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TIME-DOMAIN ASTRONOMY, AND DATA AT RISK

Elizabeth Griffin
Herzberg Institute of Astrophysics, Victoria, BC
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ABSTRACT

Astronomy's historic observations, some dating back over a century, constitute an irreplaceable resource of information particularly on periodic, serendipitous and one-time events. The unique information which such data contain can extend the present restricted span of time-domain astronomy back to many decades. Without data from the pre-digital era, many variability studies are seriously impoverished, or simply impossible. Canada is particularly rich (at the DAO) in historic spectra, but – in common with most other photographic archives – the observations are not digitized, and are thus not accessible for research. The DAO has all the required expertise to set up an efficient scanning laboratory that can, within a few years, create digital versions of many of its heritage observations and place them in the public domain. The scientific case is compelling and the requirements very modest (two technicians, 20% technical support, and up to $70K to upgrade two obsolescent but still serviceable purpose-built scanners), but time is running out because the plates are degrading and the available expertise is likely to have vanished by the end of the decade. We urge that a commitment to rescue our legacy of historic information by digital means be made, and be made soon.

1. THE DIGITAL DIVIDE

To state that progress in an observational science like astronomy depends on the quality and accessibility of its data may sound tautological, but the universal lack of due attention to this point is hobbling research to a degree that is surprising in an age that has an unquenchable thirst for digitization. The aspect of our science which is most deprived of access to essential data is long time-domain astronomy. Innovation and capability in time-domain studies are being revolutionized through the ingenious products of the Virtual Observatory, but how many (Canadian) astronomers can quickly access on-line data recorded more than $\sim$ 25 years ago? Did variability science only commence with born-digital data? How much science is still waiting to be discovered? Canada alone has a heritage of >180,000 research-quality. pre-digital (photographic) observations, of which >90% are spectra, yet as a research resource they are impotent, and will remain so until they have been accurately converted into modern digital formats.

Ever since astronomical observations became digital routinely, resources have concentrated on improving the precision and speed of access to on-line data. The ensuing polarity between born-digital and inherently non-digital data has now widened to the point where students are not asked to know anything about photographic records, and those who accidentally hear mention of them are assured that they are too inaccurate to bother with. They were in fact not inaccurate – just less high in S/N than can often be achieved nowadays. They were, and still are, fully reliable; the science of astrophysics was based upon photographic observations, and has not had to be re-worked on account of changes in detector. More particularly, of course, heritage data have captured past events that may never recur.

2. NEW SCIENCE FROM TRULY LONG TIME-DOMAIN DATA

All aspects of time-domain studies that need to refer back over $\sim$25 years require access to observations that were inherently non-digital, mostly photographic. Studies of shorter-term variability, such as can be covered adequately with data spanning just a few years, have been hot science topics in all recent years, driving the need for major legacy surveys and for data-mining techniques to match. But beyond the scope of what can be found in today's digital data archives is an enormous dearth of information – recorded and saved but inaccessible – which cannot be tapped by the vast majority of researchers and which will never be mined at all unless action is taken, and taken soon. Only when some very pressing need arises (e.g. to study the progenitor of a supernova, refine the orbit of a suspected near-Earth or other solar-system body, or to search for optical counterparts of bizarre objects) do researchers turn to the almost-forgotten hoards of plates in the basement – only to realize that the necessary instrument for digitizing the wanted information is no longer in service (or no longer exists) and there is no-one around who can help.

What sort of new science will those plates reveal? A representative selection of papers describing results which could only be achieved through access to historic observations is given in the Appendix. They demonstrate how a long time-base can be essential for deriving accurate periods from radial-velocity or photometric variations, measuring precise proper motions, defining cluster membership, identifying relatively slow spectrum changes in advanced AGB stars due to actual evolution, or recognizing stellar multiplicity through period modulations. A time-base of 70–100 years is adequate to capture the pre- and post-event states of the helium flash. To date a pathetic sample of only three stars (FG Sge, V605 Aql and Sakurai's object) have been serendipitously caught in the act, but who knows how much more cryptic evidence our heritage archives contain? Tracings of four spectra from the DAO archives are reproduced in Figs. 1–3.

Historic observations can also be re-analyzed for astronomical and transdisciplinary studies which are far removed from the purposes of the original observers. Certain hot-star spectra, for instance, recorded to investigate the interstellar medium via features in the UV, have been digitized and re-analyzed to extract information about the Earth's ozone at a time before dedicated ozone spectrographs were widely in use. Other astronomical records have been examined for evidence of atmospheric constituents such as water vapour, methane and chemical pollutants. A programme to rescue and preserve digitally our substantial historic resources can thus benefit many sub-branches of astronomy and its cousins.

