EXPLORER Concept Overview
ORION

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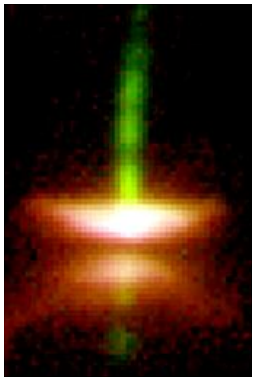
Observatory Summary

Property	Value
Aperture	1.1m, diffraction limited @ 500nm = 0.114” PSF FWHM
Wavelength Range	UV/optical: 200-1100nm
Instrument	Widefield Imager, 20’×20’, twin-channel using dichroic
Focal Planes	Twin 3×3 arrays using LBNL (*SNAP*) 3.5k w/ 10.5μm pixels (0.114” each – ½ Nyquist sampled @ 500nm) – total of 18 flight detectors
Frame Size	111 Mpixels × 2 channels × 16-bit = 444 MB
Data Volume	Worst case: 96 GB per 24 hr period
Field of View	20’×20’ = 35× areal coverage of *HST-ACS/WFC* and 55× areal coverage of *HST-WFC3/UVIS*
Optical Design	3-mirror anastigmat, yields a flat focal plane with ~2% distortion across the entire field and a Strehl ratio of >90% at all locations and wavelengths
Broadband Filters	F218M, F250W, F336W, F438W, F550M, F625W, F775W, F850W, F098M, F105M
Narrowband Filters	Mg II, [O II], He II, Hβ, [O III], [O I], Hα, [N II], [S II], [S III]
Core Mission Lifetime	2 years

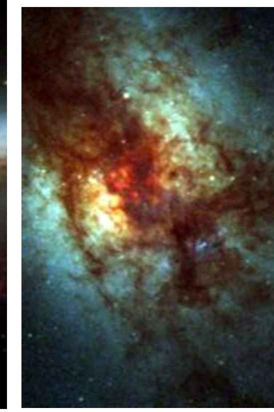
Imaging Survey of Galactic Star Formation

- The primary science goal of *Orion* is to build the first UV/optical widefield, high resolution database of star formation and its products within nearby massive stellar environments to determine how often stars and solar systems form and survive
  - survey imaging of all massive star forming regions within 2.5 kpc of the Earth to locate and characterize all protostellar and protoplanetary systems using a suite of diagnostic filters
  - locate and catalogue YSOs, Disks, Outflows, Nebulae, the Massive Stars themselves
  - on larger scales use data to better understand processes such as recycling of matter from the ISM to stars and back again, the formation and energization of superbubbles and gain insight into the nature of the Galactic Ecology
- We will temporally monitor protostars to understand the range of formation and evolutionary modes that the process of star formation allows – to use the statistical significance of the sample to explore the full apparent phase space of star formation as the fundamental process that governs the assembly of baryonic matter into stars and planets
- We will leverage data from both *Spitzer* and *GALEX* to understand the physical nature of both the protostars at the heart of each object and the circumstellar environment in which the planets are forming

Scale: Most stars form in more distant massive SF regions





Taurus –	Orion –	Carina –	30 Dor –	M82 –	Arp220
~100 pc	460 pc	2.3 kpc	50 kpc	3.3 Mpc	77 Mpc

 # O-type stars:

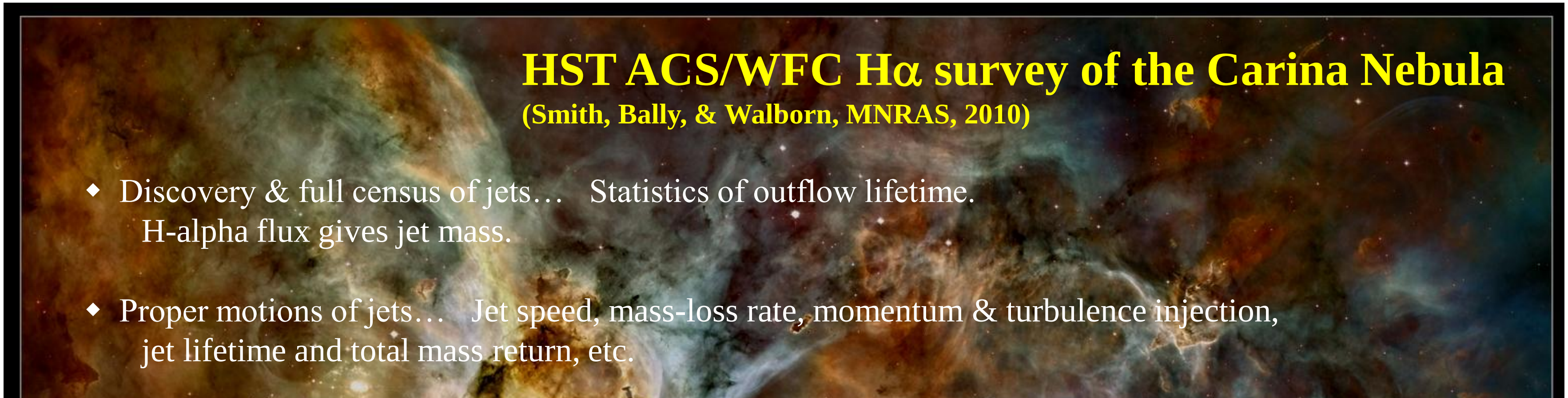
Taurus	Orion	Carina	30 Dor	M82	Arp220
0	**1**	**70**	**more**	**more**	**more**

can study low-mass stars (from space) ←

→ extreme environments with most massive stars

sweet spot: massive SF regions in the MW & MCs

Protostellar outflows and protoplanetary disks



HST ACS/WFC Hα survey of the Carina Nebula

(Smith, Bally, & Walborn, MNRAS, 2010)

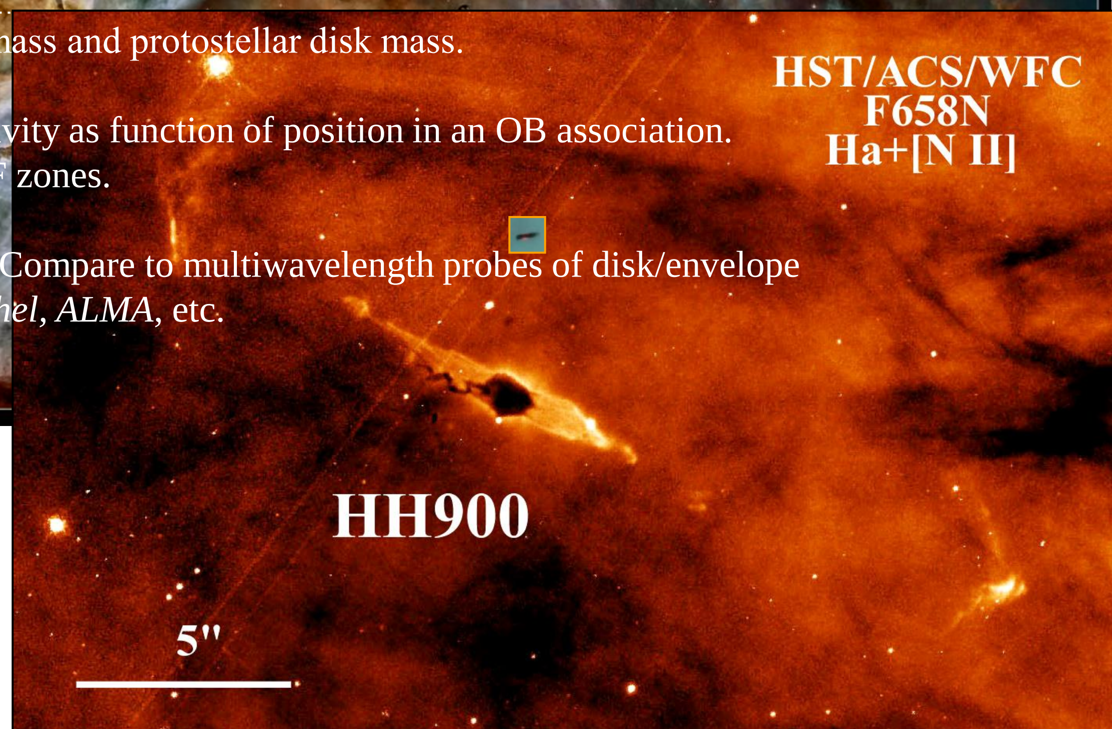
- Discovery & full census of jets… Statistics of outflow lifetime.
  H-alpha flux gives jet mass.

- Proper motions of jets… Jet speed, mass-loss rate, momentum & turbulence injection,
  jet lifetime and total mass return, etc.

  …statistics as function of YSO mass and protostellar disk mass.

