

# FOTONI E ONDE GRAVITAZIONALI: CTA E VIRGO



TOR VERGATA  
UNIVERSITÀ DEGLI STUDI DI ROMA

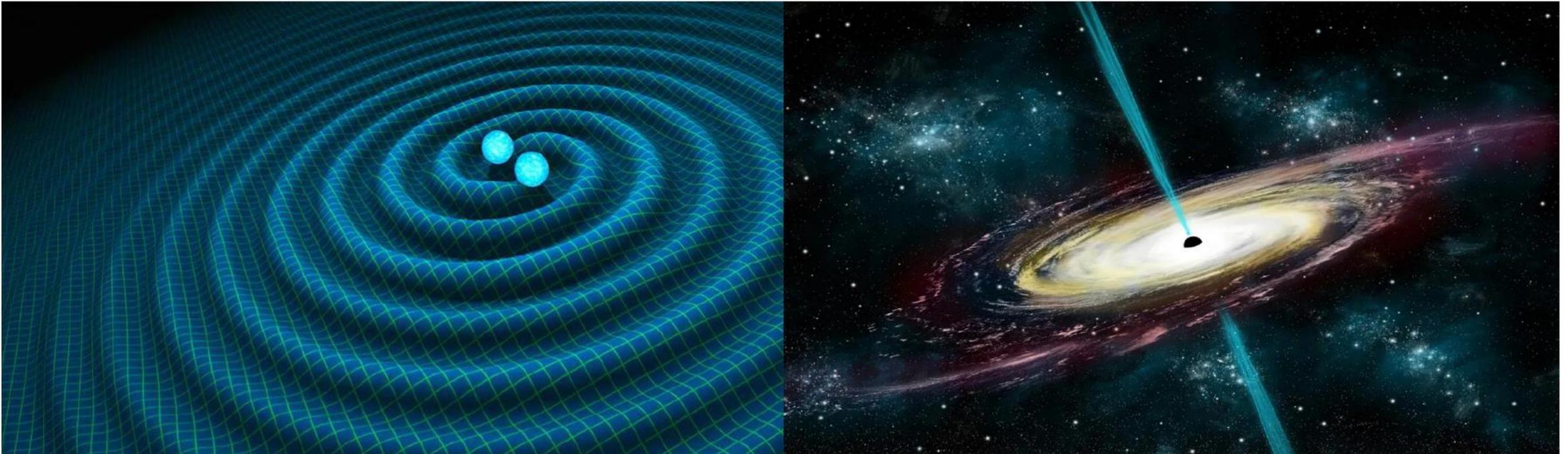
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International Cosmic Day 2023  
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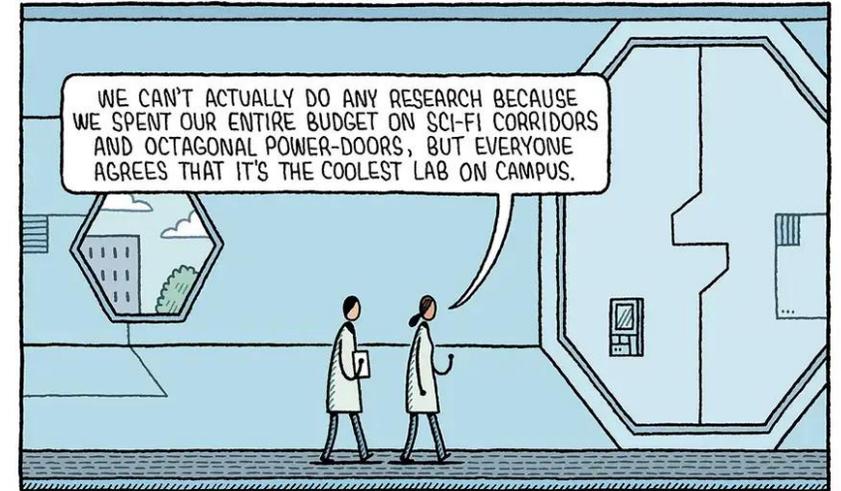


Istituto Nazionale di Fisica Nucleare  
SEZIONE DI ROMA TOR VERGATA

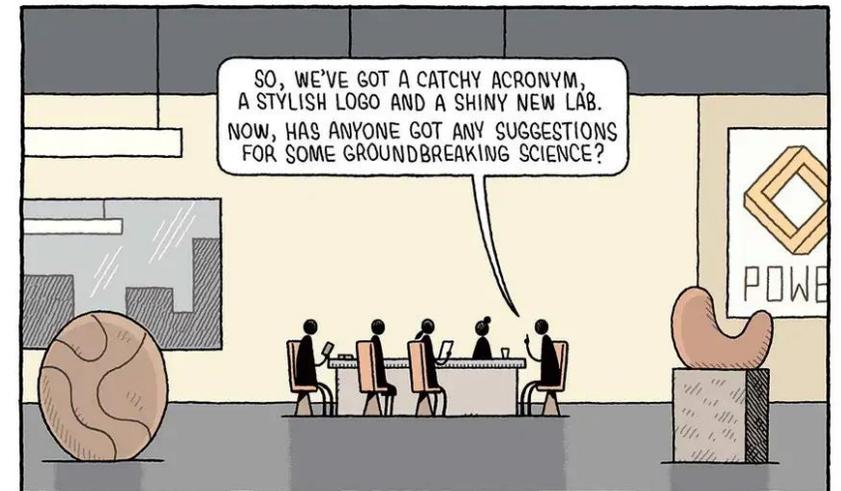


# OUTLINE

- Radiazione Elettromagnetica
- Raggi Gamma - CTA
- Onde Gravitazionali - Virgo
- Astrofisica Multimessenger
- Possibilità scientifiche dell'Astrofisica Multimessenger
  - Transienti
  - Cosmologia
  - Fisica Fondamentale



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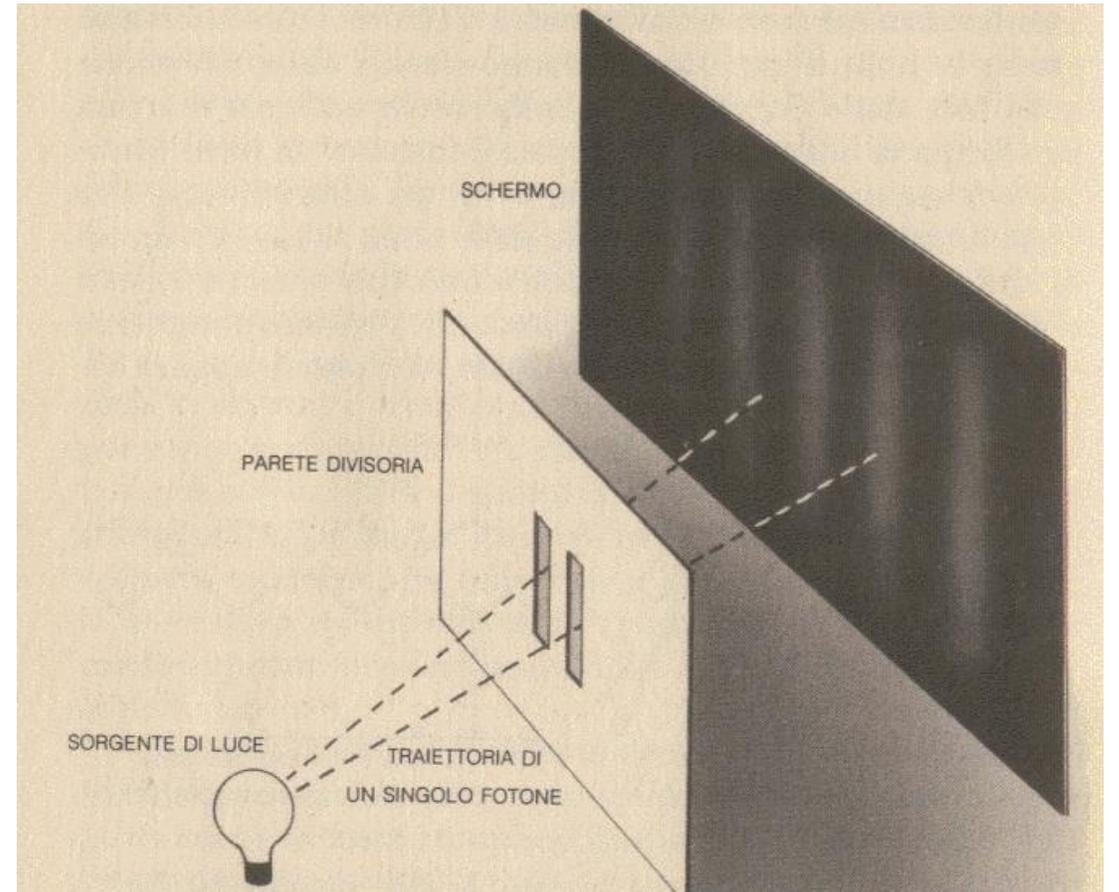
# RADIAZIONE ELETTROMAGNETICA

