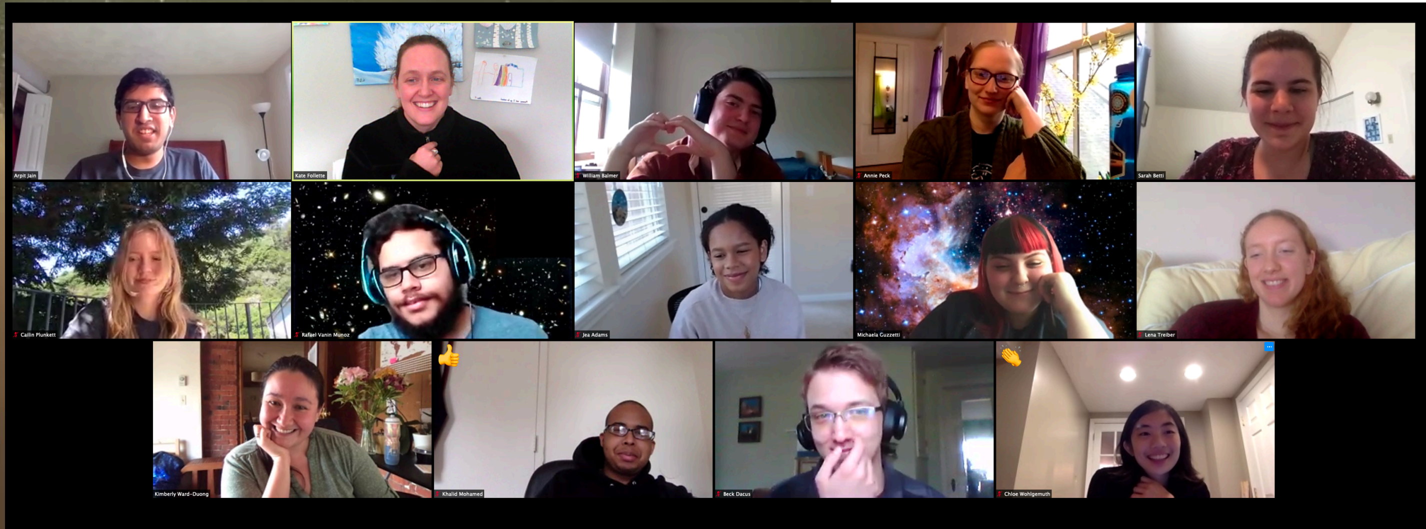
Accretion onto Planets and Circumplanetary Disks

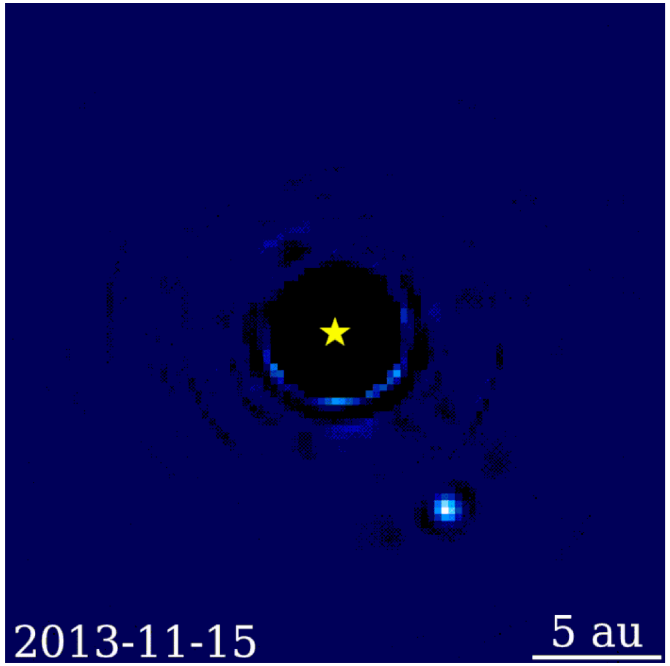
Kate Follette

Assistant Professor of Astronomy

Amherst College

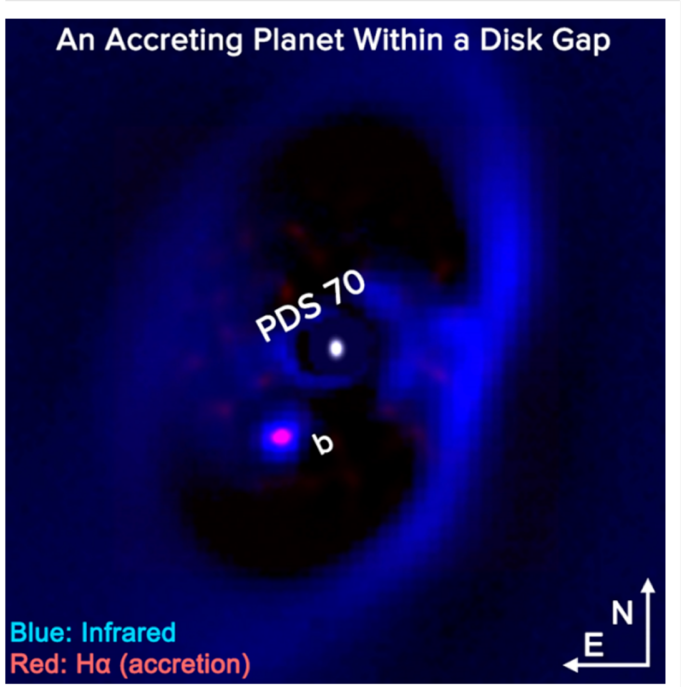


Talk Outline



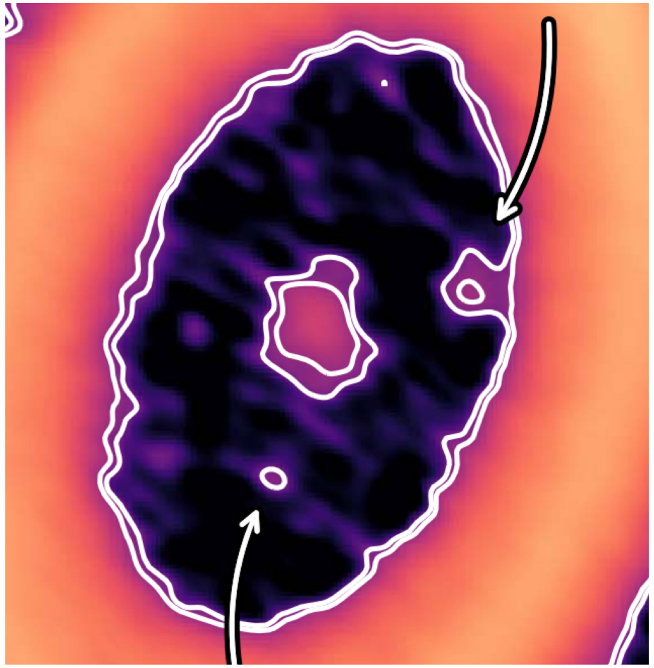
Direct Imaging

5 Reasons why you should care



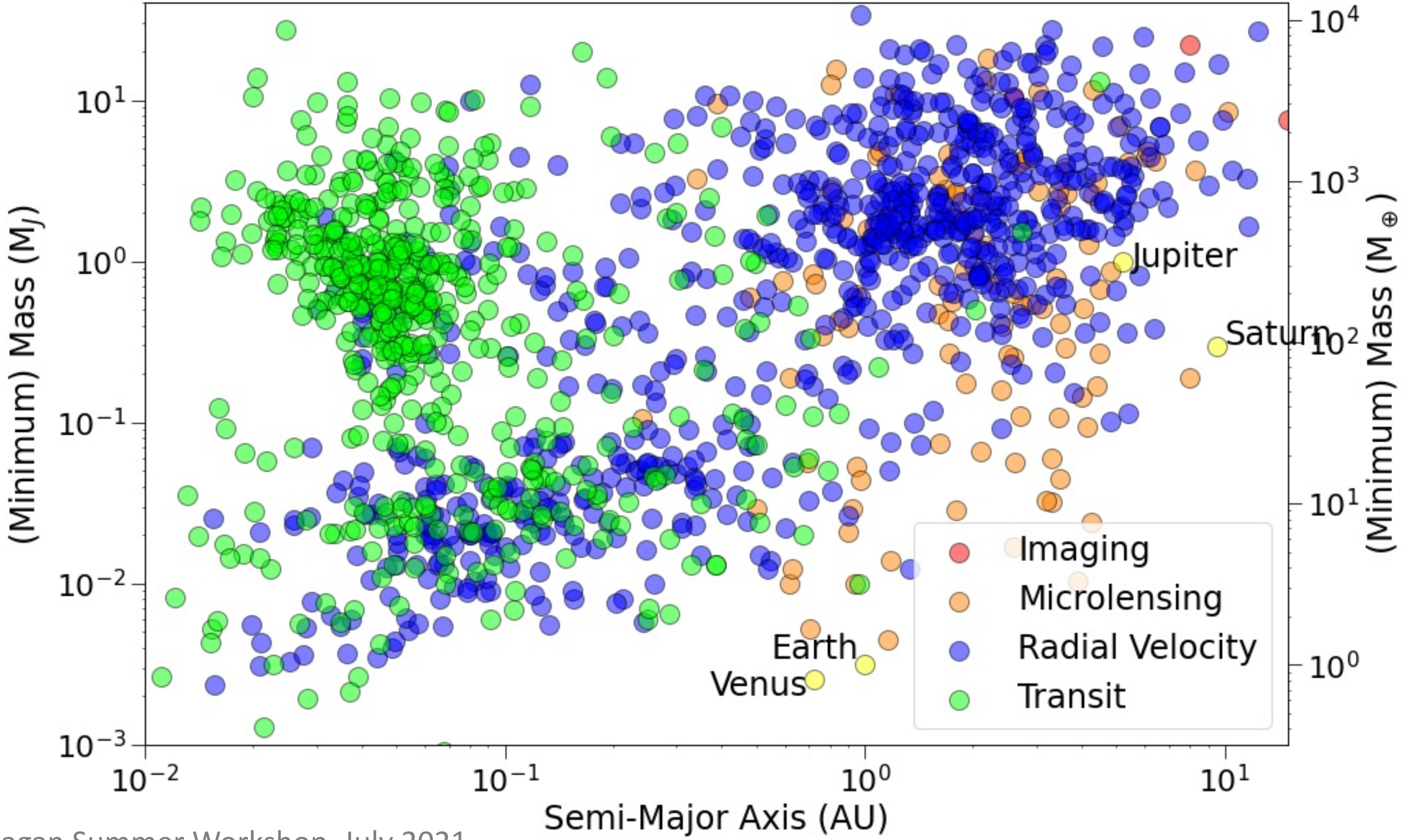
Accreting Protoplanets

4 Reasons why it's hard to study them

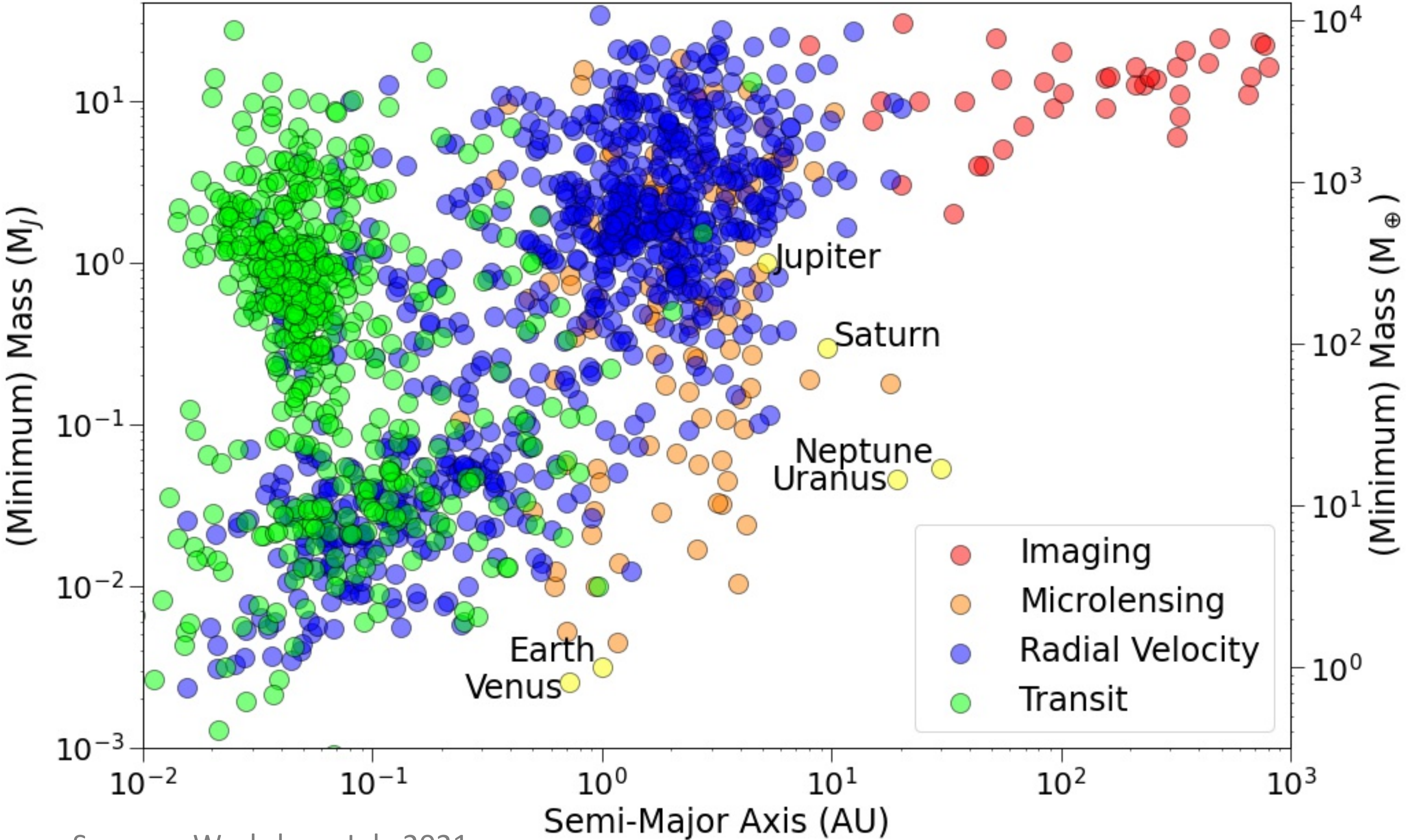


The Future

3 things that I think will revolutionize this field



K. Follette, Sagan Summer Workshop, July 2021



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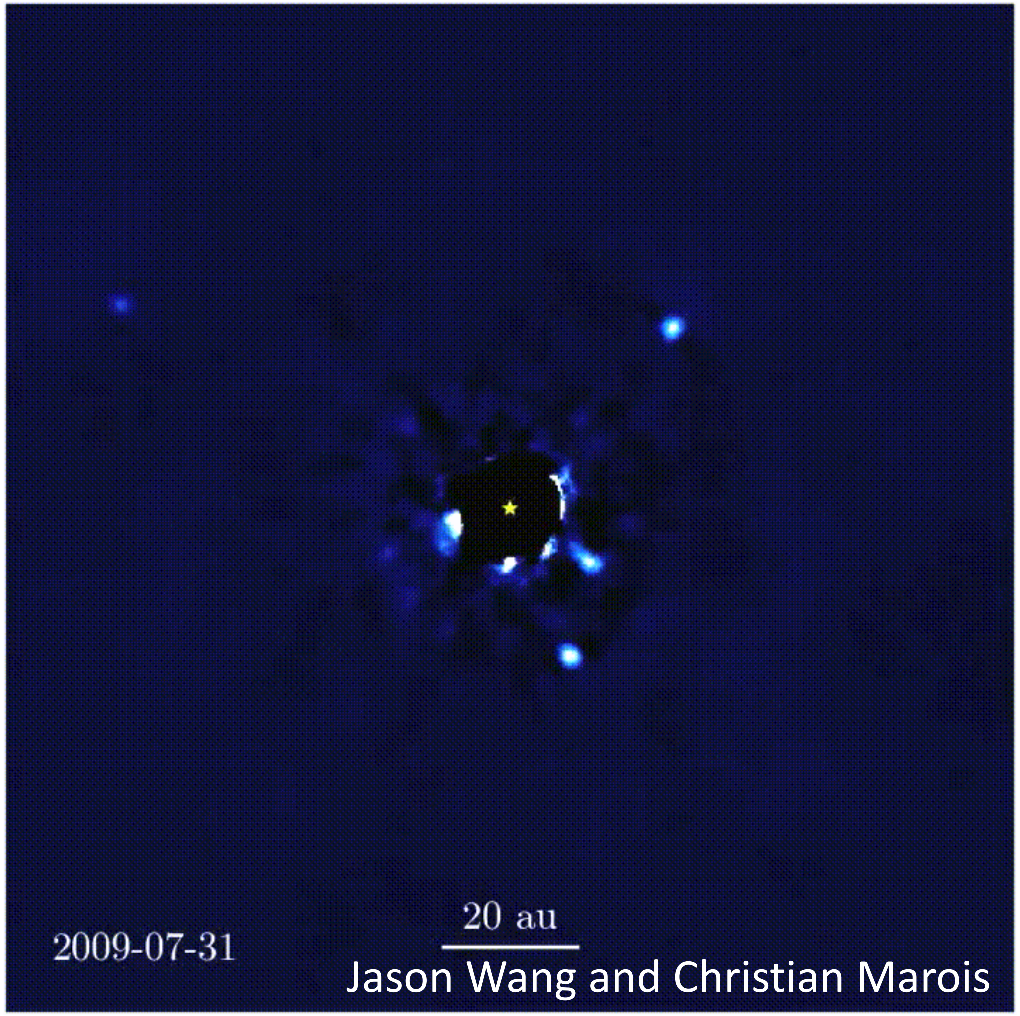
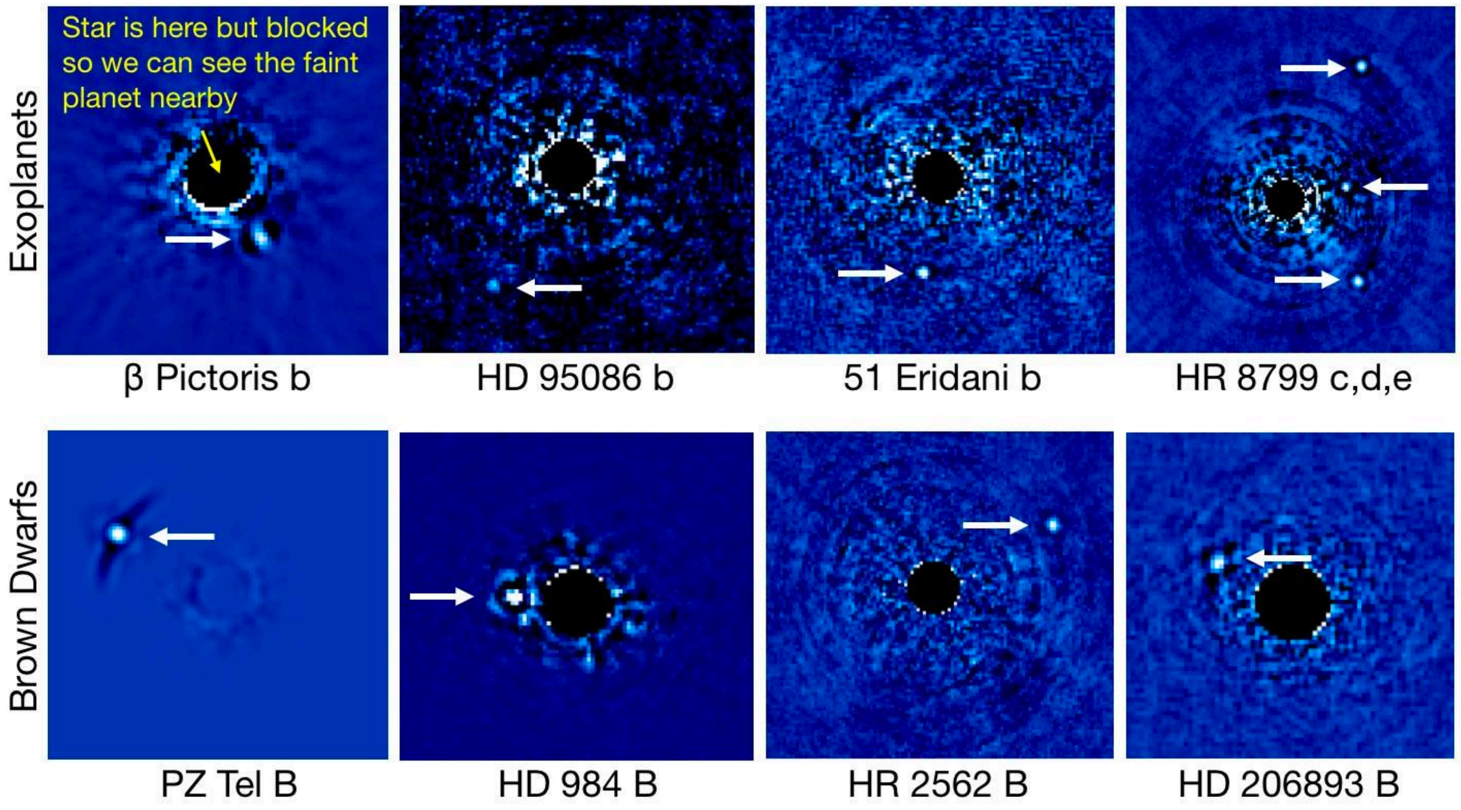
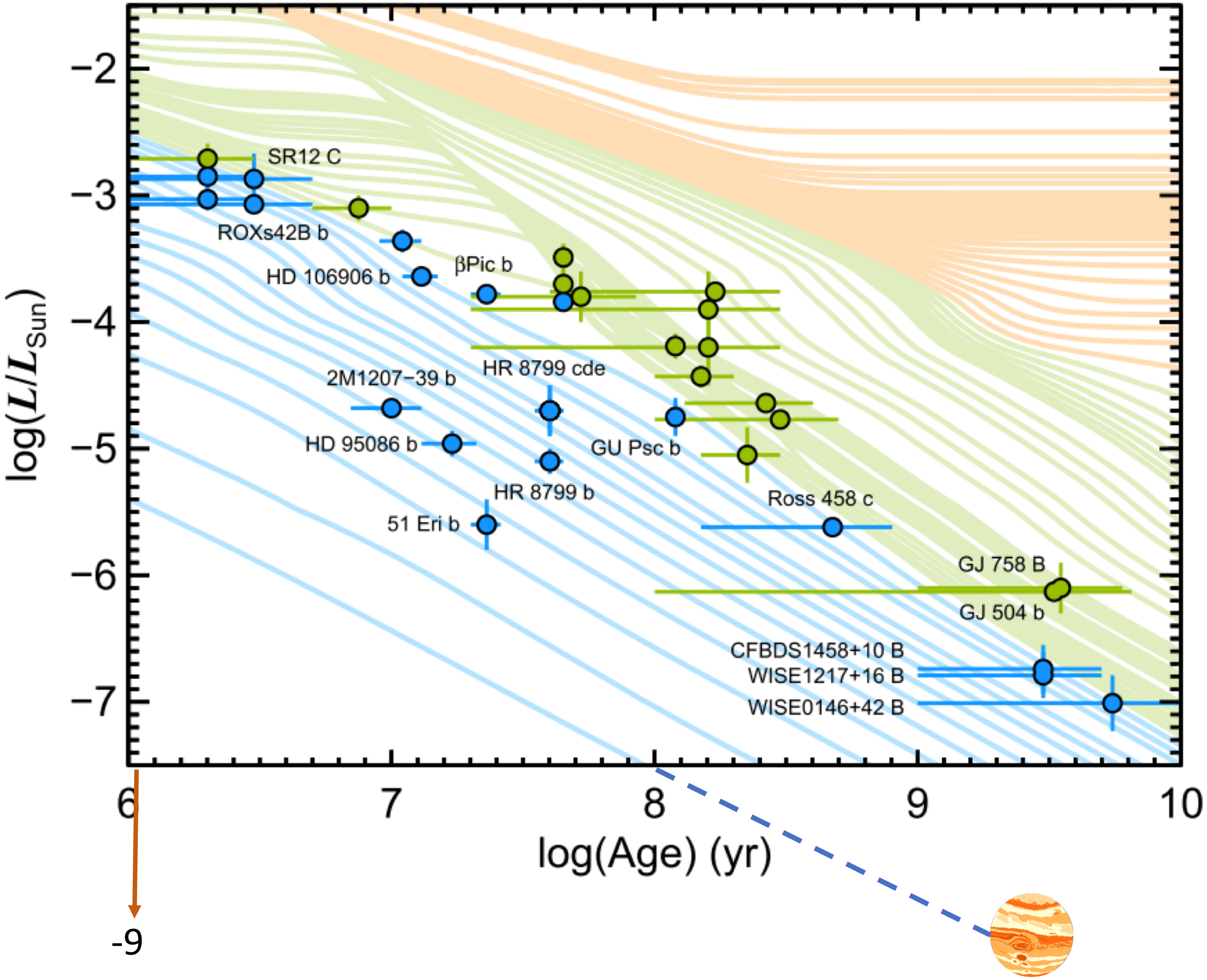
Reason 1: Visceral Satisfaction





Credit: Gemini Planet Imager Exoplanet Survey Team

Reason 2 : Directly Imaged Planets are Young



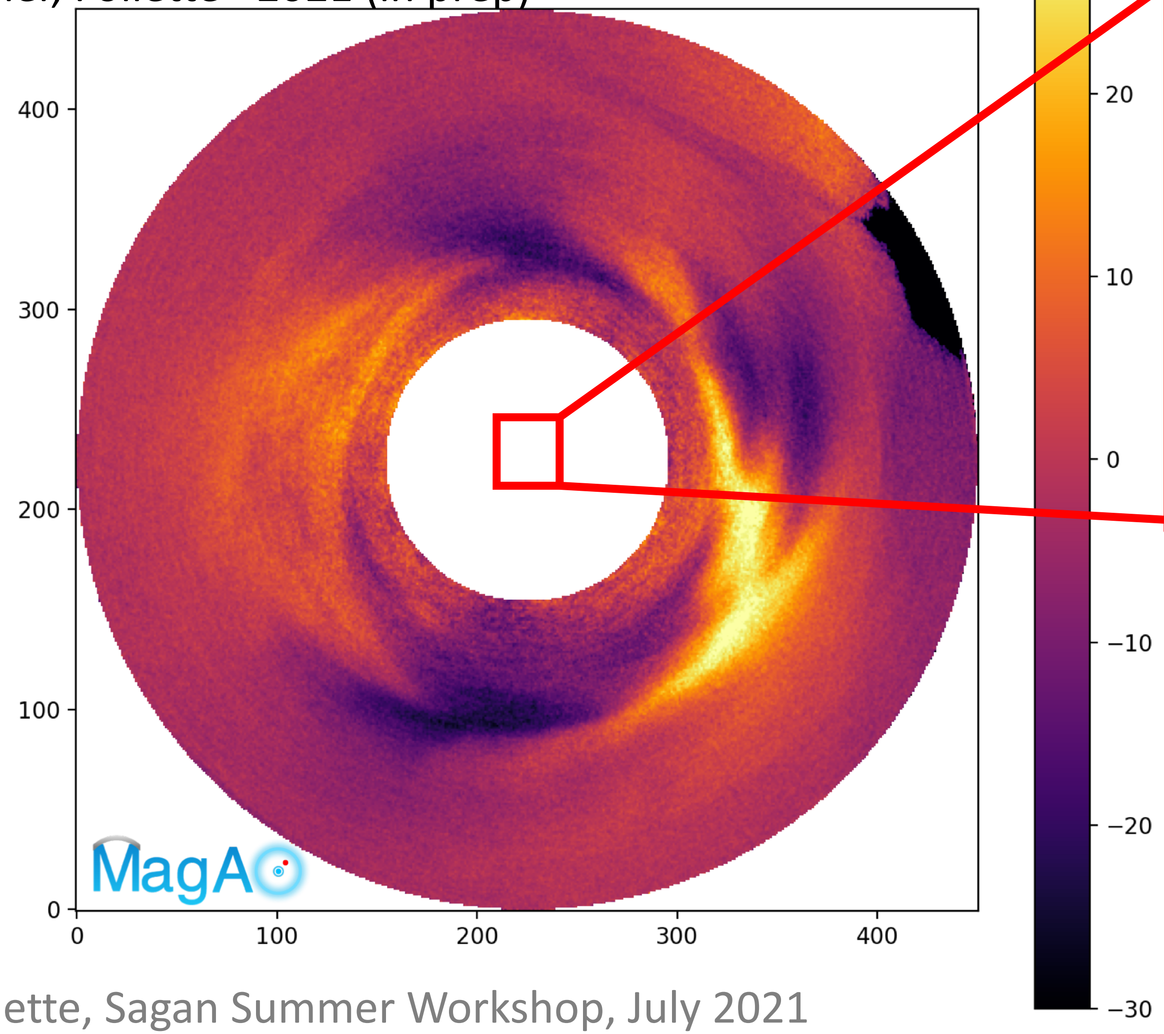
Bowler 2016

K. Follette, Sagan Summer Workshop, July 2021

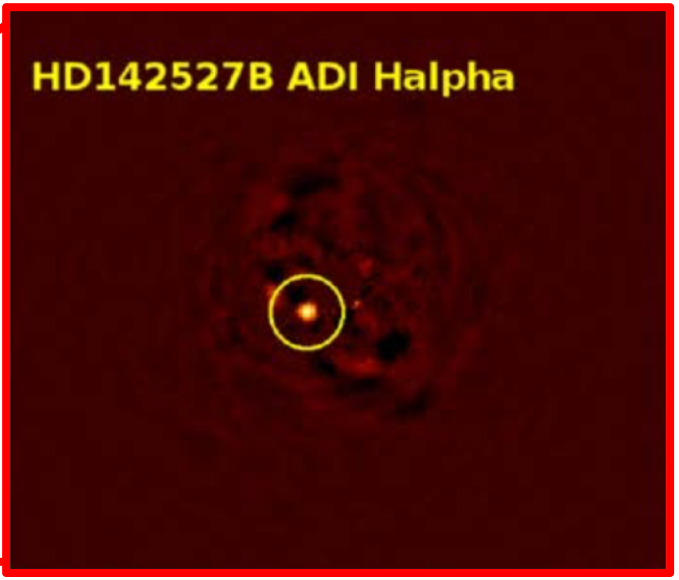
Reason 3: Orbital Characterization

HD142527 disk: R_{cavity} > 100AU

Balmer, Follette+ 2021 (in prep)



