Connecting Nuclear Astrophysics with Exoplanets and Astrobiology

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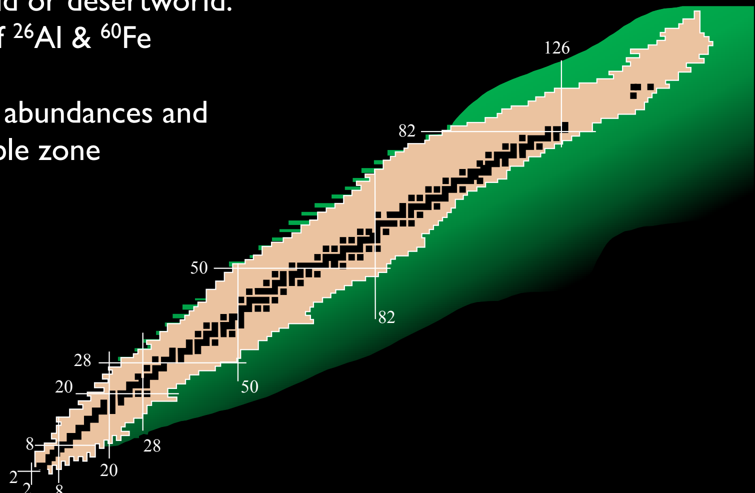
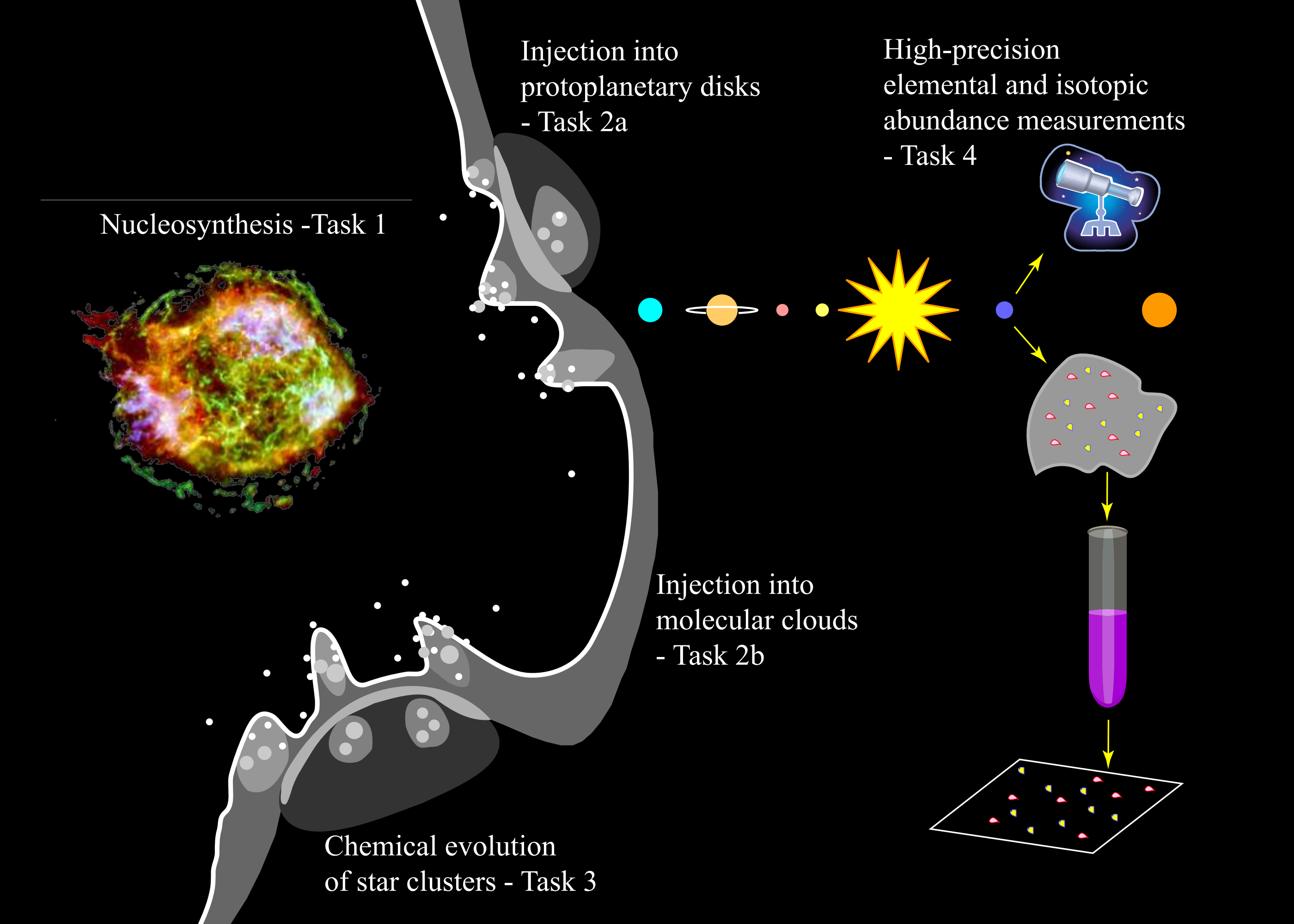
Outline:

