Physics 343
Observational Radio Astronomy

course number = 01:750:343
web page = http://www.physics.rutgers.edu/ugrad/343/
(also linked from http://www.physics.rutgers.edu/~ajbaker/)

Personnel

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Please check your email regularly!

This is how we will distribute information on schedules, labs, etc.
It is also the best way for you to reach us when we are busy and/or travelling.

Requirements

Textbook: none. Three useful books will be placed on reserve, and an online "Essential Radio Astronomy" course taught at the University of Virginia is linked from our main web page.

Pre/corequisite: Physics 341/342 ("Principles of Astrophysics," now with Professor Brooks) should be taken already or concurrently, unless you have special permission.

Other: a scientific calculator; access to a computer that can do number-crunching with Excel, a similar spreadsheet, or programs that you write yourself. (You will also be given an account on our department's "astrolab" server, if you don't already have one.)

Course meetings

Lectures: Serin 401, once a week, M 10:20-11:40

Labs: times and locations TBD (you will have assigned slots)

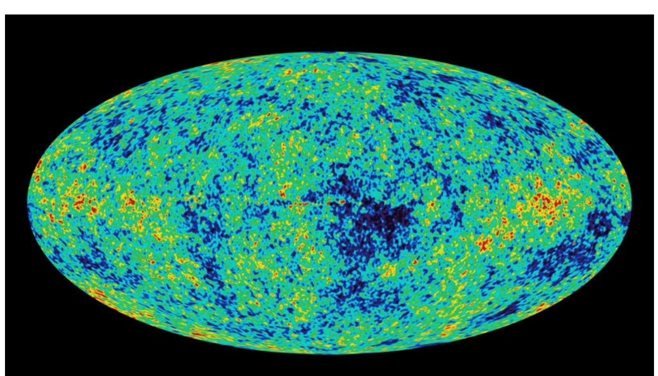
In general: one week will be "hands-on" week, one week will be "analysis" week. During analysis weeks, one of us will be "on call" in our office at each of the regular lab times.

Lectures

We'll talk about material relevant to the labs, but also about radio astronomy in general:

+ techniques: single-dish telescopes, interferometry

+ science: interstellar medium, active galactic nuclei, pulsars, cosmic microwave background



Last lecture: student choice

May 4th = last day of class:

I will lecture on 1–2 topics that you choose shortly after spring break. Any topic related to radio astronomy is fair game.

Previous years:

"Current and Future Radio Astronomy Projects"
"The Search for Extraterrestrial Intelligence"
"Gravitational Waves & Organic Material in Space"
"SETI & Galaxy Collisions"
"Exoplanets & Quasars"
"Radio Astronomy from the South Pole" (with D. Barkats)

Visit to Green Bank

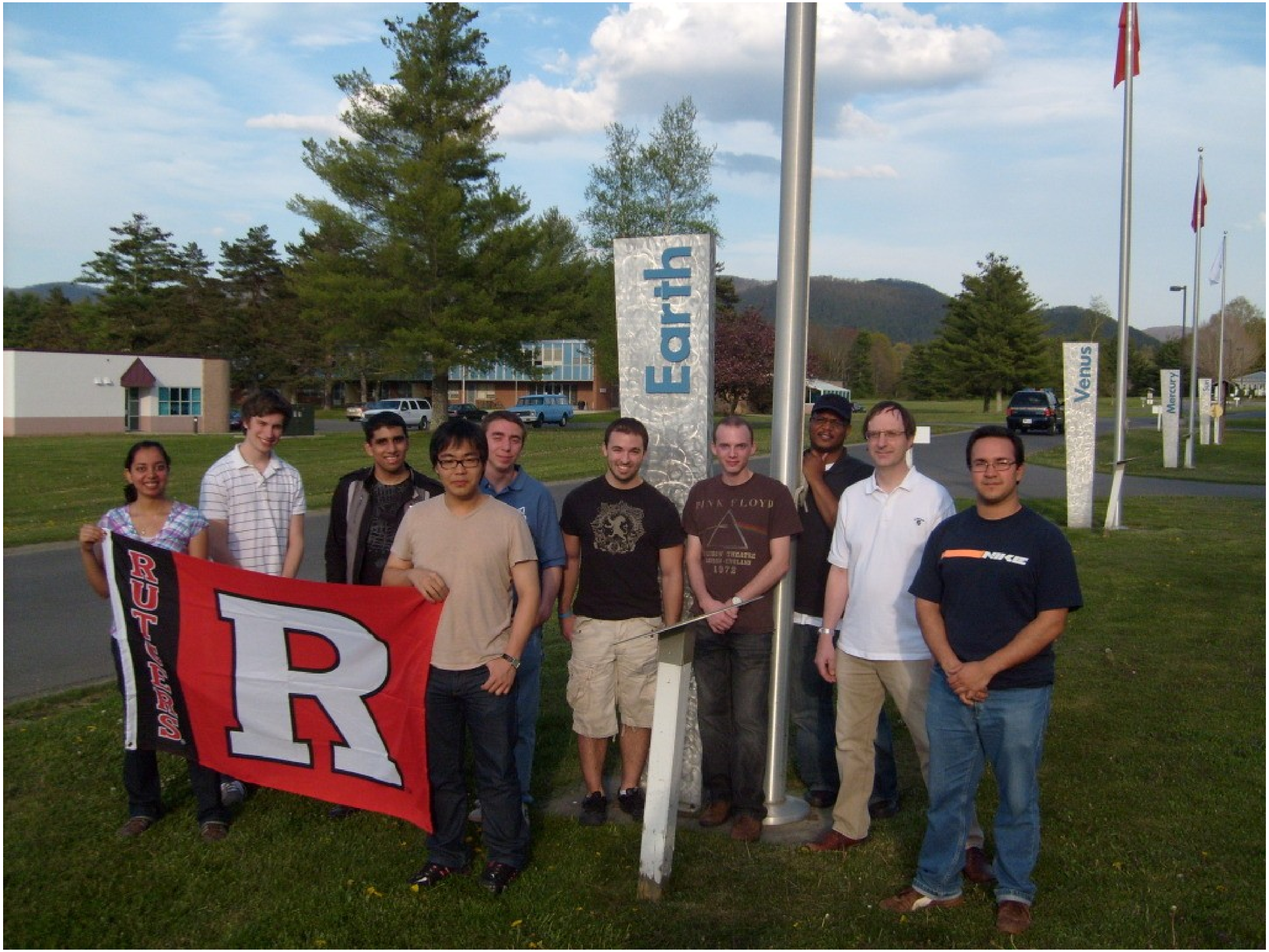
The National Radio Astronomy Observatory (NRAO) has a site in Green Bank, WV in the middle of the National Radio Quiet Zone. This is the location of the world's largest fully steerable radio telescope (100m diameter).

