AstroGrid-D

Deliverable

A Scheduler for a Robotic Telescope Network[1]

Deliverable	D5.8
Authors	F. Breitling, S. Braune, H. Enke, T. Granzer, T. Röblitz
Editors	H. Enke
Date	August 8, 2008
Document Version	1.0
Current Version	1.0
Previous Versions	

A: Status of this Document

Published.

B: Reference to project plan

Deliverable 8 of working group 5 corresponds to the task TA V-8: *"Observation requests can be delegated to robotic telescopes based on dynamic data. Software and documentation can be provided."*

C: Abstract

A scheduler has been developed to allow for observations of arbitrary duration independent of daytime within a network of robotic telescopes. The underlying algorithm maximizes the target altitude during observation for a given set of telescopes. The usage of the scheduler is explained and demonstrated for a network of five telescopes. The resulting schedule describes a 24 h observation. It can be used to generate the individual observation request for the telescopes in the schedule. The submission of the observation request within a simulated network is also described.

D: Change History

Version	Date	Name	Brief summary
0.1	17.03.2008	F. Breitling	First draft.
0.1.1	08.05.2008	S. Braune	Added scheduler plots for M31.
0.2	16.05.2008	F. Breitling	Second draft.
0.2.1	06.06.2008	T. Granzer	Contributions.
0.3	04.07.2008	F. Breitling	Third draft for circulation within WG 5.
0.3.5	14.07.2008	F. Breitling	Corrections from H. Enke.
0.4	17.07.2008	F. Breitling, S. Braune	Add. corrections from H. Enke and S. White.
0.5	22.07.2008	F. Breitling, S. Braune	Additional structure and revision.
0.6	26.07.2008	F. Breitling	Final draft for circulation within the project.
1.0	08.08.2008	F. Breitling	Final layout.

E:

Contents

1   Introduction

Research in some astronomical fields such as astroseismology or the investigation of star cycles requires uninterrupted data and light curves that exceed the observation time of a single night. The data can be obtained from observations in a network of telescopes, in which one telescope can continue the observation of another telescope whose observation is interrupted (e.g. by daylight or bad weather). For almost 20 years astronomers have collaborated in the *Whole Earth Telescope* (WET) [7] to build such a global network. The WET is a "manual" network where all coordination is done by individual people.

Certainly campaigns could be conducted more easily with a network of robotic telescopes. The software for such a network is being developed by AstroGrid-D [2]. It consists of different components: grid middleware and infrastructure, an information service, interfaces to these components for robotic telescopes, tools for the submission, cancellation and status queries of observations, a telescope broker and a network scheduler. This deliverable describes the functionality and usage of the network scheduler, which generates schedules for longterm observations.

2   Functionality of the Scheduler

The observation of an astronomical object poses constraints onto the telescope location, since each object is only visible from certain locations on earth. In astronomical terms the object has to be above horizon. Moreover, even if this is the case, observations might be prevented by the brightness during daytime. In astronomical terms the sun has to be below horizon. So in a network typically only some telescopes can perform a given observation. On the other hand, if the number of telescopes is large, there might be several telescopes which can perform an observation. Usually observations require only one telescope of a certain type at a time. So selection criteria have to be defined. The selection criterion used by the scheduler is the altitude of an object above horizon. Generally observations at high altitudes of the object are preferred, since they provide a smaller atmospheric depth and therefore a better *seeing*[2].

The scheduling algorithm calculates the observation altitude versus time for each telescope and determines their intersection points. Two neighboring intersection points provide the time interval for an observation by a telescope. The scheduler selects the telescope with the highest altitude curve at a given time. Of course only nighttime altitudes are taken into account, i.e. where the sun is at least $18°$ below the horizon. Additional selection criteria can be added. For example it is desirable to keep the number of different telescopes low for an observation, since every additional telescope can complicate the data analysis and increase the chances for technical failure. Short observation periods should be avoided, if they can be covered by another telescope.