1) Waterworld or desertworld:
   the case of ^{26}Al & ^{60}Fe

2) Non-solar abundances and
   the habitable zone




Nucleosynthesis -Task 1
Injection into protoplanetary disks - Task 2a
High-precision elemental and isotopic abundance measurements - Task 4
Injection into molecular clouds - Task 2b
Chemical evolution of star clusters - Task 3

How are key elements produced and delivered for

…elements that shape planetary formation
e.g., ^{26}Al, ^{60}Fe ?

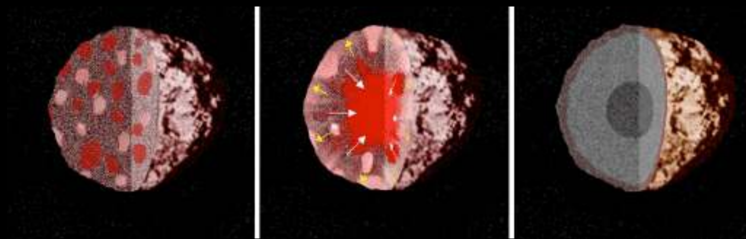
…elements that drive planetary processes
e.g., ^{40}K, $^{235,238}U$, ^{232}Th ?

…biologically important elements
e.g., C, N, P, Fe, Mo ?

What controls the volatile content of exoplanetary systems?

^{26}Al and ^{60}Fe: Sources of Heat

Differentiates and Devolatilizes Silicate Planetesimals



$^{26}Al \rightarrow {}^{26}Mg^*$

$t_{1/2} = 0.714 \pm 0.06$ Myr

$^{60}Fe \rightarrow {}^{60}Co^* \rightarrow {}^{60}Ni^*$

$t_{1/2} = 2.62 \pm 0.04$ Myr

^{26}Al was introduced in astrophysics by Harold Urey in 1955 as a heat source capable of melting chondritic meteorites having radii of 100-1000 km on million year time scales.

Harold Urey,
Cesare Emiliani,
G.J. Wasserburg
1953

This idea was confirmed from measurements of excess ^{26}Mg in the differentiated Pipliya Kalan meteorite by Srinivasan et al 1999.

What controls the volatile content of exoplanetary systems?

Tentative Answer: The abundance of ^{26}Al and ^{60}Fe in a solar system controls volatile delivery to terrestrial planets.

Earth's water came from asteroids.

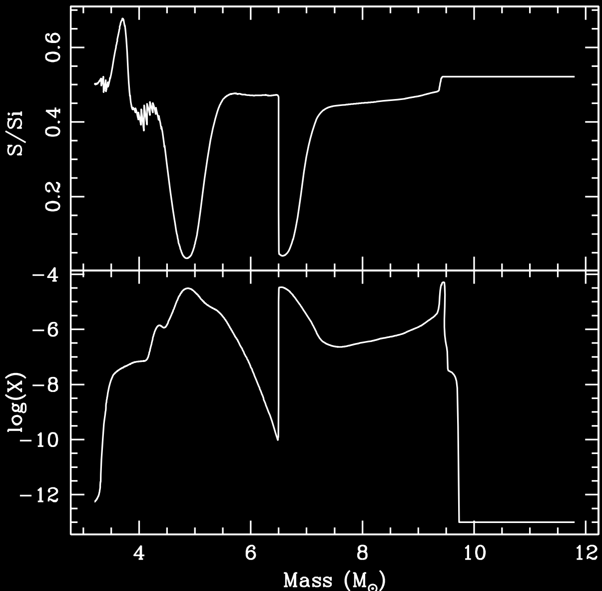
Heating by radioactive decay of ^{26}Al and ^{60}Fe devolatilizes asteroids.

