Lightening Talks

National Science Foundation
Large Facilities Workshop
May 24, 2016

Regional Class Research Vessel

NSF LARGE FACILITIES WORKSHOP

24 May 2016

Status Update✔

- Passed CDR/PDR/BSR/Acquisition Review
- FDR in October
- NSB recommended 2 vessels based on Decadal Survey. NSF has $106M in FY17 Pres Bud.

NSF Off Ramps/Stage Gates

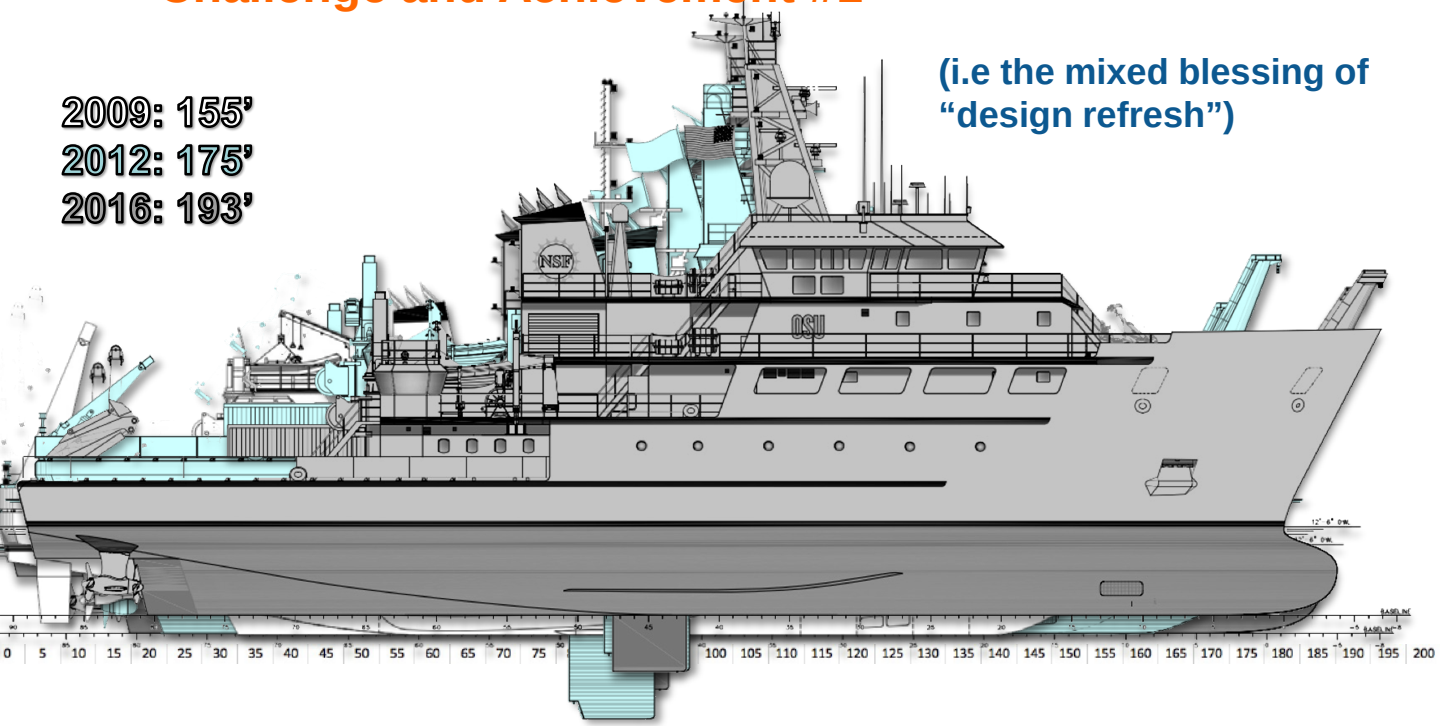
✔ 1 Determination to Award Phase I
✔ 2A Approval of CDR
✔ 2B Approval of Post-CDR Funding (Dec 2013)
✔ 3 Funding for PDR Appropriated (Feb 2014)
✔ 4A Approval of PDR
✔ 4B Approval for inclusion in MREFC Budget
5A Approval of SY Selection
5B Approval of FDR
6A Determination of Adequate Funding
6B Approval of Post-FDR Funding
7 Determination of Adequate Out-Year Funding

Establishing Scope: RCRV Over Time

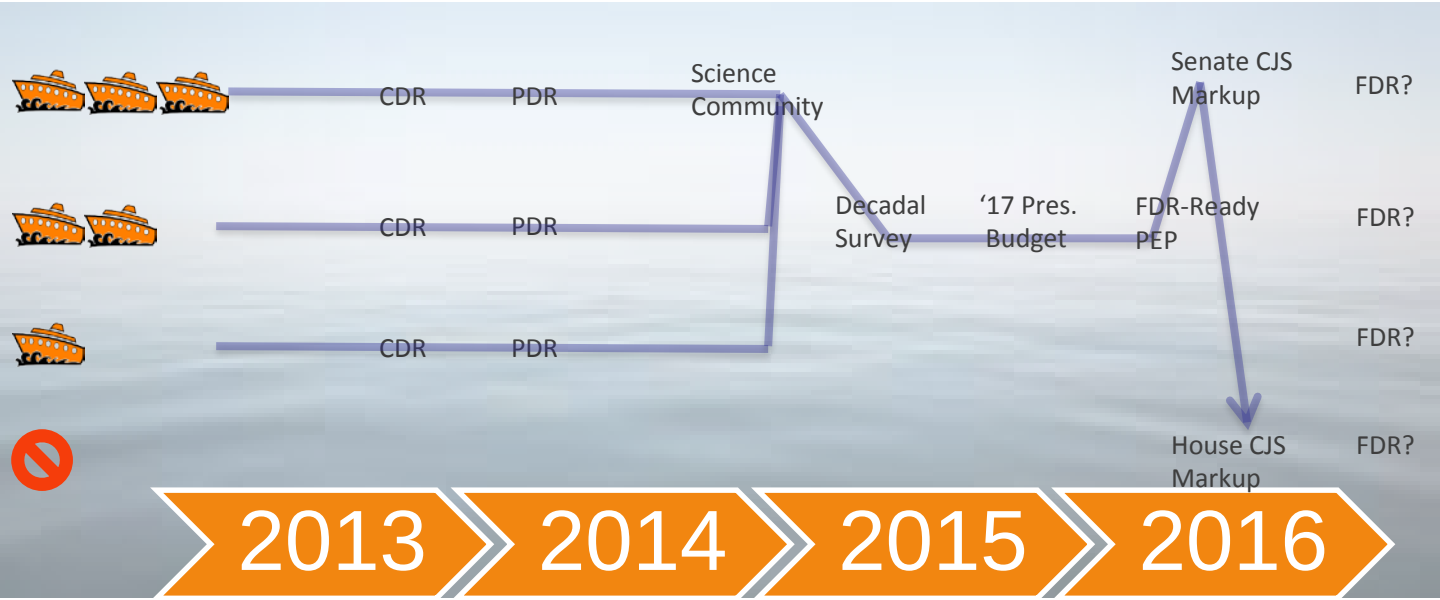
Challenge and Achievement #1

2009: 155’
2012: 175’
2016: 193’

(i.e the mixed blessing of “design refresh”)

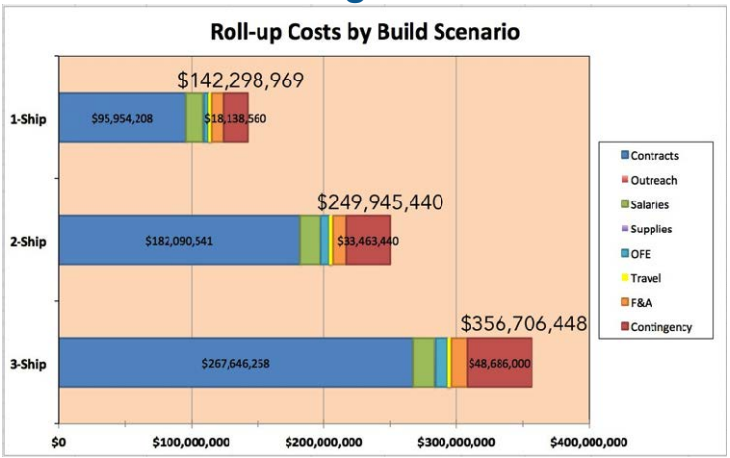


Challenge and Achievement #2
RCRV Scenario Development

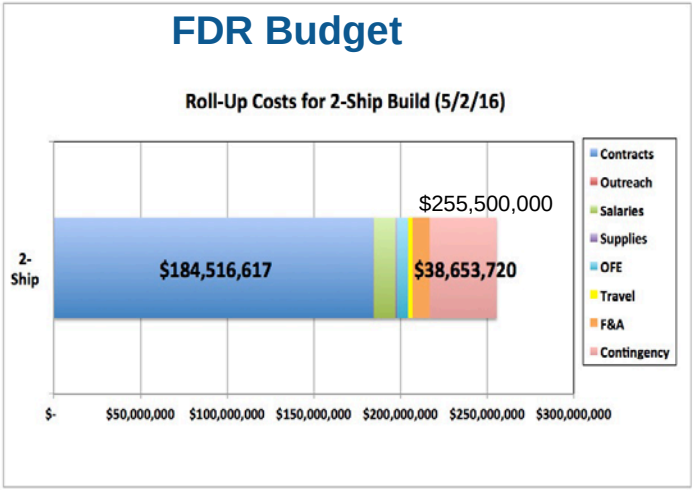


Budget Progression

PDR Budget



FDR Budget



United States Senate Committee on

APPROPRIATIONS

RFI Released May 2nd

Senate Added $56M

PROFESSIONAL MARINER

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TOPICS: DECK GEAR | ELECTRONICS | ENVIRONMENT | SAFETY | NAVIGATION

Tenure Track Engineering Faculty
Tenure Track Safety and Emergency Engineering Faculty
Application forms are located on employment

PROFESSIONAL MARINER / WEB-BULLETIN 2016 / OREGON STATE SEEKS SHIPYARD TO BUILD NEW RESEARCH VESSEL

SHARE | EMAIL | PRINT | FEED

Oregon State seeks shipyard to build new research vessel

Apr 28, 2016 02:42 PM

The 193-foot ship, designed by Glosten, will likely be delivered in 2020

Courtesy Oregon State University

The following is the text of news release from Oregon State University:

(CORVALLIS, Ore.) — The design phase for a project construct a new regional c research vessel to replenis the United States academi fleet is complete and Oreg State University will issue request for information (RF on Monday, May 2, to

shipyards that may be interested in the vessel construction phase.

