Surveys Past and Future and Their Impact on Astronomy

Jim Gunn 14/06/09

Surveys

Astrophysics is the pursuit of understanding the universe and its contents.

There are basically two approaches to this pursuit:

1. *Understand in detail how an individual object (star, galaxy, planet) works.*

2. *Realizing that there are too many objects and that their variety is too great to study them all In detail, attempt a statistical approach by studying very large numbers to study their properties and, especially, their interactions and population properties.*

General goal of astronomical surveys, starting, perhaps, with Ptolemy.

Both are necessary, clearly,
MUST have surveys before any general lessons can be learned from (1)--
must know the general characteristics of the population.
:

A Brief History

Began with Ptolemy and the Almagest in the 2^{nd} century, and set the contents and purpose of surveys for the next 1700 years

Star positions, brightnesses, and motions.

Culminated with the Bonner Durchmusterung (BD) 1863-~1900
325,000 stars to ~9^{th} magnitude. Visual at first, some later additions photographic

All basically astrometric/photometric

Somewhat later, the Henry Draper catalog, 1918-24, photographic with objective prism, first spectroscopic survey. Similar depth and numbers as BD. Spectral classes for ~340,000 stars

These data were the bread and butter of stellar astronomy for decades.

Later ....

The whole subject of extragalactic astronomy had to wait until we knew what the term meant.....

Necessary to have wide-field, large instruments to record faint obects and faint surface brightnesses.

Provided by Bernhard Schmidt in 1930,

Potential recognized by Fritz Zwicky:
18-inch at Palomar -> 48-inch with 6.5degree FOV

Survey: POSS (1958) two bands, blue and red to ~ 21^{st} magnitude, but no catalog (~50 million galaxies, ~half a billion stars, no computers)

Meanwhile, in space, NASA was learning to deal with surveys which produce digital data

IRAS (1983) 350,000 sources, electronically published, accessible to all

And Later ....

Clear that we needed a successor to POSS, *NOT* photographic, in as many bands as reasonably possible, and the technology obliged, on several fronts:

1. ***Computers. (Completely impossible without them)***

2. ***Large back-illuminated CCDs***

3. ***Lightweight, relatively inexpensive telescopes, so a dedicated facility could be built (computers)***

4. ***Ability to design and fabricate complex fast optics, required by (3) (computers)***

5. ***Availability of f/ratio preserving silica-glass optical fibers for spectroscopy, so one could do an imaging AND spectroscopic survey***

These converged in the late 1980s

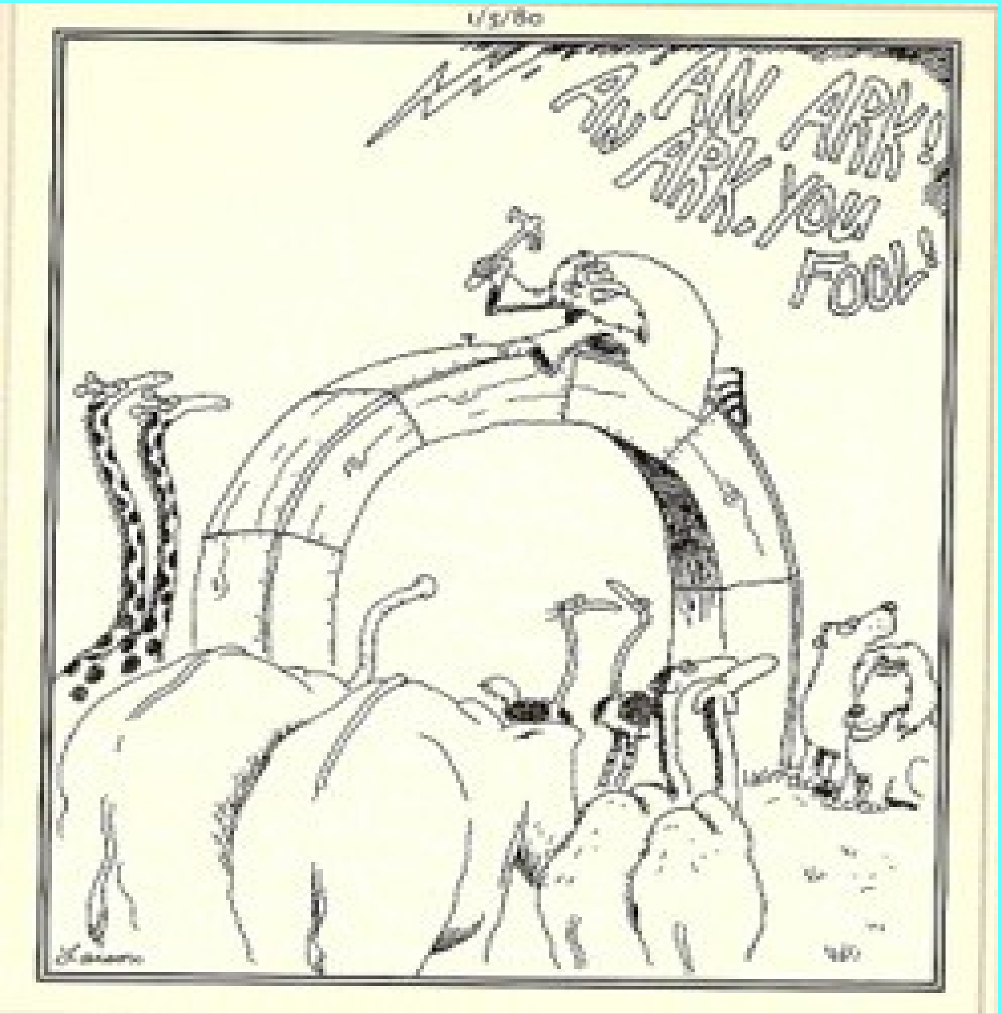
Meanwhile, Back at the Ranch...

The astronomy deparment at UW had a dream.

Don moved to UC, and it became *his* dream.

The Astrophysical Research Consortium --- ARC --- was formed, with partners

University of Washington
Washington State
University of Chicago,
Princeton,
New Mexico State U



The dream expanded from 2m to 3.5m with the advent of Roger Angel's lightweight mirror technology, into THIS:

A very modern, lighweight
3.5-meter telescope embodying
many new ideas and features, including

o Altazimuth mount

o Friction Drives

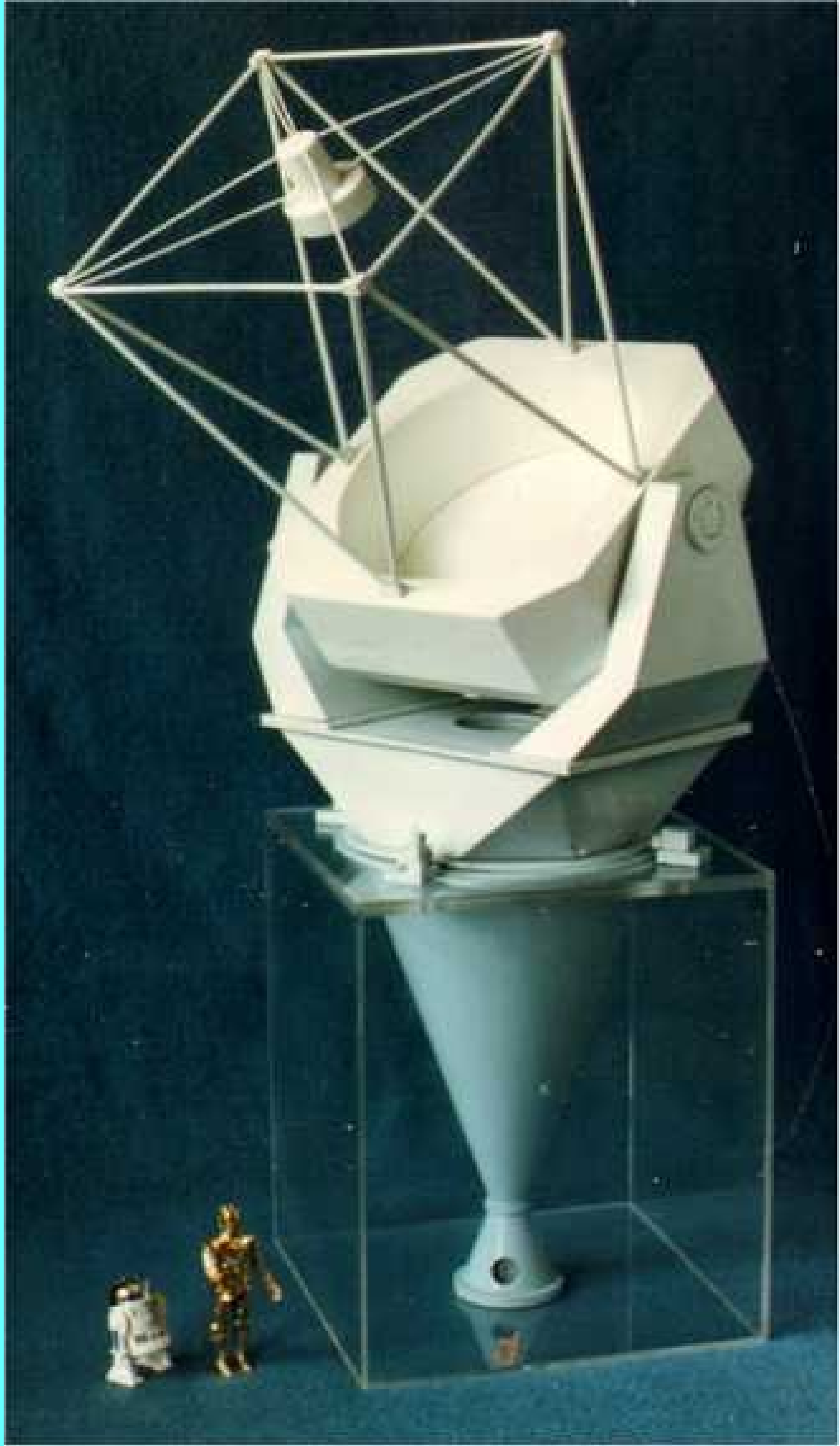
o Fast, lightweight optics

o Rapid instrument change

o Remote observing capability

All under Don's enthusiastic and
knowledgeable directorship.

The primary was one of the first
of Roger Angel's spin-cast mirrors,
in which the rough surface shape is
established in the molten glass by
carefully controlled rotation of the oven.