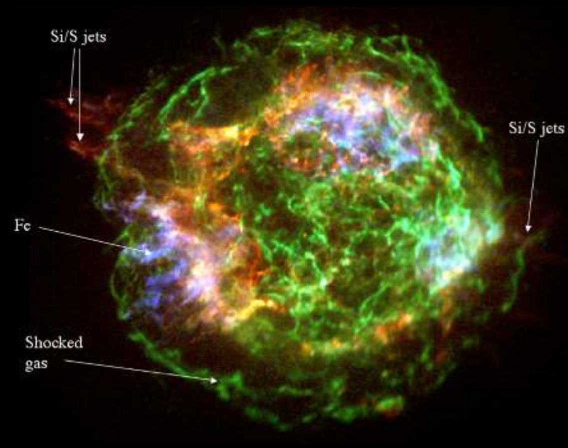
If our solar system had 10 x more ^{26}Al and ^{60}Fe, Earth would likely have < 0.2 oceans. Desertworld.

If our solar system had 10 x less ^{26}Al and ^{60}Fe, Earth would likely have > 5 oceans. Waterworld.

Earth had the right amount of ^{26}Al and ^{60}Fe to be about half land and half water.

Young et al 2009 find the most reliable indicator of the presence of ^{26}Al in unmixed core-collapse ejecta is a low, ~0.05, S/Si ratio.

