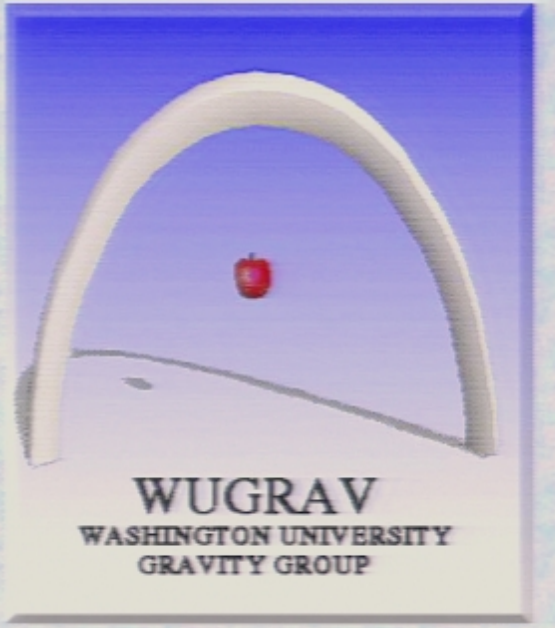
Title: Was Einstein Right? Can Einstein's Theories Survive Today's Scientific Scrutiny?

Date: Oct 05, 2005 07:00 PM

URL: http://pirsa.org/05100012

Abstract: How has the most celebrated scientific theory of the 20th century held up under the exacting scrutiny of planetary probes, radio telescopes and atomic clocks? After 100 years, was Einstein right? <kw> Clifford Will, Einstein, general relativity, spacetime, gravity wave, mercury perihelion, light, radioastronomy, gravititational lenses, quasars, pulsar</kw>

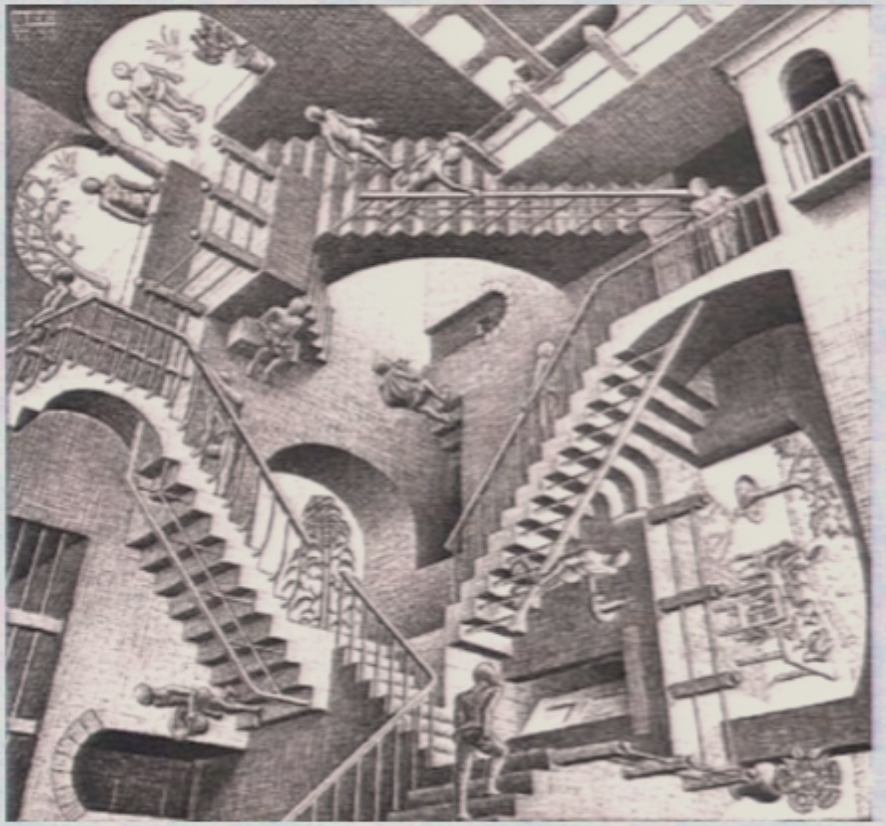
Was Einstein Right?



Clifford Will
Washington University, St. Louis

Canadian Association of Physicists
Perimeter Institute for Theoretical Physics
World Year of Physics National Lecture Tour

Relativity and Art, Philosophy, ...



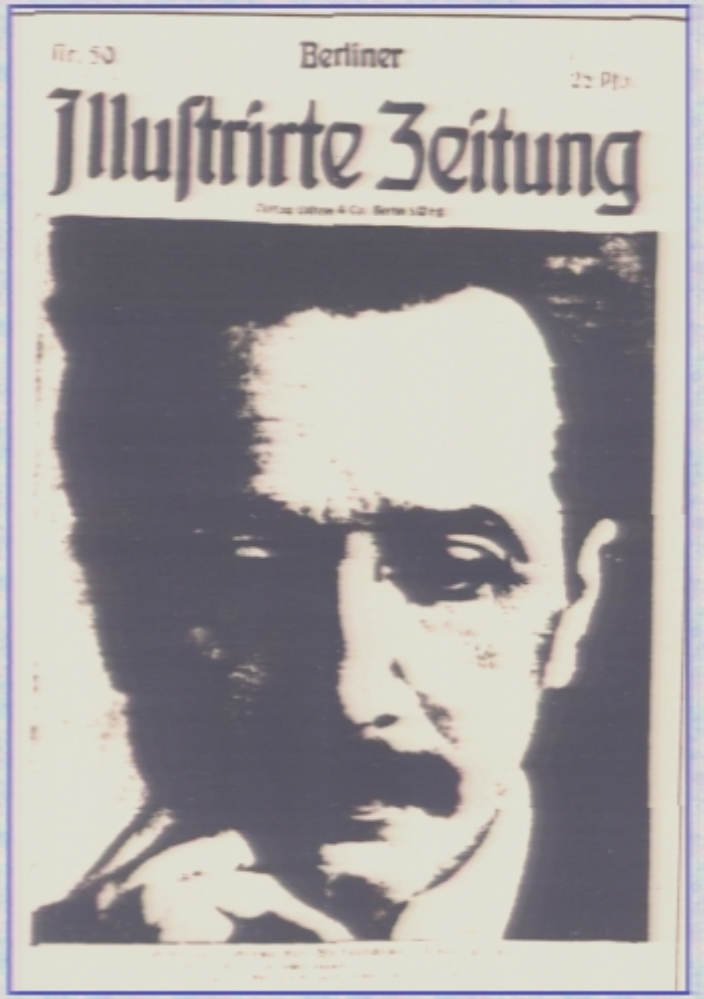
Escher

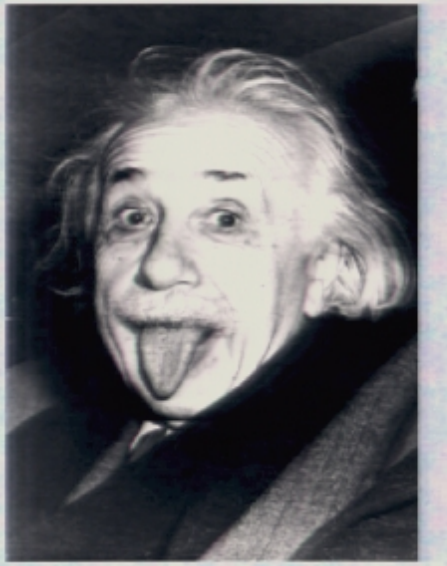
Dali

Relativity Theory and
A priori Knowledge (1920)

Philosophy of Space and
Time (1928)

Reichenbach


Nr. 50
Berliner
22 Pfg.
Illustrirte Zeitung



The public Einstein

Einstein and Song

This day and age we're living in
Give cause for apprehension
With speed and new invention
And things like fourth dimension

Yet we get a trifle weary
With Mr. Einstein's theory
So we must get down to earth at times
Relax, relieve the tension

And no matter what the progress
Or what may yet be proved
The simple facts of life are such
They cannot be removed

Herman Hupfield © 1931 Warner Bros

Einstein and Song

This day and age we're living in
Give cause for apprehension
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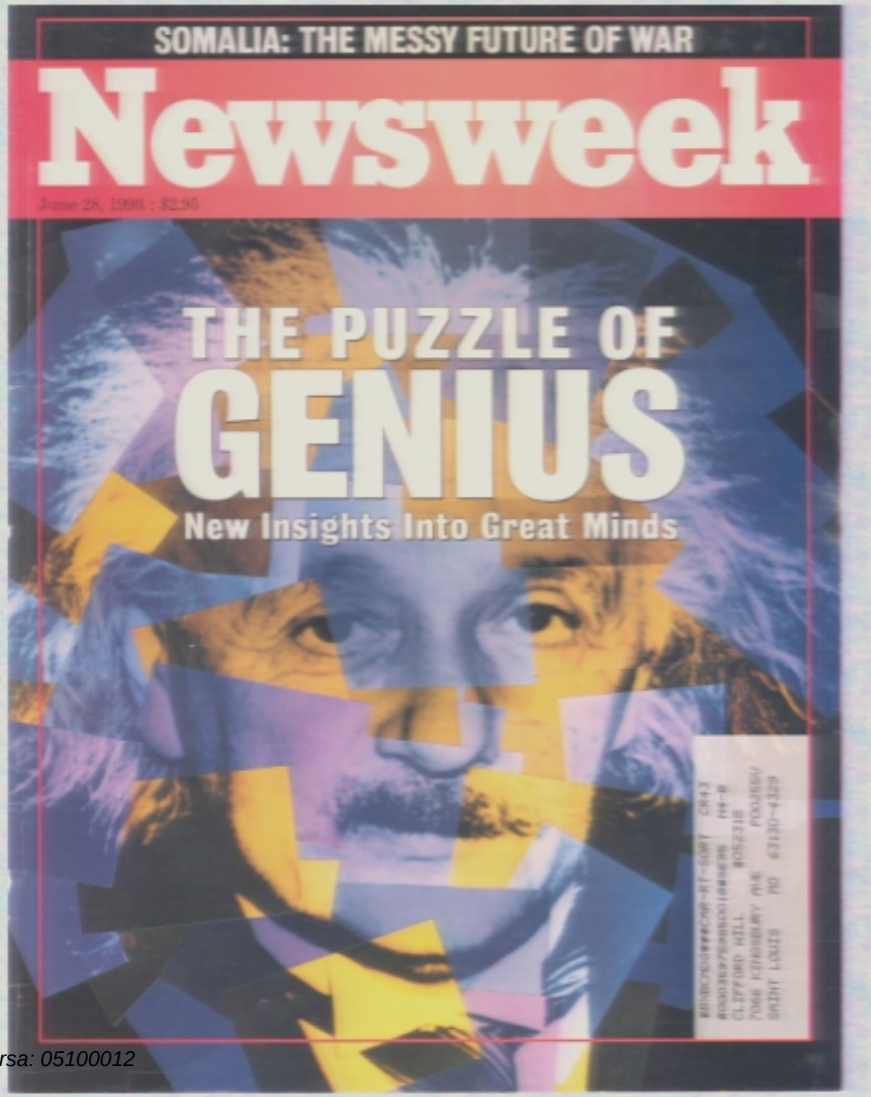
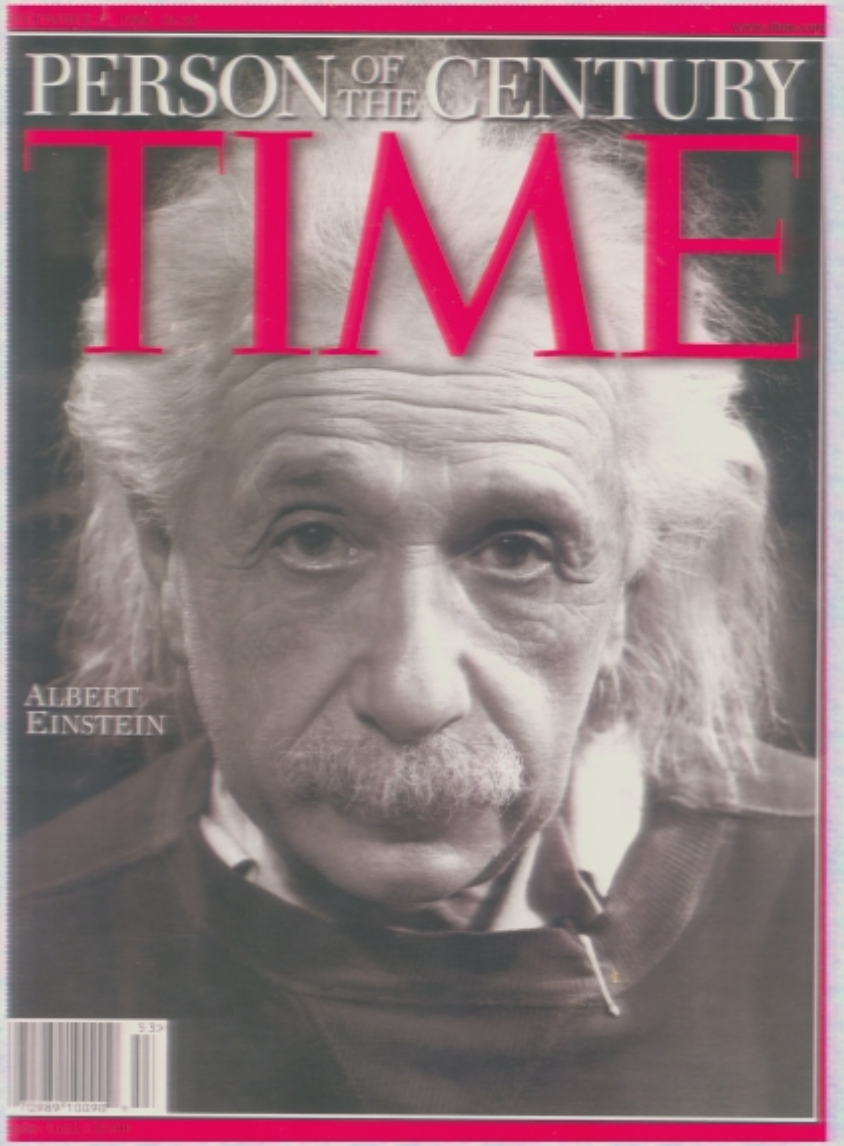
And no matter what the progress
Or what may yet be proved
The simple facts of life are such
They cannot be removed
You must remember this
A kiss is still a kiss . . . .

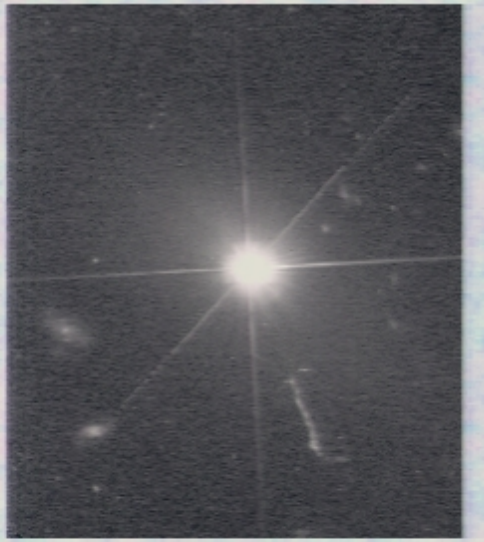
Herman Hupfield © 1931 Warner Bros


SOMALIA: THE MESSY FUTURE OF WAR
Newsweek
THE PUZZLE OF
GENIUS
New Insights Into Great Minds

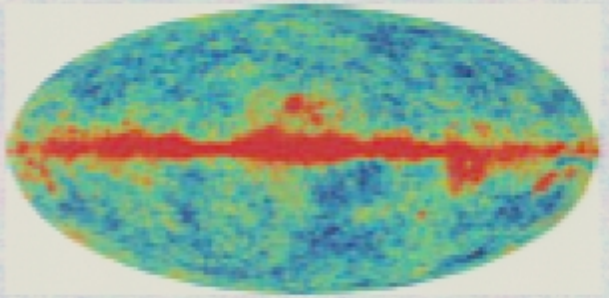

PERSON OF THE CENTURY
TIME
ALBERT
EINSTEIN

The 60's: Hippies, Vietnam, and a Revolution in Astronomy

1961
Discovery
of Quasars



1964
Discovery
of 3°
Cosmic
Background



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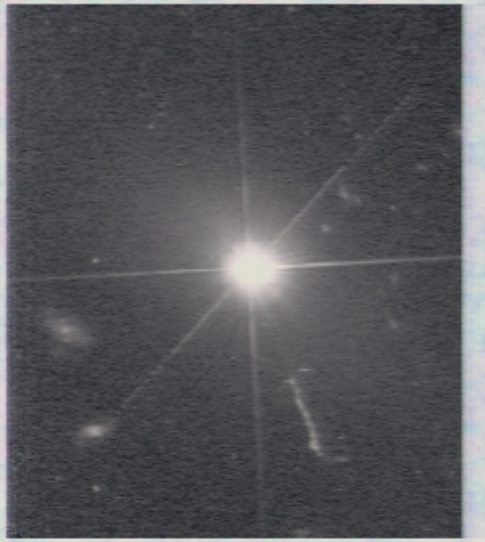

