Astro 426/526

Fall 2019

Prof. Darcy Barron

Lecture 25: X-Rays and Gamma Rays

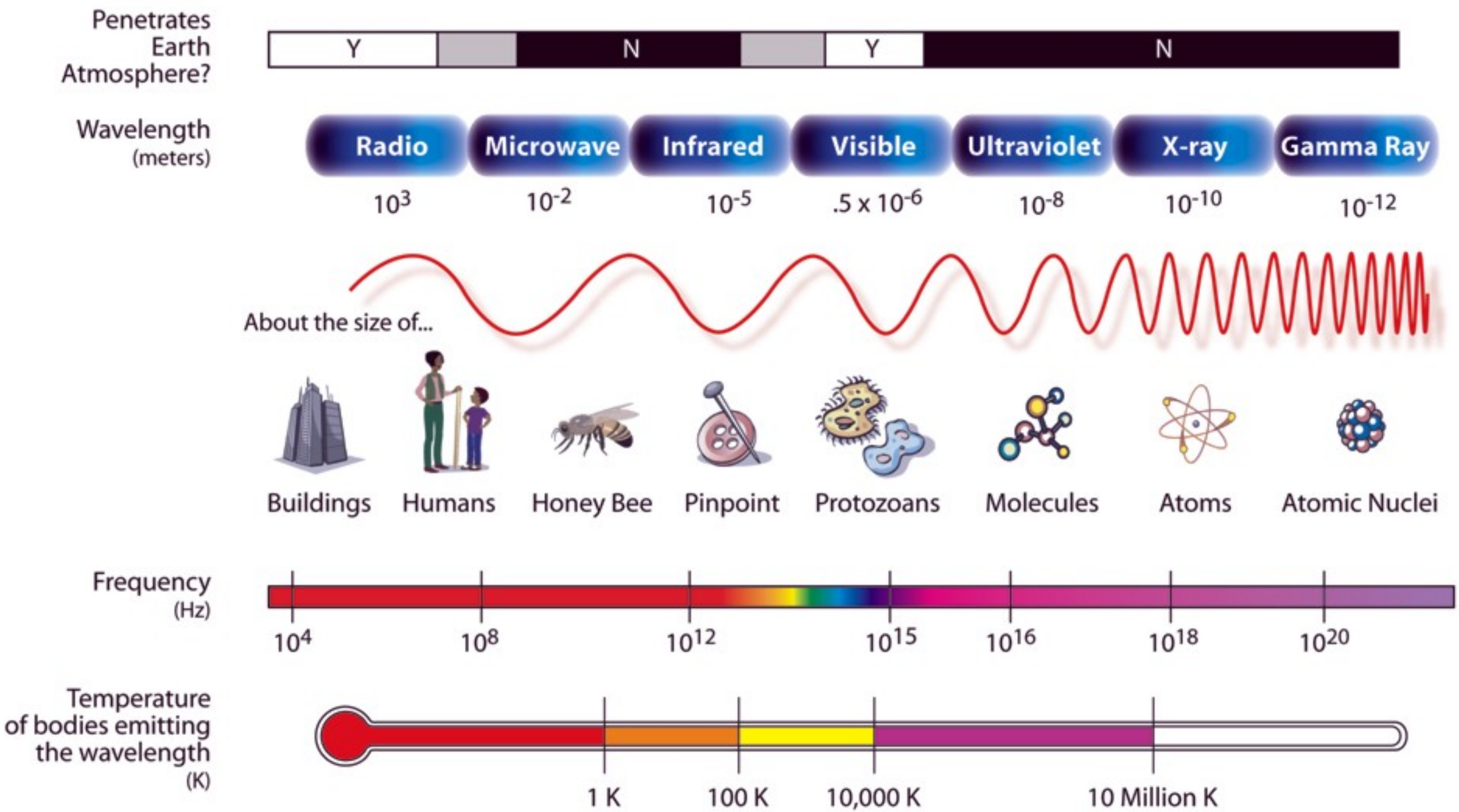
Project Update

- Research-style paper summarizing your methods and results is due **today, November 25 at 4pm**
  - Group submission *on Learn* (as pdf or word document)
  - I will make sure to allow unlimited submission attempts
- Final deadline for revisions to “Results” section: Tuesday, December 3 at 12pm (*send via email*)
- Analysis code (*submit via email*) and project contribution statement (*submit on Learn*) due at start of class, Wednesday, December 4, 2019
- All three groups will give in-class presentations on Wednesday, December 4 (25 minutes per group)
- Project guidelines, grading , and assignments all posted on Learn now

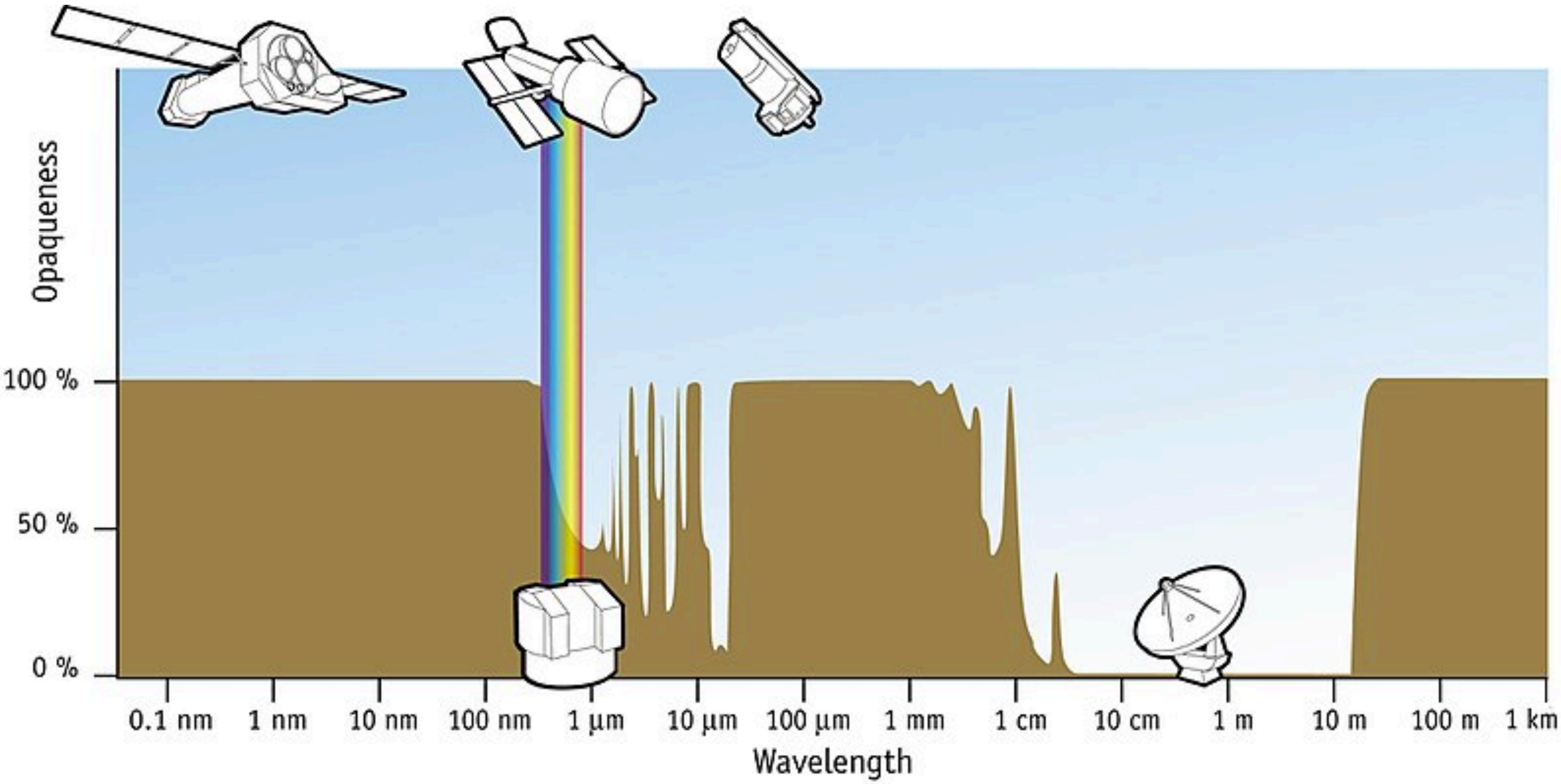
Syllabus update

- No class Wednesday November 27 (Wednesday before Thanksgiving break)
- 6 regular classes left, covering material from *Measuring the Universe*
  - Today, Wednesday Nov 13 (spectroscopy: Chapter 6)
  - Mon Nov 18, Wed Nov 20 (mm, sub-mm: Chapter 7)
  - Monday November 25 (X-ray, gamma rays: Chap 10)
  - Monday December 2 (neutrinos, gravitational waves, will also discuss final exam logistics on this day)
- Homework 3 solutions will be posted tonight
- Will catch up on posting grades this week
- Take-home final will be handed out at final class (Wednesday Dec 4), due by **12pm Thurs Dec 11**

THE ELECTROMAGNETIC SPECTRUM



- “X rays” are emitted by the electrons outside the nucleus, and “gamma rays” are emitted by the excited nucleus itself.



