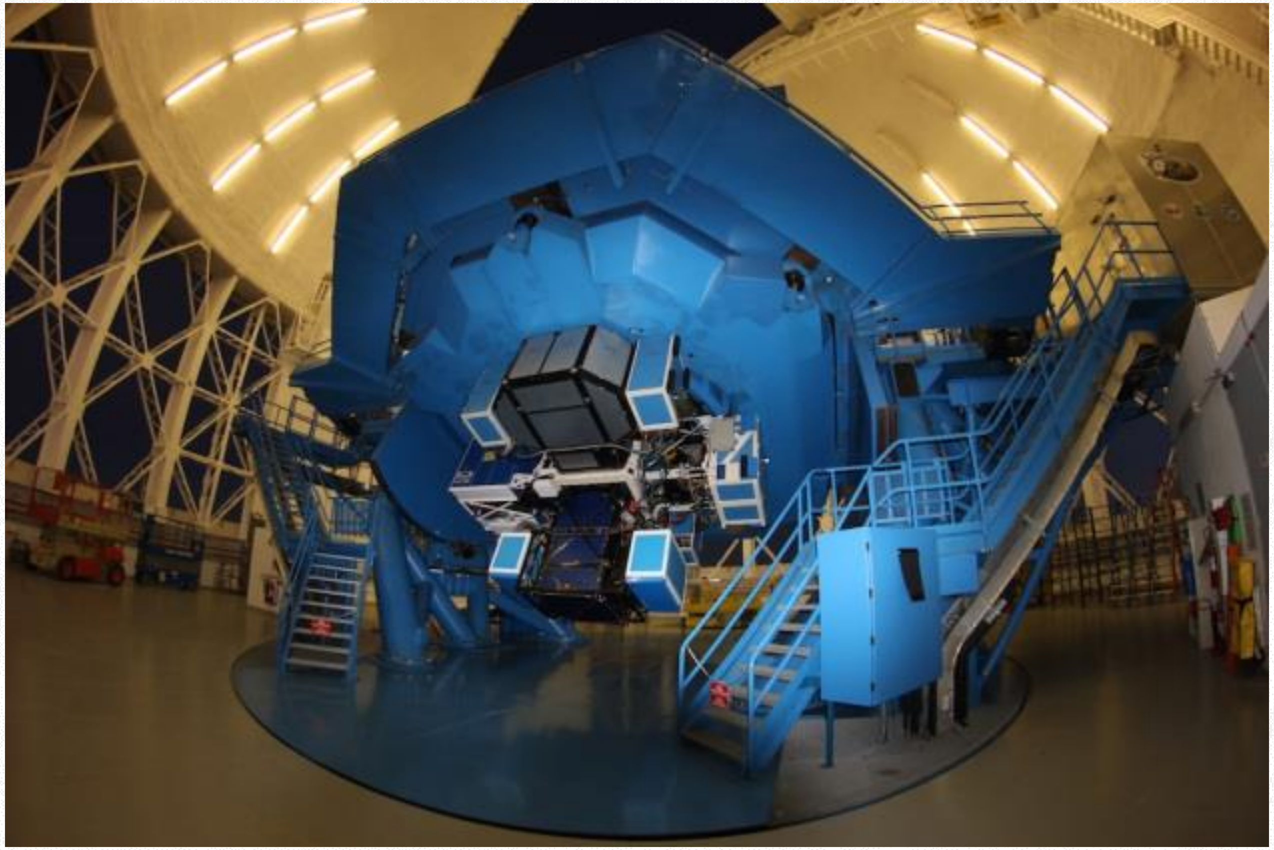

OIR Design Considerations

Scot Kleinman
Associate Director, Development
Gemini Observatory

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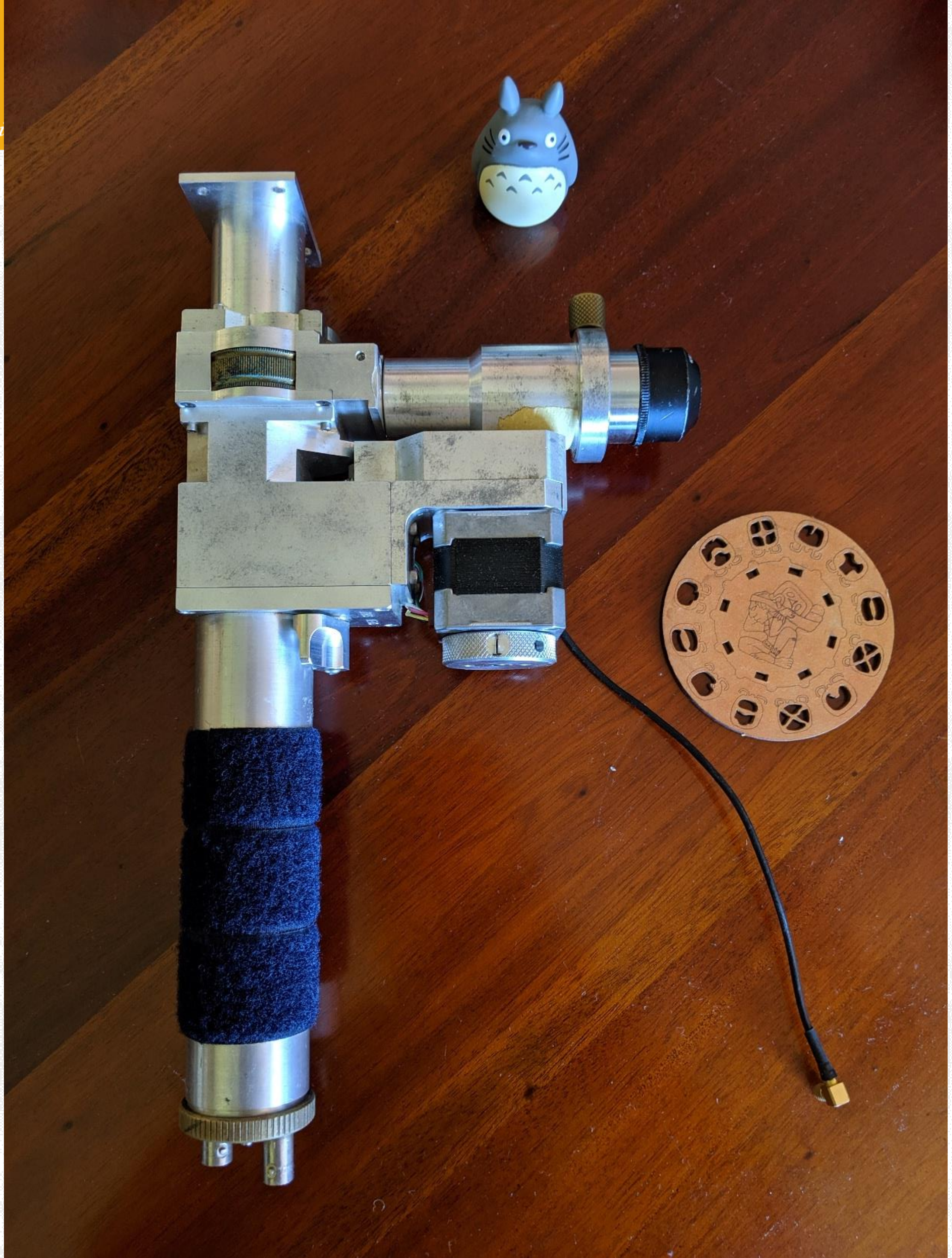
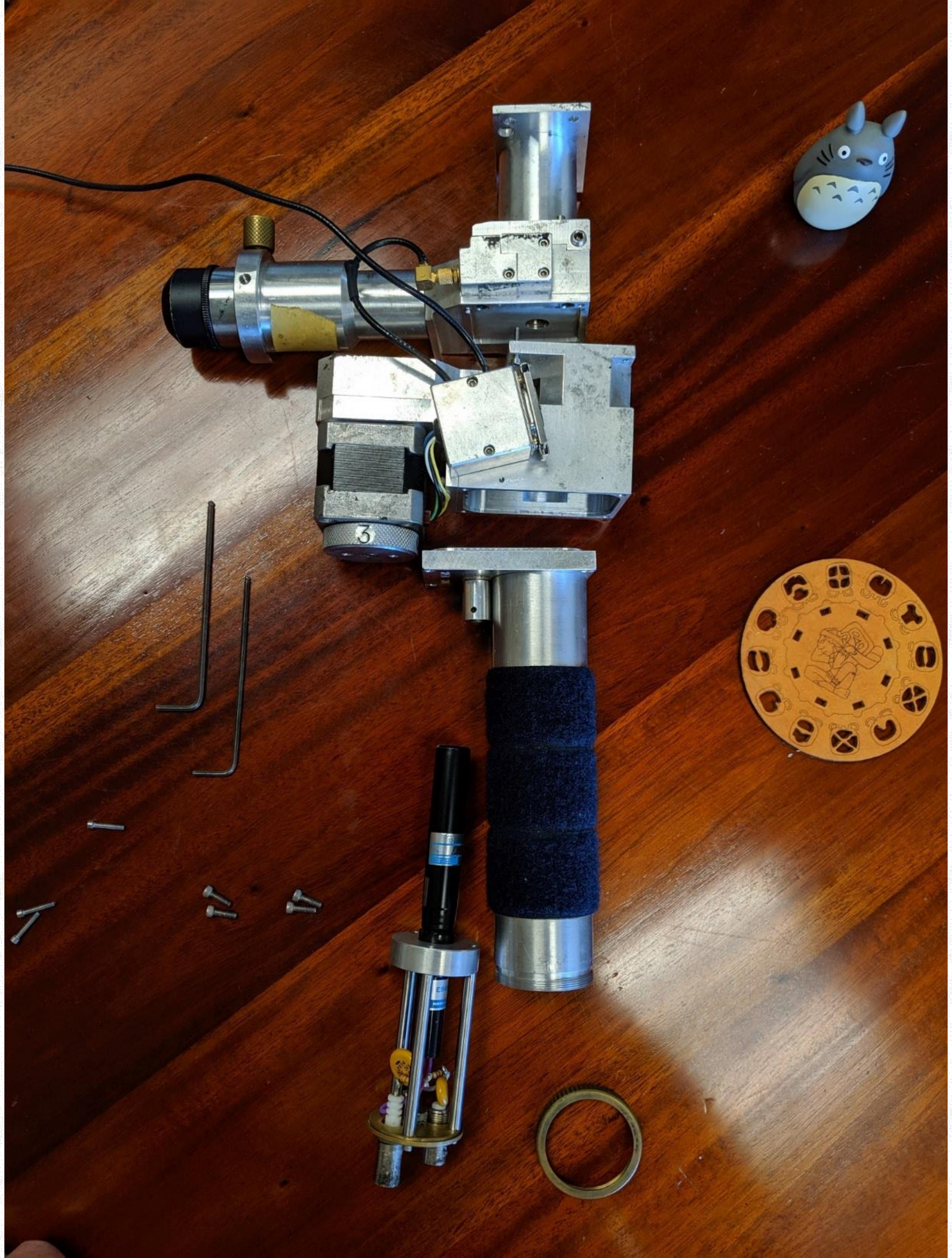
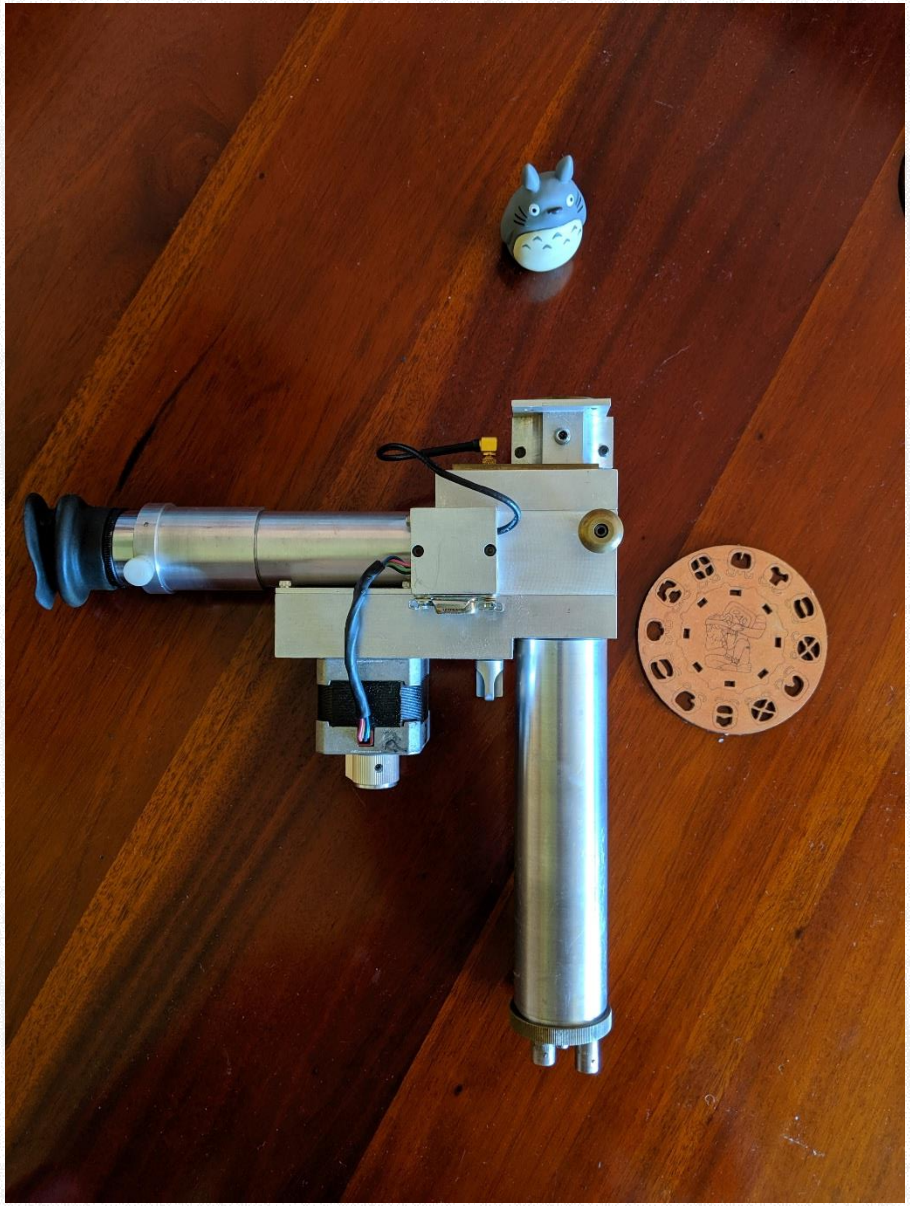
My start in astronomy instrumentation

