

# 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

## Professor

**Andrew Baker**

**Serin W309**

**445-5500 x2544 (office)**

**[ajbaker\[at\]physics.rutgers.edu](mailto:ajbaker@physics.rutgers.edu)**

## Instructor

**Amruta Deshpande**

**Serin W332**

**445-5500 x5881**

**[amrejd\[at\]physics.rutgers.edu](mailto:amrejd@physics.rutgers.edu)**



**(godfather = Emeritus Prof. Tom Devlin)**

**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 on reserve in the physics library, 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 Gawiser) 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 or programs that you write.**

# Course meetings

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

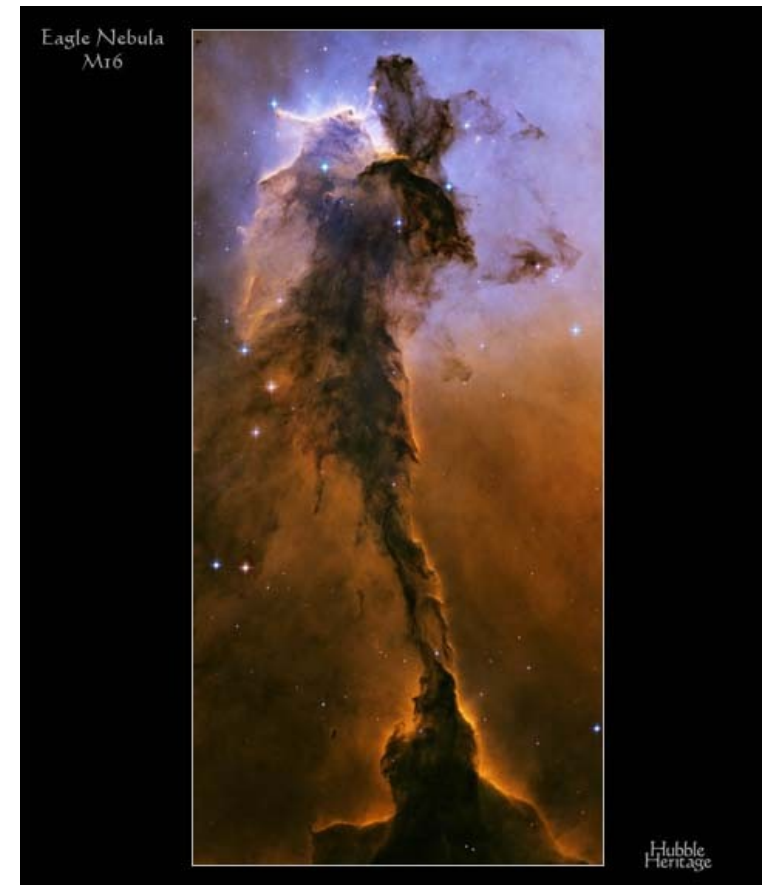
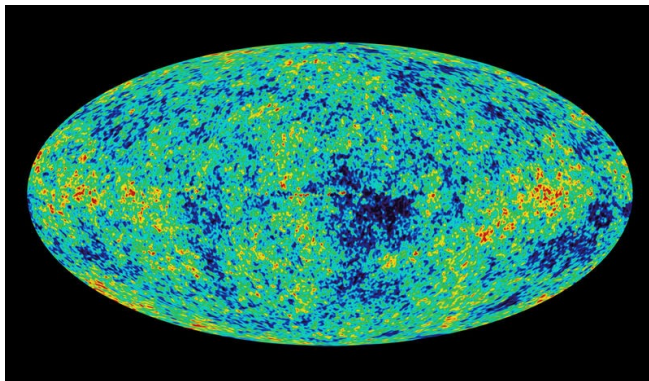
Labs: Serin 403b, times TBD (you will have assigned slots)

**In general: one week will be “observation” week, one week will be “analysis” week. During analysis weeks, one of us will be “on call” 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: stars, planets, interstellar medium, active galactic nuclei, cosmic microwave background**



