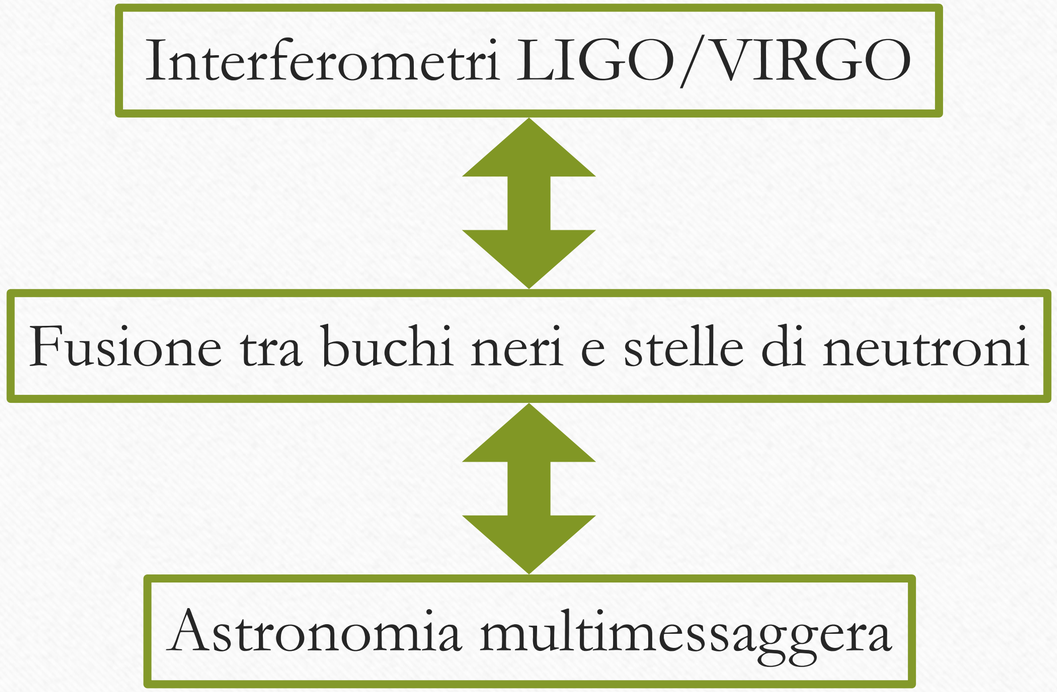
Massimiliano Matteuzzi, Corso di Astrofisica, 14/02/2025

