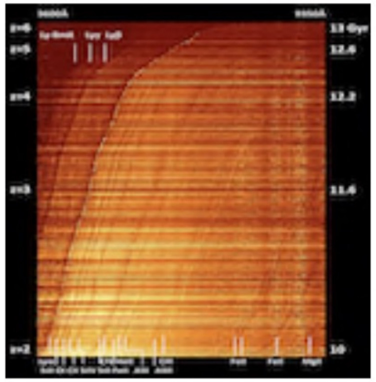


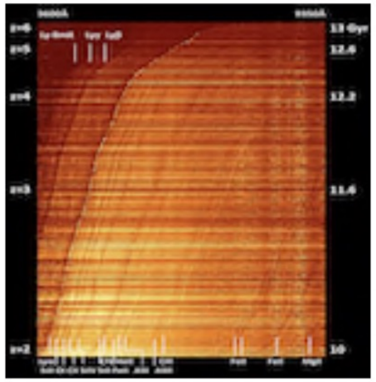
From galaxies to cosmology with deep spectroscopic surveys

A tribute to Olivier Le Fèvre. 4-8 July 2022

4-8 juil. 2022 Marseille (France)

General Introduction

Mark Dickinson, NSF's NOIRLab

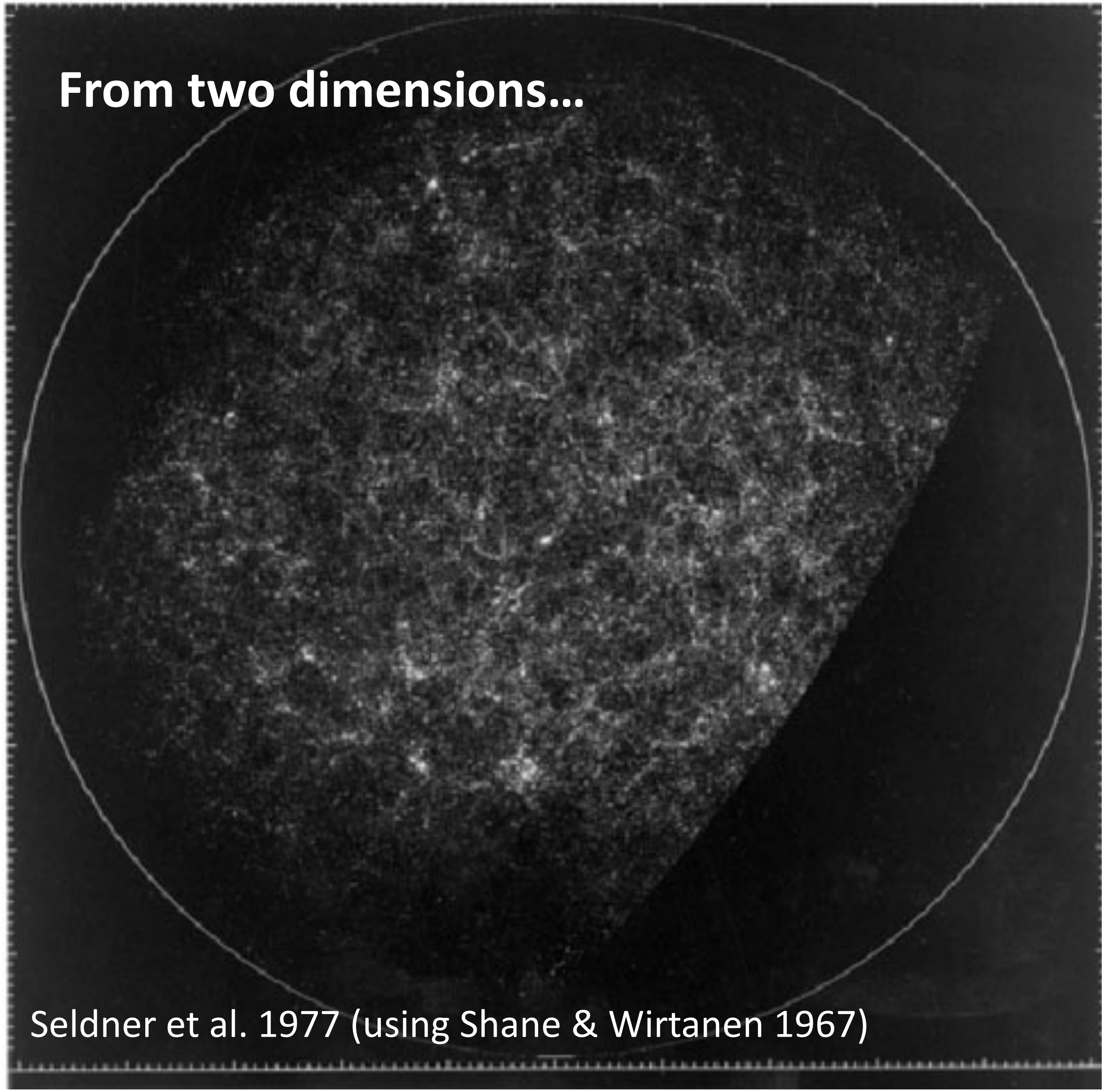


From galaxies to cosmology with deep spectroscopic surveys

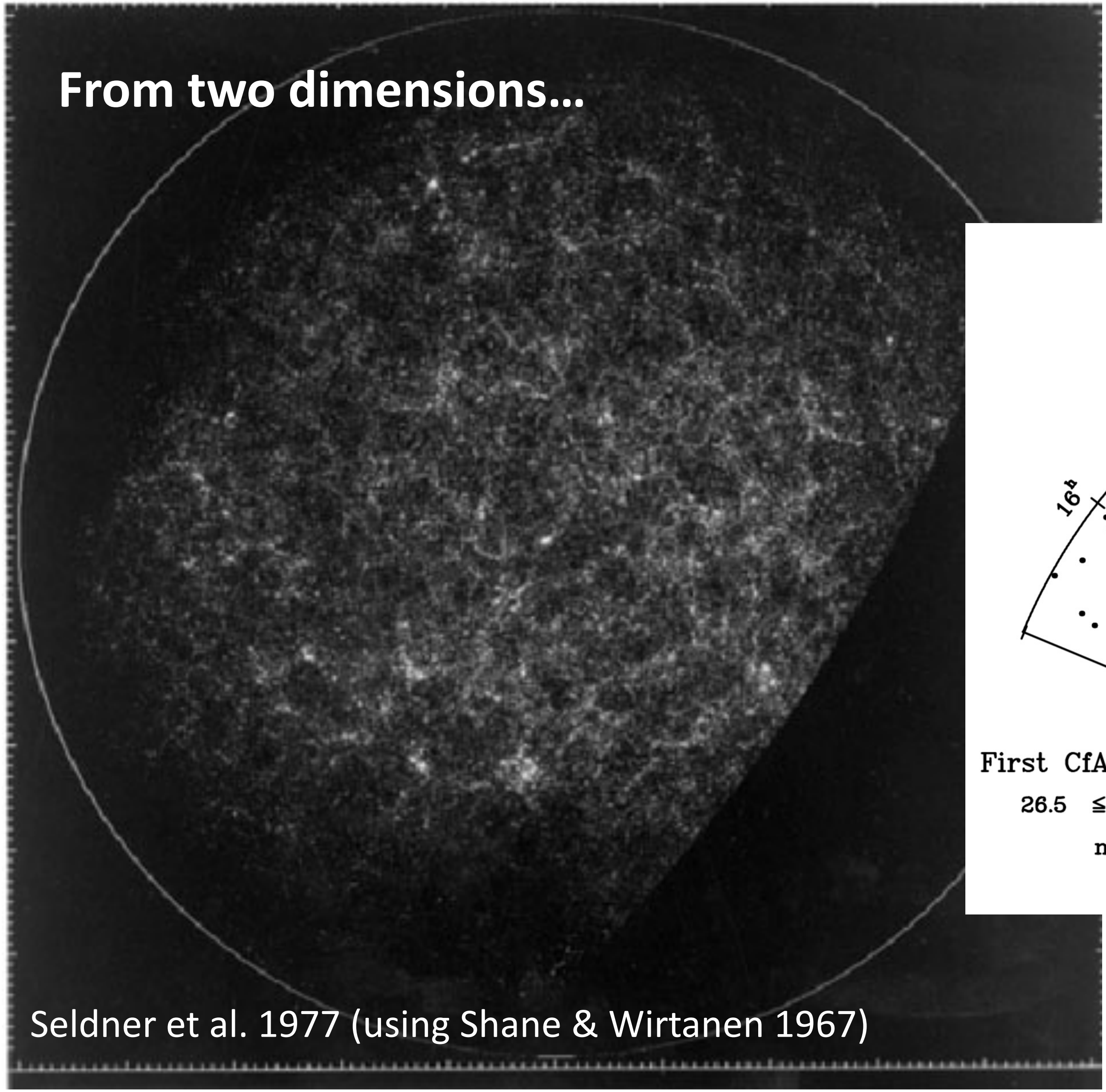
A tribute to Olivier Le Fèvre. 4-8 July 2022

4-8 juil. 2022 Marseille (France)

A spectrum is worth a thousand images.
A thousand spectra are worth…

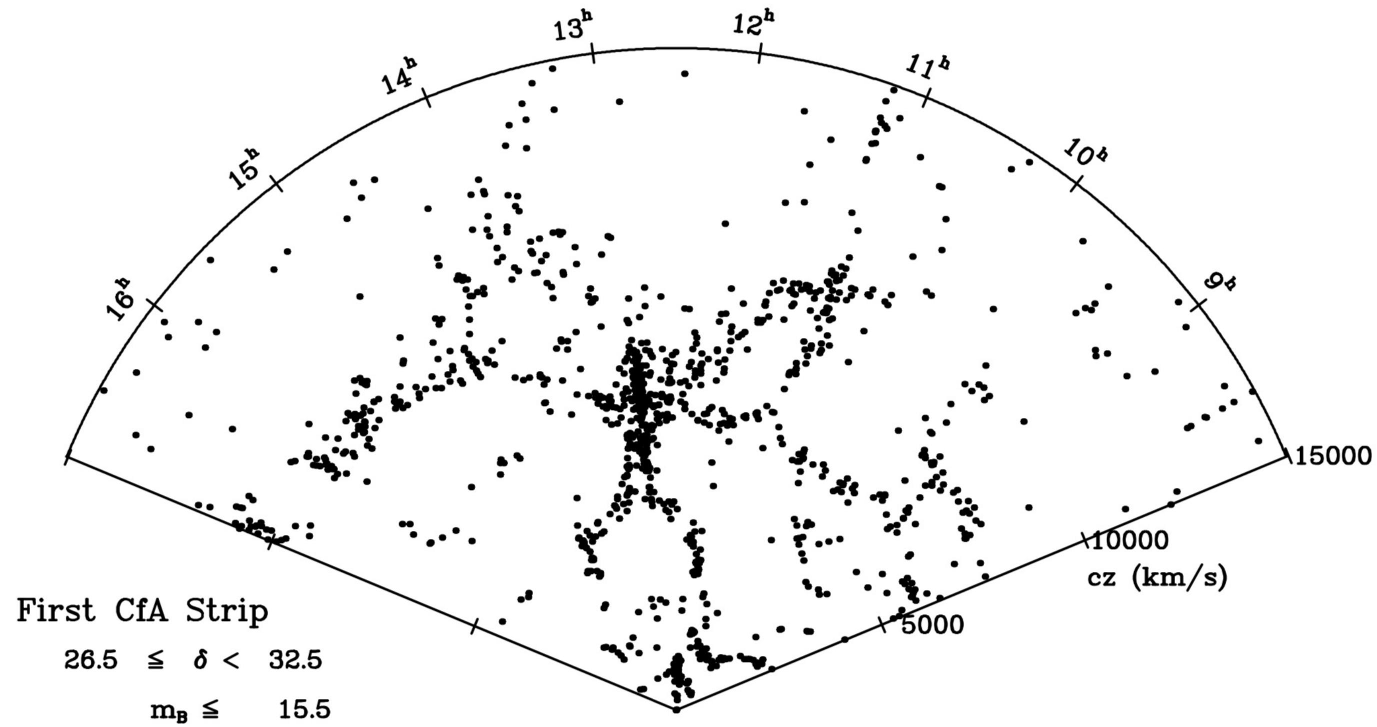

From two dimensions…
Seldner et al. 1977 (using Shane & Wirtanen 1967)

From two dimensions…



Seldner et al. 1977 (using Shane & Wirtanen 1967)

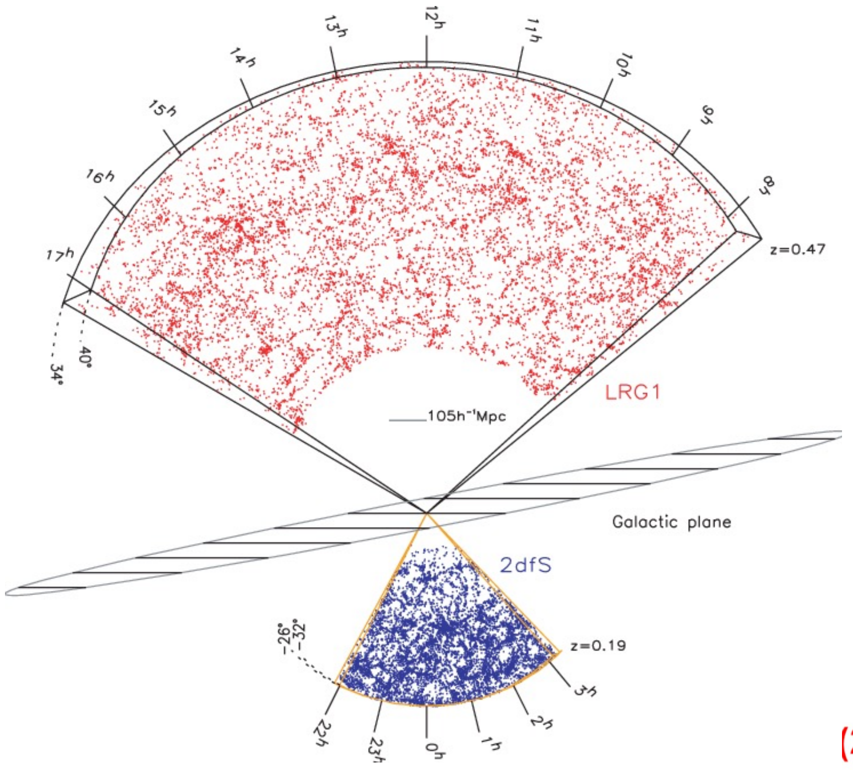
…to three



de Lapparent, Geller & Huchra 1986
1061 galaxies

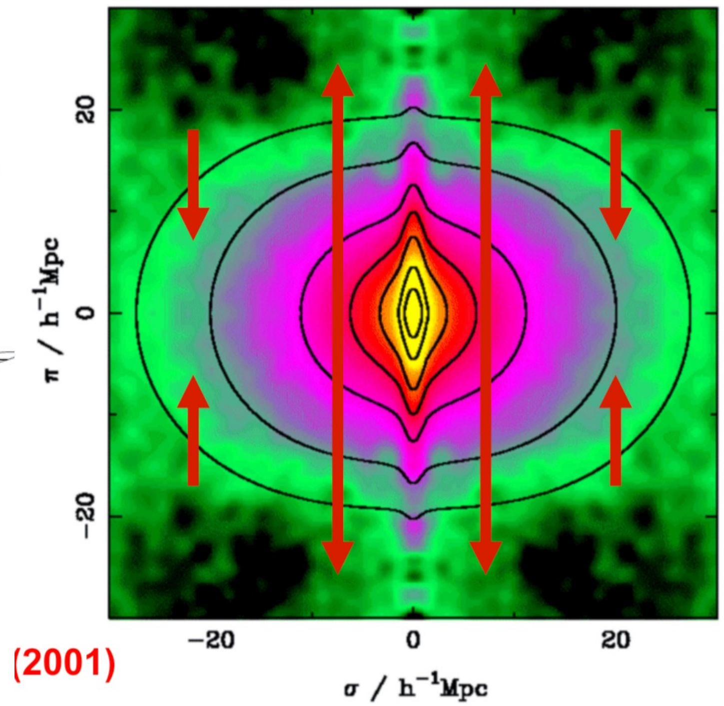
Today's talks: Sylvain de la Torre + all

