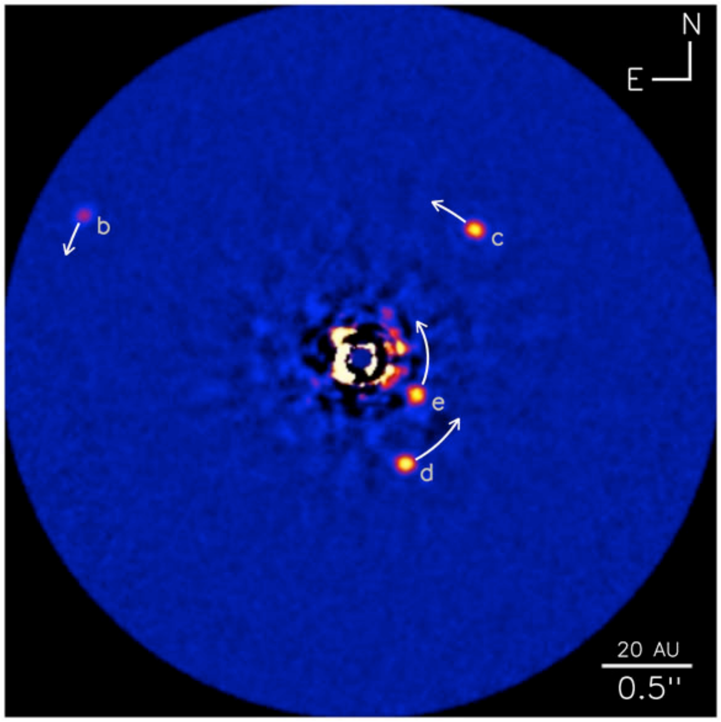
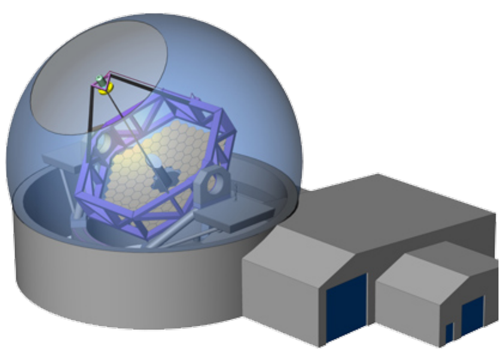
Astronomical Telescope for New York – A Proposal



An image of HR 8799e obtained at the Keck II telescope, refined using NRC's adaptive optics system, showing all four confirmed planets. Arrows illustrate possible planet orbital motions for the next ten years. Credit: NRC-HIA, C. Marois & Keck Observatory

Respectfully Submitted By

Stefi Baum, Tom Sebring,



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Toptica
Trex
Triodetic
Xoptx

Executive Summary

In response to the NYAC call for proposals and in compliance with the requirements established by the NYAC survey, we have developed a concept for a large Astronomical Telescope for New York (ATNY). The proposed ATNY is a 12 meter diameter optical/near-infrared telescope to be operational the latter part of this decade, making it likely the largest such telescope on earth at that time. The large aperture provides greater light collection and higher angular resolution than current facilities. ATNY will enable forefront science, creating a bridge from the 8-10 meter class telescopes of today such as Keck and Gemini to the extremely large telescopes of the future, such as the Thirty Meter Telescope (TMT). It will provide a first-rate capability to rapidly follow-up on important discoveries to be made by the United State's next generation of major observatories which will come on line along with the ATNY, including the Atacama Millimeter Array (ALMA, NSF's largest-ever investment in astrophysics), the Large Synoptic Survey Telescope (the Astronomy and Astrophysics Decadal Survey's number one priority), and the James Webb Space Telescope (JWST, NASA's next signature astrophysics mission). We have selected two first-light ATNY instruments to maximize scientific synergy, consisting of (1) a high spectral resolution (R~70,000 and ~15,000) near-IR spectrograph, and (2) an IFU in the near-IR with an imaging mode and moderate spectral resolution (R~1000-5000), with the next-generation instruments determined via a call for proposals to NY institutions. We expect to enable forefront Key Projects on the following topics to engage the broad range of NY State Astronomers: Searching for Habitable Exoplanets; Circumstellar Disks; Stellar Magnetic Fields, Eruptions, and Mergers; Stellar Archaeology; Supermassive Black Holes and Their Host Galaxies; Galaxy Formation; and Dark Matter.

Our proposal is for a full sky, alt/az telescope of ~126 m^2 collecting area. We propose that two major facility instruments be built in parallel and included in the proposed cost. First light is anticipated approximately five years from build start. The total cost of the telescope, inclusive of 25% contingency and two instruments is estimated at $105M, including ~$30M set aside for the two first light instruments. We estimate that operating costs will run ~$10 million/year. Considerable advances in technology, experience gleaned from predecessor telescope projects, and a willingness to make key science-expense driven tradeoffs in design decisions, provides the confidence that ATNY can be built efficiently at this cost and on this schedule, provided sufficient up front capitalization is realized. We have had encouraging discussions with NOAO and AURA regarding locating ATNY at Cerro Tololo Interamerican Observatory (CTIO) as well as possible operations cost sharing arrangements in return for US community access to ATNY proportional to NSF/AURA/NOAO investment. In this scenario, the full capital cost will be raised by the participating NY universities, in partnership, as needed, with other universities and countries. We envision that at a minimum 50% (and ideally 100%) of the capital cost would be raised within NY by combining private foundation and individual contributions, contributions by participating NY institutions, and funding by the State.

