Égboltfelmérő programok - amikor a számok tényleg csillagászatiak

Kiss László akadémikus

“Think Big, Move Smart”, 2015.05.14.

Miért csillagászat?

Csillagászat és a gyakorlati haszon

- A csillagászat alapkutatás – nem várható azonnali alkalmazás.

- Az a jó kérdésfelvetés, aminek a megválaszolásához technológiát kell fejleszteni.

- 17–18. század:
  - tökéletes optikák
  - földrajzi helymeghatározás

- 20–21. század:
  - tökéletes műszerek
  - **számítástechnikai fejlesztések**

Global Positioning System (GPS)

Alkalmazott égi mechanika!

Smithsonian National Air and Space Museum

Wifi: Legyen Ön is milliomos csillagász!

JOSA LETTERS

Image sharpness, Fourier optics, and redundant-spacing interferometry

J. P. Hamaker, J. D. O'Sullivan, and J. E. Noordam

Radio Observatory, Dwingeloo, The Netherlands

(Received 2 February 1977; revision received 7 May 1977)

We give a simple proof of the image sharpness criterion S_1 introduced by Muller and Buffington. A close connection with interferometric techniques for diffraction-limited imaging is pointed out. The method of our proof provides indications on the limited validity of several other sharpness criteria.

In a recent paper, Muller and Buffington[1] discuss a number of criteria that can be used for the real-time dynamic cancellation of phase errors introduced by atmospheric turbulence. In particular, they show that maximization of

$$S_1 = \iint I^2(\mathbf{x})\, d\mathbf{x}\ , \tag{1}$$

where **x** is the image coordinate vector, produces an error-free diffraction-limited image. The proof they offer for this assertion is cumbersome and fails to provide any insight into the physical meaning of the optimization process. We offer the following simple and illuminating proof.

According to a basic relation in the theory of Fourier optics,[2] $I(\mathbf{x})$ is (apart from scale factors which are irrelevant in the present context) the Fourier transform (FT) of the product of the mutual coherence or visibility function $V(\mathbf{u})$ in the entrance pupil and the optical transfer function $T(\mathbf{u})$:

$$I(\mathbf{x}) \xleftrightarrow{FT} V(\mathbf{u})\, T(\mathbf{u})\ . \tag{2}$$

T is the autocorrelation function of the pupil function $P(\mathbf{u})$:

$$T(\mathbf{u}) = \iint P(\mathbf{w})\, P^*(\mathbf{w}+\mathbf{u})\, d\mathbf{w}\ . \tag{3}$$

According to Parseval's theorem, then

$$S_1 = \iint I^2(\mathbf{x})\, d\mathbf{x} = \iint |V(\mathbf{u})|^2\, |T(\mathbf{u})|^2\, d\mathbf{u}\ . \tag{4}$$

$$\epsilon(\mathbf{w}) - \epsilon(\mathbf{w}+\mathbf{u}) = \Phi(\mathbf{u}) \quad \text{independent of } \mathbf{w}\ . \tag{8}$$

By expanding ϵ in a Taylor series,

$$\epsilon = a + \mathbf{b}\cdot\mathbf{u} + \mathbf{u}^T C\mathbf{u} + \cdots\ ; \tag{9}$$

and substituting, one recognizes that no terms beyond the linear one can exist. Thus,

$$\epsilon(\mathbf{a}) = a + \mathbf{b}\cdot\mathbf{u}\ . \tag{10}$$

The constant a is of no consequence. The tilt **b** corresponds to a shift of the image. Apart from this shift, maximizing S_1 leads to a perfect diffraction-limited image.

Before discussing an interesting parallel with radio-astronomical imaging techniques, we must at this point briefly digress on the concept of redundancy as it is familiar to radio practitioners. As Eq. (2) above indicates, a single measurement of the visibility function for each separation **u** present in the pupil would suffice to construct the image. This is indeed the standard practice in radio aperture synthesis. Its basic measuring device is the correlating interferometer, consisting of two antennas and an electronic correlator. Once the visibility values have been obtained, the image can be constructed with an optical transfer function $T(\mathbf{u})$ which can be arbitrarily specified. Radio interferometer arrays are therefore preferably laid out with "minimum redundancy," i.e., as many different separations as possible are realized with a given number of antennas. On the other hand, the presence of redundant element

Wifi: Legyen Ön is milliomos csillagász!

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A csillagászat “nagy kérdései”

- **Hogyan és mikor keletkezett az Univerzum? Miből jött létre?**
- **Hogyan jöttek létre a kozmikus struktúrák (bolygók, csillagok, galaxisok)?**
- **Mennyire különleges a Föld? Egyedül vagyunk a Világegyetemben?**

Másképpen: ugyanúgy “működik-e” az általunk ismert fizika mindenhol? Lehet-e új fizikát felfedezni az égi jelenségek megfigyelésével?

A csillagászat mért mennyiségei

- **Égi irányok** - koordináták
- **Fényesség** - pontszerű és kiterjedt objektumok
- **Színkép** - folytonos és vonalas spektrumok
- **Sokaságok vizsgálata** - égboltfelmérések

A pontosság/mennyiség növelése új fizikai jelenségek felfedezéséhez vezethet!

Égboltfelmérések

Nagyságrendi ugrások:

- 5000 csillag: szabad szemmel látszó égbolt (ókor)
- 100 ezer csillag: távcsöves, vizuális felmérés (19. sz.) - Tejútrendszer szerkezete
- 10 millió csillag: fotografikus felmérés, égbolt homogén határfényességű lefedése (1950)
- 1 milliárd csillag: digitális felmérés - a Tejútrendszer 1%-a (2000)
- Pánkromatikus és spektroszkópiai felmérések: precíziós kozmológia (2020)

LSST:
Large Synoptic Survey Telescope

LSST: a digital color movie of the Universe

színes, digitális mozgókép az Univerzumról

Željko Ivezić, LSST Project Scientist

University of Washington and
Konkoly Observatory
Research Centre for Astronomy and Earth Sciences
Hungarian Academy of Sciences, Budapest

June 10, 2013

MEMORANDUM OF AGREEMENT

Regarding collaboration in the scientific exploitation of data acquired with LSST by specified Principal Investigators (PI) and scientists at the Konkoly Observatory.

