Galaxy Evolution Spectroscopic Probe (GESP)

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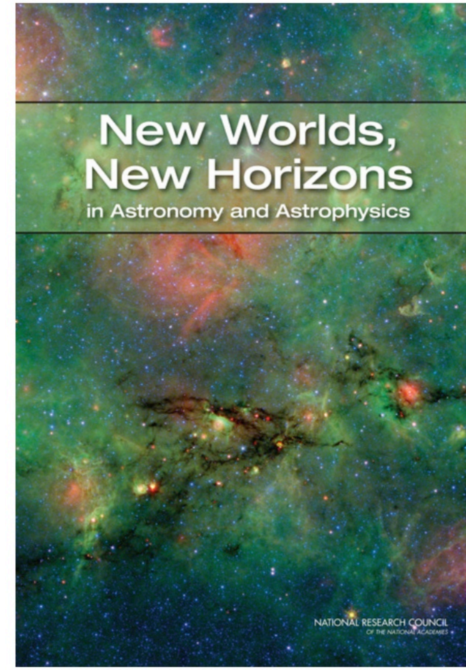
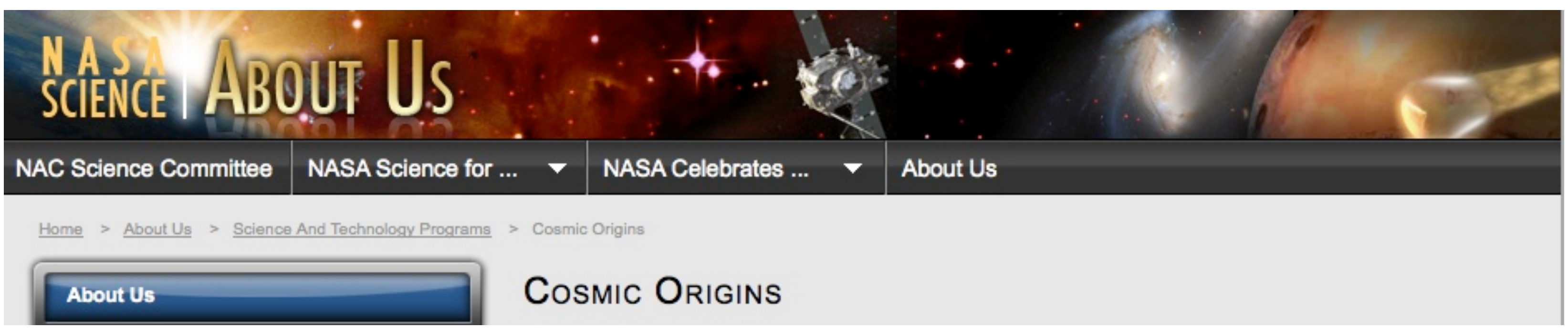
GESP reponds to:

* 2010 Decadal Survey

"A future UV space mission ... will move the subject of galaxy evolution ... to one of integrated measurements of the buildup of dark matter, gas, stars, metals, and structure over cosmic time. [It] will lay the foundation for the ultimate aim of a complete *ab initio* theory of galaxy formation and evolution." p. 7-14

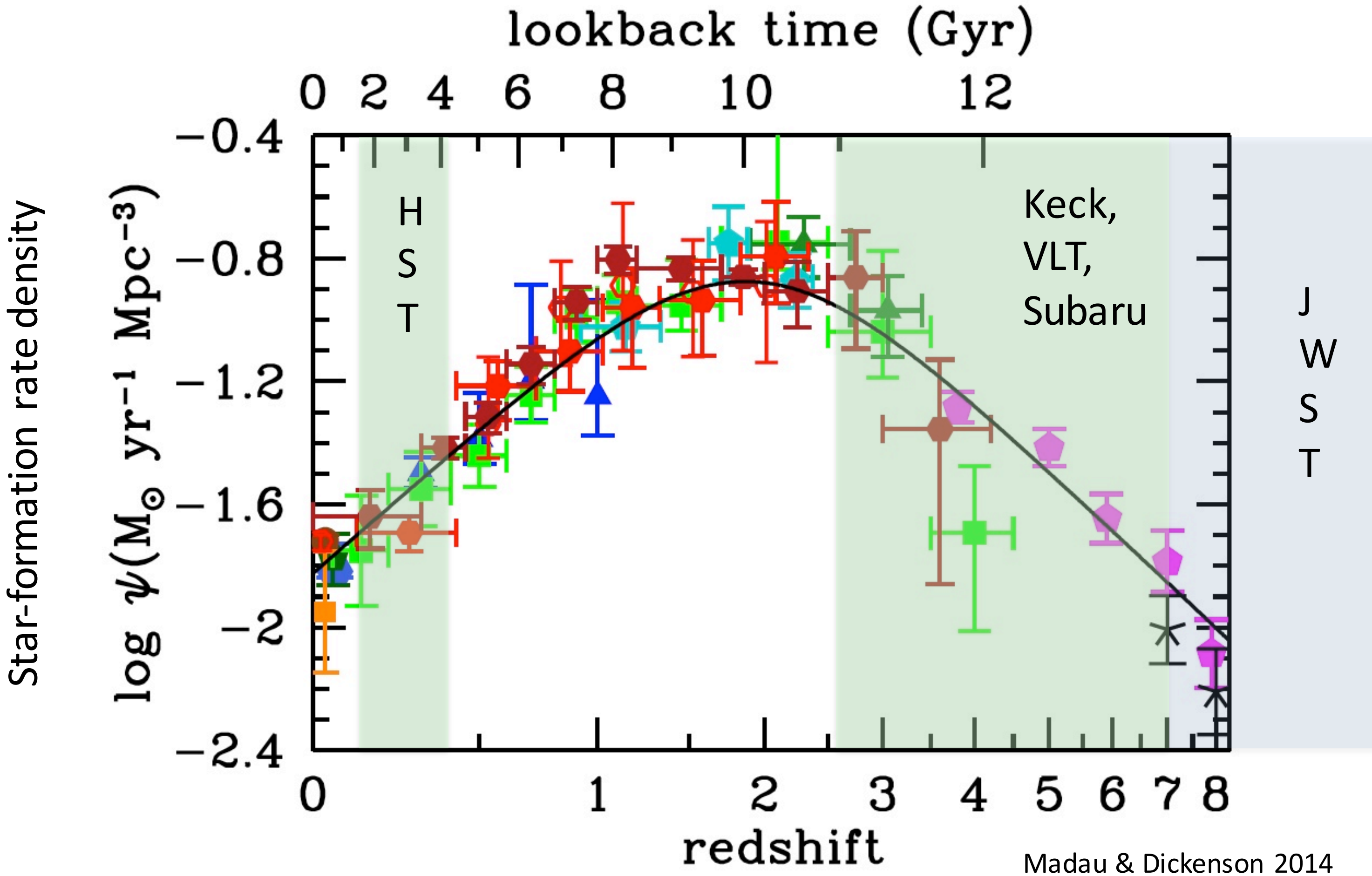


* NASA's Cosmic OriginsProgram



"Our big question: **How did the universe originate and evolve to produce the galaxies**, stars and planets **we see today**?"

