

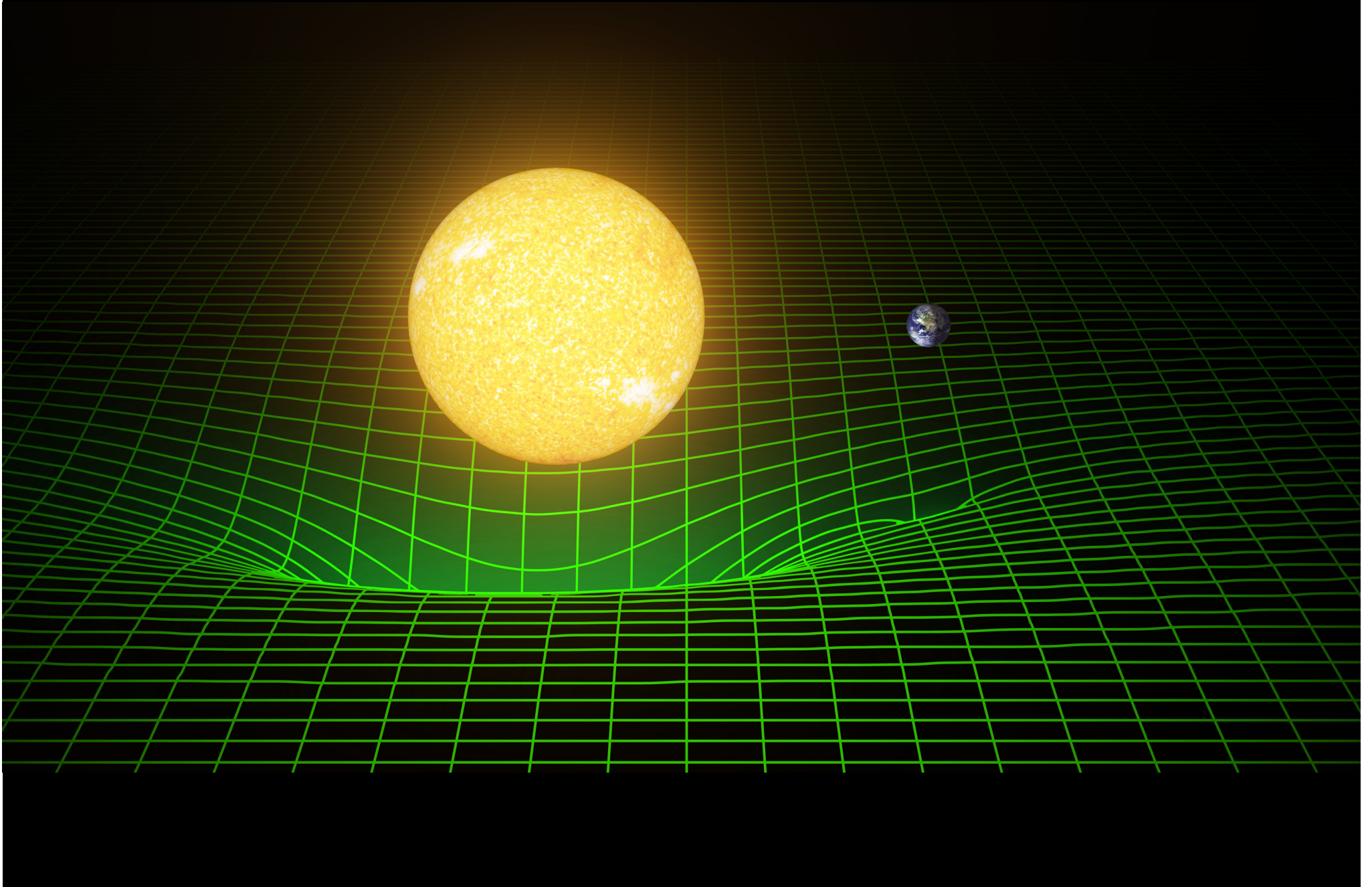


Gravitational Waves: A Crash Course

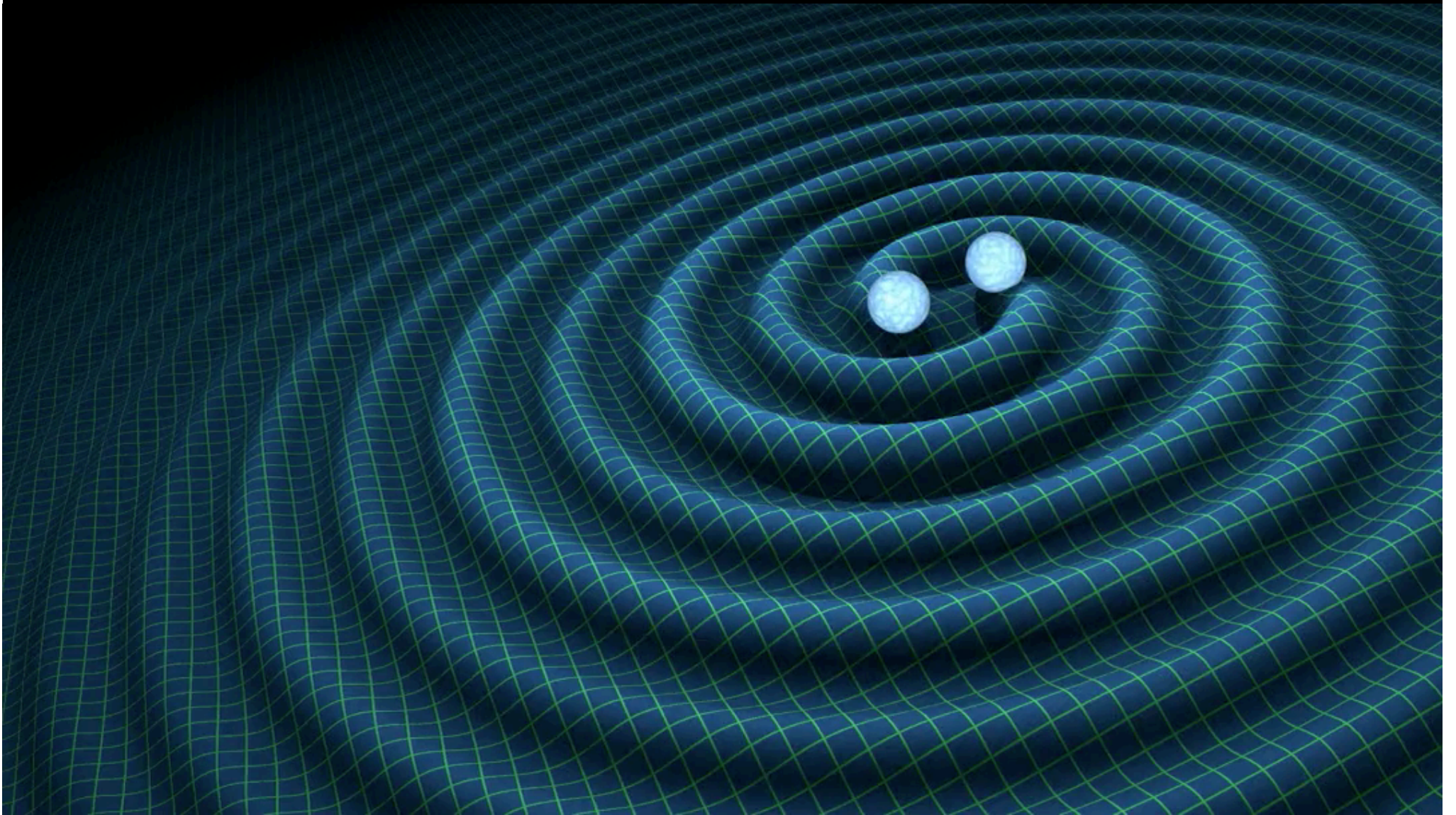
Patrick Sutton

School of Physics & Astronomy

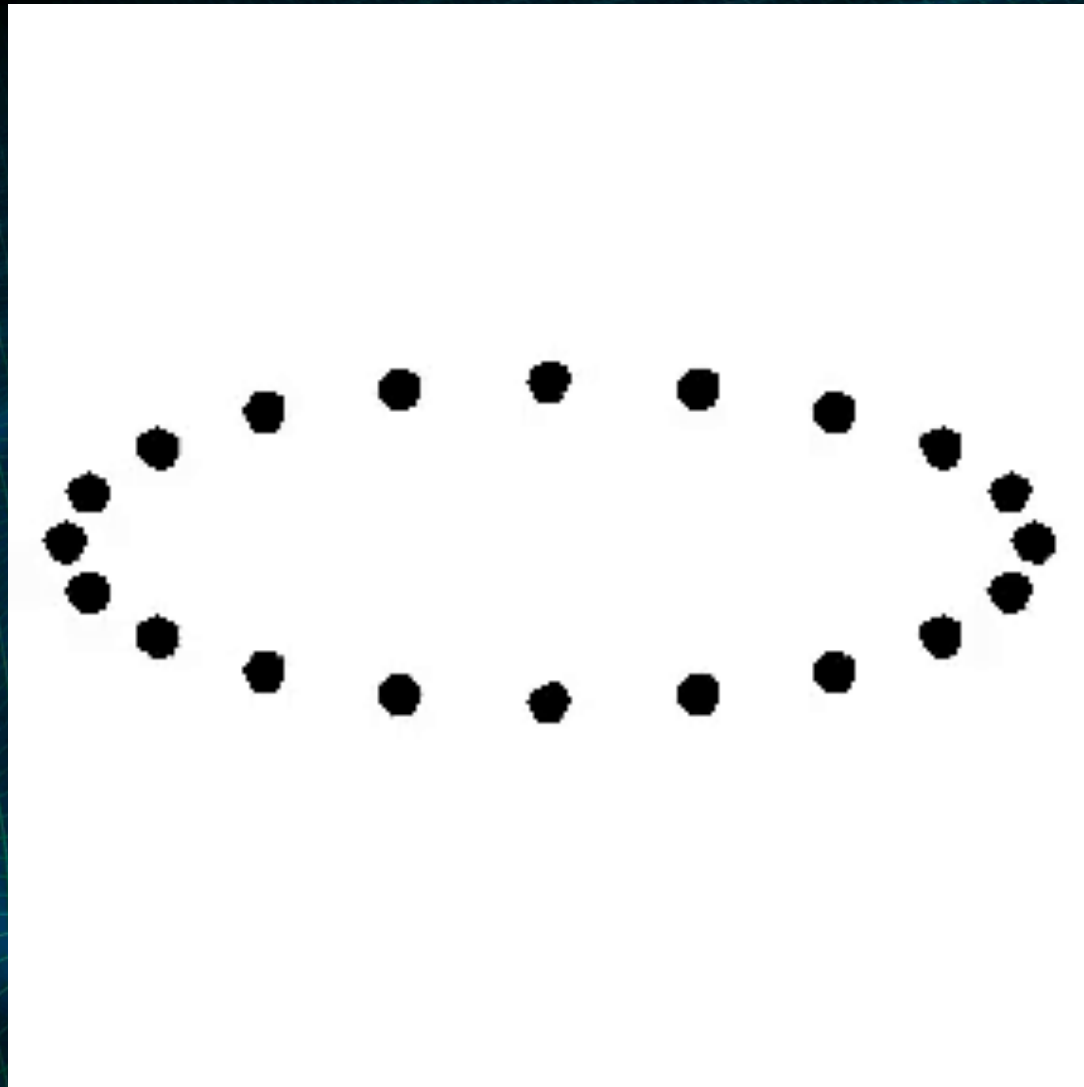
Einstein: gravity = curved spacetime



Accelerating Mass: Gravitational Waves



Accelerating Mass: Gravitational Waves



Space-time is very stiff!

Wave medium	elastic modulus (Gpa)
rubber	0.1
wood	10
steel	200
diamond	1200
spacetime	10^{24}

The Challenge

- Maximum strain from a neutron star binary in a nearby galaxy:

10^{-21}



NASA/Swift/Dana Berry

The Challenge



Sun – Earth 150 million km
distance: (*93 million miles*)