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An artist's conception of a

Oregon State University

U.S. Senate calls for building three, not two, new regional research vessels

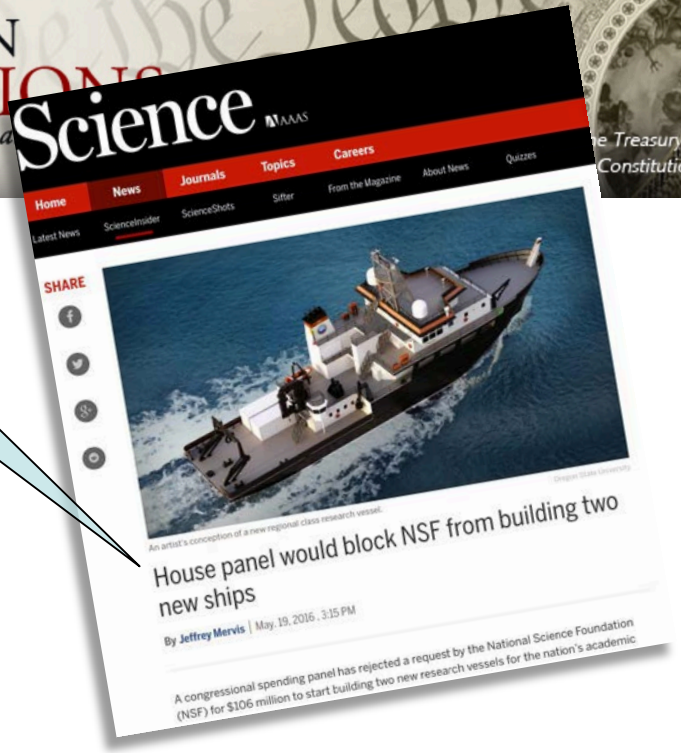
By Carolyn Gramling | Apr. 19, 2016, 5:30 PM

Every cloud has a silver lining. Along with the news that a Senate spending subcommittee today approved a paltry $46 million budget increase for the National Science Foundation (NSF) for fiscal year 2017 came what appears to be a bright spot for ocean science. In

The U.S. House of Representatives
COMMITTEE ON
APPROPRIATIONS
Chairma

...e Treasury but in Consequence of
...Constitution Article I, Section 9, Clause 7

House Removes $159M



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An artist's conception of a new regional class research vessel.

House panel would block NSF from building two new ships

By Jeffrey Mervis | May. 19, 2016 , 3:15 PM

A congressional spending panel has rejected a request by the National Science Foundation (NSF) for $106 million to start building two new research vessels for the nation's academic

Bridge Mock Up

Model Testing

- Cavitation-free to 11 kts
- No evidence of bubble sweep down under simulated survey conditions

Risk Management

Short Name Emergent Technologies

Risk ID 6

Type R **Category** ☒ Scope ☒ Budget ☒ Schedule

Risk Description The risk that new technologies will be developed or emerge that are preferable to those specified. These include, but are not limited to:
-green-ship solutions,
-navigational and communications suites, -technologies related to the Telepresence Center -Science Mission Areas – Capabilities/Outfit -Ship's Outfit

Probability Likely

Consequence Negligible

Probability Consequence Matrix

Risk Level Low **Contingency Total** $1973

Owner

☐ Bailey	☐ Lahaie-Noll	☐ Sillars
☐ Comar	☒ Reimers	☐ TOC
☒ Glosten	☐ Robertson	☐ Willis
☐ Hilliard	☐ Romsos	

Current Status Active

Retirement Date End of Phase IV

Burn Rates

Basis of Estimate Glosten Charges Estimated using $250/hr.
Phase IC: Cost of having Glosten evaluate for incorporation.

Sub Risks | Actions | Updates

Sub Risk Page

Risk Information

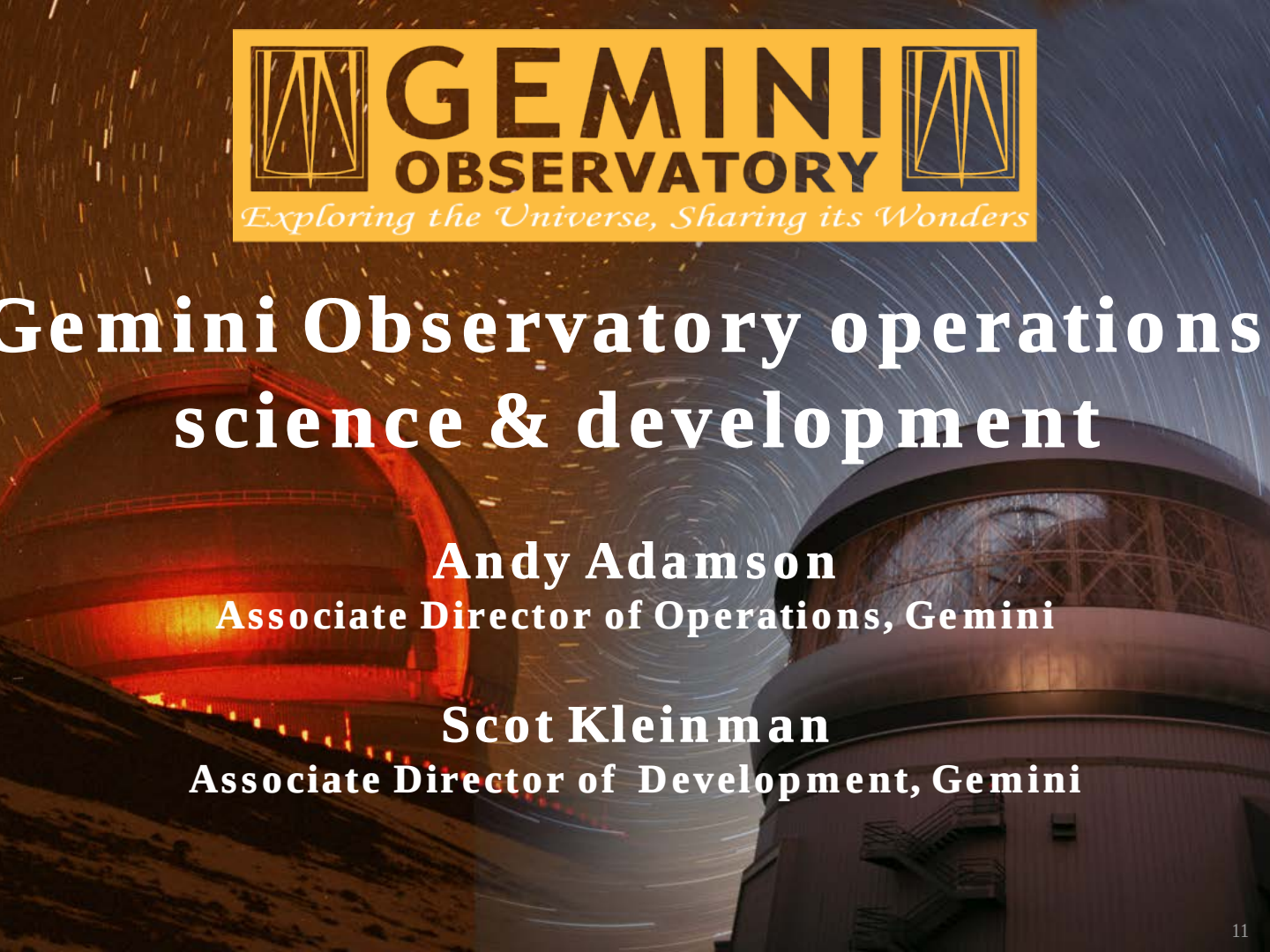
				Budget ($k)	Schedule (Months)
Sub Calc.		WBS		Best Case	
Sub ID		Phase	2	Likely Case	
Status	Active			Worst Case	
Risk Desc.				Contingency	
				Percentile Spread	

Risk Information

Sub Calc.	6.00	WBS	1.1.C.2
Sub ID	.00	Phase	1c
Status	Retired		

Risk Information

				Budget ($k)	Schedule (Months)
Sub Calc.	6.01	WBS	1.2.2	Best Case	0
Sub ID	.01	Phase	2	Likely Case	10
Status	Active			Worst Case	25
Risk Desc.				Contingency	58
				Percentile Spread	