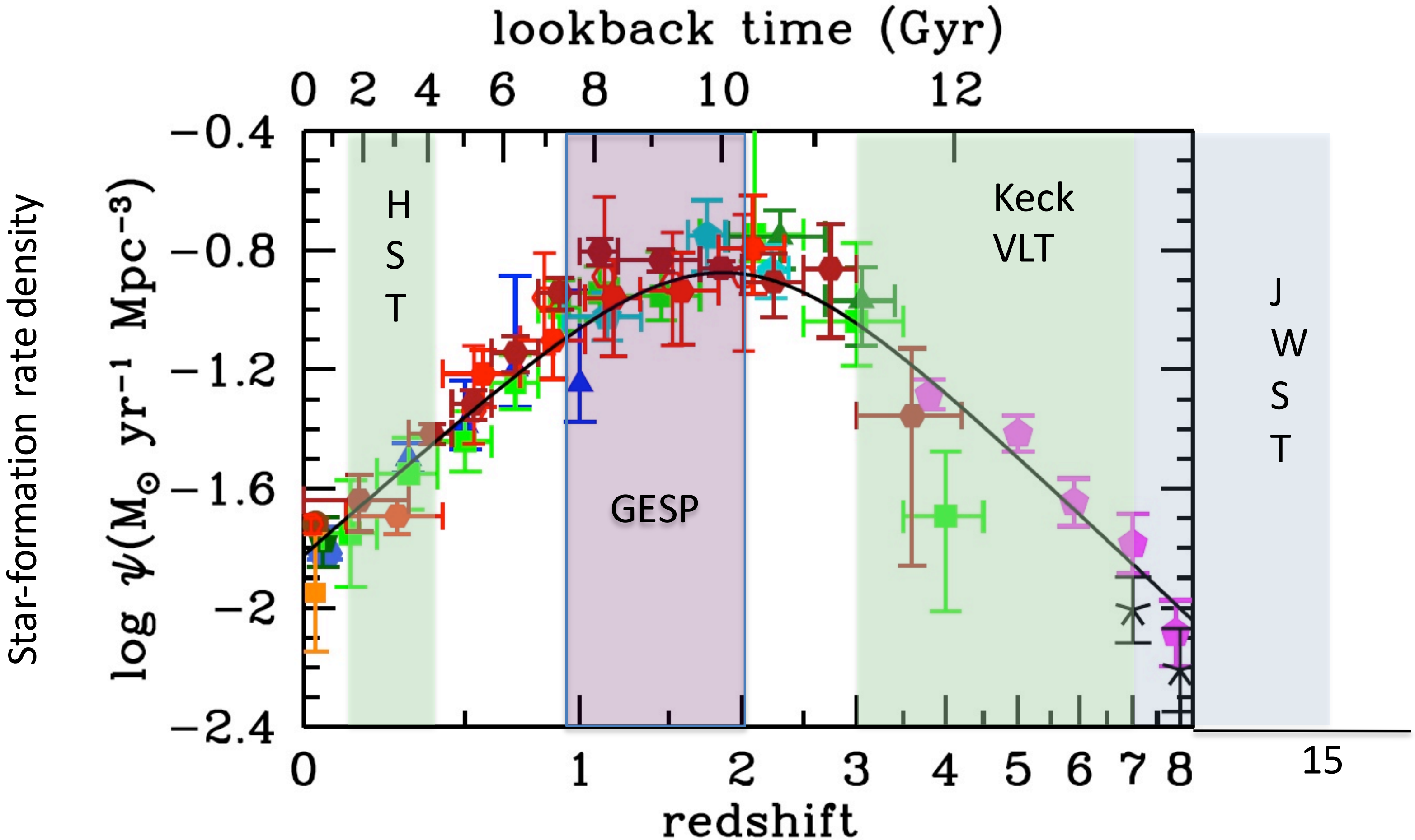
Far-UV spectra are needed for *understanding* galaxy evolution



Madau & Dickenson 2014

What processes drive galaxy evolution in the critical era of z~1-2?

GESP will identify processes driving galaxy evolution in the critical era of z~1-2



GESP will fill the hole in redshfit coverage of galaxies at z=1-2 when star formation reached its peak and started to turn down

GESP will make a massive spectroscopic survey of rest-frame far-UV spectra of galaxies at z=1-2

