Nitrogen Constraint on the Habitable Zones around Low Mass M-stars

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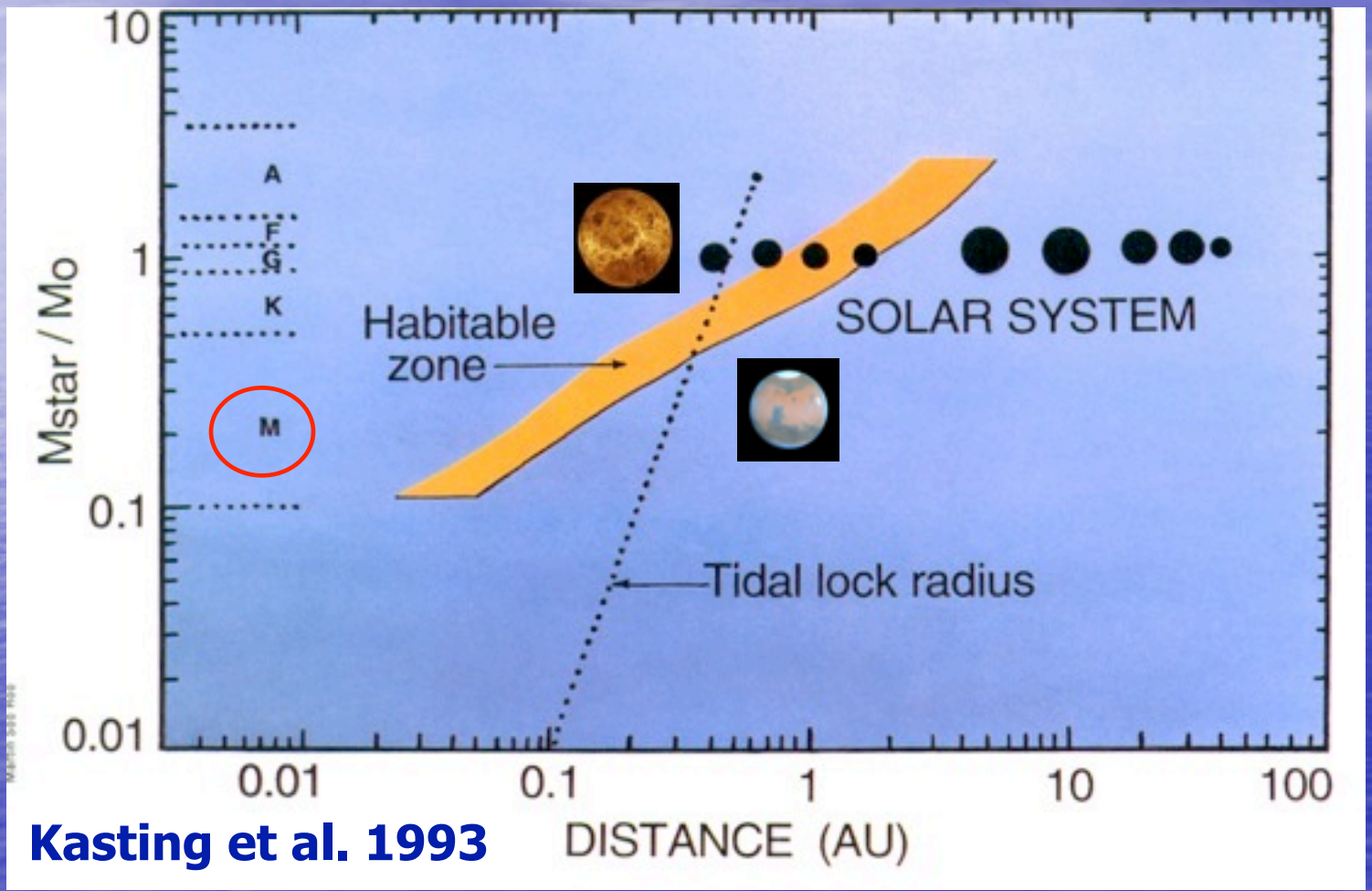
Life as we know it needs Water – the Liquid Water Habitable Zone