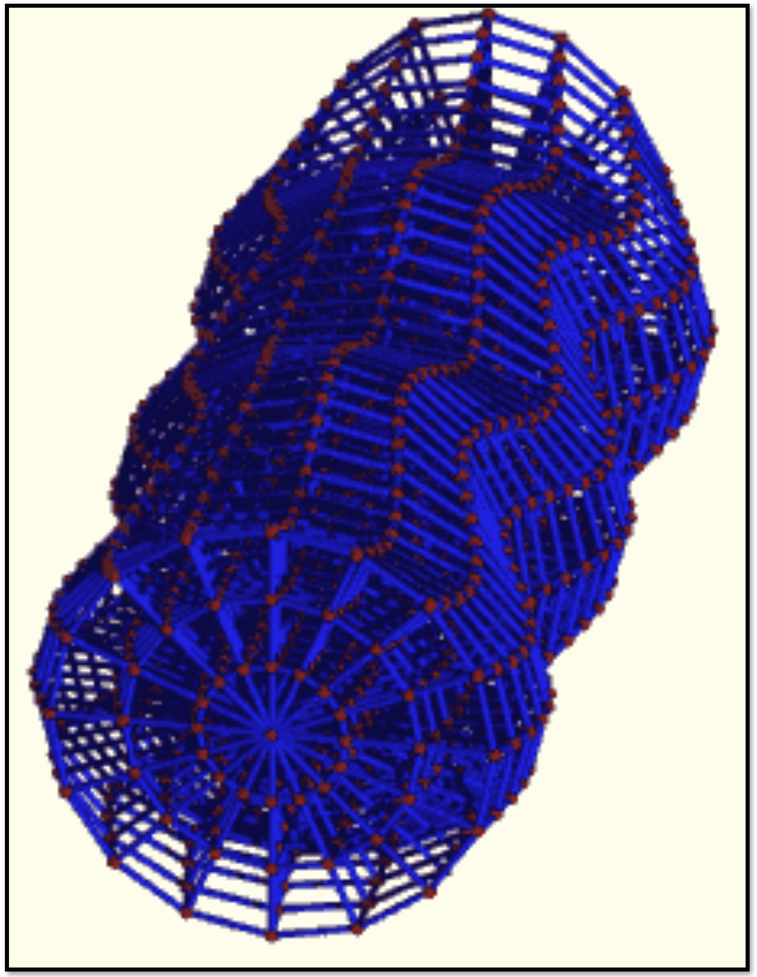
Onde Gravitazionali

Terza serata del Corso di Astrofisica

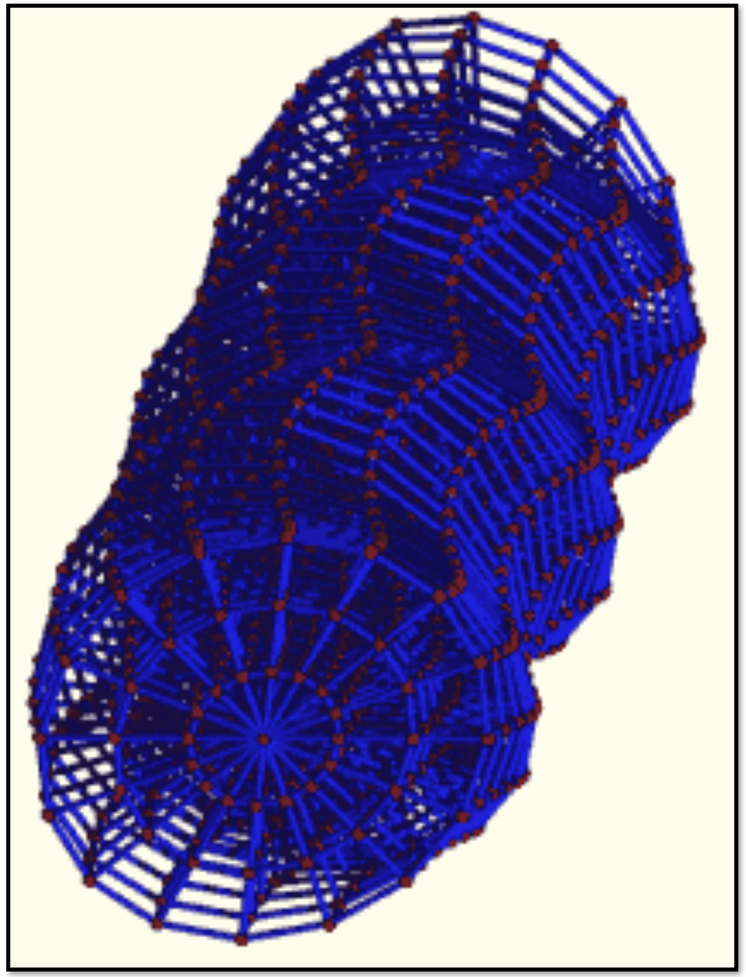
Cosa vedremo stasera



Propagazione delle onde gravitazionali

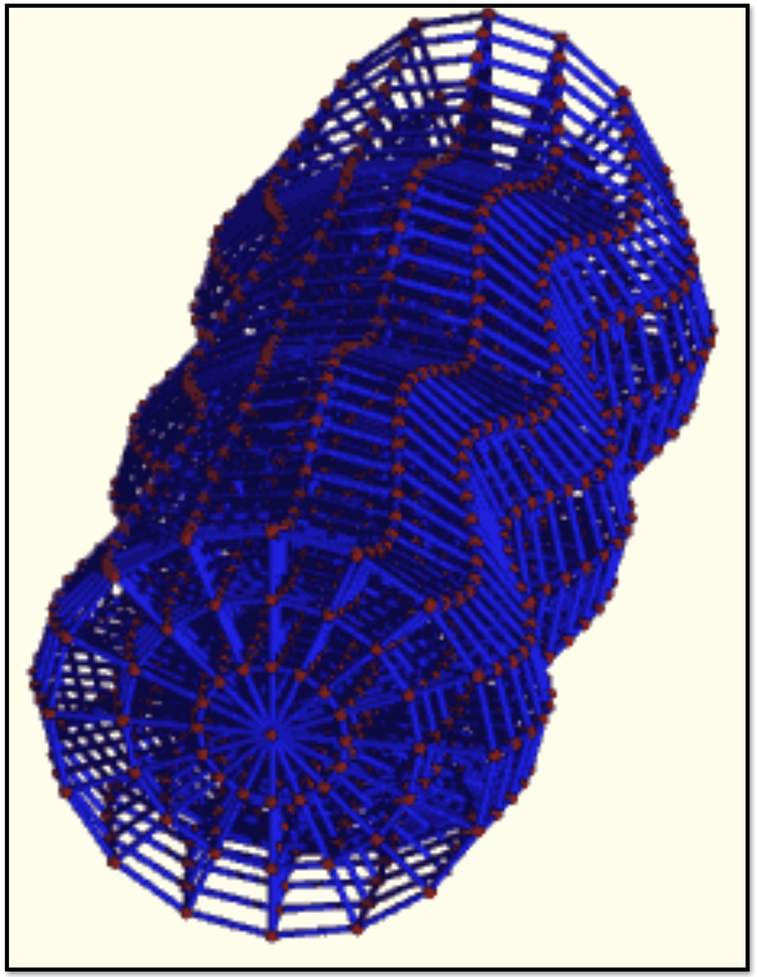


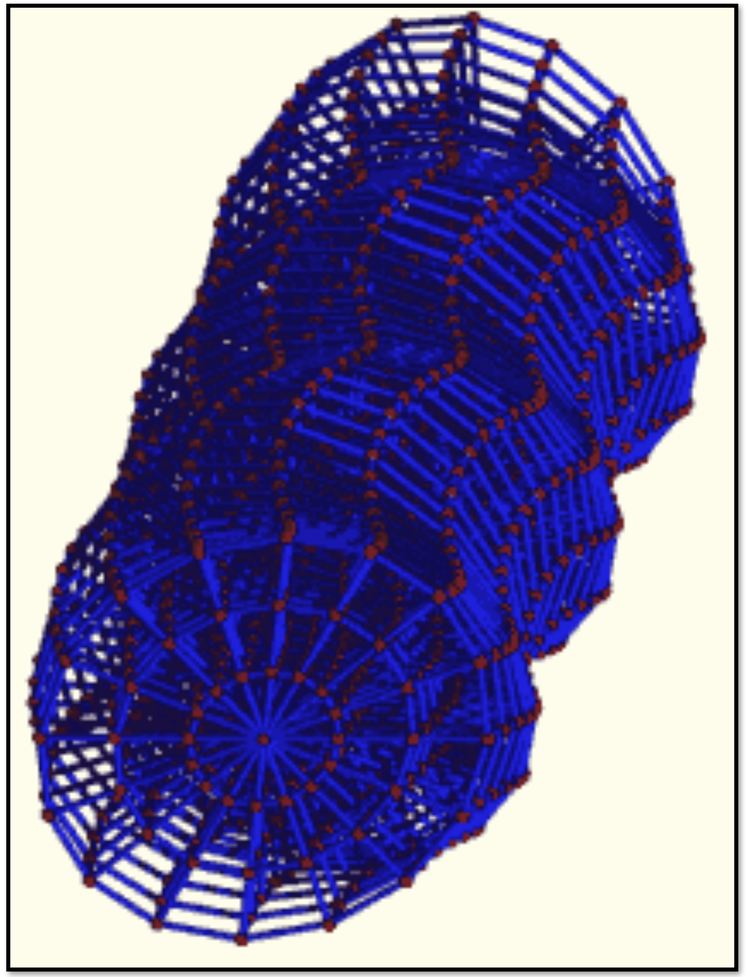
$h_+ : \quad h_{xx} = -\, h_{yy}$



$h_\times : \quad h_{xy} = h_{yx}$

Propagazione delle onde gravitazionali

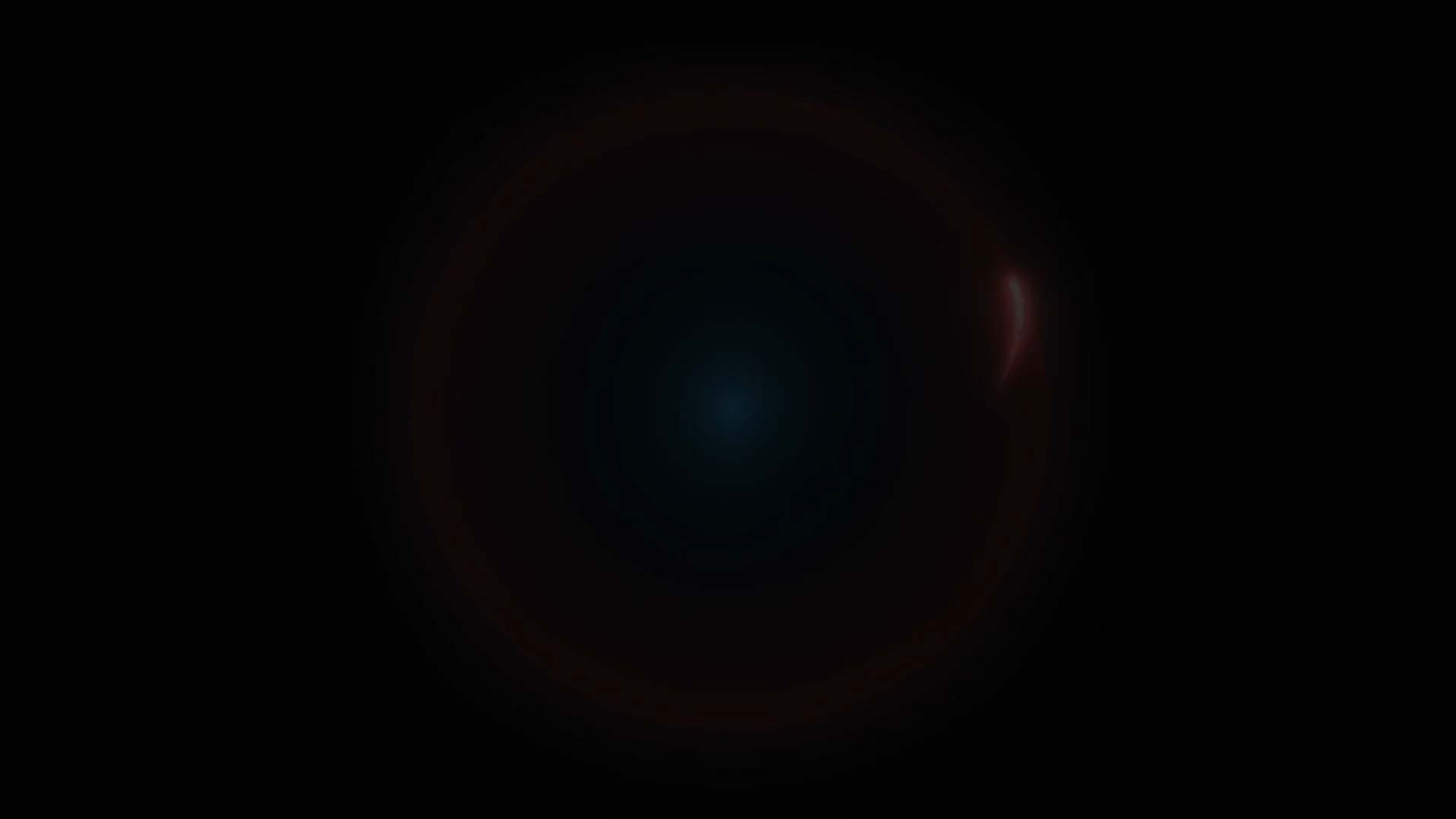




$h_+ : \quad h_{xx} = -\, h_{yy}$

$h_\times : \quad h_{xy} = h_{yx}$

Strain: $h(t) = h_0 \cos(2\pi \nu_{\mathrm{GW}} t)$ con $h_0 \approx \Delta L / L \approx 10^{-22}$

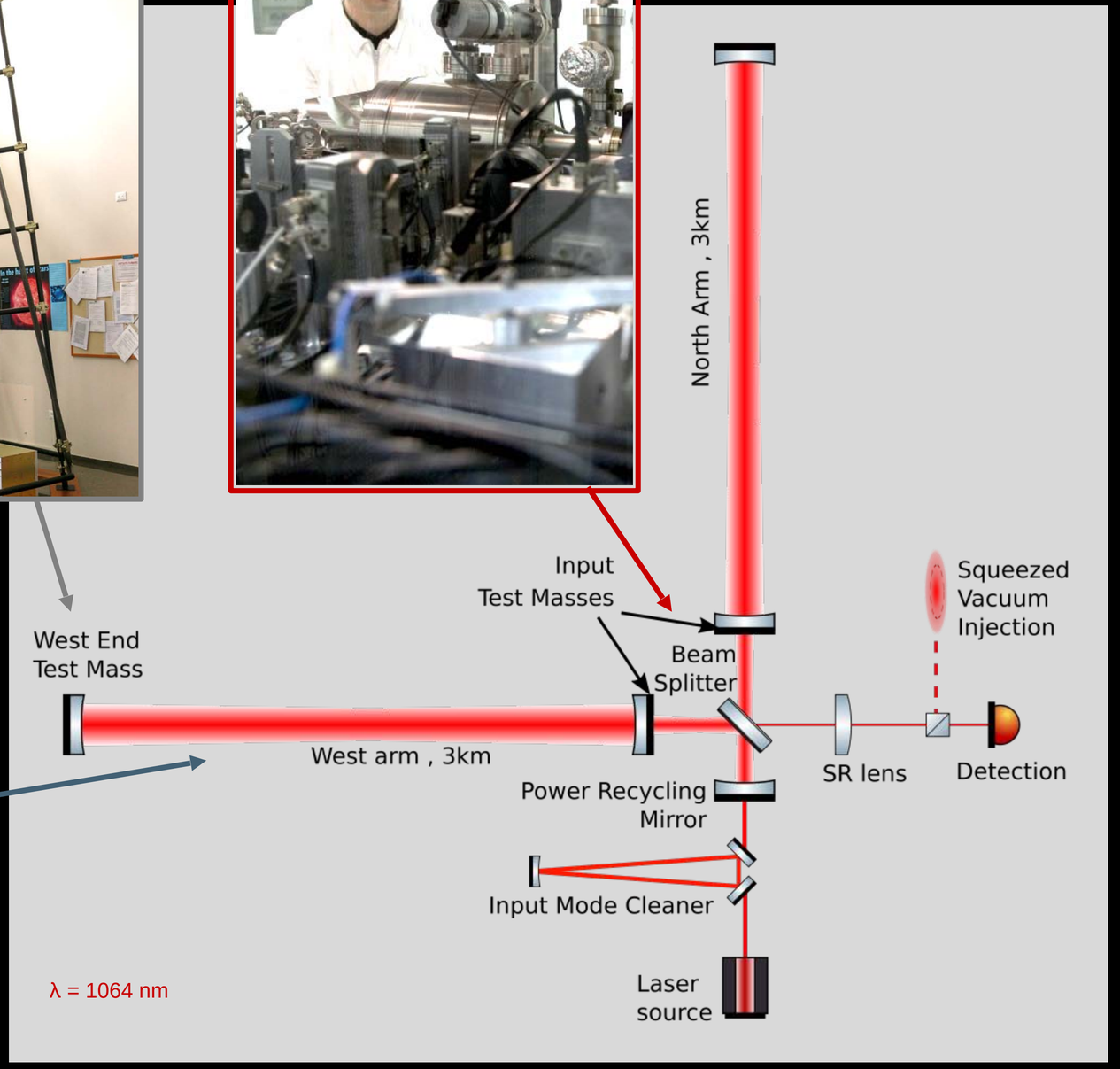


Interferometri LIGO/VIRGO

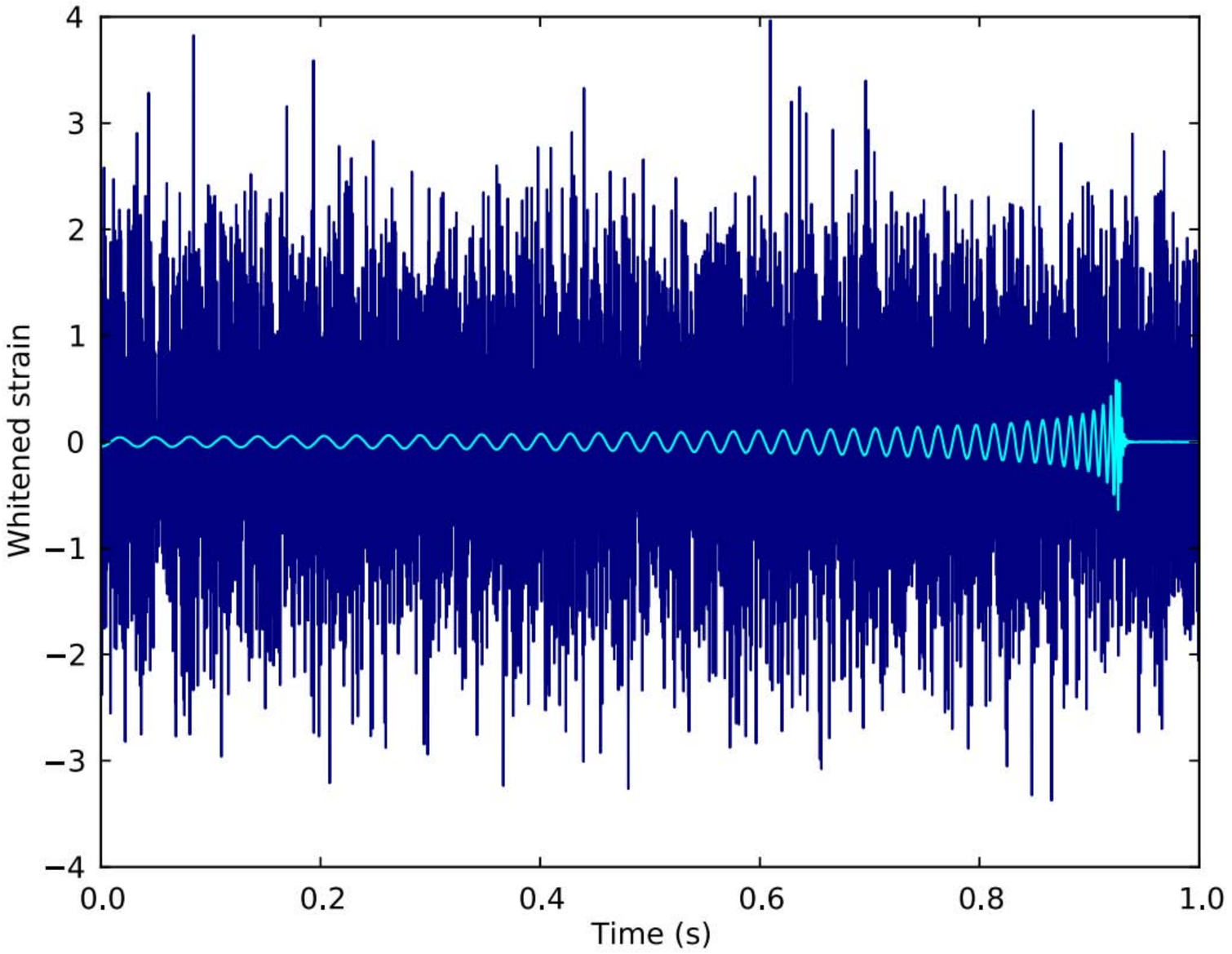

VIRGO
(Cascina, Pisa)

