Virtual Planetary Laboratory at UW
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Instituto de Ciencias Nucleares UNAM

Universidad Nacional Autónoma de México

Habitabilidad de planetas alrededor de estrellas enanas M: retos y posibilidades

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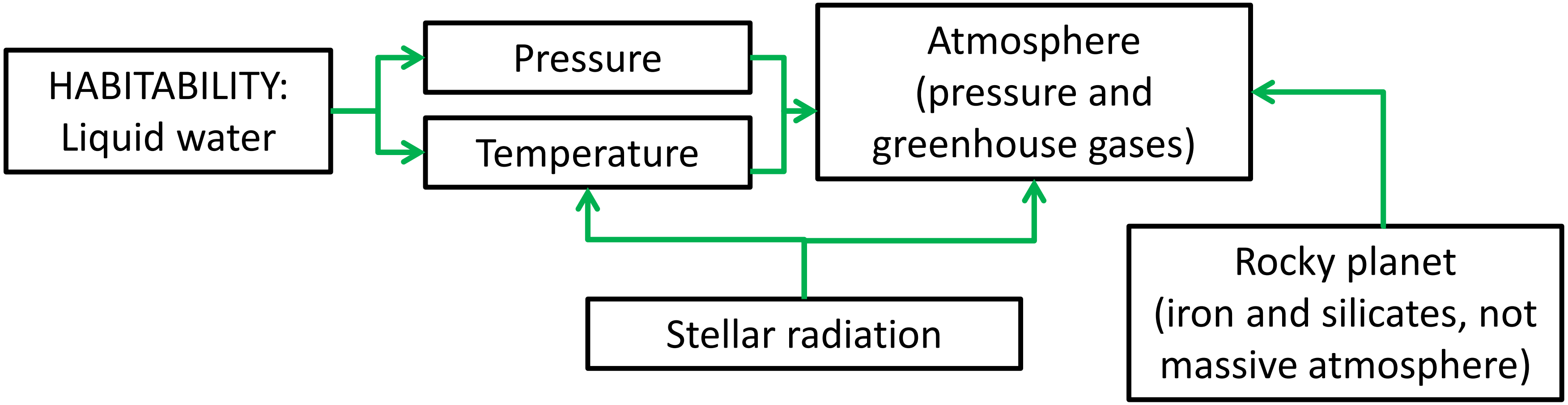
BASICS: HABITABILITY AND PROPERTIES OF M MAIN SEQUENCE STARS

Habitable planets

- Life as we know it: carbon chemistry and liquid water.
- Habitability (most general requirement): liquid water.
- For extrasolar terrestrial planets, habitability is defined as the environmental conditions required to maintain liquid water on the **surface** of the planet:



HABITABILITY: Liquid water

Pressure

Temperature

Atmosphere (pressure and greenhouse gases)

Stellar radiation

Rocky planet (iron and silicates, not massive atmosphere)

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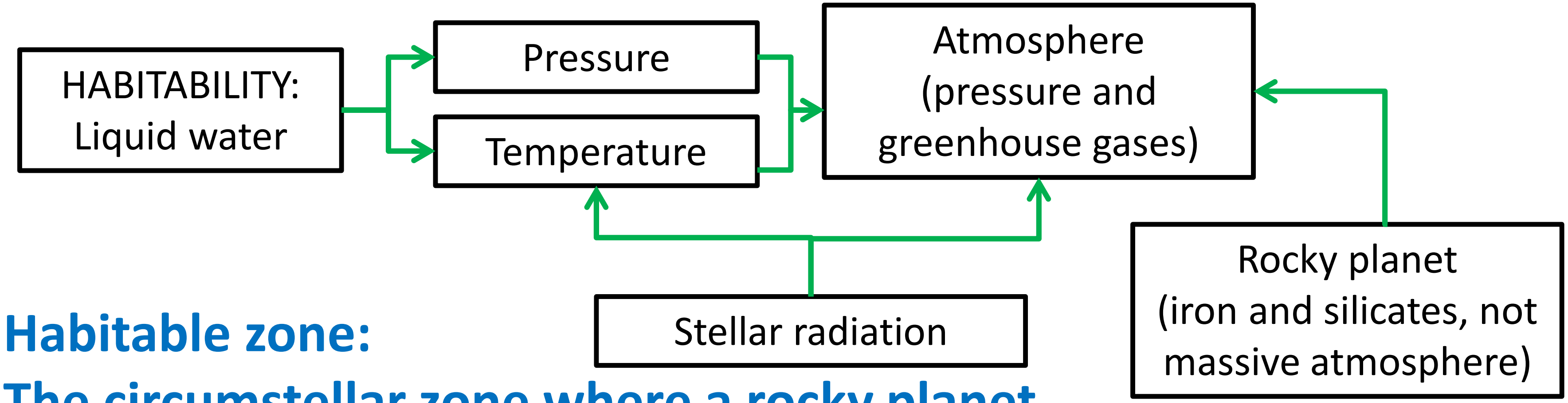

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Habitable zone:
The circumstellar zone where a rocky planet with atmosphere (CO_2-N_2- H_2O) can mantain liquid water on its surface.

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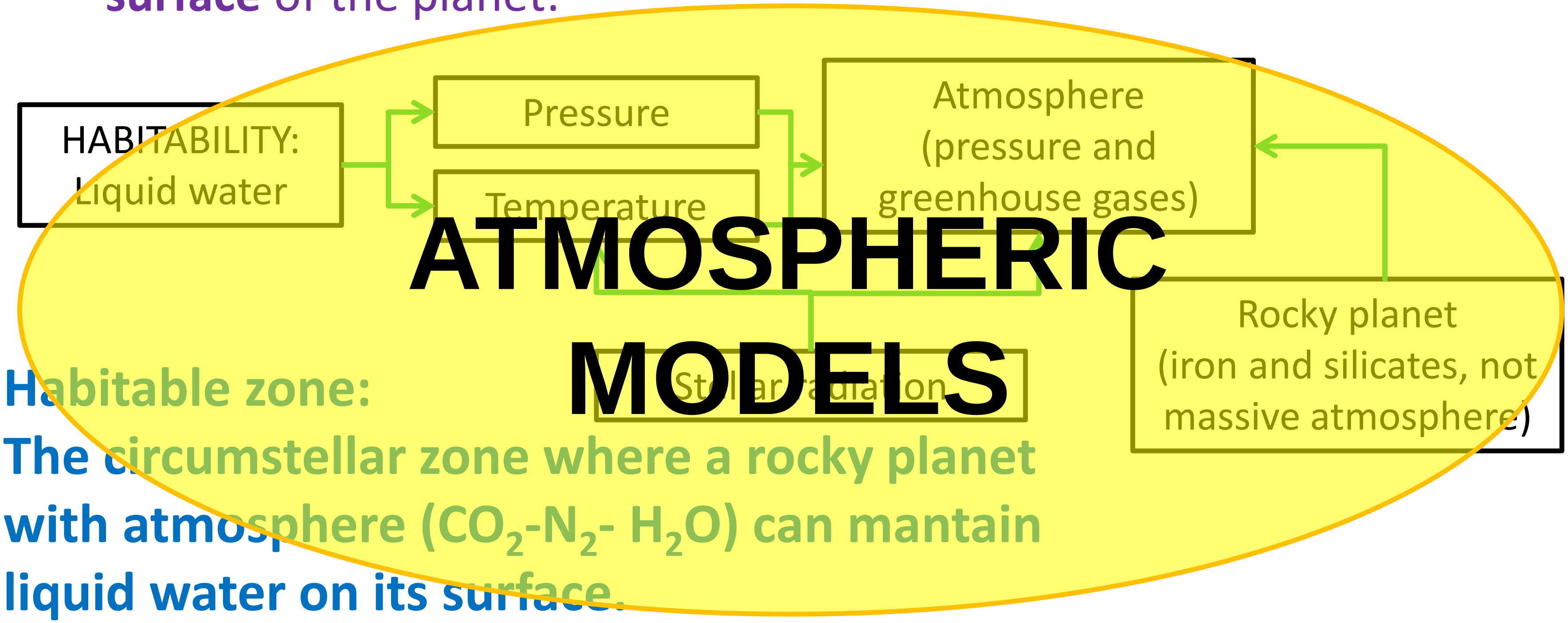

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ATMOSPHERIC MODELS

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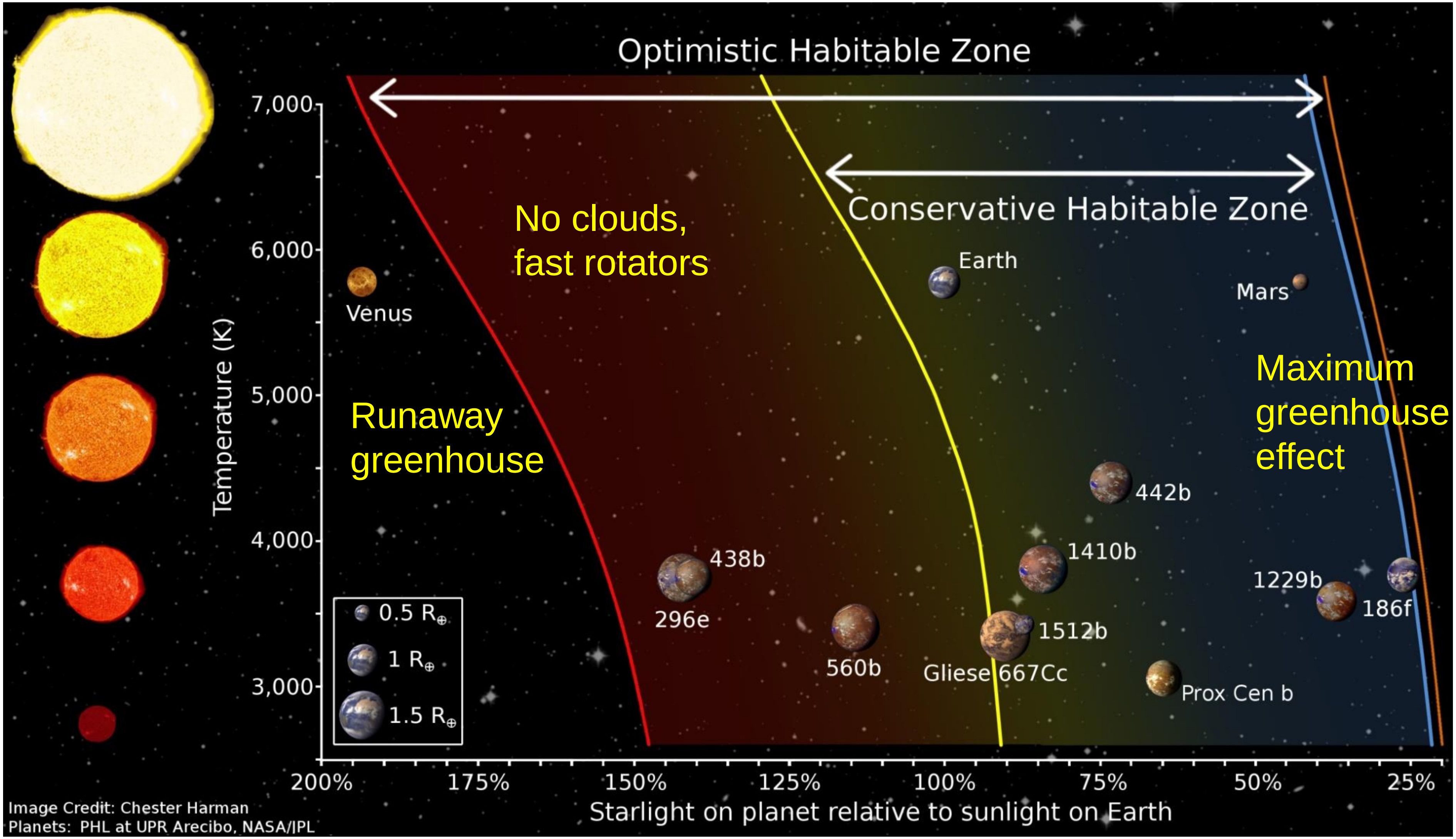
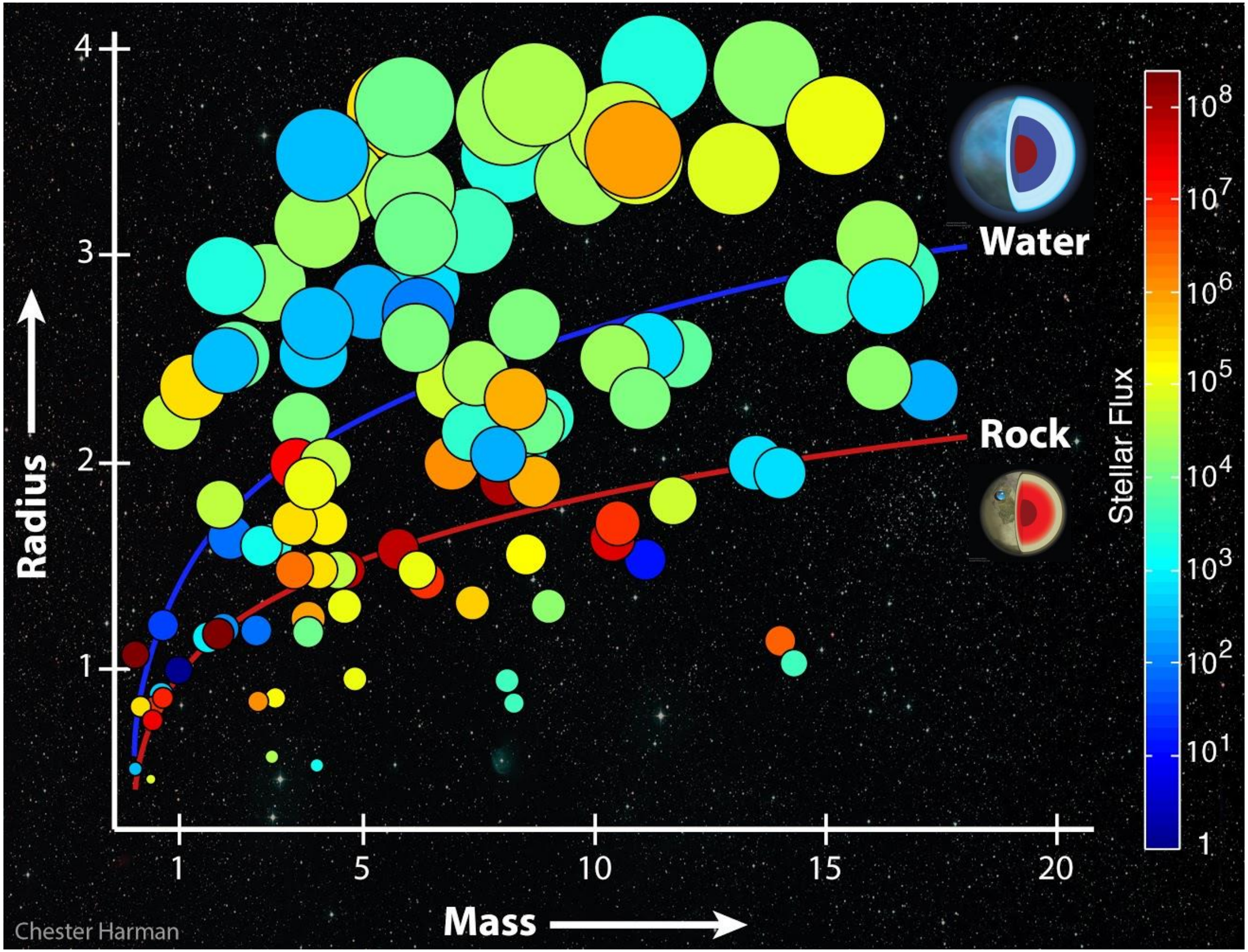
Habitable zone



