Friday April 22

Syllabus and class notes are at: www.as.utexas.edu

Reading for this week: Chapter 16

If you want help on anything covered in the course, come to discussion session Thursday at 6:00 in RLM 15.216B or to our office hours.
Topics for this week

What evidence do we have that planets exist orbiting around other stars?

Describe and compare briefly the compositions and orbits of the planets, asteroids, and comets.

Describe the nebular theory of the formation of the solar system.

How does the nebular theory explain the differences in composition among the planets?
The Accelerating Expansion of the Universe

John Updike

It is not true that developments in physics go ignored by professional humanists or by the common man. The basic facts get to us all and frame the way we think and even, in this instance of the fictional Martin Fairweather, feel. The picture physics paints of the material universe is arresting enough to make the newspapers but far from flattering to our individual identities. Astronomy is what we have now instead of theology. The terrors are less, but the comforts are nil.

John Updike
Why should it bother Martin Fairweather? In his long, literate lifetime he had read of many revisions of cosmic theory. Edwin Hubble’s discovery of universal expansion had occurred a few years before he was born; by the time of his young manhood, the theory of the Big Bang, with its overtones of Christian Creation by fiat—“Let there be light”—had prevailed over the rather more Buddhist steady-state theory claiming that space itself produced, out of nothingness, one hydrogen atom at a time. In recent decades, in astronomy as in finance, billions had replaced millions as the useful unit: a billion galaxies, a billion stars in each. Ever stronger telescopes, including one suspended in space and named after Hubble, revealed a swarm of fuzzy ovals, each a Milky Way. Such revelations, stupefying for those who tried truly to conceive of the distances and time spans, the amounts of brute matter and of vacancy seething with virtual particles, had held for Fairweather the far-fetched hope of a last turn: a culminating piece in the great sky puzzle would vindicate Mankind’s sensation of central importance and disclose a titanic mercy lurking behind the cosmic arrangements.

But the fact, discovered by two independent teams of researchers, seemed to be that not only did deep space show no relenting in the speed of the farthest galaxies but instead a detectable acceleration, so that an eventual dispersion of everything into absolute cold and darkness could be confidently predicted. We are riding a pointless explosion to nowhere. Only an invisible, malevolent anti-gravity, a so-called Dark Force, explained it. Why should Fairweather take it personally? The universe would by a generous margin outlive him—that had always been true. But he had somehow relied on eternity, on there being an eternity even if he wasn’t invited to participate in it. The accelerating expansion of the universe imposed an ignominious, cruelly diluted finitude on the enclosing vastness. The eternal hypothetical structures—God, Paradise, the moral law within—now had utterly no base to stand on. All would melt away. He, no mystic, had always taken a sneaky comfort in the idea of a universal pulse, an alternating Big Bang and Big Crunch, each time recasting matter into an unimaginably small furnace, a subatomic point of fresh beginning. Now this comfort was taken from him, and he drifted into a steady state—an estranging fever, scarcely detectable by those around him—of depression.
Evidence for quantized displacement in macroscopic oscillators. Physicists at Boston University have performed an experiment in which 500-nm-long silicon paddles sprouting from a 10.7-μm-long central spine of Si (see the figure) oscillate collectively. With the device in an external magnetic field, a current is applied to a gold-film electrode on top of the spine. The resulting Lorentz force causes the structure to vibrate at frequencies up to 1.5 GHz, which makes it the fastest macroscopic oscillator to date. At a temperature of 1 K, the device responds continuously to a changing drive force. However, at 110 mK, precisely where the researchers expect quantum effects to set in, the oscillator responds discretely.

Confirmation that this system of about 50 billion Si atoms is quantized will require more work, both theoretical and experimental. (A. Goidarts and et al., Phys. Rev. Lett. 94, 030402, 2005.)

Complex hybrid structures have been observed in a Bose–Einstein condensate (BEC). Researchers in Lene Hau’s laboratory at Harvard, using the technique of slowing and then stopping a light pulse in a BEC, sent two such pulses into a specially prepared BEC. They observed solitons, vortex rings, and their interactions, some of which created hybrid that were part vortex ring and part soliton. Never seen before, these bizarre BEC excitations sometimes opened up like an umbrella, then turned inside-out. Two such excitations could collide and form a spherical shell or, in some cases, annihilate each other. The image shows structures that arose after 2.8 ms of evolution in the trap. (L. Hau and colleagues also performed computer simulations that correlate well with the experiments and thus help the researchers to understand the phenomenology. They say that their work will help physicists gain new insights into the superfluid phenomenon and into the breakdown of superconductivity.) (N. S. Ginsberg, J. Brand, L. V. Hau, Phys. Rev. Lett. 94, 040403, 2005.)

