LUVOIR SEMINAR

REVEALING THE LAST 10 BILLION YEARS OF GAS IN AND AROUND GALAXIES

JOHN M. O'MEARA
SAINT MICHAEL'S COLLEGE
LUVOIR STDT MEMBER, COR SWG CO-LEAD

SPITZER, 1946

8. Composition of Interstellar Gas

Interstellar atoms and molecules are known to be present between the stars, and to have a total aggregate mass about equal to that of the stars. Such particles are all in their ground state; hence observations of stellar spectra in the visible give no information on the presence of many of the atoms and molecules that may be expected. Measurements in the ultra-violet would give information on the density of interstellar hydrogen in space near the sun, and would indicate how much if any of this material was in the form of molecules. Such measurements would also indicate how

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BACHALL & SPITZER, 1969

ABSORPTION LINES PRODUCED BY GALACTIC HALOS

JOHN N. BAHCALL*
Institute for Advanced Study

AND

LYMAN SPITZER, JR.
Princeton University Observatory
Received March 24, 1969

ABSTRACT

We propose that most of the absorption lines observed in quasi-stellar sources with multiple absorption redshifts are caused by gas in extended halos of normal galaxies.

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was in

2. Composition of Planetary Atmospheres

The small amount of O_2 and H_2O present in the atmosphere of Mars and Venus cannot be detected spectroscopically because of the absorption produced by these same molecules in our own atmosphere. A spectroscopic satellite telescope could observe the spectra of planetary atmospheres without any such interferences, and could supplement observations in the infra-red with equally useful ultra-violet data.

BA

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1993

1993

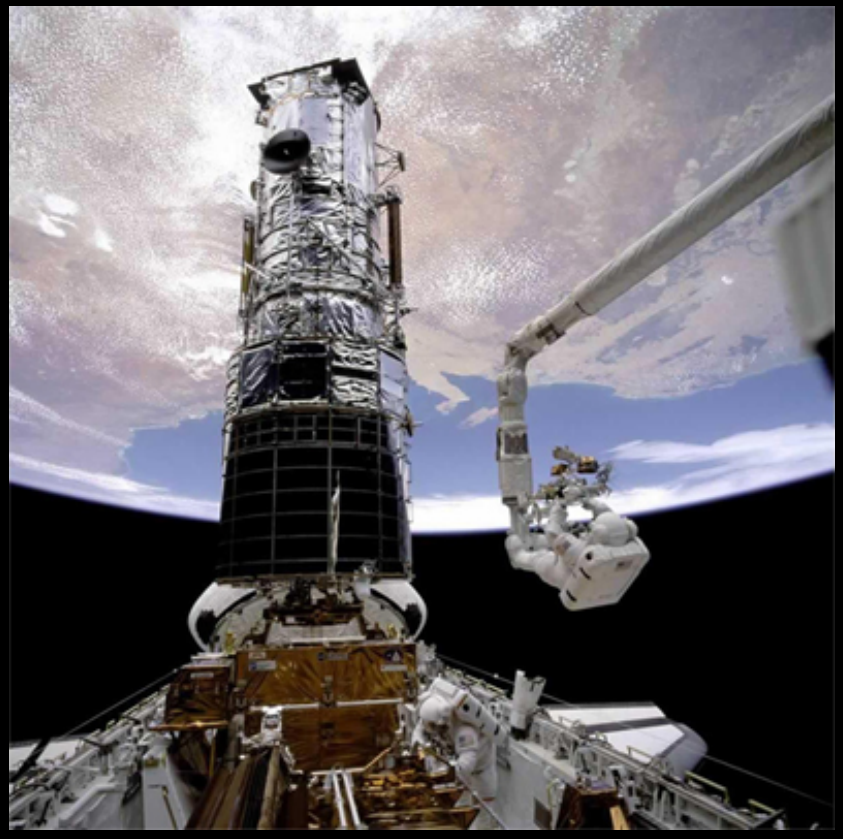
1993

2016

2016

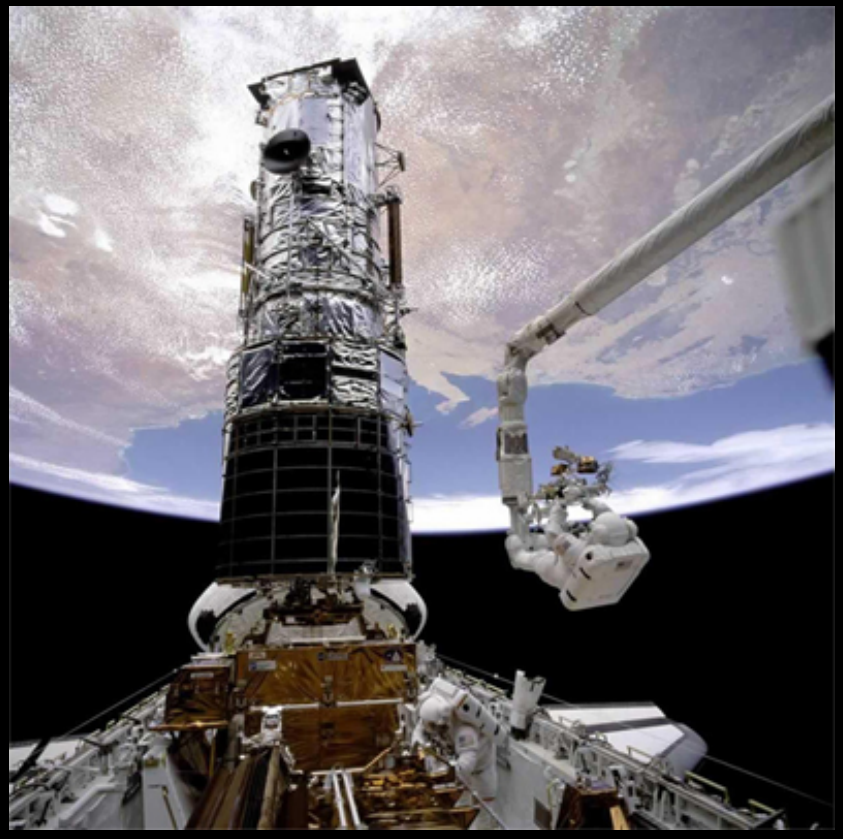
1993

1993



HST SM1

1993



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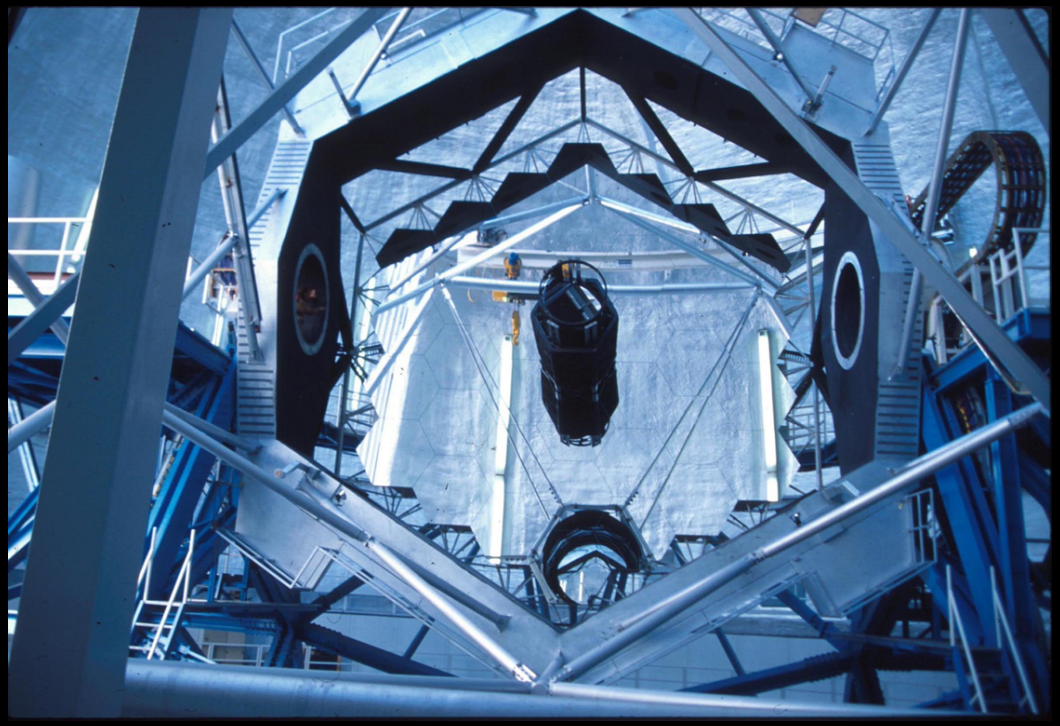
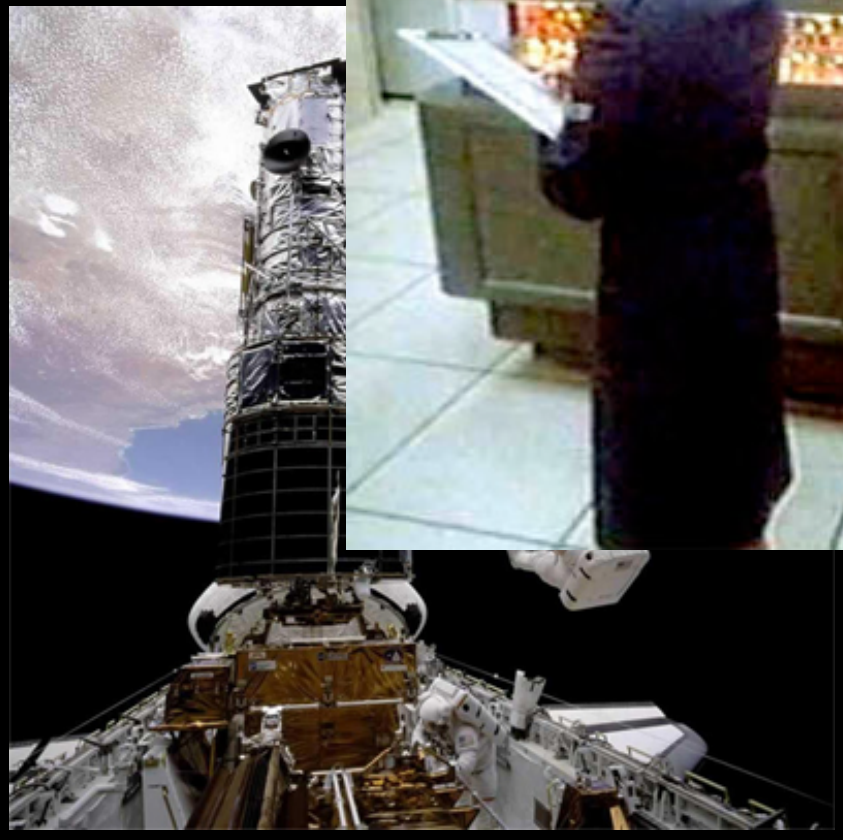
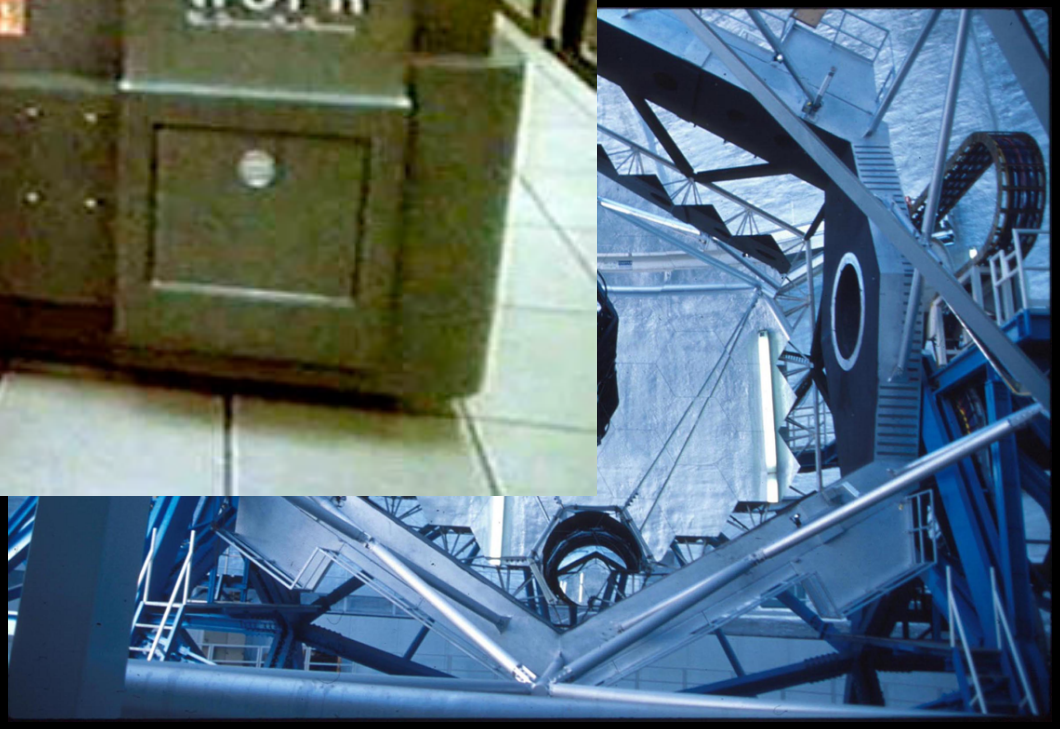


Keck 1

1993

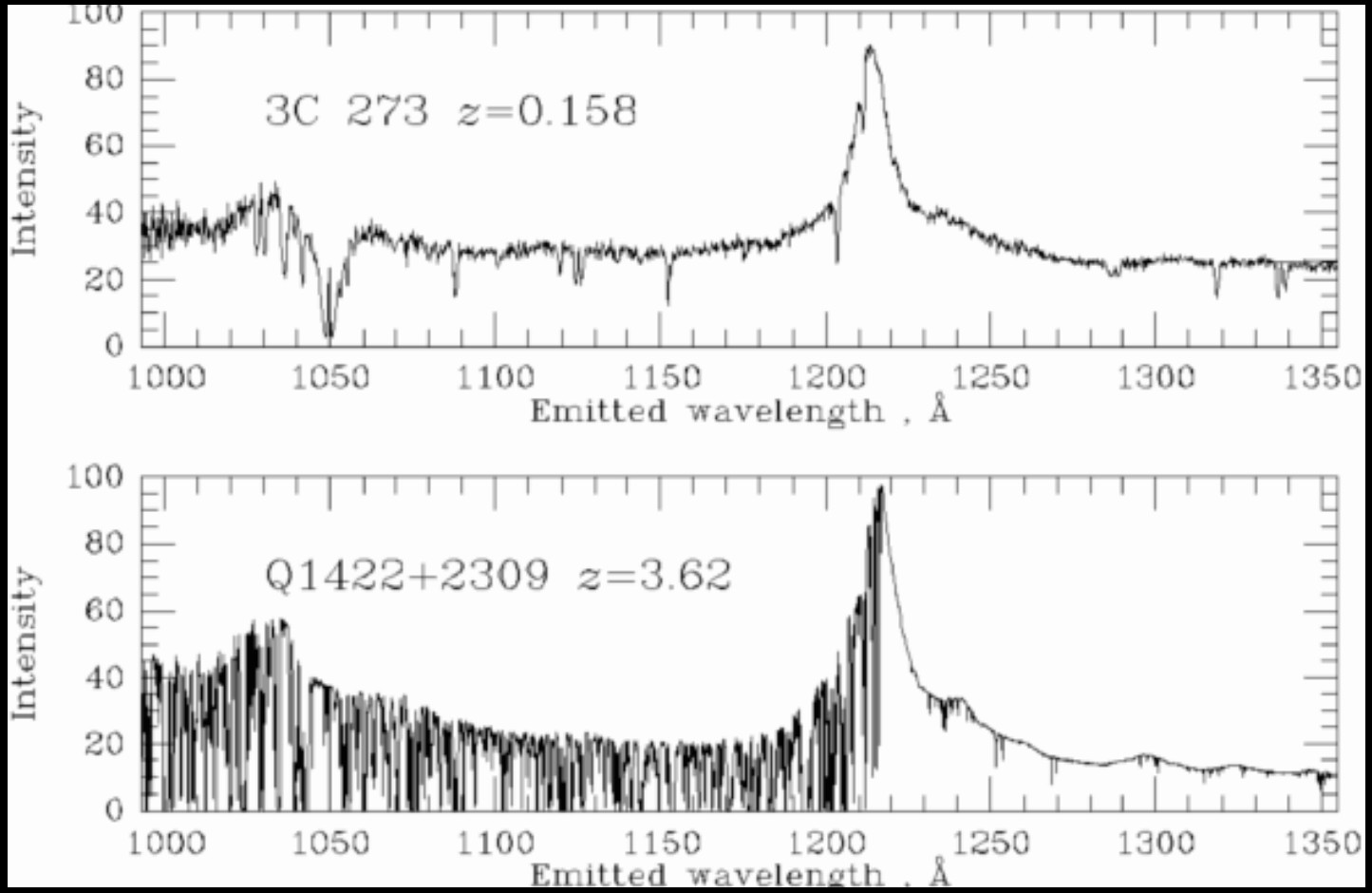




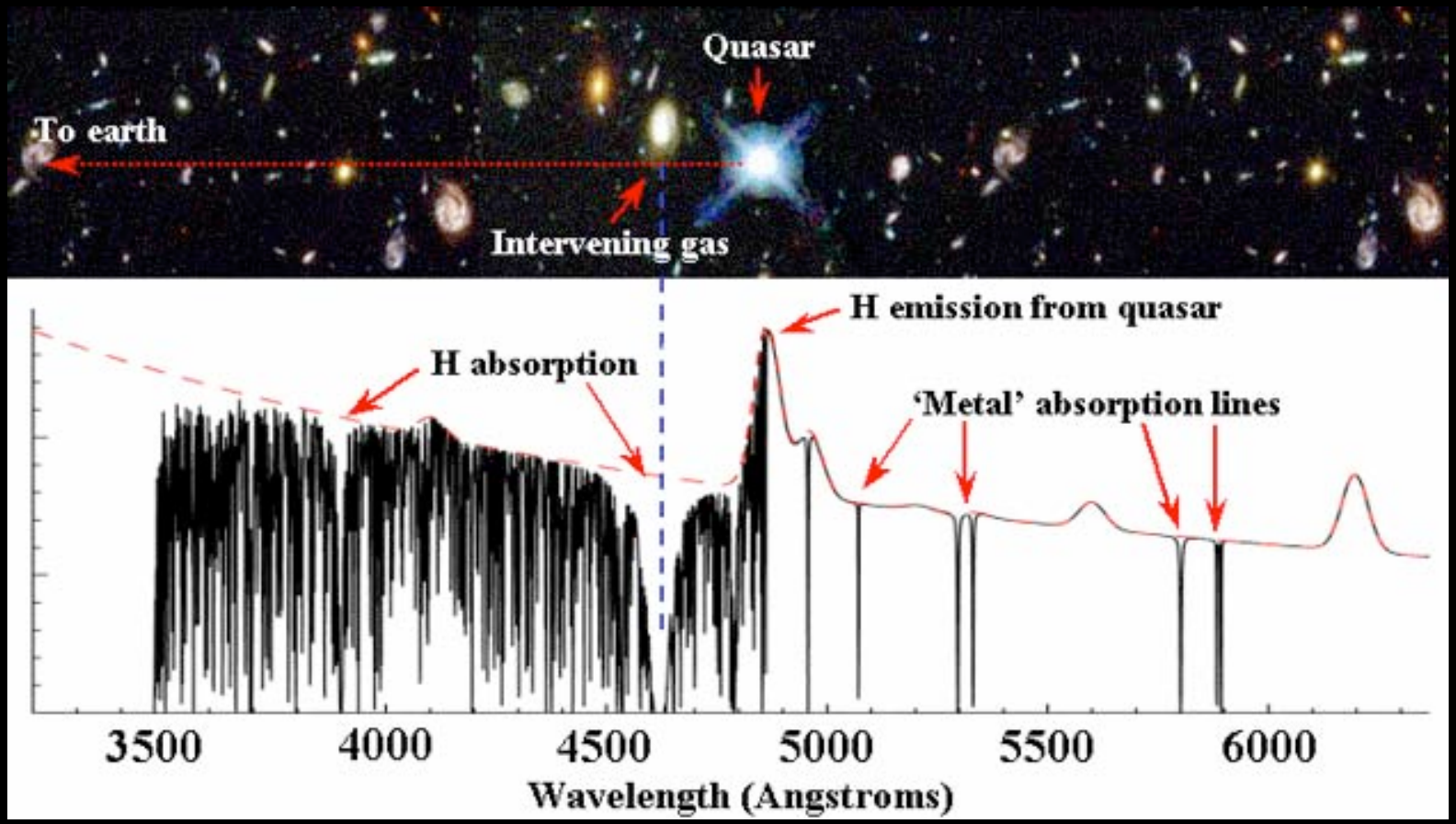
HST SM1

Keck 1

THE FIRST GOLDEN AGE FOR QAL ASTROPHYSICS AND COSMOLOGY



A VERY LONG PENCIL



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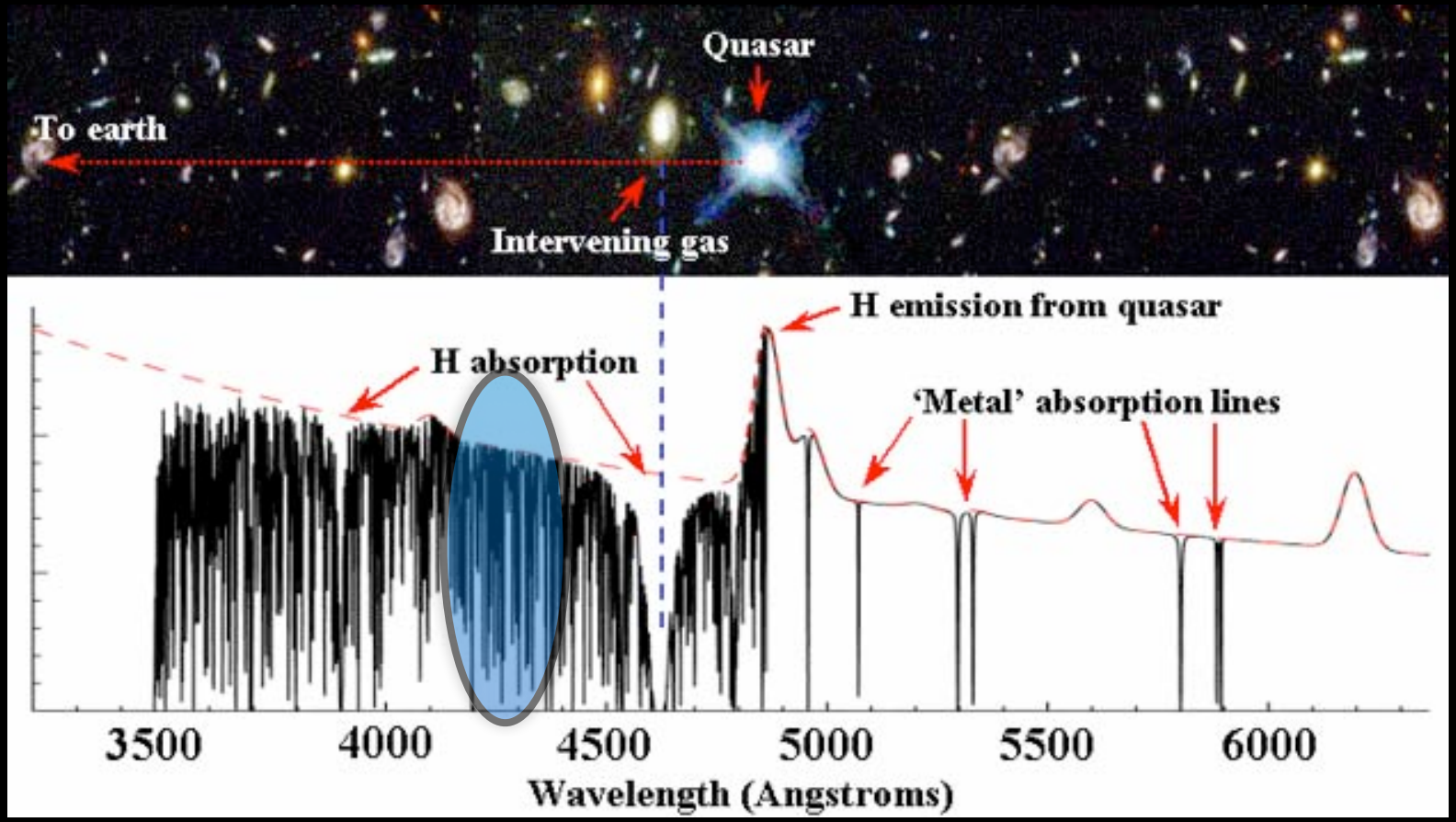
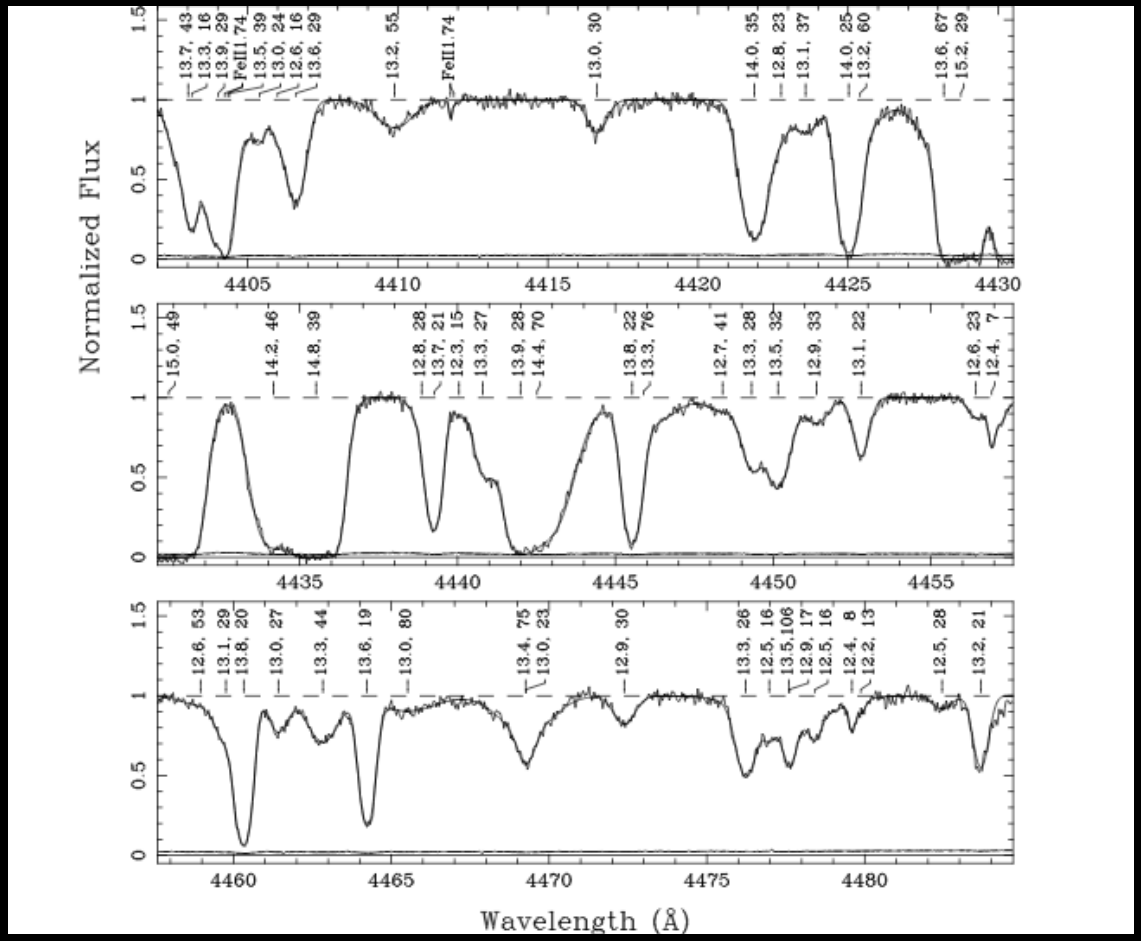


