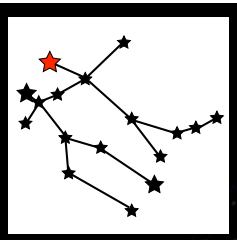


CASTOR:

The Cosmological Advanced Survey Telescope for Optical and ultraviolet Research

Patrick Côté (NRC-Herzberg),
on behalf the Canadian Space Telescope Mission Concept Study Team:

Michael Balogh (Waterloo), David Aldridge (COM DEV), Don Asquin (Magellan), Jeff Cain (COM DEV), Ray Carlberg (Toronto), Weiguo Chen (COM DEV), Patrick Côté (HIA), Jean Dupuis (CSA), Clinton Evans (COM DEV), Laurent Drissen (Laval), Wes Fraser (HIA), Frederic Grandmont (ABB), Paul Harrison (Magellan), John Hutchings (HIA), JJ Kavelaars (HIA), Christian Lange (CSA), Denis Laurin (CSA), Andrew Rader (COM DEV), Carmelle Robert (Laval), Marcin Sawicki (St. Mary's), Alan Scott (COM DEV), Warren Soh (Magellan), Robert Sorba (St. Mary's), Guillaume Theriault (ABB), Ludovic Van Waerbeke (British Columbia)

CASCA AGM, Quebec City, June 12, 2014

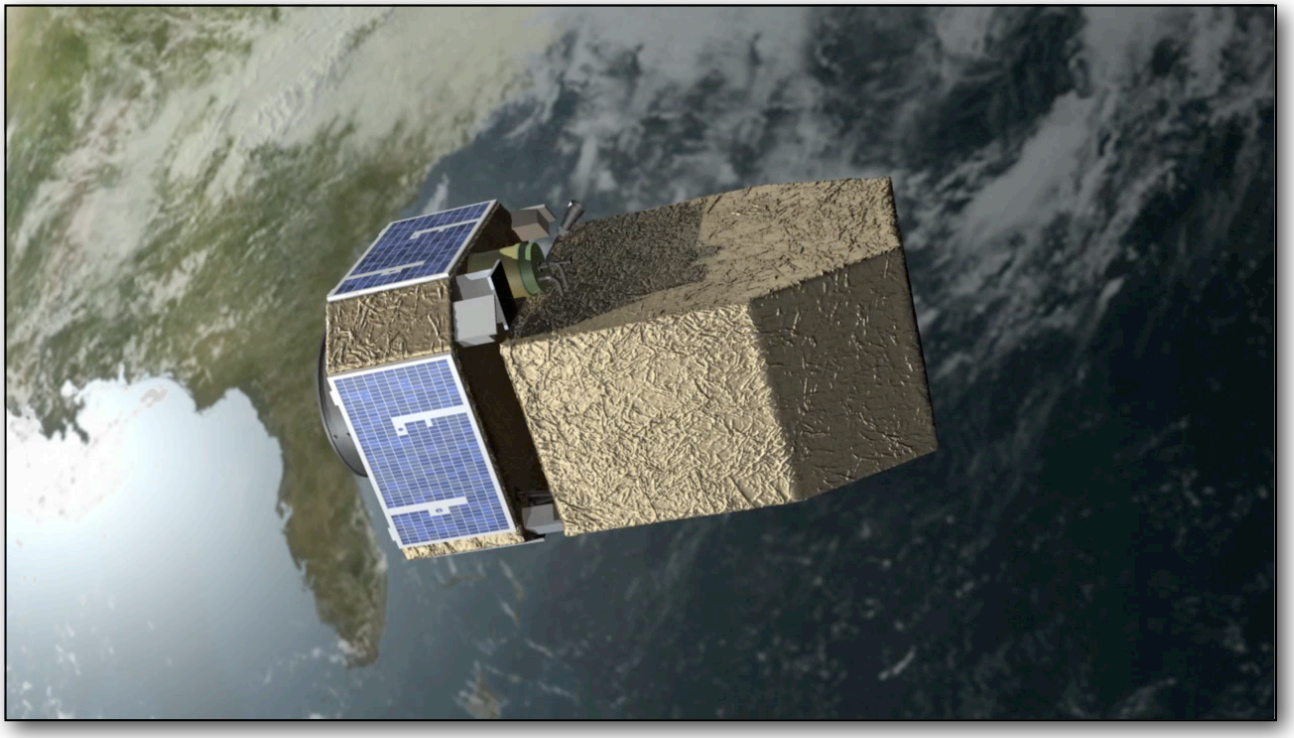
What is CASTOR?

- **CASTOR**: **C**osmological **A**dvanced **S**urvey **T**elescope for **O**ptical and UV **R**esearch.