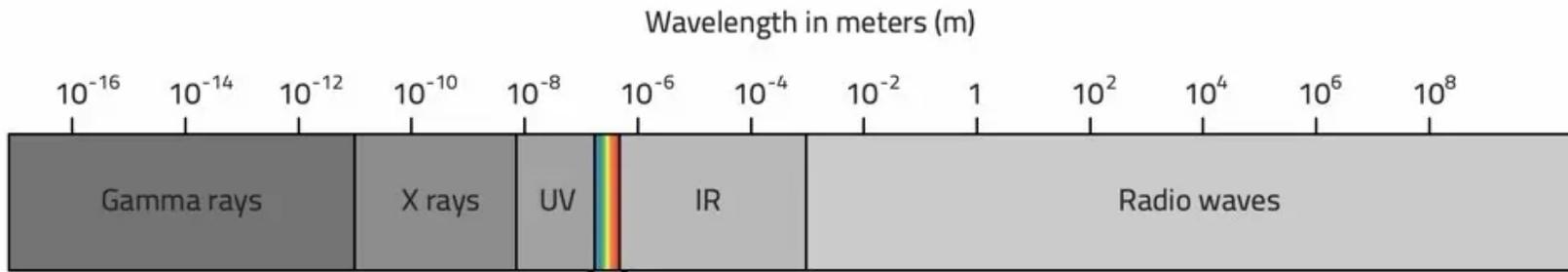
- Già parlato tanto...
- Propagazione nello spazio dell'energia di campo elettromagnetico
- Duplice natura, ondulatoria e particellare

- $E = h\nu$

E = energia  
h = costante di Planck  
 $\nu$  = frequenza  
c = velocità della luce  
 $\lambda$  = lunghezza d'onda

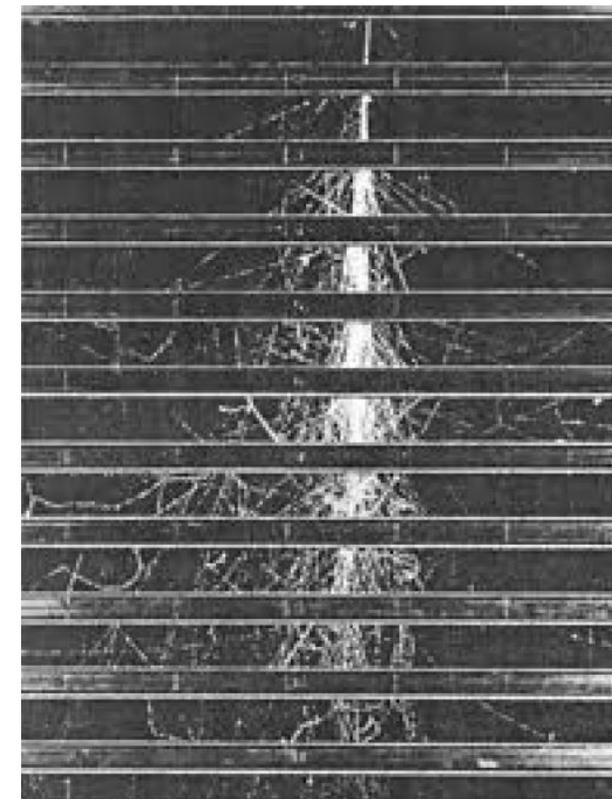
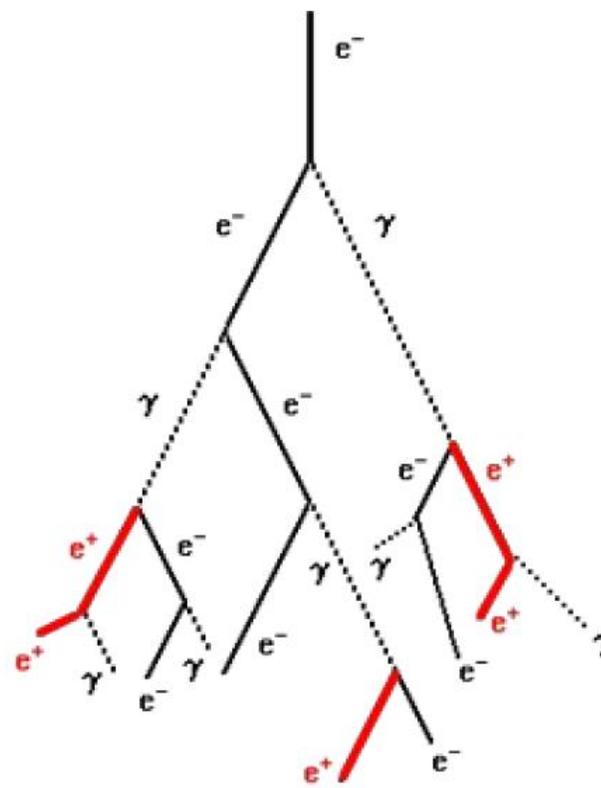
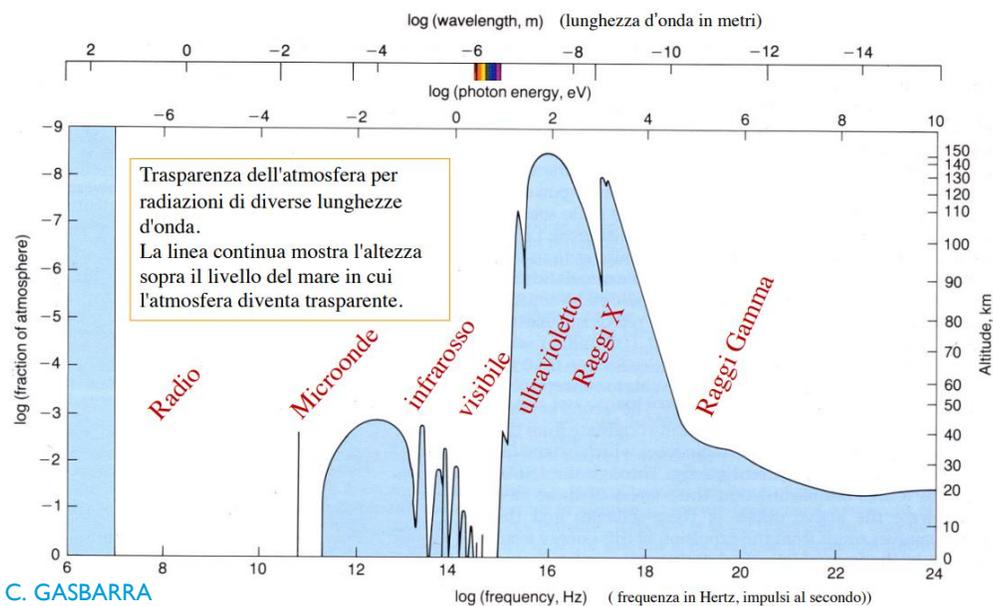
- $c = \lambda\nu$





