# The Hubble Space Telescope

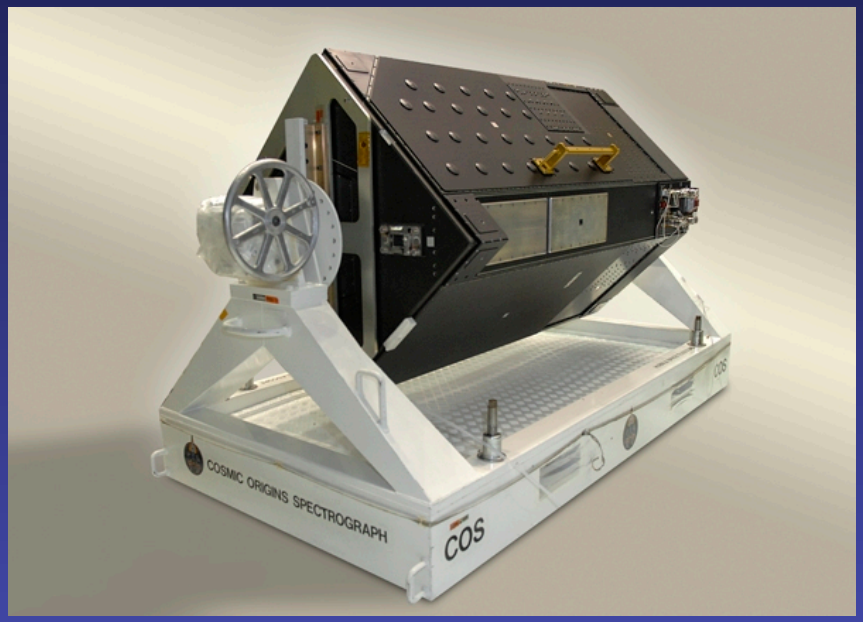
*UV, Visible, NIR pursuits….*

Dr. Jennifer J. Wiseman
HST Senior Project Scientist
NASA Goddard Space Flight Center

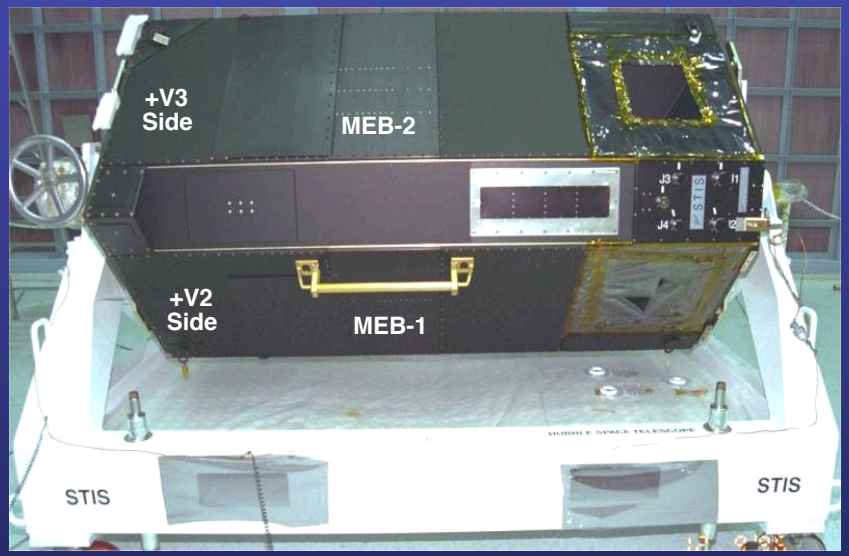
Launch of STS-125, Hubble SM4,
May 11, 2009

S125E007257

WFC-3 (new)




COS (new)



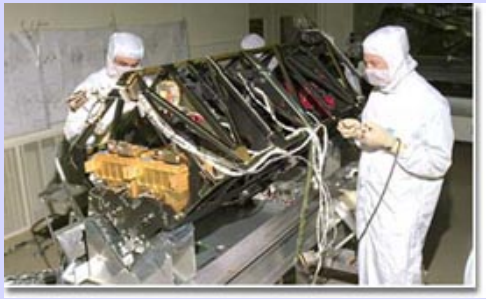

STIS-R (repaired)

