
Working Group Report on “HST in the era of Time Domain Multi-messenger Astrophysics”

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The committee reached out to 36 key time-domain scientists, who were strongly involved with the follow up of GW170817, both based in Europe and in US. We received feedback on our document from 12 of them.

This document is structured as follows:

Document 1: HST Observing Strategy of electromagnetic counterparts of gravitational wave triggers.

Document 2: Policies

Document 3: Coordination among observatories in the multi-messenger era

Document 4: Maximizing the HST impact on Time Domain Science at large

1. HST observing strategy of electromagnetic counterparts of gravitational wave triggers

Editors: S. B. Cenko, R. Margutti

We solicited community feedback on the following topics: (i) Lessons learned from HST Observations of GW170817, what was great, how can we improve; (ii) Unique contributions of HST to GW science; (iii) What HST can do, but can also be done from the ground.

HST unique contributions:

HST observations played a critical role in this multi-messenger discovery:

- The **deep sensitivity** uniquely enabled the detection of off-axis "afterglow" optical emission at late times ($dt > 100$ d) + HST provided the latest detection of the fast fading kilonova UV emission
- The **high angular resolution** afforded by HST enabled detailed characterization of the environment of the merger (host galaxy properties, location within the host) + HST data also enabled the most precise distance measurement for the host via the surface brightness fluctuation method.

Lesson learned from GW170817:

- A lack of **ultra-rapid (dt < 2 days) follow-up** precluded characterization of the early (and fast-fading) blue kilonova component. Deep UV observations **at early times**, both spectroscopy and photometry, are a) scientifically critical (to characterize the composition of this emission) and b) can be uniquely obtained by HST.
- The UV spectrum that was obtained for GW170817, at dt ~ 6 days after merger, did not detect any significant emission from the source. Given the UV light curve observed from Swift, this was apparent before the observations were executed, but operational constraints rendered it impossible to re-schedule the HST observations.
- Template host observations were repeated for each individual group. Sharing of these templates could reduce redundancy at late times (when coordination is much easier).
- For this specific event, based on the results from NIR spectroscopy from the ground, it was pretty clear that **HST IR grism spectroscopy** would have been complementary to the NIR from the ground, but not really competitive.

1.2 Unique contributions of HST to GW science

We provide below a list of key potential HST contributions to GW science divided into **PRIORITY 1** and PRIORITY 2.

- **PRIORITY 1**: Early-time UV spectroscopy and/or photometry of the blue kilonova component. **Ultra-rapid HST response over ≤ 2 days is a key need.**
- PRIORITY 2: For nearby events that can be imaged from the ground: late-time photometry to either sample the decay of the KN component or the emergence of the afterglow. Or photometry of **faint**, distant events.
- PRIORITY 2: Imaging of the environment to get precise localization and constrain the merger environment properties (not time sensitive), as well as the distance of their host galaxies.
- PRIORITY 2: Multi-epoch IR spectra to map spectral features of the KN and their evolution, if observations from the ground will not be able to reach the necessary depth.

1.3 What HST can do, but can also be done from the ground

- Optical and IR photometry of the source while bright.
- IR spectroscopy. For the specific case of GW170817 (nearby and bright) HST IR spectroscopy offered only complementary insight into the event, compared to the ground. However, this might not be the case for fainter, more distant targets (or even for nearby targets if the weather does not cooperate...)

2. Policies

... enabling several ultra-rapid observations ...

Editors: Iain Reid, Ben Farr

Community Program + Proposals Involving Multiple Teams +
DDTs + Limits on ultra-rapid ToOs

Community Program

The working group believes the best approach to enabling **several ultra-rapid observations** of GW counterparts and maximizing scientific gain is a community program. Rapid observations would be enabled by a community-developed, *predetermined* decision tree to guide the observing strategy for a given trigger. The data from such observations would be made public immediately. There would likely be **no funding** associated with these observations, but alternative schemes (e.g., pay for page charges and a conference trip for results derived from HST data products) should be considered by STScI. **Subsequent observations of events would be left to GO programs (i.e., the usual path, with PIs and proposals selected by the TAC, and associated funding).** **Proprietary periods** for such programs should be minimized, if not eliminated, to maximize scientific gain. **The community ultra-rapid ToO program has to be viewed as a backup in case nothing similar is approved by the TAC,** or if approved proposals run out of ultra-rapid triggers before the relevant HST cycle is over.

For community ultra-rapid follow-up to succeed, we need:

1. A direct channel of communication between observers and STScI.
2. A clear decision tree in place to trigger the ultra-rapid observations.
3. A mechanism for announcing the observations are happening.

