A Dynamically Informed Planet Search: Using Astrometric Accelerations to Directly Image Mature Giant Planets

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 ($\sim$500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: We advocate for a large, community-level JWST high-contrast imaging campaign using Hipparcos–Gaia astrometric accelerations to inform target selection. The sample of directly imaged planets produced by previous unbiased surveys remains small ($\sim$20 planets) owing to the low occurrence rate of wide-separation giant planets above $\sim 5\,M_{\rm Jup}$. This program aims to use astrometric accelerations to efficiently image new giant planets across a wide range of masses, ages, and effective temperatures, particularly focusing on systems at intermediate and older ages that only JWST can access. The dynamical masses of these planets will map the thermal evolution of gas giants across Gyr timescales (Fig. 1, left). By focusing on stars with dynamical evidence of planets, this large-scale, targeted JWST program has the potential to double the current sample of imaged planets, producing a legacy dataset of discoveries for community follow-up. Targeting these accelerating stars early in the JWST mission lifetime will enable orbital and atmospheric characterization of their giant planets through standard GO programs. A Legacy survey in Cycle 3 is our best opportunity to quickly and dramatically expand the small sample of imaged planets on Solar System scales, and the only way to assemble a significant sample at mature ages to complement discoveries around the youngest stars with ground-based facilities.

Anticipated Science Objectives: JWST is the first facility that can image Jovian-mass planets at field ages ($>1\,\mathrm{Gyr}$). Due to the low occurrence rate of wide-separation giant planets ($\lesssim 5\%$; [1, 2]), **a large, targeted survey informed by astrometric accelerations is the only way to image a substantial sample of mature giant planets with JWST.** Ground-based imaging campaigns targeting stars with Hipparcos–Gaia accelerations are demonstrating improvements in efficiency over blind surveys by a factor of at least ten (e.g., [3, 4]). However, these programs are only sensitive to planets around the youngest stars and massive brown dwarf companions around older stars ($>500\,\mathrm{Myr}$). At these ages, giant planets will have cooled to effective temperatures below $\sim 600\,\mathrm{K}$. With JWST, we can finally reach planet masses for these stars. While RVs can also inform imaging campaigns (e.g., [5, 6]), only a few planets have sufficiently wide orbits to be imaged with JWST. A large survey is needed to deliver a diverse sample of planets across all ages for community follow-up and characterization over the JWST lifetime.

A total of 128 stars have 3σ Hipparcos–Gaia accelerations consistent with planet masses at separations accessible to JWST ($>1''$; see Fig. 2). This number increases to 291 for a cutoff of 2σ. This program has the potential to deliver dozens of planets spanning masses of $1-13\,M_{\mathrm{Jup}}$ and semi-major axes of $10-100\,\mathrm{au}$. All of these planets would be amenable to dynamical mass measurements, providing an opportunity to test substellar models as planets evolve to Solar System ages and beyond. This is a key advantage of this approach over blind surveys, whose discoveries are not guaranteed to yield dynamical masses. With a sample of dozens of imaged planets, the evolution of orbital architectures (e.g., eccentricity, spin-orbit alignment, planetary obliquities [7, 8, 9]) can be mapped through follow-up monitoring. Spectroscopic characterization of these planets would illuminate the diversity of cold Jovian atmospheres at Solar System ages.

Urgency: It is critical that the current limited sample of imaged exoplanets is expanded early in the lifetime of JWST to take full advantage of this facility.

Risk/Feasibility: To remove binary contaminants, ground-based high-resolution imaging should be carried out for each target. The best observing strategy is likely dependent on the predicted planet's temperature, with NIRCam in F444W/F200W favored for warmer planets and MIRI in F1065C favored for colder planets.

Timeliness: This program would produce a large sample of imaged planets early in the JWST lifetime, maximizing the potential for follow-up science.

Cannot be accomplished in the normal GO cycle: The scale of this community-level survey is beyond the scope of a large GO program.

