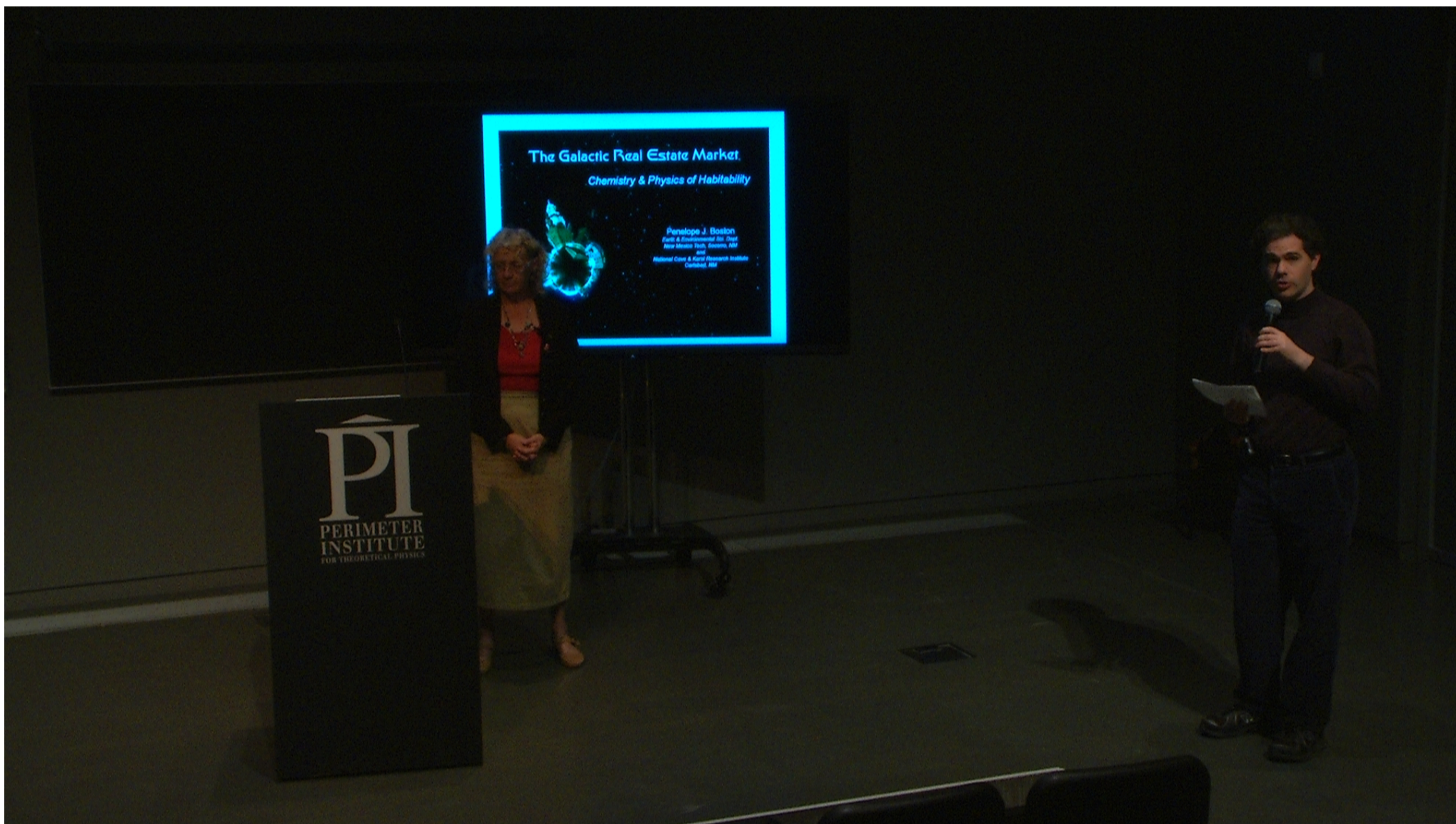


Title: The Galactic Real Estate Market: The Physics and Chemistry of Habitability

Date: Dec 04, 2013 02:00 PM

URL: <http://pirsa.org/13120044>

Abstract: <span>Exoplanets, planets circling distant stars, are proving to be an extraordinary source of new thinking about the potential for life beyond Earth. Until recently, we have assumed that our Solar System and its planets were probably representative of such systems elsewhere. But the amazing array of very odd exoplanets that are being uncovered have stimulated a renaissance of thought on the subject of potential homes for life in the universe. Combined with work on extreme lifeforms here on Earth and intensive study of Mars and several other planets and moons in our system, new paradigms for life search missions are emerging. Science fiction has long drawn from and extrapolated out from science, but the cross-fertilization has gone both ways. Some of the more outrageous planets incorporated into fiction in the past may not be so outrageous after all. I will discuss what we think we know about exoplanets so far, how they are detected, how we are beginning to characterize their environments, and ideas about what this means for our search for living neighbors in our galaxy, whether they be microbes or folks we can actually chat with some day.</span>





