(Astro)Physics 343 Lecture # 5:
Sun, Stars, and Planets; Fourier Transforms

Schedule for the next week

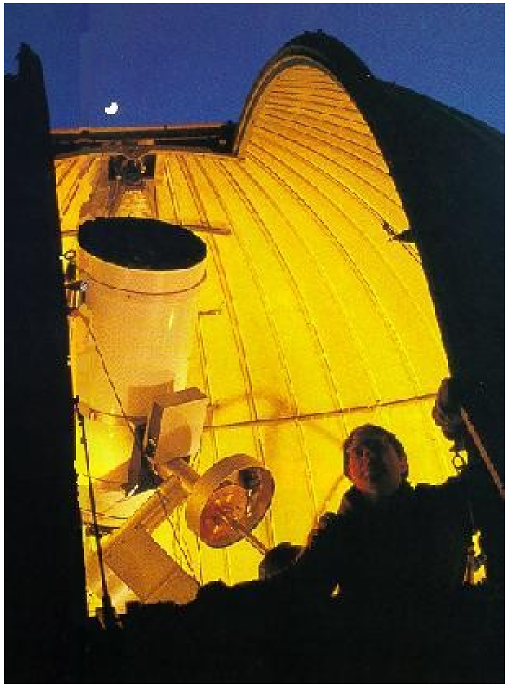
Office hours: Mon 6:40-8:00pm = Baker; Thu 10:20-11:40 = Sharon

+ Sections A, C = Baker; Sections B, D, E = Sharon

Next Monday:

Lab # 2 due.

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

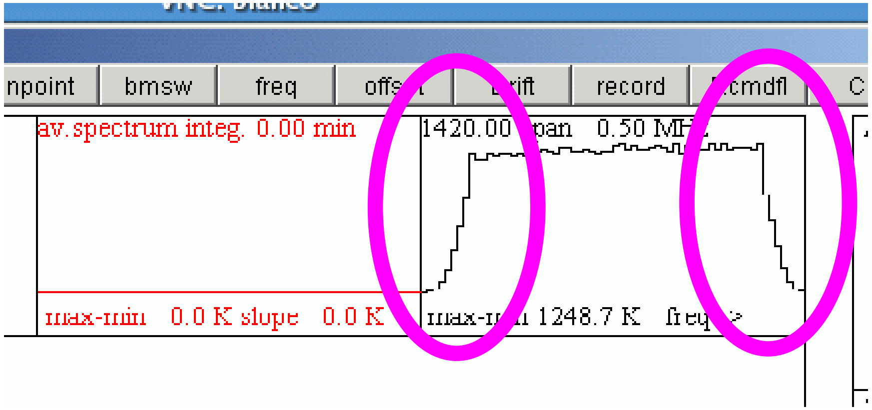


Next week's labs will be at regular times (Sections A, B, C = Sharon; Sections D, E = Baker).

Lab # 1: a few general comments

The word "data" is plural ("datum" is singular).

In calculating 1σ errors on antenna temperatures, we assume that we are making multiple measurements of the same value. That's not the case for the end channels in SRT spectra!



Az/el scans that peak away from zero result from imperfect telescope pointing. Don't forget about those npoint scans!

Lab # 2: an update

First part of lab: you should have received your data by email.

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

- **Day # 1: lost due to work on telescope**
- **Day # 2: script had to be restarted midway through, so check the actual start time of your observations carefully!**
- **Day # 3: no problems**
- **Day # 4: no problems**
- **Day # 5: running now**

Last week's problems

Problem: telescope stuck in stow position, due to recent wind storm.

Solution: get out and push.

Problem: receiver producing barely perceptible response to Sun.

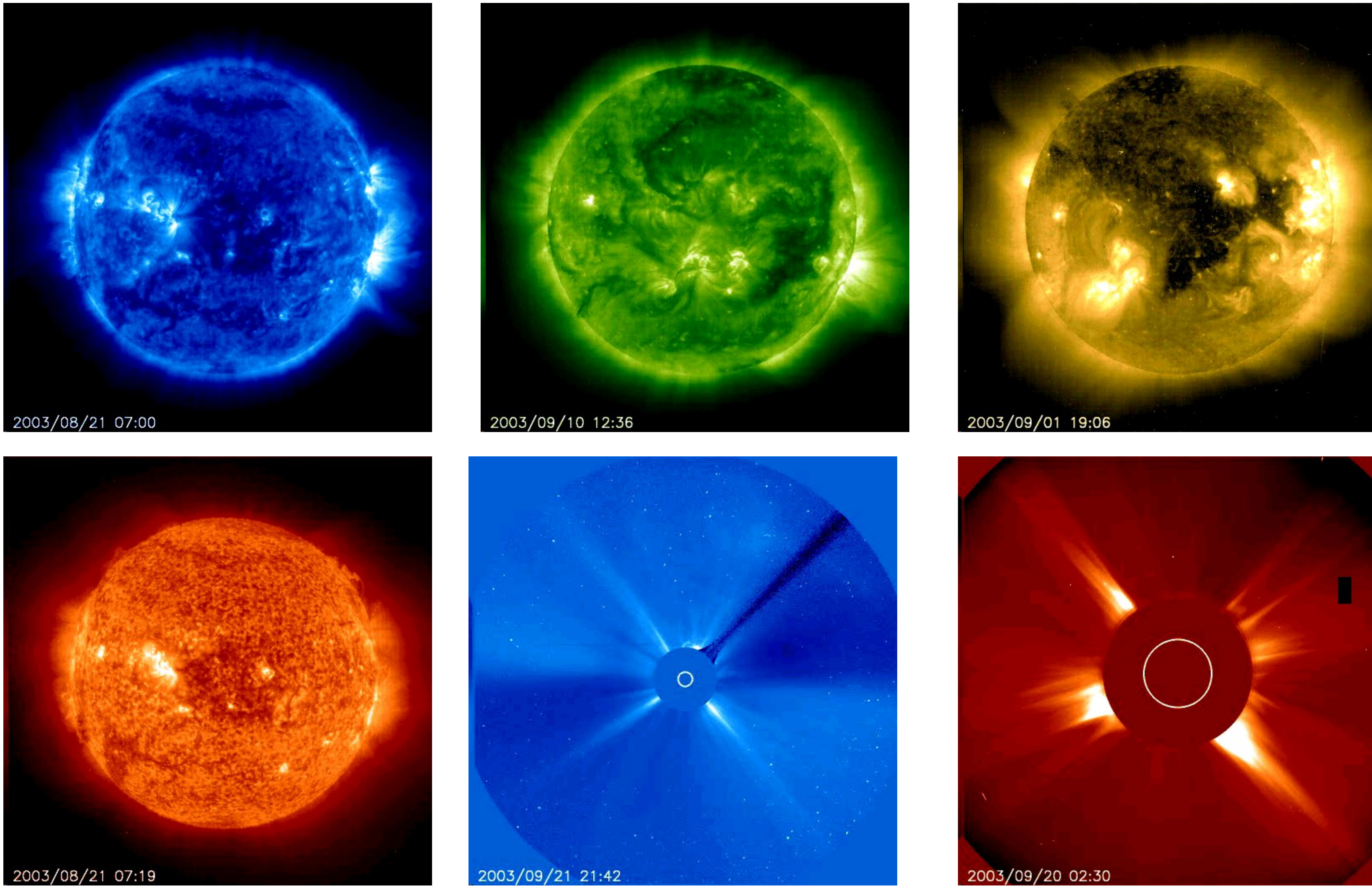
Solution: tighten up connector between feed probe and preamplifier electronics, without getting stung.

