Monday, Nov. 17

Syllabus, class notes, and homeworks are at:
www.as.utexas.edu → courses → AST 301, Lacy

Reading for this week: chapter 16

We'll go back to the old help session time and place this week: Wednesday at 5:00 in GRG 424

[The opening of Updike's short story "The Accelerating Expansion of the Universe" is reprinted here with a comment from the author, his kind permission, and that of *Harper's Magazine*, which published the entire story in its October 2004 issue.]

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 skyey 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. ■

John Updike *is a novelist, poet, short-story writer, and essayist.* Villages, *his most recent novel, was published by Alfred A. Knopf in 2004. Updike lives near Boston. Although he once called "sex, art, and religion" the three great secrets of life, readers who notice how often scientific metaphors crop up in his work know that physics belongs on the list too.*

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?

Terrestrial Planets

The inner four planets

Sizes similar to the Earth's

Interiors made of metals and rocks

Very thin atmospheres (compared to the diameters of the planets)

Earth also has oceans (and Mars may once have). These also make up a small fraction of the volume.

Jovian planets

The next four planets

Interiors made of ices and gasses (probably with small rocky cores)

Jupiter and Saturn are mostly gas.

Uranus and Neptune are mostly (partially melted) ices.

Warning

Recently found planets around other stars often do not follow the division into terrestrial and Jovian planets.

In some cases giant planets are found very near their stars.

In explaining the solar system we will assume that the planets formed near their present positions.

But this may not be correct.

Nebular Theory

The solar system formed from a part of a molecular cloud.

Molecular Clouds:

- 70% of mass is hydrogen
- 28% of mass is helium
- 1% of mass is solids (tiny rocks, soot, and metals)
- 1% of mass is molecular (other than hydrogen)

A region of the cloud was pulled together by gravity.

It must have been rotating slowly.

When it came together its rotation increased.

The rotating gas cloud flattened.

Planets formed in the disk left around the newly formed Sun.

The protoplanetary disk

The disk around the Sun was probably hot, and hotter toward its center.

Ices and probably even rocks evaporated in the inner region.

As the disk cooled different materials condensed in different regions.

Metals and compounds containing metals condensed closest to the Sun.

Between Venus and Mars rocks could also condense.

Near Jupiter and Saturn ices could also freeze onto the metals and rocks.

Seeing the gas

Both the silhouettes and the infrared emission pictures show us where the dust is in protoplanetary disks.

But dust is only 1% of the mass in disks.

Can we see the gas?

One way I've tried is by observing emission lines of molecular hydrogen (H_2).

Most of the gas is H_2, but it doesn't emit very strongly.

We haven't succeeded in taking pictures of the H_2 emission, but we can infer the distribution of the gas from the widths of the emission lines.

Fast orbiting gas near a star emits broad lines because of the Doppler effect.

THE TEXES SURVEY FOR H_2 EMISSION FROM PROTOPLANETARY DISKS

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ABSTRACT

We report the results of a search for pure rotational molecular hydrogen emission from the circumstellar environments of young stellar objects with disks using the Texas Echelon Cross Echelle Spectrograph (TEXES) on the NASA Infrared Telescope Facility and the Gemini North Observatory. We searched for mid-infrared H_2 emission in the S(1), S(2), and S(4) transitions. Keck/NIRSPEC observations of the H_2 S(9) transition were included for some sources as an additional constraint on the gas temperature. We detected H_2 emission from 6 of 28 sources observed: AB Aur, DoAr 21, Elias 29, GSS 30 IRS 1, GV Tau N, and HL Tau. Four of the six targets with detected emission are class I sources that show evidence for surrounding material in an envelope in addition to a circumstellar disk. The detected emission lines are narrow ($\sim$10 km s^{-1}), centered at the stellar velocity, and spatially unresolved at scales of $0.4''$, which is consistent with origin from a disk at radii 10-50 AU from the star. In cases where we detect

Terrestrial planets

From Mars inward, only metals and rocks could condense.

These materials first formed tiny grains.

The grains stuck together to make bigger rocks.

Once they got up about 1 km in size gravity could help bring them together.

When they were over about 100 km they could hold enough heat from radioactive decay to melt inside.

The terrestrial planets formed from these planetesimals.

The sizes of the terrestrial planets were limited by the amount of condensable materials in the inner solar system.

Jovian planets

The Jovian planets probably started to form like the terrestrial planets, by solids sticking together.

But water, ammonia, and methane were also solids (ices) where they formed.

So the planets grew faster and became more massive.

Once they had more than a few times the mass of the Earth they had enough gravity to pull gasses in.

Since there was much more hydrogen and helium than other elements in the nebula, the Jovian planets could become much more massive than the terrestrial planets.

Leftovers

The asteroids between Mars and Jupiter may be leftover rocky planetesimals (or they may be broken up small planets).

The nuclei of comets are probably leftover icy planetesimals.

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.

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

How can such massive planets be so close to stars?