HabEx Ultraviolet Spectrograph: UVS

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Starting Point

- Themes
  - Tracing the Life Cycle of Baryonic Matter
  - Assessing the Impact of Massive Stars on Star Formation
  - Measuring the Escape Fraction of Galaxies - Reionization
- Objectives
  - To gain access to the large number of diagnostic emission and absorption lines in the mid-UV and far-UV
- Measurements
  - See STM, bottom line: use of unprecedented combination of aperture, new efficient UV coatings and detectors, and wavelength coverage to open up new insight into a suite of problems that use diagnostics in the FUV
- Instrument Type
  - FUV spectrograph – possible Rowland circle, use of holographic gratings, minimal number of bounces, possible Echelle mode, possible grating turret

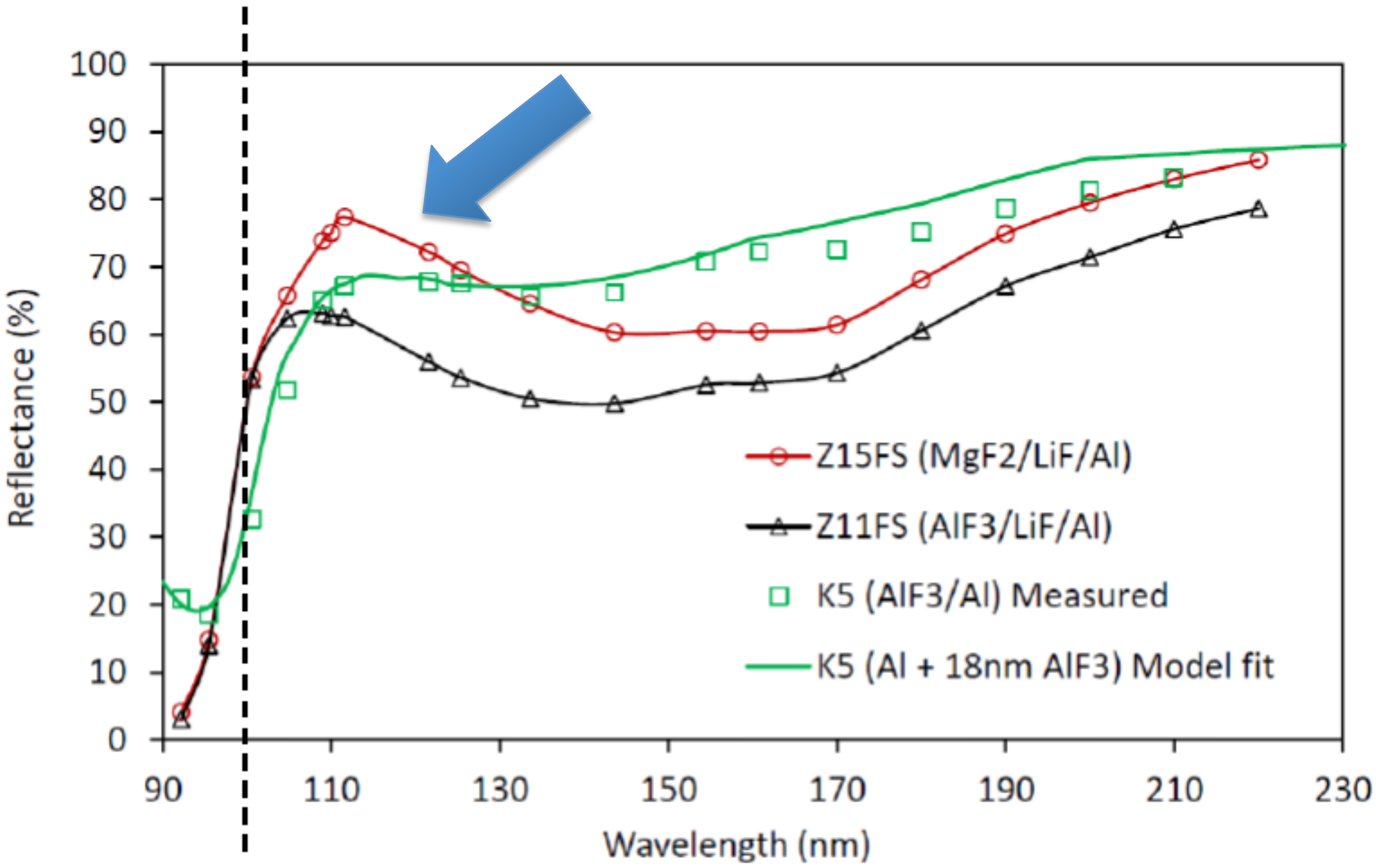
Requirements

Sub-Program	Mode	FoV	Passband	Resolution	Aperture
QSOs	Spectroscopy		92-115nm and higher	R >20,000	4m+
Census	Spectroscopy		92-310nm	R > 40,000	6-8m
AGNs	Spectroscopy	1”	115-320nm	R=40,000	6m
IGM/CGM Emission	Spectroscopy	4x4’, 20x20’	125-320nm	R=1,000-5,000	4m+
IGM Metals	Spectroscopy	10’	190-310nm	R~60,000	4m
MC Survey	Imaging	200 sq arcmin	250-1050nm	Diff Limit @ 300nm	4m
	Spectroscopy		100-250nm	R>30,000	4m
Massive Stars	Imaging	25”	90-900nm	0.1”	4m
	Spectroscopy		100-200nm	R~40	4m
FUV Diagnostics	Spectroscopy		92-350nm	R~30,000	4m+

Concept of Operations

- Observational Scenarios
  - Campaigns of multiple sources of varying brightness and wavelengths = lots of uncertainty in specific observing modes without doing a full DRM
- Instrument Modes
  - Spectral resolution modes range from R=a few hundred up to >40,000 – will probably require a grating turret to enable this
  - Wavelength coverage could be large, so Echelle mode might be needed – or combination of different gratings and a moveable FPA
  - To minimize the number of bounces and maximize throughput, we could pickoff the beam at the Cass-like focus or after the third optic
  - Will likely need to use a holographic grating to correct for beam aberration, to perform the dispersion and focus the beam at the FPA
  - Would really like a MOS mode for the wide field of view
  - Achieving a long- or short-slit capability might be challenging
  - Achieving an IFU mode might also be challenging

