Rapid Response Mode to transient events at the Very Large Telescope

F. Comerón
European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany

ABSTRACT

The ESO Vey Large Telescope (VLT) has been offering for the last seven years a Rapid Response Mode that allows authorized users to automatically trigger follow-up observations of transient phenomena. The delay between the reception of the trigger and the beginning of the science exposure is no more than a few minutes, similar to that of robotic telescopes. However, the sheer size of the VLT Unit Telescopes and the variety of its instrumentation have opened up new scientific fields where the Rapid Response capability has made a decisive difference. The mechanics of the Rapid Response Mode is described, as well as some perspectives for its future implementation at the European Extremely Large Telescope (E-ELT). Operational possibilities to be enabled by a new large bandwidth link between the observatory and Europe, recently completed, may allow in the future near-real time interactivity between the facility and observers located in another continent, leading to the full exploitation of the Rapid Response Mode.
Keywords: Target of Opportunity, Large telescopes, Service Mode, Queue Scheduling, Gamma-Ray Bursts

1. INTRODUCTION

The ESO Very Large Telescope (VLT) consists of a complex of four 4 Unit Telescopes, each 8.2m diameter, located on Cerro Paranal (Chile), at 2635m over sea level. The telescopes can be connected to form a near-infrared interferometer, with baselines of up to 120m, also using four movable 1.8m Auxiliary Telescopes (Figure 1). The first unit of the VLT had first light in May 1998 and entered regular operations 10 months later. Nowadays the facility is completed and hosts 11 instruments, one of them belonging already to the second generation of instrumentation, covering a broad range of wavelengths, spectral resolutions, and observing techniques. Three additional second-generation instruments are under construction and expected to enter operations in 2012-2013. In addition, two instruments are operating at the VLT Interferometer.

Several factors make the Rapid Response Mode (RRM) a VLT capability with a unique scientific potential. The first is of course the sheer collecting power of its 8.2m mirrors, which allow astronomers to obtain high signal-to-noise ratio snapshots of quickly varying phenomena, making possible the study of fast, faint transients in great detail. In addition, the wide range of instrumentation available (imaging, long-slit and integral field spectroscopy, polarimetry, adaptive optics, high time resolution, etc., both in the visible and near-infrared) offers a choice to follow-up transients with the most suitable instrumentation to address the specific questions of scientific interest.

RRM observing at the VLT has been available since April 2004, and is currently offered with six instruments:

- FORS2, an imager and spectrograph in the visible, offering also a polarimetric option.
- ISAAC, a near-infrared imager and spectrograph.
- UVES, a high resolution echelle spectrograph operating in the visible.
- SINFONI, a near-infrared single-field integral field spectrograph assisted by Adaptive Optics.
- X-SHOOTER, a medium-resolution echelle spectrograph providing simultaneous wavelength coverage from the ultraviolet to the near infrared.
- HAWK-I, a high throughput near-infrared imager.

Use in RRM has been made thus far of four of them: FORS2 (and formerly its near-twin FORS1), ISAAC, UVES, and X-SHOOTER.

Figure 1.The Very Large Telescope (VLT) on Cerro Paranal. Each enclosure hosts an 8.2m telescope. Note also the four smaller enclosures in the foreground, each hosting one of the four 1.8m movable auxiliary telescopes used for interferometry.

2. THE VLT OPERATIONS MODEL

The operation of the VLT in RRM has some points in common with that of a robotic telescope, in that the whole sequence of steps including the presetting of the telescope, the setup of the instrument and the execution of the observation could in principle take place without human intervention. Although VLT science operations were not designed with RRM in mind, this mode has been successfully accommodated in the VLT operations model, largely thanks to the use of the Unit Telescopes in Service Mode most of the time. Service Mode is used here to indicate the observing mode in which fully pre-defined observations are executed by observatory staff when the external conditions are best suited for them, and for any practical purposes it can be considered as equivalent to Queue Observing at other observatories (Comerón 2004).

