



Kilonova: A New Era in Astronomy

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May 14, 2018

Multi-Messenger Astronomy using Gravitational Wave Observatories

Large Interferometric Gravitational Wave Observatory



LIGO – Hanford, WA



LIGO – Livingston, LA

Virgo Observatory

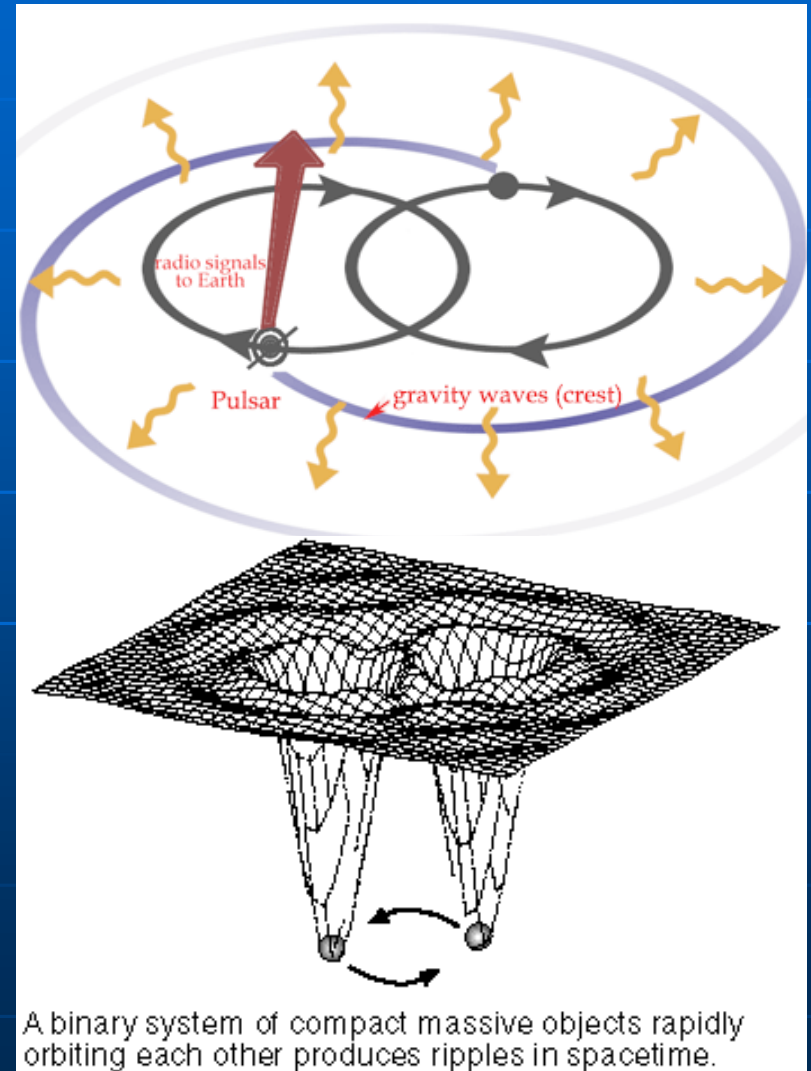
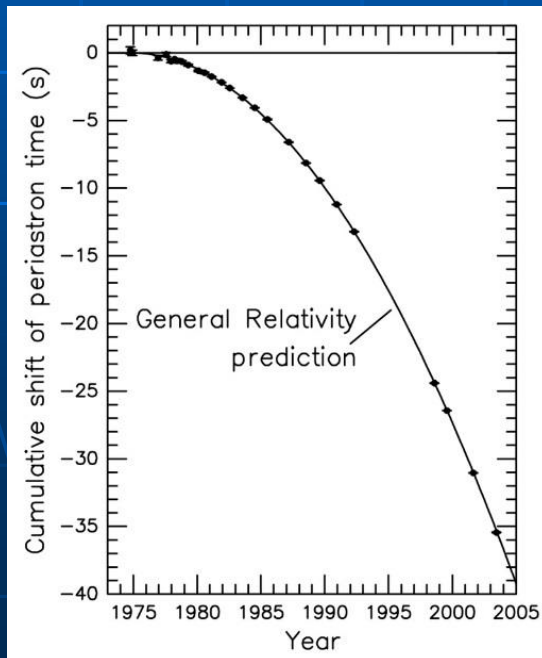


