The Next Generation CFHT: A 10m, Wide-Field, Spectroscopic Facility for the Coming Decade

Patrick Côté (NRC, Canada)
on behalf of the ngCFHT Concept Study Team

Science from the Next Generation Imaging and Spectroscopic Surveys,
ESO Garching, 15-18 October 2012

The Canada France Hawaii Telescope

- CFHT is a 3.6m optical and infrared telescope located on the summit of Mauna Kea, Hawaii (4204 m).
- It is is operated by the National Research Council of Canada, the Institut National des Sciences de l'Univers of the Centre National de la Recherche Scientifique of France, and the University of Hawaii
- Active collaborative agreements with:
  1. Republic of Korea: 2000 - 2003, 2012 -
  2. Brazil: 2002 -
  3. Taiwan: 2002 -
  4. China: 2011 -
- It is located at one of the world's premier astronomical sites:
  - median seeing (free atmosphere) of 0.4''.
  - median precipitable water vapour = 0.9 mm.
  - useable nights: 80% spectroscopic, 55% photometric.

Wide-Field Imaging/Astrometry Facilities: 2000-2020

Instrument	Telescope	D_{M1} (m)	Status	λ	Available	FOV (deg^2)	AΩ (m^2 deg^2)	$Ω_{tot}$ (10^3 deg^2)
MegaCam	CFHT	3.6	Operational	Optical	2003	1	10.2	6.1
WFCAM	UKIRT	3.8	Operational	IR	2004	0.19	2.2	...
WIRCAM	CFHT	3.6	Operational	IR	2005	0.11	1.1	4.0
Pan-STARRS-1		1.8	Operational	Optical	2009	7.3	18.6	30.9
VIRCAM	VISTA	4.1	Operational	IR	2010	0.6	7.5	20.0
OmegaCam	VST	2.6	Operational	Optical	2011	1.0	5.3	4.5
Skymapper		1.35	Operational	Optical	2011	5.7	8.2	20.6
Hyper-SC	Subaru	8.2	Pending	Optical	2012	1.7	90	2.0
ODI	WIYN	3.5	Pending	Optical	2012	1	9.6	...
DEC	Blanco	4.0	Pending	Optical	2012	3	38	5.0
Pan-STARRS-2		2x1.8	Pending	Optical	2013	7.3	37	30.9
Gaia		2x(1.4x0.5)	Pending	Optical	2013	All Sky		41.2
LSST		8.4	Pending	Optical	2019	6.7	370	24.2
Euclid		1.2	Pending	IR/Optical	2020	0.5	0.6	15 -20
WFIRST		1.5	Pending	IR/Optical	2025?	0.5	0.9	23.2

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OmegaCam	VST	2.6	Operational	Optical	[illegible]	[illegible]	5.3	4.5
Skymapper		1.35	Operational	[illegible]	[illegible]	5.7	8.2	20.6
Hyper-SC	Subaru	8.2	[illegible]	[illegible]	2012	[illegible]	90	2.0
ODI	WIYN	3.5	[illegible]	[illegible]	[illegible]	[illegible]	9.6	…
DEC	Blanco	[illegible]	[illegible]	[illegible]	[illegible]	3	38	5.0
Pan-STARRS-2		[illegible]	[illegible]	[illegible]	2013	7.3	37	30.9
Gaia		[illegible]	[illegible]	[illegible]	2013	All Sky		41.2
LSST		[illegible]	[illegible]	Optical	2019	6.7	370	24.2
Euclid		[illegible]	Pending	IR/Optical	2020	0.5	0.6	15 -20
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ESA "cornerstone-class" mission ($820M)

Top ranked ground-based facility in Astro2010 ($421M)

Approved ESA M-class mission ($765M)

Top ranked space-based facility in Astro2010 ($1.6B)