VICTORY #1: THE HOT, HIGHLY IONIZED IGM FROM THE LYMAN ALPHA FOREST



Kirkman+ 1997

TREES IN THE FOREST

- Lyman Limit Systems
- Super Lyman Limit Systems
- Damped Lyman Alpha Systems

LLS AS THE LABORATORY OF CHOICE

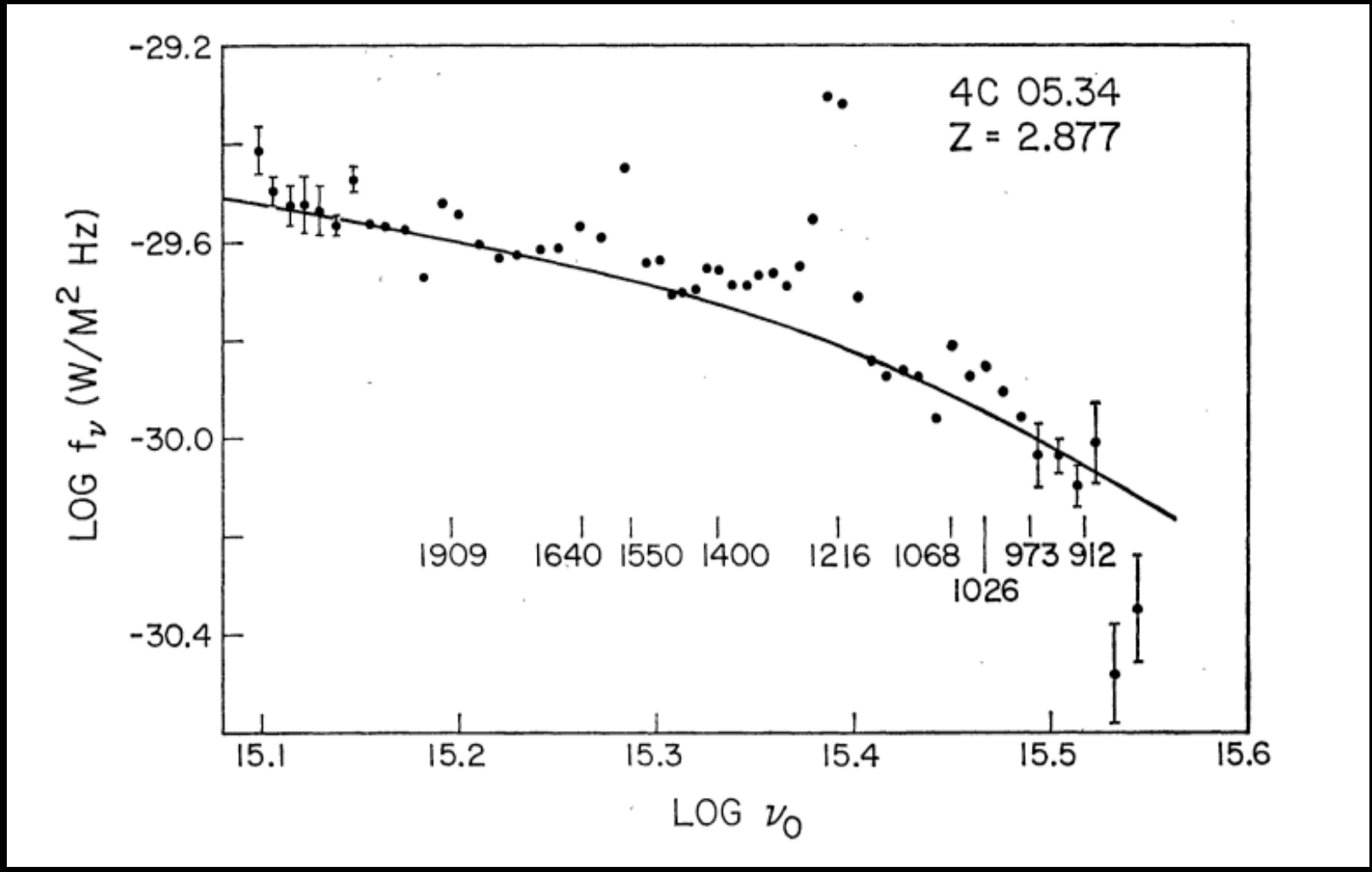
$\log(N_{NHI}) > 16$, range of ionizations & densities, metallicites can be measured

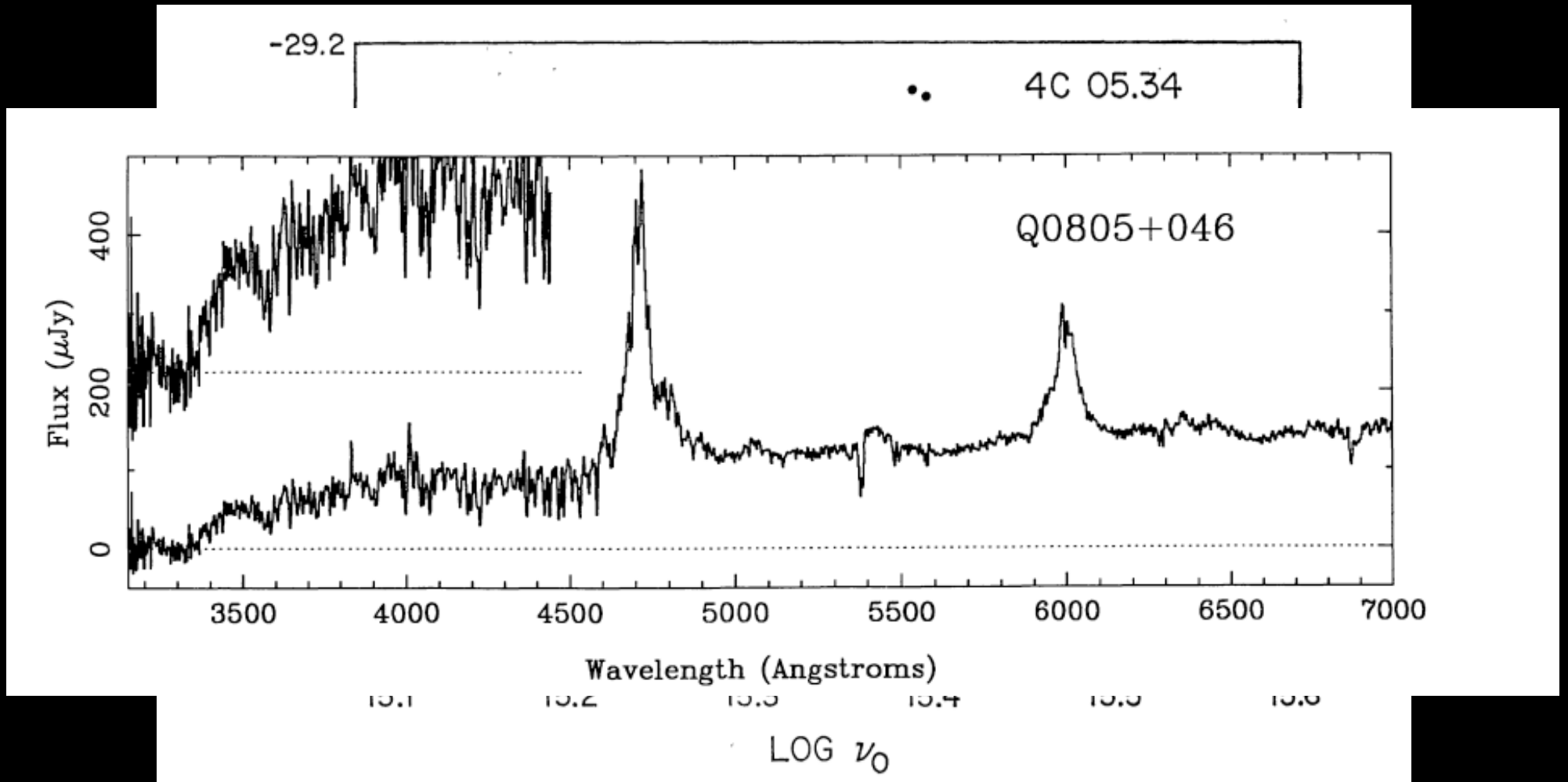
PHOTOELECTRIC SPECTROPHOTOMETRY OF 4C 05.34

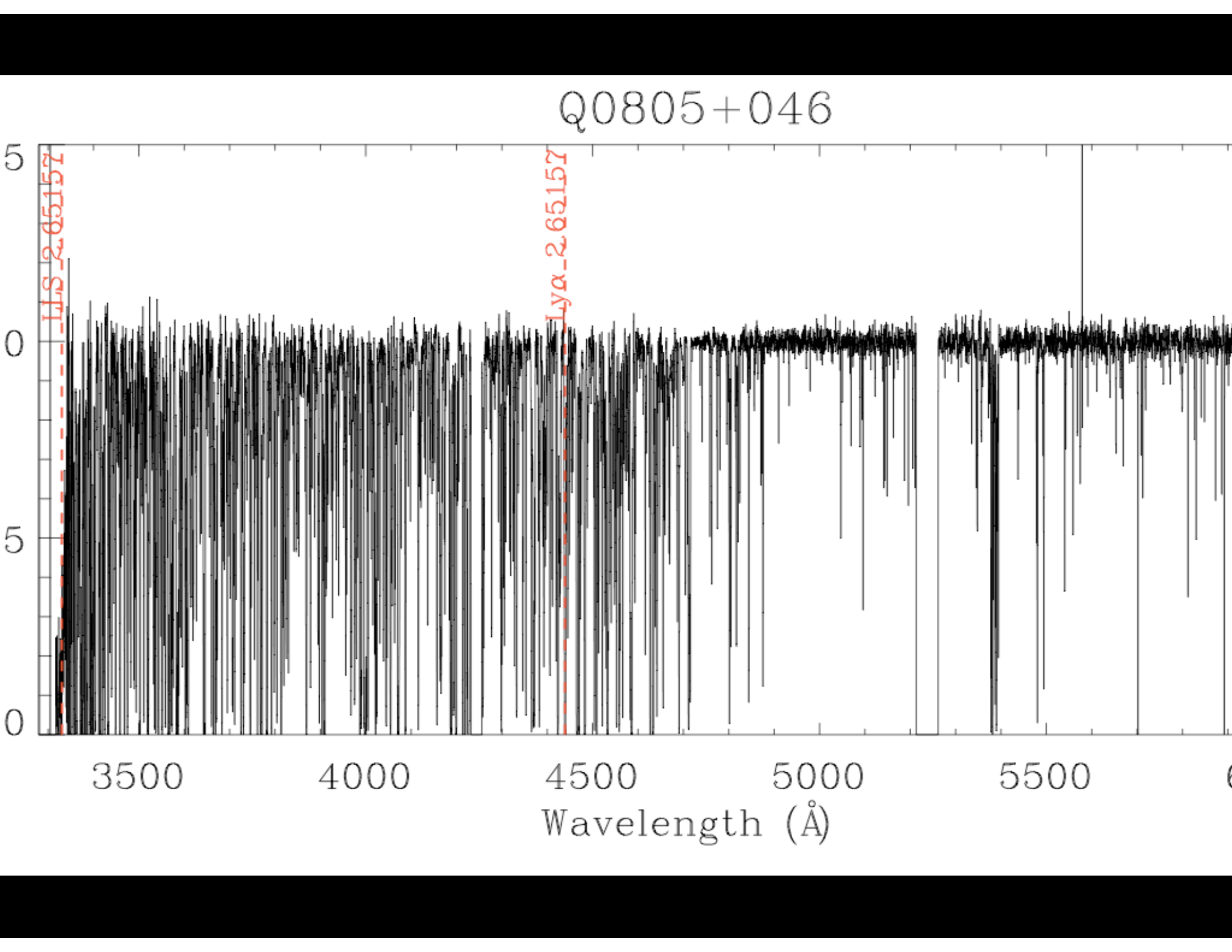
J. B. Oke
Hale Observatories, California Institute of Technology, Carnegie Institution of Washington
Received 1970 May 26

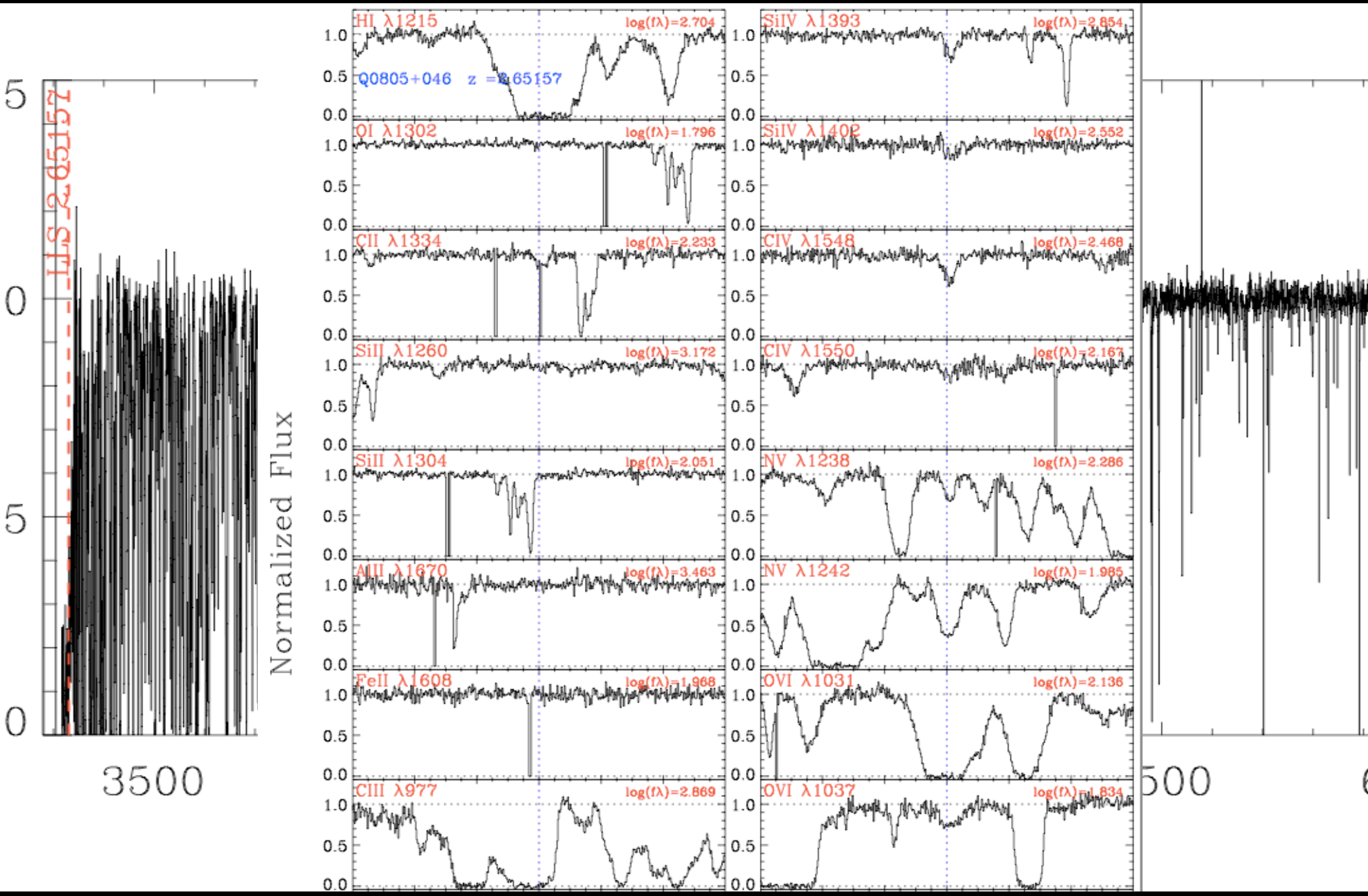
ABSTRACT

The multichannel photoelectric spectrometer has been used to obtain the absolute spectral-energy distribution in the quasi-stellar radio source 4C 05.34 from λ3220 to λ9000. The strengths of the emission lines, in terms of both equivalent width and absolute intensity, the spectral index, and the absolute flux are typical of quasi-stellar sources. Lyman β is observed, and there is a drop of intensity by a factor of 2 at the Lyman limit. From the data it is inferred that the optical depth is of the order of unity in the Lyman continuum and is approximately 3 at the center of Lβ.

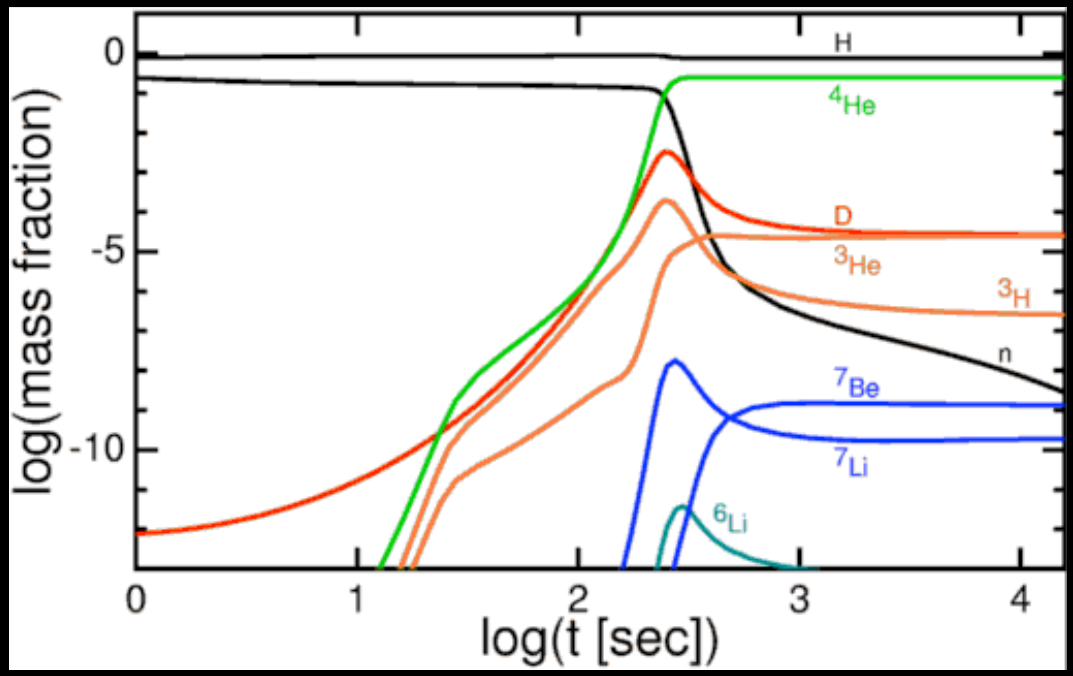

4C 05.34
Z = 2.877
-29.2
-29.6
-30.0
-30.4
LOG f_ν (W/M^2 Hz)
1909
1640
1550
1400
1216
1068
1026
973
912
15.1
15.2
15.3
15.4
15.5
15.6
LOG ν_0

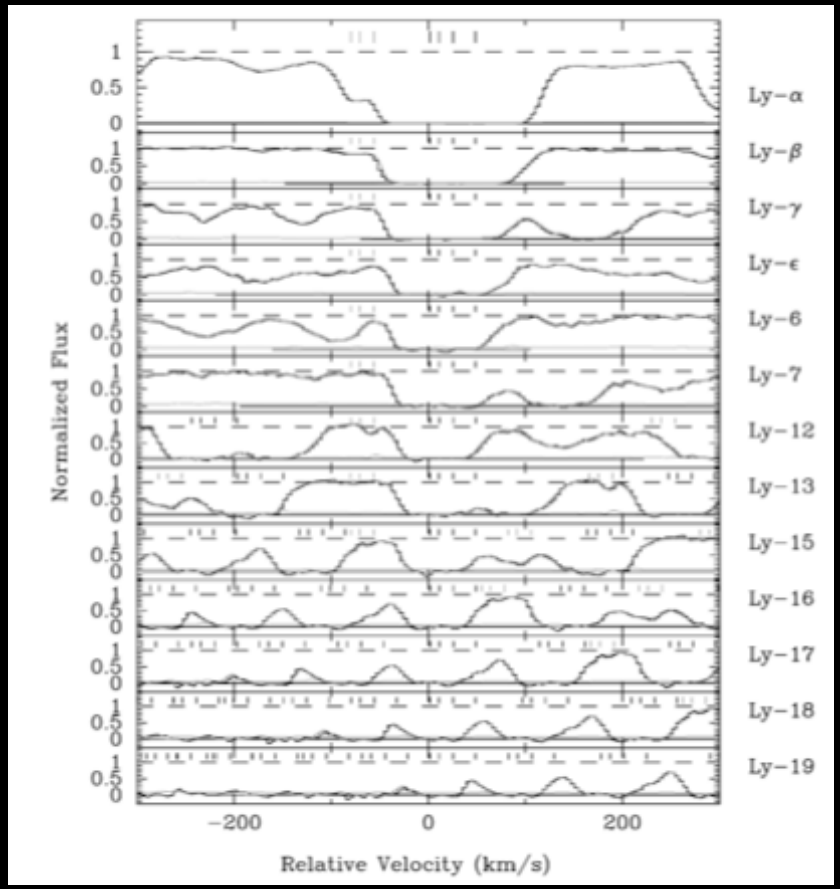

-29.2
4C 05.34
Q0805+046
Flux (μJy)
0
200
400
3500
4000
4500
5000
5500
6000
6500
7000
Wavelength (Angstroms)
LOG ν_0