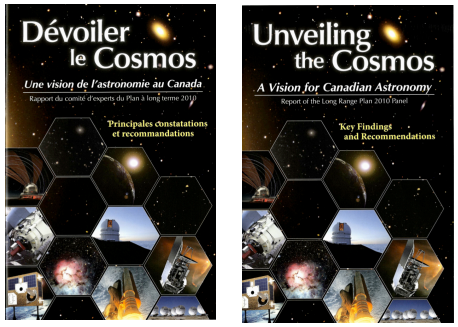
- **CASTOR** is a proposed flagship Canadian space astronomy mission that would make a significant and strategic contribution to future **Dark Energy** missions.

  - **wide field (> 0.5 deg^2), nearly diffraction-limited imaging (FWHM = 0.15″) with a 1m telescope operating at UV and blue-optical wavelengths (150 - 550 nm).**

  - **one example of a strategic survey for Euclid photo-zs: imaging to UV ~ 25.8, u ~ 27.1 and g ~ 27.8 over Ω ~ 5000 deg^2.**



1. Development History and Context



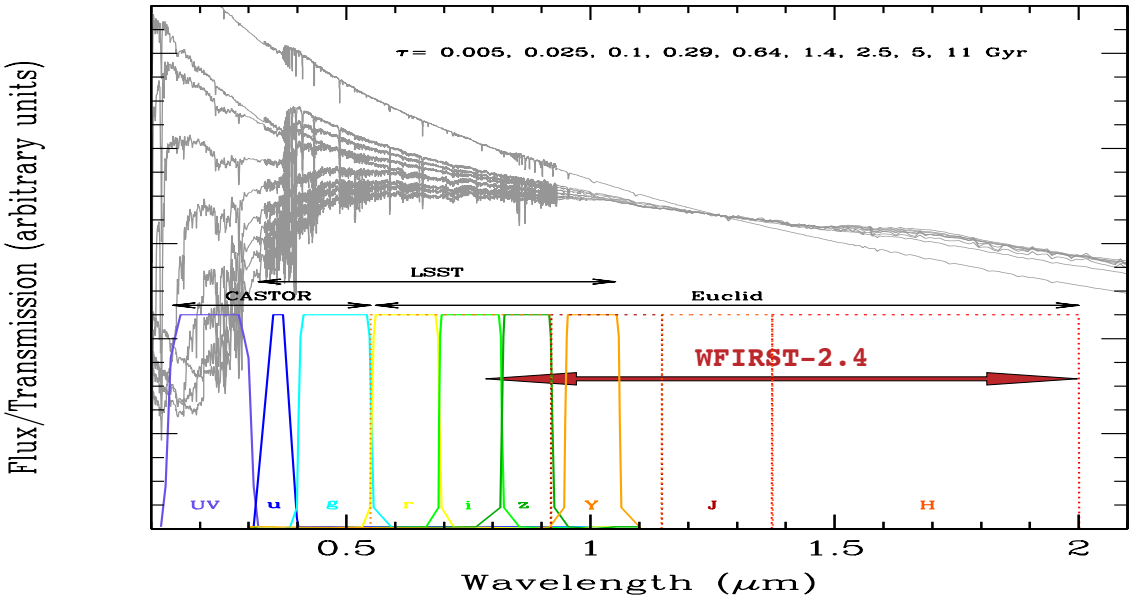
Category	Project	§	$
Large	Dark Energy Satellite (e.g. Euclid or WFIRST or CST)	5.1	$100M
Medium	1. IXO R&D	5.2	$15M
	2. SPICA	5.3	$10M
Small	1. Astro-H	5.2	$5M:
	2. Stratospheric Balloon Programme	5.5	$5M:
	3. Nanosat/Microsat Programme	5.4	$5M:

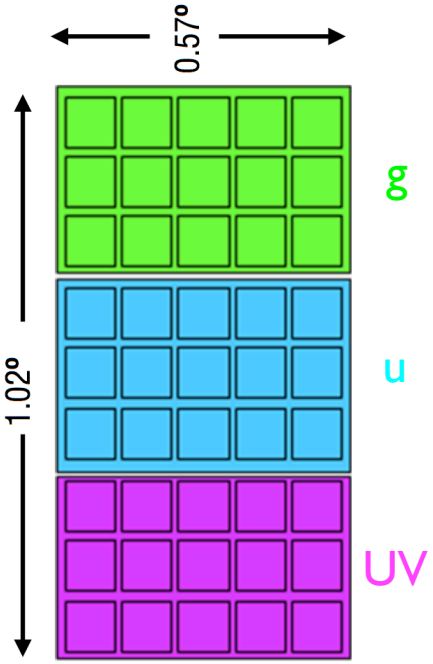
- From the **2010 Long Range Plan for Canadian Astronomy (LRP2010)**:
  - The highest priority in space astronomy is: "…significant involvement in the next generation of dark energy missions – ESA's Euclid, or the NASA WFIRST mission, or a Canadian-led mission, the **Canadian Space Telescope.**"
  - "… Canadian space astronomy technology has reached the point that we could [now] lead a large space astronomy mission (**Canadian Space Telescope, CST**)"
  - "Leading such a project would break new ground for Canadian space astronomy and present numerous opportunities for Canadian companies to showcase technological capabilities."

