Physics 343 Lecture # 10:
lab 5; stars and (exo)planets

Schedule

Tonight 11:59pm: report for lab # 4 due by email (PDF please)

Monday – Thursday: hands-on sessions for lab # 5 (using archival optical data for a time series analysis)
+ attendance mandatory; active participation (this week = getting a head start on your analysis) counts towards your course grade

Monday (Baker, 3:30–4:00pm only!) & Thursday (Wu): regular office hours

Next week: "on call" office hours for lab # 5 (due April 27th!).
May 4th: student choice lecture. Any suggestions?

18 people + 5 cars to Green Bank

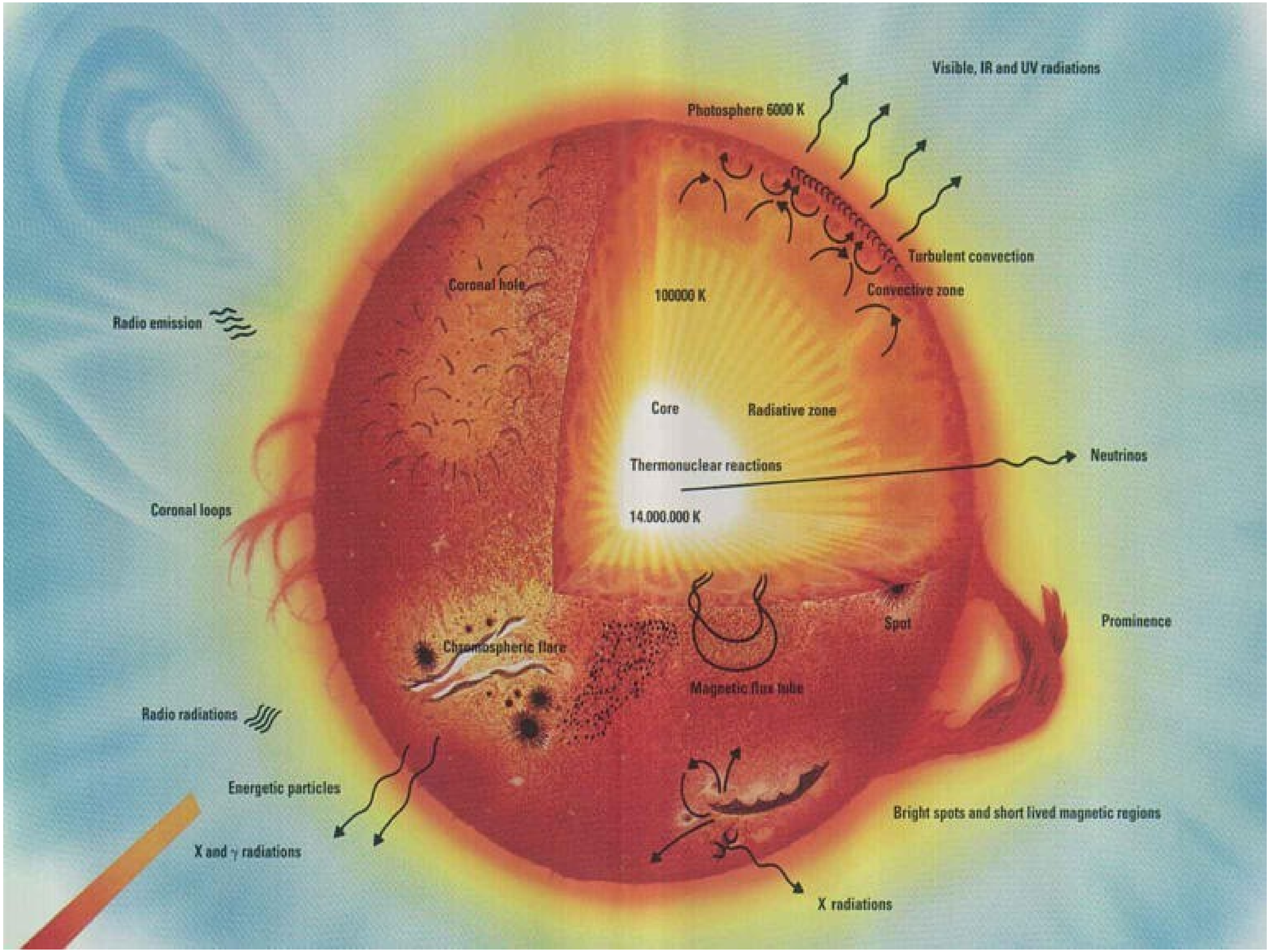
Departs	Driver	Passengers
1:00pm	Baker	Cheedella, Divakarla, Qawasmi
1:30pm	Ramekar	Agostinelli, Ioakimidis
2:00pm	Krstevska	Deshpande, Grutych, Ray
2:30pm	Sloane	Bradli, Chi, Valentin
3:00pm	Wu	Pathan, Thuppul

This is tentative (may still need to do some reshuffling).

The Sun: basic information

+ Normal star of spectral type G2V burning hydrogen in its core:
  has been doing this for ~ 5 Gyr and will continue for ~ 5 Gyr.
+ Core temperature is about 14 million K.
+ Temperature falls off with distance from the core to surface at 5800 K.
+ Photons generated in the core take ~ 1 Myr to reach the surface, due to short mean free path; last scattering defines surface photosphere.
+ Photons then pass through tenuous gas at even lower T ~ 4500 K, which produces characteristic absorption lines in the spectrum.
+ At larger radius, temperature climbs steeply to several million K in a hot, tenuous plasma known as the corona.

The Sun: structure



Temperature at and above Solar surface

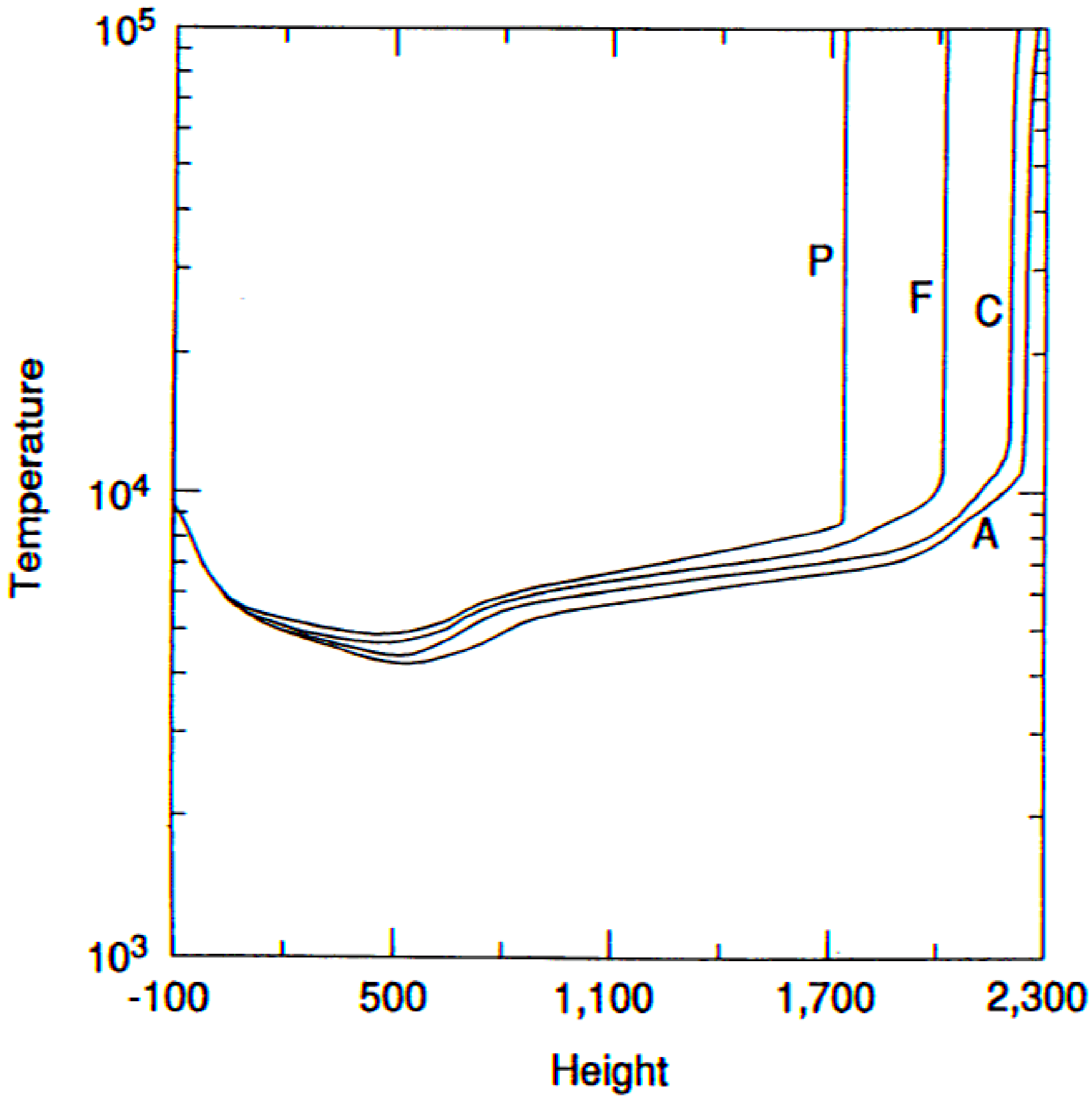
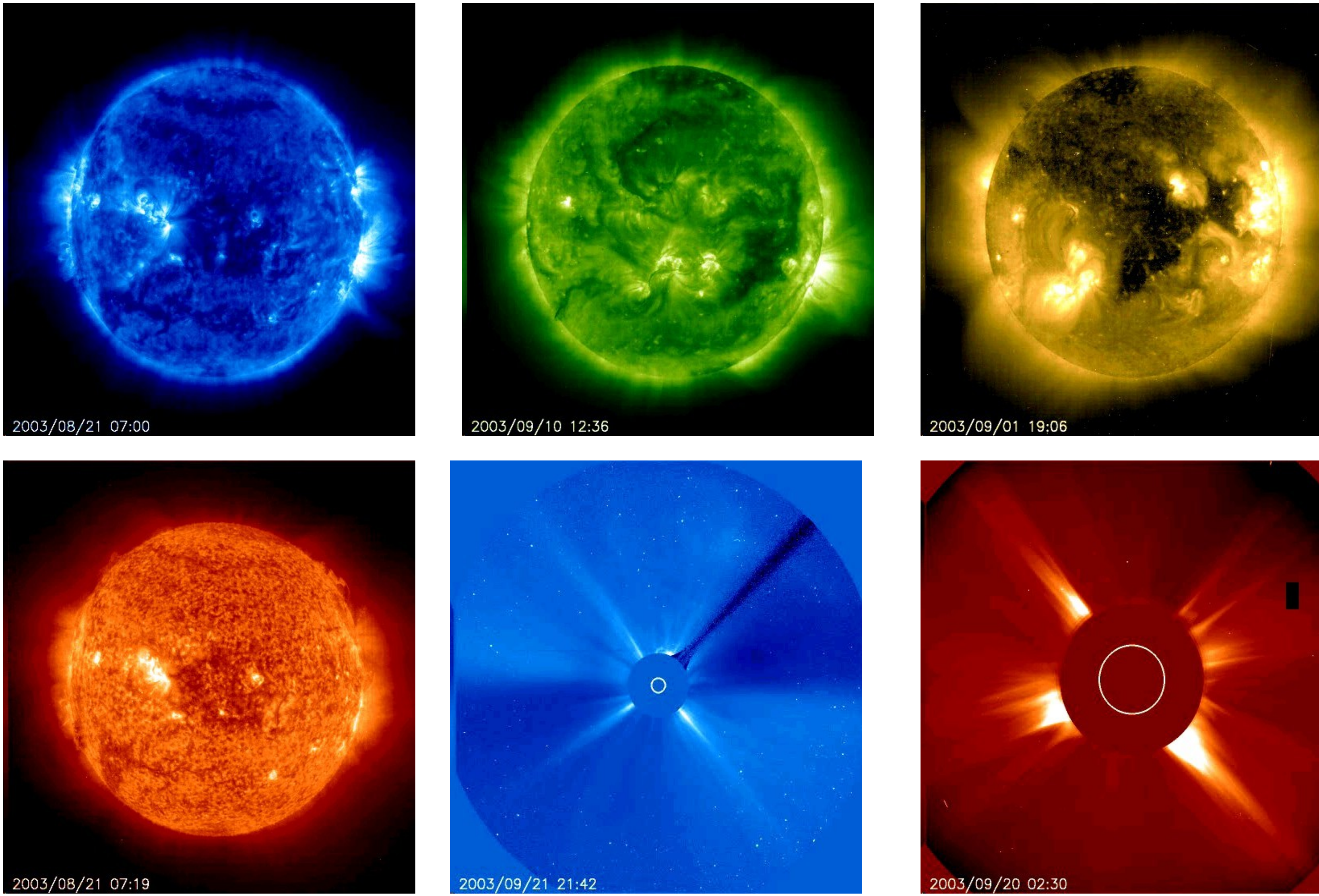


FIG. 3.—Temperature structure of our models A, C, F, and P. The height is measured in kilometers from the level; the temperature is in kelvins.