# The Scientific Instruments of SM4

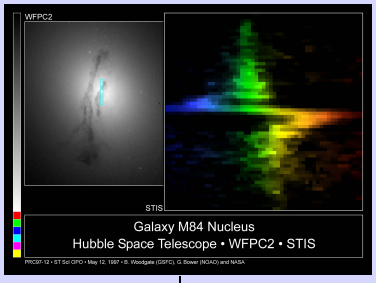
ACS-R (repaired)

# STIS is *the most versatile spectrograph ever to fly in space*

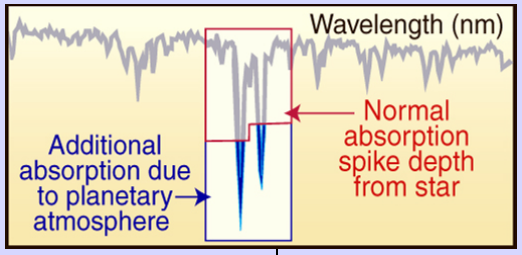
Objectives: Demographics of Supermassive Black Holes, Active Galactic Nuclei, Interstellar Medium, Exoplanetary Atmospheres, Solar System Aurorae



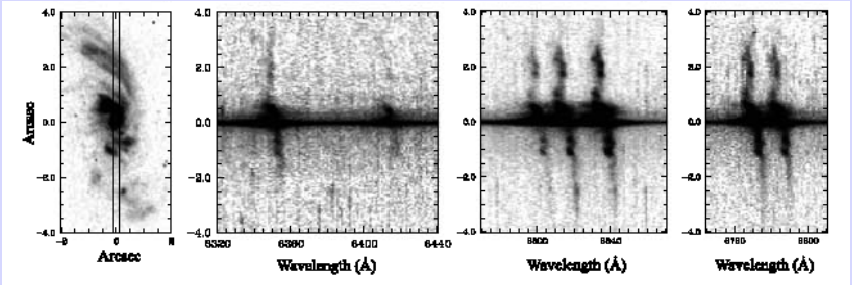
- STIS brought 2D/Hi-Res/UV-Opt-Near IR spectroscopy to HST (a unique capability)
- Pioneered studies of supermassive black holes, complex dynamics of galaxy nuclei
- Produced first (only) detection of an exoplanetary atmosphere
- With COS, has brought the full set of spectroscopic tools to HST




*Supermassive black holes & dependencies on galaxy properties*




*Exoplanetary atmospheres: increasing the sample to ~ 10!*

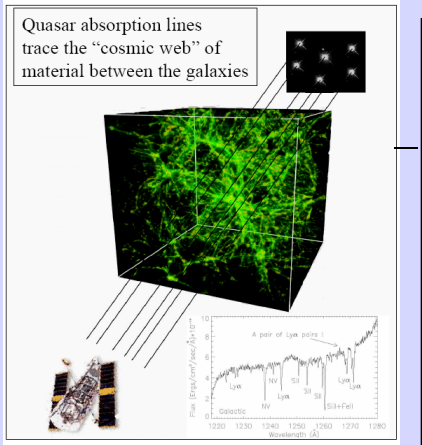



*Active galactic nuclei—making full use of STIS's unique spatial coverage to probe dynamics of complex objects*

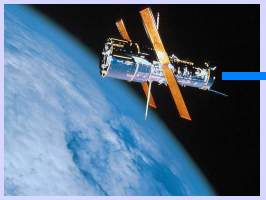
# COS is *the most sensitive UV spectrograph to fly in space*

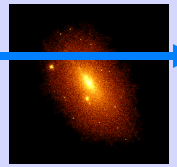
## Objectives: Structure Growth in Early Universe, Galaxy Formation & Heavy Element Production, IGM Baryon Census, Solar System Planetary Atmospheres

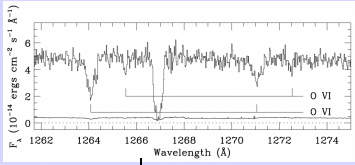
- **COS exploits an element of "performance space" STIS didn't pursue…**
  - **COS has > 10x FUV thruput of STIS & up to 70x STIS speed**
  - **COS is uniquely suited to address particular scientific questions…**




- *How many baryons are in low-density absorbing clouds?*
- *What fraction of IGM is heavy elements, what is dependence on redshift?*
- *Primordial hydrogen clouds in filament voids?*