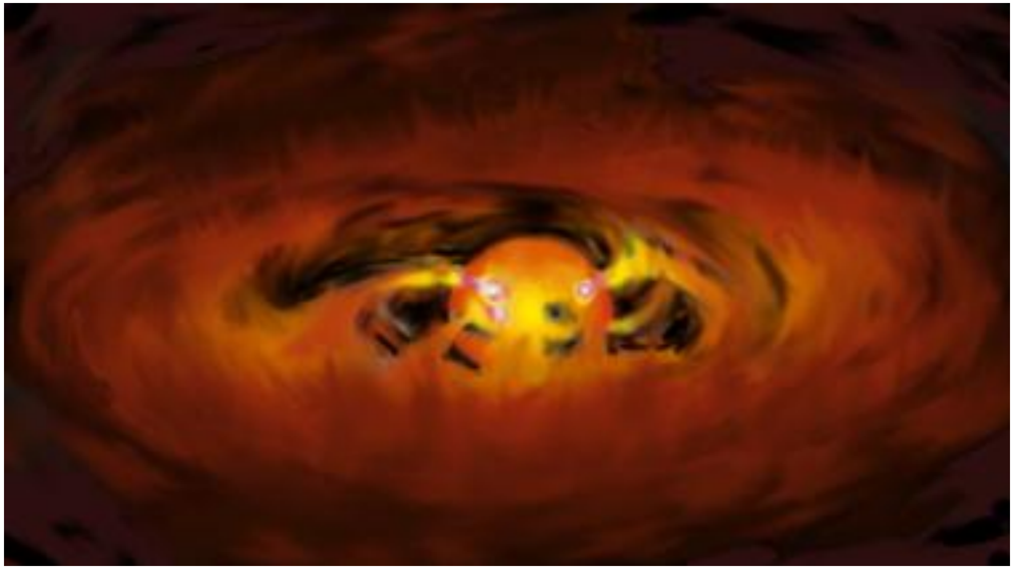
- Outflows serve as probe of SF activity as function of position in an OB association.
  Trace youngest & most active SF zones.

- Physical diagnostic of accretion. Compare to multiwavelength probes of disk/envelope accretion: synergy w/ *Spitzer, Herschel, ALMA*, etc.



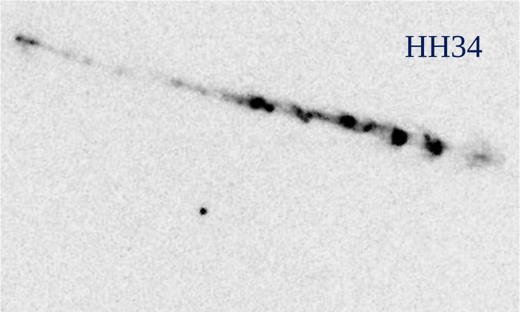
Synoptic Study of Massive Star Forming Regions

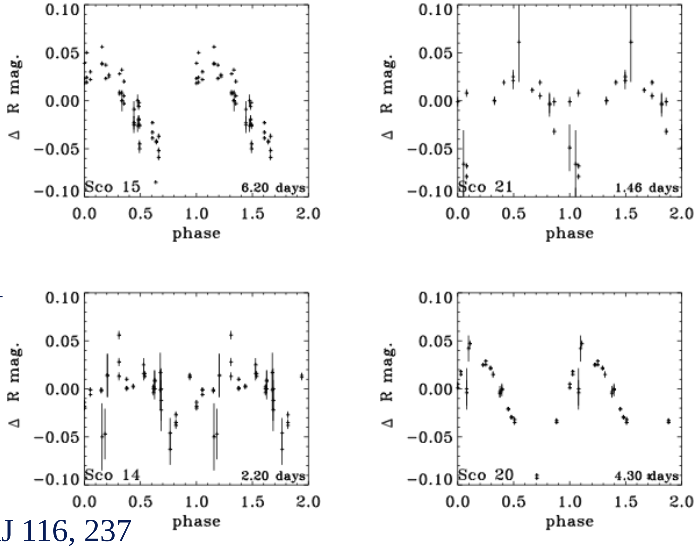
1. Observe how the following vary with age *and* stellar mass for statistically significant samples of young stars with and without disks located in different star forming regions:
   a) Circumstellar disk lifetimes
   b) Starspot activity
   c) Rotation periods
   d) Mass accretion rates (*)
   e) Mass outflow rates in jets (*)
   f) Collimation properties and velocities of jets(*)
   g) Binary frequency and mass ratios of wide systems



Synoptic Study of Massive Star Forming Regions

2. Determine Initial Mass Functions for entire star forming regions and subregions, and understand the degree to which the most massive stars influence the IMF in their vicinity
3. Quantify how clustering and subclustering develop and evolve
4. Learn how star formation proceeds through a giant molecular cloud by measuring ages and masses of all the young stars (including wTTs) over entire regions of star formation, and thereby test whether or not massive stars trigger other stars to form.
5. Find out whether or not accretion events are always followed by ejection of material in a jet
6. Explore the time domain by observing transient events and by documenting long term secular variability of young stars
7. Learn about the dynamics in stellar jets by making movies that highlight differential motions within the shocked gas (*)
8. Determine ionization fractions, electron densities, and temperatures within jets (*)
9. Observe the small-scale spatial structure of photoionized regions of star formation to learn how radiation from massive stars disrupts the nearby molecular clouds (*)

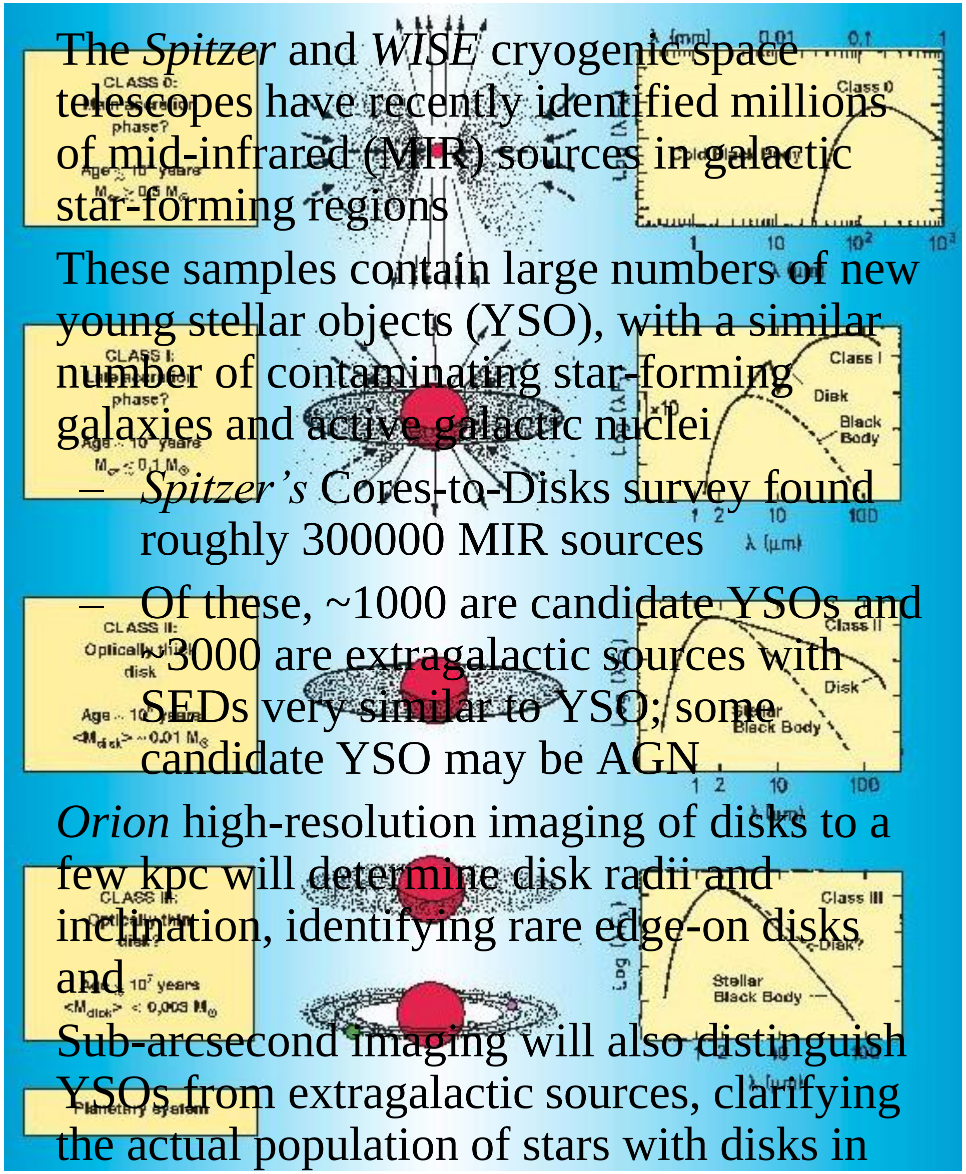




R-Magnitude Lightcurves: Adams, Walters, and Wolk 1998, AJ 116, 237

Young Disk Evolution

- The all-sky *IRAS* survey detected the faint glow of cool, circumstellar dust around 50% of nearby young stars (> 1 $L_\odot$)
- *IRAS* data allowed astronomers to classify young stellar objects according to infrared spectral energy distribution
- High resolution *Hubble* images were required to confirm that the dust was confined to planet-forming disks



- The *Spitzer* and *WISE* cryogenic space telescopes have recently identified millions of mid-infrared (MIR) sources in galactic star-forming regions
- These samples contain large numbers of new young stellar objects (YSO), with a similar number of contaminating star-forming galaxies and active galactic nuclei
  - *Spitzer's* Cores-to-Disks survey found roughly 300000 MIR sources
  - Of these, ~1000 are candidate YSOs and ~3000 are extragalactic sources with SEDs very similar to YSO; some candidate YSO may be AGN
- *Orion* high-resolution imaging of disks to a few kpc will determine disk radii and inclination, identifying rare edge-on disks and
- Sub-arcsecond imaging will also distinguish YSOs from extragalactic sources, clarifying the actual population of stars with disks in each cloud

Orion and the Magellanic Clouds

Science Questions:

- Clustering of stellar populations and relation to their ages, to address hierarchy and propagation of star formation;
- Stellar IMF: variations versus stochastic sampling and models of massive star formation;
- Diffuse ionized medium: photo- versus shock-ionized and the source(s) of ionization; energy budget of WIM.

