Mirage Earths

Extreme Water Loss and Abiotic O_2 Buildup on Planets Throughout the Habitable Zones of M Dwarfs

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The Big Picture

M dwarfs: the best targets
Scalo et al. (2007), Ricker et al. (2010)

Terrestrial planets are easiest to detect around low-mass stars

Rapid planet formation
Raymond et al. (2007), Lissauer (2007)

Both *in situ* formation and disk-driven migration into the HZ occur in $\lesssim 10$ Myr

Extended pre-MS phase
Baraffe et al. (1998), Lissauer (2007)

M dwarfs can take up to ~ 1 Gyr to reach the main sequence

Long activity timescales
Scalo et al. (2007), West et al. (2008)

High X-ray/EUV fluxes in the HZ for up to a few Gyr

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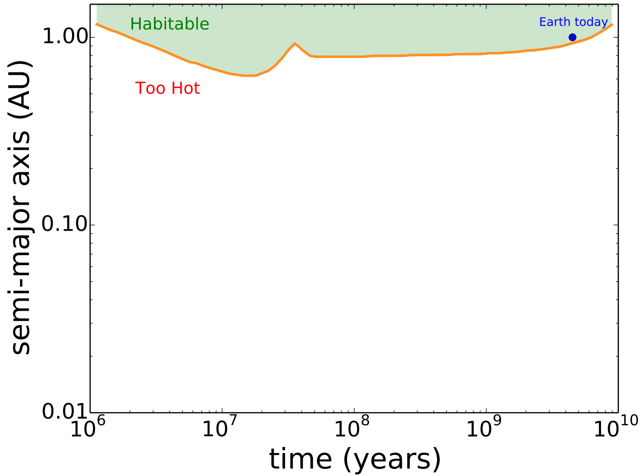
Pre-Main Sequence Evolution



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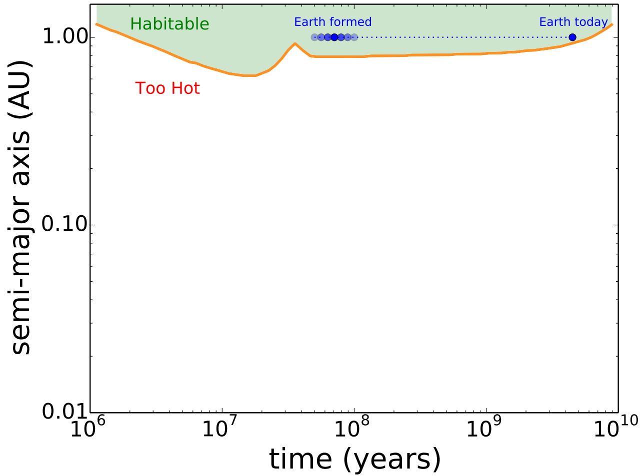

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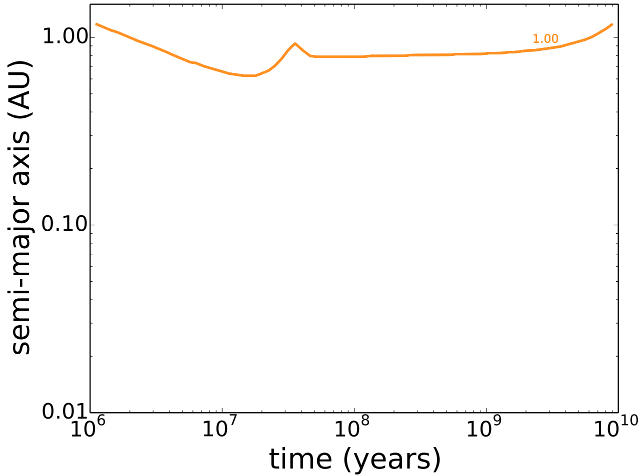

