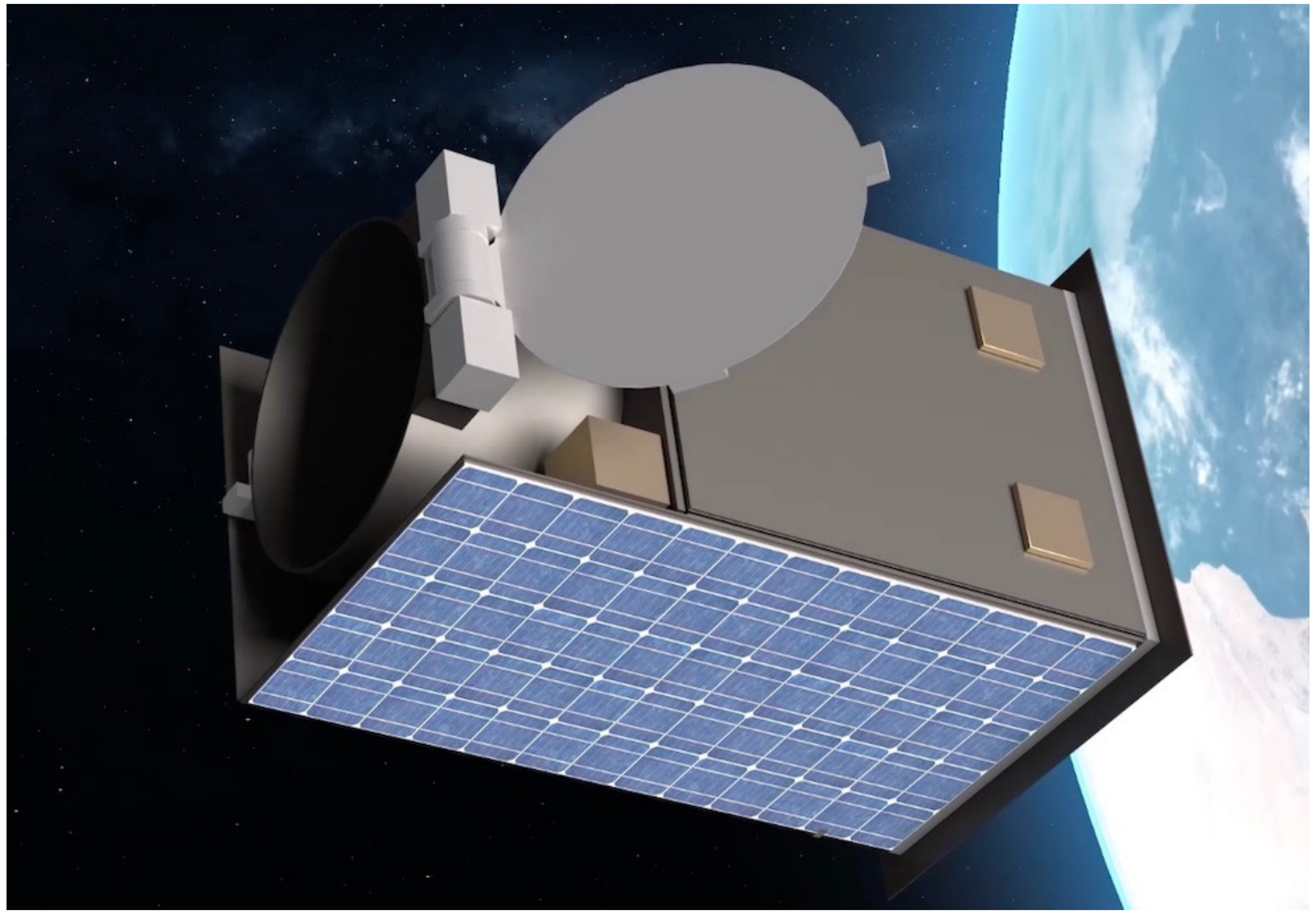
QUVIK - Quick Ultra Violet Kilonova surveyor

A Czech-led mission with a strong international contribution

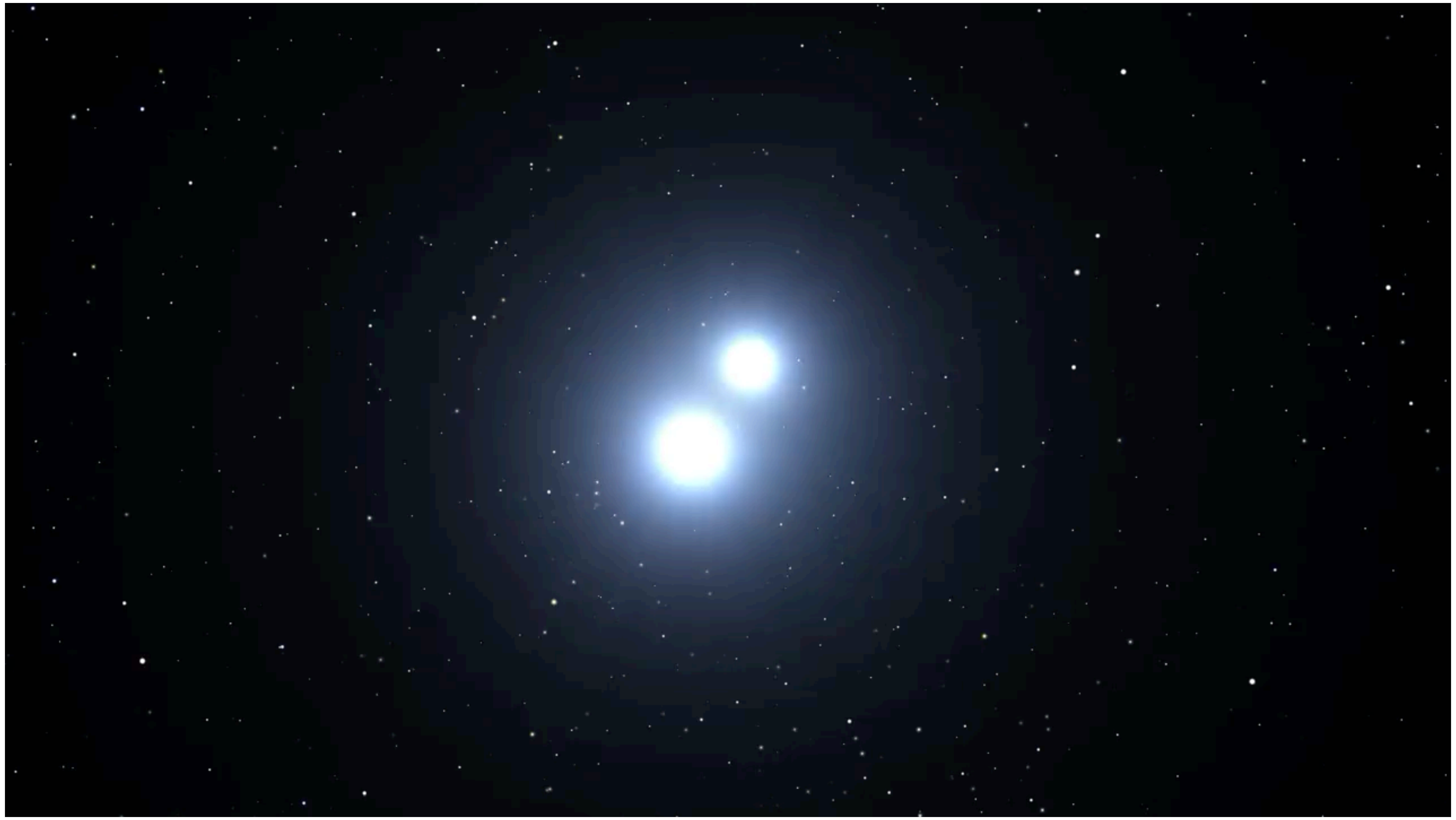


Norbert Werner (Masaryk University) on behalf of the *QUVIK* collaboration

VZLU Aerospace (prime), **Masaryk University** (science PI)

QUVIK mission objectives

The mission shall observe the sources of gravitational waves discovered by LIGO/VIRGO/KAGRA run O5 at the end of this decade.



The observations will reveal the UV emissions resulting from mergers of neutron stars and black holes, determine their role in the origin of heavy elements, and study physics under exceptionally extreme conditions, providing opportunities for new truly breakthrough discoveries.

The **QUVIK** satellite (2 years ago)

Spacecraft is based on the Czech Advanced Platform (CAP).

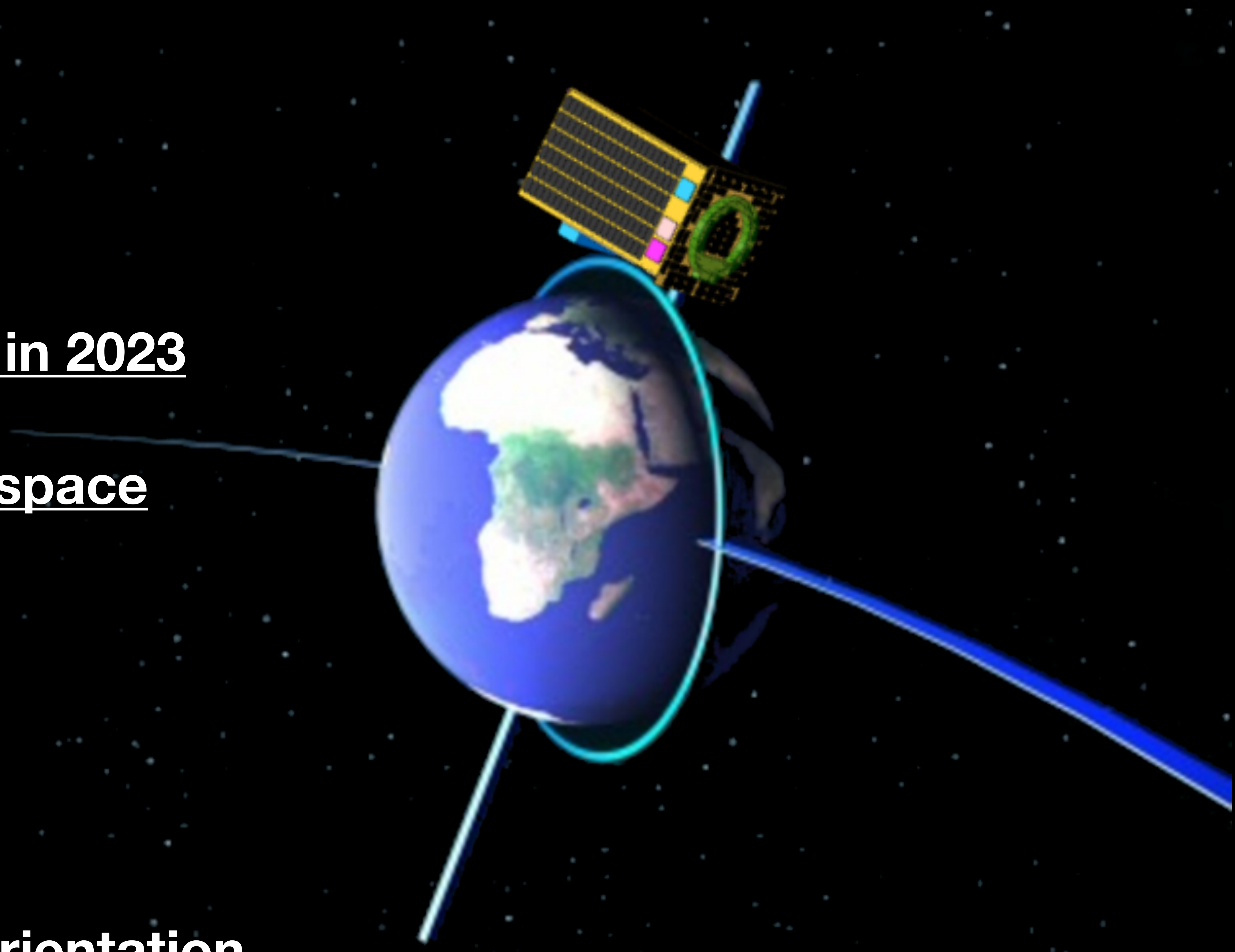
Satellite parameters:
Mass: ~130 kg
Size: 0.7 x 0.7 x 1.1 m
Mission duration: 3 years
Status: B1 phase finished, approved for funding in 2023

