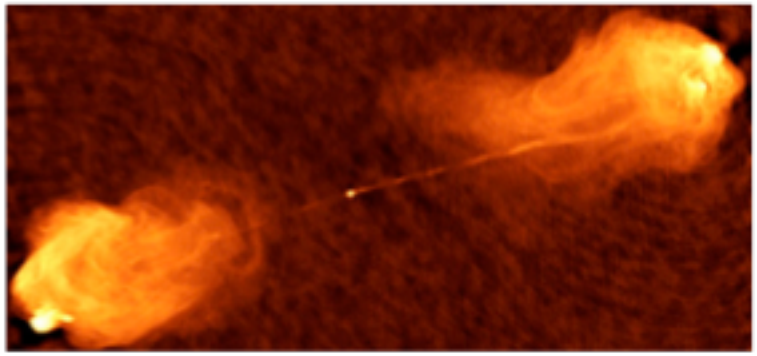
# Radio Astronomy (ASTR700)



Cygnus A (NRAO)

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## A whole class about radio astronomy?!?

2

## Course goals.

- Understand how radio instrumentation functions and is used in practice.
- Understand the physics that gives rise to radio emission.
- Know current and past science.
- Hands-on experiences!

3

## Meta-goals.

- Improve your science communication skills
  - Speaking.
  - Writing.
- Improve order-of-magnitude estimation skills.
- Learn a few (computer-based) tools of the trade.

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# Introductions…

- Preferred name.
- Are you taking (or have you taken) Bandura's related DSP course?
- What is the (planned) focus of your PhD?
- What do you hope to gain from this course?
- What's your past experience with radio astronomy?
- Are you free for either of my office hours?
- Interested in a trip to GBT?



# Class structure…



# USE THE WEBSITE!

**https://tinyurl.com/astr700**

- Lectures, homeworks, etc.
- Images and interactive tools.
- Answer keys.



# Text books

- Both free!
- ERA: Online or buy. Use as lecture notes.


- Tools of radio astro: More technical study. Get PDF free from library.

# I will help you…

- Prof-led Lectures
  - All slides posted online.
  - ERA = lecture notes.
- Problem-solving days
- Gallery walks?
  - Some homework questions will reiterate in-class exercises.
- Student-led Lectures; Office hours.



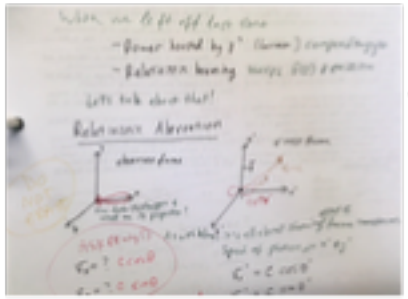
# You will help you…

- See online schedule for reading.
- Come to office hours.
- Interaction! - be ready.
- Do a good job prepping your lecture!
- **Careful with units!!!** ***note section F.3 in ERA**



# Student-led Lectures

- Important life skill!
- Put on your CV that you guest lectured for a grad class!
- Practice for oral qual!
- You will get my (overly annoted) lecture notes





# Student-led Lectures

- Tell me preferred topics and black-out dates by 1 February.
- You will get date and topic assignments by 10 Feb.
- Work in pairs to prep the topic (suggest ~50/50 presentation division)

# Advice

- Do the derivations yourself step by step to ensure you understand the material!
- Read a lot of different sources.
- Use our "official meetings" to help you, and use office hours if you want to chat more.
- Think creatively about how to communicate the material. The presentation style is up to you!



# Advice

**Conceptual understanding is just as important (if not slightly more important) as communicating the derivations!**



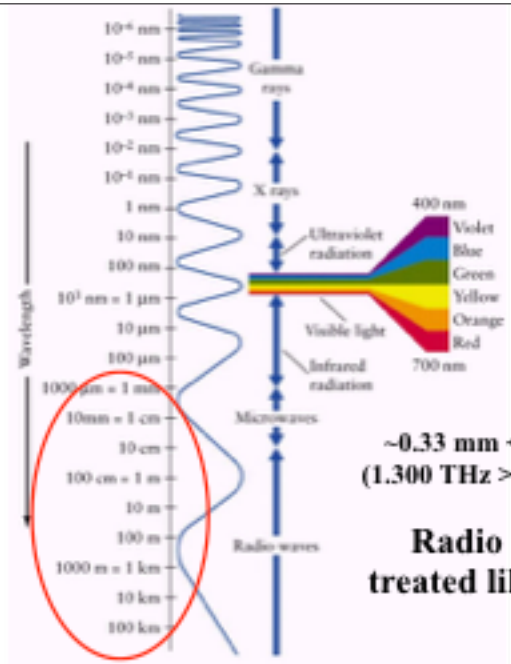
# Post-student-lecture quiz

- 2-3 brief questions on the most-critical-concepts.
- Averaged score counts toward Your-lecture grade. If you teach well, students will get 100%!
- Your score counts toward your grade. You can help yourself by doing the assigned reading.
- YOU ARE ALL LINKED!



