Canada–France–Hawaii Telescope Legacy Survey
History, strategy, and lessons learned

Jean–Charles Cuillandre (CFHT)

CFHTLS Steering Group CFHT representative (and current chairman)

AAS – ODI Session – Pasadena – June 2009
The world's top ten telescopes revealed

The best observatories ranked by their scientific impact.

Eric Hand

It doesn’t take a big mirror to have a big impact. The Sloan Digital Sky Survey, a project conducted with a modest 2.5-metre-wide telescope in New Mexico, performed the most highly cited science in 2006, according to a new analysis of the top ten ‘high impact’ astronomical observatories.

"It measures how hot the science of the telescope is," says Juan Madrid of McMaster University in Hamilton, Canada, of the top-ten table he has released for most years since 1998. "In a way it measures how good the time-allocation committee is and how good the telescope is. I will also say it measures how good the scientists are."

Also in the top five is another modest telescope — Swift, a satellite that looks for γ-ray bursts — followed by three technological giants of the astronomy world: the Hubble Space Telescope, the four 8-metre telescopes of the European Southern Observatory in Paranal, Chile, and the twin 10-metre Keck telescopes in Hawaii.

The table shows that a telescope’s technological advantages can push it to the top of the list, but also operating institution are important. However, some astronomers caution that citations are just one of assess an observatory’s value.
Gravitational lensing: a key science driver for CFHT

Discovery of the first giant arc by CFHT in 1985 (Soucail et al.)

Cluster Abell 370

2003 MegaCam: 1 square degree FOV

1985 FOCAM: ~4' x 4' FOV
1983–2003: 2 decades to get CFHT full frame digital

1994: 16 MegaPixels (MOCAM)

1995: 64 MegaPixels (UH8K)

1999: 100 MegaPixels (CFH12K)

2003: 350 MegaPixels (MegaCam)

New Era in Wide Field Imaging: MegaPrime at CFHT
The instrument: MegaCam on CFHT atop Mauna Kea

MegaPrime on CFHT (3.6m mirror)

MegaCam by CEA: 340 megapixels CCD mosaic

Wavelength coverage: from u-band to z-band

Excellent image quality (uniformity) over 1 sq. deg.
Origins and evolution of the CFHT Legacy Survey

- **1998**: CEA offered to build MegaCam and offer it to the entire CFHT scientific community on the condition a major general interest survey is undertaken with it.

- **1999**: CFH12K operational, and with MegaCam and the CFHTLS on the horizon (4 years), an evolution of the CFHT observing process is needed: start of the CFHT’s New Observing Process, including Queued Service Observing (QSO).

- **2000**: with the brisk success of the CFH12K across many communities (solar system, stellar physics, nearby Universe, cosmology), resulting with a consistent telescope allocation of 55% over its 4 years lifetime, the call for ideas for the CFHTLS with MegaCam is a success. The French and Canadian agencies allocate 30% of all the telescope time to the survey (they own 85% of the time together).

- **2001**: a science definition group is created, seeking the support of external (of C+F) reviewers. The three core topics addressing the most burning astrophysical questions tailored to make an optimal use of the u to z band sensitivity, the 0.7" median seeing, the 1 sq. degree field, the 3.6m aperture, and the dark skies of Mauna Kea were:
  - Dark energy study using a large sample (500) of high redshift SNe type Ia (Deep survey)
  - Cosmic shear and cosmological constraints (Wide survey)
  - Origins of the Solar system: Kuiper Belt Objects (Very Wide survey)
  - ...with MANY other science programs enabled: High−z QSOs, brown dwarfs, clustering, etc.

- **2002**: CFHTLS green−lighted (500 nights over 5 years) by the CFHT board and C+F agencies after review by the Scientific Advisory Committee (SAC). Steering Group created (9 members, PI−less), under a continuous review process by the SAC+Board.
**CFHTLS completed in Feb.09, 2400 hr of valid data**

<table>
<thead>
<tr>
<th>Survey</th>
<th>Area (sq. deg.)</th>
<th>Location</th>
<th>$u^*$</th>
<th>$g'$</th>
<th>$r'$</th>
<th>$i'$</th>
<th>$z'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep</td>
<td>4</td>
<td>D1/2/3/4</td>
<td>28.7</td>
<td>28.9</td>
<td>28.5</td>
<td>28.4</td>
<td>27.0</td>
</tr>
<tr>
<td>Wide</td>
<td>170</td>
<td>W1/2/3/4</td>
<td>26.4</td>
<td>26.6</td>
<td>25.9</td>
<td>25.5</td>
<td>24.8</td>
</tr>
<tr>
<td>Very Wide</td>
<td>410</td>
<td>On ecliptic</td>
<td>26.4</td>
<td>26.6</td>
<td>25.9</td>
<td>25.5</td>
<td>24.8</td>
</tr>
</tbody>
</table>
The Deep Survey – Completed integration

