AAS 229 COPAG SIG

LUMOS & HDI: TWO COR WORKHORSE INSTRUMENTS FOR LUVOIR

HISTORICAL POINT

NO MATTER WHAT YOU COME UP WITH, LYMAN SPITZER ALREADY THOUGHT OF IT

III. Astronomical Research with a Large Reflecting Telescope

The ultimate objective in the instrumentation of an astronomical satellite would be the provision of a large reflecting telescope, equipped with the various measuring devices necessary for different phases of astronomical research. Telescopes on earth have already reached the limit imposed by the irregular fluctuations in atmospheric refraction, giving rise to "bad seeing". It is doubtful whether a telescope larger than 200 inches would offer any appreciable advantage over the 200 inch instrument. Moreover, problems of flexure become very serious in mounting so large an instrument. Both of these limitations disappear in a satellite observatory, and the only limitations on size seem to be the practical ones associated with sending the equipment aloft.

While a large reflecting satellite telescope (possibly 200 to 600 inches in diameter) is some years in the future, it is of interest to explore the possibilities of such an instrument. It would in the first place always have the same resolving power, undisturbed by the terrestrial atmosphere. If the figuring of the mirror could be sufficiently accurate, its resolving power would be enormous, and would make it possible to separate two objects only .01" of arc apart (for a mirror 450 inches in diameter); an object on Mars a mile in radius could be clearly recorded at closest opposition while on the moon an object 50 feet across could be detected with visible radiation. This is at least ten times better than the typical performance of the best terrestrial telescopes. Moreover, in ultra-violet light the theoretical resolving power would of course be considerably greater; ideally an object 10 feet across could be distinguished on the moon

Spitzer, 1946

A Space Telescope Concept in the Tradition of HST

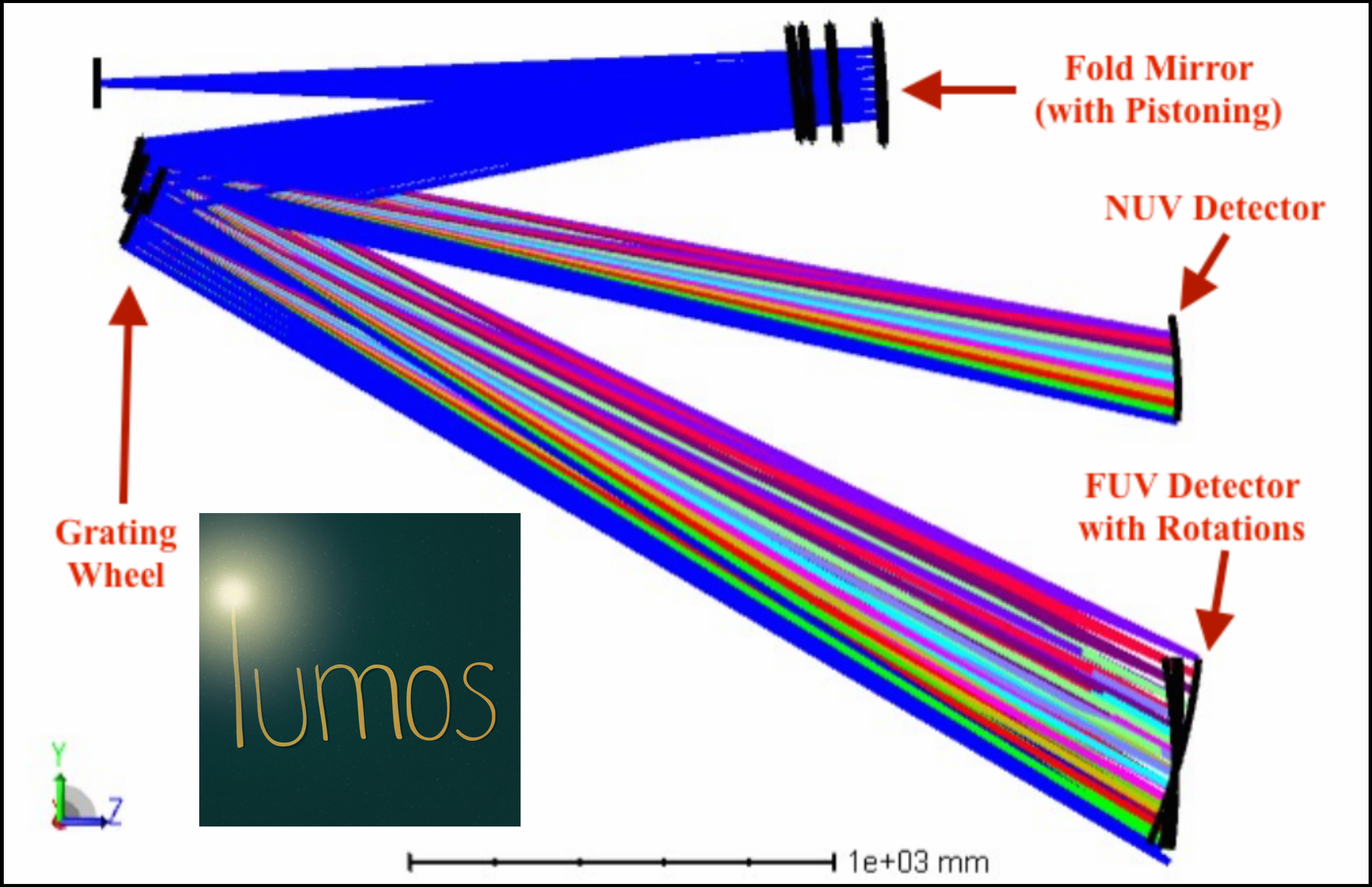
- Broad science capabilities: *"From the Big Bang to Biosignatures"*
- FUV to Near-IR bandpass
- Two architectures under consideration: 9.2 and 14.5 m
- Suite of imagers & spectrographs
- Serviceable & upgradeable

OTHER LUVOIR INSTRUMENTATION

- Coronagraph (Lead: Laurent Pueyo)
- ONIRS: Visible to Near-IR spectrograph (Lead: Courtney Dressing)
- CNES-led investigation of a UV spectropolarimeter (Contact: Marc Ferrari)

LUVOIR AT AAS229 (#LUVOIR229)

- NASA booth (W, Th, F)
- Hyperwall talks (W, Th,F)
- Hands-on splinter session, (W 2:00-3:30)
- Decadal Studies Special Session (S 10:00-11:30)
- LUVOIR ETC tools on the touchscreen at the STScI booth (W,Th,F)



LUVOIR Ultraviolet Multi-Object Spectrograph

Kevin France - Colorado

LUMOS SCIENCE TEAM

Kevin France - Colorado

John O'Meara – St. Michael's

Jane Rigby – GSFC

David Schiminovich - Columbia

Walt Harris – Arizona

Leonidas Moustakas - JPL

Jason Tumlinson - STScI

Brian Fleming - Colorado

Steve McCandliss - JHU

LUMOS Instrument Requirements

Spectral Bandpass:

Target: 100 – 400 nm

(Stretch: 90 – 400 nm)

Spectral Resolving Power:

Target: “H” = 100,000

“M” = 30,000 – 50,000

“L” = 8,000 – 15,000

“LL”~ 500

Temporal Resolution:

Target: 1 msec

(Stretch: 0.1 msec)

LUMOS Instrument Requirements

<u>UV Imaging Field-of-View</u>:
2’ x 2’

<u>UV Imaging Angular Resolution</u>:
Target: < 30 mas

<u>Bandpass and Filters:</u>

100 – 350 nm

<u>FUV</u>: 2 W filters,
GALEX-FUV, 100 – 135nm
~5 N filters, $\Delta\lambda \sim 15$ nm

<u>NUV</u>: 3 W filters,
GALEX-NUV, F225W, F275W
4 N filters, $\Delta\lambda \sim 15$ nm