HD 142527B: R ≈ 10AU

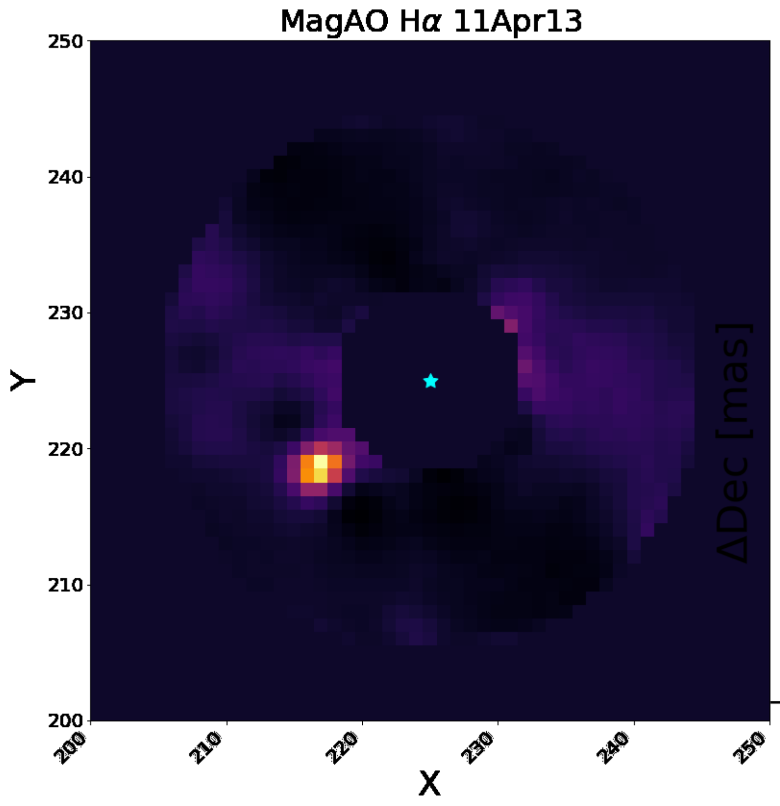


Close, Follette+ 2014

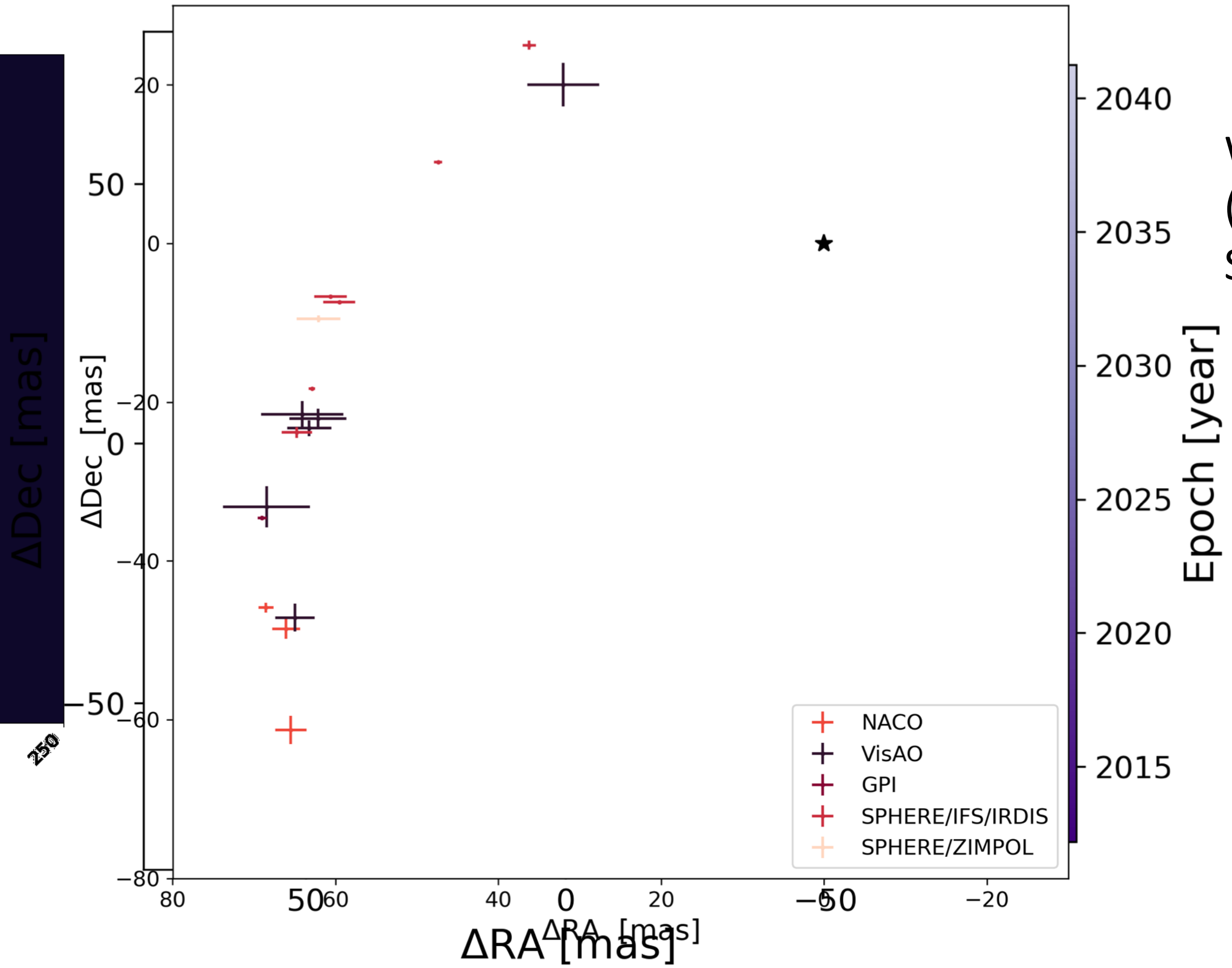
William Balmer ‘21
(they/them)
Senior Thesis
Now: JHU Grad Student

Alex Watson ‘19
(they/them)
Senior Thesis

HD 142527 B: Orbital Characterization



Balmer, Follette+ 2021 (in prep)



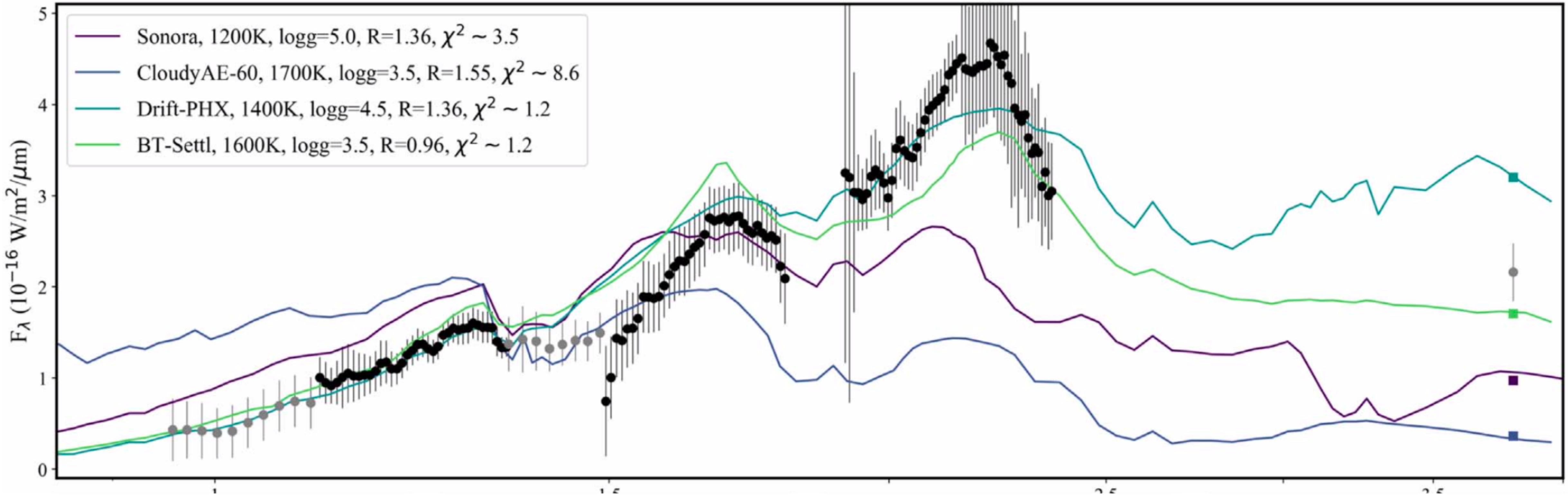
William Balmer ‘21
(they/them)
Senior Thesis

Alex Watson ‘19
(they/them)
Senior Thesis

Reason 4: Spectral Characterization

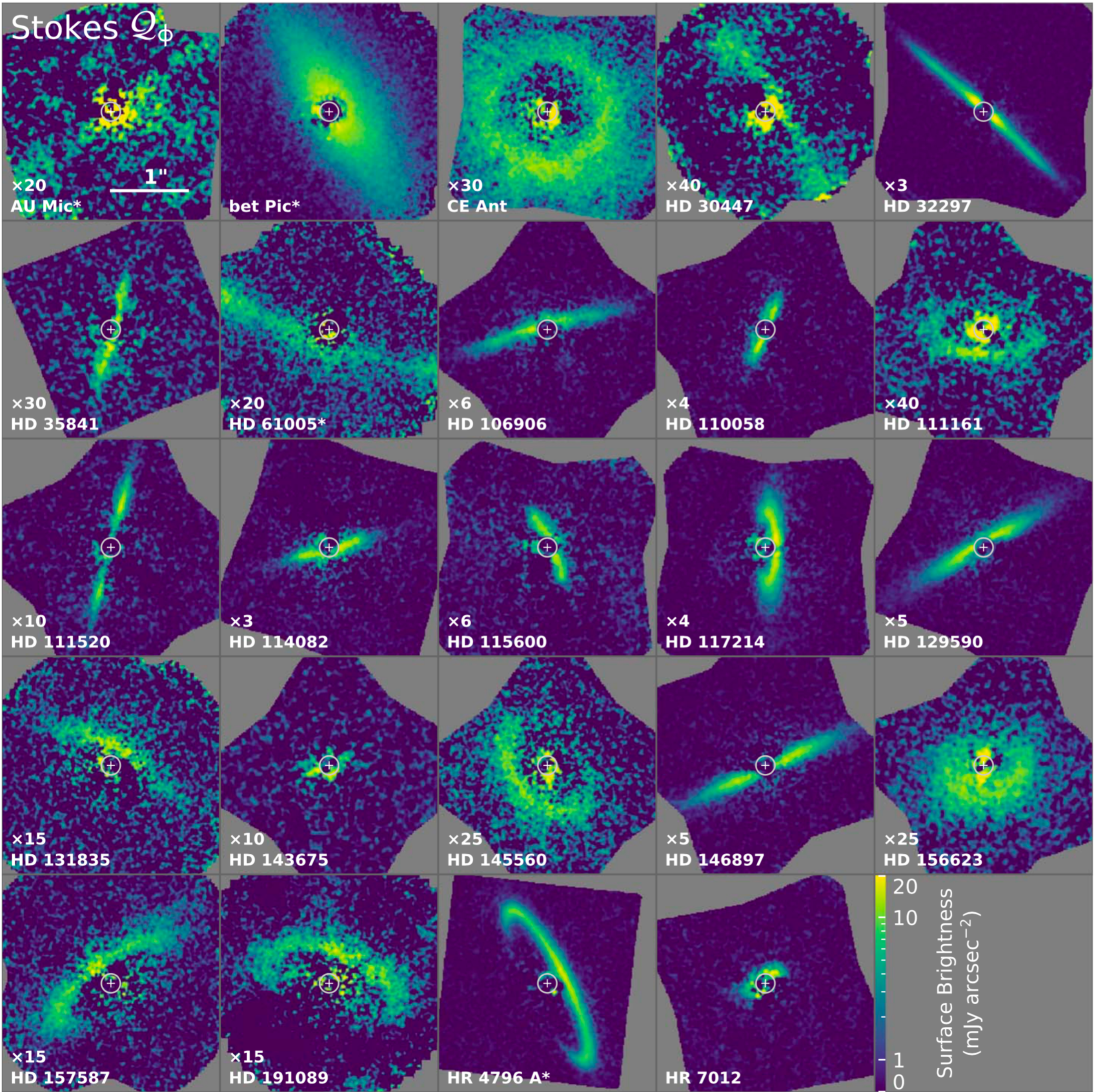
Kim Ward-Duong
(she/her)
STScI Fellow → Smith College

HD 206893 B (b?)



Ward-Duong, Patience, Follette+ 2021

Gemini Planet Imager Exoplanet Survey Debris Disk Gallery

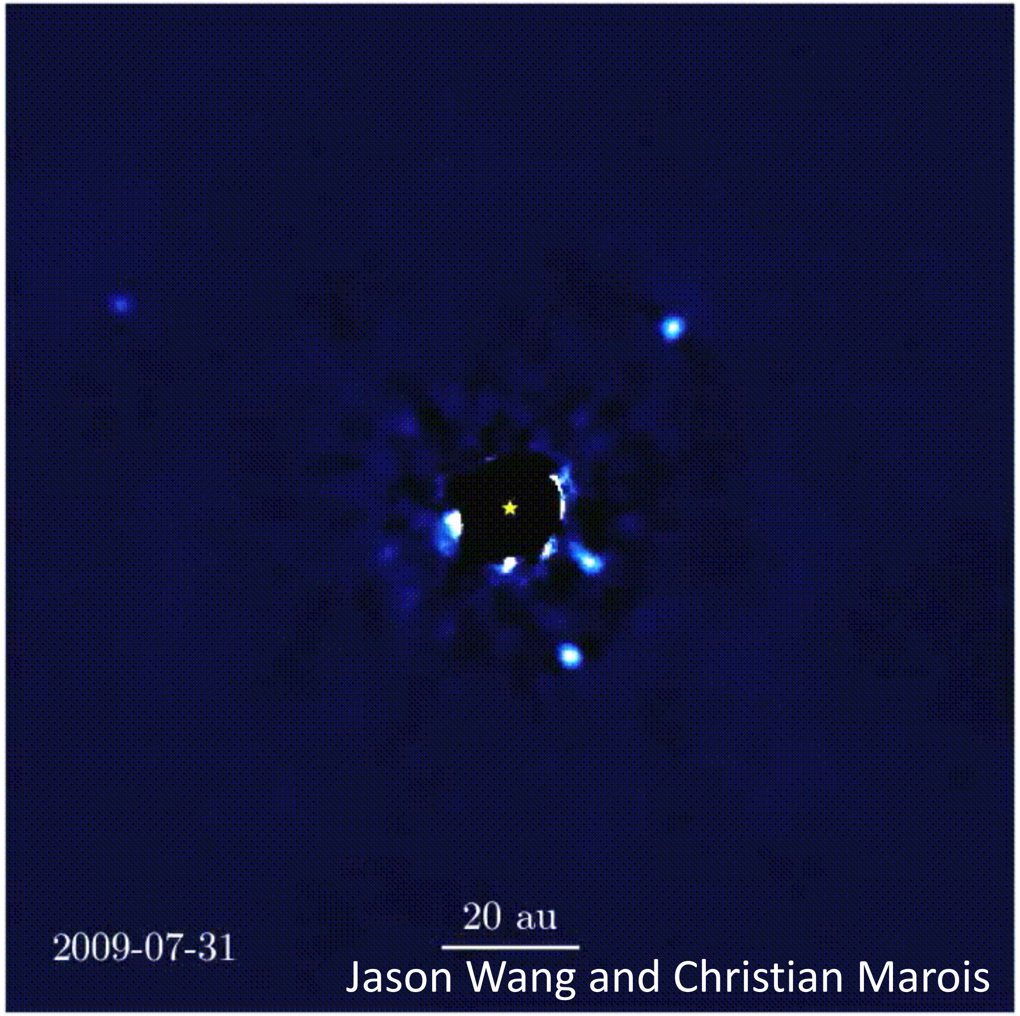


Reason 5: Collateral Disks

Esposito+ 2020

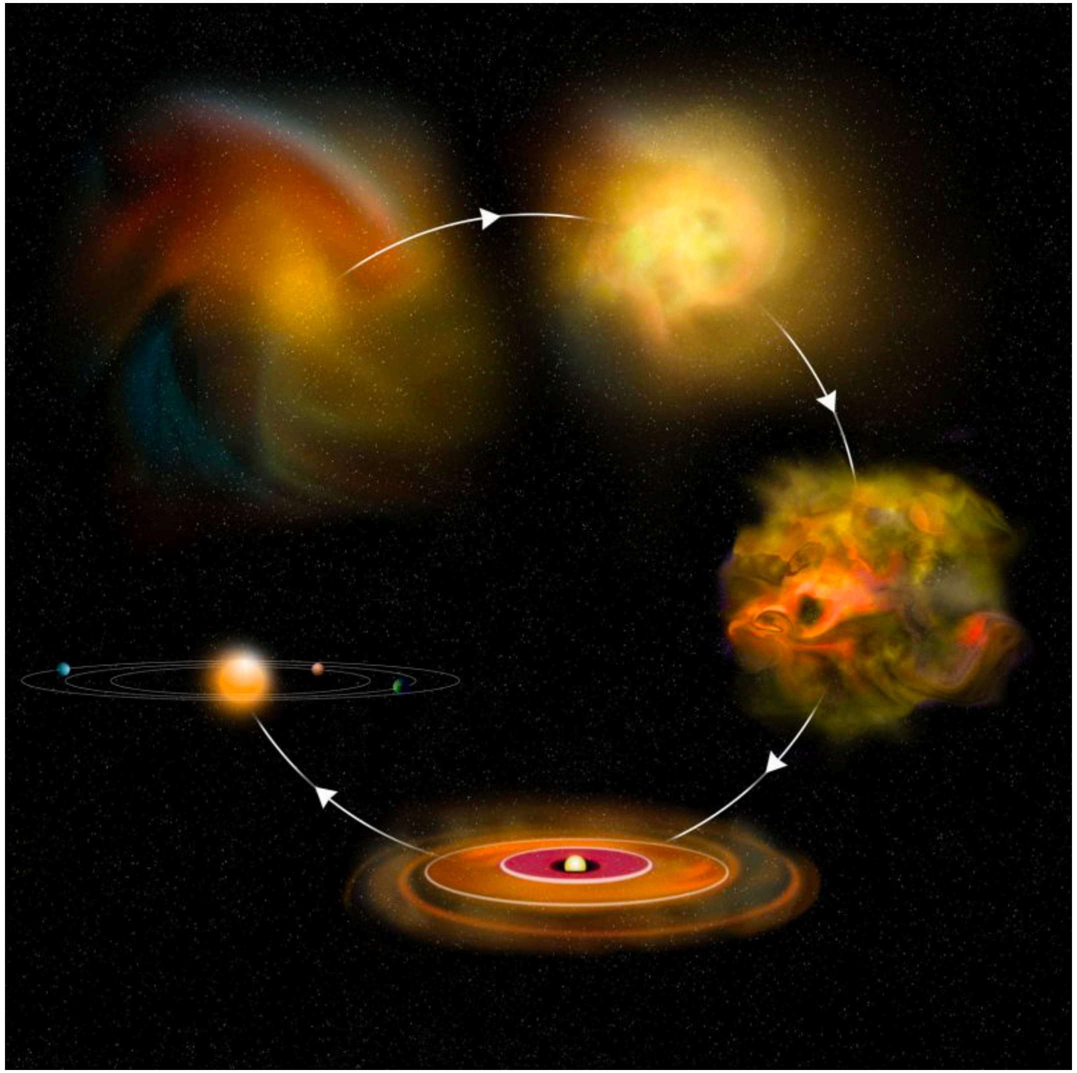
5 Reasons to Care about Direct Imaging

1. Visceral Satisfaction
2. Dynamics/Orbital Characterization
3. Spectral Characterization
4. Youngest Planets
5. Disk-Planet Interaction



How do you study the planet formation process?

Strategy 1: Take high resolution, high contrast images of the disks and look for ”signposts”



Circumstellar Disks Structures = "Signposts" of Planets?

Alex DelFranco '24
(he/him)
Amherst College

Dane Mansfield '23
(he/him)
Amherst College

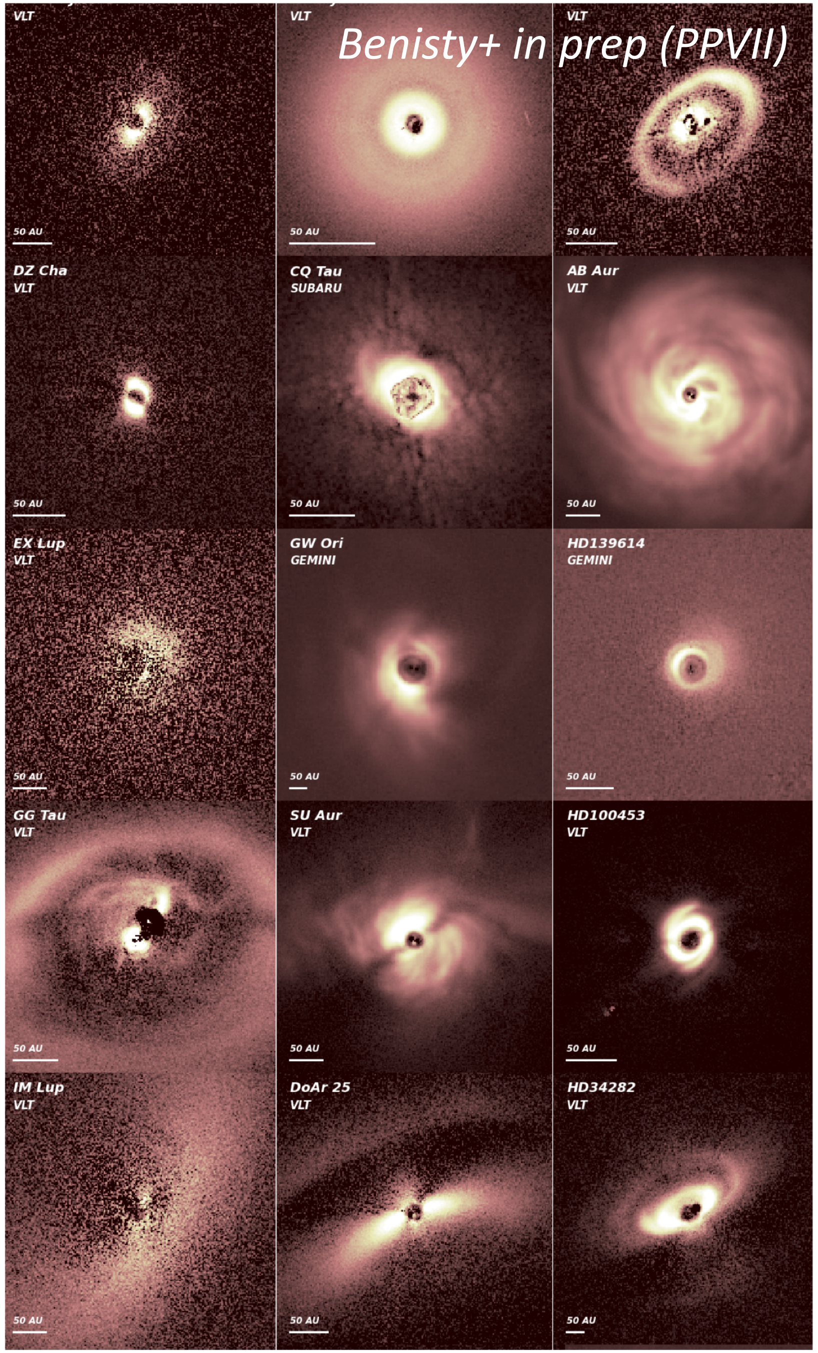
Rings

Spirals

Broad Shadows

Narrow Shadows

Back Sides

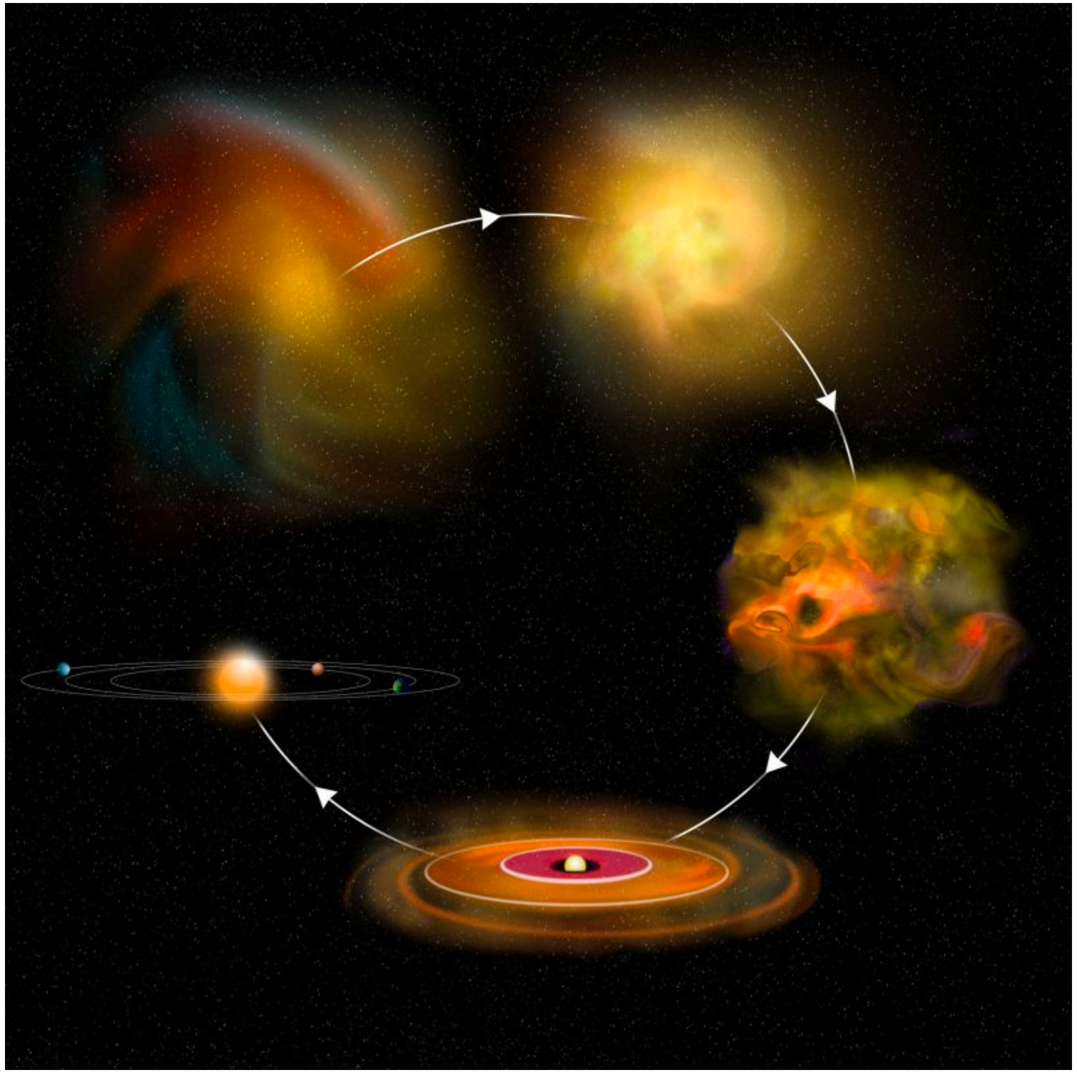


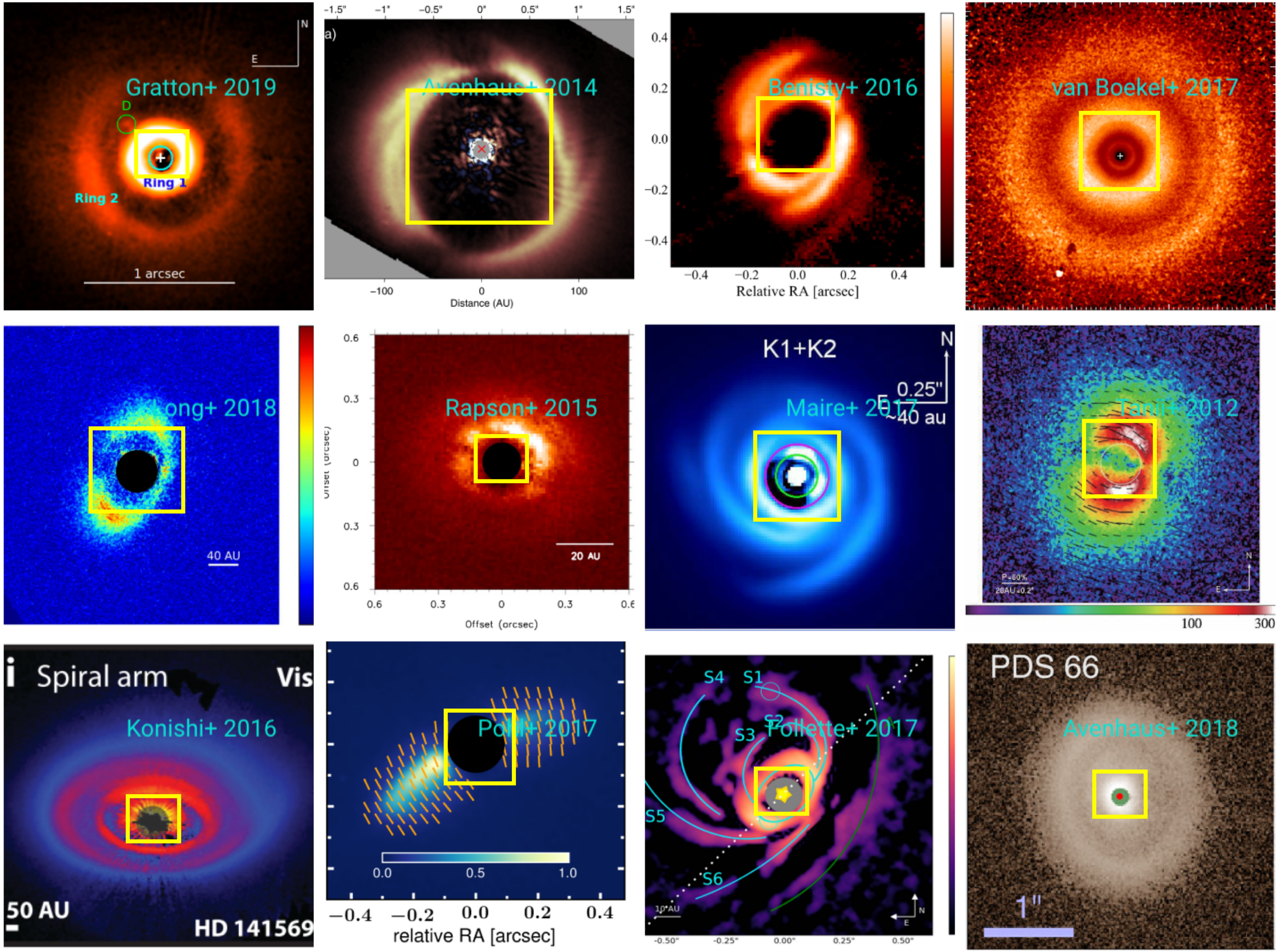
M stars FGK stars AB stars

How do you study the planet formation process?

