Large-scale Surveys ***with*** TMT; Large-scale Surveys ***and*** TMT

Michael Strauss, Princeton University

- Organizing the TMT community to do large-scale projects with the telescope; lessons from SDSS and other surveys.
- How the next generation of wide-field surveys will influence TMT.

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Should TMT be used for massive surveys?

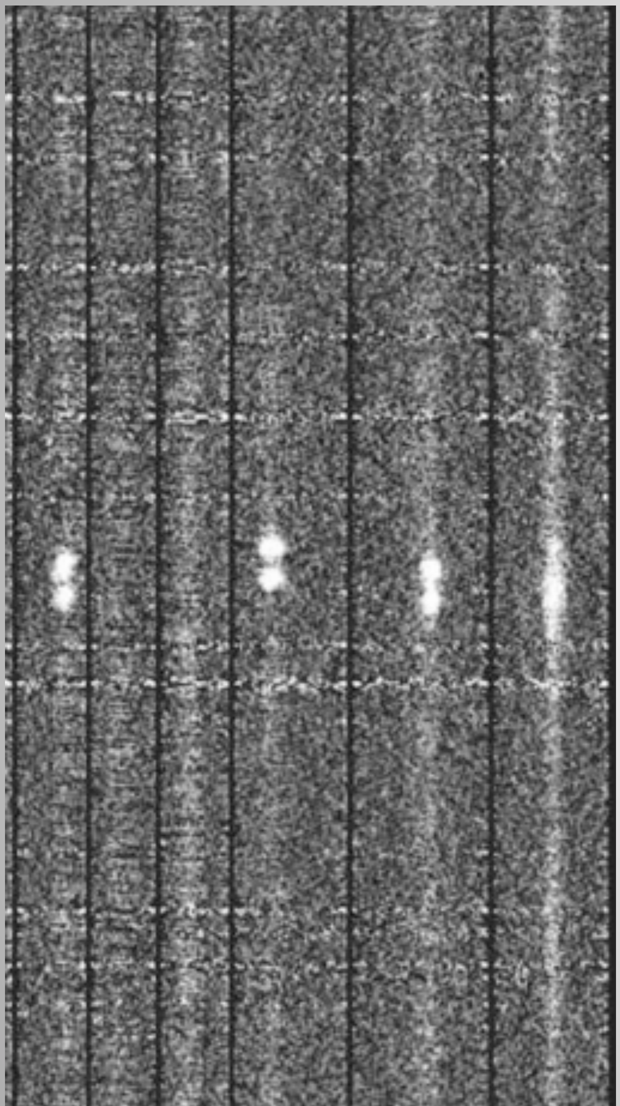
The early days of TMT will be marked by people picking low-lying fruit, working in PI mode; there is so much obvious waiting to be done, as we're learning at this meeting. Wonderful papers will be written based on observations taking a few hours to a few nights of telescope time.

However, some of the science that TMT is designed to do, and is uniquely positioned to do, will require some combination of:

- A large amount of telescope time (≥several tens of nights);
- Specialized software and extensive computation to reduce the data;
- A broad range of expertise to understand the results;
- Extensive ancillary data from many sources (both precursor and follow-up);
- Extensive theoretical investigations to interpret the findings.

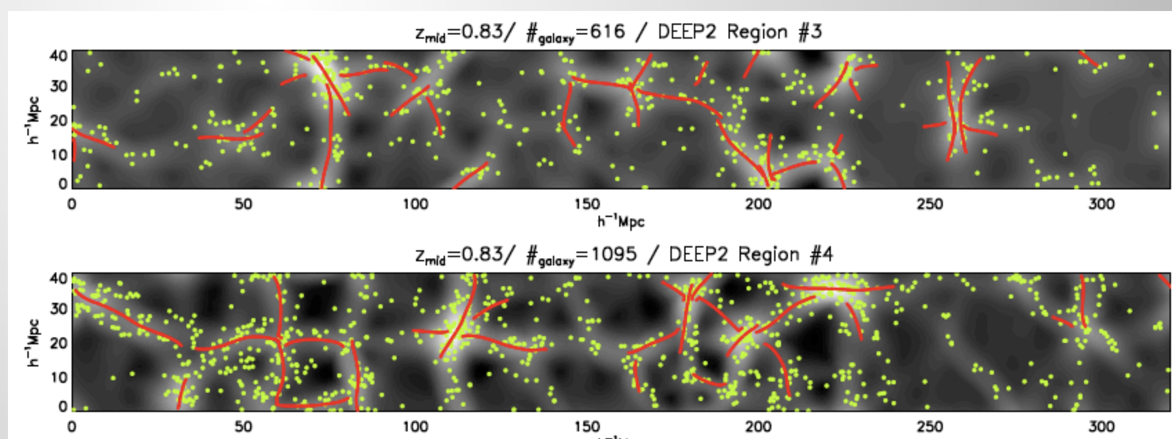
The limiting factors will be (a) telescope time, and (b) people to do the work.