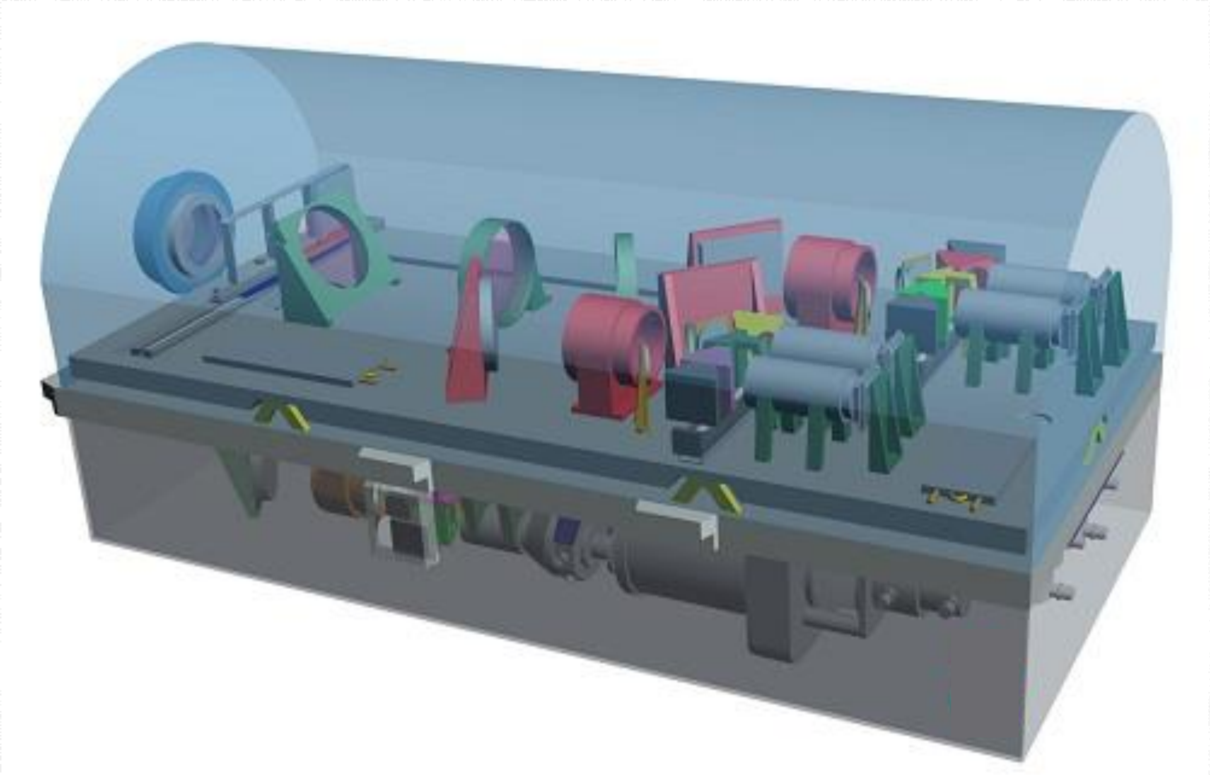
NASA
Kepler



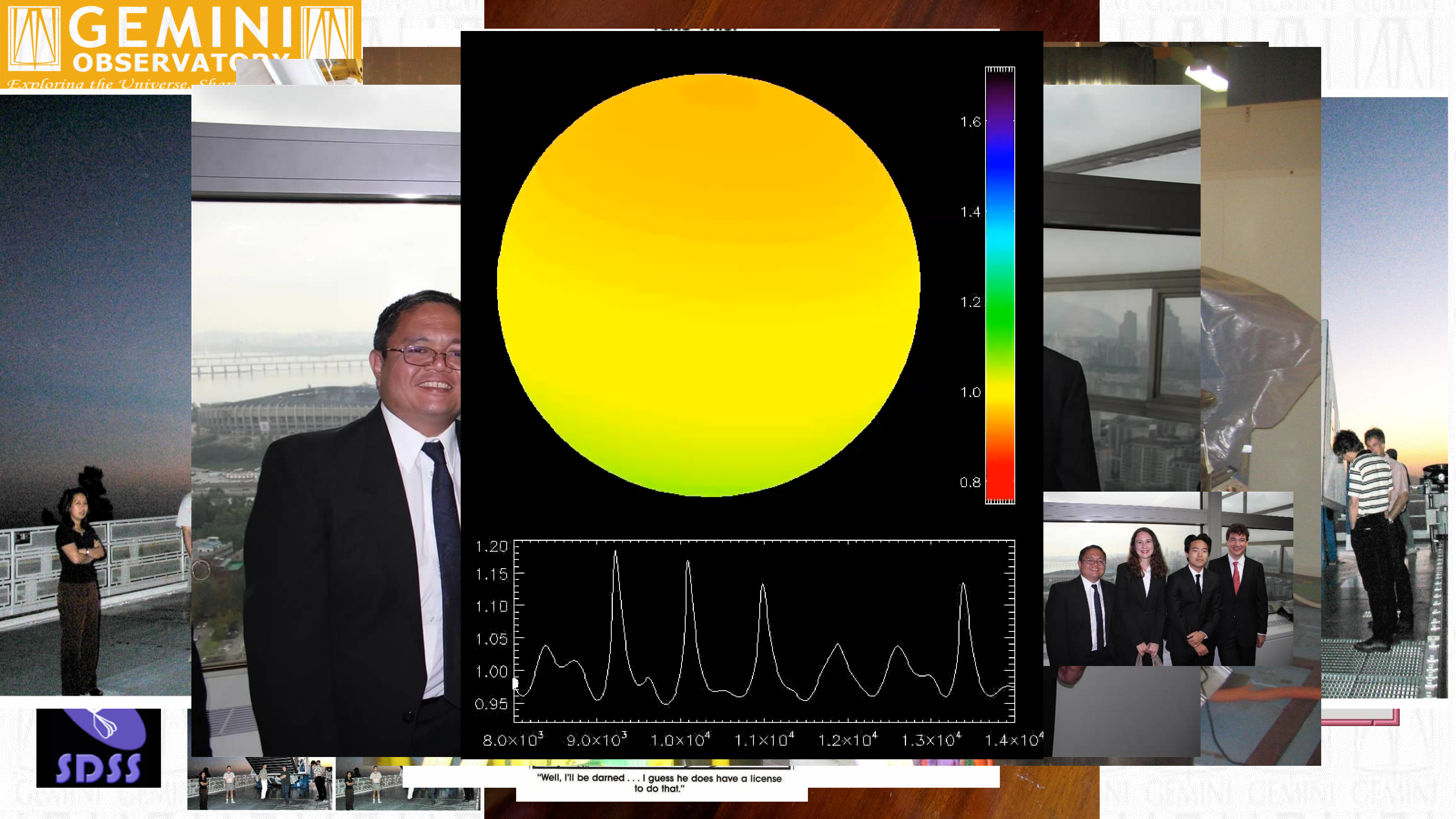


Building an astronomical instrument





STScI
SwRI
THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC
Fractal


GEMINI
OBSERVATORY
1.6
1.4
1.2
1.0
0.8
1.20
1.15
1.10
1.05
1.00
0.95
8.0x10³
9.0x10³
1.0x10⁴
1.1x10⁴
1.2x10⁴
1.3x10⁴
1.4x10⁴
SDSS
"Well, I'll be darned . . . I guess he does have a license
to do that."

Instrument scales…

Phatphot

- Motivated by a specific observational challenge
- One graduate student; one machinist
- Prior experience: rebuilding a VW engine
- Requirements: Schnock
- Review process: Thesis adviser
- No budget, no schedule
- Cost: ~$15k USD

SCORPIO

- Motivated to fill a strategic, scientific mandate
- Involves 6+ institutions
- Prior experience: many ground-based and spaced-based instruments
- Extensive requirements flowdown
- 6 formal reviews + numerous internal and peer reviews
- 292 pages of contract documents
- Fixed schedule: Working by 1Jan 2023
- $15M budget + ~20% contingency

Instrument motivation

The standard "model"

1. Start with a scientific question
2. Figure out what observations you need to answer it
3. Derive requirements for an instrument to make those observations
4. See if one already exists you have access to
5. If not, build one

Reality

1. Identify some cool new technology
2. Figure out a way to use it for your science
3. Identify the specs for the major accompanying technology and calculate what the instrument can do
4. Figure out what part of your science you can do with such an instrument
5. Find someone willing to fund your instrument
6. Derive requirements consistent with the funder's requests, your science and the technology you found

Why not just build the best you can?

If we're going base our science and instrument design on the capabilities of existing technology, why bother with requirements? Why not just build the best instrument we can? As good as possible?

Why not just build the best you can?

- How do you know when you're done?
- Impossible to control cost and schedule.
- What if as good as possible in one area means a little less than possible in another? How do you decide?
- There are always trades to be made in one capability versus another. If you don't have a consistent way to make those trades, you end up with an instrument that does noting well.

*An instrument designed to do **something** well, usually does something **else** well, too.*

An instrument designed to do nothing well, usually ends up doing nothing well.

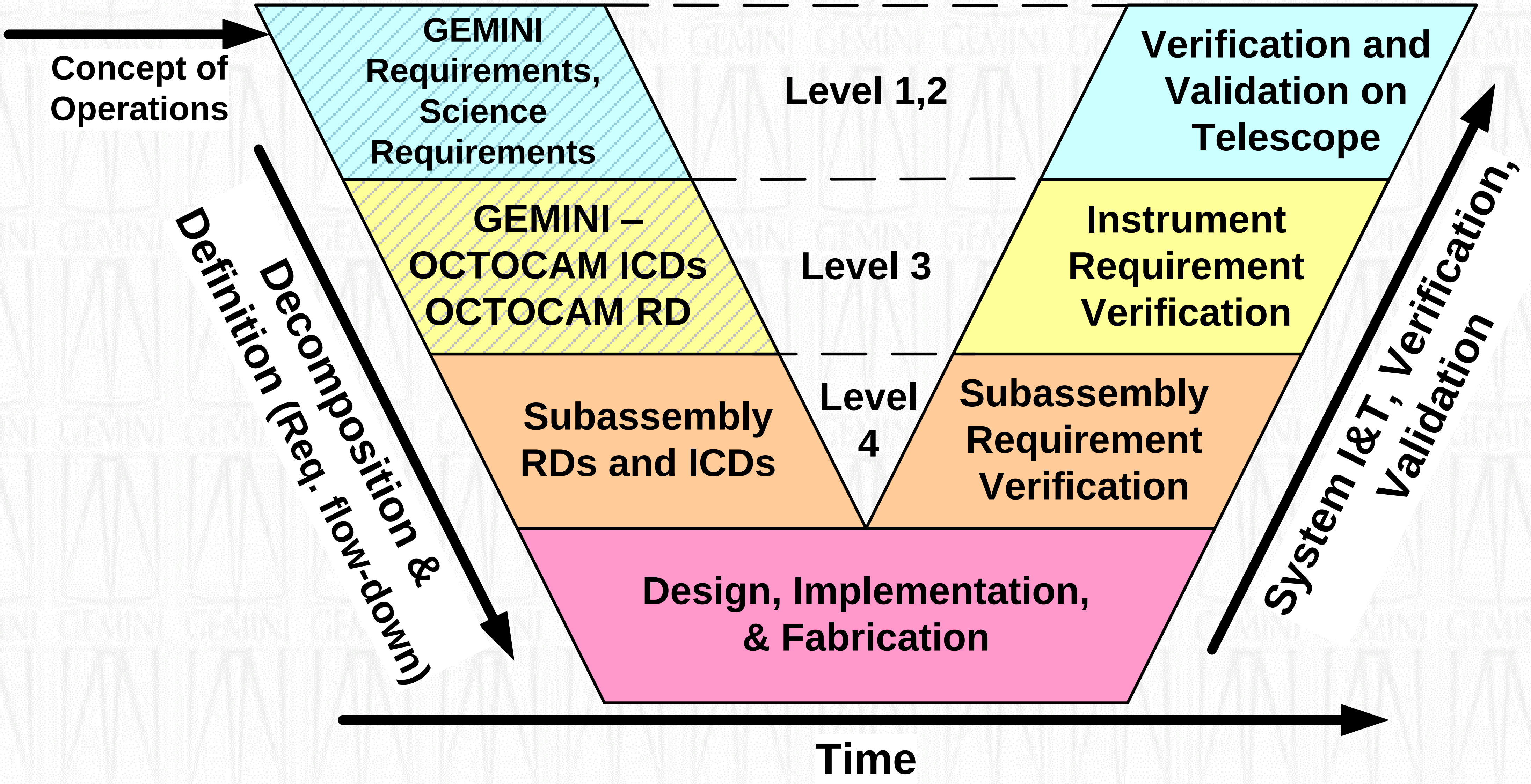
Requirements

- A requirement is a statement of one thing a product must do or a quality it must have.
- Requirements flow from and to higher and lower-level requirements.
- Requirements are testable.

