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The Our Solar Siblings Pipeline: Tackling the data issues of the scaling problem for robotic telescope based astronomy education projects

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Abstract
In this paper, a pipeline designed to produce data products for education is described. The primary goal of the pipeline is to facilitate teacher usage of robotic telescopes in the classroom and to reduce administration time for project personnel. In so doing, it produces data products that are scientifically valid and robust using multiple different photometric measurement techniques to create catalogues of both instrumental measurements as well as calibrated measurements cross matched to popular astronomical catalogues where standard stars are available. The main blocking factors that the pipeline addresses are outlined, an overview of the pipeline is provided and it's future development is forecast.

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Introduction

One of the key problems for many robotic telescope projects who focus on embedding themselves or their projects in the everyday classroom is how to scale things up to a reasonable size (Gomez and Fitzgerald (2017), Fitzgerald et al. (2014)), enlist themselves and perform well in the project. Most everyday science teachers typically will not, though, for a whole variety of different reasons, many revolving around the issue of time limitation (Fitzgerald et al., 2017).

One of the main blocking factors for teachers is the quality, nature and provision of astronomy data products available from the telescope system. Real authentic messy data is a blocking factor for teachers taking up the project, even the most keen. The more processing necessary, the more time it takes, the more load it puts on the teacher and students, the less likely it will be to happen. Teacher time, both preparation time and class time, is likely the key consideration in attempting to scale up. There is certainly a place for long, extended, authentic, hands-on, from scratch experiences in astronomy research during a school career but this should be a choice rather than an inevitability! It certainly isn't a choice that a typical classroom teacher in a typical mainstream school can make, so this approach is not an option for projects attempting to reach the masses.

Real, authentic, messy manually processed data has been part of the by-line for many projects wanting to undertake 'inquiry-based' astronomy education using robotic telescopes. However, there is a limit. This is especially true when we consider that most processing of the data by professional scientists is automated anyway! The raw data can always be available for those who would like to use it, but typically the best quality results are drawn from professionally processed data. There is so much that can go wrong in reducing an image to a catalogue of photometry, from simple silly mistakes to fundamentally misguided or poor assumptions especially in the hands of non-experts. Why get teachers and students to do something manually they we, as scientists, would immediately automate? We don't get students to create and calibrate their own multimeters when they are learning electric circuits in physics class, why would it be necessary to do something similar in scope in an astronomy class?

It is also true that a limiting factor would be time on the part of project personnel. The project personnel certainly aren't going to manually process the files for all of the users! That would hit a scaling limit very quickly! Also, even the distribution of images and data products on the project side needs to be automated unless the project has a vast amount of employees or volunteers who can manually attach images and send them through... this is time that could be much better spent!

To undertake this automatic processing and to streamline the distribution of images, photometry and catalogue, the OSS Pipeline has been developed slowly over the last 7 years. Much of the testing and continual processing has been on telescopes in the LCO (Brown et al., 2013) network, but it successfully processes any relatively straightforward optical broadband imagery. It has been successfully tested on a variety of 0.4-4m class telescopes. We also welcome collaboration with smaller observatories who may be looking for an automated pipeline for their own uses.

The pipeline itself is a Linux-based, Python-based (where possible and original), script which takes a nights images from a robotic telescope, further processes the images to increase the image quality, undertakes multiple forms of photometry, attempts an all-sky calibrated solution and attempts a full cross-matched catalogue of photometry from the night. It minimises the time investment for the teacher, the student AND the project personnel. In the long-term, the pipeline will be available open-source, and it's modular components will be making their way onto GitHub soon, but while alpha-testing it will remain proprietary. It currently runs on a Fedora 26 Virtual Machine on a dedicated computer in Melbourne, Australia. In this paper, we outline the thinking around the OSS Pipeline, outline it's general workflow and where it is heading in the future.

Definition of the Problem

There are numerous reasons that teachers do not do inquiry-based astronomy in the classroom (Fitzgerald et al., 2017). Not many of them can be solved through the use Information Technology (I.T.), but some can. We outline here the blocking factors that can potentially be addressed through the use of an image processing pipeline.

I.T.

Teachers have little to no control over the I.T. facilities available to them. Some schools allocate laptops to students or have laptops available to be wheeled into class, desktops are tending to become much rarer and use of tablets (sometimes as the only provided option) are on the rise. The idea that students should "Bring Your Own Device" (BYOD) to school is also becoming common. A rough anecdotally-derived ballpark of distribution of Operating Systems for laptops at Australian schools is approximately 74% Windows, 25% Apple, 1% Linux. The true percentage values are not important, that there are multiple non-homogenous operating systems in schools is the important point. This means that any project intending to scale to multiple schools in multiple jurisdictions will likely have to tackle a variety of I.T. scenarios. As most hands-on astronomy beyond seasons, the solar system and the phases of the moon is done on computers, this is a key limiting factor to scalability.

