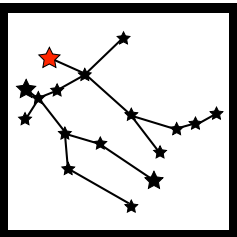
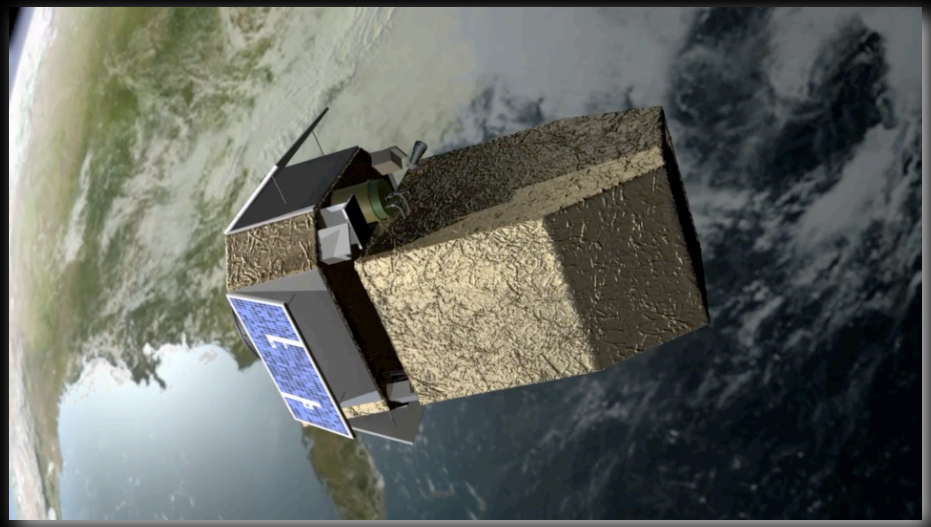


CASTOR

The Cosmological Advanced Survey Telescope for Optical and UV Research: Mission Context, Design, Capabilities and Status



Patrick Côté (NRC-HIA),

on behalf of the *Canadian Space Telescope Mission Concept Study Team*

David Aldridge (COM DEV), Michael Balogh (Waterloo), Ron Buckingham (North-East Space), Ray Carlberg (Toronto), Patrick Côté (HIA), Weiguo Chen (COM DEV), Clinton Evans (COM DEV), Laurent Drissen (Laval), Wes Fraser (HIA), Frederic Grandmont (ABB), Paul Harrison (Magellan), John Hutchings (HIA), JJ Kavelaars (HIA), Jean-Thomas Landry (ABB), Tarun Patel (Magellan), Louie Piché (COM DEV), Venka Pillay (Magellan), Andrew Rader (COMDEV), 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)

Challenges in UV Astronomy, ESO Garching, October 7-11, 2013

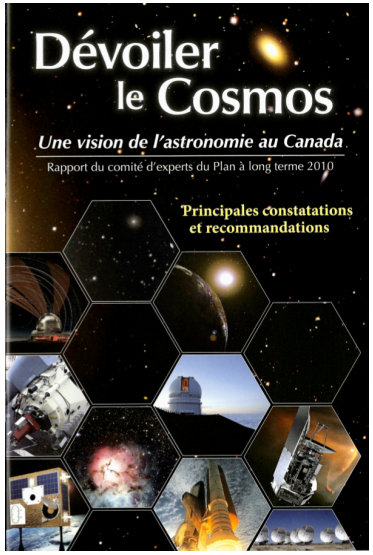
Talk Outline

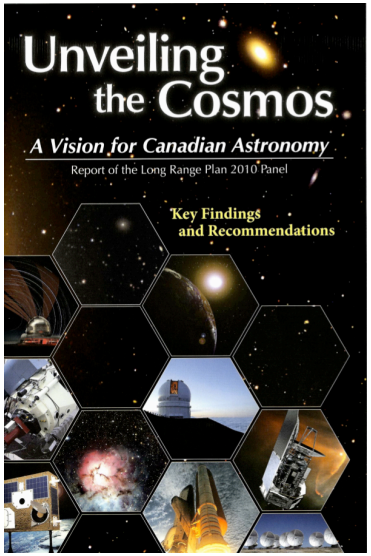
1. Background and Mission Context
2. CASTOR Overview
    - relation to other facilities: Euclid, LSST, etc.
    - alignment with Canadian plans and priorities
    - design and specifications
    - surveys and operations model
    - scientific motivation†
        - *dark energy and photometric redshifts, cosmic shear, dark matter, galaxy evolution, cosmic star formation, galaxy morphologies, strong lensing, active galactic nuclei and QSOs, Galactic structure, accretion histories, missing satellites, galactic nuclei and black holes, stellar astrophysics, the extreme outer solar system, surface chemistry of Kuiper Belt Objects, ...*
3. Development Status
4. Summary

† For full details see: **http://casca.ca/wpcontent/uploads/2013/03/CASTOR_summary.pdf**

The 2010 Long Range Plan for Canadian Astronomy

- Canadian "decadal plan" for astronomy prepared in 2010: *Long Range Plan for Canadian Astronomy*
  - The highest priority in space astronomy: *"…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."*

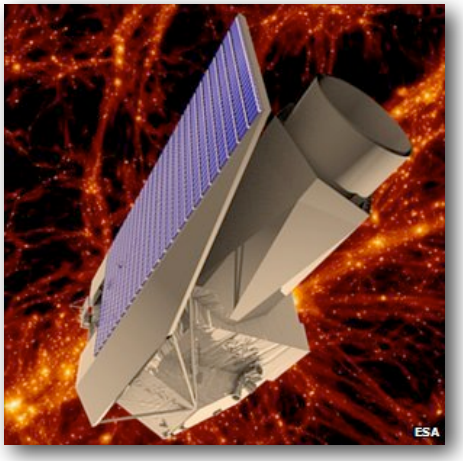




9.2 New Space-Based Facilities

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:

International Plans and Priorities

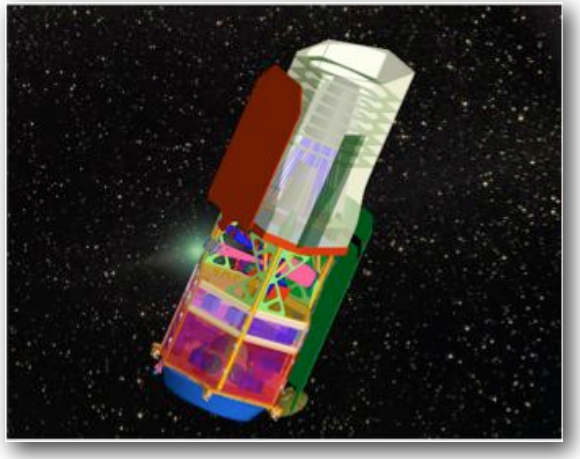


Euclid (ESA)

Lead Agency	ESA
Aperture	1.2m
Location	Earth-Sun L2 point
Launch	2020-2021?
Lifetime	6 years
Depth	24.5 AB mag
Sky Coverage	15,000 deg^2
Visible Imager	550 – 900 nm (RIZ)
IR Imager	930 – 2000 nm (YJH)
IR Spectroscopy	R ~ 250 (slitless)

LSST (USA)

Lead Agency	NSF/DoE
Aperture	6.7m (unobscured)
Location	Cerro Pacon, Chile
Start of Operations	~2021?
Lifetime	nominal 10 years
Depth	26.1 (u), 27.4 (g)
Sky Coverage	20,000+ deg^2
Visible/IR Imager	330 – 1050 nm (ugrizY)
IR Spectroscopy	None



WFIRST (NASA)

Lead Agency	NASA
Aperture	1.5m
Location	Earth-Sun L2 point
Launch	~2025:
Lifetime	5 years
Depth	25.5 AB mag
Sky Coverage	20,000 deg^2
Visible/IR Imager	400 – 2000 nm
IR Spectroscopy	R > 75 (slitless)

- The characterization of dark energy is a primary goal for each of these facilities. *No single facility is expected to solve the dark energy mystery — complementarity is essential.*

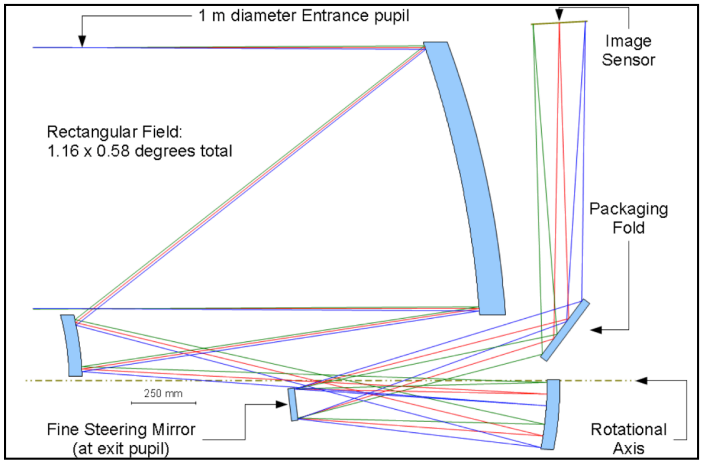
What is CASTOR?

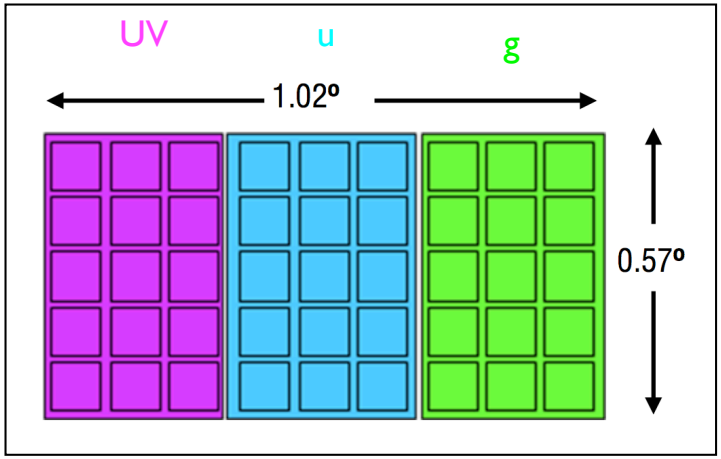
- **CASTOR**: **C**osmological **A**dvanced **S**urvey **T**elescope for **O**ptical and UV **R**esearch
  - *A nearly diffraction-limited 1m telescope (FWHM = 0.15″), focused on wide-field imaging (> 0.5 deg^2) at UV and blue-optical wavelengths (150 - 550 nm).*

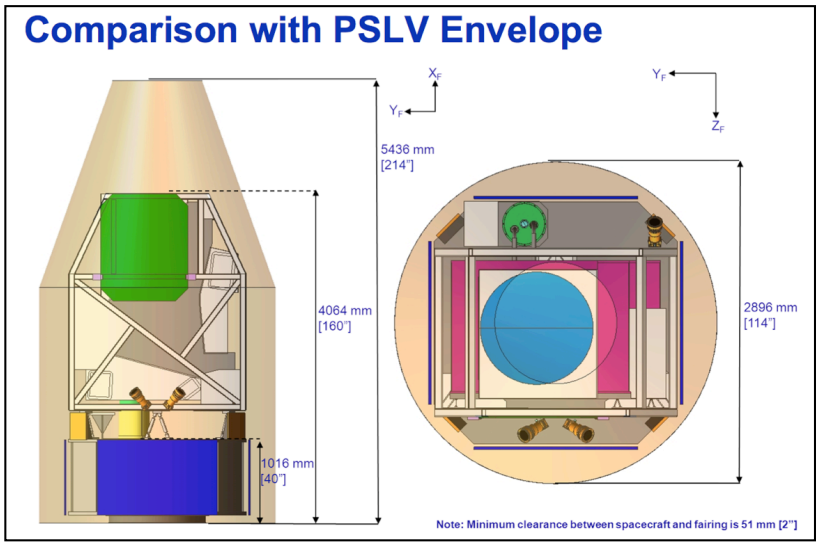
- **CASTOR** is a proposed *flagship* Canadian space astronomy mission designed to:
  - make a significant and strategic contribution to future Dark Energy missions (Euclid, WFIRST, LSST).
  - provide a natural UV/optical successor to the Hubble Space Telescope, with a 200x gain in field of view.
  - fulfill the requirements of the 2010 Long Range Plan for Canadian Astronomy.
  - take an important next step in the long-term development of the Canadian space program.

