Snowmass2021 - Letter of Interest

The US Extremely Large Telescope Program

Topical Group(s): (check all that apply by copying/pasting ☐/☑)

☐ (CF1) Dark Matter: Particle Like
☐ (CF2) Dark Matter: Wavelike
☑ (CF3) Dark Matter: Cosmic Probes
☐ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
☑ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
☑ (CF7) Cosmic Probes of Fundamental Physics
☐ (Other) *[Please specify frontier/topical group]*

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Abstract: (maximum 200 words)
Progress on many important astrophysical problems requires new observations with substantially higher angular resolution and greater sensitivity than today's optical-infrared telescopes can provide. A new generation of Extremely Large Telescopes (ELTs) with >20m primary mirror diameters, operating with next-generation adaptive optics systems that deliver diffraction-limited image quality, will provide transformational new research capabilities. ELTs will enable major advances in several research topics within the Cosmic Frontiers theme including the nature of dark matter; unprecedentedly precise measurement of the cosmic expansion rate; the physics of compact object mergers identified by gravitational wave events; and tests of General Relativity's description of gravity in close proximity to the supermassive black hole in the center of our Galaxy. The US ELT Program, a collaboration between NSF's NOIRLab and the Thirty Meter Telescope and Giant Magellan Telescope projects, proposes to complete construction of a bi-hemispheric system that will provide US researchers with unique ELT coverage of the whole sky and a powerful suite of instruments. The proposed federal funding would ensure 25% or greater open access to both telescopes for investigators at any US research institution.

Introduction

Over the last 25 years, a generation of 8m-class optical-infrared telescopes have allowed us to study faint objects from the outer reaches of our own Solar System to the first billion years of cosmic history. Over the same period, the promise of adaptive optics (AO) to correct the blurring effects of Earth's atmosphere has been realized. Today, some of the most important problems in astrophysics require observations with higher angular resolution and sensitivity than today's telescopes can provide[7];[8]. A new generation of extremely large telescopes (ELTs) is technically achievable and scientifically compelling. For diffraction-limited observations, sensitivity[1] scales with telescope primary mirror diameter (D) as D^4, or even more steeply for observations in crowded fields, so the potential gains from telescopes with D > 20m are enormous.

Three international ELT projects are underway, including two with substantial leadership from US research institutions: the 24.5m Giant Magellan Telescope (GMT) in the southern hemisphere and the Thirty Meter Telescope (TMT) in the northern hemisphere. The European Southern Observatory (ESO) is building a 39m Extremely Large Telescope in Chile.

The US ELT Program (US-ELTP)[1];[9];[10] is a joint endeavor of NSF's NOIRLab and the organizations building the TMT and GMT. The goal of the program is to complete both telescopes and to secure sufficient federal funding to make at least 25 percent of the observing time available for open access by the whole US scientific community. This two-telescope, two-hemisphere ELT system would provide the US community with greater and more diverse research opportunities than could be achieved with a single telescope. It would enable leadership by scientists anywhere in the US and coordination of talents and resources throughout the country. The US-ELTP would also create new channels for collaboration with GMT's and TMT's international partner scientists. And it would enable the execution of large-scale, systematic investigations of forefront scientific problems (Key Science Programs) that could not be achieved with smaller, uncoordinated projects. NOIRLab will develop and provide user support services and tools for all stages of research with TMT and GMT, from developing observing proposals to analyzing the data, as well as a permanent archive for all GMT/TMT data. The scientific return from a cooperative, national US ELT Program would far surpass what could be achieved without the proposed federal investment.