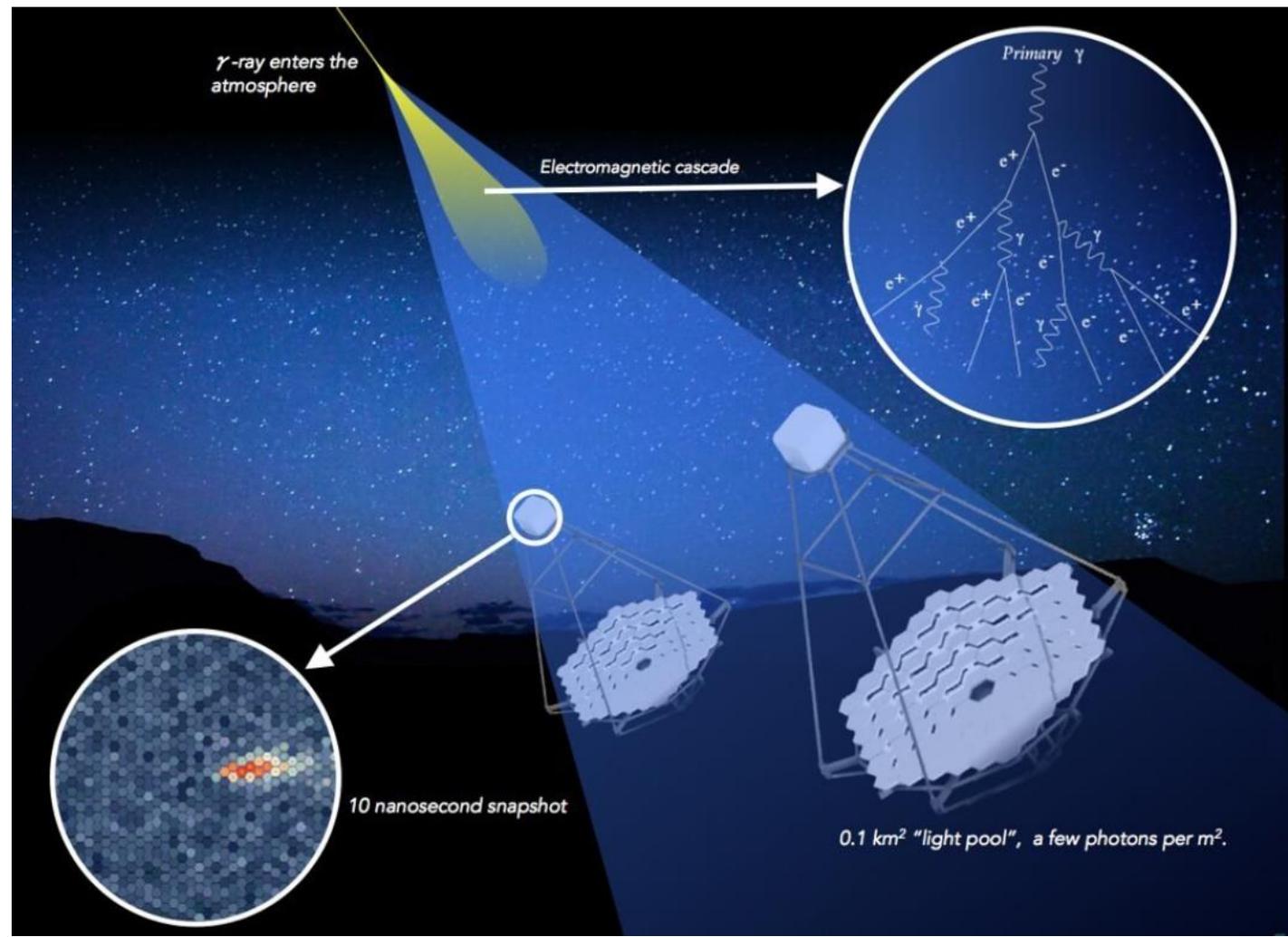
# RAGGI GAMMA

- I raggi gamma sono tipicamente osservati nello spazio
- Troppo energetici per i telescopi!
- Produzione di coppie elettrone - positrone

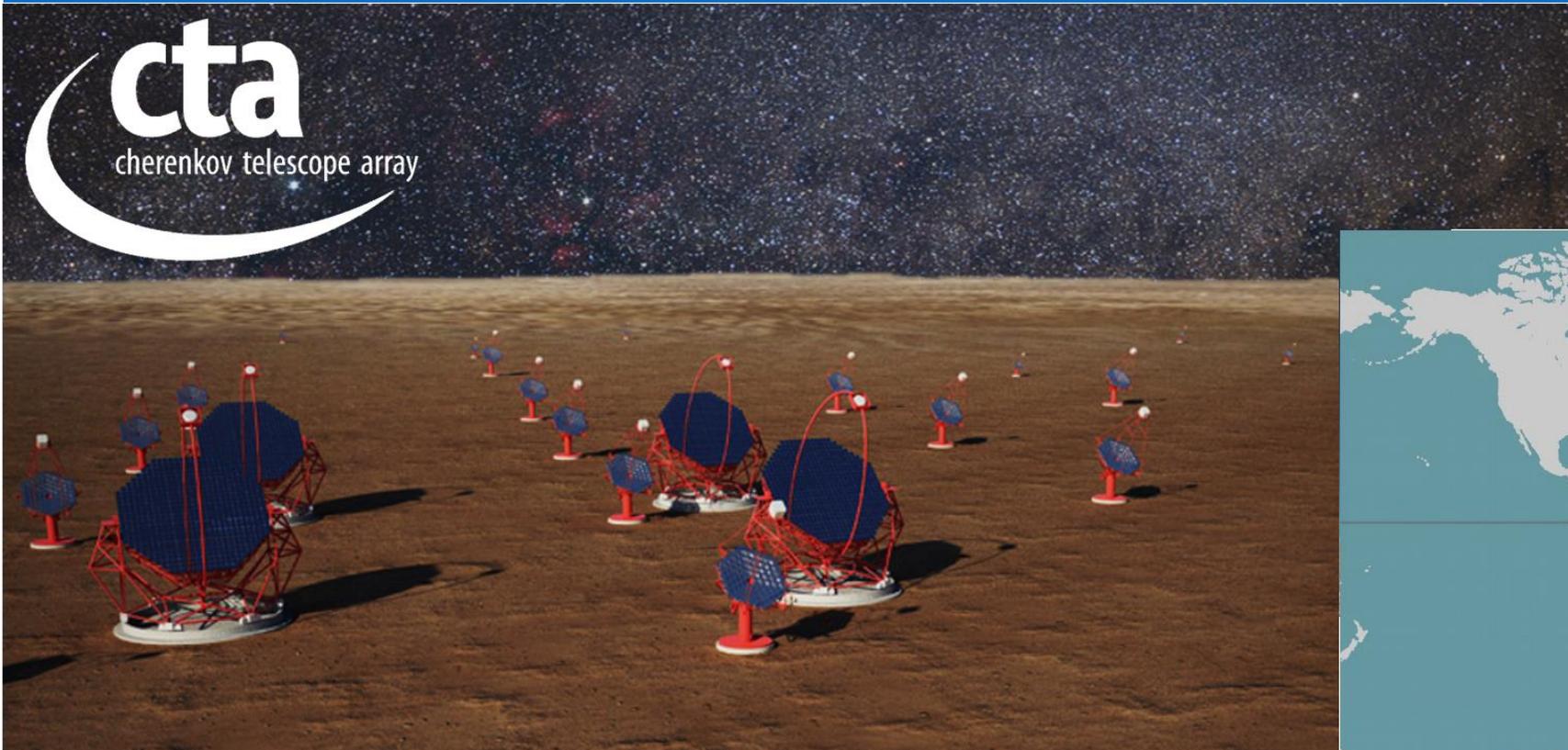


# RAGGI GAMMA OSSERVATI DA TERRA

- IACT: *Imaging Atmospheric Cherenkov Telescope*
- L'atmosfera funge da mezzo, per innescare il processo
- Effetto *Cherenkov*



