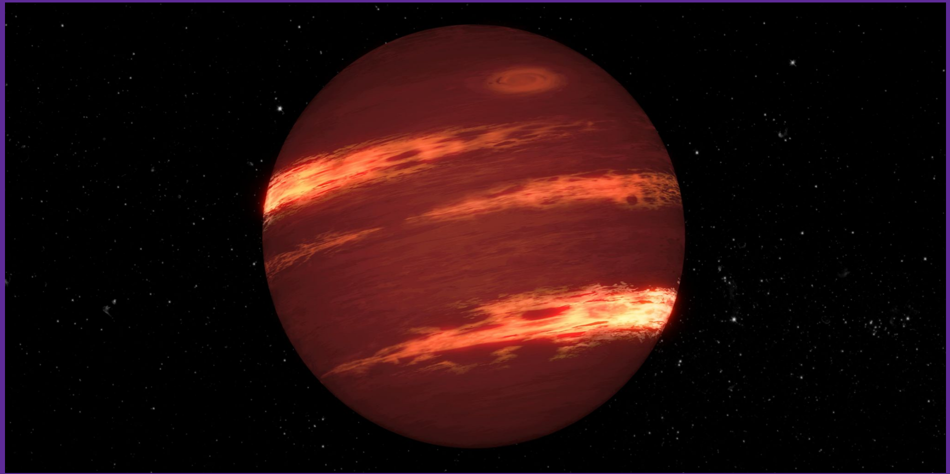
Exploring Brown Dwarf Distributions

in the Milky Way

https://webbtelescope.org/contents/articles/what-makes-brown-dwarfs-unique



Importance of Brown Dwarf Populations

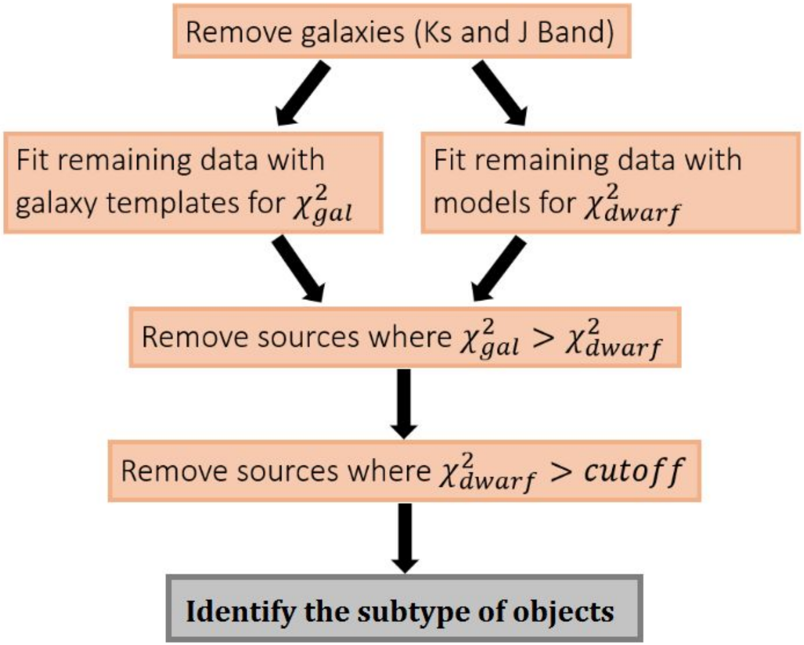
- Brown dwarfs do not fuse hydrogen
  - Very long Lifespans
  - Emit in NIR and Optical
  - Occupy latest spectral types (M8, M9 etc…)

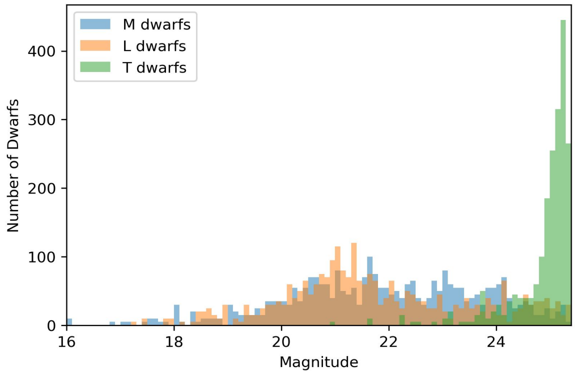
- Useful tracers of galaxy formation
- Important for understanding stellar formation and cycles
- Contaminants in high redshift galaxy surveys

Many things still unknown about brown dwarf populations!