BETWEEN

THE ASTRONOMICAL INSTITUTE (KONKOLY OBSERVATORY) OF THE RESEARCH CENTRE FOR ASTRONOMY AND EARTH SCIENCES OF THE HUNGARIAN ACADEMY OF SCIENCES
KONKOLY TH.M. UT 15-17., H-1121 BUDAPEST, HUNGARY
hereinafter referred to as **"THE KONKOLY OBSERVATORY",**

AND

THE LARGE SYNOPTIC SURVEY TELESCOPE CORPORATION,
933 N. Cherry Ave., Tucson, AZ 85721

a United States 501(c)3 non-profit corporation
incorporated in the State of Arizona

hereinafter referred to as **"LSSTC",**

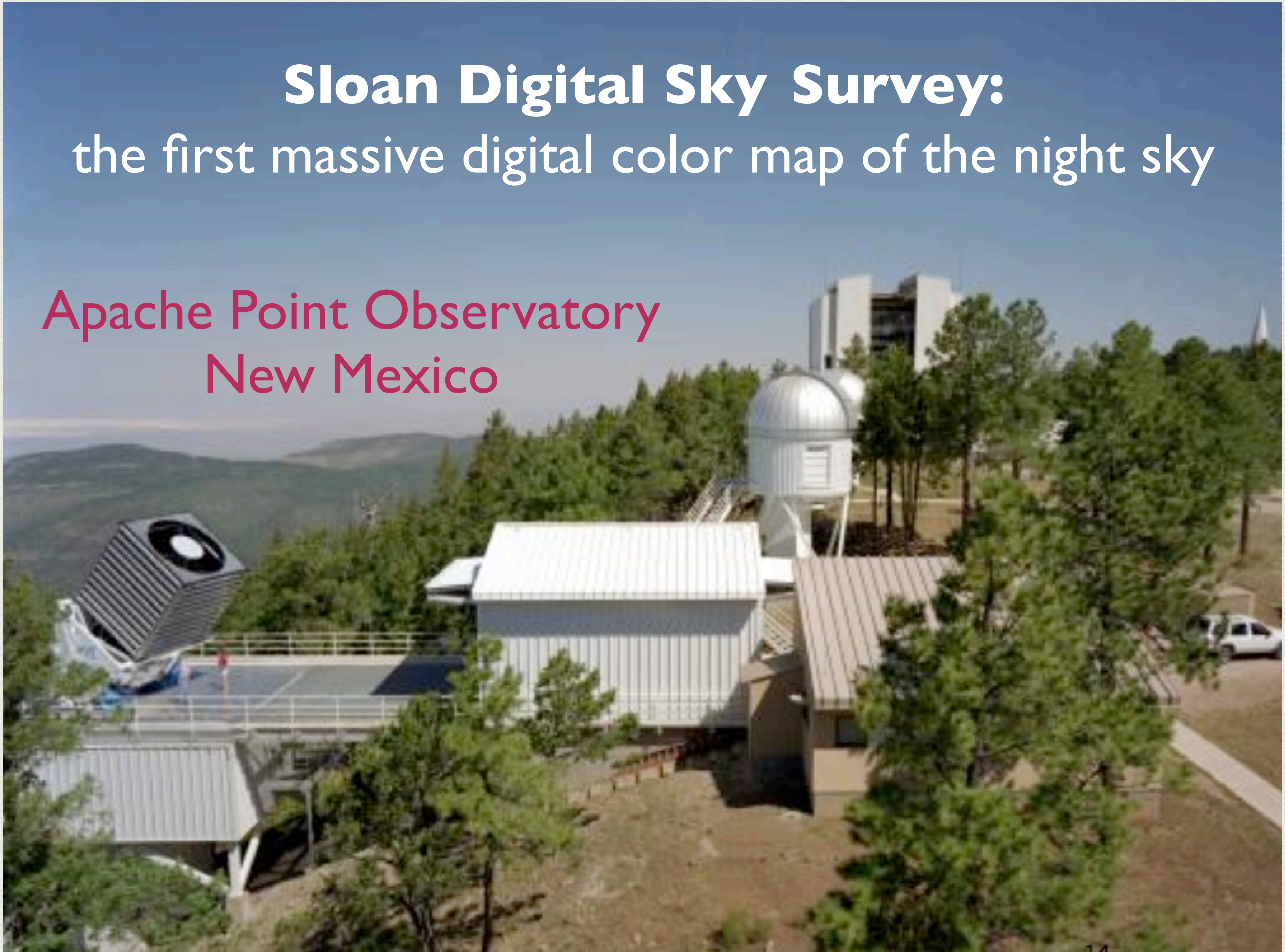
both hereinafter referred to collectively as **"the Parties"** or individually as **"the Party."**

RECITALS

WHEREAS LSSTC is a not-for-profit corporation established as a consortium of universities, United States national laboratories and other organizations to develop the LSST project and to raise private and federal funding, principally from United States agencies, to support LSST, and

Sloan Digital Sky Survey:

the first massive digital color map of the night sky



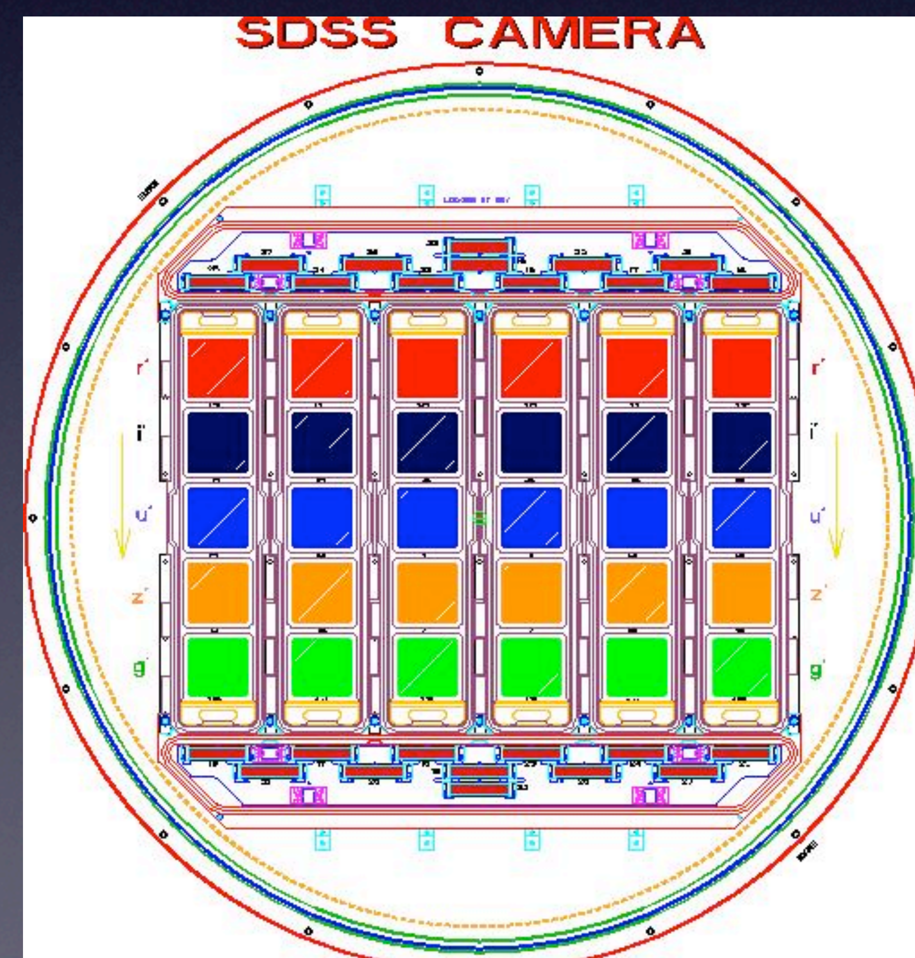
Apache Point Observatory
New Mexico

Sloan Digital Sky Survey

- Új-Mexikó, 2,5m-es teleszkóp Apache Pointban
- Öt színben képalkotás több mint 100 millió égitestről
- Kb. 700 ezer spektrum galaxisokról, kvazárokról és csillagokról
- Fontos magyar részvevők (Szalay Sándor, Csabai István és tanítványaik)

The last decade: SDSS as an example

- Digital sky survey with a 120 Megapix CCD camera
- Precise measurements for 400,000,000 objects
- Revolution in astronomy: public databases released before a substantial fraction of analysis was done by the project team



As a result of SDSS public data releases:

- Several thousands of refereed papers, a majority authored by scientists not associated with SDSS
- Delivered >100 times the total data volume

Prof. James E. Gunn accepts a National Medal of Science

- Over 300,000,000 web hits in 6 years with over a million unique users (vs. 10,000 astronomers)

