

(Astro)Physics 343 Lecture # 5:

Sun, Stars, and Planets; Fourier Transforms

Schedule for the next week

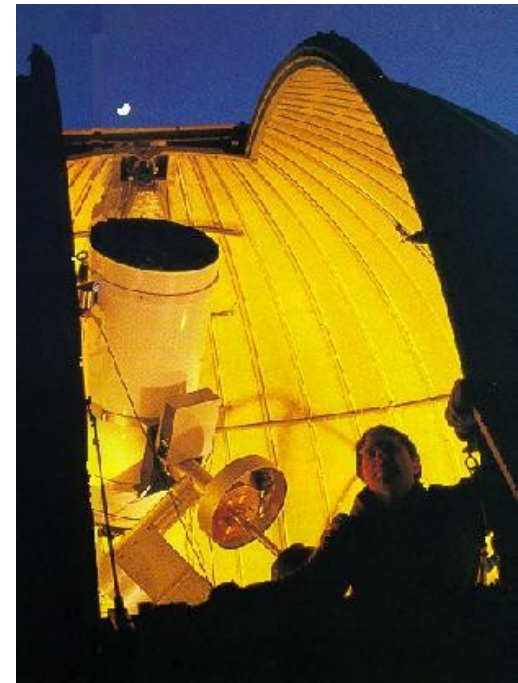
**Office hours: Mon 5:00-6:20pm = Baker; Thu 3:20-4:40 = Lindner
+ Sections A, B, F = Baker; Sections C, D, E = Lindner
I will email about availability of graded Lab # 1.**

Next Monday:

Lab # 2 due (data emailed today).

**Guest instructor: Prof. Tad Pryor,
speaking on radio observations of
the interstellar medium.**

**Next week: Lab # 3 will be at regular times
(Sections A, B, C, D, E, F = Lindner).**



Visiting SPS speakers

Monday, 2/21 at 12:00pm in Serin 401:

Dr. Elena D'Onghia (Harvard)

“Interactions between the Milky Way Halo and the Disk”

Thursday, 2/24 at 12:00pm in Serin 401:

Dr. Ian McCarthy (Cambridge)

“The Universe is a Strange Place”

Monday, 2/28 at 12:00pm in Serin 401:

Dr. Dušan Kereš (Berkeley)

“Universe in a Box”

Free pizza and soda for all who attend!

Lab # 2: an update

First part of lab: you should have received your data by email if you did not already get them in lab last week.

Second part of lab: data will be distributed later today.

Day # 1: no problems (except perhaps Section C)

Day # 2: no problem

Day # 3: data lost (high winds caused telescope to get stuck)

Day # 4: no problems

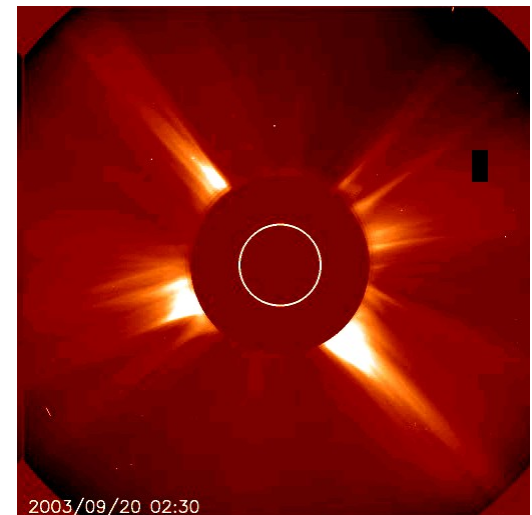
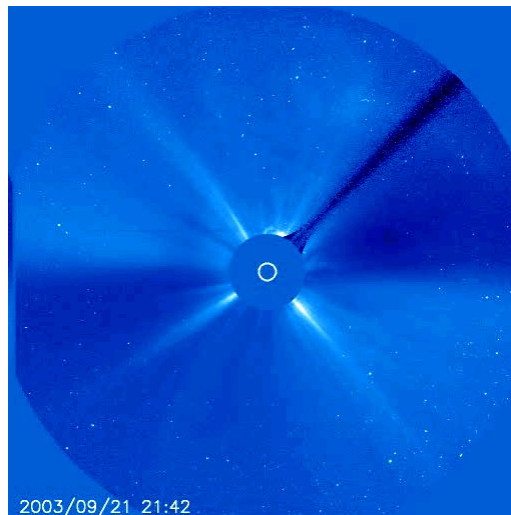
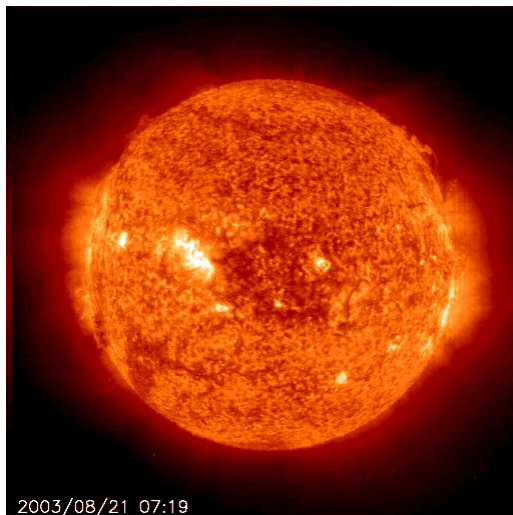
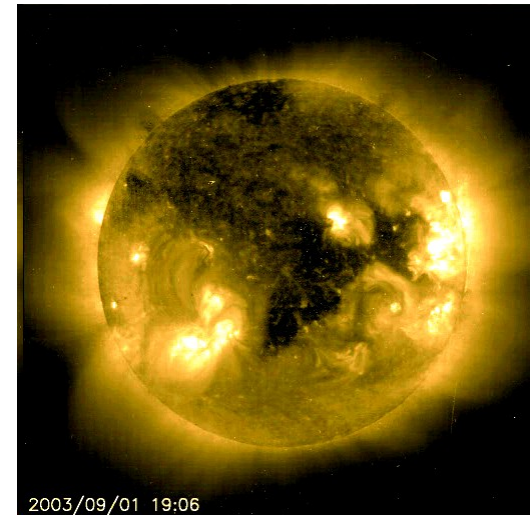
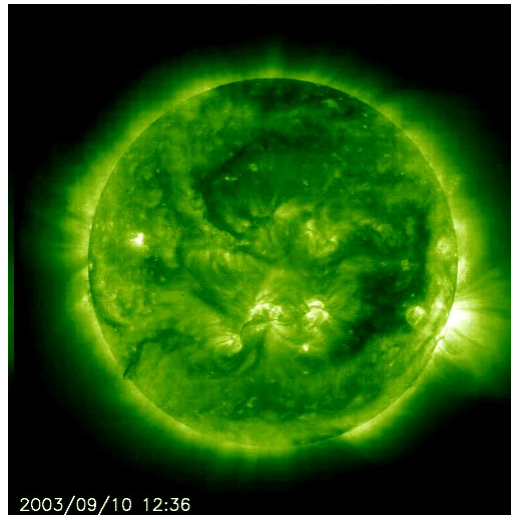
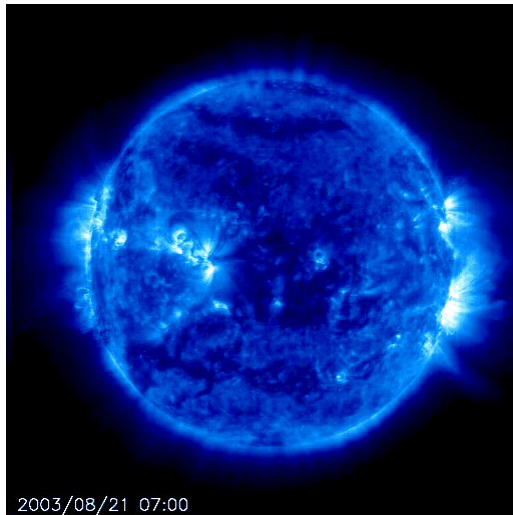
Day # 5: running now