Cosmic Frontier Research and the US ELT Program

The angular resolution and sensitivity of ELTs will enable transformational new research in several areas of cosmology and fundamental physics, including the nature of dark matter, the physics of cosmic expansion, gravitational waves and mergers of compact objects, and tests of General Relativity around supermassive black holes. The scientific community has considered and documented the potential of ELTs for these topics and many others in astrophysics over many years [REFs]. In 2018-2019, US community researchers developed concepts for Key Science Programs with a bi-hemispheric US ELT system. Many of these concepts led to science white papers that were submitted to the National Academies' Astro2020 Decadal Survey. The following notes highlight a few of these topics, with reference to relevant Astro2020 white papers. Some of these topics will also be addressed in Letters of Interest submitted to Snowmass 2021.

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[1] Here, sensitivity is defined as the reciprocal of the exposure time required to attain a given signal-to-noise ratio for observations of a point source with a given flux in the background-limited regime.

The Nature of Dark Matter[2]: Dark matter (DM) is widely assumed to be cold and collisionless, but persistent astronomical evidence suggests deviations from Lambda Cold Dark Matter (LCDM) predictions on small mass and length scales. These deviations include flat "core" density profiles in DM-dominated dwarf galaxies where steep, cuspy profiles are predicted (a possible signature of self-interacting dark matter), and a large deficit of low-mass galaxies relative to the steep LCDM halo mass function (potential evidence for warm dark matter). Precision astrometry from diffraction-limited ELT observations, combined with spectroscopy, will measure three-dimensional motions for stars in local dwarf galaxies that are the cleanest DM laboratories, clearly distinguishing cusp from core profiles. High resolution imaging and integral field spectroscopy of gravitationally lensed galaxies and quasars will measure the mass function of DM substructure down to 10^7 $M_\odot$ in the halos of the lens galaxies along the line of sight, independent of the baryonic and stellar composition of those structures. These two observational probes provide complementary information about small scale structure, with a joint self-consistent analysis mitigating limitations of either probe.

The Physics of Cosmic Expansion[3]: The Hubble Constant (H_0) measures the present-day expansion rate of the universe. New, precision measurements of H_0 suggest an increasingly significant 'tension' between values derived from local astronomical observations and values inferred from early-universe observations such as the Cosmic Microwave Background. If correct, these discrepancies may indicate new cosmological physics beyond the standard model. The unparalleled sensitivity and angular resolution of ELT observations will move astronomical measurements of H_0 into a new regime where multiple, independent techniques can be employed each with 1% or better precision. These methods will include (i) *standard candles* via a two-step distance ladder applied to metal-poor stellar populations, (ii) *standard clocks* via gravitational lens cosmography, and (iii) *standard sirens* via gravitational wave sources (see below).

Gravitational Waves and Compact Object Mergers[4];[5]: Astronomical observations of electromagnetic counterparts to gravitational wave (GW) sources provide critical information about the physics of compact object mergers, including the production and enrichment history of the heaviest chemical elements, the dense matter equation of state, and the lives and demographics of black holes. They can also improve the accuracy of *standard siren* distance measurements to GW sources by reducing degeneracy between distance and inclination, making GW sirens competitive with (and complementary to) other precision measurements of the cosmic expansion rate H_0 (see above). As the sensitivity of high-frequency (LIGO/VIRGO band) GW detectors improves, the optical-infrared counterparts to all but the closest neutron star mergers will be exceedingly faint and many observations will require the sensitivity and angular resolution that ELTs will uniquely provide.

Testing General Relativity near a Supermassive Black Hole[6]: Measuring the orbits of stars in the Galactic Center allows us to test whether General Relativity (GR) is an accurate description of gravity near a supermassive black hole (SMBH). ELTs will "zoom in" on the Galactic Center with 3 times better angular resolution and more than 80 times greater sensitivity than today's telescopes offer, allowing us to monitor orders of magnitude more stars with greater astrometric accuracy. GR effects (or those of other theories of gravity) are stronger for stars with short periods and high eccentricities. ELTs will make it possible to measure higher order changes to the orbits of many more stars closer to the SMBH, testing the Einstein equivalence principle and the form of the Kerr metric around a SMBH and allowing a search for a massive graviton or additional interactions like scalar fields. It will also be possible to detect GR effects that have no analog in classical dynamics such as the precession of the periapse and the Lense-Thirring or frame dragging effect due to the spin of the black hole.