Opaqueness
100 %
50 %
0 %
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength

X-ray and gamma ray detection

- Photons energies are very high – ionizing radiation
- Results in some unique benefits and challenges
- Can do single-photon detection easily
- Can do low-resolution spectroscopy easily
- Difficult to deflect photons with optics
    - Can still use typical optics rules to describe, but need to use index of refraction at x-ray/gamma-ray wavelengths
    - n~1, very little deflection
    - X-rays that strike mirror surfaces nearly perpendicularly are either transmitted or absorbed

X-ray and gamma ray detection

- “Soft” X-rays (up to ~ 15 keV)
  - CCDs work well for imaging (e.g. Chandra)
    - Operate in “single photon” mode – each pixel’s signal is proportional to energy of photon, instead of # of photons
  - Bolometers work well, and get good spectral resolution
    - Unfortunate series of satellites failures, so limited on-sky data
    - Astro-E: launch failure (control systems breakdown)
      - https://spaceflightnow.com/m5/astroe/000210failure.html
    - Suzaku: series of malfunctions leading to loss of cryogens
      - https://en.wikipedia.org/wiki/Suzaku_(satellite)
    - Astro-H/Hitomi: software error cascading to castrophic spin-up
      - https://en.wikipedia.org/wiki/Hitomi_(satellite)

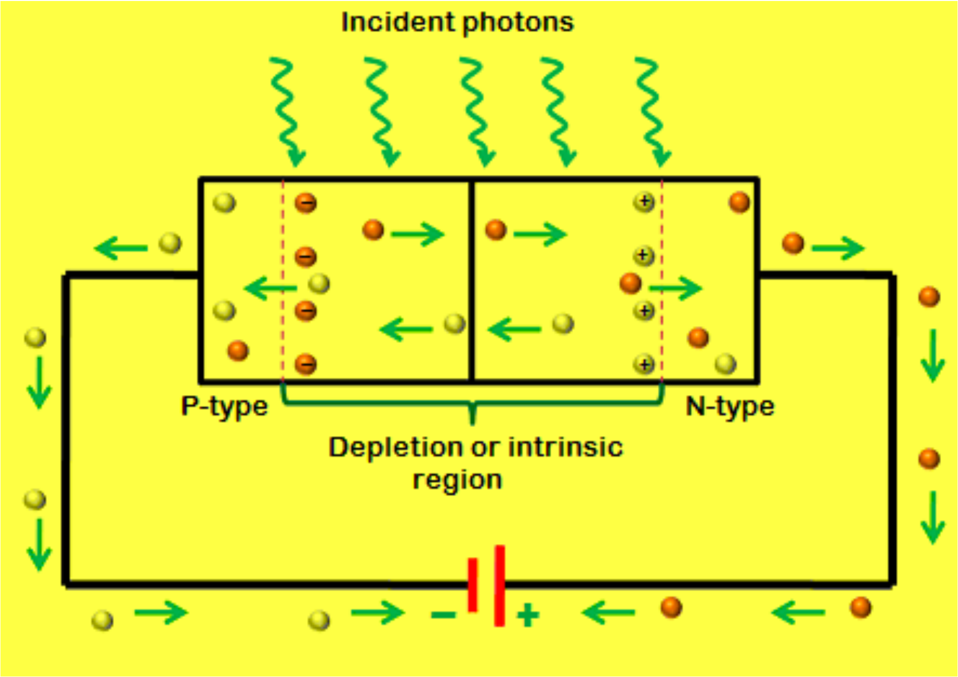
Above 100 GeV: Cherenkov radiation

Hitomi

- It was determined that the chain of events that led to the spacecraft's loss began with its inertial reference unit (IRU) reporting a rotation of 21.7 degrees per hour at 19:10 UTC on 25 March, though the vehicle was actually stable. The attitude control system attempted to use *Hitomi*'s reaction wheels to counteract the non-existent spin, which caused the spacecraft to rotate in the opposite direction. Because the IRU continued to report faulty data, the reaction wheels began to accumulate excessive momentum, tripping the spacecraft's computer into taking the vehicle into "safe hold" mode. Attitude control then tried to use its thrusters to stabilise the spacecraft; the sun sensor was unable to lock on to the Sun's position, and continued thruster firings caused *Hitomi* to rotate even faster due to an incorrect software setting. Because of this excessive rotation rate, early on 26 March several parts of the spacecraft broke away, likely including both solar arrays and the extended optical bench.

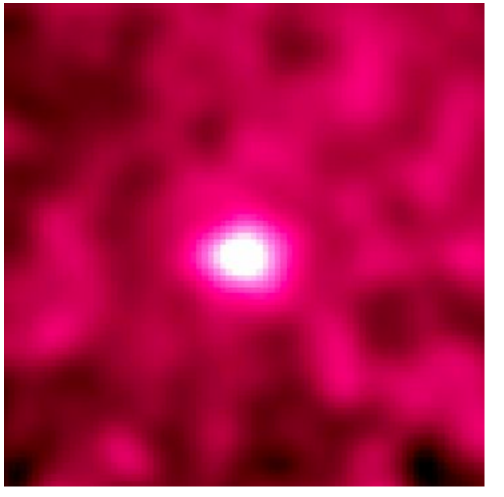
Early x-ray and gamma-ray

- Silicon photodiode detectors
- https://www.elprocus.com/photodiode-working-principle-applications/



Early x-ray and gamma-ray

- No collecting optics
- Can still create “images”



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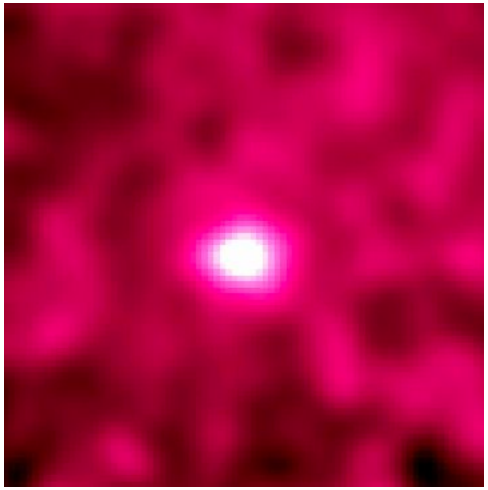
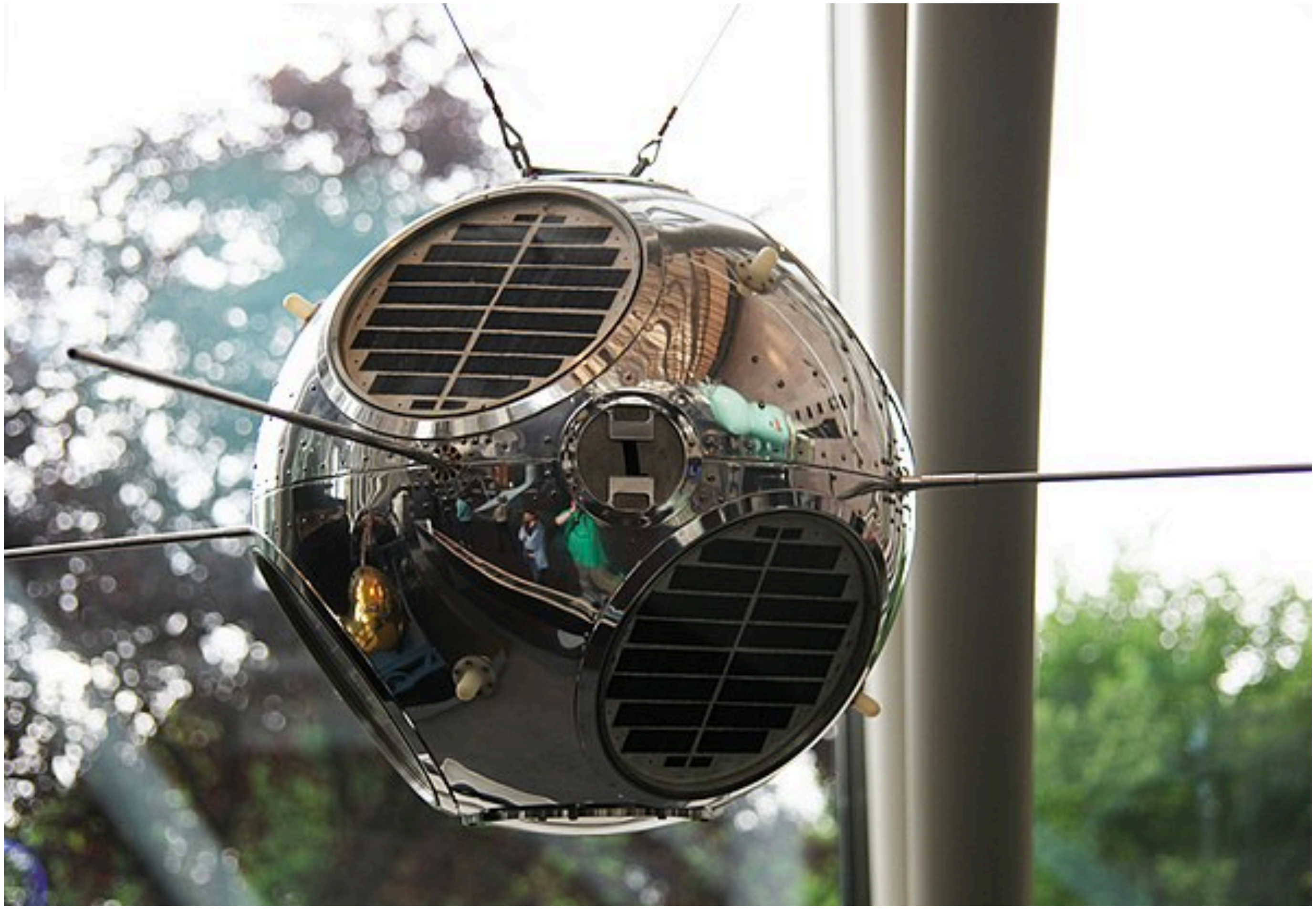