Mission Design

- 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
    - 150 - 300 nm (UV)
    - 300 - 400 nm (u)
    - 400 - 550 nm (g)
- 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 Models
  - nominal five-year lifetime
  - 4 Legacy Surveys balanced with GO (Guest Observer) programmes.

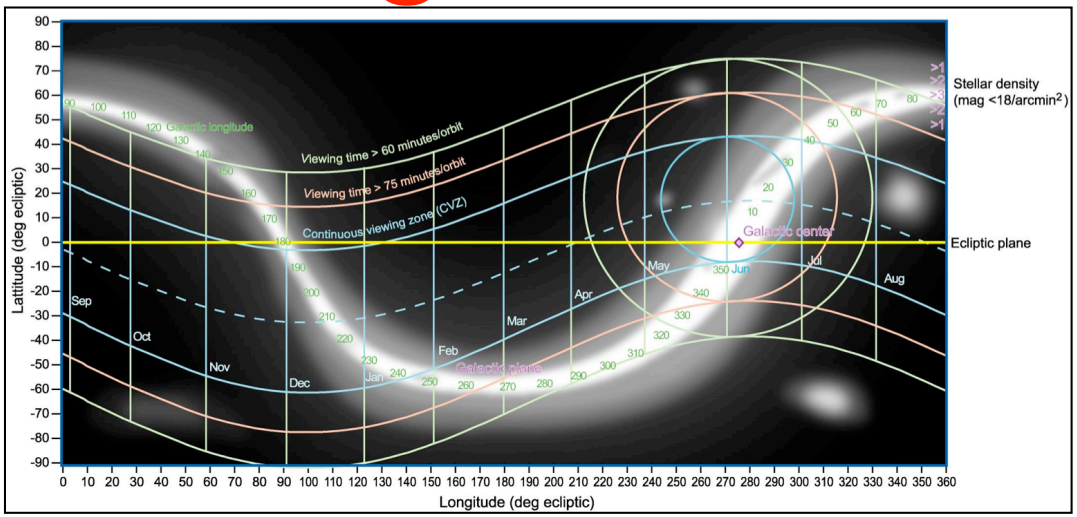






Mission Design

- 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
    - 150 - 300 nm (UV)
    - 300 - 400 nm (u)
    - 400 - 550 nm (g)
- 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 Models
  - nominal five-year lifetime
  - 4 Legacy Surveys balanced with GO (Guest Observer) programmes.



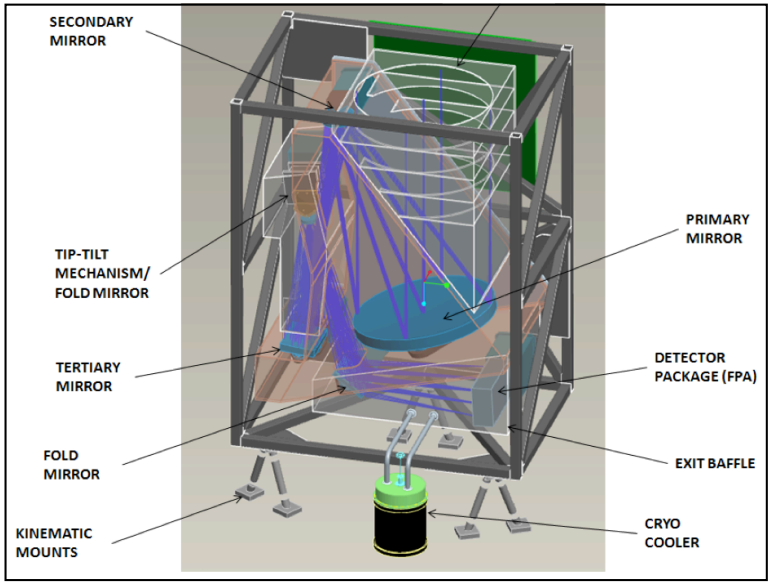
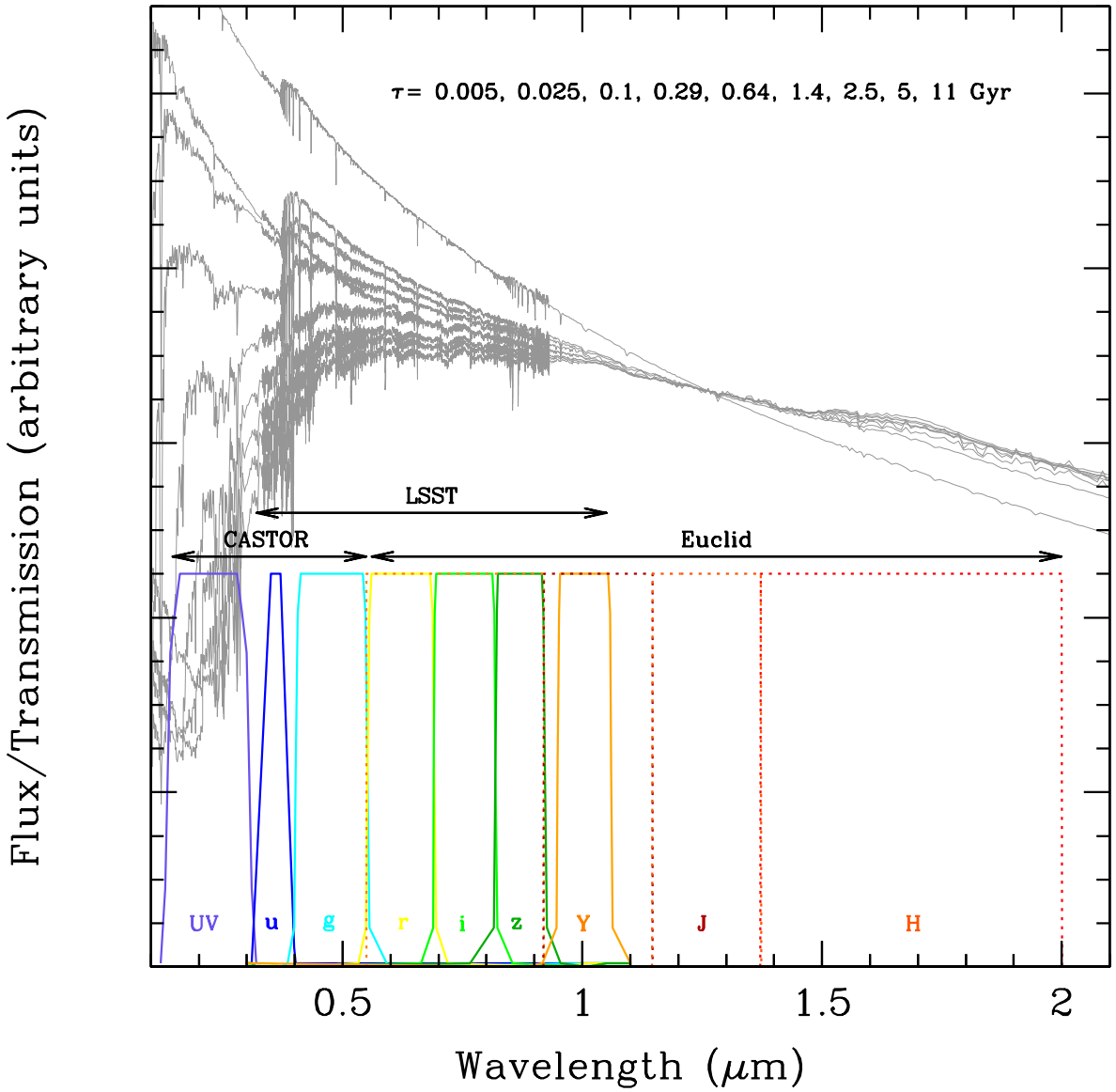