VLT operations are strongly based on *flexible scheduling*: most of the time (~70%) is devoted to Service Mode observations, in which as a part of the observation definition the users specify the conditions (seeing, transparency, lunar illumination…) under which they should be executed. The complete definition of each observation, including the conditions under which it should be executed, compose a so-called *Observation Block* (OB). The OBs submitted by users for all approved programmes enter a general pool from which the short-term schedule, this is, the actual sequence of nightly observations, is made on the basis of the prevailing conditions, user-specified constraints, relative priorities among programmes, degree of completion, time criticality, instrument in use, optimization of the share of calibrations, and perhaps other constraints.

A minor fraction (currently ~30%) of the VLT time is scheduled in Visitor Mode, when real-time decisions based on science criteria are expected to be needed during the execution of a program. Observations are also carried out in Visitor Mode when non-standard instrument modes are required. Scheduling a sizeable fraction of the time in Visitor Mode also has the purpose of keeping a strong link between the observatory and its personnel, and the astronomical community that uses it.

Target-of-Opportunity (ToO) observations of unforeseen events, such as supernovae, require fast but not necessarily immediate follow-up observations. When a request to trigger a ToO observation is received by the observatory it can be easily accommodated in the Service Mode schedule, normally to be executed on the upcoming night, in a non-disruptive manner, since no slots of time are preallocated to specific programmes. In this way the impact of the additional time needed to observe the Targets of Opportunity can often be spread over several programs or diverted to the lowest-priority ones. RRM observations do require an immediate reaction, but thanks to the probability of them happening during Service Mode slots and of compensating visiting astronomers in Service Mode when this is not the case, their impact is also minimized.

The integration of ToO and RRM observations into the operations model is facilitated by the common use of the operational concepts of the VLT Data Flow System (Peron 2008) and the tools underlying it, which allow users preparing this type of observations to use procedures largely common to those applicable to the preparation of any other observations in either Service or Visitor mode.

3. HOW RAPID RESPONSE MODE OBSERVATIONS WORK IN PRACTICE

Like for any ESO observing programs, RRM observations are requested through an observing proposal prepared in response to the by-yearly Call for Proposals, which is peer-reviewed and eventually recommended for execution on the basis of scientific merit. Users having been granted time are then requested to prepare their Phase 2 material, consisting of a set of OBs defining the instrumental setup and the exposure parameters for any foreseeable observation to be triggered later on. Obviously, only the target coordinates are left unspecified at this stage. The OBs are submitted to ESO, where they are stored in a database and are reviewed in advance by ESO user support astronomers to ensure their validity, so as to minimize the risk of failure at the time of execution.

When an event requiring RRM follow-up takes place, users arrange for a trigger signal to be sent to ESO. The trigger signal consists of an ASCII file submitted via ftp to a dedicated server at the ESO headquarters near Munich, Germany, which is automatically checked every few seconds by another machine on Paranal. The name of the ASCII file follows a strict format indicating the instrument with which the observation must be carried out and the unique identifier of the OB to be selected for execution. The content of the file is a single line with the target coordinates. Upon receiving the trigger signal the coordinates are automatically inserted in the specified OB, and the OB is sent to the telescope for execution. Simultaneously, an automatically generated e-mail must be sent to a dedicated account on Paranal that includes a link to the finding chart necessary for the identification of the target.

Although it would be technically possible to start the observation of the RRM event automatically, safety reasons require the telescope operator to manually accept that the execution proceeds. A warning message accompanied of sound effects appears in the telescope control console alerting the operator that a RRM trigger has been received and indicating the actions to be taken to proceed (see Figure 2).

Figure 2.The message that appears in the telescope control console when a RRM trigger request is received. The telescope operator is required to decide whether to go ahead with the execution (‘Preset’ button) or reject it (‘Stop’ button). If accepted, the telescope will immediately start presetting to the target coordinates specified in the OB and will abort the exposure in course at the time of receiving the alert, reading out the detector.