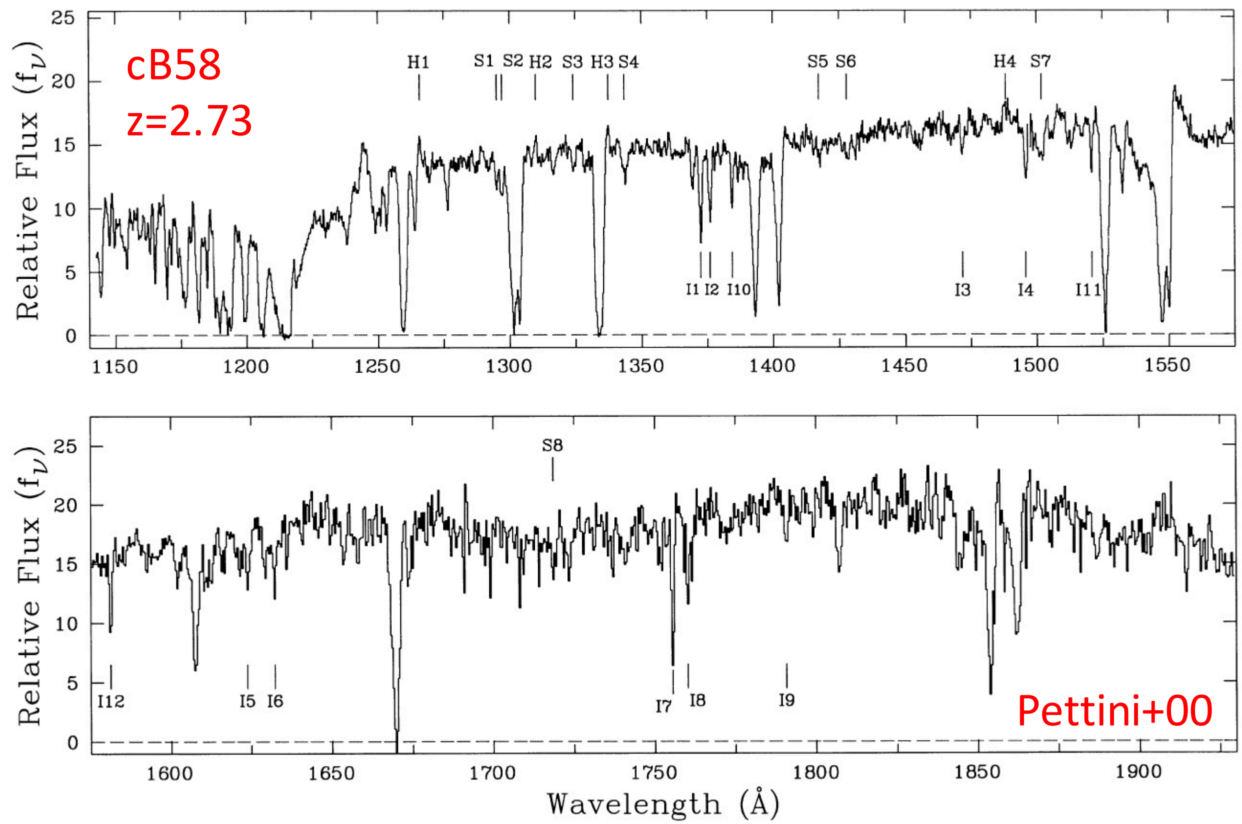


FIG. 1.—LRIS spectrum of MS 1512−cB58 reduced to the systemic redshift of the galaxy, $z_{stars} = 2.7268$. Tick marks above the spectrum identify weak stellar lines (labeled S*n*) listed in Table 1 and weak emission lines (labeled H*n*—see Table 4) that we attribute to H II gas. Tick marks below the spectrum (labeled I*n*) mark the positions of the intervening absorption lines listed in Table 6. The numerous interstellar lines in MS 1512−cB58 have not been marked

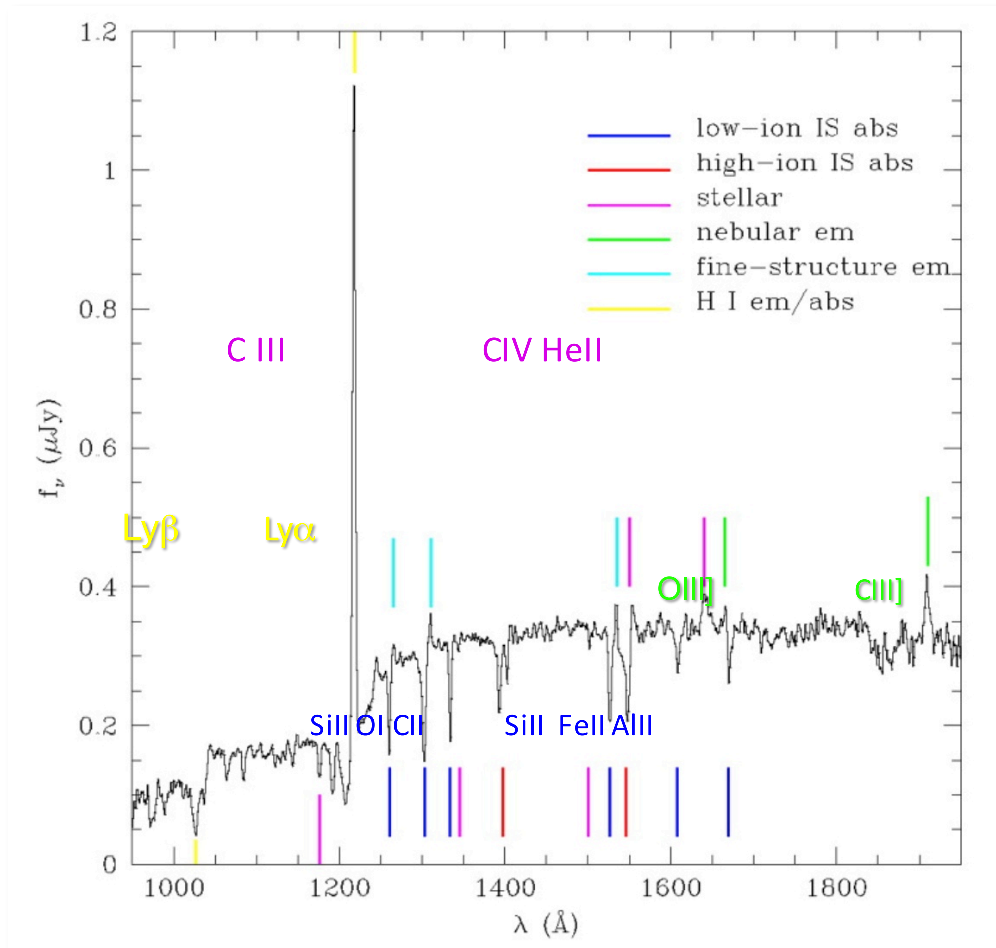
12/30/12

This far-UV spectrum yielded: SFR~40 $M_\odot$, protracted SF, IMF consistent with Salpeter IMF with M_u>50 $M_\odot$, Z~1/4 $Z_\odot$ (both stars & gas), $N_{HI}=7.5\times10^{20}$ cm^{-2}, galactic wind with velocity~ 200 km/ and rate ~60 $M_\odot$/yr, dust E(B-V)~0.1-0.3

