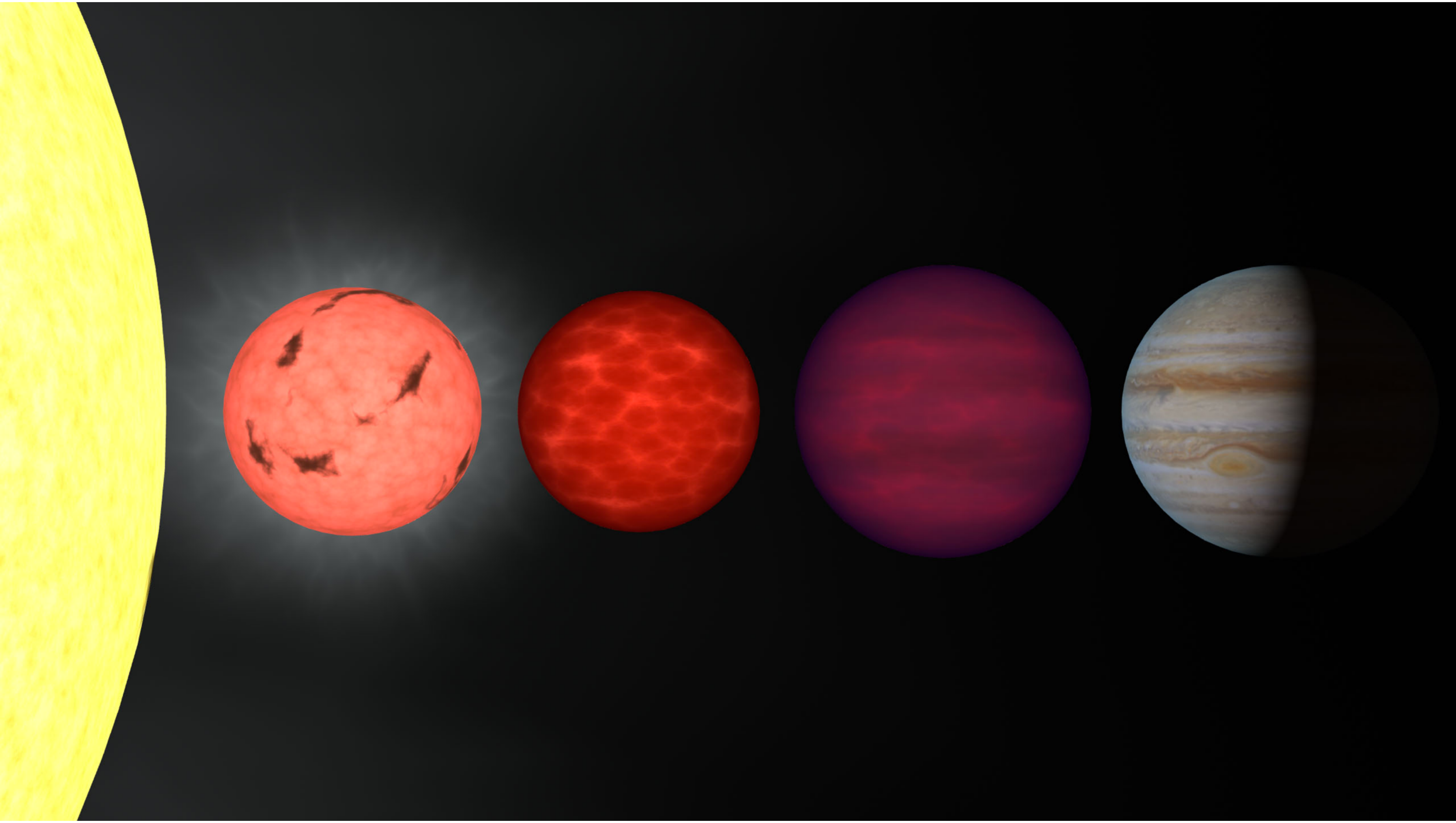
Brown Dwarf Atmospheres

Matt Wilde

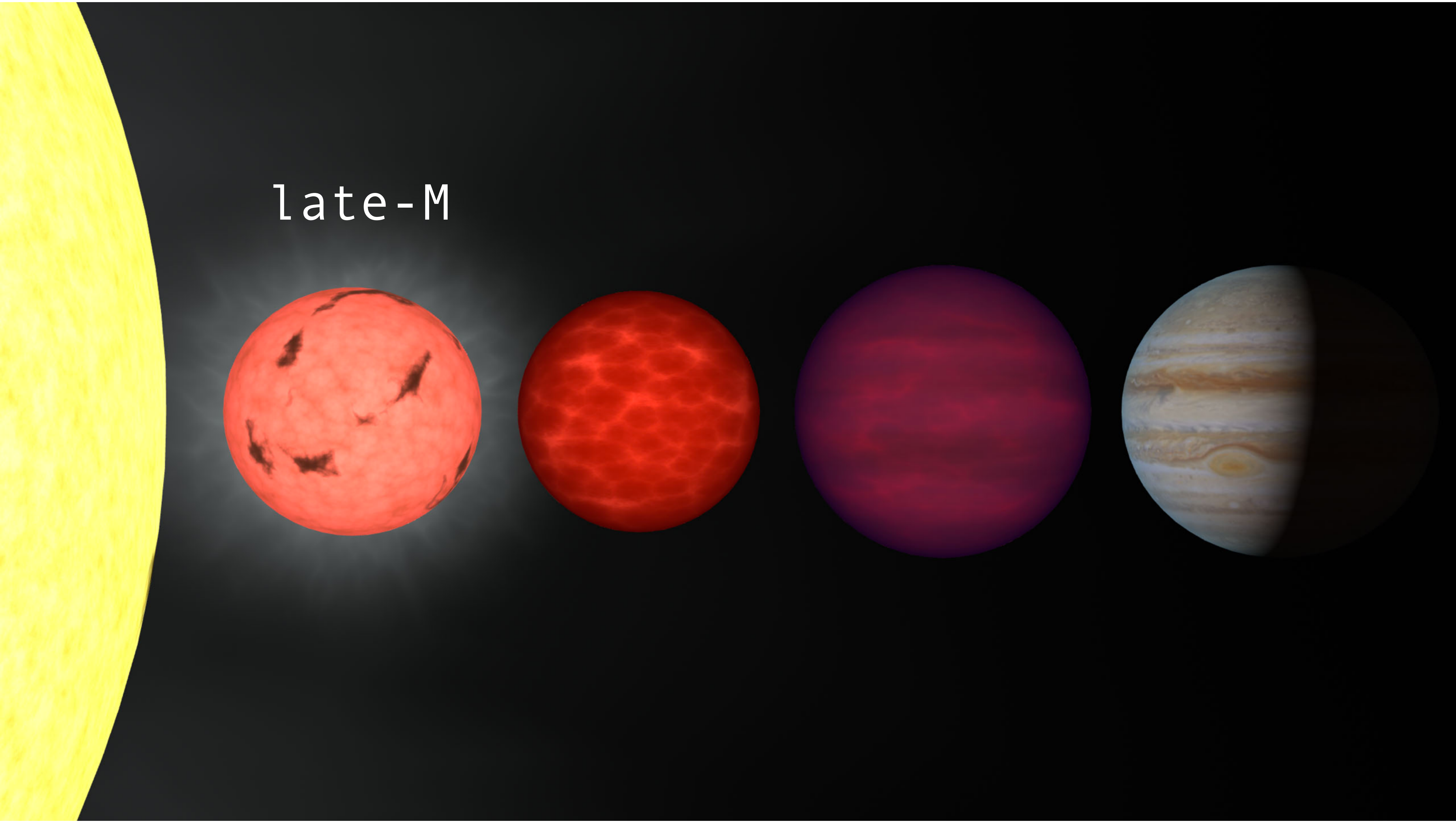
What is a brown dwarf?