# The Radio Band!



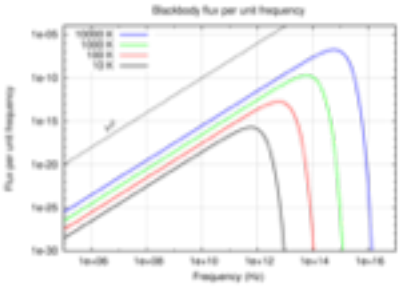





## $h\nu/kT << 1$ limit: Blackbody Radiation

- Planck's law:

$$B_\nu(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{\exp\left(\frac{h\nu}{kT}\right) - 1}$$

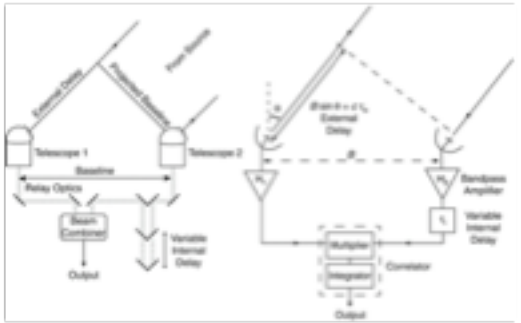


- Leads to Rayleigh-Jeans approximation, where brightness ~ $\nu^2$

$$B_\nu(\nu, T) = \frac{2kT\nu^2}{c^2}$$



## $h\nu/kT << 1$ limit: Coherent Amplifiers



- Minimum noise temperature of coherent amplifiers governed by quantum noise.
- [Derivation: Tools of Radio Astronomy 5.2.1]

# What coherent amplification can do…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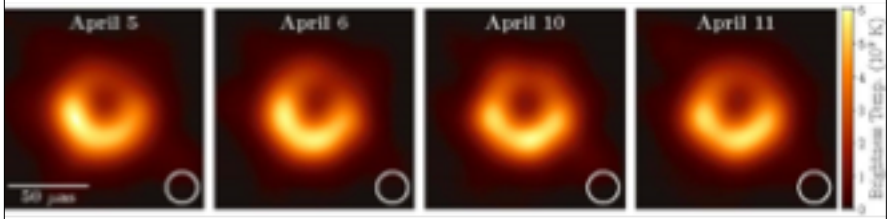
# Coherent amplification allows interferometry




EHT view of M87
(2019)

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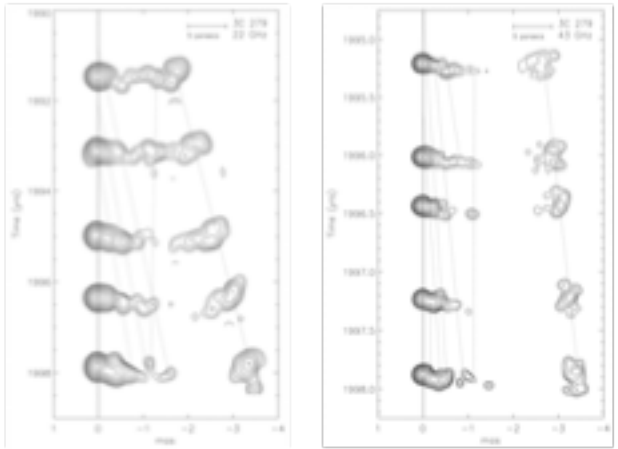
# Astrometric tracking



3C279; VLBA

Wehrle et al. 2001, ApJS, 133, 297

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# Unique features of the radio band…

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- Unique things happen at low energy and in the limit $h\nu/kT << 1$

**Radio astronomers don't lose too much sleep.**

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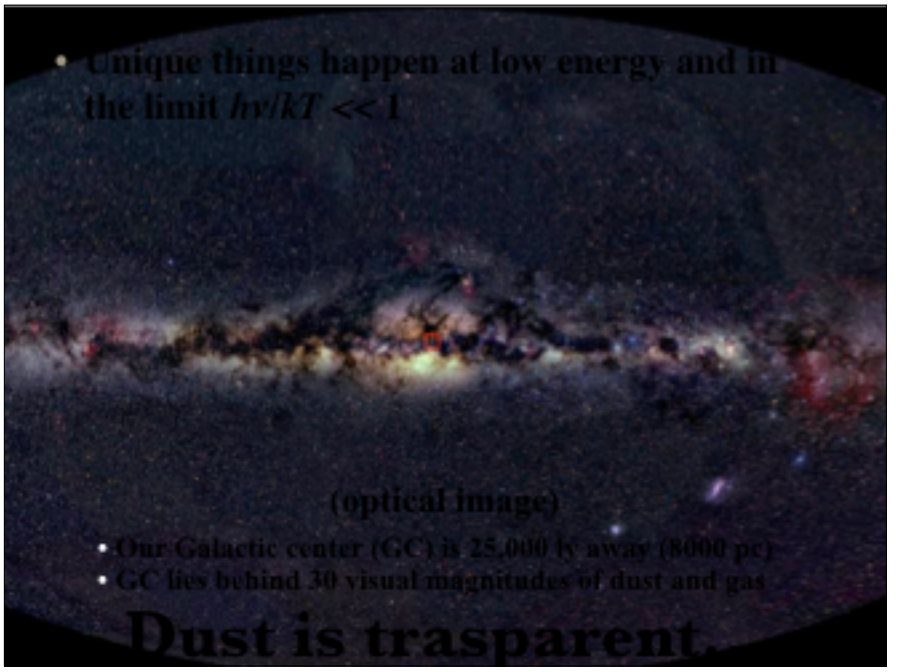


