Roman Early-Definition Astrophysics Survey Opportunity:
Submission Template

(1) Submission Title or Survey Name: The Fast and the Furious - a continuous cadence Galactic Plane survey with the Nancy Roman Space Telescope

(2) Contact author (with institutional affiliation and full contact details, including email):
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(4) Do you support the selection of a Roman Early-Definition Astrophysics Survey (as described in the "Request for Information"; yes/no, with supporting motivation, 10 lines max):

The Roman telescope combines unprecedented sky resolution with large photometric depths unreachable from the ground. We propose to use these unique capabilities as part of an Early-Definition Astrophysics Survey to conduct a continuous cadence survey of crowded parts of the Galactic Plane mainly targeted to discover rapid variability coming from a large number of compact pulsators, rapid rotators, flaring stars, supernova Ia progenitors as well as ultracompact gravitational wave sources which are ideal for multi-messenger studies for the Laser Space interferometer antenna (LISA), an approved ESA-NASA mission. The stacked images will provide the deepest images for selected Galactic Plane regions obtained with space-based quality. This will provide a unique opportunity covering the Galactic Plane which is not covered by any other Roman community survey.

[Answer the questions that follow only if proposing a specific survey concept; be aware that the content below may be made public should this concept, or one closely related to it, be documented in the Assessment Committee report.

(5) Describe the science investigations enabled by the survey *(as relevant, briefly describe: key science drivers and breadth of science areas engaged; datasets expected upon survey completion; comparison of science enabled, parameter space opened up, or complementarities with respect to ground/space-based state-of-the-art at time of Roman launch; key differences from, and/or complementarities with, Roman core community surveys; one page max):*

Compact binaries are a class of binary stars with orbital periods less than a few hours, consisting of a neutron star (NS)/white dwarf (WD) primary and a Helium-star (He-star)/WD/NS secondary. These unique binaries are sources of low-frequency gravitational wave (GW) signals as probed by the Laser Interferometer Space Antenna (LISA) making them excellent multi-messenger sources [1], are crucial to our understanding of compact binary evolution, and offer pathways towards Type Ia supernovae. Type Ia supernovae (SN Ia) are the main production site of elements such as iron or nickel, are important standard candles used to study the expansion history of the universe and constrain key cosmological density parameters. Although only the thermonuclear explosion of a WD following the interaction with a binary companion can explain the observed features, much less is known about their progenitors and relation to the cause of the explosion. Recent results have shown that SN Iae show a large range of explosion energies and decay times, photometric and spectroscopic signatures indicating different progenitor systems [2]. The aim of this proposal is to find and study an extensive and well-characterized sample of short period binaries in the Galactic Plane with the Nancy Roman Space Telescope, reaching an unprecedented sky resolution and depth which is inaccessible from the ground. In addition to the prime science goal, we also expect to discover thousands of stellar flares with flaring durations less than a few hours which are crucial to our understanding of the habitability of exoplanets as well as a large sample of compact pulsators, important for stellar evolution models and rapid rotators such as massive white dwarfs or young stars.

As part of the Zwicky Transient facility, we observed a large fraction of the Galactic Plane with continuous cadence between 1.5 and 3 hours over the last few years [3]. As part of the survey, we have doubled the number of eclipsing double white dwarfs [4], discovered a new class of mass transferring helium stars [5] as well as a new class of radial mode compact pulsators [6]. See Fig. 1 for some examples. These discoveries show the unique capabilities of continuous cadence observations, however they also revealed limitations from ground-based surveys.

1) In ground-based observations of the dense Galactic Plane fields 90% of potentially variable sources turn out to be blends due to variable seeing or bad photometry from poor weather conditions (see Fig. 2).

2) The limiting magnitude from the ground-based survey is 20.5mag, which limits the observable volume to a few hundred parsec for white dwarfs or M-dwarfs and

up to a few kpc for compact helium stars or more massive stars. This limits the number of detections substantially and only allows to probe the local environment.