Livingston, LA

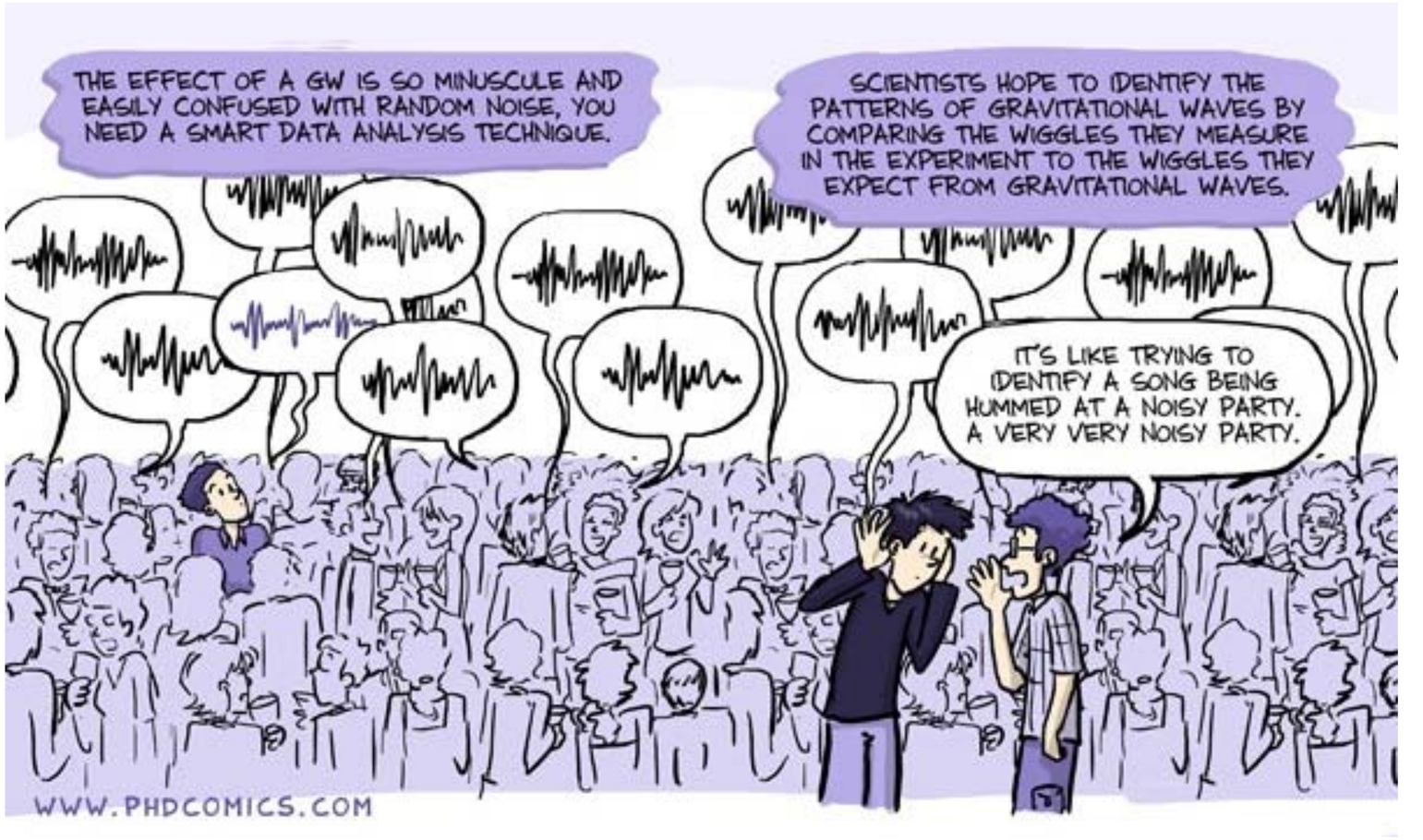
LIGO (USA)


North Arm , 3km
Input
Test Masses
Squeezed
Vacuum
Injection
West End
Test Mass
Beam
Splitter
West arm , 3km
SR lens
Detection
Power Recycling
Mirror
Input Mode Cleaner
λ = 1064 nm
Laser
source

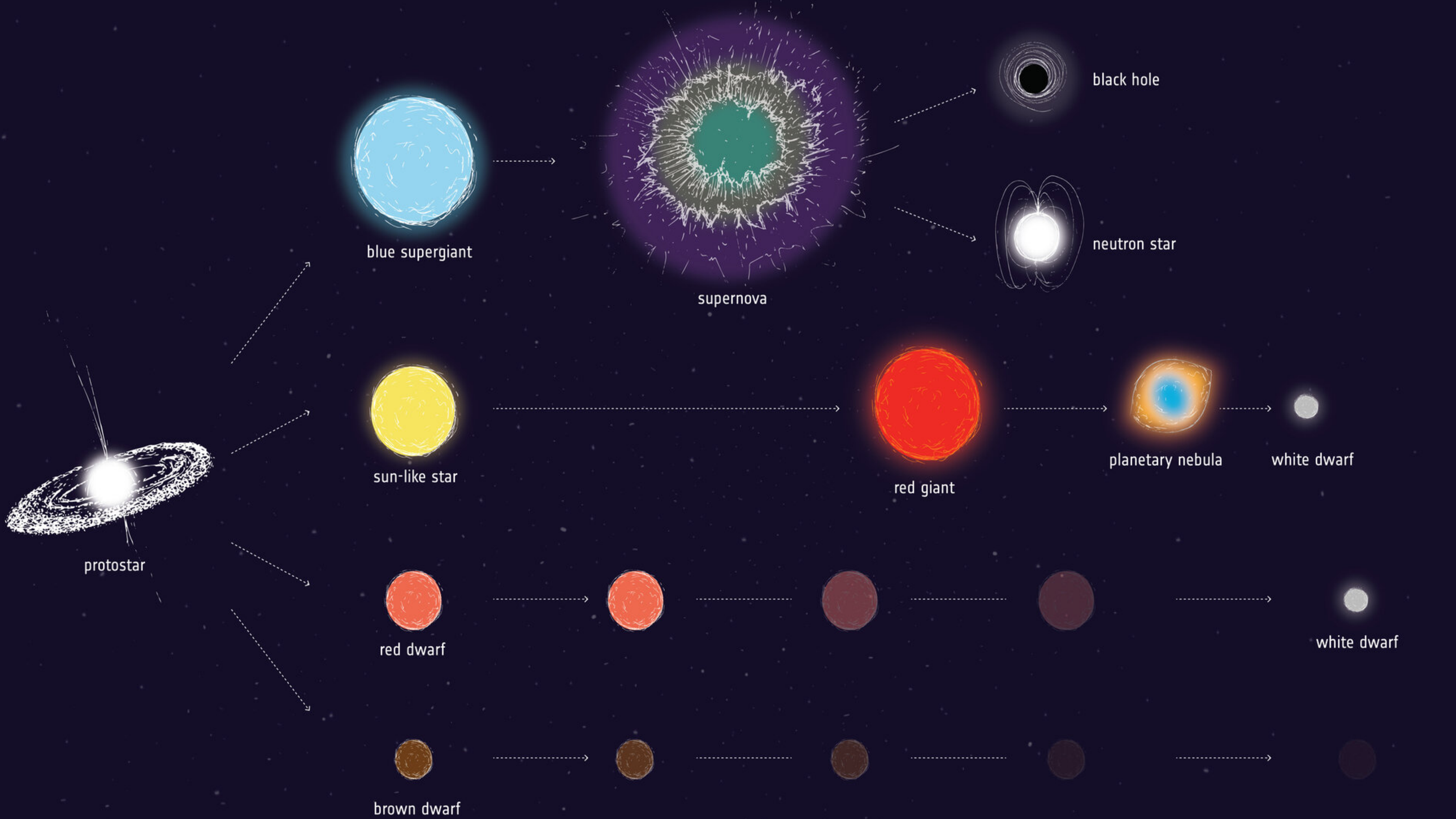
Segnale o rumore?



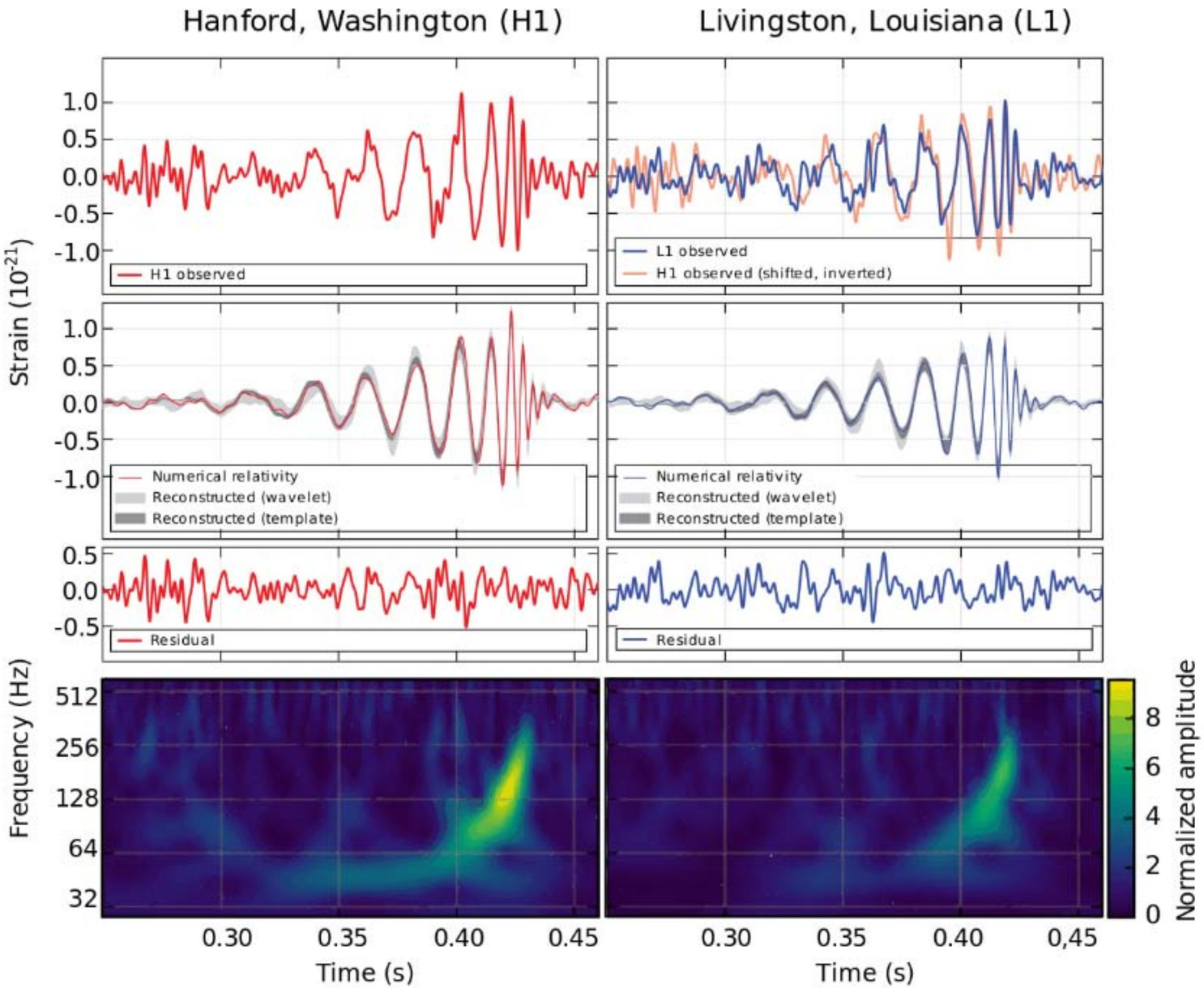
Segnale o rumore?

