Probing Accretion and Formation Paradigms in the Substellar Regime

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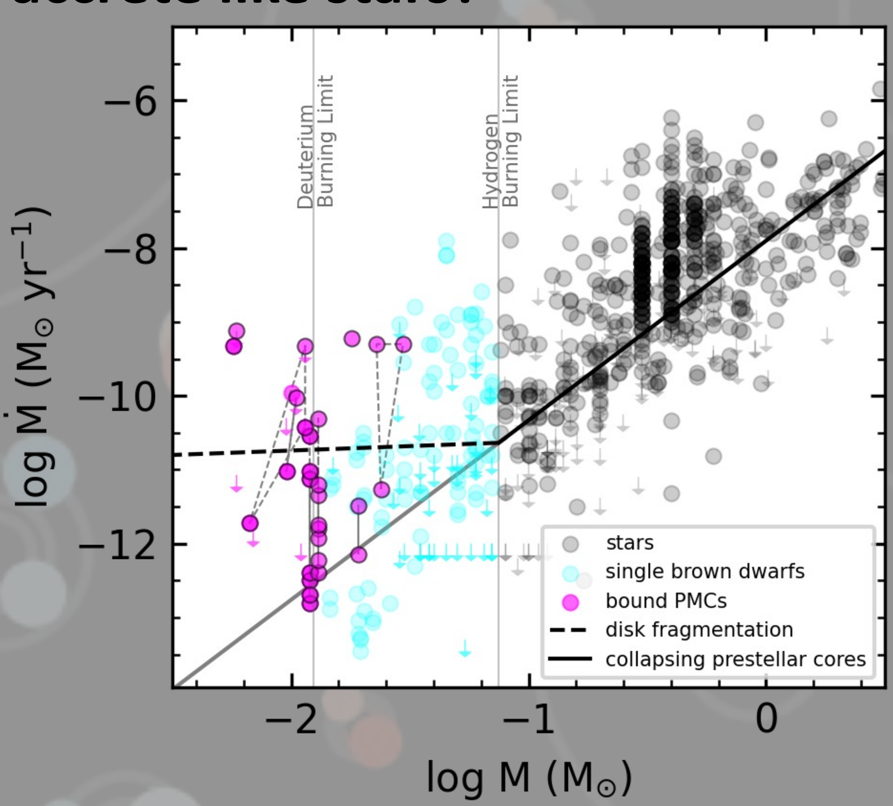
At PPVII– come find us and chat!

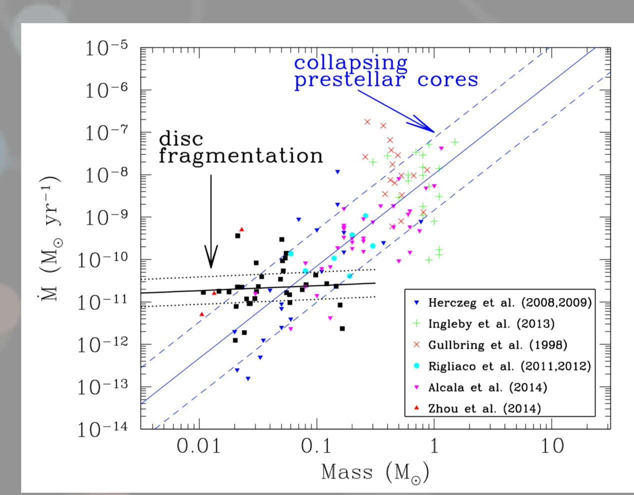
Motivation

Question 1: Do substellar objects accrete like stars?



Isolated BDs: Accretion rates follow star-like trend
Bound PMCs: Accretion rates are anomalously high

Question 2: Is this telling us about formation mechanisms?