# Last lecture: student choice

**May 6th = 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, and Organic Material in Space”**

**“SETI + Galaxy Collisions”**

# Labs

**Six labs planned, of which at least three will use the Small Radio Telescope (SRT, diameter = 2.3m) on the roof:**

**#1: measuring a telescope's beam**

**#2: calibrating a telescope's response; measuring solar variability**

**#3: measuring the thickness of the Milky Way's disk**

**#4: measuring the Milky Way's rotation curve**

**#5: millimeter interferometry of an external galaxy**

**#6: class visit to Green Bank, West Virginia, or a final project with the SRT studying “radio frequency interference”**

# 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 4/26: drive to Green Bank**

**Sat 4/27: tours of telescopes, labs;  
hands-on observing of  
a stellar nursery in the  
Milky Way**

**Sun 4/28: return to Rutgers**





# Rutgers at Green Bank: 2008



# Rutgers at Green Bank: 2009



# Rutgers at Green Bank: 2010



# Rutgers at Green Bank: 2012



# Grades

**Course grades will be based on a combination of:**

- + quizzes during lecture (10%) – can happen at any time!**
- + participation during lecture (10%)**
- + preparation for and active participation during labs (30%)**
- + lab reports (50%)**

**Lab reports should be written up individually even if observations were done 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., how many data points per position? was a script modified 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)**

## **Do not include:**

- (1) full scripts used to obtain data**
- (2) the raw data themselves**

**Write in active voice (“We did...”), and be faithful to the data!**

# 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. This means that a lab report handed in three days late will receive at best a grade of **70%...**”

# 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.**



## Two items in the “optional” category

There may be several afternoons or evenings during the semester when I am observing with the GBT **from his office**. I will alert you to these sessions as they are scheduled; you are welcome to come watch. (No extra credit, but can be educational/entertaining.)

Except in extreme cases, I will not be grading your lab reports for **quality of writing**. If you would like me to comment on the writing in your lab reports (there will be no impact on your grade), please let me know.

# What's different about radio astronomy?

Wavelengths are longer ( $\lambda = 0.35\text{mm} - 6\text{m}$ , vs.  $\sim 0.0005\text{mm}$  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<sub>2</sub> = molecular hydrogen.)

# What radio telescopes do researchers use?

**National Radio Astronomy Observatory (NRAO):**

**Green Bank Telescope (GBT, in West Virginia)**

**Jansky Very Large Array (JVLA, in New Mexico)**

**Very Long Baseline Array (VLBA, all over)**



# What radio telescopes do researchers use?

**National Astronomy and Ionosphere Center (NAIC):**

**Arecibo Observatory (in Puerto Rico; 305m diameter!)**



# Summer research opportunities

## Research Opportunities for Undergraduates (REU) programs...

- + **National Radio Astronomy Observatory (Socorro, NM; Charlottesville, VA; Green Bank, WV): deadline February 1**  
(<https://science.nrao.edu/opportunities/student-programs/summerstudents>)
- + **Arecibo Observatory, Puerto Rico: deadline February 1**  
([http://www.naic.edu/reu\\_program.html](http://www.naic.edu/reu_program.html))

# What radio telescopes do researchers use?

Small university and large international facilities...