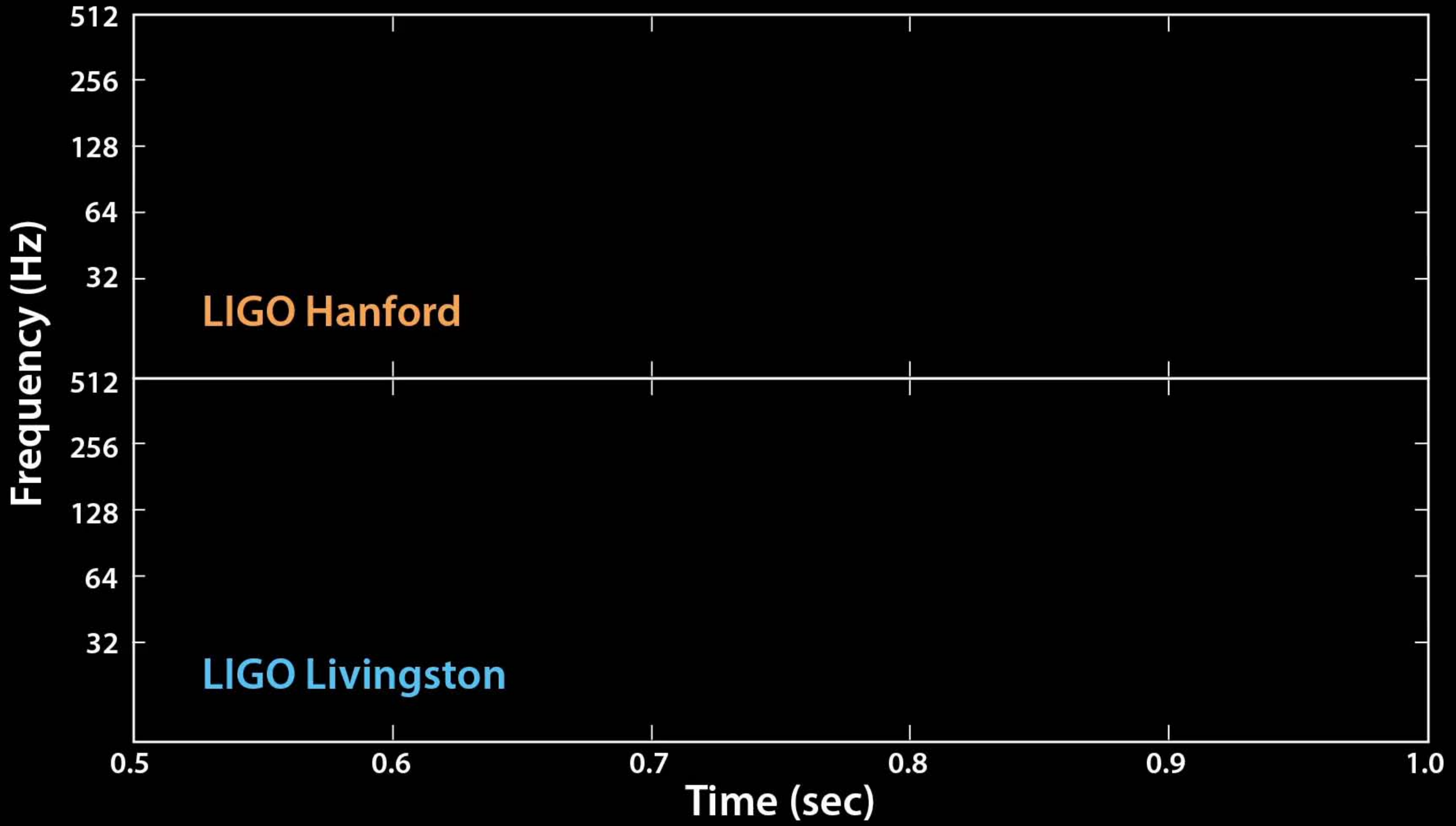


https://blackholehunter.org/game.html


black hole
blue supergiant
supernova
neutron star
protostar
sun-like star
red giant
planetary nebula
white dwarf
red dwarf
white dwarf
brown dwarf

GW150914: primo evento




512
256
128
64
32
LIGO Hanford
512
256
128
64
32
LIGO Livingston
Frequency (Hz)
0.5
0.6
0.7
0.8
0.9
1.0
Time (sec)

Massa di Chirp e distanza della sorgente

Massa di Chirp

- Massa effettiva del sistema che emette onde gravitazionali;
- $M_{\text{chirp}} := \left(M_1 M_2\right)^{3/5} / \left(M_1 + M_2\right)^{1/5}$ è legata alla frequenza dell'onda emessa ed alla sua variazione temporale;
- $M_{\text{chirp}} = \frac{c^3}{G}\left(\frac{125}{884736\pi^8}\right)^{1/5} \left(\dot{\nu}_{\text{GW}}\right)^{3/5} / \left(\nu_{\text{GW}}\right)^{11/5}$, pertanto da ν_{GW} e $\dot{\nu}_{\text{GW}}$ ricavo M_{Chirp}

Massa di Chirp

- $M_{\text{chirp}} \approx 30\,M_{\odot}$ considerando $\nu_{\text{GW}} \approx 150\,\text{Hz}$ dal grafico;
- Se assumo $M_1 = M_2$, ottengo che $M_{\text{tot}} \approx 2.3\,M_{\text{chirp}} = 69\,M_{\odot}$;
- $M_1 = M_2$ ci fa stimare una M_{tot} minima, da cui ricaveremmo: $M_1 \approx 35\,M_{\odot}$.

Massa totale e distanza

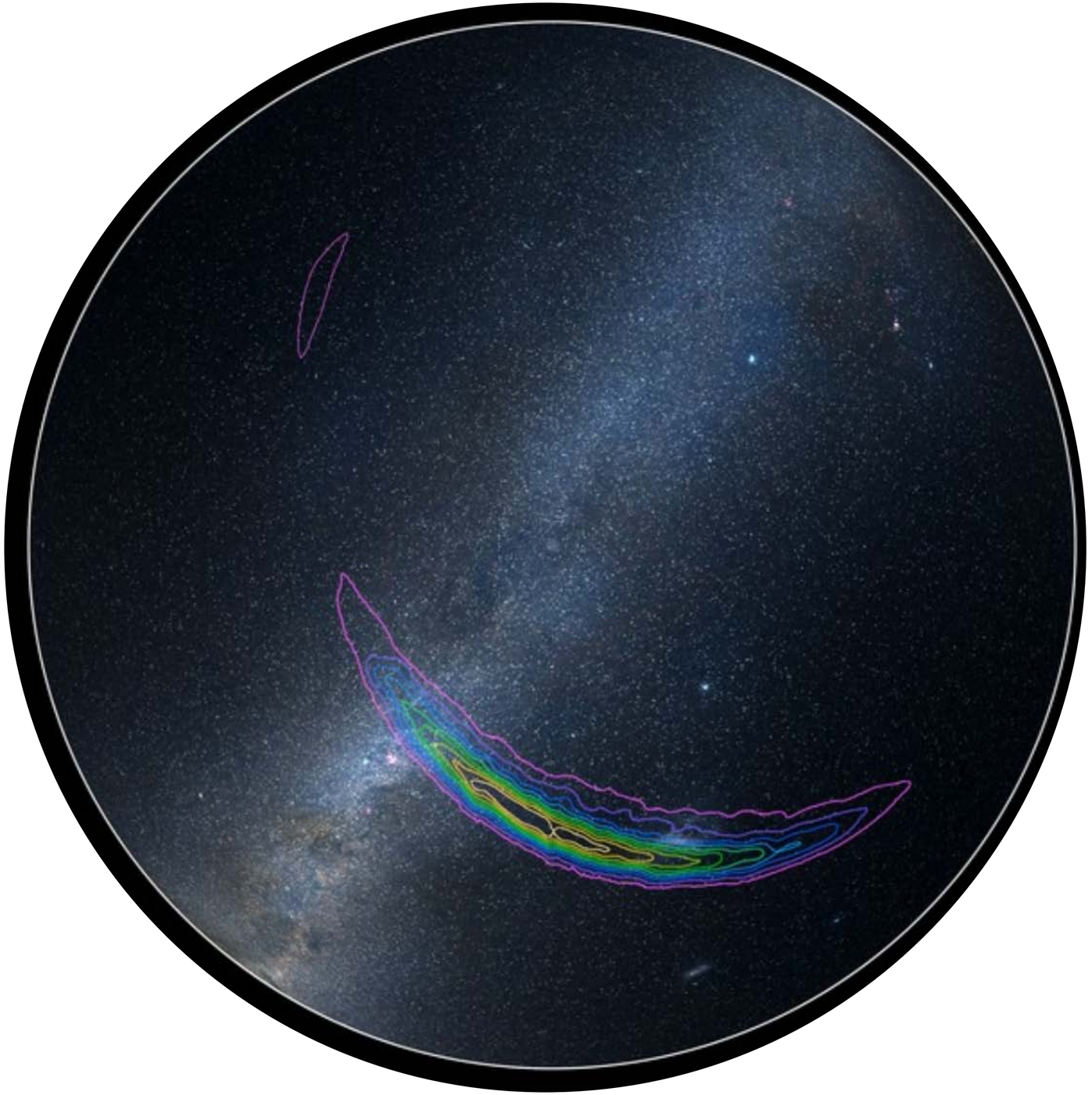
- Se riesco a misurare almeno due frequenze successive ottengo M_1 ed M_2;
- Nel caso del 2015: due BH di $29\,M_\odot$ e $36\,M_\odot$ si sono fusi;
- L'equivalente energetico di $3\,M_\odot$ sono state emesse attraverso GW in millisecondi.

Massa totale e distanza

- Da questa energia e dallo spostamento osservato posso ricavare la distanza;
- $d = \sqrt{\dot{E}_{GW} / \left(4\pi F_{GW}\right)}$ con F_{GW} ricavato da h_0 e ν_{GW}.