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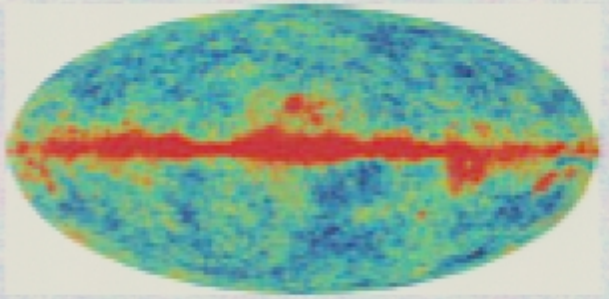

1967
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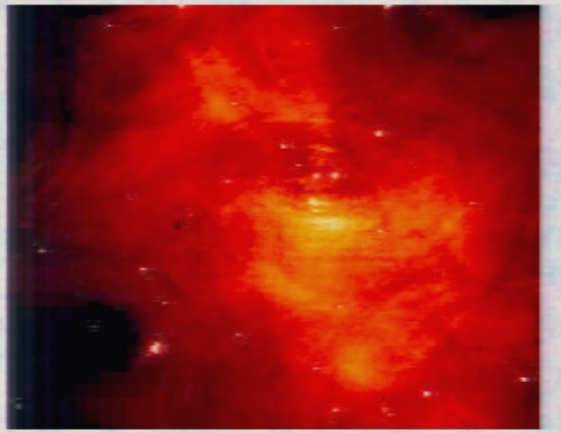

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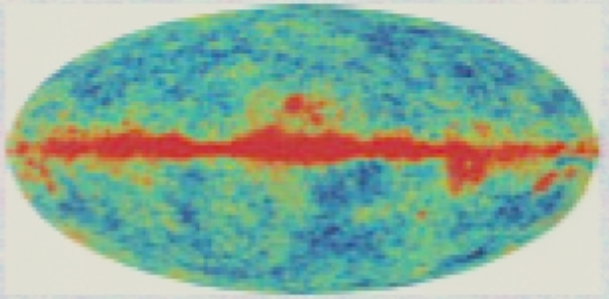

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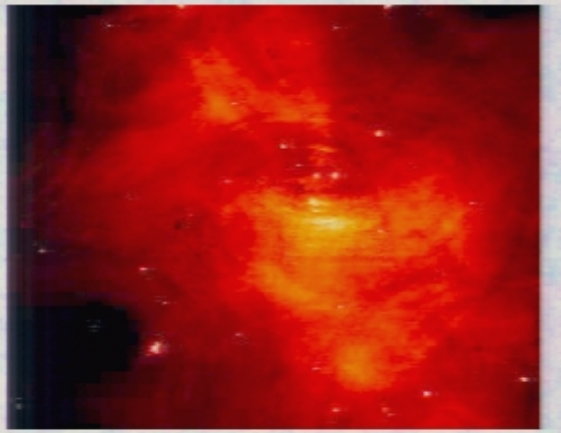
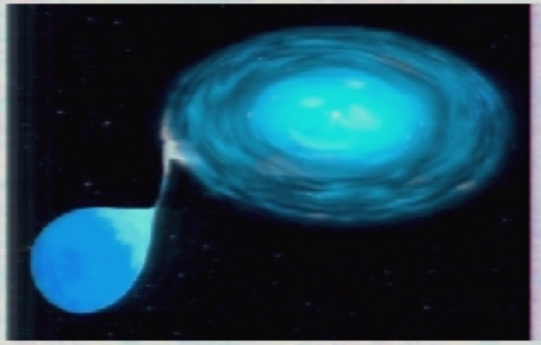


1971
Discovery of
X-ray binary
Black Hole
candidate



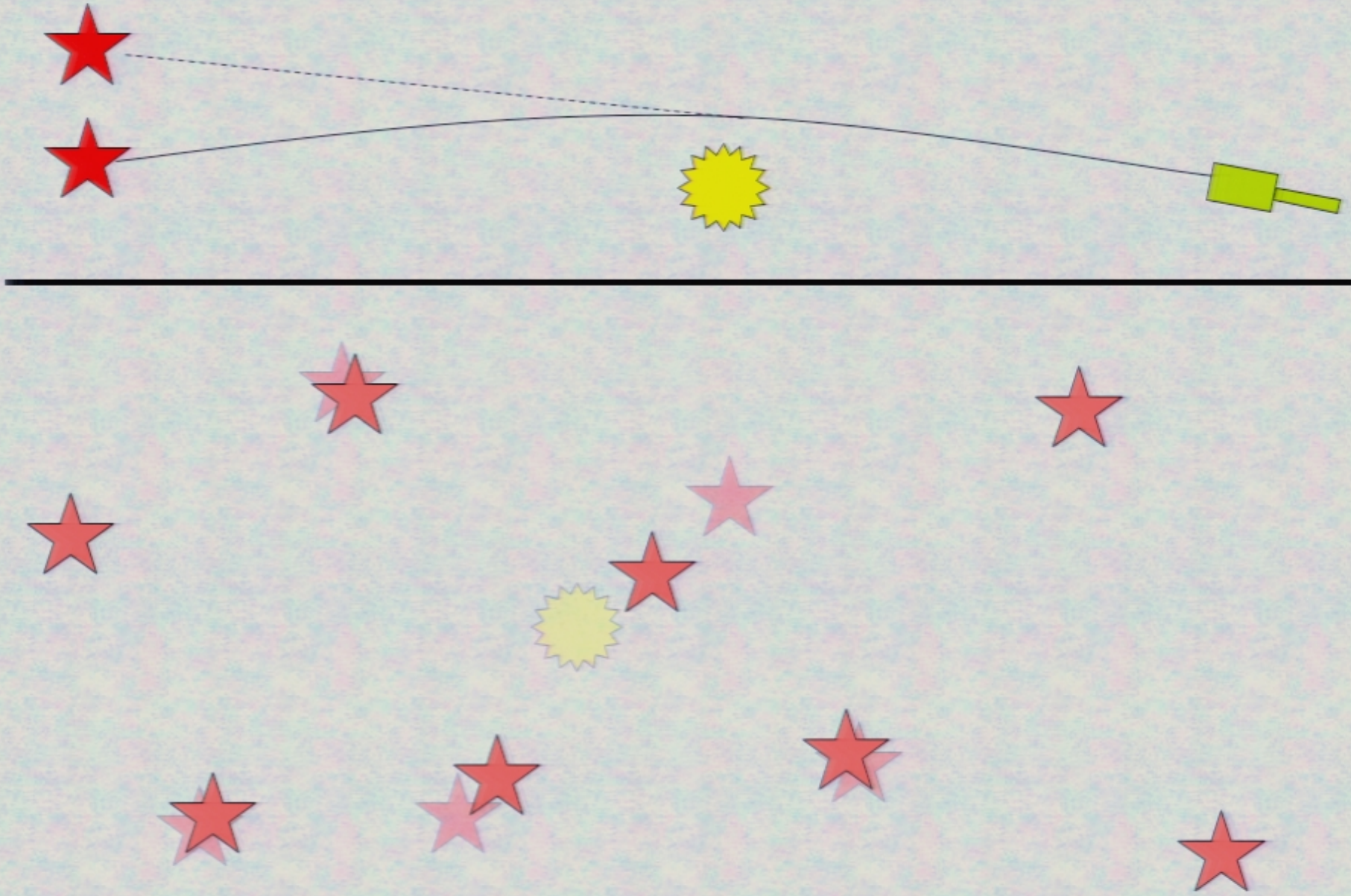
Was Einstein Right?

- INTRODUCTION
- PUTTING GENERAL RELATIVITY TO THE TEST
  - Light's Departure from the Straight and Narrow
  - Mercury's Perihelion: From Trouble to Triumph
  - Does Spacetime do the Twist?
  - The Search for Gravity Waves
  - Effect of Gravity on Time:

    Einstein and Daily Life
- EPILOGUE

Light's Departure from the Straight and Narrow

Light's Departure from the Straight and Narrow



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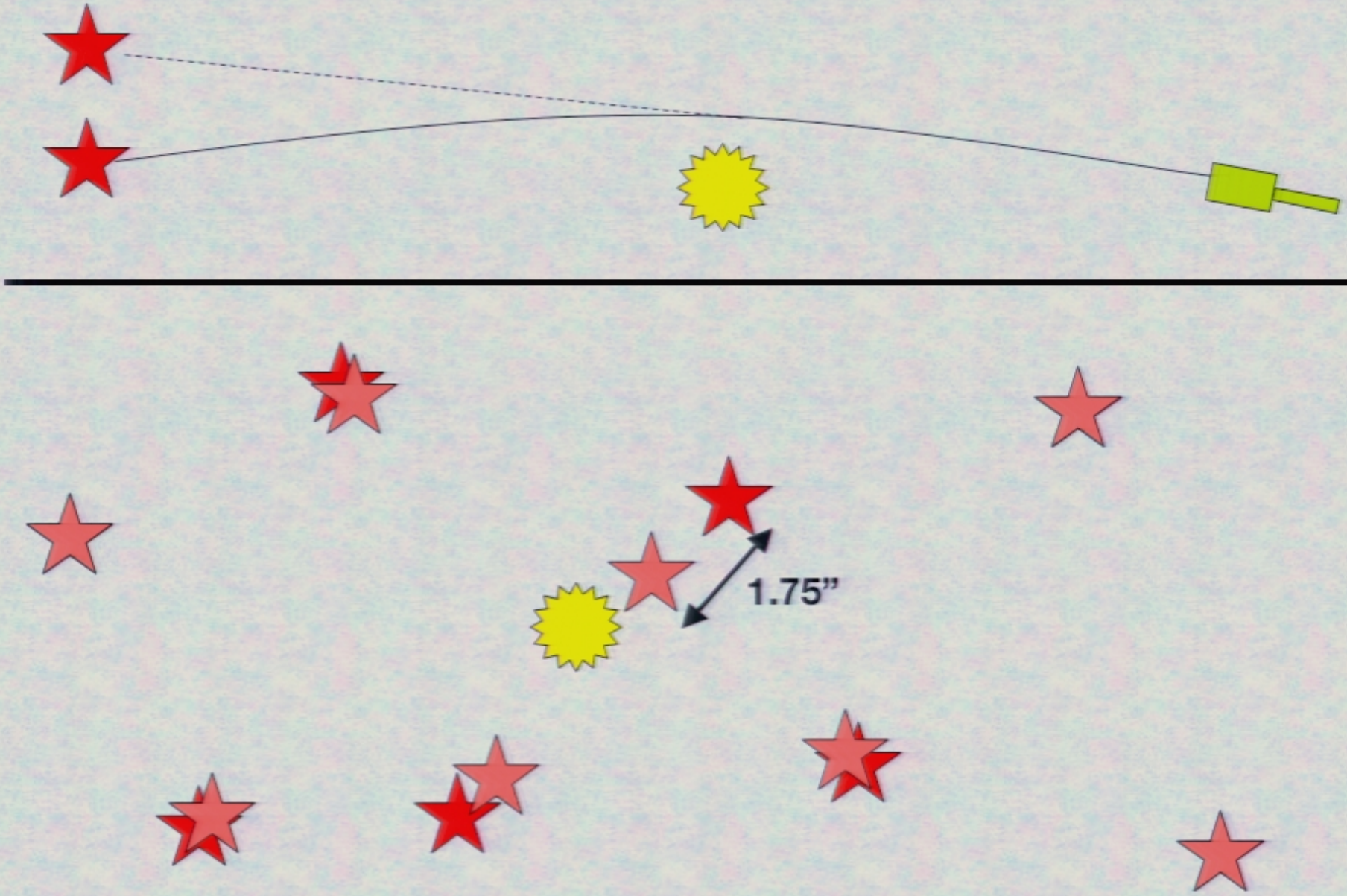
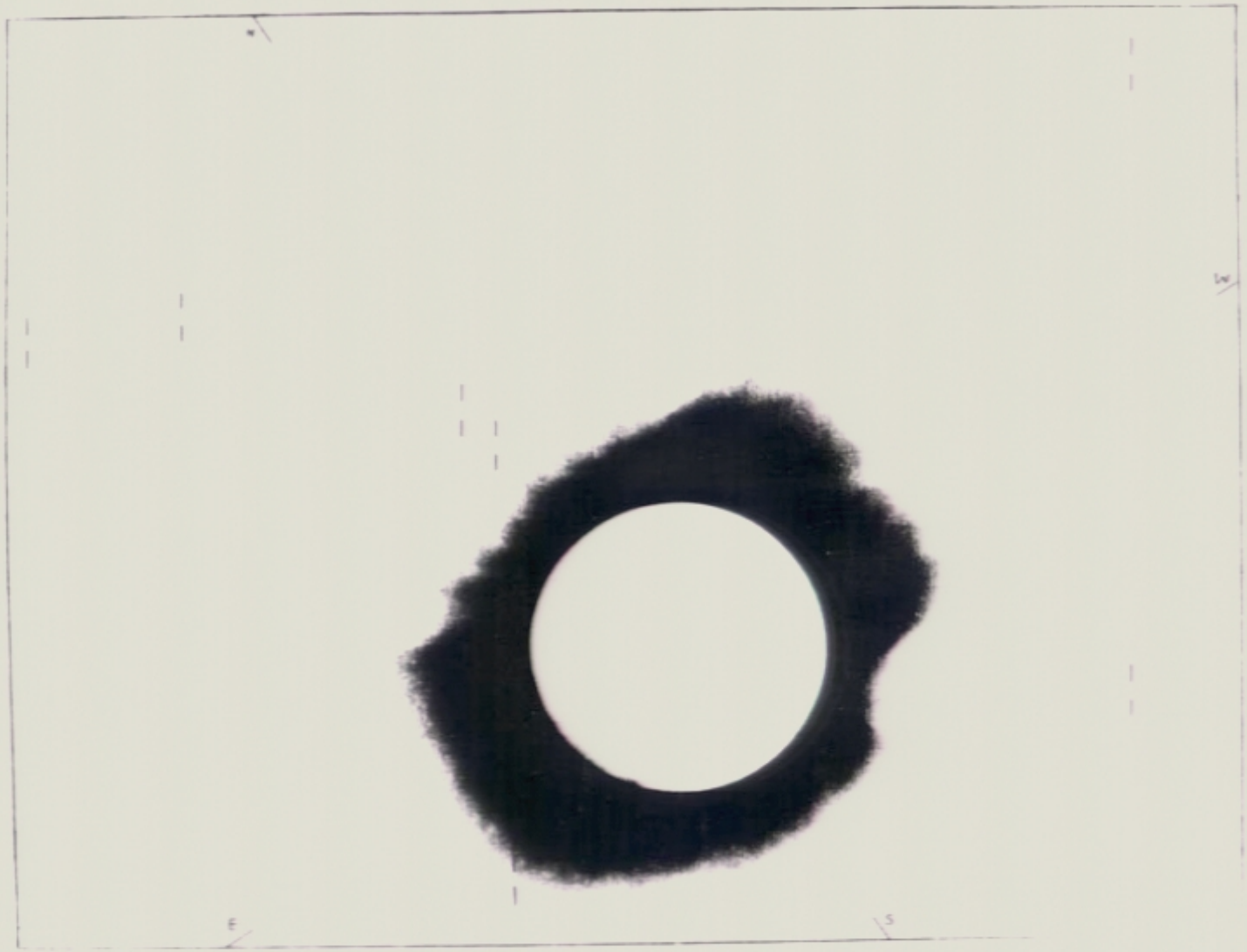