Gravitational
wave stretching: width of 1 atom



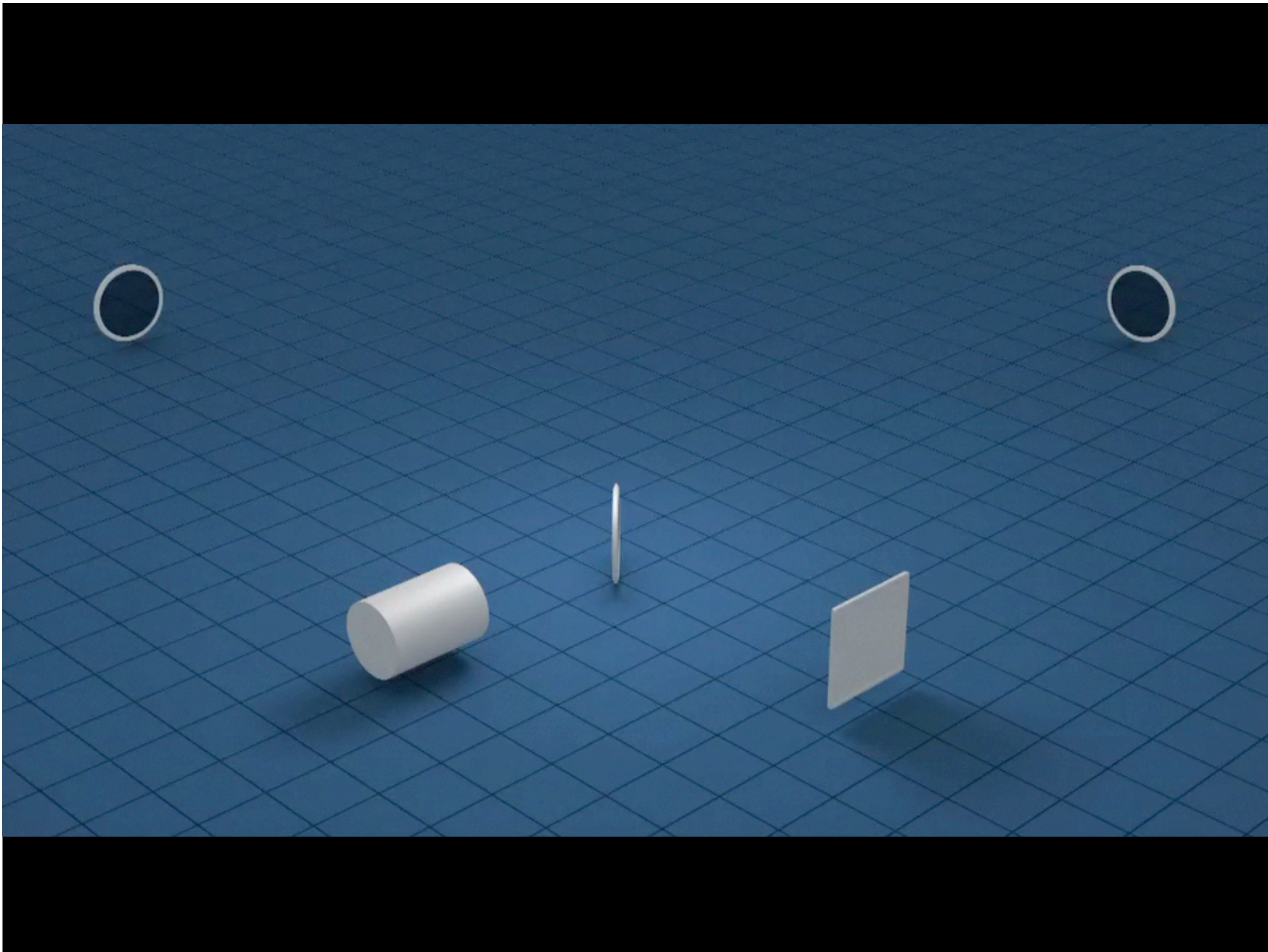
LIGO Hanford Observatory





LIGO Livingston Observatory





The Challenge:
*The GW stretches LIGO's
arms by one part in 10^{21} ...*

LIGO Hanford Observatory

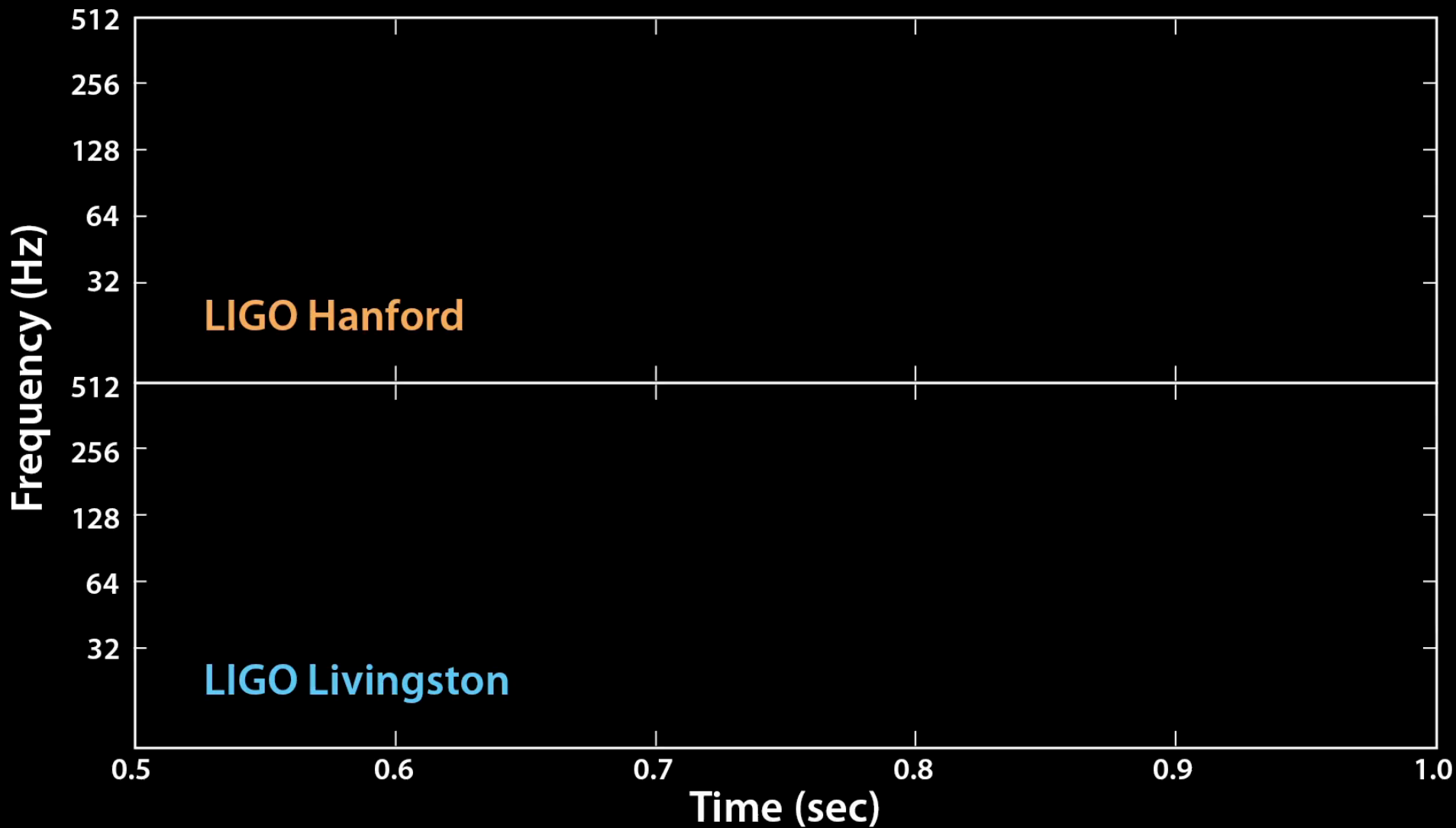


Cutting – Edge Technology



- world's largest high vacuum systems
- sophisticated multi-stage vibration isolation suspension systems
- super-polished, low-absorption mirrors
- big scary lasers!

14 Sept 2015, 09:50:45 UTC





Credit: SXS Lensing

Nature's Biggest Explosions

- Total energy emitted: 2×10^{41} kWh
- Peak luminosity: 3.6×10^{49} W
- All stars in Universe: $\sim 10^{48}$ W

At peak emission, GW150914 emitted more power than all the stars in the observable Universe.



Nobel Prize in Physics



Scientists
Rainer Weiss,
Barry C. Barish
and
Kip S. Thorne
for decisive
contributions to
the LIGO detector and the
observation of gravitational waves

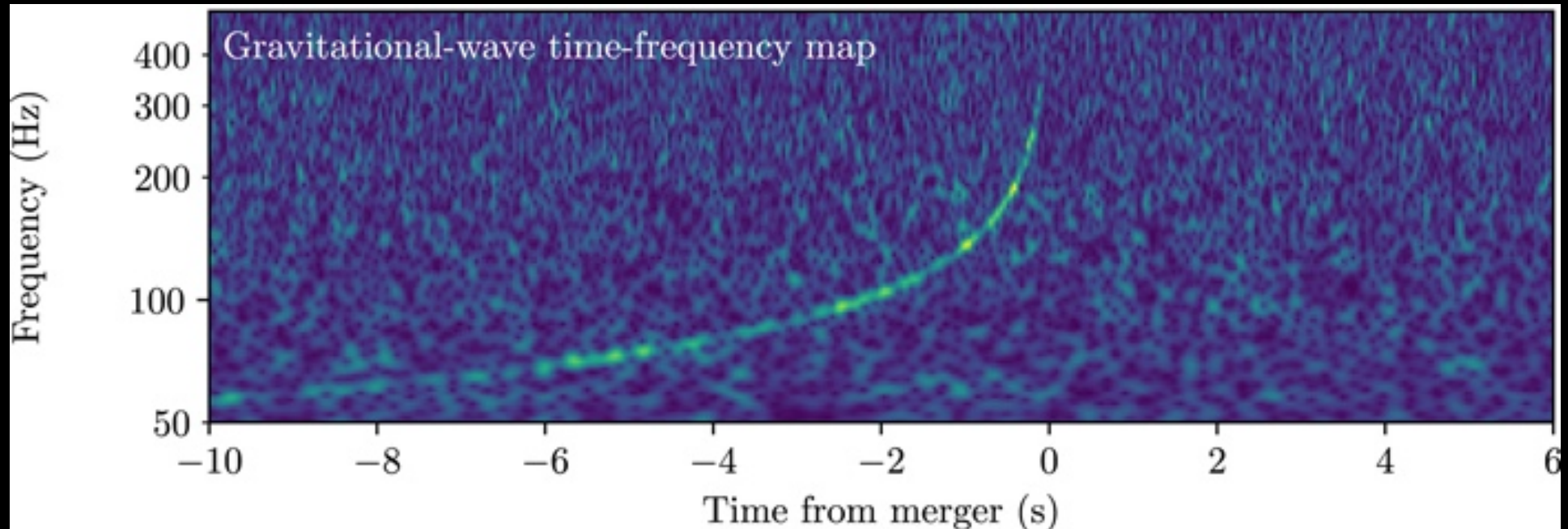


A New Phenomenon ...

