LRP2010 WHITE PAPER ON THE SCIENTIFIC IMPACT OF CANADIAN ASTRONOMY

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Scientific Impact of Canadian Astronomy

ABSTRACT

The primary scientific output from a scientific community, or an astronomical telescope, is the collection of papers published in refereed journals. While productivity of the community/telescope is measured by the number of papers published, the scientific impact of the community/telescope can be measured quantitatively by the number of citations that the papers receives. In this paper I will examine the impact the strength of the Canadian astronomical community using information published by Thomson Reuters (ISI). I will also compare the productivity and impact of Canada's international observing facilities with other similar facilities.

Subject headings:

1. INTRODUCTION

The most important output from a national scientific community is the collection of papers that are published in refereed journals. These papers represent the contribution to knowledge and the development of the country as a nation. Scientific papers are also the most important product produced by an astronomical observatory. These papers represent the facilities contribution to knowledge and the return on the capital investment in the construction of the telescope and its instruments.

As the cost of supporting astronomy increases, largely due to astronomical observatories becoming progressively more expensive to develop and operate, the return on investment has come under closer scrutiny. Increasingly, bibliometric measures - the number of publications and the number of citations - are used to measure the quantity and quality of the output of national communities and astronomical observatories.

Productivity, as measured by the number of publications, and impact, as measured by citation counts, are metrics that can be used for many purposes. They can be used to evaluate the performance of a telescope, an individual, a university department or even a country. For example, (Blustin 2007) used bibliometric measures to compare astronomy groups in the UK. Citations must be used very carefully as they are only one indicator of impact, and an imperfect one. However they are the best quantitative measure that is currently available for studying the impact of papers published in refereed journals. As the size of the aggregate grows (observatory versus individual) the more reliable citations become as a measure of impact. Also, impact should not be confused with the *quality* of the science. Impact derived from citation counts can be thought of as a measure of the relevance of the work to the scientific community.

(Abt 1981) was the first to analyze astronomical publications using bibliometric techniques. One of his goals was to compare public and private American observatories, both in the level of their output and their impact on astronomical research. (**?**) studied the papers published between January 1990 and June 1991 that were based upon data obtained with telescopes with apertures of 2-m or greater. She used citation counts to these papers in 1993 as a measure of their impact. (Trimble et al. 2005) performed a similar study of papers published in 2001 based upon data from ground-based optical/IR telescope (as well as HST and JCMT), and using citations in 2002 and 2003. (Benn & Sanchez 2001) used the 125 most-cited papers in each year between 1991 and 1998 to compare the impacts of telescopes worldwide. In this white paper, I have used published data to demonstrate the strength of Canadian astronomy in the world arena as well the impact of the facilities in which Canada has a significant share.

2. CANADIAN ASTRONOMY IN THE WORLD CONTEXT

The best numeric measure of a refereed paper's impact is the number of citations to that paper. Similarly, one can measure a country's impact by looking at the citation rate of papers published by that country's scientists. Thomson Reuters maintains the *Science Citation Index* which compiles publication and citation information for more than 6,650 journals in 150 disciplines. Their *ScienceWatch.com* site publishes weeklym brief concise reports on science in various countries, specific areas of science and other areas of interest.

Their August, 2005 report on Science in Canada[1], which covered papers published in a ten- year plus ten-month period, January 1994 - October 31, 2004, showed that Canada ranked #1 in the world in average citations per paper in the "Space Science" field. An examination of the journals included in the Space Science field shows that the field is dominated by astronomy. A paper was considered to be *Canadian* if there was at least one author based at a Canadian institution on the paper. The countries of all authors on a paper were given full "credit" for a paper.

One reason for Canada's #1 ranking is that Canada has chosen carefully the sub-fields of astronomy, and astronomical facilities, in which to invest. This result can also be interpreted as a result of Canadians, on average, being memmbers of strong international collaborations. For example, there is a Canadian on the WMAP team so all of the (very highly cited) WMAP papers get credited

[1] Gemini Observatory, La Serena, Chile

[1] http://in-cites.com/countries/canada_2005.html

to Canada along with the countries of each of the other authors.

Canadian astronomy's excellence on the world stage continues. ScienceWatch's report on Science in Canada from May 31, 2009 indicates that of all science fields, astronomy had the highest impact relative to the world. Canadian astronomy papers published between 2004 and 2008 were cited 44% above the world average. For comparison, astronomy papers from the UK and France, for a similar period, were cited 41% and 21% above the world average. This also shows that Canadian taxpayers are receiving good value for their investment in astronomy compared to some other fields.