Size, mass, and distance of the Sun

	Earth	Jupiter	Sun
Diameter	12,700 km 7,900 mi	140,000 km 87,000 mi	1,400,00 km 865,000 mi
Mass	6.0×10^{24} kg	1.9×10^{27} kg	2.0×10^{30} kg
Distance From Sun	150×10^6 km 93×10^6 mi	778×10^6 km 483×10^6 mi	---
Period	3.156×10^7 s 1 year	3.74×10^8 s 11.9 years	---

**13 – 80 times larger to be a “brown dwarf”
capable of fusing deuterium.**

Solar activity as seen in UV by SOHO

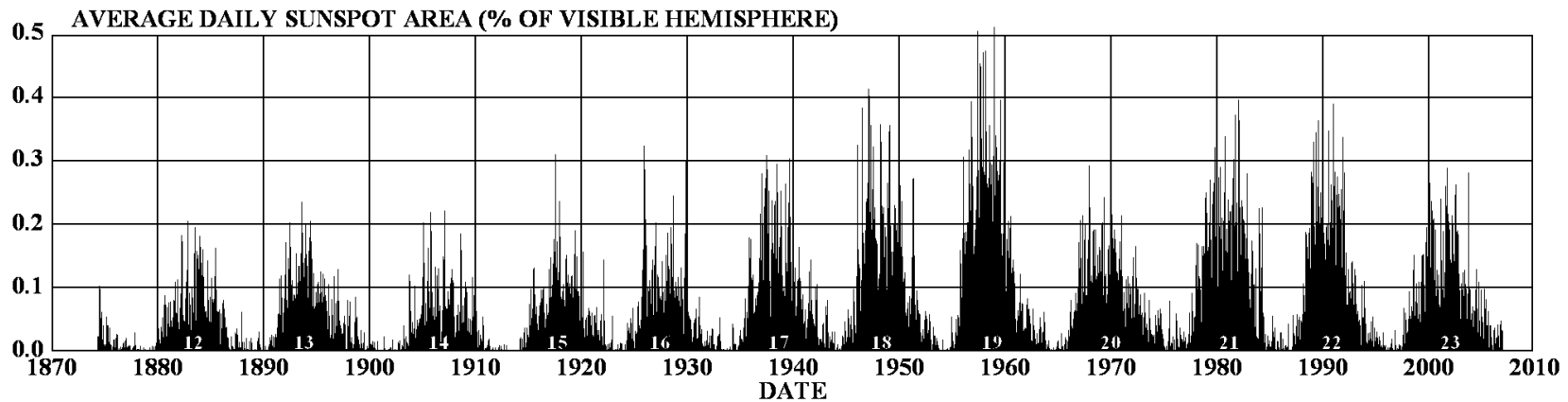
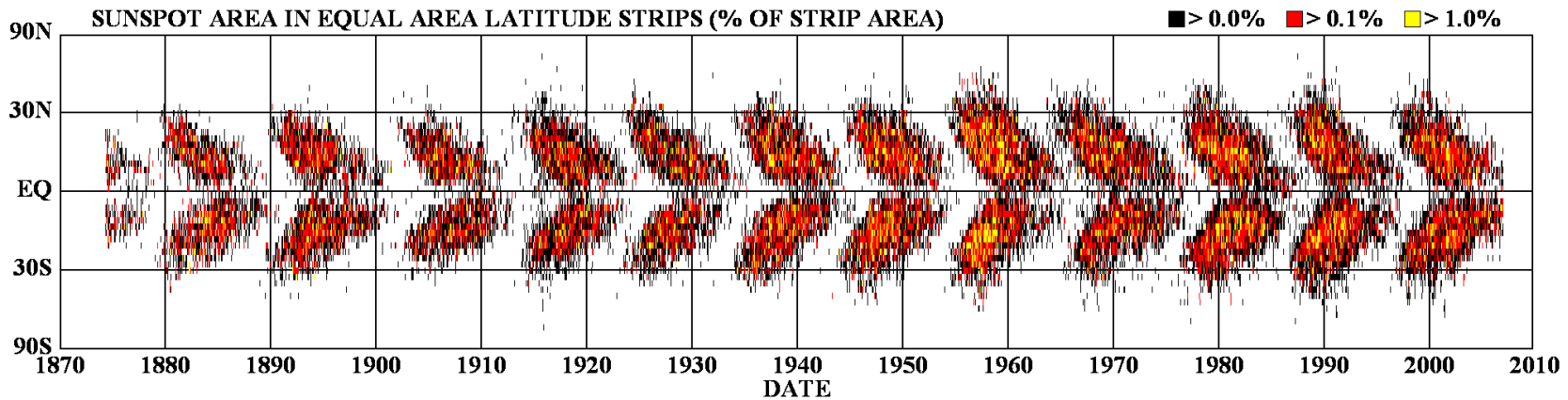


SOHO = Solar and Heliospheric Observatory (NASA + ESA)

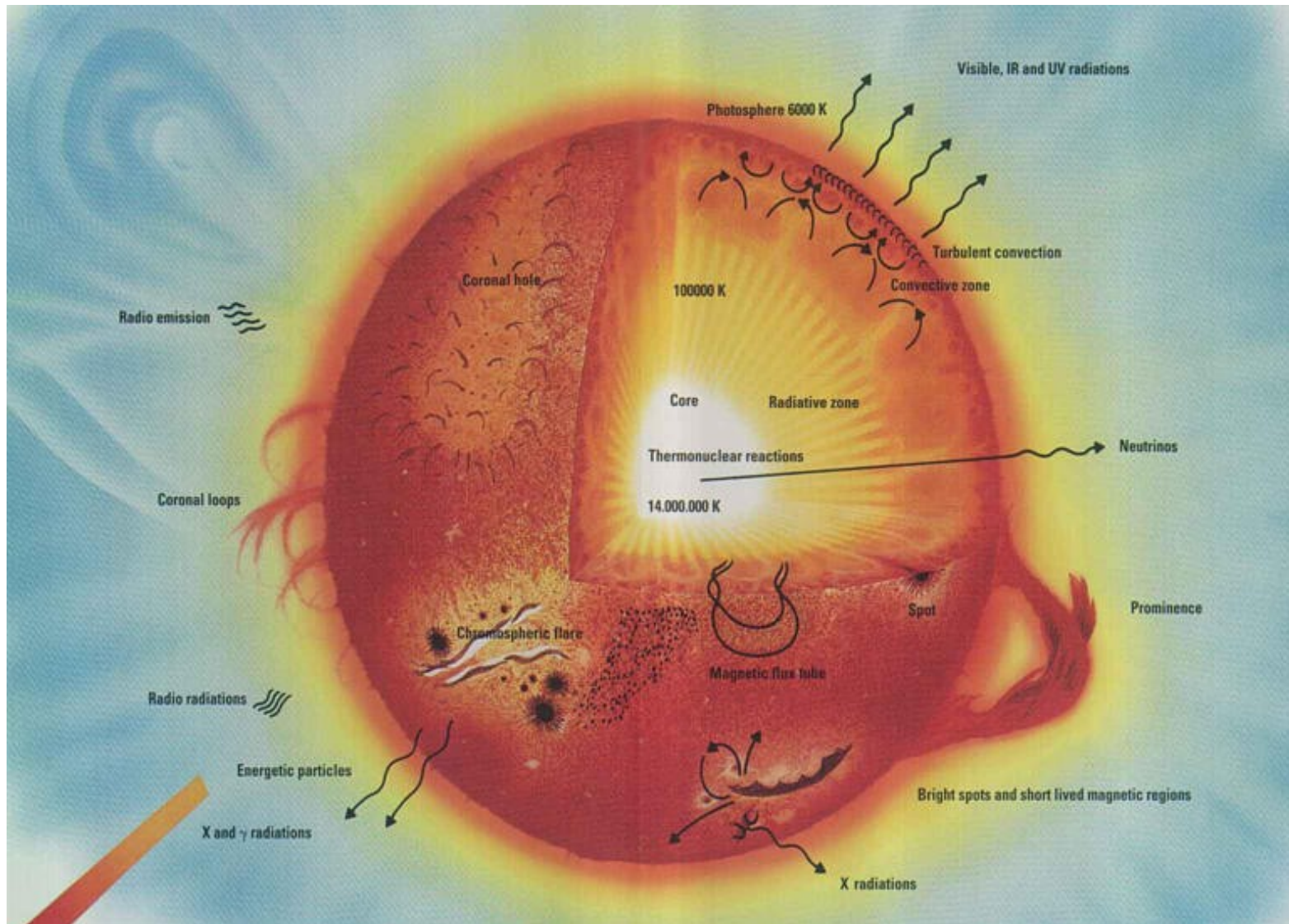
<http://sohowww.nascom.nasa.gov/data/realtime/mpeg/>

Long-term sunspot cycle = 11 years

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



Structure of the Sun



The Sun: a few numbers

- + 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 $T \sim 4500$ 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**.

