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Looking for ripples of gravity with LIGO

Phil Willems, California Institute of Technology

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LIGO:

-an experiment to measure gravitational waves from the cosmos

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Laser

Interferometer

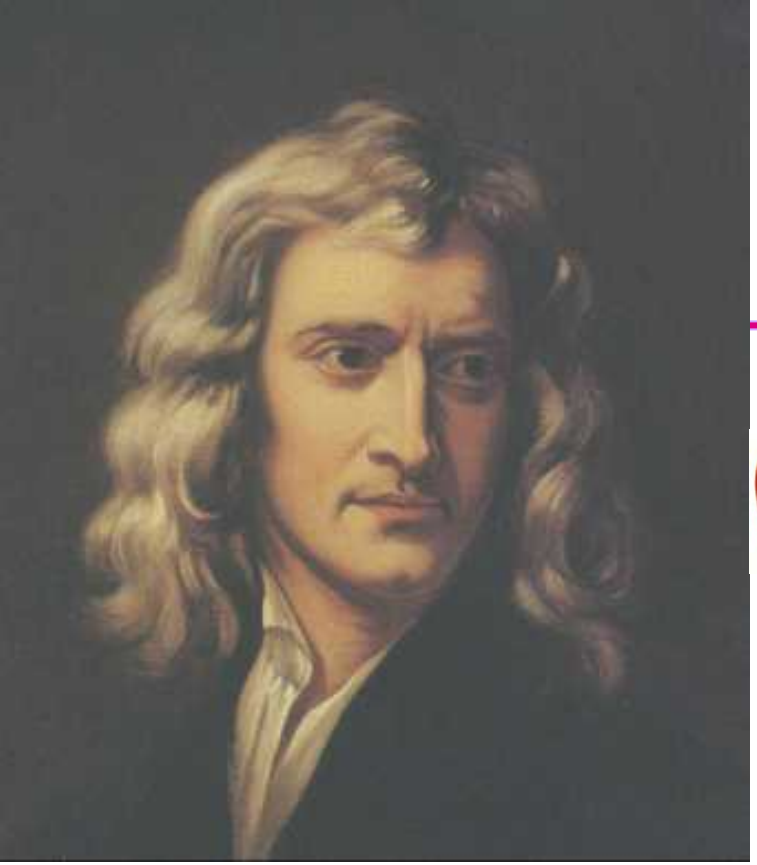
Gravitational wave

Observatory

What Is A Gravitational Wave?

What Is Gravity?

Gravity: the Old School



Sir Isaac Newton,
who invented the theory of gravity and all the math needed to understand it

The Math Worked Perfectly, but…

How does the Earth over here

pull on the Moon over there?

Sir Newton’s answer: .....

Then the Math Wasn't so Perfect Anymore…

- Mercury's orbit precesses around the sun-each year the perihelion shifts 560 arcseconds per century
- But this is 43 arcseconds per century *too much! (discovered 1859)*
- This is how fast the second hand on a clock would move if one day lasted 4.3 billion years!

Urbain Le Verrier, discoverer of Mercury's perihelion shift anomaly

Image from St. Andrew's College

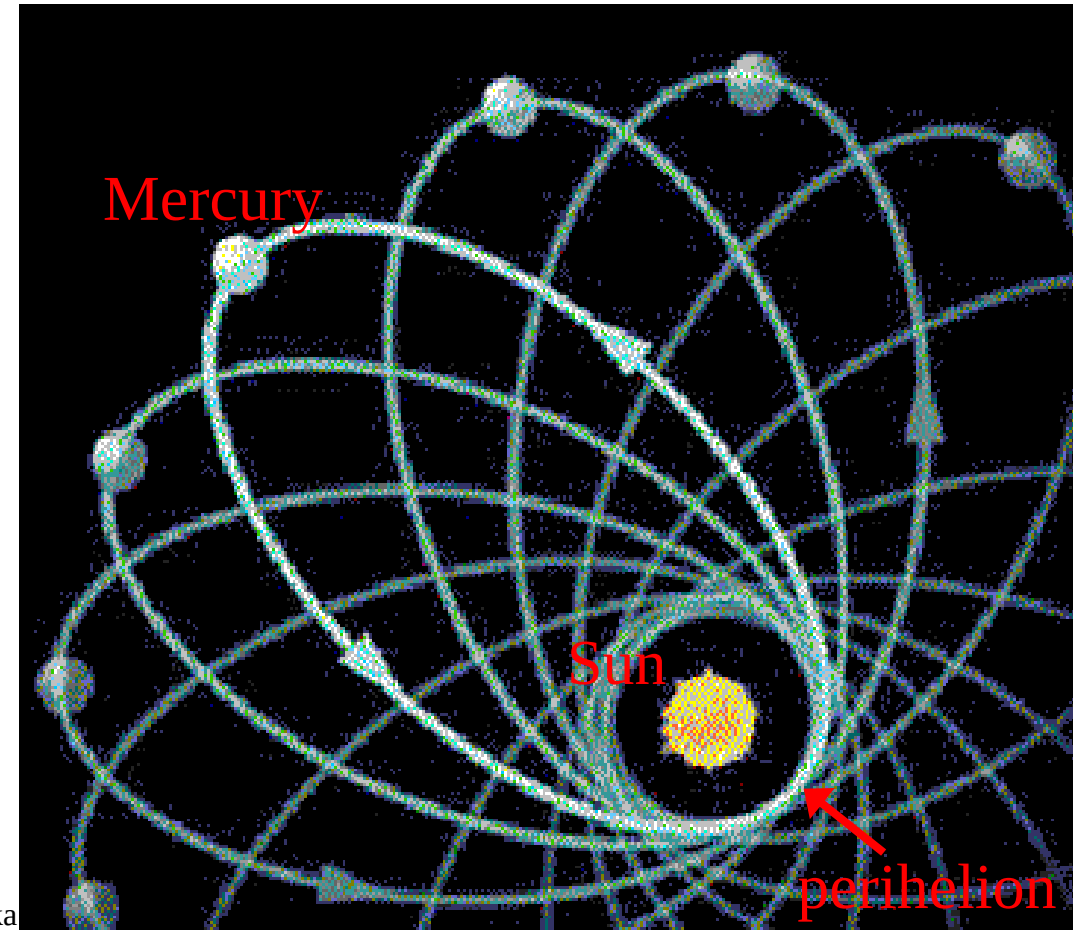
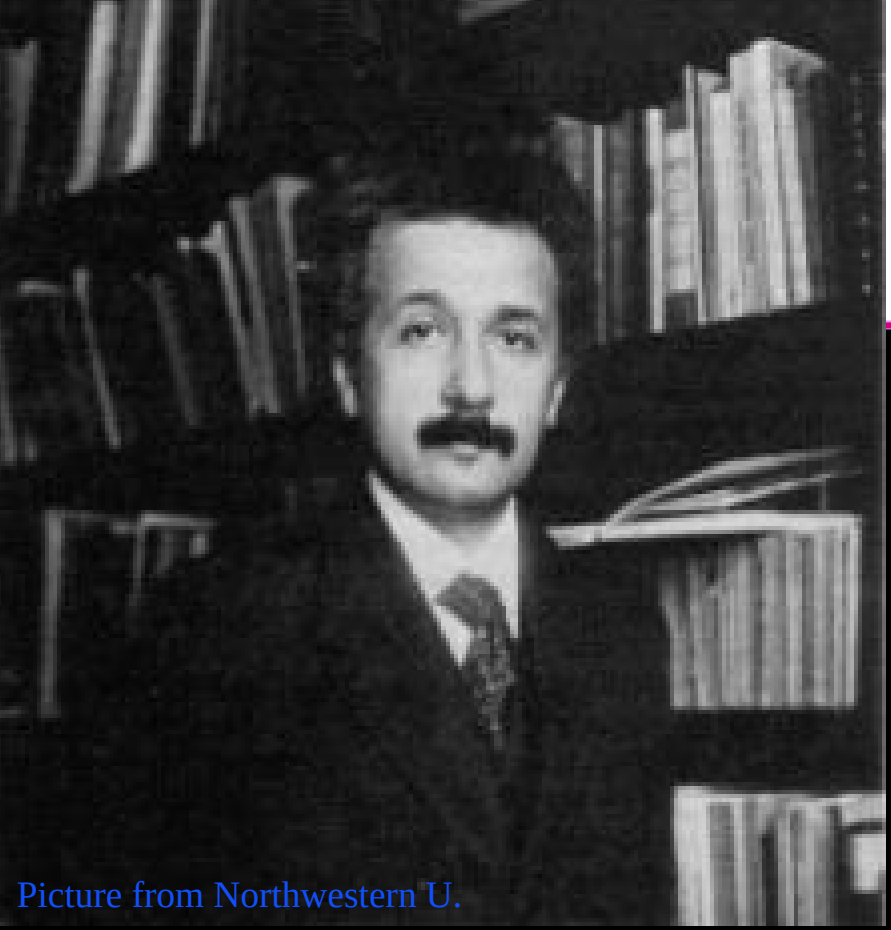
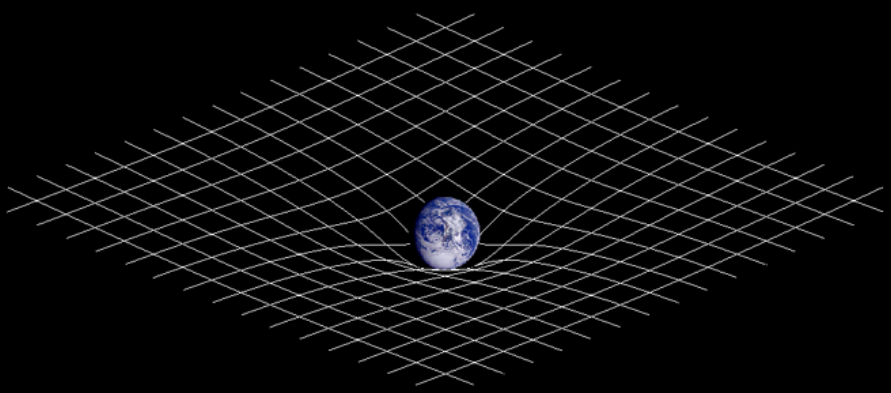


Image from Jose Wudka

Einstein's Answer: General Relativity



Picture from Northwestern U.