When the trigger is accepted, the telescope starts presetting to the indicated position and the exposure in course is simultaneously stopped, proceeding to the readout of the detector. Once arrived at the position, the operator verifies with the provided finding chart that the field is correctly acquired and, in the case of spectroscopic observations, centers the target in the slit. Once the observation has been completed, the data obtained are stored in a dedicated ftp account to which the principal investigator is given access. Given that the time elapsed between the reception of the trigger request by ESO and the readiness of the telescope to start presetting to the required position is a few seconds at most, the total response time is dominated by the time needed for the telescope to preset to the target, acquire a guide star, close the active optics loop and center the target in the slit if needed. This sequence can be typically completed in just six minutes, or even less if by chance the telescope happened to be observing a region near the RRM target at the time when the request was received.

The process of deciding whether or not an event requires RRM observations is left entirely to the users, who must set up a processing system that decides on the scientific interest of the observation and its adequacy to the goals stated in the observing proposal. The system must also find out if the event is observable from Paranal. Finally, ESO maintains a webpage where the instrument currently in use at each Unit Telescope is listed, so that the system can identify whether or not the required instrument is available.

For Gamma-Ray Bursts (GRBs), which are the most common target of RRM observations (and in fact the only targets from which RRM observations have been activated thus far at the time of this writing), event alerts are generated by high-energy space-borne observatories and followed up by robotic telescopes on the ground or on-board optical monitoring cameras that provide the information on the optical counterpart. The automatic processing system acts as a filter that decides whether or not a follow-up observation with the VLT is scientifically granted and technically feasible on the basis of the available information. Figure 3 provides a schematic view of the entire process from the generation of the alert to the storage of the data.

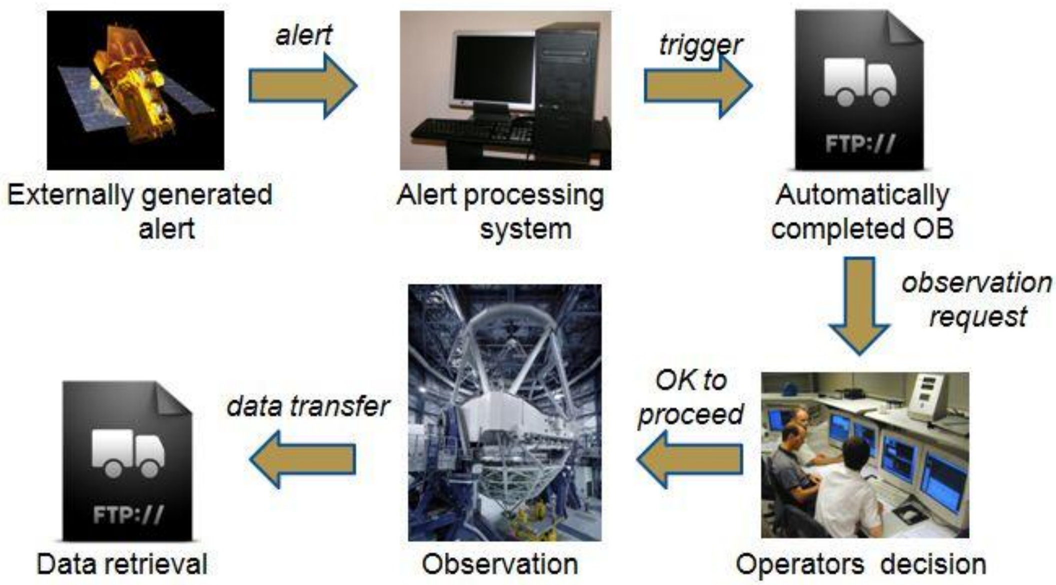

Figure 3.A schematic view of the process of triggering a RRM observation at the VLT. An event is recorded by a dedicated facility (such as a high-energy satellite in the case of Gamma-Ray Burst observations) and an alert is generated and transmitted to an automatic processing system under control of the user. The system processes the available information and decides whether or not a follow-up observation with the VLT is scientifically interesting and technically feasible. If so, it sends a trigger request to an ftp site at the ESO headquarters, from where it is transferred to Paranal. There, the request is used to insert the target coordinates in a predefined OB that is immediately sent to the telescope for execution. At that point, it is the telescope operator’s decision whether or not to proceed with the observation, for safety reasons. If the operator gives the go-ahead, the observation is started. Once completed, the results are transferred to another ftp site to which the astronomers who requested the observation have restricted access.