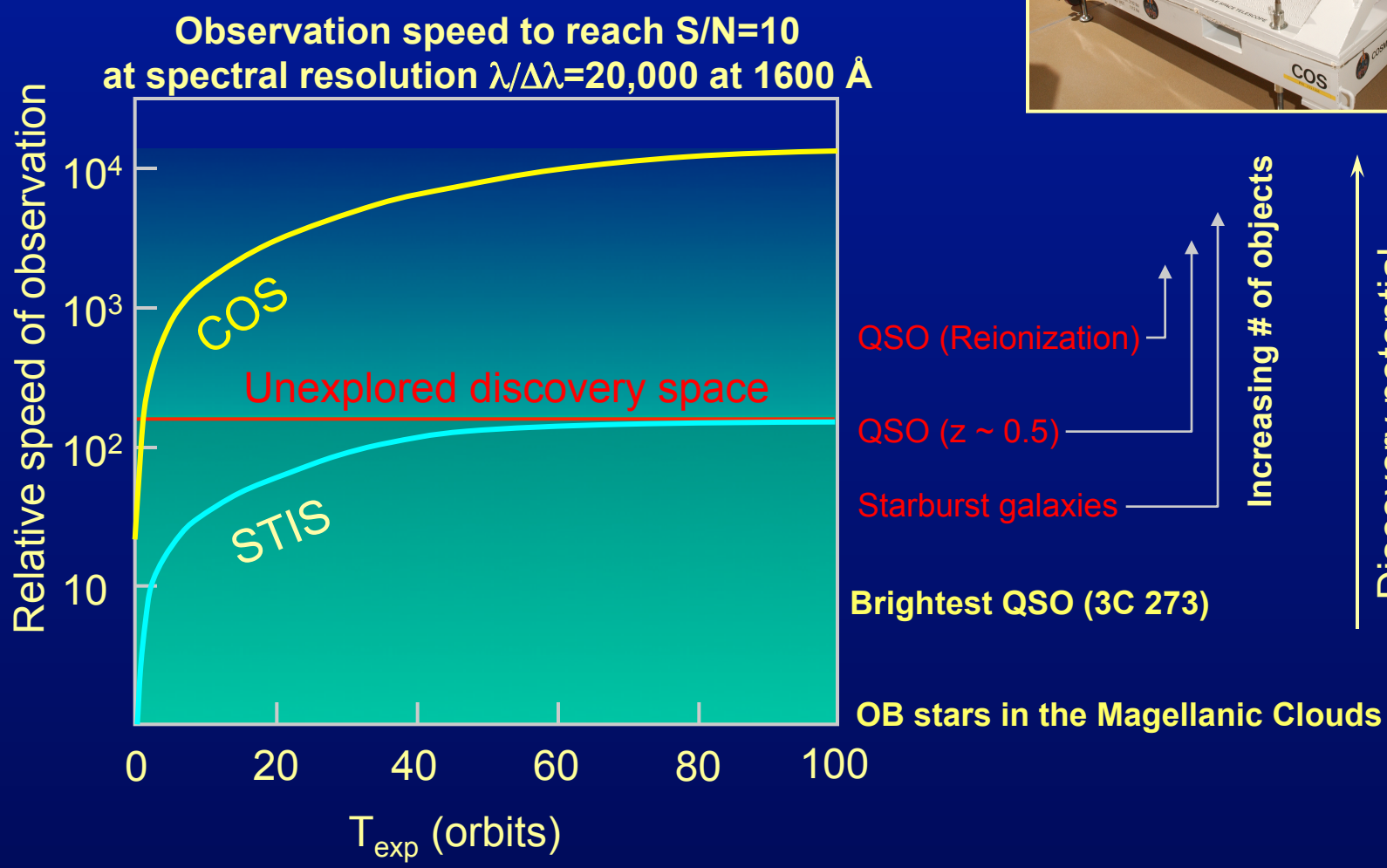


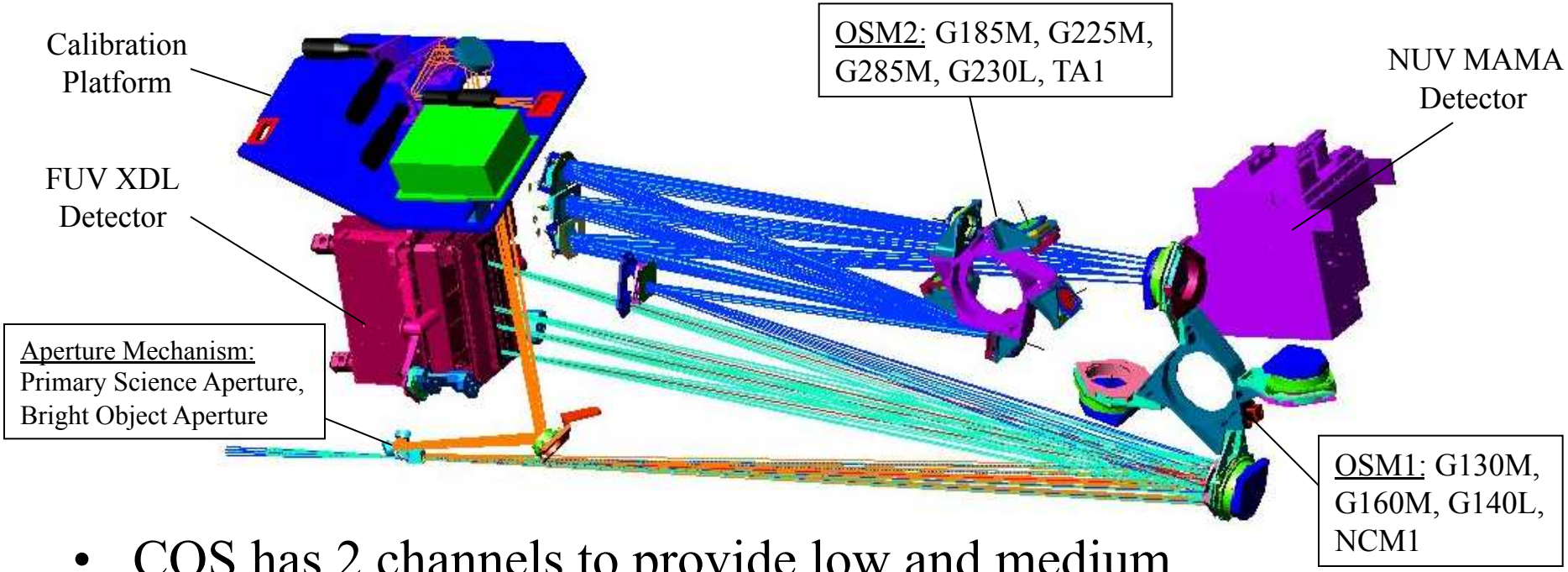





- *What are galaxy halo sizes, shapes, metallicities, and kinematics?*
- *How do galaxies transport heavy elements into IGM, and how far? What galaxy types do this?*

# COS Discovery Potential






- COS has 2 channels to provide low and medium resolution UV spectroscopy
  - FUV: 1150-1775Å, NUV: 1700-3200Å
- FUV gratings: G130M, G160M, G140L
- NUV gratings: G185M, G225M, G285M, G230L
  - All M gratings have a spectral resolution requirement of R ≥ 20,000