- Objects move along straight lines (*geodesics*) through space and time.
- Space and time (*spacetime*) are curved.
- Thus, although 'straight', geodesics converge and diverge due to spacetime curvature. This looks like a gravitational force.
- Mass curves spacetime.
- Thus, mass has gravity.

Gravitational Waves-

-are produced by accelerating objects

-are an oscillating strain of space
(ripples of spacetime)

-travel at the speed of light

-are quadrupolar

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So, Why Don't We See Them?

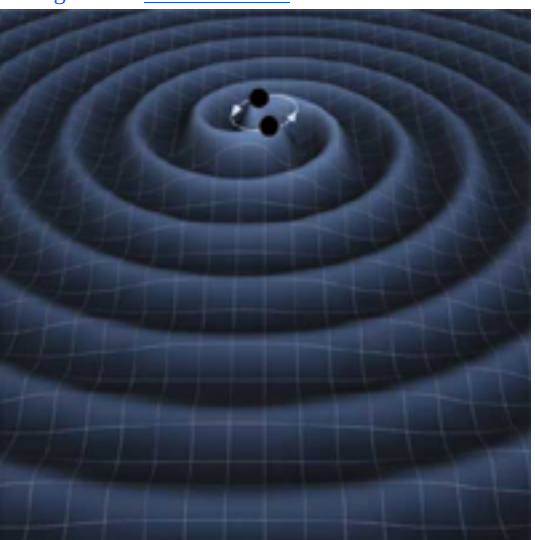
- Detectable gravitational waves are only produced by the most violent astrophysical processes
- Even these waves are astonishingly feeble
  - » A *very strong* gravitational wave will strain space by 1 part in 10,000,000,000,000,000,000,000
  - » The Earth and Moon will get 1 *trillionth* of an inch farther apart as a result

Do We Even Know They Exist?

Russell Hulse

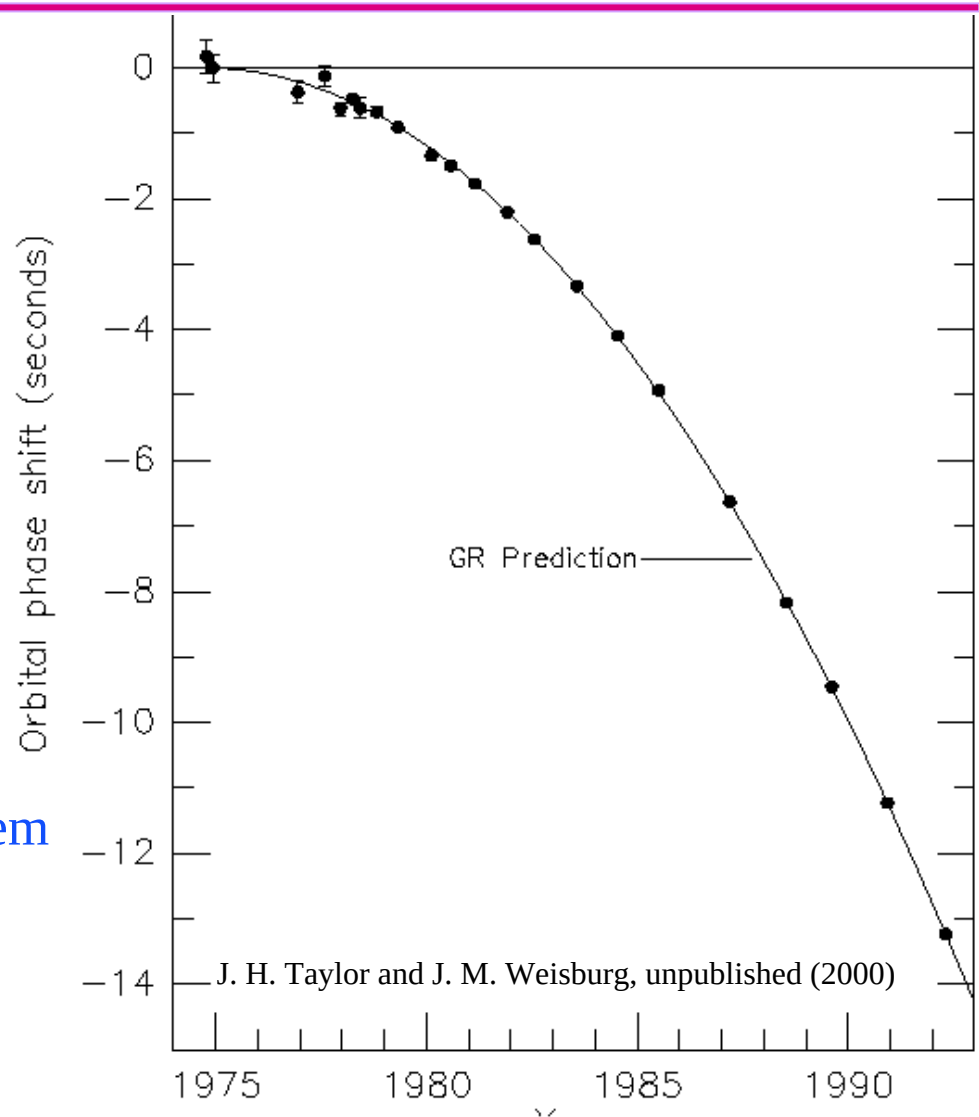
Richard Taylor

Images from Les Prix Nobel



binary pulsar system

PSR1913+16



How on Earth Do You Detect Such a Thing?

Well, you don’t have to do it on Earth, but we do.

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A 2.5 mile long Michelson interferometer

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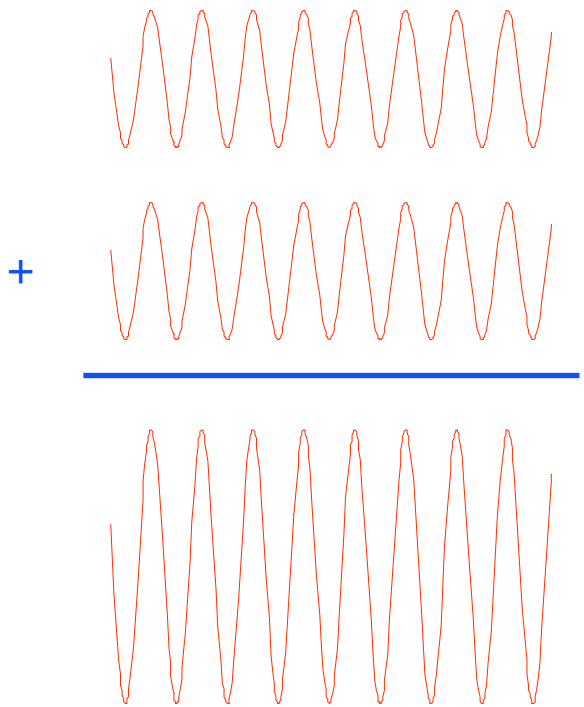
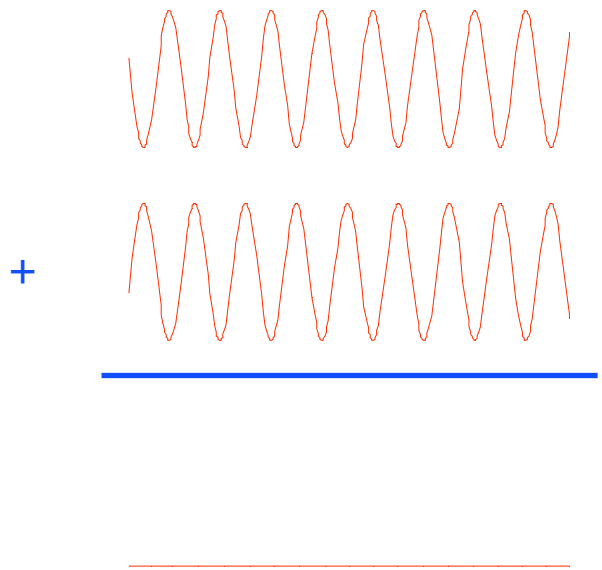
The Michelson Interferometer