Q0805+046
LLS_2.65157
Lyα_2.65157
5
0
5
0
3500
4000
4500
5000
5500
Wavelength (Å)


HI λ1215
log(fλ)=2.704
Q0805+046 z =2.65157
SiIV λ1393
log(fλ)=2.854
OI λ1302
log(fλ)=1.796
SiIV λ1402
log(fλ)=2.552
CII λ1334
log(fλ)=2.233
CIV λ1548
log(fλ)=2.468
SiII λ1260
log(fλ)=3.172
CIV λ1550
log(fλ)=2.167
SiII λ1304
log(fλ)=2.051
NV λ1238
log(fλ)=2.286
AlII λ1670
log(fλ)=3.463
NV λ1242
log(fλ)=1.985
FeII λ1608
log(fλ)=1.968
OVI λ1031
log(fλ)=2.136
CIII λ977
log(fλ)=2.869
OVI λ1037
log(fλ)=1.834
Normalized Flux
1.0
0.5
0.0
3500

VICTORY #2

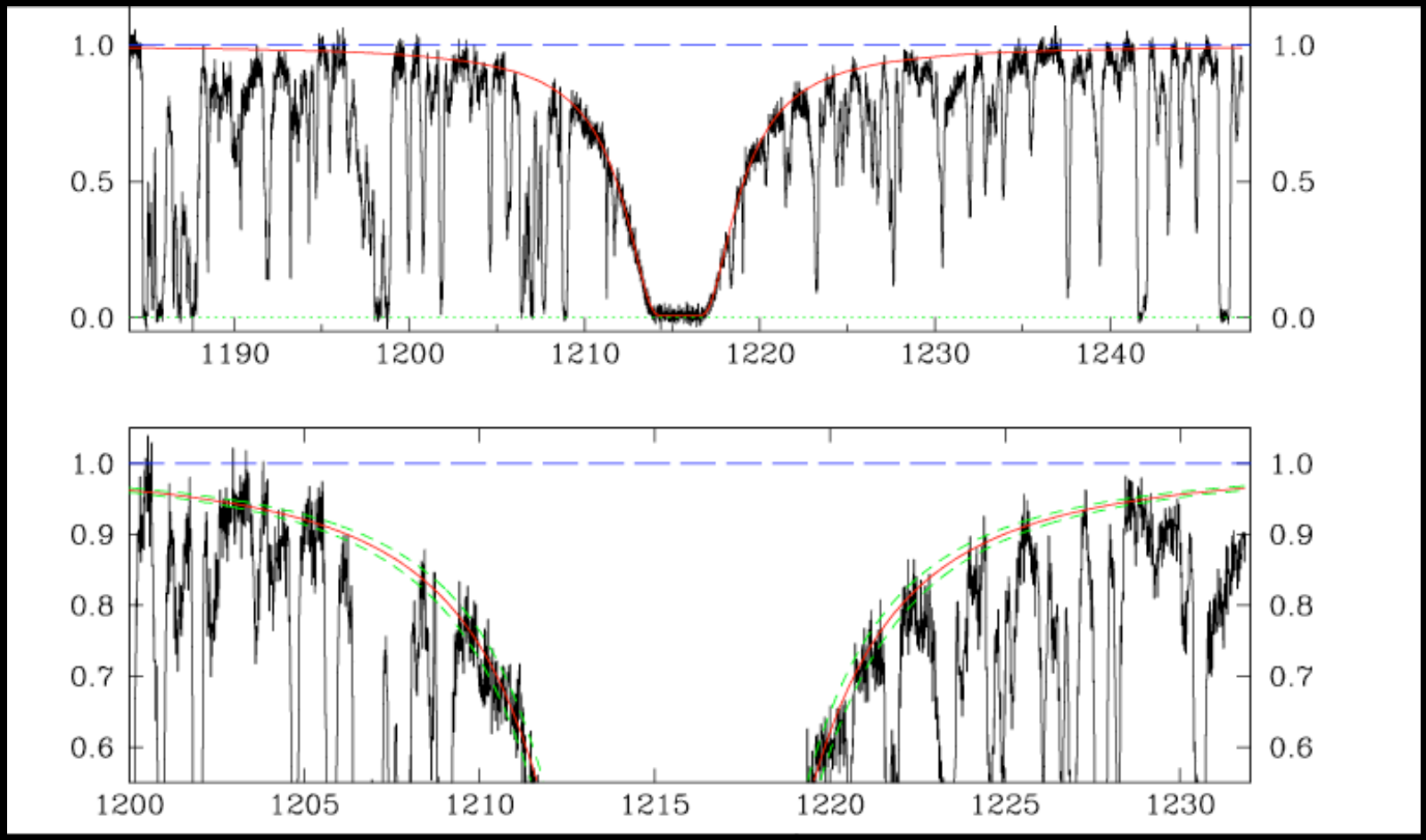




Burles & Tytler 1998

Testing BBN with D/H + LLS

VICTORY #3



Characterization of the ISM of galaxies with the DLA

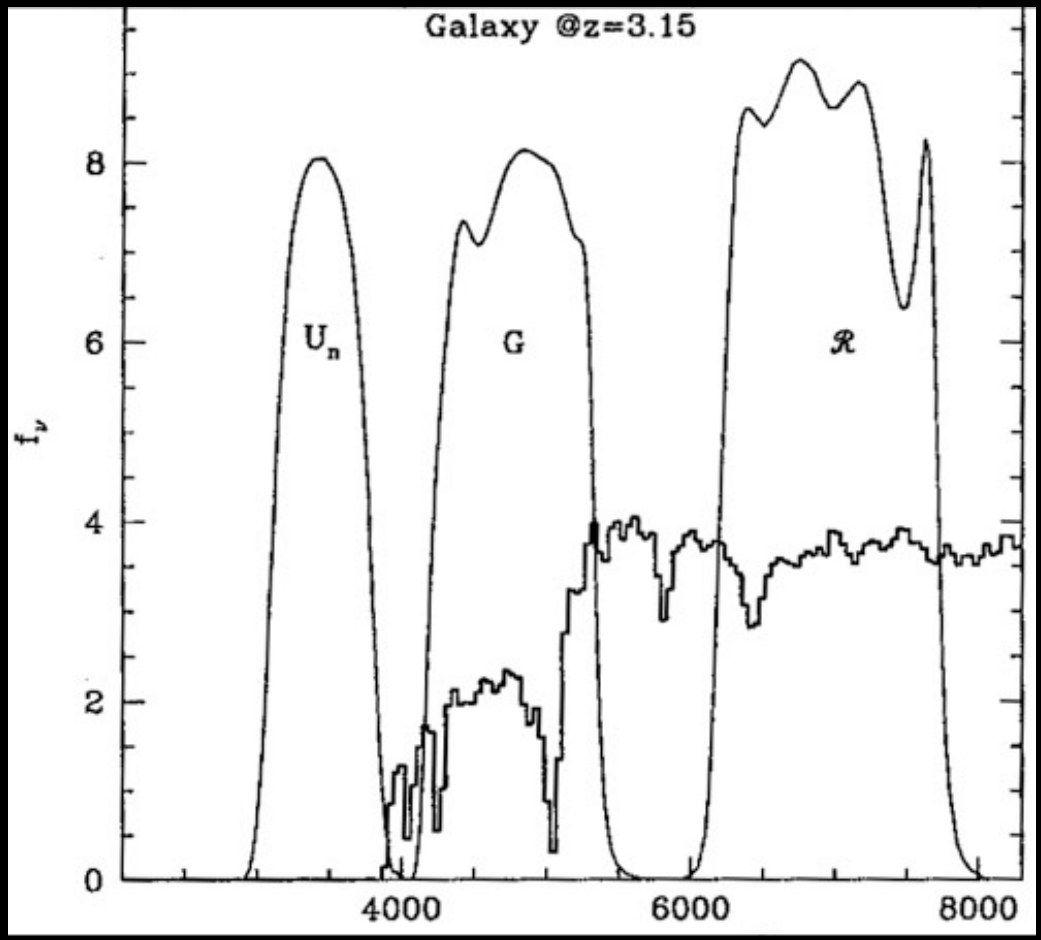
THE DLA

- $N(HI) \geq 2 \times 10^{20}$ cm^{-2}
- The hydrogen is mainly *neutral*
- Identified toward QSOs (and GRBs) in absorption

THE DLA

- The dominant neutral hydrogen reservoirs at z~3
- A significant(?) repository of metals, and a tracer of star formation histories
- ISM of (star forming?) galaxies at high redshift?

VICTORY #4



Direct detection of galaxies via the Lyman break

THE SILVER AGE: HST AND THE GAS-GALAXY CONNECTION

THE GAS-GALAXY CONNECTION

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- How do galaxies transition to quiescence?

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We need the last 10 billion years of gas history in, around, and in between galaxies

THE CIRCUMGALACTIC MEDIUM AS MAIN STAGE

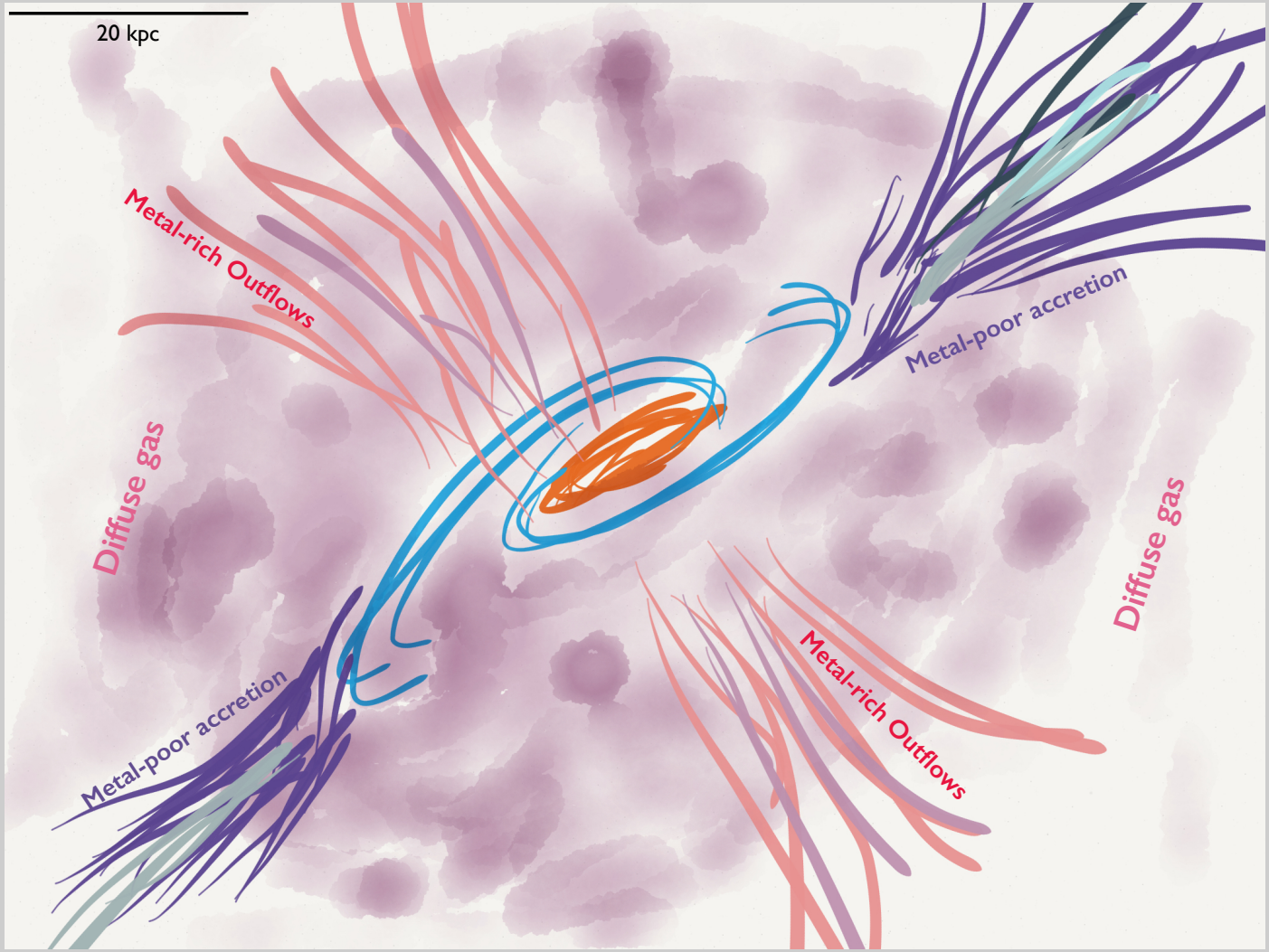
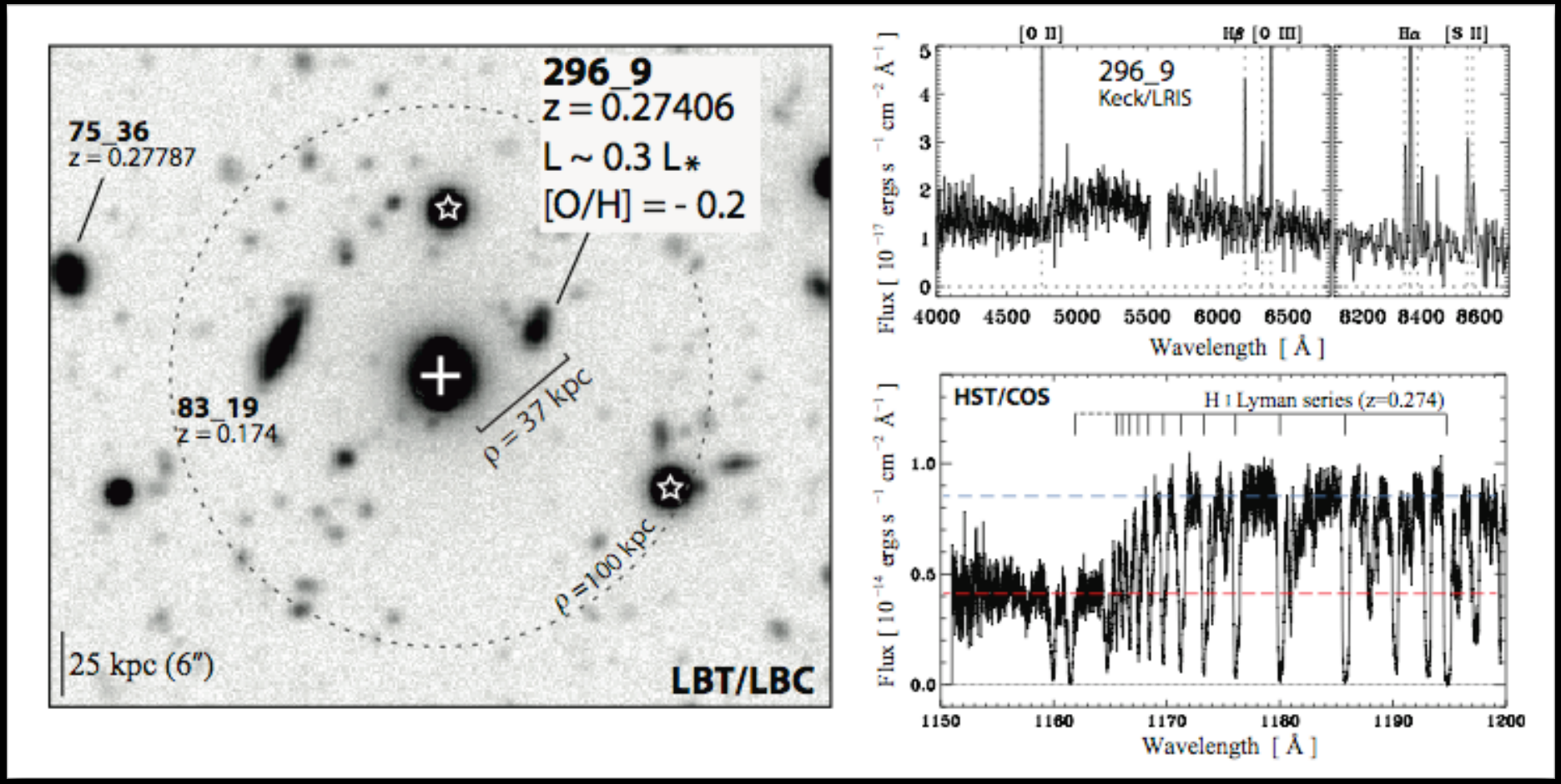


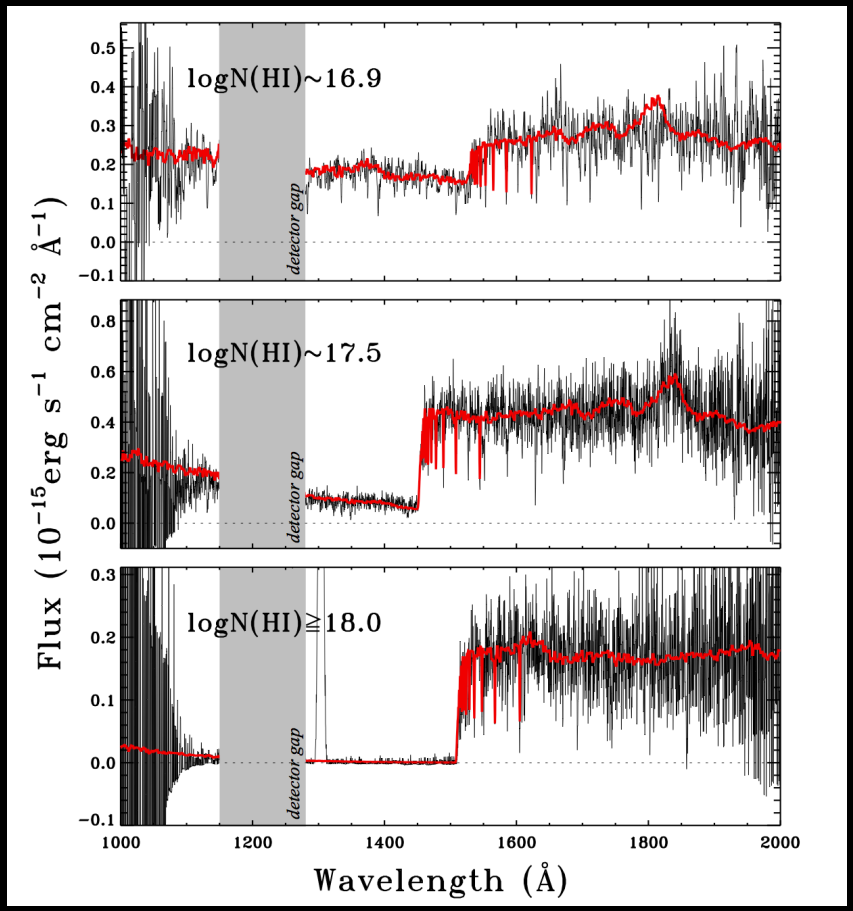
image courtesy J.C. Howk

THE CGM AT Z < 1



FOS, STIS, FUSE, COS, HIRES, LRIS
WFPC2, ACS, WFC3, AO

WHAT IS THE METALLICITY OF THE CGM AT Z<1?



Wotta+ submitted

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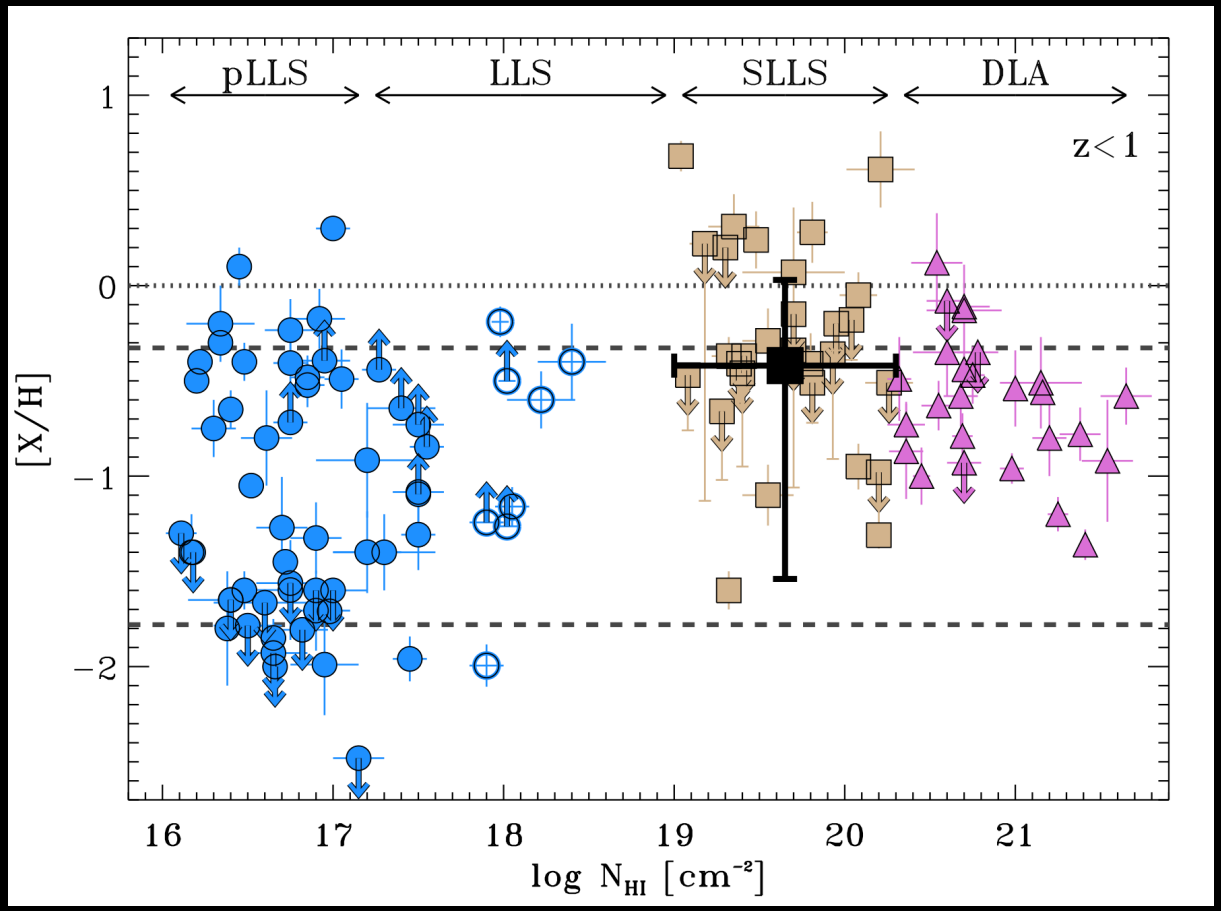

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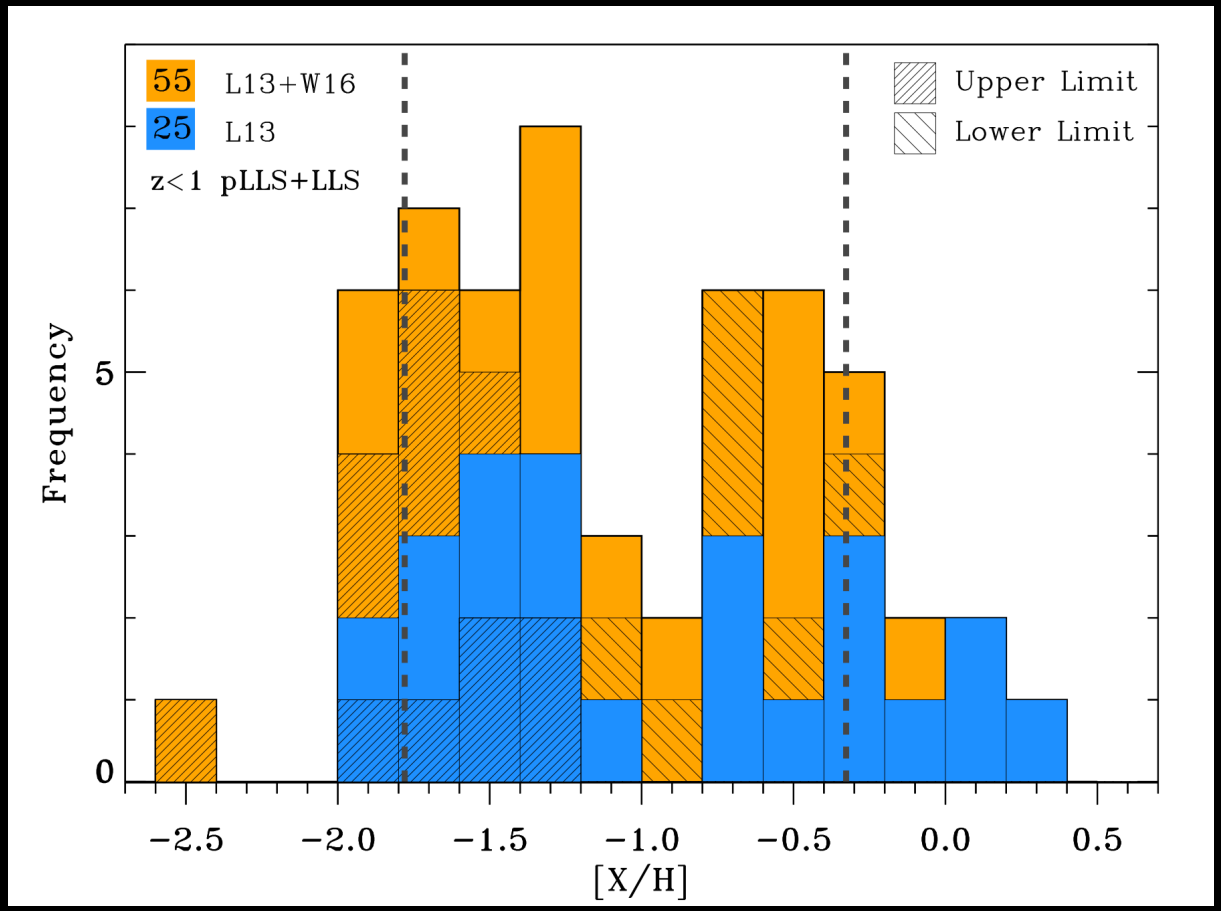


Wotta+ submitted

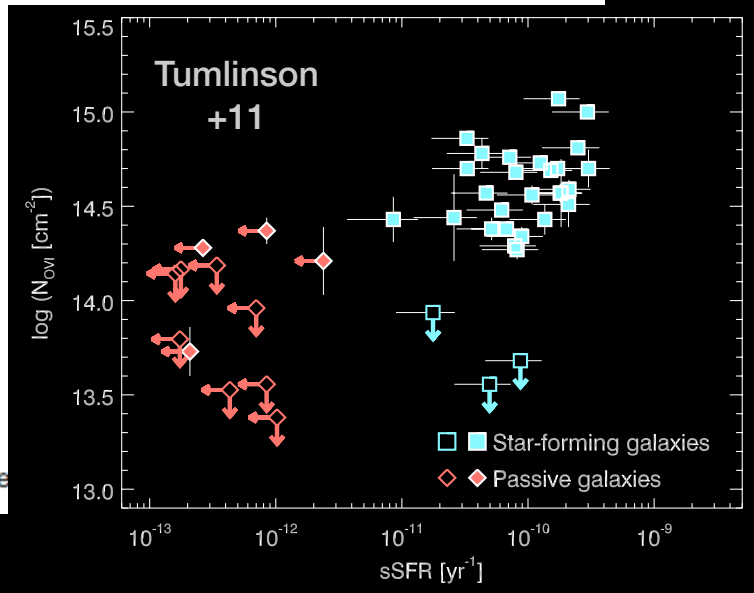
HOW MANY METALS ARE IN THE CGM AT Z<1?