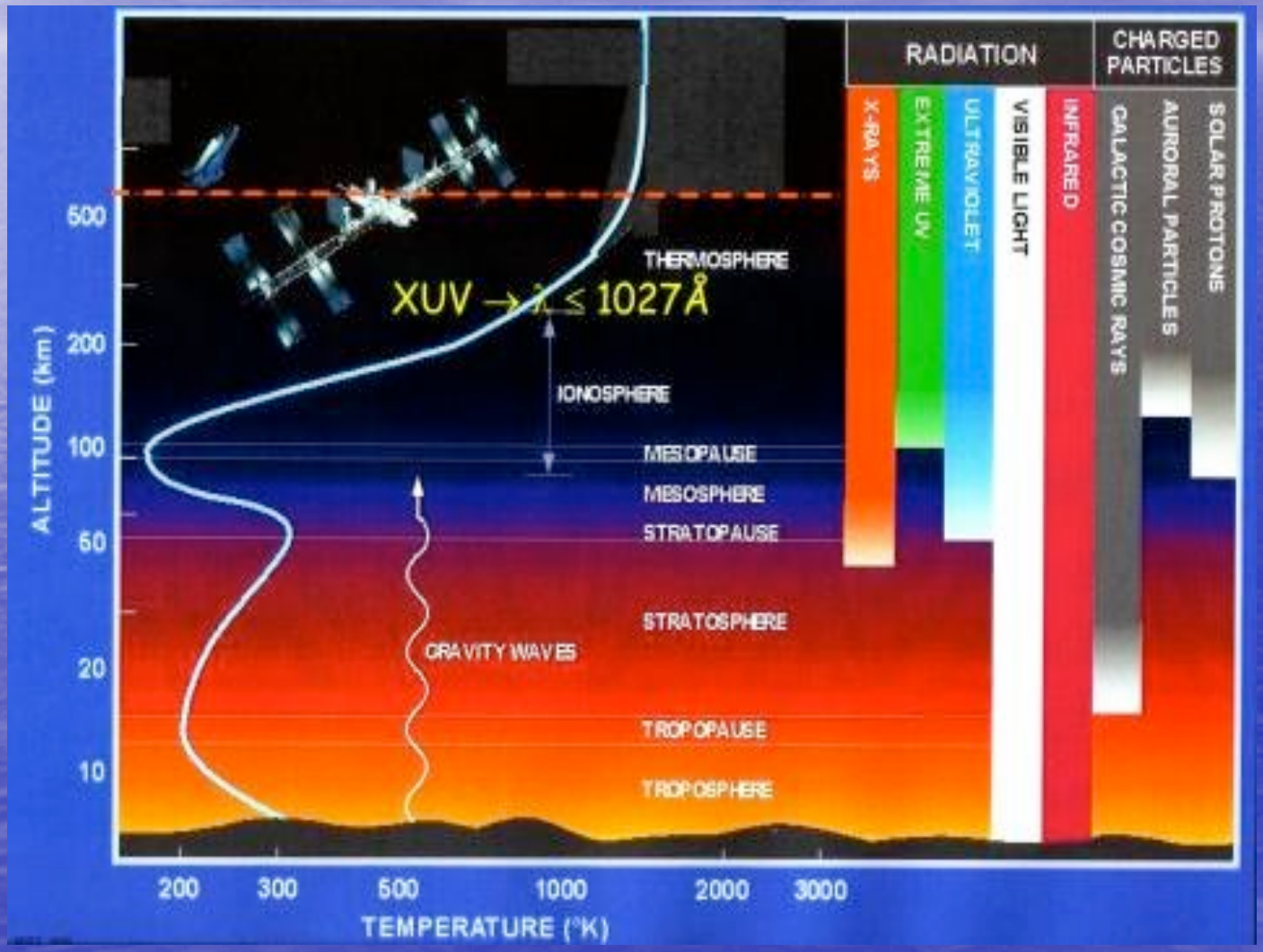
Kasting et al. 1993

Life as we know it also needs other nutrients, such as nitrogen – the nitrogen Habitable Zone

