Workshop

2-4 of April 2025, Leiden, The Netherlands

Future Role of FIR-Submm Space Observations

Defining Urgent Science and Instrumentation

Scientific importance of (F)IR time domain observations

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(free lance)

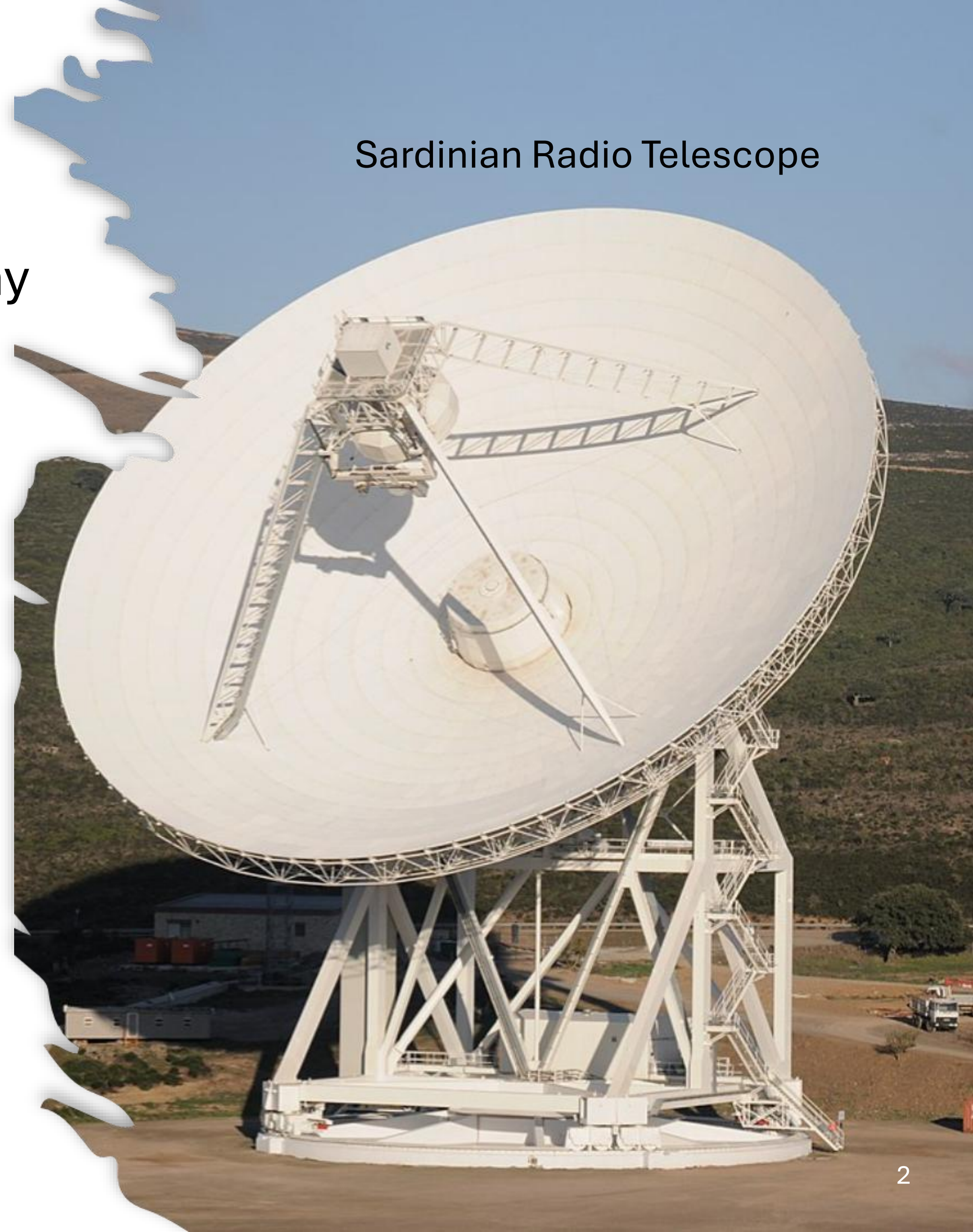
UNIVERSITÀ DEGLI STUDI FIRENZE

Universiteit Leiden

Topics

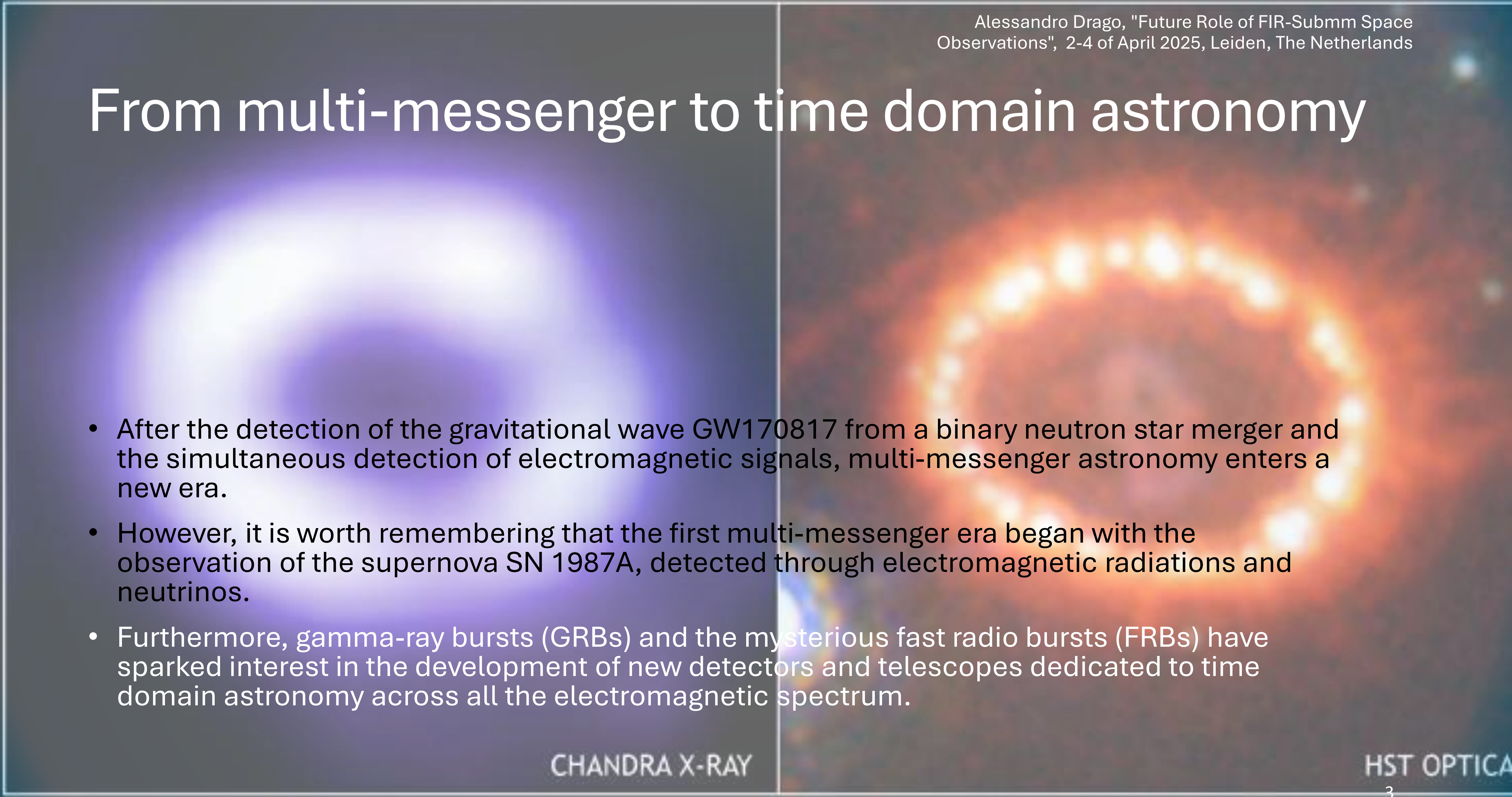
- From multi-messenger to time domain astronomy
- Observation of fast astronomical transients
- The puzzle of fast radio bursts
- Possible sources for fast infrared bursts
- How to detect fast infrared transients
- Conclusion

Keywords: multi-messenger astronomy;
time-domain astronomy; fast infrared bursts;
fast astronomical transients; infrared time-resolved detector;
infrared telescopes.



