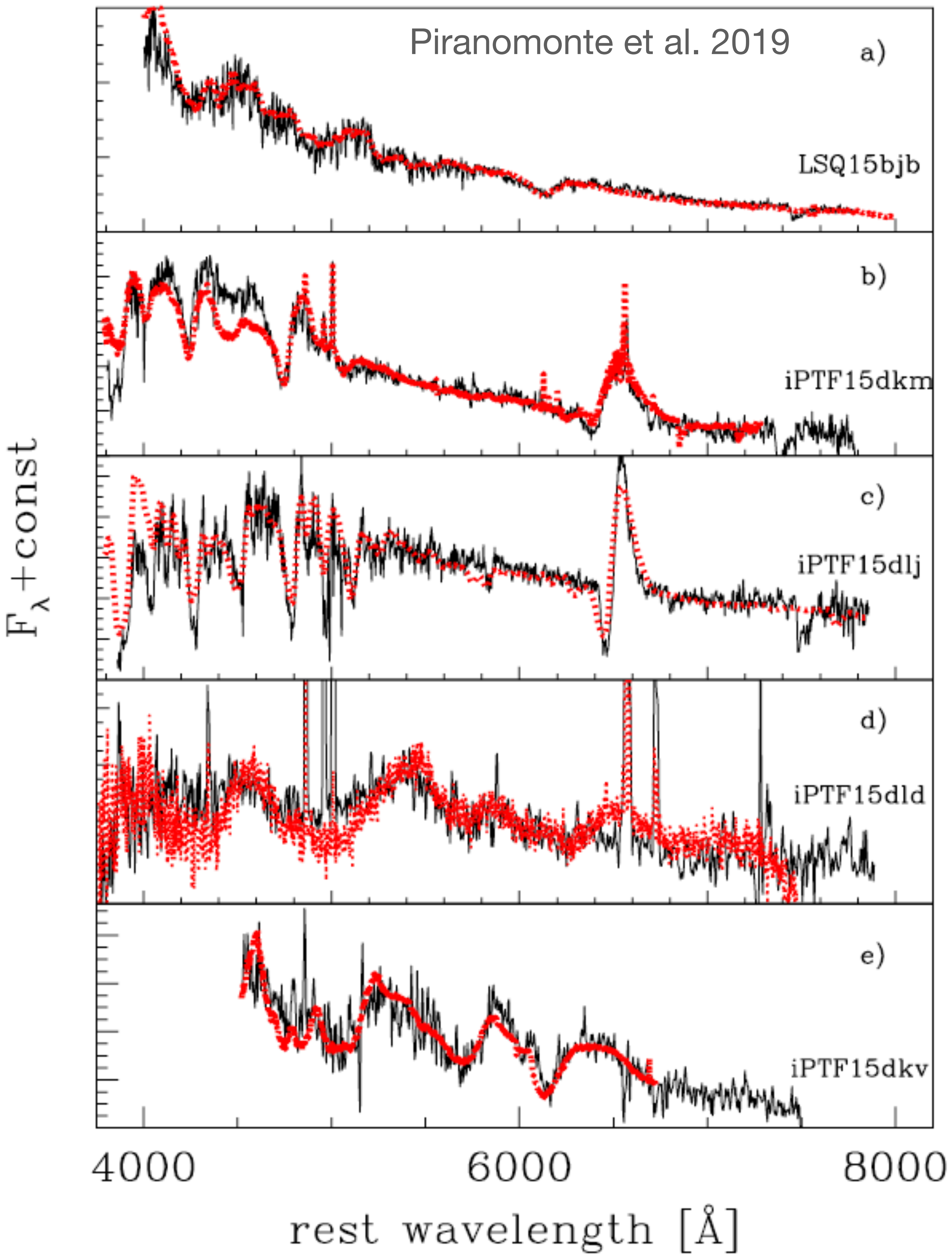
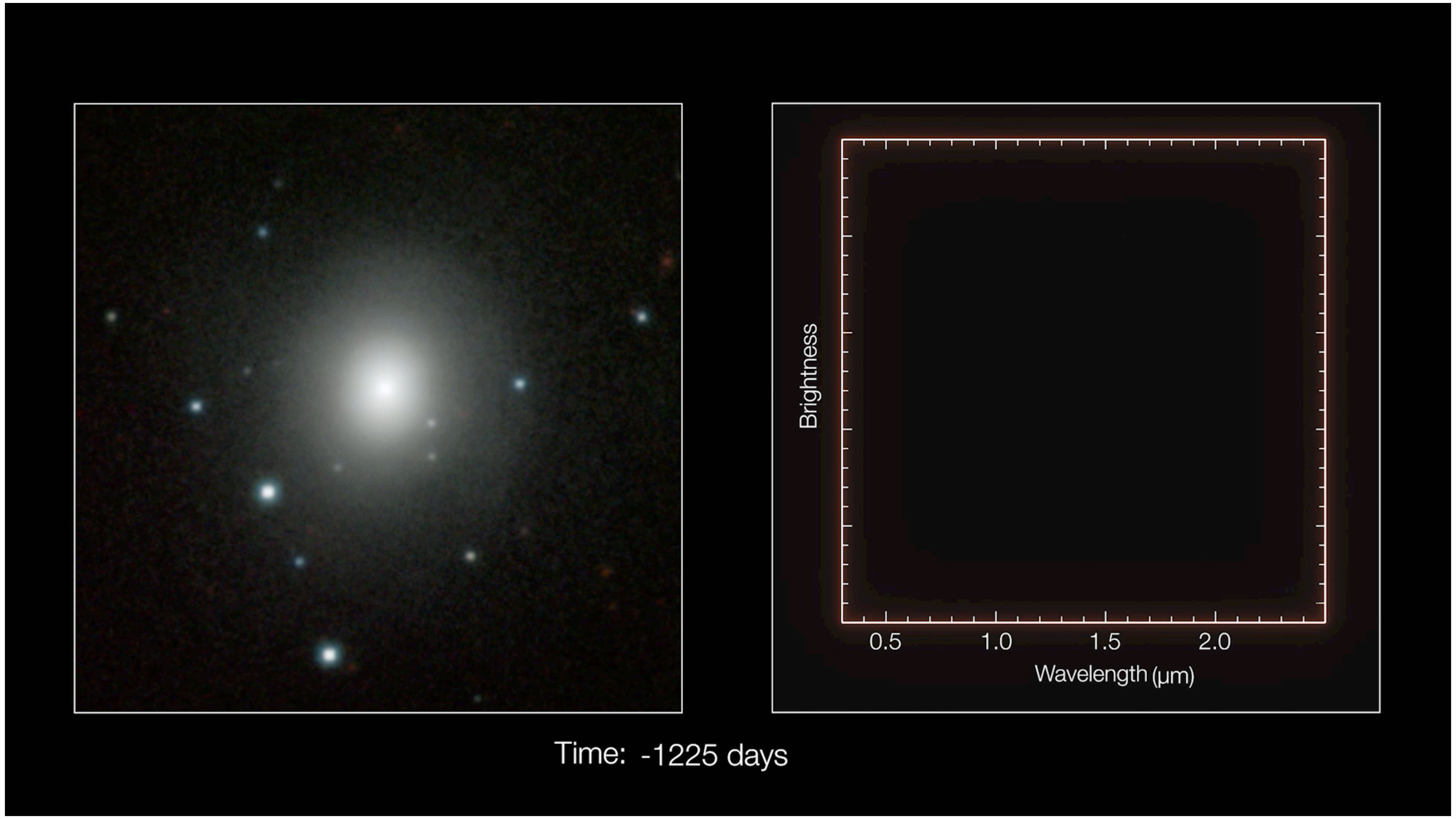
The power of spectra