Primary payload: 33cm aperture two-band UV space telescope

Fast repointing capability (15 min)
Near-real time communication

Orbit: Low Earth Orbit (LEO)
Sun Synchronous Orbit (SSO) Dawn/dusk orbit orientation

Ready for several launchers (including Vega C and Falcon 9)




CZECH AEROSPACE RESEARCH CENTRE • MUNI • QUVIK • QUICK ULTRA-VIOLET KILONOVA SURVEYOR
CZECH
AEROSPACE
RESEARCH
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The **QUVIK** satellite

Spacecraft is based on the Czech Advanced Platform (CAP).

Satellite parameters:
Mass: ~200 kg
Size: 0.7 x 0.7 x 1.1 m
Mission duration: 3 years
Status: B1 phase finished, approved for funding in 2023

Past two years QUVIK is undergoing design consolidation

Primary payload: ~25cm aperture NUV (~260–360 nm) telescope with 1 deg^2 FoV
Secondary payload 1: ~25cm aperture FUV (~150–200 nm) telescope with 1 deg^2 FoV contributed by ASI & INAF (led by INAF Brera) in Italy
Secondary payload 2: GALI GRB detector from Technion & ISA in Israel

Fast repointing capability (15 min)
Near-real time communication

Orbit: Low Earth Sun Synchronous Orbit (SSO)

Ready for several launchers (including Vega C and Falcon 9)

Mission objectives

QUVIK shall serve as an ultraviolet (UV) astrophysical observatory benefiting the broader astronomy community. The mission's science case rests on three main pillars:

1. Determining the UV properties and constraining the physics of energetic stellar transients, some of which are the counterparts of gravitational wave sources

2. Determining the UV properties of stars, in particular massive hot stars that end their lives in explosive events and of stars hosting exoplanets to better understand their habitability

3. Determining the properties of accretion flows into central supermassive black holes of galaxies, both via monitoring of luminous active galactic nuclei (AGN) and following up sudden brightening of galactic nuclei due to tidal disruption of stars or interactions between accretion flows and stellar objects.

QUVIK *papers in Space Science Reviews*

Space Science Reviews (2024) 220:11
https://doi.org/10.1007/s11214-024-01048-3

Check for updates

Science with a Small Two-Band UV-Photometry Mission I: Mission Description and Follow-up Observations of Stellar Transients

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Abstract
This is the first in a collection of three papers introducing the science with an ultra-violet (UV) space telescope on an approximately 130 kg small satellite with a moderately fast re-pointing capability and a real-time alert communication system approved for a Czech national space mission. The mission, called *Quick Ultra-Violet Kilonova surveyor—QUVIK*, will provide key follow-up capabilities to increase the discovery potential of gravitational wave observatories and future wide-field multi-wavelength surveys. The primary objective of the mission is the measurement of the UV brightness evolution of kilonovae, resulting from mergers of neutron stars, to distinguish between different explosion scenarios. The mission, which is designed to be complementary to the *Ultraviolet Transient Astronomy Satellite—ULTRASAT*, will also provide unique follow-up capabilities for other transients both in the near- and far-UV bands. Between the observations of transients, the satellite will target other objects described in this collection of papers, which demonstrates that a small and relatively affordable dedicated UV-space telescope can be transformative for many fields of astrophysics.

Keywords UV space observatory · Kilonovae · Gamma-ray bursts · Supernovae

1 Introduction

The first simultaneous detection of gravitational waves and electromagnetic radiation on 2017 August 17 (Abbott et al. 2017b,a), resulting from a coalescence of neutron stars, marked the onset of multi-messenger astrophysics involving gravitational waves. This exciting observation showed that neutron star mergers are of major importance for enriching the Universe with rare heavy elements such as gold and platinum. The radioactive decay of these heavy elements powers a thermal transient at ultra-violet/visible/infrared wavelengths

Extended author information available on the last page of the article

Space Science Reviews (2024) 220:24
https://doi.org/10.1007/s11214-024-01058-1

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Science with a Small Two-Band UV-Photometry Mission II: Observations of Stars and Stellar Systems

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Abstract
We outline the impact of a small two-band UV-photometry satellite mission on the field of stellar physics, magnetospheres of stars, binaries, stellar clusters, interstellar matter, and exoplanets. On specific examples of different types of stars and stellar systems, we discuss particular requirements for such a satellite mission in terms of specific mission parameters such as bandpass, precision, cadence, and mission duration. We show that such a mission may provide crucial data not only for hot stars that emit most of their light in UV, but also for cool stars, where UV traces their activity. This is important, for instance, for exoplanetary studies, because the level of stellar activity influences habitability. While the main asset of the two-band UV mission rests in time-domain astronomy, an example of open clusters proves that such a mission would be important also for the study of stellar populations. Properties of the interstellar dust are best explored when combining optical and IR information with observations in UV.

It is well known that dust absorbs UV radiation efficiently. Consequently, we outline how such a UV mission can be used to detect eclipses of sufficiently hot stars by various dusty objects and study disks, rings, clouds, disintegrating exoplanets or exoasteroids. Furthermore, UV radiation can be used to study the cooling of neutron stars providing information about the extreme states of matter in the interiors of neutron stars and used for mapping heated spots on their surfaces.

Keywords Techniques: photometric · Ultraviolet: stars · Stars: variables: general · Binaries: general · Open clusters and associations: general · Planetary systems

1 Introduction

The new discoveries in astrophysics during the last few decades were frequently connected with the opening of new observational windows into invisible parts of the spectrum. Recently, the advent of observatories working outside the electromagnetic domain founded a

Extended author information available on the last page of the article

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Science with a Small Two-Band UV-Photometry Mission III: Active Galactic Nuclei and Nuclear Transients

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Received: 27 June 2023 / Accepted: 12 March 2024

Abstract
In this review, the third one in the series focused on a small two-band UV-photometry mission, we assess possibilities for a small UV two-band photometry mission in studying accreting supermassive black holes (SMBHs; mass range $\sim 10^6$–$10^{10}\,M_\odot$). We focus on the following observational concepts: (i) dedicated monitoring of selected type-I Active Galactic Nuclei (AGN) in order to measure the time delay between the far-UV, the near-UV, and other wavebands (X-ray and optical), (ii) nuclear transients including (partial) tidal disruption events and repetitive nuclear transients, and (iii) the study of peculiar sources, such as changing-look AGN, hollows and gaps in accretion disks, low-luminosity AGN, and candidates for Intermediate-Mass Black Holes (IMBHs; mass range $\sim 10^2$–$10^5\,M_\odot$) in galactic nuclei. The importance of a small UV mission for the observing program (i) is to provide intense, high-cadence monitoring of selected sources, which will be beneficial for, e.g. reverberation-mapping of accretion disks and subsequently confronting accretion-disk models with observations. For program (ii), a relatively small UV space telescope is versatile enough to start monitoring a transient event within $\lesssim 20$ minutes after receiving the trigger; such a moderately fast repointing capability will be highly beneficial. Peculiar sources within the program (iii) will be of interest to a wider community and will create an environment for competitive observing proposals. For tidal disruption events (TDEs), high-cadence UV monitoring is crucial for distinguishing among different scenarios for the origin of the UV emission. The small two-band UV space telescope will also provide information about the near- and far-UV continuum variability for rare transients, such as repetitive partial TDEs and jetted TDEs. We also discuss the possibilities to study and analyze sources with non-standard accretion flows, such as AGN with gappy disks, low-luminosity active galactic nuclei with intermittent accretion, and SMBH binaries potentially involving intermediate-mass black holes.

Keywords Galactic nuclei · Accretion flows · Tidal disruption events · Transients · Photometry · Time series