Last Semester

- Sample of brown dwarfs extracted from COSMOS survey, a “catalogue” of dwarfs
- Selection chain used to identify dwarfs:
  - Various cutting procedures
  - Template fitting using eazypy
  - Fit parameter constraints
- Type of dwarf identified by using the temperature of the best fitting brown dwarf model





This Semester

1. Create a model for the distribution of brown dwarfs in the Milky Way
2. Adjust model distributions for completeness of selection chain
3. Fit the adjusted model to results from last semester to obtain scale heights
4. Investigate and compare other methods

Study	Scale Height h_Z (pc)
Chen et al. (2001)	330 ± 3 (Old-disk stars)
Pirzkal et al. (2005)	400 ± 100 (M and L)
Ryan et al. (2005)	350 ± 50 (L and T)
Bochanski et al. (2010, Table 6)	300 ± 15
Ryan et al. (2011)	290 ± 25 (rand) ±31 (sys)
Holwerda et al. (2016)	~ 600 (Includes halo)
van Vledder et al. (2016)	290 ± 20 (Includes halo)
Ryan et al. (2017)	~ 280 (Late L and T)
Sorahana et al. (2019, Table 5 and 6)	340 – 420
Carnero Rosell et al. (2019)	~ 450 (Early L)
Warren et al. (2021, Table 2)	270 ± 6 (M7-L2)
Aganze et al. (2022a); Aganze et al. (2022b)	249± ~ 55 (Late M) 153± ~ 45 (L) 175± ~ 100 (T)
Holwerda et al. (2024)	300 – 350 (M6±2) 150 – 200 (T6±2)