References:

Astro2020 Science White Papers

[1] Wolff, S., et al. 2019, "The US Extremely Large Telescope Program", BAAS 51, 7, 4
[2] Simon, J., et al. 2019, "Testing the Nature of Dark Matter with Extremely Large Telescopes", BAAS 51, 3, 153
[3] Beaton, R., et al. 2019, "Measuring the Hubble Constant Near and Far in the Era of ELTs", BAAS 51, 3, 456
[4] Chornock, R., et al. 2019, "Multi-Messenger Astronomy with Extremely Large Telescopes", BAAS 51, 3, 237
[5] Foley, R., et al. 2019, "Gravity and Light: Combining Gravitational Wave and Electromagnetic Observations in the 2020s", BAAS, 51, 3, 295
[6] Do, T., et al. 2019, "Envisioning the next decade of Galactic Center science: a laboratory for the study of the physics and astrophysics of supermassive black holes", BAAS, 51, 3, 530

GMT and TMT Science Books

[7] Giant Magellan Telescope Science Book (R. Bernstein et al. 2018)
[8] Thirty Meter Telescope Detailed Science Case (W. Skidmore et al. 2015)

US ELT Program project web pages

[9] https://www.noirlab.edu/public/projects/useltp/
[10] https://www.noao.edu/us-elt-program/

Additional Authors:

The Extremely Large Telescope (ELT) is an astronomical observatory currently under construction. When completed, it is planned to be the world's largest optical/near-infrared extremely large telescope. Part of the European Southern Observatory (ESO) agency, it is located on top of Cerro Armazones in the Atacama Desert of northern Chile. The design consists of a reflecting telescope with a 39.3-metre-diameter (130-foot) segmented primary mirror and a 4.2 m (14 ft) diameter secondary mirror, and will be Each spacecraft hosts a Schmidt telescope with a large collecting area and wide field of view. A novel focal plane is optimized to observe both the UV fluorescence signal from extensive air showers (EASs) and the beamed optical Cherenkov signals from EASs. In POEMMA-stereo fluorescence mode, POEMMA will measure the spectrum, composition, and full-sky distribution of the UHECRs above 20 EeV with high statistics along with remarkable sensitivity to UHE neutrinos. The spacecraft are designed to quickly re-orient to a POEMMA-limb mode to observe neutrino emission from Target-of-Opportunity (ToO) t Snowmass2021 - Letter of Interest Complementarity Studies of the Higgs Sector with Colliders and Gravitational Wave Detectors. Introduction. Precision Gravitational Wave Calculations. Collider Studies for the Higgs Sector. References. Snowmass2021 - Letter of Interest. Complementarity Studies of the Higgs Sector with Colliders and Gravitational Wave Detectors.Â We propose to study the Higgs sector from two complementary directions: (i) precision calculations of stochastic gravitational waves coming from phase transitions and (ii) collider studies for new resonance searches at the LHC and future colliders, in particular, for di-Higgs production. Our goal is to establish benchmark points for various models that can be used by both communities in the future. "We are leading the world into a new and dynamic era of spaceflight," NASA Administrator Jim Bridenstine said in a "State of NASA" presentation to employees. "This is a 21st century budget worthy of 21st century space exploration and one of our strongest budgets in NASA history."Â With the 2021 budget request, NASA is also proposing to terminate a flying telescope, the SOFIA flying telescope (the Stratospheric Observatory for Infrared Astronomy) airborne observatory. The SOFIA mission, which NASA has previously tried to terminate, flies a large telescope on a 747 aircraft. "The science productivity for this telescope falls short of that expected for a large mission with annual operating costs exceeding $80 million," NASA wrote in explanation of the cancellation.