Requirement flow is important:

1. To understand the impact of changing one thing here on something over there (and on your top-level objectives and science cases)
2. To provide a series of tests to catch problems at their earliest catchable time (ex. when a lens comes back from a vendor versus when the camera is assembled into the instrument and tested on sky)

Requirement flow and testing



From SCORPIO CDR material

Level 0

Measure the age of the Universe to within 10% within 5 years.

This is the motivating science.
This requirement is implementation and design agnostic. There are multiple ways to do this with multiple instruments.

Level 1

0: Measure the age of the Universe to within 10% within 5 years.

Measure 10,000,000 unique extragalactic redshifts to within 1% over a range of $z=1$ to 3.5 in 4 years.

We are now starting to select a specific approach to satisfy Level 0, but not the specific instrument or technique.

Level 2

0: Measure the age of the Universe to within 10% within 5 years.

1: Measure 10,000,000 unique extragalactic redshifts to within 1% over a range of z=1 to 3.5 in 4 years.

Obtain S/N=15, R=3000 spectroscopy over a wavelength range from 370 – 1100 nm for 11,000,000 galaxies over a range of z=1 to 3.5 in 4 years.

Now, I'm selecting an approach which will ultimately determine what kind of instrument I'm building, but this requirement is not measurable until the end of 4 years.

Level 3

0: Measure the age of the Universe to within 10% within 5 years.

1: Measure 10,000,000 unique extragalactic redshifts to within 1% over a range of z=1 to 3.5 in 4 years.

2: Obtain S/N=15, R=3000 spectroscopy over a wavelength range from 370 – 1100 nm for 11,000,000 galaxies over a range of z=1 to 3.5 in 4 years.

Obtain S/N=15, R=3000 spectroscopy over a wavelength range from 370 – 900 nm for a V=17 galaxy in 10m.

We are now getting to something that is measurable at acceptance, but only on sky. This is the first instrument science requirement.

Level 4

0: Measure the age of the Universe to within 10% within 5 years.

1: Measure 10,000,000 unique extragalactic redshifts to within 1% over a range of z=1 to 3.5 in 4 years.

2: Obtain S/N=15, R=3000 spectroscopy over a wavelength range from 370 – 1100 nm for 11,000,000 galaxies over a range of z=1 to 3.5 in 4 years.

3: Obtain S/N=15, R=3000 spectroscopy over a wavelength range from 370 – 900 nm for a V=17 galaxy in 10m.

Spectrograph throughput = 87%

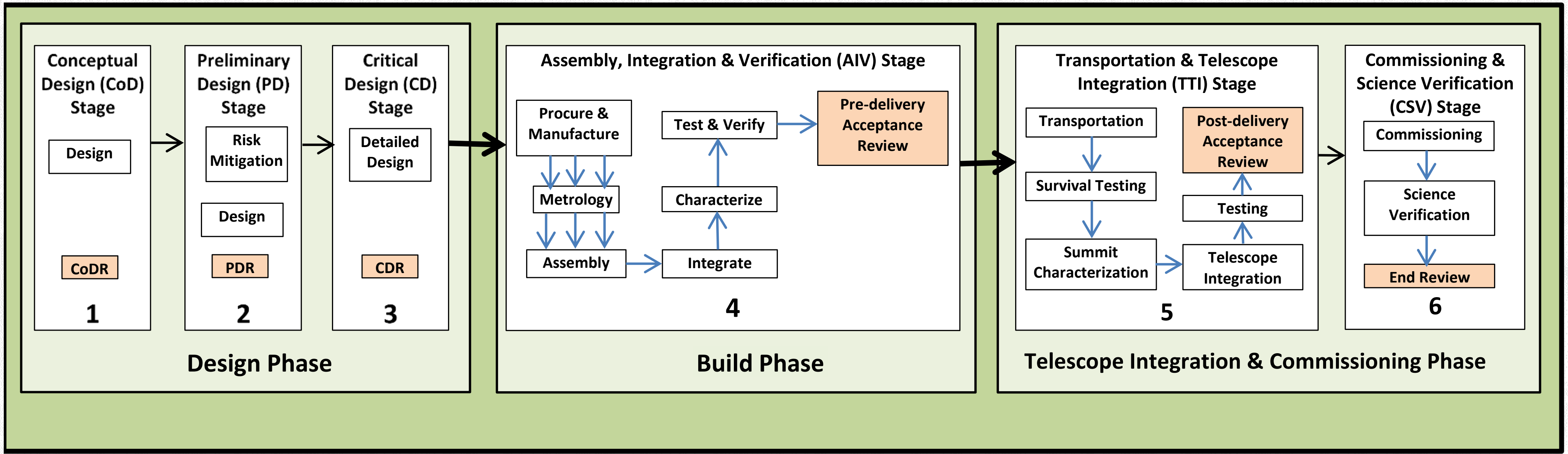
Multi-object capability = (design dependent)

…

Now we are getting to top level Instrument requirements.

The SCORPIO Process

1. Gemini governance wants next instrument to be strategically complementary to LSST +
2. Gemini Science and Technology Advisory Council have their own view on how best to do this
3. Gemini issues RfP for funded feasibility studies for instruments that support #1, stating #2 as a known viable option
4. Gemini receives multiple proposals all supporting #2 and selects 4 to fund
5. Gemini takes results of the 4 studies and issues an RfP for a specific instrument with broad bandwidth imaging and spectroscopy (i.e., #2)
6. After a complicated review process, Gemini selects one team to award the design and build contract
7. After CoD, team trouble reaches a peak and the management structure changes
8. We begin PD with a new PI and name
9. We completed CDR in June



The ~~SCORPIO~~ GIFS RfP (step 3)

The Gemini Instrument Feasibilities Studies (GIFS) project is part of a program that will provide a number of community-created science-driven instrumentation design study reports and presentations to the observatory, conforming to a number of desired principles.

Following the project, Gemini together with the Gemini Science and Technical Advisory Committee (STAC) and input from the wider community will decide on the top-level instrument requirements for the next facility instrument (Gen4#3) and launch a targeted Request for Proposals to design, build, test and deliver a suitable instrument. Gemini expects to release an RfP for Gen4#3 in 4Q-2015.

STAC Principles: The STAC identified the following principles for the feasibility study in their 2012B report: (see http://www.gemini.edu/science/public/STAC/stac2012b_report.pdf)

- *The instrument should be a workhorse instrument, meaning that it has broad scientific appeal and enables a wide range of science cases.*
- *The proposals should be science driven and include science cases. Science cases that provide synergies with new capabilities coming online (e.g. LSST, JWST, ALMA, etc) are highly desirable, especially including capabilities needed to follow up survey discoveries.*
- *The instrument should fit within the technical constraints of the Gemini telescopes as they now exist.*
- *The expected cost of the instrument shall be capped at a cost that is to be determined as part of the process of defining the RfP.*
- *The technical risk of the instrument should be modest, i.e. the success of the instrument should not depend upon some not-yet-proven technology.*
- *The instrument should be highly efficient, maintaining the 8-m aperture advantage.*
- *Although proposals for all instruments fitting these criteria will be fully considered, it is the majority opinion of the STAC that a wide-bandwidth moderate-resolution spectrograph is likely to prove most compelling.*

Gemini intends to award three or more fixed-price GIFS contracts for instrument feasibility studies, with the maximum available budget for each contract limited to USD 100,000. Our total budget for this activity is USD 300,000.

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GIFS Timeline

GIFS RfP/Selection Events	Date / Deadline
Release RfP	19th September 2014
Bidders Conference	31st October 2014
Notice of Intent to Submit Proposal	17th November 2014
Proposal Deadline	15th December 2014
Proposal Evaluation Review	12th January 2015
Selection Deadline	19th January 2015
Contract Negotiations	26th January – 6th February 2015

Contract Events	Date / Deadline
Start Feasibility Studies + Kickoff Meeting	week beginning 9th February 2015
Midpoint Site Visit	week beginning 11th May 2015
Feasibility Study Progress Presentation at the 2015 Gemini Meeting	15th - 18th June 2015
Submit Initial Feasibility Study Report	13th July 2015
Feasibility Study Review	10th - 12th August 2015
Submit Final Feasibility Study Report	12th September 2015

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GIFS → Gen4#3

Our GIFS goal was to gather differing opinions on what science to do and what instrument do to it with to best complement LSST. We got 4, rather similar, answers to this question.

1. Combine, merge, select, discard science cases from GIFS
2. We derive instrument requirements to meet what we think are the key science drivers based on the 4 studies
3. We make these requirements for the *design and build* RfP
4. We select additional capabilities based on and prioritize via additional science cases from GIFS

The Gen4#3 RfP (step 5)

AURA is soliciting proposals to design, fabricate, assemble, test, deliver, and commission the next facility class instrument, Gen 4#3. Gen 4#3 will be a wide-band medium-resolution spectrograph designed to take advantage of the Large Synoptic Survey Telescope (LSST) follow up opportunities.

Guiding Principles: Listed in priority order are the following guiding principles for the Gen 4#3 project:

- Providing core capabilities
- Meeting schedule
- Meeting budget
- Providing additional capabilities

The Gen4#3 RfP (step 5)

Proposers shall provide key requirements that shall equal or exceed those provided in Table 1.

Parameter	Value
Spectrographic	
Wavelength Range	0.4 to 1.6µm
Simultaneous Coverage	Yes
Continuous Coverage	Yes
Resolving Power (λ/Δλ)	≥ 4000
Spatial Sampling	≤ 0.2” at V, ≤ 0.15” at H
Imaging	
Natural Seeing FOV	≥ 170” x 90”
Spatial Sampling	≤ 0.2” at V, ≤ 0.15” at H
Performance	
Throughput	Maximize
Target Acquisition time	Minimize
Reliability	Maximize
Limiting Magnitude	Maximize
Night time calibration time	Minimize

The Gen4#3 RfP (step 5)

The desired additional capabilities are provided in table 2 below:

Key requirements based on any proposed additional capabilities (Table 2) shall also be provided in the key requirements table.

Capability/Parameter	Statement	Relative Priority
Wavelength Range	Extending into the K band	High
Simultaneous Multi-band Imaging	> 2 bands	Medium
AO Capable	Taking advance of Gemini AO systems	Medium
Spatially resolved targets	Ability to obtain spectra of	Medium
IFU	Inclusion of	Medium
Wavelength Range	Extending into the U band (within the telescope capability)	Low
All other additional capabilities		Low

How much do you bid for Gen4#3?

Costing:

- Top-down (quick)
- Bottom-up (harder, theoretically more accurate, but see *harder*)

Best to do both as a check.

Some information:

GHOST: $6M – optical high-resolution spectrograph

GPI: $25M – extreme AO IR coronagraph with IFU camera and calibration system

2Kx4K CCDs: ~$100k
CCD controller: $50k
2Kx2k H2RG IR detector: $300k
4Kx4K H4RG IR detector: $1M
IR controller: $100k
Gratings: $300k

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Gen4#3 RfP Schedule

Event	Date / Deadline
Release RFP	May 5, 2016
Proposers Conference (see section 3)	June 8, 2016
Notice of Intent due (see section 3)	August 1, 2016
Proposal due	August 29, 2016
Evaluation Process starts	September 2016
Contract Negotiations start	November 2016

We had a signed contract with the OCTOCAM team in March, 2017.
(This is ~2.5 years after the release of the GIFS RfP.)