# The Galactic Real Estate Market

*Chemistry & Physics of Habitability*



Penelope J. Boston

*Earth & Environmental Sci. Dept.*

*New Mexico Tech, Socorro, NM*

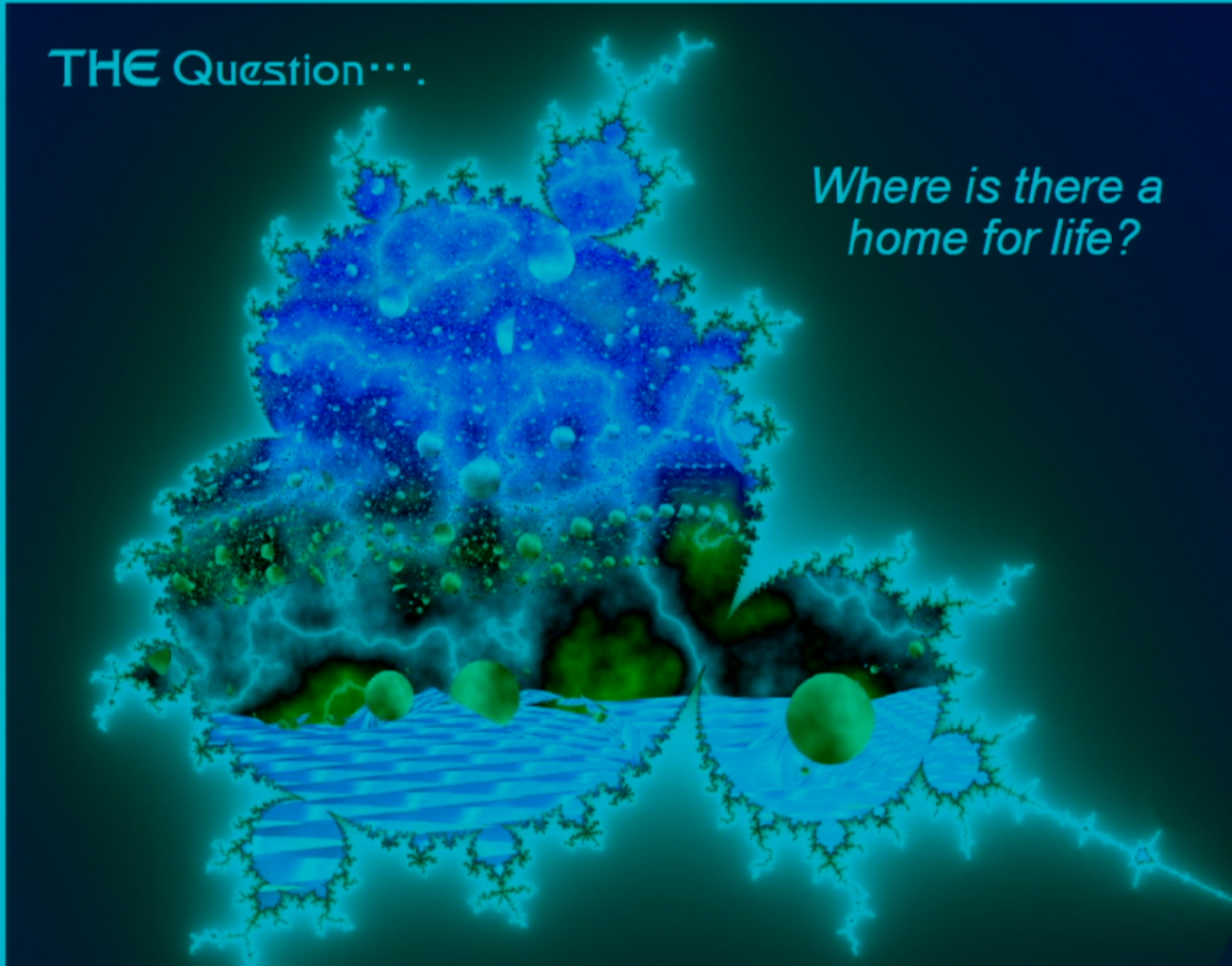
*and*

*National Cave & Karst Research Institute*

*Carlsbad, NM*

THE Question...

*Where is there a  
home for life?*





## Early Modern Thoughts on ET Life



*"There are countless suns and countless Earths all rotating around their suns in exactly the same way as the seven planets of our system."*

*We see only the suns because they are the largest bodies and are luminous, but their planets remain invisible to us because they are smaller and non-luminous."*

Giordano Bruno, *De l'Infinito, Universo e Mondi*, 1584

## Early Modern Thoughts on ET Life



*"An intrinsically improbable event may become highly probable if the number of events is very great. ..."*

*It is probable that a good many of the billions of planets in the Milky Way support intelligent forms of life. To me this conclusion is of great philosophical interest.*

*I believe that science has reached the point where it is necessary to take into account the action of intelligent beings, in addition to the classical laws of physics."*

*Otto Struve, ca ~1949, quoted in Steven J. Dick (1999). *The Biological Universe: The Twentieth Century Extraterrestrial Life Debate and the Limits of Science*.*





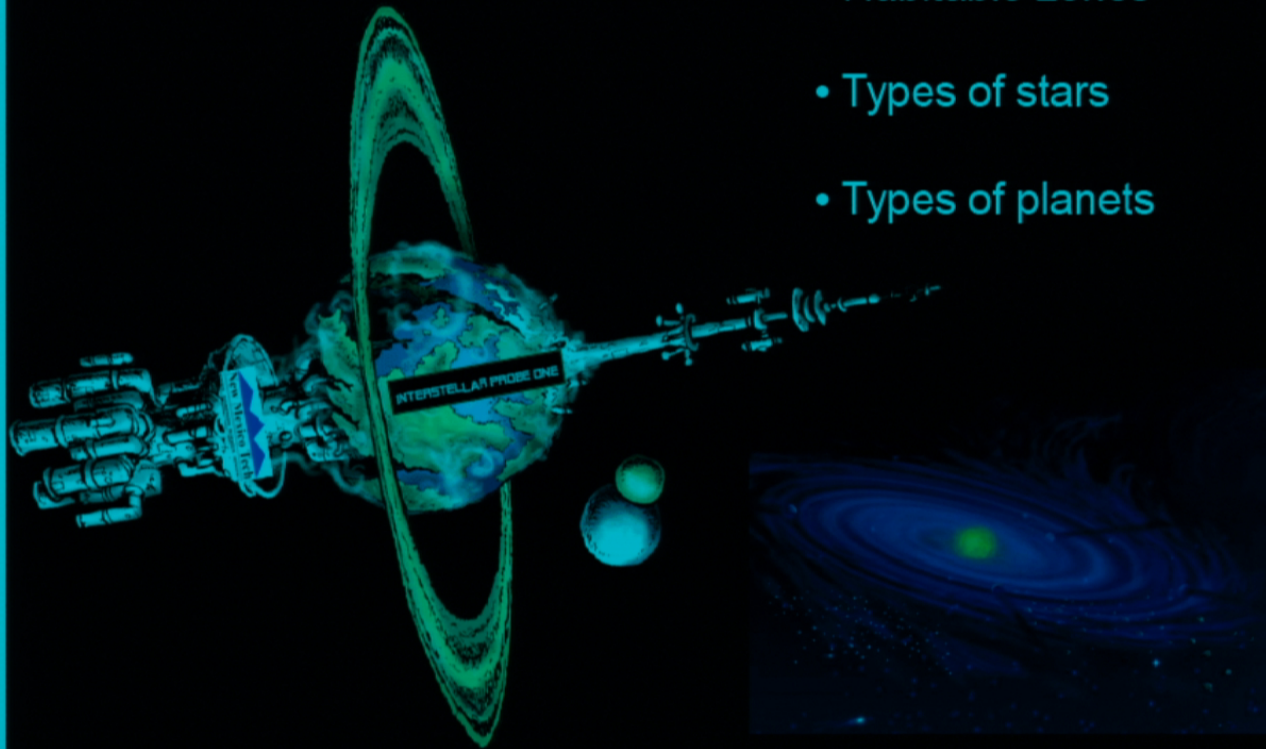
## Astrobiology Job 1:

*How do you  
**NAIL ET?***

How do you look for it?  
How do you recognize it?  
How do you protect it?  
How do you handle it?