The Roman telescope is the ideal resource to perform a continuous cadence survey of the Galactic Plane. The sky resolution is at least an order of magnitude better than the seeing limited ground-based observations leading to significantly less blending. Additionally, in a 60sec exposure we will reach a limiting magnitude of 25 mag, allowing us to observe white dwarfs and M-dwarfs up to a few kpc and compact helium stars and more massive stars to more than 10kpc. This allows us to study rapid variability across a larger volume which includes different spiral arms of the Milky Way.

Our proposed survey is closest to the planned Galactic Bulge Time Domain survey. However, compared to the Bulge survey our proposed survey uses continuous observations and focuses on selected fields in the Galactic Plane. The Galactic Plane is not covered by any other Roman community survey but is crucial to study the younger stellar population of the Milky Way. Additionally, continuous cadence is key to rapid events or events with short duty cycles. An M-dwarf flare which only lasts for 2 hours will not be resolved with the planned 15min cadence of the Bulge survey. Additionally, eclipsing double white dwarfs or compact helium stars have duty cycles of less than 10% i.e., eclipse durations can be as short as one minute up to a few minutes. Therefore, a 15min cadence is not sufficient to detect the short period variability of these binaries.

(6) Provide a possible observational outline of the survey *(as relevant/known, touch upon: survey area covered, possible location, and/or (types of) targets observed; optical element (filters/grism/prism) choices; cadence or other timing constraint (if relevant); depth to be achieved; total time needed including estimated overheads; how the survey leverages the unique observational capabilities of Roman; half-a-page max):*

The fastest stellar variabilities on timescales of minutes to hours are of great interest for a large number of scientific questions. This includes UCBs, compact pulsators and rotators, fast flaring stars as well as substellar companions in tight orbits. To capture variability on the timescale of minutes up to a few hours, continuous cadence observations are ideal.

The Roman Space telescope has a sky resolution more than an order of magnitude better than any seeing limited ground-based survey and is not affected by weather. Combined with its large field-of-view makes it an ideal resource for deep continuous observations in dense Galactic Plane regions. Here, we propose continuous observations over two hours for a selection of ~200 individual WFI fields covering a total of 56 sqd. The fields will be selected in the Galactic Plane based on high stellar density and we expect to cover several tens of million Galactic sources. We request to use the F062 or F087 filter with a 55sec exposure + 3 sec readout reaching a limiting magnitude of 24 mag. As an alternative we could also alternate between the F062 and the F087 filter which would provide additional color information. The F062 or F087 filter is a compromise to be sensitive to the hotter white dwarfs and compact helium stars and cooler M-dwarfs. We expect to find several 10s of double white dwarfs, 100s of compact pulsators, and 1000s of flaring stars or compact rotating stars to an unprecedented distance of up to several kiloparsec as well as 10s of compact supernova Ia progenitors up to a distance of ~10 kpc. We would like to emphasize that continuous cadence observations will provide a unique observing mode for the Roman telescope opening a new window to study rapid variability of compact binaries, pulsators, rotators or flaring stars in dense Galactic Plane regions with space-based quality and which are currently not being covered in any of the Roman core community surveys. The co-added stacked images will provide the deepest view in the selected Galactic Plane regions obtained so far with space-based quality.

(7) Describe specific preparatory activities enabled by early definition *(e.g., supporting facility observations, software development work, theoretical/simulation efforts etc.; describe the benefits of conducting these activities early; half-a-page max):*

