

# Discovery of CH<sub>4</sub> and metallicity constraint in an ultracool extremely metal-poor atmosphere

Jun-Yan Jerry ZHANG

PhD ABD

Representing: N. Lodieu, E.L. Martín, P. Tremblin, M.R. Zapatero Osorio,  
V.J.S. Béjar, N. Vitas, B. Gauza, Ya. Pavlenko, R. Rebolo



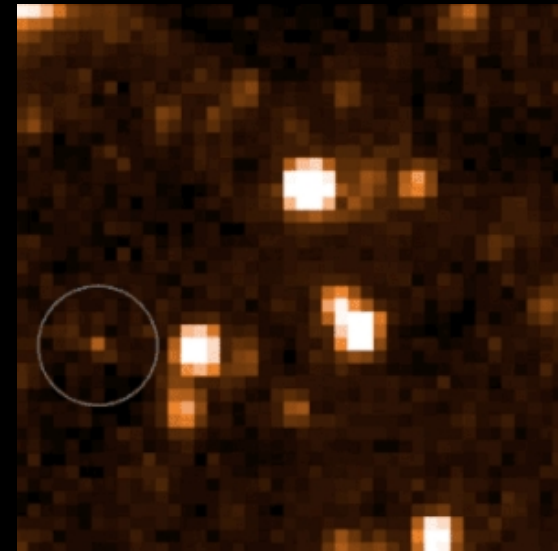
# Metal-poor brown dwarf

- **BD** preserves original element ingredients
- Halo/thick disk population (Pop.II) are as old as our Galaxy.
- We want to know the Galaxy evolution, cosmic dawn chemistry
- We want to know the metal-poor substellar evolution model & metal-poor ultracool atmospheric model
- They are **metal-poor, namely subdwarf: sd**
  - **Extreme: esd**
  - **Ultra: usd**



# Metal-poor brown dwarfs are few...

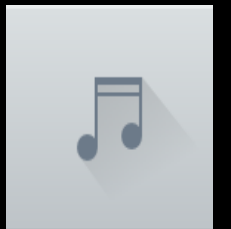
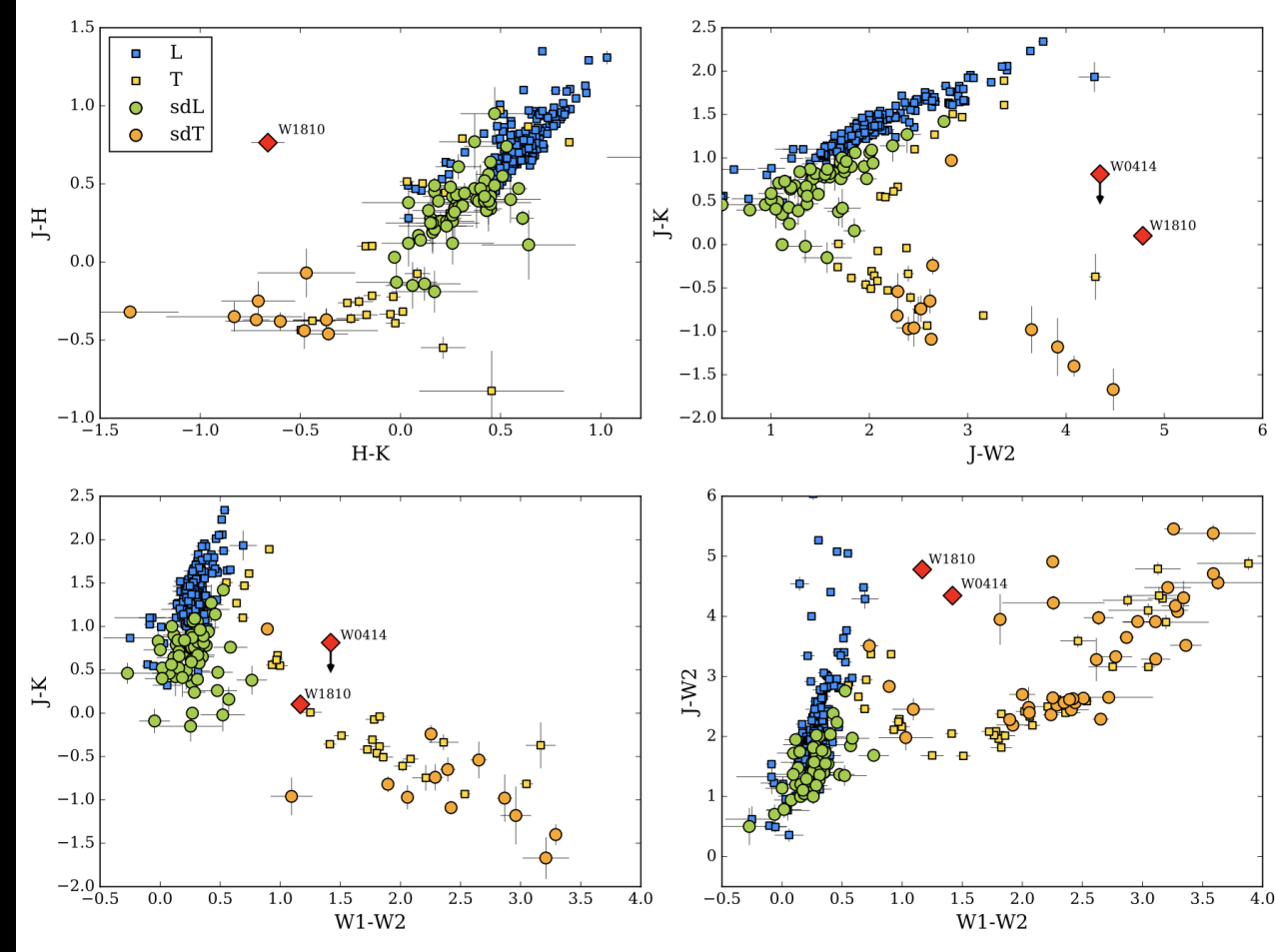
- BDs are small and cold  
→ **faint** (spec. type **M, L, T, Y**)
- Metal-poor BDs are **old**, no H-fusion  
→ even colder & **fainter** (T, Y)
- Halo/thick disk members are **rare**  
searching radius limited to 100pc
- Halo/thick disk members **move fast**  
( $> 1''/\text{yr}$ )
- Till today
  - ~20 metal-poor sdT candidates
  - 1 metal-poor sdY
  - Mainly discovered by WISE





# Our target

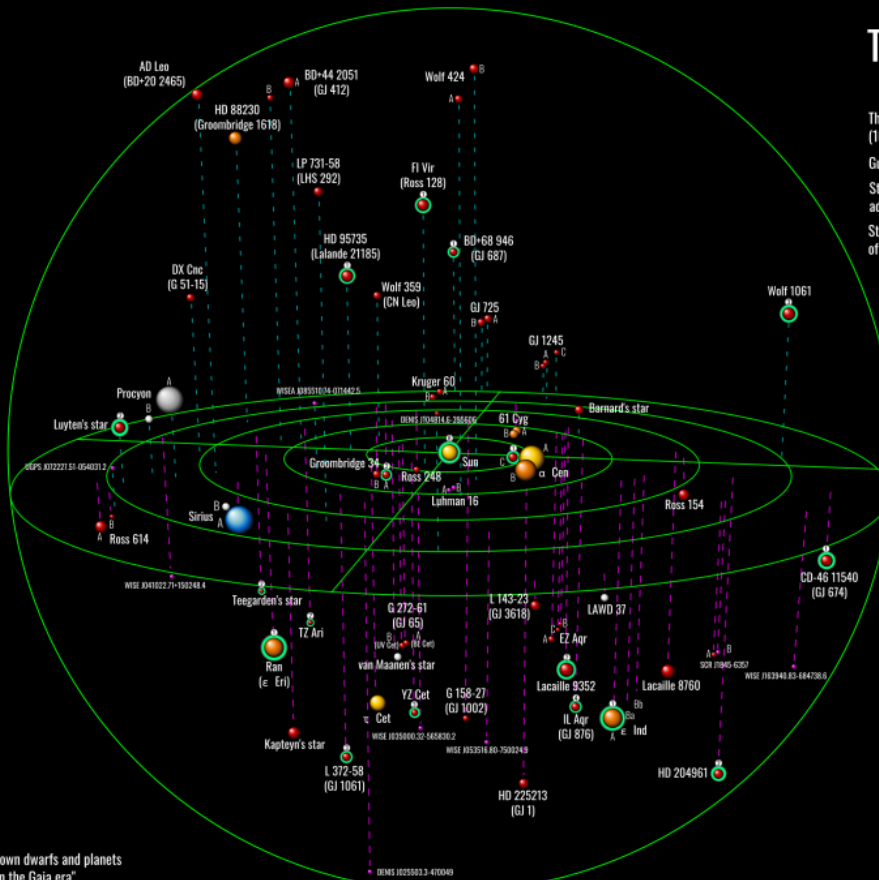
- WISEA J181006.18–101000.5
- Identified as high-proper-motion candidates in NeoWISE survey
- Discovered in the Backyard Worlds
- Peculiar colors





# Our closest metal-poor neighbor

- 8.9 pc from a robust parallax measurement



## The Closest Stars

The Sun and the other star systems within 5 parsecs (16 light years)

Guide circles in the galactic plane, every 1 parsec.

Star positions are not exact and may have been adjusted slightly to aid in visualization.