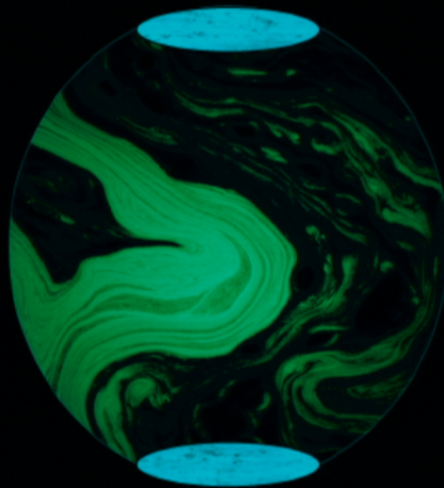
# Planets

- Home of life
- Habitable zones
- Types of stars
- Types of planets





## Life is an inherently planetary phenomenon



Planet Pond Scum

- Non-planet life:  
*Interstellar? Too little energy...?*  
*Stellar life? Too much energy....?*
- Virtually impossible to constrain the questions...
- Makes good SF plots though....  
*e.g. "Wait it Out", Larry Niven, ca 1970s*  
*e.g. "Dragon's Egg", Bob Forward, ca 1980's*

## Exoplanet studies are exploding....

<http://exoplanet.eu/>  
<http://exoplanets.org/>  
<http://kepler.nasa.gov/Mission/discoveries/>

198 exoplanets around fusing stars, Spring 2006

270 as of Spring 2008  
(228 non-controversial)

309 as of 8 Sept 2008  
(including 30 multi-planet systems)

389 as of Sept 2009

490 as of 3 Sept 2010! WOW!

And THEN there was Kepler...

Only since 1989,  
1<sup>st</sup> confirmation in 1995!



## Exoplanet studies are exploding....

<http://exoplanet.eu/>  
<http://exoplanets.org/>  
<http://kepler.nasa.gov/Mission/discoveries/>

February 2, 2011:  
1235 planet candidates (unconfirmed)

Dec 5, 2011:  
2326 planet candidates  
33 confirmed  
*"Earth-like"* Kepler 22-b

July, 2013:  
3277 planet candidates  
134 confirmed

Nov, 2013:  
 $4 \times 10^{10}$  Earth-like planets  
(around red dwarf & sun-like stars)  
 $11 \times 10^9$  orbiting sun-like stars

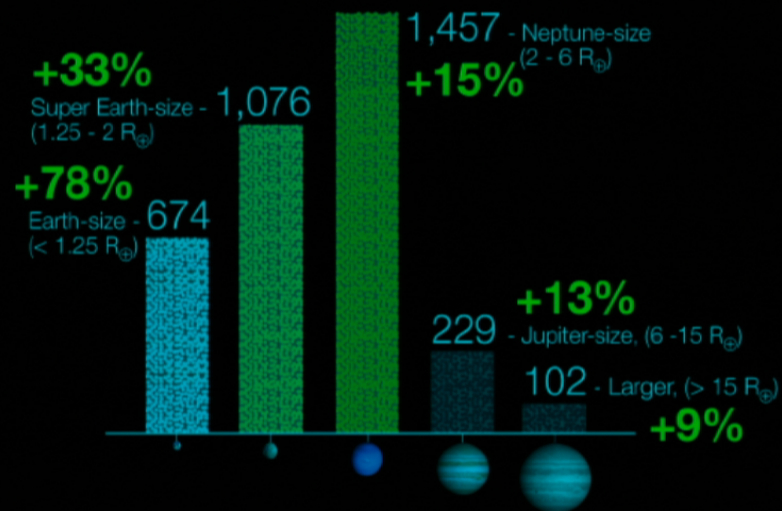
Dec 3, 2013:  
3538 candidate planets  
167 confirmed

