Calibrating Accretion Indicators in the Planetary-mass Regime with Multi-epoch UV and Hα Observations

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: Recent discoveries of accreting giant planets are enabling the first direct investigations into how, when, and where giant planets form. However, the planetary mass accretion rate, an essential parameter to characterize and interpret the formation process, is poorly constrained. Accretion onto a planet is usually probed by its Hα emission and requires empirical or theoretical correlations to convert Hα flux into an underlying mass accretion rate. The currently available correlations grounded in the stellar and brown dwarf regimes contain substantial systematic errors and unconstrained assumptions that can lead to orders-of-magnitude uncertainties and biases in the accretion estimates of giant planets. To address these issues, we have identified a sample of accreting planetary-mass objects that are analogs to giant planets and advocate the use of HST to perform multi-epoch photometry in the ultraviolet and Hα. Leveraging the wide separations of companions in our sample together with HST's excellent UV sensitivity and absolute photometric stability, these observations will directly measure the mass accretion rates using their UV excess emission in multiple epochs to constrain the accretion variability over multiple timescales. We anticipate an ensemble of UV-Hα relations spanning a wide range of planetary masses and ages to ground the interpretation of future Hα observations of gas giant planets well beyond the lifetime of HST.

Anticipated Science Objectives: The detections of protoplanets PDS 70 b and c and their circumplanetary disks [1, 2, 3] are among the most exciting results in recent exoplanet science because they allow us to directly investigate how giant planets form. These discoveries have been followed up by numerous studies aiming to understand planetary accretion, planet-disk interactions, and the early evolution of giant planets [4, 5, 6, 7]. The planet's mass accretion rate ($\dot{M}$) is central to all these processes, but accurately measuring this quantity is challenging. directly determining accretion rates, has only been detected once in PDS 70 b [7], which required substantial Hubble Space Telescope (HST) time (18 orbits for a 5σ detection, [7]). Another accretion indicator, Hα emission, is more easily observed from the ground and typically used to indirectly estimate planetary mass accretion rates [e.g., 8, 2, 9]. However, converting the Hα luminosity to the total accretion luminosity is heavily model-dependent, and more than one order of magnitude discrepancy between $\dot{M}$ estimates may occur when different accretion shock models are assumed [10]. Additionally, the accretion rate may fluctuate substantially [11, 12], and a single epoch might not adequately capture the characteristic accretion activity. When these systematics and unknowns are considered, $\dot{M}$ results may contain several orders of magnitude uncertainties. Altogether, these limitations severely hamper investigations of planet formation when using Hα alone.

To address these issues, we advocate observing contemporaneous UV and Hα excess flux of accreting planetary-mass companions over multiple epochs with HST/WFC3 observations. This effort will enable tests of accretion shock models in the planetary-mass regime and establish an empirical calibration between Hα and accretion luminosities for interpreting Hα emission from protoplanets.

Urgency: The proposed science goals require UV observations that can only be acquired with HST. The project must be completed while the UV instruments on HST are in a healthy state.

Risk/Feasibility: Accretion variability has been probed in planetary-mass regimes in limited cases, which find high-amplitude variability is likely on months/years timescales [12], supporting multi-epoch and long-term monitoring.

Timeliness: These science objectives overlap with the ExEP Science Gap list by informing the yield estimation of direct-imaging missions (SCI-06) and architectures of planetary systems (SCI-04).

Cannot be accomplished in the normal cycle: Establishing the correlation between line emission and UV excess emission requires a significant time investment. The large time demand precludes this survey from a regular GO call.

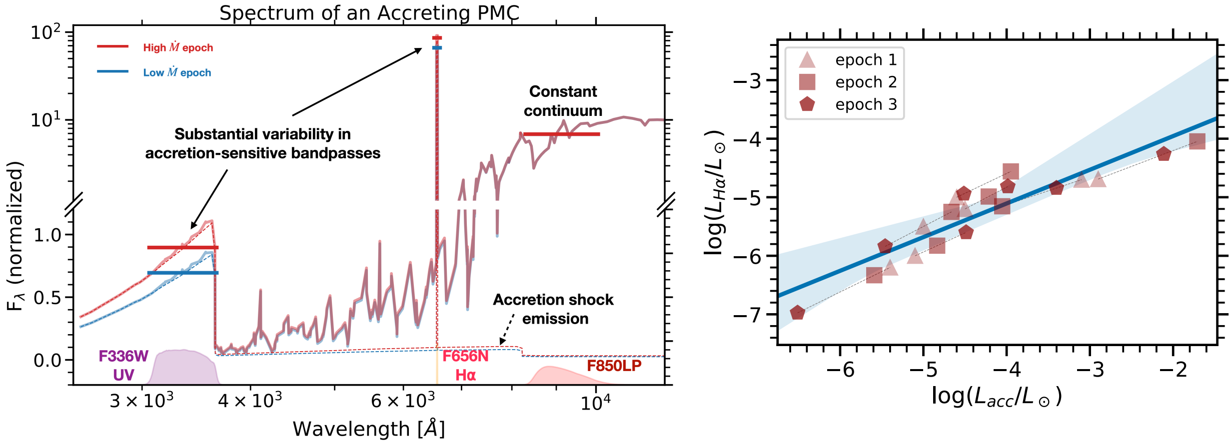

Figure 1: The proposed multi-epoch UV-Hα observations enable an empirical calibration of the accretion rate measurements for planetary mass companions. *Left:* an example SED of an accreting PMC. In the upper half of the figure, the y-axis is displayed in a logarithmic scale to accommodate the strong Hα line. The SED can be separated into two components: the photospheric component and the accretion shock component. The luminosity of the accretion shock component provides crucial information about the mass accretion rate. The photospheric emission and accretion excess emission can be constrained by multi-band photometry. Transmission curves of the selected filters (UV: F336W, Hα: F656N, and continuum: F850LP) are shown at the bottom of the plot. As the accretion rate varies, the accretion-sensitive features in the SED will exhibit significant changes while the continuum remains relatively constant. Leveraging the exceptional photometric stability of HST, we will be able to detect accretion rate variations at the percent level. *Right*: the possible assemble of correlations between Hα luminosity ($L_{\mathrm{H}\alpha}$) and the total accretion luminosity (L_{acc}). This correlation will allow robust interpretation of Hα observations of protoplanets that are expected to be detected with current and future instruments.

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