However, we cannot state at all categorically the scope of new science which our historic archives can enrich, because we simply do not know what is waiting to be discovered, and without on-line inventories of the archives we have little means of even hazarding a guess. Recent work at Harvard College Observatory is demonstrating the kind of wealth to expect. HCO has an archive of ∼650,000 direct images and objective-prism spectra, and now has a custom-built rapid scanner that is capable of digitizing everything in 5 years. As yet there is no funding for full production, but a test project involving ∼5000 plates (1% of the total) in the cluster M44 has already shown up *hundreds* of new variables with periods of the order of 20 years and amplitudes ∼0.5–1 mag. (Tang et al. 2010 and references therein). A few of the spectra also indicate quite bizarre objects, hitherto simply unrecognized as such. No-one knew that those stars were variable, and no-one yet knows why they vary as they do. Such information is foundational to astrophysics, and can only be extracted from appropriately long time-domain data.

3. HERITAGE RESOURCES

Our heritage data are at risk, not only through accelerated ageing owing to improper storage or breakages but also through the more unpredictable hazard of human ignorance. When inability to access and use plates in research becomes misinterpreted as disinterest, the collections are then at the mercy of edicts to throw them away in order to free up the space which they occupy. While photographic collections are by far the largest category of astronomy's data at risk, records on magnetic tape or in private collections, often in non-standard formats and lacking meta-data, are similarly vulnerable. Hand-written log-books – often the only source of the meta-data which are essential for variability research – are likewise at risk from deterioration and fire or water damage as well as possible mid-handling. Those, plus card-index lists, constitute the only inventories of our heritage which we presently have, and need to be converted into searchable catalogues so that any astronomer (including the archive owners!) can discover what plates are actually there. Equally important is intimate human knowledge, now a shrinking commodity as those who used to be well versed in the methods and technology of photographic plates vanish from the scene.

3.1. *On the International Scene*

In very round figures, the total world collection of astronomy's stored photographic plates is ∼3 million. Of those, some 2 million are images and objective-prism spectra; the rest are slit spectra. Detailed information about the world's direct plates and objective-prism spectra has been gathered by the IAU-initiated, Europe-based operation "SkyArchive", whose inventory catalogue currently indicates a total of 2.1 million, but there is no equivalent list of archives of photographic spectra. The latter will be found to form a bimodal distribution, according to the type and parameters of the spectrographs (coudé or Cassegrain) being used, peaking strongly at high-dispersion (say 1–15 Å/mm, $R >$ 25,000) for research-quality studies of individual stars, and low-dispersion (100–250 Å/mm) for classification purposes. However, as the Harvard experience proved, there are many occasions when classification spectra signal something unexpected which needs to be followed up, so even those may be an important first step in a research investigation.

A recent census of North American photographic-plate stores (Osborn & Robbins 2009) found that more than half of the world's images and well over half of the world's spectra are in North America. The largest archive of photographic slit spectra belongs to Mount Wilson (& Palomar), and contains ∼150,000 spectra, of which ∼30,000 are high-dispersion coudé plates, mostly from Mount Wilson. The coudé plates date back to the early 1920s, the lower-dispersion ones to 10 years or so earlier.

3.2. *Canadian Resources*

The Dominion Observatory (DO) in Ottawa was Canada's first and only professional observatory in the early 20$^{\mathrm{th}}$ century. Many, if not all, of its direct plates were discarded within living memory (and with them the tantalizing "evidence" of a Pluto-like object recorded in 1924), but its collection of 17,000 low-dispersion spectra taken between 1905 and 1937 are now at the HIA/DAO in Victoria. While many of those are categorized as "standard stars", experience from cases in which historic data have proved indispensable means that we cannot ignore those plates – though one might reasonably give them very low priority for digitizing. Unfortunately, the DO log-books prior to 1915 cannot be found.

In the formative years of astrophysics, research at the David Dunlap Observatory (DDO) concentrated on stellar classification. Its total of nearly 60,000 photographic spectra are therefore mostly at classification dispersions, and are being, or are about to be, scanned with a desk-top scanner (as a retirement project) in order to preserve images of the plates in a form that can still be of service to the classifier.

The DAO holds the world's second-largest collection of high-dispersion spectra: ∼16,000 coudé plates commencing in 1962, and >93,000 Cassegrain spectra dating from 1918. Individual spectra can be hunted down through a fairly convoluted paper-chase, but very little meta-data or actual spectra are actually available on-line.