The ATNY is structured to meet the large scale objectives of the Astronomical Society of New York:. Specifically, ATNY will provide major-facility access to the entire NY astronomical community, so as to enable front-line research, excite and train the next generation of students in the STEM disciplines, and stimulate public interest in science. The scale of the telescope, coupled with its advanced first light instrumentation, will ensure front-line research and capabilities beyond that of any existing telescope. Perhaps more significantly, operation of the telescope over the initial 20-year period will substantially advance the role of all participating NY organizations in astronomical science and instrumentation. Our project intends to engage the full range of NY State society, from industry, to our K-12 school system, to our institutions of higher learning, to our museums, to our citizens and their children. This engagement will encompass the complete end-to-end mission of ATNY, from design, engineering, construction, operation, and instrument development, to the scientific return from the world's largest optical/near-IR telescope. Our proposal team therefore includes a broad representative constituency, including PhD granting universities; liberal arts colleges; public and private universities; the K-12 school system; the museum community; and private NY State industry. We aim to assure that the NY State Telescope project will provide financial benefit to NY State industry, enhance the competitiveness of the state's universities, inspire a generation of children to pursue careers in STEM, and capture the spirit and understanding of the NY state public for future science and technology investment.

1.0 SCIENCE CASE

The proposed ATNY is a 12 meter diameter optical/near-infrared telescope to be operational the latter part of this decade, making it likely the largest such telescope on earth at that time. The large aperture provides greater light collection and higher angular resolution than current facilities. ATNY will enable forefront science, creating a bridge from the 8-10 meter class telescopes of today such as Keck and Gemini to the extremely large telescopes of the future, such as the Thirty Meter Telescope (TMT). It will provide a first rate capability to rapidly follow-up on important discoveries to be made by the United State's next generation of major observatories which will come on line along with the ATNY, including the Atacama Millimeter Array (ALMA, NSF's largest ever investment in astrophysics), the Large Synoptic Survey Telescope (the Astronomy and Astrophysics Decadal Survey's number one priority), and the James Webb Space Telescope (JWST, NASA's next signature astrophysics mission). We anticipate that the two first-light ATNY instruments will consist of (1) a high spectral resolution (R~70,000 and ~15,000) near-infrared (near-IR) spectrograph, and (2) an IFU in the near-IR with an imaging mode and moderate spectral resolution (R~1000-5000), with the next-generation instruments determined via a call for proposals to NY institutions. A list of selected science topics is given in Table 1. In the text, we set the stage for science with ATNY in 2017, describing how it will address the forefront astrophysical questions of our time and presenting examples of forefront Key Projects to engage the broad range of NY State Astronomers.

Table 1. An Illustrative Listing of Science Topics Addressable by the ATNY

Science Topic	Observations Required
A full census of nearby planetary systems down to one earth mass.	Astrometry and high precision spectroscopy (R~50,000) in the near-IR
Direct spectroscopy and imaging of hot/young super-Jupiters	Extreme AO with near-IR imaging and high resolution (R~30,000) spectroscopy
Stellar disks, magnetic fields, accretion, and jets	High resolution (R~50,000) spectroscopy, high spatial resolution near-IR imaging with moderate spectral resolution, polarimetric capability
Stellar eruptions and binary interactions	High resolution (R~50,000) spectroscopy, and high spatial resolution imaging in the near-IR with moderate spectral resolution
Stellar archaeology: constraints on Pop III stars and star formation in the early universe	High resolution (R~50,000) optical spectroscopy
Supermassive black holes and their host galaxies	Optical and near-IR Integral Field Unit (IFU) moderate resolution (R~5000) spectroscopy
Spectroscopic follow-up of LSST-discovered Active Galactic Nuclei (AGN)	Multi-object near-IR spectroscopy at intermediate (R~5000) resolution
Galaxy Formation and the Inter Galactic Medium	Imaging spectroscopy with near-IR IFU (R~3000)
Dark Matter: Power spectrum of Lyα fluctuations	Optical high resolution (R~50,000) spectroscopy
Dark Energy: SNe Ia and host galaxies at $z > 1$	Imaging spectroscopy with near-IR IFU (R~3000)

1.1 Exoplanetary and Stellar Science with ATNY

1.1.1 Key Project: Searching for Habitable Exoplanets

Exoplanetary astronomy is undergoing exponential growth, with the number of known extrasolar planets ~tripling every five years since 1995. By 2017, between 1500 and 4000 exoplanets larger than Earth will have been identified via radial velocity, transit, microlensing, and direct imaging surveys. The GAIA astrometric mission will have detected up to 8000 candidate and bona-fide exoplanets, including all extrasolar Jupiters in 1.5–9 year orbital periods within 50 pc of the Sun [5]. GAIA will dominate exoplanet detections by 2017. Its astrometric approach to planet discovery will offer greatest sensitivity to giant planets in moderately wide, ~0.3–3 AU orbits (Fig. 1), although the planet census within each newly-found system will be very incomplete, with only the one or two near-Jupiter analogs discovered. The remaining (lower-mass and/or wider-orbit) planets can nevertheless be recovered through longer-term monitoring. A recent investigation of precision astrometry with AO-assisted large telescopes [4] indicates that a 15-year follow-on astrometric campaign with a 12-meter-class telescope like ATNY will detect all $>1\ M_{Neptune}$ planets ($1\ M_{Jupiter} = 18\ M_{Neptune} = 318\ M_{Earth}$) out to 10 AU from solar-mass stars in the GAIA sample (Fig. 1). Separately, precision radial velocity measurements at cm/s precision [12] will complement the GAIA and ground-based astrometry with sensitivity to lower-mass and closer-in planets, as small as 1 M_{Earth} at <1–5 AU. Such discoveries will have profound implications for the search for habitable exoplanets. Follow-on observations will refine the masses and orbits of the GAIA-discovered planets, most of which will not have been observed over a full orbital period. With the majority of planet-host stars expected to be M dwarfs, it will be crucial to have infrared radial velocity capability [2].

