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DESAlert: Enabling Real-Time Transient Follow-Up with Dark Energy Survey Data

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Abstract

The Dark Energy Survey (DES) is currently undertaking an observational program imaging 1/4 of the southern hemisphere sky with unprecedented photometric accuracy. In the process of observing millions of faint stars and galaxies to constrain the parameters of the dark energy equation of state, the DES will obtain pre-discovery images of the regions surrounding an estimated 100 gamma-ray bursts (GRBs) over five years. Once GRBs are detected by, e.g., the Swift satellite, the DES data will be extremely useful for follow-up observations by the transient astronomy community. We describe a recently-commissioned suite of software that listens continuously for automated notices of GRB activity, collates useful information from archival DES data, and promulgates relevant data products back to the community in near-real-time. Of particular importance are the opportunities that DES data provide for relative photometry of GRBs or their afterglows, as well as for identifying key characteristics (e.g., photometric redshifts) of potential GRB host galaxies. We provide the functional details of the DESAlert software as it presently operates, as well as the data products that it produces, and we show sample results1from the application of DESAlert to several previously-detected GRBs.

Keywords: catalogs – gamma ray burst: general – methods: observational – surveys – virtual observatory tools

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1 INTRODUCTION

The Dark Energy Survey (DES) is an observational program covering 5000 square degrees of the southern sky, utilising the DECam instrument (Flaugher et al. 2015) on the Blanco 4m telescope at Cerro Tololo Interamerican Observatory, from August 2013 to February 2018 (Abbott et al. 2005). Over the 525 nights of the survey, the DES will observe in five filters broadly similar to the SDSS griz filter set (Gunn et al. 1998), but with some important differences – particularly, higher QE at near-infrared wavelengths and the additional Y filter (see Figure 1). DES will reach a photometric accuracy of 1-2% for its two interleaved surveys – the wide-field survey covering the full footprint and the supernova survey covering smaller regions with increased cadence (Diehl et al. 2014) – and it will have significant overlap with other wide-area surveys, such as the Sloan Digital Sky Survey's Stripe 82 (Abazajian et al. 2009), the Vista Hemisphere Survey (McMahon et al. 2013), and the South Pole Telescope Survey (Ruhl et al. 2004). The four Key Science programs of the DES comprise observations of SNe Ia, large-scale galaxy clustering, galaxy clusters, and weak gravitational lensing; together these four probes will be used to measure the Dark Energy Equation of State with unprecedented precision. The DES data have many uses beyond these primary science goals, however. In this work, we describe a service to provide data products to the transient observational community, particularly related to gamma-ray bursts located within the DES footprint.

Once a region of the sky has been observed by the DES, those observations will be useful whenever a transient (e.g. a gamma-ray burst) is detected in the same region. The DESAlert system is modeled upon the SkyAlert system (Williams et al. 2009), and it bears similarities to the SDSS transient notification system (Cool et al. 2006), though it focuses exclusively on data produced by the DES, and (at least initially) it relies on a single source for triggers. When a VOEvent notice (Seaman et al. 2011) is disseminated by the instruments aboard the Swift satellite (Barthelmy et al. 1999), the DESAlert system parses the notices for temporal and positional information, and then searches the DES archives to find all observations of that region. DESAlert then provides finder images of the region derived from DES data, as well as a subset of data derived from DES observations of all nearby stars and galaxies. The finder images show other objects near the GRB, while the catalog of stars provides nearby standards for the purpose of immediate relative photometry. Meanwhile, the galaxy catalog provides critical information on potential host galaxies – especially magnitude and photometric redshift – for the given GRB. All of these data products will be of use to those who need to make decisions regarding the allocation of scarce resources for follow-up observations of these GRBs. For example, if a potential host has an extremely low (or extremely high) redshift, observers may decide that the GRB warrants further study; thus they would begin follow-up observations as soon as possible. Alternately, if a host galaxy has unusual colors (as described by the multi-band DES observations), that may be indicative of unusual metallicity or dust content, again prompting observers to allocate observational resources to follow up the detection of these transients.

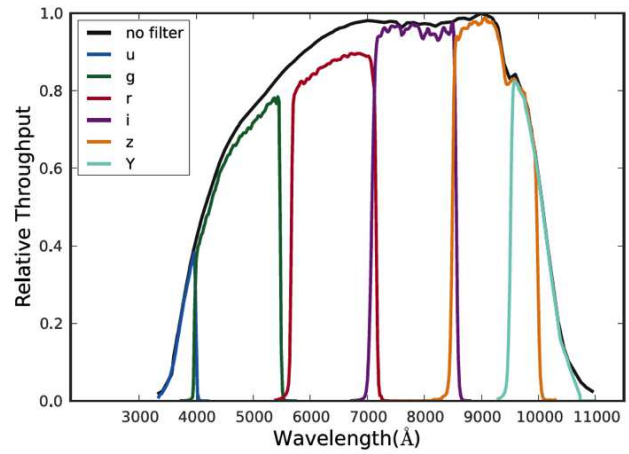

Figure 1. Throughput as a function of wavelength of the DECam optical train, including the various filters the DES uses. These throughputs are calculated relative to the use of no filter at 900 nm.

