Data analysis challenges for multi-messenger astrophysics

BoF 6

Peter Shawhan, Patrick Brady, Adam Brazier, Brad Cenko, Mario Juric, and you...



OAC-1841625 PHY-1710286





mmm

Nov 11-15, 2018 College Park, MD adass2018.astro.umd.edu

> GOES-8 image produced by M. Jentoft-Nilsen, F. Hasler, D. Chesters (NASA/Goddard) and T. Nielsen (Univ. of Hawaii)







Can look at individual sources, or populations

 Stellar core collapse
 → gravitational waves? (if non-axisymmetric collapse)

 [supernova]
 → low-energy neutrinos (from nuclear reactions)

 → UV/visible/IR light (from expanding envelope)

 → cosmic rays (shock acceleration in SN remnant)

High-energy cosmic rays interacting with ambient photons \rightarrow high-energy neutrinos (Waxman & Bahcall 1998)

Relativistic jets — generated by accretion around black hole or neutron star

- \rightarrow high-energy neutrinos (from hadronic interactions and decays)
- → EM emissions at a wide range of wavelengths (synchrotron emission from particles in turbulent magnetic fields; inverse Compton scattering)
- Neutron star binary merger \rightarrow gravitational waves
 - \rightarrow relativistic jets (see above)
 - \rightarrow UV/visible/IR light (from heated ejecta)

And other sources...

[AGN, GRB]



Swift

We have a large variety of wide-field and pointed instruments

Different observational strengths:

Gamma ray: timing, spectrum, particle acceleration signature X-ray: timing, good localization, low background Visible/IR: precise localization, spectroscopy (& redshift), thermal signature **Radio:** late-time synchrotron afterglow, precise localization VLA **Neutrino:** timing, particle acceleration signature **Gravitational waves:** timing, distance, mass parameters

Different views of the event:

Image courtesy of NRAO/AUI **Core engine**: low-energy neutrinos, gravitational waves **Outflows**: high-energy neutrinos, gamma rays, X-rays, visible/IR, radio **Environment**: X-ray and radio afterglow

Multi-Messenger Astrophysics





Fermi

Gemini





Scalable Cyberinfrastructure to support Multi-Messenger Astrophysics

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Community Strategic Planning



MMA: sample science drivers

- Early-warning of nearby compact binary mergers via gravitational waves allowing the earliest phase of the EM counterpart to be identified and measured.
- High-energy neutrinos detected and localized to a galaxy cluster trigger EM follow-up and the observation of tidal disruption event.
- Supermassive black-hole binaries detected by pulsar timing arrays would allow studies of galaxy properties and accretion disk physics.
- A Galactic or Local Group supernova observed in all the messengers!



Case study - GW170817 / GRB 170817A / AT 2017gfo / ...

GW_LIGO, Virgo Y-ray Fermi, INTEGRAL, Astrosat, IPN, Insight-HXMT, Swift, AGILE, CALET, H.E.S.S., HAWC, Konus-Wind X-ray Swift, MAXUGSC, NuSTAR, Chandra, INTEGRAL UV Swift, MAXUGSC, NuSTAR, Chandra, INTEGRAL Optical Swift, MAXUGSC, Nustar, Chandra, INTEGRAL INTERCENT Detection Divide Communication IR Remove DECam, DLT40, REM-ROS2, HST, Las Cumbres, SkyMapper, VISTA, MASTER, Magelian, Subaru, Pan-STARBBT, HCT TACL, SGIT, 117, GROND, SOAR, ESC VI, T MATINE, ESC VIST, VIRT, SALT, CHILESCOPE, TOROS, BOOTESS, ZAUGN, THEROREN, MASS, Spitzer, NITT, GROND, SOAR, NOT, ESC VIST, VIRT, SALT, CHILESCOPE, TOROS, BOOTESS, ZUSTA, Gemini-South, 2MASS, Spitzer, NITT, GROND, SOAR, NOT, ESC VILT, Manala Telescope, HST FR Redio ATCA, VLBA, GMRT, MWA, LOFAR, LWA, ALMA, OVRO, EVN, eMERLIN, MeerKAT, Parkes, SRT, Etfelisberg -100 - 50 0 50 10-2 10-1									
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Abbott et al, Ap. J. Letters, Volume 848, Number 2

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Anchor facilities ...



Image credits: IceCube, LIGO, LSST



Follow-up...



Credit: P. Hebbar, V. Bhalerao (IIT Bombay) & the GROWTH collaboration

Analysis and interpretation ...

- Efficient, robust searches for signals in GW data
 - Candidate signal identification algorithms
 - Detector characterization and data quality assurance
 - Signal modeling and multi-dimensional parameter estimation
- Image processing and photometric analysis
- Detailed source modeling and inference to extract astrophysics from the combined observational data



How to do all that effectively

- Cyberinfrastructure: the distributed data-handling, computing, analysis, and collaboration services/systems to enable discovery, education, and innovation.
- Existing cyberinfrastructure:
 - Transient sky: SNEWS, AMON, GCN, TNS, SNEx, ATEL, ANTARES, VOEvent ... IceCube, LIGO, LSST.
 - Static sky: NASA/NED, Vizier/SIMBAD



SCIMMA Project

- Goal: Identify the key questions and cyberinfrastructure projects required by the community to take full advantage of current facilities and imminent next-generation projects for Multi-messenger Astrophysics
- Deliverables:
 - **<u>Community white paper</u>** documenting needs & opportunities (April 2019)
 - Strategic plan for an institute to address these needs (June 2019)
- Process: open engagement of multiple communities

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MMA Challenges

- Highly heterogeneous facilities, data, and people
 - High-volume, high-velocity transient streams
- Rapidly developing, dynamic collaborations
- Heterogeneous data sharing policies
- Competition for follow-up resources
- Rapid modeling to inform intelligent scheduling
- Tension between human/machine communications
 - Human intervention is slow, but this is currently central to follow-up

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Examples of desired capabilities

- A framework to facilitate joint analysis, to enable teams to work together, while respecting scientific cultures
- Real-time decision making in event observation & follow-up
- Coordination of observing resources through exchanges, marshalls, or telescope observing managers
- Capability based access controls ...
- Sustainable, long-term archival storage ...



Examples of desired capabilities (continued)

- Standardization of data sets ...
- Data escrow, pre-registration of analyses, ...
- Machine-readable standards & protocols with software ...
- Communication software ... machines, human ...
- Scalable computing systems ...



Opportunities for computer/data science

- Machine learning, deep learning ...
- Purpose built hardware for real-time inference ...
- Inference/compute on data with differential privacy ...
- Uncertainty quantification & predictive modeling ...
- Tools of missing data, imbalanced data ...
- ... and much more!



SCiMMA Project - Join the conversation!

• Get involved at <u>scimma.org</u>

- https://groups.google.com/forum/#!forum/scimma
- Attend workshops (dates/topics TBD) & sessions like this one
- Contribute to activity areas (watch forum for information)

• Systems

- Integrating applications & middleware
- Data Management
 - Collaborating on heterogeneous, high-velocity, high-volume data sets.



SCiMMA activity areas (continued)

• Inference and Machine Learning

• Interpreting data & planning observations

• Modeling and theory

• Responding to and informing ongoing observing campaigns, multi-physics

• Education and workforce development

• Building capacity, increasing diversity, and communicating with public

• Policies and Management

• Coordinating an inherently distributed effort through an Institute



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• Details at <u>scimma.org</u>



• Get involved

https://groups.google.com/forum/#!forum/scimma

