NASA Ames Research Center

Astronomy 106: the cosmic origins of life

We can see the building blocks of life, and potential habitats for both simple and intelligent life, in outer space.

- What does this tell us about our own origins and fate?
- What does it tell us about the diversity of life forms in the Universe?
- What can we learn about our chances to contact other civilizations?

Answers and more, this semester.

Our primary goals in teaching Astronomy 106

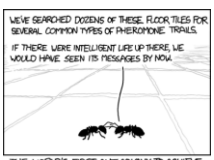
- to **demystify** the genesis of the components and habitats of life in the Universe, and the degree to which civilizations like ours are common (or rare) in the Universe;
- to show you how scientific theories are conceived and advanced in general.

In doing so we aim primarily at **non-science majors**

APOD

Take-Aways from AST 106

- you will understand and retain enough of the current understanding of cosmic and terrestrial evolution, to be able to offer correct explanations to your friends and family
- you will retain a permanent, basic understanding of how science works



THE WORLD'S FIRST ANT COLONY TO ACHIEVE SENTIENCE CALLS OFF THE SEARCH FOR US.

XKCD
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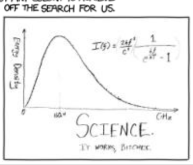
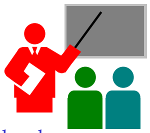
Bottom



Human and printed features of Astronomy 106

People:
- **Laura Arnold**, instructor
- **You**, student



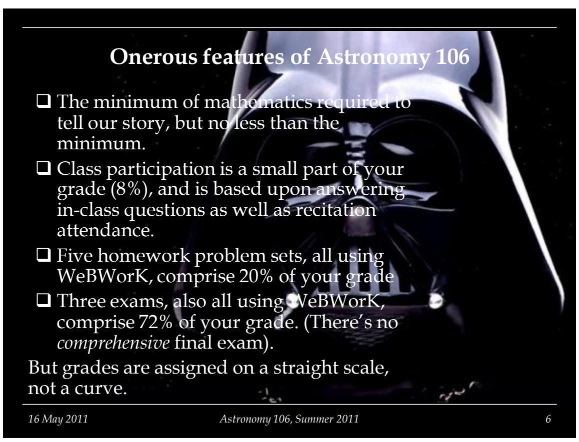
Textbooks (one required, one recommended and supplementary):
- Neal Evans, *Extraterrestrial life*, fifth edition (2002).
- Mike Seeds and Dana Backman, *Foundations of astronomy*, eleventh edition (2008). Also used in AST 102, 104, and 105.

Both on one hour reserve in the POA library

Electronic features of Astronomy 106

- **Computer-projected lectures**, for greater ease in presentation of diagrams, astronomical images and computer simulations, and for on-line accessibility on our…
- **Web site**, including all lecture presentations, schedule, practice exams, much more.
  - **Primary reference for course.**
- **Personal response system (PRS)**, for in-lecture problem-solving. (**Required**; available at the UR Bookstore.)

- **WeBWorK** , a computer-assisted personalized homework and exam generator.



Onerous features of Astronomy 106

- The minimum of mathematics required to tell our story, but no less than the minimum.
- Class participation is a small part of your grade (8%), and is based upon answering in-class questions as well as recitation attendance.
- Five homework problem sets, all using WeBWorK, comprise 20% of your grade
- Three exams, also all using WeBWorK, comprise 72% of your grade. (There's no *comprehensive* final exam).

But grades are assigned on a straight scale, not a curve.

Class Expectations

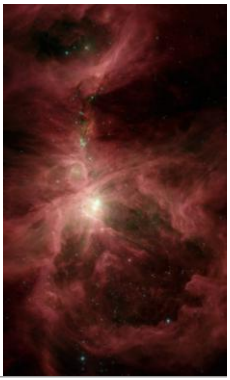
Mine
• Attend class
• Be respectful
• Tell me if you think I'm speaking a foreign language

Yours
(for me and your peers)

Mid-Lecture Break

This will be a regular feature of Astronomy 106 lectures.

If you have yours already, please **turn on** your PRS clicker, wait for it to find the course **AST106-01**, and then press the green-arrow Enter key (⮌)to join the class PRS session.



