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WIDE-FIELD INFRARED SURVEY TELESCOPE (WFIRST)

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ABSTRACT

WFIRST is a compelling space astronomy mission that will investigate key questions related to dark energy, dark matter and gravity, characterize exoplanets and study galactic and extragalactic populations in unprecedented detail and scope. The current proposed AFTA configuration is superior to the design that was the top-ranked space priority in both the LRP 2010 and the U.S. Decadal Survey. Excellent opportunities exist for Canadian participation in WFIRST science and instrumentation. We recommend that Canada contribute a significant component of the instrumentation, that access to science team participation be negotiated for all Canadian astronomers and that a mechanism be created to provide postdoctoral support for these research efforts.

1. INTRODUCTION

The top priority for space astronomy in LRP2010 is the recommendation that "Canadian astronomers participate in a major wide-field Dark Energy satellite mission. Joining Euclid or WFIRST as a significant partner would fulfill this recommendation, provided that we can (i) negotiate a partnership in the leading mission, and (ii) identify a contribution to the satellite instrumentation." While Euclid is proceeding without Canadian instrumentation, the opportunities for a contribution to instrumentation with WFIRST are excellent, as we will describe below.

WFIRST in its current 2.4m "Astrophysics Focused Telescope Assets" (AFTA) format, offers additional science opportunities beyond the dark energy projects. In particular, the addition of a coronograph module also allows for Canadian strengths in this area to be applied to WFIRST.

This white paper will describe the changes to the WFIRST concept since LRP2010, and its current status. We will then outline the Canadian perspective and opportunities for instrumentation. Finally, we will conclude with some recommendations for the MTR.

2. WFIRST-AFTA: OVERVIEW AND STATUS

2.1. *Telescope and Instruments*

The design and capabilities of WFIRST have changed considerably since LRP2010 and since the U.S. Decadal survey (National Research Council 2010) that designated WFIRST the top space-based priority. Most importantly, the telescope is now a 2.4m, donated by the National Reconnaissance Office. The increase in telescope aperture from the original 1.5m design yields improvements in sensitivity and image quality.

In addition, the current design includes a coronograph with a contrast of $\lesssim 10^{-9}$ allowing imaging and integral field spectroscopy of Neptune-mass planets in reflected light.

For further information, readers should consult the 15-page primer "WFIRST-2.4: What Every Astronomer Should Know" (Spergel et al. 2013a), or the full 2013 Science Definition Team (SDT) report (Spergel et al. 2013b), both available on arXiv.

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2.2. *Science and Surveys*

The WFIRST SDT has designed a number of nominal surveys: (1) Deep Near-IR imaging of approximately 2000 square degrees (the "High-Latitude Survey" or HLS) for weak lensing measurements of the growth of fluctuations and general science; (2) A redshift survey of the same area for galaxy clustering, i.e. baryon acoustic oscillations and redshift-space distortions; (3) A "wedding cake" of deeper surveys over smaller areas for the identification of supernovae (SNe), and spectroscopic followup with an onboard IFU. These three surveys have dual goals: first, the characterization of dark energy and/or deviations from General Relativity; second; survey astrophysics in the infrared over wide fields with space-based angular resolution (see Fig. 1). In addition, there will be a fourth survey of the Galactic Bulge for detection of planets (including free-floating planets) via gravitational microlensing. These four surveys would be performed with the Wide-field Imager (WFI) unit. Finally, the coronograph will conduct a survey of nearby stars with known planets to characterize outer gas giant planets spectroscopically (see Fig. 2). In addition to the above, approximately 25% of observing time will be reserved for Guest Observer (GO) programs.

2.3. *Synergies with other facilities of the 2020s*

WFIRST will be a powerful surveyor, finding rare objects that can then be followed up spectroscopically with TMT or JWST (assuming its operations overlap with those of WFIRST). For example, WFIRST is expected to identify a large number of candidate high-redshift ($z \gtrsim 8$) galaxies, the first stellar explosions, and stars in tidal streams in the Milky Way halo.