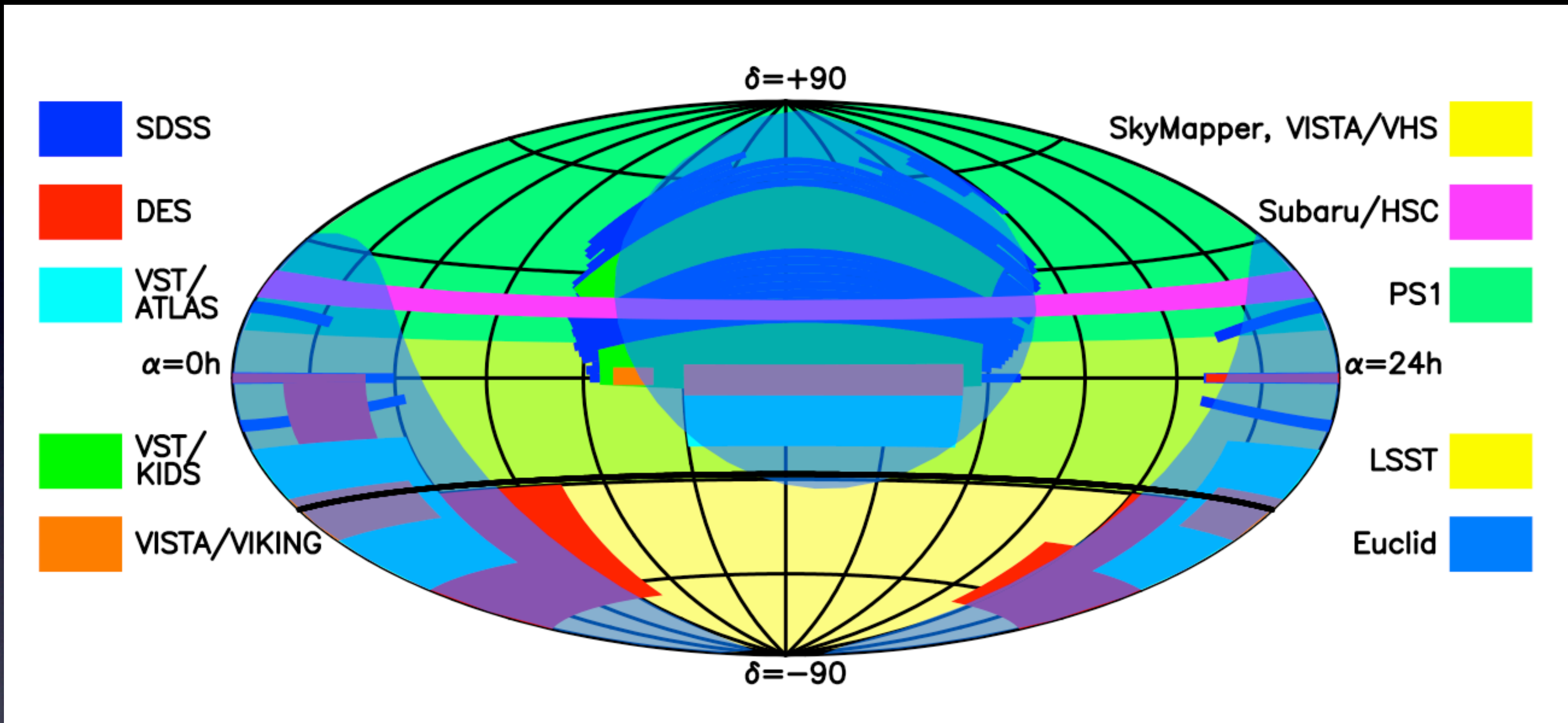
Wide-Field MOS Facilities: 2000-2020

Instrument	Telescope	D_{M1} (m)	Status	λ (μm)	Available	Ω (deg²)	AΩ (m² deg²)	N_{MOS}	R
2dF	AAT	3.9	Operational	0.37-1.0	1996	3.14	15.1	400	1000-17000
SDSS		2.5	Operational	0.38-0.92	2000	1.54	7.6	640	1800
DEIMOS	Keck	10.0	Operational	0.41-1.1	2002	0.023	1.8	150	2500-5500
VIMOS	VLT	8.2	Operational	0.37-1.0	2002	0.062	3.3	600	180-2500
FLAMES	VLT	8.2	Operational	0.37-0.95	2003	0.136	7.2	130	5600-25000
Hectospec	MMT	6.5	Operational	0.36-0.92	2004	0.79	26.1	240-300	1000-40000
Hydra	WIYN	3.5	Operational	0.37-1.0	2005	0.79	7.5	90	800-40000
IMACS	Magellan	6.5	Operational	0.36-1.0	2008	0.16	5.3	400	1100-16000
FMOS	Subaru	8.2	Operational	0.9-1.8	2012	0.20	10.4	400	600-2200
LAMOST		4.0	Pending	Optical	2013	19.6	247	4000	1000-10000
HERMES	AAT	3.9	Pending	4 windows*	2013	3.14	15.1	400	28000 (50000)
PFS	Subaru	8.2	Pending:	Optical	2017:	1.3	70.0	2400	1900-4500
Gaia		2x(1.4x0.5)	Pending	0.85-0.87	2013	All Sky (V < 17)			11500
Euclid		1.2	Pending	1.1-2.0	2020	0.55	0.6	...	250
WFIRST		1.5	Pending	1.1-2.0?	2025?	0.5	0.9	...	75-320
BigBOSS	Mayall	4.0	Proposed	0.36-1.05	2018?	7.1	88.8	5000	3000-4800
MOONS	VLT	8.2	Proposed	0.8-1.8	2018	0.14	7.3	~1000	4000-20000
4MOST	VISTA	4.1	Proposed	4 windows†	2018	3 or 5	31 or 66	1500-3000	3000-20000
ngCFHT		10.0	Proposed	0.36-1.3	2022	1.5	120	3200	2000-20000

* 0.472-0.490 μm (blue), 0.550-0.587 μm (green), 0.648-0.674 μm (red), 0.759-0.789 μm (IR).