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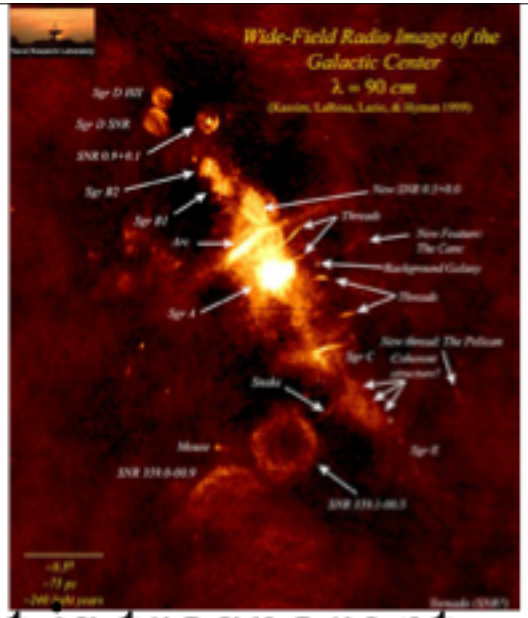
Very Large Array
λ=90 cm image
(~300 MHz)
45" resolution




**Dust is trasparent…**

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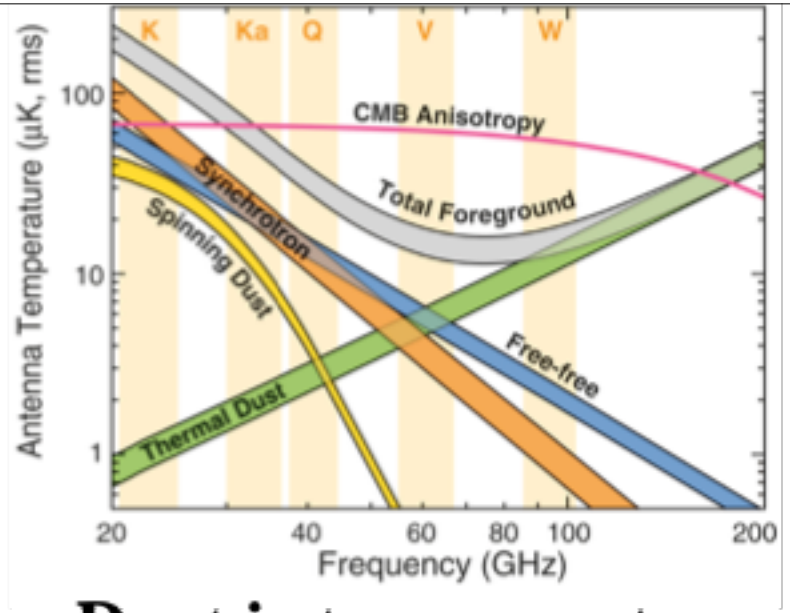


**Dust is trasparent…**

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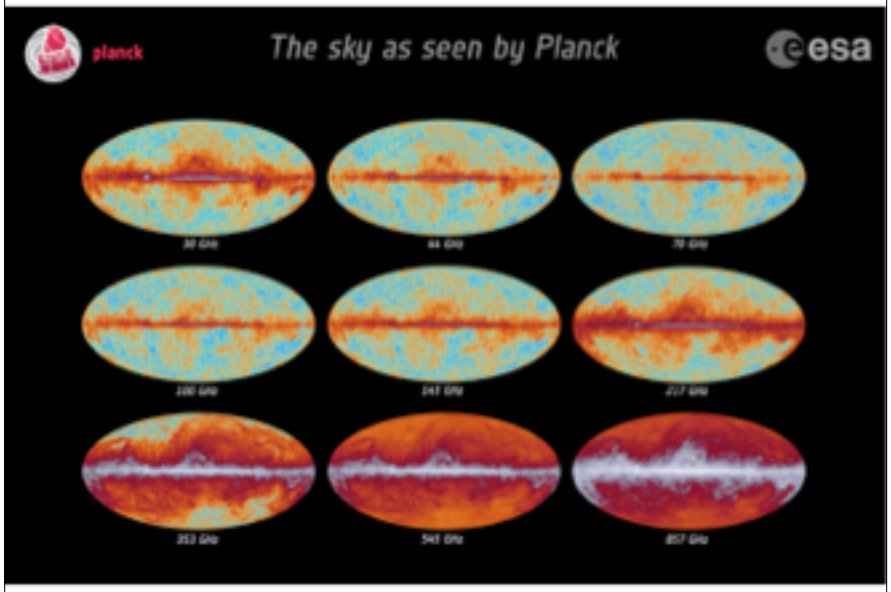


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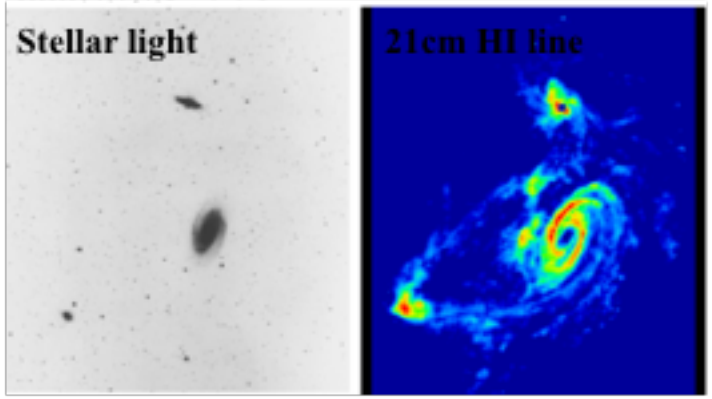
- Unique things happen at low energy and in the limit $h\nu/kT << 1$