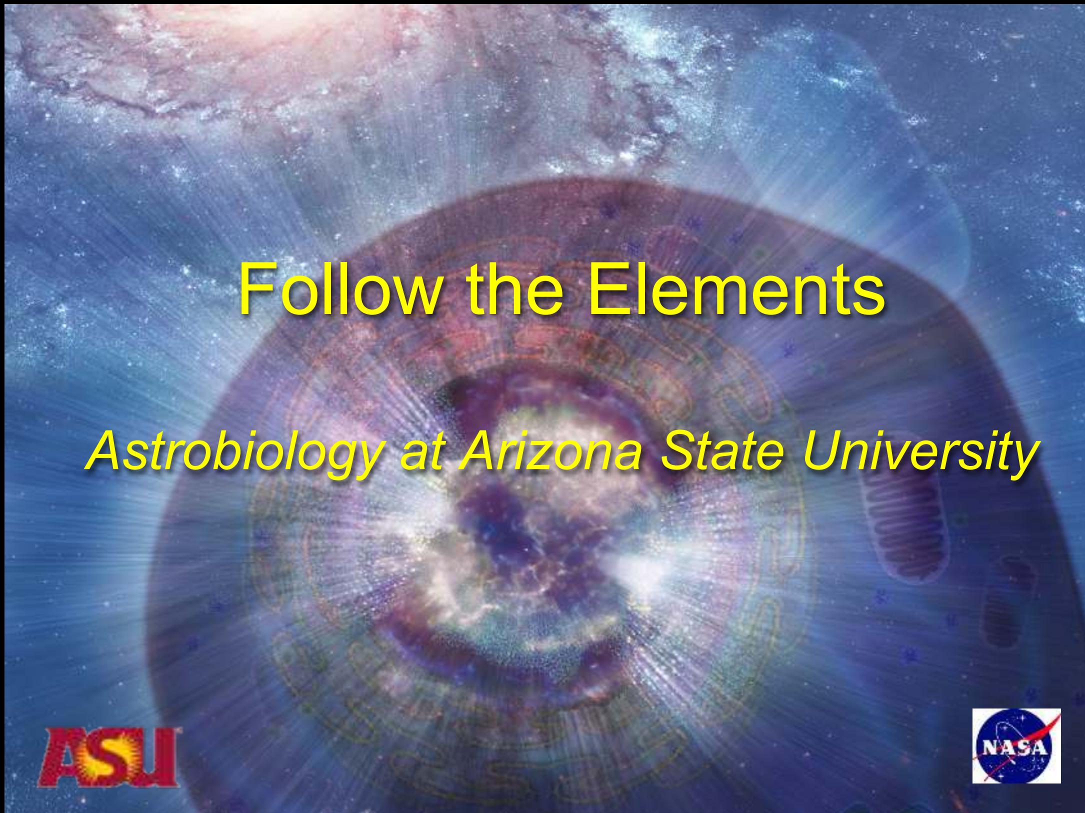




Hwang et al. 2004

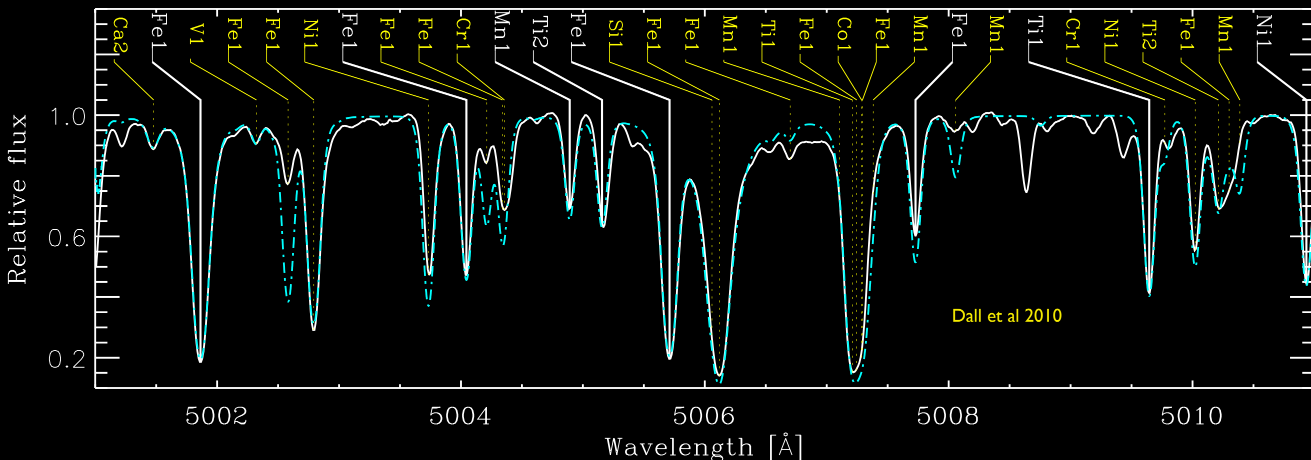
Curiously, the bioessential element phosphorous reaches its maximum abundance in the same regions in massive stars.