Sardinian Radio Telescope

From multi-messenger to time domain astronomy



- After the detection of the gravitational wave GW170817 from a binary neutron star merger and the simultaneous detection of electromagnetic signals, multi-messenger astronomy enters a new era.
- However, it is worth remembering that the first multi-messenger era began with the observation of the supernova SN 1987A, detected through electromagnetic radiations and neutrinos.
- Furthermore, gamma-ray bursts (GRBs) and the mysterious fast radio bursts (FRBs) have sparked interest in the development of new detectors and telescopes dedicated to time domain astronomy across all the electromagnetic spectrum.

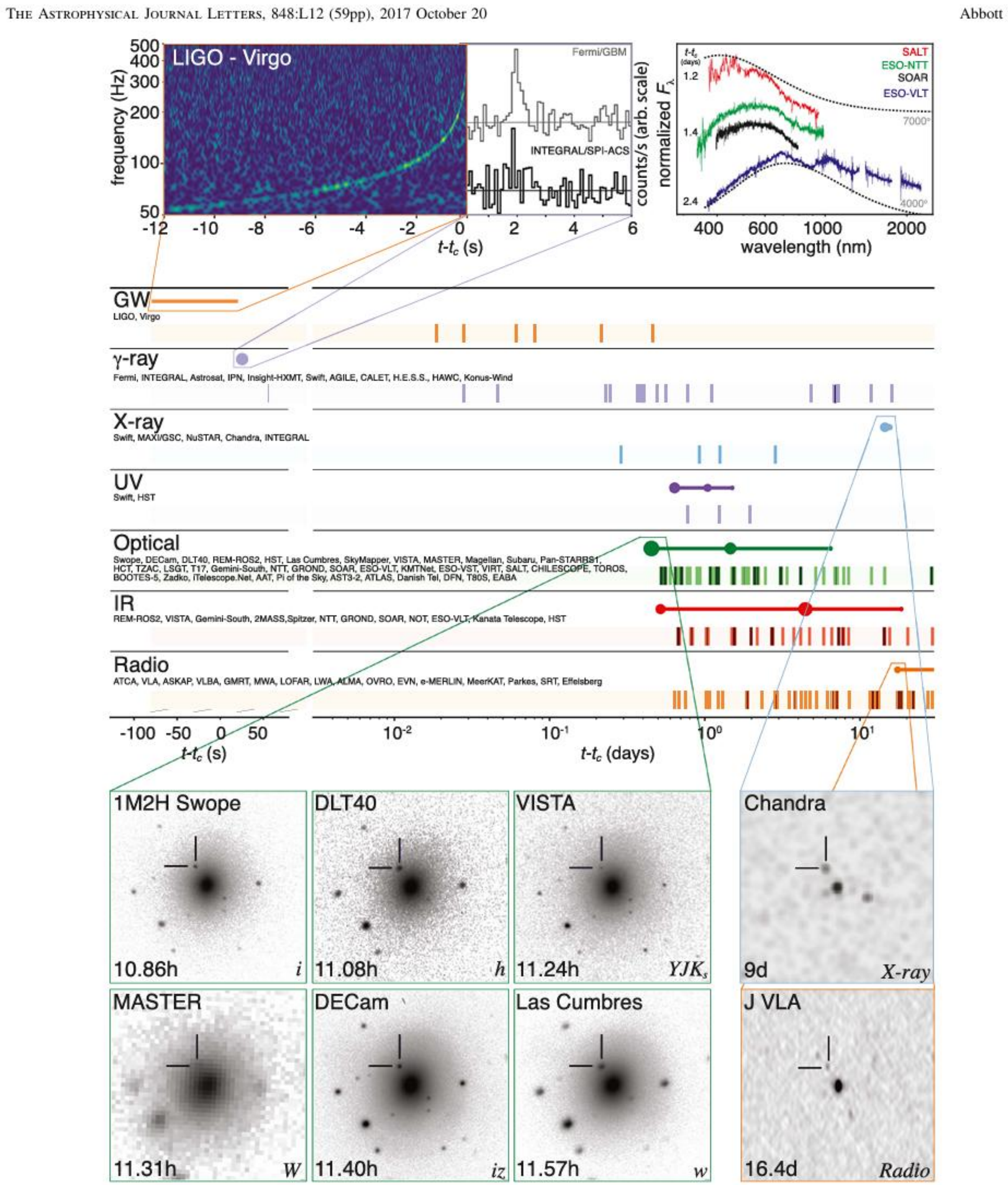
From multi-messenger to time domain astronomy

In the picture (top left) the event GW170817.

In the rest of the picture
short gamma-ray burst (sGRB) of around 2 seconds, designated GRB 170817A, that was detected by Fermi and INTEGRAL space telescopes 1.7 seconds after the GW emitted by binary neutron star merger.
(Image Credit: Abbott_2017_ApJL_848_L12).

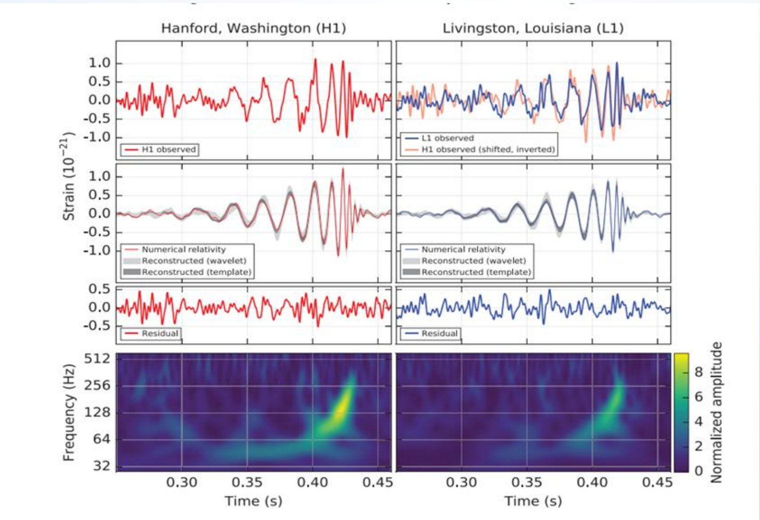
THE ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (59pp), 2017 October 20
https://doi.org/10.3847/2041-8213/aa91c9

Multi-messenger Observations of a Binary Neutron Star Merger*



From multi-messenger astronomy to time domain astronomy

LIGO measurement of the gravitational wave GW150914 (Image credit: Abbott et al. 2016b).



Neutrino

KM3NET Telescope operating under the sea in the Mediterranean.