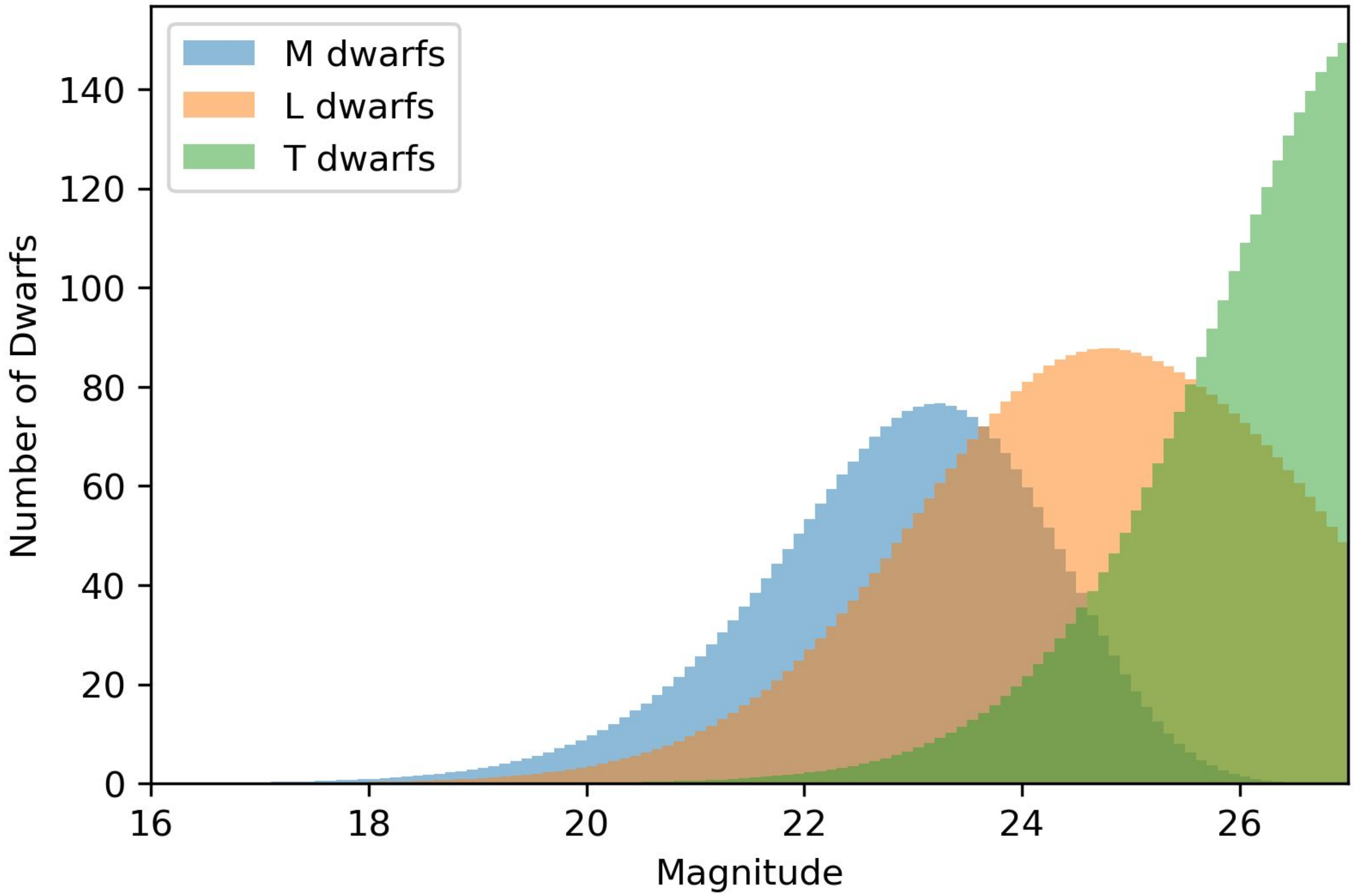
1: Thin Disk Model Distribution

- Milky Way has several galactic components
- Brown dwarf contributions from components other than the thin disk negligible (~10% error)
- Model distribution follows exponential scale height model as given by Cabellero (2008)