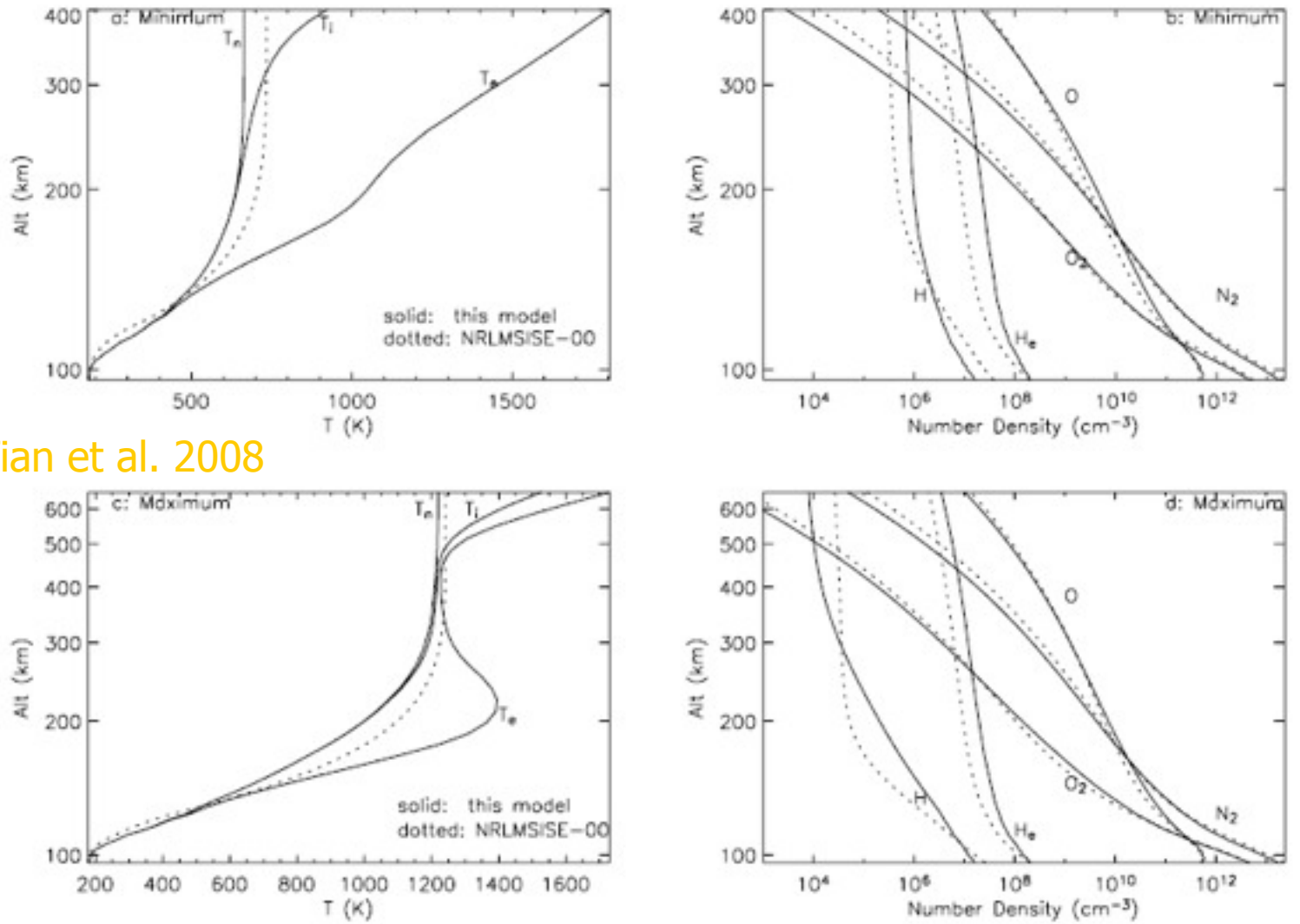
Conclusion

- There may be a conflict between the long term stability of liquid water and nitrogen on planets around highly active M-dwarfs --- Habitable Zones there are limited.

When discussing Nitrogen we need to look at the upper planetary atmosphere, where stellar XUV radiation leads to heating.



Temperature and Number Densities



Tian et al. 2008

Figure 2. Temperature and number density profiles of major neutral species in solar minimum and maximum conditions. Dotted curves are the globally averaged profiles from the empirical MSIS-00 model.