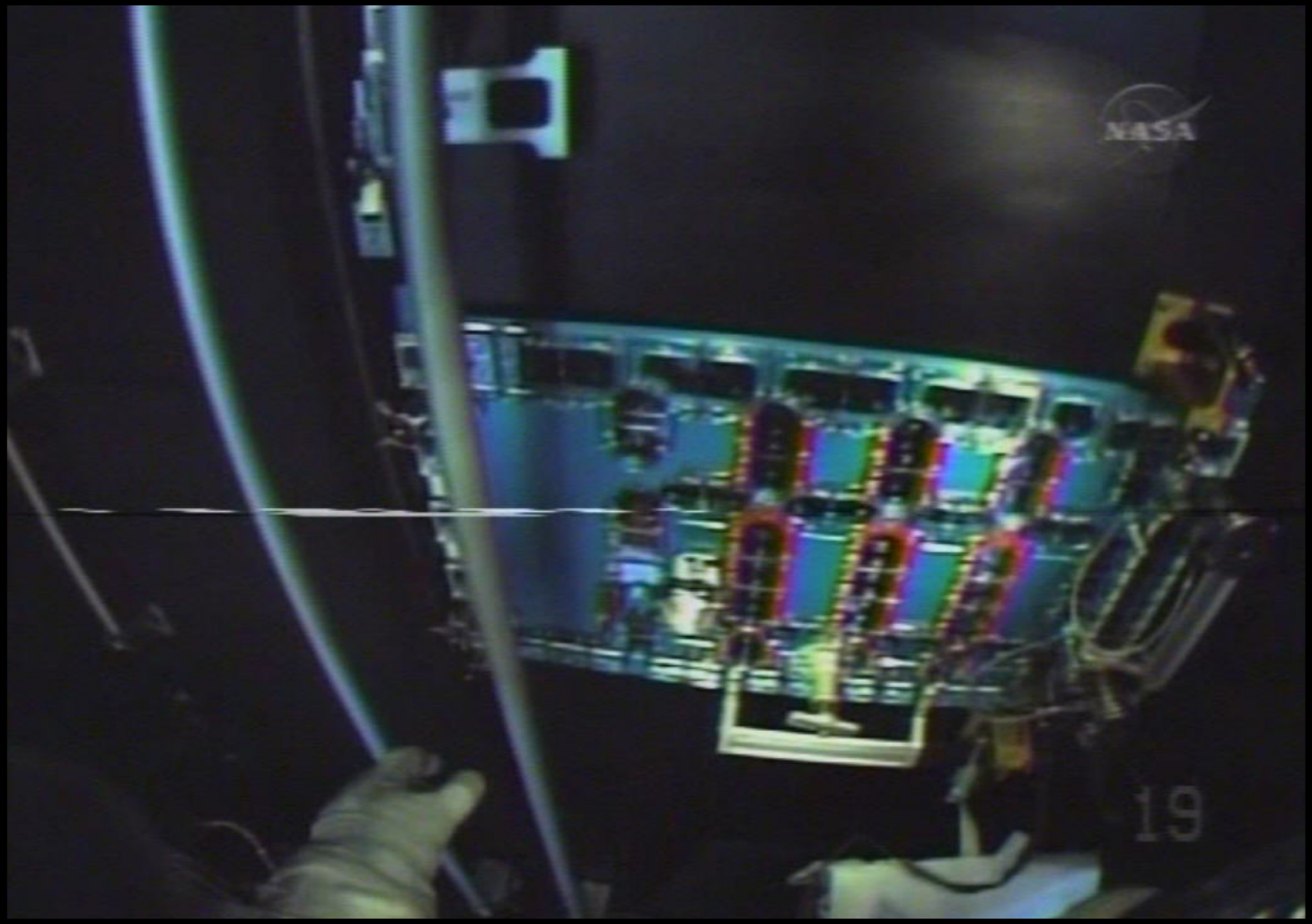
# Cosmic Origins Spectrograph Installation