$$n \approx n_A e^{-\frac{d}{d_B}}$$

$$\frac{1}{d_{B,\pm}} \triangleq -\frac{\cos b \cos l}{h_R} \pm \frac{\sin b}{h_z}$$

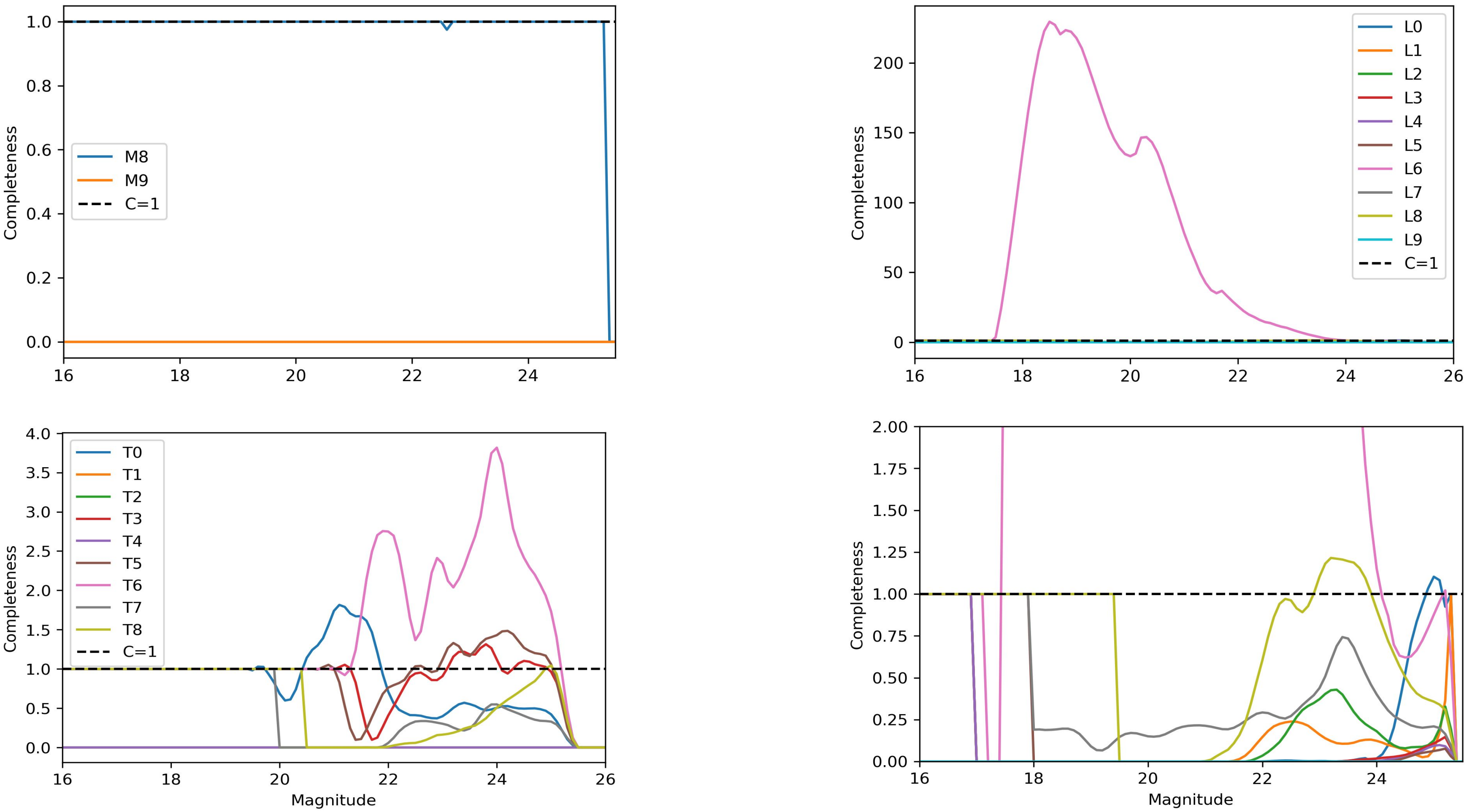
https://ui.adsabs.harvard.edu/abs/2008A%26A...488..181C/abstract