Fri 4/17: drive to Green Bank
Sat 4/18: tours of telescopes, labs; hands-on observing of a stellar nursery in the Milky Way
Sun 4/19: return to Rutgers

Rutgers at Green Bank: 2008

Rutgers at Green Bank: 2009

Rutgers at Green Bank: 2010

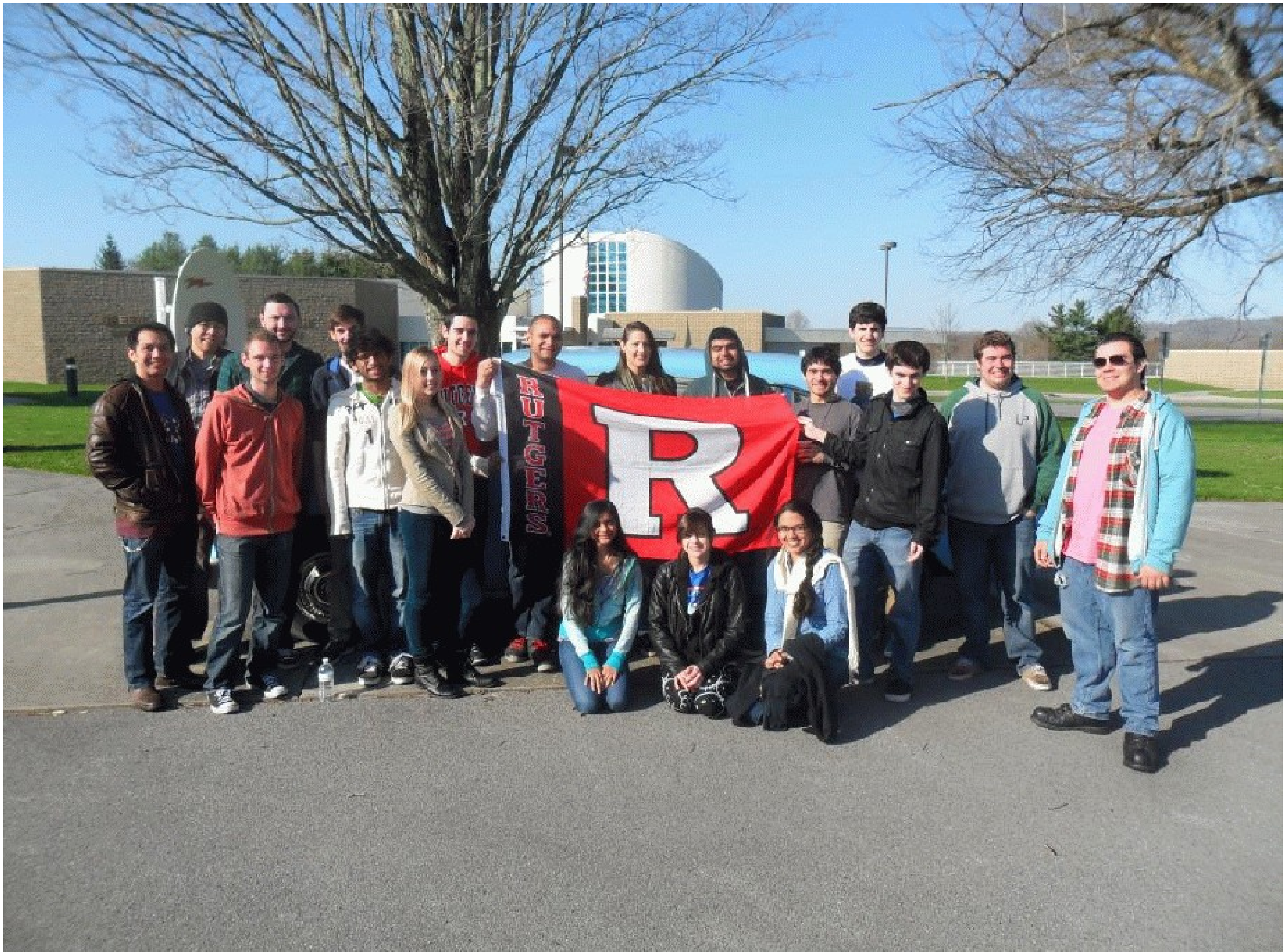


Rutgers at Green Bank: 2011

Rutgers at Green Bank: 2012

Rutgers at Green Bank: 2013

Rutgers at Green Bank: 2014



Time for something new...

This year's course will be different from previous years' versions:

+ less emphasis on the Small Radio Telescope (SRT) on the roof of Serin
+ more emphasis on working with archival data from research-grade telescopes
+ labs may include optional "stretch" goals, which will not affect your grade but will exercise skills that are relevant to research and graduate school

Labs

Six labs planned, of which at least three will be brand new:

#1: detection of atomic gas in elliptical galaxies
#2: measuring the Milky Way's rotation curve
#3: working with radio-wavelength data cubes
#4: millimeter interferometry of an external galaxy
#5: something to do with pulsars

#6: class visit to Green Bank, West Virginia,
or a substitute final project

Lab # 1: last year vs. this year

Last year...

... and this year!

Grades

Course grades will be based on a combination of:

- **+ quizzes during lecture (10%) – can happen at any time!**
- **+ participation during lecture (10%) – present and awake earns 7/10; ask a question or volunteer earns 10/10**
- **+ preparation for and active participation during "hands-on" lab meetings (30%)**
- **+ lab reports (50%)**

Lab reports should be written up individually even if observations were analyzed in teams.

The Green Bank trip will count as the sixth lab (with no report).

Regarding lab reports...

Do include:

(1) a brief description of the purpose of the observations

(2) a brief description of the observations (e.g., what telescope, frequency, target? did you edit the data in any way?)

(3) a description of your analysis (number-crunching)

(4) a discussion of your results (plots and sketches help; consider your sources of uncertainty)

(5) a summary of your most important conclusions

Do not include:

(1) full scripts/programs used to obtain/analyze data

(2) the raw data themselves

Email submission of a PDF file before 11:59pm is acceptable.

Absences and late work

Absences:

Unless you have a medical emergency, you should tell Prof. Baker in advance via https://sims.rutgers.edu/ssra/ or get zero quiz/participation points

Late penalty, quoting from website:

"I am willing to be somewhat flexible, but unless I tell you otherwise, I will deduct 10% *off the top* for each day a lab report is handed in late (the first deduction hits at 11:59pm on the nominal due date). This means that a lab report handed in three days late will receive at best a grade of 70%..."

This is not a joke:

students have failed this class in each of the last four years.

Good advice for this class (and beyond)

Ask questions (even if they seem "stupid"), and speak in lab!

Record everything you do in lab in a single, chronologically organized lab notebook. (This will help you remember what you did even days or weeks later, and will make it easier for us to help troubleshoot if there are problems.)

Remember that every measurement comes with a unit and an uncertainty.

What's different about radio astronomy?

Wavelengths are longer (λ = 0.35mm – 6m, vs. ~0.0005mm for visible light). This has several consequences:

Telescopes have larger diameters and lower surface accuracies.

Observations can often be done during day or night, and are less limited by the atmosphere (clouds, turbulence, etc.).

Detectors are often sensitive to the phase of incident radiation, not just its amplitude (in the sense of a complex number).

What do we study with radio telescopes?

Typically, we study interstellar matter:

- **+ dust grains that glow because they're warm**
- **+ ionized plasmas that glow because they're warm, or because charged particles are accelerated in magnetic fields**
- **+ clouds of atomic and molecular gas producing line emission**

(Astronomy jargon that we'll see again: HI = neutral atomic hydrogen, HII = ionized hydrogen, H_2 = molecular hydrogen.)

We can also detect radio emission from planets and stars.