The 2010 SDSS-III collaboration meeting in Paris

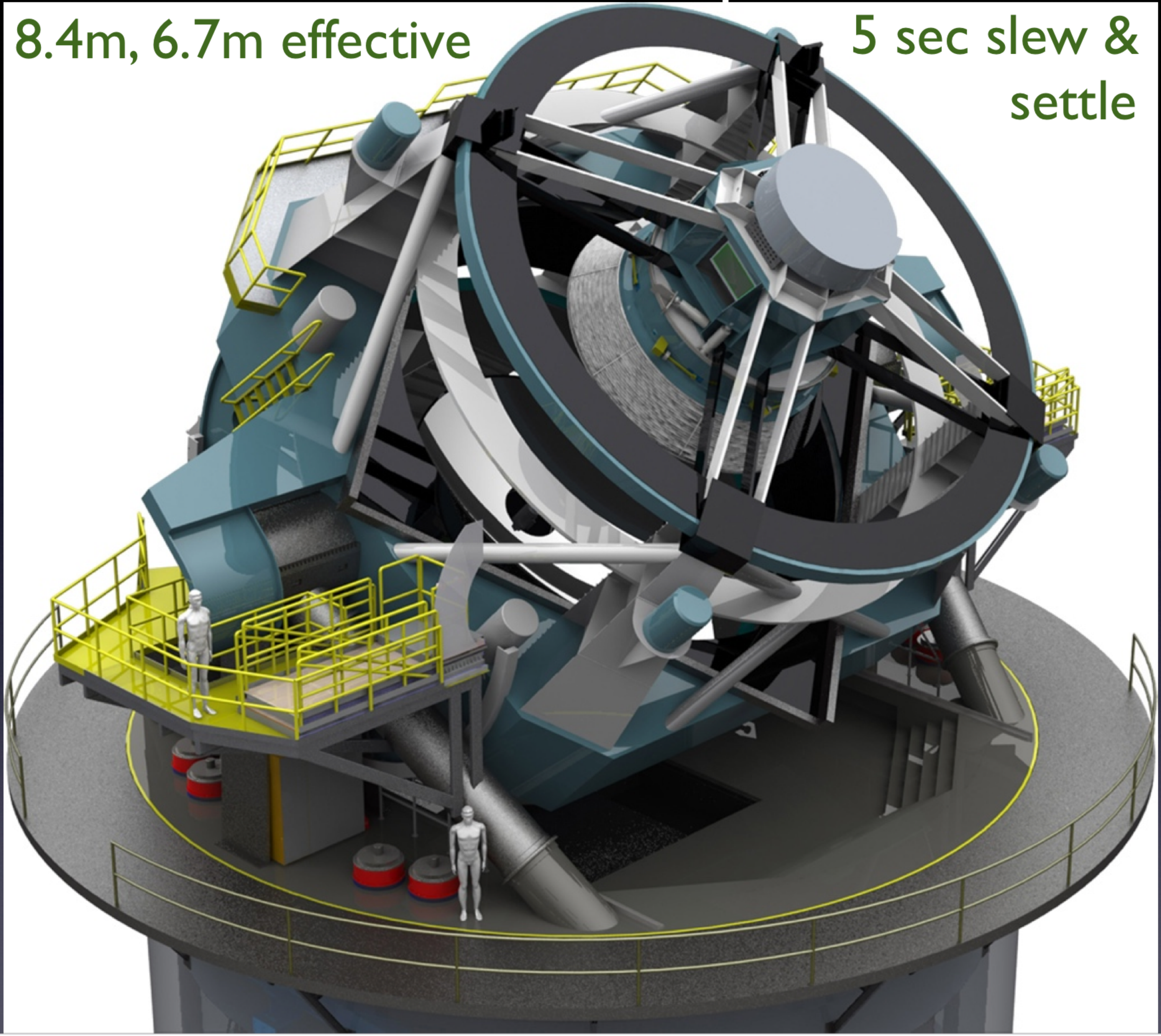
Surveys are made by real people

A peek into the future: the Large Synoptic Survey Telescope

LSST Telescope

8.4m, 6.7m effective

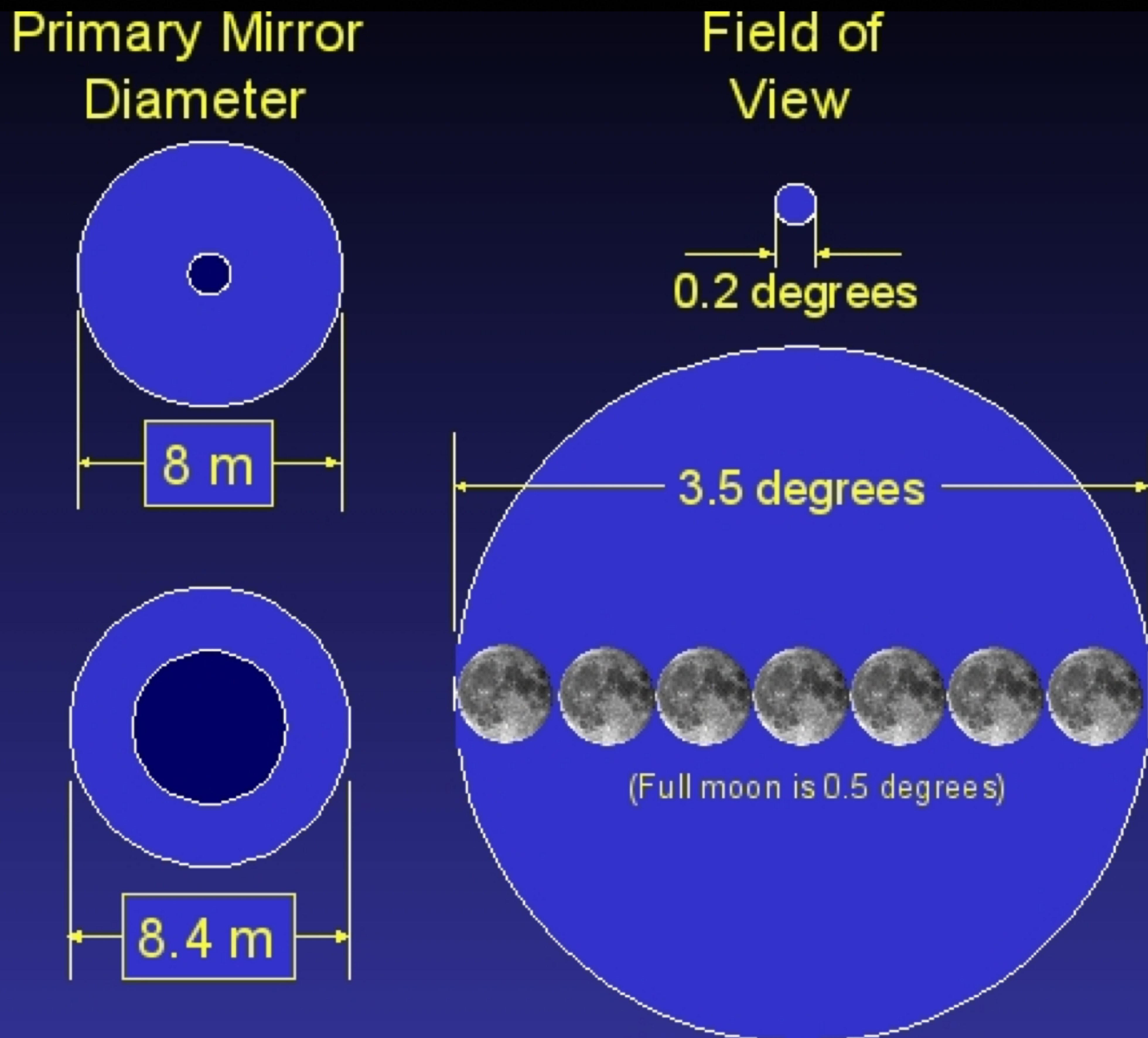
5 sec slew & settle



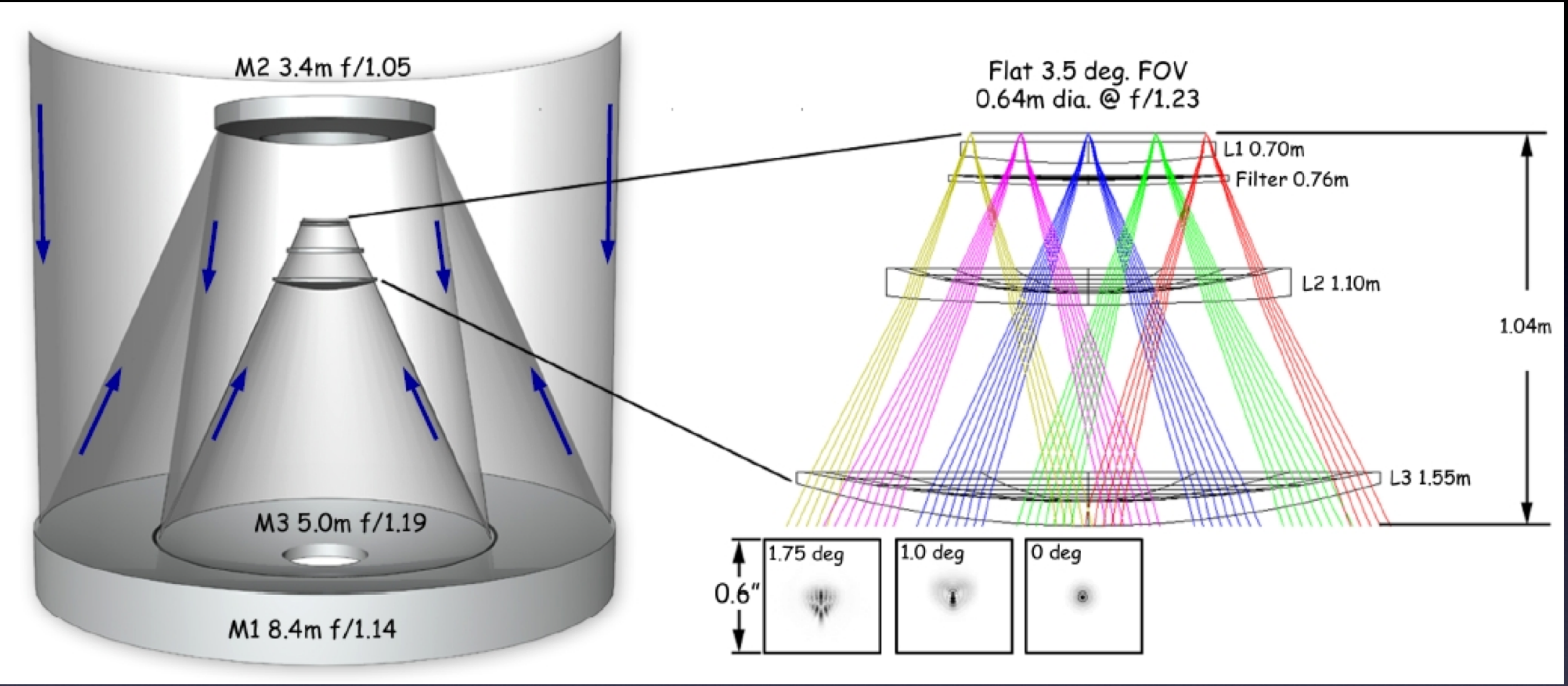
The field-of-view comparison: Gemini vs. LSST

