Cone of Darkness: Finding Blank-sky Positions for Multi-object Wide-field Observations

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Abstract. We present the Cone of Darkness, an application to automatically configure blank-sky positions for a series of stacked, wide-field observations, such as those carried out by the SAMI instrument on the Anglo-Australian Telescope (AAT). The Sydney-AAO Multi-object Integral field spectrograph (SAMI) uses a plug-plate to mount its $13 \times 61$ core imaging fibre bundles (hexabundles) in the optical plane at the telescope’s prime focus. To make the most efficient use of each plug-plate, several observing fields are typically stacked to produce a single plate. When choosing blank-sky positions for the observations it is most effective to select these such that one set of 26 holes gives valid sky positions for all fields on the plate. However, when carried out manually this selection process is tedious and includes a significant risk of error. The Cone of Darkness software aims to provide uniform blank-sky position coverage over the field of observation, within the limits set by the distribution of target positions and the chosen input catalogues. This will then facilitate the production of the best representative median sky spectrum for use in sky subtraction. The application, written in C++, is configurable, making it usable for a range of instruments. Given the plate characteristics and the positions of target holes, the software segments the unallocated space on the plate and determines the position which best fits the uniform distribution requirement. This position is checked, for each field, against the selected catalogue using a TAP ADQL search. The process is then repeated until the desired number of sky positions is attained.

1. Introduction

The SAMI instrument (Croom et al. 2012) has been developed to carry out a detailed galaxy study which will use multi-object integral field spectroscopy techniques to study gas accretion in galaxies, star formation as a function of environment, and the relationship between the star formation in a galaxy and its AGN (Fogarty et al. 2012).

SAMI uses 61-core hexabundles to observe a field of view of 15 arcsec for each of 13 targets (Bryant et al. 2012). The hexabundles are held in place on the optical plane through the use of a plug plate — that is, a pre-drilled steel plate with holes corresponding to the positions of target objects, for a given telescope pointing on the sky. For observational efficiency and to maximise the utilisation of each plug plate, several (usually 2 or 3) consecutive fields to be observed are stacked and their positions of their targets are drilled onto a single plate. This plate configuration process is carried out automatically, based on a pool of targets for each field and on the known hardware constraints which govern the placement of holes on the plate (Lorente et al. 2013).
As well as the target positions, the plate configuration process allocates the instrument’s 26 sky fibres to blank sky positions in each field. To make the best use of the available space on the plate, a sky plate hole is chosen such that it corresponds to blank sky for each of the 2 (or more) stacked pointings on the plate. Additionally, the sky positions need to be as uniformly distributed over the plate as the allocated target positions will allow, so as to provide optimal sky subtraction data.

The Cone of Darkness (COD) application has been written to carry out this task, in the first instance for SAMI, but with the flexibility and modularity to determine blank sky positions for a general multi-object instrument.

2. Cone of Darkness

To produce optimal plate coverage of sky positions, a grid of user-defined size is laid over the plate area, and the resulting grid cells form the set of candidate sky positions. From this set those cells within the exclusion zone of any allocated position (i.e. the target holes plus an instrument-specific area around them, to allow for connector size, etc.) are discarded. The most remote candidate cell is then found, based on nearest-neighbour distances (Figure 1 left).

The candidate position is then tested for suitability, by checking whether there are any objects in the field to a given magnitude limit, for each stacked field on the plate (2 fields in the example in Figure 1). This is done by means of a TAP ADQL search of the selected catalogue (Ortiz et al. 2011) which, in the case of SAMI is the SuperCOSMOS Science Archive. Because there are 26 sky fibres to be allocated to positions distributed over the entire plate, and because there are potentially many candidates to be tested before each valid position is found, it is more efficient (due to network and query overheads) to run a single catalogue search per field covering the entire one degree field-of-view of the plate, rather than to execute a catalogue query for each individual candidate.
An example of such a TAP query is as follows:

\[ \text{http://wfaudata.roe.ac.uk/ssa-dsa/TAP/sync}\]

```sql
QUERY=SELECT TOP 100 &
QUERY=SELECT objID, ra, dec, epoch, sigRA, sigDec,
muAcosD, muD, sigMuAcosD, sigMuD, chi2 FROM Source WHERE
(ra BETWEEN (centralPosRADeg - radiusDeg / 2.0 AND
(centralPosRADeg + radiusDeg / 2.0) AND
(dec BETWEEN (centralPosDecDeg - radiusDeg / 2.0 AND
(centralPosDecDeg + radiusDeg / 2.0)))
```

The object list is returned by the query service as a VOTable [Ochsenbein et al. 2011], saved to disk and then locally searched for objects within the field of view of each candidate sky position. This currently takes the form of a radial proximity check, and in future versions will also include a simple analysis of a 20 arcsec SuperCOSMOS thumbnail image of the region.

Once a candidate position is allocated to a sky fibre or discarded as unsuitable, the corresponding grid cell is removed from the candidate pool. The nearest neighbour distances of remaining candidate cells are recalculated and the most remote candidate is again identified. The process now iterates (check candidate region for sources; accept or reject position; find next most isolated candidate cell) until the required number of suitable sky positions are found.

To give the user a final way to confirm that the process has worked correctly — i.e. that there are no objects in the selected sky positions down to the detection limit of the instrument, the program downloads a set of thumbnail images for the positions chosen. This allows a quick visual inspection of the regions to be observed before the process of plate fabrication begins.

### 3. Future Work

The Cone of Darkness application was written with the general fibre-positioning instrument in mind, and the code is parametrised and abstracted to support other instruments with little extra effort. However, its user interface is specific to SAMI and there are plans to make this more general in subsequent versions of the code. Additionally, more flexible catalogue discovery, via a VO Registry or through direct user input would be a very useful addition. Finally, better consideration of catalogue object morphology (circular objects are currently assumed) would result in decreased probability of false positives, as well as better use of the available plate area.

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