Maximizing the Exoplanet Potential of the Roman Galactic Bulge Time Domain Survey via HST and JWST Precursor Imaging

Thematic Areas (Check all that apply):

☒ (Theme A) Key science themes that should be prioritized for future JWST and HST observations
☐ (Theme B) Advice on optimal timing for substantive follow-up observations and mechanisms for enabling exoplanet science with HST and/or JWST
☒ (Theme C) The appropriate scale of resources likely required to support exoplanet science with HST and/or JWST
☒ (Theme D) A specific concept for a large-scale (∼500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: The Nancy Grace Roman Space Telescope (Roman) is NASA's next large astrophysics mission, due to launch in late 2026 or early 2027. As one of the three large surveys to be excuted during the prime missiong, the Roman Galactic Bulge Time Domain Survey (RGBTDS) will monitor ~ 2 sq. degrees toward the Galactic center with a cadence of ~ 15 minutes over the course of six 62-72 day seasons for a total survey duration of 372-432 days. The primary science objective of the RGBTDS is to detect and characterize ~ 2000 cold and free-floating exoplanets using microlensing [1, 2] in order to *Carry out a statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets, including analogs to all of the planets in our Solar System with the mass of Mars or greater*. The RGBTDS will also enable a broad range of additional exciting science [3], including the detection of $\sim 10^5$ hot and warm transiting planets with sizes down to few Earth radii [4, 5]. The transit and microlensing demographic constraints with Roman will provide the first statistical census of exoplanets within a single stellar population, complete to planets with radii and masses greater than twice that of the Earth over all semimajor axes, from zero to infinity. We argue that comprehensive precursor imaging of the likely target fields with HST, as well as deep pencil beam imaging and high-cadence monitoring of a well-chosen set of subfields with JWST, will significantly enhance the exoplanet science yield of the RGBTDS. These observations will improve the knowledge of the proper motion, blending, broadband flux distribution, and extinction of the exoplanet host stars, which will in turn aid in the determination of their masses, radii, metallicities, and Galactic population memberships.

Anticipated Science Objectives:

The RGBTDS data itself will enable the measurement of the masses of over half of its detected cold planets by a combination of proper motion measurement and detection of the light of the host [6, 7]. It will also enable the elimination of false positives and characterization of the properties of a significant fraction of the transiting planet candidates [4, 5]. In both cases, however, precursor imaging with HST and JWST of the RGBTDS fields, as well targeted imaging with JWST after the systems are detected, will significantly enhance the ability to characterize the detected systems.

(1) Precursor HST imaging of the likely ~ 2 sq. deg. area targeted by the RGBTDS using ACS and WFC3 in parallel in several filters will improve the knowledge of the proper motion, blending, broadband flux distribution, and extinction of the exoplanet host stars, whereas (2) deep pencil beam imaging of a well-chosen set of subfields with JWST will enable better characterization of the target stellar population, blending, and differential extinction. Together these will improve the identification of false positives and the measurement of the masses, radii, photometric metallicities, and Galactic population memberships (older, [Fe/H]-poor, α-rich vs. younger, [Fe/H]-rich) of the host stars (see Figure 3). (3) Tailored JWST imaging of a subset of the detected exoplanet systems will provide ground truth from which to test deblending algorithms and reduce systematic errors. This will enable even better characterization of false positives and more accurate system parameters. These include snapshot observations as well as time-series observations. (4) Both HST and JWST observations of historical exoplanet microlensing events will allow for or improve the measurement of the host star mass, projected separation of the exoplanet orbit, and distance to the system. These observations will verify and refine the measurement method of these parameters for the majority of cold exoplanets detected by the RGBTDS with the Roman data itself.

Urgency: Precursor imaging with HST and JWST should be completed as soon as possible. For observations taken at time Δt before the start of the RGBTDS, the proper motion uncertainty for unblended stars degrades as $(\Delta t)^{-1}$. The uncertainties in either the flux ratio or the separation Δx between two partially blended stars when the other is known depends on $(\Delta x)^{-2} \propto (\Delta t)^{-2}$, and depends on $(\Delta x)^{-3} \propto (\Delta t)^{-3}$ when neither are known. The JWST precursor observations should also be taken promptly, as these will be used in the final RGBTDS design. For observations of exoplanets systems detected by Roman, a mixture of immediate (e.g., while the microlensing event is ongoing) imaging, imaging soon after the exoplanet is detected (e.g., when any stars blended with the host star have not moved substantially), and imaging well after the exoplanet is detected (when the host and blended star have separated substantially) will be most useful.

Risk/Feasibility: The proposed observations are not particularly risky. Similar observations of past ground-based microlensing events have been used to successfully measure to measure and/or refine properties of microlensing planets and host stars (see, e.g., Figs. 1 and 2). Previous surveys of the Galactic bulge have been used to measure proper motions of disk and bulge stars and disentangle stellar populations (e.g., [8]).

Timeliness: The GBTDS fields will be some of the longest exposures of the sky ever taken, with a total exposure time of 372-432 days. The science yield of this survey will be enormous, and will extend far beyond the exoplanet demographic science used here to motivate the proposed HST and JWST precursor observations. All of the science cases will be enhanced by the observations proposed here. We will be kicking ourselves if we do not get precursor imaging of the GBTDS fields while we still can.

Cannot be accomplished in the normal GO cycle: Imaging the entire RGBTDS area in at least two filters with HST requires a larger number of orbits ($\sim 1000 - 1700$) than is feasible with one GO cycle.