2006	Canadian Space Astronomy Workshop. First community discussions of CST as a possible "flagship mission".	**2011**	Long Range Plan (LRP) for Canadian Astronomy.
2007	Concept Study for Canadian Ultraviolet Spectroscopic Explorer (CUSE).	**2011 - 2012**	Canadian Space Telescope mission (CST ⇨ CASTOR) concept study.
2007 - 2009	Discipline Working Group (DWG) study on Wide-Field Space Imaging.	**2013 -**	CSA STDP study "Focal Plane Array Technologies for Astronomy"
2010 - 2011	CSA Dark Energy Mission Contribution Concept Study: Euclid UG Camera	**2013 -**	CSA STDP study "Single Photon Counting Large Format Detectors with Enhanced UV Response for Space Astronomy"

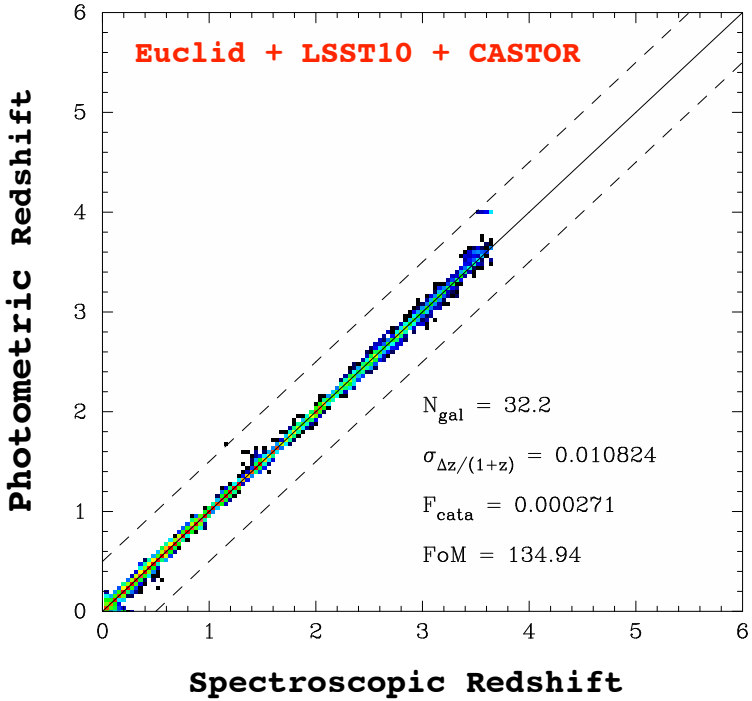
2. Design and Specifications

- **Telescope**
  - three mirror anastigmat
  - unobscured aperture = 1m
- **Focal Plane**
  - 45 4k × 4k H4RG with 10μm pitch
  - FWHM = 0.15″
  - field of view = 1.02° × 0.57°
  - three filter imaging
    - 400-550 nm (g)
    - 300-400 nm (u)
    - 150-300 nm (UV)
- **Launch Vehicle**
  - PSLV (ISRO) favoured
- **Orbit**
  - 600-1000 km
  - sun synchronous low Earth orbit
- **Mechanical Design**
  - customized MAC-200 SmallSAT bus
  - payload mass = 572 kg
  - spacecraft mass = 1320 kg
- **Operation Mode**
  - nominal 5-year lifetime
  - legacy surveys + GO programmes





CASTOR focal plane
(45 × 4k × 4k)



