Roman Early-Definition Astrophysics Survey Opportunity:

(1) Submission Title or Survey Name: A revolutionary new window into the dynamic and obscured Galactic plane with the Roman Space Telescope and Rubin Observatory

(2) Contact author (with institutional affiliation and full contact details, including email):
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(3) Co-authors (names and institutions only): Aaron Meisner (NOIRLab), Robert Jedicke (IfA), Suvi Gezari (STScI) on behalf of the Roman-Rubin Synergy Working Group

(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):

Yes, We support the selection of a Roman Early Definition Survey to create a static, wide-area and multi-color near-infrared map of 1000 square degrees of the central Galactic plane. The survey will leverage the unique synergies between the sensitivity/spatial resolution of the Roman Space Telescope (particularly in the K-band filter to study these dust obscured regions) and the time domain capabilities of the Rubin observatory to provide an unprecedented new window into i) the local demographics of stars, planets and their formation histories, ii) the population of invisible compact objects in the Galactic neighborhood and iii) the three dimensional distribution of stars and dust in the Milky Way. Early definition would uniquely allow preparatory activities for i) joint astrometric and photometric calibrations/processing and ii) coordination of observing footprint between the two observatories even before the start of Roman science operations.

(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):

The Rubin observatory and the Roman Space Telescope will transform our view of the wide-field sky, with similar sensitivities, but complementary in wavelength, spatial resolution, and time domain coverage. Rubin provides wide, deep, multi-band seeing-limited optical imaging with a daily cadence of observations. Roman provides wide, deep, multi-band diffraction-limited near-infrared imaging over a field of view 100 times larger than the Hubble Space Telescope. **Capitalizing on their sensitivity at red-optical/near-infrared wavelengths, these surveys hold the potential to revolutionize our understanding of stars, the dust they form and their dead stellar remnants.** We advocate for a wide-area (~1000 sq. deg.) early definition Roman survey of the Galactic plane, aimed at answering the following key science questions

- **What are the demographics and formation histories of stellar objects in the Milky Way?**

The Roman Space Telescope and Rubin observatory can transform our understanding of the prevalence and formation of substellar mass objects. The combination of Roman and Rubin imaging will dramatically expand the volume over which we can detect objects at the lowest end of the mass function -- L and T type brown dwarfs (Stauffer et al. 2020). This will allow us to start probing the low-mass initial mass function in the Galactic disk/halo, and thereby explore for any metallicity dependence of star formation at low masses (e.g. Bromm et al. 2013). Rubin, with its time domain sensitivity, will substantially enhance the study of young stellar object (YSO) outbursts by detecting them to larger volumes. A wide area Galactic plane map with Roman's superior resolution (e.g. Figure 1) will reveal YSOs in quiescence and outburst as discovered in Rubin, thereby allowing fundamental constraints on the accretion kinematics and geometry.

- **How do compact objects form and evolve in the Milky Way?**

Although the demographics of neutron stars (NSs) and black holes (BHs) are central to our understanding of stellar evolution, our understanding of both the accreting NS/BH population and the estimated 10^7 isolated BHs remains severely incomplete. With ~few $\times\ 10^4$ microlensing events expected during the Bulge survey (Penny et al. 2019), Roman can detect several hundred NSs/BHs (Gould et al. 2000) via microlensing, offering a novel window into the remnant mass function. Rubin ground-based coverage will be crucial to fill gaps between the Roman survey windows for these long-lived events (Figure 2), while Roman will be uniquely placed to detect astrometric light shifts to break model degeneracies. For accreting binaries, Rubin observatory will detect an enormous number of compact objects in outburst -- dwarf novae, novae and X-ray binaries. A wide area Roman map of the Galactic plane could routinely enable characterization of the quiescent counterparts of the long-lived microlensing events and progenitors of accreting binaries, and provide unique constraints on their quiescent position, distance and type.