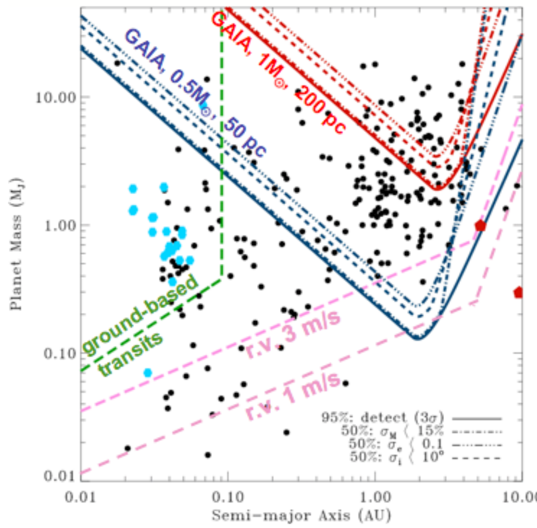


Figure 1. GAIA discovery space for planets of given mass and orbital radius compared to the present-day sensitivity of other indirect detection methods, namely Doppler spectroscopy and ground-based transit photometry. Red and blue lines of different styles represent the minimum astrometric signature for 95% probability of a 3σ detection (solid line), the minimum astrometric signature needed to determine at least 50% of the time the mass of a planet with better than 15% accuracy (dash-dotted line), the eccentricity with uncertainties <0.1 (short-dashed line), and the inclination angle with uncertainties <10° (long-dashed line), respectively. Red curves assume a 1 $M_\odot$ G dwarf primary at 200 pc, while the blue curves are for a 0.5 $M_\odot$ M dwarf at 25 pc. The radial velocity curves (pink lines) are for detection at the $3\sigma_{RV}$ level, assuming $M_* = 1$ $M_\odot$, and 10-year survey duration. For transit photometry (green curve), we adopt $\sigma_{RV} = 5$ mmag, S/N = 9, $M_* = 1$ $M_\odot$, $R_* = 1$ $R_\odot$, uniform and dense (>1000 data points) sampling. Black dots indicate the inventory of exoplanets as of September 2007. Transiting systems are shown as light-blue filled pentagons. Jupiter and Saturn are also shown as red pentagons. (Adopted with minor additions from Fig. 22 in [5].

1.1.2 Key Project: Circumstellar Disks and Stellar Magnetic Fields, Eruptions, and Mergers

By 2017, Spitzer and WISE will have identified essentially all disk-encircled pre-main sequence (pre-MS) and MS stars within ~1 kpc of Earth, while ALMA will establish the structure and gas vs. dust content of a significant number of these disks. Observations that can establish the physical conditions within pre-MS circumstellar disks are essential to understand Jovian planet formation and the origins of comets, Kuiper Belt objects, and planetary atmospheres. High-resolution, near-IR spectroscopy with ATNY will provide a primary means to detect and measure lines of ionized and neutral atomic species to diagnose disk physical conditions and irradiation [14]. The addition of polarimetric capability would enable studies of stellar magnetic field configurations and pre-MS magnetospheric accretion [7]. Furthermore, ATNY will establish the nature of the stellar eruptions that should be discovered nightly by LSST. High-resolution (R~20000) near-IR spectroscopy of pre-main sequence eruptions will track the post-outburst evolution of the star-disk interaction region (e.g., [9]). In stellar merger candidates, such observations trace mass ejecta and infall processes [15]. Adaptive Optics (AO) imaging of light echoes resulting from such eruptive events will establish event distances and luminosities [1], [3].

1.2. Science with ATNY at Low to Intermediate Redshifts

At the time of ATNY First Light (anticipated in 2017), JWST and ALMA will be providing high resolution views into the central regions of galaxies and probing the properties of cold gas and dust. LSST will discover new AGN and exotic objects which ATNY will study in detail. We detail two possible major projects below, one exploring stellar archaelogy and one supermassive black holes.

1.2.1 Key Project: Stellar Archaeology

The chemical composition of long-lived, low mass, extremely metal-poor stars reflects the composition of the interstellar medium (ISM) during the early Universe [8]. Thus, studies of the chemical composition of these stars probe the nature of the earlier Pop III stars including their masses, yields, and nucleosynthesic processes as well as formation processes of the Galactic halo. Key questions are: Are the yields of the first SNe different from those at the current epoch? Is there evidence for the predicted pair-instability SNe? What drove early star formation? How did chemical evolution occur? What do stellar chemistry and halo kinematics tell us about the halo formation process? Did the first stars form in dwarf galaxies that then merged to form the old halo? High resolution (R~50,000) optical spectroscopy with ATNY will permit detailed abundance analyzes of faint metal poor stars. A Key Project will observe 100 metal poor stars in the Galactic halo and nearby dwarf galaxies (one night per object).

1.2.2 Key Project: Supermassive Black Holes and Their Host Galaxies

Among the most important advances in astrophysics in recent years has been the discovery that most, if not all, galaxies contain supermassive black holes (ranging from a million to several billion solar masses) and, moreover, that the black hole mass is closely related to the stellar velocity dispersion (and/or mass) of the central bulge of the host galaxy [10]. The origin of this relationship is thought to be the gravitational binding energy that is released as the SMBH grows: ionizing radiation, powerful winds and relativistic jets regulate the growth of the host galaxy by heating and driving out the cold interstellar gas from which new stars are formed [6]. In this context, active galactic nuclei (AGN) represent the growth phase of the SMBH, when it is accreting gas at a high rate and injecting energy "feedback" into the host galaxy. However, fundamental details of this picture are not determined. For example, mechanisms by which AGN are fueled remain unclear (i.e., how is interstellar gas transported from kpc to < pc scales, to be accreted by the SMBH), as do the detailed processes by which AGN feedback couples to the host ISM. A Key Project will make key contributions to understanding the complex interplay between the SMBHs and their hosts by mapping the physical conditions and velocity fields of ionized and molecular gas flows within the central few kpc of 100 galaxies covering a range of redshift and luminosity.

1.3 ATNY Science at Intermediate to High Redshift

JWST and ALMA should find UV-faint IR-bright star forming galaxies - complementary to the Lyman Break Galaxies that inform much of current understanding of galaxy formation. LSST will discover new supernovae which ATNY will study in detail, providing constraints on Dark Energy.