COSTAR

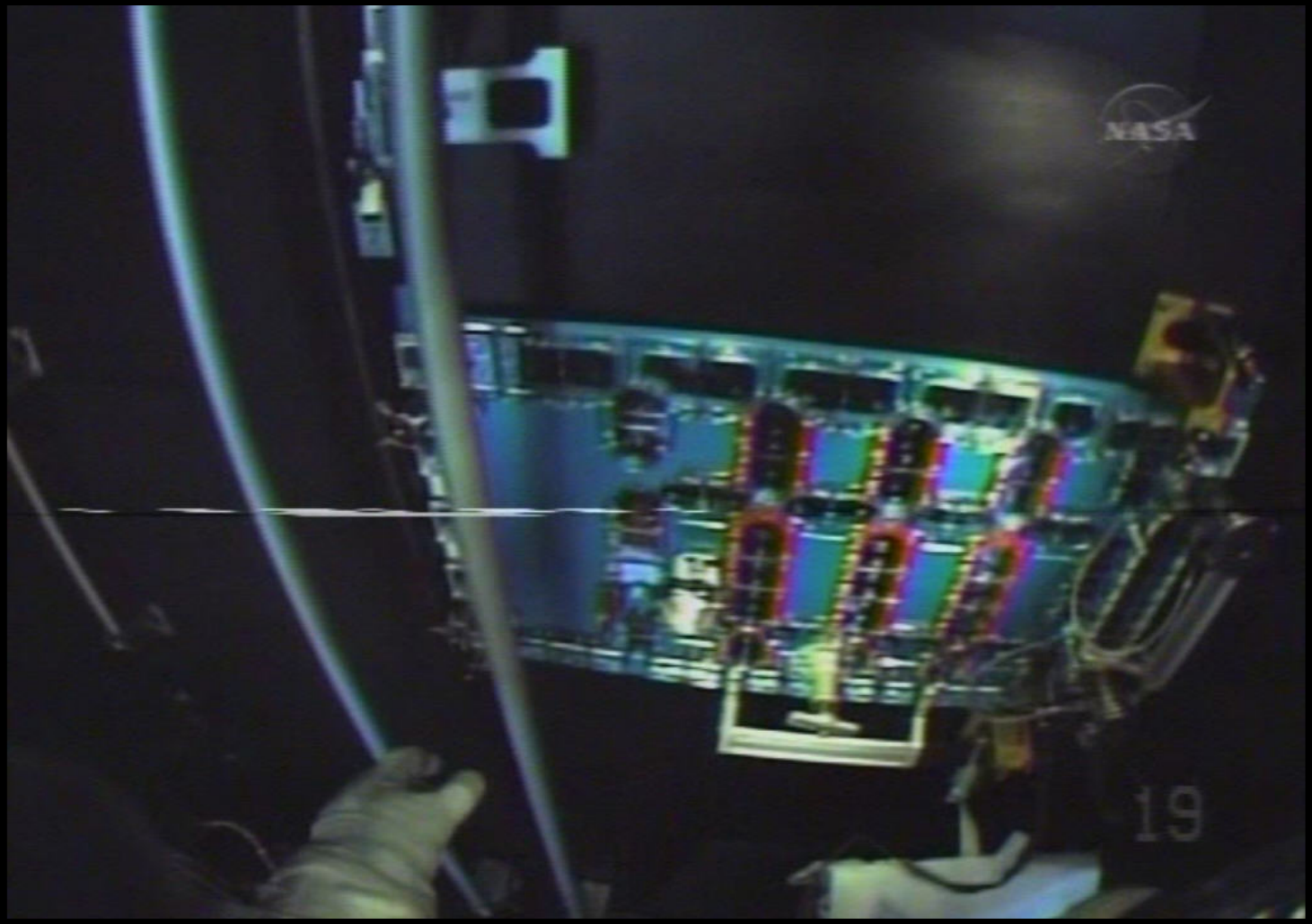
S125E008136

# Space Telescope Imaging Spectrograph Repair

Canada
FRAME 4


NASA