3. CANADA'S INTERNATIONAL OBSERVING FACILITIES - FIRST LOOK

Canada has been selective in choosing which international observing facilties to support. How do the facilities that Canada supports compare to other observing facilities? (Benn & Sanchez 2001) performed one of the first studies comparing the impact of observing facilities world-wide[2]. In their look at the 1000 highest cited papers published between 1991-1998, CFHT had the highest number of these papers of any 4-m class telescope. In addition, papers in this sample published using CFHT data, garnered the highest percentage of the citations of any 4-m class telescope. Clearly, during this period, CFHT performed at the top of its class. This period coincided with the publication of many high impact papers from larger studies using MOS-SIS data (CFRS, CNOC).

JCMT, Canada's millimeter/submillmeter telescope, also performed extremely well in this study. Of the 6 telescopes in this class, the JCMT had the second highest number of papers in the top 1000 and these papers had the highest fraction of citations. The SCUBA instrument was brought on-line at the end of this period and had a small influence on the numbers. The high ranking of JCMT may be related to its location on Mauna Kea, one of the prime locations for submillimeter astronomy due to the low water vapor.

The Benn and Sanchez study included only the highest cited papers for the period of their study. While these extremely high impact papers have a large influence in the field, one needs to understand the productivity and impact of an observatory in whole. (Trimble et al. 2005) looked at the papers published in 18 journals in 2001 and identified all of the papers that reported or analysed data from a ground-based optical/IR telescope[3]. (She also included HST and JCMT in her study which was a followup to a similar study she performed in 1996.) In this work CFHT's remained one of the more productive 4-m telescopes However, in terms of average citations per paper, CFHT ranked below the AAT, the WHT, and the Mayall telescopes but above UKIRT, the Blanco and WIYN. This difference can plausibly be accounted for by the instrumentation available during each of these peridos. The period 1991-1998 coincided with the publication of high imopact papers from MOS-SIS (noted above) while in 2001 MOS-SIS papers had lower impact and papers from CFH12K had not yet been published.

The studies mentioned in the preceding paragraph are based upon various subsets of the papers produced by the telescopes studied . They are either snapshots of papers published during a short period or utilize a subset of papers based upon citation counts. I will now investigate and compare the productivity and impact of several large ground-based telescopes complete publication lists over several years. The observatories studied are: CFHT, Gemini, HST, JCMT, Keck, Subaru, UKIRT and the VLT.

4. CANADA'S INTERNATIONAL FACILITIES - HOW DO THEY COMPARE?

I maintain a database of refereed publications from most major ground-based optical/IR telescopes, as well as HST and JCMT. The list of publications for each telescope is obtained from their websites or their librarians. Unlike Benn or Trimble, I give each observatory full credit for a paper if it is based on data from more than one telescope. The citaton count for each paper is updated periodically using software which queries the ADS database. Since the raw citation counts for a paper increase with the age of a paper, it is not possible to use these counts to directly compare papers, or aggregates of papers, of different ages. To do these, one needs to correct the raw counts for the differing ages of the papers. I normalize the citation counts for each paper by the citation count of the median AJ paper of the *same year*. To first order this use of the median AJ paper as a standard measuring stick does a very good job of allowing direct comparisons between papers of differing ages.

The simplest manner in which to compare telescopes is to look at the average and median impact per paper. The distribution of impact is far from a normal distribution. The distribution has a very long tail to high impact papers which means that a small number of papers can influence significantly the average. On the other hand, the median will not indicate the presence of extemely high impact papers, which are clearly of interest. For now let's consider both metrics.

Figure 1 shows the average impact per paper for the years 2005-2008. In 2006/2007, CFHT has the highest average impact per paper. This is mostly due to Megacam papers, specifically papers from the CFHTLS. Gemini performs as well as Subaru and the VLT but all three have lower average impact per paper than Keck. JCMT has the lowest average impact for all years except 2005. Again, this is a result of the available instrumentation not being as competitive as it once was and that SCUBA2 and HARP had not arrived yet.

Figure 2 shows the median impact per paper for the same years. The median is more robust against the long high-impact tail of the impact distribution. Again, CFHT shows very well especially after 2007. Gemini's median impact per paper is quite stable during this period and is essentially the same as that of the VLT.

It is interesting to note the difference between the average and median impact per paper for CFHT in 2006. The average is much higher due to a single paper ((Astier et al. 2006)

A single metric such as the average, or median, impact per paper does not capture an accurate picture of the impact of an observatory's publications. To get a better

[2] Benn apportioned paper count and citations to the various telscopes when a paper was based on data from more than one telescope

[3] Trimble et al. also apportioned paper count and citations when a paper was based on data from more than one telescope.

look I introduce the Impact Distribution Function (IDF) which examines the distribution of the impact of an observatories publications. The IDF is simply the percentage of an observatory's papers that fall into six impact bins from Very Low (impacts < 1) to Extreme (impact $>$ 11). The IDF for the observatories in this study is shown in Figure 3. Note the distribution of the impact bins in the IDF is not linear.