By the conclusion of Year 2 in February 2015, DES had observed nearly all of its survey footprint, with multi-epoch imagery covering the vast majority of that area – see Figure 2. Year 3 will see the completion of coverage of the entire footprint, with subsequent data-taking increasing the number of observed epochs (and thus the effective co-add survey depth) at each position within the footprint. Given the area covered, and assuming randomly-distributed GRBs detected by Swift at a rate of ∼100 per year, we expect 10-20 GRBs annually to have DES pre-discovery images that are amenable to analysis and publication via the DESAlert algorithm. We encourage all interested observers to take advantage of these data products provided to the astronomical community.

2 The DESAlert Algorithm

The DESAlert algorithm is shown schematically in Figure 3. The functional code is written in Python and SQL, and will be made available online via the Astro-

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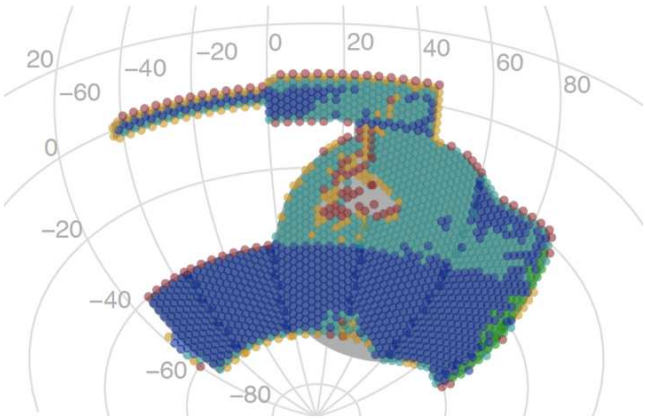

Figure 2. The DES footprint, with current coverage in the i band shown. Grey is the full survey area, while areas covered by 1, 2, 3, 4, or 5+ observations are colored red, orange, light blue, dark blue, and green, respectively.

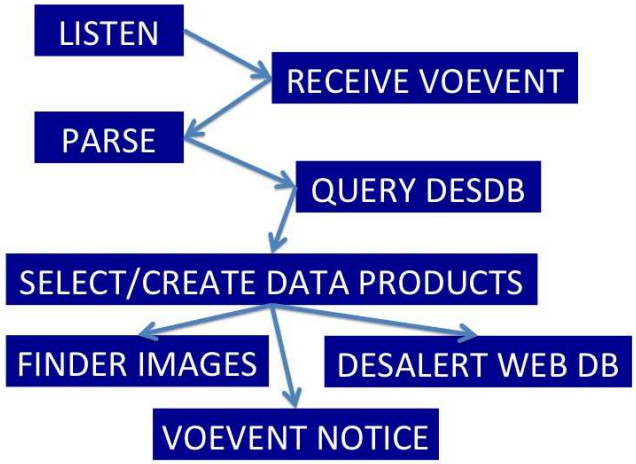

Figure 3. The DESAlert algorithm flowchart

physics Source Code Library (Allen et al. 2012). It encapsulates all functions necessary to complete the following steps:

- Listen for VOEvent Notices
- Select events confirmed to be GRBs by Swift
- Parse temporal and position data from Notices
- Query the DES database for objects and images in a pre-determined region surrounding the GRB
- Extract relevant archival DES data for stars and galaxies
- Derive data products from extracted data
- Publish DESAlert data products as VOEvent Notices, as well as to the DESAlert webpage

First, the algorithm opens a socket connection and receives (XML-formatted) messages from the VOEvent server as a series of packets, built up byte-by-byte until the full message is received. Error checking ensures that malformed (or improperly received) messages are deleted before the algorithm returns to listen mode. The XML is then parsed to determine the type of message (e.g., imalive, test, or observation). The first of these is necessary for the socket connection to be maintained at the client end, and it results in an identical reply from the client ("imalive") so that the socket connection is likewise maintained at the server end. All other types except observation are discarded. Observations, however, have relevant data for each GRB extracted, including GRB position (RA, Dec), burst time, and detecting instrument.