Nearly all high-redshift galaxies are faint
∴ Have to stack spectra

Shapley+2003: Stack of 811 LBG spectra

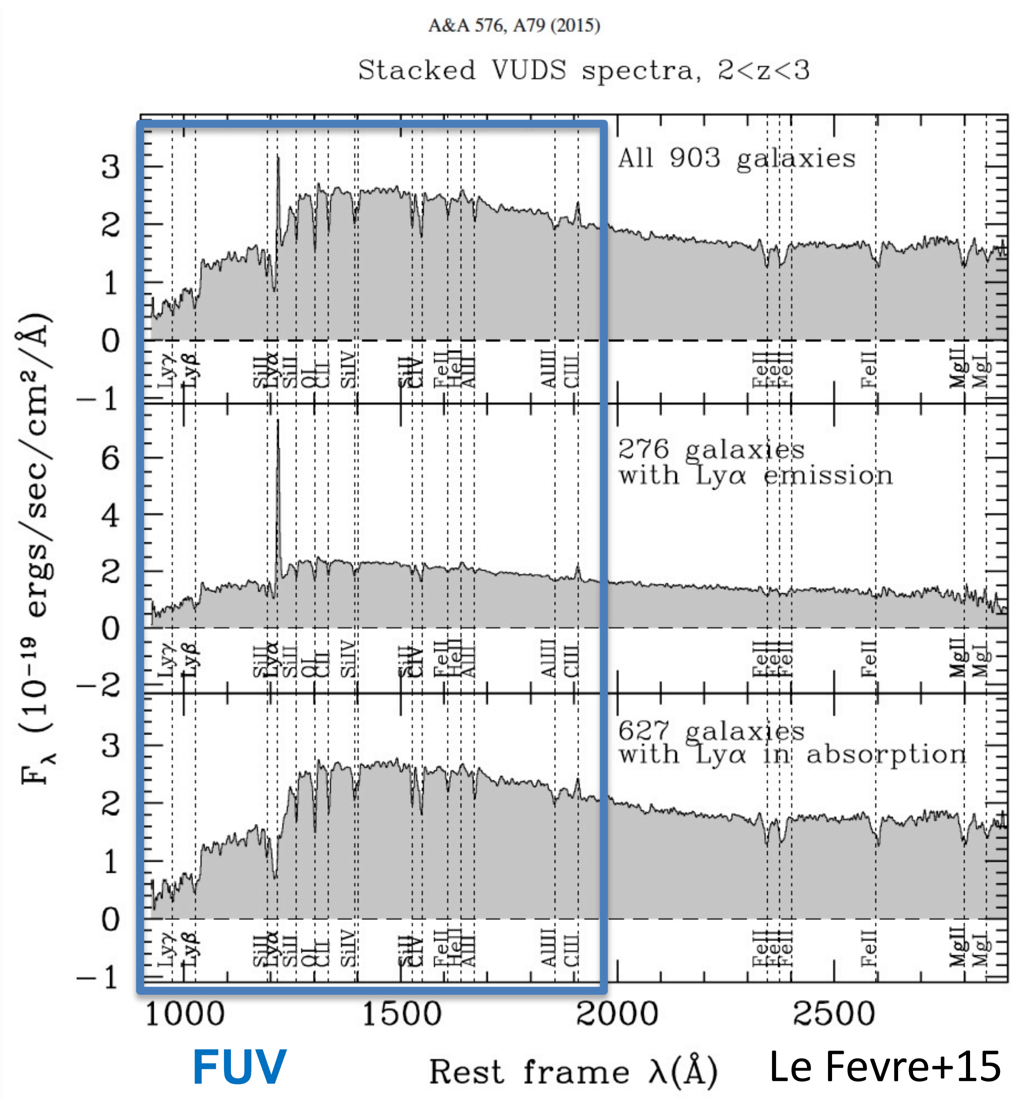
- 1320 $z_{phot}>2$ candidates observed
- Keck/LRIS spectra R~8-12 Å
- Individual spectra have S/N~4
- Galaxies with uncertain z's excluded
- 811 z>2 galaxies (not AGNs') selected



Stacks of VLT/VIMOS spectra of ~10,000 galaxies

VIMOS=Multi-object spectrograph on the European VLT

- Wavelength range: 3650-9350A
- Exposure time: 14 hr, broken up into ~1300-s integrations with dithering along the slit between integrations
- Spectral resolving power of grism is R~230 over the full wavelength range



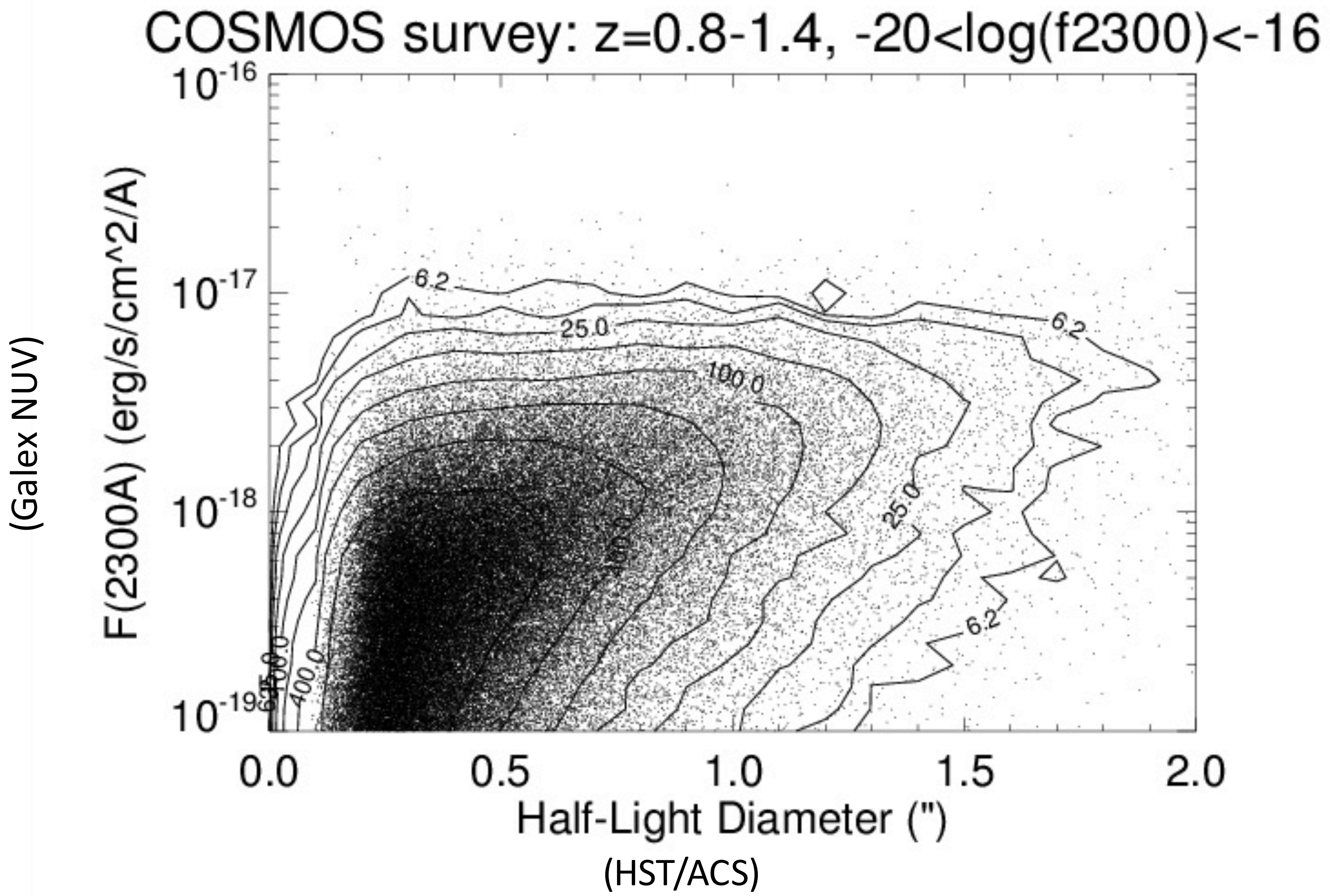
GESP will obtain ~1x10^5 restframe far-UV spectra of z~1-2 galaxies