Cosmology from large redshift surveys



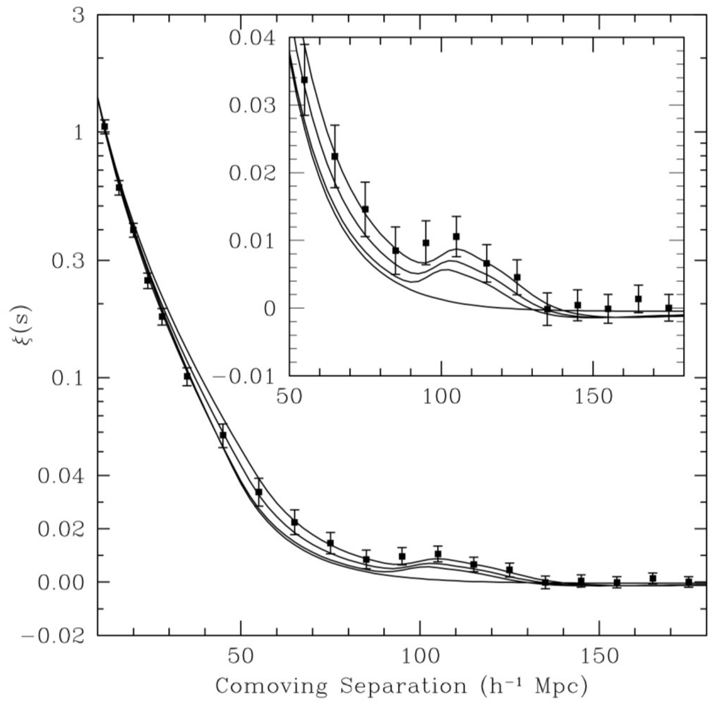
Martínez et al. 2009

Redshift Space Distortions



Peacock et al. 2001

Baryon Acoustic Oscillations

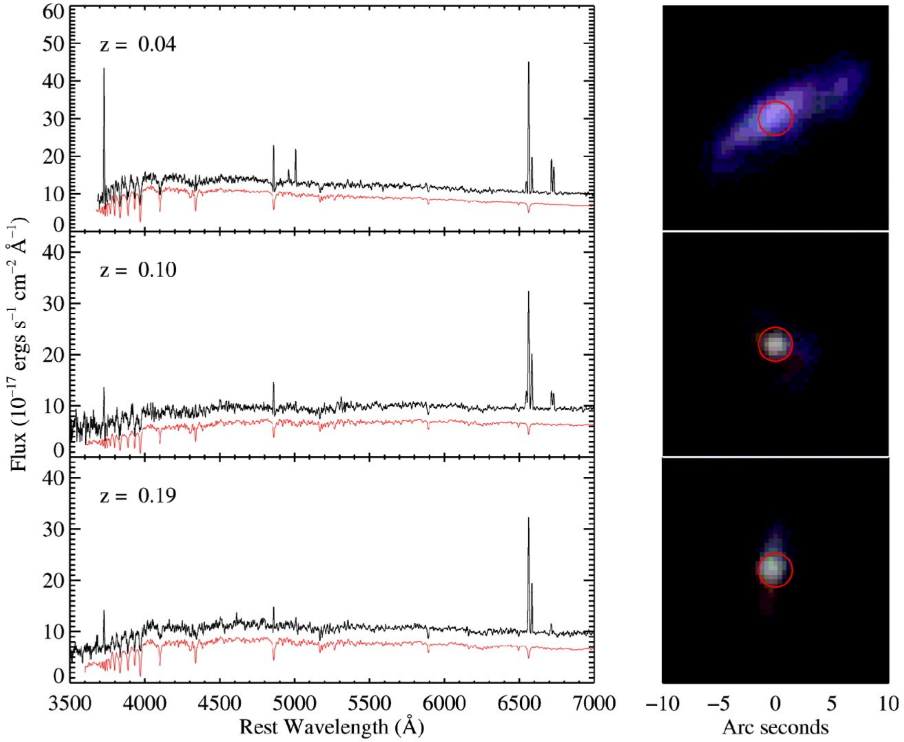


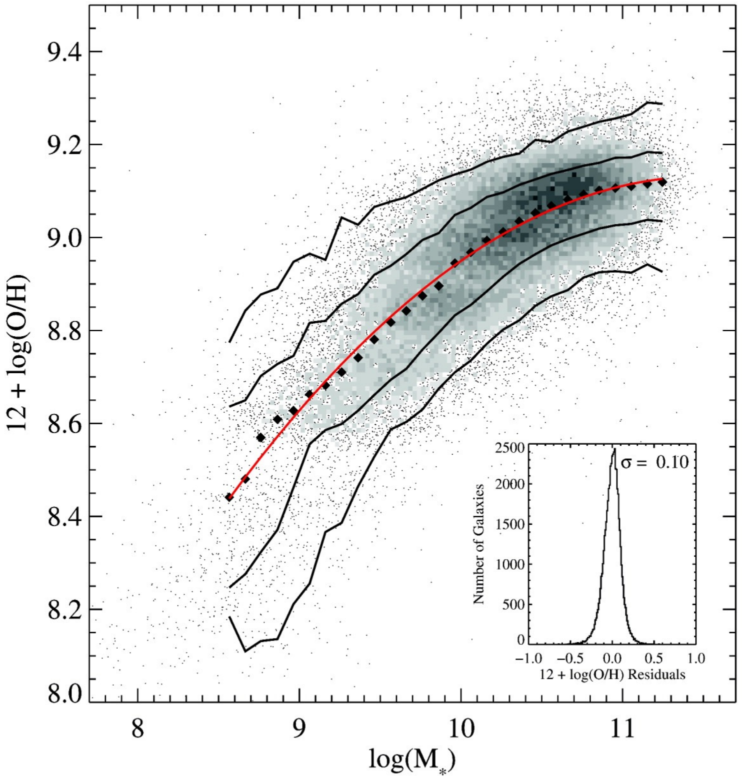
Eisenstein et al. 2005

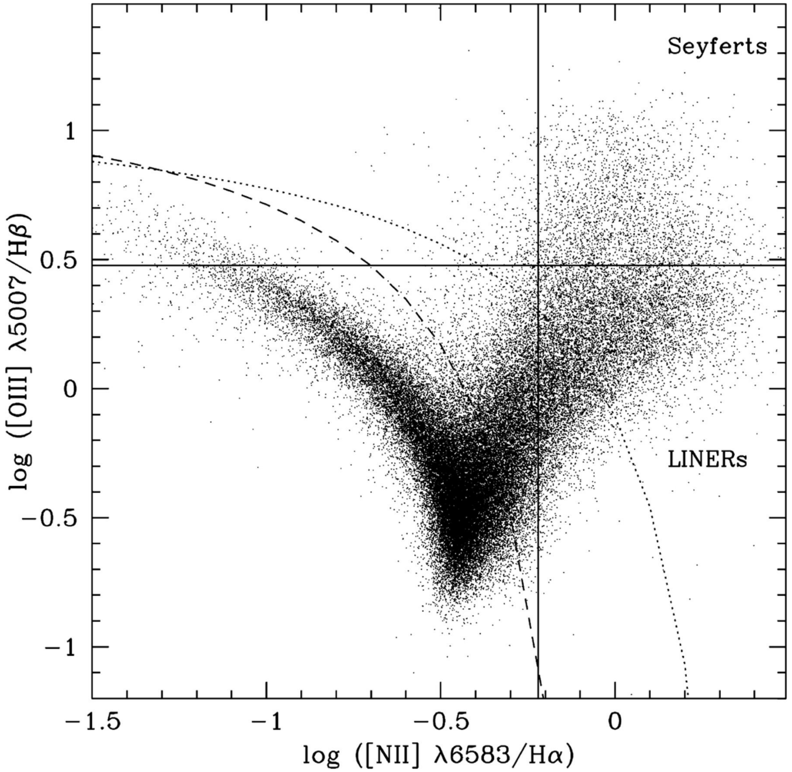
Galaxy properties

Mass – Metallicity

ISM excitation



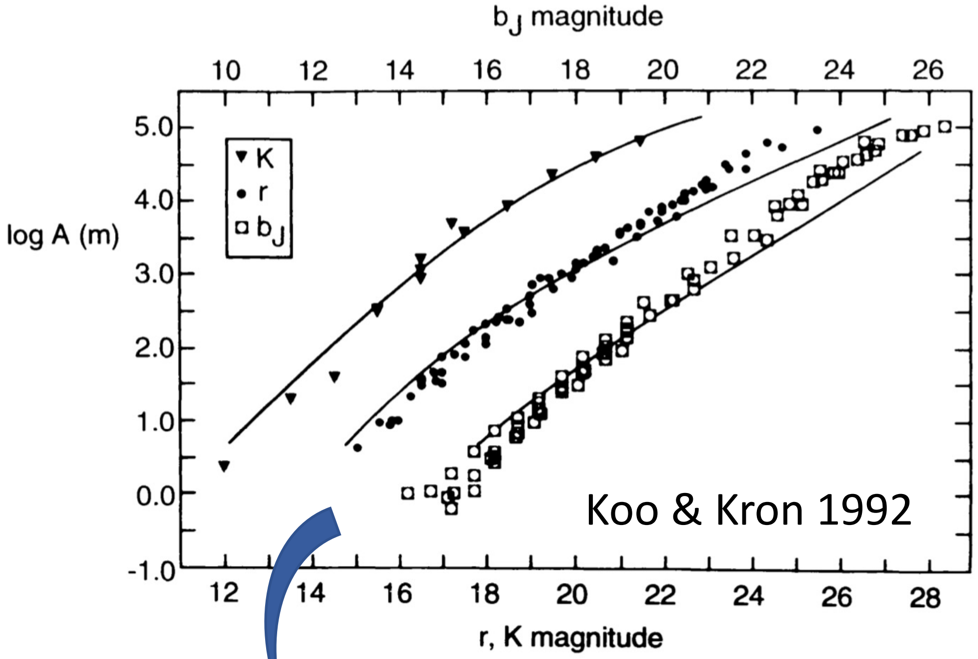


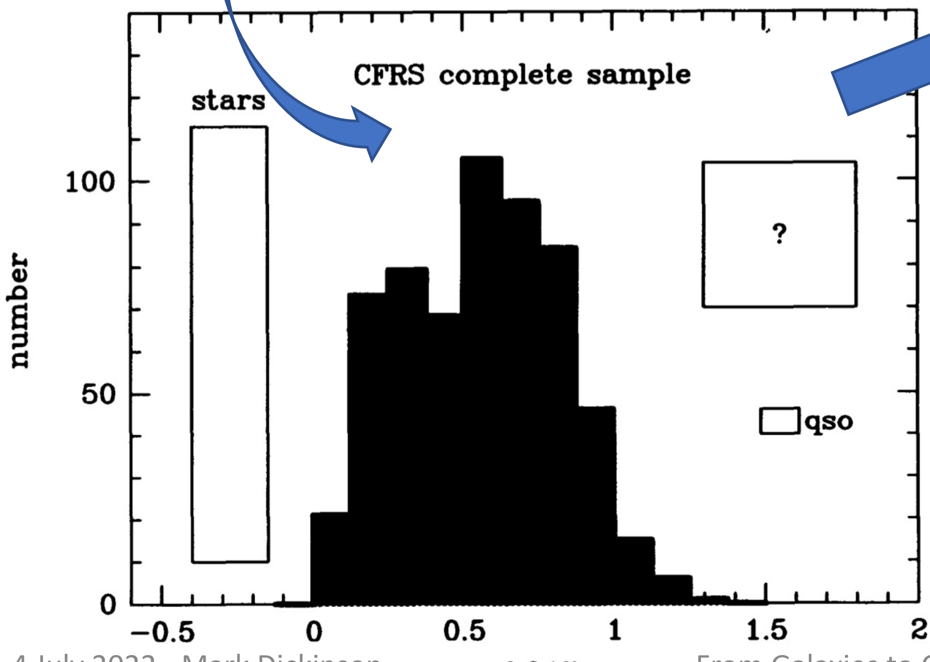


Tremonti et al. 2004

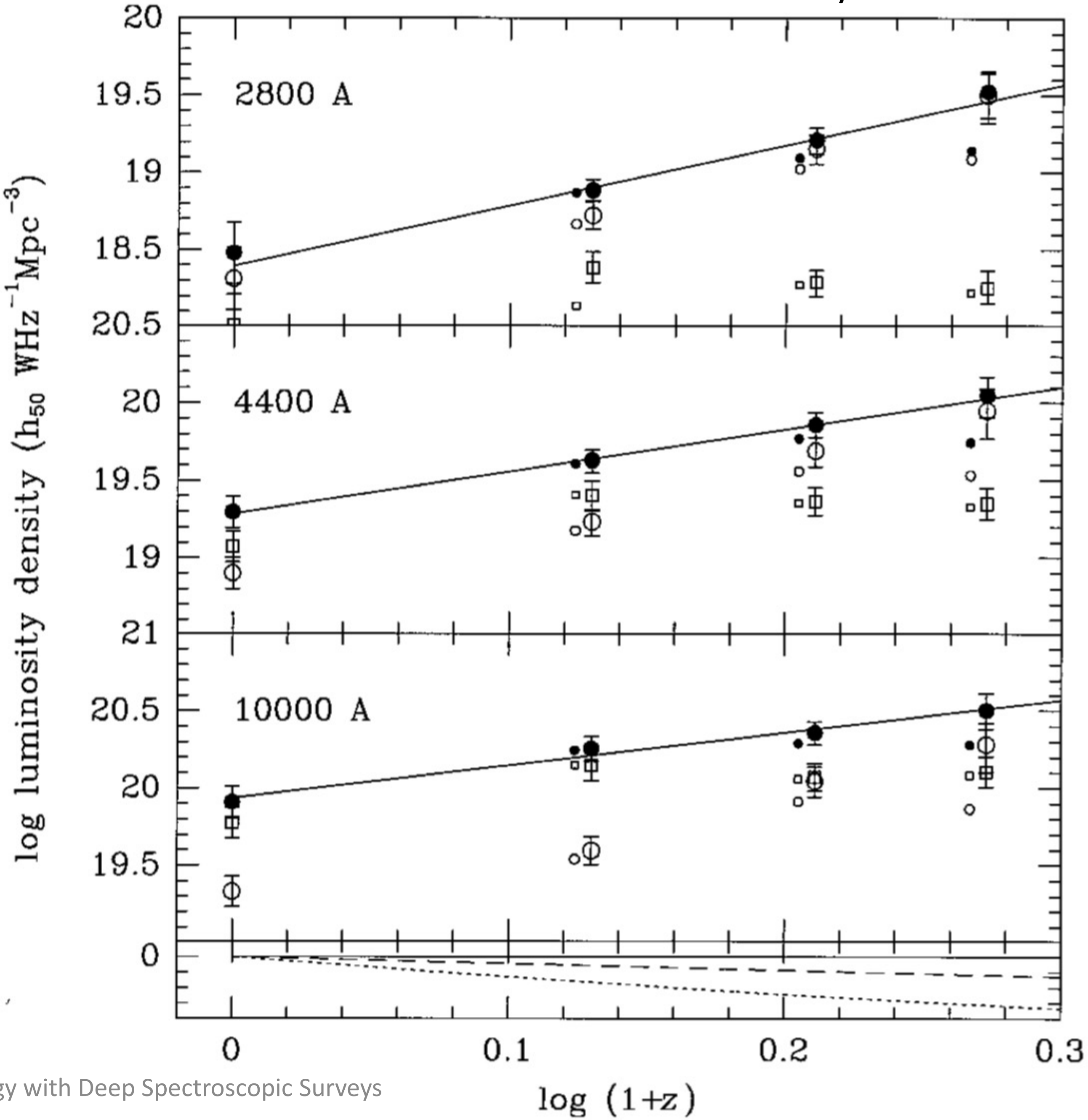
Kauffmann et al. 2003

Lilly et al. 1996

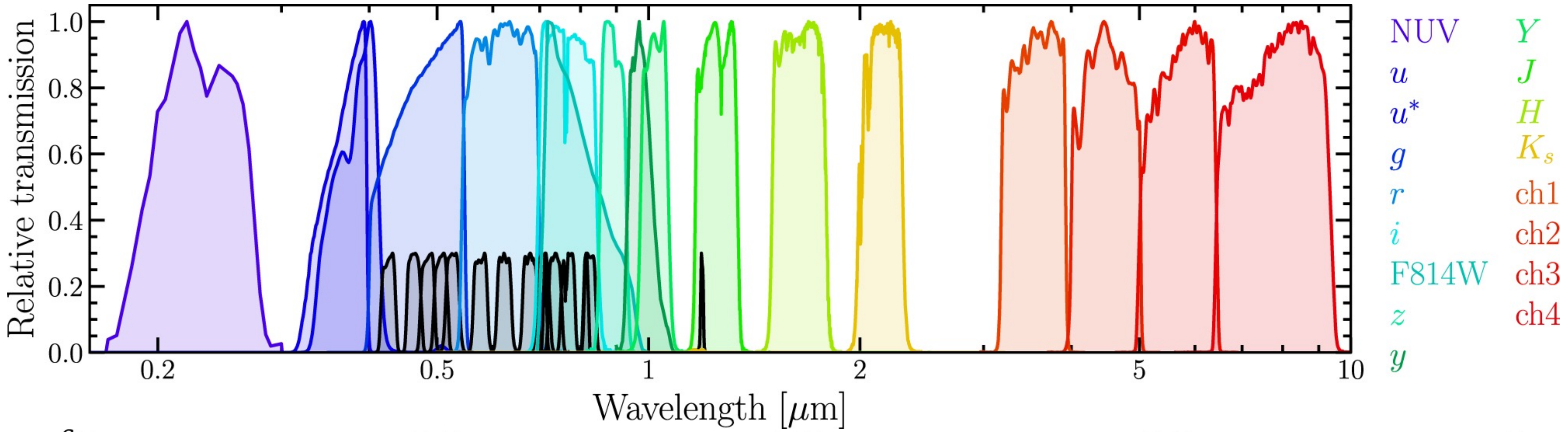




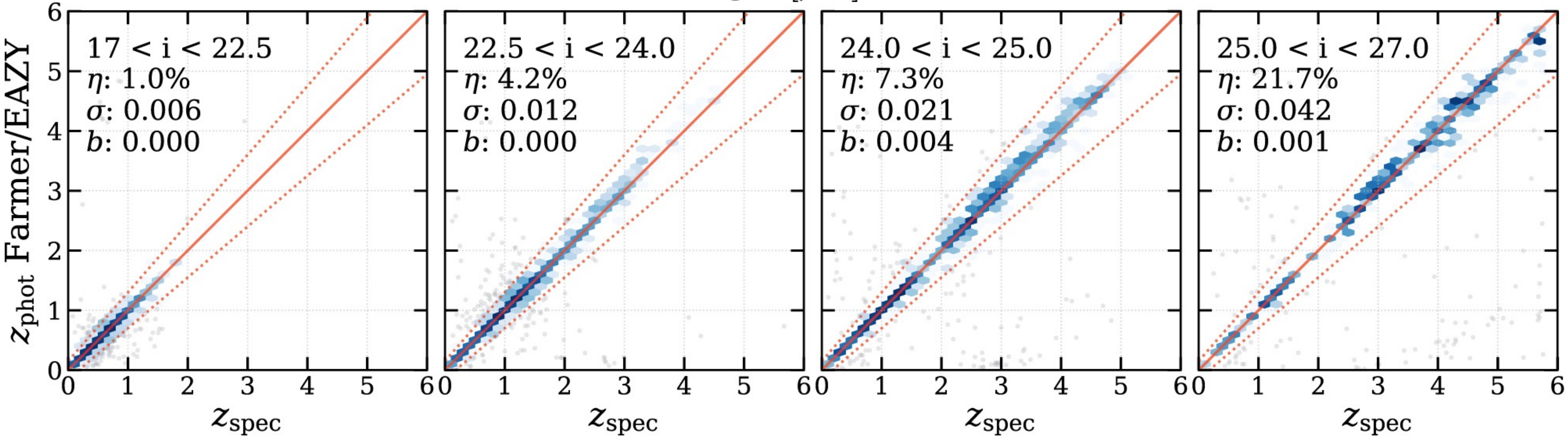
Crampton et al. 1995



Even imaging surveys are redshift surveys…



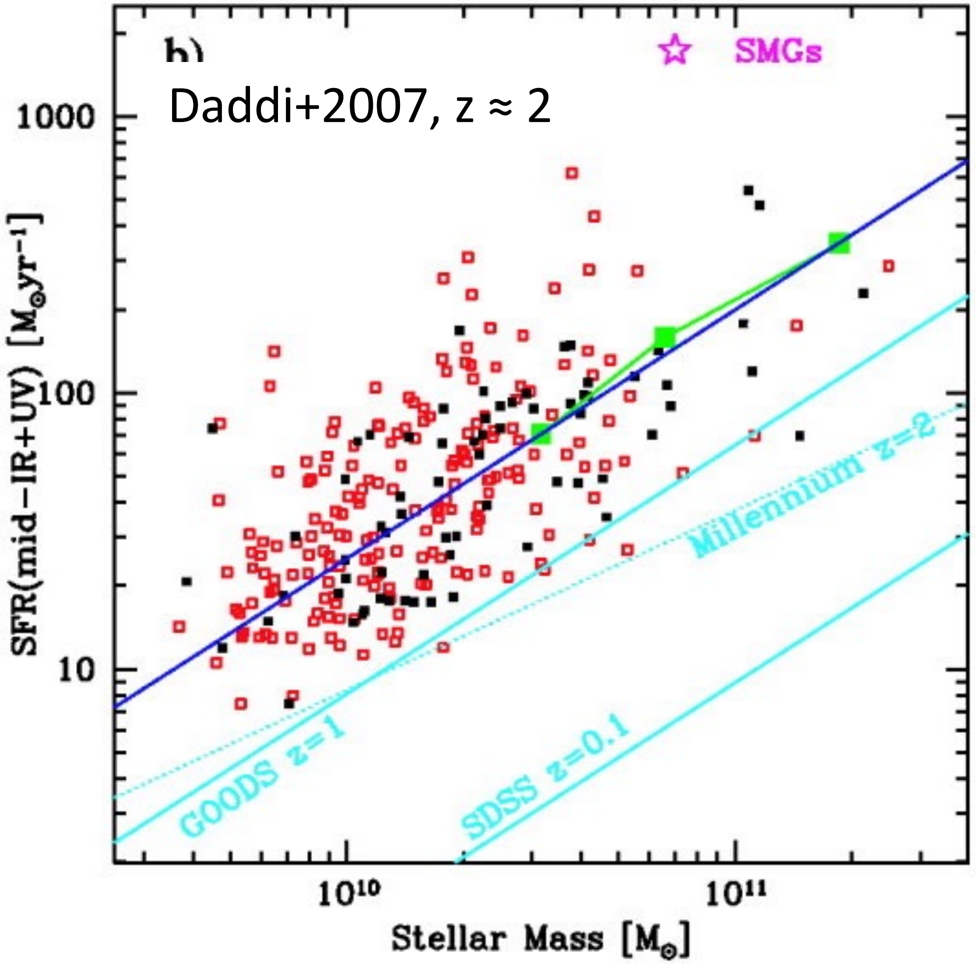
Weaver+2022 "COSMOS2020"



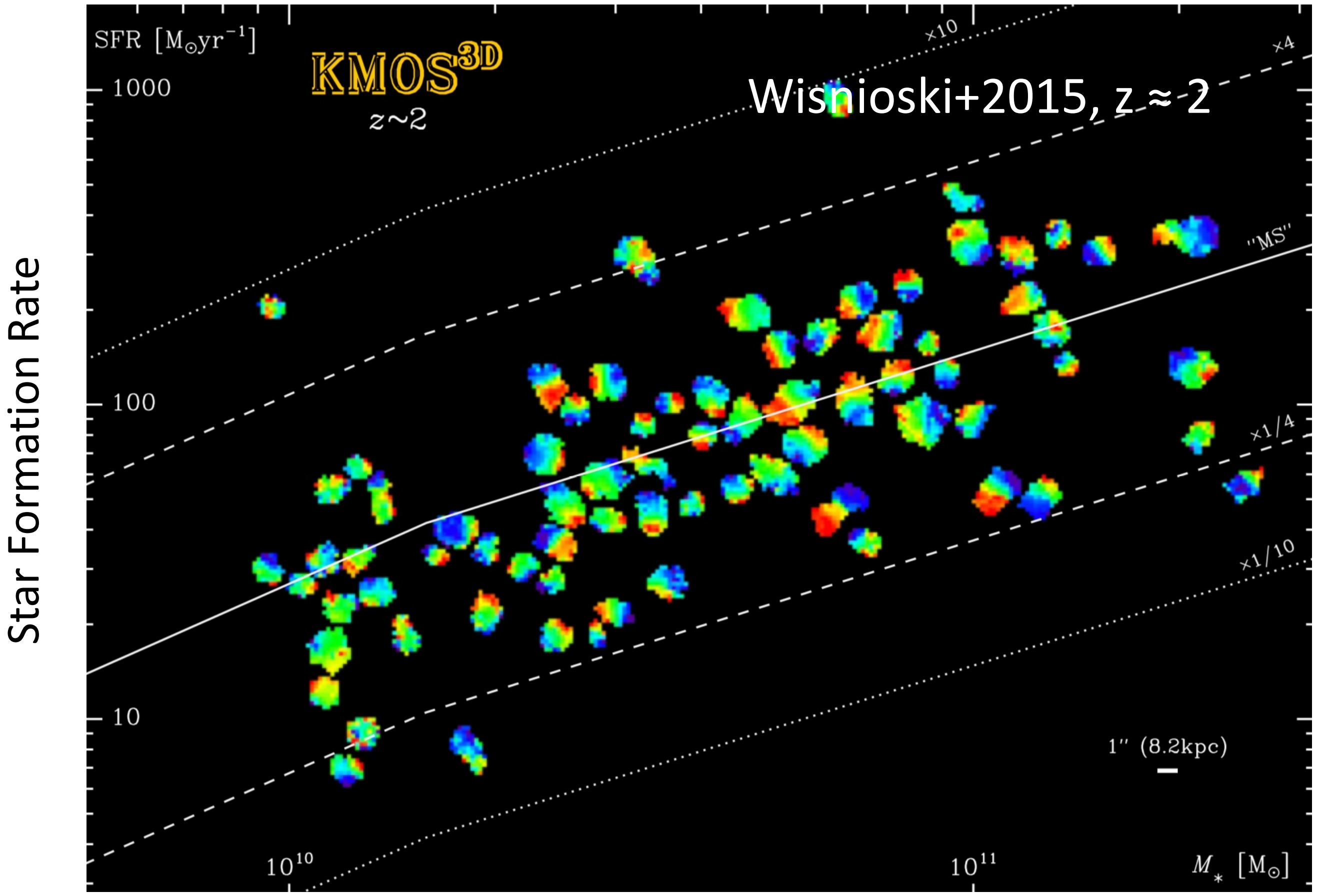
Tuesday's and Thursday's talks: Kartaltepe, Tresse, …

Galaxy properties at high redshifts

Star-forming "Main Sequence"

