

# Sonora - Bobcat

## Tables of brown dwarf and exoplanet evolution

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This directory contains tables of the evolution and photometry of brown dwarfs and self luminous extrasolar planets based on the model described in Marley et al. (2021). This publication provides a detailed description of the physics included in the model. We intend that this and future models from our group will go under the general name “Sonora”, after the desert in southeastern Arizona and adjoining Mexico, while this particular generation of models is the “Bobcat” series.

The main differences with the previously published tables by Saumon & Marley (2008) are

- updated atmosphere models used as the surface boundary conditions, primarily involving improvements in the opacities of  $H_2$ ,  $CH_4$  and alkali resonance lines. The new atmosphere models are described in Marley et al. (2021).
- including metals in the interior equation of state as an additional amount of helium. Currently, the evolution tracks are for solar metallicity and two other abundance cases ( $[M/H] = -0.5, 0.0, +0.5$ ) and, in all three cases, solar C/O ratio. (defined relative to solar, so  $C/O=1$  here) with cloudless atmospheres. Model spectra will be archived separately. This repository holds tables of the evolution and photometry of the model set as described below.

### CONTENTS OF THE EVOLUTION TABLES

In each evolution subdirectory three tables give the evolution tabulated holding the mass, the age or the bolometric luminosity fixed, with file names ending with

'\_mass' (e.g. 'nc+0.0\_co1.0\_mass'), '\_age', or '\_lbol', respectively. A fourth table (nc+0.0\_co1.0\_mass\_age) gives the mass and age as a function of  $T_{\text{eff}}$  and gravity.

All files are in ASCII and contain the basic evolution parameters. As an example, the beginning of the file 'nc+0.0\_co1.0\_mass' is

M/Msun	age(Gyr)	log L/Lsun	Teff(K)	log g	R/Rsun	log I
24						
0.0005	0.0010	-5.361	631.	2.654	0.1743	49.4144
0.0005	0.0020	-5.702	538.	2.716	0.1622	49.3782
0.0005	0.0030	-5.912	485.	2.748	0.1565	49.3604
0.0005	0.0040	-6.053	453.	2.768	0.1528	49.3488
0.0005	0.0060	-6.216	419.	2.796	0.1481	49.3343
0.0005	0.0080	-6.330	397.	2.815	0.1448	49.3243
0.0005	0.0100	-6.413	381.	2.830	0.1423	49.3164
0.0005	0.0150	-6.562	356.	2.858	0.1378	49.3014
0.0005	0.0200	-6.679	337.	2.880	0.1344	49.2894

Column 1: mass is solar mass (adopted  $M_{\text{sun}} = 1.989\text{E}+33$  g)

Column 2: age in Gyr

Column 3:  $\log (L_{\text{bol}}/L_{\text{sun}})$  ( $\log L_{\text{sun}} = 33.5827$  in erg/s)

Column 4:  $T_{\text{eff}}$  in K

Column 5:  $\log$  of gravity in  $\text{cm/s}^2$

Column 6: radius in solar units ( $R_{\text{sun}} = 6.9599\text{E}+10$  cm)

Column 7: moment of inertia ( $\log I$  in  $\text{g cm}^2$ )

Each block of lines is for one value of the mass/age/ $L_{\text{bol}}$  and is preceded by an entry giving the number of lines in the block (24 in the above example). The tables are limited to the following ranges:

$$0.0005 < M/M_{\text{sun}} < 0.080 \quad 100 < T_{\text{eff}} (\text{K}) < 2400$$

$$1 \text{ Myr} < \text{age} < 15 \text{ Gyr}$$

Fine grids in mass, age and  $L_{\text{bol}}$  are used and, when necessary, an entry is provided outside these ranges to aid with interpolation and avoid extrapolation.

Note that the early evolution (age < 10 Myr or so) is sensitive to the initial condition of the model (see Baraffe et al. 2002, A&A 382, 563; Marley et al. 2007, ApJ 655, 561) and should be used with caution. These sequences correspond to a "hot start" initial condition.