Multiplanet Systems:  
~500 candidates  
53 confirmed

# We Enter the Era of Comparative Planetology

## Sizes of Planet Candidates

Totals as of November, 2013

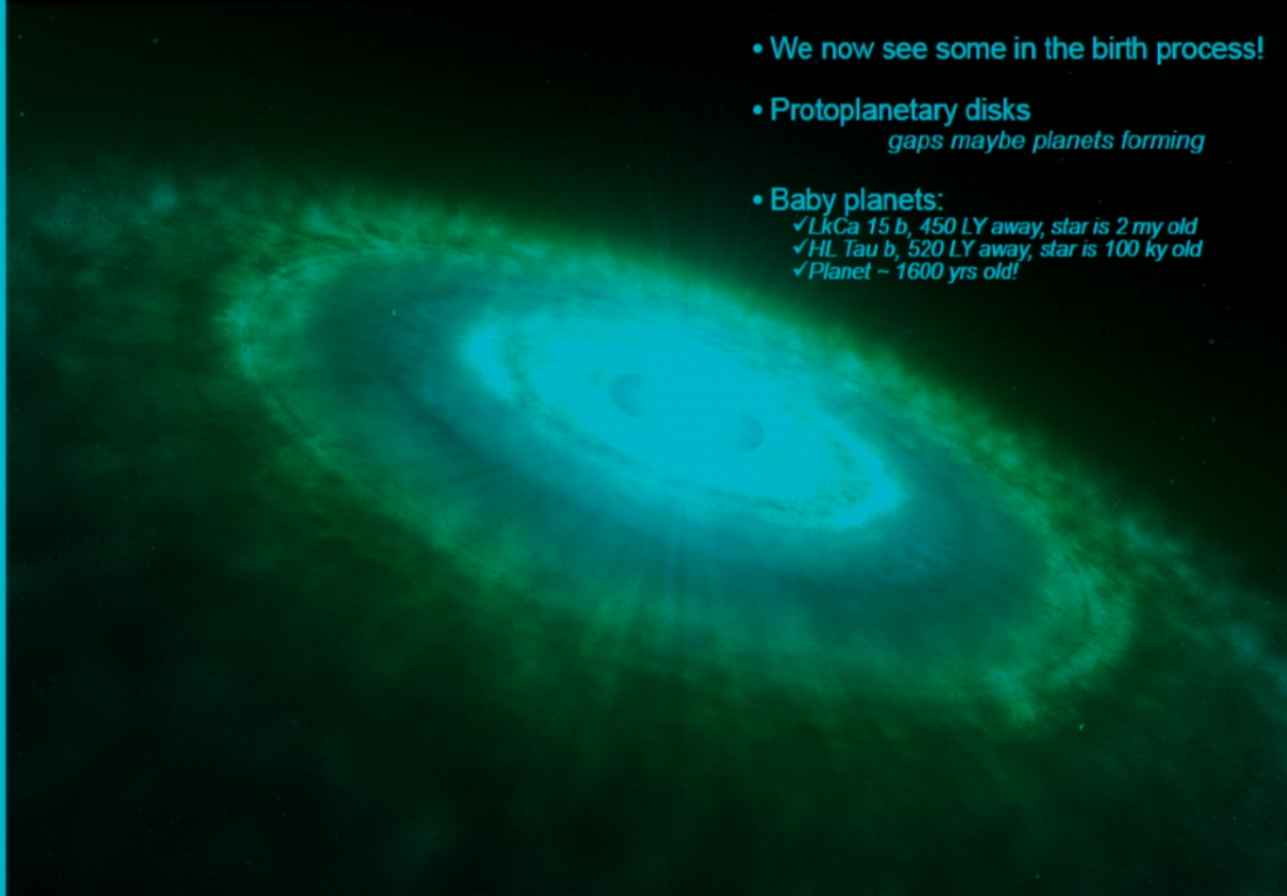


Check out: Table of Confirmed Kepler Planets

<http://kepler.nasa.gov/Mission/discoveries/>

# Suns & Planets Are Born Together

- We now see some in the birth process!
- Protoplanetary disks  
*gaps maybe planets forming*
- Baby planets:
  - ✓ LkCa 15 b, 450 LY away, star is 2 my old
  - ✓ HL Tau b, 520 LY away, star is 100 ky old
  - ✓ Planet ~ 1600 yrs old!





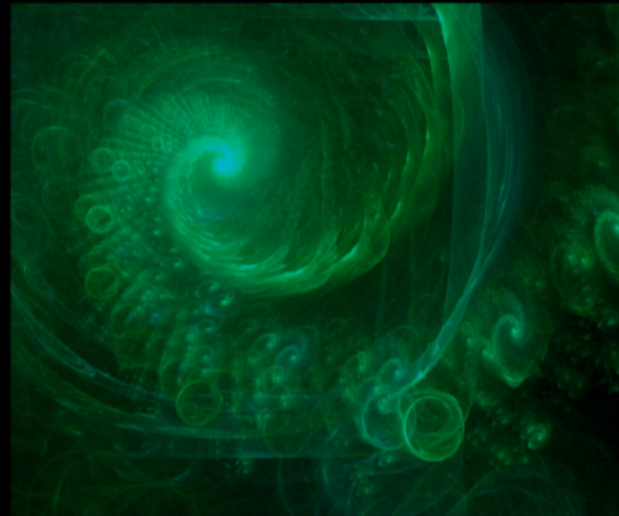
## Selecting Your Star

- ❖ Stars must "live" long enough for life to develop
- ❖ Stable & luminous

- ❖ Main sequence stars
  - < massive than type A
  - > massive than type M
  - & dwarf stars of types F, G, & K

- ❖ Type F0-4 support Earth-type life for ~ two billion yrs

- ❖ M-type red dwarf stars
  - ~ 75% of stars in the galaxy
  - Sterilizing flares?
  - Tidally lock planet in hab zone
  - Wind or fluid driven thermal equilibration?
  - Too close for liquid H<sub>2</sub>O?



## The Milky Way's Abundance of Real Estate

Half of all stars may have planets <sup>(1)</sup>

Average # planets/star = 1.6 <sup>(2)</sup>

$160 \times 10^9$  planets in the galaxy <sup>(3)</sup>

$100 \times 10^6$  habitable planets <sup>(4)</sup>

4-8% of Sun-like stars have Earth-like planets <sup>(5)</sup>

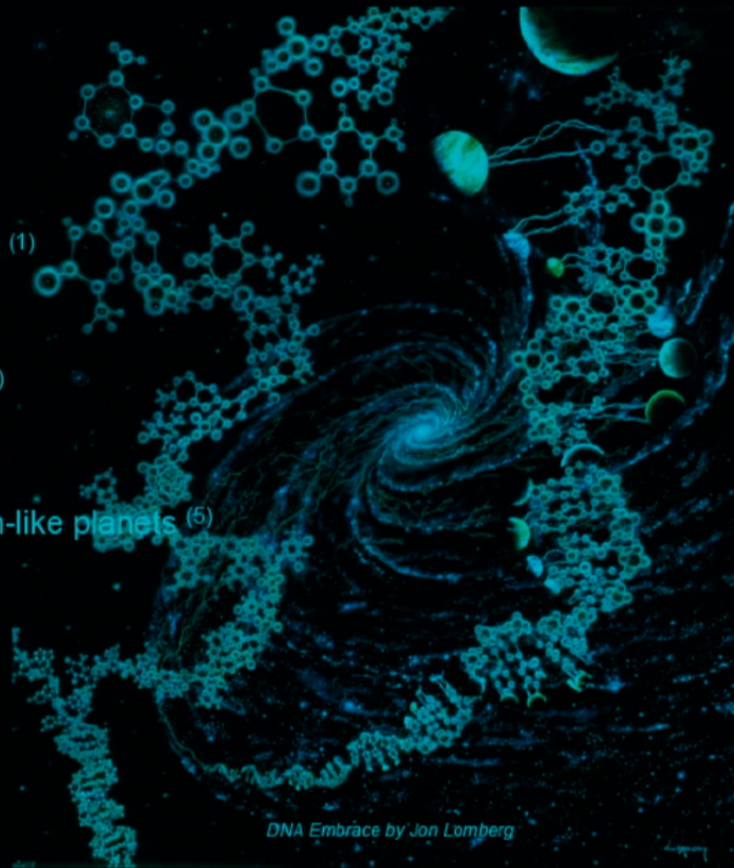
<sup>1</sup> Mayor et al 2011 HARPS spectrograph

<sup>2</sup> Cassan et al 2012 (Jan 11) Nature,  
1+ planets/star via microlensing