From experience with ZTF data we expect to find a few million short period variable sources in our survey with the Roman telescope which makes it impossible to visually inspect every individual light curve. Additionally, the vast majority will be too faint for spectroscopic follow-up. Therefore, we need to come up with an efficient method to identify and classify variable sources solely on their light curve properties which includes periods, colors or light curve shapes. Different light curve statistics provide information on the type of variability. We have also shown that for continuous light curves Fourier diagnostics can be used to identify the type of variability [7]. The goal is that we will develop supervised machine learning classifiers to classify variable objects. The success of this method depends most importantly on the quality of the training set. Over the next few years, we will build a training set based on discoveries from the Zwicky Transient Facility high-cadence survey as well as theoretical light curves computed for different types of sources computed using state of the art light curve modelling codes. Additionally, we will use state-of-the-art GPU based period finding implementations of Lomb-Scargle and conditional entropy for periodic sources which allows us to run period finding algorithms of ≈1 Mio objects per day to periods as short as 2 - 3min. The software will be developed over the next few years and tested on ZTF high-cadence data to be ready as soon as data from the Roman telescope is obtained. We will provide our full analysis code to the public. Machine learning methods for non-periodic sources such as stellar flares have already been developed and can be used immediately [8]. This survey will provide continuous cadence observations of parts of the dense Galactic Plane regions with an unprecedented resolution and depth, impossible to reach from the ground to answer questions about gravitational wave sources, supernova Ia progenitors, late stellar evolution and habitability around low mass stars.

[It is allowed to add *two additional pages* *with figures, tables, or references, as needed to support the preceding answers. This can include any past/planned white papers, community building/engagement activities, working groups, workshops, or cross-project/cross-mission planning relevant to the survey; You may use this MS Word template or any other software for editing your responses (12pt font). Once finished, please create, and submit a pdf file.]*

[1] Kupfer et al. 2018, MNRAS, 480, 302
[2] Jha et al. 2019, Nature Astronomy, 3, 706
[3] Kupfer et al. 2021, MNRAS, 505, 1254
[4] Burdge et al. 2020, ApJ, 905, 32
[5] Kupfer et al. 2020, ApJ, 891, 45
[6] Kupfer et al. 2019, ApJ, 878, 35
[7] Barlow et al. submitted to MNRAS
[8] Feinstein et al. 2020, Journal of Open Source Software, 5, 52