A Big Survey on a Big Telescope: DEEP2 on Keck



Newman et al. 2013: [OII] emitters

80 Keck nights over 4 years.
A team of over 30 people (mostly Santa Cruz/Berkeley/Caltech/Hawaii).
~ a dozen PhD theses.
150 refereed papers; 9000+ citations



Choi et al. 2010: filaments in DEEP2

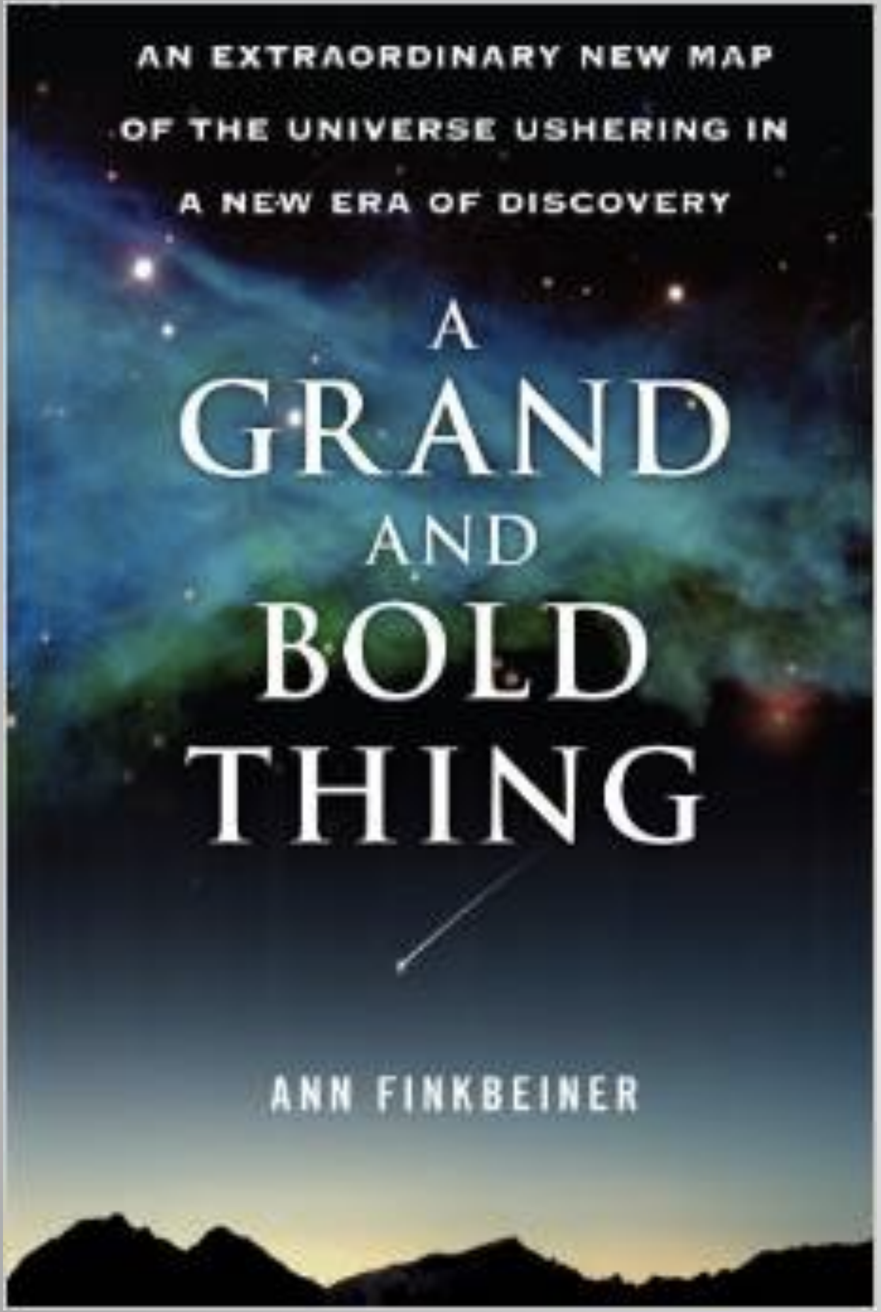
(See also talk by Mike Cooper)

Multi-Institutional, Multi-National collaborations

- The TMT community has a tremendous resource in the varied institutions and countries involved.
- A great challenge is difference in culture, scientific style, funding models, and criteria for advancement in different institutions:
  - Are first-author papers the most important goal of astronomers? How else do we assign credit for the work we do?
  - Must a given project be carried out solely with scientists from a given institution?
  - Not all science can (should?) be done in the single PI + her/his group mode
- Communication is key. E-mail, phonecons, skype are all fine, but you must have time to work face-to-face to build scientific trust.

Compare with surveys like SDSS

- SDSS is fundamentally different from TMT: it is not an ***observatory*** per se, and the observing plans are not PI-driven, but are decided years in advance.
- Yet SDSS' experience may be relevant for large surveys carried out with TMT.
- The project's responsibility is to deliver fully reduced, calibrated and vetted data products.
- We have faced the challenge of institutional rivalries and differences of culture.



An entire book was written about the SDSS turf wars that we fought!

The challenge: collaborative science is hard. (But everyone becomes much happier once the data begins to flow…)

SDSS Lessons Learned

#1: We were limited by people (work *and* creativity), not by data. The more people working, the more science got done. No point in keeping the collaboration small!

#2: Science results went *way* beyond the initial goals of the project.

#3: Releasing the data to the world was good for the project: preparing and documenting the data for these releases made it better for *our* science. But data releases are a lot of work.

#4: Software for major surveys is *hard*, comparable to the effort required to build the hardware.

#5: An emphasis on data quality. The better the calibration/software, the better the science.