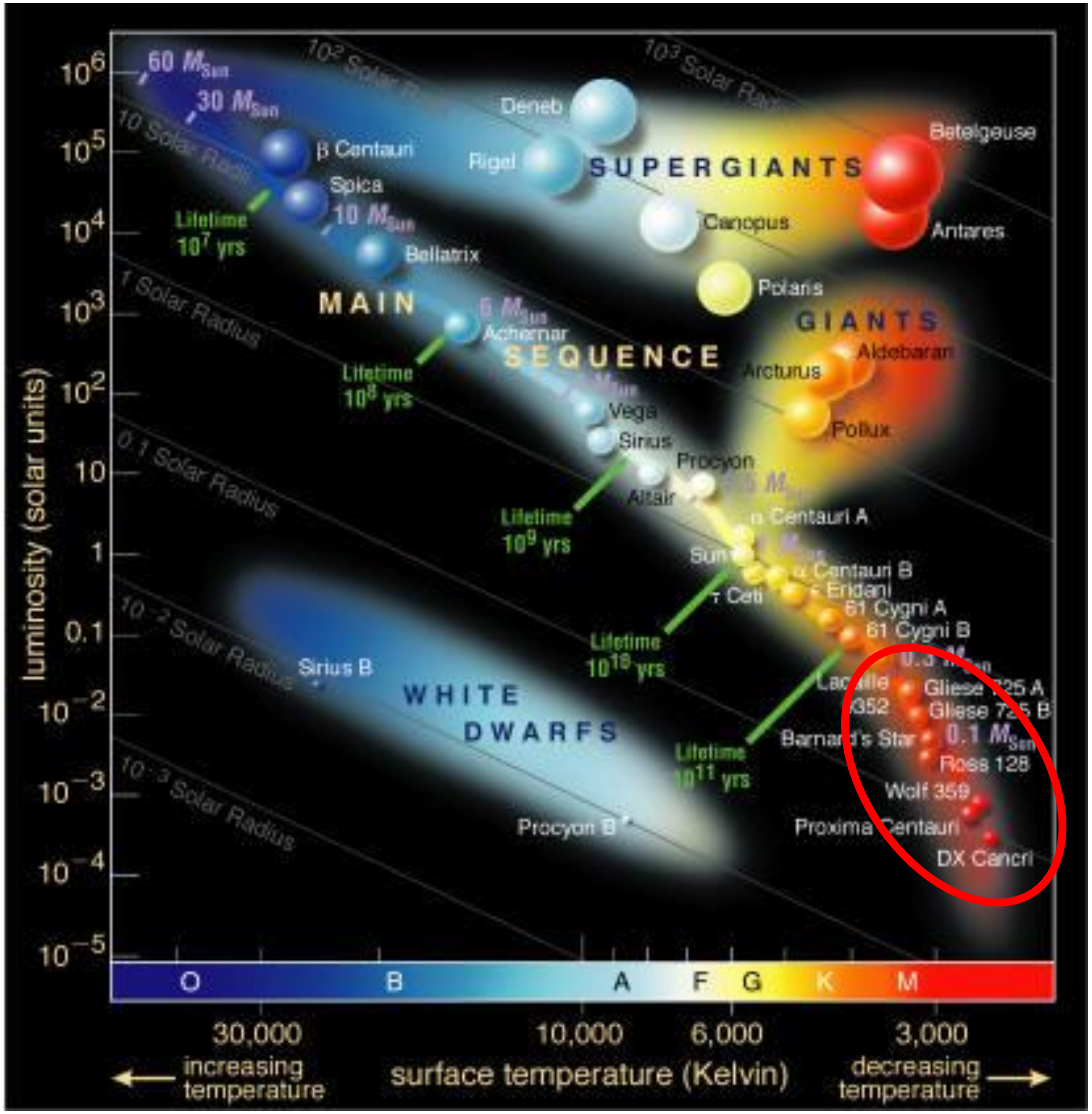
http://www3.geosc.psu.edu/~ruk15/images/

Planetary composition (units: Earth radius and mass)



http://www3.geosc.psu.edu/~ruk15/images/

Main sequence M stars:
M dwarfs a.k.a. red dwarfs

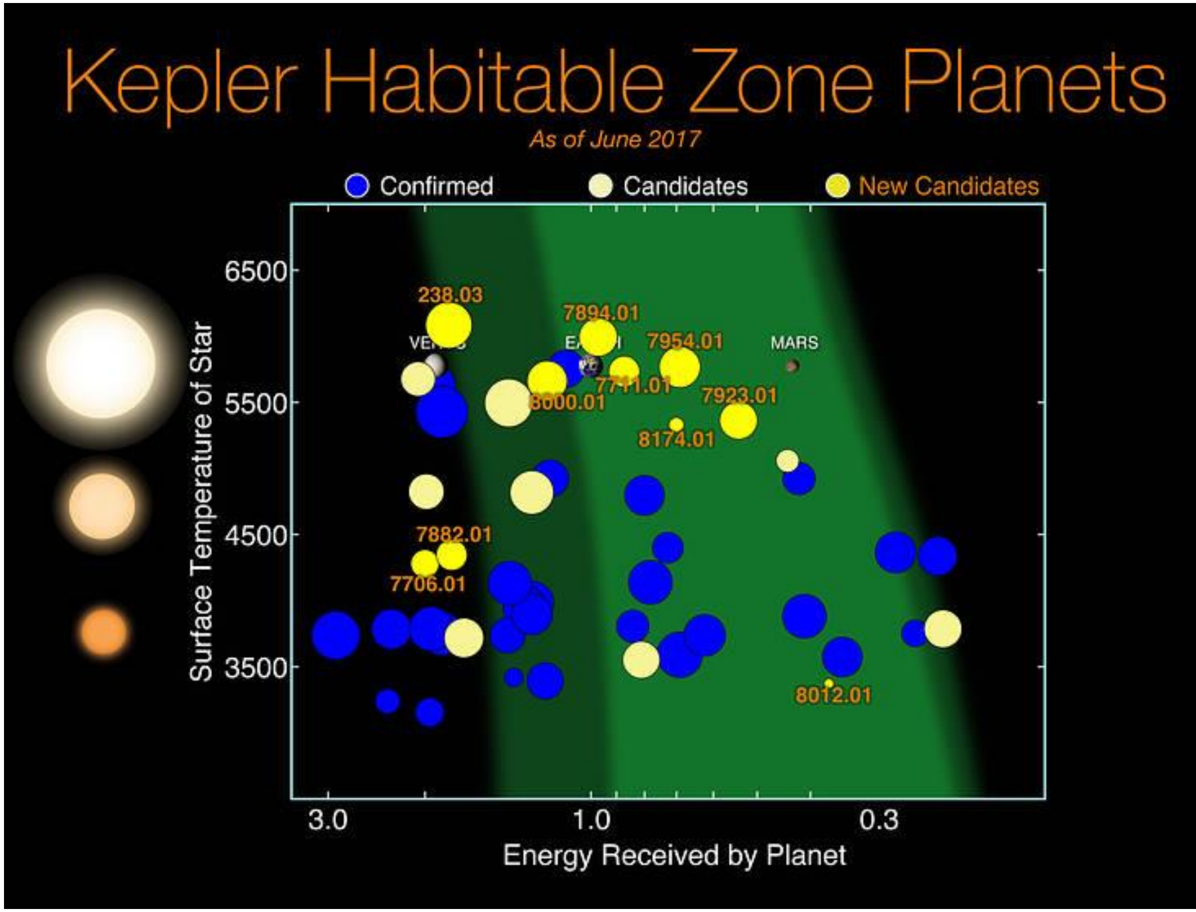


- Masses: 0.06-0.6 $M_{\odot}$.
- Luminosities: 0.6-10^{-4} $L_{\odot}$.
- Main sequence lifetime 10^{11} yr: Enough time for life to appear
- 73% of the stars in the solar neighborhood: Many of them to search for habitable planets.
- Most likely targets for characterization of potentially habitable planets.