Pisa, Italy

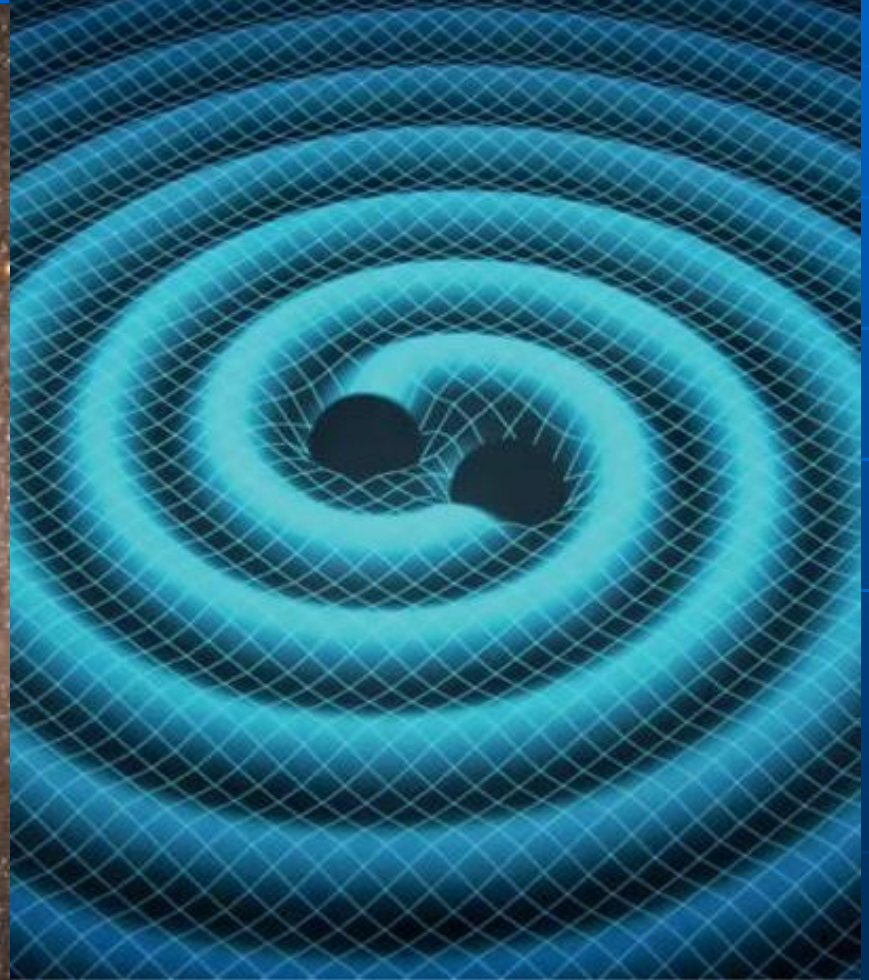


Sources of Gravitational Waves (GW)