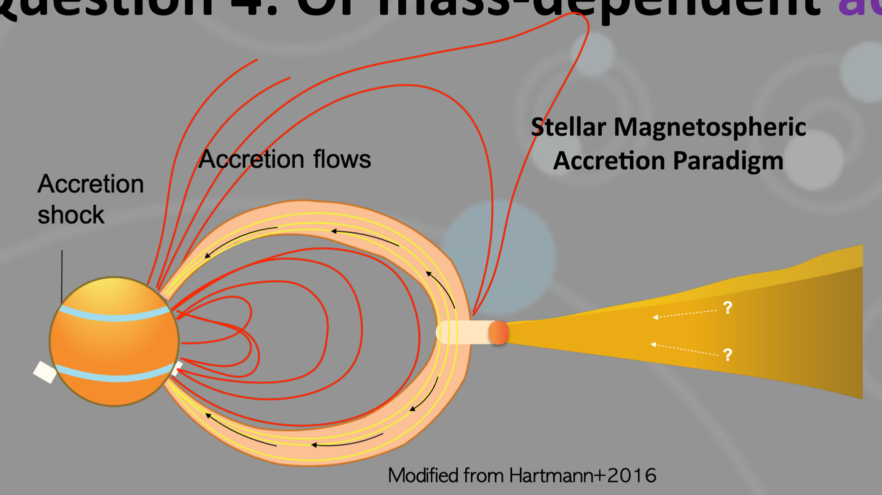


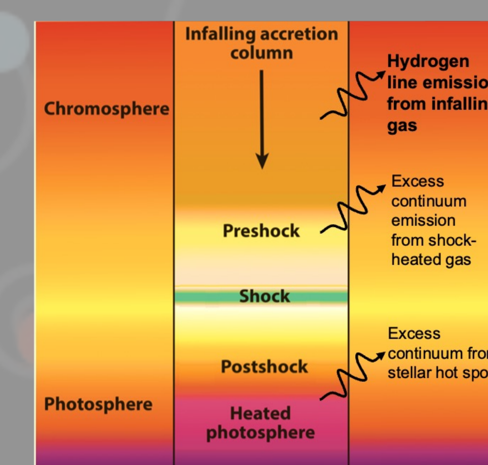
Stamatellos & Herczeg 2015 models (left) suggest that objects formed via disk fragmentation may have larger mass reservoirs for accretion and a flatter relation between object mass and mass accretion rate

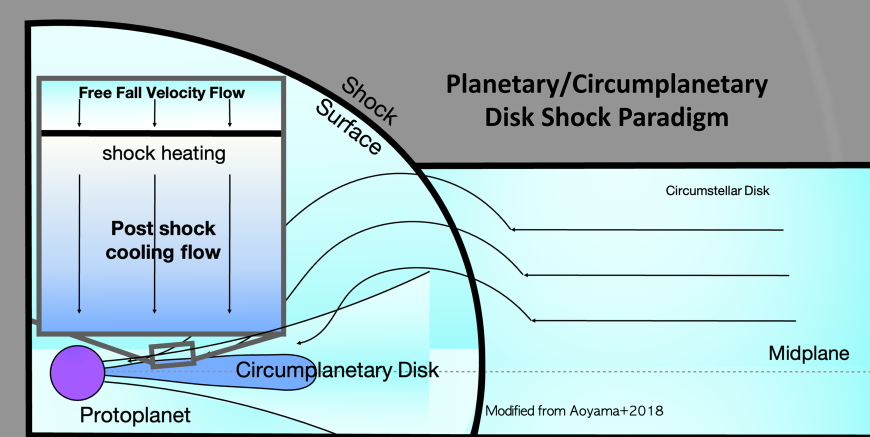
Question 3: Or is it all just selection effects and observational biases?

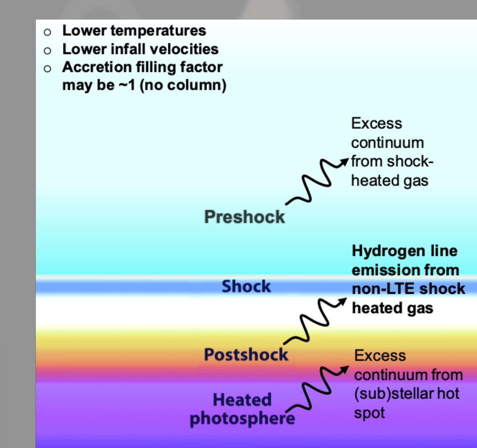
- Different studies use different accretion tracers, evolutionary models, spectral type conversions, instruments, scaling relations.
- Detections become less likely at low masses and accretion rates

Question 4: Or mass-dependent accretion processes?









