Cosmology & Culture

Lecture 7

Wednesday May 13, 2009

Life in the Universe

UCSC Physics 80C

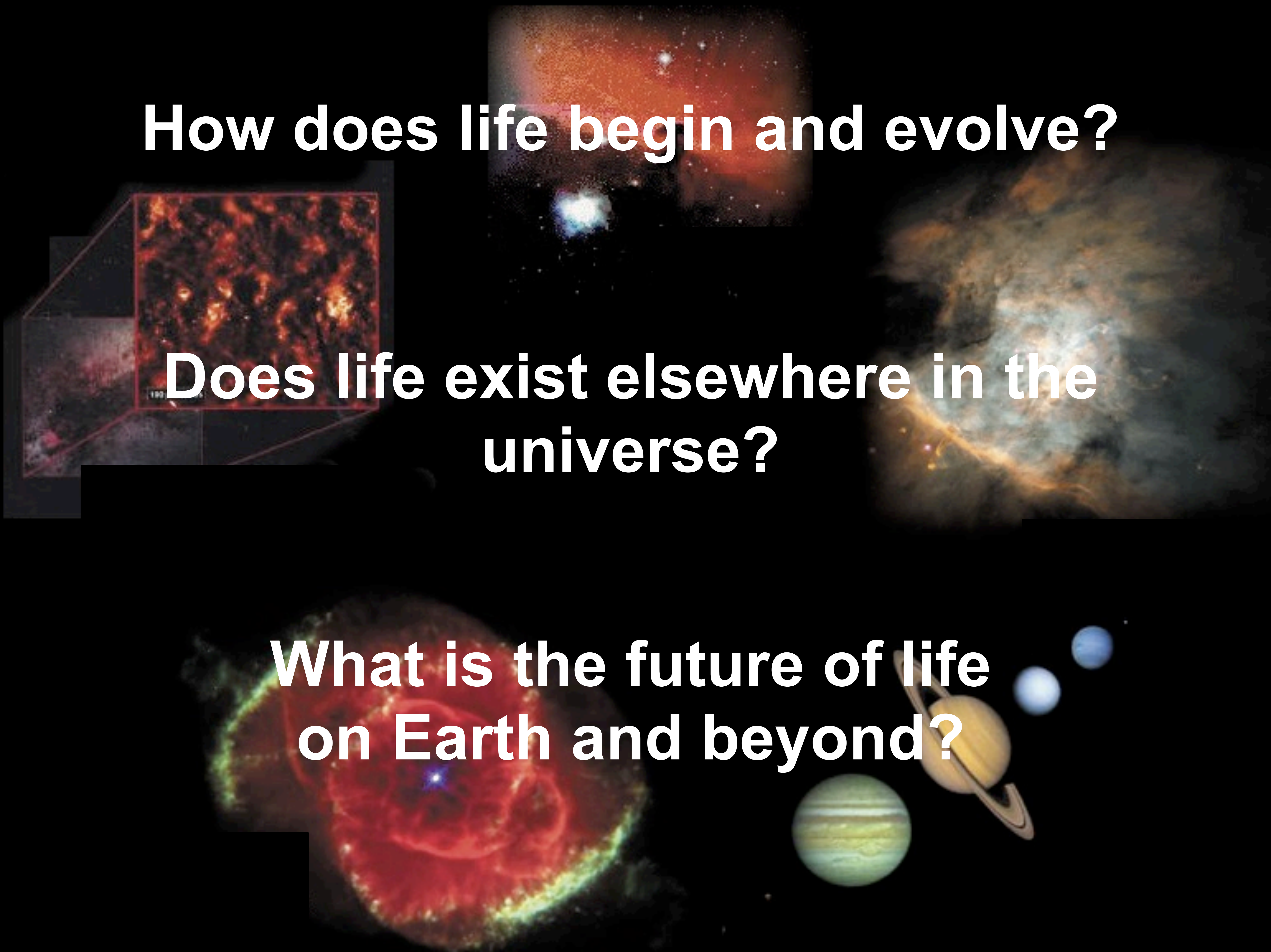
We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

from Little Gidding, the first of the
Four Quartets, by T. S. Elliot

Thinking about intelligent aliens helps tie us Earthlings into the universe. Looking at ourselves in the context of all intelligent life, we begin to see our own evolution in a new light. When we ask how likely the existence of intelligent aliens is, we are also asking how likely it is that we ourselves would have evolved. How did the Sovereign Eye open on Earth – and why Earth? By looking not only at ourselves in the context of other possible intelligent beings but at our planet in the context of other planets, we literally bring the universe down to Earth and begin to appreciate how special we and our blue planet really are.

Life in the Universe

from a talk by Carl Pilcher, Director, NASA Astrobiology Institute


How does life begin and evolve?
Does life exist elsewhere in the universe?
What is the future of life on Earth and beyond?

One method of searching for life in the universe is to listen and look for signals from intelligent life: the Search for ExtraTerrestrial Intelligence (SETI).

Thus far, we have searched only out to a distance of about 100 light years. The SETI Institute and the University of California are building a large radio telescope called the Allen Array which will extend the search to a distance of 1000 light years. If the radius extends 10 times further, how much larger is the volume enclosed?

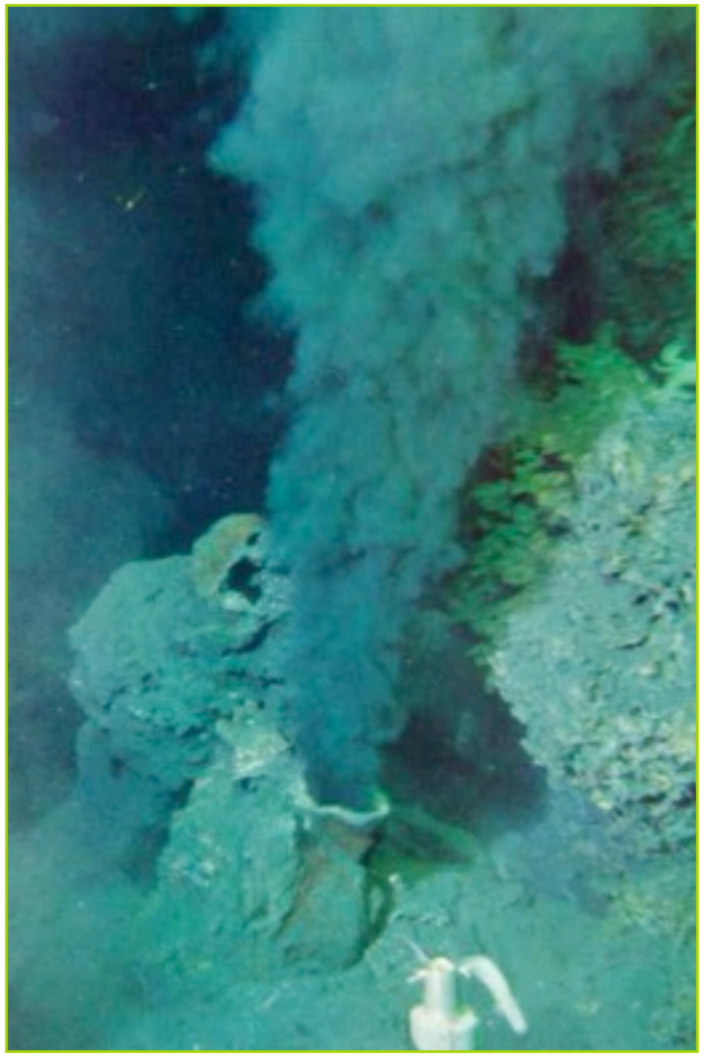
Answer: 10x10x10 = 1000 times larger

Figure 1 of Chapter 8. Our Milky Way galaxy with a sphere 1000 light years in radius around the position of our sun. The powerful new Allen Radio Telescope now under construction will allow the SETI Institute to search for signals from intelligent aliens in this volume of space. It is a relatively small part of the Milky Way, but it contains about a thousand *times* as many stars as have been searched thus far.

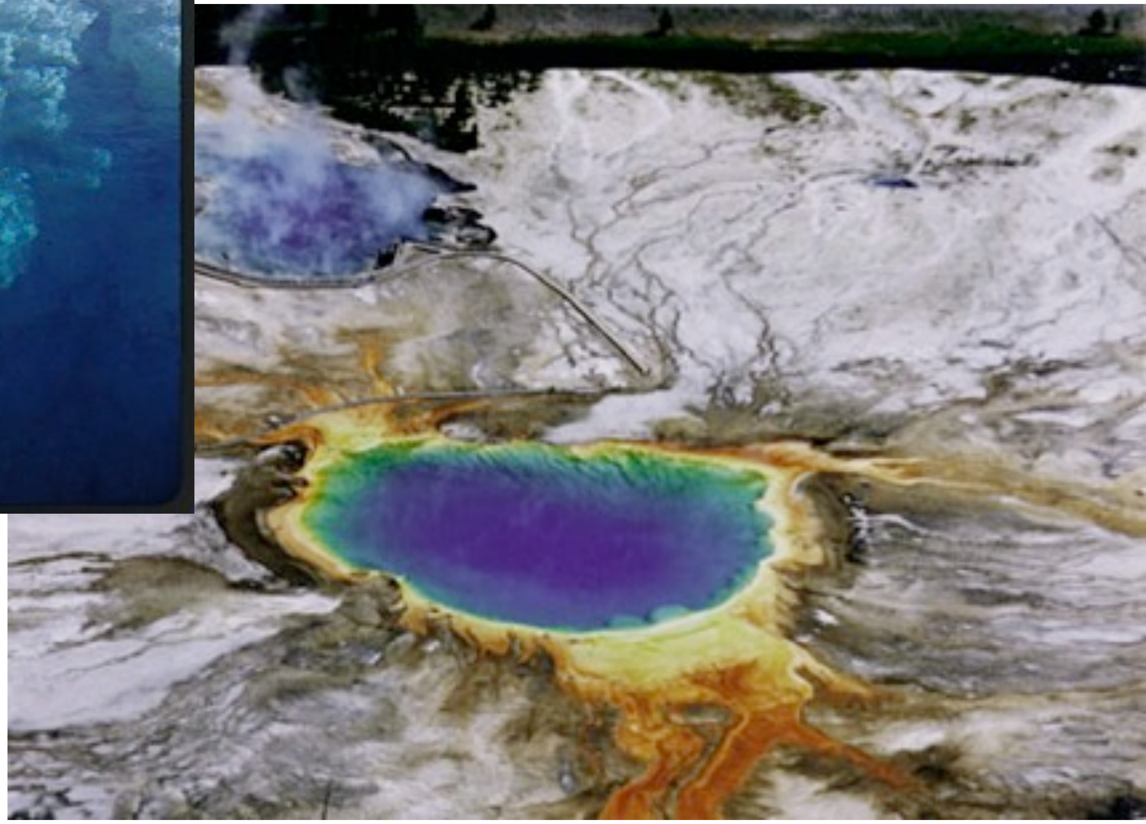
Another method of searching for life in the universe has thus far been much more productive than SETI.

This method seeks to understand the nature of life on earth, and to search for planets around other stars.

