Predicted Ratios for Mid-IR Atomic Hydrogen Lines of Embedded Accreting Young Stars

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I. Introduction

- Spectroscopy of H I lines diagnoses conditions where planet-forming accretion disks interact with their central stars
- These lines can diagnose
  - temperature and density of accretion funnels and winds
  - extinction along the line of sight to the emitting region
  - mass accretion rates from the disk onto the star
- The youngest, most deeply embedded protostars require mid-IR observations
- JWST's MIRI instrument will provide sensitive medium-resolution (R ~ 3000) spectroscopy of such objects, including those detected in our ongoing all-sky search for young stellar objects with WISE data
- We present local line excitation calculations for aid in interpreting the ratios of H I lines over the MIRI range

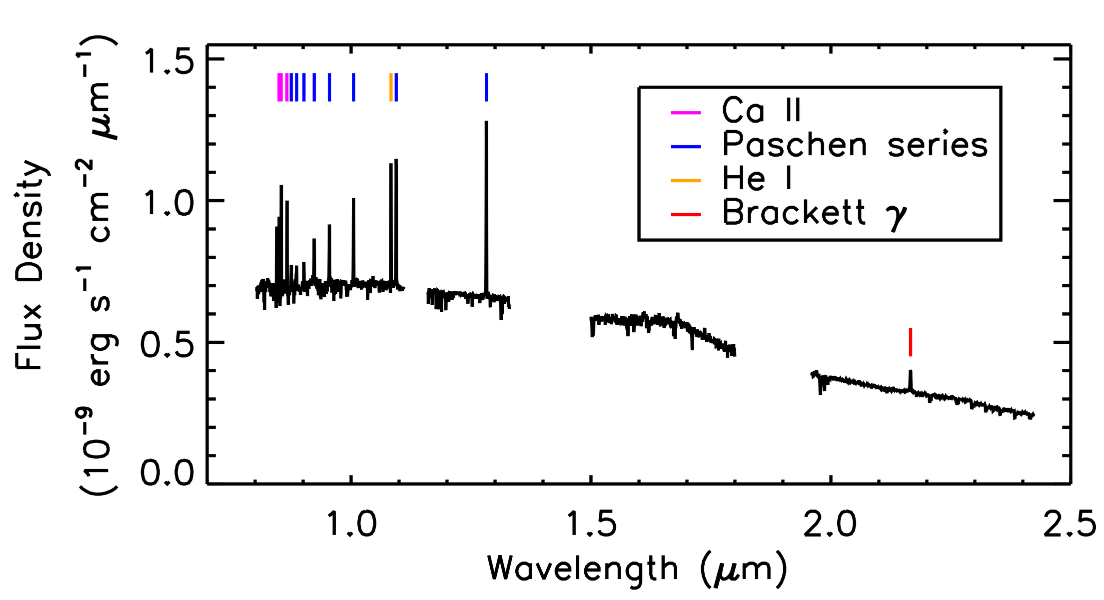
II. Success in the Near Infrared

The Drawbacks of Case B Recombination

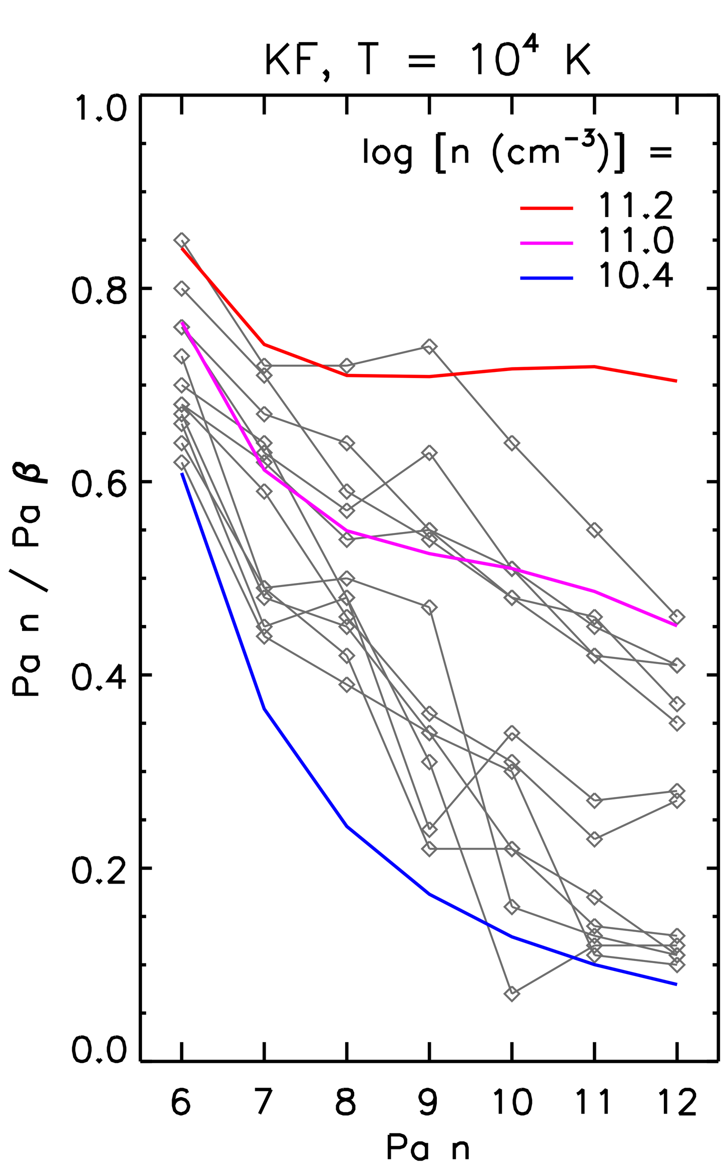
- Case B recombination (Baker & Menzel 1938) assumes transitions to the ground state of hydrogen are optically thick, and all others are optically thin
- Works well for ionized nebulae
- In T Tauri stars, however, studies assuming Case B have reported an unrealistically large range of densities (6 orders of magnitude) and temperatures (1000 to 20,000 K) across small samples