Strategy 1: Take high resolution, high contrast images of the disks and look for ”signposts”

Strategy 2: Look for the planets themselves!





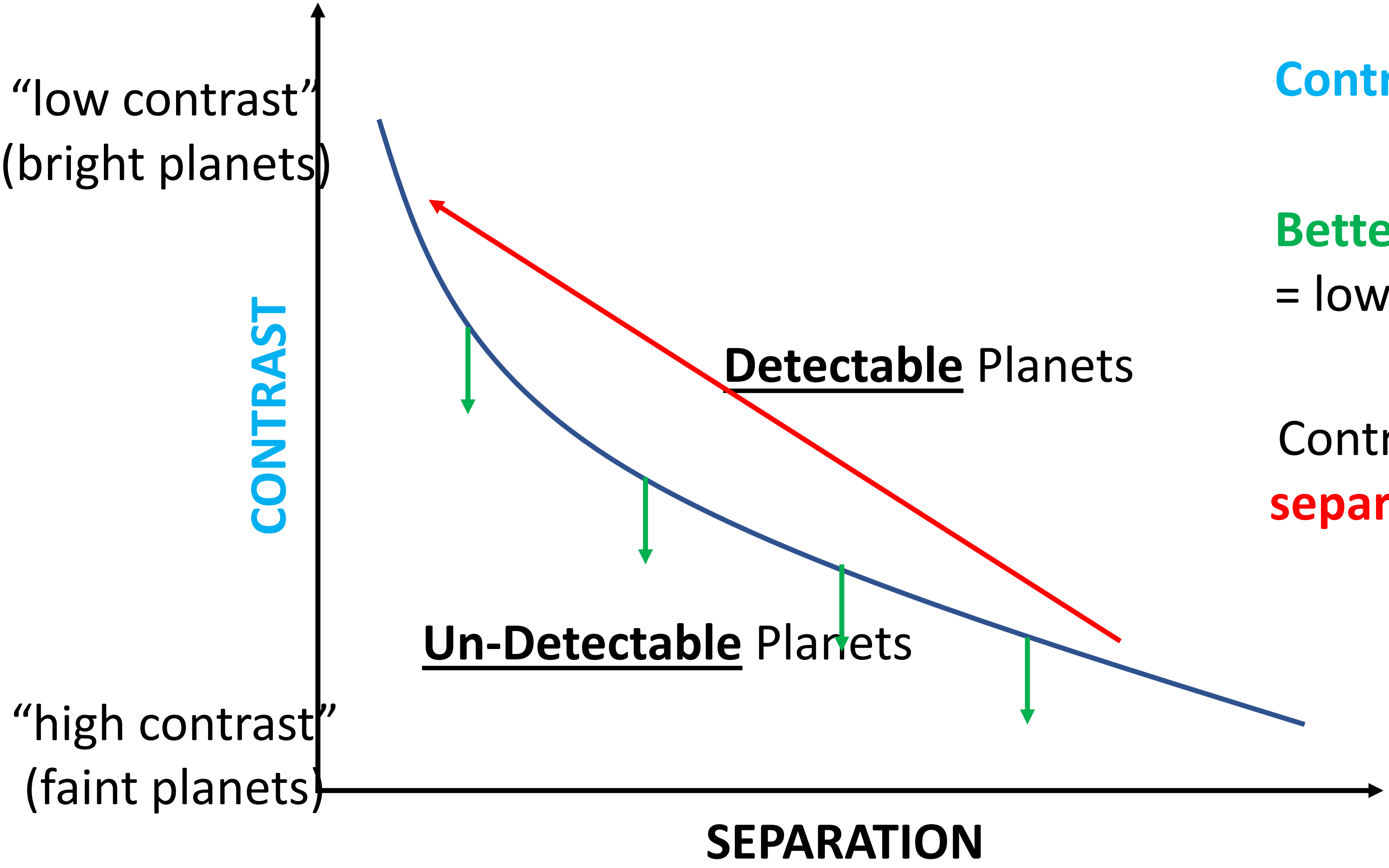
Transitional disks with cleared central cavities are likely sites of ongoing planet formation

These cavities have radii of tens of AU

Most nearby planet forming regions are ~140pc away

This translates to 0.1”-0.3” cavities for most transitional disks

Obstacle 1: Contrast
Contrast Curve 101



Contrast = planet/star brightness

Better Performance (AO, atmosphere) = lower curve

Contrast limit is a **steep function of separation**. Only very bright planets can be seen close.

Obstacle 2: Contrast

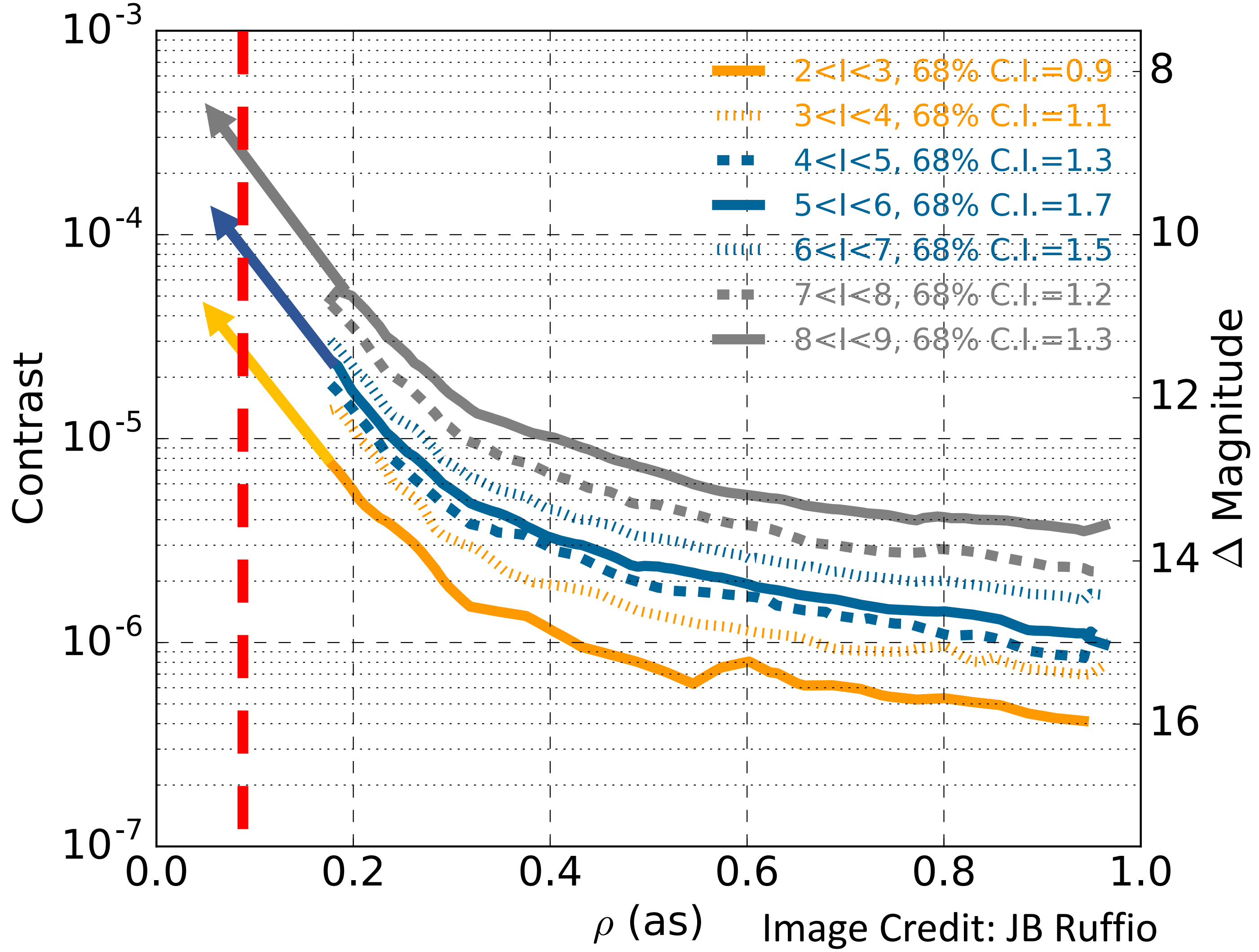
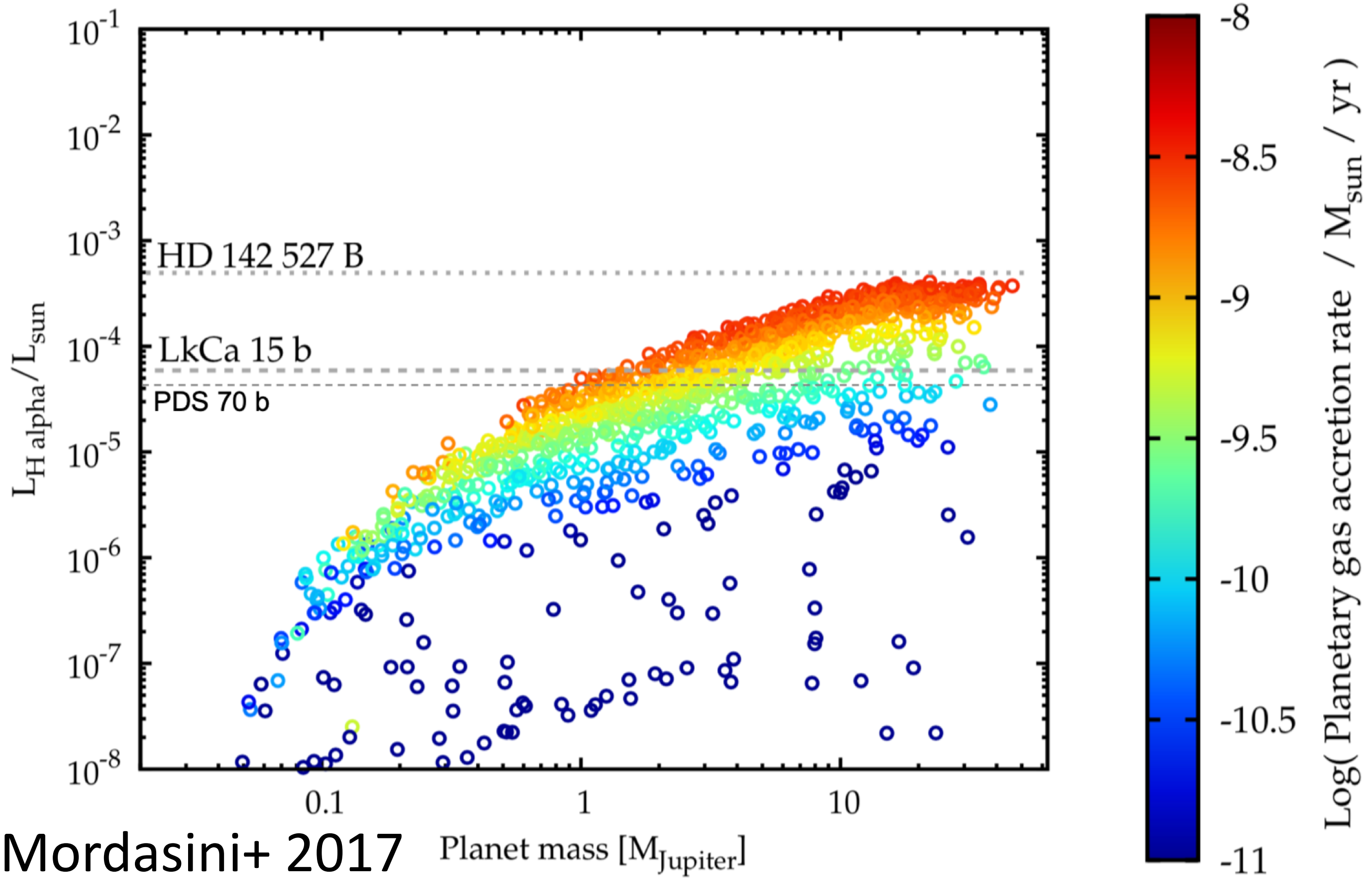


Image Credit: JB Ruffio

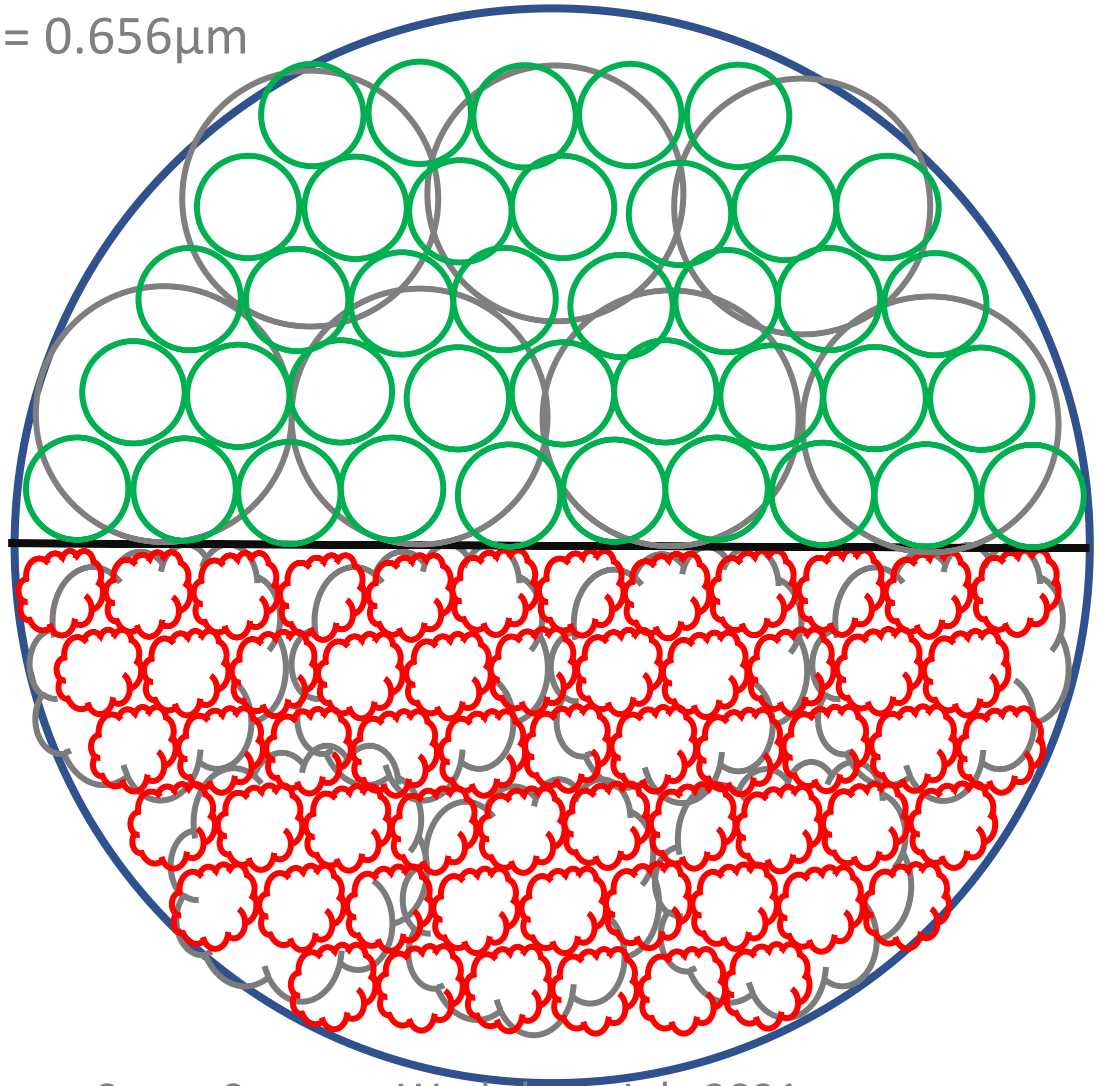
Accreting Protoplanets are Bright at H-alpha!



Mordasini+ 2017

Obstacle 2: Resolution

H-band = 1.65μm
Hα = 0.656μm



$\boldsymbol{\theta = 1.22\frac{\lambda}{D}}$ → Bigger telescope or **shorter wavelength**

Visible Light Pros

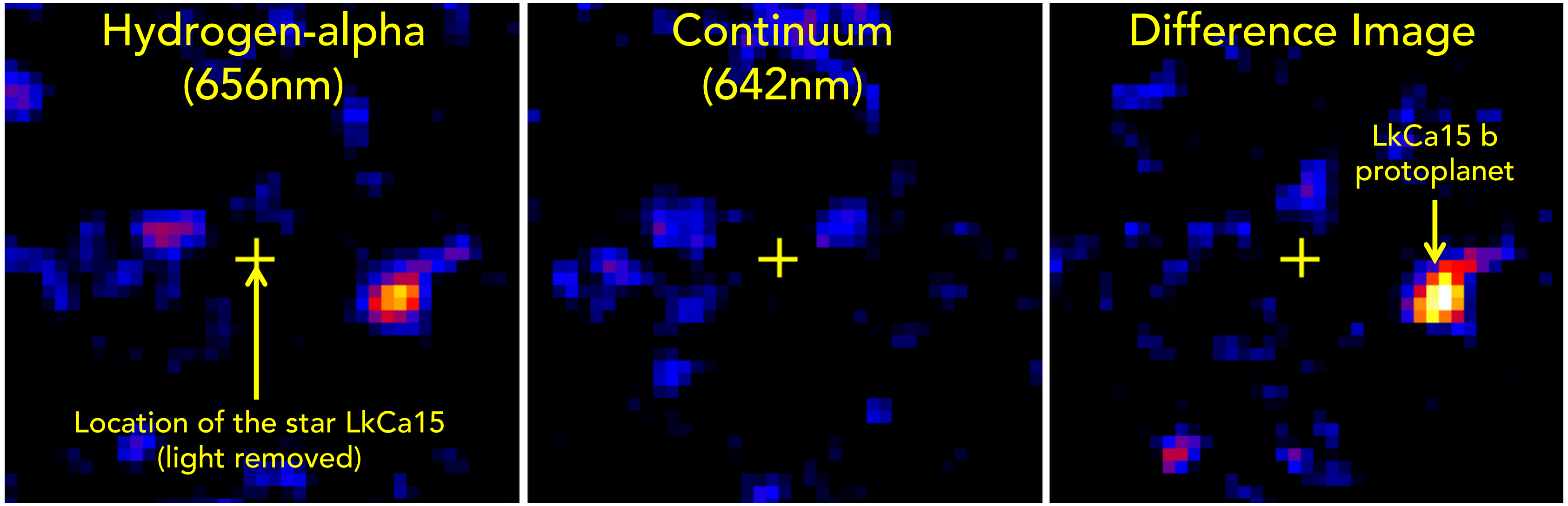
Diffraction limit $\boldsymbol{\theta = 1.22\frac{\lambda}{D}}$

Visible Light Cons

Atmo. coherence length $\boldsymbol{r_0 \sim \lambda^{6/5}}$

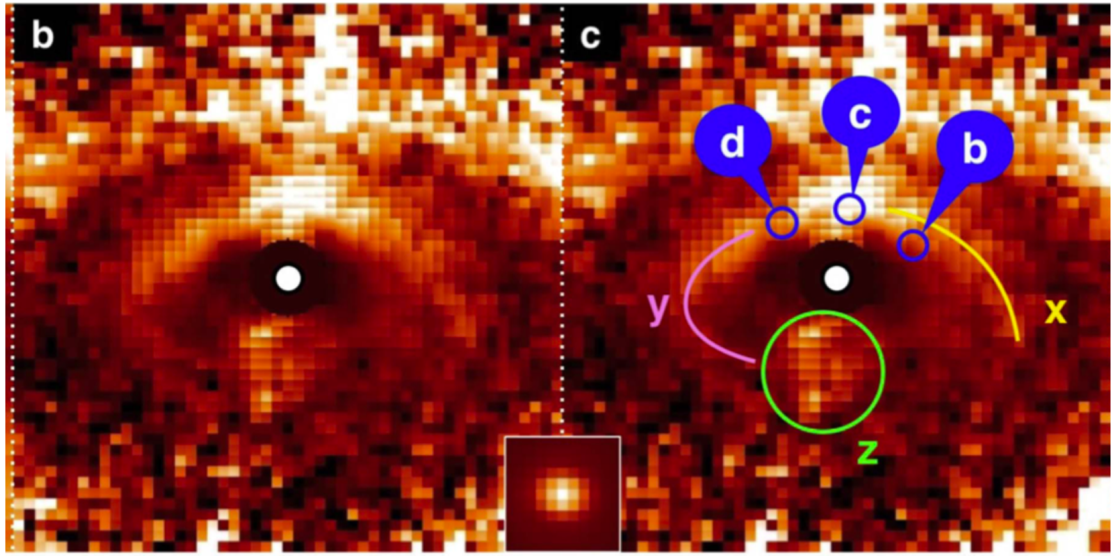
Atmo. coherence time $\tau \sim \boldsymbol{\frac{r_0}{v}}$

LkCa15 b – An Accreting Protoplanet

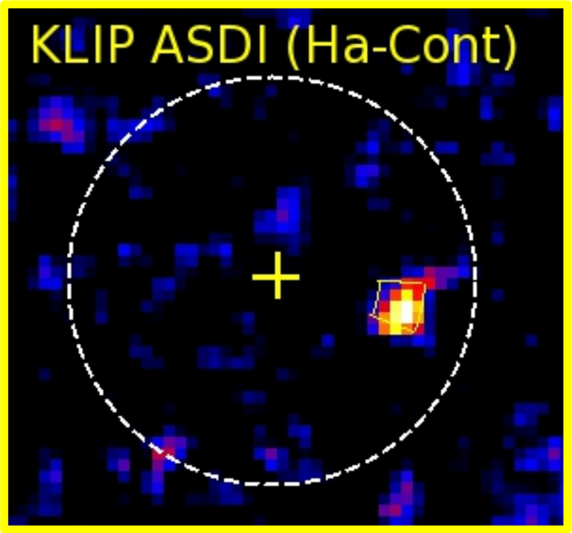


Sallum, Follette et al. 2015 *Nature*

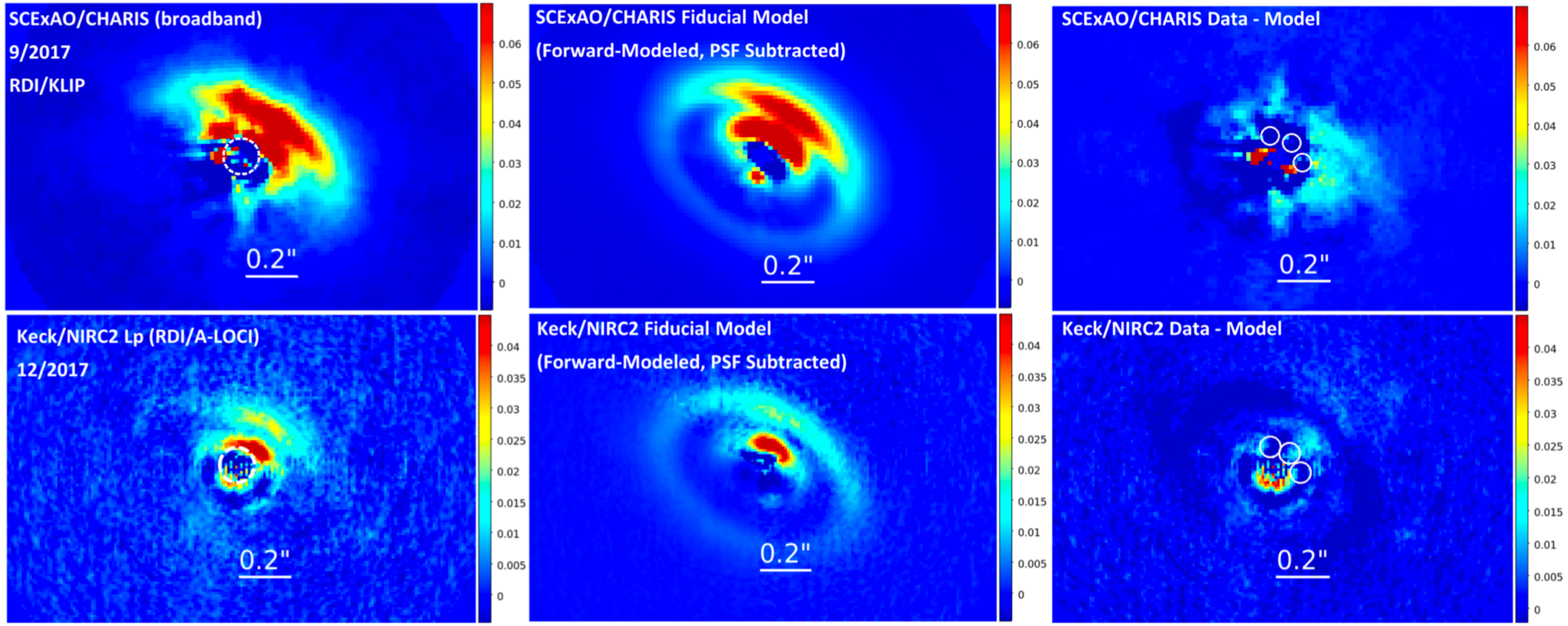
LkCa 15 b – A disk artifact?



Thalmann+ 2016

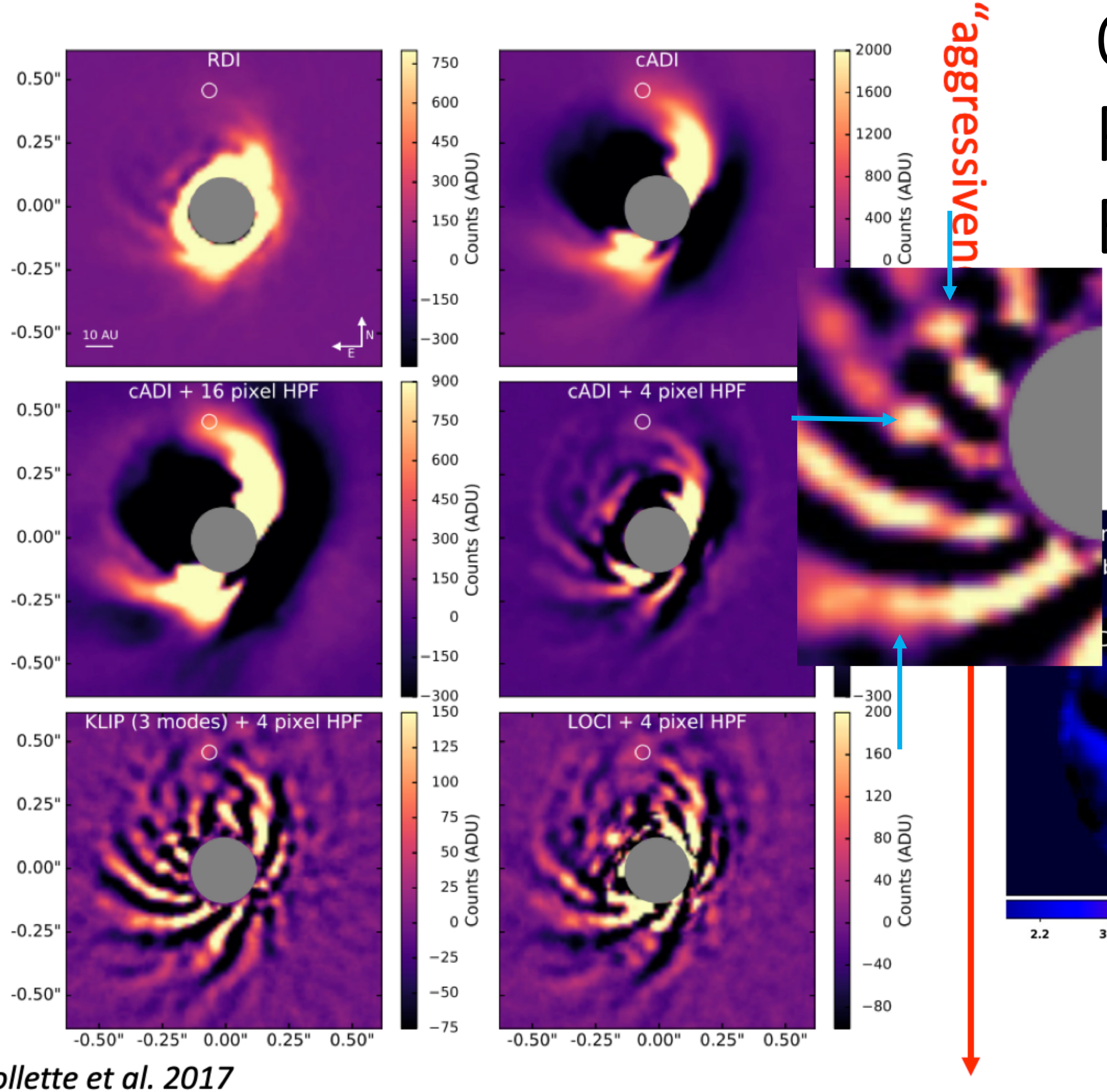


Sallum, Follette+ 2015

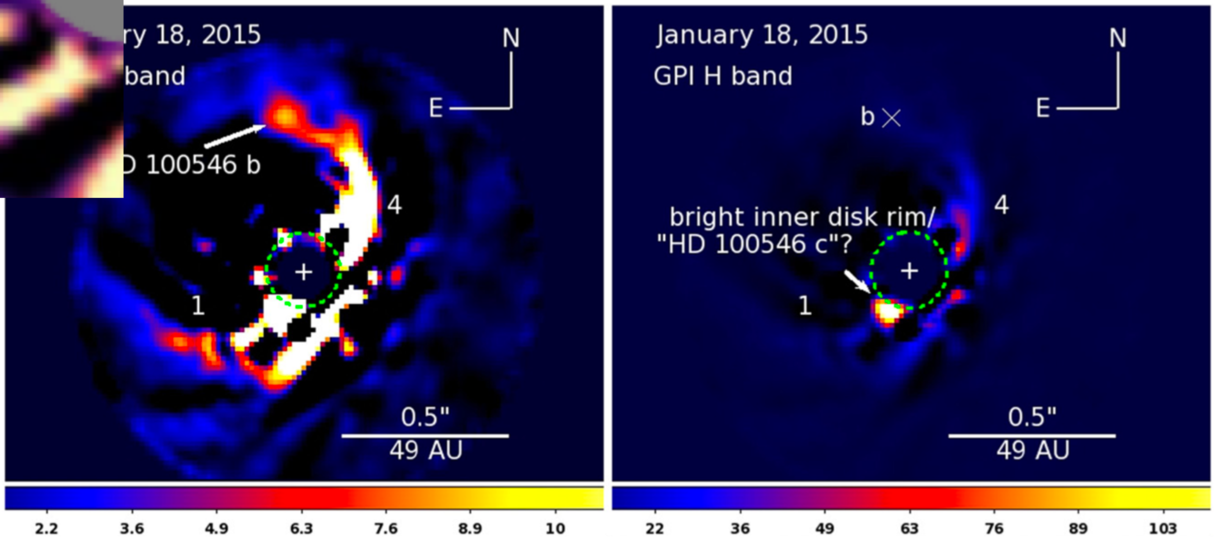


Currie+ 2019

Obstacle 3: Accreting Protoplanets are Embedded!