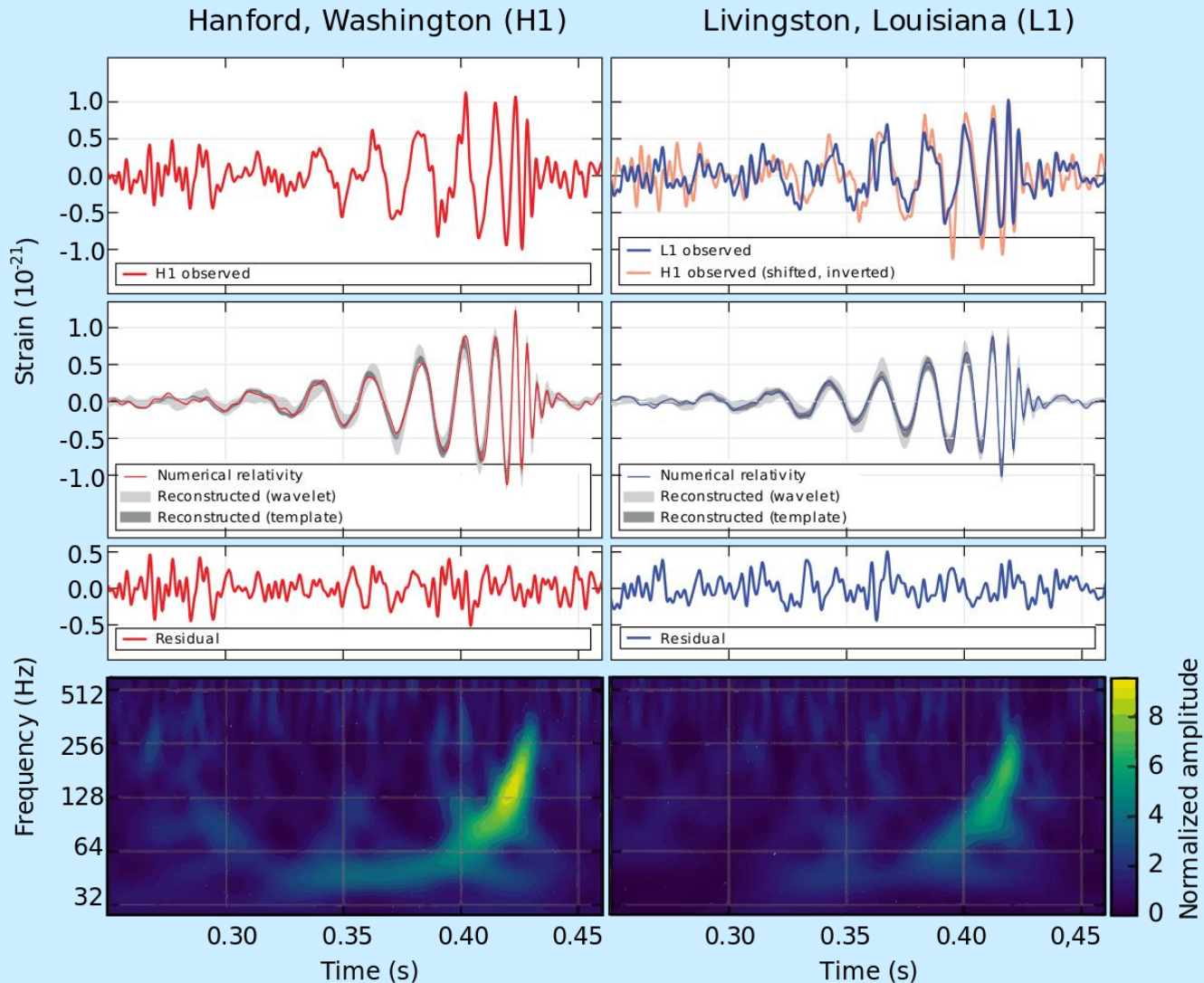
General Relativity predicts GW emitted by Accelerated Mass, e.g. rapidly orbiting binary neutron stars (pulsars), producing orbital decay.
Taylor & Hulse, Nobel Prize 1993



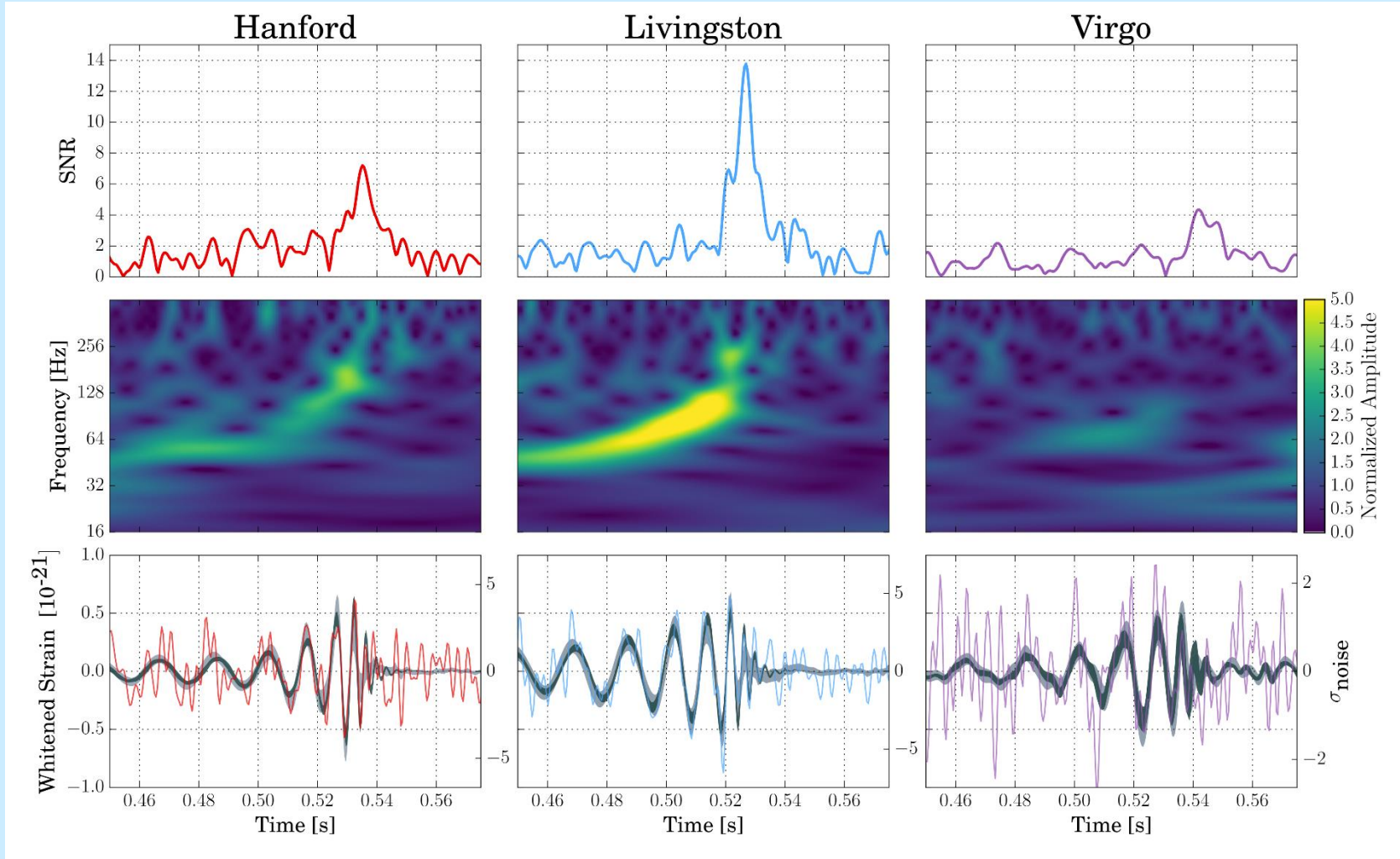
GW Strength & Frequency Increase as Binary System Approaches Merger