A network scheduler requires an accurate timing coordination with other telescopes and therefore scheduling is done in advance. This is different from a local telescope scheduler. Local schedulers often don't have a fixed schedule far in advance. They select the next target dynamically from a pool of targets shortly before the next observation can take place. So the local scheduler has the necessary flexibility to react to unpredictable changes of the observing conditions e.g. due to the weather. To still accomplish a fixed scheduling with the local scheduler, the network observations should be scheduled with a sufficiently hight priority which can not be easily overrule by another

---

[2]Astronomical seeing is a measure for the resolution that can be achieved at given atmospheric conditions.

target of the local scheduler. Moreover, if an observation is canceled by the local scheduler (e.g. due to bad weather or higher priority targets), notification of the network scheduler would be desirable, so that an alternative telescope can be selected. However, such a dynamic rescheduling is beyond the implementation described here.

One of the advantages of a network shows by comparison of the likelihoods for observing a given astronomical object. Bad weather excluded, the likelihood is about 12% for a single telescope site to observe a given target at an altitude of at least $30°$ above horizon while the sun is at least $18°$ below the horizon. But the likelihood is roughly 85% in a network, where many telescopes are available and no restriction on the location applies. Moreover, continuous observation in excess of 24 h can not be achieved from single sites except for those close to the poles.

3   Example Scenario

To demonstrate the usage of the scheduler we create a schedule for the observation of Gl586A by five robotic telescopes. The simulated telescope network is shown in the Telescope Map of Fig. 1.

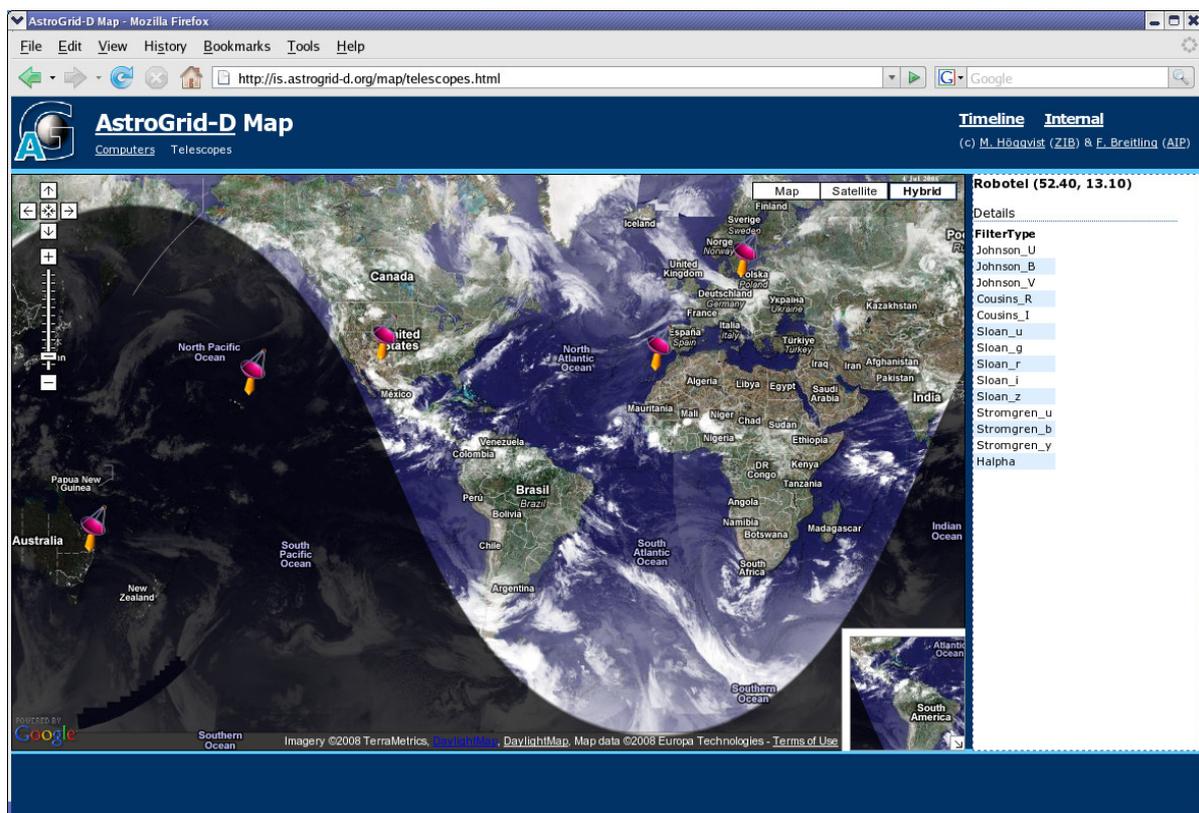Three simulated telescopes are at locations of Robotic Telescopes owned by the Astrophysical Institute Potsdam (AIP):