Solar activity as seen in UV by SOHO

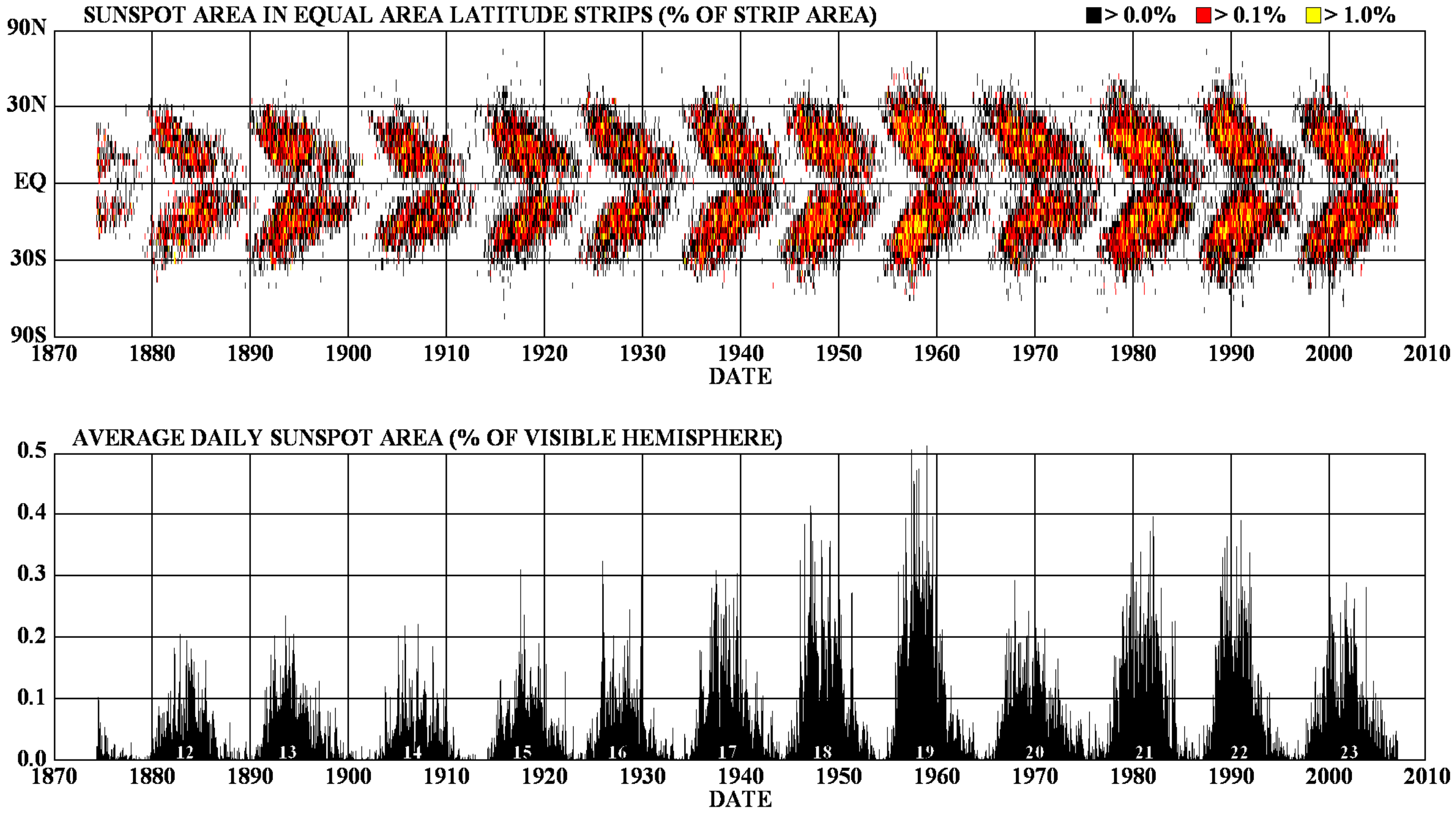


SOHO = Solar and Heliospheric Observatory (NASA + ESA)

http://sohowww.nascom.nasa.gov/data/realtime/mpeg/

Long-term sunspot cycle = 11 years

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



http://solarscience.msfc.nasa.gov/

NASA/MSFC/NSSTC/HATHAWAY 2007/02

Intensity vs. frequency of solar emission

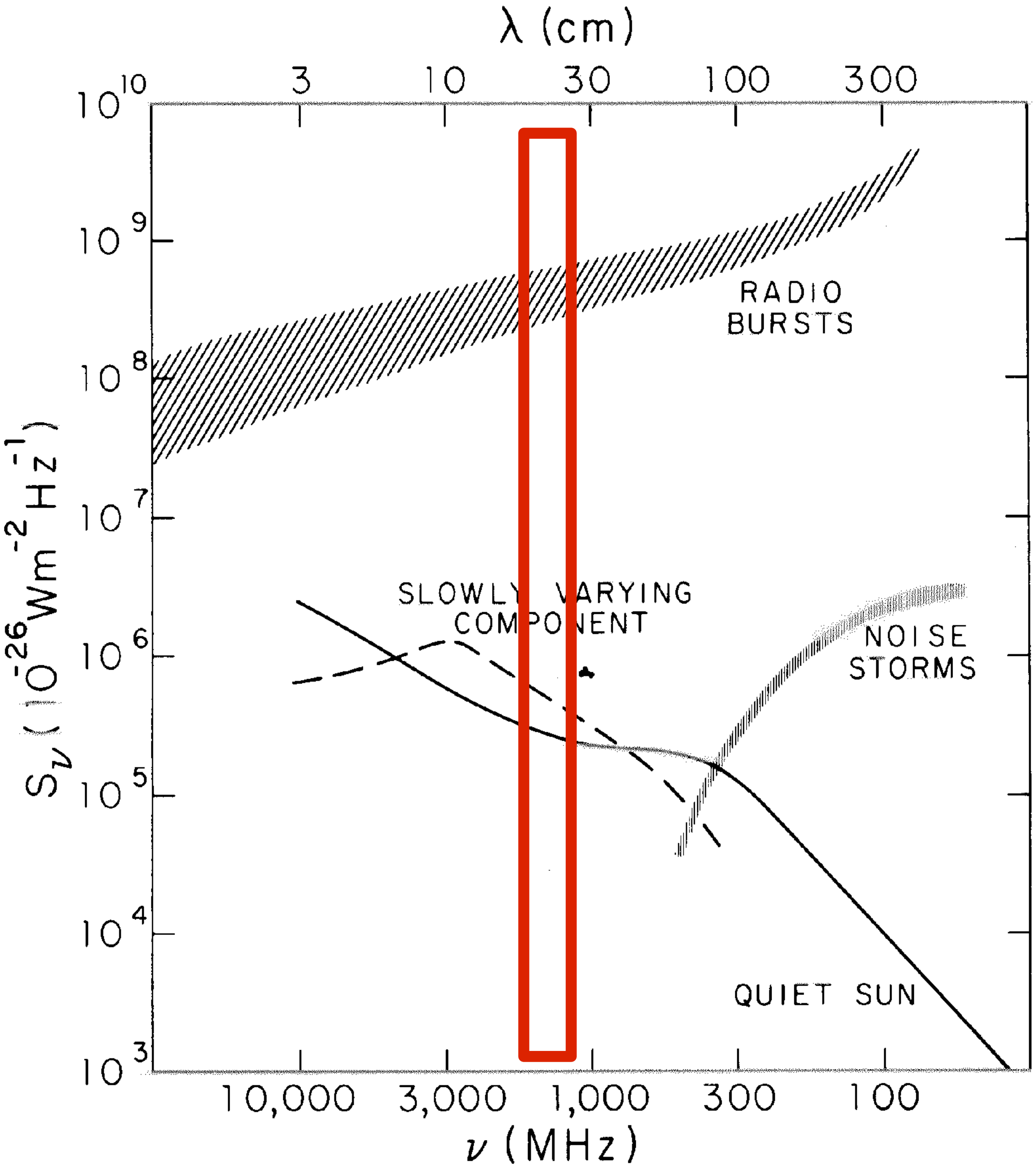
There are four broad types of radio waves from the Sun:

(1) quiet Sun emission

(2) slowly varying component

(3) noise storms

(4) bursts.



Note: frequency increases to left! Box marks SRT operation.

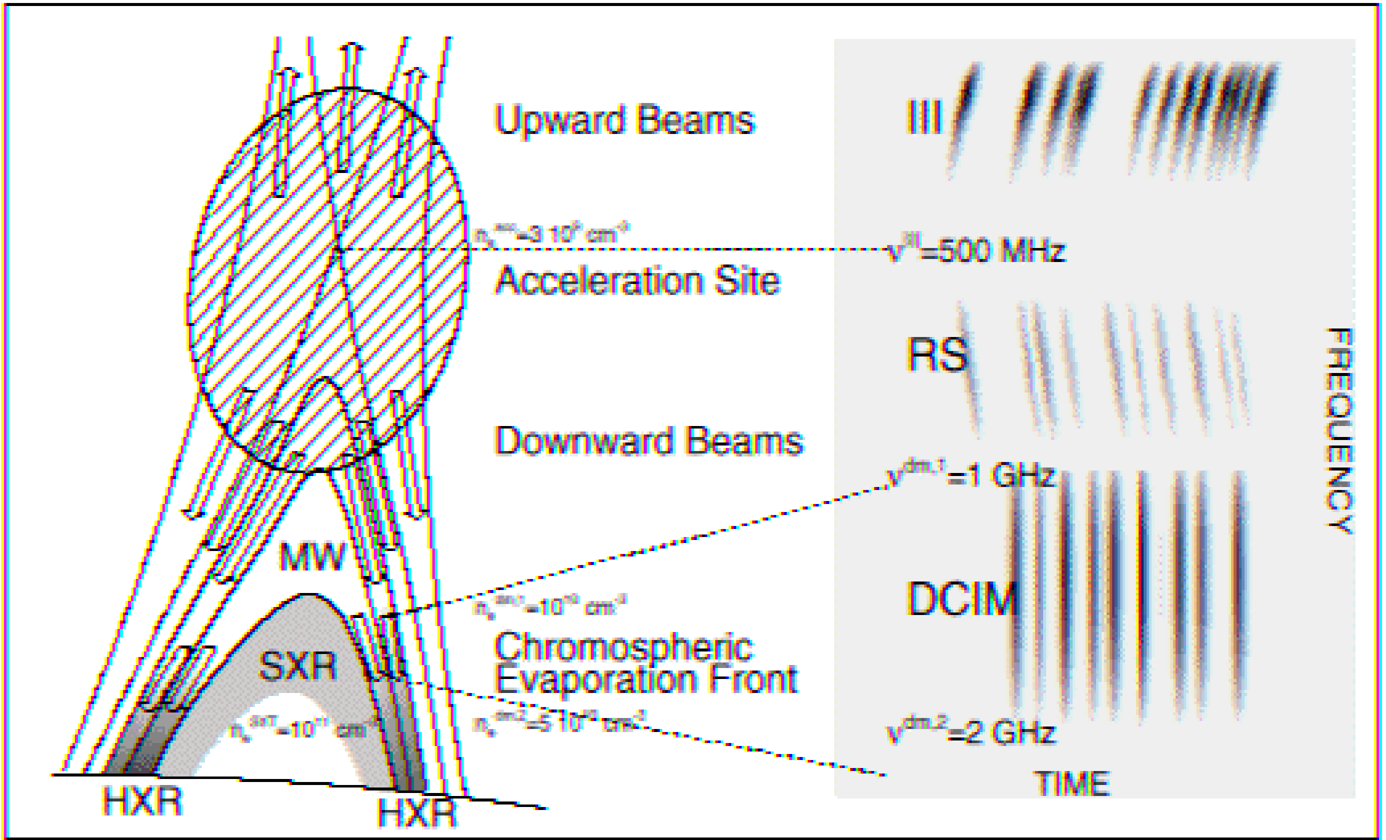
Solar radio bursts

Strongest and most complex solar radio events.

Usually associated with solar flares.