LUMOS Instrument Requirements

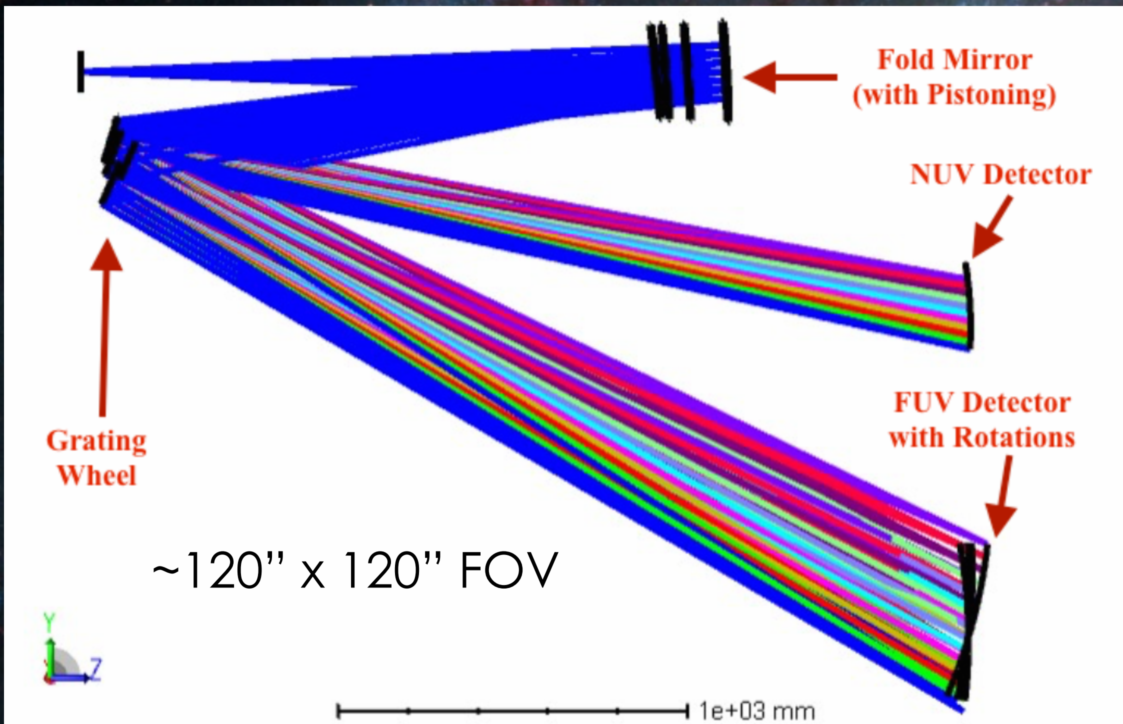
Multi-Object Field-of-View:
2’ x 2’

Angular Resolution in MOS mode:
Target: 50 mas
(Stretch: 30 mas)

Heritage/TRL: Design, technology, ConOps based on HST UV spectrographs, FUSE, and suborbital instrument designs and component level testing; NASA APRA and SAT programs (e.g., J. Vallerga, O. Siegmund , K. France, S. McCandliss, B. Fleming, S. Nikzad, M. Quijada, and others)

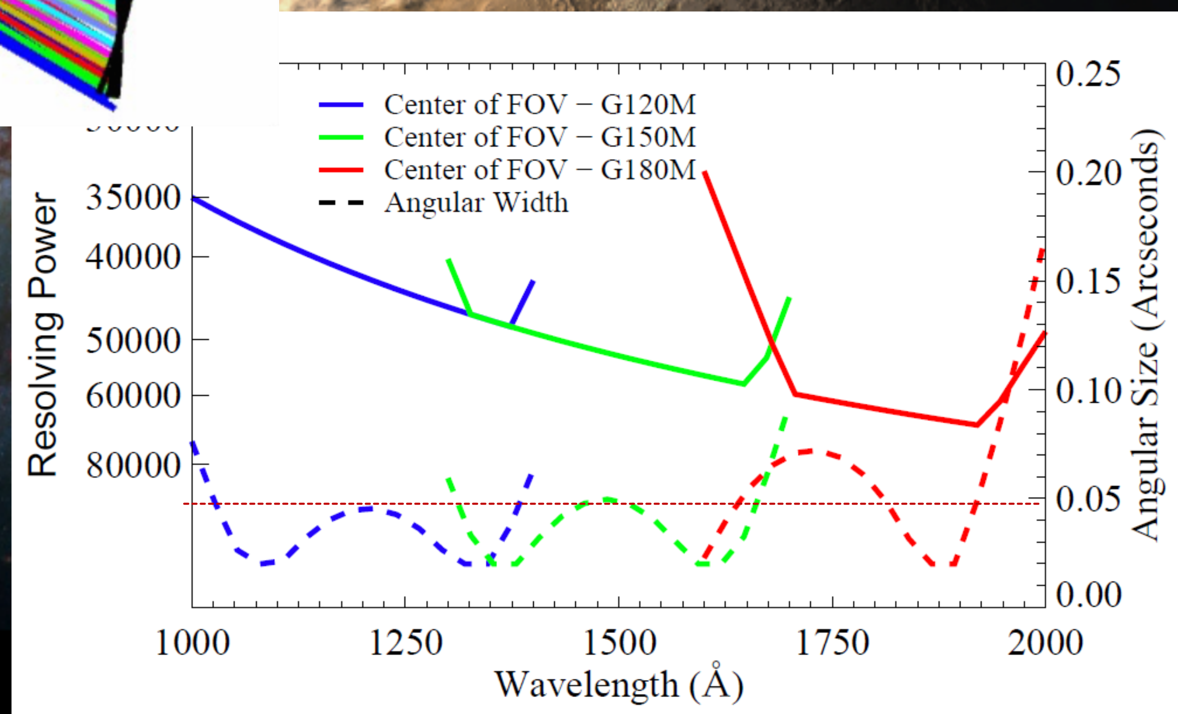
LUMOS IDL at GSFC in May

LUMOS – Design

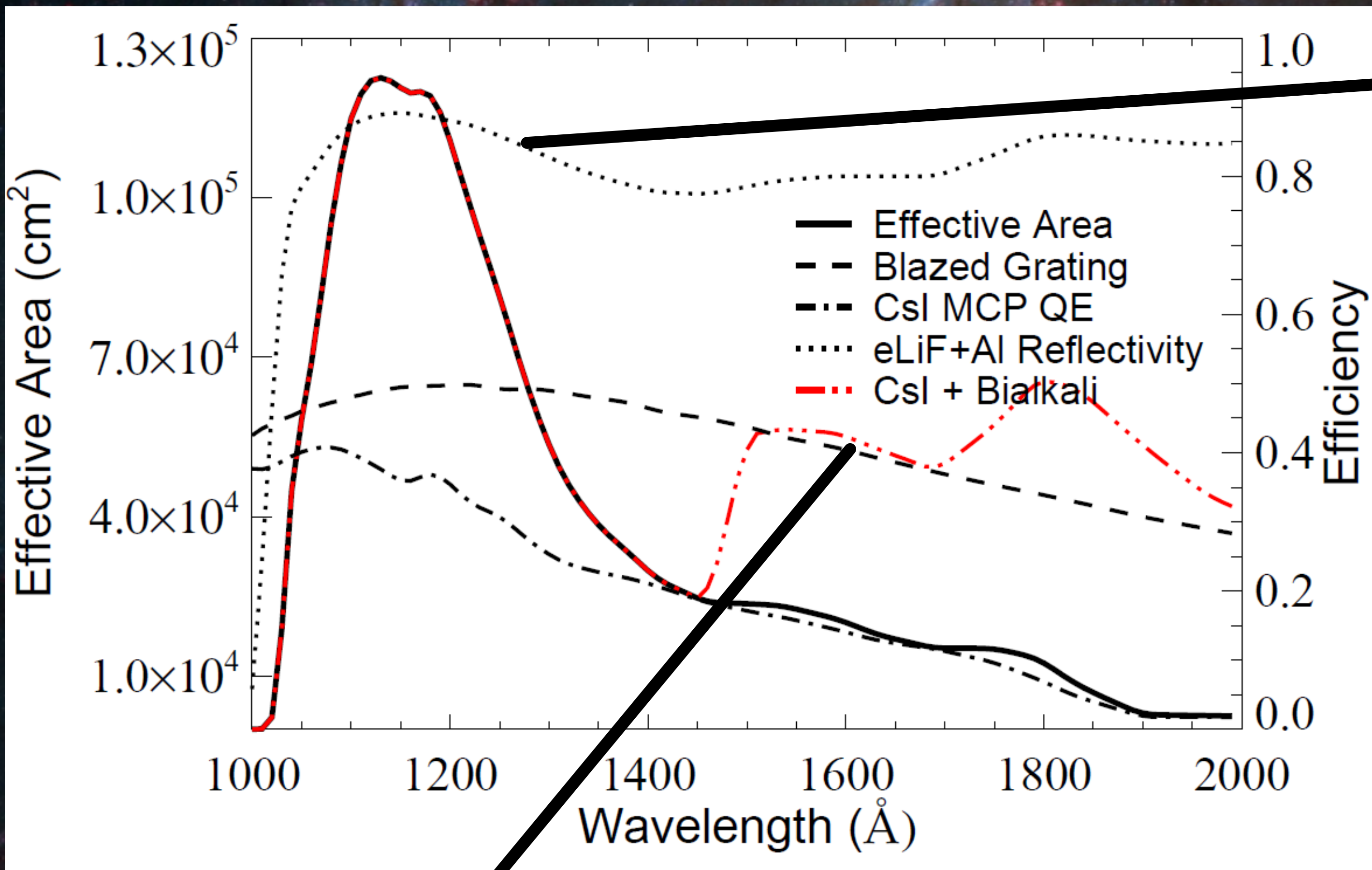


- "JWST-like" microshutter array Holographic grating
- Fold mirrors, grating wheel, detectors