3.3. *The DAO Collections*

The 1.8-m Plaskett Telescope has been in use, since its inauguration in 1918, by staff members, by Canadians and by visiting researchers. Prevailing protocol required plates that were taken away for analysis to be returned eventually, so the DAO collections are reasonably complete. On both that telescope and the newer, dedicated-coudé 1.2-m one, variability studies have been pursued relentlessly over the decades by countless observers, resulting in long time-series of the spectra of many objects. At the time, most of those spectra will have been measured manually for just one parameter – the stellar radial velocity, leaving possibly unique astrophysical information contained in the strengths and profiles of the spectroscopic lines largely untouched. Between them, those plates constitute a veritable gold-mine of spectra of variable stars in particular, and of many other objects besides.

The DAO has no digital inventory of its plates, so we cannot easily discover which objects have been observed there, or how many times and at what resolutions or wavelengths. What we do know is that the number of observations exceeds 100,000, and that the plates are presently stored in reasonable conditions. We also have all the log-books, so in principle the crucial meta-data can be retrieved, albeit with only as much detail as the observers entered.

4. A FUTURE FOR OUR PAST?

Time-domain astronomy is burgeoning as a focus for new survey instruments and for VO-type studies, and the IAU has been asked to support a Symposium on that topic in 2011. However, what time-domain studies deliver this decade will be badly skewed unless or until adequate support can be devoted to research into long-term as well as short-term variability. The time is now ripe to make that commitment.

Science-driven initiatives are starting up around the world to push for preserving *and digitizing* selections of astronomy's photographic heritage. The AAS, joined by the AIP, plans to host a Workshop later in 2010 to draw up an "Action Plan" for plate preservation and digitization in North America; the

Royal Observatory Belgium has had built a new rapid scanner to preserve the information on films of aerial photography as well as astrophysical plates. But at the same time observatory scanning giants like the APM (IoA), SuperCOS (ROE) and StarScan (USNO) have been closed down through lack of institutional support. In Canada the closure of the DDO entailed the removal of its PDS scanner, leaving the one at the DAO the only machine of its calibre presently available in the whole of North America for digitizing photographic spectra. Add to those losses the ageing of the people who still have the right skills for these tasks, and the challenge takes on a growing sense of urgency.

5. A NATIONAL PLATE-SCANNING LABORATORY AT THE DAO

Preparing a searchable public inventory of the DAO plate archive is the first step to undertake. Exposure information (meta-data) is hand-written, and transcribing the entries correctly can be carried out by short-term workers (e.g. students or retirees), but needs careful supervision.

To prepare a digital database of the spectra themselves requires the skilled use of an instrument such as a PDS (or similar microphotometer) that was specifically designed for the job. Desk-top scanners are usually *not* appropriate substitutes for quantitative scanning, regardless of what is claimed for the top end of the range. Tests have shown that positional fidelity can vary, increasingly so off-axis, while photometric fidelity cannot in principle be fully reliable on account of scattered light, the principal effect of which is to reduce the dynamic range. Positional accuracy is of greater concern when digitizing direct plates for astrometry, but good photometric accuracy is a *sine qua non* for spectroscopy whenever line-profiles are to be measured.

The DAO's PDS instrument presently receives only slender institutional support. Its present performance is passable but flakey, and it wants only a modest amount of technical manpower to get it operating correctly and up to speed. Even in its present state it has been used to digitize plates in order to extract new information regarding the Earth's ozone layer (e.g. Griffin 2006). It is currently operated by another volunteer, partly as a service for outside users. The situation is clearly unsustainable, and is no basis for the wholesale scanning of plate archives which time-domain astronomy requires.

One machine alone is inadequate to the task of digitizing the entire DAO plate collection within a reasonable number of years, and needs up to two other PDS instruments to be imported, upgraded and put into parallel operation. A few redundant PDS machines can be located, and one has in fact already been imported. The necessary upgrading tasks (both hardware and software) are well understood, will cost an estimated few tens of $K per machine, and will take only a few months under available expert supervision to implement. The laboratory should then have part-time (~20%) technical support. 'Pipelines' have already been created for calibrating and converting the digital information rapidly and efficiently into 1-D spectra.