https://data.cardiffgravity.org/waveform-fitter/?lang=en

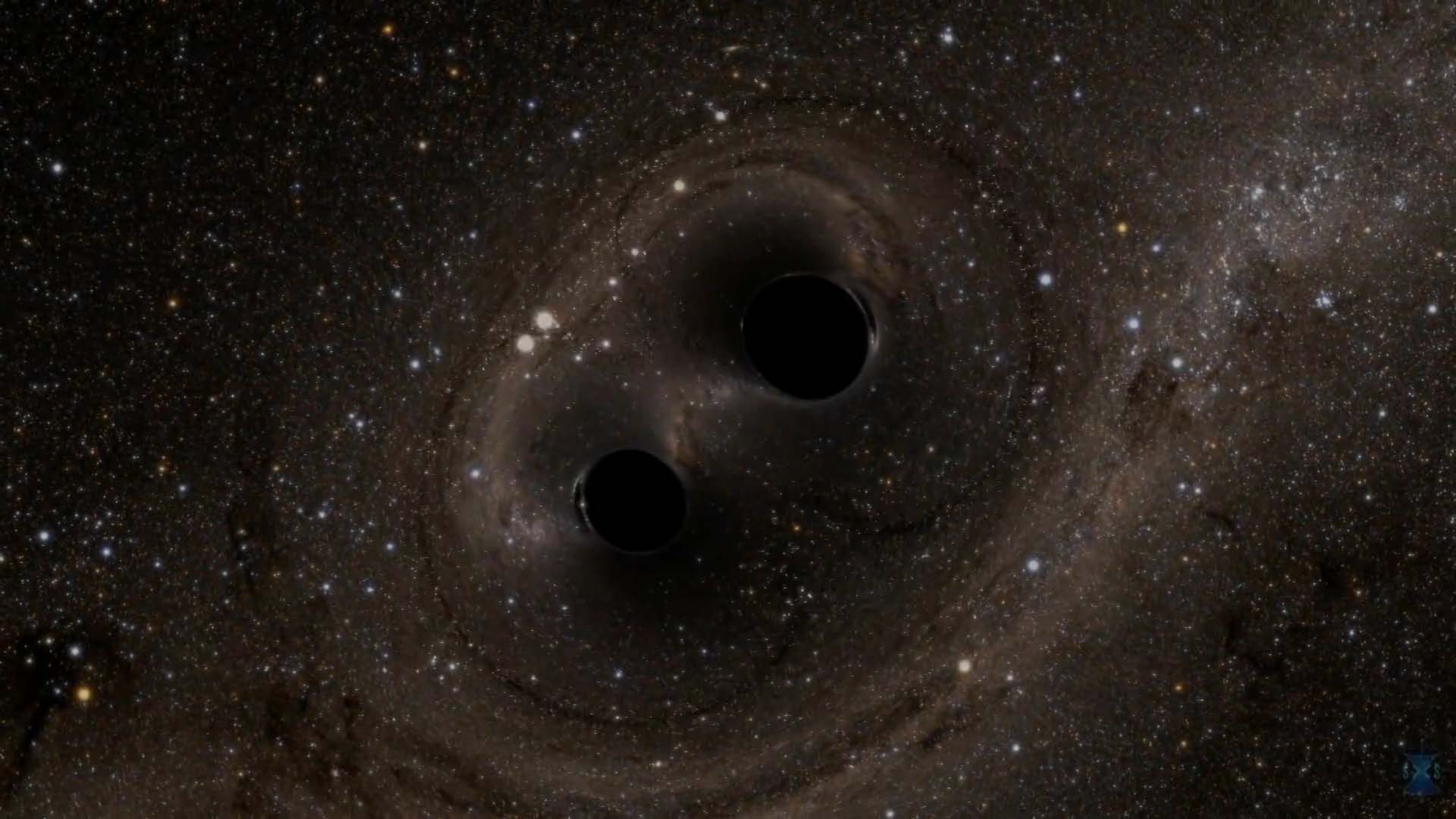
GW150914: localizzazione



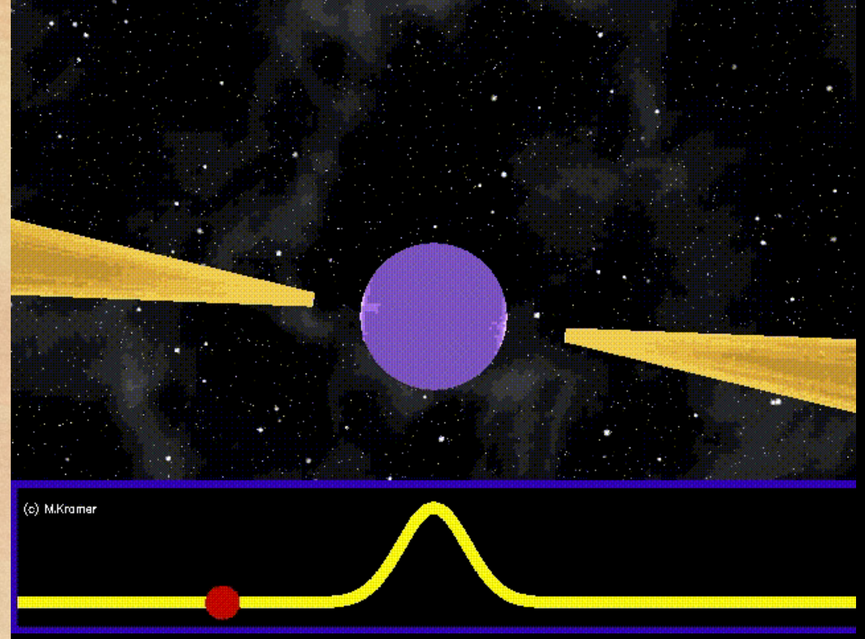
GW150914: localizzazione

NGC 6744 - Galassia a Spirale barrata, molto simile alla Via Lattea

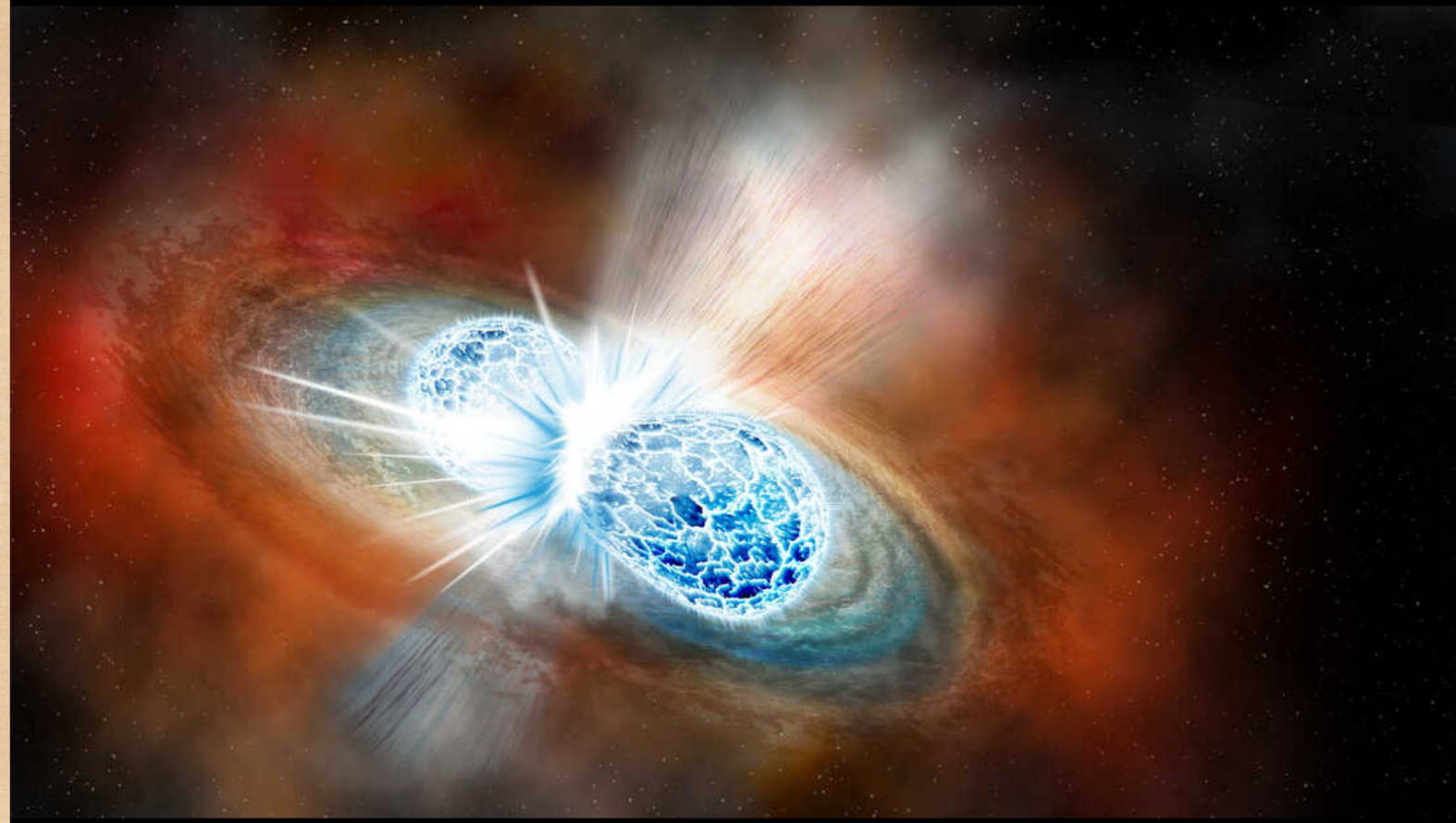
dist = 30 Mly D = 150’000 ly T_{rot} = 100-300 Myr ~$10^{11\text{-}12}$ stars