Collaboration IT-FR-NL

Image credit: https://web.infn.it/

Photons

2 µm

1 mm

γ-ray

X-ray - UV

VIS - NIR

MID & FAR IR

µ wave & radio

GRB

UCSD & SETI

Time resolved IR detector needed

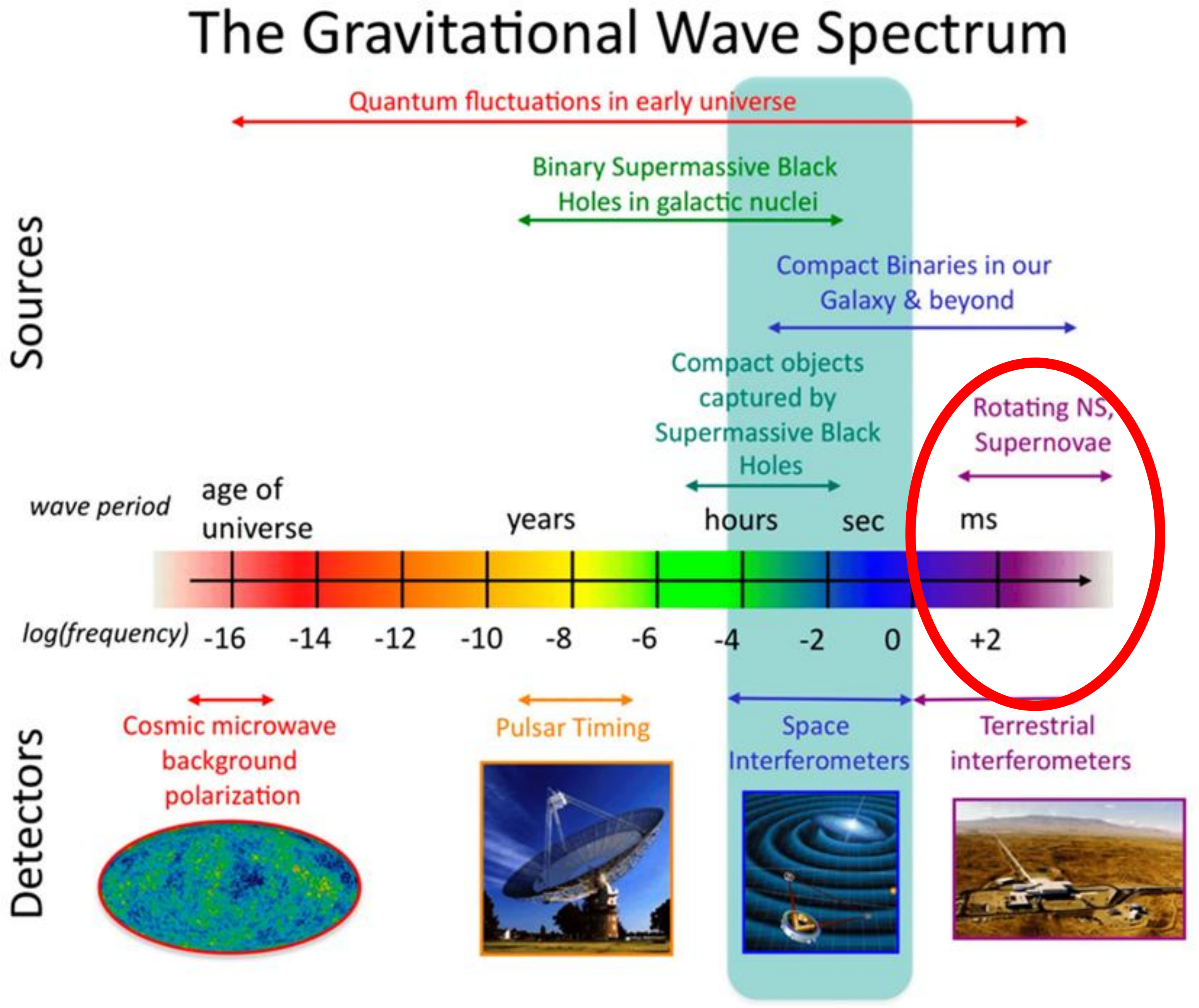
FRB

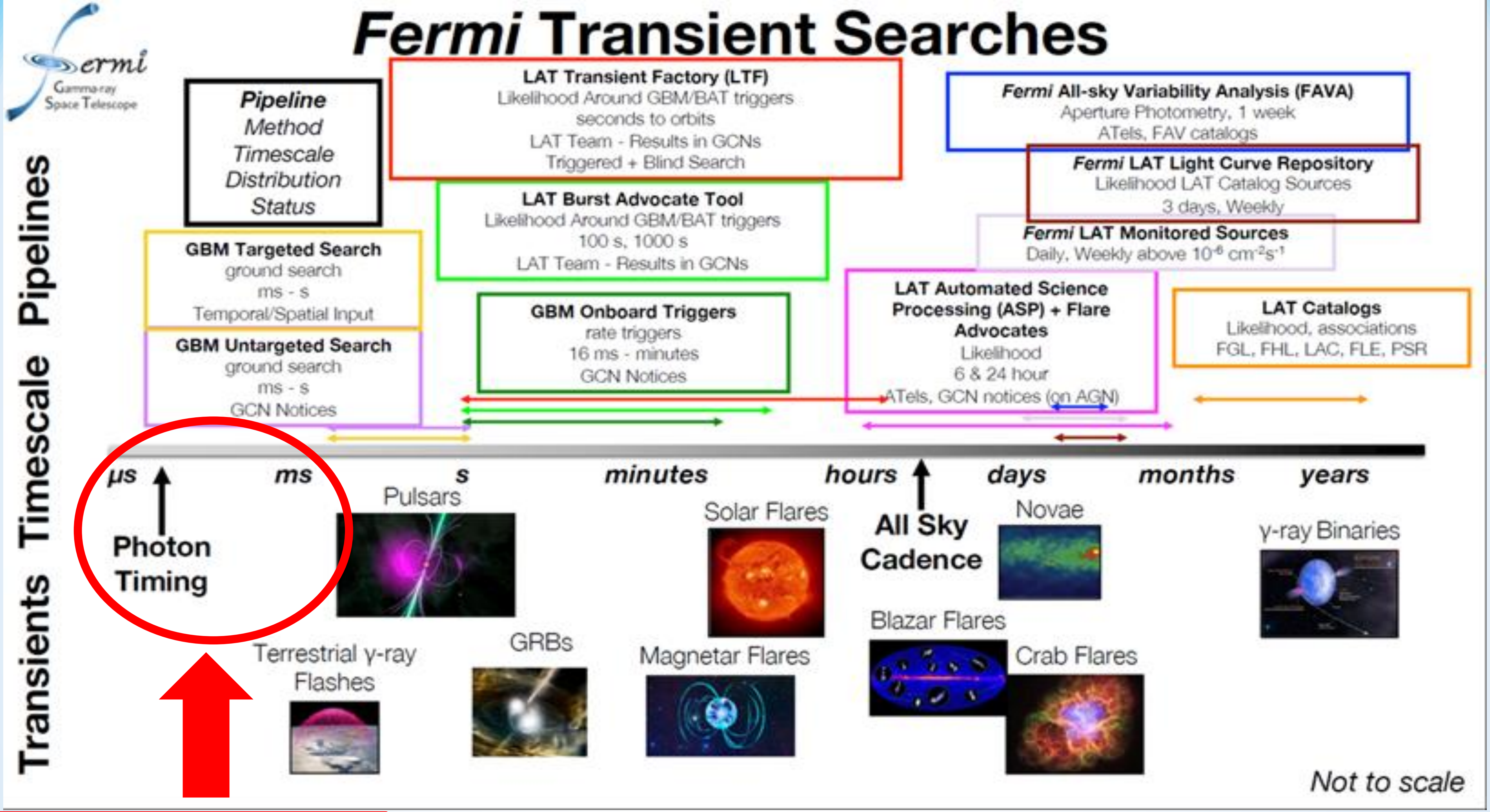
Different space or ground-based detectors & telescopes are used to observe different phenomena

In this picture, gravitational wave spectrum is showing wave period and frequency, versus predicted sources and type of detectors that might be used.