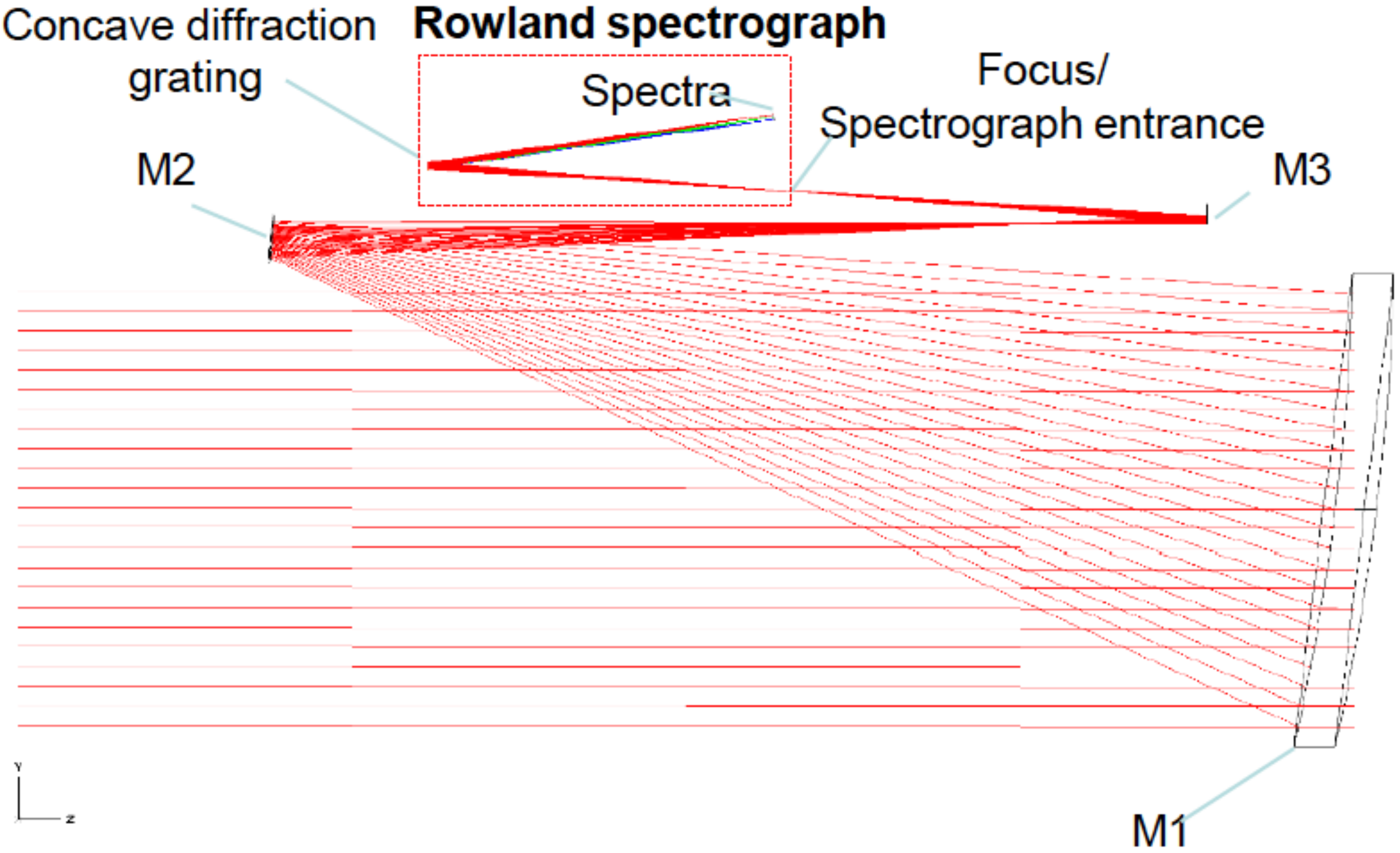
Step #1: Choice of Coatings



"Aluminum Mirror Coatings for UVOIR Telescope Optics including the Far UV" Kunjithaptham Balasubramanian et al. 2015

Step #2: Optical Considerations

- All GA instruments must “do no harm” to the primary science goals − as such we take the OTA “as is”
- The Cass-like focus is too aberrated to allow anything but a point-source capability
- To enable any kind of long slit / MOS mode we have to pick off after the third optic and eat the throughput hit
- At that point in the optical path we have had 3 bounces before entering the instrument
- To minimize the number of bounces we must invoke the properties of a holographic grating: correction, dispersion and focus − all in one element