THE ELEVENTH AND TWELFTH DATA RELEASES OF THE SLOAN DIGITAL SKY SURVEY: FINAL DATA FROM SDSS-III

Shadab Alam[1], Franco D. Albareti[2], Carlos Allende Prieto[3,4], F. Anders[5], Scott F. Anderson[6],
Timothy Anderton[7], Brett H. Andrews[8,9], Eric Armengaud[10], Éric Aubourg[11], Stephen Bailey[12],
Sarbani Basu[13], Julian E. Bautista[11], Rachael L. Beaton[14,15], Timothy C. Beers[16], Chad F. Bender[17,18]
Andreas A. Berlind[19], Florian Beutler[12], Vaishali Bhardwaj[6,12], Jonathan C. Bird[19], Dmitry Bizyaev[20,21,22],
Cullen H. Blake[23], Michael R. Blanton[24], Michael Blomqvist[25], John J. Bochanski[6,26], Adam S. Bolton[7],
Jo Bovy[27,28], A. Shelden Bradley[20], W. N. Brandt[17,29,30], D. E. Brauer[5], J. Brinkmann[20], Peter J. Brown[31],
Joel R. Brownstein[7], Angela Burden[32], Etienne Burtin[10], Nicolás G. Busca[33,34,11], Zheng Cai[35], Diego Capozzi[32],
Aurelio Carnero Rosell[33,34], Michael A. Carr[36], Ricardo Carrera[3,4], K. C. Chambers[37],
William James Chaplin[38,39], Yen-Chi Chen[40], Cristina Chiappini[5,34], S. Drew Chojnowski[21], Chia-Hsun Chuang[2],
Nicolas Clerc[41], Johan Comparat[2], Kevin Covey[42,43], Rupert A.C. Croft[1], Antonio J. Cuesta[44,45],
Katia Cunha[33,35], Luiz N. da Costa[33,34], Nicola Da Rio[46], James R. A. Davenport[6], Kyle S. Dawson[7],
Nathan De Lee[47], Timothée Delubac[48], Rohit Deshpande[17,18], Saurav Dhital[49], Letícia Dutra-Ferreira[50,34,51],
Tom Dwelly[41], Anne Ealet[52], Garrett L. Ebelke[14], Edward M. Edmondson[32], Daniel J. Eisenstein[53],
Tristan Ellsworth[7], Yvonne Elsworth[38,39], Courtney R. Epstein[8], Michael Eracleous[17,29,54,6],
Stephanie Escoffier[52], Massimiliano Esposito[3,4], Michael L. Evans[6], Xiaohui Fan[35], Emma Fernández-Alvar[3,4],
Diane Feuillet[21], Nurten Filiz Ak[17,29,55], Hayley Finley[56], Alexis Finoguenov[57], Kevin Flaherty[58],
Scott W. Fleming[59,60], Andreu Font-Ribera[12], Jonathan Foster[45], Peter M. Frinchaboy[61],
J. G. Galbraith-Frew[7], Rafael A. García[62], D. A. García-Hernández[3,4], Ana E. García Pérez[14,3,4],
Patrick Gaulme[20], Jian Ge[46], R. Génova-Santos[3,4], A. Georgakakis[41], Luan Ghezzi[33,53], Bruce A. Gillespie[63],
Léo Girardi[64,34], Daniel Goddard[32], Satya Gontcho A Gontcho[44], Jonay I. González Hernández[3,4],
Eva K. Grebel[65], Paul J. Green[53], Jan Niklas Grieb[41], Nolan Grieves[46], James E. Gunn[36], Hong Guo[7],
Paul Harding[66], Sten Hasselquist[21], Suzanne L. Hawley[6], Michael Hayden[21], Fred R. Hearty[17],
Saskia Hekker[67,39], Shirley Ho[1], David W. Hogg[24], Kelly Holley-Bockelmann[19], Jon A. Holtzman[21],
Klaus Honscheid[68,69], Daniel Huber[70,71,39], Joseph Huehnerhoff[20], Inese I. Ivans[7], Linhua Jiang[72],
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Timothy C. Licquia[9], Jian Liu[46], Daniel C. Long[20,21], Martín López-Corredoira[3,4], Diego Lorenzo-Oliveira[50,34],
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Daniel Margala[25], Sarah L. Martell[79], Marie Martig[75], Karen L. Masters[32], Savita Mathur[80],
Cameron K. McBride[53], Peregrine M. McGehee[81], Ian D. McGreer[35], Richard G. McMahon[82,83],
Brice Ménard[63,74,84], Marie-Luise Menzel[41], Andrea Merloni[41], Szabolcs Mészáros[85], Adam A. Miller[86,87,88],
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Eric Morganson[53], Xan Morice-Atkinson[32], Heather L. Morrison[66], Benoît Mosser[90], Demitri Muna[8],
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Robert C. Nichol[32], David L. Nidever[93], Pasquier Noterdaeme[56], Sebastián E. Nuza[5], Julia E. O'Connell[61],
Robert W. O'Connell[14], Ross O'Connell[1], Ricardo L. C. Ogando[33,34], Matthew D. Olmstead[7,94],
Audrey E. Oravetz[20,21], Daniel J. Oravetz[20], Keisuke Osumi[1], Russell Owen[6], Deborah L. Padgett[95],
Nikhil Padmanabhan[45], Martin Paegert[19], Nathalie Palanque-Delabrouille[10], Kaike Pan[20], John K. Parejko[96],
Isabelle Pâris[97], Changbom Park[98], Petchara Pattarakijwanich[36], M. Pellejero-Ibanez[3,4], Joshua Pepper[99,19],
Will J. Percival[32], Ismael Pérez-Fournon[3,4], Ignasi Pérez-Ràfols[44,100], Patrick Petitjean[56],
Matthew M. Pieri[101,32], Marc H. Pinsonneault[8], Gustavo F. Porto de Mello[50,34], Francisco Prada[2,102,103],
Abhishek Prakash[9], Adrian M. Price-Whelan[104], Pavlos Protopapas[105], M. Jordan Raddick[63], Mubdi Rahman[63],
Beth A. Reid[106,12], James Rich[10], Hans-Walter Rix[75], Annie C. Robin[107], Constance M. Rockosi[108],
Thaíse S. Rodrigues[64,109,34], Sergio Rodríguez-Torres[2,102], Natalie A. Roe[12], Ashley J. Ross[32,69],
Nicholas P. Ross[110], Graziano Rossi[111,10], John J. Ruan[6], J. A. Rubiño-Martín[3,4], Eli S. Rykoff[112],
Salvador Salazar-Albornoz[113,41], Mara Salvato[41,114], Lado Samushia[115,116], Ariel G. Sánchez[41],
Basílio Santiago[117,34], Conor Sayres[6], Ricardo P. Schiavon[118,119], David J. Schlegel[12], Sarah J. Schmidt[8],
Donald P. Schneider[17,29], Mathias Schultheis[120], Axel D. Schwope[5], C. G. Scóccola[3,4], Caroline Scott[53],
Kris Sellgren[8], Hee-Jong Seo[121], Aldo Serenelli[122], Neville Shane[14], Yue Shen[15,72], Matthew Shetrone[123],
Yiping Shu[7], V. Silva Aguirre[39], Thirupathi Sivarani[124], M. F. Skrutskie[14], Anže Slosar[125], Verne V. Smith[126],
Flávia Sobreira[34,127], Diogo Souto[33], Keivan G. Stassun[19,128], Matthias Steinmetz[5], Dennis Stello[39,70],
Michael A. Strauss[36,129], Alina Streblyanska[3,4], Nao Suzuki[74], Molly E. C. Swanson[53], Jonathan C. Tan[46],
Jamie Tayar[8], Ryan C. Terrien[17,18,130], Aniruddha R. Thakar[63], Daniel Thomas[32,131], Neil Thomas[46],
Benjamin A. Thompson[61], Jeremy L. Tinker[24], Rita Tojeiro[132], Nicholas W. Troup[14], Mariana Vargas-Magaña[1],
Jose A. Vazquez[125], Licia Verde[89,44,133], Matteo Viel[97,134], Nicole P. Vogt[21], David A. Wake[77,135], Ji Wang[13],
Benjamin A. Weaver[24], David H. Weinberg[8], Benjamin J. Weiner[35], Martin White[12,106], John C. Wilson[14],
John P. Wisniewski[136], W. M. Wood-Vasey[9,129], Christophe Yèche[10], Donald G. York[137], Nadia L. Zakamska[63],
O. Zamora[3,4], Gail Zasowski[63], Idit Zehavi[66], Gong-Bo Zhao[138,32], Zheng Zheng[7], Xu Zhou (周旭)[139],