Exoplanets around M dwards

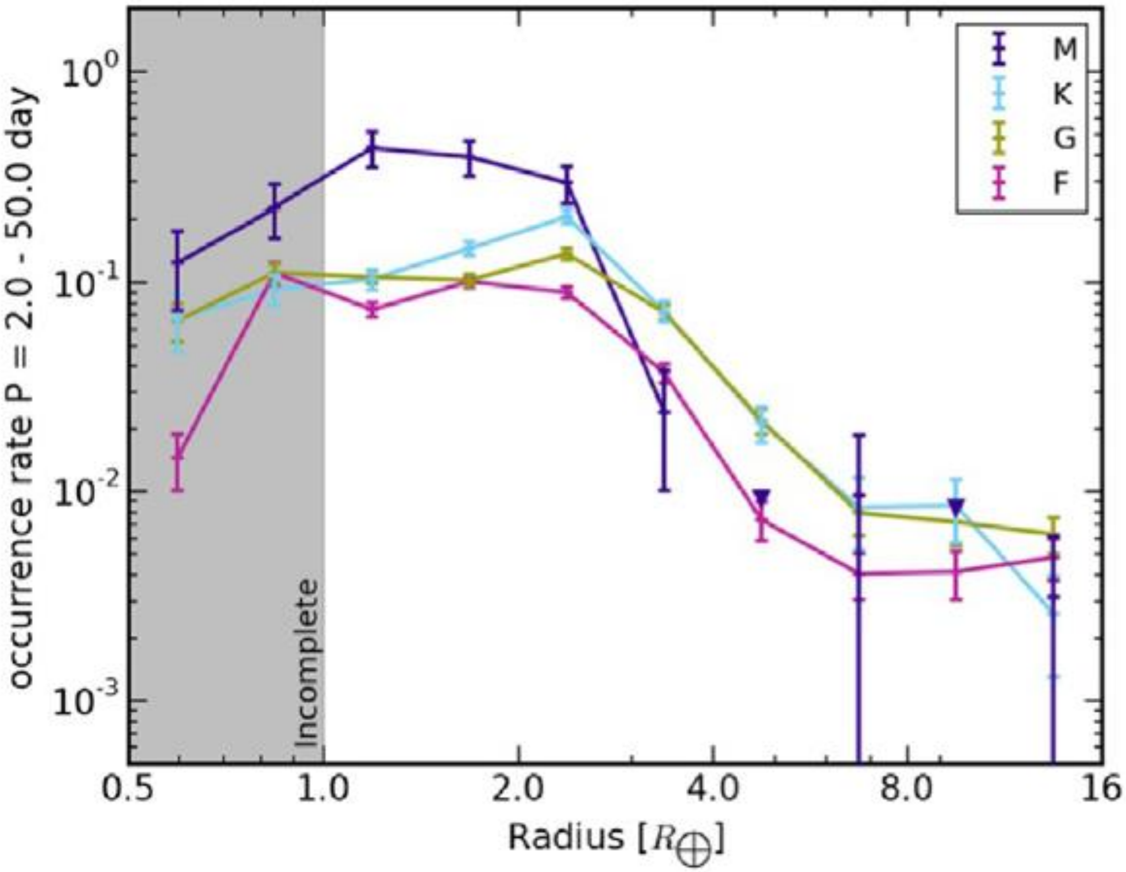
Small planets are easier to detect orbiting small stars via the radial velocity and transit techniques (smaller star-to-planet mass and size ratios, respectively).

The probability of a transit for a planet residing in the habitable zone is 1.5% (M4V dwarf) and 2.7% (M8V dwarf), significantly above the Earth–Sun value of 0.47% (Charbonneau and Deming, 2007)



NASA/Ames Research Center/Wendy Stenzel

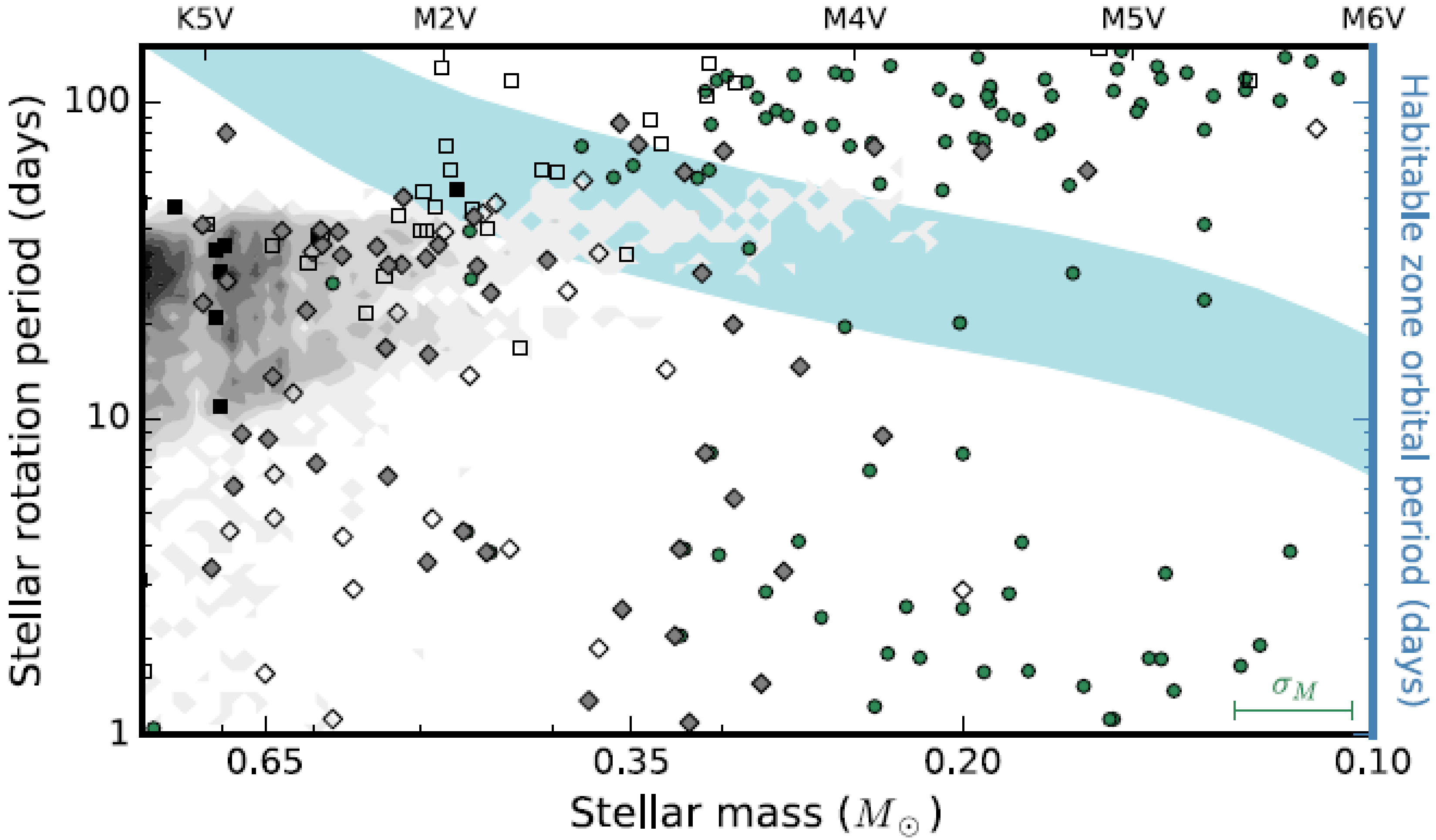
Exoplanets around M dwarfs



Mulders et al. 2015

3.5 times more small planets (1.0–2.8 $R_\oplus$) orbiting M dwarfs than main-sequence FGK stars.

But…



Stellar activity will be an unavoidable contaminant in radial velocity surveys that are searching for habitable planets around early M dwarfs (Newton et al. 2016).

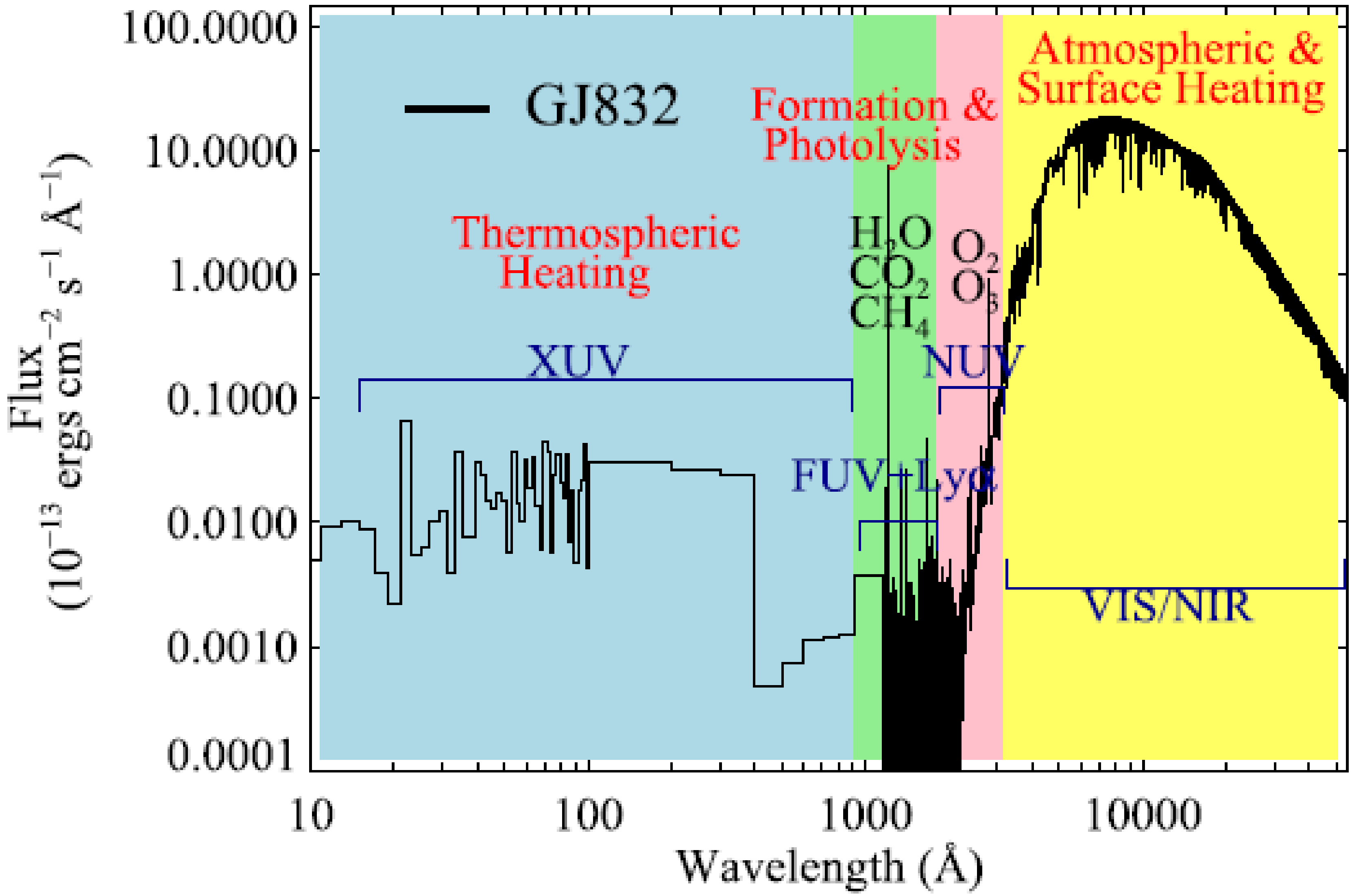
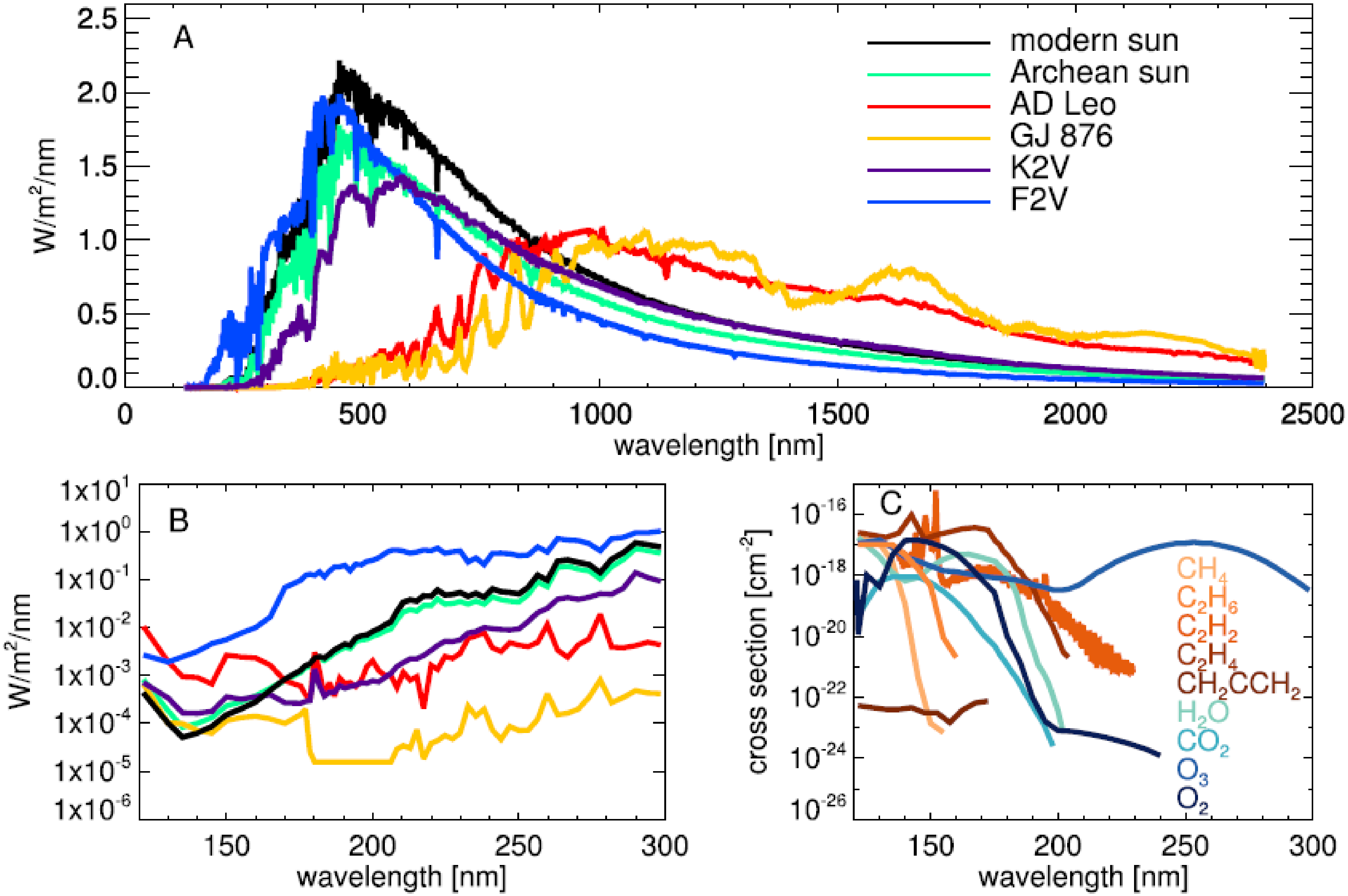