- HI emission (hyperfine splitting)
- Recombination lines (e.g. interstellar atoms)

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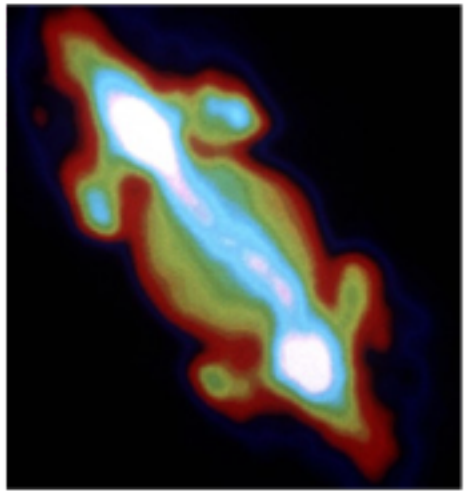
- Unique things happen at low energy and in the limit $h\nu/kT << 1$



VLA image

Unique emission physics: synchrotron

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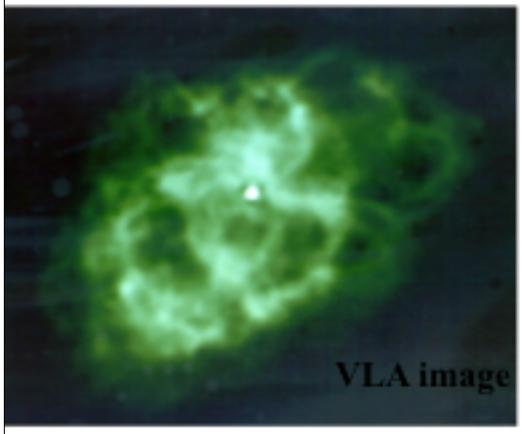
- Unique things happen at low energy and in the limit $h\nu/kT << 1$




Unique emission physics: synchrotron

34

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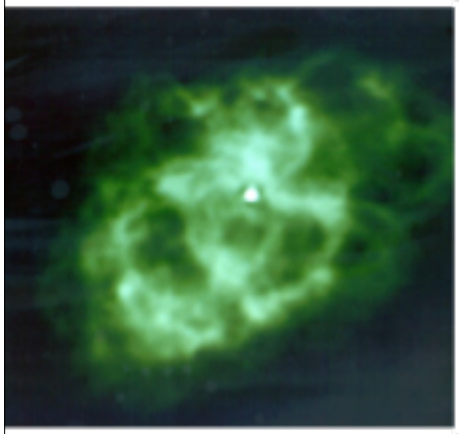

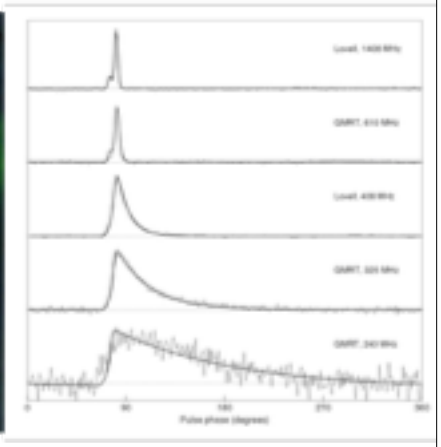

Unique emission physics: coherent pulses

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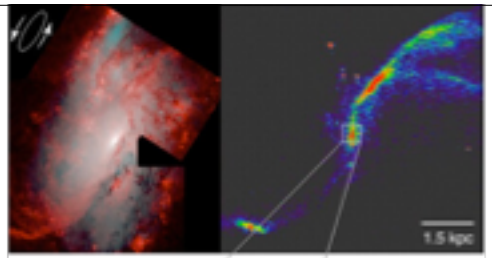
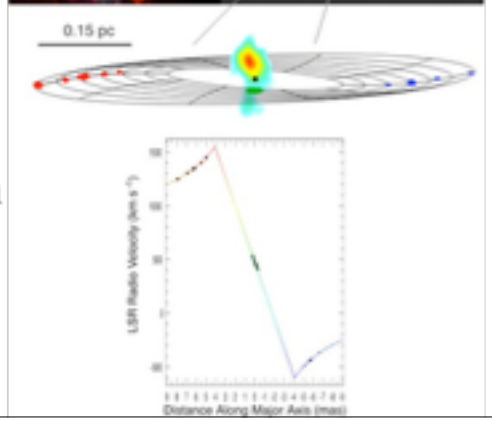
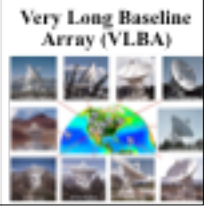