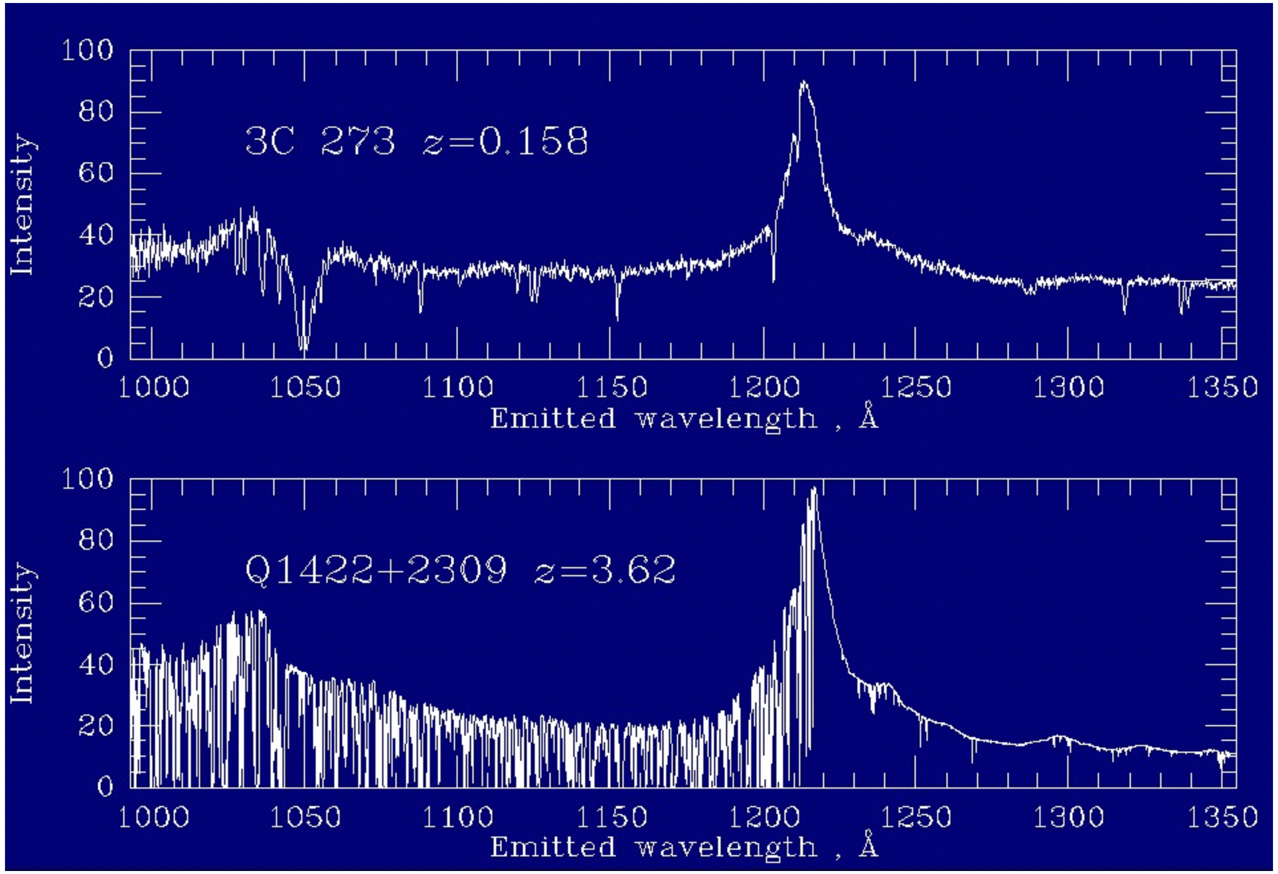


Galaxy dynamics and ISM properties



Stellar Mass

Mapping the IGM in 3D



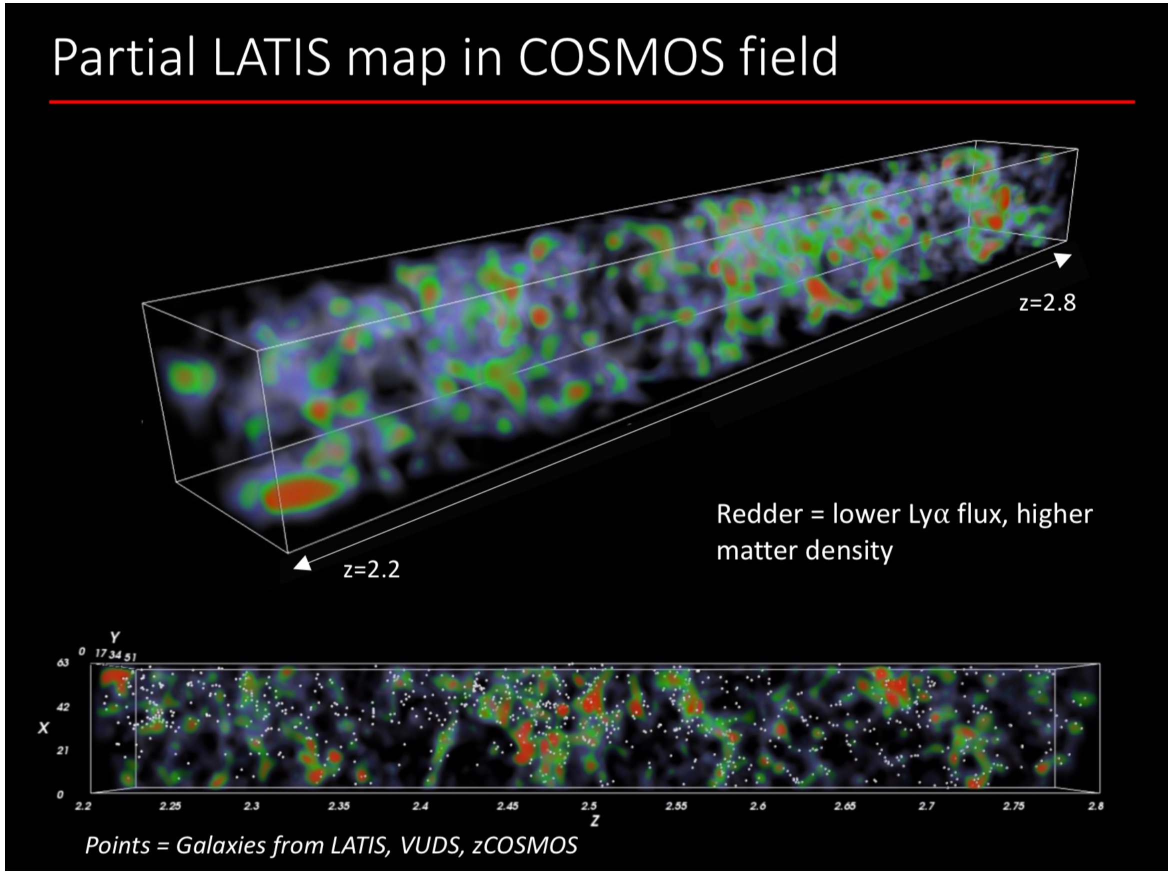


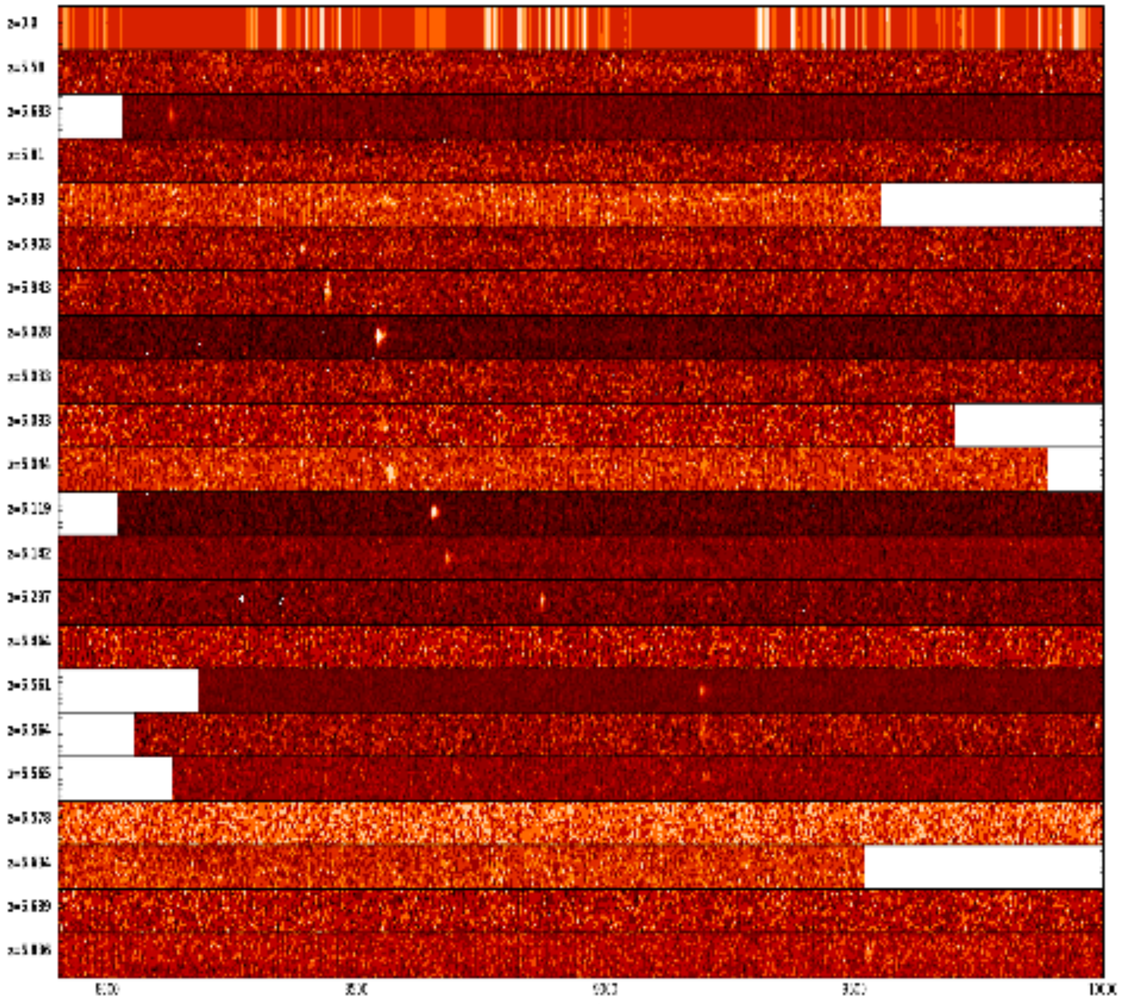
Figure: Bill Keel

Newman et al. 2020

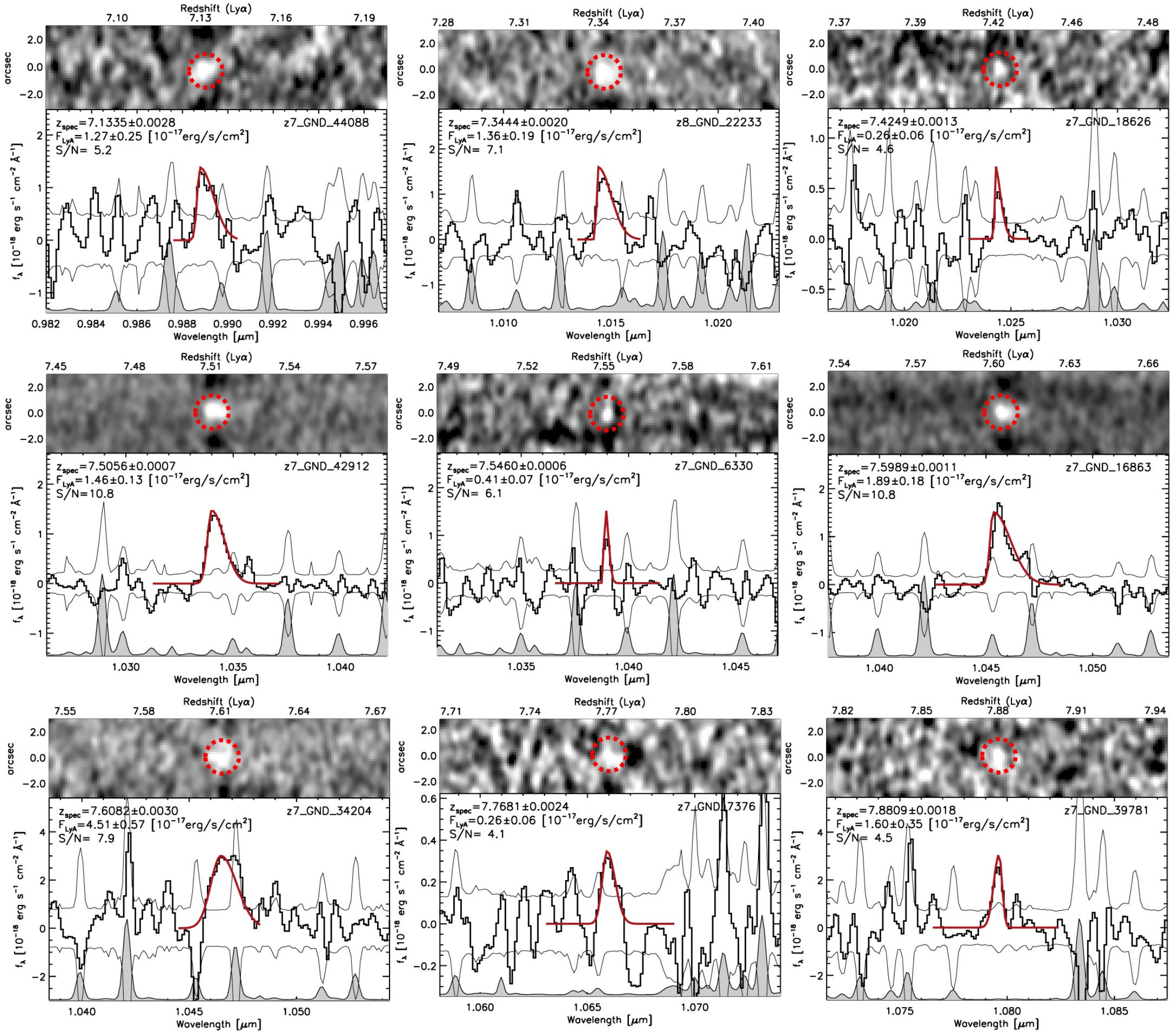
Thursday’s talks: Pentericci, Cassata, …

Surveying the redshift frontier

Pentericci+2018, FORS2, 5.5 < z < 7.2



Jung+2020, MOSFIRE, 7.1 < z < 7.9



The Landscape of Redshift Surveys

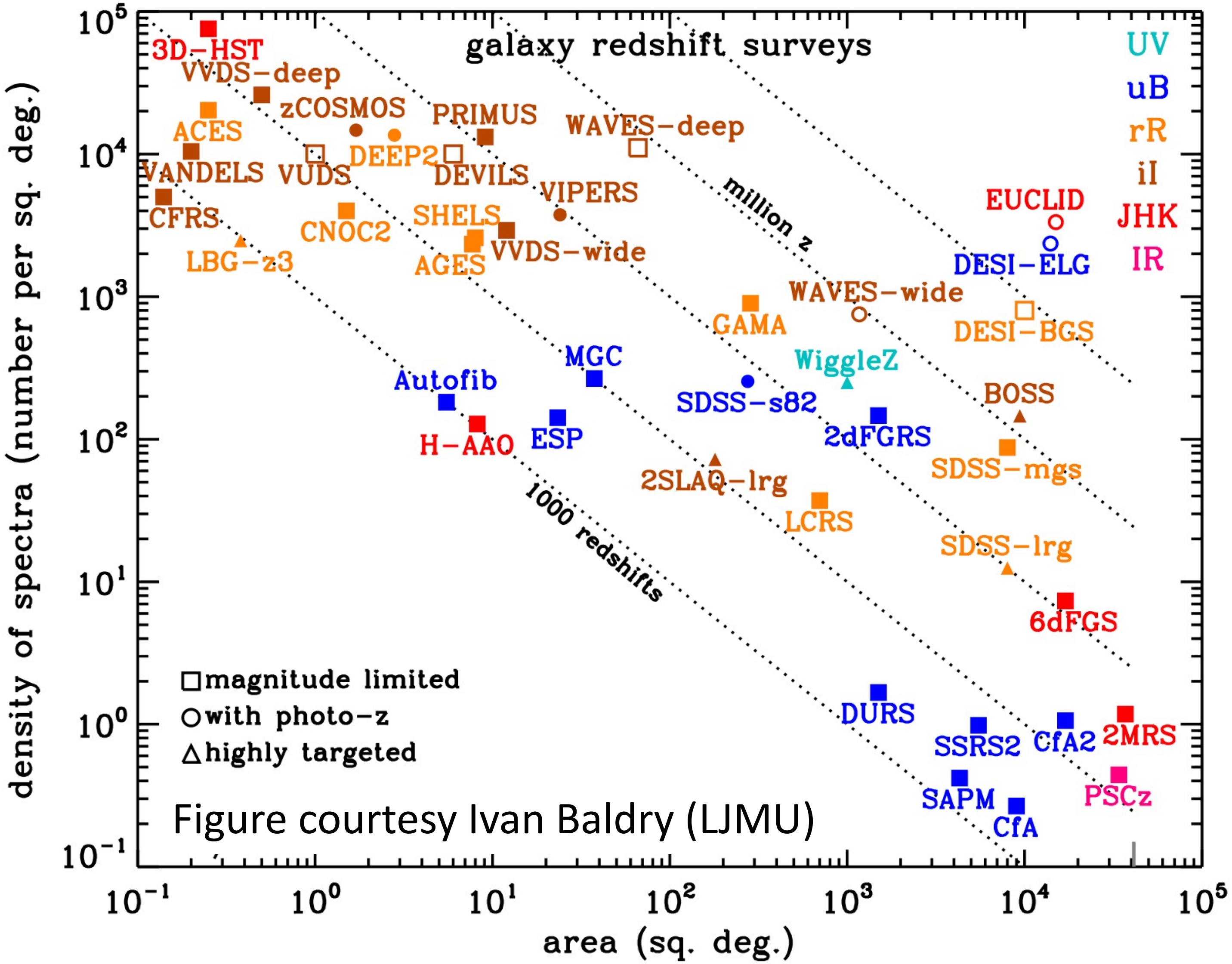
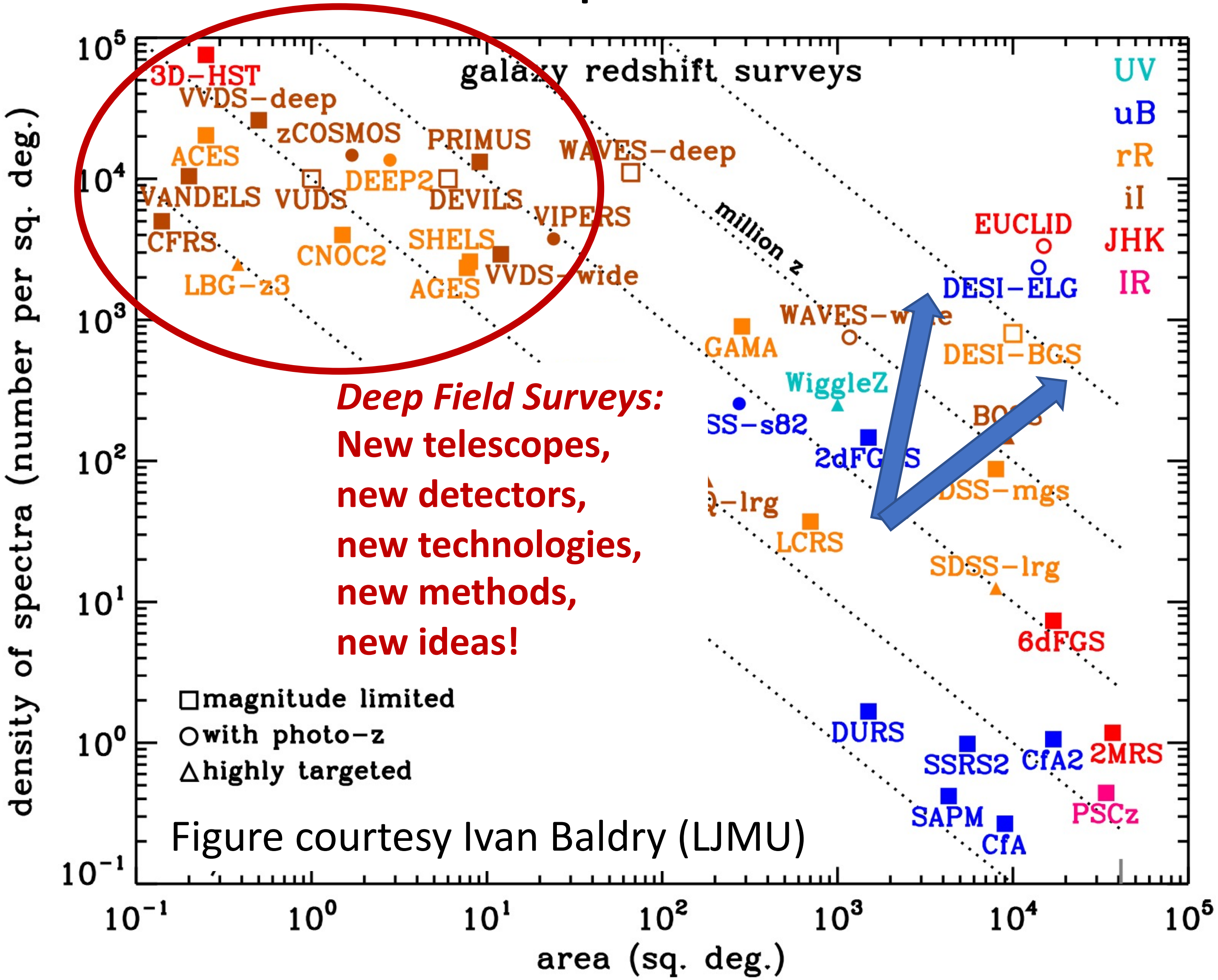


Figure courtesy Ivan Baldry (LJMU)

The Landscape of Redshift Surveys



Deep Field Surveys:
New telescopes, new detectors, new technologies, new methods, new ideas!

Figure courtesy Ivan Baldry (LJMU)

Wide-Area Surveys:

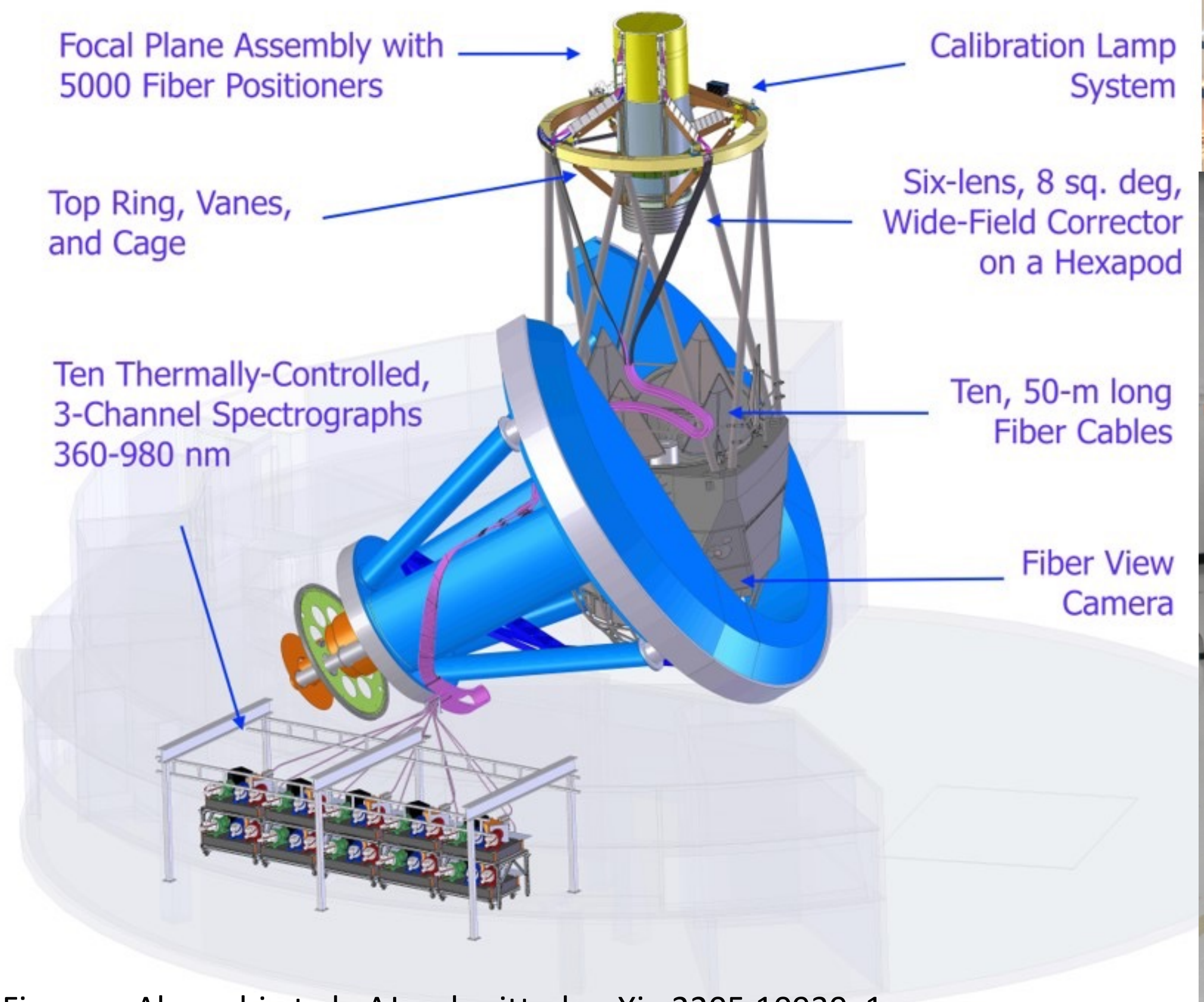
Progress in multiplexing technology + increased investment