Heating and Cooling Tian et al. 2008

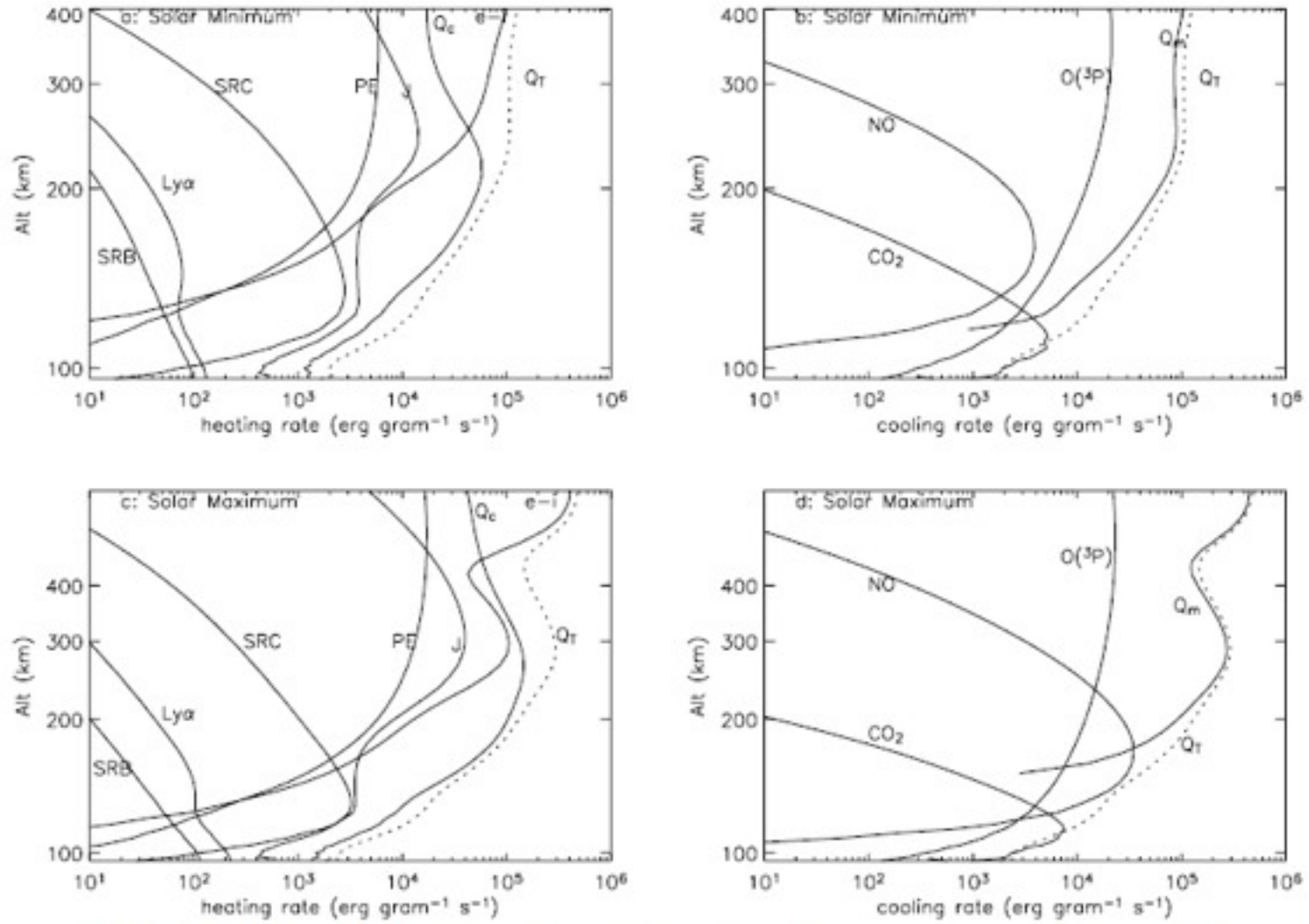
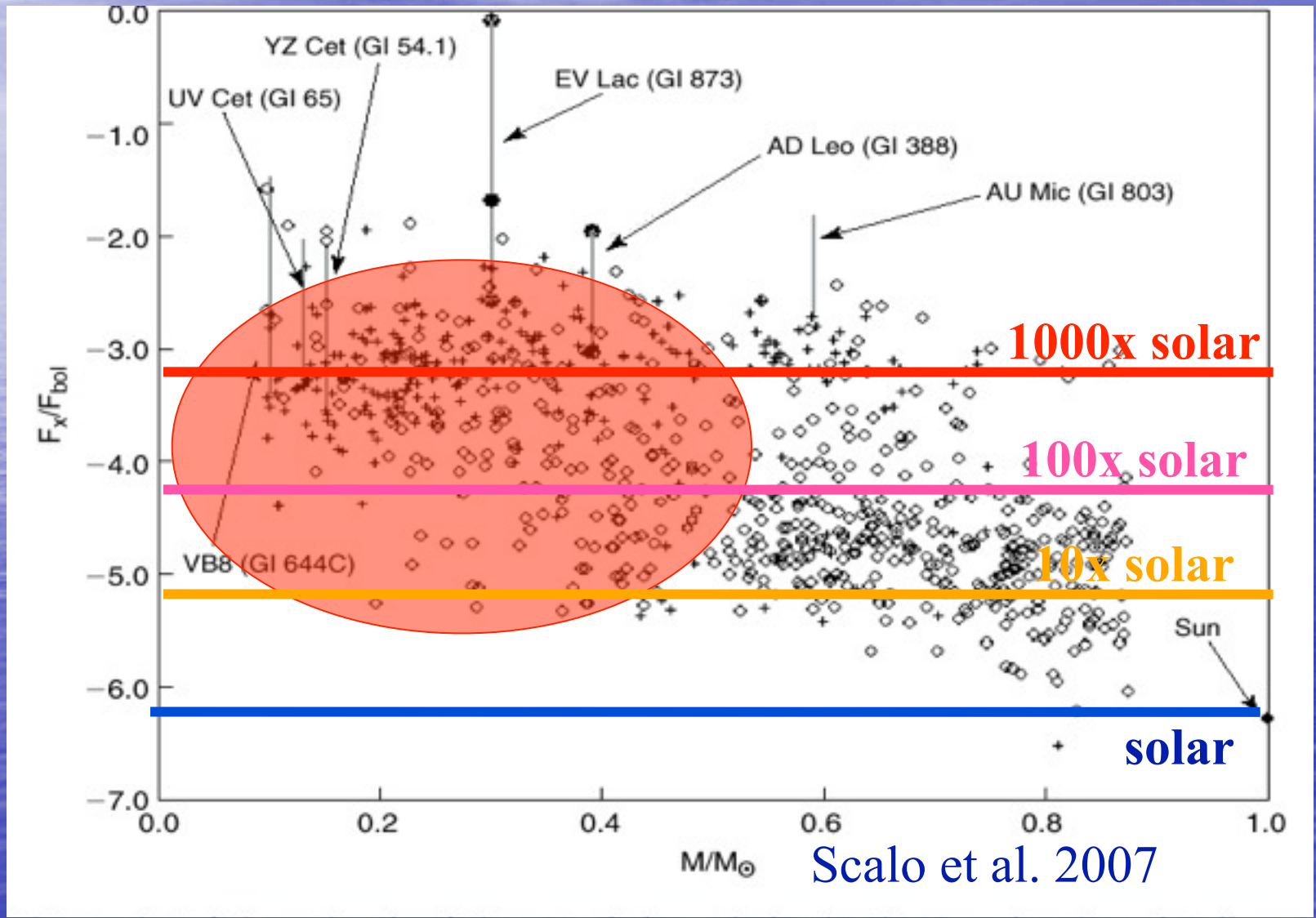