The 1919 Eclipse Expedition: Principe

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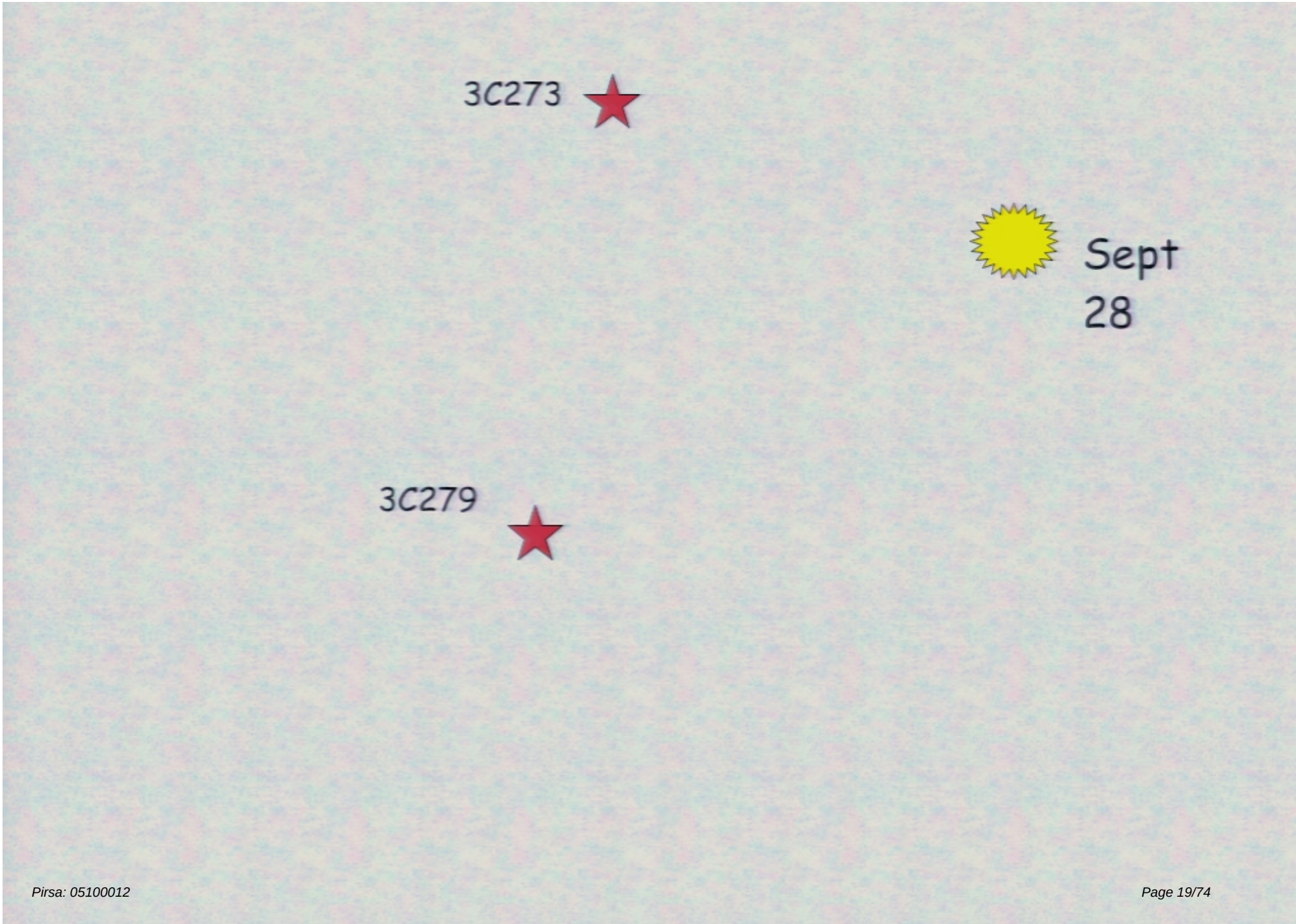
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Sept
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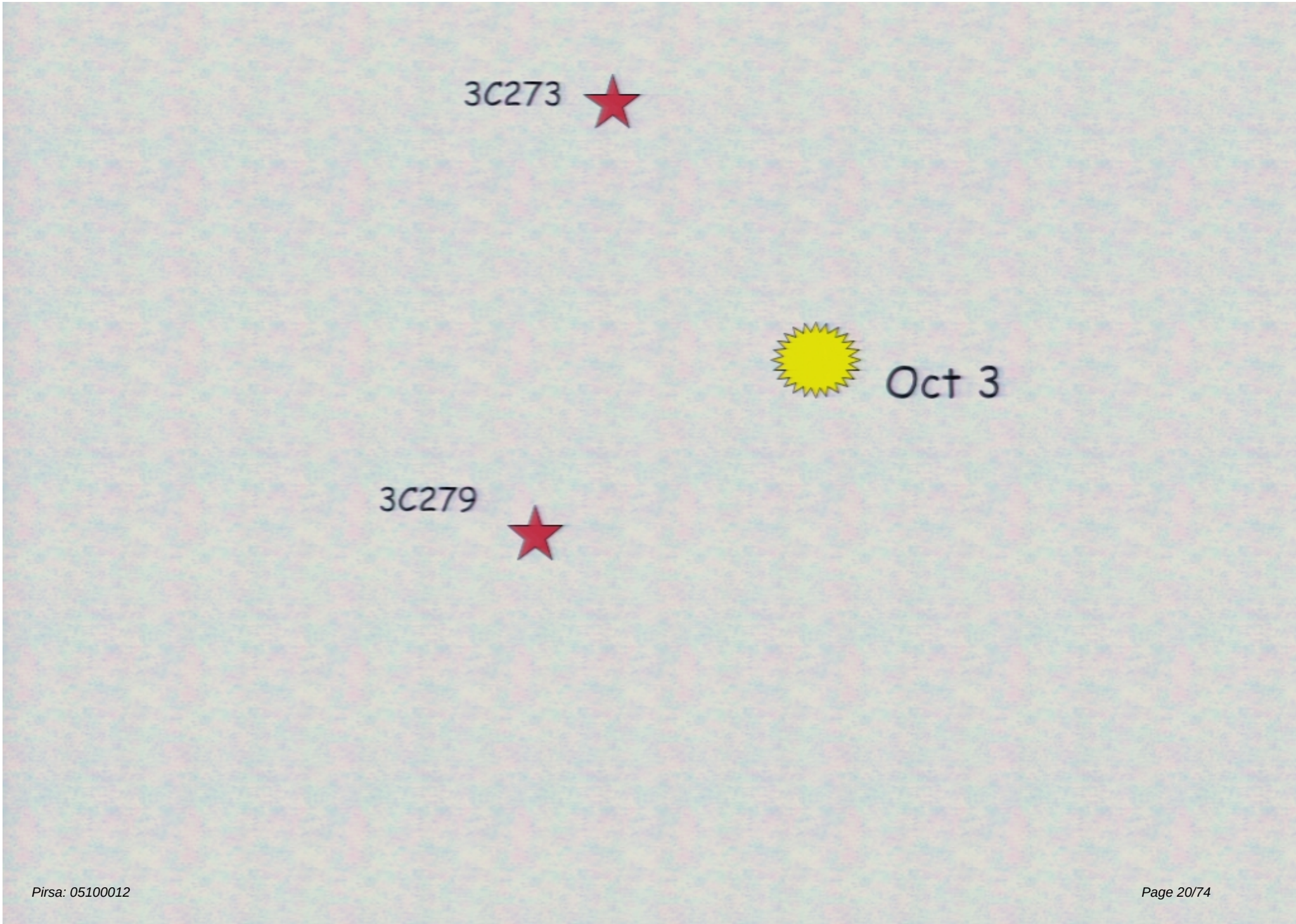
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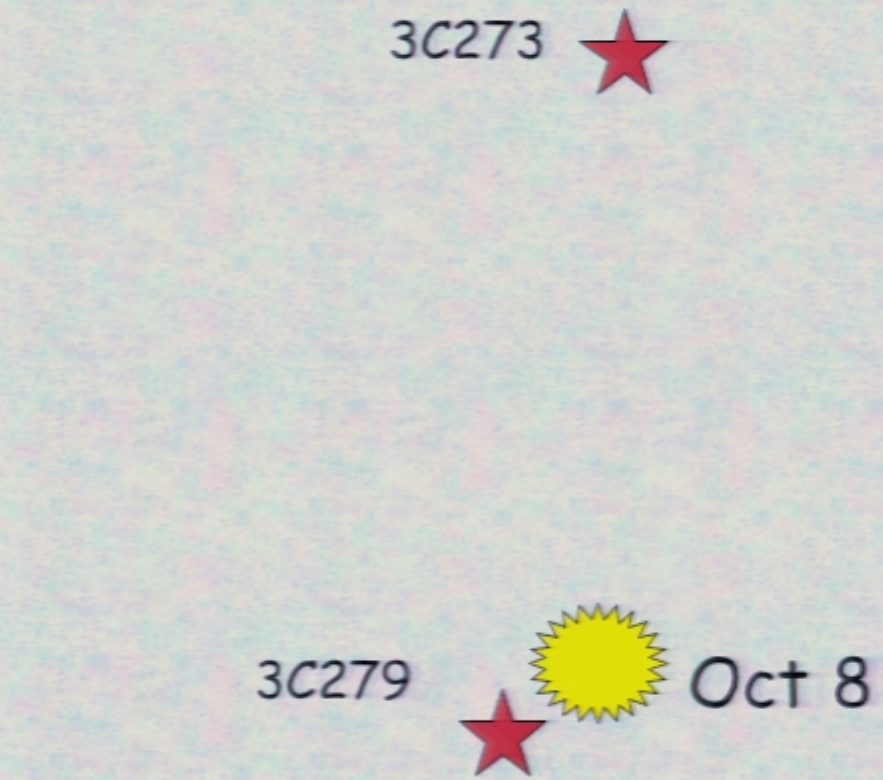
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Oct 8


3C273
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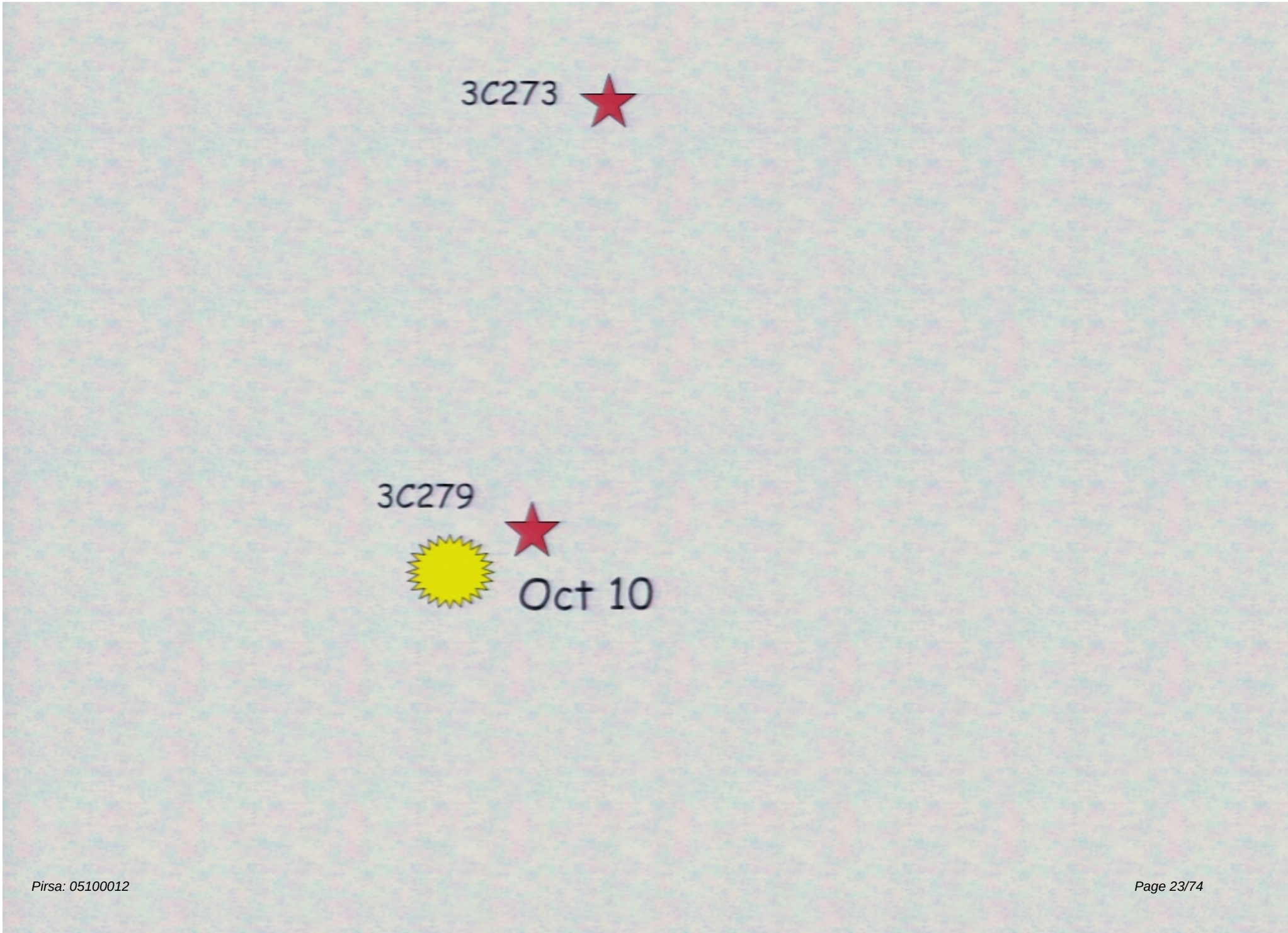
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Oct 10

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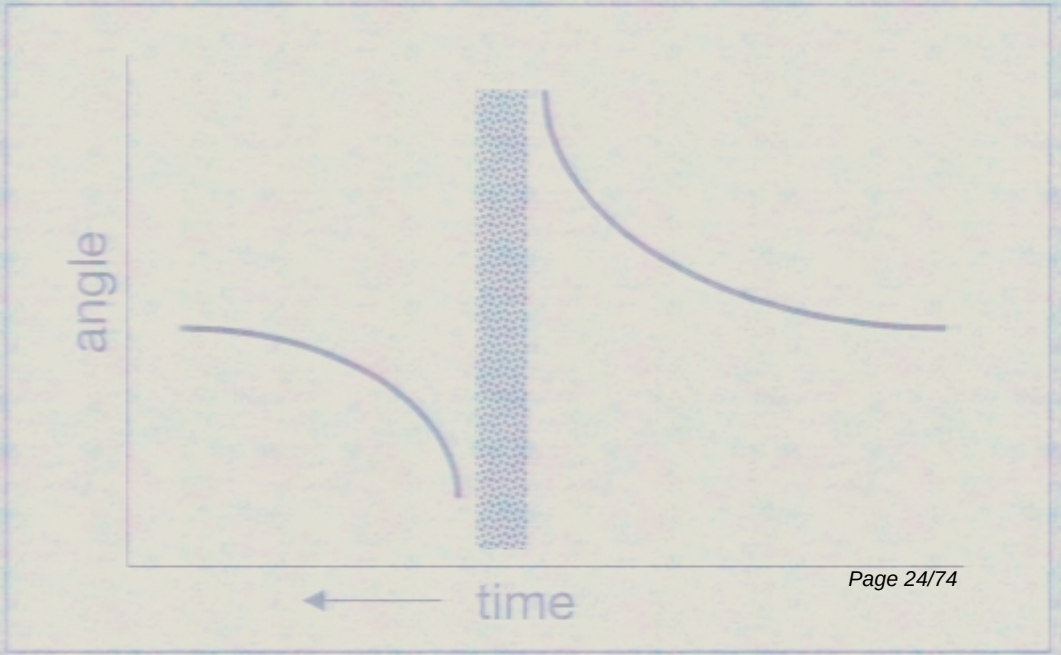
3C279