Brown Dwarf

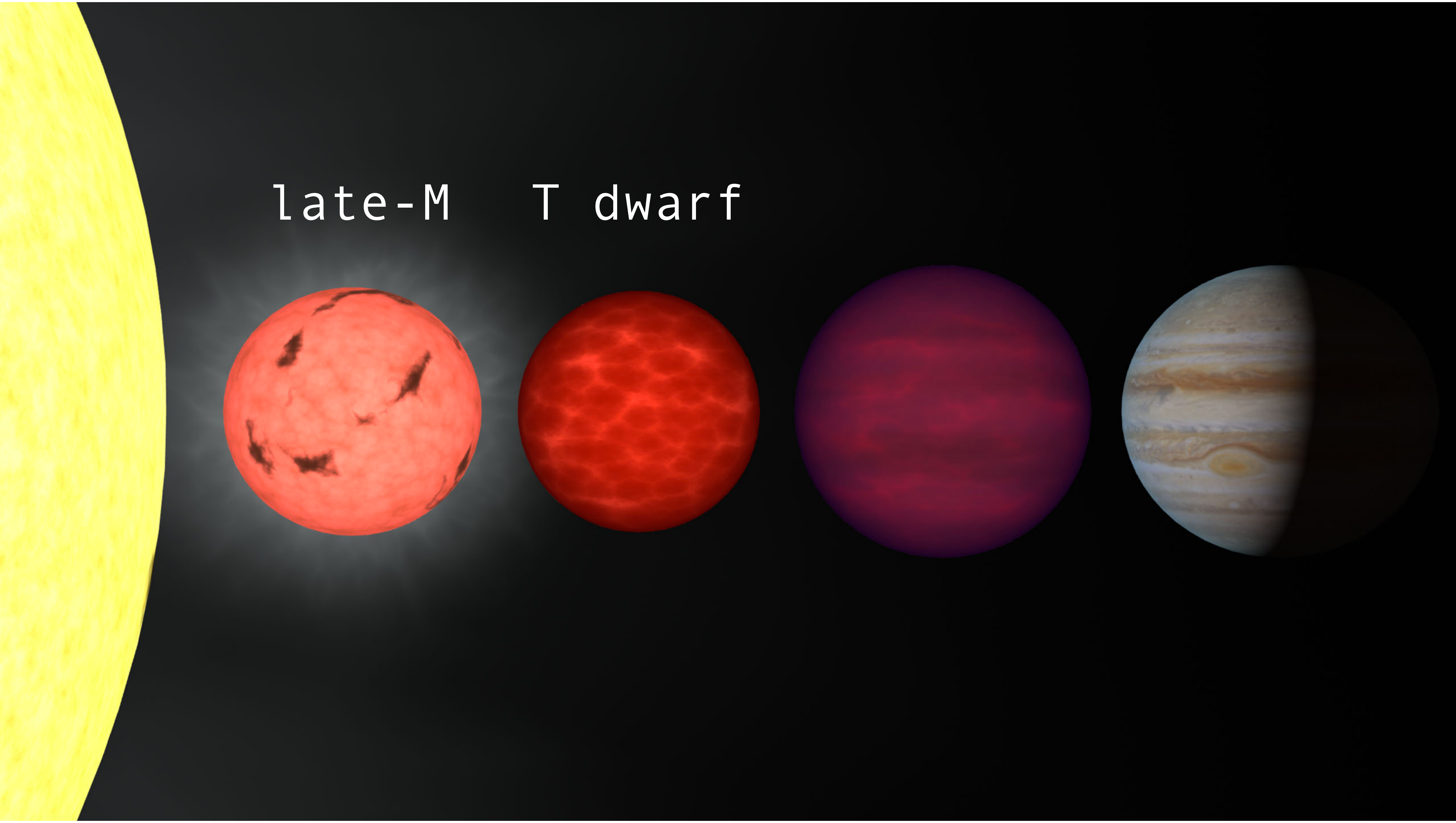
- M = 13 - 75 Mjup
- Mass too low to sustain Hydrogen fusion
- don't have constant luminosity and temperature unlike MS stars
- Cool overtime, SED evolves through progressively later spectral types