1.3.1 Key Project: Galaxy Formation

Observations have sketched the global star formation history of the universe [13]. Galaxy formation was already well underway by redshift (z) z ~ 6 and rose steadily to a peak near z~2 after which the star formation rate fell dramatically to the current epoch. The reasons for the rise and fall are not understood. Many questions remain. What triggers the epoch of galaxy formation and what turns it off? What is the relationship between the distribution of dark matter and that of gas and stars? Does the process of star formation at high z differ from that at the current epoch? How do feedback from star formation, black hole accretion, radio activity, and supernovae impact galaxy formation? JWST and ALMA will provide revolutionary imaging of the epoch of galaxy formation. An ATNY Key Project will provide critical accompanying measurements of the distribution and metallicity in and around galaxies, star formation rates, galaxy morphology, stellar populations, and dynamics, particularly at intermediate redshifts.

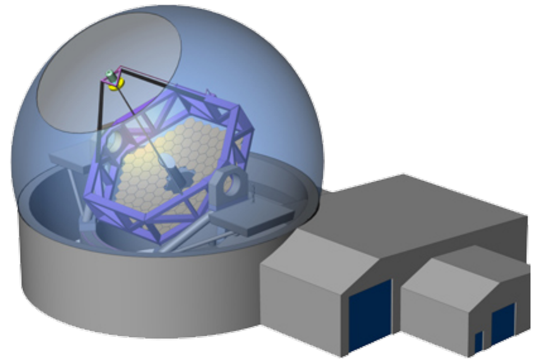
1.3.2 Key Project: Dark Matter

The Lyman alpha forest absorption lines are produced in ~100 kpc scale photoionized gas structures at $\sim 10^4$ K and with densities close to that of the universal average. The gas density is closely related to the dark matter density on large scales [11]. The power spectrum of fluctuations in the Lyα forest flux can be measured using ground based spectroscopy between redshifts of 2 to 6 over size scales (along the line of sight) which tend to be smaller than those measured by other tracers of structure (e.g., Cosmic Microwave Background anisotropies). The combination of these small- and large-scale structure tracers is sensitive to the shape of the primordial spectrum of fluctuations, which is one of the few observationally accessible probes of the early universe. These observations are therefore directly testing the models of the early universe such as inflation. A Key Project will obtain high spectral resolution spectra of 200 quasars that will sample small spatial scales not present in the SDSS Lyman-alpha catalog [11].

References

[1] Afsar, M., & Bond, H. 2007, AJ, 133, 387
[2] Bean, J., et al. 2010, ApJ, 713, 410,
[3] Briceno, C., et al. 2004, ApJ, 606, L123
[4] Cameron, P, Britton, M., & Kulkarni, S. 2009, ApJ, 137, 83
[5] Casertano, S. et al. 2008, A&A, 482, 729
[6] Di Matteo et al. , 2005. Nature, 433, 604
[7] Donati, J.-F., & Landstreet, J.D. 2009, ARAA, 47, 333
[8] Frebel, A., 2010, AN, 331, 474
[9] Greene, T.P., Aspin, C., & Reipurth, B. 2008, AJ, 135, 1421
[10] Gultekin, K., et al., 2009. ApJ, 698, 198
[11] McDonald, P. et al., 2005, ApJ, 635
[12] Osterman, S., et al., 2010, arXiv:1003.0136
[13] Reddy, N., et al., 2008, ApJS, 175, 48
[14] Salyk, C. et al. 2007, ApJ, 655, L105
[15] Tylenda, R., Kaminski, T., & Schmidt, M. 2009, A&A, 503, 899

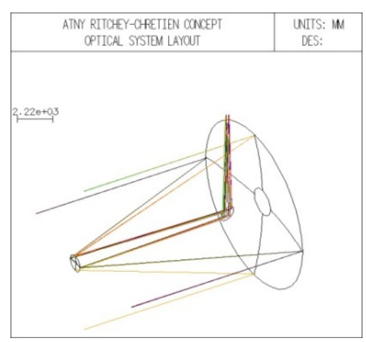
2.0 TECHNICAL CONCEPT



2.1 Overview In response to the ASNY call for proposals and in compliance with the requirements established by the ASNY survey, we have developed a concept for a large astronomical telescope. ATNY is about 1.5 X larger in collecting area than the Keck telescope and takes advantage of many of the technologies developed for Keck and other recent projects. The development of the Keck telescope pioneered a new cost regime based on a segmented primary mirror. Since Keck, only three additional segmented mirror telescopes have been developed, Hobby Eberly Telescope (HET) and the South African Large Telescope (SALT), both spherical primary designs with limited sky coverage, and the Gran Telescopio de Canaris. More recently, the TMT and EELT Projects have been investing in cost effective methods for mirror segment fabrication and other relevant technologies. Other observatories have developed adaptive secondary mirrors, and recent developments in approaches to telescope mount and dome design have offered efficient and low cost approaches to these traditionally expensive components. Our proposed design employs many of these approaches to yield a design that although significantly larger, is substantially lighter, more compact, and less expensive than Keck.

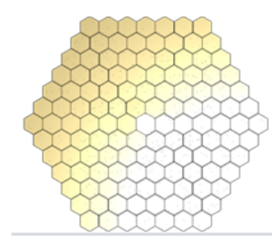
Our proposal is for a full sky, alt/az telescope of ~126 m^2 collecting area. We propose that two major facility instruments be built in parallel and included in the proposed cost. The development of funding is anticipated to require several years and five years will be required for construction, hence first light is anticipated approximately seven years from the date of this proposal. The total cost of the telescope, including 25% contingency, and two first light instruments, is estimated at $105M with $30M set aside for the two first light instruments. Possible sites for the telescope include Cerro Tololo or Cerro Pachón in collaboration with AURA/NOAO.

2.2 Optical Design



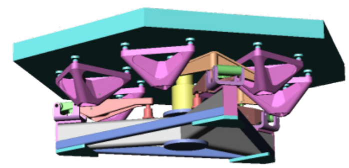
Optical design was performed by Robert Junquist (Univ. of Rochester). The optical layout of is a Ritchey-Chretien design similar to the Keck Telescope but scaled to 126 m^2 collecting area, 1.5x that of Keck. The telescope focal ratio is f/16, the same as Keck. An f/1.25 Primary Mirror (PM) (Keck is f/1.75 and TMT is f/1.0) and diameter of ~12 meters dictates that the focal length of the PM be ~15.0 meters. The conic constant is -1.0014 making the PM almost a parabola. The convex Secondary Mirror (SM) has a radius of curvature equal to ~-3.3 meters to yield a back focal distance long enough to place the focus outside the telescope elevation bearings about 20 meters from the secondary mirror. The spacing between the PM and SM is 13.6 meters. To provide 10 arcminutes diameter Field of View (FOV), the Clear Aperture diameter of the SM is 1.26 meters. This design can be modified to adjust FOV and other parameters, but is a well-proven approach used in many modern astronomical telescopes with good image quality performance.