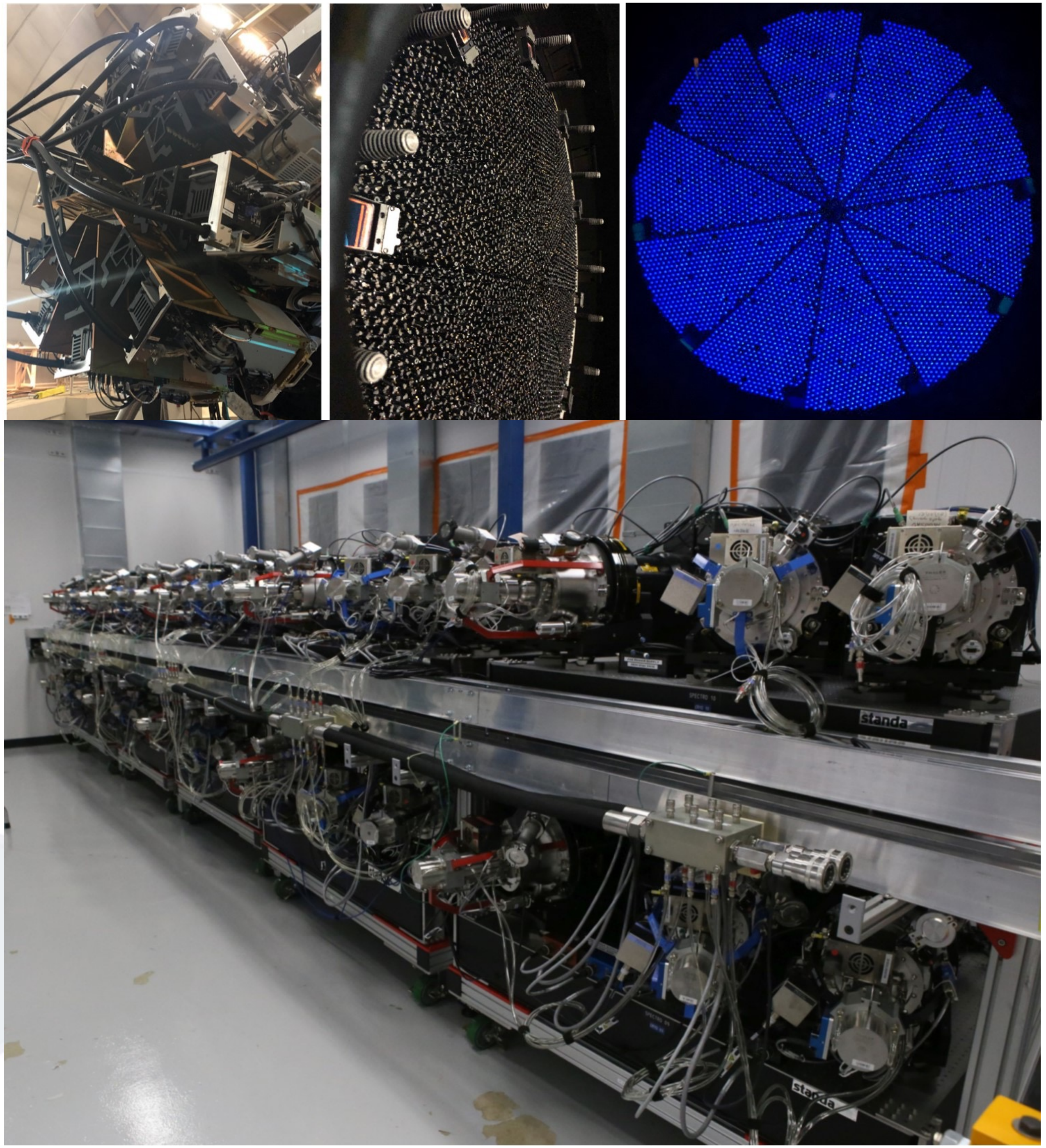
Larger apertures → fainter galaxies, higher redshifts

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI at the 4m Mayall Telescope, Kitt Peak National Observatory, NSF’s NOIRLab



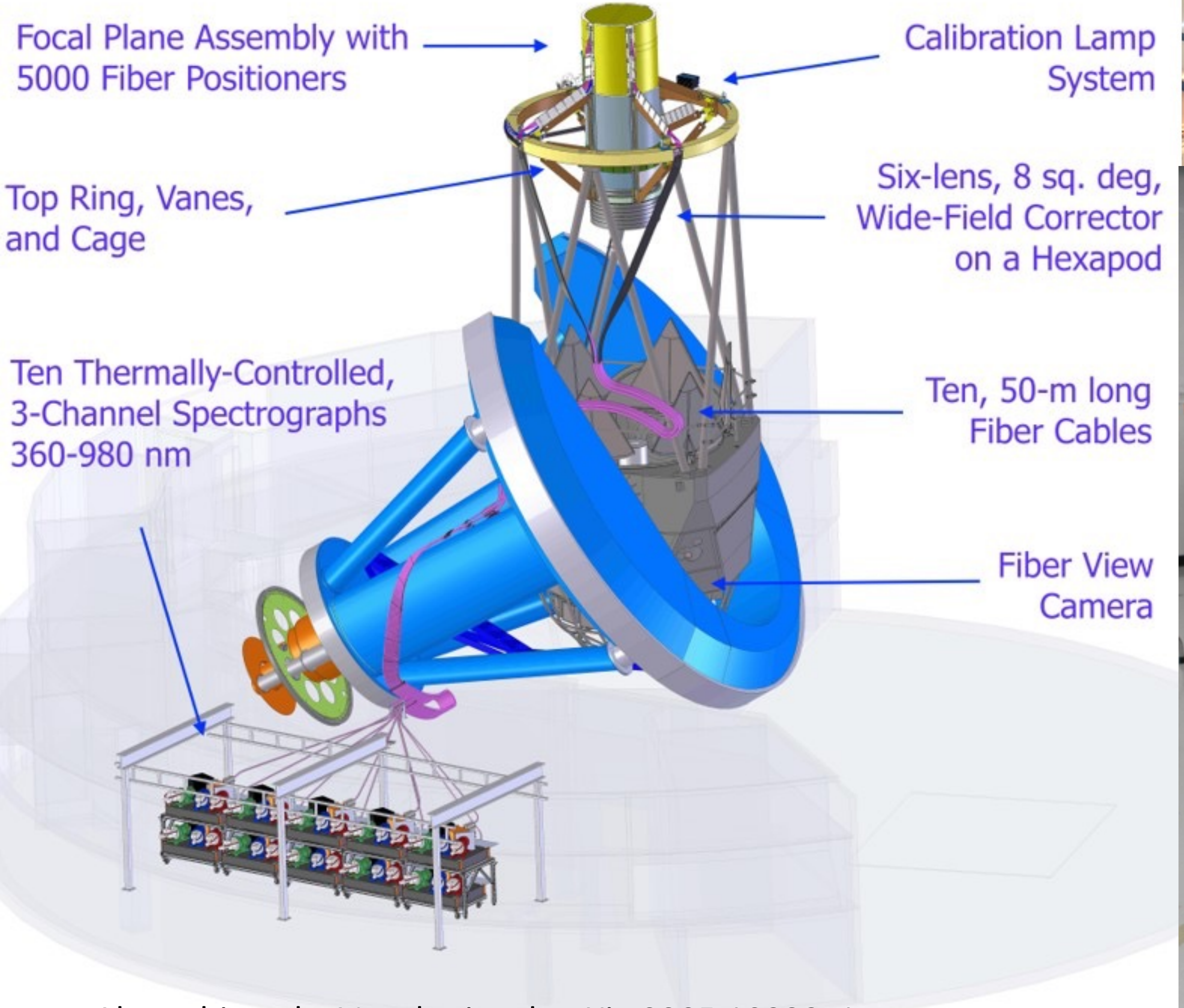


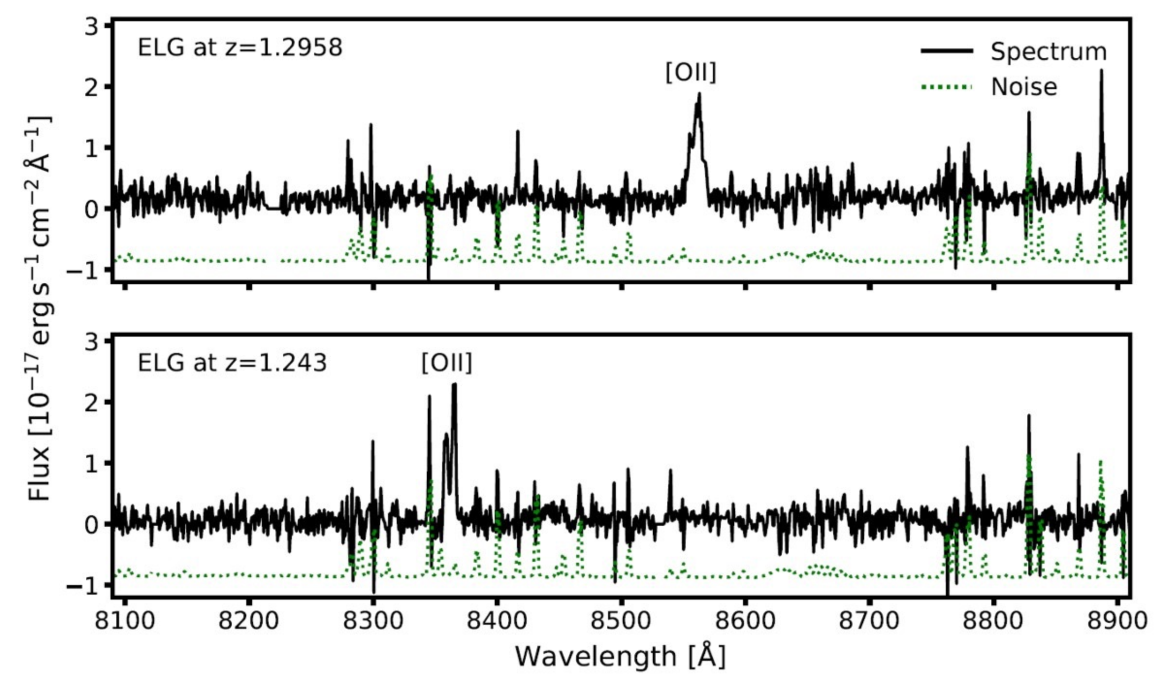
Figures: Abareshi et al., AJ, submitted, arXiv:2205.10939v1

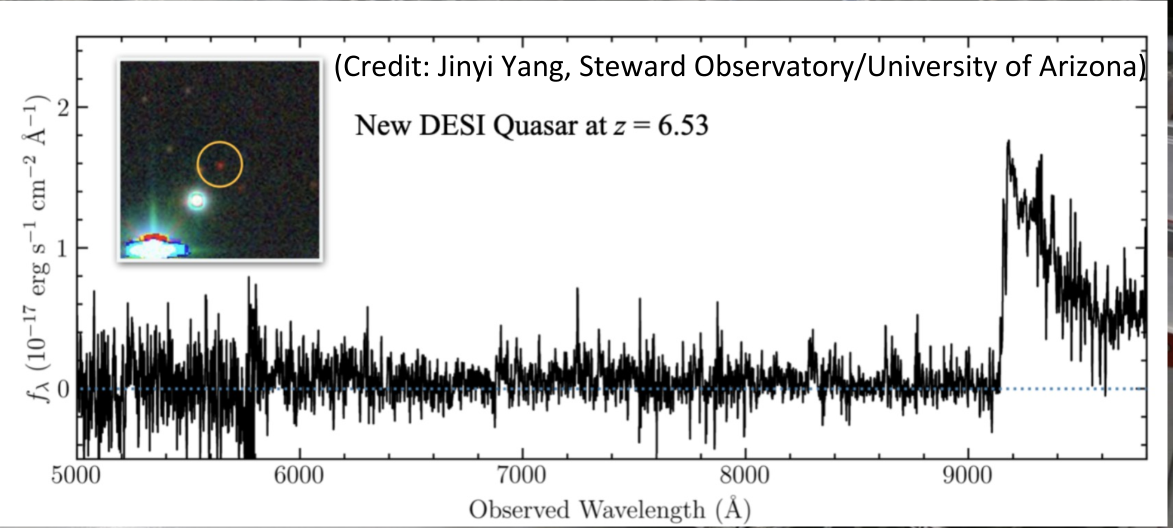
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI at the 4m Mayall Telescope, Kitt Peak National Observatory, NSF's NOIRLab







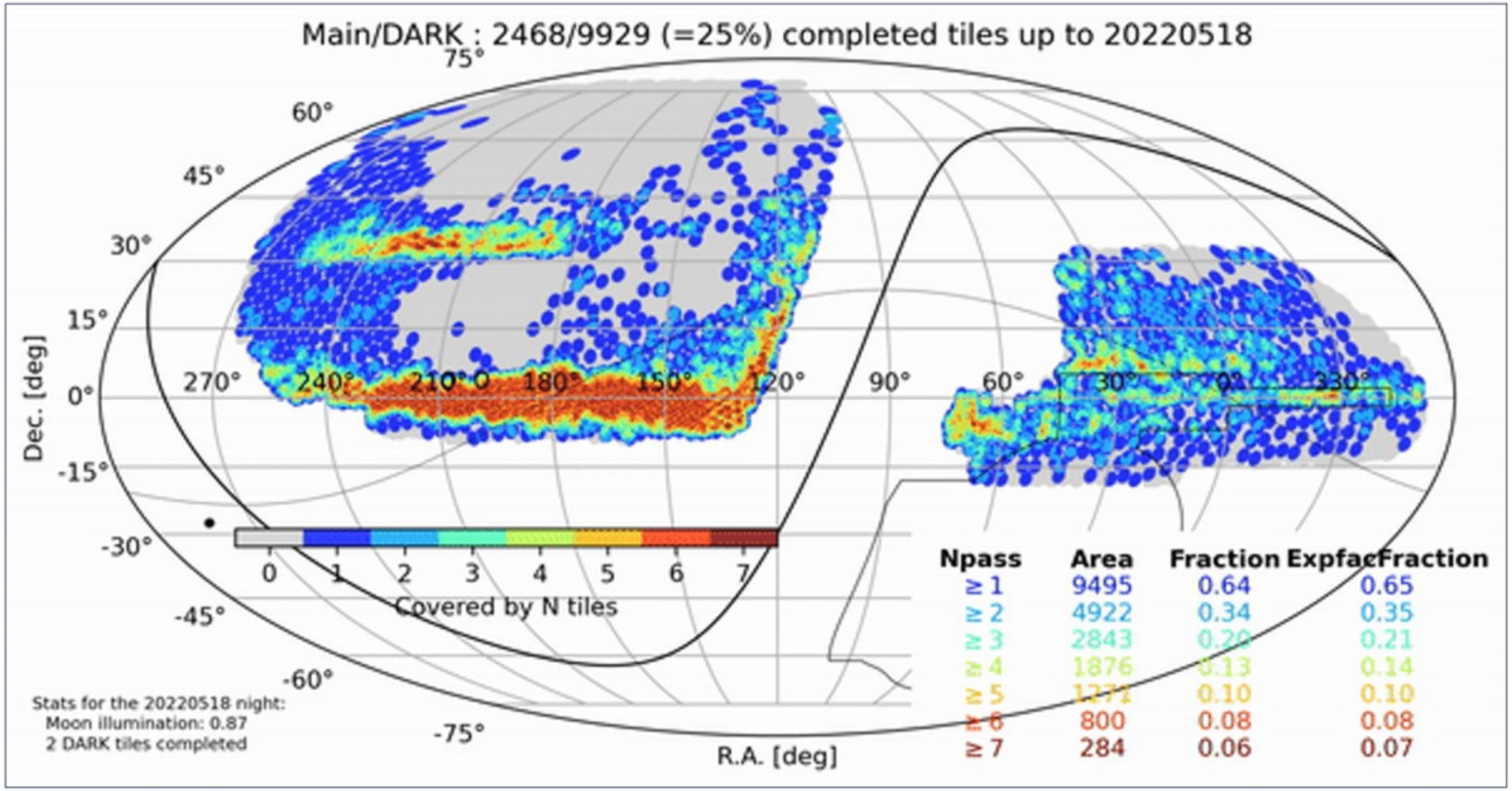
(Credit: Jinyi Yang, Steward Observatory/University of Arizona)

Figures: Abareshi et al., AJ, submitted, arXiv:2205.10939v1

Main Survey Coverage: DARK

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

DARK survey: ~5 visits to each patch of sky to achieve full depth.



The DARK survey has already carried out **~9500 deg^2 with at least one visit**.

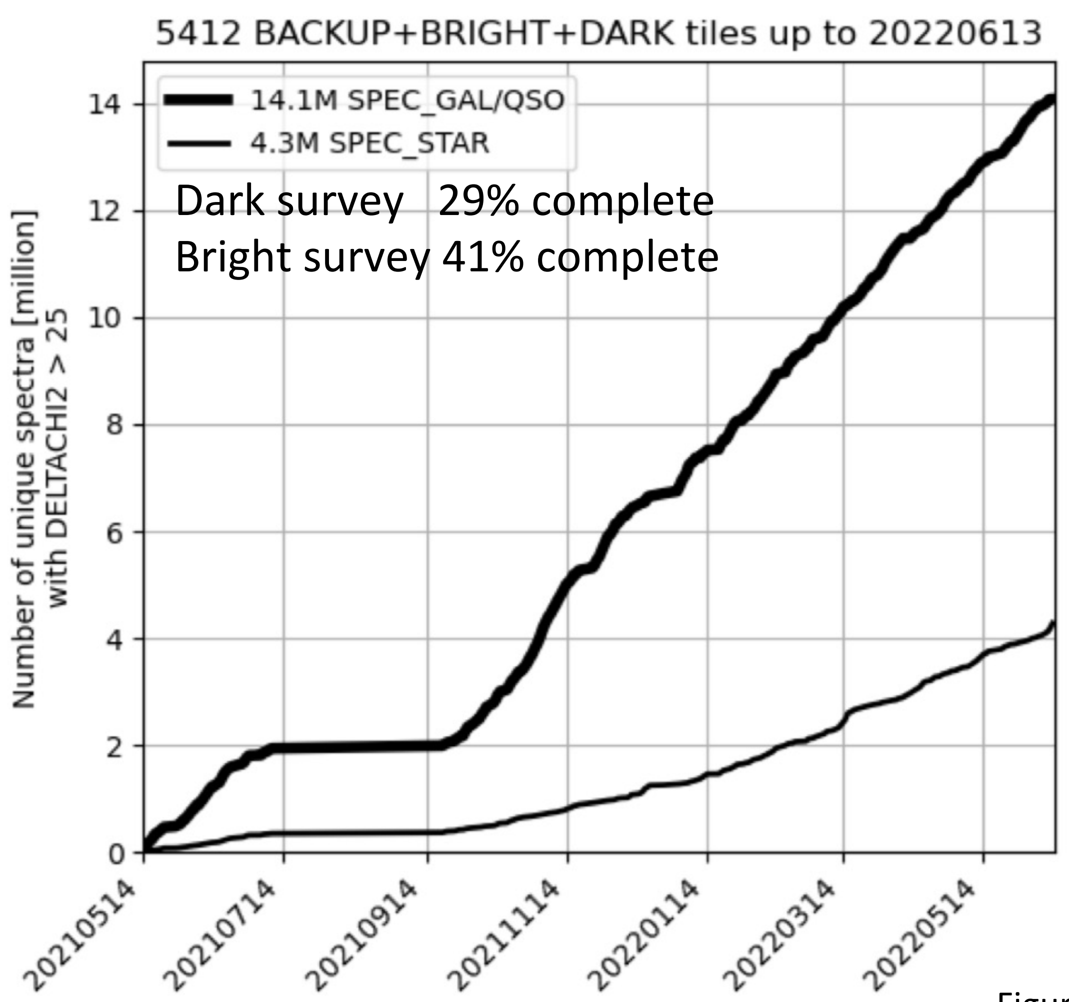
Roughly **1300 deg^2 already complete** with multiple visits.

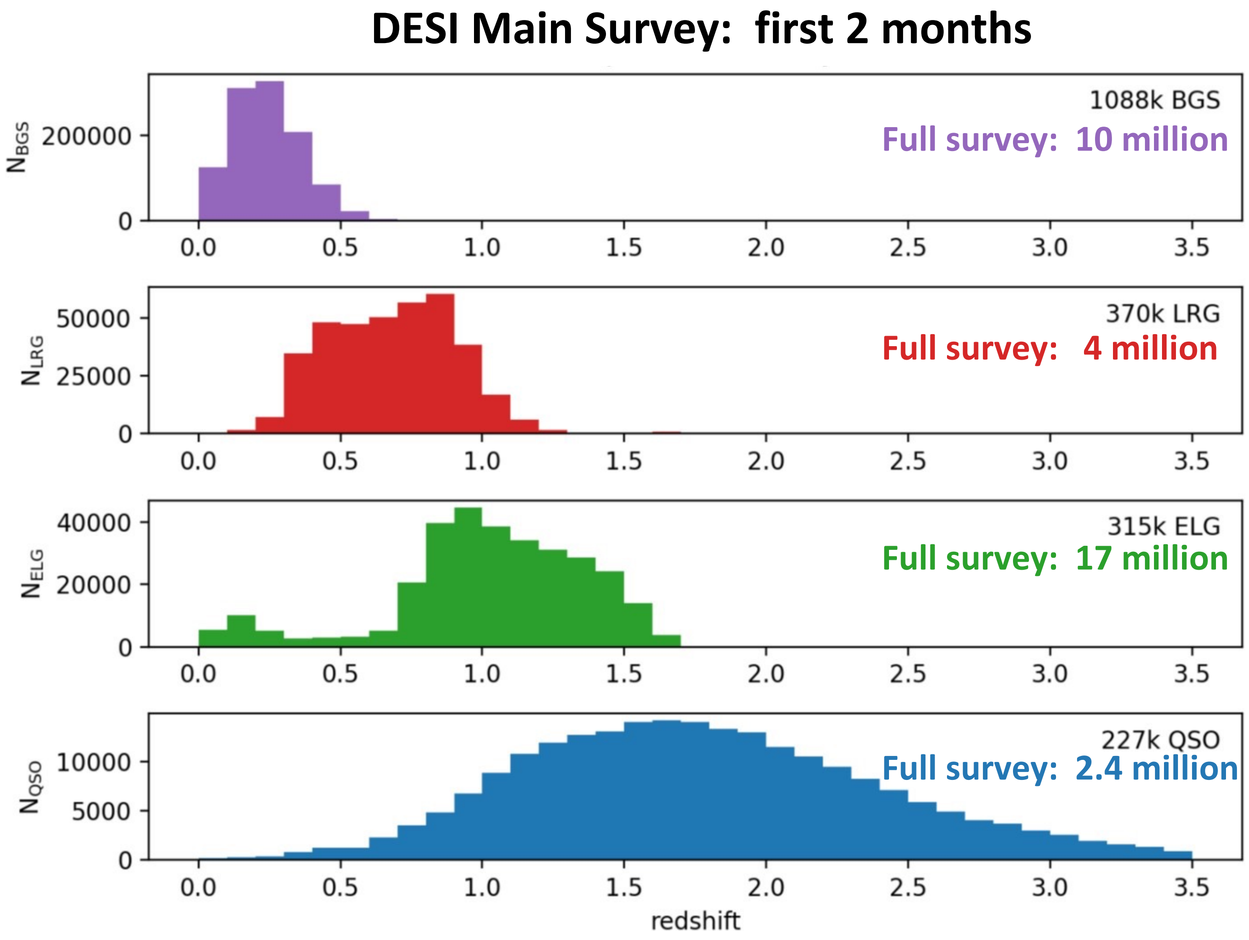
Animation credit:
A. Raichoor / LBNL

Slide credit: DESI Speakers Board

DESI Year 1 Data

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science





Figures: DESI Speakers Board

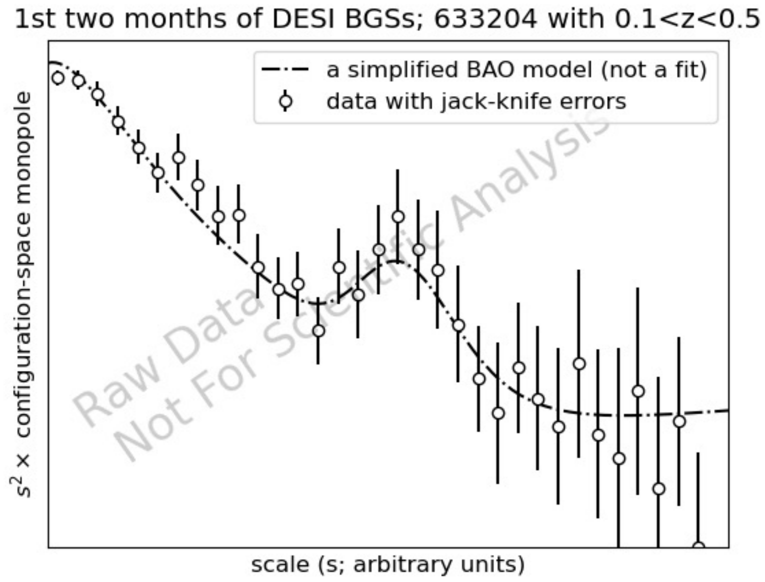

Z:1
2022-06-17 05:49:11
KPNO Mayall 4m
Z:3
2022-06-15 17:44:59
KPNO Mayall 4m
Z:16
2022-06-16 18:37:17
KPNO Mayall 4m
Z:4
2022-06-17 03:29:34
KPNO Mayall 4m