Zhimin Zhou (周志民)[139], Hu Zou (邹虎)[139] Guangtun Zhu[63,88],

Draft version May 22, 2015

It takes a lot of people to build such a survey (274 authors on SDSS DR12 paper), and data releases require a huge amount of work.

SDSS: 6400+ refereed papers (~600 in the last year); 287,000 citations. *Surveys are high impact!*

Alam et al. 2015: DR11/12 paper

Organizing a collaboration to do science

- In SDSS, all participants had equal rights to work on any scientific project, but were required to announce their projects to the project. No projects were assigned to any teams a priori, but PhD theses were protected.
- Later components of SDSS had more focused science goals: supernova Hubble diagram, BAO studies, etc. We organized ourselves into working groups with well-defined leadership, that resulted in high-impact papers.
- “We need to talk…” Lots of phonecons, e-mail exploders, wikis. But face-to-face time is crucial; collaboration meetings are really important.
- SDSS had very poor gender balance in the beginning, especially in project management. We are getting better, but this is something we needed to be far more sensitive to from the beginning.

A coherent Publications Policy is key!

- Astronomers are obsessed by questions of authorship…
- SDSS publication policy worked to support, not hinder, science: the few times we found ourselves fighting over authorship were when we found ourselves bending our own rules…

Prime Focus Spectrograph:
A Wide-Field Spectroscopic Survey involving scientists on four continents