We need to obtain enough spectra of galaxies to be able to constuct stacked groups of like galaxies to compare effects of:

- H I Lyman α in emission vs. Lyman α in absorption
- Spectral energy distribution → estimate of dust extinction
- Level of ionization of stellar spectrum → stellar ages, presence of exotic stars (WR stars, Pop III stars)
- Presence and strength of stellar winds
- Presence and velocity of galaxy outflows & mass-loss rate
- Ionization structure of the star-forming regions
- Correlation of properties with X-ray emission, etc.

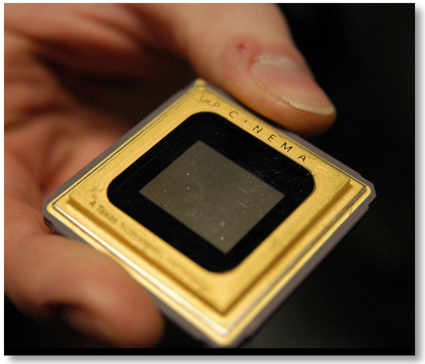
The S/N of individual spectra must be sufficient to identify like galaxies (S/N>4-6)

Star-forming galaxies at z=~1-2 are faint in the UV

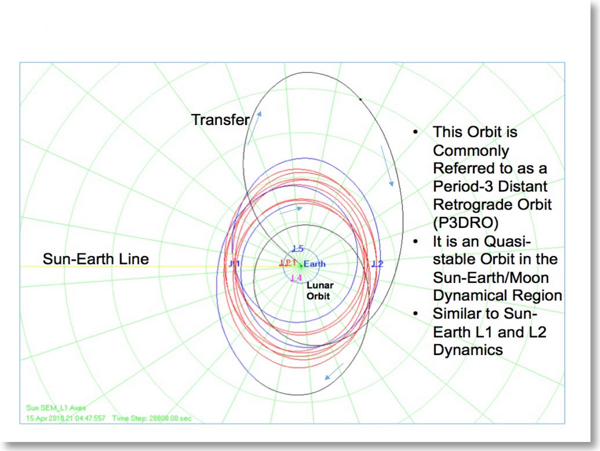


GESP will get >50,000 spectra in a 3-year mission by:

1. **Multiplexing** – Multi-object slit spectrograph
   - Slit generator – DMD's
   - Wide field of view



2. **High UV Sensitivity**
   - Telescope aperture – D_{tel}>1.5m
   - Optical throughput - # of reflections; slit size vs. galaxy size
   - Detector UV QE – 4Kx4K CCD from e2v
   - Exposure time
3. **High Observing Efficiency**
   - Custom Orbit
   - Science partnership with Subaru/PFS



GESP has a Science Partner: Subaru/PFS

	GESP	Subaru/PFS
Scientific Goal	Galaxy evolution	Galaxy evolution
Primary targets	z~0.8-2.0 galaxies	z~1-2 galaxies
Wavelength coverage	0.2-0.4 μ	0.4-1.3 μ
Coverage of Lyα	z~0.7-2.2	z>2.2
Telescope	1.2 m	8.2 m
Orbit	Custom orbit	Ground-based
Primary mission	3 years (~26,000 hr)	100? nights
Exposure time	10 hr	~0.3-3 hr
Galaxy spectra per exposure	100	2000
Spectra density	~1000 spec/deg^2	1800 spec/deg^2
Sensitivity	few x10^{-18} erg/s/cm^2/Å	few x10^{-18} erg/s/cm^2/Å

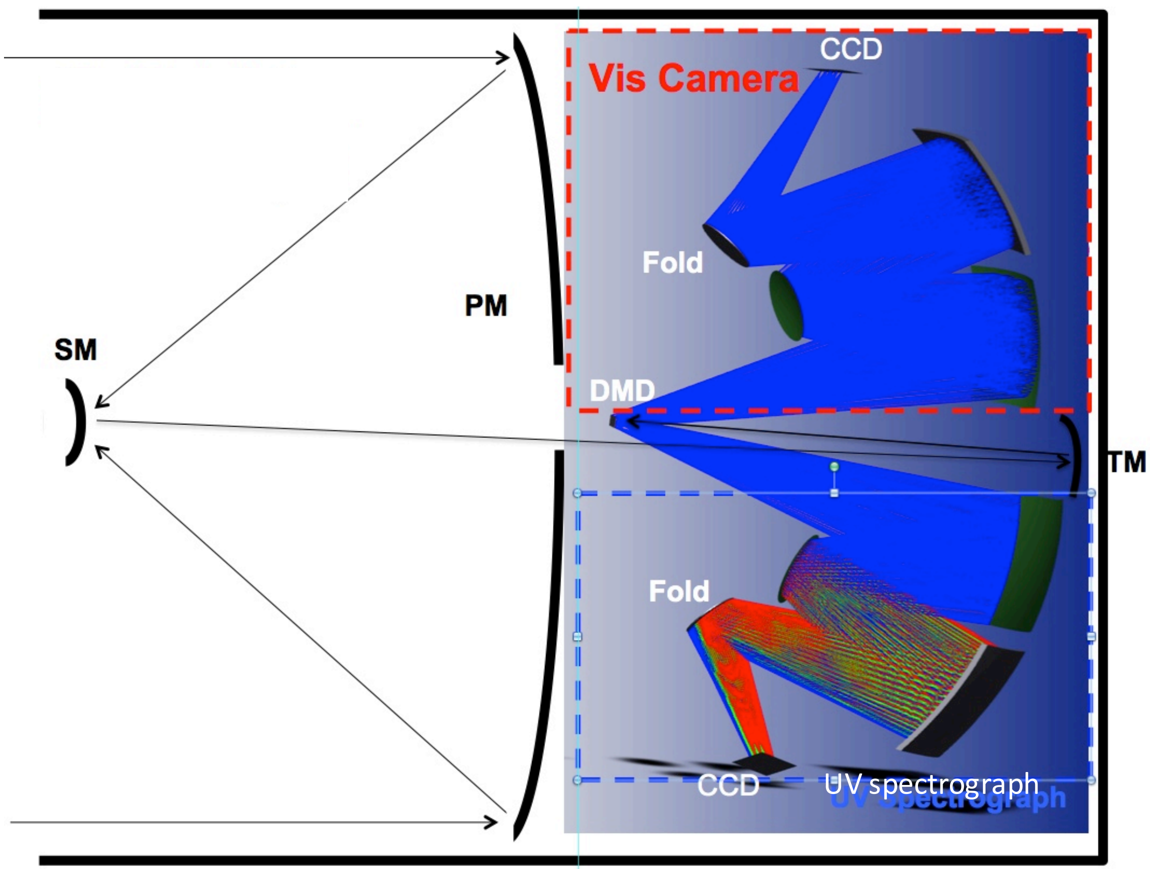
The value of GESP and Subaru/PFS spectra grows in combination, producing a UV-optical-IR spectrum (200-1300 nm)