Meta-Analysis

Coming Soon: Comprehensive Archive of Substellar and Planetary Accretion Rates (CASPAR)

Goal: Create a comprehensive archive of uniformly rederived substellar accretion rates

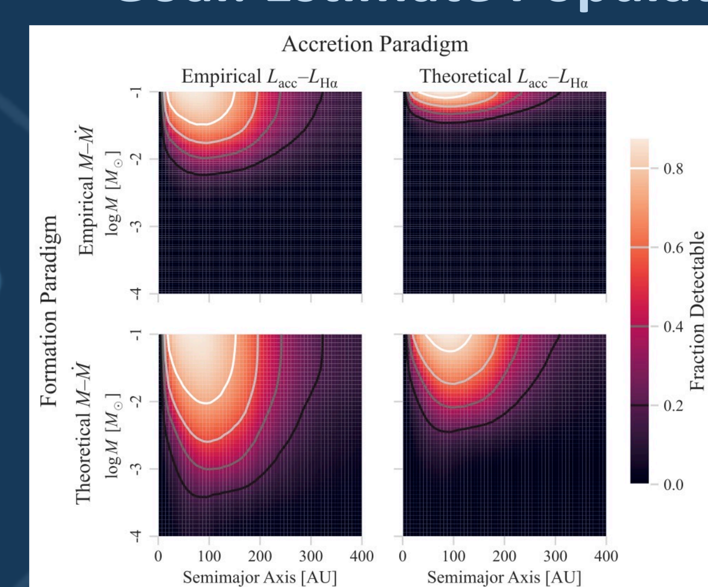
- 802 unique objects and counting
- 16 young associations, moving groups, etc.
- 31 studies spanning masses from ~ 5M$_J$ to ~1M
- 22 unique accretion diagnostics
- Unified Rederivation of :
  - Distances from Gaia DR3
  - Membership probabilities from Banyan Σ (Gagne+ 2018)
  - Accretion rates from unified scaling relations (mainly Alcala+ 2017)
  - SpT → T from Herczeg & Hillenbrand 2014
  - Masses from Baraffe+ 2015
- Will be available to the community in 2023

Key Questions:

1. How much of the variation in the mass-mass accretion rate relation can be attributed to differences in methodology?
2. Is the apparent ~5 order of magnitude scatter reduced by unifying assumptions?
3. How do inferred accretion rates vary with observational strategy (e.g. accretion tracer, line or continuum) and physical properties (e.g. age, mass, isolated vs. companion)?

Completeness

Goal: Estimate Population Properties of Protoplanets



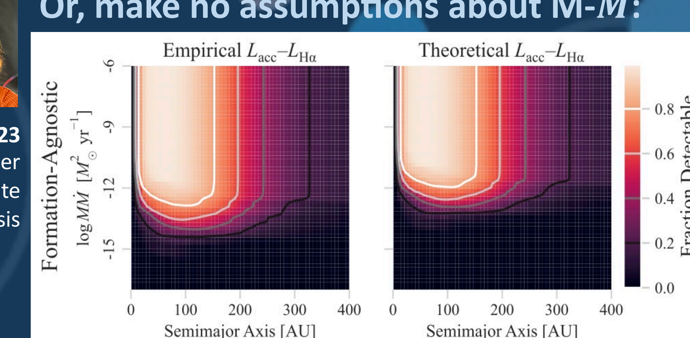
The Opportunity:
Several Hα protoplanet surveys have been conducted in the recent past (e.g. Follette+ 2023, Zurlo 2020), enabling the first population constraints on accreting protoplanets

The Challenge:
Protoplanet masses are poorly constrained, and the observable (Hα contrast) is not directly translatable to mass but rather to the product of object mass (M) and mass accretion rate ($\dot{M}$)