# CTA: CHERENKOV TELESCOPE ARRAY



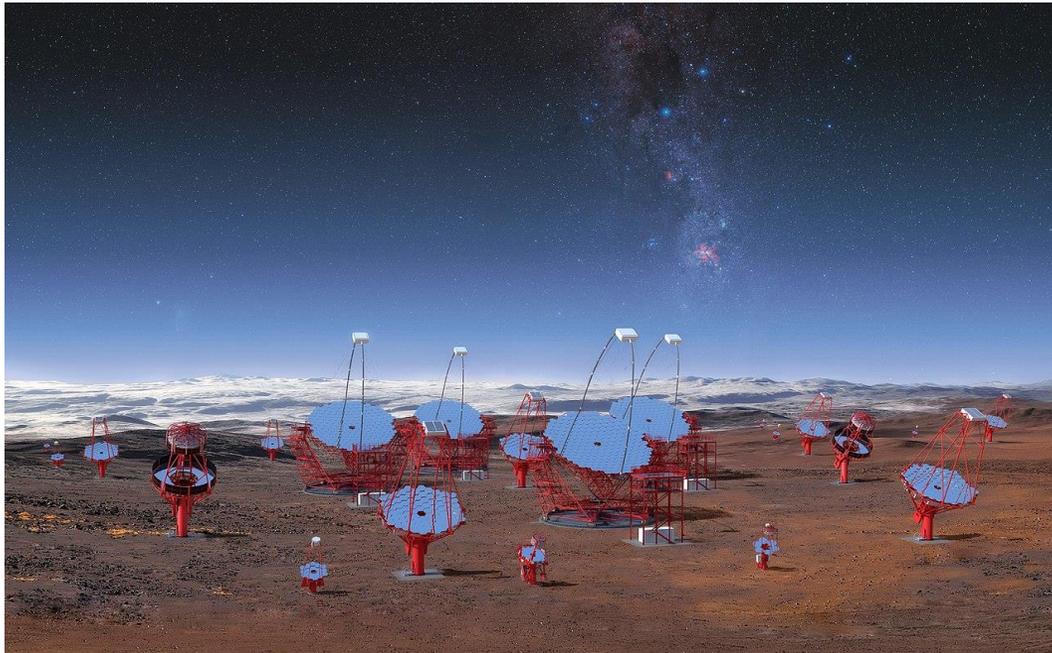
Due siti per osservare il cielo

Telescopi di tre grandezze per tre range di energia



# CTA: SITO NORD E SUD

- Sud: Paranal, Deserto di Atacama, Chile



- Ottimo per osservazioni della Via Lattea

- Nord: Roque de los Muchachos, La Palma, Spagna



- Ottimo per osservazioni extra-galattiche

# LST-1



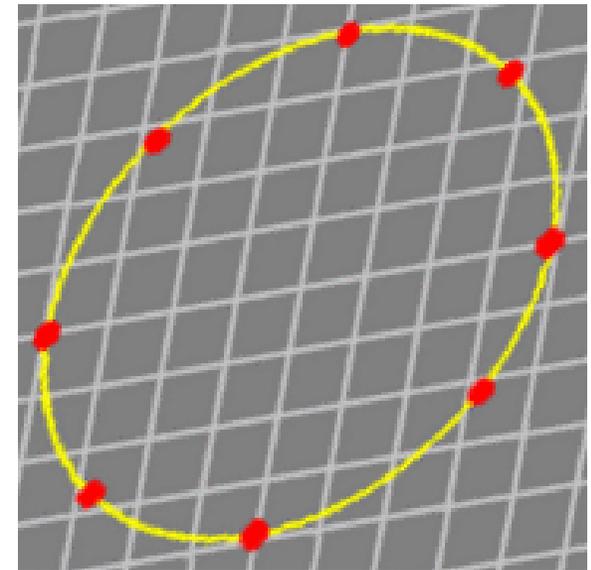
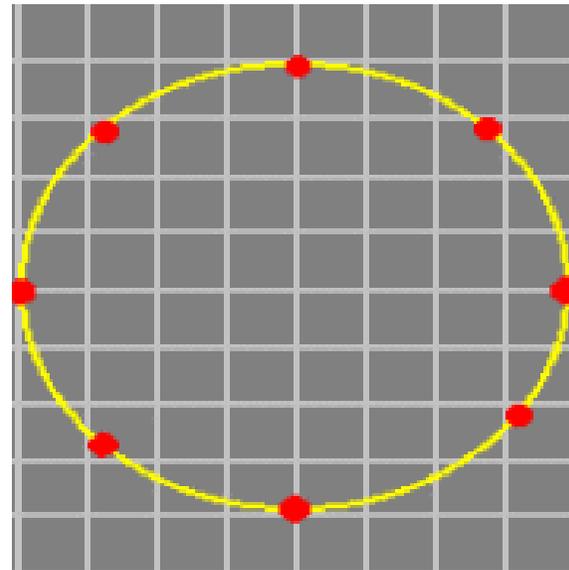
- Diametro 23 m, Range energetico 20 GeV – 300 TeV
- Può ruotare completamente in 30 s

- Presto altri tre a La Palma e quattro a Paranal



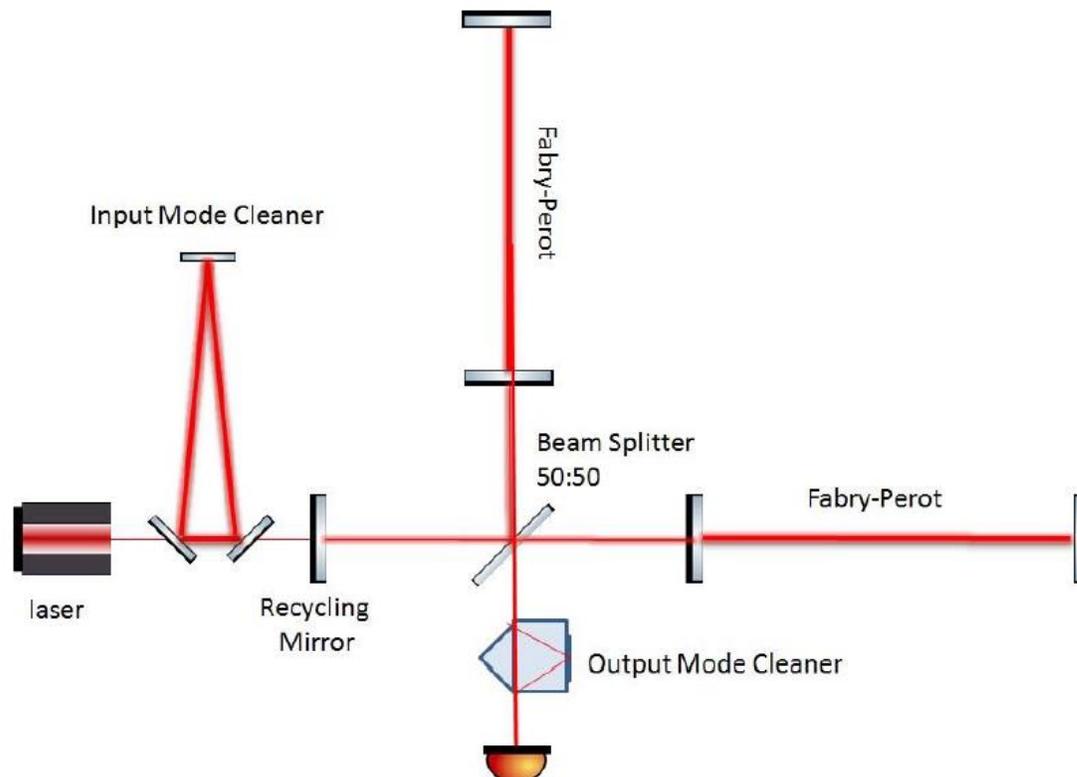
# ONDE GRAVITAZIONALI

- 1915: Einstein → Teoria della Relatività Generale
- La gravità è una proprietà geometrica dello spazio-tempo dipendente dalla distribuzione di massa
- 1916: Onde Gravitazionali
- Increspature dello spazio-tempo che si propagano come onde alla velocità della luce
- Possibile natura particellare: Gravitoni