Many of the available high quality pro-am packages, as well as many of the smaller hobbyist-built tools, tend only to be written for Windows (with some uncommon exceptions). In the large-scale Space to Grow program (Danaia et al., 2012), this meant that (at that time) there was no easily available and reliable simple photometry tool for an entire jurisdiction of 21 high schools which exclusively used MacOS. A juryrigged version of Makali'i (A simple windows only image analysis tool from NAOJ, makalii.mtk.nao.ac.jp) bottled via Wine was created to overcome this. Since this time, a viable cross-platform alternative, AstroImageJ (Collins et al., 2017), has arrived on the scene for simple aperture photometry with some very nice features. For advanced scientific grade aperture photometry, the current best option (also cross-platform) is Aperture Photometry Tool (Laher et al. (2012a), Laher et al. (2012b))

There is no known accessible PSF photometry package capable of use by student level users and certainly none accessible via a GUI in Windows. It is certainly not an option that students use IRAF to access DAOPhot to analyse images, such as undertaken in some pro-am areas (Artusi et al., 2016). IRAF is an aging, difficult to control, install and use software that even scientists tend not to use much anymore. For simple image viewing and stretching in preparation for colour imaging, FITS Liberator works on both Windows and Mac and is the best for a simple non-analysis viewer. Matching this with GIMP (free) or Photoshop is a wonderful match for exploring colour imaging.

Money

The budget for a typical school per student is tiny with much of the science department budget being swallowed up by chemistry consumables. This, of course, is an enhanced issue for lower socioeconomic schools as well as public schools compared to private schools. Hence, if equity of access is of any concern to project personnel, the cost to the individual school should be as close to zero cost as possible and certainly not more than a few dollars per student. School systems and their budgets obviously work in a multitude of ways between cities, states, counties and nations, but it is likely a true enough blanket statement that an individual teacher or school will not have access to any significant financial resources. At the level of the teacher or school, it should be aimed to be cost free.

If a project is thinking of charging for their services, then it would likely best be aimed at a service or consultation charge for implementation and training charged at the level of a school jurisdiction, or for going into the school to actually run the project rather than simply charging for materials and software at the school or teacher level. A project will still come up against a social justice issue at this level. Lower socioeconomic, remote and rural low population jurisdictions will not be able to budget as much money as higher socioeconomic, city-based, high population jurisdictions. In terms of the pipeline, this means that teachers and students are not likely to be able to spend on many of the off-the-shelf pro-am software suites available to undertake many of the advanced image processing tasks that the pipeline can do automatically for them for free.

Prep Time

If part of a project's aim is to educate and inspire the general public about astronomy, the universe and the cosmic perspective, it is going to have to aim prior to where the school system makes taking science compulsory (Year 10 or roughly age 14 in Australia) and also where astronomy is undertaken within the local curriculum (also Year 10 in Australia). If the aim is to stem the 'leaky pipeline' or inspire students to a STEM career then it is prudent to aim as low down the year levels as possible as intentions towards scientific careers seem to be likely to be mostly set by middle school and some in high school (e.g, see The Royal Society (2006), Maltese and Tai (2010)). In OSS's case, the elementary and middle school components at Years 3, 5 and 7 (day & night, the seasons, phases of the moon and the solar system) are addressed by the CSU/OSS Remote Telescope Project (Mckinnon, 2018) while the main OSS project utilizing the LCO telescopes aims at Year

10 level.

If this is to be the approach, then the most scalable method is to leverage the use of the teachers in the classroom. There is one thing to remember if so. Science teachers are not Scientists. This bears repeating. Science teachers are not Scientists. Furthermore, the core content area of a general classroom science teacher is almost never astronomy and only rarely physics with most tending towards having a background in biology (at least in Australia). If a project is aiming for large-scale, then a given teacher must be assumed to be an astronomical blank slate with no great level of astronomy knowledge and that the teacher will be learning just-in-time or along with the students through the project the first time through.

Teachers already have a wonderful array of expert skills, such as understanding and applying *how* students learn, how to interact and build relationships with adolescents in a manner that produces motivation and learning, and how to work five tough crowds day in and day out, which can be leveraged to implement the project in the classroom. While it should be expected that they come to be more familiar with the astronomical content knowledge over time, it should not be expected that they will have a store of deep astronomical skills and knowledge to bring to the classroom. It should also not be expected that they have enough free time to dabble and tinker and collect these skills.

During teaching periods, a full-time teacher is swamped with duties. They are likely teaching 5 out of 6 teaching periods during the day, while using the 6th to rapidly get through administration for the other 5 periods so they can get to go home and spend what could have been their quality family time prepping their classes for the next day, generally going to bed close to midnight. What time they may get to develop themselves professionally comes in the form of “professional development days”, which are undertaken at high monetary cost to the school or jurisdiction and tend to be only a small number of days per year.

So, the reality is that, if you would like an everyday non-specialist classroom science teacher to participate in your project, then a rough guideline is that for every 50 minute class they teach, they have less than 50 minutes to prepare for it. That includes familiarizing themselves with the materials and concepts they need to teach, which OSS deals with via an educative curricula (e.g., see Fitzgerald (2018), Townsend et al. (2017)) as well. So, to scale this to a great body of teachers, there cannot be an expectation that teachers will have time to download and organize files in any way prior to class, let alone learn how to process them and then process them in any unnecessary manner that could feasibly be automated.

