The Antarctic Planet Interferometer

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ABSTRACT

The Antarctic Planet Interferometer is an instrument concept designed to detect and characterize extrasolar planets by exploiting the unique potential of the best accessible site on earth for thermal infrared interferometry. High-precision interferometric techniques under development for extrasolar planet detection and characterization (differential phase, nulling and astrometry) all benefit substantially from the slow, low-altitude turbulence, low water vapor content, and low temperature found on the Antarctic plateau. At the best of these locations, such as the Concordia base being developed at Dome C, an interferometer with two-meter diameter class apertures has the potential to deliver unique science for a variety of topics, including extrasolar planets, active galactic nuclei, young stellar objects, and protoplanetary disks.

Keywords: interferometer, infrared, Antarctica, exoplanets.

1. Introduction

The grand questions in astrophysics answered in the twentieth century were predominantly related to cosmological questions. While unanswered questions remain, cosmology and the astrophysics of galaxies have largely converged to consensus models. The expanding frontier of astrophysics that will pose the grand questions for the 21st century is the study of extrasolar planets. It is less than a decade since the first solid discovery of an extrasolar planet around a sun-like star. This past decade has seen an explosion in the number of discovered planets (now numbering more than 100) and the emerging maturity of exoplanets as a field of study. There have been surprises and remarkable discoveries in this field, yet no exoplanet has been directly detected, nor has any planetary system like our own been found. The direct study and astrophysical characterization of exoplanets, and the discovery of rocky planets, perhaps even Earth-like planets, are the next important discoveries. These tasks are beyond the capabilities of any existing ground or space-based observatories and will require an extensive investment in large facilities such as the TMT and TPF/DARWIN.

Exoplanets are small, cold, and therefore faint when compared to their host stars. This drives any observations aimed at direct detection to extreme precision, infrared wavelength, and high resolution. These characteristics suggest this is a task for an interferometer. Study using existing interferometers is limited by the properties of the atmosphere and does not promise to yield significant progress. The best site available, however, has not yet been exploited. The Antarctic plateau offers a unique opportunity to enable an interferometer with the sensitivity, precision, and resolution required to make the first extensive studies of the astrophysics of extrasolar planets.

The Antarctic Plateau Interferometer (API) concept has unique discovery space potential and could make important contributions to the study of exoplanets and other astrophysical problems. Phase 1 of the API project could achieve substantial science goals and will demonstrate the key technology to enable the larger, phase 2, facility. API phase 1 could directly test models of Jovian planet atmospheres and study formation of planetary systems. API phase 2, based on three or more two-meter class telescopes, would be capable of sustained unique discovery space potential in a broad range of topics, including measuring the frequency of Earth-like planets, detecting protoplanets in young stellar objects' disks, and studying dynamical processes in the accretion disks of active galactic nuclei (AGN). These and other scientific discoveries are made possible by the unique atmospheric characteristics at Dome C and cannot be achieved anywhere else on earth.

Our approach has **four key elements**. **I.** We consider a concept for the API phase 1 instrument, which is the smallest and most simple infrared interferometer still capable of unique measurements of exoplanets and AGN. **II.** This concept for API phase 1 ***requires no new technology*** and relies instead on interferometer technology inheritance from the Keck and Very Large Telescope interferometer projects. **III.** Our concept for API phase 1 is an international partnership, as required to take advantage of this unique site at the Concordia base. **IV.** The instrument concept is scalable and upgradeable, so the investment made in the API phase 1 can be directly incorporated in the larger-scale API phase 2. ***Our approach is focused on our primary goal of demonstrating the scientific potential of the site and gaining interferometer operational experience at Dome C as a necessary precursor to a more capable interferometer.***

2. Unique Discovery Space Science

The extensive unique discovery space potential for API[1,2] phase 1 and phase 2, arises from a combination of key instrument performance parameters, **exclusively enabled by the Dome C site**[2], which would allow the API program to answer a number of compelling questions on a wide range of astrophysical topics. As we show, there is a crucial role for the combination of high-sensitivity, high-angular-resolution, and high-dynamic-range infrared measurements to make unique contributions to answering important astrophysical questions. We explore a number of the key topics in what we see as a long-term, infrared interferometry science program at Dome C and show how questions in each of these topics are answered by different phases of an instrument development program.

