Astro 2299

The Search for Life in the Universe

Instructors: Jim Cordes & Shami Chatterjee

http://www.astro.cornell.edu/academics/courses/astro2299/
The Search for Life in the Universe

What the course is about:
Nominally, where and when we may find life elsewhere

Three big words

• **Universe:**
  The big picture, fundamentals, profound basic facts

• **Life:**
  Finding bacteria vs. finding counterparts to us?

• **Search:**
  How will we find, detect, or infer life elsewhere?
  Space probes vs. remote sensing vs. abductions vs. ?
  When?
The Course

Originated by Frank Drake c. 1985 with influences by Carl Sagan

Hiatus when Drake → UC Santa Cruz

Reinitiated c. 1995

Texts:  
- *Planets and Life*  
- *Rare Earth*  
- *The Astrobiology Primer*

Course topics are rapidly changing so there will be additional reading from notes and articles from *Science, Nature, Scientific American,* …
ASTRONOMY 2299
Spring 2018

THE SEARCH FOR LIFE IN THE UNIVERSE
Instructors: James Cordes, Shami Chatterjee
http://www.astro.cornell.edu/academics/courses/astro2299/

Place and Time: 105 Space Sciences Building TTR 11:40-12:55 pm

Texts: Planets and Life W. Sullivan & J. Baross
Rare Earth P. Ward & D. Brownlee
The Astrobiology Primer v2.0 link Domagal-Goldman, Wright et al.

Additional Reading: A2299 Articles, as assigned

Style: Lectures will parallel the reading but will not cover it item by item.
We assume you have read the material before each class. The class is meant to be a two-way dialog as much as possible

Requirements: Attending lectures is mandatory.
Class participation = 15%
Short papers & assignments = 20% total
Mid-term Exam = 15%
Term Paper (or Oral Presentation/Debate + short paper) = 20%
Final Exam = 30%

Office Hours: Jim Cordes (jmc33@cornell.edu), SSB 520
Shami Chatterjee (shami@astro.cornell.edu), SSB 524
Aims of the course

Understand, discuss, speculate about:

• The nature of the observable universe
• Terrestrial life in the context of modern astrophysics
• Prospects for life existing elsewhere
• Exploration and remote sensing (solar system, cosmos)
• The future of terrestrial life (esp. *H. Sapiens*)
• Methods and status of science
Main Topics
1 to 2 weeks each

• Origins of Everything:
  *The Universe, the first elements, galaxies, and the Cosmic Web.*
• Stars, elements, and stellar graveyards.
• Formation of planetary systems:
  *Our solar system, structure, planets, and debris.*
• Life on Earth:
  *Requirements, timelines, hazards, extinctions.*
• Life in the solar system:
  *Exploration of the usual suspects (What are they?)*
• Exoplanets and the number of Earths in the Galaxy.
• Remote sensing of exoplanet atmospheres and the Galaxy:
  *Biomarkers and technomarkers.*
• Future prospects for terrestrial life: whither Homo Sapiens?
Enduring Quests
Daring Visions
NASA Astrophysics in the Next Three Decades
# LECTURES

Reading: SB = Sullivan & Baross, WB = Ward & Brownlee; additional articles specified in class
AP = Astrobiology Primer

<table>
<thead>
<tr>
<th>DATE</th>
<th>TOPIC</th>
<th>WHO</th>
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<tbody>
<tr>
<td>Jan 25</td>
<td>Intro/organization</td>
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<td>AP1, SB2, WB1</td>
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<td>Jan 30</td>
<td>Origins of Everything:</td>
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<td>Feb 01</td>
<td>The Universe, 1st elements, Cosmic Web, galaxies</td>
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<td>Notes</td>
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<td>Feb 08</td>
<td>Stars, Elements, and Stellar Graveyards</td>
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<td>Feb 13</td>
<td>Formation of Planetary Systems</td>
<td>SB3</td>
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<td>Feb 15</td>
<td>Break 17-20 Feb</td>
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<td>Feb 22</td>
<td>Solar system structure, planets, and debris</td>
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<td>AP2-AP5</td>
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<td>Feb 27</td>
<td>Life on Earth</td>
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<td>SB4-SB16</td>
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<td>Mar 01</td>
<td>Requirements, habitable zones, timelines, hazards and extinctions</td>
<td>JMC</td>
<td>WB2-WB13</td>
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<td>Mar 08</td>
<td>Life on Earth, continued</td>
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<td>Mar 13</td>
<td>Life on Earth, continued</td>
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<td>Mar 15</td>
<td>Life in the solar system</td>
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<td>Mar 20</td>
<td>Exploration of the usual suspects: Mars, Titan, Europa</td>
<td>SB 18-SB20</td>
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<td>Mar 22</td>
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<td>Apr 01</td>
<td>Mars, Titan, Europa</td>
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<td>Apr 12</td>
<td>Exoplanets and the number of Earths in the Galaxy</td>
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<td>Apr 19</td>
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<td>Apr 24</td>
<td>Remote sensing of exoplanetary atmospheres</td>
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<td>AP7-AP8</td>
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<td>Apr 26</td>
<td>and the Galaxy (and beyond):</td>
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<td>SB22-SB27</td>
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<td>May 01</td>
<td>Biomarkers and technomarkers</td>
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<td>May 03</td>
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<td>May 08</td>
<td>Wrap up and student talks</td>
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<td>Final Exam (TBD; will be at College-designated date/time)</td>
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COURSE WORK

MIDTERM & FINAL:

The MIDTERM is on **March 15**. It will cover all material in class and in the readings and will consist of a mixture of short questions and longer essays/calculations.