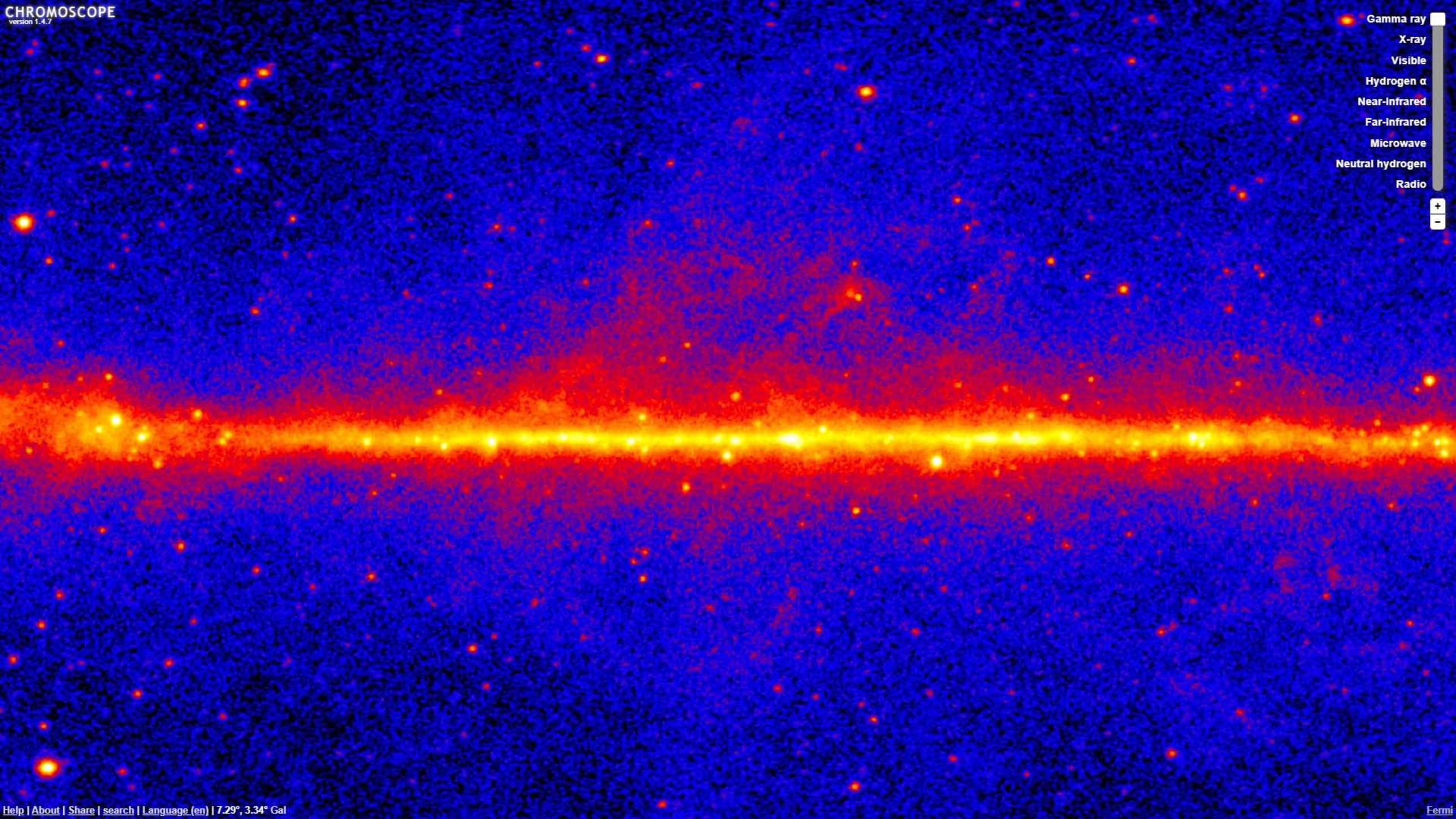
Stelle di Neutroni come Pulsar

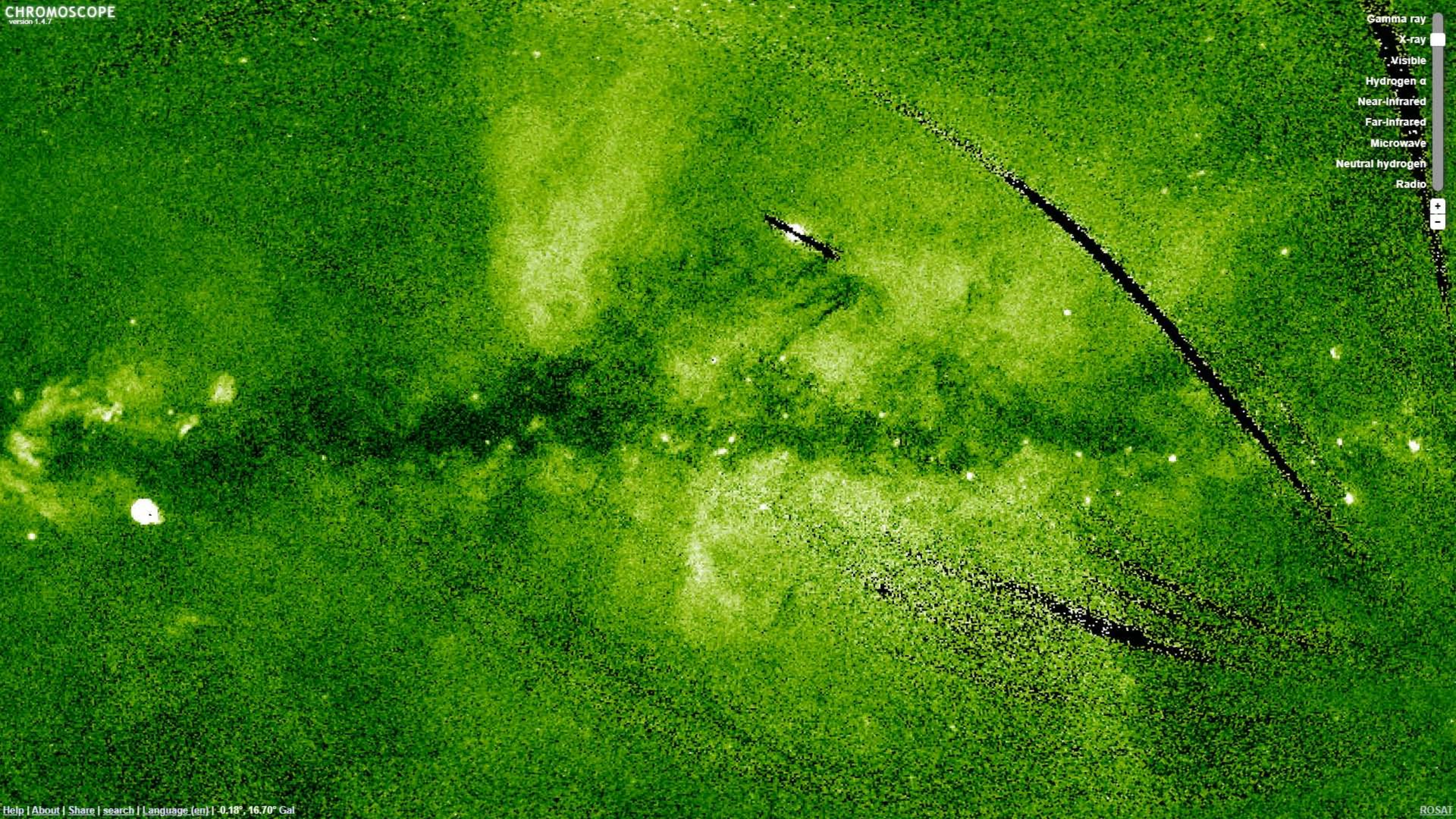


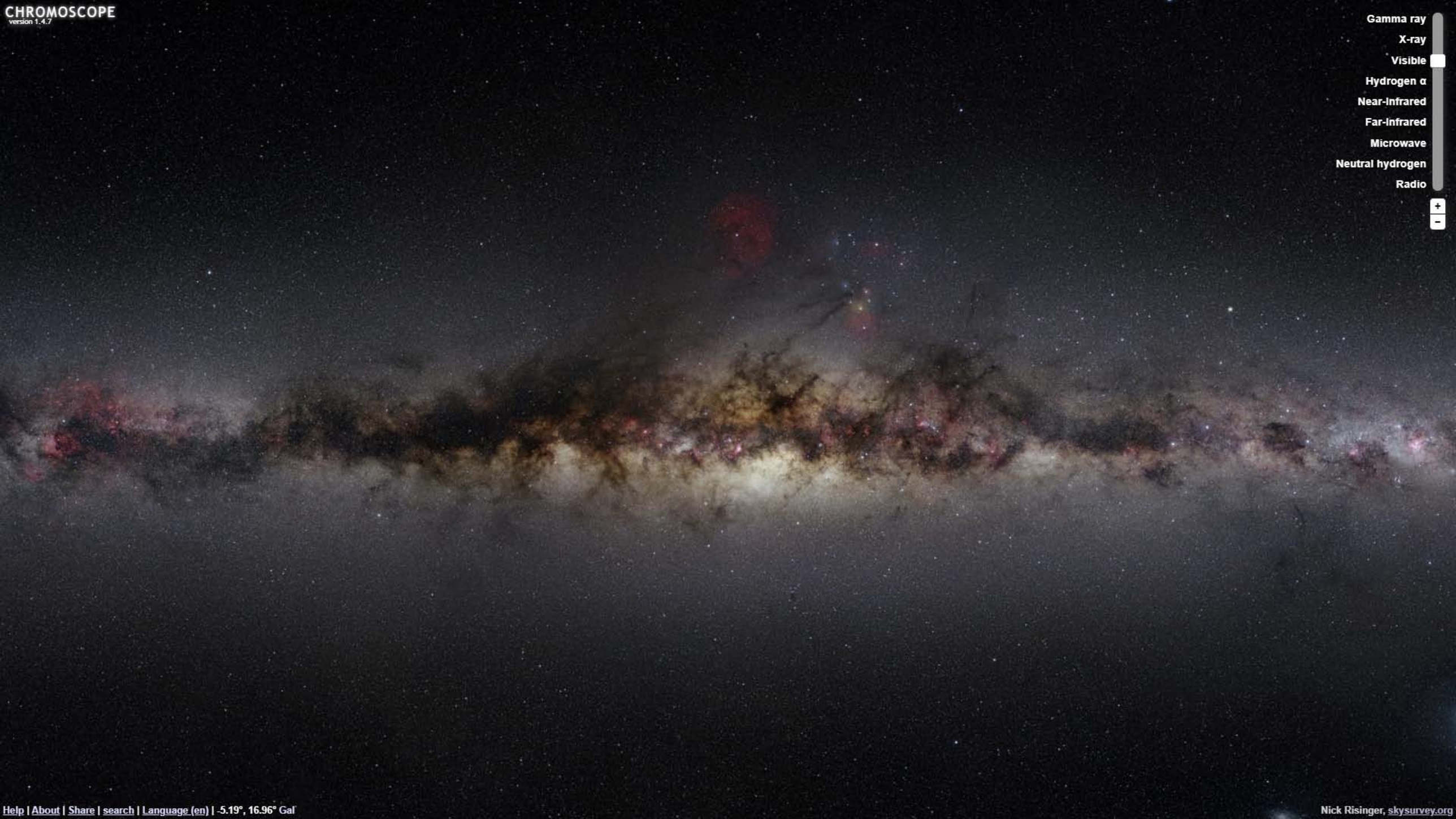
GW170817: coalescenza di stelle di neutroni