NGC 4258

Unique emission physics: masers



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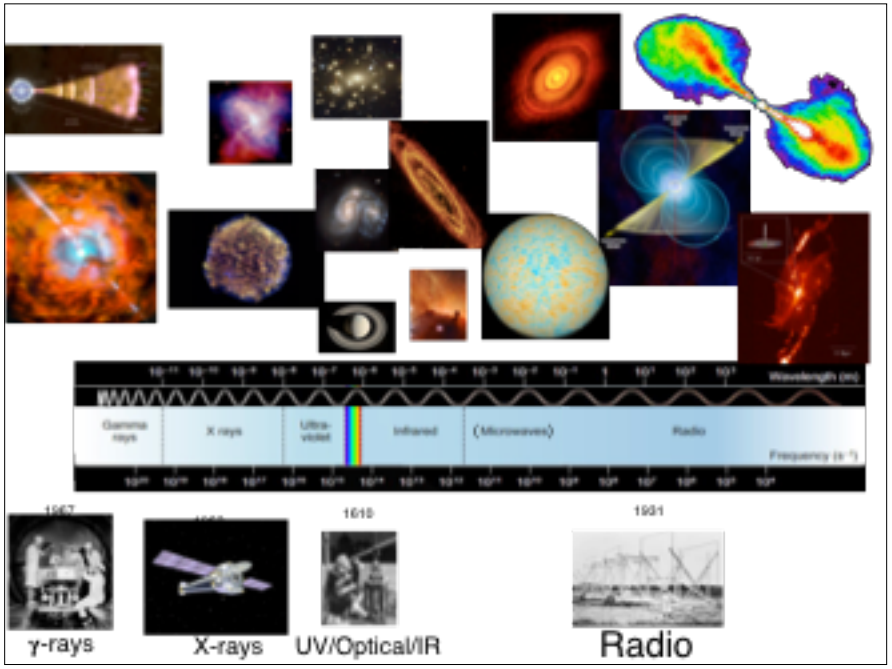


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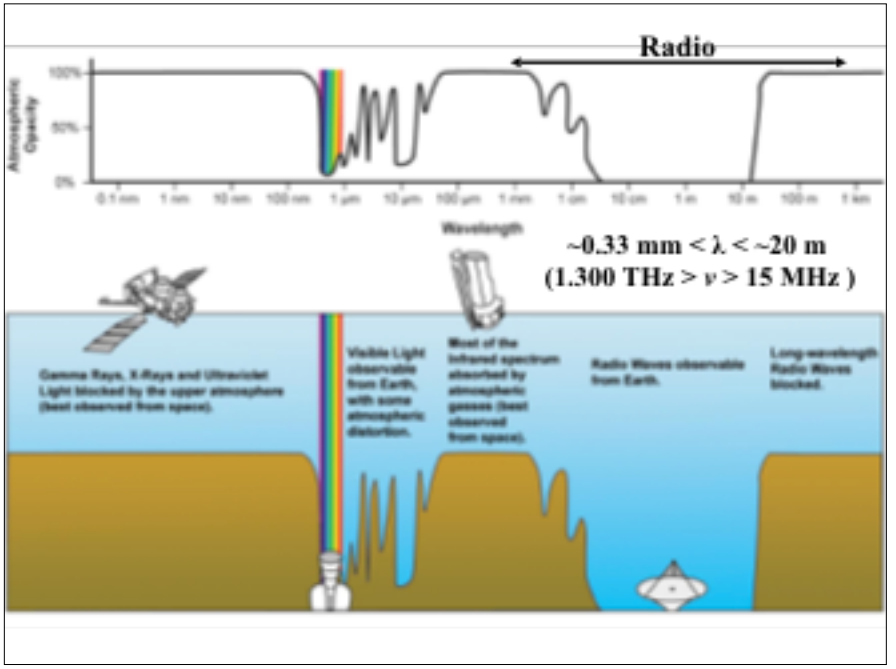


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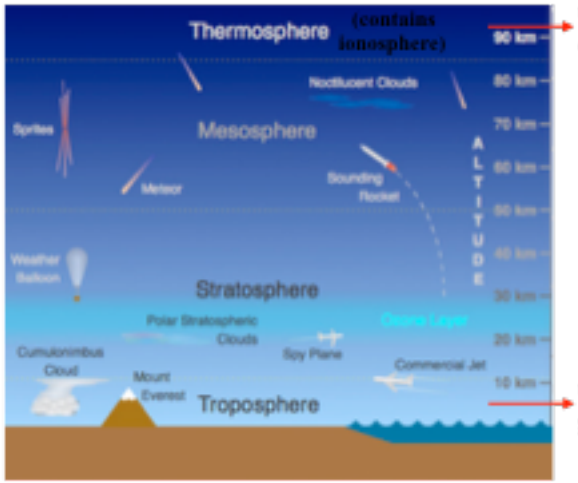


too many free electrons

too much gas/water

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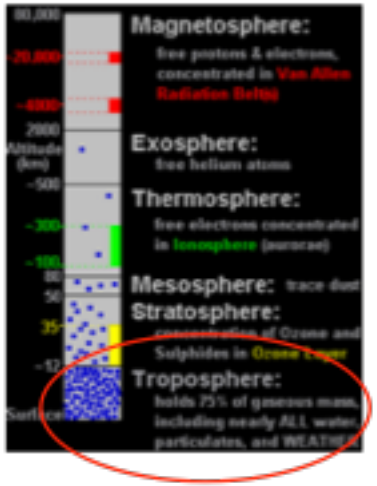
# High-ν Cut-off