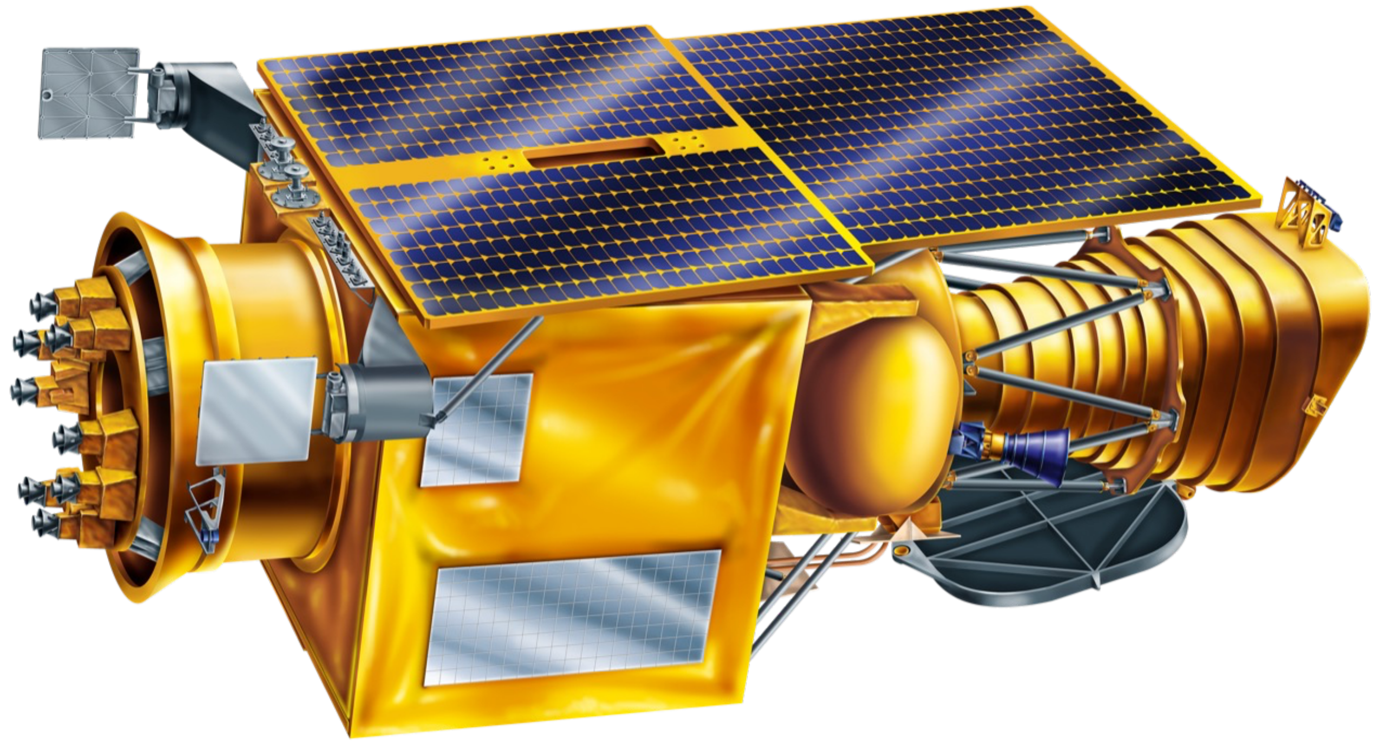
1 Introduction

The growth of supermassive black holes (hereafter SMBHs) residing in the centres of galaxies is a crucial topic in modern astrophysics (Di Matteo 2019). SMBHs can grow by accre-

Extended author information available on the last page of the article

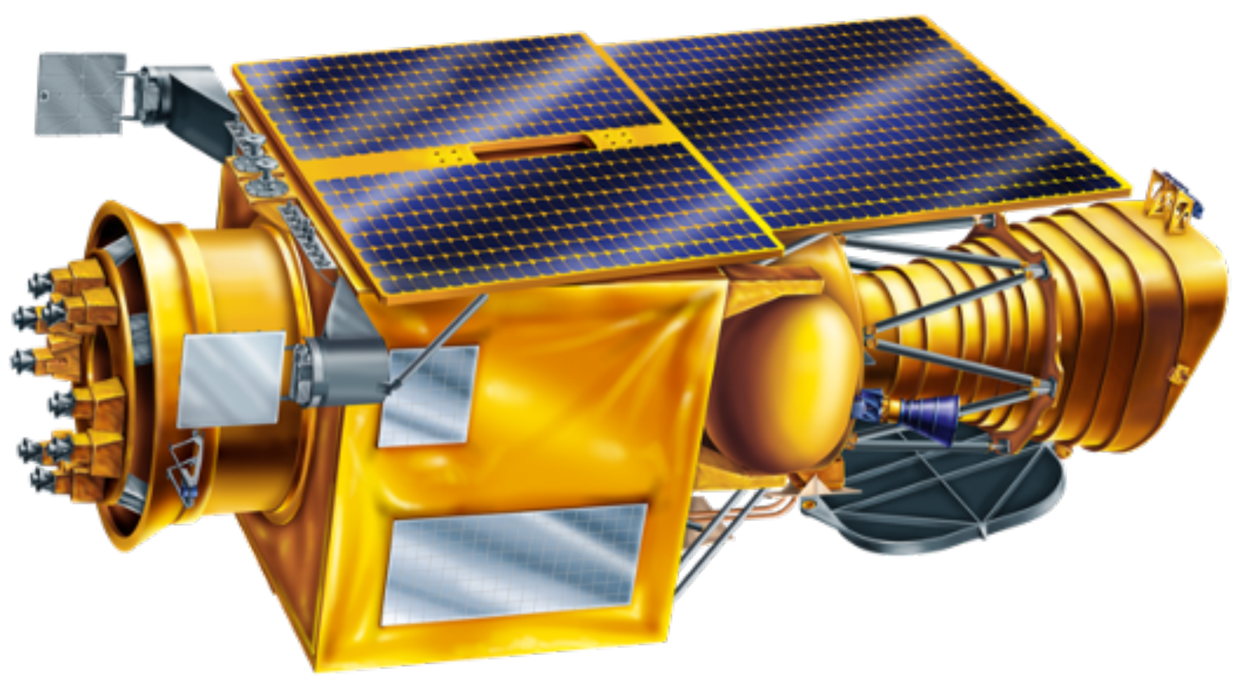
Published online: 29 March 2024

Synergy with other observatories

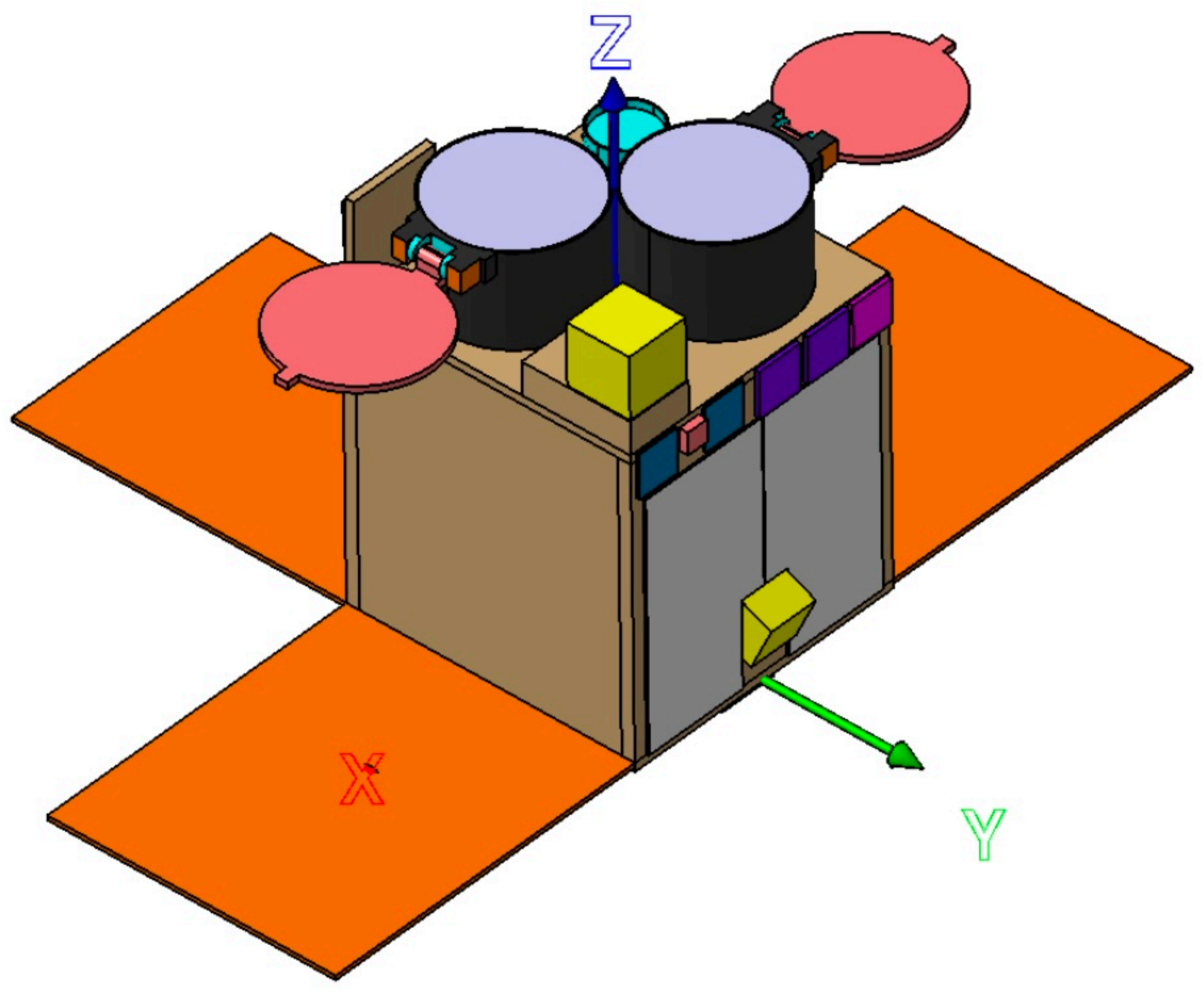


- QUVIK will fly during the 5th run of the LIGO/VIRGO/KAGRA gravitational detector network, providing key follow-up capabilities and increasing its discovery potential
- QUVIK is complementary to ULTRASAT, providing unique follow-up capabilities in FUV and complementary NUV, multiplying the discovery potential of the mission
- QUVIK will dedicate part of its observing time to the follow-up of transients discovered by the Vera C. Rubin LSST
- QUVIK will provide open observing time to the international astronomy community as well as an online data archive

A collaboration from which everybody benefits



QUVIK and *ULTRASAT* provide complementary capabilities that multiply the discovery potential of both missions. *ULTRASAT* will discover the most interesting targets for *QUVIK*, which will then perform unique simultaneous NUV-FUV observations.



The picture does not reflect the final configuration!

	QUVIK	*ULTRASAT*
FoV	~1deg^2	204 deg^2
Bandpass	~260—360 nm ~150—200 nm	230—290 nm
Sensitivity	21.5 mag in 3000 s	22.3 mag in 900s
Resolution	<5 arcsec	8.3 arcsec
Observations	pointed	survey
Launch date	2030	2027