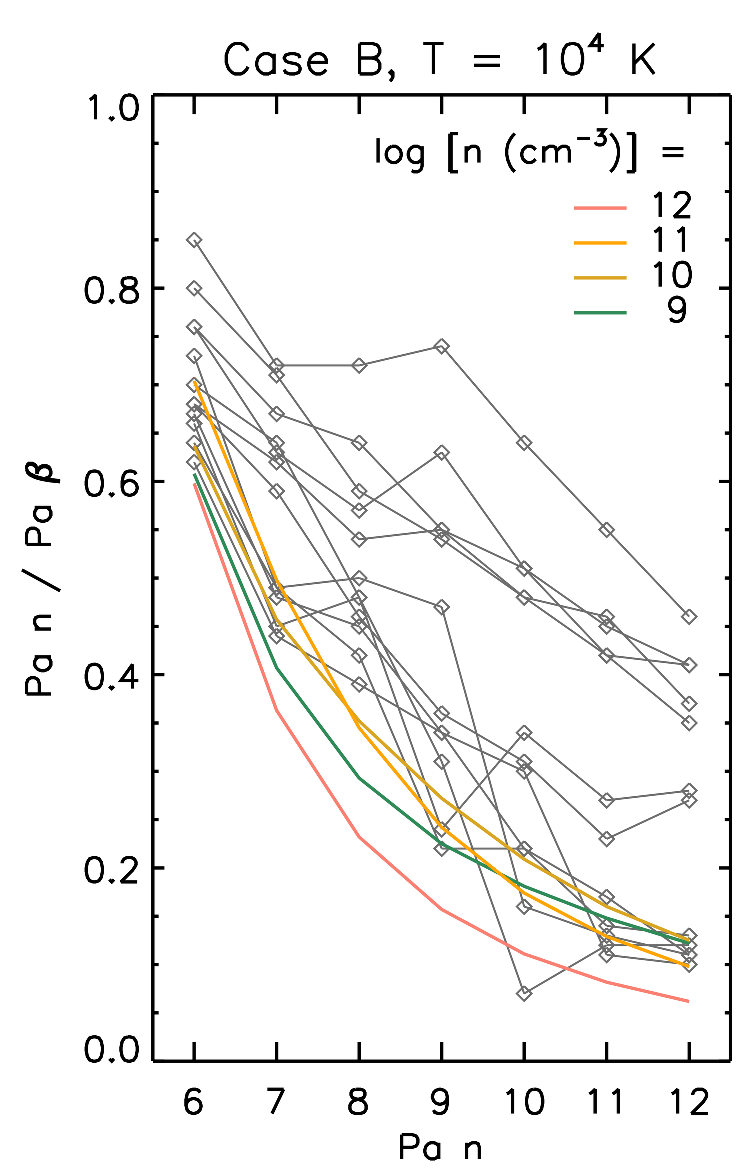
Local Line Excitation Models

- Kwan & Fischer (2011; KF) developed local line excitation models including recombination and collisional excitation for a range of densities and temperatures
- Edwards et al. (2013) applied the KF models to a sample of 16 T Tauri stars for which 0.8–2.5 μm spectra were obtained with SpeX at the IRTF



Sample SpeX spectrum of a classical T Tauri star with strong emission lines indicated. The Paschen series of H I is discussed below.

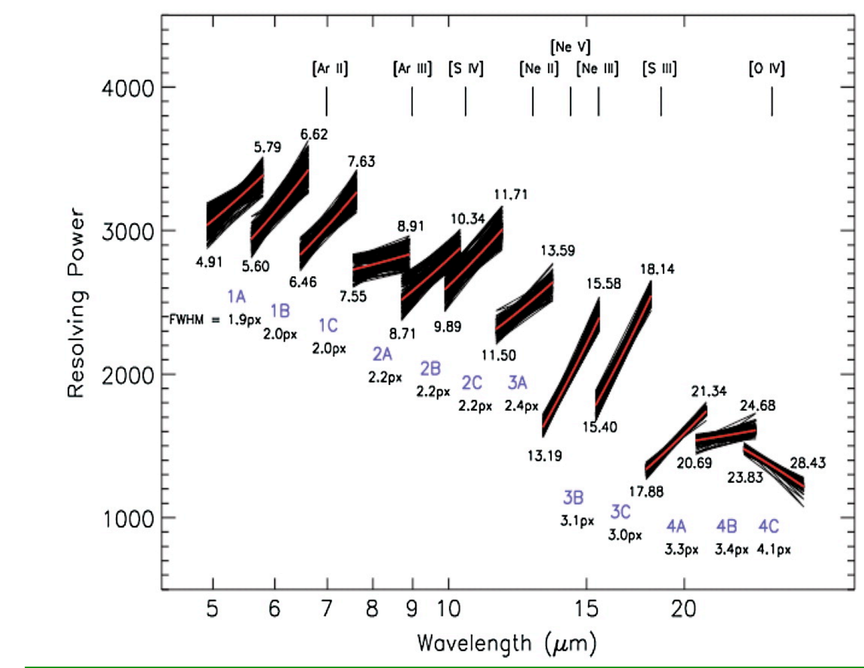




Observed and modeled Paschen decrements, showing the flux ratios of near-IR Paschen lines to Paschen β. Gray curves are for *observed* T Tauri stars with a range of mass accretion rates. Other curves are for *models* with T = 10,000 K and a range of densities as indicated. The KF models (left) are able to reproduce the full range of observed decrements over a narrow range of densities, with larger densities corresponding to larger mass accretion rates. The poor agreement for the Case B models (right) persists for other choices of temperature (not shown).