2.3 Primary Mirror Design:

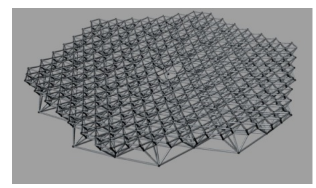


2.3.1 Segments: The primary mirror has 126 hexagonal segments currently sized at 1.1 m minor diameter. Note that a relatively small change from 1.1 to 1.2 m minor diameter increases the telescope size from 1.5 times that of Keck to about 2 times larger. Segments are 50 mm thick. In contrast the Keck segments were 75 mm thick. Total weight of glass in Keck was about 5.7 tons and ATNY's segments total 6.0 tons. We propose segments of Corning's Ultra Low Expansion (ULE) material, and Corning has provided a modified production process that yields historically low cost for this near zero CTE material. Segment fabrication is proposed to be via the process currently under development for TMT. This process uses a "warping fixture" to deform the segments prior to optical fabrication such that fabrication to a sphere yields the appropriate aspheric shape when the segments are released. ITT Corporation is contracted to develop this process for TMT, and their proprietary ion figuring process is used for final figuring as was done for Keck. Concepts for the segment fabrication process and inputs to cost estimation have been provided by ITT.

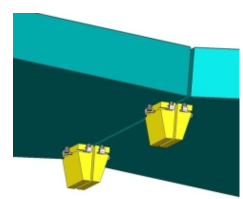
2.3.2 Segment Support & Actuation: Segments are mounted using multi point support whiffle tree mounts similar in concept to Keck's and TMT's, but engineered for low cost. The segment size for ATNY permits use of only 18 support points whereas the 1.4 m TMT segments require 24 and the 1.8 m Keck segments required 36. The ATNY mounts use die casting of components that makes them light and inexpensive to replicate. The use of wire electrical discharge machining (EDM) flexures is also anticipated to keep costs low. The segment mounts incorporate levers to achieve tip/tilt/piston motion for segment phasing. The levers provide 10:1 reduction allowing use of commercially manufactured off-the-shelf actuators for segment positioning. PI commercially manufactures actuators meeting the requirements and provided a cost estimate for this system for the proposal, including all wiring, electronics, and computer control of the suite of actuators.



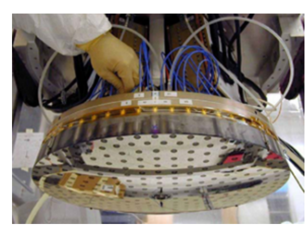
2.3.3 Primary Mirror Truss: The segment mounts are supported by a primary mirror truss manufactured by Mero Structures of Wurzburg, Germany. This approach was used for the HET primary mirror truss and was far less expensive than the welded truss used for Keck. The low cost is a function of the automated manufacturing processes developed at Mero and the use of bolted connections make the shipping and assembly of the truss simple. The truss is supported from its corners from the elevation ring of the telescope mount. Design of the truss for this study has been performed by Stutzki Engineering of Milwaukee, WI. Christian Stutzki, the principal, was formerly Director of Engineering for MERO in Germany.



2.3.4 Segment Edge Sensors: Control of segments is to be enabled via edge sensors mounted at the interfaces between segments. On a typical segment, there are 12 edge sensors, two on each edge. Sensors from Fogale Nanotech of Nimes, France are baselined and Fogale provided the cost estimate for this system. The HET with 91 segments achieves good mirror control based on a similar suite of sensors and the increase from 91 to 120 segments will not cause significant sensor noise problems. The Fogale sensors measure segment gap and dihedral angle in addition to relative piston, and hence are more capable than those used for HET. The system cost provided includes all necessary wiring, electronics, and computer hardware and software for interface to the TCS.



2.4 Adaptive Secondary Mirror Design:
The ATNY is to have single laser guide star adaptive optics at first light. In order to minimize the number of reflections and warm mirrors before the instruments, ATNY will implement an adaptive secondary mirror. This technology is fairly mature, with such secondary mirrors implemented on the Multi Mirror Telescope (MMT), Magellan telescopes, and the Large Binocular Telescope (LBT). Advanced designs are being developed for the European Extremely Large Telescope (EELT). The ATNY design requires an ~ 1.3 m Outside Diameter (OD) (1.26m Clear Aperture (CA)) secondary, only slightly larger than those manufactured for the LBT and planned for the Giant Magellan Telescope (GMT). This approach uses Corning ULE substrates with a thick substrate as a metrology body behind a thin meniscus facesheet actuated by electro-magnetic actuators. Evaporated metal coatings on the back of the thin meniscus and the front of the metrology body allow closed loop shape control using these as capacitance sensors. Corning's abrasive laden waterjet process simplifies the fabrication of the metrology body and ITT has substantial experience in manufacture of thin meniscus facesheets. The secondary is supported by a hexapod, most likely employing COTS components from a commercial PI hexapod. The overall support of the secondary mirror is via three composite (CFRP) spars forming a tripod. The legs are about 16-18 meters long, a length that is consistent with manufacturing of composite sailboat masts. There are multiple facilities capable of mechanized fabrication of these

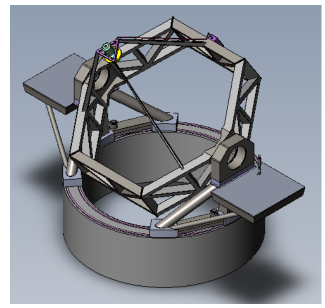


structures and autoclaves for pressure enhanced curing. The legs may include viscous damping layers to minimize resonance.