3.1 Policies

The effective implementation of the RRM in VLT science operations has led to the definition of specific policies to ensure that its use is restricted to the cases requiring it and to protect normal programs from its potentially disruptive effects. In recognition of its unique scientific potential and strict time-criticality, RRM observations are always granted overriding status, meaning that any observations, be it in Service or Visitor Mode, can be interrupted by RRM triggers, regardless of their priority. The only exceptions are those cases in which the observation to be interrupted is of high priority and strictly time-critical, but those are rare and no such conflict has yet taken place in the seven years in which RRM has been offered.

Since RRM observations need to be executed as closely as possible to the onset of the event, no triggers that involve a change of instrument are accepted. Each VLT Unit Telescope is equipped with two or three instruments at its Nasmyth and Cassegrain foci which are usually ready to start observing, but the change of instrument involves the reconfiguration of the tertiary mirror to feed the appropriate focus, which would add an overhead of approximately ten minutes to the acquisition. Triggers received for an instrument that is not in operation at the time of arrival are ignored and no time is charged to the user.

To ensure the proper use of the RRM and prevent abuse of the overriding priority assigned to RRM observations, triggers are only accepted within the first four hours after the onset of the event. Follow-up observations can extend for a longer period, but further observations after the one triggered as RRM follow the standard ToO channel.

Given the strong competition among teams nowadays carrying out GRB research, and the fact that time on a given semester is frequently allocated to more than one group working in this field to ensure that programs with complementary objectives can be carried out, ESO has worked together with the GRB community to establish fair policies establishing the rights to trigger RRM observations and to have immediate access to data. The current ESO policy is that any of the groups having been granted RRM observing time is entitled to trigger observations anytime during the period, and that concurrent RRM requests for a given event, if occurring, are dealt with in a first-come-first-served basis. Since each group is normally assigned a maximum number of triggers, any given trigger is charged to the group that submitted it. However, to optimize scientific exploitation the data obtained are made immediately available to all groups having been granted RRM time for this type of targets.

The high degree of competitiveness of research making use of the RRM mode justifies the efforts to make the data immediately available through authorized access to the groups requesting it. However, RRM data are no exception to the proprietary period policy of ESO, by which all science data obtained with ESO telescopes are made publicly available to the whole astronomical community through the ESO Science Archive Facility normally after one year since they were made available to the principal investigators of the programs for which they were obtained.

Since the override status of all RRM observations can mean that time assigned in Visitor Mode can be affected by RRM triggers, ESO has established a policy of compensation by which the amount of time from a Visitor Mode program that needs to be assigned to the observation of a RRM event is then returned to the principal investigator of the affected program in the form of Service Mode time.

Finally, identified abuses of the RRM for purposes different from those described in the original observing proposal can be penalized with the termination of the program. This is thus far a hypothetical case, as no such abuse has ever occurred.

4. USAGE AND PERFORMANCE

Events requiring RRM follow-up and that are technically observable by the VLT (this is, occurring during nighttime on Paranal, when the target is high enough in the sky, and with the required instrument in operation) are rather rare. However, a steady use of this mode keeps being made. Until 17 February 2011, ESO statistics show that 14 approved observing programs have requested the execution of RRM observations (a few more have been approved and entitled to trigger RRM observations, but they never did it because of lack of suitable events). The number of executable trigger requests received in this time has been 39, resulting in 53 hours of observations executed in this mode. This has proven to be a highly productive investment of telescope time, as the RRM observations carried out thus far have been used in 28 refereed papers. As noted above, despite the lack of restrictions in the science cases that can apply for RRM observations, the only targets observed thus far in this mode have been GRBs. This may change soon however, as there is currently an approved program at the VLT that intends to make use of RRM for the observation of giant stellar flares.

As noted above, RRM is currently offered in six VLT instruments, and has been actually used in four of them thus far. Most of the triggers have been addressed to UVES for high-resolution spectroscopy follow-up, but the second-generation instrument X-Shooter, in operations since late 2009, is quickly gaining popularity –not surprisingly, since GRB follow-up simultaneously covering the entire spectral range from 0.35 to 2.3 microns figured prominently as one of the drivers of the scientific case of that instruments.