Life is Hardy

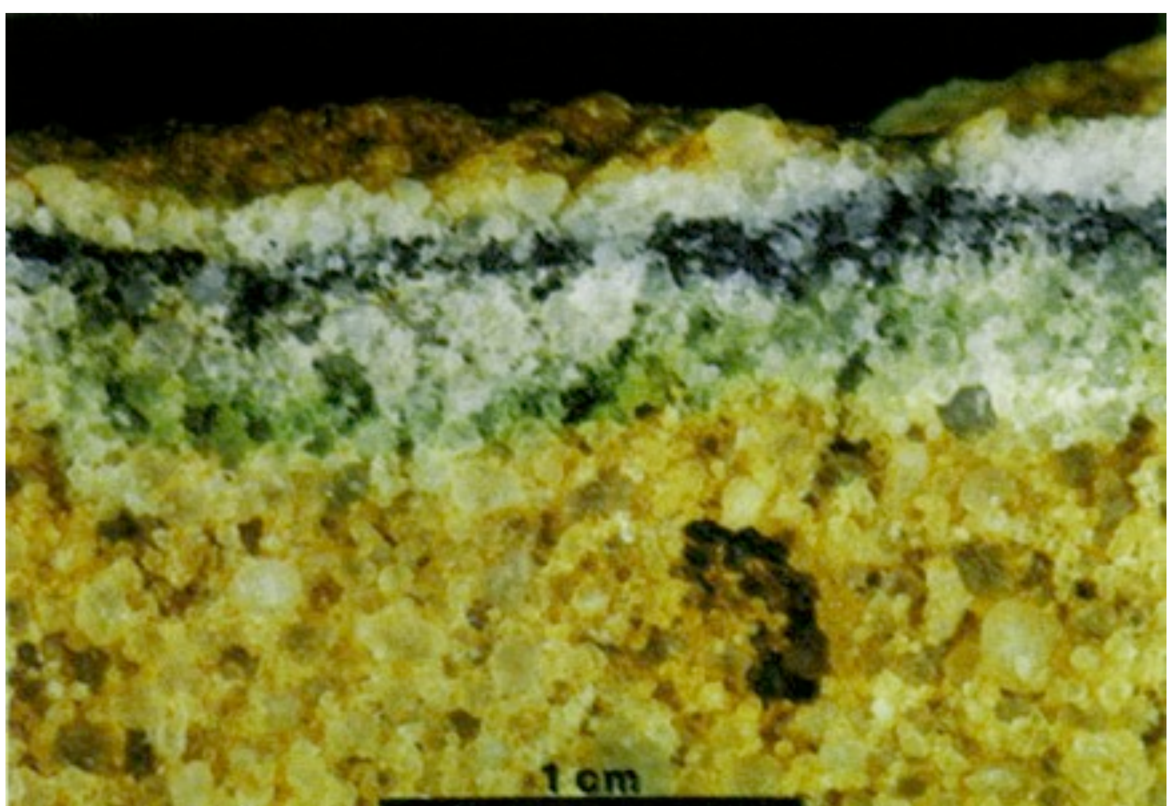


Microbial life (extremophiles) can make a living near undersea volcanic vents, in deep underground aquifers, within rocks, or in hot (~120 C!) acid lakes



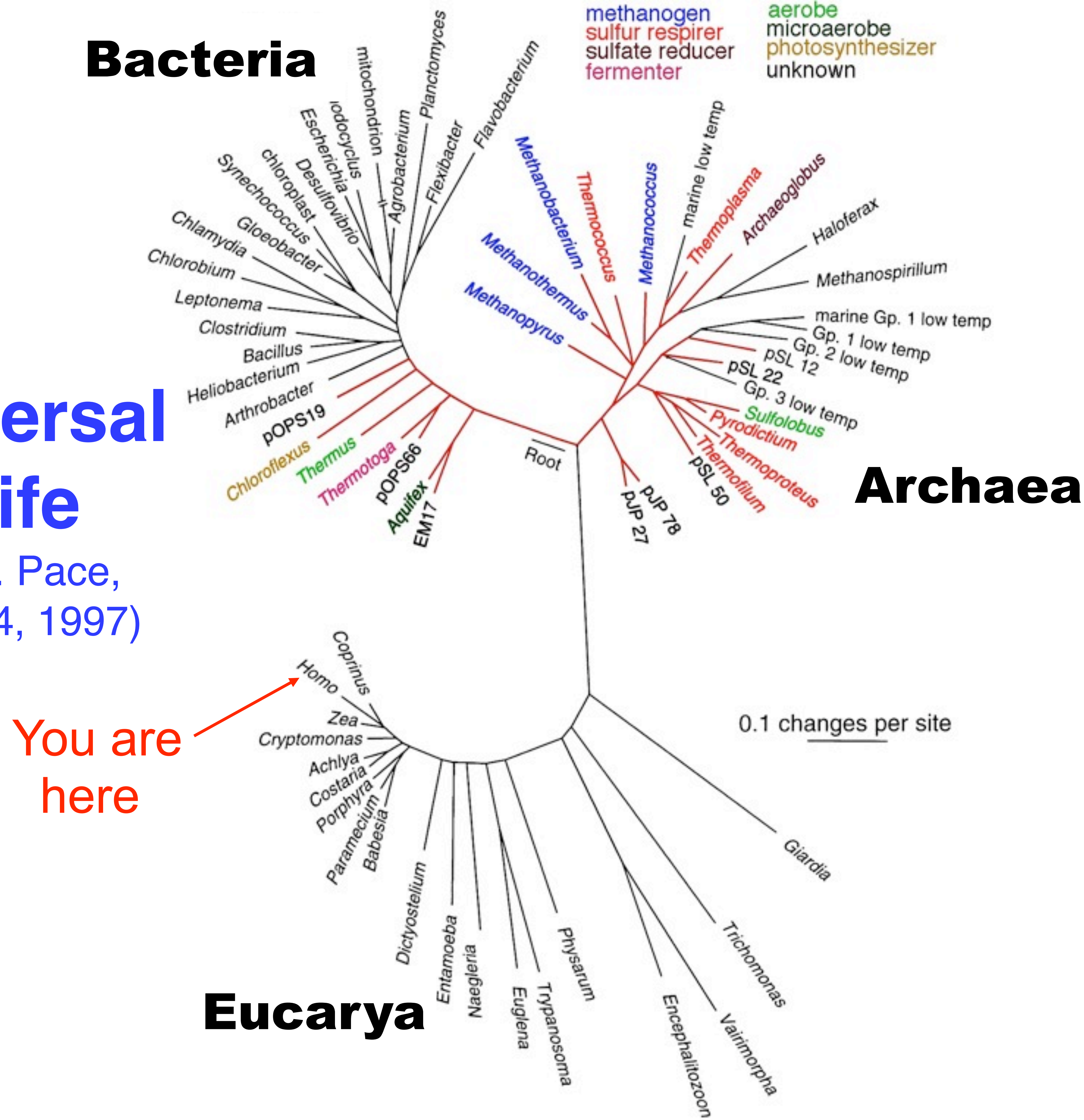
Life is Everywhere

- Existence of life in these environments implies that life needs only water, a source of energy, and common chemical compounds



The Universal Tree of Life

(adapted from N. Pace, *Science* 276, 734, 1997)

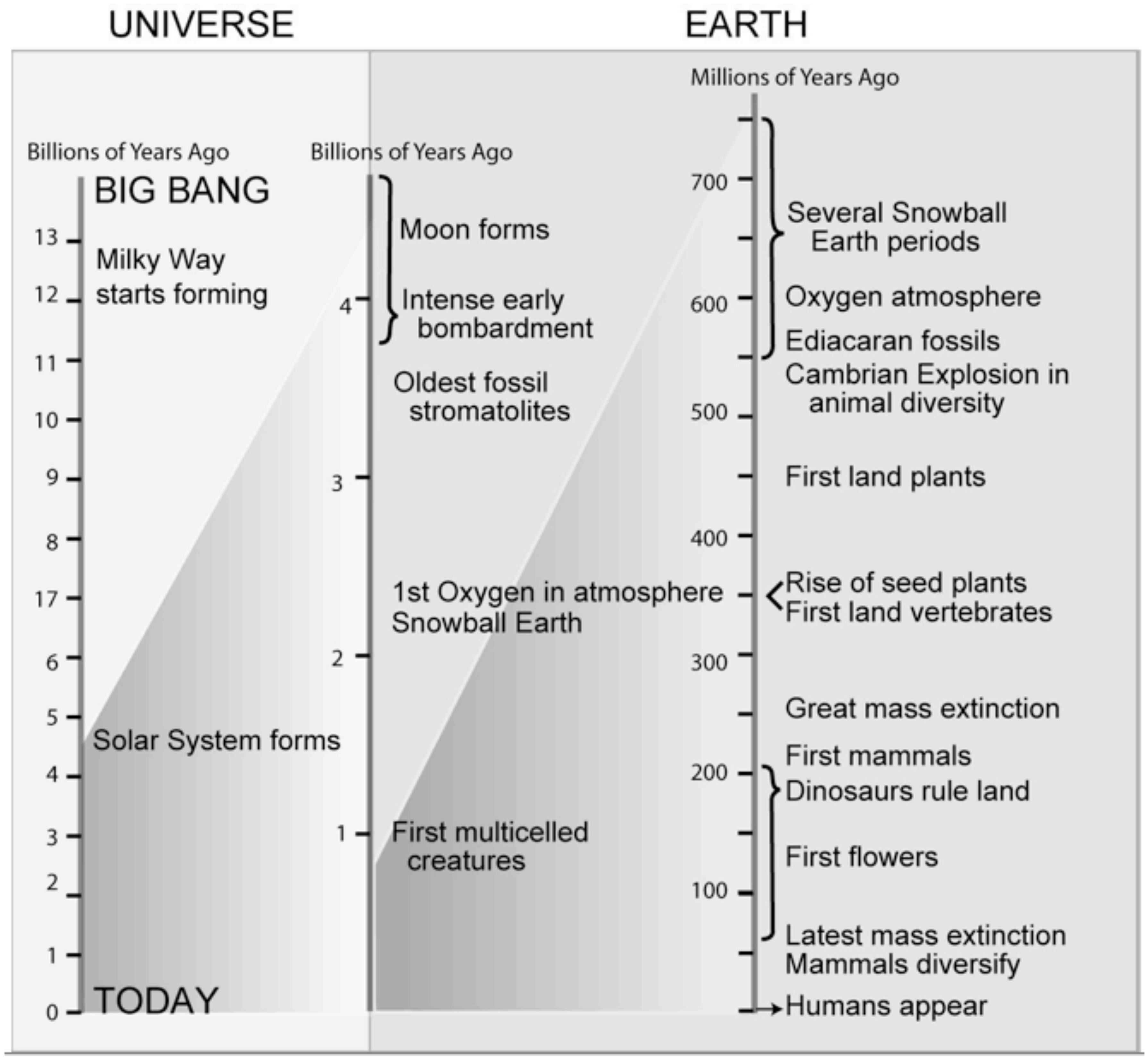


Life is Old

3-1/2 billion year-old remains of microbial communities

Australian *stromatolites*

A common occurrence on Earth ~4 billion years ago?

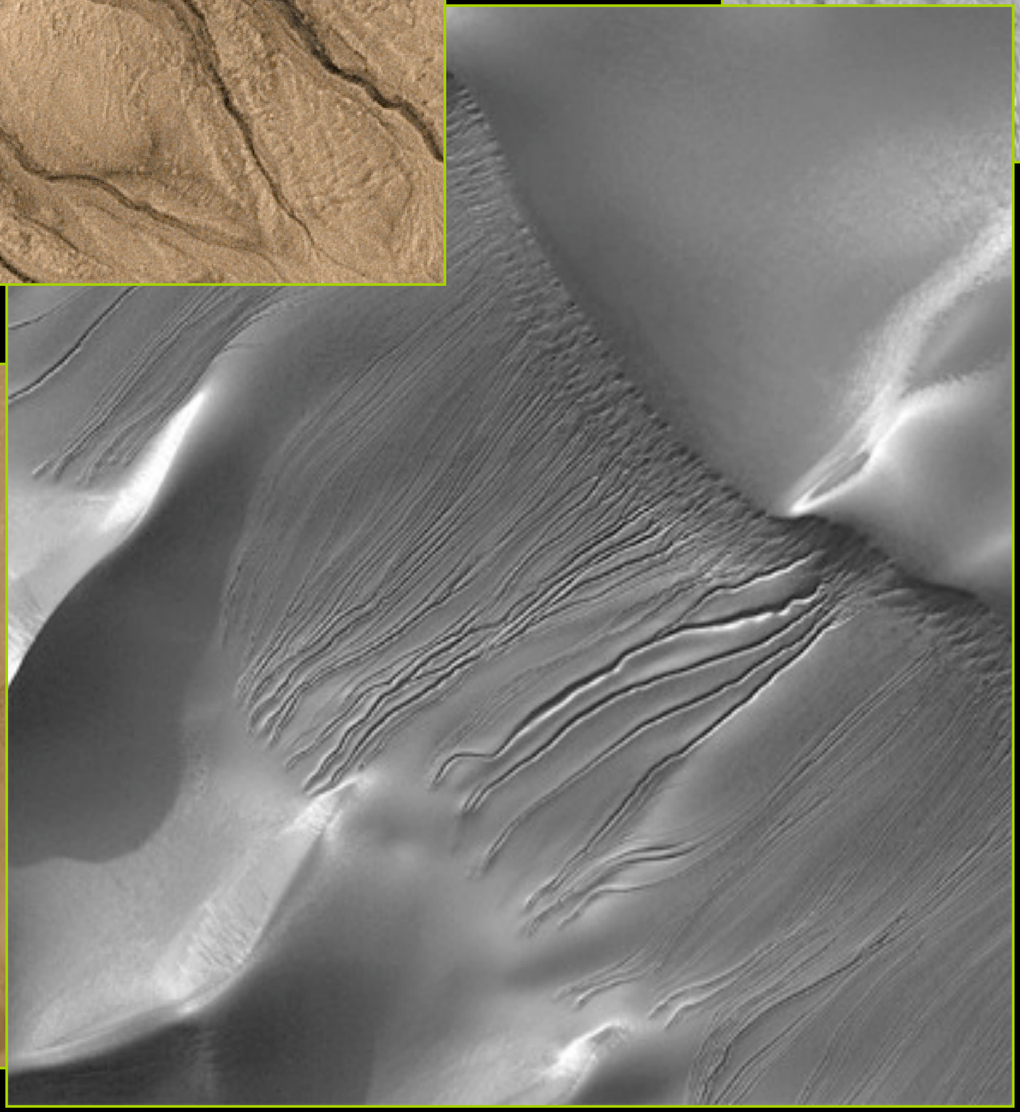


Pivotal Events in the Development of Life on Earth. Since so much more happened in the last 750 million years, we have expanded the timeline to show details.