Brief Interlude

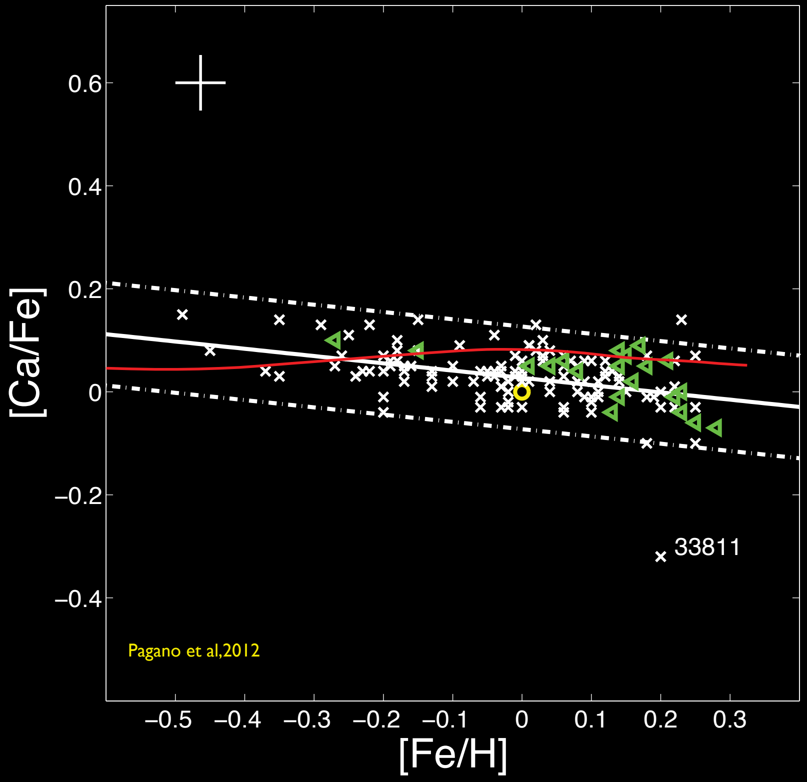


What impacts do nuclear physics and stellar abundance variations have on stellar habitable zones?

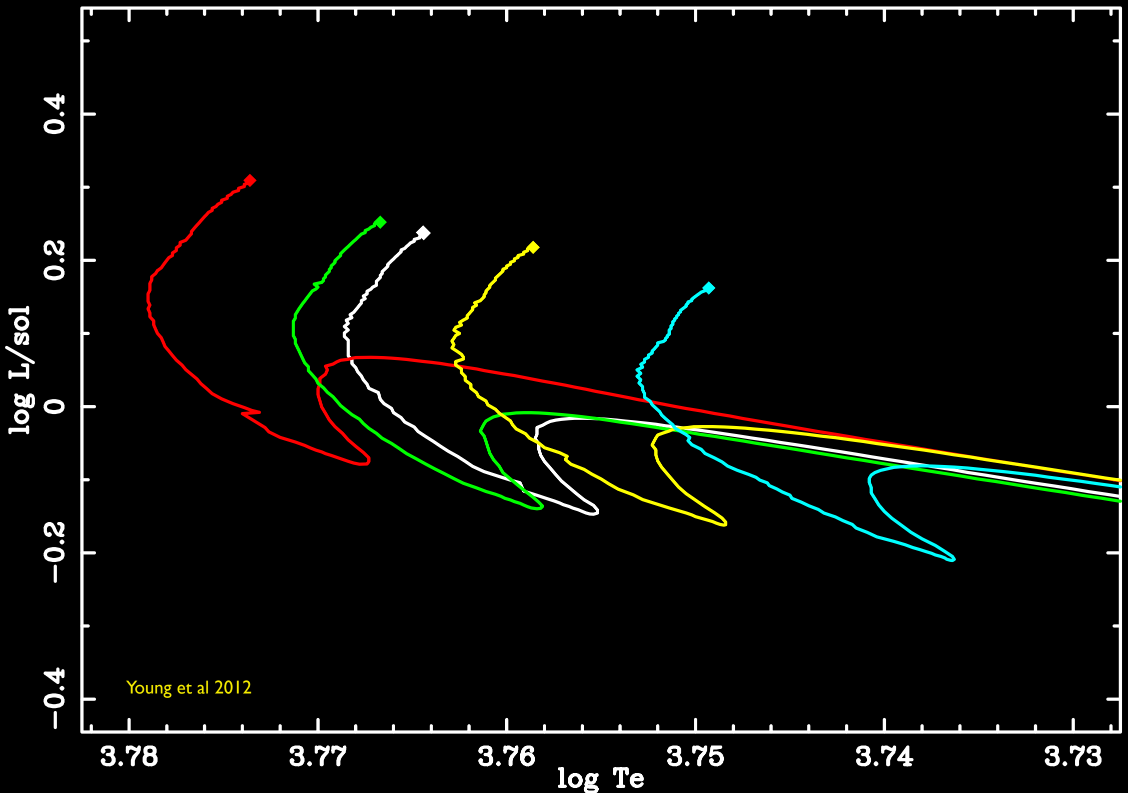
The high-quality spectra required for radial velocity planet searches are well suited to providing abundances for a wide array of elements in large samples of stars.