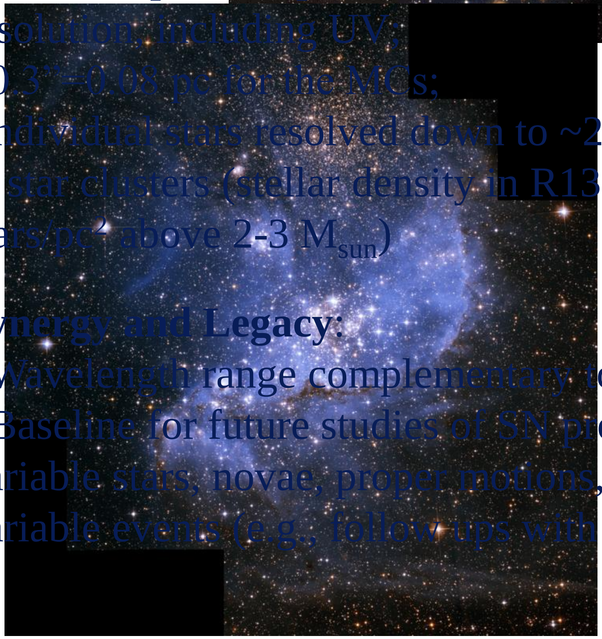
Intended Survey:

- Complete mapping in UV/B/R/I : complete census of stellar colors (ages), stellar luminosities (masses), distribution;
- Complete mapping (10 deg contiguous for LMC) in Hα, [OII], [OIII],[SII]: distribution of ionized gas, ionization conditions;
- Depth: S/N=100 down to V=21 mag (1.7 M_{sun} star)

LMC: *HST* image of LH95

Unique features:

- First complete map of MCs at 0.3'' uniform resolution, including UV;
- 0.3''=0.08 pc for the MCs;
- Individual stars resolved down to ~2-3 M_{sun} even in star clusters (stellar density in R136 ~ 50 stars/pc^2 above 2-3 M_{sun})



SMC: *HST* image of NGC346

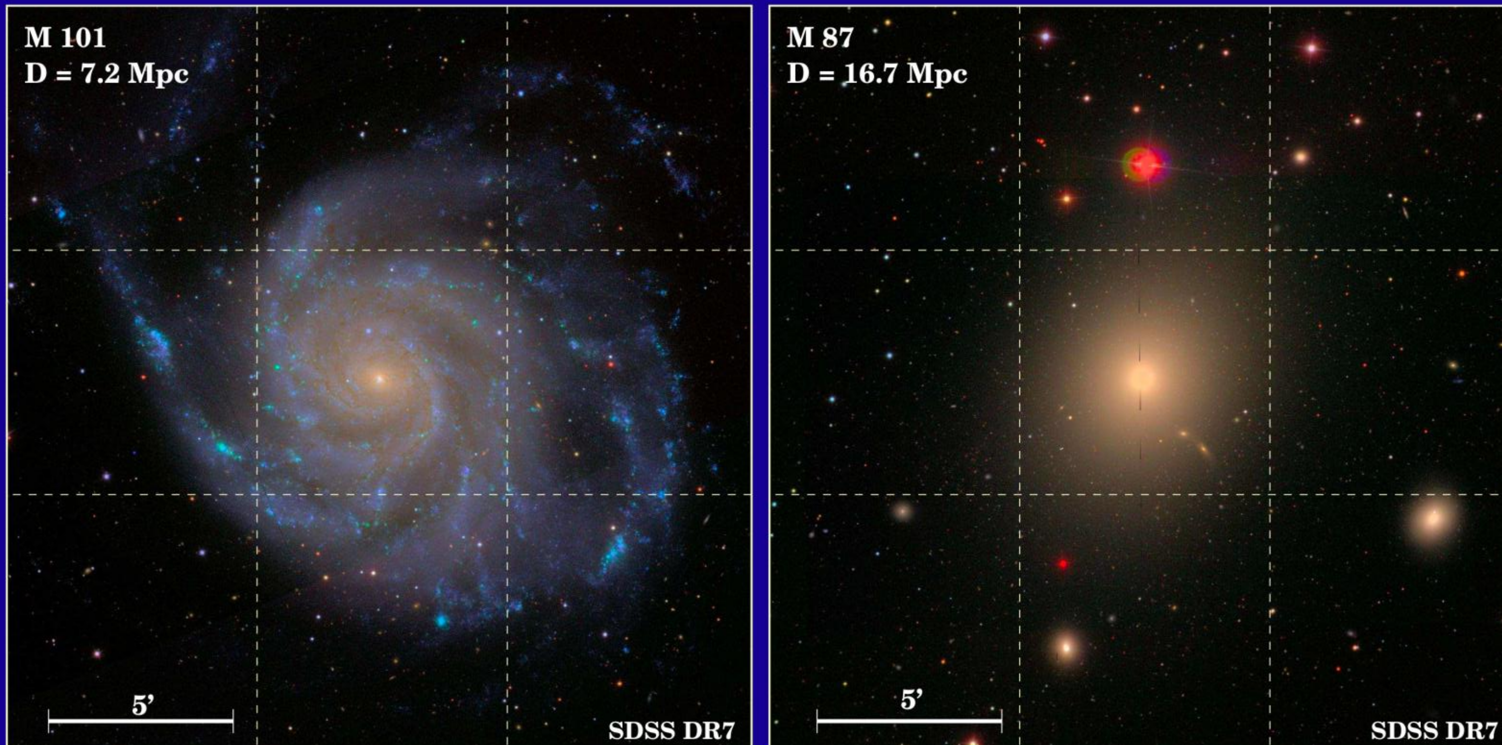
Synergy and Legacy:

- Wavelength range complementary to *JWST*;
- Baseline for future studies of SN progenitors, variable stars, novae, proper motions, and time variable events (e.g., follow ups with *LSST*)

Extragalactic Science with ORION

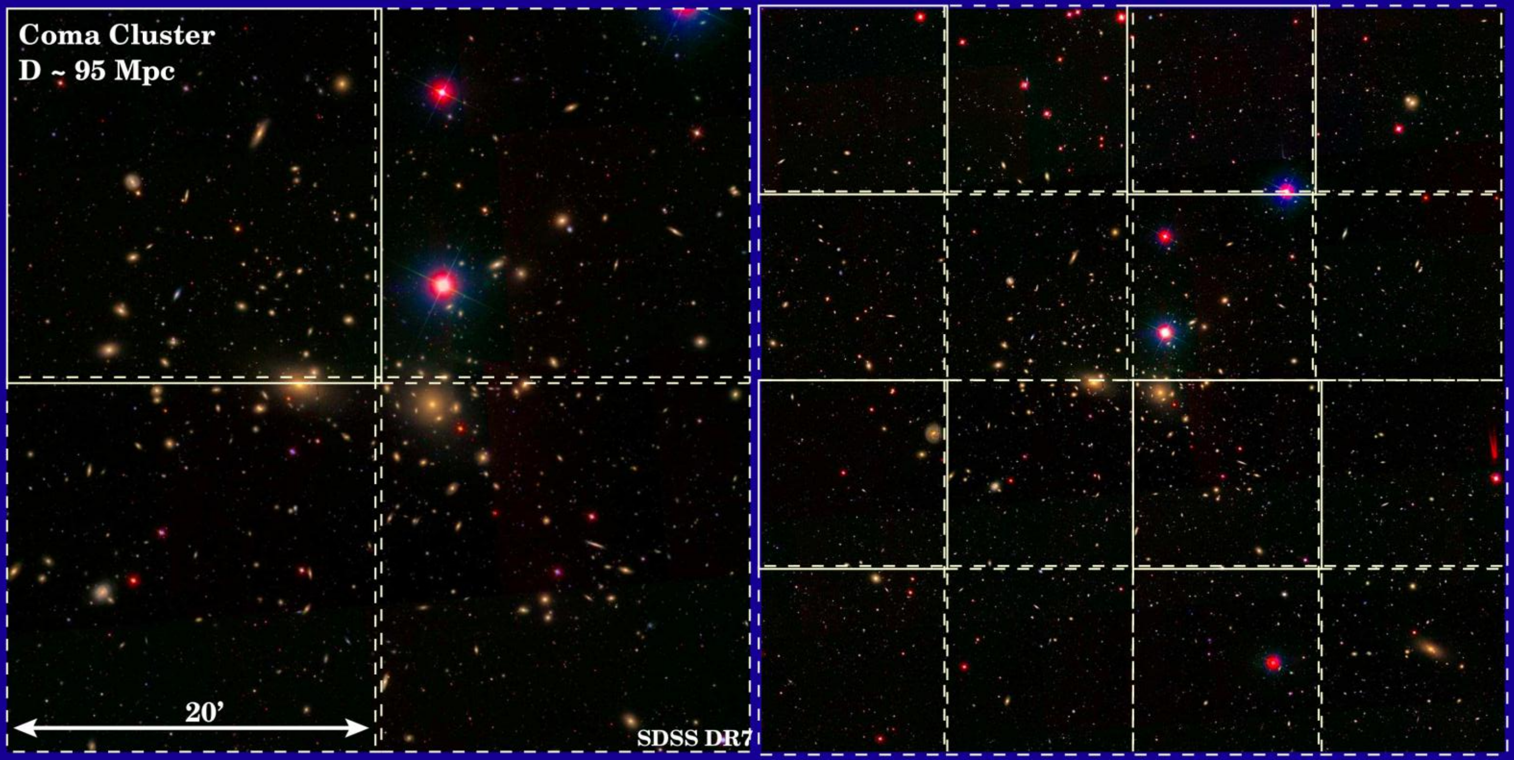
- near-field cosmology or galactic archeology:
  - *Orion* field is well matched to sizes of nearby galaxies
  - 8-filter, panchromatic (190-1050nm) pixel-photometry of nearby galaxies
  - pixel-based 2-D reconstruction of pixel-averaged star formation histories
  - self-consistent solution without prior assumptions on extinction curve, metallicity
  - external constraints at lower resolution in hand: far-UV (*GALEX* at ~5.5" fwhm) and mid-IR 3.6,4.5 micron (*Spitzer*/*IRAC* at ~1.8" fhwm)
- a 0.114" *ORION* pixel spans 5.5 pc at 10 Mpc distance, comparable to the sizes of star-forming regions
  - matched redshifted H-alpha and continuum narrow-bands allow high-quality mapping of H recombination emission out to ~90 Mpc
  - redshifted [O II] and H-beta narrow-band images provide matched information on gas-phase metallicity and HII-region extinction.
  - resolution is well matched to sizes of massive star clusters, which are the birth sites of **<u>most</u>** stars; age-dependence of mass-function probes cluster destruction mechanisms
- evolution of clusters of galaxies
  - clusters are most massive bound entities in universe
  - *Orion* field is well matched to sizes of intermediate-redshift clusters
  - simultaneous panchromatic photometry of hundreds of cluster members probes dramatic evolution of populations and morphologies through interactions
  - trace preprocessing of galaxies in Group environments before entering the Cluster environment proper
- high-quality photometric redshift estimates possible for wide-field cosmological survey of the bright end of the galaxy luminosity function
  - excellent rejection of low-z interlopers via mid-near-UV filters
  - excellent rejection (or detection if so inclined) of brown dwarfs
  - properly defined wide z-band (F870X) and F990M filter ➔ reliable photometric redshift estimates to z~6.9