In addition to the substantially improved instrument performance, the long baseline (400 meters), relatively high sensitivity for 3-5 μm operation, and $R \sim 10^4$ spectral resolution give API phase 1 unique capabilities when compared to other existing or planned interferometers. We would exploit this unique capability and the crucial role high-angular-resolution infrared measurements have for making fundamental contributions to compelling astrophysical questions. Below, we discuss the unique contributions API phase 1, and the second generation Antarctic infrared interferometer concepts such as API phase 2 or KEOPS[3], can make to high-priority astrophysical questions. API phase 1 is a science-capable "pathfinder" for instruments such as API phase 2 and KEOPS, which have the potential to answer Grand Challenge questions.

2.1 Exoplanets

The discovery of numerous instances of planets orbiting solar-type stars[4] connects to fundamental questions, such as "Is there other life in the universe?" and "Are we alone?". These questions are important to the public and are a major motivation for proposed missions such as the Terrestrial Planet Finder (NASA) and DARWIN (ESA). Understanding the formation, migration, mass distribution, and atmospheres of exoplanets is a major objective of work in the field of exoplanets. The contrast ratio between the planet and the star is more favorable in the infrared, making observations of exoplanets more tractable in this wavelength range. Because of the ability to make high-angular-resolution, high-contrast measurements, infrared interferometry will have an essential role in determining the properties of exoplanets. The best sites on the Antarctic plateau enable infrared interferometer measurements rivaling space experiments in terms of sensitivity and unique discovery space science potential.

Key Question: What is the nature of exoplanet atmospheres? Measurement of the spectral energy distribution (SED) of a hot Jovian exoplanet is probably the most important near-term objective in observational exoplanet astronomy. Theoretical models for the SED of hot Jovian class exoplanets make predictions that could be directly tested by observations; however, the observations are difficult with single aperture telescopes[5,6,7]. Extensive attempts to observe an exoplanet SED have resulted in only one direct measurement[8]. With API phase 1, we could directly test the 4 μm "bump" predicted in the SED of hot Jovian exoplanets[9,10] and the dependence of the SED on orbital phase angle[11,12]. With API phase 1, we could study **exoplanet weather** by measuring intrinsic SED variations due to circulation induced atmosphere variation[13,14]. With API phase 2, we could extend these measurements from 1.2 to 28 μm and include ~300 K Jovian-class exoplanets in the habitable zone. ***Thus, API phase 2 could begin the observation and study of other worlds where life could exist.***

Key Question: What is the frequency of Earth-like planets? Measurement of the frequency of Earth-like planets around solar-type stars, η_{Earth} would constitute a major scientific achievement and would provide crucial information for the sensitivity requirements for the Terrestrial Planet Finder (TPF) and Darwin missions. Using high-contrast modes such as differential closure phase, capable of $1{:}10^6$ contrast ratios at Antarctic Dome C, API phase 2 could detect Earth-mass planets in ~0.25 AU orbits. To infer the frequency of occurrence of Earth-like planets (Earth-mass planets occurring in the habitable zone) we would invoke the premise which is true in our solar system, namely that $\eta_{hot\ Earth} = \eta_{Earth}$.

The ESA Darwin and NASA TPF missions have the objectives of discovering and characterizing Earth-like planets—the pale blue dots—that may occur around some nearby stars. Knowledge of the frequency of occurrence of Earth-like planets is critical to the design of these space missions since this parameter determines the size of the target set (and thus instrument p arameters s uch a s s ensitivity a nd t elescope s ize) r equired f or a chieving a h igh p robability o f de tecting several of these pale blue dots.