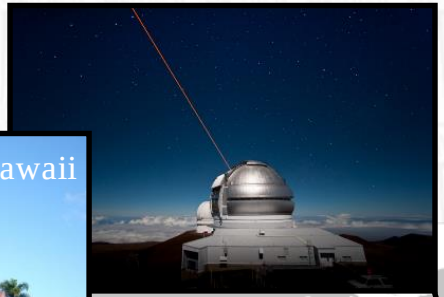
Gemini Observatory operations science & development

Andy Adamson
Associate Director of Operations, Gemini

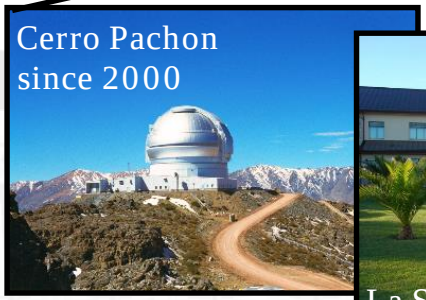
Scot Kleinman
Associate Director of Development, Gemini

GEMINI OBSERVATORY
Exploring the Universe, Sharing its Wonders

Gemini Observatory:
Operating twin 8m telescopes
on Mauna Kea and Cerro Pachon:
providing access to the entire sky



We are Here
We are Here
We are Here
We are Here
We are Here
We are Here
We are Here



The International Partnership

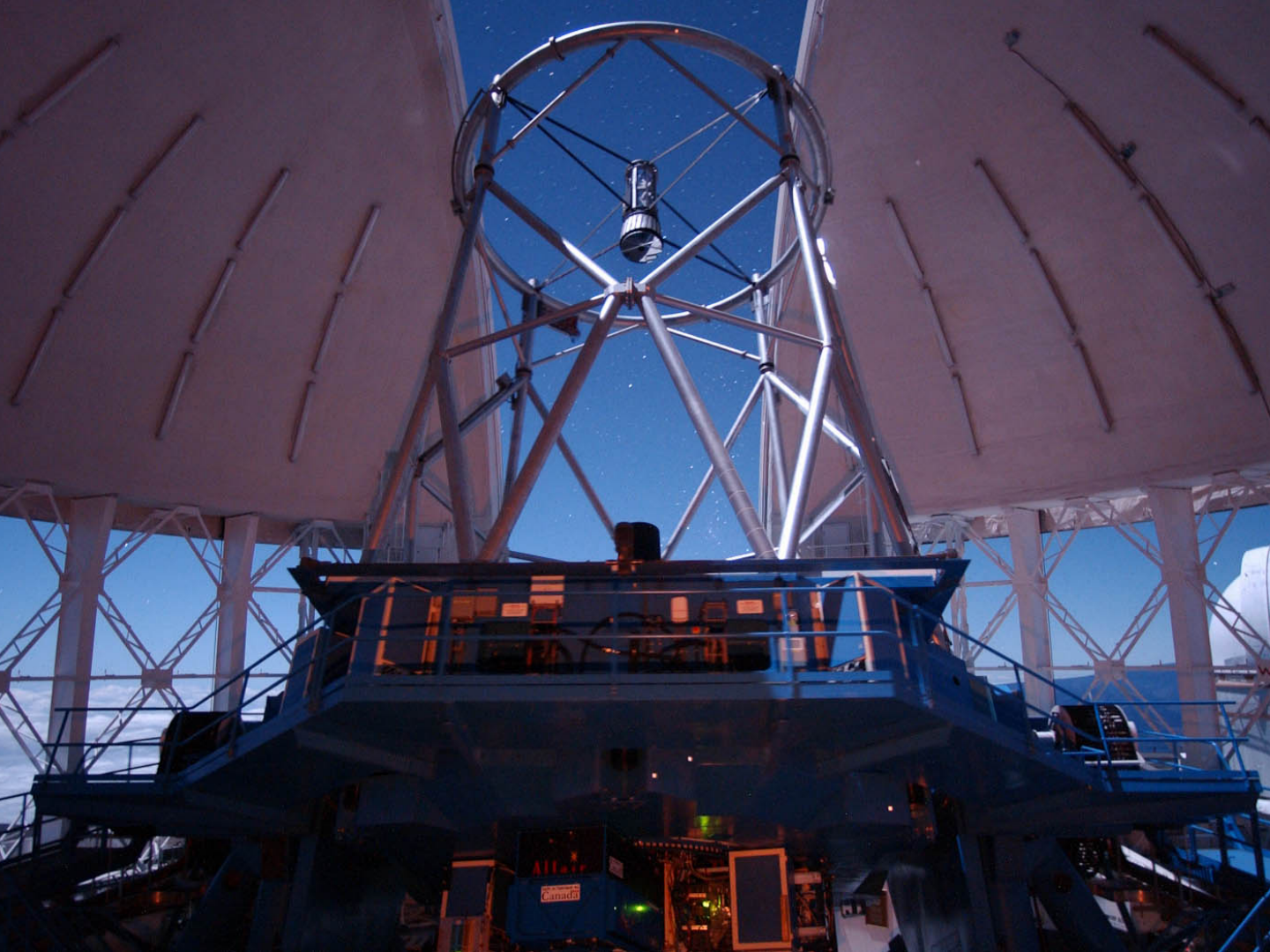
International Agreement *2016-2021* includes as partners:
USA, Canada, Brazil, Argentina, and Chile

Shares **2016-2021:**
(Budget **~27+x $M/year**)

US 70 %
CA 20 %
BR 7 %
AR 3%
AUS+KOR +x%

KASI (Korea) is a limited-term partner since *2015*, aspiring to become a full partner

Australia did not remain a full partner beyond *2015*, but is continuing in *2016* as limited-term partner


Canada

Proposing for time at Gemini

The regular proposal: *once per semester*, through the national Time Allocation Committees (TAC)
for regular proposals

70%

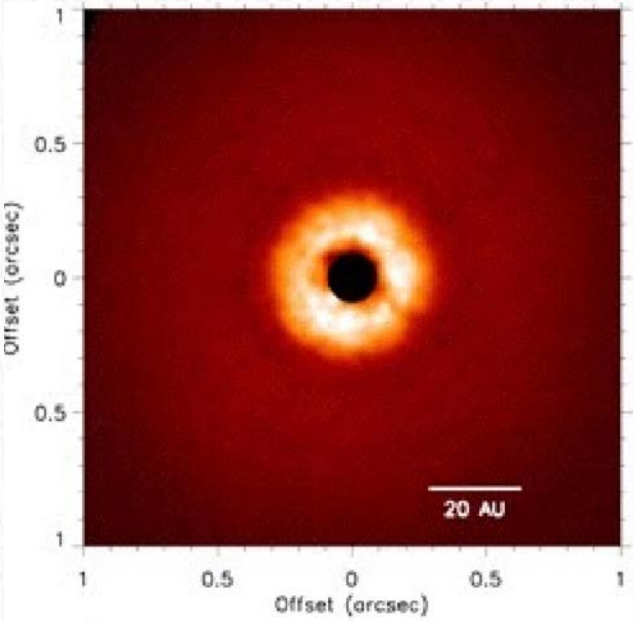
Large & Long Programs: *once per year*, through the Large Program TAC
for large and/or long **ambitious** proposals

20%

Fast turnaround programs: *once per month*, 'peer reviewed', no TAC
for short, rapid, immediate and/or follow-up proposals

10%

Recent Science Highlights



TW Hydrae
1.2 micron (near-infrared)
Polarized intensity image from GPI

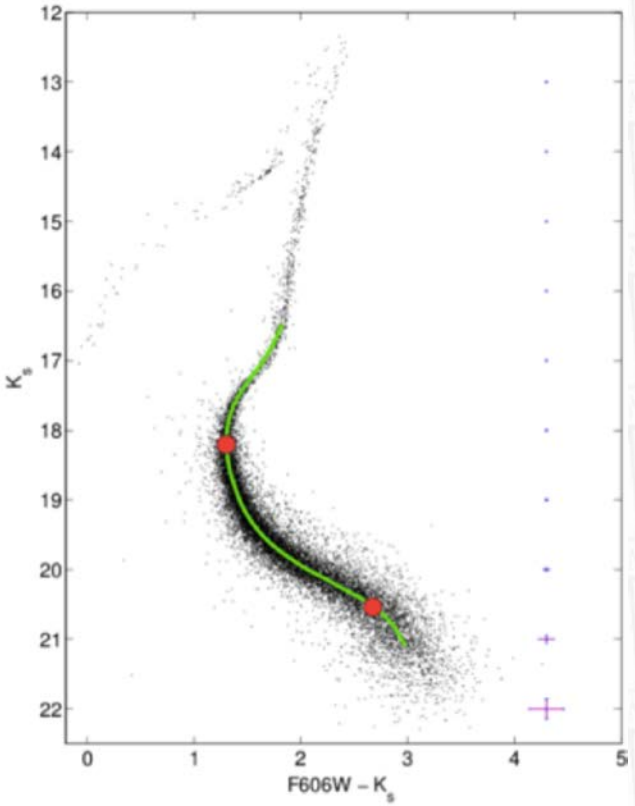
Rapson et al. 2016

- GPI probes w/in 10AU of TW Hydrae
- Comparison with simulations suggests 0.2M Jupiter planet at 21A