19

# rewind...STIS repair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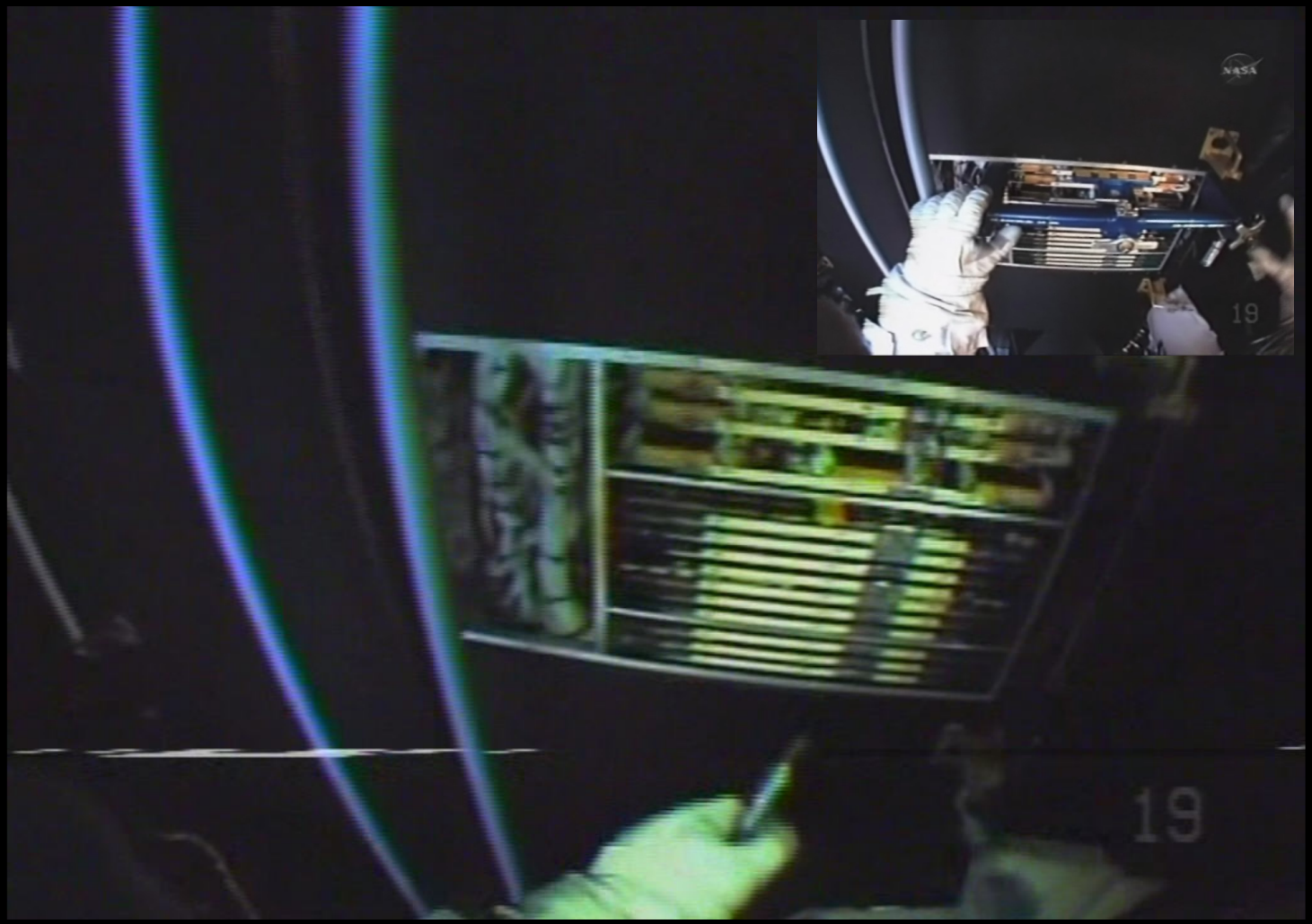
NASA