Together, GESP + Subaru/PFS spectra will give diagnostics of the basic processes driving galaxy evolution at z~1-2

Drivers of Galaxy Evolution	Rest-UV Diagnostic	Rest Optical Diagnostic
Infall/Accretion	Z_{HI}	M^*, Z_{HII}
Star Formation	Far-UV flux	$H\alpha$ flux
Stellar Feedback		
-- Stellar winds	Far-UV line spectrum	
-- Photo-ionization and heating	Far-UV line spectrum	Optical nebular line spectrum
-- SN→galaxy outflows	Far-UV line spectrum	
AGN Feedback	Far-UV line spectrum	Optical nebular line spectrum

GESP will identify target galaxies on *g*-band images of PFS field

1.5m f/4 telescope with DMD slit generator



<u>HOW IT WORKS</u>

1.Identify GESP targets in Vis Camera g-band images with all DMD mirrors OFF

2. Turn DMD mirrors on GESP targets to ON

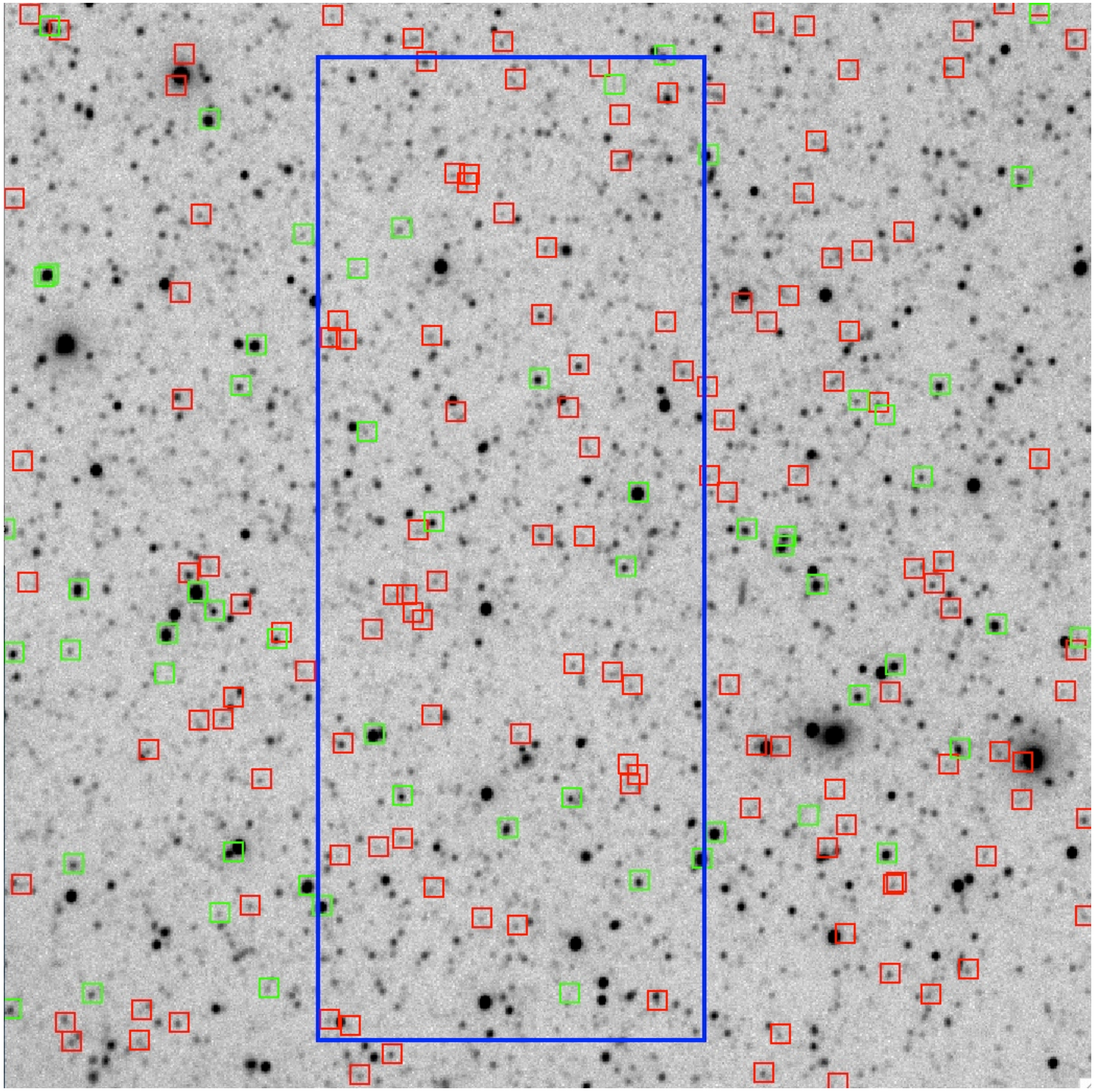
3. Get NUV spectra of target galaxies while Vis Camera gets deep image of field