NEED: stable advanced coatings, large-format detector arrays (~200mm x 200mm x 2)



LUMOS – Performance

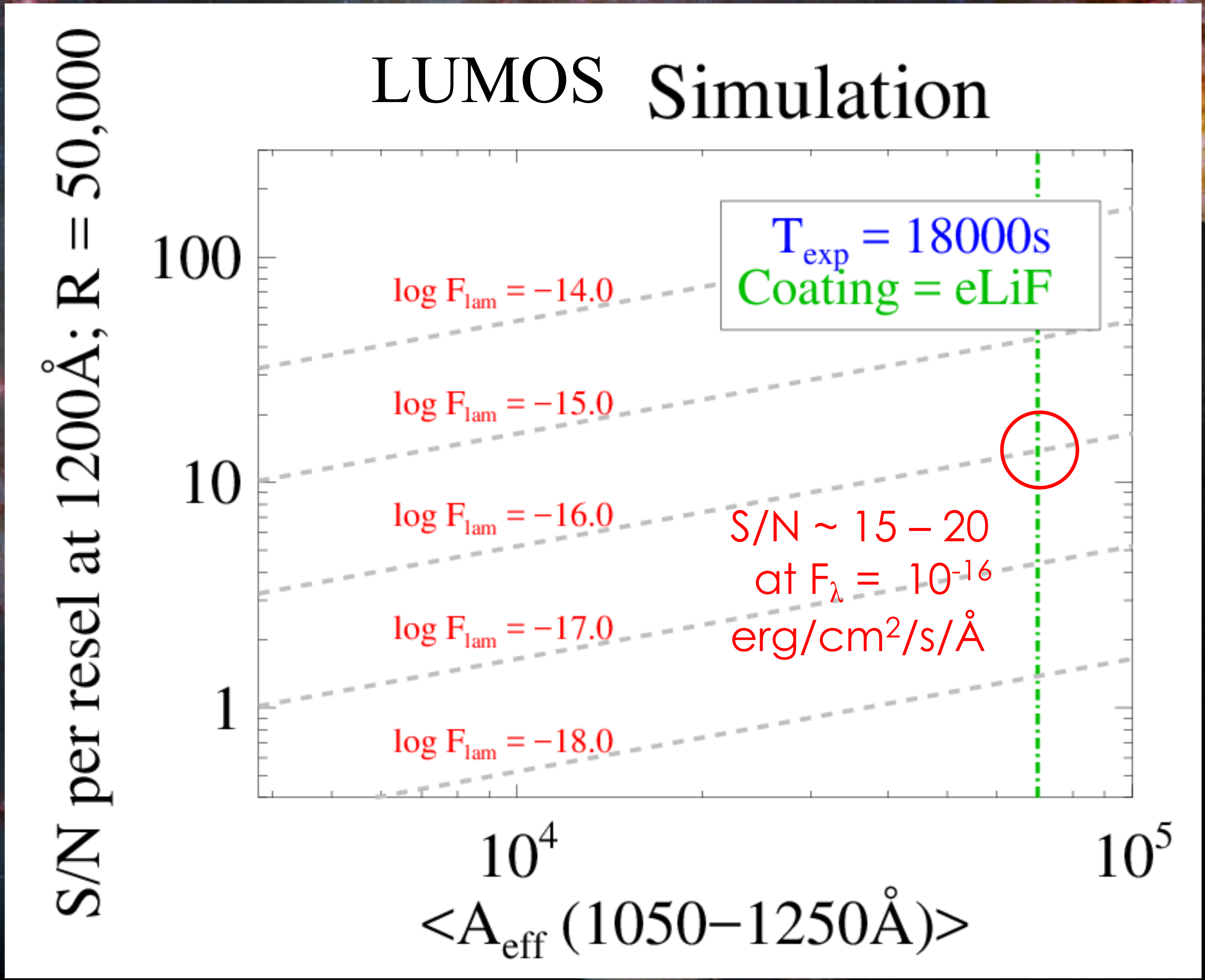


-Quijada et al. 2014;
-Fleming et al. 2016;
-Hennessey et al. 2016
Balasubramanian et al. 2015

-Siegmund et al. 2014;
-Nikzad et al. 2012;
-Vallerga et al. 2016

$A_{eff} \sim A_{geom} * (R_{coat})^4 * (G_{grat}) * DQE_{det}$

LUMOS – Performance

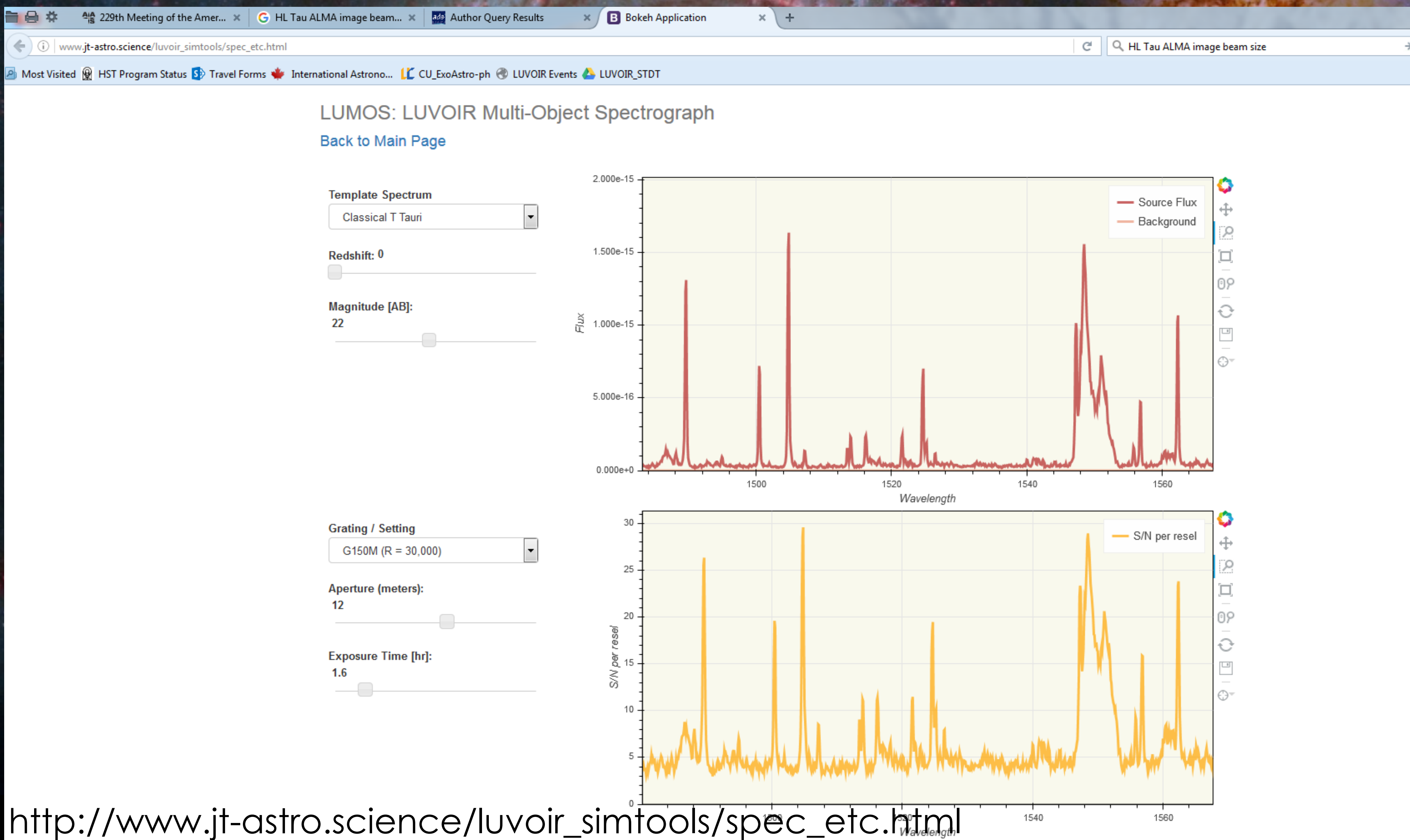


LUMOS – Performance

Comparison with HST-STIS

Instrument Parameter	STIS G140M	LUMOS FUV (Imaging Modes)
Spectral Resolving Power	10,000	8,000 – 50,000 (NUV: 20k – 40k)
Total Spectral Bandpass	1140 – 1740 Å	1000 – 2000 Å (NUV: 2000 – 4000 Å)
Spectral Bandpass per Exposure	50 Å	450 – 1000 Å (NUV: 1600 Å)
Number of Exposures to Cover Spectral Bandpass	12	1 (Low Res) 3 (Med Res) (NUV: 1 – 2)
Imaging Field-of-View	0.2" x 28"	~120" x 120" (OTA-dependent)
Spectrograph Throughput	1.2%	10.5%