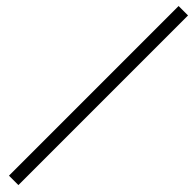


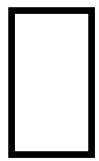
constructive interference



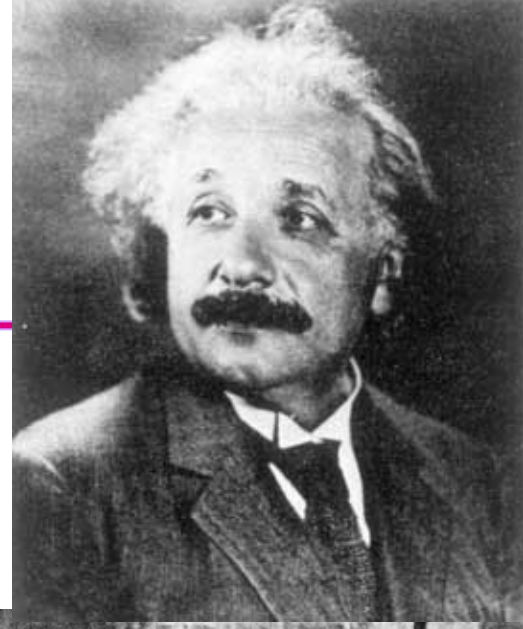
destructive interference

LASER



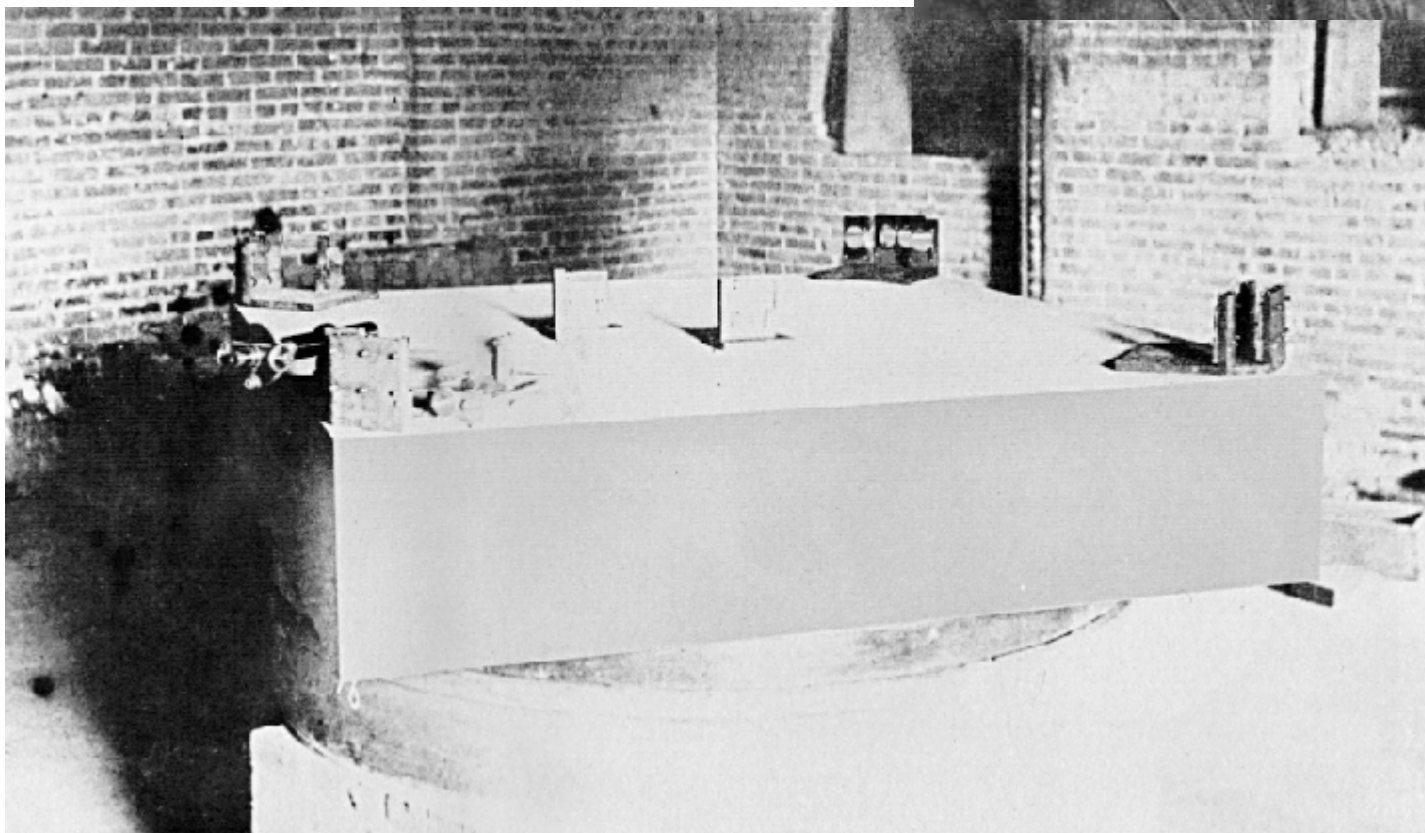


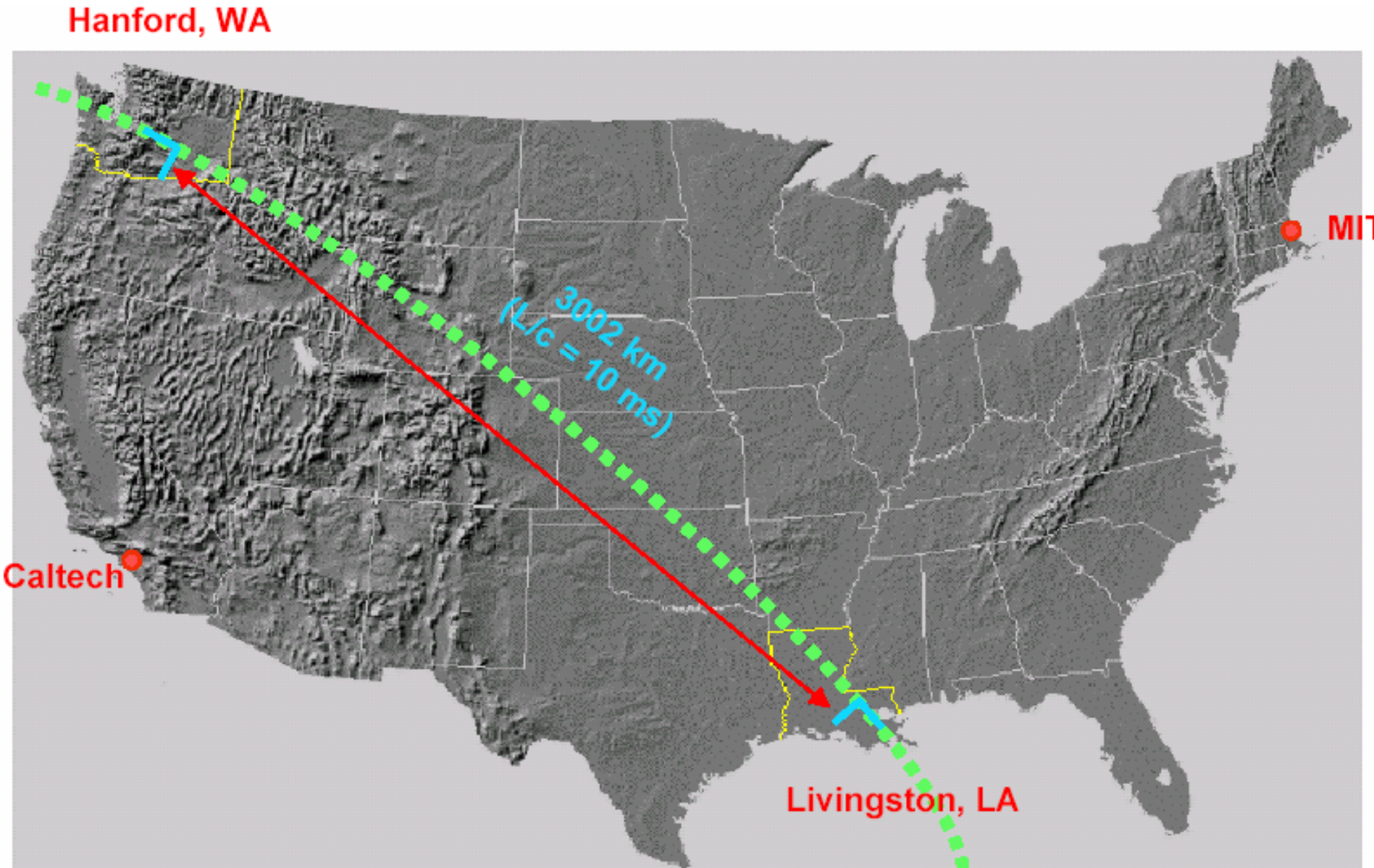
Michelson-Morley Experiment



Result: “The speed of light is the same, whatever the speed of the observer.”

Interpretation: the Theory of Relativity



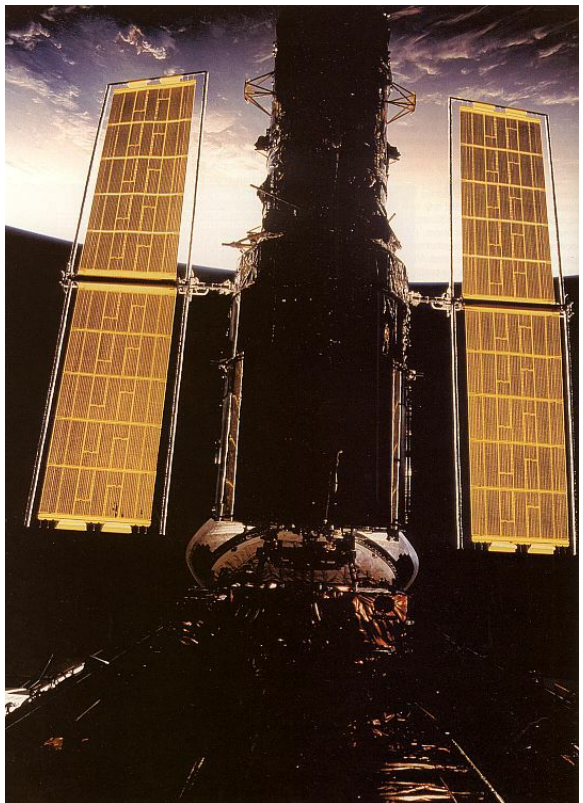

Hanford, WA
MIT
3002 km
(L/c = 10 ms)
Caltech
Livingston, LA

So What If They Exist- Why Look for Them?