Recent Science Highlights

Turri et al. 2015

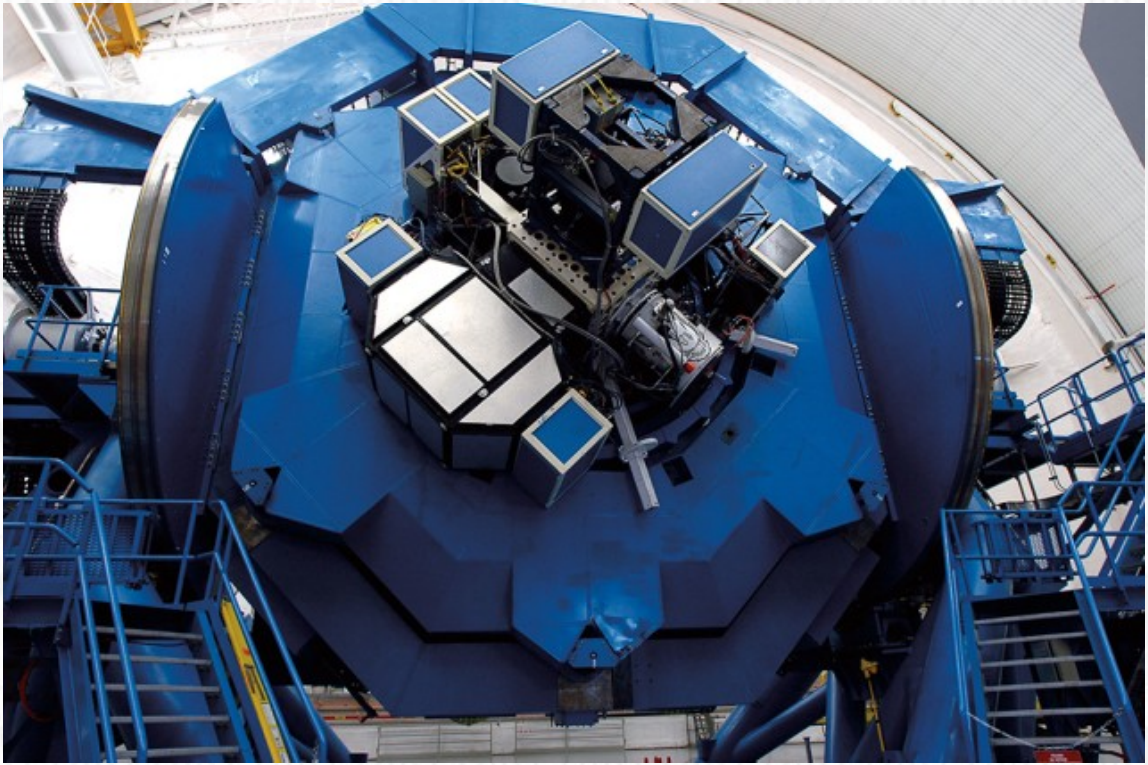
- Globular cluster NGC 1851
- Around 16,000 stars
- Depth and precision allow combination with HST
- Double subgiant branch
- Main sequence “knee” reddening- and distance-independent age



GeMS/GSAOI
Multiconjugate, laser-supported AO

Gemini Instruments

Gemini Instruments



Engaging the Community

Bring your Projects
Apply for Long and Large, Fast Turnaround, or standard TAC;
Upgrade a current instrument, or build part or all of a new one

Bring your Instrument
Contact us if you would like to bring a Visiting Instrument or propose for our new projects and initiatives

Bring yourself
Rediscover the advantages of classical observing and mitigate weather loss with Priority Visiting Observing

Bring your Student
Give your student the extra boost of motivation by taking her/him along and we'll chip in to pay for it!

Bring your Code
Share your reduction/analysis code or just expertise on our new User Forum. Win observing time.

Contracting Issues

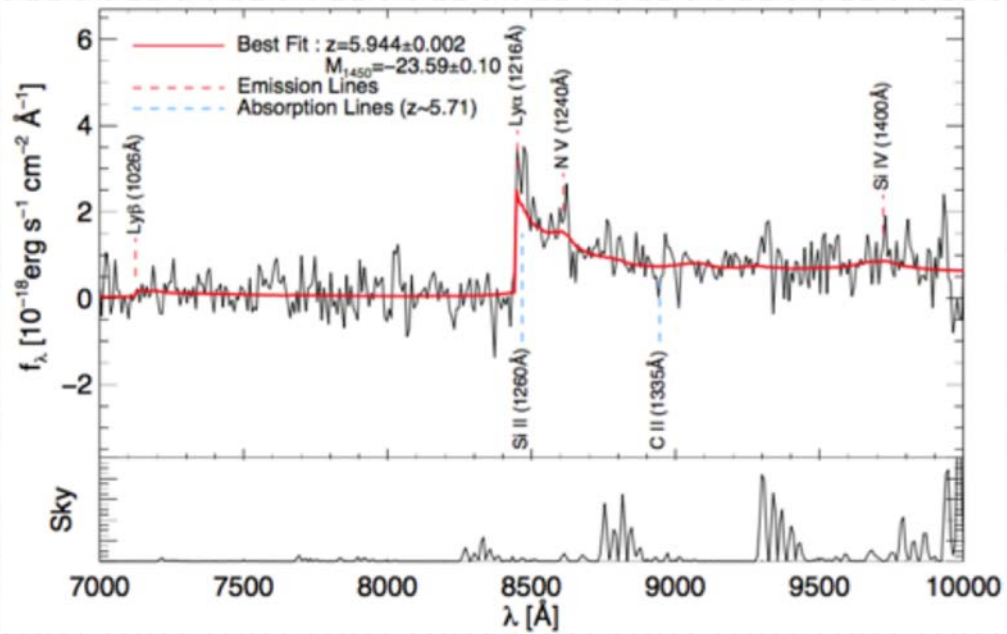
- Negotiations typically drag on longer than hoped
- Approval process through oversight and NSF takes a long time
- Sometimes difficult to take advantage of opportunities while adhering to procurement requirements
- Reserves, contingency, risk mitigation funds: a moving target in policy, but critical for projects
- Typical university teams still used to grad students and duct tape; hard to move to more rigorous project management and systems engineering approaches

… and one more thing

Very interested in how you do resource planning for both current and future operations and projects in your organizations.

