Physics 343 Lecture # 5:
Sun, Stars, and Planets; Fourier Transforms
Schedule for the next week

Office hours: Mon 3:20-4:40pm = Baker; Thu 3:20-4:40 = Naudus
+ “on call” Sections A, B, F = Baker; Sections C, D, E = Naudus

I will email about availability of graded Lab # 1 (aiming for
the “on call” office hours of your section, if not before).

Next Monday:
Lab # 2 due (data from second part emailed tomorrow;
day # 4 script running now).

Next week: Lab # 3 will be at regular section times.
Lab # 2: script corrections

Original scripts for some sections needed to be modified, e.g.,

: record mydata.rad
:2012:050:16:30:00
: freq 1418 1
: Sun
: offset -20 0
:30
: Sun
: npoint
: offset 0 0
:60
...

this order records useless data
should be combined as “: Sun n”
overwrites offsets from pointing
Size, mass, and distance of the Sun

<table>
<thead>
<tr>
<th></th>
<th>Earth</th>
<th>Jupiter</th>
<th>Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>12,700 km (7,900 mi)</td>
<td>140,000 km (87,000 mi)</td>
<td>1,400,000 km (865,000 mi)</td>
</tr>
<tr>
<td>Mass</td>
<td>$6.0 \times 10^{24}$ kg</td>
<td>$1.9 \times 10^{27}$ kg</td>
<td>$2.0 \times 10^{30}$ kg</td>
</tr>
<tr>
<td>Distance From Sun</td>
<td>150 x $10^6$ km (93 x $10^6$ mi)</td>
<td>778 x $10^6$ km (483 x $10^6$ mi)</td>
<td>---</td>
</tr>
<tr>
<td>Period</td>
<td>3.156 x $10^7$ s (1 year)</td>
<td>3.74 x $10^8$ s (11.9 years)</td>
<td>---</td>
</tr>
</tbody>
</table>

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

SUNSPOT AREA IN EQUAL AREA LATITUDE STRIPS (% OF STRIP AREA)

AVERAGE DAILY SUNSPOT AREA (% OF VISIBLE HEMISPHERE)
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.
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
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 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

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).

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