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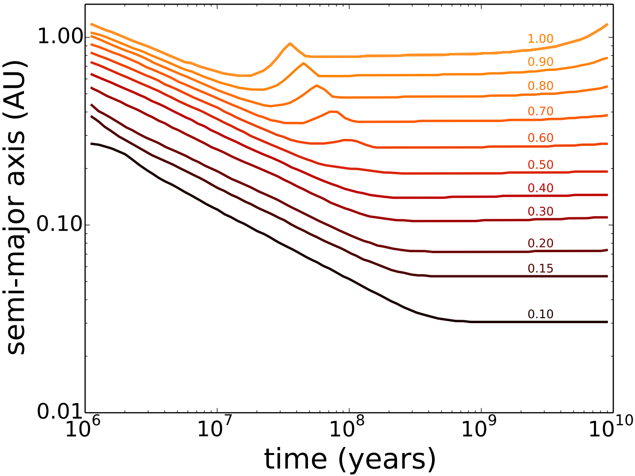

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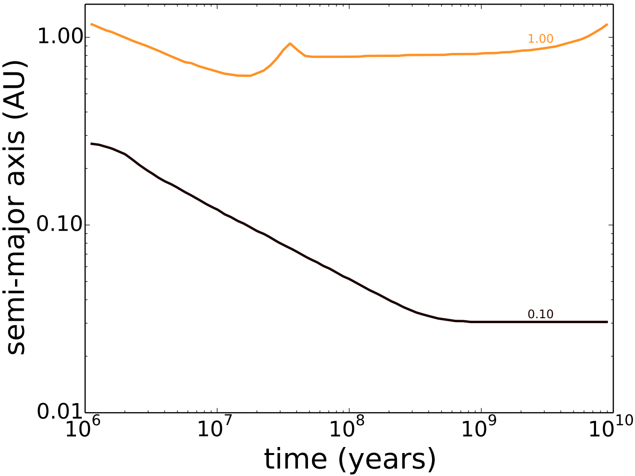

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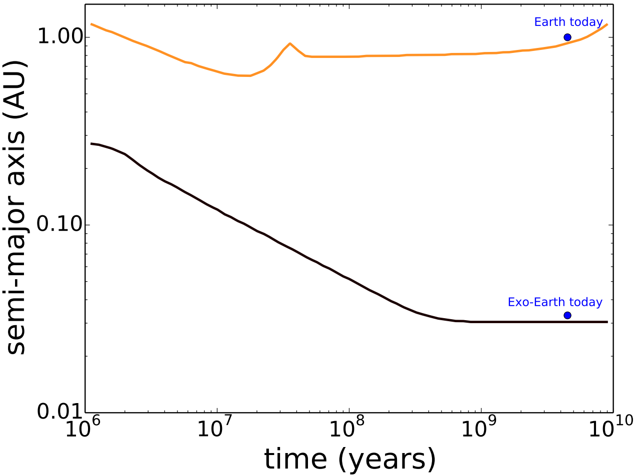

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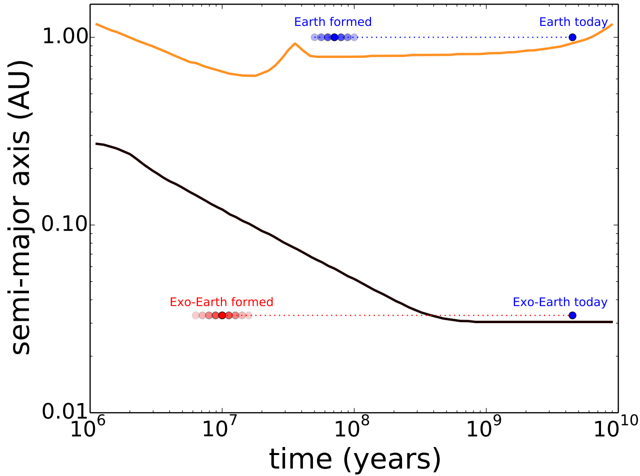

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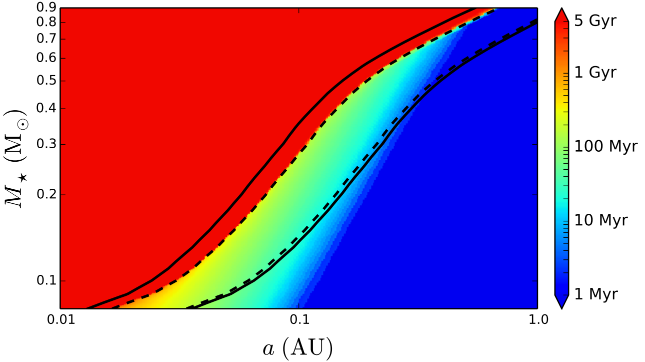
Duration of the Runaway Greenhouse