Figure 1: Telescope Map showing the five telescopes which are used for a 24 h observation. The map also shows the current day and night regions, clouds as well as properties of selected telescopes. The Telescope Map is a web browser user interface for telescope selection [3] developed in OpenTel.

- RoboTel in Germany (52.40 N , 13.10 E) [8],

- STELLA-I in Tenerife (28.30 N, 16.51 W) [8],

- Amadeus in Arizona (31.39 N, 110.69 W).

Two simulated telescopes are at locations of to the Las Cumbres Observatory Global Telescope Network (LCOGT, [6]):

- Faulkes North in Hawai (20.71 N, 156.26 W),

- Faulkes South in Australia (31.27 S, 149.07 E).

The equatorial coordinates of Gl586A are (J2000) (15.46h -9.34°).

4   Usage of the Scheduler

The scheduler is part of the OpenTel package [1] and is executed through the *Bash* wrapper script `ot-schedule`.

4.1   Input Files

The required input consists of two files: the first file contains a list of telescopes and the second file contains an RTML [5] observation request. Details about the usage of RTML (Remote Telescope Markup Language) developed by the Heterogeneous Telescope Network consortium as standard in OpenTel can be found in [10]. The list of telescopes can be either obtained from a broker as discussed in [11] or it can be created manually, e.g. by selecting telescopes from the Telescope Map or from the list of RTML telescope descriptions in the `telescopes` folder of the OpenTel package. In the TELLIST.txt file each telescope is specified by its fully qualified domain name. This name is defined in the `id` attribute of the `Telescope` element of the telescope's RTML description. The input files for this example are shown in listing 1 and 5.

Listing 1: The list of telescopes as contained in the input file TELLIST.txt.

```
1 Amadeus.aip.de
2 FaulkesTelescopeNorth.faulkes-telescope.com
3 FaulkesTelescopeSouth.faulkes-telescope.com
4 STELLA-I.aip.de
5 RoboTel.aip.de
```

All necessary information is extracted via XSLTs from the observation request and from the RTML telescope descriptions in the `telescope` folder of the OpenTel package. All telescopes are integrated by adding their RTML description to this folder.

The observation time is also extracted from the RTML observation request, but it can be overwritten with the `--start` and `--duration` option. The start time is provided in ISO 8601 format, the duration in decimal value of hours. For the example of the observation described in Listing 5 the duration would be 24 h, if it is not changes.

4.2   Execution

Invocation of the `ot-schedule` program without parameters explains its usage (Listing 2).

Listing 2: Usage of the `ot-schedule` program for the scheduler.

```
$ ot-scheduler
Usage:  ot-schedule [OPTIONS] TELLIST.txt TARGET.rtml
Generate a schedule for sequential observations in a telescope network.

    -h, --help                        show this info
    -d, --duration 24                 overwrite duration [h] of observation
    -s, --start 2008-09-01T12:00:00   overwrite start time of observation
```

The schedule is created using

`ot-schedule TELESCOPES.txt Gl586A.rtml`

For comparison schedules have been created at four different times of the year.