Based on the extracted GRB data, the python code then calls a custom-made jython-based command-line database interface to query the DES archival catalog of sources in order to find any stars or galaxies within a 0.25 degree box centered on the GRB position. These objects have previously been extracted from the processed (and coadded) DES Multi-Extension FITS images, and have had a great many parameters determined by the Data Management pipeline (Desai et al. 2012) running Source Extractor (Bertin & Arnouts 1996), including magnitudes (and uncertainties) for every observed filter, as well as object classification (either star or galaxy). A second database query finds all g, r, and i images containing the GRB position, from which the nearby objects have been extracted. Once the algorithm ingests all objects in the large search area, it selects a smaller region centered on the GRB that is 60 arcseconds (plus 90% uncertainties in the GRB position) on a side, and finds all objects that have any portion within this region. This is especially important for extended objects like galaxies, since GRBs are properly associated with galaxy hosts even when their positions correspond to the outer fringes of the object. These data are then stored, via SQL Insert commands, in a local database connected to the machine running the DESAlert python code, and are made available to the public in several ways, as detailed in Section 3.

3 DESAlert Data Products

Once the algorithm has selected the relevant image segments and composed its catalog of nearby objects, it promulgates the information of potential relevance to those seeking to follow up the GRB detection with further observations. The primary data products produced by DESAlert are based on pre-discovery images of the regions around Swift-detected GRBs. The initial products are (XML-formatted) VOEvent Notices, listing:

- Basic GRB parameters, including position, time, and discovering instrument
- Closest stars to the GRB, including positions and magnitudes
- Closest galaxies to the GRB, including positions, magnitudes, and photometric redshifts
- Links to the finder images (in .fz and .jpg formats)
- Links to the DESAlert webpage containing a database with additional information for all objects near the GRB

Finder images provided by DESAlert are processed and coadded DES images, each of which covers an area on the sky of approximately 0.75 degrees on a side – although depending on the position of the GRB and its associated uncertainty, several images may be provided to completely cover the nominal search area. These images are provided in g, r, and i filters, when available. Links to the original images for each filter are published in the VOEvent Notice, and also provided on the DESAlert webpage (http://aao.gov.au/DESalert).

In order to faciliate relative photometric measurements of GRBs (or, more likely, their afterglows), the VOEvent Notices provide magnitudes (and uncertainties) in each filter in a range of magnitudes (typically 16-23, depending on filter) for several of the nearest stars within 30 arcseconds of the GRB position. Faint stars are far more likely to be positioned closest to any given GRB (and thus included in the XML notice), but information for all stars in the full region is stored in a similar format in the ancillary data available on the DESAlert website.

Likely of greatest interest to those desiring to follow up GRB observations are the DES pre-discovery catalogs of potential GRB host galaxies. The VOEvent Notices provide positions, magnitudes (and uncertainties), and photometric redshift information (when available) for several of the nearest galaxies within 30 arcseconds of the GRB position. Information for all galaxies in this same region is stored in a similar format in the ancillary data available on the DESAlert website. For the subset of galaxies with no photometric redshift determination, we estimate the redshift "on the fly" with an empirical method based upon their relative *gri* magnitudes (Lopes 2007). In the DESAlert database, we only report physically realistic (i.e., positive) calculated values in the DESAlert data products (failures of the estimator are assigned a value of "-9999"). Because of the limited applicability of this empirical method, we stress that these values are approximations that will be supplanted by more precise determinations from the DES Data Management pipeline as they become available.

4 Results of the DESAlert Algorithm

By the conclusion of Year 1 in February 2014, DES had observed of order 2500 square degrees across the southern sky. A variety of tests were performed with the DESAlert algorithm using both the Year 1 and Science Verification ("Year 0") data (Diehl et al. 2014). First, we simulated VOEvent Notices with systematically-varying positions throughout the DES footprint – though of course the real-time nature of DESAlert was not exercised in this way, we nevertheless could determine in a statistical way the expected impact of DESAlert. Of the 45 simulated notices input to DESAlert, 23 were found to have archival DES data matching the locations, each of which had of order 500 objects (stars or galaxies) within 0.1 degrees of the nominal GRB position. This yield is consistent with statistical expectations from a survey region that is 50% covered; with the data from Year 1 and Year 2 now populating the DES database, the future yield for DESAlert should be significantly higher. Next, to test the real-time processing capabilities of DESAlert, a Swift VOEvent Notice of a newly-discovered GRB was received and processed, with the software taking approximately 1 minute to execute the full algorithm – parsing the Notice, querying the relevant DES databases, building the VOEvent Notice, and "submitting" it (albeit to an internal recipient rather than the public VOEvent network).