Extragalactic Science with ORION



* Integral coverage of nearby galaxies in a single 20'x20' shot
* Simultaneous observations in a UV–blue and a visible/near–IR filter
* Stable PSF and 0.114" resolution (FWHM) for all wavelengths <= 500 nm (not attainable from the ground; ~10x better than SDSS in optical; ~50x better than GALEX NUV)
* Instantaneous FoV of ORION is ~35x larger than HST/ACS WFC; ~55x larger than HST/WFC3 UVIS

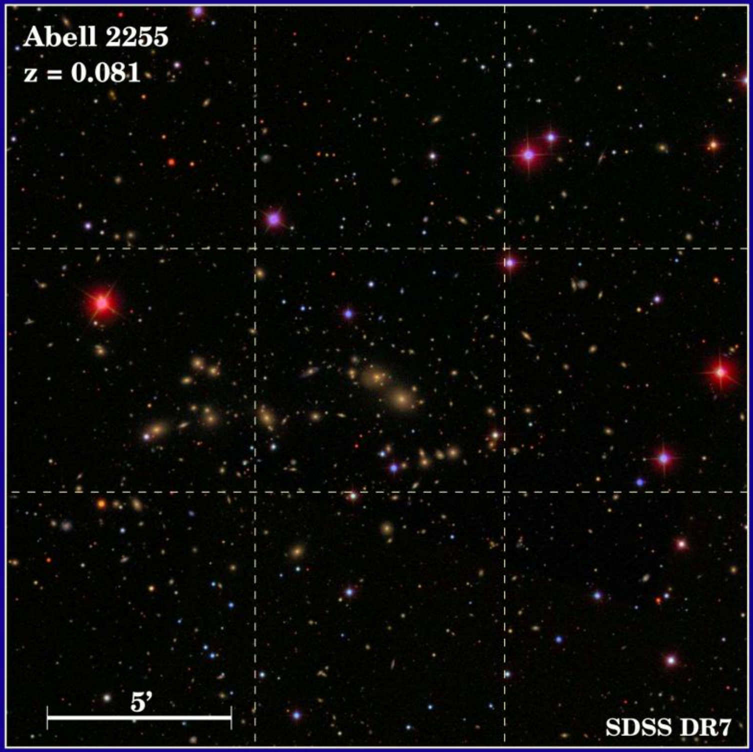
Extragalactic Science with ORION

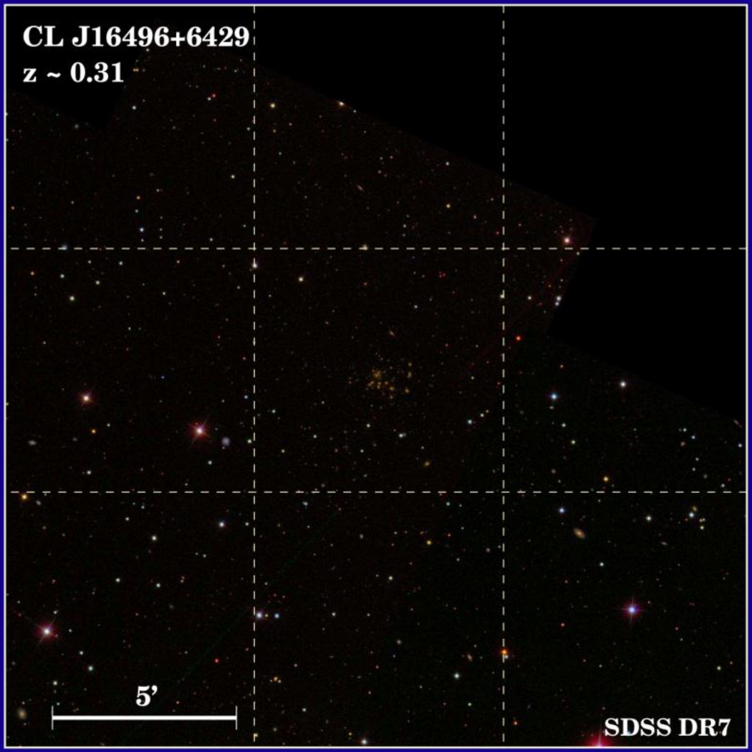


* Integral coverage of nearby cluster cores in 2x2 mosaic; entire clusters in 4x4 mosaic (example: Coma Cluster at ~95 Mpc distance)

* Rich filter complement, including redshifted narrow–bands that capture H–alpha, H–beta, and [O II] out to the Coma Cluster

Extragalactic Science with ORION





* Integral coverage of intermediate redshift clusters in a single 20'x20' shot
* Simultaneous observations in a UV–blue and a visible/near–IR filter
* Stable PSF and 0.114" resolution (FWHM) for all wavelengths <= 500 nm (not attainable from the ground; ~10x better than SDSS in optical; ~50x better than GALEX NUV)
* Instantaneous FoV of ORION is ~35x larger than HST/ACS WFC; ~55x larger than HST/WFC3 UVIS