Spitzer Space Telescope infrared false-color image of the Orion Nebula, the nearest region of massive star formation. (Tom Megeath, U. Toledo.)

Test PRS question

In which city would you rather live?

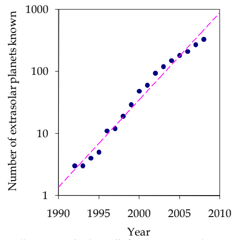
A. Boston B. Chicago C. New York
D. San Francisco E. Washington

Today in Astronomy 106: the frontiers of the search for life and our origins

Now is a great time to study the origins of life, due to a flood of new facts from two sources:

- ❑ The discovery of liquid-water oceans on moons of Jupiter and Saturn, that apparently have been there for billions of years.
- ❑ The discovery of an increasing number and diversity of planets outside the Solar system.

We will discuss both of these fields in detail this semester. But first, the punch lines.



"Moore's law" for extrasolar planets: the number doubles every 26 months (dashed curve).

Life on Europa and Enceladus?

When Jupiter and Saturn were formed, their moons were probably formed from the leftovers, and probably in orbits smaller than they have now, rotating rapidly.

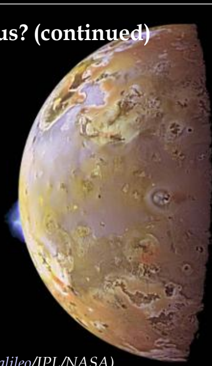
- ❑ The giant planets' tidal forces "quickly" caused the moons to rotate more slowly, and to drift to larger orbits.

Life on Europa and Enceladus? (continued)

- ❑ As the moons drifted outwards, their own gravity also began to have an influence, and some of them captured each other in special **resonant orbits:**
  - …meaning that pairs of moons have orbital periods that are **exact** integer multiples of each other.
  - For example, Jupiter's moons Io, Europa and Ganymede. Their periods are in the ratio 1:2:4.
  - This means, for example, that Io and Europa reach their closest separation always at the **same point in their orbits,** every two Io orbits and one Europa orbit.
  - Thus, though they pull each other rather gently, they do so "in sync," like pushing someone on a swing.

Life on Europa and Enceladus? (continued)

- The orbits of these moons are slightly non-circular in shape…
- …so the tidal force from Jupiter's gravity changes through the orbit
- …yielding a never ending cycle of stretching and relaxing.
- This tidal heating on Io is most severe. In fact, Io is the most volcanic object in the Solar system.

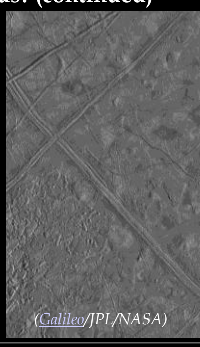


(*Galileo*/JPL/NASA)

16 May 2011 Astronomy 106, Summer 2011 13

Life on Europa and Enceladus? (continued)

- Next on the tidal heating scale is the icy moon Europa, for which tidal heating is enough to keep the interior warm, though not molten.
- Sure enough, Europa's surface looks like Arctic pack ice, → very few craters.
- The *Voyager* team gave described the surface as palimpsest.
- Europa distorts Jupiter's magnetic field as liquid salty water would.



(*Galileo*/JPL/NASA)

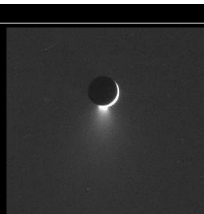
16 May 2011 Astronomy 106, Summer 2011 14

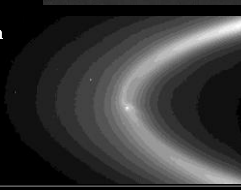
Life on Europa and Enceladus? (continued)

In 2005, the first visits by the *Cassini* probe to Saturn's icy moon Enceladus revealed a pack-ice-looking surface, and vigorous geysers of liquid water.

It's been erupting long enough to have made one of Saturn's rings.

- Billions of years of Arctic-ocean conditions: could life have developed on Europa and Enceladus?