Gemini South Telescope

LSST

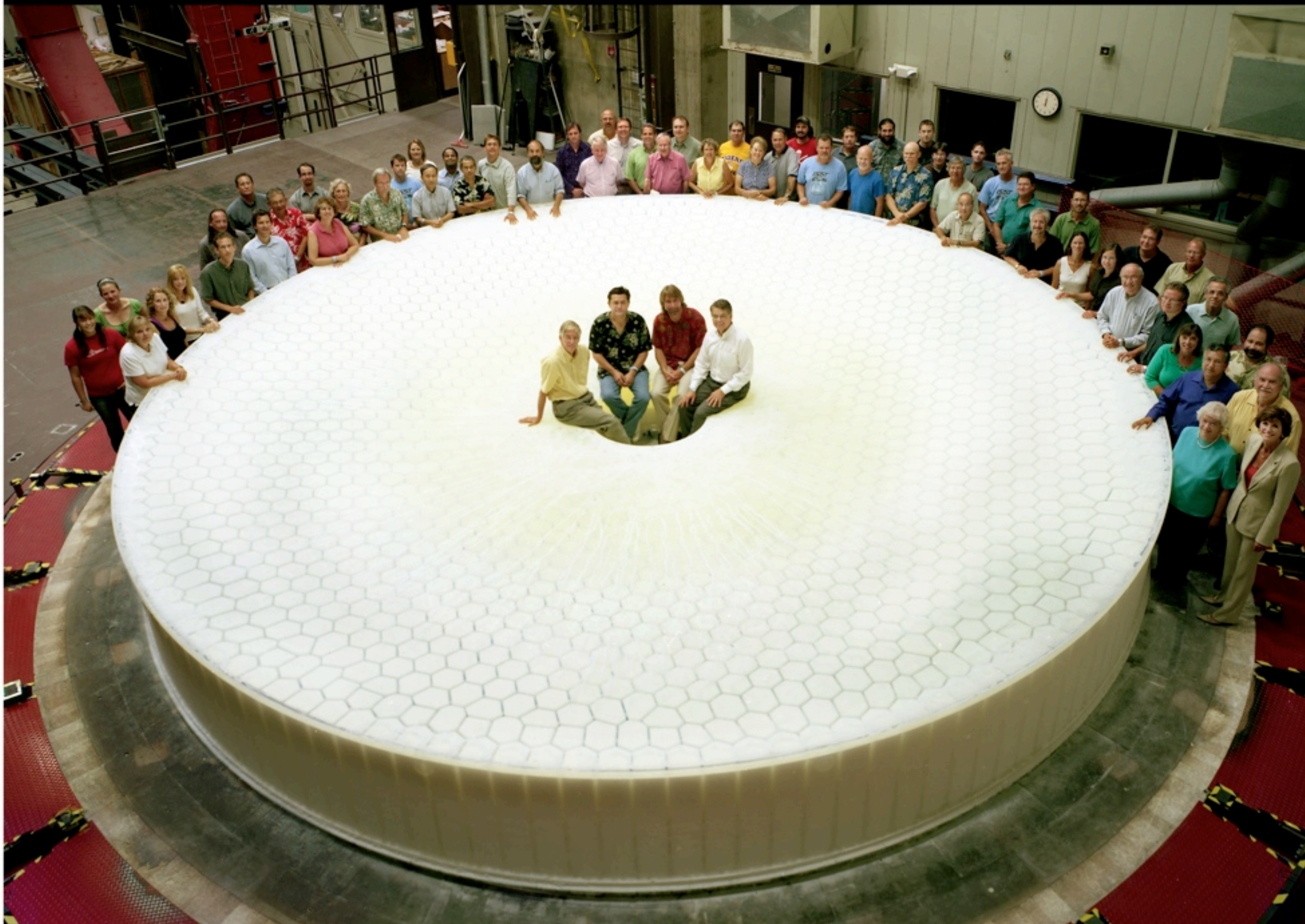


Optical Design for LSST



Three-mirror design (Paul-Baker system)
enables large field of view with excellent image quality:
delivered image quality is dominated by atmospheric seeing

