Whitepaper on

Transient Astrophysics Probe (TAP)

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Transient Astrophysics Probe (TAP) Concept

The recent announcement of a Binary Black Hole merger detected by LIGO has stimulated enormous interest in the possibility of observing electromagnetic counterparts to gravitational wave (GW) sources. The Transient Astrophysics Probe will host a set of X-ray and near IR instruments that will provide an optimal means for EM follow-up and localization of GW detections by the ground-based LIGO as well as the planned space-based GW observatory LISA (assuming launch dates for TAP and LISA late next decade). Counterparts to very massive GW sources identified by Pulsar Timing Arrays may also be detected.

TAP will also revolutionize our knowledge of the time domain universe. It will provide capabilities for a major step forward in high redshift universe and epoch of reionization studies by detecting gamma-ray bursts to redshift $z > 12$, answering questions about the nature of the first stars and chemical evolution. It will provide a bonanza of detections of tidal disruptions and supernova shock break-outs. In its survey mode, TAP will perform a deep and wide survey of the X-ray sky, most notably active galactic nuclei, whose variability determination will allow us to effectively distinguish them from candidates for LISA and PTA GW counterparts. Inspired by the model of Swift, sensitive X-ray and IR rapid follow-up instruments will give valuable information on each detected transient.

To this end, TAP (Figure 1) is a mission concept that combines an X-ray wide-field imager (WFI) with a sensitive X-ray telescope (XRT) and a wide-field IR telescope (IRT). The WFI has a sensitivity of 10^{-11} erg/sec/cm^2 (2000 sec) in a combined 2 sr field of view that covers ~80% of the sky every 3 hr in multiple pointings. It is based on CCD technology and lobster-eye microchannel optics. The XRT ($2x10^{-15}$ erg/sec/cm^2 in 3000 sec) will have a relatively large field of view (1 deg^2) and 5 arc sec resolution, facilitating LISA follow-ups. The IRT has a 40 cm diameter mirror, a wavelength range of 0.6 – 2.4 μm, a 1 deg^2 FoV, and is capable of multiband photometry and $\lambda/\delta\lambda=30$ slit spectroscopy. A rapid response, autonomously pointed spacecraft directs pointing of TAP’s instruments.

TAP is then ideally suited for the challenging job of detecting EM counterparts of GW transients. Only the Lobster technology offers a wide enough field of view and high sensitivity needed to cover large error boxes that will still be the norm for LIGO gravitational wave events in the 2020’s. The IR and X-ray telescopes will be mainly tasked for WFI follow-up measurements, but will also be available to search for GW counterparts not identified by the WFI. The IR telescope will be a powerful instrument for detection of predicted isotropic kilonova signatures from binary neutron star mergers that GW instruments will detect, with a potentially large increase in rate relative to the (beamed) X-ray afterglow. The sensitive, 1 deg^2 FoV XRT will allow the follow-up of LISA detections of SMBH binary mergers potentially out to z~2. The combination of GW and EM detection will greatly increase the science return from the GW networks of the late 2020’s.

Further, the tantalizing glimpses afforded us to date by serendipitous sources such as tidal disruption events, high redshift GRBs and supernova shock break-outs have underscored the necessity of more efficient discovery techniques in order to enhance the future rate of discovery in time domain astronomy. TAP offers enormous advances in capabilities compared to current missions. The WFI is 30 times more sensitive than existing wide-field X-ray monitors. The rapid-response spacecraft and sensitive IR telescope will provide immediate information on the transient's nature and distance. The XRT will employ state-of-the art optic fabrication techniques to offer high sensitivity with unusually large FoV.

Finally, there will be considerable synergy in the time-domain X-ray analysis afforded by TAP with other wavelength time-domain facilities including LSST (optical) and LOFAR and SKA (radio).

The detection rates expected in the late 2020s are impressive:

LIGO GW Counterpart: NS-NS/NS-BH	~monthly	(so far undetected)
LISA GW Counterpart: SMBH-SMBH	~several/yr[1]	(so far undetected)
PTA GW Counterpart: SMBH-SMBH	~10(5 years)[1]	(so far undetected)
GRBs	twice daily	(current rate 2/week)
High-z GRBs (z>7)	bi-monthly	(current rate 1/3yr)
SN shock breakout	weekly	(current rate yearly)
Tidal disruption flares	weekly	(current rate yearly)
Stellar super flares	weekly	(current rate yearly)

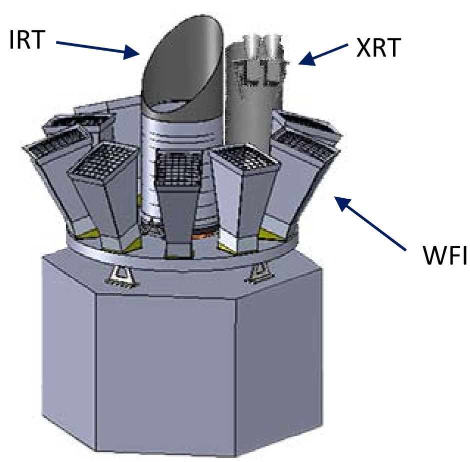

Fig. 1 Schematic of TAP, showing 8 WFI modules, IRT (center), and XRT

The cost of TAP was estimated from experience at Goddard in generating cost estimates for the (independently reviewed) 2010 Lobster free-flyer mission proposal, and from Goddard MDL runs in 2010 and 2015. To the \$200M Lobster cost, we added inflation, 5 more Lobster modules, the XRT, and a launch vehicle, bringing the total cost to ~\$750M. All technologies are TRL 6 or higher, with no technology development needed.

[1] Private communication, A. Sesana