The Moon as seen by the Compton Gamma Ray Observatory, in gamma rays of greater than 20 MeV. These are produced by cosmic ray bombardment of its surface.

https://en.wikipedia.org/wiki/Gamma_ray

“World's first orbiting astronomical observatory”



X-rays, gamma rays, and the space race

- https://en.wikipedia.org/wiki/Timeline_of_artificial_satellites_and_space_probes
- SOLRAD ("SOLar RADiation"): a "solar x-ray observatory"
- https://en.wikipedia.org/wiki/SOLRAD

X-rays, gamma rays, and the space race

- http://articles.adsabs.harvard.edu/pdf/1968SoPh....5..546L

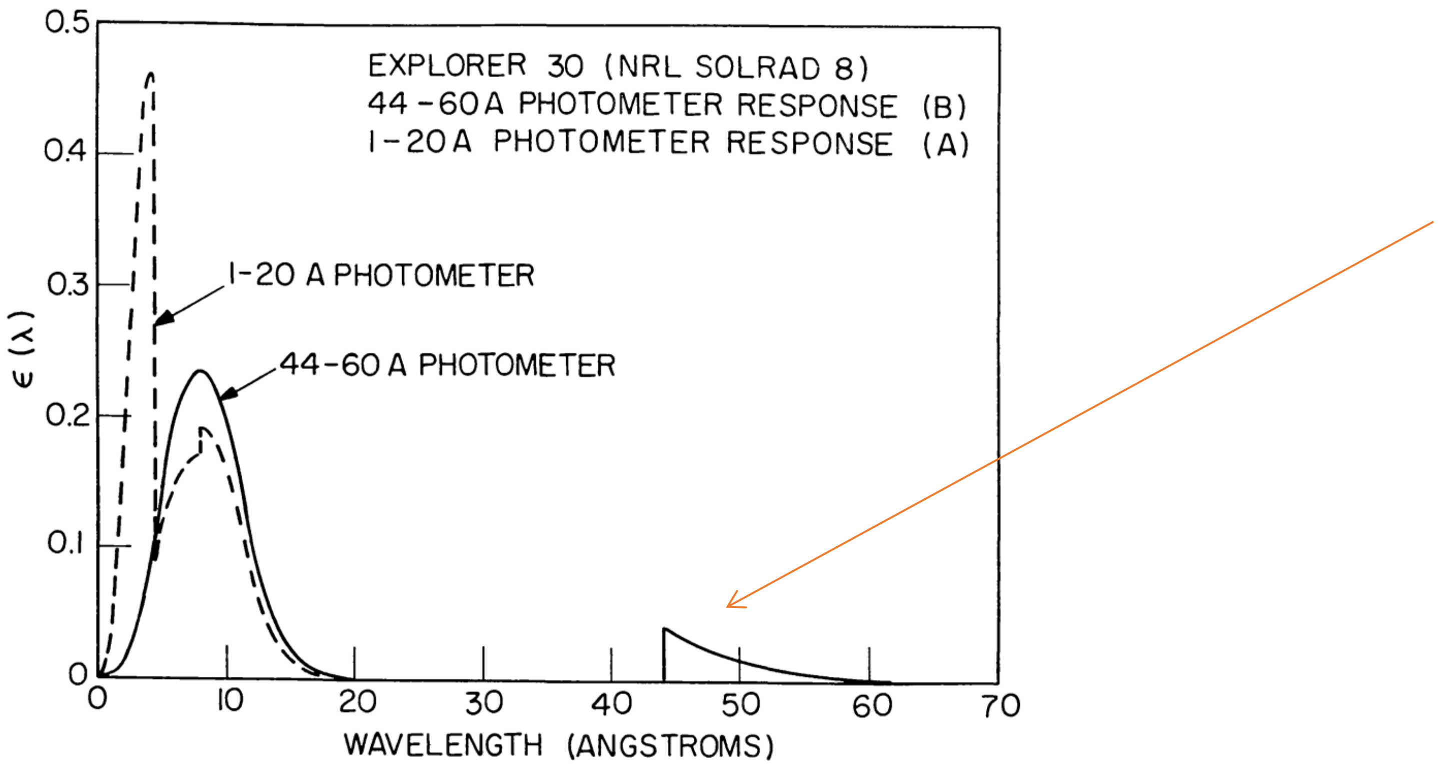


Fig. 1. Spectral efficiency of the 44–60 Å (solid line) and 1–20 Å (dotted line) ion chamber photometers.

X-rays, gamma rays, and the space race

- http://articles.adsabs.harvard.edu/pdf/1968SoPh....5..546L

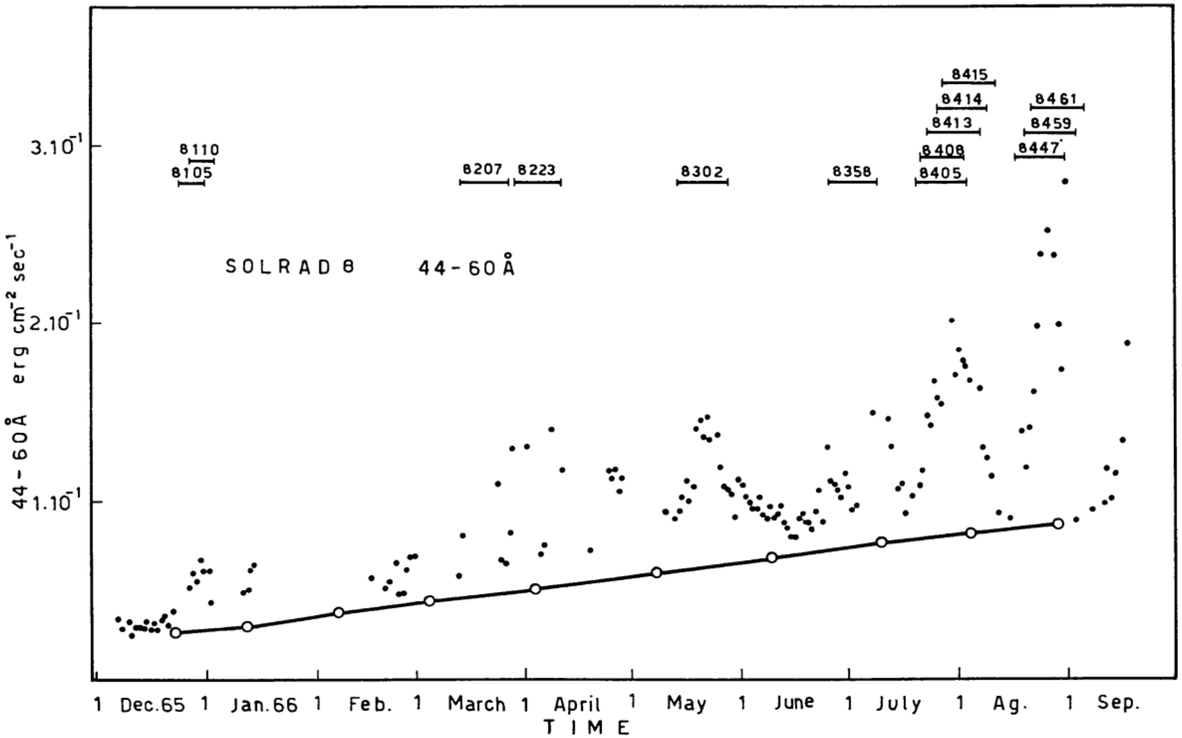
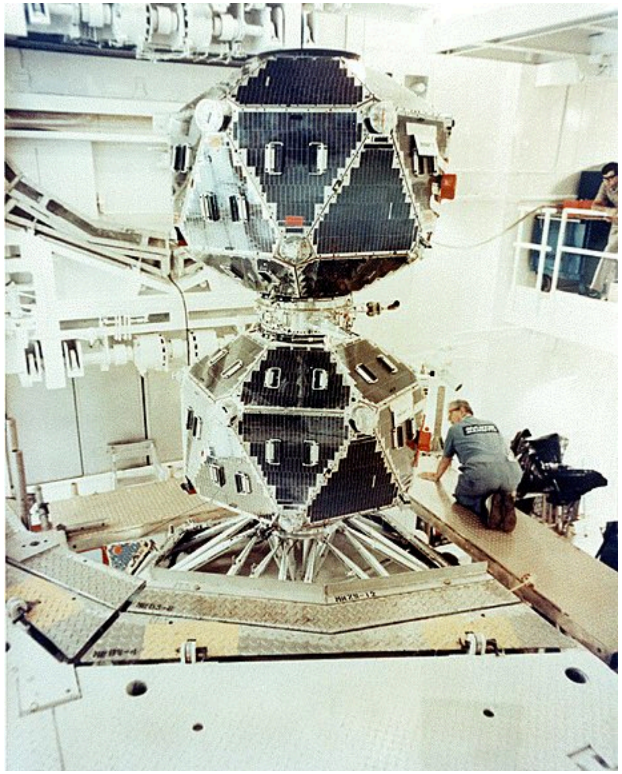


Fig. 3. The 'corrected' 44–60 Å flux derived from the first life months of the Solrad 8 satellite. The solid line shows the estimated increase of the base component. The most important chromospheric plages present on the disk during this period are indicated by bars and by the corresponding McMath numbers. (See text.)