Grappling with the same cross-continental collaboration issues as did SDSS

Optical/NIR Wide-field surveys are a major theme of the next decade

Now, imaging: DES, Pan-STARRS, SkyMapper, VISTA, HSC

Now/soon, spectra: SDSS-IV, LAMOST, HETDEX

2018, spectra: PFS, DESI, 4MOST, MOONS, WEAVE…

2020: Euclid, LSST

2023: WFIRST

2025: MSE

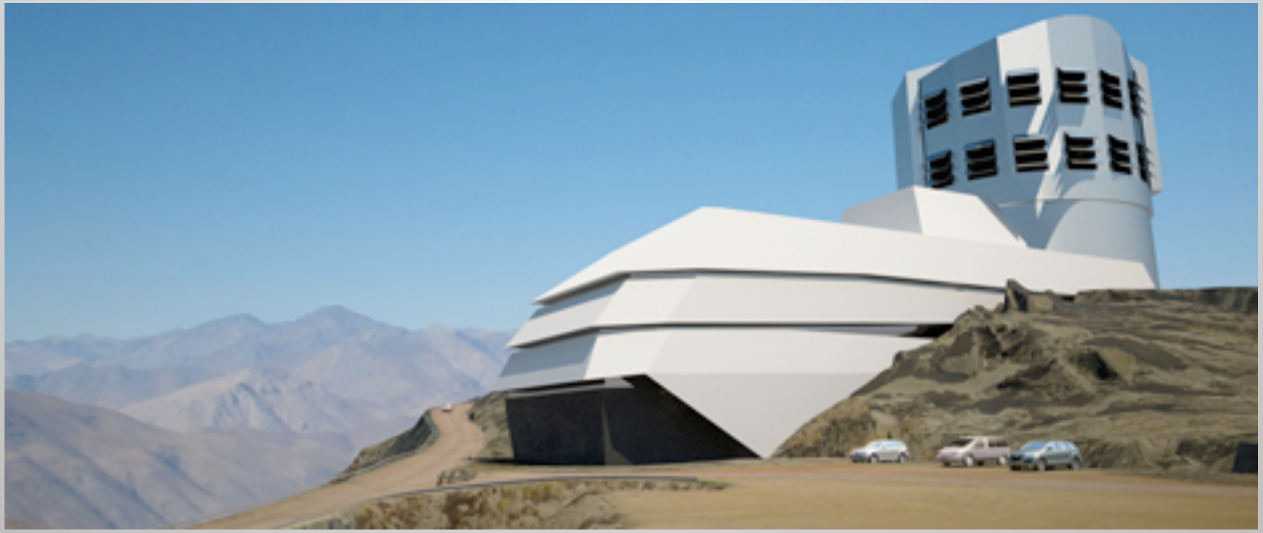
(+eROSITA, VLASS, etc at other wavebands)

(I certainly have missed some important projects)

I didn't have time to cover the following slides; they are included here for reference.

LSST: 6.7-m wide-field telescope on Cerro Pachón in Chilean Andes

Telescope will be dedicated to imaging survey, and will operate for ten years.