4.3   Output Files

`ot-schedule` produces a text file containing the schedule. It has the base name of the RTML file and the suffix `.sch`. It contains the fully qualified domain names of the telescopes as well as the start and end time for the observation. The schedule for the observation on November 1st 2008 is shown in listing 3.

Listing 3: Schedule `Gl586A.sch` for the 24h observation of the star Gl586A.

```
1 Amadeus.aip.de                 2008-11-01T02:30:00   2008-11-01T06:50:00
2 FaulkesTelescopeNorth.faulkes-telescope.com          2008-11-01T06:40:00
    2008-11-01T10:20:00
3 FaulkesTelescopeSouth.faulkes-telescope.com          2008-11-01T10:10:00
    2008-11-01T17:50:00
4 RoboTel.aip.de                 2008-11-01T17:40:00   2008-11-01T19:50:00
5 STELLA-I.aip.de                2008-11-01T19:40:00   2008-11-02T02:40:00
```

The actual observation time in the RTML file was specified from 2008-11-01T00:00:00 to 2008-11-02T00:00:00. In comparison the generated schedule covers the slightly different period from 2008-11-01T02:30:00 to 2008-11-02T02:40:00. The reason is the ability of the scheduler to combine observations by same telescopes. Without this flexibility the observation schedule would consist of six individual observations starting and ending with the telescope STELLA-I. With the two STELLA-I observations combined only five observations remain. Consequently the start and end time of the observation changes. The advantage is a simpler schedule and a simplified data analysis.

In addition the scheduler also produces a file with the suffix `.out`. This file contains the target's altitudes in time steps of 10 minutes for each telescope. This file can be used for plotting the altitudes of the telescopes.
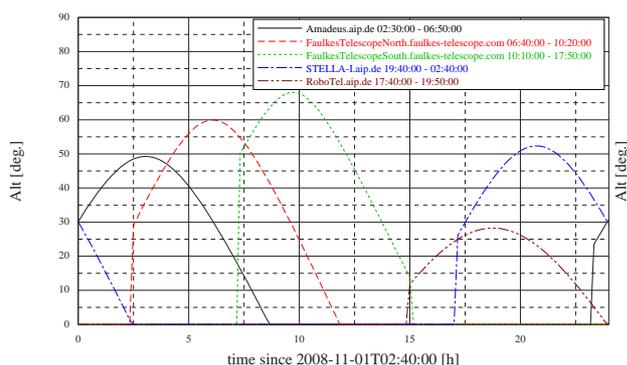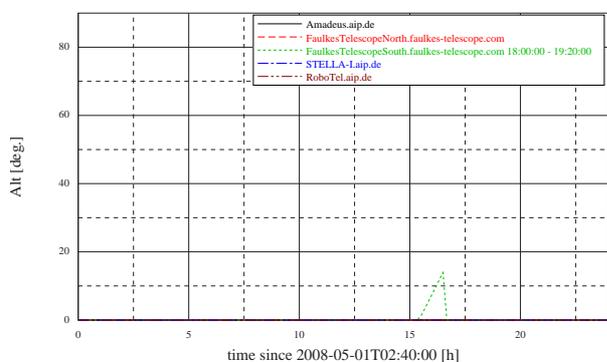
Figure 2: Observation altitudes of Gl586A in November at telescopes of the schedule.
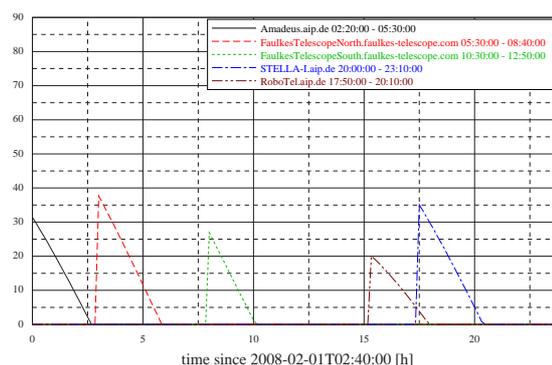
Figure 3: Observation altitudes of Gl586A in February at telescopes of the schedule.