Once the machines are all working correctly and up to speed, the photographic spectra in the DAO archives can be digitized, reduced and placed in a public domain within a few years, offering to the research world for the first time a whole new dimension of resources. That activity will need two full-time research assistants. A suggested budget for this laboratory is outlined in Table 1. The finished data sets will be made available through, and managed by, the CADC. The service could then be extended to scanning the Lick and the Mount Wilson & Palomar coudé archives, neither of which has any likelihood of getting digitized at the home institution.

It is important, both for our scientific history and for time-domain astronomy, that the new decade come to grips with this challenge *before it is too late and the raw information becomes lost through natural ageing or destructive actions.* In the whole of North America only the DAO has the equipment, the expertise and the skills to carry out the required scanning. By placing the digitized spectra in the public domain, the modest amount of resources necessary will not only pay dividends of unforeseen value across astronomy. It will also establish Canada as pioneer and leader (which it already is, but unofficially) in this exciting new field. Given the potential to set a valuable precedent, it will in fact be to our public discredit if we fail to carry out this very modest but much needed project during the next 5 years.

6. SUMMARY

There is a compelling scientific case for rescuing the information now latent in plate archives before the material finally degrades and the necessary expertise goes. The DAO is presently the only institution in North America to possess a working PDS capable of scanning spectra accurately, and the only institution in the world actually supporting such a programme. But in fact the DAO is only investing minimal resources in that project, relying completely on volunteers to carry out the scanning. Creating a scanning laboratory needs very modest funding (see Table 1). In return, the output will enrich time-domain astronomy worldwide, will establish Canada as pioneer and leader, will set an important precedent, and will justify the maintenance of plate archives.

TABLE 1
BUDGET FOR LABORATORY (ROUGH GUIDE)

Preparation:	$K
on-line inventories (student labour)	40
import (transport) of 3rd PDS	2
upgrades: hardware, s/w, labour, per machine	35
Operation:	
2 technical staff, per year	140
0.2 skilled support staff, per year	14

APPENDIX

Over 70 publications can be cited in which major or subordinate use has been made of photographic plates in research since 2000. Most involve direct plates, because very few spectra are available on-line. They also demonstrate how use is made eagerly of whatever on-line resources are accessible. The selection below illustrates some of the points made in this paper.

Bus, S.J., A'Hearn, M.F., Bowell, E., & Stern, S.A., 2001. *(2060) Chiron: evidence for activity near aphelion.* Icar, 150, 94.
Beck, T.L., & Simon, M., 2001. *The Variability of T Tauri, RY Tauri, and RW Aurigae from 1899 to 1952.* AJ, 122, 413.
Brock, K.L., Clayton, G.C., & Wollmann, E.R., 2002. *X-ray binary AO538-66 during the years 1897 through 1951.* AAS, 201, 5417.
Clayton, G.C., & De Marco, O., 1997. *The evolution of the final helium shell flash star V605 Aquilae from 1917 to 1997.* AJ, 114, 2679.
Girard, T.M., et al., 2000. *A redetermination of the mass of Procyon.* AJ, 119, 2428.
Griffin, R.E.M., 2006. *Detection and measurement of total ozone from stellar spectra: Paper 2. Historic data from 1935–42.*

Atmos. & Chem. Phys., 6, 2231.
Meaburn, J., Lloyd, M., Vaytet, N.M.H., & López, J.A., 2008. *Hubble-type outflows of the high-excitation poly-polar planetary nebula NGC 6302, from expansion proper motions.* MNRAS, 385, 269.
Omizzolo, A, Barbieri, & Rossi, C., 2005. *3C 345: the historical light curve (1967-1990) from the digitized plates of the Asiago Observatory.* MNRAS, 356, 336.
Osborn, W., & Robbins, L., 2009. *Preserving Astronomy's Photographic Legacy: current state and the future of North American astronomical plates.* ASP Conf. Series, vol. 410.
Roosen, R.G., & Angione, R.J., 1977. *Variations in atmospheric water vapor: baseline results from Smithsonian observations.* PASP, 89, 814.
Scholz, R.-D., et al, 2000. *New high-proper motion survey in the Southern sky.* A&A, 353, 958.
Siegel, M.H., Majewski, S.R., Cudworth, K.M., & Takamiya, M., 2001. *A cluster's last Stand: the death of Palomar 13.* AJ, 121, 935.
Szabados, L., Kiss, L.L., & Derekas, A.,2007. *The anomalous Cepheid XZ Ceti.* A&A, 461, 613.
Tang, S., Grindlay, J., Los, E., & Laycock, S.. *DASCH discovery of large amplitude ∼10–100 year variability in K giants.* ApJ, 710, L77.
Turner, D.G., et al., 2006. *The long-term behavior of the semiregular M supergiant variable BC Cygni.* PASP, 118, 1533.
Winn, J.N., et al., 2003. *Limits on eclipses of the pre-main-sequence star KH 15D in the first half of the 20th century.* ApJ, 593, L121.
Wu, K., & Kiss, L.L., 2008. *High and low states of the system AM Herculis.* A&A, 481, 433.
Zijlstra, A.A., et al., 2004. *Period and chemical evolution of SC stars.* MNRAS, 352, 325.