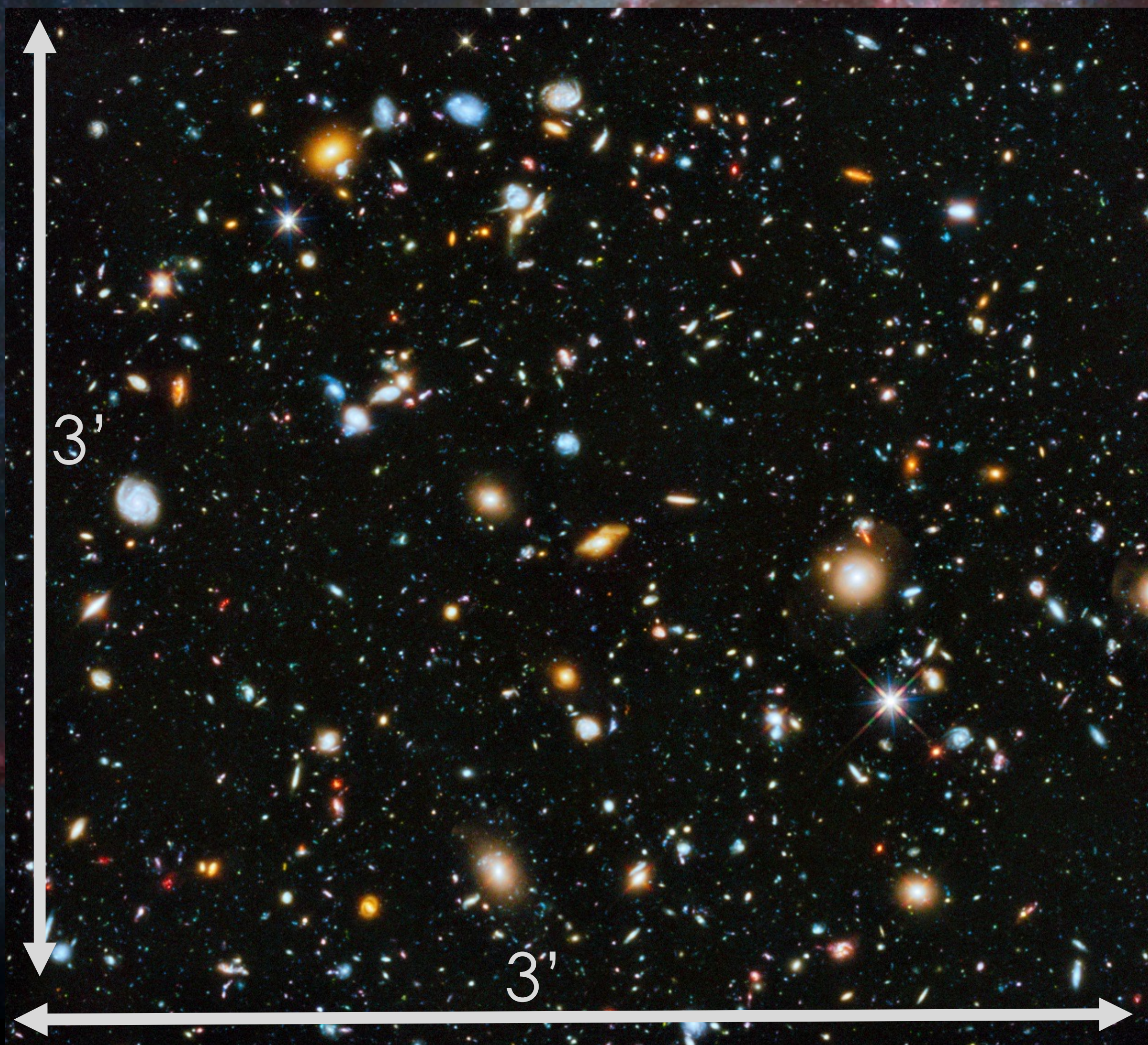
LUMOS – Exposure Time Calculator (Jason Tumlinson, see LUMOS Hands-on Meeting on Thursday Jan 04, 2pm)



http://www.jt-astro.science/luvoir_simtools/spec_etc.html

LUMOS Concept of Operations

What can we do with LUVOIR + LUMOS?



Deep fields will be produced automatic via parallel observations during coronagraphy (HDI sim)

Spectroscopic follow-up observations of low/ intermediate redshift galaxies and CGM/ IGM

LUMOS ConOps

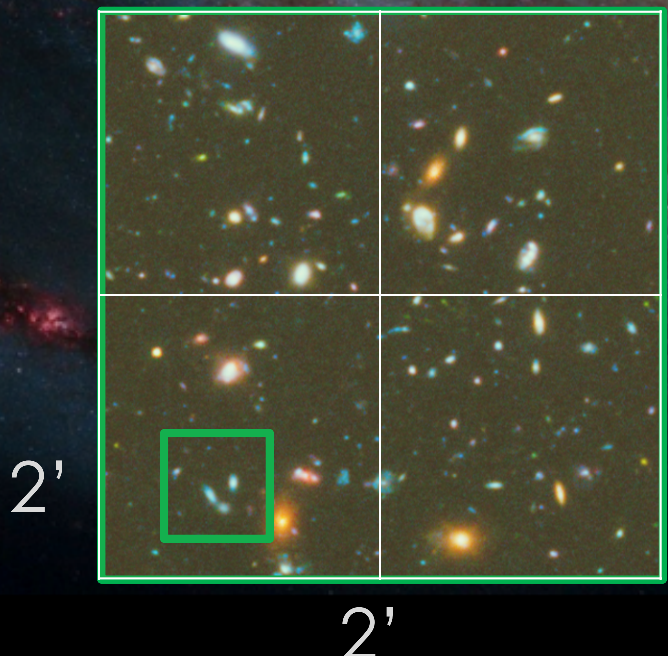
What can we do with LUVOIR + LUMOS?

Spectroscopic observations of low/intermediate redshift galaxies and CGM/IGM

LUMOS ConOps

What can we do with LUVOIR + LUMOS?

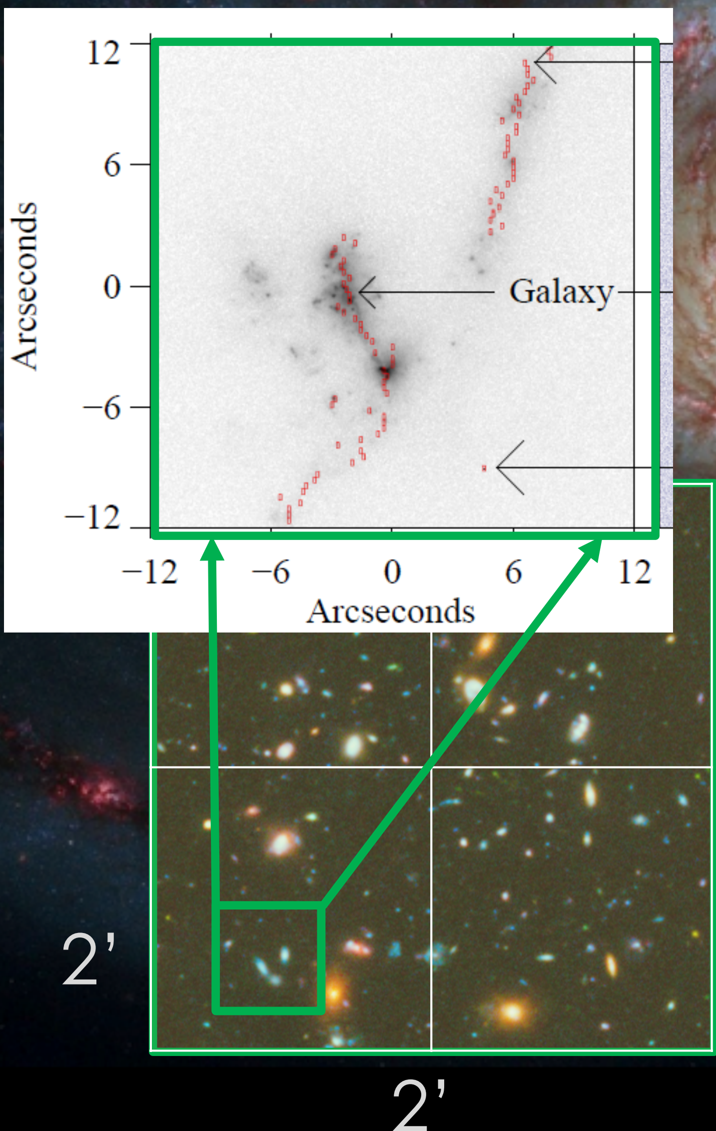
- N x N microshutter arrays, 100 x 200 micron slits



- < 0.05” spectral imaging across most of FOV
  - (0.03” – 1.0” spectral imaging across full FOV)

LUMOS ConOps

What can we do with LUVOIR + LUMOS?



