Picturing a Panchromatic Past and Future

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Thematic Areas

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Secondary: Multi-Messenger Astronomy and Astrophysics

Principal Author

Sara R. Price
Harvard-Smithsonian Center for Astrophysics
E-Mail: sara.price@cfa.harvard.edu

Co-Authors

Daniel Castro, Harvard-Smithsonian Center for Astrophysics
Martin Elvis, Harvard-Smithsonian Center for Astrophysics

Figure 1: The Great Observatories worked together to detect and image CL J1001+0220, which beat the existing record for furthest known galaxy cluster from Earth and provided new details about the process of early galaxy cluster evolution. *Credit* - X-ray: NASA/CXC/Université Paris/T.Wang et al; Infrared: ESO/UltraVISTA; Radio: ESO/NAOJ/NRAO/ALMA

Introduction

The synthesis of observations from the comparably sensitive set of space based telescopes *Spitzer* (infrared), *Hubble* (optical/UV), and *Chandra* (X-ray) that span the entire electromagnetic spectrum has shaped some of the most significant conceptual breakthroughs in astrophysical knowledge that have taken place in the current decade. These “Great Observatories”, as they have familiarly been designated, were planned intentionally by NASA to be synergistic and panchromatic. It is important to take stock of the accomplishments and advances in the frontiers of research made possible by this panchromatic model and the images it has produced in order to grasp the importance of discoveries encompassing the electromagnetic spectrum to the forthcoming generation of missions.

Multi-wavelength research in astronomy and astrophysics does not simply arise from a series of simultaneous observations, and it cannot easily be pieced together from historical versions of data, although having access to archival material and developing innovative new ways to analyze it can assist in filling observational gaps. Instead, multi-wavelength studies should involve active interaction and clear collaboration between missions, instruments, and specialists that are focused on different wavelengths of light.

The upcoming launch of James Webb Space Telescope will surely lead to many discoveries over a wide variety of astrophysical and planetary science fields in the more immediate future as well as throughout the next decade. However, the high cost of its ‘flagship mission’ approach used for its commissioning, design, and construction also brings about the end of panchromatic access to the Universe that drives twenty first century astrophysics. Practically, a far-infrared, UV, or X-ray successor mission cannot commence for a decade or more after this launch, by which time JWST will likely have been decommissioned and therefore will not be sharing a simultaneous time window. This white paper highlights some of the most exciting results that relied on incorporating observations in different wavelengths from NASA’s “Great Observatories” in order to argue for an approach enabling a similar multi-wavelength perspective for the future.

A. Collection and Categorization of Data from Chandra Press Releases

In order to analyze the impact that the Great Observatories model had on the expansion of the astronomy community’s potential for breakthroughs, we conducted a detailed review of all Press Releases and Image Releases from the *Chandra* X-ray Observatory over the nearly two decades of discovery that have elapsed since its First Light. The citations of the primary scientific paper associated with a given release were counted and recorded, along with notes on whether the research made use of data from *Chandra*, *Hubble*, *Spitzer*, or some combination of these telescopes. The most highly cited papers that relied on observations from two or three of these Great Observatories were focused on in greater detail, and information on the essential contributions of each relevant telescope to the content of the image or press release was collected. Below a few case studies that illustrate some of the key themes in astrophysics research moving forward over the next decade are presented, along with suggestions for future inquiry.

B. Impact on Imagery and Aesthetics for Data Visualization and Outreach

It is integral to note that departure from a panchromatic approach will prevent the complete picture of available data from appearing in images that will visualize data from forthcoming missions. This absence has implications for information science and public outreach as well as for the advancement of research and understanding in astrophysics. Images are a key representation of data and component of analysis in astrophysics, and the deficiency of richer and more detailed imagery that includes data in many different wavelengths will have the effect of reducing the clarity, precision, and diversity of the vision that the astronomy community makes use of to delve into the mysteries of the Universe over the coming decade.

In addition to perhaps making these images notably less visually interesting and appealing from an aesthetic perspective, astrophysicists' loss of the ability to detect new and enriched data in certain wavelengths will prevent these pictures from shedding light on new discoveries from a variety of different electromagnetic frameworks. This in turn will slow the integration of insights from a variety of sub-fields that currently occurs as a natural part of panchromatic efforts. The remarkably deep images derived from surveys such as The Great Observatories Origins Deep Survey (GOODS) that depend upon the unusually broad range of technological perception enabled by the synergy of the Great Observatories will no longer be accessible. This loss of imaging opportunity could serve to discourage future large-scale collaboration, which should instead be promoted in order to further develop the potential for multi-messenger astronomy research efforts that involve data from a variety of electromagnetic wavelengths.