The log of GRB afterglows observed with the VLT and other facilities at high spectral resolution, allowing in many cases the determination of redshifts, intervening hydrogen column densities and metallicities of the intragalactic medium of the host galaxy, gives an appreciation of the high effectiveness of the RRM at the VLT as compared with other facilities. A summary of such observations until the end of 2008 is listed in Table 1, which has been kindly provided by Paul Vreeswijk. Observations carried out with the VLT are marked in boldface characters. As can be seen, the shortest response time by far has been provided by the VLT, in which high-resolution spectroscopic observations with UVES have started as quickly as less than 8 minutes after the GRB detection.

5. SOME RESEARCH HIGHLIGHTS

RRM observations of GRB afterglows have a strong scientific potential in areas such as the GRB-supernova connection or the investigation of the composition and dynamics of the intergalactic medium up to high redshifts, using GRBs as background illumination sources. As noted above, much of the GRB research carried out with the VLT using the RRM has focused on high resolution spectroscopy that uses GRBs as probes of the interstellar medium of the host galaxy along the line of sight, in which unique results have been obtained. The wealth of information provided by high resolution, high signal-to-noise spectroscopy is illustrated in Fig. 4, displaying the rich metallic spectrum along the line of sight to a GRB where multiple kinematic components can be discerned. Scientific highlights produced by RRM observations have been presented by Vreeswijk et al. (2010), and some of them are summarized here.

GRB	ΔT (hh:mm)	Z	Exp.time (hours)	Log N_{HI}	[X/H]
020813	20:48	1.255	2.1		
021004	13:31	2.329	2.0	19.0	
050730	04:09	3.969	1.7	22.10	-2.18
050820	00:34	2.615	1.7	21.05	-0.39
050922C	03:47	2.199	1.7	21.55	-1.82
060418	**00:10**	**1.490**	**2.6**		
060607	**00:08**	**3.075**	**3.3**	**17.20**	
071031	**00:09**	**2.692**	**2.6**	**22.15**	**-1.73**
080310	**00:13**	**2.427**	**1.3**	**18.80**	**-1.39**
080319B	**00:09**	**0.937**	**2.1**		
080330	01:32	1.51	2.3		
080413	03:42	2.435	2.3	21.85	-1.60
080805	**00:50**	**2.205**	**1.3**		
081008	04:30	1.967	1.1		
081029	**00:23**	**3.848**	**0.5**		

Table 1. GRB afterglows spectroscopically observed at high resolution by the VLT (highlighted in boldface) and other facilities. ΔT is the time of start of the observation after the GRB event, z is the measured redshift, of the GRB host galaxy, N_{HI} is the atomic hydrogen column density in cm^{-2} and [X/H] is the metallicity.