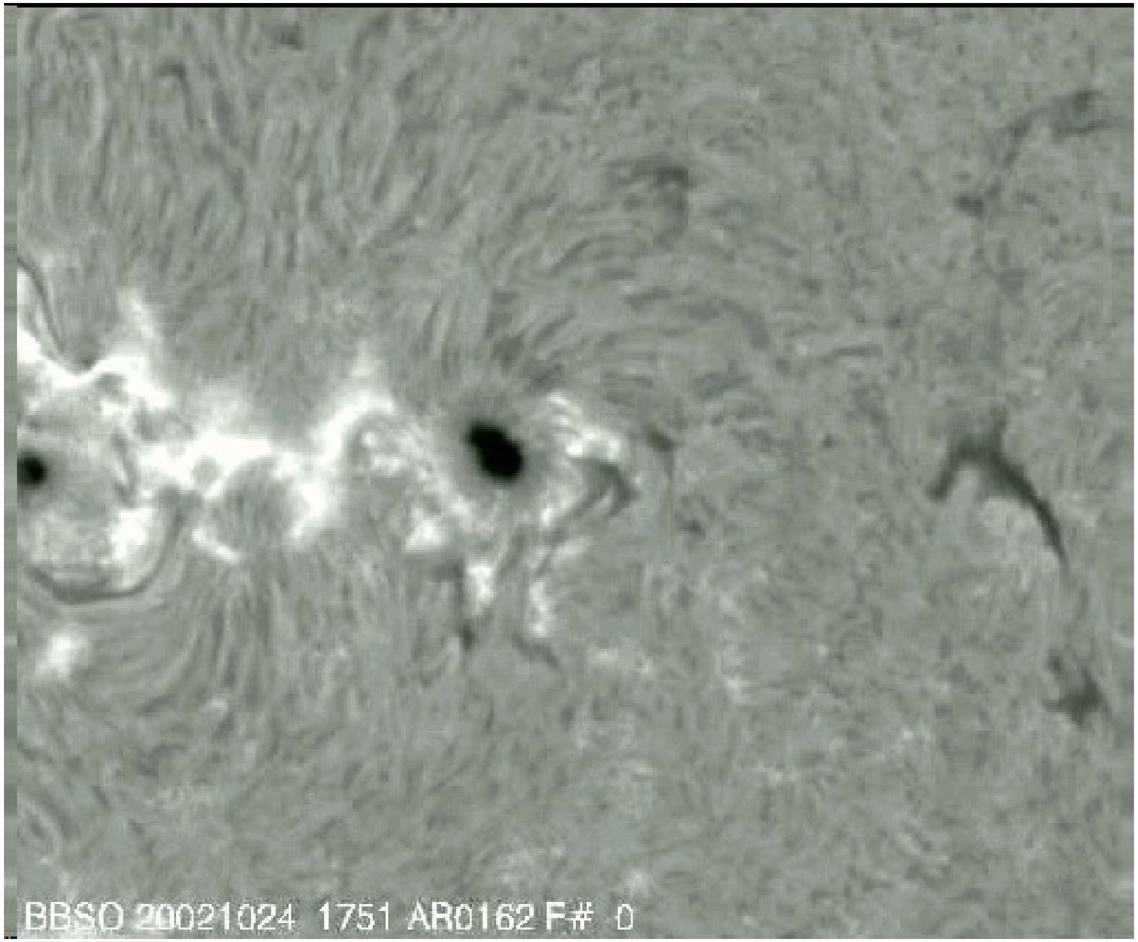
Brightness temperatures up to 10^{12} K; non-thermal spectra.

Duration: a few minutes to a few hours.



Solar Flare

X-ray flare (and optical flare observed in Hα) with several eruptive centers. Produced by release of coronal magnetic energy.



http://www.bbso.njit.edu/Research/Events/2002/10/24/event_20021024_1810/

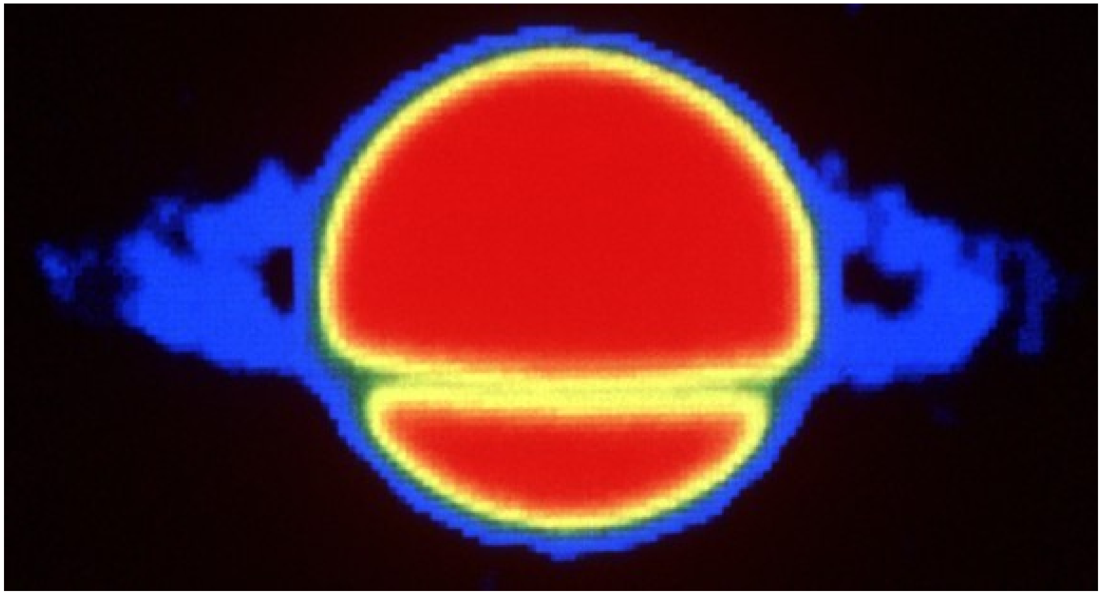
Radio observations of planets

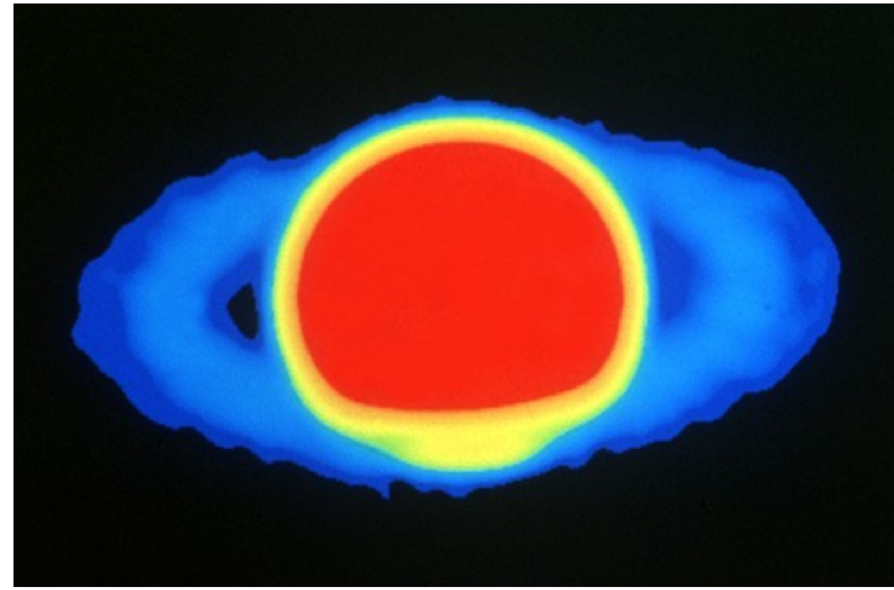
Planets and other solar system objects are cold relative to stars: ~700 K for Mercury, ~30 K for Pluto vs. ~6000 K for the Sun.

In the optical, we see only reflected light; however, in the radio, we see thermal emission.

In addition, Jupiter has a very large magnetosphere (larger in angular diameter than the Moon), which traps high-energy electrons that produce nonthermal synchrotron radiation.

Saturn imaged with the Very Large Array





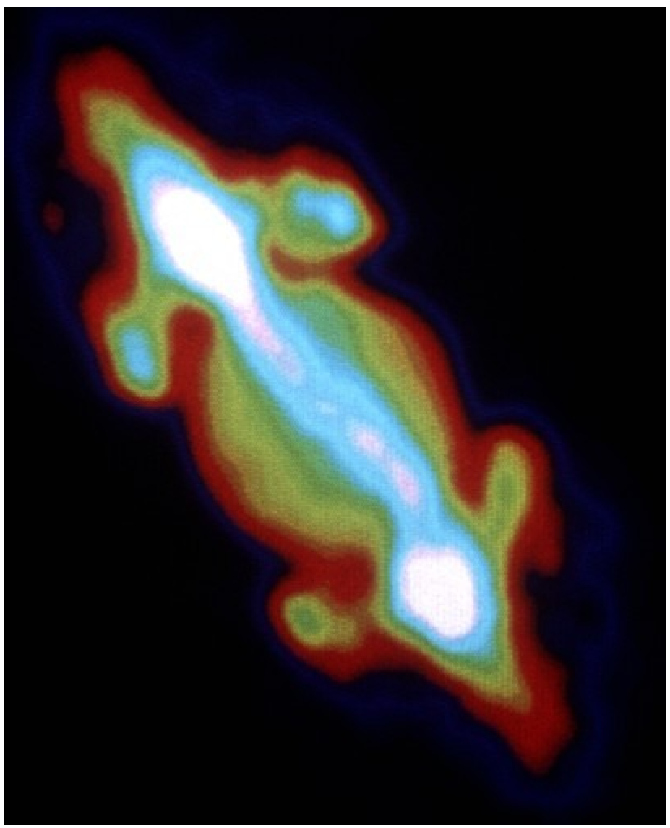
1982-01-25 Red hot, blue cool. 1986-12-00

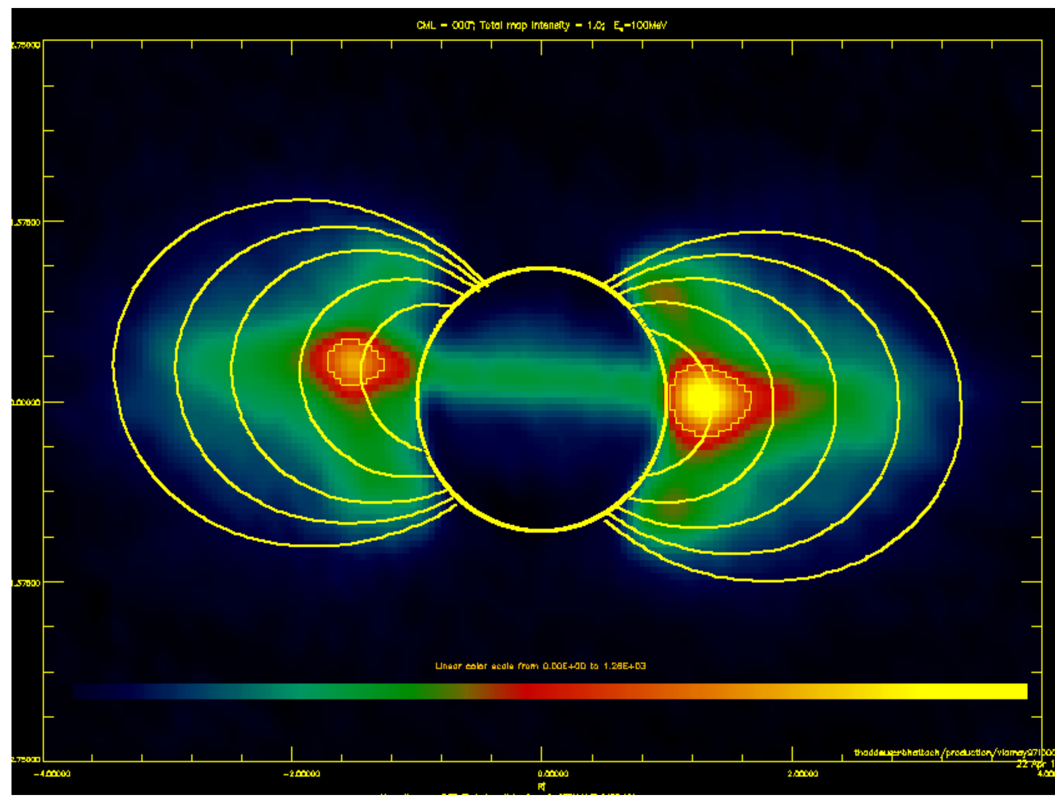
Bright disk with gradual fading towards edge (limb darkening) illustrates gradual cooling outward in Saturn's atmosphere.

Rings seen in emission outside disk, but in front of planet they absorb radiation from disk. (In optical, they are bright in all directions due to reflected sunlight.)

Jupiter

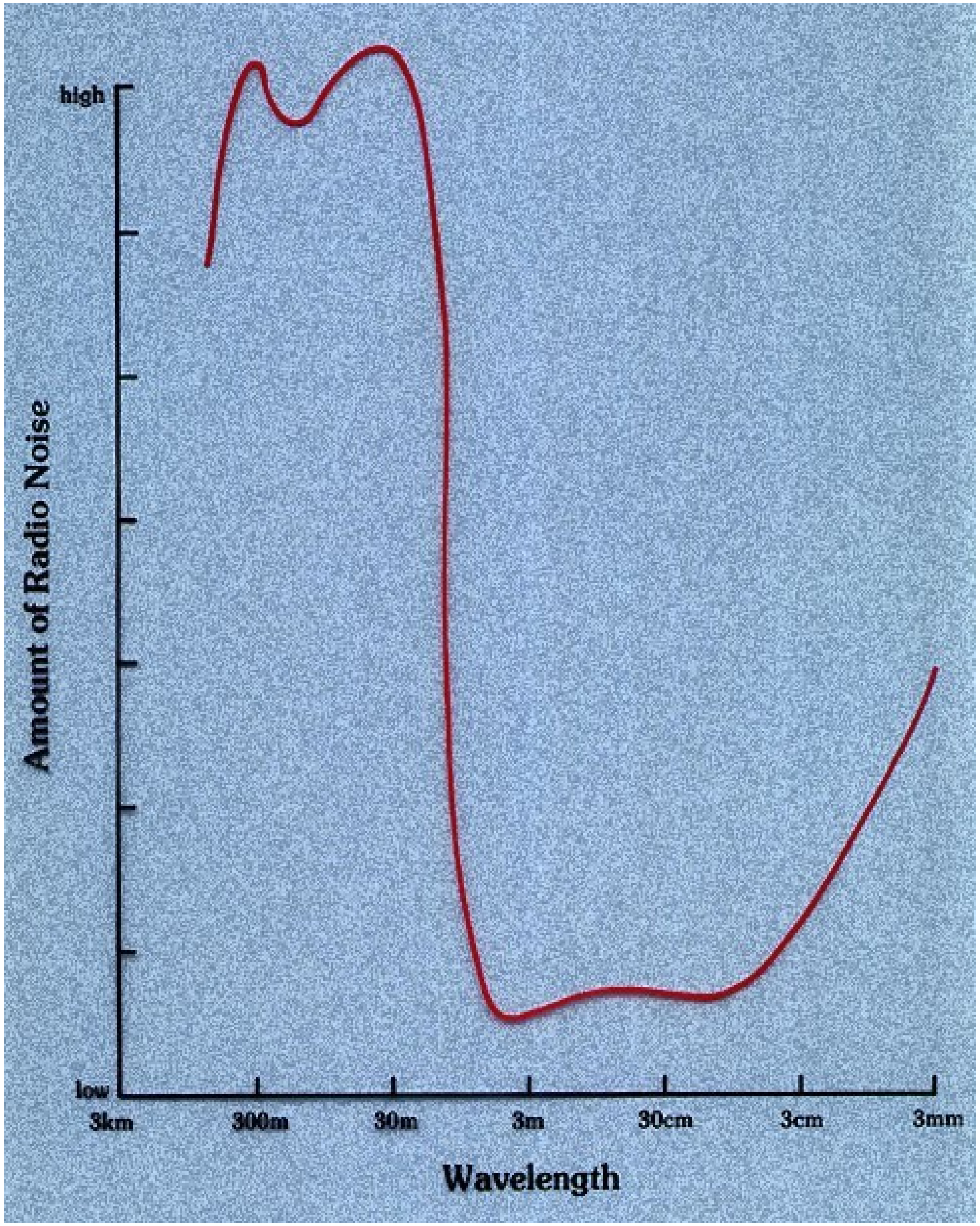
Jupiter has a strong magnetic field, which gives rise to huge Van Allen belts of (synchrotron) radiation around the planet, in addition to the thermal emission from the planet itself.