The FINAL will be during the scheduled exam period for this course time. It will cover all material of the entire semester, including lectures, readings, debates and student presentations. It will be somewhat overweighted toward the second half of the semester. The format will be the same as the midterm, but it will be longer.

In addition to short assignments, you are to complete ONE of the following for the course:

1. **TERM PAPER:**

   **When:** Due the last day of class, **8 May**

   **Format:** A ~10-page paper (double-spaced, 1-inch margins, 10pt to 12pt font, with abstract and bibliography) that goes into detail on a major topic of relevance to the course. Your topic needs to be pre-approved by talking to the instructor and submitting an abstract of your paper by the day of the midterm (**15 March**).

2. **DEBATE:**

   **When:** In the last few weeks of the semester. Time will permit only a few debates so it is first come, first served.

   **Format:** One person on each side of the debate and one person as moderator/summarizer. Ten minutes each plus questions by the whole class. In addition, each person is to submit a 5-page paper that expresses their position in the debate. **The paper is due on the last day of class, 8 May.**

   If you want to do a debate, organize a team and submit a team abstract to the instructor by **15 March.** In the case of overbooking, we will choose debate proposals that best fit the goals of the course.

   All in the class are expected to participate in the debates through questions and comments. If you decide to participate in the debate presentations, then you will be excused from the full Term Paper described above.
Quiz!
Our Background

Primarily Galactic astronomy and astrophysics mostly using radio telescopes + theory

Science interests:
- Neutron stars (pulsars) and black holes
- Turbulence in the interstellar medium
- Gravitational waves (pulsars as detectors)
- Bursts of radio emission from outside our Galaxy (FRBs)
- Evolution of black holes over cosmological time
- Astrobiology, SETI = search for extraterrestrial intelligence

Collaborations: worldwide (primarily Europe, Australia)
Fast radio bursts
Milliseconds in duration

3 billion years to get to us from powerful source in a non-descript dwarf galaxy
Two of the largest radio telescopes

Green Bank Telescope
West Virginia
100 meter diameter

Arecibo Observatory
Puerto Rico
305 meter diameter
FAST  Five hundred meter astronomy spherical telescope

- 500 m aperture
- Prime-focus
- 300m illuminated
- Beam size ~2 arcmin at 1.5 GHz
- Active surface: instantaneous paraboloid
- 0.3 to ~2 GHz
Radio Telescope Arrays
Radio: Very Long Baseline Array
Optical Telescopes
High Energy (X-ray, gamma-ray) Telescopes
Telescope Parameters

- Wavelength
- Resolution
- Sensitivity

Sensitivity: Larger light buckets. ➔ More area, larger bandwidth, …

Resolution: $\theta \sim \lambda/D$. 
Using Pulsars for Gravitational Wave Detection
Pulsars Orbiting Sgr A*

Stellar populations near Sgr A*:
- Post-MS OB giants, supergiants
- B stars within 1 arc sec

Origins not understood but:
- these are progenitors of neutron stars
- many should be active pulsars
- some should be on very compact orbits

Simulation for TMT+AO
Ghez et al. (Astro2010)
The Milky Way: How Many Spiral Arms?

“As viewed from a great distance our Galaxy would appear to be a grand-design two-armed barred spiral with several secondary arms: the main arms being the Scutum-Centaurus and Perseus arms and the secondary arms being Sagittarius, the outer arm, and the 3 kpc expanding arm.”

The Milky Way: How Many Spiral Arms?


“The Perseus spiral arm has a pitch angle of $16^\circ \pm 3^\circ$, which favors four rather than two spiral arms for the Galaxy.”

“Two armed spirals can account for most of the known large H ii regions only if the arms wrap twice around the Galaxy; this requires pitch angles of $\approx 8^\circ$. With pitch angles greater than $\approx 12^\circ$, the Galaxy needs to have four arms in order to account for the approximate locations of H ii regions.”
Drake Equation

- N = number of planets in the Milky way that have civilizations with high-tech that are potentially detectable.

- The Drake equation is a means for guesstimating N.

- It is useful as a catalog of our ignorance in relevant areas of astrophysics, biology, and evolution (especially our own).
The Big Question

• Do we exist as a result of common, inevitable processes or are humans a fluke phenomenon?

• This question can be considered on three levels:
  
  **Cosmic and astrophysical:**
  
  We know a lot about the universe.
  
  • Elements are universal.
  
  • Solar-like stars are very common (a coincidence?)
  
  • Planets are a natural outcome of star formation.

  **Biological:** not so clear.
  
  • Bacteria are probably widespread. (Same biochemistry?)
  
  • Megafauna (including humans) may be rare or very rare. (N=1?)

  **Intelligence/technology:** no one knows.
  
  • Why did humans (high-tech) take so long to evolve?
  
  • Why haven’t we detected any signals or other evidence of ET technology if it is common and other planetary systems are up to billions of years older than the solar system?
Principles and Paradox

Copernican principle
- We find ourselves on an ordinary planet around an ordinary star in an ordinary galaxy.
- AKA the assumption of mediocrity (we’re mediocre & there must be lots more like us).

Anthropic principle
- The universe necessarily has properties that allow complex beings like ourselves and life generally to have evolved.
- Is the universe ordinary?

Fermi Paradox
- Given CP + AP, if N is large, where is everybody?