M dwarfs
L dwarfs
T dwarfs
Number of Dwarfs
Magnitude
0
20
40
60
80
100
120
140
16
18
20
22
24
26

2: Completeness

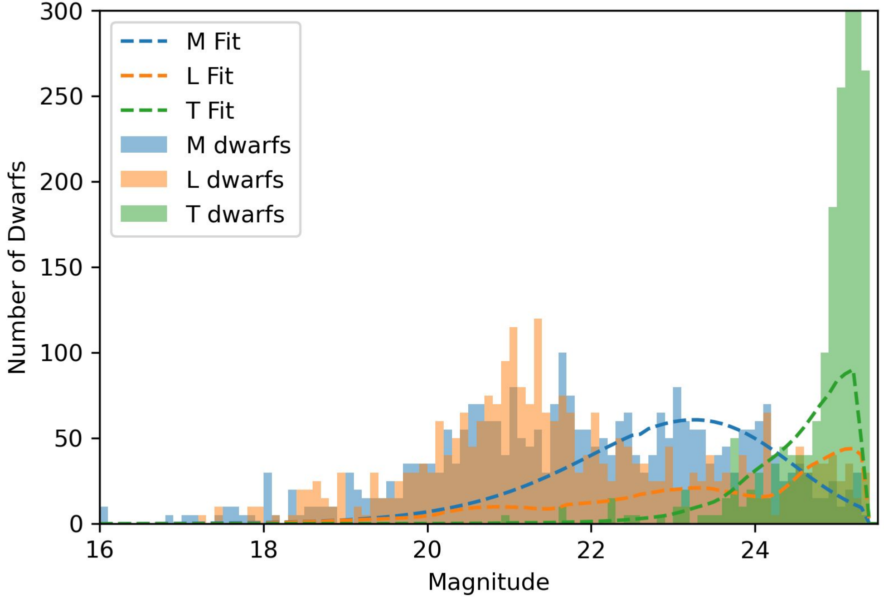
- Measure of how well our selection chain selects brown dwarfs from COSMOS
- Selection chain may contain biases that need to be accounted for in our model

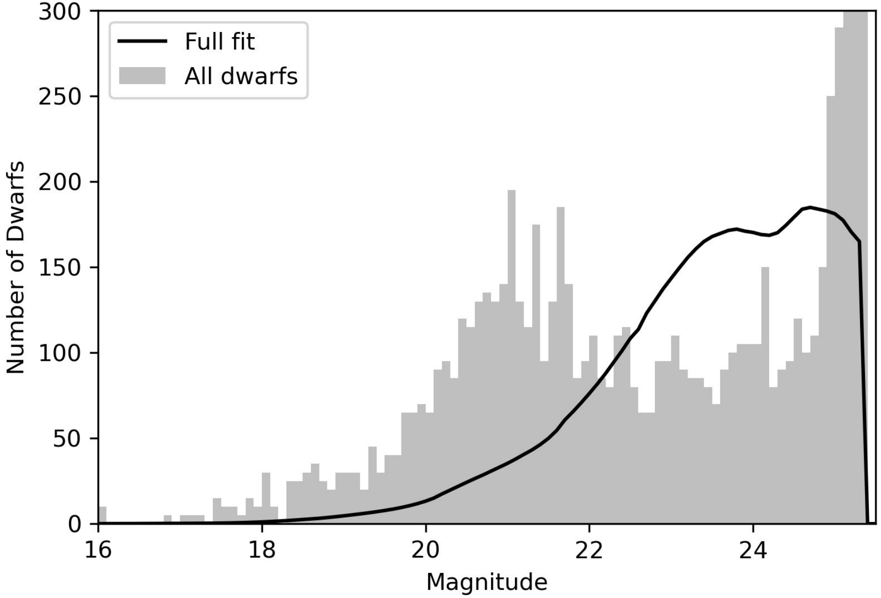
- Create a “fake catalogue” of brown dwarfs using our model distribution and spectra from SPeX standards library
- Fake catalogue passed through selection chain
- Definite biases found from this type assignment method