Large Synoptic Survey Telescope



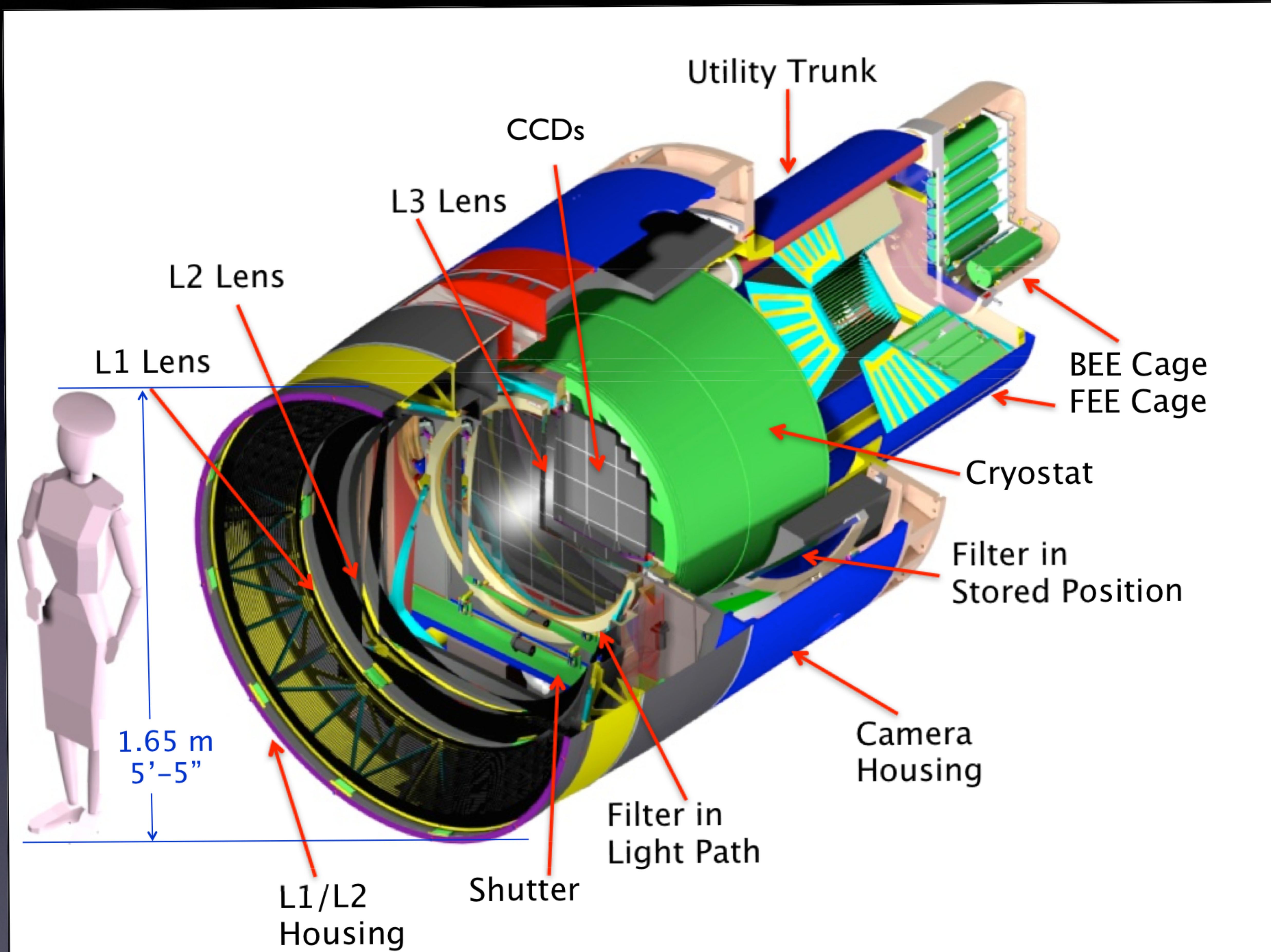
The University of Arizona
Tucson Arizona

SOML

LSST Primary/Tertiary Mirror Blank
August 11, 2008, Steward Observatory Mirror Lab, Tucson, Arizona

Large Synoptic Survey Telescope

The largest astronomical camera: 2800 kg, 3.2 Gpix



Software: the subsystem with the highest risk

- 20 TB of data to process every day
- 100 PB of data
- 1000 measurements for 20 billion objects during10 years
- Existing tools and methods (e.g. SDSS) do not scale up to LSST data volume and rate