Spectroscopy is pivotal for classification and characterisation, to mainly exclude transient sources unrelated to GW signals !!





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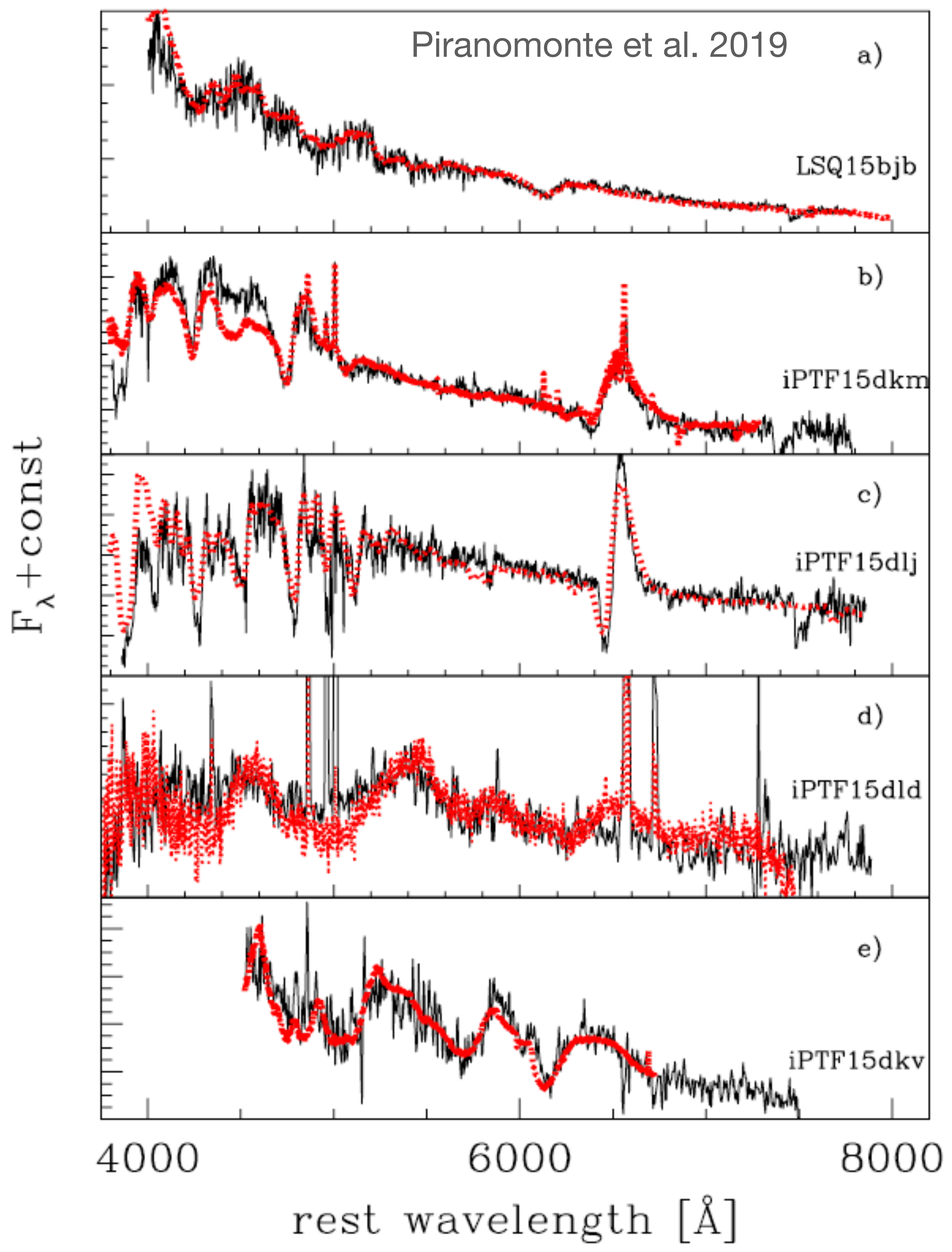
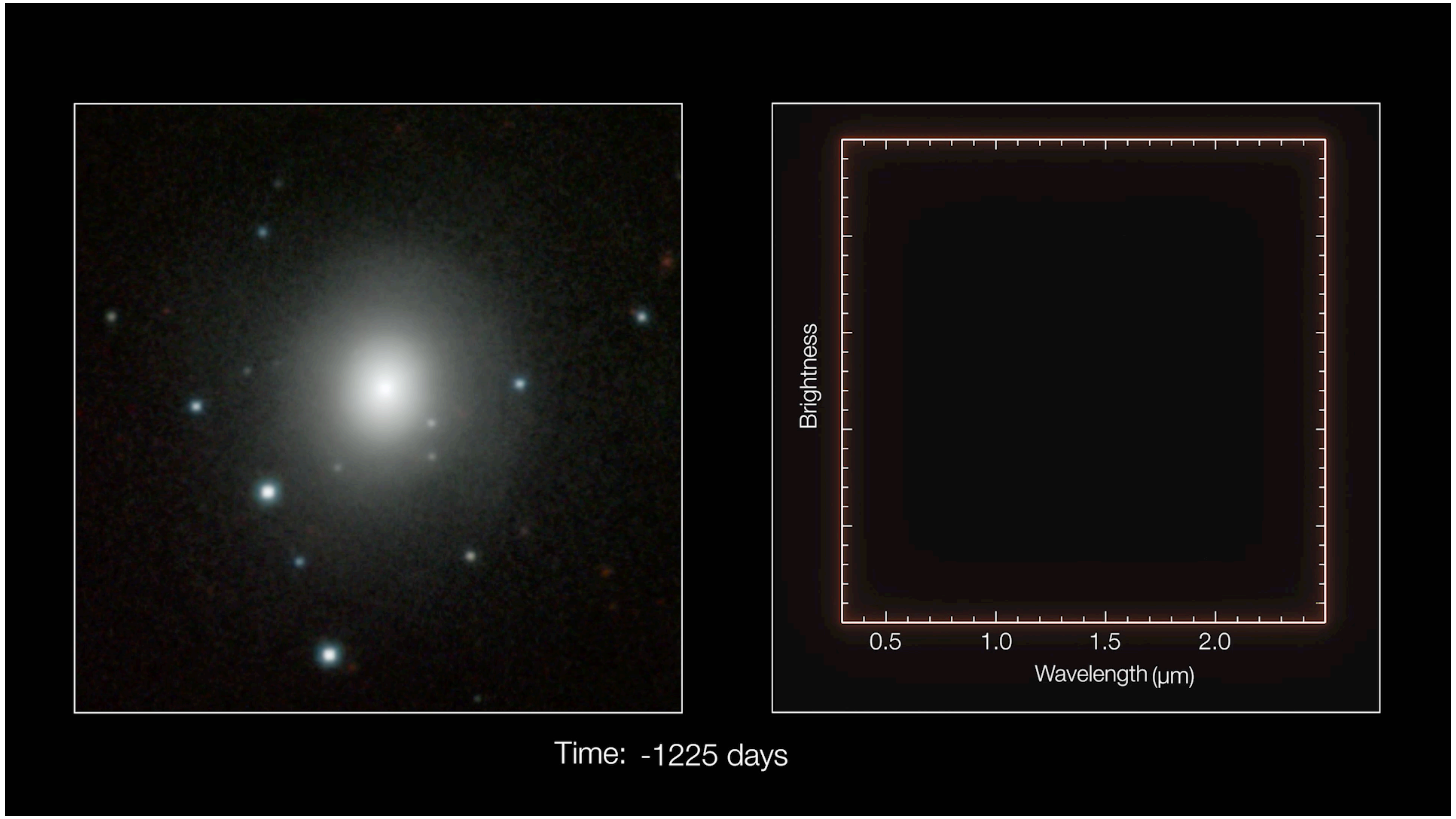