Key Question: What are the properties of protoplanets? The conditions and process of planet formation are poorly understood but are essential to understanding why different kinds of planets and planetary systems form. Observations of protoplanets in the environment in which they form, the disks surrounding young stellar objects (YSOs), would be a powerful tool for answering questions such as "Where do planets form?" and "How do they evolve?"' Observations of YSO disks indicate a disk lifetime of 3 to 6 million years[15]. Do the planets form throughout the life of a disk or in a particular phase? Structure in the debris disk around Vega has been interpreted as a possible signature of the presence of planets[16]. Analysis of known exoplanets indicates that planets form quickly relative to the timescale of planet migration[17], as predicted by some models[18,19,20]. This implies protoplanets undergoing formation, and recently formed planets will have a temperature higher than the local disk temperature; these systems would be excellent targets for high-contrast interferometry measurements. ***Thus, we expect to detect and measure the properties of protoplanets in nearby YSO disks using API.***

2.2 Young Stellar Objects

In recent years, long baseline interferometers operating at near-IR wavelengths have opened a new observational window into young star-disk systems by probing their structure with unprecedented sub-AU spatial resolution. Initial interferometer measurements revealed characteristic near-IR sizes to be much larger than expected based on the models that were favored at the time, both for disks around solar-like (T~Tauri) and higher-mass (Herbig~Ae/Be) young stars[21-25]. These surprising initial results have motivated, in part, a revision of disk models. The existence of an inner wall located at relatively large radii from the central stars is now hypothesized. For intermediate-mass young stars, the location of this putative wall is set by the sublimation of dust frontally heated by the central star[26,27], while in T Tauri stars additional accretion heating pushes the inner disk edge even farther outward[28]. These new scenarios change our understanding of the physical conditions of the inner disk (sub-AU to a few AU) and the initial conditions for planet formation in this critical region of the disk that spans the habitable zone. It is exactly this portion of the YSO disks that we intend to study with API phase 1 and phase 2 instruments.

Key question: What is the nature of the putative inner wall? As a thermal infrared instrument (L and M bands), API phase 1 opens a completely new observational window into YSO-disk systems, as this wavelength regime has never been coupled to milliarcsecond angular resolution. Using its single baseline (of lengths ~100 m and ~400 m for the two first observing seasons, respectively) API phase 1 will measure for the first time the characteristic disk sizes in this new wavelength r egime, which p otentially p robes dif ferent e mission mechanisms (thermal o nly r ather t han t hermal p lus scattered) and different disk regions. Coupled with near-IR (H and K band) measurements, API phase 1 will be able to put the basic predictions of the inner wall models on firmer ground by measuring the characteristic sizes of a relatively large number of YSOs across the wavelength and mass range with better accuracy than currently possible.

Specifically, the precise location of the putative inner wall depends on the heating mechanisms (only stellar irradiation vs. stellar irradiation plus active accretion), geometry (scale height), and whether the gas inside the inner wall radius is optically thin or thick, all of which are uncertain model inputs at best. Multi-wavelength measurements with API phase 1 will provide powerful constraints on these questions. For example, different disk models predict different dependencies of the characteristic sizes as a function of wavelength. In particular, a very different signature is expected between the near-IR and the L/M bands for inner-wall models (essentially same sizes) compared to traditional single power-law models (emitting region moves outward with wavelength).

Key question: What is the proper star-disk flux decomposition? Until true direct images are obtained, all interferometer measurements rely on model-fitting techniques for data interpretation. For composite objects such as a young star plus extended disk, one free parameter is the relative contribution to the total flux by each component. All the YSO measurements to date depend on estimating the stellar contribution to the total flux by decomposing the measured spectral energy distribution, a procedure that has never been validated empirically. The initial baseline (~100 m) of API phase 1 will partially resolve the extended disk component of most systems, while the 400~m baseline will completely resolve this component, exposing a baseline-independent fringe amplitude that equals Fstar/Ftotal, directly measurable to the accuracy of API phase 1 visibility amplitude calibration (sub-percent).

Another ambiguity arises in the interpretation of sparsely sampled visibility amplitudes, in that if the star-disk system contains an additional large (over-resolved) emitting region, such as from scattering in the nebulosity known to exist around most YSOs, the incoherent flux decreases and, if not accounted for, the effect is indistinguishable from a larger disk. All current measurements are susceptible to this interpretation error, and thus far only indirect arguments have been offered to quantify the plausible magnitudes of a scattering component. The degeneracy can, however, be lifted if measurements at more than one wavelength are available, such as the HKLM API phase 1 capabilities, since the resolved emission will be redder for thermal emission than for scattered emission.