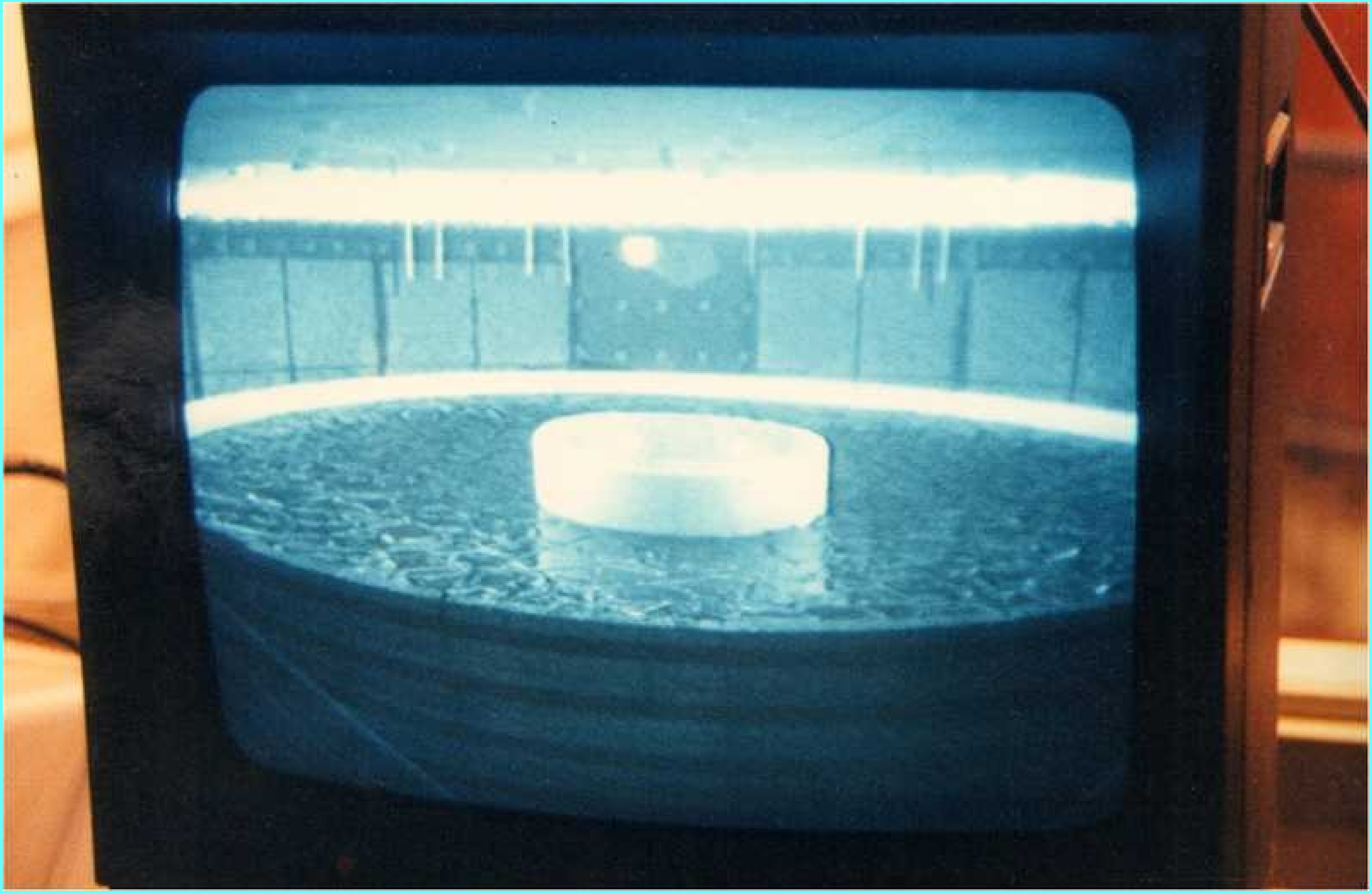


here:

Finishing Touches on the Mold

Mold loaded with Glass

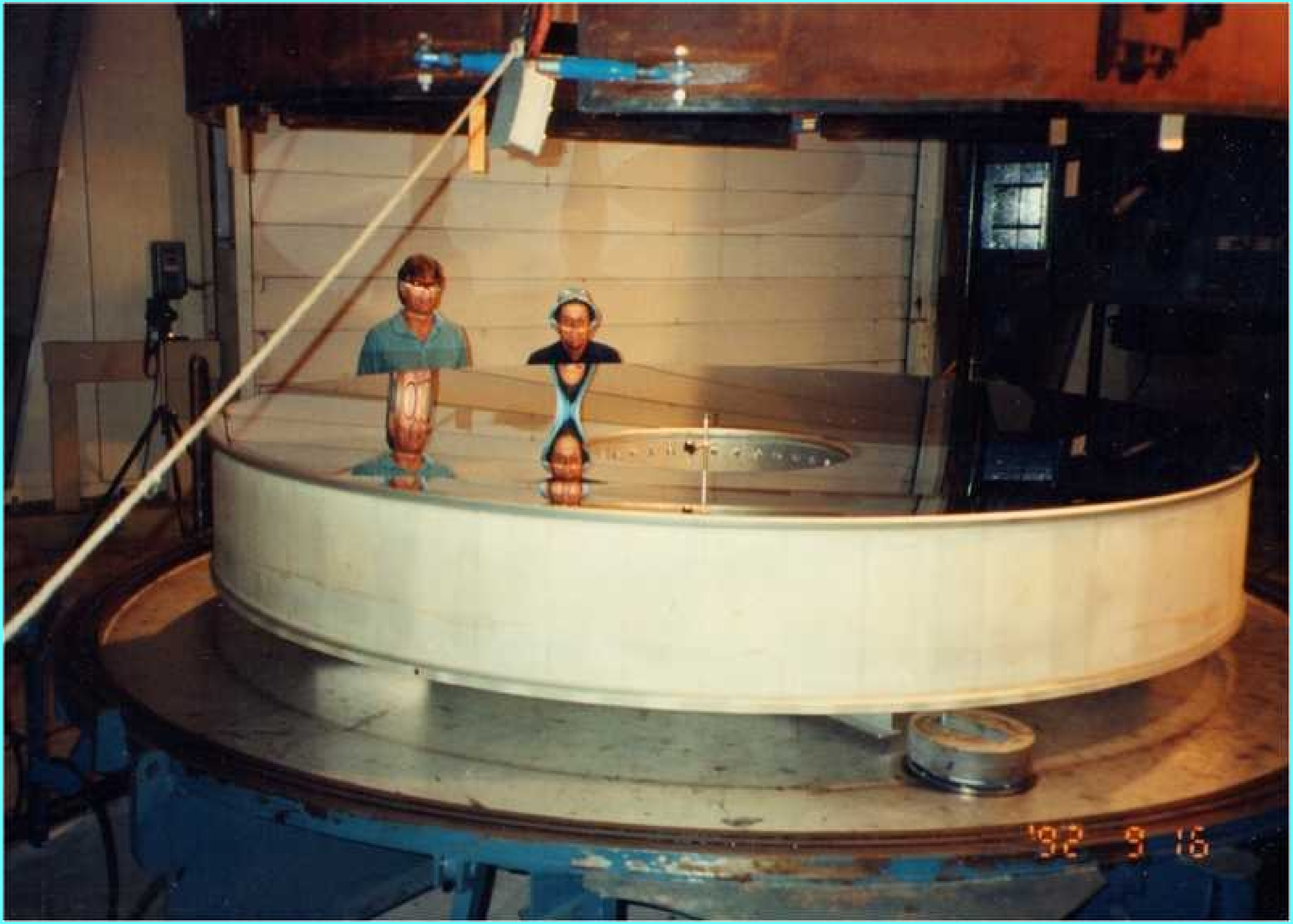
In the Oven, Molten

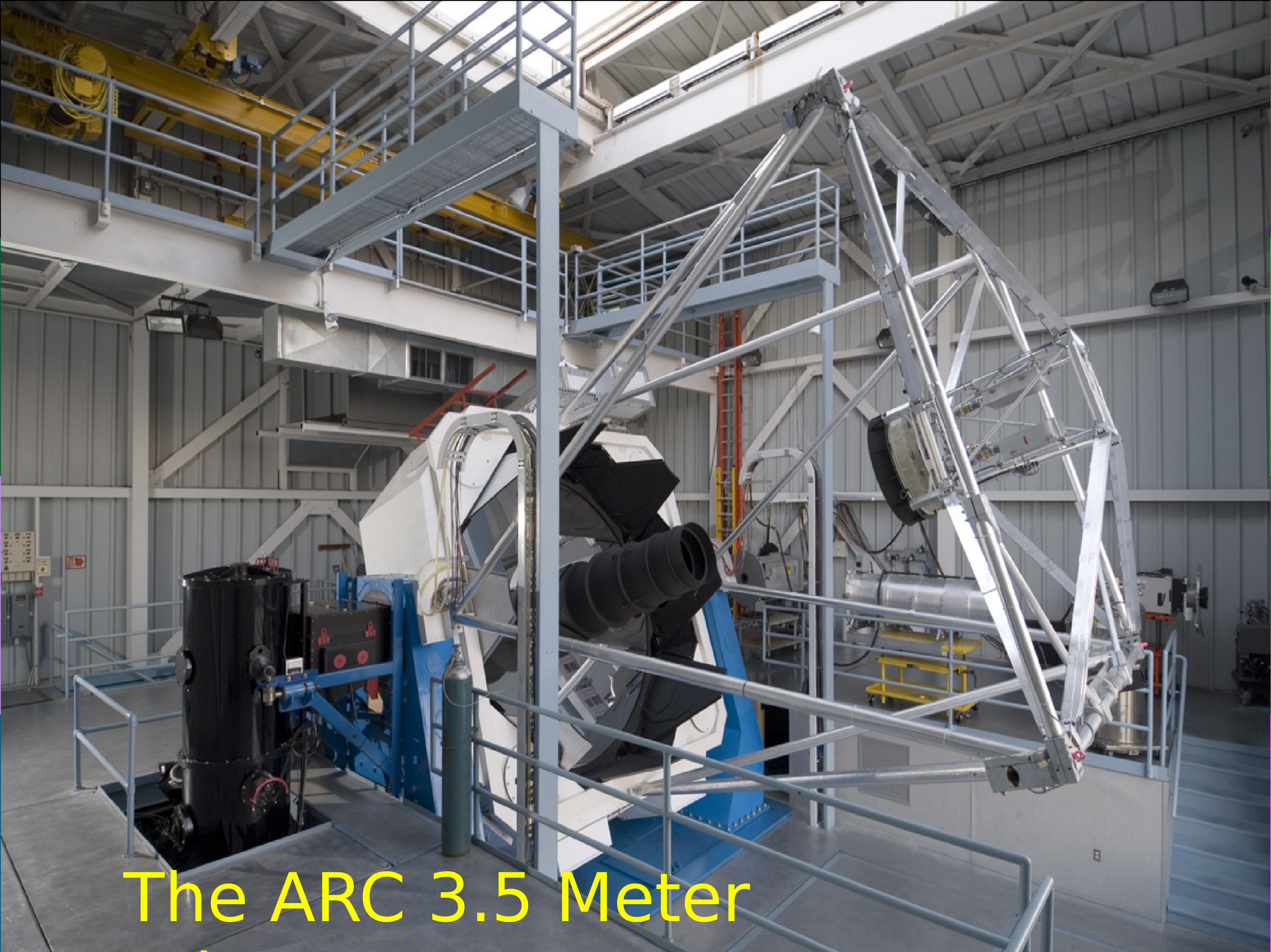


Finished Perfect Blank

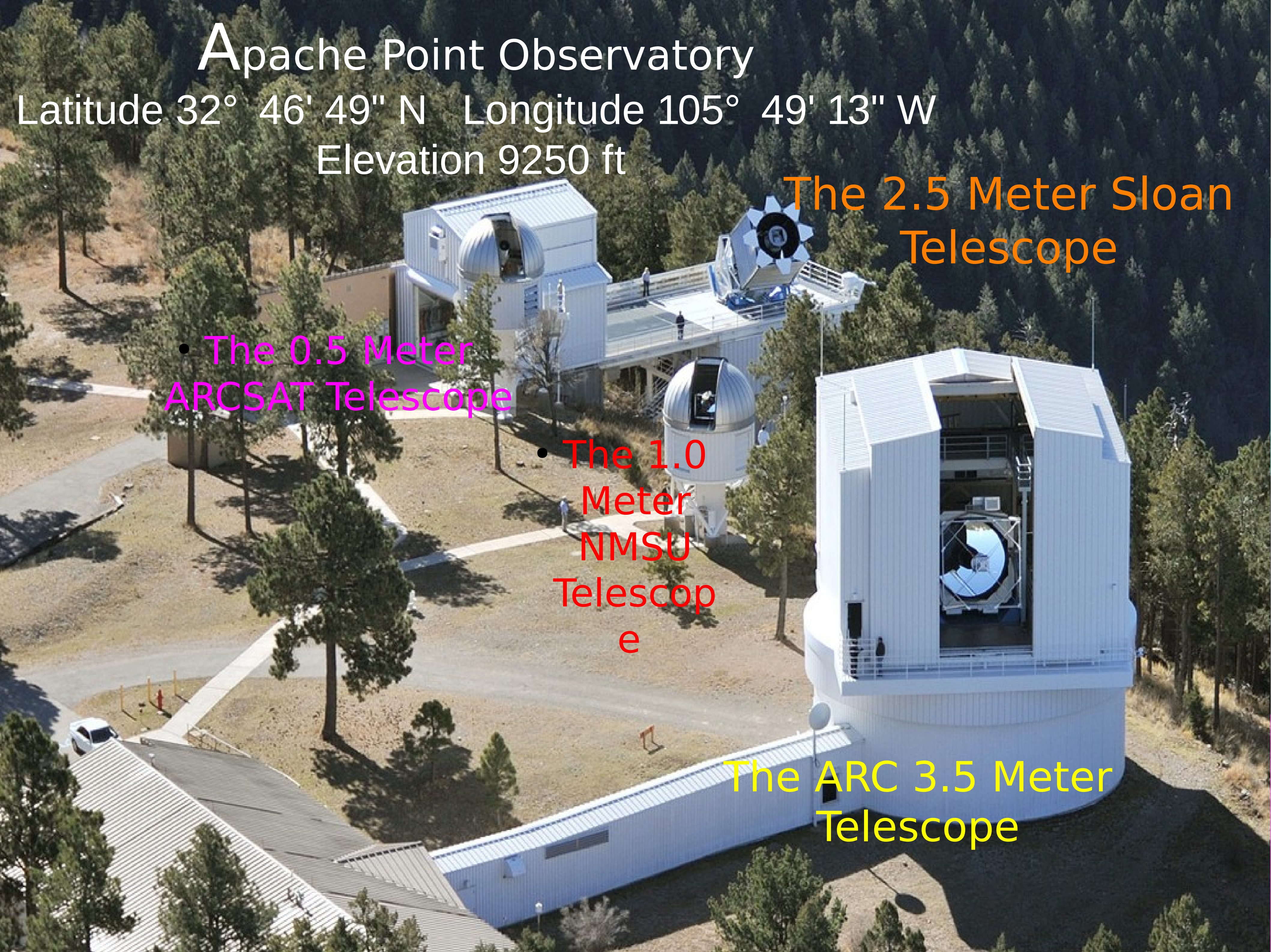
And a Small (?) Celebration at the Event

Ground, Polished, Figured and Coated





The ARC 3.5 Meter


Apache Point Observatory
Latitude 32° 46' 49" N Longitude 105° 49' 13" W
Elevation 9250 ft
The 2.5 Meter Sloan Telescope
• The 0.5 Meter ARCSAT Telescope
• The 1.0 Meter NMSU Telescope
The ARC 3.5 Meter Telescope

And Now, to the Little Telescope in the Back ....

Clear that we needed a successor to POSS, *NOT* photographic, in as many bands as reasonably possible, and the technology obliged, on several fronts:

1. ***Computers. (Completely impossible without them) to reduce, store, and access the data)***

2. ***Large back-illuminated CCDs***

3. ***Lightweight, relatively inexpensive telescopes, so a dedicated facility could be built (computers)***

4. ***Ability to design and fabricate complex fast optics, required by (3) (computers)***

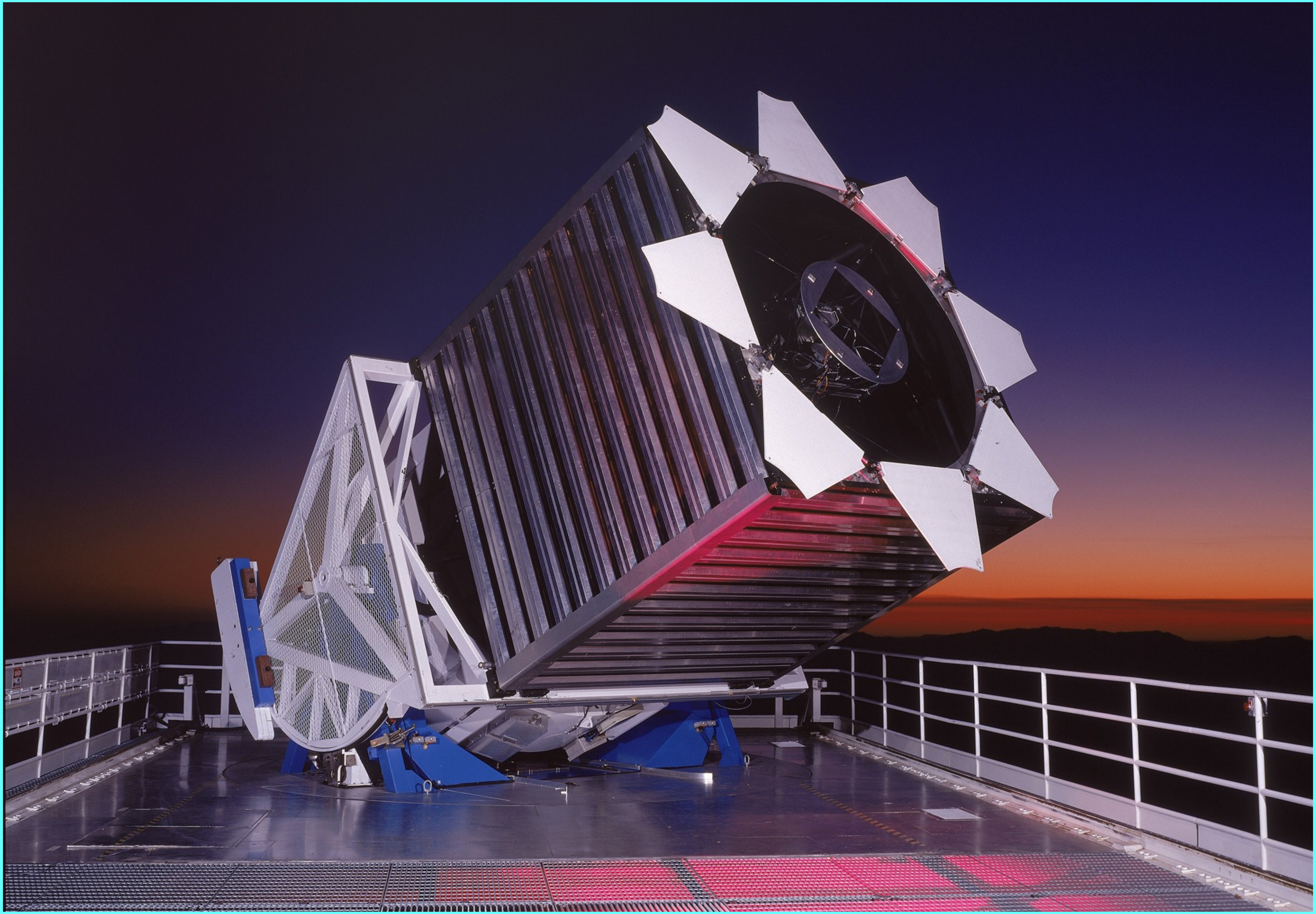
5. ***Availability of f/ratio preserving silica-glass optical fibers for spectroscopy, so one could do an imaging AND spectroscopic survey. 600 fibers – survey takes 5 years, not 3000 if done one by one.***

These converged in the late 1980s, and we built one, again under Don's directorship, with lots of help from our friends.

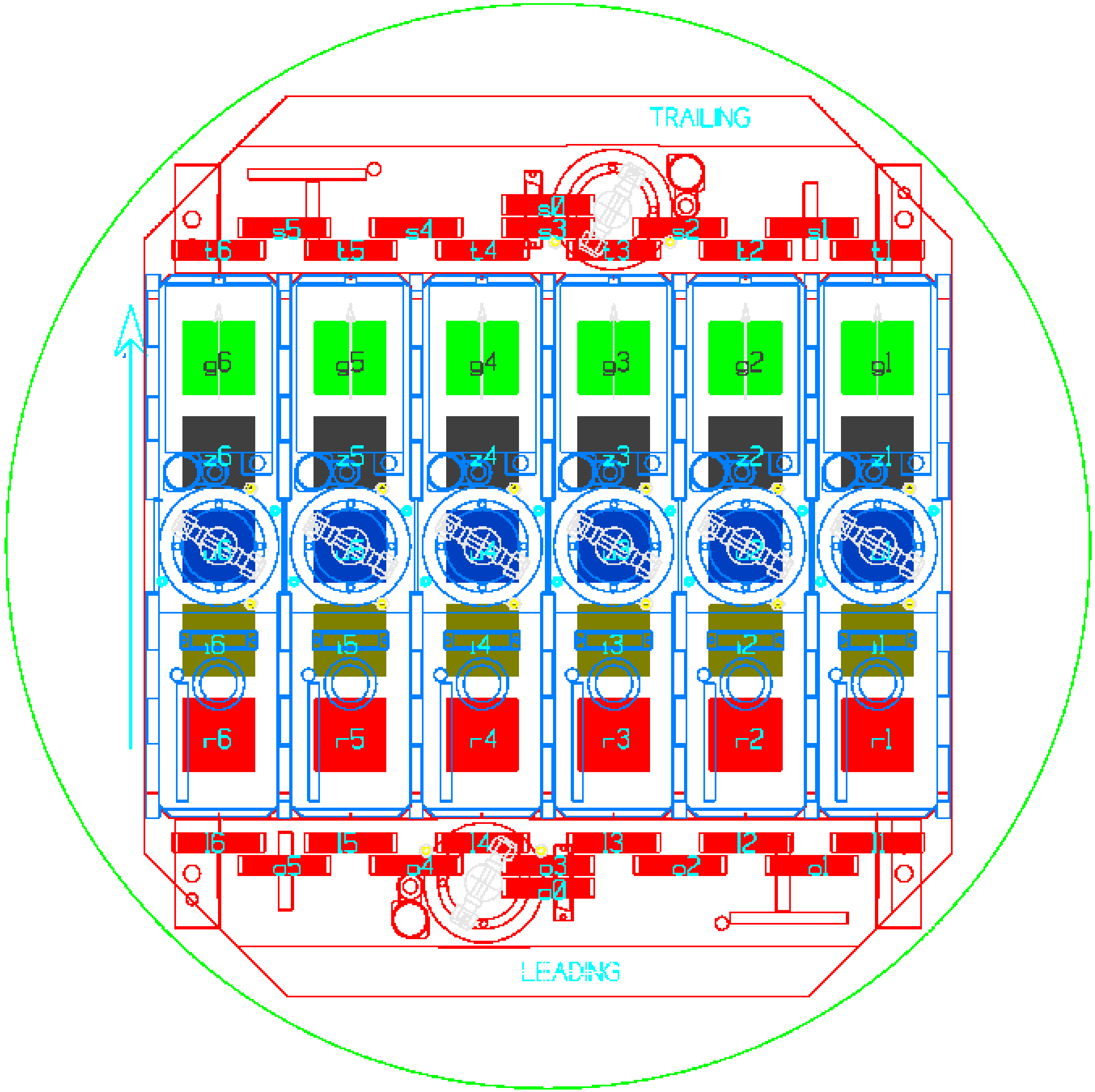
SDSS: MAPPING THE NEARBY UNIVERSE

Princeton University
The University of Chicago
The Johns Hopkins University
The University of Washington
The Japan SDSS Promotion Group
Fermi National Accelerator Laboratory
The US Naval Observatory
Los Alamos National Laboratory
The University of Pittsburgh
New Mexico State University
Max Planck Institute
Korean Astronomy Group
University of Portsmouth
Ohio State University

