### THE RICHNESS OF DIVERSITY IN THE NEW EXPLORATION OF THE UNIVERSE







#### 2003-2008 University of Bologna/Istituto di RadioAstronomia INAF



#### Astronomy Astronomy

#### l am an astronomer..



Chandra point-source counts in distant galaxy clusters\*

M. Branchesi<sup>1,2</sup>, I. M. Gioia<sup>2</sup>, C. Fanti<sup>2,3</sup>, R. Fanti<sup>2,3</sup>, and N. Cappelluti<sup>4</sup>



#### 2009 – From Bologna.....





....to Urbino



Credit: Paolo Mini

#### THE FIRST YEAR in a LARGE COLLABORATION...











### ... searching for electromagnetic signals...







#### THE FIRST EM-FOLLOW UP OF CANDIDATE GW SIGNALS



FIRST SEARCHES FOR OPTICAL COUNTERPARTS TO GRAVITATIONAL-WAVE CANDIDATE EVENTS

J. AASI<sup>1</sup>, J. ABADIE<sup>1</sup>, B. P. ABBOTT<sup>1</sup>, R. ABBOTT<sup>1</sup>, T. ABBOTT<sup>2</sup>, M. R. ABERNATHY<sup>1</sup>, T. ACCADIA<sup>3</sup>, F. ACERNESE<sup>4,5</sup>, C. ADAMS<sup>6</sup>, T. ADAMS<sup>7</sup>, R. X. ADHIKARI<sup>1</sup>, C. AFFELDT<sup>8</sup>, M. AGATHOS<sup>9</sup>, N. AGGARWAL<sup>10</sup>, O. D. AGUIAR<sup>11</sup>, P. AJITH<sup>1</sup>, B. ALLEN<sup>8,12,13</sup>

#### NEW FRONTIER IN ASTRONOMY: GW ASTRONOMY ?!?













GW PHYSICISTS, ASTRONOMERS, OBSERVERS, THEORETICIANS STARTED TO COMMUNICATE COLLABORATE, AND WORK TOGETHER ...

I was member of restricted LIGO and Virgo committee to define the observing plan for the advanced detector, the policy and organization of the EM followup program ...



...and I found many inspiring mentors and colleagues..





..freedom to express my view!



# **01-02 EM follow-up EM program**



LIGO & Virgo have signed MOUs with 95 groups for rapid

EM/neutrino follow-up of GW candidate events found in low-latency

#### **INVOLVED:**

About 200 EM instruments - satellites and ground based telescopes covering the full spectrum from radio to very highenergy gamma-rays

Worldwide astronomical institutions, agencies and large/small teams of astronomers

#### 2014-2018 I served as co-liaison of the LVC EM follow-up group







### Italy..opportunity to build a research group!

2013-2016: Principal Investigator in the FIRB research project: "New perspectives on the violent Universe: unveiling the physics of compact objects with joint observations of gravitational waves and electromagnetic radiation". Grant for excellent young researchers funded with 1MEUR by the Italian Ministry of Education, University and Research.



#### ISTITUTO NAZIONALE DI ASTROFISICA: the birth of GRAWITA

















Gravitational waves @ INAF

### A new window into the Universe

Earth





Credit: LIGO–Virgo







### O1 and O2: 11 CONFIDENT GW DETECTIONS

**GRAVITATIONAL-WAVE TRANSIENT CATALOG-1** 

ELIGO (///VIRG) 🎆 Georgia



LVC arxiv:1811.12907

### Source modelling



2015 September 14: GW150914 2015 October 12, GW151012 2015 December 26: GW151226 2017 January 04: GW170104 2017 June 06:GW170608

2017 August 14: GW170814 + other 4 BBHs



Low-latency GW data analysis pipelines to promptly identify GW candidates and send GW alerts



LSC ////VIRG



## Counterpart search



### 2017 August 14, 10:30:43 UT



#### Virgo observed its first BBH coalescence,GW170814



Credit: LIGO-Virgo

### 2017 August 14





### LH 1160 square degrees LHV 60 square degrees

## 17 August 2017, 12:41:04 UT

Credit: University of Warwick/Mark Garlick





Credit: NASA's Goddard Space Flight Center/CI Lab

# Coalescence of neutron star binary



17 August 2017, 12:41:04 UT

ata SIO NOAA, U.S. Navy NGA





### GW170817

Credit: LIGO/Virgo/NASA/Leo Singer



### The most extensive observing campaign ever....







#### GRB 170817A

- 100 times closer than typical GRBs observed by Fermi-GBM
- it is also "subluminous" compared to the population of long/short GRBs
- $10^2 10^6$  less energetic than other short GRBs



Abbott et al. 2017, APJL, 848, L13

Intrinsically sub-luminous event

or a classical short GRB viewed off-axis?



#### X-ray and radio emissions 9 and 16 days after the merger



10

Time since GW trigger [d]

100

### After 150 days from the BNS merger...





..unexpected slow achromatic flux—rise until ~ 150 days!