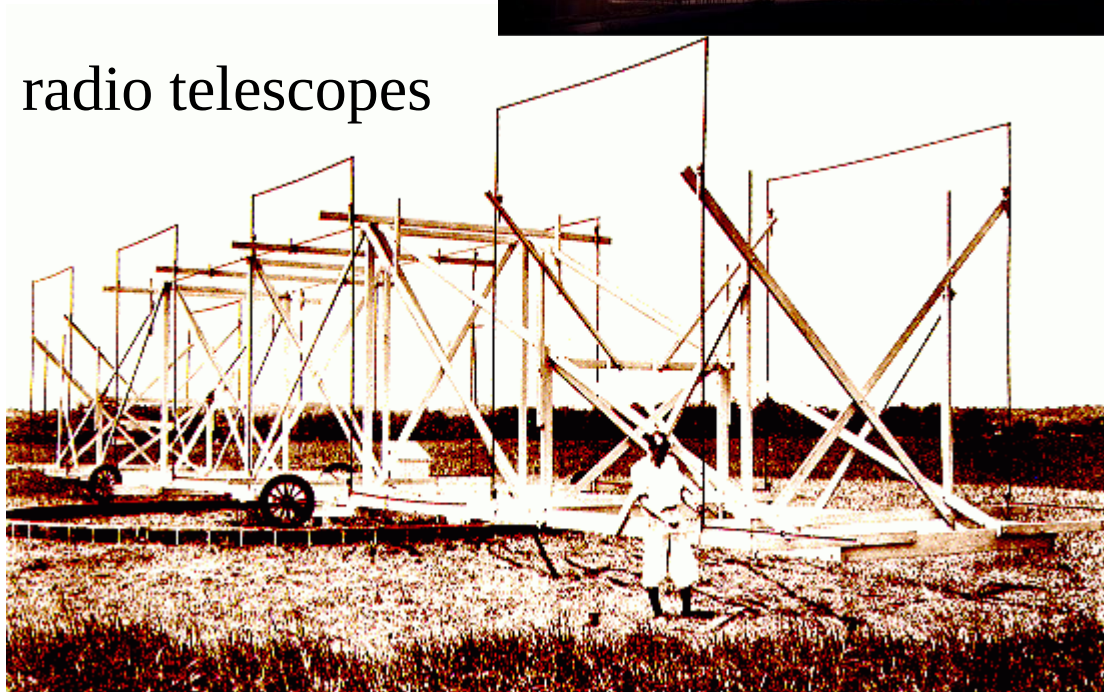
- Physicists are fussy- we don’t like to believe in anything until we detect it.
- Gravitational waves provide a completely new window to the cosmos.