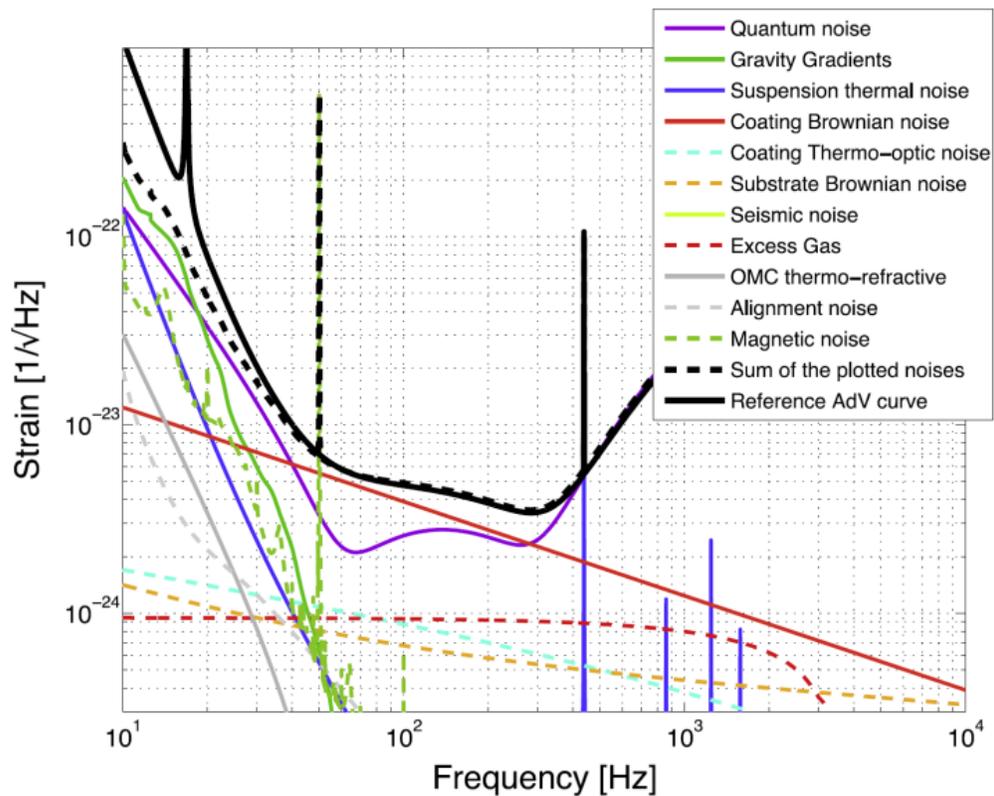
# RIVELATORI DI ONDE GRAVITAZIONALI

- Interferometri di Michelson



# (ADVANCED) VIRGO

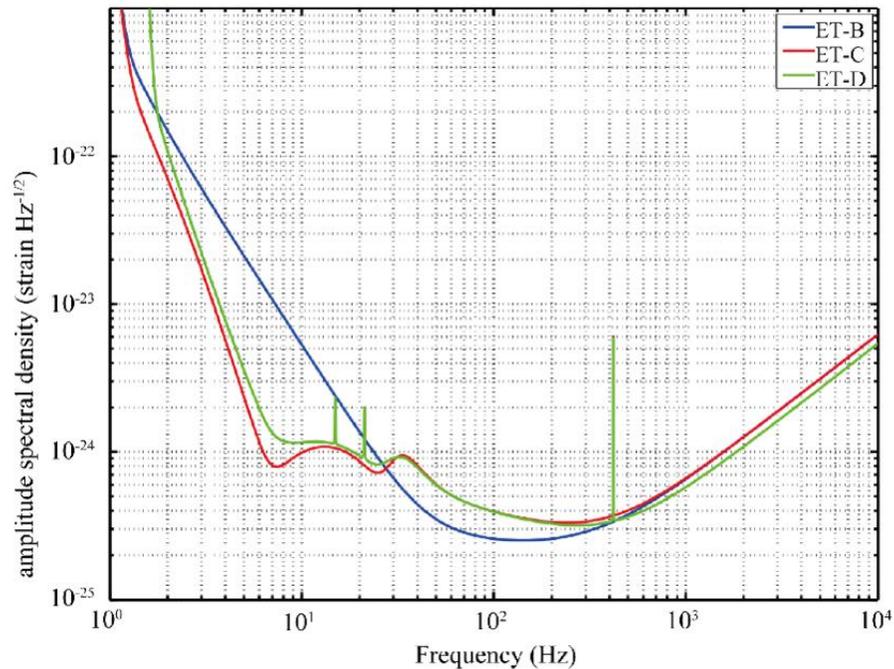
- Sensibilità limitata dal rumore



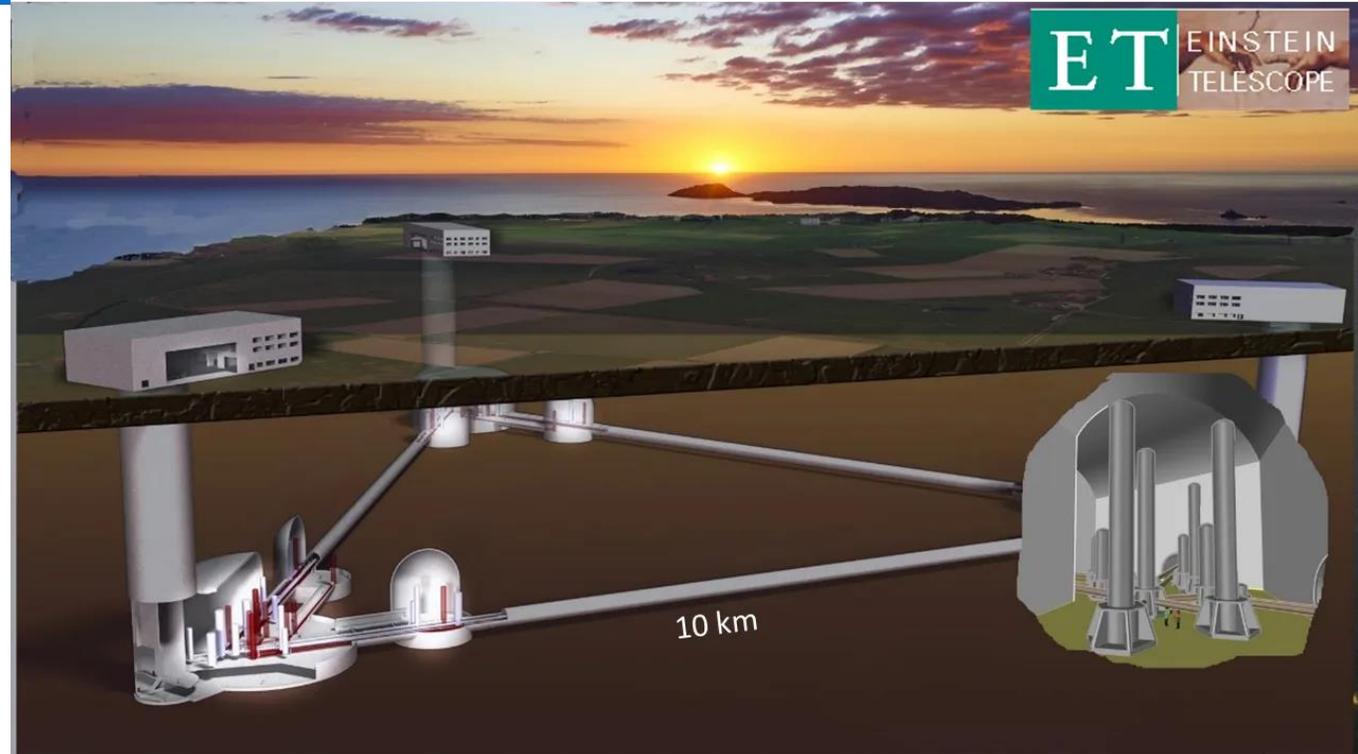
- Bracci di 3 km
- Componenti ottici sospesi
- Sistemi di limitazione del rumore termico o quantistico

# 3G DETECTOR: EINSTEIN TELESCOPE

- Sardegna o Euregio Meuse-Rhin
- Underground
- Ottiche criogeniche



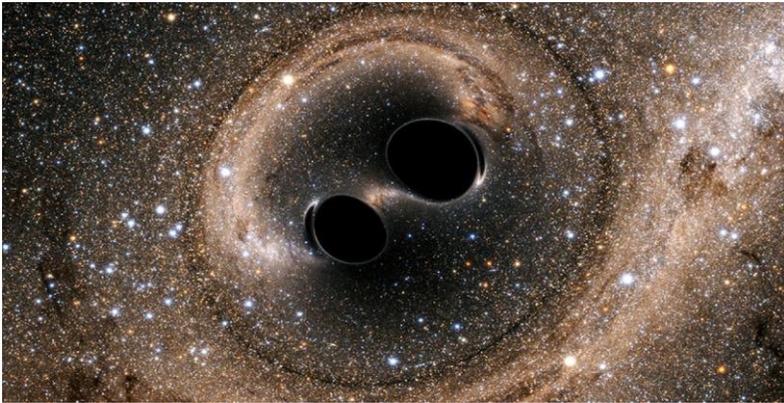
Natural Science, 2014, 6, 305-322, Iqbal et al.



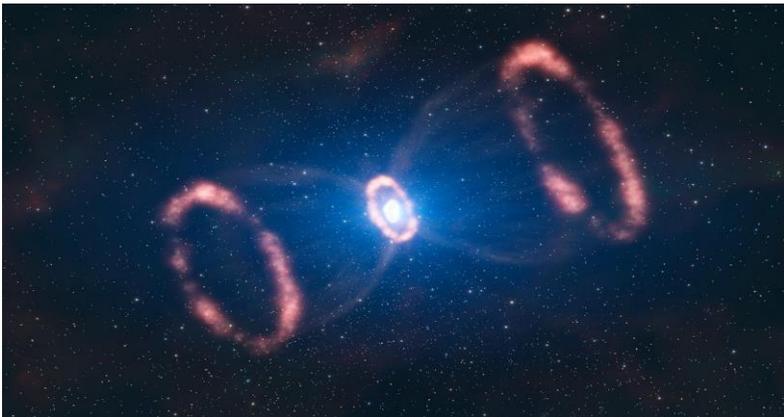
- Distanza di rivelazione 10 volte quella di Virgo → 1000x eventi!
- Possibilità di studio molto maggiori