Oct 15



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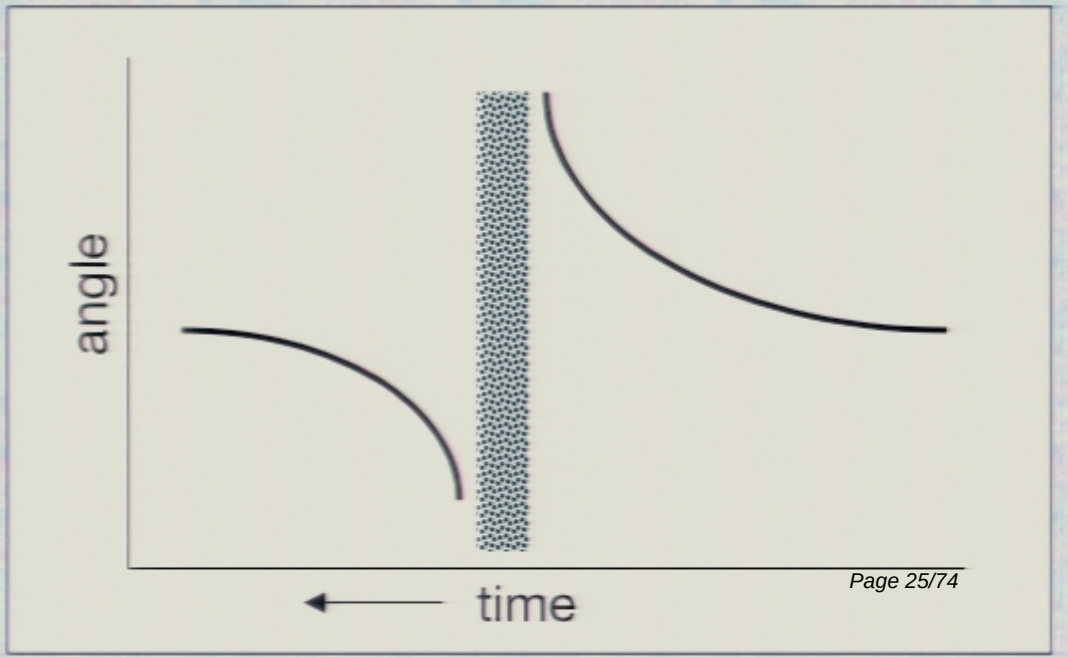
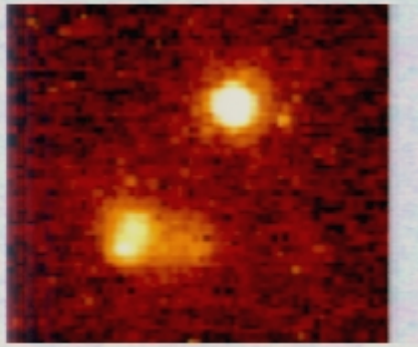
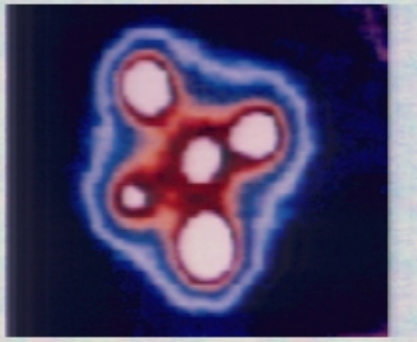
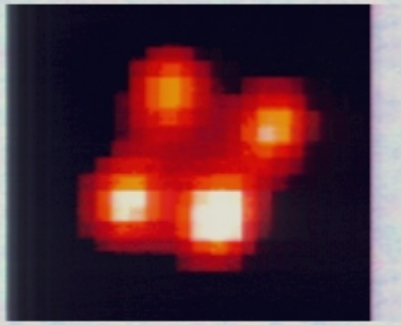
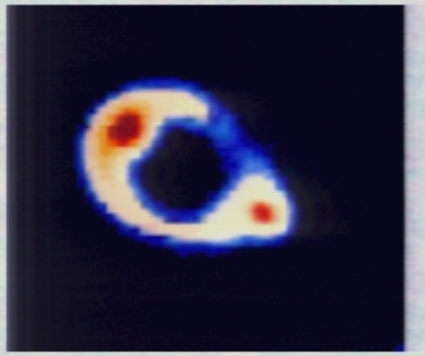
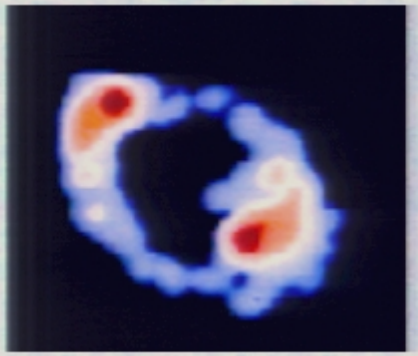
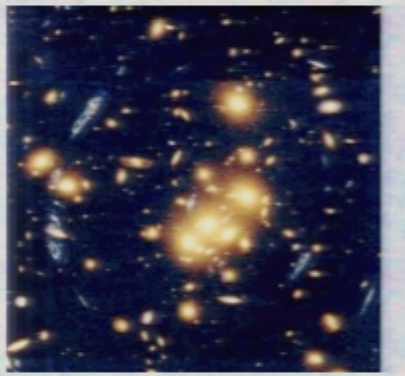
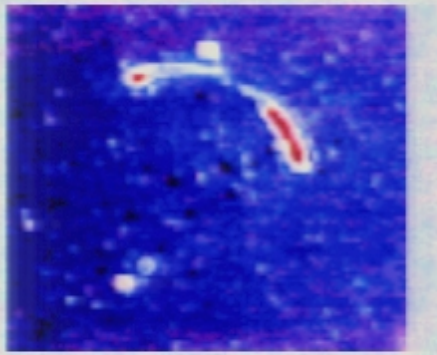


Gravitational Lenses: Einstein's Gift to Astronomy



Distant Object Gravitationally Lensed by Galaxy Cluster Abell 2218 **HST • WFPC2**

NASA, ESA, R. Ellis (Caltech) and J.-P. Kneib (Observatoire Midi-Pyrenees) • STScI-PRC01-32

Mercury's Perihelion: from Trouble to Triumph

- 1687 Newtonian triumph
- 1859 Leverrier's conundrum
- 1900 A turn-of-the century crisis

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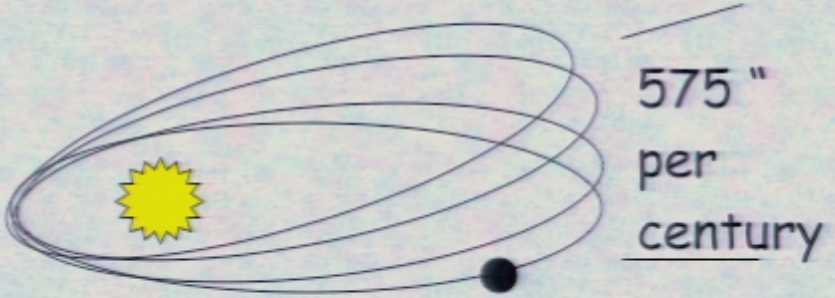

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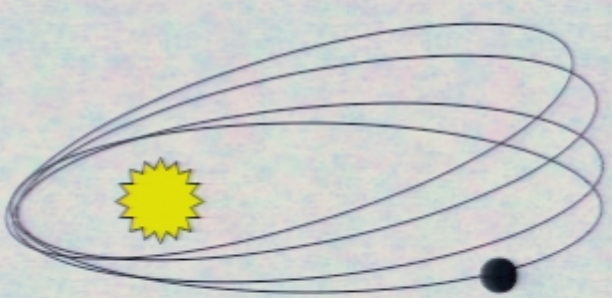

Cause	Rate (per century)

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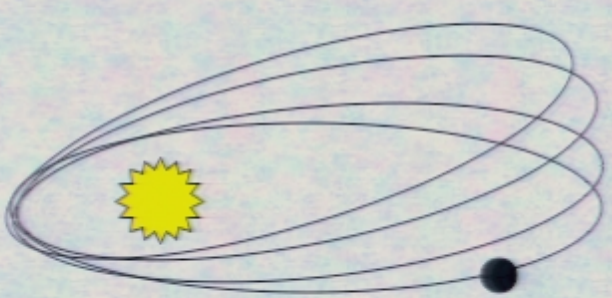

575 " per century

Cause	Rate (per century)
Venus	278 "

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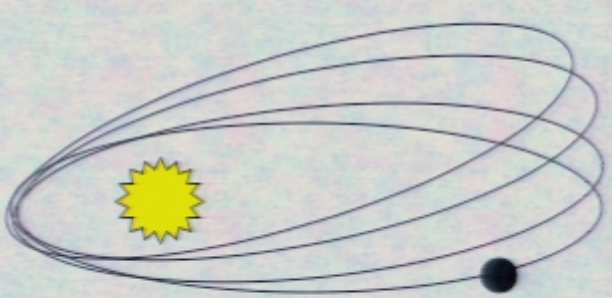

575 " per century

Cause	Rate (per century)
Venus	278 "
Earth	90 "

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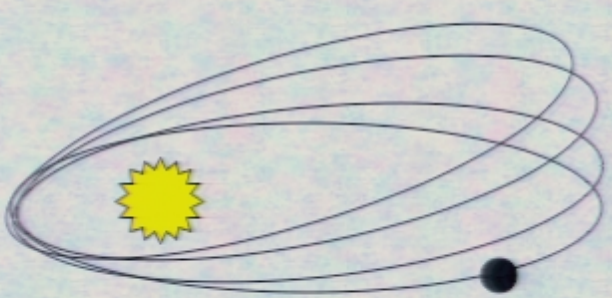

Cause	Rate (per century)
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Earth	90 "
Jupiter	154 "

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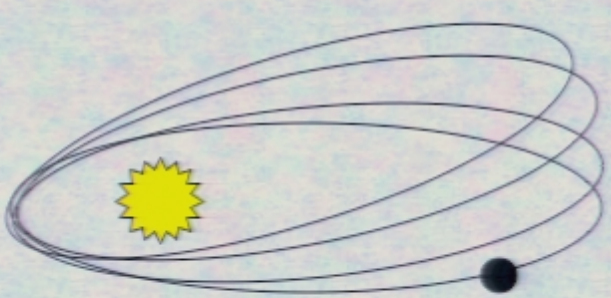

575 " per century

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Jupiter	154 "
Others	10 "

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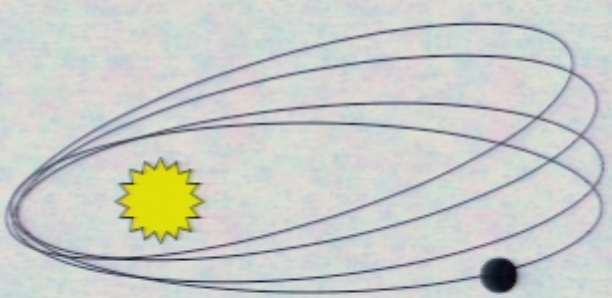

575 " per century

Cause	Rate (per century)
Venus	278 "
Earth	90 "
Jupiter	154 "
Others	10 "
Total	532 "
Discrepancy	43 "

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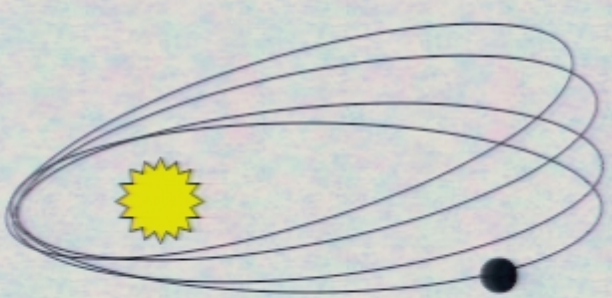

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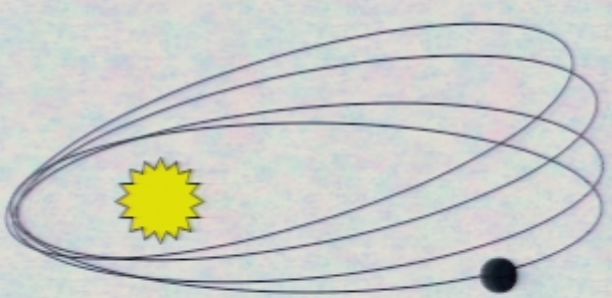

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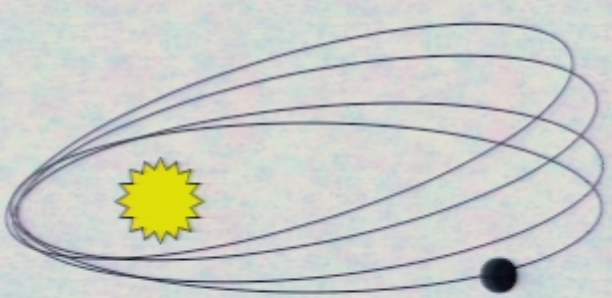

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Discrepancy	43 "
Modern value	42.98 ± 0.04 "

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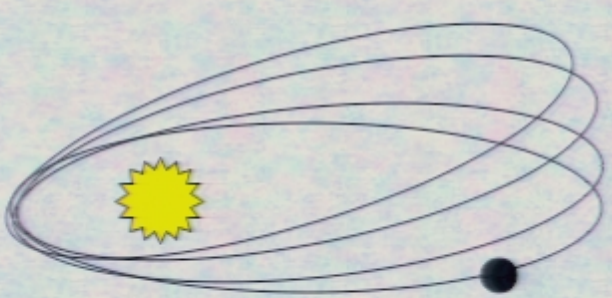

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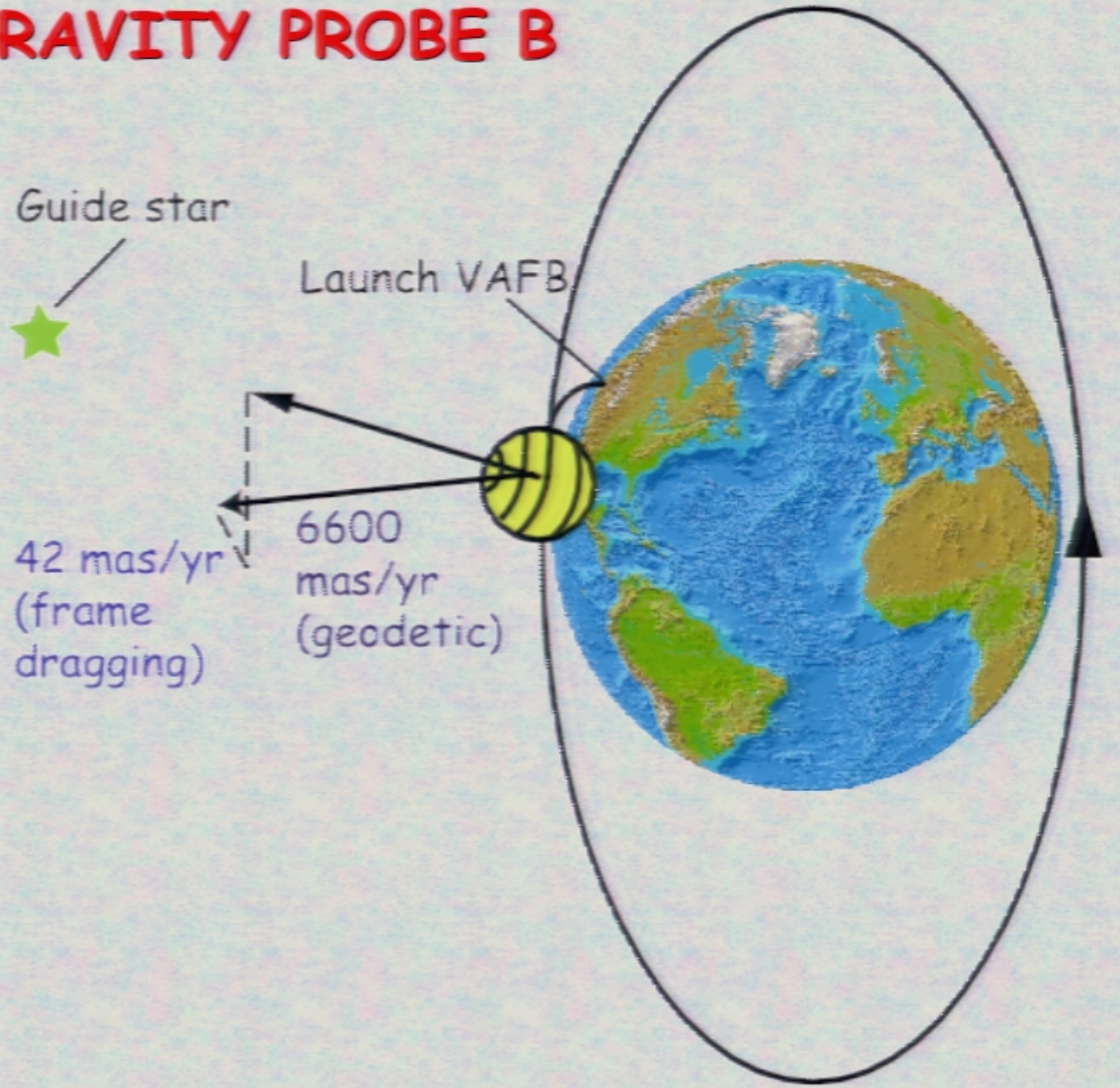
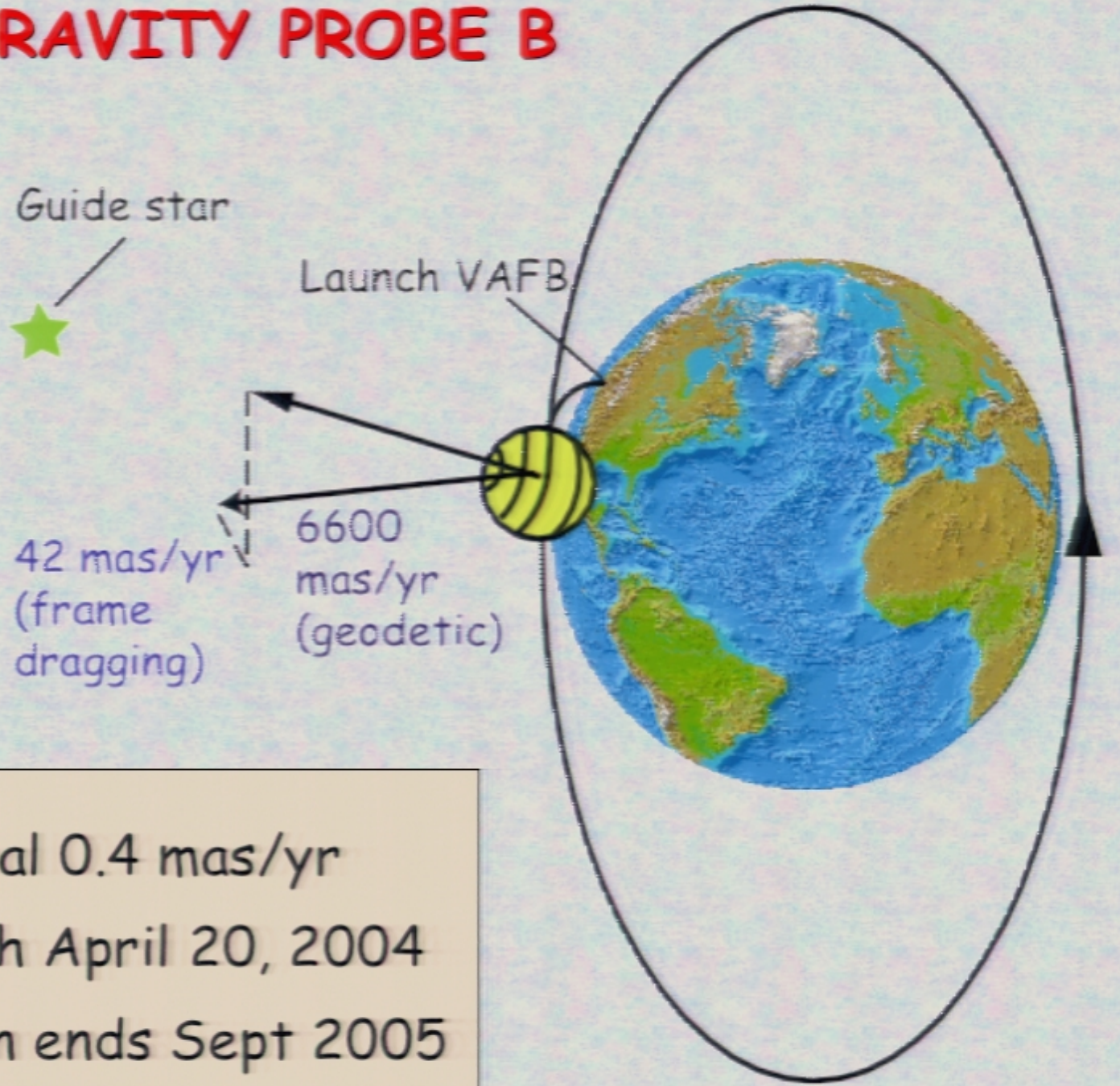
Total	532 "
Discrepancy	43 "
Modern value	42.98 ± 0.04 "
GR Prediction	42.98 "