Table 3-2: CASTOR Legacy Surveys

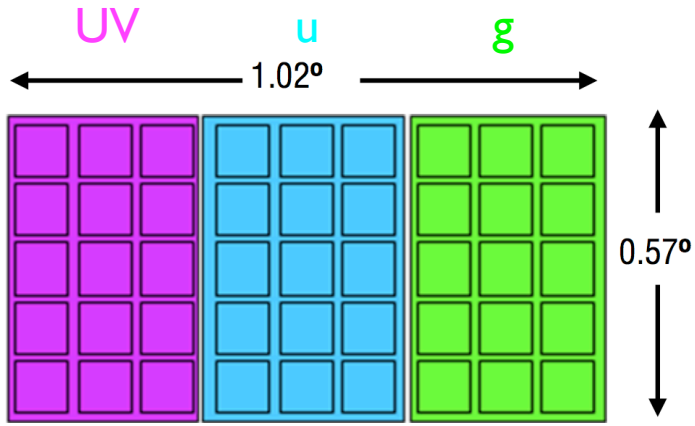
Survey	Area (deg^2)	Mode	UV_{lim} (mag)	u_{lim} (mag)	g_{lim} (mag)	T (years)
Wide	5000	contiguous	25.79	27.10	27.78	1.8
Deep	40	contiguous	29.35	29.84	29.90	0.4
Nearby Galaxies	N ≈ 125	pointed	26.82	28.00	28.44	0.15
Nearby Clusters	150	contiguous	26.82	28.00	28.44	0.15