Ideally, an observatory has a relatively smaller number of papers at the low impact end of the IDF and a relatively higher number at the high impact end. In the IDF the underperformance of the JCMT as a result of non-competitive instrumentation clearly stands out. CFHT has the lowest percentage of papers with Very Low impact and the highest percentage of papers with either Very High or Extreme impact. Gemini's IDF is almost identical to that of HST with a fairly high percentage of low impact papers and relatively few Extreme impact papers. Currently Gemini is underperforming the other 8-10 meter class telescopes. This can be linked to a lack of instrumentation at Gemini South (the loss of GNIRS and the delay of Flamingos-2).

5. CONCLUSIONS

Canadian astronomy is very strong as measured by quantitative measures of scientific impact. In fact, based on the numbers published by Thomson Reuters, one can argue that astronomy is Canada's strongest field of science in impact compared to the rest of the world. Canada was the #1 ranked country in asronomy in average impact per paper in 2005, the latest year for which Thomson-Reuters has published this ranking information.

In various comparisons of the productivity an impact of different telescopes, CFHT consistently is at or near the top in terms of impact. This is indicative of many factors including the instrumentation available and the strength of our community. Gemini is performing reasonably well as the "youngest" of the 8-m class telescopes. Gemini has been hampered by either delays, or losses, of instrumentation, particularly at Gemini South. JCMT has suffered from delays in new instrumentation including HARPS and SCUBA2. Finally, Canadians have used Gemini very well publishing more than their share of papers using Gemini data and with these papers having higher than average impact.

Canada's approach of focussing its investment in astronomy facilities strategically has served our community well. Canada has had access to forefront telescopes such as CFHT, JCMT and Gemini and has made very effective use of them.

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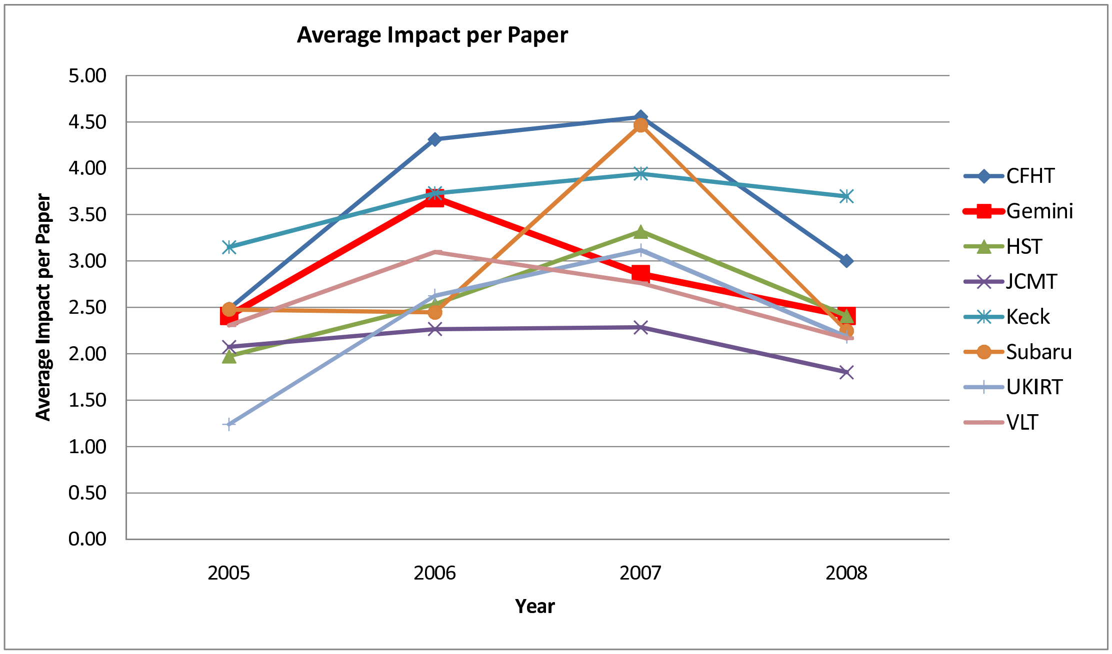

FIG. 1.— The average impact per paper for the telescopes included in this study for each year between 2005-2008