Line and continuum emission/absorption

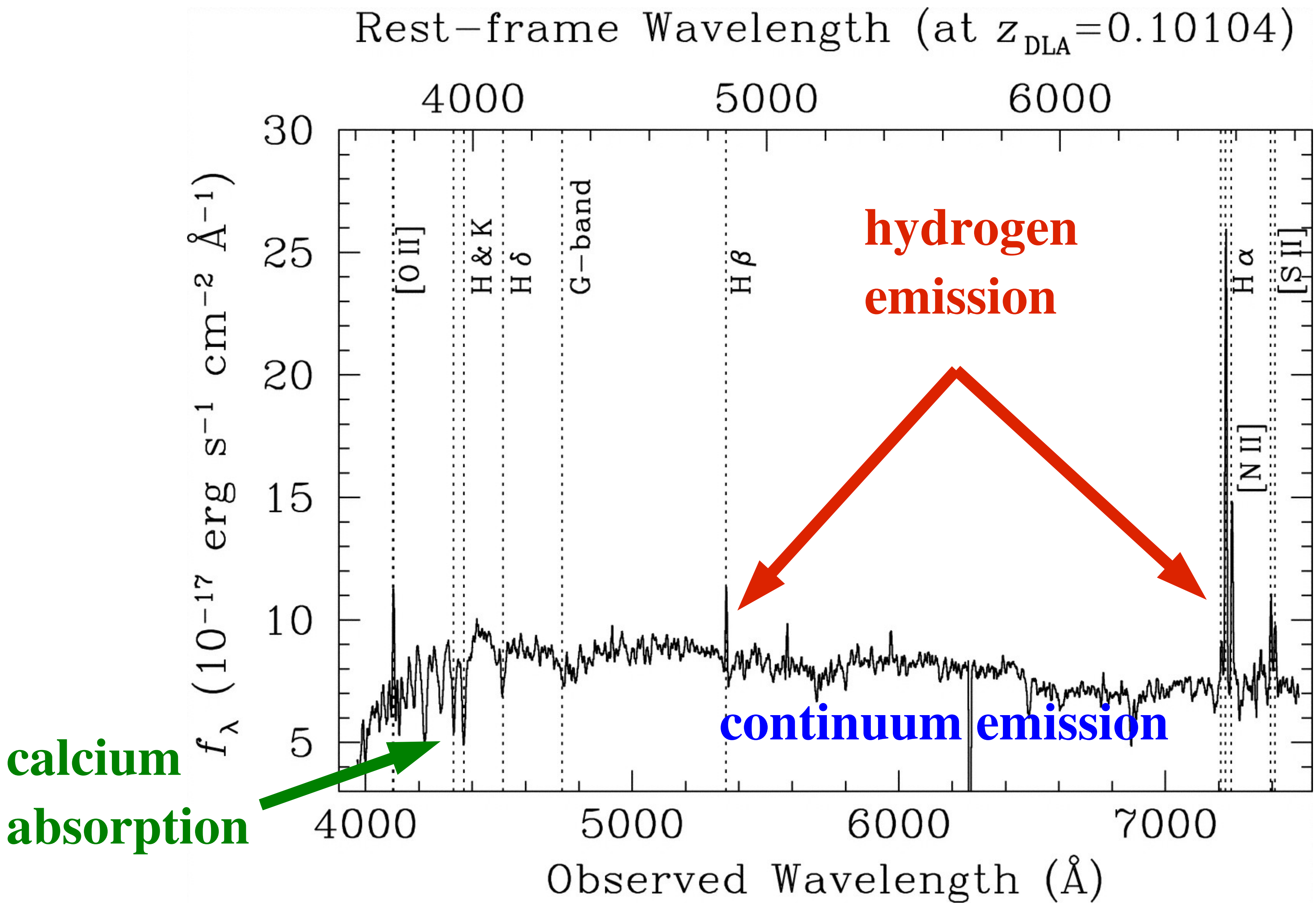
When we look at astronomical spectra (at all wavelengths), we classify features in two ways:

(1) line vs. continuum (roughly, narrow vs. broad)

(2) emission vs. absorption

Note: for an absorption line to be produced, there must be "background" continuum emission to be absorbed!

Example: optical spectrum of a galaxy



Radio continuum emission

Three principal mechanisms:

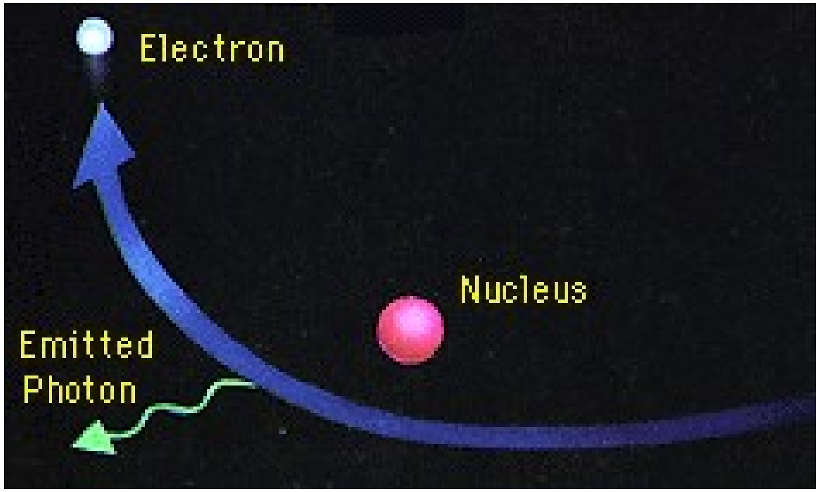
(1) **free-free emission** (a.k.a. "bremsstrahlung" = "braking radiation") from ionized gas