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Atmospheric Escape Model

- XUV power law decline (Ribas et al. 2005)

$$\frac{L_{\mathrm{XUV}}}{L_{\mathrm{bol}}} = \begin{cases} f_0 & t \leq t_0 \\ f_0 \left(\frac{t}{t_0}\right)^{-\beta} & t > t_0 \end{cases} \tag{1}$$

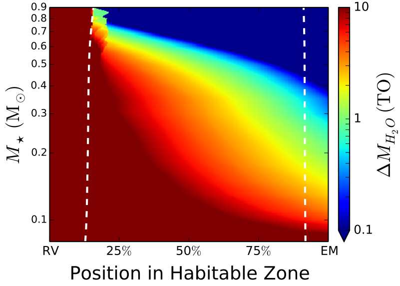
- XUV-driven energy-limited escape (Erkaev et al. 2007)

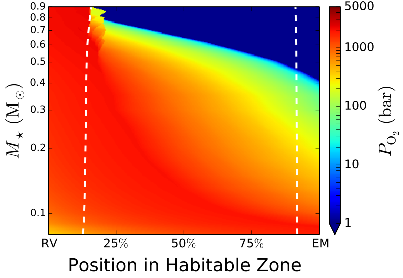
$$F_{\mathrm{H}} = \frac{\epsilon_{\mathrm{XUV}} \mathcal{F}_{\mathrm{XUV}} R_{\mathrm{p}}}{4 G M_{\mathrm{p}} K_{\mathrm{tide}} m_{\mathrm{H}}} \tag{2}$$

- Hydrodynamic mass fractionation (Hunten et al. 1987)

$$F_{\mathrm{O}} = \frac{X_{\mathrm{O}}}{X_{\mathrm{H}}} F_{\mathrm{H}} \left(\frac{m_{\mathrm{c}} - m_{\mathrm{O}}}{m_{\mathrm{c}} - m_{\mathrm{H}}}\right) \tag{3}$$

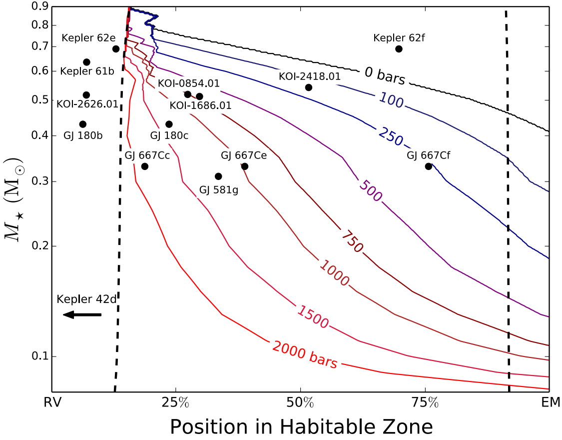
Water Loss & O_2 Buildup





A 5 $M_\oplus$ super-Earth can lose up to a few tens of Earth oceans of water and build up several thousands of bars of O_2, particularly near the inner HZ of low-mass M dwarfs.

O_2 Buildup on Known Exoplanets



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Summary & Conclusions

- Planets in the HZs of *all* M dwarfs can lose several Earth oceans of water and build up hundreds to thousands of bars of O_2. Both processes **threaten the habitability of many terrestrial planets**

- **Water loss scales with planet mass.** Super-Earths lose more water than Earths because of inhibited oxygen escape

- **O_2 buildup rates also scale with planet mass:** ~ 5 bars/Myr on Earths and ~ 25 bars/Myr on super-Earths. These rates are controlled by diffusion

- Fast O_2 production could overwhelm surface sinks, leading to detectable levels of atmospheric O_2. **Oxygen may not be a reliable biosignature on M dwarf planets**

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Thank you

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