**Combined Array for Research in  
Millimeter Astronomy (CARMA)**



**Giant Metrewave Radio**

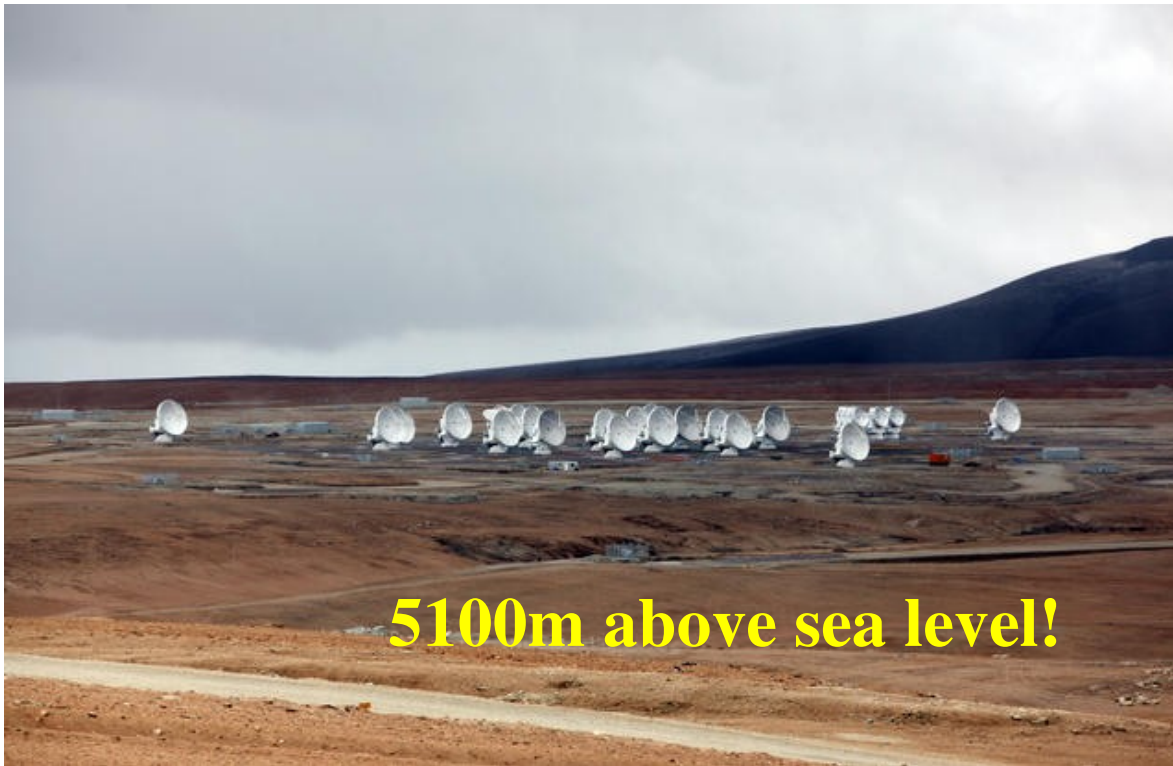
**Telescope (GMRT)**



**Institute for Radioastronomy  
in the Millimeter (IRAM)**

# What radio telescope do researchers use?

**ALMA = Atacama Large Millimeter/submillimeter Array  
in northern Chile**



**operations support facility**



# What radio telescopes *will* researchers use?

**MeerKAT = “more” Karoo Array Telescope” in northwest South Africa; engineering office is in Cape Town**

**early artist's conception**



**This will be a precursor for the Square Kilometer Array (SKA – name refers to collecting area), which there are plans to build in western Australia and southern Africa.**

# A common thread: go to high/remote sites

For cutting-edge research, the two big obstacles are:

(1) at shorter wavelengths ( $\lambda < 1\text{cm}$ ), **atmospheric water vapor**

