Time-domain Spectroscopic Observatory (TSO)

Astrophysics

Overview:

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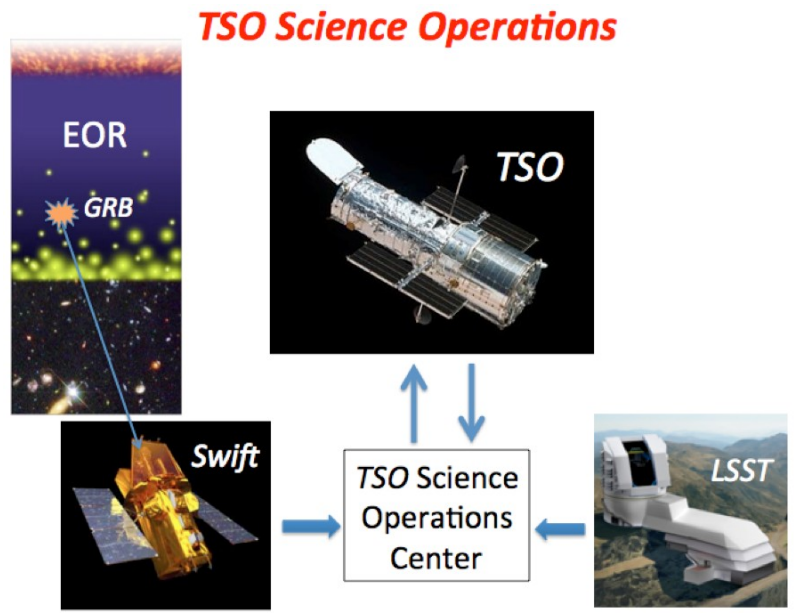
Primary science goals for *TSO*:

1. Measure and map first stars and galaxies during Epoch of Reionization by IR spectroscopy of Gamma Ray Bursts at z >6-8
2. Measure supermassive black hole mass vs. z by measuring variability power spectra from LSST photometry of 10^5 bright quasars
3. Provide unparalled spectroscopic sensitivity for studies of transients discovered by LSST and other Time Domain Astrophysics surveys



Description:

***TSO* concept:** passively cooled space telescope for high sensitivity *spectra* to enable fundamental studies of the Early Universe and the astrophysics of time-variable objects discovered with LSST

Observations: Imaging for target acquisition and low/high resolution spectra of Gamma Ray Bursts (GRBs) at redshifts z >6. Spectra of thousands of variable Quasars and variable sources discovered with LSST and also PTF and PanSTARRS (optical) and LOFAR, SKA (radio)

Technical readiness: A prototype of the focal plane instrument has been designed and is under construction at GSFC as the RIMAS instrument for use on ground-based telescopes

External collaboration: The *TSO* mission is of significant importance to LSST, the large ground-telescope being built with NSF support

Human exploration utilization: None; but possibly useful if in L1 orbit

Value to NASA:

Benefits to NASA: The *TSO* mission concept for a space observatory in geosynch orbit (or possibly L1) might present NASA human exploration with interesting options for instrument changeout in a non-low Earth orbit. If this were of interest, detector arrays in the focal plane instrument could be designed for change-out options

Advances in science, technology or exploration? *TSO* would be a major science (astrophysics) space observatory at relatively low cost. It would literally enable the first direct measurements of the very first stars, which are likely to produce GRBs during the still mysterious Early Universe. The use of the Large Space Optic (LSO) to achieve fundamental science would be highly synergistic with the overall NASA science (astrophysics) goals, of great significance for the NSF LSST project, and engender public support

SALSO Concept: Time-domain Spectroscopic Observatory (*TSO*)

POC: Jonathan Grindlay, Harvard/CfA, Cambridge, MA (josh@cfa.harvard.edu)
Qualification: PI of *EXIST (BEPAC & Astro2010)* studies; PI of *MIRAX-HXI* instrument on Brazil *Lattes-MIRAX* mission (2017); assembled qualified Team of Key Collaborators.
Concept Summary: *TSO* is an imaging (field acquisition) and spectroscopy (resolution R = 25/4000) telescope with two primary science objectives: i) *Mapping the Epoch of Reionization (EOR) with GRBs* and ii) *Tracing supermassive black hole (SMBH) mass vs. z with LSST transients*. The 2.4m Large Space Optic (LSO) is configured with a focal plane instrument based on the RIMAS instrument (0.9 – 2.4μm) developed at GSFC. GRB triggers are from *Swift*, *MIRAX-HXI* or future more sensitive GRB imagers are observed (within ~1-3h of trigger) and redshifts measured with a R = 25 objective prism sensitive to AB = 25 in 300sec. Those with z >6 are then observed with R = 4000 for integrations sufficient to measure both host and intervening IGM absorption redshifts to map growth of cosmic structure. JWST is not fast enough and GMT/TMT are not sensitive enough to do this. *TSO* would provide the spectroscopy to enable astrophysics of countless classes of LSST variables, from extreme stellar flares to the most luminous pair instability supernovae (PISNe), each identified uniquely by spectra. The mission would best operate in an equatorial geosynch orbit, which also optimizes LSST overlap and telemetry.
Primary concept goal category: Astrophysics