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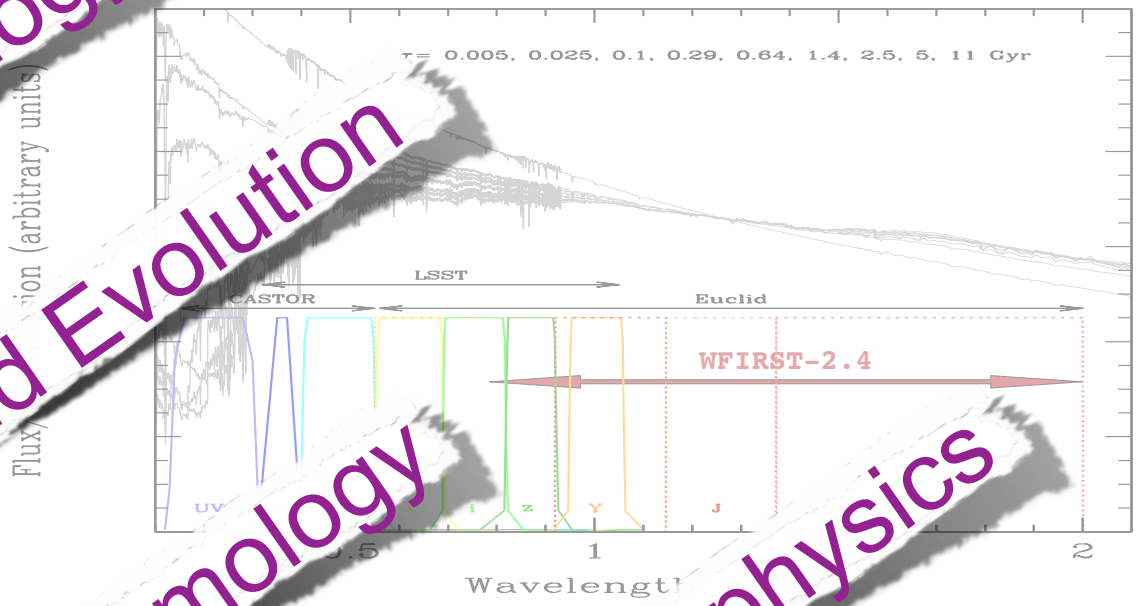
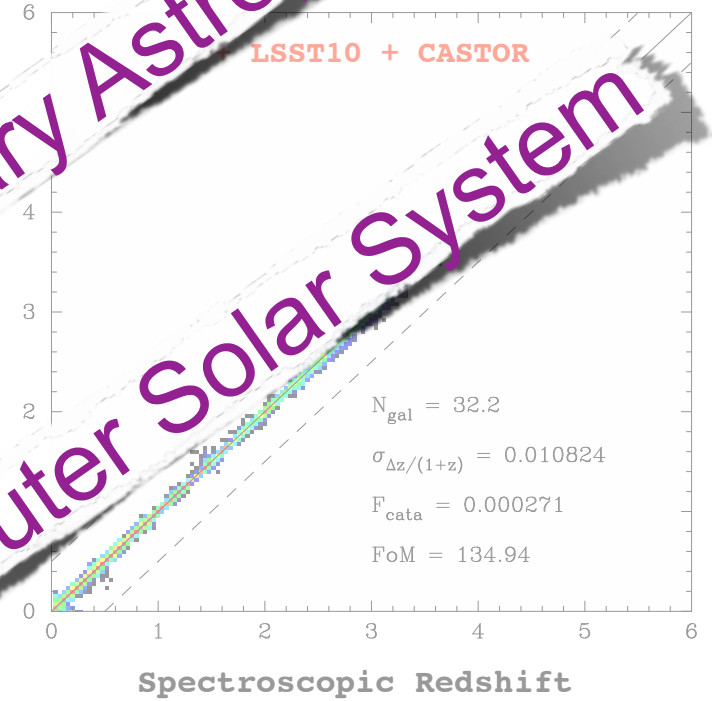




Dark Energy and Cosmology

Galaxy Formation and Evolution

Near-Field Cosmology

Stellar and Planetary Astrophysics

The Outer Solar System

3. Partnership-Building Efforts

- CASTOR concept study report delivered to CSA in March 2012.

- Since then, CASTOR science team efforts have focused on: (1) support of the ongoing FPA characterization study; and (2) community outreach and, especially, **international partnership building:**

    1. Canadian Aeronautics and Space Institute Conference (Quebec City, Canada), April 2012.
    2. UV Astronomy: HST and Beyond (Kauai, USA), June 2012.
    3. COSPAR 2012 (Bangalore, India), July 2012.
    4. SPIE 2012 (Amsterdam, The Netherlands), July 2012.
    5. Science with Surveys (Garching, Germany), October 2012.
    6. Challenges in UV Astronomy (Garching, Germany), October 2013.
    7. SPIE 2014 (Montreal, Canada), June 2014.

- While there has been considerable interest from possible international partners (e.g., France, India, Taiwan, Australia, Switzerland, USA), all want to see leadership from CSA: i.e., a Phase 0 study.