Science Objectives

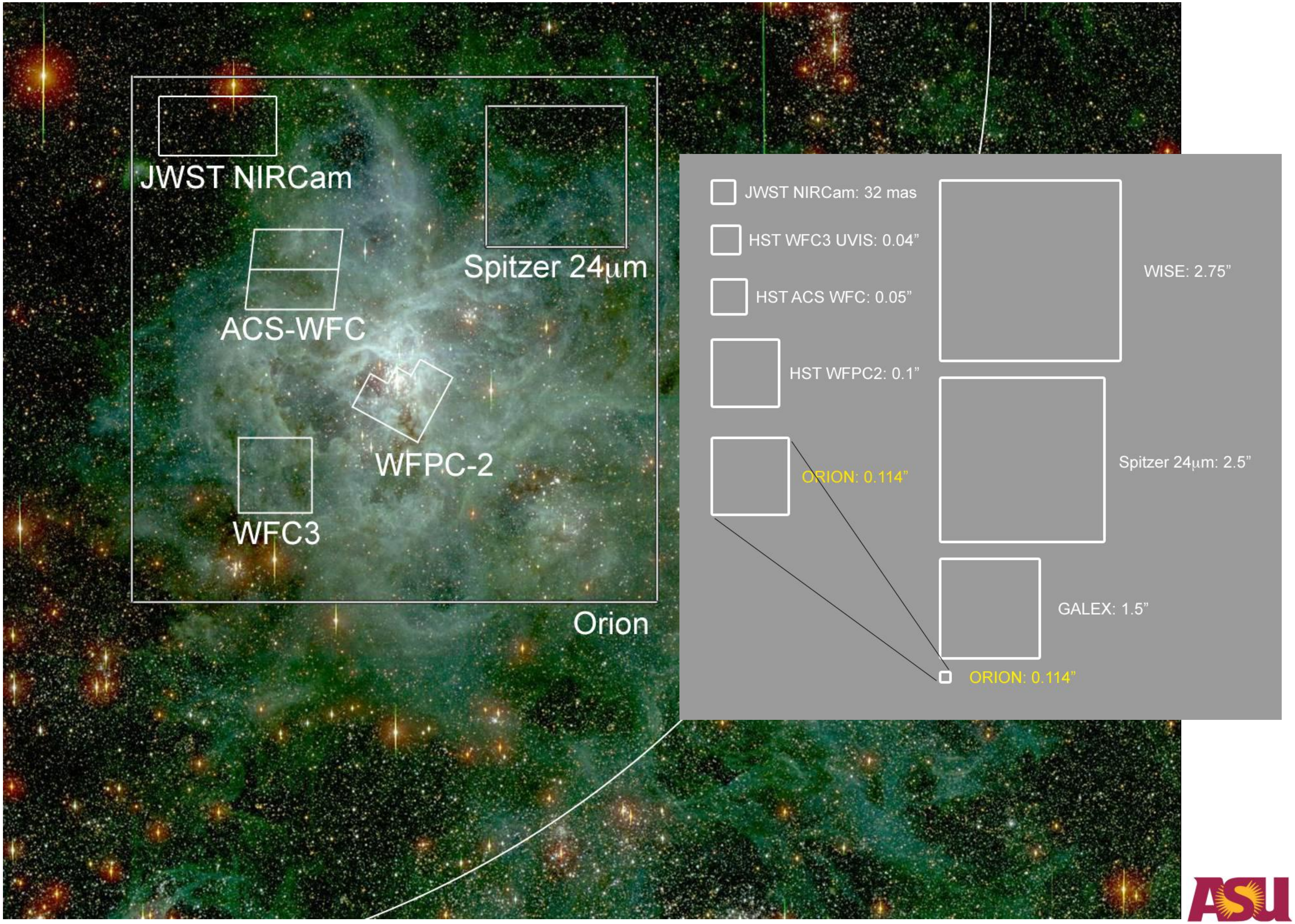
- To build the first UV/optical widefield, high resolution database of star formation and its products within nearby massive stellar environments to determine how often stars and solar systems form and survive
- *Orion* observations will directly address science goals of the NASA Space Science Enterprise, including:
  - Origins:
    - Investigate the origins of galaxies, stars, and planets.
    - Understand how stars and planetary systems form and evolve.
  - SEU:
    - Trace the life cycles of matter.
- The database *Orion* will produce will provide the necessary and complementary results to address the range of star formation modes, the spread of masses, accretion rates and frequency of formation of both stars and planetary systems to augment data from *Spitzer*, *Kepler* and *JWST (*when launched). It will test whole suites of theories ranging from accretion modes in protostellar disks, to proving the existence of star formation triggering, to establishing whether there truly are variations in the IMF that the star formation process produces. The range of topics that will directly benefit from the data *Orion* will produce is too many to list here – the output from *Orion* will be truly transformational and advance many different facets of the study and understanding of star formation as a global process.
- We have already developed an online ETC for *Orion* and expect to reach S/N of 100 in stellar sources down to a V=25, and surface brightnesses of 10^{-16} ergs/cm^2/s/arcsec^2 for extended gaseous emission, in sets of 600 second exposures.

  http://www.public.asu.edu/~rjansen/orion/etc_v4.html
- Based on exemplar data from *HST* in target areas such as the Carina Nebula we expect to assemble data on literally thousands of protostellar and protoplanetary systems at the limiting resolution of our system, as well as extend photometric studies to millions of stars both locally and in the Magellanic Clouds.

Competition

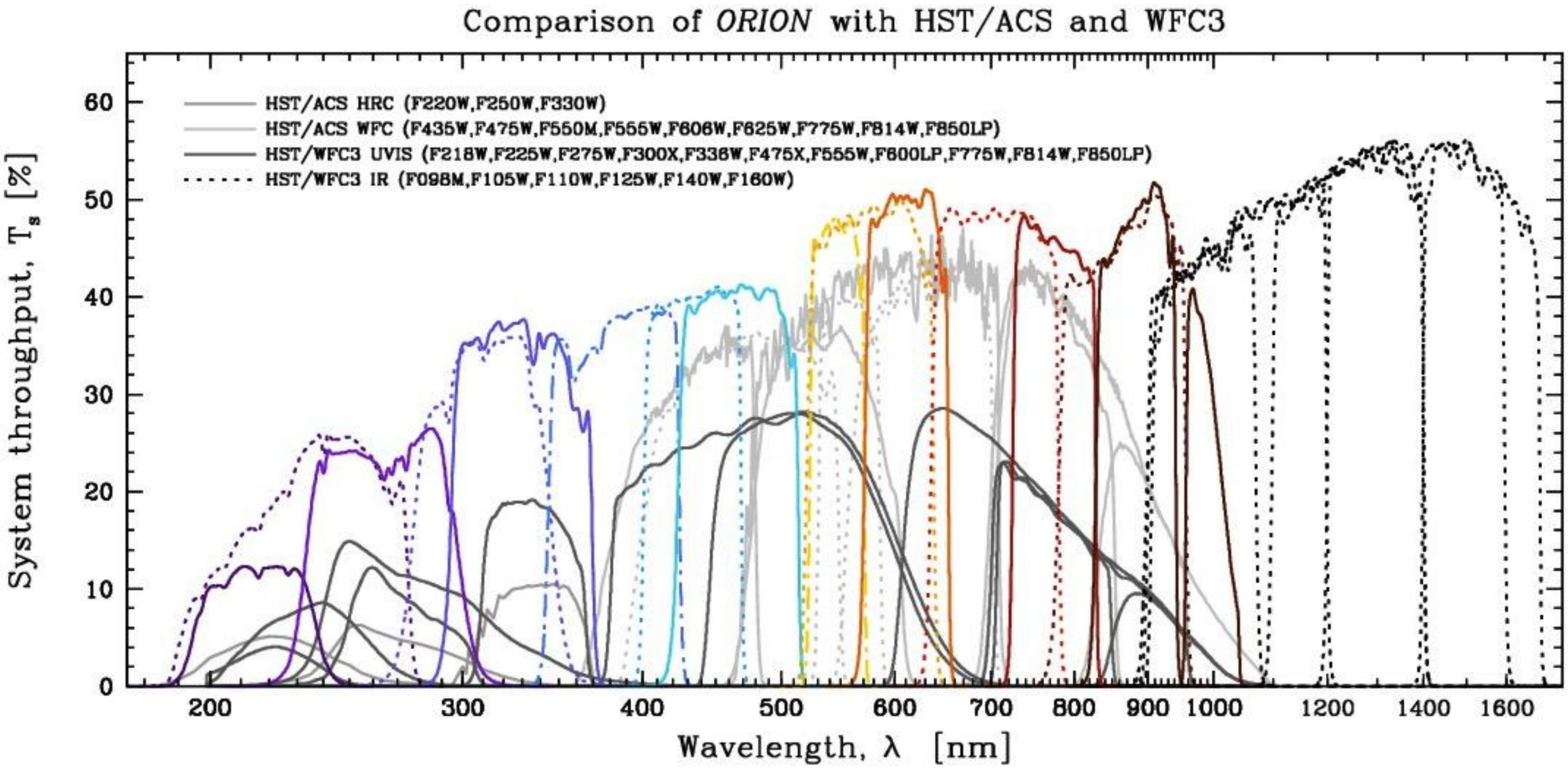
- We need to do this experiment from space to gain access to **both** a wide field of view **and** diffraction-limited resolution, over passbands that extend **down to 200nm**.
- There are no ground-based experiments that can compete with *Orion* – while optical AO can get down to 0.1”, it cannot do it over 20’ field of view, and ground-based experiments cannot reach below 350nm with any reliability.
- While technically *HST-ACS* and *HST-WFC3* could make some of the individual measurements we are proposing, they can never cover the wide angular field we will be offering and cannot achieve the observational efficiency *Orion* will achieve with its dual-channel design
- We do not expect any competition within EX AO or other mission opportunities – to our knowledge we are the only mission proposing to do this kind of widefield UV/optical imaging

Comparison



JWST NIRCam
Spitzer 24μm
ACS-WFC
WFPC-2
WFC3
Orion
JWST NIRCam: 32 mas
HST WFC3 UVIS: 0.04"
HST ACS WFC: 0.05"
HST WFPC2: 0.1"
ORION: 0.114"
WISE: 2.75"
Spitzer 24μm: 2.5"
GALEX: 1.5"
ORION: 0.114"

Comparison



Comparison of ORION with HST/ACS and WFC3
HST/ACS HRC (F220W,F250W,F330W)
HST/ACS WFC (F435W,F475W,F550M,F555W,F606W,F625W,F775W,F814W,F850LP)
HST/WFC3 UVIS (F218W,F225W,F275W,F300X,F336W,F475X,F555W,F600LP,F775W,F814W,F850LP)
HST/WFC3 IR (F098M,F105W,F110W,F125W,F140W,F160W)
System throughput, T_s [%]
Wavelength, λ [nm]
0
10
20
30
40
50
60
200
300
400
500
600
700
800
900
1000
1200
1400
1600