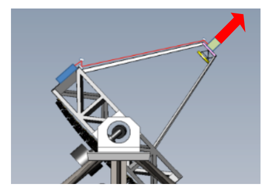
2.5 Tertiary Mirror Design:

ATNY has a tertiary mirror on a rotating table supported by the primary mirror truss, which is reinforced to support this additional load. The mirror is a plano lightweight ULE substrate, elliptical in shape, ~1.1 x 0.8 m. If desired, tip/tilt could be incorporated at this mirror to achieve a "woofer/tweeter" Advanced Optics (AO) scheme. The turntable allows the image to be directed quickly to either Nasmyth focus.

2.6 Telescope Mount Design:



The telescope mount follows recent design practices developed in studies of the EELT and incorporated in concepts for the Advanced Technology Solar Telescope (ATST). Traditional telescope mounts have substantial structure connecting the two elevation towers. Studies by MT Mechatronics in Germany for the EELT have shown this structure is unnecessary, and superior structural dynamics can be achieved by minimizing or eliminating this structure enabling the elevation towers to be shortened substantially. A second innovation is the use of curved linear guides (such as provided by THK Co. Ltd) in place of the hydrostatic bearings typically used on large telescopes. The large machine tool industry made this change about 10 years ago and nearly all large bridge milling machines and similar tools are made using these recirculating roller guide systems. A third innovation is the use of direct drive for azimuth employing large direct current (DC) servomotors with no gearboxes and only helical gear drives. This simplifies the drive system and reduces hysteresis and backlash. Elevation bearings are comprised of two angular contact roller bearings on each side and frameless DC Servo motors. This system is well proven and provides adequate beam pass through clear diameters. Encoding of both axes is anticipated to be via tape encoders (e.g. Heidenhain) as is common. Computer Aided Design (CAD) estimates the rotating weight of the mount at ~142 tons. Adding 12 tons for mirrors, truss, and M2/M3, the total rotating mass is around 155 tons as compared to 270 tons for Keck (M2 is the secondary, M3 the tertiary mirror). The concept is designed to be modular to allow trial assembly at the manufacturer's facility, disassembly and shipping to the site for final assembly.

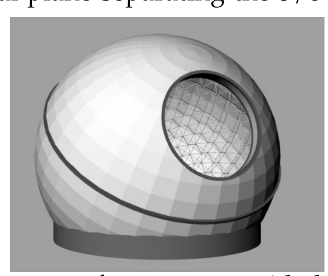


2.7 Adaptive Optics:

On the recommendation of NOAO, ATNY will incorporate laser guidestar AO at first light. The concept provides for mounting of a laser on the elevation ring and use of turning mirrors to propagate the laser beam up the back side of one of the M2 support struts. A launch telescope behind M2 provides a coaxial location of the guidestar minimizing elongation problems. Toptica in Victor, NY is an industrial partner in ATNY, and is under contract to the European Southern Observatory (ESO) and Keck to develop robust 30 w lasers for AO. The use of a wavefront sensing guider at each Nasmyth location is anticipated, though no specific designs have been proposed in this area. Development of ATNY will keep multi-conjugate AO in mind and ensure that the telescope is compatible with this emerging technology.

2.8 Dome Design:

The ATNY dome concept employs a Calotte design as currently being studied by TMT and the Cornell Caltech Atacama Telescope (CCAT). This approach uses two rotation planes, one a more or less conventional azimuth rotation, and the other being a rotation along a diagonal plane separating the 5/8 sphere dome into roughly two halves. This provides a dome system that has higher natural frequencies, weighs much less, is completely balanced, uses substantially less power, and implies uniform loads on the bearing elements than any existing dome approach. The structure is a factory manufactured geodesic design. Our dome concept (developed by Stutzki Engineering) uses structural design elements employed by Temcor and Conservatek for architectural and technical applications. An internal shutter on a third rotating stage closes the dome. The dome is 27 m inside diameter (ID) as compared to the Keck that is 37 meters. The Keck dome weighs 630 tons, and initial estimates of the ATNY dome are less than 100 tons. Multiple manufacturers provided estimates of about $1 M for the dome structures.



2.9 Facility Design:

Only a very rough initial footprint for the facility for ATNY has been developed. It is anticipated that the building would be a very simple steel framed and clad building similar to those employed at CTIO by Southern Astrophysical Research Telescope (SOAR) and Gemini. This is a construction method very familiar to the Chilean construction industry and very inexpensive to build. A well-insulated building downwind of the telescope will incorporate a control room, instrument workspace, and on separate isolated foundations, any vibration causing equipment. A cost estimate of 2x the actual cost of the SOAR telescope facility on Cerro Pachon scaled at 3%/year is used.

2.10 Schedule for Development:

Development of funding is anticipated to take several years with design work continuing in parallel. Facility development will begin in year three and take 1 year. Manufacturing and integration of telescope subsystems will require 3 years, and First Light will occur 7 years after the start of the Project. If funding is available more rapidly, the telescope project could be completed as much as two years sooner.

2.11 Cost Estimate:

The following initial cost estimate for the telescope is provided, including 25% contingency. An additional $30M is estimated for two First Light Instruments for a total Project Cost of $105M. Considerable advances in technology, experience gleaned from predecessor telescope projects, and a willingness to make key science-expense driven tradeoffs in design decisions, provides the confidence that ATNY can be built efficiently at this cost and on this schedule, provided sufficient up front capitalization is realized.