Vela

- Launched to detect nuclear detonations to monitor compliance with the 1963 Partial Test Ban Treaty by the Soviet Union.
- Photodiodes to detect x-rays, gamma-rays, no imaging optics (but still is making images)
- Also had two “bhangmeters” – fast light meters, to get light intensity vs time
- https://en.wikipedia.org/wiki/Vela_(satellite)



Observations of Gamma-Ray Bursts of Cosmic Origin

- http://articles.adsabs.harvard.edu/pdf/1973ApJ...182L..85K
- Sixteen short bursts of photons in the energy range 0.2-1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from ^10~5 ergs cm-2 to ~2 X 10-4 ergs cm“2 in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources. Subject headings: gamma rays — X-rays — variable stars

Gamma-ray bursts

- On several occasions in the past we have searched the records of data from early Vela spacecraft for indications of gamma-ray fluxes near the times of appearance of supernovae. These searches proved uniformly fruitless. Specific predictions of gammaray emission during the initial stages of the development of supernovae have since been made by Colgate (1968). Also, more recent Vela spacecraft are equipped with much improved instrumentation. This encouraged a more general search, not restricted to specific time periods. The search covered data acquired with almost continuous coverage between 1969 July and 1972 July, yielding records of 16 gamma-ray bursts distributed throughout that period. Search criteria and some characteristics of the bursts are given below.

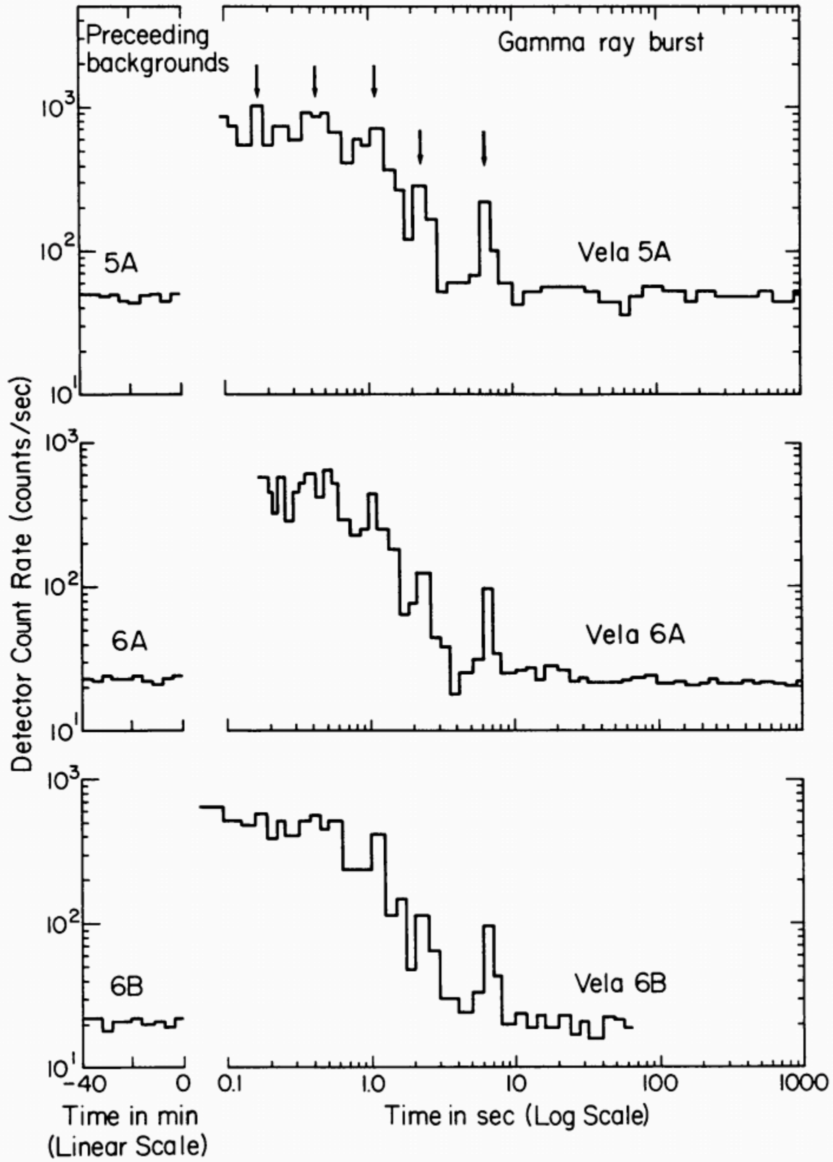
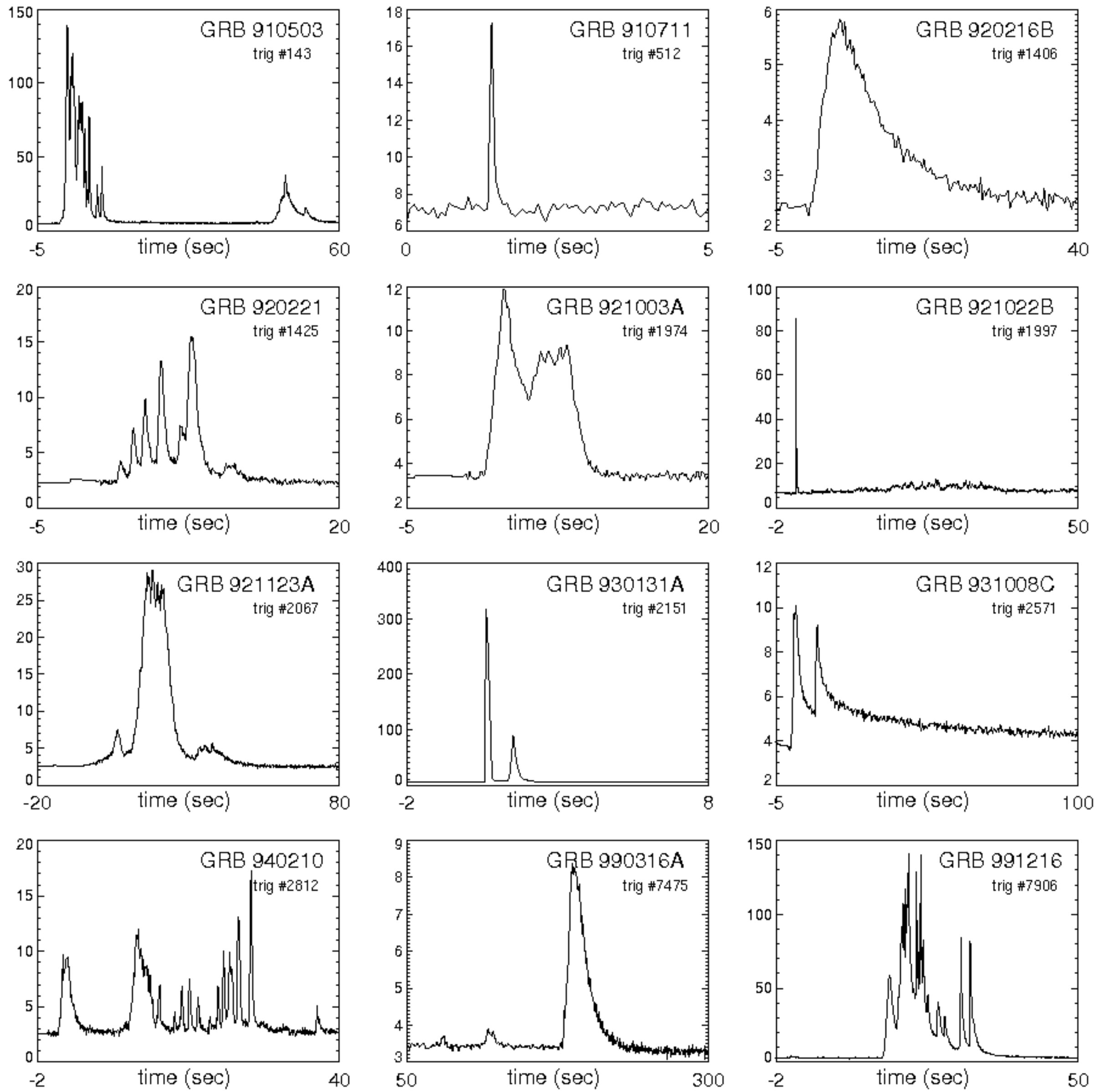
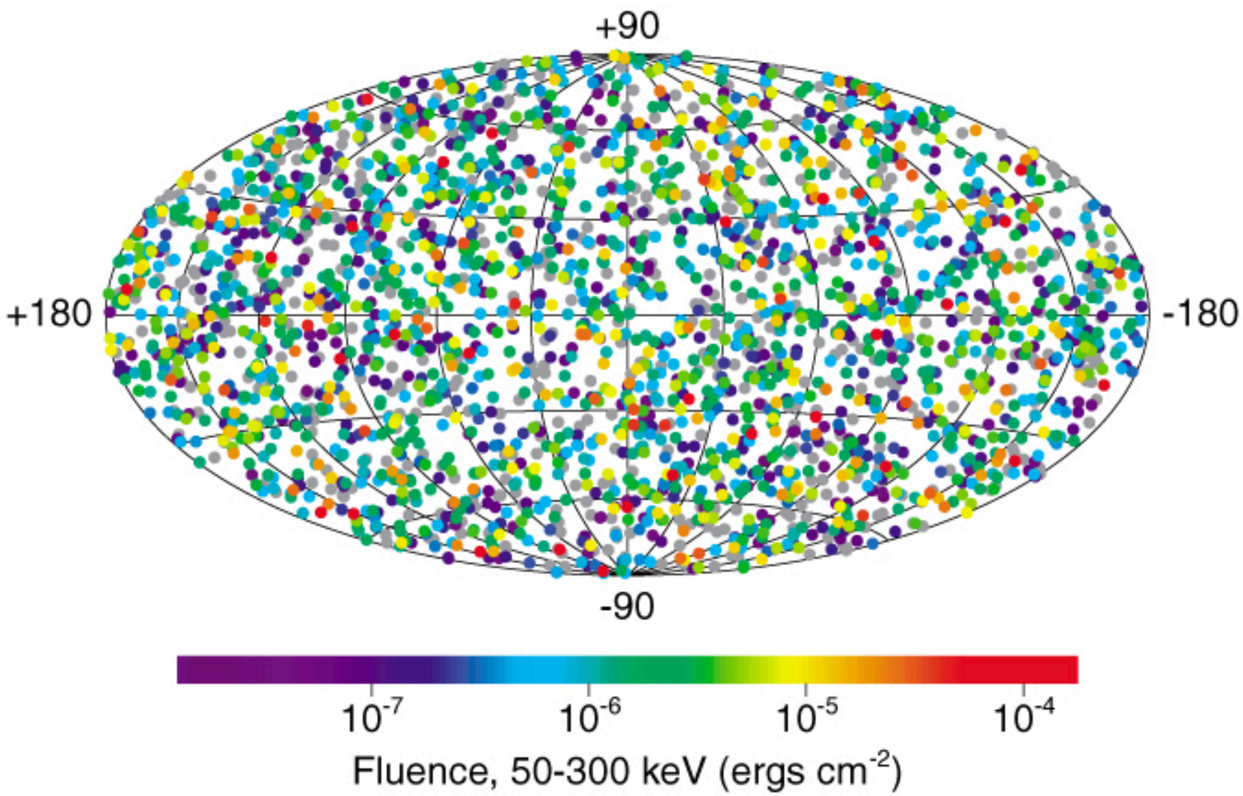