- **What is the distribution of stars and dust in the Galaxy?**

Prior surveys like SDSS, Gaia and Pan-STARRS have enabled enabled detailed Milky Way tomography of (mostly) extragalactic fields (Juric et al. 2008), revealing for the first time large-scale substructures in the Galactic distribution of stars like the Sagittarius and Monoceros streams, as well as the three dimensional maps of dust (Green et al. 2015). However, these surveys are fundamentally limited in their depths and wavelength coverage, which does not extend beyond 1 μm and limits the extent to which the Galactic plane's distant and heavily obscured reaches can be mapped. The combination of Rubin optical and Roman near-infrared photometry throughout the Galactic plane can make an unprecedented map of the 3D distribution of stars and dust in dense regions of the Milky Way (Figure 3). Utilizing Rubin's long-term time domain coverage with Roman static photometry can complete the RR Lyrae census in the central bulge and unravel the assembly history of the nuclear star cluster (Minniti et al. 2016).

(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; <u>half-a-page max</u>):

To enable the powerful synergies between the Rubin observatory and Roman Space Telescope, we propose a wide-area survey covering ~1000 square degrees of the central Galactic plane ($|l|\ <\ 50^{\circ};\ |b|\ <\ 5^{\circ}$) using the F129 and F213 filters of the Wide Field Instrument (WFI). The choice of filters is motivated by i) overlap with the Rubin filter set going out to Y-band at the reddest wavelengths and ii) to probe the largest volume in these heavily obscured regions by selecting the near-infrared filters, especially with the recent addition of the F213 band. Roman's angular resolution is highly complementary to Rubin in terms of the improved deblending of Rubin detected sources that it can offer in dense Galactic plane fields, making the filter overlap highly desirable. The entire proposed sky area is accessible for regular time domain monitoring with the southern location of the Rubin observatory, and based on recent estimates for the Galactic mass distribution (Cautun et al. 2020), **would cover 75% of the stellar mass in the Galaxy.** We propose to use the Fast/Wide limit of the WFI to obtain 55 s exposures each in F129 and F213, reaching a 5σ point source sensitivity of ~25.0 and 23.7 mag respectively. **Based on current estimates of the overheads in this mode (Ref. 14), we estimate a total time requirement of ~250 hours to cover this region in two filters.** We propose the survey to be carried out early during the five-year mission to enable maximal overlap with the expected timeline of the Rubin Observatory (starting regular science operations in ~2024) to i) enable the preparatory data analysis activities described in the next section, particularly the development of forced photometry and deblending tools/pipelines and ii) the unique science possible with routine characterization of active outbursts as well as quiescent counterparts of transient events detected during the Rubin baseline (~10 year) survey.

(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):

The proposed wide area Roman map of the Galactic plane is expected to be a legacy dataset for stellar and Galactic astronomy, that will enable science much broader than the goals defined here. To maximally leverage the joint capabilities of Roman and Rubin, we highlight the need for joint processing of data and source catalogs between these surveys. In addition to deblending sources in the ground-based Rubin data, homogenized astrometry will enable proper motion measurements between the superior spatial resolution of the static Roman map and the decade-long baseline of the Rubin survey for selecting objects like brown dwarfs in the disk. Combined photometric analysis across this footprint will be crucial for joint analysis of faint/distant stars in the Galactic disk and bulge for dust mapping, studies of variable stars and characterization of quiescent counterparts of transient sources. Such efforts have just begun to be carried out for joint pixel-level modeling of high Galactic latitude fields from the Hubble Space Telescope (e.g. Faisst et al. 2021). Such analyses will require timely development of software capabilities for processing these very large datasets; moreover, we expect these efforts to be more challenging in dense Galactic plane fields. The Rubin observatory is expected to be already running for ~ 2 years at the start of Roman science operations, and hence **early definition and execution of this survey will be crucial to begin early preparation for the joint data processing technical efforts.** Furthermore, **early definition can provide the necessary technical motivation to coordinate observations and carry out denser Rubin monitoring of the selected footprint even before Roman begins operations.** To this end, there is already ongoing effort from our team to engage the community in defining the science synergies between the Rubin observatory and the Roman Space Telescope, including a planned white paper.