† 0.420-0.650 μm (blue), 0.650-0.900 μm (red). High-resolution mode = 0.390-0.450 μm (blue), 0.585-0.675 μm (green).

Survey Visibility from Mauna Kea



- full visibility: SDSS, Pan-STARRS 1 and 2, Hyper Suprime Cam, etc.
- overlap with Skymapper and LSST: ≈9,400 deg^2 ($X < 1.5$).
- overlap with Euclid: 7,500-10,000 deg^2.

The Next Generation CFHT (ngCFHT) Proposal

- Concept introduced in late-2010 as a grassroots movement that has gained momentum.
- The project aims to create a new and expanded partnership to:

1. replace the present 3.6m primary mirror with a 10m-class (segmented) mirror, mounted on the existing pier.
2. install a dedicated wide-field (1.5 deg^2) multi-object spectrograph that can simultaneously collect spectra for >3000 sources.
3. do this by ≈2020 and immediately begin spectroscopic surveys.

- For maximum scientific impact, the facility should also enable focussed science on key targets (i.e., PI or GO observations).
- ngCFHT would be the only dedicated, 10m-class, wide-field MOS facility capable of capitalizing fully on the many upcoming imaging and astrometric surveys.

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MPower

ngCFHT Concept Study: The Process

- In January 2011, a Concept Study was launched to examine the desired scientific capabilities and requirements for ngCFHT, as well as its technical feasibility and level of readiness.

1. Scientific Components.
    1. Identify the key science drivers.
    2. Assess synergies and competitions from other facilities.
    3. Develop survey strategies and set the technical requirements.
2. Technical Components.
    1. Load capacity of telescope and enclosure piers.
    2. Telescope and enclosure configuration.
    3. Aerothermal study.
    4. Telescope optical design.
    5. Spectrograph conceptual designs.
    1. Telescope downtime study.
    6. Cost, schedule and development plan.
3. Lay the Groundwork for an Expanded Partnership.

Science Working Groups

- Science working groups (SWGs) formed to examine the concept in 10 distinct sub-fields.
- The ngCFHT science case has been developed by roughly 60 scientists from Canada, France and Hawaii, as well as Australia, Brazil, China, India, Japan, South Korea, Taiwan, and the USA.

1. Exoplanets
   - Magali Deleuil (Laboratoire d'Astrophysique de Marseille, France)
   - Francois Bouchy (IAP, France)
   - Ernst de Mooij (Toronto, Canada)
   - Norio Narita (NAOJ, Japan)
2. The Interstellar Medium
   - Rosine Lallement (GEPI/Observatoire de Paris, France)
   - Patrick Boissé (Institut d'Astrophysique de Paris, France)
   - Ryan Ransom (Okanagan College, DRA, Canada)
3. Stars and Stellar Astrophysics
   - Kim Venn (University of Victoria, Canada)
   - Katia Cuhna (NOAO, USA)
   - Patrick Dufour (Montreal, Canada)
   - Zhanwen Han (Yunnan Observatory, China)
   - Chiaki Kobayashi (ANU, Australia)
   - Rolf-Peter Kudritzki (IfA, Hawaii, USA)
   - Else Starkenburg (Victoria, Canada)
4. Milky Way Structure and Stellar Populations
   - Piercarlo Bonifacio (GEPI, Université Paris Diderot, France)
   - Nobou Arimoto(NOAJ, Japan)
   - Ken Freeman (ANU, Australia)
   - Bacham Eswar Reddy (IIA, India)
   - Sivarani Thirupathi (IIA, India)
5. The Local Group
   - Alan McConnachie (Herzberg Institute of Astrophysics, Canada)
   - Andrew Cole (Tasmania, Australia)
   - Rodrigo Ibata (Strasbourg, France)
   - Pascale Jablonka (Observatoire de Paris, France)
   - Yang-Shyang Li (KIAA, China)
   - Nicolas Martin (Strasbourg, France)
6. Nearby Galaxies and Clusters
   - Michael Hudson (University of Waterloo, Canada)
   - Richard de Grijs (KIAA, China)
   - Simon Driver (ICRAR ,Australia