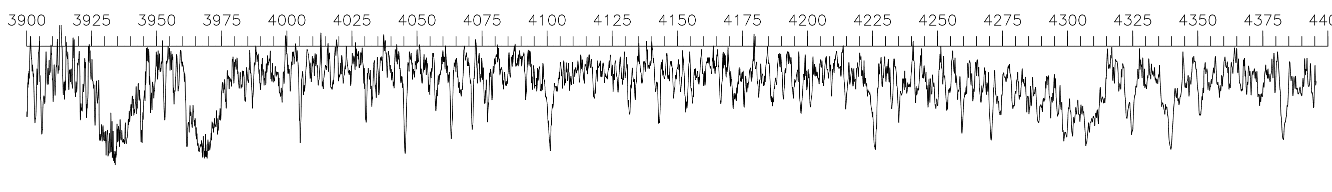

Fig. 1.— A digitized version of the first plate ever exposed with the 1.8-m Plaskett Telescope, on 1918 May 6. The spectrum is that of the G0V eclipsing star β CVn.

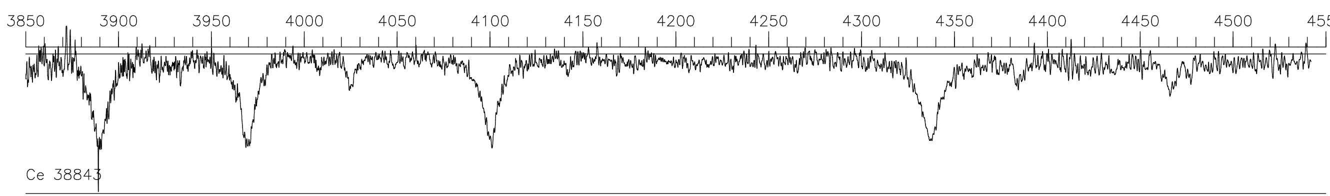

Fig. 2.— A newly-digitized spectrum of the eclipsing binary DI Her, exposed over 60 years ago with the Plaskett Telescope.

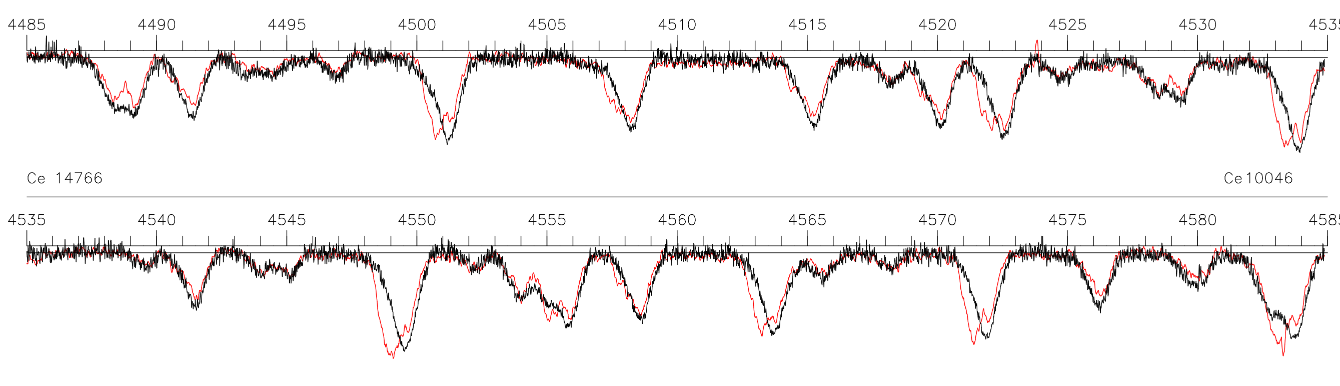

Fig. 3.— Scans of two plates of ϵ Aur, observed in 1975 August (black; phase .80) and in 1983 December during eclipse (red; phase .11). Although it is widely held that the spectrum of this enigmatic object "does not change" during eclipse, these plates (among the earliest in any archive at this resolution) show that rather a lot is in fact changing.