# SORGENTI DI ONDE GRAVITAZIONALI

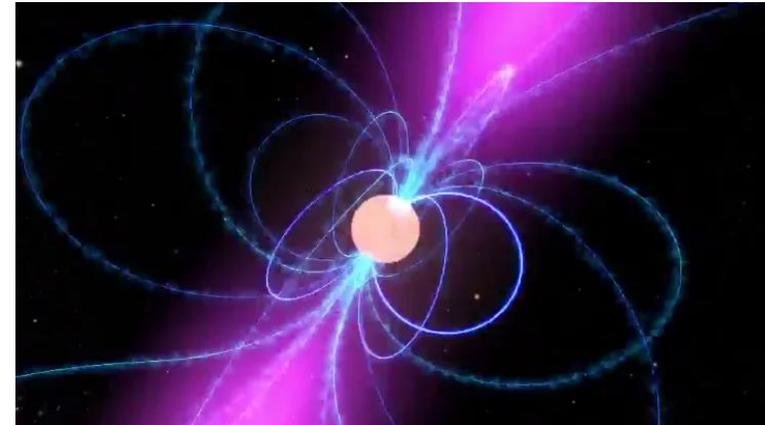
- **Binarie coalescenti: BH o NS**



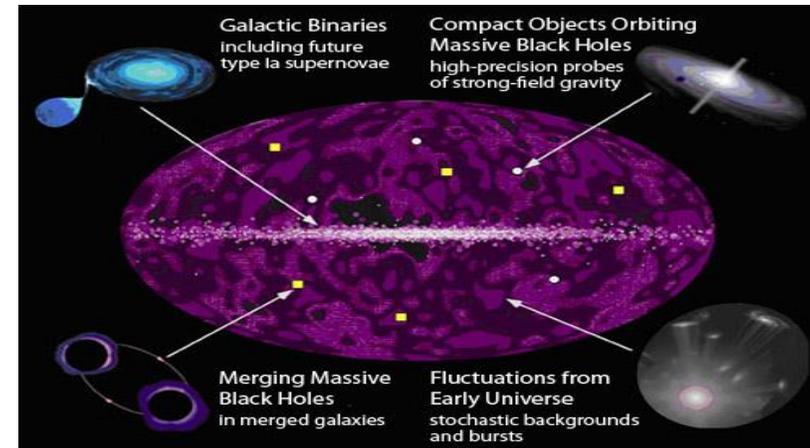
- **Core-Collapse Supernovae**



- **Pulsar**

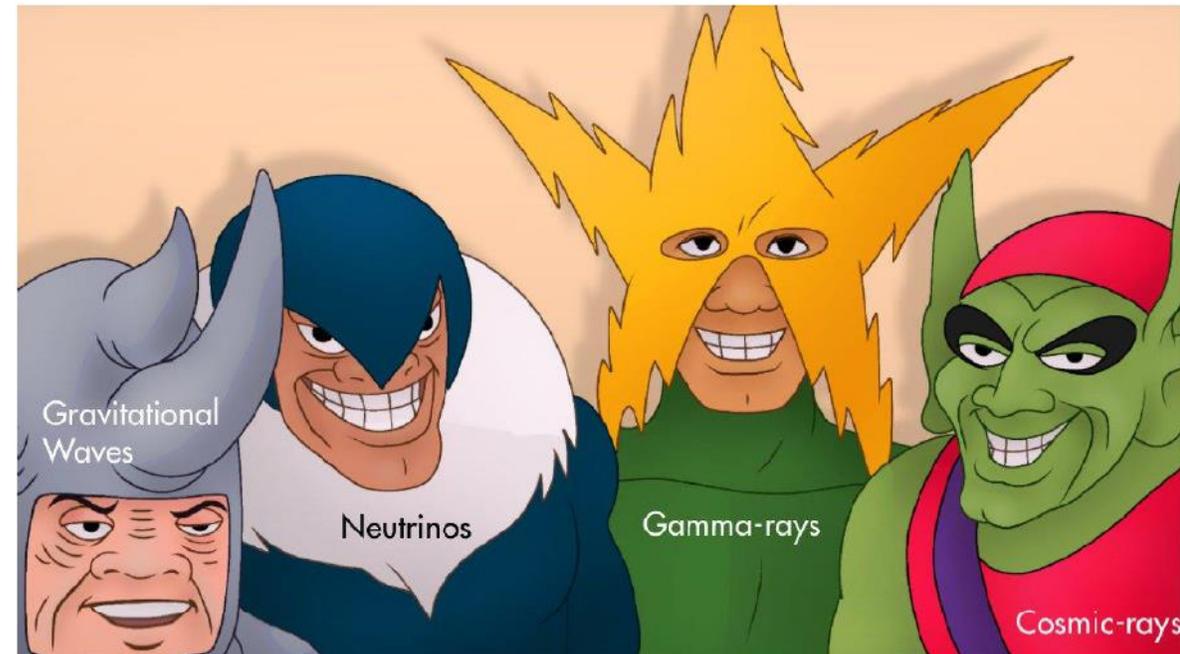


- **Background di onde gravitazionali**



# ASTROFISICA MULTIMESSENGER

- La rivelazione delle onde gravitazionali ha portato alla nascita dell'Astrofisica Multimessenger!
  - Diversi “messaggeri” cosmici portano informazioni diverse sulla stessa sorgente
- **Radiazione Elettromagnetica (Fotoni)**
  - Onde Gravitazionali (Gravitoni?)
  - Neutrini
  - **Raggi Cosmici**

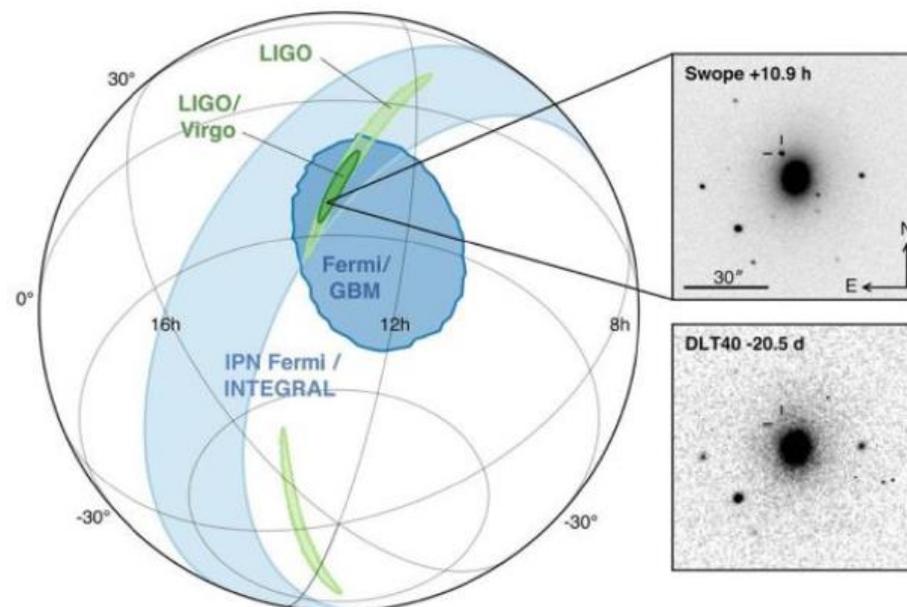




## Multi-messenger Observations of a Binary Neutron Star Merger

### Abstract

On 2017 August 17 a binary neutron star coalescence candidate (later designated GW170817) with merger time 12:41:04 UTC was observed through gravitational waves by the Advanced LIGO and Advanced Virgo detectors. The *Fermi* Gamma-ray Burst Monitor independently detected a gamma-ray burst (GRB 170817A) with a time delay of  $\sim 1.7$  s with respect to the merger time. From the gravitational-wave signal, the source was initially localized to a sky region of  $31 \text{ deg}^2$  at a luminosity distance of  $40_{-8}^{+8}$  Mpc and with component masses consistent with neutron stars. The component masses were later measured to be in the range  $0.86$  to  $2.26 M_{\odot}$ . An extensive observing campaign was launched across the electromagnetic spectrum leading to the discovery of a bright optical transient (SSS17a, now with the IAU identification of AT 2017gfo) in NGC 4993 (at  $\sim 40$  Mpc) less than 11 hours after the merger by the One-Meter, Two Hemisphere (1M2H) team using the 1 m Swope Telescope. The optical transient was independently detected by multiple teams within an hour. Subsequent observations targeted the object and its environment. Early ultraviolet observations revealed a blue transient that faded within 48 hours. Optical and infrared observations showed a redward evolution over  $\sim 10$  days. Following early non-detections, X-ray and radio emission were discovered at the transient's position  $\sim 9$  and  $\sim 16$  days, respectively, after the merger. Both the X-ray and radio emission likely arise from a physical process that is distinct from the one that generates the UV/optical/near-infrared emission. No ultra-high-energy gamma-rays and no neutrino candidates consistent with the source were found in follow-up searches. These observations support the hypothesis that GW170817 was produced by the merger of two neutron stars in NGC 4993 followed by a short gamma-ray burst (GRB 170817A) and a kilonova/macronova powered by the radioactive decay of  $r$ -process nuclei synthesized in the ejecta.