Rowland spectrograph

Concave diffraction grating

Spectra

Focus/ Spectrograph entrance

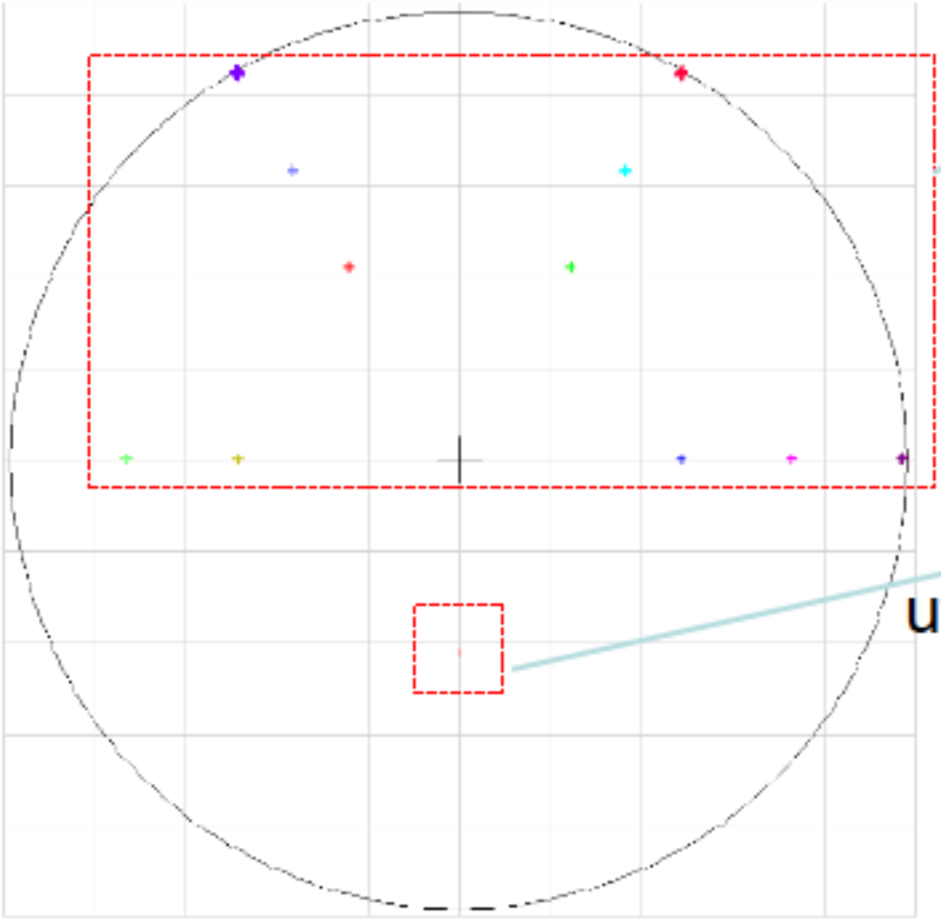
M2

M3

M1

Step #3: Packaging

- The current HabEx OTA design is an off-axis 4m monolith − both M2 and M3 are on the side of the “telescope tube”
- However there is a 4th mirror that takes the beam back towards the space behind the primary for the coronagraphs − we need to pick off before that M4
- This involves the need for the sole design lien UVS places on the HabEx OTA − the ability to flip out the M4 mirror to allow the beam to enter the UVS instrument aperture
- This removes the capability of doing spectroscopy in parallel with coronagraphy − this would not prevent parallel observations with a starshade implementation