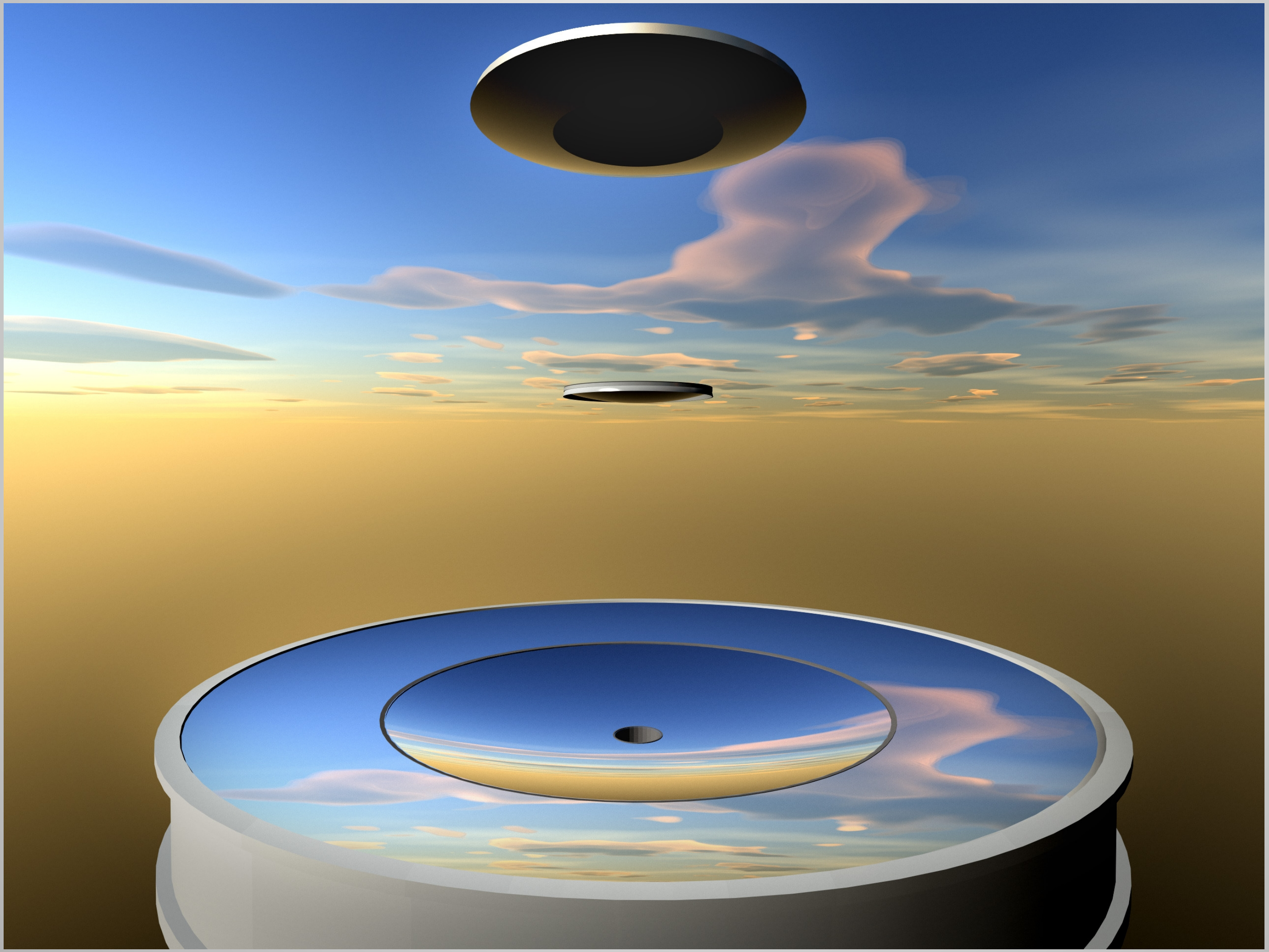


Site has been leveled; construction is underway

My wife and me standing on the spot LSST will be built

The LSST optics

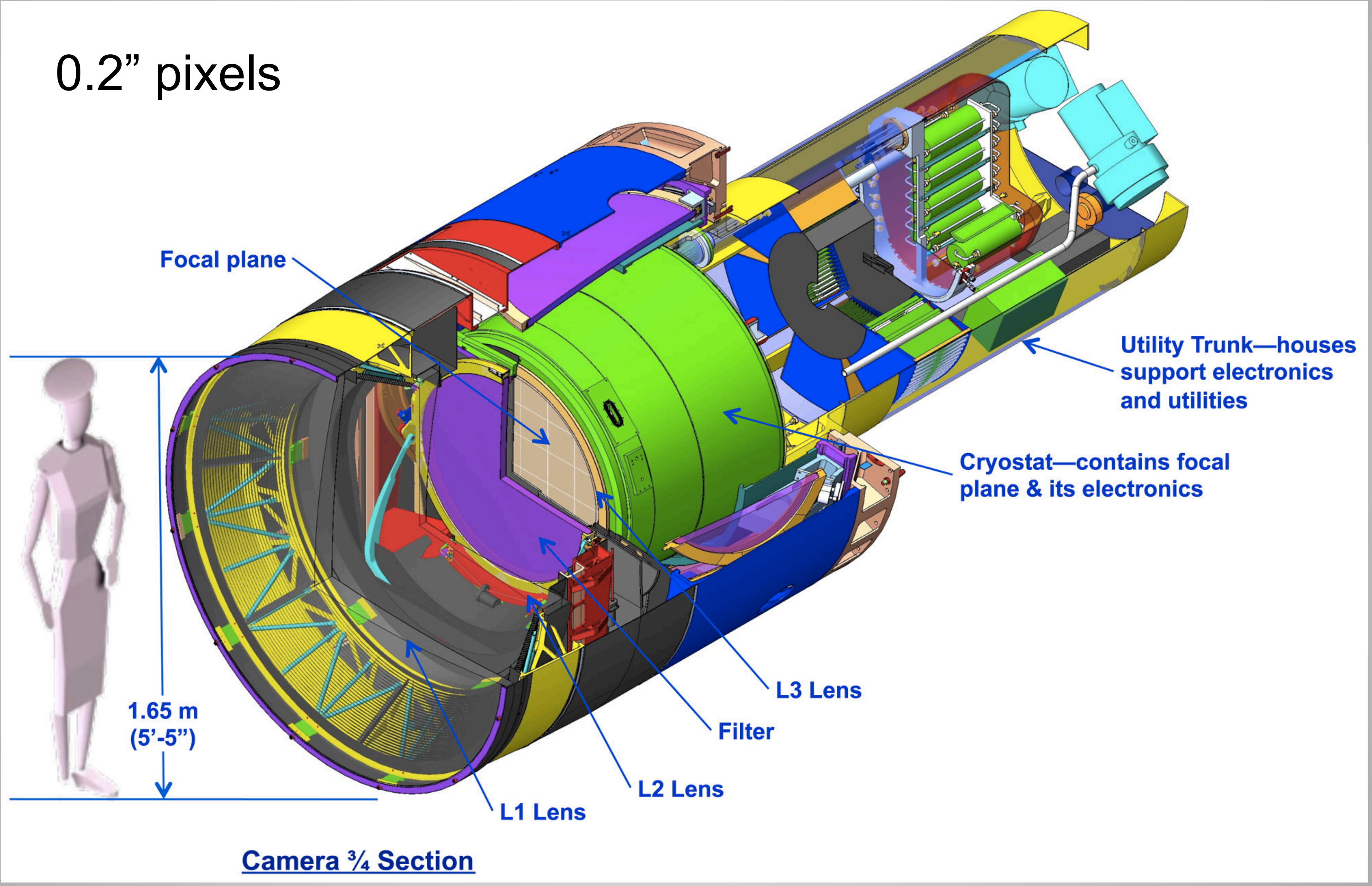
3-mirror design gives 9.6 deg^2 field of view.