The SDSS 2.5-meter telescope



SDSS CAMERA



TRAILING
s0
s5
s4
s3
s2
s1
t6
t5
t4
t3
t2
t1
g6
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g3
g2
g1
z6
z5
z4
z3
z2
z1
i6
i5
i4
i3
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i1
r6
r5
r4
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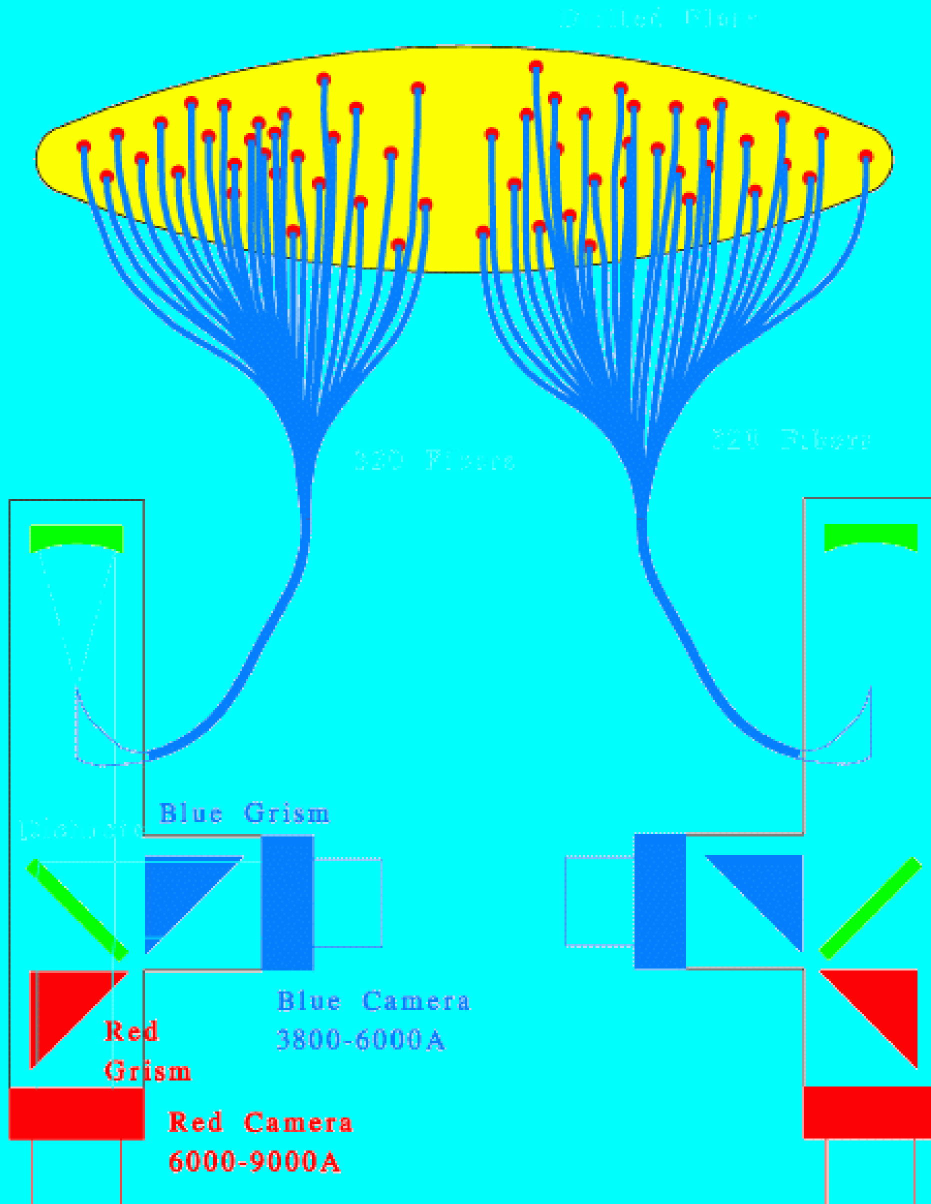
r2
r1
LEADING

SDSS Spectra



SDSS started in 2000,

Effective wavelengths and magnitude limits (95% complete for pt sources)

u	g	r	i	z
3551A	4686A	6165A	7481A	8931A
22.0	22.2	22.2	21.3	20.5

Median PSF FWHM, r-band 1.3 arcsec
Pixel scale 0.396 arcsec

Optical imaging data statistics
Total unique area covered 14,555 square degrees
Total area of imaging (including overlaps, but excluding supernova runs)
31,637 square degrees
Individual image field size 1361x2048 pixels (0.0337 square degrees)

Number of individual fields		938,046
Number of catalog objects		1,231,051,050
Number of unique detections		932,891,133
Number of unique, primary sources		469,053,874
	Stars	260,562,744
	Galaxies	208,478,448
	Unknown	12,682

Photometric calibration accuracy (RMS)

u	g	r	i	z
1.3%	0.8%	0.8%	0.7%	0.8%

(Padmanabhan et al. 2008)

Global astrometric precision 0.1 arcsec

*Comoving Volume ~0.04*Gpc^3h^{-3} *for L* galaxies*

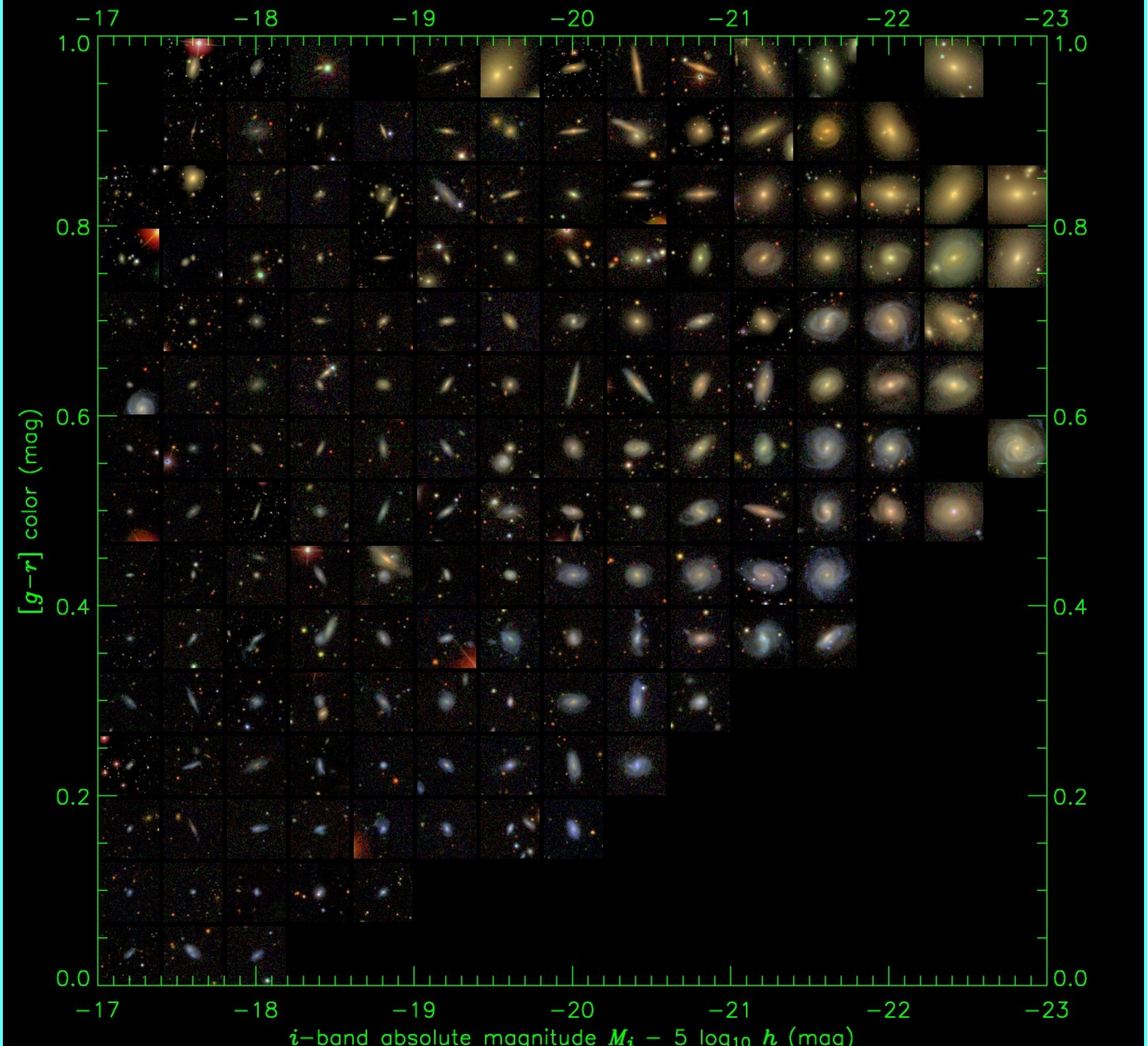
Galaxies Today

This mosaic from Hogg and Blanton illustrates the sequence of properties of normal galaxies with color and luminosity today.