1. Crab Pulsar: Case Study in Stellar Evolution

Multiple observations made over several months with NASA's *Chandra* X-ray Observatory and the *Hubble* Space Telescope captured the variable nature of the relativistic lepton nebula around the Crab Pulsar. Combining observations from both *Chandra* and *Hubble*, the time-evolution of the emission reveals features not ever seen in single images. Bright wisps can be seen moving outward at half the speed of light to form an expanding ring that is visible in both X-ray and optical images. These wisps appear to originate from a shock wave that shows up as an inner X-ray ring. This ring consists of about two dozen knots that emerge, increase in brightness and then recede, move around, and occasionally experience outbursts that give rise to expanding clouds of particles, but remain in approximately the same place.

Hester et al. (2002) reported that both the *Chandra* and *Hubble* bands show similar structures. In the future, multi-wavelength observations could test and confirm the contents of further key structures such as the Crab Pulsar's ring that are not clear from only viewing the details of their composition with a single type of light.

2. Bullet Cluster: Case Study in Cosmology

The galaxy cluster 1E0657-56 is often called the bullet cluster since it contains a spectacular bullet shaped cloud of hundred-million-degree gas. The *Chandra* X-ray image shows that the bullet shape is caused by a wind arising from the high-speed collision of a smaller cluster with a larger one. In addition to the *Chandra* observation, the *Hubble* Space Telescope, the European Southern Observatory's Very Large Telescope, and the Magellan optical telescopes were used to refine the location of the mass in the galaxy clusters. This was done by measuring the effect of gravitational lensing. The hot gas in this collision slowed down due to a drag force that resembles air resistance. However, the dark matter did not change its speed as a result of the impact. This difference came about because dark does not interact directly with itself or with the gas, other than via gravity. The discrepancy in speed brought about the separation of the dark matter and normal matter seen in the data. Dark matter is required to produce this result, rather than an abundance of hot gas that would potentially make up the bulk of the clusters.

Figure 2: The separation shown between differently colored regions in this image serves as evidence for the existence of dark matter.

Credit **- X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.**

Clowe et al. (2006) created gravitational lensing maps of the cluster cores, using HST/ACS images and those from ground-based telescopes, and therefore made clear that the gravitational potential fails to follow the plasma distribution, the most prominent baryonic mass component, revealed by the *Chandra* observations, but instead roughly traces the galaxy distribution. The majority of matter within this system is actually invisible. This scientific breakthrough is a direct result of the synergy between two of the NASA Great Observatories, *Chandra* and *Hubble*. A new generation of missions that observe the Universe in multiple wavelengths could build upon these findings to resolve questions about the nature and role of dark matter and dark energy.

3. Kilonova: Case Study in Multi-Messenger Astronomy and Astrophysics

Margutti et al. (2017) made use of X-ray vision from *Chandra* to investigate a neutron star merger that served as a source of gravitational waves. The kilonova that emerged from this event was detected by telescopes across the whole range of light, from radio waves to gamma rays, in addition to gravitational waves found by LIGO and Virgo. This kilonova enabled the astronomy community to understand in greater depth how neutron star mergers are related to the r-process that creates the Universe’s store of heavier elements. All Great Observatories were involved in the study of GW170817, and in the future interplays of gravitational waves and light should be a topic of inquiry.