- **TROPOSPHERIC!**
- $H_2O$, $O_2$ absorb incoming "high frequency" radio photons
- Particularly bad:
  - $H_2O$ at 22.2 GHz (1.35 cm)
    183 GHz (1.63 mm)
  - $O_2$ at 60 GHz (5 mm)
    119 GHz (2.52 mm)
- Water/oxygen "bands" are closely spaced absorption lines

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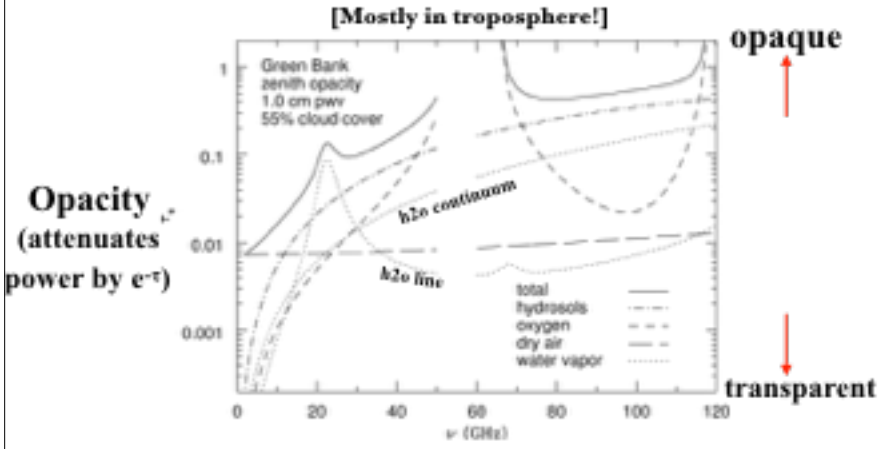
# Atmospheric absorption

[Mostly in troposphere!]

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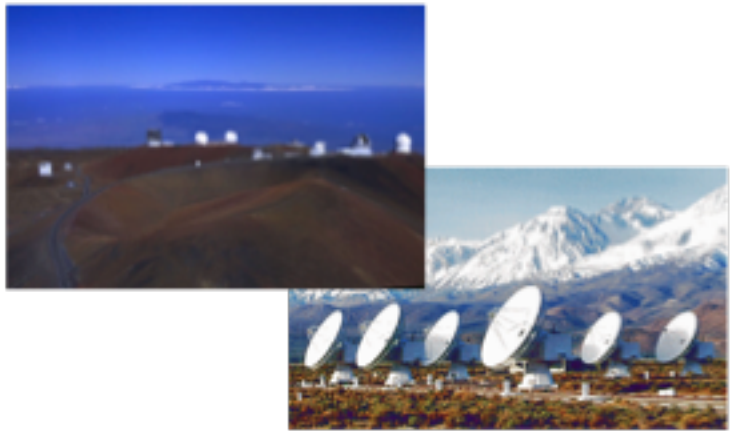
# High-frequency (>100GHz) observing

Because the main culprit is WATER VAPOR,
you **can** improve your observing conditions!



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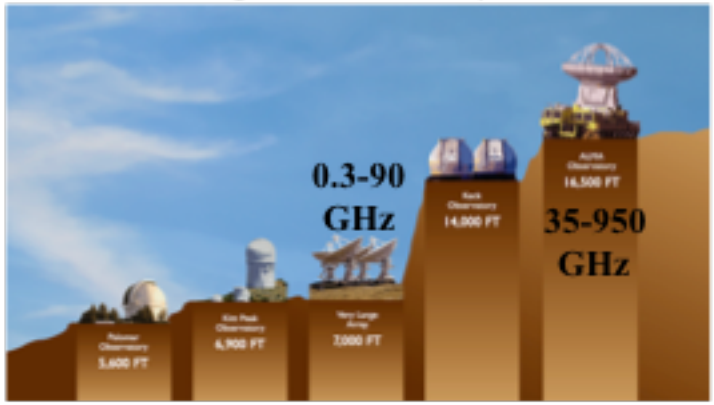
# High & Dry…




Highest, driest, most spacious telescope site:
Atacama desert, Northern Chile

Site of Atacama Large Millimeter Array (ALMA)

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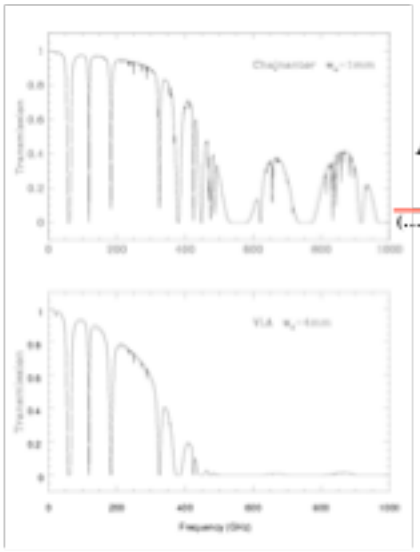
# Improving Atmospheric Opacity Constraints