Software: the subsystem with the highest risk

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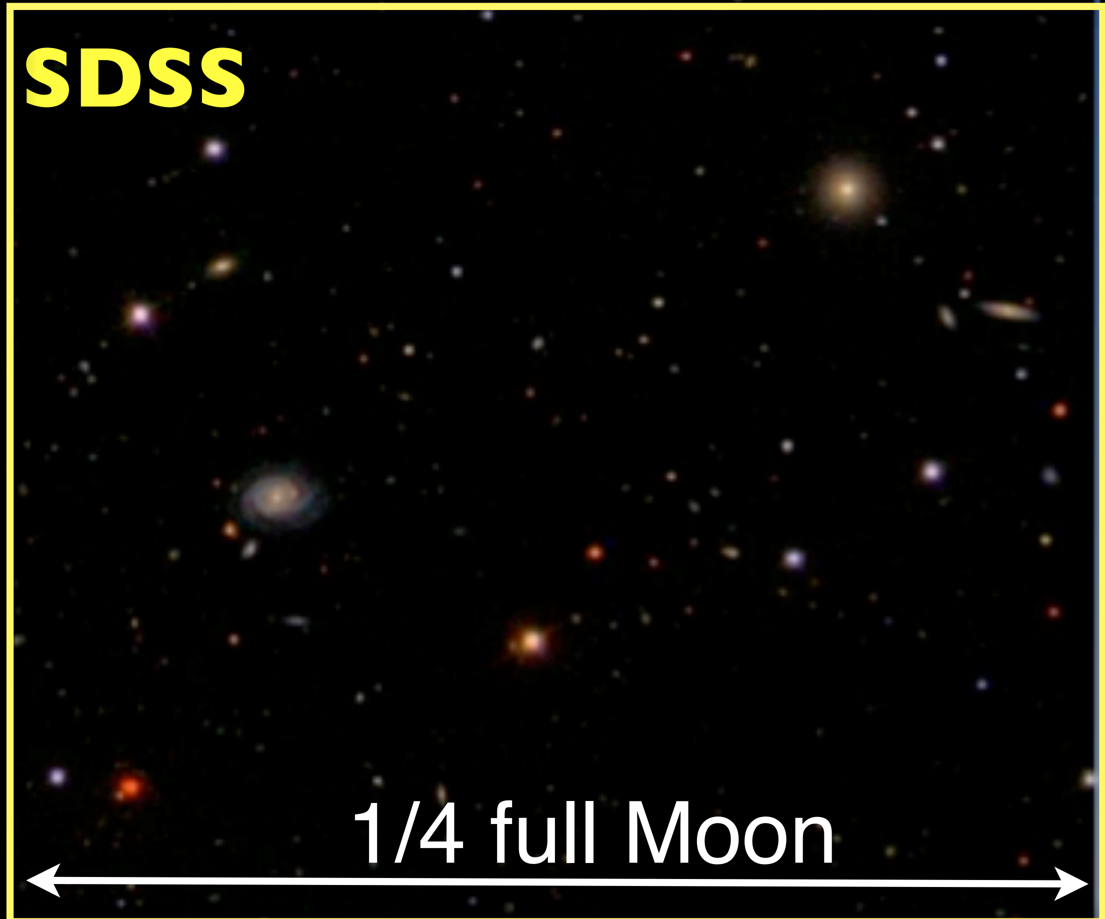
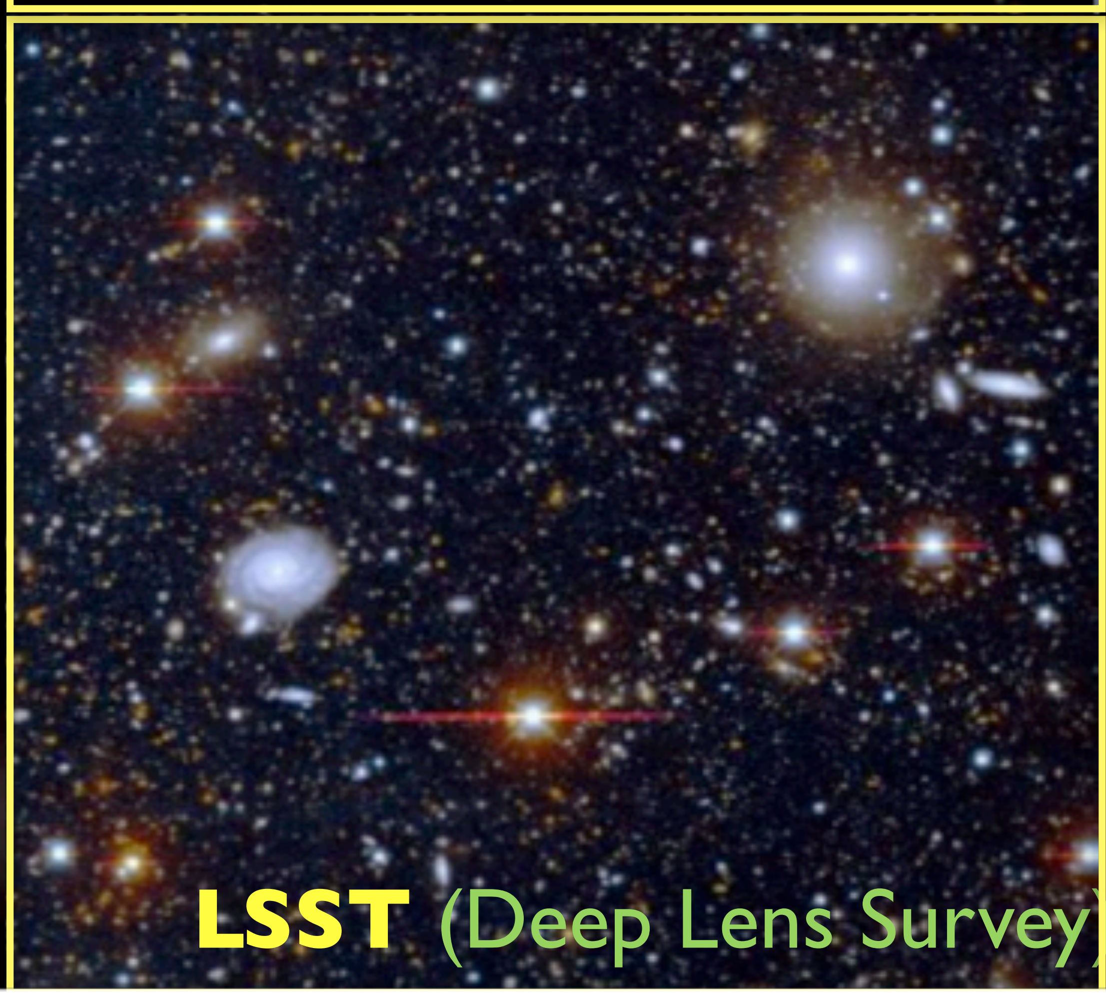
- 100 PB of data
- 1000 measurements for 20 billion objects during10 years
- Existing tools and methods (e.g. SDSS) do not scale up to LSST data volume and rate

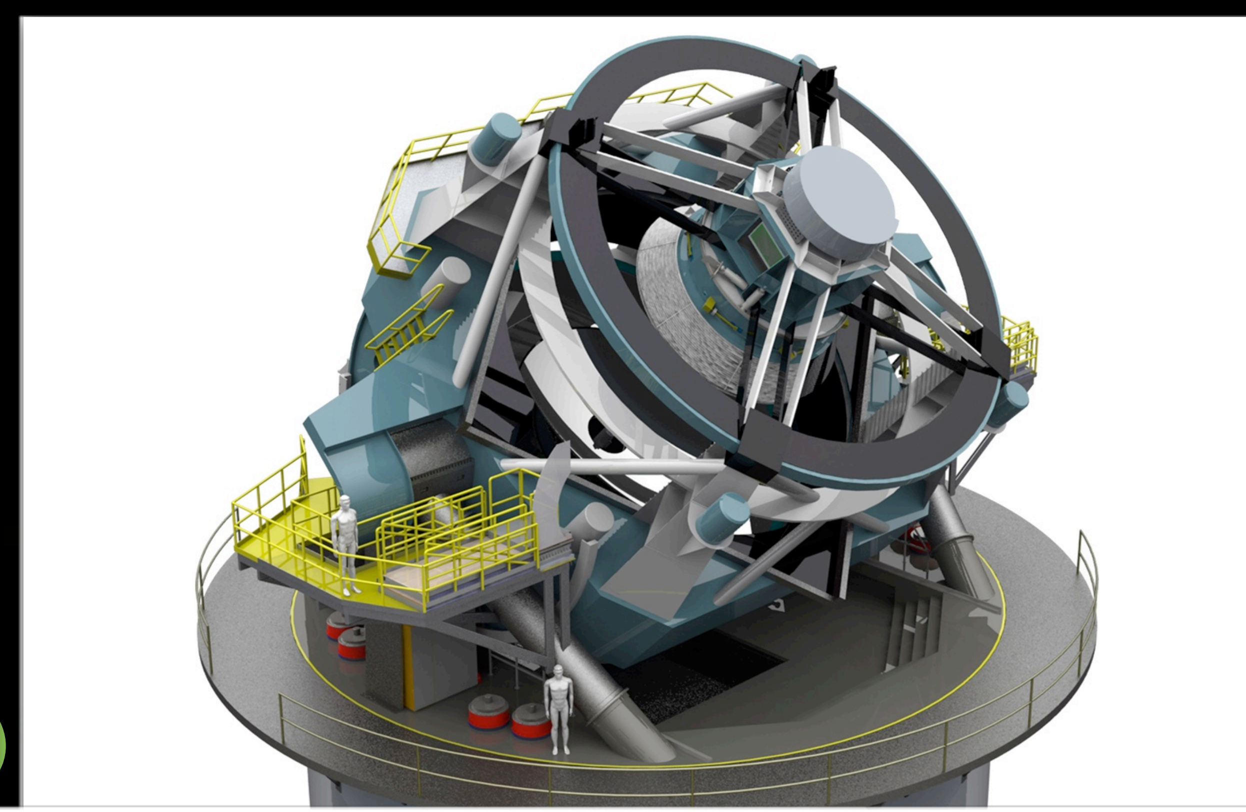
- About 5-10 million lines of new code
- C++/python
- A collaboration of astronomers, physicists and professional programmers