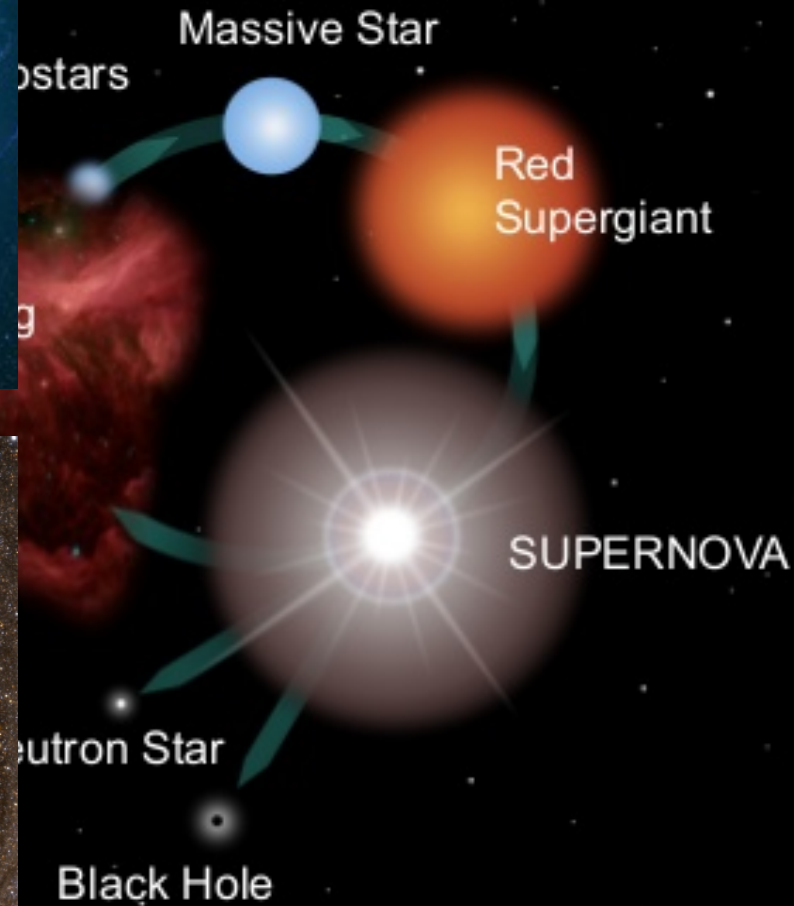


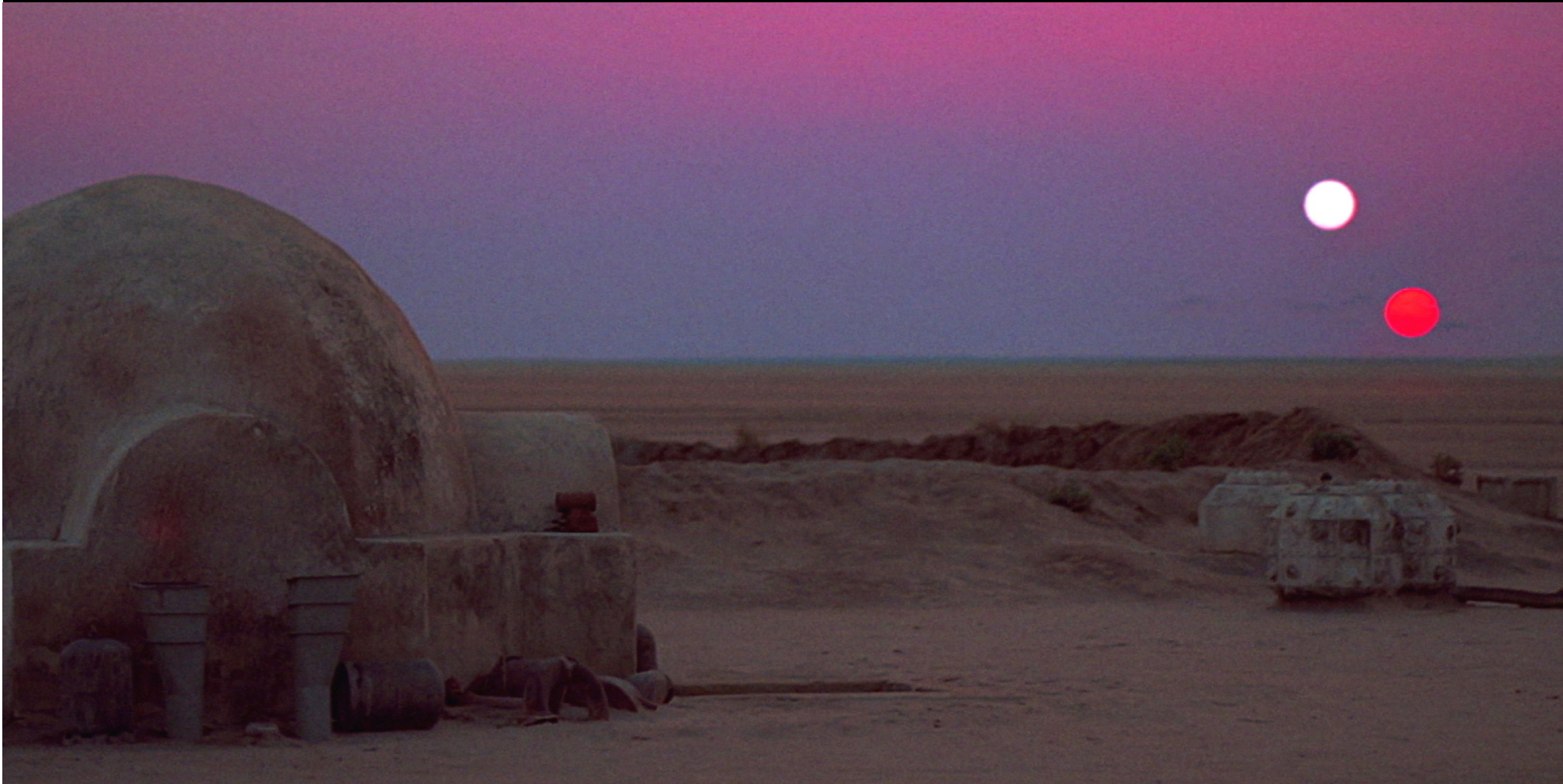


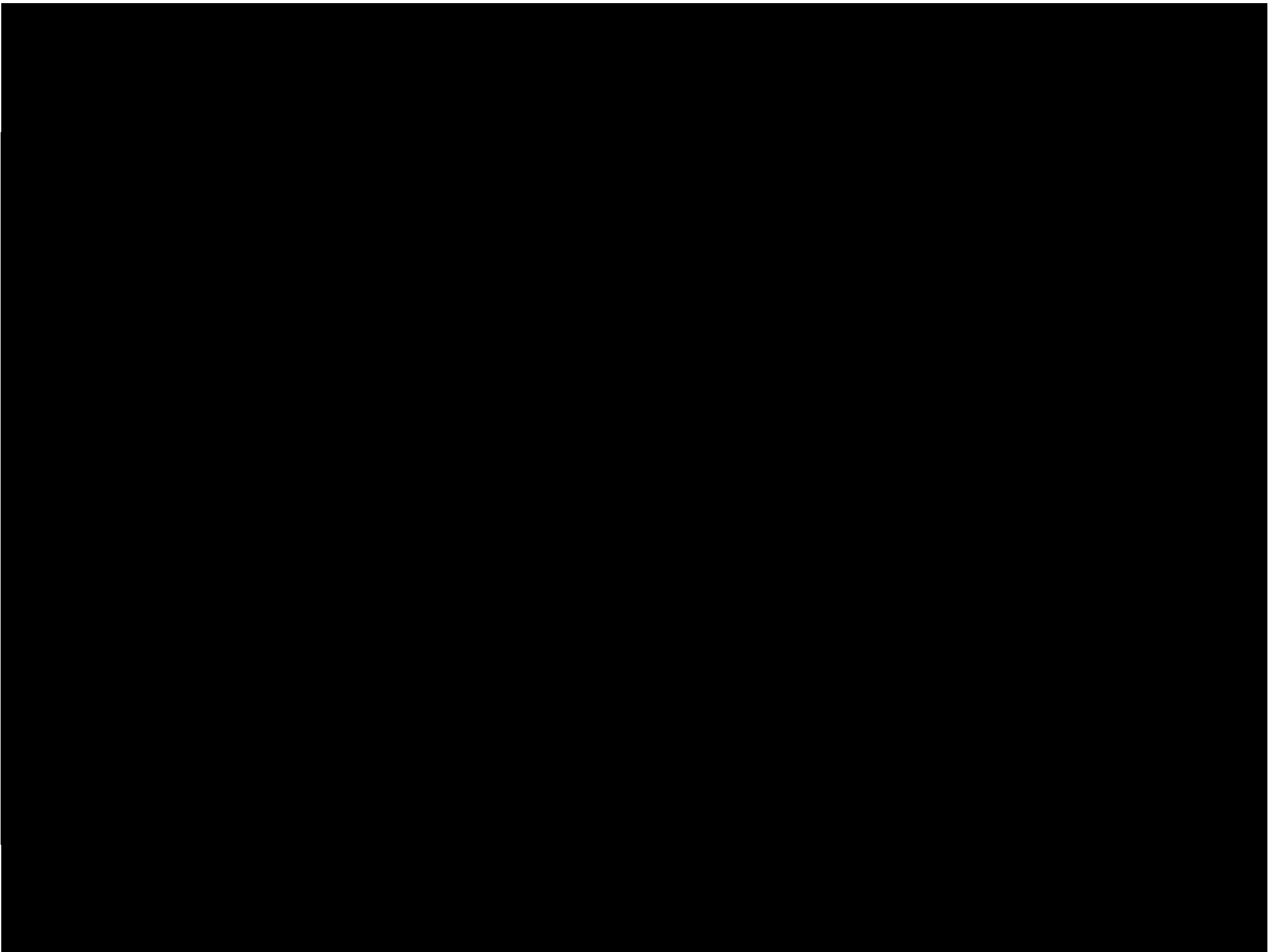
17th Aug 2017, 1:41 pm:



of a Massive Star



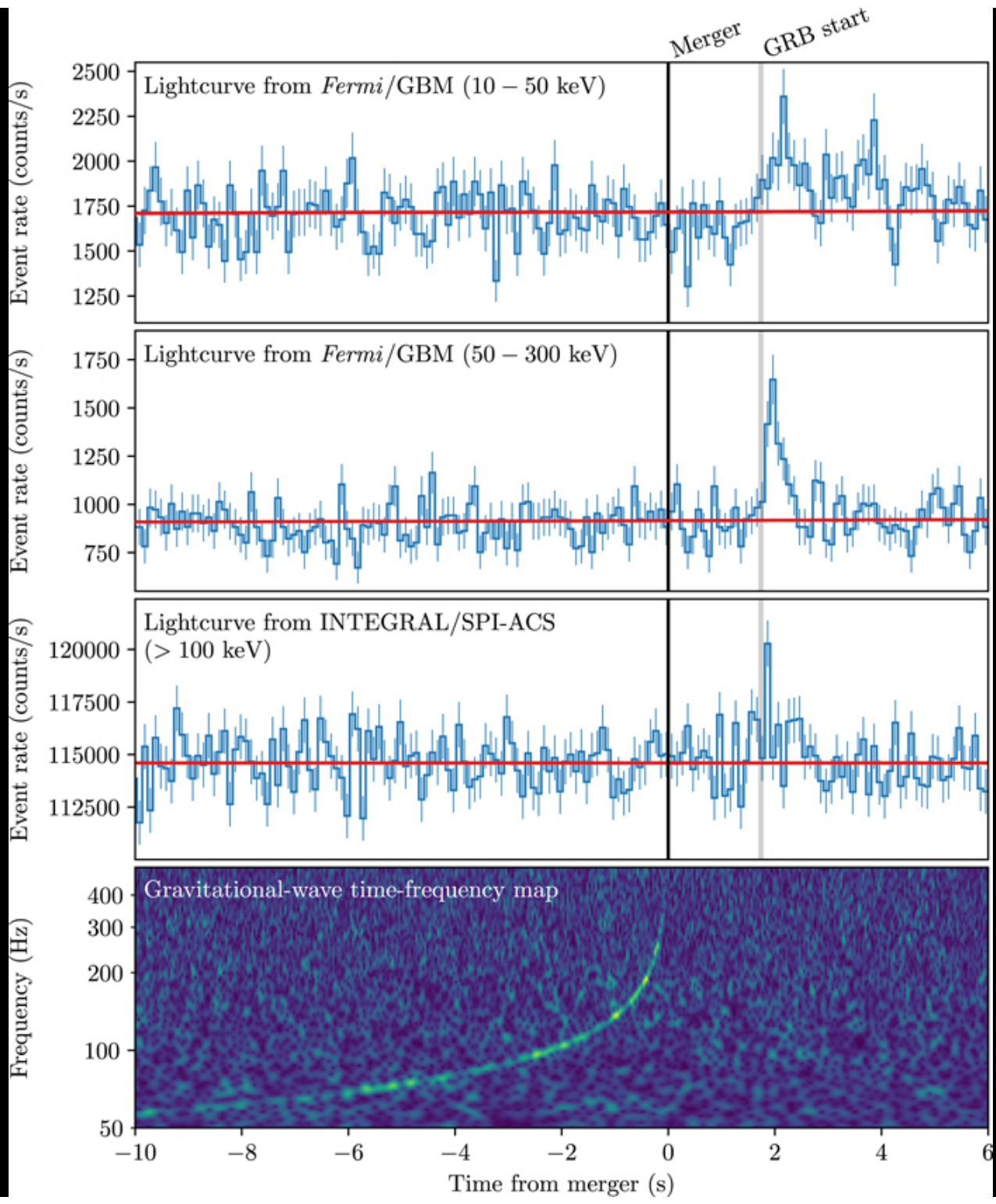




Short Gamma-Ray Bursts

the brightest explosions in the universe

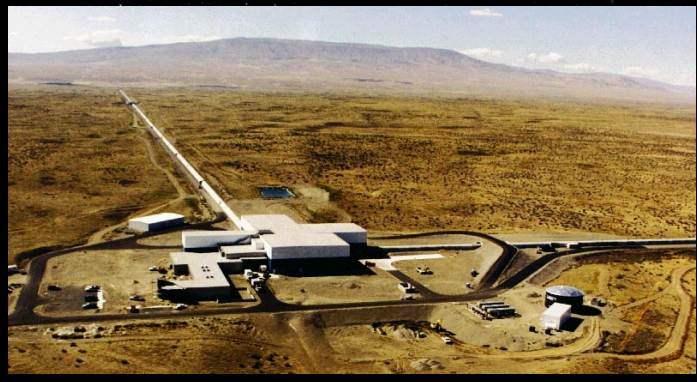
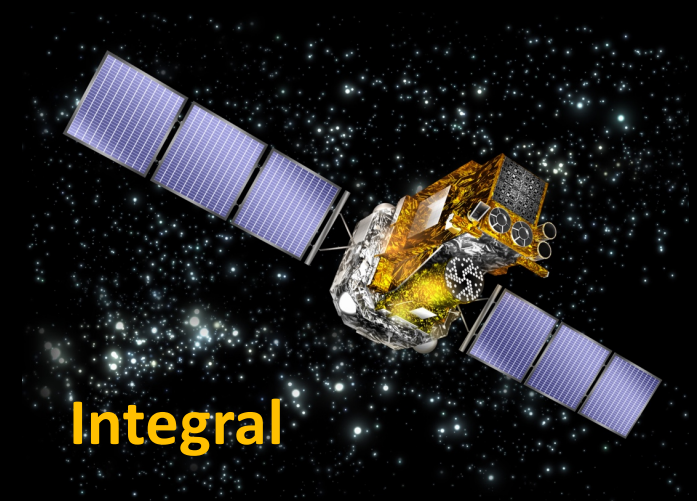