The Large, Oxygen-Rich Halos of Star-Forming Galaxies Are a Major Reservoir of Galactic Metals

J. Tumlinson,[1]* C. Thom,[1] J. K. Werk,[2] J. X. Prochaska,[2] T. M. Tripp,[3] D. H. Weinberg,[4] M. S. Peeples,[5] J. M. O'Meara,[6] B. D. Oppenheimer,[7] J. D. Meiring,[3] N. S. Katz,[3] R. Davé,[8] A. B. Ford,[8] K. R. Sembach[1]

The circumgalactic medium (CGM) is fed by galaxy outflows and accretion of intergalactic gas, but its mass, heavy element enrichment, and relation to galaxy properties are poorly constrained by observations. In a survey of the outskirts of 42 galaxies with the Cosmic Origins Spectrograph onboard the Hubble Space Telescope, we detected ubiquitous, large (150-kiloparsec) halos of ionized oxygen surrounding star-forming galaxies; we found much less ionized oxygen around galaxies with little or no star formation. This ionized CGM contains a substantial mass of heavy elements and gas, perhaps far exceeding the reservoirs of gas in the galaxies themselves. Our data indicate that it is a basic component of nearly all star-forming galaxies that is removed or transformed during the quenching of star formation and the transition to passive evolution.

Galaxies grow by accreting gas from the intergalactic medium (IGM) and converting it to stars. Stellar winds and explosions release gas enriched with heavy elements [or metals (*1*)], some of which is ejected in galactic-scale outflows (*2*). The circumgalactic medium (CGM)—loosely defined as gas surrounding galaxies within their own halos of dark matter (out to 100 to 300 kpc)—lies at the nexus of accretion and outflow, but the structure of the CGM and its relation to galaxy properties are still uncertain. Galactic outflows are observed at both low (*2*–*4*) and high (*5*–*7*) redshift, but it is unclear how far they propagate, what level of heavy-element enrichment they possess, and whether the gas escapes the halo or eventually returns to fuel later star formation. Models of



JUST GET TO LUVOIR ALREADY!

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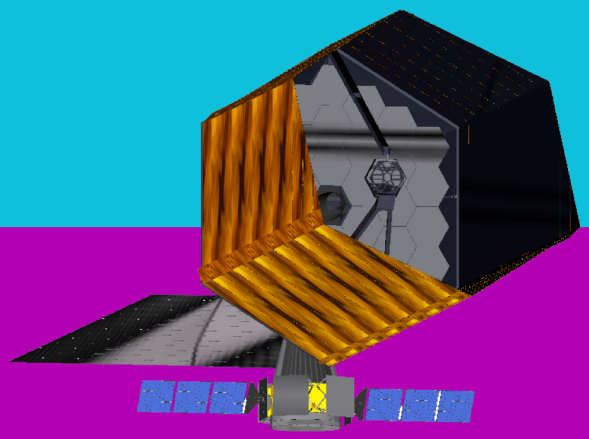
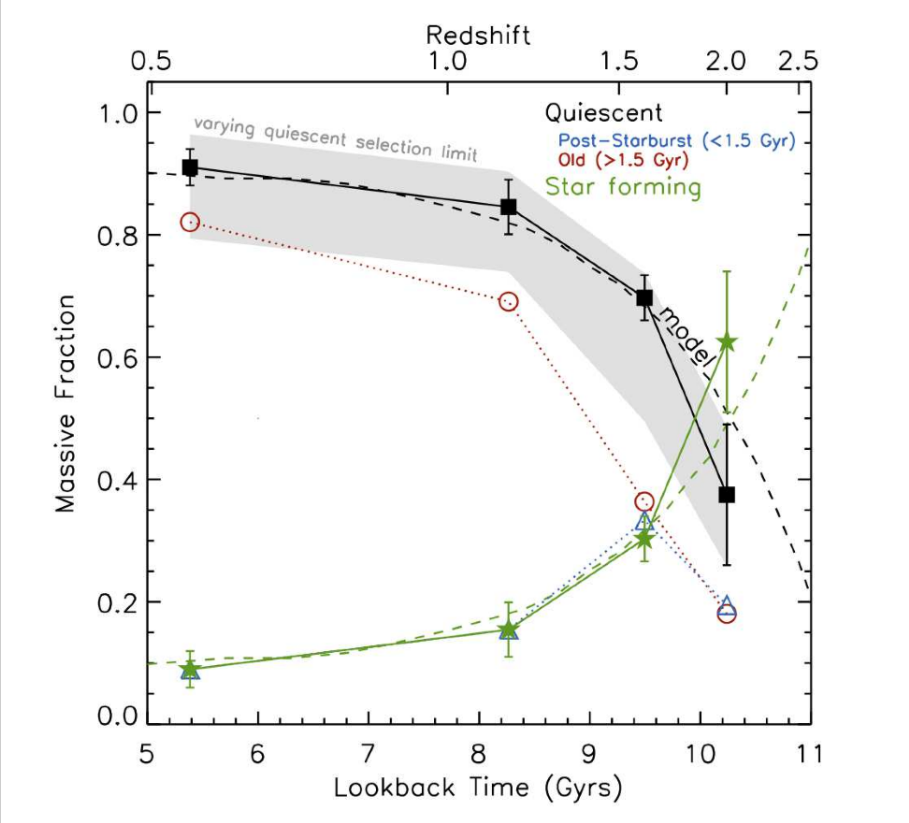


Keep the LUV

in LUVOIR!

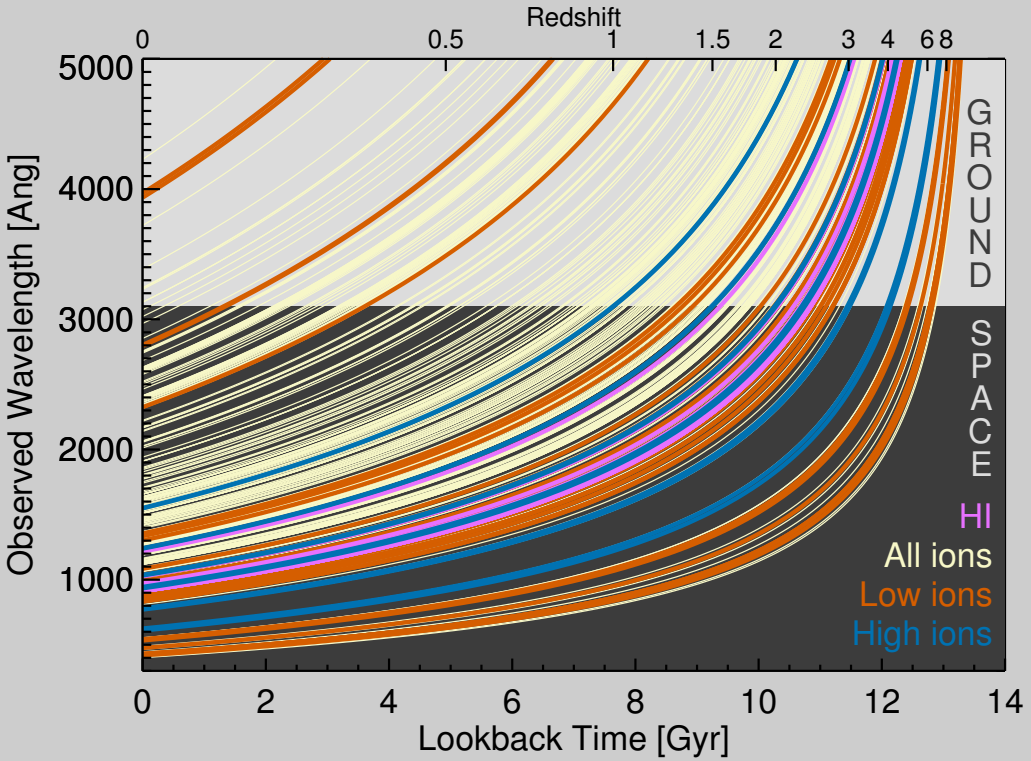
THE NEED FOR UV



Whitaker et al. 2010

Massive galaxies transition from star-forming to quenched at 0.5<z<1.5

Most of the powerful line diagnostics still in the UV



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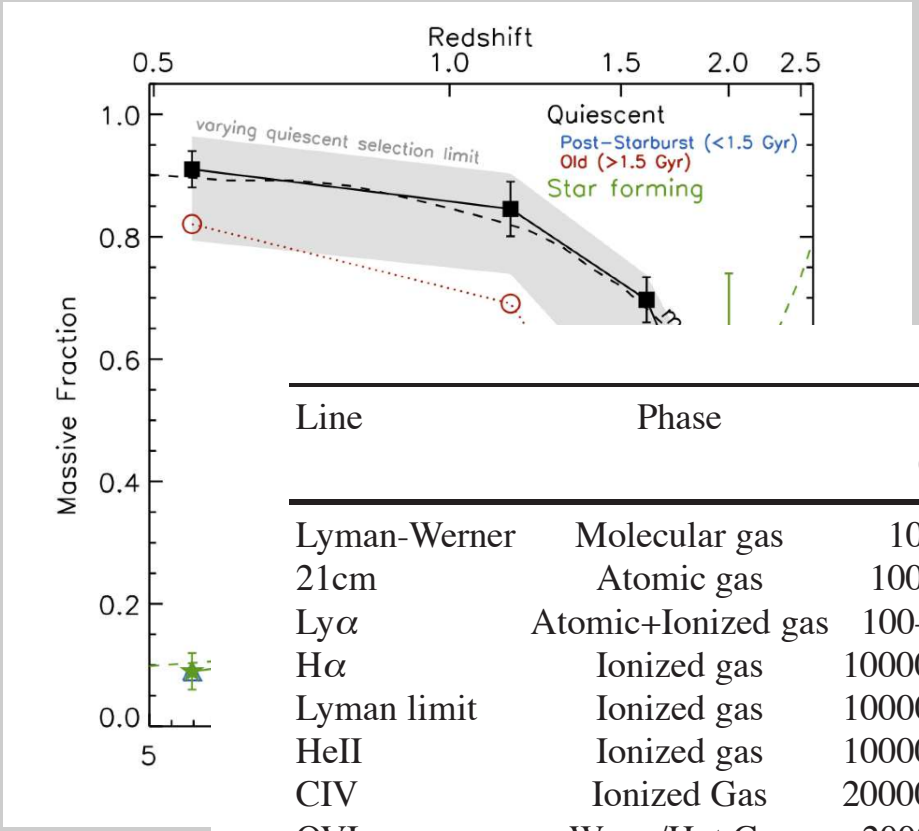


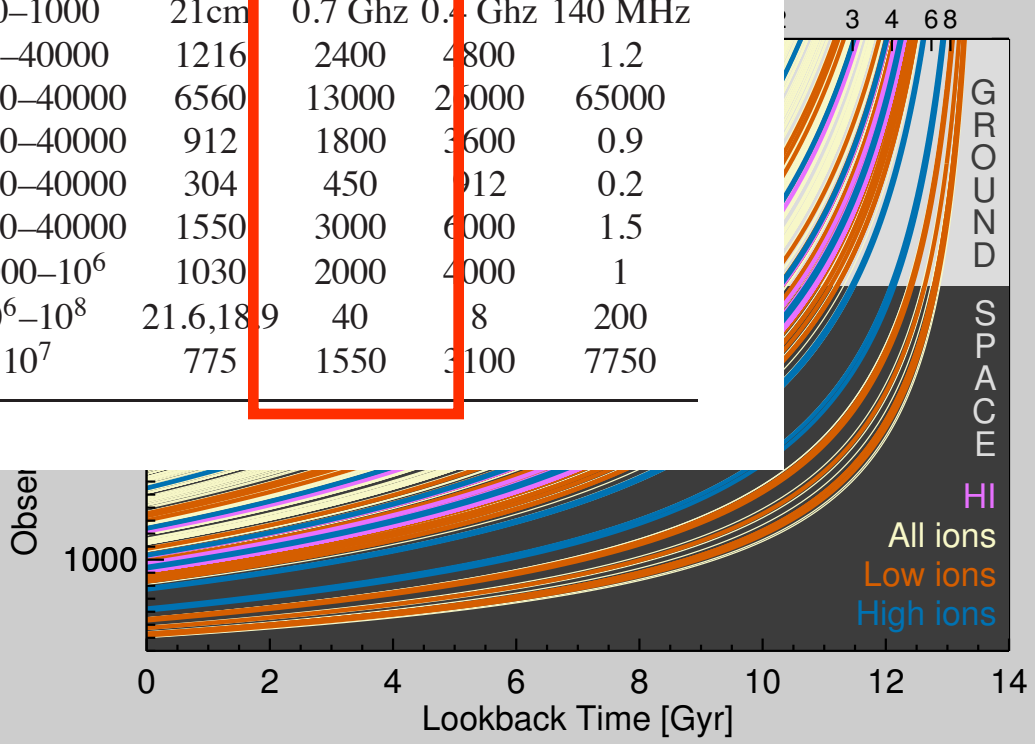
Massive galaxies transition from star-forming

<z<1.5

Line	Phase	T (K)	λ_{rest} (Å)	$\lambda_{z=1}$ (Å)	$\lambda_{z=3}$ (Å)	$\lambda_{z=9}$ (μm)
Lyman-Werner	Molecular gas	10–100	∼1000	2000	4000	1
21cm	Atomic gas	100–1000	21cm	0.7 Ghz	0.4 Ghz	140 MHz
Lyα	Atomic+Ionized gas	100–40000	1216	2400	4800	1.2
Hα	Ionized gas	10000–40000	6560	13000	26000	65000
Lyman limit	Ionized gas	10000–40000	912	1800	3600	0.9
HeII	Ionized gas	10000–40000	304	450	912	0.2
CIV	Ionized Gas	20000–40000	1550	3000	6000	1.5
OVI	Warm/Hot Gas	20000–10^6	1030	2000	4000	1
OVII,OVIII	Hot Gas	10^6–10^8	21.6,18.9	40	78	200
NeVIII	Hot Gas	10^7	775	1550	3100	7750

Mos

line diagnostics still in the UV



THE PROBLEM

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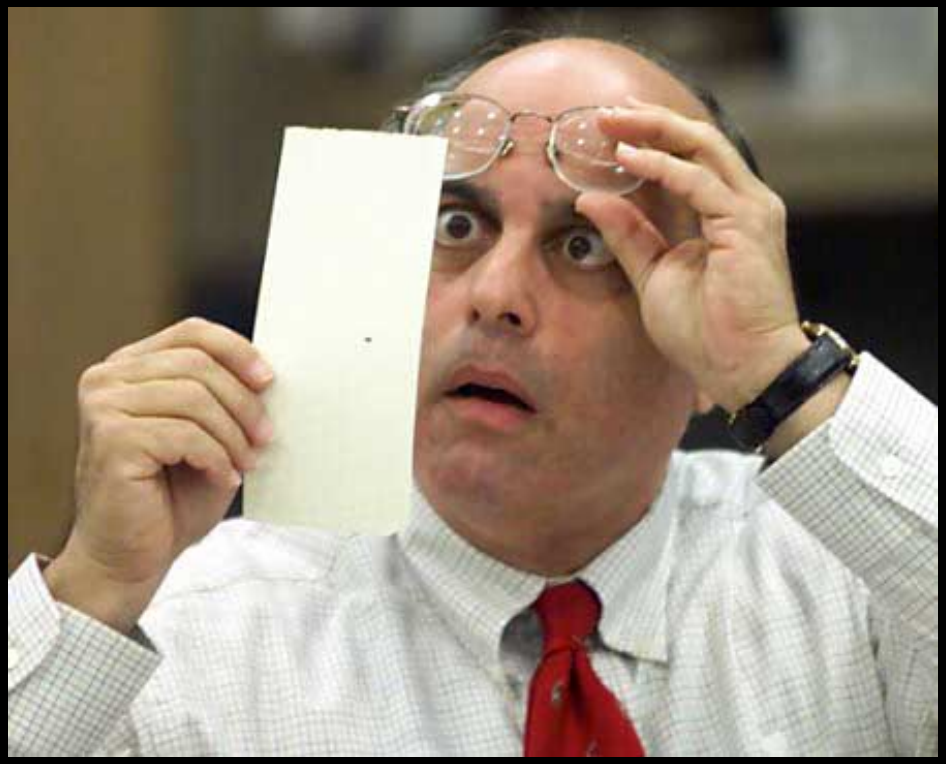

THE NEED FOR SAMPLING

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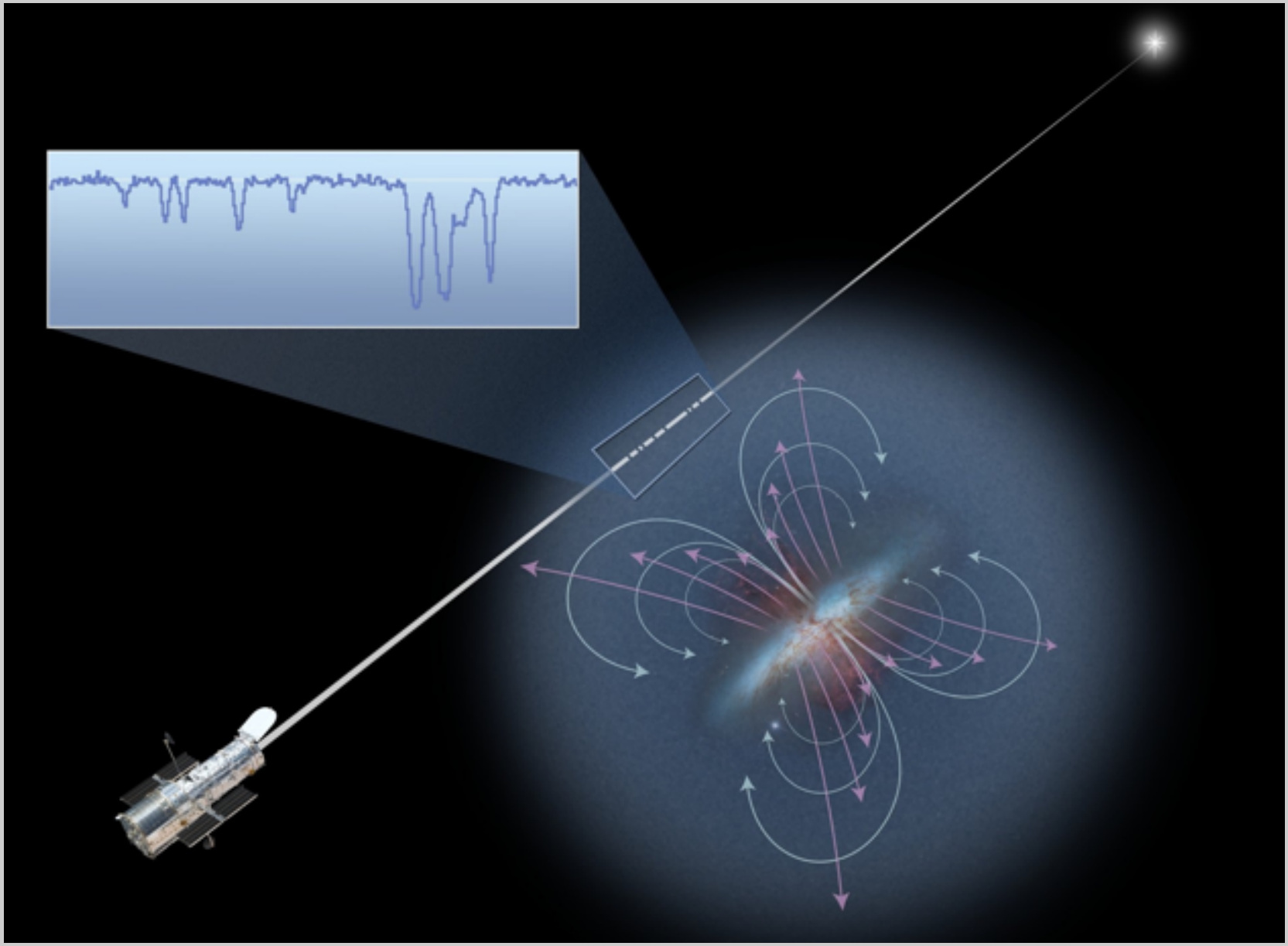

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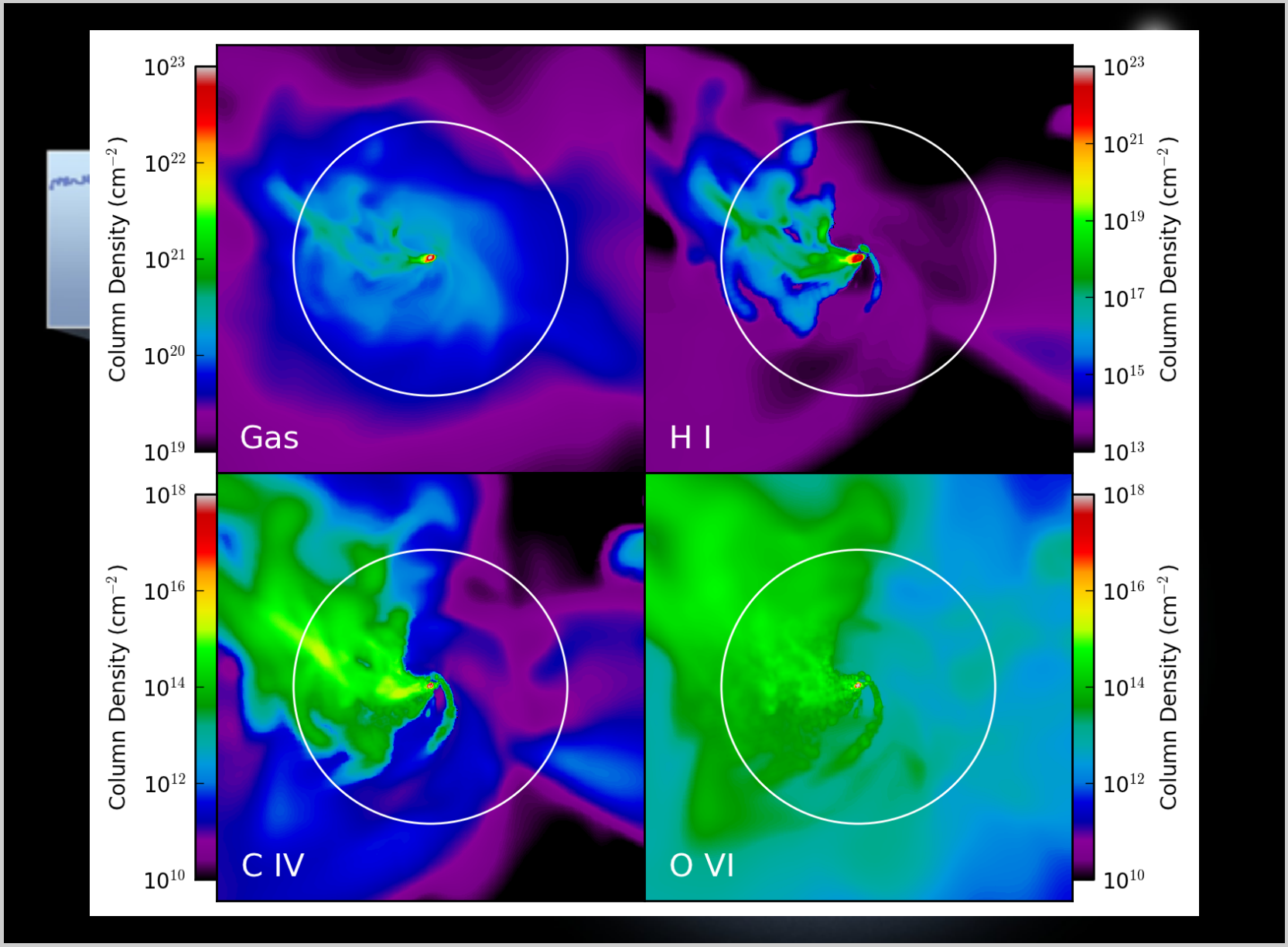