GRAVITY PROBE B



GRAVITY PROBE B

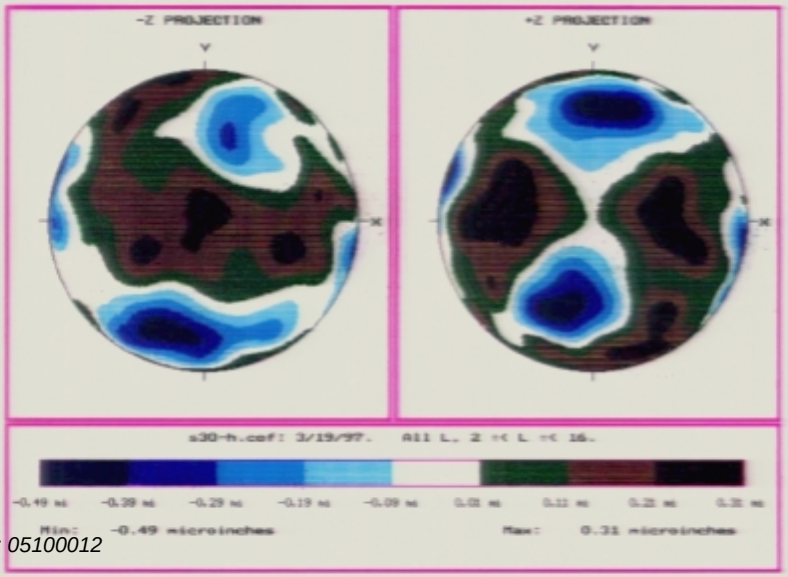


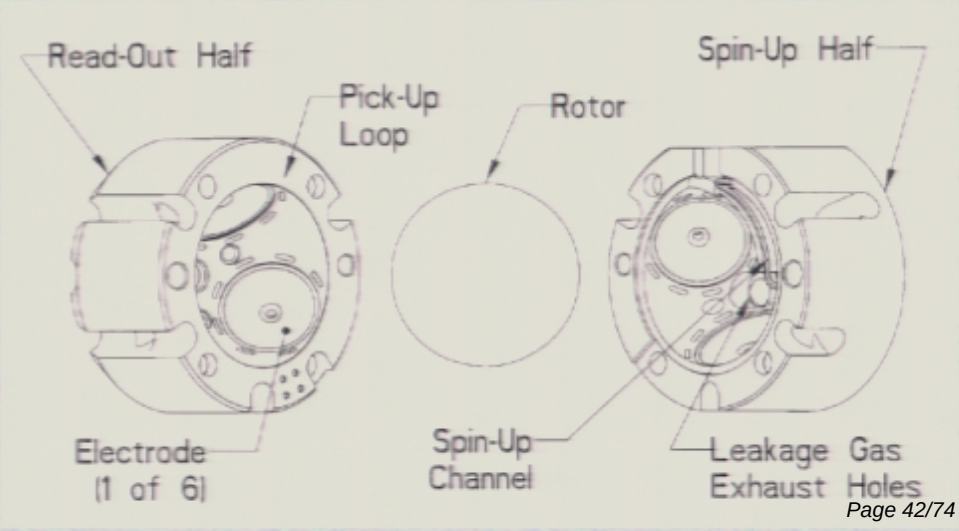
Goal 0.4 mas/yr

Launch April 20, 2004

Mission ends Sept 2005

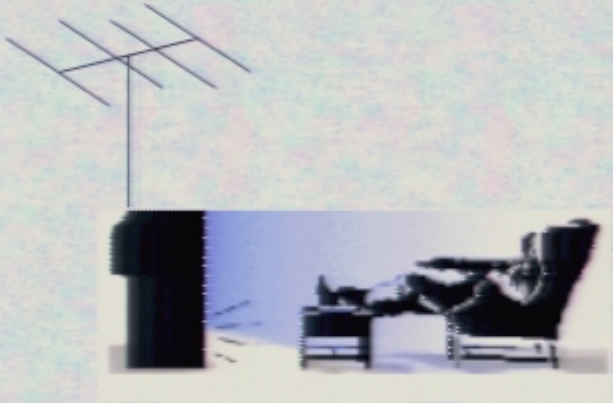
Gravity Probe B: The Experiment -- Gyroscopes



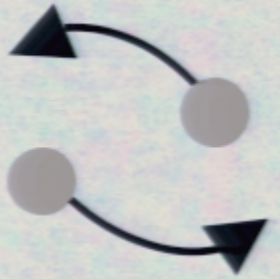


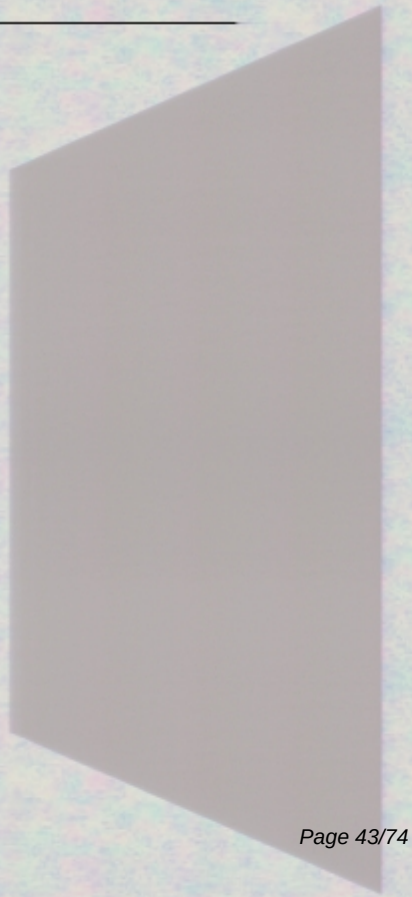
The Search For Gravitational Waves

Electro-Magnetic Waves (light)



Gravita-tional Waves





The Search For Gravitational Waves

Electro-Magnetic Waves (light)

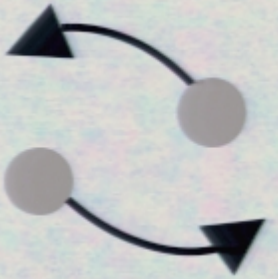
Gravita-tional Waves

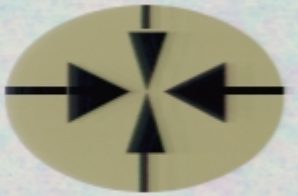
The Search For Gravitational Waves

Electro-Magnetic Waves (light)

Hertz 1887; practical uses

Gravita-tional Waves





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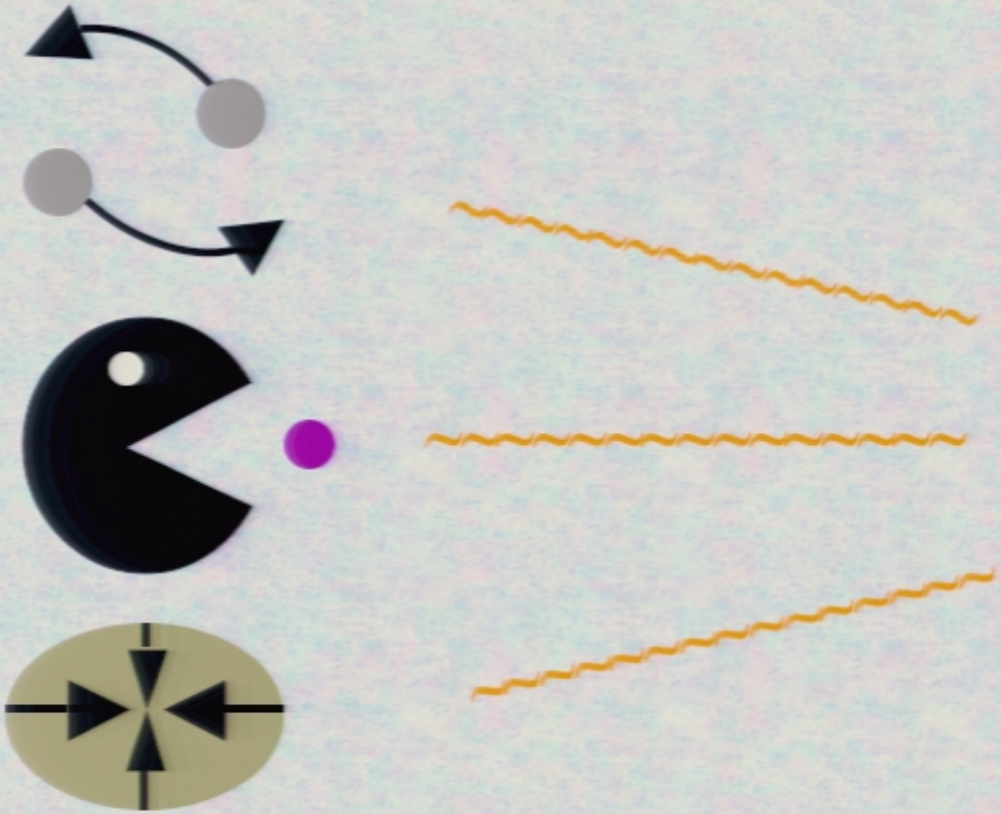

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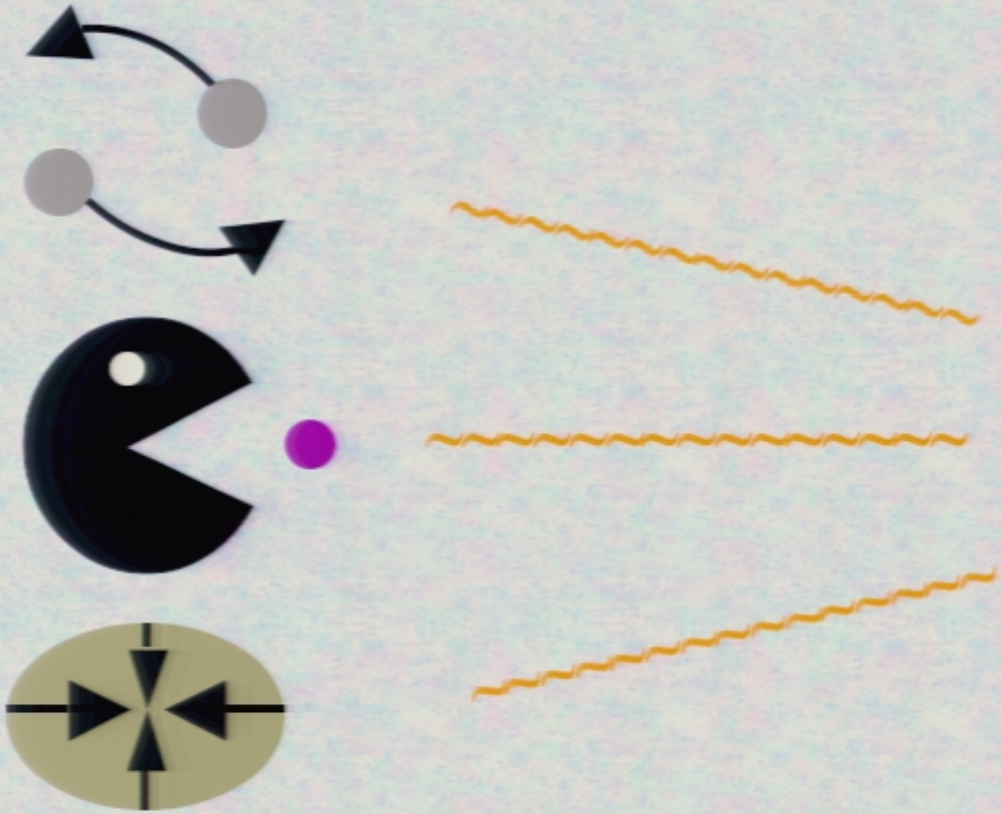

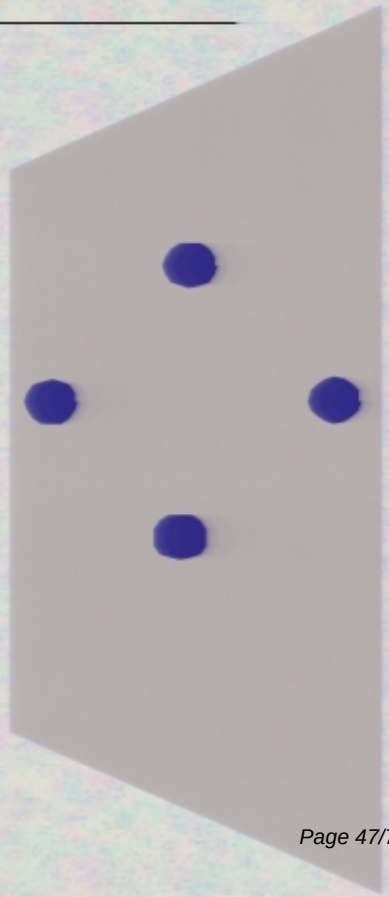

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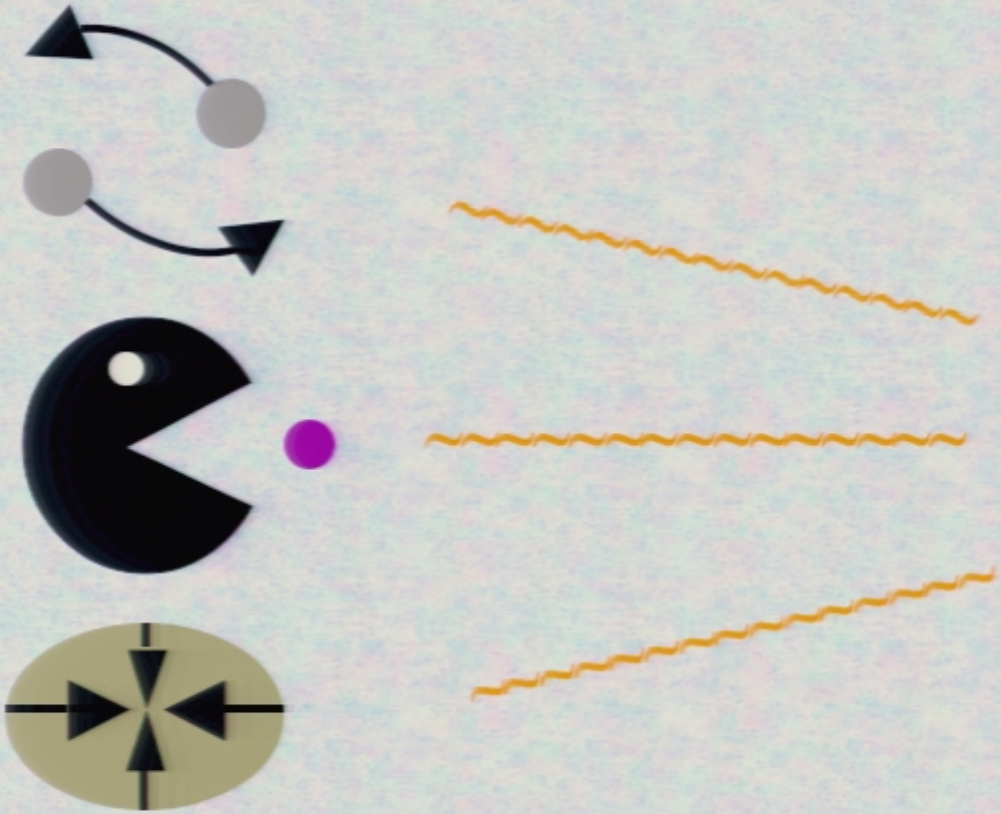