They have used four photometric indices

luminosity
color
surface brightness
Sersic index n

Sersic:
$B(r) \sim \exp(-r^{1/n})$

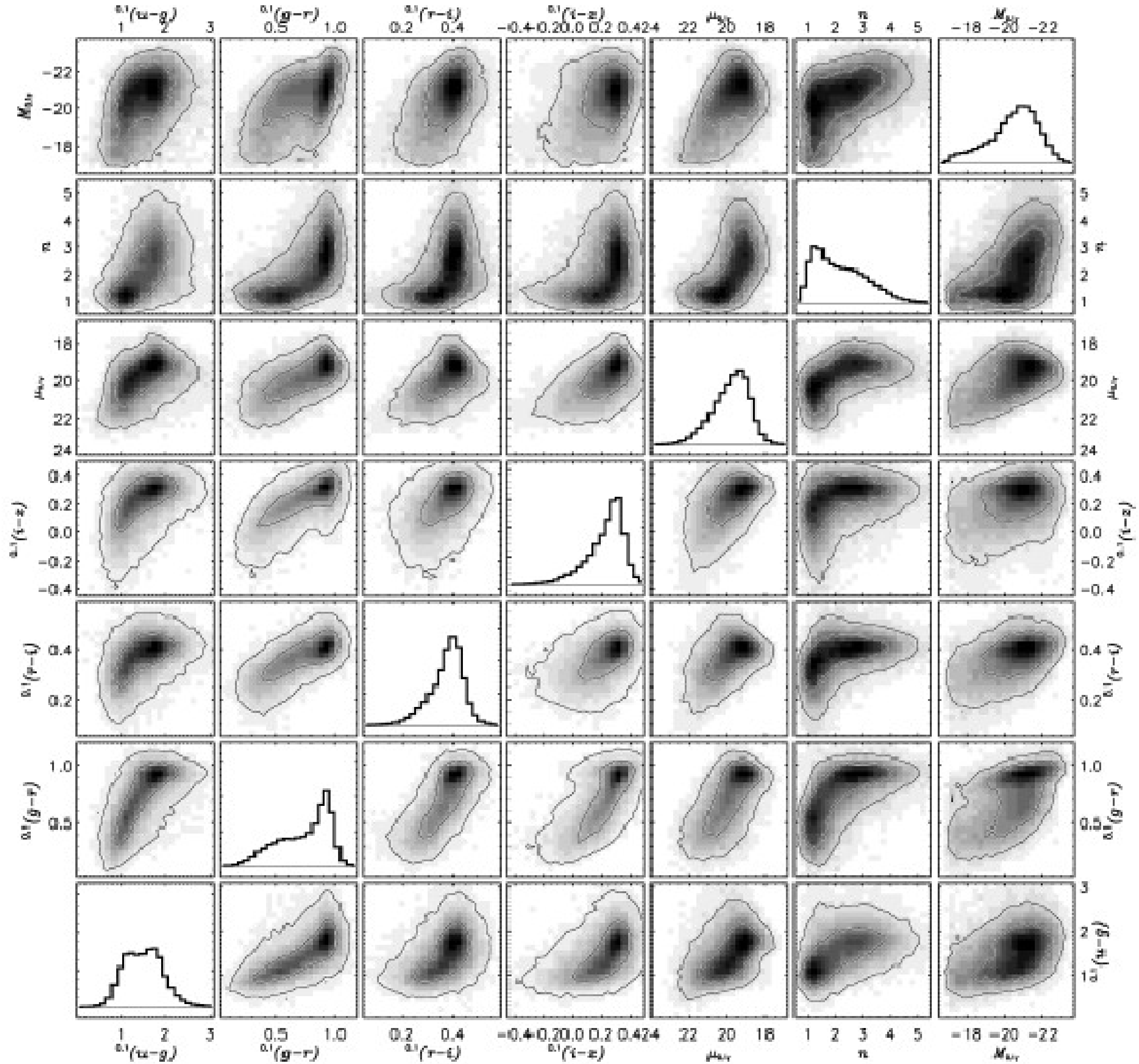


Galaxies Today

This is the distribution in the SDSS sample of these indices. today.

MOST of the luminosity (and stellar mass) in the universe today is in bright galaxies.

There are two sequences, narrow red and broad blue.

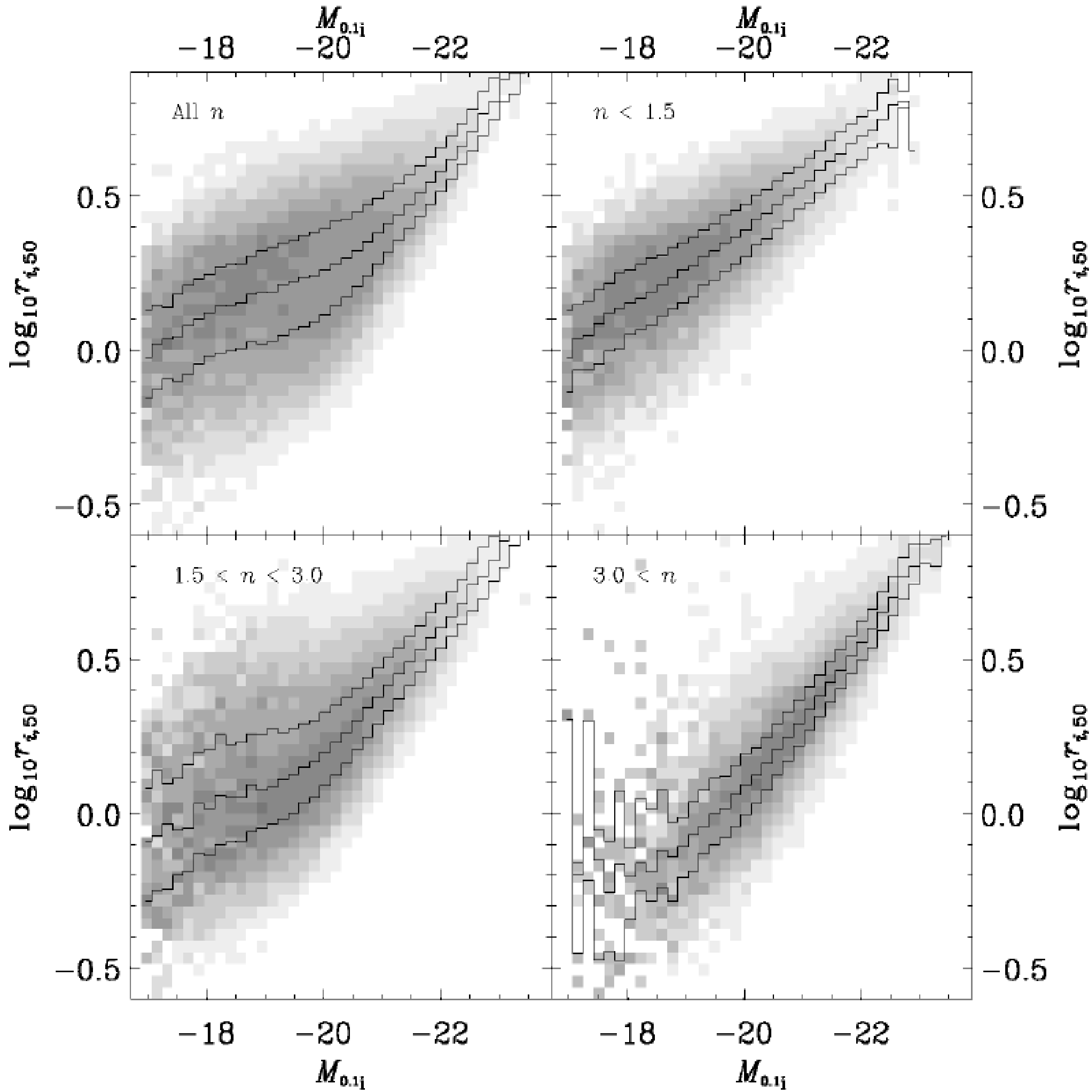


Half-light radii for galaxies with various Sersic profiles.

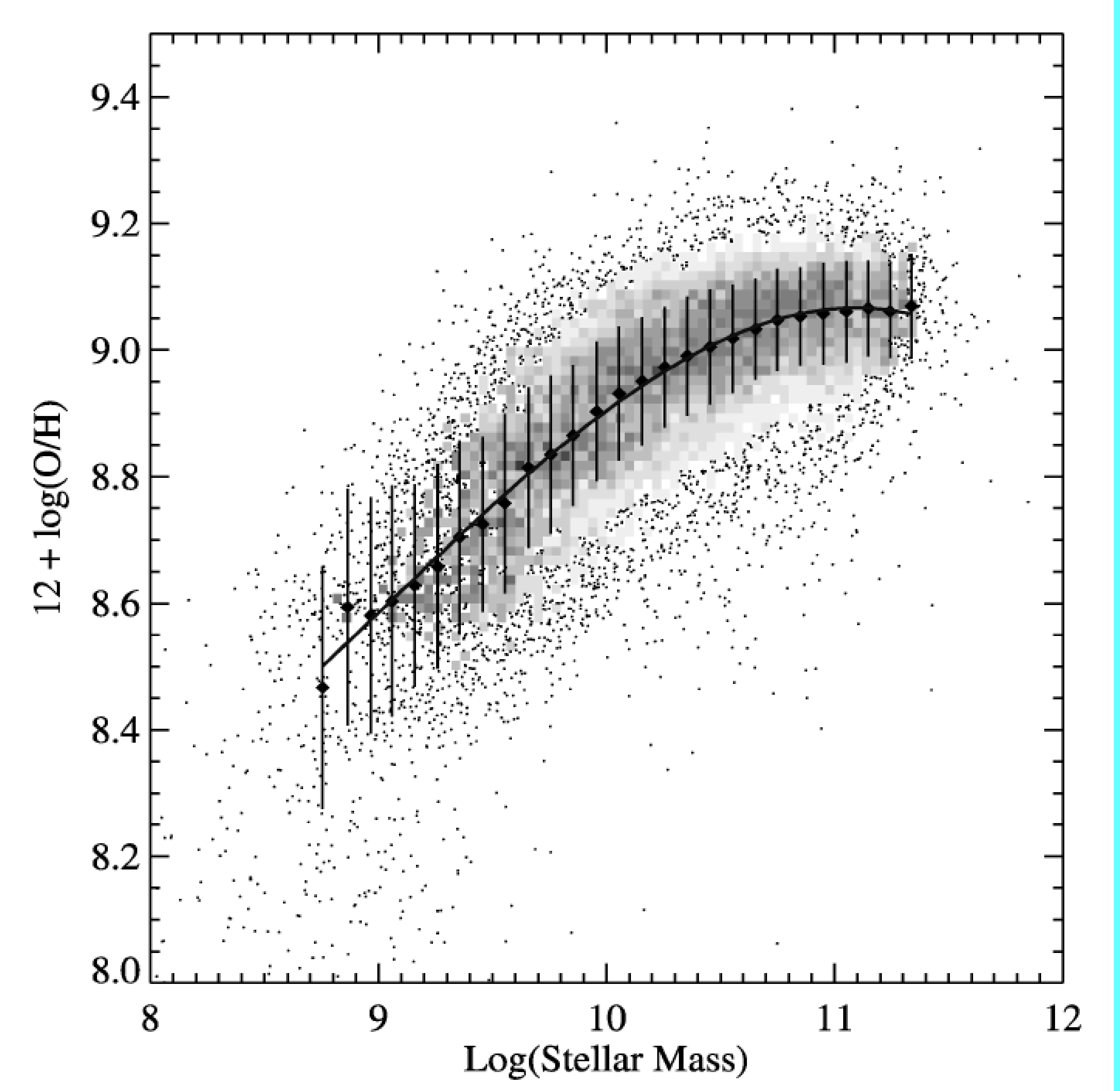
Typical bright (L*) galaxies have r_es between 2 and 4 h^{-1} kpc, larger for late-type systems than early-type. (3 kpc ~ 0.5 " for z > ~0.6

($r_e \sim 1.7/a$ for an exp. disk)

relations similar for all n.



This plot from Christy Tremonti's thesis shows the gas-phase oxygen abundance as a function of stellar mass for SDSS galaxies. It is clear that the metallicities of galaxies are lower at high redshift from data on small samples, but the quantitative trend and the environmental dependence are unknown.