<sup>3</sup> Walli, 2012 (Jan 11) space.com

<sup>4</sup> Sasselov, 2011

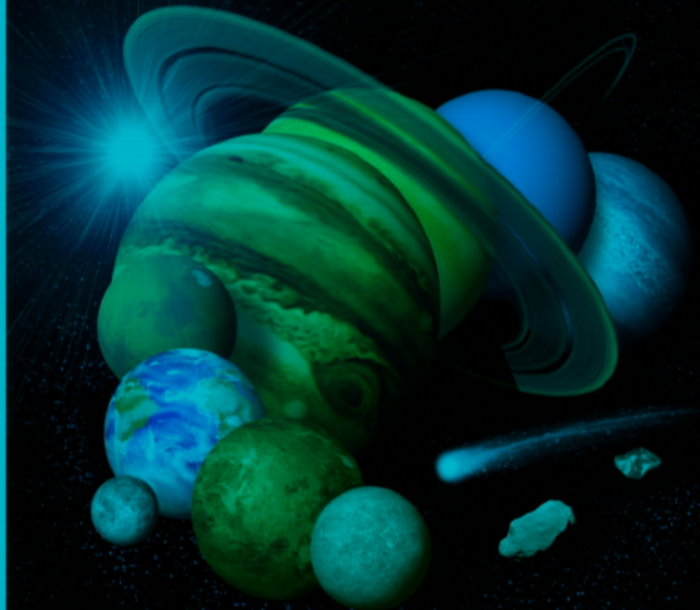
<sup>5</sup> Petigura et al, 2013, PNAS



DNA Embrace by Jon Lomberg

# The Solar System

One Big Happy Family!





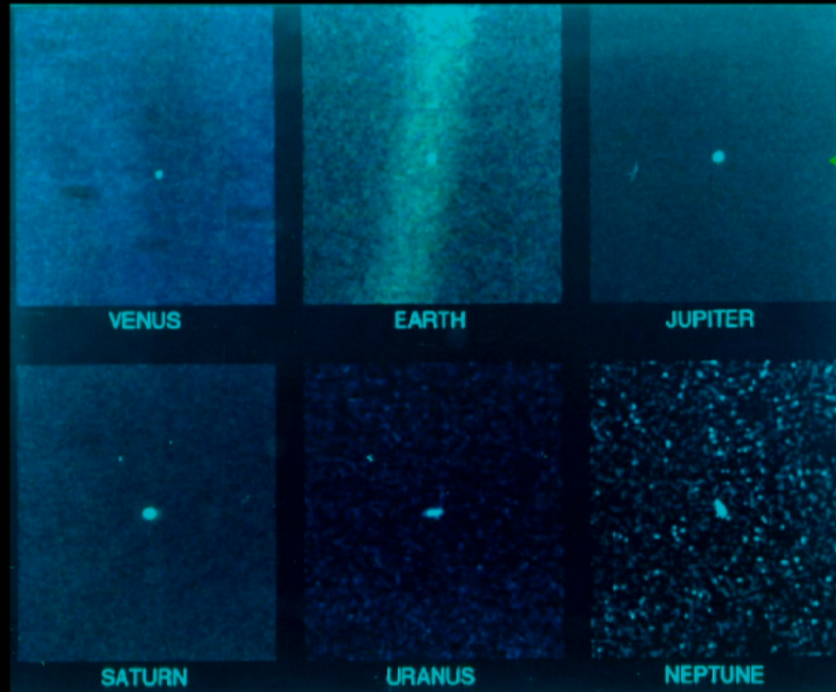
# The Solar System

Or maybe one big dysfunctional family???

POOR  
PLUTO



# Family Portrait from Voyager 1



Sept 5 1977 launch

Dec 7 1979 cameo as V'ger

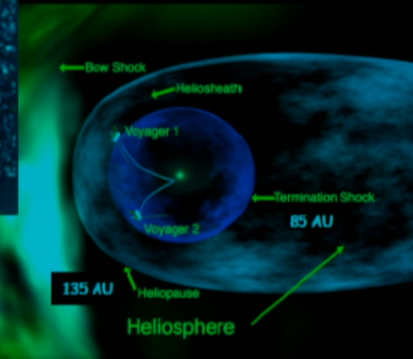
Dec 14 1996 these images

Nov 5 2003, leaves bowshock

May 2008, 106 AU

a few months ago,  
out of SS influence!!!

126 AU from us



# What Is Life?

Dr. Boston's Most Excellent  
*Operational Checklist*

- Boundary conditions
- Energy flow through system
- Energy acquisition
- Plausible energy sources
- Disequilibria with environment
- Internal lowering of entropy
- Non-crystallomorphic growth
- Reproduction of similar units
- Information coding
- Evolvable, respond to changes





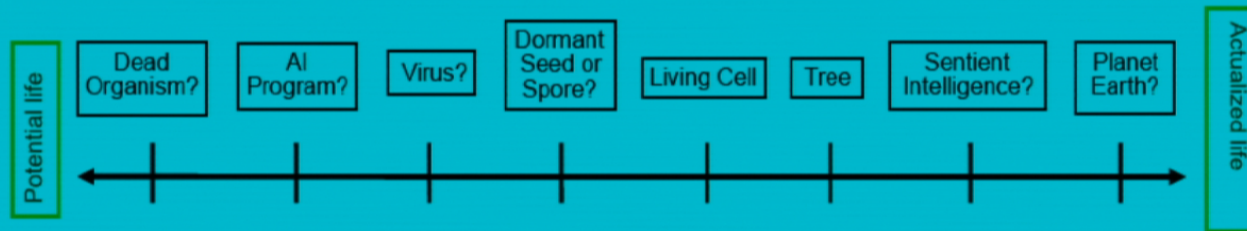
# Problems with Most Definitions of Life

Confusion between levels of analysis

*e.g. biomolecules, cells, organisms, etc.*

No distinction between **active life** vs. **potential life**

*e.g. a virus, a dehydrated tardigrade, a dormant seed*



Is “life” really a continuum rather than an irreducible set of properties?