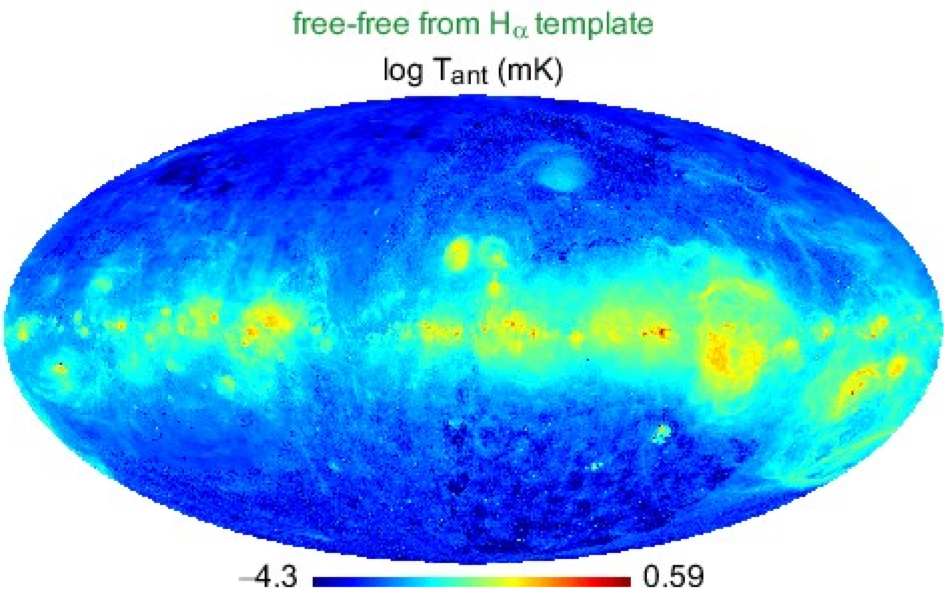
(2) **synchrotron emission** from electrons being accelerated in a strong magnetic field

(3) **thermal emission** (i.e., produced due to heat) by dust grains

Free-free emission

Mechanism: electrons are accelerated by the Coulomb potential of ions (higher temperature ⇔ faster motions ⇔ higher-energy photons).