Temperature at and above Solar surface

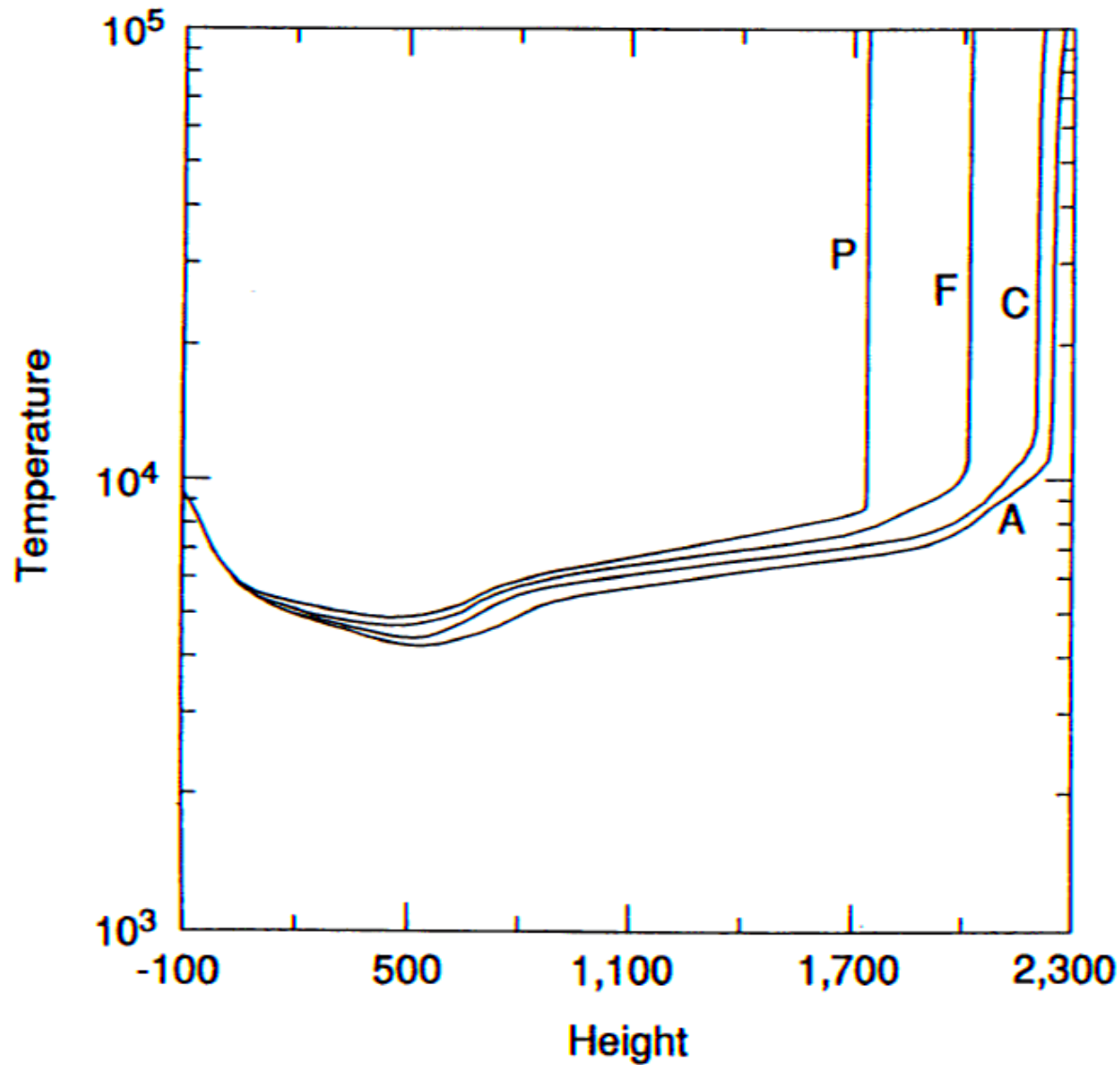


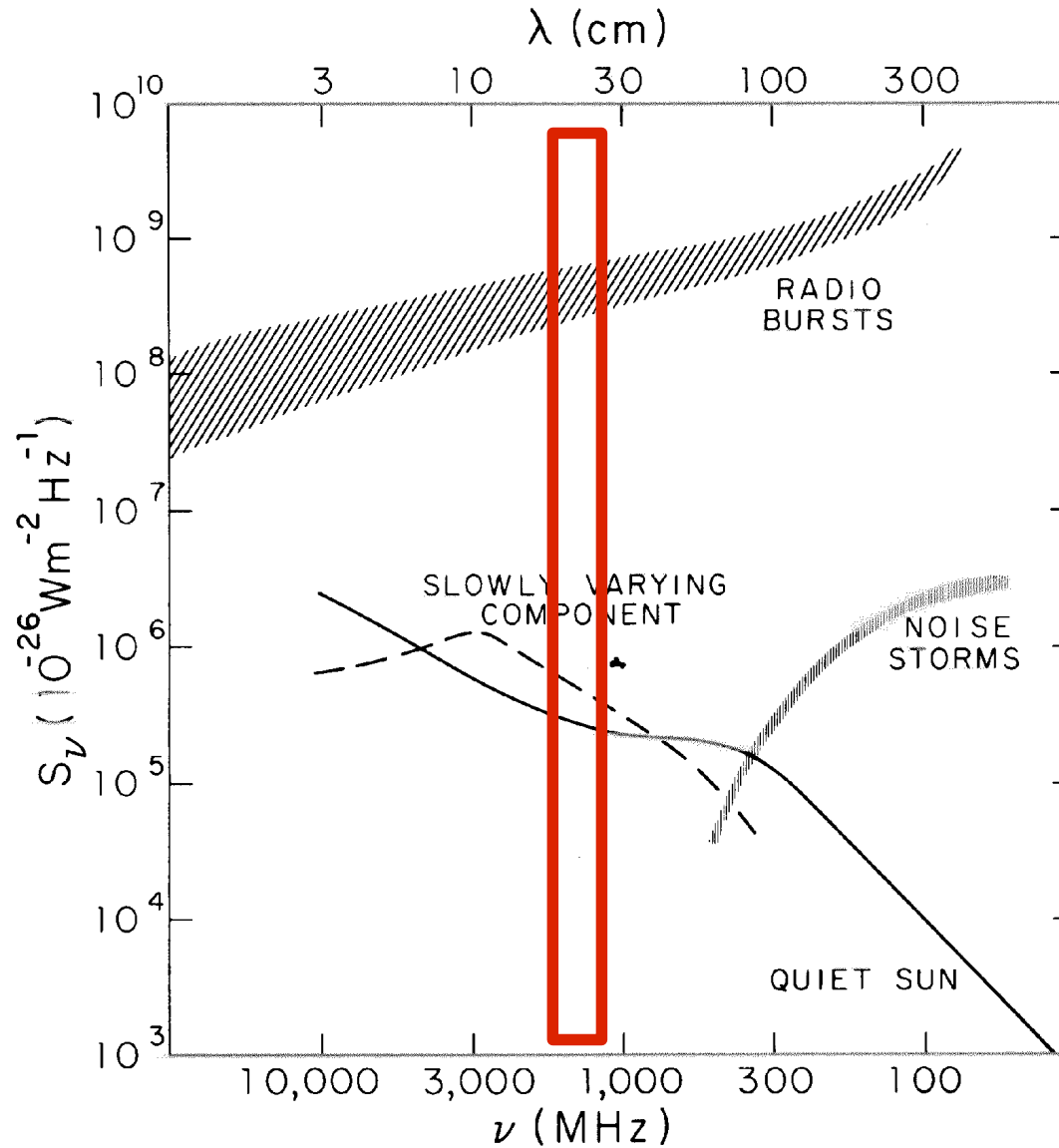
FIG. 3.—Temperature structure of our models A, C, F, and P. The height is measured in kilometers from the level; the temperature is in kelvins.