Class Time

In Australia, there is roughly 3 weeks in Year 10 to do extra-solar astronomy and that is it for a given student’s entire mandatory school career. Within those three weeks, those 5*50minutes*3weeks = 12.5 hours, they need to learn about the components of the universe, the big bang and how the big bang led to those components. They also are mandated to learn about science as a human endeavour as well as more generic science inquiry skills. Teachers get audited and need to prove they have covered these topics sufficiently and reasonably. They also need to typically complete it within that constricted time-frame, hence if they request an image in the first week and are expecting in the second week (a week being a very conservative maximum length of time to get an image), there is no capacity for the teacher to resubmit and get a further image to use in a later week if something has gone wrong.

On top of that, there is the larger non-curriculum-based project goals of inspiring students in science and astronomy and getting students interested in doing an independent research project beyond the classroom. In the educational design of any project, it needs to be asked: To achieve these intended mandated and extended goals, what fraction of the 12.5 hours should be spent on image processing or data reduction? It is something that each project independently should consider. The OSS answer is: "as little as possible to be educational and authentic but no less than that." There are four major considerations:

1. Is the student learning anything about the intended content or being inspired in astronomy or science through going through this process?

2. Is the class time that this process takes worth the eventual payoff in outcomes?

3. Is the process the student is going through the same process a scientist would go through anyway?

4. Would an actual scientist even be going through this process manually?

Once these questions have been thought through for each application, typically there is a strong case for automated processing for most applications in the everyday high school classroom. There still exists a strong case for many applications for independent or group student research projects as well, although part of the shroud may be lifted and some raw data may be explored given the extra time available (usually). Much of the more advanced OSS curriculum (that most classes will not get to) deals with going through and doing manual photometry on an open cluster to understand the nature and lives of stars and astronomical measurement in careful detail. In contrast, many of the independent student research projects undertaken in OSS typically use the processed photometry and catalogues as their starting point and move forward from there.

Partial Solution to the Problem: The Pipeline

As a partial solution to these problems, the OSS pipeline has grown over the last 7 years to fully automate processing and delivery into useful educational data products. The pipeline can be sent a batch of files manually but usually is scheduled to run automatically and collect a whole night's worth of images from a particular observatory. It is undertaken this way because an all-sky photometric solution is attempted using detected standard stars within the observed fields of view, hence all science and standard frames from a given night are needed to undergo this process. Hence, rather than being focused on rapidly delivery of single images, this pipeline is focused on processing a whole night's observations completely.

The main pipeline is divided into four parts that are run in sequence, as shown below with a rough estimation of the typical percentage of time taken during a run:

1. The image processing and cleaning pipeline (25%)

2. The photometry pipeline (50%)

3. The all-sky calibration pipeline (10%)

4. The catalogue construction pipeline (15%)

The Image Processing and Cleaning Pipeline

The images available from many robotic telescopes are usually flatfielded, debiased and dedarked already but there are further tweaks to make these into usable education products. These are listed below.

1. any compression of the fits file is removed. Teachers and students learning how to decompress such files as fzipped files is clunky on Windows. While some packages deal with compressed fits in an efficient manner. . . many do not. The 70% filesize saving hasn't been worth the trouble in the OSS project.

2. files are renamed to something more human-readable. An LCO example is "elp1m008_kb74_20150925_0068_e90.fit"

which makes sense to someone who has been using the telescopes for a little while, but the resulting renamed file "NGC189_V_40s_2015d09d26T14c35c02_1a315457400_57291d4172104167_kb74.fit", makes a lot more sense (well... not initially!) to the teacher and the student and also scientist. It contains the object name, the filter, the exposure time, the UTC time and date, the airmass, the MJD and the camera (and hence observatory location) the image was taken from.

3. The known bad parts of the image for that camera are marked bad. A database of the bad pixels for each camera the pipeline access is stored. At most these can be a column defect here or there or an obvious dead or hypersensitive pixel.

4. The edge pixels are removed from the image. For a larger format camera, 100 pixels are removed from around the edges, for a smaller, 20 pixels are removed. Many ccd images misbehave around the edges (an example is shown in Figure 1) and, while measurements can be made there, they can throw off sky models and other estimations in the image by various software packages. It is best that these edges be jettisoned.

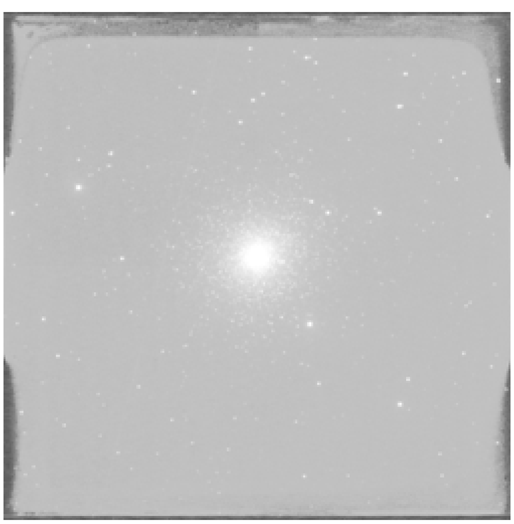

Figure 1. *A heavily stretched image illustrating the problematic edge pixels in an image.*

5. A lower threshold count value for the image is estimated and pixels below this value are marked bad. Due to the known count distribution for any particular given image, it can be very clearly ascertained what the smallest physically reasonable value in the image should be. Any values below this are marked bad. There may only be a few low values, but it has effects both aesthetic (getting a good image balance) and photometric (if the tool used makes any assumption about the distribution of sky values using simple statistics or if this low pixel is in a sky aperture, these low values will throw the estimated sky value off).