FIG. 1.—Count rate as a function of time for the gamma-ray burst of 1970 August 22 as recorded at three Vela spacecraft. Arrows indicate some of the common structure. Background count rates immediately preceding the burst are also shown. *Vela 5A* count rates have been reduced by 100 counts per second (a major fraction of the background) to emphasize structure.


GRB 910503
trig #143
GRB 910711
trig #512
GRB 920216B
trig #1406
GRB 920221
trig #1425
GRB 921003A
trig #1974
GRB 921022B
trig #1997
GRB 921123A
trig #2067
GRB 930131A
trig #2151
GRB 931008C
trig #2571
GRB 940210
trig #2812
GRB 990316A
trig #7475
GRB 991216
trig #7906
time (sec)

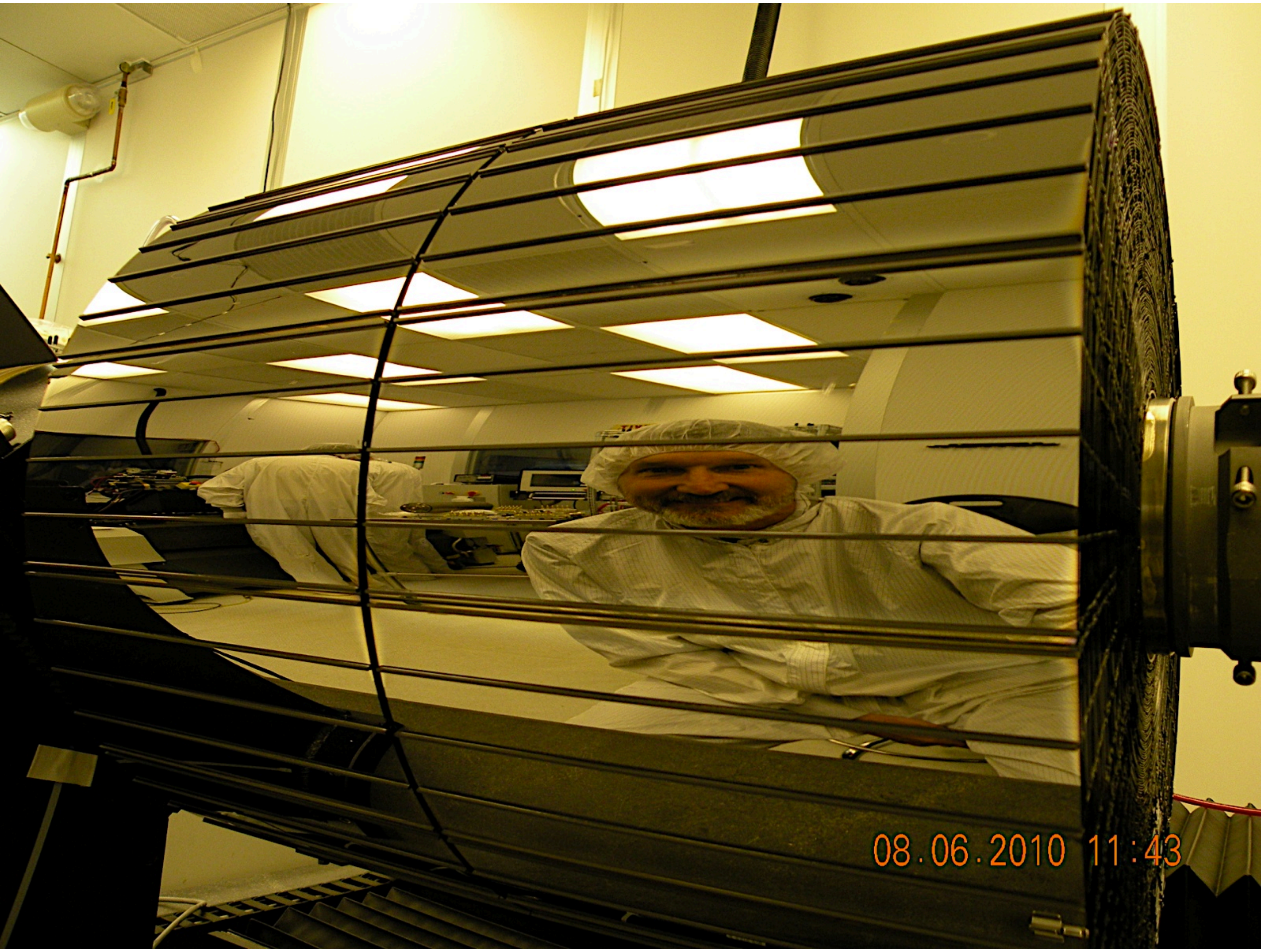
2704 BATSE Gamma-Ray Bursts

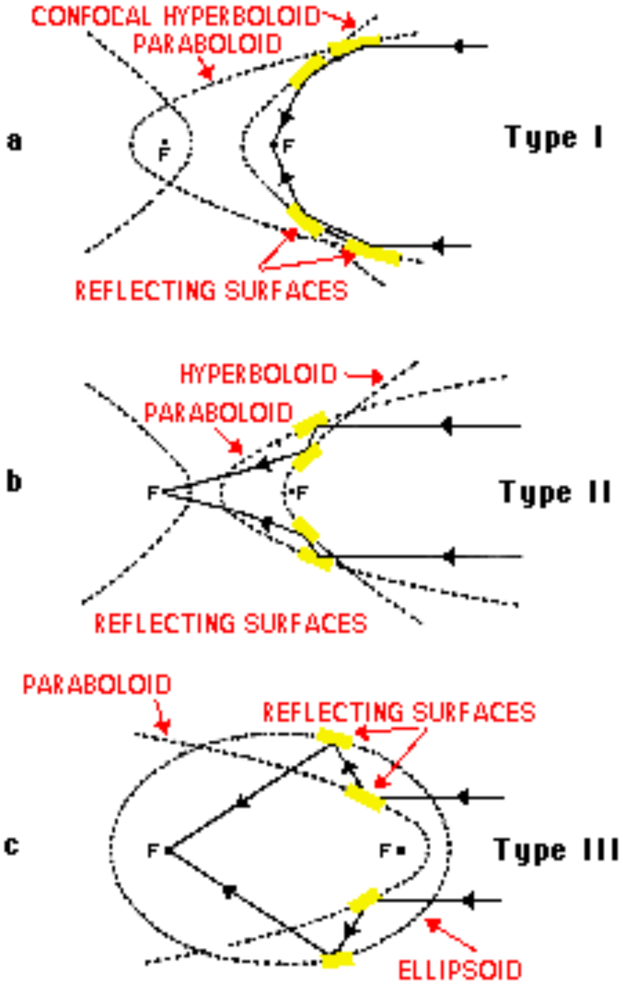


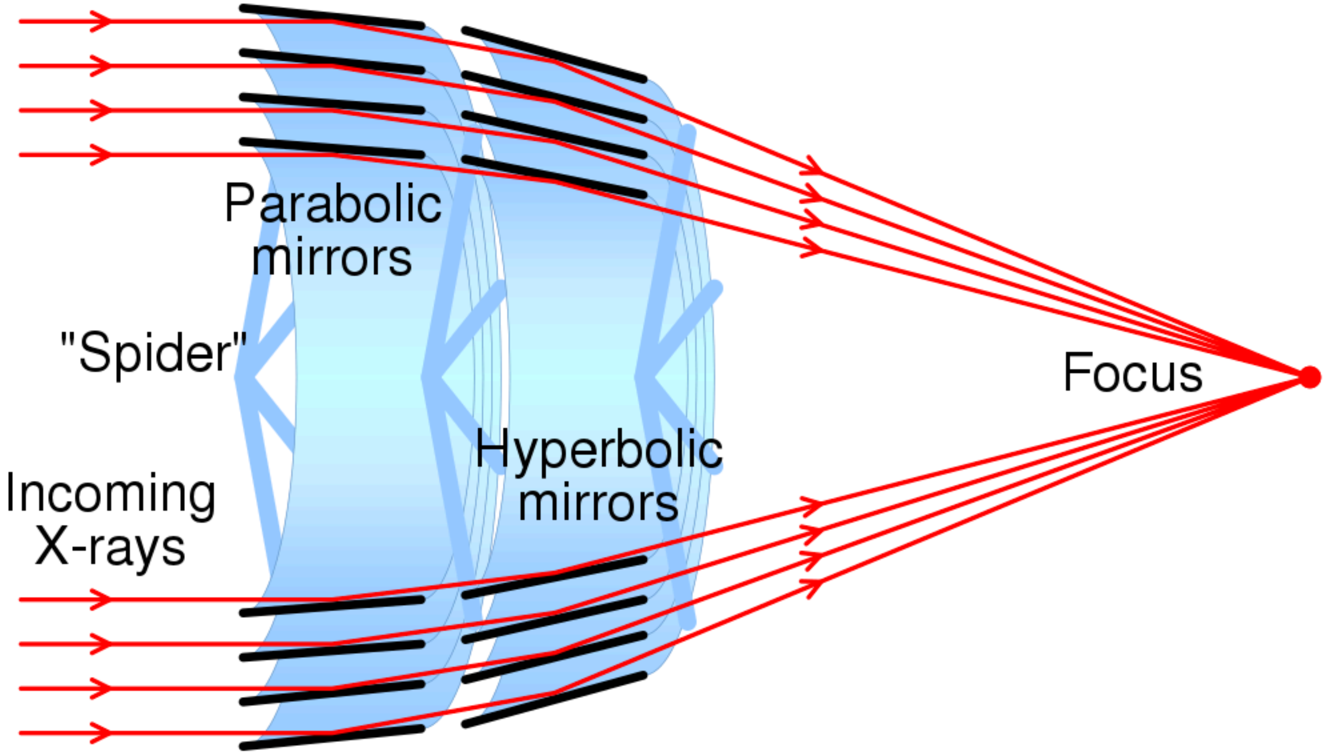
Wolter telescope

- https://en.wikipedia.org/wiki/Wolter_telescope
- X-ray mirrors need a very low angle of incidence
  - 10 arc-minutes to 2 degrees
- “Grazing incidence” mirrors
- “Wolter” telescopes, of type I, II, and III
- With two mirrors can create a telescope with a usably wide field of view.
- Grazing incidence telescope with just one parabolic mirror can focus X-rays, but only in a small paraxial region
  - The rest of the image would suffer from extreme coma.