Key question: Can planet signatures be detected? A growing planet is believed to open a gap in the circumstellar disk in which it is forming[29]. Such gaps would be undetectable in the spectral energy distributions but are apparent as low-level features in visibility amplitude curves. These signatures could be extracted by exploiting the high-accuracy (sub-1%) mode of API phase 1, made possible by the extreme seeing conditions and the photometric calibration capability of the L/M beam combiner. As an extreme example, the putative inner hole at 4 AU in the 10 Myr old system TW~Hya is believed to have been carved by a growing planet[30] and results in few-% excess emission at short IR wavelengths. Although easily resolvable, such a gap is apparent only via structure in the visibility response at sub-% levels, beyond the reach of current instruments but accessible to API phase 1 high-accuracy mode. In fact, it has been shown[31] that, in the thermal IR, visibility curves calculated from 3D hydrodynamical/radiative transfer disk simulations differ, with and without a gap carved by a Jupiter-sized planet, by as much as 5%.

2.3 Active Galactic Nuclei

The origin of the nuclear infrared emission in AGN remains an unsolved question after more than 30 years of observations; infrared interferometry is the only way to obtain the necessary angular resolution to definitively understand the origin of infrared emission and thus the physics of AGN on the scale of the broad-line region (BLR).

Key Question: What is the location and structure of the inner edge of the dust tori? The prevailing interpretation of unresolved nuclear near-infrared emission is that it arises from thermal dust that *reprocesses* UV and optical emission from the central accretion disk. Mid-infrared (10 μm band) observations show compact features at the location of the nucleus[32,33,34]. This is interpreted as warm dust (T~300 K), and this dust is thought to extend inward towards the nucleus to the sublimation radius[35,36]. If the dust is distributed as an optically thick torus, it can be invoked to unify seemingly different classes of AGN[37] (*eg.* Seyfert 1 and Seyfert IIs). The possibility of a clumpy torus has been proposed[38] to explain infrared reverberation mapping results[39] in the Seyfert I, Fairall 9. API phase 1 and phase 2 instruments can make unique contributions in this area due to a combination of better angular resolution and operation in the critical 3 and 5 μm bands where the largest wavelength dependence is seen in the reverberation mapping data[39,40]. By measuring the diameter of the central feature at a variety of wavelengths from 1.5 to 5.4 μm, API phase 1 and phase 2 instruments can determine conclusively if the infrared nuclear emission arises from dust or the accretion disk; this distinction would be drawn by measuring the H and K band diameters to see if emission is present on scales that exceed the dust sublimation temperature. If the source of the infrared emission is dust, API phase 1 and phase 2 observations can determine if the dust torus is clumpy by making angular diameter measurements in the L and M band and determining if the change in angular size is consistent with a central illumination model.

Key Question: What determines the size and variability of AGN accretion disks? Recent observations with the Keck interferometer find extremely compact nuclear emission[41] that, together with the absence of an infrared bump[42] and a correlation between time delay and wavelength in broad band infrared reverberation mapping date[43], imply that the 2 μm emission is unlikely to arise from an optical and physically thick torus and thus may originate directly from the accretion disk. Mazer detections in NGC 4258 have been interpreted as arising in the accretion disk[45] at a radius of 0.15 pc. This is a larger feature than is predicted by a viscously heated thin disk[46] and is comparable to the 0.1 pc diameter feature detected by the Keck Interferometer in NGC 4151; the NGC 4258 maser detections support the interpretation that nuclear infrared emission arises directly from an accretion disk approximately the diameter of the BLR. If the infrared emission does arise from an accretion disk of this size, infrared interferometry can be used to study accretion disk dynamics by measuring changes in the size and shape of the disk; even if the disk is substantially smaller, high-contrast differential interferometry would detect brightness asymmetries. ***The potential of API to directly observe dynamical processes in relativistic accretion disks is an exciting and remarkable possibility.*** Time-resolved, broad-band, multi-wavelength, angular-diameter measurements could detect dynamical changes in the accretion disk on timescales of a few months in low-luminosity AGNs; this same approach, with higher spectral resolution, could be used to study the dynamics of the BLR.