LIGO Signals on Sept. 14, 2015 implied Distant Black Hole Merger



LIGO – Virgo Signals on Aug 17, 2017

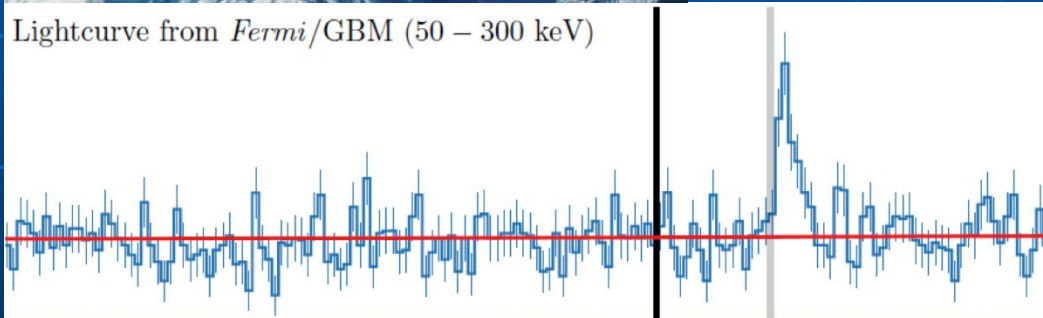


Fermi Gamma Space Telescope sees Signal just 1.7 sec later!

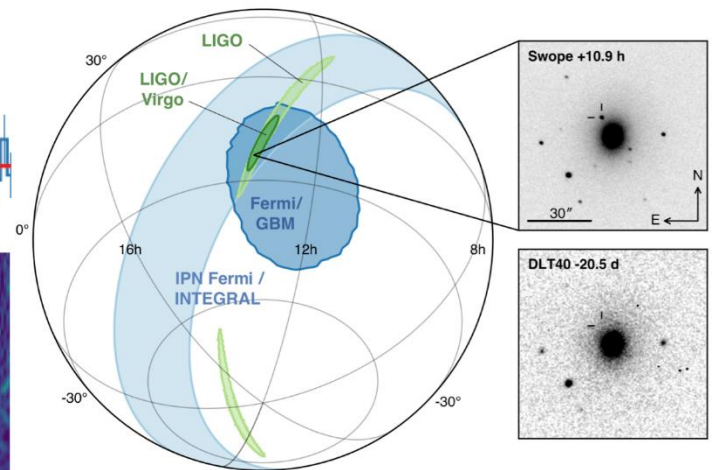
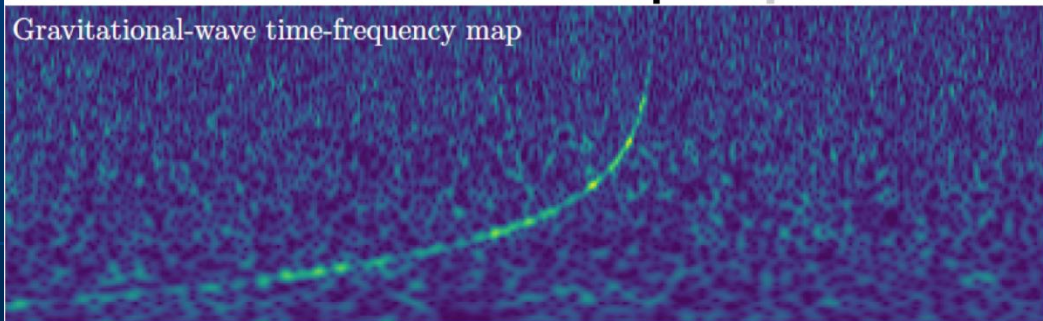