SDSS: one US Library of Congress worth of data

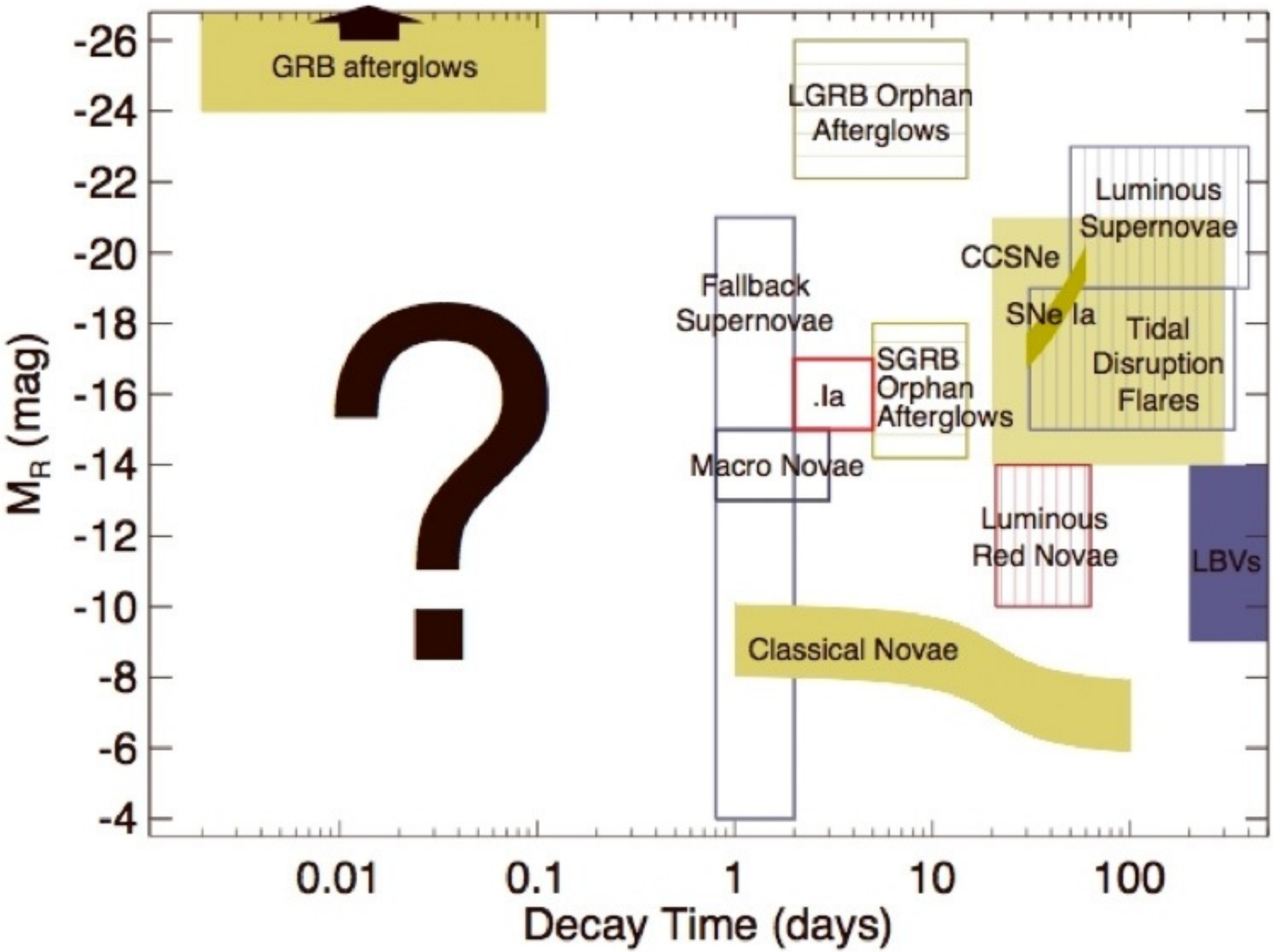
LSST: one SDSS per night, or all the words ever printed!



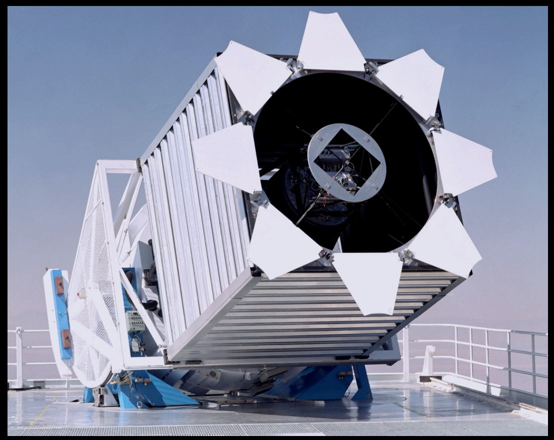


Az LSST tudományos témái

- **Sötét anyag, sötét energia, kozmológia (galaxistérképek, szupernóvák, kvazárok)**
- **Időtartomány (tranziensek, változócsillagok)**
- **A Naprendszer szerkezete (kisbolygók)**
- **A Tejútrendszer szerkezete (csillagok)**



GRB afterglows
LGRB Orphan Afterglows
Luminous Supernovae
CCSNe
Fallback Supernovae
SNe Ia
Tidal Disruption Flares
SGRB Orphan Afterglows
.Ia
Macro Novae
Luminous Red Novae
LBVs
Classical Novae
?
M_R (mag)
Decay Time (days)
-26
-24
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
0.01
0.1
1
10
100



More information at
www.lsst.org
and arXiv:0805.2366

The Excitement of LSST

- **The Best Sky Image Ever:** 60 petabytes of astronomical image data (resolution equal to 3 million HDTV sets)
- **The Greatest Movie of All Time:** digital images of the entire observable sky every three nights, night after night, for 10 years (11 months to "view" it)
- **The Largest Astronomical Catalog:** 20 billion sources (for the first time in history more than living people)

Köszönöm a figyelmet!

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