Science Traceability: Baseline

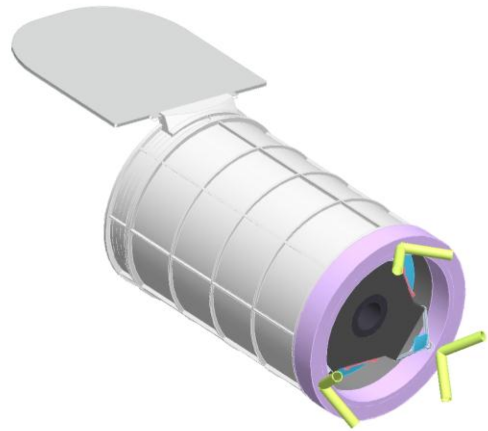
Science Objectives	Science Meas. Requirements	Instrument Functional Requirements (Preliminary)	Mission Functional Requirements (Top-level) (Preliminary)
Imaging Survey of Star Formation within our Galaxy	Survey image all nearby massive star forming regions to build database of protostars, protoplanetary systems at sufficient resolution and range of wavelengths to model the structure and physical nature of each object.	Widefield UV/optical imaging (200-1100nm) using a 1.1m to yield 0.114" angular resolution, diffraction limited at 500nm. Field size of at least 20' square to allow mapping of up to 40 square degrees over the 3 year mission lifetime. Use of dichroic and 2 focal planes to increase observing efficiency. Throughput necessary to achieve S/N=10 in broadbands for targets V<25.0, or SB > 10^{-16} ergs/cm^2/s/arcsec^2 in narrowbands. Optimized dichroic @ 517nm to deliver 2 channels (red/blue). Two channels co-aligned to better than 1 pixel. Optimized filter suite for broad and narrow bands. Out of band rejection needed to achieve S/N specifications. Buttable Si CCDs, optimized for blue and red, with appropriate AR coatings. Modular Imaging Cell design.	Relative photometry better than 5% requires pointing knowledge at the 1/10th pixel level = 12mas over 600 second exposure times. In survey mode, data acquisition will be ~96 GB per 24 hr period. Sufficient bandwidth and storage to handle and download data.
Synoptic Survey of Star Formation Products	Widefield images of nebular volumes to build sample of thousands of protostars and protoplanetary systems. One image in red channel, one in blue. Cadence: every 0.5 day for 10 days; and every 5 days for 100 days.	Same as above, except: throughput necessary to achieve S/N=10 in broadband filters for targets V<23.0 in 10 minutes or less of exposure time.	Same as above, except: data load ~33 GB per 24 hrs.
Young Disk and YSO Evolution	High resolution imaging using a set of diagnostic filters to determine physical nature of Spitzer MIR catalogue targets	UV/optical imaging (200-1100nm) using a 1.1m to yield 0.114" angular resolution, diffraction limited at 500nm. Throughput necessary to achieve S/N=10 in broadbands for targets V<25.0, or SB > 10^{-16} ergs/cm^2/s/arcsec^2 in narrowbands. Optimized filter suite for broad and narrow bands. Out of band rejection needed to achieve S/N specifications.	Relative photometry better than 5% requires pointing knowledge at the 1/10th pixel level = 12mas over 600 second exposure times.

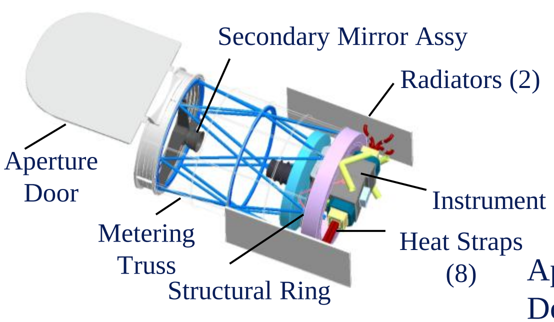
Descopes

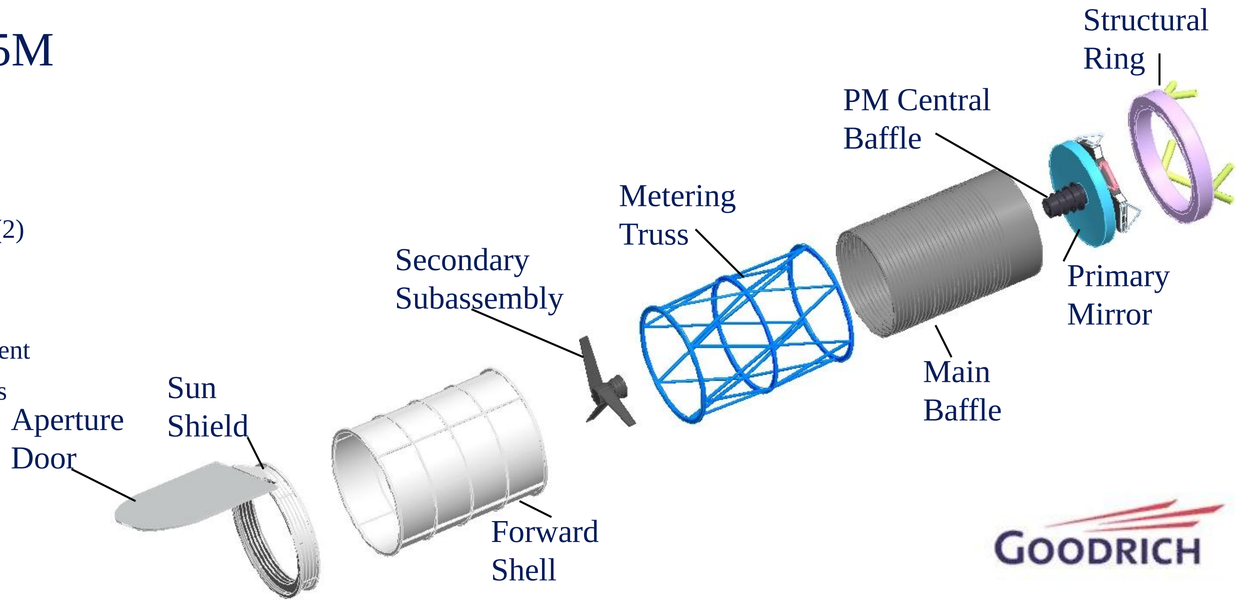
- Possible descopes being considered:
  - **Movement to one imaging channel from two** – huge reduction in observing efficiency and change in detector manufacture strategy – probable reduction in size of filterset – huge impact on possible science with Observatory
  - **Reduction of Field of View** – again, huge reduction in observing efficiency and reduction in unique discovery space possible with *Orion* as currently conceived – possible size and completeness of database will be greatly reduced
  - **Reduction in size of primary optic** – reduction in diffraction-limited resolution of system, as well as reduction in collecting area – poorer view of target objects, possible elimination of advantage of going to orbit, longer exposure times to get to same depth for stars and gas emission
  - **Mission lifetime** – we are currently baselining a 2-year mission because of the sheer angular coverage, depth and frequency of imaging necessary to complete the mission – a move to 1 year would seriously curtail this

Telescope

- Primary mirror
  - 1.1m diameter
  - 1.65m focal length; f/1.5 primary
  - Wavelength at which diffraction limited: 500nm
- Zerodur
- Estimated mass: 119 Kg
- Heritage (if any): ORS
- Operating temperature: Room Temperature – focal planes cooled to 175K
- Estimated price: $30.5M
- Block diagram:







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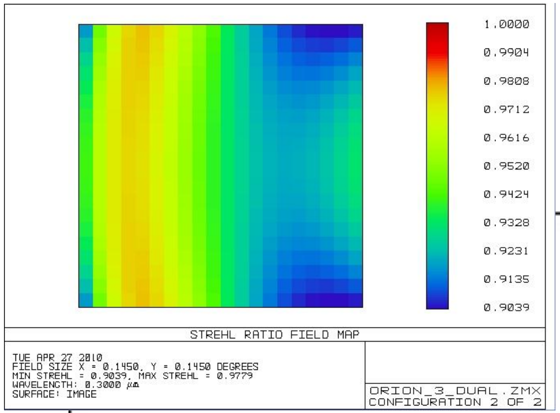
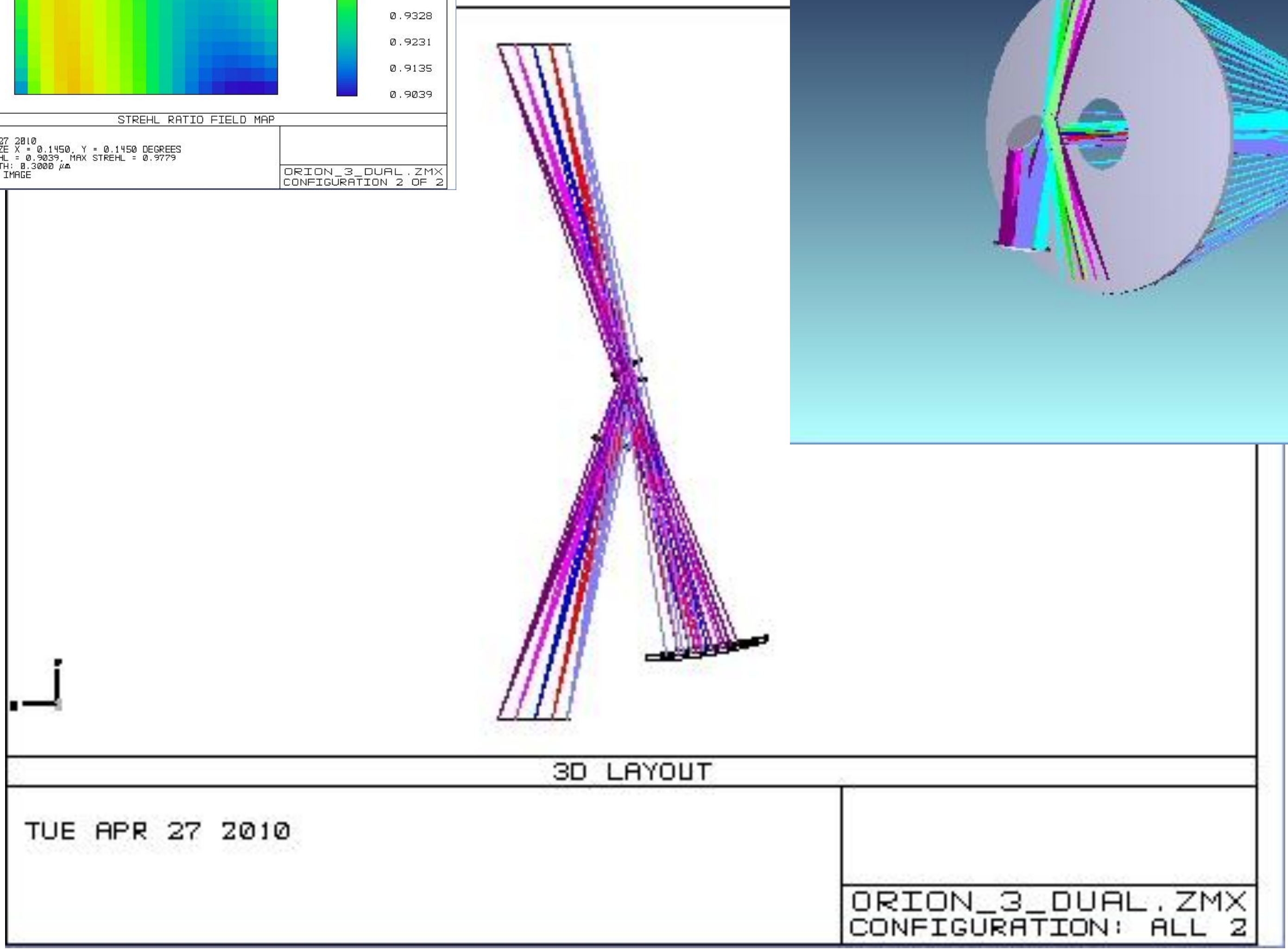
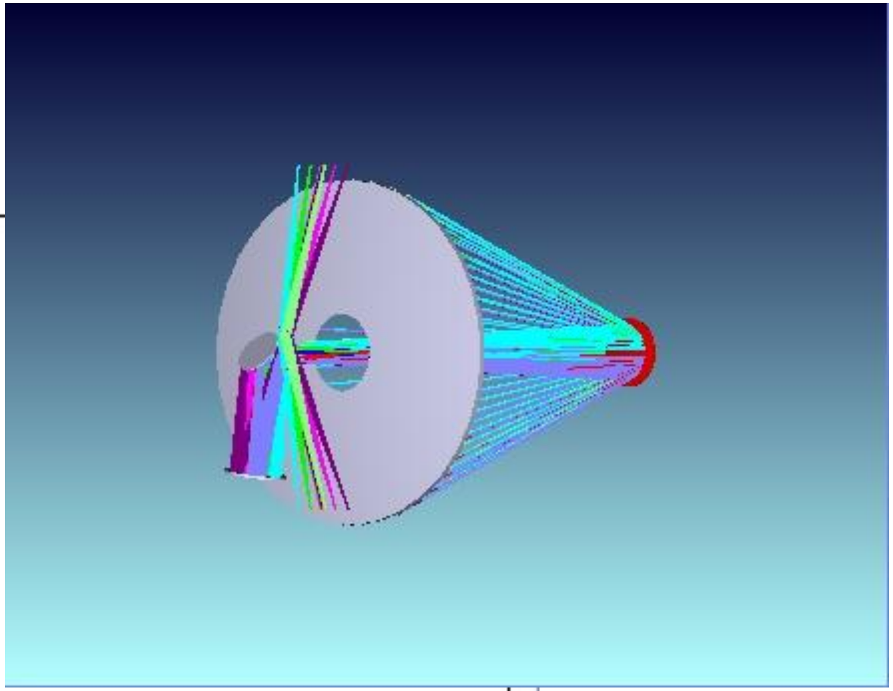
Optical Design







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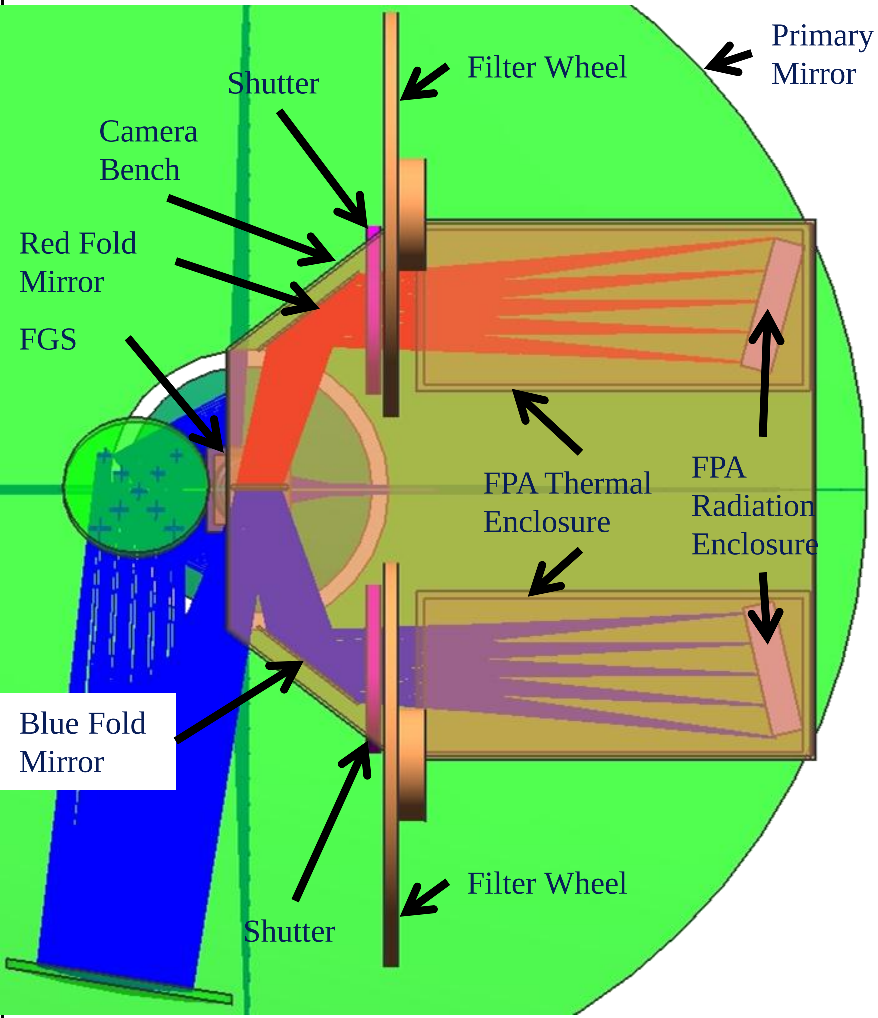
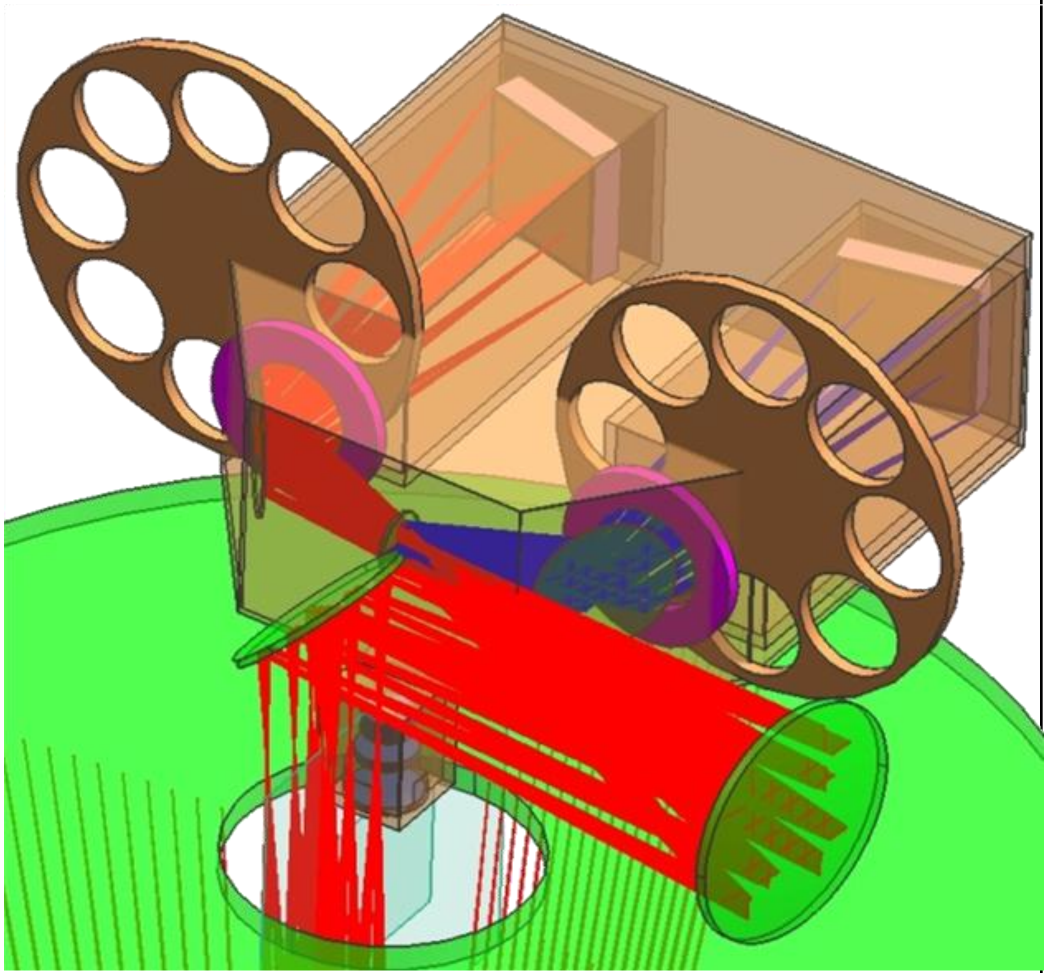
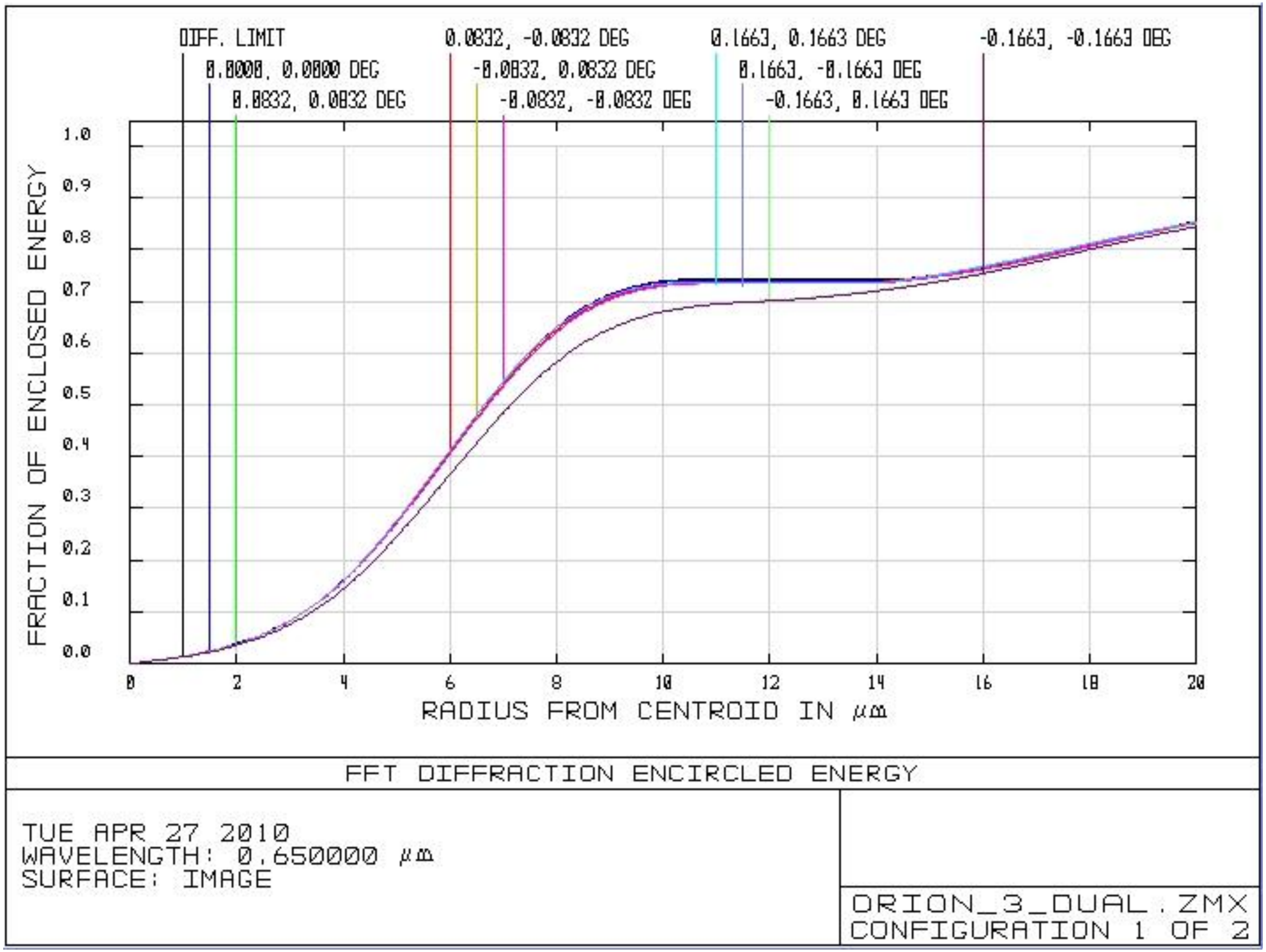




