Key Issue and Overview of Impact on the Field:

The traditional model of ground and space observations of astronomical objects tends to be heavily siloed. Certainly, the community makes joint observations all the time, but it does so in a generally un-coordinated way. For example, the Hubble Space Telescope might make a deep imaging observation of a field, and the Keck telescope might obtain spectra of selected objects from those images. There exist some mechanisms for joint proposals (such as joint NOAO/HST time allocations), but these occur *after* the missions have been designed, and the instruments built on the ground. The general state of affairs is for ground and space facilities and instrumentation to be funded, built, and operated independently of each other.

Nature, however, does not present itself with siloed thinking in mind. The science outlined in the recently submitted Astro2020 white papers and other reports such as the NAS Exoplanet Science Strategy report detail bold, transformative science that in many cases not only benefits from ground/space coordination, but *requires* it. Our current mode of siloed operations slows, hampers, and in some cases, halts scientific progress. Indeed, NSF and NASA are exploring some partnerships like the NASA-NSF Exoplanet Observational Research (NN-EXPLORE) program, but they are fairly narrow in scope and application.

Rethinking our current model ground/space coordination has many motivations. First and foremost is capability: instruments and facilities on the ground designed from the beginning to work with space missions that are designed to incorporate and require them can lead to significant gains in scientific return. Second is cost: even small investments by space mission standards can create transformative capabilities on the ground. Commensurate with cost is risk: targeted ground investments can significantly lower space mission risk, particularly since the ground offers the ability of servicing and upgradeability that space does not. A final motivation is time: with coordinated and/or cadence scheduling, the ground offers significant scheduling power, particularly for transient events.

Strategic Plan:

Given the demands of the science likely to be at the forefront of the 2020s and beyond, the community will be best served by significantly enhancing ground and space collaboration and coordination. The goal of this enhancement is to maximize the value of the data obtained from the ground and space. A robust plan for evolving the ground/space synergy is well beyond the scope of this white paper, but we outline a number of key questions and suggestions for moving forward. We suggest that the Decadal Survey recommend that the key stakeholders--the agencies, Congress, and the astronomical community--make a deliberate effort to best maximize coordination of current and future resources to advance the field, and to maintain U.S. leadership in astronomy.

Some key questions include:

What are the major scientific topics that benefit the most from enhanced ground/space collaboration?

Naturally, a primary output of the Decadal Survey is a detailed assessment of the science landscape of the next decade and beyond, so this document does and can not claim to know the answer to this question. Nevertheless, the science white papers already submitted to Astro2020 clearly show a number of emerging fields that will play significant roles going forward. These include the robust exploration of exoplanets (and the search for life on a subset of them), transient astrophysics, and multi-messenger astrophysics. In each of these cases, it has already been demonstrated that ground/space coordination is not only enhancing for the science, but is essential. For exoplanets, direct imaging from space is coupled with precision radial velocity measurements from the ground before a planet can be characterized as ‘Earth-like’. Transient phenomena require quick response from ground and space assets for source localization and characterization, and the same is true for multi-messenger events like Ligo+Virgo gravitational wave observations. In each of these cases, the current state of the art is certainly enabling science, but not optimizing its returns.

Are there ways we can lower space mission costs through targeted instrumentation on the ground?

Current ground-based instrumentation, especially for large facilities, is developed with broad scope of utility in mind. Instrument cost is a major driver for this choice: in general, the funding simply does not exist to build multi-million dollar instruments to serve singular or narrow science cases. NASA astrophysics missions, even at the SMEX level, have funding profiles significantly larger than any instrument funding mechanism on the ground. There exists then the possibility that some fraction of a space mission’s cost could be used for targeted ground-based instrumentation whose purpose is primarily for mission enhancement, if not enablement. Taking the idea further, there could be the opportunity that by developing such instrumentation for the ground, certain aspects of the space mission could be removed, and the total mission cost lowered. Pushing adaptive optics technology further into the visible wavelengths would open significant opportunities in this model. This philosophy requires, however, that the missions be given the flexibility to consider such a strategy from day one, and broaden their team expertise accordingly.

Are there ways we can change traditional observing models to better enhance the science from the ground or space?

One change that explicit coordination with space missions might require is a switch to a results-based figure of merit, similar to the level one requirements a mission might have. For example, some number of exoplanets at some level of radial velocity accuracy could be the target instead of N number of nights (or hours) devoted to a program. This mode of observing would be a significant departure from the norm for classically scheduled observatories. Additional observing strategies like cadence observing or automated twilight observing could also support space missions. Adding new flexibility to scheduling could enable new types of joint 'key projects' between ground and space, with science returns coming out simultaneously instead of piecemeal. Large observatories must also enhance their ability to perform target of opportunity observations given the increased focus on transient objects frequently localized from space. Finally, how the time itself is awarded is likely to change, as capabilities from the ground targeted ad specific missions would likely require joint ground/space GO programs.