6. Cosmic rays are removed as much as possible. While it is noted by some that asteroids and other "streaky" objects might be erroneously identified as cosmic rays (although this doesn't seem all that likely as the 'streaky' asteroid-like objects are not 'sharp' objects), cosmic rays for most uses, aesthetic and photometric are a hassle. They certainly need to be removed to make aesthetic images (a large part of the core in-class OSS curriculum) as removing thousands of cosmic rays manually would be tedious and ineffective for the teacher and/or student. The McCully version (github.com/cmccully/lacosmicx) of the LACosmic (Van Dokkum, 2001) algorithm makes short automated work of most cosmic rays in a few seconds. The effect can be aesthetically seen in Figure 2. The parameters are set quite conservatively such that targets of actual interest are not affected, but even still, about 99% of the cosmic rays do get removed at this step.

7. The bad pixels are interpolated. The bad pixels are interpolated currently using a Gaussian Kernel. This works quite well as most bad pixels are either individual or 'thin' (as in a bad column or a sharp cosmic ray). We are looking for a higher powered

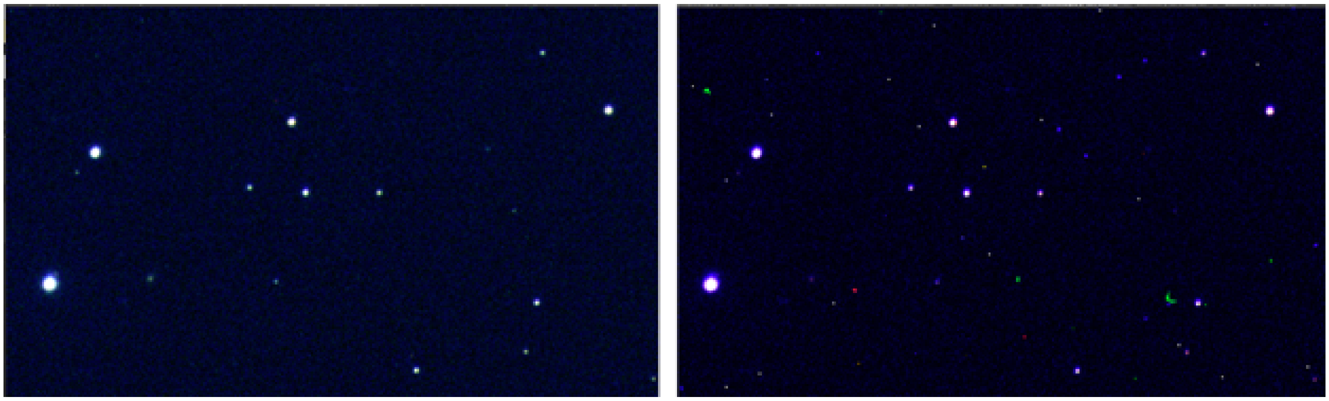

Figure 2. *The very noticeable effects of cosmic ray removal. The cutouts are about 8 arcminutes wide. The field is presented in colour as this makes the cosmic rays pop out to the eye as they are either blue, green or red depending on which image they were in. No great effort was made to colour balance the image.*

interpolation method and have a few options being considered.

8. Preview tifs and jpgs are made. This makes it easy for project personnel as well as users to flip through the images quickly to see if any images need to be resubmitted.
9. A new WCS is calculated and implemented. Any existing WCS is removed from the image, as the shape of the image has changed. Initially an astrometry.net (Lang et al., 2009) WCS solution is attempted using 2MASS (Skrutskie et al., 2006) and USNOB-1 (Monet et al., 2003) catalogues which is usually successful. For poorer quality images or for those with a lower stellar population, SCAMP (Bertin, 2006) and USNOB-1 is used to apply the WCS (sometimes forcibly if there are really only a few stars) as it requires less identifiable stars in the image.
10. Adjustments to the fits header are made. A number of different software packages have different quirks that require fits header items to be set a particular way. These changes are made at this point to facilitate easy usage.
11. Images are distributed to users' Google drive accounts. Based on the USERID in the fits header, the final processed images are distributed straight into users' Google drive accounts. Other file sharing options are available, but Google drive seems to be the most popular at the current moment, perhaps because of the popularity of Google For Education.

These are the main steps of the Image Processing section of the pipeline. Future automation includes automated deblooming of overexposed stars, automated infrared fringing removal and asteroid trail removal. These three are in process of testing. Further processing steps will be considered and incorporated after this. This level of automated processing is very useful in general (remember you can always go back to raw!) for education (they need their one image to be as pristine as possible!) and for science (we want to feed the most cleaned idyllic image we can into our further analysis software… except for a few rarer exceptions).