⇒ go to a **high** site

(2) at longer wavelengths, ( $\lambda > 1\text{cm}$ ), **radio frequency**

**interference (RFI) from man-made sources**

⇒ go to a **remote** site

**Note: Serin is neither high nor (more key for  $\lambda = 21\text{cm}$ ) remote...**

# Quiz

# More details about the SRT...

**Antenna diameter = 2.3m  
(standard satellite dish).**

**Aluminum frame + mesh  
surface (will reflect all light  
if holes are  $< \lambda/10$ ).**

**Mount = azimuth/elevation  
design (with some limits).**



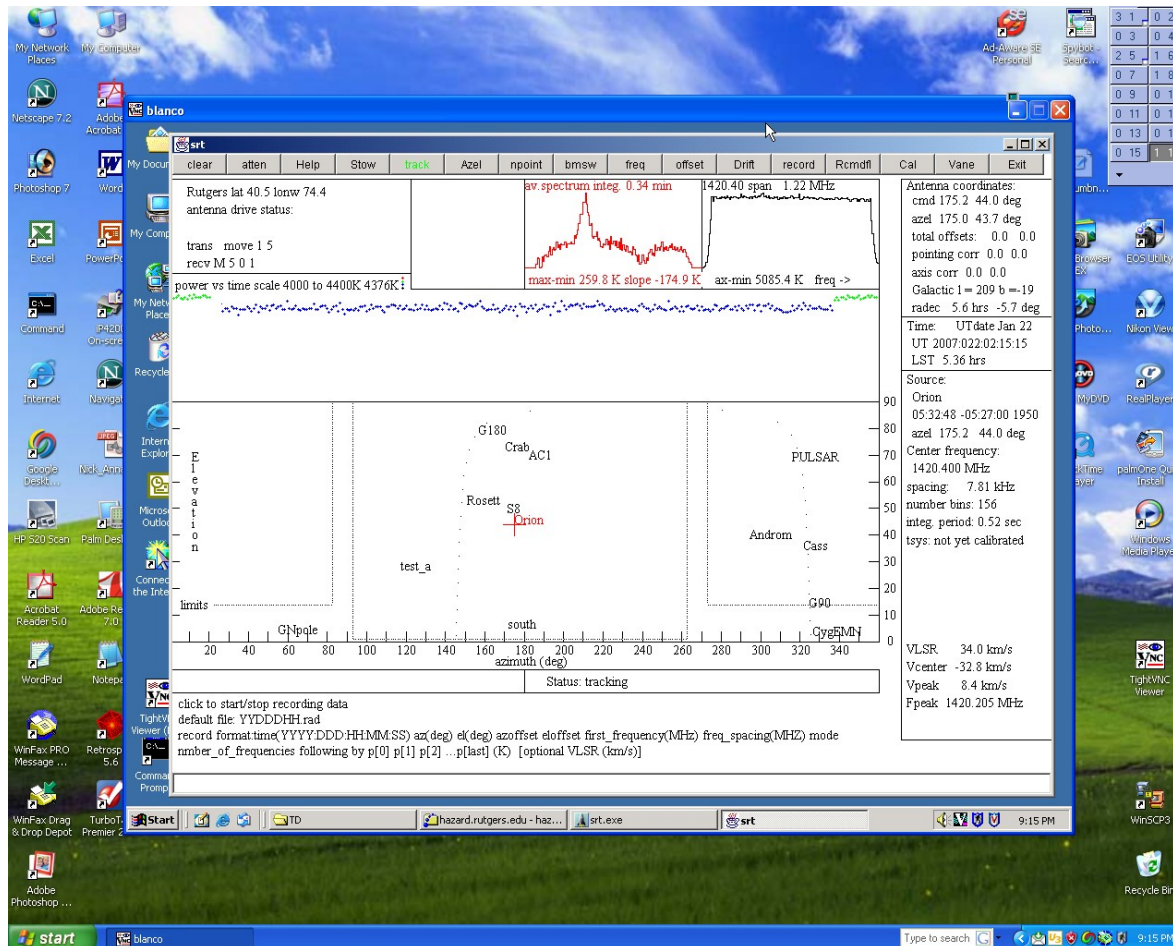
# More details about the SRT...

**Receiver** is sensitive to light with  $\lambda = 21\text{cm}$ , which is where the main transition of atomic hydrogen (HI) lies.

**Both continuum and line observations are possible.**



# More details about the SRT...



**Control software is written in Java for a Windows platform.**  
**Command sequences are prepared using a scripting language.**

# ...but some issues in the wake of Sandy



**Unclear to what extent we will be working with archival data.**

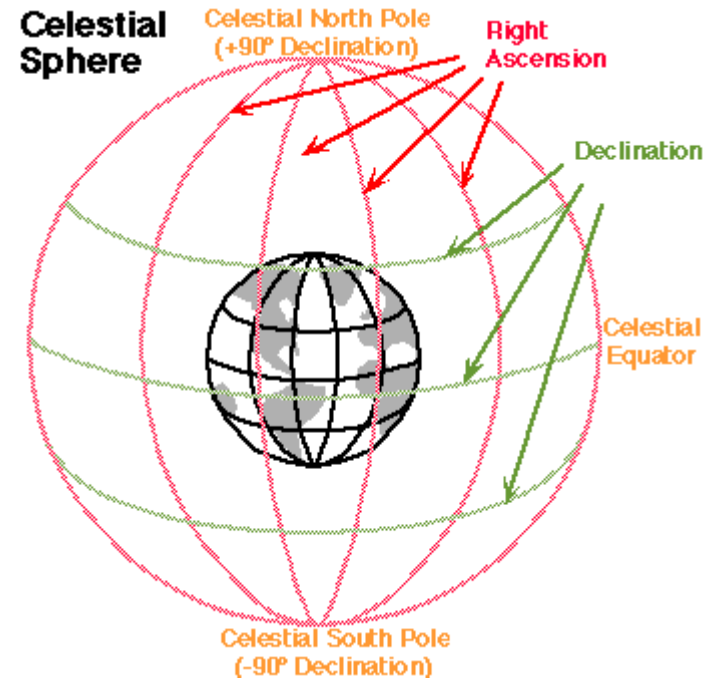
# Coordinate systems: earth's point of view