Typical NUV Image

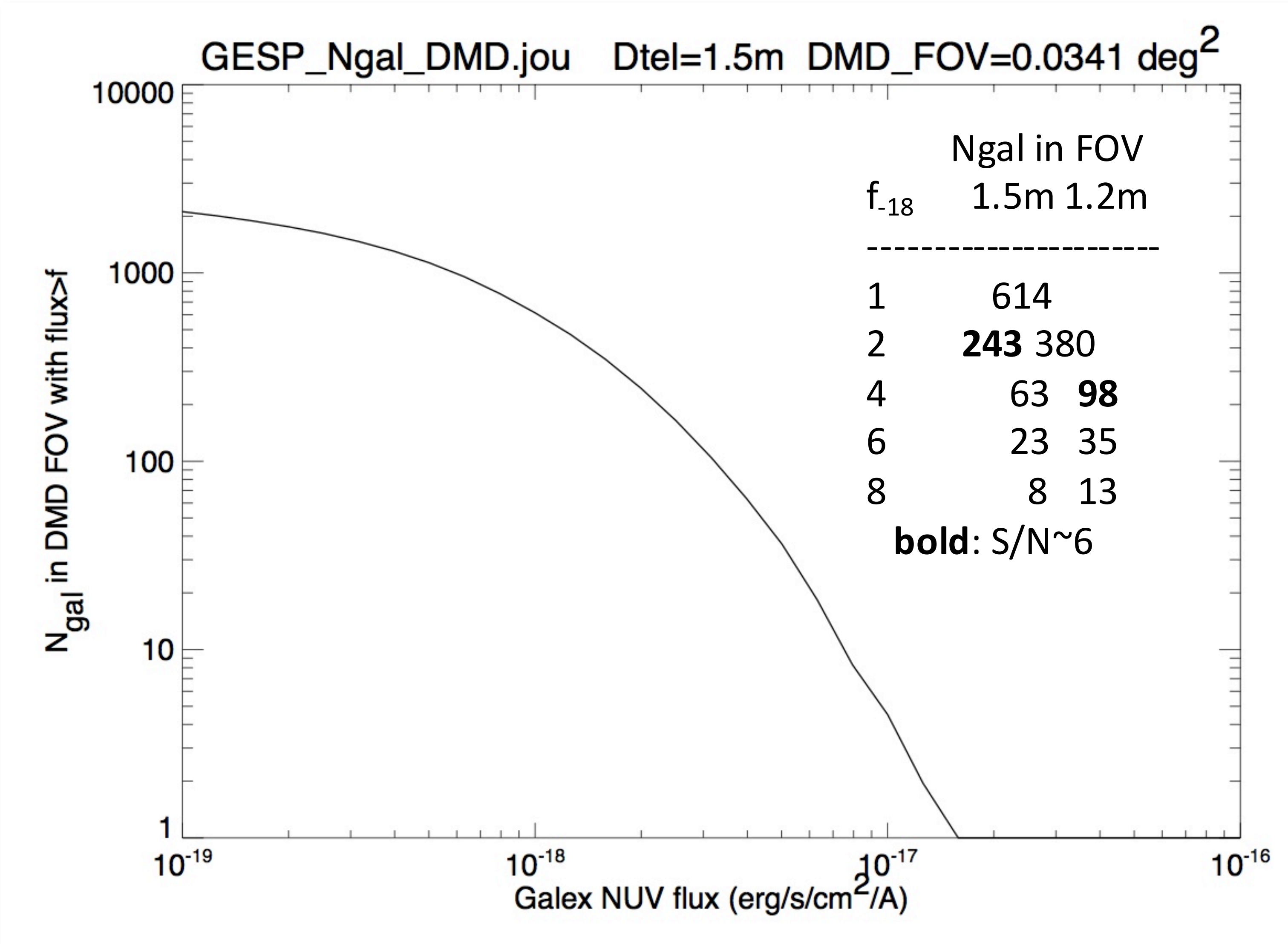
Galex NUV image of the central COSMOS field

Red boxes:
- z=0.8-1.3 galaxies
- *g*≤24 mag
- *g*-*r* ≤ 0.6

Green boxes
- z<0.4 galaxies



The number of galaxies in the FOV decreases exponentially at NUV fluxes above ~1×10^{-18} erg/s/cm^2/Å