## TABLES OF FLUXES AND MAGNITUDES

The directory also contains tables of fluxes and of absolute magnitudes in a number of photometric systems commonly used in brown dwarf and exoplanet research (MKO, Keck, 2MASS, SDSS, WISE, Spitzer IRAC, etc). Fluxes and magnitudes for the full set of JWST filters is also included in separate tables. Magnitudes are computed on the Vega system (using the Vega spectrum of Bohlin & Gilliland 2004) or on the AB system (e.g. for SDSS). As an example, the beginning of the magnitude table nc\_m+0.0\_co1\_mags is

Fluxes computed from the atmosphere models of Marley										/feb18_cloudless+0.5
MKO/UFTI Filter bandpasses are defined in ftp://ftp.jach.hawaii.edu/pub/ukirt/skl/filters										
*** These are log(fluxes) (in mJy) computed for d= 10.00pc ***										
Teff	log g	mass	R/Rsun	Y	log Kzz	Y	Z	J	MKO H	K
200.	3.000	0.52	0.1169	0.28	-99.00	-9.0089	-8.8190	-8.2531	-8.4935	-8.6650
225.	3.000	0.55	0.1197	0.28	-99.00	-7.5622	-7.5969	-7.0288	-7.4282	-7.1015
250.	3.000	0.57	0.1226	0.28	-99.00	-6.2790	-6.7217	-5.9553	-6.5584	-5.9426
275.	3.000	0.60	0.1255	0.28	-99.00	-5.1265	-5.9089	-4.9558	-5.7989	-5.0739
300.	3.000	0.63	0.1282	0.28	-99.00	-4.2515	-5.1839	-4.1040	-5.1139	-4.4067
325.	3.000	0.65	0.1308	0.28	-99.00	-3.5965	-4.5340	-3.4168	-4.4745	-3.8608
350.	3.000	0.68	0.1334	0.28	-99.00	-3.0931	-3.9901	-2.8737	-3.8954	-3.3957
375.	3.000	0.70	0.1353	0.28	-99.00	-2.6832	-3.5352	-2.4366	-3.3980	-2.9941

Where columns to the right that correspond to other filters have been deleted here for clarity. Bandpasses are grouped by photometric systems indicated by the first line of the table header, delimited by vertical bars ( | ).

Column 1:  $T_{\text{eff}}$  in Kelvin

Column 2:  $\log g$  ( $\text{cm/s}^2$ ). In the spectrum files,  $g$  is in  $\text{m/s}^2$

Column 3: Mass of the corresponding model, in  $M_{\text{Jupiter}}$

Column 4: Radius of the corresponding model in  $R_{\text{sun}}$

Column 5: Helium mass fraction  $Y$

Column 6:  $\log K_{zz}$ , the coefficient of eddy diffusion used to parametrize vertical transport. Models in chemical equilibrium are given a large negative value (-99), i.e.  $K_{zz}=0 \text{ cm}^2/\text{s}$

Column 7: MKO Y absolute magnitude

Column 8: MKO Z absolute magnitude

...

Column 14: 2MASS J absolute magnitude and so forth.

The masses and radii are obtained from the evolution sequences described in Marley et al. (2020; in prep.) and use the appropriate model atmospheres as surface boundary conditions for self-consistency.

The flux tables (e.g. nc\_m+0.0\_co1.0\_flux) follow the same format, giving  $\log(F)$  integrated over the bandpass with  $F$  in mJy at Earth for  $D=10\text{pc}$ .

## CREDITS

If you use these tables in your research, please cite Marley et al. (2021)

## REFERENCES

Baraffe, I., Chabrier, G., Allard, F., Hauschildt, P.H., 2002, A&A 382, 563

Marley, M.S., Fortney, J.J., Hubickyj, O., Bodenheimer, P., & Lissauer, J.J. 2007, ApJ 655, 541  
Saumon, D. & Marley, M.S. 2008, Astrophys. J. 689, 1327

Marley, M.S., Saumon, D.S. et al. (2021) The Sonora Brown Dwarf Atmosphere and Evolution Models. I. Model Description and Application to Cloudless Atmospheres in Rainout Chemical Equilibrium, Astrophys. J. submitted.

## INQUIRIES

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These tables have been approved by LANL for unlimited release (LA-UR-18-28199)

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