QUVIK summary

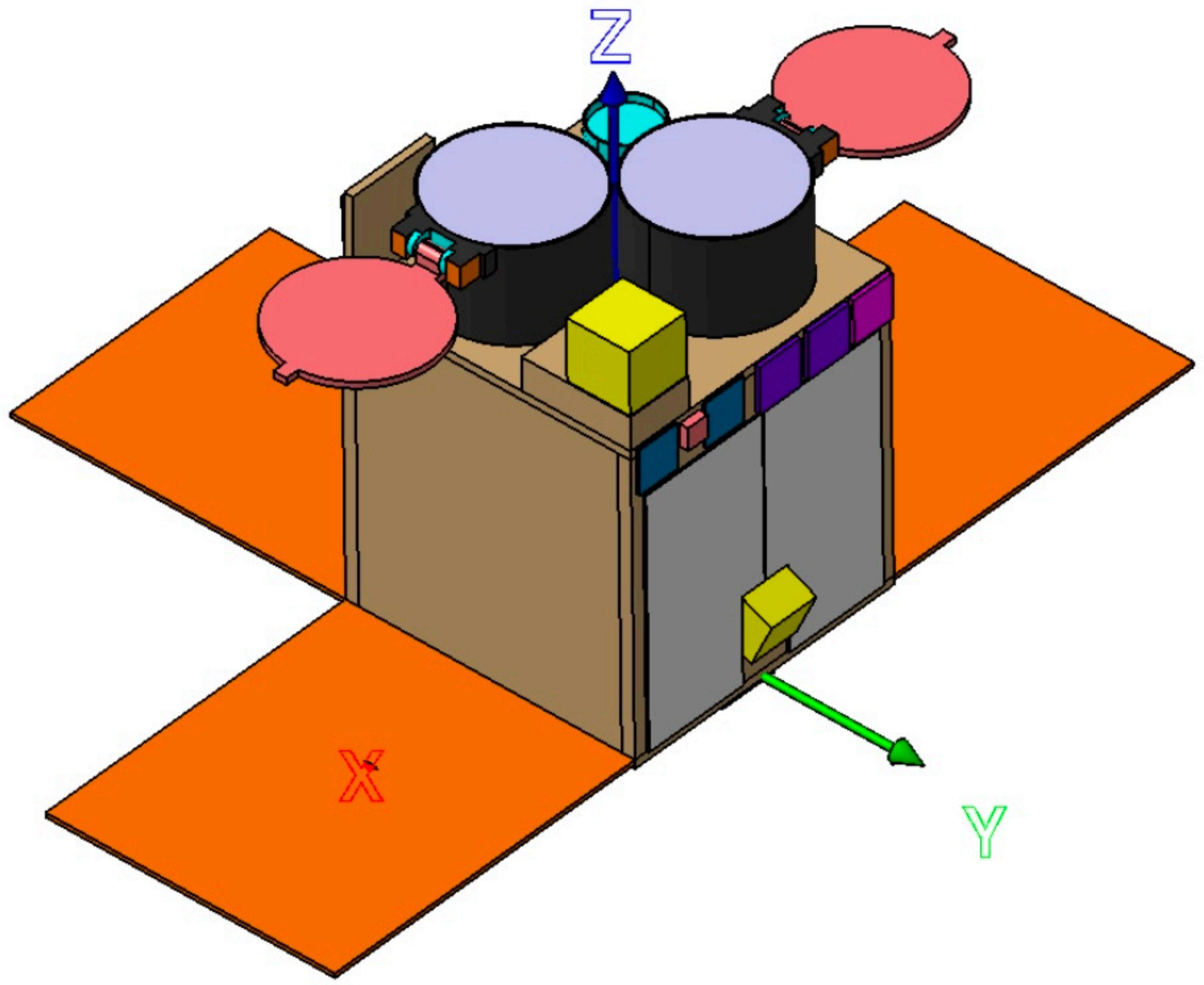
Mass: ~200 kg
Size: 0.7 x 0.7 x 1.1 m
Mission duration: 3 years
Status: B1 phase finished, approved for funding in 2023,

Primary payload: ~25cm aperture NUV (~260–360 nm) telescope with 1 deg^2 FoV
Photometric sensitivity in NUV: 21.5 mag (5 sigma in 3000 s) in an early type galaxy at 1.5 effective radii
Resolution: <5 arcsec

Secondary payload 1: ~25cm aperture FUV (~150–200 nm) telescope with 1 deg^2 FoV contributed by ASI & INAF (led by INAF Brera) in Italy
Secondary payload 2: GALI GRB detector from Technion & ISA in Israel

Observation start latency: <15 min
Near-real time inter-satellite communication for triggers
Data downlink: X-band (1600 images per day)

Orbit: Low Earth Sun Synchronous Orbit (SSO)
Launch: 2030



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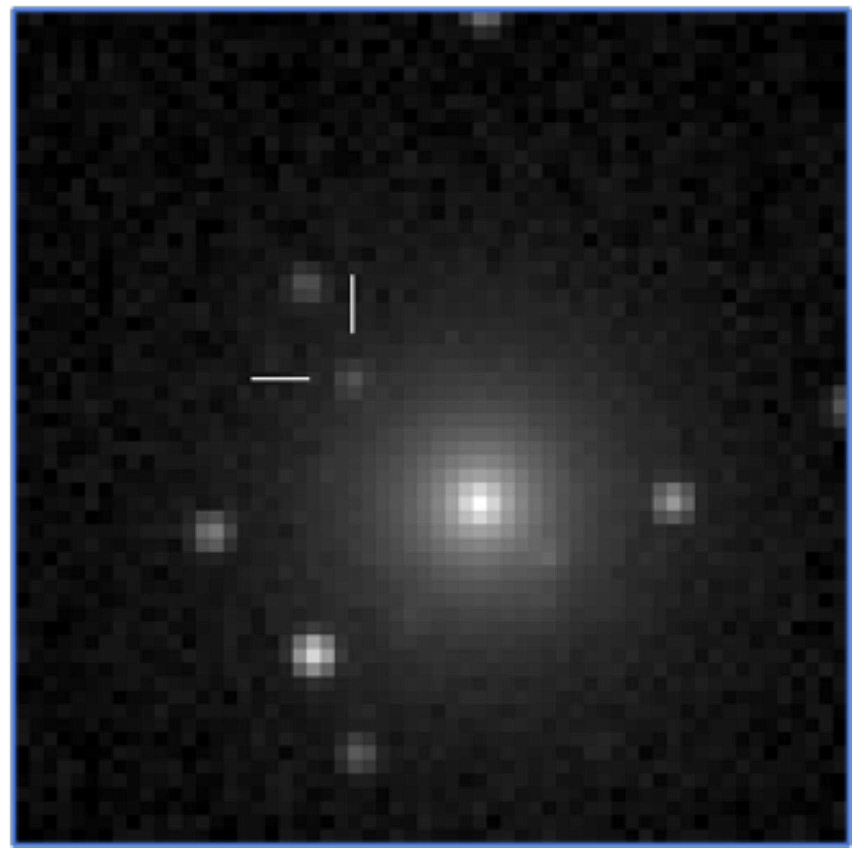
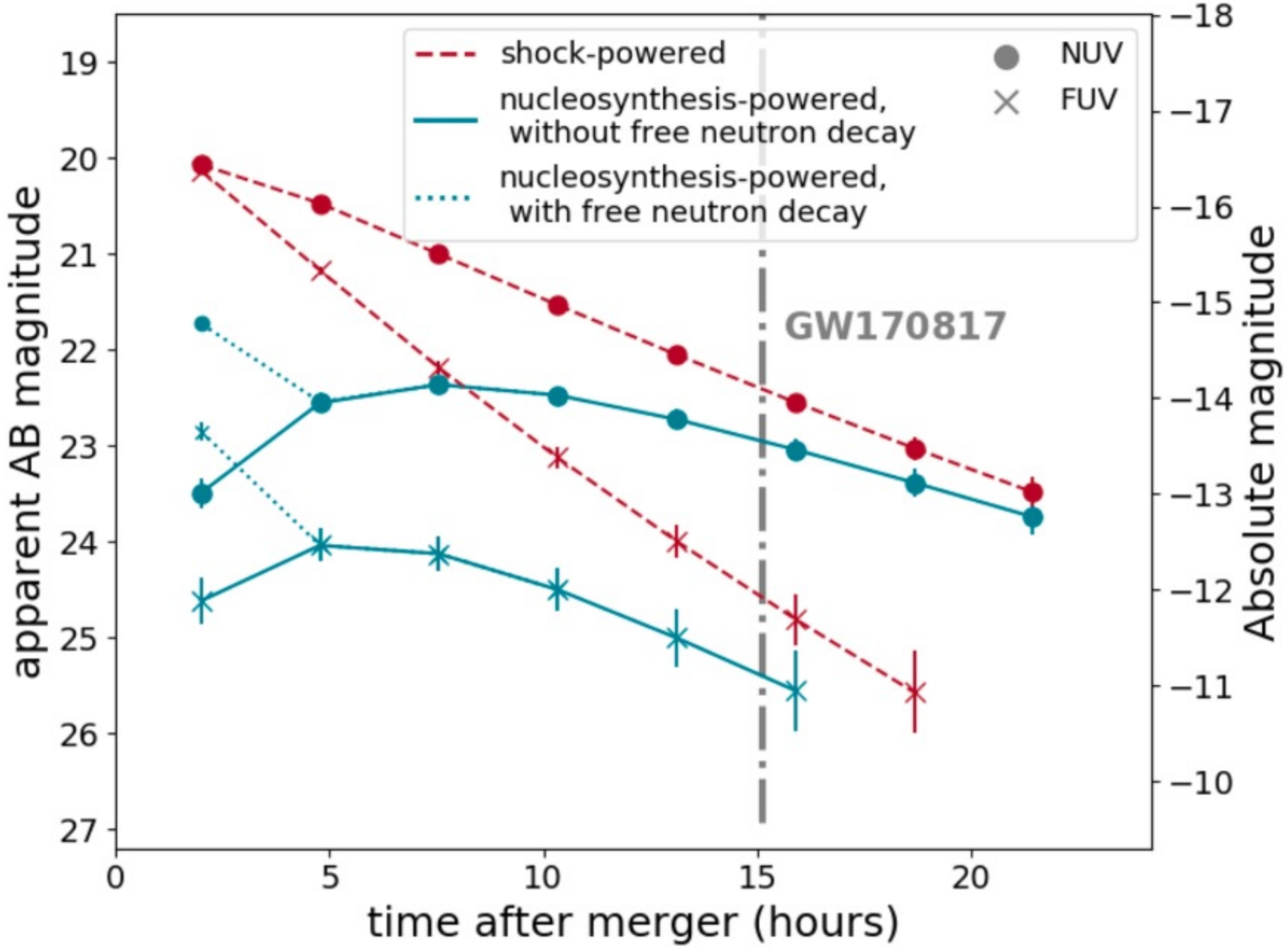
Detection of kilonovae