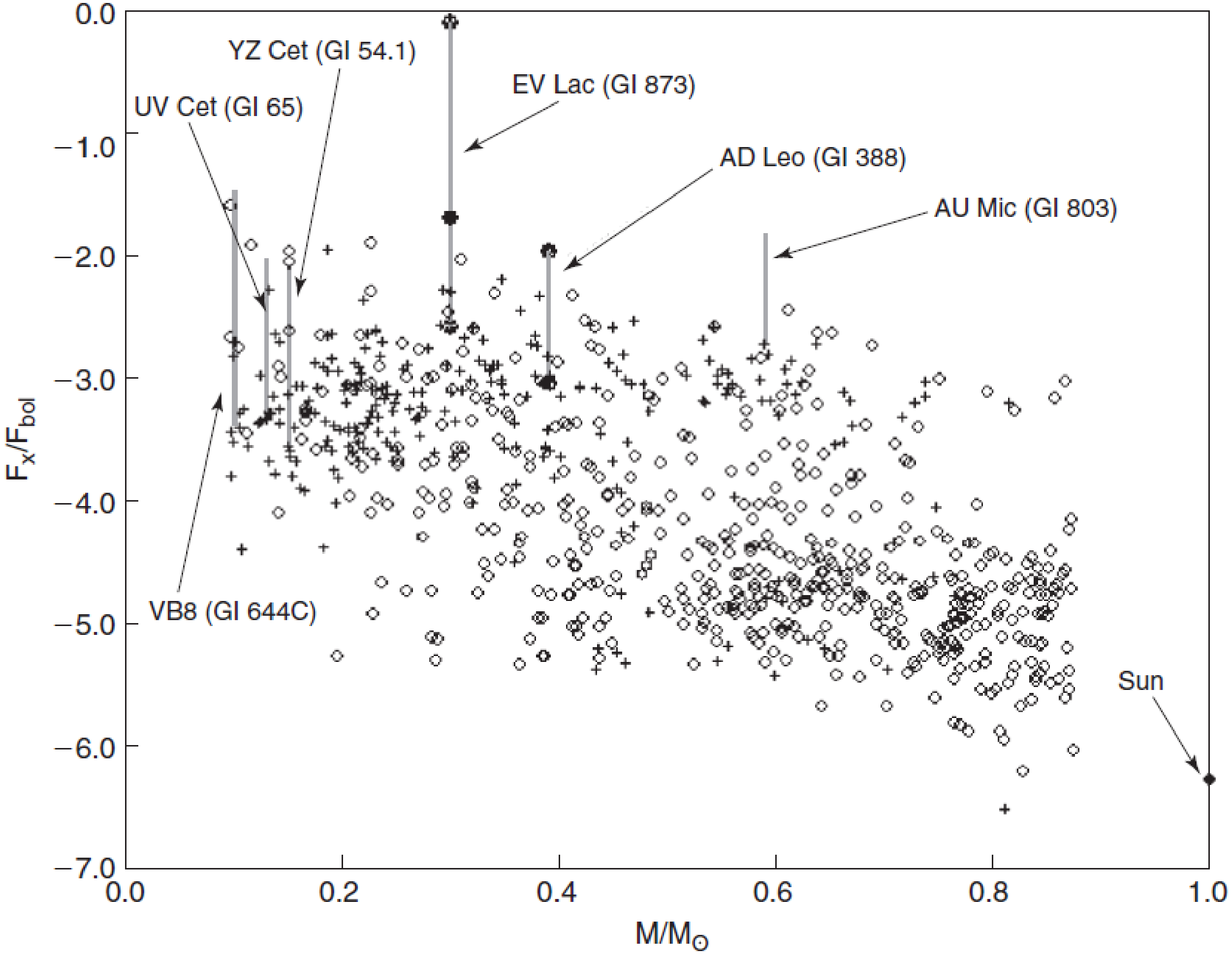
Figure 1. Panchromatic spectrum of GJ 832, illustrating the influence of each spectral bandpass on an Earth-like planet orbiting this star. GJ 832 has a super-Earth mass planet located in the HZ (Wittenmyer et al. 2014).

France et al. 2016



Normalized stellar flux $\int F d\nu$ = 1360 W/m^2 (Arney et al., ApJ 2017)

Stellar activity



Scalo et al. 2007

X-ray luminosity compared to the total luminosity of the star is a proxy of the stellar activity.
For the average active M star, the steady coronal X-ray flux above the atmosphere of a habitable planet would be about a thousand times larger than at the Earth, while during the largest flares this flux could be a million times larger.

Chromospheric activity: flares

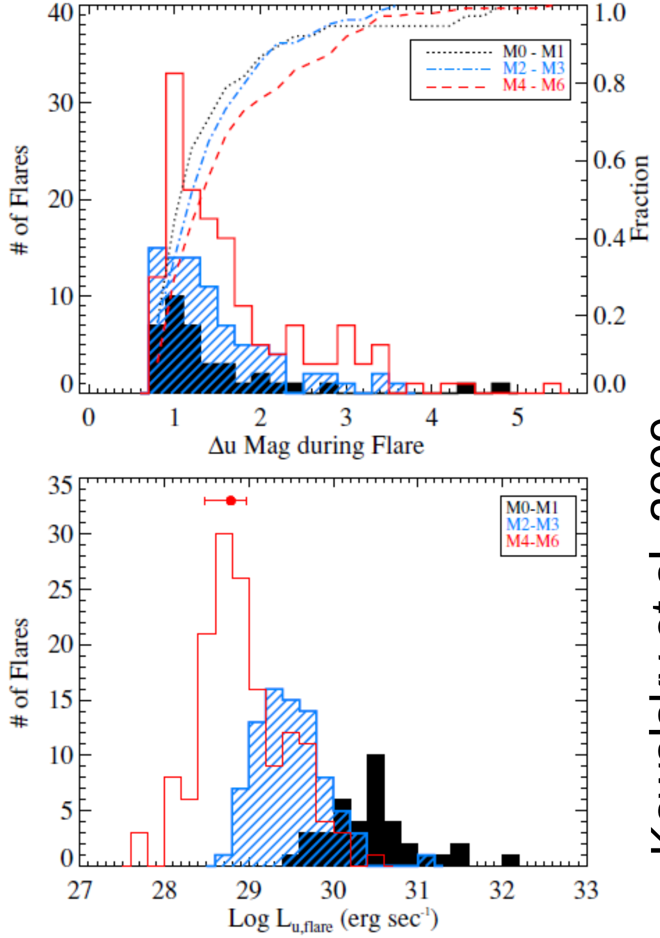
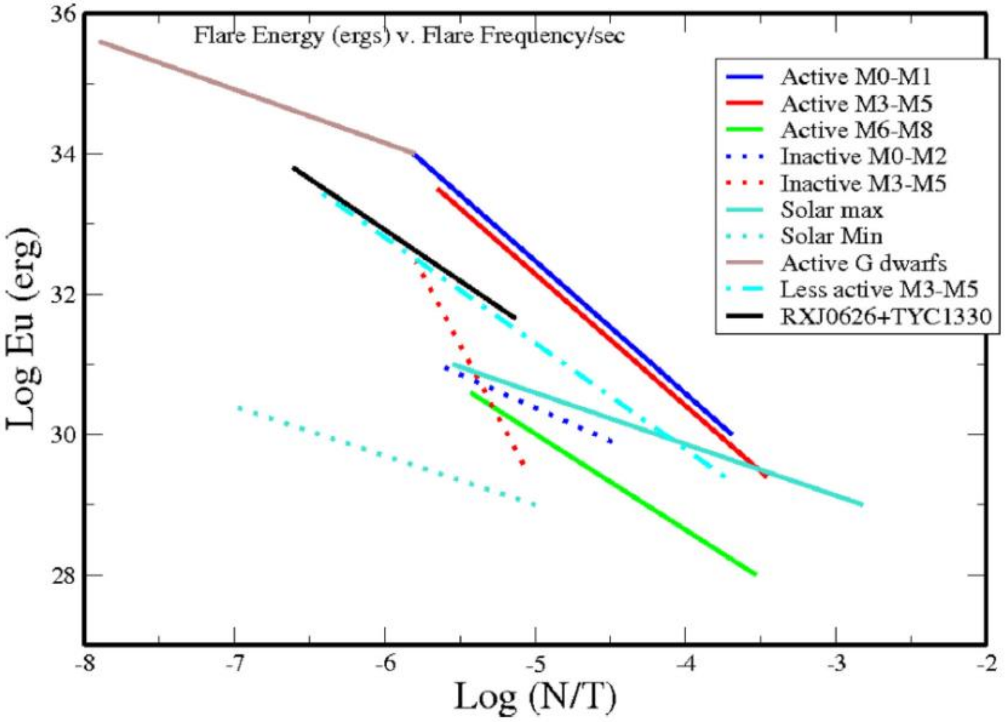


Figure 11. Top: the distribution of *u*-magnitude enhancements during flares. The dotted lines show the cumulative distributions. Later-type (lower mass) stars have the most detected flares and generate very large magnitude enhancements (due to their smaller quiescent luminosity). When converted to luminosities (bottom), the flares on the higher mass stars are the most luminous. Both of these results are consistent with previous flare observations. The errors in luminosities are ~50%, and we show a typical error bar.