Follette et al. 2017



Currie+ 2015

KLIP Parameter Optimization

Jéa Adams ‘21
(she/her)
Senior Thesis
Now: CfA Grad Student

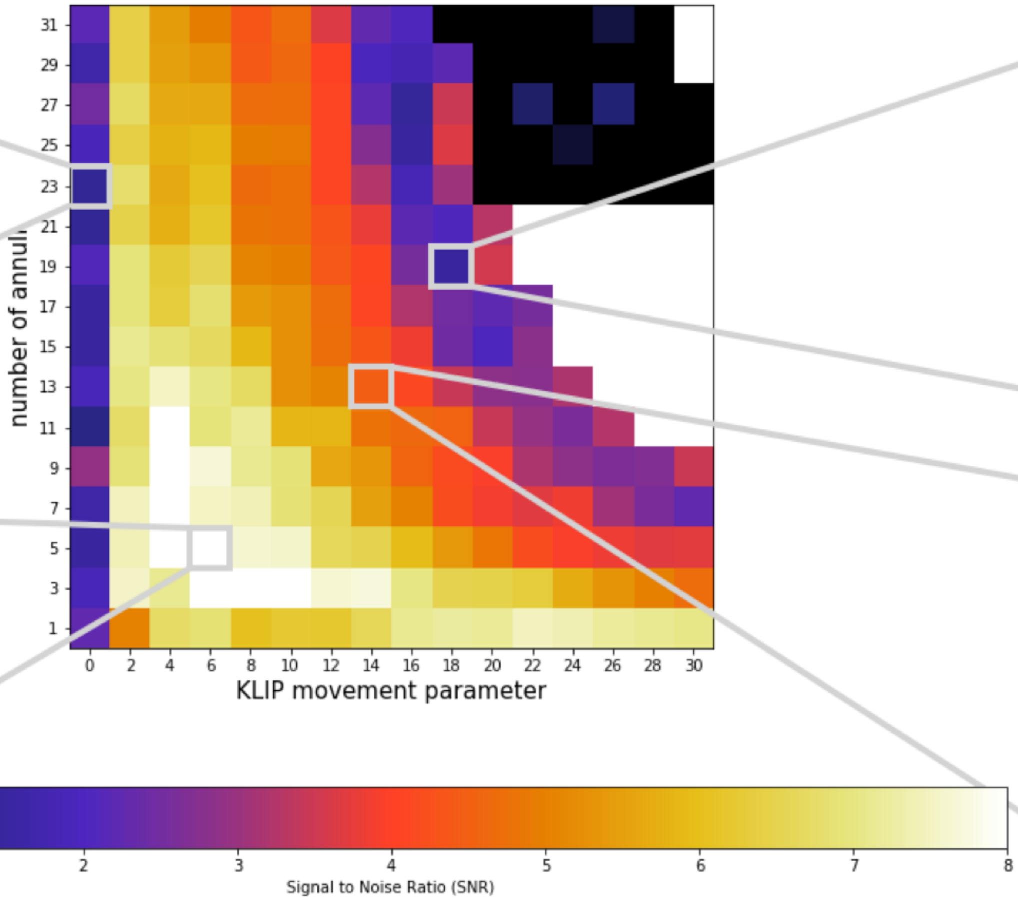
Clare Leonard ‘19
(she/her)
Senior Thesis

m0 a21

m18 a19

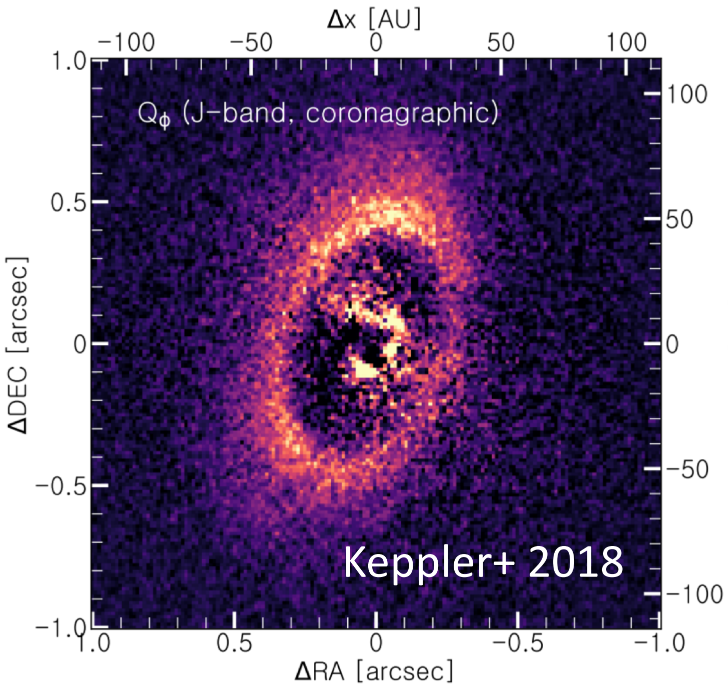
m6 a5

m14 a13

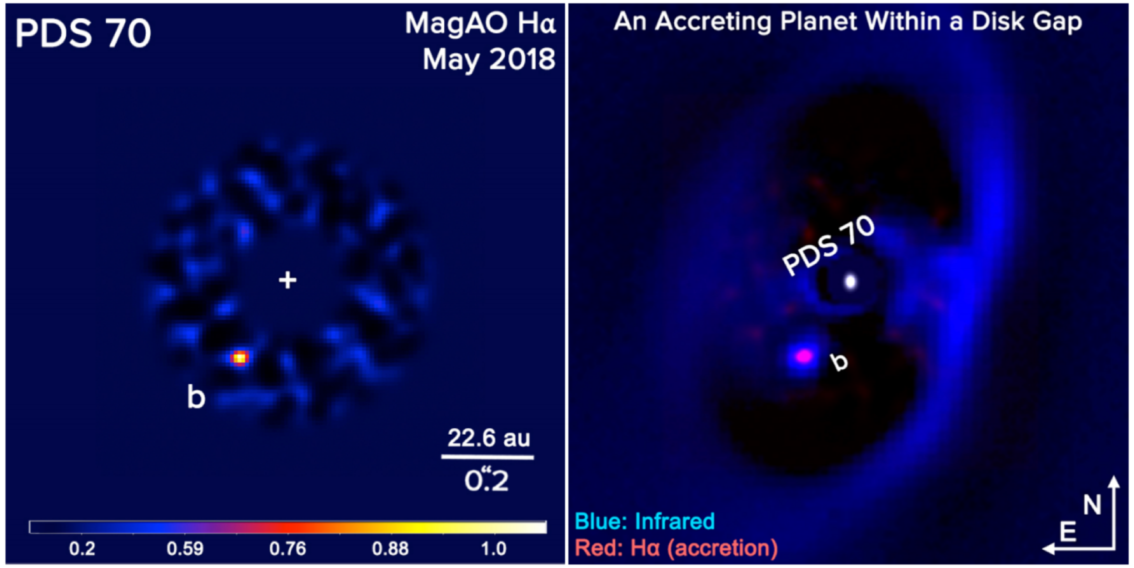


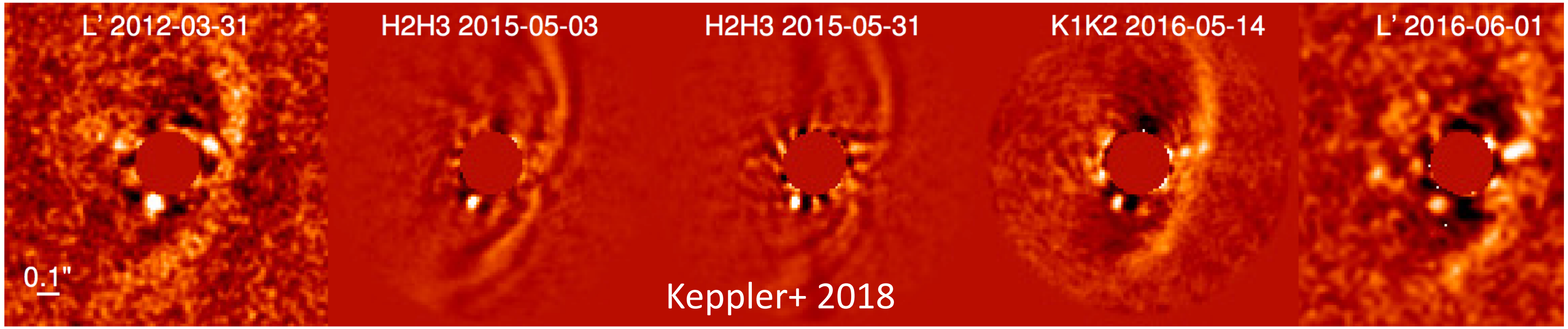
Adams, Follette+ 2021 in prep

PDS 70 b to the rescue!

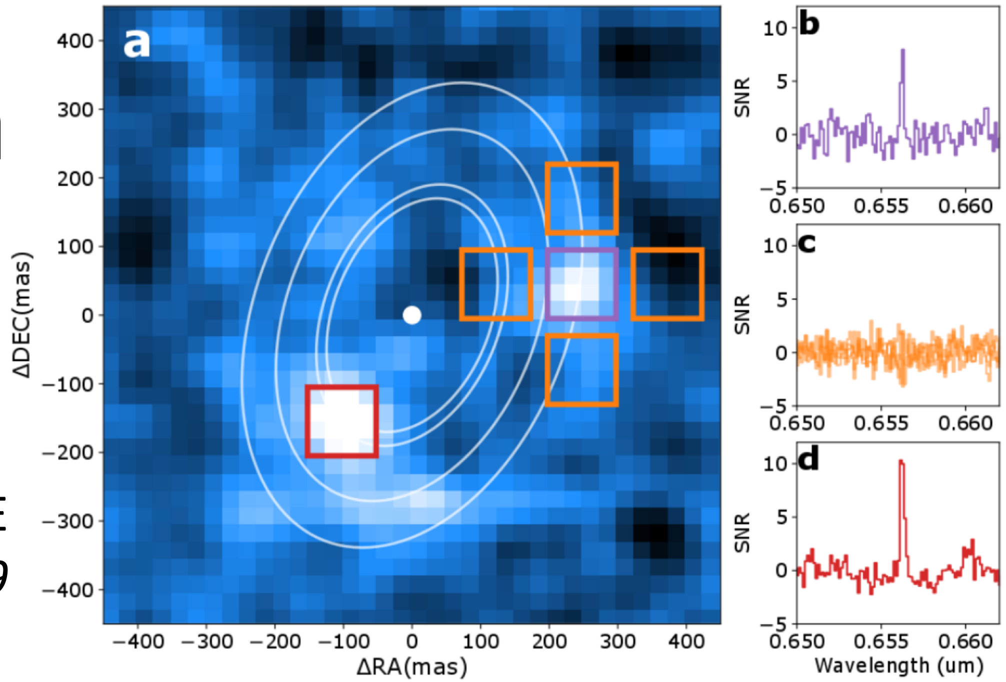


Wagner, Follette et al. 2018

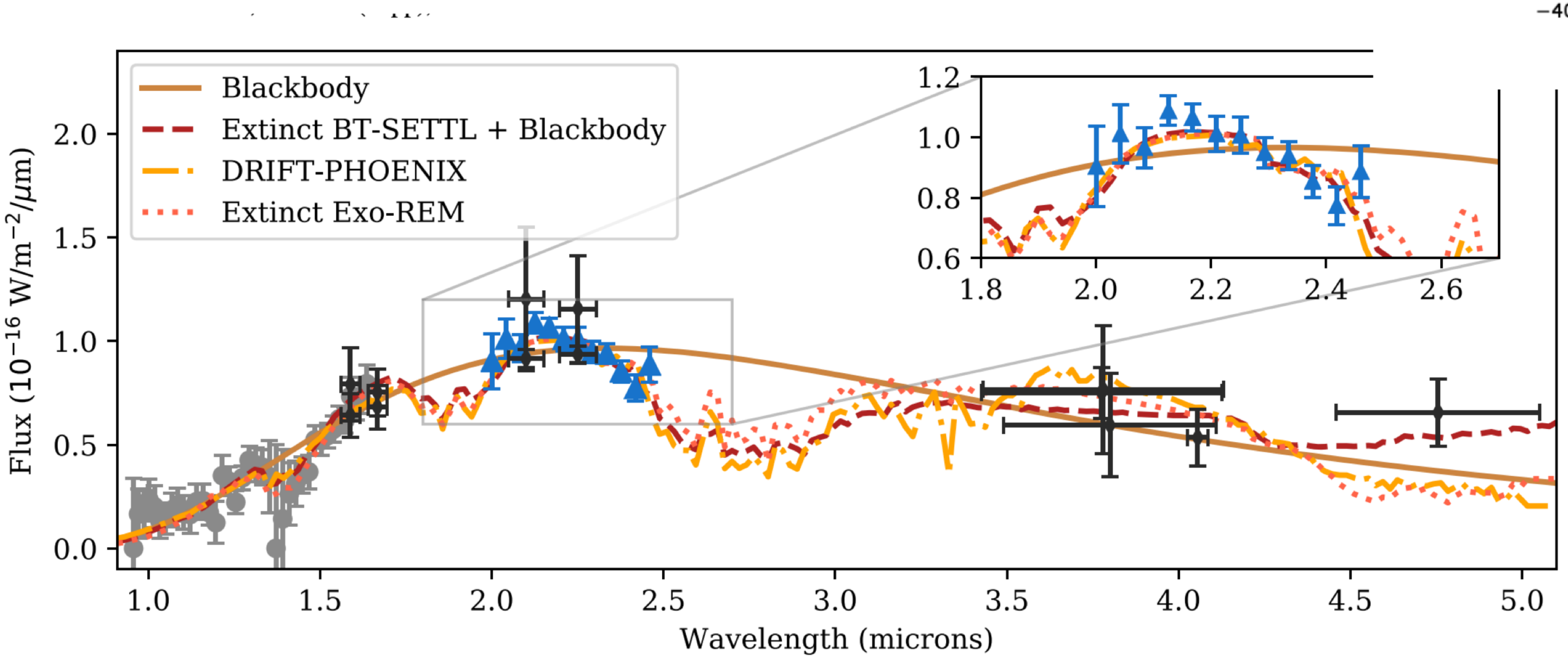




Accreting Protoplanet Spectra

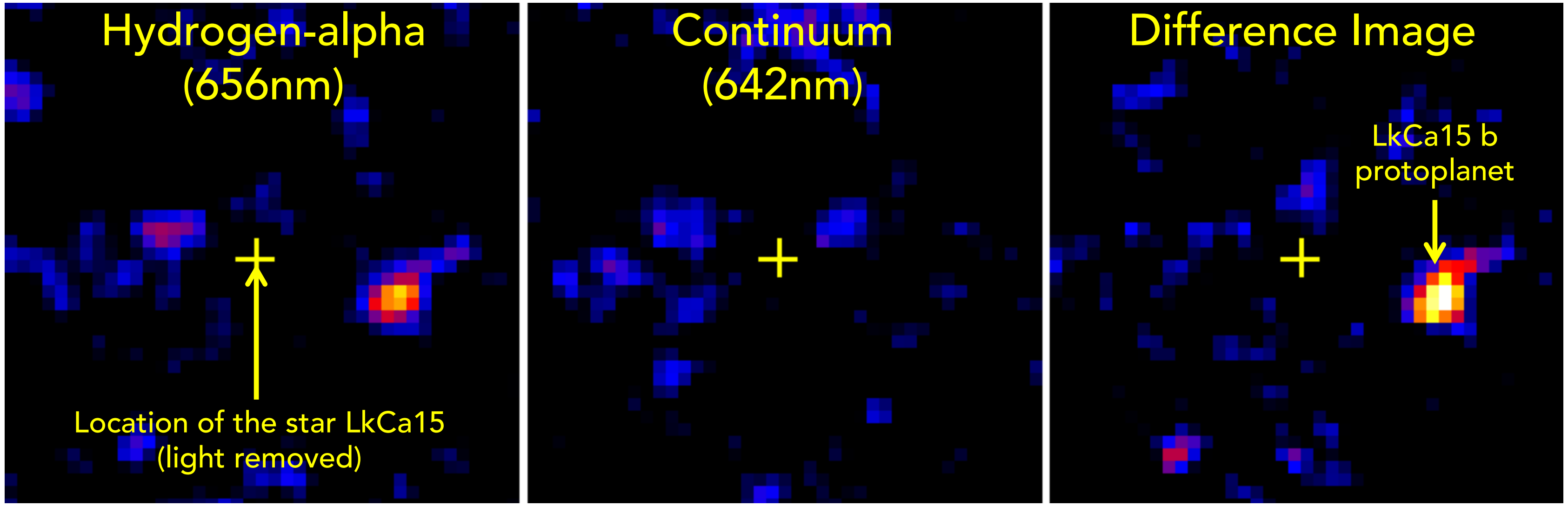


MUSE
Haffert+ 2019



GRAVITY
Wang+ 2021

Accretion Diagnostics and Paradigms



Sallum, Follette et al. 2015 *Nature*

Contrast = $8 \times 10^{-3} \rightarrow L_{H\alpha} \approx 6\times10^{-5}\ L_\odot \rightarrow L_{acc} \approx 4\times10^{-4} L_\odot \rightarrow M_P\dot{M} \approx 3\times10^{-6} M_J^2 yr^{-1}$