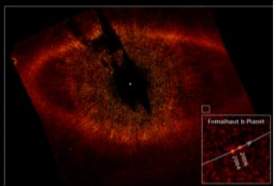
(*Cassini*/JPL/NASA)

16 May 2011 Astronomy 106, Summer 2011 15

Habitable planets outside the solar system?

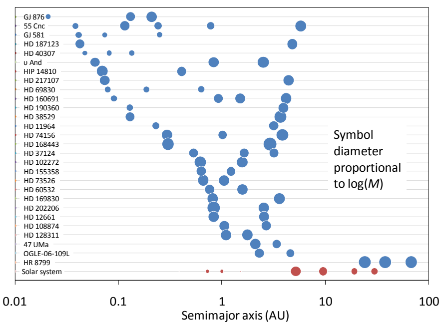
As of today, 548 planets that have been detected in orbit around stars besides our Sun. See the census, updated in real time, at exoplanet.eu.

- Nomenclature: these objects are called extrasolar planets, or **exoplanets**.
- These 548 planets are hosted by 458 stars: there are 56 multiple-planet systems, of which the star Kepler-11 is the current planet record-holder, with six planets.



Disk and planet around the nearby star Fomalhaut (Paul Kalas, UC Berkeley/ STScI/ NASA).

Some prominent, multiple exoplanetary systems



Habitable planets outside the solar system? (continued)

As we will discuss later this semester, planets are found more easily the more massive they are, and the closer their orbits are to their host stars.

- Thus the first exoplanets found were both massive and close, a thitherto-unexpected class of planets we now call **hot Jupiters**. By the same token,
- …we are only recently getting to know "real Jupiters:" giant planets (hundreds of times as massive as Earth) in systems arranged more like our Solar system, and
- …we have just reached the verge of discovering Earth-size exoplanets in the **habitable zones** around their host stars.

Habitable planets outside the solar system? (continued)

A couple of examples of how close we are to finding Earth equivalents elsewhere in the Universe:

The first that **might** be habitable: GJ 581 c and d (2007).

- Masses: 5.0 and 7.7 times the mass of the Earth ($M_\oplus$), respectively. **Estimated** surface gravity 1.7-1.9 Earth *g*s.
- Temperatures, if rapidly rotating and no greenhouse effect: 310 K (98 F) and -106 K (-158 F).
  - Unfortunately, both planets are likely *not* to be rapidly rotating, as Earth is: instead, they're likely to be rotating once per orbit, like the Moon is.
  - So GJ 581c probably has permanently hot and cold sides and is not habitable by thirsty life forms.

Habitable planets outside the solar system? (continued)

The first exoplanet to definitely have an Earth-like rocky composition: COROT Exo-7b (2009).

- Its mass and radius are modestly super-Earth-like:

$$M = 4.80 M_\oplus \quad , \quad R = 1.68 R_\oplus$$

- So its density (mass per unit volume) is similar to Earth's

$$\rho = 5.58 \text{ gm cm}^{-3} \quad \text{(COROT Exo-7b)}$$
$$= 5.50 \text{ gm cm}^{-3} \quad \text{(Earth)}$$

- Unfortunately it's very close to its host star, and hot enough to be molten: T = 1100 K .

Habitable planets outside the solar system? (continued)

The first "waterworld": GJ 1214b (2009).

- Again super-Earth-like mass and radius:

$$M = 5.70 M_\oplus \quad , \quad R = 2.70 R_\oplus$$

- But its density is not much more than that of liquid water, which has density 1 gm cm^{-3}:

$$\rho = 1.3 \text{ gm cm}^{-3} \quad \text{(GJ 1214b)}$$

  Maybe about ¼ rock, ¾ water?
- Again too hot to be habitable: T = 400 F. In fact the water couldn't be liquid on the surface

Habitable planets outside the solar system? (continued)

With the NASA *Kepler* mission, designed to find hundreds of Earthlike planets, we seem to be on the verge of characterizing the diversity of solar systems, and the frequency of occurrence of planets that are habitable by life-forms resembling us.

- As we will see, this mission constrains two terms in the **Drake equation**:
  - the **fraction of stars that host planets**, f_p, and
  - …the **number of habitable planets in each planetary system**, n_e .

16 May 2011 *Astronomy 106, Summer 2011* 22