Telescope nominal field positions (FOV)

Field position utilized by Spectrograph

Step #4: Design Elements

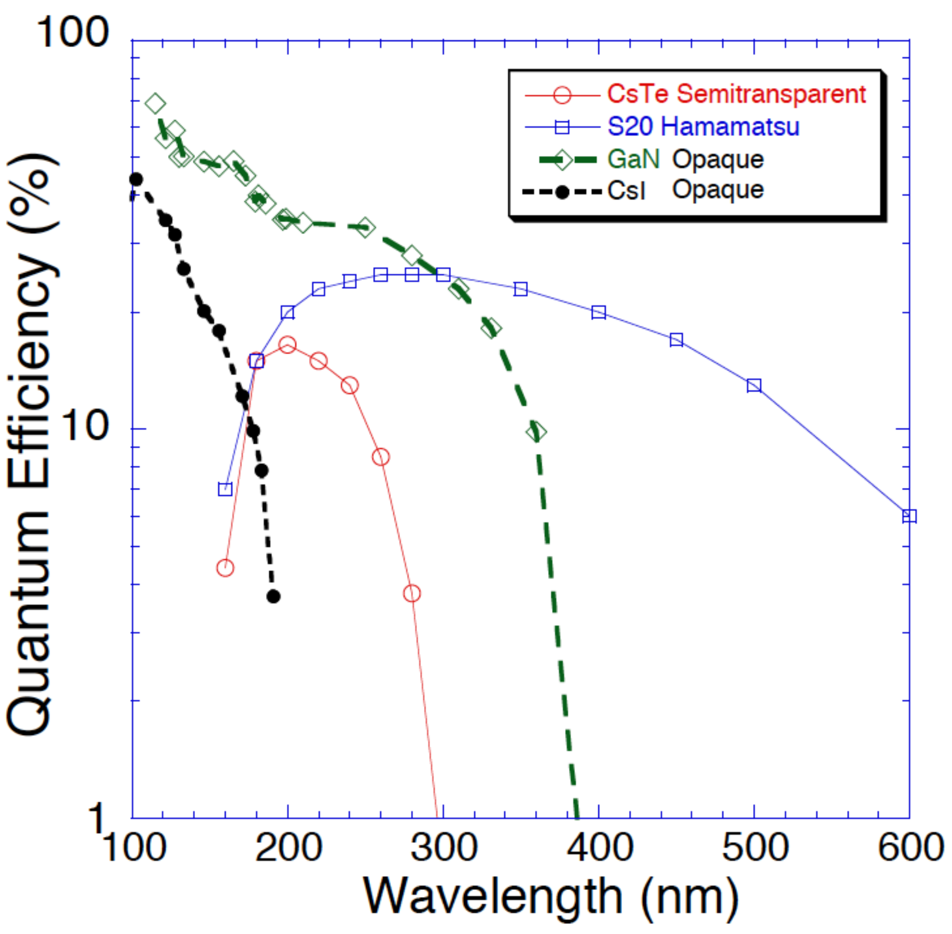
- 1st element: MOS target selector − mosaicked microshutter assemblies, 10’s of cm in size
- 2nd element: holographic grating − mounted on a grating turret to provide multiple R’s − again, 10’s of cm in size
- 3rd element: MCP FPA − on a sliding rail allowing selection of wavelength range for observation − solution to replace Echelle since we can’t afford another reflection − MCPs with heritage exist in sizes as large as 100mm with response down to 30nm − room temperature operation