A_R=0.75mag

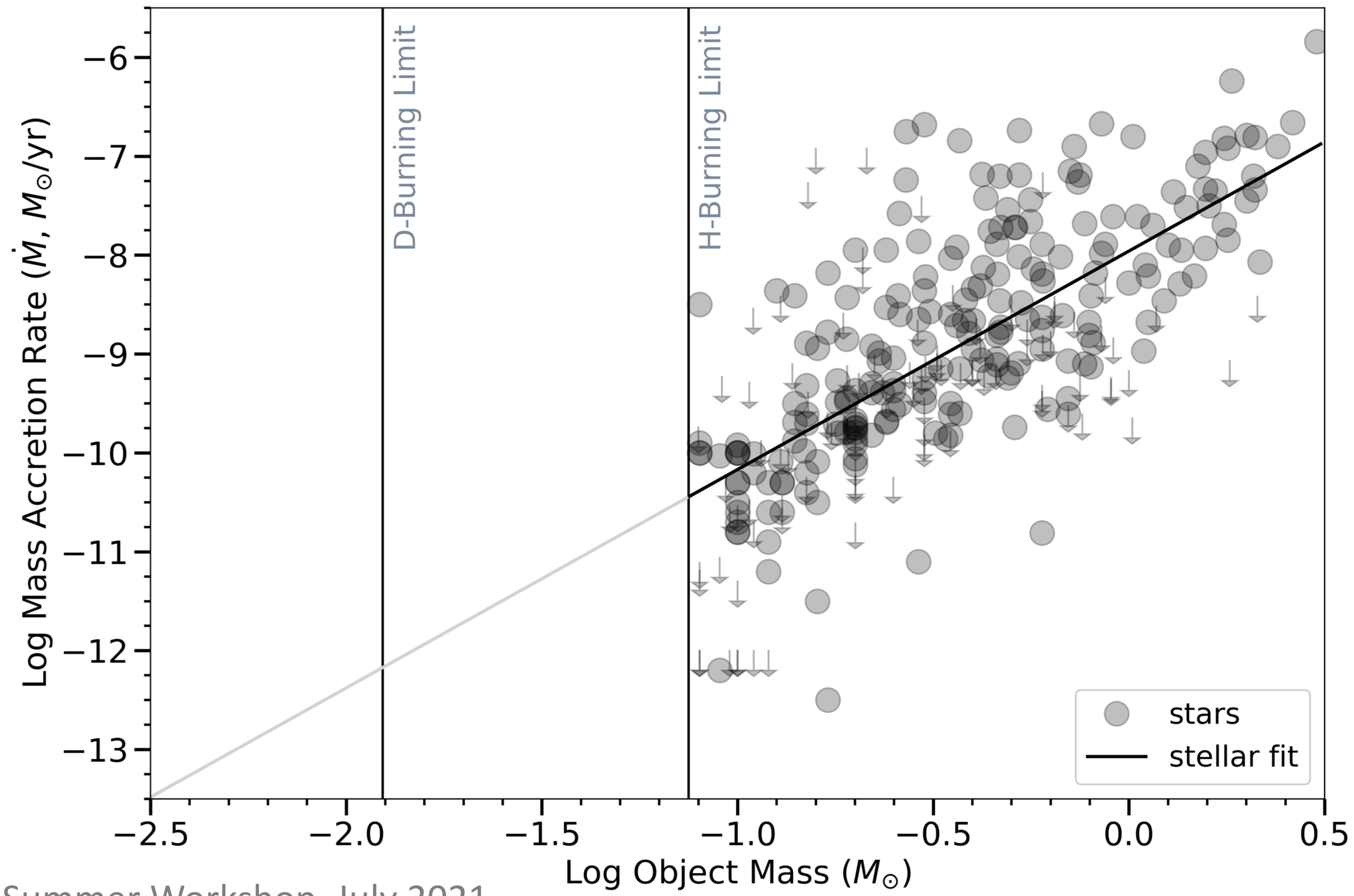
T Tauri Relation

$L_{H\alpha} \rightarrow L_{acc}$

Lacc→$M_P M$

$R=1.6R_J$

Accreting Stars



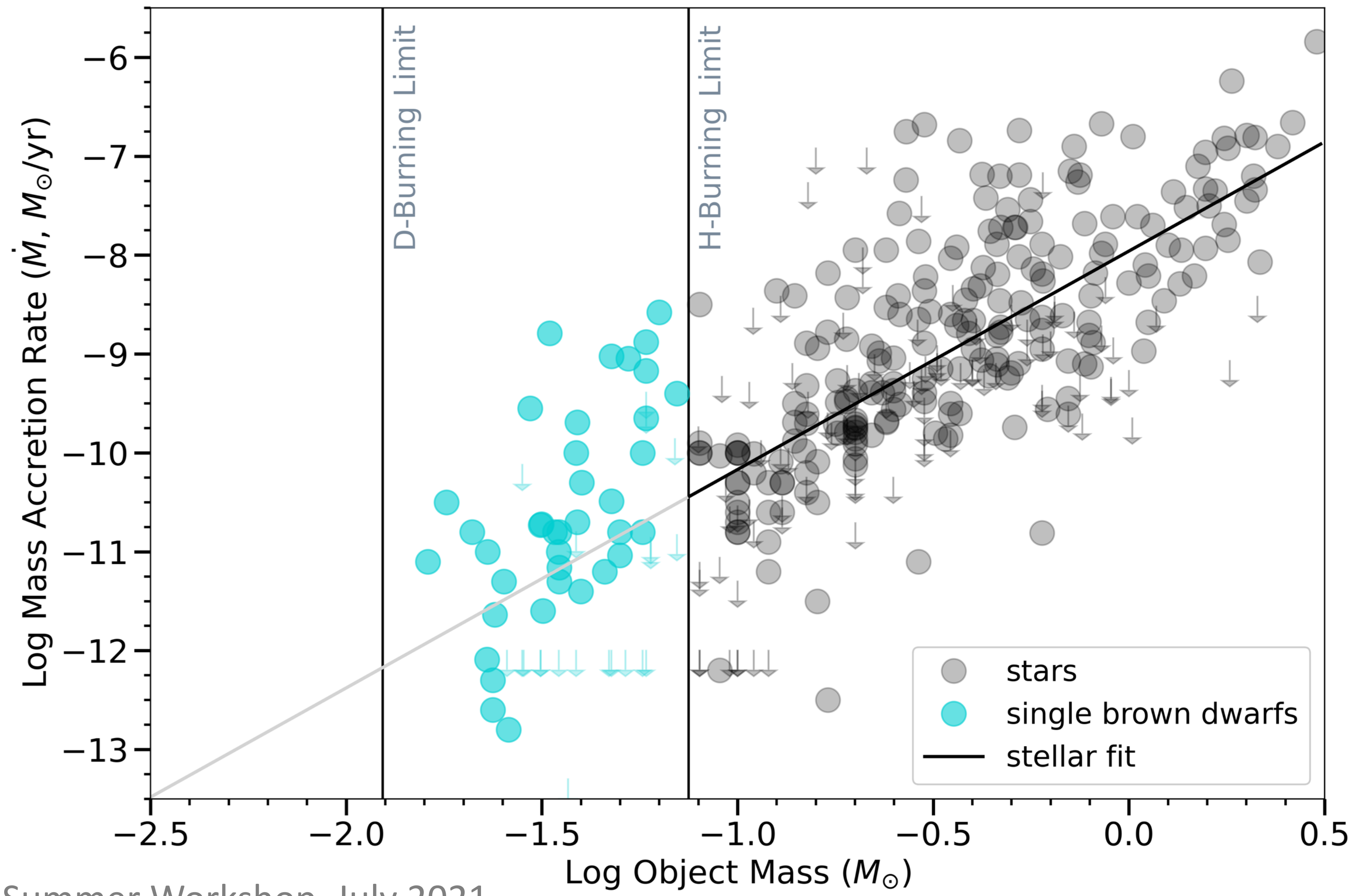
Significant Scatter

General Trend

$\log(\dot{M}) \sim \log(M)^{2.1}$

K. Follette, Sagan Summer Workshop, July 2021

Accreting Stars and Brown Dwarfs



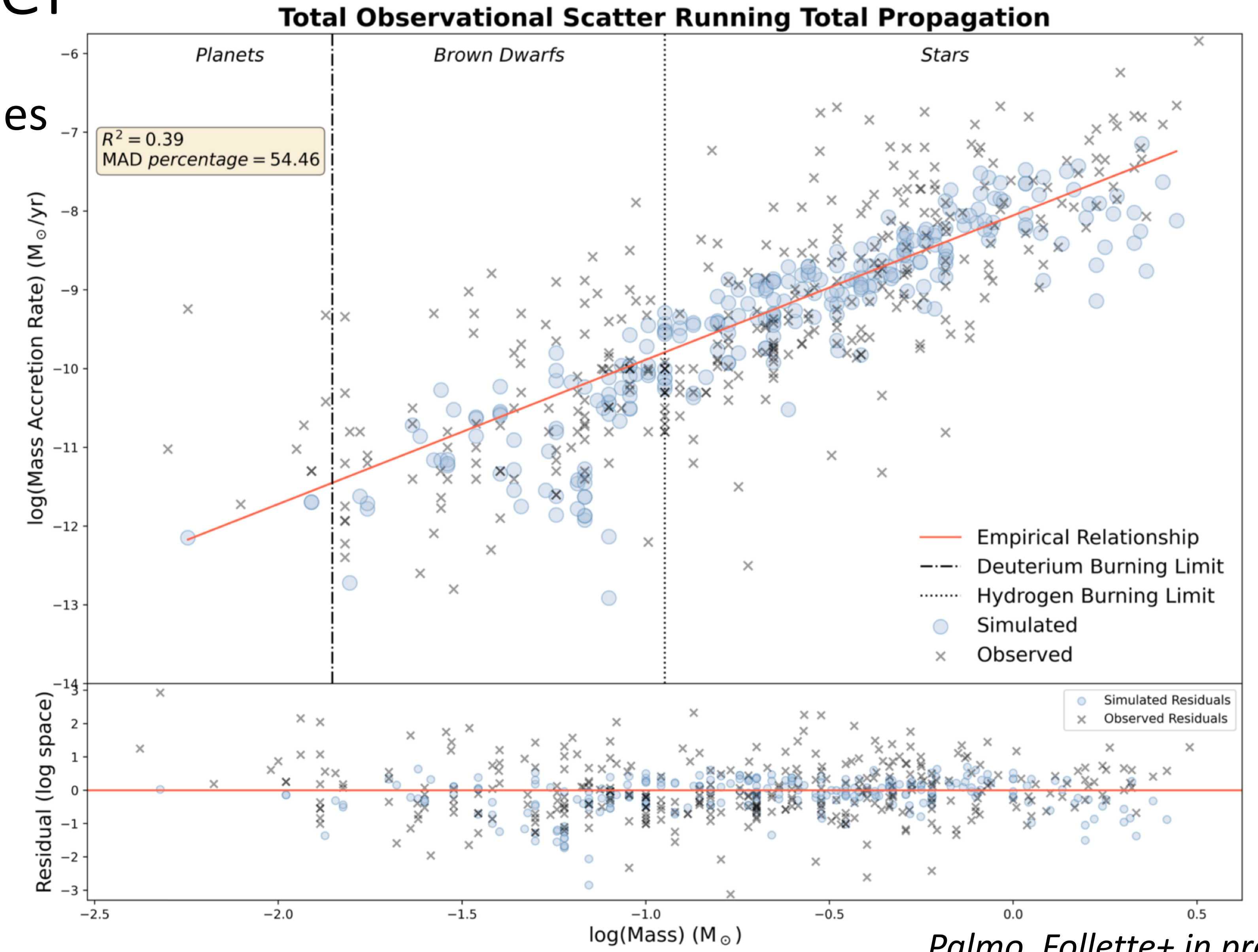
Significant Scatter

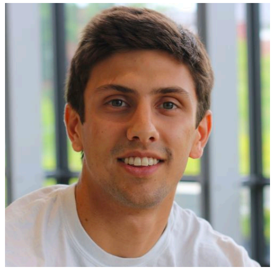
General Trend

$\log(\dot{M}) \sim \log(M)^{2.1}$

Sources of Scatter

1. Observational Uncertainties



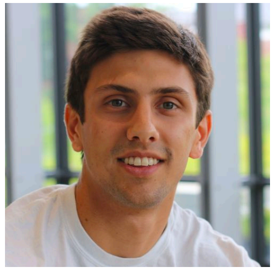


Joe Palmo
(he/him)
Senior Thesis

Palmo, Follette+ in prep

Sources of Scatter

1. Observational Uncertainties
2. Age



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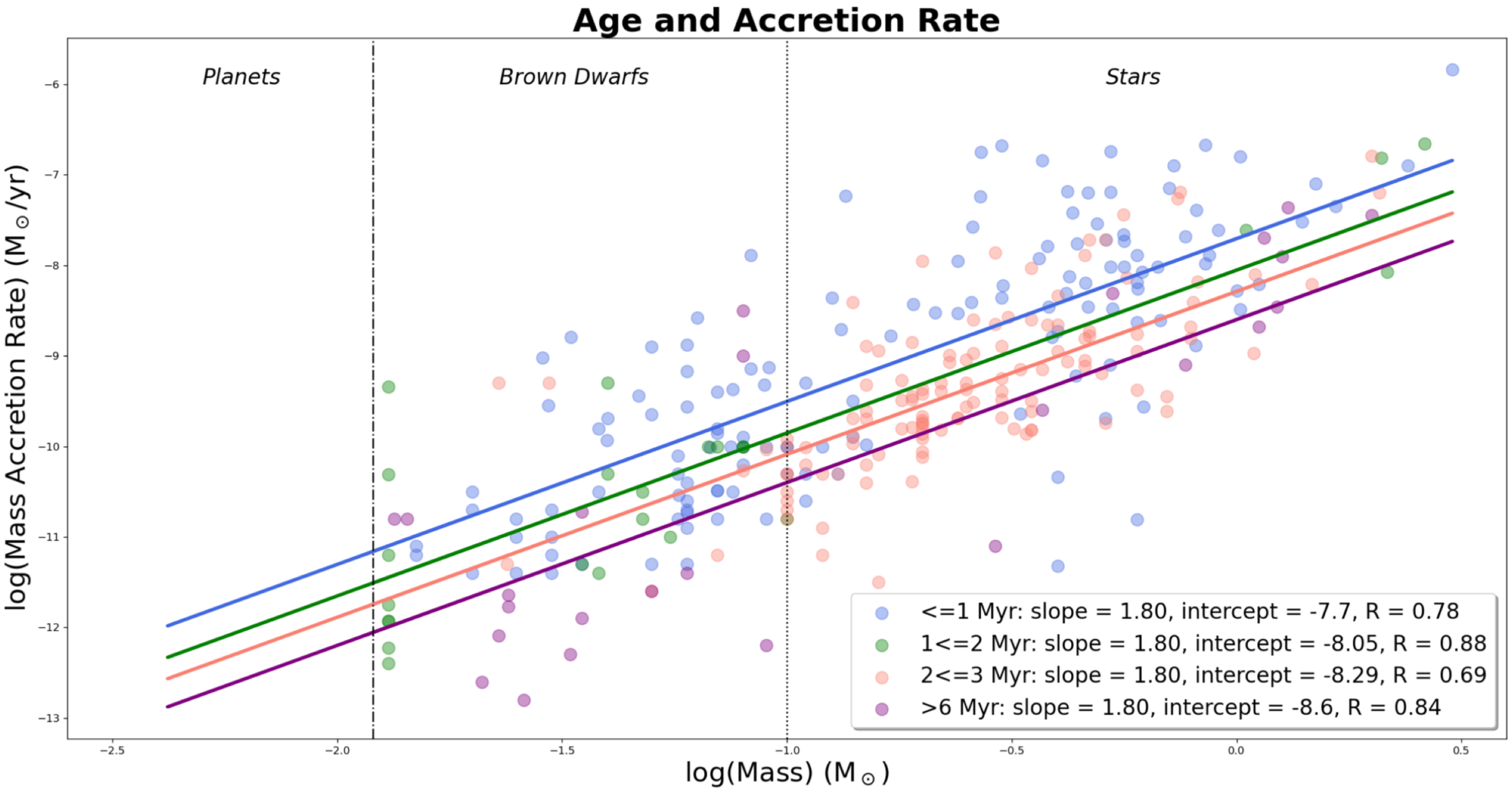
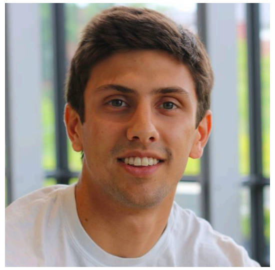
Senior Thesis



Palmo, Follette+ in prep

Sources of Scatter

1. Observational Uncertainties
2. Age
3. Variability



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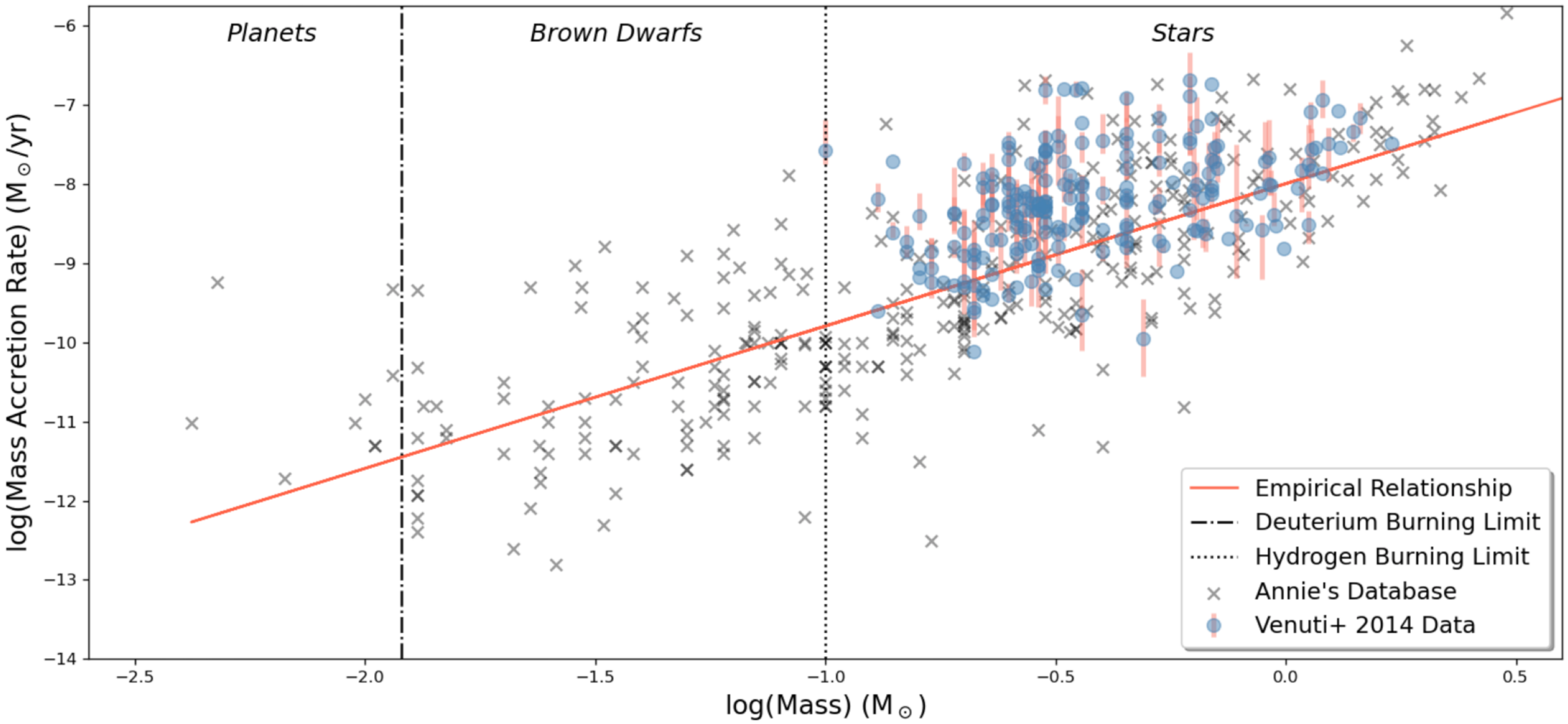
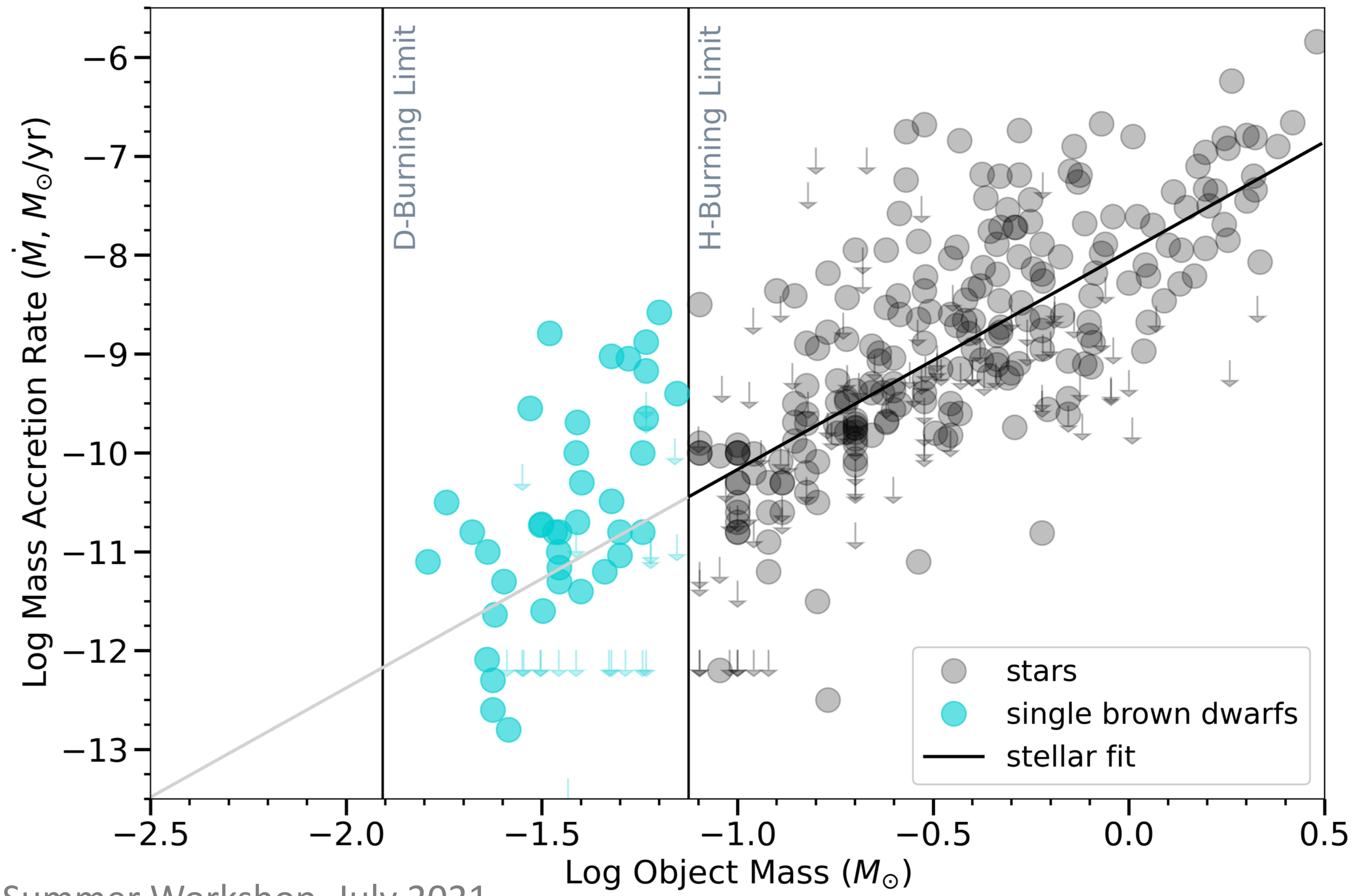
(he/him)
Senior Thesis



Palmo, Follette+ in prep

Accreting Stars and Brown Dwarfs



Significant Scatter

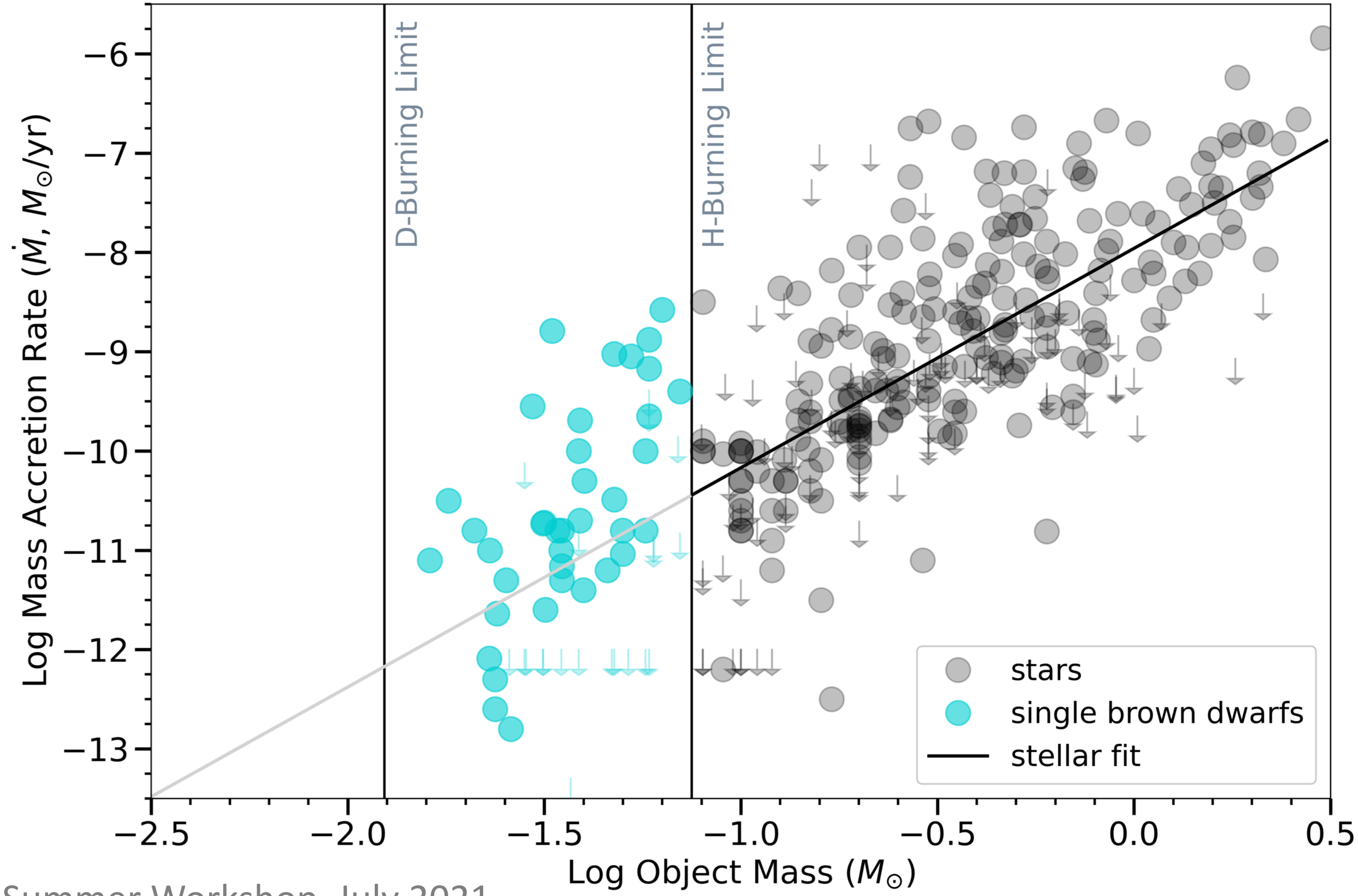
variability

age

General Trend

$$\log(\dot{M}) \sim \log(M)^{2.1}$$

Accreting Stars and (Isolated) Brown Dwarfs



Significant Scatter

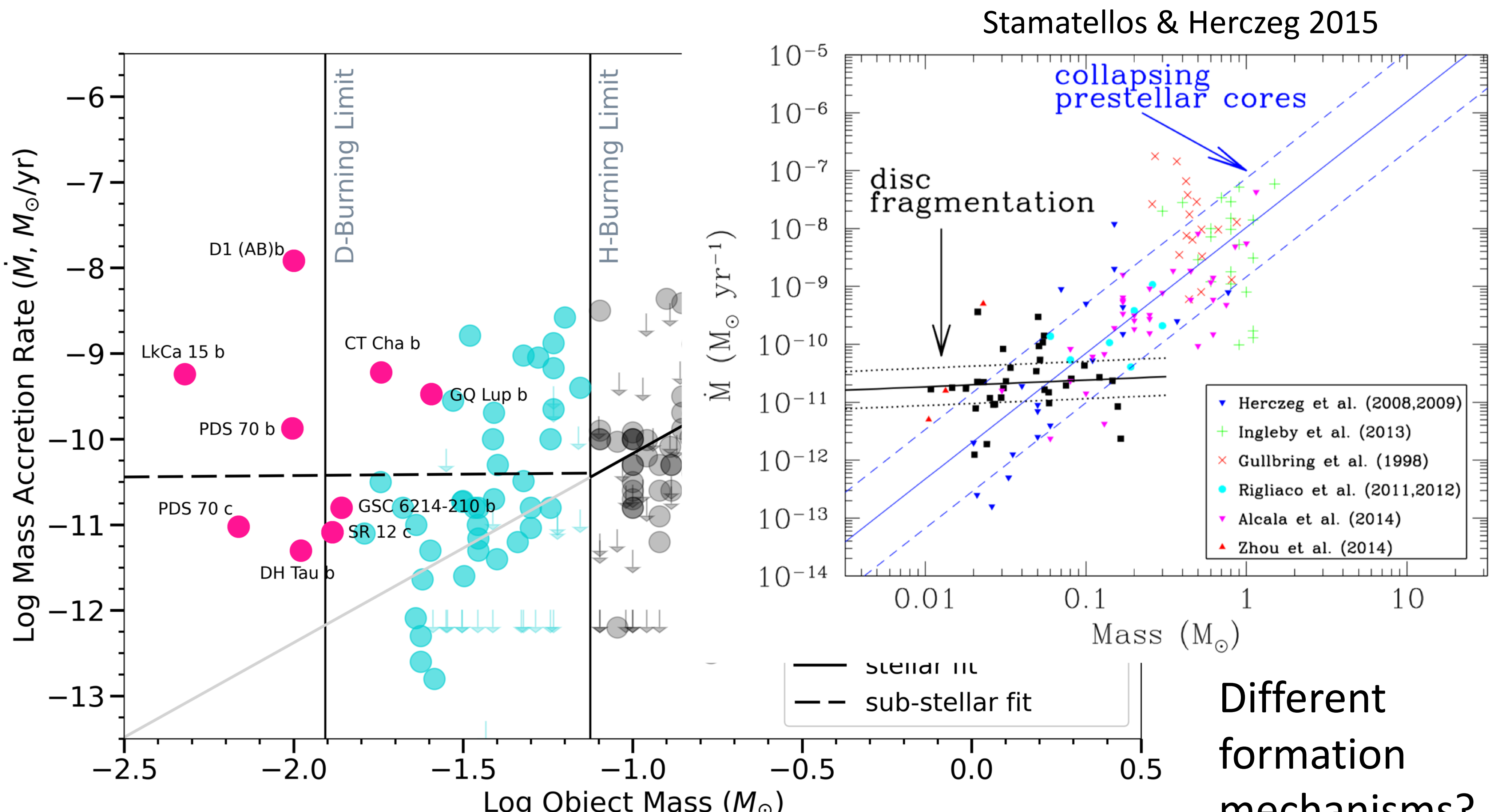
variability

age

General Trend

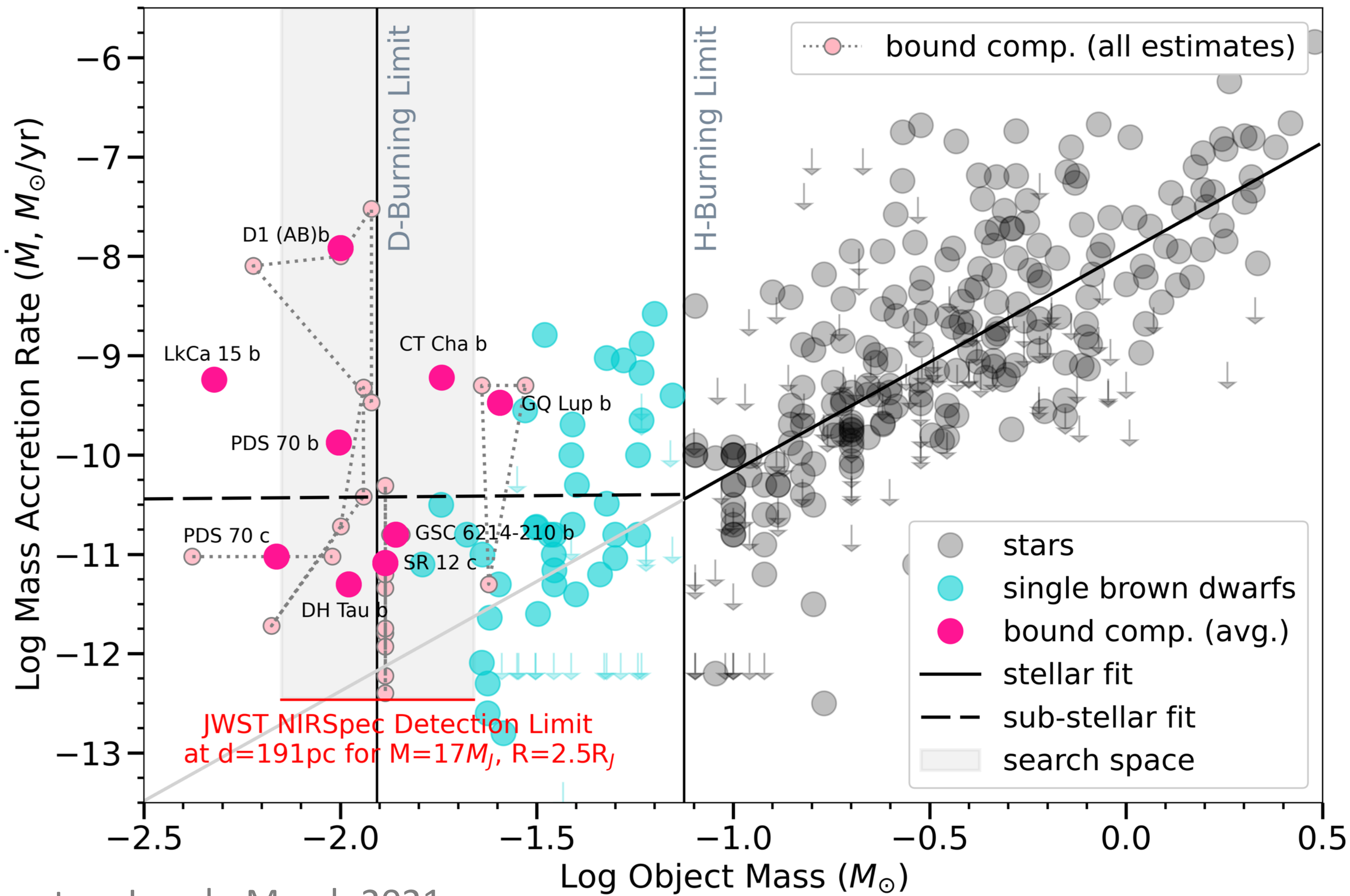
$$\log\left(\dot{M}\right) \sim \log(M)^{2.1}$$

Accreting Stars and (Isolated) Brown Dwarfs and PMCs



Different formation mechanisms?

Obstacle 4: We don't understand protoplanetary accretion



Invalid scaling relations?

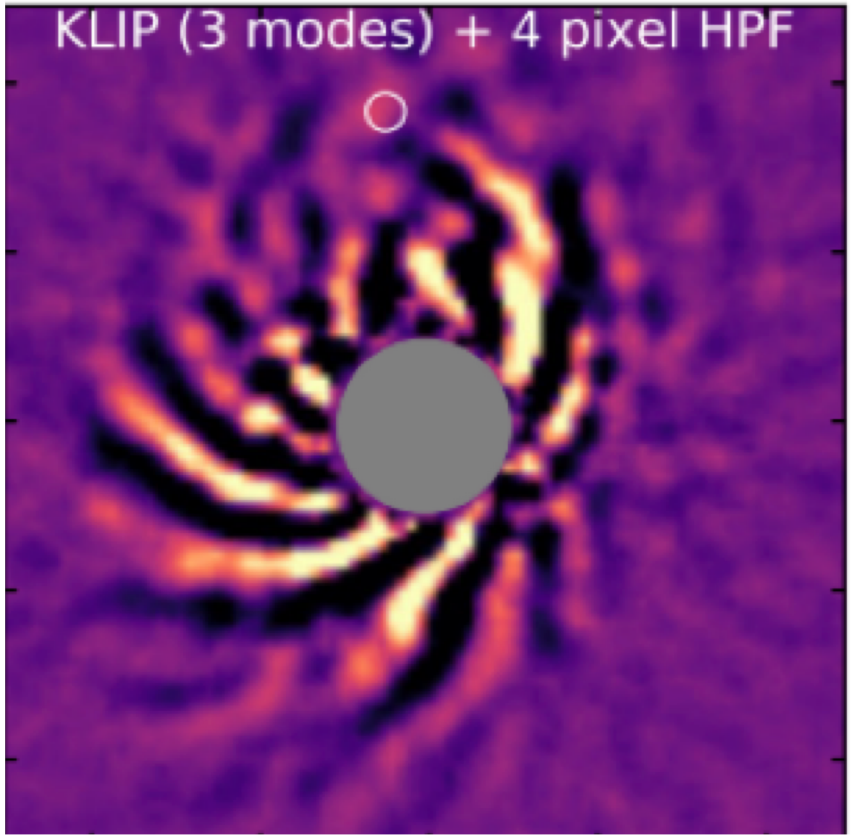
Artifact of detection limits?

Different accretion paradigms?

Different formation mechanisms?