Figure 4: Observation altitudes of Gl586A in May at telescopes of the schedule.
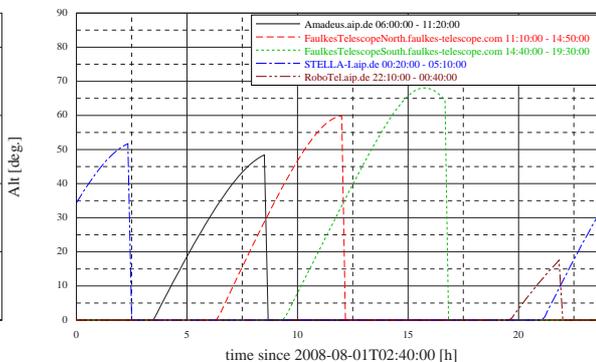
Figure 5: Observation altitudes of Gl586A in August at telescopes of the schedule.

4.4 Plotting

The scheduler contains the program `ot-plotschedule.sh` which plots the generated schedules. `ot-plotschedule.sh` needs the `.out` file as input. It uses the open source tool *xy2ps* [12] to produce PS files. *xy2ps* is also included in the scheduler. Fig. 2-5 are produced using:

```
ot-plotschedule Gl586A.out
```

As Fig. 2 shows, in November an uninterrupted 24 h observation of Gl586A is possible using just five telescopes - suitable weather conditions presumed. However, it is important to notice, that at other times of the year an uninterrupted observation is not possible due to the altitude of the sun. The situation is illustrated in Fig. 3 to 5 for February, May and August.

5 Submission of a Schedule

If all telescopes were actually integrated and operational the schedule could now be submitted to the network. Here this is demonstrated for a simulated network. The submission program provided

with OpenTel is called `ot-submit`. The command line syntax of `ot-submit` is shown in Listing 4.

Listing 4: Submission of the schedule `G1586A.sch` to the robotic telescope network.

```
$ ot-submit
Usage:  ot-submit [OPTIONS] TARGET1.rtml [TARGET2.rtml ...]
Submit targets to one or more telescopes.

    -f, --force                       overwrite existing files
    -h, --help                        show this info
    -n, --nosubmit                    only write RMTL files, no submission
    -s, --schedule schedule.txt       use schdule file or telescope list
```

For a network observation it needs the schedule and the RTML observation description as input. So the command line is

```
ot-submit -s G1586A.sch G1586A.rtml
```

The submission command will then create individual RTML observation requests for each telescope and store them into a folder with the name of the target RTML request. The RTML observation requests are generated using XSLT. The new request is then submitted to the different telescopes of the network. Each telescope confirms or denies the scheduling of the target for the given time.

A job status can be obtained by `ot-status`, jobs can be canceled by `ot-cancel`.

6   Components of the scheduler

The scheduler consists of three components:

- `ot-schedule` — command line interface

- `scheduler.java` — program for the generation of the schedule

- `astro.java` — class for astronomical calculations

`ot-schedule` extracts the target and telescope coordinates from the input files and generates the auxiliary input file `telescopes.txt`. `telescopes.txt` contains the list of the telescopes and their coordinates.

Next it calls the Java scheduler as follows:

```
java -classpath $OpenTel/scheduler/classes scheduler <START> <END> <RA> <Dec> telescopes.txt
```

<START> and <END> represent the start and end time in ISO 8601 format. <RA> and <Dec> represent the equatorial coordinates. They are given in decimal numbers of hours and degrees.