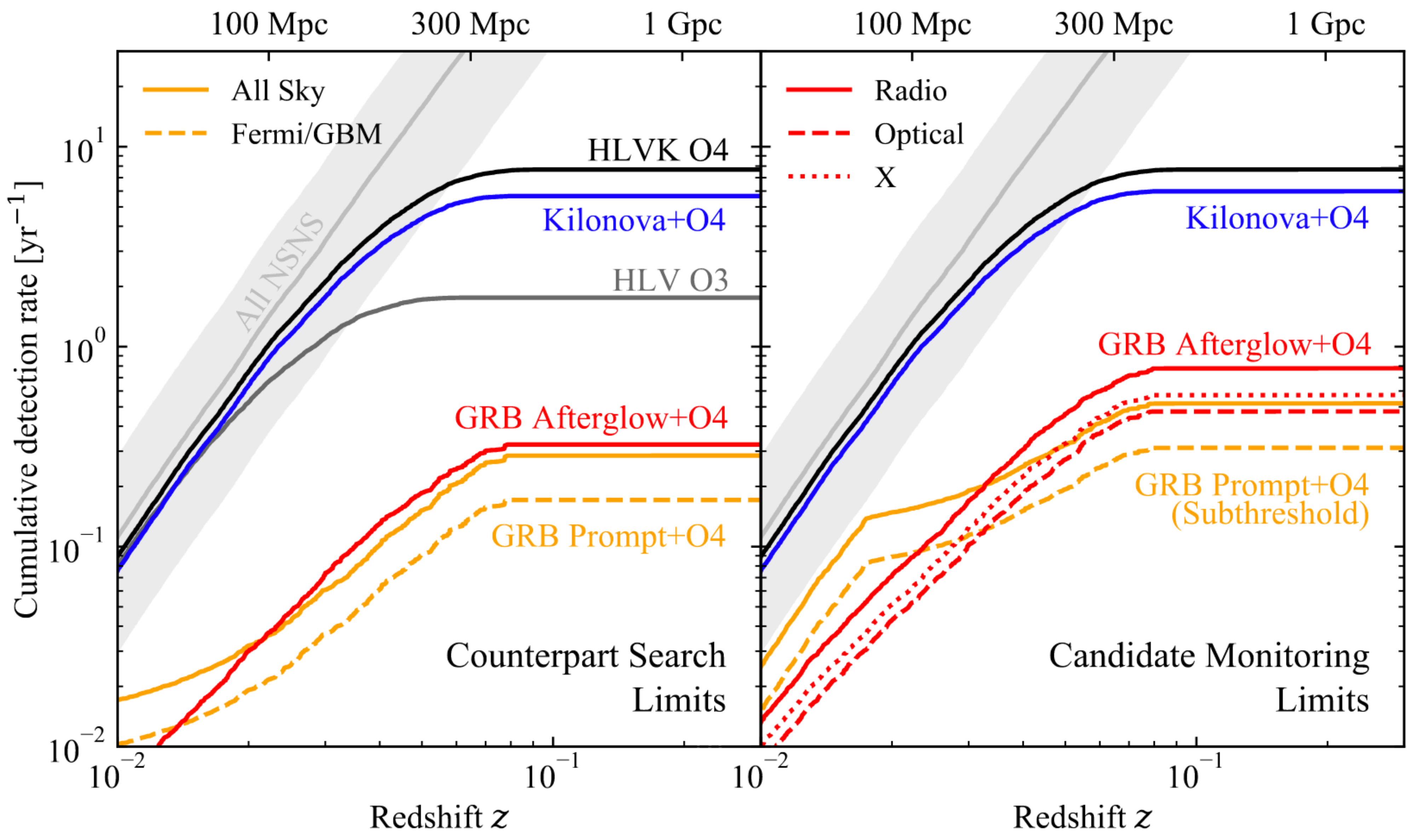


The power of spectra

The power of spectra

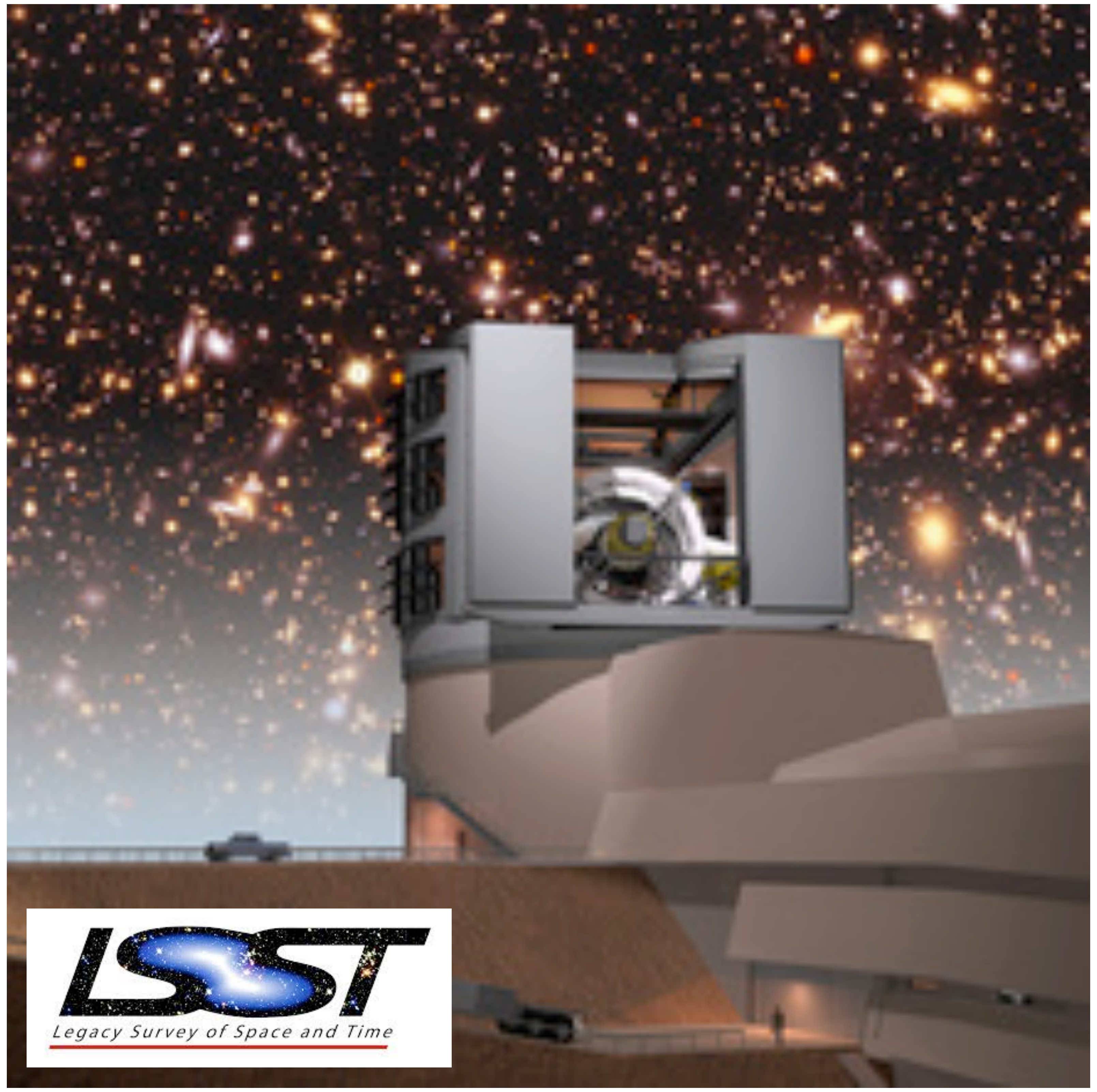
The power of spectra

Observing run	Network	Source class		
		BNS	**NSBH**	**BBH**
O4	HLVK	10^{+52}_{-10}	1^{+91}_{-1}	79^{+89}_{-44}



Colombo et al. 2022

The power of spectra



10^5 transients/night
Information within 60s (brokers)