Figure 4. Heating and cooling rate profiles in solar minimum and solar maximum conditions. Q_T is the

M-dwarfs are good places to search for Habitable Planets But their XUV radiation levels are HIGH!



Scalo et al. 2007

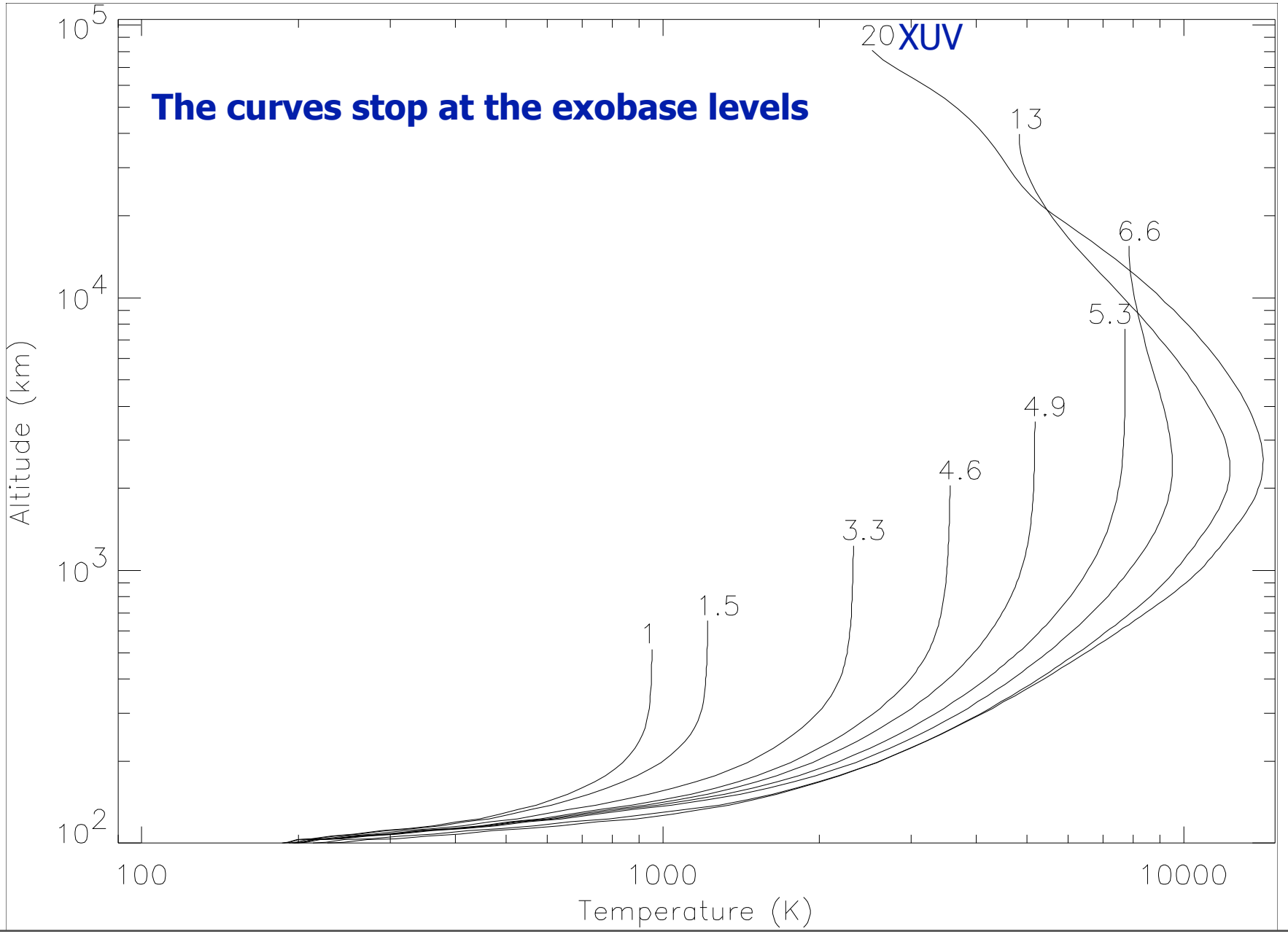
1-D multi-fluid hydrodynamic model

(Tian et al. 2008a, b, 2009)