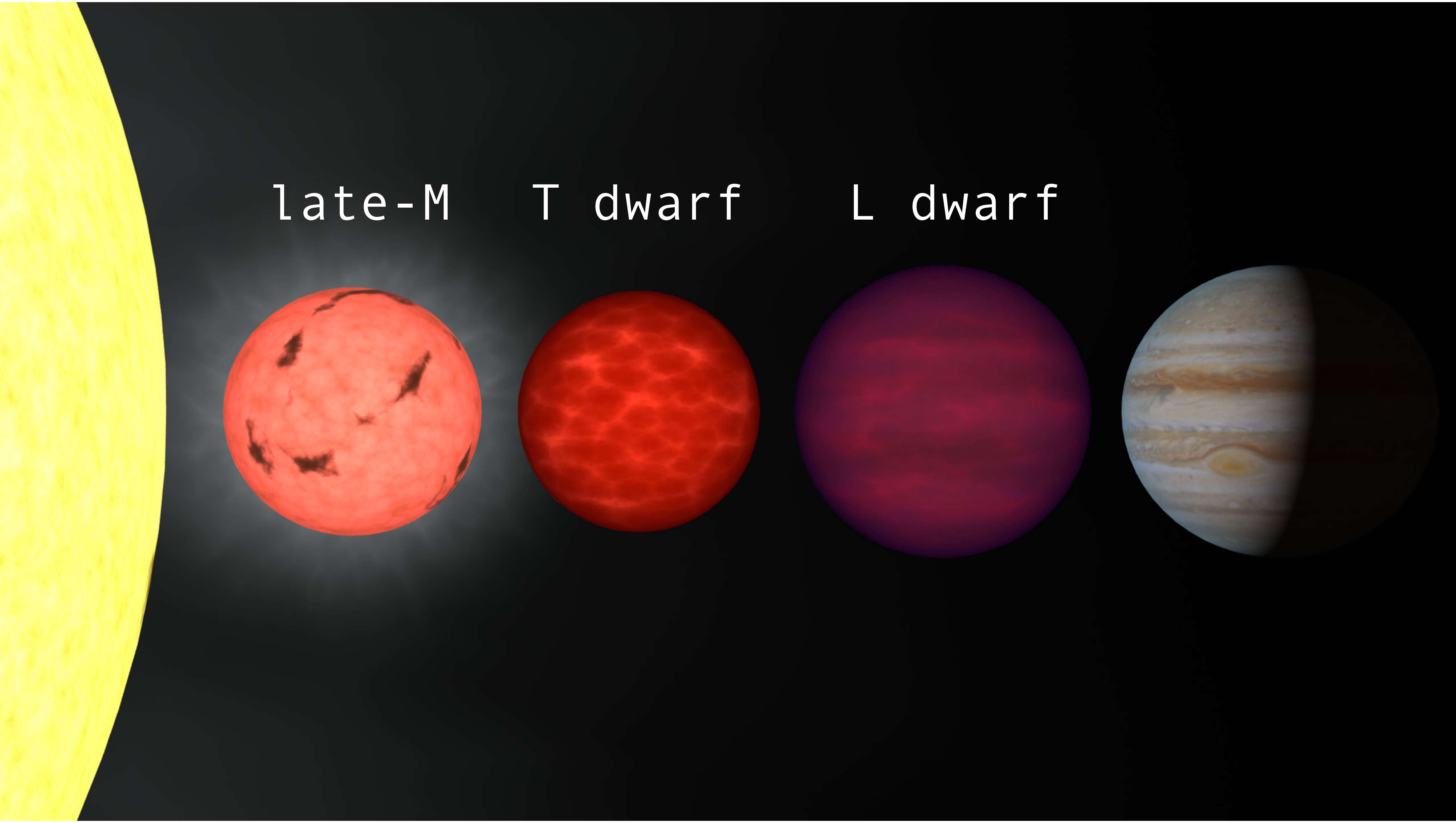
http://spider.ipac.caltech.edu/staff/davy/2mass/science/comparison.html



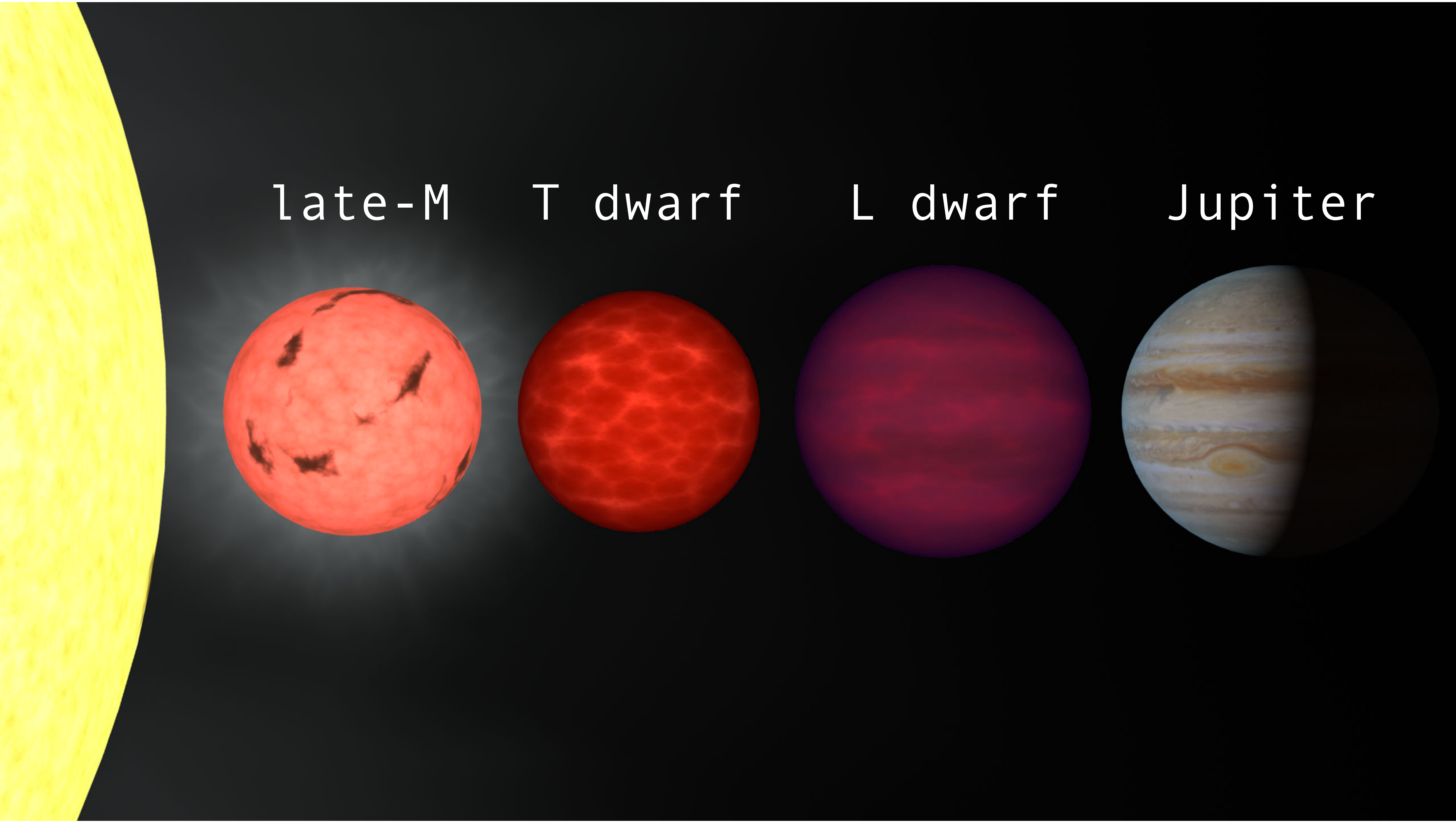
http://spider.ipac.caltech.edu/staff/davy/2mass/science/comparison.html