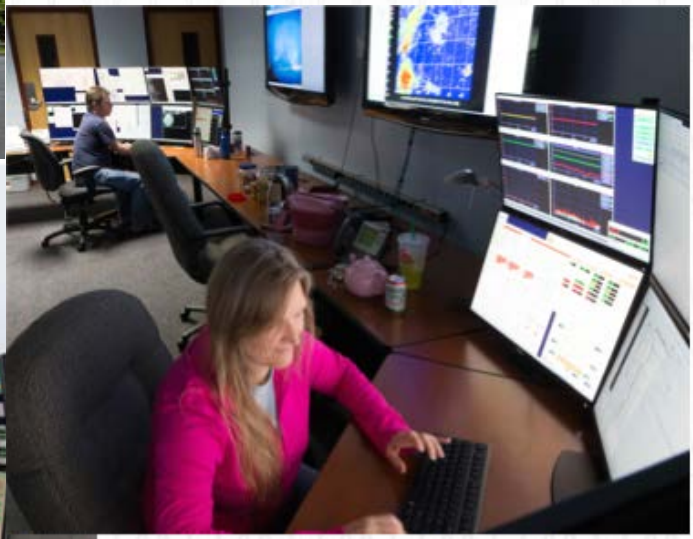

GEMINI
OBSERVATORY
Exploring the Universe, Sharing its Wonders
Thank You

Recent Science Highlights

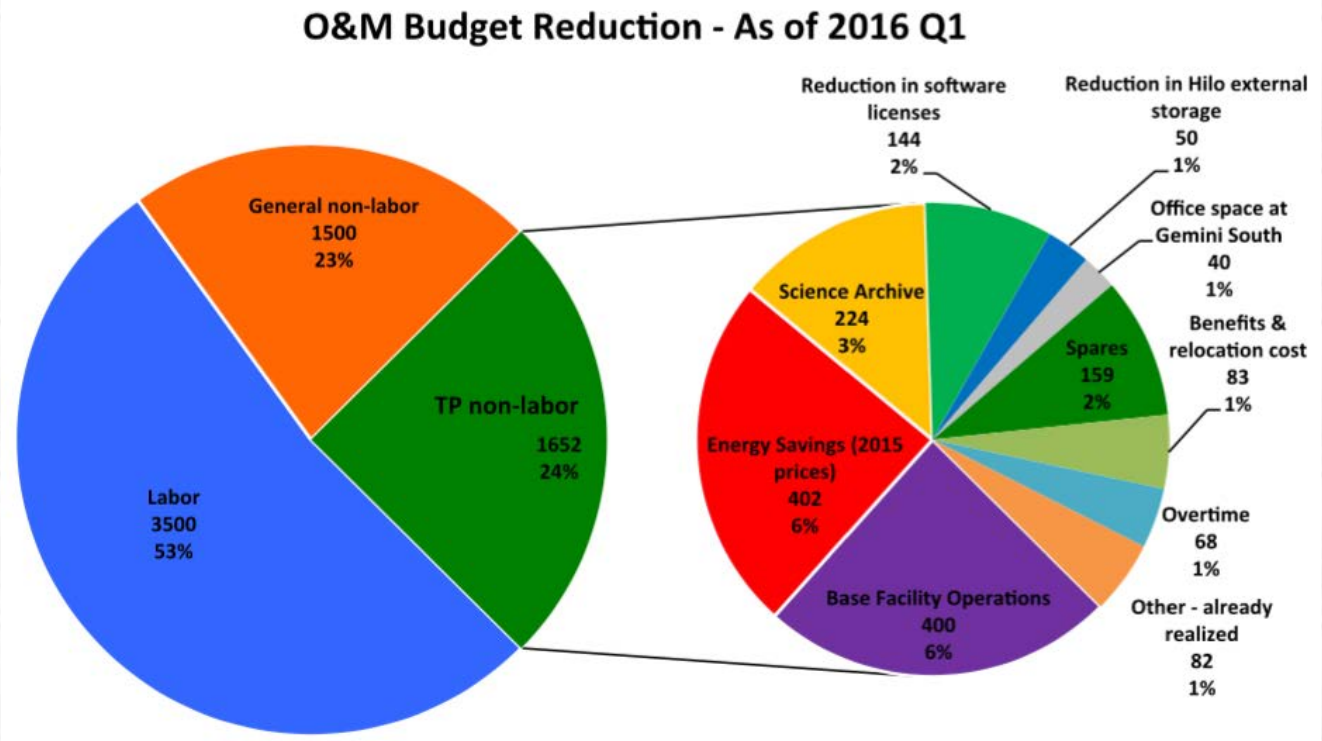


Kim et al. 2015 • first publication from Korean participation in Gemini partnership • GMOS-S spectroscopy confirm source as quasar, and redshift • sample from Infrared Medium-Deep Survey • not enough quasars for cosmic reionization, even considering candidates as well as confirmed quasars in the survey

Gemini North runs from Hilo since November



UK withdrawal: 25% budget reduction



The Governance

International Partner countries

GFC | Board | STAC

Community

Executive Agency

US Government

Managing Agency

AURA members

AURA

AOC-G

CAS/HRS

Shared services with UH and AURA-O

Observatory

Users' Committee

NOAO-S

MKSS

National Gemini Offices

Community

Partner countries

Lightning Talk

Integrated
Cost-Schedule
Risk Analysis

Mike Carrancho, P.E.
Smithsonian Institution
NSF Large Project Workshop 24 May 2016

Smithsonian

Integrated Cost-Schedule Risk Analysis

National Air & Space Museum

- *Very Large, complex, renovation project*
- *Complete HVAC replacement*
- *Complete stone envelope and primary weather barrier replacement*
- *Museum to remain open and operational during project*
- *“Like rebuilding a 747 while in flight” Ret. Gen J. Dailey*

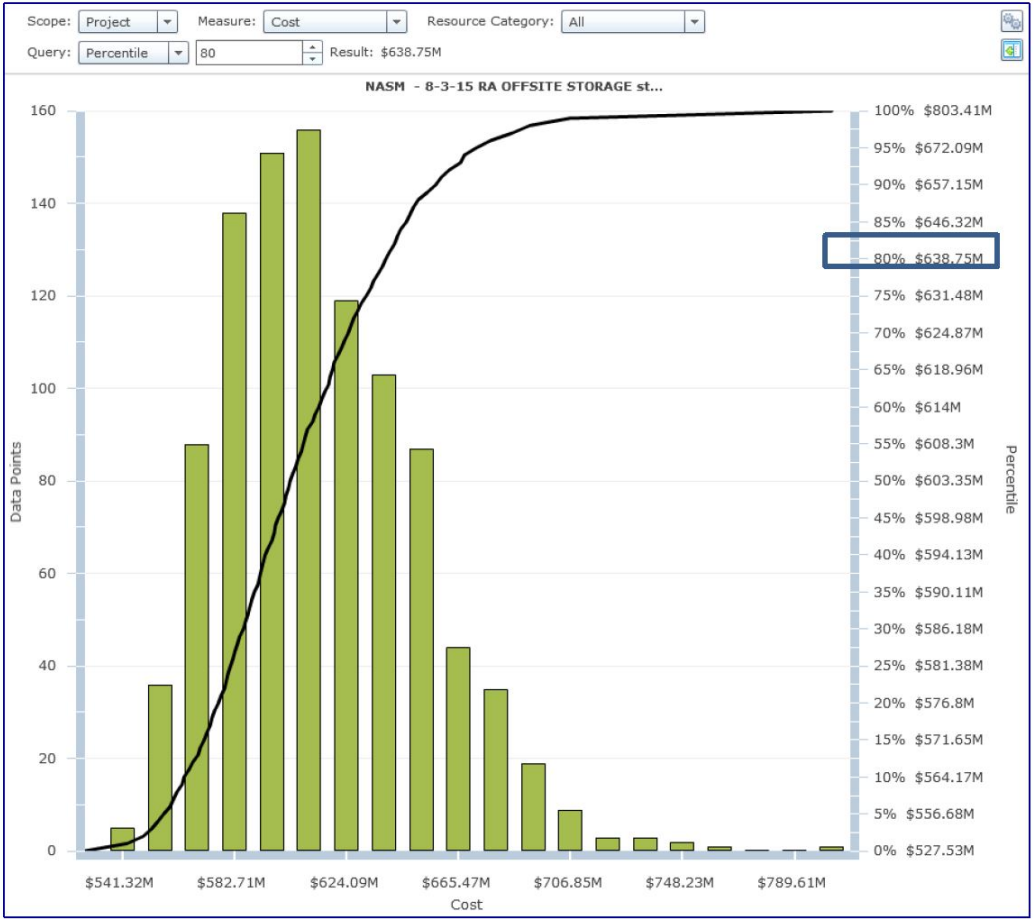
Cost Risks & Impacts

Top Cost Risk Drivers			
No.	**Risk Description**	**Cost Impact**	**Time Impact (days)**
1	Congressional approval of funding amount may be less than requested	$24,306,400	96
2	Uncertainty	$22,178,500	121
3	Client initiated/requested changes	$18,246,100	75
4	Impact of delayed funding for any particular sequence (construction)	$13,917,700	59
5	Stone Risk - Production (Fabrication and Inspection)	$8,495,210	96
6	Contractor's construction management team may not be competent to manage project of this complexity	$7,996,700	21
7	Major design defect or error	$4,963,780	6
8	Lack of laydown & staging areas requiring close in off site storage for construction for GC	$4,773,020	13
9	Lack of adequate SI "Supervision and Administration" budget	$4,407,350	0
10	Proposed schedule for de-mount/deinstallation of 3-5 months may be insufficient.	$4,202,490	27

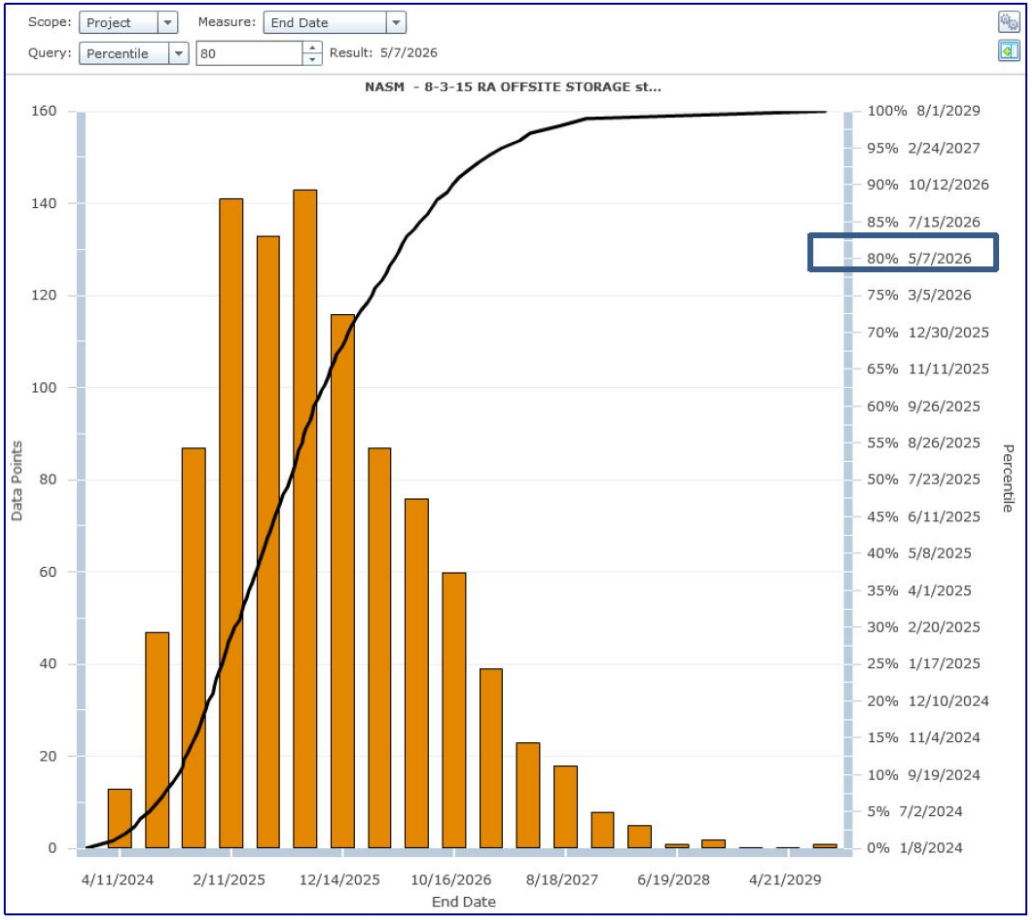
Schedule Risks & Impacts

Top Schedule Risk Drivers			
No.	**Risk Description**	**Time Impact (days)**	**Cost Impact**
1	Uncertainty	121	$22,178,500
2	Congressional approval of funding amount may be less than requested	96	$24,306,400
3	Stone Risk - Production (Fabrication and Inspection)	96	$8,495,210
4	Client initiated/requested changes	75	$18,246,100
5	Planned 24 hour construction operations will have negative impact (morale, fatigue, union grievances, tying up supervisors time) - from collections movement perspective.	66	$2,553,200
6	Impact of delayed funding for any particular sequence (construction)	59	$13,917,700
7	Proposed schedule for re-mount/reinstallation of 10-12 months may be insufficient.	31	$740,064
8	Proposed schedule for de-mount/deinstallation of 3-5 months may be insufficient.	27	$4,202,490
9	Contractor's construction management team may not be competent to manage project of this complexity	21	$7,996,700
10	Protest from unsuccessful bidders	19	$984,379