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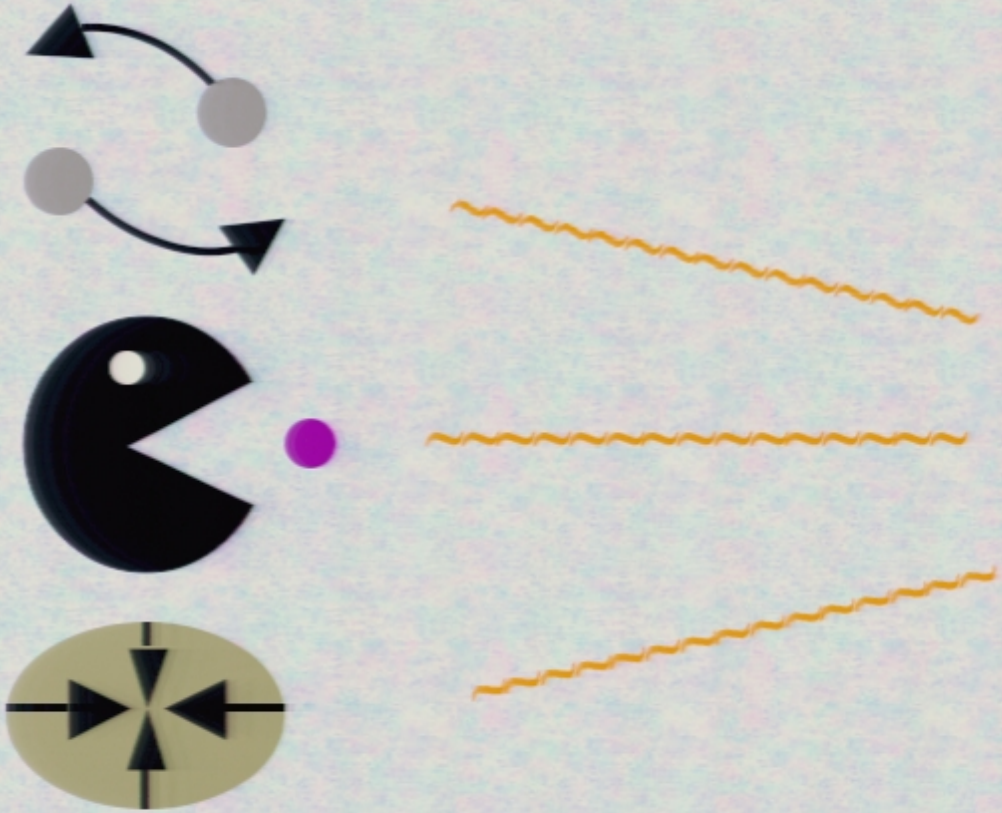

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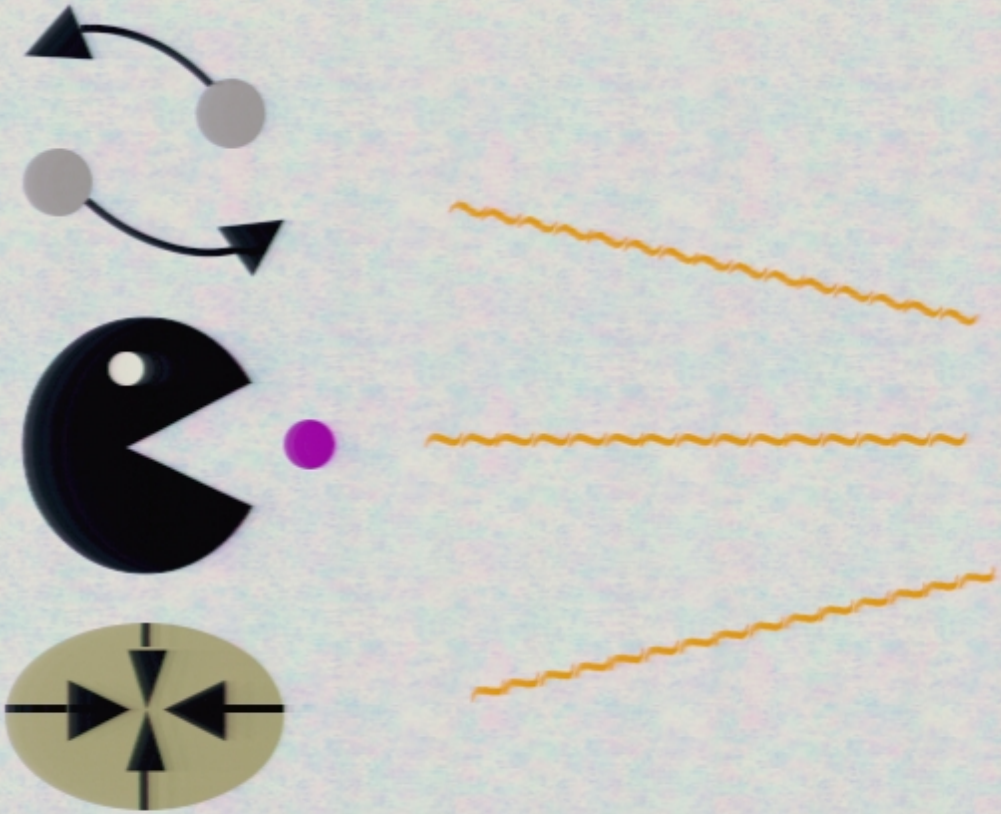

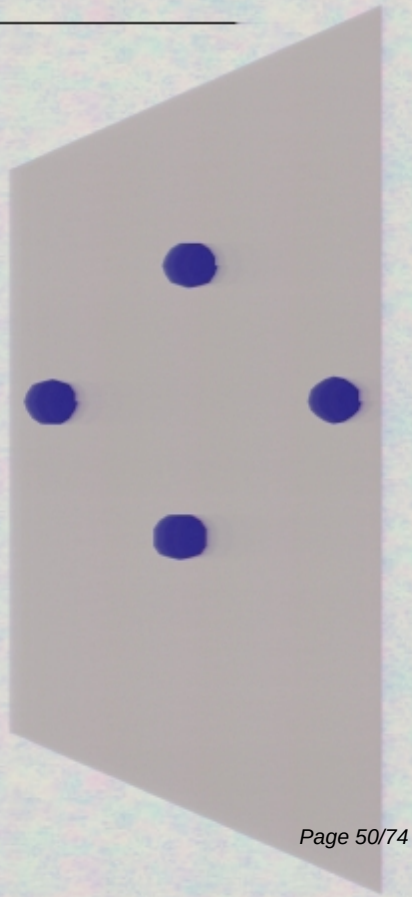

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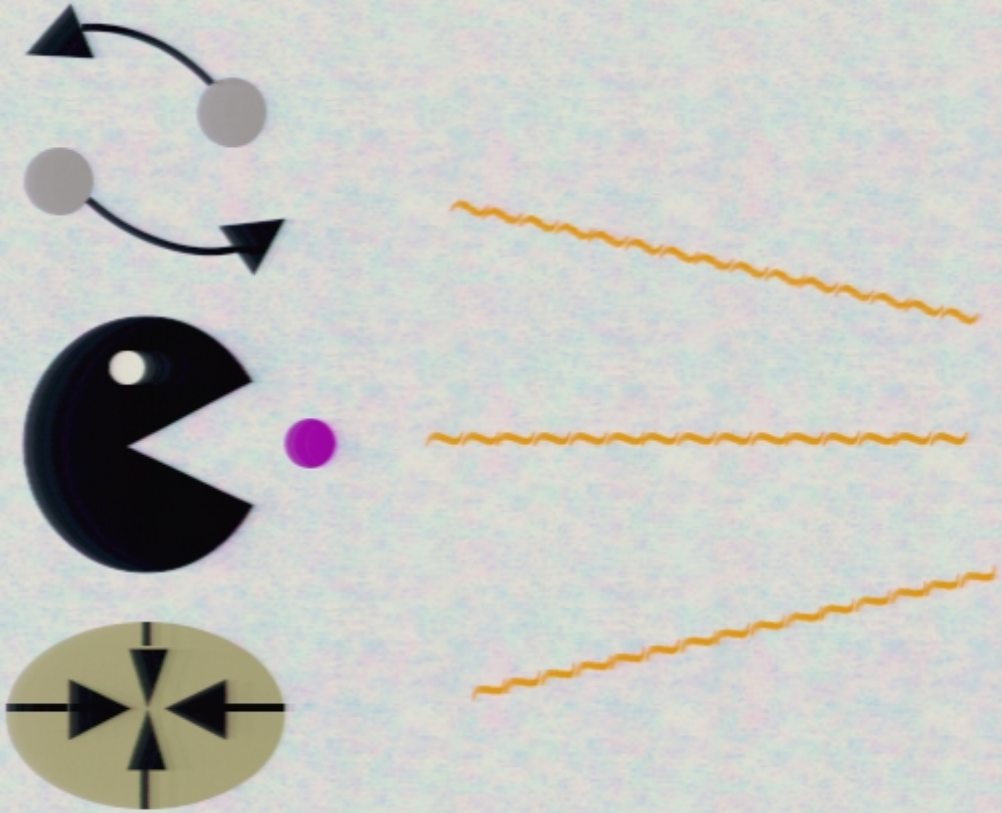

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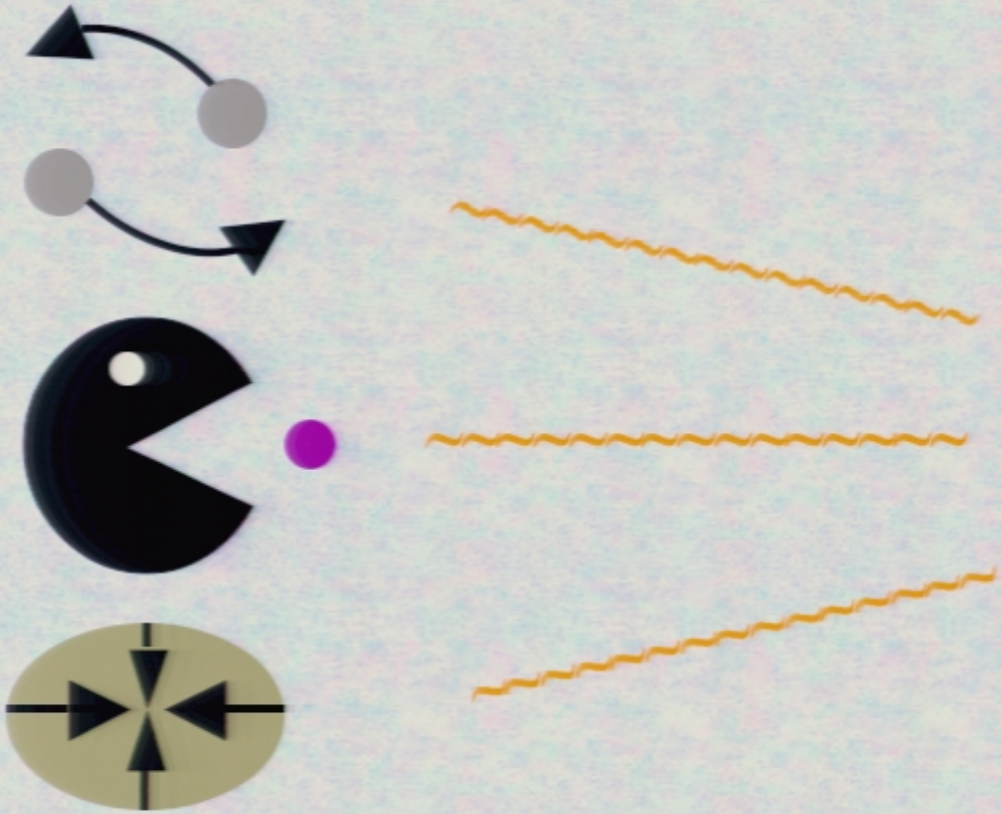

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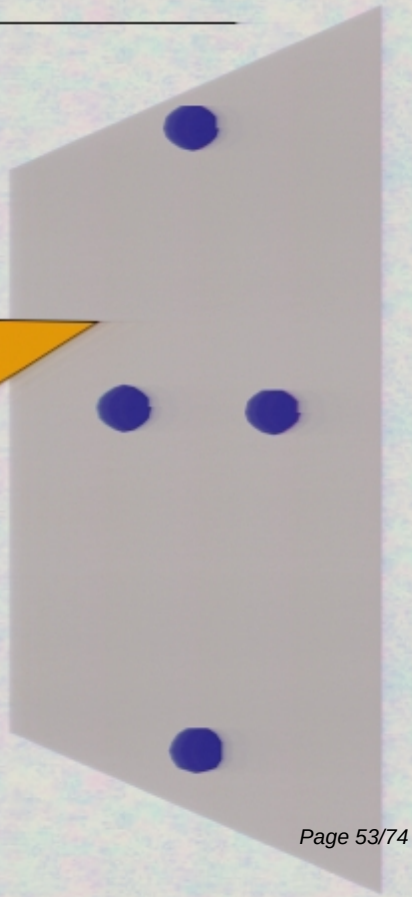
Gravita-tional Waves

Collapse or merger in our galaxy causes change in a 1 m antenna of 1/1000 diameter of an atomic nucleus



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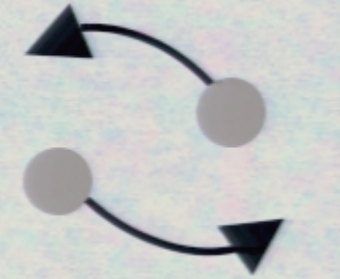


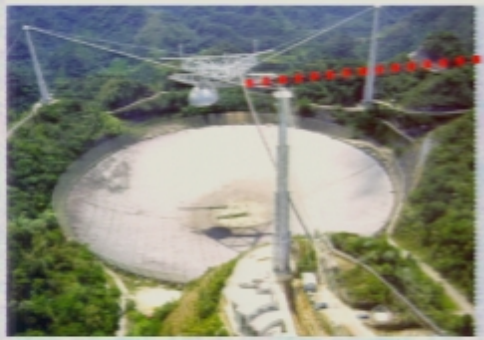
No direct detection
As of today, but ...

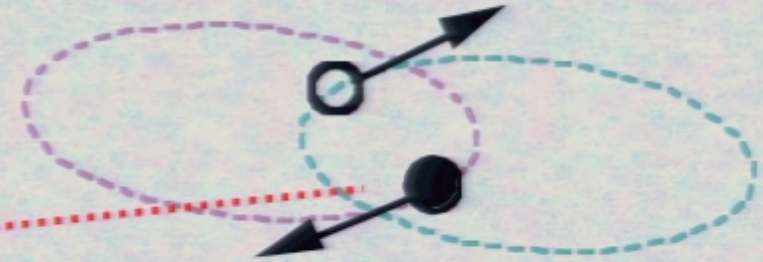
The Binary Pulsar: Gravitational Waves Exist!