- Solves the continuity, momentum, and energy equations of one background fluid with variable molecular weight
- Solves minor constituent diffusion equations in a moving background for 16 long-lived species (O, O_2, N, N_2, H_e, H, H_2, CO, CO_2, C, NO, H_2O, O^+, N^+, H^+, C^+)
- Chemical equilibrium for short-lived species (O_3, HO_2, OH, H_2^+ , H_3^+ , $O^+(^2P)$, $O^+(^2D)$, N_2^+ , CO^+ , CO_2^+ , O_2^+ , NO^+ , OH^+ , $N(^2D)$, $O(^1D)$, H_2O_2, O_2 ($^1\Sigma_g$), O_2 ($^1\Delta_g$))
- 200+ chemical reactions (include reactions in existing thermosphere/ionosphere models for terrestrial planets and hot Jupiters)
- No assumption on heating efficiency -- couple energetic electron transport model to compute ionization and ambient electron heating rates (Tian et al. 2008b)

Responses of an Earth-like atmosphere to strong XUV

(Tian et al. 2008a)



Number Density Profiles in a N2-O2 Upper Atmosphere

(Tian et al. 2008a)

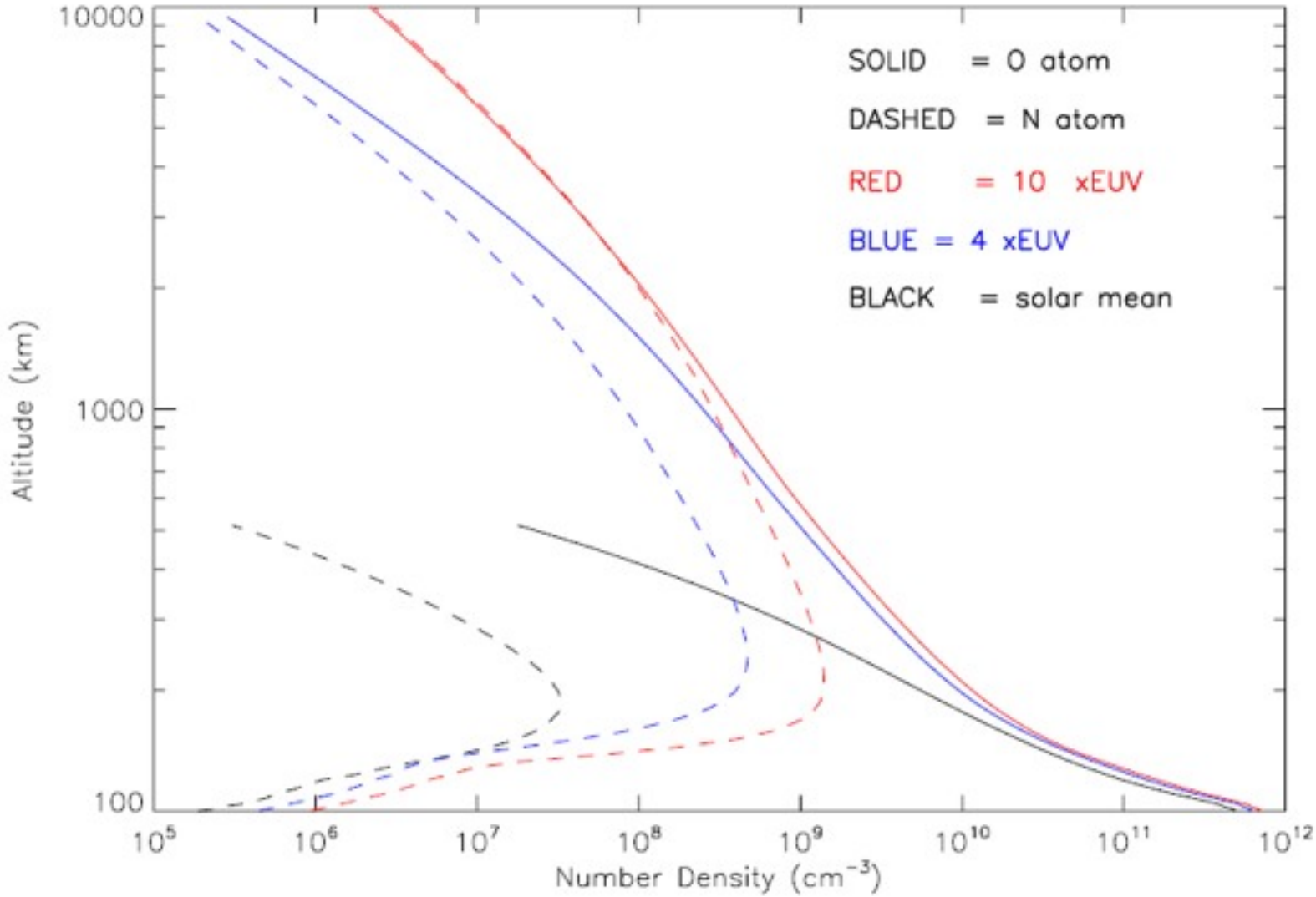
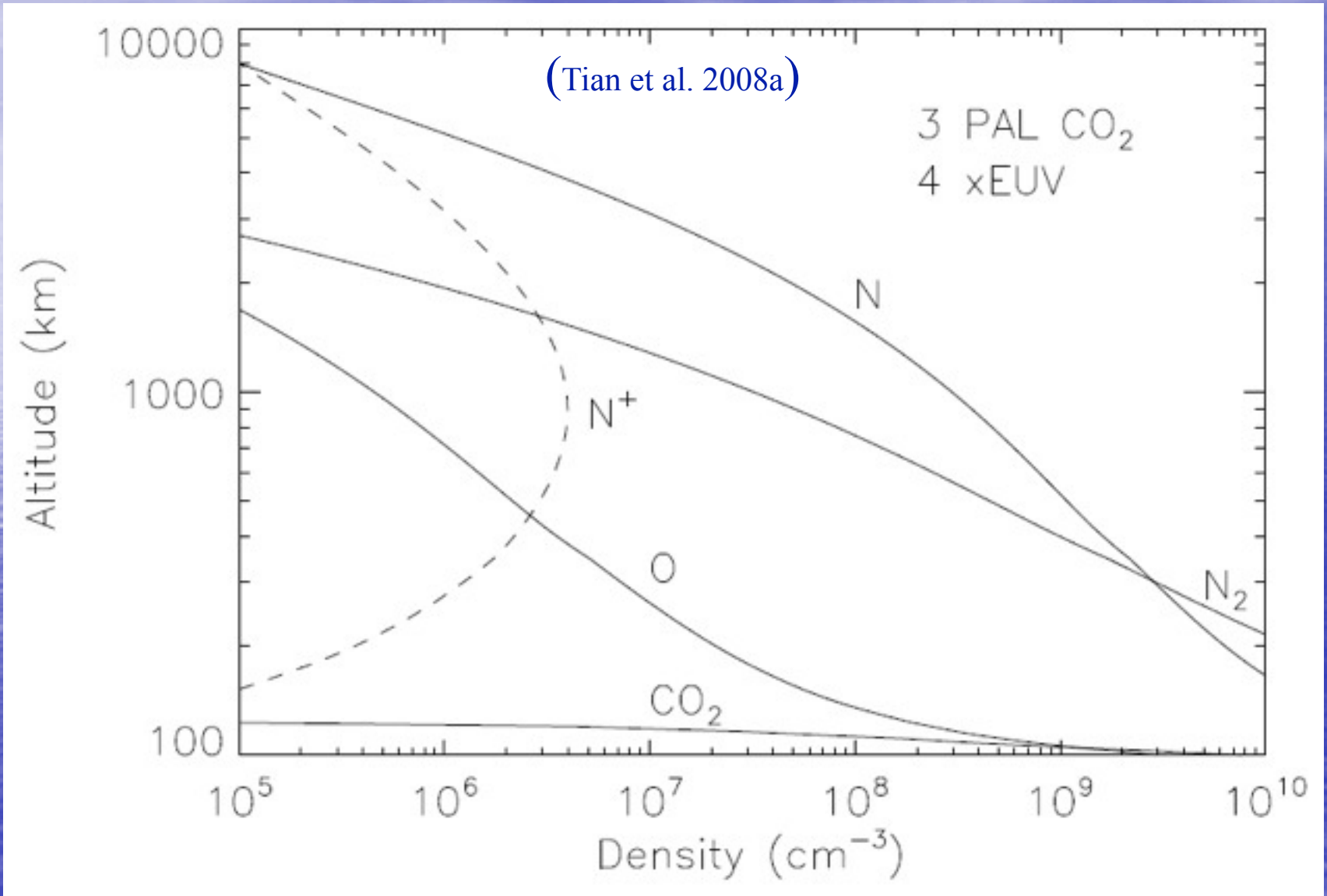


Figure 6. The density profiles of atomic oxygen (solid curves) and atomic nitrogen (dashed curves) under different solar EUV conditions.

