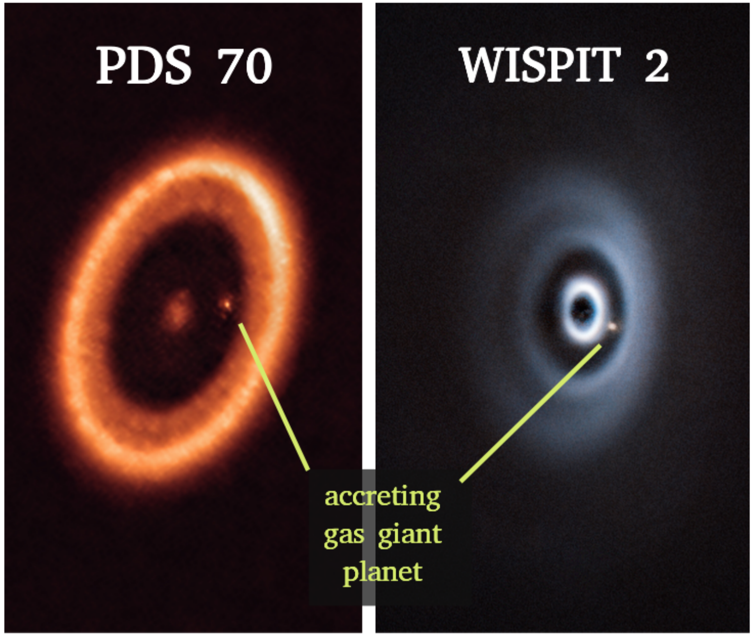
Medium- and high-resolution hydrogen-line spectroscopy of planetary accretion tracers: data and models for and with JWST and ELT

Gabriel-Dominique Marleau
(*Uni Bern*, *Uni Duisburg–Essen*, *MPIA*)
Christoph Mordasini (*Bern*), Thomas Henning (*MPIA*), Myriam Benisty, Roy van Boekel,
Yuhiko Aoyama (*Sun Yat-sen University*), Jun Hashimoto (*Academia Sinica*),
Yifan Zhou (*U Virginia*), …

UNIVERSITÄT BERN
UNIVERSITÄT DUISBURG ESSEN *Offen im Denken*
Max-Planck-Institut für Astronomie Heidelberg

Planetary-mass accretors in discs

- Small numbers still…
- … but growing!
- There are also some isolated accretors



Benisty et al. (2021), Haffert et al. (2018)
van Capelleveen et al. (2025), Close et al. (2025b)

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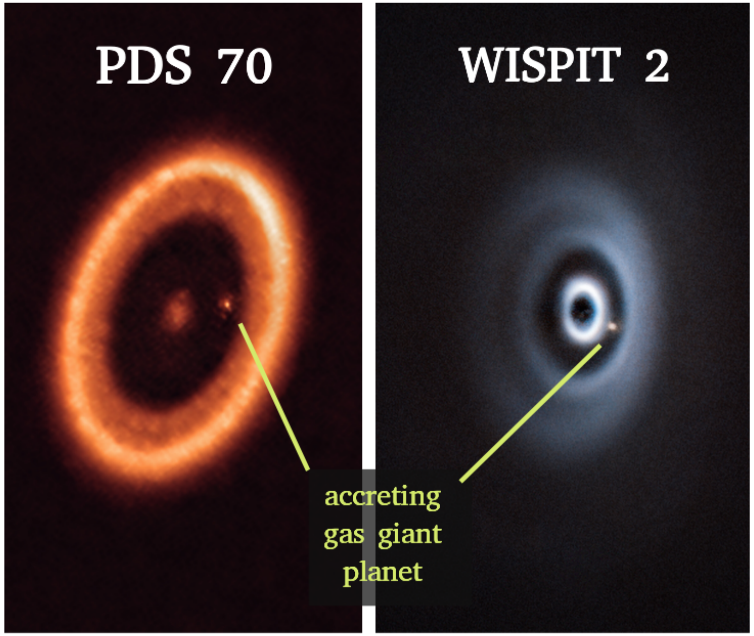

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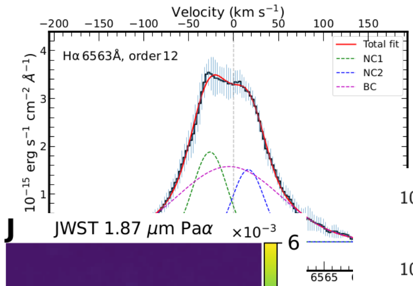
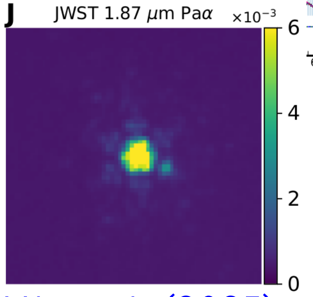
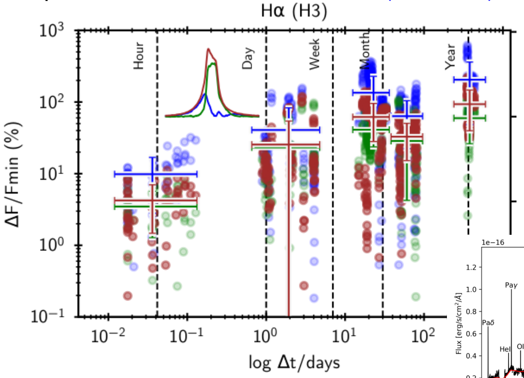


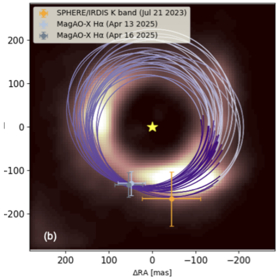
Viswanath et al. (2024)



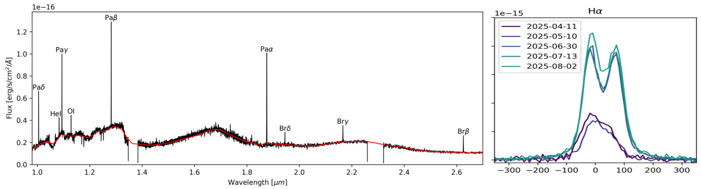
Vila et al. (2025)

Demars et al. (in rev.)



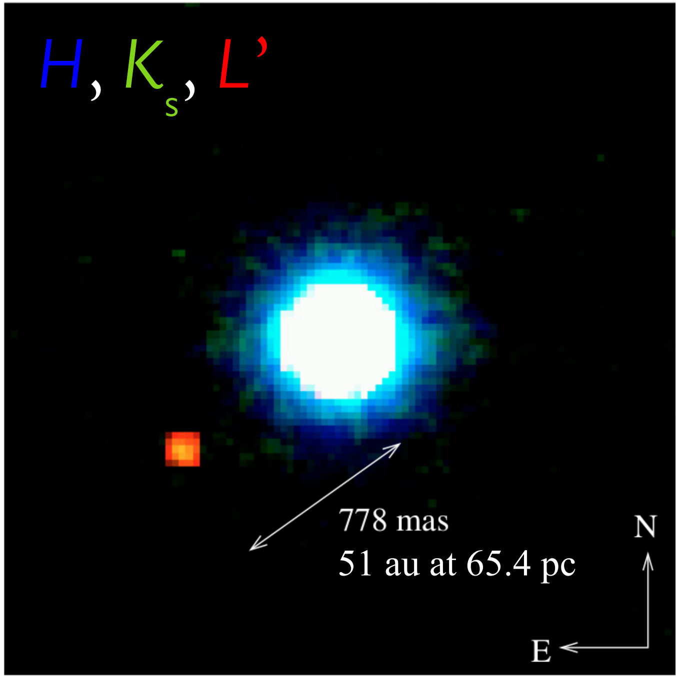


Li et al. (2025)



Almendros-Abad et al. (2025)

TWA27B *a.k.a.* 2M1207b



Chauvin et al. (2004)
VLT/NaCo

- First directly-imaged planetary-mass object
- Puzzling atmospheric properties
- $M_p \sim 5 \pm 2\ M_{Jup}$ (TWA27A: 25 M_{Jup})

system age: 10±2 Myr

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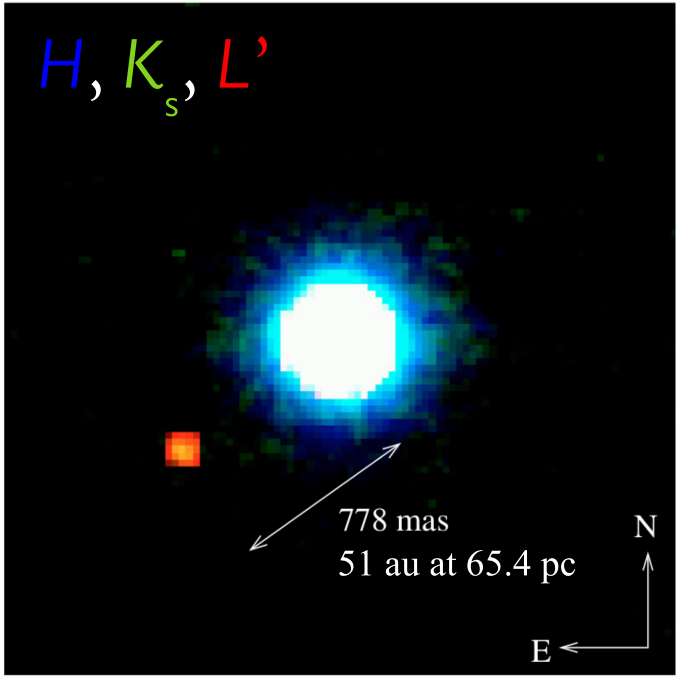

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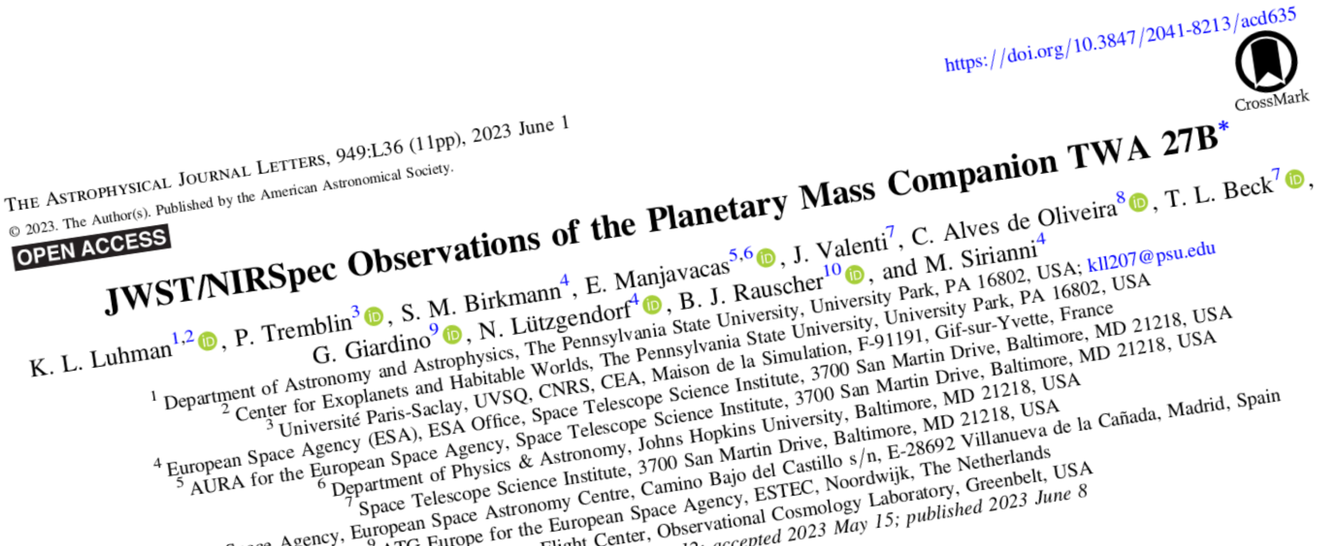