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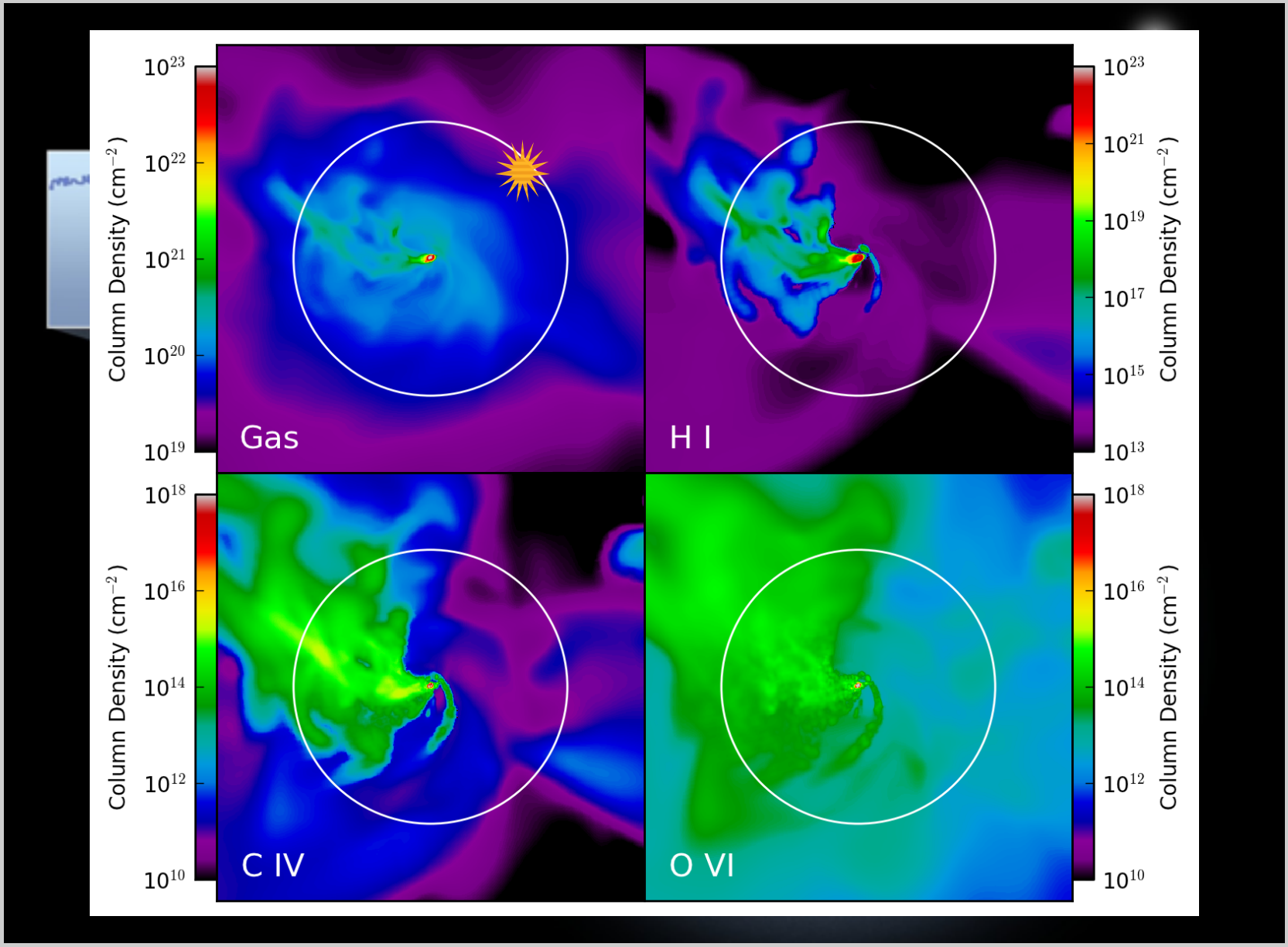

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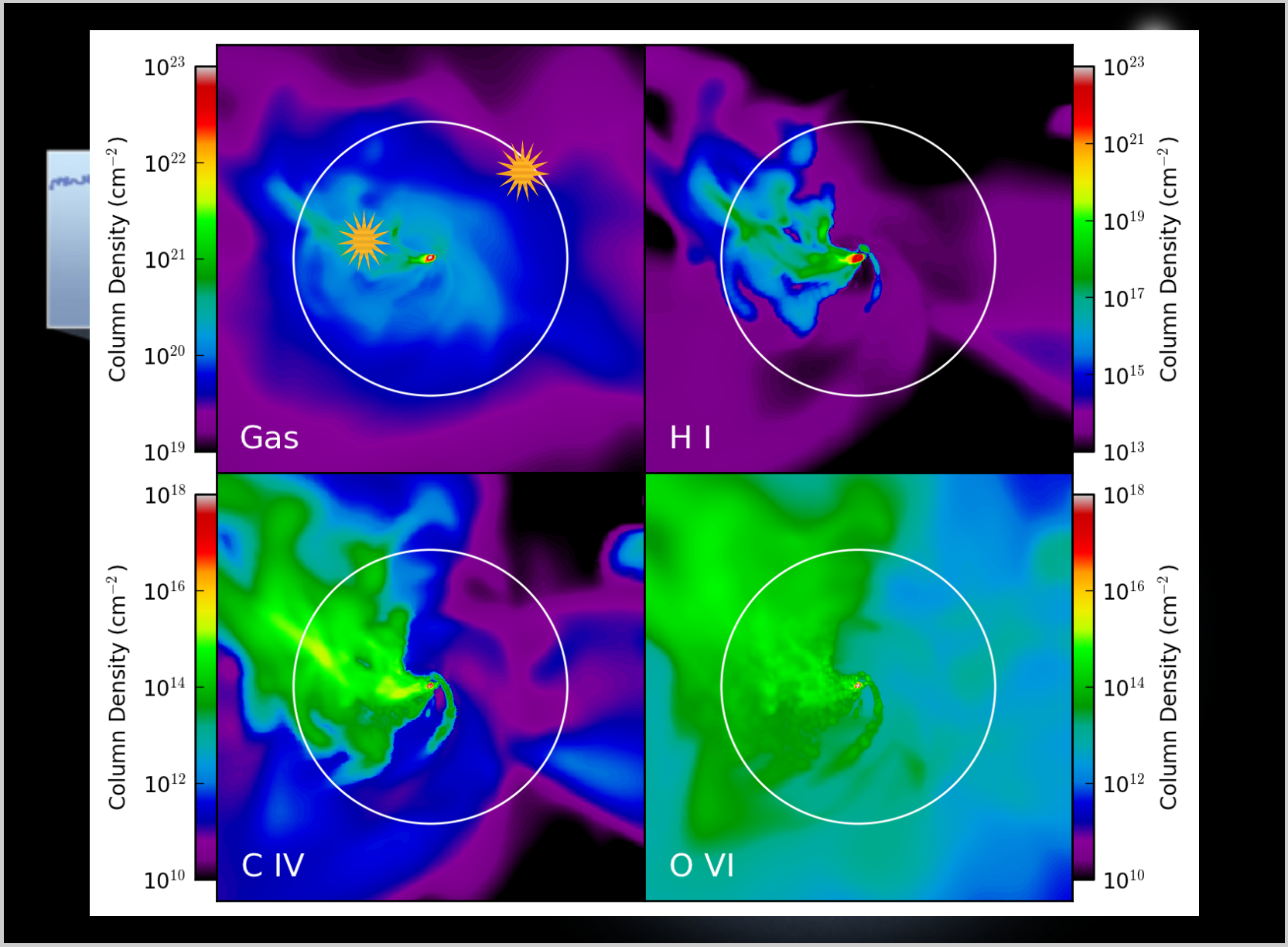

THE SOLUTIONS

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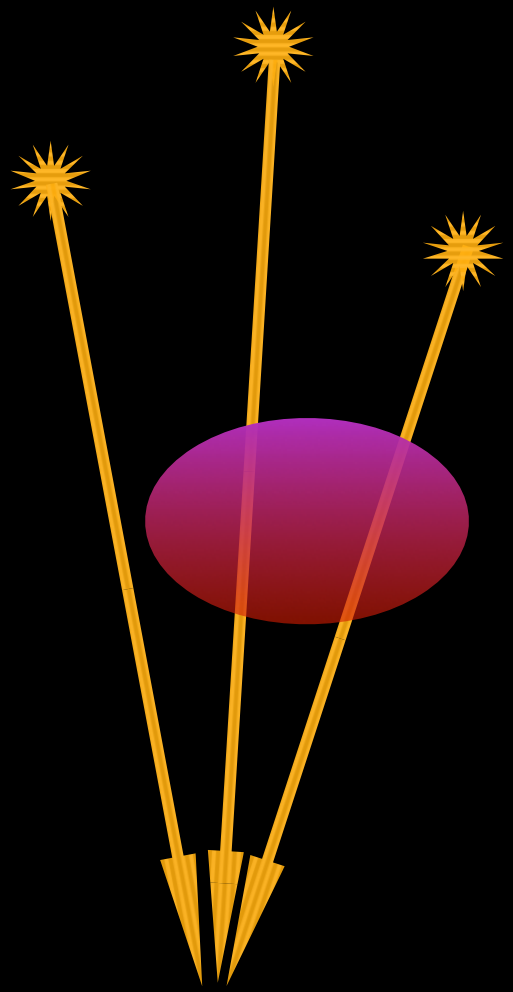

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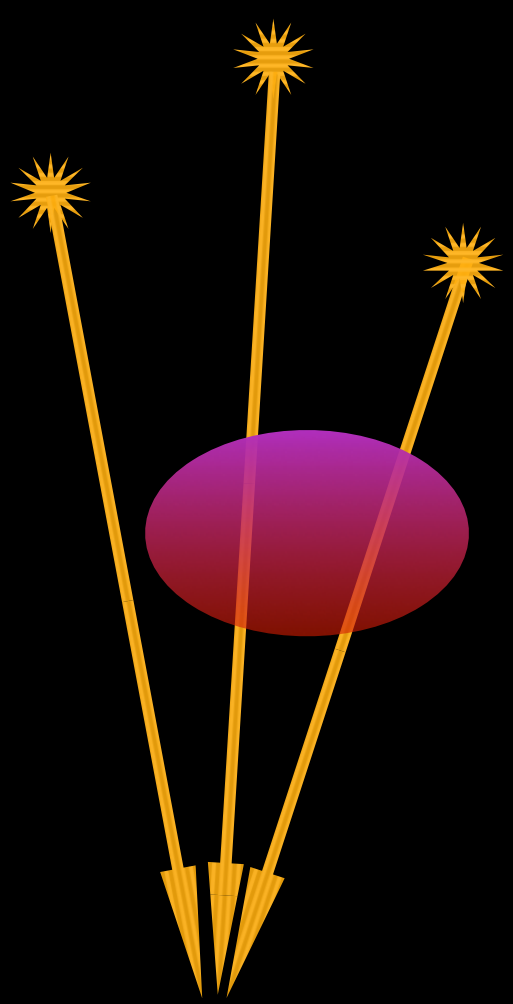
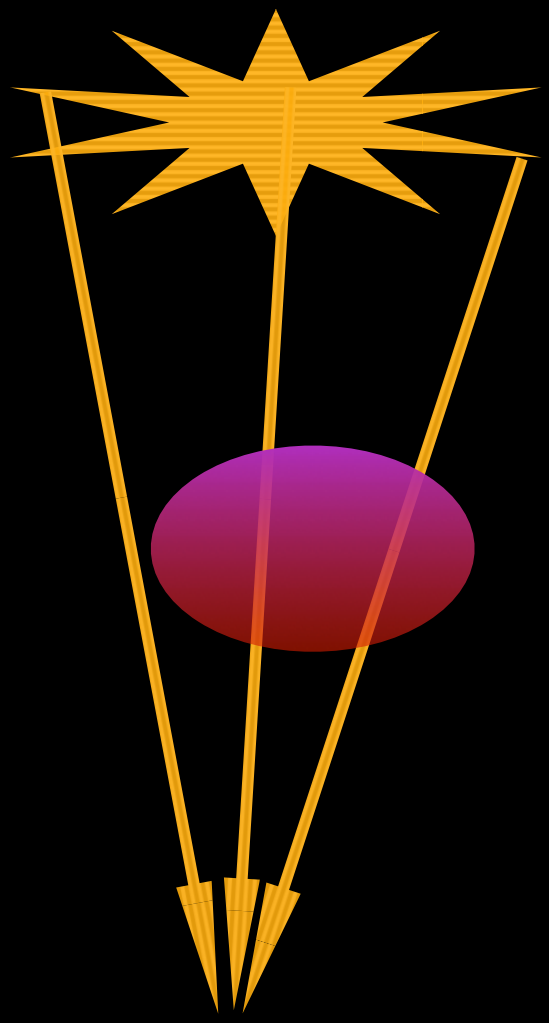
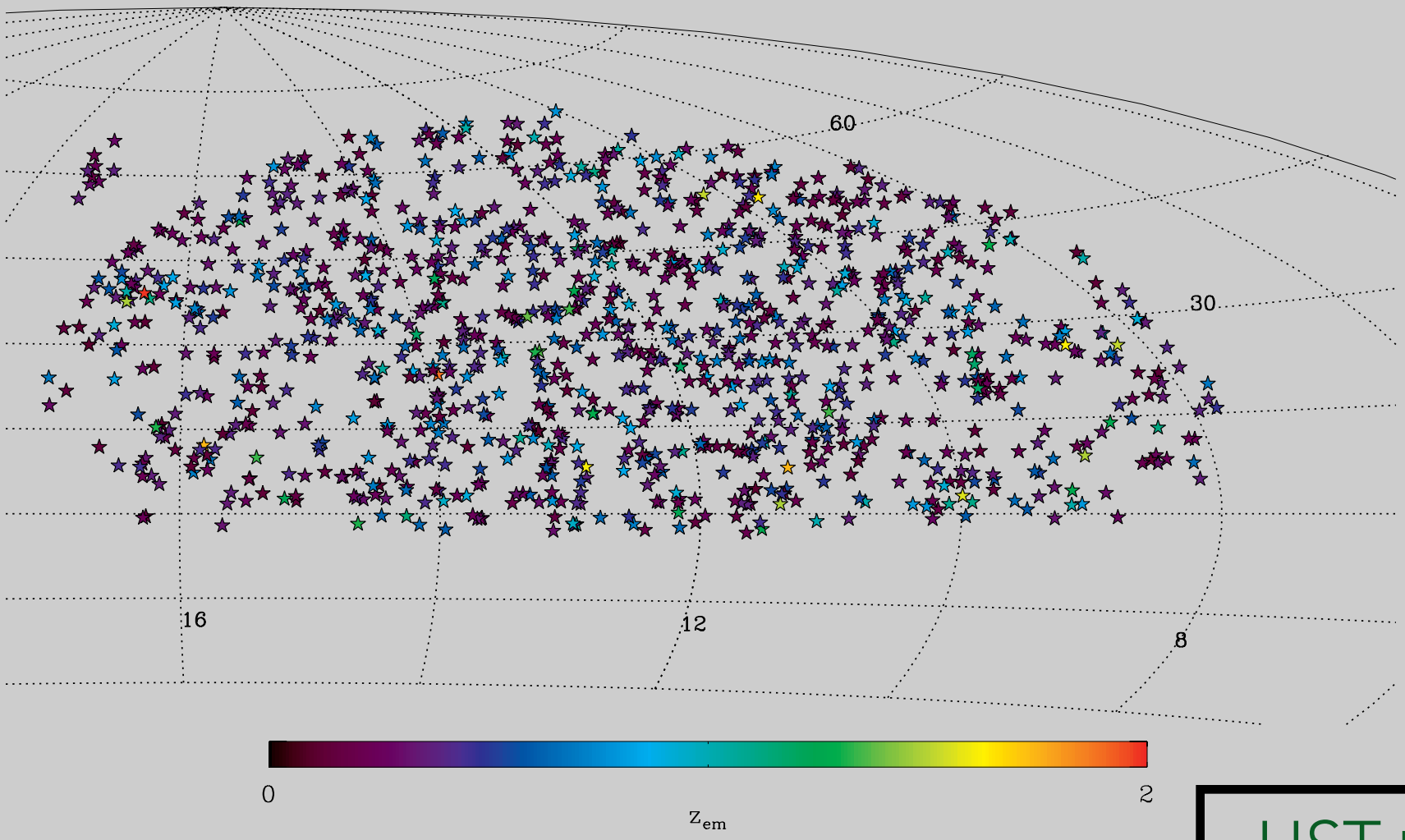




THE POWER OF APERTURE



HST+COS
FUV AB<18.5

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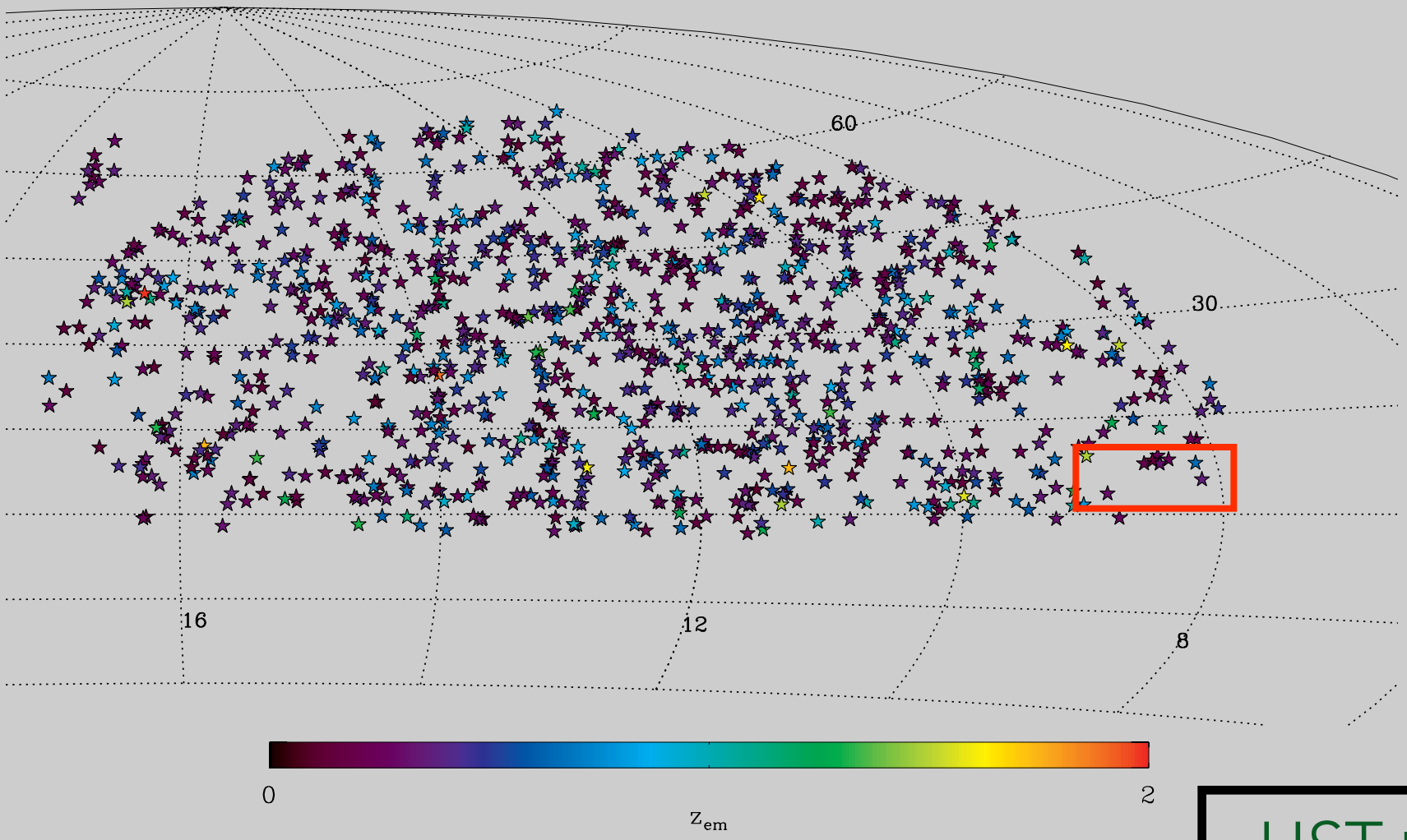
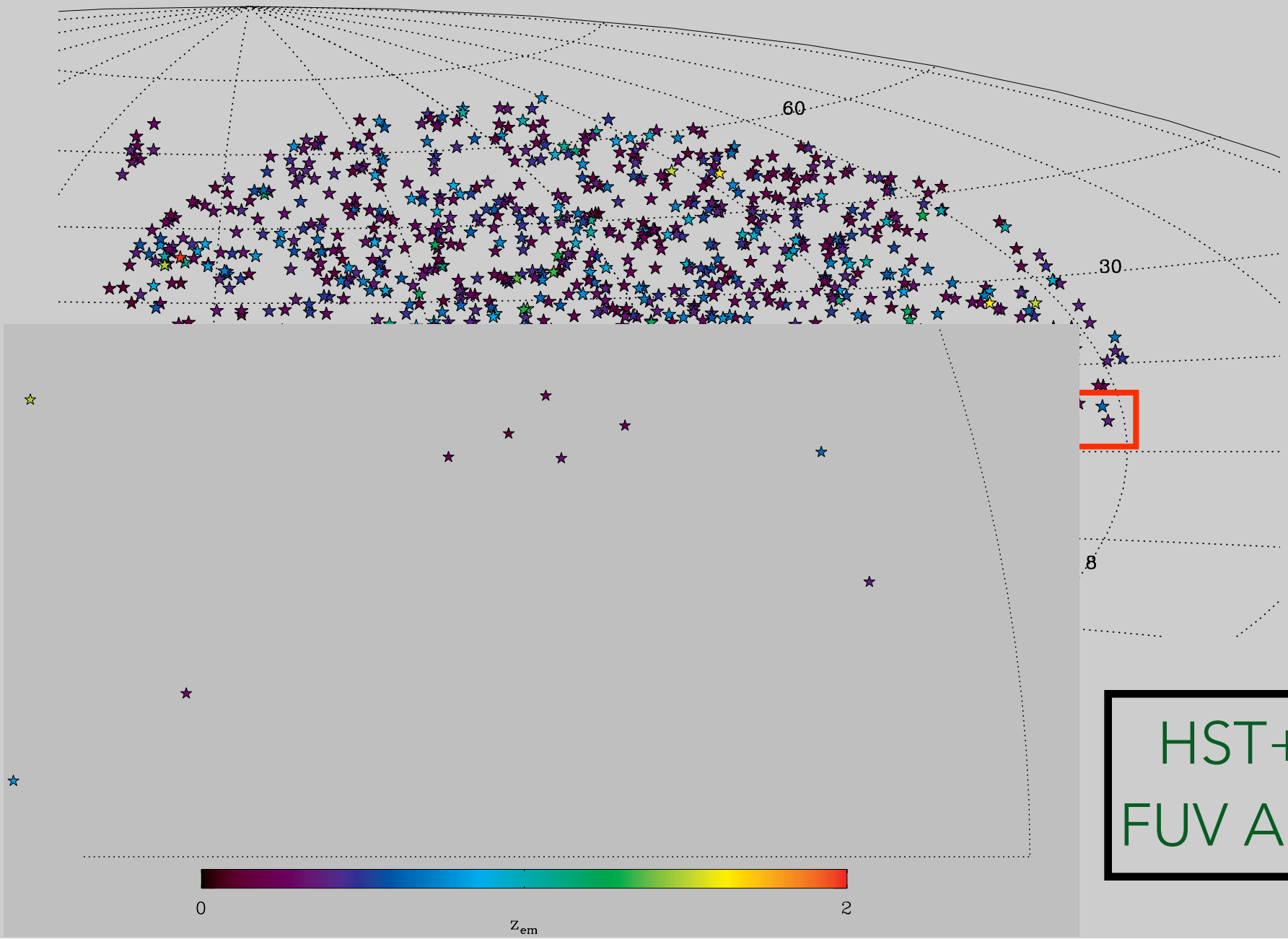