D'Avanzo et al. 2017, A&A

#### **RADIAL or ANGULAR STRUCTURE?**



# Mildly relativistic isotropic outflow (choked jet)





#### Structured Jet (successful) off-axis jet





[see e.g. Rossi et al. 2002, Zhang et al. 2002, Ramirez-Ruiz et al. 2002, Nakar & Piran 2018, Lazzati et al. 2018, Gottlieb et al. 2018, Kasliwal 2017, Mooley et al. 2017, Salafia et al. 2017, Ghirlanda et al. 2019]

### After 150 days from the BNS merger...decaying phase!





#### MULTI-WAVELENGTH LIGHT CURVES CANNOT DISENTANGLE THE TWO SCENARIOS!

[Margutti, et al. 2018, Troja, et al. 2018, D'Avanzo et al. 2018, Dobie et al. 2018, Alexander et al. 2018, Mooley et al. 2018, Ghirlanda et al. 2018]

#### **RADIO HIGH RESOLUTION IMAGING**



At the same epoch: structured jet has LARGER DISPLACEMENT and SMALLER SIZE than isotropic midly relativistic outflow!

[Gill & Granot 2018; Nakar+2018; Zrake+2018; Mooley+2018; Ghirlanda+2018]

#### SIZE CONSTRAINTS

Observations 207.4 days after BNS merger by global VLBI network of 33 radio telescopes over five continents constrain SOURCE SIZE < 2 mas





Ghirlanda et al. 2019, Science See also Mooley, Deller, Gottlieb et al. 2018

#### SIZE CONSTRAINTS

#### Ghirlanda et al. 2018, arXiv:1808.00469





Ruled out nearly isotropic, mildly relativistic outflow , which predicts proper motion close to zero and size > 3 mas after 6 months of expansion



A relativistic energetic and narrowly-collimated jet successfully emerged from neutron star merger GW170817!

Structured jet with a narrow ( $\theta c = 3.4$ ) and energetic core ( $10^{52}$  erg) seen under a viewing angle of ~15 degrees

### KILONOVA AND NUCLEOSYNTHESIS OF HEAVY NUCLEI



#### Courtesy of S. Ascenzi

#### Tidal Ejecta

unbound by hydrodynamic interaction and gravitational torques

#### Secular – isotropic

accretion disk matter unbound by viscous and nuclear heating

### **Red Macronova**

Peaks at days - 1 week after the merger

#### Shock-heated

squeezed mass at NS contact interface ejected by remnant pulsations

### **Blue Macronova**

Peaks at 1-2 day after the merger

#### **Disk Winds**

neutrino absorption or magnetically launched winds

### UV/Optical/NIR Light Curves



Extremely well characterized photometry of a Kilonova: thermal emission by radiocative decay of heavy elements synthesized in multicomponent (2-3) ejecta! ESO-VLT/X-Shooter

Brightness



Credit: ESO/E. Pian et al./S. Smartt & ePESSTO/L. Calçada



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# First spectral identification of the kilonova emission

- the data revealed signatures of the radioactive decay of r-process nucleosynthesis (Pian et al. 2017, Smartt et al. 2017)
- BNS merger site for heavy element production in the Universe!

(Cote et al. 2018, Rosswog et al. 2017)

#### Radioactively powered transients



### ...birth of MULTI-MESSENGER ASTRONOMY INCLUDING GW

THE ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (59pp), 2017 October 20 © 2017. The American Astronomical Society. All rights reserved. OPEN ACCESS





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

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-HXMT Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, HE.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT (See the end matter for the full list of authors.)

Received 2017 October 3; revised 2017 October 6; accepted 2017 October 6; published 2017 October 16





A discovery by 3500 world-wide physicists, astronomers, engineers, many others and their diversity... 16 October 2017 Member of the panel who announced GW170817 at the NSF international press-release





M. Branchesi Gran Sasso Science Institute









#### MARICA BRANCHESI: Merger maker

An astronomer helped scientists make the most of a historic gravitational-wave event.

BY DAVIDE CASTELVECCHI



Credit: Jim Watson/AFP/Getty

For a few weeks starting on 17 August, it seemed as if every telescope on Earth and in space was looking in the same direction. Prompted by the latest detection of gravitational waves by facilities in Italy and the United States, some 70 teams of astronomers rushed to capture the first direct observations of the collision between two inspiralling neutron stars. What they saw solved several astrophysical mysteries at once

#### TIME... what?



#### Opportunity to talk a wider audience















#### OpenLAB day – Laboratori Nazionali Del Gran Sasso /INFN











#### Stereotypes...



the genius solitary scientist ...

.

#### Satisfy your curiosity of knowledge....



#### L'Aquila 2009

### Where I am now...L'Aquila



### Resiliency



#### Resilienza:

La Resilienza è l'abilità di superare le avversità, di affrontare i fattori di rischio, di rialzarsi dopo una crisi, più forti e più ingegnosi di prima.

index1





GSSI GW group



#### Holy party!



The multi-messenger discoveries of the last years are the results of **PIONEERING SCIENTISTS** who worked for years to reach the dream of detecting GWs



+ the efforts of THOUSANDS OF WORLD-WIDE SCIENTISTS PHYSICISTS, ASTRONOMERS, ENGINEERS, MANY OTHERS AND THEIR DIVERSITY Now, more than ever, the importance of different scientific communities collaborating to overcome technological, observational and theoretical challenges with the aim of expanding our knowledge of the cosmos is evident.



#### NO WALLS BUT BRIDGES

#### Marcel Proust wrote:

The only real voyage consists not in seeking new landscapes, but in having new eyes; in seeing the universe through the eyes of another, one hundred of others, in seeing the hundred universes that each of them is.

### Ready for new discoveries...





This is only the beginning. New detections and discoveries are expected. We have instruments now able to observe what was invisible.....