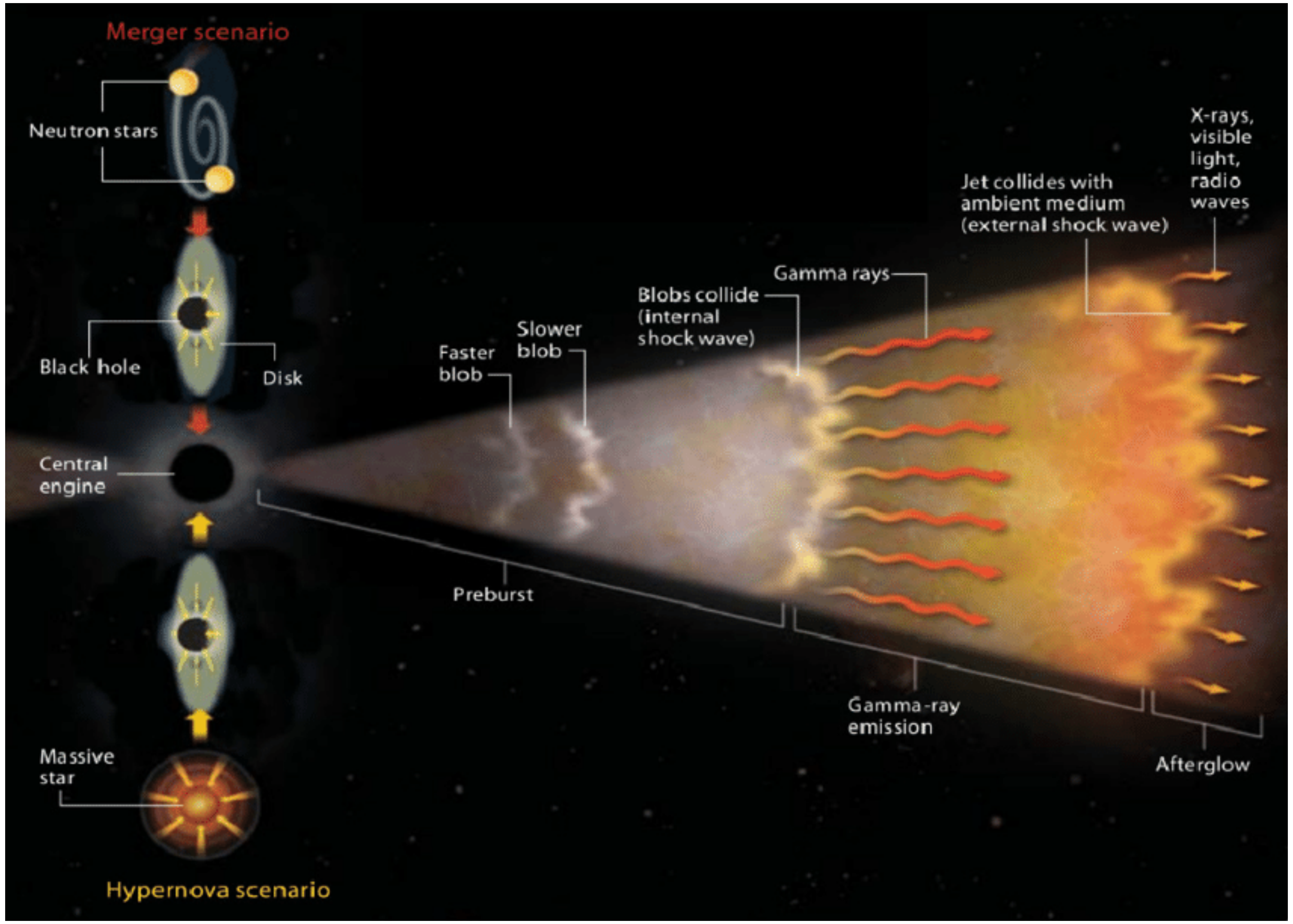


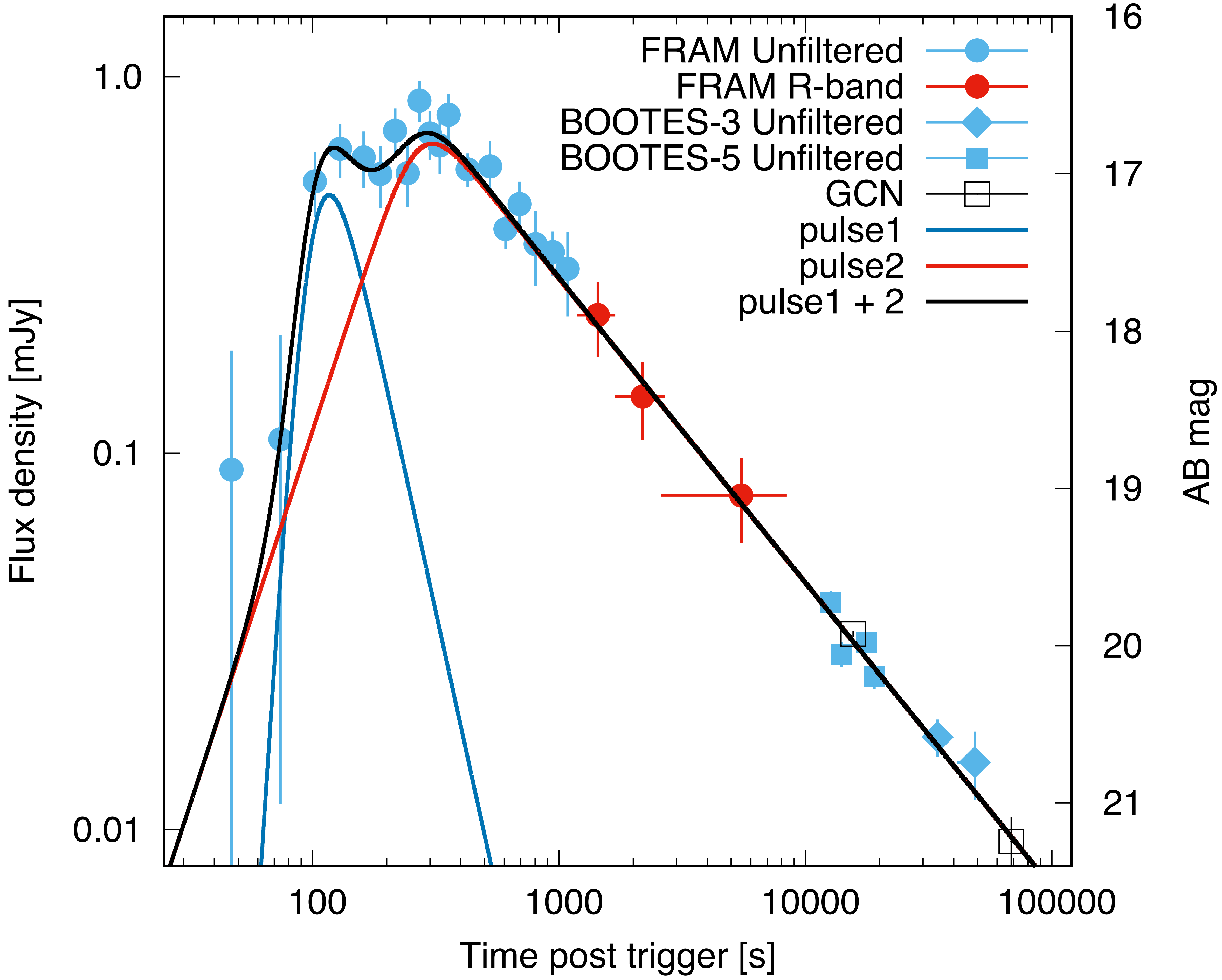


Kulkarni et al. 2022

- With a limiting magnitude 21.5, we expect to see 5 kilonovae per year, with 22nd mag 9 kilonovae per year (uncertainties are large)
- We designed the instrument to reach the 21.5 magnitude in a single orbit
- To distinguish between kilonova models, observations shall be performed early after the explosion