Observed and model images courtesy of NRAO/AUI andNASA/JPL.

Jupiter: radio spectrum



λ ~ 3cm: bremsstrahlung

= free-free in atmosphere

λ ~ 10cm: synchrotron

from magnetosphere

λ > 3m: radio bursts due to Io

building up a huge charge

(potential difference ~ 400,000 V)

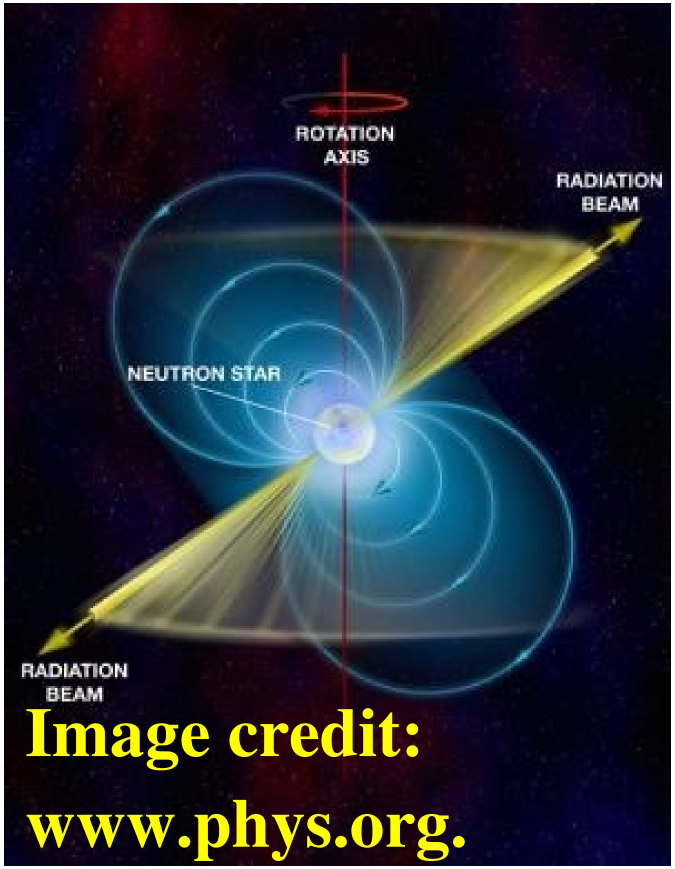
before violently discharging

Radio JOVE project

NASA has created antenna+receiver kits that can be used to detect meter-wave emission from Jupiter's radio storms. These have been assembled around the world (e.g., M. Dumitru, Mebourne).

Quiz

Stars outside the solar system: pulsars



Stars more massive than the Sun explode as supernovae when they reach the ends of their lives, often leaving behind a rapidly spinning neutron star that we can see as a pulsar.

Pulsars are laboratories for testing gravity

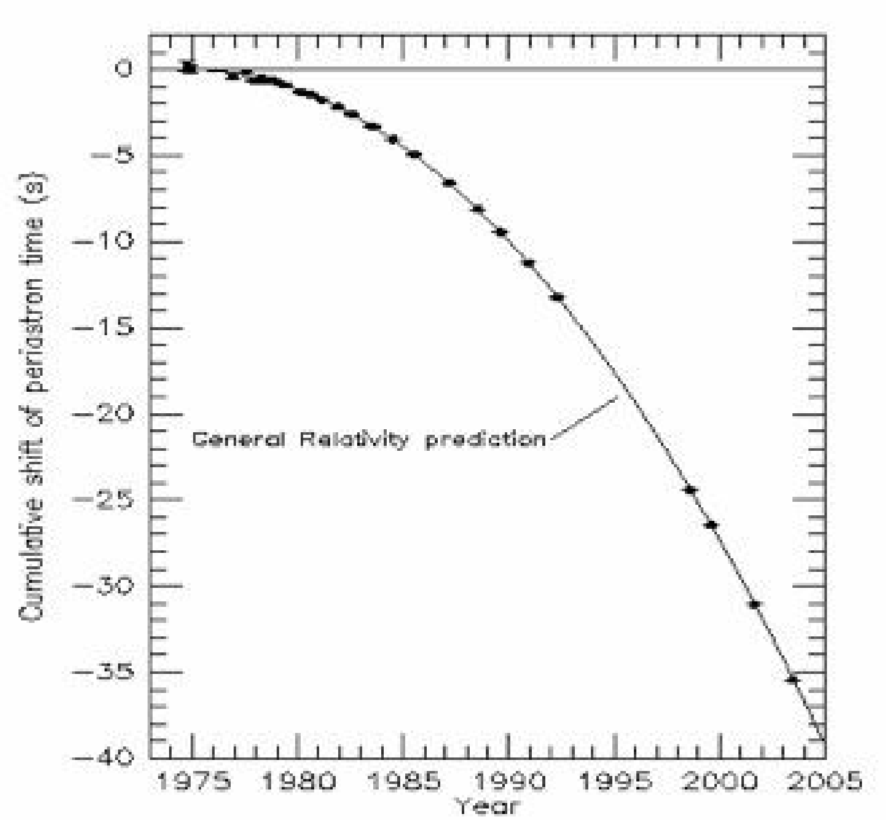
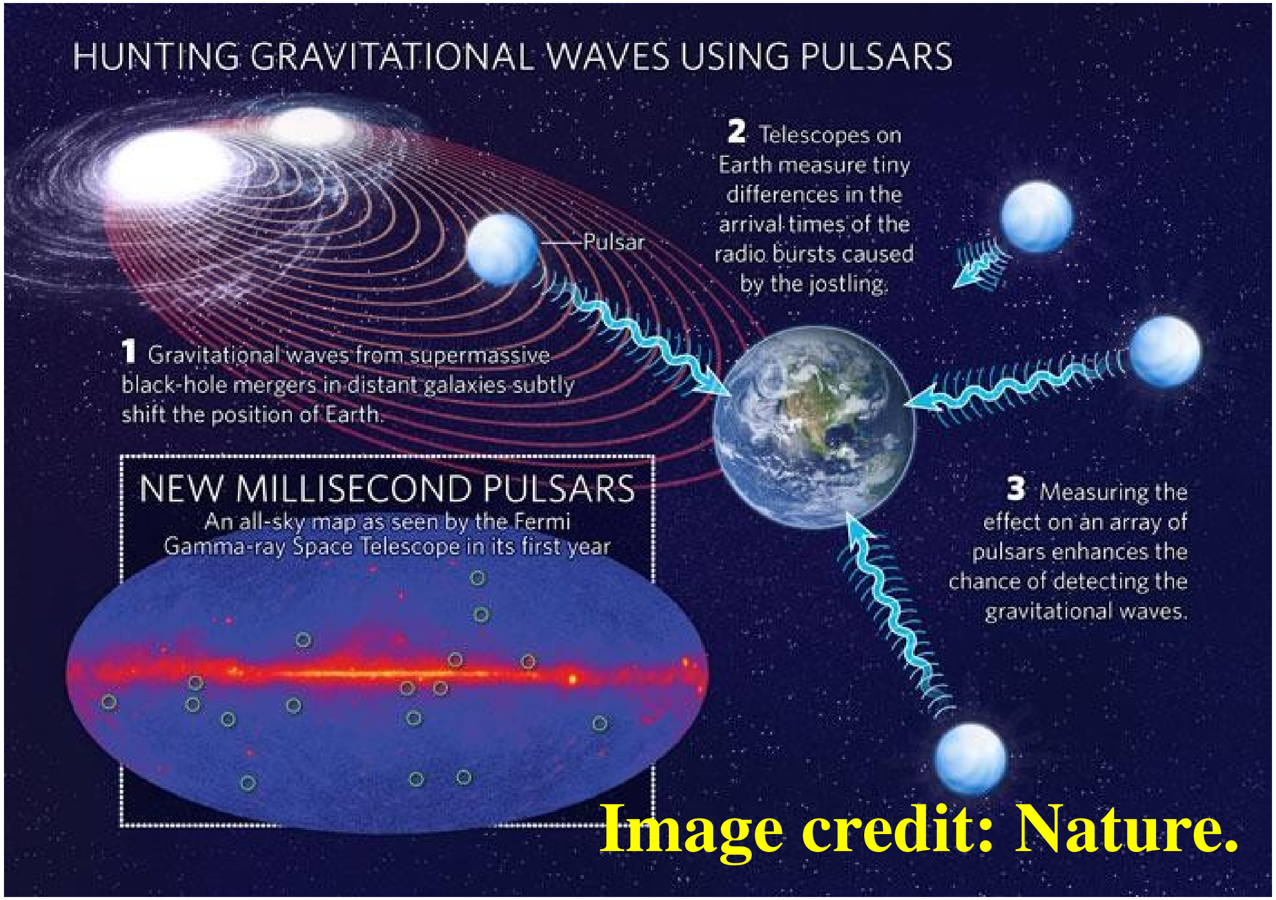


Figure from Weisberg & Taylor (2004) shows that change in orbit of PSR1913+16 with its stellar companion is consistent with prediction of general relativity. This work earned a Nobel prize in physics for Hulse and Taylor.

Can pulsar timing detect gravitational waves?



A network of exquisitely timed pulsars all over the sky can detect the gravitational wave signatures of massive black hole mergers in the centers of galaxies. Need a large sample and extended followup observations.

Astrobiology: a key driver for exoplanets

astrobiology (Lafleur 1941)
cosmobiology (Bernal 1952)
exobiology (Lederberg 1960)
bioastronomy (IAU 2004)

1941 definition by Lafleur: “consideration of life in the universe elsewhere than on earth”

1964 comment by Simpson: “this 'science' has yet to demonstrate that its subject matter exists!”

2008 definition by NASA: “study of the living universe”

Quantifying our ignorance...

UC Santa Cruz astronomer Frank Drake in Green Bank, WV

November 1960: a secret meeting in WV

Ten scientists met in Green Bank, WV to discuss the prospect for existence and detection of extraterrestrial life.

Location inspired by Drake's first SETI experiment.

Participants included astronomers, biologists, engineers, and a chemist whose Nobel Prize was announced during the meeting; nicknamed themselves “Order of the Dolphins.”