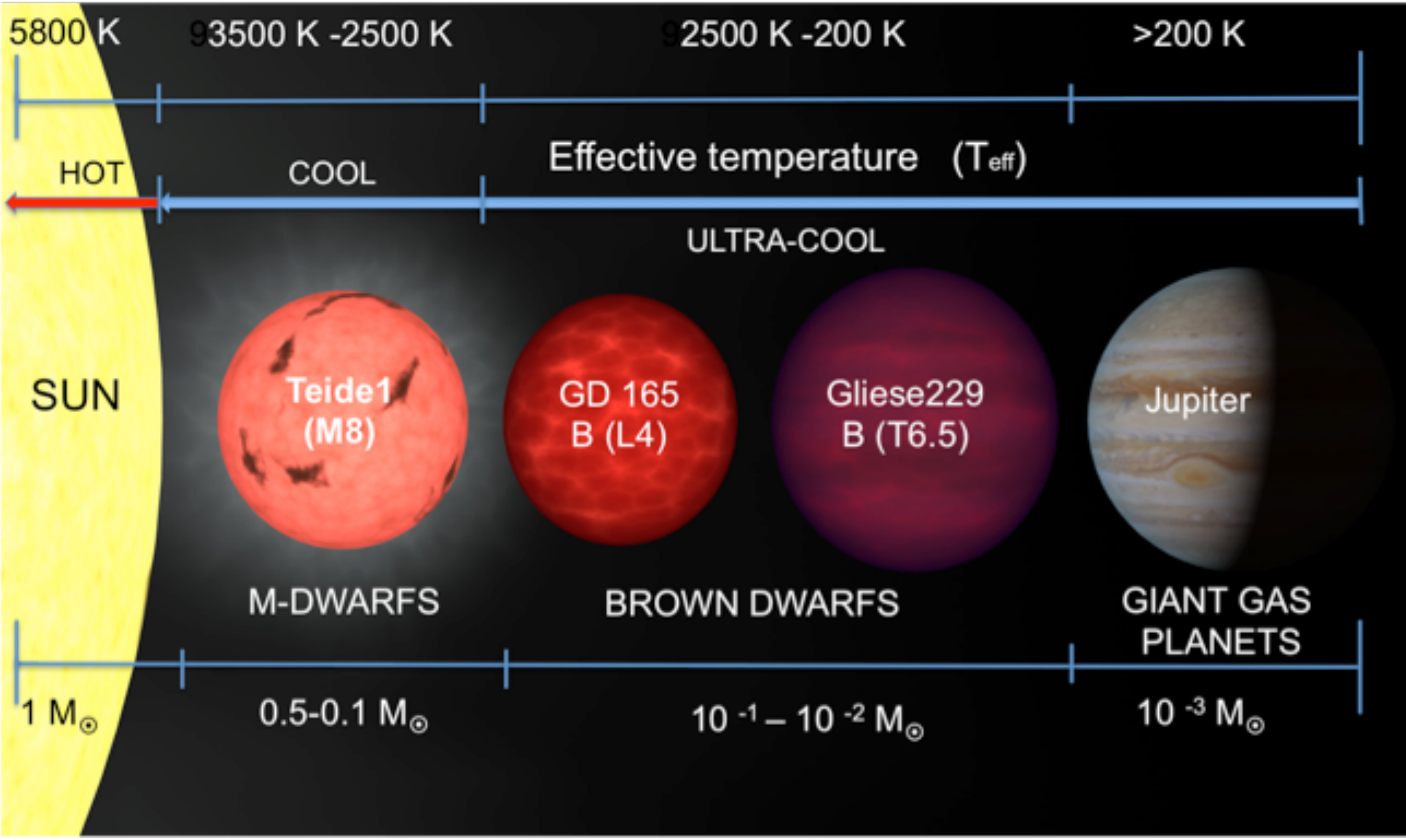
http://spider.ipac.caltech.edu/staff/davy/2mass/science/comparison.html