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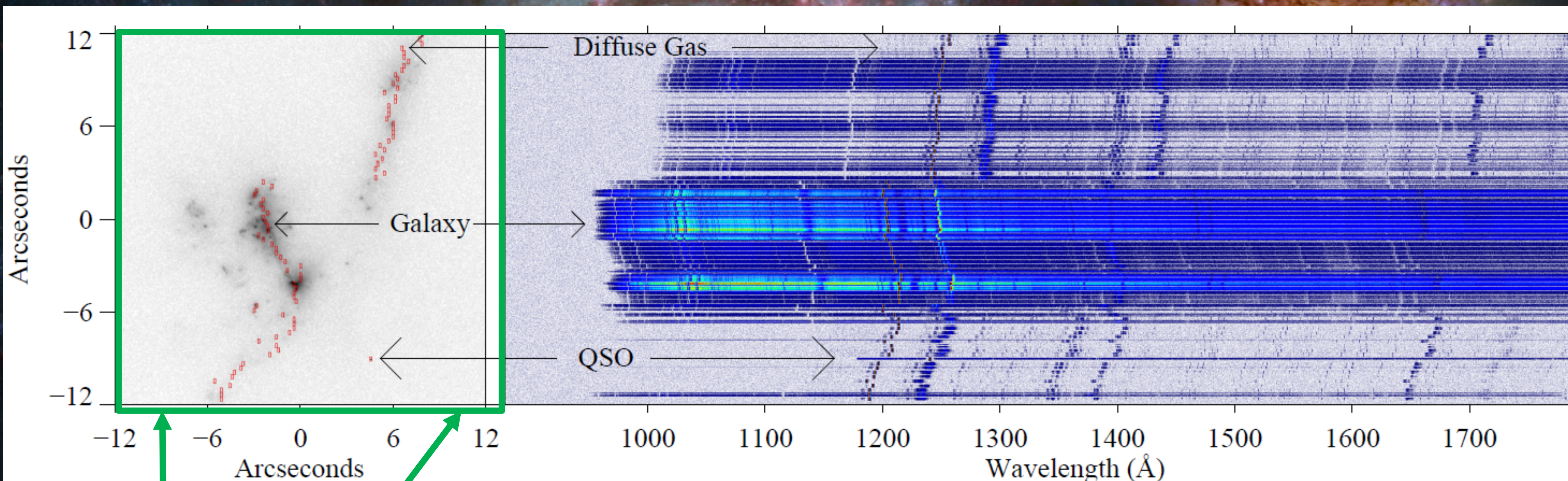
LUMOS ConOps

What can we do with LUVOIR + LUMOS?



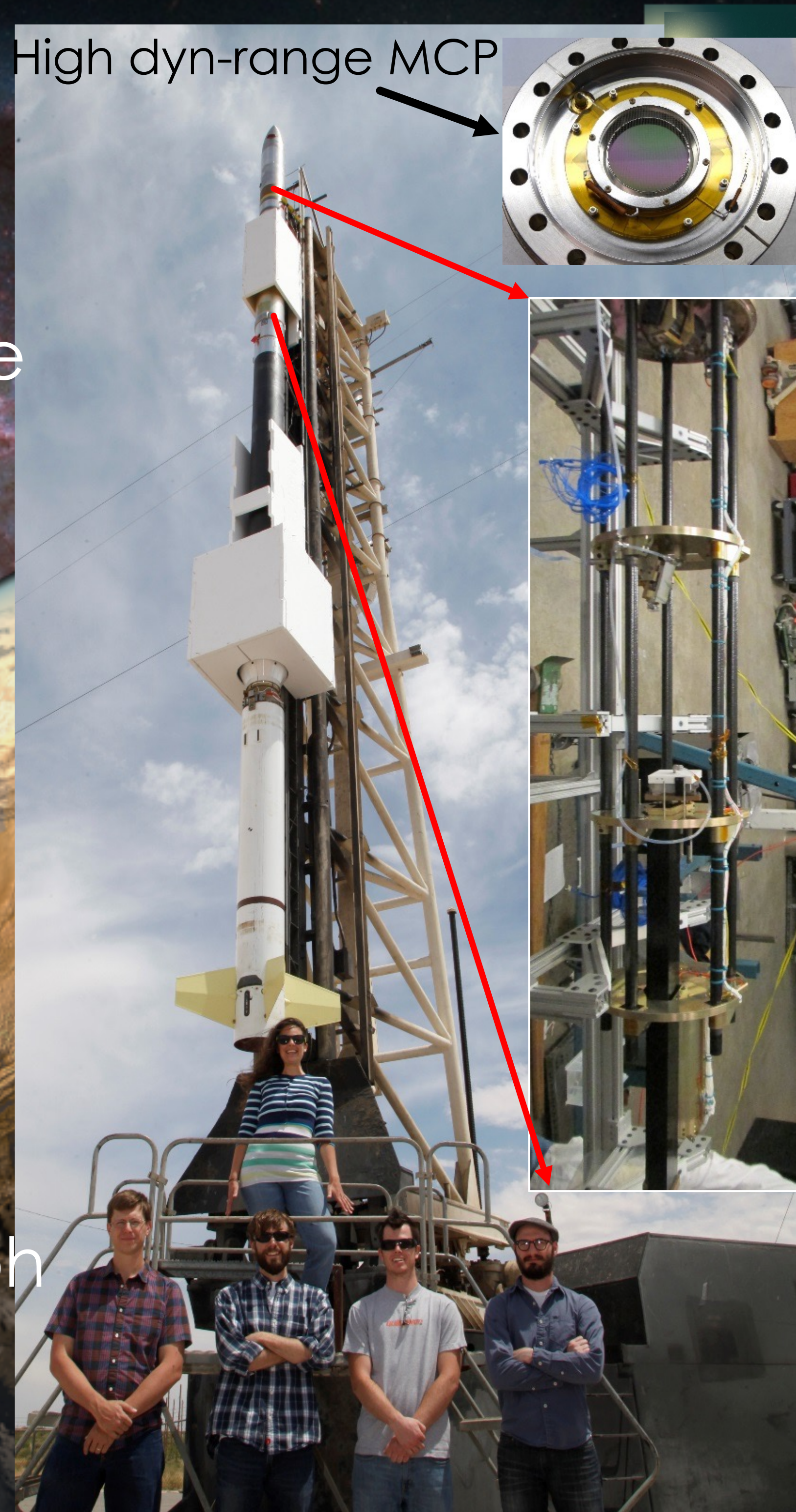
R > *8,000* 1000 – 2000 Å spectroscopy of hundreds of objects *simultaneously*.

(-or- *R* > 30K over ~400 Å)

Background quasars, numerous galactic regions, circumgalactic halo

LUMOS Technology Development: Current Laboratory/Flight Programs

1) CHESS (CU): high dynamic-range MCPs (X-strip) echelle gratings, deformable mirror holographic recording
2) FORTIS (JHU): prototype MSAs
3) DEUCE (CU): large format photon-counting detectors (200mm x 200mm)
4) SISTINE (CU): Advanced UV coatings, large format high resolution MCPs, high angular and spectral res UV spectrograph design



SUMMARY

LUMOS: UV SPECTROGRAPH AND IMAGER FOR LUVOIR

1) IMAGING / MULTI-OBJECT SPECTROGRAPH OVER 'A FEW' SQUARE ARCMINUTES FOV ($2'^2$) AT LOW AND MEDIUM RES [R = 500 TO >50,000]

2) UV SPECTROSCOPIC PERFORMANCE 50 – 1000 X HST DEPENDING ON THE MODE AND MULTIPLEXING

3) DEVELOPMENT AND FLIGHT-TESTING HAPPENING TODAY TO SUPPORT LUVOIR-LIKE MISSION IN THE NEXT DECADE

kevin.france@colorado.edu

HDI

HDI: The LUVOIR High Definition Imager

MARC POSTMAN (STScI)

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

HDI SCIENCE TEAM

HDI

Marc Postman – STScI
Daniela Calzetti – U. Mass., Amherst
Stefano Casertano – STScI
Don Figer - RIT
Steven Finkelstein – U. Texas, Austin
Walt Harris – Arizona
Tod Lauer – NOAO
Ilaria Pascucci – Arizona

Dave Redding – JPL
Jane Rigby – GSFC
David Schiminovich – Columbia
Britney Schmidt – Georgia Tech
Vicky Scowcroft – U. Bath, UK
Mike Shao – JPL
Warren Skidmore - TMT
Kate Whitaker – U. Mass., Amherst

HDI

HDI OVERVIEW

Multi-channel instrument:

1) UV-Visible imaging channel (200 – 1000 nm) – overlap with LUMOS instrument but FOV will be >2x – 4x larger.