DARK ENERGY SPECTROSCOPIC INSTRUMENT

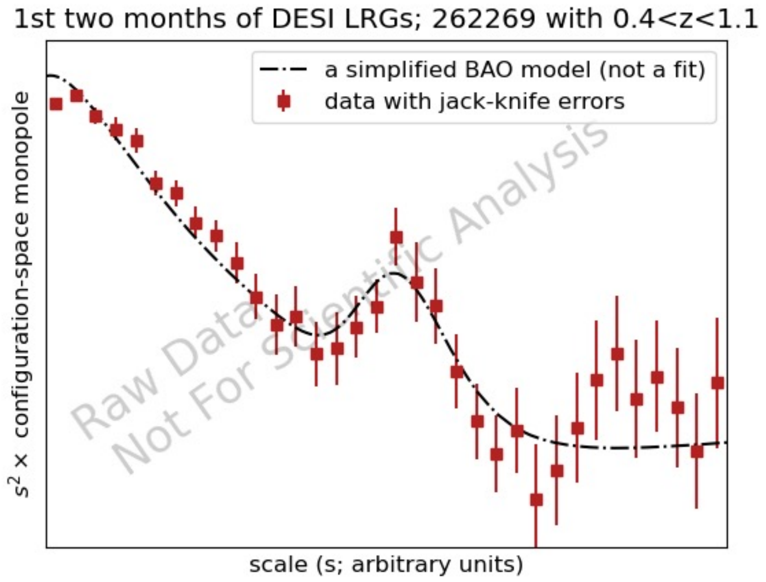
U.S. Department of Energy Office of Science

BAO, early results

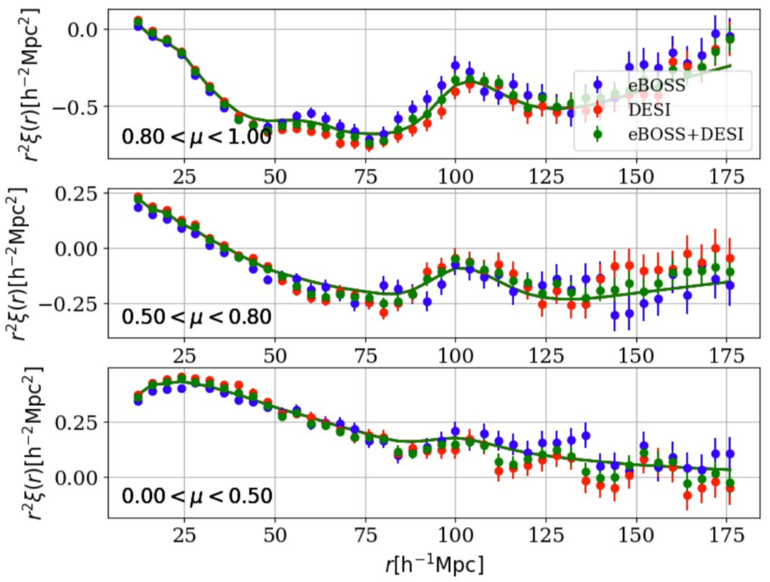
Bright Galaxy Sample, 0.1 < z < 0.5



Luminous Red Galaxies, 0.4 < z < 1.1



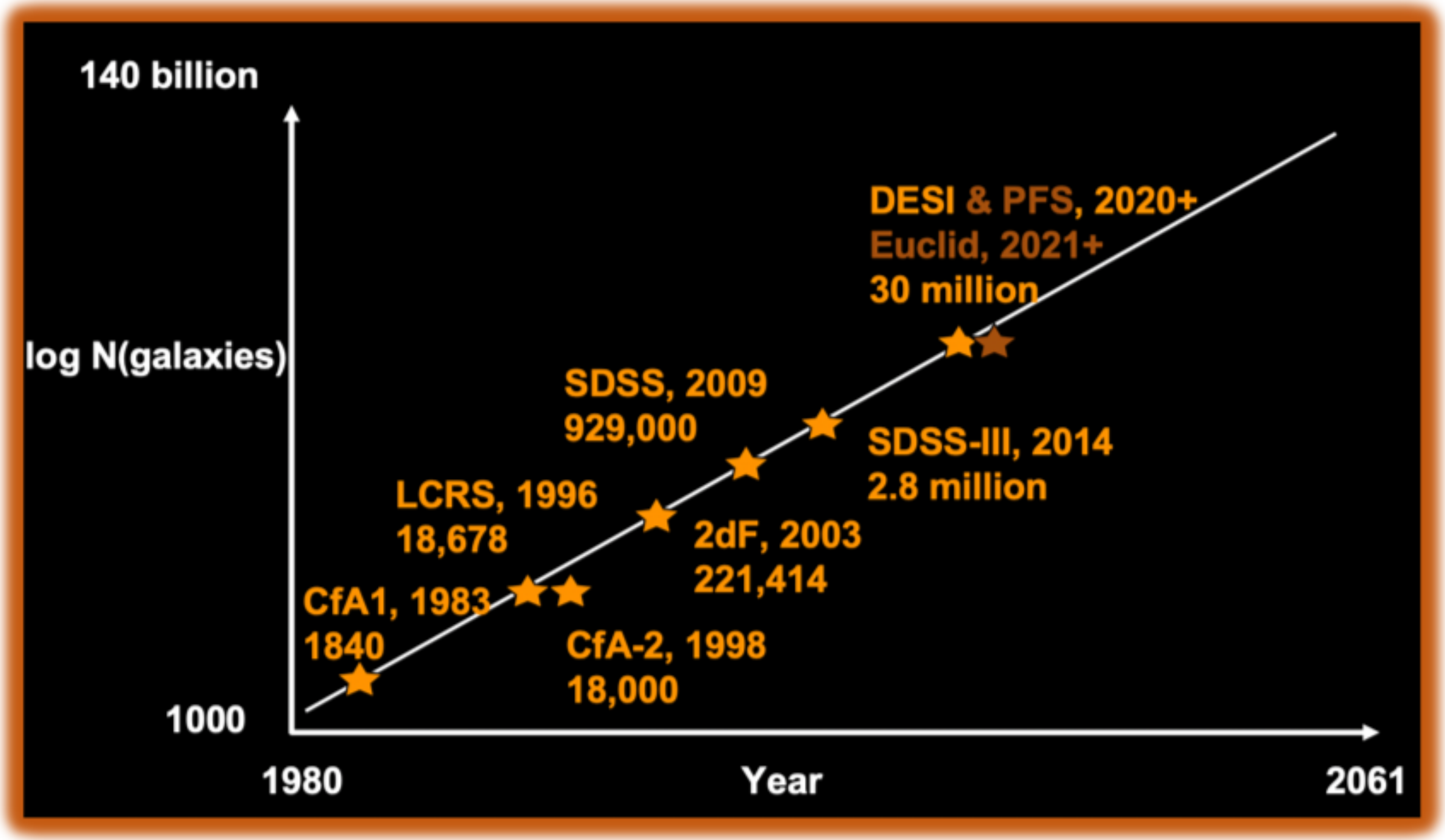
Ly-α forest, z > 2.1, 3D autocorrelation



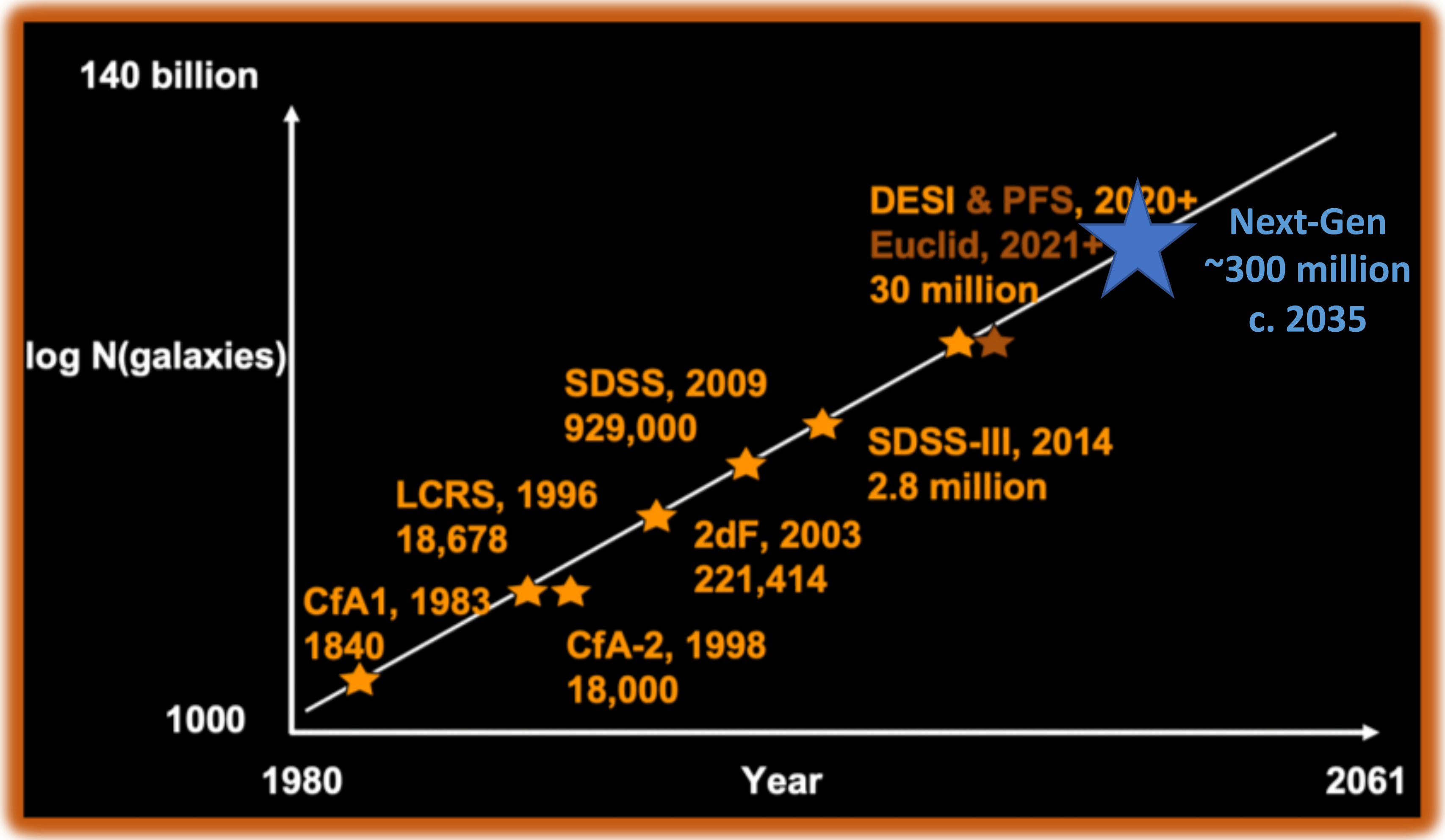
Figures: DESI Speakers Board

Figure: J. Guy, LBNL, DESI

The future is massively multiplexed…



The future is massively multiplexed…

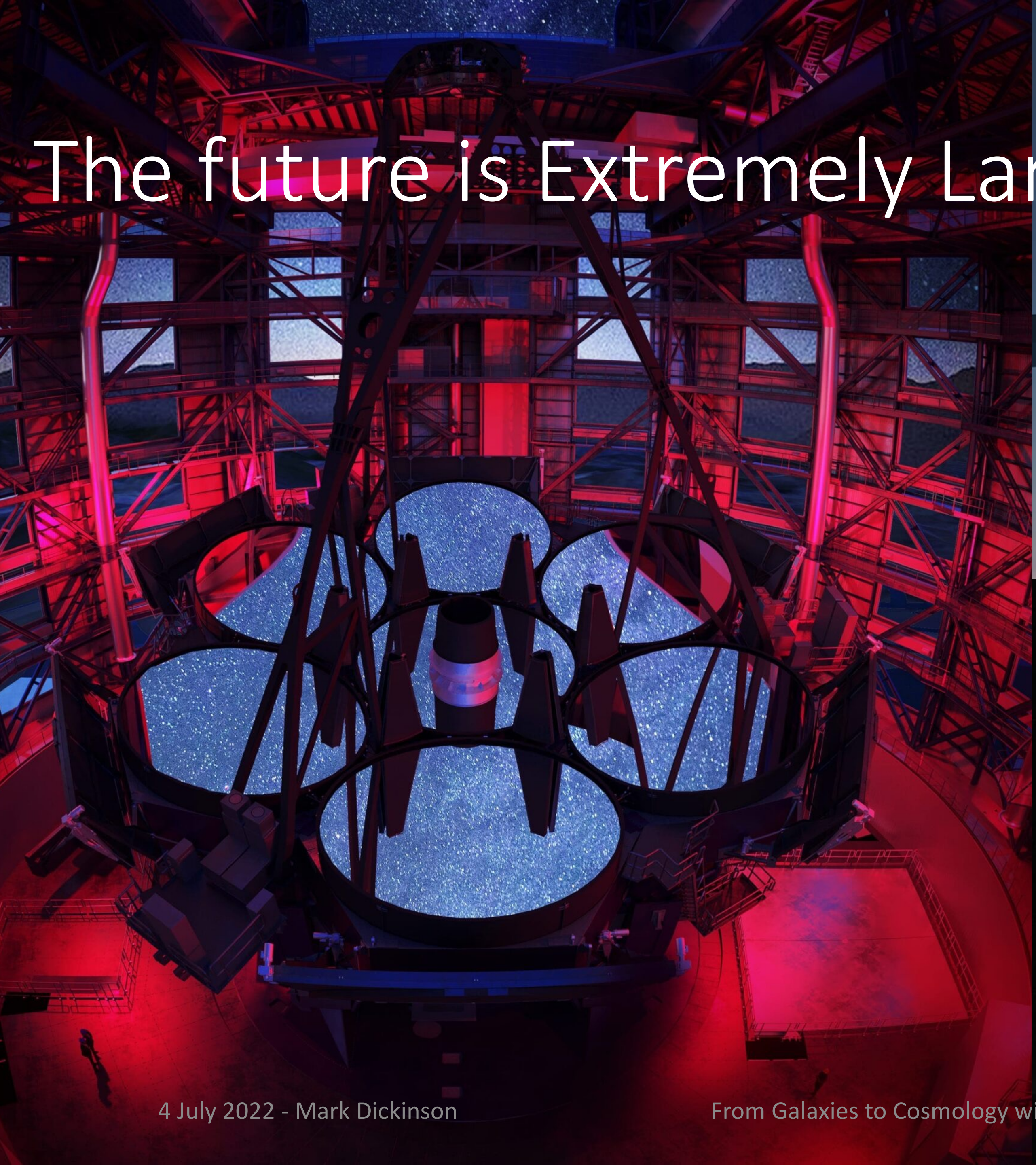


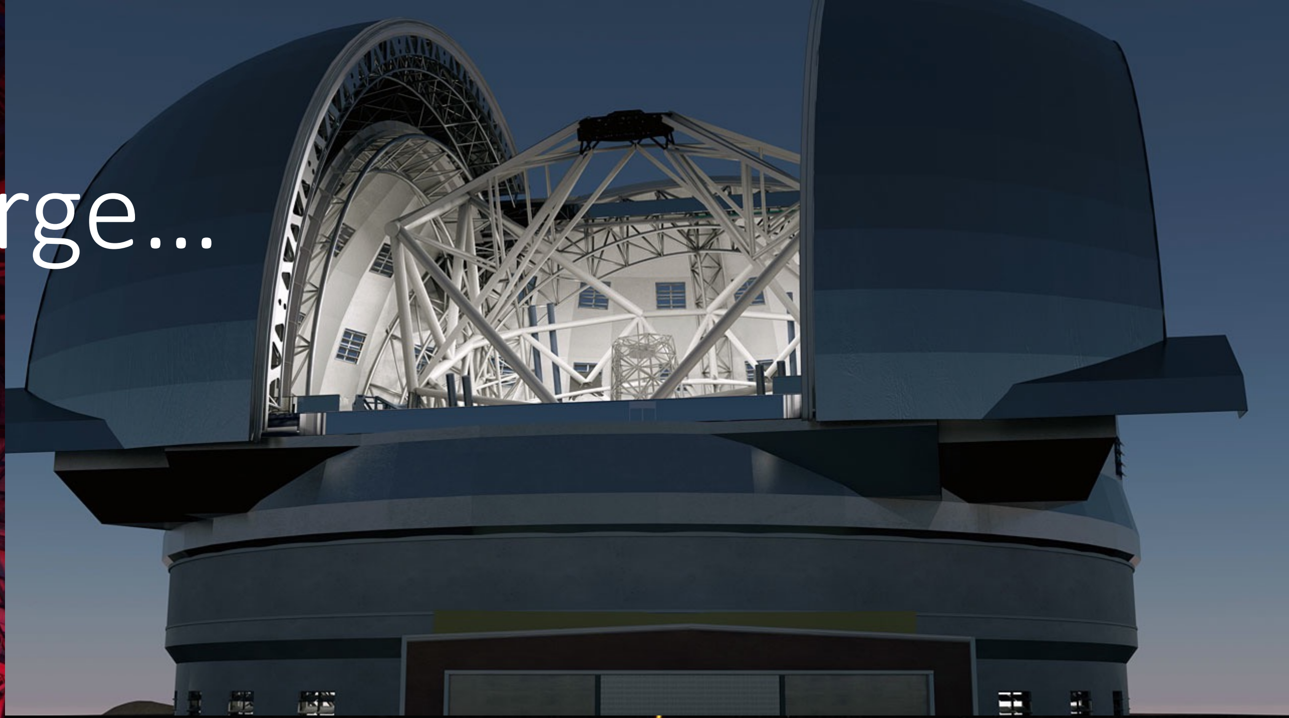
Tuesday: Richard Ellis, John Silverman …

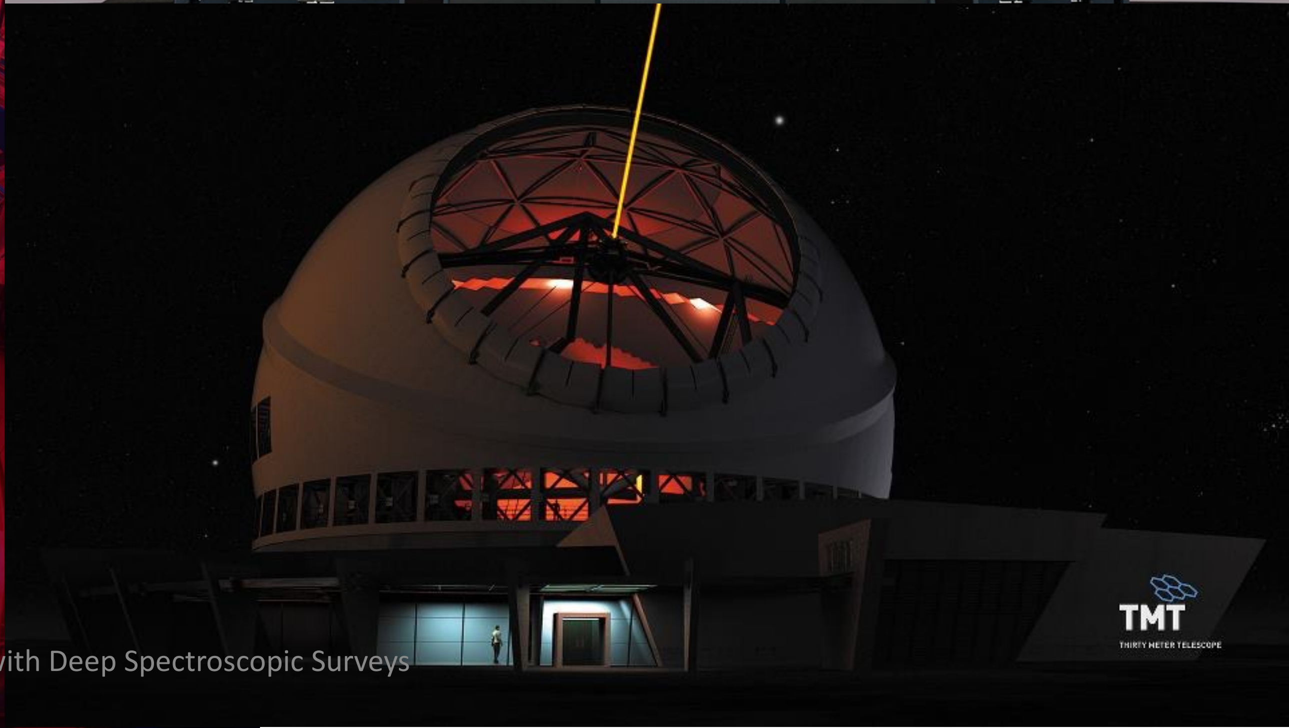
The future is massively multiplexed…

Telescope / Instrument	Telescope diameter (m)	Collecting area (m^2)	FoV (deg^2)	Multiplex	A x Ω vs. SDSS	A x N vs. SDSS	Target density ($arcmin^{-2}$)
Mayall 4m / DESI	4.00	9.5	7.08	5000	2.6	20.2	0.20
Subaru / PFS	8.20	53.0	1.25	2400	2.5	54.0	0.53
MegaMapper	6.50	28.0	7.06	20000	7.6	237.8	0.79
Keck / FOBOS	10.00	76.0	0.09	1800	0.3	58.1	5.73
MSE	11.25	80.8	1.50	3249	4.7	111.5	0.60
ESO SpecTel	11.40	87.9	4.91	15000	16.6	559.8	0.85