## What kind of life are we expecting???

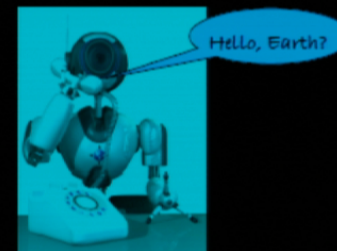
- In our Solar System:

- Probably microscopic
- May be very different  
*chemistry, size, speed, etc.*
- Cryptic Locations  
*Entirely subsurface...Mars?*  
*Under kms of ice...Europa?*

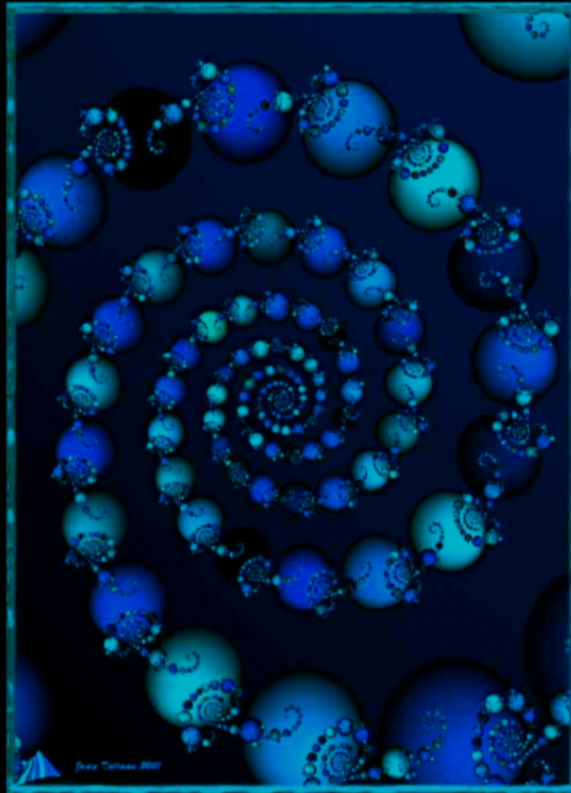
- On exoplanets:

- robust biospheres
- atmospheric gases
- liquid water

- Guys that send messages...



# What Does Life Need?



- Conditions of origin  $\neq$  extremes of adaptation
- Functional and structural biomolecules
- Coding mechanism (biomolecules, clay, etc.)
- Solvent
- Energy sources:
  - Solar energy, visible & UV?
  - Geochemical energy
  - Geothermal energy?
  - Radiogenic energy?
- Stellar lifetime
- Planetary stability?
- Big satellite?
- Recycling, e.g. plate tectonics



## Can you detect life on Earth?

Mass of the earth =  $6 \times 10^{24}$  kilograms ( $10^{27}$  g)

Mass of the atmosphere =  $5 \times 10^{21}$  kilograms ( $10^{24}$  g)

Biological material on surface of earth =  
a few  $\times 10^{14}$  kilograms ( $10^{17}$  grams )

· THEREFORE ·

Life = 0.01% of the mass of the atmosphere ( $10^{-3}$ )

Life =  $10^{-10}$  of the mass of the Earth

*"Biological Rust" is a very small effect*

*Shklovskii and Sagan - page 248*

# What Kind of Planet Is It?

## Planet Type 1 Biosphere

*Sunlight "just right"*

*Green*

*Goosey*

*Gases in non-equilibrium*

**Critical Zone** is top-down

*Photosynthetically driven*

Well mixed-Critical Zone



*Earth*

# What Kind of Planet Is It?

## Planet Type 1 Biosphere

*No visible means of support*  
*Not green*  
*Not gooey*  
*Gases in chemical equilibrium*  
*Exceptions dependent upon crustal leakiness*  
***Critical Zone** is bottom-up*  
*Chemosynthetically driven*

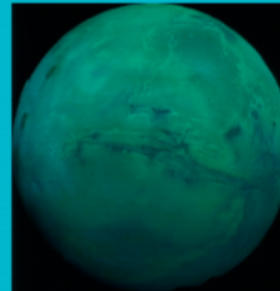


## Planet Type 2 Biosphere

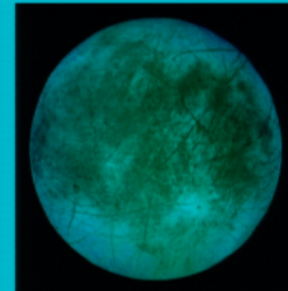
*No visible means of support*  
*Not green*  
*Not gooey*  
*Gases in chemical equilibrium*  
*Exceptions dependent upon crustal leakiness*