6. Nearby Galaxies and Clusters (cont'd)
   - Eric Peng (Peking University, China)
   - Yen-Ting Lin (IPMU, Japan)
7. Galaxy Evolution
   - Michael Balogh (University of Waterloo, Canada)
   - Sebastien Foucaud (NTNU, Taiwan)
   - Damien Le Borgne (IAP, France)
   - Karl Glazebrook (Swinburne, Australia)
   - Lihwai Lin (ASIAA, Taiwan)
   - Changbom Park (KIAS , South Korea)
   - Swara Ravindranath (IUCAA, India)
   - Marcin Sawicki (St. Mary's, Canada)
   - Luc Simard (HIA, Canada)
8. The Intergalactic Medium
   - Céline Péroux (Laboratoire d'Astrophysique de Marseille, France)
   - James Bolton (Melbourne, Australia)
   - Sara Ellison (Victoria, Canada)
   - Raghunanathan Srianand (IUCAA, India)
9. QSOs and AGNs
   - Pat Hall (York University, Canada)
   - Len Cowie (IfA, Hawaii)
   - Scott Croom (Sydney, Australia)
   - John Hutchings (HIA, Canada)
   - Patrick Petitjean (AIP, France)
   - Thaisa Storchi-Bergmann (UFRGS, Brazil)
   - Ting-Gui Wang (USTC, China)
   - Chris Willott (HIA, Canada)
   - Jong-Hak Woo (Seoul, South Korea)
   - Xue-Bing Wu (Peking University, China)
10. Cosmology and Dark Energy
   - Jean-Paul Kneib (Laboratoire d'Astrophysique de Marseilles, France)
   - Carlo Schimd (LAM, France)
   - Charling Tao (CPPM, France and Tsinghua, China)
   - Martin Makler (Rio de Janeiro, Brasil)
   - Keiichi Umetsu (ASIAA, Taiwan)

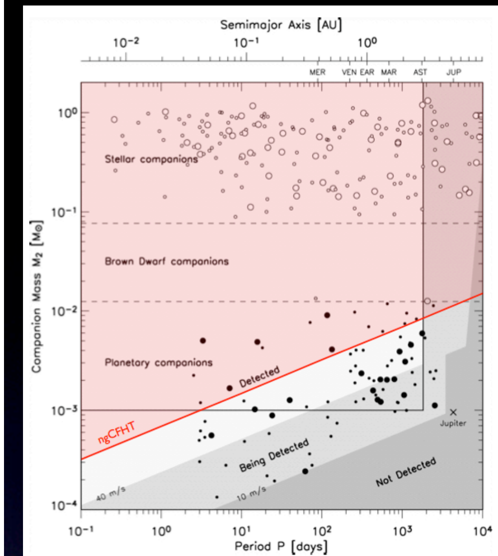
Science Work Groups and Technical Requirements

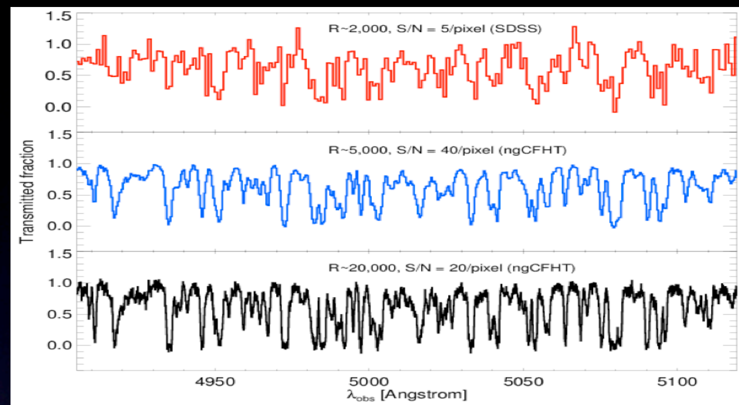
- A multi-stage process used to prepare the science cases and settle on the technical requirements:

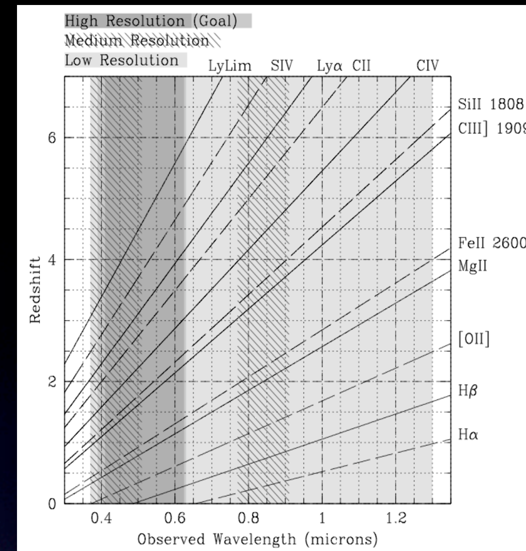
1. Start with a "baseline" design for the facility and its surveys (see Ellis et al. 2009, Côté et al. 2010).
2. Interim SWG reports submitted in Nov 2011; used to refine technical parameters and survey designs.
3. Final reports, based on updated facility parameters, submitted in the summer of 2012.