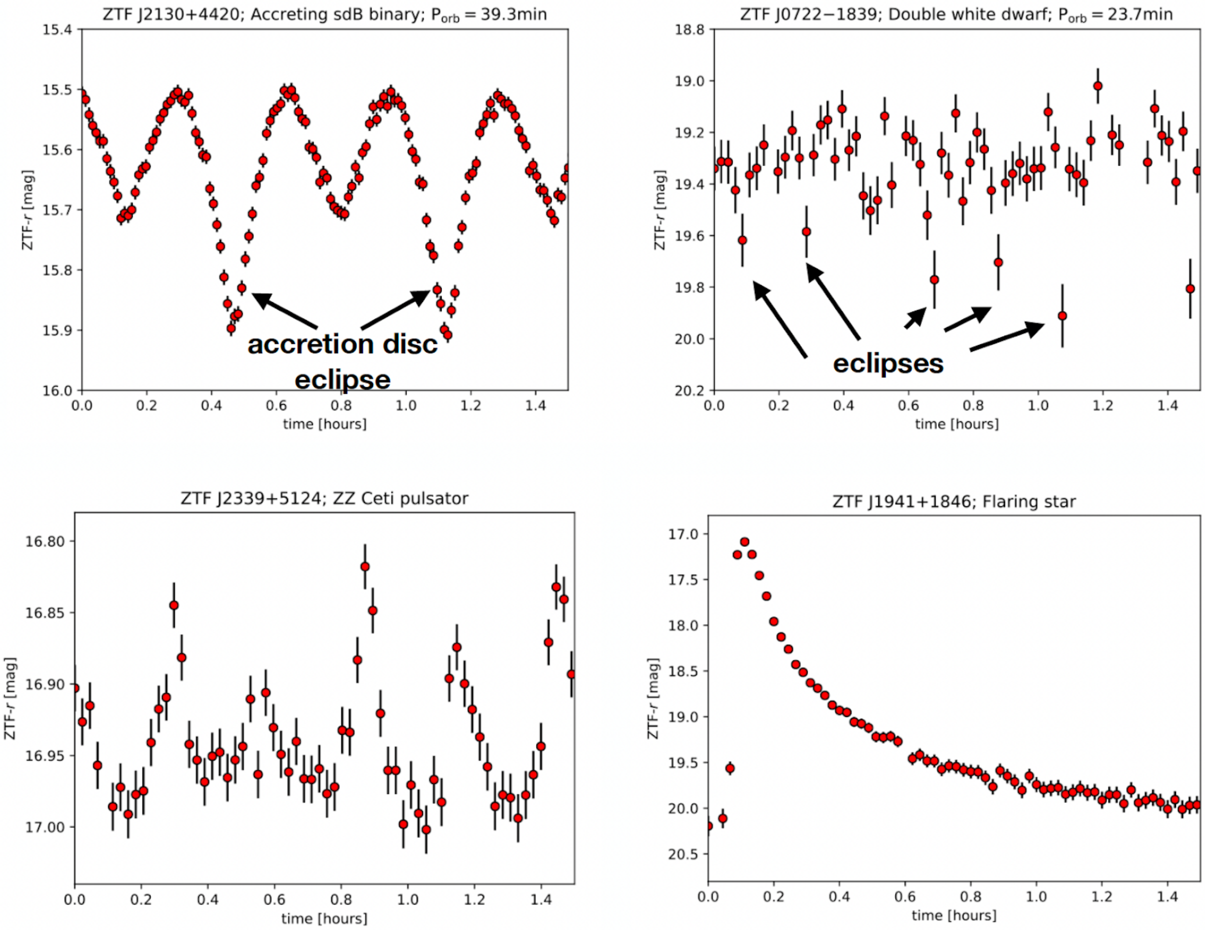

Fig 1: Examples of discoveries from the ZTF continuous cadence observations. The continuous cadence was required to resolve the rapid variability. We expect that the Roman telescope will provide higher quality lightcurve for fainter sources.

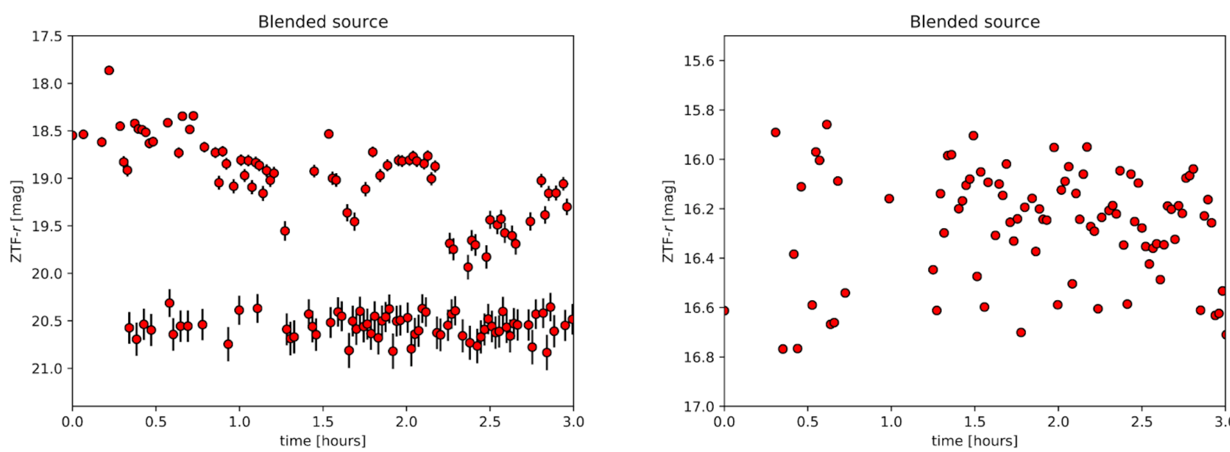

Fig 2: Example of blended sources due to variable seeing from the ground. The Roman telescope will have a >10x better resolution and a stable PSF.