**Transmission, not opacity. 1 is clear! 0 is opaque.**

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# ALMA

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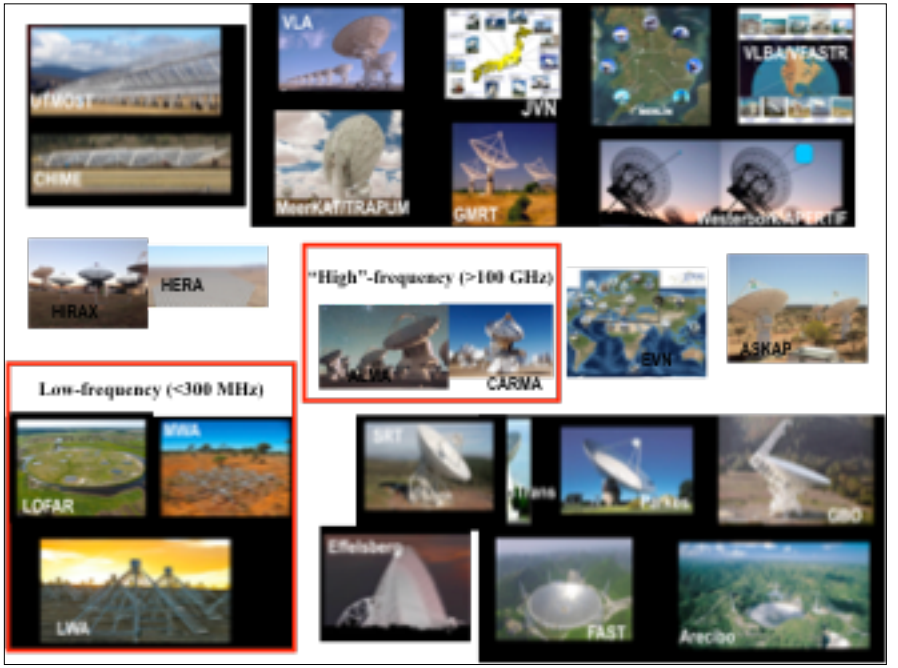


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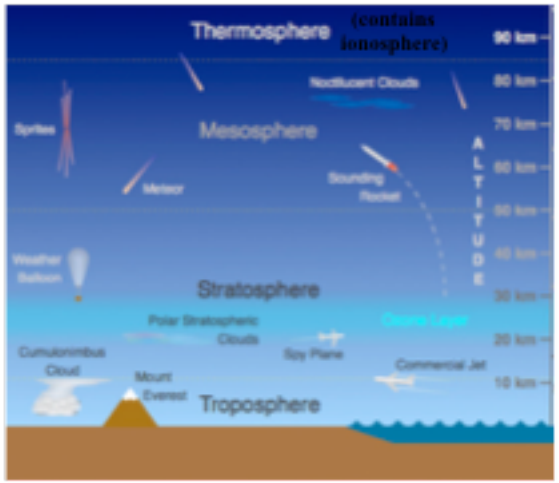


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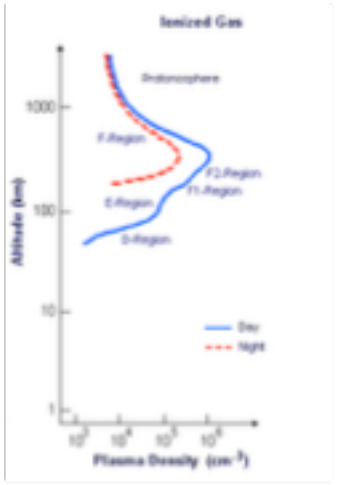
# Low-ν Cut-off

- **IONOSPHERIC!**
- Recall: waves reflected if frequency < plasma frequency, $\nu_p$:

$$\nu_p = \sqrt{\frac{e^2 n_e}{\pi m_e}} \simeq 8.97\,\mathrm{kHz}\left(\frac{n_e}{\mathrm{cm}^{-3}}\right)^{1/2}$$

$n_e$, electron density ($cm^{-3}$)

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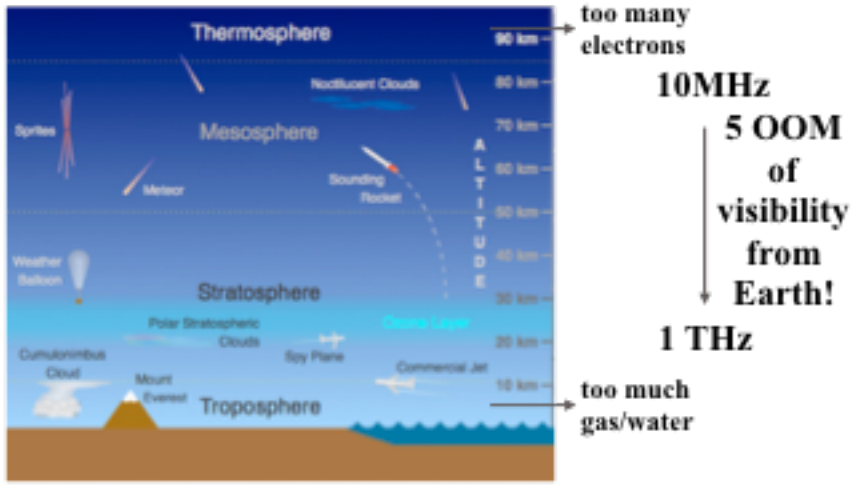