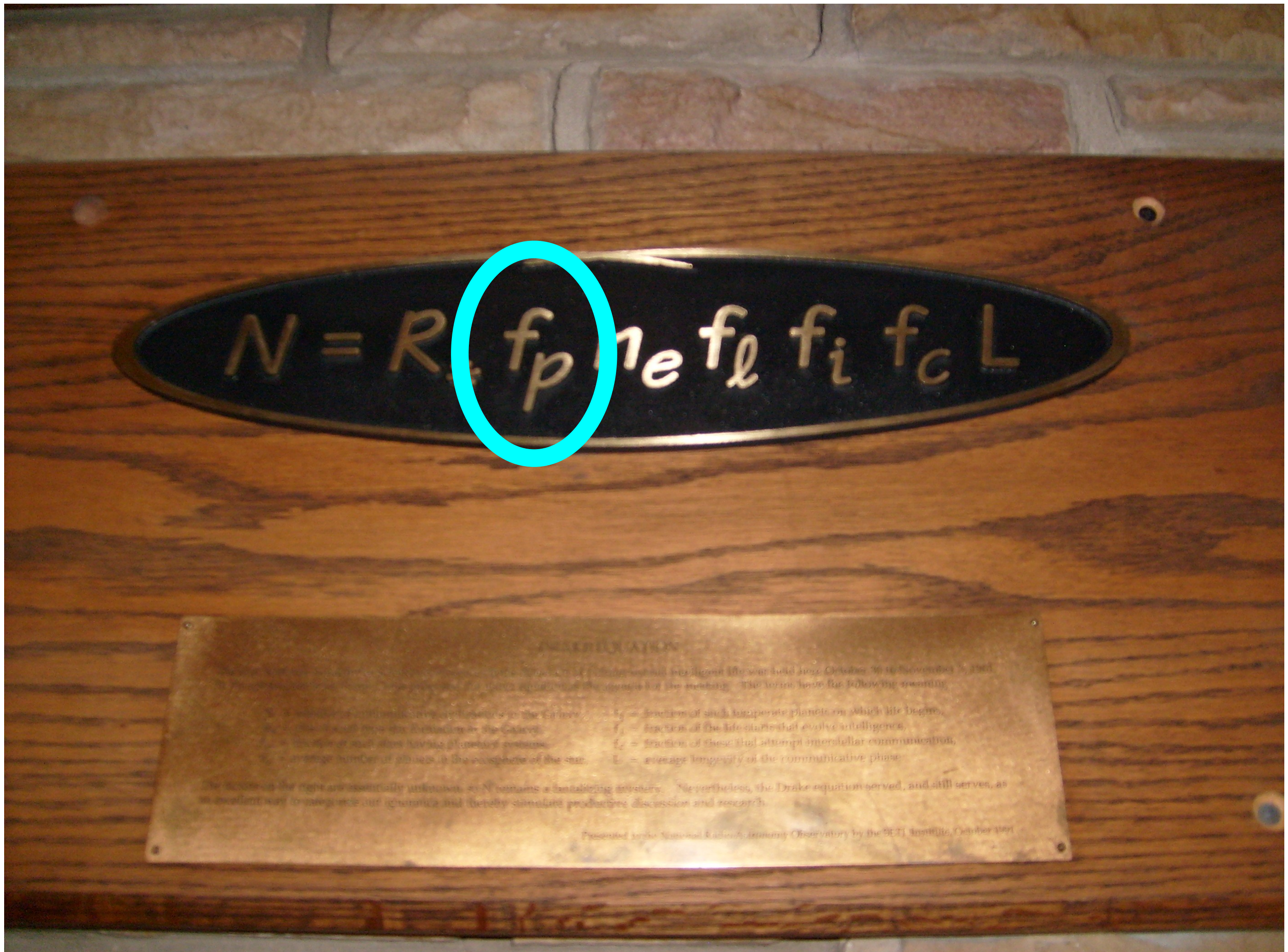
The Drake Equation

***N* = number of transmitting civilizations in the Milky Way**

The Drake Equation

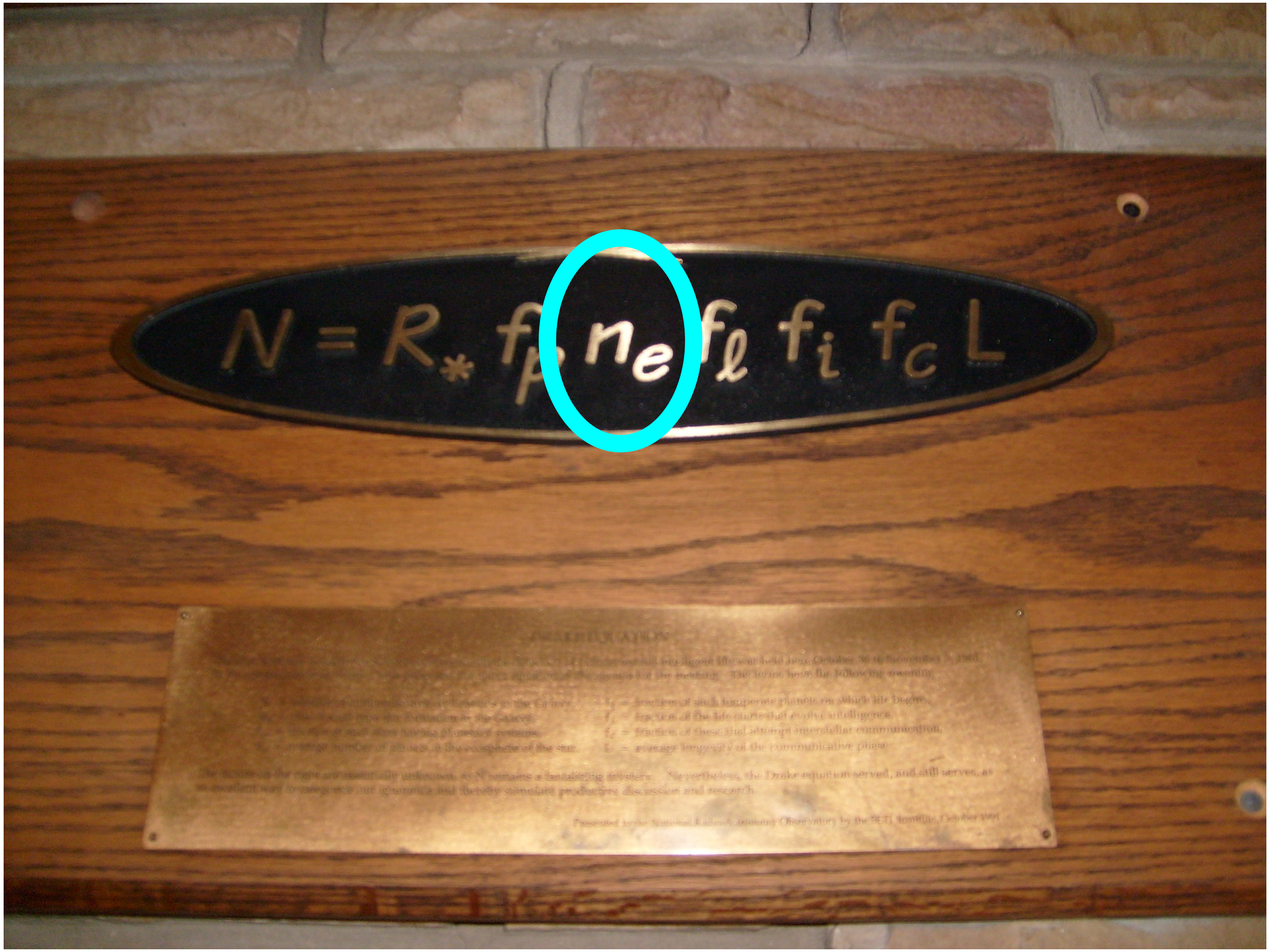
R_* = rate at which suitable stars form in Milky Way (yr^{-1})

The Drake Equation



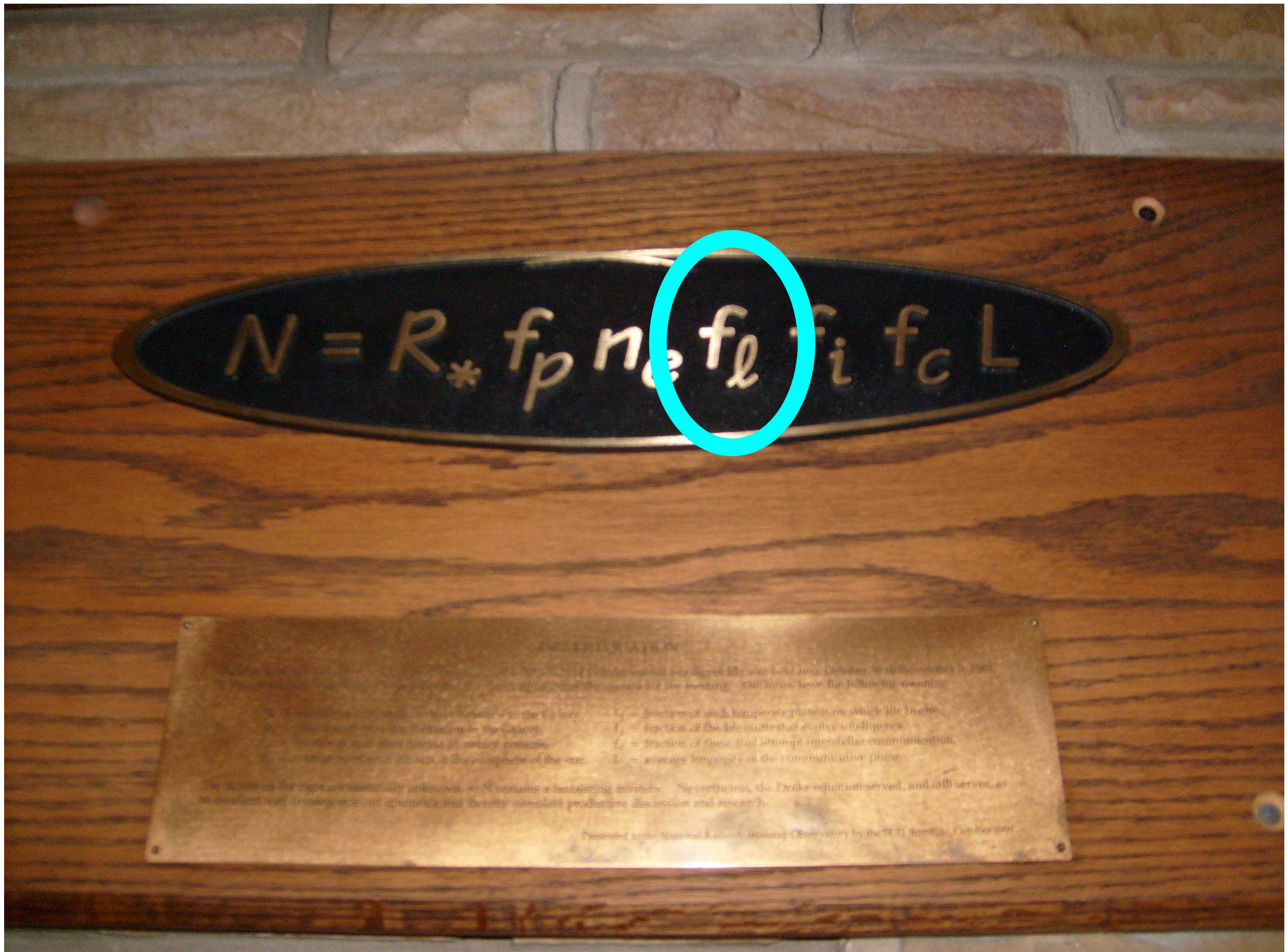
f_p = fraction of such stars that have planets

The Drake Equation



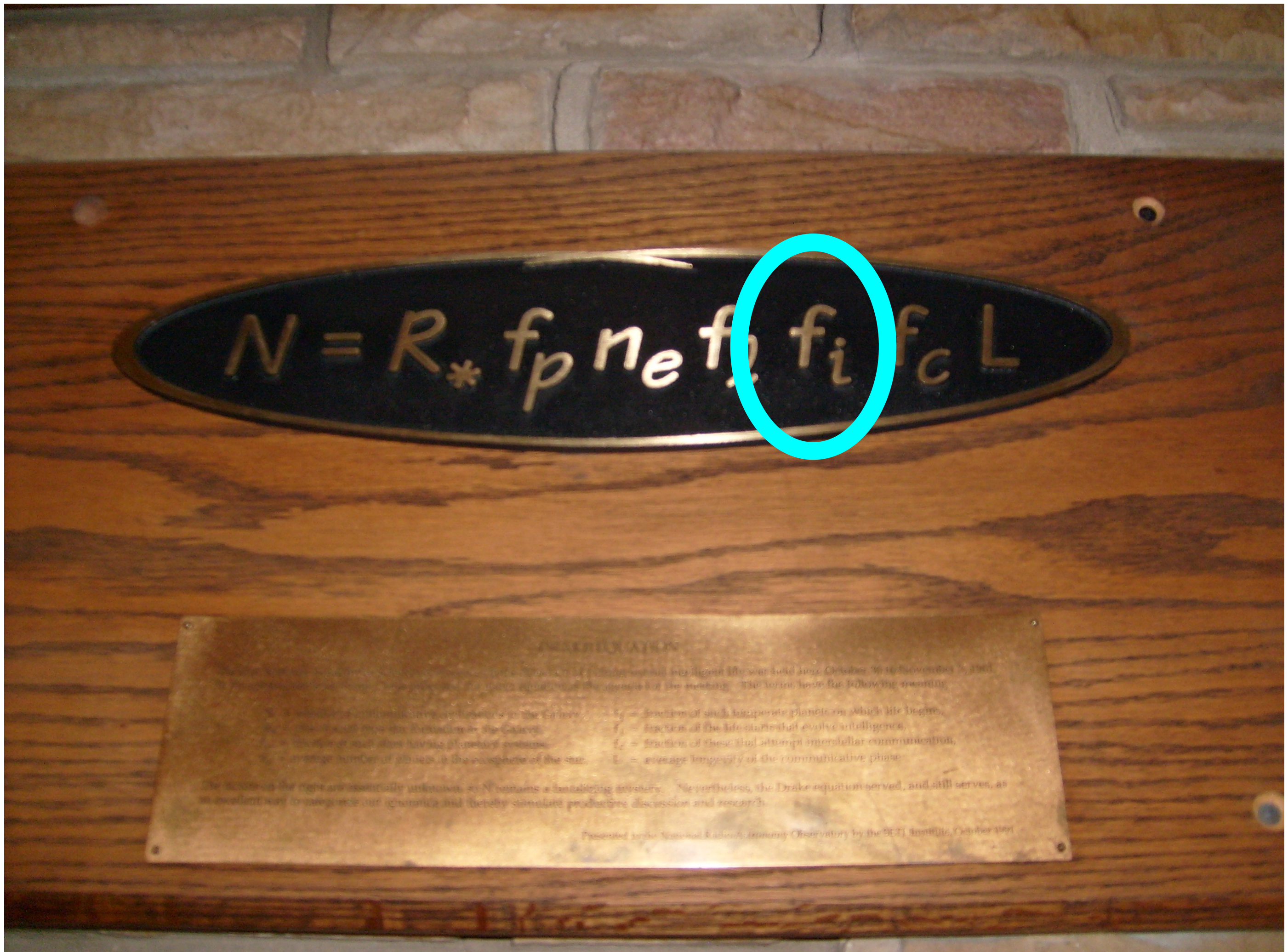
n_e = mean number of planets per solar system that *could* support life