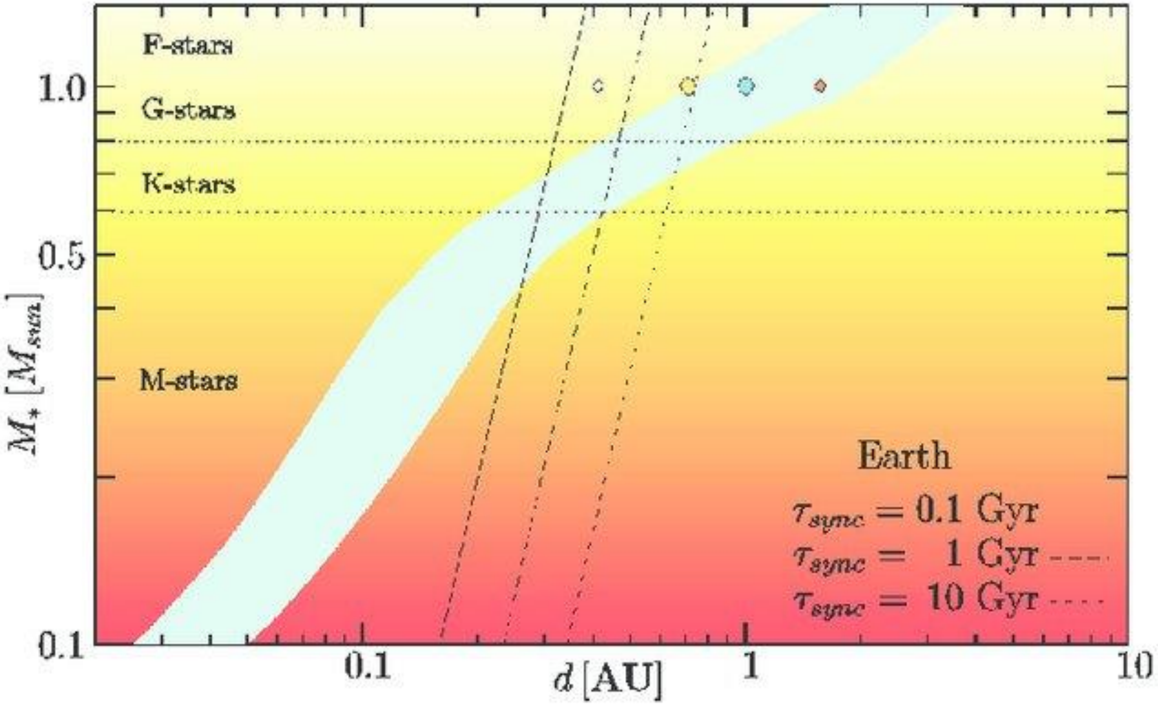
Kowalsky et al. 2009



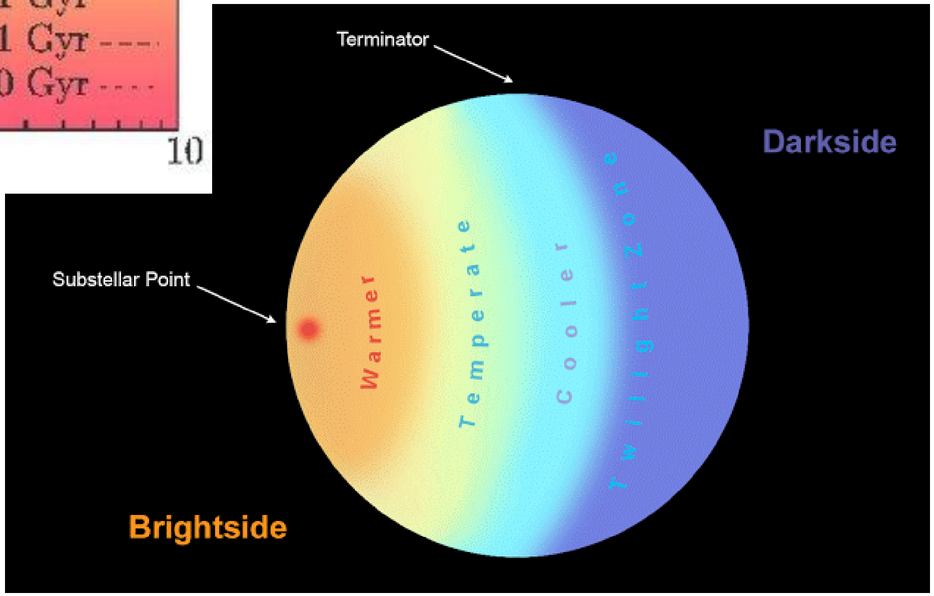
Ramsay & Doyle 2015

HABITABLE ZONE AND CLIMATE OF PLANETS AROUND RED DWARFS

Tidally locked planets

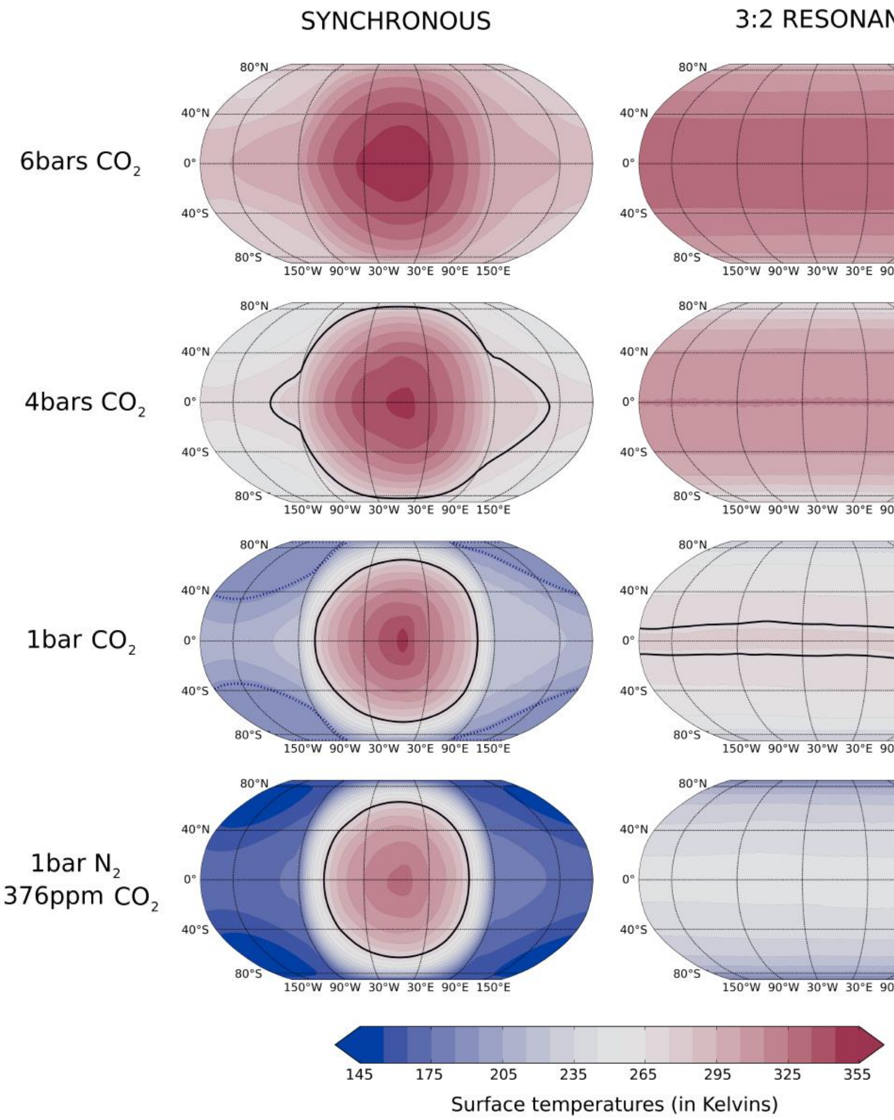


Credit: F. Selsis and J.-M. Grießmeier



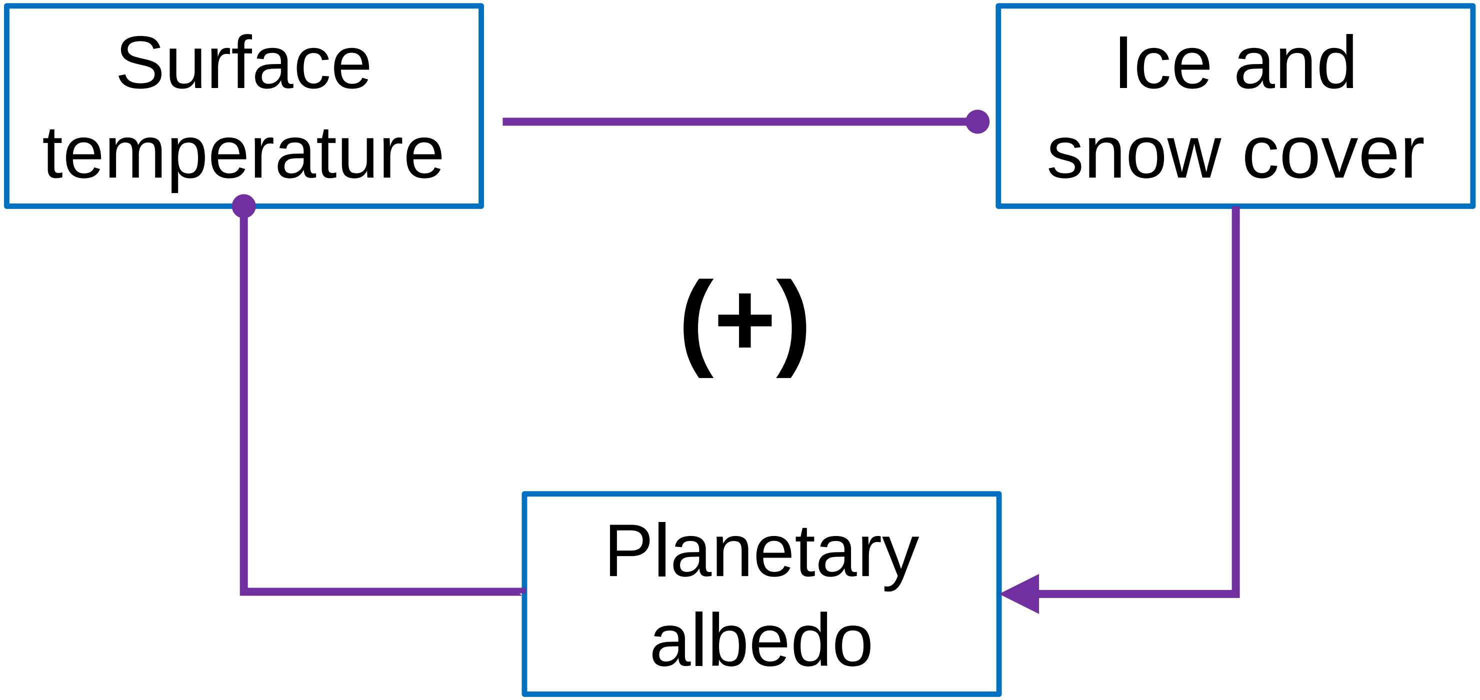
http://backalleyastronomy.blogspot.com/2016/04/daydream-destinations-part-2.html