Additionally, we compared the photometric redshifts from DESAlert with a selection of spectroscopically-confirmed GRB host galaxies from The Optically Unbiased GRB Host (TOUGH) Survey (Hjorth et al. 2012; Jakobsson et al. 2012), as well as GHostS, the GRB Host Studies (Savaglio et al. 2006). Of the 48 TOUGH bursts selected, 7 had corresponding DES observations, while 29 of the 239 GHostS bursts had corresponding DES observations. Because of the presently sparse sampling of the DES-determined photometric redshifts, only a single burst from these datasets (GRB070110 at $z\approx2.35$) had nearby objects with photometric redshifts already determined by the DES Data Management pipeline. Unfortunately, none of the 12 closest objects found in the DES catalogs match the redshift of the known host, though that is not surprising given that very few galaxies with photometric redshifts determined by DES are at a redshift higher than $z\sim1.3$. We also applied the photometric redshift estimation method for objects observed by DES around other GRBs with spectroscopically-redshifted hosts, including two from the TOUGH dataset and five from the GHostS dataset – specifically GRBs 050406 ($z\approx2.44$), 050822 ($z\approx1.43$), 060614 ($z\approx0.125$), 060719 ($z\approx1.53$), 061007 ($z\approx1.26$), 070318 ($z\approx0.84$), and 070802 ($z\approx2.45$). For GRB060614, three of the eleven closest objects classifed as galaxies had estimated redshifts that were reasonably close (within 20%) to the known value for the

host. Of the closest objects to the other six bursts, none matched the known redshifts – though again, given the extreme distance to these GRBs (as well as the limitations of the estimator) this failure in host identification is not surprising. In the coming years of DES operation, as more galaxies are observed and more photometric redshifts are determined by the Data Management pipeline, many more accurate redshifts for potential host galaxies are expected.

Finally, we tested the DESAlert algorithm with a sub-sample of bursts detected by Swift during the Year 1 observations of DES. In Appendices A and B, we present an example of the data products related to a single burst (GRB131105A) that are provided to the community by DESAlert – specifically, the VOEvent XML Notice and Finder Image, respectively. Table 1 shows a subset of the relevant data for selected stars and galaxies near this GRB as well. Table entries include object position, *grizY* magnitude, spread_model value, object separation from the nominal GRB positon (in arcseconds), object classification, photometric redshift, and object number (where the same number indicates additional observational epochs of the same object). The spread_model quantity is a star/galaxy classifier with values less than 0.003 corresponding to stars (Desai et al. 2012); we calculate the mean of the spread_model values for all filters, with each weighted by the inverse square of the uncertainty in the observations for that filter. This yields a value that relies most heavily upon the most accurate observation, but still incorporates all available data. As with other GRBs we tested, the photometric redshifts are calculated following the method described above in Section 3 – for those observations with physically realistic values (i.e., PhotoZ > 0), the values derived from repeated observations of the same object are broadly consistent (generally within $\pm$10-20% of one another). All stars and galaxies in the region around the GRB are stored in a similar fashion in the ancillary data available on the DESAlert website.

5 Conclusions

DESAlert is an algorithm implemented in Python and SQL to receive automated notices of GRB parameters from VOEvent Notification triggers, and to provide the astronomical community with finder images as well as catalogs of nearby stars and galaxies (with relevant quantities such as positions, magnitudes, and photometric redshifts). The details of the algorithm have been laid out in the previous Sections, and a sample image and catalog shown to familiarise readers with the DESAlert data products. During the five-year lifetime of the DES, we expect to provide data for of order 100 Swift GRBs – though the DESAlert system is expected to function well beyond the formal lifetime of the Survey itself. Extensions to DESAlert (dubbed DESAlert++) are currently being explored based upon other GRB-detecting instruments such as Fermi (Atwood et al. 2009), or even other multi-messenger detections (e.g., gravitational wave observations) stemming from the Astrophysical Multimessenger Observatory Network (Smith et al. 2013). To estimate the annual rate of GRBs likely to be within the DES footprint, we searched the SkyAlert database for unique GRB positions from all sources from one year; of the 230 bursts in the database, 34 fall within the DES footprint and could potentially trigger DESAlert++.

We encourage all observers interested in follow-up observations of GRBs to avail themselves of the VOEvent Notices and web-based data archive provided by DESAlert.