Radio emission from the Sun

Composition of the Sun:

- + The matter in the Sun is mostly hydrogen and helium.**
- + The physical state of this matter is a plasma:**
 - an ionized gas of electrons (- charge) and ions (+ charge).**
- + There are four broad categories of radio waves from the Sun:**
 - quiet Sun emission**
 - slowly varying component**
 - noise storms**
 - bursts**

Intensity vs. frequency of solar emission



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

Quiet Sun emission

**Radio emission from the “quiet” Sun is always present,
and it is relatively stable in time.**

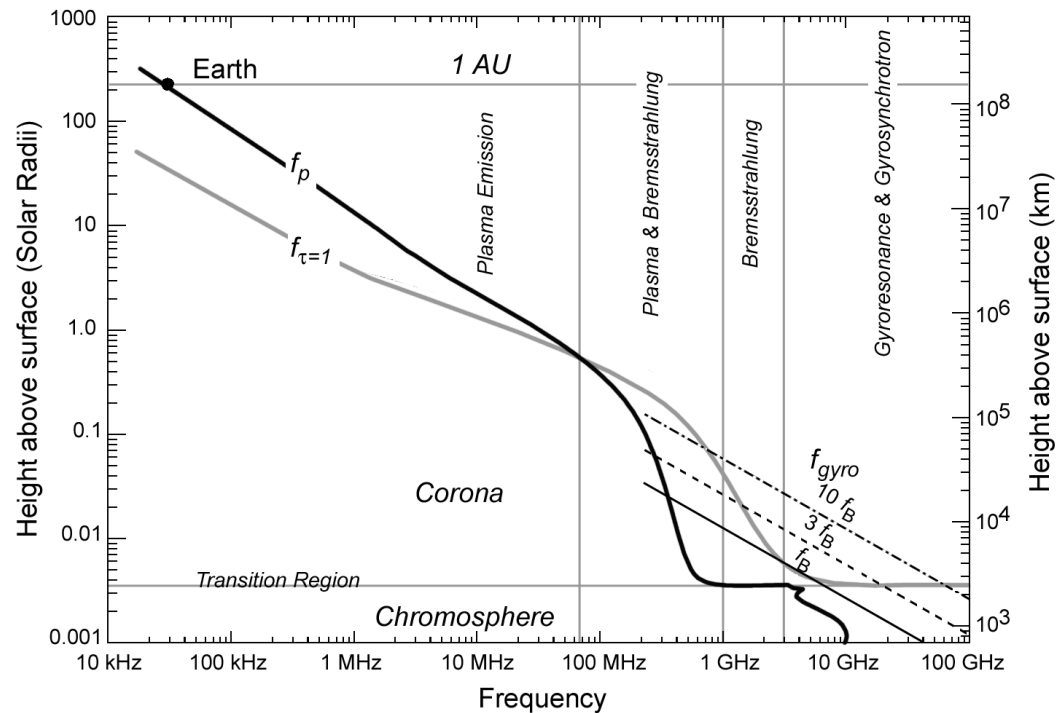
**The mechanism is thermal bremsstrahlung,
i.e., “braking” radiation due to collisions
between particles in or near Sun’s outer surface.**

Quiet Sun processes

Electron density n_e tends to increase with altitude above solar surface.

Observations at different frequencies tend to “see” different depths.

Higher frequency = deeper penetration into Sun’s surface.



Highest curve: emission mechanism dominant at each frequency.

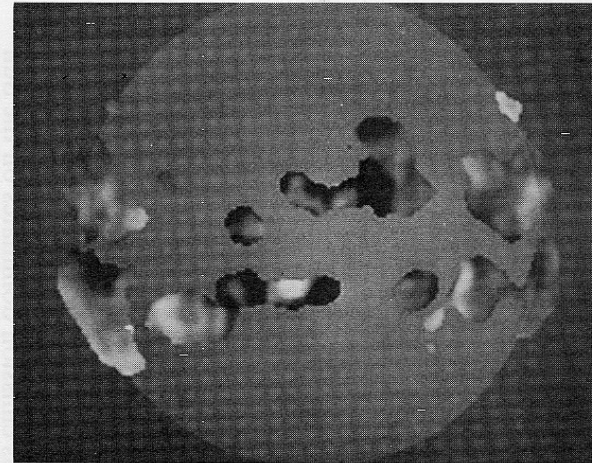
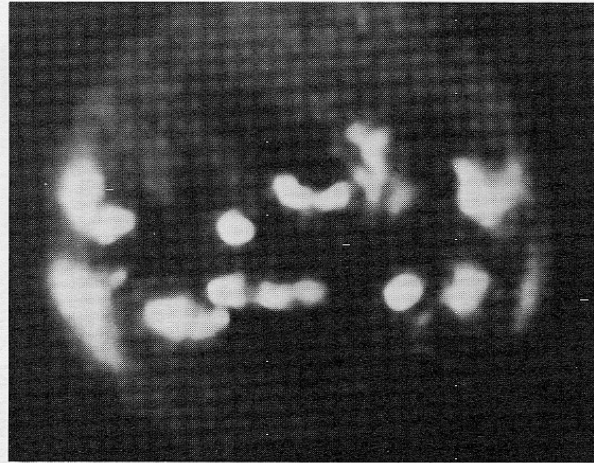
Stems from the dependence of different emission mechanisms on the plasma parameters of temperature, density, and magnetic field strength.

Slowly varying component

Dominates radio emission at ~1 GHz.

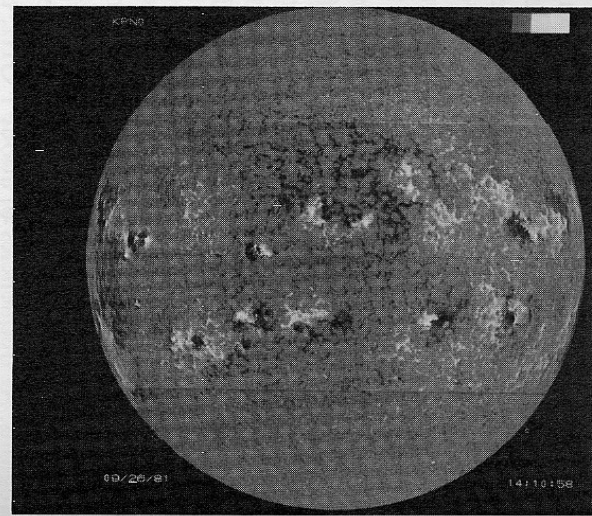
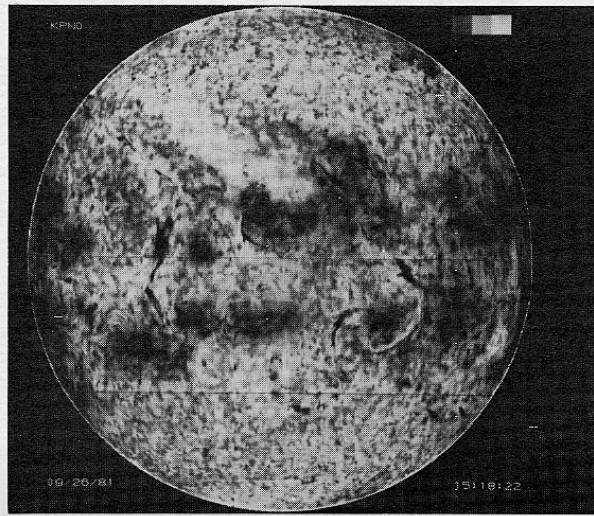
Effective brightness temperatures ~ 1-2 million K.

