Penn Arts & Sciences

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Dear NAC Astrophysics Subcommittee Colleagues,

In your deliberations on plans for potential NASA funding of the WFIRST and Euclid projects, perhaps you will consider unsolicited opinions from a researcher who has spent most of the last decade devising theory and instrumentation strategies for exploring dark energy. I have served on every national panel devoted to dark energy issues to date,[1] providing a large fraction of the quantitative technical and scientific analyses intended to guide the US dark energy program and the JDEM effort in particular.

My main point is to emphasize that if ESA selects Euclid for implementation, then **US collaboration in Euclid will be the *only* route to a leading US dark energy program and to successful implementation of the three-pronged science program given top priority by the Decadal Review**. This is true even if WFIRST is funded on the budget and schedule proposed in NWNH. It is even more the case if WFIRST is delayed and/or descoped. No matter the long-term fate of WFIRST, missing the opportunity to join our European colleagues would, in my opinion, close out the possibility for US leadership in dark energy exploration, and lead to a WFIRST mission that would be at best a pale echo of NWNH goals.

In your shoes I would therefore recommend that **NASA be prepared to negotiate partnership in Euclid as soon as ESA makes its M-class selection.** This would mean having the WFIRST SDT return a report *before* this selection that assesses the cost and impact of WFIRST – and this report *must* consider the case in which WFIRST follows a successful Euclid mission. Continuing to discuss WFIRST in isolation is a recipe for spending a lot of money and time for a scientific return that is underwhelming in its day. Likewise, skipping the Euclid opportunity while we ponder the availability of a WFIRST-sized budget wedge will leave us at best with a minor role in the top science priorities of the Decadal Review, and at worst leaves us with no NASA contribution at all to these priorities.

Let me justify the above assertions by anticipating the results of the WFIRST SDT's technical evaluations. The Decadal Review proposes WFIRST as "measurements of weak gravitational lensing, supernova distances, and baryon acoustic oscillations…to determine the effect of dark energy on the evolution of the universe" plus a vigorous microlensing survey and an infrared sky survey in both programmed-survey and guest-investigator modes. The JDEM Omega concept is given as a starting point, and the independent cost estimate of $1.61B for JDEM Omega saturates the proposed WFIRST budget, so let's examine the capabilities of the Omega concept with reference to Euclid and the WFIRST science charter. All assume 5-year nominal missions, so let's look at the science per unit time:

[1] The Dark Energy Task Force, JDEM Science Definition Team, Figure of Merit Science Working Group, JDEM Science Coordination Group, and JDEM Interim Science Working Group, plus relevant DOE/NSF prioritization panels.

- **Microlensing:** Effectiveness scales primarily[2] with the product of collecting area and aperture (etendue). The 1.5m Omega primary and 0.25 deg^2 instrumented imaging field of view give a product of **0.44** m^2 deg^2. The Euclid 1.2m primary and 0.47 deg^2 instrumented NISP FOV give **0.54** $\mathbf{m^2}$ deg^2 of NIR etendue. Euclid could gain microlensing reach using simultaneous imaging with the 0.45 m^2 deg^2 of etendue in the VIS instrument.
- **Supernovae:** Neither Omega nor Euclid include the NIR integral-field spectroscopy or slit spectroscopy that would enable the most efficient high-redshift NIR supernova survey as described by the JDEM ISWG report. Omega gains a factor 1.5 speed advantage for photometry or slitless spectroscopy by virtue of its larger aperture. Neither the Euclid mission nor the nominal WFIRST mission described by NWNH budgets mission time for a SN survey.
- **Baryon oscillations:** The etendue of the NIR slitless spectrograph is the critical parameter. This is **0.94** m^2 deg^2 for Omega, a 1.75x gain over the Euclid NISP.
- **Weak lensing:** this technique requires not just a high-throughput telescope in space, but a true space telescope that exploits the angular resolution available only in space: optics, attitude control, and pixel scale that do not greatly degrade the diffraction limit of the telescope, and a pixel count sufficient to *fully sample* the sky at the telescope's resolution. *The JDEM Omega concept lists the WL science as "goal," i.e. cannot be expected to meet WL requirements.* Through all the JDEM design exercises, the GSFC JDEM Project Office has emphasized the mission expense of obtaining high resolution and adequate sampling over large FOV, and the risk of implementing large device counts, high quality optics, and good attitude control to the mission.[3] So we should not expect this capability to exist in WFIRST without dedicating significant resources.[4] The Omega imaging etendue of **0.44** m^2 deg^2 equals the **0.45** m^2 deg^2 of the Euclid VIS, which *is* designed to satisfy WL resolution and sampling requirements.
- **NIR sky surveys:** the etendue is again the principal parameter. The strongest case for an Omega-like WFIRST is a survey whose science requires NIR spectroscopy and imaging in a ratio exactly matched to the instrument, but gains nothing from the Euclid VIS: in this case the WFIRST throughput is 2.5x better than sharing the Euclid NISP time. The need for angular resolution and sampling will depend upon the science goals of the survey and is hence uncertain; also uncertain are the ability of WFIRST to deliver high resolution and sampling, and the ability of Euclid's VIS imager to meet the science needs for resolution.