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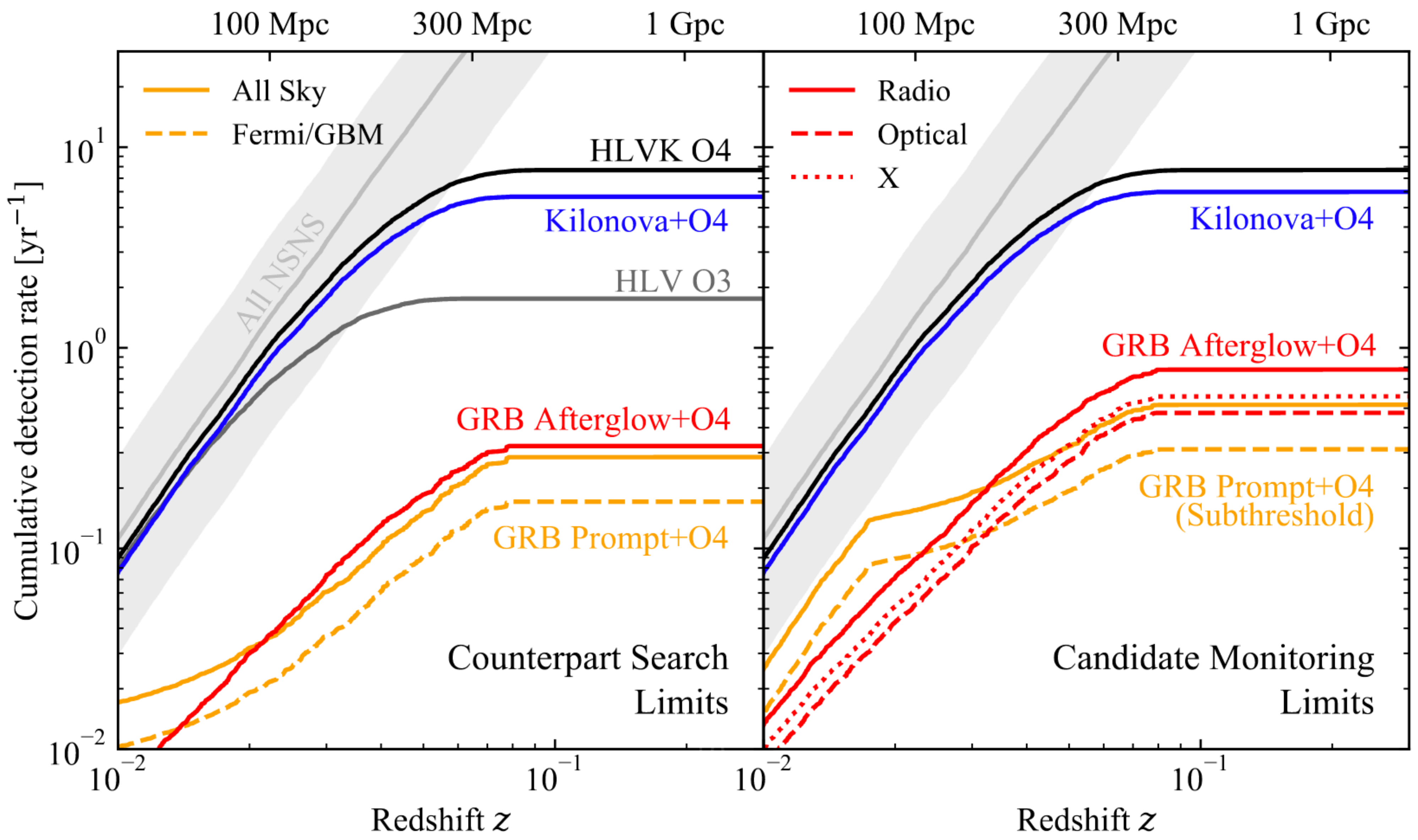
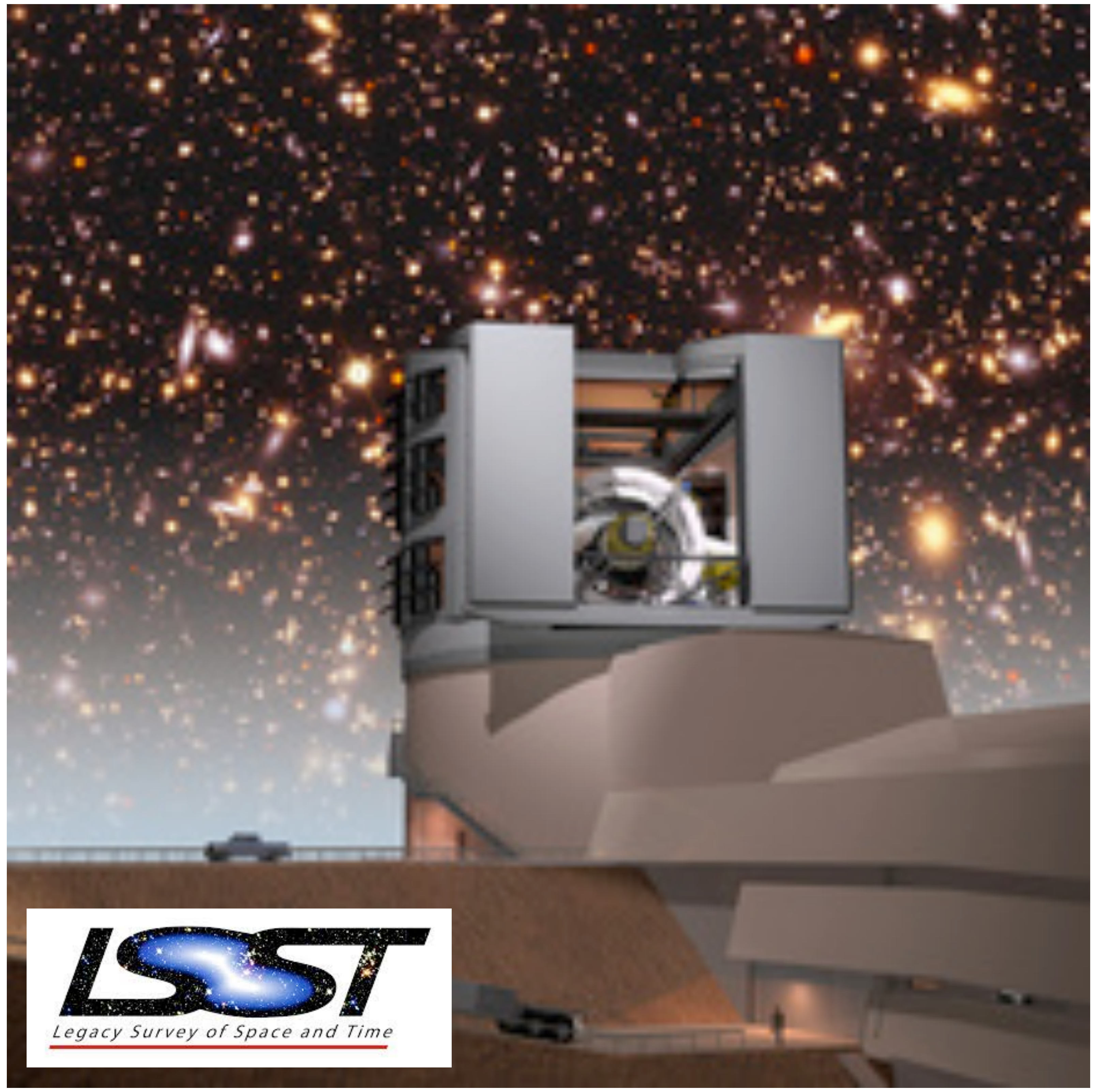