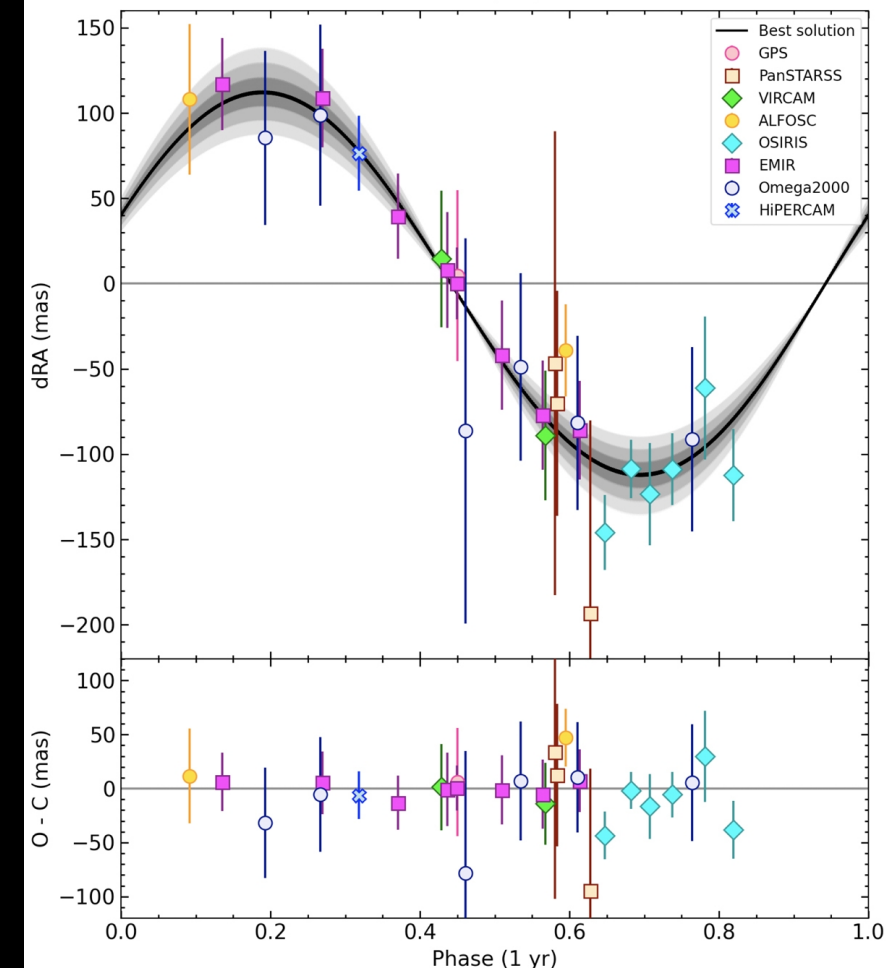
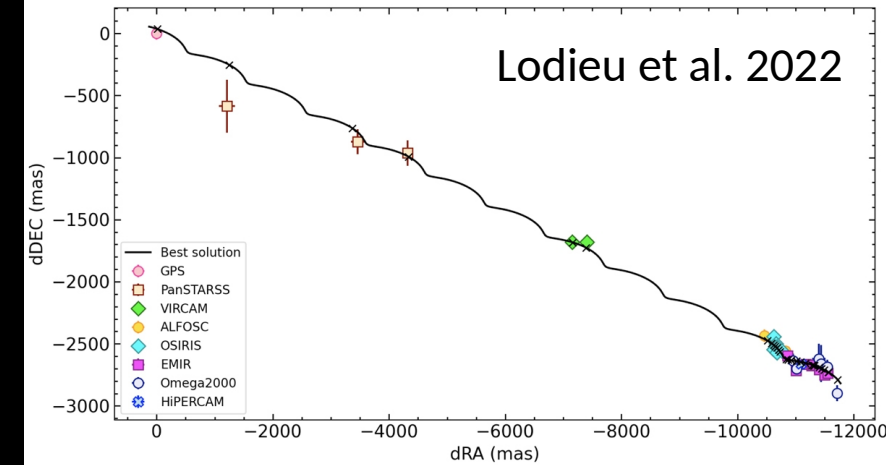
Stars with light green circles have the stated number of confirmed exoplanets.

- A-type
- F-type
- G-type
- K-type
- M-type
- Brown dwarf
- White dwarf

**Galaxy Map**  
Twitter: @galaxy\_map

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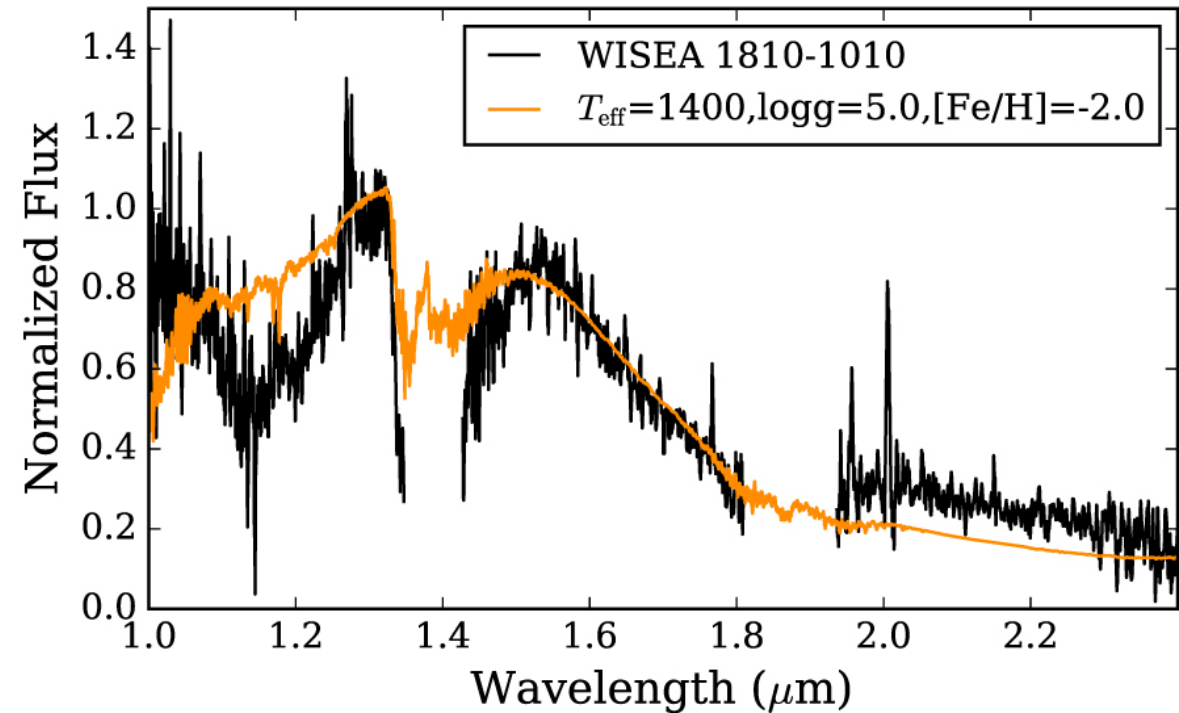
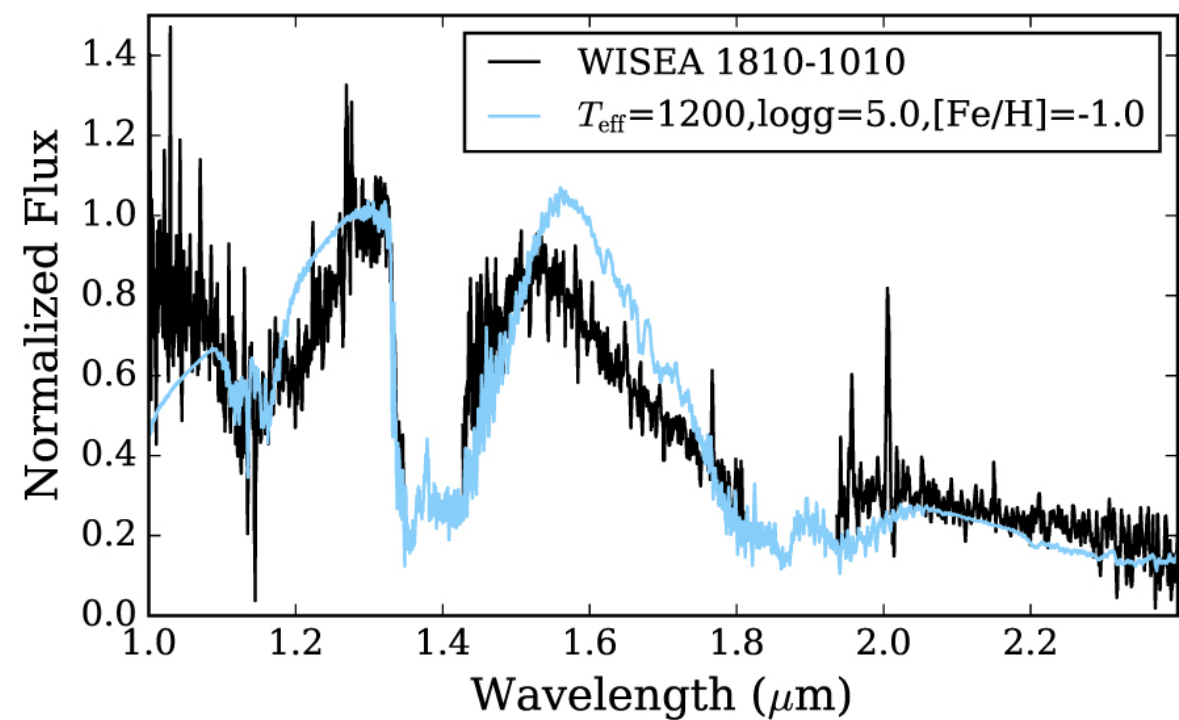
Based on the catalog of stars, brown dwarfs and planets described in "The 10 pc sample in the Gaia era", Reylé, Jardine et al, Astronomy & Astrophysics (2021).