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The Astrophysical Journal Letters, 949:L36 (11pp), 2023 June 1

JWST/NIRSpec Observations of the Planetary Mass Companion TWA 27B*

K. L. Luhman[1,2], P. Tremblin[3], S. M. Birkmann[4], E. Manjavacas[5,6], J. Valenti[7], C. Alves de Oliveira[8], T. L. Beck[7], G. Giardino[9], N. Lützgendorf[4], B. J. Rauscher[10], and M. Sirianni[4]

[1] Department of Astronomy and Astrophysics, The Pennsylvania State University, University Park, PA 16802, USA; kll207@psu.edu
[2] Center for Exoplanets and Habitable Worlds, The Pennsylvania State University, University Park, PA 16802, USA
[3] Université Paris-Saclay, UVSQ, CNRS, CEA, Maison de la Simulation, F-91191, Gif-sur-Yvette, France
[4] European Space Agency (ESA), ESA Office, Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
[5] AURA for the European Space Agency, Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
[6] Department of Physics & Astronomy, Johns Hopkins University, Baltimore, MD 21218, USA
[7] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
European Space Agency, European Space Astronomy Centre, Camino Bajo del Castillo s/n, E-28692 Villanueva de la Cañada, Madrid, Spain
[9] ATG Europe for the European Space Agency, ESTEC, Noordwijk, The Netherlands
Flight Center, Observational Cosmology Laboratory, Greenbelt, USA

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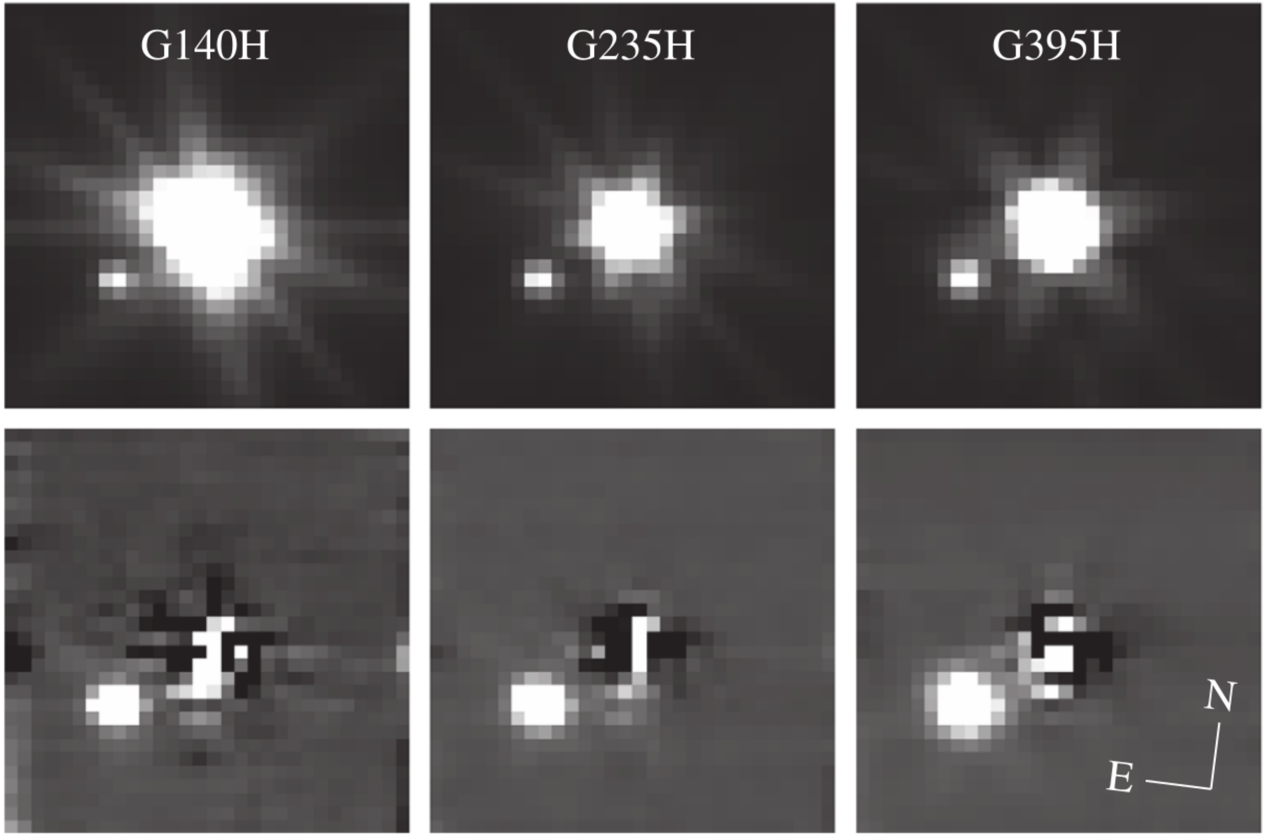
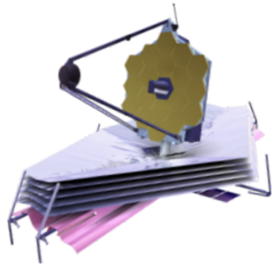
TWA27B with JWST/NIRSpec

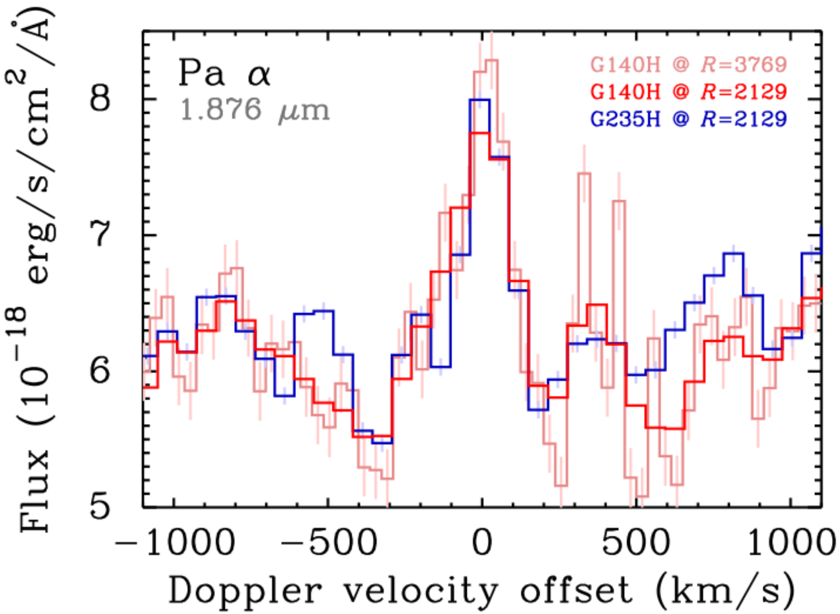


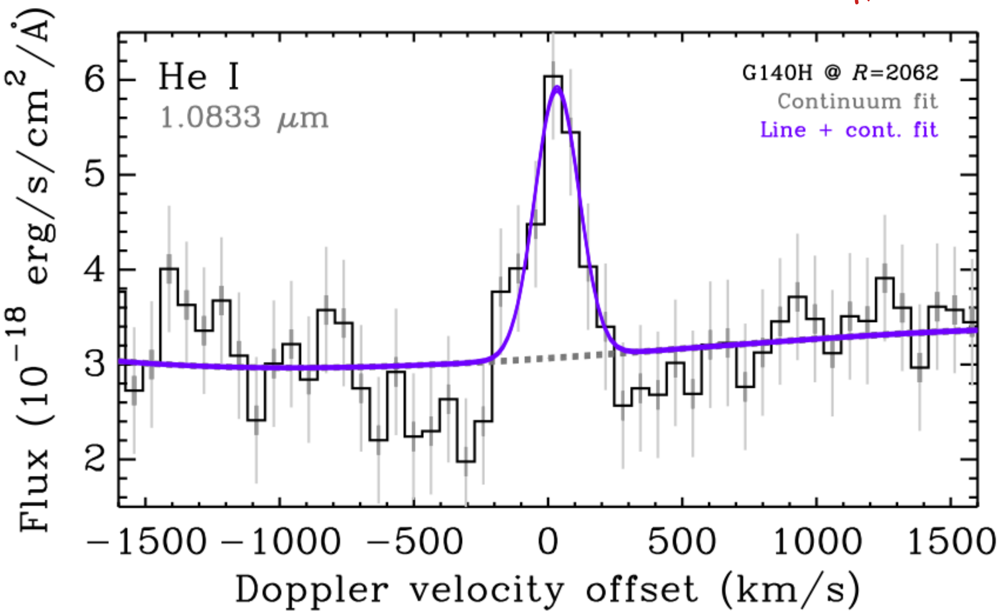


Luhman et al. (2023c)

TWA27B: Reanalysing Luhman et al.'s data

thanks, Kevin!





Marleau et al. (2024)

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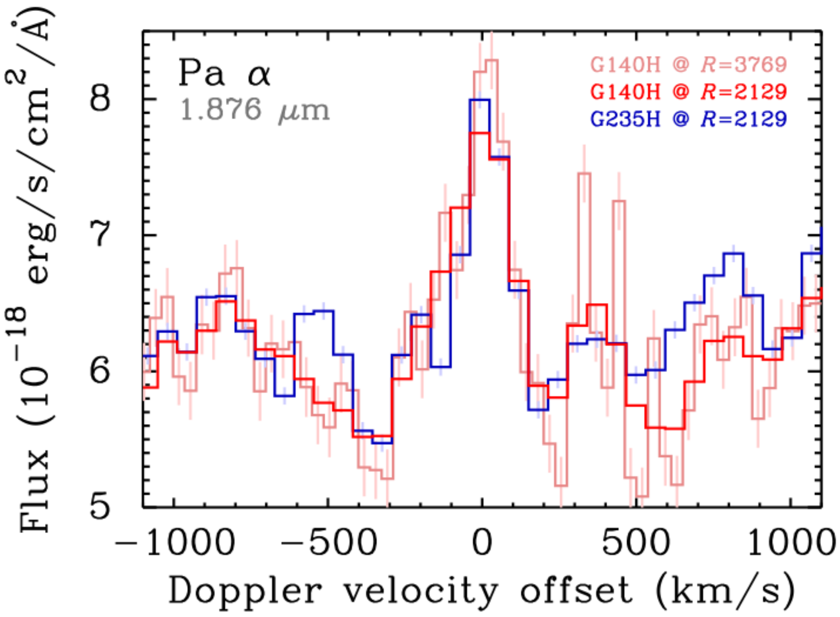