Fermi localizes gamma signal
to same region of sky as
LIGO/Virgo GW signal –
likely same source!

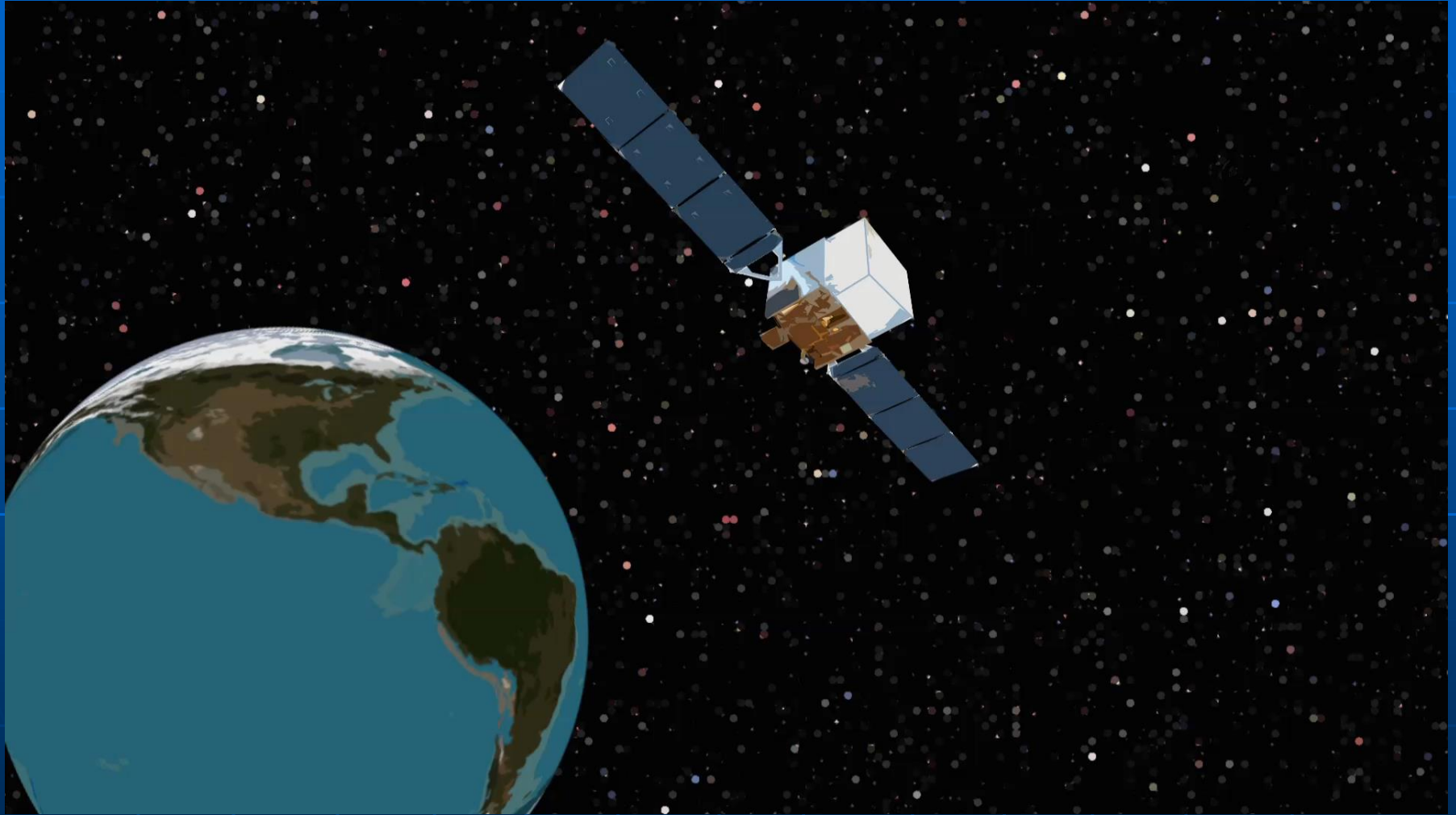
Lightcurve from *Fermi*/GBM (50 – 300 keV)