## Celestial coordinates:

+ **declination** ranges from  $90^\circ$  (north celestial pole)  
to  $-90^\circ$  (south celestial pole) – like latitude

+ **right ascension** ranges from  $0^\circ$  (for stars, galaxies, etc.  
that transit at midnight on 9/21) to  $90^\circ$  (farther east)...  
to  $360^\circ$  – like longitude

Celestial coordinates of  
solar system objects  
change (relatively)  
rapidly.



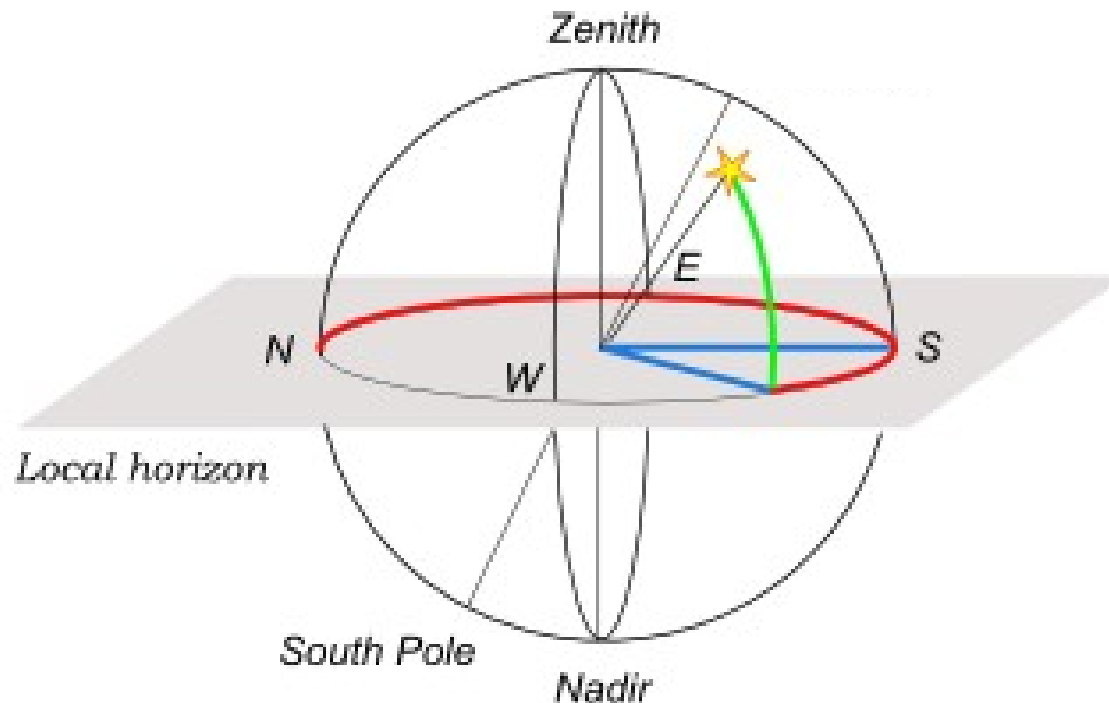


# Coordinate systems: telescope's point of view

## Horizontal coordinates:

+ **elevation** ranges from  $90^\circ$  (zenith) to  $0^\circ$  (horizon)

+ **azimuth** ranges from  $0^\circ$  (north) to  $90^\circ$  (east) to  $180^\circ$  (south) to  $270^\circ$  (west) to  $360^\circ$  (north) around the horizon



# Preparation for lab #1

**Homework for next time:**

**Read the documentation on the SRT.**

**Write a script that does the following:**

- (1) sets the frequency to 1415 MHz**
- (2) slews to the Sun and does an “npoint” scan**
- (3) moves 30 degrees in azimuth away from the Sun**
- (4) pauses for 30 seconds before moving back to the Sun**