HST+COS
FUV AB<18.5

THE POWER OF APERTURE



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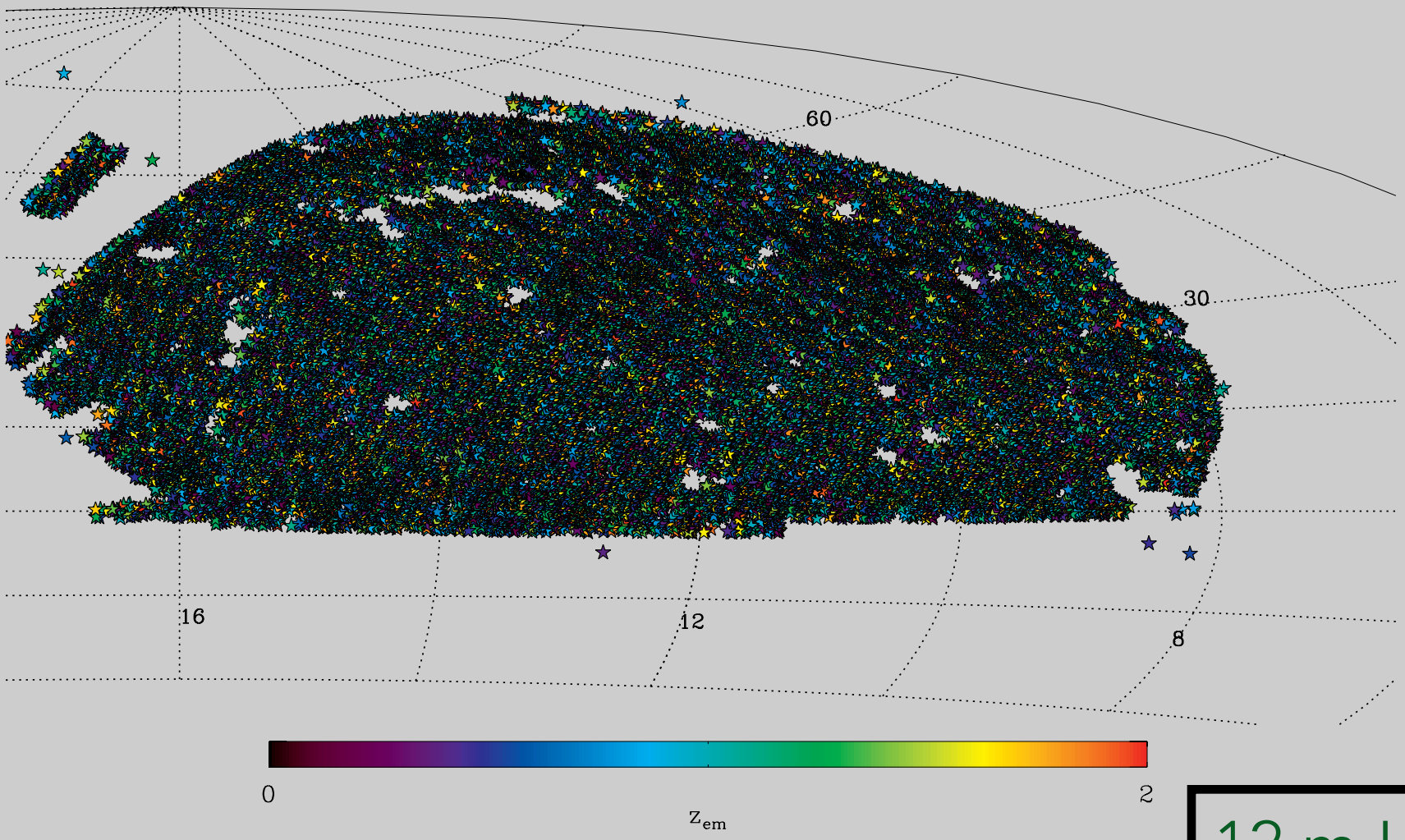
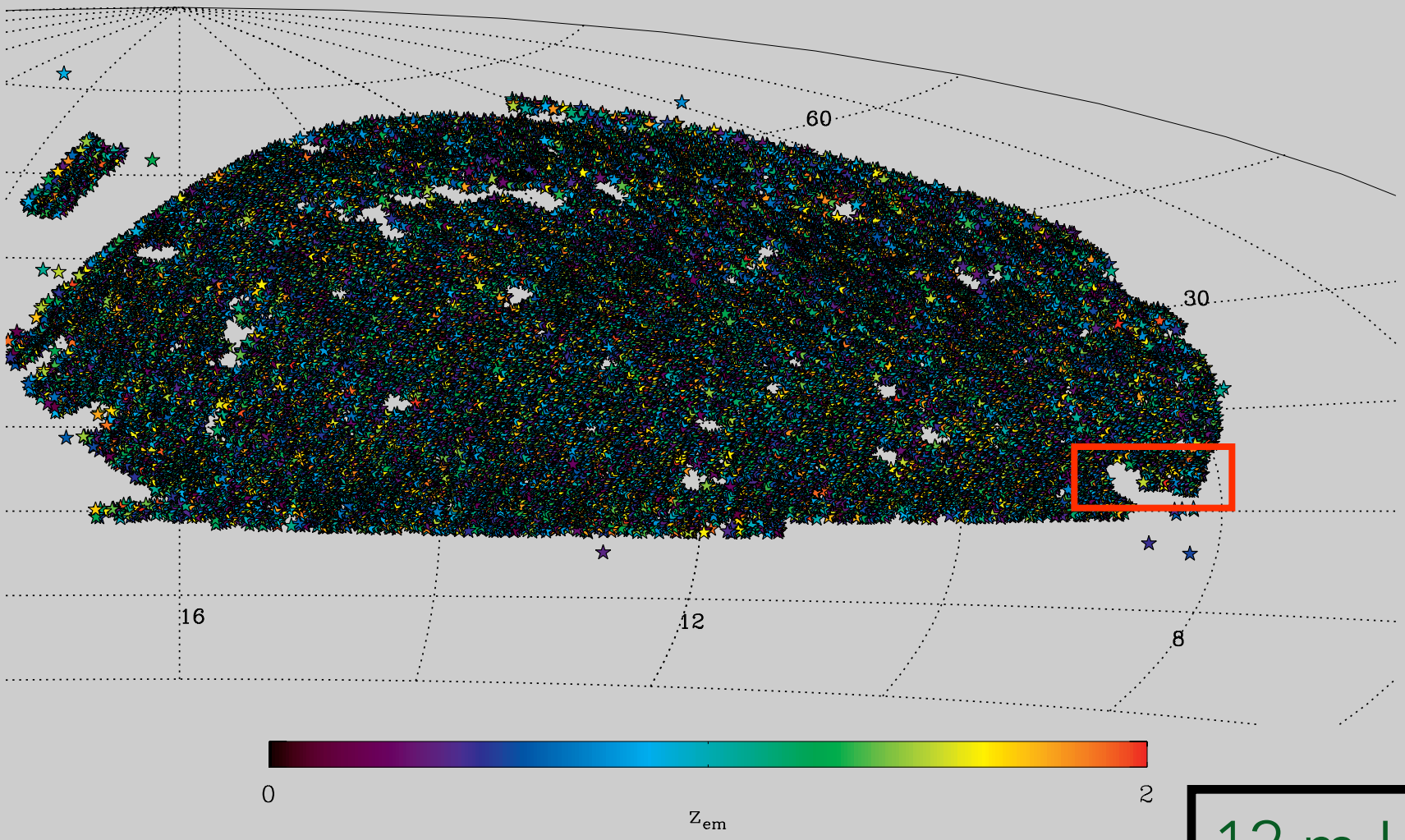