The future is Extremely Large…

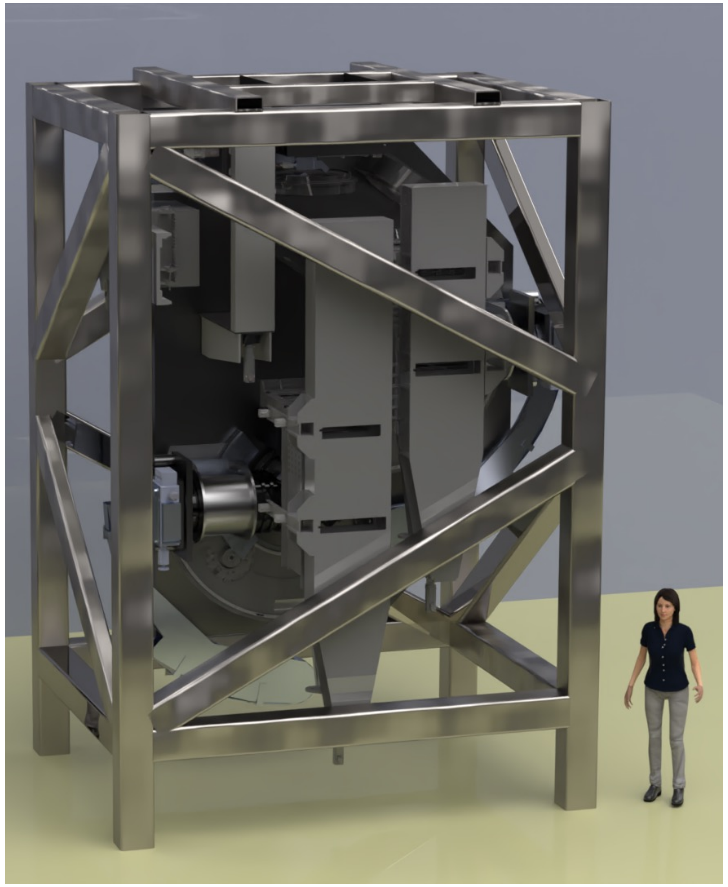






Thursday: Lidia Tasca, ELT MOSAIC

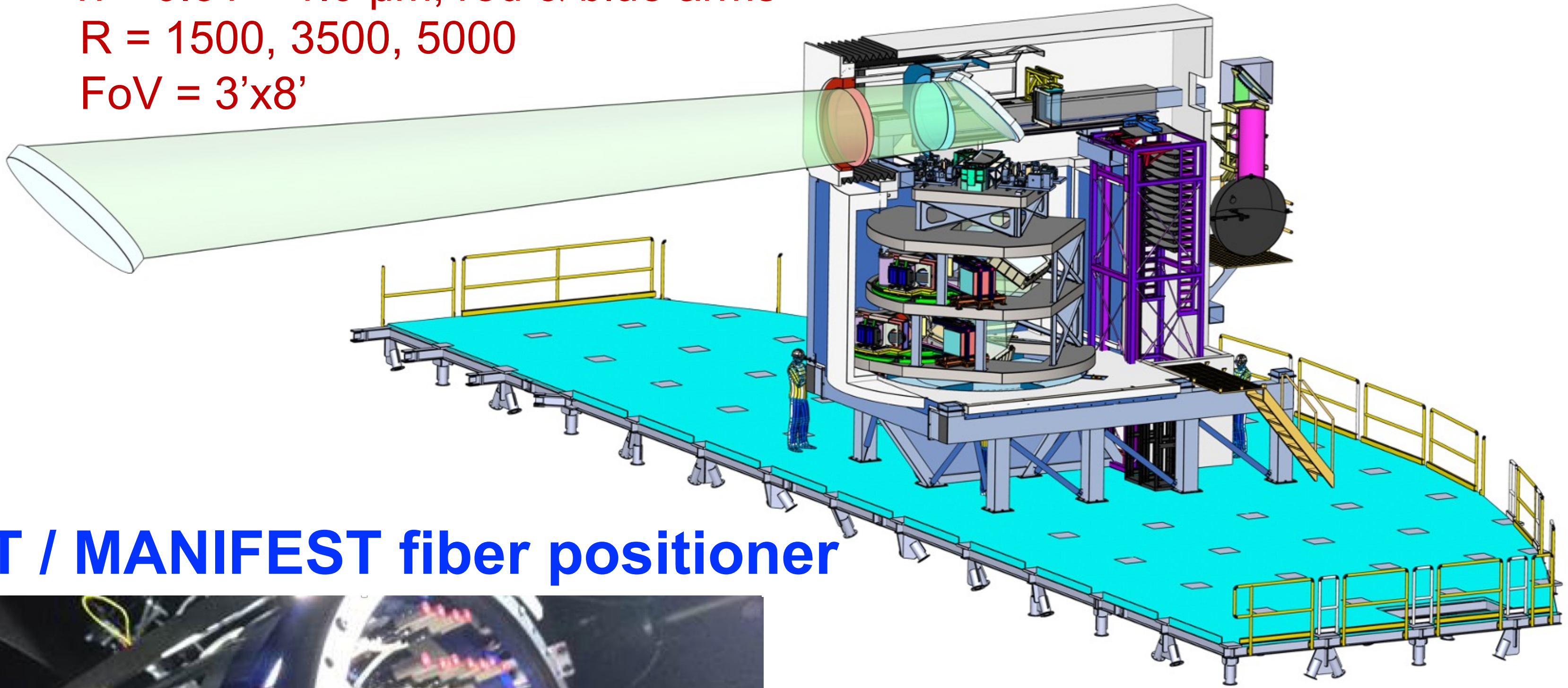
GMT / GMACS



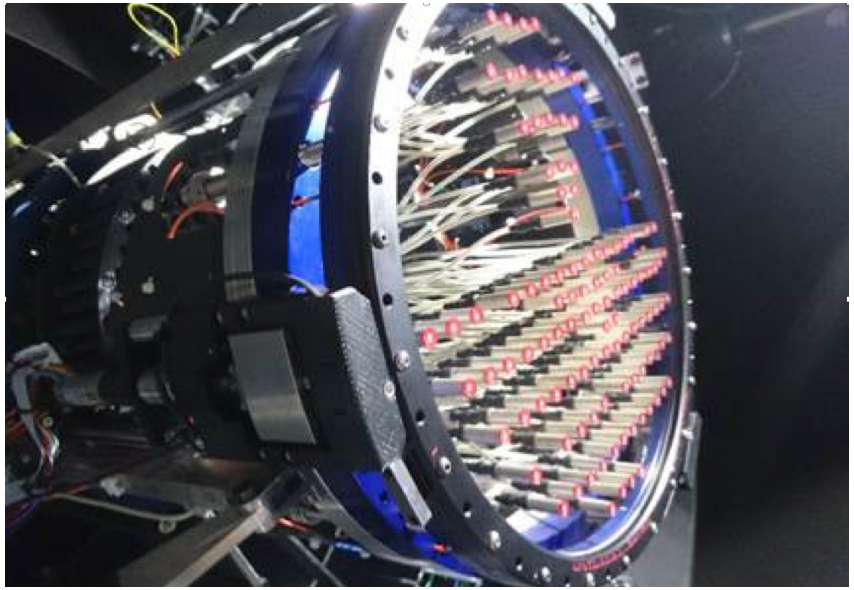
λ = 0.32 – 1.0 μm, red & blue arms
R = 1000 – 6000
FoV = 6'x7'
Natural Seeing or Ground-Layer AO

TMT / WFOS

λ = 0.31 – 1.0 μm, red & blue arms
R = 1500, 3500, 5000
FoV = 3'x8'



GMT / MANIFEST fiber positioner



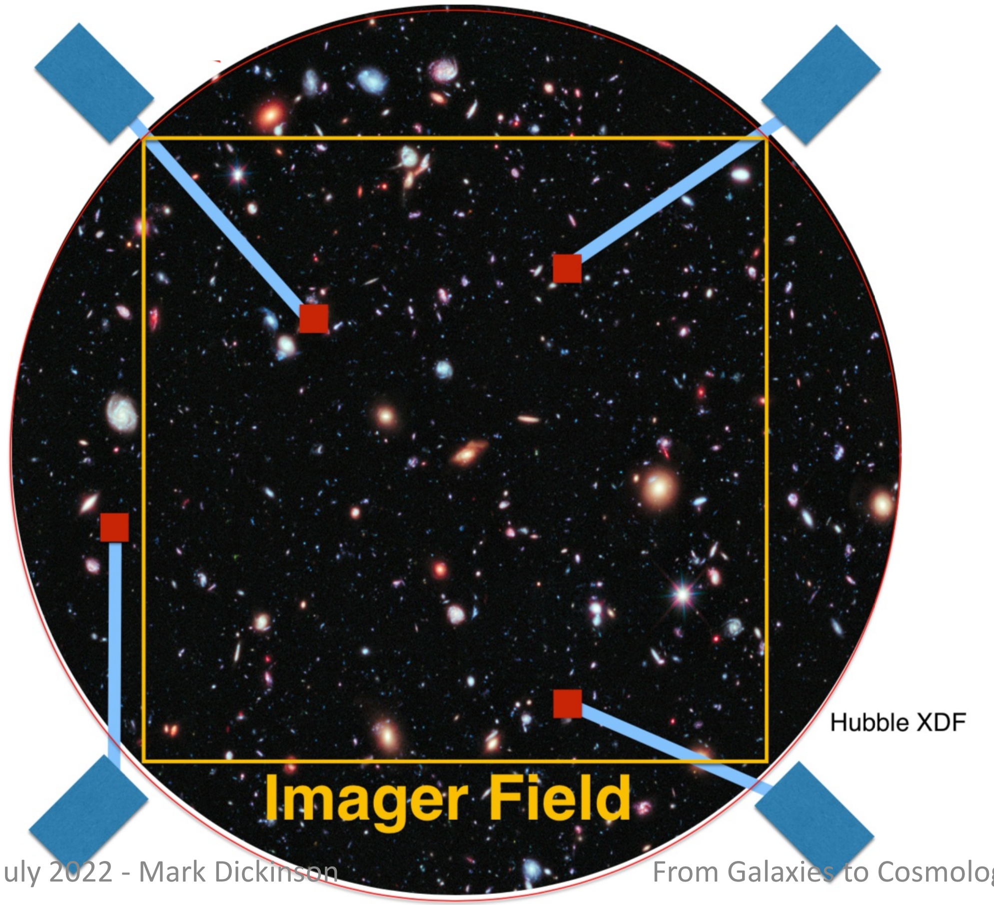
Facility Fiber Positioner
for GMT spectrographs

Access 20' diameter GMT FoV
+ IFU configurations

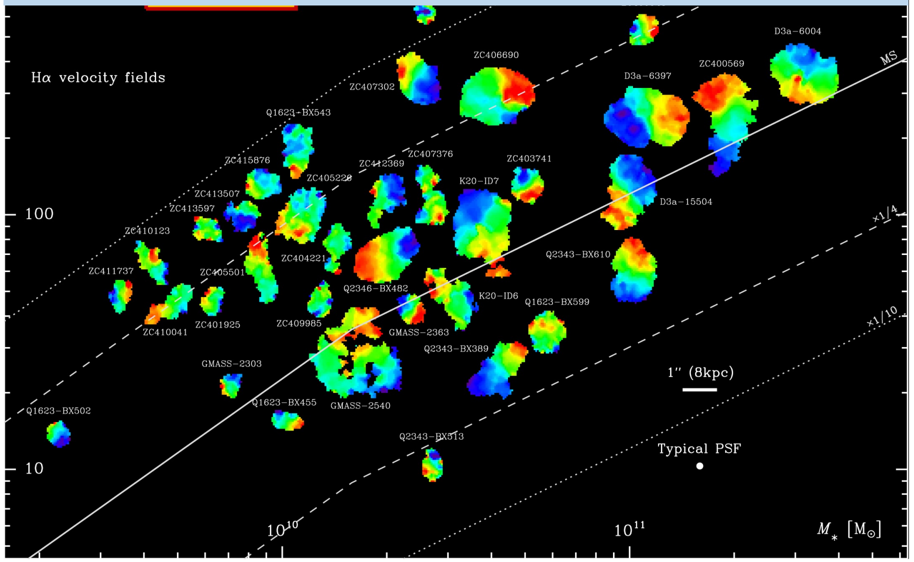
Gemini GIRMOS

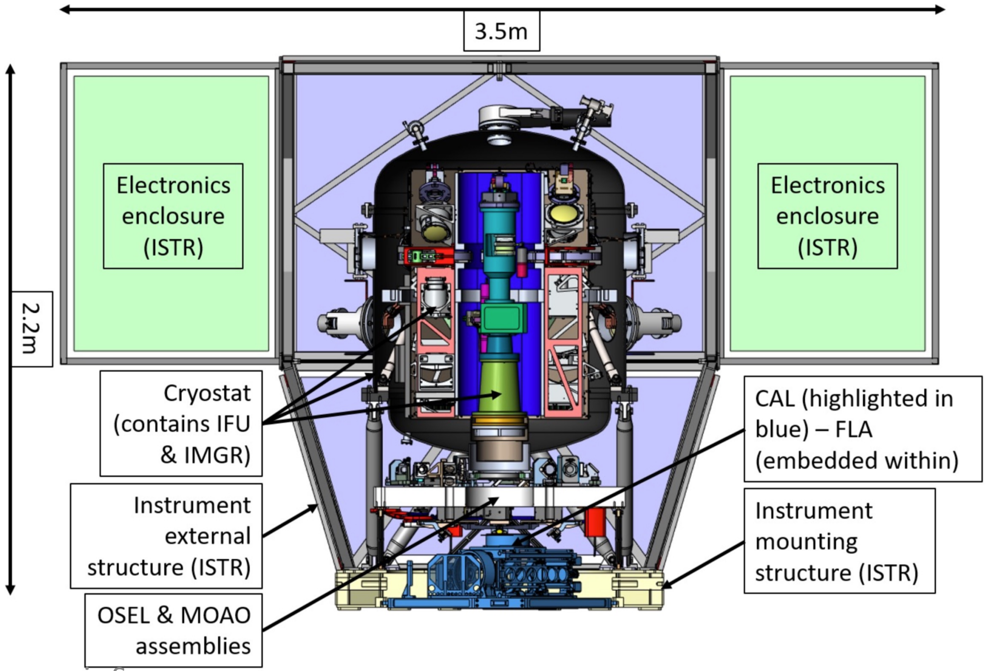
A Pathfinder for the ELTs

Gemini-North AO + GIRMOS Multi-Object AO
IFU spectroscopy of up to 4 objects within 2’ AO-corrected patrol field
Simultaneous imaging of the AO-corrected field
PI: Suresh Sivanandam (Dunlap Inst. / Univ. of Toronto)



SINS/zC-SINF AO IFU Survey, Förster-Schreiber+2018
36 galaxies, 450 hours with VLT



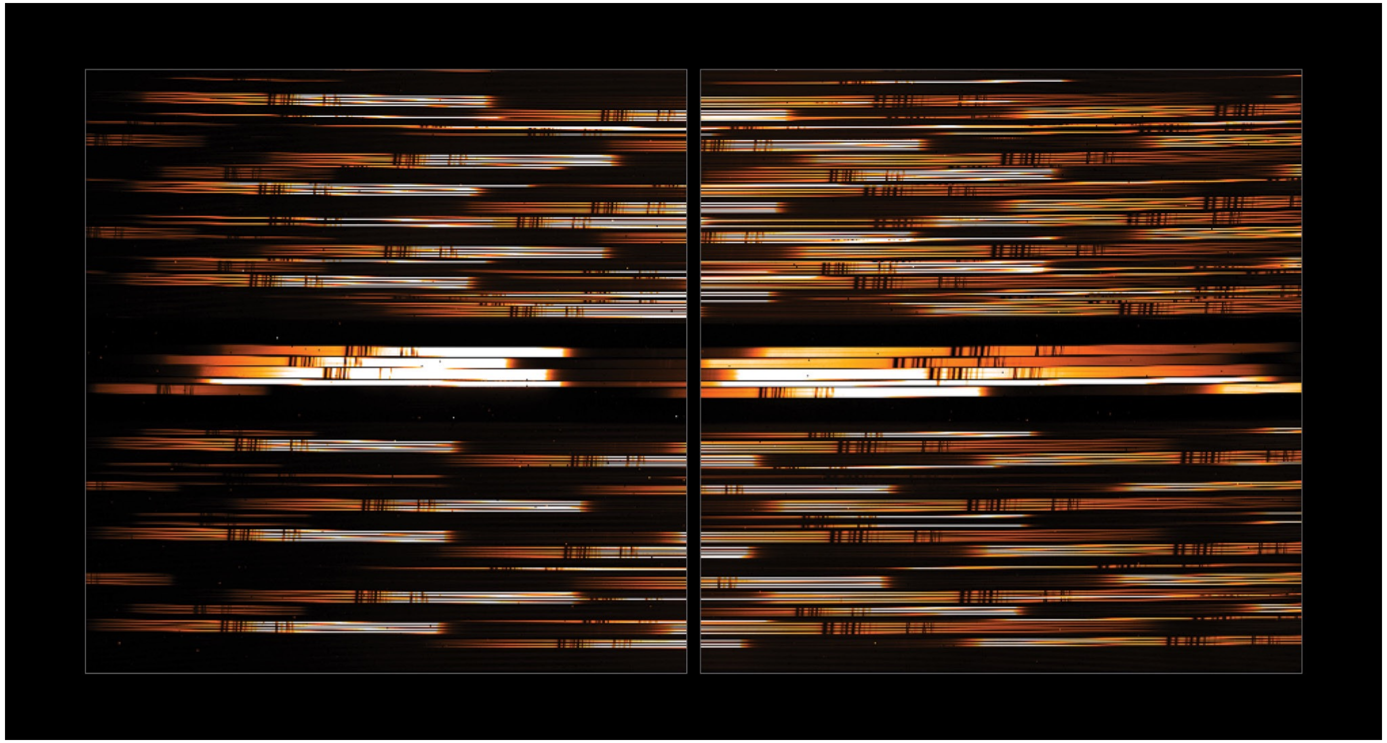


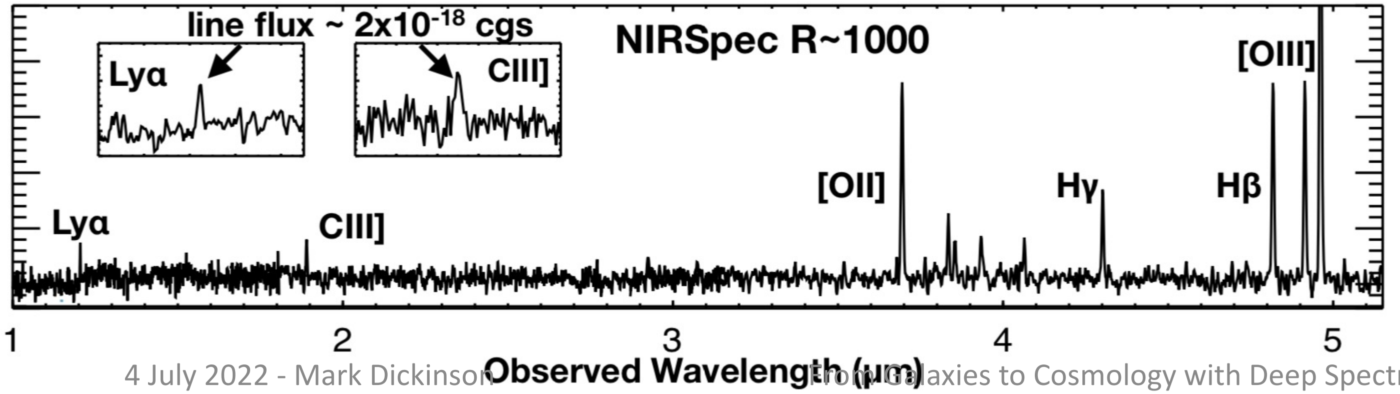
The future is in space…

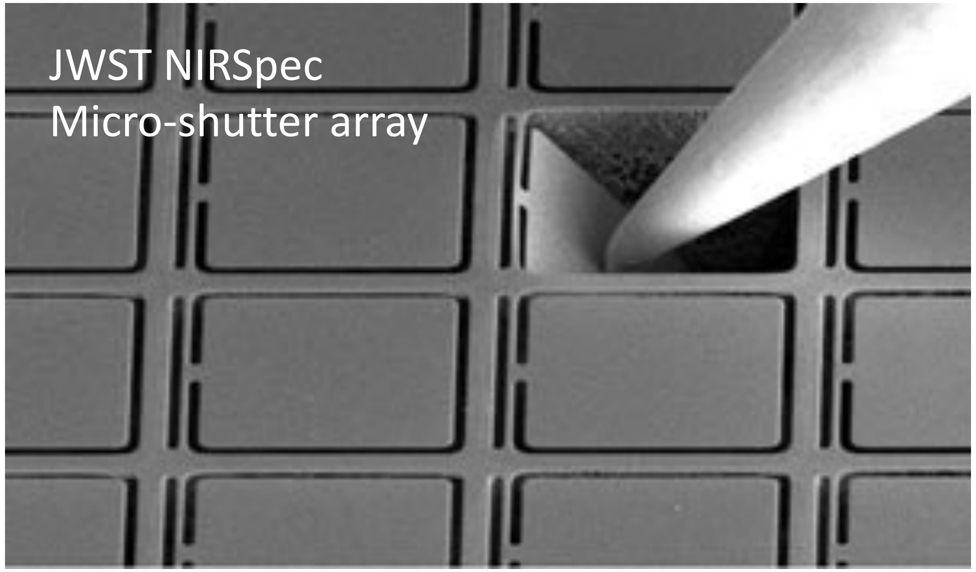
Figure credit: ArianeGroup

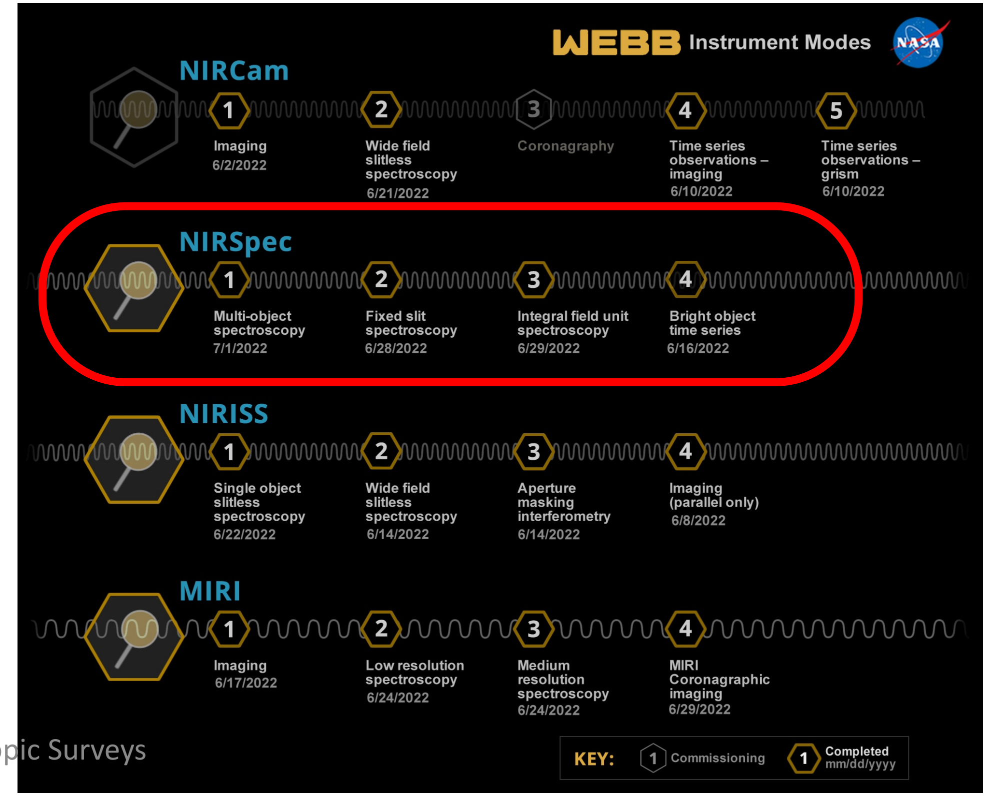
Thursday: Andy Bunker's talk

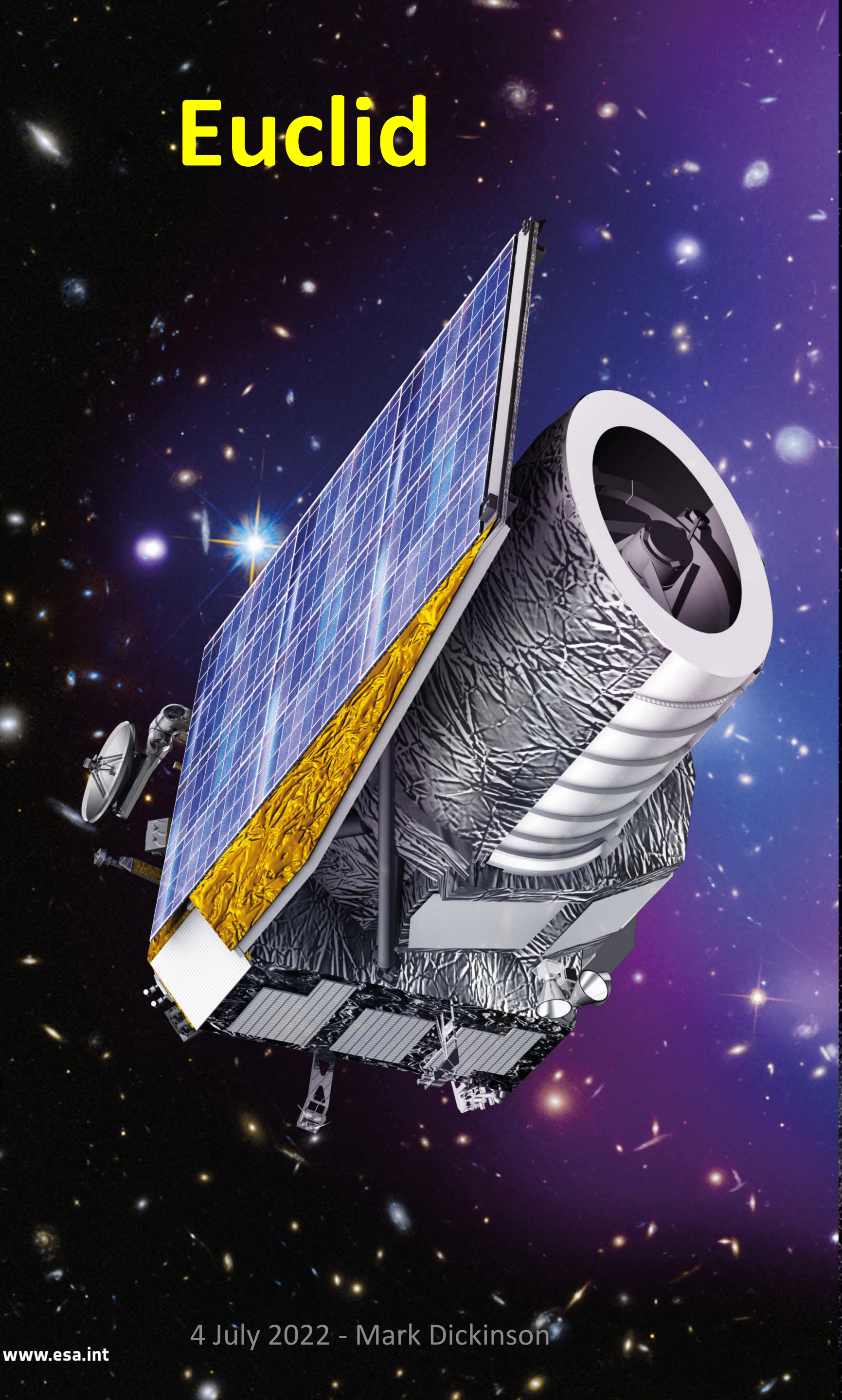
And the future is almost here!