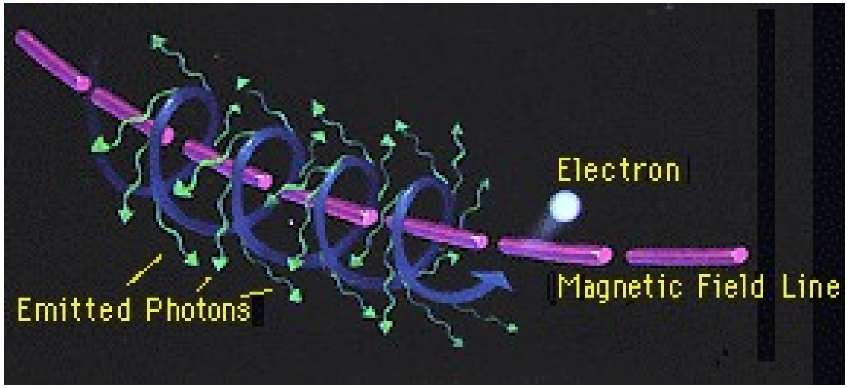


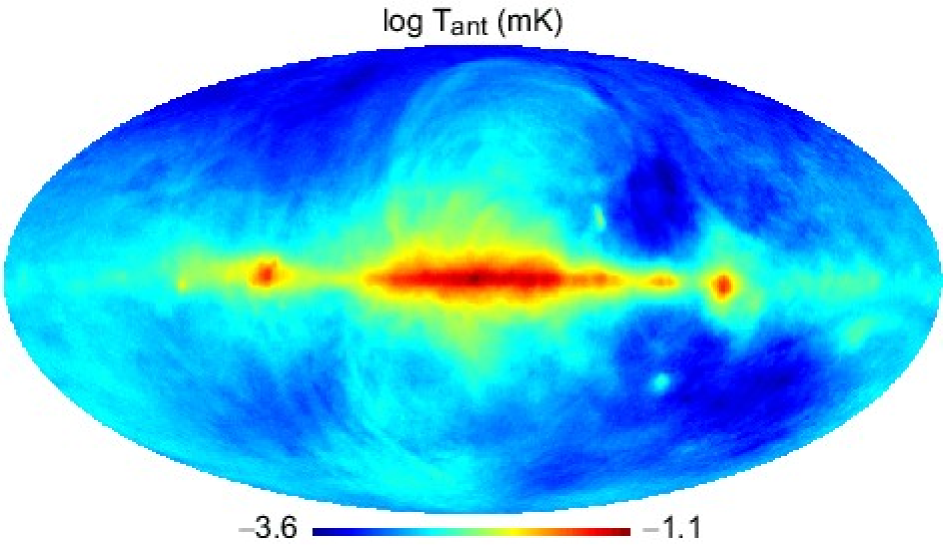


Burigana et al. (2004):
free-free emission from Milky Way at 100 GHz

Synchrotron emission

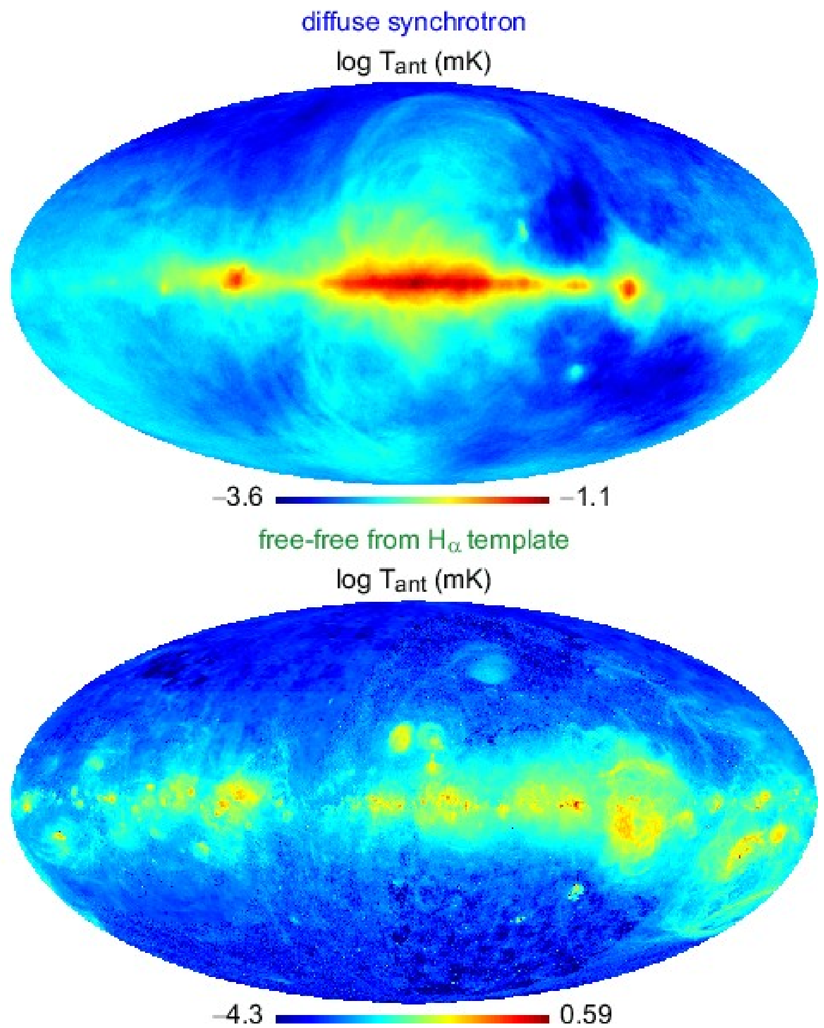