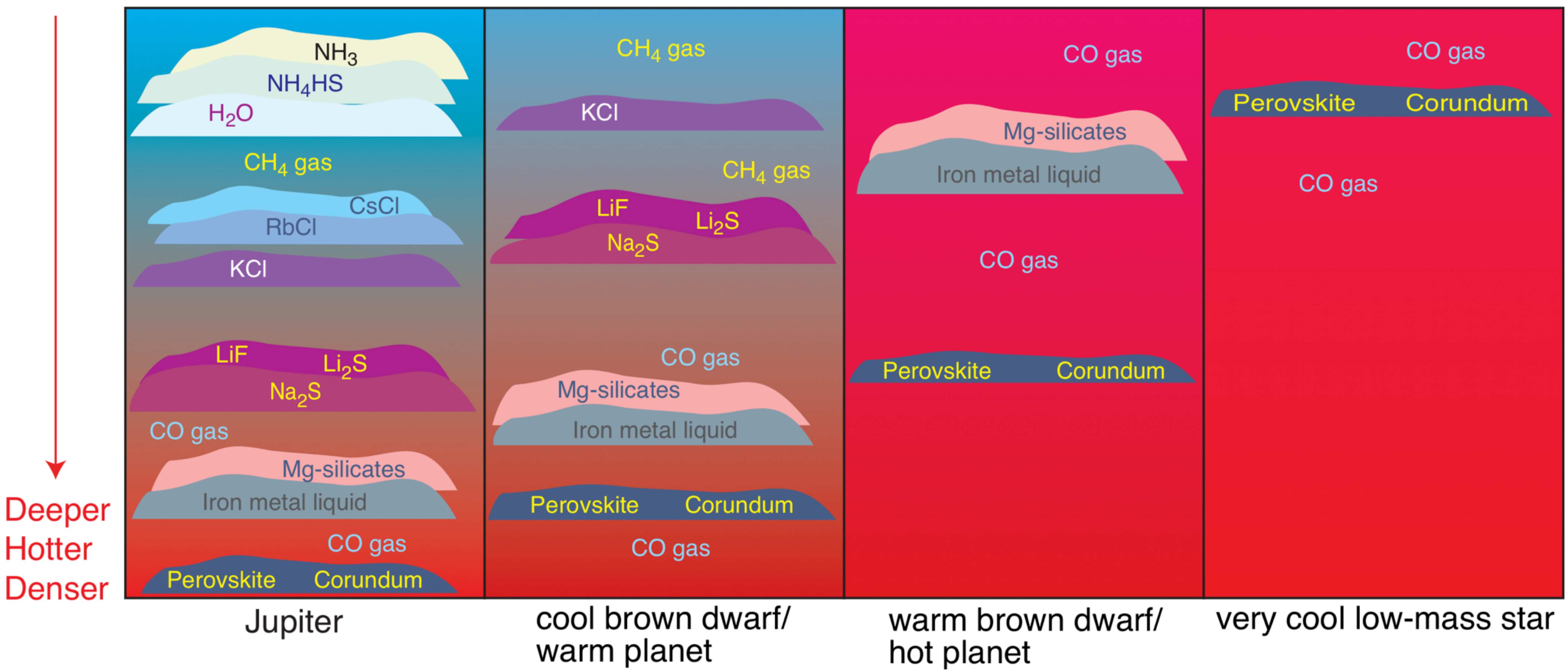
http://spider.ipac.caltech.edu/staff/davy/2mass/science/comparison.html



http://spider.ipac.caltech.edu/staff/davy/2mass/science/comparison.html



http://spider.ipac.caltech.edu/staff/davy/2mass/science/comparison.html



Deeper
Hotter
Denser
NH3
NH4HS
H2O
CH4 gas
CsCl
RbCl
KCl
LiF
Li2S
Na2S
CO gas
Mg-silicates
Iron metal liquid
CO gas
Perovskite
Corundum
Jupiter
CH4 gas
KCl
CH4 gas
LiF
Li2S
Na2S
CO gas
Mg-silicates
Iron metal liquid
Perovskite
Corundum
CO gas
cool brown dwarf/ warm planet
CO gas
Mg-silicates
Iron metal liquid
CO gas
Perovskite
Corundum
warm brown dwarf/ hot planet
CO gas
Perovskite
Corundum
CO gas
very cool low-mass star

The 0.8–14.5 μm Spectra of Mid-L to Mid-T Dwarfs: Diagnostics of Effective Temperature, Grain Sedimentation, Gas Transport, and Surface Gravity

Stephens et al.,2009

Overview

- 0.8–14.5 μm low-resolution spectra of mid-L to mid-T dwarfs
- Saumon & Marley models

Data

Table 1
L and T Dwarfs Newly Observed with *Spitzer* IRS

Name[a]	Epoch[a] YYYYMMDD	Sp. Type[b] (IR/Opt)	$J–K$[c] (MKO)	Relative Color[d]	D[e] (pc)	μ[f] ($''$ yr^{-1})	PA[f] (deg)	v_{tan} (km s^{-1})	Notes
2MASS J22443167+2043433	19971005	L7.5/L6.5	2.43	Very red	21 ± 5	0.33 ± 0.01	130.3 ± 2.1	33 ± 8	1, 2
SDSS J115553.85+055957.5	20010416	L7.5	1.54	Normal	18 ± 3	0.41 ± 0.03	266.3 ± 3.1	35 ± 6	3, 4
SDSS J085758.44+570851.4	20000406	L8/L8	1.86	Red	11 ± 2	0.54 ± 0.01	229.8 ± 1.4	28 ± 5	4, 5
SDSS J133148.88−011652.5	20010524	L8/L6	1.25	Blue	18 ± 4	1.11 ± 0.01	201.6 ± 0.9	92 ± 19	4, 6
2MASS J09083803+5032088	19990306	L9/L5	1.51	Normal	10 ± 2	0.62 ± 0.02	219.6 ± 2.0	30 ± 5	7
SDSS J080531.83+481233.1	20000425	L9.5/L4	1.10	Blue	13 ± 2	0.46 ± 0.02	276.8 ± 2.1	28 ± 4	6, 8
SDSS J120747.17+024424.8	20000504	T0/L8	1.22	Normal	18 ± 3	0.52 ± 0.02	285.5 ± 2.1	43 ± 8	4, 6
SDSS J152039.82+354619.8	20030326	T0	1.45	Normal	18 ± 3	0.48 ± 0.04	144.1 ± 4.1	41 ± 8	4, 9
SDSS J151643.00+305344.3	20030623	T0.5	1.67	Red	31 ± 6	0.13 ± 0.03	271.7 ± 10.8	19 ± 6	9
SDSS J105213.50+442255.6AB	20021213	T0.5	1.43	Normal	30 ± 6[g]	0.15 ± 0.02	173.2 ± 6.4	21 ± 5	9, 10
SDSS J075840.32+324723.3	20011219	T2	0.91	Normal	15 ± 3	0.40 ± 0.02	208.7 ± 2.9	28 ± 6	3, 4
2MASS J22541892+3123498	19980622	T4	−0.02	Normal	17 ± 3	0.21 ± 0.01	18.7 ± 3.9	17 ± 3	11
SDSS J000013.54+255418.6	20030929	T4.5	−0.09	Normal	13 ± 2	0.13 ± 0.02	2.6 ± 5.8	8 ± 2	3
SDSS J111009.99+011613.0	20000505	T5.5	0.07	Very red	20 ± 4	0.34 ± 0.02	225.6 ± 3.3	32 ± 6	5

Model

- Assumptions: LTE & radiative-convective equilibrium

- 2-stream approx. applied to vertically inhomogeneous atmospheres (Toon et al. 1989)

- Marley et al. solve a diffusion equation that aims to balance the advection and diffusion of each species vapor and condensate at each layer of the atmosphere.