4 Obstacles to Understanding Protoplanets

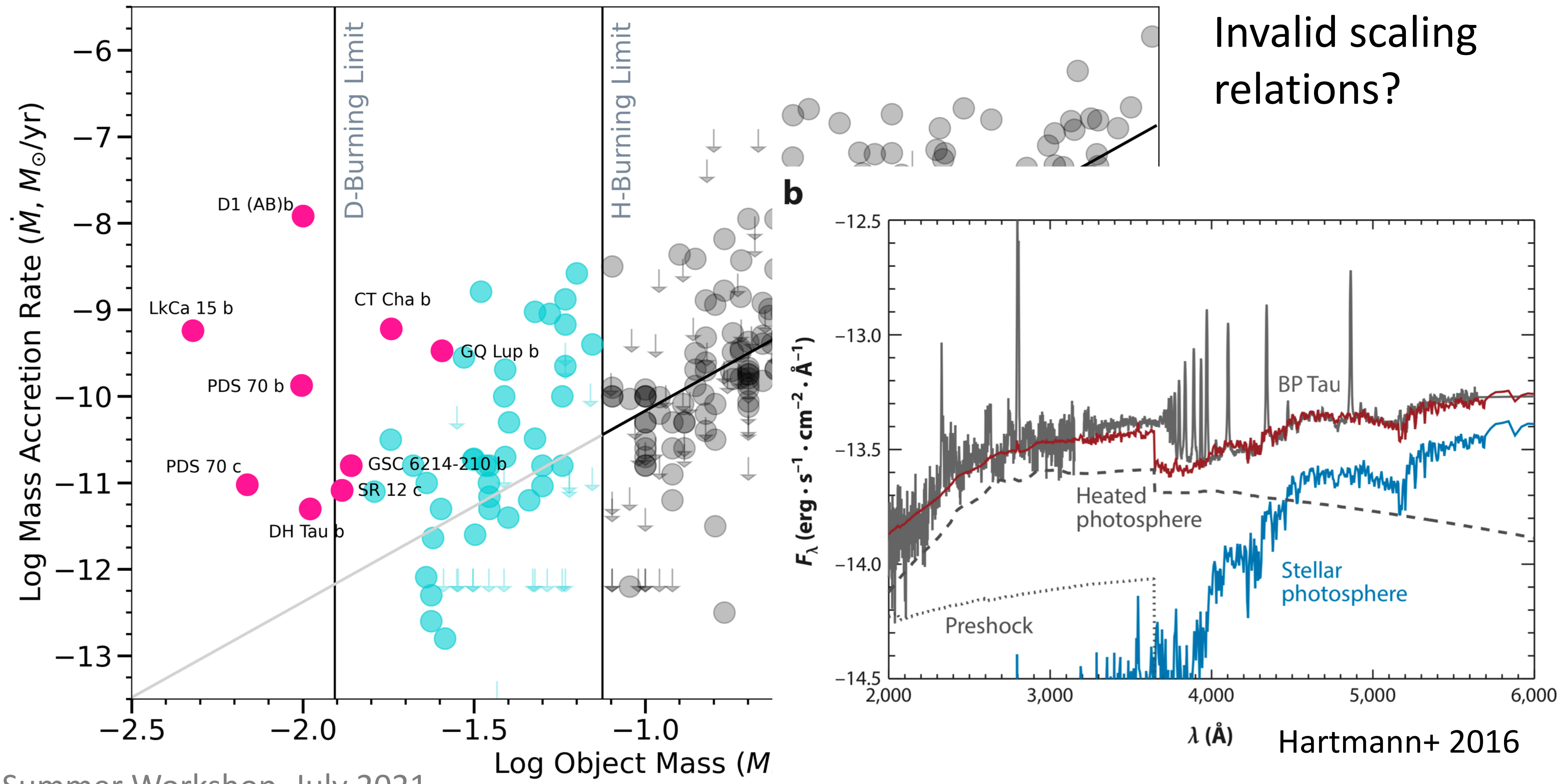
1. Resolution
2. Contrast
3. Embedded
4. Interpretation



3 Things I’m Excited About

1. Multiwavelength Accreting Object Spectral Templates

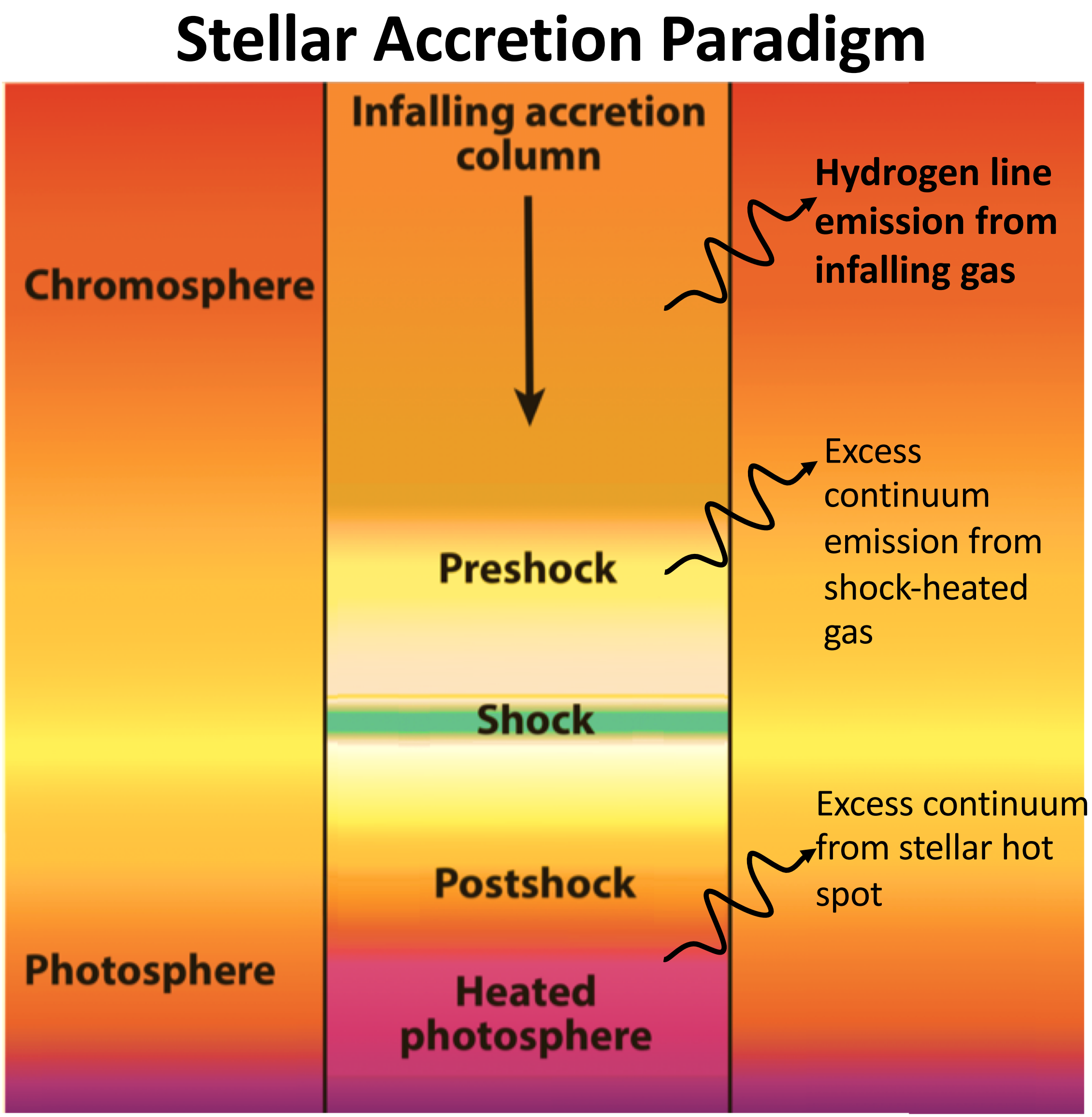
Accreting Stars and (Isolated) Brown Dwarfs and PMCs



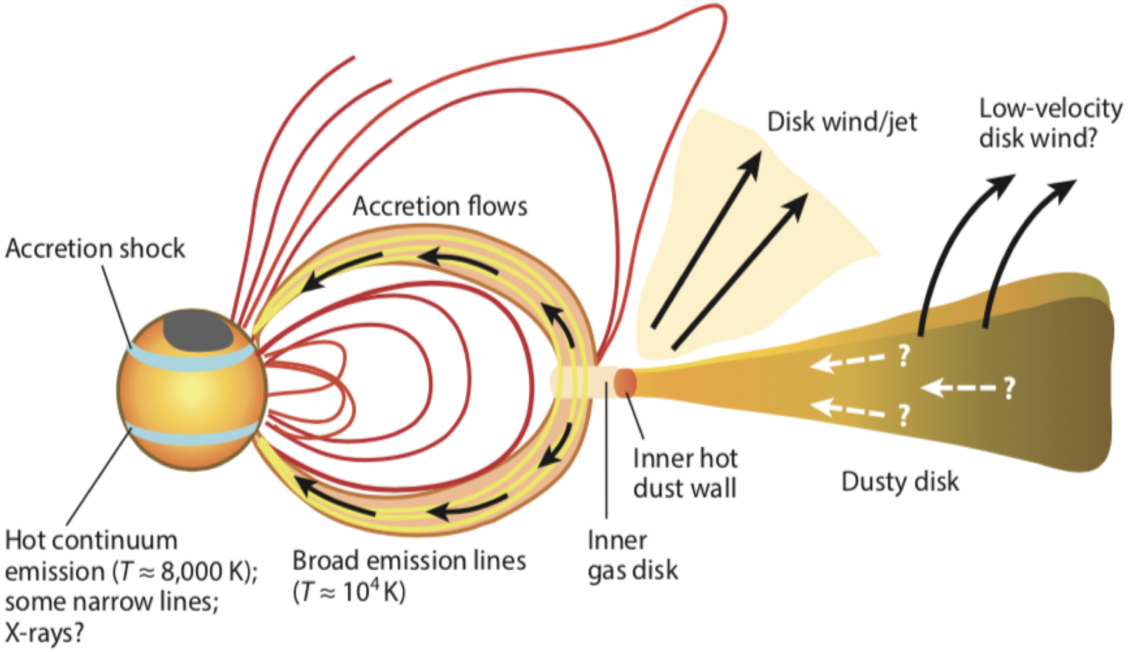
Invalid scaling relations?

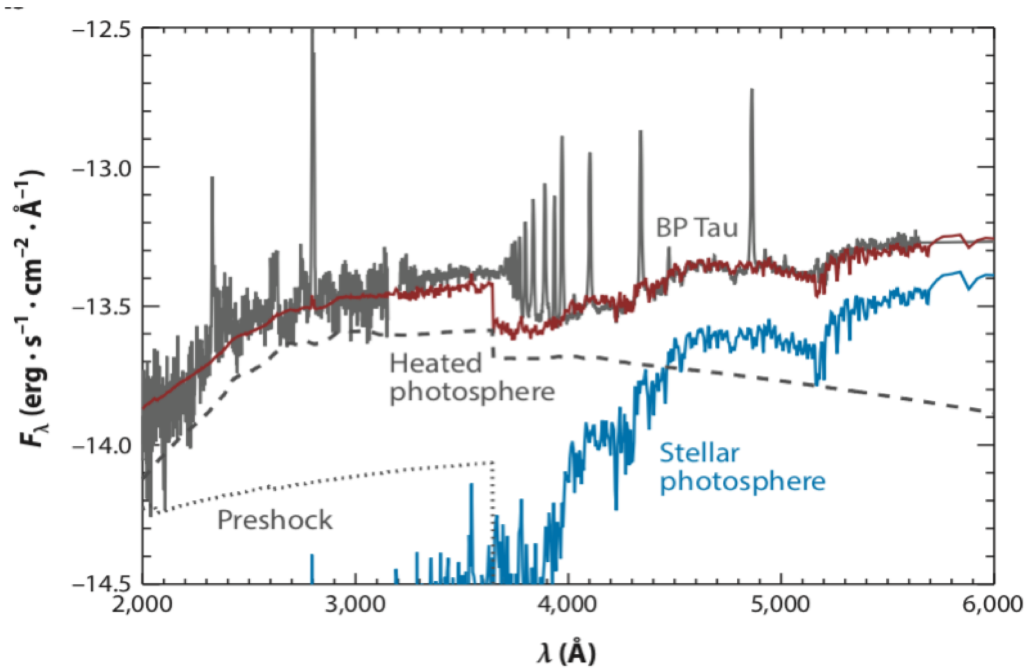
Hartmann+ 2016

Magnetospheric Accretion



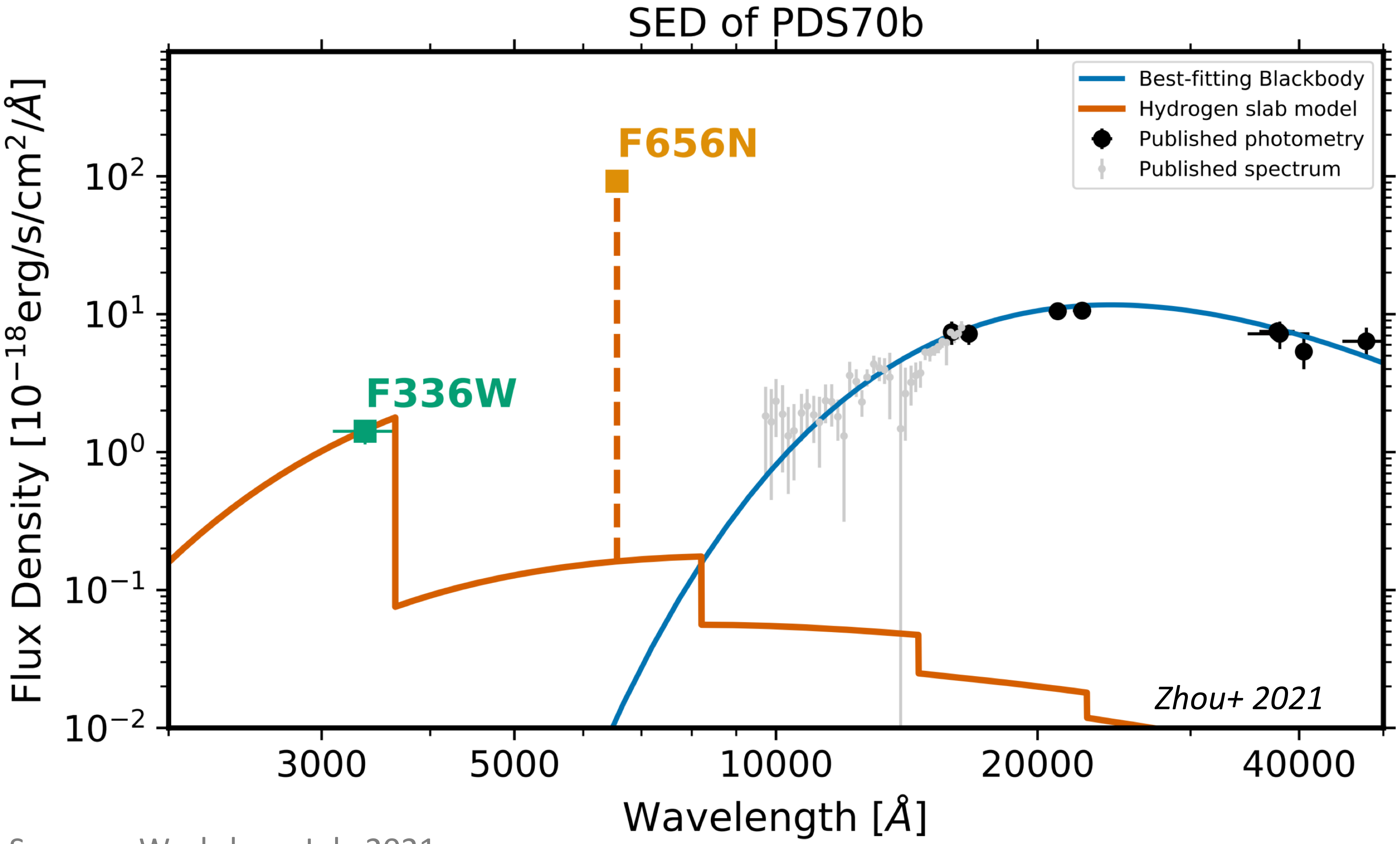
Hartmann, Herczeg & Calvet 2016



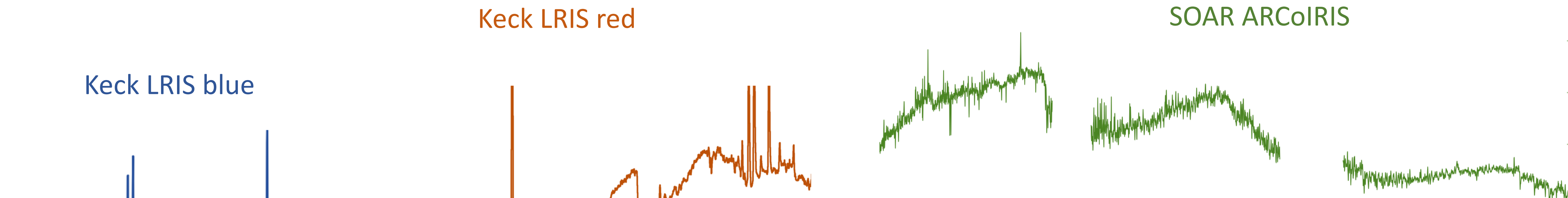


K. Follette, Sagan Summer Workshop, July 2021

Multiwavelength SEDs for Accreting Companions



Accreting Brown Dwarf Templates



Lillian Jiang ‘22
(she/her)
Smith College

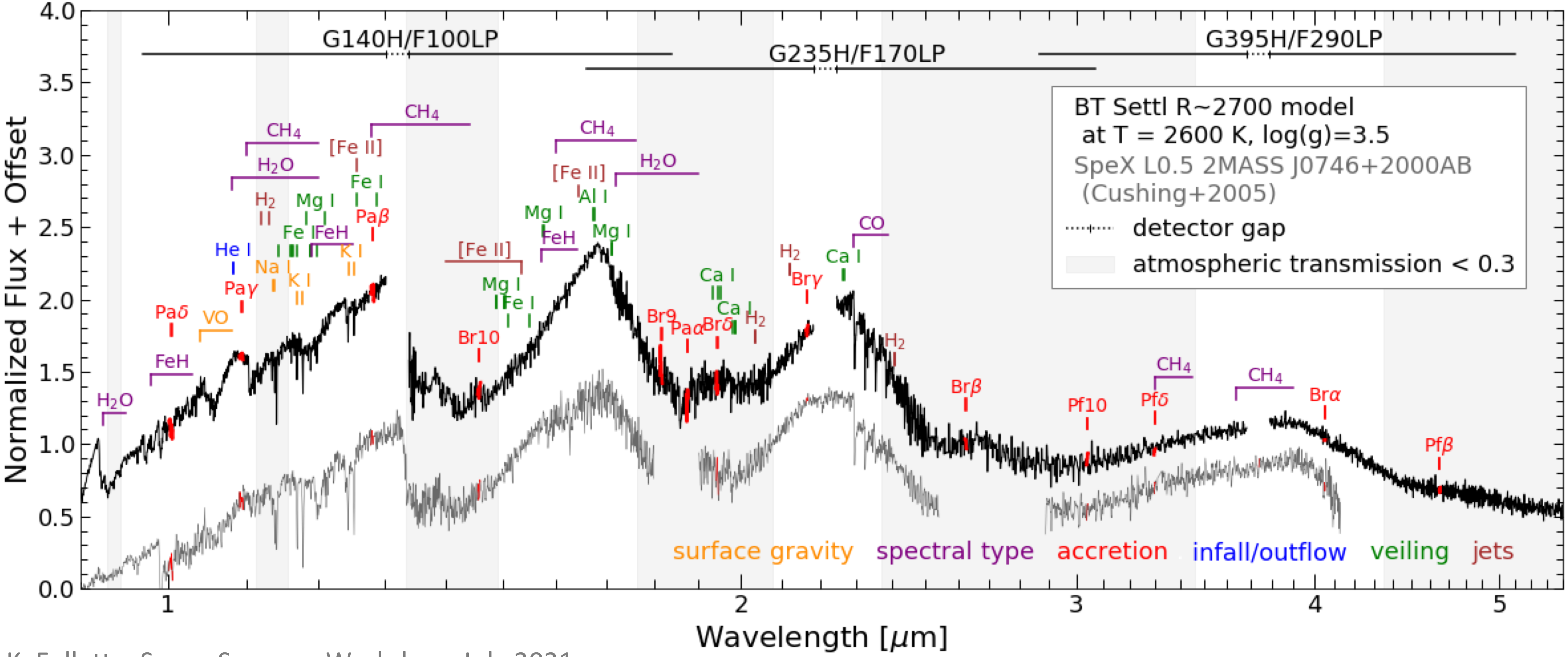
Sierra Gomez ‘22
(she/her)
UMass

Sarah Betti
(she/her)
3rd year grad
UMass

Follette+ in prep
Betti+ in prep

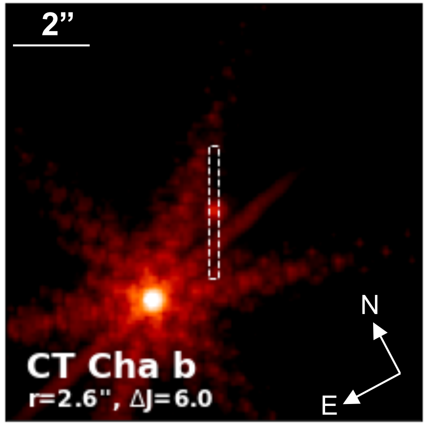
Accreting Brown Dwarf Templates

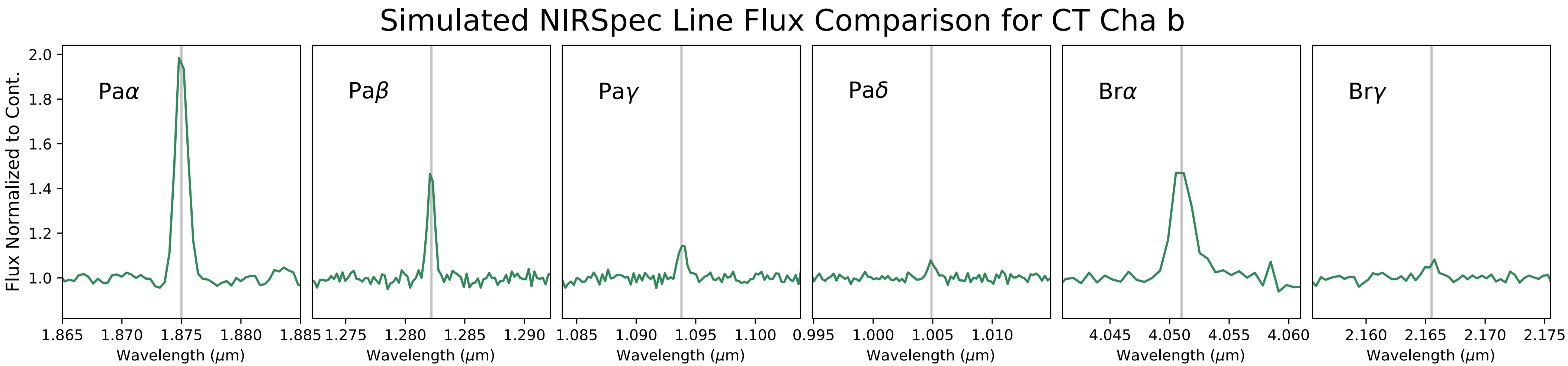
Sarah Betti
(she/her)
3rd year grad
UMass



Line Ratios = Accretion Physics

Lena Trieber ‘22
(she/her)
Amherst College

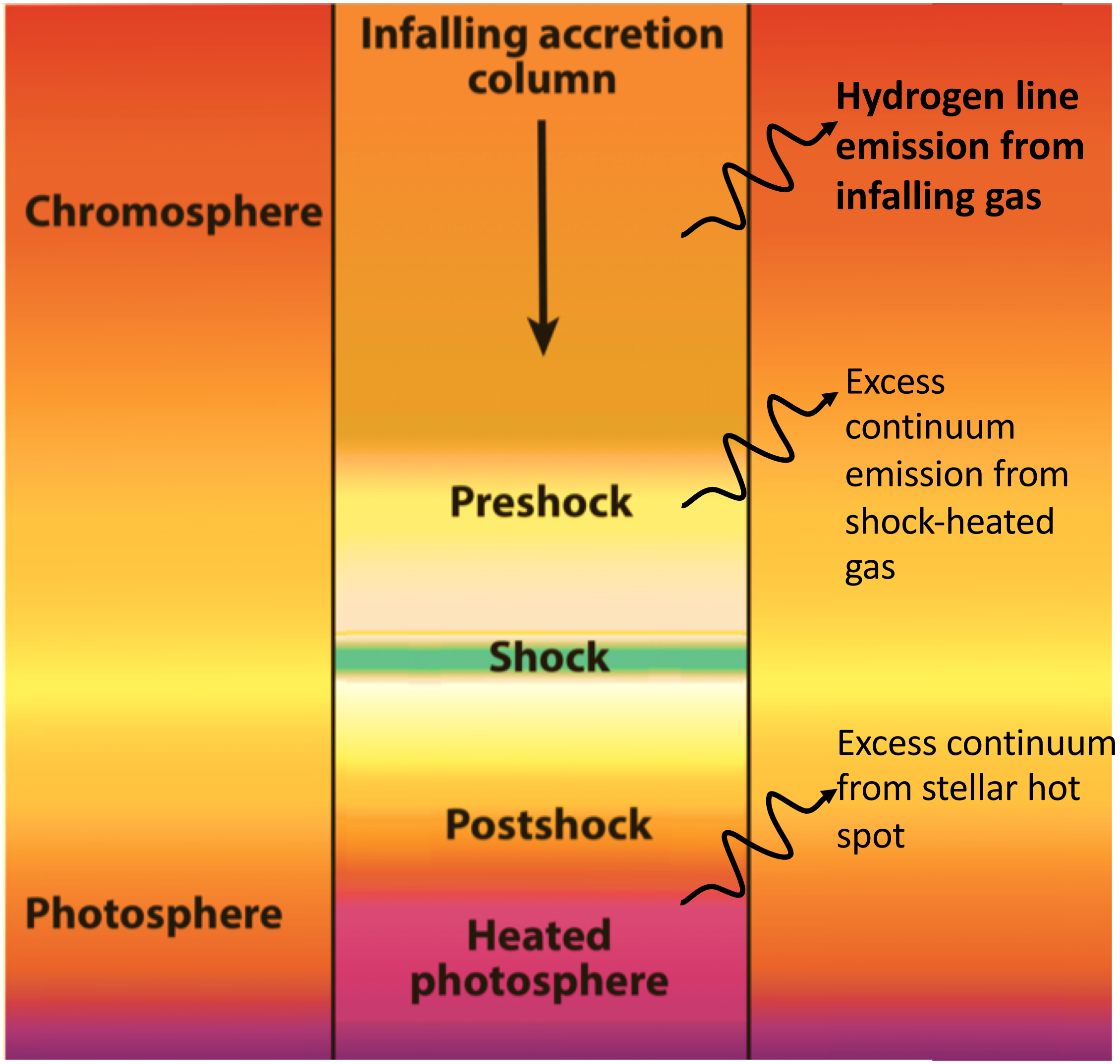




Accretion Paradigms

Stellar Accretion Paradigm

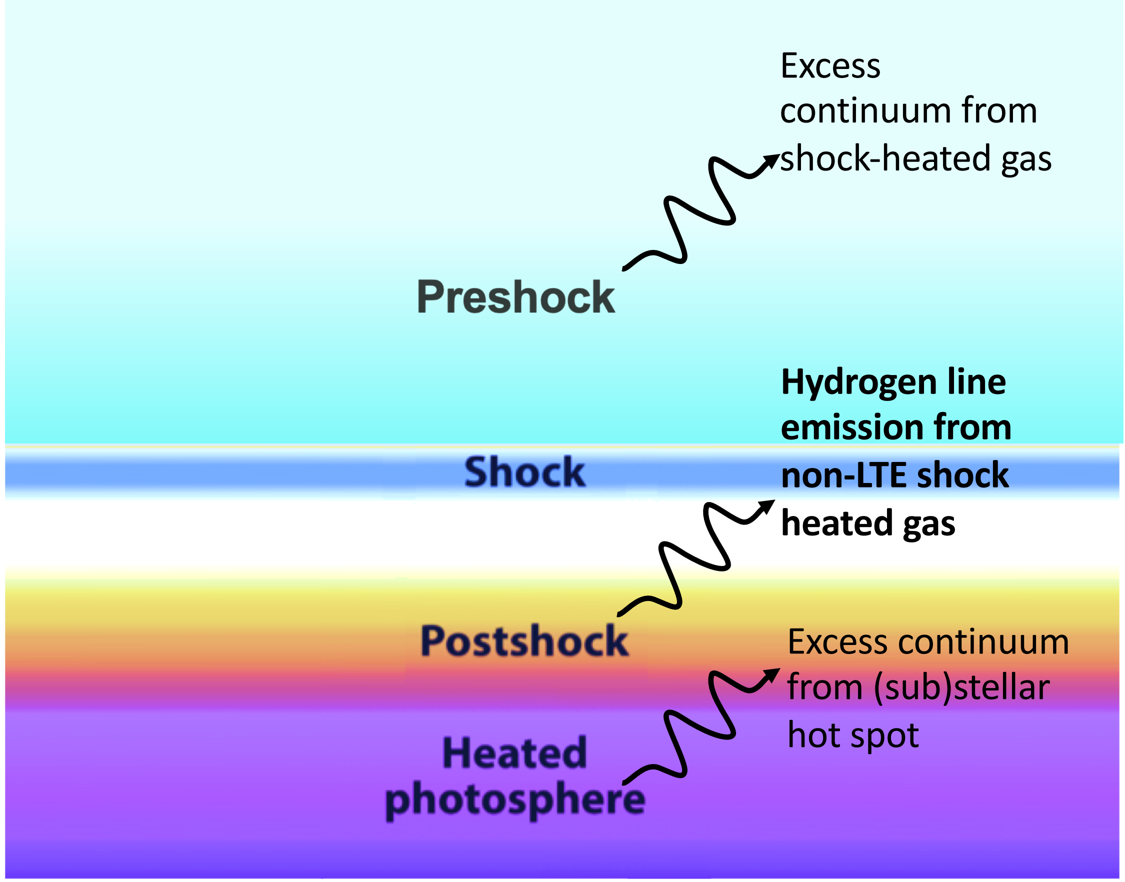
Hartmann, Herczeg & Calvet 2016



Planetary Accretion Paradigm

Aoyama+ 2019, 2020, Marleau 2019

- Lower temperatures
- Lower infall velocities
- Accretion filling factor may be ~1 (no column)

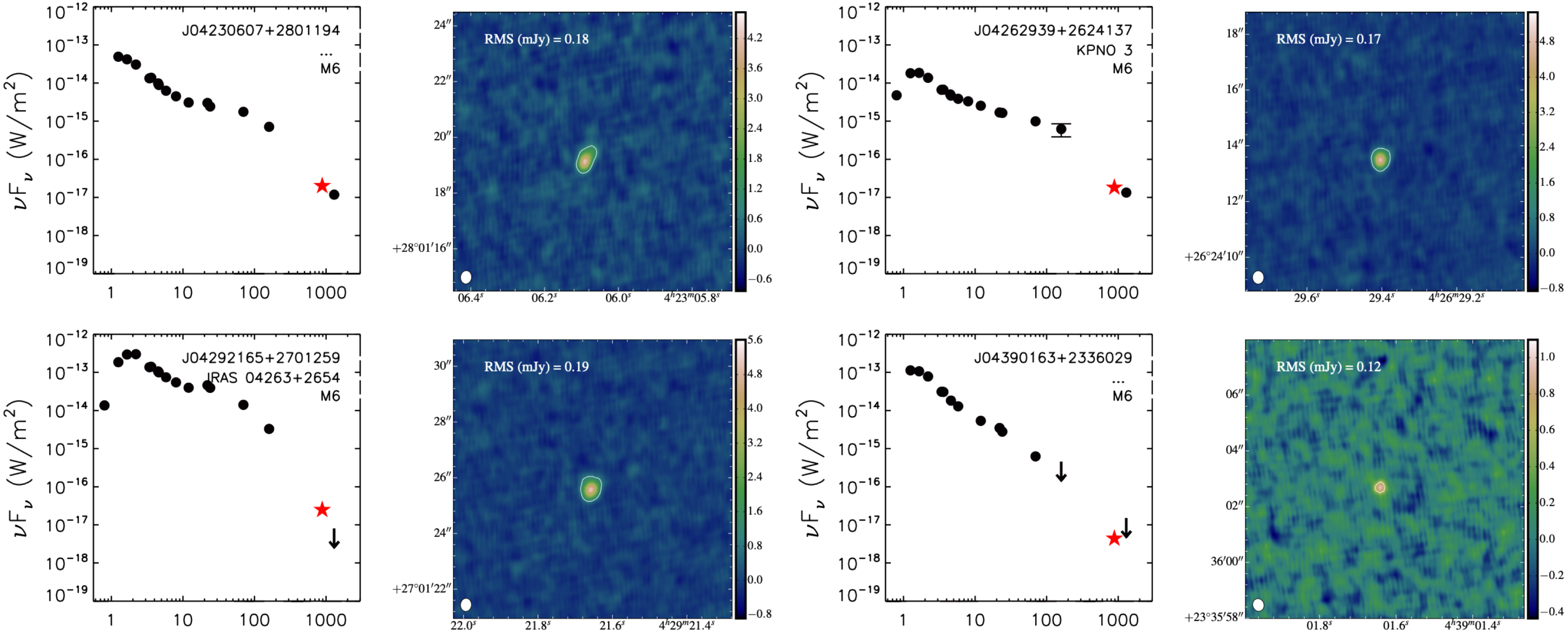


K. Follette, Sagan Summer Workshop, July 2021

3 Things I'm Excited About

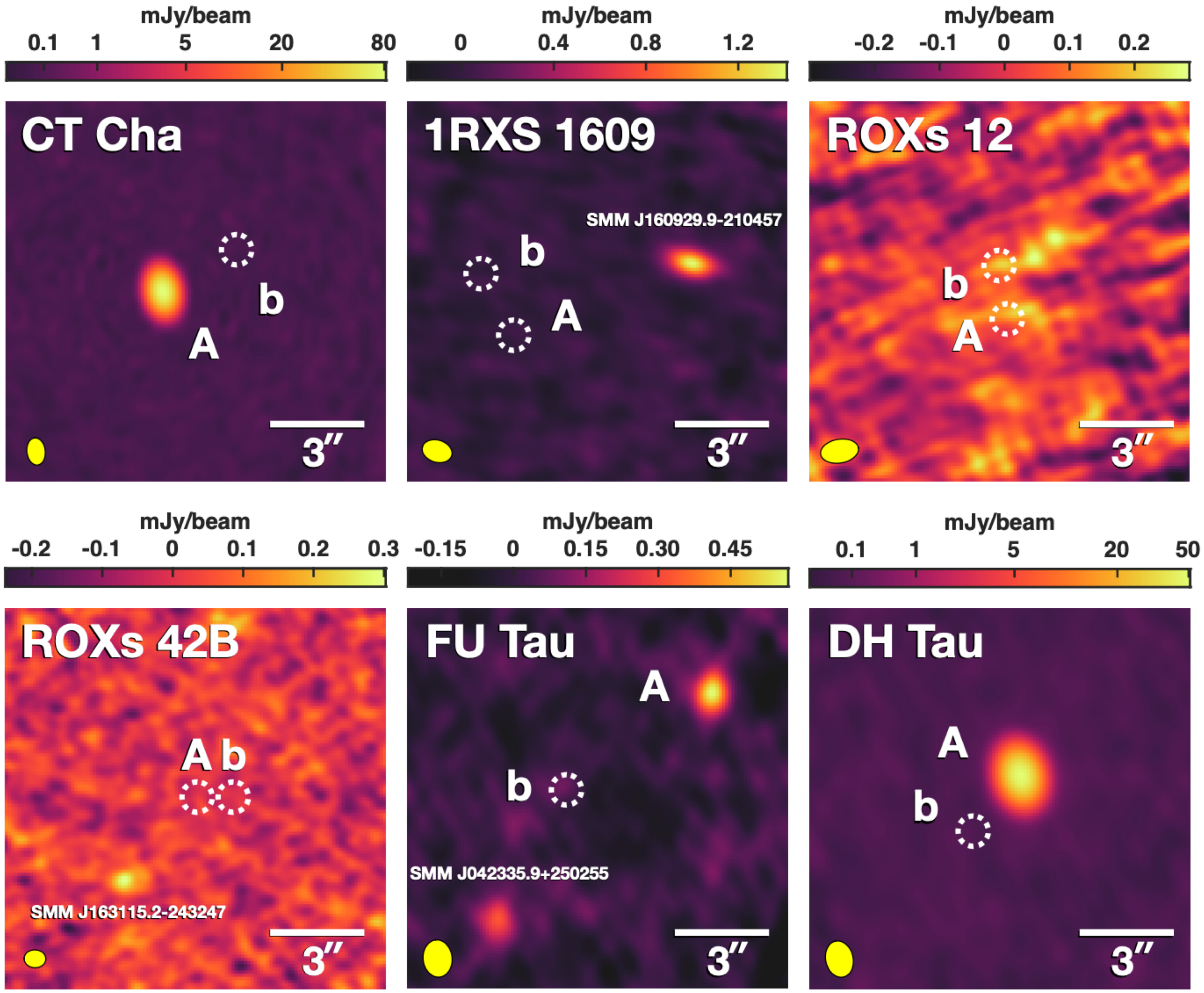
1. Multiwavelength Accreting Object Spectral Templates
2. CircumPLANETARY disk detection

Brown Dwarf Disks – they exist!