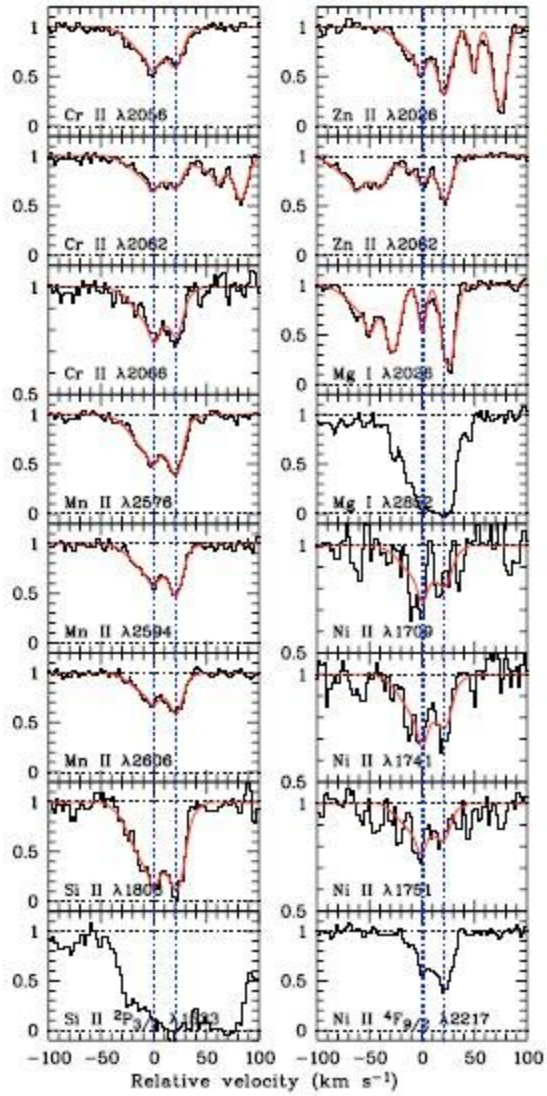

Figure 4.A sample of metallic absorption lines observed with UVES in the direction of GRB 060418, from Vreeswijk et al. (2007). Rest wavelengths are indicated together with the species. Note the combination of high signal-to-noise ratio and velocity resolution that allows one to study in detail each of the components of the kinematical components of the line.

Using a combination of RRM observations with immediate ToO follow-up, Vreeswijk et al. (2007) have been able to detect time variability on the absorption lines due to transitions among metastable and fine-structure levels of FeII and NiII superimposed on the spectrum of high redshift GRBs. The rapid variability is interpreted as the reaction of clouds in the interstellar medium of the host galaxy to the sudden illumination of the nearby GRB. An analysis of the variation of the lines of the different species shows that the excitation mechanism of the lines that produces the best fit to the data is ultraviolet pumping caused by the GRB radiation, followed by fluorescent emission. Collisional excitation and direct excitation of the lines by infrared photons are discarded as significant mechanisms. The models also provide an estimate of the distances of the absorbing clouds to the GRB. In the cases where it has been possible to carry out such analysis, a large range of distances are found, ranging from tens of parsecs to kiloparsecs. The results suggest that all the material between the absorbing clouds and the GRB is ionized by the latter, and the surprisingly large distances found in some cases (Ledoux et al. 2009, D'Elia et al. 2009a, 2009b) are indicative of the large-scale disturbance in the interstellar medium of the host galaxy that the GRB can produce. Finally, a byproduct of the modeling of line variability is the derivation of the slope of the spectral energy distribution of the GRB and its ultraviolet flux.

6. THE FUTURE

6.1 Fast data transfer and remote real-time interaction

In their current implementation, the integration of RRM and ToO observations in the VLT operations model benefits from the commonalities between these modes and regular Service Mode, and on the fact that the observatory is prepared to operate normally in an autonomous mode on the basis of fully predefined observations, without the need for real-time interaction with the user. While this capability lies at the basis of flexible scheduling, it also limits the ability to make real-time decisions based on scientific judgment and prevents the implementation of observing strategies that are conditioned by results immediately obtained. While this is a weak limitation in practice for the vast majority of Service Mode programs, the case for real-time interaction is stronger when observing transient and rapidly changing phenomena such as those that trigger RRM observations.

The main technical barrier to the implementation of real-time interaction capabilities is the usually intercontinental distances that separate the scientist from the observatory, combined with the need to have near-instantaneous access to the data just obtained, which places strong demands on the network bandwidth available over the whole path from the observatory to the user. Given typical sizes of current astronomical detectors, a transfer speed at the Gbit/s level is needed. In this regard, recent improvements in the network infrastructure of Paranal may open the possibility in the future to allow near-real time interaction between a remotely located observer and the observatory, allowing the transfer of images to the users' location within seconds of them having been obtained at the telescope.