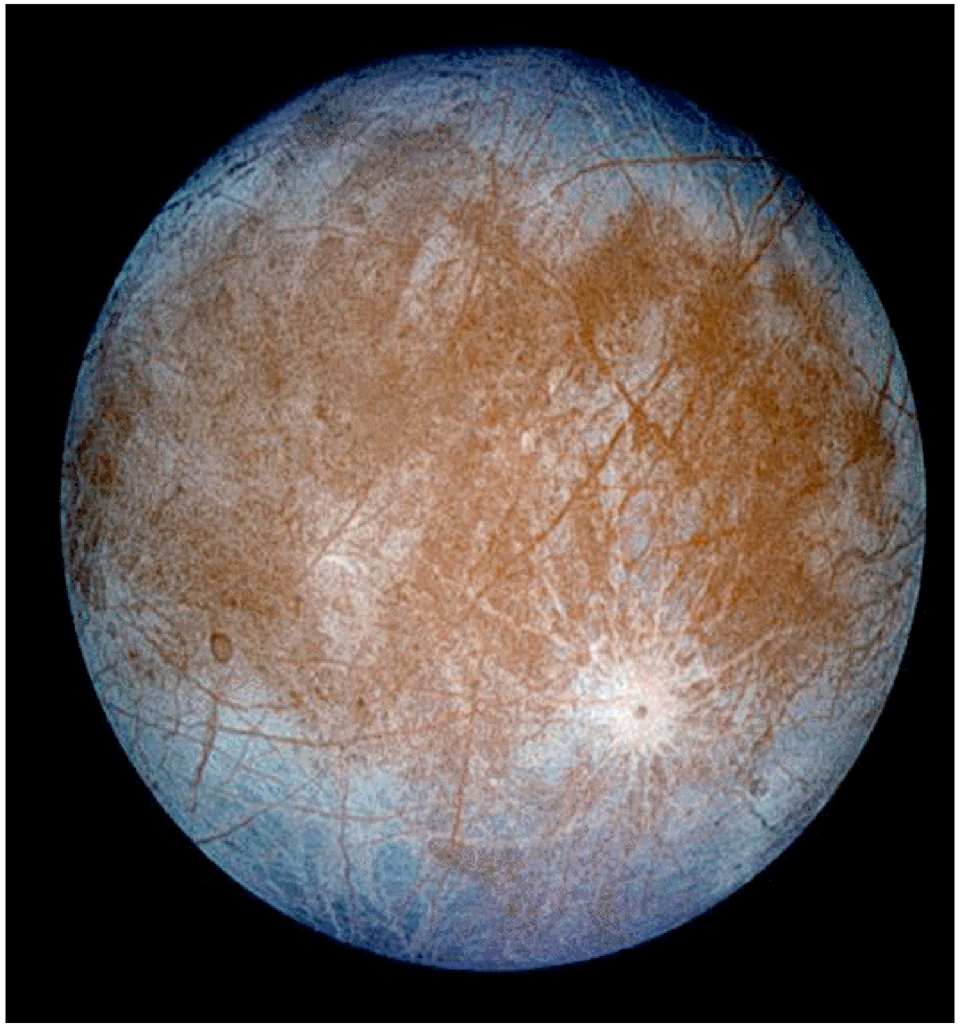
Earth is amazingly hospitable for life. It is the only planet in the solar system with liquid water on its surface. Moreover, Earth has been in the solar system's habitable zone for its entire existence.

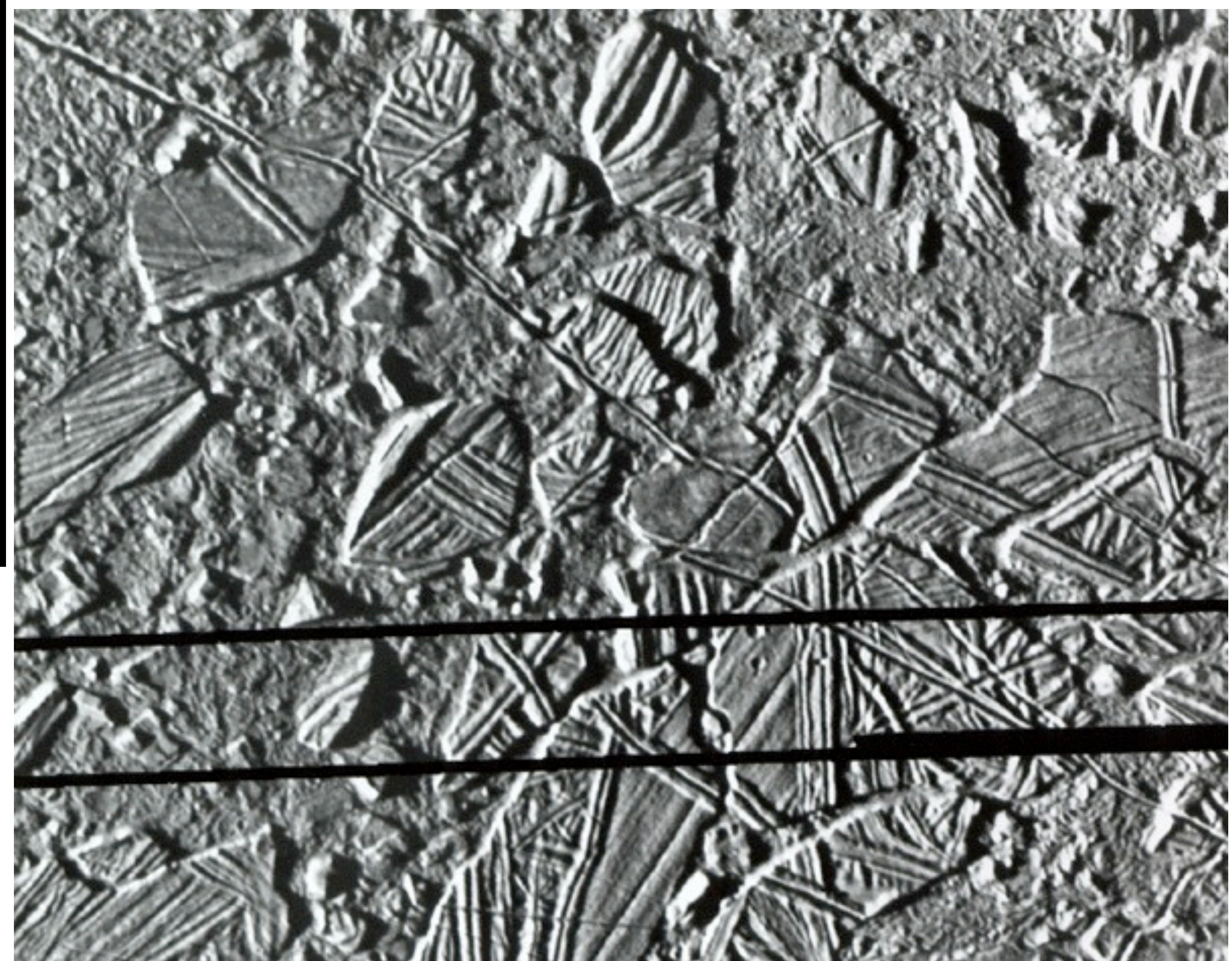
The other best bet places to find life in the solar system are Mars and Europa.
Mars has had water in its past -- maybe even today.
Jupiter's moon Europa has water under its changing ice covering.

Martian Gullies



An Ocean on Jupiter's moon Europa?