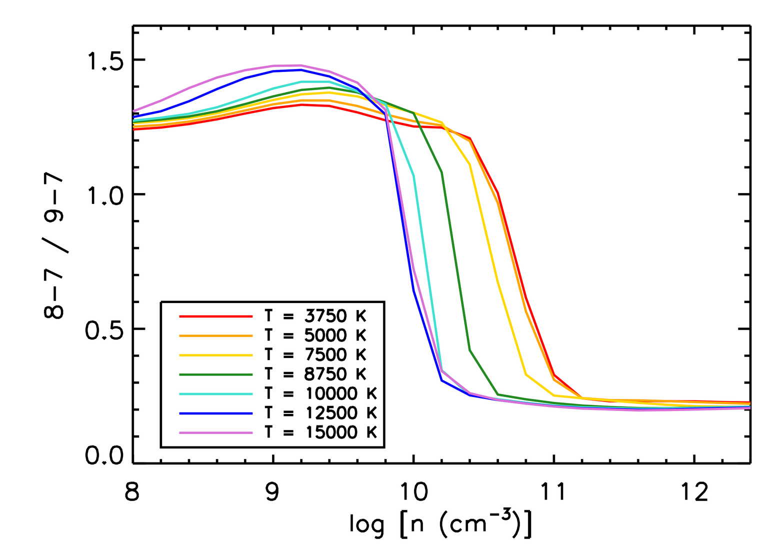
III. Extension to the Mid Infrared

- MIRI will enable sensitive, medium-resolution spectroscopy of a wide range of H lines, including Pfund α (6 → 5) and other transitions with lower level 6 and up
- This will enable the study of deeply embedded protostars that are too faint for optical & near-IR studies
- Whether conditions in the inner regions of deeply embedded protostars resemble those in their more evolved siblings is of long-standing interest

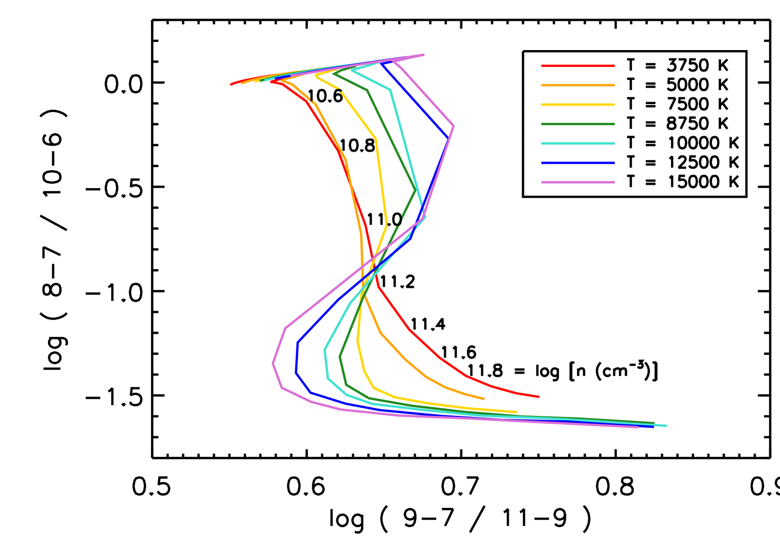


MIRI MRS capabilities (Wells et al. 2015)

