Multiwavelength studies of fast transients: GRBs, FRBs and GWs

OAS DAYS
Bologna, 17-18 dicembre 2018
GRBs and FRBs

The OAS GRBs and FRBs member team:

L. Amati, M. Dadina, G. De Cesare, E. Maiorano, N. Masetti, L. Nicastro, E. Palazzi, E. Pian, A. Rossi, G. Stratta
**Progenitor indications:**
- GW/GRB170817
- Lack of observed SN
- Association with older stellar population
- Larger distance from the host galaxy center (~ 5-10 kpc)

**Progenitor strong evidence:**
- Observed Type Ic SN spectrum
- Close to the center of the host galaxy
- Hosted in star-forming galaxies

**Kilonovae**
(Optical/IR, radio remnant)

**Supernovae Type Ib/c**

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**Merger of NS-NS / NS-BH**

**Core collapse of massive star**

**SHORT HARD GRBs**

**LONG SOFT GRBs**

~ 2 seconds
GRB-related works @ OAS

- Active members of the national CIBO (Coordinamento Italiano Burst Ottici) and the European STARGATE collaborations for the search and follow-up GRB afterglows at the INAF and ESO Telescopes respectively
- GRB-SN connections
- Host galaxies multiwavelength observations and studies
- Studies of the high energy prompt GRB emission and of the X-ray afterglow properties
- Use of GRBs as cosmological probe
GRB-SN connections

- **All the observed GRB-SNe are type Ic**: their ejecta contain no H and no He.
- Estimated **progenitor** masses are in the range $30-50 \, M_\odot$ and **ejecta** masses in the range $8-12 \, M_\odot$.
- Their **kinetic energy** after correction for asymmetry is still **one order mag larger than typical SNe Ic**.
- Two contending scenarios for the powering mechanism: **collapsar or magnetar**?
- Both scenarios may contribute → more GRB-SN data needed.

Adapted from Ashall, Pian et al., arXiv: 170204339
GRB-SN connections

light-curve modeling:
- GRB afterglow
- SN

Multiband SED modeling of afterglows:
- double broken power-law
- synchrotron emission

Spectroscopic follow-up of GRB-SNe

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GRB170105A/ATLAS17aeu

GRB180728A, the closest high-luminosity GRB ever
Rossi et al., in prep.
GRB Host galaxies

- **Short GRBHs**
  - Short: both quiescent and star forming, generally more massive

- **Long GRBHs**
  - Star forming galaxies, with preference for low metallicity blue dwarf galaxies at low redshift
  - 30-40% of all long GRBs are dark. Half of them may be host by extremely red objects

Fong et al., 2014

Arbsalmani et al., 2018

Rossi et al., 2012
GRB Host galaxies

Missing host problem:
- high-z?
- low-luminosity HG?
- Kicked progenitor

Multiband SED modeling

Nicuesa et al., 2015
Hunt et al. 2014
Rossi et al., in prep
Long and short GRBs seem to follow the same well known B vs P correlation of accreting PSR

1) Confirmation of past evidence on the presence of a central magnetar injection power into the afterglow
2) Evidence that long GRB have faster spinning magnetar w/r to short GRB possibly due to larger accreting matter

GRB as cosmological probes

193 long GRBs as of 2015

Amati et al, 2002...2016
Fast Radio Bursts

Mysterious radio transients with ms duration ⇒ must be compact

Mostly detected around 1GHz

High Dispersion Measure, greater than local Galaxy value ⇒ extragalactic

Possibly two types: repetitive vs non repetitive

Unknown origin; there are still more models that detected FRBs
Follow-up of FRB 180301, 180309, 180311

Search of the candidates:
- Large FOV instruments: OMEGACAM/VST and VIRCAM/VISTA
- Swift/XRT

Methods:
- photometric relative variability
- image subtraction.

Characterization of candidates with VLT-X-Shooter

FRBs-related works @ OAS

Lorenzo Milizi Master Thesis

FRB 180301. Zoom-in on the FRB error circle observed with VST, i band. ESF galaxies (green peas), variable sources within 1 day (magenta)
Gravitational Waves: Activities on the electromagnetic follow-up

The OAS GW member team:

L. Amati, A. Bulgarelli, F. Cusano, A. De Rosa, M. Dadina, G. De Cesare, V. Fioretti, G. Lanzuisi, E. Maiorano, N. Masetti, L. Nicastro, E. Palazzi, N. Parmiggiani, E. Pian, A. Rossi, G. Stratta, E. Torresi, D. Vergani (+ DIFA and IRA colleagues)
High Frequency (10-1000 Hz) GW sources

- The frequency range at which GW detectors are sensitive tell us the type of sources we can observe.