Model

- Input parameters: Teff, log(g), fsed, Kzz, line lists.

Model

- large fsed ==> rapid particle growth and large mean particle sizes

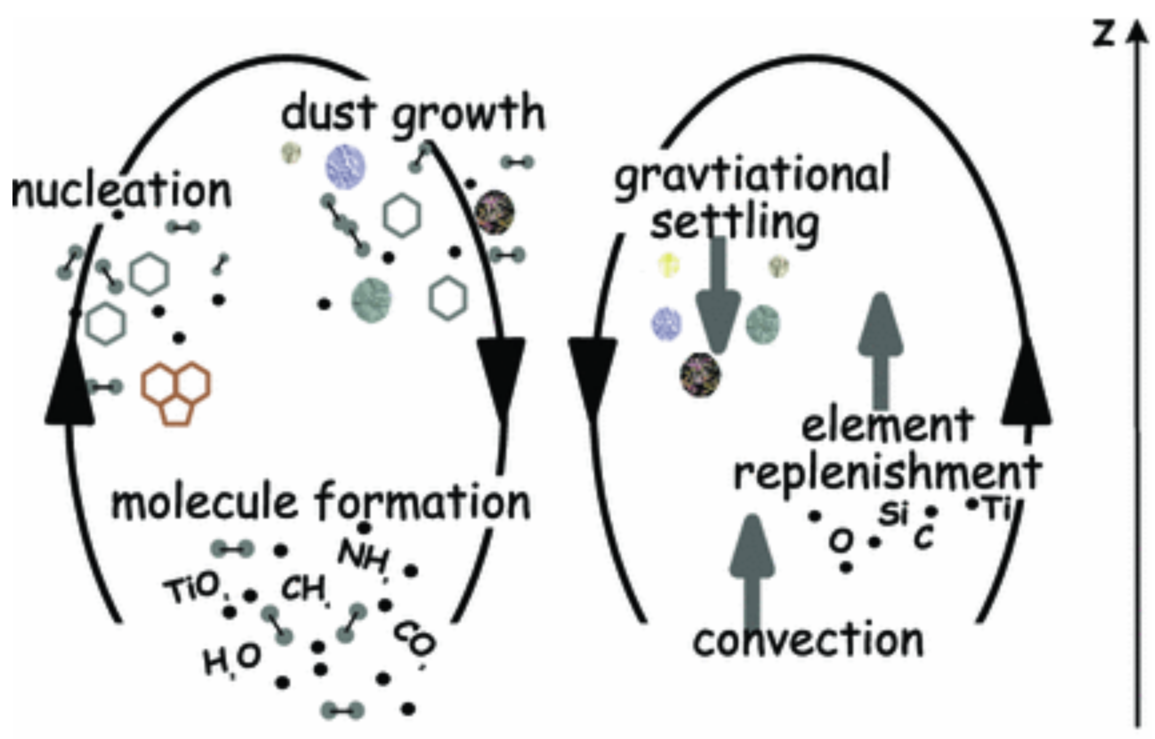
- sedimentation is efficient, which leads to geometrically and optically thin clouds.

- small fsed ==> particles grow slowly and the amount of condensed matter in the atmosphere is larger and clouds are geometrically more extended

Model

- Kzz: eddy diffusion coefficient
- measures the turbulent mixing

Kzz


dust growth
nucleation
gravtiational settling
element replenishment
molecule formation
Si
Ti
O
C
TiO
CH
NH
H O
CO
convection
z

fsed

Model

- line lists: H_2O, CH_4, CO, NH_3, H_2S, PH_3, TiO, VO, CrH, FeH, CO_2, HCN, C_2H_2, C_2H_4, and C_2H_6, Li, Na, K, Rb, and Cs