The WFIRST 2000 sq. deg. High Latitude Survey is likely to be in the southern sky so that LSST can provide deep optical photometry for photometric redshifts. If the

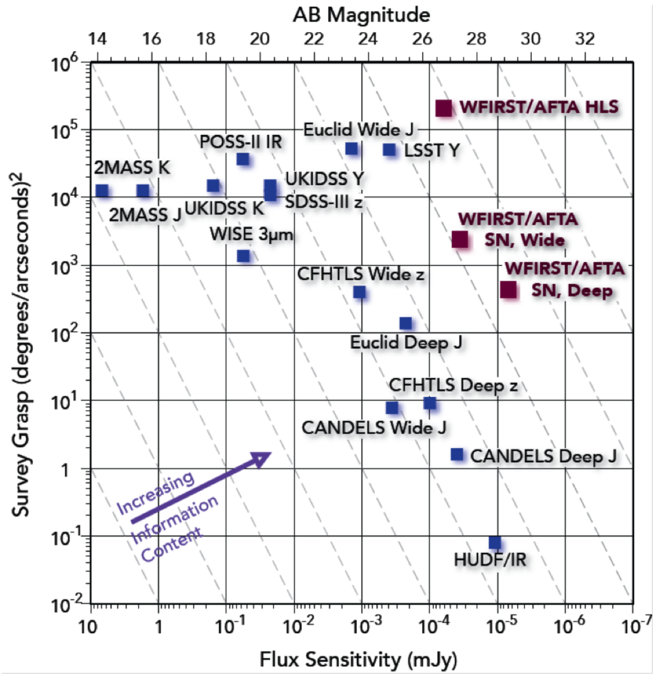

Figure 1. WFIRST surveys compared to other near-IR surveys as a function of survey "grasp" (angular area/area of resolution element) vs. flux limit.

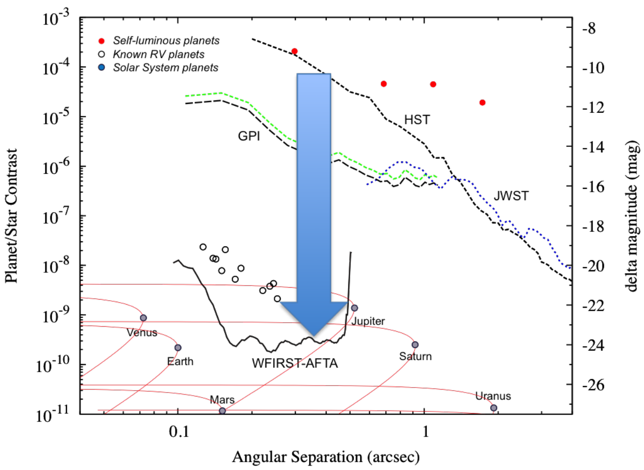

Figure 2. Contrast vs. angular separation from host star, showing the WFIRST coronograph compared with other coronographs. Locations of some known radial-velocity planets are also indicated, along with Solar System planets as viewed from a distance of 10 pc.

CASTOR mission is approved its UV/blue capabilities would be useful for photometric redshifts. Of course, the wider wavelength coverage is useful for a range of science goals.

WFIRST is complementary to the Euclid mission. Two of the WFIRST surveys are similar to the primary Euclid surveys: weak lensing and galaxy clustering. Euclid covers more sky but to a shallower depth, in the visible, whereas WFIRST will cover a smaller field but deeper, in the NIR, and with more passes. The latter should give WFIRST a better handle on potential systematics, which are likely to limit the precision of the DE experiments. Euclid has no dedicated SN program, nor exoplanets (coronography or microlensing). Nor does

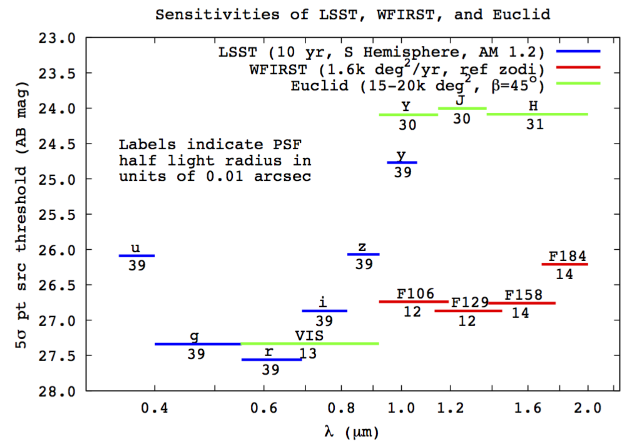

Figure 3. Depth in AB magnitudes of the WFIRST-2.4 high latitude survey (red), Euclid (green), and LSST (blue) imaging surveys. Labels below each bar indicate the size of the PSF (specifically, the EE50 radius) in units of 0.01 arcsec. The near-IR depth of the WFIRST-2.4 is well matched to the optical depth of LSST (10-year co-add).