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.

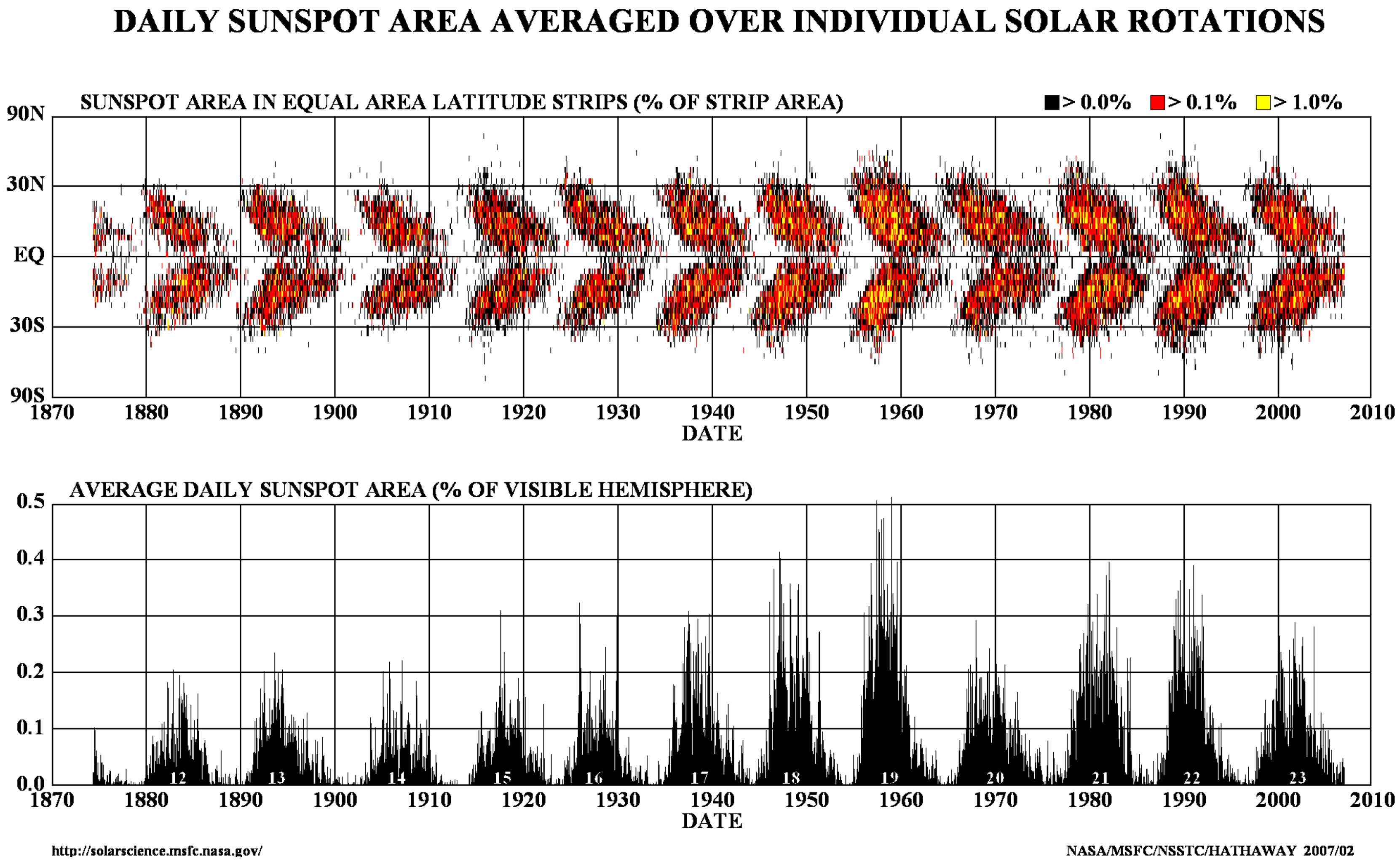
Solar activity as seen in UV by SOHO



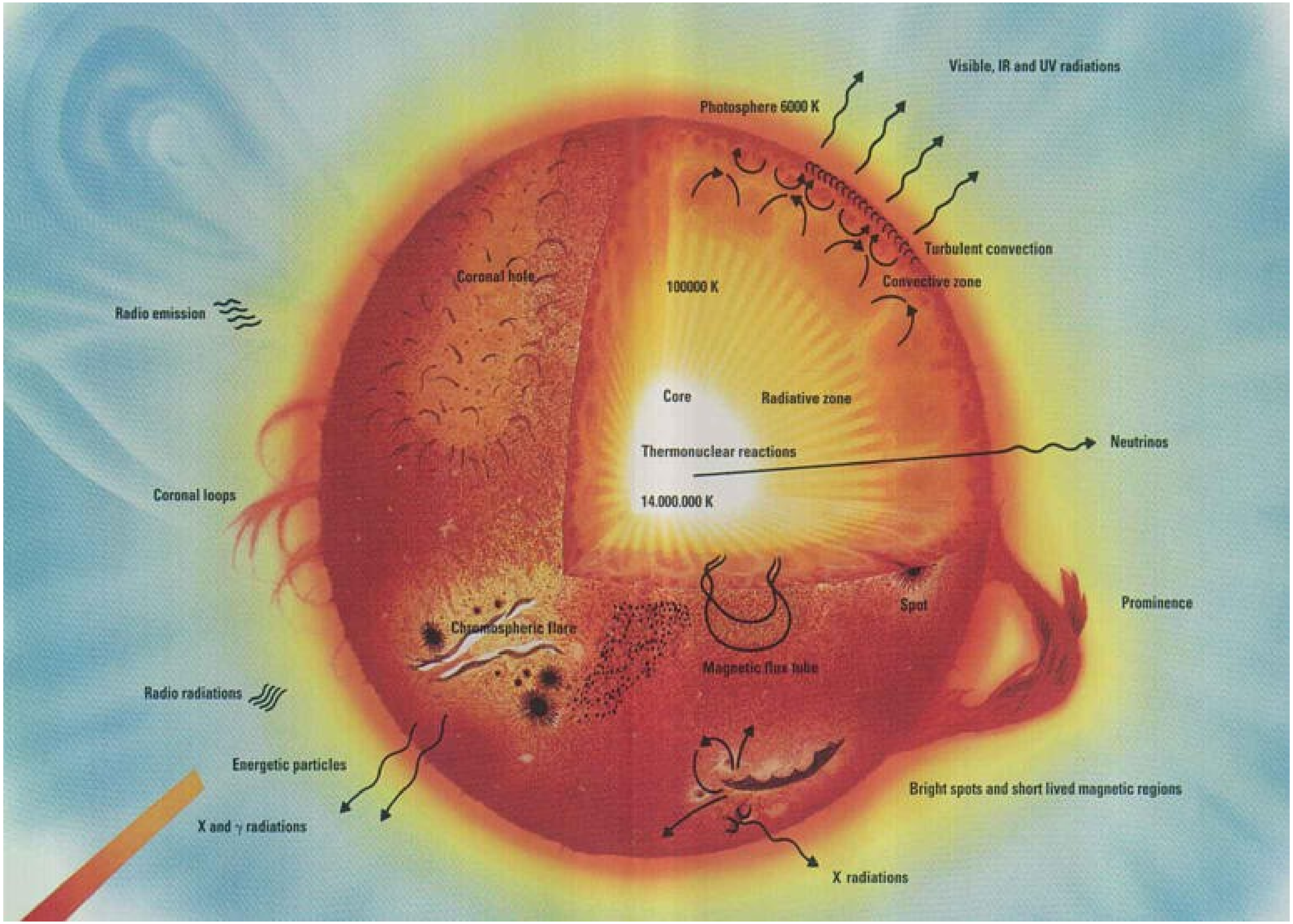
SOHO = Solar and Heliospheric Observatory (NASA + ESA)