Gravitational-wave time-frequency map



The Era of Multi-Messenger Astronomy



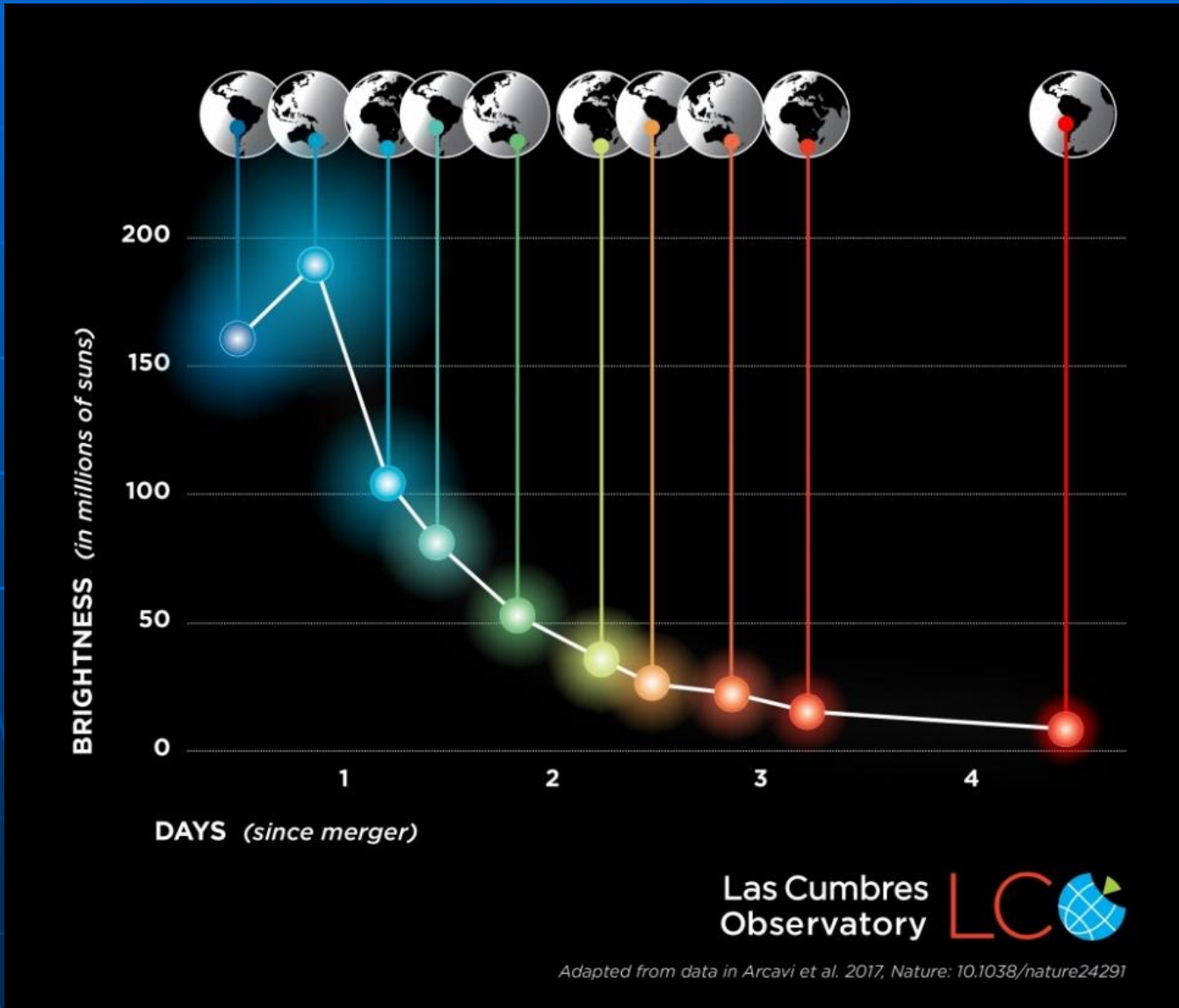
Swope Telescope in Chile Finds New Light Source



After 10 hours a new light source is found in the constellation Hydra on the outskirts of galaxy NGC 4993

Accompanying Light Signals in addition to the lengthy 100 second long GW Signals strongly suggest Merging Binary Neutron Star System – Kilonova!