<table>
<thead>
<tr>
<th>Field</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA/DEC</td>
<td>02:26/-04:30</td>
<td>10:00/02:12</td>
<td>14:17/+52:30</td>
<td>22:15/-17:44</td>
</tr>
<tr>
<td>Overlap</td>
<td>in W1</td>
<td>On COSMOS field</td>
<td>in W3</td>
<td>LBQS2212–17</td>
</tr>
<tr>
<td>Dust</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Int.</td>
<td>289 hr.</td>
<td>252 hr.</td>
<td>285 hr.</td>
<td>270 hr.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Filter</th>
<th>Fraction</th>
<th>Mean IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>u*</td>
<td>9%</td>
<td>0.91&quot;</td>
</tr>
<tr>
<td>g'</td>
<td>10%</td>
<td>0.88&quot;</td>
</tr>
<tr>
<td>r'</td>
<td>20%</td>
<td>0.79&quot;</td>
</tr>
<tr>
<td>i'</td>
<td>40%</td>
<td>0.76&quot;</td>
</tr>
<tr>
<td>z'</td>
<td>21%</td>
<td>0.75&quot;</td>
</tr>
</tbody>
</table>

SNLS’ SNe Ia light curve tracking

i’ FWHM
The Wide Survey – Completed integration

<table>
<thead>
<tr>
<th>Field</th>
<th>W1 – 8x9 sq.deg.</th>
<th>W2 – 5x5 sq.deg.</th>
<th>W3 – 7x7 sq.deg.</th>
<th>W4 – 5x5 sq.deg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA/DEC</td>
<td>02:18/-07:00</td>
<td>08:54/-04:15</td>
<td>14:17/+54:30</td>
<td>22:13/+01:19</td>
</tr>
<tr>
<td>Overlap</td>
<td>XMM LSS</td>
<td>Groth Strip</td>
<td>VVDS&amp;UKIDSS</td>
<td></td>
</tr>
<tr>
<td>Dust</td>
<td>![Grid Image]</td>
<td>![Grid Image]</td>
<td>![Grid Image]</td>
<td>![Grid Image]</td>
</tr>
<tr>
<td>Int.</td>
<td>361 hr.</td>
<td>139 hr.</td>
<td>242 hr.</td>
<td>126 hr.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Filter</th>
<th>u*</th>
<th>g'</th>
<th>r'</th>
<th>i'</th>
<th>z'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction</td>
<td>17%</td>
<td>16%</td>
<td>17%</td>
<td>28%</td>
<td>22%</td>
</tr>
<tr>
<td>Mean IQ</td>
<td>0.90&quot;</td>
<td>0.88&quot;</td>
<td>0.76&quot;</td>
<td>0.67&quot;</td>
<td>0.72&quot;</td>
</tr>
</tbody>
</table>
The Very Wide Survey – Completed integration

Sky Coverage: 410 sq. deg. ...

<table>
<thead>
<tr>
<th>Filter</th>
<th>$g'$</th>
<th>$r'$</th>
<th>$i'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration</td>
<td>47 hr.</td>
<td>75 hr.</td>
<td>70 hr.</td>
</tr>
<tr>
<td>Fraction</td>
<td>24%</td>
<td>40%</td>
<td>36%</td>
</tr>
<tr>
<td>Mean IQ</td>
<td>0.90&quot;</td>
<td>0.80&quot;</td>
<td>0.80&quot;</td>
</tr>
</tbody>
</table>
Science with the CFHT Legacy Survey

**Solar System**
- The Kuiper Belt
- Asteroids

**The Galaxy**
- Stellar Populations
- Brown Dwarfs
- Low Mass Stars
- White Dwarfs
- Dynamics
- Variability

**Galaxies & Clusters**
- Redshift Distribution
- Evolution
- Clusters
- Morphology
- Clustering
- Weak Lensing
- Star Formation
- Luminosity Function
- Environment
- AGNs

**Cosmology**
- Dark Energy
- Cosmic Shear
- Strong Lensing
- Large Scale Struct.
- Supernovae
- GRBs
- QSOs

**The Kuiper Belt Stellar Populations**
- Brown Dwarfs
- Low Mass Stars
- White Dwarfs
- Dynamics
- Variability

**Very Wide**
- The Kuiper Belt
- Asteroids

**Very Wide / Wide / Deep**
- Stellar Populations
- Brown Dwarfs
- Low Mass Stars
- White Dwarfs
- Dynamics
- Variability