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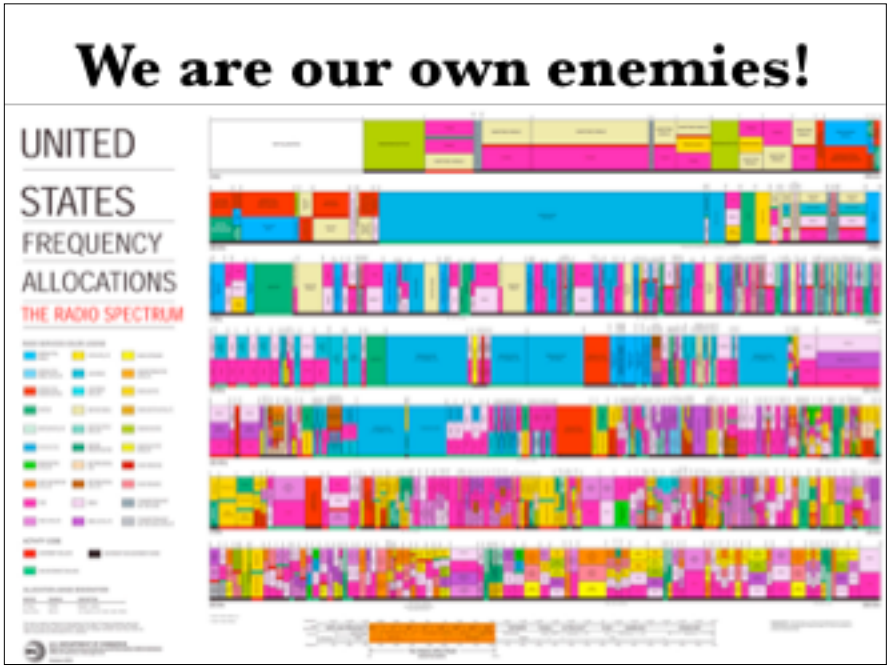


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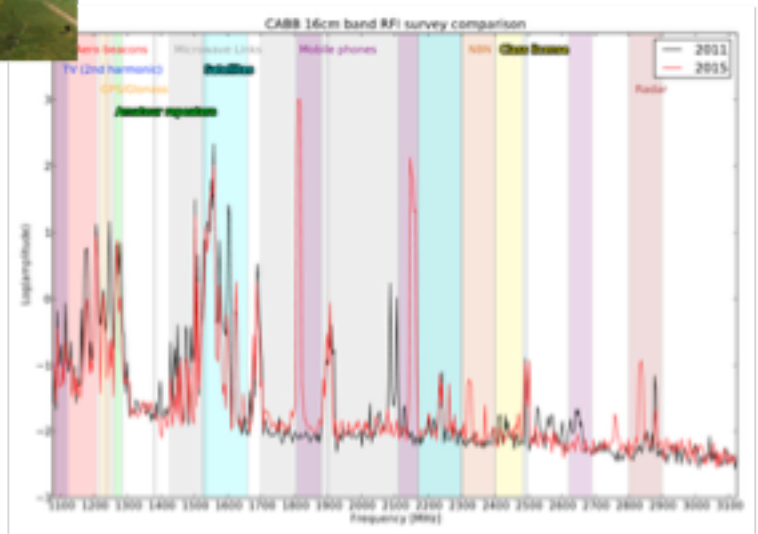
ATCA




Note: minimum detectable flux ~ 1/sqrt(Bandwidth)

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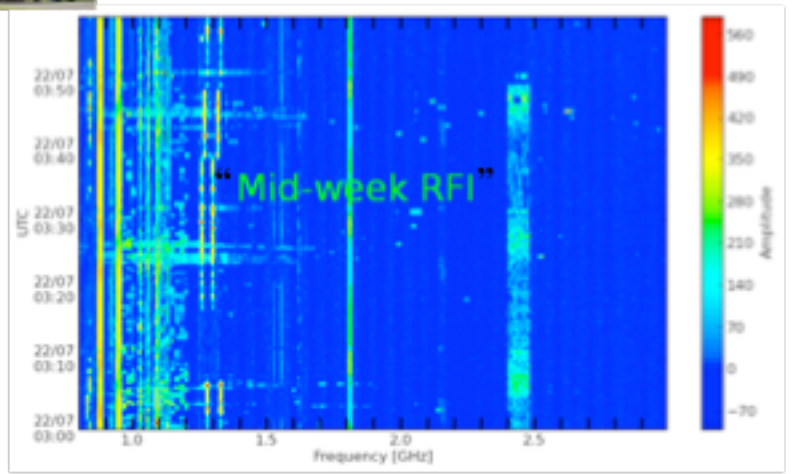
Parkes

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# Unique targets…

- **Galactic structure** (molecular lines, HI)
- **Transients** (supernovae, pulsars, FRBs)
- **Supermassive black holes** (active nuclei, masers)
- **Gravitational Waves** (pulsar timing)
- **Cosmology and galaxy evolution**
  (CMB, masers, HI, active nuclei)
- **Planetary and star formation**
  (HII regions, high-frequency radio)
- **Interstellar, Intergalactic, and Intracluster Media**

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**Next class: to the blackboard…**

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