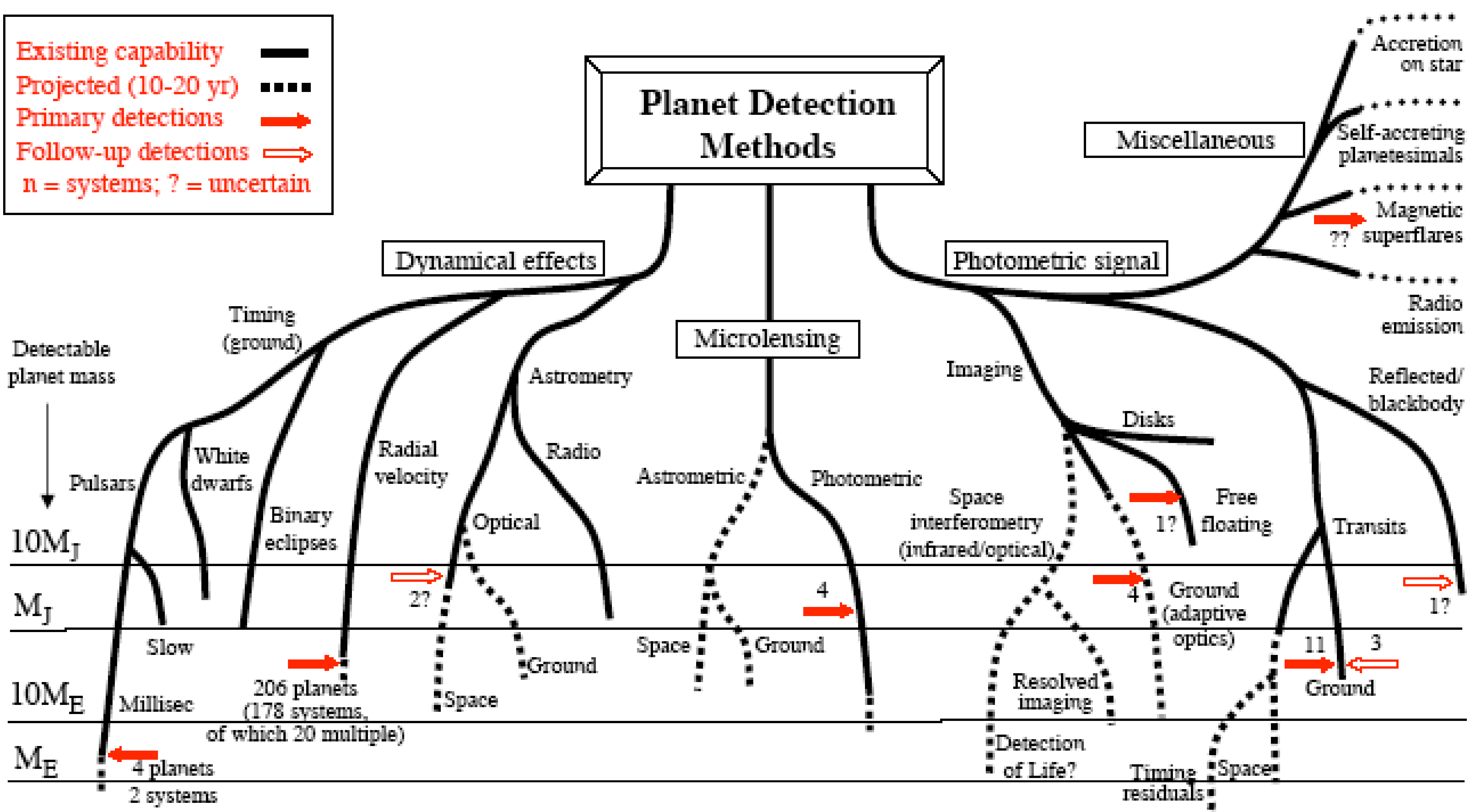




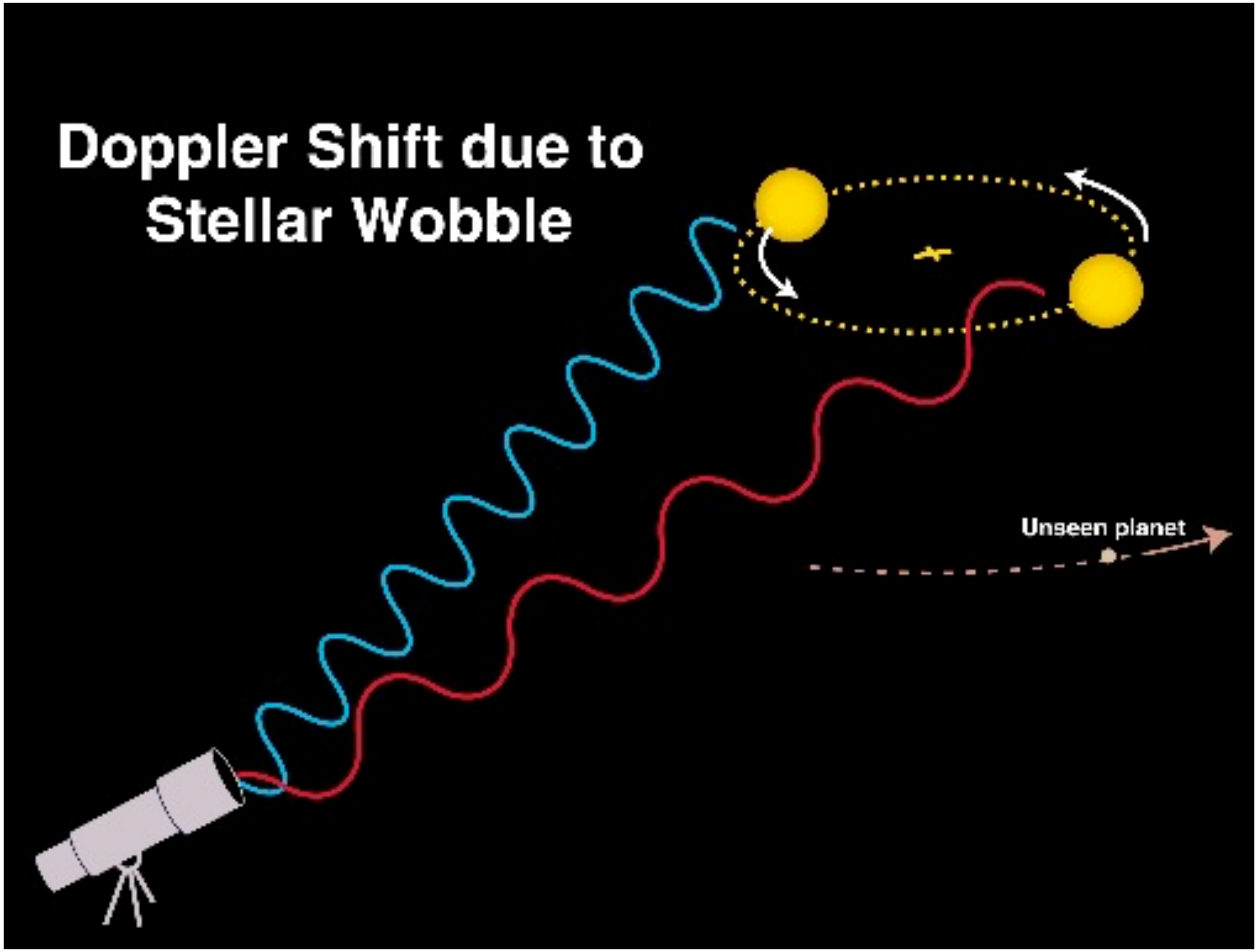
Planetary systems are being discovered rapidly, and new methods will find still more systems. Most of the systems discovered so far have large Jupiter-like planets near their stars. But that's because such systems are the easiest to discover. Soon we will see whether systems like our own solar system are common. But thus far it appears that in planetary systems with Jupiter-like planets as far from their star as earth is from the sun, the Jupiters have noncircular orbits -- which would make it hard for inner earth-like planets to survive.

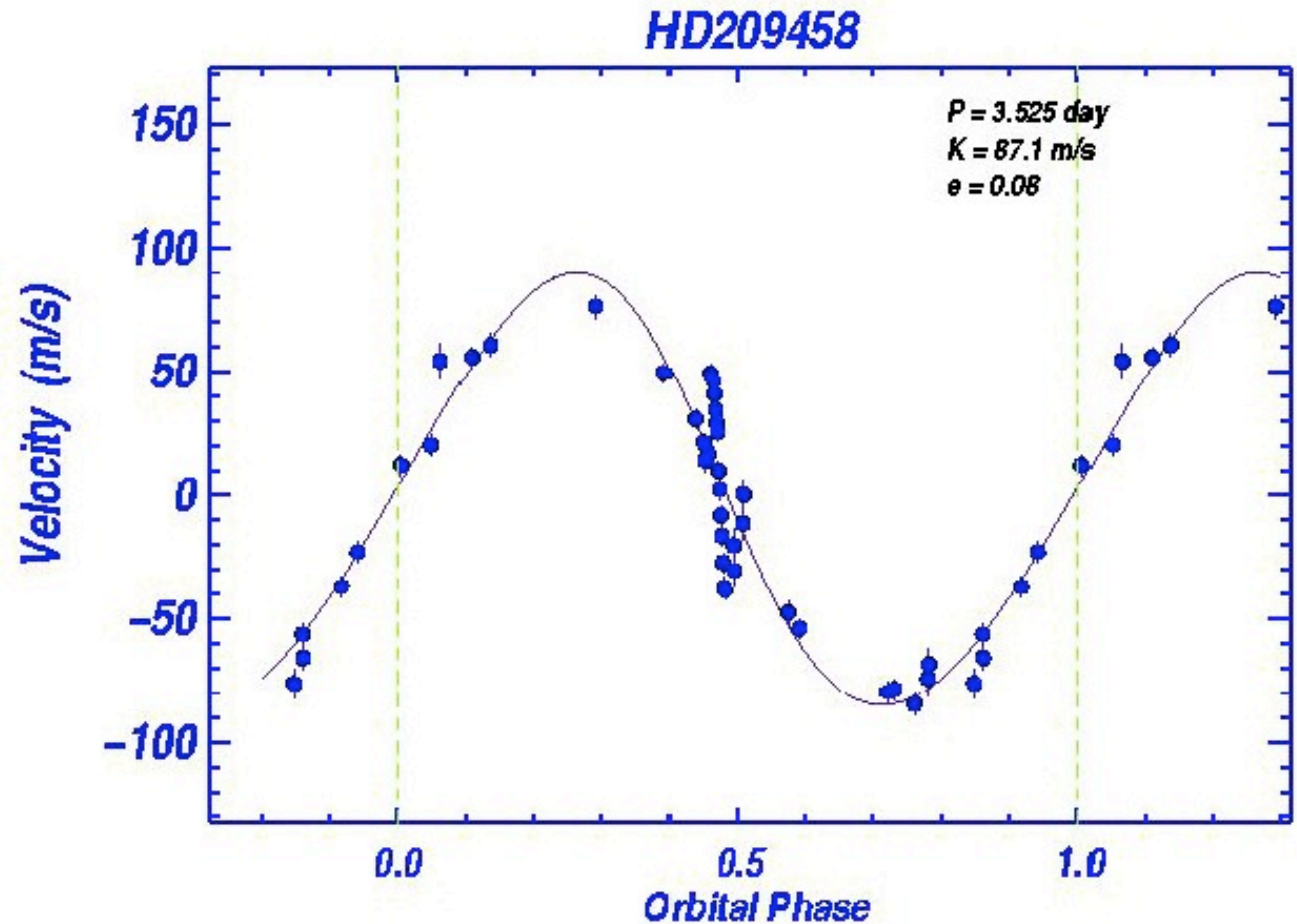
Planet Detection Methods

Michael Perryman, Rep. Prog. Phys., 2000, 63, 1209 (updated April 2007)
[corrections or suggestions please to michael.perryman@esa.int]