- At high frequencies we expect to see:
  - Compact-binary coalescences
  - Core-collapsing stars
  - Instability phenomena on NSs
Expected e.m. counterparts

GW170817 → first GW source associated with an EM counterpart!
+1.7 s → short GRB (Fermi+INTEGRAL)
+ 11 hrs → optical counterpart (Swope + many others and REM!)
+1.5 days → optical spectrum (VLT/X-shooter, GMOS, Soar Magellan Telescope)
+ 9 days → X-ray counterpart (Chandra)
+ 16 days → radio counterpart

Metzger & Berger 2012
Expected e.m. counterparts

Abbott et al. 2018 ApJL 848, L13
GW source localization

Triangulation → $100-1000$ deg$^2$ with 2 detectors, $10-100$ deg$^2$ with 3 detectors

10 BH-BH and 1 NS-NS localization at 90% CL in the range 1500-16 deg$^2$

GW-related expertises @ OAS

- Transient sources observational strategies and follow-up (GRBs and FRBs)
- High energy (keV, MeV GeV) data analysis
- Multi-wavelength data analysis
- Photometry + Spectroscopy
- GW data analysis
- Infrastructure and outreach


premio INAF!

premio “Occhialini”!
Follow-up results during the O1 & O2 LVC runs

OAS members participated to the e.m. follow-up campaigns during the first two LVC observational runs O1 (Sept-Dec 2015) and O2 (Jan-Aug 2017)

Large FoV telescope = VST  
→ tiling strategy → candidate list

Small FoV telescopes = Asiago, REM, Loiano, TNG, Campo Imperatore  
→ candidate characterization

GW150914, GW sky localization: 600 deg$^2$ at 90% CL
VST tiling (90 deg$^2$) +2.9 days (23hr after the alert)

Follow-up results during the O1 & O2 LVC runs

- Several e.m. candidates have been characterized via spectroscopic and photometric observations
- Results have been published in a number of papers (e.g., Melandri et al. 2018, Grado et al. 2018, Pian et al. 2017)

SN Ibn discovered during follow-up of GW151226,
(Piranomonte et al. in prep.)

SN candidate in GW150914 survey
(Brocato et al. 2018)
GW170817 is associated with the merger of two NSs and is the only GW source with e.m. counterpart so far.

- **REM**: optical transient early observations at ~11 hrs
- **VLT-X/shooter**: kilonova KN 170817 follow-up and high quality spectra
- **LBT/LBC**: Unique ground-based detection of the afterglow of GRB 170817A

![Graphs and plots showing observational data related to GW170817](image)
AGILE Real Time Analysis for GW Alerts during O1 and O2

- AGILE system reacts to LIGO/VIRGO GW Alerts sending notifications to the AGILE Team and performing a real-time analysis of AGILE data to detect possible EM counterparts
- The full AGILE pipeline has been developed and is running @OAS Bologna
- OAS Bologna has also the responsibility of the follow-up operations
- Results also accessible through a mobile App (AGILEScience)

A. Bulgarelli, N. Parmiggiani, V. Fioretti, L. Baroncelli, M. Trifoglio, F. Gianotti
The case of GW170817

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Multi-band campaign for GW170817 (Abbott et al. 2017 ApJL, 848, L12)
GW-related ongoing works @ OAS

● Kilonova 170817:
  ○ Could we had seen a kilonova like KN170817 in past short GRB afterglows?
  ○ Which chemical abundances of freshly synthesized heavy elements are shaping the spectra?