The Drake Equation



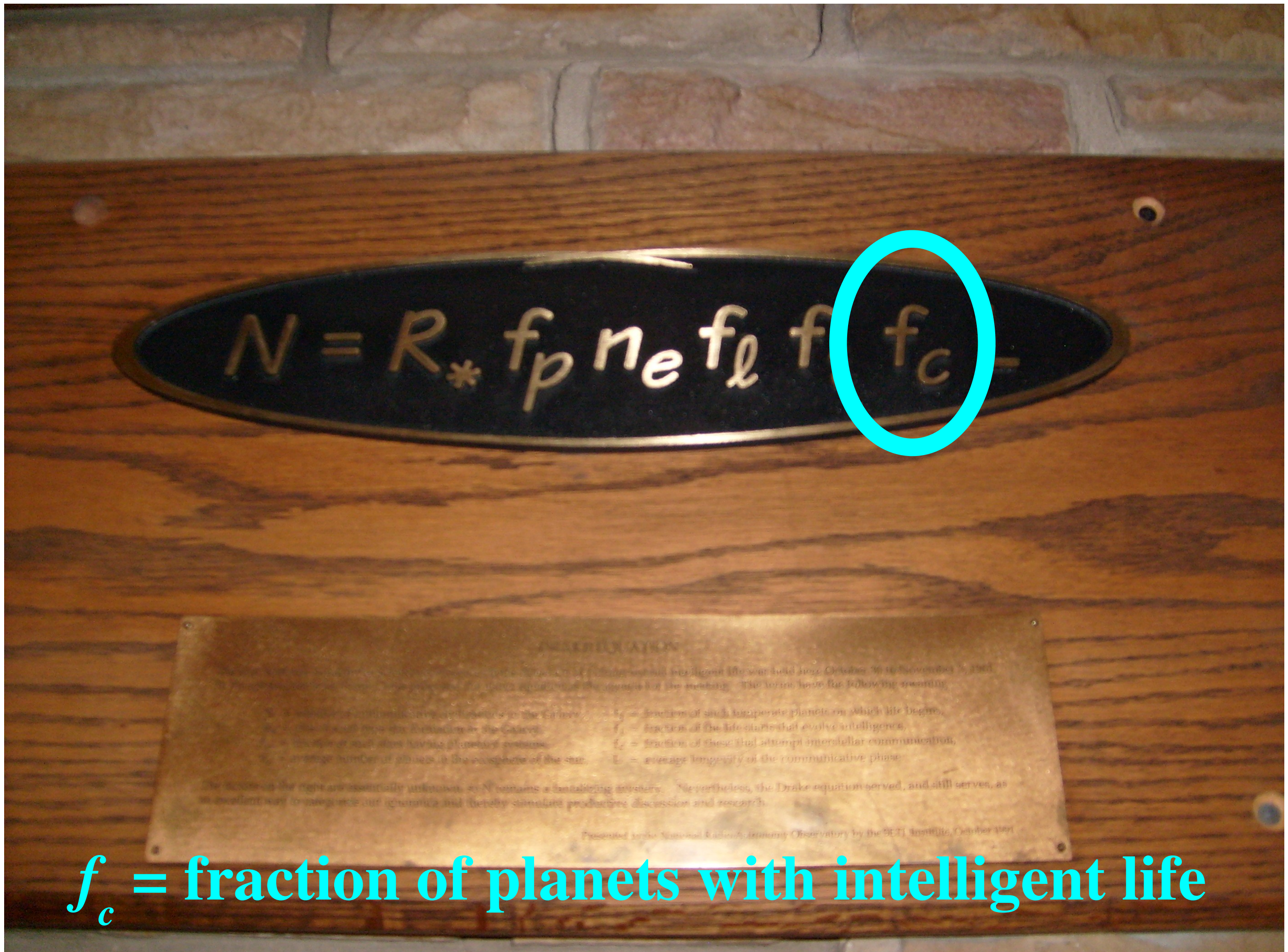
f_l = fraction of habitable planets on which life *did* evolve

The Drake Equation



f_i = fraction of planets with life on which intelligence evolved

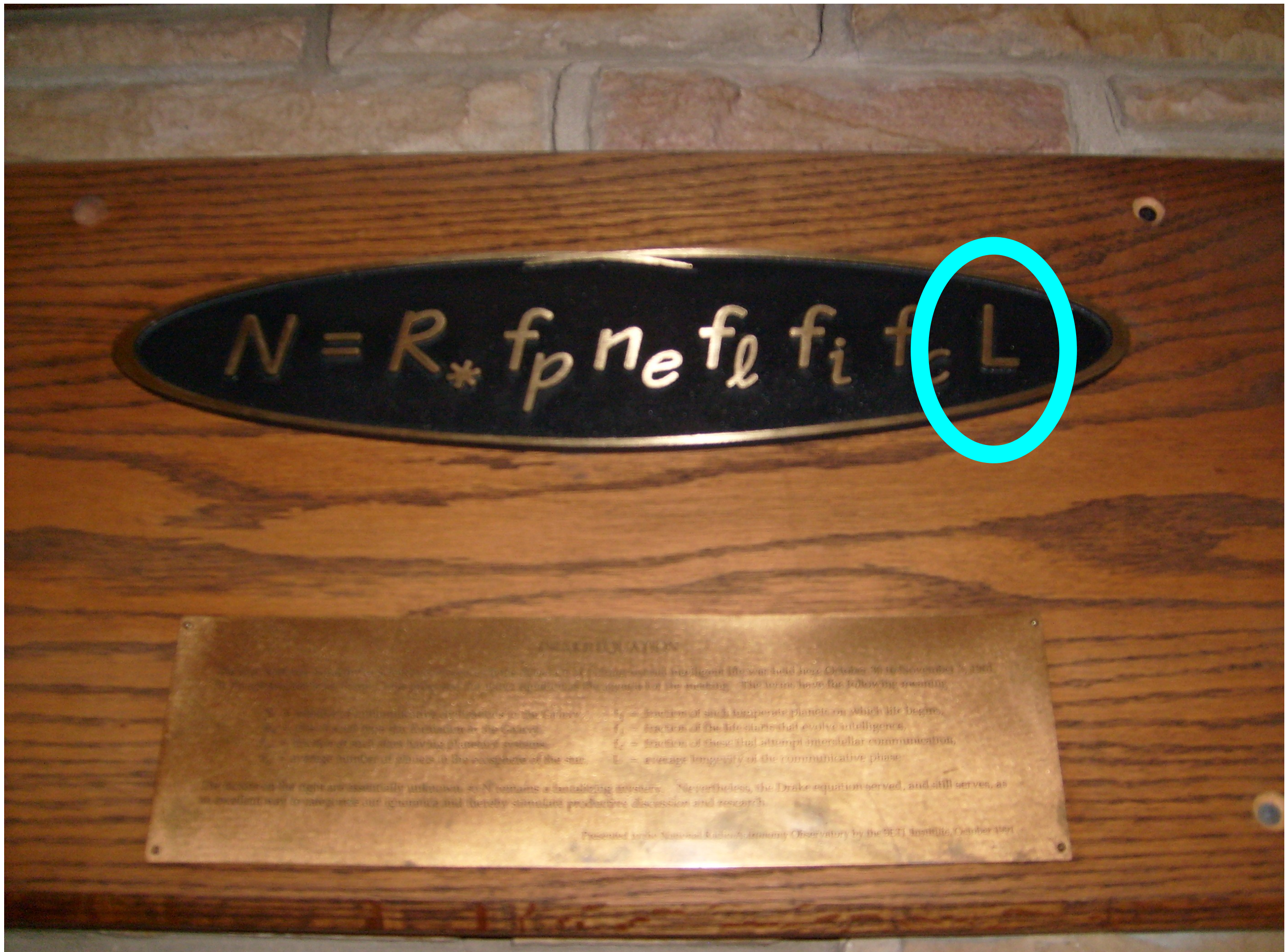
The Drake Equation



f_c = fraction of planets with intelligent life

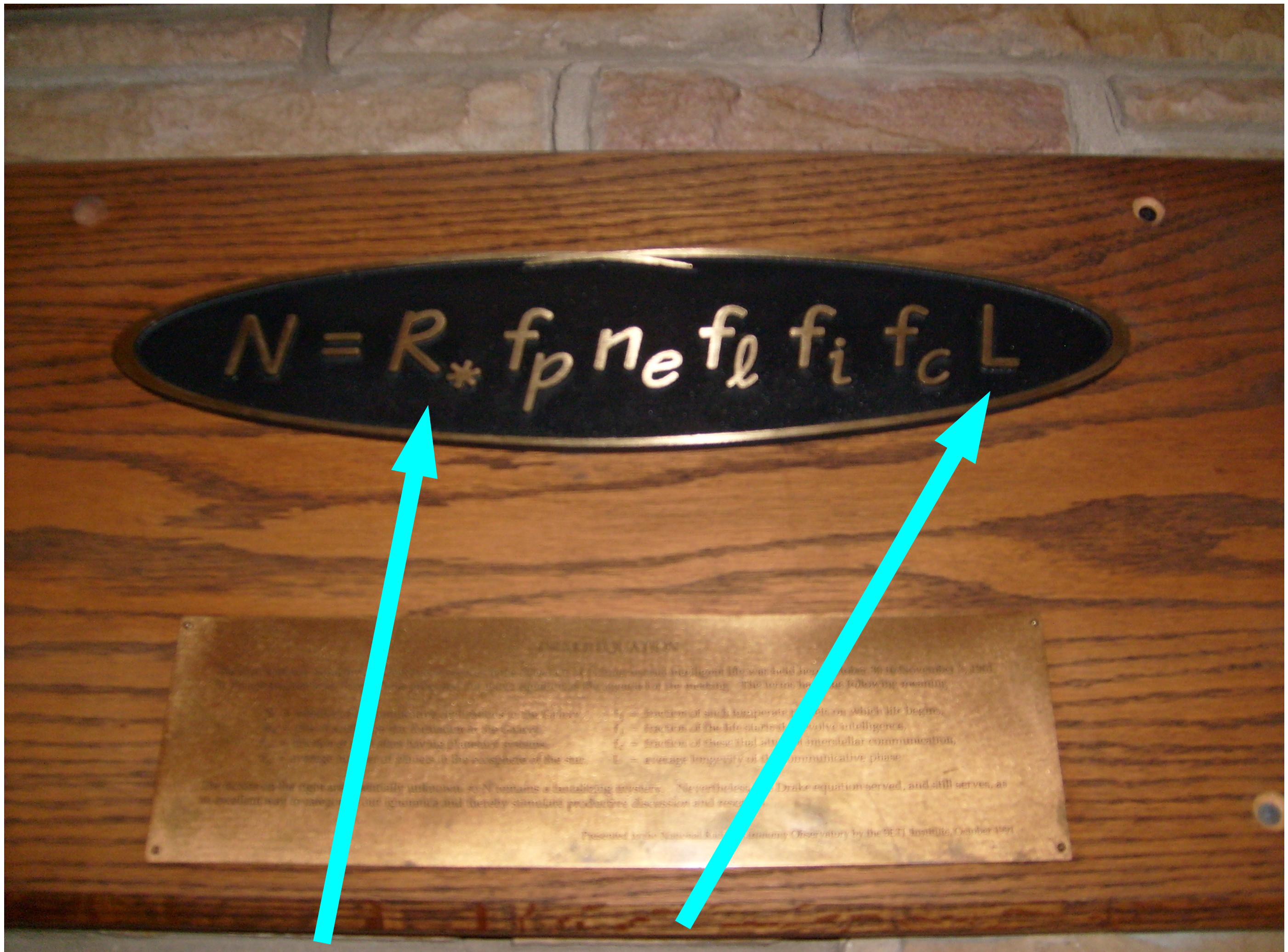
on which a transmitting *civilization* arises

The Drake Equation



***L* = mean lifetime of a transmitting civilization (yr)**

The Drake Equation



units: R_* ~ yr^{-1} and L ~ yr ⇒ N is dimensionless

What did Frank Drake guess in 1961?