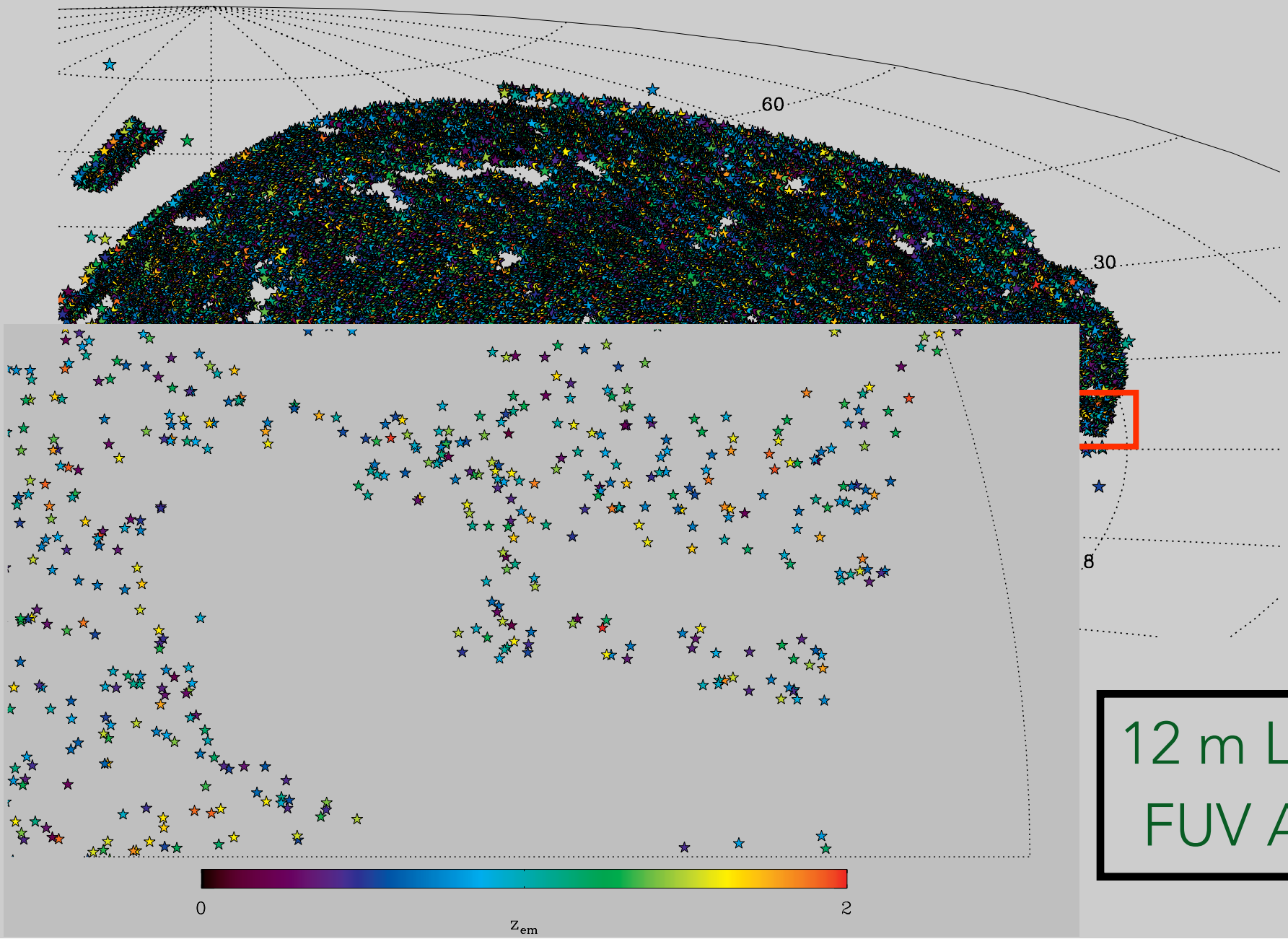
12 m LUVOIR
FUV AB<22

THE POWER OF APERTURE



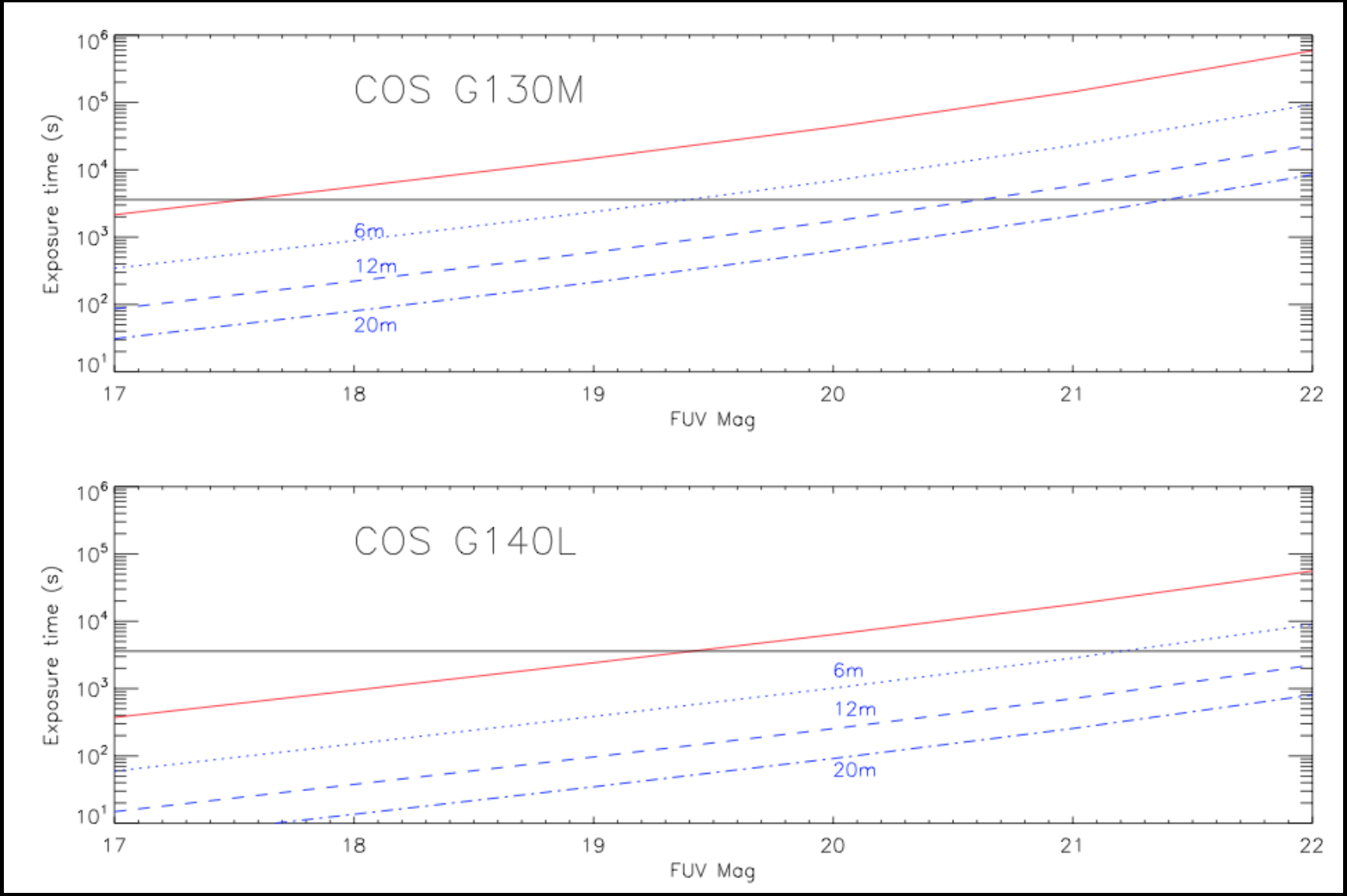
12 m LUVOIR
FUV AB<22

THE POWER OF APERTURE

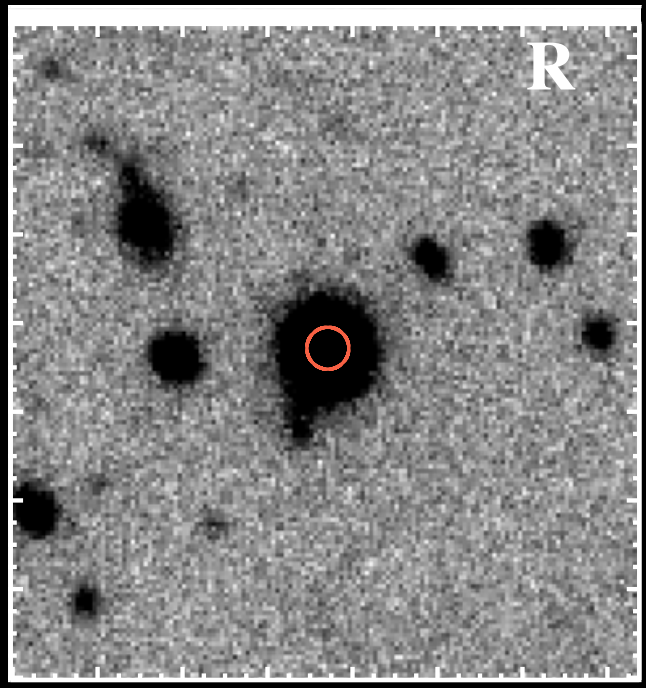


12 m LUVOIR
FUV AB<22

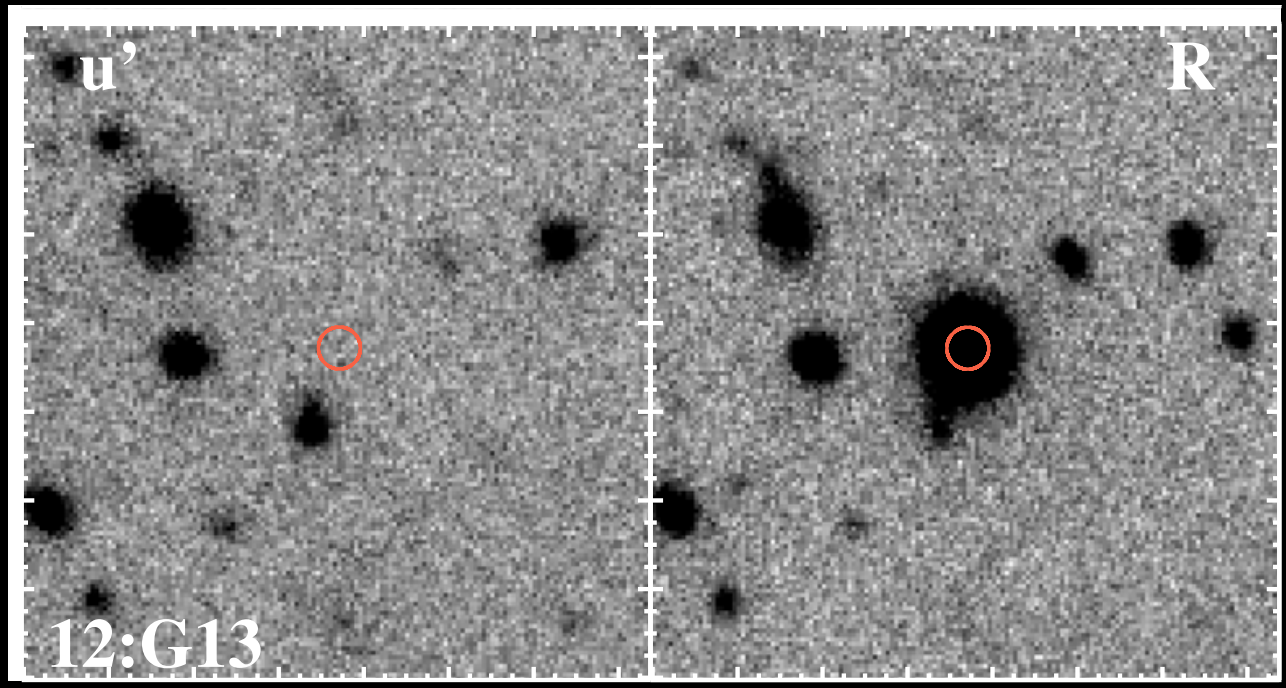
THROUGHPUT UNDER-ESTIMATE



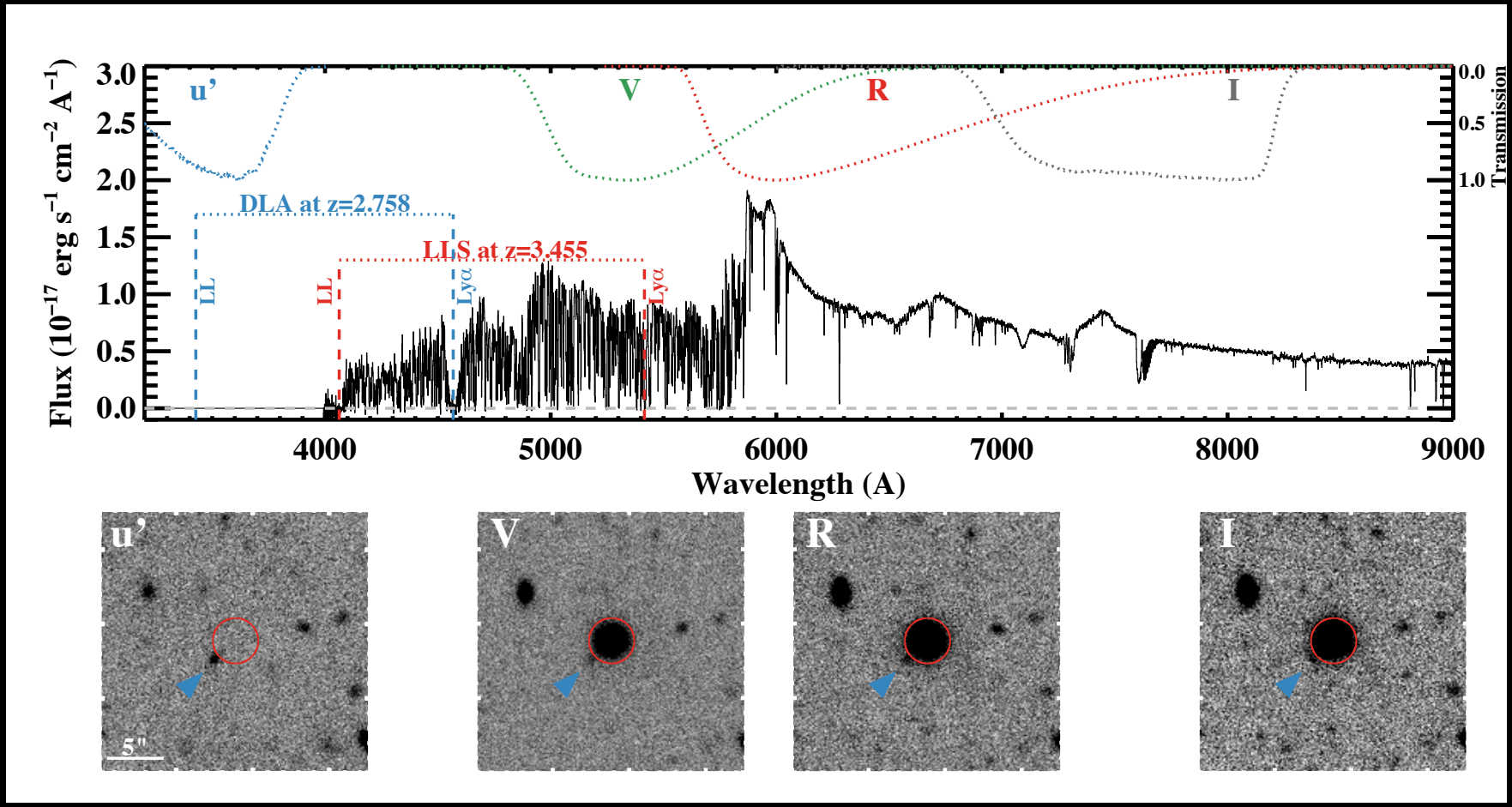
THE PROBLEM



THE PROBLEM

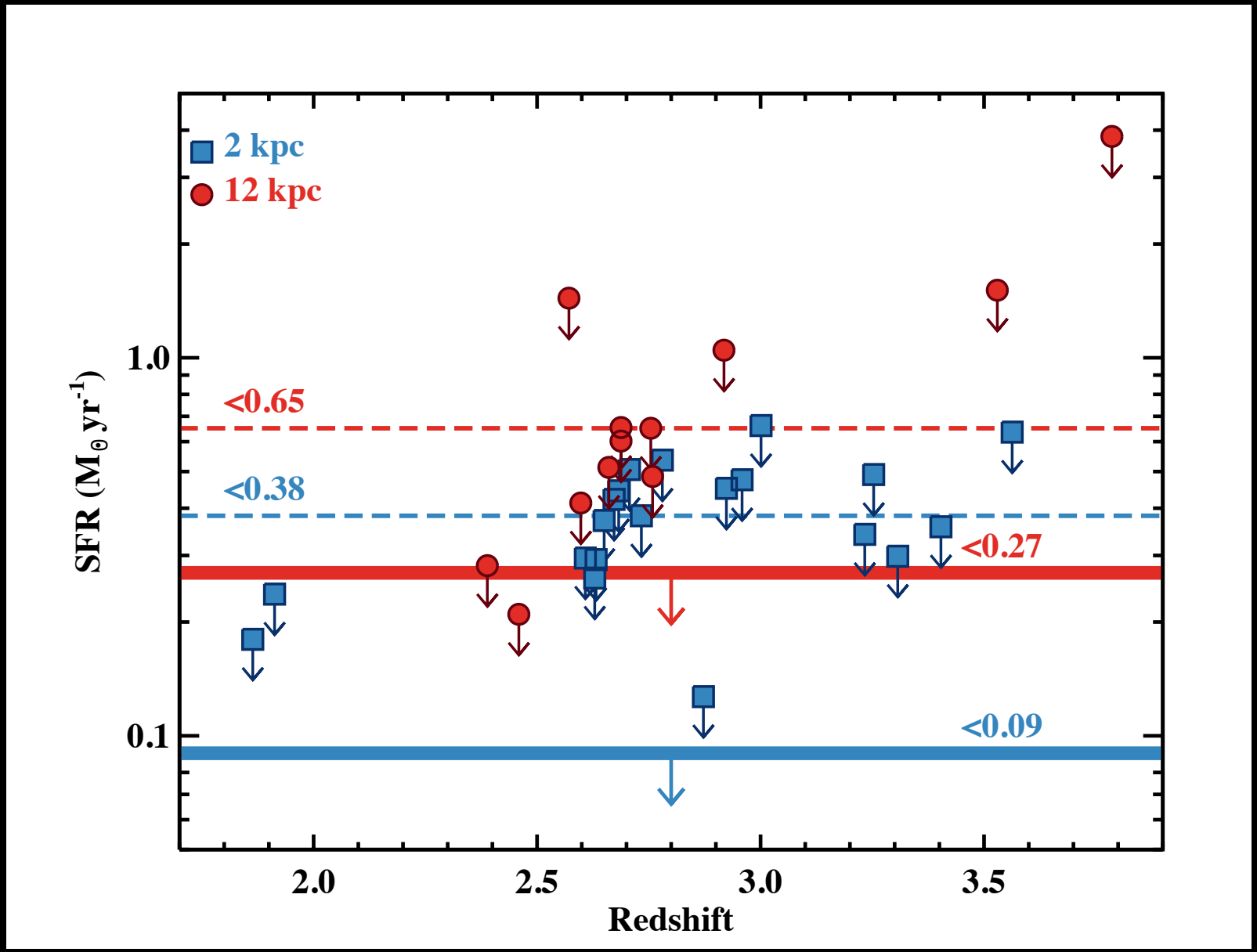


THE SOLUTION



O'Meara et al. 2006
Fumagalli et al. 2014

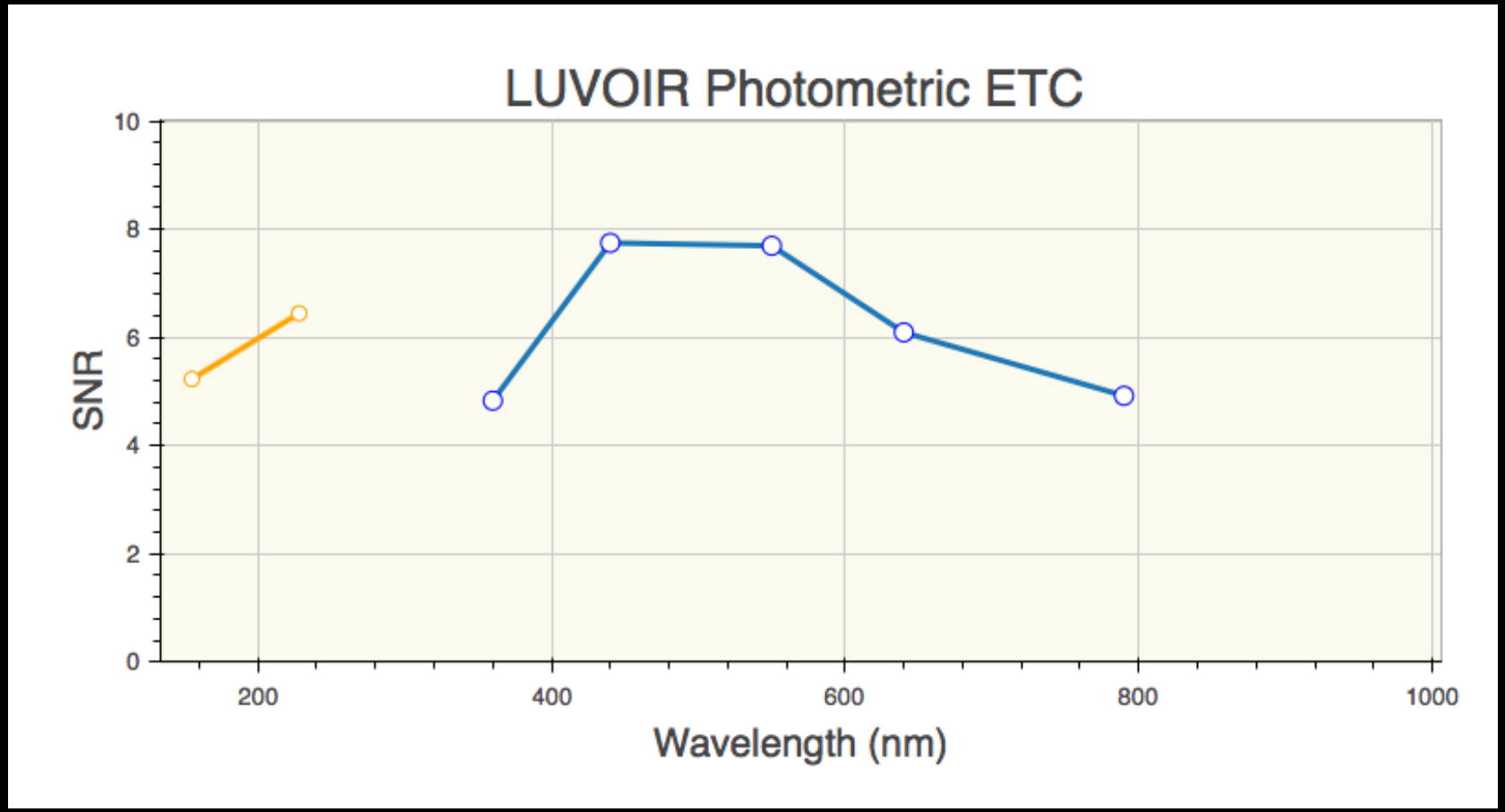
THE RESULTS SO FAR FROM HST+KECK



WHAT DOES THIS MEAN?

- The *average* DLA does not have a large star formation rate (in situ)
- The *average* DLA is not a bright galaxy at larger impact parameters
- Are the DLA low luminosity LBG-like galaxies?

THE POWER OF APERTURE, PART 2



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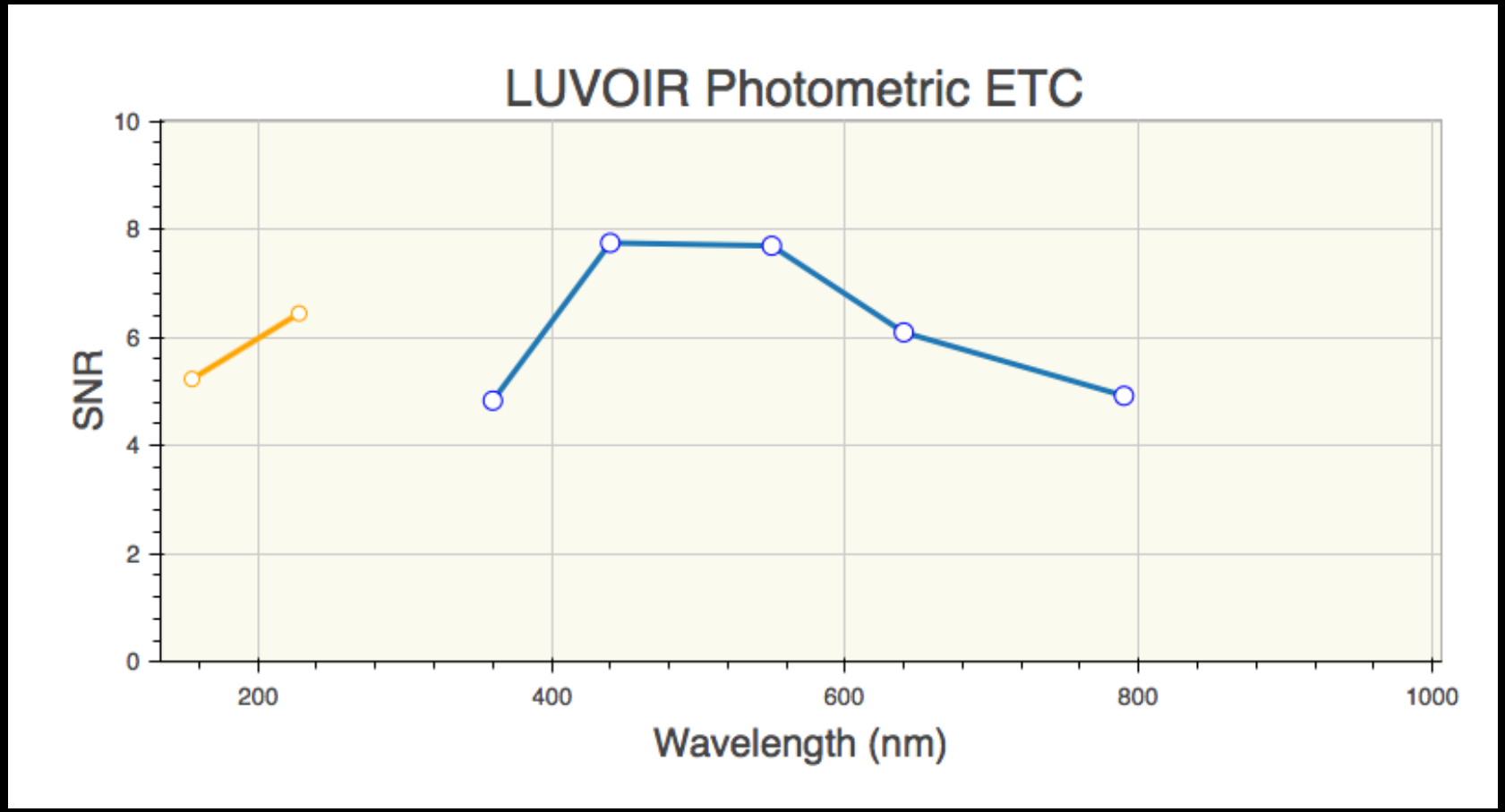

AB magnitude 31.8 in 1.2 hours!

THE POWER OF MULTIPLEXING

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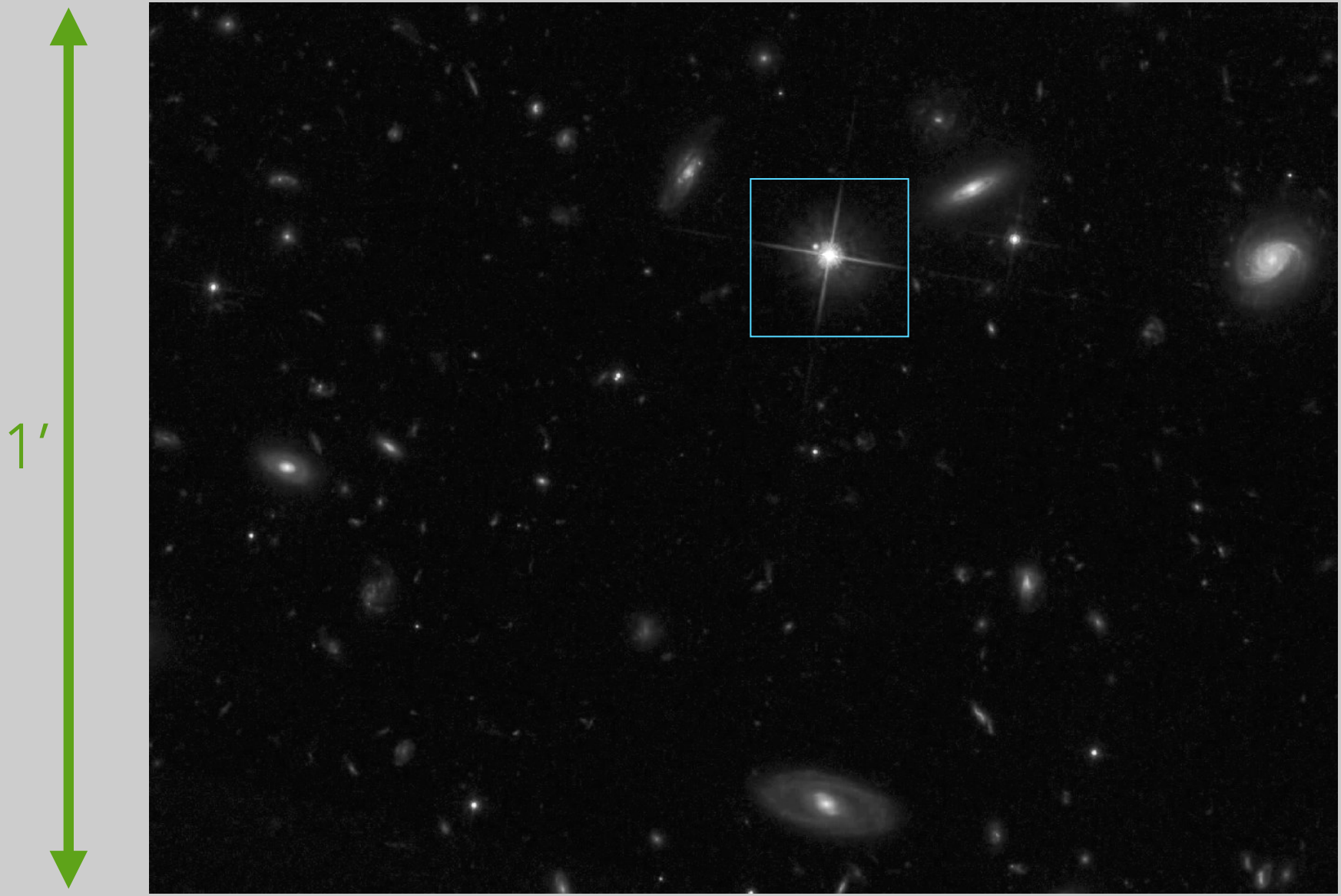
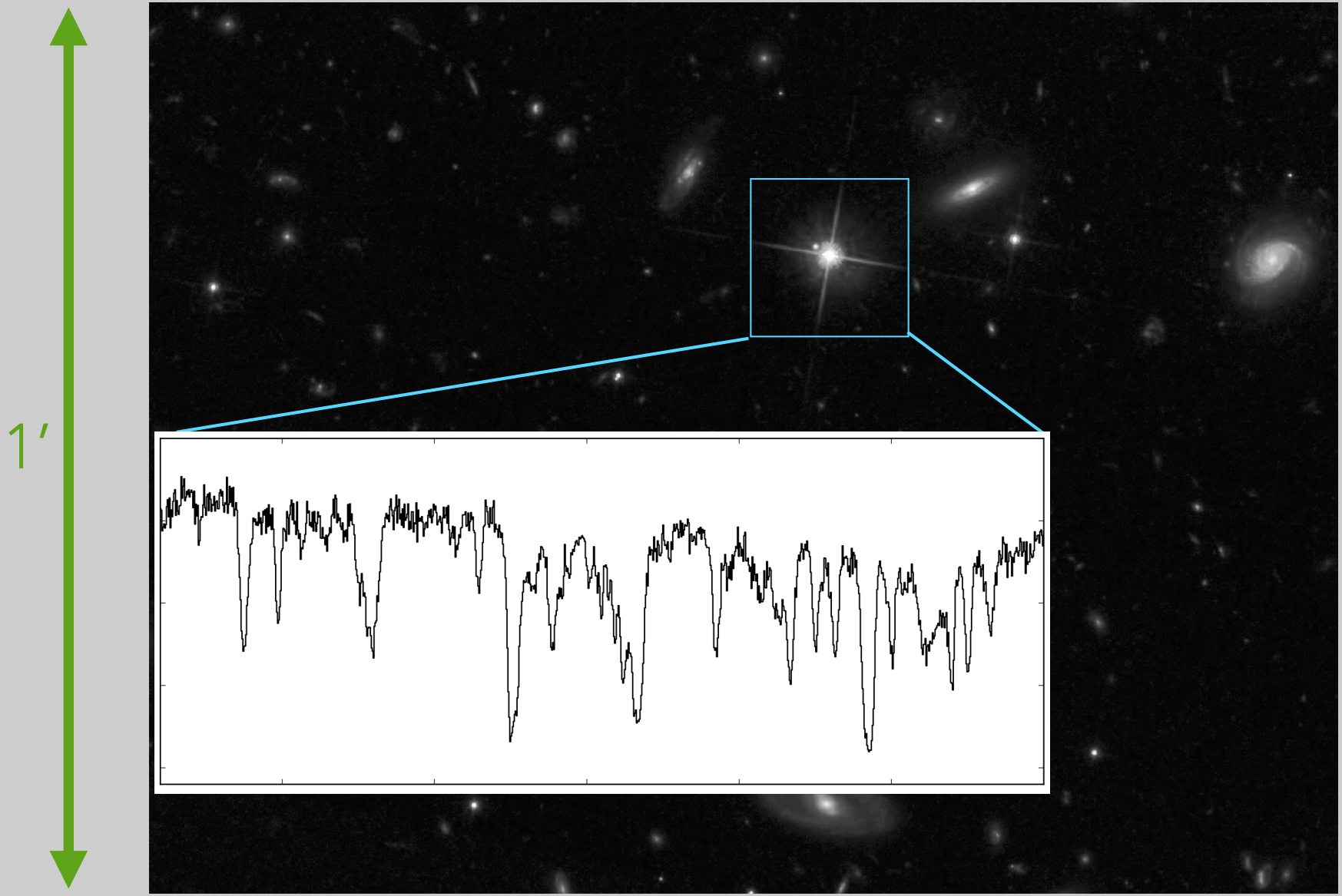


THE POWER OF MULTIPLEXING



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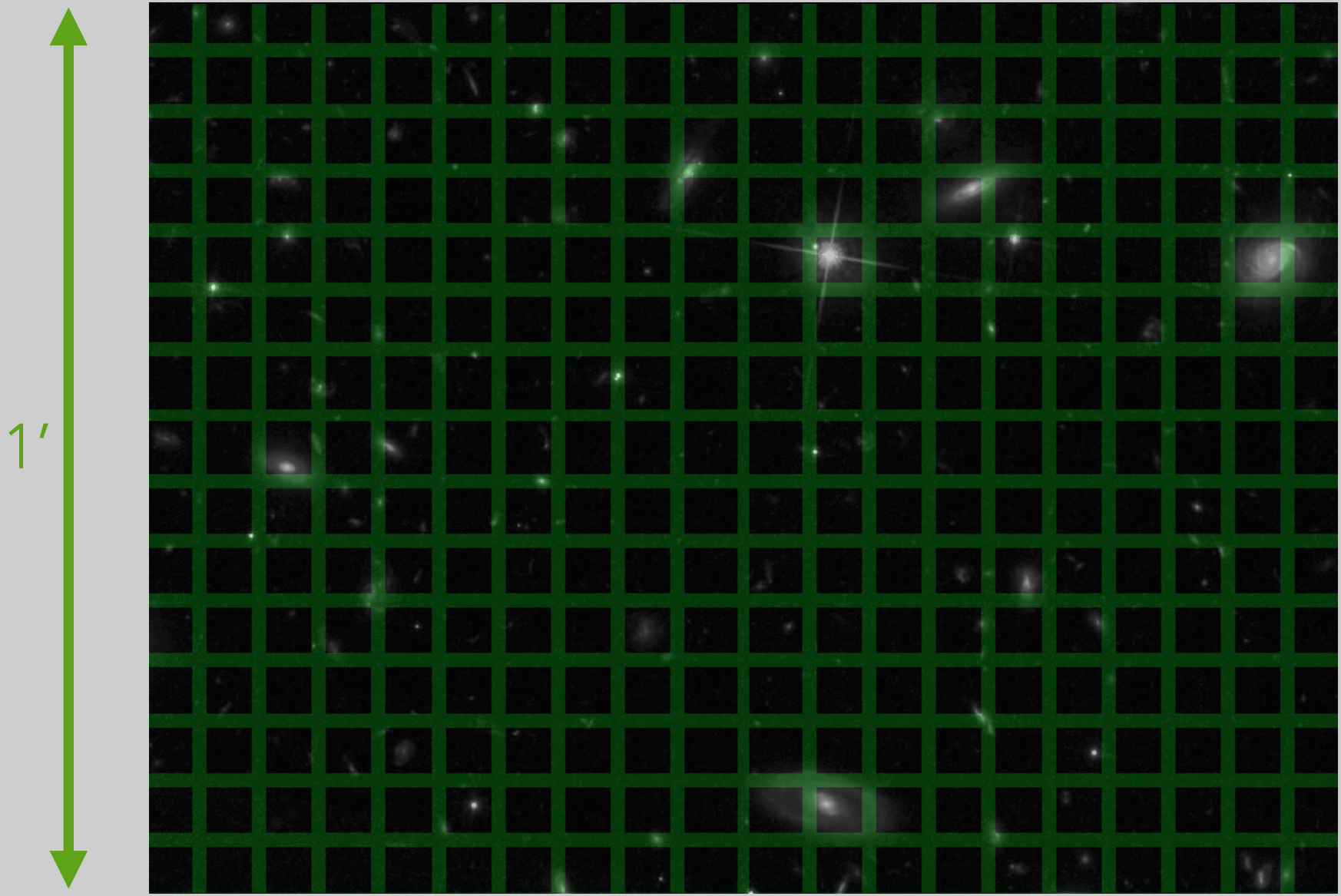

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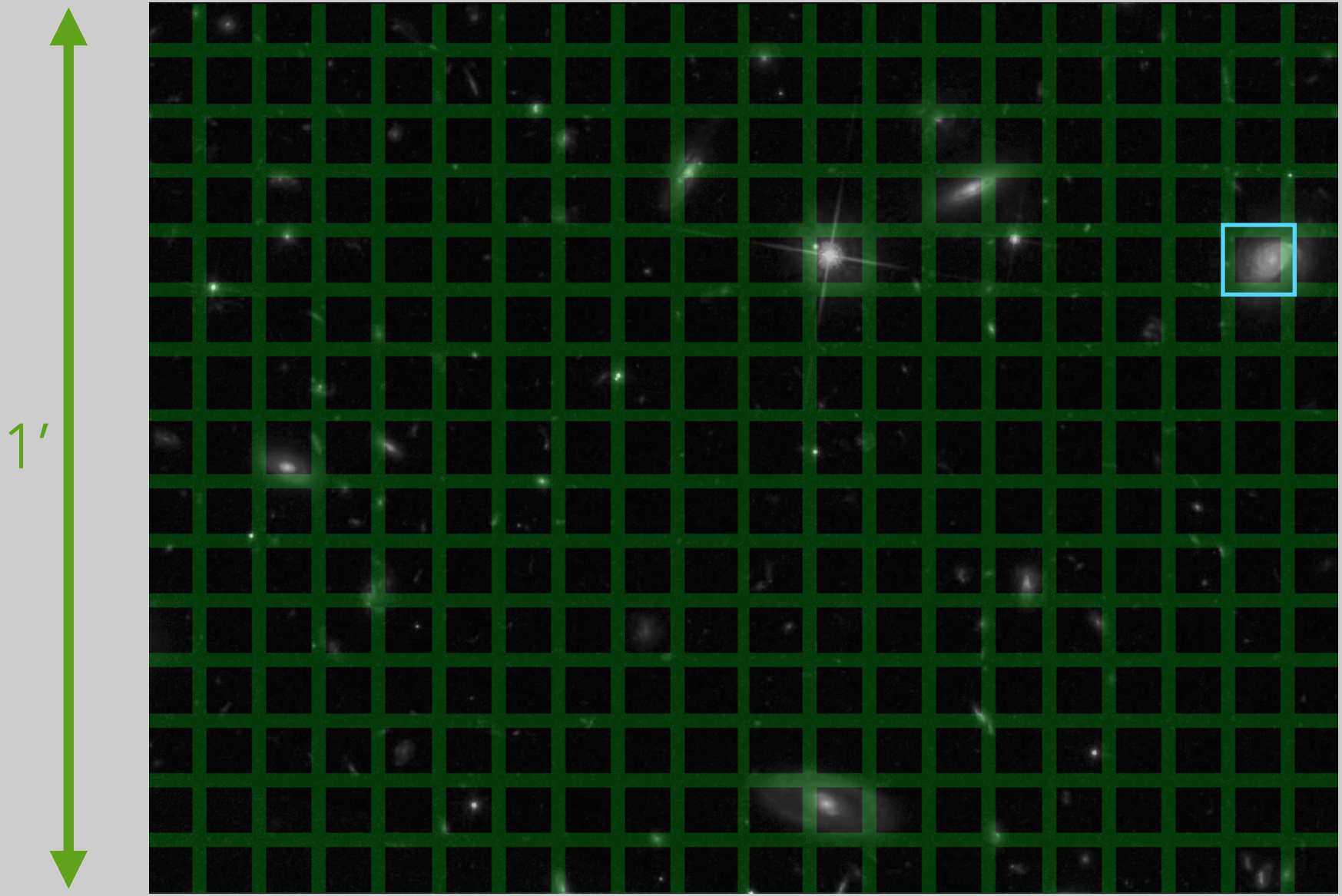