2) NIR channel (1000 – 1800 nm)

3) Each channel will contain a suite of narrow (R~50 - 100), medium (R~20 - 40), and broadband (R~3 - 5) filters. Likely also to desire at least one grism/prism option (R ~ 200 – 500).

UVIS array to be ~2 Gpixels (depends on aperture*)
NIR array to be 200 – 400 Mpixels (depends on aperture*)

* LUVOIR Study is assessing 2 telescope apertures: 9.2m and 14.5m

HDI

HDI Instrument Requirements

Spectral Bandpass:
Target: 200 – 1800 nm
(Stretch: 200 – 2500 nm)

Field-of-View:
Target: 2' x 3' (for 14.5m), 4' x 4' (for 9.2m)
(Stretch: 3' x 4' for 14.5m; 6' x 6' for 9.2m)

Angular Resolution:
Target: Nyquist sampled down to 400 nm (stretch: 200 nm)
Diffraction limited down to 500 nm (stretch: 400 nm)
WFE across FOV ≤ 36 nm
(more details on next slide)

HDI Instrument Requirements

HDI

<u>Angular Resolution *continued*</u>:

Telescope Aperture	HDI FOV	Nyquist Sampling Scale (mas) at 400 nm	Nyquist Sampling Scale (mas) at 1200 nm	Total Pixels in UVIS Channel (Gigapixels)	Total Pixels in NIR Channel (Megapixels)	Number of 8K x 8K Detectors Required: UVIS	NIR
9.2 m	4 x 4 arcmin	5.471	16.412	1.92	213.8	36	4
9.2 m	6 x 6 arcmin	5.471	16.412	4.33	481.2	64	9
12 m	4 x 4 arcmin	4.194	12.582	3.27	363.9	49	6
14.5 m	2 x 2 arcmin	3.470	10.413	1.20	132.8	18	2
14.5 m	**2 x 3 arcmin**	**3.470**	**10.413**	**1.79**	**199.2**	**28**	**4**
14.5 m	3 x 3 arcmin	3.470	10.413	2.69	298.8	42	6
14.5 m	4 x 4 arcmin	3.470	10.413	4.78	531.2	75	8

We will be designing a baseline HDI concept using the highlighted parameters for the 14.5 m telescope concept. This design will be scalable to smaller telescope apertures (e.g., 12m, 9.2m) as well.

HDI Instrument Requirements

HDI

Special Modes

High-Speed Photometry

Temporal Resolution:

Target: 100 msec

(Stretch: 50 msec)

HSP may not require entire FOV

High Precision Astrometry

Astrometric Precision:

Target: 5 x 10^{-4} pixels

(Stretch: 10^{-4} pixels)

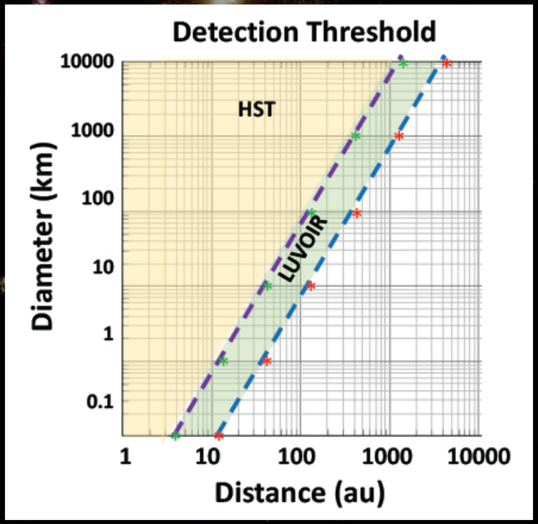
High astrometric precision will require pixel geometry calibration system (e.g., Shao et al.) – Laser interference pattern generated onto focal plane for absolute high-precision calibration of detector and pixel distortions.

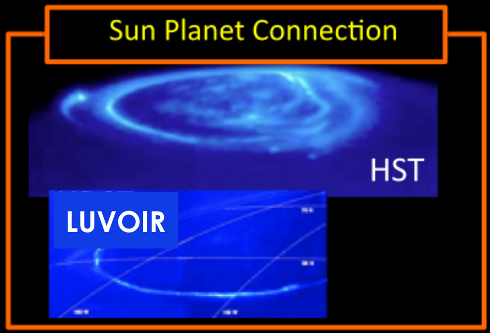
HDI Instrument Requirements

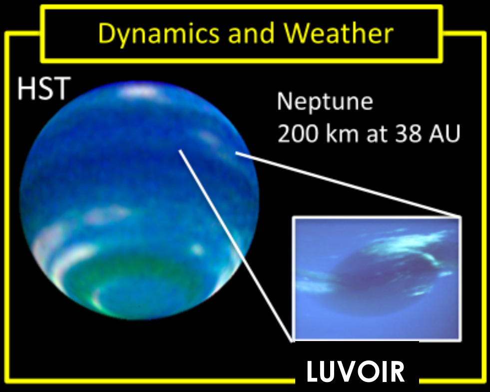
HDI

Solar System Imaging considerations:

- Solar blind performance: UV imaging requires high red leak rejection (10^{-8})
- Region in array with reduced sensitivity will enable high dynamic range near bright planetary targets.
- Non-sidereal tracking (up to 60 mas/s) supported.