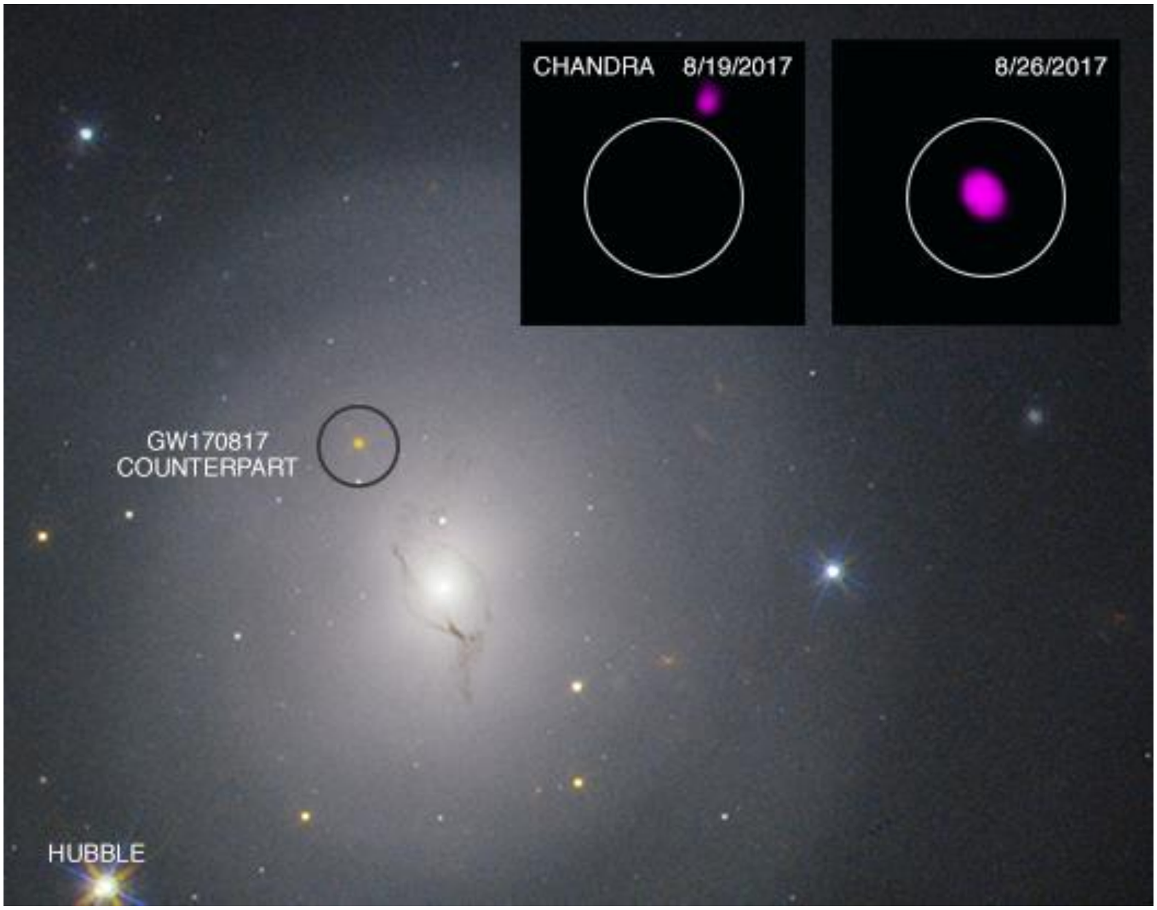

Figure 3: ***Chandra*** **observed a gravitational wave source with X-rays for the first time, and its finding of a jet was a crucial component helping to piece together the overall picture of this multi-messenger event.**
Credit **- X-ray: NASA/CXC/GSFC/UMC/E. Troja et al.; Optical and infrared: NASA/STScI**

4. Conclusion and Recommendations

The Great Observatories have helped to build what is widely acknowledged as the "Golden Era" of astronomy, demonstrating insight into astrophysical objects and systems that can only be obtained from a genuinely multi-wavelength view of the sky.

The three case studies of scientific discovery presented here clearly illustrate that the Great Observatories paradigm has resulted in innovative research inquiries and deep observational schemes that depend upon an expansive view of data that has been obtained from a variety of different missions. The sum total of results from *Chandra*, *Hubble*, and *Spitzer* is of significantly greater scientific value than its component parts, as information in a combination of wavelengths allows different types of data to shine a light on one another.

NASA's Great Observatory programs allowed for giant leaps in astrophysics during the last 3 decades. A panchromatic view of the sky, with state of the art space observatories that are contemporaneously gazing at the Universe, can suitably build on this legacy. This feat can be accomplished through a mixture of small scale missions.

References

Clowe, D. et al. 2006, ApJ, 648, 109
Hester, J.J. et al. 2002, ApJ, 547, 49
Margutti, R. et al. 2017, ApJL, 848, 2, L20

Acknowledgment

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