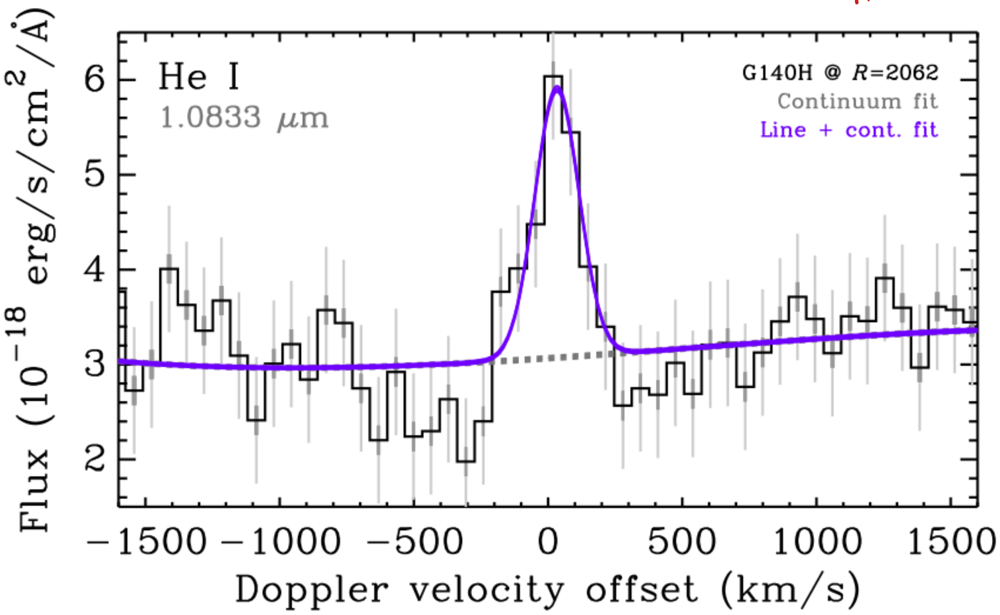

Marleau et al. (2024)

- Consistent line between overlapping gratings
- Find more lines than in original paper, also upper limits

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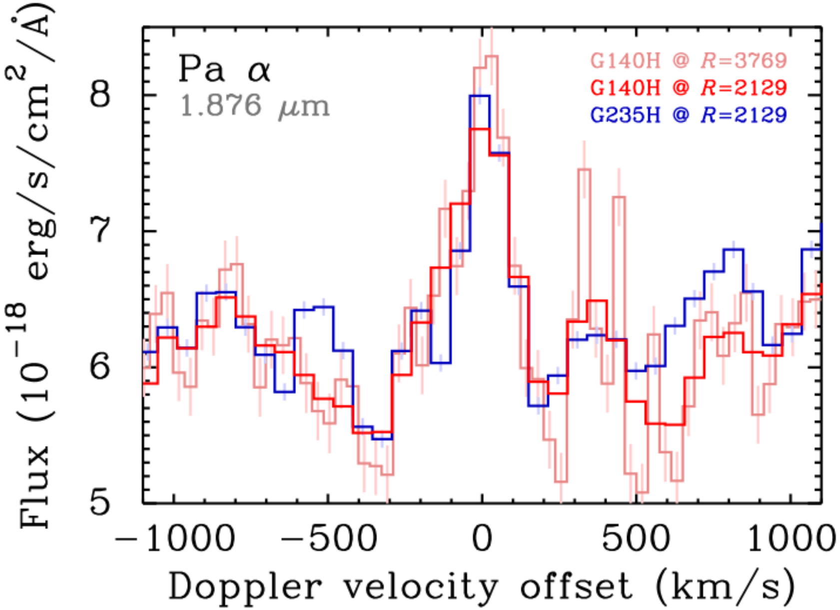

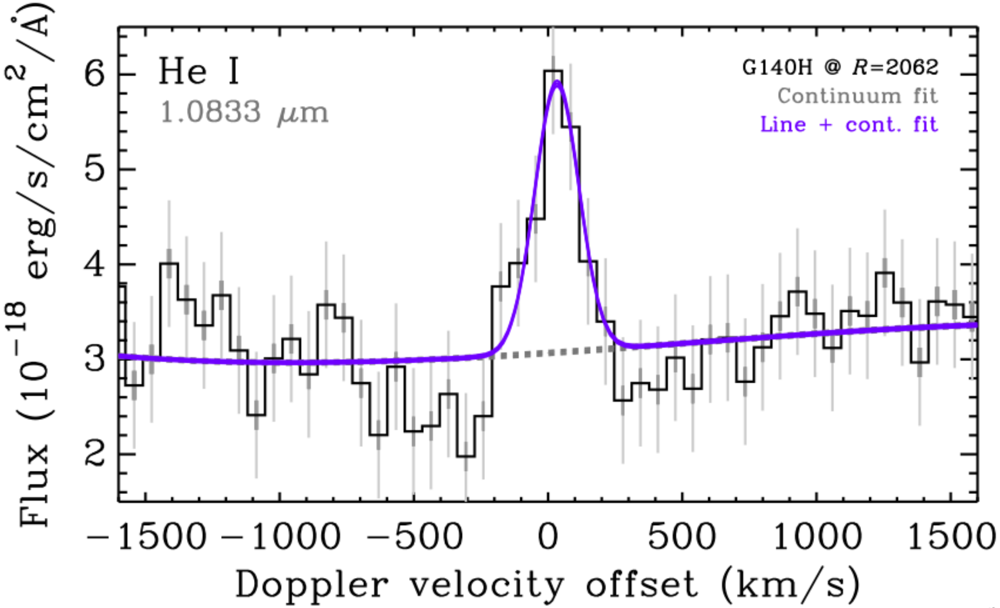

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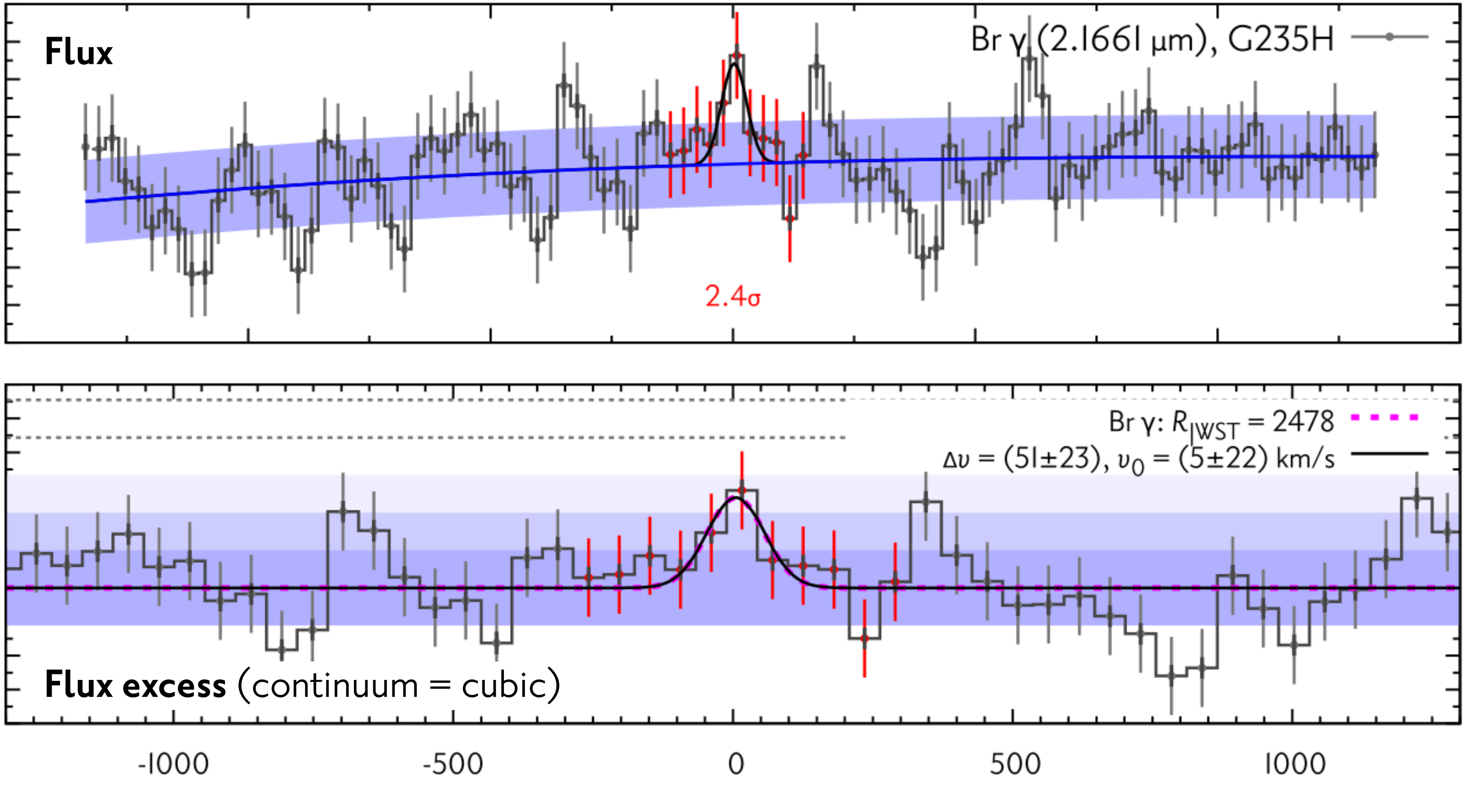
Table 1

Helium-triplet and Hydrogen Lines Covered by Luhman et al. (2023)'s JWST Spectrum of TWA 27B

Line	λ_0 (μm)	$\mathcal{F}_{\rm cont}/10^{-18}$ (erg s^{-1} cm^{-2} Å^{-1})	$F_{\rm line}/10^{-17}$ (erg s^{-1} cm^{-2})	$L_{\rm line}$ (10^{-9} $L_\odot$)	R	N_σ^F	v_0 (km s^{-1})
He I$_1$	1.083	3.05 ± 0.65	2.16 ± 0.50	2.81 ± 0.65	2062	4.3	32 ± 12
Paα_1	1.876	6.02 ± 0.61	2.41 ± 0.67	3.13 ± 0.88	3769	3.6	6 ± 12
Paα_2	1.876	6.33 ± 0.41	1.44 ± 0.33	1.88 ± 0.43	2129	4.4	11 ± 11
Paβ_1	1.282	5.98 ± 0.62	2.72 ± 0.61	3.54 ± 0.79	2461	4.5	17 ± 10
Paγ_1	1.094	3.20 ± 0.50	1.57 ± 0.31	2.04 ± 0.40	2084	5.1	24 ± 9
Paδ_1	1.005	2.12 ± 0.61	1.58 ± 0.40	2.06 ± 0.52	1908	3.9	17 ± 16
Brα_3	4.052	3.81 ± 0.10	0.56 ± 0.24	0.73 ± 0.31	2780	2.3	47 ± 25
Brβ_2	2.626	6.05 ± 0.23	0.73 ± 0.23	0.95 ± 0.30	3052	3.2	-16 ± 14
Brγ_2	2.166	8.75 ± 0.22	0.50 ± 0.21	0.65 ± 0.27	2478	2.4	5 ± 22
	1.945	6.69 ± 0.32	<1.32	<1.72	2213	0.7	…
		6.80 ± 0.62	<1.47	<1.92	3629	0.2	…
			<1.48	<1.92	2061	0.4	…
			<1.36	<1.76	3438	0.5	…
				<1.97	1965	2.2	…
						1.4	