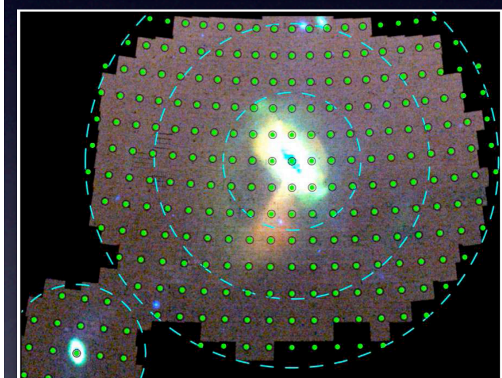
Primary Mirror	10m (segmented)		
Field of View	Ω=1.5 deg^2 (hexagonal)		
Vignetting	<15%		
Wavelength Range	0.37 - 1.3 µm		
Image Quality	FWHM < 0.55″ (free atm. ~0.40 +/- 0.05)		
Total system throughput	≥ 0.15 (requirement), ≥ 0.2 (goal)		
Spectral Resolution	2,000	6,500	20,000
Wavelength Range (SWG)	0.37–1.3 µm	0.37–0.51 µm (blue) 0.77–0.91 µm (red)	0.40–0.62 µm
Wavelength Range (Current Design)	0.37–1.3 µm	0.37–1 µm 1. Two selectable windows (width ≈ λ/7) 2. Full λ coverage for ~1/4 of the fibres.	0.37–1 µm Two selectable windows (width ≈ λ/7)
Fibre diameter*	0.90″ (core)		
Number of fibres	3200 (low + medium-res) / 800 (hi-res with complete wavelength coverage)		
Positioner patrol region	100″ diameter (with some overlaps)		
Configuration time	~40 seconds		
g_{lim} [T_{exp}=1hr]	23.5 (R=2,000, S/N=5 per Å) / 20.4 (R=20,000, S/N=20 per Å)		