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Table 1 Parameters of Selected Galaxies and Stars near GRB131105A

RA	DEC	g Mag	r Mag	i Mag	z Mag	Y Mag	Spread_Model	Angular Sep.	Classification	PhotoZ	Obj. ID
71.010459	-62.981106	23.593	22.590	21.9224	21.410	22.1738	0.018498927	3.458843	'galaxy'	0.23	1
71.010427	-62.981092	23.7424	22.5189	22.1338	21.6095	21.690	0.013836282	3.581942	'galaxy'	0.14	1
71.010423	-62.981093	23.8376	22.5841	22.0679	21.5207	21.7249	0.012960439	3.595277	'galaxy'	0.21	1
71.010417	-62.981093	23.7965	22.5226	22.1545	21.18	21.490635	0.013708704	3.616410	'galaxy'	0.14	1
71.005637	-62.982534	20.091	19.166	18.7471	18.442	18.31	0.022508474	21.217083	'galaxy'	0.09	2
71.005634	-62.982541	20.0997	19.1777	18.795	18.4226	18.3994	0.020458435	21.232932	'galaxy'	0.08	2
71.005627	-62.982542	20.1639	19.1930	18.7888	18.4934	18.4327	0.019630763	21.258325	'galaxy'	0.10	2
71.005625	-62.982542	20.178	19.2376	18.7750	18.5005	18.4751	0.019633984	21.265364	'galaxy'	0.12	2
71.005136	-62.984396	24.0161	23.7648	23.0734	22.6591	21.2315	0.006713695	25.154421	'galaxy'	0.09	3
71.005104	-62.984409	23.7728	23.0274	23.2069	22.8056	23.1421	0.00546193	25.278434	'galaxy'	-9999	3
71.005094	-62.984408	23.8635	23.8751	23.3745	22.9305	23.1033	0.006561965	25.309126	'galaxy'	-9999	3
71.005087	-62.984402	23.5691	23.7012	23.189	22.9157	23.0332	0.007252764	25.322199	'galaxy'	-9999	3
71.00603	-62.973686	23.4046	21.8176	21.2638	20.877	20.7282	0.005382299	33.541858	'galaxy'	0.30	4
71.006024	-62.973688	23.4994	21.824	21.2165	20.7241	20.7792	0.00507246	33.548430	'galaxy'	0.34	4
71.006016	-62.973687	23.3925	21.7974	21.2504	20.9140	20.7968	0.005116145	33.567992	'galaxy'	0.30	4
71.006008	-62.973675	23.266	21.806	21.2686	21.0181	20.8664	0.005521086	33.619892	'galaxy'	0.26	4
71.019195	-62.988072	24.8818	23.4806	22.8323	20.592	21.8983	0.014396693	37.172856	'galaxy'	0.31	5
71.019204	-62.98807	24.7736	23.4127	22.851	21.9901	21.5149	0.016176819	37.192602	'galaxy'	0.26	5
71.019199	-62.988085	24.7754	23.409	22.8492	22.120	20.5813	0.011954677	37.214428	'galaxy'	0.26	5
71.019266	-62.988055	24.2942	23.3733	22.6429	22.4922	22.0360	0.014129282	37.326285	'galaxy'	0.25	5
71.011806	-62.982318	25.2184	25.1636	25.2770	24.8448	23.7046	-0.007674766	3.945508	'star'	N/A	6
71.01514	-62.979312	19.5227	18.1375	17.2282	16.8141	16.6992	8.14E-06	15.247920	'star'	N/A	7
71.015141	-62.979313	19.5625	18.1592	17.2257	16.8203	16.7661	1.42E-05	15.249410	'star'	N/A	7
71.015155	-62.979323	19.3986	18.1119	17.1693	16.7849	16.6846 -	0.000367476	15.277135	'star'	N/A	7
71.01515	-62.979311	19.4206	18.0851	17.2285	16.7273	16.6455	-3.34E-05	15.281404	'star'	N/A	7
71.011328	-62.988991	24.5252	23.4328	22.9022	22.6418	22.3605 -	-0.003714577	27.688813	'star'	N/A	8
71.011365	-62.988997	24.7727	23.3702	22.9376	22.7773	29.8774 -	-0.006086132	27.709486	'star'	N/A	8
71.011332	-62.988998	24.4302	23.4112	22.8971	22.4062	22.4493 -	-0.002221881	27.713881	'star'	N/A	8
71.011336	-62.988999	24.5632	23.4743	22.9106	22.4970	22.5220 -	-0.003041352	27.717357	'star'	N/A	8
71.003013	-62.977362	22.0296	21.4894	21.3428	21.0796	21.0010	-0.000343104	33.355823	'star'	N/A	9
71.003009	-62.977364	21.9317	21.5417	21.2548	21.0258	21.1811	-0.000362367	33.365800	'star'	N/A	9
71.003007	-62.977363	22.1659	21.5624	21.3411	20.4306	21.2169	-0.000345776	33.373848	'star'	N/A	9
71.003006	-62.977364	22.1268	21.5383	21.3457	20.6537	21.1871	-0.000565474	33.375578	'star'	N/A	9