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

Long-term sunspot cycle = 11 years



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* ~ 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

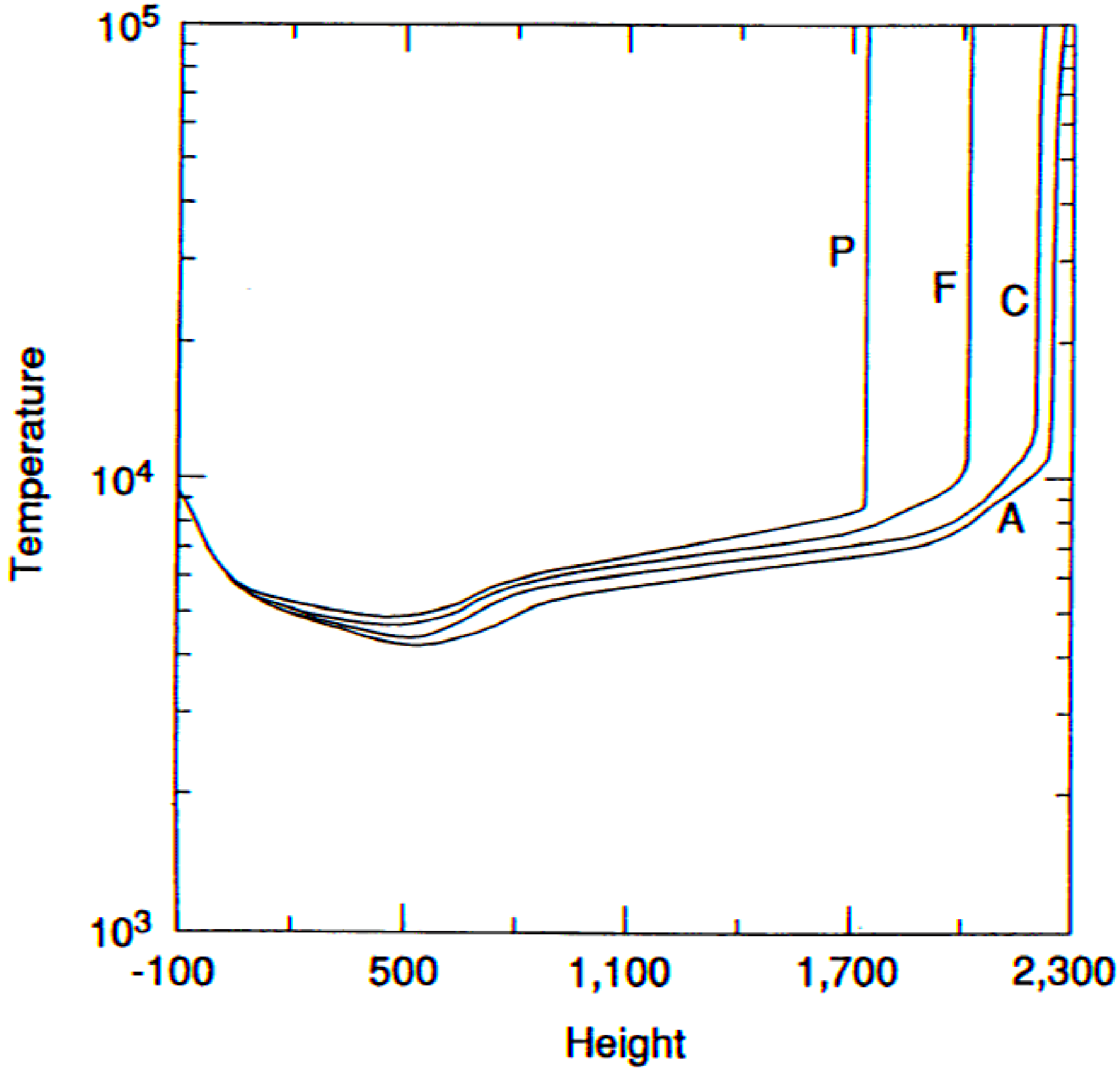


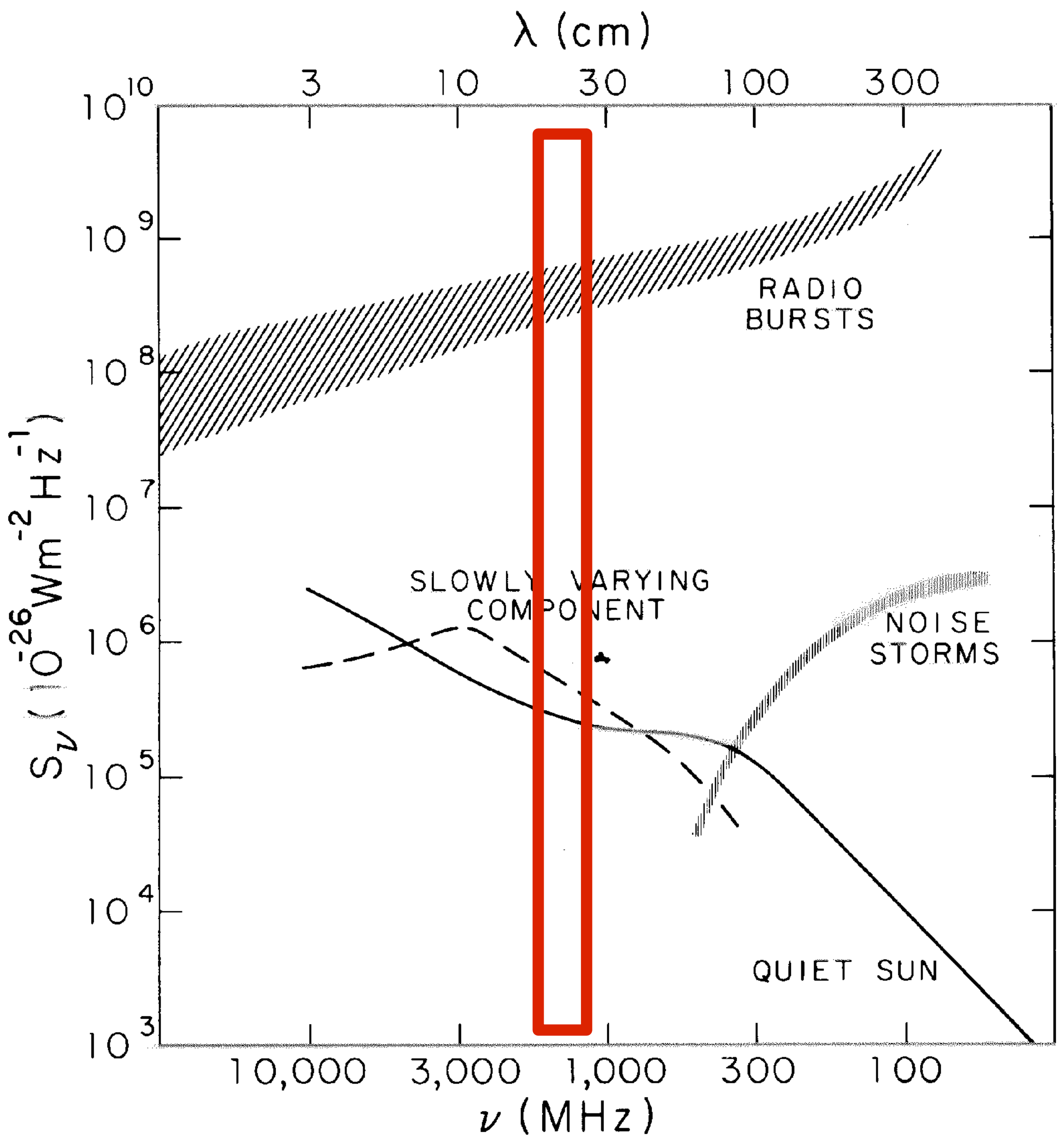
FIG. 3.—Temperature structure of our models A, C, F, and P. The height is measured in kilometers from the level; the temperature is in kelvins.