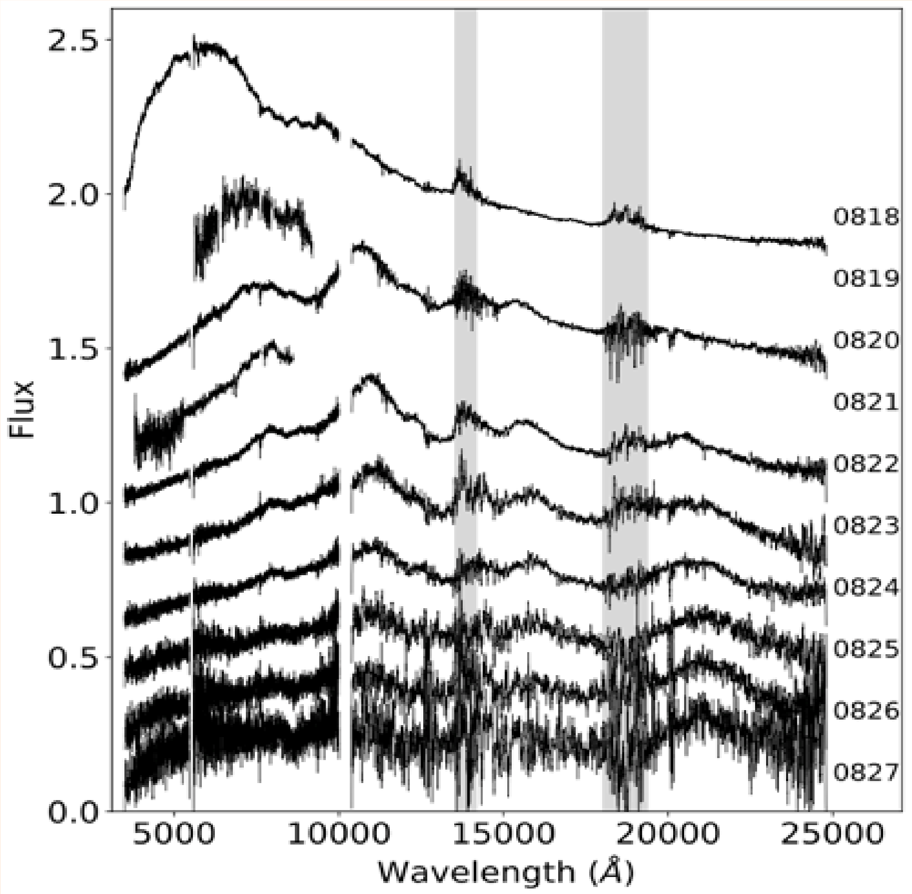
Driving & Enabled Science Cases

- Broad range of scientific topics (19 in total)
- Driving science cases (13 in total): make optimal use of the different characteristics/strengths of SCORPIO on Gemini
  - Combine simultaneous optical-to-near-infrared multiband photometry, broadband optical-to-near-infrared spectroscopy, and/or time domain astronomy, on an 8-meter class telescope with great sensitivity and observing efficiency, over a large wavelength range
  - Significant fraction of SCORPIO driving science cases are linked to core science cases for LSST (see LSST Science Book)
  - Scientific requirements flow down to Concept of Operations and instrument requirements
- Enabled science cases (6 in total)
  - Part of SCORPIO capability
  - Do not drive the scientific requirements of the instrument

Science Drivers

- Transients discovered with high-cadence optical/radio/X-ray surveys (LSST, SKA, etc.)
- Gravitational wave counterparts
- First generation of stars and their environments through gamma-ray bursts
- Supernova explosion physics and dust evolution in the Universe
- Extreme physics of black holes, neutron stars and white dwarfs
- Origin of our solar system: comets, asteroids and trans-neptunian objects
- Characterize exoplanets, their stellar systems and atmospheres
- Evolution of the Universe since the first galaxies

Gravitational Wave Sources



Pian et al. 2017

- First electromagnetic counterpart: GW 170817
- Rapidly evolving transient, in brightness and color
- Several spectral components

- SCORPIO: characterization
- Broadband photometry and spectroscopy
- Follow-up within hours

SCORPIO PS & Gemini PS presented at STScI Spring EMMA Workshop

STM: Source Properties

Science Case Number	Science Case	Source Type	Spectral Energy Distribution	Particular Properties	Rapid Response	Magnitude Range (AB)	Number of Sources
	Driving science cases						
SCD1	New Transients	Point	Blue, BB with temperature of 10,000 to 2,000 K	Fast evolving, declining 1-2 mag per day; visible for 1-2 weeks	Minutes: fast characterization	18-25 (O)	Tens per night
SCD2	Gravitational Wave Sources	Point	BB varying from 10,000 K (hours) to 1,000 K (weeks)	Blue bands fade in hours-days, near-infrared constant for week	Hours: spectral evolution	20-25 (O), 21-23 (NIR)	1 per week
SCD3	Gamma-Ray Bursts	Point/Extended	Power-law with index 0.7; possible reddening/absorption	Fade as power-law in time with index 1; host galaxy constant	Minutes: jet & emission physics	13-20 in mins, 18-25 in hours-days (O/NIR)	Few per week
SCD4	Supernovae	Point/Extended	BB with temperature 1,000 to 10,000 K	Many different types, with various variability time scales	Minutes: shock break-out, flash spectroscopy	16-25 (O/NIR)	Few per night
SCD5.1	X-Ray Binaries	Point	Multi-colored BB plus possible power-law with spectral break	Periodic at minutes to hours; variability down to sub-second	Day: outburst onset	18-23, up to 12 in outburst (O)	2-3 per year
SCD5.2	Active Galactic Nuclei	Point/Extended	Power-law with index 0.7 to 1	Day-month variability; hour-day variability for blazars	Hours-day: outburst onset, spectral evolution	18-26 (O), 16-25 (NIR)	Few hundred per year
SCD5.3	Tidal Disruption Events	Point/Extended	BB with temperature 20,000 K	Brightening in weeks to months; fades as power-law, index 5/3	Day: outburst onset	16-24 (O)	Few hundred per year
SCD6.1	Isolated Neutron Stars	Point	Non-thermal power-law, Rayleigh-Jeans, or combination	Periodic at 0.05-10 sec	N/A	23-26 (O)	2-3 per year
SCD6.2	Magnetars	Point	Intrinsically flat/blue, but significant reddening	Periodic at 2-10 sec; outbursts with weeks-months decays	Hours: high-energy outburst peak	17-22 (NIR)	1-2 per year
SCD6.3	Binary Millisecond Pulsars	Point	Star BB with peak in NIR or optical	Periodic: pulsar 1-50 milliseconds; binary 3-10 hours	N/A	14-25 (O/NIR)	2-3 per year
SCD6.4	Interacting Binary Systems	Point	Stellar BB with possible blue excess	Variability from seconds to month/year time scales	Hours: outburst maximum	8-20 (O)	Tens per year
SCD7	Extrasolar Planets	Point	Stellar BB of FKGM dwarfs	Time series of transits	N/A	12-21 (O)	Few hundred
SCD8	Primitive Small Solar System Bodies	Point/Extended	BB with temperature 5,800 K	Rotational variation in hours; asteroid activity	Hours: occultations, bursts	18-25 (O/NIR), up to 12 (occasional brightening)	100
	Enabled science cases						
SCE1	Pulsating Variable Stars	Point	BB with varying temperature; possibly emission lines	Periodic in light curve and radial velocity	N/A	Large range, down to 21 (O/NIR)	Few hundred
SCE2	Low-Mass Binary Systems	Point	BB with peak at 2,000 nm	Binary period in days; variability in minutes	N/A	Large range, mean 18 (O), 13 (NIR)	Few hundred
SCE3	Brown Dwarfs	Point	Strong molecular bands dominate near-infrared	Rotation period of 2-8 hours	N/A	17-26 (O), 16-24 (NIR)	20-30
SCE4	Massive Stars	Point/Extended	BB with varying temperature	Periodic or irregular variability	N/A	3-20 (O/NIR)	Few hundred
SCE5	Supernova Remnants	Extended	Thermal continuum plus line emission	No variability	N/A	17-25 (O)	Few hundred
SCE6	Microlensing	Point	BB of late-type stars, both dwarfs and giants	Short-lived anomalies (minutes to days)	Minutes: anomalies	12-21 (O)	Few tens per year

STM: Observing Requirements

Science Case Number	Science Case	Seeing	Acquisition Requirements	Astrometric Accuracy	Calibration Requirements	Atmospheric Dispersion Corrector
	Driving science cases					
SCD1	New Transients	IQ = Any	Short exposure; sometimes blind if host galaxy is bright	< 1"	5% absolute, 2% relative	Yes: imaging and spectroscopy
SCD2	Gravitational Wave Sources	IQ = Any	Short exposure early; long/blind late; sometimes NIR	< 1"	5% absolute, 1% relative	Yes: imaging and spectroscopy
SCD3	Gamma-Ray Bursts	IQ = Any	Short exposure; in NIR for high-redshift sources	Few arcseconds	5% absolute, 1% relative	Yes: imaging and spectroscopy
SCD4	Supernovae	IQ = Any	Short exposure possible	< 1"	5% absolute, 2% relative	Yes: imaging and spectroscopy
SCD5.1	X-Ray Binaries	IQ = Any	Short exposure possible	< 1"	5% absolute, 2% relative	No
SCD5.2	Active Galactic Nuclei	IQ>20, IQ>85, IQ = Any	Short exposure possible	< 1"	5% absolute, 2% relative	Yes: imaging and spectroscopy
SCD5.3	Tidal Disruption Events	IQ = Any	Short exposure possible	< 1"	5% absolute, 1% relative	Yes: imaging and spectroscopy
SCD6.1	Isolated Neutron Stars	IQ>20	Blind	< 1"	5% absolute, 2% relative	No
SCD6.2	Magnetars	IQ>20	Blind	Few arcseconds	5% absolute, 2% relative	No
SCD6.3	Binary Millisecond Pulsars	IQ>70	Short exposure possible	< 1"	5% absolute, 2% relative	Yes: spectroscopy
SCD6.4	Interacting Binary Systems	IQ>85	Short exposure possible	Few arcseconds	5% absolute, 2% relative	Yes: imaging and spectroscopy
SCD7	Extrasolar Planets	IQ>20, IQ>70	Short exposure possible	< 1"	5% absolute, 1% relative	Yes: spectroscopy
SCD8	Primitive Small Solar System Bodies	IQ>20, IQ>85	Short exposure possible	< 1"	5% absolute, 2% relative	Yes: spectroscopy
	Enabled science cases					
SCE1	Pulsating Variable Stars	IQ = Any	Short exposure possible	< 1"	5% absolute, 1% relative	Yes: spectroscopy
SCE2	Low-Mass Binary Systems	IQ > 85	Short exposure; long exposure; blind	< 1"	5% absolute, 2% relative	Yes: spectroscopy
SCE3	Brown Dwarfs	IQ = Any	Short exposure possible	Few arcseconds	5% absolute, 2% relative	Yes: spectroscopy
SCE4	Massive Stars	IQ > 70	Short exposure possible	< 1"	5% absolute, 2% relative	Yes: imaging and spectroscopy
SCE5	Supernova Remnants	IQ > 20	Short exposure possible	1"	5% absolute, 2% relative	No
SCE6	Microlensing	IQ > 85	Short exposure possible	< 1"	5% absolute, 2% relative	Yes: spectroscopy

STM: Imaging Requirements

Science Case Number	Science Case	Imaging Bands	Imaging S/N	Field of View	Imaging Cadence	Imaging Temporal Resolution	Imaging Exposure Time
	Driving science cases						
SCD1	New Transients	grizYJHK	10-50	3'x3' square	Few times in first night; later once per night or less	50 milliseconds in some cases	Few seconds to tens of minutes
SCD2	Gravitational Wave Sources	grizYJHK	5-20	3'x3' square	Few times in first night; later once per night or less	Seconds, only early	Minutes to hours
SCD3	Gamma-Ray Bursts	grizYJHK	5-20	3'x3' square	10 sec to minutes in first hour; hours to nights later	Seconds, only early	Few seconds to tens of minutes
SCD4	Supernovae	grizYJHK	5	3'x3' square	Minutes to days	Minute, only early	Few minutes
SCD5.1	X-Ray Binaries	grizYJHK	20	3'x3' square	Several hour per night in outburst; later daily/weekly	50 milliseconds in outburst	Few seconds to minutes
SCD5.2	Active Galactic Nuclei	grizYJHK	5-10	3'x3' square	Days to months; hours for blazars	Seconds sometimes	Minutes to hours
SCD5.3	Tidal Disruption Events	grizYJHK	5-20	3'x3' square	Days to weeks	Seconds, only early	Minutes to hours
SCD6.1	Isolated Neutron Stars	gr(izY)	5-10	3'x3' square	Multiple epochs for astrometry	50 milliseconds	Hours
SCD6.2	Magnetars	(gri)zYJHK	5-10	3'x3' square	Multiple epochs for astrometry	200 milliseconds	Hours
SCD6.3	Binary Millisecond Pulsars	griz(YJHK)	10	3'x3' square	Several hours or multiple nights	Minutes	Hours
SCD6.4	Interacting Binary Systems	griz(YJHK)	100	3'x3' square	Hours to nights	Seconds to minutes	Seconds to Minutes
SCD7	Extrasolar Planets	(g)rizYJHK	100	3'x3' square	N/A	500 millisecods to tens of seconds	Hours
SCD8	Primitive Small Solar System Bodies	grizYJHK	30	3'x3' square	Minutes to hours	Tens of seconds	Few seconds to tens of minutes
	Enabled science cases						
SCE1	Pulsating Variable Stars	grizYJHK	200-400	3'x3' square	30-50 obs. per cycle, vary from 100 seconds to hours	Seconds	Minutes to tens of minutes
SCE2	Low-Mass Binary Systems	(griz)YJHK	10	3'x3' square	Half nights for 1 week	Minutes	Minutes
SCE3	Brown Dwarfs	izYJHK	500	3'x3' square	Few months between observations	Minutes	Hours
SCE4	Massive Stars	grizYJHK	50-150	3'x3' square	N/A	N/A	Seconds to minutes
SCE5	Supernova Remnants	(g)r(iz)	5-10	3'x3' square	N/A	N/A	Hour
SCE6	Microlensing	rizYJHK	100	3'x3' square	Tens of minutes to days	Seconds	Minutes