The Java program calculates the altitude of the target and the sun for each telescope during observation time in time steps of 10 minutes. Only times with the sun's altitude lower than $-18°$ are included. For each of the remaining times the telescope with the largest altitude is determined. The union of these times provides the observation periods of the schedule. Each period contains an overlap of 10 minutes between observations with different telescopes. Also observations starting and ending with the same observation are combined. Both is important for calibration and the reduction of systematic errors.

The astronomical functionality of the scheduler is provided through the class in `astro.java`. The code was taken from the controller software [9] of the robotic telescope STELLA.

7   Installation

The installation of the scheduler is straight forward. The scheduler becomes available with an installation of the OpenTel packages. This can be downloaded from the OpenTel web page [1] or the AstroGrid-D repository. The syntax is

```
svn co svn://svn.gac-grid.org/software/OpenTel
```

OpenTel should reside in the `/opt` folder. Finally the `OpenTel/bin` folder needs to be added to the path (in the *Bash* shell the command is `export PATH=$PATH:/opt/OpenTel/bin`). With the installation the commands discussed above become available. However, the submission, cancellation and status query of observations also requires an installation of the Globus Toolkit [4].

8   Conclusion

A network scheduler for robotic Telescopes has been developed in AstroGrid-D and is provided with the OpenTel package [1]. It produces schedules of arbitrary duration for observation of astronomical objects within a network of telescopes. A command line interface is included which uses RTML observation requests and a list of telescopes to generate a schedule. A tool for plotting the schedule is included as well. The current implementation takes into account visibilities of astronomical objects during daytime at different locations of the telescopes. Future implementations should also allow for a dynamic rescheduling in case an observation with a particular telescope is canceled e.g. due to bad weather. Moreover, more advanced algorithms should be added to optimize schedules not only on the observation altitude but also on additional constraints, such as a limited number of telescopes. This scheduler provides a solid basis for further improvements.

A Listings

Listing 5: RTML observation request of Gliese object Gl586A. The `DateTimeConstraint` element contains the observation time. Target coordinates are specified in the target element. The coordinates in the catalog element refer to the position of reference stars.

```xml
 1 <?xml version="1.0" encoding="UTF-8"?>
 2 <RTML version="3.2" mode="request" uid="rtml://OpenTel.astrogrid-d.org/
      observations/Gl586A"
 3   xmlns="http://www.rtml.org/v3.2" xmlns:xsi="http://www.w3.org/2001/
        XMLSchema-instance"
 4   xsi:schemaLocation="http://www.rtml.org/v3.2 file:RTML-v3.2.xsd"
 5   xmlns:grddl="http://www.w3.org/2003/g/data-view#"
 6   grddl:transformation="http://www.astrogrid-d.org/xml2rdf.xsl">
 7   <History>
 8     <Entry timeStamp="2007-02-07T15:30:00">
 9       <Agent name="T. Granzer"/>
10       <Description>RTML Example: Simple Example</Description>
11     </Entry>
12   </History>
13   <Project ProjectID="gl586perihel">
14     <Title>Gl 586A perihel</Title>
15     <Abstract>This target is active 3 days before and after perihel</
          Abstract>
16     <Contact>
17       <Name>Strassmeier</Name>
18       <Username>AIP</Username>
19       <Communication>
20         <Email>kstrassmeier@aip.de</Email>
21       </Communication>
22     </Contact>
23   </Project>
24   <Schedule status="active">
25     <Spectrograph>
26       <SpectralRegion>optical</SpectralRegion>
27     </Spectrograph>
28     <AirmassConstraint maximum="2"/>
29     <DateTimeConstraint>
30       <DateTimeStart value="2008-10-01T00:00:00"/>
31       <DateTimeEnd value="2008-10-02T00:00:00"/>
32     </DateTimeConstraint>
33     <Priority>3</Priority>
34     <Target name="Gl 586A">
35       <Coordinates>
36         <RightAscension>
37           <Value units="hours">15.46933652</Value>
38         </RightAscension>
39         <Declination>
40           <Value units="degrees">-9.3480694</Value>
41         </Declination>
42       </Coordinates>
43       <TargetBrightness>
44         <Magnitude>6.86</Magnitude>
45         <Type>V</Type>
46       </TargetBrightness>
47     </Target>
48     <Catalogue>
```

```
49          <Target>
50            <Coordinates>
51              <RightAscension>
52                <Value units="hours">15.46934383</Value>
53              </RightAscension>
54              <Declination>
55                <Value units="degrees">-9.348610555555556</Value>
56              </Declination>
57            </Coordinates>
58            <TargetBrightness>
59              <Magnitude>6.95</Magnitude>
60              <Type>V</Type>
61            </TargetBrightness>
62          </Target>
63          <Target>
64            <Coordinates>
65              <RightAscension>
66                <Value units="hours">15.470066629</Value>
67              </RightAscension>
68              <Declination>
69                <Value units="degrees">-9.35839</Value>
70              </Declination>
71            </Coordinates>
72            <TargetBrightness>
73              <Magnitude>7.74</Magnitude>
74              <Type>V</Type>
75            </TargetBrightness>
76          </Target>
77        </Catalogue>
78        <Exposure>
79          <Value units="seconds">600.0</Value>
80        </Exposure>
81        <Observation id="single"/>
82      </Schedule>
83      <Telescope name="RoboTel" id="RoboTel.aip.de" uref="rtml://RoboTel.aip.de
         "/>
84  </RTML>
```