Ward-Duong+ 2018

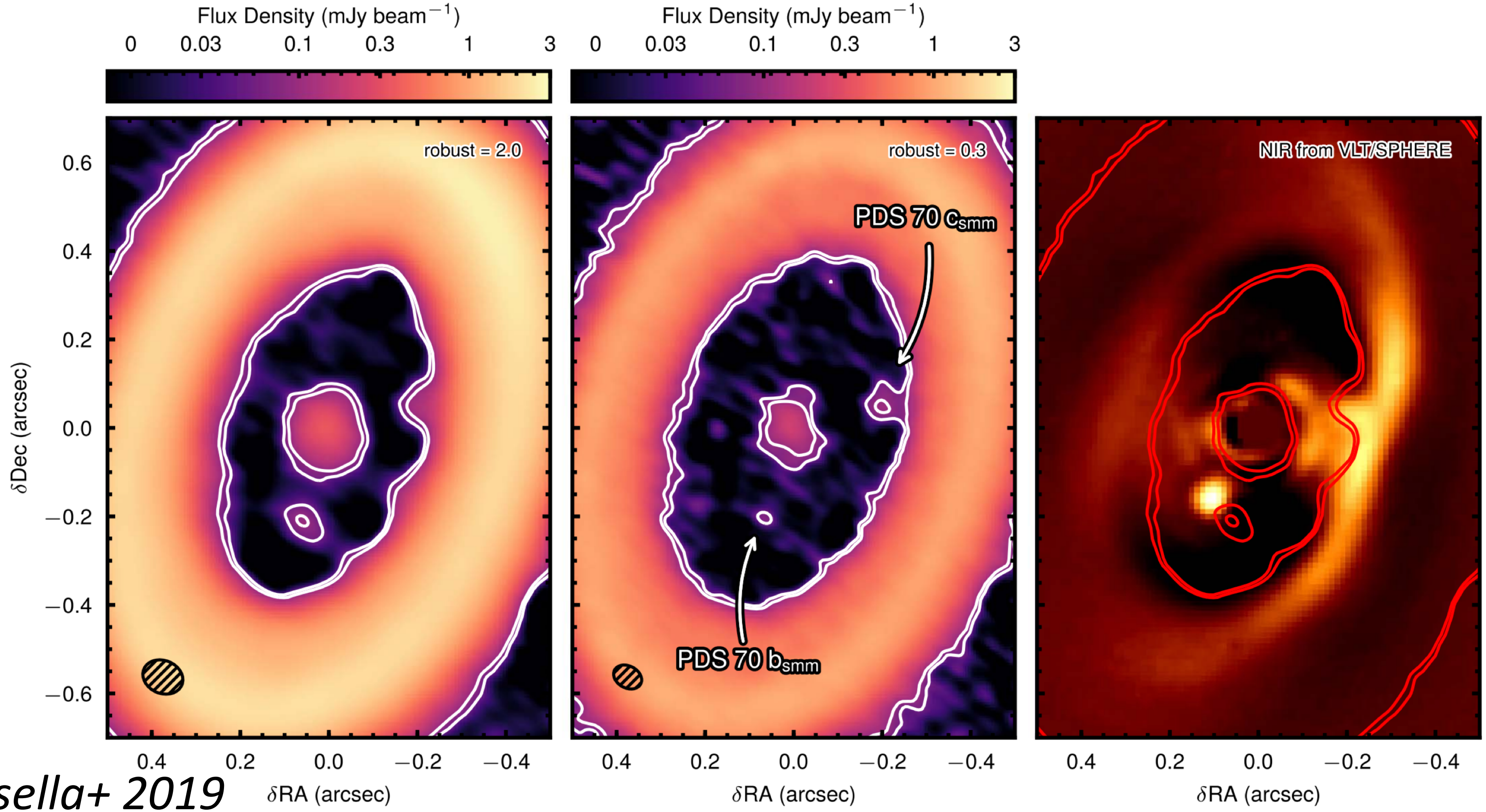
Circumplanetary Disks – do they exist?



Wu+ 2020

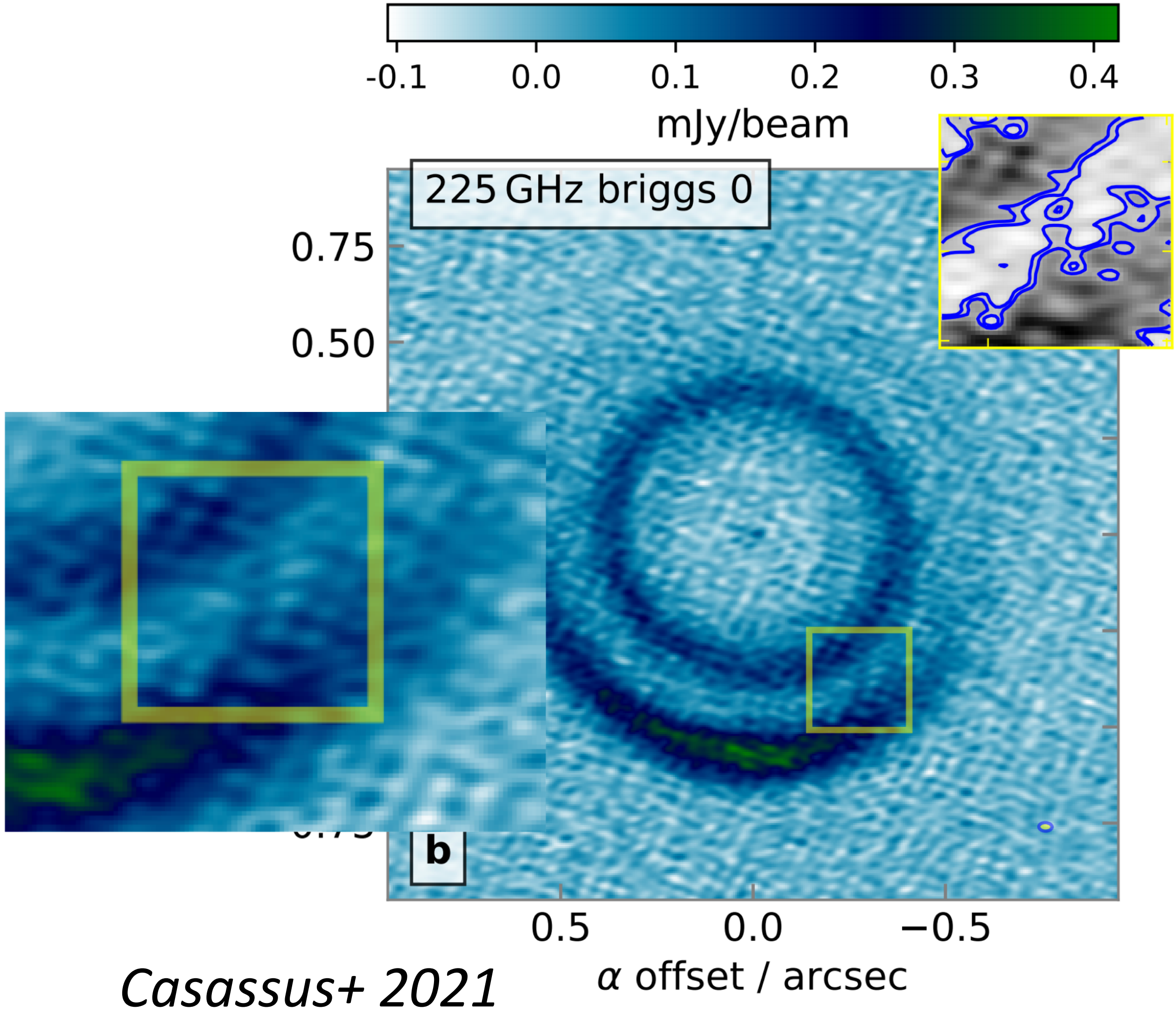
Circumplanetary Disks – they exist!

PDS 70 to the rescue (again)!

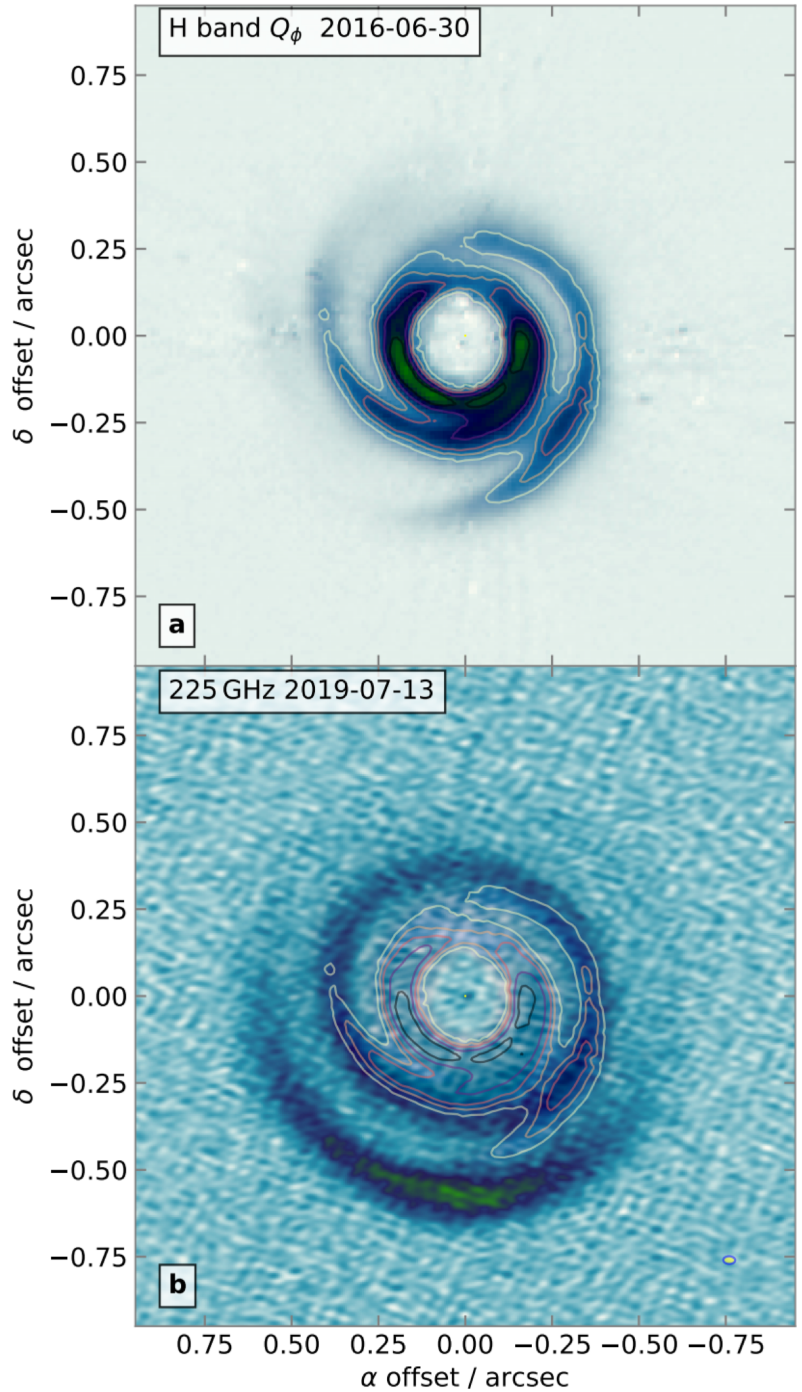


Isella+ 2019

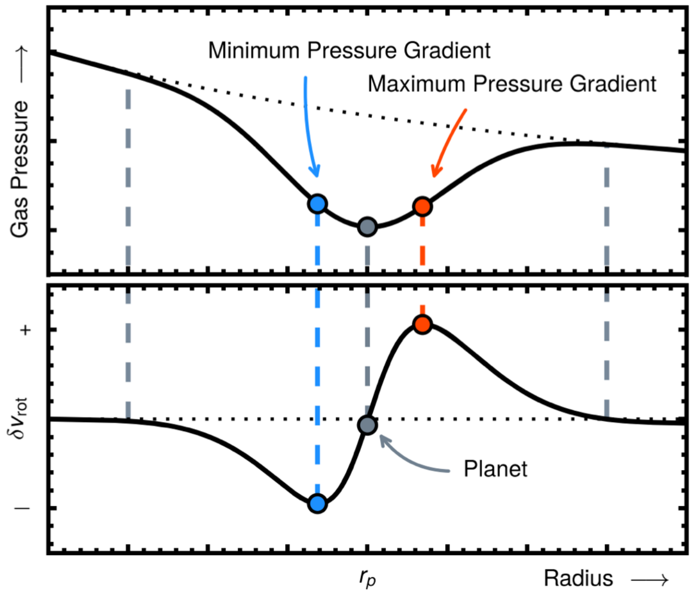
Delivery of Material to CPDs– Accretion Streamers

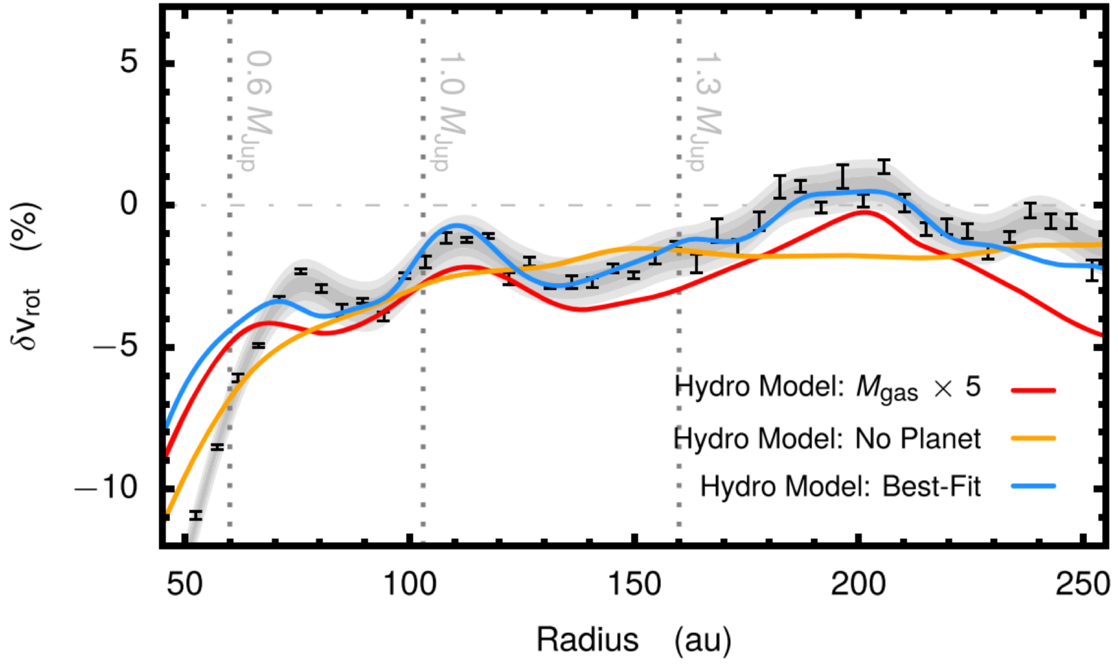


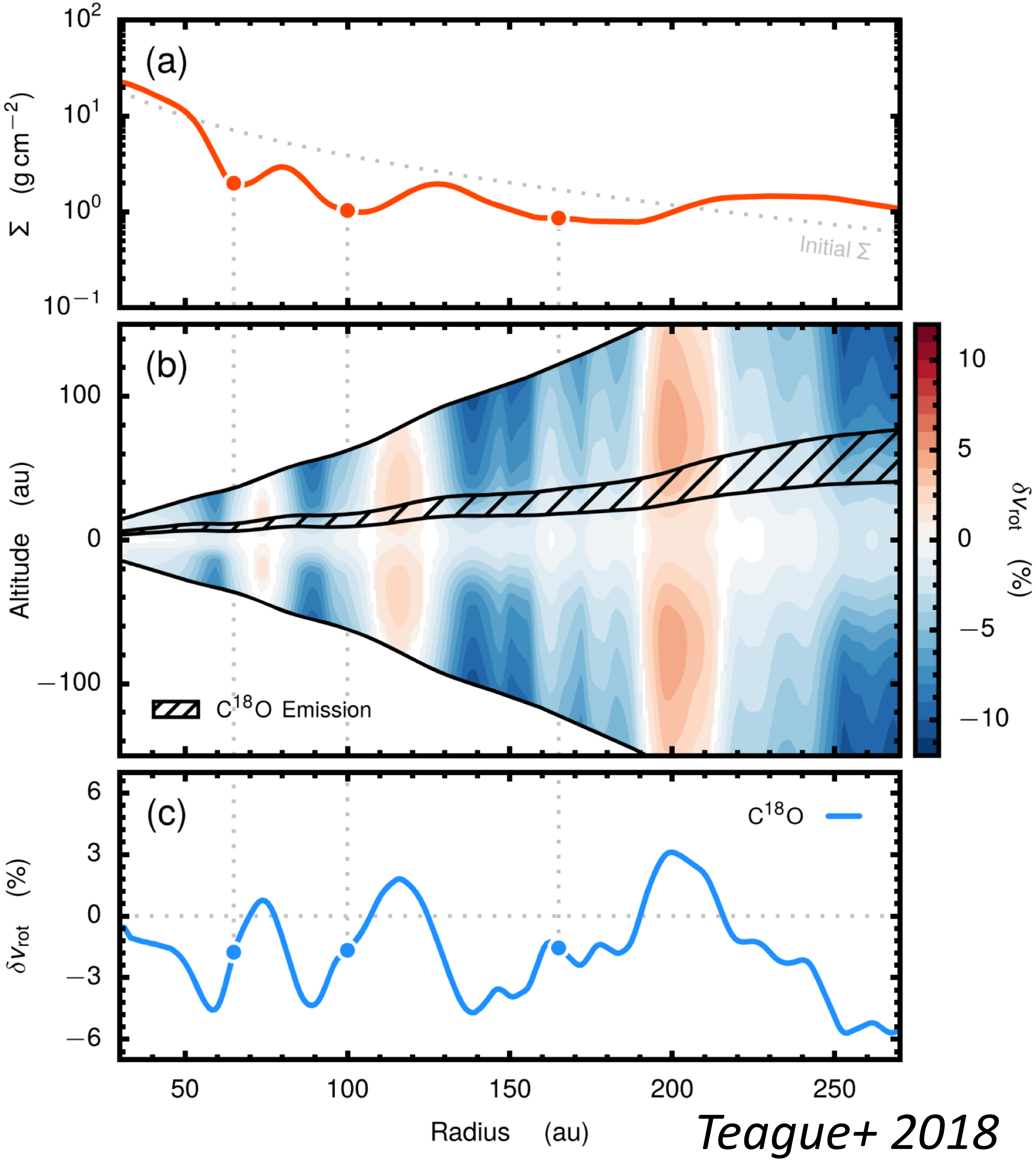
Casassus+ 2021



Gas Kinematics as a Probe of Substructure –

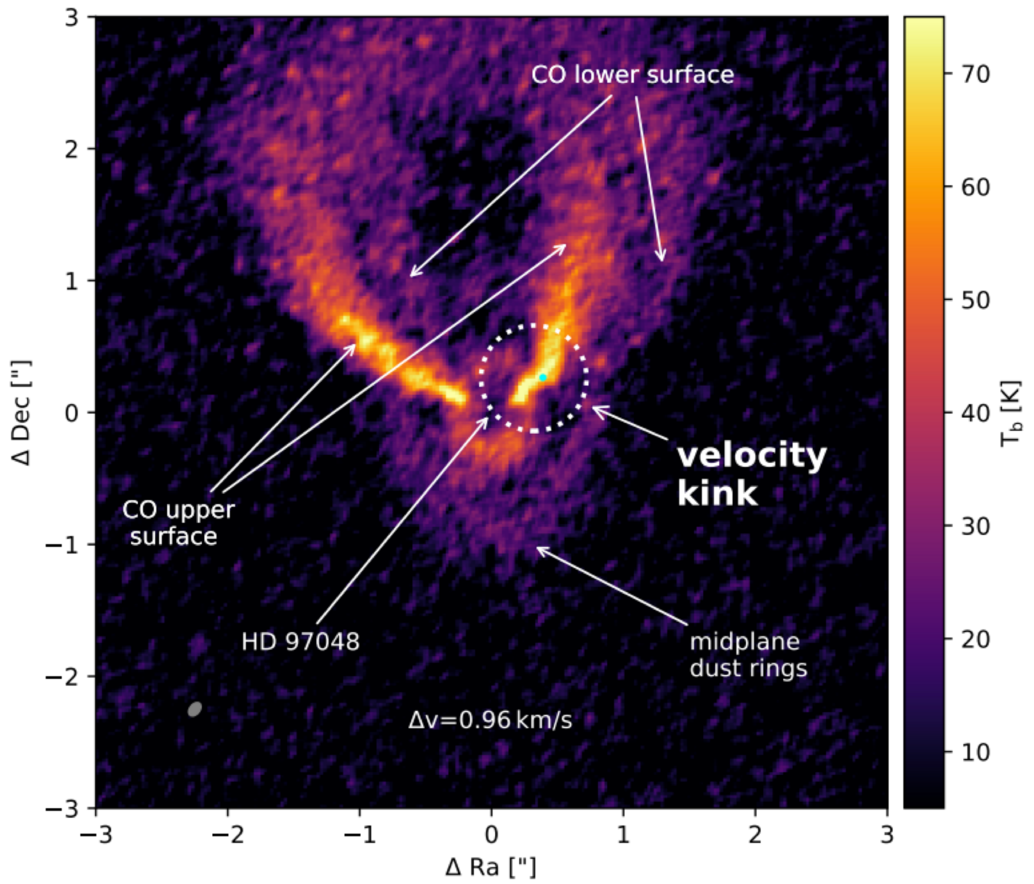


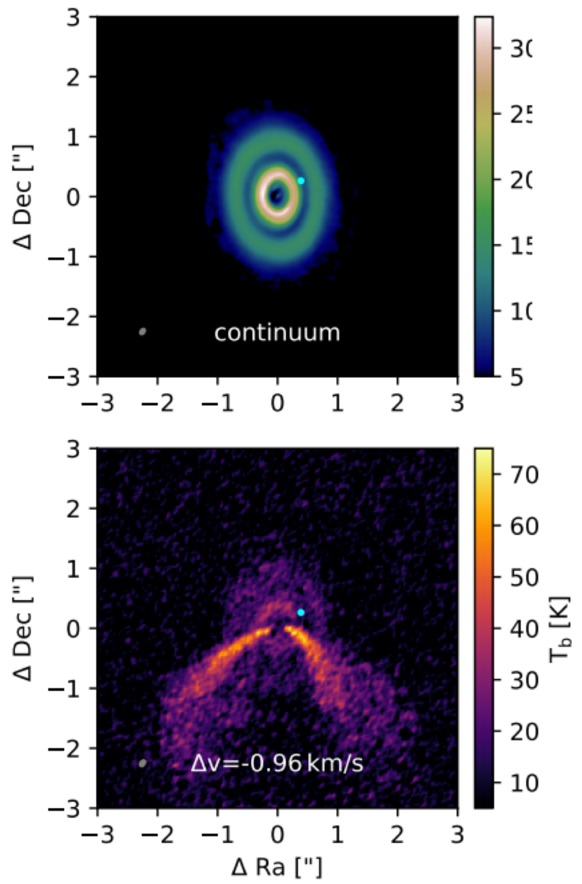


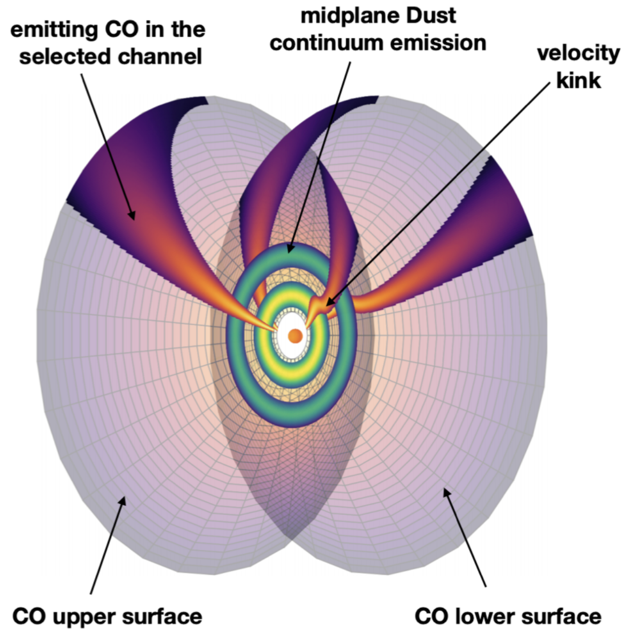


Teague+ 2018

Delivery of Material – CO Velocity “Kinks”

