Cosmological Complementarity of Roman & Euclid

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Prelude

- I have been a member of the Euclid Collaboration, via the NASA sponsorship and the Rhodes-led team. However, I have not had a substantial leadership role in the collaboration.
- I am not a member of any Roman group. I did serve on the panel of the 2017 WFIRST Independent External Technical/Cost/Management Review.
- I was chair of the Astro 2020 Science Panel on Cosmology (but I am here to offer my own opinions, not to represent that panel).
- I am heavily involved with the Dark Energy Spectroscopic Instrument (DESI, former Spokesperson, 2014-2020).
- I served as Director of SDSS-III (2007-2014).

What is "Cosmology"?

- As the questions posed to me refer to "cosmology objectives", let me start with the general statement that I think the line between "cosmology" and other areas of astrophysics is grey.
- Of course, we know that wide-field survey data can serve many purposes. And that these archives provide high legacy value.
- But more deeply, achieving the cosmological goals depends on successful modeling of astrophysical "systematics", e.g., about the relationship of galaxies to halos.

A. What is complementary or redundant between Euclid and Roman in terms of their cosmology objectives?

- Euclid and Roman do of course have overlap: both seek to do weak lensing and large-scale structure (BAO, RSD, photometric clusters).
- Both missions complement the opportunity of Rubin/LSST.
  - NIR Photometry is a key need for photometric redshifts.
  - Sharper imaging enables substantial lensing improvements.
- Euclid is wider & shallower; Roman provides deeper & higher quality data, but of less area.
- Roman plans for supernova cosmology; Euclid does not.

NIR Photometry and Photometric Redshifts

- The lensing science of Euclid, Roman, and Rubin depends critically on the performance of photometric redshifts.
  - This can easily be the dominant systematic error.
- Rubin (ugrizy) will support photo-z's, but NIR data considerably improves the reliability.
  - Need to bracket the 4000A/Balmer break from z=0 out to z~2.5, at which point the Lyα forest & break enters on the blue end.
  - Without the NIR, galaxies at z ~ 1.5-2 are hard to pin down.
- Euclid is not deep enough to match the full Rubin depth. Roman could help considerably.
  - Remember that "point source depths" over-favor space imagers; these galaxies are resolved, so the signal-to-noise ratio is lessened at fixed total flux.

Sharp, stable images

- Euclid VIS and Roman NIR both will improve on ground-based image quality.
- Obvious gain in resolving compact galaxies.
- But also a major gain in deblending crowded sources, another vexing systematic error issue for lensing programs.
- Roman further improves this by measuring color variations/gradients on scales sharper than the ground will allow.

Survey Area

- Euclid will conduct a wide survey, comparatively shallow relative to Roman HLS.
- Wider surveys tend to be preferred in cosmological performance metrics.
  - Can measure more galaxies and more volume per unit telescope time.
  - Study of dark energy doesn't press one to extremely high redshift.
  - But note we can survey low redshifts from the ground.
- Roman's deeper surveys will probe to higher redshift, more distinguished from the ground-based work.
  - Higher redshift clustering is less evolved and hopefully cleaner.

Depth and Data Quality

- In my opinion, Euclid lives on the edge regarding data quality.
  - Undersampled NIR pixels; not enough dither positions; minimal signal-to-noise ratio for the required sample; single lensing band.
  - This will put lots of pressure on the quality of the reduction & analysis pipelines. Will we meet the burden of proof for an exotic finding?
- Roman has a considerable advantage in data quality.
  - More than just depth. More exposures, roll angles, filters, and pixel-level redundancy.
- Personally, I caution against sacrificing this quality in search of survey speed. Fisher matrices don't easily reward fault-tolerance, but real-world analyses do. Design for more robust, easier-to-use data!

Supernova Cosmology with Roman

- Supernovae remain a highly competitive way to measure the cosmological distance scale, particularly at $z<1$, and hence the dark energy equation of state.
  - Methods based on large-scale structure don't have enough volume at low redshift; supernovae really win there.
- Systematic control is critical.
- Rubin will do excellent supernova work, but the NIR offers great opportunity at low redshift.
  - Reduce the dust systematic; more homogeneous candles; space-based image quality and stability.
- NIR is required for high redshift ($z>\sim1$); must have the rest-frame optical.
- Roman is the opportunity to do the definitive measurement.

B. How important are Roman's cosmology objectives in light of cosmology data that will become available over the next 5 years?

- Roman's cosmology objectives are closely in keeping with those of other current/near-term wide-field surveys. The opportunities are about statistical scope and systematic control.
- The NIR photometry is, to me, irreplaceable.
- The image sharpness and stability are also a great opportunity for lensing.
- The NIR SNe program will remain very compelling.

NIR Spectroscopy

- The combination of lensing and 3-d mapping is very powerful.
  - Complexity of the cosmic web is best seen in 3-d.
  - We will increasingly need to step beyond two-point functions and the linear regime to leverage the non-Gaussian information in the density field.
  - Comparing lensing and redshift-space distortions tests the theory of gravity.
- High-redshift surveys offer new opportunities:
  - Line-of-sight BAO at high redshift measures H(z) particularly effectively.
  - Gravitational non-linearity is less advanced.
- But there are multiple ways to build a large redshift survey.
  - NIR spectroscopy is needed to access the Hα line at $z>1$, but one could use other redshift tracers. Notably [OII] and Lyα from ground-based telescopes.
- I therefore see the NIR spectroscopic program as more tradable.
  - Note that Roman's reach to denser samples at $z>1.5$ is more novel than Euclid's spectroscopic depth.
- That said, we need the redshifts from somewhere, and Roman slitless spectroscopy can assure prompt coverage of a well-coordinated footprint.

C. Under the assumption that Euclid is successful and in view of the existence of Rubin, could the cosmology objectives of Roman be achieved with less observing time?

- It depends what Euclid (and Rubin and DESI/PFS and CMB and…) find!
  - If they find cosmological variations from LCDM, we surely will want to look more, with cleaner data. That might argue for more observing time!
- Rubin likely provides a strong argument for NIR imaging deeper than Euclid, which Roman could provide.
- As for less time, we are pressed against the sample sizes that Euclid will provide. Unless Euclid is found to be faltering with systematics, I doubt one would want to go substantially smaller with the HLS imaging.
- The SNe program stands on its own, regardless of Euclid or Rubin; this is the chance to do something definitive.
- For both the SNe and HLS imaging, the data have great value for extragalactic astrophysics at moderate and high redshift.

D. Any additional comments you have about optimizing Roman observing time allocations.

- No matter how much modeling one has done in advance, one gains so much more confidence in the capabilities of a facility with even the early data.
  - DESI is now well understood (and working well!)
  - Rubin, PFS, 4MOST, Euclid are still in front of us.
- Further, the landscape of cosmological results will evolve, with results from DES, HSC, DESI, CMB, eROSITA, etc.
- Allowing the Roman program to maintain flexibility to incorporate those assessments and results is an important opportunity.