ASTR 405: Exoplanetary Science

Stephen Kane
A405: Exoplanetary Science

- Please do not use laptops, tablets, cell phones in class.

- My office hours are every Wednesday 2pm-4pm in TH 309.

- The class web page is live: http://physics.sfsu.edu/~skane/teaching/a405

- The course syllabus is available from the web site.

- No class on Thursday, February 18.
Welcome to the course webpage for ASTR 405: Exoplanetary Science.

Class Announcements:
2016-01-26: Class announcements will appear here periodically.

Class times:
- Tuesday, 11:00pm-12:15pm BH 331
- Thursday, 11:00pm-12:15pm BH 331

Text:
- "The Exoplanet Handbook" by Michael Perryman
- I also recommend "Exoplanets" edited by Sara Seager

Important Dates:
- February 9: Last day to drop without a W
- February 23: Last day to add by exception
- March 17: Literature Review due
- March 21-25: Spring Break (No class)
- March 31: No class (Cesar Chavez Day)
- April 28: Data Project report due
- May 17: Last class meeting
- May 23: FINAL EXAM 10:45pm-1:15pm in BH 331

Assessment:
- Homework (40%): There will be five homeworks during the semester. Most problems will require analytic solutions, however there will usually be one problem per assignment that will involve graphing and numerical solution with computer software such as Mathematica, MATLAB, or any programming language.
- Literature Review (15%): Students will be

Download the class syllabus here.
Class Assessment

- Assessment: Homeworks – 40%
  Literature Review – 15%
  Data Project – 15%
  Final Exam – 30%
Class Assessment

• Assessment: **Homeworks – 40%**
  Literature Review – 15%
  Data Project – 15%
  Final Exam – 30%

• Homeworks will be due Thursdays in class. Times between issue and due dates will vary.

• Programming will be required (IDL, python, MATLAB).

• First homework will be handed out on Tuesday (February 2).
Class Assessment

- Assessment: **Homeworks – 40%**
  - Literature Review – 15%
  - Data Project – 15%
  - Final Exam – 30%

- Working in groups is encouraged, but must hand in your own work.

- Late homeworks are 50% off until following Monday and 100% off after that.

- Cheat at your own risk!
Class Assessment

• Assessment: Homeworks – 40%
  Literature Review – 15%
  Data Project – 15%
  Final Exam – 30%

• Choose a peer-review published exoplanet-related paper.

• Write a 4-page critique of the paper including summary of the paper, why you chose it, key results and significance, and original ideas on future work.

• Due on Thursday, March 17 in class.
Class Assessment

- Assessment: Homeworks – 40%
  Literature Review – 15%
  Data Project – 15%
  Final Exam – 30%

- The Data Project consists of utilizing an online data resource to conduct analysis of exoplanet data.

- Final report may be up to 5 pages long, in the form of a lab report, and is due on Thursday, April 28, in class.
Class Assessment

• Assessment: Homeworks – 40%
  Literature Review – 15%
  Data Project – 15%
  Final Exam – 30%

• Possible Data Project sources include:
  - The NASA Exoplanet Archive
  - The Exoplanet Data Explorer
  - The Habitable Zone Gallery
  - The Systemic Console
Class Assessment

• Assessment: Homeworks – 40%
  Literature Review – 15%
  Data Project – 15%
  Final Exam – 30%

• The Final Exam will be in this room (BH 331)
  Monday, May 23, 10:45am-1:15pm.

• Questions will cover the entire class.
Class Assessment

- Assessment: Homeworks – 40%
  Literature Review – 15%
  Data Project – 15%
  Final Exam – 30%

- For homeworks, literature review, and data project, hard copies are required. No email submissions!

- Do not miss homeworks/exams. There are no make-ups or extra credit!

- Extensions always require documentation!
Textbook/Lectures


• Lectures will (mostly) be available on the class website but many things covered in class won't be.

• Discussion of peer-reviewed papers.

• Guest speakers: Fred Adams (UM) on March 17
  Jonathan Fortney (UCSC) on March 29
Topics

- Solar System
- History of exoplanets
- Keplerian orbits
- Detection techniques
- Space-based missions
- Exoplanet host stars
- Orbital dynamics
- Planet formation
- Planetary atmospheres
- Exoplanet statistics
- Planetary diversity
- Habitability
Numbers you should know: The Sun

- Mass $\approx 2 \times 10^{30}$ kg = $1 \, M_\odot$
- Radius $\approx 7 \times 10^8$ m = $1 \, R_\odot$
- Distance $= 1.5 \times 10^{11}$ m = $1 \, \text{AU}$
- Luminosity $= 4 \times 10^{26}$ W = $1 \, L_\odot$
- Surface temperature $= 5800$ K
- Age $\approx 4.5$ Gyr
- Spectral type = G2 V

All other stars are scaled to these parameters for convenience.

source: SOHO/EIT
Numbers you should know: planets

• **Mass**: Sun, Jupiter, Earth are units of measurement

• **Radius**: Sun, Jupiter, Neptune, Earth are units of measurement
“There are infinite worlds both like and unlike this world of ours...We must believe that in all worlds there are living creatures and plants and other things we see in this world.”