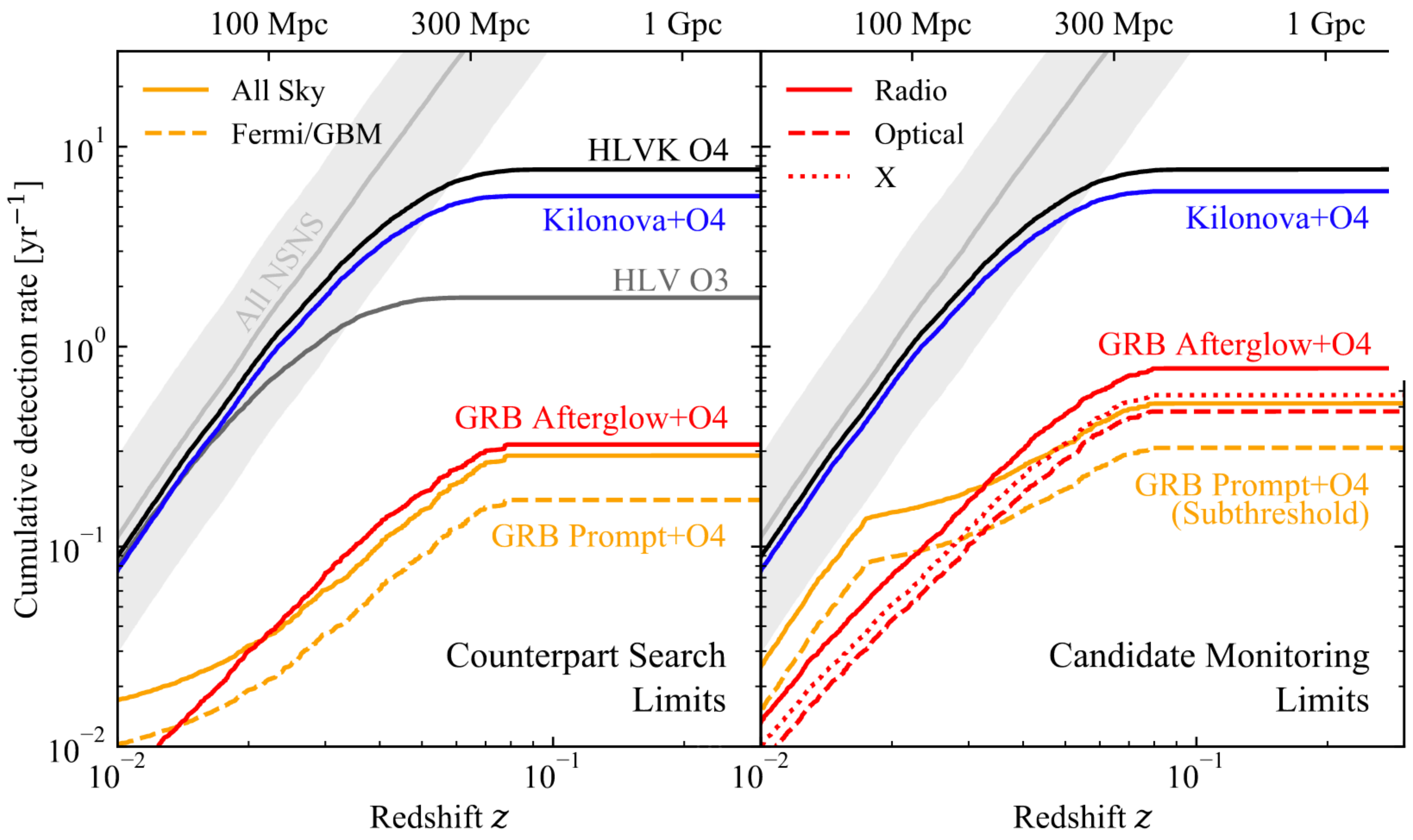
Colombo et al. 2022

The power of spectra



10^5 transients/night
Information within 60s (brokers)

Observing run	Network	Source class		
		BNS	NSBH	BBH
O4	HLVK	10^{+52}_{-10}	1^{+91}_{-1}	79^{+89}_{-44}



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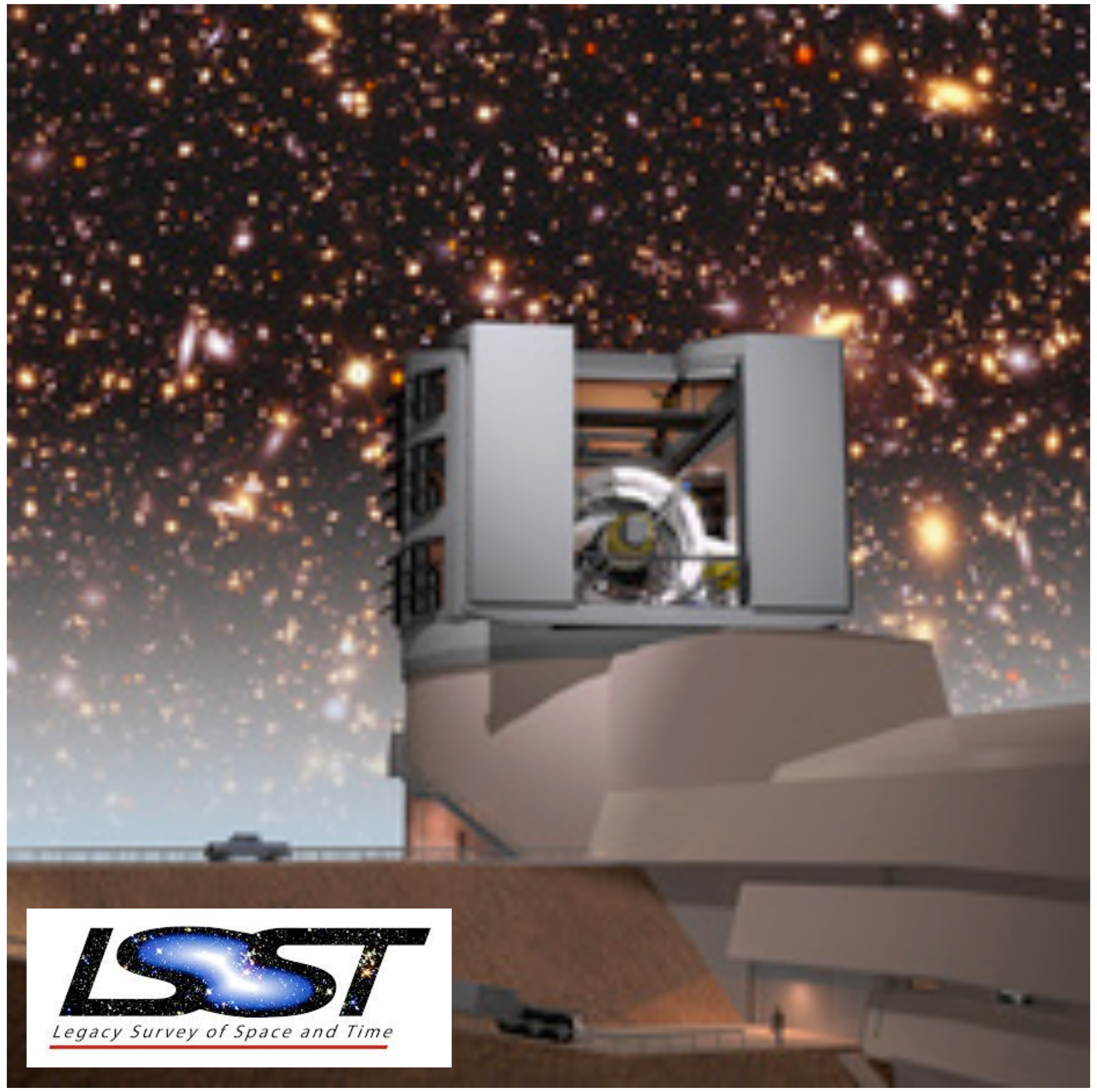
NTT/SOXS