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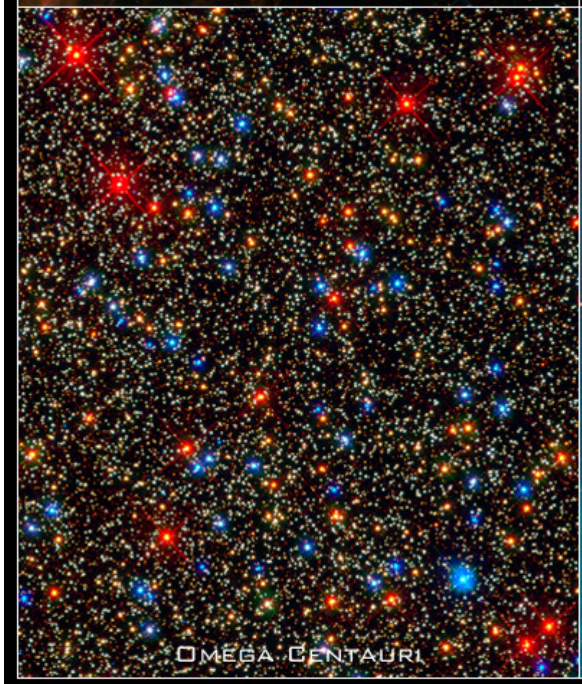
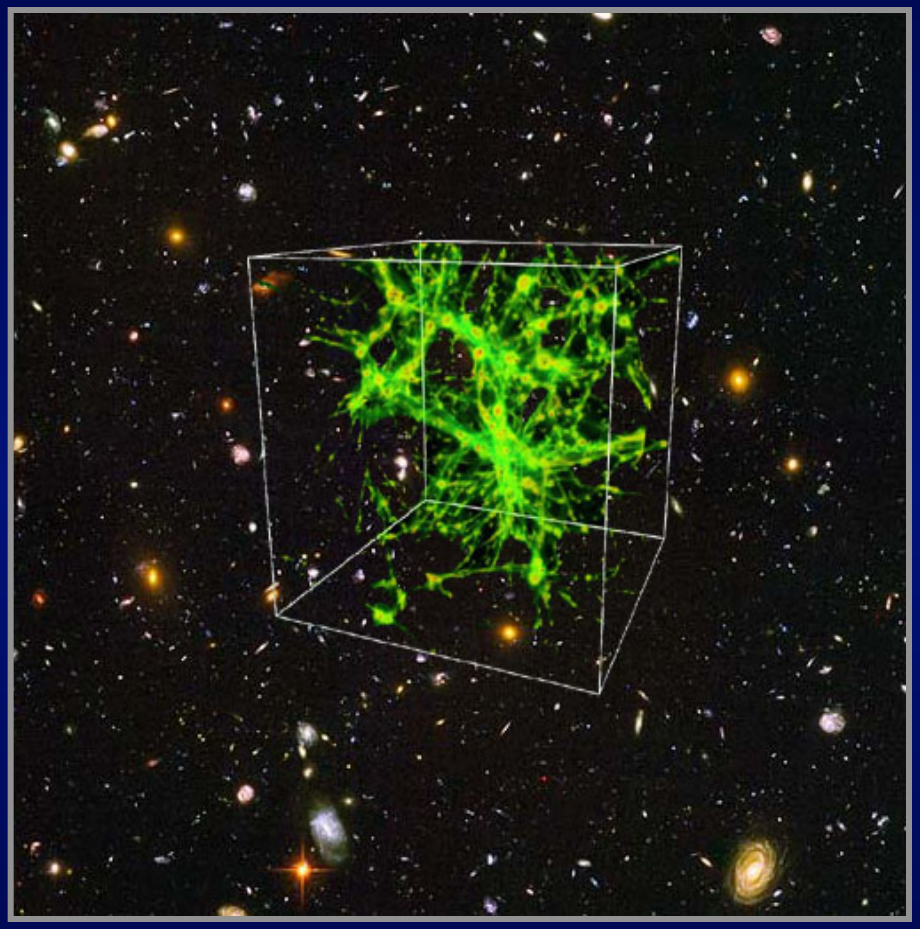