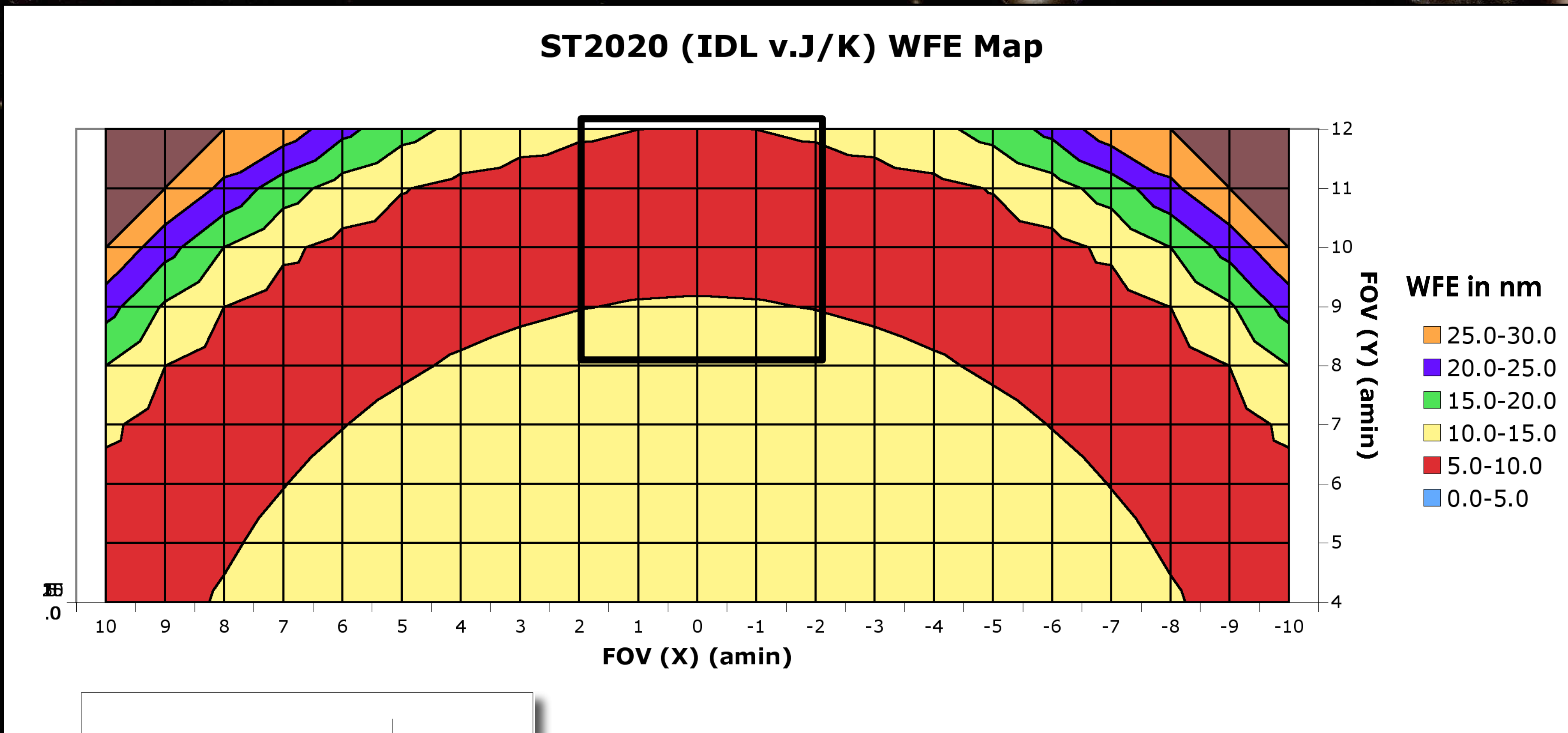


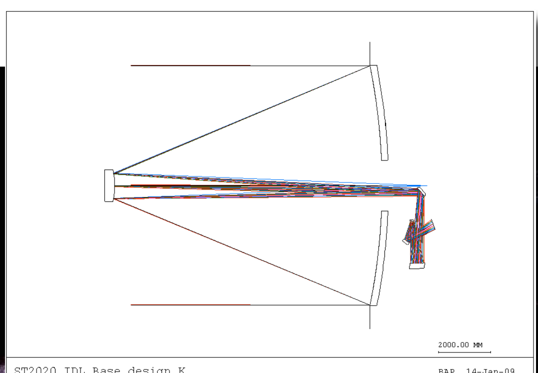


HDI

HDI – Notional Design

Achieving diffraction-limited performance over desired FOV is feasible in TMA design





Pasquale 2008 ATLAST 9.2m

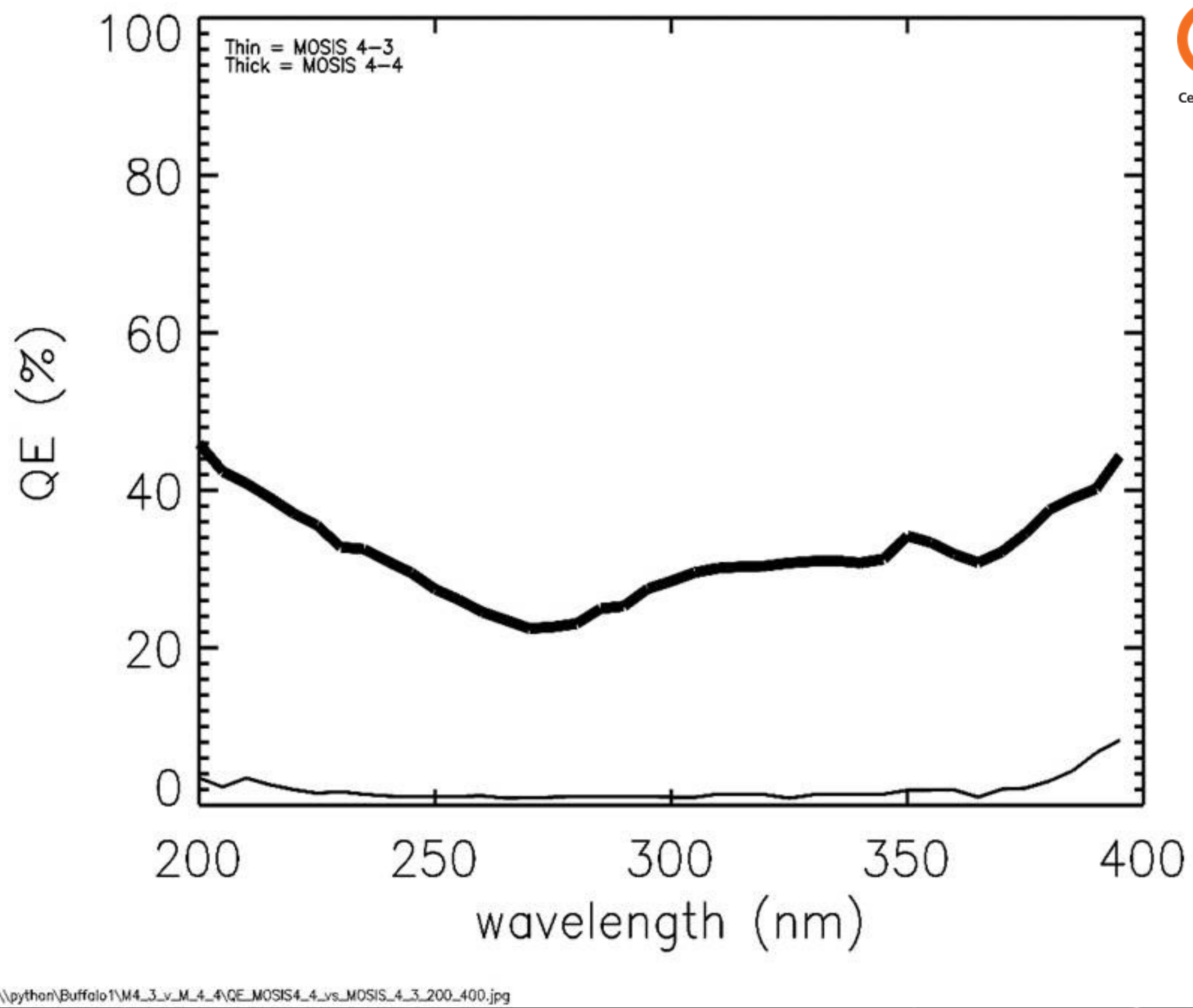
IDL at GSFC in February

Ball Aerospace for optical design

HDI – Detectors

RIT has been developing CMOS detectors that have good sensitivity in NUV and in visible. They also exhibit very low read noise.

Graph credit: D. Figer, RIT



Challenge: thinned devices don't work as well at longer wavelengths.

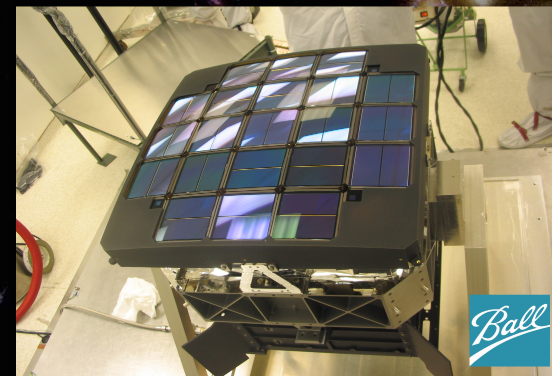
To avoid needing separate UV and Vis channels for HDI, should strive to engineer devices that get excellent response from 200 – 900 nm.

Also need large formats (8K x 8K)

GIGAPIXEL CAMERAS IN SPACE

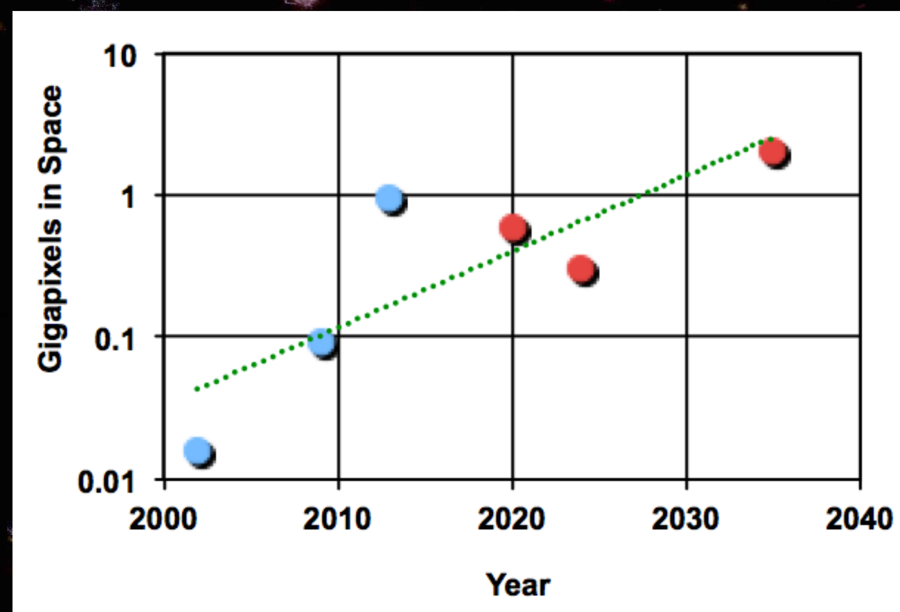
HDI

- Recent space heritage:
  - ACS/HST: 16 Megapix (2002)
  - Kepler: 95 Megapix (2009)
  - Gaia: 937 Megapix (2013)
- Near future space FPA:
  - EUCLID: 604 Megapix (~2020)
  - WFIRST: 302 Megapix (~2024)
  - LUVOIR: 2 Gigapix (~2035)