Discovery: 1974

Pulse period: 59 ms (16cps)

Orbit period: 8 hours





$P_p = 0.059029997929883 \pm 7$ sec

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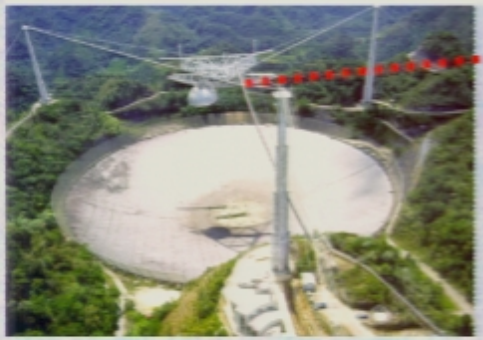

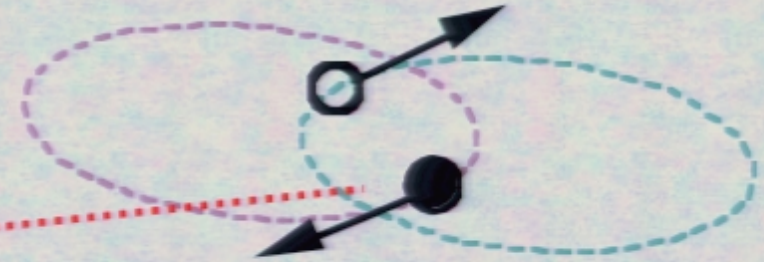

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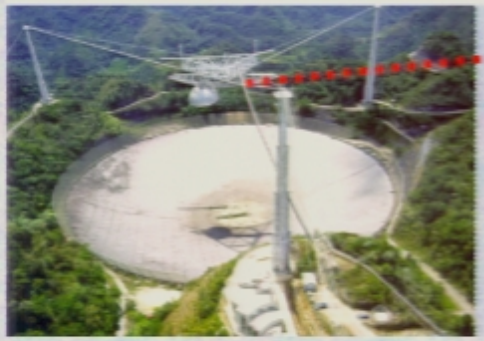

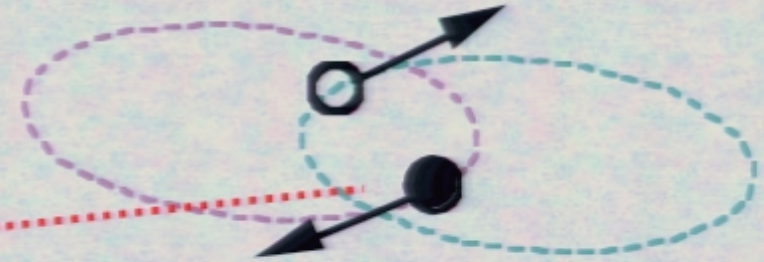

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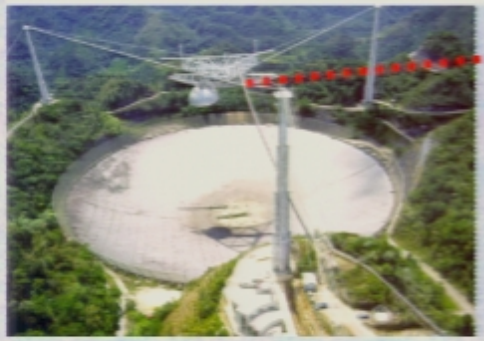

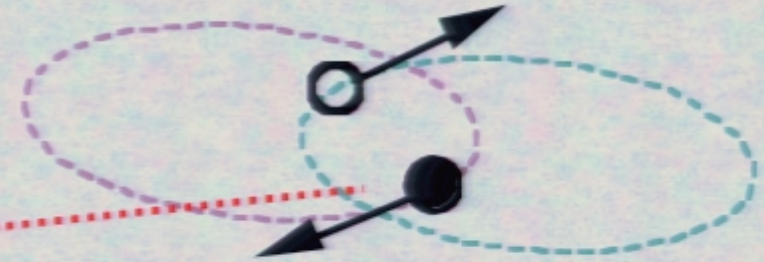

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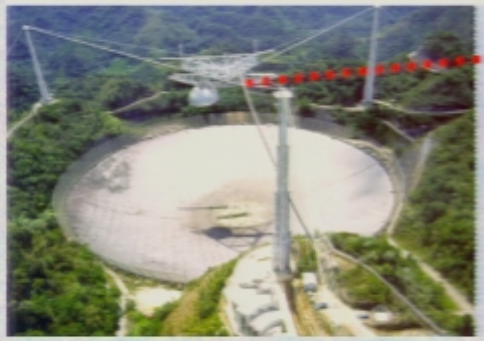

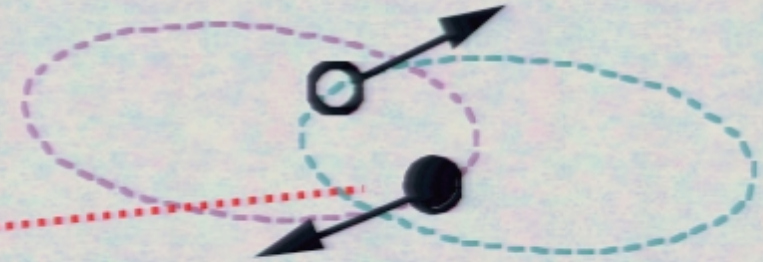

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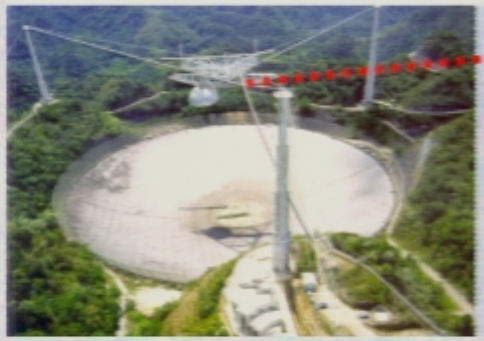

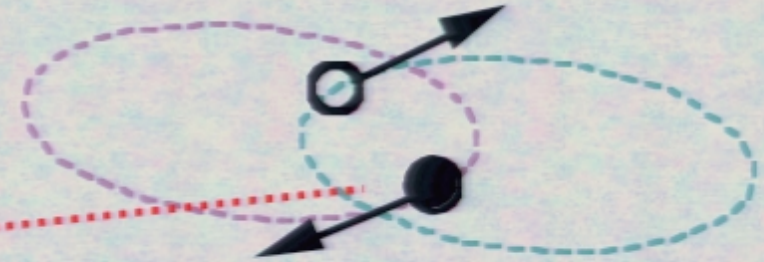

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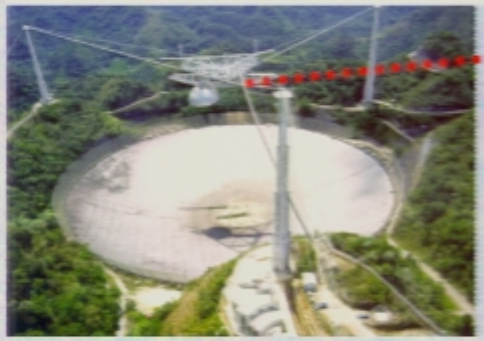

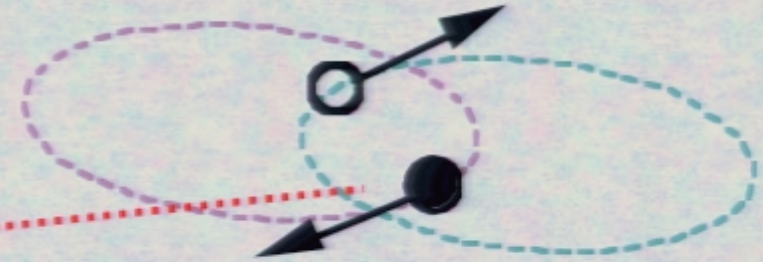

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- Observed rate

  0.0000759 ± 2 seconds/year

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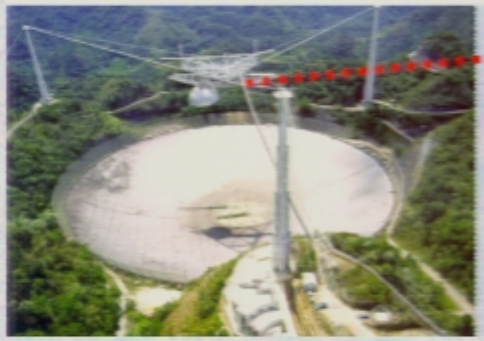

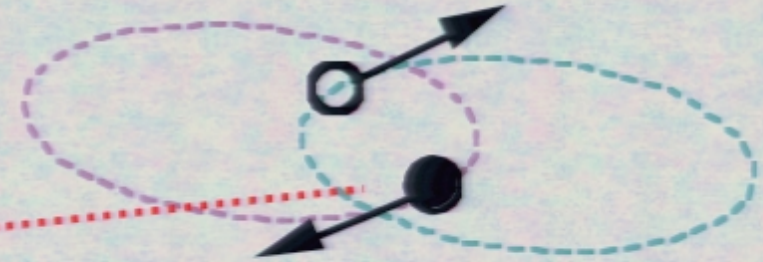

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1993 Nobel Prize to Joe Taylor & Russell Hulse

Interferometers Around The World

LIGO Hanford 4&2 km

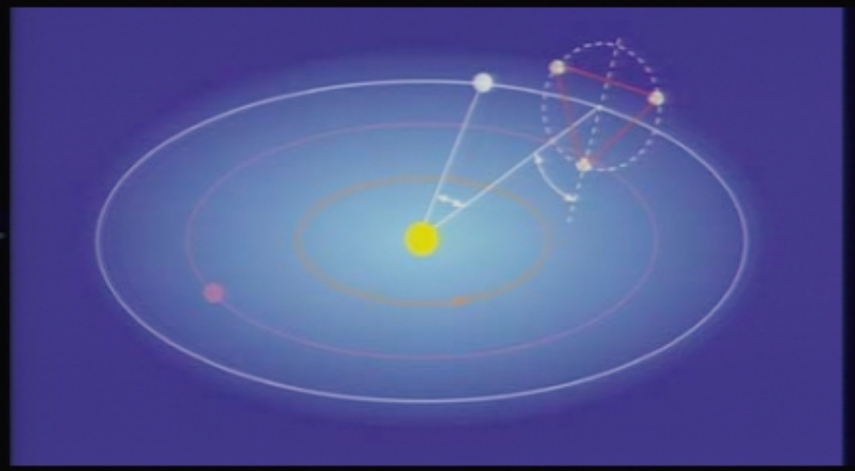
GEO Hannover 600 m

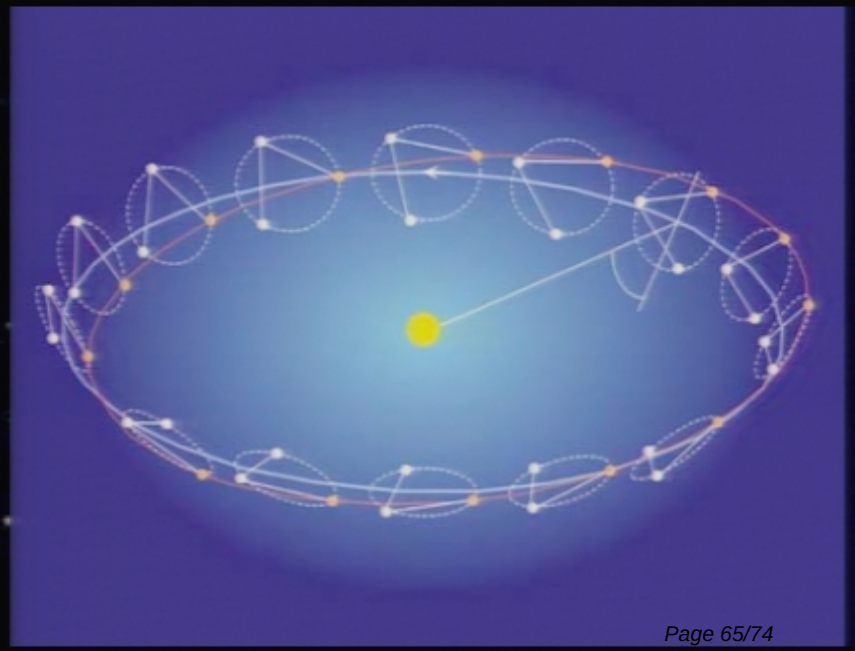
LIGO Livingston 4 km

Virgo Cascina 3 km

TAMA Tokyo
300 m

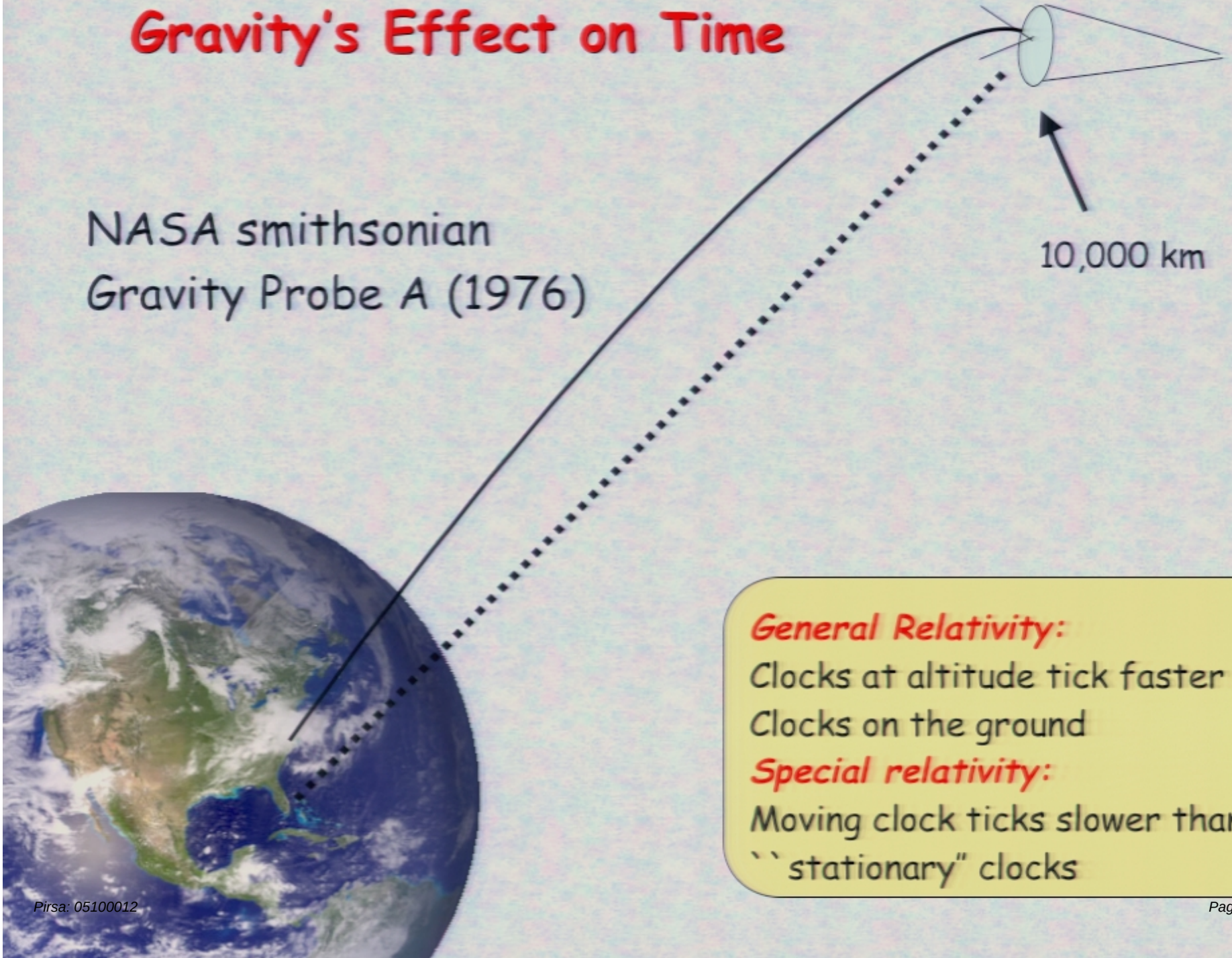
LISA: a space interferometer for 2013





Gravity's Effect on Time

NASA smithsonian
Gravity Probe A (1976)

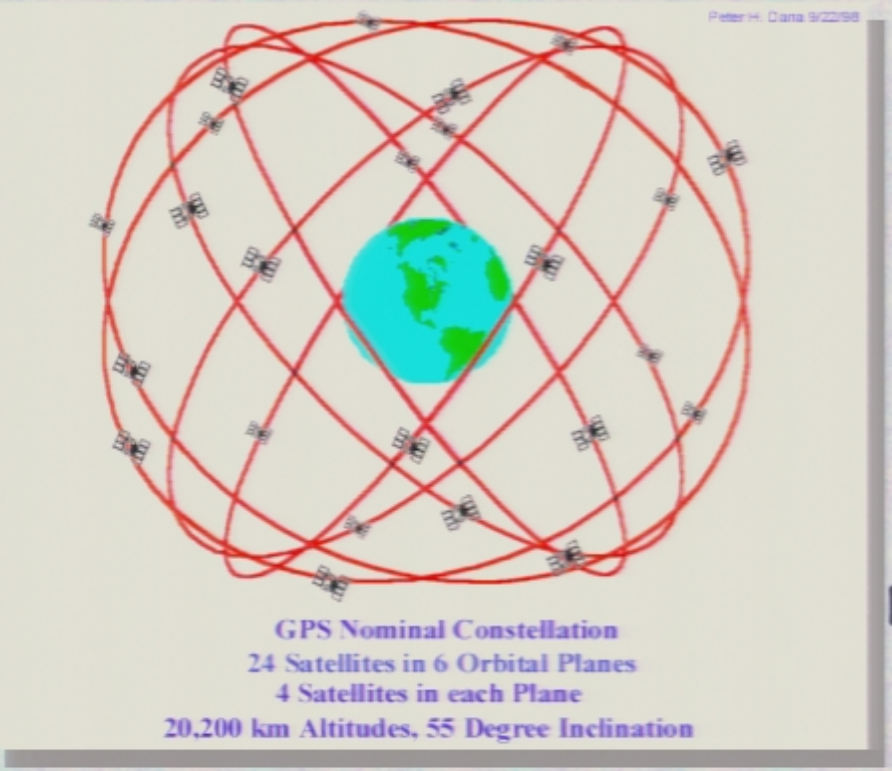


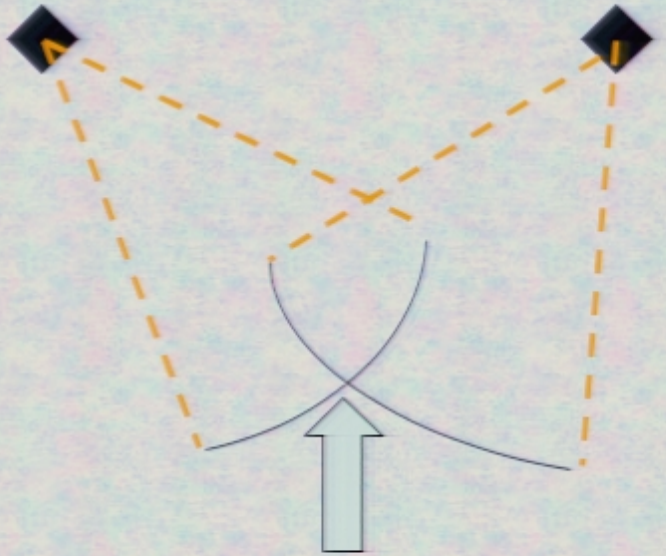
General Relativity:
Clocks at altitude tick faster than
Clocks on the ground