COST ELEMENT		AMOUNT		BASIS	SOURCE
Primary Mirror					
	ULE Segments	$4,375,000		$35k/segment * 125 segments	Corning ROM Estimate
	Optical Fab & Test	$9,375,000		$75,000/segment*125 segments	ITT based on TMT Development
	Segment Mounts	$812,500		$6500/mount*125 segments	ROM Estimate
	Actuator System	$1,620,000		$4500/actuator * 360 actuators	PI USA Quote
	Edge Sensor System	$945,000		$750/sensor*1260 sensors	Fogale Nanotech Quotation
	PM Truss	$1,000,000		Quote for 25 m Truss	Mero letter Quote for 25 m truss
	Total PM		**$18,127,500**		
Secondary Mirror & AO					
	ULE Adaptive M2 Substrates	$490,558		Metrology Body and Facesheet	Corning Quote
	Development of Adaptive M2	$3,500,000			WAG
	M2 Hexapod	$450,000		Uses components from PI	
	M2 Support System	$1,500,000		CFRP Wound on Mandrels	WAG
	Laser for AGS				
	Total SM		**$5,940,558**		
Tertiary Mirror					
	ULE Substrate	$375,000			
	Optical Fab	$400,000			
	Rotator	$875,000			
	Total M3		**$1,650,000**		
Telescope Mount			**$11,250,000**	150 tons @ $75k/ton	Historical Cost * Est Weight
Dome					
	Dome Structures	$1,000,000		Estimate for Structures for CCAT	Triodetic
	Dome Mechanisms	$3,000,000		Estimate Based on Concept	WAG
	Total Dome		**$4,000,000**		
Facility			**$4,500,000**	SOAR Actuals Scaled at 1.03/yr	Historical Cost
Software & Controls			**$2,010,000**	SOAR Actuals Scaled at 1.03/yr	Historical Cost
Integration & Assembly			**$2,680,000**	2x SOAR Scaled at 1.03/year	
Project Labor & Management			**$10,000,000**	2.5x SOAR Labor	
Contingency			**$15,000,000**		
	TOTAL COST		**$75,158,058**		

3.0 RESPONSIVENESS OF PROPOSED CONCEPT

The ATNY is structured to meet the large scale objectives of the Astronomical Society of New York: provide access to the entire NY astronomical community, enable front-line research, excite and train the next generation of students in the Science, Technology, Engineering and Mathematics (STEM) disciplines, and stimulate public interest in science. The scale of the telescope, coupled with advanced first light instrumentation, ensure front-line research and capabilities beyond that of any existing telescope. Perhaps more significant, operation of the telescope over the initial 20 year period will substantially advance the role of all participating NY organizations in astronomical science and instrumentation. The development of the world's largest astronomical telescope by New York institutions will garner significant publicity, enhance the profile of the participants, increase the role of NY State in astrophysics, and spawn substantial growth of faculty, students, and research funding.

The results of the ASNY survey indicated a desire for a general purpose, visible/IR wavelength telescope. The respondents considered undergraduate student training, PhD research/thesis projects, and faculty research all to be important outcomes of a NY State telescope, with PhD research being the mostly highly ranked. Targeted observations were ranked far more important than survey activities. Spectroscopy and imaging predominate the desired usage guiding how the telescope design has been optimized. ATNY consortium members have also indicated strong desire to build instruments, collaborate in scientific research, and for the telescope to be unique and significant as opposed to "another" small or mid-sized telescope.

The proposed ATNY is a multi-purpose, visible/IR telescope comparable in FOV and overall f/ratio to the Keck telescope. It can support multiple hot instruments that can be large scale facility instruments or multiple, smaller, PI instruments. Development of large instruments (e.g. first light instruments) is envisioned to be done by groups of the participating institutions with the possibility of technical and programmatic support from the National Optical Astronomy Observatories (NOAO). NOAO has built numerous leading edge instruments providing invaluable experience. Collaboration with the participating NY institutions will support training of a new generation of instrumentalists in NY, fund laboratories for instrument development, and generate experience in design and execution of such programs. These capabilities will, in the long run, enable NY institutions to compete more successfully for ational funding for instrument development; further enhanced by the ability to field these instruments on the largest telescope in the world.

NY institutional participation in the project will be encouraged across the full spectrum of engineering, design, analysis, manufacturing, and instrumentation activities. Engineering faculty and students will be offered the opportunity to participate in development, and contractors providing major system elements will offer related co-op jobs and opportunities for embedded faculty and students in engineering development teams. Students participating will have experience valuable to NY contractors enhancing their career prospects and helping to retain a technology-savvy workforce for the state's industry.

As the founding consortium, New York institutions will play the predominant role in steering the development and future of the ATNY. This is fundamentally different and preferable to NYAC becoming a minor partner in an established organizational hierarchy. Over time, New York institutions will assume a higher profile role in the world of astronomical research, increasing the number and quality of students and faculty, garnering more federal research funding, and expanding the NY workforce with qualified students with top-ranked education and experience in optics, imaging science, engineering, physics, astronomy, and mathematics. These are core issues for the economic development of New York State.

NY State institutions of higher learning span a broad range; from a major state university system that encompasses community colleges, minority-serving institutions, 4-year colleges, and R1 PhD granting institutions, to an unusually rich set of high-quality small liberal arts colleges, to a wealth of high quality private universities, including two Ivy League universities. The ATNY needs to be built and operated in a way that serves the full range of professors and students at these institutions and we have developed an observing plan that takes these needs into account. Fortunately, remote observing capabilities now allow

NY State to construct and operate a state of the art telescope at a high dry site outside the USA, and still allow routine seamless access to the wider NY state community of scientists and educators.

We envision that all time on ATNY will be competitively allocated through a peer review process; this ensures that ATNY science will be world class. We envision a distribution of observing time across targets of opportunity (e.g., in response to LSST discoveries), traditional observing proposals, and Key Projects. Key Projects support large programs that address significant issues with large data sets. To ensure that faculty at non-PhD granting institutions engage fully in ATNY science and observing, despite their typically greatly reduced time for scientific research, we will require that at least 1/3 of the Co-Is on Key Projects be from non-PhD granting institutions. Further, we will adopt the ALFALFA (The Arecibo Legacy Fast ALFA Survey -http://egg.astro.cornell.edu/index.php/) model of engagement of students and their faculty. This will ensure students at 2-year and 4-year colleges get the full benefit of the ATNY. 27% of students in NY State are enrolled in 2 yr colleges; 57% of the total are enrolled in public colleges (NY State Education Dept). Additionally, we will encourage small student-driven instrument development projects as collaborations between astrophysics and engineering at member institutions. For example, an RIT graduate student on the proposal team has put forth a plausible design for an inexpensive high time resolution photometer constructed of off the shelf components (30 ns rms, 10ns resolution, traceable to UT, using small avalanche photodiode arrays and fast Field Programmable Gate Array (FPGA) gated logic). The ATNY Project, then, will provide a training ground for technically motivated students at all NY State educational institutions to participate in hands-on projects that will increase ultimately NYS competitiveness.