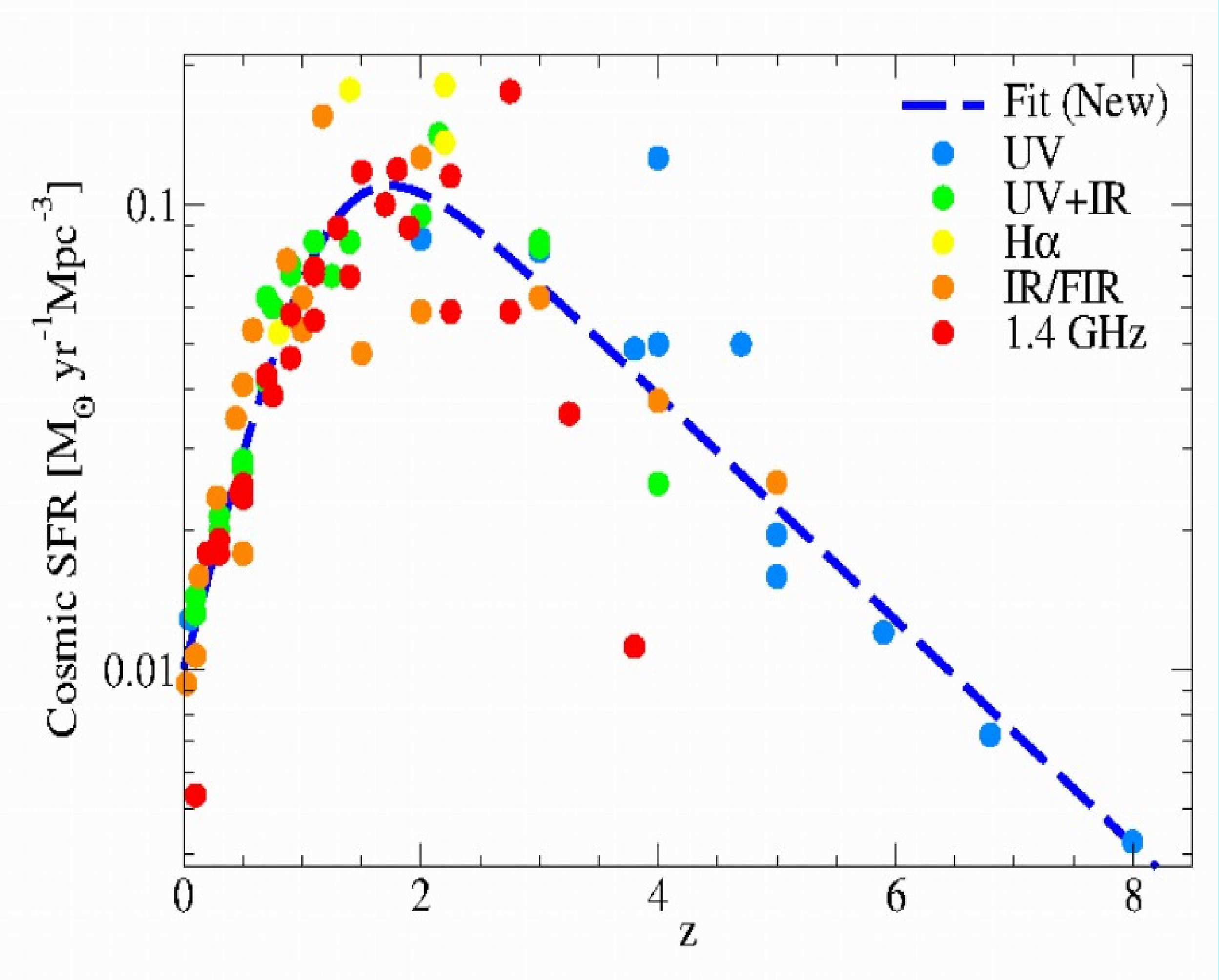
SDSS has painted a wonderfully complete picture of the universe of galaxies at essentially the present epoch....their masses, stellar populations, star formation rates, chemical makeup.

But there is an important dimension missing in the SDSS. It tells us what the universe is like TODAY, but gives us little evidence for the processes that brought it to its present state.

And we know that the universe did not always look the way it does today; It is clear that we see it now in its dotage:

The Universe in its Youth was Enormously More Active Than Now:

The rate of forming new stars has dropped by a factor of more than 20 since it peaked between redshift 1 and 2.



If we could do a survey to redshift 2, we could map most of the history of the formation and evolution of galaxies and the stars which make them up in detail over the last 10 billion years of cosmic history. The universe began 13.5 billion years ago, so this is 75% of its history.

So the dream is to do a survey like SDSS with both imaging and spectroscopy to z~2, when the universe was 25 percent of its present age, to trace the properties of galaxies with time and try to understand their evolution during the period that most of the mass of stars in the universe were formed..

Things we know:

Galaxies are bluer and younger at high redshift (!!)
Galaxies are less metal-rich at high redshift
Galaxies are less clustered at high redshift
Galaxies (some galaxies) are smaller at high redshift

These (except perhaps for the last) we expect from simple considerations

We know all of these from relatively small samples, most with strong and not-well-understood selection effects.
We need much larger samples to study them well.

Questions for Such a Survey:

1. *What is the history of the stellar populations of galaxies ?*

2. *The history of star formation and the initial mass function (IMF) of stars ?*

3. *What establishes the dynamics of the baryonic component—in simple terms, $\rho_{DM}(r,t)$ and $\rho_{baryon}(r,t)$, as reflected in sizes and radial profiles?*

4. *The history of heavy-element abundances ?*

5. *The growth and activity of supermassive black holes in galactic nuclei ?*

6. *The effect of environment and history thereof ?*

7. *What are the feedback mechanisms which regulate star formation, and how important are they?*

8. *What are the history and driving forces for outflows and infall, and what finally establishes the baryon/dark matter ratio?*

How Can We Do Such a Survey ?

We need a very large telescope. Cannot repeat the Sloan story of building our own—it is too expensive.

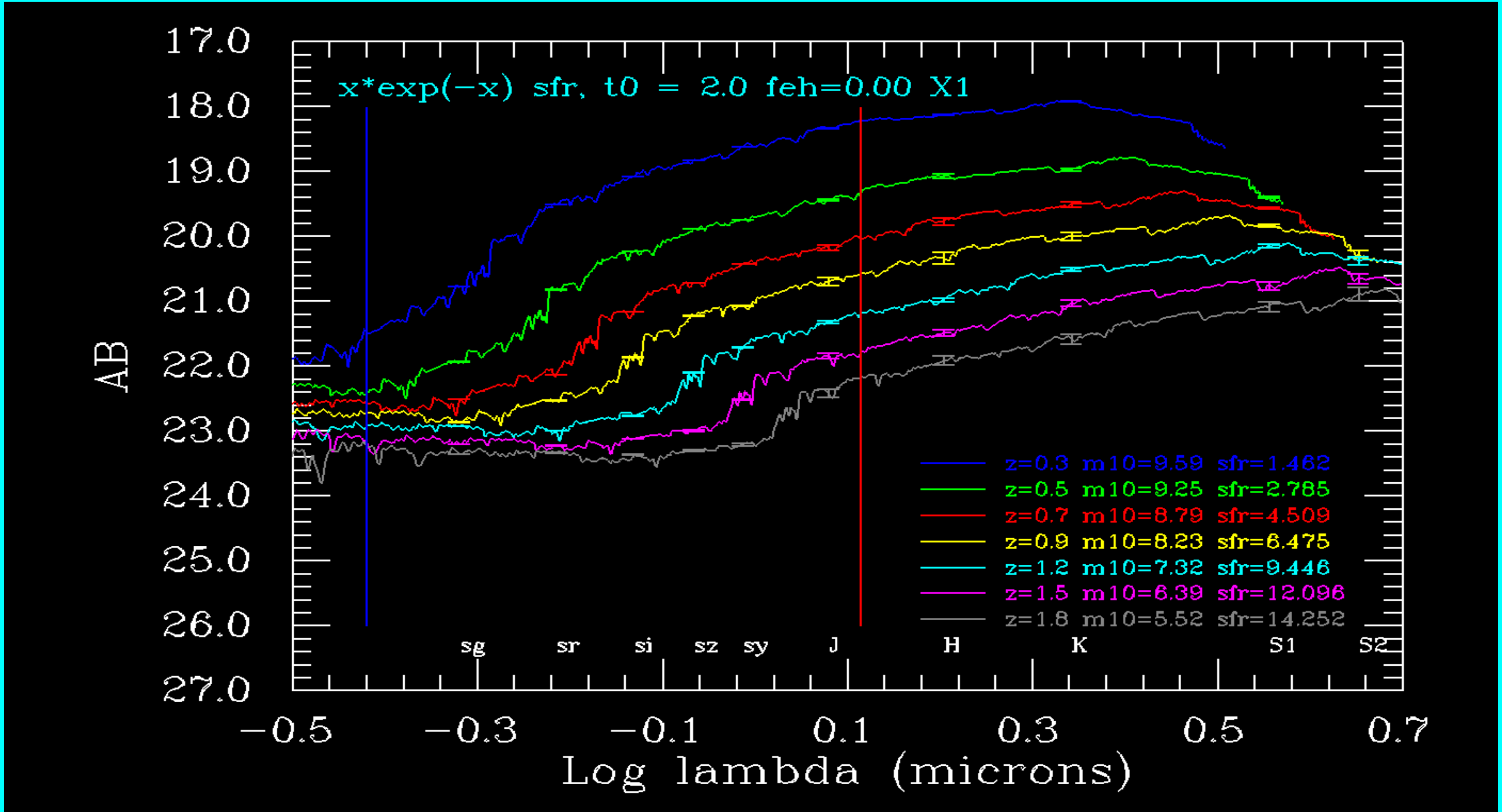
But there exists one such with a very wide field, the Japanese Subaru telescope.

The imager, HyperSuprimeCam, with 114 2Kx4K CCDs, has just finished commissioning, and the imaging survey is, in fact, just getting started.

It will provide photometry, shapes, sizes for objects to 26th magnitude in i in the `wide' (~1500 sq. degree) survey and to 27th in I in the `deep' (~30 sq deg) layer in 5 bands – g, r, i , z, y, spanning 4000 → 11000A

x*exp(-x) sfr, t0 = 2.0 <feh>,sd=0.0 0.3
Mi.1 = -21.54 .1colors(ug,gr,ri,iz) = 1.46 0.89 0.34 0.29

z	Volc	knL*	1''	m*	m*dot	Mi.1	gr.1	g	r	i	z	y	j
0.10	(ref)		1.8	9.8e+10	6.1e-01	-21.73	0.89	17.78	17.02	16.69	16.43	16.24	16.01
0.50	0.009	29	6.1	9.3e+10	2.8e+00	-22.32	0.72	21.89	20.89	20.26	19.92	19.75	19.39
0.70	0.010	34	7.2	8.8e+10	4.5e+00	-22.54	0.66	22.47	21.91	21.06	20.71	20.45	20.10
0.90	0.018	58	7.9	8.2e+10	6.5e+00	-22.71	0.60	22.78	22.49	21.85	21.27	21.06	20.64
1.20	0.027	87	8.4	7.3e+10	9.4e+00	-22.88	0.54	22.97	22.95	22.73	22.15	21.70	21.25
1.50	0.032	104	8.6	6.4e+10	1.2e+01	-22.96	0.49	23.14	23.22	23.14	22.98	22.46	21.84
1.80	0.037	122	8.6	5.5e+10	1.4e+01	-23.00	0.45	23.34	23.36	23.43	23.31	23.21	22.27
					HSCDeep 5 sigma limits:			27.80	27.30	27.10	26.20	25.70	
					HSCWide 5 sigma limits:			26.70	26.10	26.10	25.20	24.70	

