To remain competitive, Columbia must upgrade its observational facilities to keep pace with the state of the art: either a major space telescope (prohibitively expensive unless we adopt operations of an older astronomical satellite - at least a few $M/year), or enhanced ground-based astronomy (at radio/millimmeter/sub-millimeter wavelengths or optical/near-infrared). Astrophysics in non-photon modes – gravitational waves, neutrinos, dark matter and ultra high-energy particles (including ultra-energetic gamma photons) – are being pursued by our colleagues in Physics e.g., Marka, Conrad, Shaevitz, Aprile, Westerhout, Hailey, and Mukherjee.

We need a facility sufficiently advanced and versatile in applications to allow the members of our Department to use it to advance a variety of ideas. Cost limitations direct us to ground-based facilities, which we can advance in one of several ways:

Buy into an existing or planned state-of-the-art – e.g., 6-10 meter – optical telescope:

There is less choice in new telescope partnerships than in times past. Early 6-10 meters (Keck, Magellan, LBT, VLT, HET, MMT) are taking no more partners, and even the GranTeCan 10.4-meter and SALT 10-meter projects are closed. South Korea (BOAO) is contemplating a still poorly-defined 6-meter, for operation by about 2015. Perhaps 10 years from now, the U.S. national observatories will be selling shares of the existing 8-meters. A 10% share of such a project (25-30 nights/year) might cost $5-10M. Within the next decade these prospects seem poor.

Join an advanced optical project of size over 10 meters (or of corresponding complexity):

There are a few of these planned for the next 10 years or more, and they are extremely expensive. The GMT (22-meters, $500M?, by 2015?) is looking for partners, as is the LSST (advanced 8-meter, $250 million?, by 2013?). The Thirty-Meter Telescope, CELT (30-meter), and OWL (100-meter) have prices approaching or exceeding $1 billion and will not operate until late in the next decade. A minimum share of these projects (perhaps 10%, or 30 nights/year) would cost at least $50-150 million, except for LSST, which we consider below. We cannot afford to be a driving force in these projects.

Join an advanced radio telescope project:

These are dominated by ALMA (closed to partners) and SKA (and precursors), with costs and completion dates similar to the advanced optical projects, which likewise will discourage our persuasive influence. We might construct smaller arrays to study special problems and sources e.g., the cosmic microwave background, as will Miller in Physics.

Buy an older telescope (4-meter or smaller) from the national observatories:

This is an option being pursued by some institutions, but it is expensive, especially since reaching the cutting edge on these telescopes requires new, ambitious instrumentation. For example, Fermilab plans to acquire a 30% share of the CTIO 4-meter for five years by building the Dark Energy Camera for $19M starting in 2009. Similiarly, Maryland is acquiring a 20% share of the KPNO 4-meter for an investment of about $10M. In contrast Lowell Observatory is building a 4.2-meter for $38M. At the other extreme one could buy time on SMARTS telescopes (0.9 to 1.5-meter) for $1,400/night.

Build our own state-of-the-art telescope (likely with partner institutions):

Prospects are more inviting here, since we have spent several years perfecting the technology and design for an 8-meter telescope (ALPACA) which has great, unique potential.

Superficially, ALPACA resembles the LSST in diameter and angular field, but operates radically differently and has separate, important science goals that cannot be fulfilled by any other planned project. LSST will never operate spectroscopically, and will be so constrained by competing projects as to never accomplish the principal goals in ALPACA's domain. A key design characteristic is how complexity and expense is avoided when possible, making it much more cost-effective than most telescopes. It simply scans the sky passing overhead, making it intrinsically survey-oriented, but for a wide variety of topics from cosmology to near-Earth asteroids.

This program would progress incrementally. We have built the LZT, a 6-meter near Vancouver, BC, which has shown how this approach can produce images limited by atmospheric, not telescope, effects. This test facility was built for $1M, but is not useful for research given the site's weather. We can build a science-worthy 8-meter ("Proto-ALPACA") on Cerro Tololo, Chile, which would scan nightly about half of a 90 deg^2 field, for a first-light cost of $5M (plus $3M for contingency, and for operations costs of $0.2M/year), and could be completed by 2009 if funded soon. We envision the full ALPACA feeding a larger camera which would survey 1000 deg^2 and have an information-gathering power exceeding all optical telescopes except possibly LSST. This new camera might add $10M in cost, and we are finding partners who might ease this burden significantly. Finally, we are scientifically compelled to consider a spectrograph on ALPACA, which might cost $5M.