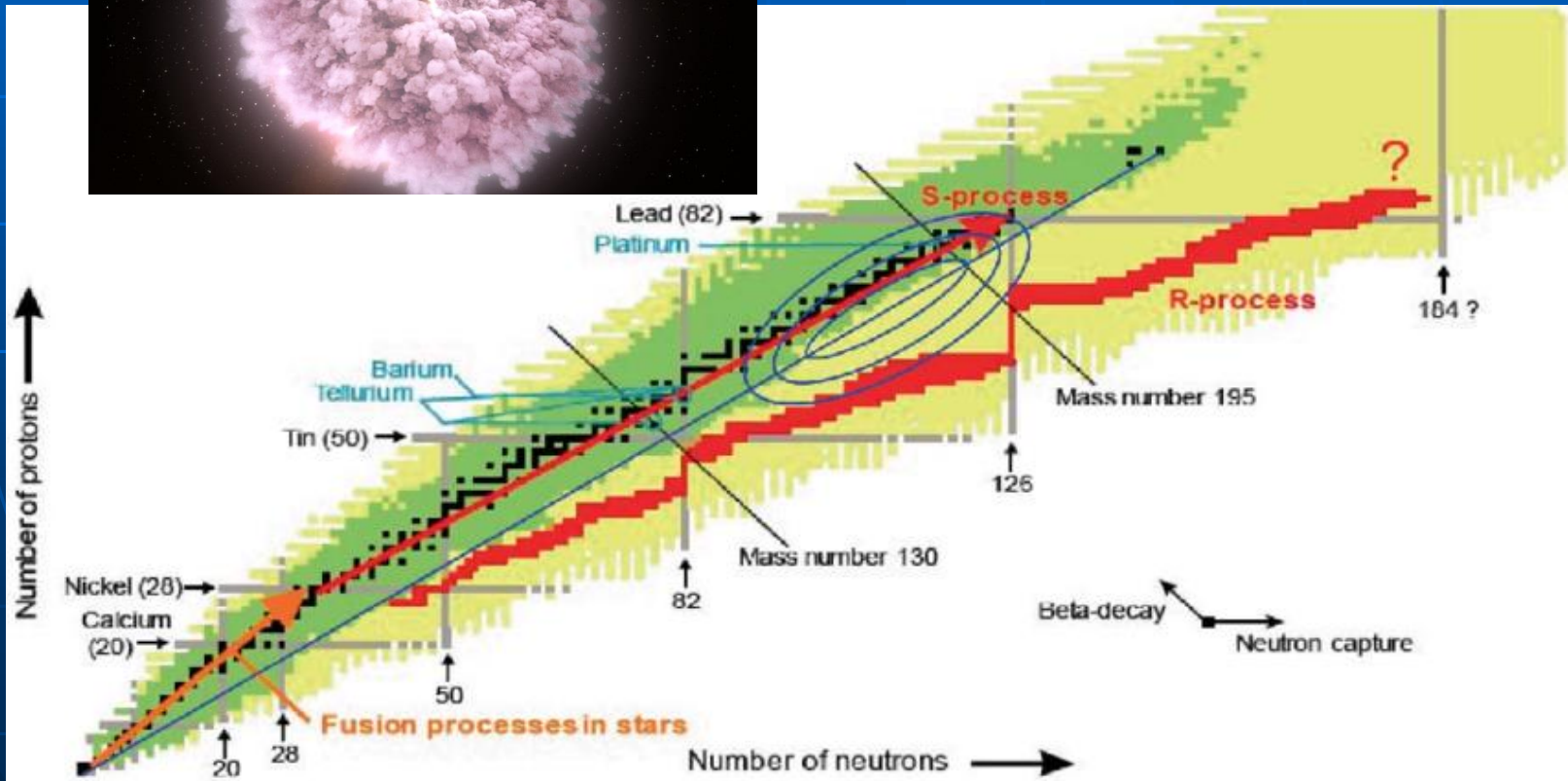
Ground-Based Observatories



Modeling the Kilonova Event



Kilonova – Site of R-Process Nucleosynthesis of Heavy Elements



New Version of Origin of Elements

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 | | | | | | | | | | | | | |