Two axes of possibility considered:

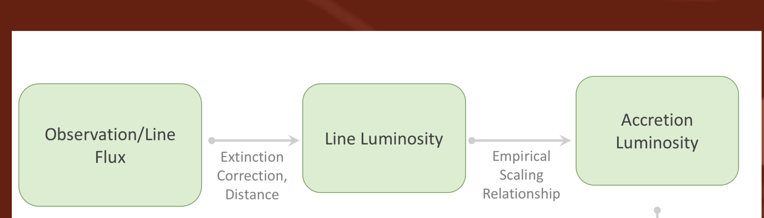
- Protoplanets may follow stellar L_{acc}-$L_{H\alpha}$ scaling laws, or unique protoplanet scalings (e.g. Aoyama+ 2021)
- The protoplanet M-$\dot{M}$ relation may follow the empirical stellar relation or a flatter one (e.g. Stamatellos & Herczeg 2015)

Or, make no assumptions about M-$\dot{M}$:



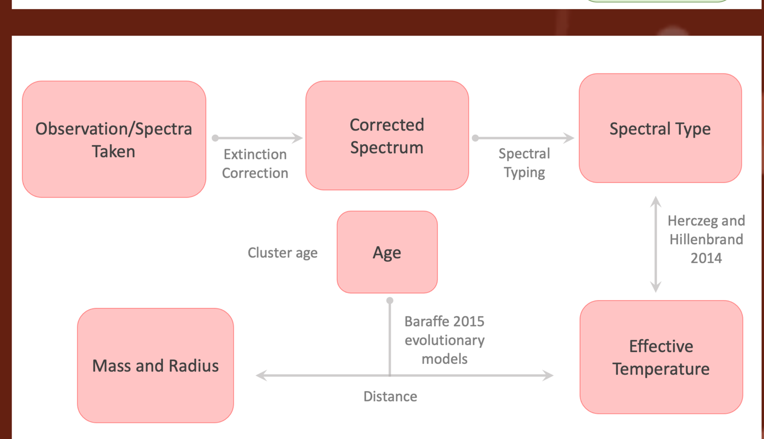
Simulation Tools

Goal: Develop a Monte Carlo simulation tool capable of reproducing the observed population of accreting objects