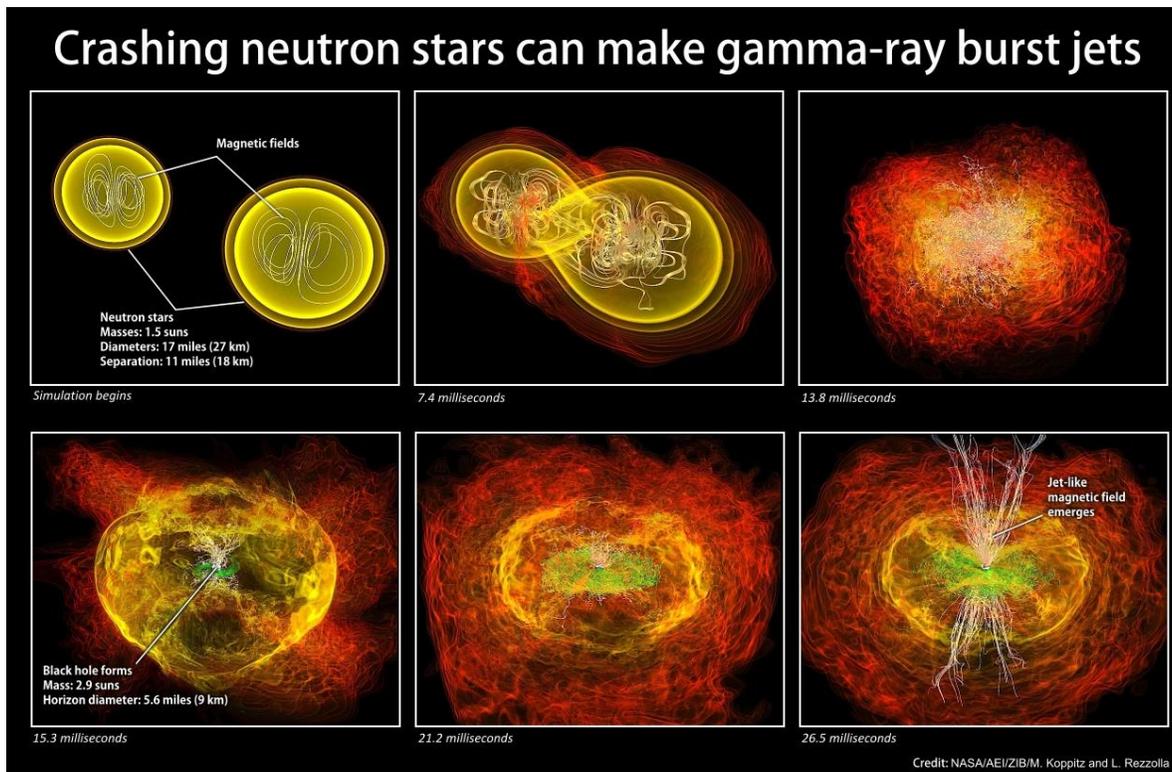
**Figure 1.** Localization of the gravitational-wave, gamma-ray, and optical signals. The left panel shows an orthographic projection of the 90% credible regions from LIGO ( $190 \text{ deg}^2$ ; light green), the initial LIGO-Virgo localization ( $31 \text{ deg}^2$ ; dark green), IPN triangulation from the time delay between *Fermi* and *INTEGRAL* (light blue), and *Fermi*-GBM (dark blue). The inset shows the location of the apparent host galaxy NGC 4993 in the Swope optical discovery image at 10.9 hr after the merger (top right) and the DLT40 pre-discovery image from 20.5 days prior to merger (bottom right). The reticle marks the position of the transient in both images.



Ma quali sono le possibilità scientifiche dell'astrofisica delle onde gravitazionali e, più in generale, dell'astrofisica multimessagger?

# TRANSIENTI

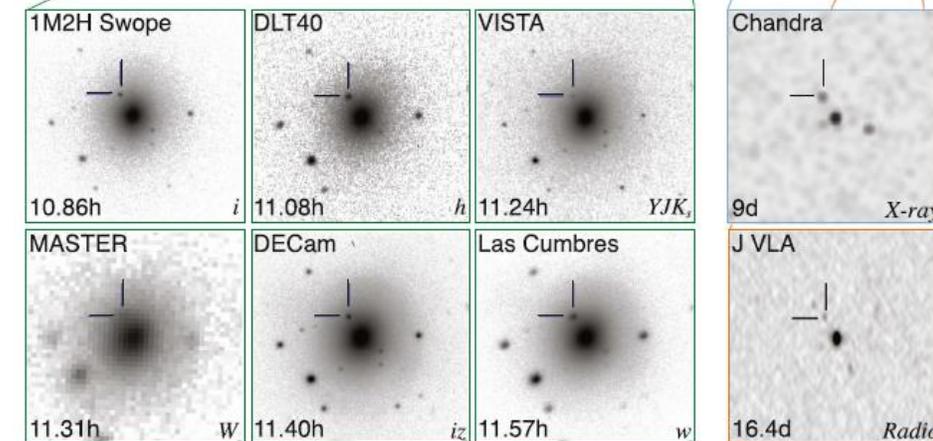
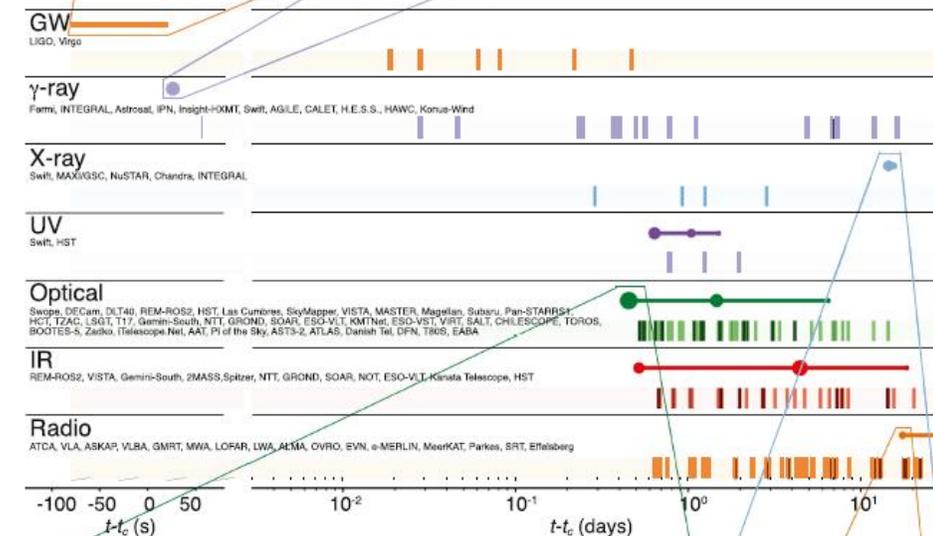
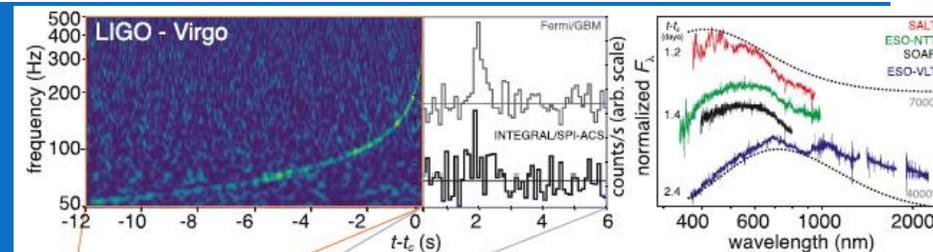
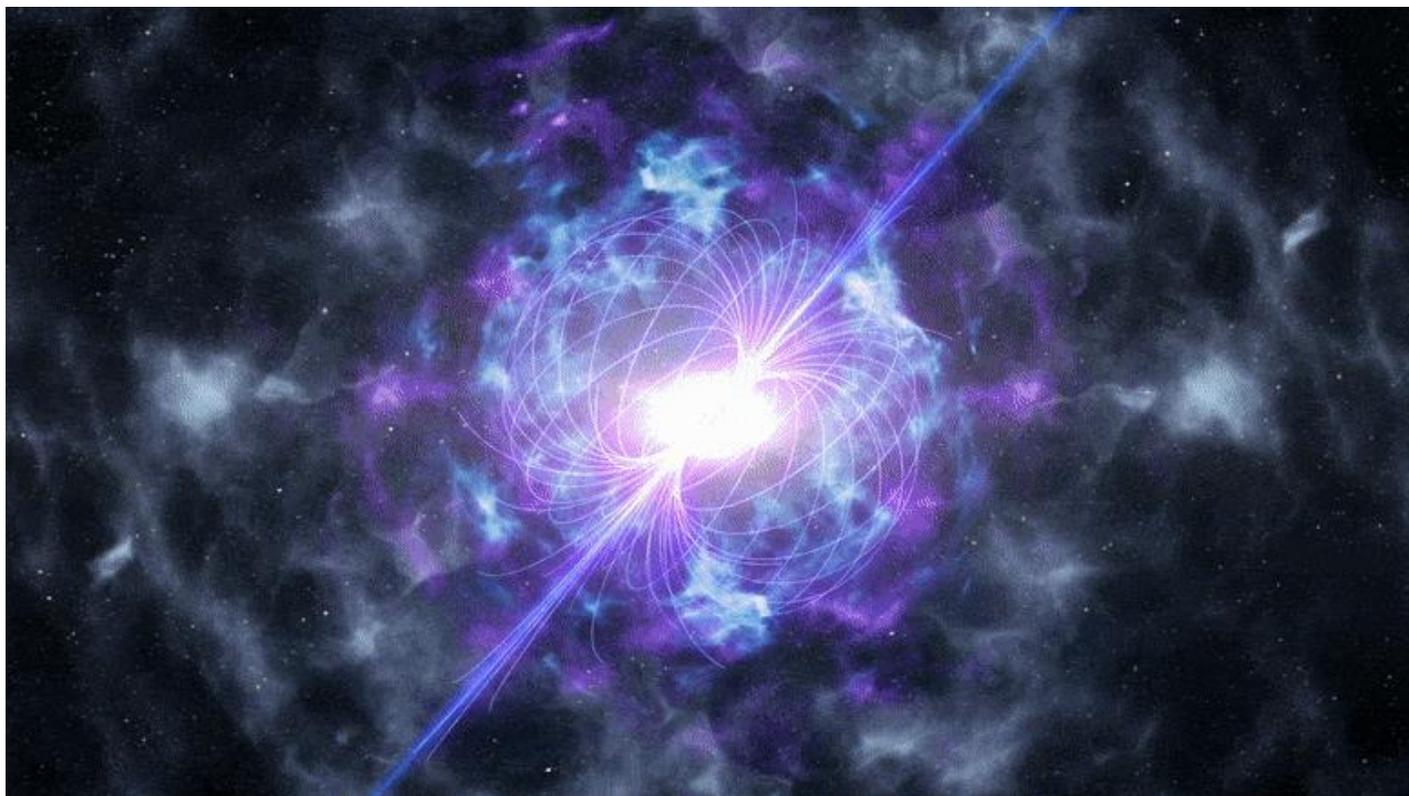
- La più importante classe di eventi per l'Astrofisica MM, nonché quella che racchiude gli eventi più interessanti