The Photometry Pipeline

Now that the images have been trimmed, cleaned up and WCS'ed, they are ready to have measurements undertaken on them. The photometric pipeline undertakes multiple automated photometry routines on the images. Each of the photometry routines have their own quirks and their own optimal settings which are sorted out. Many of these settings are relative to the FWHM of the stellar profile of the image, either as a starting value to iterate from or to set certain fitting boundaries and apertures. The FWHM of each image is estimated by running SExtractor (Bertin and Arnouts, 1996) and pulling out the mean FWHM for star-like objects from the resulting catalogue. The current list of photometric methods is:

1. DoPhot: (Schechter et al. (1993), Alonso-García et al. (2012))
2. DAOPhot: (Stetson, 1987)
3. Source Extractor Kron: (Bertin and Arnouts, 1996)
4. Source Extractor Aperture: (Bertin and Arnouts, 1996)
5. Aperture Photometry Tool: (Laher et al. (2012a), Laher et al. (2012b))
6. PSFEx (Bertin, 2011)

The results of each photometric method is parsed into a standard photometry catalogue file for each image consisting of columns: RA, Dec, X Pixel, Y Pixel, Counts, Err(Counts). These files are then distributed to the users' Google drive accounts.

The settings for each photometric method are tested and trialed in combination with the output of the third part of the pipeline which produces calibrated photometry. It makes for very robust comparative sanity checking because if any photometric method experiences systematic, random or sometimes simply crazy errors, it is quite clear which one is the culprit.

Sometimes the photometry by itself would look fine, but once it goes through the calibration part of the pipeline, it becomes clear that a setting in the photometry section has led to the zero point being shifted between images and therefore unsuitable for all-sky photometry. A "typical" comparison (there have certainly been nicer sharper nights) between calibrated magnitudes from photometry is shown in Figure 3.
It can be seen that, as this is typical, that DAOPhot typically performs the "best", in terms of S/N as well as depth of detection. The only times this tends not to be the case is with poorer images where there are less stars to create a suitable PSF model. Aperture Photometry Tool tends to be the best aperture-based method as it has sophisticated aperture corrections and sky estimation tools. It is also the most overall robust method in terms of the photometry always being successful and relatively decent, rain, hail or shine[1]. DoPhot performs great PSF photometry, but is overshadowed by the performance of DAOPhot although it is more robust. PSFEx most of the time performs well but sometimes there is strange slopes in the data and odd scatter compared to the other methods. The two SExtractor methods are ok but they suffer from problematic sky value estimations. In future, the sky value issue may be explored deeper to see if this can be calibrated out, but considering there are higher quality S/N photometry methods that work great already, this has not been a priority.

Future methods are intended to be added to the six already present with a particular interest in incorporating a variety of new automated PSF routines as Aperture Photometry Tool does as good a job as any aperture based method could likely possibly do. The final photometry files are distributed to the users' Google drive accounts.

The All-Sky Calibration Pipeline

The All-Sky Calibration routine searches through the photometry files to identify standard stars available from a custom standard catalogue consisting of (Clem and Landolt (2013); Clem and Landolt (2016)) UBVRI standard stars as well as, where possible, matching ugriz photometry from various catalogues SDSS (Smith et al. (2002); Alam et al. (2015)) and Skymapper (Wolf et al., prep). The selection of targets has usually been selected using a standards picker script that maximises the airmass, colour and number spread for any given time, date, location at any observatory which is outlined in Dolley &

[1]Metaphorically speaking. Literally this is, of course, not true.