Fundamentals

- Size: design fits in a 1x2x3m volume
- Mass: 204 Kg
- Power: 79 W
- Passband: 100-350nm
- R’s: 500, 2600, 5000, 10000, 20000, 60000
- FPA size: 100mm square
- Grating size: 20-30cm square
- Microshutter mosaic: 20-30cm square = 10’ field

Throughput

- The protected LiF coatings have a peak throughput of 80% at 110nm
- 4 reflections makes this 41%
- The MCPs have a range of possible cathodes but have DQEs of around 50% at 110nm
- This turns a 4m mirror with a collecting area of 12.6 m^2 into an effective area in the FUV of 2.6 m^2 @ 110nm
- This compares with previous missions:
  - FUSE: 0.008 m^2 @ 120nm
  - WFC3-UV: 0.45 m^2 @ 250nm
  - HST-COS: 0.3 m^2 @ 130nm
  - GALEX: 0.004 m^2 @ 150nm



Note: open face up to 200nm, sealed tube 115-350nm

Challenges

- Optical alignment and stability
- TRL of process to apply chosen coatings to a 4m optic
- Mechanism to move M4 out – lack of parallel capability in UVS vs. coronagraphy
- TRL of mosaicked microshutter arrays

Conclusions

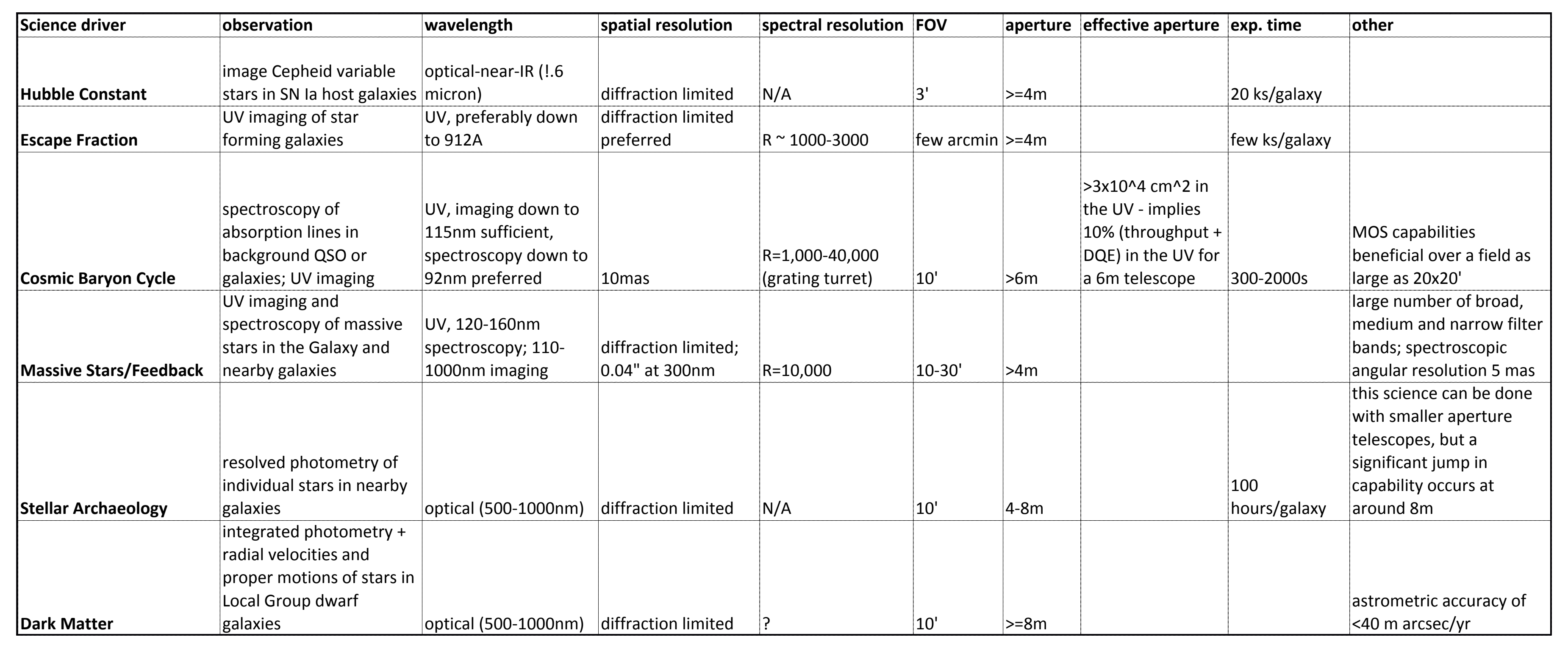
- A design solution exists for the UVS instrument that:
  - Meets the science goals for the FUV spectroscopy science portfolio
  - Can co-exist with the 4m monolith OTA design without placing requirements on the OTA prescription itself
  - Does require M4 to flip out − removes parallel mode
  - Uses protected LiF to provide as high a throughput as possible for 4 reflections − peak throughput is at 110nm − 41% - turns a 4m telescope into a 1m telescope @ 110nm = factor of 8 better in A_{eff} than HST-COS