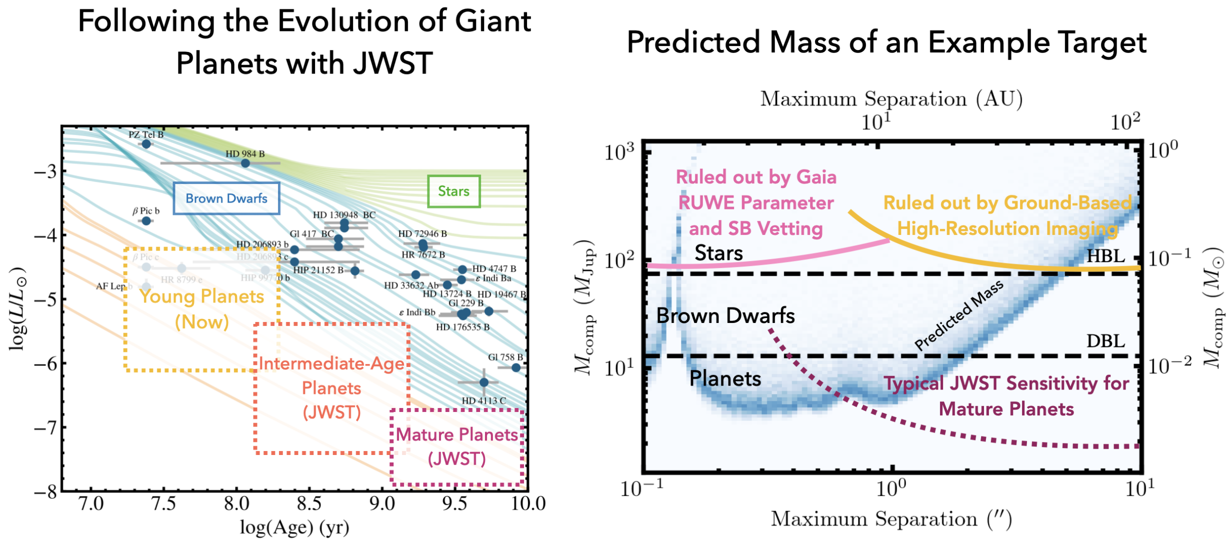

Figure 1: *Left:* Luminosity-age plot of imaged substellar companions with dynamical masses and well-constrained ages. The curves show the luminosity evolution for stars (green), brown dwarfs (blue), and giant planets (orange) from Burrows et al. [10]. Planets found through this large JWST campaign will populate the currently empty intermediate-age and mature regions of this diagram, mapping the thermal evolution of giant planets as they cool. *Right:* Predicted mass of an example target for this type of program. The blue regions signify the companion masses and separations most likely to produce the observed Hipparcos-Gaia astrometric acceleration. The yellow and pink curves illustrate how ground-based high-resolution imaging, Gaia parameters such as RUWE [11], and spectroscopic binary vetting in Gaia DR3 [12] can combine to eliminate the chance of a binary causing the acceleration, dramatically improving the chance of JWST recovering a planet.

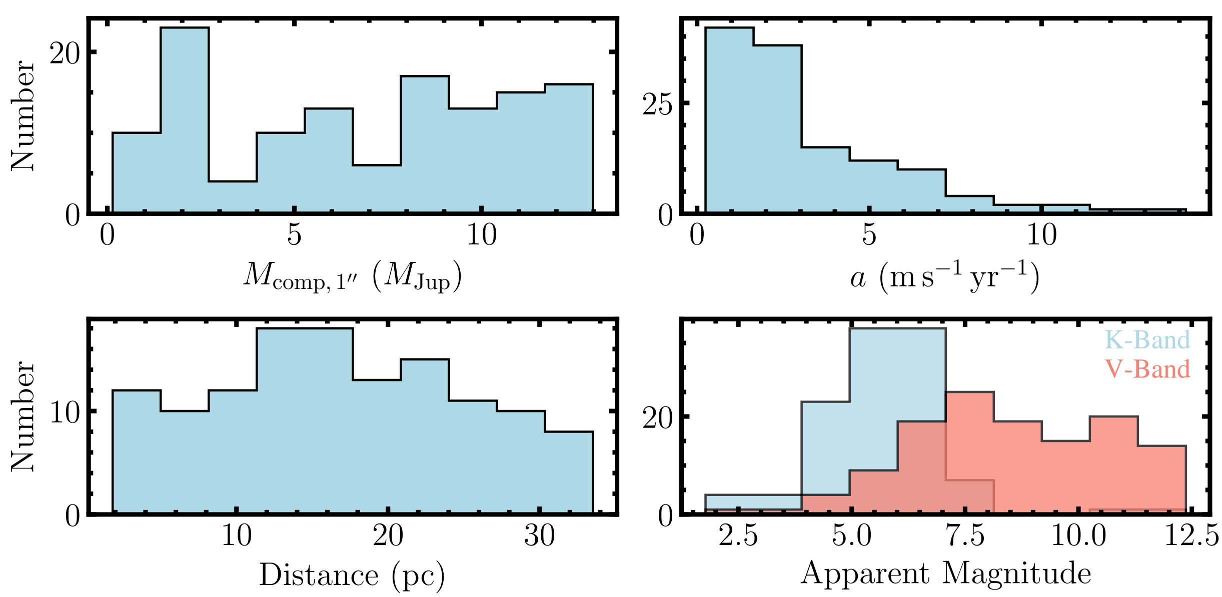

Figure 2: Properties of nearby accelerating (3σ) stars with companion mass predictions amenable to recovering planets with JWST ($<13\,M_{\rm Jup}$ at 1 arcsec). The top left panel shows the predicted companion mass at a separation of 1 arcsec for this sample.

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