Proposal with multiple teams: to minimize conflicts and maximize science

DDT Proposals:

There was consensus that any steps that could be taken to **streamline the review process** would be beneficial. Those steps include:

- Establishing direct, proactive communications between LIGO/Virgo and STScl to verify high-priority alerts.
- Creating a decision tree to guide what types of proposal might be appropriate to particular events.
- Identifying a group of knowledgeable community members who would agree in advance to respond quickly to requests to review DDT proposals.

Limits on ToO allocations:

Hubble currently limits the number of ultra-rapid and rapid ToO activations allowed within a cycle; this reflects both the **resources** required to execute those observations and the overall **impact on the scheduling efficiency**. Currently, Hubble also does **not allow ultra-rapid ToO observations with COS, ACS/SBC and the STIS-MAMA detectors**; all of these detectors require bright object screening in order to ensure that the safety of the detectors, so this restriction is also largely a matter of resources.

The working group recommends that STScI consider allocating additional resources in both areas, to respond the science priorities enabled by observations of multiple sources, as discussed elsewhere in this report, and **to allow full exploitation of HST's unique UV capabilities at the earliest opportunity**.

3. Coordination among observatories in the Time Domain and Multi- messenger era

Editors: Erik Kuulkers, Emily Levesque

SUMMARY OF MAIN GOALS and OBJECTIVES: Efforts are underway on an international basis to explore the design of an **effective system for coordinating transient follow-up among multiple observatories**. That structure can complement and enhance HST observational initiatives. Topics of interest include: getting the alerts, **improving coordination and communication**, planning the observations, and the prioritization of follow-up efforts.

A particular advantage of good communication is in **designing ground-based (or space-based) observations that can complement or improve observations to be done with HST.** With a maximum HST response time of ~48 hours, ground-based (or space-based) observations in the immediate aftermath of a trigger can provide key initial data that can be used in planning HST observations, and ensure rapid acquisition of specific observations (e.g., IR spectroscopy) where ground-based coverage is equivalent or even superior to HST's capabilities, thus freeing up HST time for observations that are impossible from the ground (e.g., UV observations, high-resolution imaging).

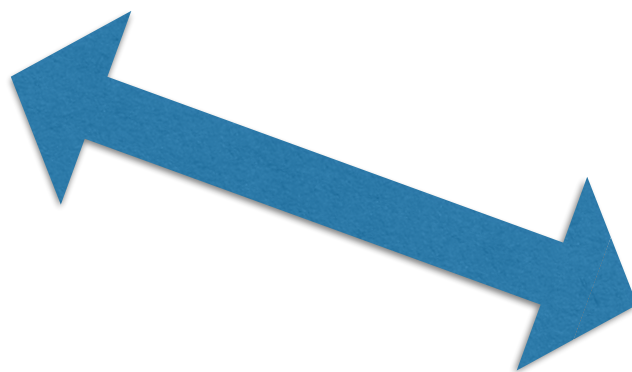
FINAL RECOMMENDATION: We recommend implementing a public and easy-to-use communication system that the community can use to share information about guaranteed, planned, and recently-executed observations. The planning information for these observations should follow existing VO protocols. Follow-up complementing HST observations should also be prioritized over other ToO triggers. **We recommend exploring the possibility for larger HST joint observing proposals.**

4. Maximizing the HST impact on Time Domain Science at large

Editors: Ori Fox and Dan Milisavljevic

SUMMARY OF MAIN GOALS and OBJECTIVES: As new surveys (e.g., ZTF, LSST) come online, HST will need to keep pace with the increasing number of discovered transients, which will increase from a rate of thousands per year to thousands per night. The traditional number of ToOs may not be sufficient, so it is important to understand types of science, required observations, and expected frequency of triggers in this new era.

Transformative Science Opportunities (SBO, flash spec)



Ultra-rapid ToOs

A community program for ultra-rapid ToOs for non-GW science

The implementation of such a community program is not clear, given any science would have to go through the TAC process. However, the current number of rapid ToO's would potentially limit the number of proposal submissions, especially risky ones, to the current TAC process. A **community *ultra-rapid community trigger*** may be considered in the future as science demands evolve. In the more immediate future, however, the committee recommends the institute harness the advantage that most non-disruptive ToOs are executed in less than 21 days. This fact opens the possibility that a general set of non-disruptive ToO trigger criteria be allowed with the expectation that a significant fraction of will be executed much sooner.

FINAL RECOMMENDATION: **There is consensus from the working group about obtaining ToOs on the 2-5 day timescale for non-GW science (e.g. shock breakout, interaction, very fast evolving transients).** We anticipate that other research areas would benefit from increasing the number of ultra-rapid triggers (e.g., including asteroids, novae). We also urge HST to prioritize **developing a more complete archive of nearby galaxies in multiple bands spanning UV and optical.** This legacy data set would be invaluable for time domain science and have synergy with many other research areas.