$R_* \sim 10\ \mathrm{yr}^{-1}$

$f_p \sim 0.5$

$n_e \sim 2$

$f_l \sim 1$ $\Rightarrow N \sim 10$

$f_i \sim 0.01$

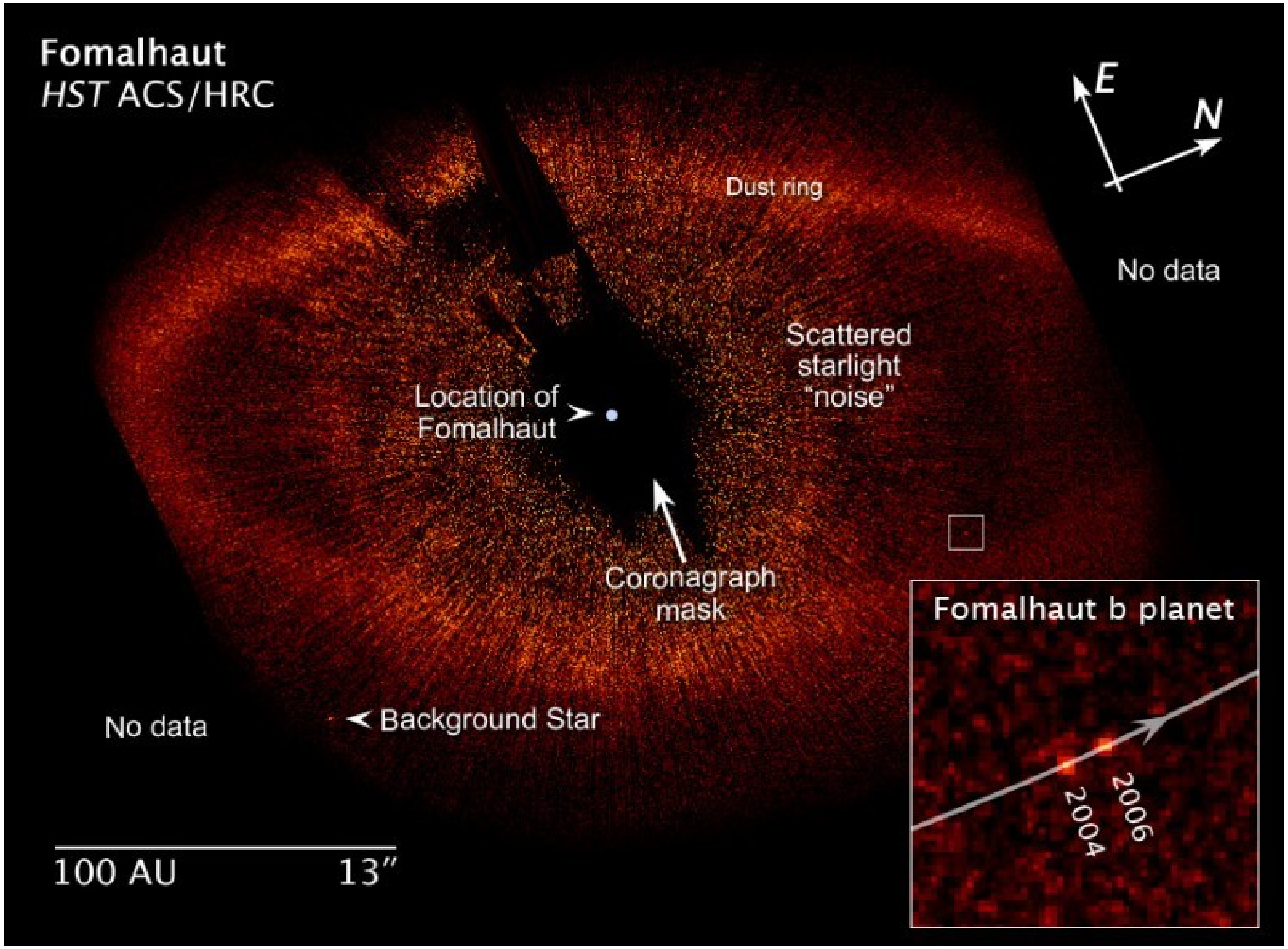
$f_c \sim 0.01$

$L \sim 10^4\ \mathrm{yr}$

Key value of the Drake Equation: highlights the fact that some factors are less certain than others!

Hunting for exoplanets: direct

Direct, high-resolution imaging (especially at infrared wavelengths where planet vs. star contrast is more favorable).



Courtesy NASA/ESA.

Hunting for exoplanets: indirect

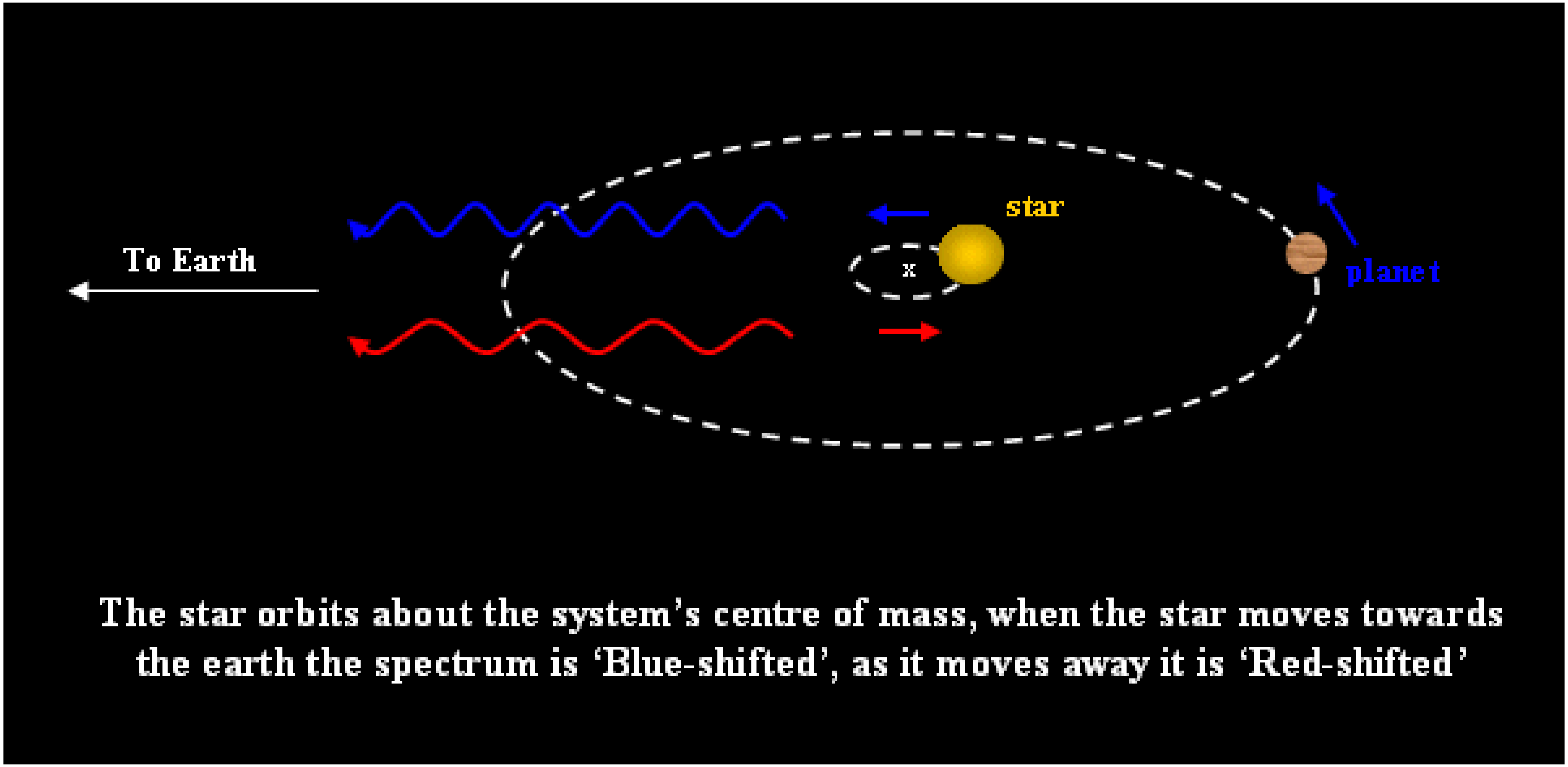
Astronomical jujitsu: turn a weakness (bright stars) into a strength!

(1) radial velocity method
(2) astrometric method

(3) microlensing method
(4) transit method

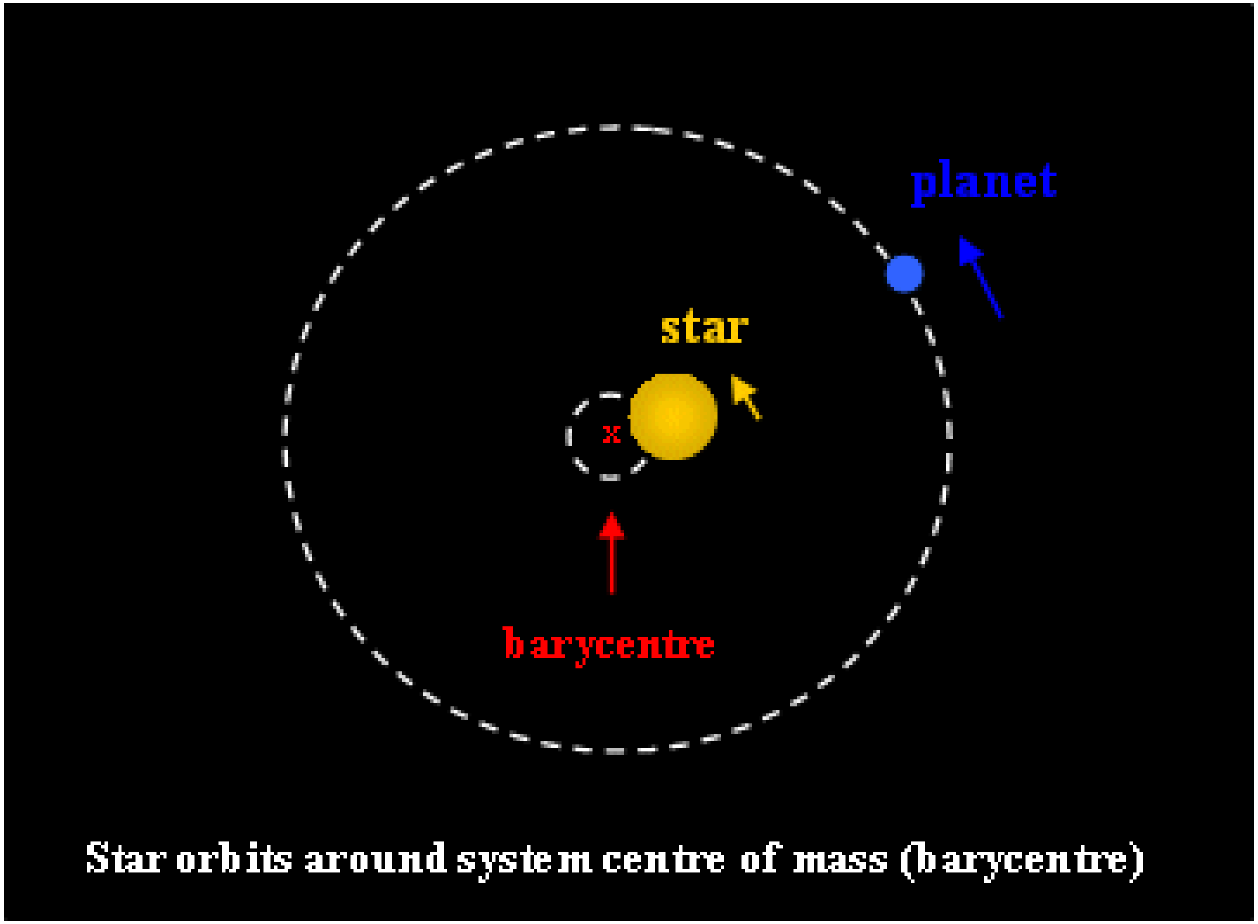
There are also other indirect methods that rely on observations of circumstellar dust disks.

Radial velocity method: basis of lab 5!



Courtesy SuperWASP.

Astrometry method



Courtesy SuperWASP.

Radio observations of *low-mass* stars

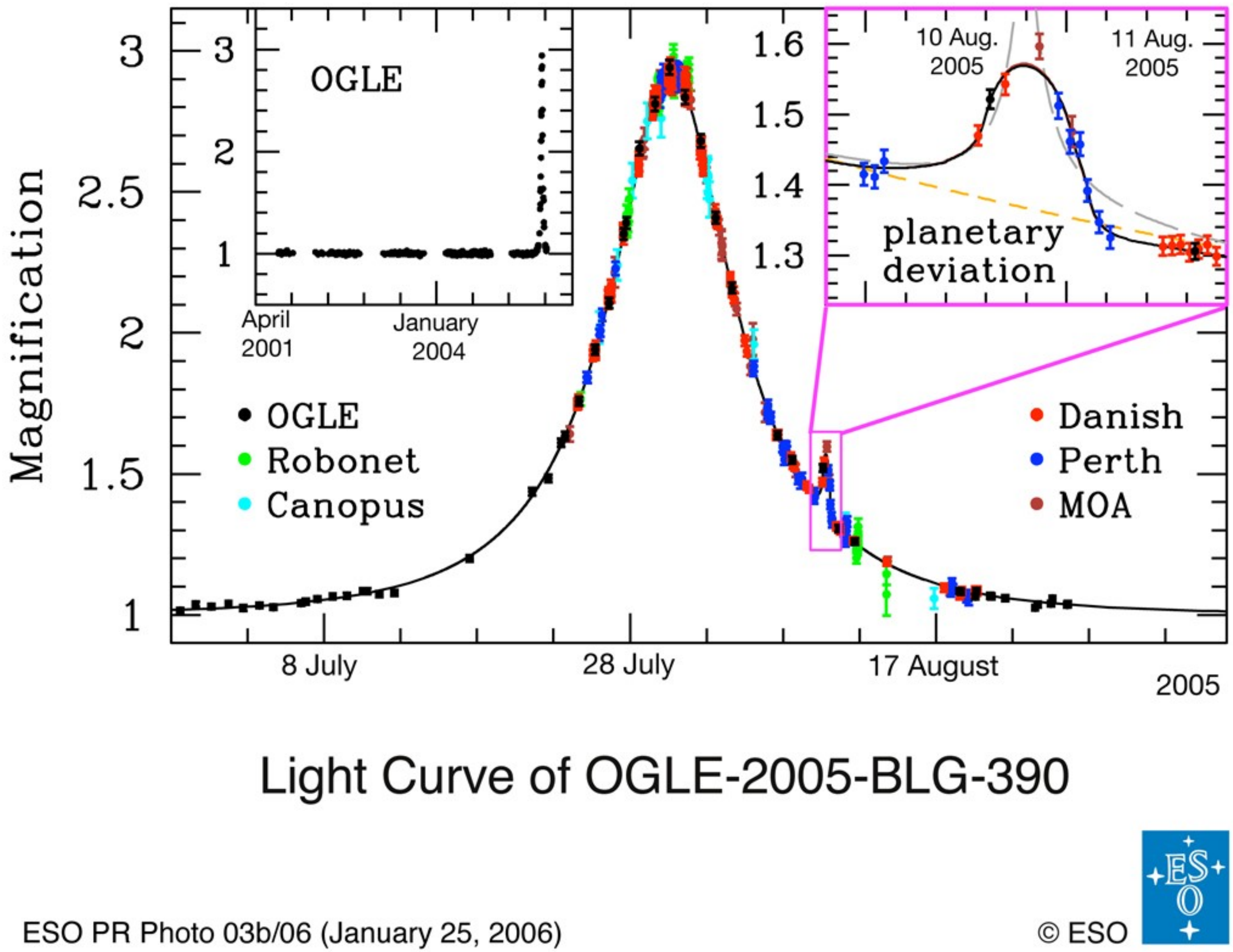
The Radio Interferometric Planet (RIPL) Search:
http://astro.berkeley.edu/~gbower/RIPL/

Use the VLBA+GBT to detect wobbles of stars due to planets in orbit about them.