Kepler Focal Plane Array (95 Mpix)

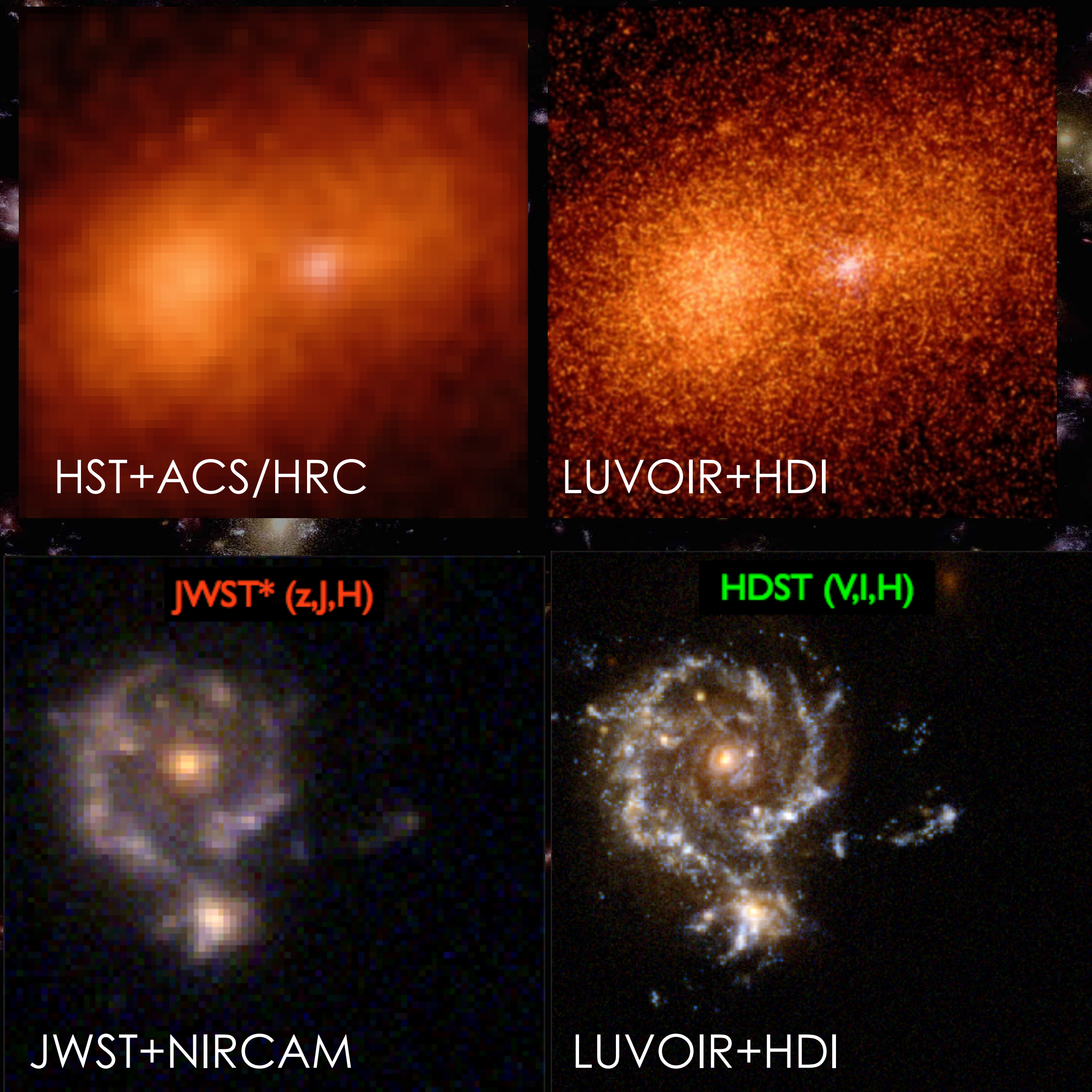
Gaia Focal Plane Array (937 Mpix)



HDI

HDI SCIENCE

Ultra Faint … Ultraviolet … Ultra Precise … Ultra High Resolution



Characterize stellar populations to rigorously test star formation theories

Measure cosmological parameters with well-calibrated distance indicators out to the distance of the Coma Cluster

Explore outer planet atmospheres, discover and characterize distant objects in the solar system

Reveal the impact of the epoch of reionization on galaxy formation and visualize the evolution of galaxies

Map dark matter by measuring proper motions of galaxies

Astrometric detection of 100s of exoEarths

HDI – Exposure Time Calculator HDI

(Marc Postman, Jason Tumlinson)

LUVOIR: The Large UltraViolet Optical Infrared Surveyor

High Definition Imager (HDI) ETC

Controls | Info

Aperture (meters): **14**

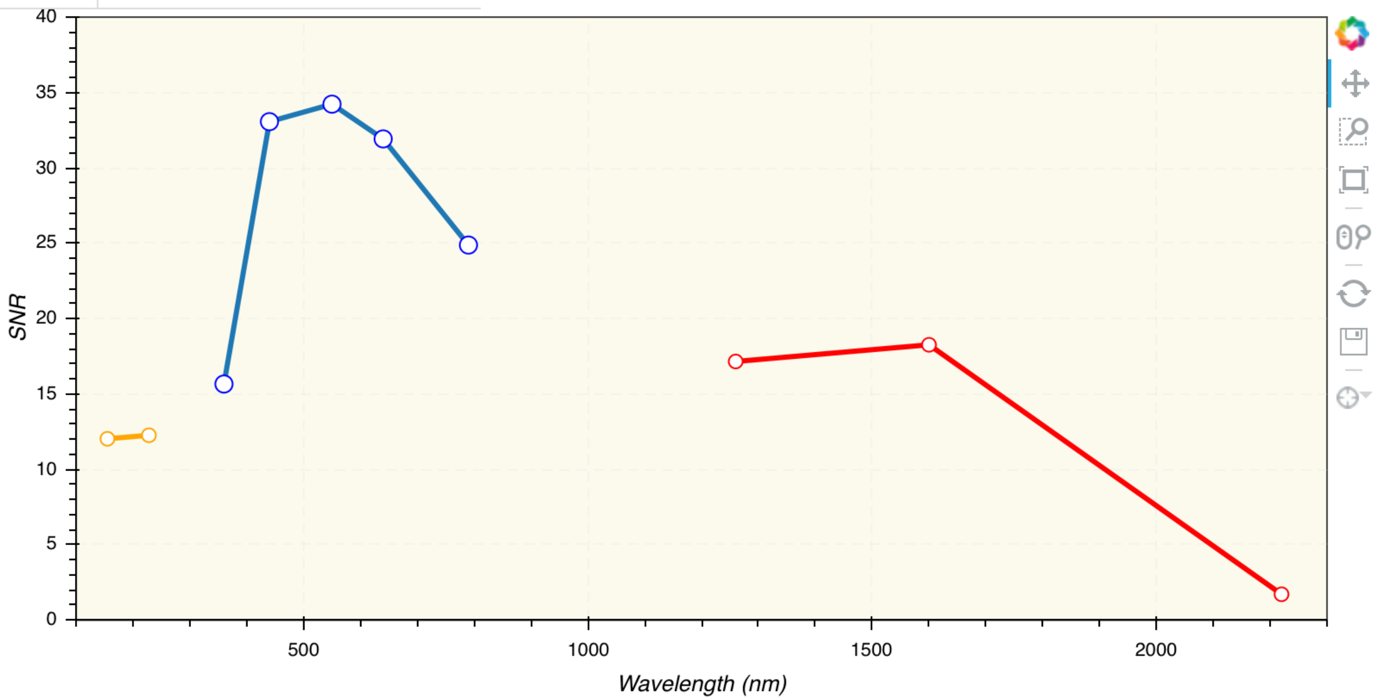
Exptime (hours): **1**

V Magnitude (AB): **30**

Template Spectrum

Flat (AB)

SNR | SED



http://www.jt-astro.science/luvoir.html

SUMMARY

HDI

<u>HDI</u>: High Definition Imager Concept For LUVOIR

1) High-Angular resolution Imager for General Astrophysics Covering Range 200 – 1800 nm.
   a. Nyquist sampling important for optimal (noiseless) image co-addition. Implies need for ~2 Gigapixel array in UVIS channel and ~200 Megapixel array in NIR channel.
2) Special Modes include:
   a. High Astrometric Precision Mode for observations of Nearby Stars for Exoplanet detection; Galaxy Proper Motions.
   b. High Speed Photometric Mode for observations of Stellar Pulsation Phenomena and Solar System Occultations
3) Detector Developments in work but additional studies needed to assess feasibility of Gigapixel array in Space.