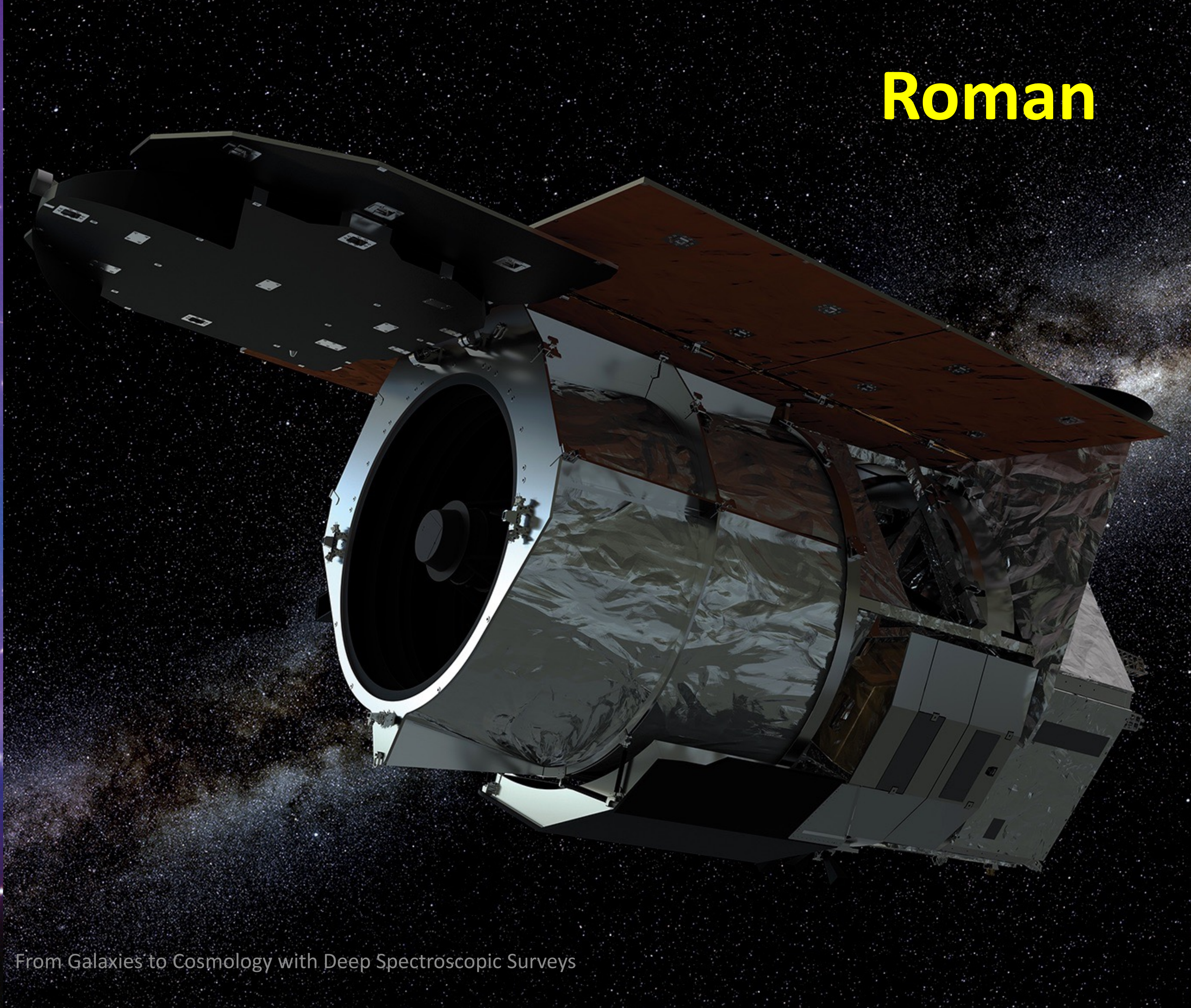






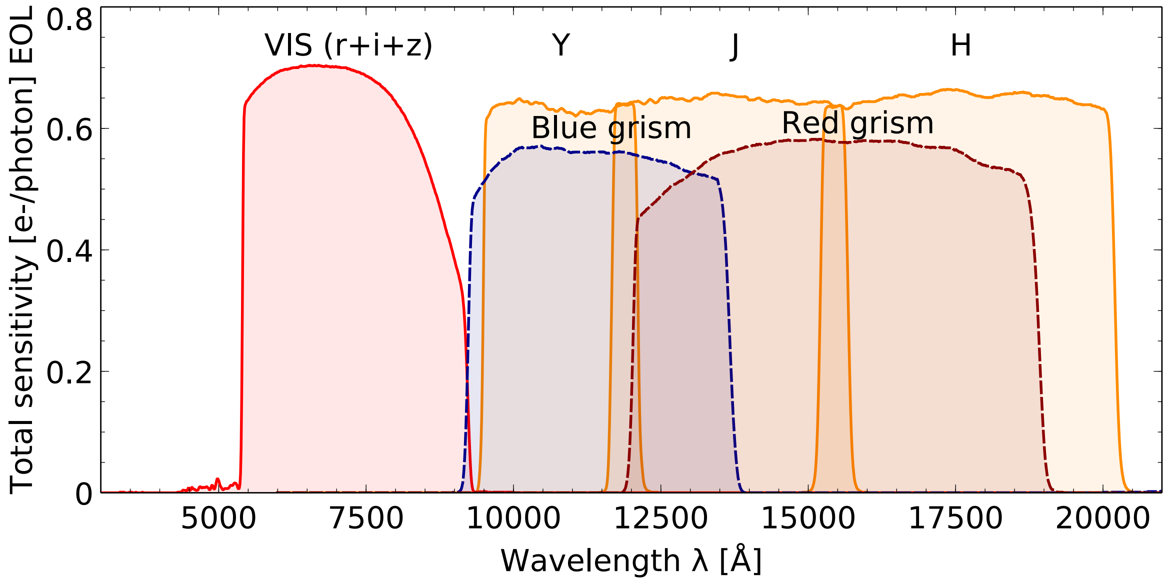



Euclid
www.esa.int

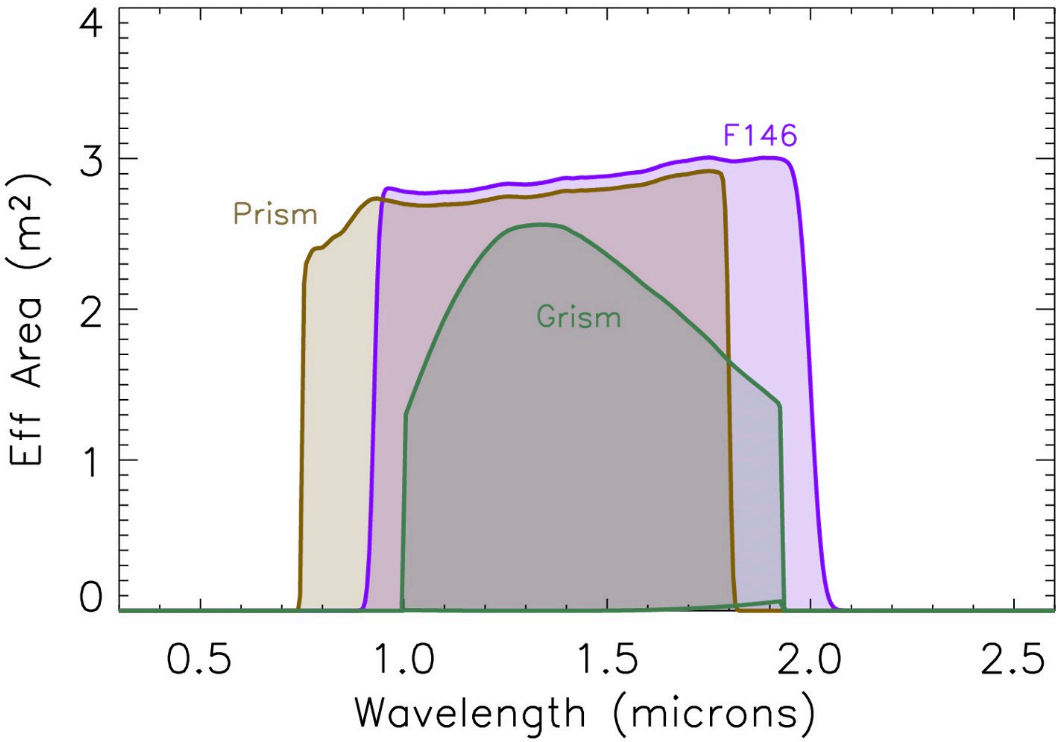

Roman

Euclid + Roman slitless spectroscopy

Euclid



Roman



Telescope aperture: 2.4m Field of View (NISP): 0.53 deg^2

Blue grism: 0.92–1.25 μm

Red grism: 1.25–1.85 μm, 1.354 nm/pix → R ≈ 550 (2 pix) @ 1.5 μm

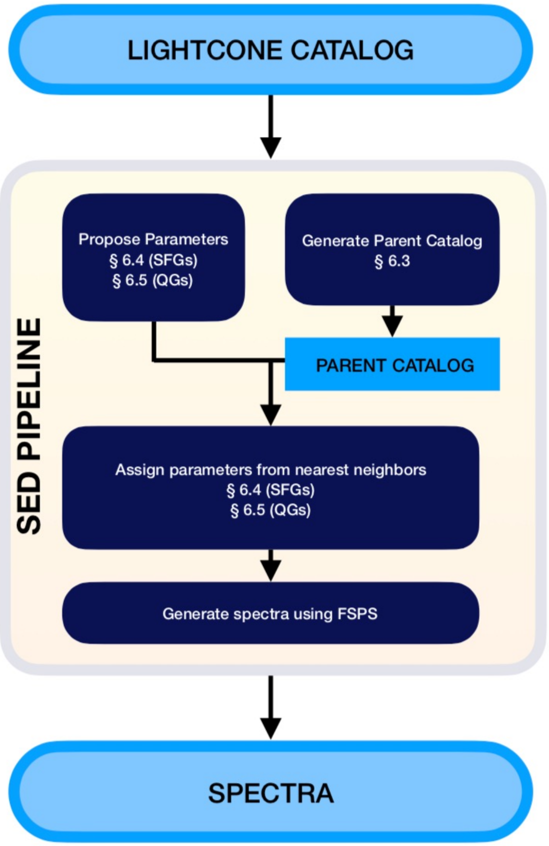
Telescope aperture: 2.4 m Field of View (WFI): 0.28 deg^2

Prism: 0.75–1.80 μm, 2-9 nm/pix → 80 < R < 180

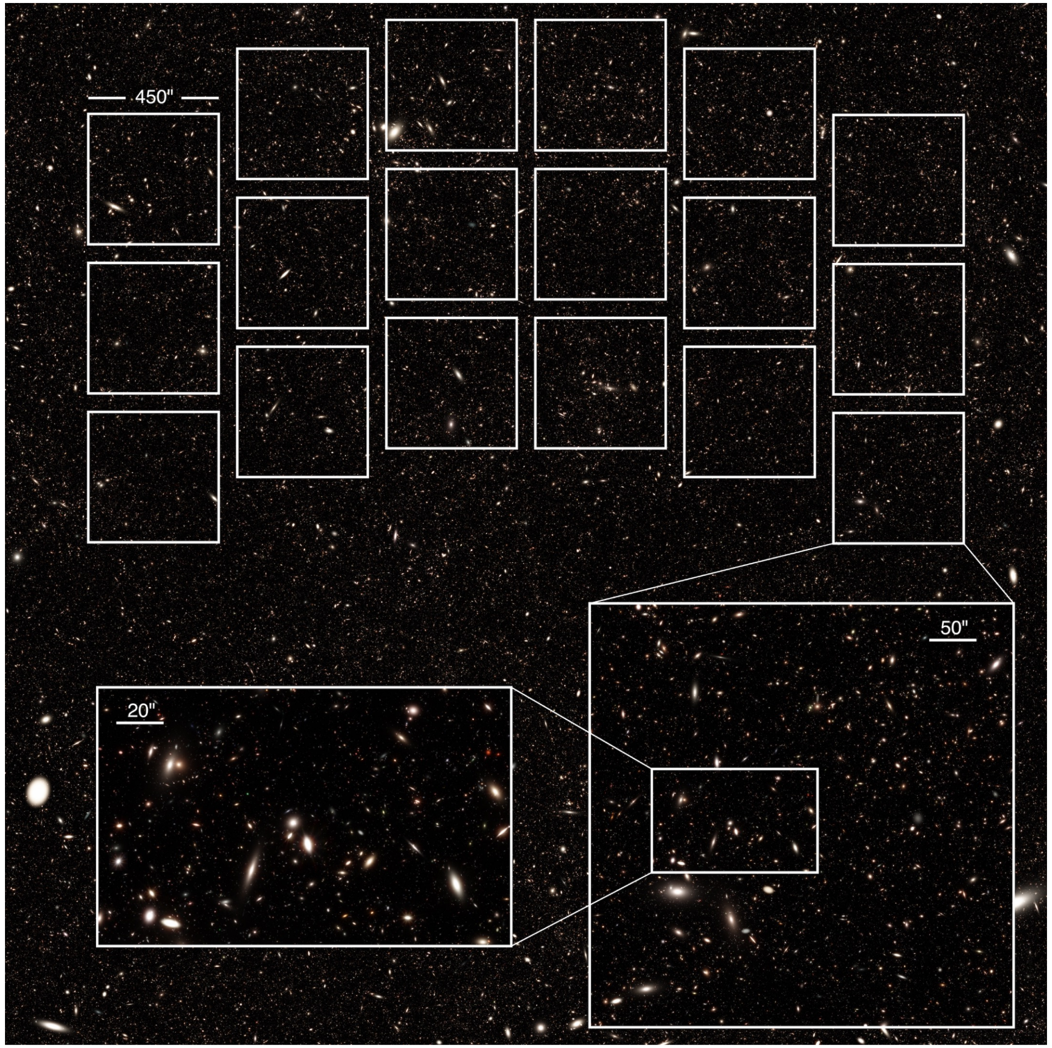
Grism: 1.00–1.93 μm, 1.1 nm/pix → R ≈ 680 (2 pix) @ 1.5 μm

DREaM: Simulated Roman Ultradeep Legacy Field

N. Drakos et al. 2022, Roman EXPO Science Investigation Team

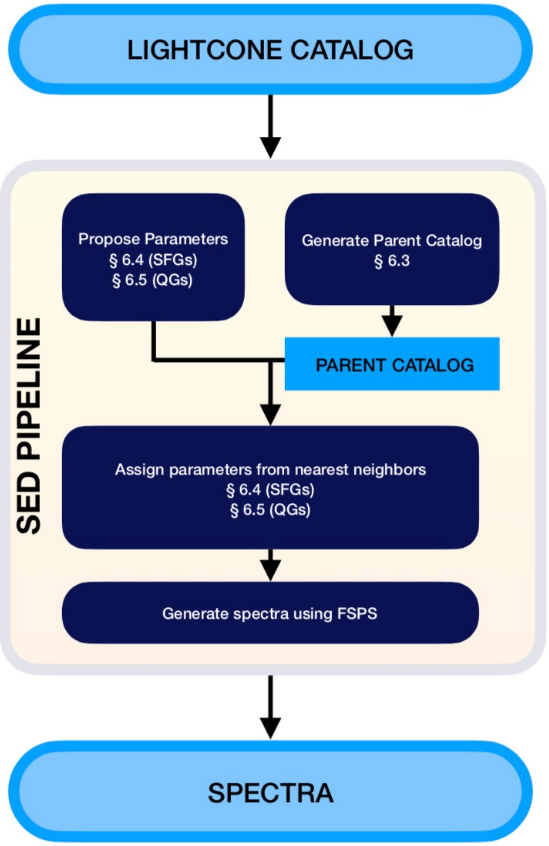


- DREaM assigns galaxy properties to dark matter haloes) (M^*, SFR, t, Z, A_V, etc.)
- FSPS (Conroy+2009) stellar population synthesis + nebular emission (Byler+2017)
- 1 deg^2: 5×10^6 galaxies, $m < 30$, $0 < z < 13$