Simultaneous 2-band observation of GRB afterglows

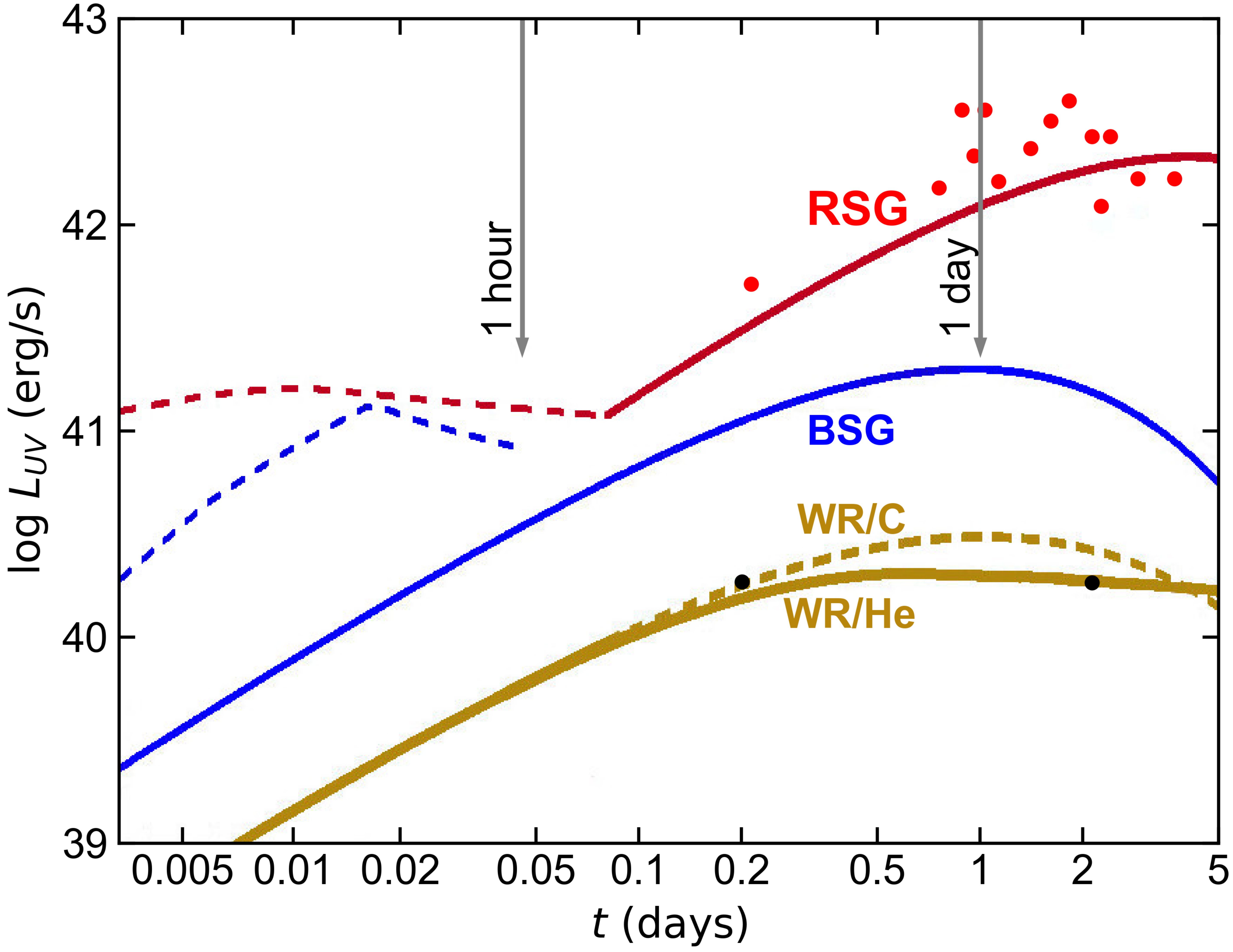




Gehrels et al. 2002

Jelinek et al. 2022

Early UV emission of supernovae

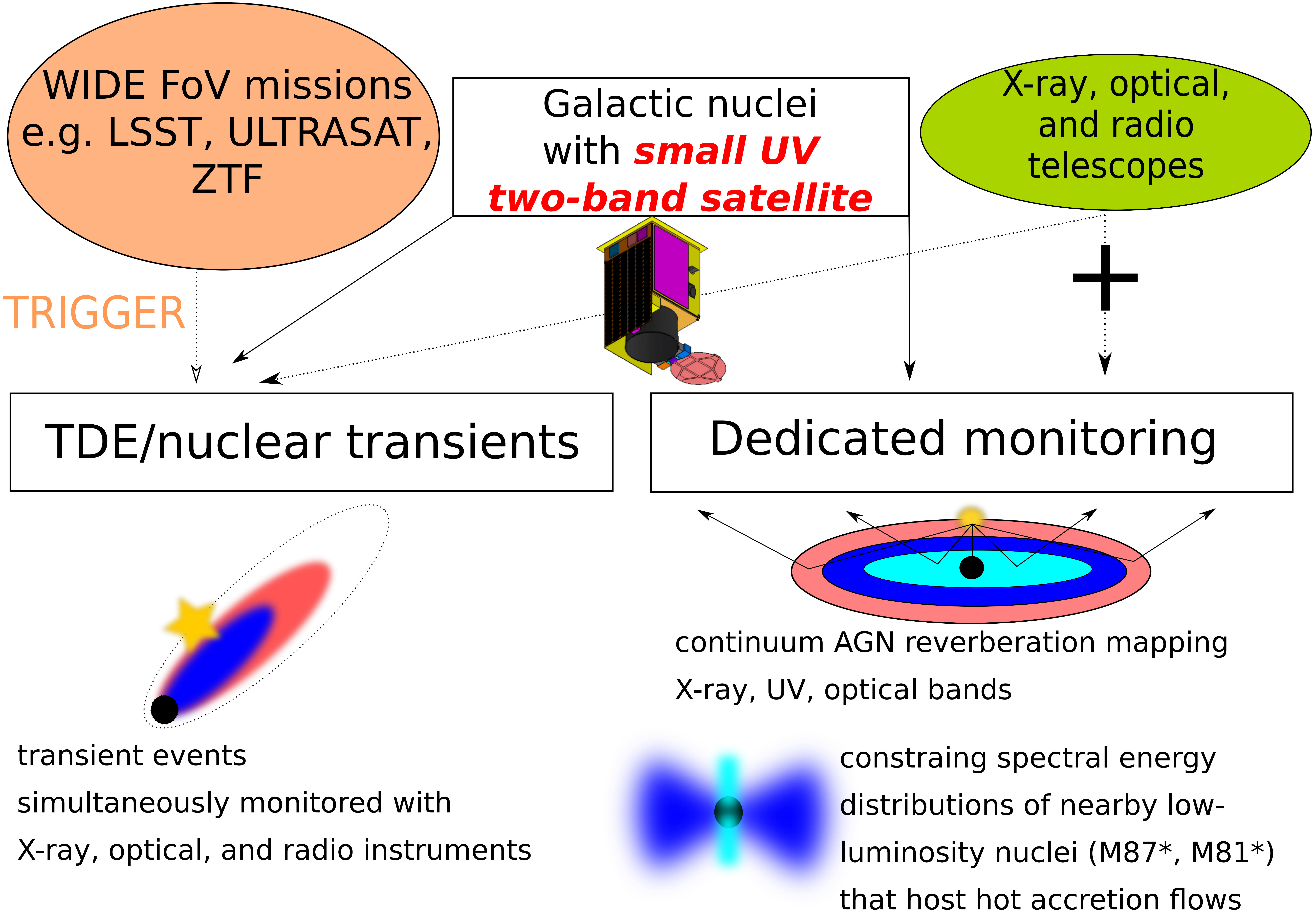


Ganot et al. 2016 adapted by Petr Kurfurst

Observations of stellar systems

- Hot stars (emit maximum of their SED in the UV)
- Cool stars (chromospheres, flares)
- Binaries
- Stellar clusters
- Interstellar matter
- Stars hosting exoplanets (flares and transits)

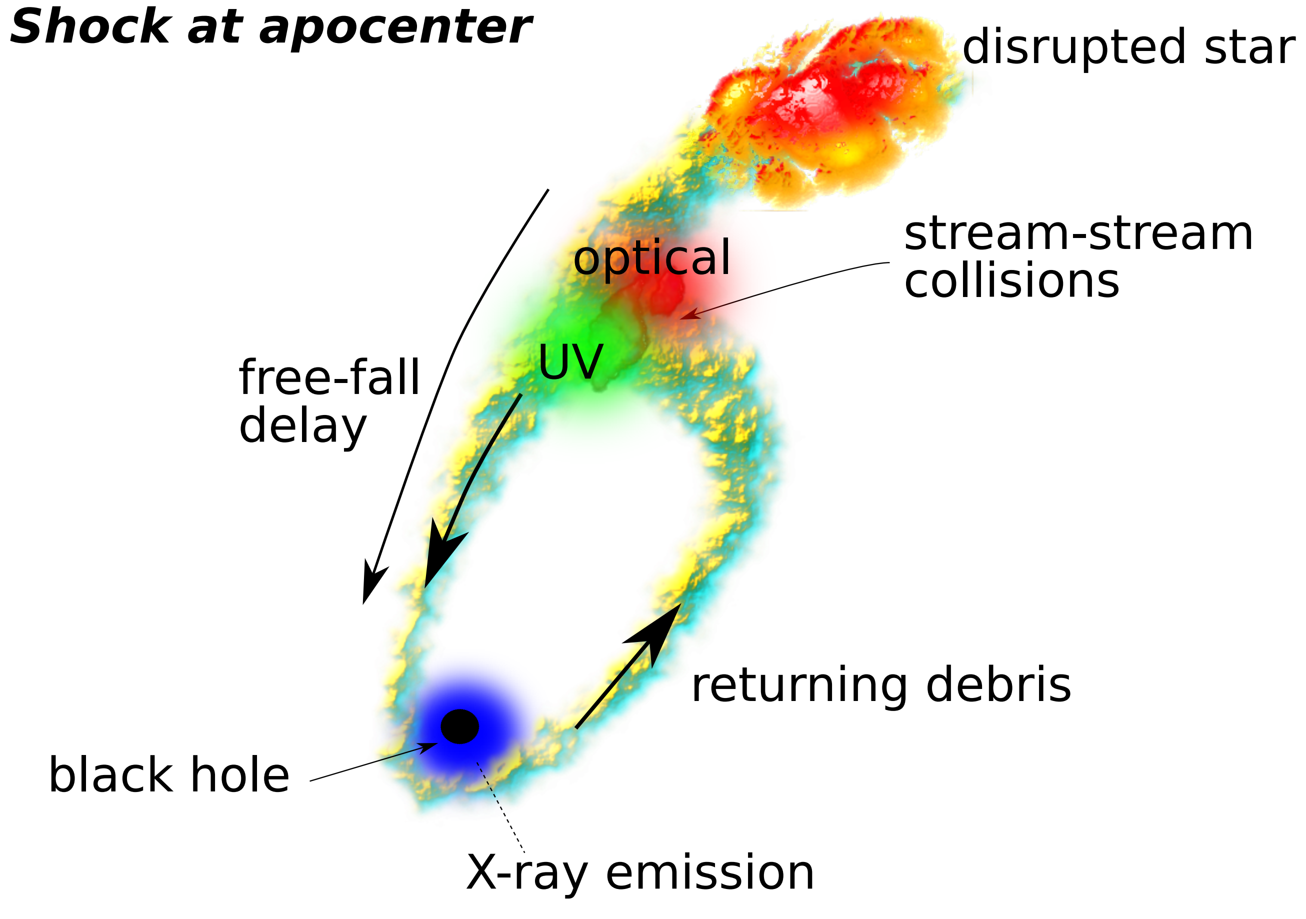
Krtička et al. 2023


WIDE FoV missions
e.g. LSST, ULTRASAT,
ZTF
Galactic nuclei
with *small UV*
two-band satellite
X-ray, optical,
and radio
telescopes
TRIGGER
+
TDE/nuclear transients
Dedicated monitoring
continuum AGN reverberation mapping
X-ray, UV, optical bands
transient events
simultaneously monitored with
X-ray, optical, and radio instruments
constraing spectral energy
distributions of nearby low-
luminosity nuclei (M87*, M81*)
that host hot accretion flows

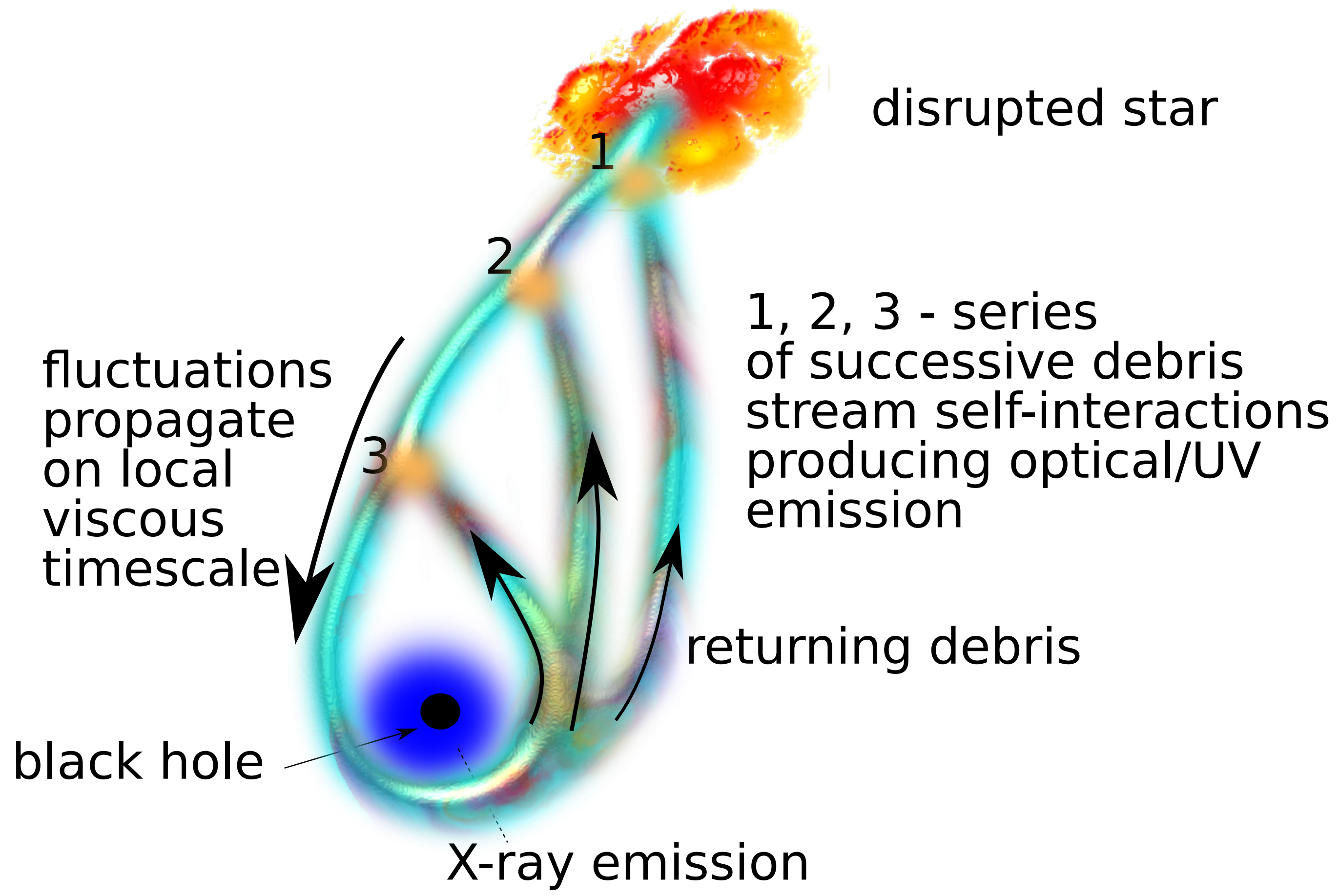
Origin of the TDE emission

- tidal disruption events are accompanied by bright optical/UV emission that decreases as a power-law ($L \propto t^{-5/3}$)
- **unclear origin of the UV emission:** shock-produced or accretion-disc emission?