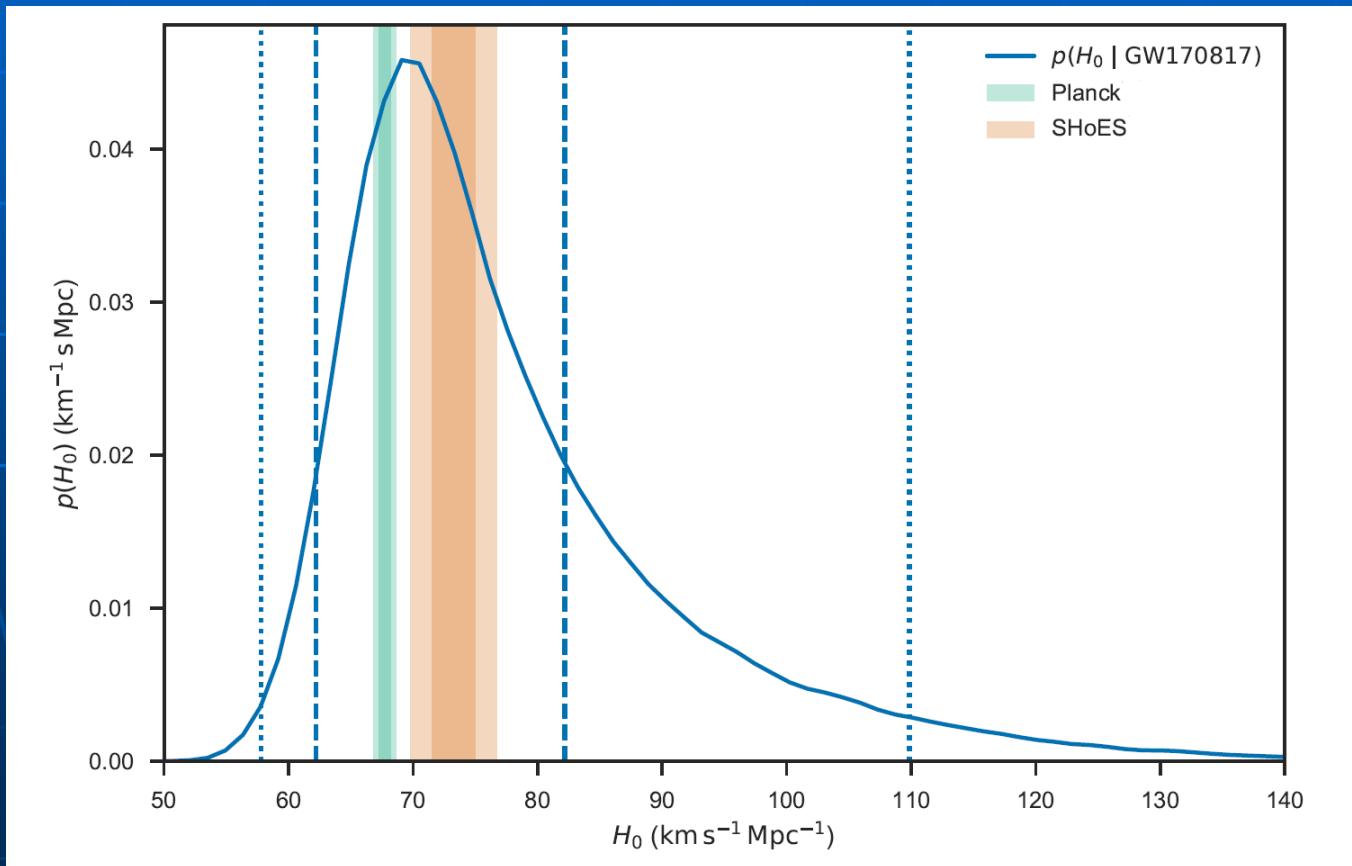
Merging Neutron Stars
Dying Low Mass Stars

Exploding Massive Stars
Exploding White Dwarfs

Big Bang
Cosmic Ray Fission

Based on graphic created by Jennifer Johnson

Hubble Expansion Rate Using GW Signal Strength



Conclusion: Kilonova A New Era in Astronomy