Fast events are in the red circle.

Image credit: NASA Goddard Space Flight Center.



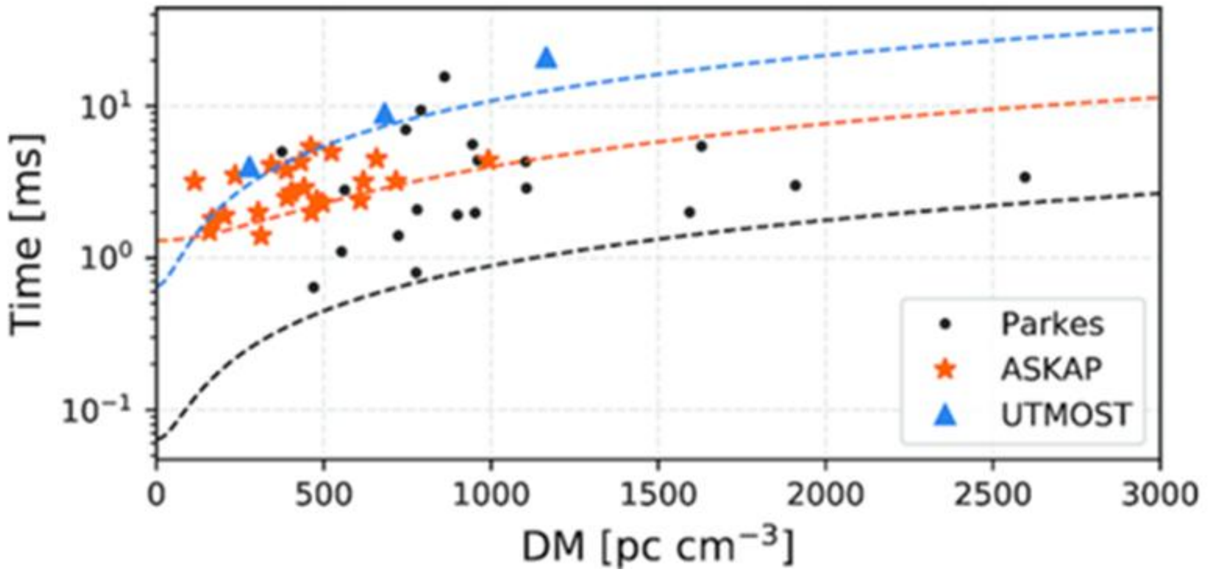


Fast events in the red circle

Image credit: Fermi LAT and GBM Collaboration, by courtesy of Bissaldi, 2018 & 2023.

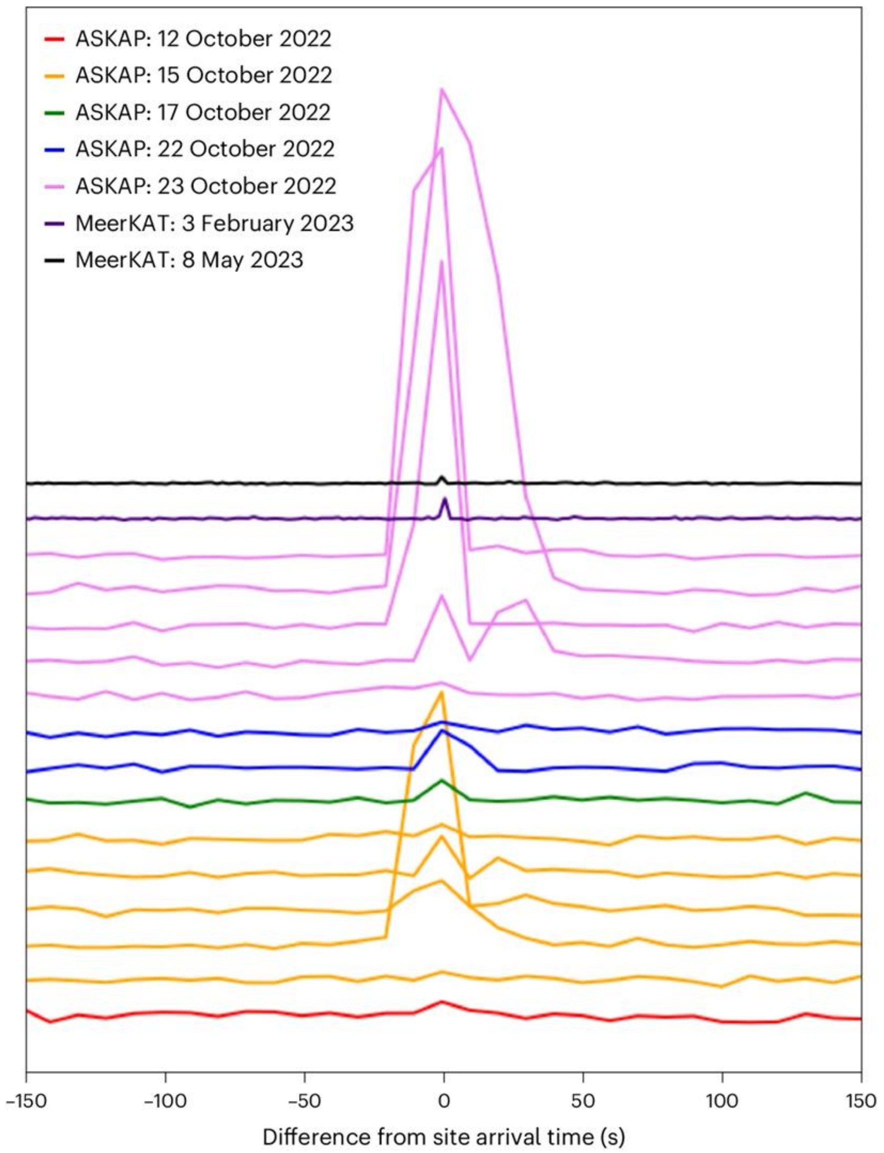
The puzzle of Fast Radio Bursts (FRBs)

- An astronomical transient is broadly defined as any event that appears and fades on a human-observable time scale or smaller.
- An FRB is a radio frequency transient usually lasting between a fraction of a millisecond and 3 seconds.
- In the figure, a distribution of FRB duration versus dispersion measurement (DM) obtained by Parkes, ASKAP, UTMOST telescopes. Image credit: Connor 2019



The puzzle of Fast Radio Bursts (FRBs)

- Given their implied small emitting regions and large distances, FRBs should be generated by perfect point sources and still appear point-like when they arrive at the Milky Way .
- In the picture, radio transients from ASKAP J1935+2148, a neutron star or magnetar at 4.85 kpc. The peak flux densities are in the vertical axis. The different colors represent the dates of the observations. (Credit: Caleb et al. 2024)



The puzzle of Fast Radio Bursts (FRBs)

Researchers have come up with multiple explanations for the sources of FRBs.