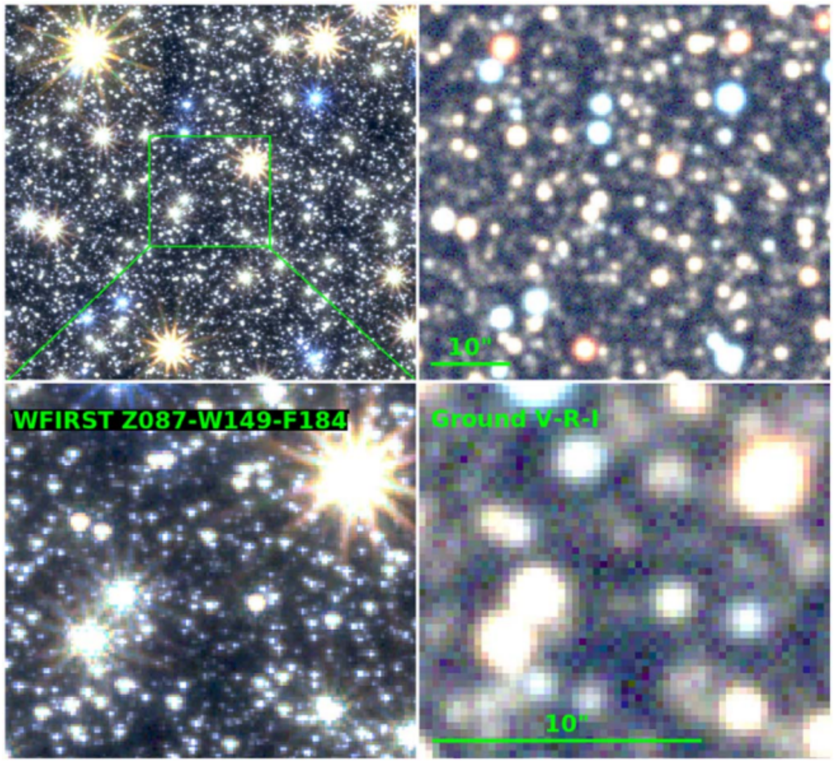

Figure 1: Images simulated for an example bulge field imaged using Roman, compared with a ground-based observatory like Rubin, based on the OGLE survey (Udalski et al. 2015) in optical filters. Roman's superior resolution will provide a unique complement to Rubin's discovery potential for variables/transients in these extremely crowded regions (from Penny et al. 2019).