Tidally locked planets: Proxima b

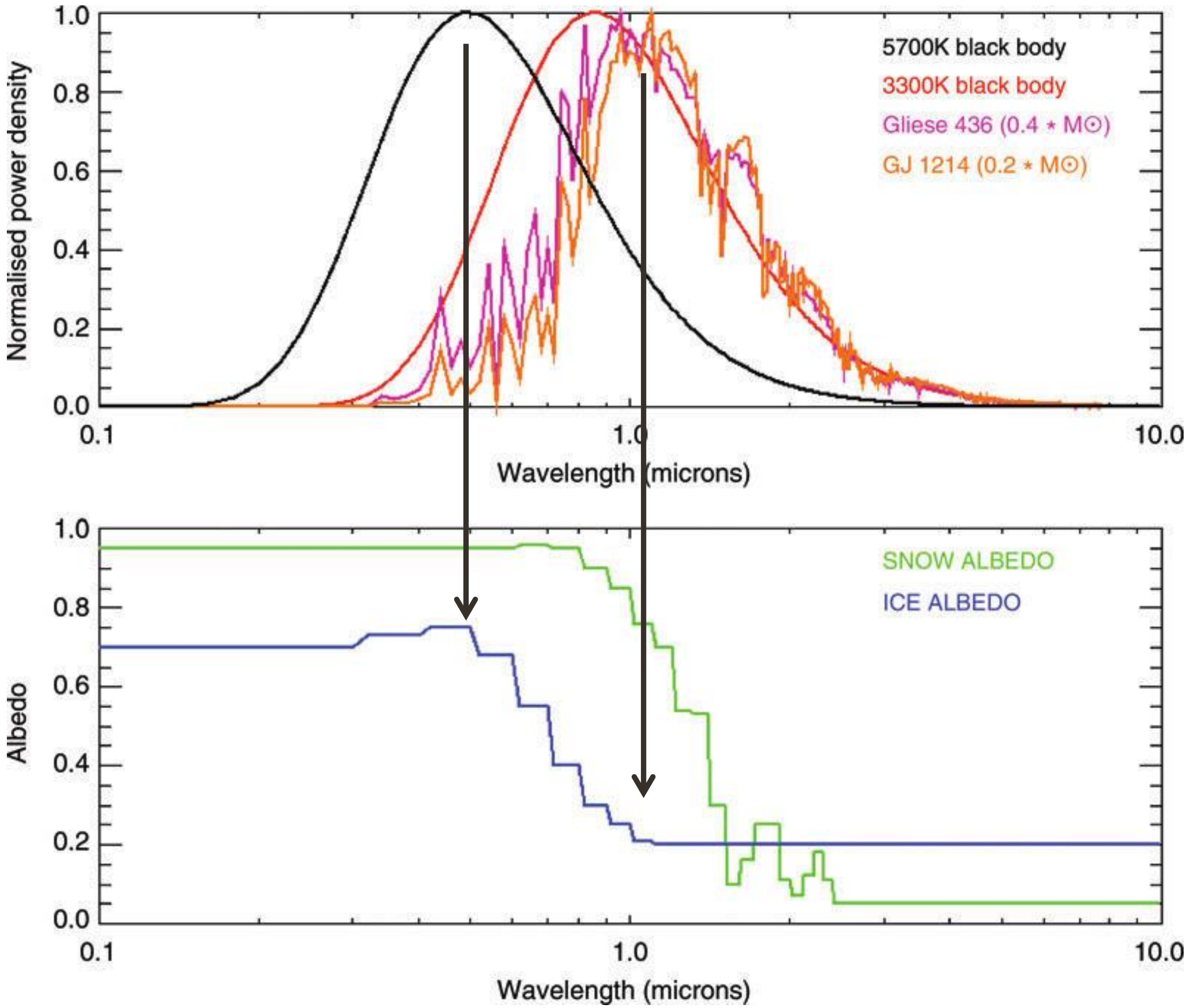


Turbert et al, 2016

Water ice and albedo feedback



BUT…

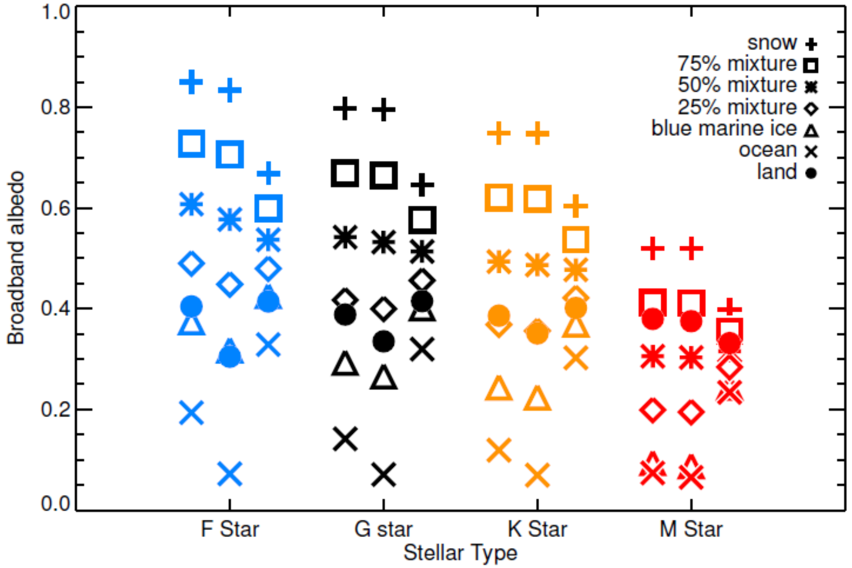


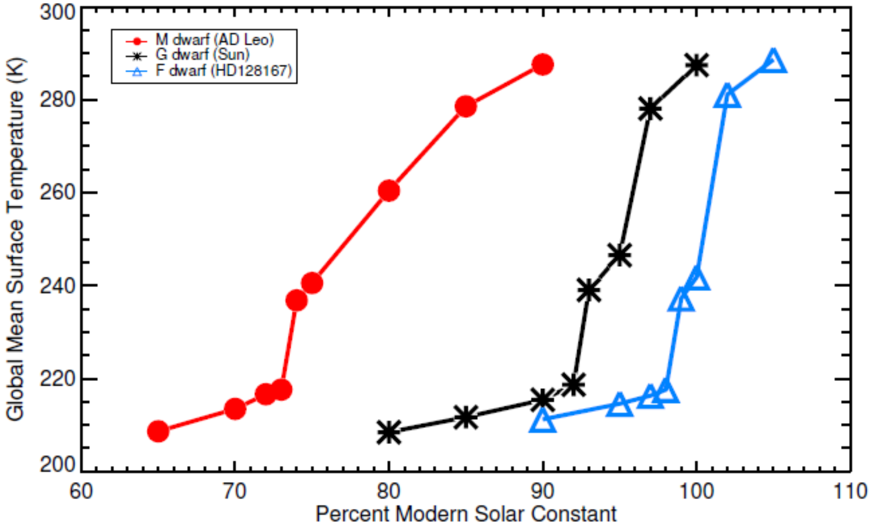
Ice and snow albedos are lower where M dwarfs emit most of their light.

Planets with snow-ice covered hemispheres will be hotter.

Joshi and Haberle (2012)

Ice and snow albedo feedback: 1D and 3D models



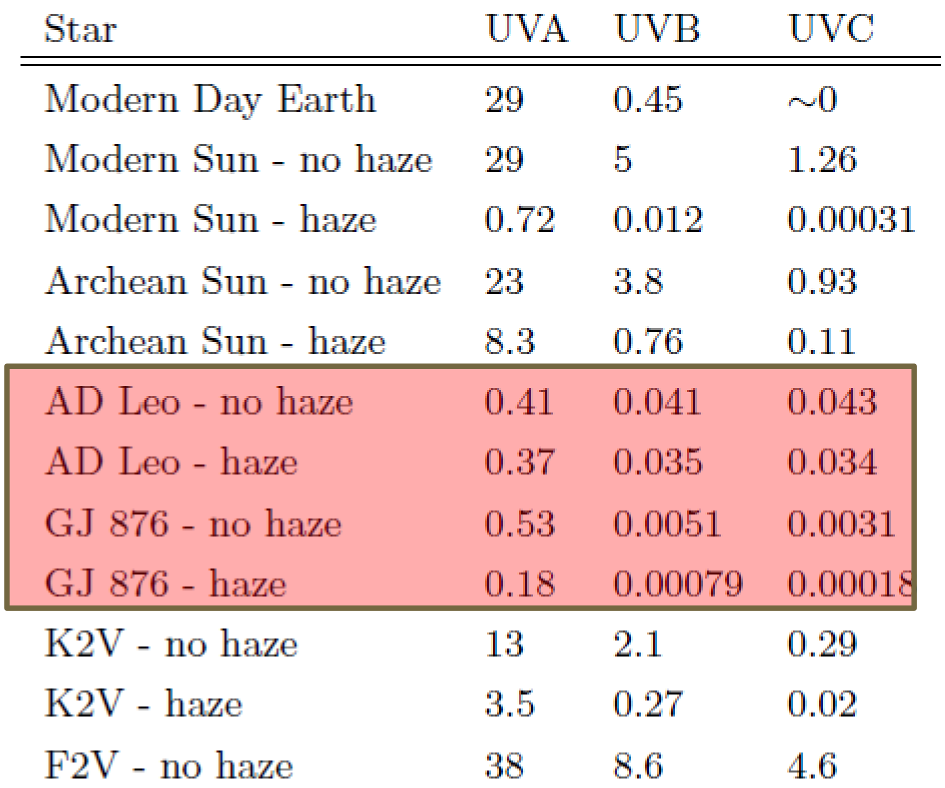


M-dwarf planets maintain surfaces free of global glaciation with larger decreases in stellar flux, essentially existing "snowball-free" at greater distances before more CO_2 would be required to keep the surface habitable.

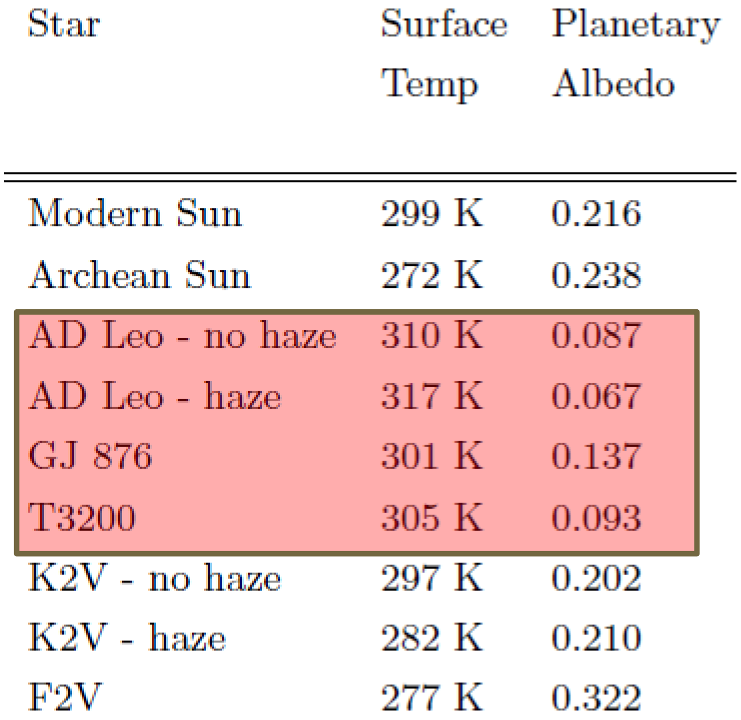
Shields et al. 2013

Photochemical hazes in Archean-like atmospheres (CO_2 -N_2):

shield the surface from UV but cool the surface EXCEPT for planets around M dwarfs (hazes are opticaly thin in IR)



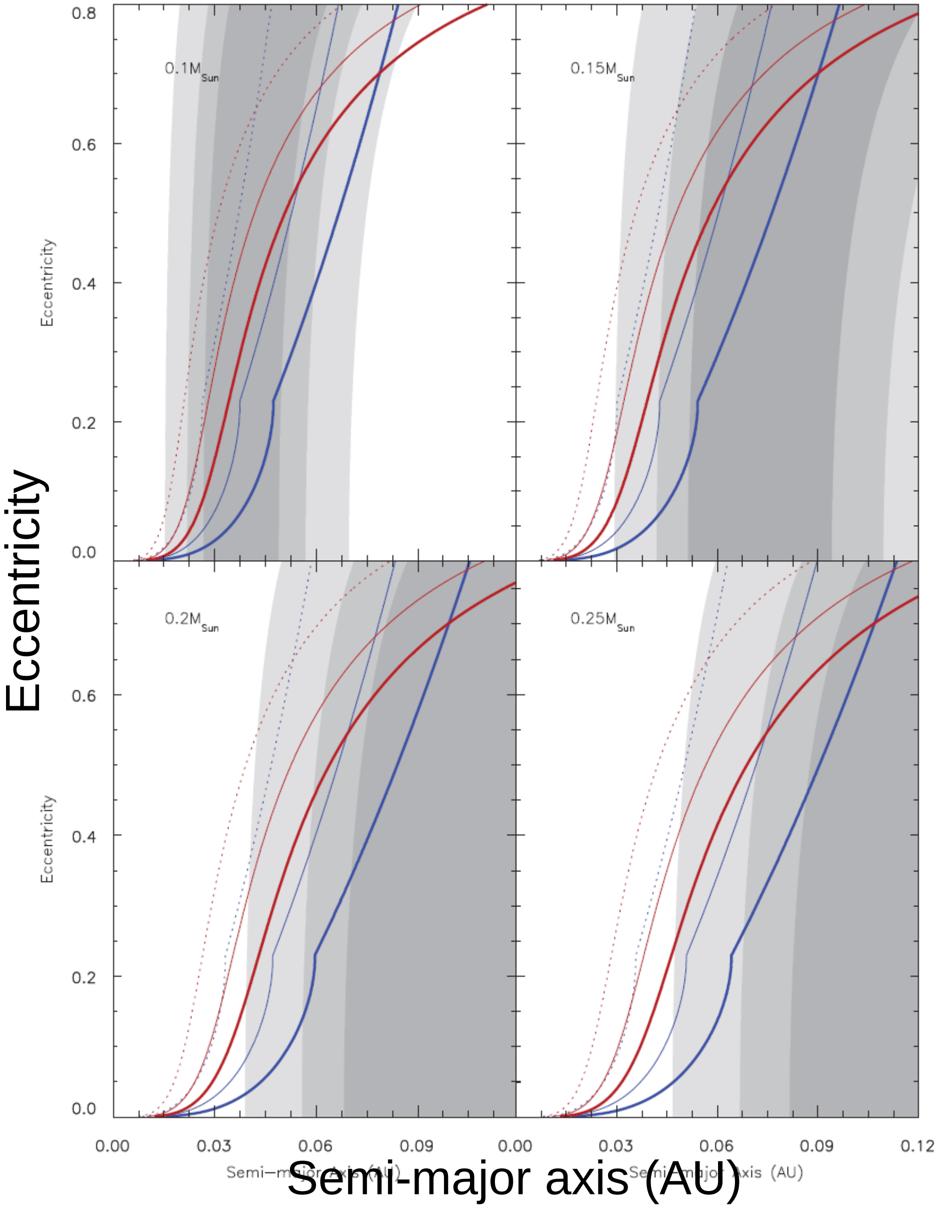
Star	400 UVA	315 UVB	<280 nm UVC
Modern Day Earth	29	0.45	~0
Modern Sun - no haze	29	5	1.26
Modern Sun - haze	0.72	0.012	0.00031
Archean Sun - no haze	23	3.8	0.93
Archean Sun - haze	8.3	0.76	0.11
AD Leo - no haze	0.41	0.041	0.043
AD Leo - haze	0.37	0.035	0.034
GJ 876 - no haze	0.53	0.0051	0.0031
GJ 876 - haze	0.18	0.00079	0.00018
K2V - no haze	13	2.1	0.29
K2V - haze	3.5	0.27	0.02
F2V - no haze	38	8.6	4.6