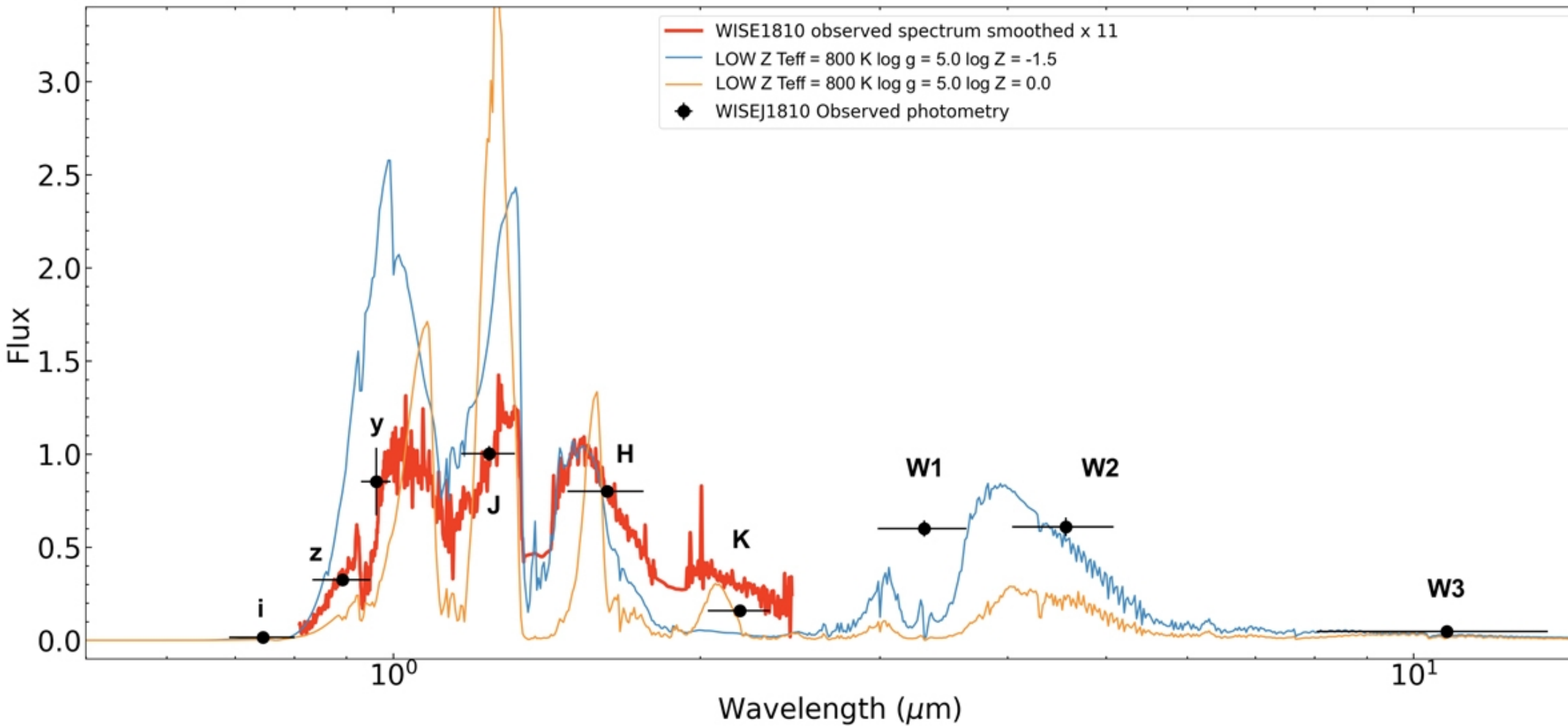


# Previous spectroscopy

- No methane
- Strong CIA H<sub>2</sub>
- Inferred T = 1300 K - 800 K
- No good template fit
- Nor model fit







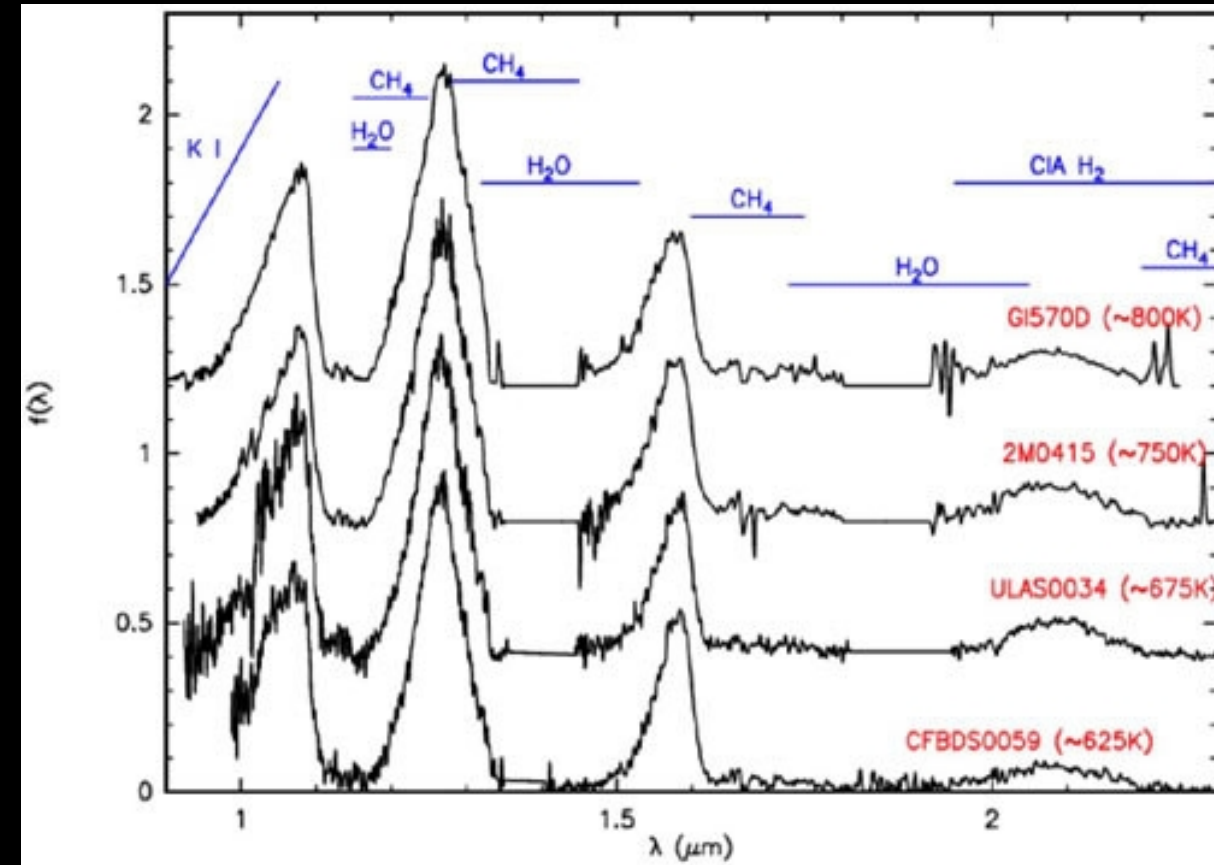
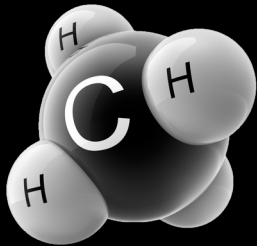


Name	Parameter	Value
Parallax	$\omega$	$112.5^{+8.1}_{-8.0}$ mas
Distance	$d$	$8.9^{+0.7}_{-0.6}$ pc
Proper motion in RA	$\mu_{\alpha}\cos\delta$	$-1027.0 \pm 3.5$ mas yr $^{-1}$
Proper motion in dec	$\mu_{\delta}$	$-246.4 \pm 3.6$ mas yr $^{-1}$
Heliocentric velocity	$v_h$	$45.6 \pm 3.5$ km s $^{-1}$
Tangential velocity	$v_t$	$44.5 \pm 3.6$ km s $^{-1}$
Galactic velocity	$U$	$-36.9 \pm 2.9$ km s $^{-1}$
Galactic velocity	$V$	$-44.5 \pm 1.8$ km s $^{-1}$
Galactic velocity	$W$	$-29.1 \pm 2.7$ km s $^{-1}$
Luminosity	$\log (L/L_{\odot})$	$-5.78 \pm 0.11$ dex
Bolometric magnitude	$M_{\text{bol}}$	$19.850^{+0.082}_{-0.074}$ mag
Effective temperature	$T_{\text{eff}}$	$800 \pm 100$ K
Gravity	$\log g$	$5.0 \pm 0.25$ dex (cm s $^{-2}$ )
Metallicity	[Fe/H]	$-1.5 \pm 0.5$ dex
Radius	$R$	$0.067^{+0.032}_{-0.020} R_{\odot}$
Mass	$M$	$17^{+56}_{-12} M_{\text{jup}}$

# Classified as esdT0-3, but T dwarf ...



- $500\text{ K} < T < 1300\text{ K}$
- Known as methane dwarf
- Characteristic molecule:  $\text{CH}_4$





# What is the problem?

- Wrong classification as esdT?
- New spectral classification scheme?
- Physical parameter wrongly measured?
- Binary?
- Strongly modified atmosphere chemistry in metal-poor environment?