As important as engaging faculty and students from NY State's institutions of higher learning in front line research are our missions in engaging K-12 teachers, motivating and informing K-12 students through in-class and out-of-class opportunities, and exciting the families of NY state residents. Via strong collaborations with K-12 teachers, Schools of Education at NY State institutions of higher learning, and the unusually strong network of science and technology museums in NY State we envision an active program to embed the ATNY project in all aspects of education. The Rochester Museum and Science Center is a project collaborator and has provided a letter of engagement for the ATNY education and outreach activities (see www.cis.rit.edu/ATNY). NY State has an active Space Grant, administered through Cornell, that synergistically supports K-20 education and outreach throughout the State. Example projects with which we already have considerable successful experience include what we have termed a "stepping stones to research" program that includes; (1) K-12 teacher summer research opportunities, (2) K-12 teacher professional development opportunities, (3) paid high school student university research internships, (3) family science programs, and (4) museum exhibit development. We will collaborate with NY State educators and museums on development and robust evaluation of science and engineering curricula and extra-curricular modules, activities, and exhibits that encompass all aspects of the ATNY project and mission, building NY State's capacity to build a strong STEM workforce through the next generation.

Thus, our project intends to engage the full range of NY State society, from industry, to our K-12 school system, to our institutions of higher learning, to our museums, to our citizens and their children, encompassing the complete end-to-end mission of ATNY, from design, engineering, construction, operation, instrument development, and scientific return from the world's largest optical/near-IR telescope. Our proposal team therefore includes a broad representative constituency, including PhD granting universities, liberal arts colleges, public and private universities; the K-12 school system; the museum community; and private NY State industry. We aim to assure that the NY State Telescope project will provide financial benefit to NY State industry, enhance the state's universities' competitiveness, inspire a generation of children to pursue careers in STEM, and capture the spirit and understanding of the NY state public for science and technology investment.

4.0 FUNDING MODEL AND PARTNERSHIPS

The ATNY construction, including 25% contingency and two first-light instruments is projected to cost $105M. Operating costs will run ~$10 Million/year. We envision various funding scenarios. In one model, NYAC is very successful in raising the full funds through collaboration with Universities, State Government, Industry, Foundations, and private donors. This is obviously ideal in that it maximizes the observing time for NY State. However, we can also foresee other scenarios where NY State astronomers share time and expense with a broader community, reducing the total cost to NY state venues. With a 12 Meter telescope on a top site, this would still provide ample scientific return, and as we describe below, would still provide significant investment in NY State industry and university communities.

We have had encouraging discussions with NOAO and AURA regarding situating ATNY at Cerro Tololo Interamerica Observatory (CTIO) as well as possible operations cost-sharing arrangements in return for US community access to ATNY proportional to NSF/AURA/NOAO investment. In this scenario, the full capital cost will be raised by the participating NY universities, in partnership, as needed, with other universities and countries. We envision that at a minimum 50% (and ideally 100%) of the capital cost would be raised within NY by combining private foundation and individual contributions, contributions by participating NY institutions, and funding by the State. ASNY has about 27 members, and there are many more potential participant institutions in NY. The city of New York has substantial concentration of foundations and personal wealth, and NYAC would tap these sources for a portion of the NY share. NYSTAR, the NY State Foundation for Science, Technology and Innovation, is the NY State government S&T organization. "NYSTAR supports technology development, innovation and commercialization leading to economic growth in New York State", and includes a vision to " make NY a national leader in high-technology academic research and economic growth" (see www.nystar.state.ny.us). To obtain state funding, the ATNY project must support the NYSTAR goals, a straightforward task for ATNY. We have worked to identify NY companies to provide major subsystems for the telescope to keep ATNY funding within NY. Companies to date who have agreed to participate are:

- ITT, Rochester, NY: Already under contract to develop optical fabrication techniques for the TMT project, they would provide system engineering, optical fabrication, mirror mounts, and other optics for the system,
- Corning, Canton, NY: Corning would provide the glass for all optics for the telescope,
- Triodetic, Syracuse, NY: Triodetic would provide space frame structures for the dome,
- Toptica, Victor, NY: Already under contract to ESO and Keck, they would provide the laser for the synthetic guide star for the adaptive optics system,
- EMF, Ithaca, NY: An optical coating vendor since 1939, they would coat all optics and develop and set up a coating facility at the observatory for recoating optics,
- Others: We would also expect to hire New York companies to develop architectural designs, provide major opto-mechanical systems, develop control systems, and provide steel fabrication for major subsystems, including Trex Enterprises Corporation and Sigmadyne, Inc.

Letters of support can be found at www.cis.rit.edu/ATNY. The companies identified have agreed to participate in lobbying for ATNY funding with NY and, as needed, federal funding, and several have indicated willingness to provide co-op jobs and other opportunities to enhance the benefit to NY universities. We aim to keep 100% of the NY contributions to ATNY in state.

Any capital funding that can't be raised within NY will come from strategic partnerships with out-of-state universities and/or foreign countries. As the largest visible/near-IR telescope in the world, at a small fraction of the cost of the proposed much larger TMT and GMT, ATNY could reasonably expect to fill the partnership with well-qualified astronomical entities. This would spawn further scientific and instrumental collaboration, enhancing the rate of development. When the substantial majority of capital funding for the telescope itself has been identified the consortium may elect to seek instrument funding from the federal government (there are many successful historical precedents to this approach and expectation of success is reasonable). While there will be substantial work to be done to garner funding for ATNY, the organization of ATNY correlated to state and regional institutions most closely parallels the situation in California, where the University of California and Caltech have collaborated to develop several significant observatories over the past 100 years. New York would do well to aspire to this model as it strives for remarkable growth in capabilities, profile, academic and research funding, institutional development, workforce enhancement, and the growth of associated high tech NY State industries.