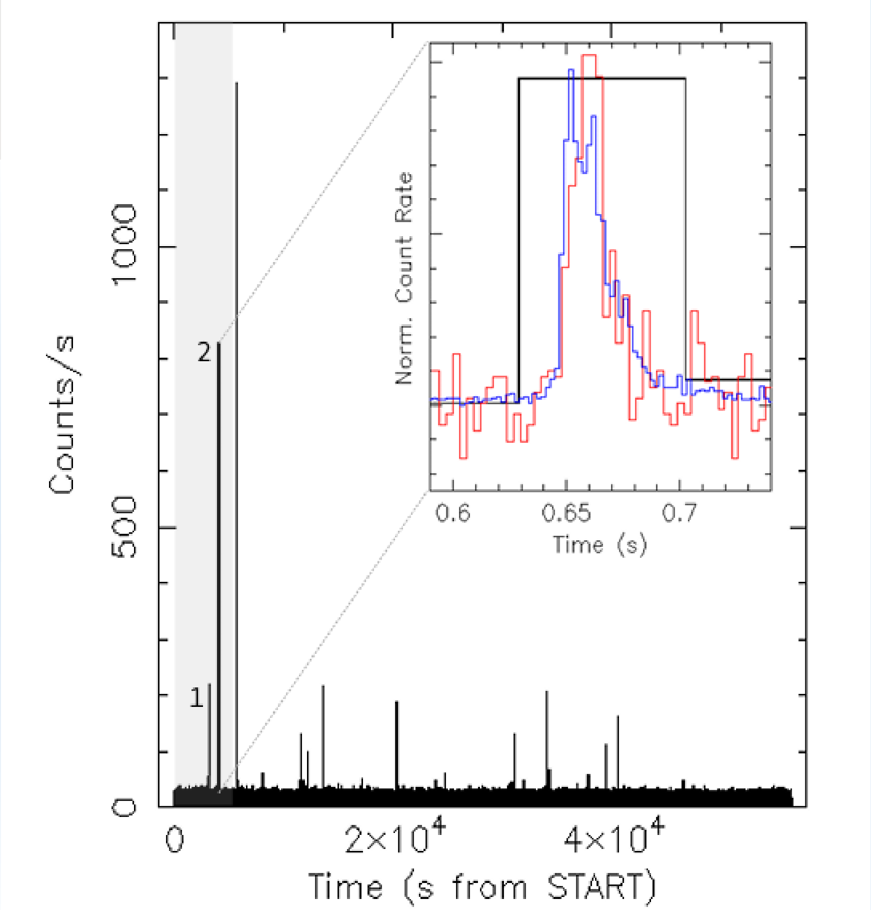
No dominant theory has emerged about the sources of FRB in recent literature, where many different interpretations of these phenomena have been proposed.

Possible sources of fast burst, radio or infrared (Israel, Burgay et al. 2020) are collected and discussed in the web catalog

https://frbtheorycat.org

and in the Transient Name Server

https://wis-tns.weizmann.ac.il/



In the picture, detected X-ray bursts with radio overlap. From Chandra and XMM-Newton EPIC-pn 210 keV light curve binned at 0.5 s, where the gray area marks the time interval covered by Parkes observations. The inset shows burst 2 as observed by EPIC-pn in the 2-10 keV band (black line; time resolution 73.4ms), Swift/BAT in the 15100keV band (red line; time resolution of 3ms) and KW (Konus-Wind) in the 201400keV band (blue line; time resolution of 2ms)- Credit: X-RAY AND RADIO BURSTS FROM THE MAGNETAR 1E1547.05408 G.L. Israel, M. Burgay, et al. ApJ, 907:7 (7pp), 2021 January 20

The puzzle of Fast Radio Bursts (FRBs)

A partial list of proposed source models to explain fast bursts, radio or infrared, follows here:

a) *Black hole (BH) to white hole (WH) quantum transition (Haggard & Rovelli 2015).*

b) Evaporating primordial BH (Steve Hawking, 1974).

c) Binary neutron star (NS) merger with short hard GRBs (Keane et al. 2012, Totani et al 2013).

d) Core Collapse Supernovae (Thornton, Burgay et al. 2013).

e) Binary white dwarf (WD) merger to highly magnetic spinning WD (Kashiyama et al 2013).

f) Asteroid/planet/WD magnetosphere interaction with the wind from an orbited pulsar/NS (Mottez & Zarka 2014).

g) Explosive decay of axion mini-clusters (Tkachev 2015).

h) Collision between axion stars and neutron stars (Iwazaki 2014).

i) Superconducting cosmic string (SCS) loops (Cao & Yu. 2018) oscillating in cosmic magnetic field (Yu et al. 2014).

j) Blitzar collapse to BH of a supermassive NS (Falcke & Rezzolla 2014).

k) *Magnetar giant flares (Popov et al. 2018; Thornton et al. 2013; Israel, Burgay, et al. 2021).*

l) Hyper pulses from extra-galactic NSs (Cordes & Wasserman 2016).

m) Pulsar magnetosphere “combed” by plasma stream (AGN, SN, GRB,...) (Zhang et al. 2017).

n) Astronomical masers (Elitzur, M., 1992), cyclotron or synchrotron maser emission (Lyubarsky 2014; Beloborodov 2017; Waxman 2017).

o) Extragalactic civilizations to power light sails (Lingam & Loeb 2017, Petty 2024).

The puzzle of FRBs

BH to WH quantum transition

Comment to item a):

the transition from black hole to white hole (Rovelli 2015, 2021 and 2023) has been hypothesized by Hal Haggard and Carlo Rovelli in 2015 in base at consideration on the quantum nature of the General Relativity in the article *Black Hole Fireworks: Quantum-gravity Effects Outside the Horizon Spark Black to White Tunnelling* (Haggard & Rovelli, 2015).

Another article, *Fast Radio Bursts and White Hole Signals,* (Barrau, Rovelli, Vidotto 2014) states that: "A strong explosion in a small region should emit a signal with a wavelength of the order of the size of the region or somehow larger and convert some fraction of its energy in photons. Therefore, it is reasonable to expect from this scenario an electromagnetic signal emitted in the infrared

λ predicted >= 0.02 cm."

Carlo Rovelli, in a private communication (2024) to the author of this presentation, does not exclude cases with shorter λ, in the mid-infrared, but he states that calculations should be made.

The puzzle of FRBs

Magnetar giant flares

Comment to item k):

Gelfand and Gaensler (2007, rev. 2018) present X-ray, infrared and radio observations of the field centered on X-ray source magnetar 1E 1547.0-5408 (PSR J1550-5418) in the galactic plane at a distance of 9 kpc.

A near-infrared observation of this field shows a source with magnitude Ks ≈ 16 near the position of the magnetar, but the implied X-ray to infrared flux ratio indicates the infrared emission is most likely from an unrelated field source, allowing us to limit the IR magnitude of any counterpart to > 17.5 (Zhang et al. 2023).