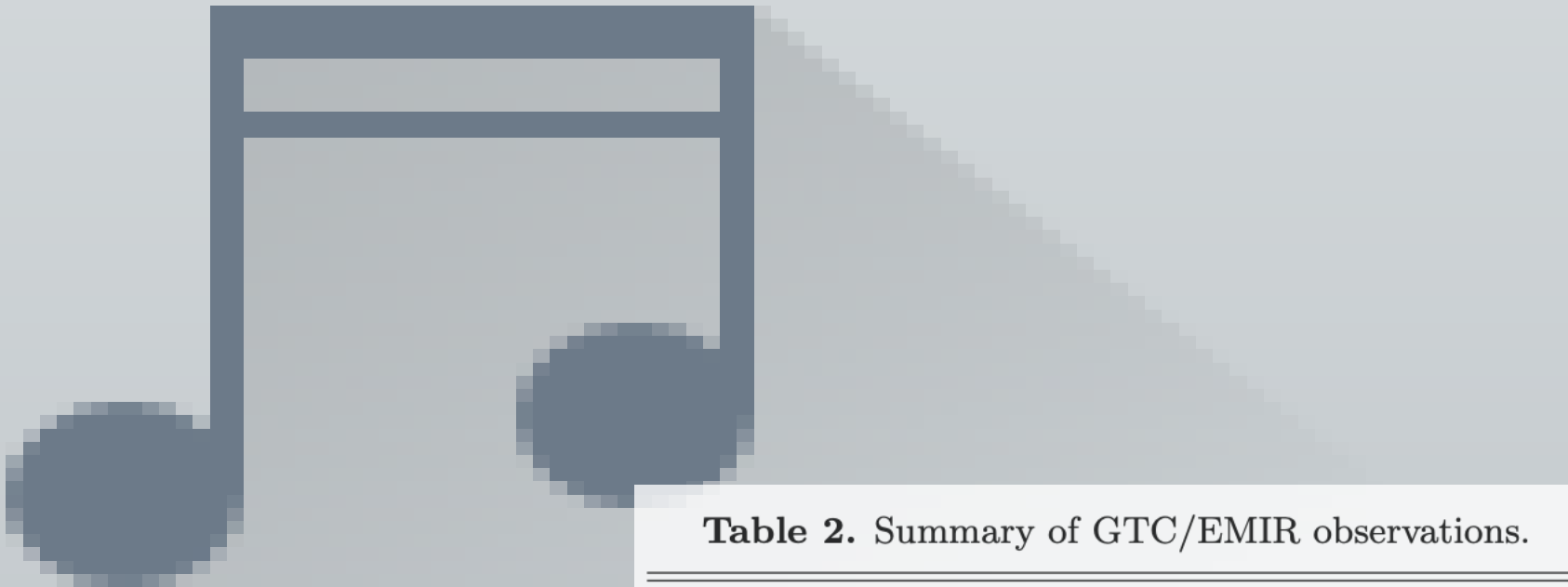


# GTC observation





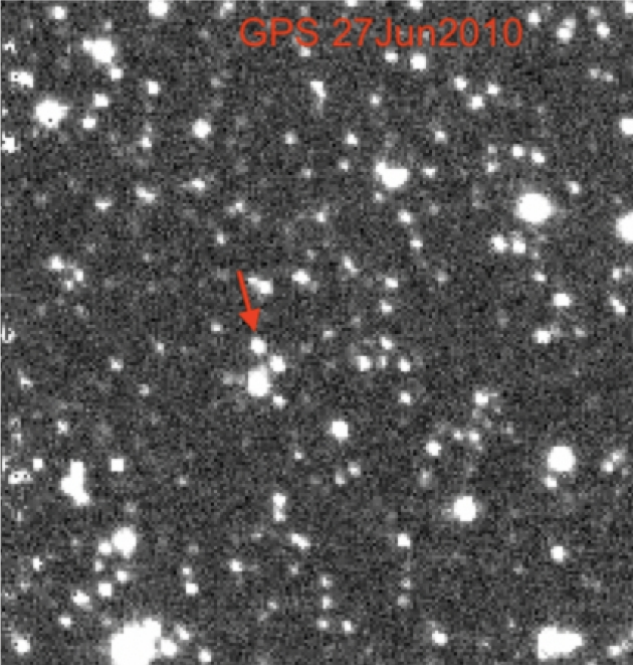
- Instrument: EMIR (Infrared multi-object spectrograph of GTC)
- *JHK* mid resolution grism  $R \sim 5000$
- Visitor mode 5 days
- Sahara Haze
- Superb seeing



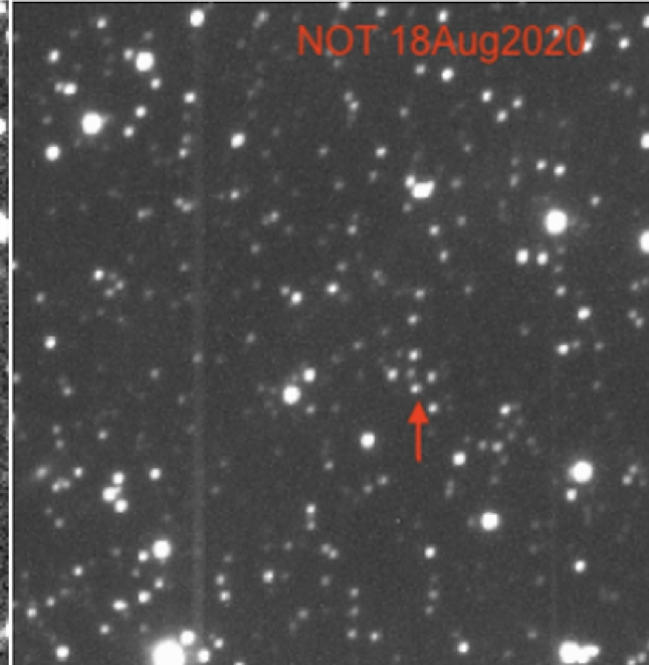
**Table 2.** Summary of GTC/EMIR observations.

Target	MJD	Exp.	Seeing	Fil/Grism
WISE1810	60512.90	7×10s	0''6	<i>J</i>
WISE1810	60512.91	7×10s	0''6	<i>K<sub>s</sub></i>
WISE1810	60512.91	7×10s	0''6	<i>H</i>
WISE1810	60513.03	24×360s	0''6	spec <i>J</i>
WISE1810	60514.00	36×360s	0''5	spec <i>H</i>
WISE1810	60515.00	36×360s	0''5	spec <i>K</i>
WISE1810	60516.00	36×360s	0''5	spec <i>K</i>
WISE1810	60517.00	12×360s	0''5	spec <i>J</i>



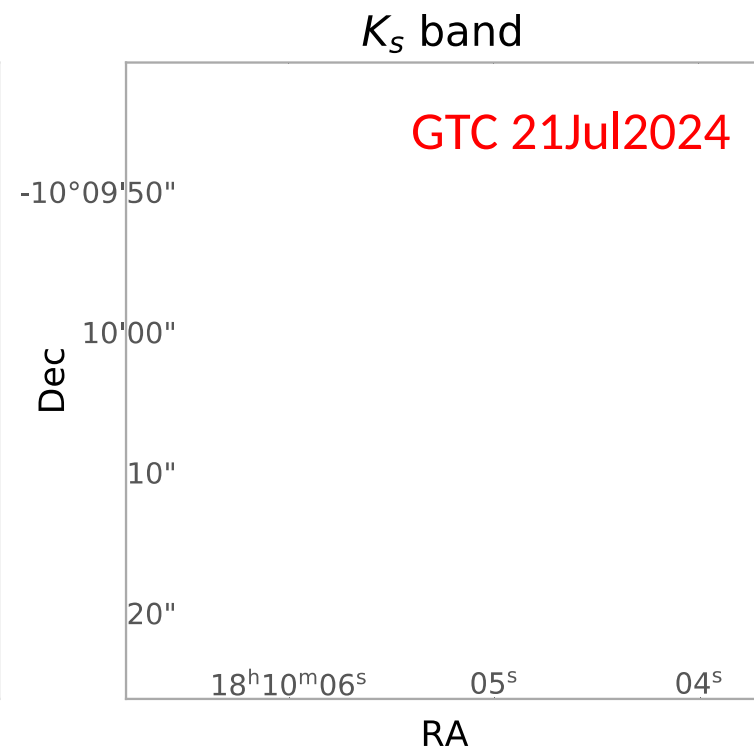
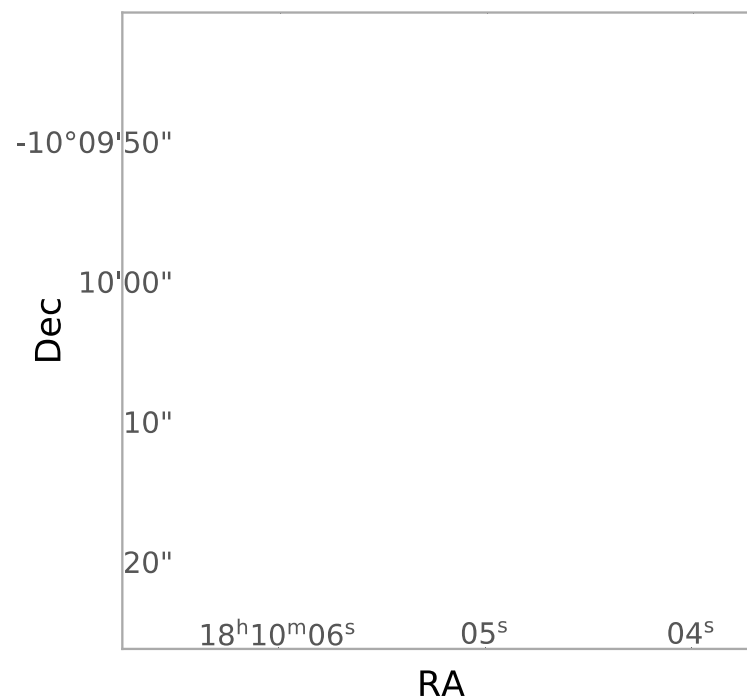
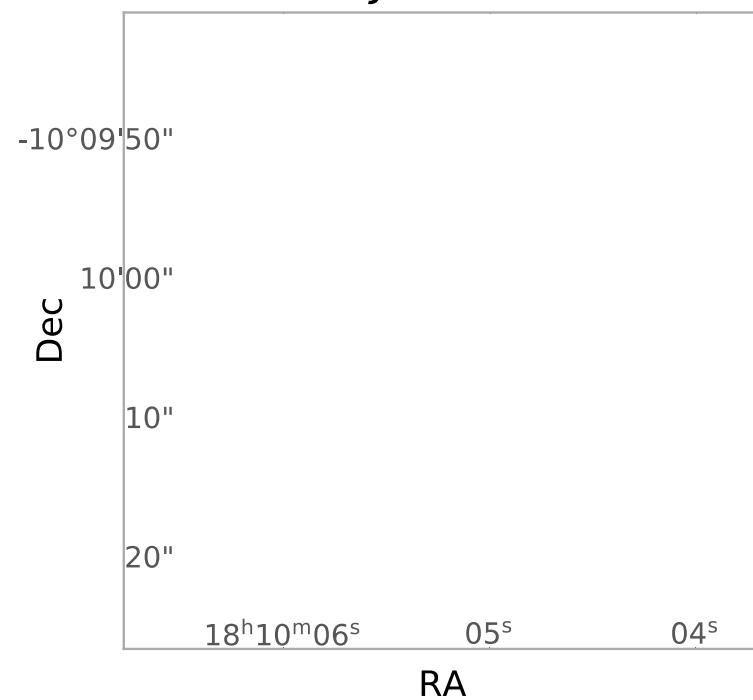