Synergy with Euclid, LSST

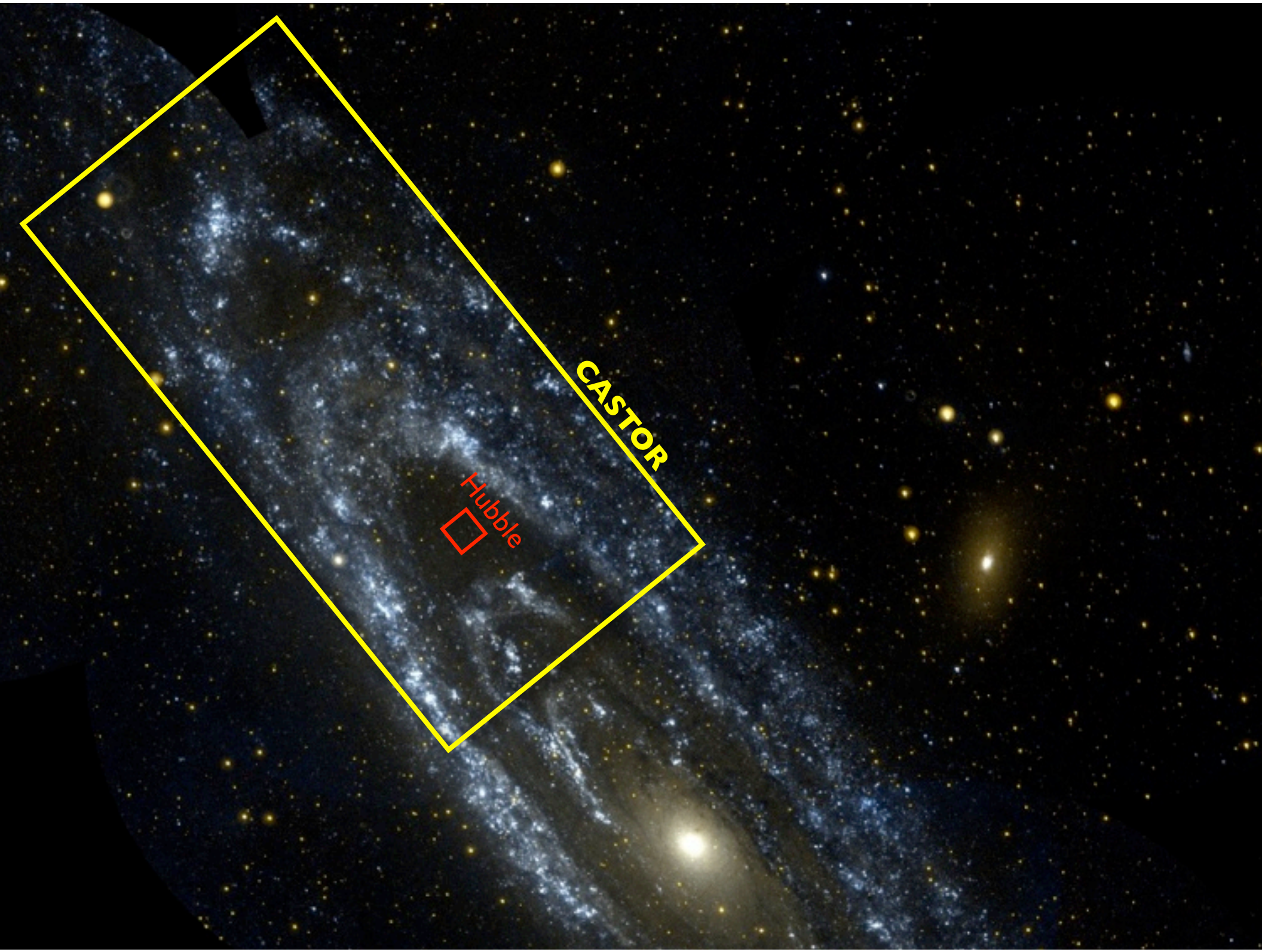


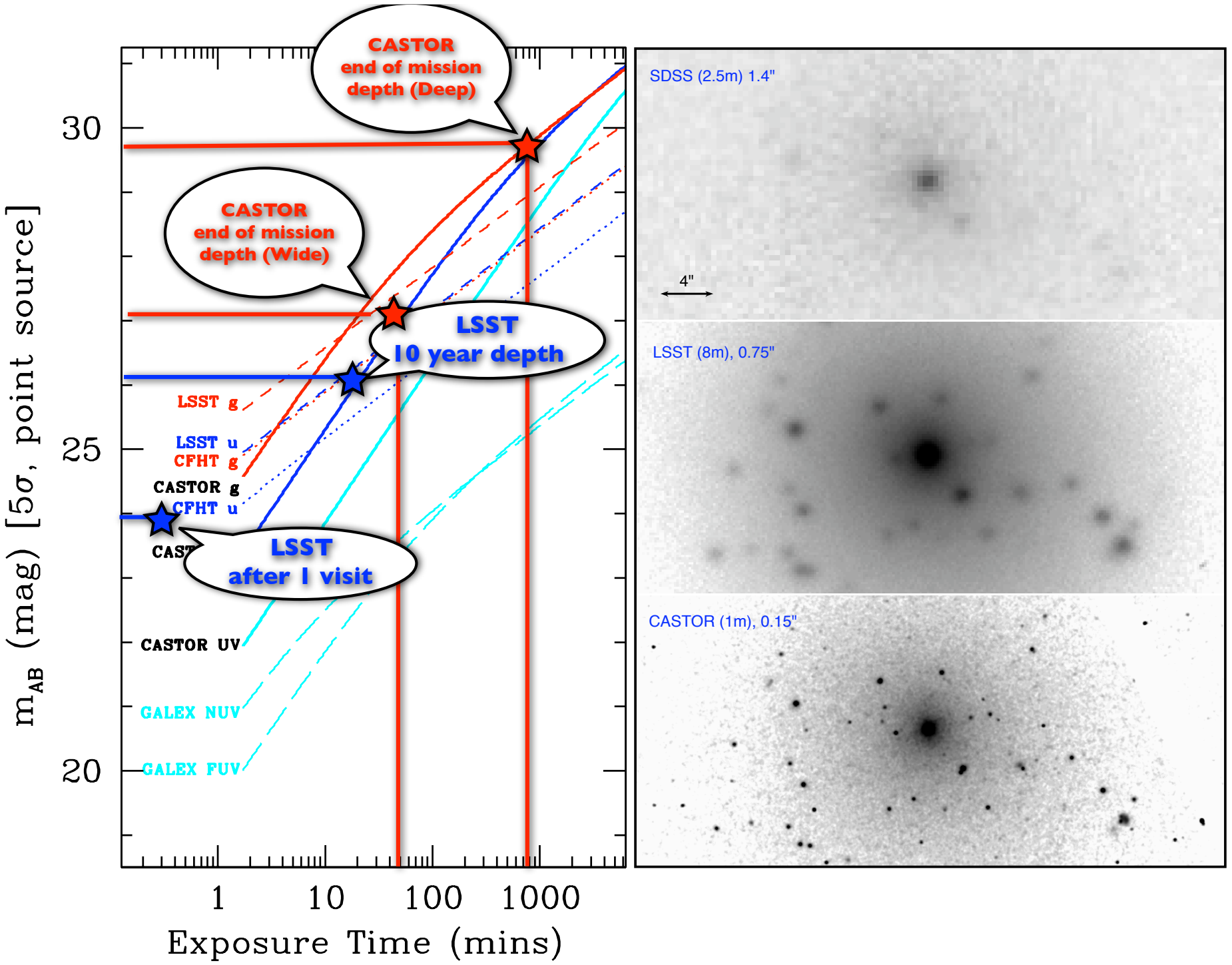
Advantages of wide-field imaging in a space environment:

1. *Image Sharpness and Atmospheric Turbulence.*
2. *Access to the Ultraviolet Region.*
3. *Photometric Calibration and PSF Stability.*
4. *Low Scattered Light.*



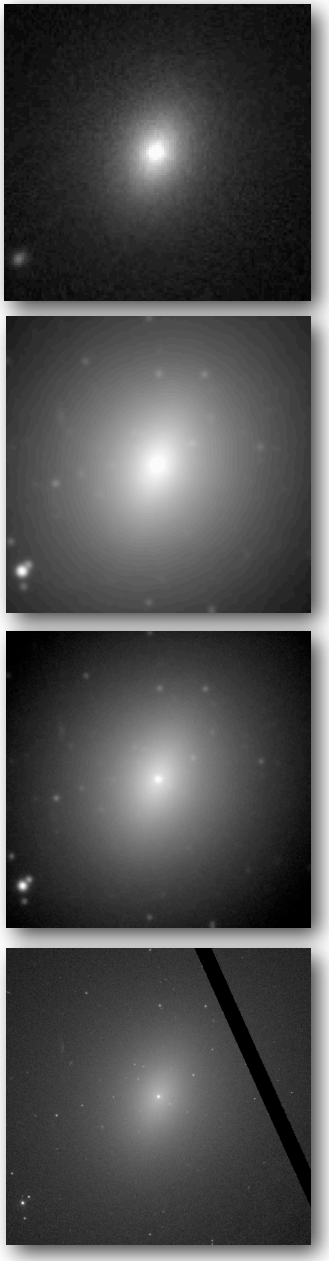
CASTOR focal plane array (45 × 4k × 4k).