***Critical Zone** is bottom-up*  
*Chemosynthetically driven*

## Stratified Critical Zone?



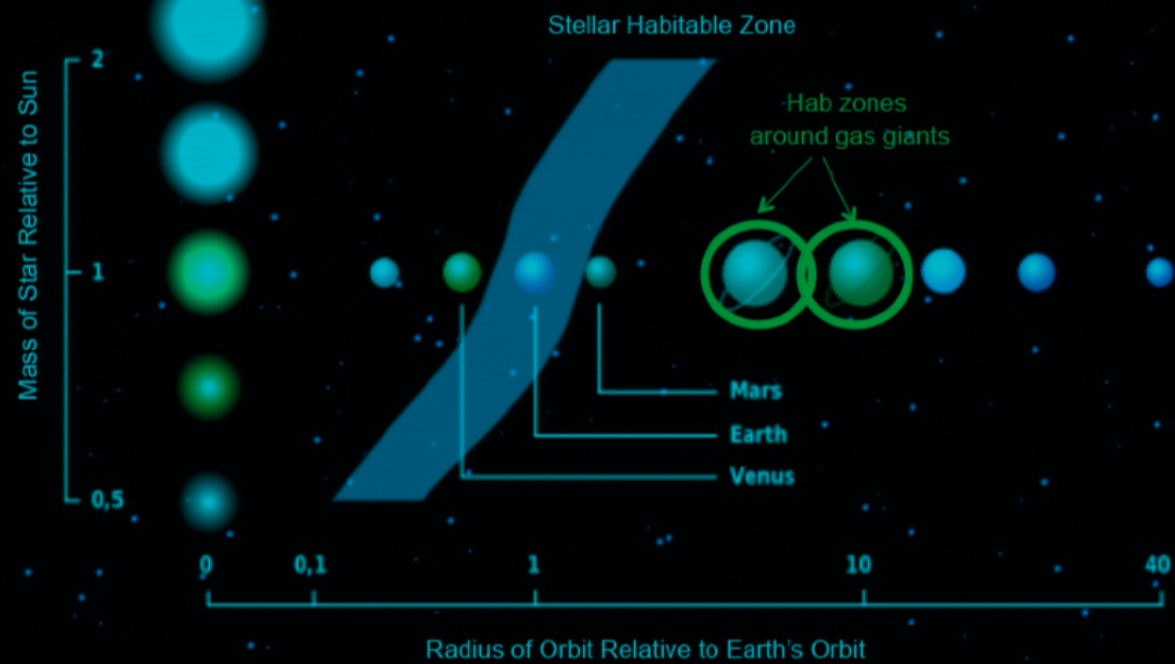
*Mars*



*Europa*



# Habitable Zones



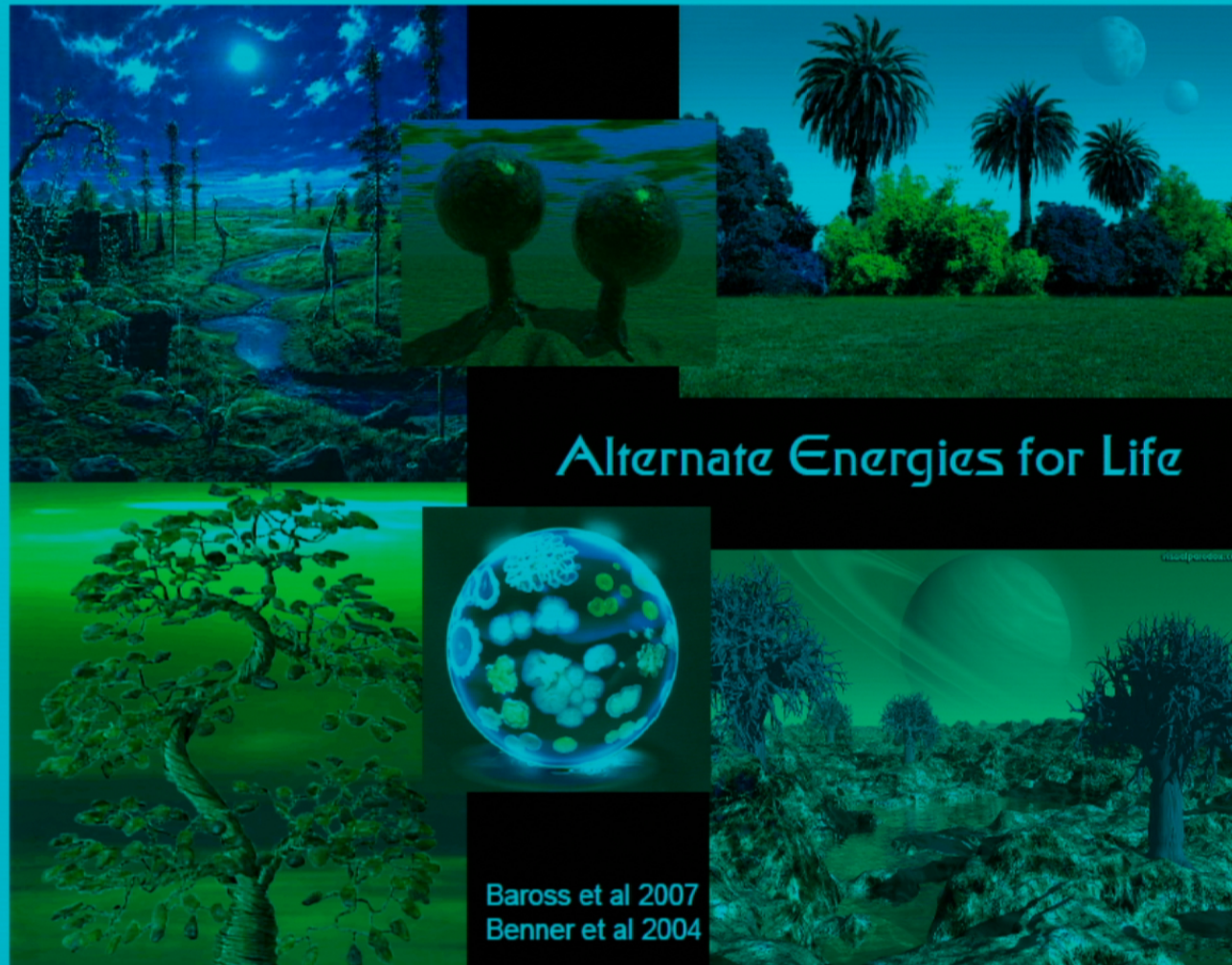
# Planetocide!

How many SS's have homicidal family members?

Oh no! It's crazy  
Uncle Marvin again!

Goldreich & Tremaine, 1980; Boss, 1995;  
Minton & Malhotra, 2011, etc.



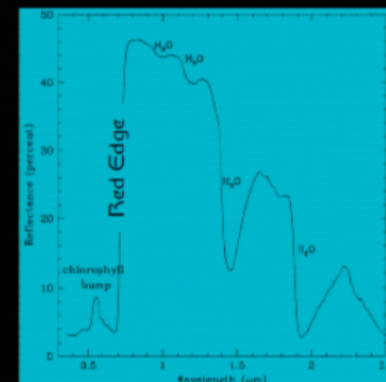
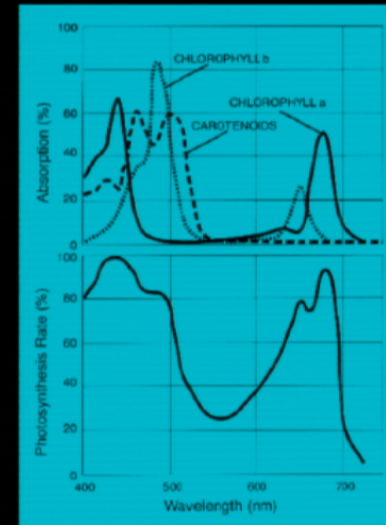


Baross et al 2007  
Benner et al 2004

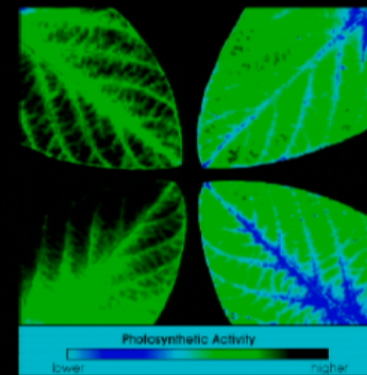


## Alternate Wavelengths for Life

- ✧ For aqueous carbon-based life:
  - ✓ Sufficiently energetic to support biosynthesis
  - ✓ But not chemically destructive
  - ✓ Constrained to 300 to 1500 nm wavelengths (UVA to NIR)
- ✧ Vegetation Red Edge?
  - ✓ High reflectivity 700-750 nm
  - ✓ Look for other anomalous reflectivities?
- ✧ Alternatives?
  - ✓ UV (~10 to 400 nm)
  - ✓ Metabolite chains to “step-down” energies
  - ✓ Physical screening mechanisms
  - ✓ Other life chemistries
  - ✓ Infrared (Red Dwarf stars peak there...)



