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GOTO and Gravitational Wave Transient Followup

ASTR 581 Annotated Bibliography

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1. INTRODUCTION

For my bibliography I decided to investigate more about GOTO and transient follow up for gravitational wave events. I've previously worked on projects about LISA and LIGO predictions and heard a lot about GOTO so wanted to learn more.

GOTO, the gravitational wave optical transient observer, is a telescope designed specifically for quickly and efficiently following up on short-lived transients that occur after gravitational wave events. This sort of follow up is essential for connecting gravitational wave events to their electromagnetic counterparts and can help us learn more about the endpoints of massive stars, the neutron star equation of state and r-process enrichment.

Each of the papers that I discuss below consider the working of GOTO, design choices that went into it and some examples of how it can be used. I also touch on how other telescopes can do the same, in particular I focus on LSST. Try and spot the moment where I realise I am running out of time to submit this and need to reduce the details (:

2. GOTO TELESCOPE CONTROL SYSTEM

Dyer et al. (2018, 2020a) describe the GOTO telescope control system and highlight how it can operate entirely robotically, with no need for human technicians except in the case of errors.

The first of these papers (Dyer et al. 2018) outlines how the telescope control and scheduling system will work. GOTO is controlled by a series of daemons, the most important of which are the conditions, sentinel, scheduler and pilot daemons. The conditions daemon keeps track of the weather (e.g. rain, humidity, temperature, wind) and other system conditions and, if necessary, causes the dome to close or sets off an error. The sentinel daemon listens for alerts of new transients and adds them to database of potential pointings.

The scheduler then takes this database and ranks each of the potential transients based on a *variety* of parameters, but in particular prioritises gravitational wave events over all other transients. If at any point there is no transient then GOTO performs an all-sky survey in order to perform image differencing at a later time. Importantly, the GOTO scheduler operates on a "just-in-time" scheduling model rather than creating a plan at the start of the night. This allows it to be very reactive to new events, though does mean that its choice of targets may be less efficient. Finally, the pilot daemon reacts to the input of the other daemons and skews the telescope, operates the dome, performs calibrations and takes images. If the pilot runs into any errors that can't be solved then it will alert a human technician but otherwise it is able to operate without any human intervention. Very cool!

Dyer et al. (2020a) follows up to this initial paper to further specify more clearly how alert scheduling will work and detail their ranking system (e.g. see Eq. 1 Dyer et al. 2020a). They now clarify how they will separate events into 3 sub-classes: gamma-ray bursts, gravitational wave events and gravitational wave event retractions (oop). The scheduler now also takes into account whether the gravitational wave event included a neutron star or included a black hole and the distance to the source. Closer sources with more neutron stars are prioritised over far sources with black holes (since closer sources are easier to observe and transients are not expected for binary black holes and are reduced for black hole neutron star binaries). Finally, this paper covers interesting possibilities of having multiple mounts (since the initial prototype). The two separate mounts can cover separate areas of the sky for greater coverage or they could focus on the same event and achieve greater

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depth. Decisions on exactly how they will put the multiple mounts is put off for the GOTO collaboration to decide in the future.

3. GOTO TELESCOPE

Now let's talk more about the GOTO telescope in detail, which is described in Dyer et al. (2020b). GOTO is built with speed in mind, additionally trying to maintain a wide field of view and depth. Each telescope is built around a fast-slewing German equatorial mount, which holds up to 8 unit telescopes. This modular nature is by design and allows a cost-effective large field of view whilst also allowing for more unit telescopes as more funding becomes available. They use the OnSemi KAF-50100 CCD, each telescope has a set of Baader LRGBC filters and the mount is housed in an 18ft Astrohaven clamshell dome.

The current plan is to have two independent mounts in separate domes in each site. Each mount will have 8 unit telescopes and thus provide a total instantaneous field of view of around 80 square degrees. They intend to have two sites, one in each hemisphere and thus attain all-sky coverage. However as of the writing of this paper they only have one site at the Observatorio del Roque de los Muchachos on La Palma in the Canary Islands. The second site is planned for Siding Spring Observatory in New South Wales, Australia and funding has been secured. In total this will give GOTO a field of view of 160 square degrees, which can observe to ~ 20 mag in a set of three 60 s exposures.

3.1. *Prototype performance*

Steeghs et al. (2022) Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

4. GOTO IN PRACTICE

4.1. *General*

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4.2. *Lightcurves*

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4.3. *Kilonovae*

Chase et al. (2022) Sed commodo posuere pede. Mauris ut est. Ut quis purus. Sed ac odio. Sed vehicula hendrerit sem. Duis non odio. Morbi ut dui. Sed accumsan risus eget odio. In hac habitasse platea dictumst. Pellentesque non elit. Fusce sed justo eu urna porta tincidunt. Mauris felis odio, sollicitudin sed, volutpat a, ornare ac, erat. Morbi quis dolor. Donec pellentesque, erat ac sagittis semper, nunc dui lobortis purus, quis congue purus metus ultricies tellus. Proin et quam. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Praesent sapien turpis, fermentum vel, eleifend faucibus, vehicula eu, lacus.

5. OTHER TELESCOPES

5.1. *LSST*

Andreoni et al. (2022) Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Donec odio elit, dictum in, hendrerit sit amet, egestas sed, leo. Praesent feugiat sapien aliquet odio. Integer vitae justo. Aliquam vestibulum fringilla lorem. Sed neque lectus, consectetuer at, consectetuer sed, eleifend ac, lectus. Nulla facilisi. Pellentesque eget lectus. Proin eu metus. Sed porttitor. In hac habitasse platea dictumst. Suspendisse eu lectus. Ut mi mi, lacinia sit amet, placerat et, mollis vitae, dui. Sed ante tellus, tristique ut, iaculis eu, malesuada ac, dui. Mauris nibh leo, facilisis non, adipiscing quis, ultrices a, dui.

REFERENCES

Andreoni, I., Margutti, R., Salafia, O. S., et al. 2022, ApJS, 260, 18, doi: 10.3847/1538-4365/ac617c

Burhanudin, U. F., Maund, J. R., Killestein, T., et al. 2021, MNRAS, 505, 4345, doi: 10.1093/mnras/stab1545

Chase, E. A., O'Connor, B., Fryer, C. L., et al. 2022, ApJ, 927, 163, doi: 10.3847/1538-4357/ac3d25

Dyer, M. J., Dhillon, V. S., Littlefair, S., et al. 2018, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 10704, Observatory Operations: Strategies, Processes, and Systems VII, 107040C, doi: 10.1117/12.2311865

Dyer, M. J., Dhillon, V. S., Littlefair, S., et al. 2020a, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 11452, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 114521Q, doi: 10.1117/12.2561506

Dyer, M. J., Steeghs, D., Galloway, D. K., et al. 2020b, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 11445, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 114457G, doi: 10.1117/12.2561008

Gompertz, B. P., Cutter, R., Steeghs, D., et al. 2020, MNRAS, 497, 726, doi: 10.1093/mnras/staa1845

Steeghs, D., Galloway, D. K., Ackley, K., et al. 2022, MNRAS, 511, 2405, doi: 10.1093/mnras/stac013