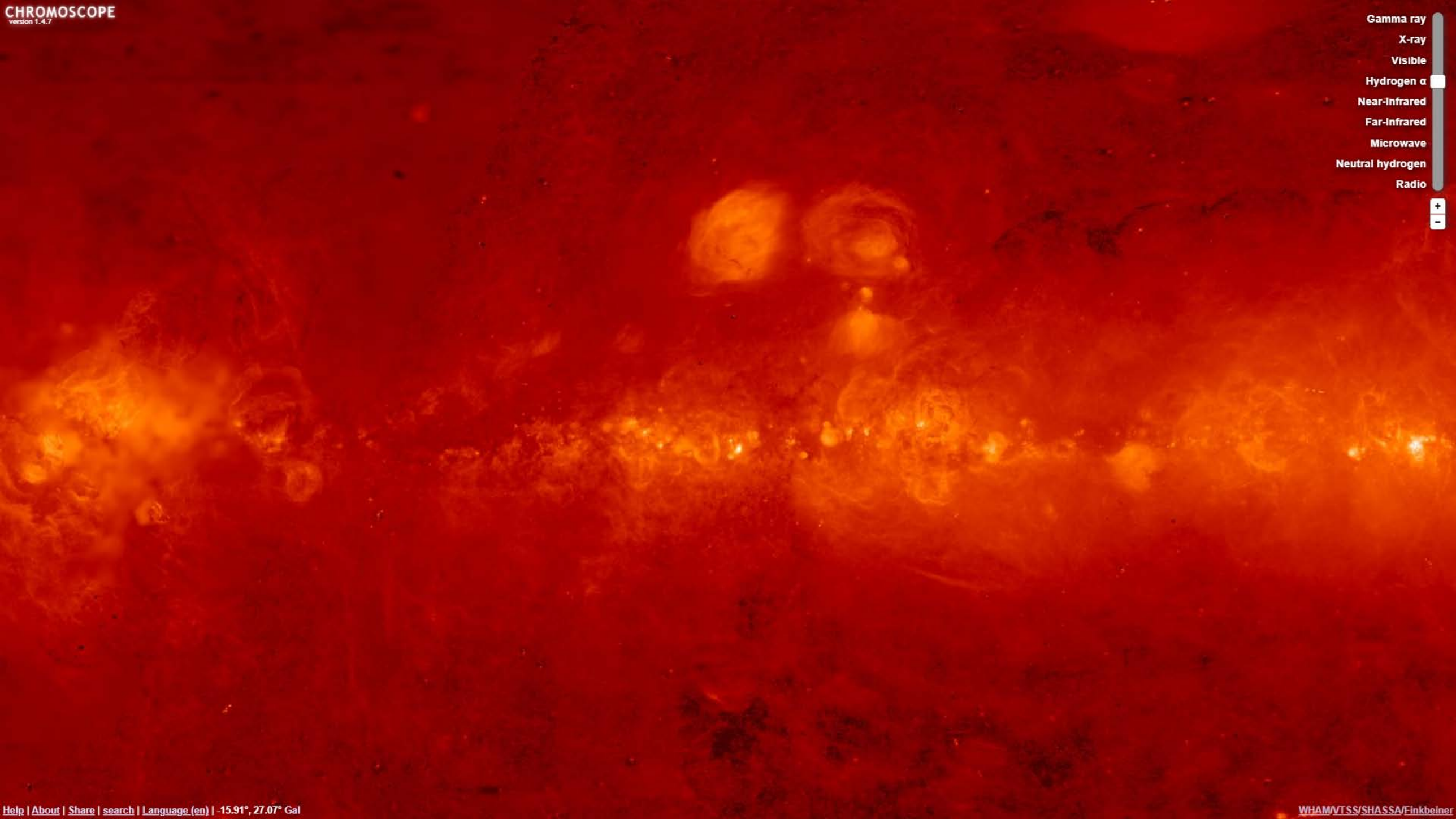


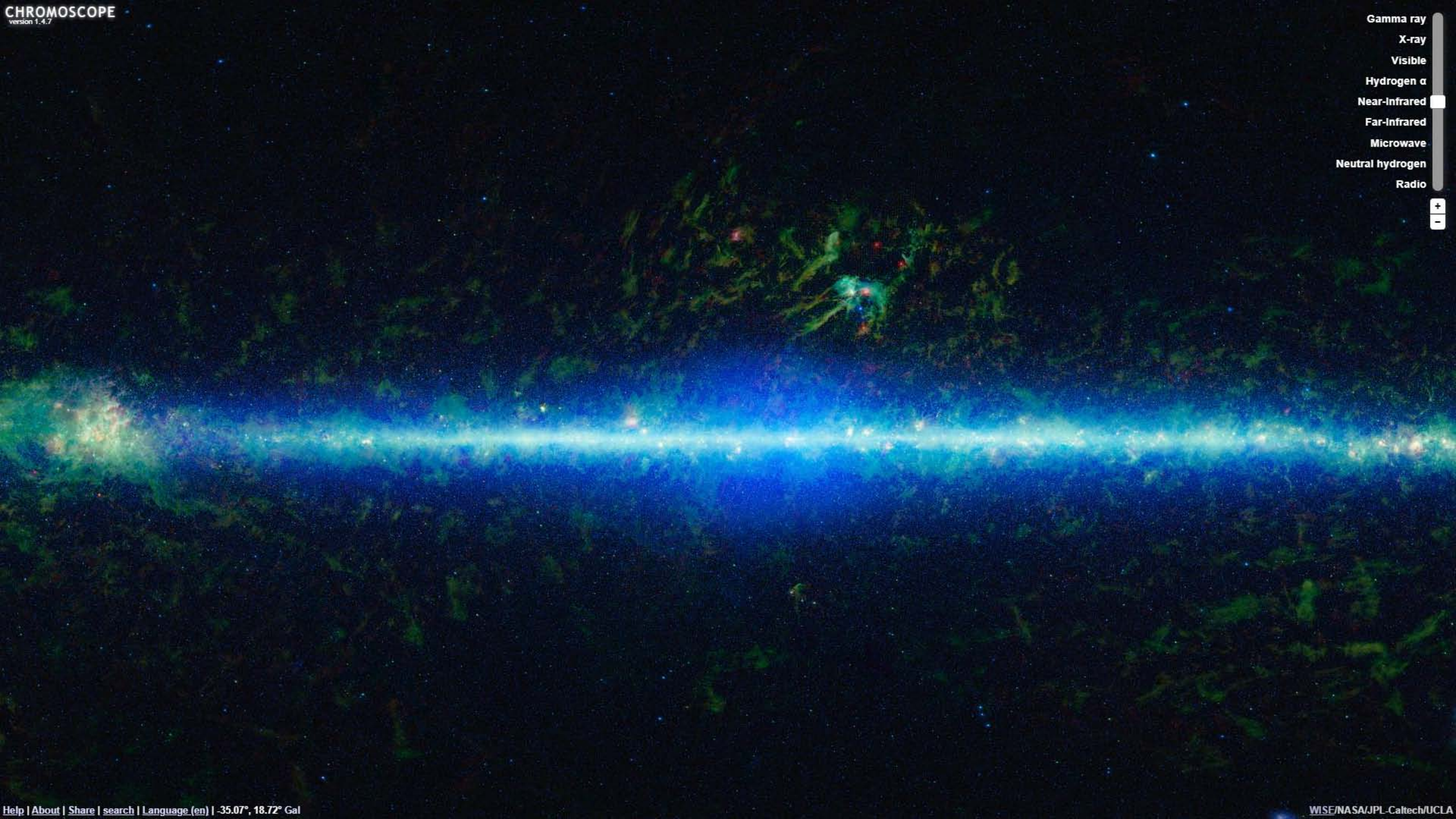
Astronomia multimessaggera


CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
-
Help | About | Share | search | Language (en) | 7.29°, 3.34° Gal
Fermi


CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
-
Help | About | Share | search | Language (en) | -0.18°, 16.70° Gal
ROSAT

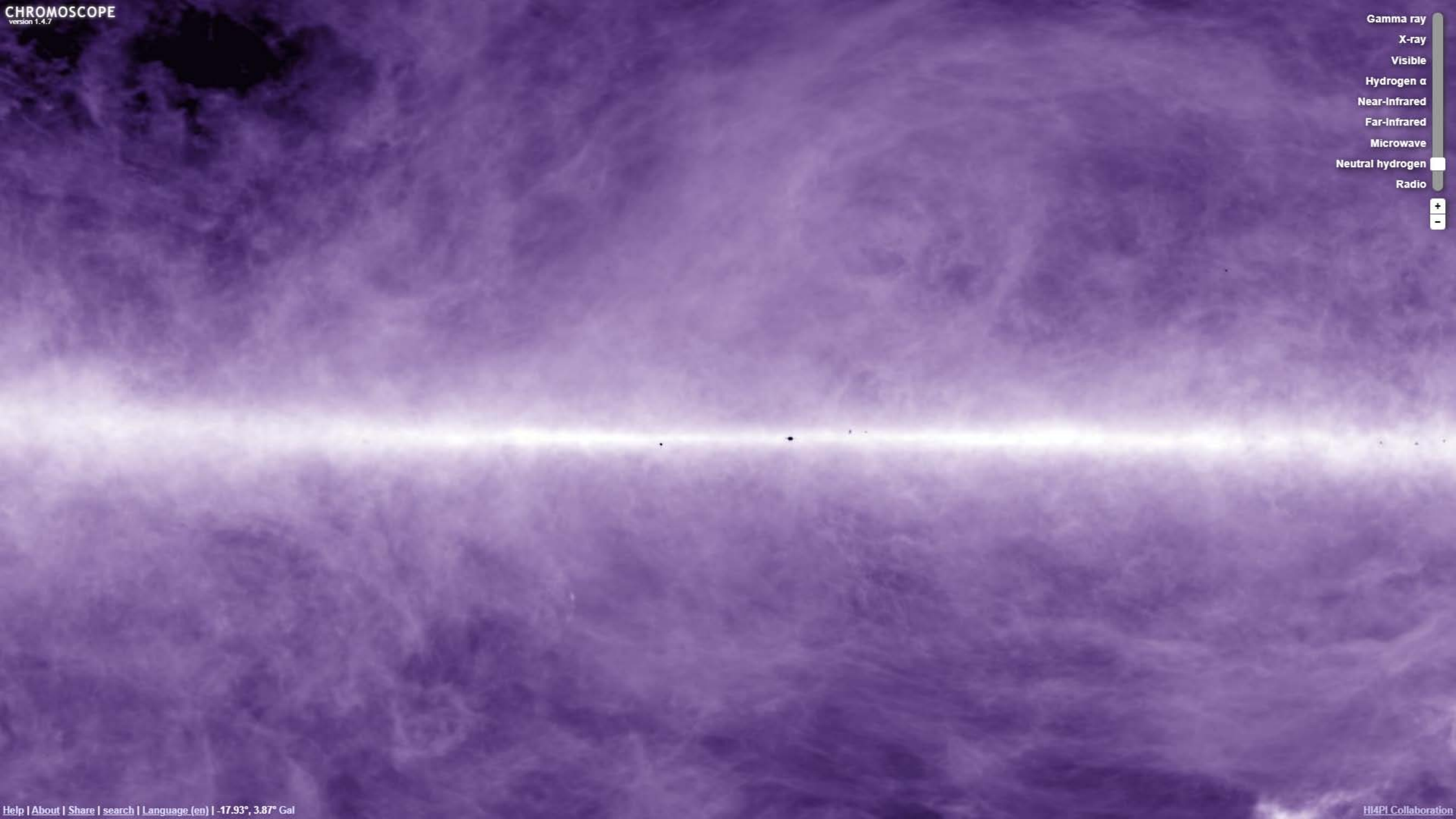

CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
-
Help | About | Share | search | Language (en) | -5.19°, 16.96° Gal
Nick Risinger, skysurvey.org

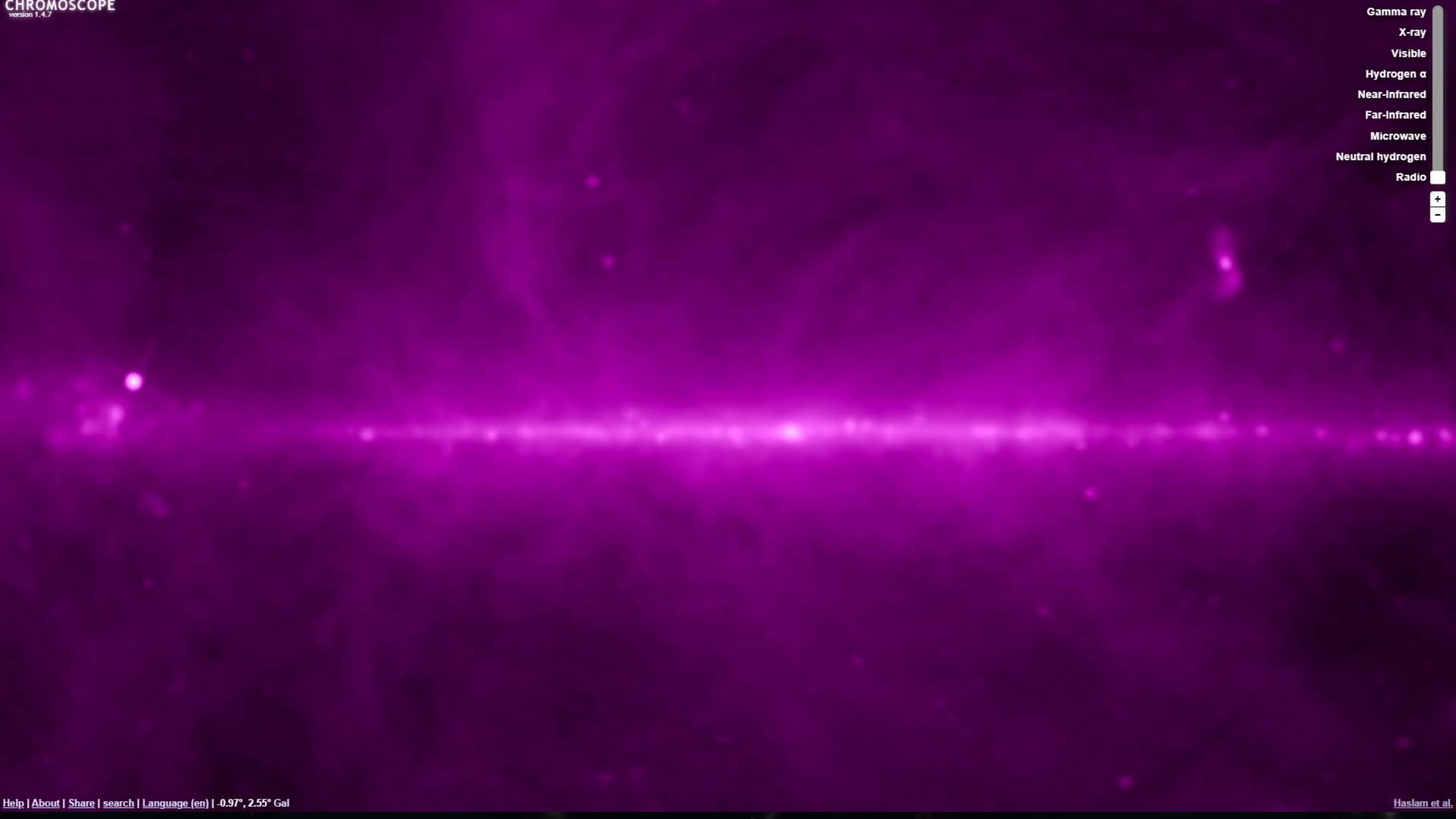

CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
−
Help | About | Share | search | Language (en) | -15.91°, 27.07° Gal
WHAM/VTSS/SHASSA/Finkbeiner