Completeness
M8
M9
C=1
L0
L1
L2
L3
L4
L5
L6
L7
L8
L9
C=1
T0
T1
T2
T3
T4
T5
T6
T7
T8
C=1
Magnitude

3: Initial Results





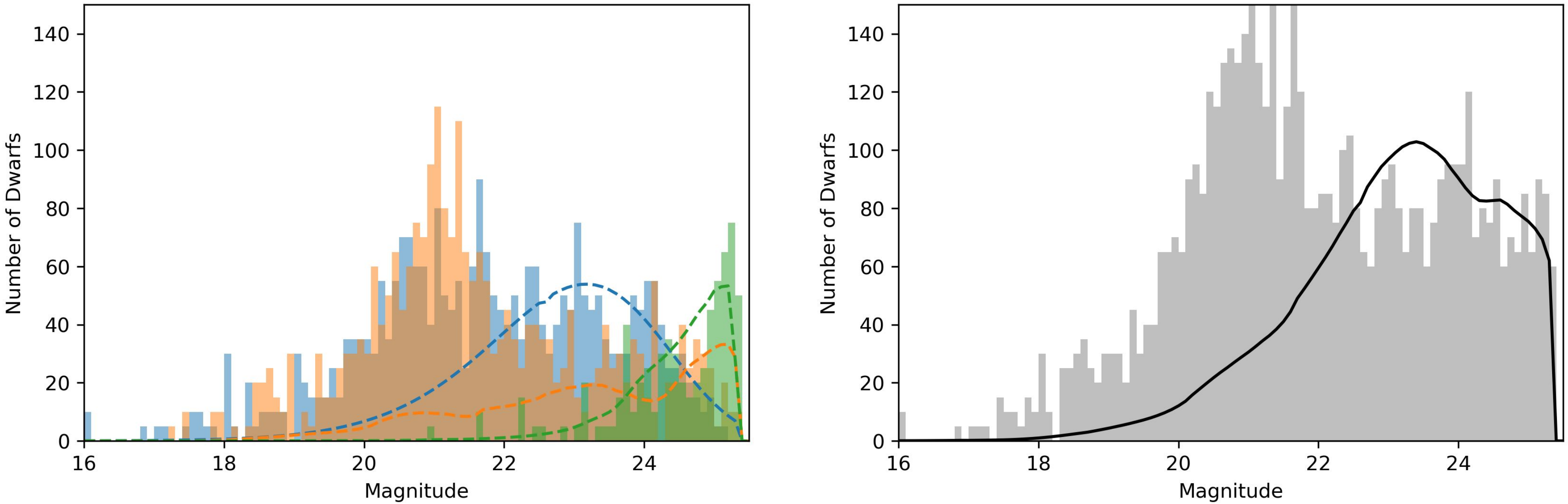
M Scale Height	L Scale Height	T Scale Height	Overall Scale Height
440 ± 54 pc	480 ± 84 pc	0.04 ± 9 x10^9 pc	610 ± 77 pc

3: Removing Invalid Data Points

- Clearly unphysical T value (larger than Milky Way radius)
- Investigation revealed eazypy failing to initialise templates for some cases
- These objects always pass χ^2 cuts
- Results in contamination of catalogue

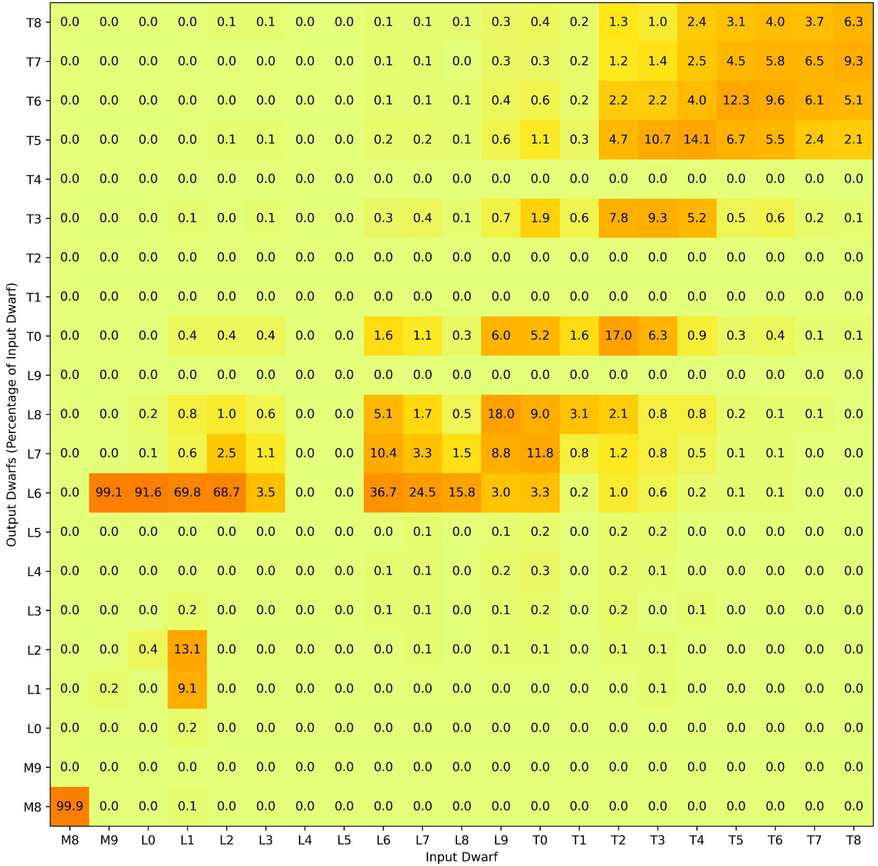
- Objects with infinite χ^2 values were removed
- Objects with χ_{dwarf} and χ_{galaxy} very similar removed