The power of spectra



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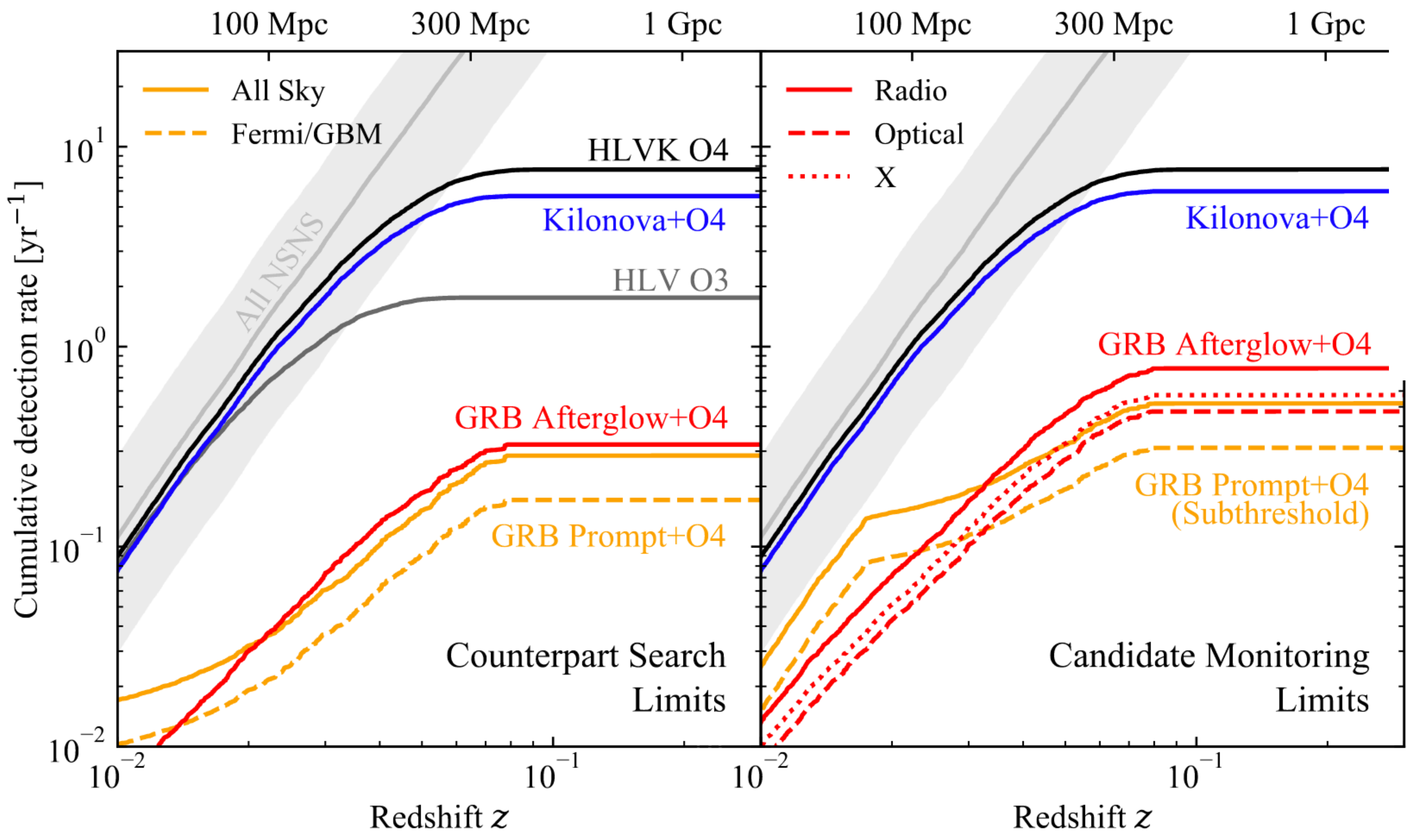