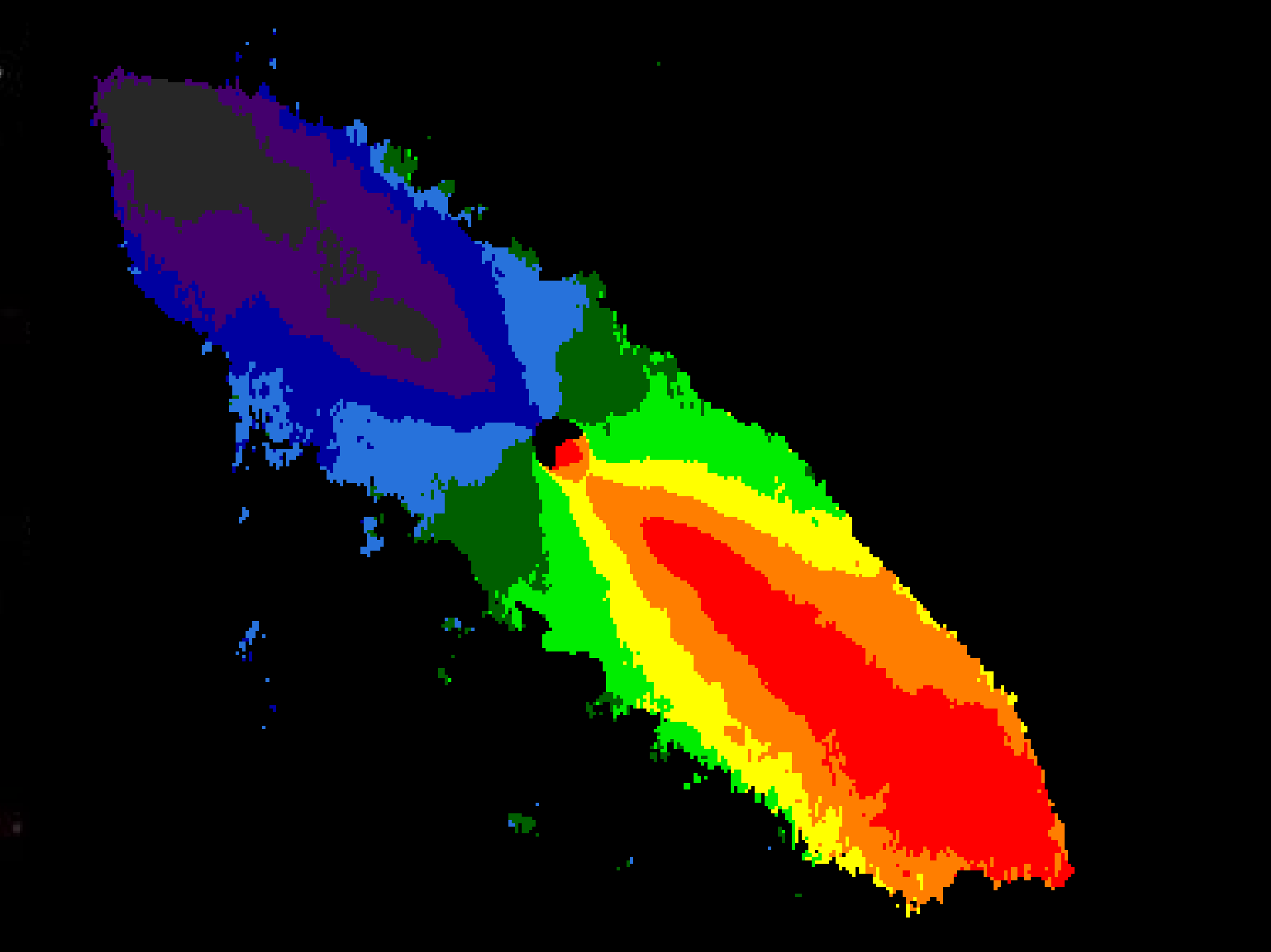
New Instruments, New Discoveries

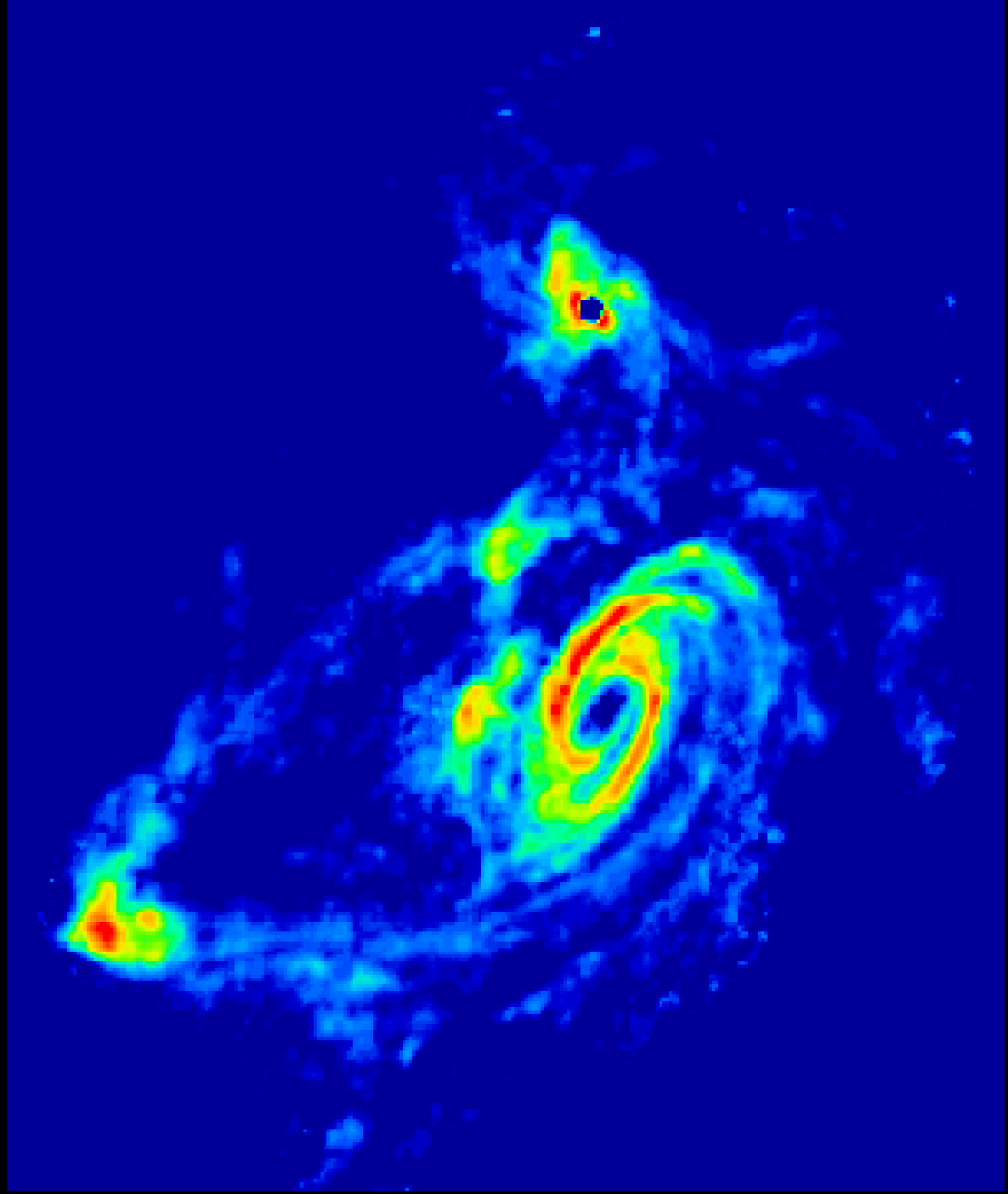
optical telescopes



radio telescopes







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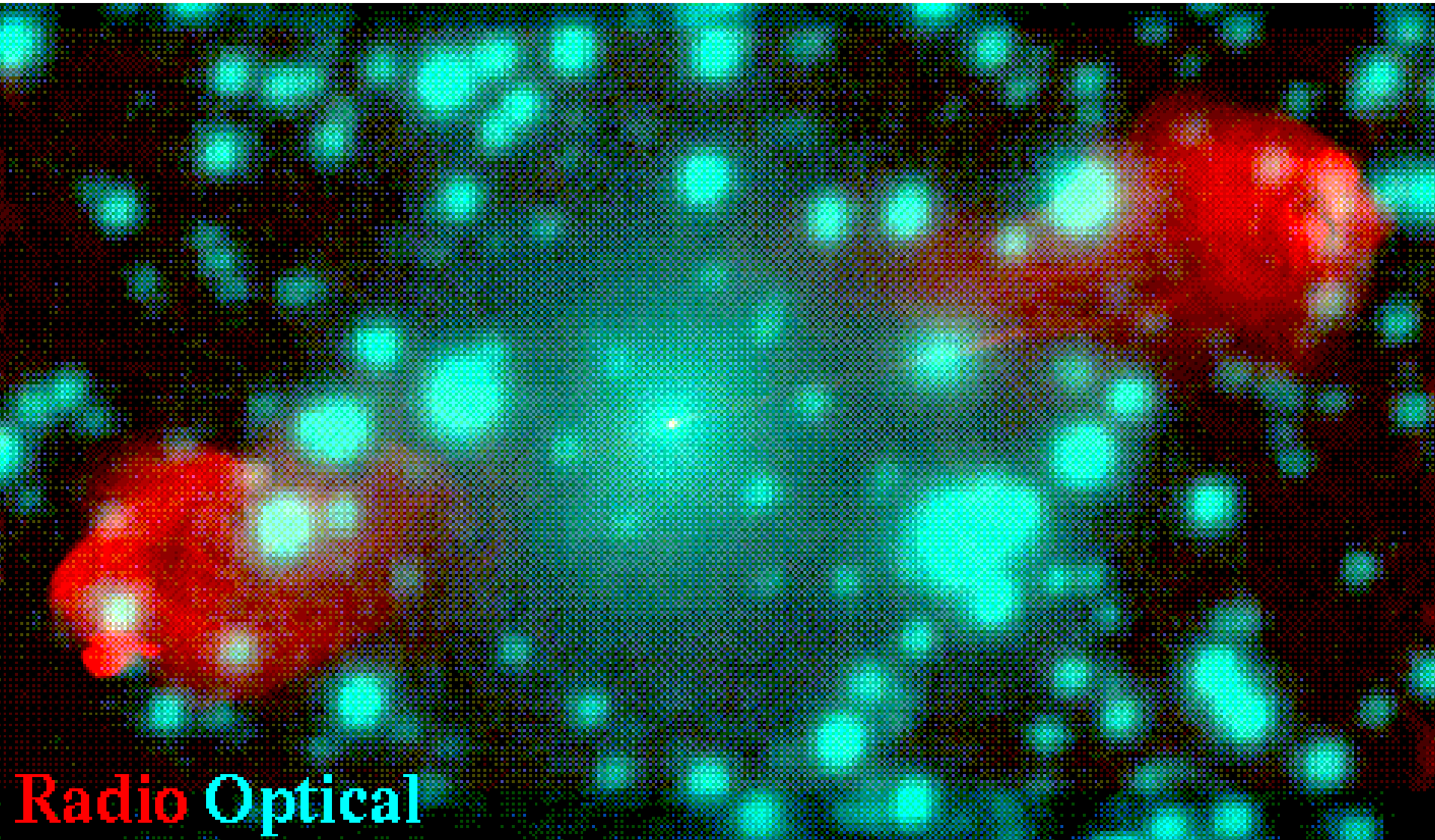
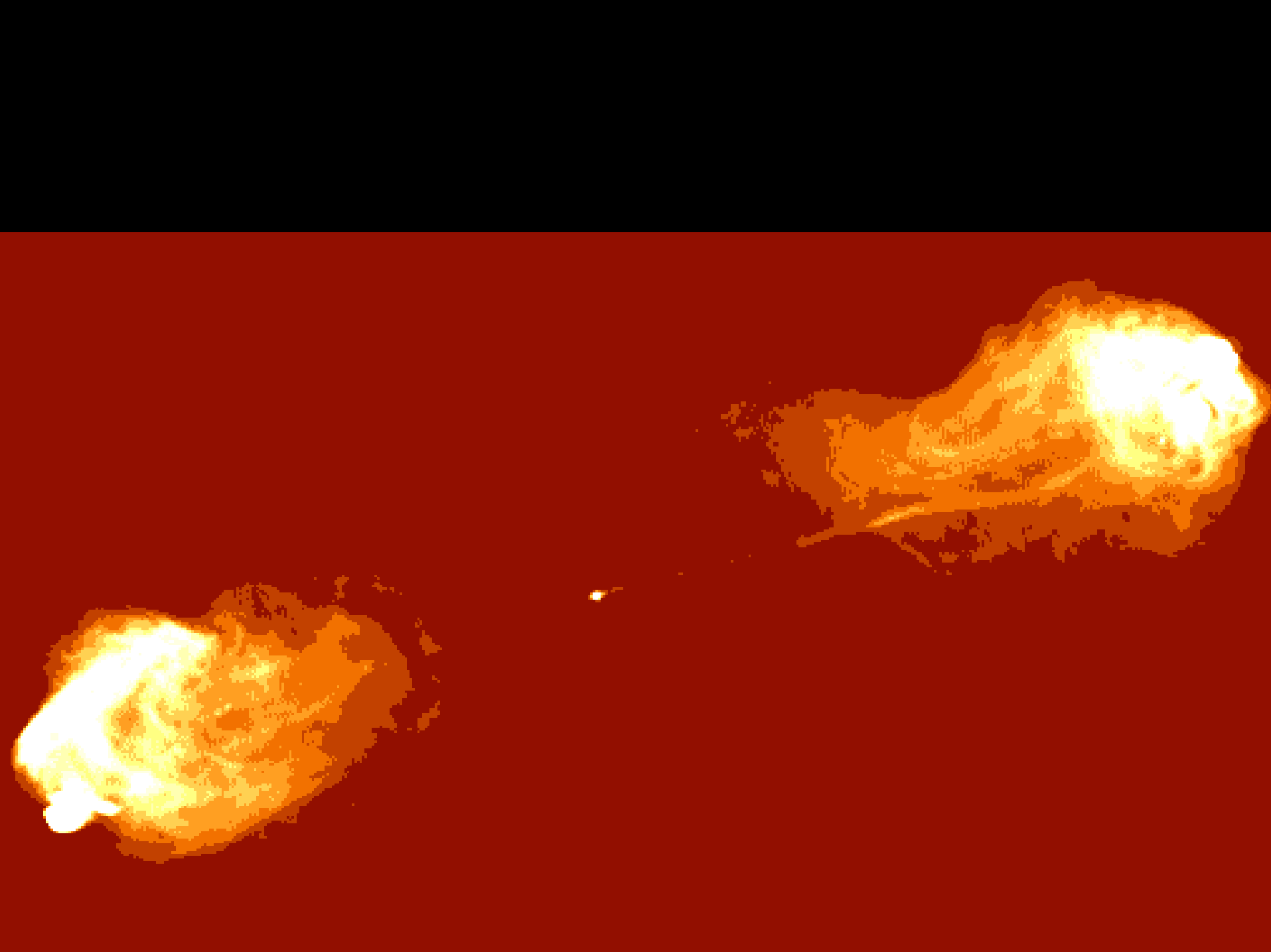
Cygnus A