CASTOR
Hubble

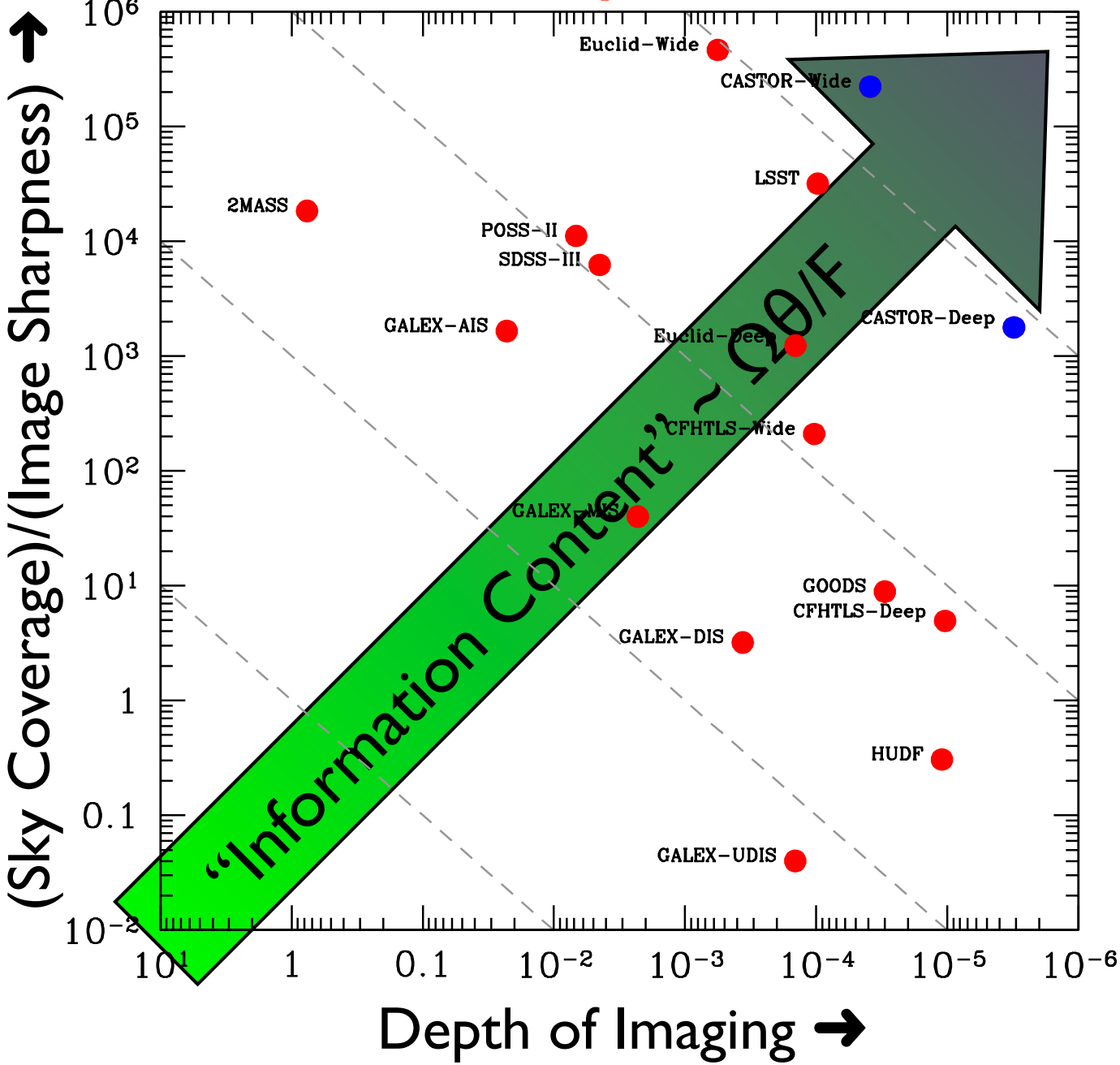

CASTOR
end of mission
depth (Deep)
CASTOR
end of mission
depth (Wide)
LSST
10 year depth
LSST
after 1 visit
LSST g
LSST u
CFHT g
CASTOR g
CFHT u
CASTOR UV
GALEX NUV
GALEX FUV
30
25
20
1
10
100
1000
Exposure Time (mins)
m_AB (mag) [5σ, point source]
SDSS (2.5m) 1.4"
4"
LSST (8m), 0.75"
CASTOR (1m), 0.15"