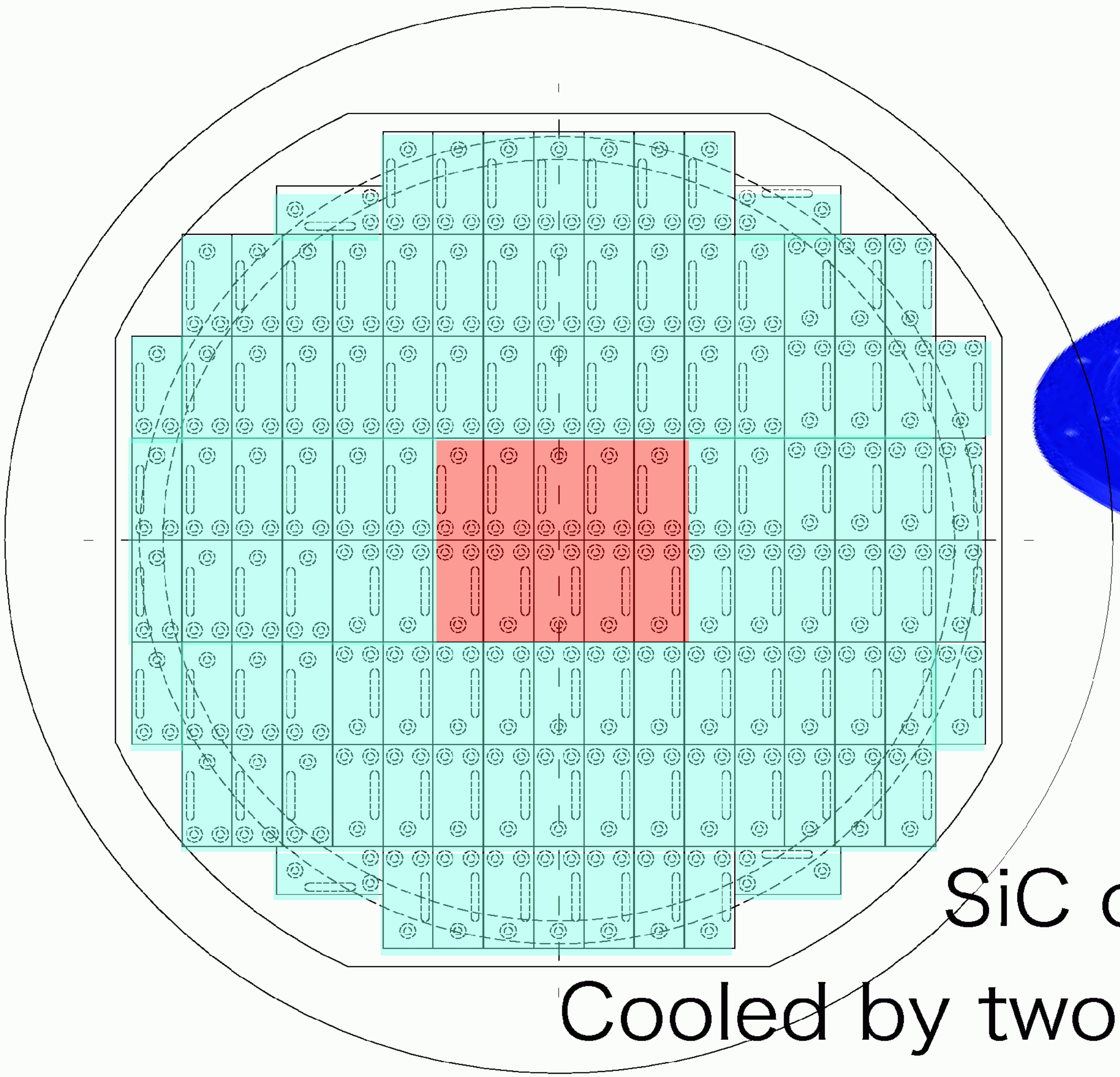


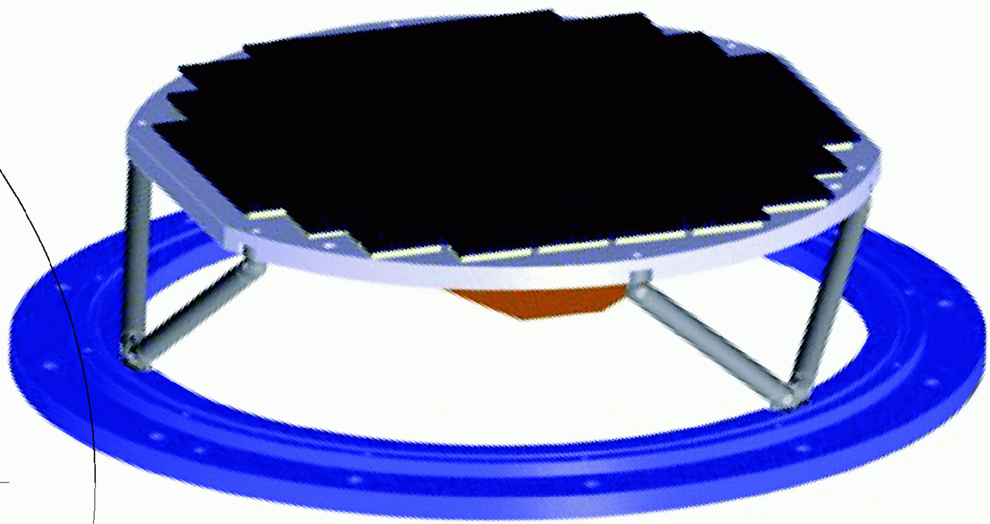
The Telescope

8.2 meters, Mauna Kea

Superb seeing, tracking
Median image size ~0.7 arcseconds

HSC Focal Plane





112 + 4 Guides

SiC cold plate

Cooled by two pulse tube coolers

45 W@-100 C each

Spectroscopy --- A little more distant (2017)

SuMIRe/PFS: WFMOS reborn

A 2400-fiber spectrograph covering 3800 – 12600A in 3 channels, now under construction, also for Subaru. Shares the Wide Field Corrector with HSC.

Copies the Sloan model – HSC does the imaging, PFS does the spectroscopy.

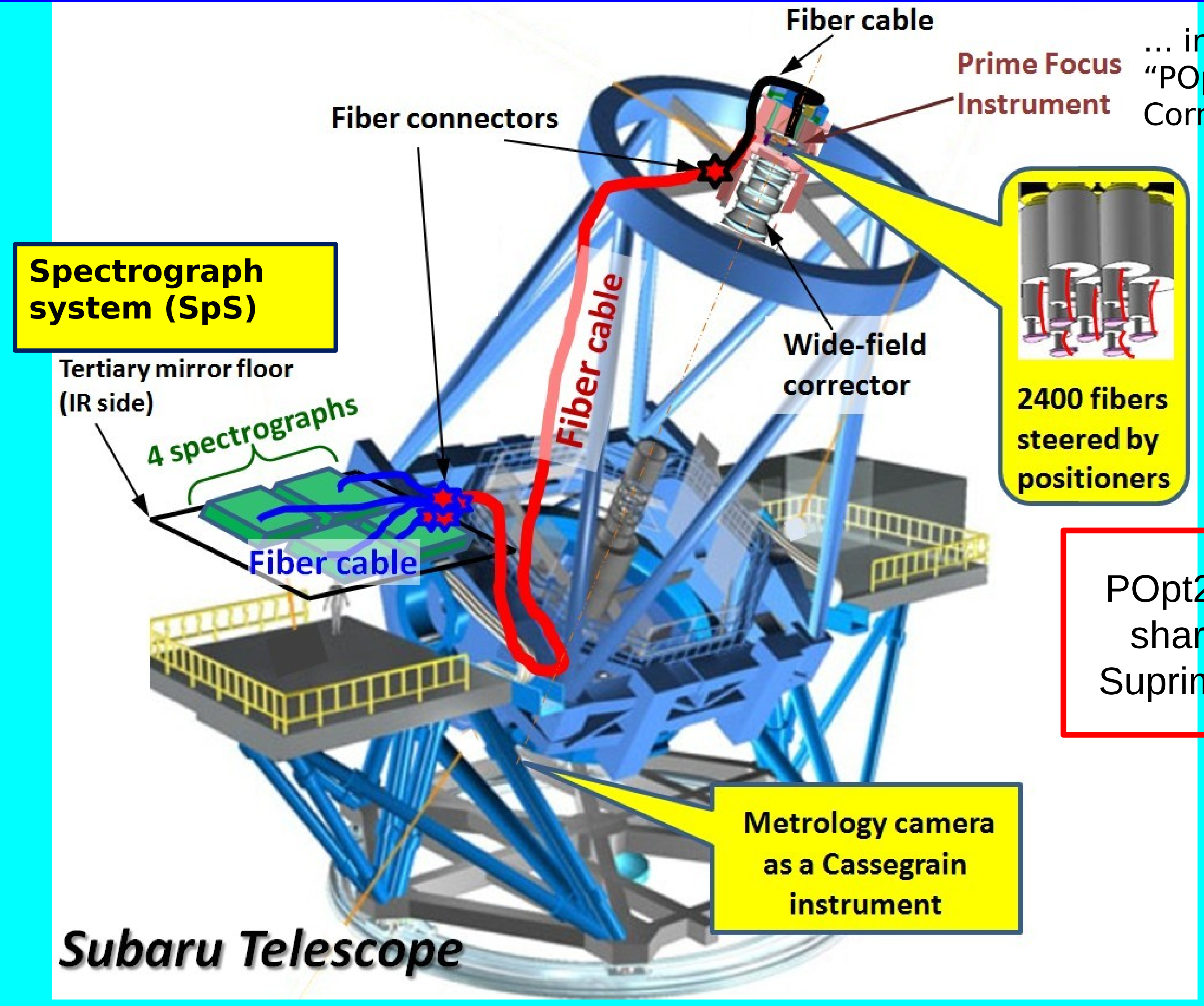
3 major programs:

1. *A Baryon Acoustic Oscillation cosmology program, deeper than the planned DESI project but smaller area, to z ~ 2.3, i ~ 22*

2. *A galaxy evolution program (zSDSS) to z~ 1.8, j_{ab} ~ 22.5*

3. *A stellar archaeology program to the outer halo of the Galaxy and the halo of M31.*

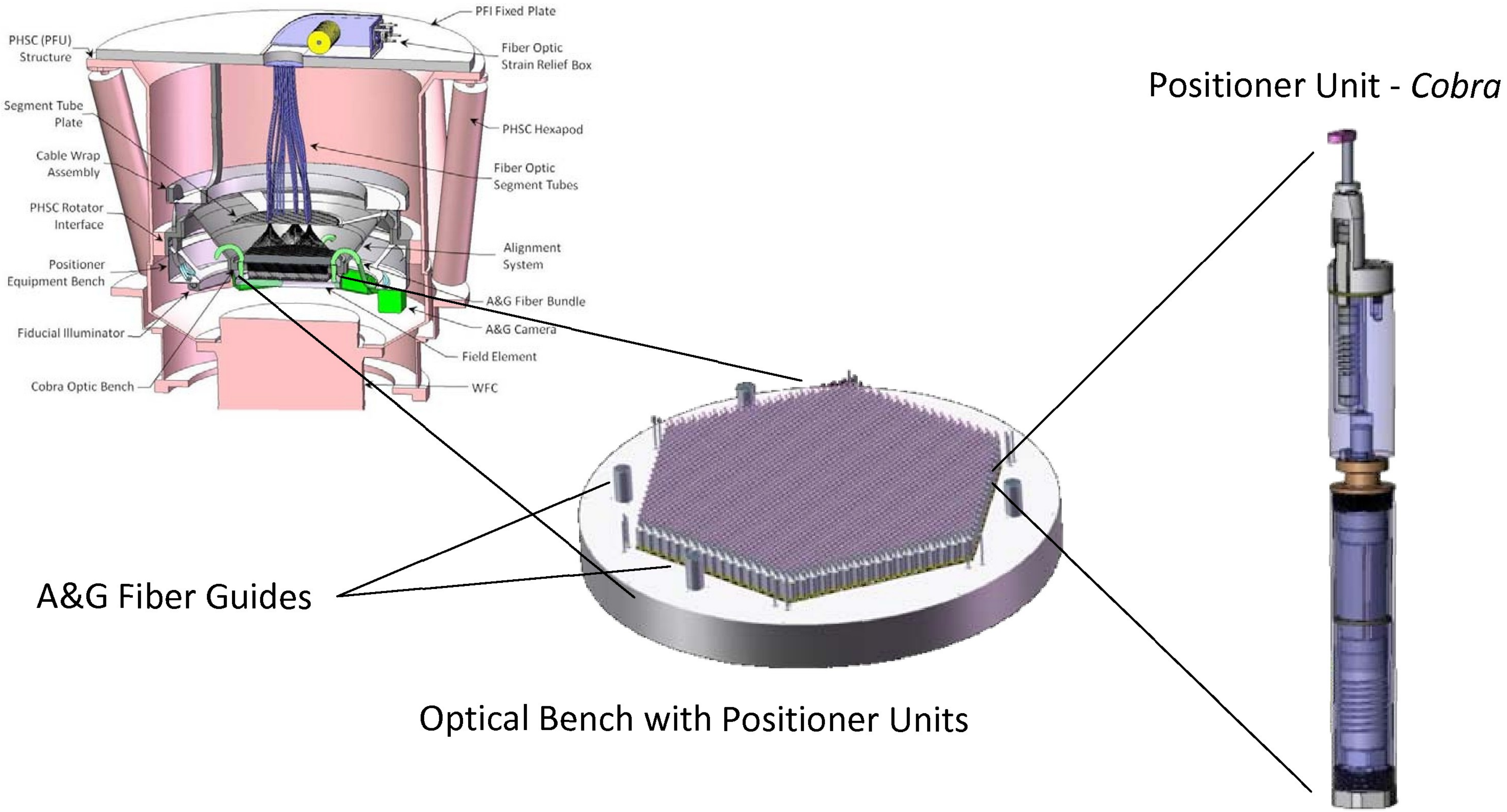
PFS subsystems



... in Prime focus unit “POpt2” with Wide Field Corrector “WFC”.