DREaM: Simulated Roman Ultradeep Legacy Field

N. Drakos et al. 2022, Roman EXPO Science Investigation Team



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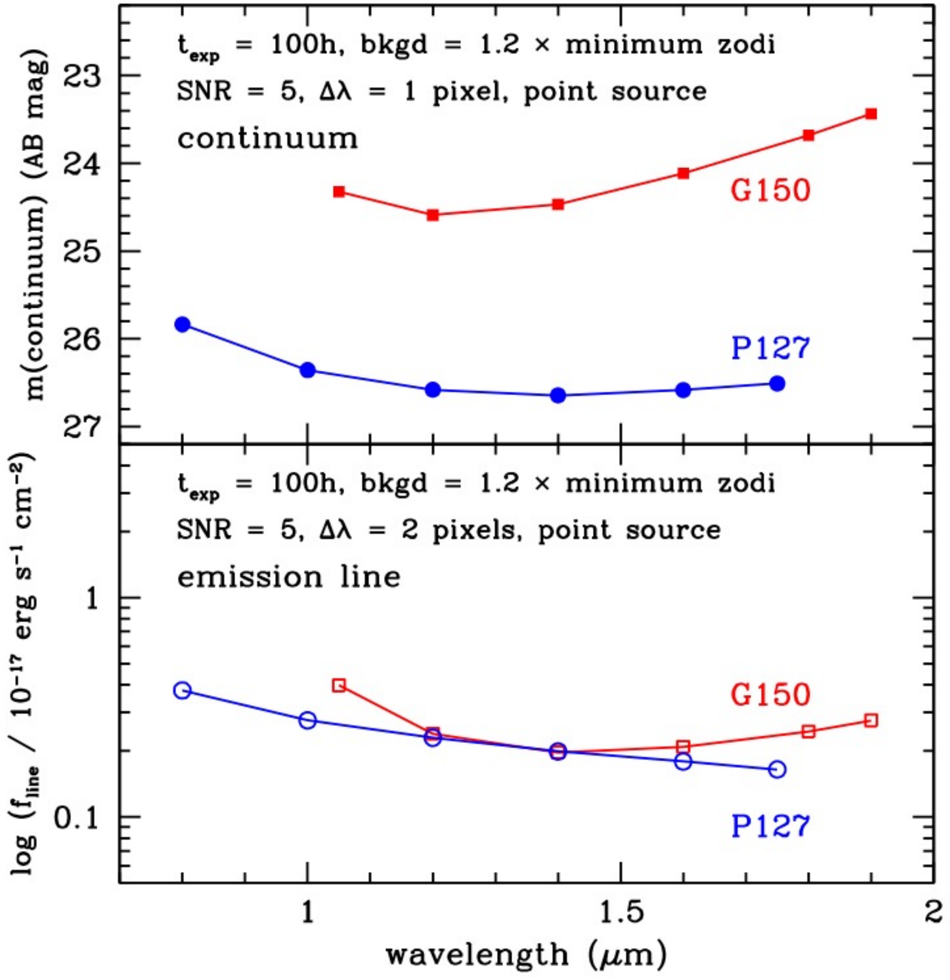
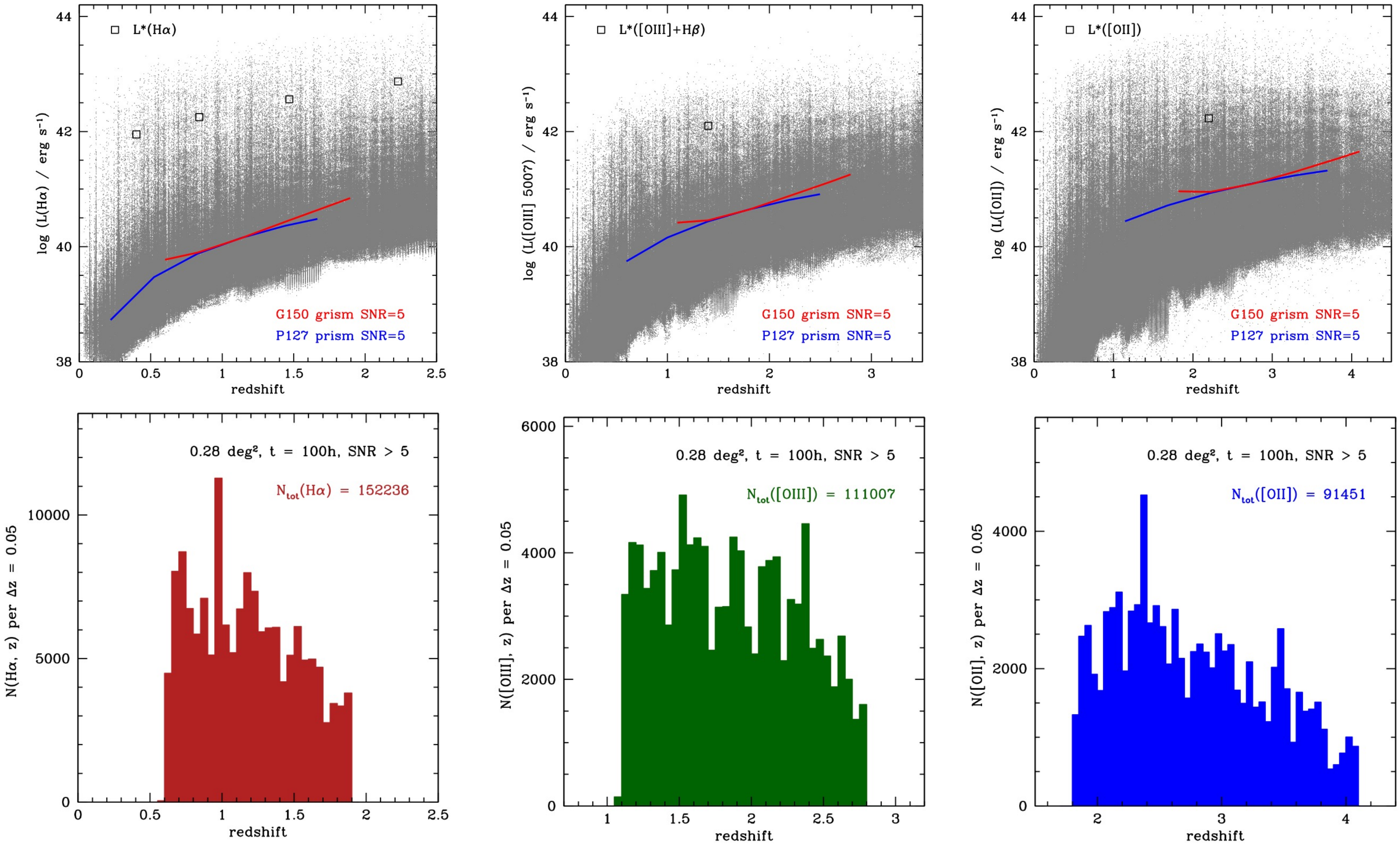
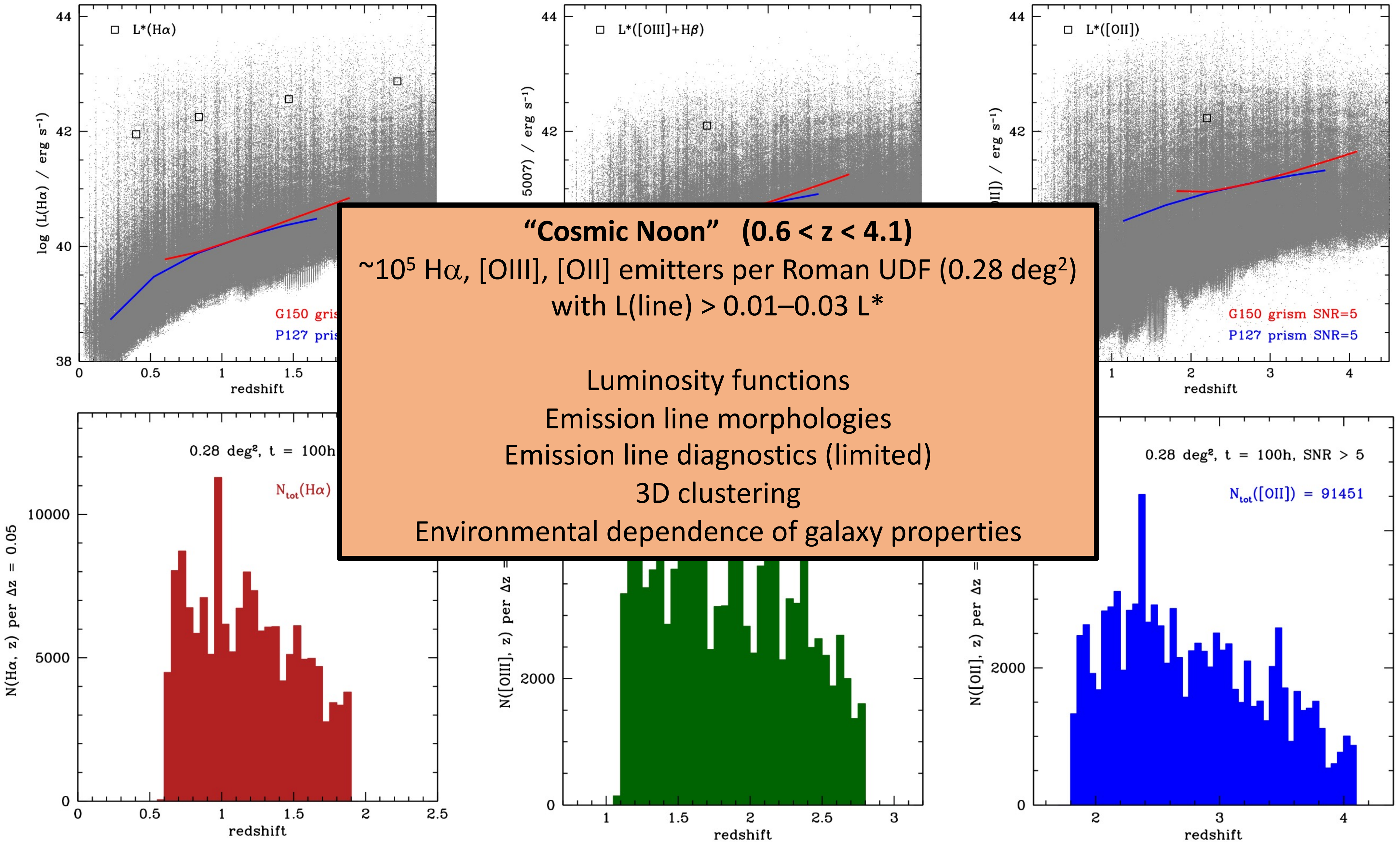
- 1 deg^2: 5x10^6 galaxies, m < 30, 0 < z < 13

Roman Ultradeep Spectroscopy (100h)
Simplified simulation using nominal Roman WFI performance

Spectral Sensitivities:
Line: 2-4 x 10^{-18} erg s^{-1} cm^{-2}
Contin. (prism): AB ≈ 25.8 – 26.6




L*(Hα)
log (L(Hα) / erg s⁻¹)
G150 grism SNR=5
P127 prism SNR=5
redshift
L*([OIII]+Hβ)
log (L([OIII] 5007) / erg s⁻¹)
G150 grism SNR=5
P127 prism SNR=5
redshift
L*([OII])
log (L([OII]) / erg s⁻¹)
G150 grism SNR=5
P127 prism SNR=5
redshift
0.28 deg², t = 100h, SNR > 5
N_tot(Hα) = 152236
N(Hα, z) per Δz = 0.05
redshift
0.28 deg², t = 100h, SNR > 5
N_tot([OIII]) = 111007
N([OIII], z) per Δz = 0.05
redshift
0.28 deg², t = 100h, SNR > 5
N_tot([OII]) = 91451
N([OII], z) per Δz = 0.05
redshift



"Cosmic Noon" (0.6 < z < 4.1)

~10^5 Hα, [OIII], [OII] emitters per Roman UDF (0.28 deg^2) with L(line) > 0.01–0.03 L*

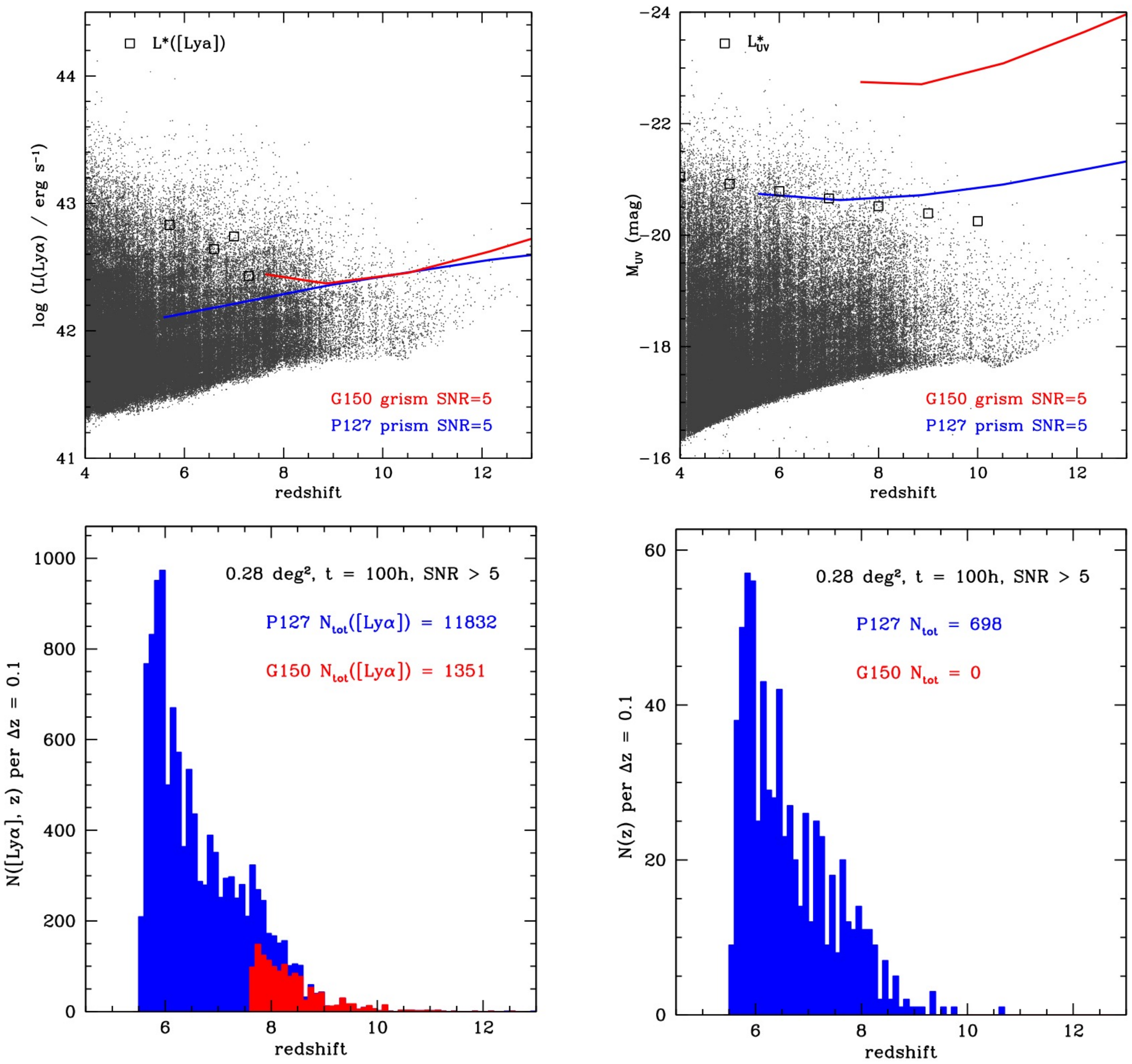
Luminosity functions

Emission line morphologies

Emission line diagnostics (limited)

3D clustering

Environmental dependence of galaxy properties



"Cosmic Dawn / early morning-ish"

P127 Prism: ~10^4 Lyα at z > 5.2
G150 Grism: ~10^3 Lyα at z > 7.2

P127 Prism: ~700 Lyα breaks at 5.2 < z < 11

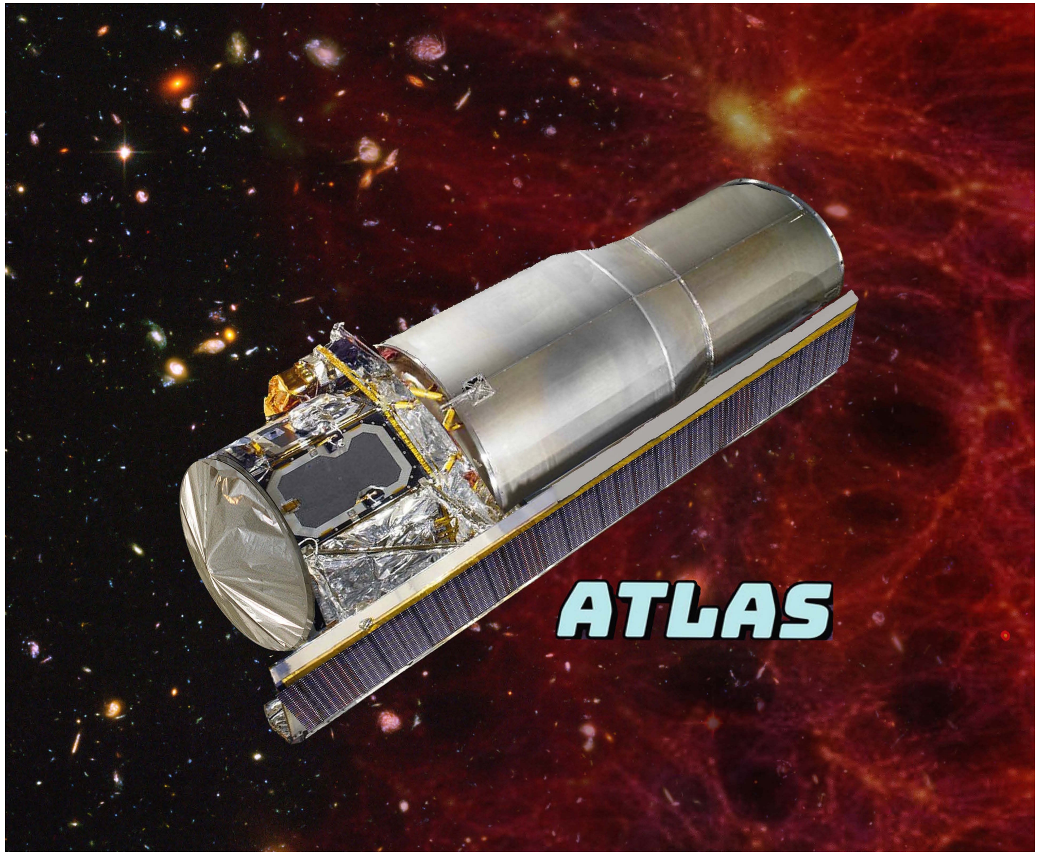
Astrophysics Telescope for Large Area Spectroscopy (ATLAS)

Galaxy Evolution & Cosmology from Spectroscopy of 200M Galaxies out to z=7

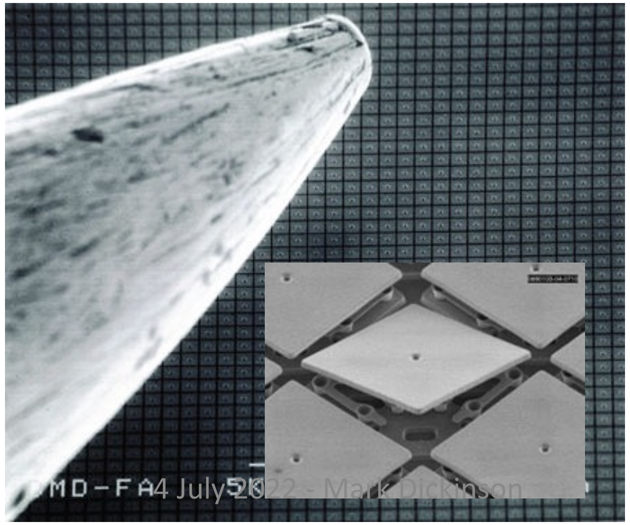
Conceived as a NASA Probe Mission concept
Heritage from ESA Euclid precursor 'SPACE'

- **1.5m aperture telescope with 0.4 deg² FoV**
- **R = 1000 slit spectroscopy over 1 to 4 μm**
  - Hα + [NII] at 0.5 < z < 5
  - Hβ + [OIII] at 1 < z < 7
  - [OII] at 1.7 < z < 9.7
- **6,000 spectra simultaneously**
- **Slit selectors: Digital Micromirror Devices**

Now being rescaled to ~1m NASA Explorer-class

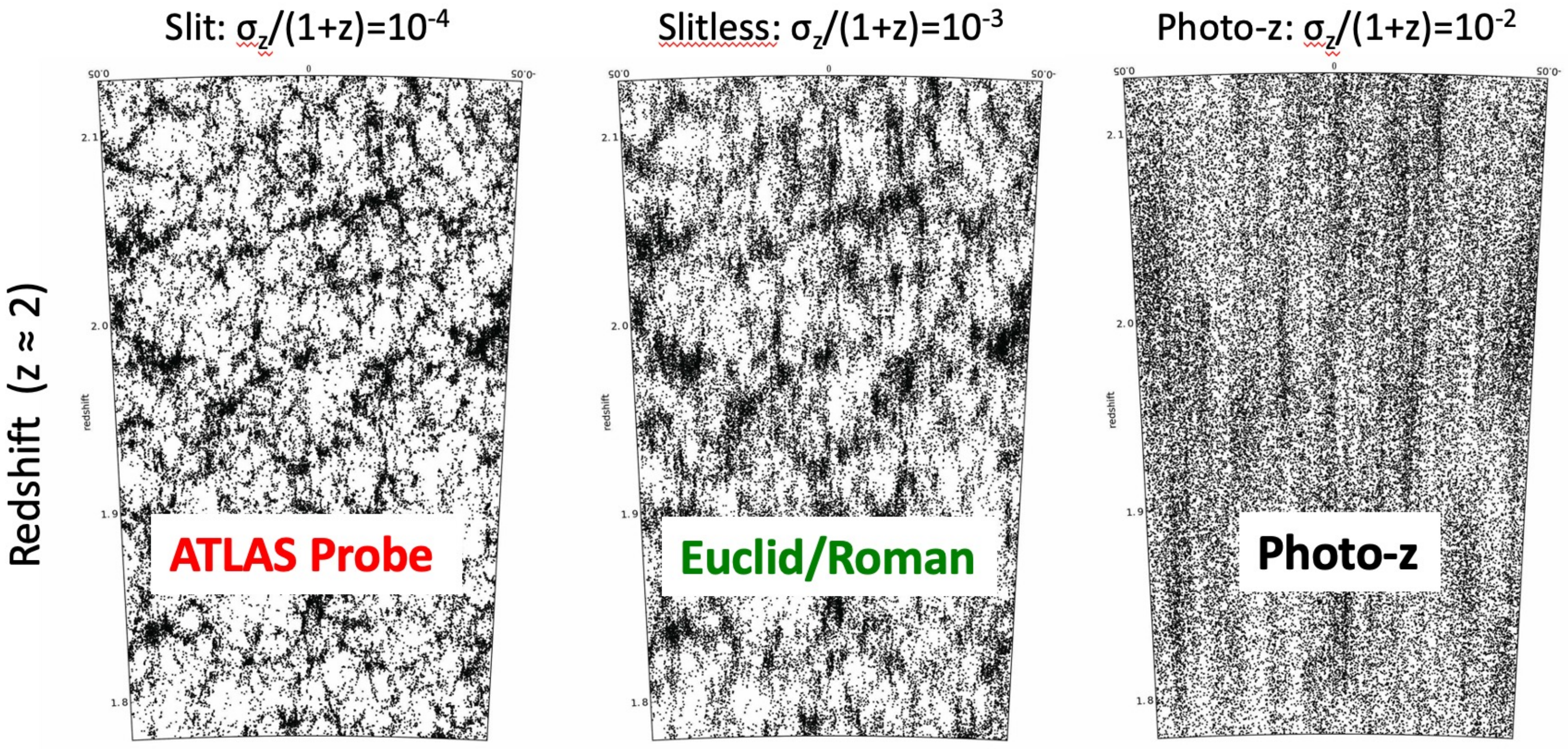


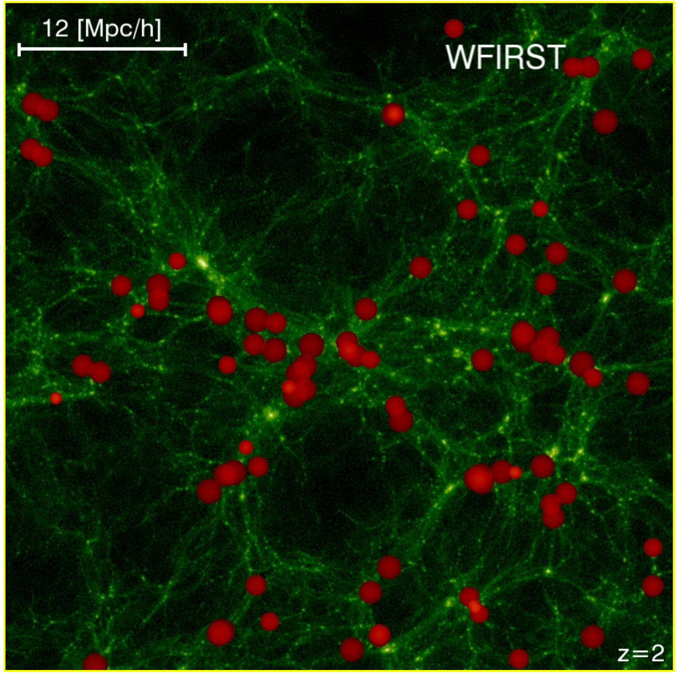
PI: Yun Wang (Caltech/IPAC)
Instrument Lead: Massimo Robberto (STScI & JHU)
Wang et al. 2019, PASA, 36, e015, arXiv:1802.01539
https://atlas-probe.ipac.caltech.edu/

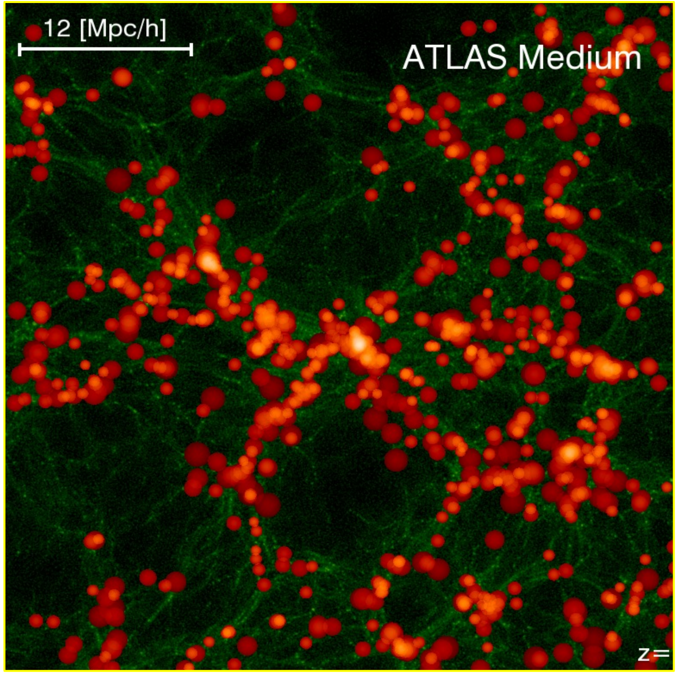


ATLAS Science Objectives

- **Map the cosmic web to shed light on the physics of galaxy evolution**
- **Trace large scale structure densely to illuminate the nature of dark energy**
- **Probe the Milky Way's dust-shrouded regions to the far side of the Galaxy**
- **Explore Kuiper Belt Objects in the outer Solar System**







(Figures by Alvaro Orsi)

Summary

- 40+ years of multi-object spectroscopy have revolutionized astronomy
  - Cosmology
  - Large Scale Structure
  - Galaxy properties and evolution
- The next 10-20 years: The revolution continues
  - Massively multiplexed, dedicated spectroscopic observatories
  - New infrared spectroscopic instruments and technologies
  - MOS on Extremely Large Telescopes
  - Space-based MOS from JWST, Euclid, Roman and beyond
- It’s not just the technology, it’s the people who use it