Discovery Potential

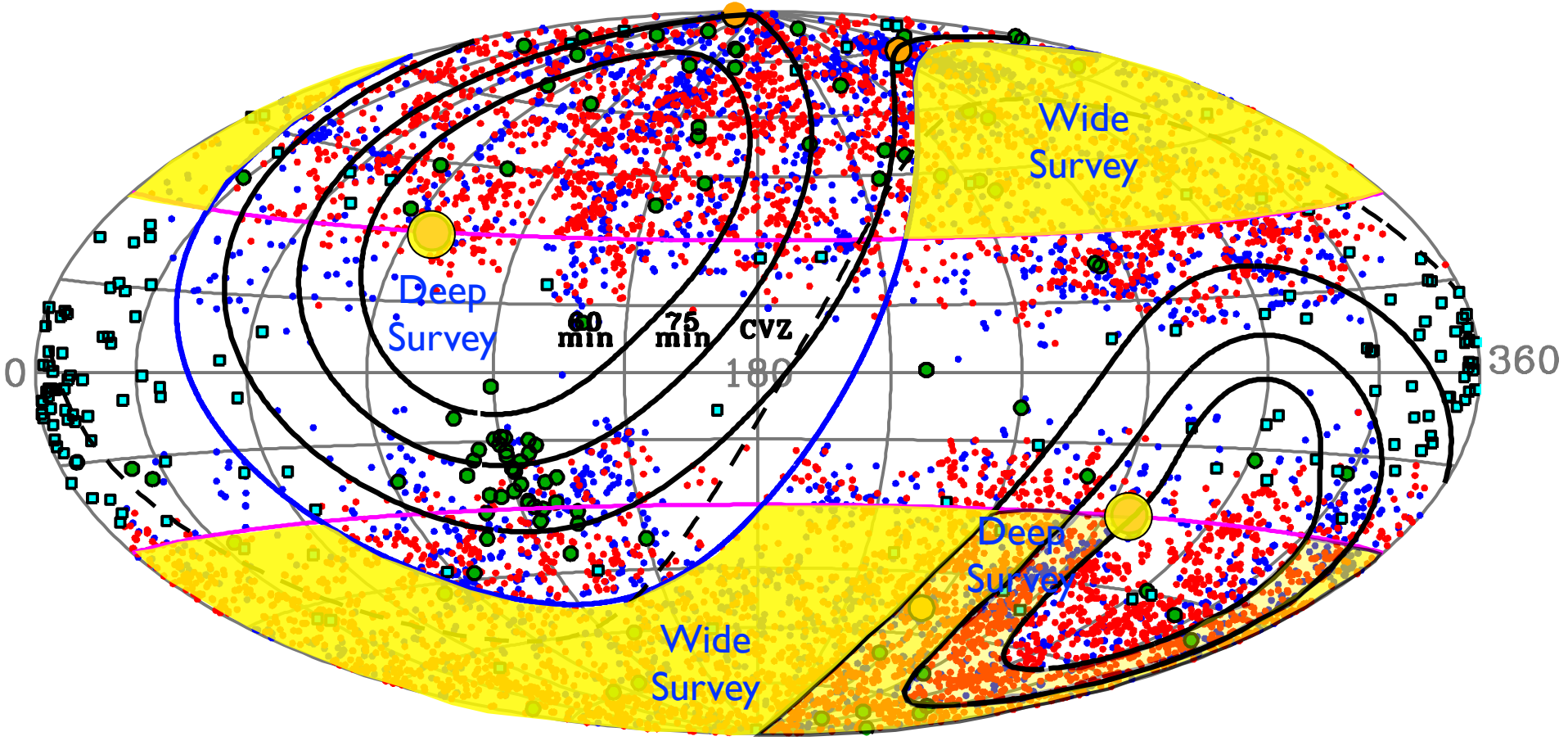
Resolution



Depth



CASTOR Legacy Surveys



CVZ, 75min, 60min viewing zones

Ecliptic Plane

Euclid Wide Survey Limits ($|b| > 30°$)

Euclid Deep Fields

LSST Survey Limit ($\delta < +10°$)

Nearby Galaxies (D < 3 Mpc)

RC3 Galaxies

Abell Clusters

Milky Way Globular Clusters

Virgo, Fornax, Coma

CASTOR Science

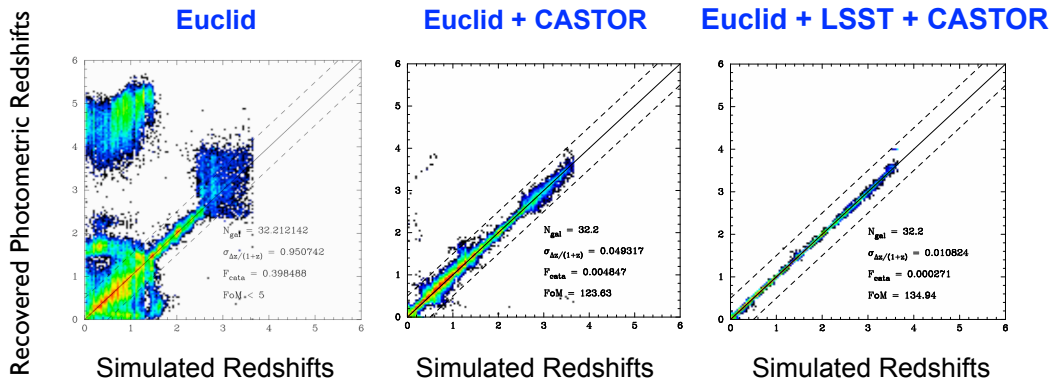
- Dark Energy and Cosmology
- Galaxy Evolution
- Near-Field Cosmology
- Stellar Astrophysics
- The Outer Solar System

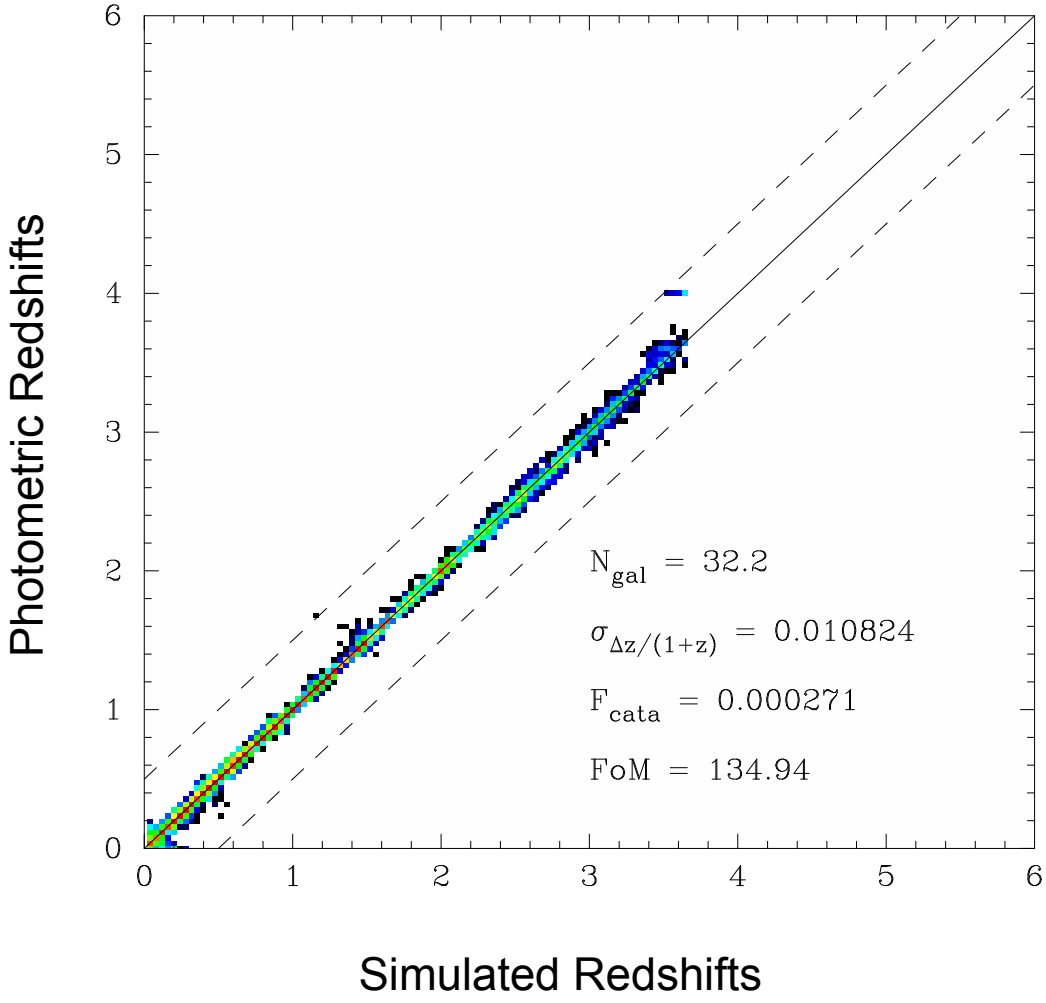
- What is dark energy? How does it evolve with redshift?
- What is the structure of dark matter halos?
- When did star formation begin in the oldest galaxies?
- How did cosmic structures form and evolve as the universe expanded?
- How did the subcomponents of galaxies arise, and when?
- How did supermassive black holes form and grow?
- What is the "mass function" of galaxies? How many faint galaxies are there?
- How important were mergers and accretions in the formation of the Milky Way and nearby galaxies?
- Where are the oldest and most metal-poor stars in the Galaxy?
- How common are central stellar nuclei in galaxies? Is there a connection to supermassive black holes?
- Do "intermediate-mass" black holes exist?
- Where are the smallest galaxies in the local universe? How did they form?
- What is the three-dimensional structure of the local universe?
- How many objects, including dwarf planets, exist in the extreme outer solar system? What is their distribution of sizes and masses?
- What is the surface chemistry of these small bodies? Is there evidence for organic ices? Has their chemistry changed with time?