TWA27B: Reanalysing Luhman et al.'s data

(cont'd)



Marleau et al. (2024)

TWA27B: Reanalysing Luhman et al.'s data

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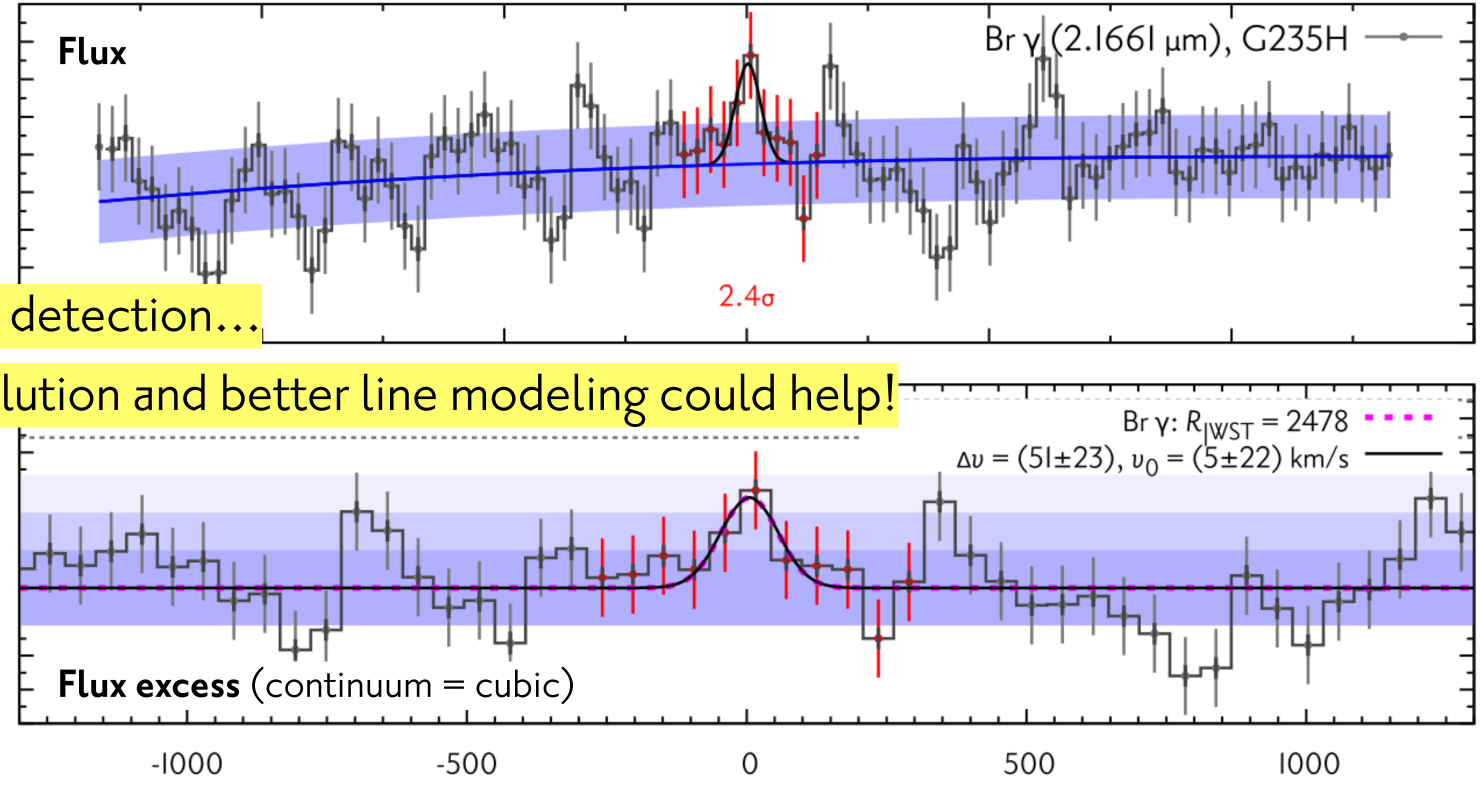
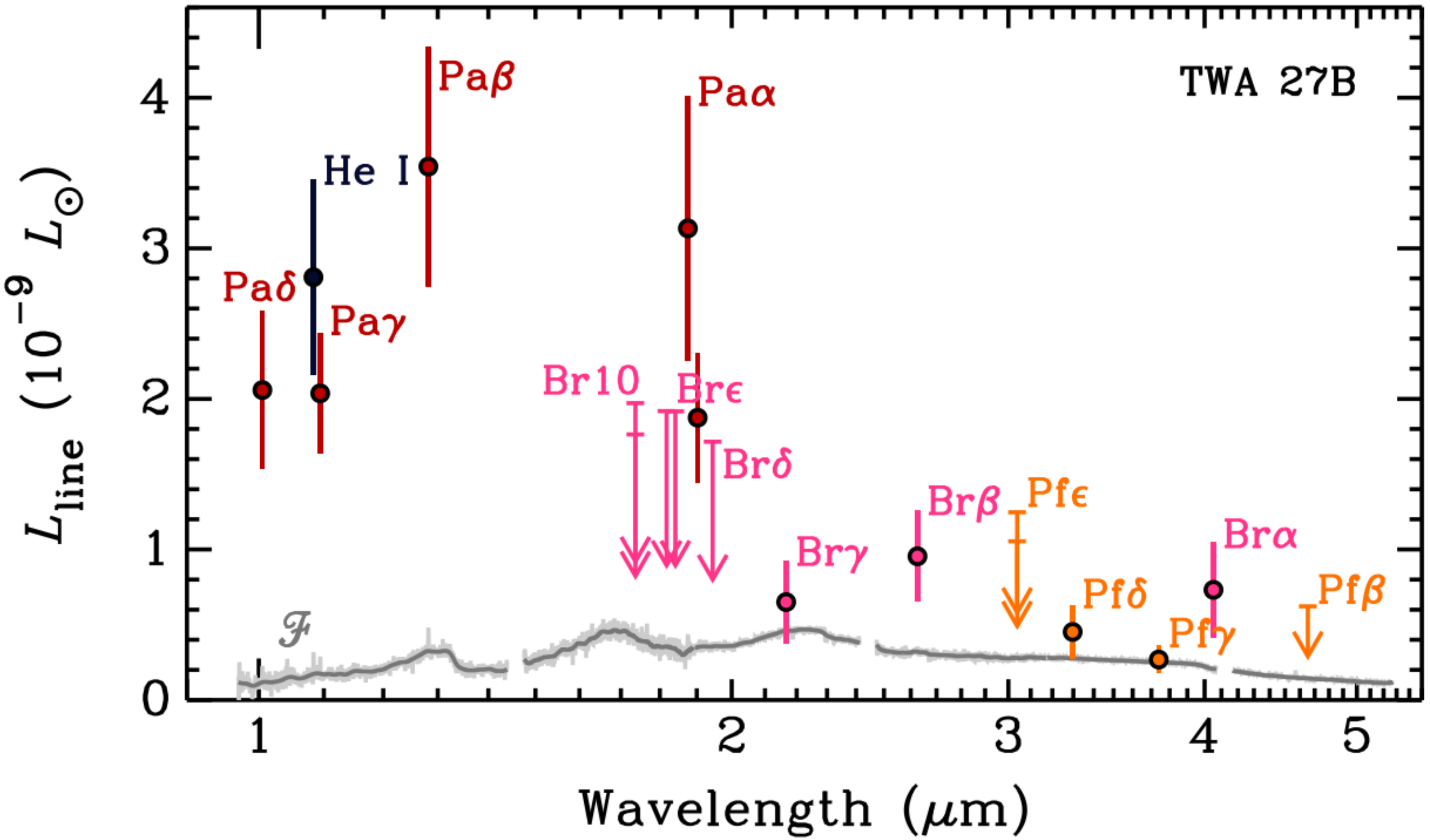


Marleau et al. (2024)

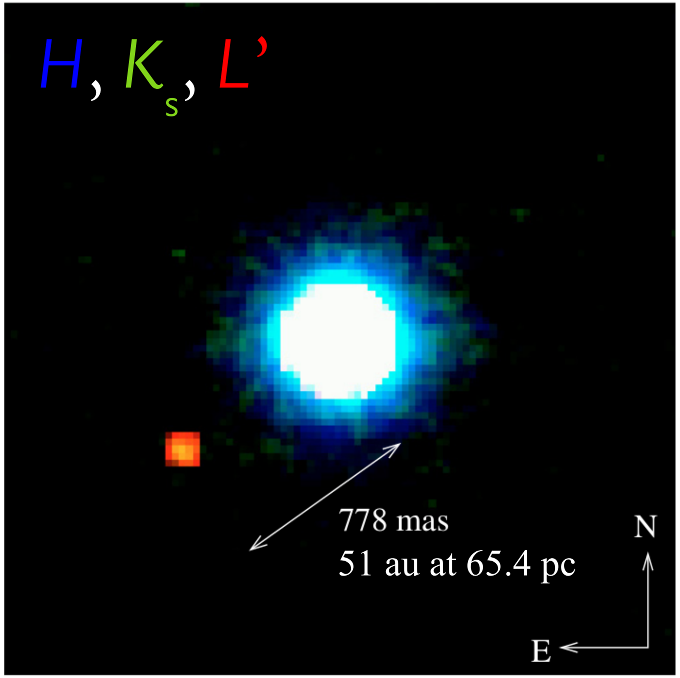
- Formally, no clear detection…
- … but higher resolution and better line modeling could help!

TWA27B: H and He I lines



Marleau et al. (2024)

TWA27B: Back in 2011...