*J* band

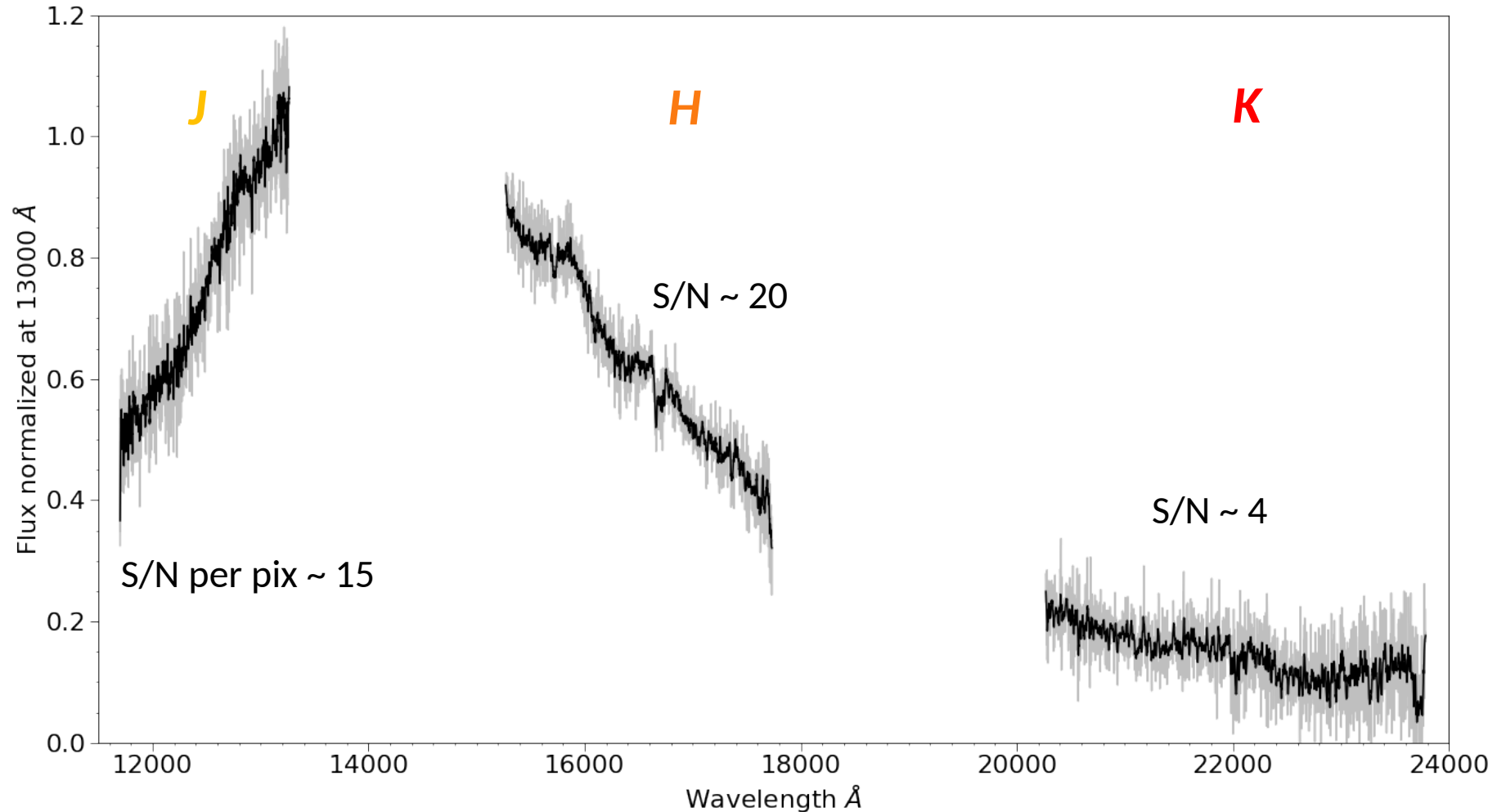


*H* band

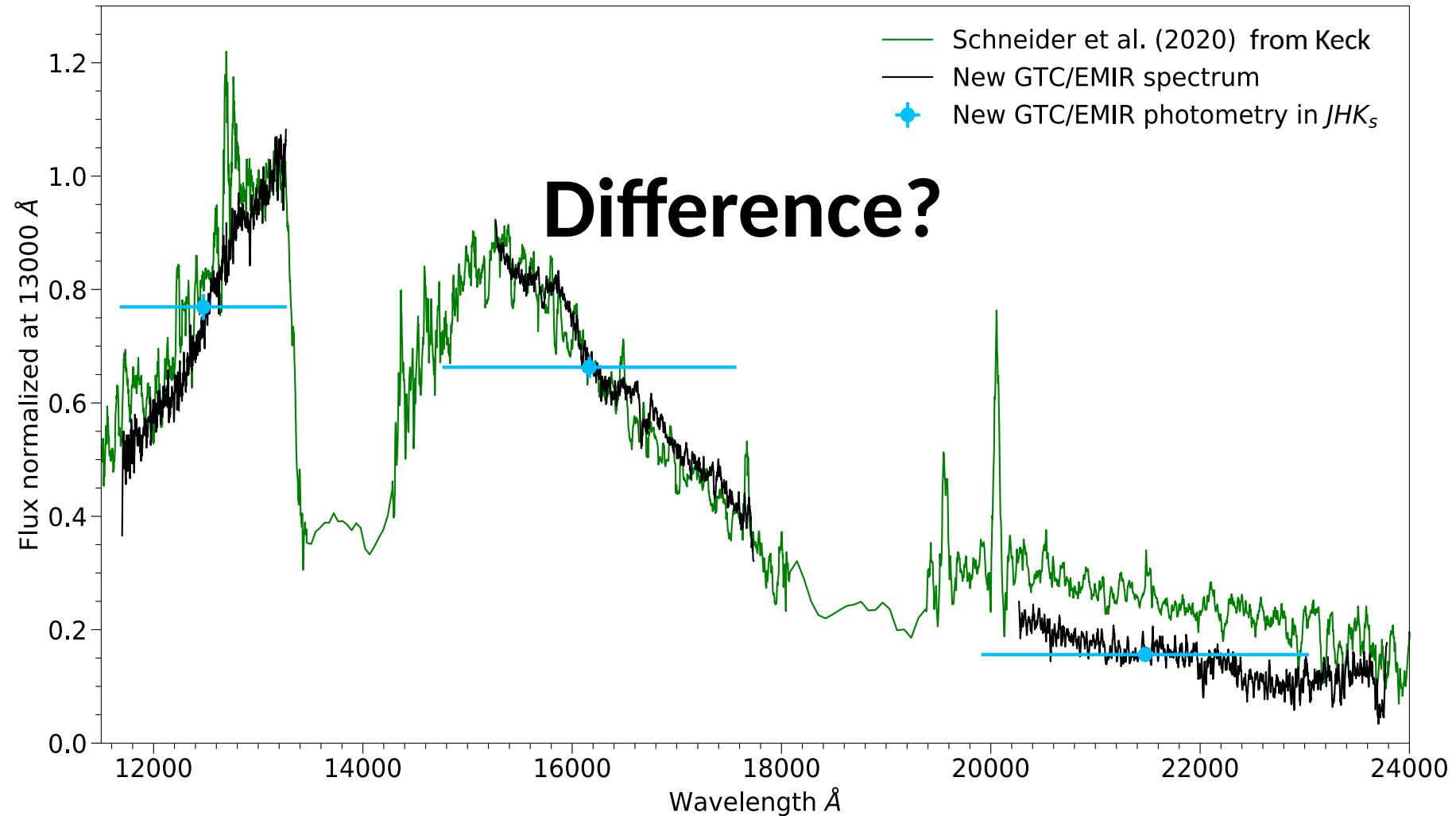
- 2024 WISE1810 was on a relatively empty field!