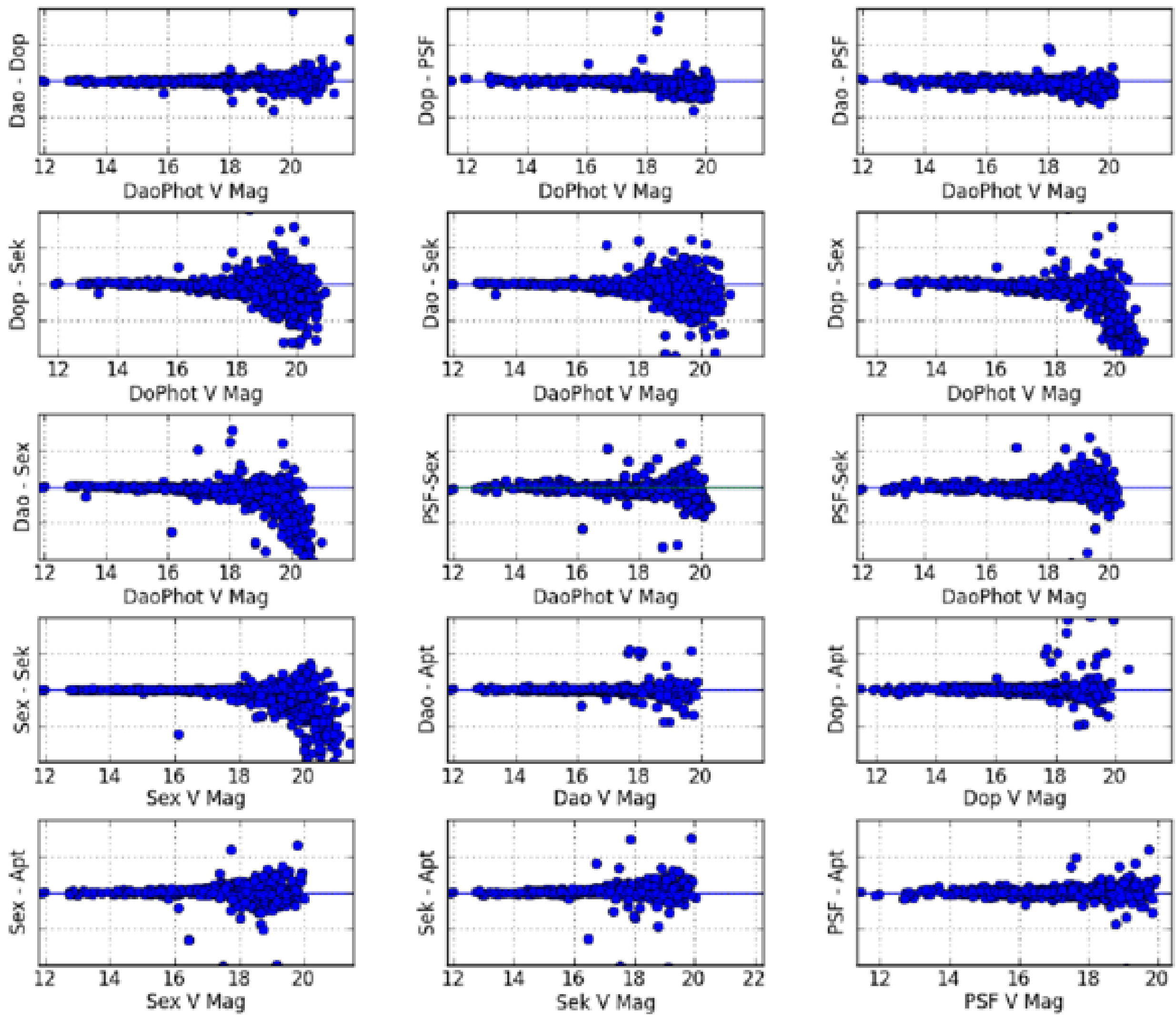

Figure 3. *Comparison of *calibrated* magnitudes between the methods. The y-axis goes from -0.25 to 0.25 and the comparison abbreviations are straightforward to interpret from the list above.*

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After the standards are identified, the photometric solutions for the UBVRI bands are determined and applied, after outlier and low S/N rejection, by solving for the coefficients in the following equations (e.g. Harris et al. (1981); Da Costa (1992); Padmanabhan et al. (2008)) with a similar analogous approach for ugriz filters. A fuller description of this part of the pipeline will be available in the Dolley & Fitzgerald prep article. 10pt

$$U = U_{INST} + Z_U + K_U A + C_U(U-B) + K_{U2}A(U-B) + C_{U2}(U-B)^2 + t_U t$$

$$B = B_{INST} + Z_B + K_B A + C_B(B-V) + K_{B2}A(B-V) + C_{B2}(B-V)^2 + t_B t$$

$$V = V_{INST} + Z_V + K_V A + C_V(B-V) + K_{V2}A(B-V) + C_{V2}(B-V)^2 + t_V t$$

$$R = R_{INST} + Z_R + K_R A + C_R(V-I) + K_{R2}A(V-I) + C_{R2}(V-I)^2 + t_R t$$

$$I = I_{INST} + Z_I + K_I A + C_I(V-I) + K_{I2}A(V-I) + C_{I2}(V-I)^2 + t_I t$$

where V_{INST} is the instrumental magnitude, Z_V is the zero point of the optical system, C_V and C_{V2} are the colour correction terms, K_V and K_{V2} are the extinction coefficients and the $t_V t$ term models any time dependence. Only the minimum number of coefficients required for a satisfactory fit should be used.

As yet, the UBVRI/ugriz catalogue is not normally distributed to each user automatically as currently scheduling standards is not trivial. We are working to help make adequate standards scheduling a reality using our software so that the catalogue can be distributed to each user who requested an image at that observatory on that night, allowing calibrated photometry of each field of interest be available.

The Catalogue Construction Pipeline

Once the night's images have been calibrated, the resultant catalogue is then cross matched using STILTS (Taylor, 2006) against various commonly useful databases which are stored locally. APASS (Henden and Munari, 2014) is used as a rough comparison, although commonly we have found significant deviations between our photometry and APASS even when our photometry compares exceptionally well with the (Clem and Landolt (2013); Clem and Landolt (2016)) Standards and with other studies of the same object. This is potentially a result of the large pixel scale (2.57 arcseconds/pixel) and large aperture (17 arcsecond diameter) used in APASS and the fact we tend to use photometry from relatively crowded fields (Open Clusters and Globular Clusters). The catalogue is also cross matched against SDSS DR12 (Alam et al., 2015) for comparison for ugriz data. It is intended, in the near future, to incorporate SkyMapper (Wolf et al., prep) data into the catalogue as well.