Mechanism: electrons are accelerated along helical trajectories in magnetic fields (stronger magnetic fields ⇔ higher-energy photons).





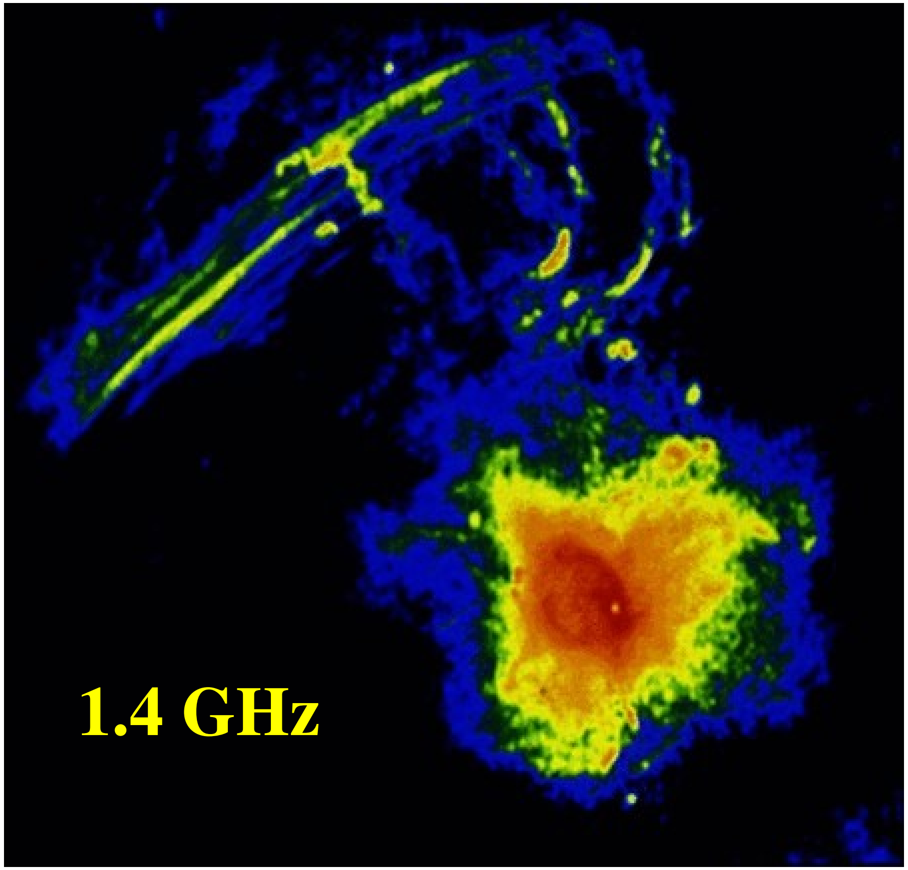
Burigana et al. (2004):
synchrotron emission from Milky Way at 100 GHz