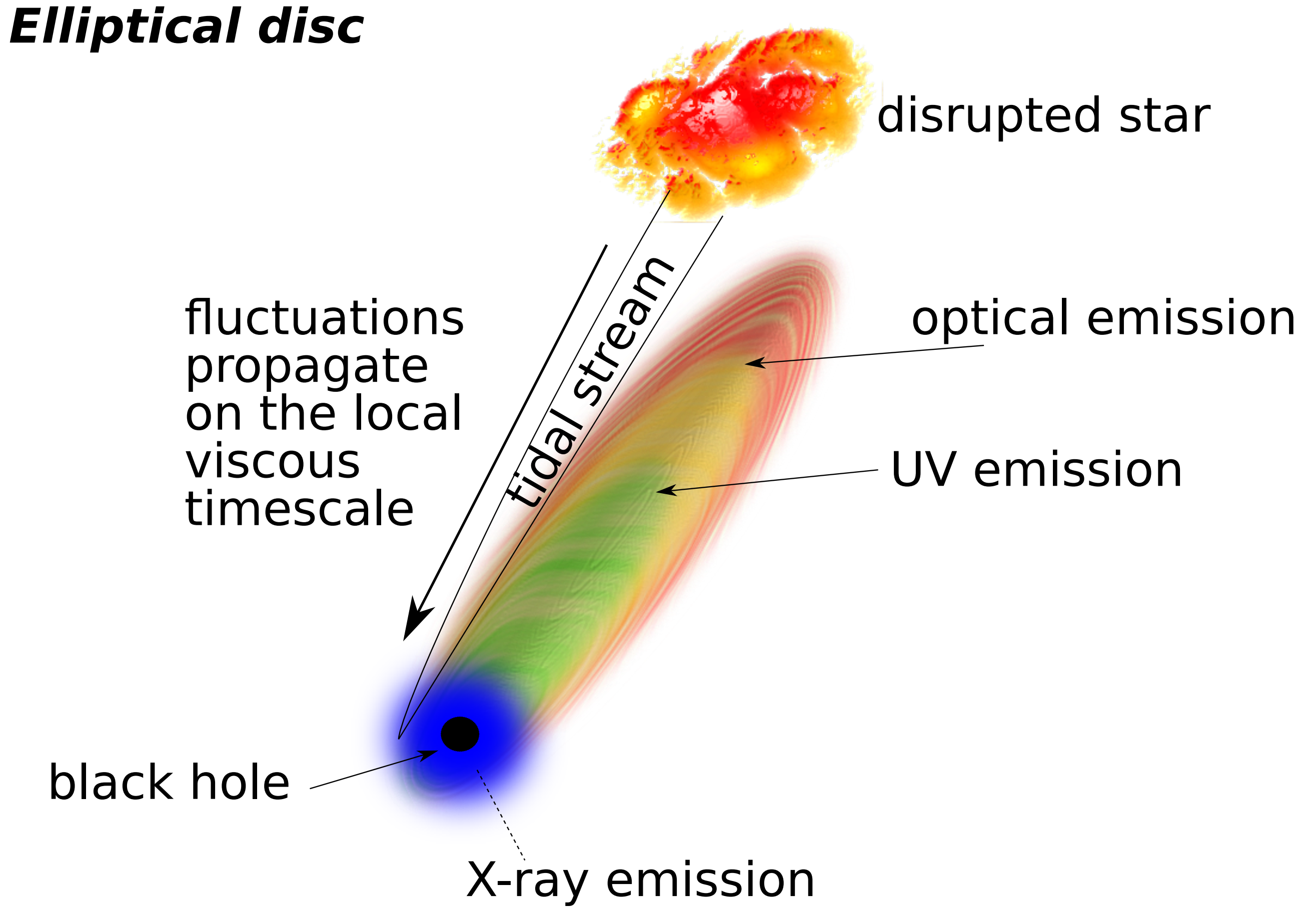
Shock at apocenter



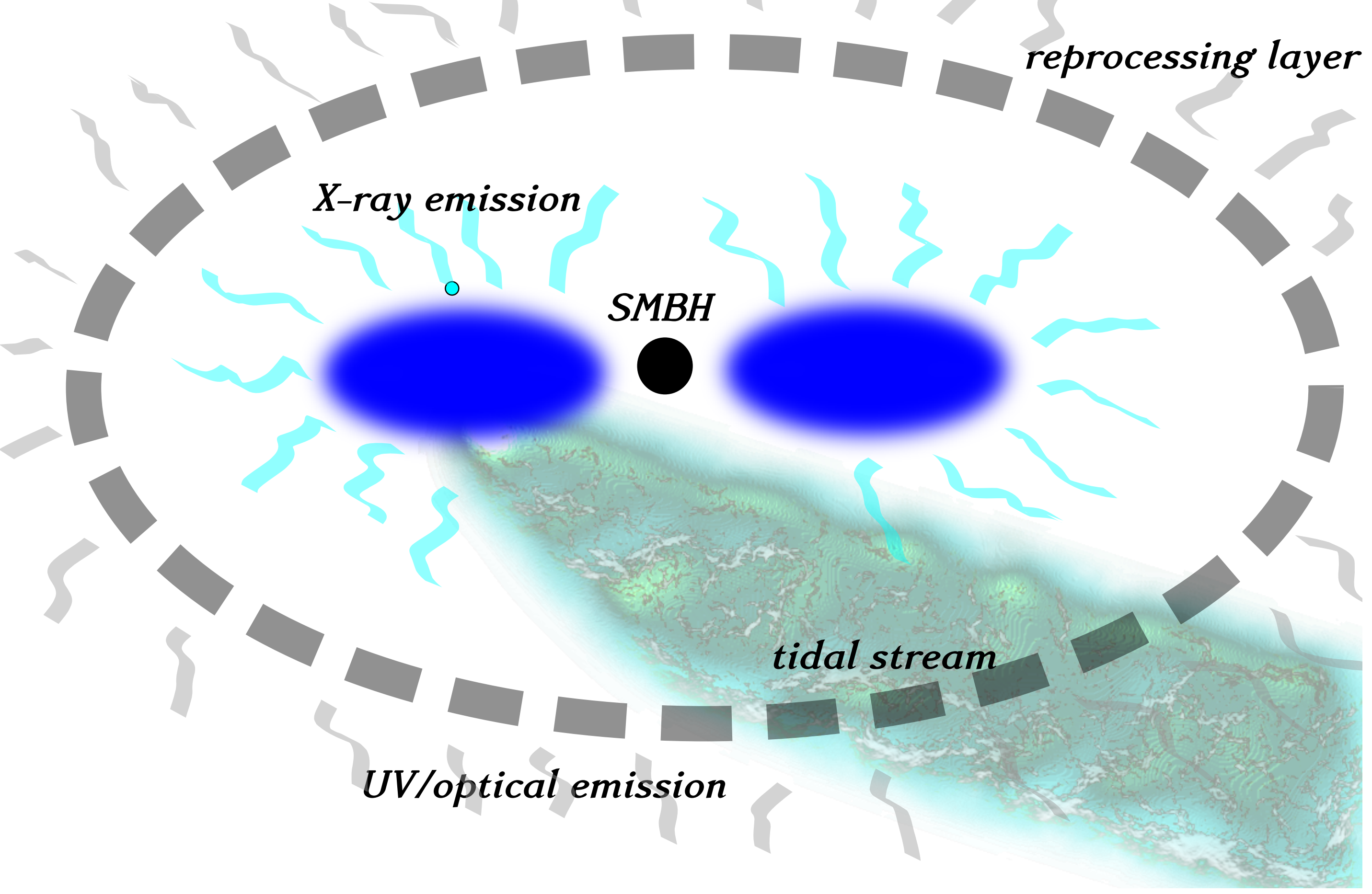
Series of discrete self-interactions



Elliptical disc

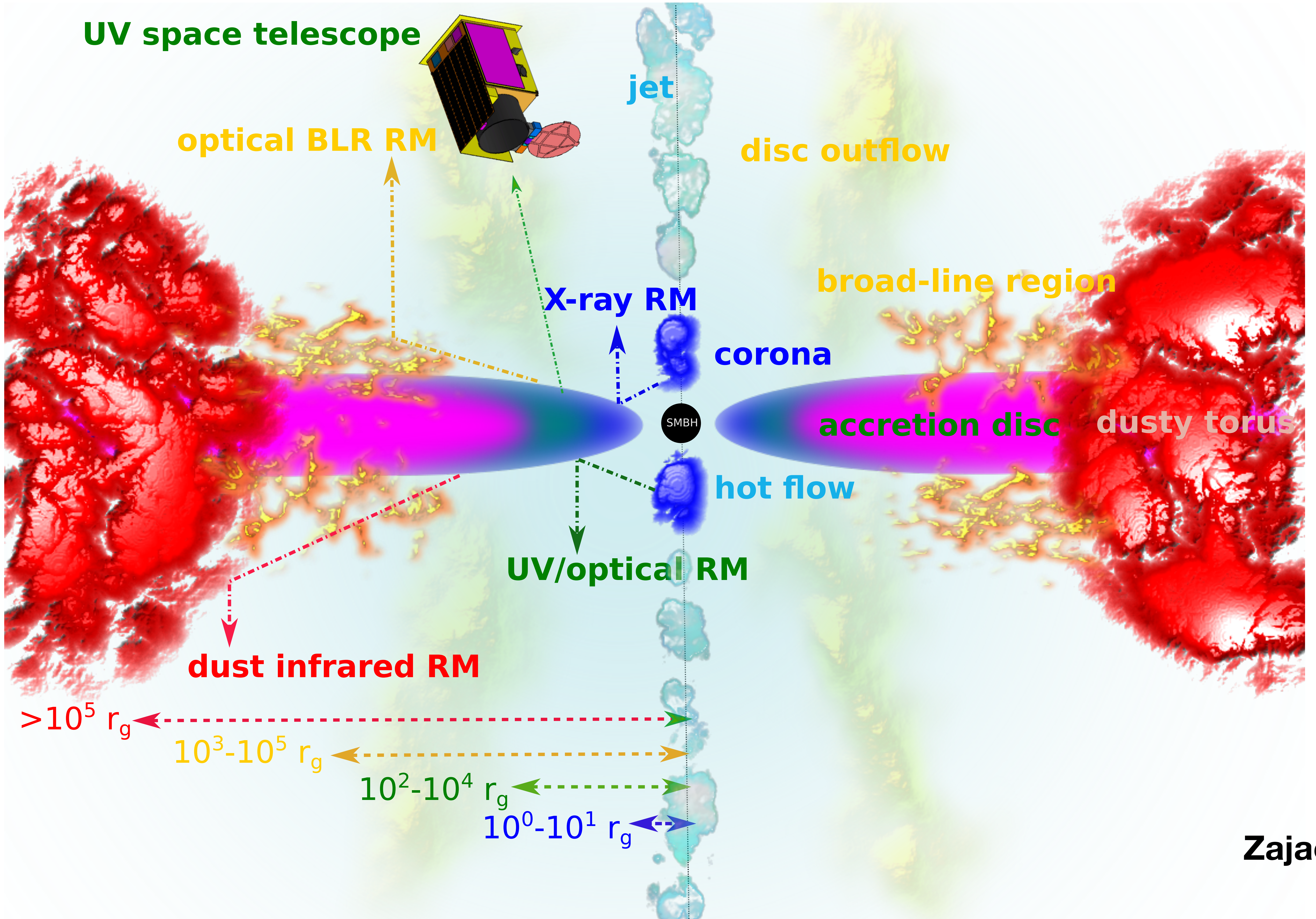


Reprocessing scenario



Reverberation mapping of galactic nuclei

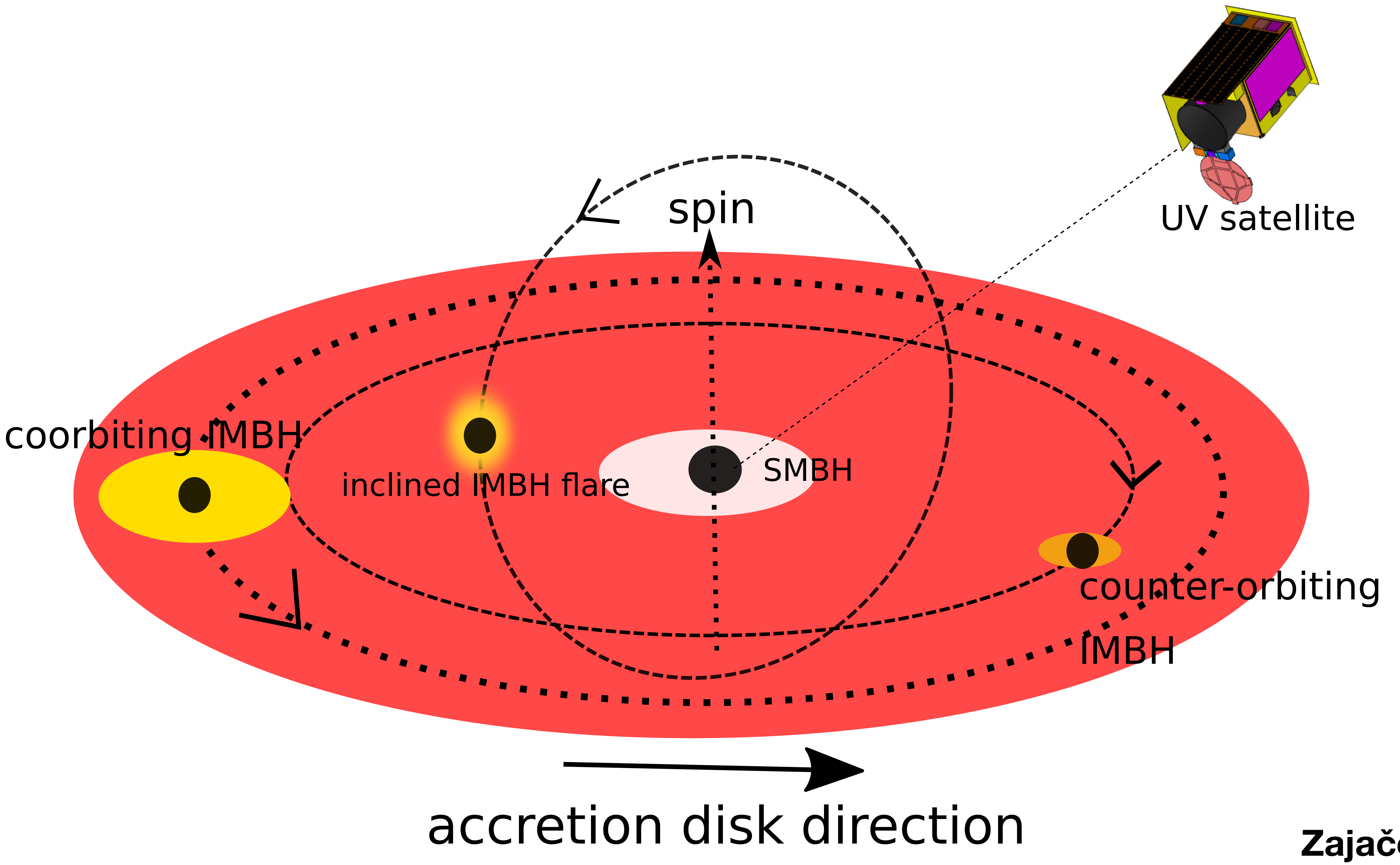
- **Spatial resolution ⇔ Temporal resolution**
- Different wavelength probe different scales of an accretion flow



Zajaček et al. 2023

Non-standard accretion flows: perturbations by an orbiting IMBH

- For an AGN disk, IMBH passing through the disk can produce (quasiperiodic) UV flashes
- Function of IMBH mass and inclination



Zajaček et al. 2023


supermassive black hole
accretion disk
two lighter black holes merge
orbital direction
migration trap