- 185: più antica supernova osservata
- 1604: Supernova di Keplero
- 1967: il volo di un razzo scopre la prima sorgente transiente di raggi X, CenX2
- 1968: “Observation of a Rapidly Pulsating Radio Source”, J. Bell et al., Nature
- 1973: annuncio della scoperta, da parte dei satelliti Vela, dei Gamma-Ray Burst

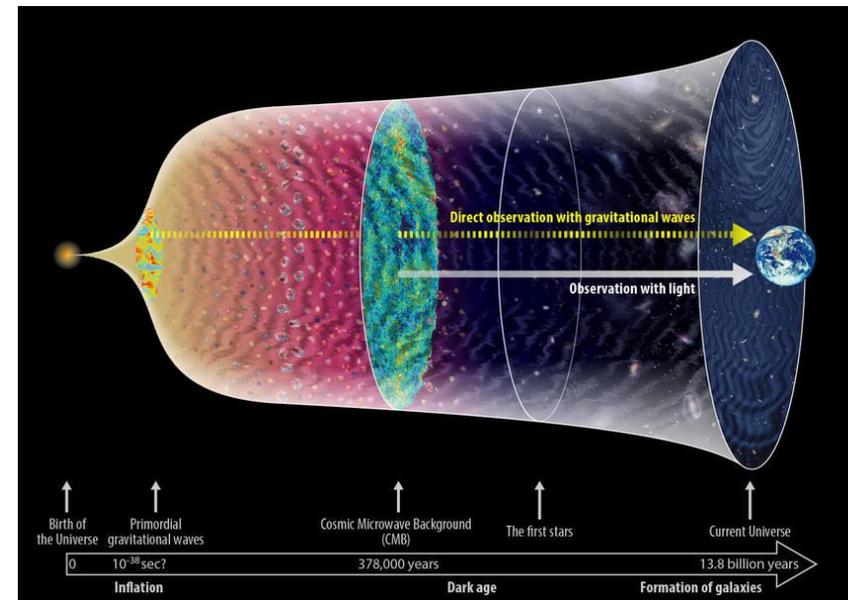
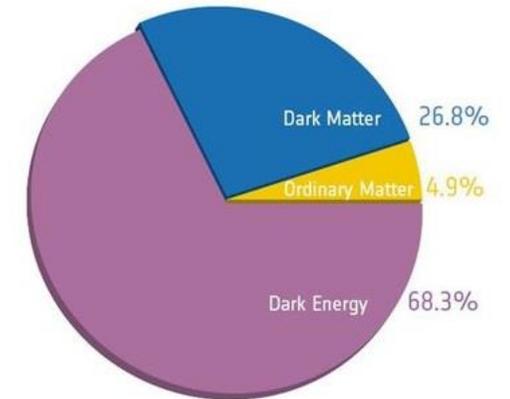
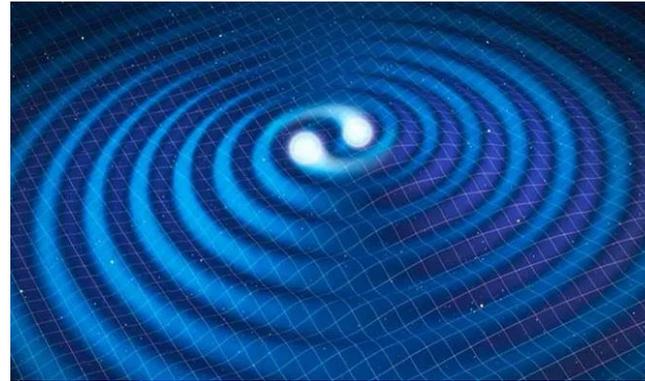
# TRANSIENTI – GW170817

- Gamma-Ray Burst
  - Prompt emission
  - Afterglow emission
- Kilonova
  - Emission legata alla nucleosintesi
  - Massimo nell'infrarosso



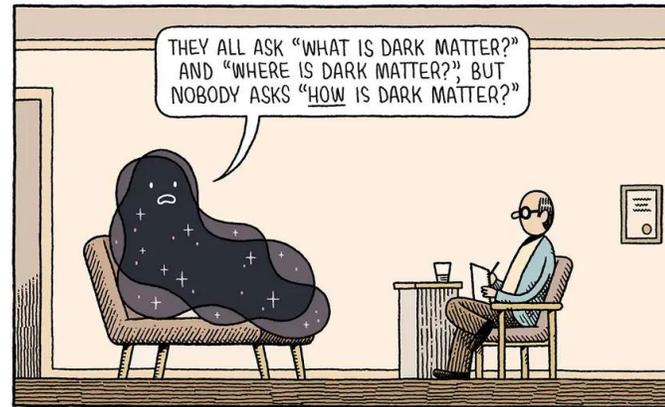
# COSMOLOGIA

- Costante di Hubble:  $v = H_0 D$
- Tasso di formazione stellare
- Energia oscura (grazie ai rivelatori 3G)
- Background di Onde Gravitazionali

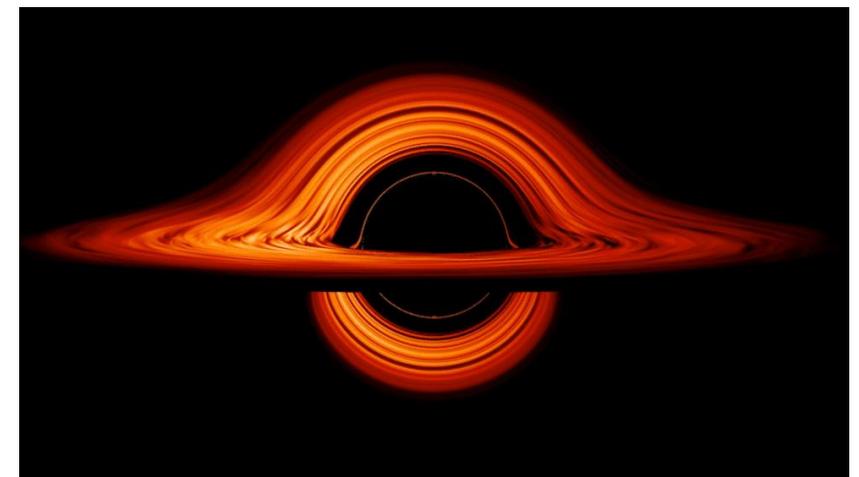
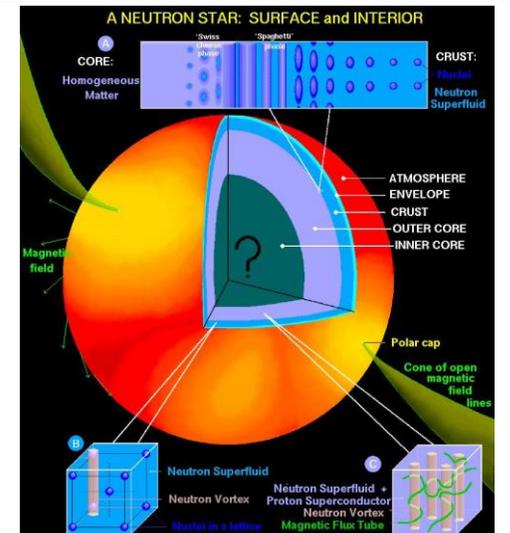


# FISICA FONDAMENTALE

- Materia oscura
- Struttura delle Stelle di Neutroni
- Velocità della gravità
- Gravità in condizioni estreme



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# Grazie dell'attenzione