Cost Probabilities



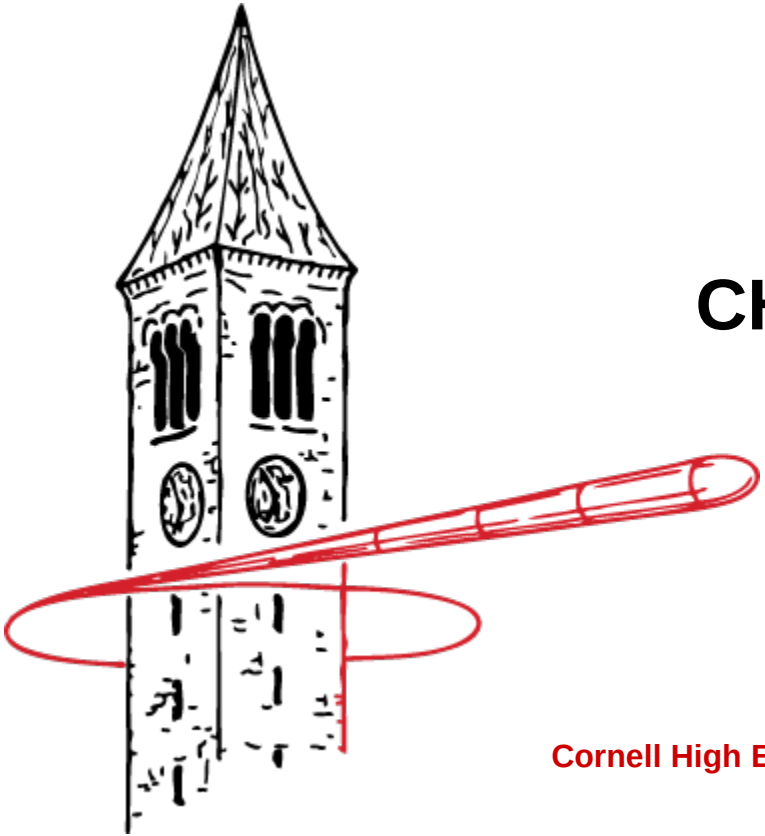
Schedule Probabilities



Questions

Mike Carrancho, PE

Smithsonian Institution
Deputy Director, Office of Planning, Design and Construction
CarranchoM@si.edu



CHESS Highlights

Joel D. Brock, Director

Cornell High Energy Synchrotron Source (CHESS)

joel.brock@cornell.edu

CHESS is supported by the NSF and the NIH/NIGMS under NSF award DMR-1332208

CHESS at a Glance

- NSF stewarded, national user facility providing synchrotron x-ray facilities to an international, multidisciplinary user community.
- Located on central campus of Cornell University, Ithaca, New York
- Our X-ray facilities are optimized for high-flux, high-energy applications in: Materials Research, Life Science, Engineering, Biology, Physical Sciences, and Cultural Heritage.
- Over 1,300 user visits, 800 unique visitors each year
- 11 experimental stations
- > 3600 hours per year of x-ray operations.
- >$20M/year in funding
- ~75 FTEs, ~150 people on payroll
- 60 undergraduates per year participate in laboratory research.
- X-ray Beam time awarded via competitive proposal process
  - Proposals rated by (domain science) experts
  - ~ 60% success rate
  - ~1 publication / day of operations

Nanocrystal self-assembly sheds its secrets: a new approach gives a real-time look

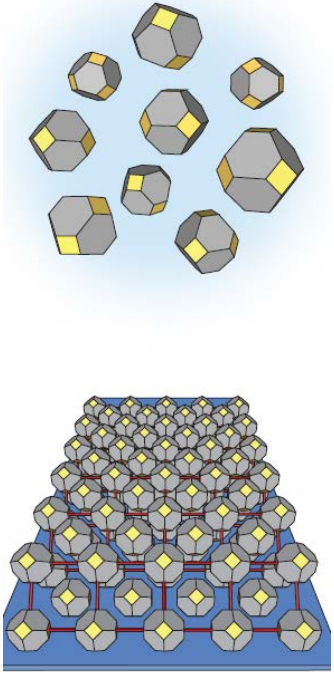
Tisdale (MIT) DMR-1332208

The transformation of simple colloidal particles — bits of matter suspended in solution — into tightly packed, beautiful lace-like meshes, or superlattices, has puzzled researchers for decades. Pretty pictures in themselves, these tiny superlattices, also called quantum dots, are being used to create more vivid display screens as well as arrays of optical sensory devices. The ultimate potential of quantum dots to make any surface into a smart screen or energy source hinges, in part, on understanding how they form.

Through a combination of techniques including controlled solvent evaporation and synchrotron X-ray scattering, the real time self-assembly of nanocrystal structures has now become observable *in-situ*. The findings were reported in the journal Nature Materials in a paper by Assistant Professor William A. Tisdale and grad student Mark C. Weidman, both at MIT's Department of Chemical Engineering, and Detlef-M. Smilgies at the Cornell High Energy Synchrotron Source (CHESS) [1].

To make the nanoscale movies (see third page), the group took advantage of a CHESS-developed experimental chamber and a recently developed dual detector setup with two fast area detectors, while environmental conditions were changed during the formation of superlattices. Using lead sulfide nanocrystals, they were able to conduct simultaneous small-angle X-ray scattering (capturing the structure of the superlattice) and wide-angle X-ray scattering (capturing atomic scale orientation and alignment of single particles) observations during the evaporation of a solvent.

"We believe this was the first experiment that has allowed us to watch in real time and in a native environment how self-assembly occurs," Tisdale says. "These experiments would not have been possible without the experimental capabilities developed by Detlef and the CHESS team." [2]



(top) Illustration of randomly oriented nanocrystals in solution.

(bottom) Illustration of two layers of the atomically aligned bcc nanocrystal superlattice on the substrate, where the bcc (110)SL plane is parallel to the substrate

[1] Mark C. Weidman, Detlef- M. Smilgies, and William A. Tisdale, "Kinetics of the self-assembly of nanocrystal superlattices measured by real-time in situ X-ray scattering," Nat Mater advance online publication (2016).

[2] Text quoting an MIT report by Michael Patrick Rutter; https://mitei.mit.edu/news/nanocrystal-self-assembly-sheds-its-secrets

Nanocrystal self-assembly sheds its secrets: a new approach gives a real-time look

Tisdale (MIT) DMR-1332208

Science - What was found? What is new?

- Demonstrated the first experiment to view in real time and in a native environment how self-assembly occurs
- Developed a new method to observe self-assembly of nanocrystals using controlled solvent evaporation and synchrotron X-ray scattering
- The discovery will lead to refined models for self-assembly of a wide range of organic soft materials.

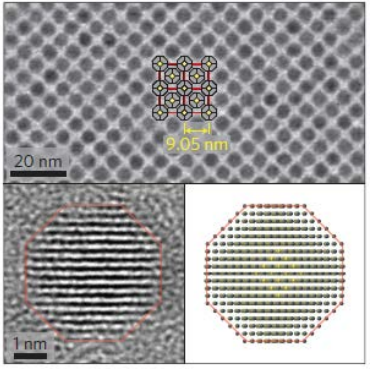
Impact - Why is it important?

- The broader adoption of nanocrystals into energy conversion technologies has been limited by the lack of knowledge about how they self-assemble
- These tiny superlattices, also called quantum dots, are being used to create more vivid display screens as well as arrays of optical sensory devices.
- The ultimate potential of quantum dots to make any surface into a smart screen or energy source hinges, in part, on understanding how they form
- This new findings will enable direct manipulation of resulting superlattices, with the possibility of on-demand fabrication and the potential to control the formation of related soft materials such as proteins and polymers and materials needed for new technologies

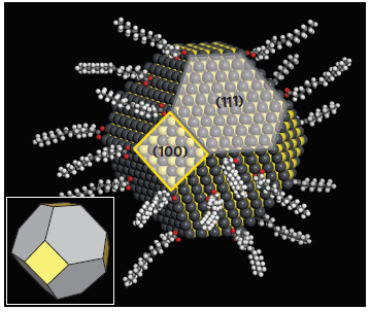
Why did this research need CHESS?