A Concept for the API Phase 1 Instrument

The concept for the API phase 1 instrument discussed here is primarily catalyst for further discussion; the expectation is that this concept will be refined and improved over the next few months. The current concept for API phase 1 is the smallest, simplest instrument based on proven technology that can achieve the following objectives during winter operations at Dome C. API phase 1 should:

- Make unique science measurements of exoplanets, YSO's, and AGN.
- Exploit the Antarctic plateau's low thermal background in the K, L, and M bands.
- Measure the interferometric co-phasing angle.
- Require no new technology.
- Have a clear path for instrument upgrade and growth.
- Have a modular design for Northern hemisphere testing and Dome C installation.

These objectives are met by a modest instrument based on minor adaptations of technology developed for the Keck and VLT interferometers.

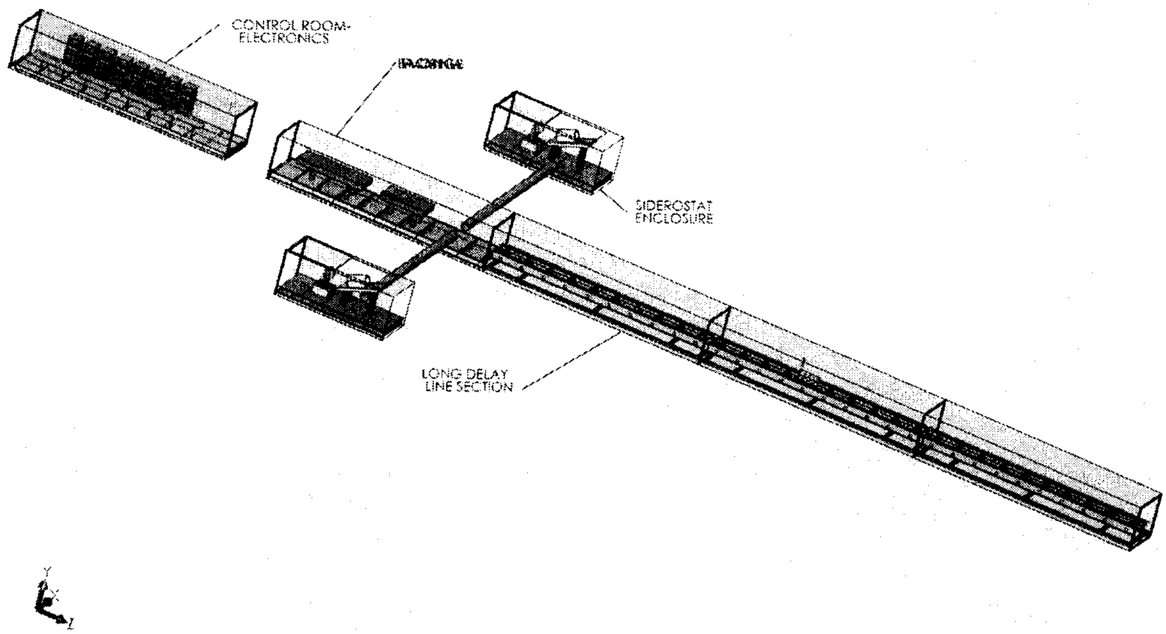

Fig. 1. A concept design for the API phase 1 instrument. The instrument would be modularized in shipping containers (represented as rectangular sections in the drawing above). The containers would be moved by overland traverse, as part of regular Concordia station cargo, to the Concordia base at Dome C. Once on site, the containers would be positioned and attached. All interferometer optics and electronics equipment would be mounted on damped, isolation mounts for shipping. Once the containers were attached, the isolation mounts would be removed and precision assemblies would mount to hard points. This approach allows the entire interferometer to be deployed and tested on sky in the Northern hemisphere prior to deployment to the Antarctic plateau. The instrument is designed to be upgraded with the addition of larger telescopes (2-meter-class) at the positions of the siderostats. In addition, the design accommodates additional delay range by adding additional long-delay line segments.