# NIR high-Q medium-R Spectroscopy

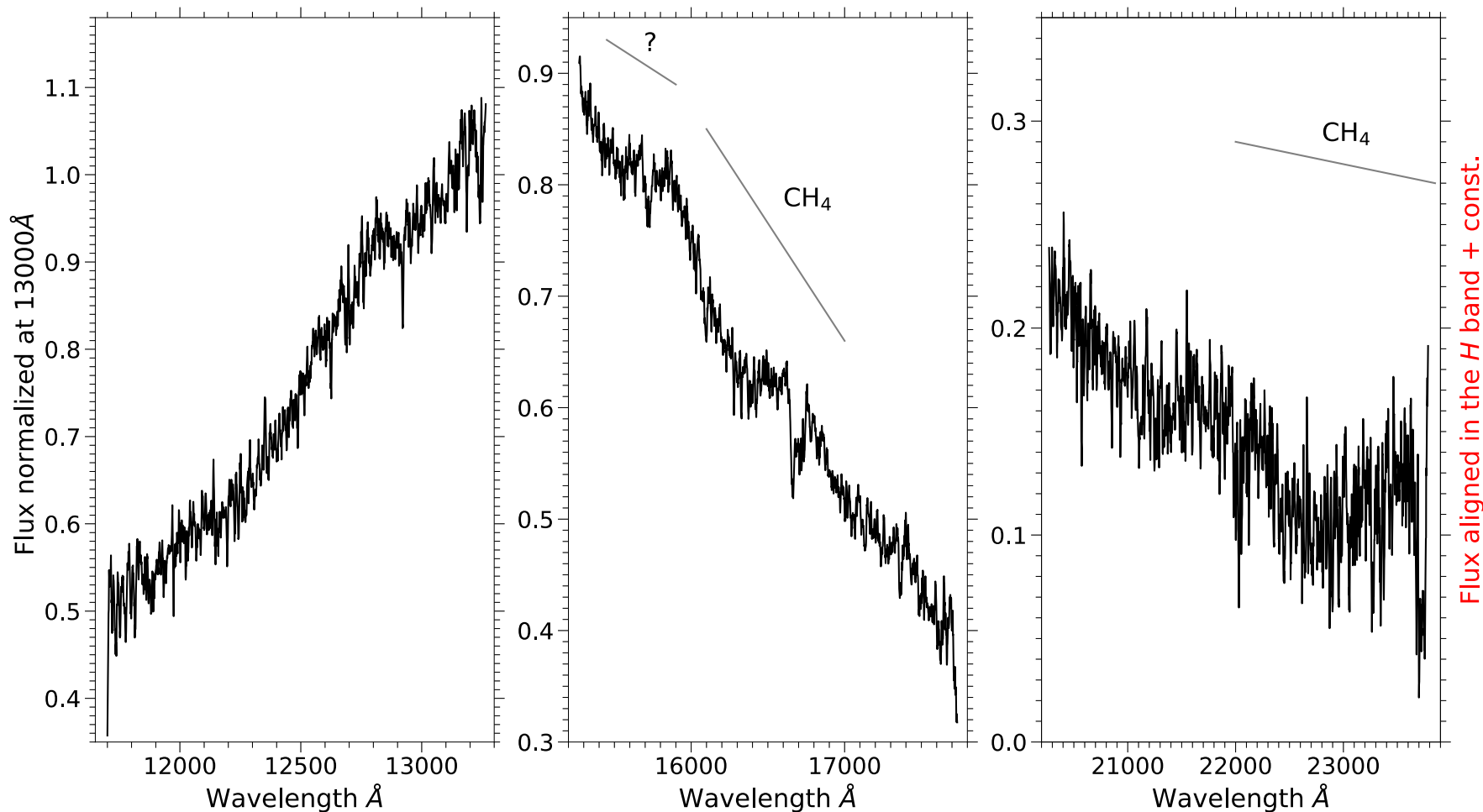


# NIR Spectroscopy comparison

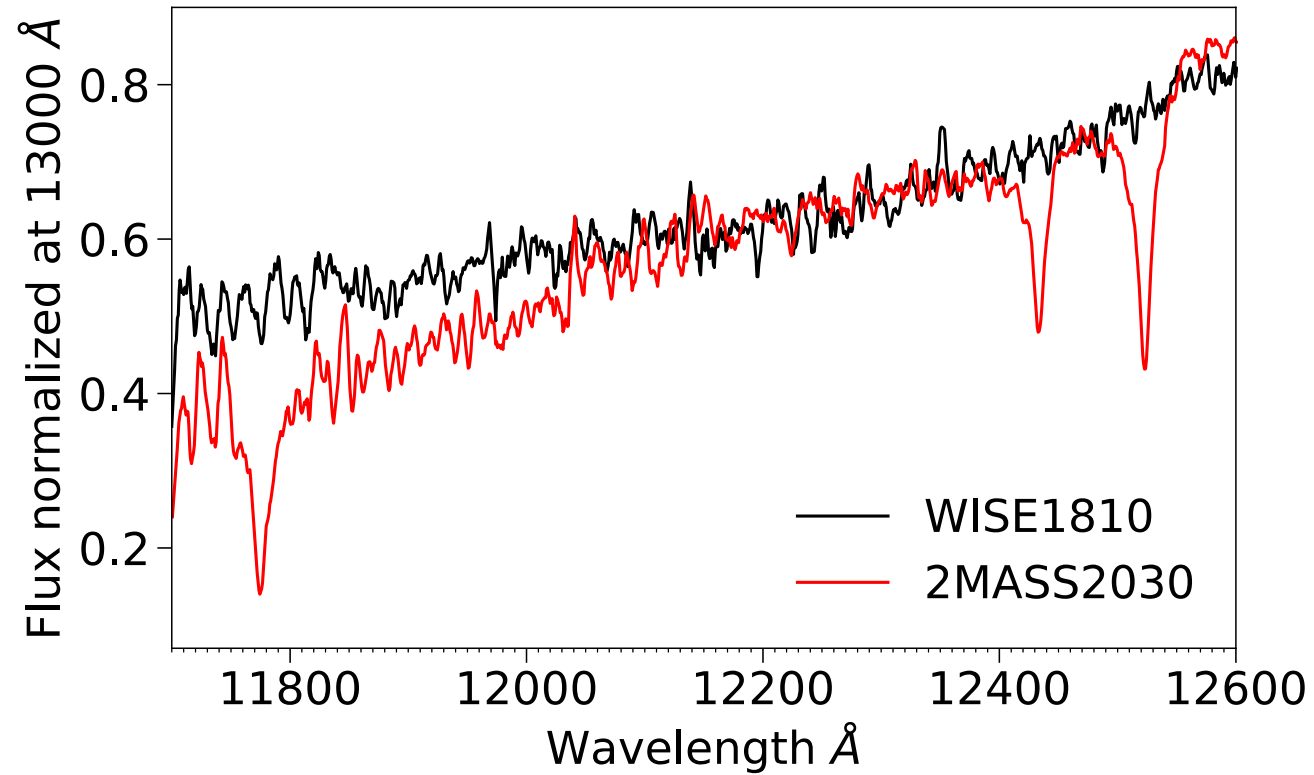




# We undoubtedly detected **CH<sub>4</sub>** !! But no CO ...



# Still no potassium



# Observationally:

- Confirms as a T dwarf by definition
- Favors a cooler temperature:  $< 1200$  K
- Favors a low metallicity



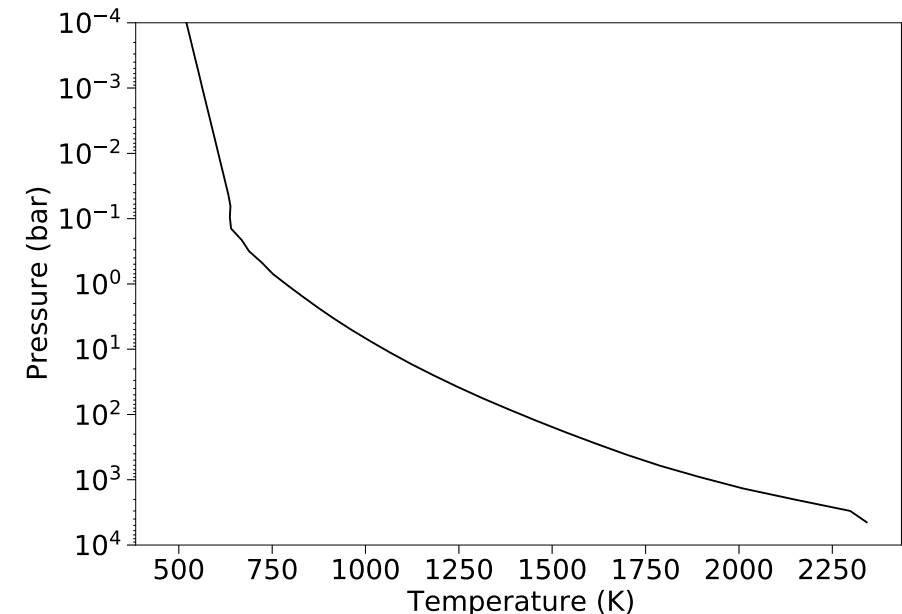


# Model fit

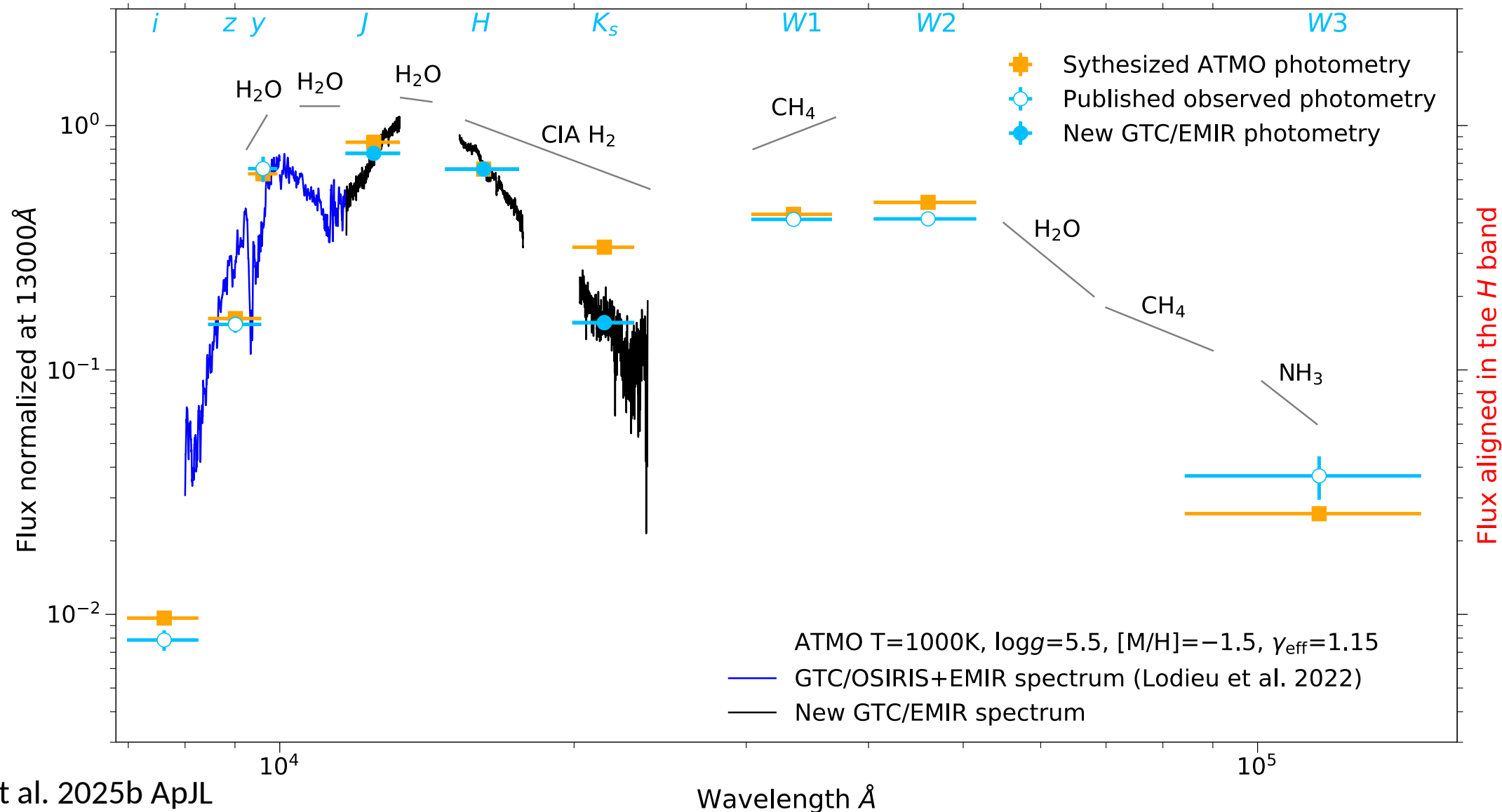
- ~~ATMO2020++~~ (Leggett et al. 2021; Meisner et al. 2023)
- ~~Grid step size~~
  - 100 K for Temp.
  - 0.5 dex for  $\log g$
  - 0.5 dex for  $[M/H]$
- Adjust TFP profile, and adiabatic coefficient..
- Lowering  $[M/H]$  to match the  $\text{CH}_4$  feature