Special relativity:
Moving clock ticks slower than
``stationary'' clocks

General Relativity and Daily Life

The Global Positioning System (GPS)





Navigation Requirement: 15 m ⇨ 50ns

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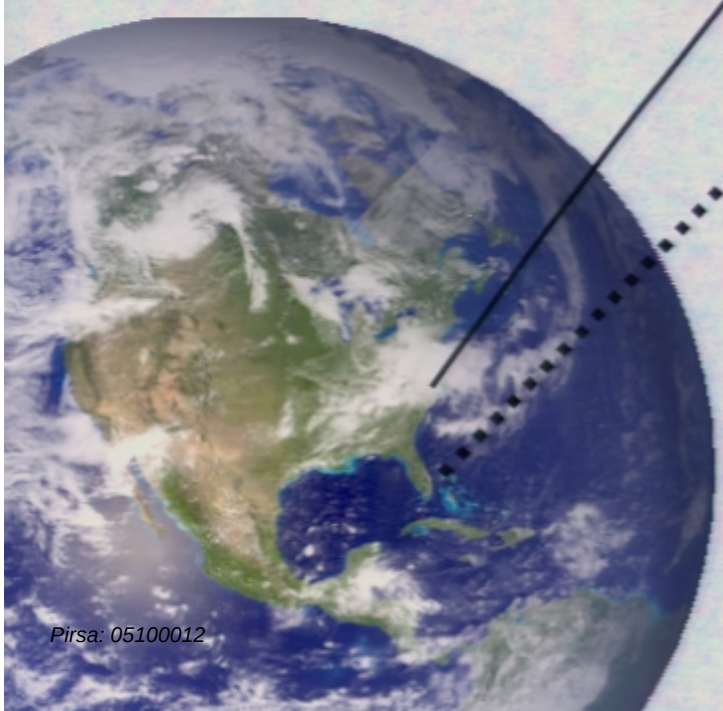

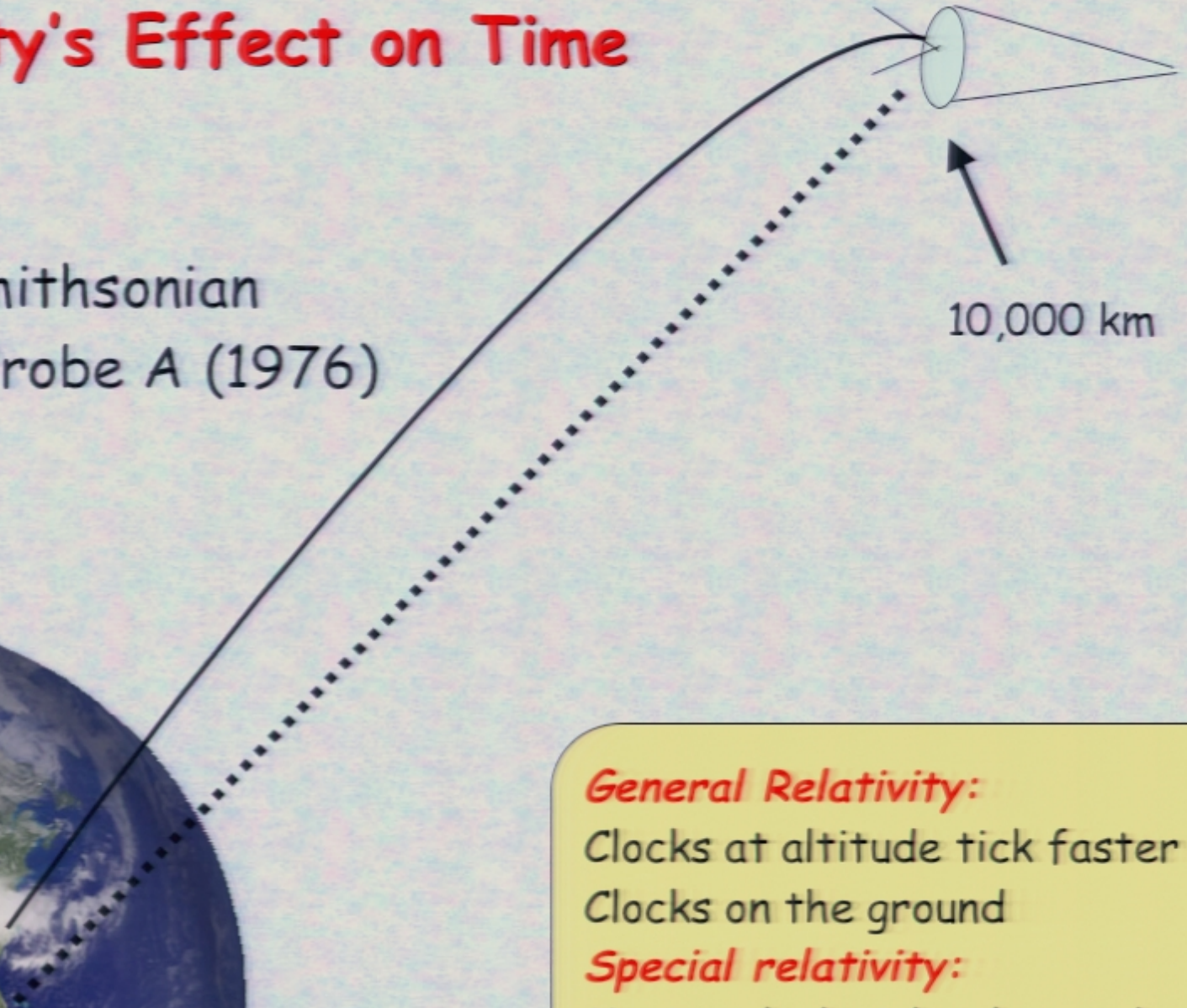

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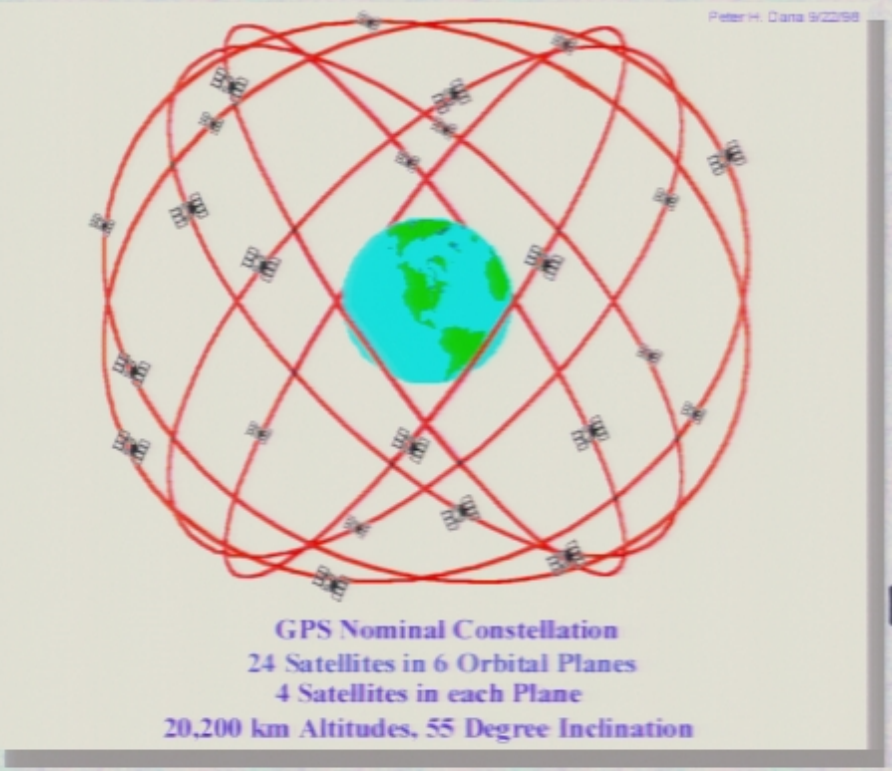

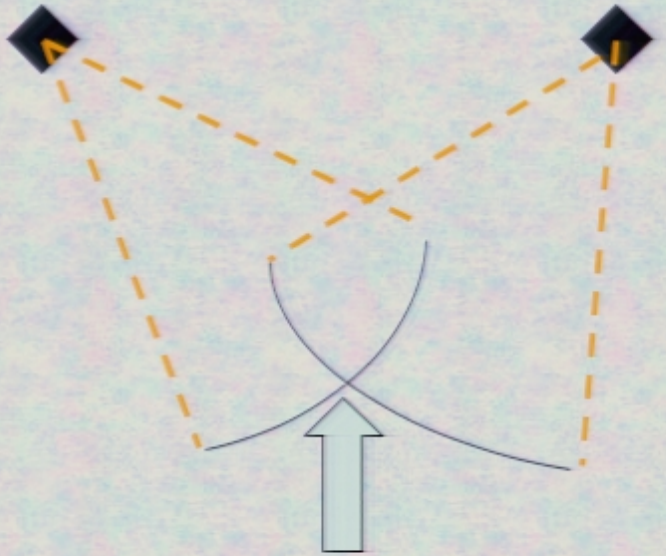

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General Relativity and Daily Life

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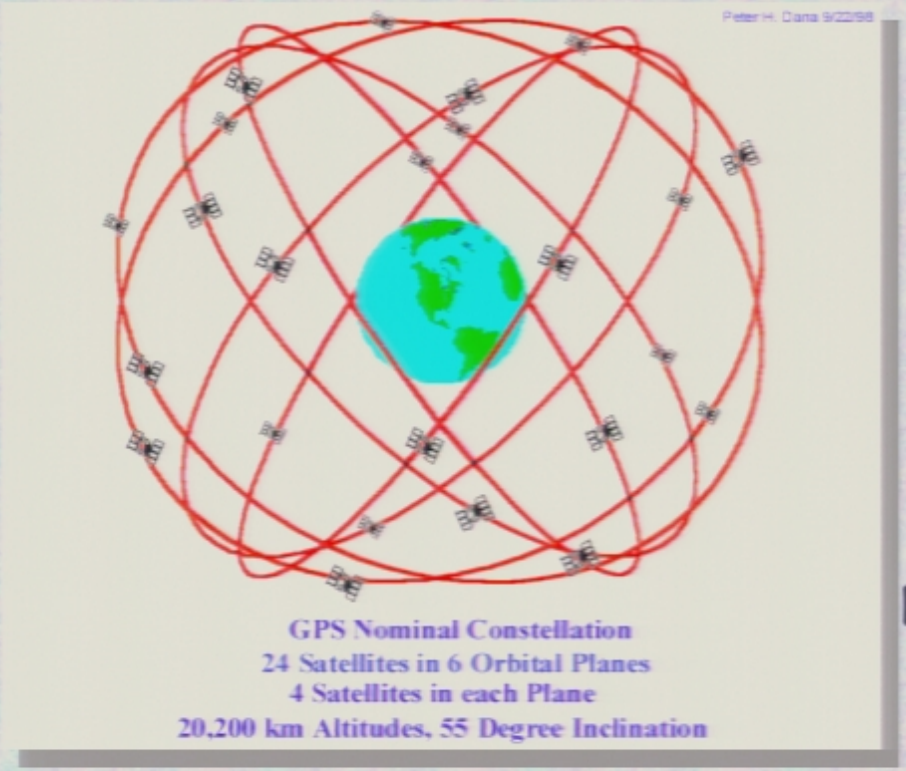

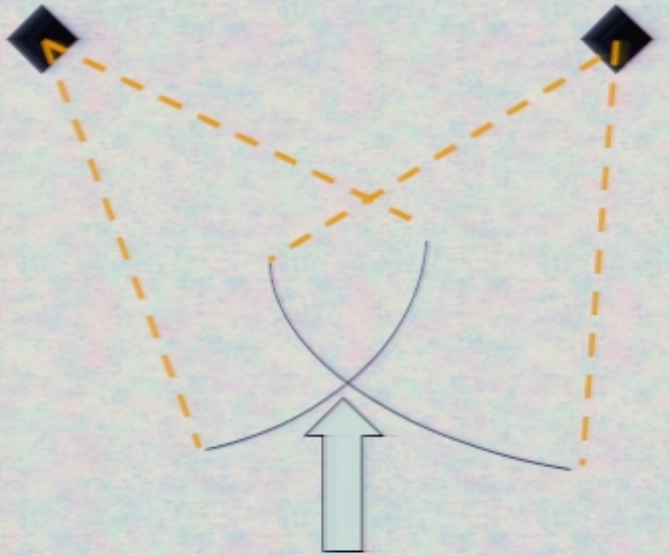

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Relativistic effects: 39,000 ns per day!

GR = 46,000 SR = -7,000

General Relativity and Daily Life

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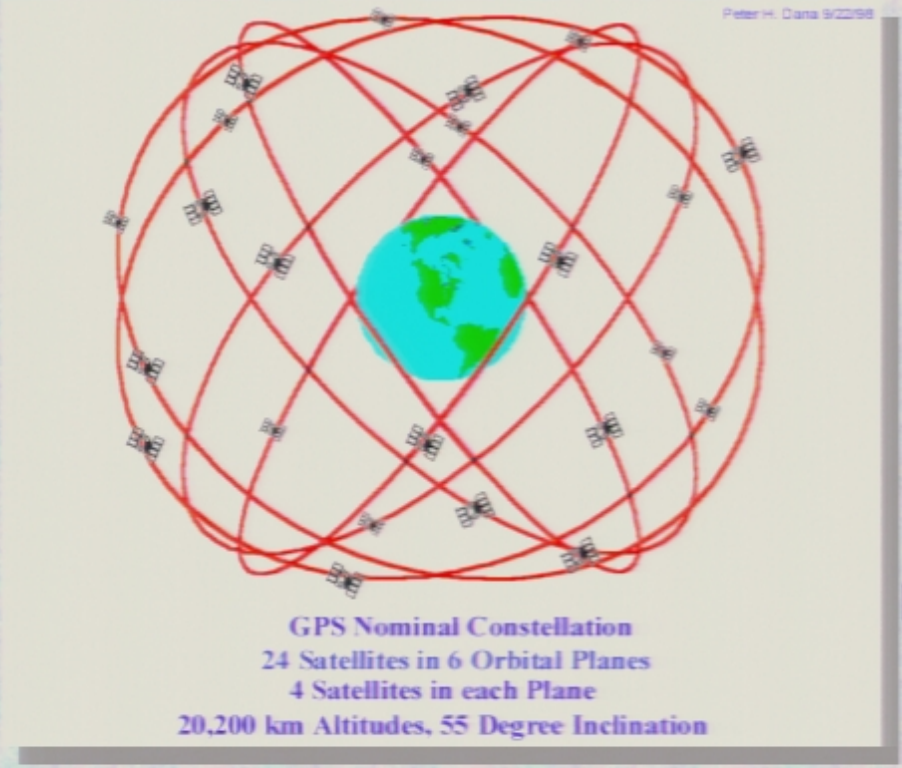

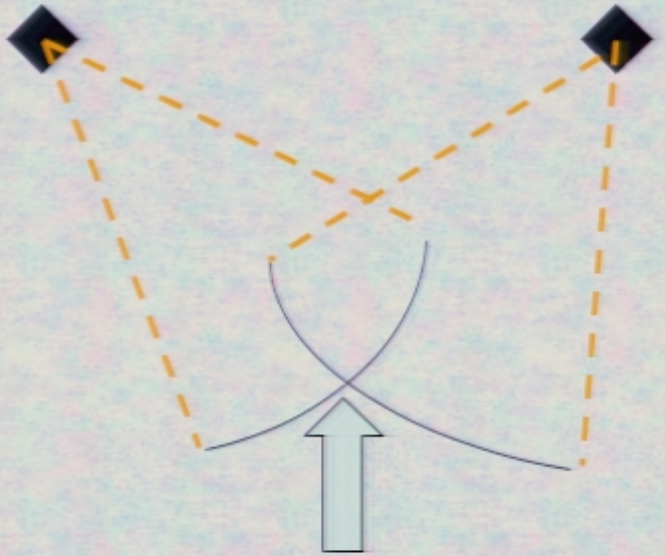

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Relativity **must** be taken into account, for GPS to function

Was Einstein Right?

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- PUTTING GENERAL RELATIVITY TO THE TEST
  - Light's Departure from the Straight and Narrow
  - Mercury's Perihelion: From Trouble to Triumph
  - Does Spacetime do the Twist?
  - The Search for Gravity Waves
  - Effect of Gravity on Time:

    Einstein and Daily Life
- EPILOGUE