3: Updated Results



M Scale Height	L Scale Height	T Scale Height	Overall Scale Height
420 ± 53 pc	440 ± 84 pc	950 ± 185 pc	490 ± 64 pc

4: Investigating the Completeness

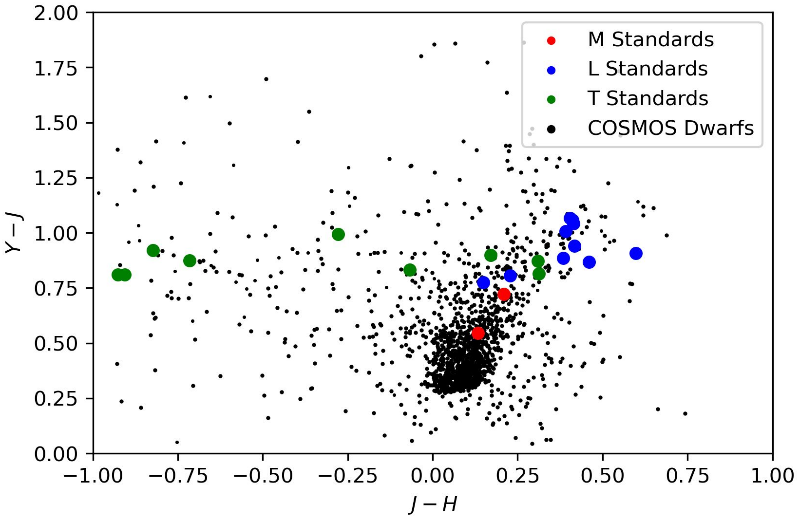


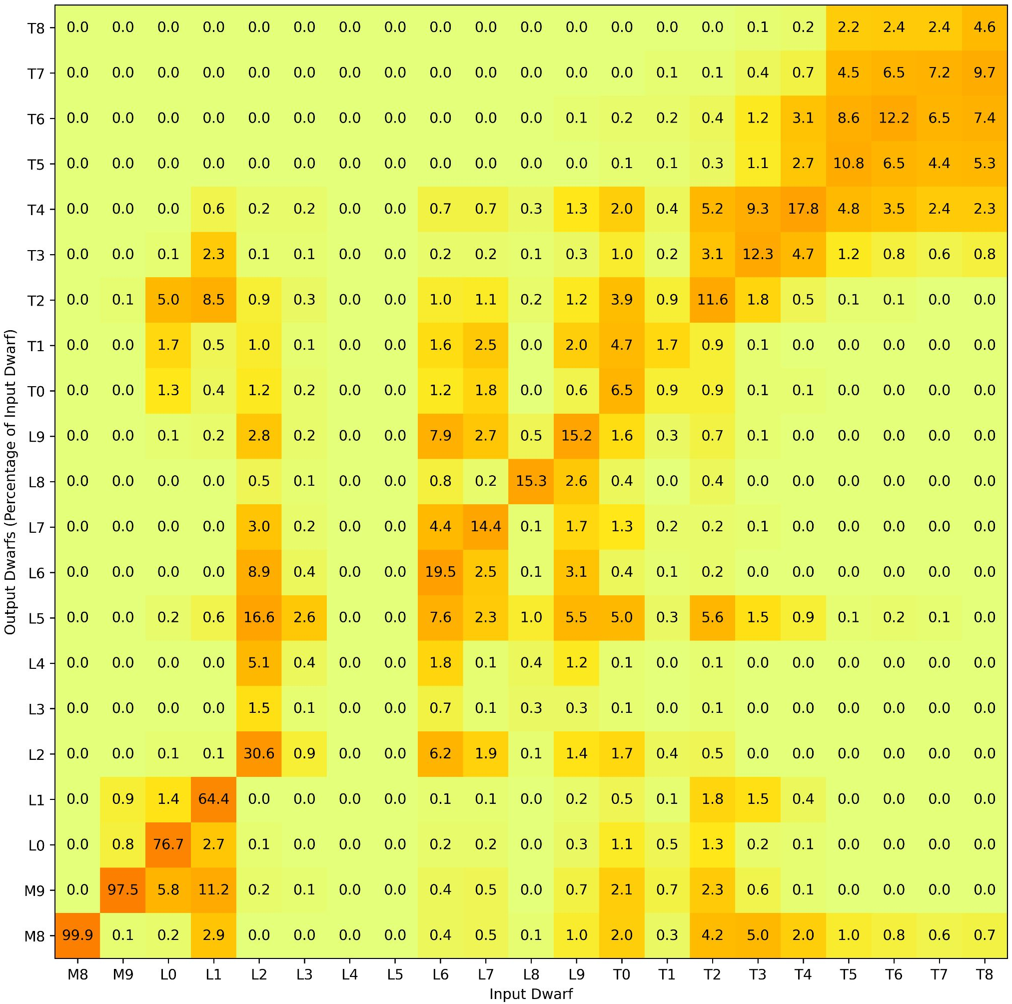
4: Typing by Colour

- Assign dwarf types using colour-colour space method

- Take nearest neighbour SpeX standard

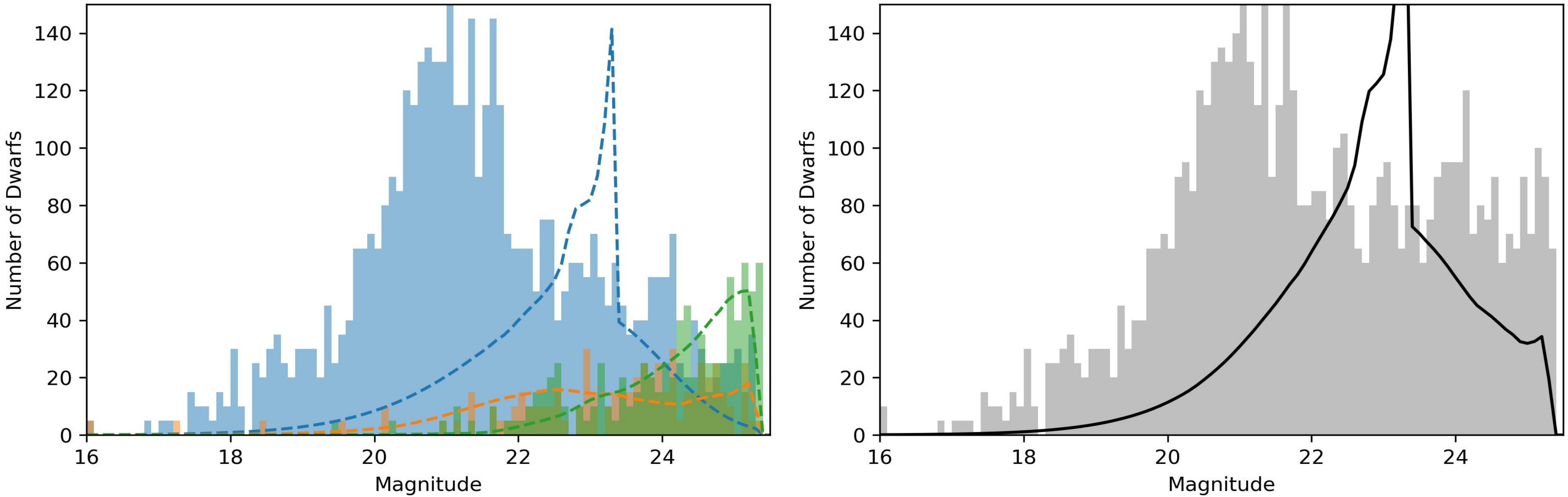
- Significantly more robust than previous method