With the above in mind, consider launching WFIRST when Euclid has already conducted a ~4-year BAO/WL survey (splitting NISP time between imaging and spectra), plus a 1-year microlensing survey. The strawman 2-year WFIRST dark-energy survey would have modestly deeper (1.75x) BAO than Euclid's, and the WL survey would fall well short of Euclid's even if WFIRST met WL quality requirements. This would be too little, too late for US leadership in the dark-energy field. The proposed WFIRST microlensing survey could also have been largely accomplished by Euclid in its primary mission. Data from WFIRST would no doubt make important contributions to survey science, but would not engender the multi-pronged leadership role nor breakthrough capability sought by NWNH.

How can we insure stronger impact of WFIRST if it follows Euclid? WFIRST will need higher imaging and/or spectroscopic throughput, and/or the addition of an integral field unit for high-precision supernova cosmology. But barring major departures from the design and costing philosophies of JDEM Omega, capabilities cannot be added even if the full NWNH-recommended funding becomes available. Collaboration with Euclid is the only

[2] For difference imaging in crowded microlensing target fields of Galactic stars, pixel scale and sampling are not critical performance parameters.
[3] For example: the JDEM ISWG proposed concepts "A" (meeting BAO and SN requirements) and "B" (meeting WL requirements as well). The GSFC Project Office cost estimates were $650M and >$900M, respectively, a 40-50% higher cost for a mission with high resolution and good sampling
[4] The 21-member WFIRST SDT has only 1 member with experience in WL observing, which we might interpret as an acknowledgment that WL requirements will not become a priority in WFIRST design exercises.

route that I see [which I consider programmatically and technically more feasible than a single merged mission]. One possible route is that the Euclid telescope meets the stringent requirements for image quality and sampling that are needed for WL and some survey science. WFIRST could then use wider-field optical configurations, and cost-saving measures such as weaker attitude-control and alignment requirements if it were not attempting to repeat high-resolution elements of the Euclid program. A higher-etendue “light-bucket” WFIRST would allow a greater scientific impact if it could rely on Euclid data for the elements of the program that require fully-sampled space-quality angular resolution.

If Euclid is implemented by ESA then there are three possible paths for NASA:

1. Ignore Euclid, build WFIRST resembling JDEM-Omega: as described above, this will lead to loss of US leadership in dark energy and microlensing fields. Budget cuts/delays in WFIRST would obviously lead to further loss of US leadership.
2. Redesign WFIRST to complement Euclid, no US participation in Euclid: potential for US to regain some leadership in dark energy and NIR survey science c. 2025 when WFIRST results exceed power of already-published Euclid data.
3. Redesign WFIRST to complement Euclid, fund US participation in Euclid: US/NASA scientists can retain leadership roles in the science fields highlighted by NWNH. Money spent on US Euclid participation (<15% of WFIRST budget) may delay WFIRST launch, but the net return on NWNH goals for US science is higher, especially if US participation improves Euclid. If the WFIRST budget wedge never appears, Euclid participation enables a substantial fraction of NWNH goals.

There is of course a last option, which is that we skip the Euclid opportunity *and* watch WFIRST be cancelled or descoped into irrelevance over the years. There are those who feel this would be a faithful implementation of NWNH recommendations, but I strongly disagree with both this interpretation and its consequences. I hope you feel the same way.

Sincerely,

Gary Bernstein