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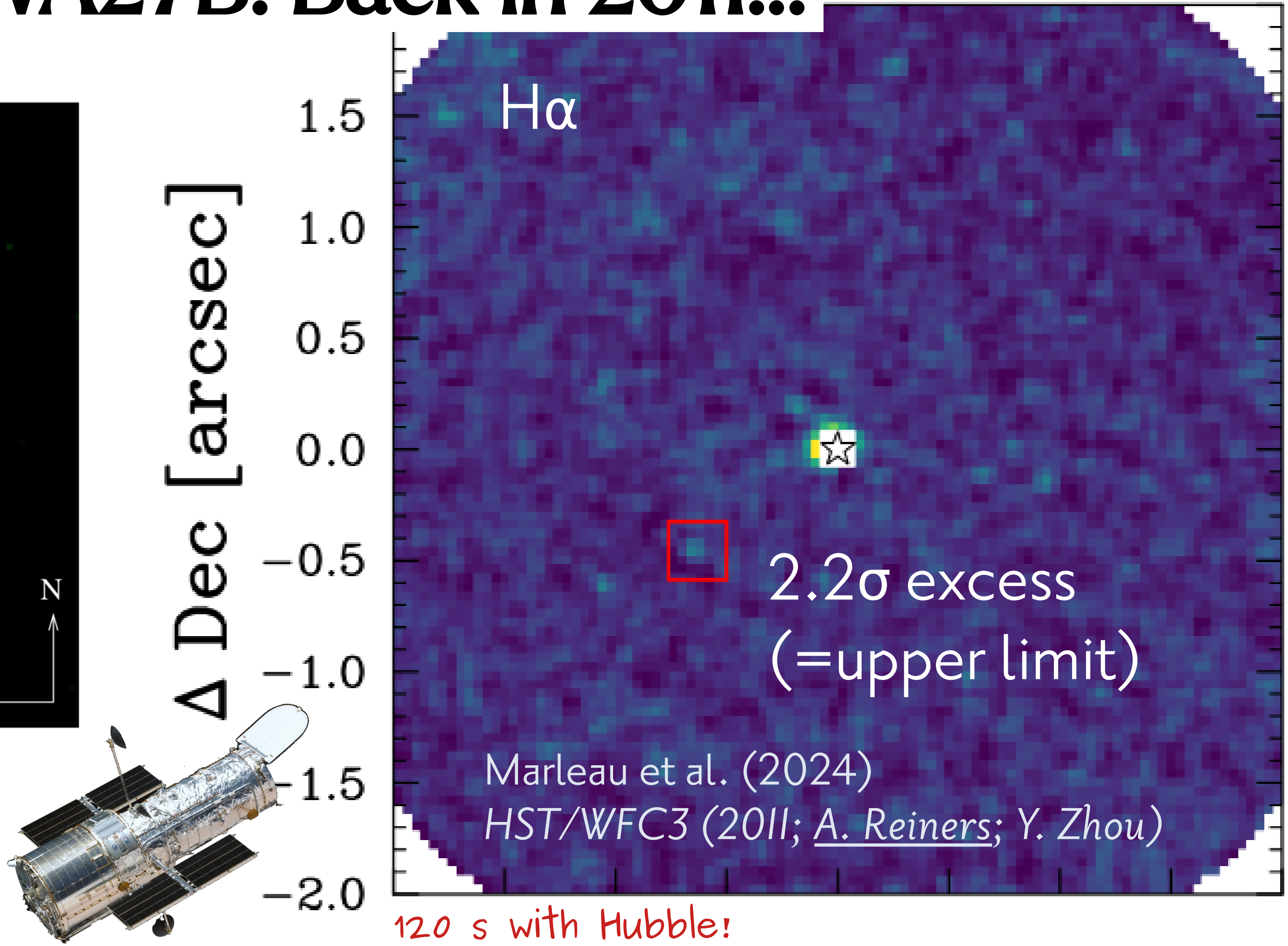
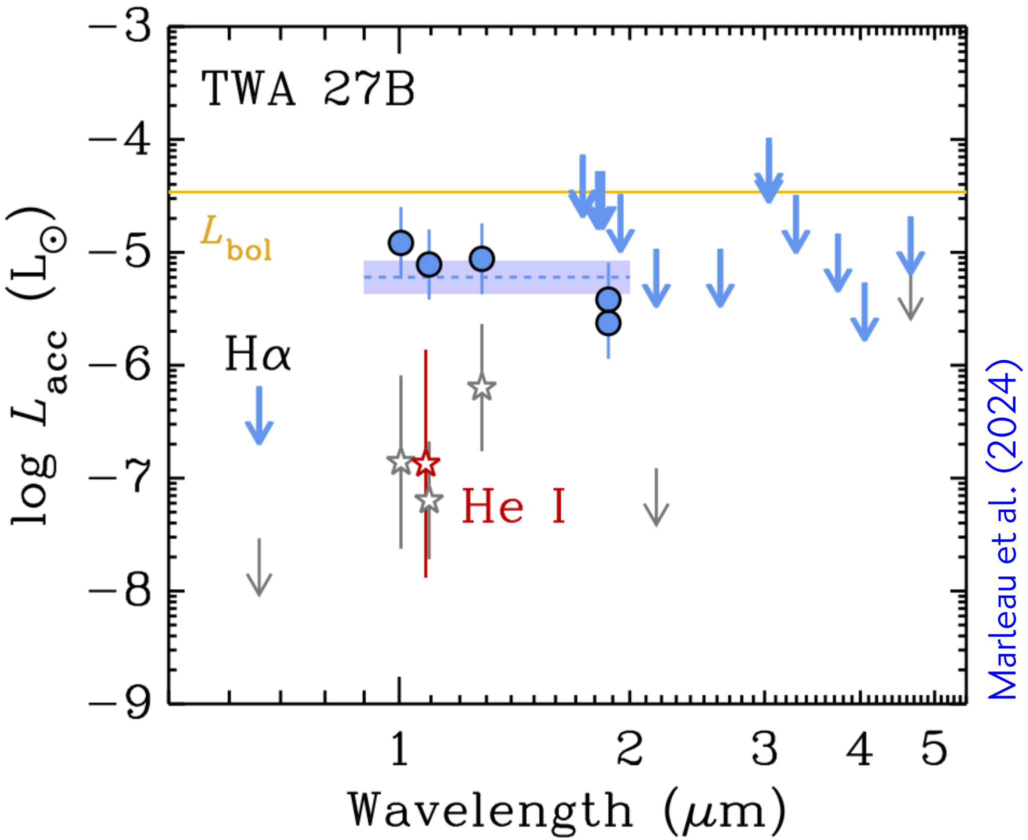


Marleau et al. (2024)
HST/WFC3 (2011; A. Reiners; Y. Zhou)

120 s with Hubble!

TWA27B: H and He I line fluxes



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- Only Hα is much lower!

  → Variability 2011–2023?

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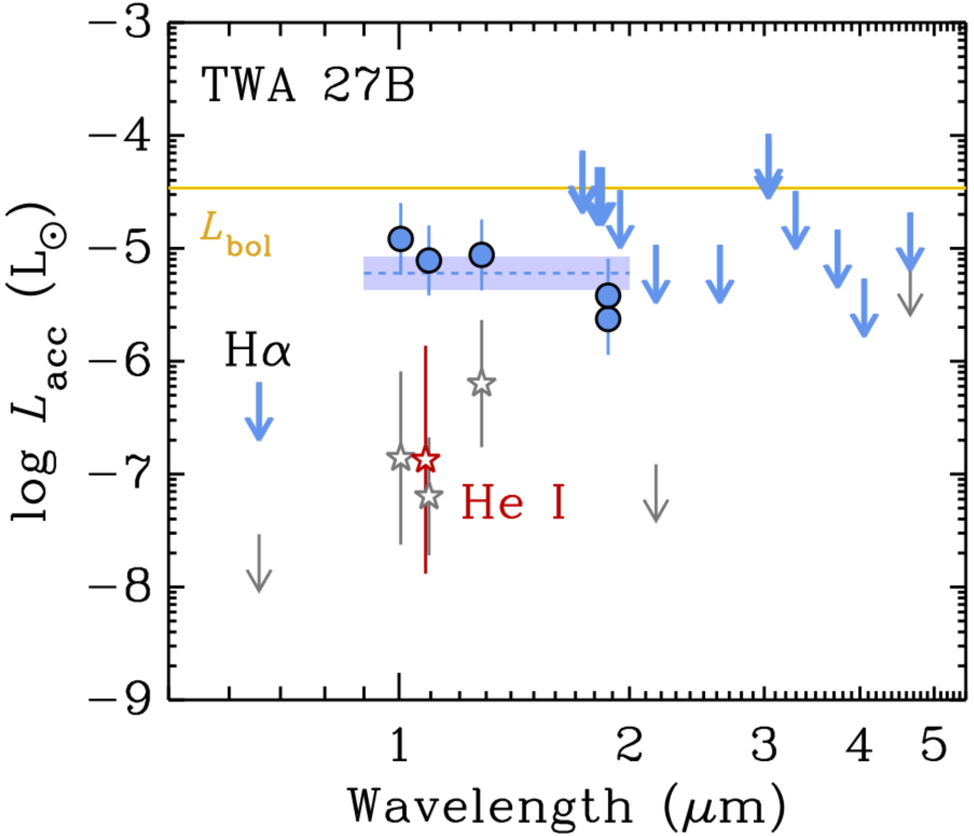

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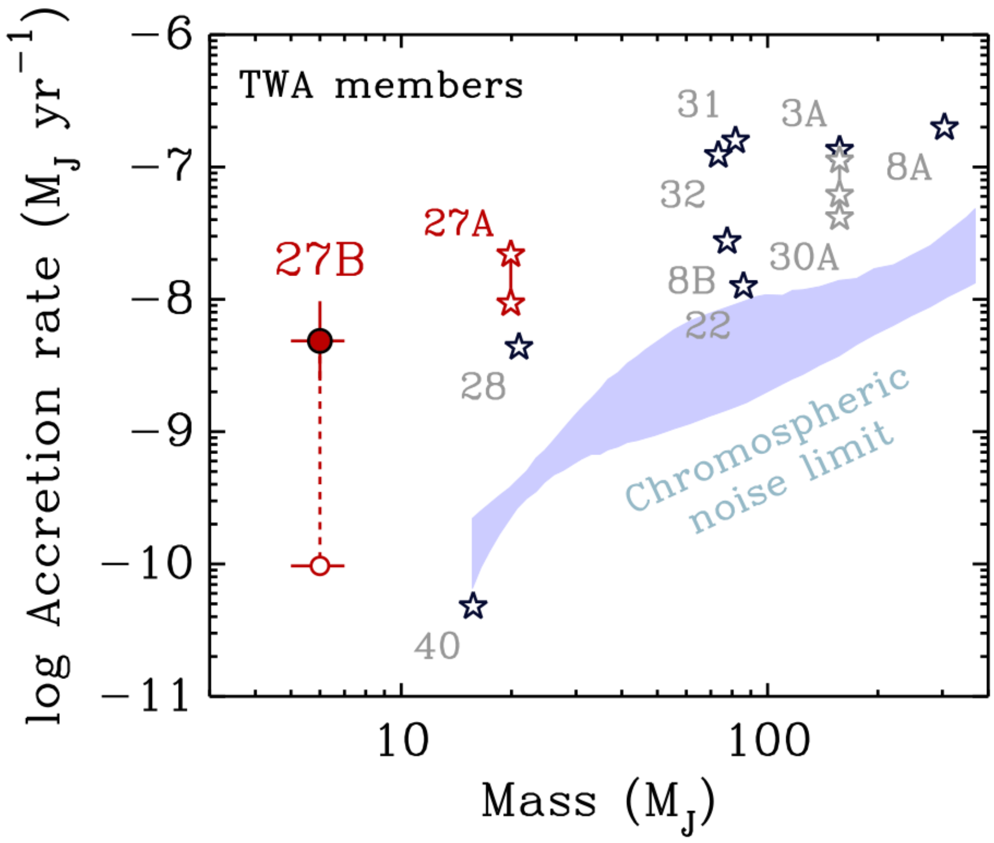