Instrument description: The current API phase 1 instrument concept is a 2-element, active fringe tracking infrared interferometer incorporating 50 cm telescopes and bearing many similarities to the Palomar Testbed Interferometer[47]. API phase 1 would be designed to make interferometric measurements from 1.4 to 5.4 μm (the telluric H, K, L, and M infrared bands). Active tilt-correction (star tracking) would be done in the J band. The instrument would operate initially with a 100 m baseline and would then be extended to a 400 m baseline. The key API phase 1 instrument specifications are derived from science requirements; for example, a 400 m baseline and photometrically calibrated, L and M band fiber optic combiner capable of 0.1% precision direct V^2 measurements[48] are required for detection of the anticipated emission[49] from 1000 K EGPs.

The interferometer design supports active fringe tracking[47,50] on either the H/K or L/M band beam combiner; a small phasing delay line permits simultaneous phasing of the instrument on the H/K and L/M beam combiners. When the instrument is fringe tracking on either the H/K or L/M beam combiner, active feed forward[51] extends the instrument coherence time on the other beam combiner. With feed forward enabled, the phasing delay line can be operated as a Fourier transform spectrometer with interferometric angular resolution[52] ; this would permit spectral resolution $R\sim10^4$ on bright sources. A chromatic field-separating/re-injection module behind each siderostat allows the instrument to have a field of regard of ~20 arcmin; this permits the interferometer to fringe track on a bright source and integrate substantially longer than the atmospheric coherence time on faint science targets.

Instrument design drivers: The goals of unique science measurements of exoplanets, YSO's, and AGN, as well as the goal of exploiting the low Antarctic thermal background, led to the combination of baseline length and wavelength coverage. It also led to the 2-color feed forward phasing support in the design, which permits the instrument to fringe track either at H/K or L/M bands while integrating for much longer than the atmospheric coherence time (and thus increasing sensitivity) in the other color. The chromatic "dual star module" (DSM) in the design is required to measure the interferometric co-phasing angle. The DSM gives the instrument the ability to fringe track on two stars simultaneously (one star in H/K and one star in L/M) and thus measure the interferometric co-phasing angle.

Instrument Parameter	Design Driver
H & K bands	maximum resolution and sensitivity
L & M bands	hot Jovian SED measurement
L/M band fiber combiner with photometric outputs	hot Jovian SED measurement, goal is 0.1% V^2 accuracy
chromatic dual star co-phasing L/M from H/K	improved sensitivity to thermal dust in AGN and YSOs; atmospheric co-phasing angle measurement
100 m baseline	YSO disk measurements

Tab. 1. This table captures the major API phase 1 design features together with the science requirement for that feature.

Technology maturity: The API phase 1 design relies extensively on technology from the Keck Interferometer and the Very Large Telescope Interferometer. In both cases, the technology is used for production science in a facility-class instrument. Not only do all of the key techniques have implementation technology that we will inherit from KI or VLTI, but all the techniques have been demonstrated on the sky prior to the KI and VLTI projects; this is true of feed forward co-phasing, high-precision V^2 measurements using single mode fiber combiners, double Fourier mode, and high-performance delay lines. Automated interferometer observing sequences are standard practice on KI, VLTI, PTI, and NOPI. The technology to implement ambient temperature (~ 220 K) delay lines for API phase 1 exists and is well understood. Cryogenic delay lines operating at 77 and ~120 K have been demonstrated[53] at JPL using the same real time control as that used with the KI.

Software: Based on the PTI and KI experience, about half the cost of an active fringe tracking interferometer is software. The API phase 1 and API instruments would be based on the JPL Real Time Control (RTC) package and associated software. This represents an enormous development cost savings of ~5 million USD for the API phase 1 project. Using RTC reduces schedule, cost, and performance risk by using a proven product and thus saving the non-recurrent engineering costs. Also, since RTC is the package that will run the KI indefinitely, relying on RTC reduces the operations maintenance cost for the API phase 1 project. Put simply, using RTC leverages an enormous and proven technology investment.