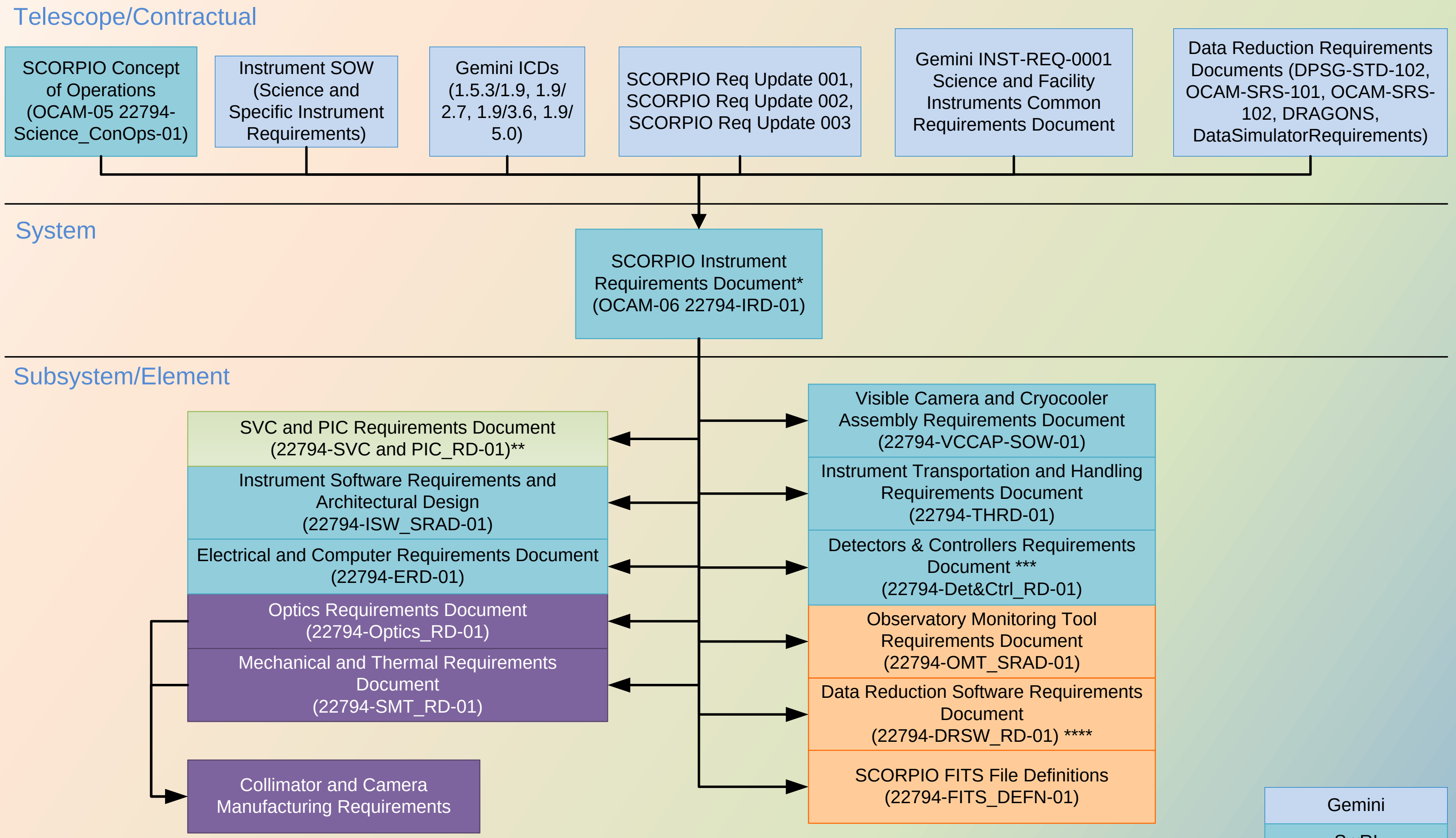
STM: Spectral Requirements

Science Case Number	Science Case	Spectral Coverage	Spectral S/N	Spectral Resolution	Slit Width	Spectroscopic Cadence	Spectroscopic Temporal Resolution	Spectroscopic Exposure Time	Spectroscopic Position Angle
	Driving science cases								
SCD1	New Transients	385-2350	10	1000-2000	0.54 – 4.32	Few times in first night; later once per night or less	N/A	Few minutes to hours	Parallactic, sometimes any
SCD2	Gravitational Wave Sources	385-2350	5-20	100-500	1.08 – 4.32	Few times in first night; later once per night or less	N/A	Few minutes to hours	Parallactic, sometimes any
SCD3	Gamma-Ray Bursts	385-2350	5-20	4000	0.54 – 4.32	5 minutes early on; hours to nights later	N/A	Few minutes to hours	Parallactic, sometimes any
SCD4	Supernovae	385-2350	10	2000-4000	0.54 – 4.32	Minutes to days	N/A	Tens of minutes to hours	Any
SCD5.1	X-Ray Binaries	385-2350	20	1000-2000	1.08 – 4.32	10-15 spectra over weeks, 1-2 per night	N/A	Tens of minutes	Parallactic
SCD5.2	Active Galactic Nuclei	385-2350	5-50	1000-4000	0.54 – 4.32	Days to months; hours for blazars	N/A	Minutes to hours	Parallactic, sometimes any
SCD5.3	Tidal Disruption Events	385-2350	5-20	500-4000	0.54 – 4.32	Days to weeks	N/A	Tens of minutes to hours	Parallactic, sometimes any
SCD6.1	Isolated Neutron Stars	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SCD6.2	Magnetars	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SCD6.3	Binary Millisecond Pulsars	385-2350	3-5	4000-6000	0.36 – 0.54	10-15 spectra over weeks, 1-2 per night	N/A	Tens of minutes to hour	Any
SCD6.4	Interacting Binary Systems	385-2350	50-100	1000-4000	0.54 – 1.08	Hours to nights	Minutes	Minutes	Parallactic, sometimes any
SCD7	Extrasolar Planets	385-2350	100	100-2000	1.08 – 4.32	N/A	Tens of seconds	Hours	Align target and reference
SCD8	Primitive Small Solar System Bodies	385-2350	5	100-5000	0.54 – 4.32	Minutes to hours	N/A	Minutes to hours	Parallactic, sometimes any
	Enabled science cases								
SCE1	Pulsating Variable Stars	385-2350	50-100	4000-8000	0.54 – 1.08	30-50 obs. per cycle, vary from 100 sec to hours	Minutes	Minutes	Any
SCE2	Low-Mass Binary Systems	650-2350	10	4000	0.36 – 0.54	10-15 spectra over weeks, 1-2 per night	N/A	Hours	Any
SCE3	Brown Dwarfs	600-2350	20-30	500-4000	0.54 – 4.32	N/A	Minutes	Hours	Align target and reference
SCE4	Massive Stars	385-2350	50-150	10000	0.36 – 0.54	Seconds to hours	N/A	Minutes to tens of minutes	Parallactic, sometimes any
SCE5	Supernova Remnants	400-700	5	4000	0.54 – 4.32	N/A	N/A	Hours	Any
SCE6	Microlensing	385-2350	100	500-1000	1.08 – 4.32	One spectrum per day at event peak	N/A	Hours	Any

STM: Derived Requirements

Science Case Number	Science Case	Bright Imaging	Normal Imaging	Faint Imaging	Bright Spectroscopy	Normal Spectroscopy	Faint Spectroscopy
	Driving science cases						
SCD1	New Transients	No	Yes	Yes	No	Yes	Yes
SCD2	Gravitational Wave Sources	No	Yes	Yes	No	Yes	Yes
SCD3	Gamma-Ray Bursts	Yes	Yes	Yes	Yes	Yes	Yes
SCD4	Supernovae	No	Yes	Yes	No	Yes	Yes
SCD5.1	X-Ray Binaries	Yes	Yes	Yes	Yes	Yes	Yes
SCD5.2	Active Galactic Nuclei	No	Yes	Yes	No	Yes	Yes
SCD5.3	Tidal Disruption Events	No	Yes	Yes	No	Yes	Yes
SCD6.1	Isolated Neutron Stars	No	No	Yes	No	No	No
SCD6.2	Magnetars	No	No	Yes	No	No	No
SCD6.3	Binary Millisecond Pulsars	Yes	Yes	No	Yes	Yes	No
SCD6.4	Interacting Binary Systems	Yes	Yes	No	Yes	Yes	No
SCD7	Extrasolar Planets	No	No	No	Yes	Yes	No
SCD8	Primitive Small Solar System Bodies	Yes	Yes	Yes	Yes	Yes	Yes
	Enabled science cases						
SCE1	Pulsating Variable Stars	Yes	Yes	No	Yes	Yes	No
SCE2	Low-Mass Binary Systems	Yes	Yes	No	Yes	Yes	No
SCE3	Brown Dwarfs	Yes	Yes	No	Yes	Yes	No
SCE4	Massive Stars	Yes	Yes	No	Yes	Yes	No
SCE5	Supernova Remnants	No	Yes	Yes	No	Yes	Yes
SCE6	Microlensing	No	Yes	Yes	No	Yes	Yes

Requirements Flow



Gemini
SwRI
JHU
FRACTAL

*   Includes two DOORS modules (SOW and IRD) to ensure all requirements are captured
** PIC and SVC requirements currently reside in IRD module
*** Includes sections for the ARCHON, MACIE, Pre-Amp, and Sync Board Element requirements
**** Includes Data Simulator and Data Quality Assessment requirements

Key Technical Performance Metrics (1/2)

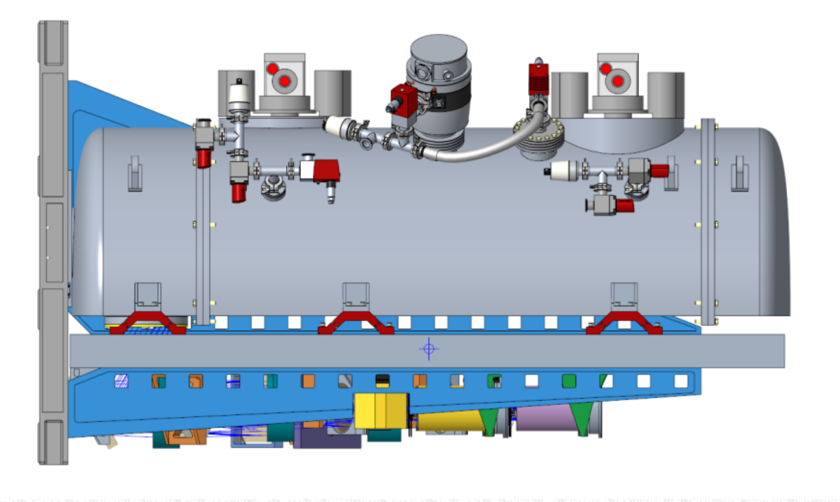
SOW Req # in DOORS	Requirement		CBE	Margin	Notes/IRD flowdown
Spectrographic					
SOW1	Wavelength Range	0.385-2.3 µm	0.385-2.35 µm	Comp	IRD94, IRD96, IRD97
SOW1	Simultaneous Coverage	Yes	Yes	Comp	IRD94, IRD96, IRD97
SOW2	Continuous Coverage (excluding atmospheric bands)	Yes	Yes	Comp	IRD94
SOW4	Spatial Sampling (all bands)	0.18±0.02”	0.18±0.02”	Comp	IRD85, IRD88
Resolving Power (slit of 0.54”)					
SOW3	g @ 468.5 nm	≥ 3500	3529	0.8%	IRD87, IRD90, IRD91, IRD92, IRD94
	r @ 621.5 nm	≥ 4000	4512	28.9%	
	i @ 754.5 nm	≥ 4000	4527	29.3%	
	z @ 889 nm	≥ 4000	4533	29.5%	
	Y @ 1040 nm	≥ 4000	4055	1.4%	
	J @ 1250 nm	≥ 4000	4002	0.1%	
	H @ 1630 nm	≥ 4000	4016	0.4%	
	K @ 2175 nm	≥ 4000	4028	0.7%	
Imaging					
SOW5	Natural Seeing Field-of-View	>170” x 170”	180” x 180”	12.10%	IRD94
SOW4	Spatial Sampling (all bands)	0.18±0.02”	0.18±0.02”	Comp	IRD85, IRD88
Photometric Time Resolution					
SOW8	For a 30x30pix window @50kHz in griz band	≤ 50 ms	10.7	78.6%	IRD243
SOW7	@10 MHz in YJHK band	≤ 50 ms	4.5	91%	IRD242
General requirements					
SOW9	Target Acquisition Time (for automatic target acquisition and grism/slit setup)	Integration time +10s	~60s	Neg	IRD244
SOW10	Reliability – Lifetime (without a major overhaul due to failure or degradation, with annual usage time of 1200h)	12 years	Comply by design	Comply	IRD141
SOW11	Reliability – Downtime due to faults (as compared to scheduled time on the telescope)	<2%	Comply by design	Comply	IRD245
SOW12	Observing Efficiency (for a one-hour exposure, exclusive of telescope acquisition time and losses attributable to weather or other systems)	>90%	Comply by design	Comply	IRD25

* Non-compliance discussed in Presentation 02

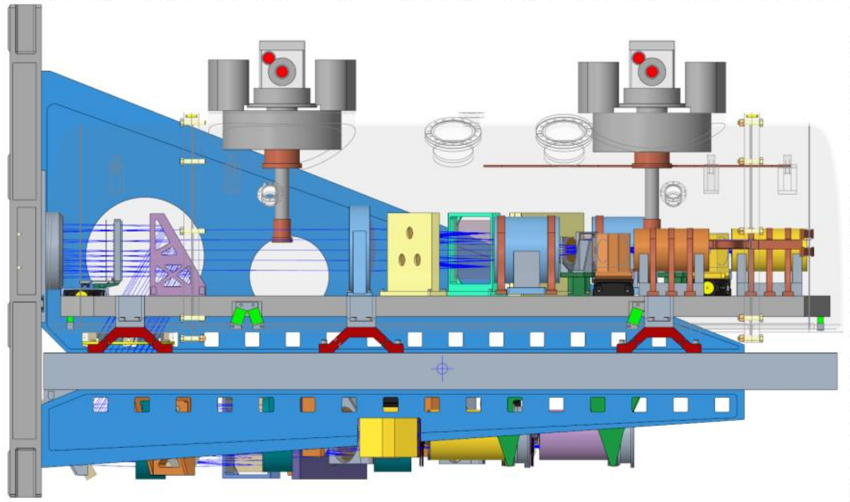
Key Technical Performance Metrics (2/2)