## Result:

- $T$   $10000 \pm 1000 \text{ K}$
- $\log g$   $5.55 \pm 0.5 \text{ dex}$
- $[M/H]$   $-1.5 \pm 0.2 \text{ dex}$



# Model fit



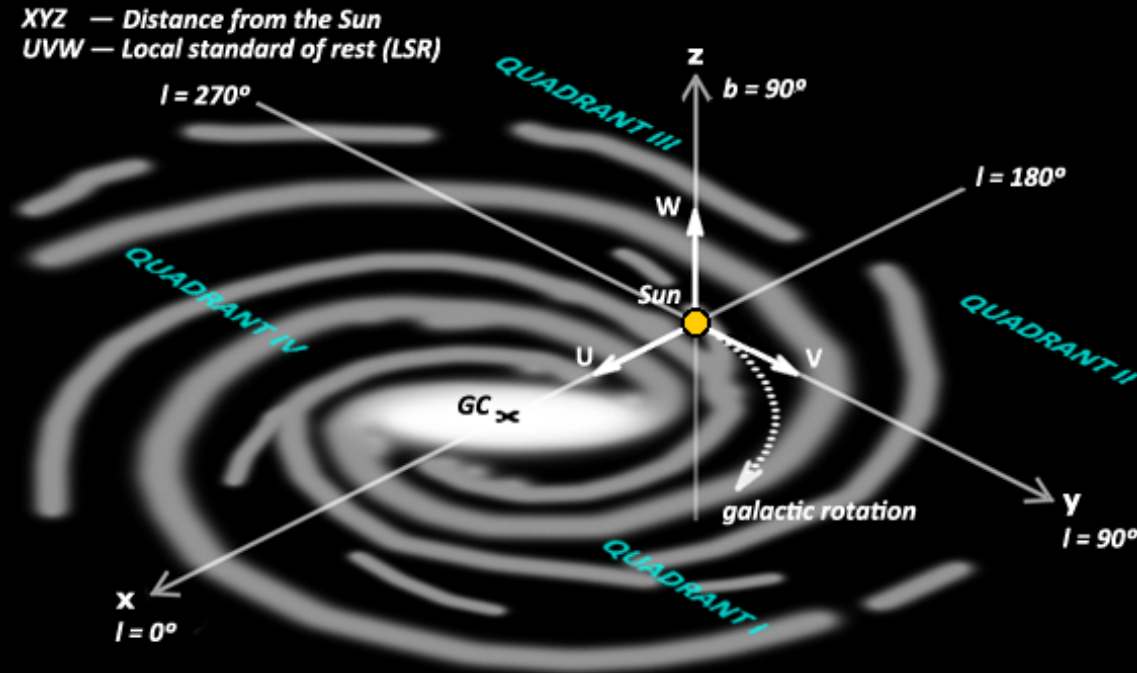
# Methane and metallicity?

- $\text{CH}_4$   $17 \pm 6$  ppm
- $[\text{M}/\text{H}]$   $-1.5 \pm 0.2$  dex
- $[\text{C}/\text{Fe}]$  0.2 dex for thick disk stars (Nissen et al. 2014)
- $[\text{Fe}/\text{H}]$   $-1.7 \pm 0.2$  dex



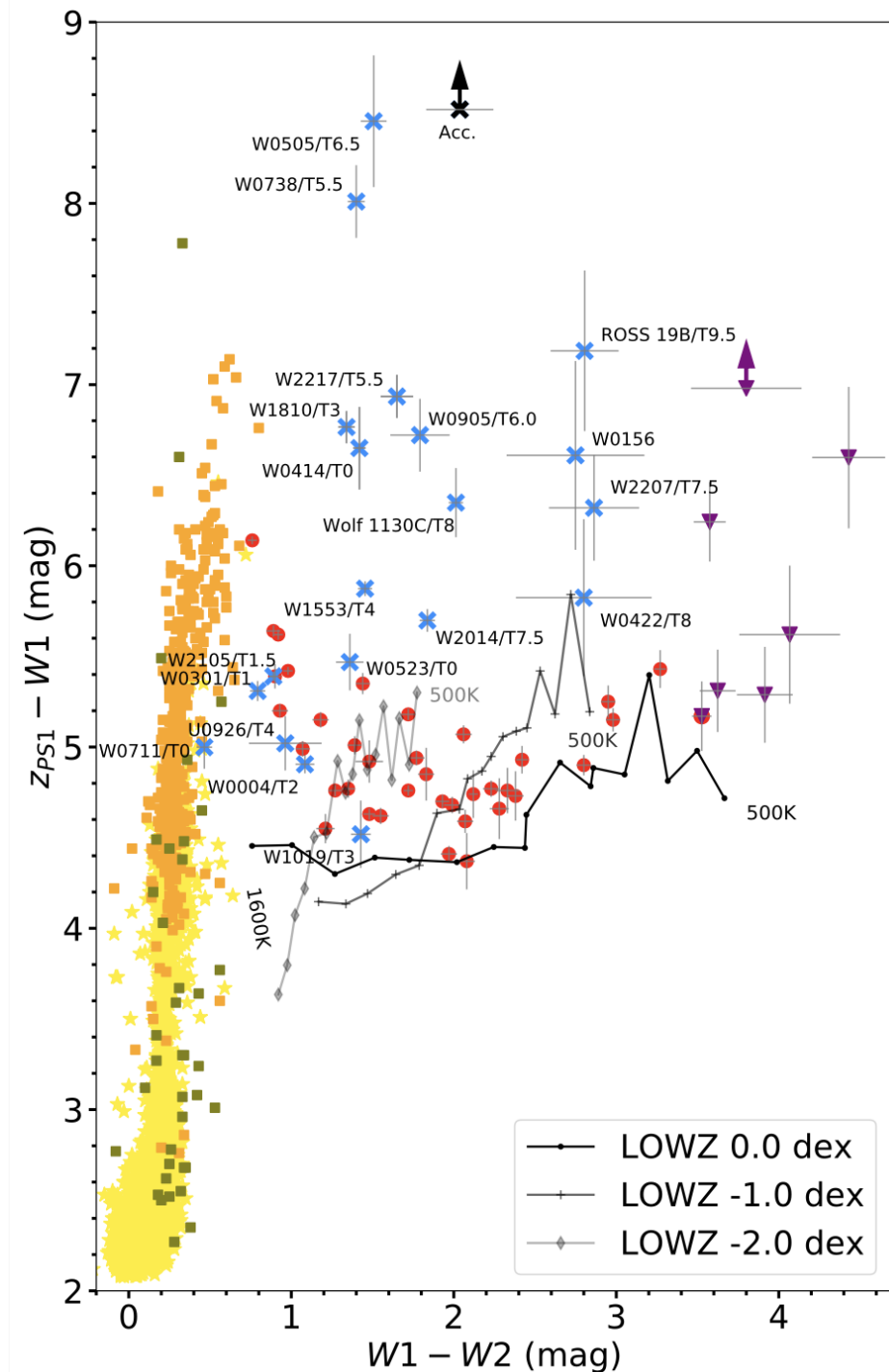
# Why thick disk? RV measurement.

- Triple-band CCF
- Heliocentric RV  $-83 \pm 13$  km/s
- $UVW$  wrt LSR  $(-62 \pm 13, -43 \pm 5, -33 \pm 2)$  km/s



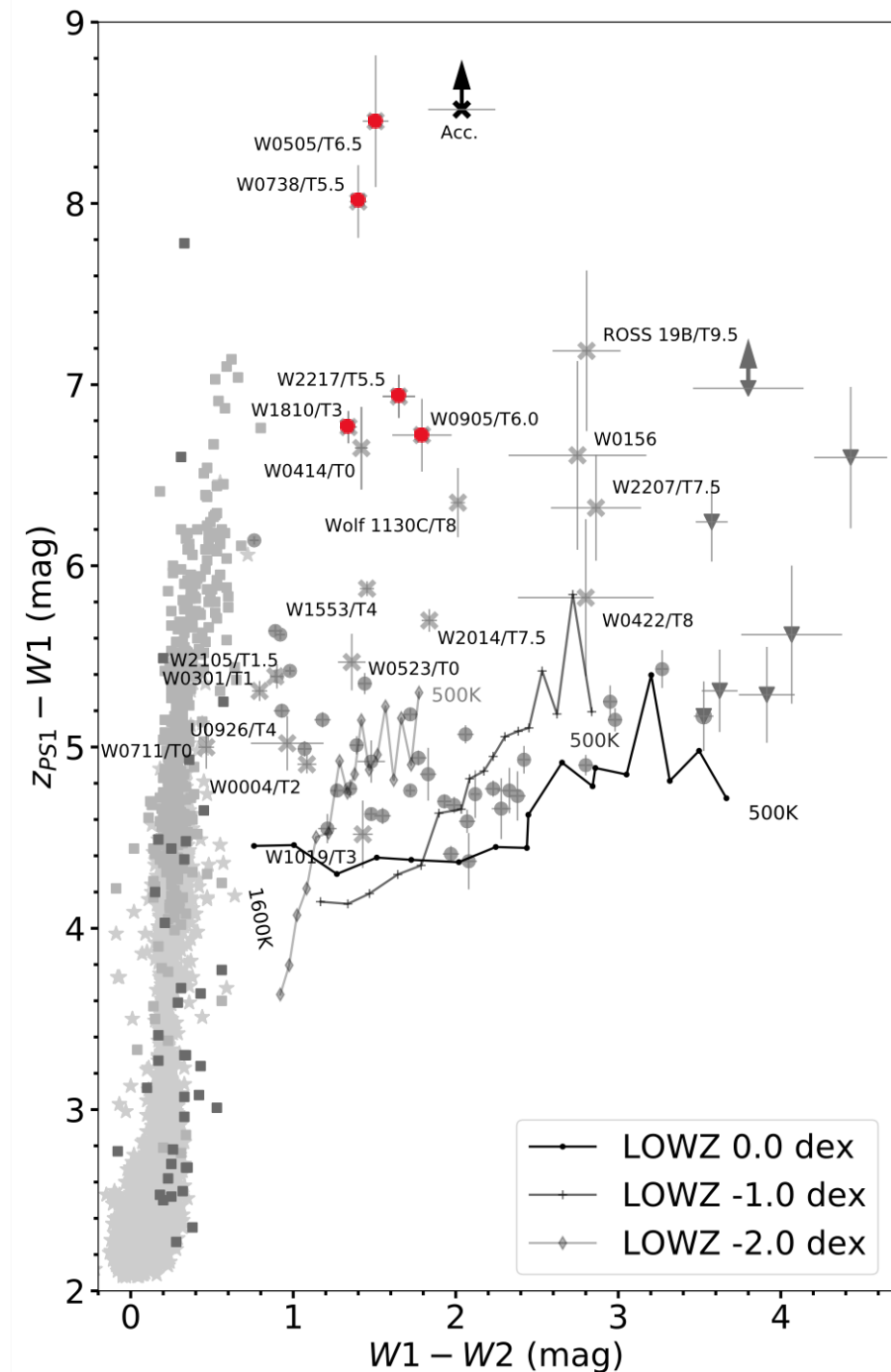
# More esdT<sub>s</sub>?