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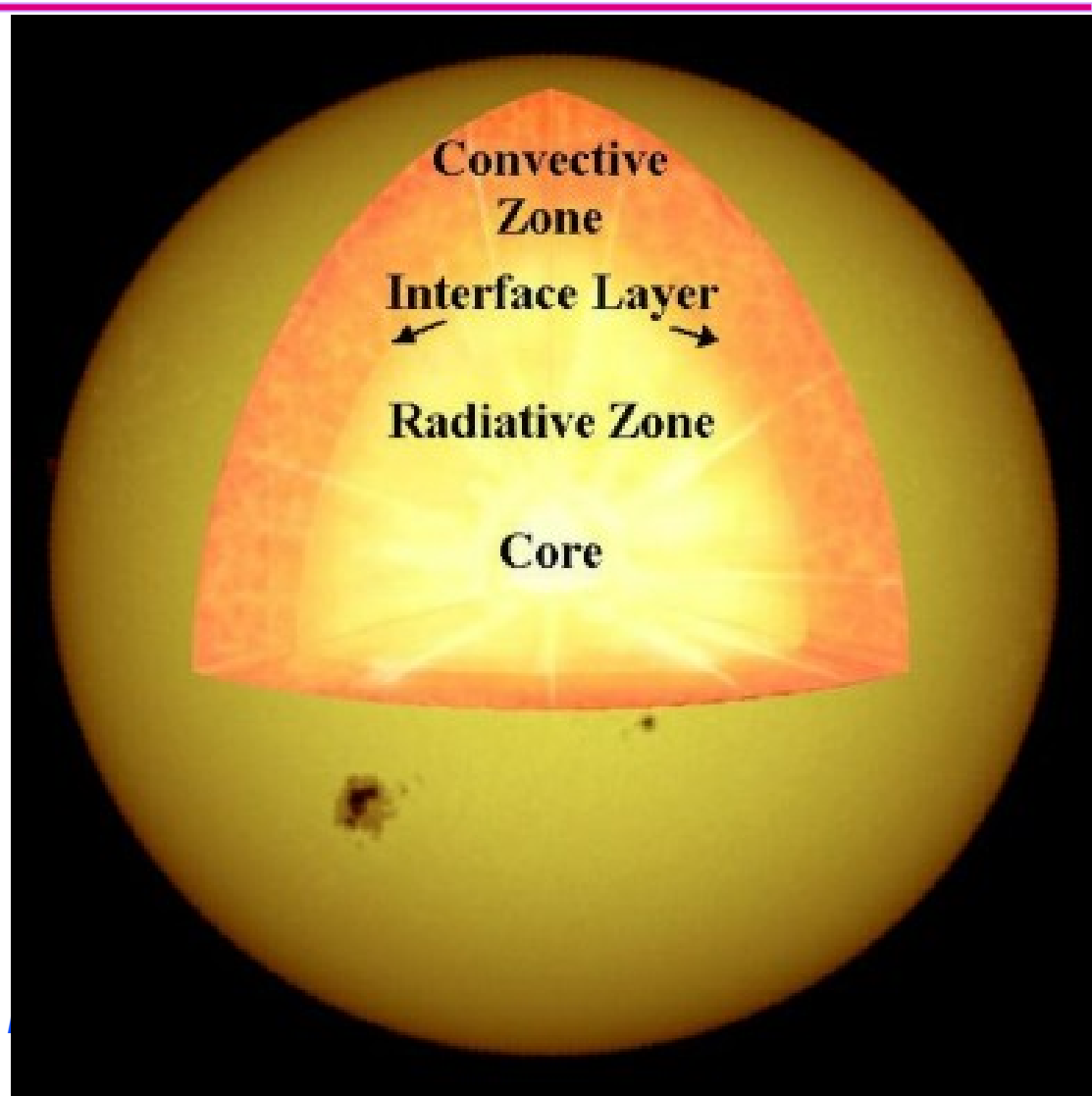
Different Forms of Radiation…

- Originate in different places
- Are caused by different processes
  - » Light, radio waves: generated by heat and moving electric charge
  - » Gravitational waves: generated by moving mass
- Are more or less blocked by intervening matter
  - » Light is blocked by interstellar dust
  - » Gravitational waves pass through everything

Sources of Gravitational Waves 1: Supernovae

- Stars fuse hydrogen into helium within their cores
- This nuclear fusion powers the star-
  - » producing the heat the makes it shine
  - » creating the pressure that keeps it from collapsing under its own weight
- But the supply of hydrogen is limited



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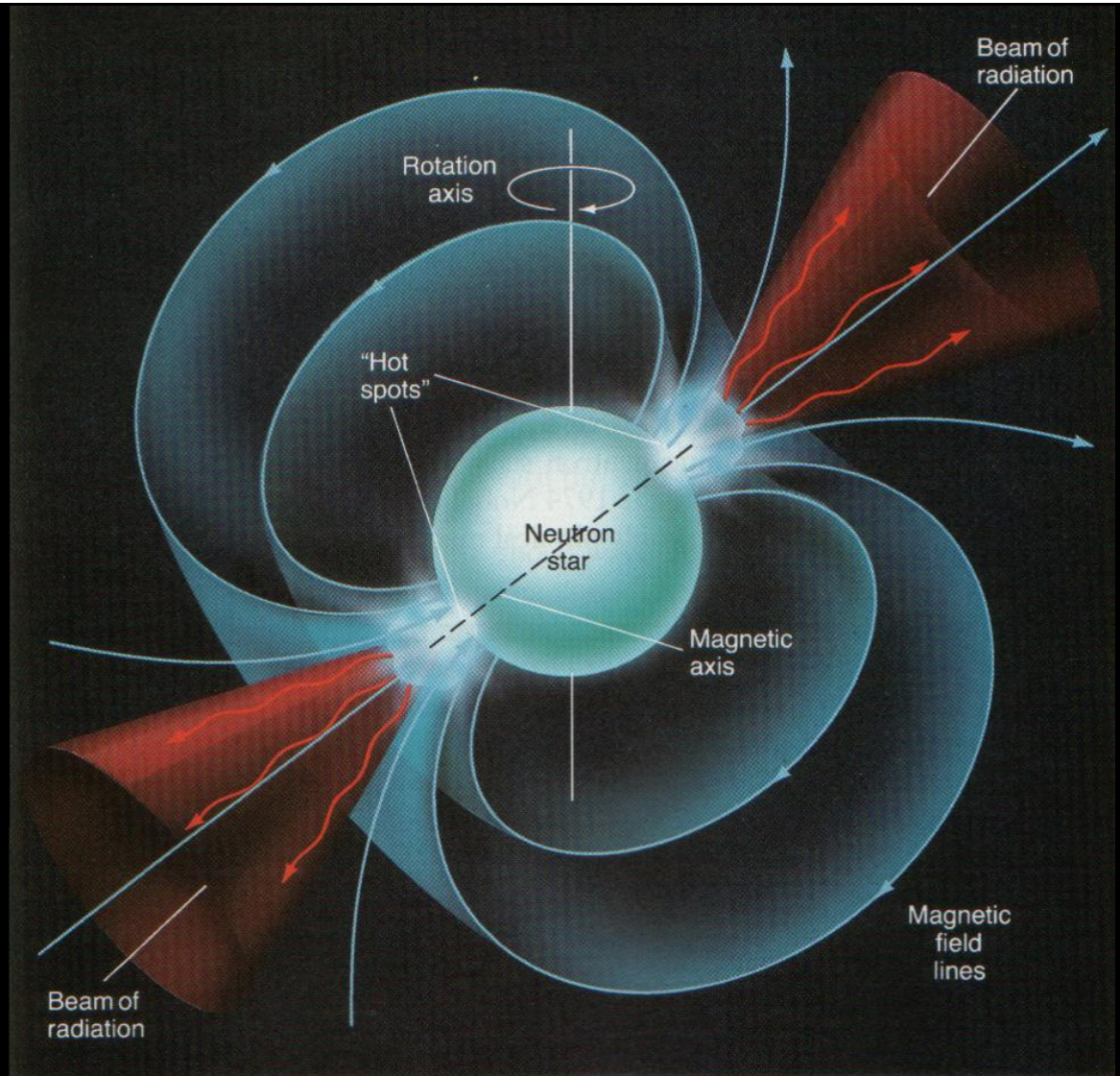
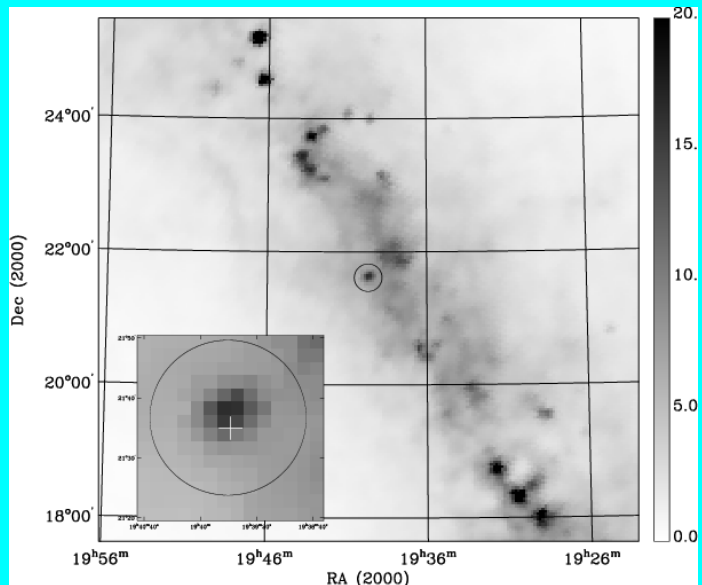
Sources of Gravitational Waves 2: Neutron Stars and Pulsars