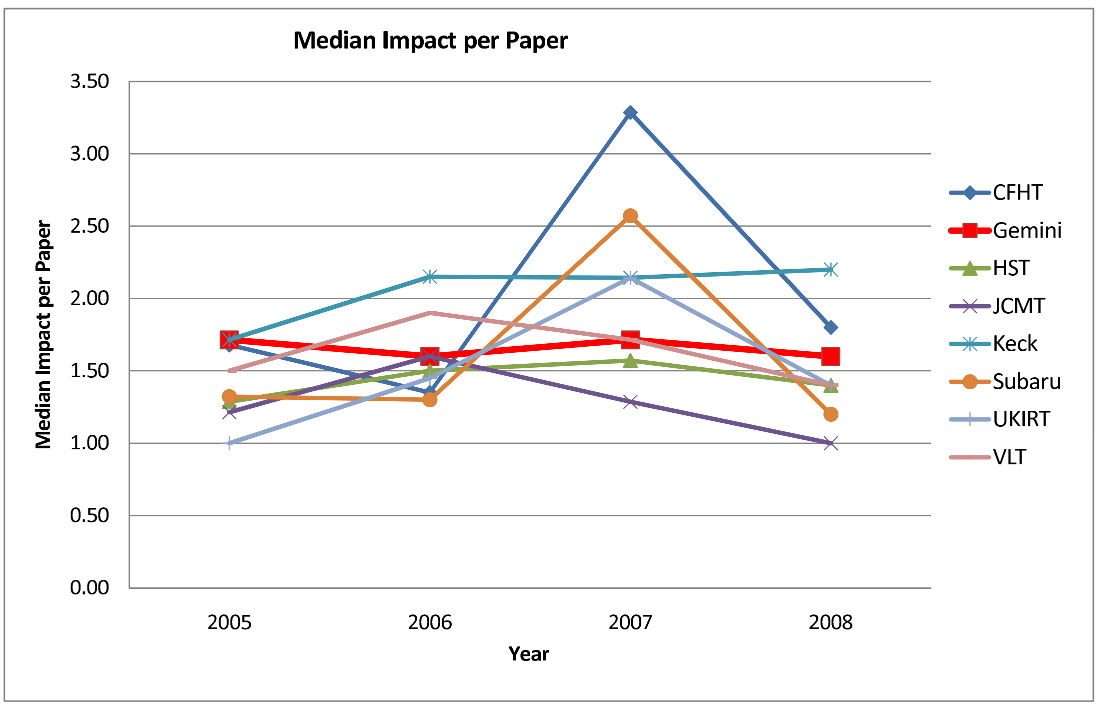

FIG. 2.— The average impact per paper for various the telescopes included in this study for each year between 2005-2008

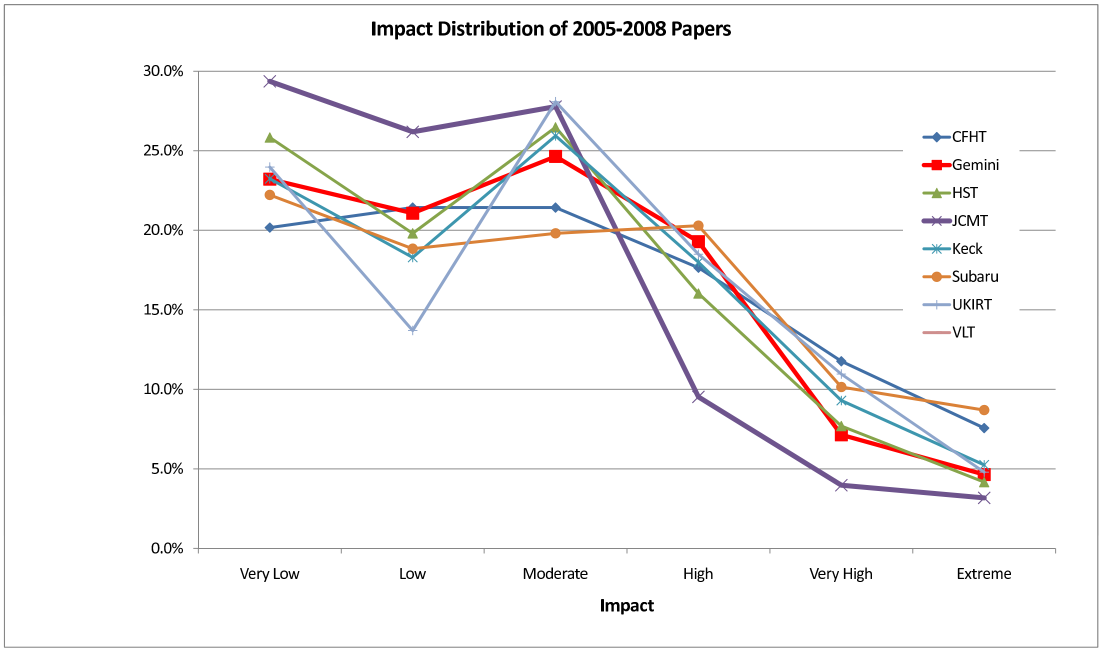

FIG. 3.— The Impact Distribution Function for the telescopes included in this study for the years 2005-2008.