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

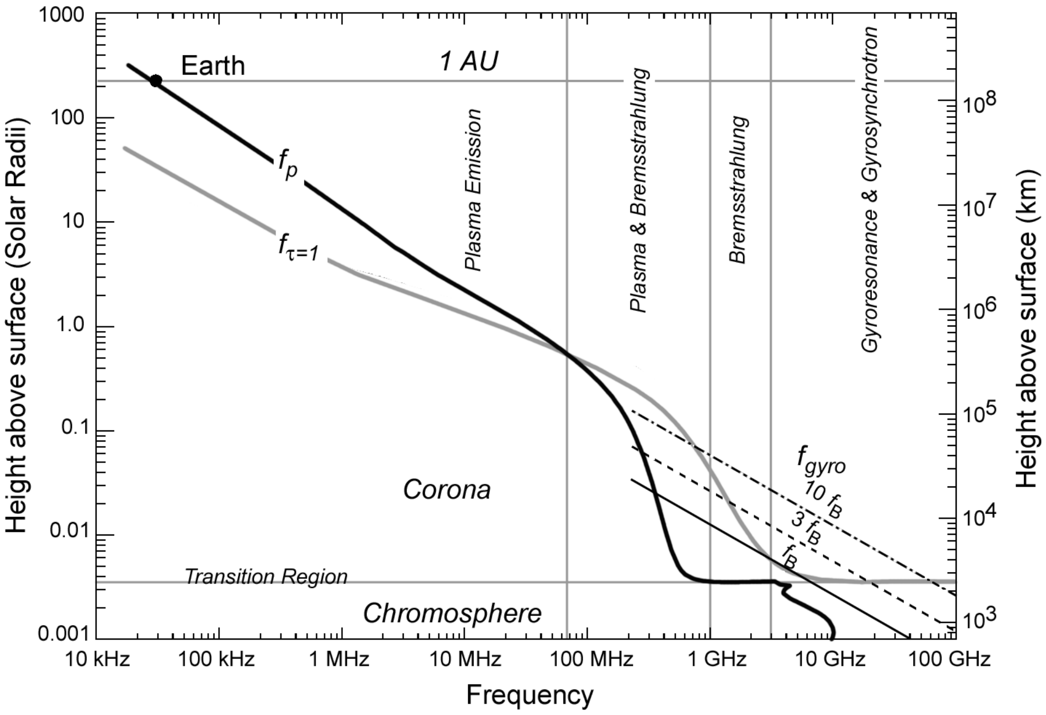
Radio emission from the "quiet" Sun is always present, and it is relatively stable in time. The mechanism is thermal bremsstrahlung, i.e., "braking" radiation due to collisions between particles in or near Sun's outer surface.

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.