Free-free vs. synchrotron emission



Why do these look different?

Galactic Center filaments: which mechanism is responsible?

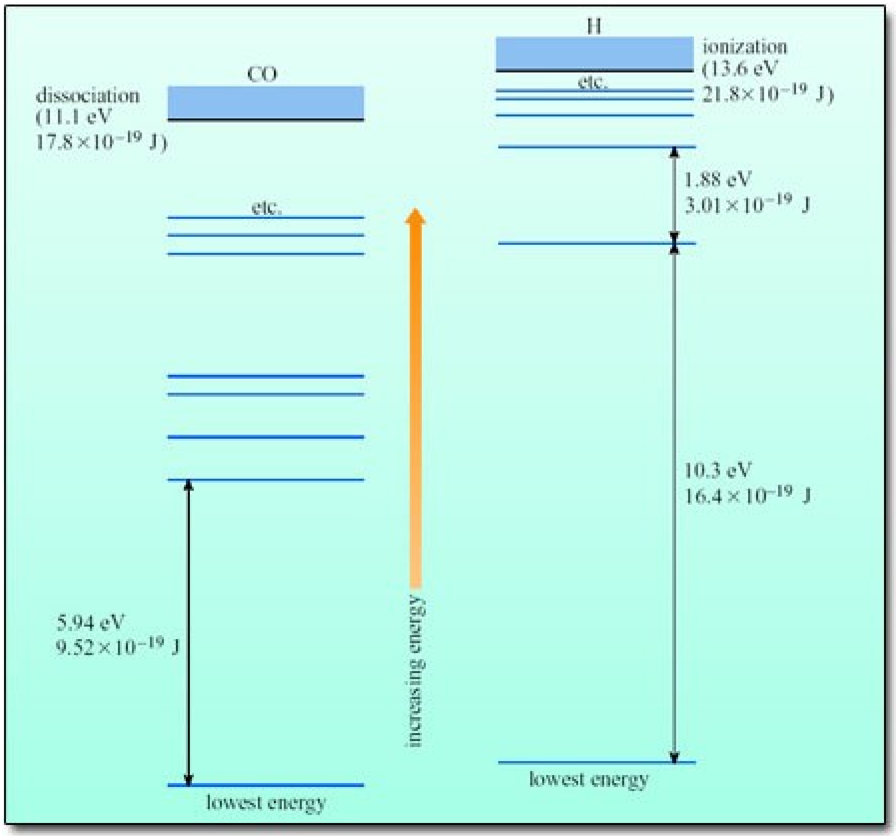


Line emission

A sharp line feature occurs when there is a transition in the electronic or spin state of an atom, or in the electronic, vibrational, or rotational state of a molecule.

This sharp feature is broadened by line-of-sight motions in the emitting/absorbing material (i.e., by the Doppler effect).