Grazing incidence mirrors

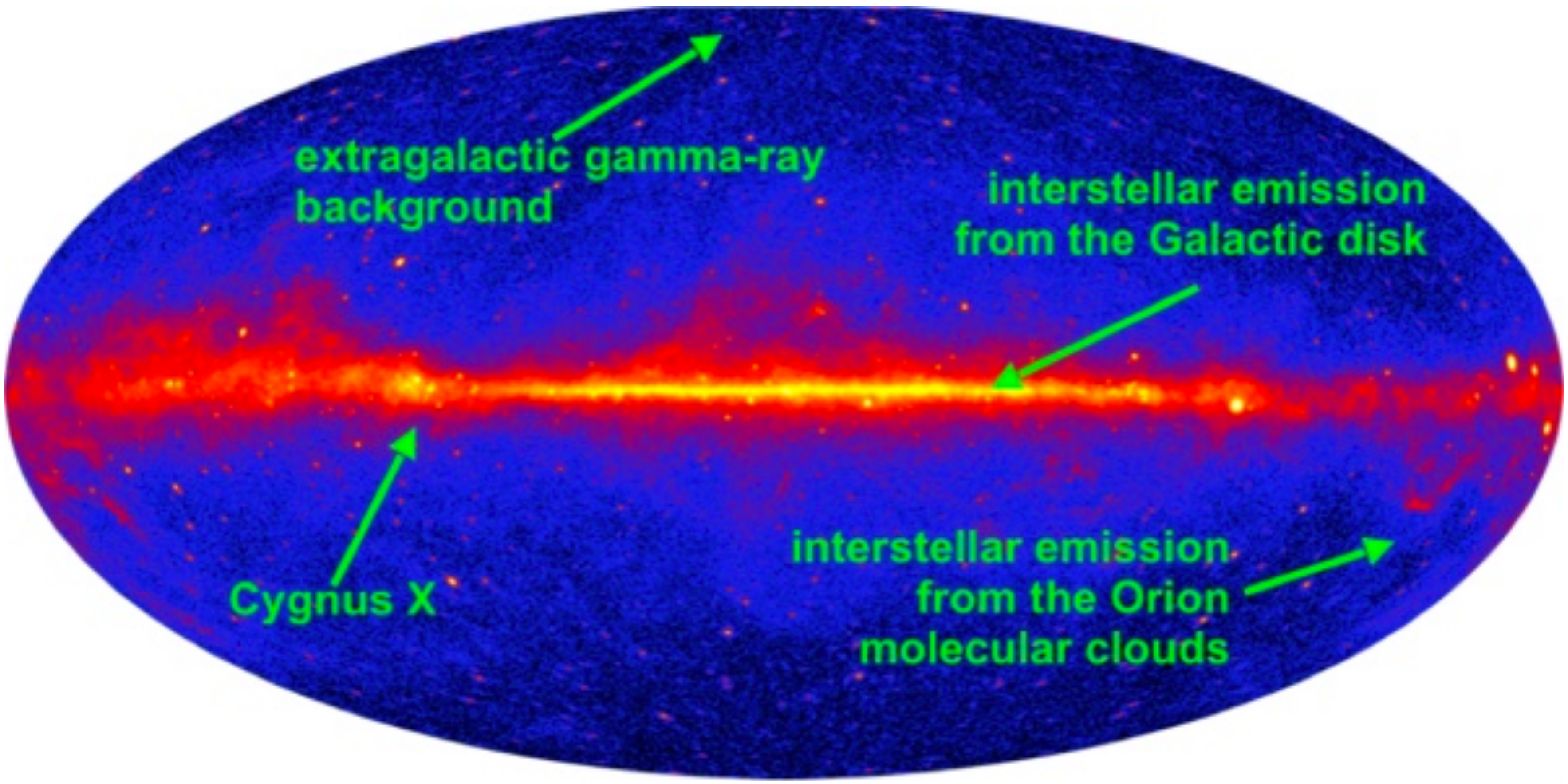




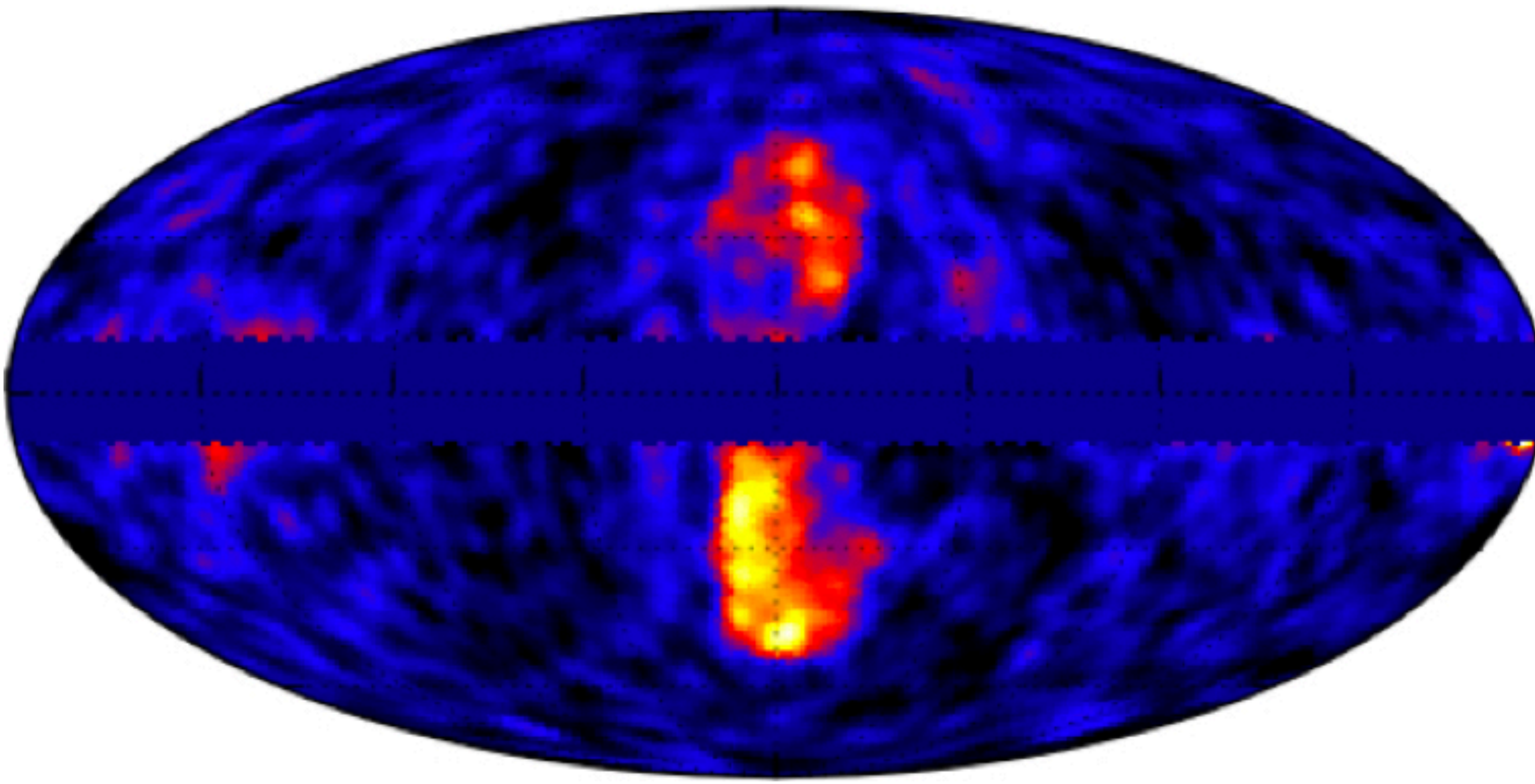


Parabolic
mirrors
"Spider"
Incoming
X-rays
Hyperbolic
mirrors
Focus

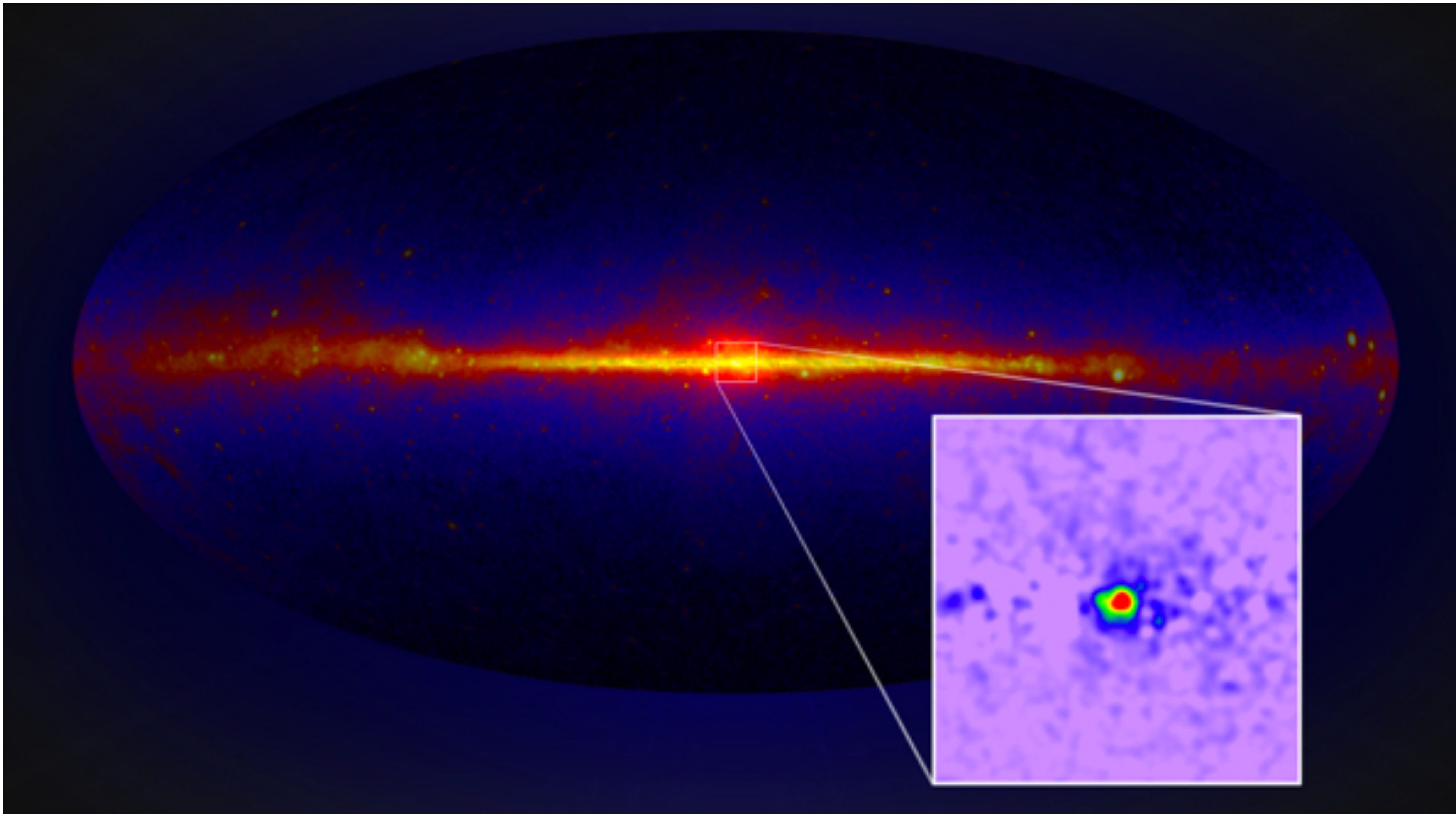