Fermi



Integral





Einstein says

Speed of gravity

----- = 1

Speed of light

Einstein says

Speed of gravity

$$\text{-----} = 1$$

Speed of light

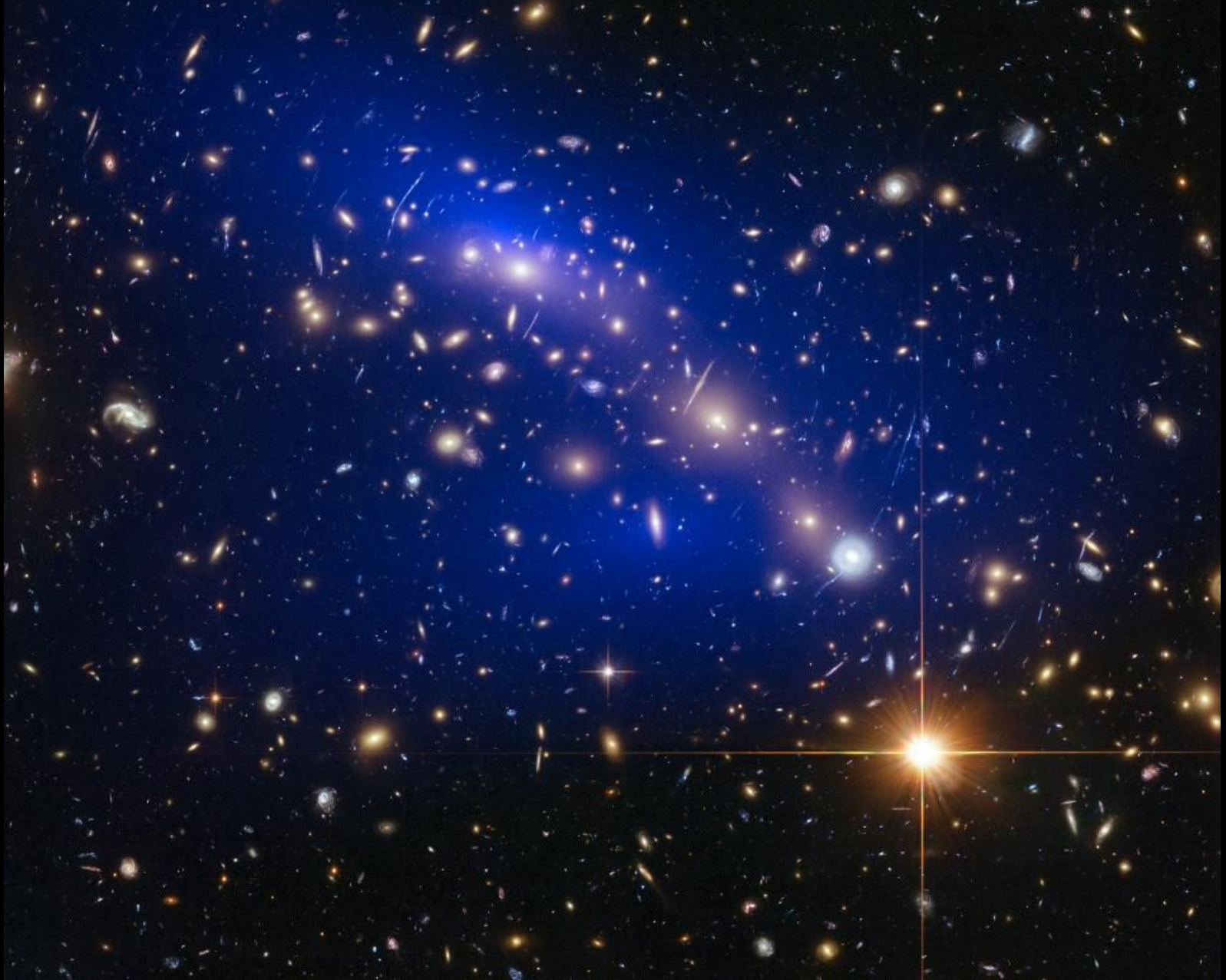
We measured

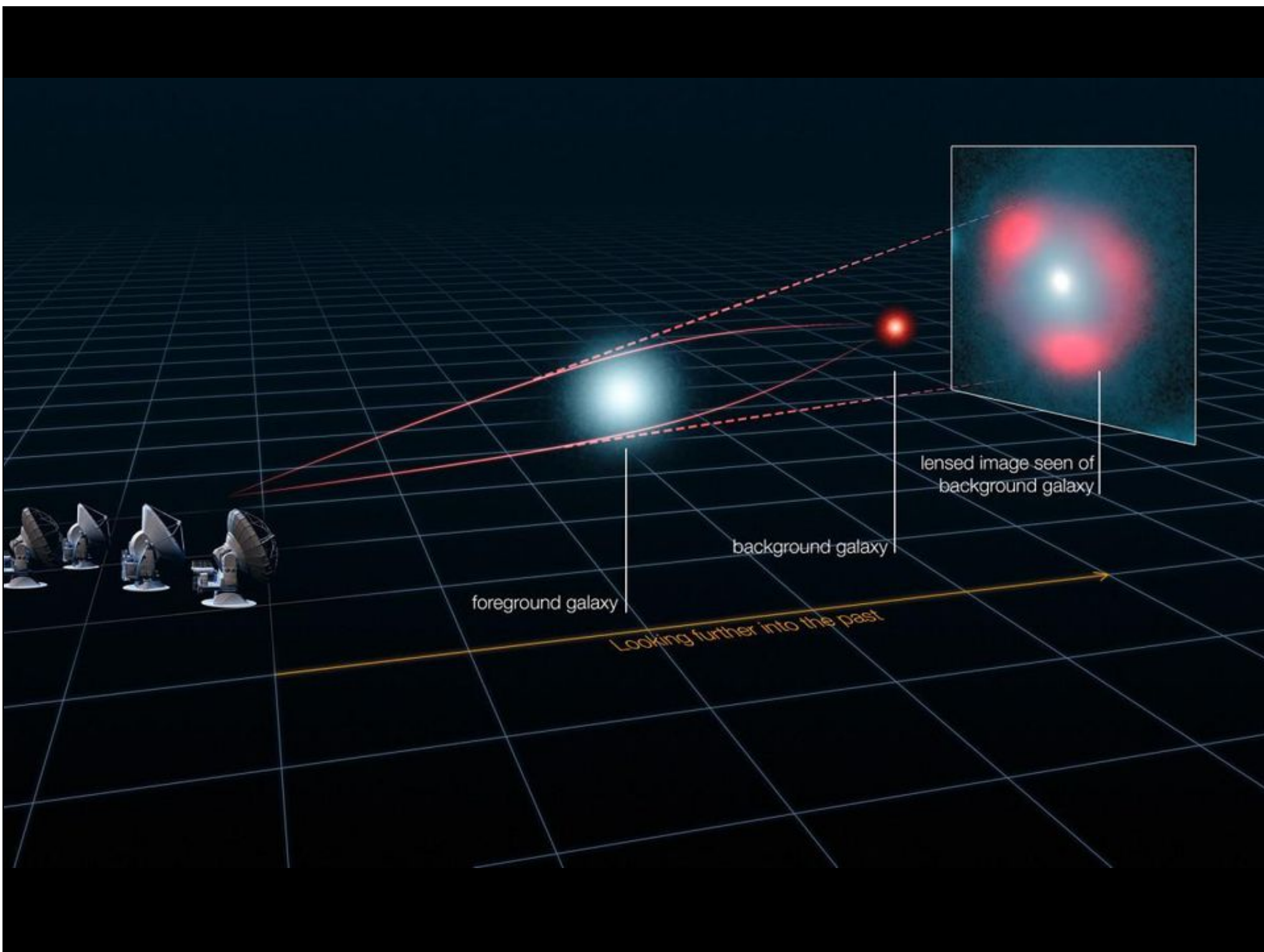
few seconds

$$1 \pm \text{-----} = 1 \pm 0.000000000000000001$$

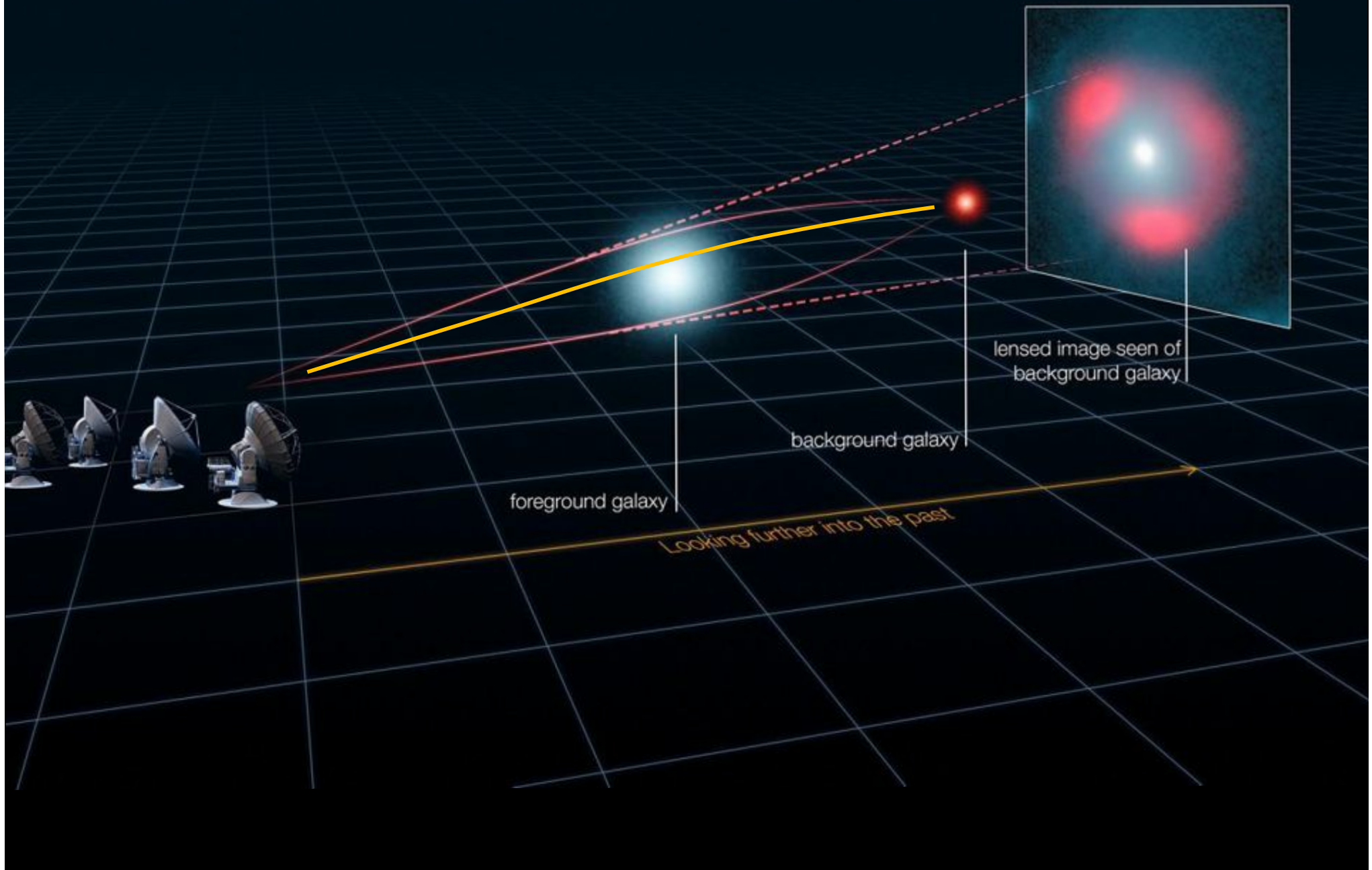
130 million years

More Evidence for Dark Matter



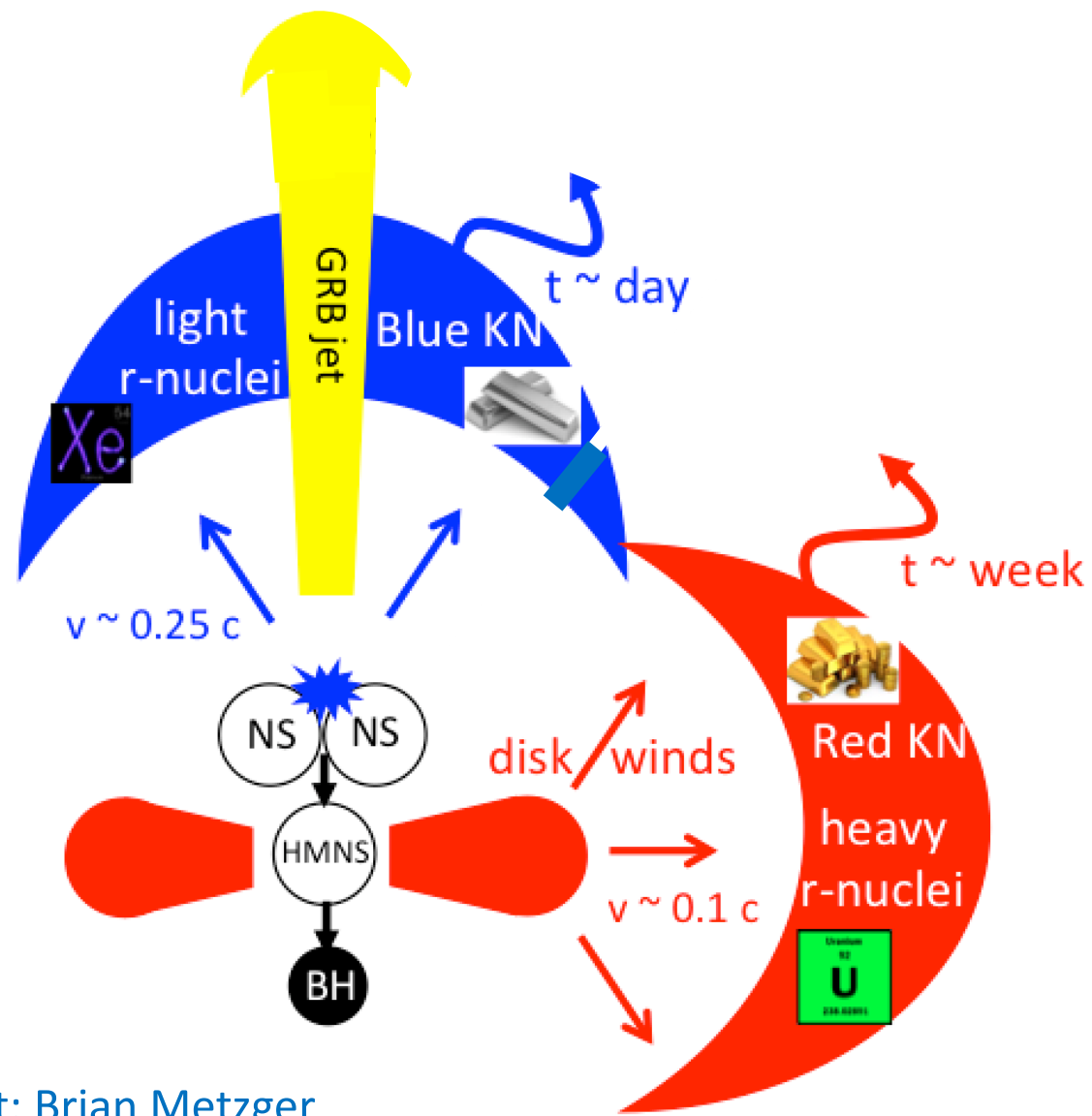


Without Dark Matter ...



The Origin of the Elements





Credit: Brian Metzger

SSS17a



August 17, 2017



August 21, 2017

Swope & Magellan Telescopes

Element Origins

1 H																	2 He	
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne	
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba			72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra																	
			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
			89 Ac	90 Th	91 Pa	92 U												

Merging Neutron Stars
Dying Low Mass Stars

Exploding Massive Stars
Exploding White Dwarfs

Big Bang
Cosmic Ray Fission

Based on graphic created by Jennifer Johnson

What's next?





DAWN
OF
TIME
?