F: References / Bibliography

References

[1] AstroGrid-D Collabortaion. OpenTel.
    http://www.gac-grid.org/project-products/Software/RoboticTelescopes.htm%l,
    2008. [Online; accessed 01-July-2008].

[2] AstroGrid-D Collabortaion. The German Astronomy Community Grid.
    http://www.gac-grid.org/, 2008. [Online; accessed 01-July-2008].

[3] F. Breitling, M. Braun. Providing Static Metadata of Robotic Telescopes to Stellaris.
    Technical Report D2.4, AstroGrid-D project, March 2007.

[4] Ian T. Foster. Globus toolkit version 4: Software for service-oriented systems. In *NPC*, pages
    2–13, 2005.

[5] F. V. Hessman. Remote Telescope Markup Language (RTML). *Astronomische Nachrichten*,
    327:751−+, September 2006.

[6] LCOGT. Las Cumbres Observatory Global Telescope. http://lcogt.net/, 2008. [Online;
    accessed 01-July-2008].

[7] R. E. Nather, D. E. Winget, J. C. Clemens, C. J. Hansen, and B. P. Hine. The whole earth
    telescope - A new astronomical instrument. *Astrophysical Journal*, 361:309−+, September
    1990.

[8] K. G. Strassmeier, T. Granzer, M. Weber, M. Woche, M. I. Andersen, J. Bartus, S.-M.
    Bauer, F. Dionies, E. Popow, T. Fechner, G. Hildebrandt, A. Washuettl, A. Ritter,
    A. Schwope, A. Staude, J. Paschke, P. A. Stolz, M. Serre-Ricart, T. de la Rosa, and
    R. Arnay. The STELLA robotic observatory. *Astronomische Nachrichten*, 325:527−+,
    October 2004.

[9] T. Granzer. STELLA, API specification.
    http://www.aip.de/~granzer/javadoc/standard/, 2008. [Online; accessed
    01-July-2008].

[10] T. Granzer, F. Breitling. Robotic Telescopes as GRID Resources. Technical Report D5.3,
     AstroGrid-D project, March 2007.

[11] T. Röblitz. A Broker for a Robotic Telescope Network. Technical Report D5.5, AstroGrid-D
     project, May 2008.

[12] M. Toshio. xy2ps. http://members.jcom.home.ne.jp/maegawa/pub/xy2ps, 2003.
     [Online; accessed 24-Feb-2008].