The EVALSO project (for Enabling Virtual Access to Latin South American Observatories) (Filippi et al. 2010), funded by the European Union under its Framework Program 7, is expected to provide such capabilities for Paranal and the neighboring Cerro Armazones observatory in the future. The main goal of EVALSO is to create the missing parts of the physical infrastructure to connect the Paranal and Cerro Armazones observatories to Europe with a high capacity link. To this end, a consortium was formed in 2007 by seven European institutions (the GARR consortium, the University of Trieste, and the Astronomical Observatory of Trieste in Italy, Queen Mary University of London, NOVA in the Netherlands, the Astronomical Observatory of the Ruhr University of Bochum, and ESO, plus the REUNA and RedCLARA networks in Chile). The project will use the ALICE/ALICE2 research network infrastructure within South America and transatlantic connection to European National Research Networks (NREN) via GEANT2. ESO has procured the infrastructure needed to connect Paranal to the existing networks linking Santiago de Chile with Europe, and in particular a 75 km-long fiber link between Paranal and the access point to the Chilean backbone. The EVALSO infrastructure has been completed in November 2010 and is currently undergoing commissioning and integration in the Paranal operations network infrastructure. In the EVALSO implementation currently being put in place, the capacity of the path between Paranal and Armazones is limited by that of the transatlantic link, which with the planned ALICE2 upgrade is expected to exceed 1 Gbit/s. Tests on this segment using the current ALICE infrastructure have already achieved a sustained transfer rate exceeding 100 Mbit/s between Santiago and Garching using UDP-based file transfer tools. Considering that all existing links have higher nominal capacity and that the planned upgrade within ALICE and the trans-Atlantic link will even increase such limits, even faster transfer rates are foreseen in the near future.

6.2 The European Extremely Large Telescope

The next generation of extremely large telescopes in the 30-40m class is already at an advanced stage of planning and their construction is expected to begin very soon. The expanded Paranal observatory will host the European Extremely Large Telescope (E-ELT), currently expected to enter operations around 2020 or shortly after, for which a location in the nearby Cerro Armazones has been selected. The E-ELT will be a fully adaptive telescope with a segmented primary mirror near 40m in diameter, equipped to address a wide range of astrophysical and cosmological questions (Figure 5). The order-of-magnitude gain in light collecting power with respect to the largest telescopes currently in operation, together with the high spatial resolution achievable by the use of adaptive optics combined with the diffraction limit of such a large mirror, will open new regions of the discovery parameter space to be exploited by a wide range of science cases (Kissler-Patig 2009). A number of those will probably benefit from the RRM being available at the E-ELT as well.

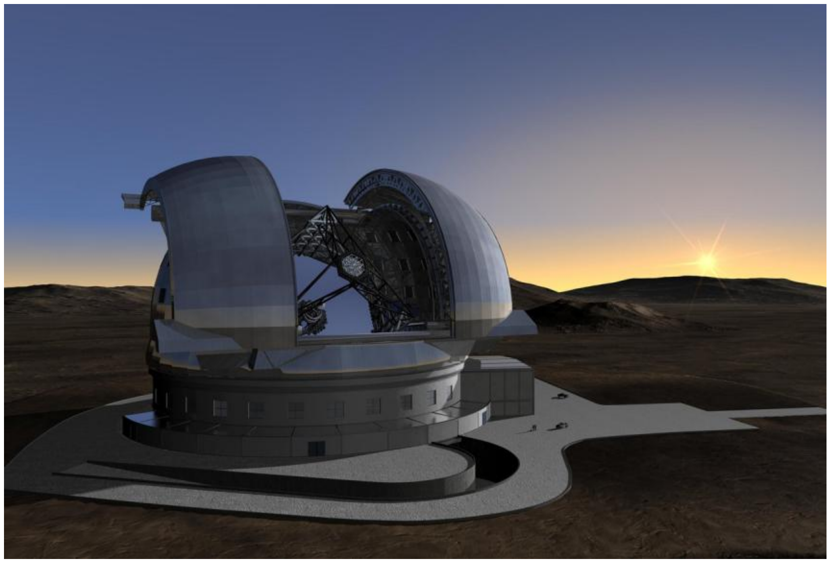

Figure 5.Artist conception of the European Extremely Large Telescope (E-ELT) within its enclosure. The E-ELT will be located on Cerro Armazones, near Paranal, and will be operated as part of the same observatory. The equivalent diameter of its segmented primary mirror will be about 40m, and it is expected to start operations around 2020 or shortly thereafter.