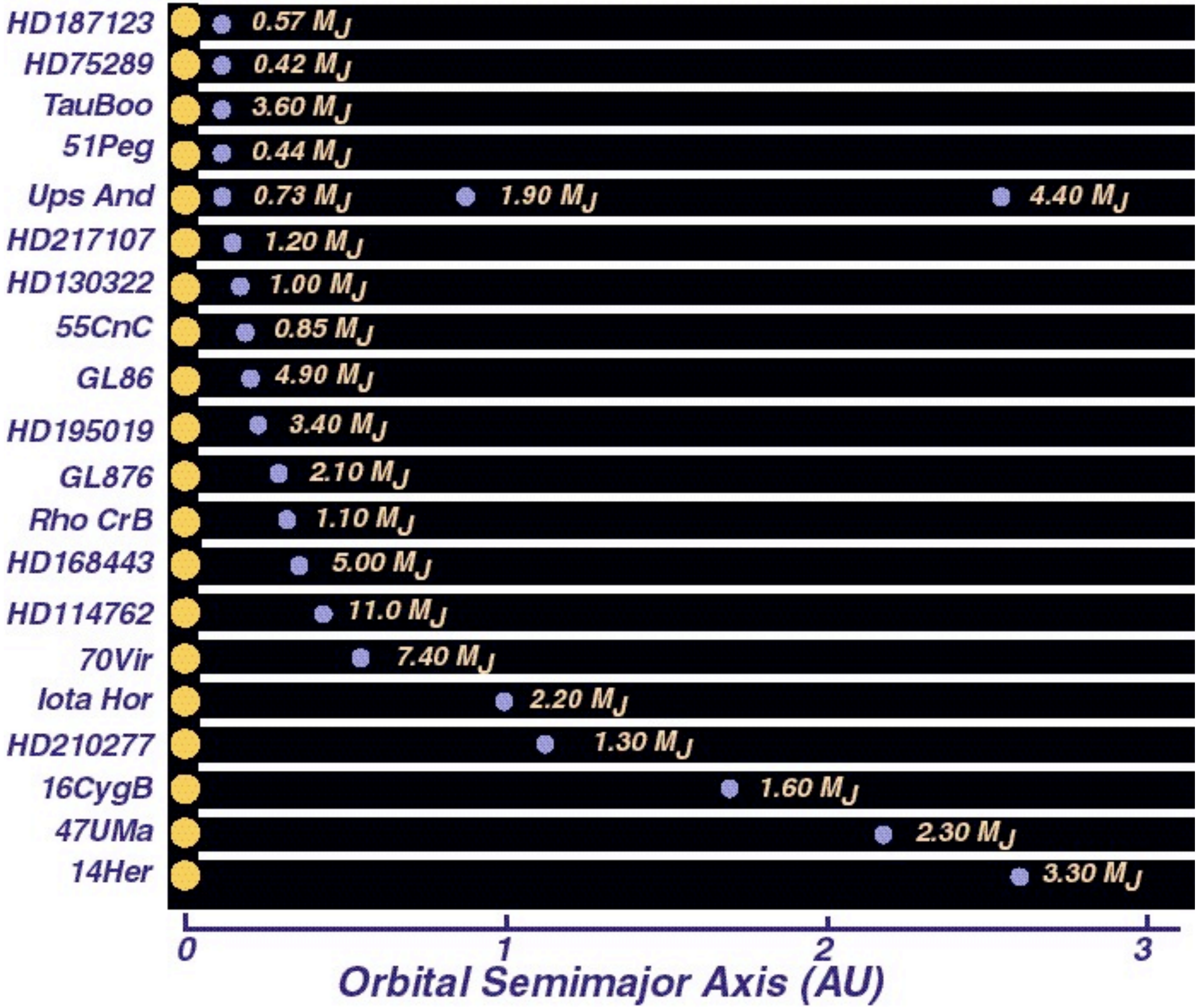
Radial Velocity Planet Detection

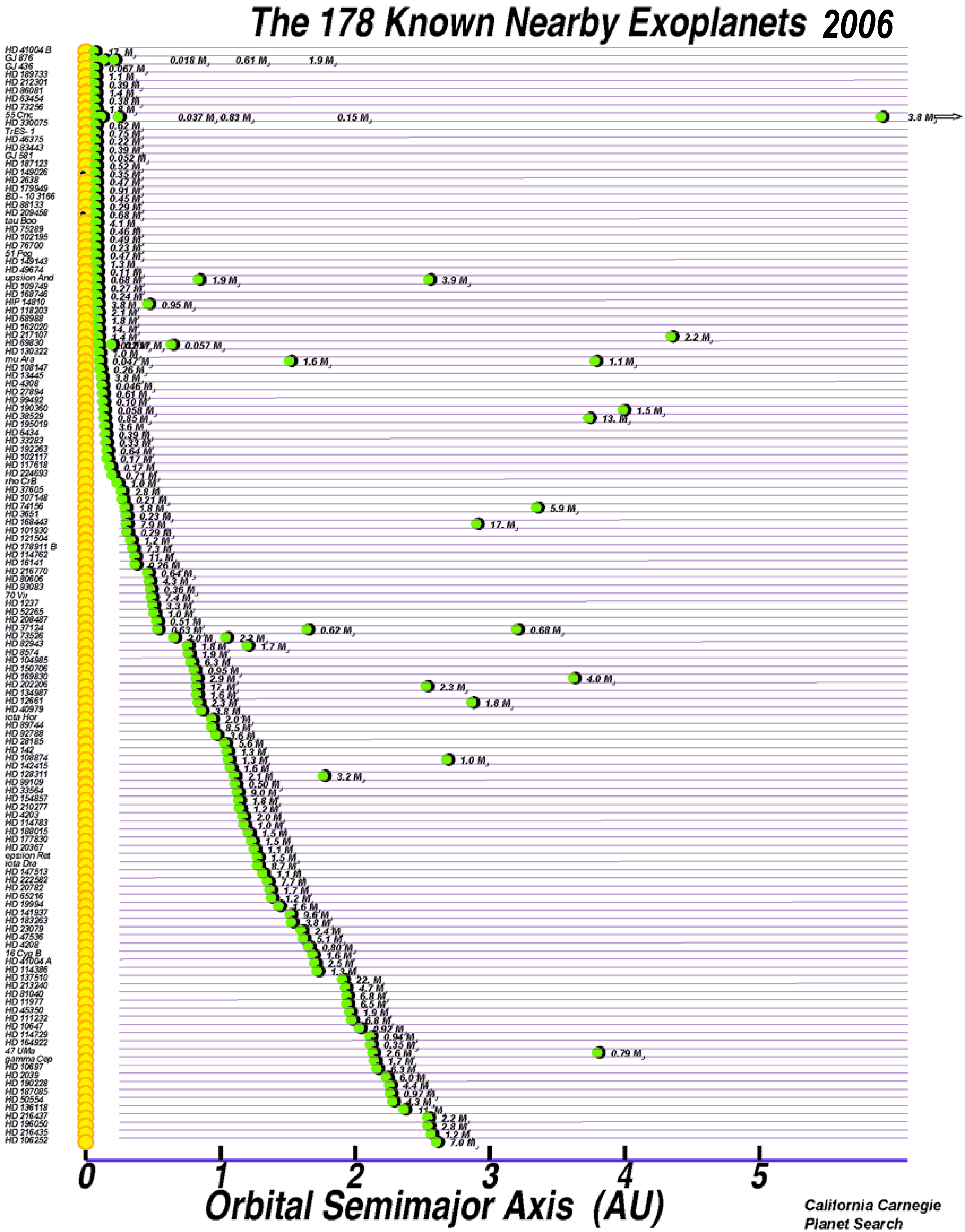




HD209458
P = 3.525 day
K = 87.1 m/s
e = 0.08
Velocity (m/s)
150
100
50
0
-50
-100
0.0
0.5
1.0
Orbital Phase

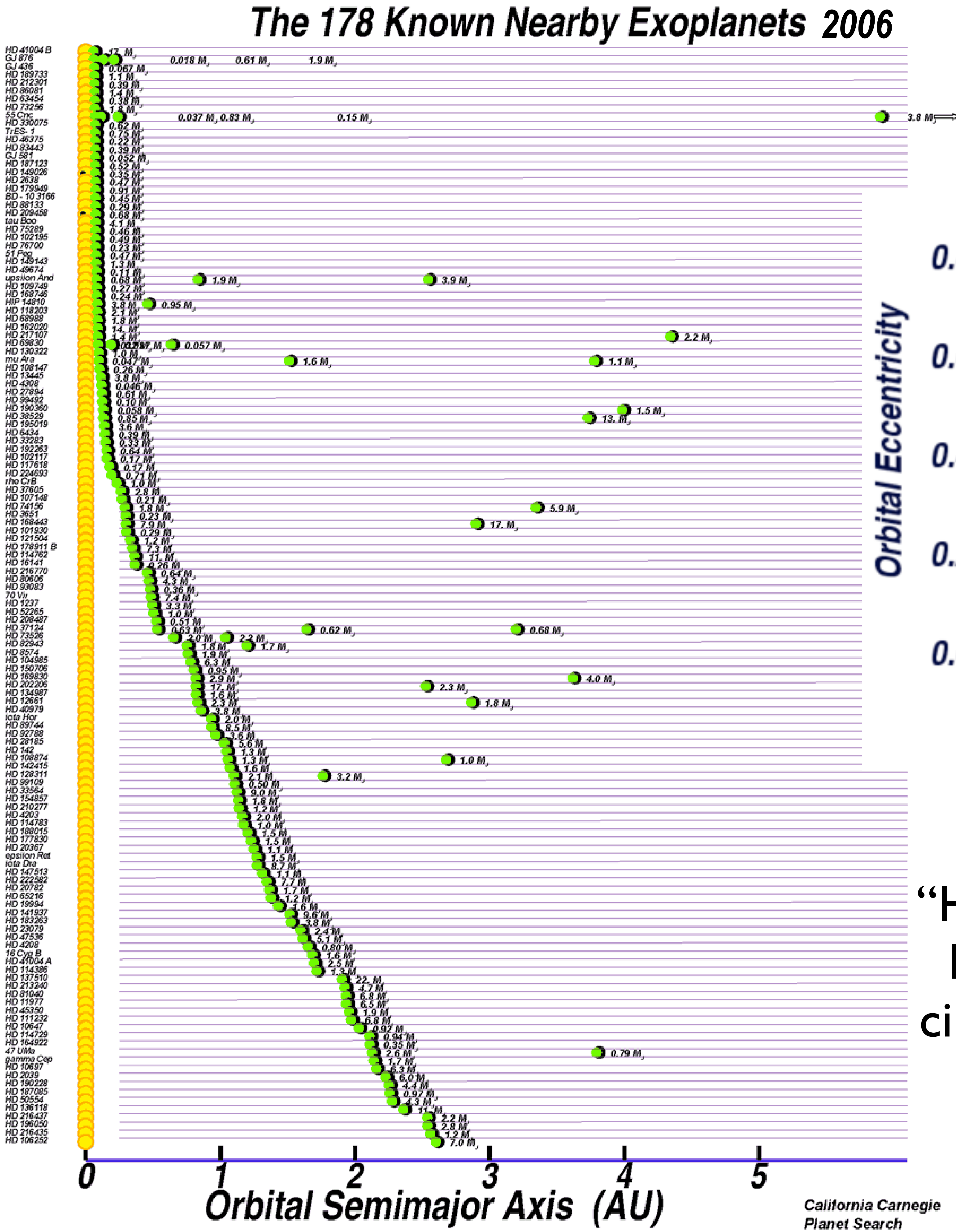
Early Planet Census from Radial Velocities (Marcy et al.)

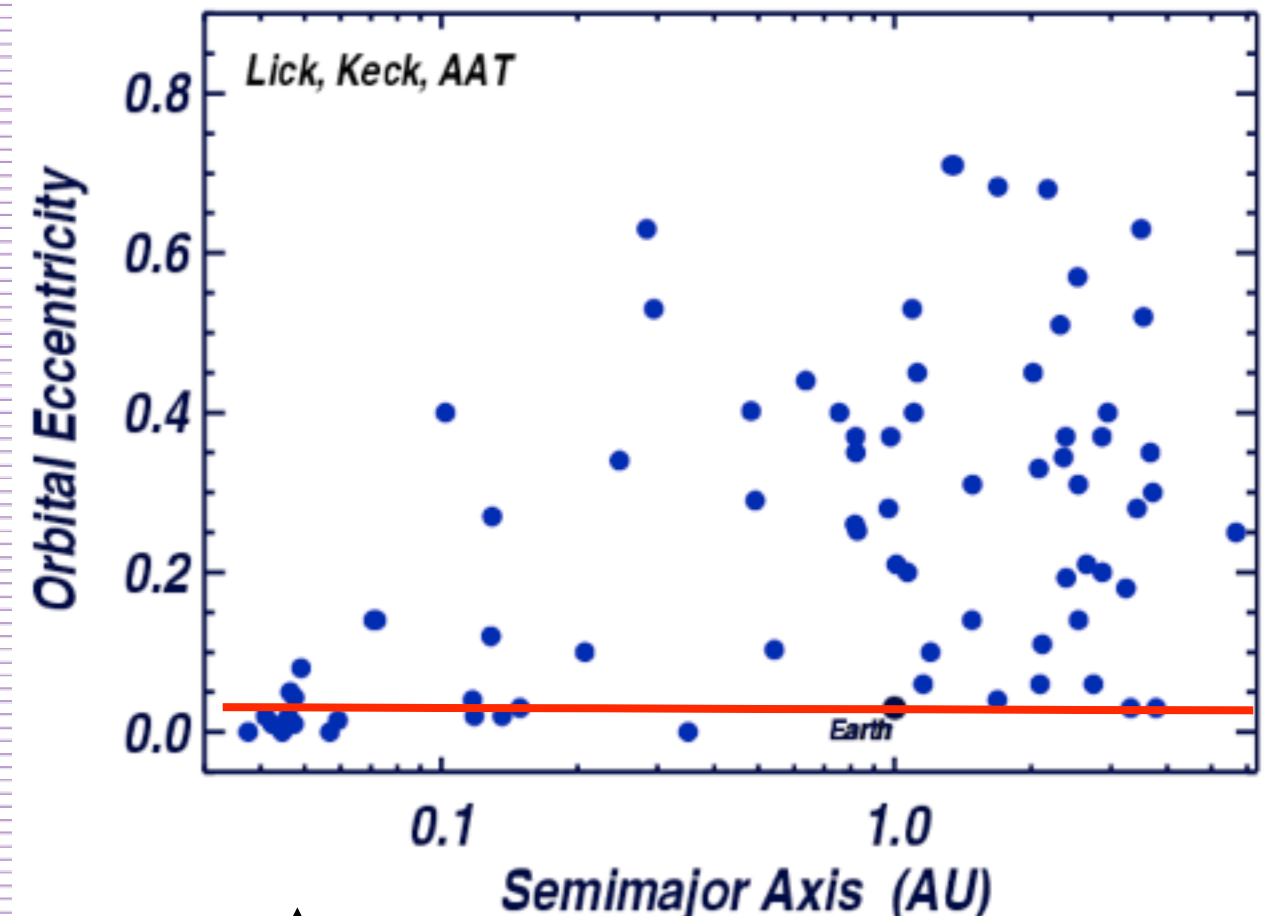




ESO News Flash April 21, 2009: Well-known exoplanet researcher Michel Mayor today announced the discovery of the lightest exoplanet found so far. The planet, "e", in the famous system Gliese 581, is only about twice the mass of our Earth. The team also refined the orbit of the planet Gliese 581 d, first discovered in 2007, placing it well within the habitable zone, where liquid water oceans could exist.