Sample KF Ratios in the Mid IR

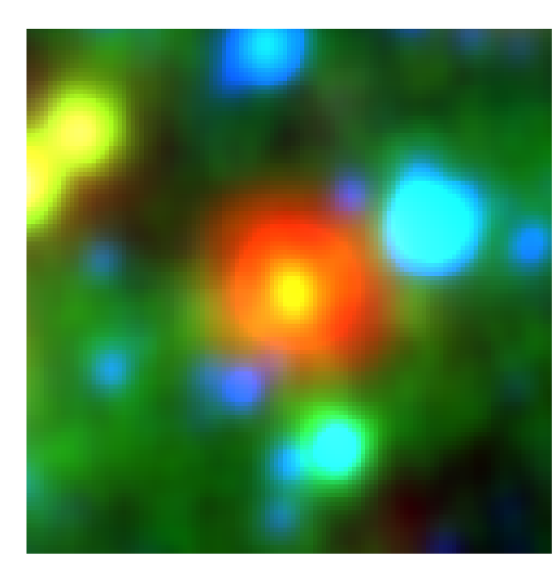


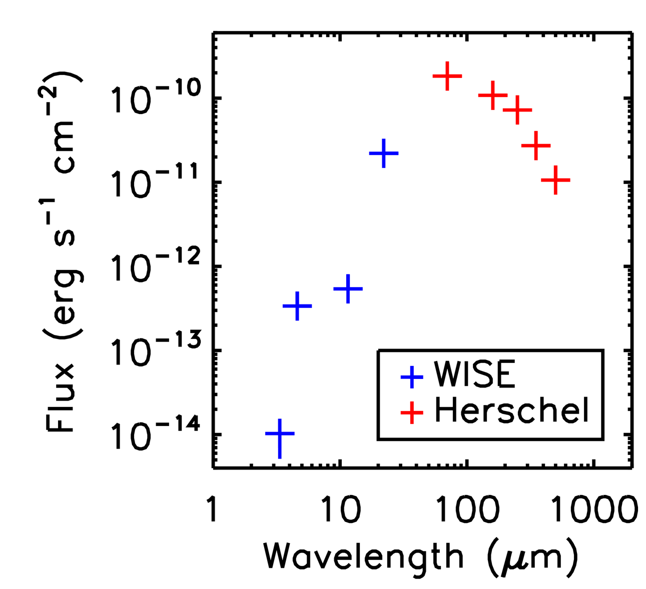
Dependence of the 8–7 / 9–7 ratio (19.1 μm and 11.3 μm) on density and temperature



For certain densities and temperatures, these ratios well constrain the physical conditions

IV. Applications



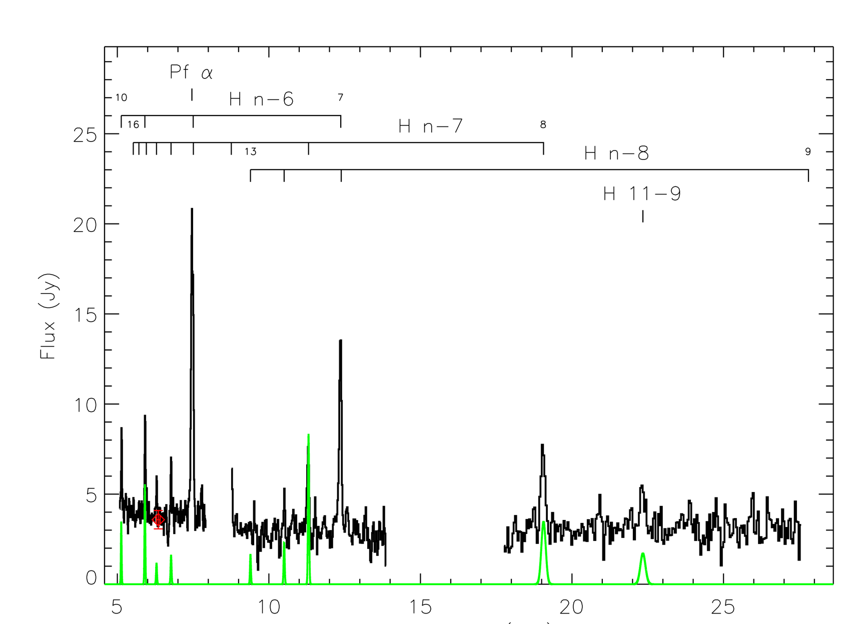


Left: WISE image (blue = 3.4 μm, green = 12 μm, red = 22 μm) of a source in a cluster of young stellar objects in Canis Major (Fischer et al., in prep.). Field is 2′ on a side.

Right: WISE + Herschel spectral energy distribution of the source, typical of a deeply embedded, young Class 0 protostar. (Herschel data are from Elia et al. 2013.)

MIRI spectroscopy will add significantly to the physical understanding of such objects, which are inaccessible to optical and near-IR instruments

The spectral range and resolution of SOFIA's FORCAST instrument partially overlap with MIRI MRS. This spectrum of Nova Del 2013 (V339 Del; Gehrz et al. 2015; Vacca et al., in prep.) shows good agreement with KF model lines for log [n (cm^{-3})] = 10.8.



See http://www.wjfischer.net/line-ratios/ for selected model ratios

References: Baker & Menzel 1938, ApJ, 88, 52; Edwards et al. 2013, ApJ, 778, 148; Elia et al. 2013, ApJ, 772, 45; Gehrz et al. 2015, ATel, 5299; Kwan & Fischer 2011, MNRAS, 411, 2383; Wells et al. 2015, PASP, 127, 665