Quantum-dot photon detectors. Physicists at Toshiba Research Europe and the University of Cambridge have developed a device that can efficiently detect single photons. The device employs a layer of self-assembled quantum dots—acting as artificial atoms with quantized electron energy states—encased in a resonant tunneling diode that has two conducting gallium arsenide layers separated by an insulating aluminum arsenide layer. If the GaAs layers have the right voltage alignment, a current can tunnel between them; but the physicists purposely misaligned them a bit to prevent such tunneling. A photon striking the diode generates an electron or a hole that can be captured by a nearby quantum dot whose suddenly altered energy state restores the resonance, and the resulting tunneling current is detected. Thus far, the low-noise detection scheme has allowed the researchers to detect single photons with 12.5% quantum efficiency and 150-nsec time resolution, but they expect improvements in both quantities. (J. C. Blakeley et al., Phys. Rev. Lett. 94, 067401, 2004.)

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Sticky ice can help planets form quickly.
Stars and their planets are typically born in dusty nebulae. However, in just a few million years or less, a newborn star blows away dust from its neighborhood, removing most of the raw material for planet formation. Although gravitationally bound kilometer-sized protoplanets will grow rapidly, getting from dust to protoplanets in a million years has proven elusive using the available van der Waals forces. The outer reaches of our own sun’s early nebula were at temperatures below 120 K, and researchers at the Pacific Northwest National Laboratory have now studied cryogenically formed water ice, which is amorphous and fluffy rather than crystalline and solid. They discovered that it has two other unusual properties that can expedite the agglomeration of fragile, micron-sized dust grains. First, cryogenic ice has a persistent, macroscopic electric dipole that is unmasked when an asymmetry is introduced by, for example, a collision with another ice-coated dust grain. Second, the fluffy amorphous ice is mechanically inelastic. In experiments, the scientists found that a free-falling ceramic bead rebounds from a cryogenic ice film to only about 10% of its original height, compared to about 80% for normal kitchen ice. Taken together, the electrostatic and mechanical properties mean that colliding particles are more likely to stick than bounce and the resulting agglomerates can continue to grow rather than shatter on subsequent impacts. (H. Wang et al., *Astrophys. J.* **620**, 1027, 2005.)

—SGB
STARQUAKE!

Magnetar temblor
gives Earth
gamma-ray bath
Magnetar Flare Flooded Solar System with Gamma Rays

The brightest radiation flare ever recorded washed through the solar system on December 27, swamping detectors in more than a dozen satellites and disrupting Earth's ionosphere. Astronomers have concluded the event may solve the mystery of the origin of short-duration gamma ray bursts (GRBs).

Until recently, the origin of GRBs — random bursts of gamma rays seen from all over the sky — has been a mystery. GRBs are separated into two categories: long-duration and short-duration (those lasting less than two seconds). Most astronomers now agree that the former are caused by distant stars exploding as supernovae and then collapsing to form black holes. The source of the latter had remained a mystery.

Scientists pinpointed a magnetar — an intensely magnetic neutron star — 50,000 light-years away on the opposite side of the Milky Way as the source of December 27 burst. The magnetar in question, SGR 1806-20, was already known for its lesser gamma-ray outbursts. And its rotation period, 7.5 seconds, matches the fluctuation period of the December 27 flare's afterglow.

If this magnetar had flared from inside a distant galaxy, scientists say, it would look to us like a short-duration GRB. The connection between magnetars and GRBs hadn't been solidified before. The right instruments weren't in place to detect and locate the GRB sources.

Launched November 20, the Swift satellite was designed for this purpose, but was still in early operations mode in late December. Next time, according to Kevin Hurley of The University of California, Berkeley, "if a magnetar flares up in a distant galaxy within 100 million light-years of Earth, we should be able to detect it. Since there are very many galaxies within this distance range, we should see these events frequently."