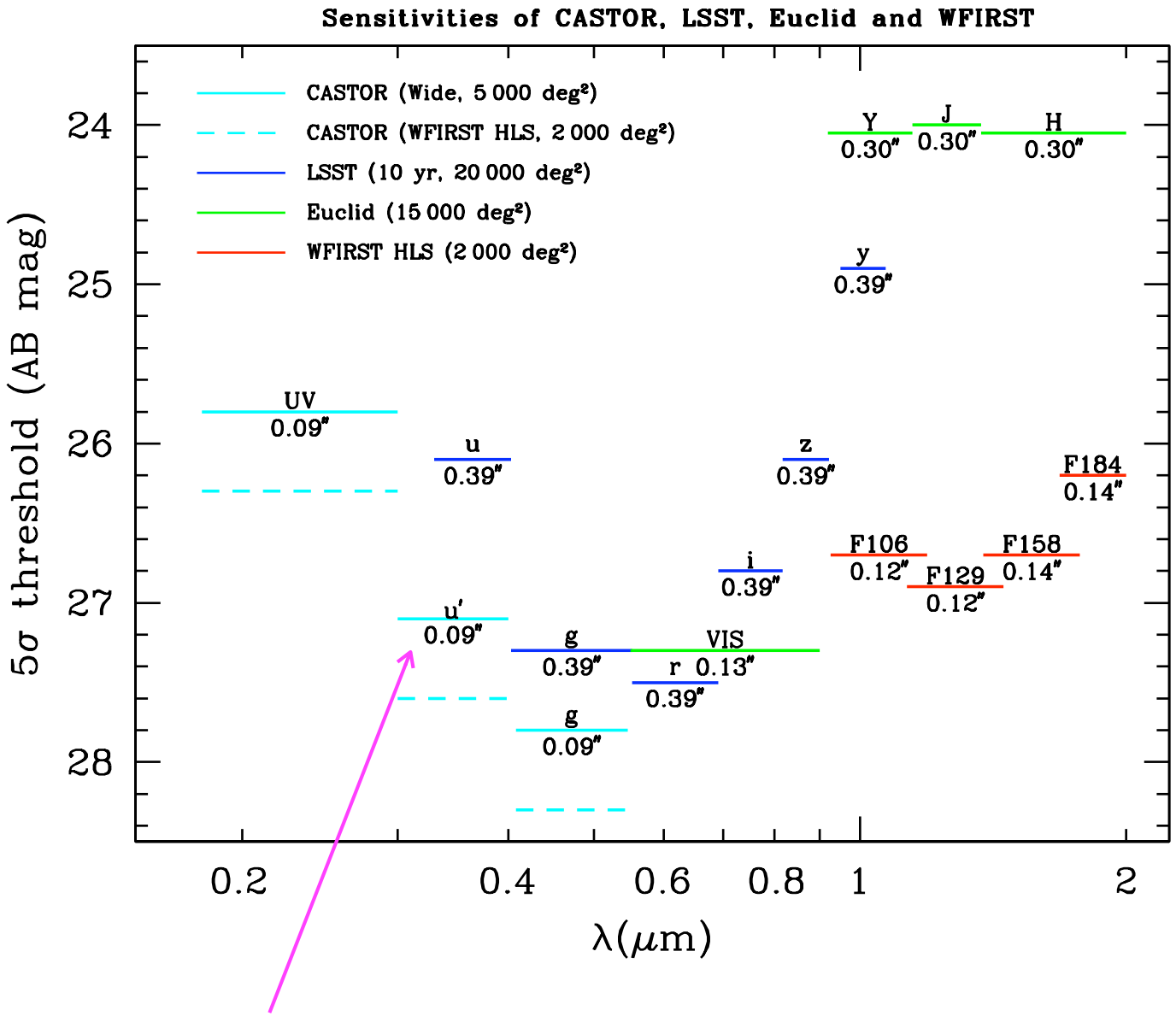
4. Ongoing Technology Studies

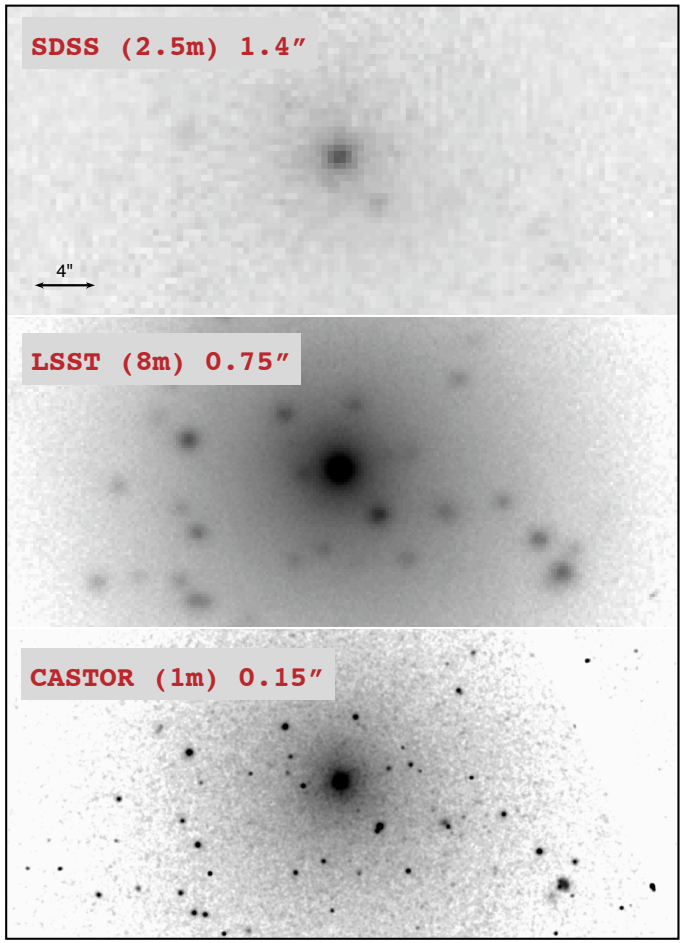
- two-year STDP study started in October 2013 (lead contractor = COM DEV).
- scope of work:
  - review science cases and update detector requirements.
  - review state-of-the-art UV-sensitive sensor technology and select leading candidate for CASTOR.
  - procure and characterize UV sensitivity of available detector technology as risk reduction for CASTOR.
- currently compiling RFQ responses from (five) major manufacturers.
- **Preliminary conclusion: there are multiple silicon detector candidates that could meet the needs of CASTOR.**

Table 2: Comparative Analysis of Detectors

Detector	ROE	Number of Detectors	TRL (UV)	TRL (Det)	TRL (Pkg)	IPC	Subwindow	Up-ramp sampling	Readnoise	EOL I_{dark}
E2V BICMOS TAOS II	Custom analog LVDS	36	5	4	4	none	yes	yes	~5 e-	
Teledyne H4RG HyVisI	JWST re-use	45	5	6	5	~5%	yes	yes	~10 e-	
Raytheon PIN Hybrid	Custom analog LVDS	6 or 18	2	5	4	none	yes	yes	~5 e-	
SRI Mk x Nk	JWST re-use	12	2	4	2	none	yes (by row)	yes	<6 e-	
BICCD	Custom analog CCD	45	2	4	2	none	No	not needed	<1.5 e-	