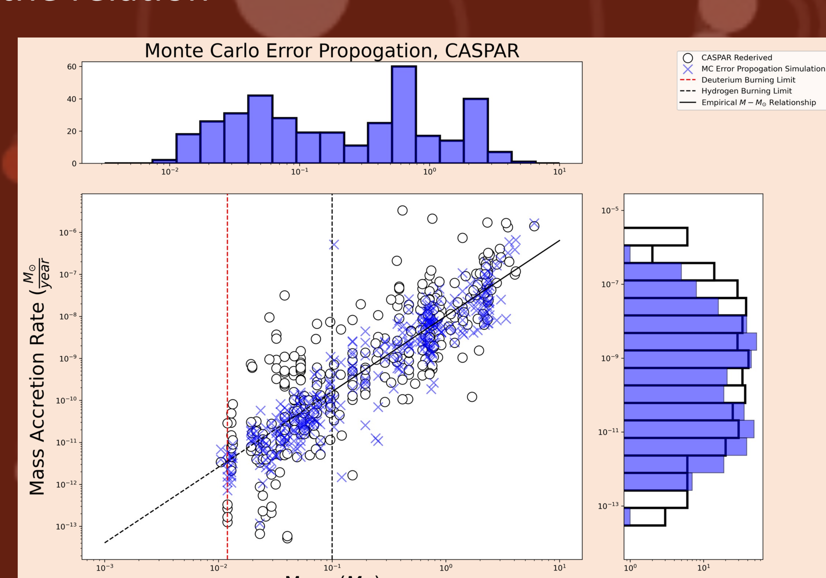


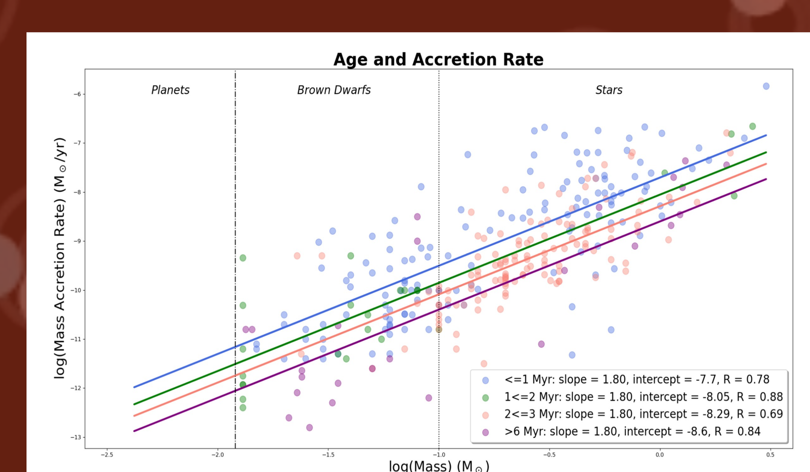
Our simulation encodes the path between observation and mass accretion rate estimation (top, green) and propagates observational and physical property uncertainties into these estimations (bottom, red)

$$\dot{M} = \frac{L_{acc}R_*}{GM_*}\left(1-\frac{R_*}{R_{in}}\right)^{-1}$$

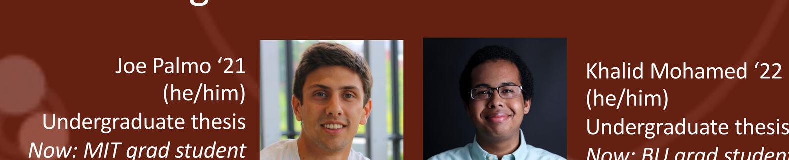


Finding 1: Observational uncertainties in distance, age, spectral type, and extinction account for ~50% of the observed scatter in the relation





Finding 2: Reasonable prescriptions for **physical effects**, namely age and intrinsic accretion variability, can account for the majority of the remaining 50% of observed variance



Remaining Tasks/improvements:

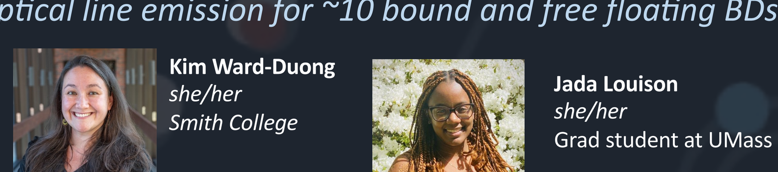
1. **Draw synthetic objects from an IMF** rather than bootstrapping from the observed mass distribution
   → *inform completeness and role of selection effects, synthesize true population*
2. **Build in detection limits** for current and future instruments → *inform role of completeness in trends at low masses, design future surveys*
3. **Assign realistic interdependencies** among parameter uncertainties
   → *create more accurate synthetic observations*
4. Draw **synthetic populations** from different underlying distributions
   → *synthesize blend of molecular cloud core collapse and gravitational instability objects*