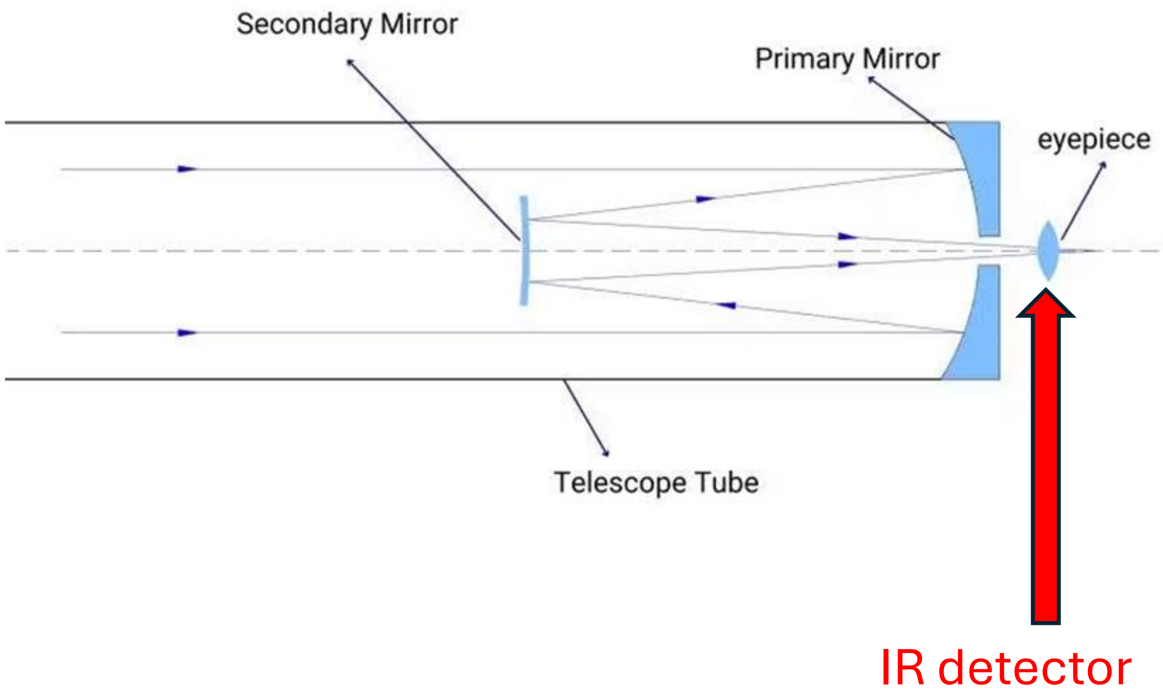
Searching for Fast InfraRed Bursts (FIRBs)

Summarizing, the possible models proposed for the explanation of the FRBs can in many cases be revised or adapted for astronomical photons of different energy, as the infrared range.

This is the case of the model proposed for the white holes.

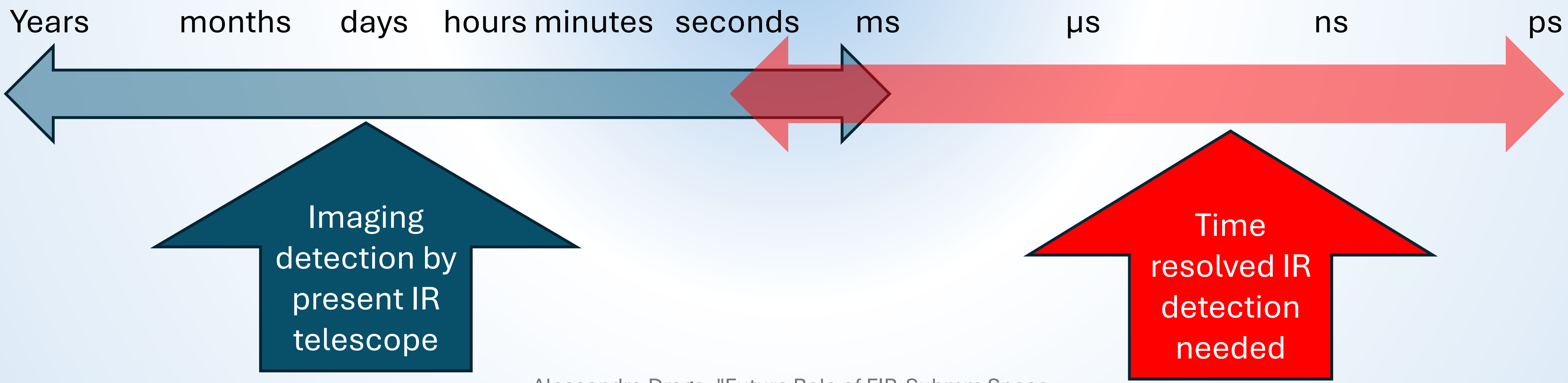
The search for Fast InfraRed Bursts (FIRBs) in time scale from 1 s down to ns or ps, requires special dedicated detectors that can be interfaced with traditional reflecting telescopes as Ritchey-Chrétien or Cassegrain.

Ritchey-Chrétien telescope



From multi-messenger astronomy to time domain astronomy

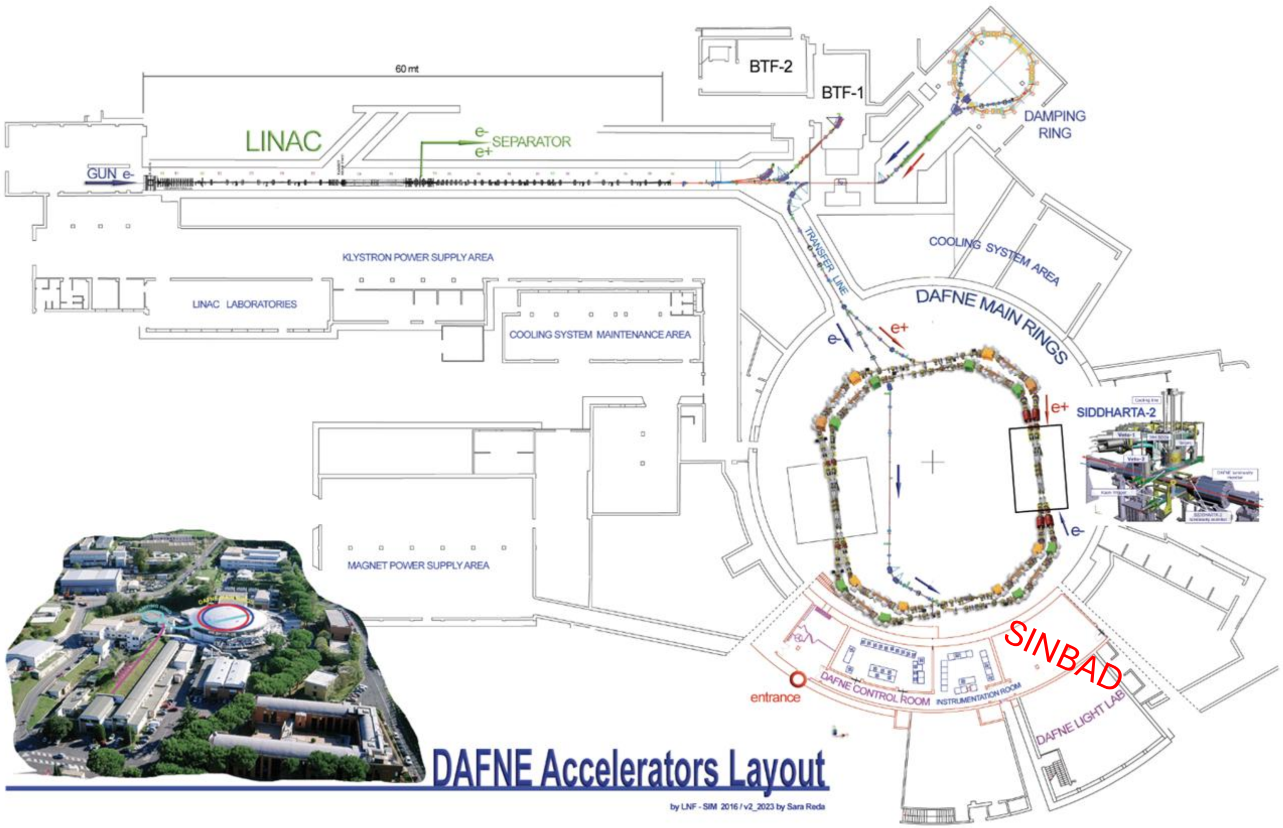
- Goal: Searching for fast astronomical infrared bursts (FIRBs)
- Question: How fast ?
- Answer: The time range should be between seconds and picoseconds (or at least between 1 millisecond and 1 nanosecond)
- Comment: A large time range may require different detection systems