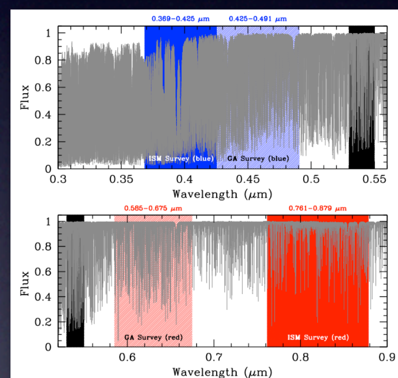
Sample Science

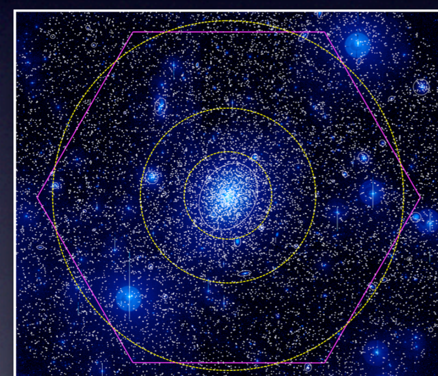


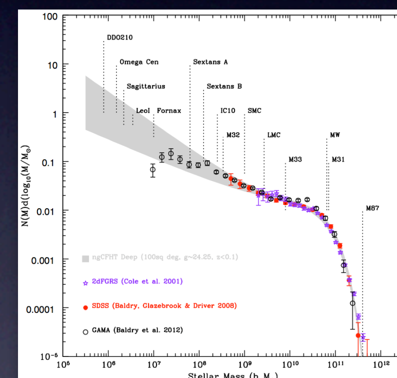


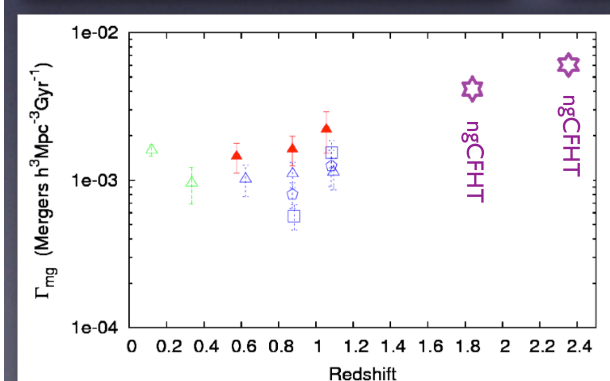


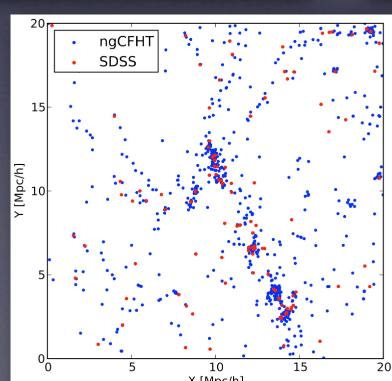


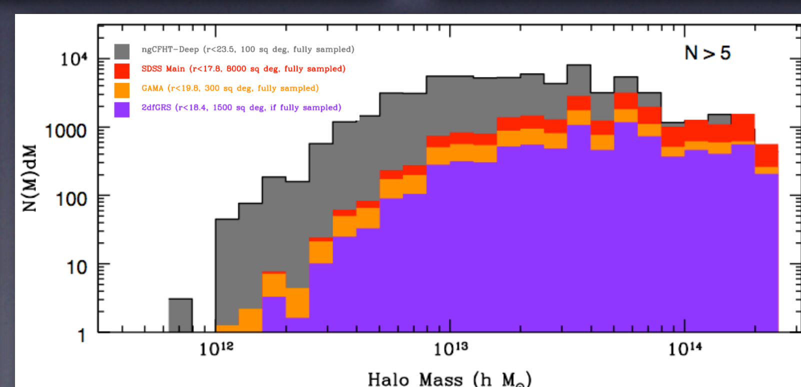












Representative Surveys

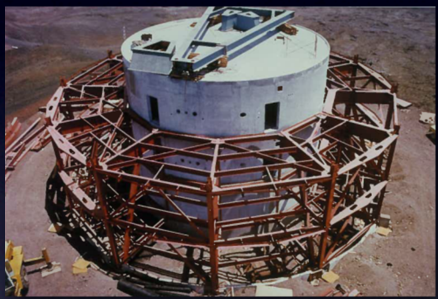
- Assume a 10 year lifetime for the facility's primary surveys.
  - 80% of time assigned to surveys; remaining 20% reserved for PI/GO programs.

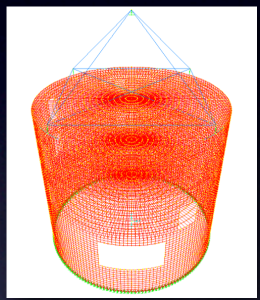
Survey	$u(g)_{sky}$	Area (deg^2)	Resolution	λ (nm)	g_{lim} (mag)	T (yrs)
Stellar Multiplicity	bright	100	20,000	425-491 (blue) 585-675 (red)	16.0	0.44
ISM Survey	bright	4,950	20,000	369-425 (blue) 761-879 (red)	16.0	0.47
Galactic Bulge	bright	200	20,000	452-520 (blue) 770-889 (red)	18.0	0.09
Galactic Disk	bright	750	20,000	370-540 (red) 560-950 (blue)	19.0	0.52
Halo Chemical Labeling	bright/grey	1,250	20,000	370-540 (red) 560-950 (blue)	19.0	0.87
Galactic Archaeology I	bright/grey	10,000	20,000	425-491 (blue) 585-675 (red)	20.4	2.92
Galactic Archaeology II	grey	10,000	6,500	381-439 (blue) 770-889 (red)	21.4	0.72
Quasar Reverb. Mapping	dark	1.5	2,000	370-1300	22.95	0.32
Dark-Wide	dark	4,300	2,000	370-1300	23.5	1.25
Dark-Medium	dark	100	2,000	370-1300	24.25	1.40
Dark-Deep	dark	1.5	2,000	370-1300	26.0	0.26

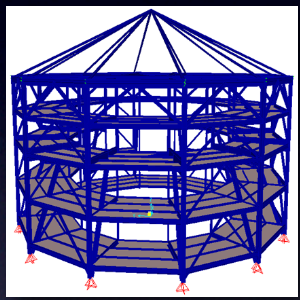
Overview of Technical Studies

- The Office of Mauna Kea Management has produced a Comprehensive Management Plan (CMP) that outlines the redevelopment principles for CFHT:
  - Requires the new facility to stay within the current three dimensional "footprint".

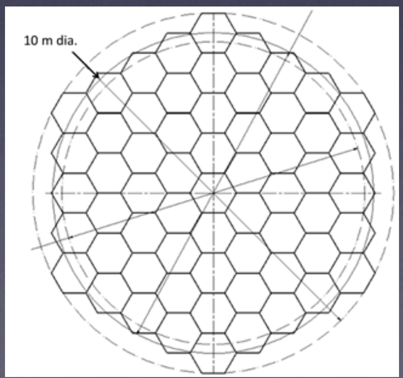
1. Load Capacity Studies
   - Evaluate the capacity of the current telescope and enclosure piers based on modern design codes.
   - The load capacity studies did not identify major structural deficiencies.