- We found an indicator of metallicity for objects as cool as T and Y dwarfs.
- Some of them are supposed to be more metal-poor than WISE1810



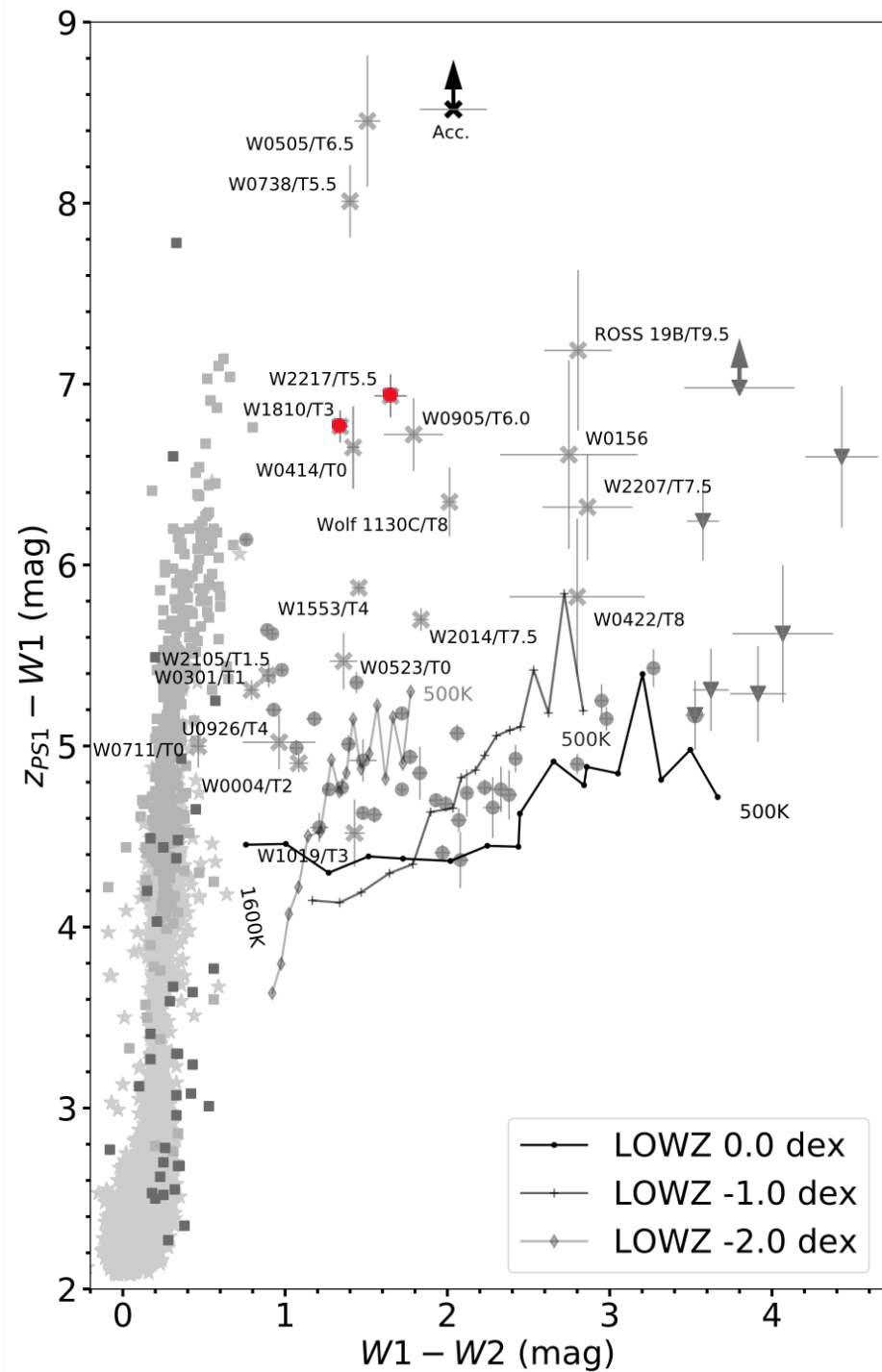
# IR Spectroscopy

- IR spectra for these esdTs or usdTs
- JWST NIRSpec & MIRI program (Burgasser et al. 2025) is finished but ground-base observation can provide more information at red optical/NIR
- Still difficult observationally...
- More robust metallicity estimation?



# WISE2217

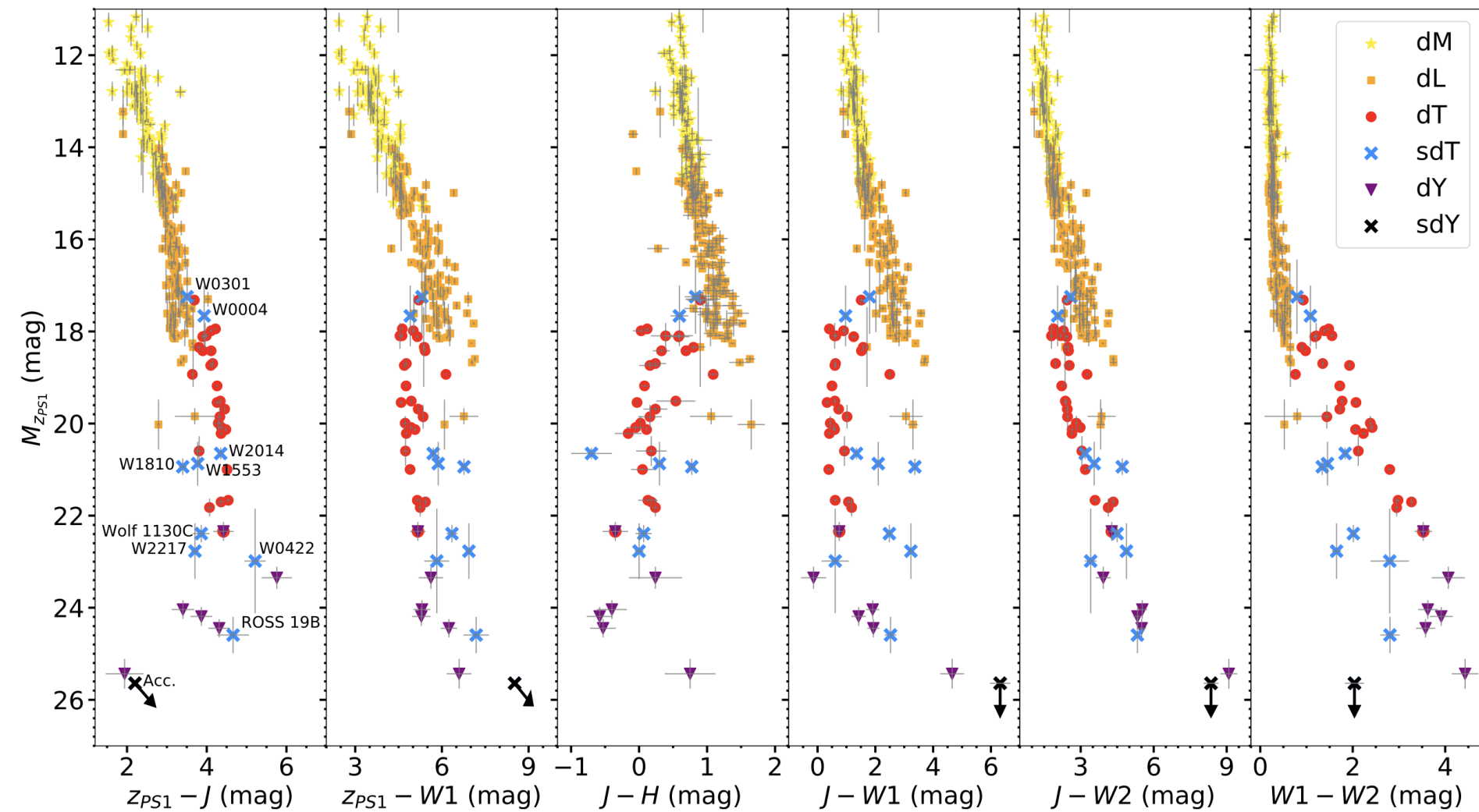
- WISE1810 twin?





# WISE2217

- Ground-based  
parallax CAHA  
 $48 \pm 13$  mas



# WISE2217 SED

- Colder ( $< 1000$  K)
- More metal-poor ( $< -2.0$  dex)

# WISE2217 future observation

- Could we apply the same metallicity measurement on WISE2217?
- GTC/EMIR scheduled observation
  - Oct 7<sup>th</sup> – 11<sup>th</sup> 2025 visitor mode
  - 40 hours guaranteed time
  - YJ + HK low-resolution