- continuum opacity: H_2 collision-induced absorption

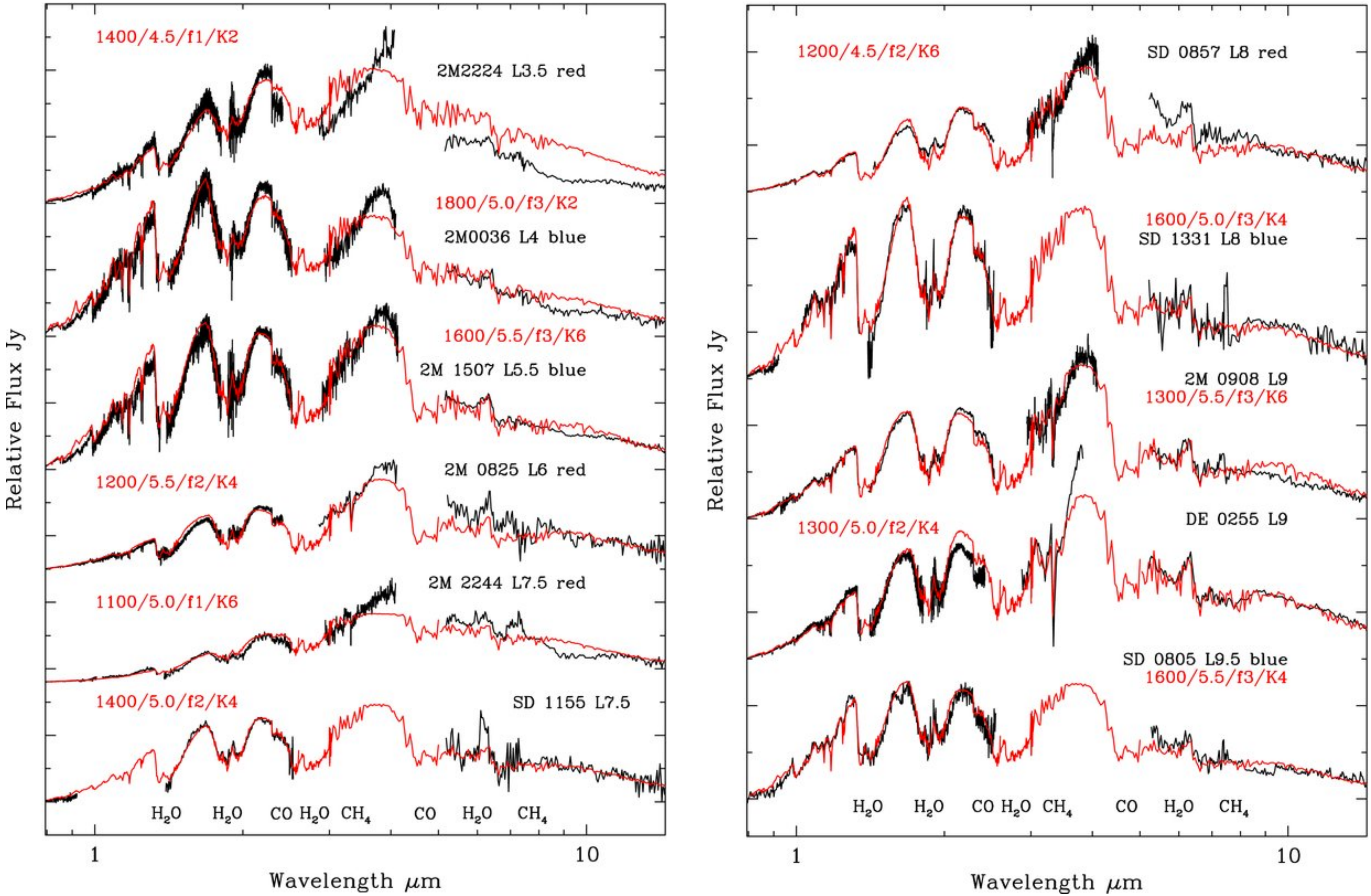
- Rayleigh scattering by H_2, H, He

- bound–free opacity: from H^- and H_2^+;

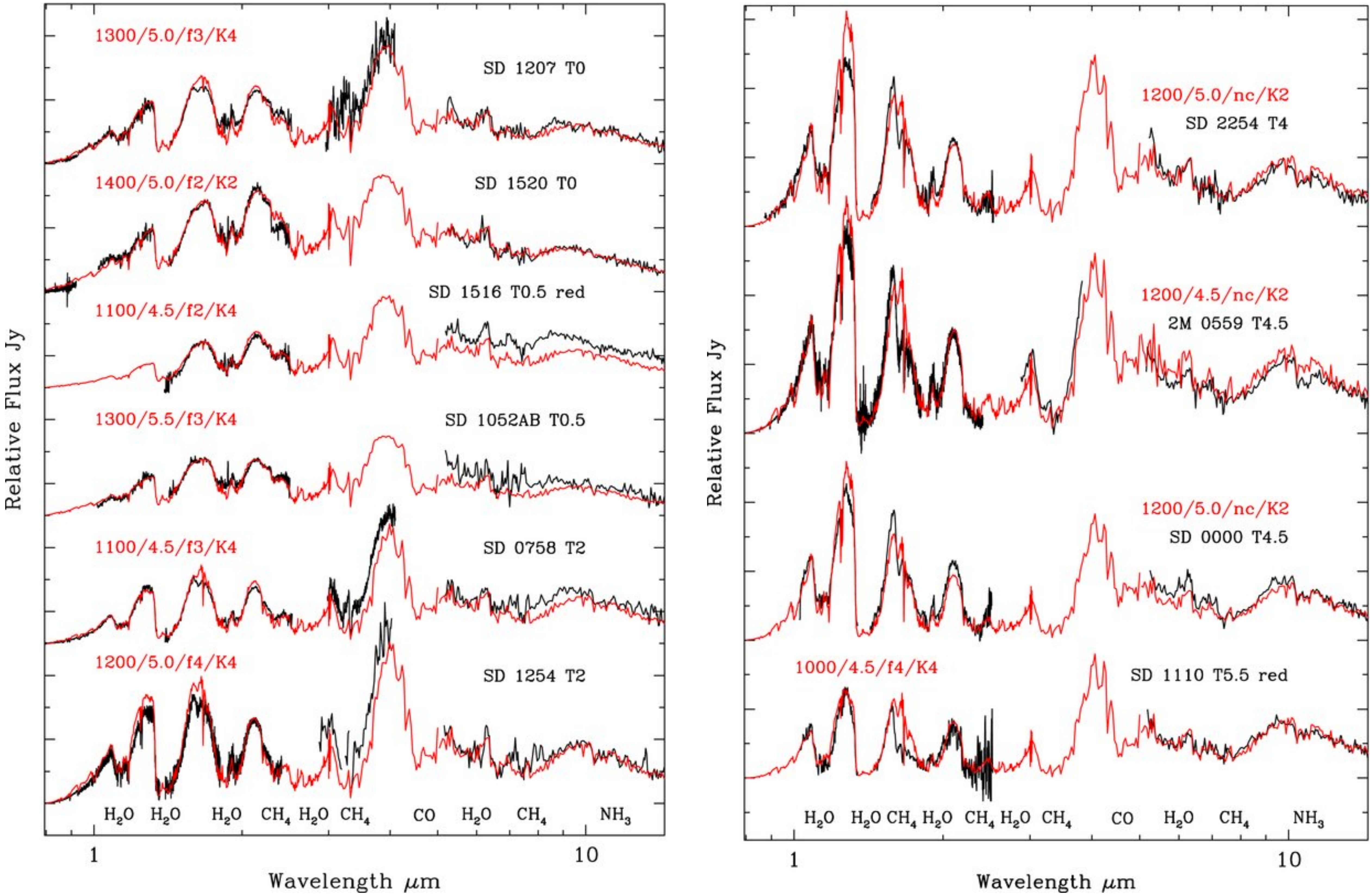
- free–free opacity: from H^-, He^-, H_2^-, and H_2^+