Despite the technical challenges involved in the construction of the E-ELT, nothing in its current detailed design precludes the implementation of a RRM in its operational scheme. The top-level requirements specify a preset time, including the setup of the telescope adaptive optics and the instrument, not exceeding 20 minutes, which still offers a very attractive response time to sudden phenomena. It is of course risky to forecast what science cases will motivate the use of RRM at the E-ELT ten years in advance, but surely its availability will represent a boost to the capabilities of the facility, much in the same way as it is for the VLT today.

7. CONCLUSIONS

The implementation of a Rapid Response Mode at the Very Large Telescope and its integration in its operations model demonstrates that observations in a quasi-robotic mode are also feasible at the largest telescopes currently in existence, expanding their scientific capabilities and complementing observations carried out at other facilities with the specific capabilities that their state-of-the-art instrumentation offer. Although a niche observing mode at the VLT, the Rapid Response Mode has been in sustained demand since it started being offered in 2004 and has produced a remarkable number of papers presenting new science. Improvements in network infrastructure and available bandwidth may make possible in the future to enhance the capabilities of this mode by enabling near real-time interaction between the remotely located observer and the telescope, and the adjustment of the sequence of observations to the observed evolution of transient phenomena. Finally, it is expected that the future European Extremely Large Telescope will be able to incorporate RRM capabilities as well, thus offering unprecedented sensitivity and spatial resolution to the observation of rapidly evolving transient phenomena.

Acknowledgements

I am thankful to the organizers of the conference Telescopes from Afar for their invitation to present this work. The credit for it actually goes to the scientists and engineers at the Paranal Observatory who designed and implemented it, with special mention to Alvio Renzini who, as VLT Program Scientist, strongly advocated for it and foresaw its potential for unique science. Last but not least, I am indebted to Paul Vreeswijk for providing me with the scientific input on GRB afterglow observations, and to Giorgio Filippi for his work on making EVALSO possible and the technical information supplied about it.

8. REFERENCES

Comerón, F., 2004, Organizations and Strategies in Astronomy, vol. 5, ed. A. Heck, ASSL Vol. 31, Kluwer Acad. Publ., Dordrecht

D'Elia, V., Fiore, F., Perna, R., Krongold, Y., Covino, S., Fugazza, D., Lazzati, D., Nicastro, F., Antonelli, L. A., Campana, S., Chincarini, G., D'Avanzo, P., Della Valle, M., Goldoni, P., Guetta, D., Guidorzi, C., Meurs, E. J. A., Mirabel, F., Molinari, E., Norci, L., Piranomonte, S., Stella, L., Stratta, G., Tagliaferri, G., Ward, P., 2009a, ApJ 694, 332

D'Elia, V., Fiore, F., Perna, R., Krongold, Y., Vergani, S.D., Campana, S., Covino, S., D'Avanzo, P., Fugazza, D., Goldoni, P., Guidorzi, C., Meurs, E.J.A., Norci, L., Piranomonte, S., Tagliaferri, G., Ward, P., 2009b, A&A **503**, 437

Filippi, G., Jaque, S., Liello, F., Chini, R., Utreras, F., Wright, A., Lemke, R., 2010, SPIE 7740, 77401G

Kissler-Patig, M. (ed.), 2009: "An expanded view of the Universe: Science with the European Extremely Large Telescope", ESO

Ledoux, C., Vreeswijk, P.M., Smette, A., Fox, A.J., Petitjean, P., Ellison, S.L., Fynbo, J.P.U., Savaglio, S., 2009, A&A 506, 661

Peron, M., 2008, in "The 2007 ESO Instrument Calibration Workshop", Springer-Verlag.

Vreeswijk, P.M., Ledoux, C., Smette, A., Ellison, S.L., Jaunsen, A.O., Andersen, M.I., Fruchter, A.S., Fynbo, J.P.U., Hjorth, J., Kaufer, A., Møller, P., Petitjean, P., Savaglio, S., Wijers, R.A.M.J., 2007, A&A 468, 83

Vreeswijk, P.M., Kaufer, A., Spyromilio, J., Schmutzer, R., Ledoux, C., Smette, A., de Cia, A., 2010, SPIE 7737, 77370M.