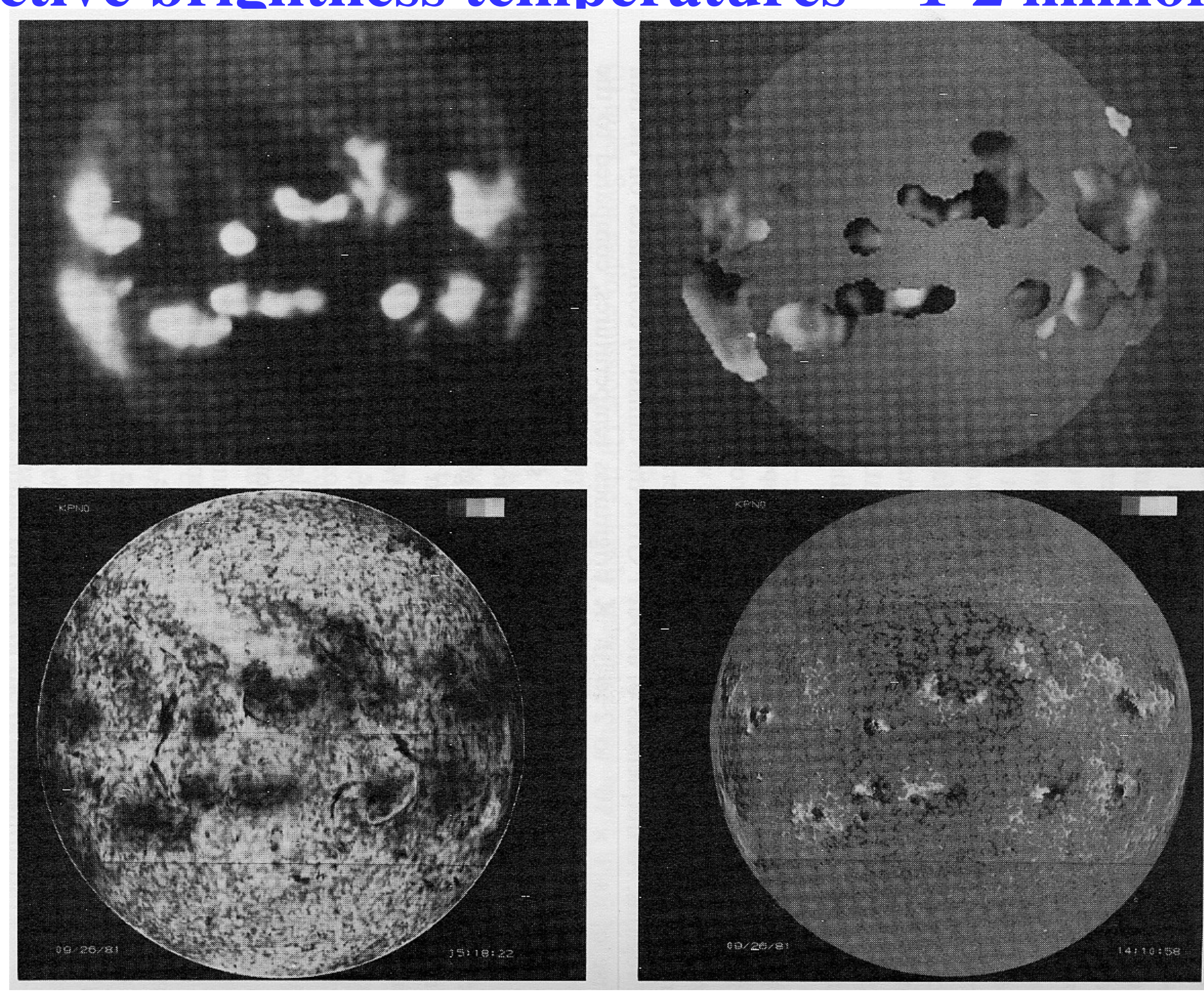
Slowly varying component

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.

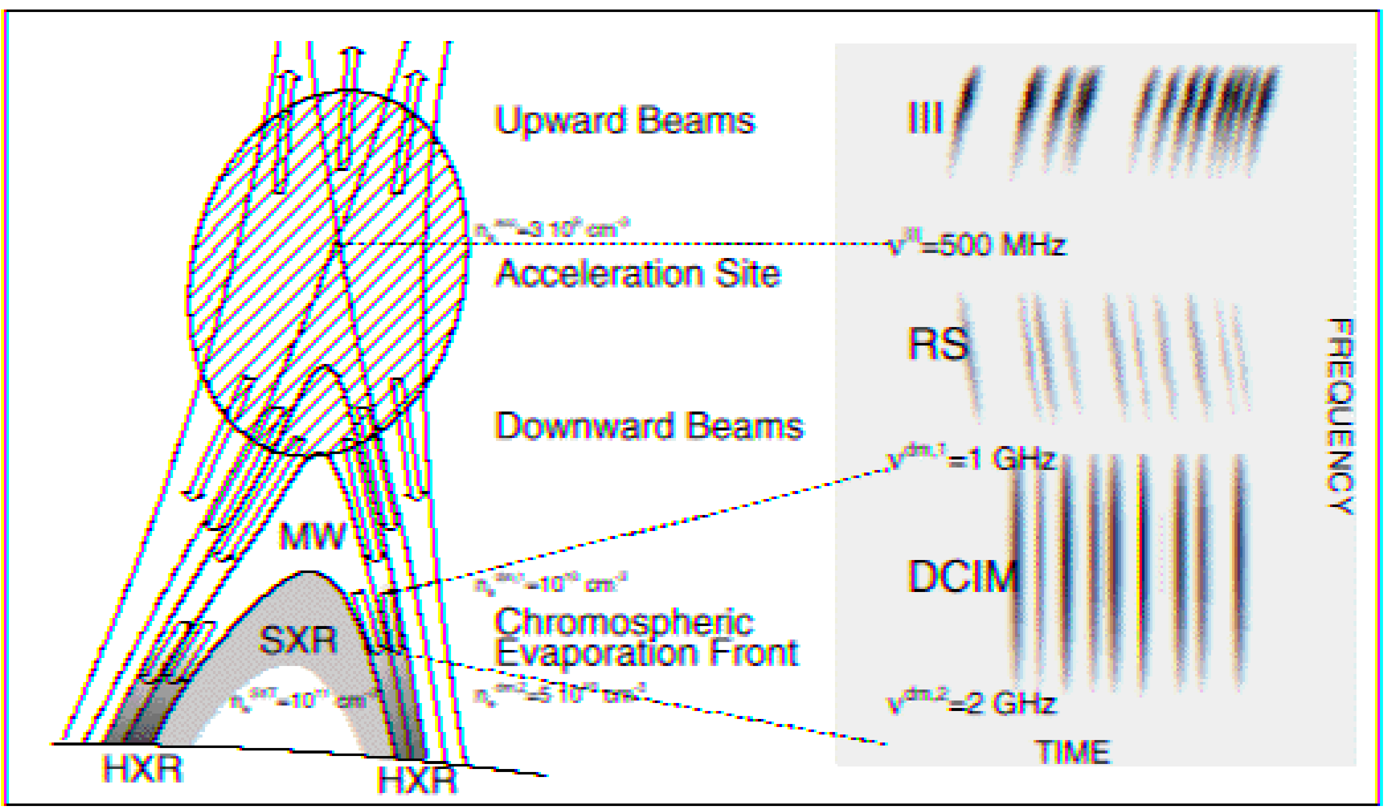
<u>Solar radio bursts</u>

Strongest and most complex solar radio events.

Usually associated with solar flares.

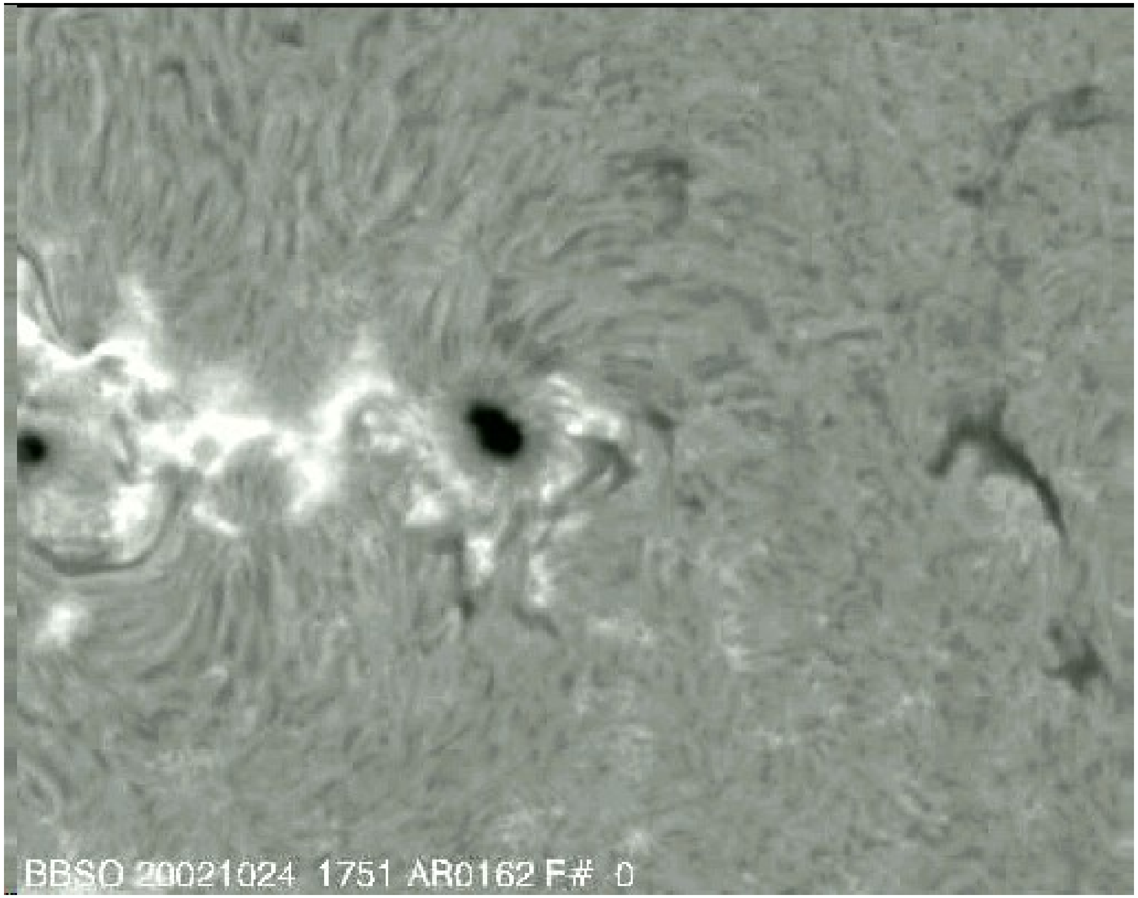
Brightness temperatures up to 10^{12} K; non-thermal spectra.