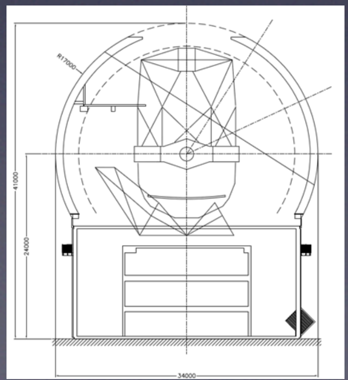


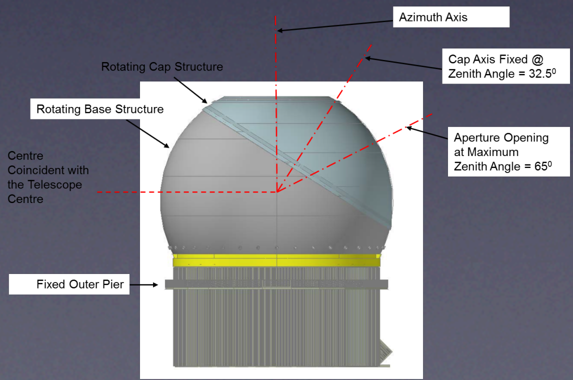




2. Telescope and Enclosure Configuration Studies
   - current preferred solution: 1-mirror design with f/1.83 segmented primary mirror of 10m diameter.
   - A Calotte design is the adopted enclosure configuration; provides a zenith observing range of 0° to 65°.
   - The enclosure height is currently 2.5m taller than the existing dome; further optimization of the telescope and enclosure geometry will reduce the overall height to meet the CMP requirement.

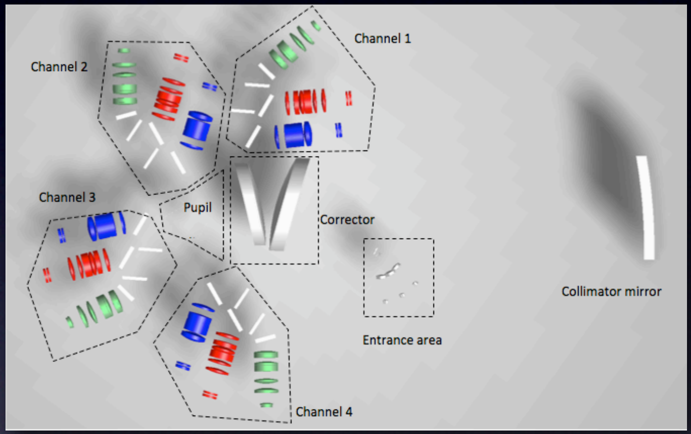






Overview of Technical Studies (cont'd)

3. Spectrograph Concept Studies
   - Two being options explored:
     - two distinct spectrographs:
       1. a dedicated, PFS-like instrument for R≈2,000 resolution; and
       2. separate spectrograph for R≈6,500 and 20,000.
     - a triple-resolution spectrograph design using pupil slicing technologies (4 channels, 3 arms per channel).



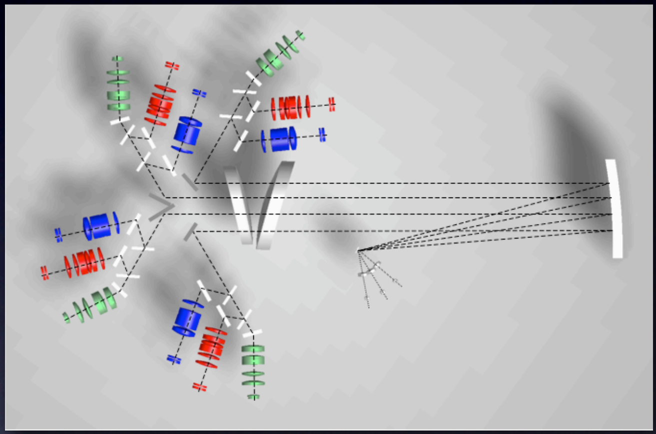


Table I - Characteristics of Spectrograph Observing Modes

Mode	Resolution in visible (Blue + Red arms)	Resolution in NIR arm	Simultaneous Coverage	# of Objects	
LR	2,000	2,000	Full	Nx4	
HR	20,000	NA	Two windows of λ/7 in visible	N	
MR-FC	6,500	NA	Full (visible only)	N	Full Wavelength Coverage
MR-HM	6,500	2,000	Two windows of λ/7 in visible	Nx4	High Multiplexing