gravitational wave
background

10^{-22}
seconds

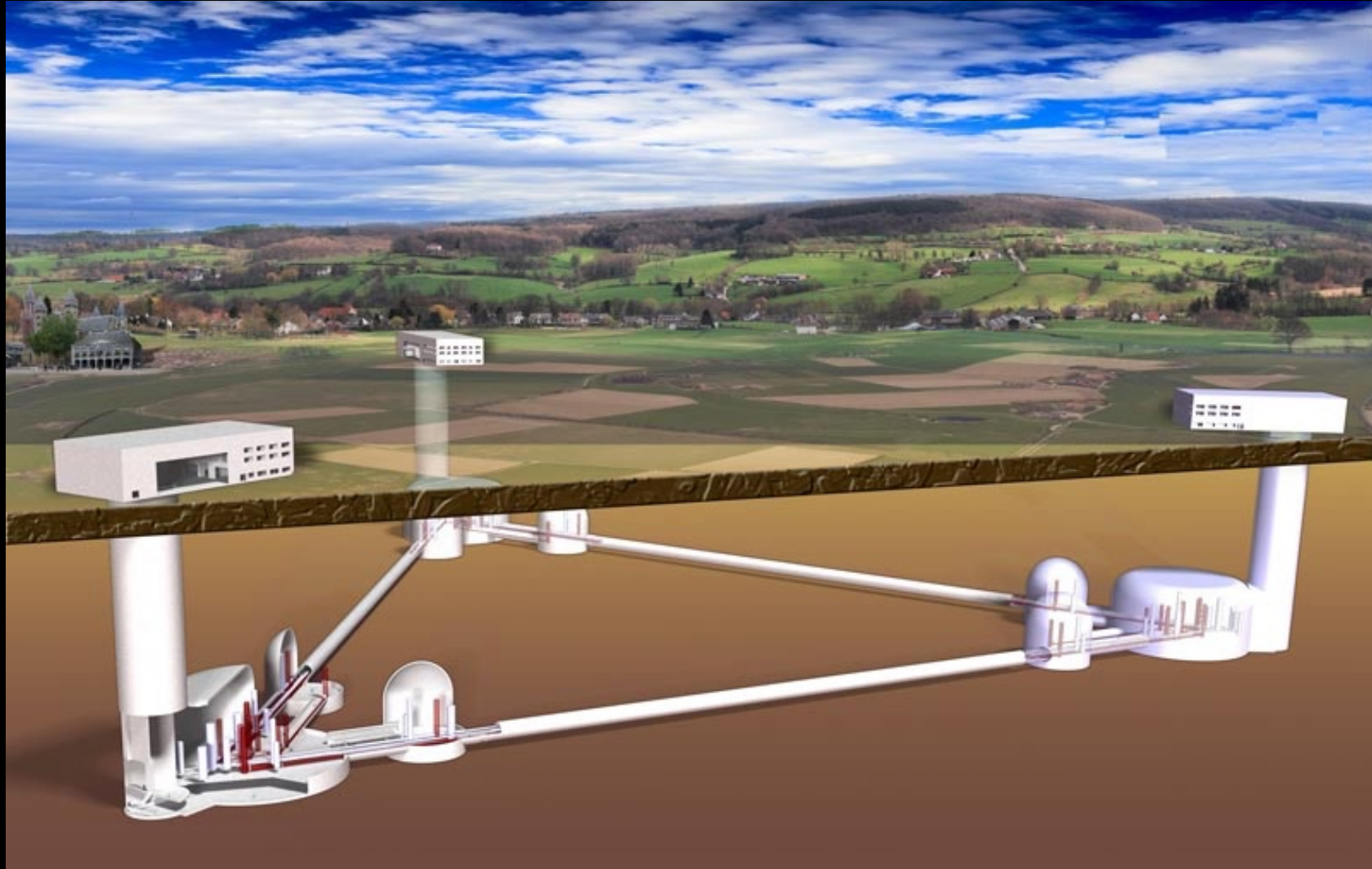
cosmic
microwave
background

380,000
years

13.7
billion
years

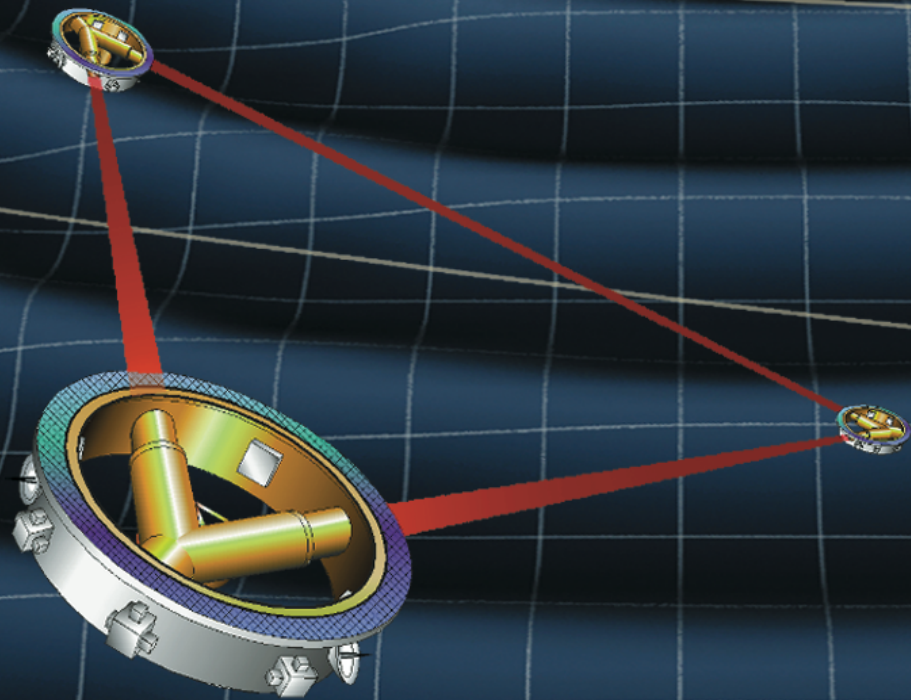
“Einstein Telescope” (2030s)

an underground cryogenic detector in Europe



LISA : Laser Interferometer Space Antenna

(launch 2034)



Black-Hole Cannibalism

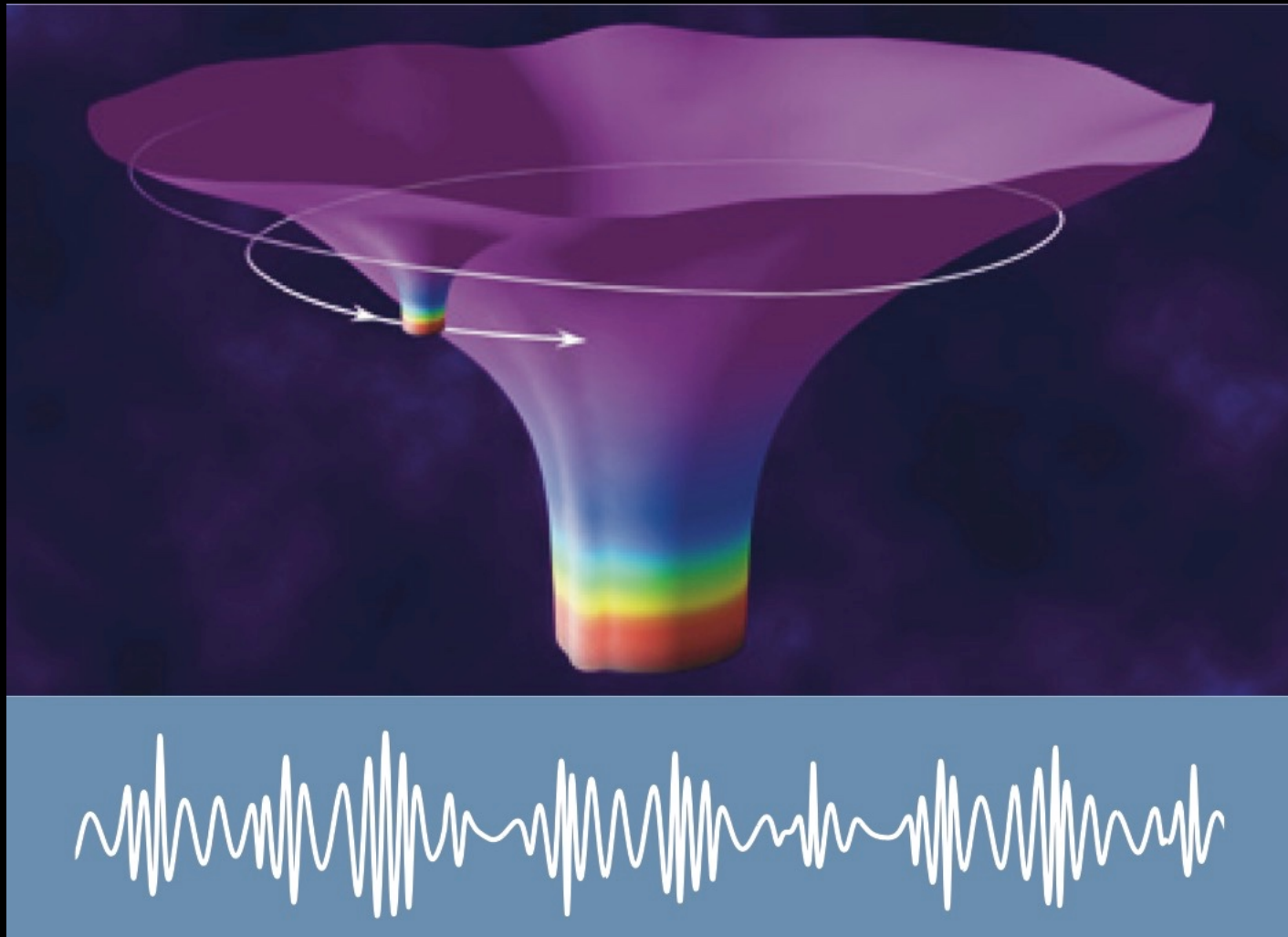


image: NASA / eLISA; sound: S. Hughes

FLAVOR SO
YOU COULD SLAP IT

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212-storage

Scientists
found
gravitational
waves in
outer space.
**If only it
were that
easy to find
a walk-in
closet in
NYC.**

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