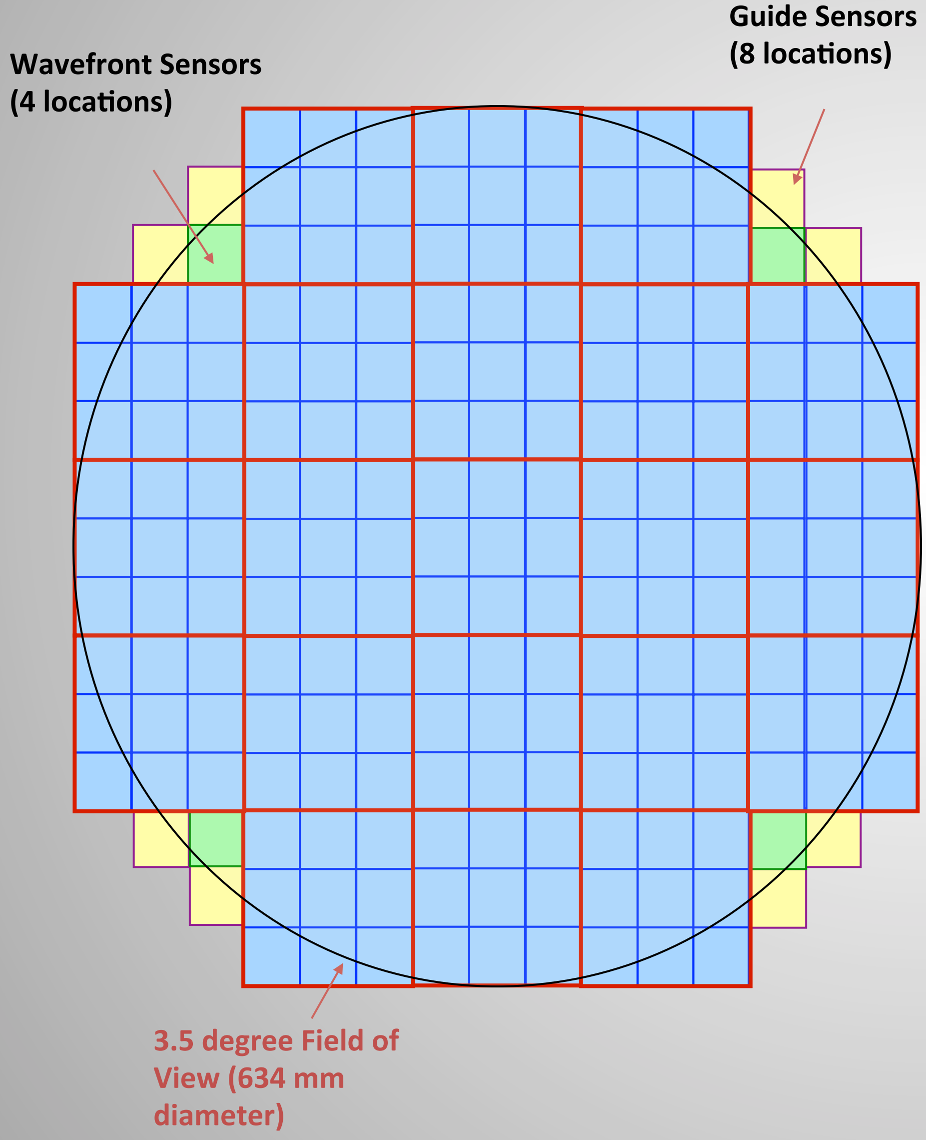
Grinding/polishing of primary/tertiary has been completed!