Fermi LAT all-sky maps



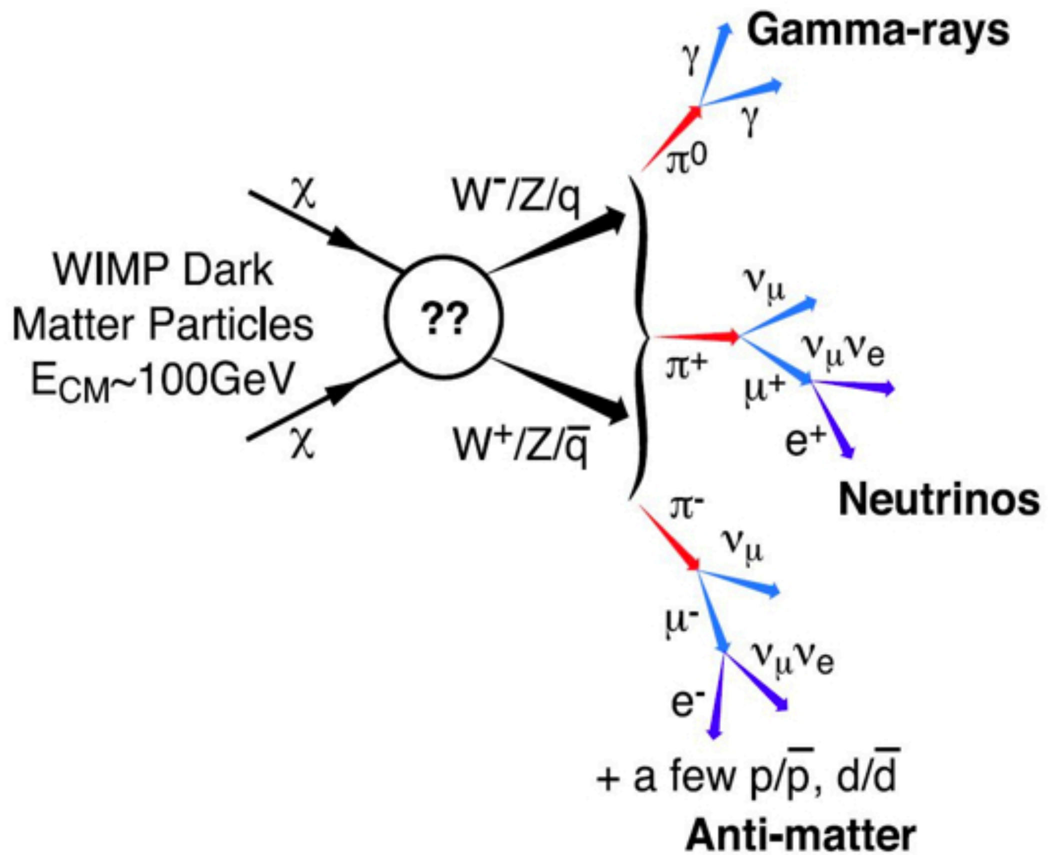
Fermi Bubbles



Fermi LAT "gamma ray excess"

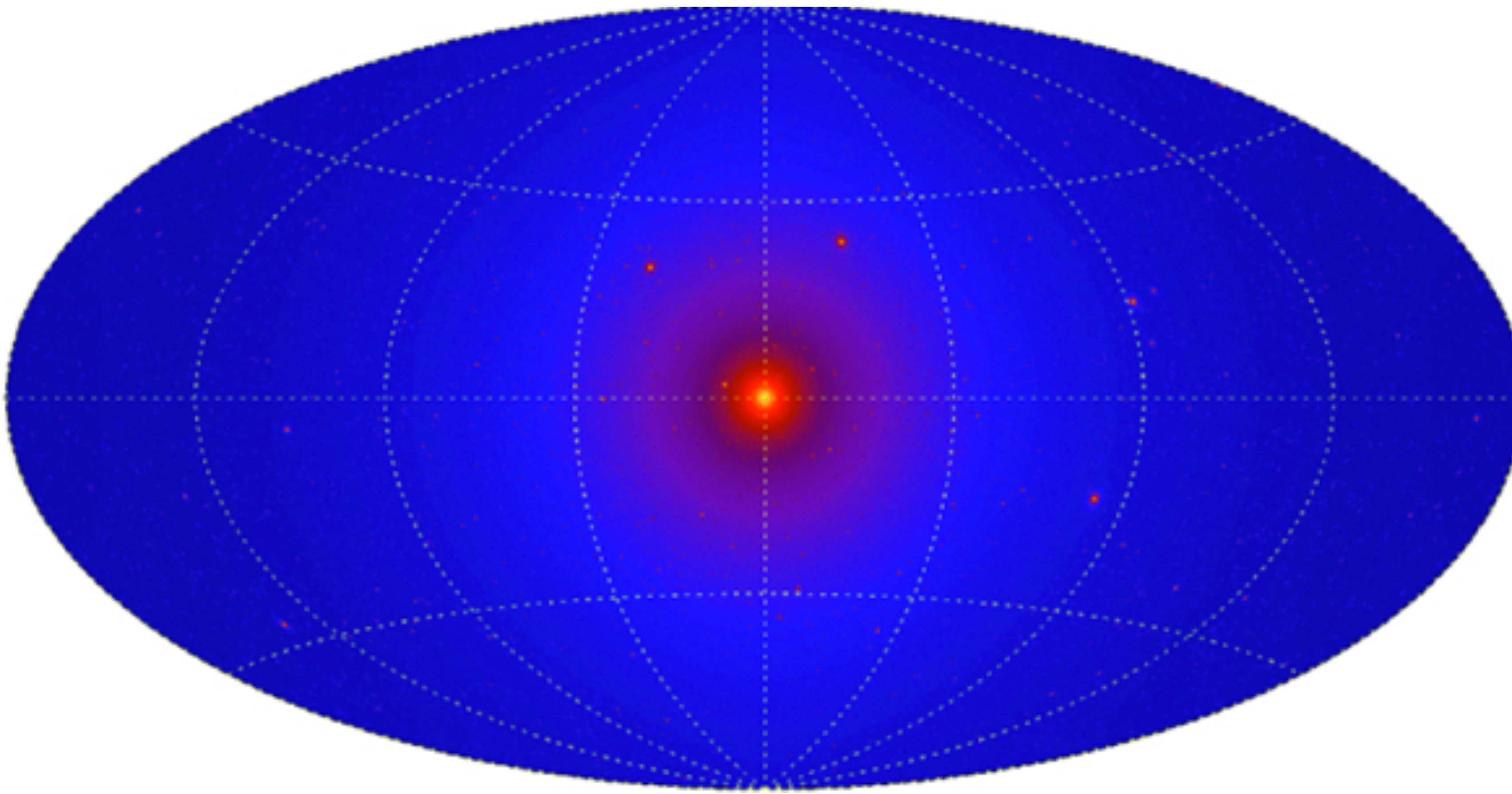


Indirect dark matter detection