Euclid have GO time. The depths as a function of wavelength are compared in Fig. 3.

2.4. *Science Teams and Data Access*

WFIRST will be driven by its surveys, which have the specific science goals described above. In that sense, WFIRST is closer to the mode of operation of SDSS or CMB experiments, than it is to the general observatory mode of HST or JWST (although it will function more like the latter for the 25% GO time).

Policies regarding access to WFIRST data for instrument teams, international partners, and the global astronomical community have yet to be finalized. The situation is further complicated because, as with other large projects, there will be many layers of data products ranging from simple pixel data, to catalogues of increasing levels of complexity and sophistication, some of which may be tailored for specific scientific goals (e.g. weak lensing).

The history of recent large projects in astronomy (e.g. SDSS, some HST Treasury programs, CFHTLenS) is that, even in the case where the data is publicly available immediately (or on a short timescale), the scientific results with the greatest impact have usually come from the teams that worked closest to the data, designing the survey, and understanding the instrumental artifacts. Likewise, in the case of WFIRST, it is expected that the scientific rewards of the surveys will flow to researchers who participate fully in the science teams, assist in preparatory scientific studies or develop simulation or analysis software packages that are aligned with the survey goals and who are therefore well-positioned to exploit the survey data.

Sometime close to Phase A (FY17, see below), WFIRST science teams will be formally established. The organizational structure of these teams is not yet certain; it will depend in part on whether NASA contracts out the main instrument components. It is likely that they will be structured as a number of "investigations" plus an overarching Science Working Group. For previous space astronomy missions, NASA has funded the research by these teams (i.e. via postdocs). NASA funds can only be held by U.S. PIs, so for Canadians to participate at an equal level, some funding mechanism would be highly desirable.

It is recommended that Canadian participation in WFIRST be timed in such a way as to maximise participation in the science teams as early as is feasible.

2.5. *Status, Budget and Timeline*

The U.S. NRC commissioned a review of the AFTA design. The committee report (National Research Council 2014) concluded that the new telescope would meet or exceed the goals envisaged by the U.S. Decadal survey.

WFIRST will be the next large NASA mission to follow JWST. An independent cost assessment performed for NASA for WFIRST/AFTA without the coronagraph (est. \$270M) estimated the full cost (construction, launch and operations) for this implementation at \$2.1 billion (FY2012 dollars) (National Research Council 2014).

After the launch of JWST, it is expected that a large "wedge" of NASA astrophysics budget, previously allocated to JWST construction, will become available. NASA's current plan, following the recommendations of the U.S. Decadal plan, is to apply this funding to WFIRST construction. At present, JWST is on time and on budget for a launch in Oct 2018. Significant funding for WFIRST pre-Phase A studies was *added* to the NASA budget by Congress for FY13 and FY14 totaling \$66M. NASA is interested in international partnerships. At present, Japan, Korea and Europe as well as of course Canada all have ex-officio members on the WFIRST SDT.

The timeline for WFIRST is as follows: The SDT will deliver its report in January, 2015. The mandate of the SDT may be extended by a year. NASA will make a decision in mid-2015 regarding a formal Phase A start in FY17. Launch is expected in 2023 or later. The current reference design envisages a 6 year lifetime, with a goal of 10 years.

3. CANADIAN PARTICIPATION

3.1. *Science*

WFIRST remains an excellent match to the strengths of Canadian astronomy, even more so now than in 2010 given the increase in aperture, as well as the addition of the coronograph module.