How to detect fast infrared transients

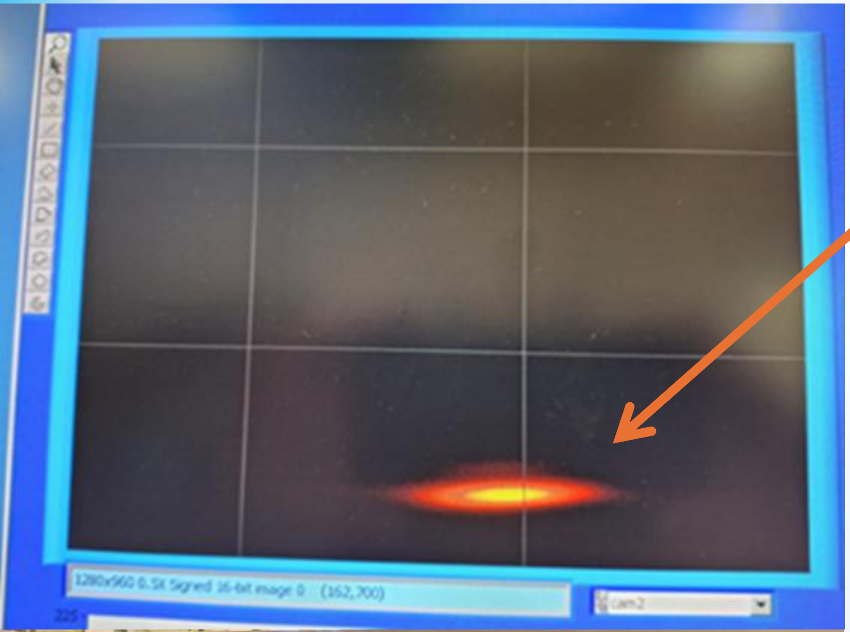
Experience developed for synchrotron light diagnostics in particle accelerators can be used to design time domain devices for astronomy.

At SINBAD, the IR beam line of DAFNE, lepton collider in Italy, HgCdTe detectors have acquired fast infrared pulses with 2-12 μm wavelengths and 1 ns rise times with sensitivity that can arriving to 1 photon for 0.1% of the infrared bandwidth (δλ/λ) if using the proper 80 dB amplification stage as demonstrated by the experiment **FAIRTEL - Fast InfraRed TELescope**



INFN/LNF Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati - Italy

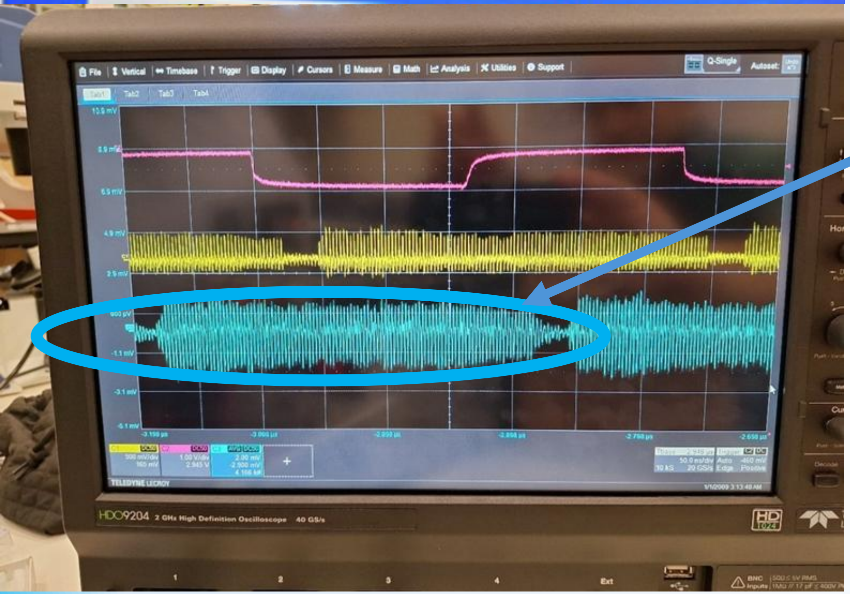
Synchrotron light detection



Imaging (or transverse) detection of synchrotron light source

Synchrotron light monitor (SLM) in DAFNE.
This standard detector does not show any evidence of bunches.

Images from DAFNE & SINBAD



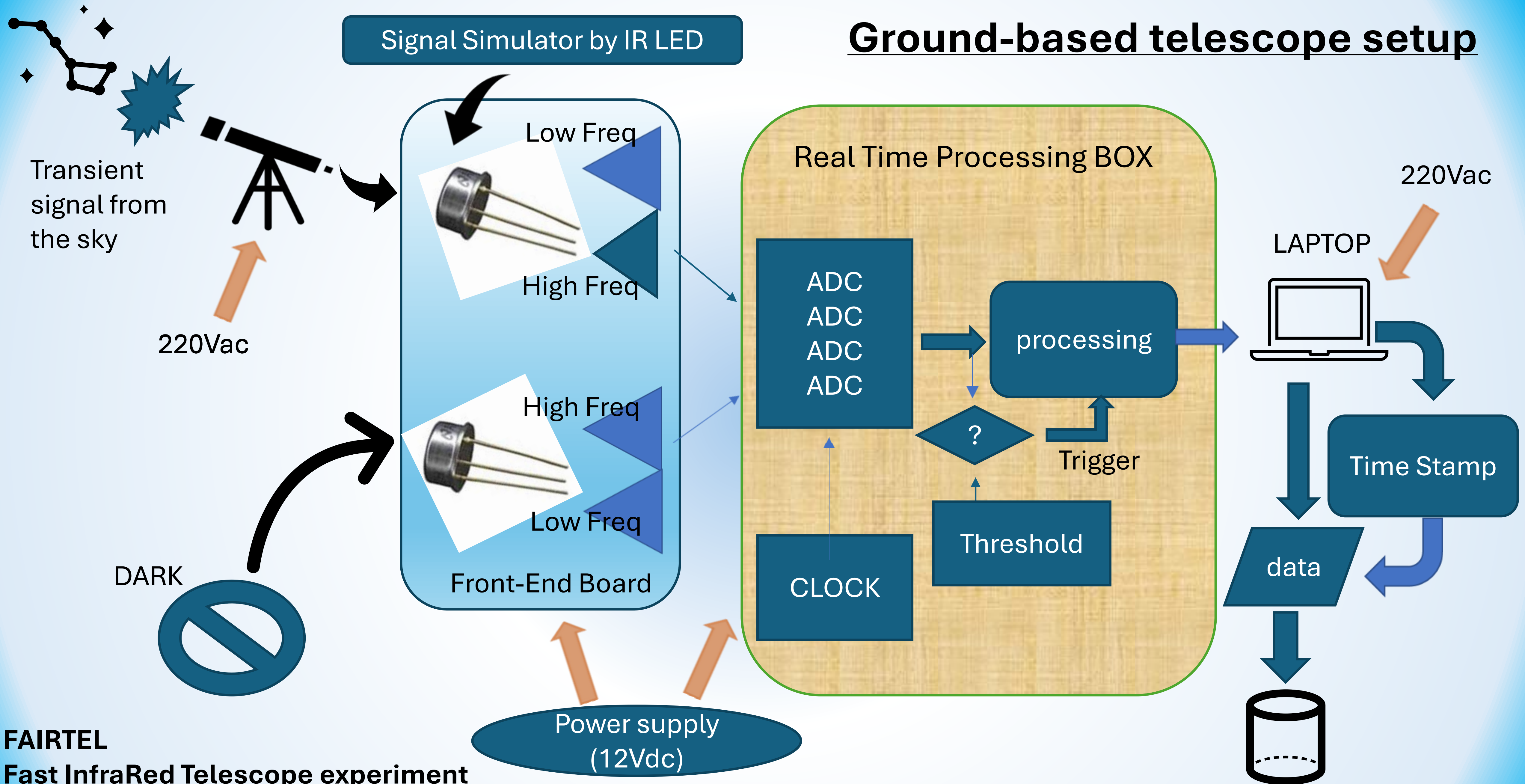
Infrared synchrotron light detected in time domain (or longitudinal)