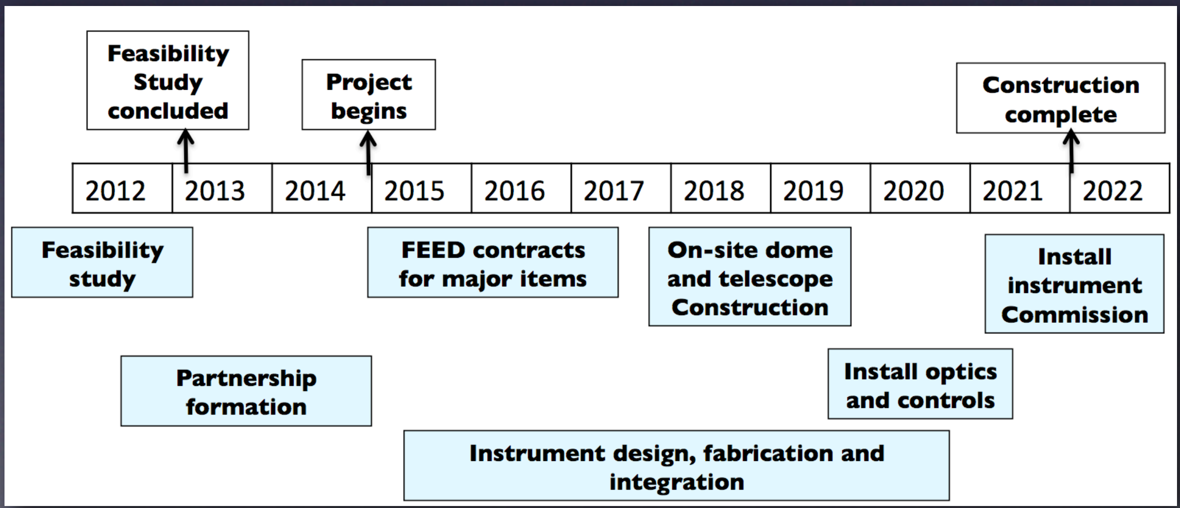
Overview of Technical Studies (cont'd)

4. Thermal Management Studies
   - CFD analysis is underway to evaluate aero-thermal performance of the proposed enclosure configuration.
   - Dome ventilation efficiency through floor vents, without vent doors on the rotating base structure.

5. Telescope Downtime Study
   - Dynamic Structures Ltd. are currently leading a study of the minimum time need to deconstruct the existing dome, remove the telescope, and prepare the sitefor redevelopment.

6. Costing and Valuation Study
   - Final costing from the concept study to be carried out in late October 2012.
   - Fidings to date suggest that the cost will be consistent with initial estimates from late 2010 (based mainly on the heritage from CFHT, Keck, WFMOS, Subaru and TMT/E-ELT).
   - ROM cost: $173M ($108M for telescope, enclosure; $65M for instrument; contingencies included).

7. Schedule
   - schedule as of June 2012, to be revisited at the conclusion of the concept study:



Upcoming Milestones

1. Deliverables from the ngCFHT Concept Study (Dec. 2012):

   - The Next Generation CFHT Concept Study. I. Science Report
   - The Next Generation CFHT Concept Study. II. Technical Report
   - The Next Generation CFHT Concept Study. III. Construction and Operations Plan

2. "The Next Generation CFHT: A 10m, Wide-Field, Spectroscopic Telescope for the Coming Decade"

   - *"This workshop is intended as a forum for discussion of the science cases and technical plans that have emerged from the feasibility study. It will last for 2.5 days, with summary talks discussing the science drivers and current technical status. Contributed talks are encouraged to highlight synergies with current and future facilities, and to propose opportunities for subsequent development. A large amount of time will be reserved for discussion. This will be a key opportunity to define a strategic road map for the scientific and technical development of the project, and to establish a foundation for the growth of the new partnership that will deliver this unique scientific facility to the international community."*

   - Location = University of Hawaii, Hilo
   - Dates = 27-29 March, 2013
   - Scientific Organizing Committee = N. Arimoto (Japan), M. Balogh (Canada), P. Bonifacio (France), B. Castilho (Brazil), P. Côté (co-chair), L. Cowie (Hawaii), K. Freeman (Australia), A. McConnachie (co-chair), E. Peng (China), S. Ravindranath (India), S.-Y. Wang (Taiwan), J.-H. Woo (South Korea)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ngCFHT Workshop
"The Next Generation of the CFHT: A wide field spectroscopic facility for the coming decade"
27 - 29 March 2013, 'Imiloa Astronomy Center of Hawai'i, (University of Hawai'i at Hilo), Hilo, Hawaii
For over 30 years the Canada-France-Hawaii Telescope and its international community have developed innovative capabilities to support advanced research. CFHT was among the first on Mauna Kea to develop a facility class adaptive optics system, multi-object and integral field spectrographs, and wide field panoramic imagers. Today we look to a future that builds upon our past, including the possibility of replacing the current 3.6 m telescope with a 10 m facility dedicated to wide field spectroscopy. If pursued, the next-generation CFHT (ngCFHT) would re-use the existing facility except for the telescope and dome, which would be replaced, leaving ngCFHT within the current 3D envelope of CFHT. While this concept is in infancy from a technical development perspective, considerable work has been completed in defining the science objectives for such a facility and we look forward to hosting members of the international astronomy community in Hawaii to discuss ngCFHT.