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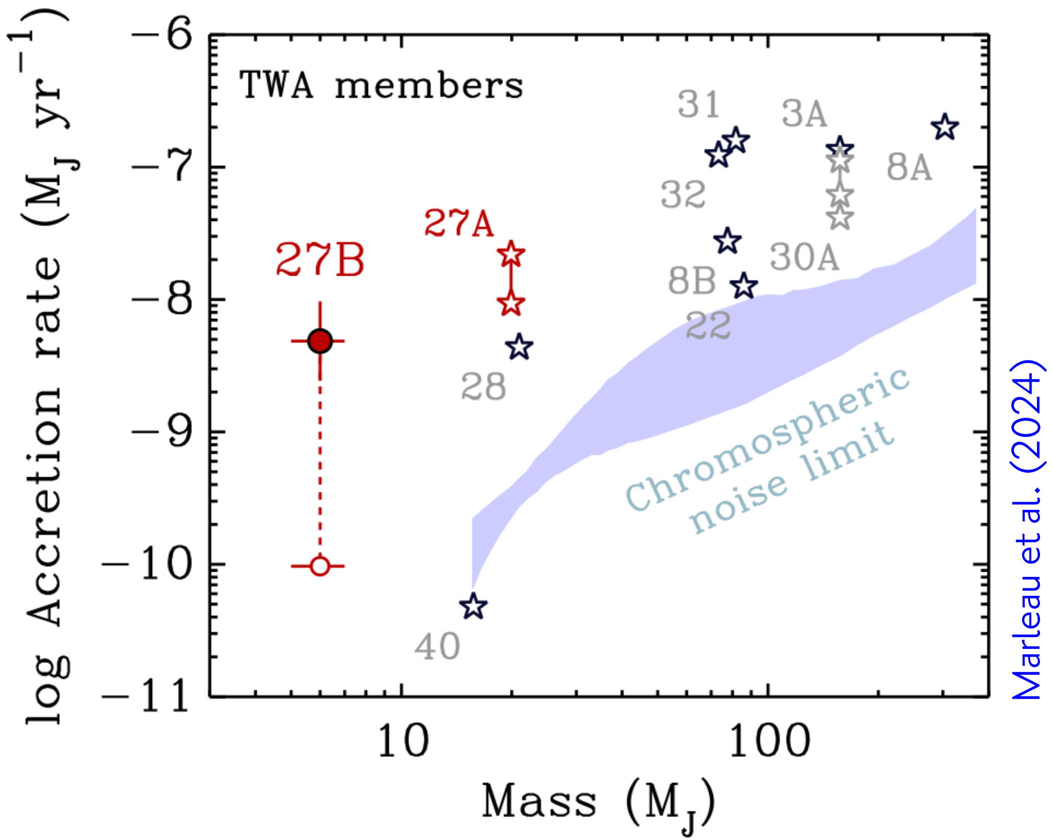

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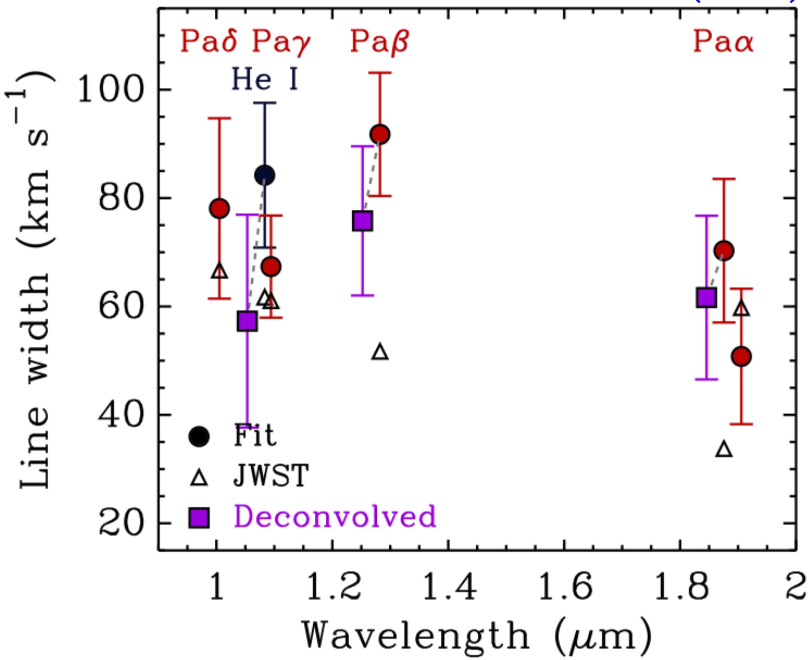
- Line-emitting accretion rate: dM/dt ~ 5×10^{-9} M_{Jup}/yr or (with stellar scalings) 50× less
- Lines: securely mainly from accretion
- Hydro simulations of binaries: should have similar dM/dt for A & B

TWA27B: Intrinsic line width

Marleau et al. (2024)



Can deconvolve three clearly-detected lines
(He I: 4.3σ; Pa α: 3.6σ; Pa β: 4.5σ)

Find: Intrinsic width = 67 ± 9 km/s
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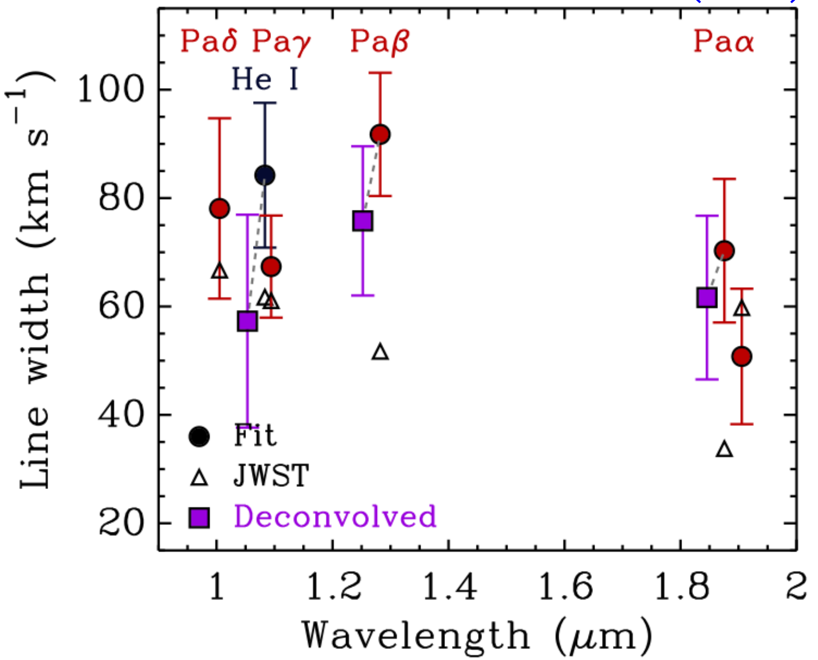

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→ Lines: from shock and/or magnetospheric accretion

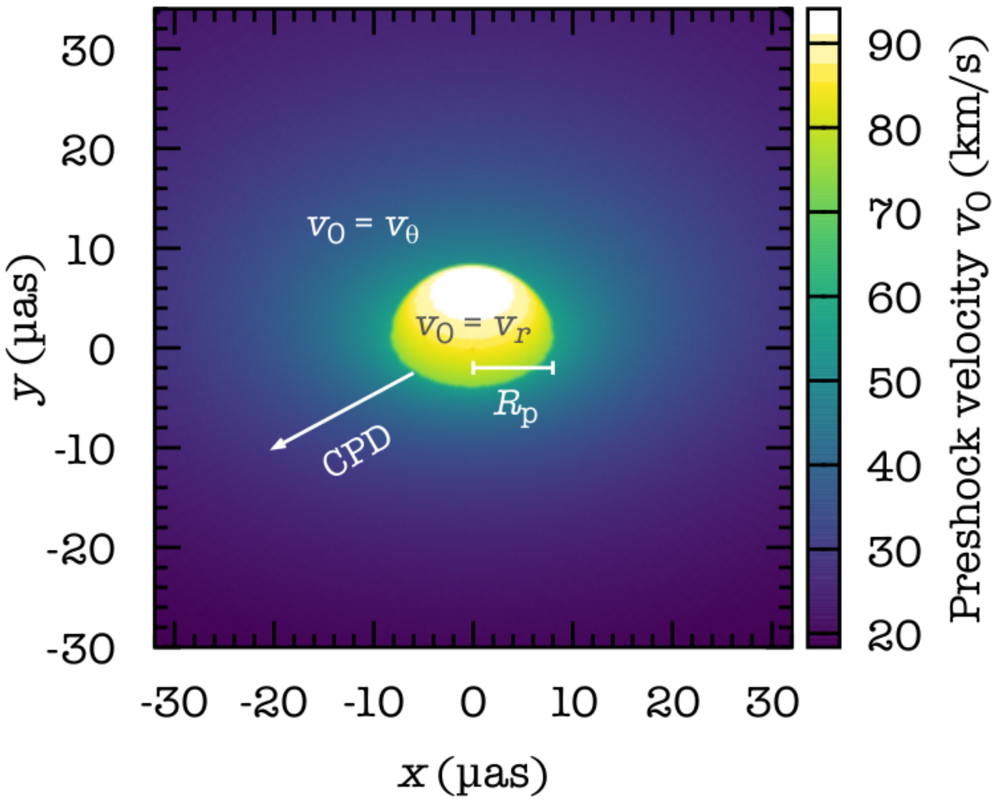
→ TWA27B is not an obscured high-mass object

Deeper analysis: find $f_{\text{fill}} \sim 0.01$–$0.4\%$
→ magnetospheric accretion

Aoyama et al. (2024)

Line emission regions

Marleau et al. in prep.



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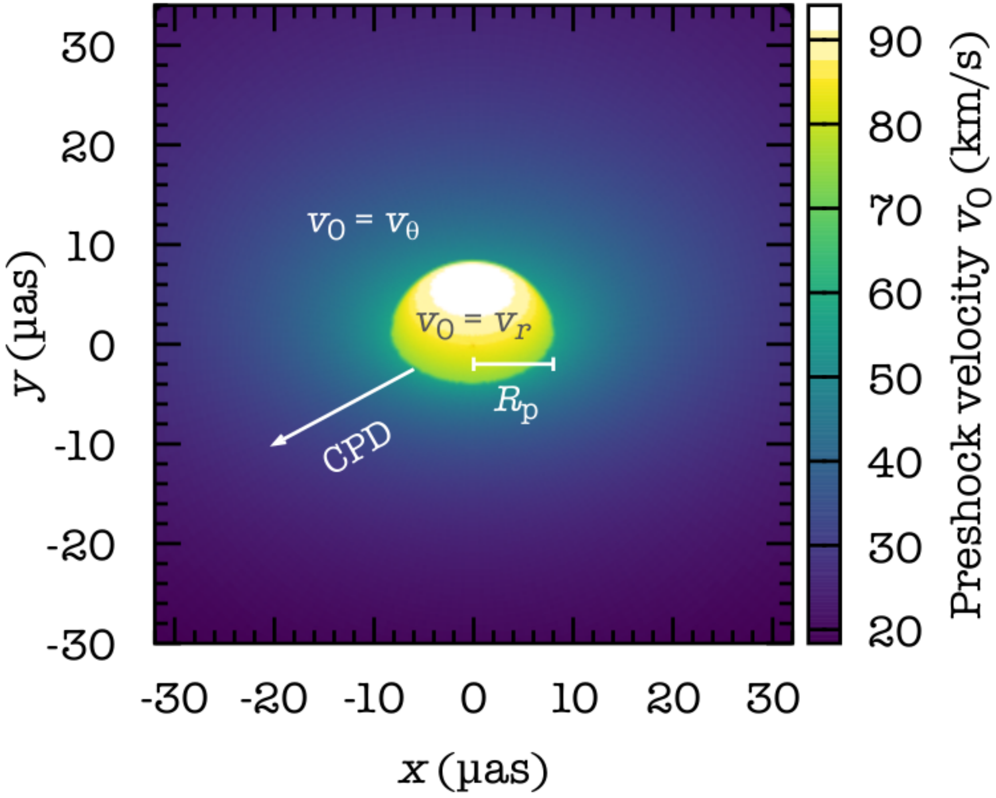