1.4 GHz



**1.4 GHz
Circ. Pol.
Dark = LH
Light = RH**

**1083 nm
Wavelength
He line**



Magnetogram

Dulk & Gary (1983)

Noise storms

Solar noise storms frequently dominate radio emission at wavelengths of 1-10m; they last a few hours to a few days.

Near the maximum of solar sunspot cycle they are in progress ~10% of the time.

They originate 0.1 to 1 solar radius above the photosphere and they are beamed ~radially outward.

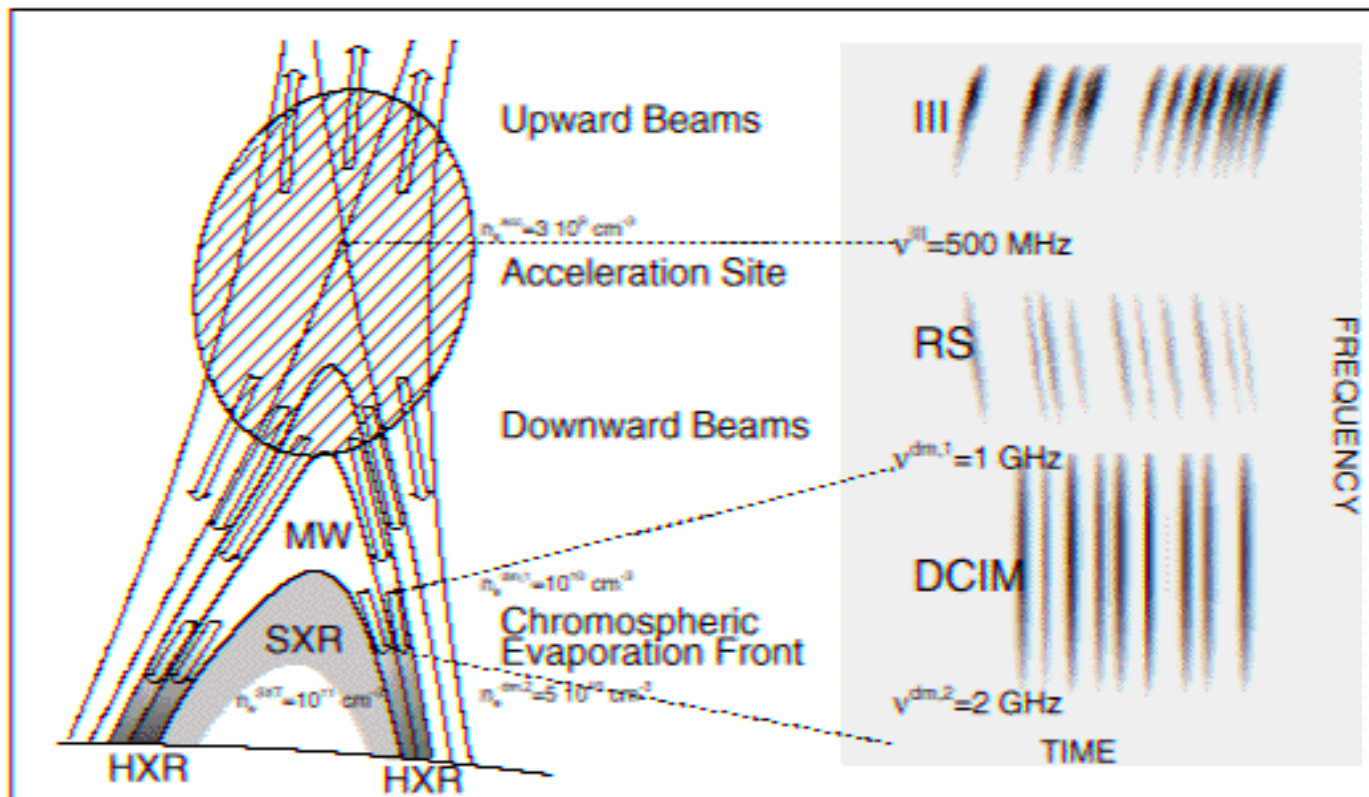
Solar radio bursts

Strongest and most complex solar radio events.

Usually associated with solar flares.

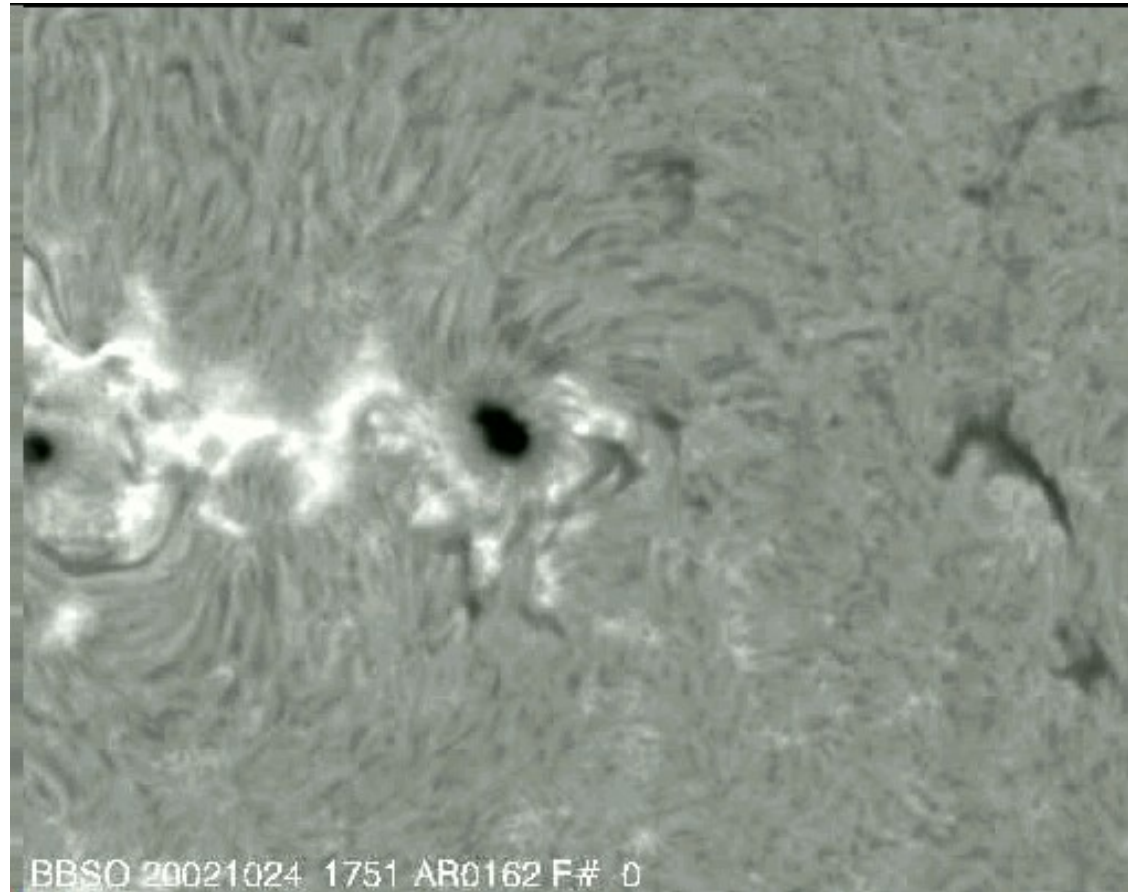
Brightness temperatures up to 10^{12} K; non-thermal spectra.