http://exoplanet.eu/pictures.html





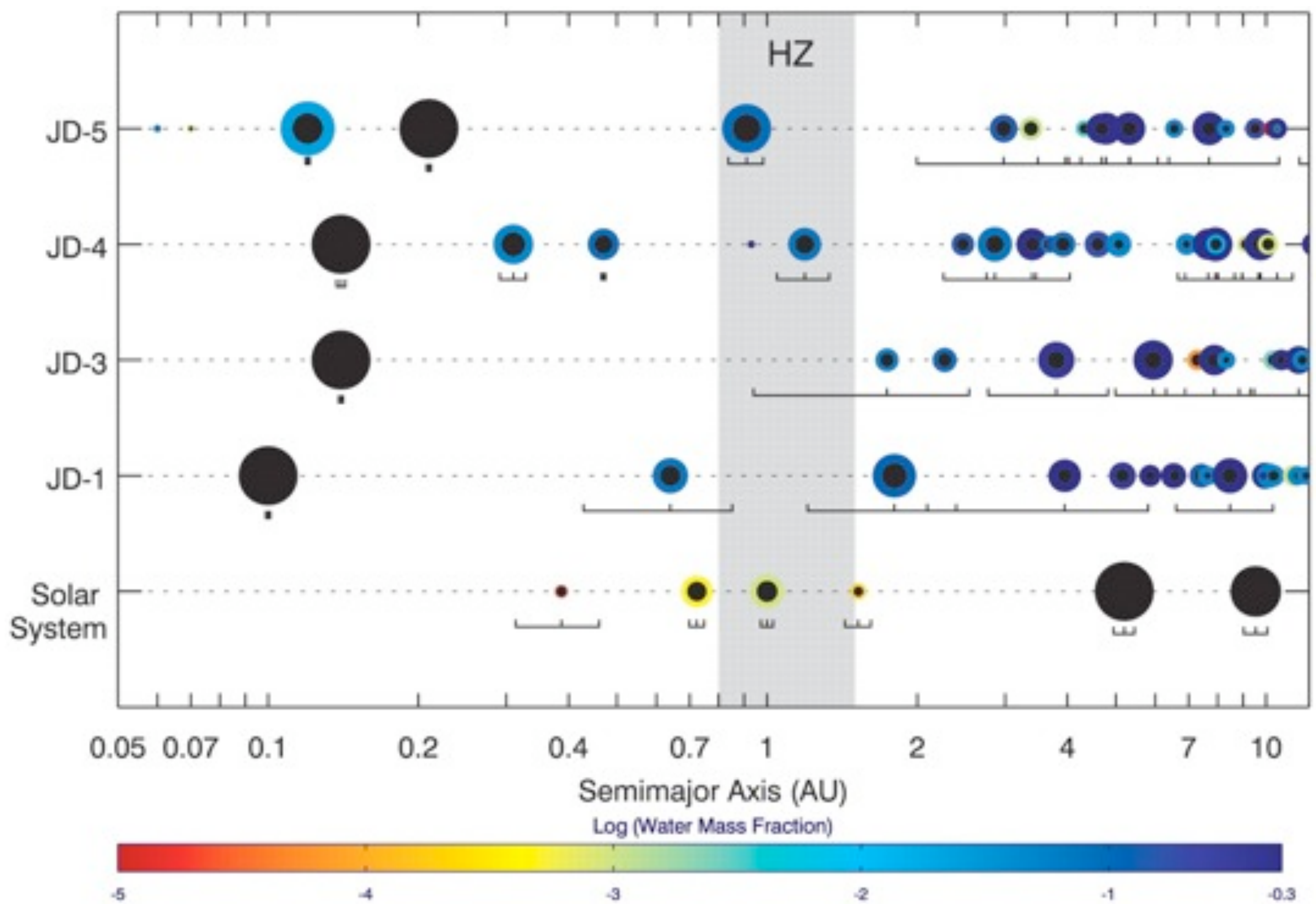
"Hot Jupiters" have nearly circular orbits

But more distant planets mostly have elliptical orbits

http://exoplanet.eu/pictures.html

Exotic Earths

NASA ASTROBIOLOGY INSTITUTE

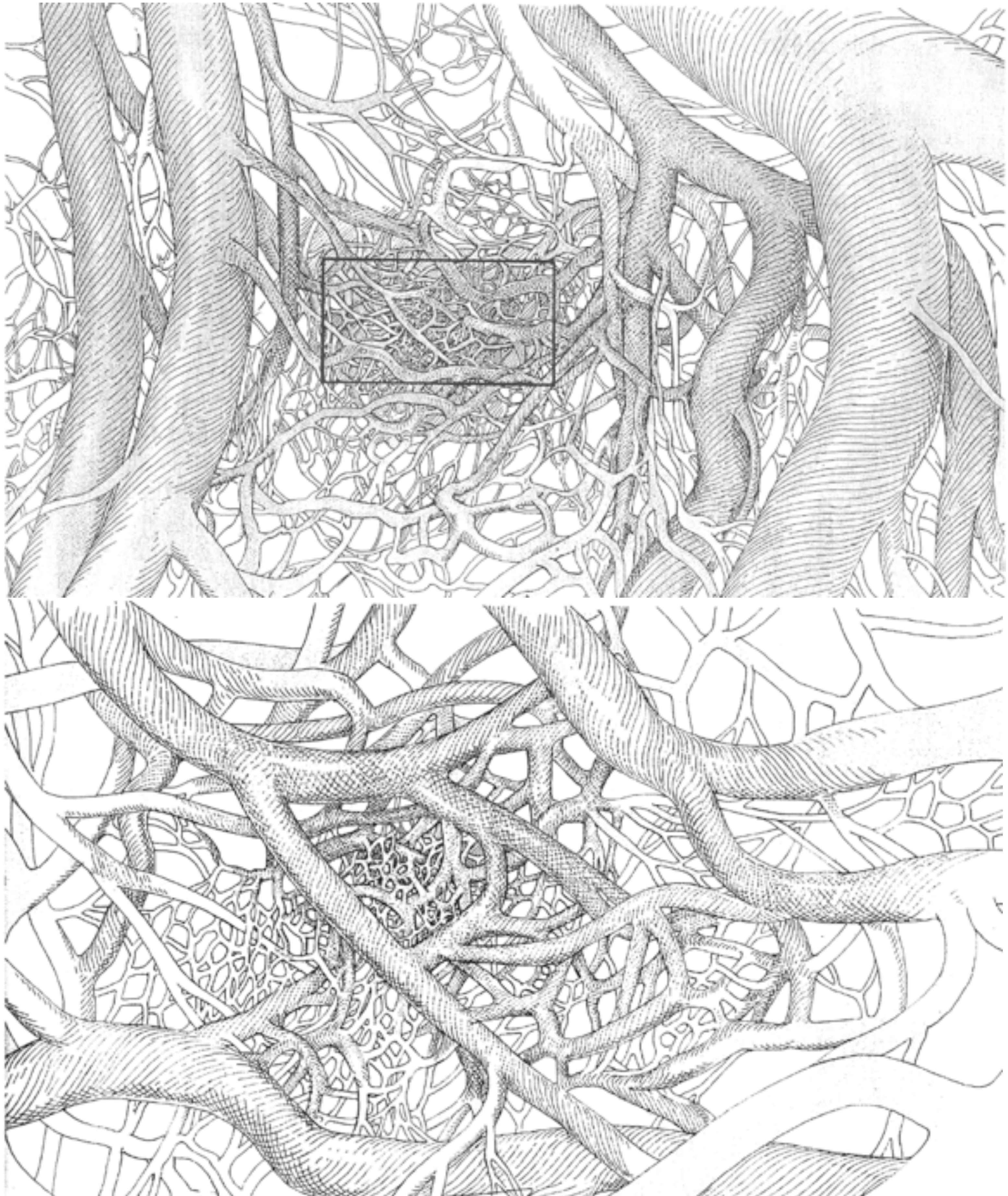


- Hot Jupiters push and pull proto-planetary disk material during their journeys, flinging rocky debris outward where it is likely to coalesce into Earth-like planets
- At the same time, turbulent forces from the dense surrounding gas slow down the orbits of small, icy bodies in the outer reaches of the disk, causing them to spiral inward and deliver water to the fledgling planets

These new results may allow planet hunters to determine "rough limits" indicating where to search for habitable planets in known systems of giant planets

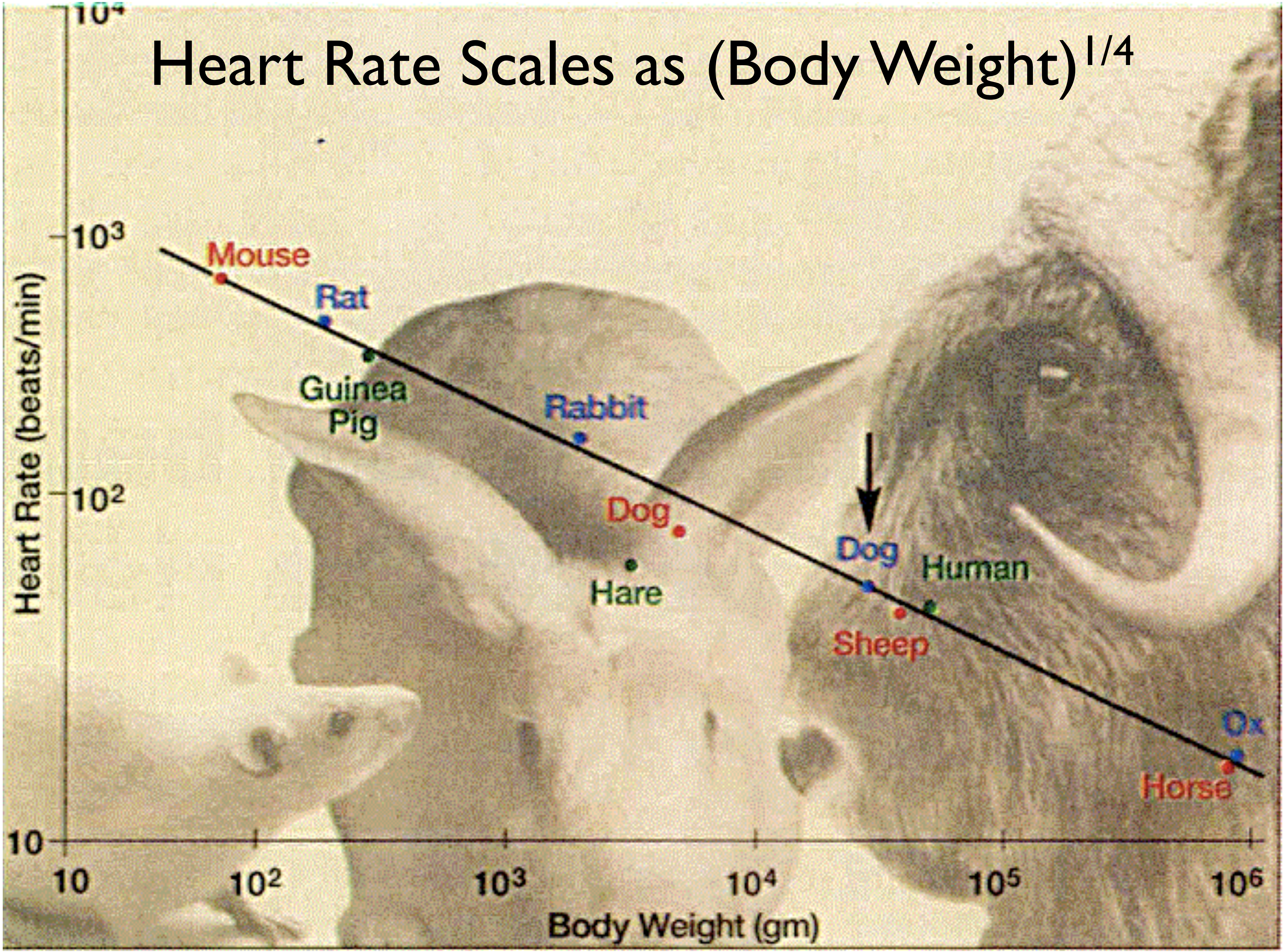
Even though we don't yet know whether there are other living creatures in the universe, we nevertheless know some things about whatever ones do exist -- because they follow the same laws of physics that apply throughout the universe.