Duration: a few minutes to a few hours.



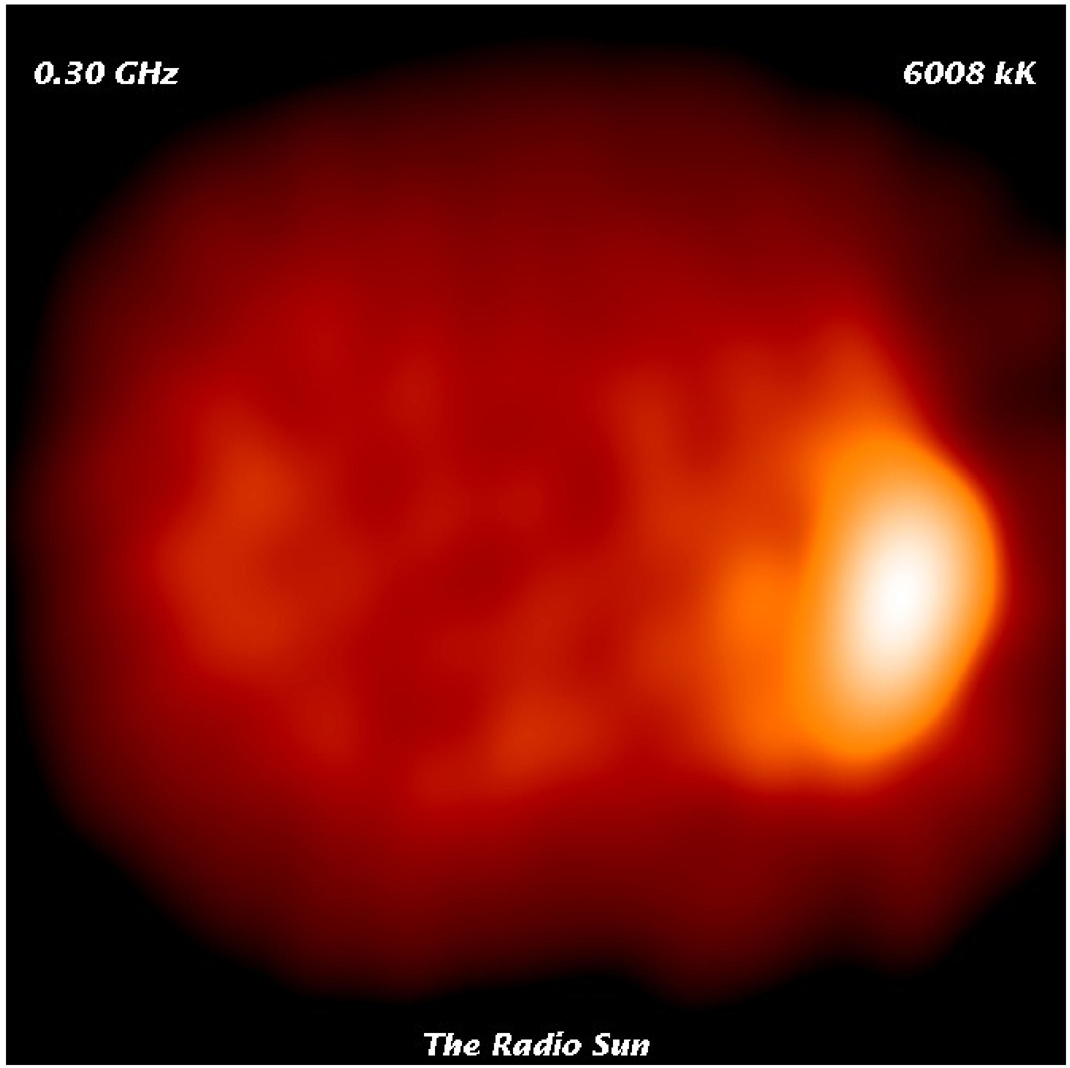
Solar Flare

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/

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

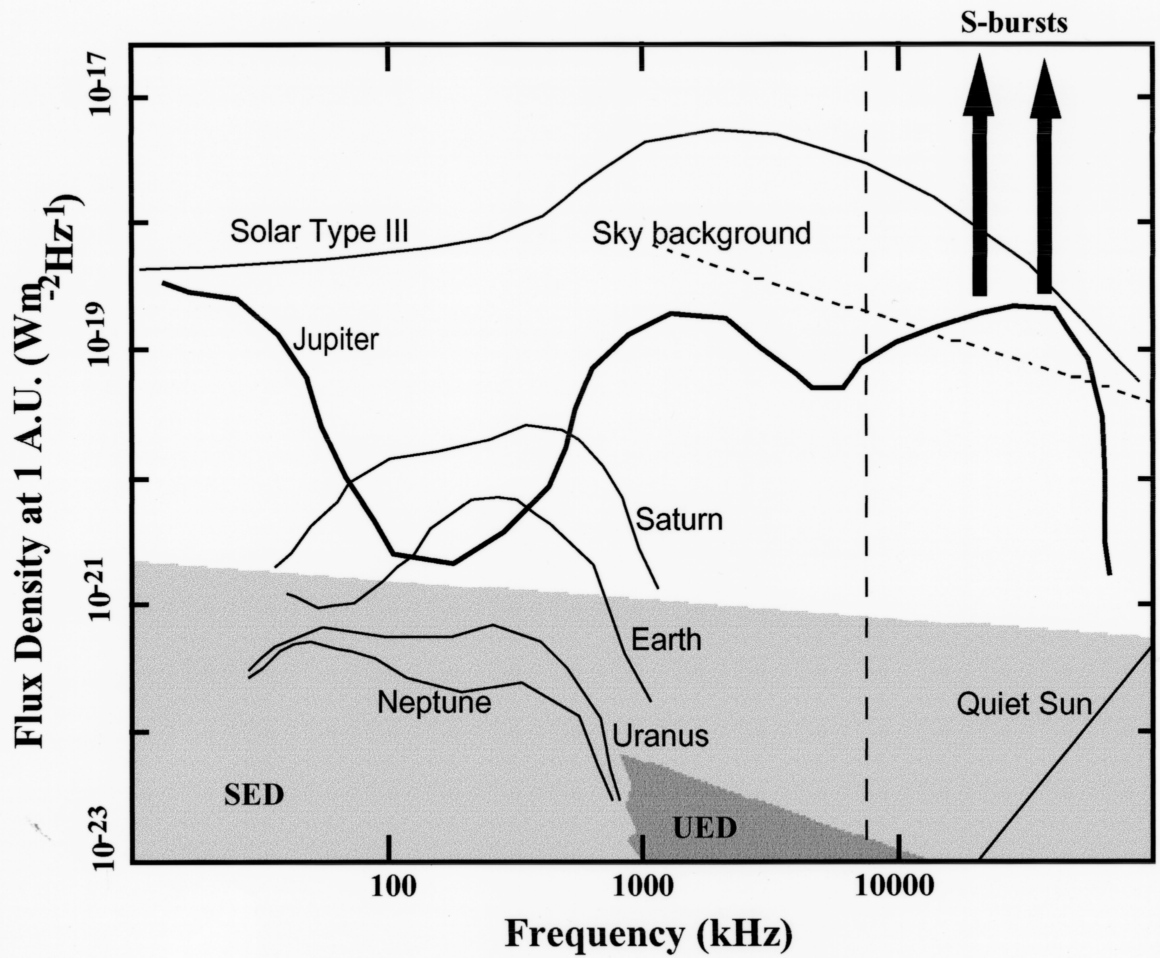
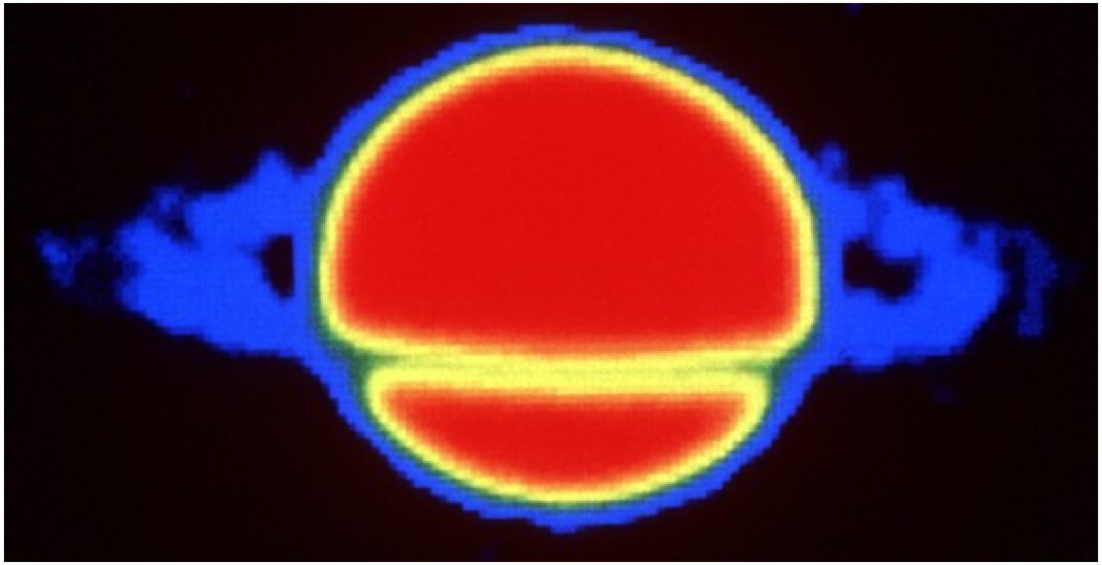
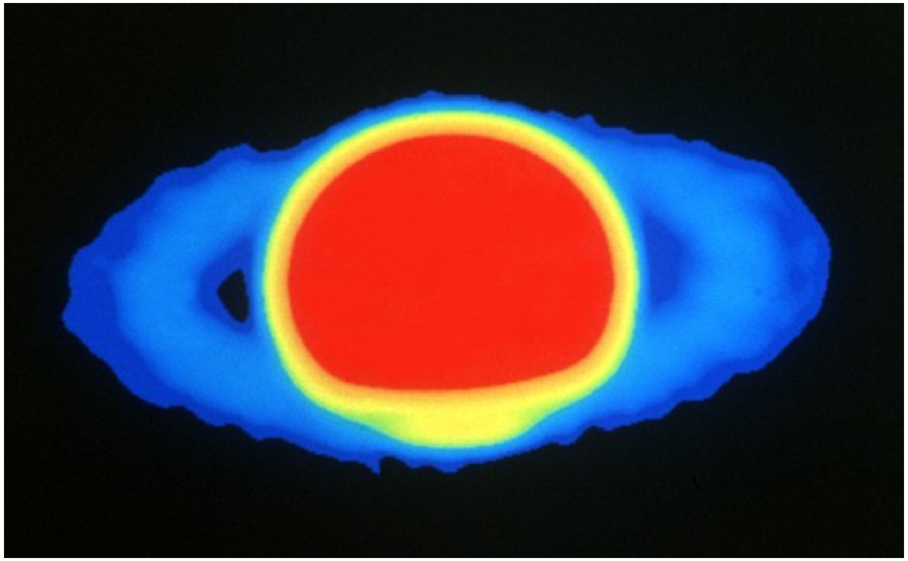


Figure 1 : *Comparative spectra of solar system radio emissions in the decameter-to-kilometer range, normalized