- CHESS-developed experimental chamber and a recently developed dual detector setup with two fast area detectors was needed to control environmental conditions during the formation of superlattices.
- The CHESS D1 experimental station has high-flux, wide energy-bandpass x-ray optics and can support multiple simultaneous fast 2D detectors and a fast data-acquisition compute farm to capture time-resolved kinetics of the in-plane and out-of-plane molecular ordering

Work supported by an Energy Frontier Research Center (DOE-BES), made use of MRSEC Shared Experimental Facilities at MIT (NSF DMR-08-19762), a NSF Graduate Research Fellowship (1122374), and CHESS (DMR-1332208).



(top) TEM image of a bcc superlattice of the nanocrystals with a superimposed [100]SL view of four unit cells with a lattice constant of 9.05 nm. Inset (left) shows a high-resolution TEM image of a single nanocrystal in which the atomic planes are visible and the corresponding nanocrystal model (right) that leads to this pattern.



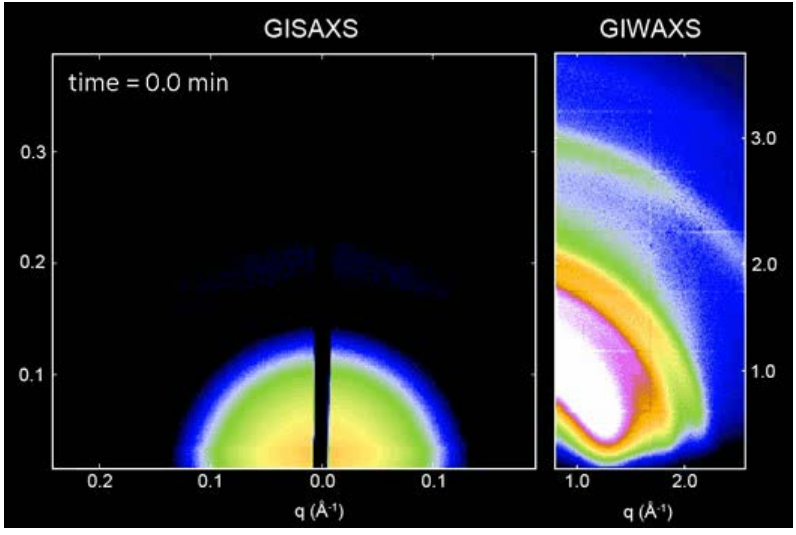
(bottom) Atomic model of the nanocrystals used in this study highlighting a hexagonal (111)NC face and a square (100)NC face. The ligand coverage density has been decreased for the image to better show the nanocrystal core.

[1] Mark C. Weidman, Detlef- M. Smilgies, and William A. Tisdale, "Kinetics of the self-assembly of nanocrystal superlattices measured by real-time in situ X-ray scattering," Nat Mater advance online publication (2016).

[2] Text quoting an MIT report by Michael Patrick Rutter; https://mitei.mit.edu/news/nanocrystal-self-assembly-sheds-its-secrets

Nanocrystal self-assembly sheds its secrets: a new approach gives a real-time look

Tisdale (MIT) DMR-1332208



Time-resolved X-ray scattering reveals the transition from a disordered colloid to a highly ordered superlattice. a–h, Temporal evolution of GISAXS (square panels) and GIWAXS (vertical panels) patterns during the in situ measurement of nanocrystal self-assembly. The GISAXS patterns show the transition from a colloidal suspension to an fcc superlattice to a bcc superlattice via contraction of the c axis. The white circles on the left halves of the GISAXS patterns are the predicted scattering locations for the superlattice parameters indicated above each image. The GIWAXS patterns show the early onset of orientational alignment as well as the shape transformation of the 200NC scattering peak.

The Future: optimizing for high-flux, high-energy x-rays
CHESS-U

Funding (awaiting public announcement by Governor Cuomo)

- New York State's Upstate Revitalization Initiative (URI)
- $15M over 3 years (completion 12/31/2018)
- Goal is regional economic development (job creation and retention in Southern Tier) – public/private partnerships

Capital Project – optimize for high-flux, high-energy x-rays

- Single particle beam operation
- Increase storage ring energy from 5.3 → 6.0 GeV
- Increase storage ring current from 100 → 200 mA
- Decrease storage ring emittance
- Increase number of undulator sources from 2 to 10
- (re)build/upgrade 6 x-ray beamlines and experimental stations

end

International Ocean Discovery Program

JOIDES Resolution facility
Texas A&M University as
Science Operator

Scientific Ocean Drilling

Largest and longest running international research program dedicated to exploring Earth's history and structure

- Project Mohole: 1958-1966
- Deep Sea Drilling Project (DSDP): 1968-1983
- Ocean Drilling Program (ODP): 1985-2003
- Integrated Ocean Drilling Program (IODP): 2003-2013
- International Ocean Discovery Program (IODP): 2013-2023

IODP Member Countries


Australia


Austria


Belgium


Canada


China


Denmark


France


Finland

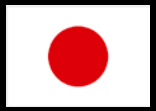

Germany


Iceland


India


Ireland


Italy


Japan


Netherlands


New Zealand


Norway


Portugal


South Korea


Spain


Sweden


Switzerland


United Kingdom


United States

The International Ocean Discovery Program: Multiple Platforms

JOIDES Resolution

Chikyu

Mission Specific Platforms

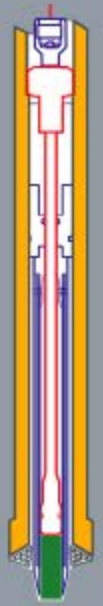
Tools of Exploration

Beacon

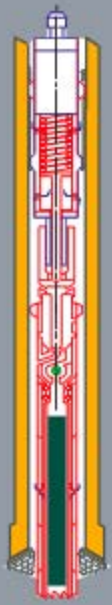
Reentry Cone

Not to scale

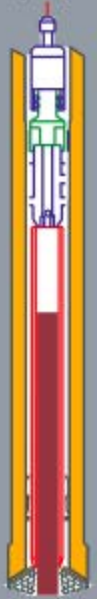
Advanced Piston Corer (APC)



Extended Core Barrel (XCB)



Rotary Core Barrel (RCB)

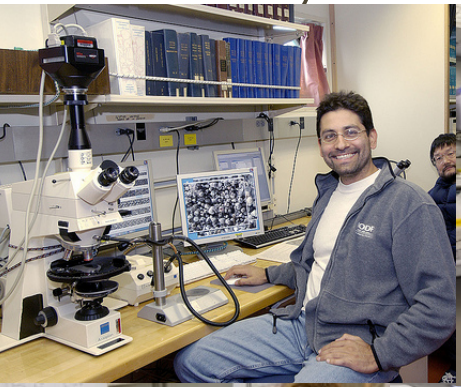


Soft Sediment

Hard Sediment

Hard Rock

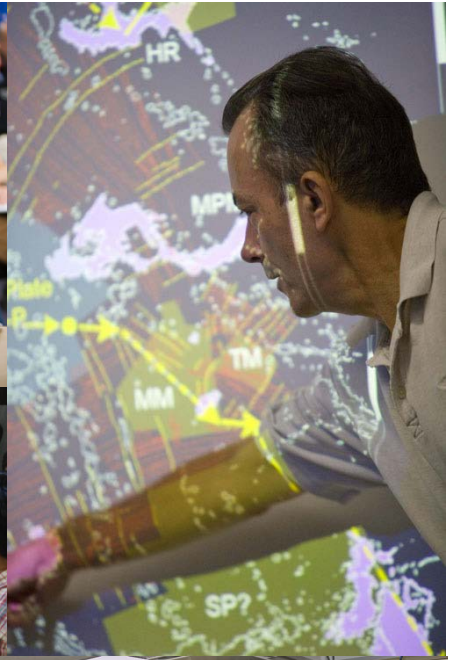
The *JOIDES Resolution* is a 1300m^2 floating laboratory…

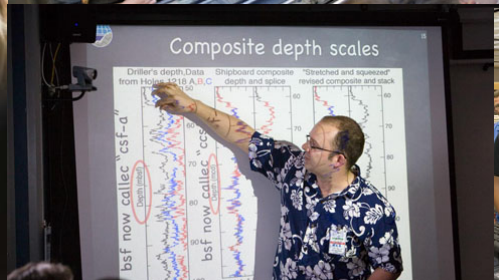






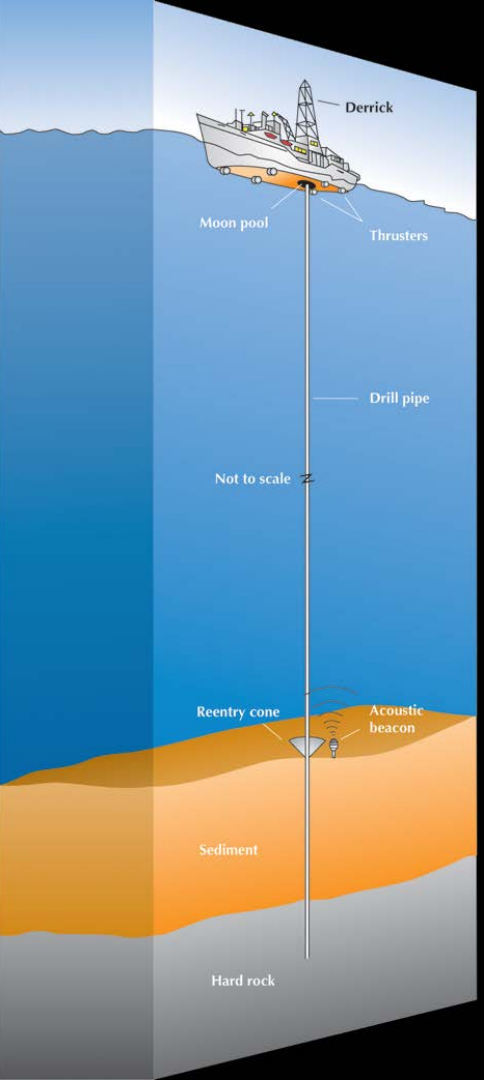
…and a floating university





Major Accomplishments of Scientific Ocean Drilling

- Confirmation of the Seafloor Spreading Hypothesis
- Discovered that the Mediterranean Sea completely dried repeatedly ~5 million years ago
- Recovered direct evidence that a bolide impact caused the mass extinction that killed off the dinosaurs
- Recovered an intact section of the upper oceanic crust
- Recovered first samples of gas hydrates from continental margins
- Discovered that deep ocean waters flow vigorously through the crust (world's largest aquifer)
- Discovered that the deep seafloor hosts abundant microbial life.