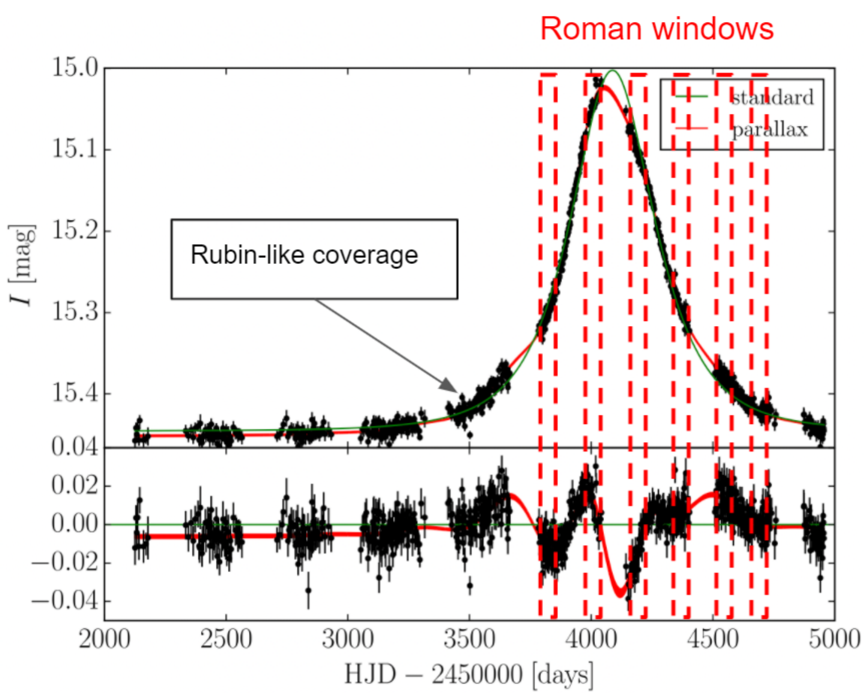

Figure 2: A candidate BH microlensing event from the OGLE survey (Wyrzykowski et al. 2016). The black dots show the observable cadence with a ground-based survey like Rubin to

derive a microlensing parallax model (red line). The green line shows a model without including a parallax, with the lower panel showing the parallax residuals. The red dashed boxes show expected Roman observing windows to observe astrometric light shifts during the event.

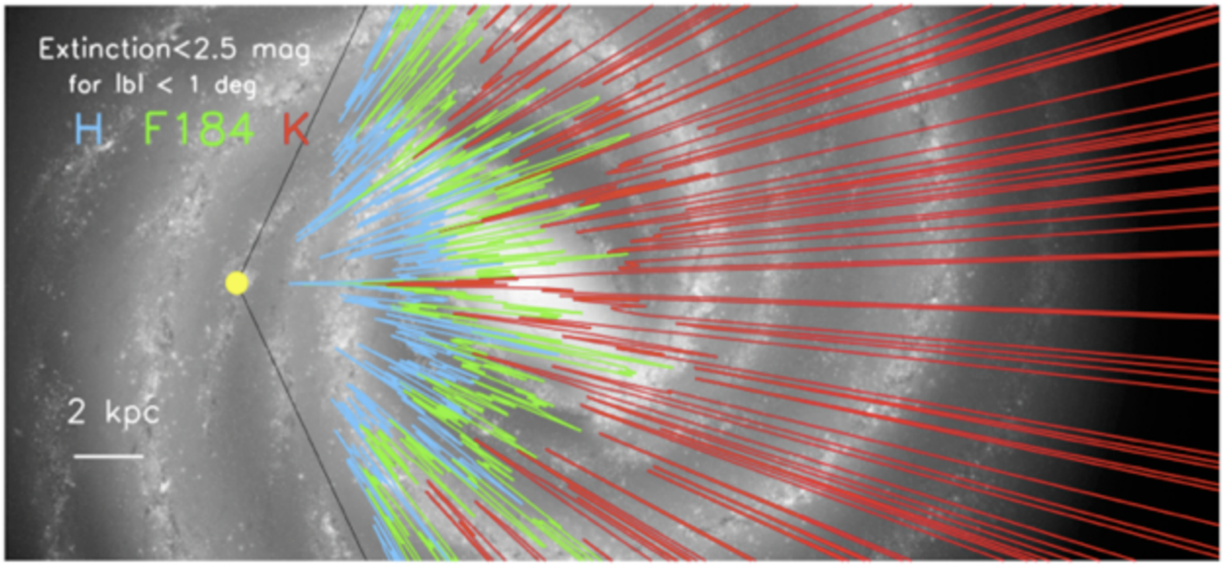

Figure 3: The map shows the extinction horizon in the H, F184 and K band based on the dust extinction model of Marshall et al (2006). The line lengths in the respective filters show the maximum distance accessible in each direction such that the extinction along the line of sight is less than 2.5 mag at any Galactic latitude. The map is laid on an artist's conception of the Milky Way Galaxy. With the significantly lower extinction, The F213 (K-band) filter makes the farthest reaches of the galaxy accessible, such that Roman and Rubin can together map stars and dust throughout essentially the entire Milky Way plane, providing an unprecedented three-dimensional view of our Galaxy (figure from Helou et al. 2019).

References

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