A successful recent example of physics explaining basic facts about living creatures on earth is the explanation of the biological scaling laws based on the fractal nature of the circulatory system.



The fractal nature of the blood vessels of the human heart.
The blowup of the central part of the top image looks like the full image

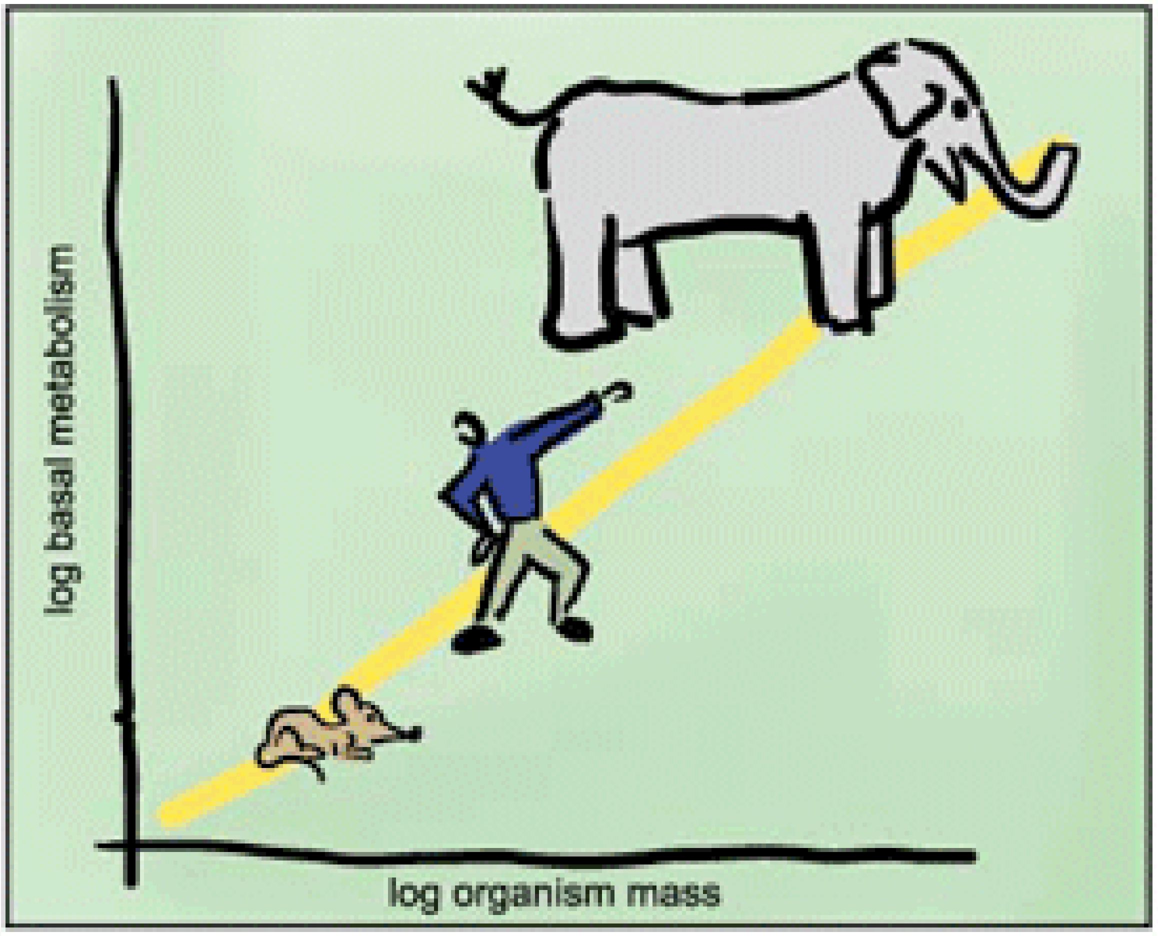
Heart Rate Scales as (Body Weight)$^{1/4}$



Geoffrey West

Scaling Laws in Biology

All living things share a power law relationship between their mass and their basal metabolic rate



Life is the most complex system in the universe. It's extraordinarily diverse and stretches over very large scales from microscopic to the blue whale. It covers 27 orders of magnitude and if we include the biosphere, it's 40 orders of magnitude. But some characteristics of life are extremely simple.

A fundamental, shared phenomenon is the metabolic rate—how we stay alive. When you plot the basal metabolic rate (watts) vs. mass of the organism on a log log plot, simplicity emerges. There's a simple straight line indicating a power law meaning that the relationship between metabolic rate and mass is an exponent of ¾ (3 orders of metabolic magnitude over 4 orders of mass). Human metabolism is a little less than a light bulb, at 100 watts.

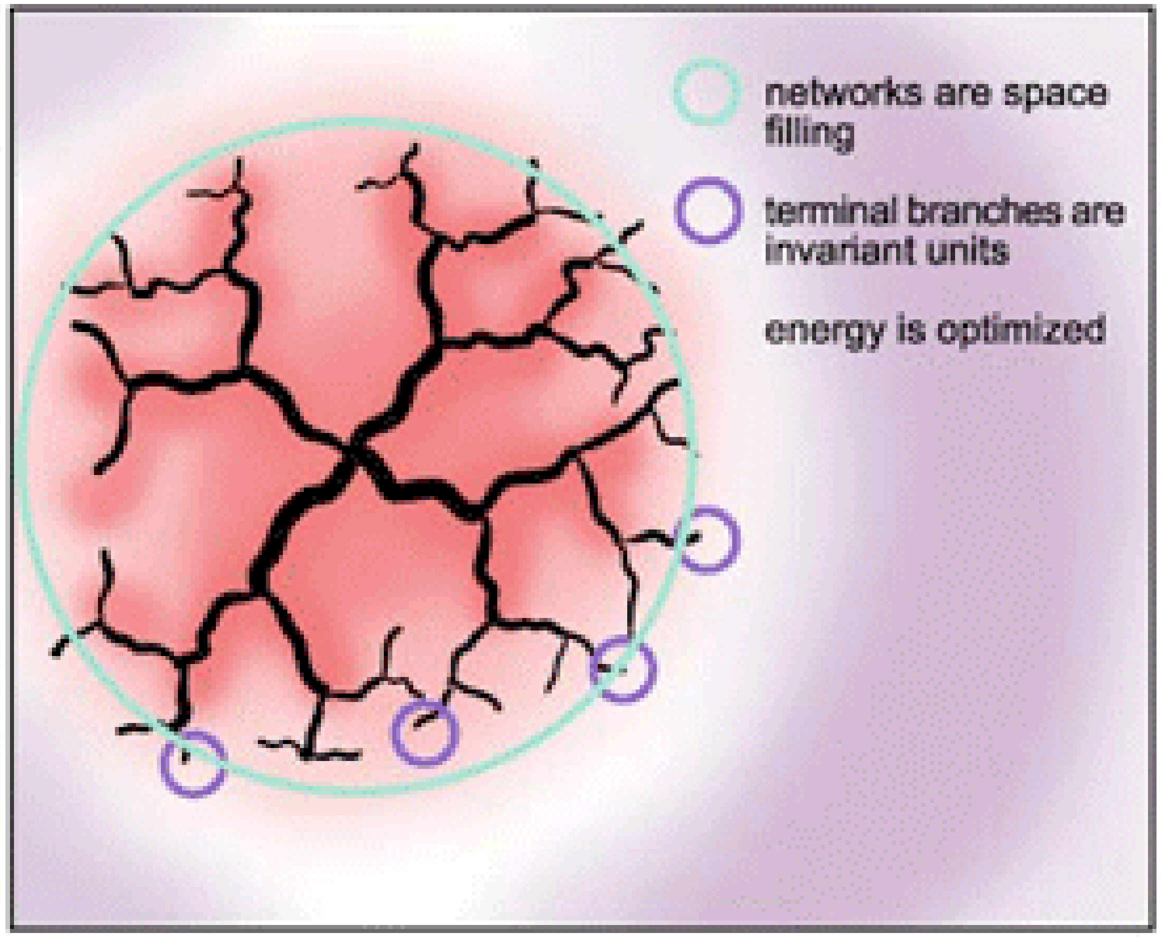
There is a sequence of these scaling laws. Unicellular, cold-blooded and warm-blooded organisms have the same scaling law and exponent of ¾. We extended unicells and then added mitochondrions and human cells. These all end up on the same line. Even enzymes end up on the same line.

If the metabolic rate scales as mass to the ¾, then power or energy required to support each unit mass decreases with size by a ¼ power exponent. Therefore there is an economy of size. Even though all mammals are made of the same stuff, the amount of energy needed to keep a gram of rat alive is significantly more than that required to keep a gram of elephant alive. Therefore, in this sense, getting bigger is better. Maybe, that's why companies merge.

Geoffrey West

Hierarchical Branching Network Systems

Evolution has created hierarchical branching networks to sustain, feed and inform the components of living systems



Organisms are made up of a huge number of individual components. How do you sustain, feed and inform those individuals in a roughly efficient and democratic way so they can perform their tasks? Evolution has created a bunch of hierarchical branching network systems. Almost all of a person's biology is nothing more than branching network systems. The skin is almost superficial because it only holds us together.

What are general properties of these networks? All of these derive from Darwinian natural selection—continuous change and feedback. First, they are space filling. Second, the terminal branches of the network are invariant units. These are the most important biological parts of the living system because they are the interface for exchange of matter and energy. For example, you can live in a tiny house or a large building, or a shack, but the electrical outlets and the water faucets are invariably the same size. The same is true for computers.

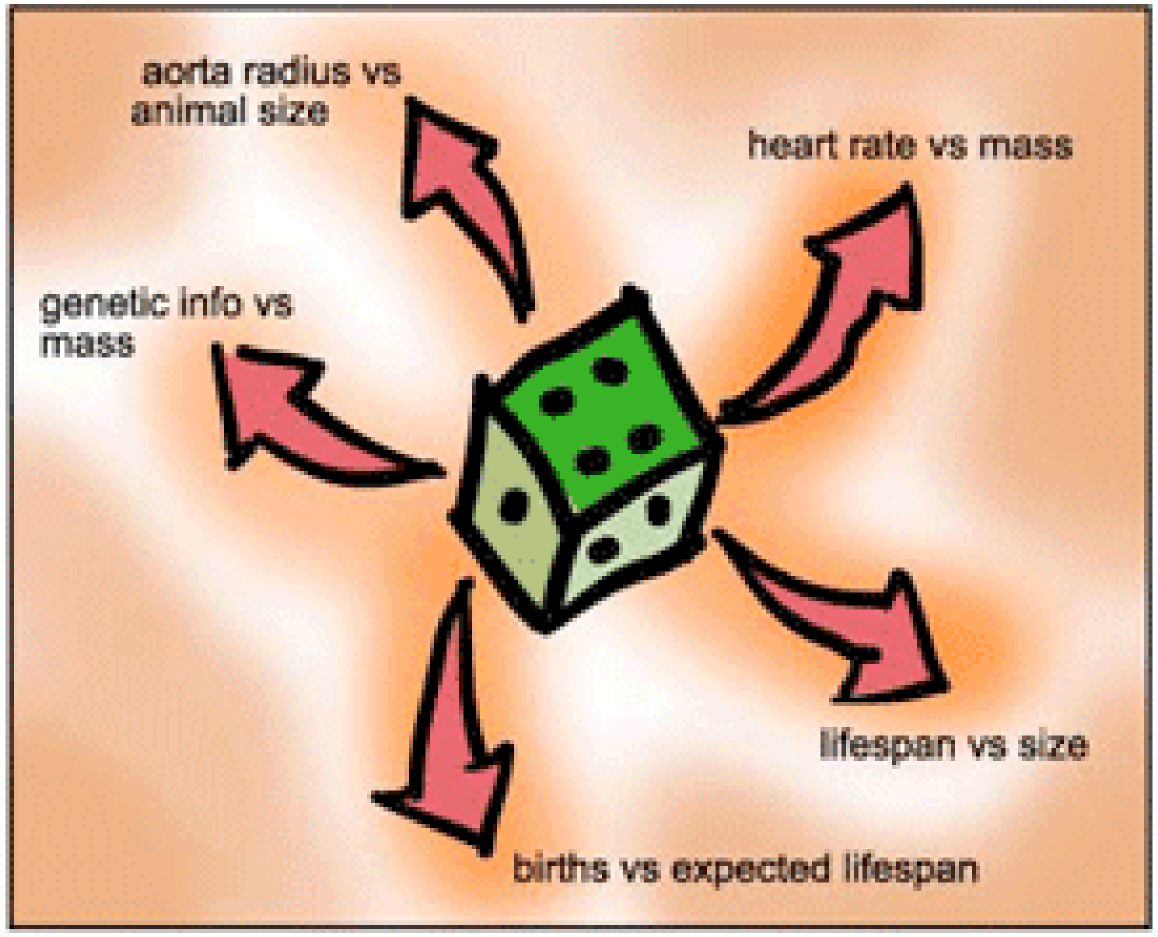
The third postulate: just as natural selection didn't reinvent the fundamental units, the continuous feedback leads to a certain optimization which minimizes the energy needed to sustain the organism.