The ALPACA program will produce superlative results on scales from cosmology to the near-Earth solar system. Its primary strength will include repeated monitoring of variable sources in 5 photometric bands, ultra-deep exposures on sources, and an otherwise unreachably powerful spectroscopic sample. A key characteristic of ALPACA is that it will produce a huge data base comparable in richness to the Sloan Digital Sky Survey, and will allow numerous projects in data-mining, for which Columbia will develop valuable expertise. Perhaps its premier results will come from an unparallelled survey of supernovae capable of refining their use as cosmological probes of dark energy (of keen interest to Crotts, Hui and others at Columbia), ultra-large galaxy surveys (Helfand, Schiminovich, Crotts, Bryan, Hui, Haiman), an extremely deep galaxy cluster catalog (Haiman, Bryan, Paerels, Schiminovich, Miller), detailed studies of galaxy environments (van Gorkom, Schiminovich), unprecedentedly detail monitoring of active galactic nuclei (Kay, Halpern, Menou), extremely deep and complete variable star samples (Crotts, Patterson, Johnston), huge samples for studying stellar populations and Galactic structure (Johnston, Dalcanton), transit and microlensing detections of large numbers of extrasolar planets (Menou, Haiman, Hui, Crotts), and a huge sample of Kuiper-belt objects and many near-Earth asteroids (Ebel at AMNH, Crotts). The ALPACA data base will serve a generation of Columbia astronomers in their research.

ALPACA will motivate us not only to repeat our construction of a large telescope (LZT), but to develop the skills in large-format CCD arrays and multi-object spectrographs. Both of these promise superlative science results. Additionally, we have studied how to include tracking optics and interferometry in zenith-scanning telescopes (LAMA). ALPACA can expand into telescopes with different, and greater, capabilities.

ALPACA poses some technological risk. There is a chance that moving from the LZT near Vancouver to ALPACA with better atmospheric conditions in Chile might reveal fundamental technological limits, at the level of 1-arcsecond imaging. We must weigh this investment of a few years and $5M against a "surer thing" of a more conventional but expensive telescope that will likely cost several ten million dollars for a minimal share. Furthermore, ALPACA cannot be all things to all astronomers; a more expensive, steerable telescope of comparable size will allow projects that ALPACA cannot (and vice versa). Flexibility and risk-avoidance in our actions are desirable, but likely to be more expensive.

Ground-based facilities for top 20 U.S. astronomy departments (optical with diameter $\geq$ 2m equivalent, radio/mm/submm with diameter $\geq$ 10m equivalent)

Arizona: LBT 2x8.4m,Magellan 2x6.5m,MMT 6.5m,Bok 2.3m,SMT 10m radio,
ARO 12m radio

Berkeley: Keck 2x10m,Lick 3m

Caltech: Keck 2x10m,Palomar 5m,CARMA 6x10.4m+10x6.1m radio,CSO 10.4m radio

Chicago: APO 3.5m,SDSS 2.5m

Columbia: MDM 2.4m

Cornell: Arecibo 305m radio,Palomar 5m

Harvard: Magellan 2x6.5m,MMT 6.5m,SMA 8x6m radio

Hawaii: Keck,Subaru 8m,Gemini-N 8m,UKIRT 3.8m,AEOS 3.7m,CFHT 3.6m,SMA
IRTF 3m,UH 2.2m,Magnum 2m,Faulkes 2m,JCMT 15m radio,CSO 10.4m radio

Hopkins: APO 3.5m,SDSS 2.5m

Maryland: Kitt Peak 4m,CARMA 6x10.4m+10x6.1m radio

Michigan: Magellan 2x6.5m,MDM 2.4m

MIT: Magellan 2x6.5m,Haystack 37m radio

Princeton: APO 3.5m,SDSS 2.5m

Santa Cruz: Keck 2x10m,Lick 3m

Texas: HET 9m,SALT 10m,McDonald 2.7m

UCLA: Keck 2x10m,Lick 3m

Virginia: LBT 2x8.4m,Magellan 2x6.5m,MMT 6.5m,Bok 2.3m,SMT 10m radio

Washington: APO 3.5m,SDSS 2.5m

Wisconsin: SALT 10m,WIYN 3.5m

Yale: WIYN 3.5m

Ohio State?: LBT 2x8.4m,MDM 2.4m

Stanford?: HET 9m,SALT 10m

UNC CH?: SOAR 4m,SALT 10m

Appendix - Glossary of telescope projects and sources of further information:

AEOS: Advanced Electro-Optical System
http://www.globalsecurity.org/space/systems/aeos.htm

ALMA: Atacama Large Millimeter Array
http://www.alma.nrao.edu/

ALPACA: Advanced Liquid-mirror Probe for Astrophysics, Cosmology and Asteroids
http://www.astro.ubc.ca/LMT/alpaca/

APO: Apache Point Observatory
http://www.apo.nmsu.edu/

Arecibo Observatory
http://www.naic.edu/

ARO 12-meter Telescope
http://aro.as.arizona.edu/12m_docs/12_meter_description.htm

BOAO: Bohyunsan Optical Astronomy Observatory
http://www.kao.re.kr/html/english/division/index.html

Bok Telescope
http://james.as.arizona.edu/ psmith/90inch/90inch.html

CARMA: Combined Array for Research in Millimeter-wave Astronomy
http://www.mmarray.org/

CELT: California Extremely Large Telescope
http://celt.ucolick.org/

CFHT: Canada-France-Hawaii Telescope
http://www.cfht.hawaii.edu/

CTIO: Cerro Tololo Inter-American Observatory
http://www.ctio.noao.edu/

Faulkes Telescope
http://kilo.ifa.hawaii.edu/faulkes/intro.jsp

Gemini Observatory
http://www.noao.edu/usgp/

GMT: Giant Magellan Telescope
http://www.gmto.org/

GTC or GranTeCan: Gran Telescopio Canarias
http://www.gtc.iac.es/

Haystack Observatory

http://www.haystack.mit.edu/

HET: Hobby-Eberly Telescope

http://www.as.utexas.edu/mcdonald/het/het.html

IRTF: Infrared Telescope Facility

http://irtfweb.ifa.hawaii.edu/

JCMT: James Clerk Maxwell Telescope

http://www.jach.hawaii.edu/JCMT/

Keck Observatory

http://www2.keck.hawaii.edu/geninfo/about.php

Kitt Peak National Observatory

http://www.noao.edu/kpno/

LAMA: Large-Aperture Mirror Array

http://www.astro.ubc.ca/LMT/lama/

LBT: Large Binocular Telescope

http://lbto.org/

Lick Observatory

http://mthamilton.ucolick.org/

Lowell Observatory (Discovery Channel Telescope)

http://www.lowell.edu/DCT/

LSST: Large Synoptic Survey Telescope

http://www.lsst.org/

LZT: Large Zenith Telescope

http://www.astro.ubc.ca/LMT/lzt/

Magellan Project

http://www.ociw.edu/magellan/

Magnum Telescope

http://merope.mtk.nao.ac.jp/ yuki/magnum_hp/about.htm

McDonald Observatory

http://www.as.utexas.edu/mcdonald/facilities/2.7m/2.7.html

MDM Observatory

http://www.astro.lsa.umich.edu/obs/mdm/

MMT Observatory
http://www.mmto.org/

OWL: OverWhelmingly Large telescope
http://www.eso.org/projects/owl/

Palomar Observatory
http://www.astro.caltech.edu/palomar/

SALT: Southern African Large Telescope
http://www.salt.ac.za/

SDSS: Sloan Digital Sky Survey
http://www.sdss.org/

SKA: Square Kilometre Array
http://www.skatelescope.org/

SMA: Submillimeter Array
http://sma-www.harvard.edu/

SMARTS: Small and Moderate Aperture Research Telescope System
http://www.astro.yale.edu/smarts/
http://www.ctio.noao.edu/smarts_2_opportunity.html

SMT: Submilimeter Telescope
http://aro.as.arizona.edu/smt_docs/smt_telescope_specs.htm

SOAR: Southern Astrophysical Research Telescope
http://www.soartelescope.org

Subaru Telescope
http://www.subaru.naoj.org/

Thirty-Meter Telescope
http://www.tmt.org/

UKIRT: United Kingdom Infra-Red Telescope
http://www.jach.hawaii.edu/UKIRT/

VLT: Very Large Telescope
http://www.eso.org/projects/vlt/

WIYN: Wisconsin-Indiana-Yale-NOAO Consortium
http://www.noao.edu/wiyn/