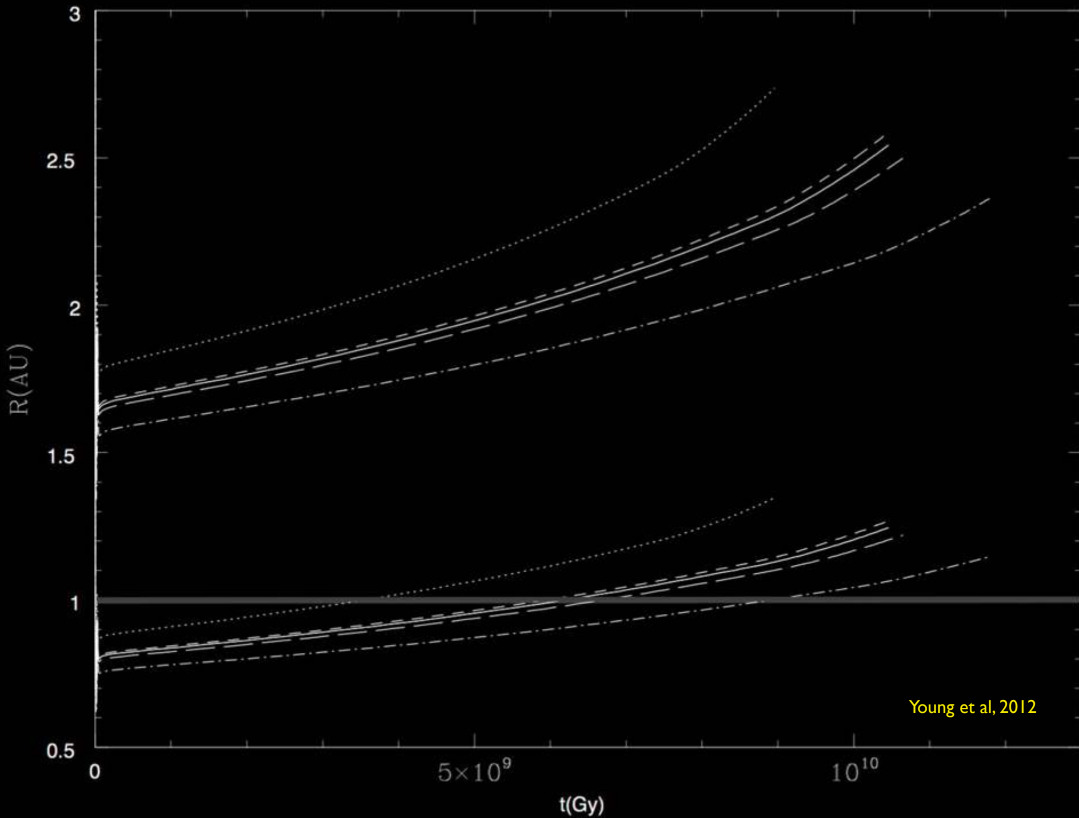
Abundance ratios of the most common elements relative to Fe vary by more than a factor of two in planet host candidates.



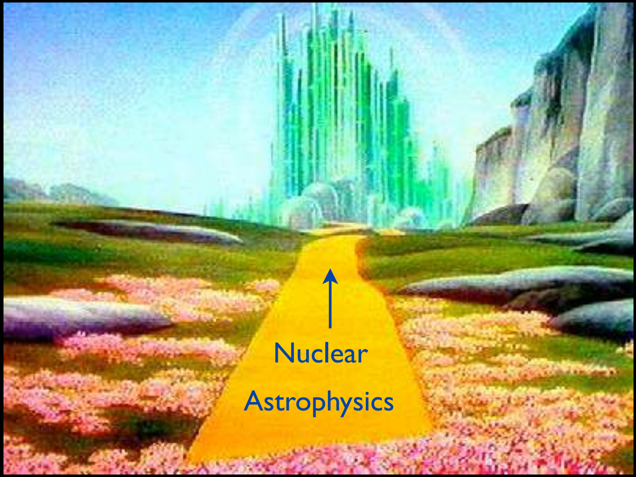
This level of variation has a substantial impact on the evolution of the host star and the extent of its habitable zone.



The effects of varying [O/Fe] over the observed range can vary the habitability lifetimes for some classes of orbits by gigayears.



Nuclear Astrophysics - experimental, observational, and theoretical - can, and should, embrace opportunities to apply itself to exoplanets and astrobiology.



with apologies to
L. Frank Baum