Examples are the circulatory system, the structure of the brain, the structure of mitochondrial pathways inside cells over time, freeways in LA, and so on. Whether this can be ported to organizations or not is not known, but is at least extremely suggestive.

Geoffrey West

Four is the Magic Number of the Universe

The number 4 occurs in all power law relationships in all types of phenomenon of living systems



The radius of the aorta plotted vs. size for mammals is a slope of 3/8. If you squared the radius, you'd get an exponent of ¾. Heart rate decreases as mass to the ¼. Lifespan varies with size as mass to the ¼. There is a lot of spread in the data, but the best fit is 0.235. Therefore, there's an invariant in the system—the total number of heart beats in a lifespan. Namely, 1.5 billion. This number is a crucial number of biology. If we understood the origins of this number, we'd understand something fundamental about life. There's nothing fundamental about heart beats. What is fundamental is what goes on in the molecules in the respiratory process producing your energy. The number of turnovers of that reaction rate is invariant.

One other invariant is birth rate. Births per expected lifespan is roughly a constant for different organisms. This is also true for humans taken separately as a species. Number of children varies inversely with average lifespan.

If you assume an engine lasts 100k miles, it has about the same number of turnovers or cycles as a human being. No particular meaning, but it's amusing to know.

The genetic information (length of DNA) also varies as mass to the ¼.

There are many, many scaling power laws that cover the whole scale from sub-cellular to ecosystems.

http://www.in-cites.com/scientists/BrianEnquist.html

The basis of the scaling work is an ongoing collaboration with Geoffrey West at Los Alamos National Labs and the Santa Fe Institute and James H. Brown at the University of New Mexico. Recently, several others have joined the extended network of scaling enthusiasts (see below).

"The work hypothesizes that many scaling phenomena in biology...are the result of the processes that control the scaling of cellular metabolism."

Why do you think your work is highly cited?

In many ways that is a good question. I was surprised that the work has attracted so many citations in the last few years. The number of citations is likely due to several items:

First, the scaling work touches on many fundamental issues of biology, ranging from cellular physiology to organismal anatomy and physiology to evolutionary biology and population and community ecology all the way to large-scale variation in the flux of matter and energy through ecosystems and the biosphere. In short, the work has implications for fundamental issues in evolution, biodiversity science, and large-scale ecology in general. Thus, many of the citations are from vastly differing fields (including the fields of biomedical science, physics, ecology, genetics, population biology, global change biology, and even geosciences).

Second, another important aspect of the work is that it is inherently capable of making quantitative predictions. After the important findings from the understanding of non-linear dynamics, chaos and complex systems ecology in particular seemed to be heading down the path that concludes that "prediction is difficult if not impossible." The scaling work emphasizes law-like behavior in biology. It shows that it is possible to make quantitative predictions for numerous aspects in biology. In doing so, the work offers the intriguing hypothesis that many aspects of biology are mechanistically related by first principles. Naturally, this is an intriguing proposition. SO perhaps it is not surprising that many papers citing our work claim to test the assumptions and or predictions of the model.

In at least six ways, Earth is an unusually suitable planet for life.

First of all, about a quarter of the extra-solar planets astronomers have found so far are "hot Jupiters," massive gasball planets like Jupiter, zipping fast in tight circular orbits around their star – closer in than little Mercury is to our sun. These hot Jupiters probably formed far away and then spiraled in closer to their star in a process that would most likely have destroyed any small earth-like planets.

Second, not only has massive Jupiter not destroyed Earth by moving inward; both Jupiter's and Earth's nearly circular orbits have been favorable for the evolution of life on Earth. Ever since the end of the bombardment era in the solar system, Jupiter's gravity has helped protect Earth from being hit by comets.

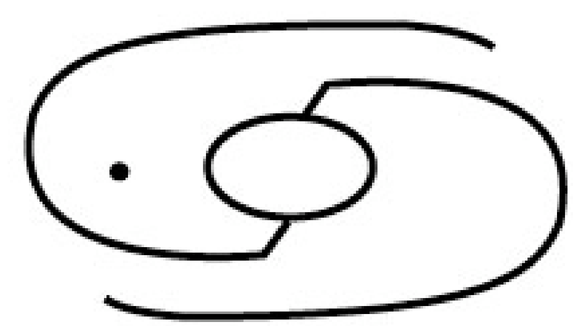
Third, Earth's distance from the sun is in what's called the "habitable zone" of the solar system – far enough from the sun for water to be liquid and not evaporate and ultimately be lost, but not so far that water would be permanently frozen. Earth is the only object in our solar system that now has liquid water on its surface. What's more, the orbit of the earth has been in the habitable zone for Earth's entire lifetime. In the early solar system, when (according to the standard theory of how stars evolve) the sun was emitting about 30% less heat than it does now, the earth was at the outside edge of the habitable zone. As the aging sun grows hotter, the habitable zone is slowly moving outward and Earth is now nearer to the inside edge. Since evolution of intelligent life here required the entire 4.5 billion year history of the earth, a planet that was not so fortunately located with such long periods of climatic stability might not have had time.

Fourth, Earth's relatively thin crust and abundant surface water allow continued geological activity – especially plate tectonics moving the continents, forming new mountain ranges and other features, and continually recycling carbon and other elements essential for life.

Fifth, the Moon, created by that chance impact, stabilizes Earth's rotation and climate.

Sixth, our solar system lies in the "galactic habitable zone." Our Milky Way galaxy, like other galaxies, has a lot of stars near its center, but the stars become more spread out the farther they are from the center. Our sun orbits in the disk of the Milky Way Galaxy about halfway out from the center. Dangerous radiation is likely to have destroyed or prevented life on planets around stars that happened to lie closer to the center. Such radiation comes occasionally both from the giant black hole at the center of the Galaxy, and also from the nearby supernovas that are plentiful because of the greater density of stars closer to the galactic center. Out in the galactic suburbs where we live, the nearest supernovas were far enough away from our solar system that their radiation was weak enough for the earth's atmosphere to provide adequate protection. But if the sun had formed much farther from the center of the Milky Way where stars are even less abundant than they are nearby, there would have been too few supernovas over the history of our Galaxy to make enough stardust (heavy elements) to form rocky planets like the earth. There may be a "ring of life" encircling the galactic center at about our distance.

In all these respects, Earth has been a fortunate planet for life.



Is Intelligent Life on Earth a Fluke?

One way biologists have dealt with this possibility is to ask themselves whether, if evolution on Earth were starting all over again at the Cambrian explosion, would anything like humans ever evolve again? They are adamantly divided into two camps on this question.

The first camp argues that it's impossible. The evolutionary biologist Stephen J. Gould argued that the diversity of life was greatest at the time of the Cambrian explosion, when many body types were tried out but only a few became the basis for subsequent evolution. He said, "Replay the tape a million times from a Burgess beginning, and I doubt that anything like *Homo sapiens* would ever evolve again." Many biologists agree with Gould. According to Loren Eisley, "Every creature alive is the product of a unique history. The statistical probability of its precise duplication on another planet is so small as to be meaningless….[N]owhere in all space or on a thousand worlds will there be men to share our loneliness." Ernst Mayr agrees. He says, "We must conclude that if high intelligence had as high a fitness value as eyes or bioluminescence, it would have emerged in numerous lineages of the animal kingdom. Actually, it happened only in a single one of the millions of lineages, the hominid line."

Is Intelligent Life on Earth a Fluke?

But the other camp argues that it's inevitable: intelligence would evolve again. Simon Conway Morris argues that creatures would have evolved with the original distinguishing characteristics of *humans* – not only intelligence but manual dexterity and tool-making. He gives several examples of convergent evolution to show that these basic "human" characteristics actually have already evolved independently in other animals, although not all in one. The octopus has the ability to learn and remember, as well as independently evolved camera-like eyes. Birds, toothed whales (including dolphins, which until 1.5 million years ago had the biggest brains for their body size on the planet), and primates that have larger brains show more innovative behaviors. In the case of the elephants, whales, dolphins, and higher primates, their dynamic social organizations – involving networks of as many as a hundred individuals in the case of dolphins – were at least partly the cause of the evolution of their excellent memories and high intelligence. It may be that the role of chance, which the Impossible camp believes determines which characteristics evolve, may only determine when and where, but not whether, good survival characteristics such as intelligence and tool use will evolve. Conway Morris concludes, "Rerun the tape of life as often as you like, and the end result will be much the same."

Impossible or Inevitable? We can't say yet whether human-type intelligence would evolve all over again on Earth, but a closely related question may have an answer. Once early hominids appeared, their brains – and correspondingly their intelligence – increased astonishingly rapidly in size and ability during the last two million years. This was practically overnight by Earth's standards. Why did it happen so fast? Darwin proposed the first plausible explanation for this, and it may help us see a new angle on the alien intelligence question. Darwin explained not the total evolution of intelligence but this last enormous spurt as being a result of what he called "sexual selection."   The idea is that the human mind is like the peacock's tail: it evolved because it was selected in mating. In other words, humans are *attracted* to intelligence when choosing mates. Contemporary evolutionary biologist Richard Dawkins agrees that sexual selection may very well explain human braininess, as well as bipedalism and hairless skin. Maybe aliens need to think intelligence is sexy, too, in order to have it.

Non-technical problems of space travel

Who should go? Who might interact best with aliens? Scientists? Artists? Adventurers? Children?

Assuming that, like scientists, they come from different cultures on Earth, by what code should they live and collaborate? How should they resolve disputes?

What should be their highest value? Their shared purpose?

Volatility plus unpredictability are certainly essential to humans and probably to the passion and creativity necessary to sustain the continued development of any intelligence. How can such beings work together over extremely long time periods?

Perhaps with a shared commitment to harmony with the real universe?

IF AN ALIEN LANDED IN FRONT OF YOU AND SAID, "TAKE ME TO YOUR LEADER," WHO WOULD YOU TAKE THEM TO????

The question “are we alone?” is almost always asked as if it were about the existence of aliens, but it’s really a question about ourselves. Are you alone when you’re near an insect? Most people would say yes. How about a dolphin? Fewer people say yes. What characteristics does an alien lifeform need to have before we humans will agree that by knowing it exists, we are not alone?   What qualities, what compassion, what emotional potential, what ability of self-reflectiveness must they have? Any? Would we still be alone if on some alien world we discovered machines that had been created and left running by a now extinct race, but the machines were still operating and renewing themselves and superb in all kinds of artificial intelligence – would that do? This is not just science fiction speculation, and here’s why. *Whatever it is* that we require in an alien race before we’d be willing to say that the existence of such aliens has dissolved our cosmic aloneness – *that* is the essence of humanity. That is what it is in ourselves we most identify with, and value.

The qualities that we would require of such aliens are what a long-lived civilization on Earth should aim to cultivate in ourselves.

Dealing wisely with aliens or simply contacting them may be a distant goal, but understanding what it would mean can have an immediate and powerful effect. It makes clear what truly matters today: to *be* the kind of human beings we aspire to be in the long run, and to adopt this perspective *now.* The best way to get through the short run is to focus on the long run.