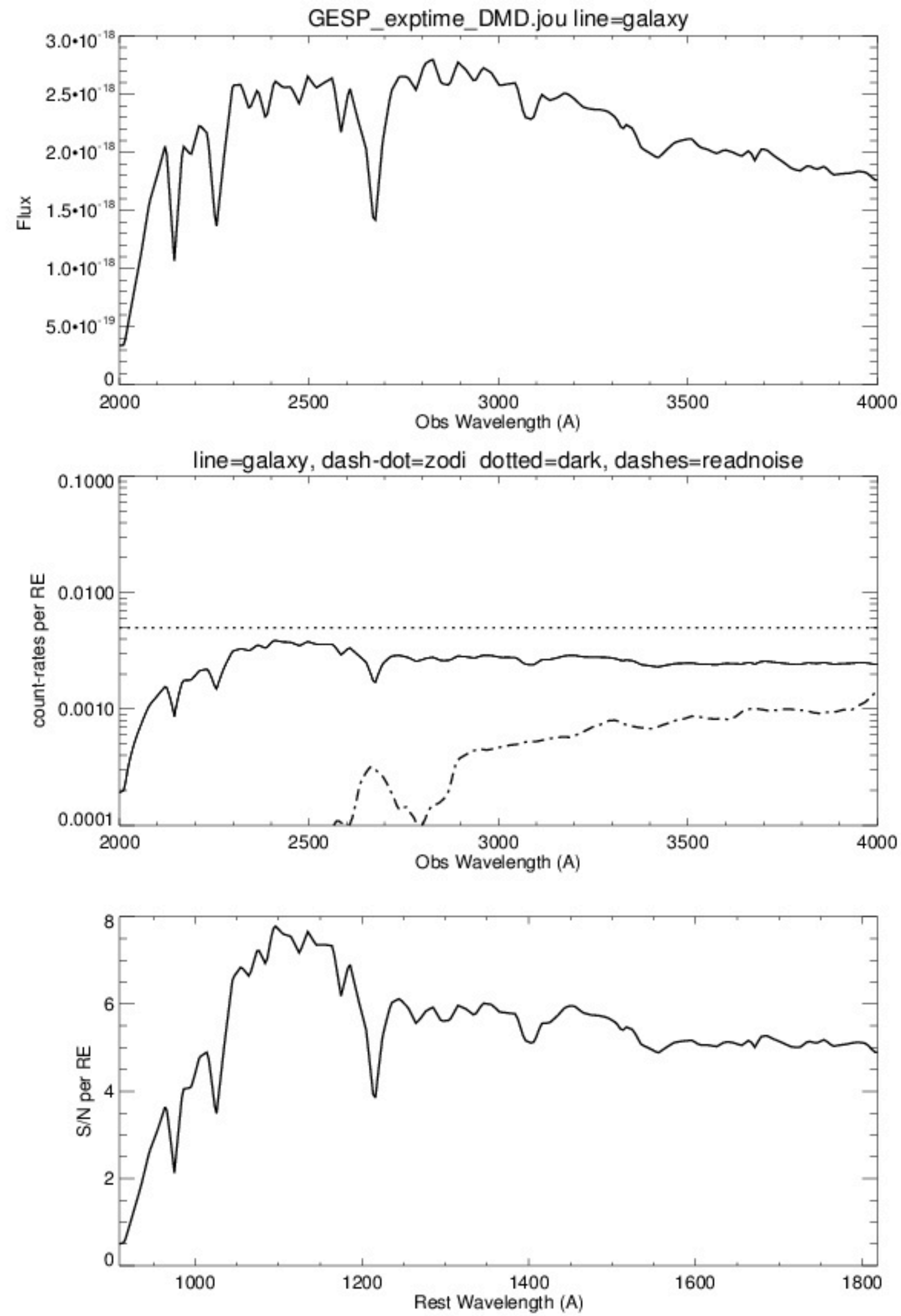


SIMULATIONS

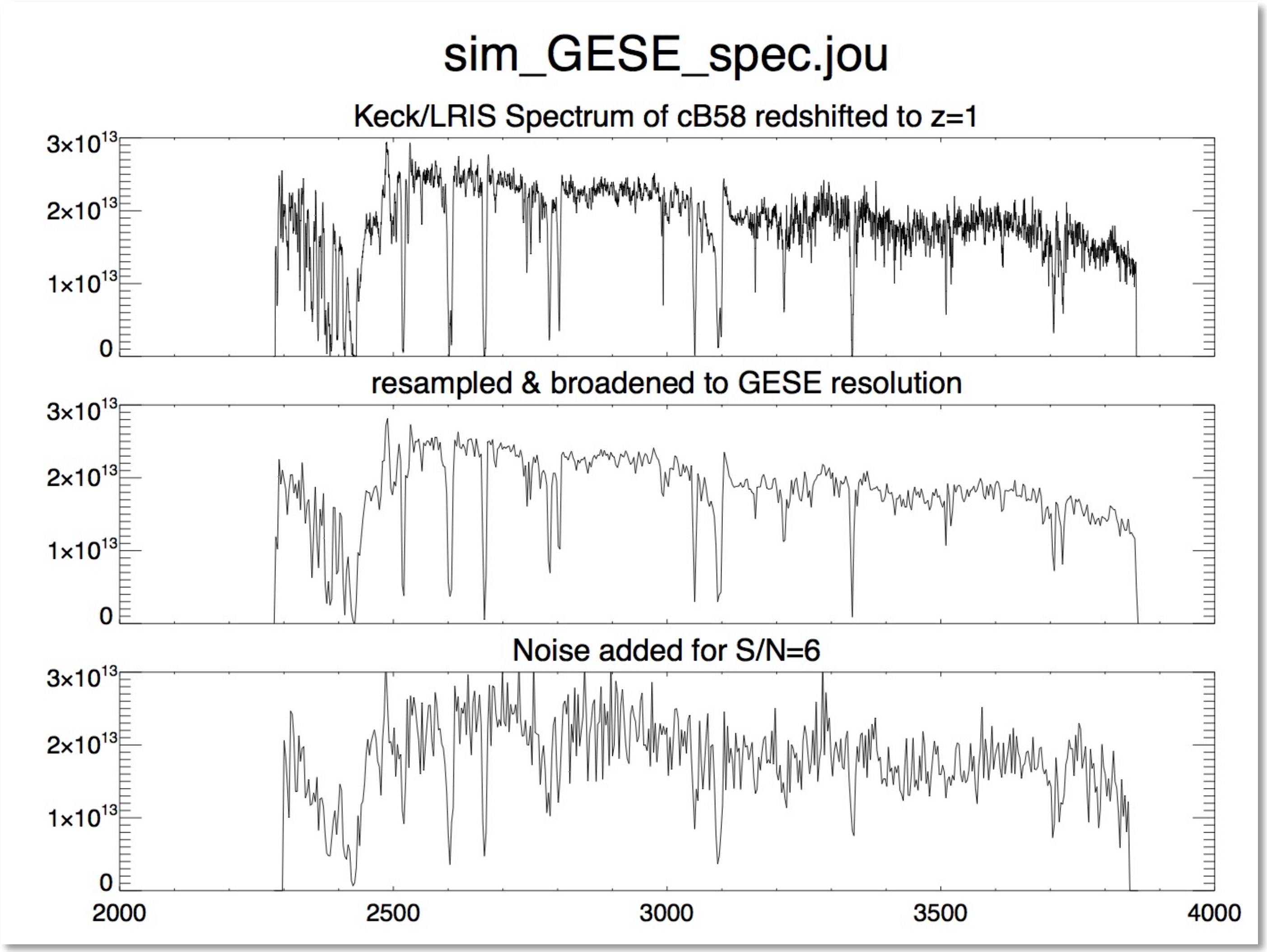
Redshift, z = 1.20
Galaxy model 28
E(B-V) = 0.20
F(2300)= 2.000 10^(-18) erg/s/cm2/A
Galaxy Dhalf = 1.00 arcsec
Zodi factor = 1.20

Exposure time (hr) =10 hr
Dtel = 1.50 m
Telescope f/ 4.00
DMD slit size =0.46 x 1.40 arcsec
DMD FOV =469 x 939 arcsec
Omega = 0.034 sq degrees

CCD Pixel size = 0.413 arcsec
Mirror size = 0.470 arcsec
X-disp bin (pix = 3
Obs, rest RE = 6.00, 2.72 A
Readnoise per RE = 0.0
Dark Rate per RE = 0.0050 C/s/pix



Strong spectral features make registration and coaddition possible



GESP Technical, Schedule, and Cost Risks

Key Component	Source	Technical	Schedule	Cost
Telescope PM	1.5m zerodur -- AOS polish --	Low Low	6 months 9 months	$2.5 M $0.7 M
Detector	e2v 4Kx4K CCD dev. for Euclid	Low	12 months	$2.0 M catalog item
Slit Generator	Modified TI DMD 2Kx1K mirrors	Low-moderate	9 months 1 yr tests	$0.2 M actual SAT
Large convex grating	Zeiss	Low	9 months	$0.2 M (eng. Grade)

SUMMARY

- GESP will make fundamental contributions to our understanding of the evolution of galaxies in the critical era, z=1-2
- GESP is the *only* mission concept that can survey the far-UV spectra of z=1-2 galaxies
- GESP is ready for development once probe-class missions are approved by NASA ASD
- The cost of GESP is likely the same as that of Discovery missions (i.e. ~$400M).