Electronic transitions

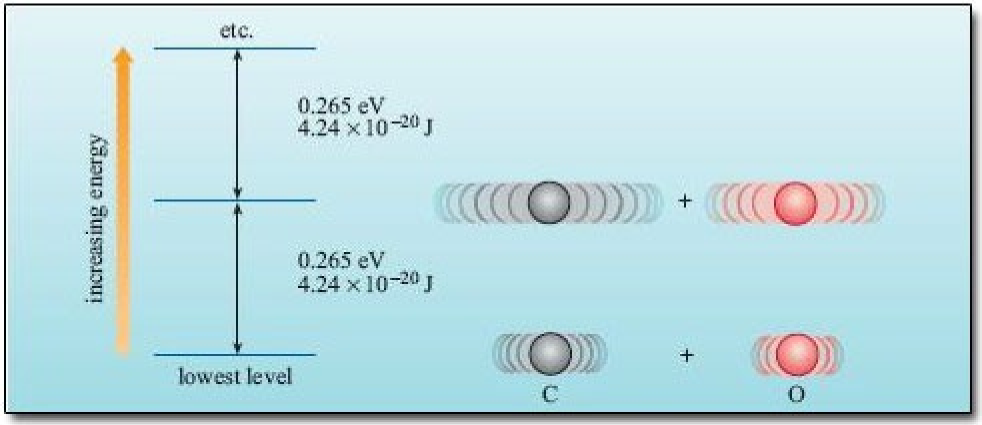


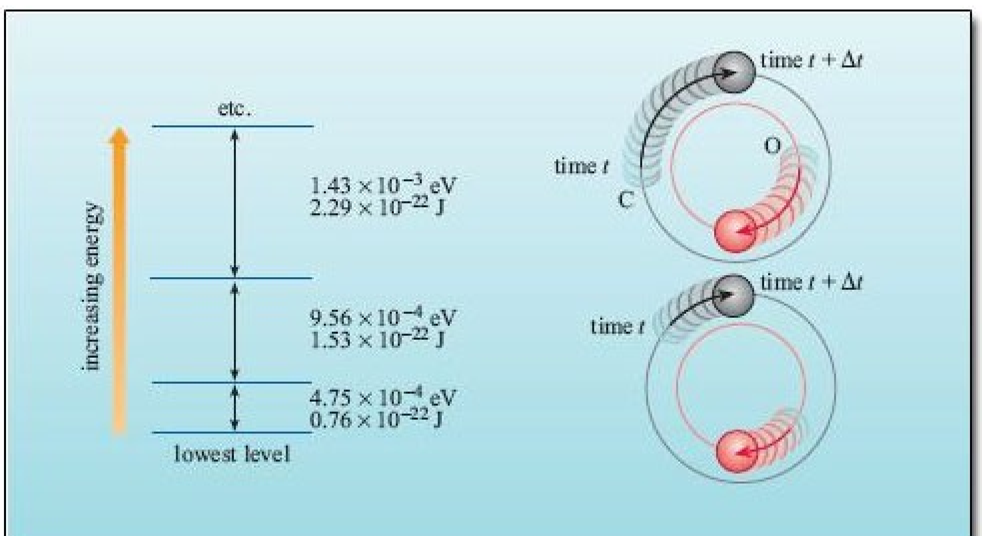
When an electron in an atom or molecule drops from a higher energy level to a lower energy level, a photon is emitted.

An incoming photon of the right wavelength/frequency can also be absorbed.

Courtesy of Open University.

Vibrational and rotational transitions





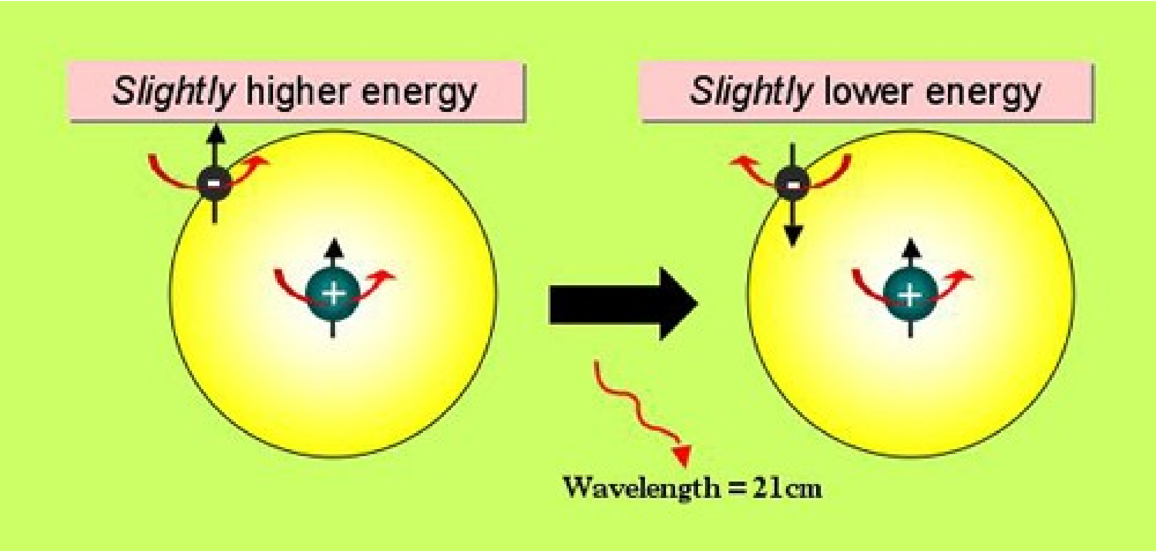
Courtesy of Open University.

Molecules also have quantized levels of vibrational and rotational energy (spacings are higher for the former).

Transitions are associated with absorption/emission of photons.

The key "spin flip" transition: 21cm H line

In a H atom, when the electron and the proton switch from having parallel spins to having antiparallel spins, a 21cm photon is emitted.



Doesn't trace ionized or molecular gas – just neutral atomic gas!

Courtesy of Swinburne University.

Quiz