to a distance of 1 A.U. (except for the sky background - Kraus, 1986). Average spectra of the auroral radio emissions of the five "Radio-planets" are displayed (adapted from Zarka, 1992). That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

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

Saturn imaged with the Very Large Array





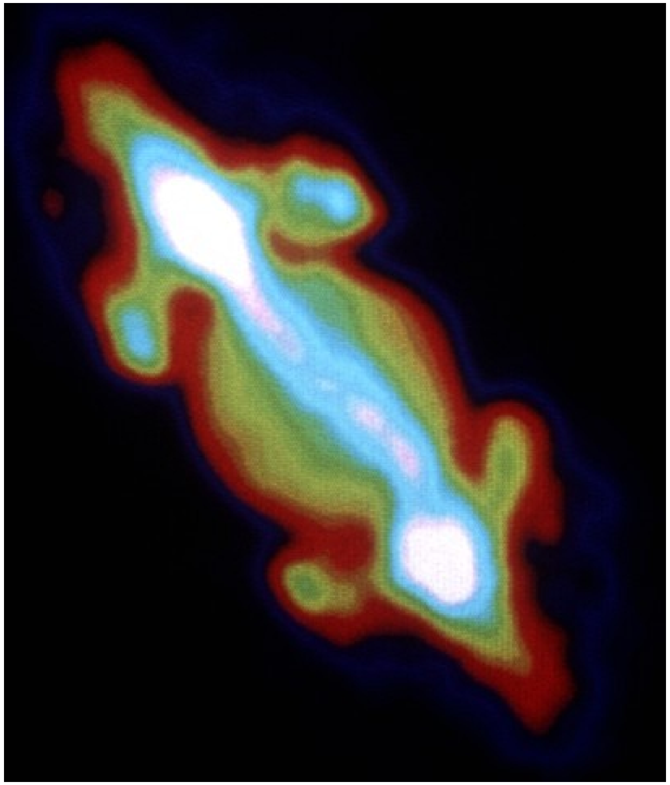
1982-01-25 **Red hot, blue cool.** **1986-12-00**