POpt2 & WFC will be shared with Hyper Suprime Cam (HSC).

PFS Positioner



Cobra system tested at JPL in partnership with New Scale Technologies
Designed to achieve 5 μ m accuracy in < 8 iterations (40 sec)
Up to 4000 positioners 8mm apart in hexagonal pattern to enable field tiling

The Spectrographs

Desiderata:

1. High Throughput

2. As wide a wavelength range as is practical (3800-12600 is doable)

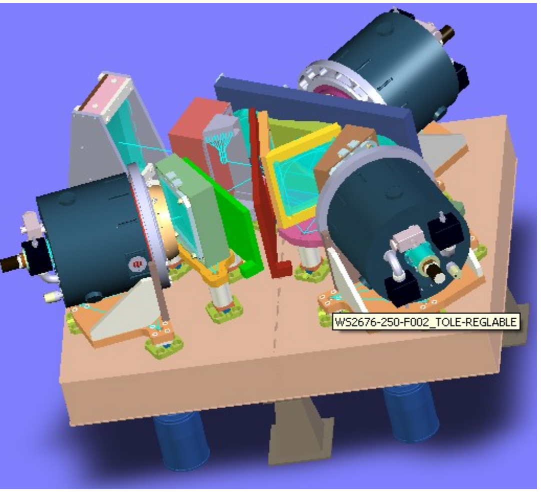
Important scientific note: All galaxies forming stars have Ly-alpha 1216A and [OII] 3727 in strong emission lines; often nothing else. We can follow [OII] to redshift 2.48; Ly-alpha enters our range at z=2.12. No `redshift desert'.

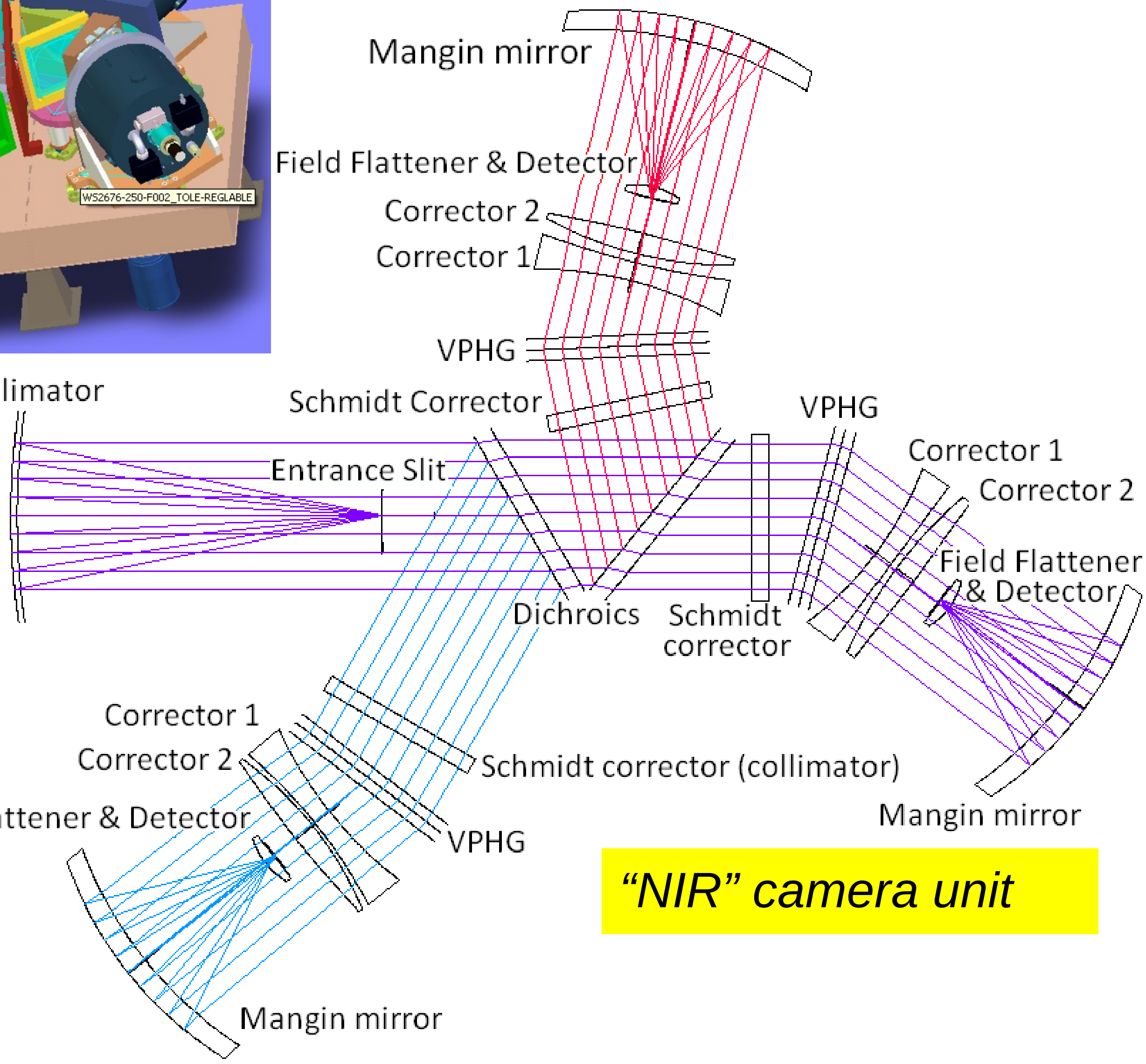
3. Sufficient resolution to
   a. Do the science
   b. Work on faint objects in the red, *between* the OH lines

4. Simple optics to keep the surface count and costs low.

5. A state-of-the-art faint object instrument. Subaru is the ONLY large telescope on which it can be effectively used.

Spectrograph system (SpS)





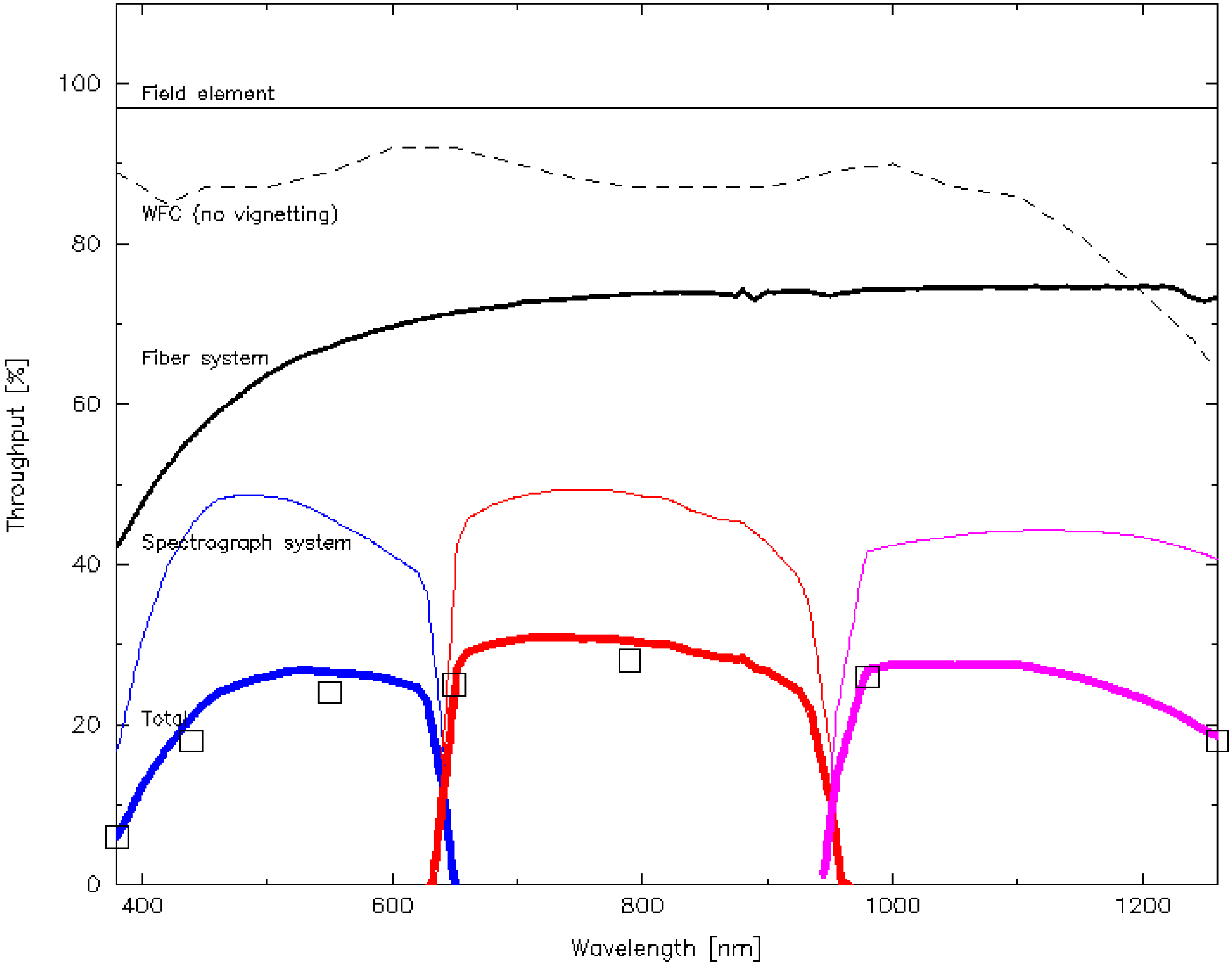
380-1260nm is simultaneously observed by this “3-arms” design.

~600 fibers are fed to one spectrograph
~2400 fibers in total are fed to 4 identical sets of spectrograph & cameras.

Proposed location for these systems is the “IR-side” 3rd floor in the Subaru dome.

Throughput estimation

http://sumire.pbworks.com/w/page/65089522/Throughput%20prediction



Field Element

WFC transmission

Fiber system

Spectrograph system

Total (instrument only)

The Punchline:

You cannot teach old dogs new tricks, but perhaps can teach them to do the old ones better.

The spectroscopic survey will start in 2018, if all goes well, and will last 5 years. If it does a fraction of what we hope it will do, it will be fantastic.