Schedule & Organization:

Again, the actual implementation of any significant changes to the current model of ground/space synergy is outside the scope of this white paper, and requires all stakeholders to be engaged in making new policy. Nevertheless, we can envision how each of the relevant sectors might begin to think about this issue.

What might change on the ground:

Ground based observatories, especially those operating an a 'classical' mode (as opposed to purely queue-scheduled) will need to invest in the appropriate observing infrastructure to maximize returns to the partner space missions. As mentioned previously, cadence scheduling is one consideration. Another is calibration: space missions have rigorous calibration protocols which flow down directly into enhanced return on the value and range of utility of the data. By contrast, ground based observations vary wildly in their calibration consistency, and observatories that integrate significantly with space missions must adopt new calibration policies. Data reduction and archiving on the ground must also become more open and robust (see the APC white paper on data services by J. M. O'Meara et al. for details).

What might change in space:

Space missions do not currently generally view ground based efforts as part of the level one requirements of the mission (a notable near-exception is the TESS Followup

Program, for which the ground data plays a critical role in the level one requirements). Targeted instrumentation and new observing modes could enable a change in this philosophy, and change mission design and execution. Space missions would need to partner with ground institutions as early as possible in mission development (i.e. at the process of mission proposal development), and NASA would need to create new cooperative agreement schema in conjunction with these observatories once a mission is selected. New funding mechanisms for instrument development, and requisite technology development, as well as new partnerships with the NSF on instrumentation, are likely needed.

What might change in the community:

As the agencies, missions, and observatories evolve, so must the community. The ground-based community varies significantly in how it returns data to the community, and at what level of propriety. Observatories can build data infrastructure to closer approximate that of space missions, but cannot do so without community buy-in. Beyond the mechanics of observing, the community is likely to change how it trains its next generation. Tighter integration of ground and space requires expanded knowledge, new tools, and new methods. The instrument building community will likely need to expand, and in some cases, further specialize. Collaboration between observatories, academic institutions, and NASA centers will need to increase, and our current systems of professional advancement and development (e.g. tenure, postdocs, graduate student funding) must evolve to recognize the value of collaborative efforts. Finally, the systems by which the community proposes for time on telescopes, be they ground or space, will need to adapt to incorporate GO-like programs that utilize joint facilities. In many cases, current systems need only evolve, not be cast aside.

A candidate path forward:

One mechanism already exists to help foster new advances in ground/space coordination: advisory committees in general, and the Astronomy and Astrophysics Advisory Committee in particular (for the purposes of full disclosure, note that the lead author on this white paper currently serves as Chair of the AAAC, but this white paper is not written on behalf of the committee). The AAAC was established in the 2001 National Science Foundation authorization act by Congress with the purpose of monitoring and evaluating the performance of NASA, NSF, and the DoE on issues of astronomy and astrophysics, with a focus on those issues requiring inter-agency coordination. In addition to their annual reports, the AAAC often explores specific issues through task force assignments. Recent task force reports include those on Dark Matter and Dark Energy, Exoplanets, the Cosmic Microwave Background Stage Four concept definition and the Gemini-Blanco SOAR telescopes in the era of Multi-Messenger Astronomy.

In principle, the AAAC could expand its current remit to identify key areas where enhanced ground/space synergy would directly yield science outcomes that exceed the sum of the inputs from either realm individually. Task forces could then be formed around these areas, with the role of finding those mechanisms of collaboration and coordination that might best maximize science return (e.g. instrumentation, joint proposal mechanism, modes of observing, etc.). The final output of the task forces would be a set of public recommendations to the agencies.

While this path is merely one possibility, it is important to recognize a set of underlying principles that would accompany it or other possible paths forward. First, monetary resources are not simply transferred, i.e. no agency is subsidizing another. Instead, partnership agreements should be formed around key science goals. Second, facilities derived from these partnerships must have community access. This access applies not only to the facility, but the data, and the tools that produced the data, i.e., an appropriate community archive should be identified, and an open-access model for data and code should be employed.

Cost Estimates:

Cost estimates for enhanced ground/space synergy are not possible without knowing the final scope of the change. Nevertheless, some new investment will likely be required before cost savings at the mission level are realized. Again, all stakeholders must work together to both define the new era, and to suggest changes to traditional funding mechanisms. We encourage the Decadal Survey to recommend that the US community begin this process of collaborative evolution of ground and space to maximize the scientific returns of the 2020s and beyond.