Duration: a few minutes to a few hours.



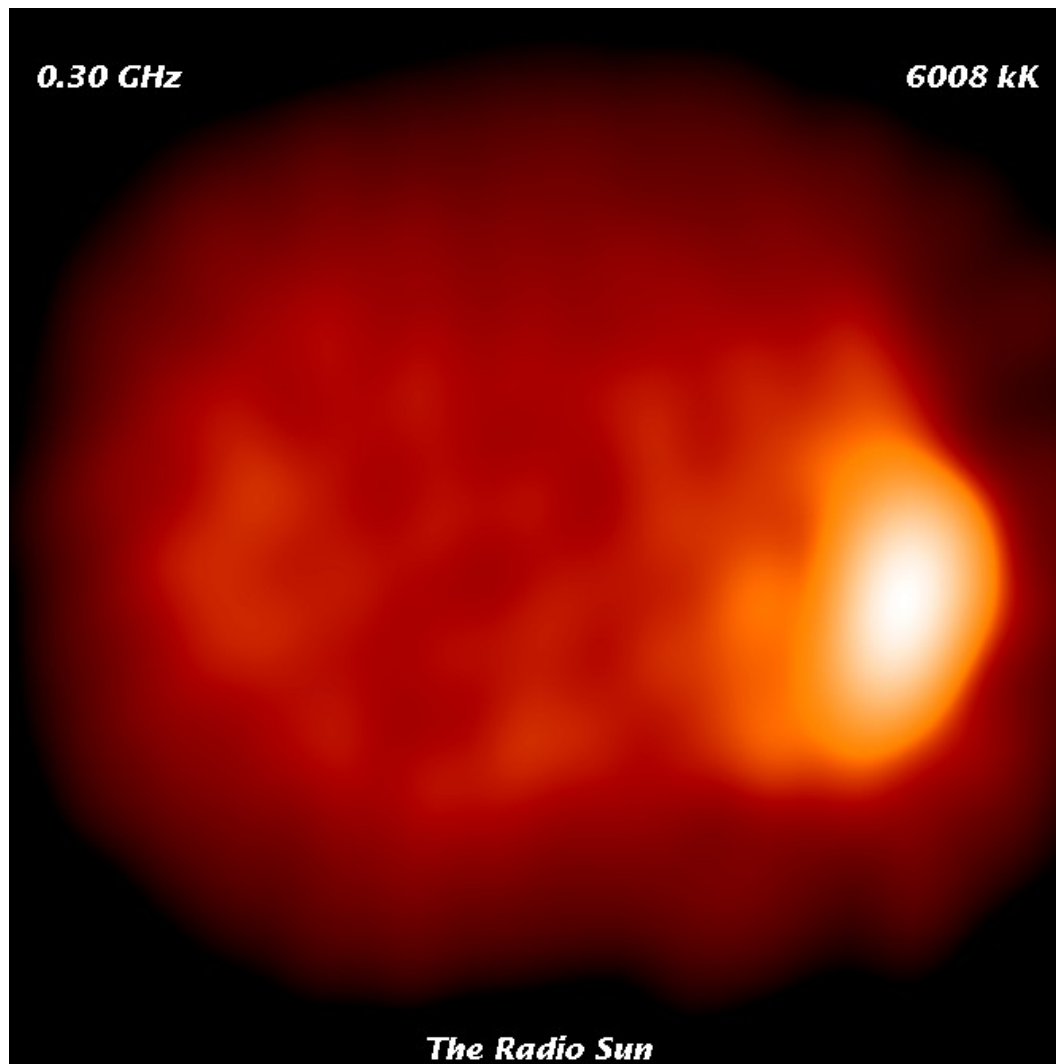
Solar Flare

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



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

Solar appearance vs. radio frequency



http://physics.njit.edu/~dgary/728/montage_anim.gif

Radio observations of *other* 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.

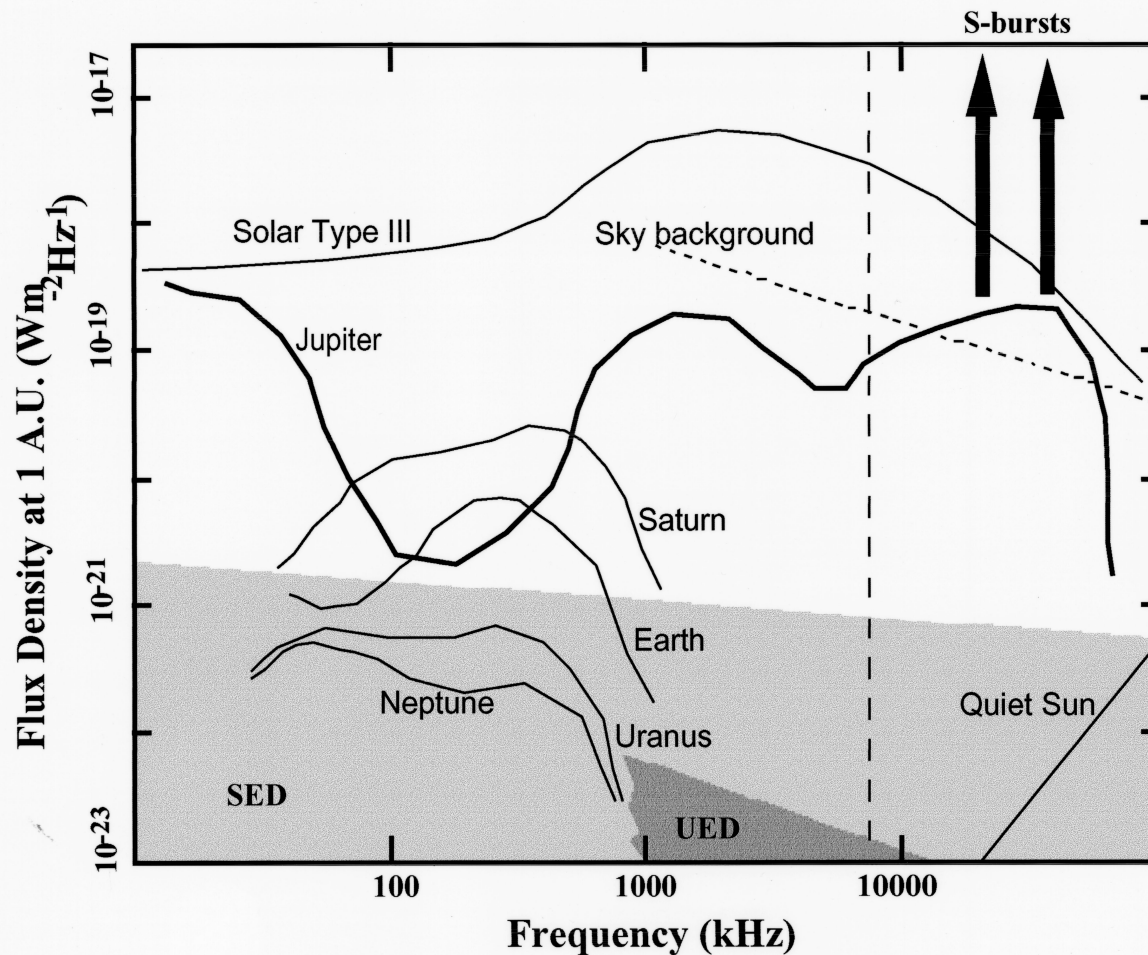
Planets: radar and radio observations

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.