Canada has traditional strength in wide-field imaging by virtue of the Canada-France-Hawaii Telescope (CFHT), and in particular Megacam, the CFHT Legacy Survey (CFTHLS) and the CFHT Large Programmes. The Supernova Legacy Survey, based on the CFHTLS-Deep is the state-of-the-art SN survey in the world at present. It is a joint project between Canadian and French astronomers. Similarly, the CFHTLenS analysis of the Wide component of the CFHTLS is the current state-of-the-art weak lensing survey. These two programmes have had a very significant scientific impact. Participation in WFIRST will allow existing team members and their students and postdocs to apply their expertise to the next state-of-the-art SN and weak lensing surveys of the 2020s. WFIRST is also of great interest to the exoplanet community in Canada. The WIRST coronagraph would be a natural extension and complementary to several on-going and future ground- and spaced-based facilities that will enable a wide range of exoplanet research programs dedicated to the detection and characterization of exoplanets. Those facilities includes the the Gemini Planet Imager, JWST, TMT and SPIRou that have strong participation/support from the Canadian exoplanet community. Finally, note that WFIRST has roughly 200 times the field of view of HST/WFC3, so for wide-field NIR imaging, 25% of WFIRST is equivalent to 50 Hubble Space Telescopes! Clearly, the GO programme allows a wide variety of powerful science for Canadians either as PIs or as members of international teams.

3.2. *Instrumentation and Data Handling*

Canada's recent involvement in space astronomy is outlined in the JCSA white paper submission to LRP2010 and has been updated for the MTR. Building on this heritage, CSA has been rapidly advancing the study of potential WFIRST instrumentation contributions, including data management. In 2014, CSA issued an RFI on potential contributions, and this led to an RFP for two WFIRST studies, one for contributions to the WFI component, and the other for contributions to the coronograph. Based on the RFI submissions and other considerations, for the WFI study, CSA selected the following instrumentation options for further study:

1. Integral Field Unit (IFU) or subsystem(s)
2. Photometric calibration (pre-flight ground or flight)
3. Fine Guidance System

Instrumentation options for the coronograph were:

1. EMCCDs
2. Integral Field Spectrograph (IFS) or subsytem(s)
3. Other optical sub-systems
4. Image processing (speckle suppression algorithms)

Both of these studies will also analyze options for data processing and archiving contributions. The Canadian Astronomy Data Centre has a long history of productive collaboration with NASA on HST data management, and there are clearly opportunities to enhance WFIRST science potential for the Canadian community.

At the time of writing these studies are ongoing. The WFI study is being led by COM DEV and the coronograph study by ABB Canada. In the second phase of the studies, a subset of these options will be studied in greater detail. CSA also issued a call for a "Pool of Experts" to assist with the studies which received a strong response (over 20 Canadian researchers). The studies are expected to be completed by mid-2015. In summary, from an instrumentation perspective, things are proceeding rapidly.

4. RECOMMENDATIONS FOR THE MID-TERM REVIEW PANEL

LRP2010 recommended participation in a DE space mission at a level of \$100M. WFIRST is the only realistic option to fulfil this recommendation. WFIRST has the further advantage that, by virtue of the AFTA upgrade and substantial GO time, it will also conduct exciting science of interest to the broad Canadian astronomical community across a wide range of topics from high-redshift galaxies to exoplanets. We recommend that the MTR reaffirm this recommendation. Specifically:

1. Canada, through CSA, should make a substantial contribution to WFIRST, in the form of instrumentation and/or software.

2. By virtue of this contribution, there should be opportunities for significant and early Canadian participation in WFIRST science teams, spanning all of the potential WFIRST science areas, and not only those areas most closely linked to provided contribution(s).

3. To obtain maximum scientific return from science team membership and from exploitation of survey data, a mechanism needs to be identified to fund postdocs to assist Canadian researchers in WFIRST science activities, at a level similar to their NASA-funded science team collaborators.

5. CONCLUSIONS

WFIRST is now a more powerful 2.4m telescope than the design recommended in LRP2010. Its status and timeline in the U.S. remain favourable for a launch around 2023. Canada should be involved in a substantial way, so that we can enhance our capabilities in instrumentation and participate in the key science teams. We should take advantage of the opportunity to be involved early in the process.

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