SOW Req	Requirement			CBE	Margin	Notes
Spectrographic Throughput (ADC through detector)						
SOW6	g	@ 400.0 nm	≥ 20%	27.2%	36.2%	IRD87, IRD90, IRD91, IRD92, IRD94
	g	@ 468.5 nm	Average ≥ 30%	36.2%	20.7%	
	r	@ 621.5 nm				
	i	@ 754.5 nm				
	z	@ 889 nm				
	Y	@ 1040 nm				
	J	@ 1250 nm				
	H	@ 1630 nm				
	K	@ 2175 nm				
Imaging Throughput (ADC through detector)						
SOW6	g	@ 468.5 nm	Average ≥ 35%	48.7%	39.1%	IRD87, IRD90, IRD91, IRD92, IRD94
	r	@ 621.5 nm				
	i	@ 754.5 nm				
	z	@ 889 nm				
	Y	@ 1040 nm				
	J	@ 1250 nm				
	H	@ 1630 nm				
	K	@ 2175 nm				

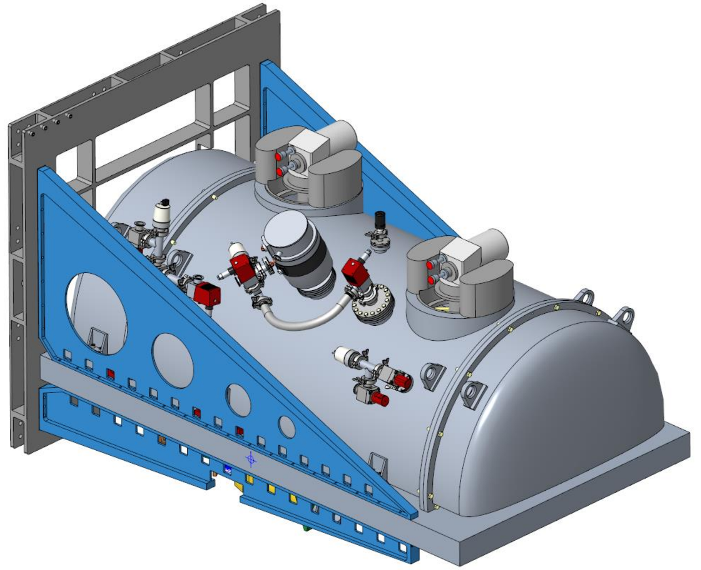
SCORPIO PDR Design



Cryostat attached to main optical bench - bipods

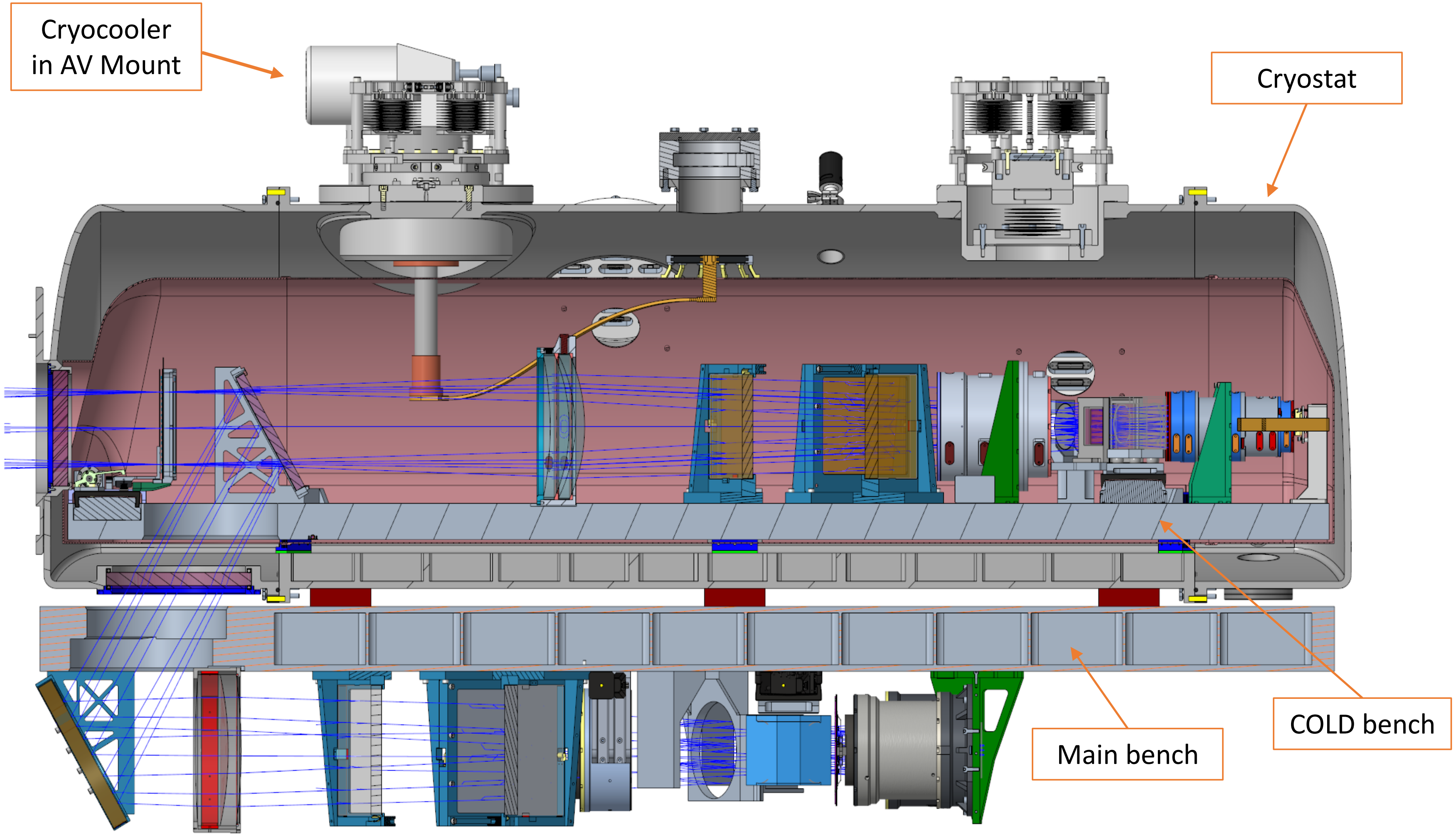


Cold bench inside cryostat

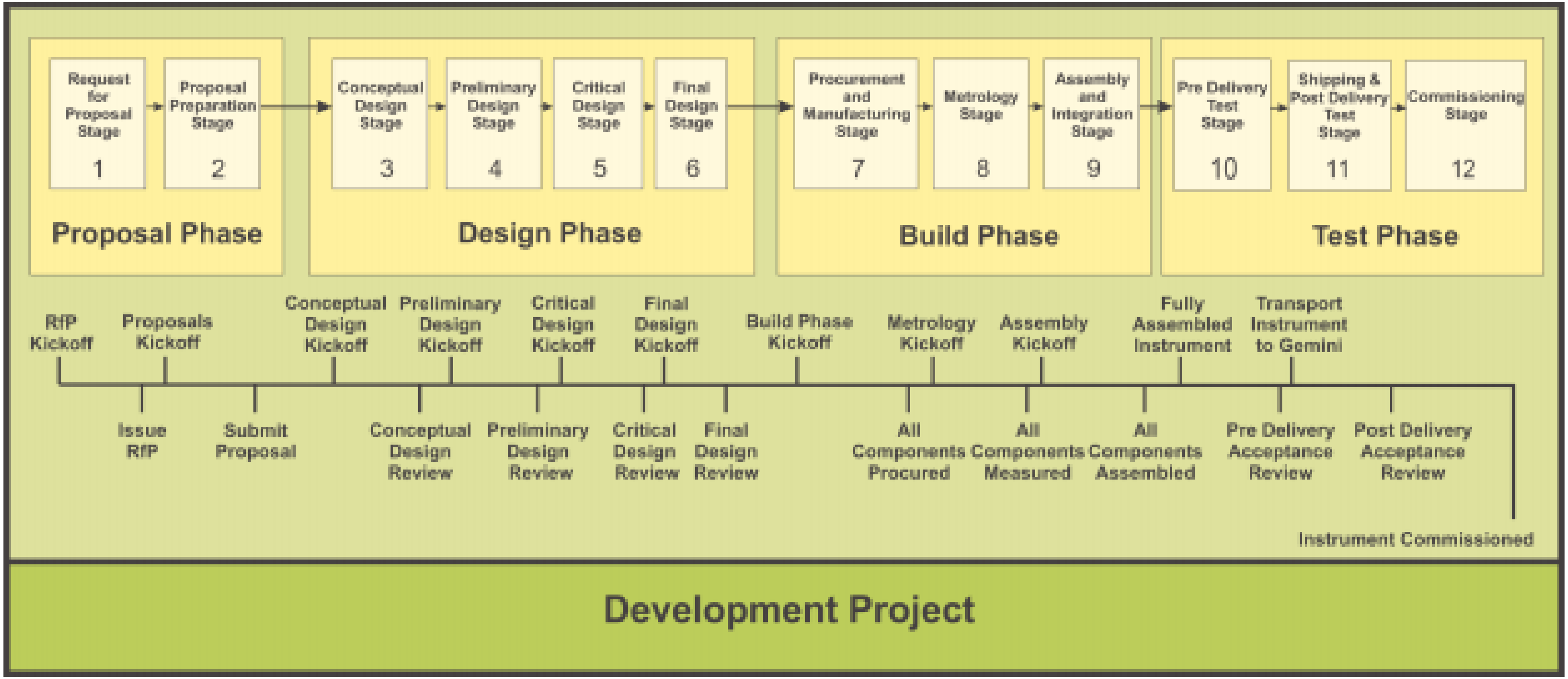


Optical bench attached to I/F structure with 4 lateral plates

SCORPIO CDR design



Instrument work structure



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Project management

Cost

Schedule

Scope

For most real projects, it is essentially impossible to fix all three of these.
→ You need priorities and contingencies.
Ability to use scope contingency decreases as the instrument progresses.
→ You should descope early, even when you may have cost contingency available.

Team

Stakeholders

Stakeholders: team, users, funders, vendors, contractors, governance, line management, customers: facility director and support staff, …

Risk

The risk register is a primary tool to convince stakeholders of the need to take action.

This is not project management

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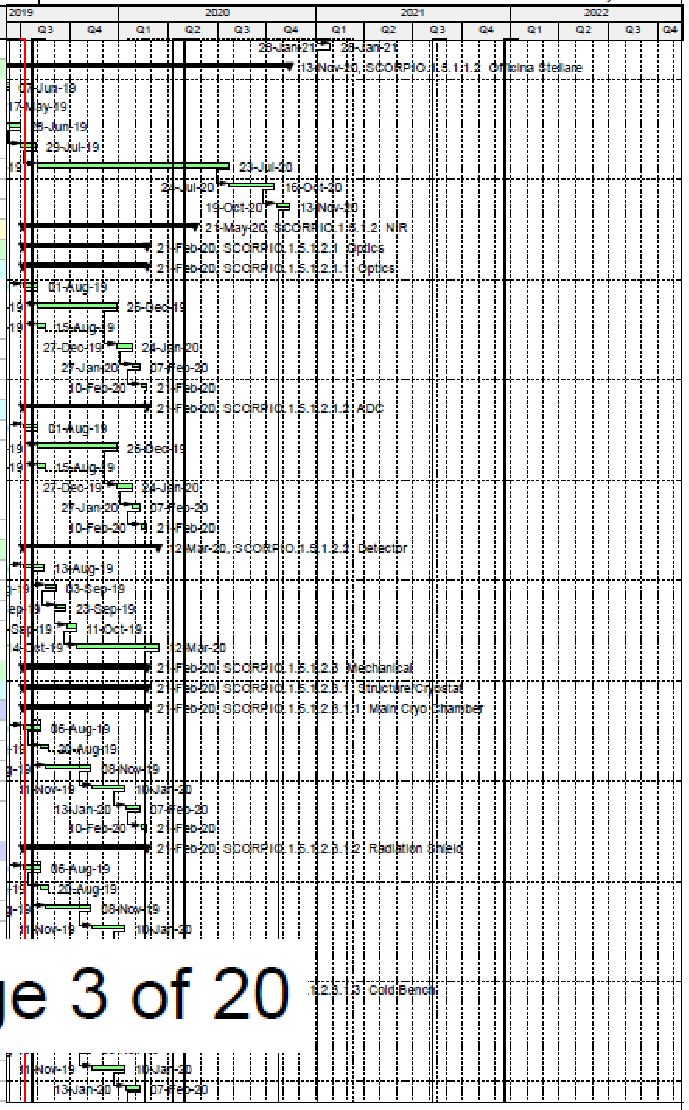
Southwest Research Institute
SCORPIO Project Management Plan