3.2 gigapixel camera. 9.6 deg^2 FoV

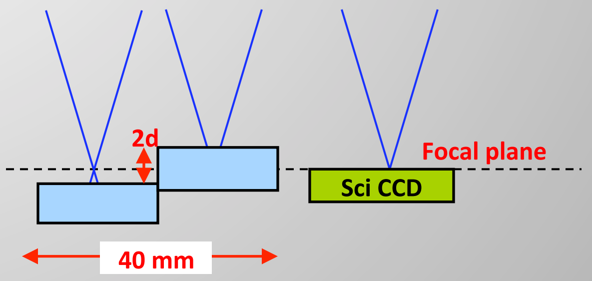
0.2" pixels



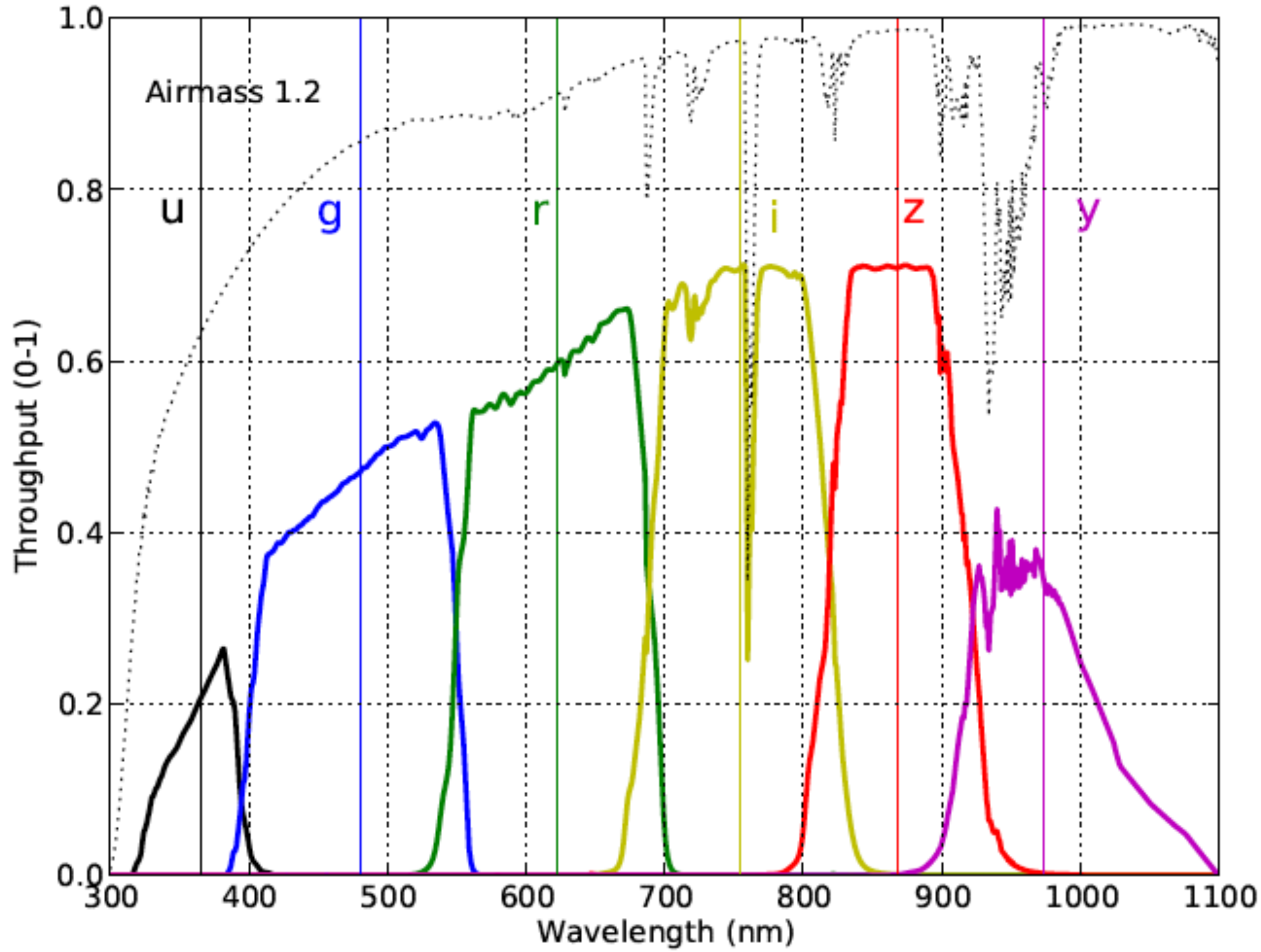
The LSST Focal Plane



Wavefront Sensor Layout



Curvature Sensor Side View Configuration



Airmass 1.2
u
g
r
i
z
y
Throughput (0-1)
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
600
700
800
900
1000
1100

LSST: A dedicated 10-year survey: 2022-2032

- Main survey will cover 18,000 deg^2 in Southern Hemisphere. Each "visit" is 2 15-second exposures. >800 30-sec visits across 6 filters over 10 years.
- 5σ point-source depth (1 visit, dark sky, at zenith) : 23.9 (*u*), 25.0 (*g*), 24.7 (*r*), **24.0** (*i*), 23.3 (*z*), 22.1 (*y*)
- Depth at end of the survey: 26.3 (*u*), 27.5 (*g*), 27.7 (*r*), **27.0** (*i*), 26.2 (*z*), 24.9 (*y*)
- Perhaps 10% of the time will be devoted to 'deep fields' ~1 mag deeper. Plus observations of ecliptic plane, low latitudes, South pole.
- ***40 trillion observations of 40 billion objects***

Extremely high-quality data

- Median delivered image quality of 0.67".
- Probes of variability on timescales from 15 seconds to 10 years.
- Stellar photometric calibration to 1% or better; stellar repeatability to 0.5%.
- Astrometry to 10 milli-arcsec per visit, allowing proper motion uncertainty of 0.2 mas/year, and parallax uncertainty of 0.6 mas over the course of the survey. LSST matches Gaia's astrometric precision at r~20, and extends it 4 magnitudes fainter.

LSST data releases

- No proprietary period for US and Chilean astronomers.
- No proprietary period for international affiliates who contribute to LSST operations (the list of these is growing).
- "Alerts" about objects whose properties have changed in repeat imaging will be released immediately (*see talks by Mahabal, Szkody*).
- Stacked data (images, catalogs) of the static sky will be released yearly.
- The limiting factor will be computational power to deal with the tens of petabytes of data.

Doing science with LSST

- LSST Project is funded by NSF and DOE to *construct* the facility. NSF: the goal of the LSST Project is to produce a database usable by the world. DOE: The LSST Project should do Dark Energy science.
- LSST has 10 science collaborations to prepare to do science with the project. Funding to support their work is a constant challenge.

Follow-up of discoveries by LSST and other big surveys will be key

- Amazing individual objects (such as transients) to be studied in great detail.
- Large samples of objects to be fully characterized.

(The amazing individual discoveries in early days of these surveys will become statistical samples by the time they finish).

- Bulk of LSST, WFIRST, Euclid objects will be faint: a thirty-meter telescope is what is needed!

Summary

- TMT time allocation should allow for major (multi-national?) surveys. They have the potential to be among the biggest impact science that TMT will do.
- Building major surveys requires attention to collaboration issues, data releases, software, etc…
- Major imaging and spectroscopic surveys over the next 15 years will be a major source of targets and scientific synergy with TMT.