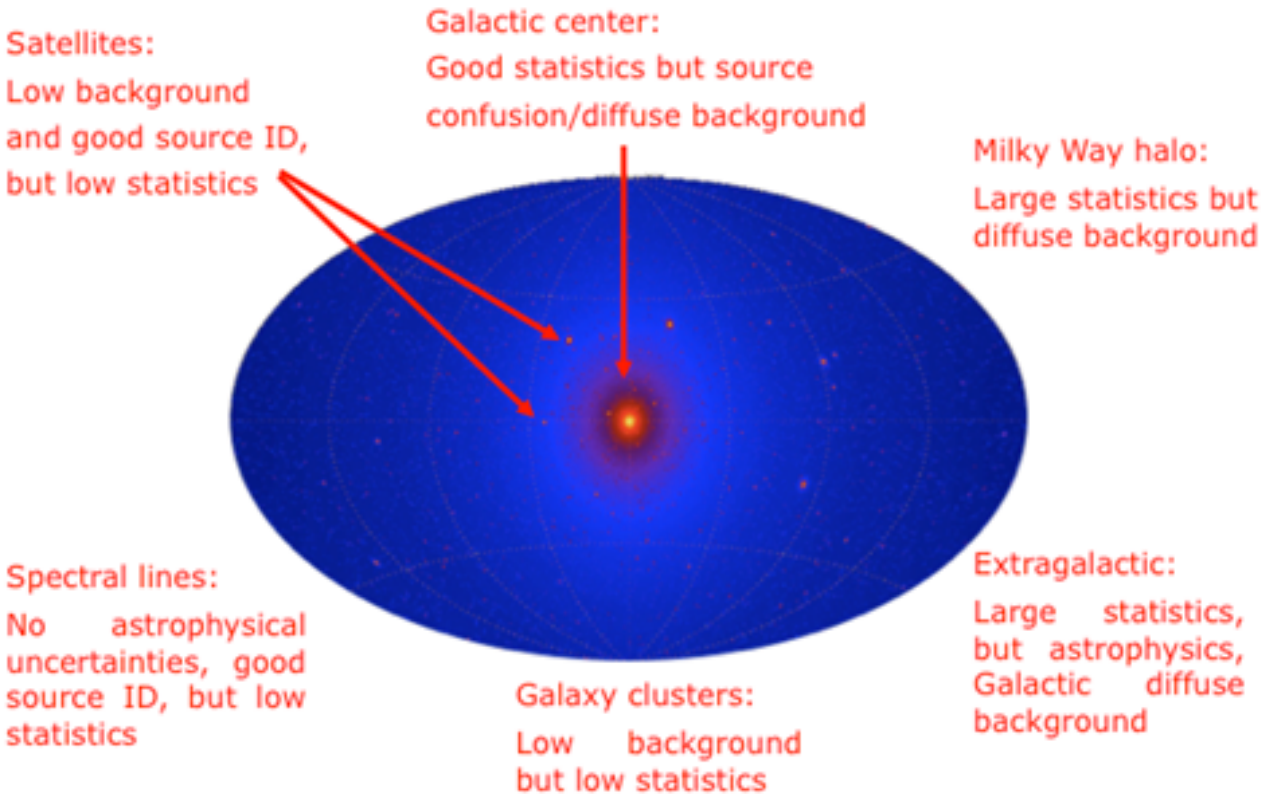


https://fermi.gsfc.nasa.gov/science/eteu/dm/

Fermi Simulated Data



Targets for detection



https://kipac.stanford.edu/research/topics/indirect-dark-matter-detection