Hardware: Every single major subsystem in the API phase 1 design has been built, deployed, and regularly operates on the sky as part of a facility-class instrument. In addition to the instrument software, this includes the fringe tracker, angle tracker, beam combination optics, active delay lines, laser metrology, transport optics, auto-alignment system, and motion control. Not only are the designs for all the subsystems in hand, but the parts list, purchase orders, installation plans, and *operational procedures* for these systems exist as well. Because API phase 1 seeks only to duplicate existing technology the cost estimates for this project are excellent. *In this formulation, the API phase 1 instrument concept design is mostly complete.* The outstanding design work for this project is cold operation (winterization) and packaging, which is discussed later.

Expandable Design: This concept for the API phase 1 instrument is designed to be used as the core of API; our design supports direct replacement of the 40 cm siderostats with 2-meter-class telescopes. In addition, the delay line containers will support a third delay line, as required for three telescope operation. The API phase 1 control software, metrology, angle tracking, fringe tracking, and precision fringe measurement techniques would all remain unchanged. Besides the siderostats, only the beam-train mirror diameters would need to be upgraded to support long-wavelength operation. *Thus nearly the entire investment in API phase 1 can be directly applied to API.* This growth path not only saves money, it saves time and reduces risk.

By using the RTC, associated software products, and JPL delayline technology, API phase 1 and API have a clear growth path. High-precision modes such as nulling and differential phase are being developed for the KI. As these modes are deployed, they can be directly deployed on the API phase 1 and API since the control system will be the same as the KI. Using this approach, only sky validated technology would be deployed for API phase 1 and 2. As discussed above, the precision modes would typically be expected to realize greater than order of magnitude performance increases with the atmosphere at Dome C. As new modes are developed and demonstrated at the KI, they could be deployed on the API phase 1 or API for a reduced cost because of the common instrument control architecture between API phase 1 and KI.

Testing: The API phase 1 would be fully assembled and tested on sky prior to deployment to Antarctica. Each subsystem would be validated with functionality and performance tests. The instrument design includes an internal stimulus that can be used (at any time) for system testing and verification. The final system level test would be on-sky operation demonstrating source acquisition, angle tracking, fringe tracking, calibration, and sequencing. The final system-level test would include a deployment and sky demonstration; the objective of this activity is to validate the deployment and operation of the instrument. By ``deployment" we mean that the containers housing the instrument would be picked up by a commercial carrier and moved to a temporary observing location. The instrument would then be assembled in exactly the same configuration we would be using in Antarctica and demonstrated on the sky. Only after successful completion of this exercise would the instrument ship to Antarctica.

Deployment: The API phase 1 instrument design packaging concept is modular and intended for transport. All components of the interferometer will be built into standard shipping containers. The containers will serve both for shipping the instrument components and as enclosures for operation. We require five 40-foot containers and two 20-foot containers. The two 20-foot containers would each contain a siderostant, a beam-compressing telescope, a fast-steering dichroic, acquisition camera, and a chromatic dual star module. Three of the 40-foot containers (connected end-to-end) would contain the long active delay lines. One 40-foot container would house the beam combination optics (both free-space and fiber) as well as the cameras for fringe tracking and angle tracking. The final container would serve as a control room and would contain the majority of the instrument electronics and computers (this same approach is used at the Keck Interferometer to remove heat sources from the beam combination area). A few pieces of electronics are not possible to locate remotely; these would be housed in insulated, ducted boxes to prevent heat from entering the interferometer. To minimize the effect of local turbulence, light would travel in sealed, insulated pipes from the siderostat containers to the delay-line containers. The long delay-line design could accommodate longer ranges of travel by adding additional delay line containers.

Antarctic Operations: The API phase 1 instrument would be designed to be operated with one person during winter, although we expect to have two people for the "winter over" crew. Operating an interferometer with one person (a trained telescope operator) has been routine with PTI for the last three years. The interferometer alignment process would be automated such that it could be preformed by one person operating from within the warm control room; this is currently done with the Keck Interferometer. This approach is desirable both for the operator and for instrument stability. Debugging of problems would be supported by the engineering team, with the operator performing experiments under direction from the engineering team. Observing sequences of source acquisition and observation, sky calibration, and internal calibration, would largely be automated (as it has been at PTI for six years). Once the nighttime temperature has been reached, the instrument alignment is expected to be very stable.

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