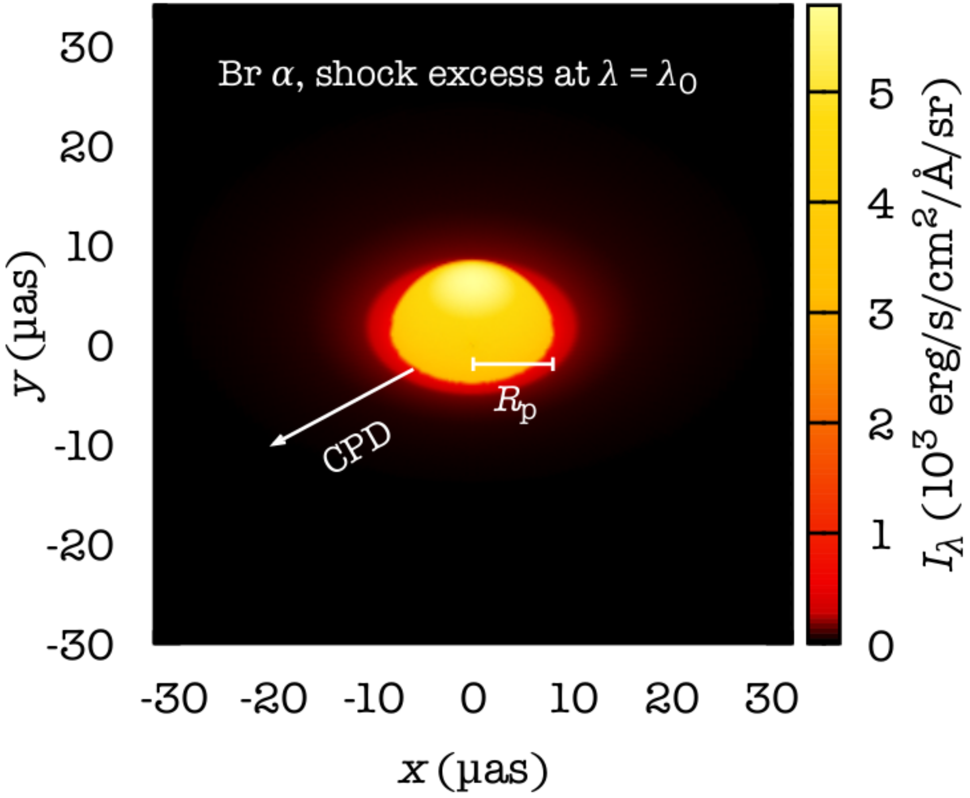

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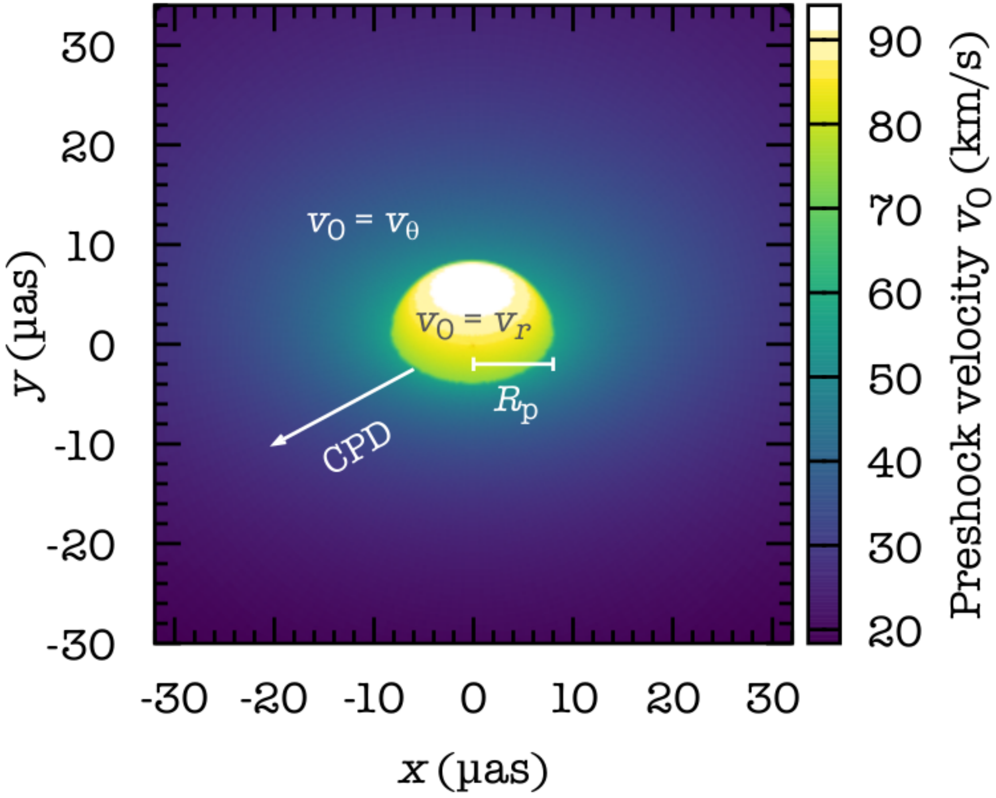

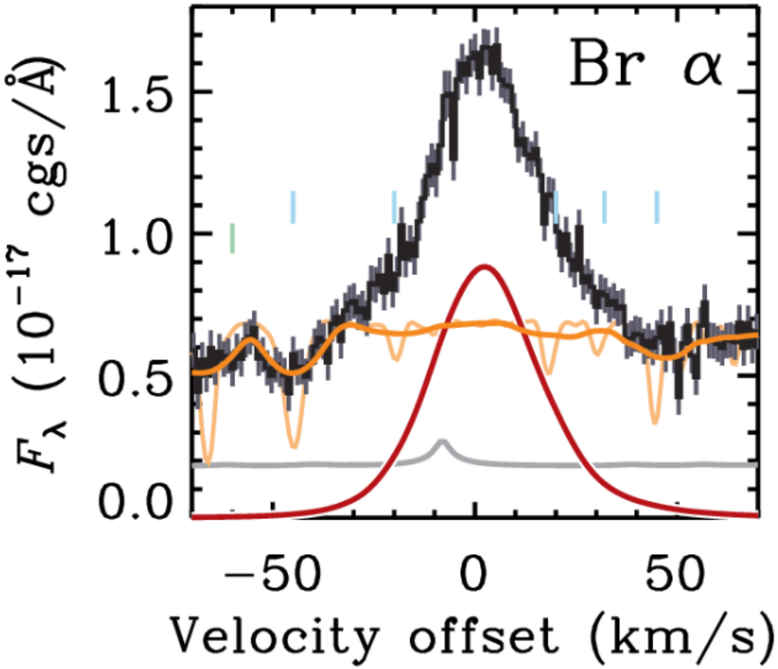

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Take-away points

- JWST/NIRSpec extremely sensitive even to low accretion rates
- Medium-resolution line profiles: some constraints on emission mechanism
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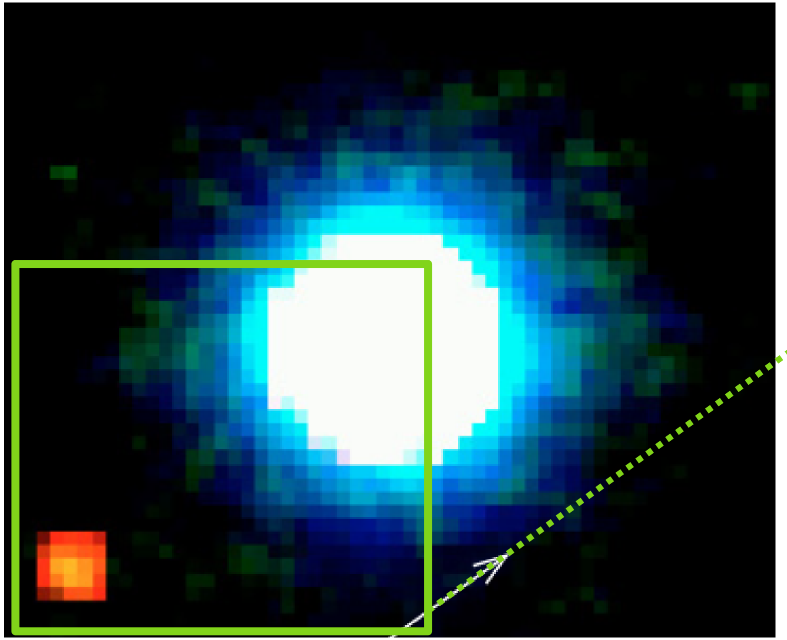
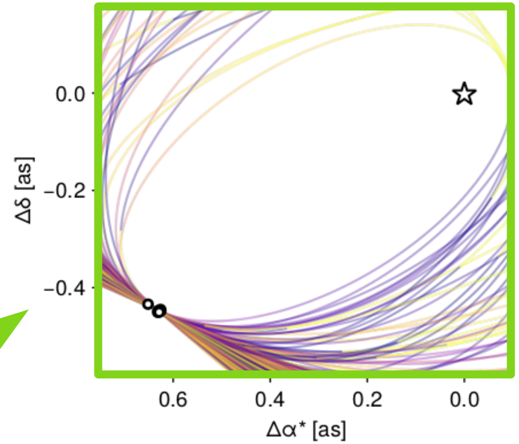
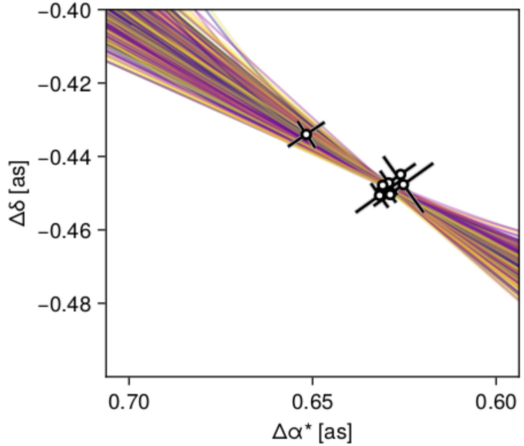
Merci pour votre attention!

Extra slides

Orbital constraints

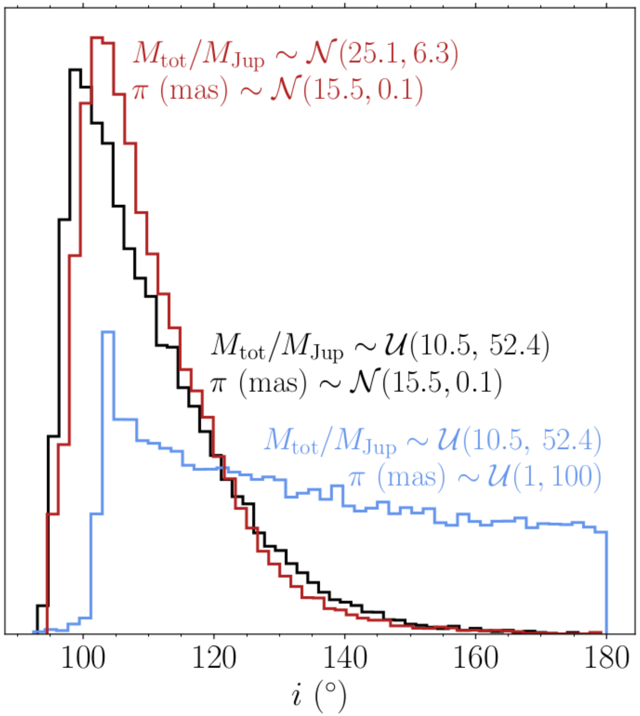






Inclination relatively well constrained!