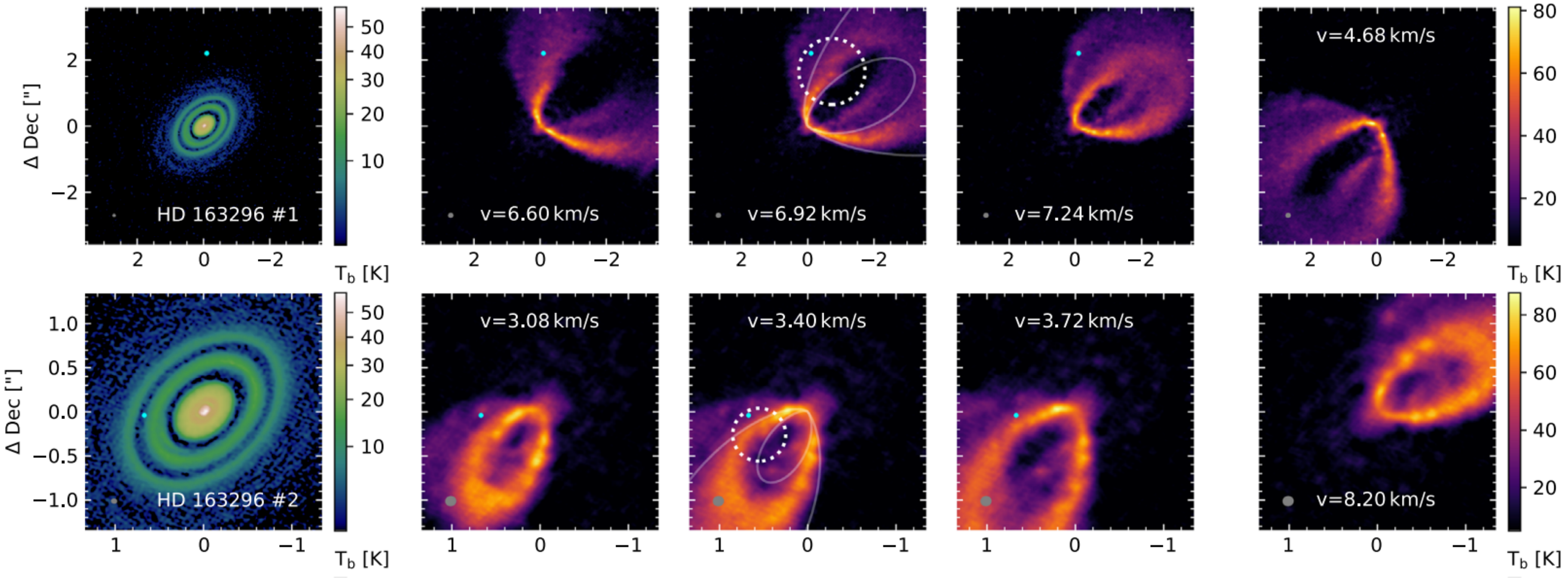






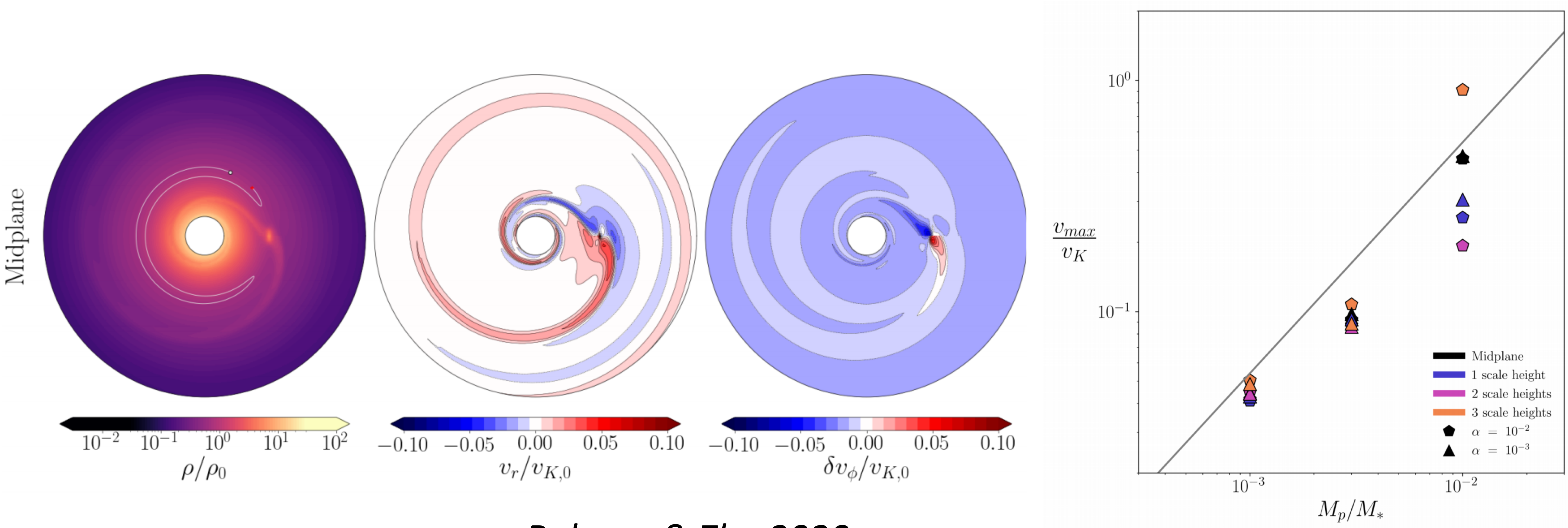
Pinte+ 2019

Delivery of Material – CO Velocity "Kinks"



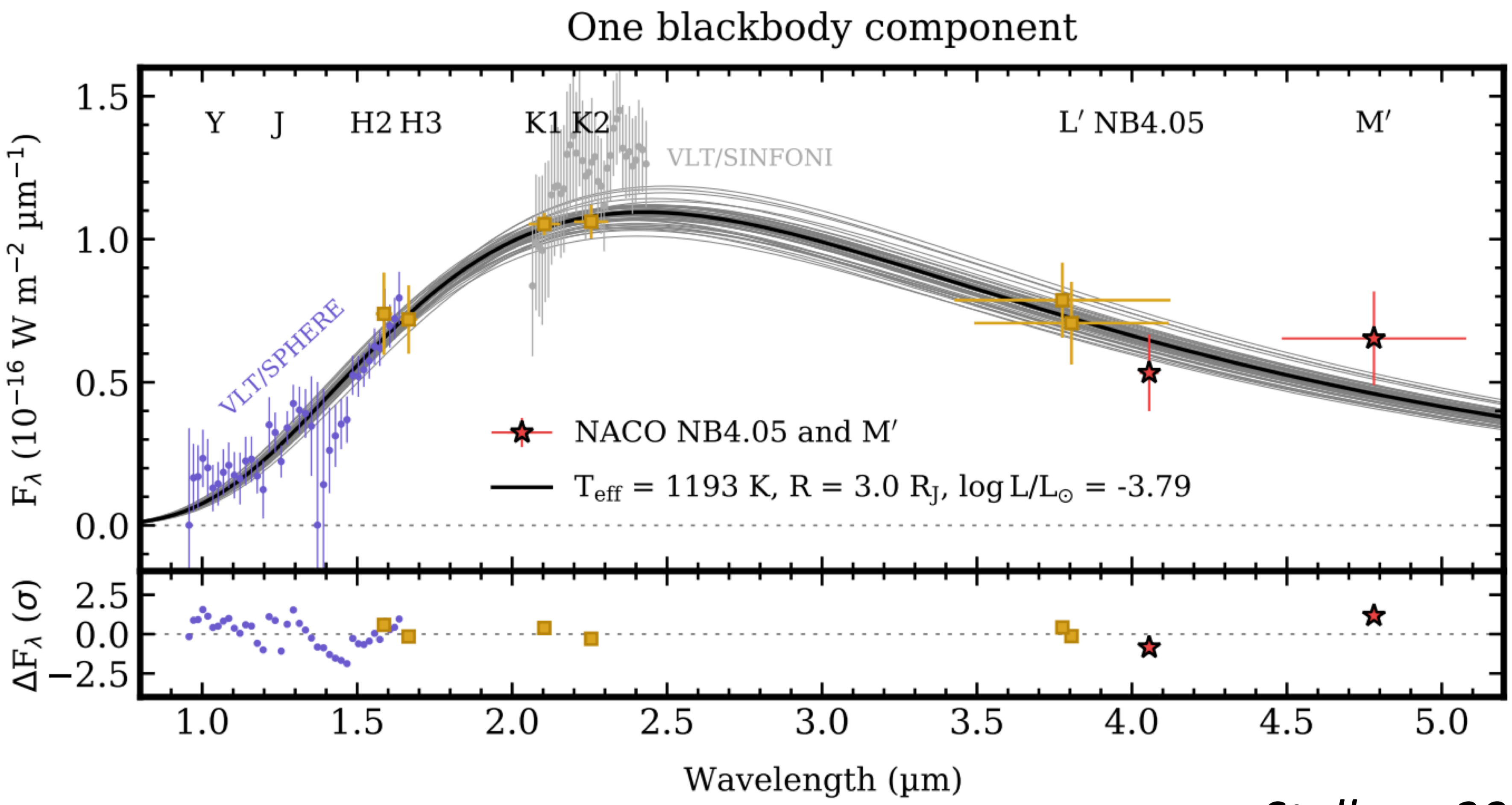
Pinte+ 2020

Gas Kinematics as a Probe of Planet Mass



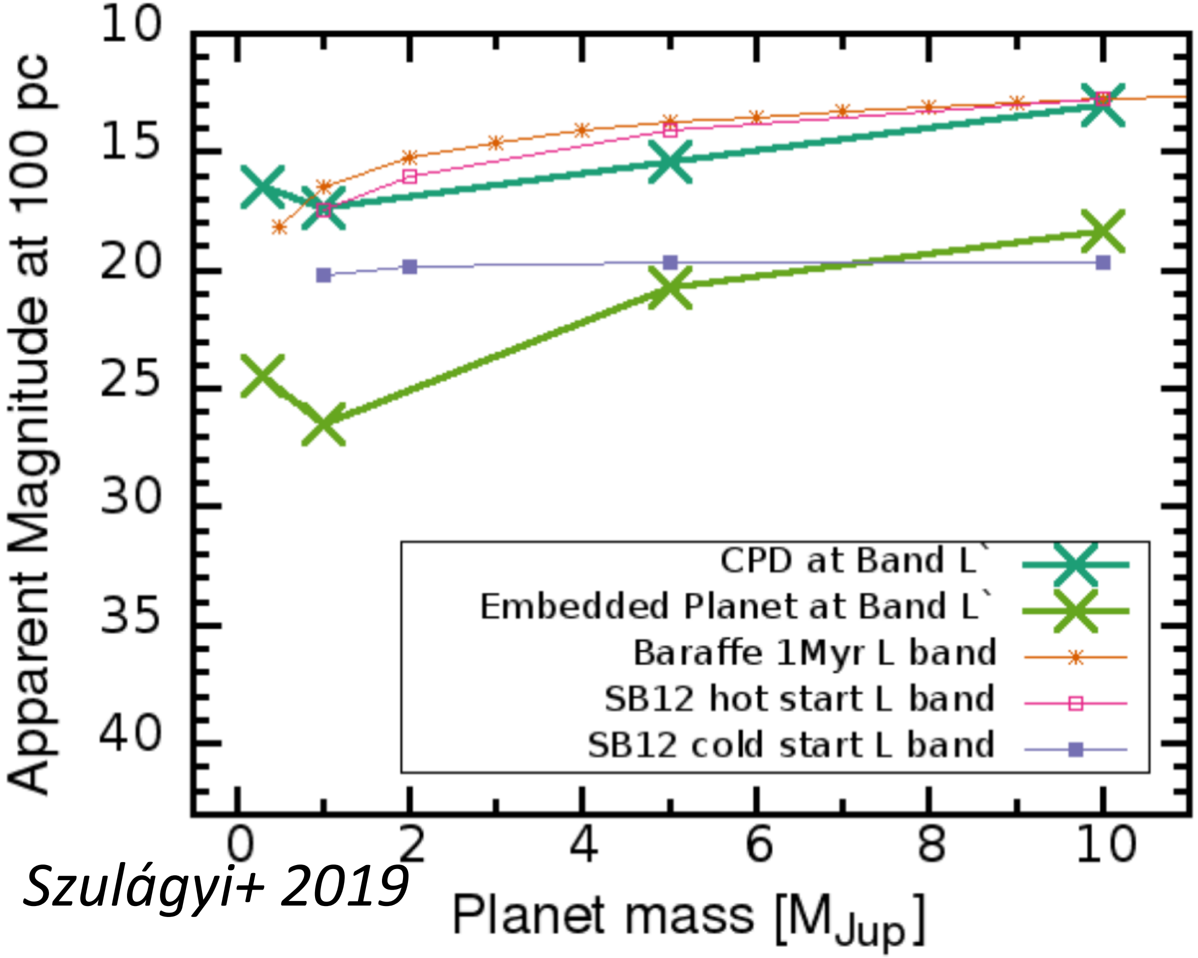
Rabago & Zhu 2020

Circumplanetary Disks and Infrared Emission

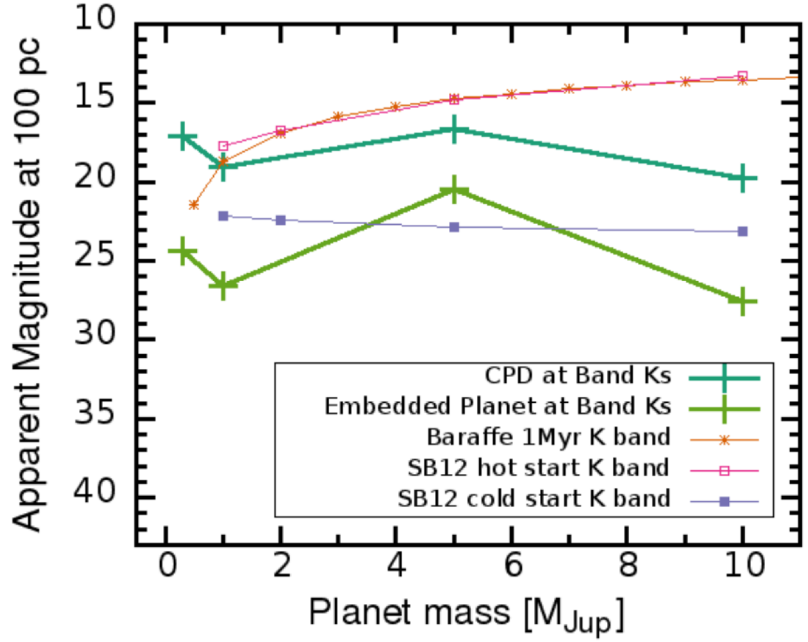


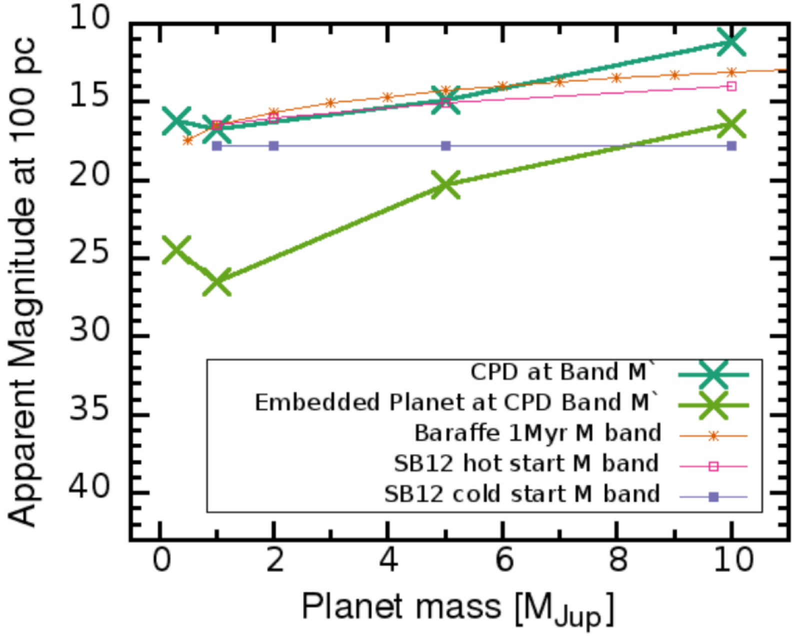
Stolker+ 2020

Circumplanetary Disks May Dominate NIR Emission



Szulágyi+ 2019





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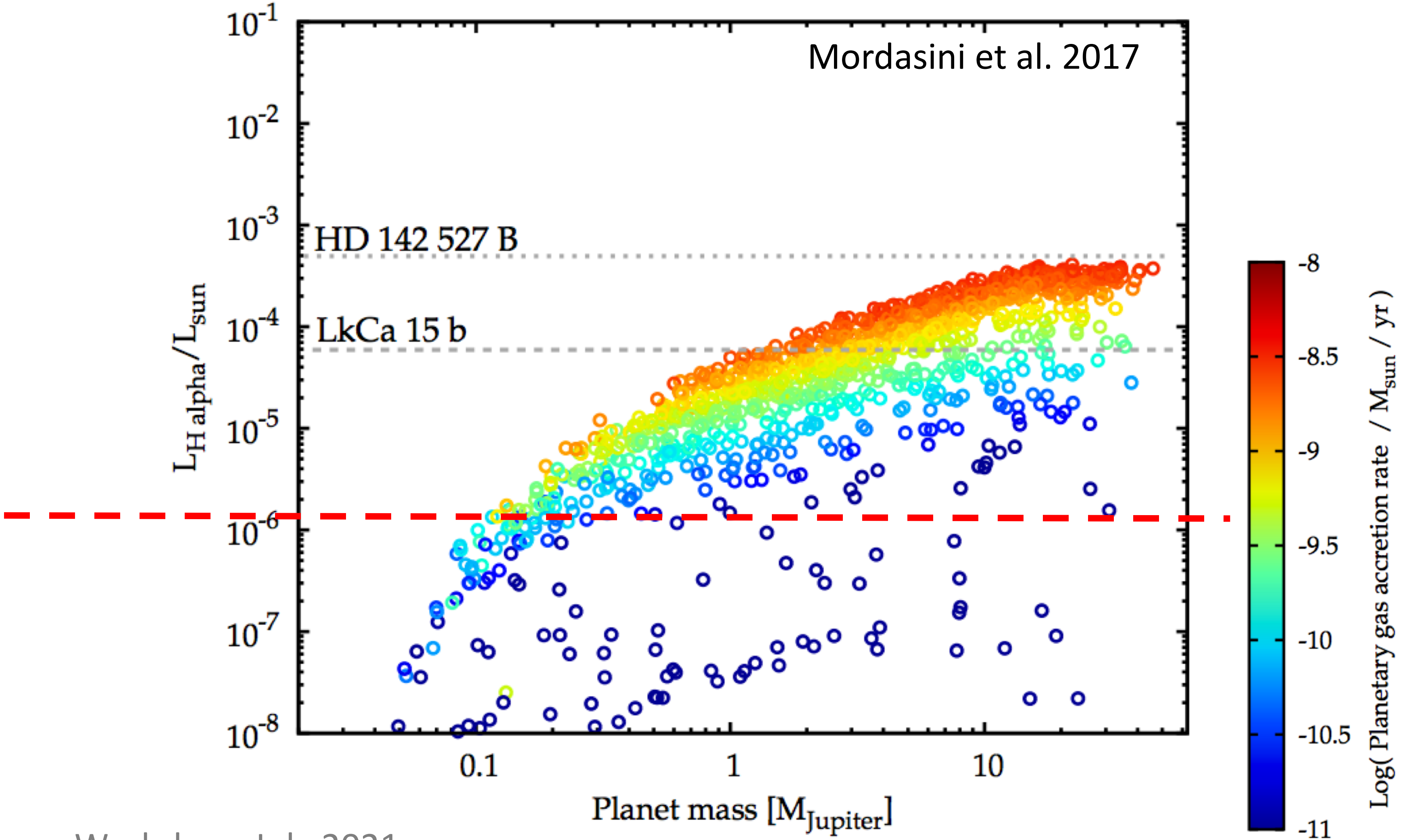
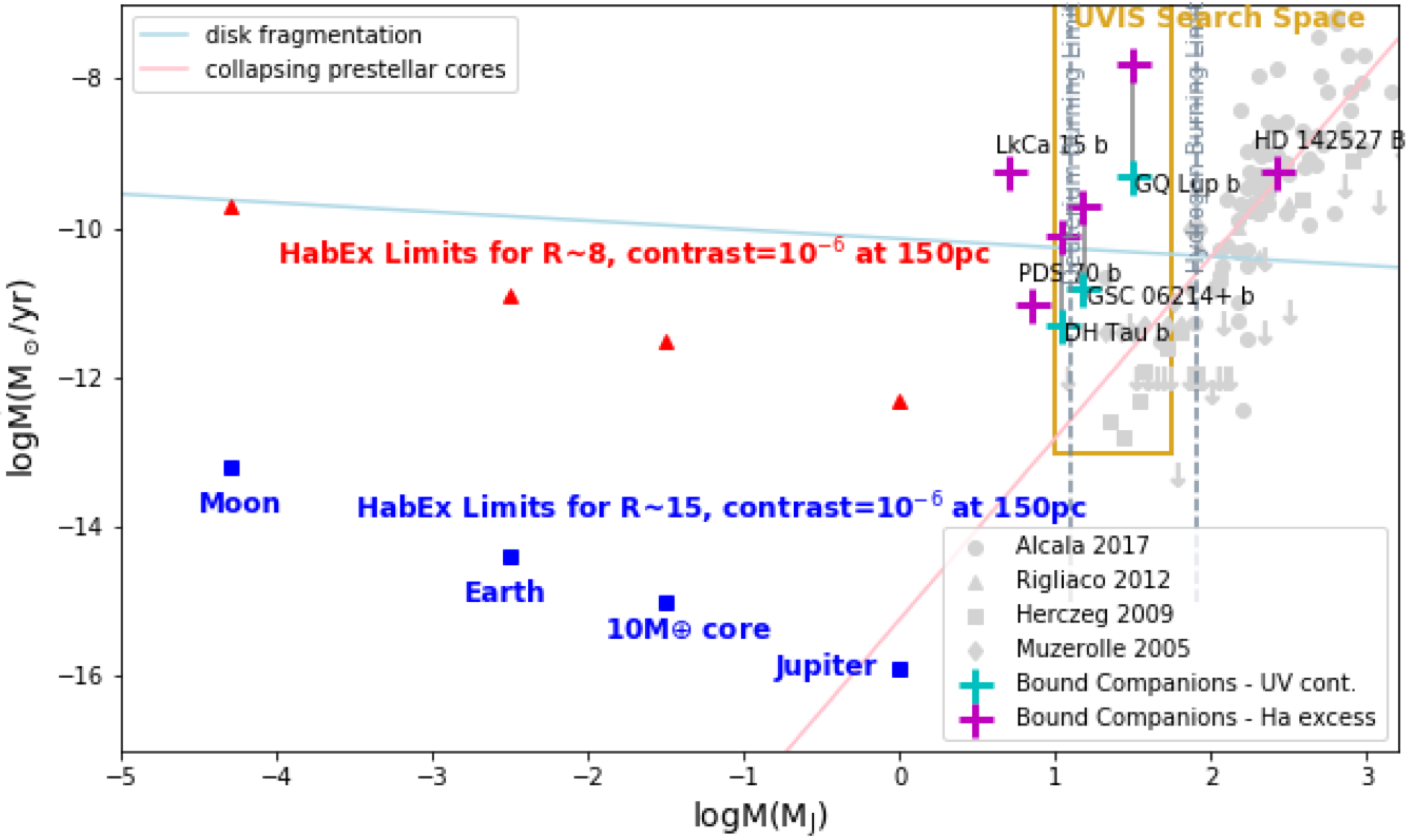
3. Future technologies and instruments

Improving Sensitivity to Accreting Protoplanets

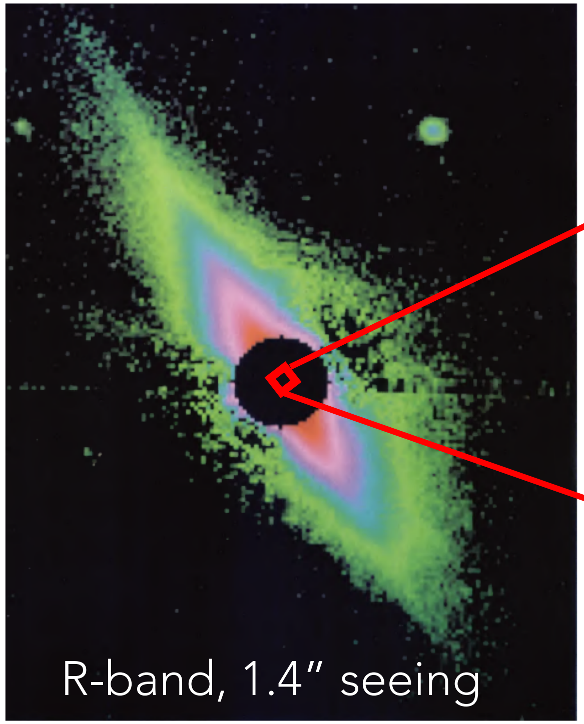


Future – Next Generation Space Telescopes



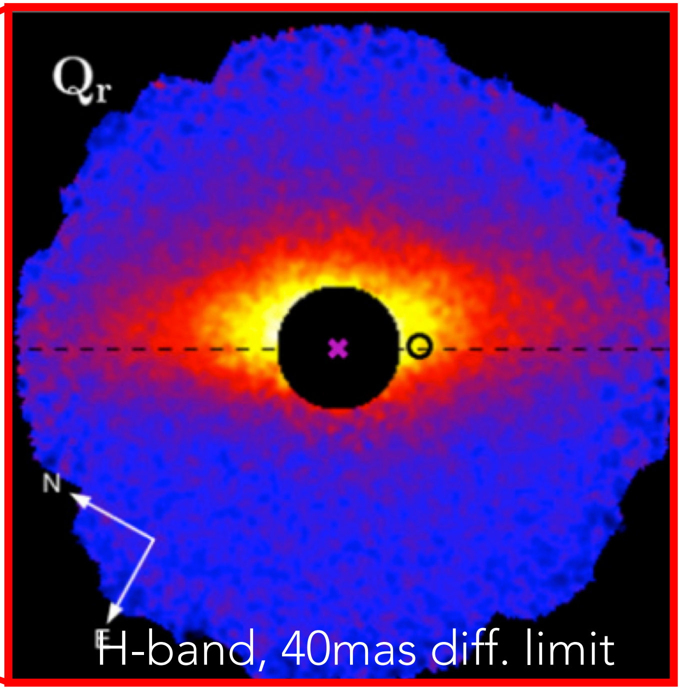
Prospects for ELTs

Kalas & Jewitt 1995
UH 2.2m



Beta Pic
d=19pc

Millar-Blanchaer+ 2015
Gemini South 8.3m



Taurus SFR
d=140pc

ELT Resolution ~ 4 mas at R, 13mas at H
at 140pc …. 4mas = 0.6AU and 13mas = 1.8AU

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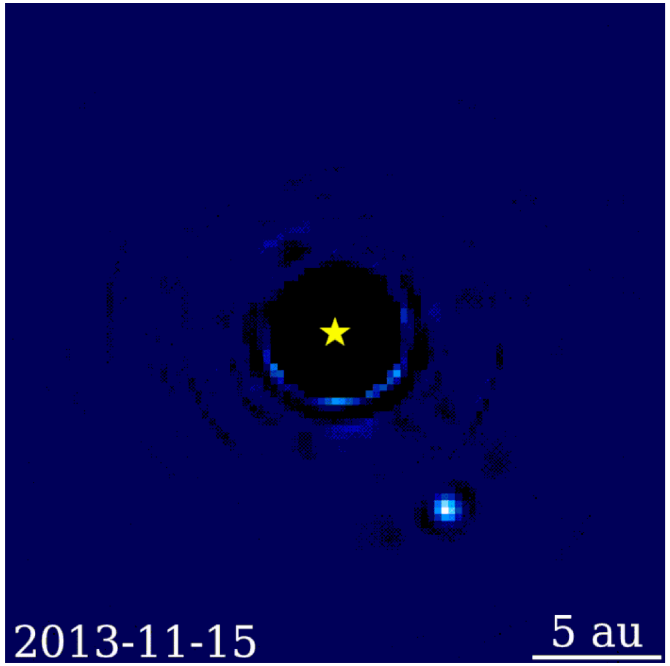
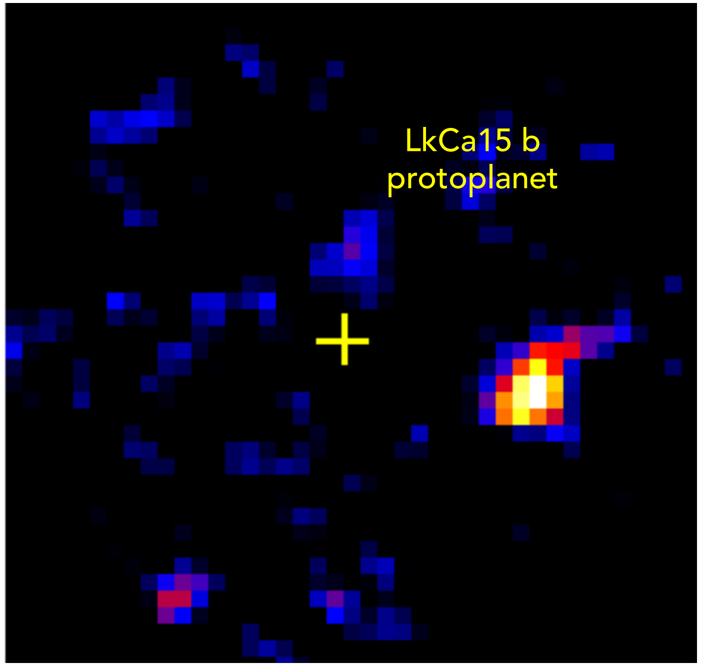
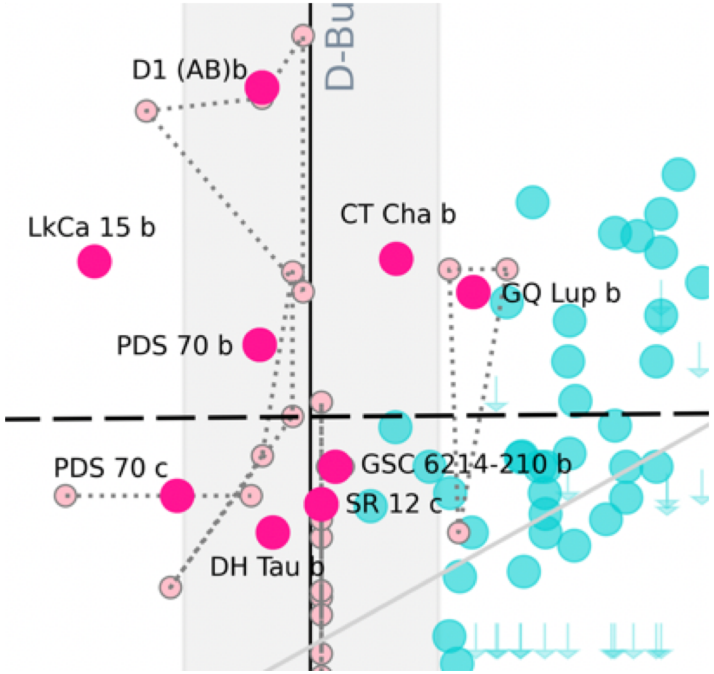
Talk Summary



Direct Imaging is the best way to characterize exoplanets



Protoplanets are a window into planet formation



We have some work to do in learning how to interpret them