Primary Science Goals

1. The very first stars (Pop III) are no longer thought to be stars of ~200 M_o which would likely explode as PISNe and thus not produce a black hole and GRB, but rather to be more "normal" ~30 – 100 M_o which also may have binary companions (see Bromm 2012). Thus both conditions needed for GRBs, namely stellar BHs and high angular momentum, are met and GRBs are very likely from the first stellar populations that are formed and then responsible for the Epoch of Reionization (EOR). This further strengthens the motivation for the long-held notion that GRBs are the best (and in fact only) stellar objects to trace the evolution of the EOR as well as the star formation rate (SFR) vs. z during the EOR, which were the highest science priorities from the Galaxies across Cosmic Time Panel of the Astro2010 Decadal Survey. This motivates the first priority science for *TSO*, which would significantly exceed the sensitivity of the smaller IRT proposed to Astro2010 as *EXIST* or to PCOS as *EREXS*, thereby allowing not just GRB redshifts but also measures of the ionization and metallicity of the host IGM.

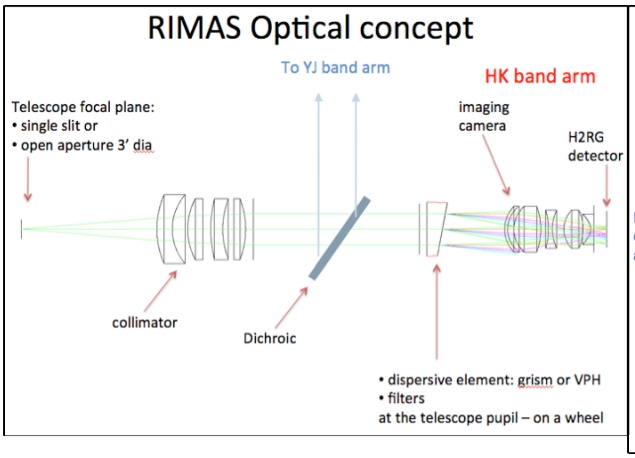
2. The growth of supermassive black holes in galactic nuclei and their mass scaling with the Bulge mass of their host galaxy (M-sigma relation) are keys to the formation and evolution of galaxies. Of primary importance is the formation epoch of the first SMBHs and the subsequent dependence of the SMBH mass spectrum on z. With the large sample of AGN and QSOs both known (e.g. from SDSS) and to be discovered (e.g. from DES), LSST will have enormous samples (>10^6) for which repeated magnitude measures will produce power spectra and break frequencies that scale with SMBH mass (see McHardy+2006). With *TSO* spectra (0.9 – 2.5μm) sampled during large flares, reverberation mapping in emission lines (e.g. Ha at z = 2; or MgII at z = 6) will yield SMBH masses directly for comparison to constrain SMBH mass vs. z. LSST discovery of tidal disruption events (TDEs) will measure quiescent SMBHs and their host galaxy mass.

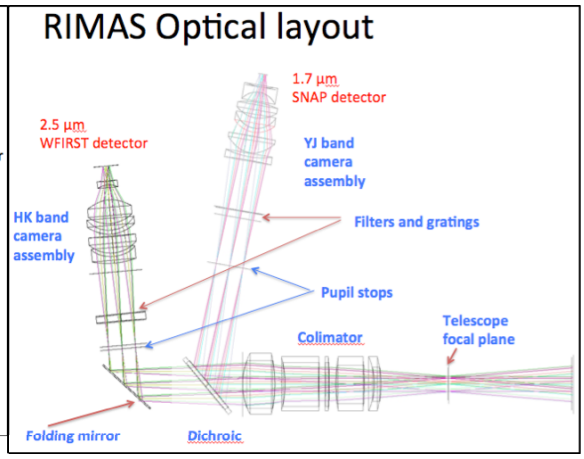
More generally, *TSO* provides highest sensitivity or priority spectroscopic followup of countless classes of variables discovered each night with LSST, "solving" what is widely recognized as a significant bottleneck for this dominant telescope for Time Domain Astronomy (TDA) for the coming decade. It is already the case that current TDA surveys (PTF, CRTS and PanSTARRS) are limited by spectroscopic followup; with LSST this problem will increase by orders of magnitude since the era of building the new >6-8m class telescopes required (for AB >23 spectra) is very limited. With a 2.4m cold telescope in space at JHK wavelengths, as proposed for *TSO*, AB ~23/25 spectroscopy is feasible at R =4000/25 for modest exposure times. *TSO will enable TDA**strophysics***.