--- Epicurus (c. 300 B.C)
“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. The countless worlds in the universe are no worse and no less inhabited than our Earth.”

Giordano Bruno (1584) in De L'infinito Universo E Mondi

Burned at the Stake - 1600
Planet Detection

- **Direct**: Uses either starlight reflected from or thermal radiation emitted by the planet

- **Indirect**: Uses effects of the planet on the parent star or random background star
Kepler

NASA's First Mission Capable of Finding Earth-size & Smaller Planets
How Many Exoplanets?

• We currently know of 1,935 confirmed exoplanets and 4,696 Kepler candidates.
• Kepler results show planet frequency increases towards smaller (terrestrial) size.
The Stages of my Planetary Research

1. Planet hunting using transits, microlensing, radial velocities, and imaging

2. Studying planetary orbits and atmospheres

3. Habitable Zones and planetary habitability
What is a planet?

- Size
- Mass
- Distribution
- Free-floating
- Formation mechanisms
What Counts as a Planet?

Definition from the International Astronomical Union (IAU) 2006:

- The object is in orbit around the Sun
- Has sufficient mass to be round
- Has “cleared the neighborhood” around its orbit
THE PLANET HYGEA.

M. Gasparis, of Naples, who discovered this planet on April 12, 1849, has furnished the following elements of its orbit, derived from several observations:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoch, May 1, 1849</td>
<td></td>
</tr>
<tr>
<td>Mean anomaly</td>
<td>326 34 22.44</td>
</tr>
<tr>
<td>Longitude of perihelion</td>
<td>242 47 3.44</td>
</tr>
<tr>
<td>Node</td>
<td>285 32 29.72</td>
</tr>
<tr>
<td>Inclination</td>
<td>3 46 51.27</td>
</tr>
<tr>
<td>Mean daily motion</td>
<td>590''.3784</td>
</tr>
</tbody>
</table>

This newly discovered planet belongs to the same group with Astræa, Hebe, Iris, Flora, and Metis, all of which are, as will be seen below, of very recent discovery. The planets known from high antiquity are Mercury, Venus, Earth, Mars, Jupiter, and Saturn. To these, in 1781, was added Uranus, or Herschel, as it is sometimes called, from the name of its discoverer. Early in the present century, astronomers became convinced that a planet existed between Mars and Jupiter, and an association of twenty-four observers was formed to examine the whole heavens. But, early in January, 1801, the present planet Ceres was accidentally discovered by Piazzi, in Sicily. In March, 1802, Pallas was discovered by Olbers, in Bremen, and this was followed, in 1804, by the discovery of Juno, and, in 1807, by that of Vesta. On December 8, 1845, Astraea was discovered by Professor Hencke, and on July 1, 1847, he also discovered Hebe. Iris was discovered August 13, 1847, and Flora, October 18 of the same year, both by Mr. Hind. Metis was, we believe, discovered by Mr. Graham, in Ireland, on April 25, 1848. The recent extraordinary discovery of Neptune is familiar to all. The total number of primary planets discovered, up to the present time, is, it will be seen, 18. Many of them are never visible to the naked eye. — Editors.
EVIDENCE FOR A DISTANT GIANT PLANET IN THE SOLAR SYSTEM

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ABSTRACT

Recent analyses have shown that distant orbits within the scattered disk population of the Kuiper Belt exhibit an unexpected clustering in their respective arguments of perihelion. While several hypotheses have been put forward to explain this alignment, to date, a theoretical model that can successfully account for the observations remains elusive. In this work we show that the orbits of distant Kuiper Belt objects (KBOs) cluster not only in argument of perihelion, but also in physical space. We demonstrate that the perihelion positions and orbital planes of the objects are tightly confined and that such a clustering has only a probability of 0.007% to be due to chance, thus requiring a dynamical origin. We find that the observed orbital alignment can be maintained by a distant eccentric planet with mass \( \gtrsim 10 m_\oplus \) whose orbit lies in approximately the same plane as those of the distant KBOs, but whose perihelion is 180° away from the perihelia of the minor bodies. In addition to accounting for the observed orbital alignment, the existence of such a planet naturally explains the presence of high-perihelion Sedna-like objects, as well as the known collection of high semimajor axis objects with inclinations between 60° and 150° whose origin was previously unclear. Continued analysis of both distant and highly inclined outer solar system objects provides the opportunity for testing our hypothesis as well as further constraining the orbital elements and mass of the distant planet.

Key words: Kuiper Belt: general – planets and satellites: dynamical evolution and stability