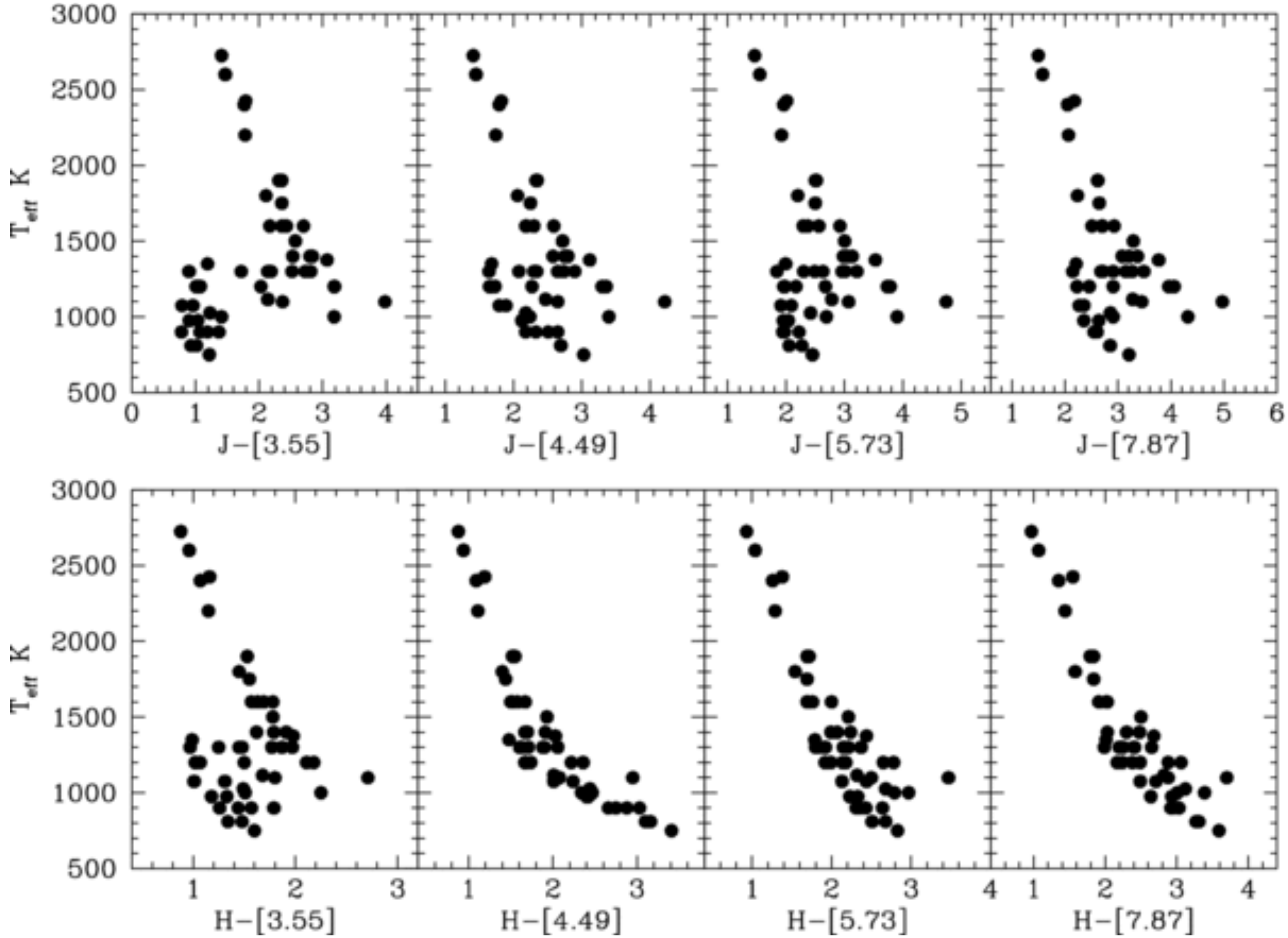
Models

- synthetic spectra grid
- 900K ≤ Teff ≤ 1800K; ΔTeff = 100K
- log g = 4.477, 5.0, 5.477
- fsed = 1, 2, 3, 4, ∞ (no clouds)
- Kzz = 0 (no vertical mixing), 10^2 10^4 and 10^6 cm2 s−1



1400/4.5/f1/K2
2M2224 L3.5 red
1800/5.0/f3/K2
2M0036 L4 blue
1600/5.5/f3/K6
2M 1507 L5.5 blue
2M 0825 L6 red
1200/5.5/f2/K4
2M 2244 L7.5 red
1100/5.0/f1/K6
1400/5.0/f2/K4
SD 1155 L7.5
H_2O H_2O CO H_2O CH_4 CO H_2O CH_4
Relative Flux Jy
Wavelength μm
1
10
1200/4.5/f2/K6
SD 0857 L8 red
1600/5.0/f3/K4
SD 1331 L8 blue
2M 0908 L9
1300/5.5/f3/K6
1300/5.0/f2/K4
DE 0255 L9
SD 0805 L9.5 blue
1600/5.5/f3/K4
H_2O H_2O CO H_2O CH_4 CO H_2O CH_4
Relative Flux Jy
Wavelength μm
1
10


1300/5.0/f3/K4
SD 1207 T0
1400/5.0/f2/K2
SD 1520 T0
SD 1516 T0.5 red
1100/4.5/f2/K4
1300/5.5/f3/K4
SD 1052AB T0.5
1100/4.5/f3/K4
SD 0758 T2
1200/5.0/f4/K4
SD 1254 T2
H2O H2O H2O CH4 H2O CH4 CO H2O CH4 NH3
Relative Flux Jy
1
10
Wavelength μm
1200/5.0/nc/K2
SD 2254 T4
1200/4.5/nc/K2
2M 0559 T4.5
1200/5.0/nc/K2
SD 0000 T4.5
1000/4.5/f4/K4
SD 1110 T5.5 red
H2O H2O CH4 H2O CH4 H2O CH4 CO H2O CH4 NH3
Relative Flux Jy
1
10
Wavelength μm



T_{eff} K
J−[3.55]
J−[4.49]
J−[5.73]
J−[7.87]
H−[3.55]
H−[4.49]
H−[5.73]
H−[7.87]

Analysis

- “The models satisfactorily fit all the spectra except for the very red L dwarf 2MASS 2224−01 (L3.5)”
- average deviation: 10%-20%

Future Work

- Add non solar metallicities
- Impact of smaller grains