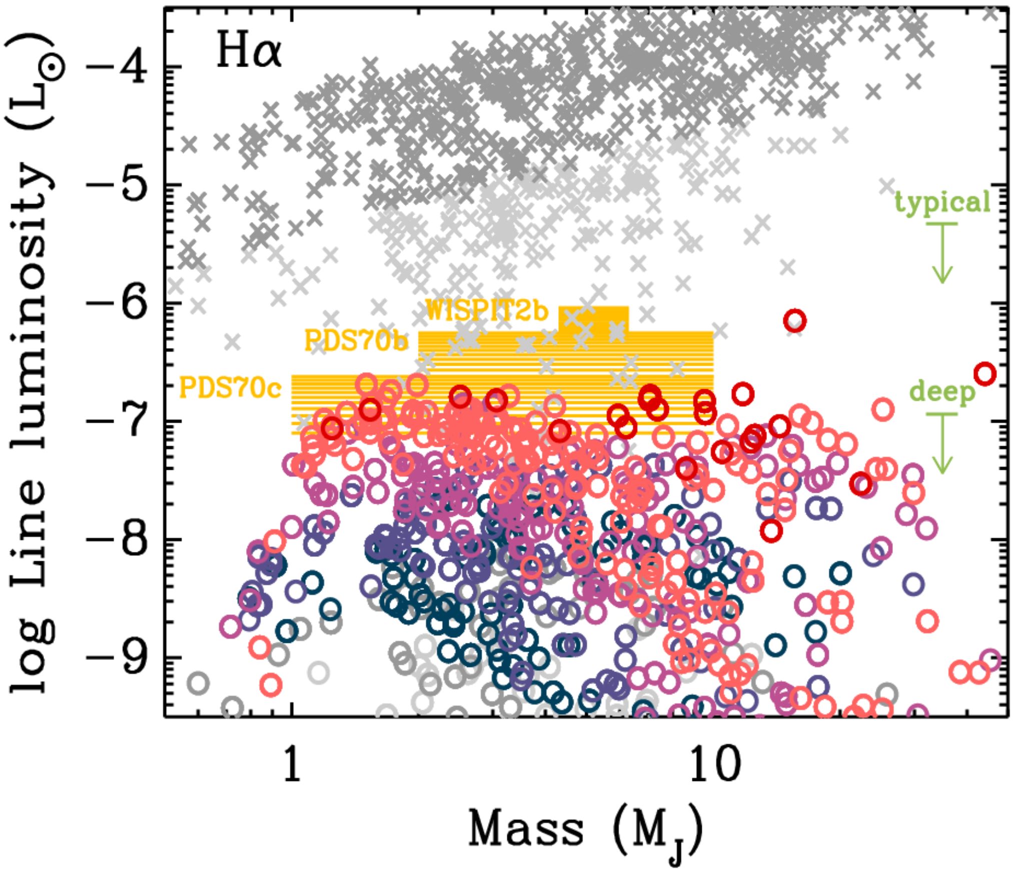
Adams et al. (2025)



Predicting line flux from dM/dt

Marleau (2025)

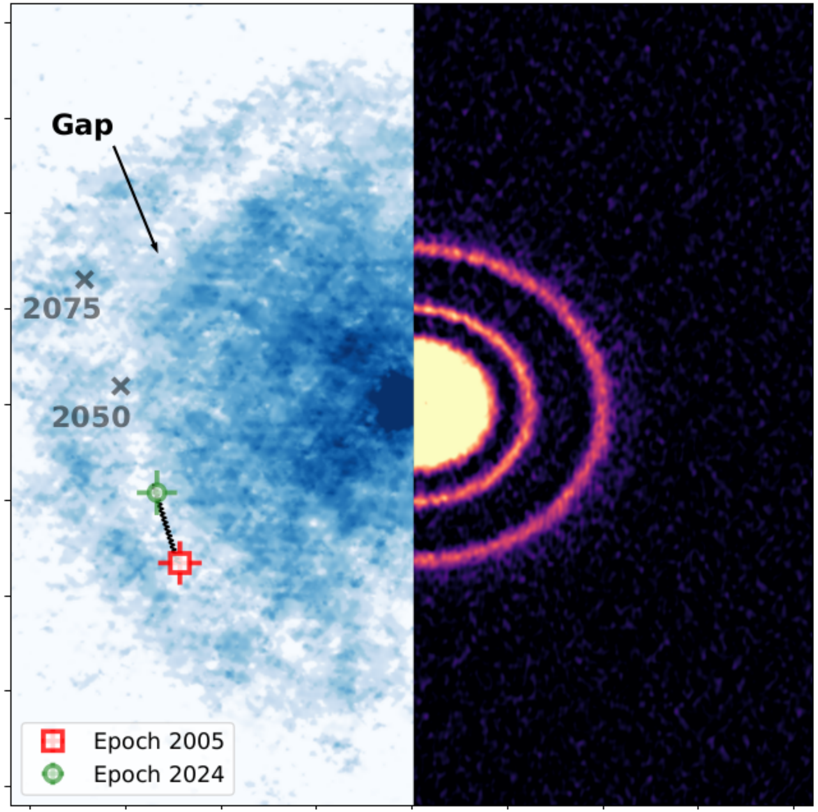
- Take synthetic forming planets
- Huge difference whether using "planetary" L_{acc}–L_{line} relationship and angular-momentum conservation (*coloured points*) or "stellar" and none (*grey*)



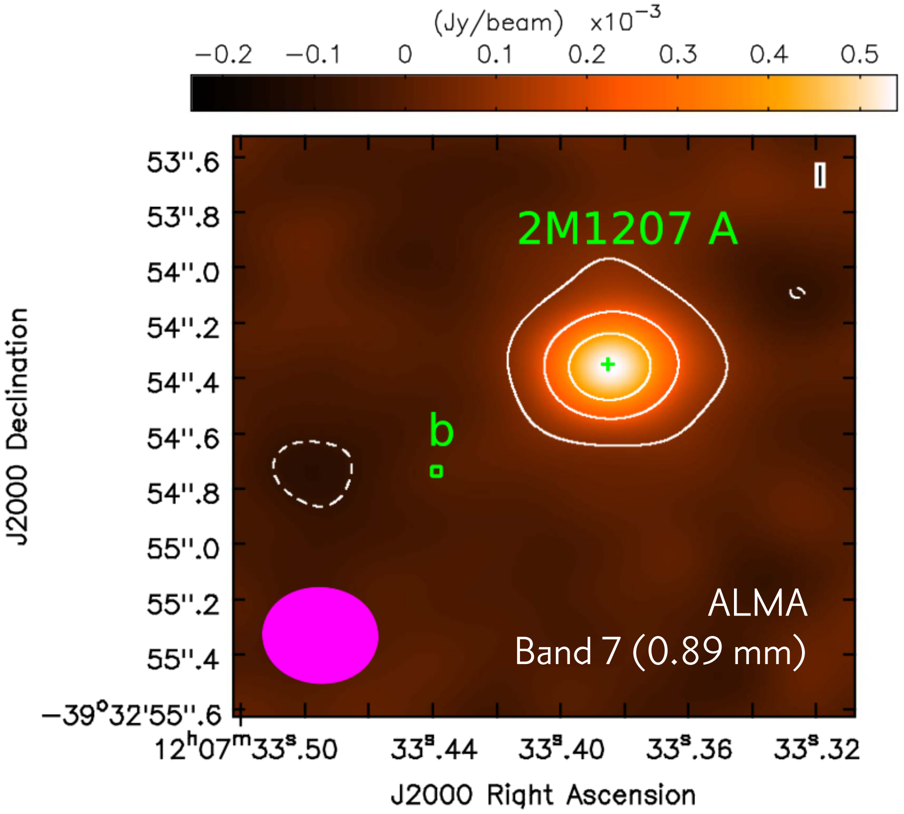
Extinction in gaps...

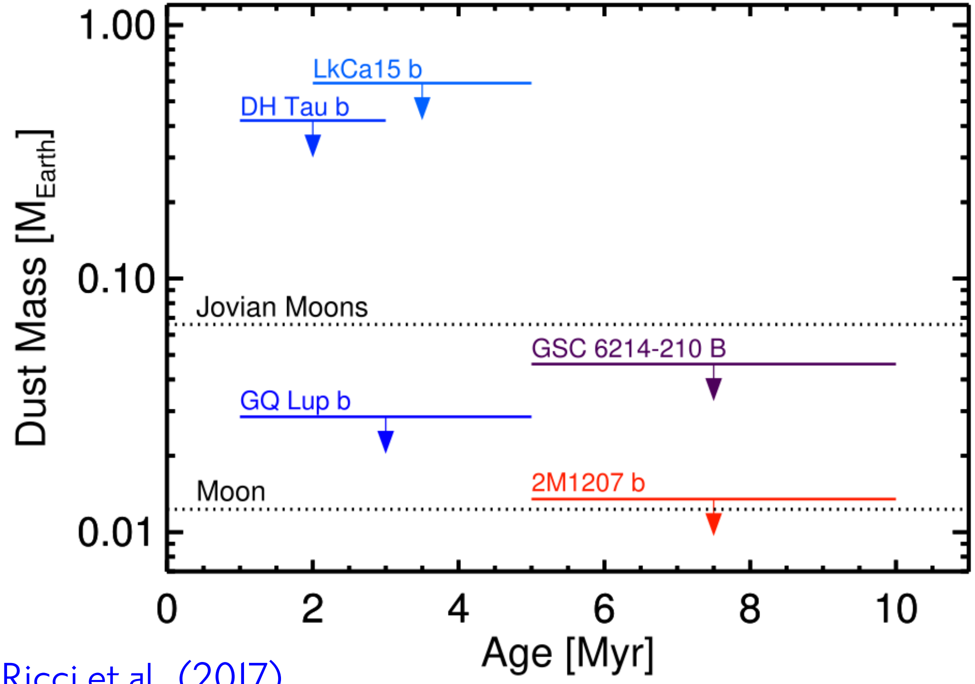
Cugno et al. (2025)

component. This points to the presence of grains in the disk outer gap that are larger than in the ISM. We find that the extinction in the gap at $\lambda \sim 4.0\ \mu$m is $A_{4\,\mu\mathrm{m}} = 2.7^{+0.7}_{-0.7}$ mag, while at Hα ($\lambda = 0.656\ \mu$m), where most searches for accretion signatures take place, the extinction could be as high as $A_{\mathrm{H}\alpha} = 4.2^{+0.9}_{-1.2}$ mag ($A_V = 4.6^{+1.0}_{-1.3}$). This suggests that even wide, deep gaps can significantly obscure emission from protoplanets, even those following a hot-start evolutionary model. Our extinction measurements help reconcile the discrepancy between ALMA-based predictions of planet-disk interactions and the non-detections from sensitive optical and near-infrared imaging campaigns.



Mass reservoir at TWA27B? Upper limit...





Ricci et al. (2017)

with old distance but no big change