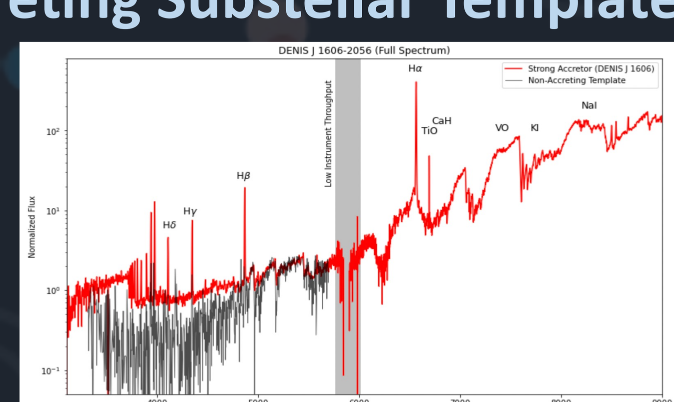
New Observations

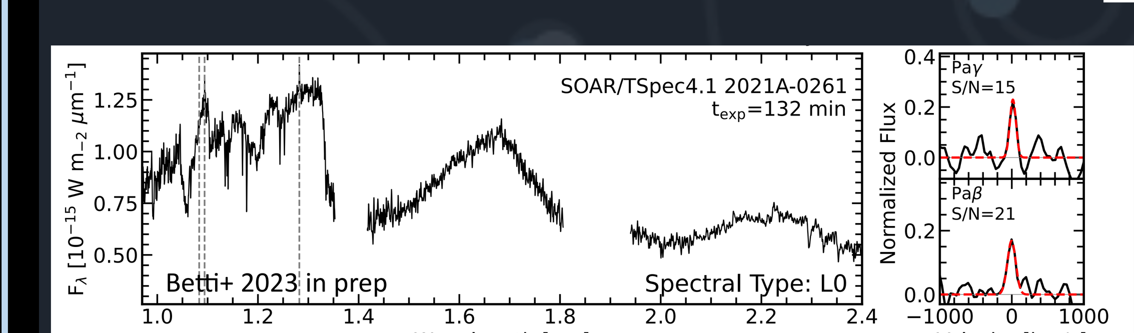
Goal: Assemble Multiwavelength Accreting Substellar Templates

Keck LRIS NUV-Optical Program
(2021A, 2021B, 2022B, PI: Follette, Ward-Duong)

Aim: Obtain NUV-optical spectra covering the Balmer jump and optical line emission for ~10 bound and free floating BDs

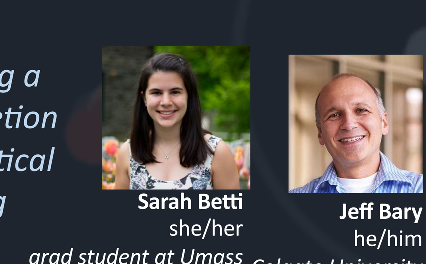






SOAR+ APO TripleSpec Program
(2021A, 2021B, 2022A, 2022B, PI: Betti)

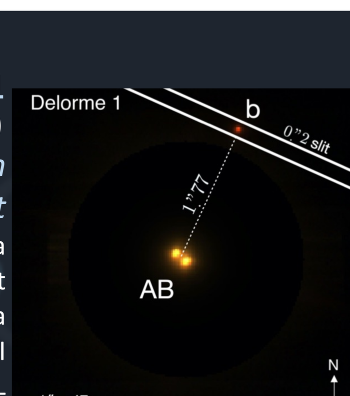
Aim: Obtain NIR spectra spanning a number of accretion lines for a statistical sample of young brown dwarfs

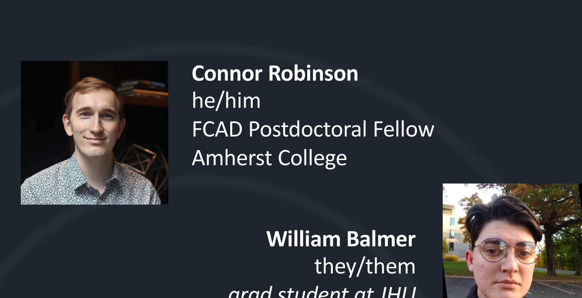


Delorme 1 (AB)b HST STIS Program
(Cycle 30, 8 orbits, PI: Robinson)

Aim: Obtain a comprehensive spectrum of a benchmark accreting planet

- COS FUV medium res spectra
  - 1342-1784A, incl CIV doublet
- STIS NUV MAMA G230L low res spectra
  - 1570-3180, incl. SiII, MgII, SiII
- STIS Optical 430L
  - 2900-5700, incl. Hβ, Hγ, Hδ and Balmer jump