Optical Design



Instrument/Sensors

- Format
  - Size of detectors: 3.5k square Si CCDs (*SNAP* LBNL)
  - Pixel size: 10.5 micron pitch, 0.114” on the sky
- Operating Wavelength range: blue: 200-517nm, red: 517-1100nm
- Quantum efficiency (avg): employing JPL delta-doping: blue: 70%, red: >90%
- Operating temperature and stability requirement: 175K, stable over 600 seconds
- Heritage: None
- Mass and power – 60 Kg, 120W
- Price estimate - $50M (JPL Team-X estimate)
- Volume of data produced – 96 GB per 24 hrs
- TRL
  - CCDs are TRL 6 (LBNL), JPL Delta Doping TRL 5 (BEPAC), MIC (prototype being built and flown this year – should bring to TRL 7)
  - There is a high-TRL backup, if needed – adoption of e2v chips flown on *HST-WFC3*
- No on-board processing is required

Customized Detector Response

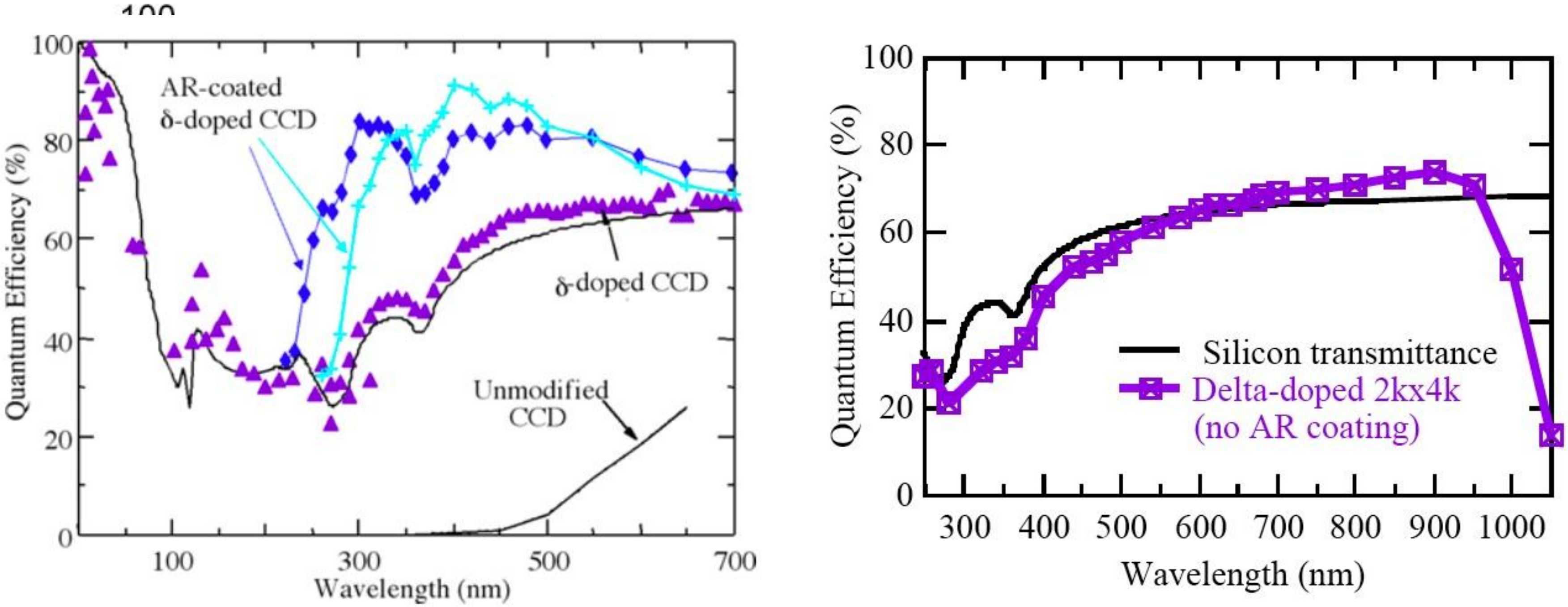


Figure 1. Measurements of the response of the delta-doped n-channel array with two antireflection coating examples (left). On the right, the measurement of delta doped p-channel CCD are displayed. Similarly to the n-channel design, with delta layer closer to the surface (~ 2 nm cap layers) on the p-channel CCD, we measure nearly 100% internal QE (reflection-limited response). Both designs have showed very good response. In this effort, each design and approach, implemented with the similar pixel count will be evaluated in the same system. AR coatings suitable to the blue/UV will also be designed and incorporated to the final CCD.

200 250 300 350 400 450 500 550 600 650

Wavelength (nm)

Additional Technology Development