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The Collaborating Institutions are Argonne National Laboratory, the University of California at Santa Cruz, the University of Cambridge, Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas-Madrid, the University of Chicago, University College London, the DES-Brazil Consortium, the Eidgenössische Technische Hochschule (ETH) Zürich, Fermi National Accelerator Laboratory, the University of Edinburgh, the University of Illinois at Urbana-Champaign, the Institut de Ciencies de l'Espai (IEEC/CSIC), the Institut de Fisica d'Altes Energies, Lawrence Berkeley National Laboratory, the Ludwig-Maximilians Universität and the associated Excellence Cluster Universe, the University of Michigan, the National Optical Astronomy Observatory, the University of Nottingham, The Ohio State University, the University of Pennsylvania, the University of Portsmouth, SLAC National Accelerator Laboratory, Stanford University, the University of Sussex, and Texas A&M University.

A Appendix A: Sample DESAlert VOEvent Notice


```
<?xml version="1.0" ?>
<voe:VOEvent xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:voe="http://www.ivoa.net/xml/VOEvent/v2.0"
xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/v2.0 \protect\vrule width0pt\protect\href{http://www.ivoa.net/xml
 version="2.0" role="observation" ivorn="ivo://DESAlert.AAO/DESAlert#2013-11-05T02:04:44.76_16601">
    <Who>
        <Author>
            <shortName> DESAlert </shortName>
            <contactName> Kyler Kuehn </contactName>
            <contactEmail> kyler.kuehn@aao.gov.au </contactEmail>
        </Author>
    </Who>
    <What>
        <Param name="Burst_TJD" dataType="string" value="16601" ucd="time" unit="days"/>
        <Param name="TrigID" dataType="string" value="576738" ucd="meta.id"/>
        <Group name="Full_Data_Set">
            <Param name="collaboration" dataType="string" value="collabURL" ucd="meta.ref.url"/>
            <Param name="finder_chart" dataType="string" value="finderURL" ucd="meta.ref.url"/>
            <Param name="data_tables" dataType="string" value="dataURL" ucd="meta.ref.url"/>
        </Group>
        <Table name="Nearest Galaxies">
            <Description> Positions of the nearest galaxies. </Description>
            <Field dataType="string" name="Type"/>
            <Field dataType="string" name="RA"/>
            <Field dataType="string" name="RAerr"/>
            <Field dataType="string" name="DEC"/>
            <Field dataType="string" name="DECerr"/>
            <Field dataType="string" name="Mag(g)"/>
            <Field dataType="string" name="Magerr(g)"/>
            <Field dataType="string" name="Mag(r)"/>
            <Field dataType="string" name="Magerr(r)"/>
            <Field dataType="string" name="Mag(i)"/>
            <Field dataType="string" name="Magerr(i)"/>
            <Field dataType="string" name="Mag(z)"/>
            <Field dataType="string" name="Magerr(z)"/>
            <Field dataType="string" name="Mag(y)"/>
            <Field dataType="string" name="Magerr(y)"/>
            <Field dataType="string" name="concentration(g)"/>
            <Field dataType="string" name="concentration(r)"/>
            <Field dataType="string" name="concentration(i)"/>
            <Field dataType="string" name="concentration(z)"/>
            <Field dataType="string" name="concentration(y)"/>
            <Field dataType="string" name="photo_z"/>
            <Data>
                <TR>
                    <TD>Galaxy</TD>
                    <TD>71.010459</TD>
                    <TD>0.0</TD>
                    <TD>-62.981106</TD>
                    <TD>0.0</TD>
                    <TD>23.59304</TD>
                    <TD>0.10887075</TD>
                    <TD>22.59042</TD>
                    <TD>0.06785176</TD>
                    <TD>21.922462</TD>
                    <TD>0.07562234</TD>