Backup Slides

MCP Flight Heritage

- COS HST - 20 x 90mm, x 2 segments (curved) with XDL and electronics
- Pluto-ALICE, 40 x 20 curved, with XDL and electronics
- JUNO-UVS, 40 x 20 curved, with XDL and electronics
- LRO-LAMP, 40 x 20 curved, with XDL and electronics
- DMSP-SSULI 40mm with XDL and electronics launched 2012-2016
- GOLD 40mm with XDL and electronics launch 2017-2018
- ICON 50 x 20mm with XDL and electronics launch 2017-2018
- ICON 25mm sealed tube intensifier with CCD launch 2017-2018
- Solar Orbiter- SPICE 25mm intensifier launch 2018
- JHU - 40 x 160 mm (3 segments) with XDL and electronics FORTIS rocket flown a couple of times
- Colorado - 40mm XS, with XS electronics CHESS rocket launched 2013, 2015

Overall Capabilities Matrix



Science driver	observation	wavelength	spatial resolution	spectral resolution	FOV	aperture	effective aperture	exp. time	other
Hubble Constant	image Cepheid variable stars in SN Ia host galaxies	optical-near-IR (!.6 micron)	diffraction limited	N/A	3'	>=4m		20 ks/galaxy	
Escape Fraction	UV imaging of star forming galaxies	UV, preferably down to 912A	diffraction limited preferred	R ~ 1000-3000	few arcmin	>=4m		few ks/galaxy	
Cosmic Baryon Cycle	spectroscopy of absorption lines in background QSO or galaxies; UV imaging	UV, imaging down to 115nm sufficient, spectroscopy down to 92nm preferred	10mas	R=1,000-40,000 (grating turret)	10'	>6m	>3x10^4 cm^2 in the UV - implies 10% (throughput + DQE) in the UV for a 6m telescope	300-2000s	MOS capabilities beneficial over a field as large as 20x20'
Massive Stars/Feedback	UV imaging and spectroscopy of massive stars in the Galaxy and nearby galaxies	UV, 120-160nm spectroscopy; 110-1000nm imaging	diffraction limited; 0.04" at 300nm	R=10,000	10-30'	>4m			large number of broad, medium and narrow filter bands; spectroscopic angular resolution 5 mas
Stellar Archaeology	resolved photometry of individual stars in nearby galaxies	optical (500-1000nm)	diffraction limited	N/A	10'	4-8m		100 hours/galaxy	this science can be done with smaller aperture telescopes, but a significant jump in capability occurs at around 8m
Dark Matter	integrated photometry + radial velocities and proper motions of stars in Local Group dwarf galaxies	optical (500-1000nm)	diffraction limited	?	10'	>=8m			astrometric accuracy of <40 m arcsec/yr