Star	Surface Temp	Planetary Albedo
Modern Sun	299 K	0.216
Archean Sun	272 K	0.238
AD Leo - no haze	310 K	0.087
AD Leo - haze	317 K	0.067
GJ 876	301 K	0.137
T3200	305 K	0.093
K2V - no haze	297 K	0.202
K2V - haze	282 K	0.210
F2V	277 K	0.322

Planets orbiting each spectral type for $CH_4/CO_2 = 0.2$ except “AD Leo - haze" which has $CH_4/CO_2 = 0.9$ and “K2V - haze" which has $CH_4/CO_2 = 0.3$. (Arney et al. 2017)

Tidal heating



Tidal forces heat the planet and can drive a runaway greenhouse.

For stars with masses <0.3 M_{Sun}, planets in their Insolation HZs with low eccentricity, can be uninhabitable regardless of insolation.

Grayscale Selsis et al. (2007) IHZ boundaries: from lightest to darkest gray, cloud coverage 100%, 50%, and 0%. Red curves CTL model, blue: CPL.
Solid curves: Pierrehumbert (2011) runaway greenhouse model; dotted: dry world model of Abe et al. (2011).
Thick lines: 10 $M_\oplus$ planet; thin: 1 $M_\oplus$ **Tidal Venuses lie to the left of these curves.**