● Host galaxy NGC4993:
  ○ How peculiar is it (w/r to e.g. short GRB hosts)?
  ○ Optimization of galaxy target strategies

● DB of nearby galaxy reference images for small telescopes as Savelli, REM, ITM
GW-related future works @ OAS

**SoXS(+2021)@ESO-NTT** followup+characterization of GW e.m. candidate counterparts + host galaxies (https://www.eso.org/sci/facilities/develop/instruments/SoXS.html)

**ELT(2025+)** science case on characterization of GW e.m. candidate counterparts + host galaxies

**Cherenkov Telescope Array (2025+):**
- **Science Alert Generation System**
- **Instrumental response** for transient sources
- **Simulations** of scientific observations in different modes

**THESEUS (2032+):** sky localization of GW sources detected but very poorly localized with 3G interferometers

*THESEUS GW source localization capabilities (Amati et al. 2018, Stratta et al. 2018)*
Infrastructure & tools

The OAS member team:

L. Nicastro
**Infrastructure & tools**

- **Gravitown server** (OA-Roma)
  - CPU: 24 core @ 2.4 GHz
  - RAM: 256 GB
  - 16 + 4 TB disk (raid 0 + 1) + 48 TB

- **Reference catalogues**
  - Gaia-DR1/2, IGSL, USNO, TMASS, GSC, UCAC, ...

- **Objects catalogues tools**
  - query, X-match, export, ...

- **Website**
  - (wordpress)

- **Website**
  - Public info
  - Images & Products
  - Blog
  - References

**OAS resources**

- 5 rack servers + backup + edu.inaf
  - ross, ross2, luna, cats, oastrodb1
- ~ 25 TB RAID1
- Use: storage + computing + Web server + DB server
- Projects: REM, QSFit, Gaia + AstroCats, X-ray + Optical/IR data analysis, BeppoSAX-GRBM, etc.
- S/W: public + Custom s/w
- Access: ssh, web, db

https://owncloud.iasfbo.inaf.it/owncloud/

https://gravita.inaf.it/VSTbrowse/GW170814/
Data (ERDA) Computing  
Turku (Finland)

Infrastructure & tools

Data analysis teams

- ESO Tools: ESOREX, IFUANAL, …
- IRAF (various flavours), DAOPHOT, SExtractor
- Custom s/w

Website (Git + Jackall)  
Public info

Wiki (MediaWiki)  
Private docs

Blog (Slack)  
Discussion

Papers (overleaf)
DB & Web tools

- MCS: https://github.com/gcalderone/MCS
- Spectra: http://qsfit.inaf.it/
- DB course: http://ross2.iasfbo.inaf.it/wp/imprs18/

- Images: http://ross.iasfbo.inaf.it/REMDBdev/ – https://grawita.inaf.it/VSTbrowse/GW170814/
- Spectra: http://qsfit.inaf.it/

Ingredients:

- DB server ⇒ MySQL/MariaDB
- Web server ⇒ Apache
- Language ⇒ HTML5, CSS3, PHP, JavaScript

Main JS packages: AladinLite, JS9, amCharts
Catalogue of spectral properties of Type 1 AGN (selected from SDSS DR10)

Drag & drop your spectral file here... or Browse...

- spetro-loiano_ncg4051_e-17.txt (type: text/plain) - 36814 bytes
  
  Redshift: 0.00234  E(B-V): 0.011  
  
  Process this file

Customize analysis

- Use a separate component for the [OIII]5007 blue wing
- Use the Balmer continuum component
- Use a Lorentzian profile for the emission lines (instead of a Gaussian one)

7590, 7618, 6859
Comma separated list of rest frame wavelengths of the absorption lines

Free

Fixed continuum slope (leave blank for free parameter)

1000
Minimum line resolution (in km/s) to fit the line

SWIRE_ELL5
Host galaxy template
Catalogue of spectral properties of Type 1 AGN (selected from SDSS DR10)

Uploaded by user luciano.nicastro@inaf.it (ID 0) on MJD 58466.6960 (2018-12-14 16:42:17 UT) \[ z = 0.00234, E(B-V) = 0.011 \]
TOCats - HiPS cats browser - Version 1.0 - Developed using DIF / SID.

Catalogue

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There are 126,147 objects in the field. Got 291 brightest.

VO Cone Search link (e.g. for use in TOPCAT - URL http://cats.iasbo.inaf.it/gaiadr2_mini_hips10/) - size in degrees - add &json=1 to get a JSON structure:

http://cats.iasbo.inaf.it/gaiadr2_mini_hips10?size=0.5492&ra=253.6455&dec=-42.362
Perspectives

Fast transients work continues as usual, but...

- Personnel: no “full time” appointed ⇒ investment/support from OAS
  - About 15 people involved ⇒ relevant resources (internal + external) are required
- HW / SW packages / algorithms - in particular ML
  - Expertise scarce at the moment - people involvement always welcome
- New requirements / challenges in view of future facilities like LSST, CTA, ET, THESEUS, SKA, etc.