**Wide / Deep**
- Redshift Distribution
- Evolution
- Clusters
- Morphology
- Clustering
- Weak Lensing
- Star Formation
- Luminosity Function
- Environment
- AGNs

**Very Wide / Wide / Deep**
- Dark Energy
- Cosmic Shear
- Strong Lensing
- Large Scale Struct.
- Supernovae
- GRBs
- QSOs
The 5 most cited CFHTLS publications

<table>
<thead>
<tr>
<th>Article, citations, CFHTLS component, and title (as of June 2009):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astier et al. 2006</td>
</tr>
<tr>
<td>Hoekstra et al. 2006</td>
</tr>
<tr>
<td>Ilbert et al. 2006</td>
</tr>
<tr>
<td>Sullivan et al. 2006</td>
</tr>
<tr>
<td>Semboloni et al. 2006</td>
</tr>
</tbody>
</table>

Yearly publication rate:
- 2005: 4
- 2006: 19
- 2007: 25
- 2008: 19
CFHTLS data flow

Definition QSO

Observation QSO NEO Elixir-RT

Archive DADS

Processing Elixir

Distribution DADS

Raw Archive CADC

Archive CADC

Processing Terapix

Archive CADC

RT Products C, F, World

STACK/CAT C, F

T_exp < 2 Days

T_run < 3 Weeks

T_source < 1 Day

T_field ~ 1 year

1 Week

1 Day

Minutes

1 Week (network)

1 Day

1 Week

1 Day

1 Week (network)

1 Week

1 Week (network)

1 Week (network)
The CFHTLS seen by Queued Service Observing

- Time critical observations on a large-scale
  - SNe fields every 4 nights, 2 fields per run
  - Each Very Wide patch has 5 time constraints

- Balancing Agency Time
  - PI programs (50%) versus CFHTLS (50% or "49" nights at best per semester)

- Balancing time share between CFHTLS programs
  - Deep (44%), Wide (34%), Very Wide (22%)

- Example of conflicts just with the CFHTLS:

- Time constraints are a real challenge, require planning, understanding of programs and priorities, and constant attention to the general balance.
The real world: weather and technical downtime

CFHT’s MegaPrime Observing Statistics
Starting June 2003, with 6 to 7 runs per semester since (m01->m06/7)
"A" semesters = February to July / "B" semesters = August to January
The night length varies from 8.7 hr (June) to 11.2 hr (December)

Mid-term review advanced to May 2005
- Priority to core science (SNLS, Cosmic Shear)
- Wide cut to u/2 & z/2
- Very Wide ramped down
... and addition of the W4 field
... plus a 6 months extension with top priority to get the core CFHTLS completed.

Flexibility = Salvation
Observing flexibility & Environment monitoring

QSO’s validation rate is high (80% for the entire CFHTLS – 26,000 exposures) because non adequate conditions are tracked down very quickly through real–time tracking of the key parameters for direct imaging:

- Image quality
- Sky background
- Airmass
- Filter
- Sky transparency

Elixir Real Time
Telescope Control System
Instrument control
SkyProbe (Elixir)

SkyProbe Archive Plot for 2004 January 12
Keys to the success of the CFHT Legacy Survey

- The survey was community driven, with key core science topics while tailored to provide a high quality data set for a broader usage, as well as legacy value.
- Not a blind allocation: though it came with its burdens, the constant overseeing process by various groups ensured the proper success of the project.
- Users first! Constant quality service to please the scientists: Observations (QSO), Processing (Elixir, Terapix), Distribution (DADS, CADC).
- Human factor: the CFHT QSO team was very flexible and motivated to make it work! There always was a "can do" attitude in a group of dedicated people.
- Stable staff: knowledge of the system and programs is key. Staff turnover at CFHT is very low, no change in the observing staff (4) over the 6 years of the survey.
- Focused science teams with funding over the whole survey (e.g. SNLS)
- Stable and steady data delivery. Interaction with the community on processing.
- Terapix and CADC: evolution upon users’ needs. Plus followed the technical computing advances which move faster than today’s cameras pixel count.
- We had two years before the survey started to tweak the tools and procedures.
- CFHTLS is not over: data collection is complete, but in depth calibration and global release to the world still pending (large fraction is already public)
- It worked so well, we are doing it again: Andromeda and Virgo surveys (2008–2012)
Future of Wide-Field Imaging at CFHT: 'IMAKA

'IMAKA (scenic view in Hawaiian) – 2015
One square degree imager delivering 0.2” to 0.3” in the visible

Figure 1: Block diagram of 'IMAKA/CFHT. The key components of CFHT and 'IMAKA are the telescope primary, adaptive secondary, wide field correcting optics, facility wavefront sensing unit, and science camera.