Two useful databases are cross matched to extend the available spectral energy distribution, JHKs from 2MASS (Skrutskie et al., 2006), W1W2W3W4 from WISE (Wright et al., 2010) even though only W1 and W2 are really all that useful for stars. Currently for stellar proper motion, the pipeline cross matches with UCAC4 (Zacharias et al., 2013) but will be updated to GAIA data (Brown et al., 2016), such as that resulting in the recent Fitzgerald et al. (2015) paper. The resultant catalogue can be directly opened in Pysochrone (Fitzgerald, 2018) to examine the data across a variety of Colour-Magnitude and Colour-Colour Diagrams. The full cross matched catalogue is not yet automatically distributed to users for the same reason as the UBVRI/ugriz catalogue is not.

Future Directions and Conclusion

Much like everything else in Our Solar Siblings, the pipeline is being continually developed in response to teacher, student and project personnel needs. It is currently doing a wonderful job creating educationally feasible and scientifically valid data products to users by automating image processing, undertaking high quality photometry and delivering this to the user. The pipeline is fully capable of delivering automated all-sky calibrated photometry catalogues cross matched to various databases with the only thing really holding it back being more the *scheduling* of the standards, rather than the *processing* of the standards.

The pipeline has enabled the project to run at a larger scale taking a lot of the manual preparation and processing time off the table for project personnel, allowing OSS members, teachers and students to focus more on the more pressing pedagogical and scientific questions. The pipeline takes the images in the form processed enough for use by professional scientists who can further process the images relatively easily and processes and analyses them for scientific and education use for those who cannot further process them easily. This facilitates uses for both education and scientific research undertaken by students and also any scientists who would wish to use the pipeline.

References

Alam, S., Albareti, F. D., Prieto, C. A., Anders, F., Anderson, S. F., Anderton, T., Andrews, B. H., Armengaud, E., Aubourg, É., Bailey, S., et al. (2015). The eleventh and twelfth data releases of the sloan digital sky survey: final data from sdss-iii. *The Astrophysical Journal Supplement Series*, 219(1):12.

Alonso-García, J., Mateo, M., Sen, B., Banerjee, M., Catelan, M., Minniti, D., and Von Braun, K. (2012). Uncloaking globular clusters in the inner galaxy. *The Astronomical Journal*, 143(3):70.

Artusi, E., Conselvan, G., Tegon, A., and Zardin, D. (2016). Crowded fields photometry with daophot. *Journal of the American Association of Variable Star Observers (JAAVSO)*, 44:149.

Bertin, E. (2006). Automatic astrometric and photometric calibration with scamp. In *Astronomical Data Analysis Software and Systems XV*, volume 351, page 112.

Bertin, E. (2011). Automated morphometry with sextractor and psfex. In *Astronomical Data Analysis Software and Systems XX*, volume 442, page 435.

Bertin, E. and Arnouts, S. (1996). Sextractor: Software for source extraction. *Astronomy and Astrophysics Supplement Series*, 117(2):393–404.

Brown, A. G., Vallenari, A., Prusti, T., De Bruijne, J., Mignard, F., Drimmel, R., Babusiaux, C., Bailer-Jones, C., Bastian, U., Biermann, M., et al. (2016). Gaia data release 1-summary of the astrometric, photometric, and survey properties. *Astronomy & Astrophysics*, 595:A2.

Brown, T., Baliber, N., Bianco, F., Bowman, M., Burleson, B., Conway, P., Crellin, M., Depagne, É., De Vera, J., Dilday, B., et al. (2013). Las cumbres observatory global telescope network. *Publications of the Astronomical Society of the Pacific*, 125(931):1031.

Clem, J. L. and Landolt, A. U. (2013). Faint ubvri standard star fields. *The Astronomical Journal*, 146(4):88.

Clem, J. L. and Landolt, A. U. (2016). Faint ubvri standard star fields at+ 50° declination. *The Astronomical Journal*, 152(4):91.

Collins, K. A., Kielkopf, J. F., Stassun, K. G., and Hessman, F. V. (2017). Astroimagej: image processing and photometric extraction for ultra-precise astronomical light curves. *The Astronomical Journal*, 153(2):77.

Da Costa, G. (1992). Basic photometry techniques. In *Astronomical CCD Observing and Reduction Techniques*, volume 23, page 90.

Danaia, L., McKinnon, D., Parker, Q., Fitzgerald, M., and Stenning, P. (2012). Space to grow: Lcogt. net and improving science engagement in schools. *Astronomy Education Review*, 11(1).

Dolley, T. and Fitzgerald, M. (in prep). Oss optimal standards selector. *Astronomy and Computing*.

Fitzgerald, M., Danaia, L., and McKinnon, D. H. (2017). Barriers inhibiting inquiry-based science teaching and potential solutions: perceptions of positively inclined early adopters. *Research in Science Education*, pages 1–24.

Fitzgerald, M. e. a. (2018). Our solar siblings project outline. *This proceedings*.