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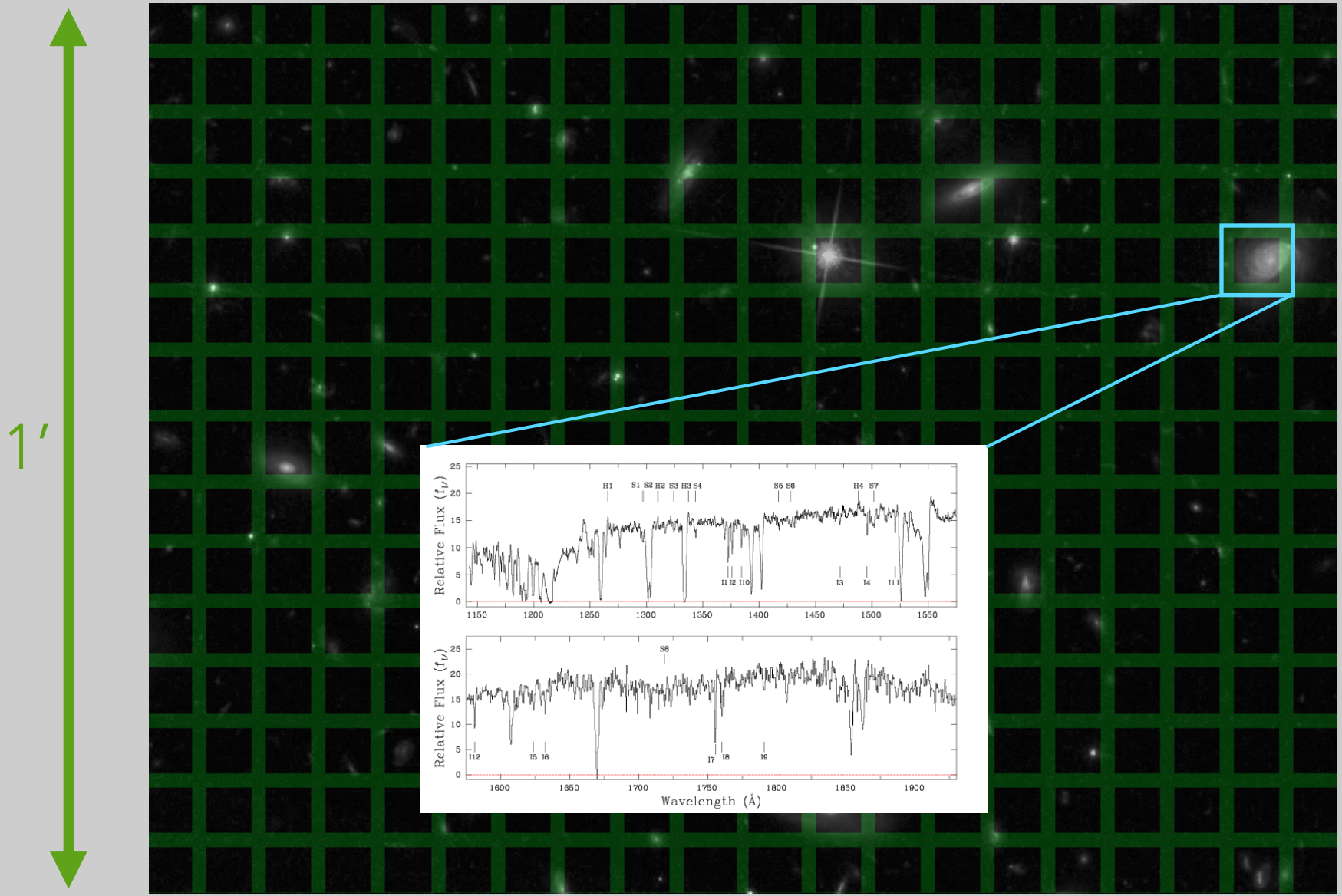
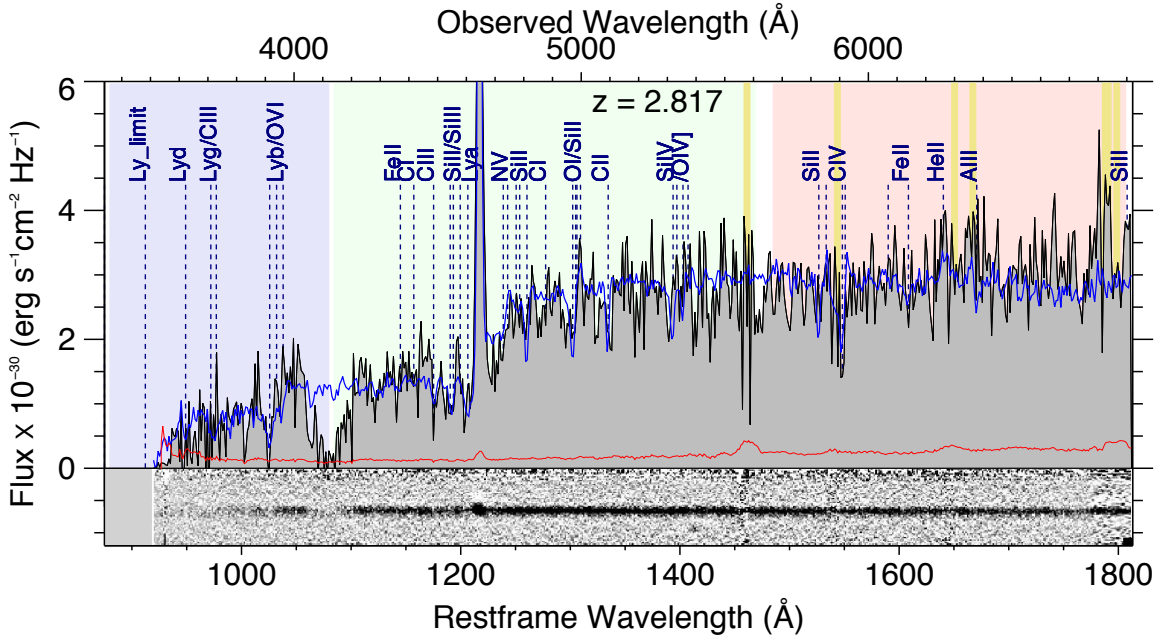
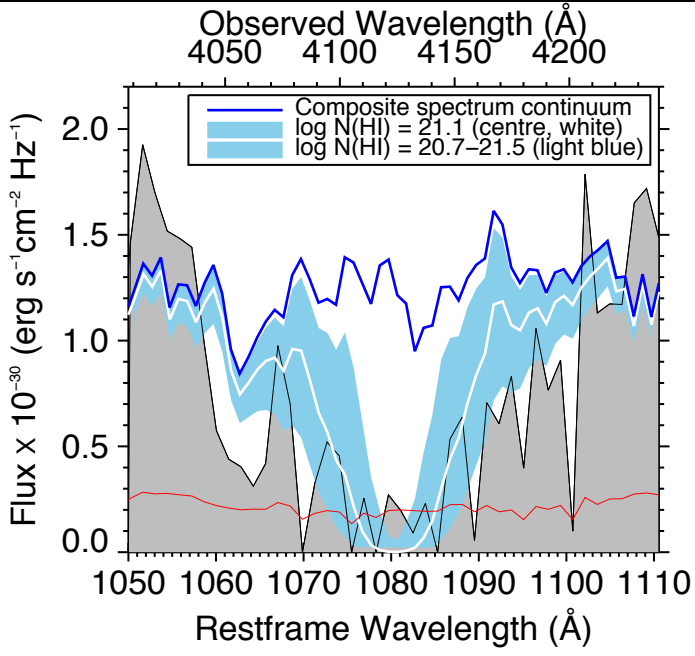


GALAXIES AS BACKGROUND SOURCES REVEALING THE TRUE GAS EXTENT OF THE DLA

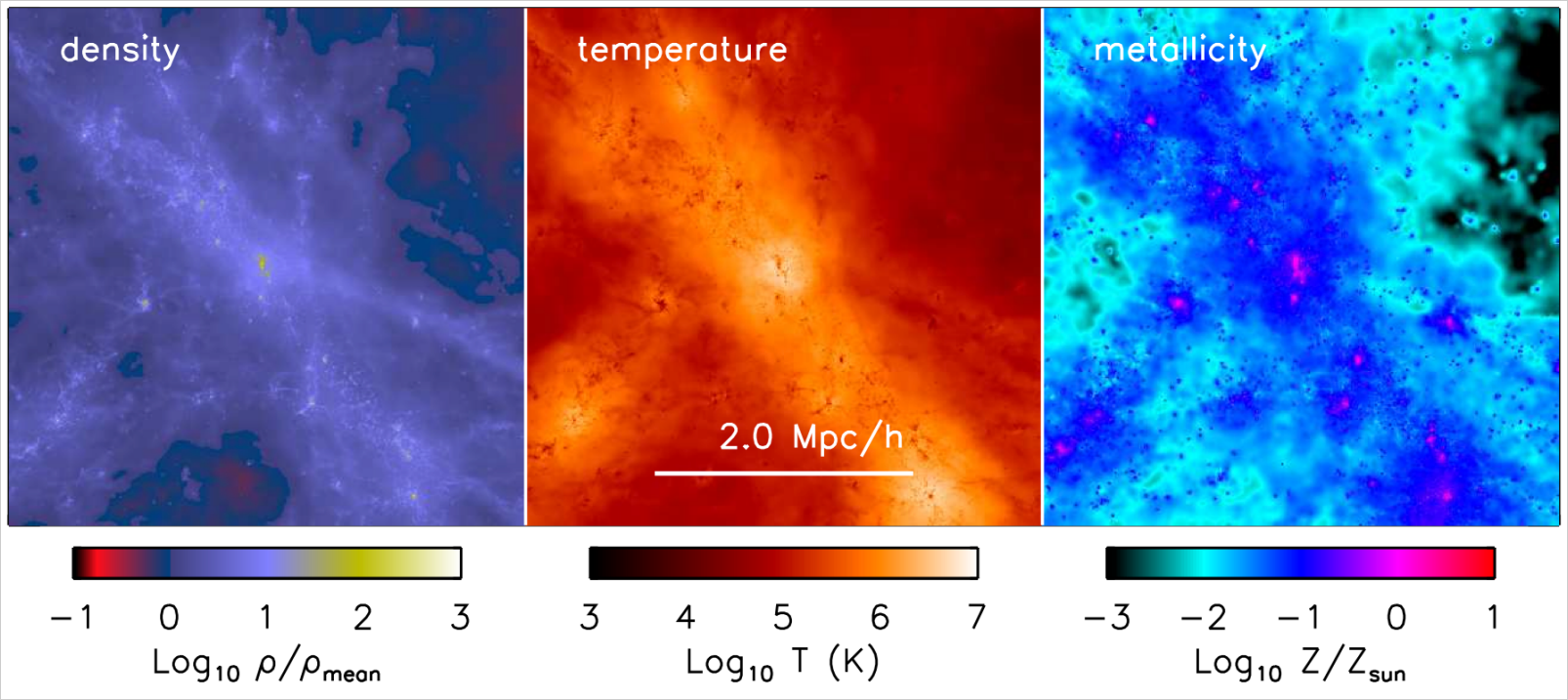




Cooke & O'Meara 2015

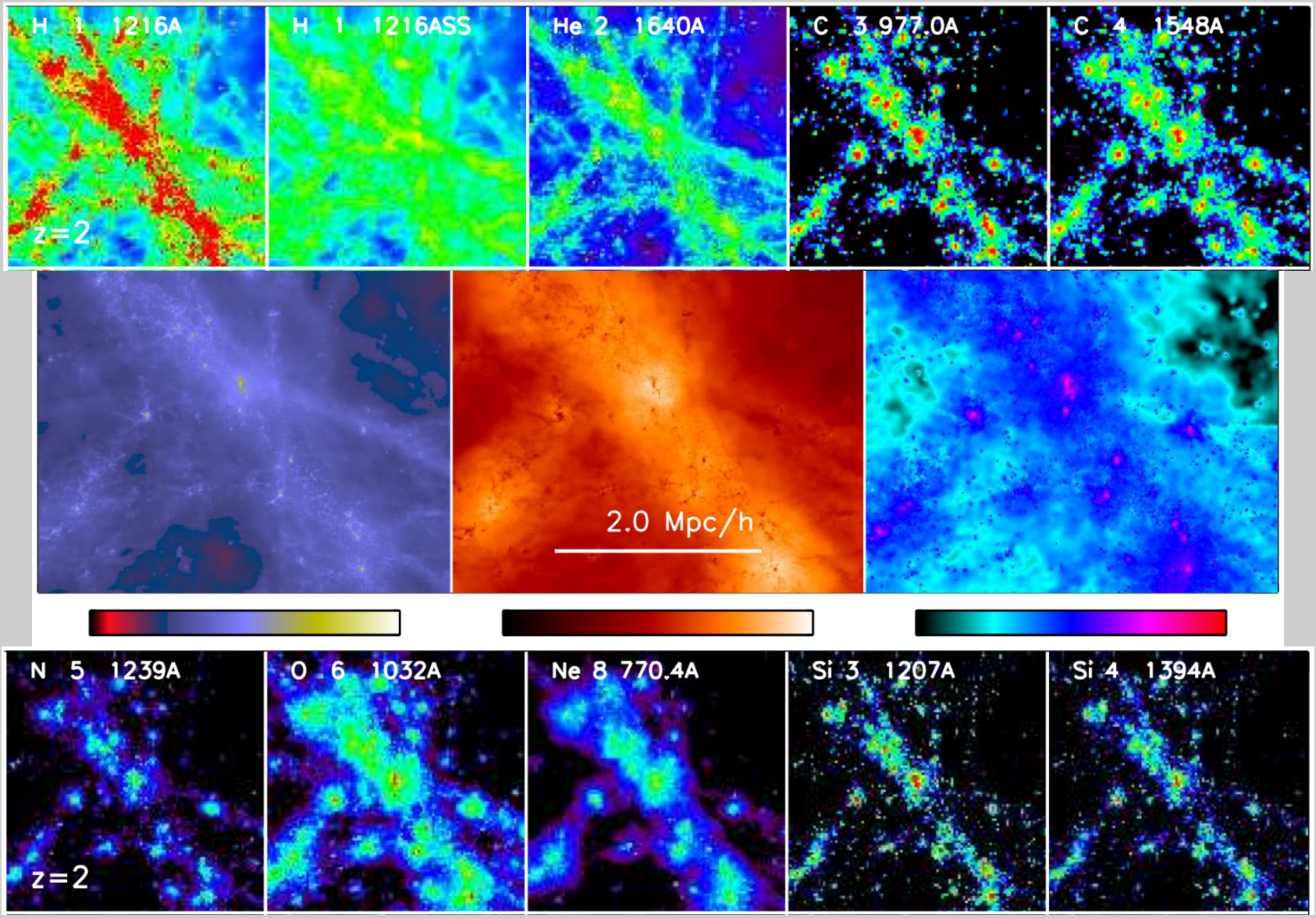
LUVOIR could do this for thousands of galaxies

THE UNIVERSE IN 3D



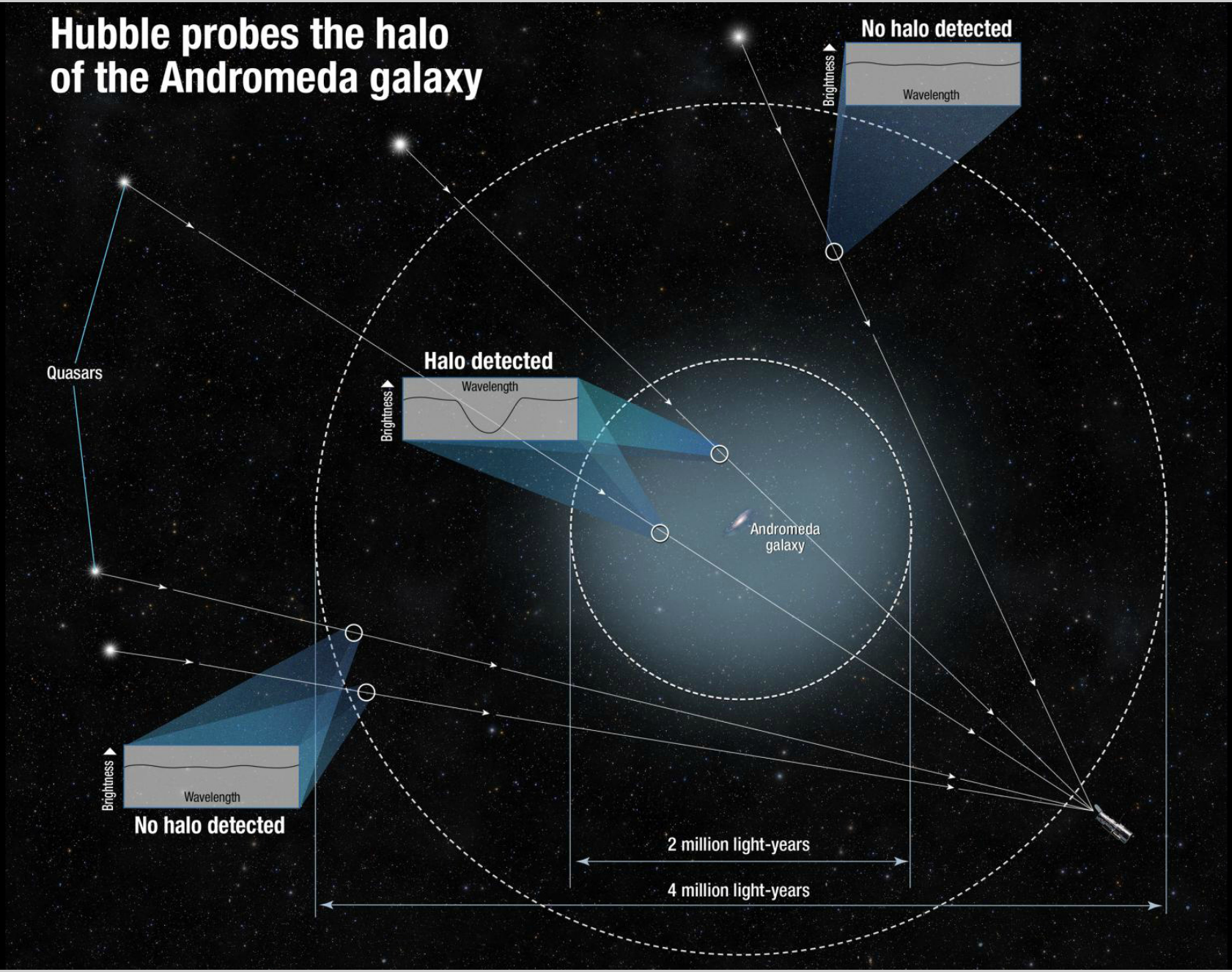
Bertone+ 11

THE UNIVERSE IN 3D



Bertone+ 11

THE LOCAL GROUP REVEALED



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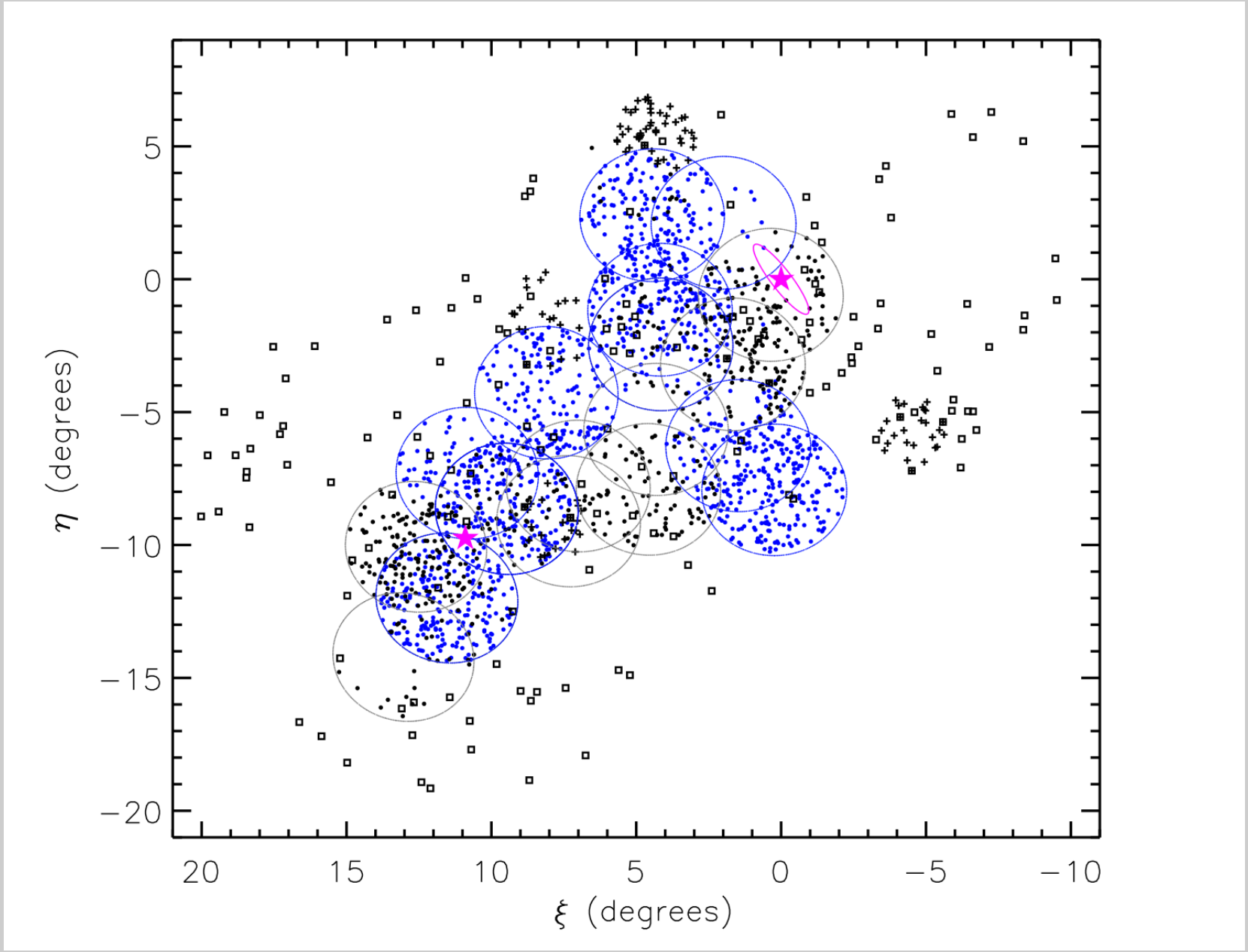

Huo+ 2015

REVOLUTIONIZING OUR UNDERSTANDING OF THE GAS-GALAXY CONNECTION WITH LUVOIR

- Large (12+ m) aperture
- High sensitivity in UV
- High resolution point source spectroscopy
- Intermediate resolution MOS/IFU

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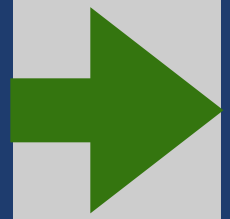

- Factor of 100-1000 increase in viable high S/N point source probes
- Millions of galaxies as new probes
- Emission line mapping and tomography of the CGM
- The Unknown Unknowns

ALMOST LIVE SHOT