                    <TD>21.41031</TD>
                    <TD>0.10268566</TD>
                    <TD>22.173864</TD>
```

```
                <TD>0.34277472</TD>
                <TD>0.0</TD>
                <TD>0.0</TD>
                <TD>0.0</TD>
                <TD>0.0</TD>
                <TD>0.0</TD>
                <TD>-9999.0</TD>
            </TR>
            Additional items omitted from sample Notice...
        </Data>
    </Table>
    <Table name="Nearest Stars">
        <Description> Positions of the nearest stars. </Description>
        <Field dataType="string" name="Type"/>
        <Field dataType="string" name="RA"/>
        <Field dataType="string" name="RAerr"/>
        <Field dataType="string" name="DEC"/>
        <Field dataType="string" name="DECerr"/>
        <Field dataType="string" name="Mag(g)"/>
        <Field dataType="string" name="Magerr(g)"/>
        <Field dataType="string" name="Mag(r)"/>
        <Field dataType="string" name="Magerr(r)"/>
        <Field dataType="string" name="Mag(i)"/>
        <Field dataType="string" name="Magerr(i)"/>
        <Field dataType="string" name="Mag(z)"/>
        <Field dataType="string" name="Magerr(z)"/>
        <Field dataType="string" name="Mag(y)"/>
        <Field dataType="string" name="Magerr(y)"/>
        <Field dataType="string" name="photo_z"/>
        <Data>
            <TR>
               <TD>Star</TD>
                <TD>71.011806</TD>
                <TD>0.0</TD>
                <TD>-62.982318</TD>
                <TD>0.0</TD>
                <TD>25.218458</TD>
                <TD>0.0985755</TD>
                <TD>25.16365</TD>
                <TD>0.15268297</TD>
                <TD>25.276981</TD>
                <TD>0.2645791</TD>
                <TD>24.844833</TD>
                <TD>0.6104301</TD>
                <TD>23.704622</TD>
                <TD>0.30417484</TD>
                <TD>-9999.0</TD>
            </TR>
          Additional items omitted from sample Notice...
        </Data>
    </Table>
</What>
<WhereWhen>
    <ObsDataLocation>
        <ObservatoryLocation id="GEOLUN"/>
        <ObservationLocation>
            <AstroCoordSystem id="UTC-FK5-GEO"/>
            <AstroCoords coord_system_id="UTC-FK5-GEO">
                <Time unit="s">
                    <TimeInstant>
                        <ISOTime>
```

```
                2013-11-05T02:04:44.76
              </ISOTime>
                      </TimeInstant>
                  </Time>
                  <Position2D unit="deg">
                      <Name1>
              RA
            </Name1>
                      <Name2>
              Dec
            </Name2>
                      <Value2>
                          <C1>71.011400</C1>
                          <C2>-62.981300</C2>
                      </Value2>
                      <Error2Radius>0.050000</Error2Radius>
                  </Position2D>
              </AstroCoords>
          </ObservationLocation>
      </ObsDataLocation>
      <Description>
      The RA,Dec coordinates are of the type: source_object.
    </Description>
  </WhereWhen>
  <How>
      <Description> This program uses the DES database to compile a list of nearby objects. </Description>
      <Description> DES uses the Blanco 4m telescope on Cerro Tololo, equipped with the DECam </Description>
      <Reference type="url" uri="http://gcn.gsfc.nasa.gov/swift.html"/>
      <Reference type="url" uri="http://lib.skyalert.org/VOEventLib/"/>
      <Reference type="url" uri="https://www.darkenergysurvey.org/DECam/DECam_add_tech.shtml"/>
  </How>
  <Citations>
      <EventIVORN cite="followup">ivo://nasa.gsfc.gcn/SWIFT#BAT_GRB_Pos_576738-279</EventIVORN>
      <Description> Telescope used: Swift Satellite, BAT Instrument </Description>
  </Citations>
  <Description> GRB real-time followup with additional objects </Description>
</voe:VOEvent>
```