By using a single pixel HgCdTe detector, the infrared signal (cyan trace) reproduces correctly the bunches in the train corresponding to the signal from the electromagnetic pickup (yellow trace).

- FAIRTEL uses direct detection in baseband

– no heterodyne technique to exploit all the frequency band

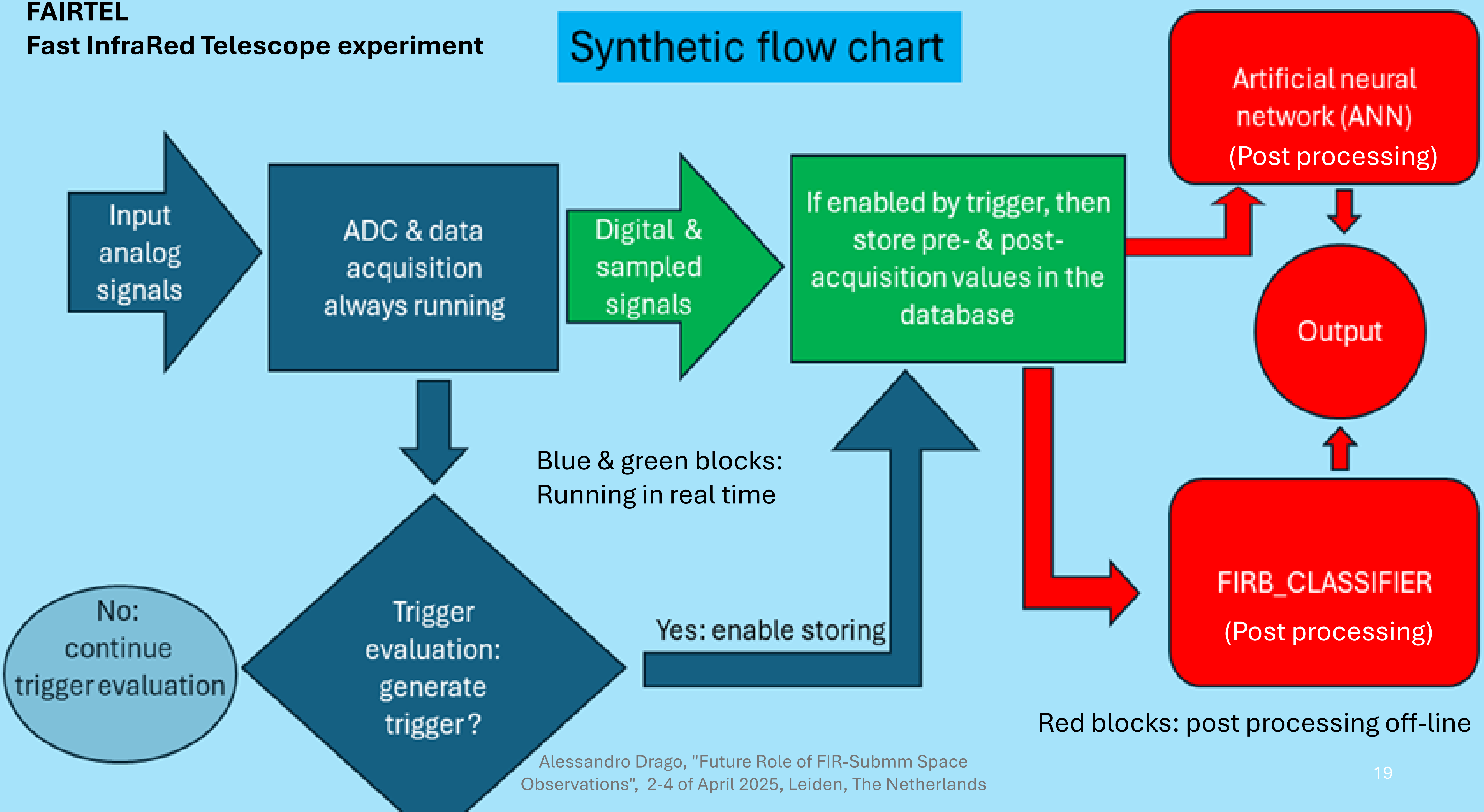
Ground-based telescope setup



FAIRTEL
Fast InfraRed Telescope experiment

FAIRTEL
Fast InfraRed Telescope experiment

Synthetic flow chart



Conclusion

- Multi-messenger astronomy, GW, neutrinos, GRBs and the mysterious FRBs have sparked interest to detectors and telescopes dedicated to time-domain astronomy across all the electromagnetic spectrum.
- Researchers have proposed multiple explanations for the sources of FRBs that can be extended to mid & far infrared.
- Among the models proposed, primordial black hole explosion generating transition from BH to WH has been hypothesized by Hal Haggard and Carlo Rovelli in base at consideration on the quantum nature of the General Relativity. BH-to-WH transition should emit in the Far or Mid IR range.
- Fast InfraRed Bursts (FIRBs) in the mid and far infrared, have been relatively understudied, for the lack of appropriate instruments.
- In fact, at the present, most of the astronomical infrared telescopes are designed to make imaging, photometry and spectrography so it could be convenient to build systems dedicated to fast or ultra-fast detection that can acquire transients between 1 s and 1 ns.
- On the other hand, in the diagnostics for particle accelerators, integrating devices, designed to get “transverse” image of the beams, are technically different from time domain (or “longitudinal”) diagnostic devices.
- FAIRTEL experiment, derived from synchrotron light infrared diagnostics for lepton accelerators and using direct detection in baseband (no heterodyne), is an option for new time-domain devices in astronomy.

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Preferred capabilities for the FAIRTEL telescope

- Spectral range: 2 – 12 μm wavelength (extended version: 1 μm - 1 mm)
- Number of pixels: one (plus one for dark signal)
- Interferometry: no (single telescope)
- Preferred implementation for ground-based telescope:
  - Optical configuration: Ritchey-Chrétien
  - Primary mirror diameter: 800 mm
  - Focal length: 6400 mm
  - Focal ratio: F/8
  - Tube length: 2030 mm
  - Tube diameter: 1010 mm
  - Mount: German equatorial
- Implementation for space telescope: to be evaluated

Thank you for your attention

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