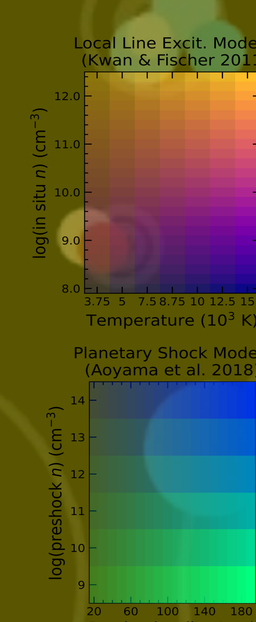




Line Ratio Studies

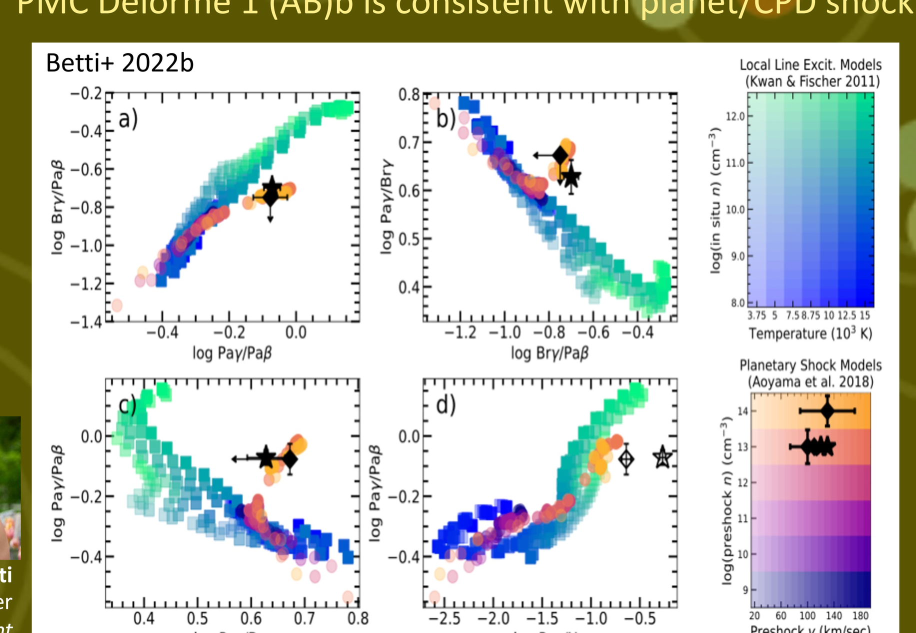
Goal: Use Line Ratios to Inform Accretion Paradigms

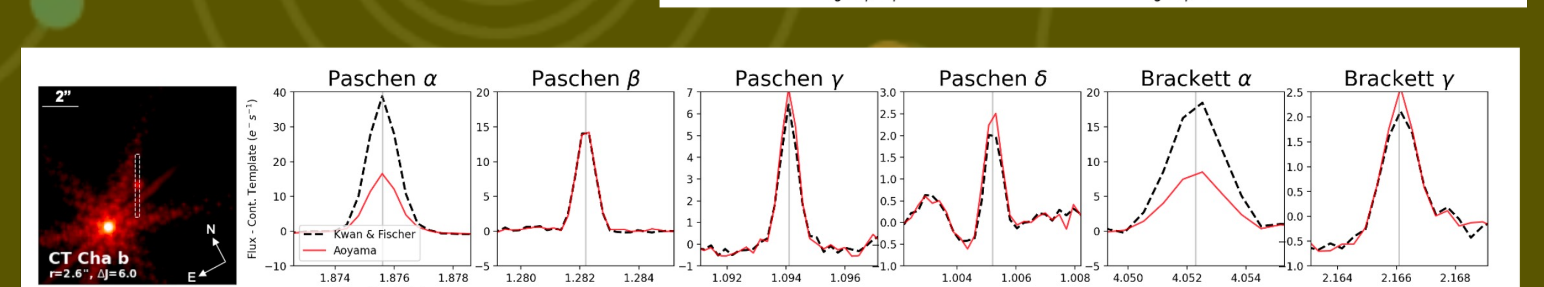
PMC Delorme 1 (AB)b is consistent with planet/CPD shock



Local Line excitation models: describe infalling accretion columns

Planet/CPD shock models: describe line emission from shocked gas





Additional lines accessible only with JWST will help better distinguish physical parameters within models and discriminate between them