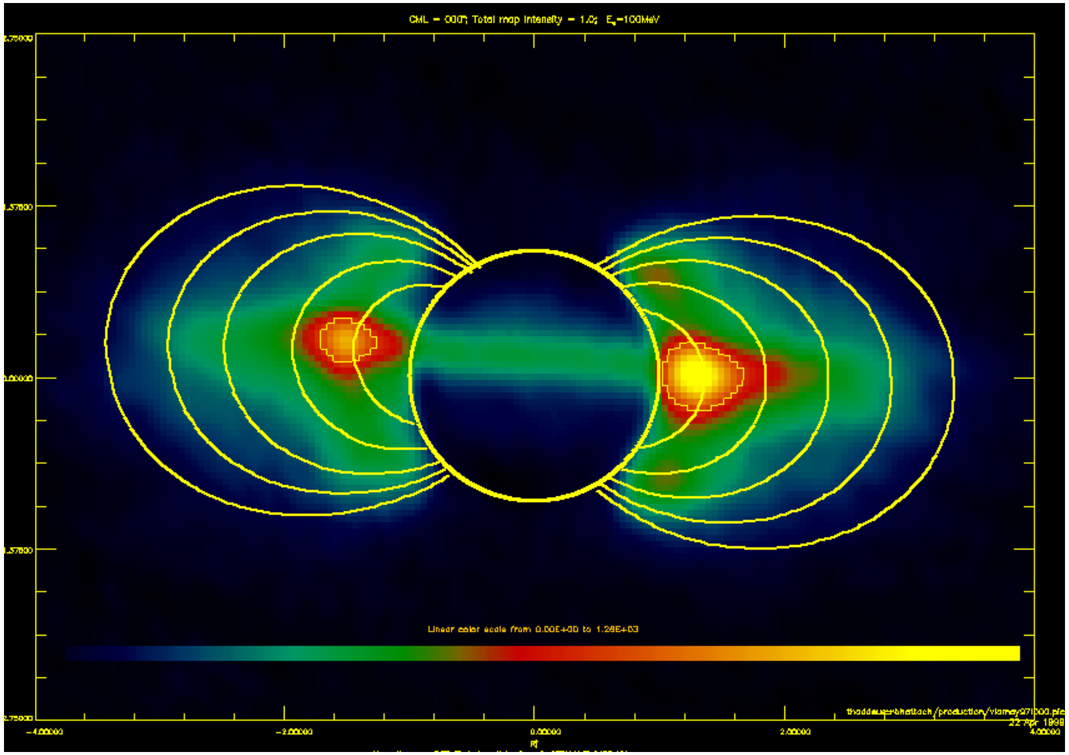
Bright disk with gradual fading towards edge (limb darkening) illustrates gradual cooling outward in Saturn's atmosphere.

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

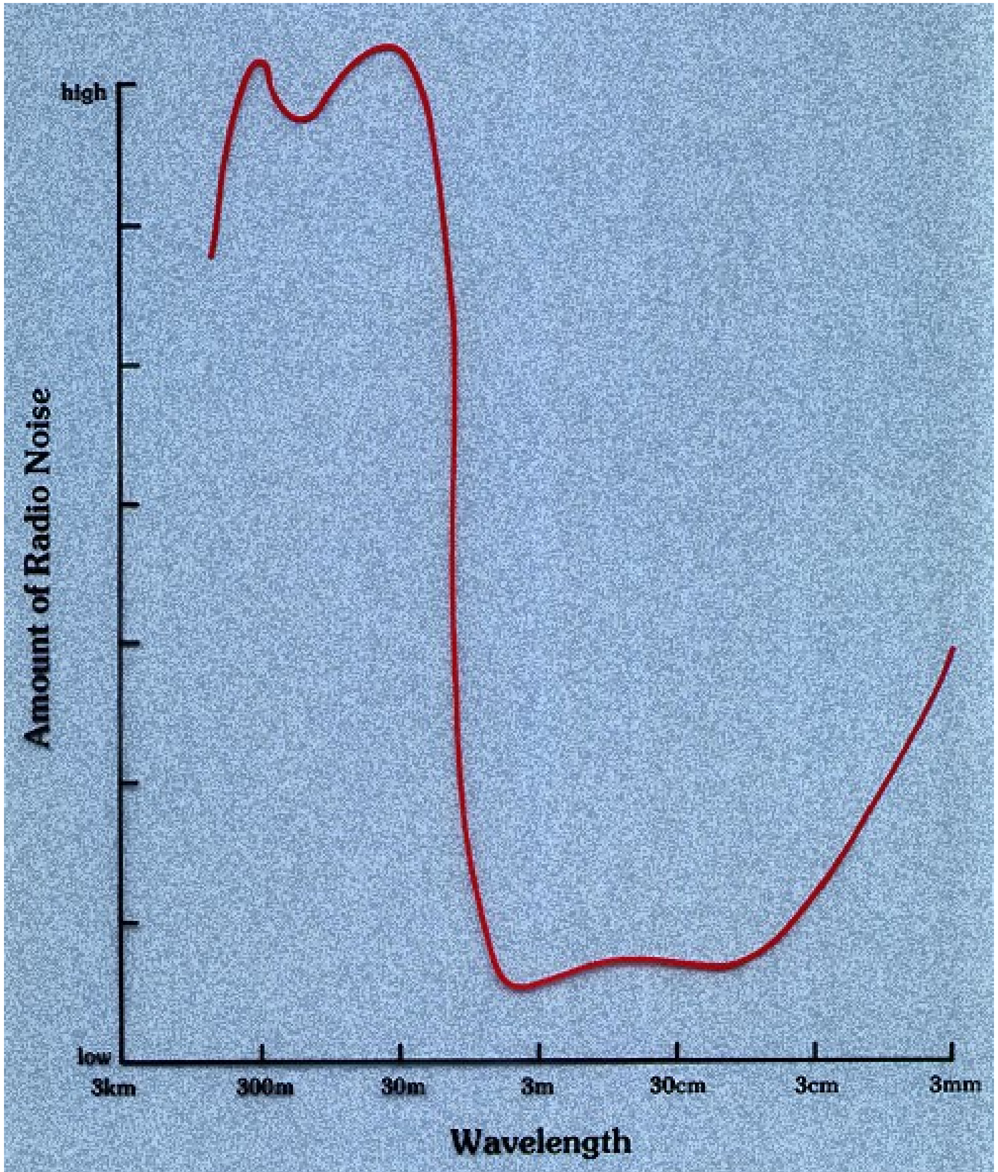
Jupiter has a strong magnetic field, which gives rise to huge Van Allen belts of (synchrotron) radiation around the planet, in addition to the thermal emission from the planet itself.





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

Quiz