## How Efficient is Photosynthesis?

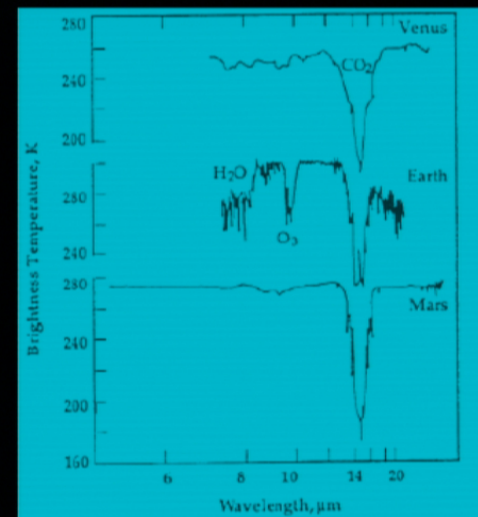


- ✧ Solar constant ~ 15,000 X all energy consumed on Earth
- ✧ Photosynthetic energy capture is 10 X total consumption,
- ✧ ~45% of solar constant is in Photosynthetically Active Wavelengths (PAR = ~400-700 nm)
- ✧ Max utilization of PAR as it falls on photosynthetic surfaces is ~25%
- ✧ Overall theoretical efficiency of photosynthesis as a process is 11%
- ✧ Practical efficiency ~ 2-5%

## Atmospheric Signals of Life

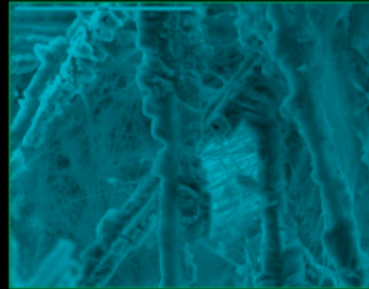
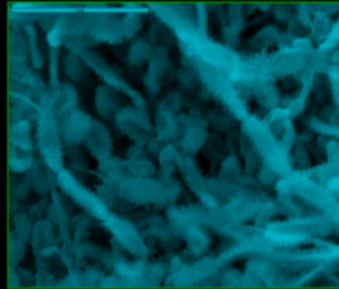


- Is a complex atmospheric signal an indication of life processes?
- Photocatalytic half- life of life-associated gases
  - ✓  $\text{NH}_3$  - Few hrs to few days
  - ✓  $\text{CH}_4$  - 10 years
  - ✓  $\text{O}_2$  - Several months to seconds
  - ✓  $\text{H}_2\text{S}$  - 18 hrs - 43 days in  $\text{O}_2$  atmosphere
  - ✓ Organic volatiles - Few days to 5 ky





On Earth we study organisms in extreme conditions



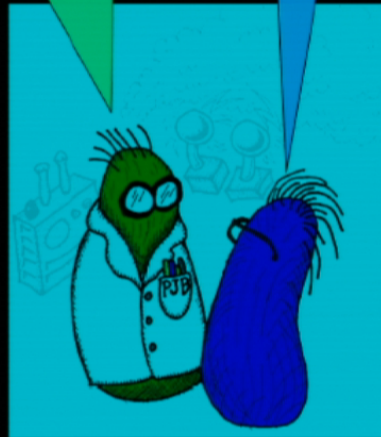
We hope this will help us to identify organisms on other planets that we can reach.



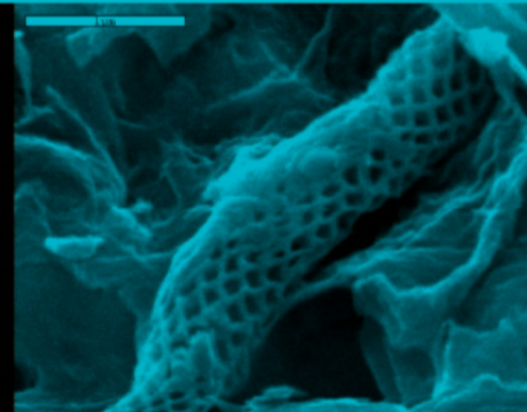
In many caves, we operate in extreme environments with sensitive "alien" biology...

What are these, o Wise Omnipotent Professor Boston?

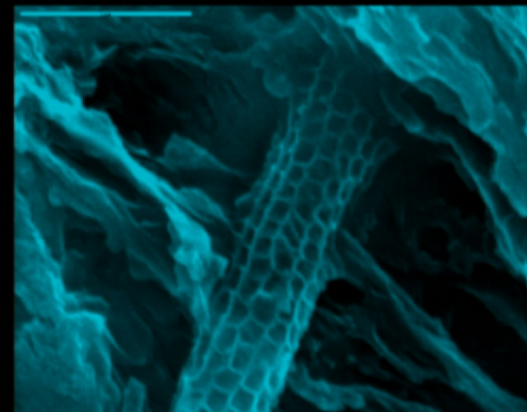
Gosh, Eager Young Student... I haven't the foggiest...



Melin, L.A., Northup, D.E., Spilde, M.N., Jones, B., Boston, P.J., and Bixby, R.J., 2006, "Reticulated Filaments in Cave Pool Speleothems: Microbe or Mineral?", *Journal of Cave and Karst Studies*, v. 70, p. 135-141.



What are these???  
Do you know?  
We don't....





## RIP VAN WINKLE Microorganisms

Go to sleep in geological materials  
Wake up when released!



Giant Crystal Cave - National Geographic TV Special, Oct 2008  
& National Geographic Magazine, Nov. 2008  
Into the Lost Crystal Cave - National Geographic TV Sequel, Oct. 2010

Image courtesy of Carsten Peters,  
National Geographic Society, © 2008



## Spacegoing Microbes?

✧ **Geogenetic latency** on Earth driven by tectonics & other processes?

✧ Microbial swapping from one planet to another?

- Impact excavation of the geogenetic "bank"?
- Tapping into populations that would be the *MOST* likely to survive this



*Spit-swapping Amongst The Rocky Terrestrials*

## Life in Earth's Future?