Output Dwarfs (Percentage of Input Dwarf)
T8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.2 2.2 2.4 2.4 4.6
T7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.4 0.7 4.5 6.5 7.2 9.7
T6 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.2 0.2 0.4 1.2 3.1 8.6 12.2 6.5 7.4
T5 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.3 1.1 2.7 10.8 6.5 4.4 5.3
T4 0.0 0.0 0.0 0.6 0.2 0.2 0.0 0.0 0.7 0.7 0.3 1.3 2.0 0.4 5.2 9.3 17.8 4.8 3.5 2.4 2.3
T3 0.0 0.0 0.1 2.3 0.1 0.1 0.0 0.0 0.2 0.2 0.1 0.3 1.0 0.2 3.1 12.3 4.7 1.2 0.8 0.6 0.8
T2 0.0 0.1 5.0 8.5 0.9 0.3 0.0 0.0 1.0 1.1 0.2 1.2 3.9 0.9 11.6 1.8 0.5 0.1 0.1 0.0 0.0
T1 0.0 0.0 1.7 0.5 1.0 0.1 0.0 0.0 1.6 2.5 0.0 2.0 4.7 1.7 0.9 0.1 0.0 0.0 0.0 0.0 0.0
T0 0.0 0.0 1.3 0.4 1.2 0.2 0.0 0.0 1.2 1.8 0.0 0.6 6.5 0.9 0.9 0.1 0.1 0.0 0.0 0.0 0.0
L9 0.0 0.0 0.1 0.2 2.8 0.2 0.0 0.0 7.9 2.7 0.5 15.2 1.6 0.3 0.7 0.1 0.0 0.0 0.0 0.0 0.0
L8 0.0 0.0 0.0 0.0 0.5 0.1 0.0 0.0 0.8 0.2 15.3 2.6 0.4 0.0 0.4 0.0 0.0 0.0 0.0 0.0 0.0
L7 0.0 0.0 0.0 0.0 3.0 0.2 0.0 0.0 4.4 14.4 0.1 1.7 1.3 0.2 0.2 0.1 0.0 0.0 0.0 0.0 0.0
L6 0.0 0.0 0.0 0.0 8.9 0.4 0.0 0.0 19.5 2.5 0.1 3.1 0.4 0.1 0.2 0.0 0.0 0.0 0.0 0.0 0.0
L5 0.0 0.0 0.2 0.6 16.6 2.6 0.0 0.0 7.6 2.3 1.0 5.5 5.0 0.3 5.6 1.5 0.9 0.1 0.2 0.1 0.0
L4 0.0 0.0 0.0 0.0 5.1 0.4 0.0 0.0 1.8 0.1 0.4 1.2 0.1 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0
L3 0.0 0.0 0.0 0.0 1.5 0.1 0.0 0.0 0.7 0.1 0.3 0.3 0.1 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0
L2 0.0 0.0 0.1 0.1 30.6 0.9 0.0 0.0 6.2 1.9 0.1 1.4 1.7 0.4 0.5 0.0 0.0 0.0 0.0 0.0 0.0
L1 0.0 0.9 1.4 64.4 0.0 0.0 0.0 0.0 0.1 0.1 0.0 0.2 0.5 0.1 1.8 1.5 0.4 0.0 0.0 0.0 0.0
L0 0.0 0.8 76.7 2.7 0.1 0.0 0.0 0.0 0.2 0.2 0.0 0.3 1.1 0.5 1.3 0.2 0.1 0.0 0.0 0.0 0.0
M9 0.0 97.5 5.8 11.2 0.2 0.1 0.0 0.0 0.4 0.5 0.0 0.7 2.1 0.7 2.3 0.6 0.1 0.0 0.0 0.0 0.0
M8 99.9 0.1 0.2 2.9 0.0 0.0 0.0 0.0 0.4 0.5 0.1 1.0 2.0 0.3 4.2 5.0 2.0 1.0 0.8 0.6 0.7
M8 M9 L0 L1 L2 L3 L4 L5 L6 L7 L8 L9 T0 T1 T2 T3 T4 T5 T6 T7 T8
Input Dwarf

4: Typing by color results



M Scale Height	L Scale Height	T Scale Height	Overall Scale Height
330 ± 49 pc	330 ± 41 pc	500 ± 74 pc	360 ± 48 pc

Conclusions

- Final results show thin disk of M and L dwarfs and a larger disk of T dwarfs
- Scale height dependance on type inconclusive
- Brown Dwarf templates not suitable for type assignment
  - Colour method superior
- More robust constraints required for fitting
- Improvements
  - Non-constant completeness
  - ‘Unique’ selection criteria
  - Other sources of uncertainty

M Scale Height	L Scale Height	T Scale Height	Overall Scale Height
330 ± 49 pc	330 ± 41 pc	500 ± 74 pc	360 ± 48 pc