22794-PMP-01
Rev 2 Chg 0

SCORPIO — SCORPIO_PDF — 14-May-19 10:20

Activity ID	Activity Name	At Completion Duration	Start	Finish	Predecessors	Successors
A3040	DA	1	28-Jan-21	28-Jan-21	A3030	A2400
SCORPIO.1.5.1.1.2 Officina Stellare		380	17-May-19	13-Nov-20		
A2860	Blank materials order	15	17-May-19	07-Jun-19	A2850	A2870
A2850	Purchase order	0	17-May-19*	17-May-19		A2860
A2870	Optics Pre-manufacturing Review	15	10-Jun-19	28-Jun-19	A2860	A2880
A2880	Opto-mechanics Pre-manufacturing Review	20	01-Jul-19	29-Jul-19	A2870	A2890
A2890	Pre-Integration Acceptance	250	30-Jul-19	23-Jul-20	A2880	A2900
A2900	Factory Acceptance	60	24-Jul-20	16-Oct-20	A2890	A2910
A2910	Delivery Acceptance	20	19-Oct-20	13-Nov-20	A2900	A2310
SCORPIO.1.5.1.2 NIR		224	05-Jul-19	21-May-20		
SCORPIO.1.5.1.2.1 Optics		160	05-Jul-19	21-Feb-20		
SCORPIO.1.5.1.2.1.1 Optics		160	05-Jul-19	21-Feb-20		
A9630	NIR Optics Post CDR Update & Drawings	20	05-Jul-19	01-Aug-19	A1010	A9640, A9650
A9650	NIR Optics Procurement	100	02-Aug-19	26-Dec-19	A9630	A9660
A9640	NIR Optics MPS	10	02-Aug-19	15-Aug-19	A9630	A9660
A9660	NIR Optics Fab	20	27-Dec-19	24-Jan-20	A9640, A9650	A9670
A9670	NIR Optics Assembly	10	27-Jan-20	07-Feb-20	A9660	A9680
A9680	NIR Optics Test	10	10-Feb-20	21-Feb-20	A9670	A8290
SCORPIO.1.5.1.2.1.2 ADC		160	05-Jul-19	21-Feb-20		
A9570	NIR ADC Post CDR Update & Drawings	20	05-Jul-19	01-Aug-19	A1010	A9580, A9590
A9590	NIR ADC Procurement	100	02-Aug-19	26-Dec-19	A9570	A9600
A9580	NIR ADC MPS	10	02-Aug-19	15-Aug-19	A9570	A9600
A9600	NIR ADC Fab	20	27-Dec-19	24-Jan-20	A9580, A9590	A9610
A9610	NIR ADC Assembly	10	27-Jan-20	07-Feb-20	A9600	A9620
A9620	NIR ADC Test	10	10-Feb-20	21-Feb-20	A9610	A8290
SCORPIO.1.5.1.2.2 Detector		174	05-Jul-19	12-Mar-20		
A8730	NIR Detector Post CDR Update & Drawings	28	05-Jul-19	13-Aug-19	A1010	A8750
A8750	NIR Detector MPS	14	14-Aug-19	03-Sep-19	A8730	A8760
A8760	NIR Detector Fab	14	04-Sep-19	23-Sep-19	A8750	A8770
A8770	NIR Detector Assembly	14	24-Sep-19	11-Oct-19	A8760	A8780
A8780	NIR Detector Test	104	14-Oct-19	12-Mar-20	A8770	A8290
SCORPIO.1.5.1.2.3 Mechanical		160	05-Jul-19	21-Feb-20		
SCORPIO.1.5.1.2.3.1 Structure/Cryostat		160	05-Jul-19	21-Feb-20		
SCORPIO.1.5.1.2.3.1.1 Main Cryo Chamber		160	05-Jul-19	21-Feb-20		
A10690	NIR Main Cryo Chamber CDR Update & Drawings	23	05-Jul-19	06-Aug-19	A1010	A10700, A1020
A10700	NIR Main Cryo Chamber MPS	10	07-Aug-19	20-Aug-19	A10690	A10720
A10710	NIR Main Cryo Chamber Procurement	60	16-Aug-19	08-Nov-19	A1020	A10720
A10720	NIR Main Cryo Chamber Fab	40	11-Nov-19	10-Jan-20	A10700, A10710	A10730
A10730	NIR Main Cryo Chamber Assembly	20	13-Jan-20	07-Feb-20	A10720	A10740
A10740	NIR Main Cryo Chamber Test	10	10-Feb-20	21-Feb-20	A10730	A8290
SCORPIO.1.5.1.2.3.1.2 Radiation Shield		160	05-Jul-19	21-Feb-20		
A10750	NIR Radiation Shield CDR Update & Drawings	23	05-Jul-19	06-Aug-19	A1010	A10760, A1020
A10760	NIR Radiation Shield MPS	10	07-Aug-19	20-Aug-19	A10750	A10780
A10770	NIR Radiation Shield Procurement	60	16-Aug-19	08-Nov-19	A1020	A10780
A10780	NIR Radiation Shield Fab	40	11-Nov-19	10-Jan-20	A10760, A10770	A10790
A10790	NIR Radiation Shield Assembly	20	13-Jan-20	07-Feb-20	A10780	A10800
A10800	NIR Radiation Shield Test	10	10-Feb-20	21-Feb-20	A10790	A8290
SCORPIO.1.5.1.2.3.1.3 Cold Bench		160	05-Jul-19	21-Feb-20		
A10810	NIR Cold Bench CDR Update & Drawings	23	05-Jul-19	06-Aug-19	A1010	A10820, A
A10820	NIR Cold Bench MPS	10	07-Aug-19	20-Aug-19	A10810	A10840
A10830	NIR Cold Bench Procurement	60	16-Aug-19	08-Nov-19	A1020	A10840
A10840	NIR Cold Bench Fab	40	11-Nov-19	10-Jan-20	A10820, A10830	A10850
A10850	NIR Cold Bench Assembly	20	13-Jan-20	07-Feb-20	A10840	A10860



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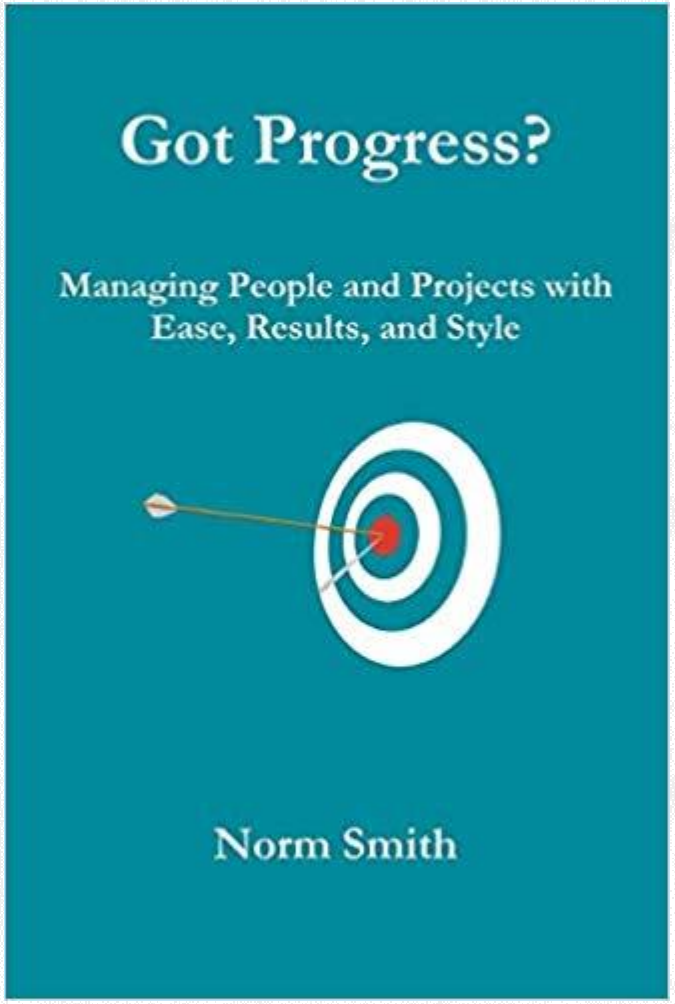
Remaining Level of Effort — Actual Work — Critical Remaining Work
Actual Level of Effort — Remaining Work — ◆ Milestone

TASK filter: All Activities

Thoughts on project plans



Situational Awareness

Use the minimum amount of detail required to successfully manage the project at a given point in time.

Flat Schedule: Use as few levels as necessary (see above)
Agile scheduling: Block in your constraints; flexibly work a plan within them
Rolling wave: Diminishing granularity with time; plan what you know now; plan the next bit when you know it

Project management

Cost

Schedule

Scope

For most real projects, it is essentially impossible to fix all three of these.

→ You need priorities and contingencies.

Ability to use scope contingency decreases as the instrument progresses.

→ You should descope early, even when you may have cost contingency available.

Team

Stakeholders

Stakeholders: team, users, funders, vendors, contractors, governance, line management, customers: facility director and support staff, …

Risk

The risk register is a primary tool to convince stakeholders of the need to take action.

Project Followership

Marco Sampietro

Technical approach	Project Followership
Waste of time. It is not strictly related to my work, I can read the meeting minute to get directly to the point.	•Opportunity to ask clarifications, to understand how my work fits into the project. •Opportunity to modify the project before is too late. •Ability to understand the choices made at the C level. •Opportunity to “sell” myself.

Project Followership

Technical approach	Project Followership
People that should provide requirements are not able to do so and it seems that they do not speak my language.	It is my duty to translate business requirements into technical requirements.
If requirements are incomplete, I will define them by myself. I know our business.	Making mistakes during this phase will lead to huge reworks in the future and even to project failure.

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Project Followership

Technical approach	Project Followership
Trying to provide good estimates is useless, since the project schedule will change many times and priorities change every day.	•Providing good estimates increases the stability of my agenda. •In addition, my colleagues consider me a reliable person and my reputation is improving.
The project manager should manage the interfaces between the activities, otherwise why we are paying him/her?	Understanding the activity network facilitates the communication with my colleagues. Reworks and conflicts are reduced.

Project Followership

Technical approach	Project Followership
Inserting data related to the activity status is a waste of time. I know where I am. The Project Manager should trust me.	•Calculating the work done and work left increases my ability to estimate and thus my ability to organize my activities. •Having data on the other activities permit me to better plan my work.

SCORPIO expertise needed

- Science – determine and assess ability to do driving science cases
- Observations/Operations – translate science objectives and approach to operating scenarios
- Systems Engineering – build requirements flow from science cases to instrument/systems/sub-systems/…; oversee multi-level requirement testing
- Engineering – machining, optics, mechanics, cryogenics, electronics, software, computing, ….
- Legalese – read and respond to RfPs; negotiate work contracts; purchasing
- Finance – budget estimation; deliver to a fixed cost
- Task management – develop and deliver to a fixed schedule
- General management – manage stakeholders, write reports, document, …

What's missing?

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What's missing?

Managing your team.

Leading your team.

Managing …

Directing

Controlling

Overseeing

Allocating

Deciding

Administrating

Terina Allen: What is the difference between management and leadership. Forbes:
https://www.forbes.com/sites/terinaallen/2018/10/09/what-is-the-difference-between-management-and-leadership/#51cbebb374d6

Leadership vs. Management

Manage stuff.

Lead people.

Traits of good leaders

Form groups ~3 people.

Each person describe a leader you've admired.

What characteristics did that leader have?

What are the common characteristics of your identified leaders?

Report back in ~7m.

Leadership Traits

Leadership traits

humility respect self-control honesty commitment determination gratitude discipline vision integrity listener hard-working self-sacrificing accountable compassionate trustworthy coach tough love

Is this sufficient?

Leadership = influence

(without the need to resort to power)

humility respect self-control honesty commitment determination
gratitude discipline vision integrity listener
hard-working self-sacrificing accountable compassionate trustworthy
coach tough love

Character + Skill

Leadership = Character + Skills

The good news is both can be learned.

Lao Tzu

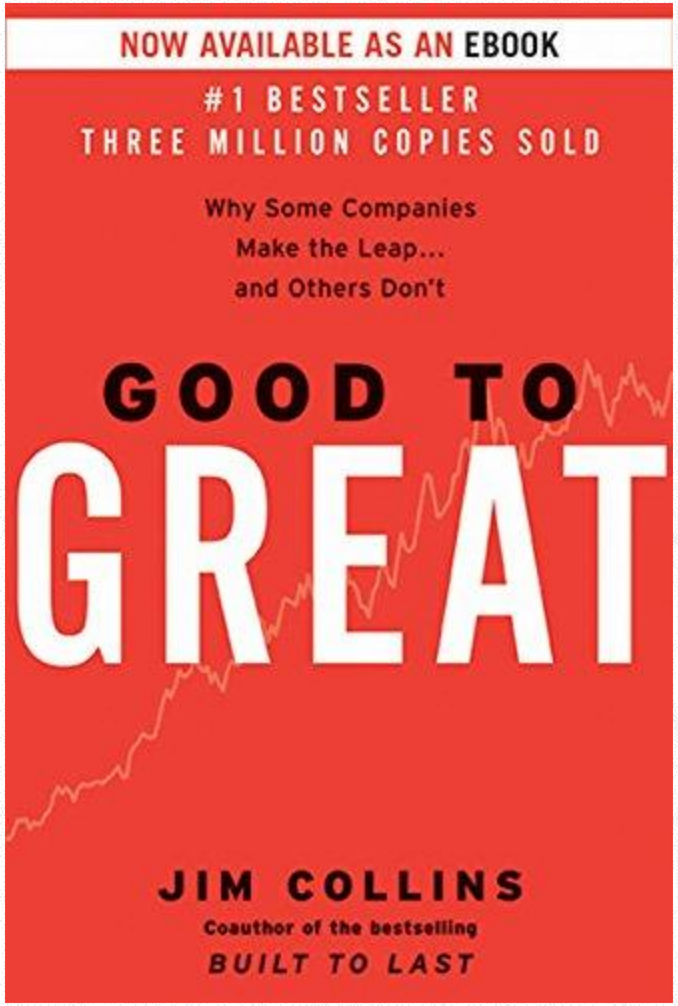
If you do not change your direction, you may end up where you are heading.