Fitzgerald, M. T., Hollow, R., Rebull, L. M., Danaia, L., and McKinnon, D. H. (2014). A review of high school level astronomy student research projects over the last two decades. *Publications of the Astronomical Society of Australia*, 31.

Fitzgerald, M. T., Inwood, L., McKinnon, D. H., Dias, W., Sacchi, M., Scott, B., Zolinski, M., Danaia, L., and Edwards, R. (2015). Photometric and proper motion study of the neglected open cluster ngc 2215. *The Astronomical Journal*, 149(6):190.

Gomez, E. L. and Fitzgerald, M. T. (2017). Robotic telescopes in education. *Astronomical Review*, 13(1):28–68.

Harris, W. E., Fitzgerald, M. P., and Reed, B. C. (1981). Photoelectric photometry: An approach to data reduction. *Publications of the Astronomical Society of the Pacific*, 93(554):507.

Henden, A. and Munari, U. (2014). The apass all-sky, multi-epoch bvgri photometric survey. *Contrib. Astron. Obs. Skalnate Pleso*, 43:518–522.

Laher, R. R., Gorjian, V., Rebull, L. M., Masci, F. J., Fowler, J. W., Helou, G., Kulkarni, S. R., and Law, N. M. (2012a). Aperture photometry tool. *Publications of the Astronomical Society of the Pacific*, 124(917):737.

Laher, R. R., Rebull, L. M., Gorjian, V., Masci, F. J., Fowler, J. W., Grillmair, C., Surace, J., Mattingly, S., Jackson, E., Hacopeans, E., et al. (2012b). Aperture photometry tool versus sextractor for noncrowded fields. *Publications of the Astronomical Society of the Pacific*, 124(917):764.

Lang, D., Hogg, D., Mierle, K., et al. (2009). Blind astrometric calibration of arbitrary astronomical images. *Astrometry. net*, pages 1–55.

Maltese, A. V. and Tai, R. H. (2010). Eyeballs in the fridge: Sources of early interest in science. *International Journal of Science Education*, 32(5):669–685.

Mckinnon, D. H. (2018). Some philosophical musings on the rtsre conference. *This proceedings*.

Monet, D. G., Levine, S. E., Canzian, B., Ables, H. D., Bird, A. R., Dahn, C. C., Guetter, H. H., Harris, H. C., Henden, A. A., Leggett, S. K., et al. (2003). The usno-b catalog. *The Astronomical Journal*, 125(2):984.

Padmanabhan, N., Schlegel, D. J., Finkbeiner, D. P., Barentine, J., Blanton, M. R., Brewington, H. J., Gunn, J. E., Harvanek, M., Hogg, D. W., Ivezić, Ž., et al. (2008). An improved photometric calibration of the sloan digital sky survey imaging data. *The Astrophysical Journal*, 674(2):1217.

Schechter, P. L., Mateo, M., and Saha, A. (1993). Dophot, a ccd photometry program: Description and tests. *Publications of the Astronomical Society of the Pacific*, 105(693):1342.

Skrutskie, M., Cutri, R., Stiening, R., Weinberg, M., Schneider, S., Carpenter, J., Beichman, C., Capps, R., Chester, T., Elias, J., et al. (2006). The two micron all sky survey (2mass). *The Astronomical Journal*, 131(2):1163.

Smith, J. A., Tucker, D. L., Kent, S., Richmond, M. W., Fukugita, M., Ichikawa, T., Ichikawa, S.-i., Jorgensen, A. M., Uomoto, A., Gunn, J. E., et al. (2002). The ugriz standard-star system. *The Astronomical Journal*, 123(4):2121.

Stetson, P. B. (1987). Daophot: A computer program for crowded-field stellar photometry. *Publications of the Astronomical Society of the Pacific*, 99(613):191.

Taylor, M. B. (2006). Stilts-a package for command-line processing of tabular data. In *Astronomical Data Analysis Software and Systems XV*, volume 351, page 666.

The Royal Society (2006). *Taking A Leading Role*. London: The Royal Society.

Townsend, A., McKinnon, D. H., Fitzgerald, M. T., Morris, J., and Lummis, G. (2017). Educative curricula and pck development driven by stem professional learning in rural and remote schools: a longitudinal type iv case study. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, 24(4).

Van Dokkum, P. G. (2001). Cosmic-ray rejection by laplacian edge detection. *Publications of the Astronomical Society of the Pacific*, 113(789):1420.

Wolf et al. (In prep). Paper in preparation.

Wright, E. L., Eisenhardt, P. R., Mainzer, A. K., Ressler, M. E., Cutri, R. M., Jarrett, T., Kirkpatrick, J. D., Padgett, D., McMillan, R. S., Skrutskie, M., et al. (2010). The wide-field infrared survey explorer (wise): mission description and initial on-orbit performance. *The Astronomical Journal*, 140(6):1868.

Zacharias, N., Finch, C., Girard, T., Henden, A., Bartlett, J., Monet, D., and Zacharias, M. (2013). The fourth us naval observatory ccd astrograph catalog (ucac4). *The Astronomical Journal*, 145(2):44.