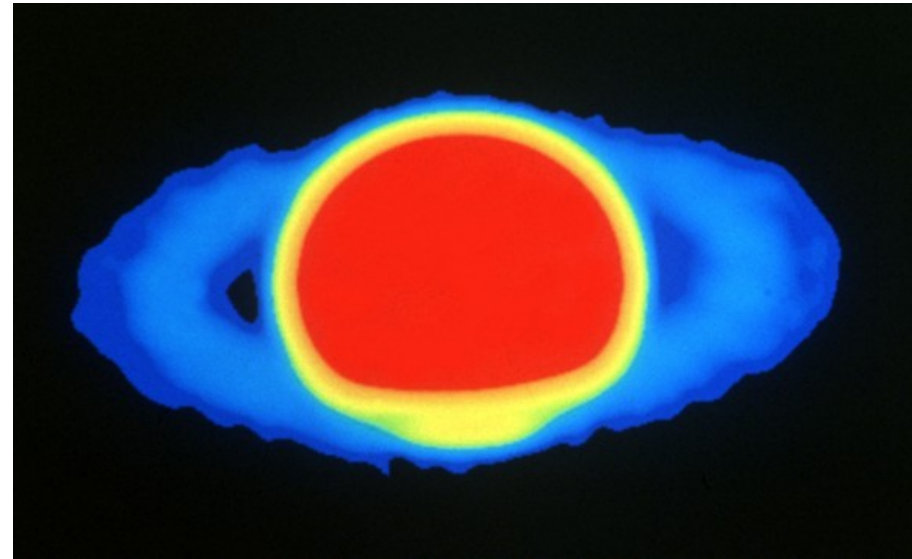
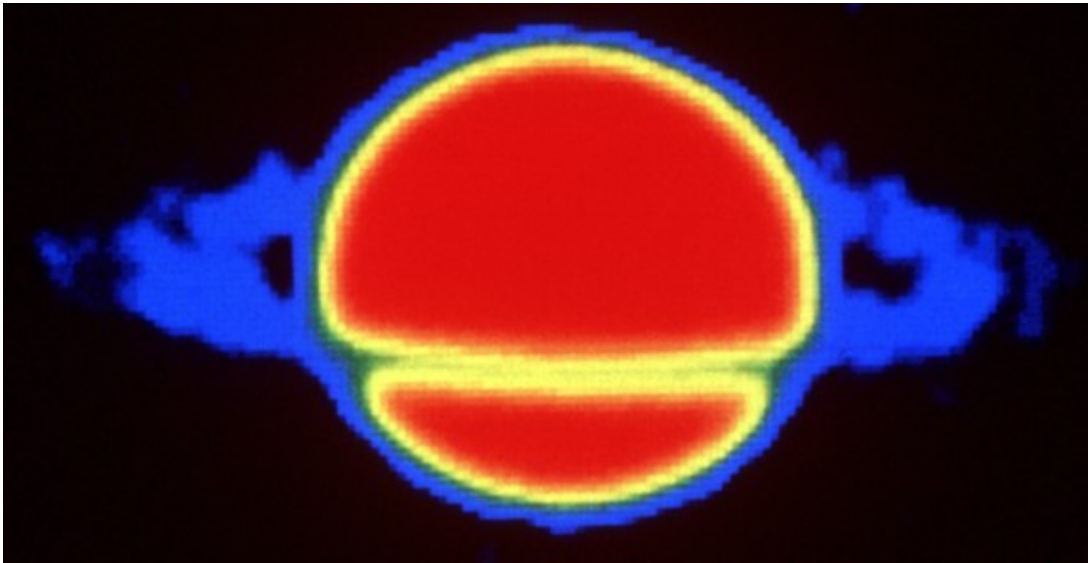
Spectra of solar system bodies



Note: SRT operates at much higher frequency (1420 MHz = 1,420,000 kHz).

Figure 1 : Comparative spectra of solar system radio emissions in the decameter-to-kilometer range, normalized to a distance of 1 A.U. (except for the sky background - Kraus, 1986). Average spectra of the auroral radio emissions of the five "Radio-planets" are displayed (adapted from Zarka, 1992). That of Jupiter (boldface) is often as intense as solar type III radio bursts. Peak levels

Saturn imaged with the Very Large Array



1982-01-25

Red hot, blue cool.

1986-12-00

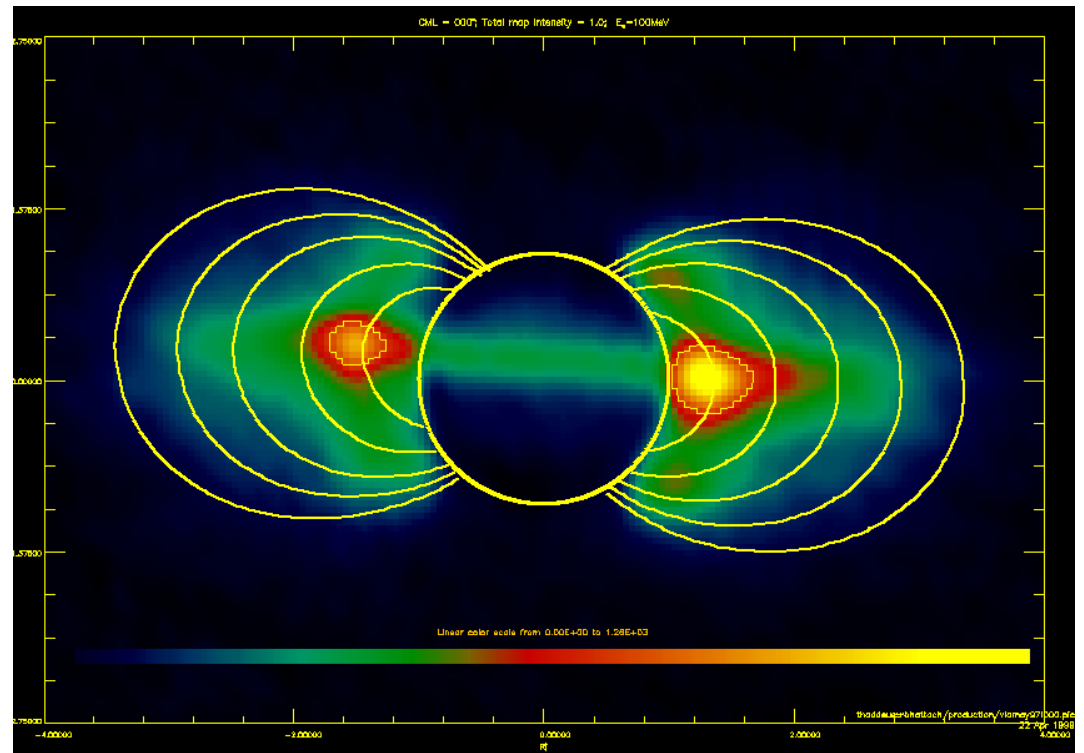
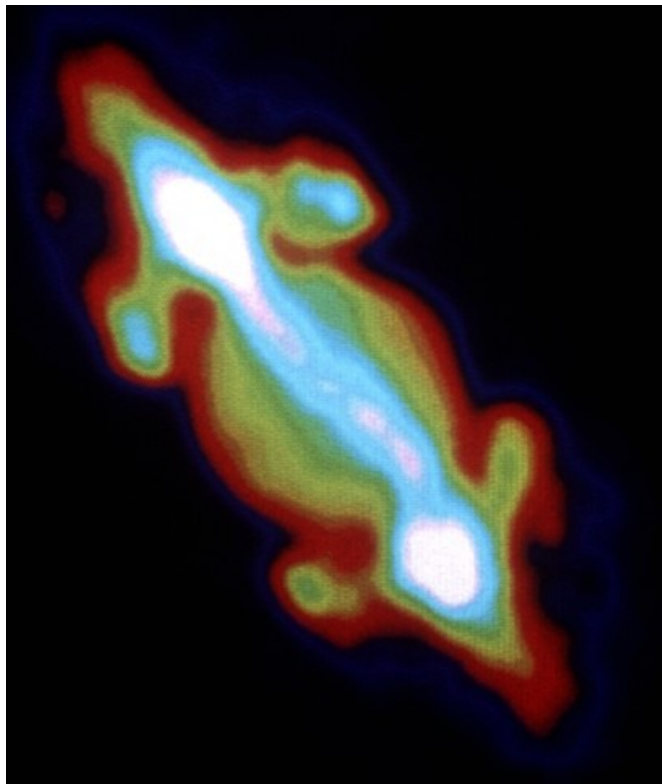
Bright disk with gradual fading towards edge (limb darkening**)**