5. CASTOR-WFIRST: The Ultimate Synergy





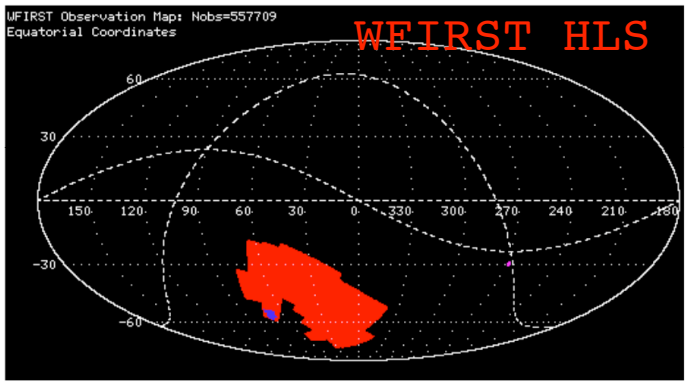
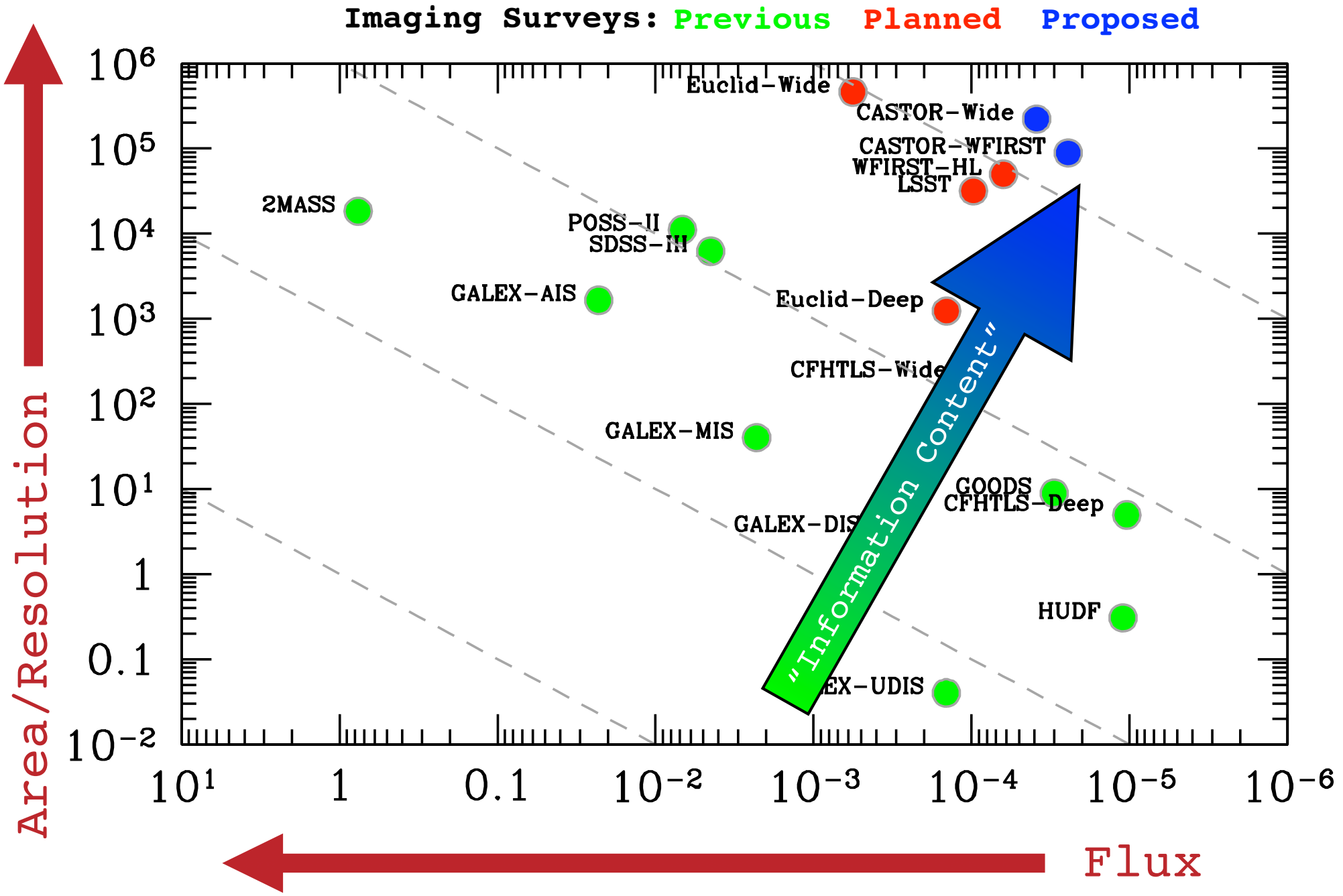


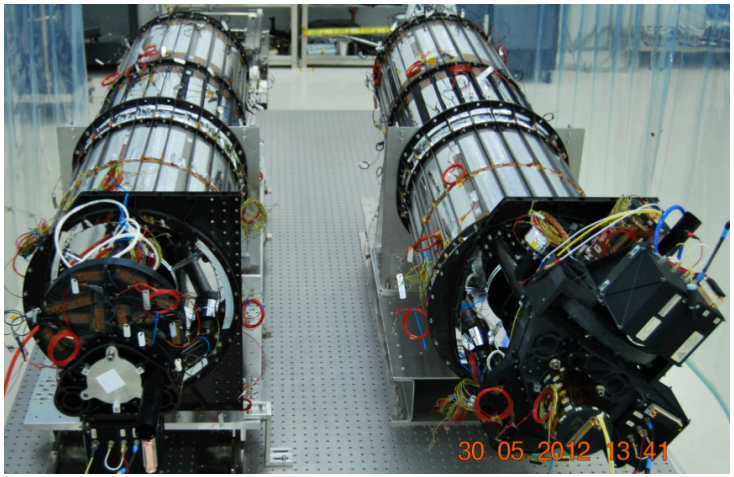
Figure 3-28: The footprint of the WFIRST-2.4 observations. The red region shows the HLS, the blue shows the supernova survey, and the magenta spot shows the microlensing survey. The HLS footprint area is 2054 deg².