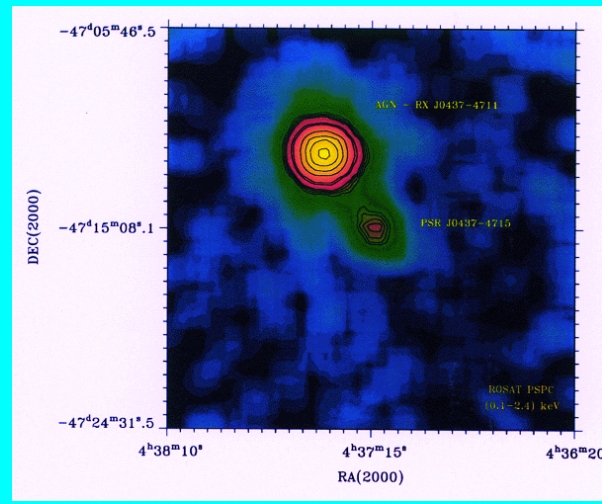


PSR B0329+54

Crab pulsar

Vela pulsar

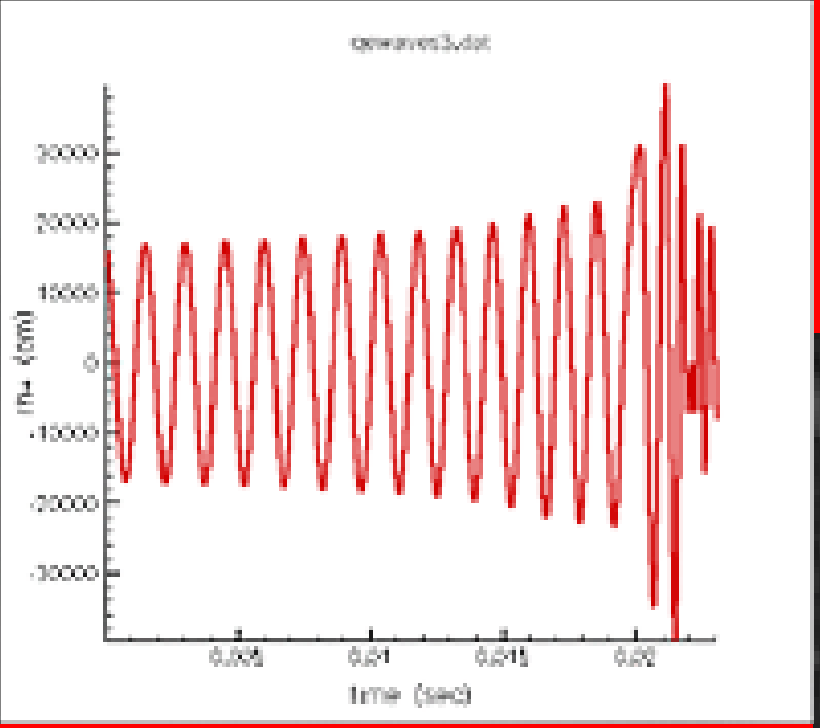


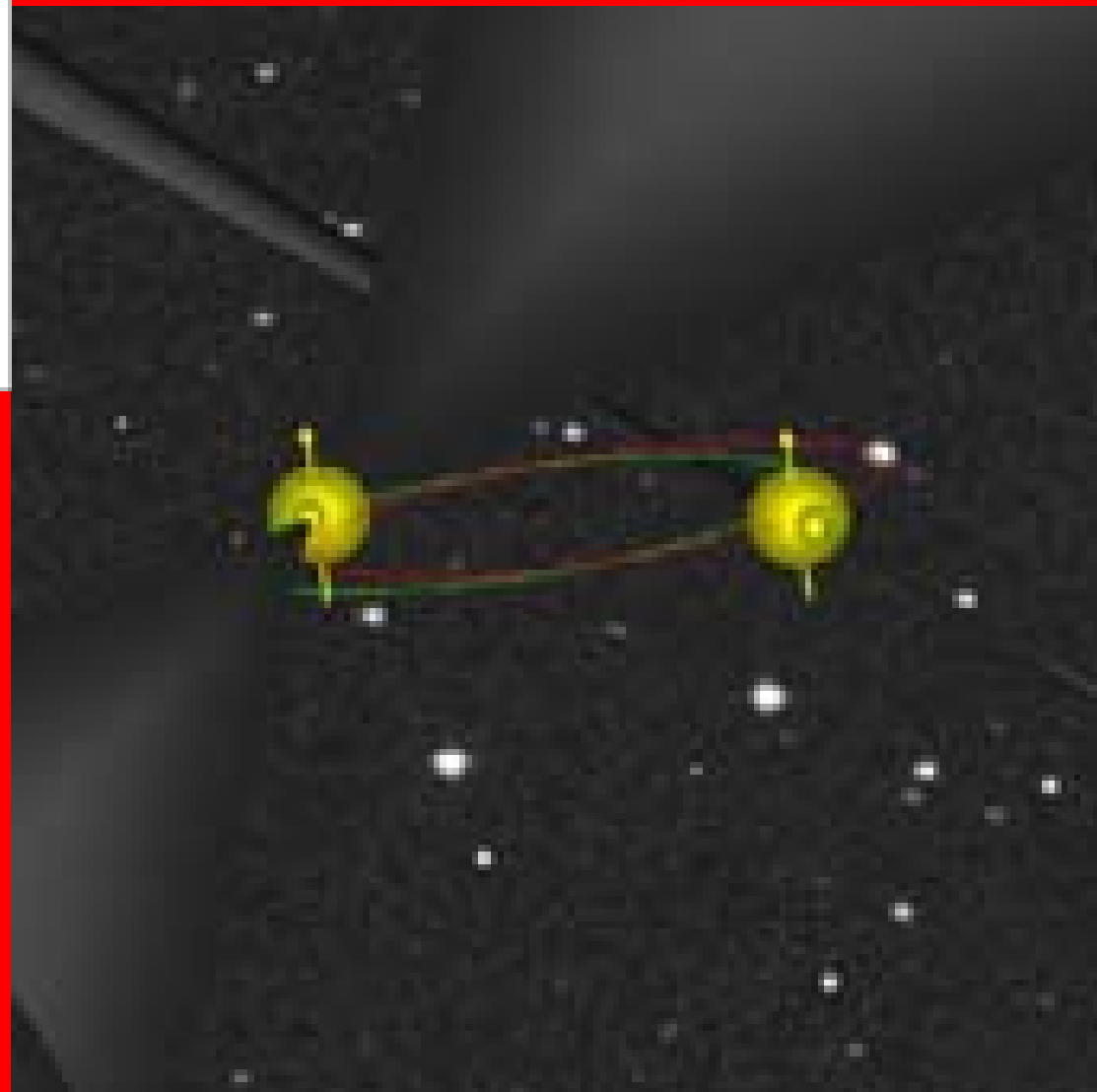


PSR J0437-4715

PSR B1937+21

Binary Neutron Star: Inspiral, Collision, Merger



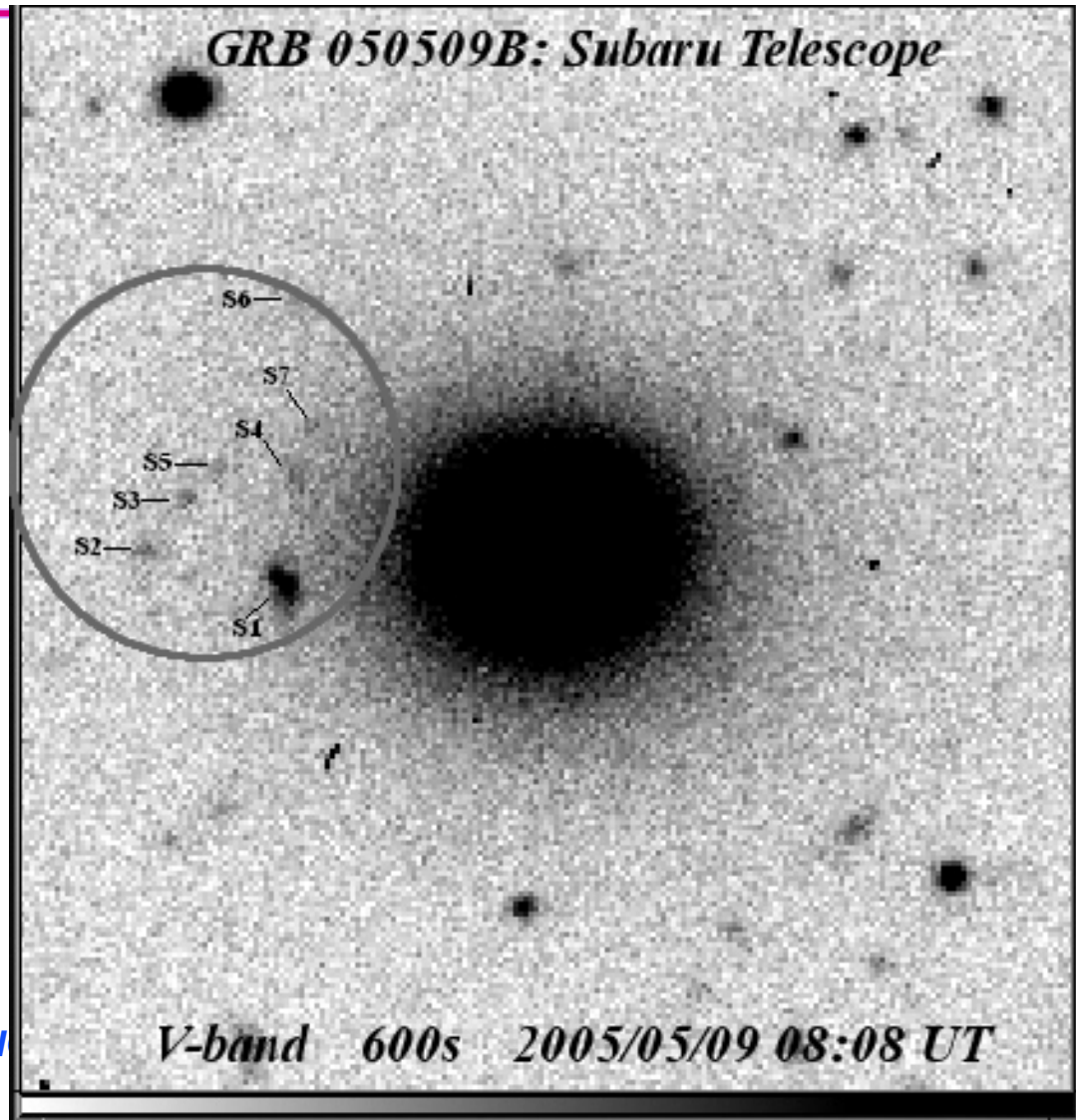


This is our favorite source:

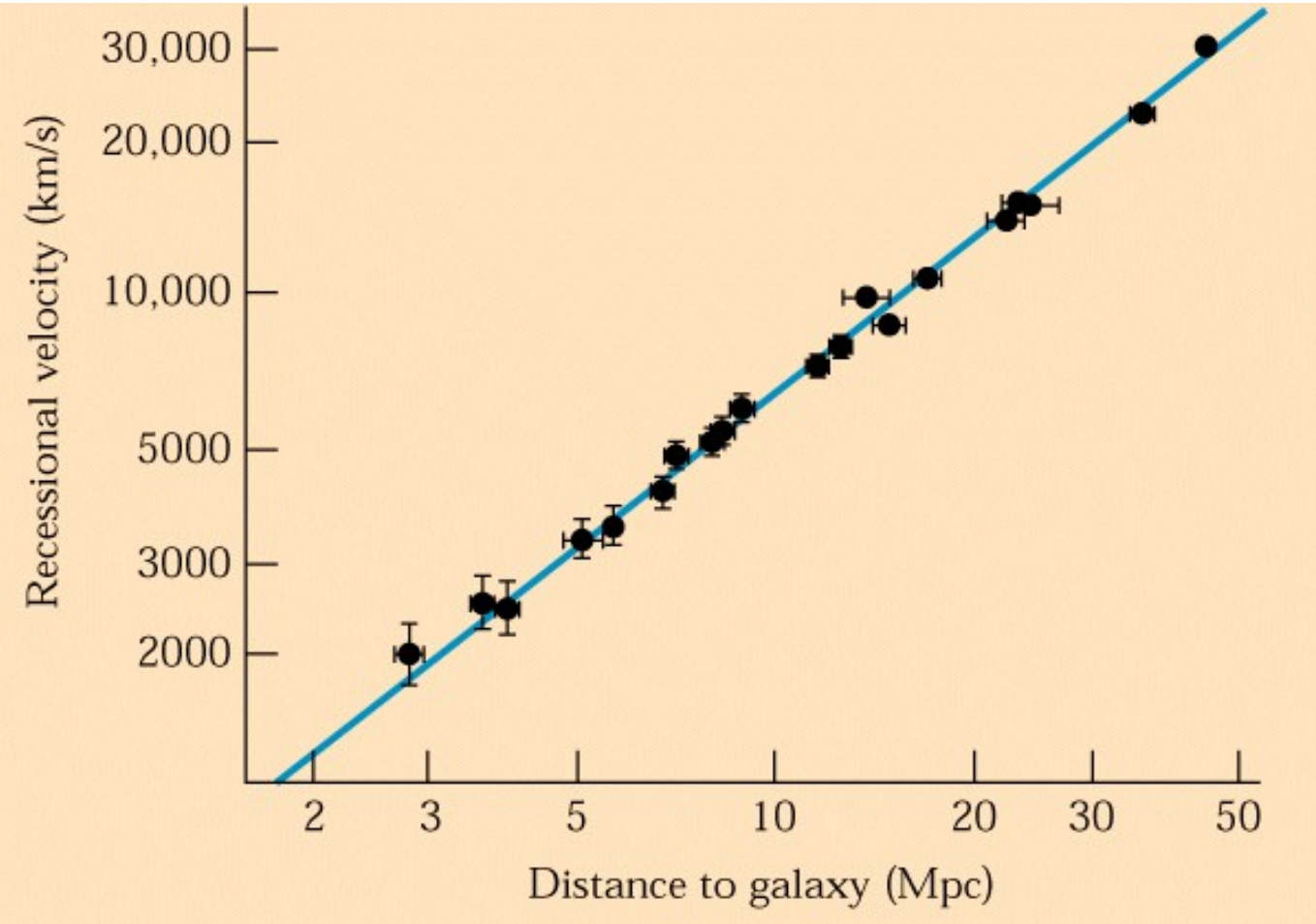
- -very predictable
- -very powerful

Binary Neutron Stars and "Short and Hard" Gamma Ray Bursts

- Two weeks ago GRB050509b was detected by the Swift satellite, both in the initial gamma ray burst and in the X-ray afterglow- the first time an afterglow of a 'short and hard' burst was detected.
- The afterglow was undetectable after 400s, and a search for the source location is ongoing
- 'Short and hard' GRBs are believed to be the optical signature of binary neutron star collisions



Sources of Gravitational Waves 3: The Big Bang



The farther away a galaxy is, the fast it is moving away from us- the Universe is still expanding after its birth in an explosion 15 billion years ago.

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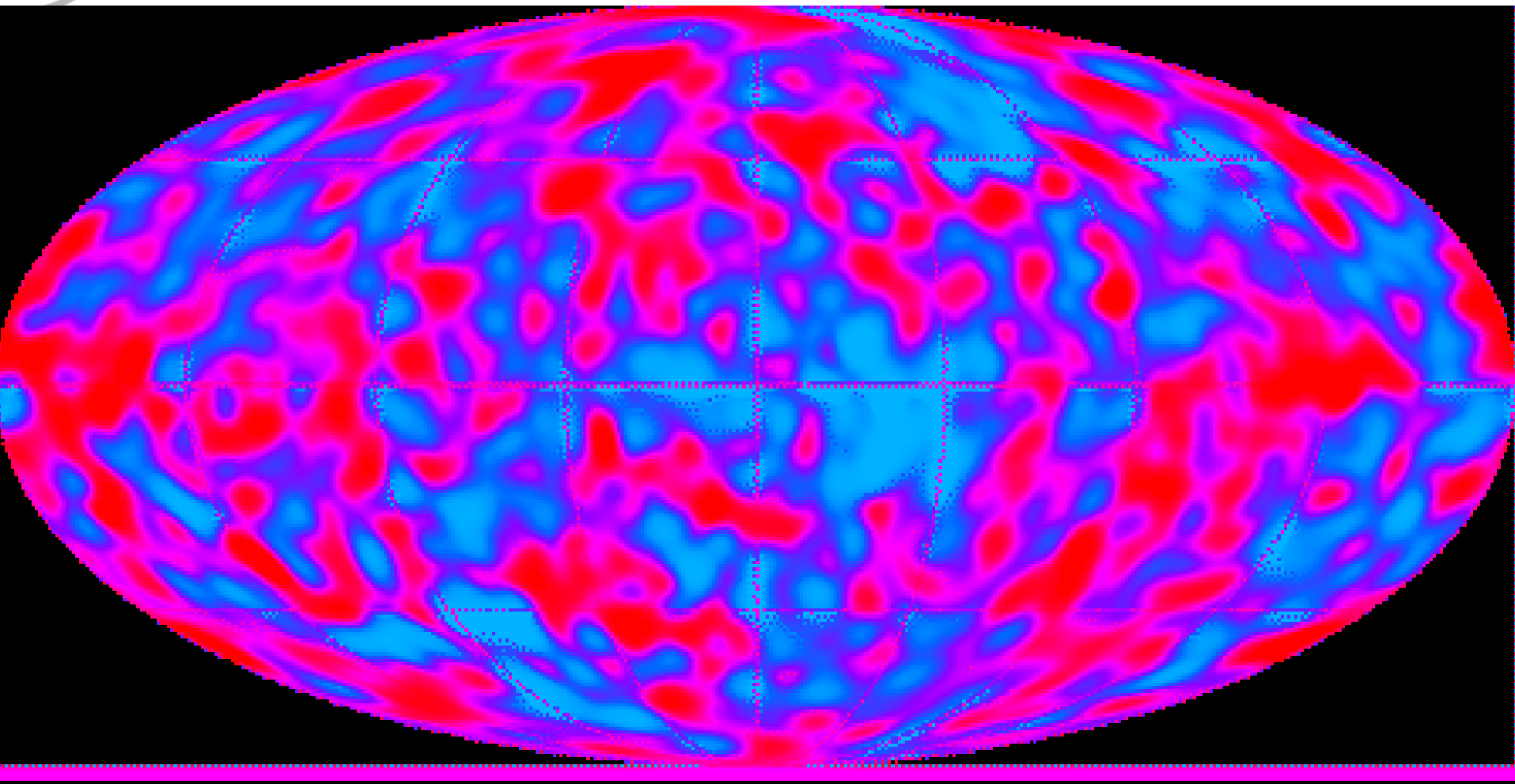
The Heat of the Big Bang is Still Visible



This heat was emitted 300,000 years after the Big Bang.

The gravitational waves were emitted within a fraction of a second of the Big Bang.

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Sources of Gravitational Waves 4: Truly Bizarre and Unexpected Stuff