"Swift will open up a new field of astronomy: the study of extragalactic magnetars," said Robert Duncan of The University of Texas at Austin. Along with Christopher Thompson, Duncan predicted the existence of magnetars in 1992. About a dozen are now known, and only two others have produced large flares in the last 55 years — neither as large as the recent event.

Duncan and Thompson theorized that a magnetar's great magnetic field causes its crust to shift around. The magnetic field, connected to the crust, breaks and re-connects, causing a "starquake." This releases a flood of charged particles. They annihilate each other, causing a giant burst of gamma rays — as was seen on December 27, when SGR 1806-20 emitted as much energy in one-tenth of a second as the Sun gives off in 100,000 years.

"Had this happened within 10 light-years of us, it would have severely damaged our atmosphere and possibly triggered a mass extinction," said Bryan Gaensler of the Harvard-Smithsonian Center for Astrophysics. "Fortunately, there are no magnetars anywhere near us."
Detection of Extrasolar Planets

How could we find planets orbiting around other stars?

See them in pictures
See them in infrared pictures
Measure the spectra of star+planet
Observe them blocking the star’s light
Observe the effects of their gravities on the star
    causing the position of the star to change
    causing the velocity of the star to change
European team releases image of possible planet

European team releases image of possible planet (April 12, 2005) - A team of European astronomers has released an image of what may be an extrasolar planet orbiting within the dusty disc surrounding a young star. The estimated mass of the substellar companion is between one and 42 times that of Jupiter.

FULL STORY>>

+ Spitzer sees signs of alien asteroid belt
+ Scientist hails 'exciting step' toward seeing extrasolar planets
European team releases image of possible planet

April 12, 2005

(PLANETQUEST) -- A team of European astronomers has released an image of what may be an extrasolar planet orbiting within the dusty disc surrounding a young star. The estimated mass of the substellar companion is between one and 42 times that of Jupiter. It is located about twice as far from the star as Jupiter is from the Sun and takes about 1,200 years to complete a single orbit.

The star, GQ Lupi, is located in the constellation Lupus and belongs to a class known as T Tauris -- very young, lightweight stars at an intermediate stage prior to becoming main sequence stars like our Sun. Whether the companion object is a planet or some other object, such as a brown dwarf, depends on its mass. The team based its estimated mass of the object by comparing it with theoretical models, which they acknowledge are unreliable when applied to such a young system.

"There's no question that there's an object out there," said Dr. Rachel Akeson, an astronomer at the Michelson Science Center in Pasadena who has studied T Tauri stars. "The question is - what is the object?"

Because of the distance from us, and the object's long orbital period, it will be difficult to confirm or deny its status anytime soon.

The image was obtained using an infrared camera on the Very Large Telescope in Chile. A paper announcing the discovery has been accepted for publication in the journal Astronomy and Astrophysics. More information is available on the website of the Astrophysical Institute and University of Jena Observatory.
First Exoplanet Discovered by the Transit Method

HD209458 Transit

$P=3.524 \text{ days}$
$a=0.046$, $e=0.02$
$M_{\text{ini}}=0.63 \text{ Jupiter Masses}$

JD $- T_c$ (days)
There are many professional websites that deal with extrasolar planets. One of the most comprehensive is the Extrasolar Planets Encyclopedia, which is what Extrasolar Visions uses for its chief reference.

Most extrasolar planets have been discovered via the radial velocity method, which infers a planet's orbital period, orbital distance, and approximate mass from the wobble of its parent star. So, in most cases, we have these three pieces of data from which to determine a planet's properties. In most cases, as well, good data is available for the parent star itself, information such as spectral class, mass, radius, and surface temperature. If such stellar data is available, then the planet's temperature can be approximated. Armed with a planet's mass and temperature, we can go a long way in our speculations.
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The velocity curve of HD 200458 showing the wobble caused by its planet

![Graph showing the velocity curve of HD 200458.]

The light curve of HD 209458 dims during the transit of its planet

Some planets have been discovered by the transit method, which detects the dimming of a star as a planet passes in front of it. Transits give a planet's radius, orbital period, and orbital inclination (which must be near 90° for the transit to be possible). Transits also allow astronomers to probe a planet's atmospheric density by detecting the rate of dimming just as the planet begins to cross the disk of its star, as well as the planet's chemistry by detecting how the starlight is absorbed as it passes through the planet's atmosphere.