R. Hurt (Caltech/IPAC)

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Mission duration: 3 years
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Primary payload: ~25cm aperture NUV (~260–360 nm) telescope with 1 deg^2 FoV
Photometric sensitivity in NUV: 21.5 mag (5 sigma in 3000 s) in an early type galaxy at 1.5 effective radii
Resolution: <5 arcsec
Detector: Developed by the Dunlap Institute, University of Toronto, based on CMOS (GSENSE4040BSI) by GPIXEL

Secondary payload 1: ~25cm aperture FUV (~150–200 nm) telescope with 1 deg^2 FoV contributed by ASI & INAF (led by INAF Brera) in Italy
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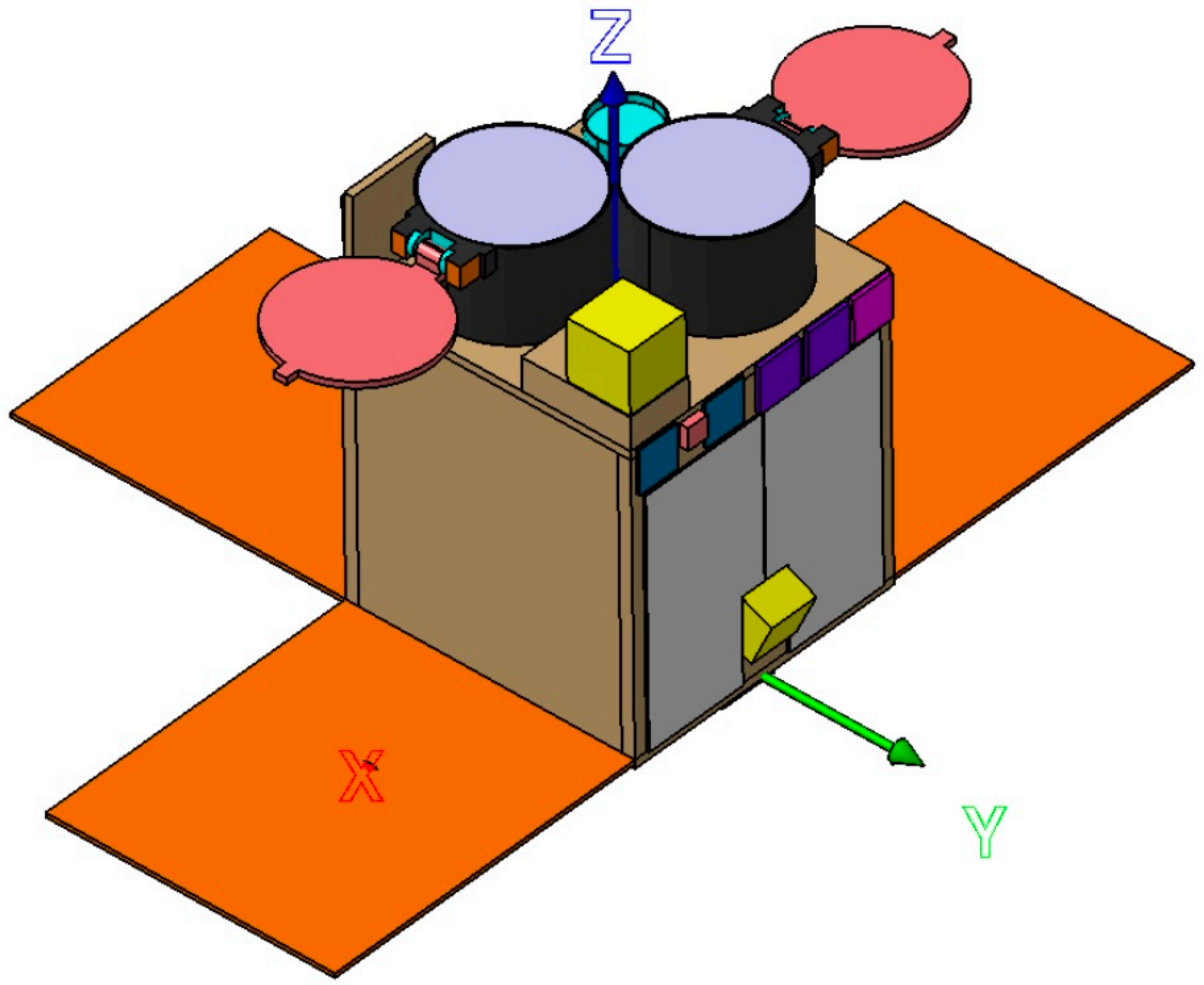

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