***TSO* implementation on the LSO**

To achieve these high priority science objectives, it is imperative to have a cold telescope in space with coverage from the visible Y band through JHK. A dedicated telescope with high sensitivity, broad band coverage, and diffraction-limited resolution that can point to variable targets (satisfying Sun-Moon, etc., observing constraints) within relatively short (<2h) times (e.g. for GRB afterglows in early-bright phases) is required. The sensitivity required demands both zodiacal-limited background and a moderate imaging FoV. *JWST cannot achieve the <3 hour response time or dedication to a single (but broad-ranging) science need – TDA; rather, it must serve a much broader community.*

The *TSO* concept is to instrument a single LSO with a focal plane imager-spectrometer similar to the RIMAS (Rapid IMAger Spectrometer) now under development at GSFC. The optical concept and layout for RIMAS below are similar to our *EXIST*-IRT design.





The gratings parameters for RIMAS are given in the Table. As with the optical layout, these are representative design values for what would be appropriate for *TSO* but are provided to show the reality of the instrument design, which could be accommodated within the specifications of the LSO hardware. RIMAS is being developed now as a ground based instrument, with a mechanical cryocooler and dewar, which dominates the total instrument mass of about 400 lbs. This total mass would be reduced significantly (~200 lbs) with a pulse tube cryocooler for *TSO*

RIMAS Gratings parameters

YJ-band:	1st surface tilt	substrate	# grooves/ mm	2nd surface tilt	orders
Low-R grism	none	CaF2*	10	-0.55 deg	1
Echelle	none	ZnSe	25	-42.8 deg	30-44
X-disperser VPH	11.6 deg	-	270	none	1

HK-band:	1st surface tilt	material	# grooves/ mm	2nd surface tilt	orders
Low-R grism	none	CaF2*	6	-1.4 deg	1
Echelle	-3.0 deg	ZnSe	20	-57.0 deg	23-39
X-disperser VPH	4.85 deg	-	120	-3.8 deg	1

which will would keep the H2RG detectors at the desired operating temperature (~60K) and the entire primary-secondary mirror optical system as well as the slit module is radiatively cooled to -90C to bring thermal backgrounds below the zodiacal value out to 2.4μm. With this design, and including a microshutter multi-object spectral capability, the approximate sensitivities and operating modes shown in the Table are possible which will meet the *TSO* science goals and provide a powerful space observatory. The magnitude limits are some 2-4mag fainter than anything yet achieved with VLT or Keck at J, H and K due to the thermal foregrounds and large OH line emission backgrounds ever-present from ground based sites. Even a 4m cold (-30C) telescope on Dome A in Antarctica (Grindlay 2012) cannot compete with *TSO* sensitivity.

***TSO* Instrument Parameter**	**value**
FoV	3’
Spatial resol.	0.15”
Image/spectral bands	Y+J, H+K
Spectral range	0.9-2.4 μm
Sp. Op. modes	2 (low/hi res)
Sp. Resol. R	25 or 4000
Sensitivities	**AB mag**
300s, Y+J image	26
300s, H+K image	26
300s, Y+J, R=25 spec	24
3hr, Y+J, R=4000 spec	21
300s, H+K, R=25 spec	24
3hr, H+K, R=4000 spec	21

TSO mission operations

GRB triggers to candidate bursts from z >6, which enable direct study of the EOR, would come from *Swift/BAT*, which is projected (on basis of orbit lifetime) to operate for an additional 8-10 years. *Swift/XRT* positions (~2”) are available from afterglows for ~90% of GRBs, and UVOT and ground-based optical IDs for ~70% of GRBs. Any “dark” GRB is an immediate candidate for high z >8 and would alert *TSO*; any i-band or z-band (only) is also possibly z >6 and would also trigger an alert. The Brazil *MIRAX-HXI* scanning high-resolution HXI detector system is comparably sensitive to BAT and so will yield an additional comparable number of GRBs (~100/y) after its projected 2017 launch, with ~10-40” positions from the direct HXI trigger (Grindlay 2012). The same optical (i or z band, or dark) trigger, will trigger *TSO*. Other possible GRB missions (Lobster?) would also trigger *TSO*, so that with (present) ~30% dark GRBs x ~300 GRBs/y, some ~100 GRBs/y as high-z candidates are available for deep *TSO* spectra measures of the EOR.

For TDA spectroscopic followup and study of LSST variables, automated variable classification schemes (Bloom et al 2012) will enable “automated” triggers, based on proposed science objectives, from the LSST transient stream to trigger *TSO* spectra. This could easily consume 100% of *TSO* observing time. An additional source of variables and transient alerts will come from *MIRAX-HXI* X-ray variables, since this mission in a i = 15deg inclination orbit operates by continuously scanning the southern hemisphere at -25deg offset from its local (S/C) zenith so that over the orbit precession the entire sky with declinations -90° :S o :S 30° is scanned, also giving maximal overlap with LSST. Given the LSST observing constraints, a geosynch orbit over S. America for *TSO* is optimal for near real-time *TSO* followup of LSST transients or variable studies, with GRB triggers always priority. Wide-field TDA surveys with LOFAR and SKA will also trigger *TSO*.

References

Bloom, J.S. et al 2012, *Automating Discovery and Classification of Transients and Variable Stars in the Synoptic Survey Era*, PASP, 124, 1175

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