An Example: Cosmology and Dark Energy

- Euclid aims to provide a definitive measurement of the geometry of the universe through weak lensing and baryon accoustic oscillations.
- For weak lensing, Euclid will perform shape measurements in a single, broad, red-optical filter.
- Galaxy shapes will then be combined with distances to measure the dark energy "equation of state" ($w = P/\rho$).
- Distances are derived using *photometric redshifts*, in which broadband photometry is used to measure each galaxy's spectral energy distribution and distance (i.e., redshift).
- But Euclid does not cover the UV or blue-optical region, so its IR photometry must be combined with optical data (from, e.g., LSST) in order to measure accurate distances.
- Simulations confirm that CASTOR − which has been optimized to provide short-wavelength imaging that is deeper and better calibrated than LSST − gives improved photometric redshifts and dark energy constraints.

- *Combining data from Euclid, LSST and CASTOR would allow the definitive characterization of dark energy and its evolution with redshift.*





Mission Development Status

- The **CASTOR** concept was identified as a top priority in Canada's 2010 Long Range Plan for Astronomy and it continues to receive strong support from the Canadian community (i.e., 2012 and 2013 reports from the Joint Committee on Space Astronomy).

  - **May 2013**: CSA Request for Proposal, *Focal Plane Detector Array (FPA) Technologies with Enhanced UV Response for Space Astronomy Applications* (issued under the Space Technology Development Program)

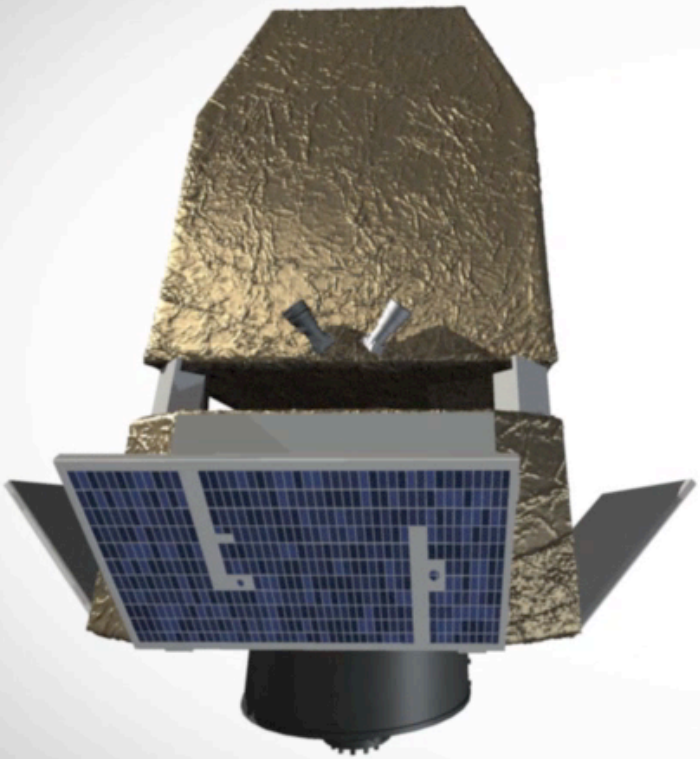
    - *scope of work: compare, procure and fully characterize state-of-the-art, large-format high-resolution focal plane arrays with high-efficiency UV photon detection. Perform a technical readiness and risk assessment of key technologies, and prepare a technology development plan.*
    - *2-year contract issued to COM DEV, with participation of the CASTOR science team, in September 2013.*

  - **August 2013**: CSA Request for Proposal, *Single Photon Counting Large-Format Detectors with Enhanced UV Response for Space Astronomy Applications* (issued under the Generic Technologies Program)

    - *scope of work: develop a plan to support future Canadian astronomical, atmospheric science and earth-observation missions operating in the UV and visible spectral regions*
    - *proposals under review.*

- Mission development plan calls for CASTOR to proceed to a Phase 0 study in the second quarter of 2014.
  - *international participation in this Phase 0 study (both scientific and technical) is welcomed.*
  - opportunities for technical contributions might include:
    - launch vehicle.
    - ground station support.
    - optics, electronics, detectors.


CASTOR
COSMOLOGICAL ADVANCED SURVEY TELESCOPE FOR OPTICAL AND ULTRAVIOLET RESEARCH



Summary

- **CASTOR**: **C**osmological **A**dvanced **S**urvey **T**elescope for **O**ptical and UV **R**esearch
  - *A nearly diffraction-limited, 1m telescope (FWHM = 0.15″), focused on wide-field imaging (> 0.5 deg^2) at UV and blue-optical wavelengths (150 - 550 nm).*

- **CASTOR** is a potential CSA-led space astronomy mission that would:
  - make a significant and strategic contribution to future Dark Energy missions (Euclid, WFIRST, LSST).
  - provide a natural UV/optical successor to the Hubble Space Telescope, with a 200x gain in field of view, and continued access to the UV region.

  - international collaborators/partners would be welcome.