5. CASTOR-WFIRST: The Ultimate Synergy

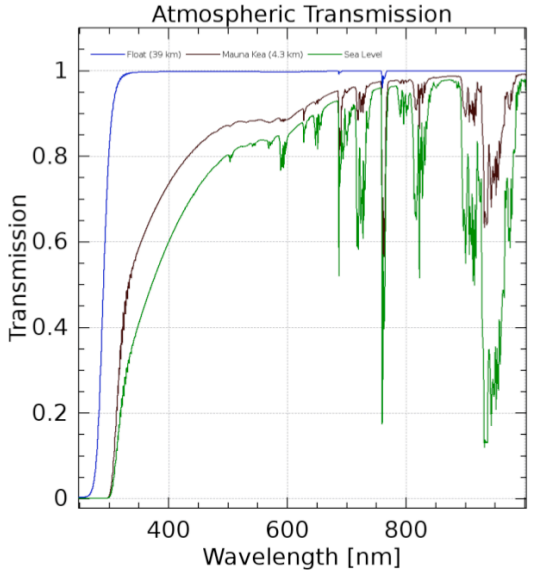


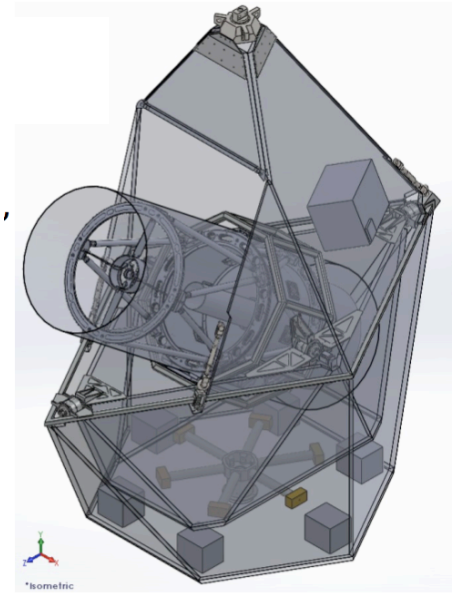
6. Strategic Blue-Optical/UV Efforts in Canada

- **CFHT MegaCam (2015-2020).**
  1. **LUAU** (PIs = Ibata, McConnachie; 2015-16)
     - $\Omega \approx 3500$ deg^2, S/N ≈ 5 @ u=24.2
  2. **HSC and/or MS-DESI coordinated surveys?**
- **Ultraviolet Imaging Telescope (2015-2020).**
  - wide-field (28′ diameter), medium-IQ (FWHM ~ 1.5″) imaging at λ = 1300-3200 Å.
  - 5% Canadian guaranteed time.
- **Optical/UV Ballooning (2015-2020s).**
  - wide-field, high-resolution optical/UV balloon-borne imaging (PI = Netterfield)
  - BIT (Balloon Borne Imaging Testbed), 0.5m telescope, 0.25″ resolution.
  - BIT0 (2015), 8-hrs, Canadian launch.
  - SuperBIT (2017), 60-100 nights, southern hemisphere.
  - GigaBIT (2019-), 1.2m, 0.1″ res., opt/NUV, 2 Gpix camera, 100 nights.
- **CASTOR (2022-2027?) or CASTOR-WFIRST.**



Ultraviolet Imaging Telescope





BIT (courtesy S. Li, B. Netterfield)

7. Necessary Conditions for Development

- The CASTOR concept has been developed with the following "necessary conditions" for success in mind. It must:

1. enable scientific discoveries of the highest order, thanks to a dramatic increase in capabilities over any existing or planned facility.
2. complement and enhance (not compete with) the LSST, Euclid, WFIRST dark energy missions (and thus fulfill the requirements of the LRP).
3. be compatible with the Government of Canada's Space Policy Framework.

4. appeal to broad segment of the Canadian astronomical community (e.g., ALMA, JWST, TMT).
5. have widespread involvement by Canadian industry, showcasing Canadian technologies.
6. be one part of a strategic portfolio of astronomy facilities for Canada in the 2020s.

8. Anticipated Industrial Involvement

Company	Location	Technical Contribution
Magellan Aerospace	Winnipeg MB Ottawa ON	Spacecraft Systems Design and Integration
COM DEV	Cambridge, ON Ottawa ON	Payload Design, Integration and Testing
ABB	Quebec QC	Optical Sensors Design, Integration & Testing
DRS Technologies	Carleton Place ON	Electronics Manufacture
M2S	Quebec QC	Electronics Manufacture
SEM Electronic	Saint-Nicolas QC	Electronics Manufacture
Xiphos Technologies	Montreal QC	FPGA based Electronics
IMP Electronic Systems	Halifax NS	Harness Manufacture
Composites Atlantic	Lunenburg NS	Substrates
Maya HTT	Montreal QC	Thermal Design and Modelling
Groupe Meloche	Montreal QC	Structural Flight Parts

8. Anticipated Industrial Involvement

9. Key Issues for the MTR

- CASTOR would:
  1. meet the goals of LRP2010 (in spectacular fashion).
  2. be a powerful scientific complement to LSST, Euclid and WFIRST.
  3. present unprecedented opportunities for Canadian industry.
  4. supplant Canadarm as the highest-visibility space project ever undertaken by CSA and Canada.

- **It must proceed, without delay, to a Phase 0 study in order to:**
  1. better understand risk, cost and schedule.
  2. explore options for a possible coordinated development with Euclid and/or WFIRST.
  3. begin building an international partnership.
  4. guide community decisions in implementing LRP2010.