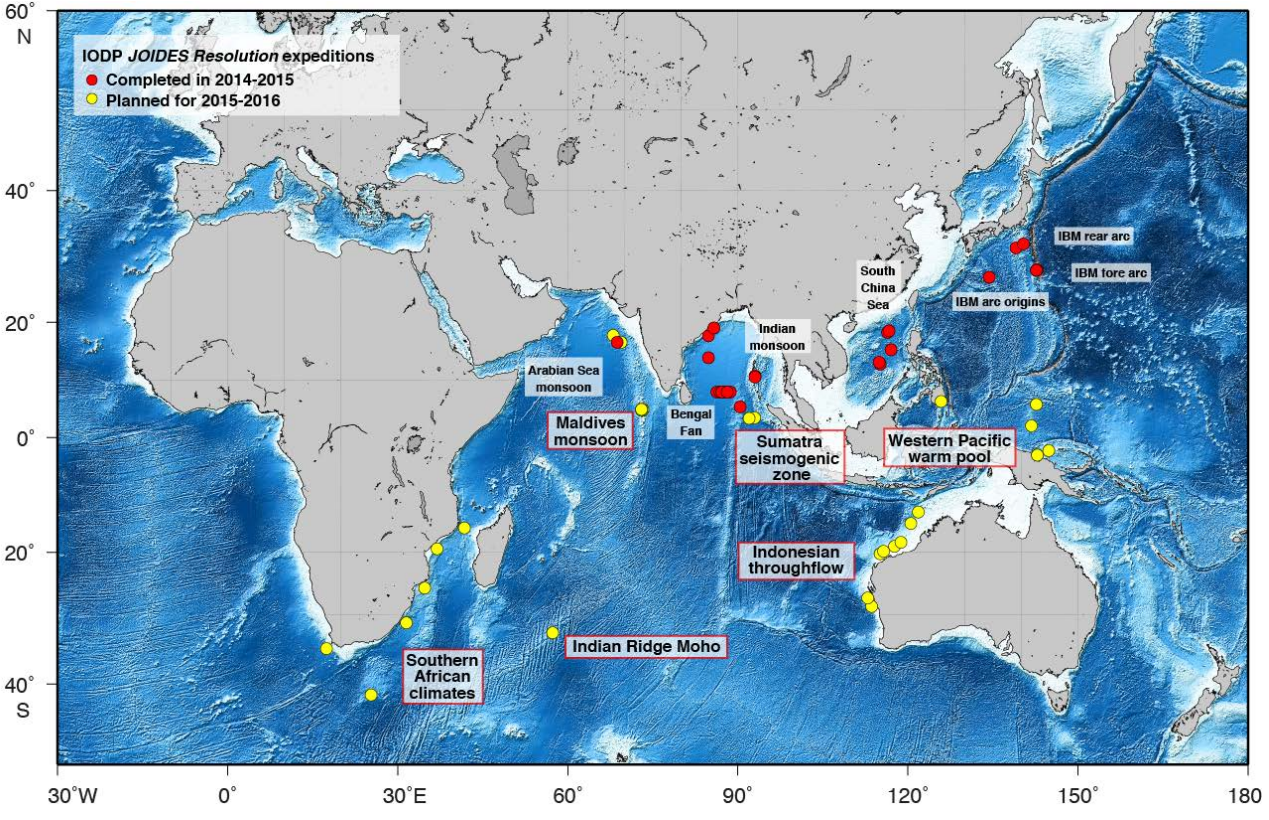


JR Facts

- **Owned:** Overseas Drilling Limited, Inc.
- Built 1978 as exploration vessel *Sedco/BP* 471
- Converted to science research in 1985
- Rebuilt 2009; facility is reliable- breakdown contract rate 0-2% 2009 -2016

- **Length:** 143 m (471 ft)
- **Drill pipe:** 5” and 5.5” tapered string
- **Drill string capacity:** >9 km (~30,000 ft)
- **Deepest hole penetration:** 2111 m (6924 ft)
- **Shallowest water:** 35.5 m (123 ft)
- **Deepest water:** 5980 m (19,614 ft)
- **Most core on single cruise:** 8003 m (26,250 ft)
- **Total core recovered:** >230 km (>146 miles)

JOIDES Resolution Recent and Upcoming Expeditions



Richard Farnsworth PhD PMP
Senior Program Manager

Battelle/NEON

March 3, 2016

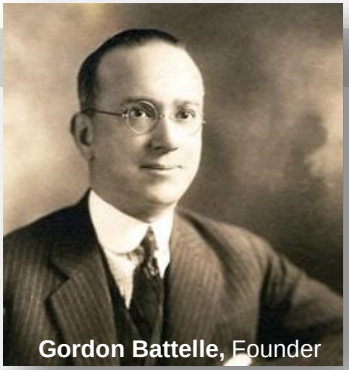
National Ecological Observatory Network

- Battelle was recently selected by the National Science Foundation (NSF) to assume management of the construction and initial operations of the NEON observatory
- Battelle began transition in Mid-March
  - Transitioning key staff to Battelle Ecology Inc.
  - Ensuring smooth transition of permitting, contracts, etc.
  - Continuing construction and Operations
  - Expect to complete transition of Observatory by June 2016

NEON is a continental-scale observation system for examining ecological change over time.

Battelle Mission and Purpose

Our mission: To translate scientific discovery and technology advances into societal benefits


Gordon Battelle, Founder

- Nonprofit, charitable trust formed in 1925
- Profits reinvested in science & technology and in charitable causes, making the world better for generations to come

Project Sikuliaq

NSF Builds a Ship With Capabilities Like No Other!

Schedule Change Highlights

- Following Final Design Review there were five major areas that could potentially cause Project schedule changes
  - Funding to continue the project – Accelerated from FDR because the Project was "shovel ready" when American Recovery and Reinvestment Act of 2009 funding became available, no impact on Project schedule.
  - Shipyard Contract Award – Accelerated from FDR because of availability of ARRA funding, no impact on Project schedule.
  - Delivery of Owner Furnished Z-Drives to the Shipyard – Accelerated from FDR because of shortened lead time for gear sets, no impact on Project schedule.
  - Shipyard Execution and Ship Delivery Date
  - Post-delivery trials

Shipyard Execution and Ship Delivery Date

- Original contract delivery date – 22 January 2013
- Actual delivery date – 06 June 2014
- Two shipyard contract modifications that contractually extended delivery a total of 197 days:
  - Mod 34 added 185 days due to lengthening of the ship – 26 July 2013
  - Mod 50 added 12 days due to OFE Z-drive issue – 07 August 2013
- Shipyard was 303 days late with delivery of the ship:
  - Significantly protracted shipyard tests and trials
  - Shipyard paid $2,250,000 in liquidated damages (maximum allowed by the contract) for late delivery

Change Orders

- Decided to:
- Increase length to 6 feet to increase reserve buoyancy
- Change from Steel to Aluminum structure above 02 deck
- Eliminate elevator service above 01 deck
- Other weight savings: light-weight joinery, steel reductions
- VCG is below the line, including full icing and science loads

Post-Delivery Trials

- Late delivery and two funded science cruises in late 2014 reduced time for warm water trials and pushed piston coring trials off until 2016.
- Plan for post-delivery shipyard availability was reduced in scope necessitating a second post-delivery shipyard availability in late 2015:
  - Timeline for original post-delivery shipyard period was too early
  - Funded science cruises in the Arctic in summer/fall 2015 didn't allow for extending the post-delivery shipyard period
- Complexity of the ship required more time for fully testing the systems than originally planned.
- Replacement A-frame schedule and timeline for discovery of post-delivery issues from trials necessitated second post-delivery shipyard period.

The Greening of R/V Sikuliaq

- Bottom Coating
- Waste Incinerator
- Integrated Power Plant
- Waste Heat Recovery System
- Biodegradable Lubricants
- Double Bottom Hull
- State of the Art MSD
- Ballast Water Management System
- Specialized Hull Configuration and Propulsion

The Greening of R/V Sikuliaq

Shrinking a Ship's Environmental Footprint

THE END

The National Science Foundation