If a planet is detected both by transit and by radial velocity, its total mass can be determined because both the planet's radius and mass are known. The planet of HD 209458 has been detected using both these methods and much of what we know about Hot Jupiters is based on the properties of this particular world.

Extrasolar Visions contains a great deal of actual data about extrasolar planets. Unfortunately, the recent pace of exoplanet discovery has been quite fast. Not only are new discoveries being made, but data about earlier discoveries are constantly being refined. I update planetary data on the site as I find out about it, but it is certainly possible that some planets have out dated information.
HD 40979

Lick and Keck Data

P = 263 d, e = 0.25, Msini = 3.28 M(J)
Examples of Radial Velocity Data

- P(c) = 241.18 d, e = 0.26, K = 53.0 m/s, Msin = 1.98 M(J)
- P(d) = 1282.6 d, e = 0.25, K = 60.9 m/s, Msin = 3.9 M(J)

**Velocity Residuals (m s⁻¹)**

**Time (yr)**


**Ups And**  **Lick Obs**
Just as someone walking a lively dog is tugged around, the star 51 Pegasi is tugged around by the planet that orbits it every 4.2 days. The wobble is detectable in precision observations of its Doppler shift. Someone walking three dogs is pulled about in a more complicated pattern, and you can see something similar in the Doppler shifts of Upsilon Andromedae, which is orbited by three planets.
Two Neptune-Mass Planets Discovered

NSF Press Release
NASA Announcement
Planet Graphics

136 planets are known outside our Solar System (Feb 5, 2005).

A Neptune-Mass Planet Orbiting the Nearby M Dwarf GJ436

Detection of a Neptune-Mass Planet in the 55 Cancri System by the HET
The occurrence of extrasolar planets varies inversely with mass. The graph shows the number of planets found with various masses compared to the minimum mass (Jupiter masses).
Spectrum of an Earth-like Planet
Prebiotic and Evolved Methane Spectra

Shown below are two spectrums of methane (CH4) present in the Earth's atmosphere. The early prebiotic Earth shows no methane. The later prebiotic Earth is modified by methane producing bacteria as shown in the second spectrum.
Classification of Exoplanets from Spectra

HST Image of Gliese 229 System
RA=06:10:35.07
Dec=-21:51:17.6

Gliese 229A
r=5.7 pc
V=8.14
B=9.65
Type=M1/M2V

Gliese 229B
M=0.025-0.065
R=0.9-1.1 Jup
T=950-1050 K
About 44 AU from Gl229A
Atm: H2O, CH4
A puzzle

We have evidence for planets even more massive than Jupiter in orbit around other stars, orbiting closer to their stars than Mercury is to the Sun.

I claimed that the Jovian planet first formed icy cores, and once the cores were massive enough they pulled in gas.

But ices could not have formed that close to a star, so the cores should not have been massive enough to pull in hydrogen and helium.

How can such massive planets be so close to stars?
After photographing a region that some planetary scientists say may be a vast reservoir of buried ice on Mars, the Mars Express spacecraft will try to confirm the finding with an instrument that's scheduled to begin operating in May.

Deployment of the European craft's radar boom has been delayed for more than a year by concerns that it could damage both itself and other instruments as it extends from the body of Mars Express. The system's radar beam is designed to penetrate up to three feet (one meter) beneath the Martian surface. Reflections from these depths should tell scientists whether frozen water is mixed with the planet's powdery soil or is buried in layers just beneath the surface.

An early target for the radar may be Elysium Planitia, a plain near the Martian equator where Mars Express images revealed evidence of a possible "sea" of ice buried just beneath the surface. The images show terrain that's covered by large blocks. The blocks resemble "rafts" of ice that break off of large ice sheets on Earth. There are few craters in this region, suggesting that the ice could have formed within the last few million years.

Mission scientists, writing in the journal *Nature*, say the ice probably formed when water gushed to the surface through a series of cracks. This torrent flowed into a basin that covers an area the size of Texas. Water at the top of this new-born sea was covered with dirt and volcanic ash, allowing it to freeze before it boiled away into the thin Martian atmosphere. The scientists say that the possible ice makes Elysium Planitia a leading site to search for evidence of past or present Martian life. DB