Canada–France–Hawaii Telescope MegaCam Surveys

History, strategy, and lessons learned

Jean–Charles Cuillandre (CFHT)

One Degree Imager Survey Workshop – Yale – October 2009

Legacy Survey 2003–2009

Virgo Survey 2009–2012

Pan–Andromeda Survey 2009–2012
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 the ways to 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

1985 FOCAM: ~4’x4’ FOV

2003 MegaCam: 1 square degree 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 Commitee (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>
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<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>
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</table>
The Deep Survey – Completed integration

<table>
<thead>
<tr>
<th>Field</th>
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<th>D2</th>
<th>D3</th>
<th>D4</th>
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<tbody>
<tr>
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<td>02:26/–04:30</td>
<td>10:00/02:12</td>
<td>14:17/+52:30</td>
<td>22:15/–17:44</td>
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<tr>
<td>Overlap</td>
<td>in W1</td>
<td>On COSMOS field</td>
<td>in W3</td>
<td>LBQS2212–17</td>
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<table>
<thead>
<tr>
<th>Dust</th>
<th></th>
<th></th>
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</table>

| Int. | 289 hr. | 252 hr. | 285 hr. | 270 hr. |

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<tr>
<th>Filter</th>
<th>Fraction</th>
<th>Mean IQ</th>
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<td>0.91″</td>
</tr>
<tr>
<td>g’</td>
<td>10%</td>
<td>0.88″</td>
</tr>
<tr>
<td>r’</td>
<td>20%</td>
<td>0.79″</td>
</tr>
<tr>
<td>i’</td>
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<td>0.76″</td>
</tr>
<tr>
<td>z’</td>
<td>21%</td>
<td>0.75″</td>
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</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>
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<td>08:54/−04:15</td>
<td>14:17/+54:30</td>
<td>22:13/+01:19</td>
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<td>Overlap</td>
<td>XMM LSS</td>
<td>Groth Strip</td>
<td>VVDS&amp;UKIDSS</td>
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<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
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<tr>
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<td>139 hr.</td>
<td>242 hr.</td>
<td>126 hr.</td>
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</table>

<table>
<thead>
<tr>
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<th>r'</th>
<th>i'</th>
<th>z'</th>
</tr>
</thead>
<tbody>
<tr>
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<td>16%</td>
<td>17%</td>
<td>28%</td>
<td>22%</td>
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<tr>
<td>Mean IQ</td>
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<td>0.88''</td>
<td>0.76''</td>
<td>0.67''</td>
<td>0.72''</td>
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</table>
The Very Wide Survey – Completed integration

<table>
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<tr>
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<td>36%</td>
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<tr>
<td>Mean IQ</td>
<td>0.90''</td>
<td>0.80''</td>
<td>0.80''</td>
</tr>
</tbody>
</table>

Sky Coverage: 410 sq. deg. ...
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 5 most cited CFHTLS publications

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Citations</th>
<th>CFHTLS Component</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>Astier et al. 2006</td>
<td>987</td>
<td>SNLS</td>
<td>The Supernova Legacy Survey: Measurement of Omega_M, Omega_Lambda and w from the First Year Data Set</td>
</tr>
<tr>
<td>Hoekstra et al. 2006</td>
<td>128</td>
<td>Wide</td>
<td>First cosmic shear results from the Canada–France–Hawaii Telescope Wide Synoptic Legacy Survey</td>
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<tr>
<td>Ilbert et al. 2006</td>
<td>121</td>
<td>Deep</td>
<td>Accurate photometric redshifts for the CFHT Legacy Survey calibrated using the VIMOS VLT Deep Survey</td>
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<tr>
<td>Sullivan et al. 2006</td>
<td>109</td>
<td>SNLS</td>
<td>Rates and Properties of Type Ia Supernovae as a Function of Mass and Star Formation in Their Host Galaxies</td>
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<tr>
<td>Semboloni et al. 2006</td>
<td>74</td>
<td>Deep</td>
<td>Cosmic Shear Analysis with CFHTLS Deep data</td>
</tr>
</tbody>
</table>

### Yearly publication rate:
- 2005: 4
- 2006: 19
- 2007: 25
- 2008: 19
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:**

  ![Diagram of time constraints and observing schedules]

- **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

<table>
<thead>
<tr>
<th>Period</th>
<th>Runs</th>
<th>Nights</th>
<th>Validation</th>
<th>CFHTLS</th>
<th>Unvalidated</th>
<th>Weather</th>
<th>Overheads</th>
<th>Night Length</th>
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<td>0.8</td>
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<td>4.8</td>
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<td>0.8</td>
<td>1.7</td>
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<tr>
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<td>16.8</td>
<td>6.4</td>
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<td>1.8</td>
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<tr>
<td>07A</td>
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<td>14.3</td>
<td>5.1</td>
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<td>0.8</td>
<td>2.3</td>
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<td>9.3</td>
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<td>4.9</td>
<td>53%</td>
<td>1.0</td>
<td>3.7</td>
<td>18%</td>
<td>10.8</td>
</tr>
</tbody>
</table>

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
CFHTLS data flow

Definition
QSO

Observation
QSO NEO Elixir–RT

Archive
DADS

Processing
Elixir

Distribution
DADS

RT Processing
Elixir–RT

SNe – C
SNe – F
GRB – F

RT Products
C, F, World

CFHT’s NOP

T_source < 1 Day

T_exp < 2 Days

C, F

1 Day

1 Day

1 Week

T_run < 3 Weeks

1 Week (network)

1 Week

CADC

CADC

T_field ~ 1 year

~ 1 year

1 Day

1 Week (network)

STACK/CAT
C, F

1 Week (network)

RAW
C, F

C, F

Months / Weeks / Days

Minutes

Minutes

1 Week (network)
The Next Generation Virgo Survey
700 hours over 3 years (2009–12) to cover 104 sq. deg. in u*g'r'i'z'

Messier 49 field (1 sq. deg.)
The Pan–Andromeda Survey

450 hours over 5 years (2007–12) to cover 350 sq. deg. in g’ and i’

Depth: g=25.5 i=24.5
Detects surface brightness ~32 mag/sq.arcsec

Messier 33 field (1 sq. deg.)