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.)**

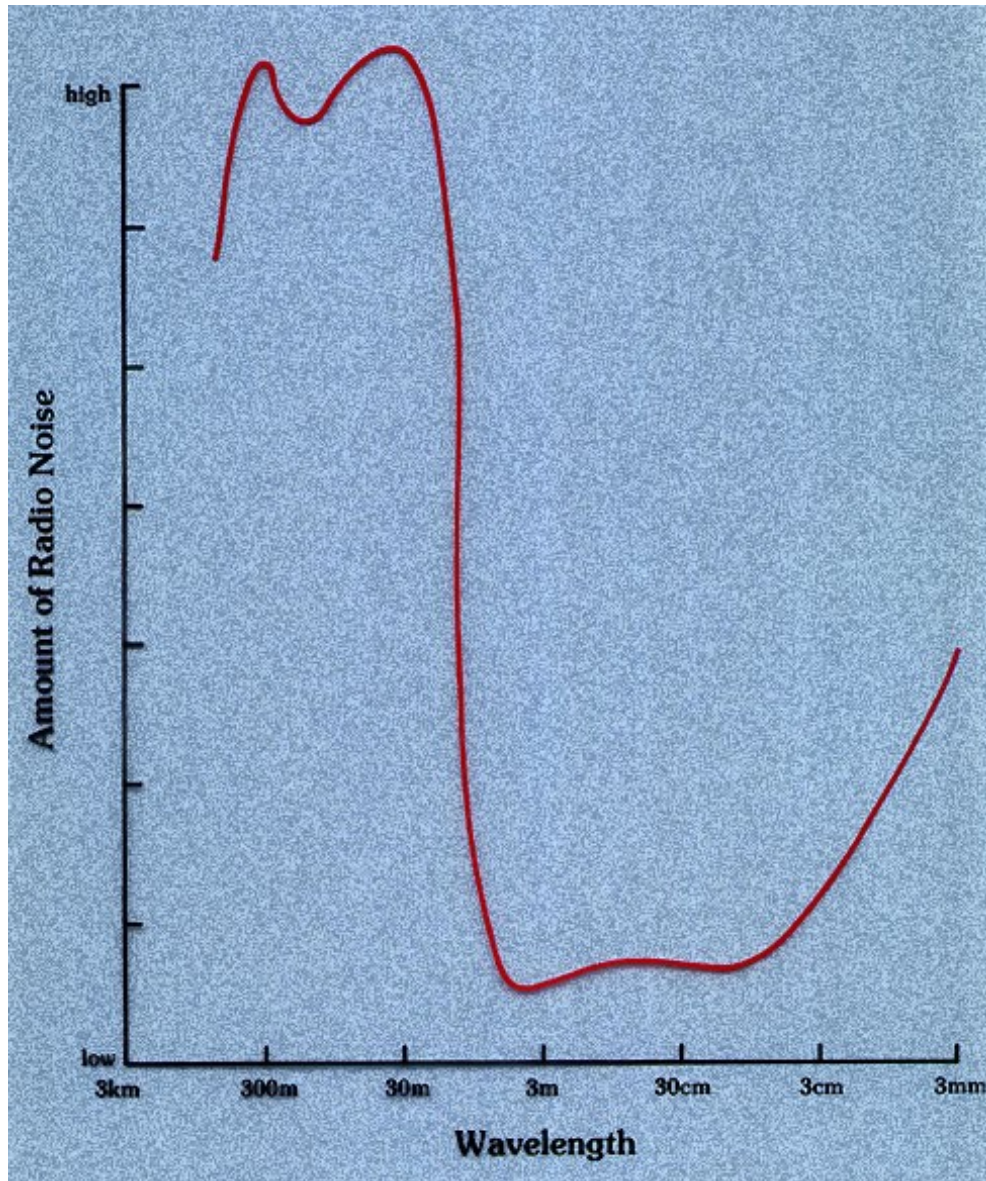
Jupiter

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 and NASA/JPL.

Jupiter: radio spectrum



$\lambda \sim 3\text{cm}$: bremsstrahlung
= free-free in atmosphere

$\lambda \sim 10\text{cm}$: synchrotron
from magnetosphere

$\lambda > 3\text{m}$: radio bursts due to Io
building up a huge charge
(potential difference $\sim 400,000\text{ V}$)
before violently discharging

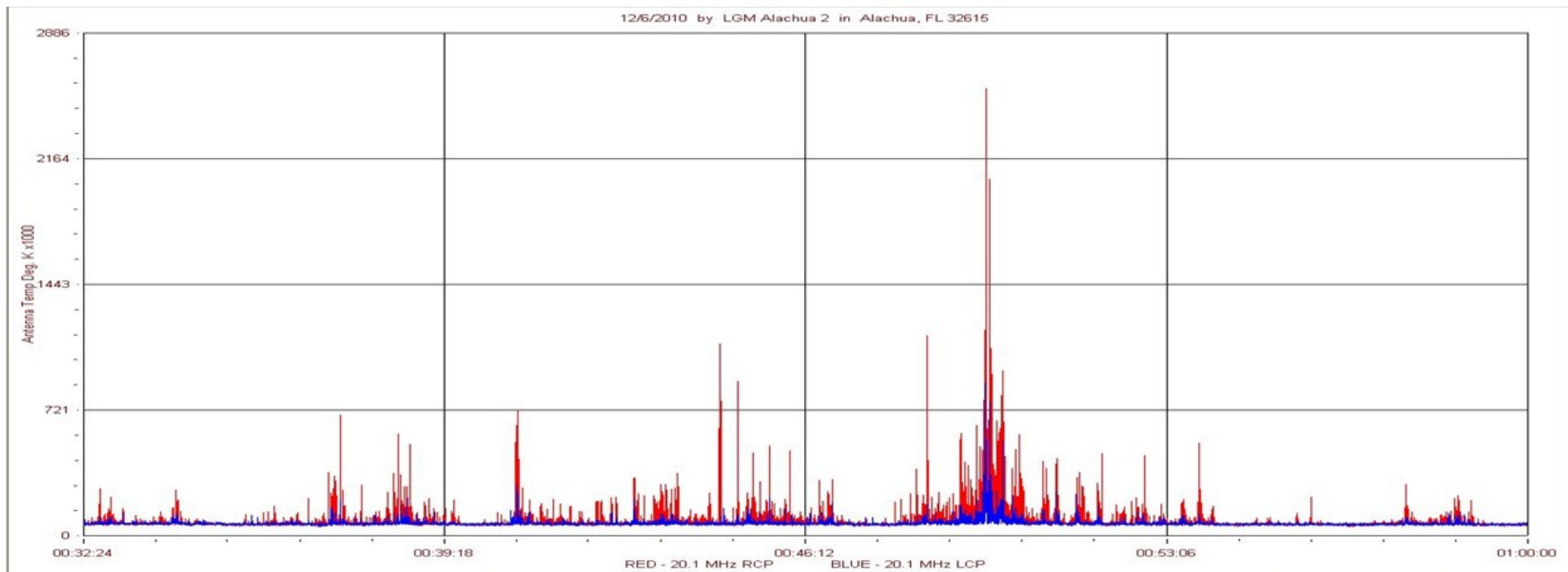
Radio JOVE project



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).

Example of Radio JOVE data

<http://radiojove.gsfc.nasa.gov/>



December 6, 2010: radio burst stronger in right circular polarization, which is typical for an “Io-B” (Jupiter longitude-specific) burst.

Quiz