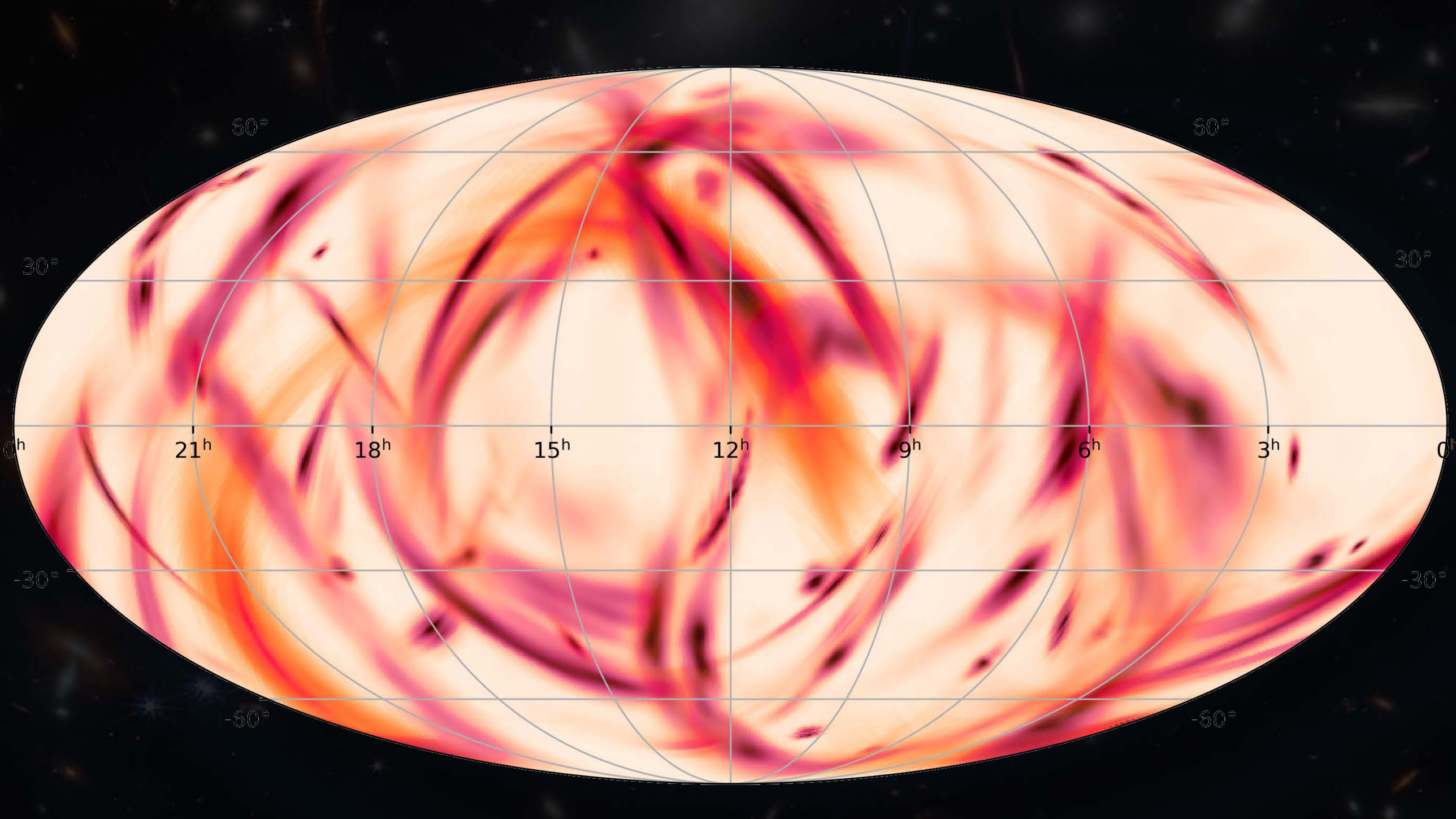

CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
−
Help | About | Share | search | Language (en) | -35.07°, 18.72° Gal
WISE/NASA/JPL-Caltech/UCLA

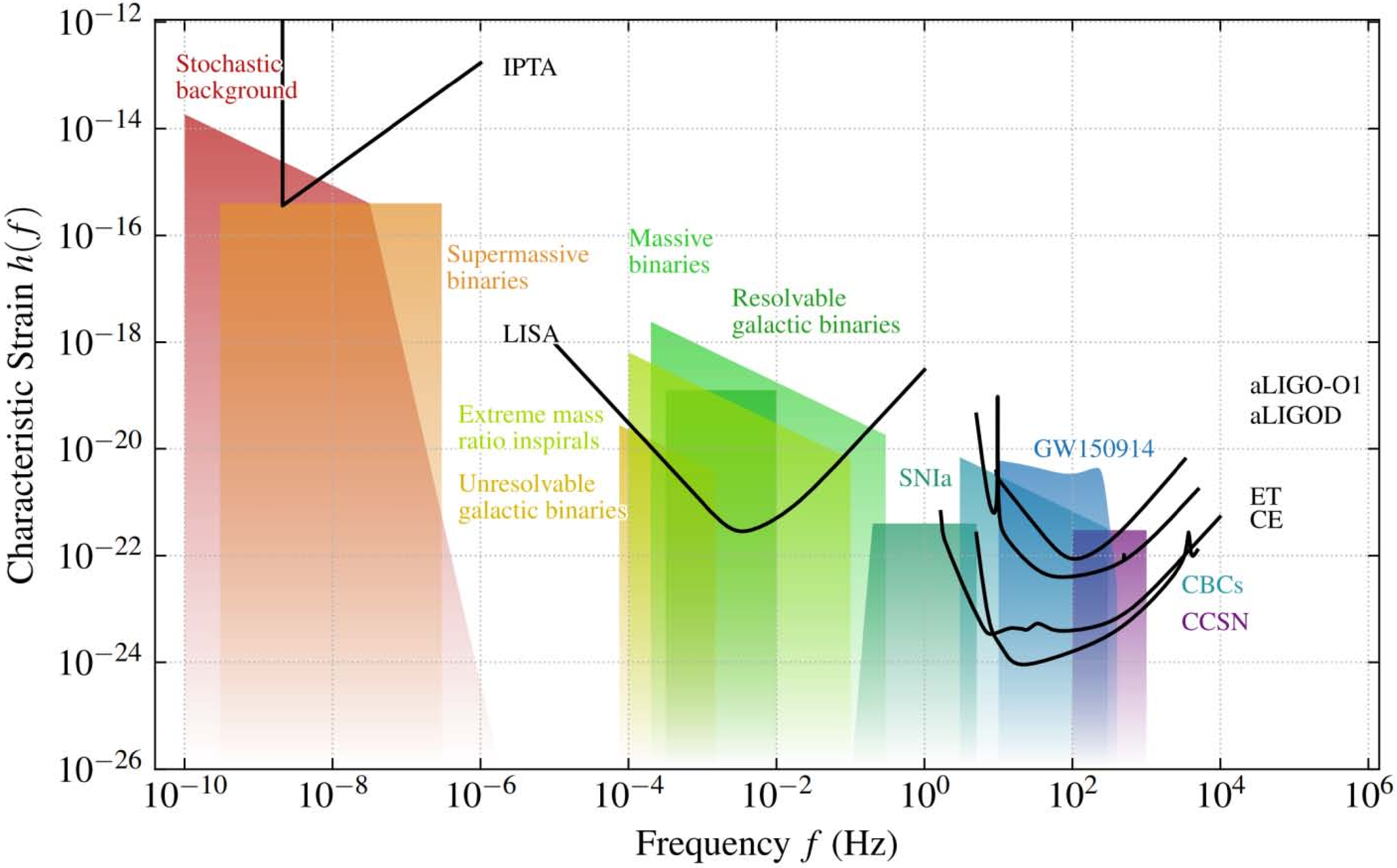

CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
-
Help | About | Share | search | Language (en) | -26.28°, 20.04° Gal
IRAS/NASA

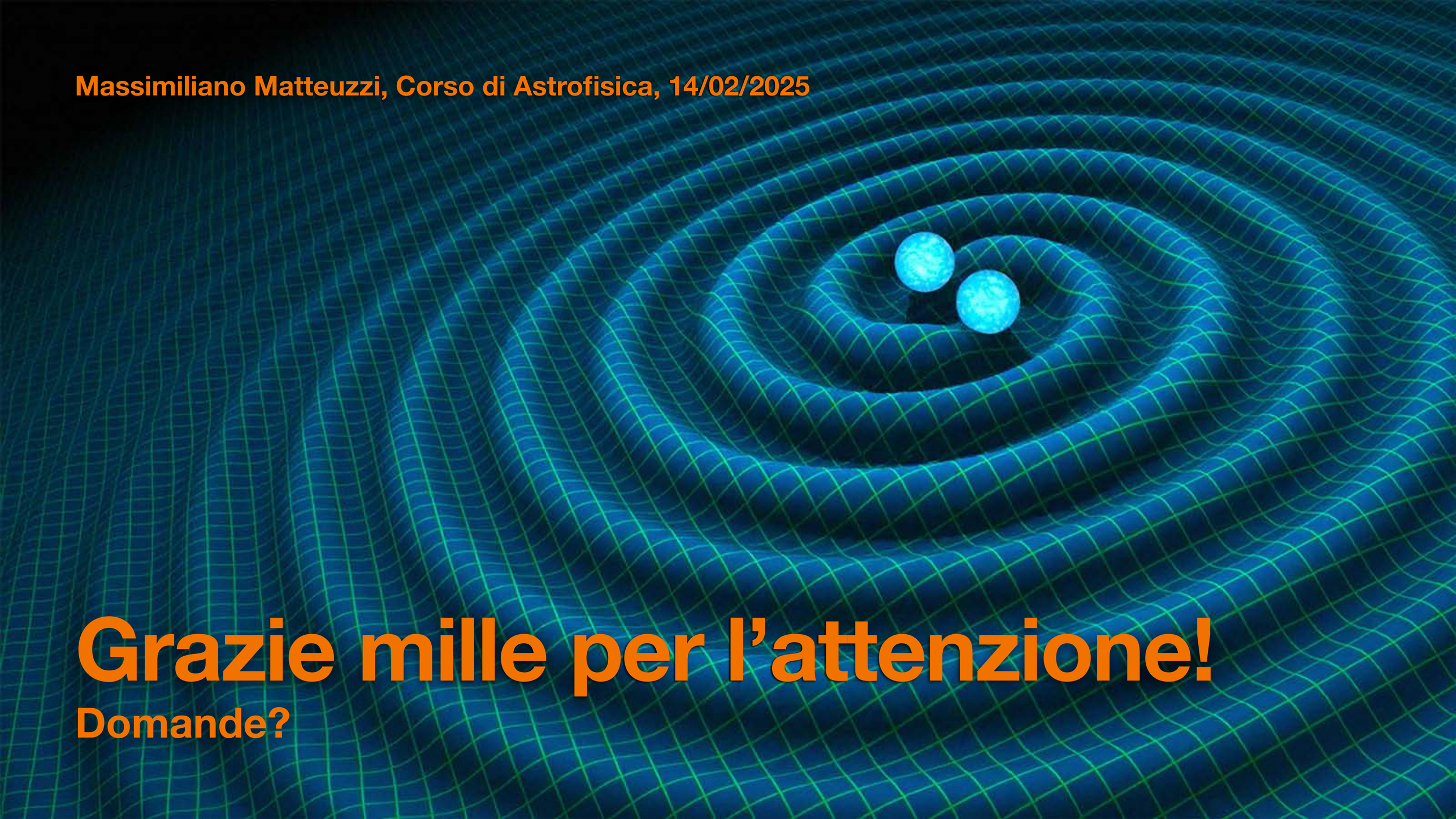

CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
-
Help | About | Share | search | Language (en) | -17.93°, 3.87° Gal
ESA Planck LFI and HFI Consortia (2010)


CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
-
Help | About | Share | search | Language (en) | -17.93°, 3.87° Gal
HI4PI Collaboration


CHROMOSCOPE
version 1.4.7
Gamma ray
X-ray
Visible
Hydrogen α
Near-Infrared
Far-Infrared
Microwave
Neutral hydrogen
Radio
+
-
Help | About | Share | search | Language (en) | -0.97°, 2.55° Gal
Haslam et al.


60°
30°
0h
21h
18h
15h
12h
9h
6h
3h
-30°
-60°


Characteristic Strain $h(f)$
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
10^{-24}
10^{-26}
Stochastic background
IPTA
Supermassive binaries
Massive binaries
Resolvable galactic binaries
LISA
Extreme mass ratio inspirals
Unresolvable galactic binaries
SNIa
GW150914
aLIGO-O1
aLIGOD
ET
CE
CBCs
CCSN
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
Frequency f (Hz)



Grazie mille per l'attenzione!

Domande?

Bibliografia

- https://www.virgo-gw.eu
- https://www.ligo.caltech.edu/images
- https://data.cardiffgravity.org/waveform-fitter/?lang=en
- https://blackholehunter.org/game.html
- https://peviewer.igwn.org/?event1=GW150914
- Nicola Borghi (https://nicoborghi.github.io)