Number Density Profiles in a N2-CO_2 Upper Atmosphere



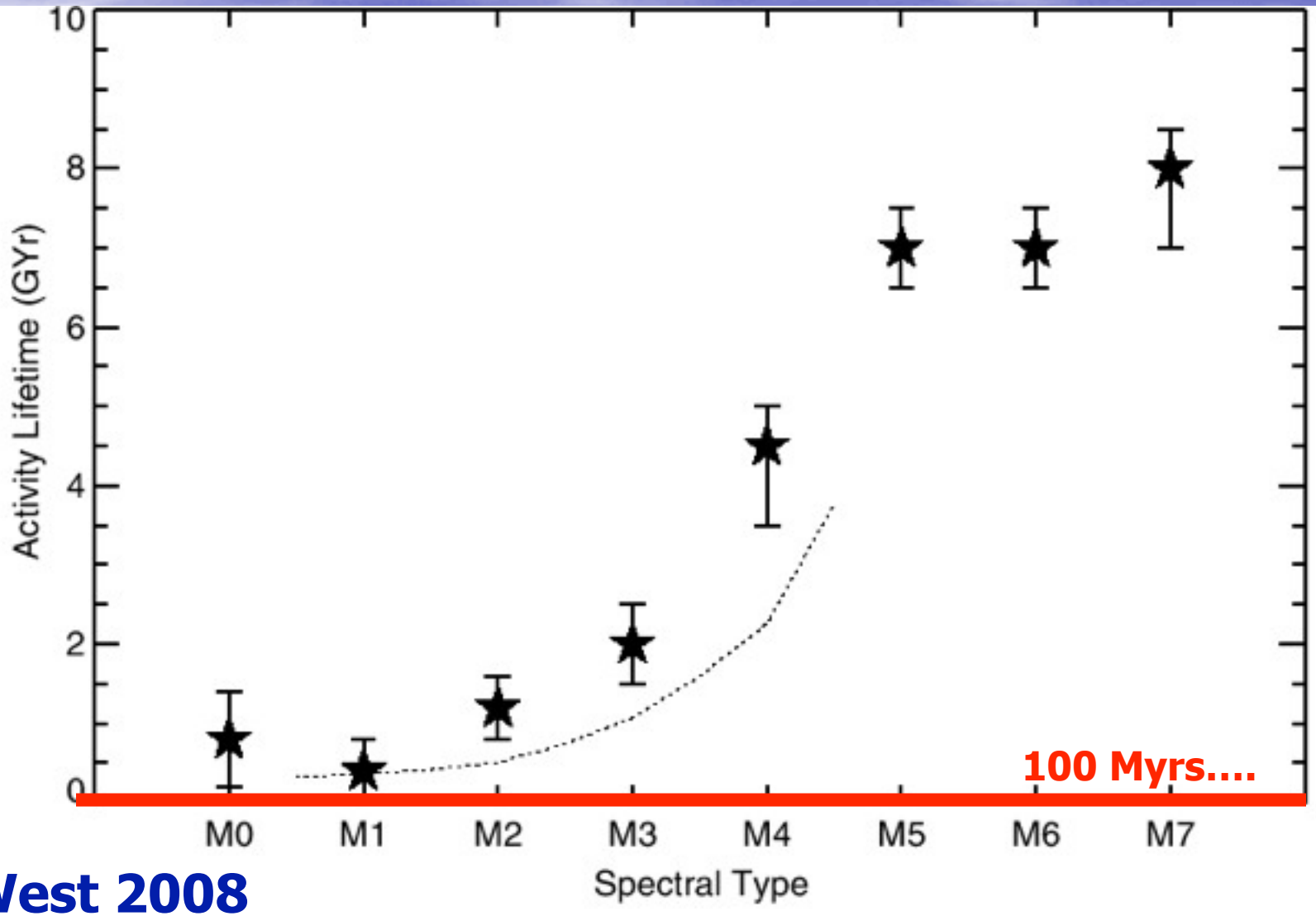
Planets around M-dwarfs are in danger of losing their nitrogen rapidly.

$P(N_2) \sim p(CO_2)$ cases

Tian et al. in prep.

Loss of 1 Earth ATM of N_2 in 60 Myrs

And M-dwarfs stay active for long long time – nitrogen-rich atmospheres are unstable



West 2008

CO_2-rich Atmospheres are more stable under Strong XUV

Tian ApJ 2009

But higher CO_2 warms up the surface and causing the inner edge of the habitable zone to move outward.

TABLE I

Critical Orbital Distances around Our Sun for Different Planetary Parameters

Case	Inner edge: Runaway greenhouse	Inner edge: Water loss	Outer edge: 1st CO_2 condensation	Outer edge: Maximum greenhouse
Standard model	0.84	0.95	1.37	1.67
Mars-sized planet*	0.88	0.98	1.49	1.67
Big planet**	0.81	0.91	1.29	1.64
pN_2 = 0.1 bar	0.84	0.96	1.36	1.67
pN_2 = 10 bars	0.84	0.88	1.39	1.69
$pCO_2 = 3 \times 10^{-5}$ bar	0.84	0.94		
$pCO_2 = 3 \times 10^{-3}$ bar	0.84	0.97		
$pCO_2 = 3 \times 10^{-2}$ bar	0.84	0.99		
pCO_2 = 0.3 bar	0.84	1.00		
pCO_2 = 3 bar	0.84	0.95		
pCO_2 = 30 bar	0.84	0.90		

Kasting et al. 1993

And the weathering process should draw down atmospheric CO_2 in the timescale of 10 million years

(from Lenardic's talk this morning).

The HZ's of active M-dwarfs are narrower because of the conflict between nitrogen and liquid water.