Precision radial velocities measure wobble along line of sight.
Precision astrometry measures wobble in plane of sky.

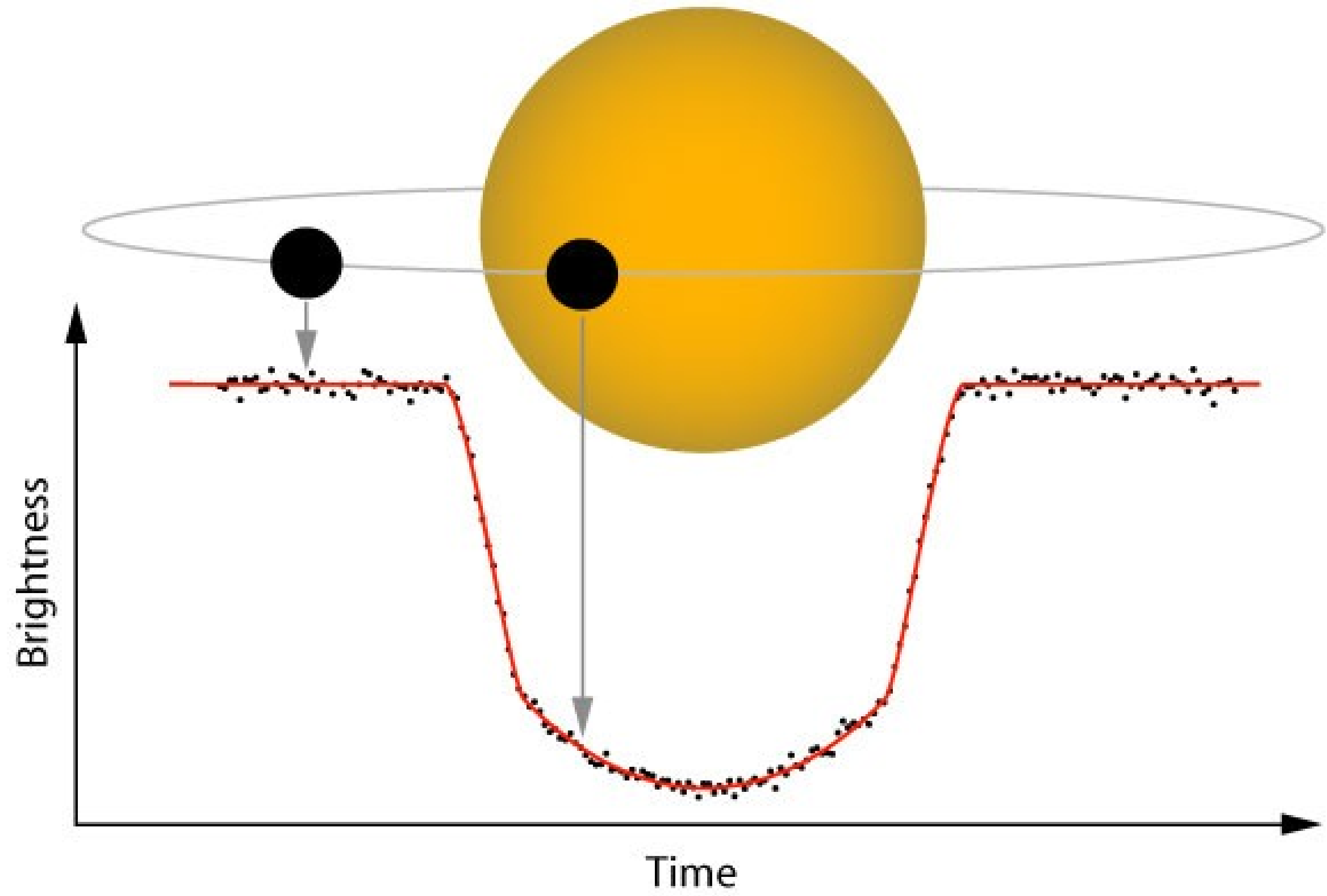
RIPL is looking for companions to lower-mass stars than can be studied with radial velocities.

Microlensing method



Courtesy ESO.

Transit method

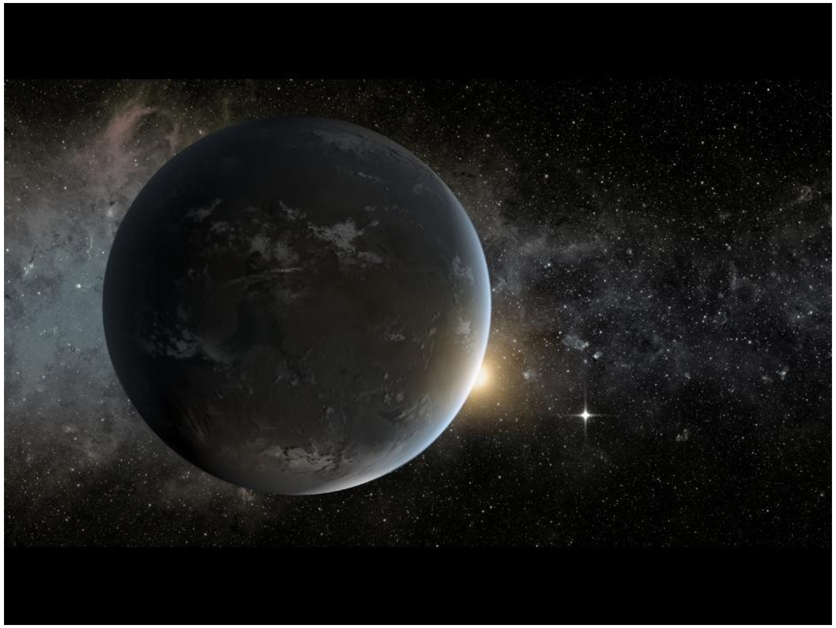


Courtesy U. Michigan.

The *Kepler* mission

Initial mission repeatedly observed one patch of sky in the constellation Cygnus. Extended mission observing larger areas towards Leo, Virgo, Scorpius (at lower precision).

Current totals: 1023 confirmed planets, 4175 additional candidates.

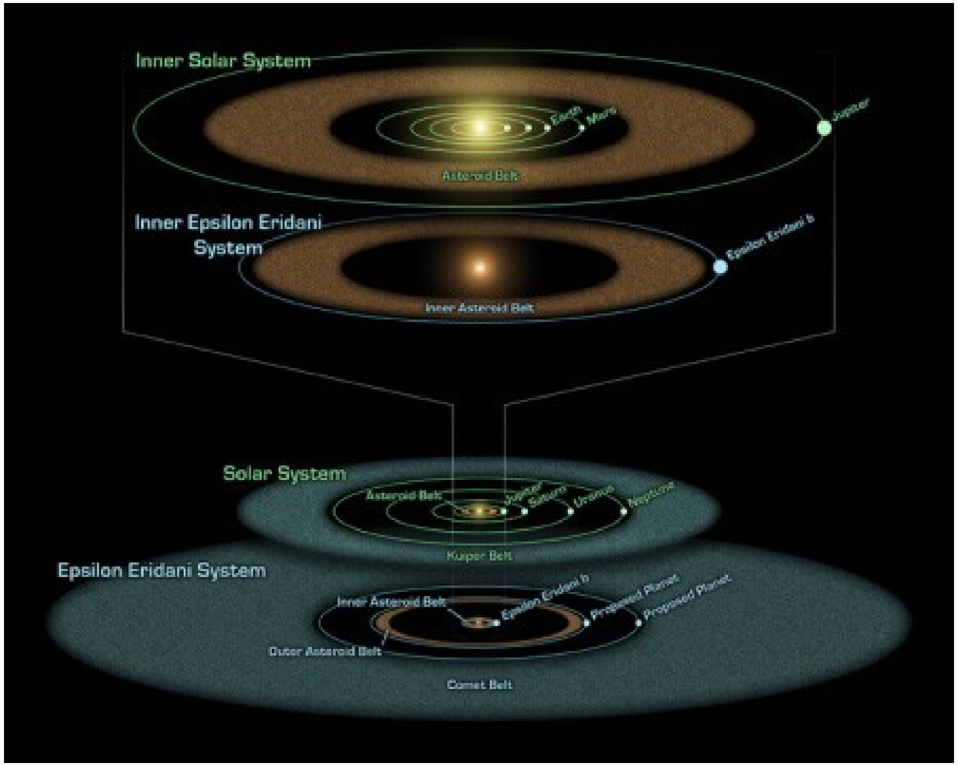


Artist's impression of Kepley-62f, courtesy NASA:

40% larger than Earth, 267-day orbit, in habitable zone!

Epsilon Eridani: an early Ozma target

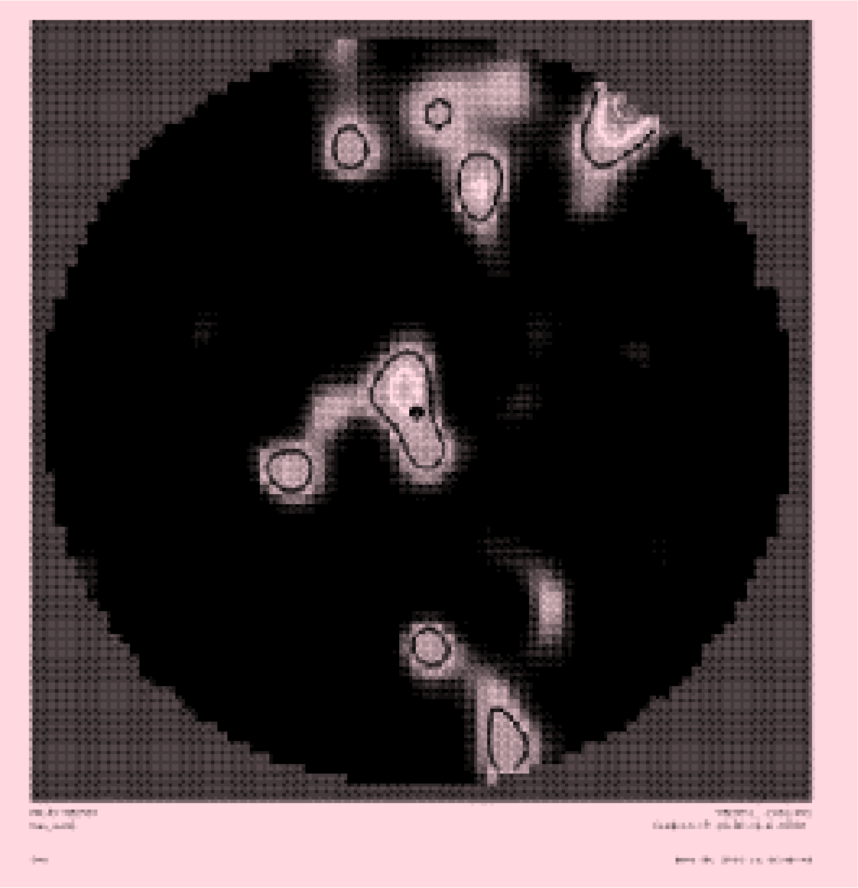
Bumps in dust spectrum imply existence of two asteroid belts confined by three planets (one also seen in radial velocities) and an icy quasi-“Kuiper belt”... but only 850 Myr old, so no time for intelligent life to develop (Backman et al. 2008).



Courtesy NASA/JPL.

Tau Ceti: another early Ozma target

No evidence for planets in radial velocity searches, but submillimeter photometry indicates a debris disk ten times as massive as our Kuiper belt... which presumably implies a ten-times-higher rate of major impacts than what the Earth suffers.



Greaves et al. (2004)