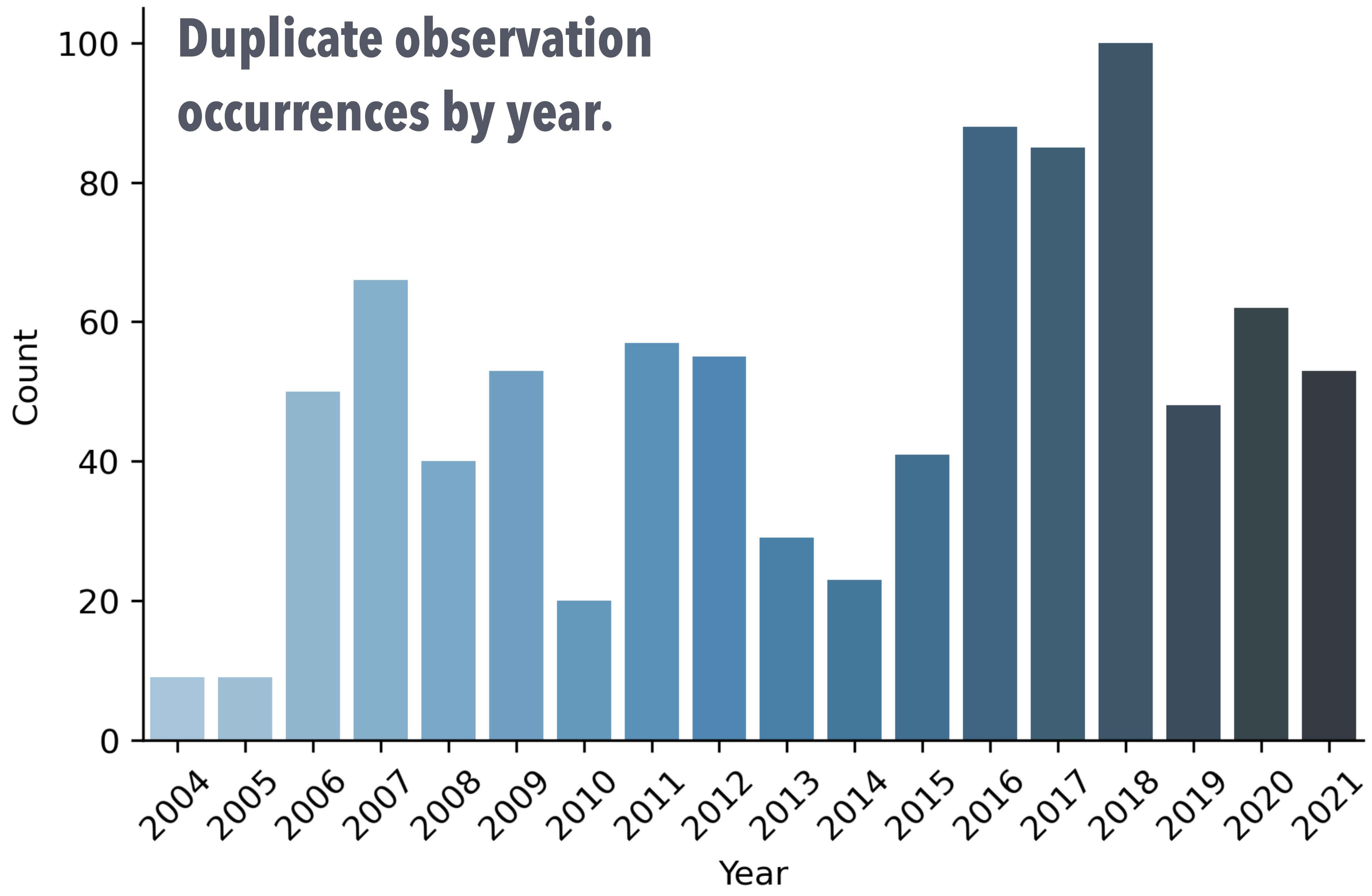
Colombo et al. 2022

NTT/SOXS

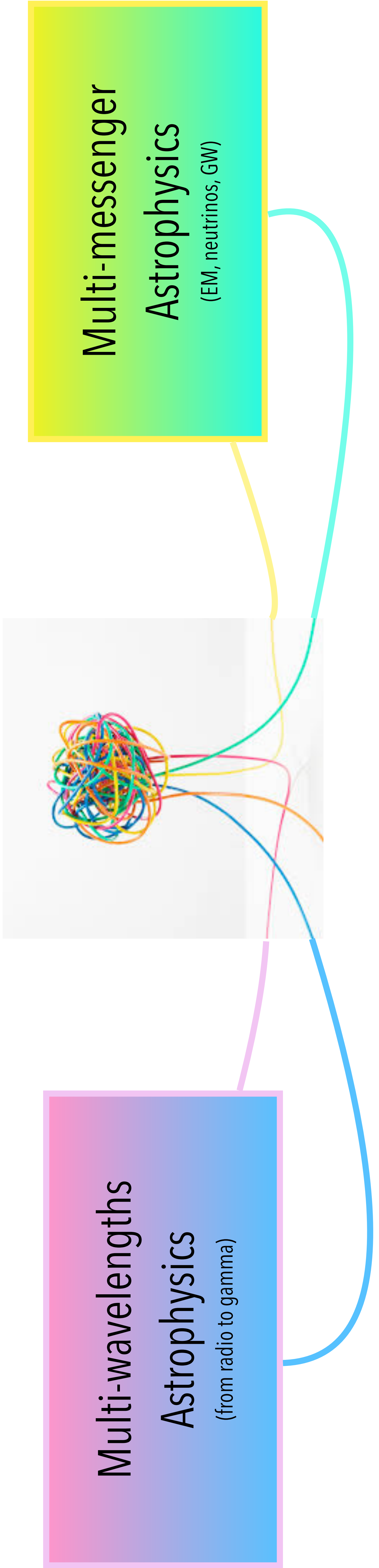
NOT/NTE

The power of spectra

- M_{Lim} from surveys is well matched for classification spectra with moderate-aperture telescopes
- For MMA: world-wide coordination is beneficial to avoid duplication (Treasure Map)
- Need to build large unbiased sample –> machine learning –> better understanding
- Critical to guide the usage of more limited follow-up with large-aperture facilities (present and future)



Time Domain MM science desiderata



Discovery & Monitoring

- All sky monitor (dedicated wide field facilities)
- Daily cadence
- Science drivers: GW counterparts, GRBs, FRBs, SNe shock breakout, accretion, TDEs, …

Rapid response

- Rapid slew (< 1hr)
- High Availability
- Science drivers: GW counterparts, GRBs, FRBs, stellar flares, space weather, transients, …

High resolution

- Sub-ms timing
- High sensitivity
- MW for detailed follow-ups
- Science drivers: Strong Gravity, NS and AGN physics, QPOs, …

Adapted from Battersby+19

Summary (wishes for the future)

- Timely notification of alerts is critical for follow-up and classification (e.g. GCN and TNS)
- Improvement of scientific understanding if the observing systems is efficient (collaborations over single)
- Spectra, spectra and even more spectra (current bottleneck for MMA) + fast imaging
- Coordination to avoid duplication (if possible): common science goals
- 'Survey Era' means we have to adapt/enhance our observing model (robotic, dedicated time, ToO)