Level 5 leaders

Jim Collins

The Level 5 Leader

https://www.youtube.com/watch?v=q-KyQ90XByY



Some of Scot's lessons learned

Starting with…

- Scientist Dilemma
- Engineering Dilemma
- Management corollary
- Merging academia and industry
- Valuing diversity

Scientist Dilemma

- Scientist Dilemma
  - Observatories want scientists because they make the best support staff
  - Scientists want to do science, not support

The solution: Do science

(Learn to say no)

- Engineering Dilemma
- Management corollary
- Merging academia and industry
- Valuing diversity

Scientist Dilemma

- Scientist Dilemma
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  (Learn to say no)
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Management Corollary

- Scientist Dilemma
- Engineering Dilemma
- Management corollary
  - Scientists are not trained in management; managers are not trained in science
  - Scientists are trained to be independent, objective, challenging, and anti-management

The solution: Learn both

- Merging academia and industry
- Valuing diversity

Why I do this

- Scientist Dilemma
- Engineering Dilemma
- Management corollary
- Merging academia and industry

  Combine the objective, data-based, scientific method of problem solving with best practices and ideologies from industry to create opportunities and build teams that deliver better products more efficiently
- Valuing diversity

Diversity

What is diversity?

Why is it important?

Diversity of thought, experiences, and mindset …

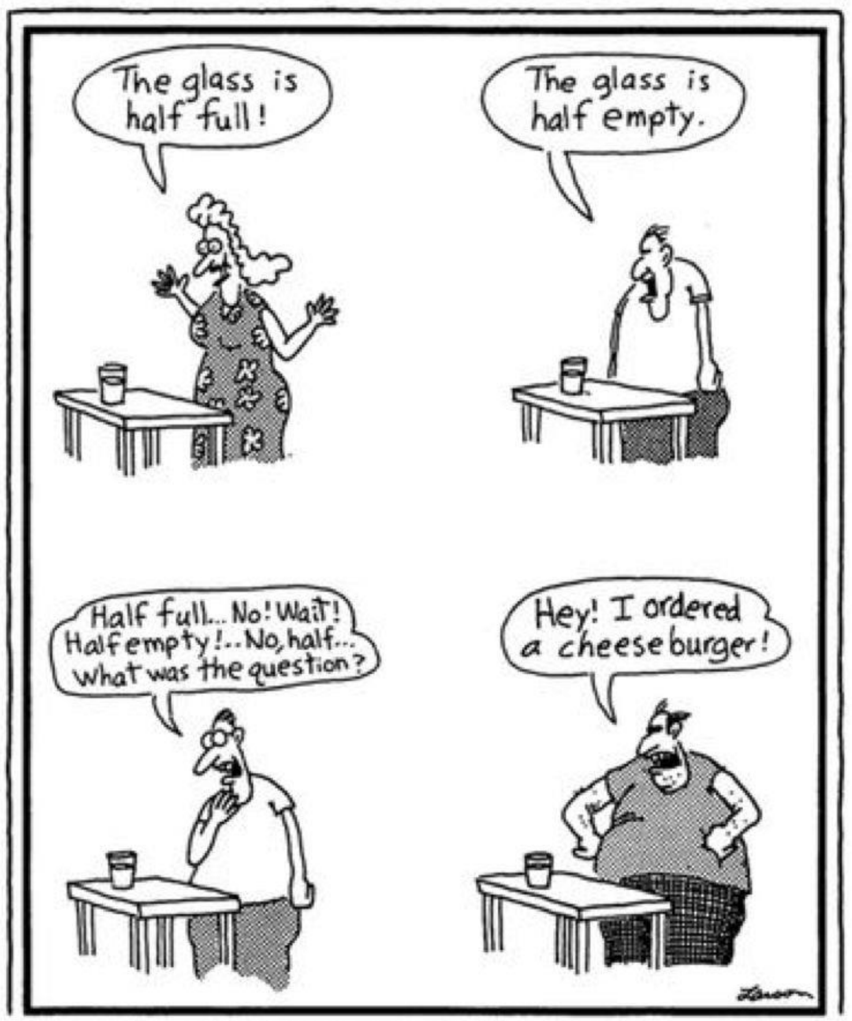
Diverse teams can be harder to lead …

and are more productive.

The Enneagram

9 types, not 4

References: The Enneagram made Easy
https://www.enneagraminstitute.com
Matt Schlegel's ideas on problem solving and the enneagram:
http://sdforumelsig.blogspot.com/search?q=matt+schlegel



The four basic personality types

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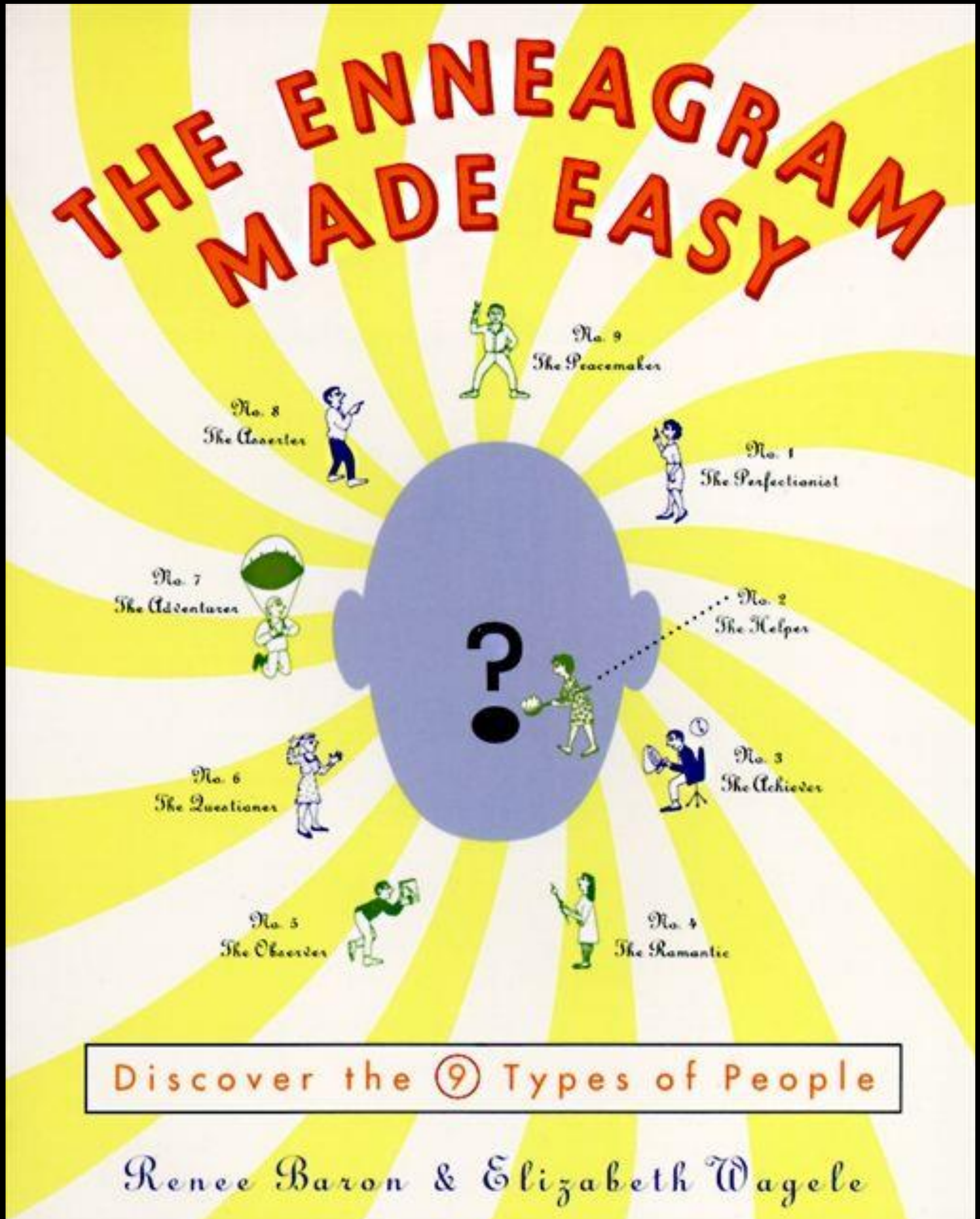
The 9 types

1 - Perfectionist
2 - Helper
3 - Achiever
4 - Romantic
5 - Observer
6 - Questioner
7 - Adventurer
8 - Asserter
9 - Peacemaker



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What can the enneagram tell us?

3 Triads with 3 Centers

- Anger / Instinctive (8,9,1)
- Emotion / Feeling (2,3,4)
- Anxiety / Thinking (7,6,5)

3 Primary Responses

- External (8,2,7)
- Suppressed (9,3,6)
- Internal (1,4,5)

For example:

- *8s can appear overpowering and aggressive without ever realizing it*
- *3s' emotions can be so intense, the only way to deal with life is to suppress them*
- *5s are so focused on collecting data, they can appear aloof and disconnected*

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Enneagram core patterns

Anger

8 - fine with external anger; desires justice and control (fears losing it)
9 - very sensitive to anger; strives to keep peace; avoids conflict
1 - highly critical of self; strives to make things right / be perfect

Emotion

2 - focuses on others' emotions and relationships; desires emotional connections and appreciation for self
3 - can detach from emotions and appear very logical; desires recognition for achievements and success
4 - sees life through an emotional filter; desires a unique identity

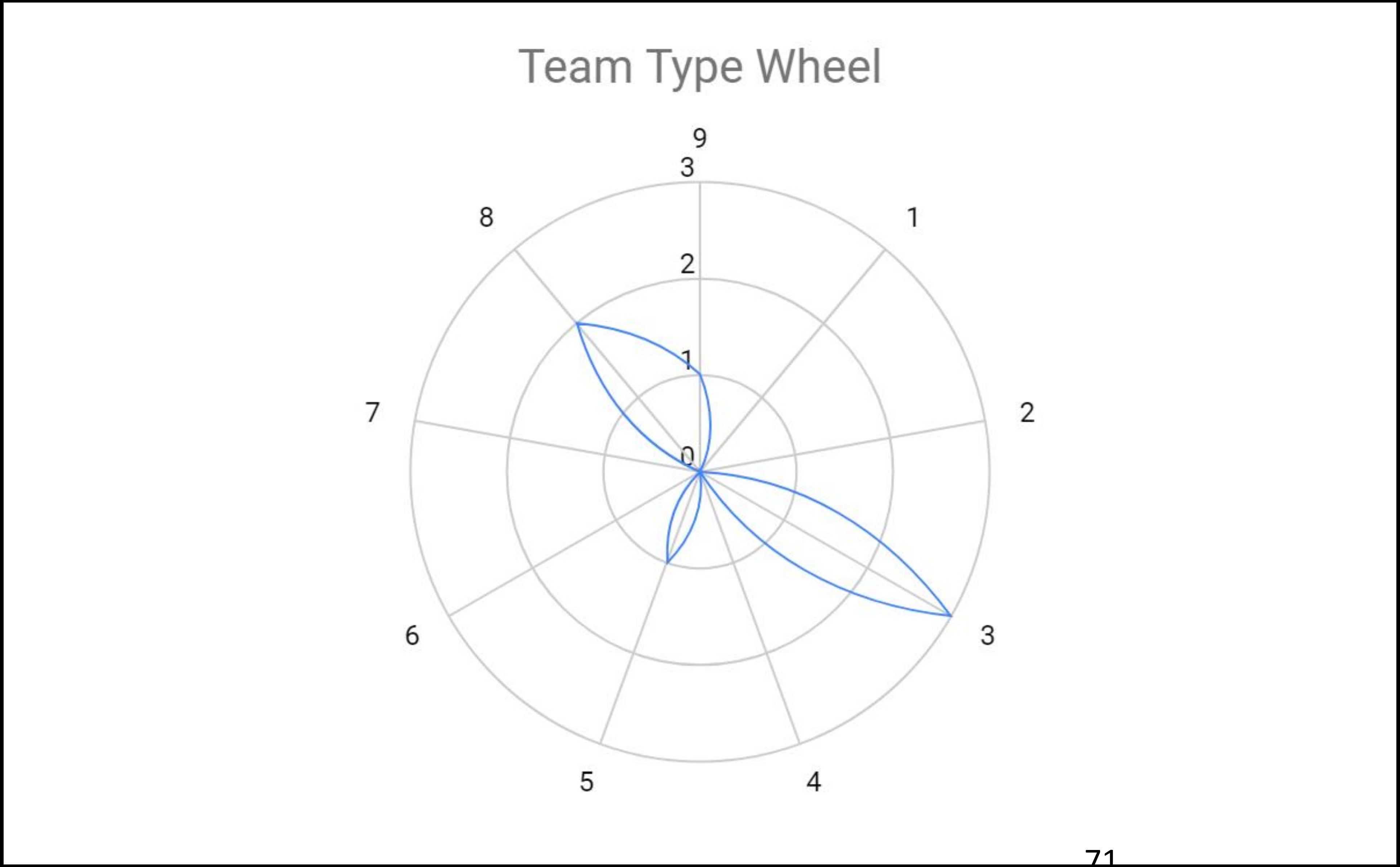
Anxiety

7 - deals with anxiety by hitting it head-on; desires fun, a sense of place, and a strong network
6 - sees all the ways things will go wrong; desires stability
5 - gathers resources to fend off anxieties; desires competence and being capable

Why does this matter in a team?

1 - Identifying a problem:	*There's something wrong here.*
2 - Who needs to be involved:	*We need Joann involved in this.*
3 - Brainstorms solutions:	*Here are 5 ways we could solve this.*
4 - Emotional responses:	*That's a great/terrible idea.*
5 - Technical analysis:	*Here are the pros and cons.*
6 - How could it go wrong?	*This approach is the least risky.*
7 - Get buy-in:	*Rally the troops!*
8 - Do it already!	*Let's do this.*
9 - Did we solve the problem?	*Is this working for you?*

Scot's leadership team



What got you here won't get you there