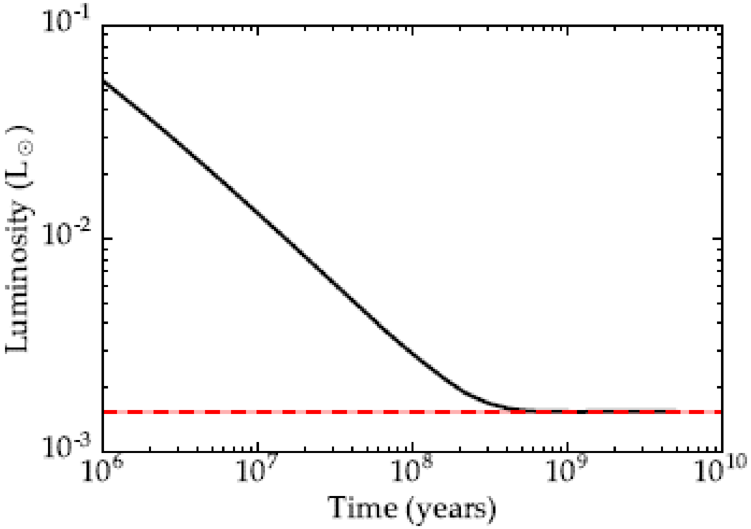
Barnes et al. 2013

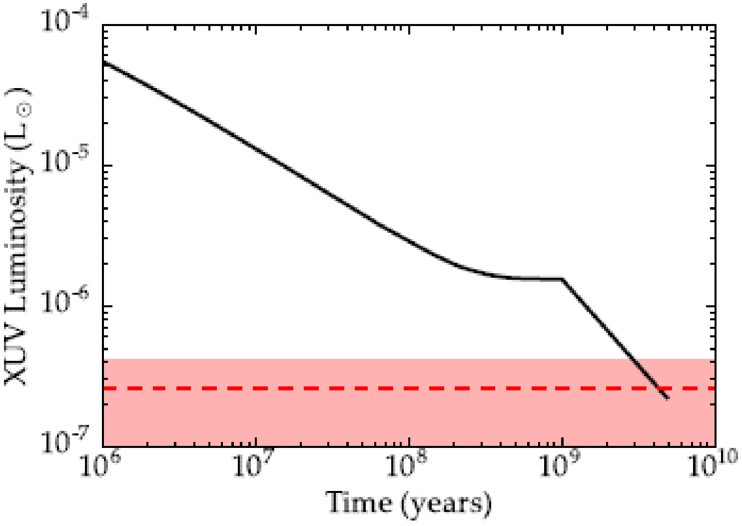
FAMOUS EXOPLANETS AROUND M DWARFS: PROXIMA B AND THE TRAPPIST-1 SYSTEM

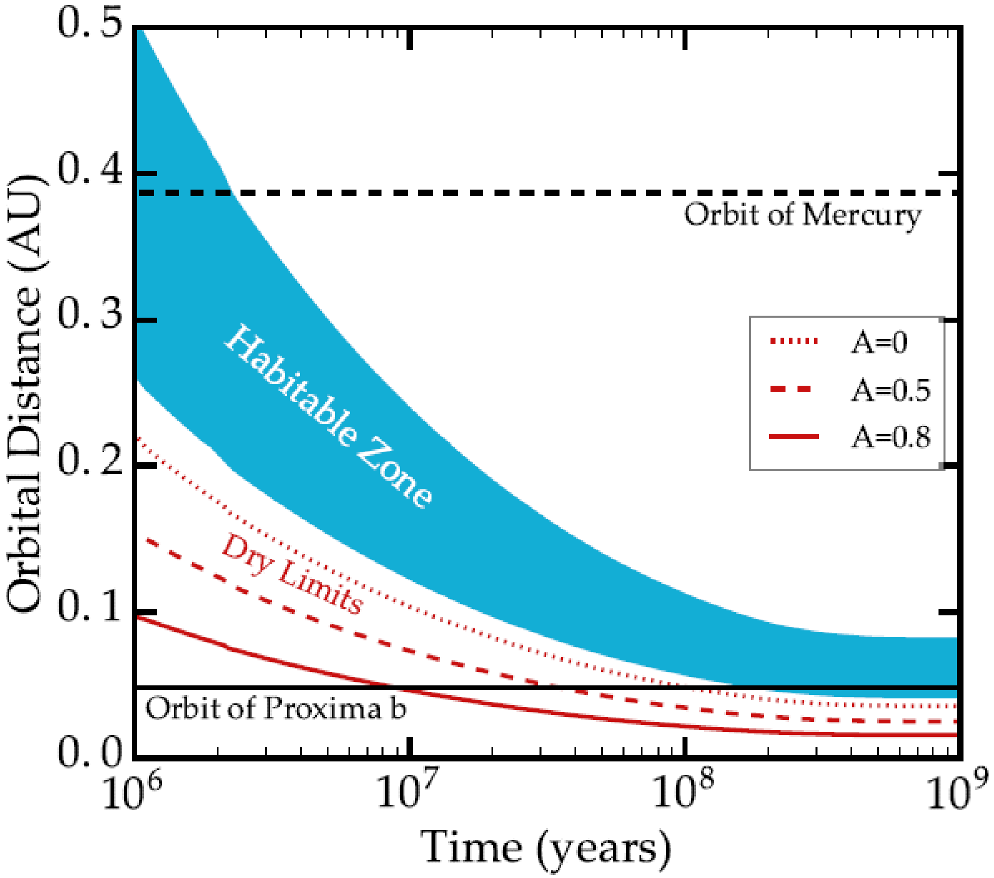
Proxima b

Proxima: M5.5V, T_{eff} =3050 K,
$L = 1.55\times10^{-3}\ L_\odot$

Proxima b: $m_p \sin i$ =1.27 $M_\oplus$, a= 0.0485 AU



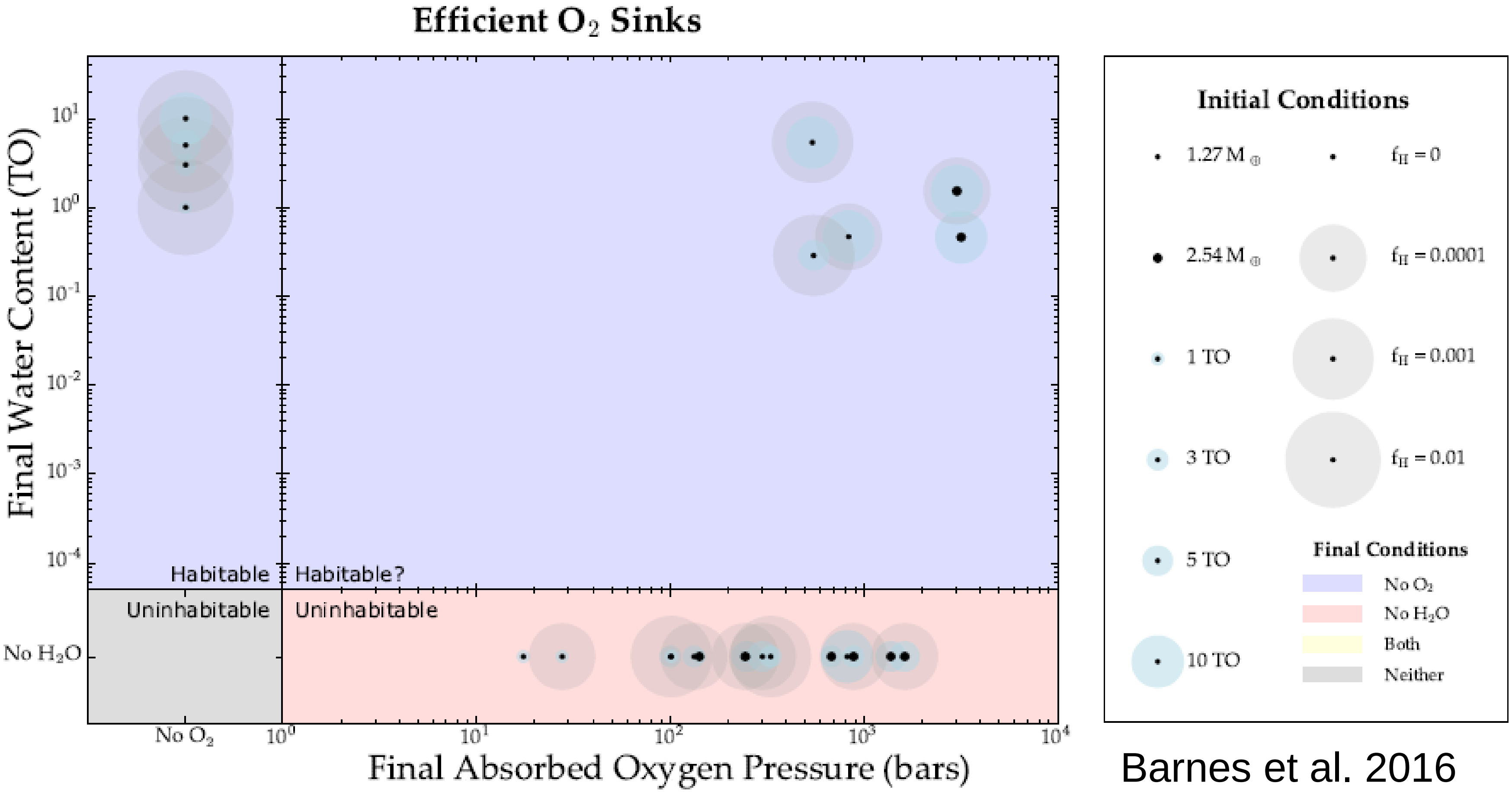




Barnes et al. 2016

Proxima b

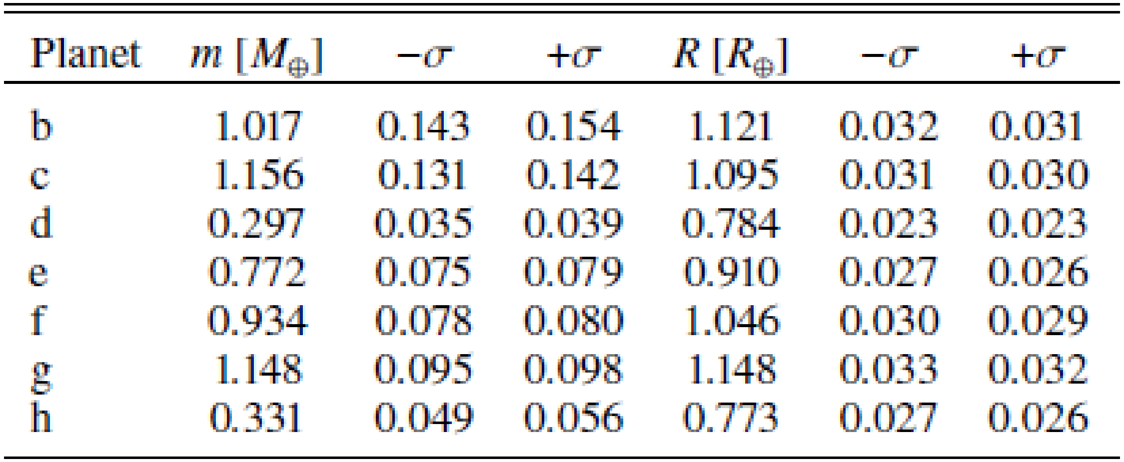
Runaway greenhouse scenarios



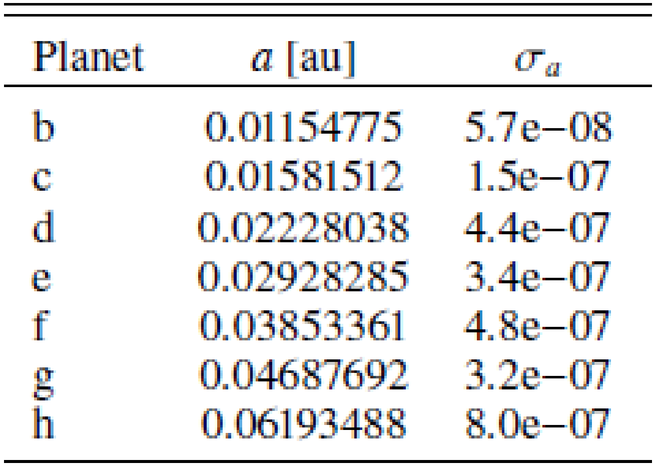
Barnes et al. 2016

Trappist-1 exoplanets

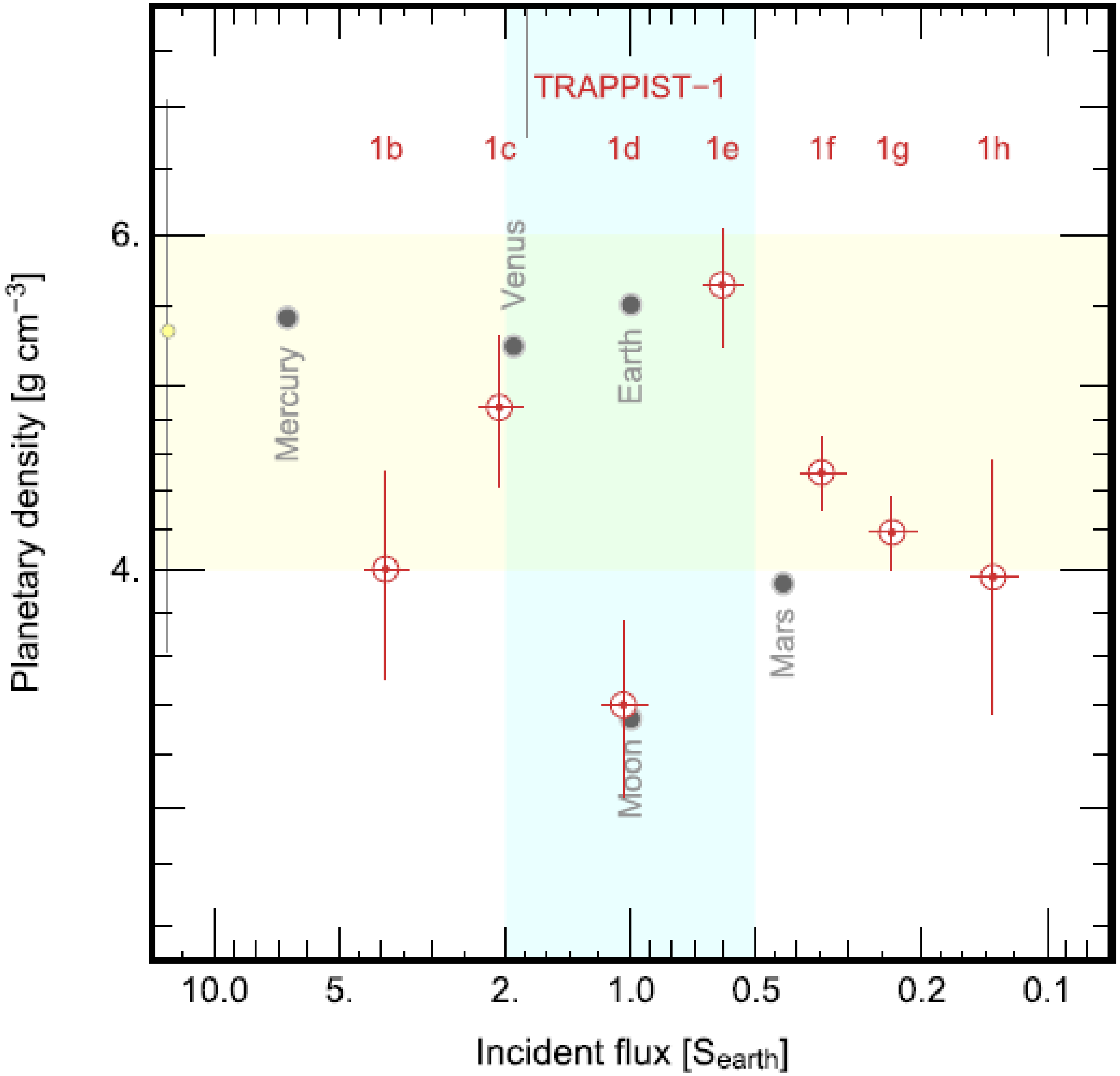
Trappist-1:	
Distance:	40 ly
Mass:	0.08 $M_{\odot}$
Radius:	0.117 $R_{\odot}$
Luminosity:	0.000524 $L_{\odot}$
Teff:	2559 K



Planet	m [$M_\oplus$]	$-\sigma$	$+\sigma$	R [$R_\oplus$]	$-\sigma$	$+\sigma$
b	1.017	0.143	0.154	1.121	0.032	0.031
c	1.156	0.131	0.142	1.095	0.031	0.030
d	0.297	0.035	0.039	0.784	0.023	0.023
e	0.772	0.075	0.079	0.910	0.027	0.026
f	0.934	0.078	0.080	1.046	0.030	0.029
g	1.148	0.095	0.098	1.148	0.033	0.032
h	0.331	0.049	0.056	0.773	0.027	0.026



Planet	a [au]	σ_a
b	0.01154775	5.7e−08
c	0.01581512	1.5e−07
d	0.02228038	4.4e−07
e	0.02928285	3.4e−07
f	0.03853361	4.8e−07
g	0.04687692	3.2e−07
h	0.06193488	8.0e−07



Grimm et al. A&A 2018

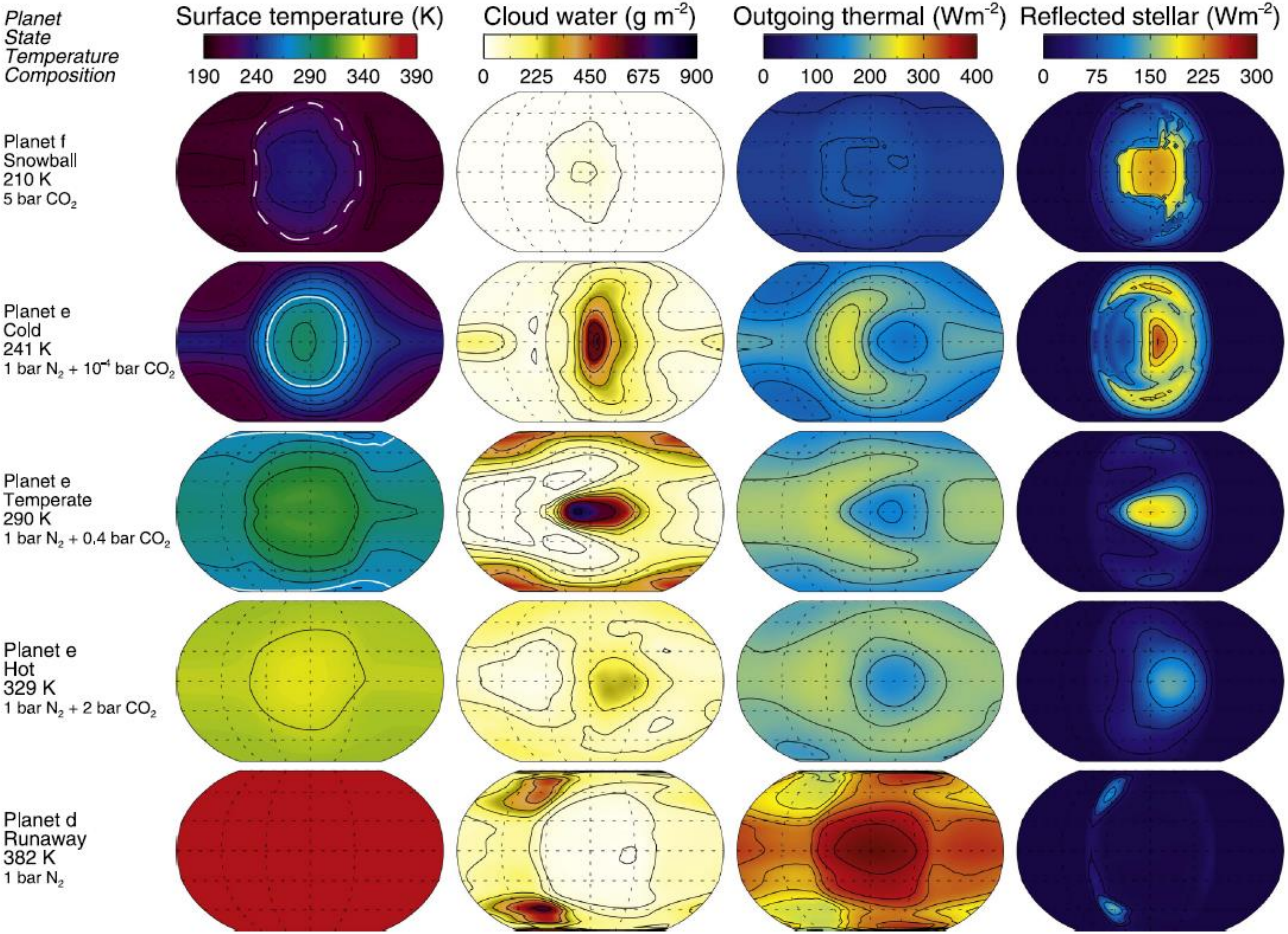


Figure 4. Contour plots of surface temperature, cloud water column, net outgoing thermal flux, and reflected stellar flux for several atmosphere types, including snowball, cold, temperate, hot, and runaway. Note the description of each simulation in the left-hand margin of the figure. In the surface temperature maps, a white solid line indicates the sea-ice margin and a dashed white line indicates CO_2 condensation onto the surface.

Wolf, ApJ 2017

Concluding remarks

- Thanks to the interest on M dwarfs as hosts of habitable planets we are learning more about these stars.
- Stellar radiation is fundamental for climate and atmospheric chemistry on habitable planets.
- Characterization of stellar radiation is needed for interpreting future observations.
- Confirming life as the source of atmospheric compounds – and ruling out false positives is the HARD (and fun) part.
- We won’t know anything for sure until we can detect atmospheres of planets in the HZ of M dwarfs.