References

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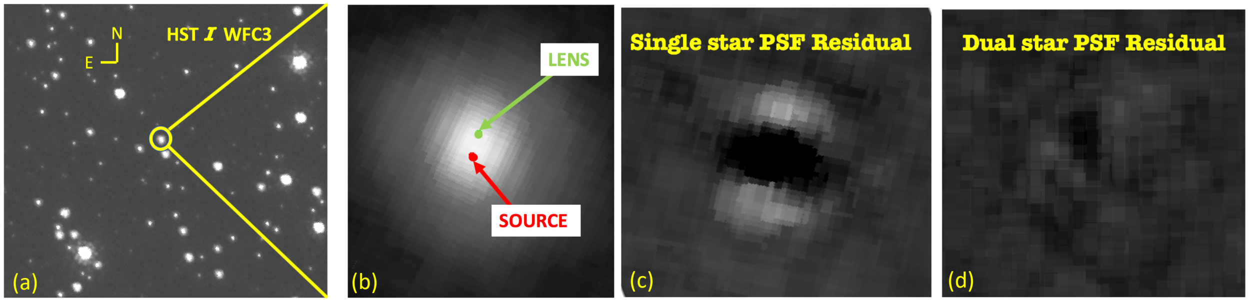

Figure 1: Stacked HST image of exoplanet microlensing event OGLE-2012-BLG-0950 [9], showing the elongated blend of the source and lens stars as they separate after the event. It is well fit by a 2-star blended PSF model.

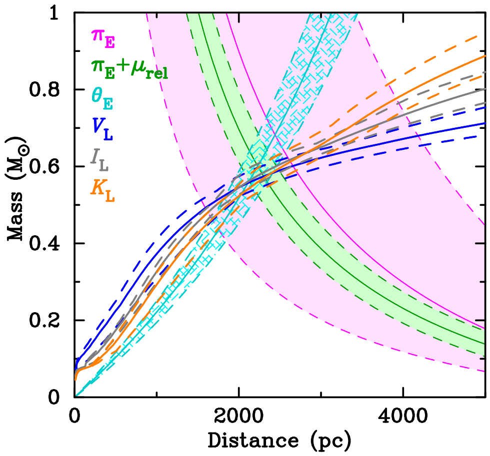

Figure 2: OGLE-2012-BLG-0950 [9] host star mass measurement. Blue, grey, and orange lines show lens star brightness constraints, with dashed curves indicating the uncertainties. The cyan curve is the θ_{E} constraint, and the magenta shaded region indicates the constraint from the light curve measurement of microlensing parallax, π_{E}, and the green shaded region indicate the π_{E} constraint when the HST measurement of the lens-source separation is included. The light curve mass ratio measurement yields the planet's mass.

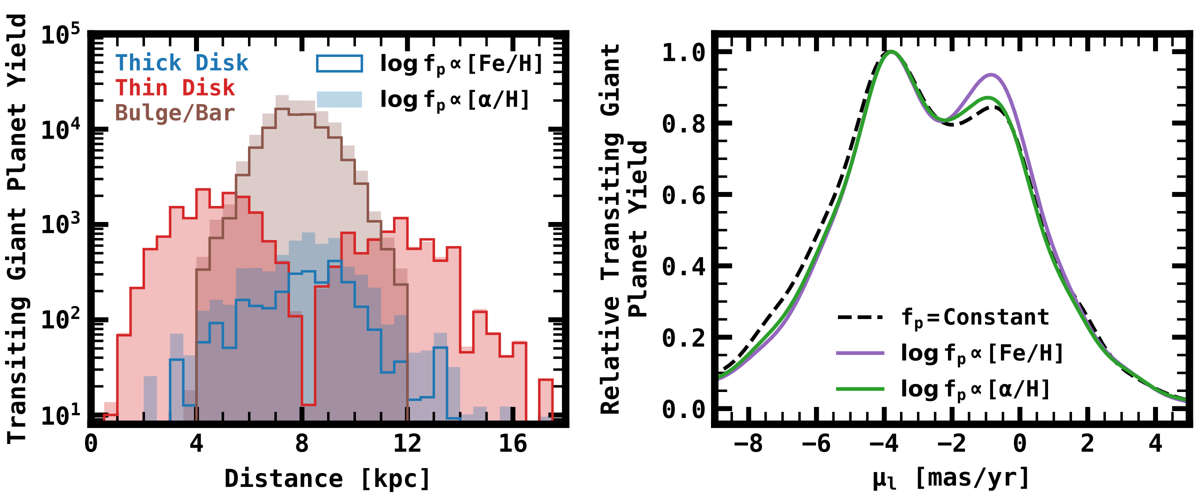

Figure 3: Precursor imaging of the proposed GBTDS fields will constrain the membership of surveyed stars within the young, Fe-rich thin disk and the old, α-rich thick disk and bulge, aiding in the characterization and interpretation of the GBTDS transiting planet sample. **Left:** The expected yield for transiting giant planets in the GBTDS for each major Milky Way population under the assumption that planet occurrence (f_p) correlates more strongly with enhanced [Fe/H] (solid lines) or with enhanced [α/H] (shaded regions), which is difficult to test in the Solar neighborhood due to the majority of such stars belonging to the thin disk. **Right:** The dependence of planet occurrence on Galactic environment and stellar composition is encoded in the asymmetry of the Milky Way velocity curve as traced by the proper motions of transiting planet host stars.