B Appendix B: Example Finder Image

REFERENCES

Abazajian, K., et al., ApJS, 182:543558, 2009

Abbott, T., et al., White Paper Submitted to the Dark Energy Task Force; arXiv: astro-ph/0510346 (2005)
For more information regarding the DES, see http://www.darkenergysurvey.org

Allen, A., et al., arXiv:1212.1916 (2012)

Atwood, W.B., et al., Astrophys.J.697:1071-1102 (2009)

Barthelmy, S.D., et al., Space Science Reviews Volume 120 Issue 3-4 (2005) pp. 143-164

Bertin, E. and S. Arnouts, *Astronomy & Astrophysics Supplement* 117 (1996) 393

Cool, R., et al., PASP 118 (2006) 733-739

Desai, S., et al., ApJ 757, 83 (2012) arXiv:1204.1210

Diehl, H. T., et al., Proc. SPIE 9149, 9149-31 (2014)

Flaugher, B., et al., AJ, submitted (2015)

Gunn, J. E., et al., AJ 116, 3040 (1998)

Hjorth et al. ApJ, 756, 187, 2012

Jakobsson et al. ApJ, 752, 62, 2012

Lopes, P.A.A, MNRAS, 380:1608-1620, 2007

McMahon, R.G., et al., ESO Messenger, vol. 154, (2013) pp. 35-37

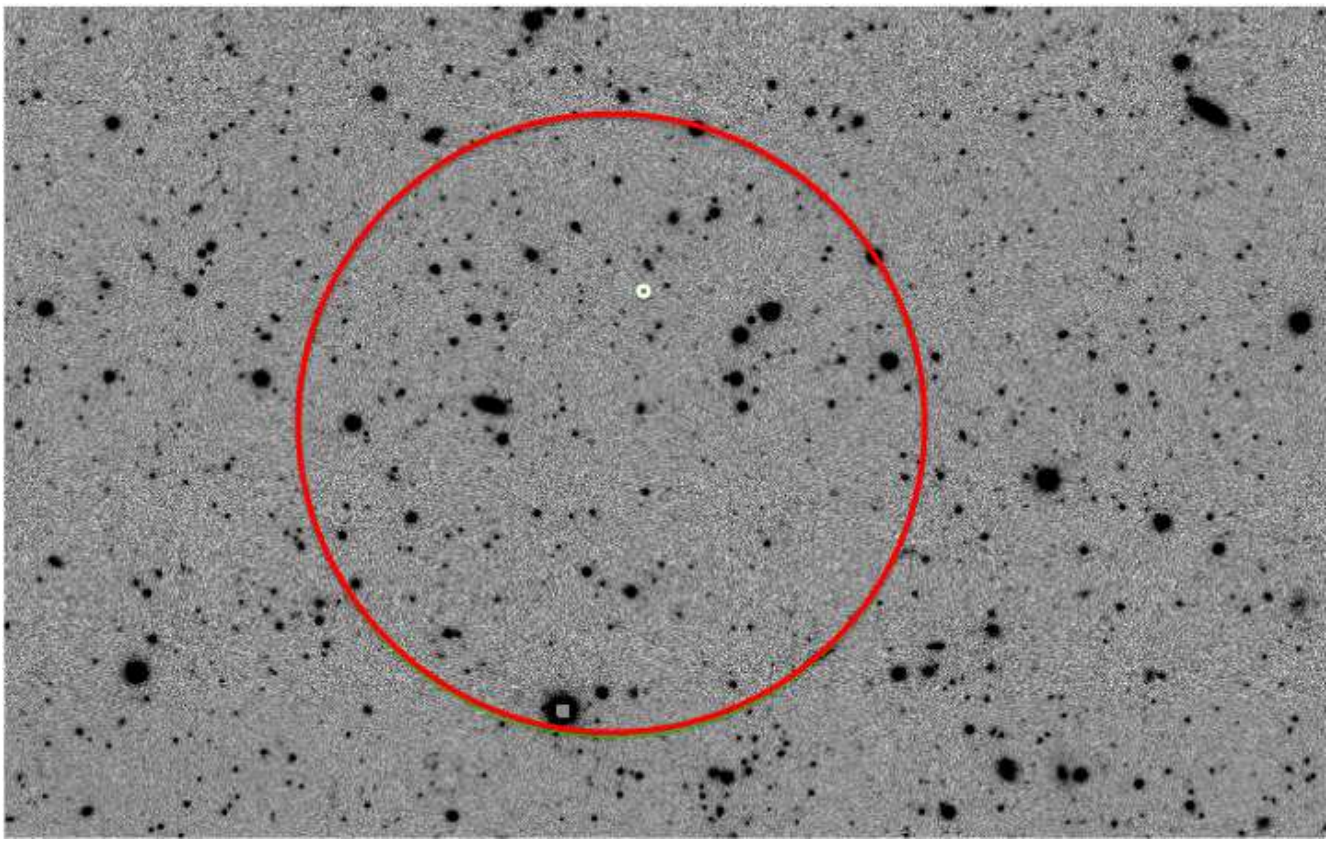

Figure B1. This is an example of (a zoomed-in segment of) a GRB Finder Image. The initial Swift-BAT 90% error circle with 1.5' radius is shown (large red circle), as is the refined Swift-XRT 90% error circle with 1.4" radius (small white circle).

Ruhl, J.E., et al., Proc. SPIE, Vol. 5498, pp. 11-29, 2004

Savaglio S., Glazebrook K., Le Borgne D., 2006, AIP Conf. Proc., 836, 540, 2006

Seaman, R., et al., IVOA Recommendation, arXiv:1110.0523

Smith, M.W.E., et al., Astropart. Phys. V45 (2013) pp. 56-70

Williams, R.D., et al., arXiv:0906.2186 (2009)

For more information regarding skyalert, see http://www.skyalert.org