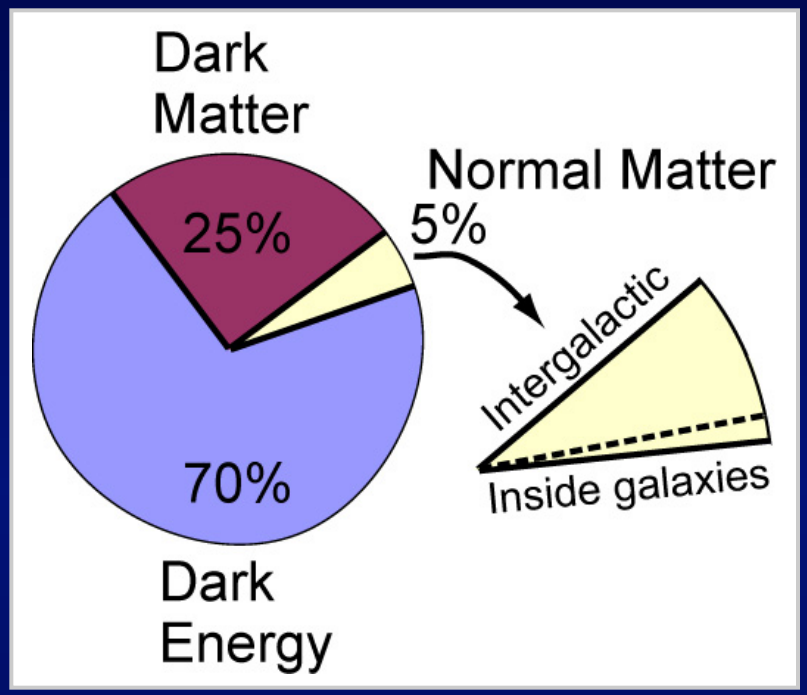
*Hubble Space Telescope* ▪ Wide Field Camera 3
Early Release Observations

## *COS Science Themes*

- What is the large-scale structure of matter in the Universe?
- How did galaxies form out of the intergalactic medium?
- What types of galactic halos and outflowing winds do star-forming galaxies produce?
- How were the chemical elements for life created in massive stars and supernovae?
- How do stars and planetary systems form from dust grains in molecular clouds?
- What is the composition of planetary atmospheres and comets in our Solar System (and beyond)?

# The Cosmic Web of Intergalactic Matter

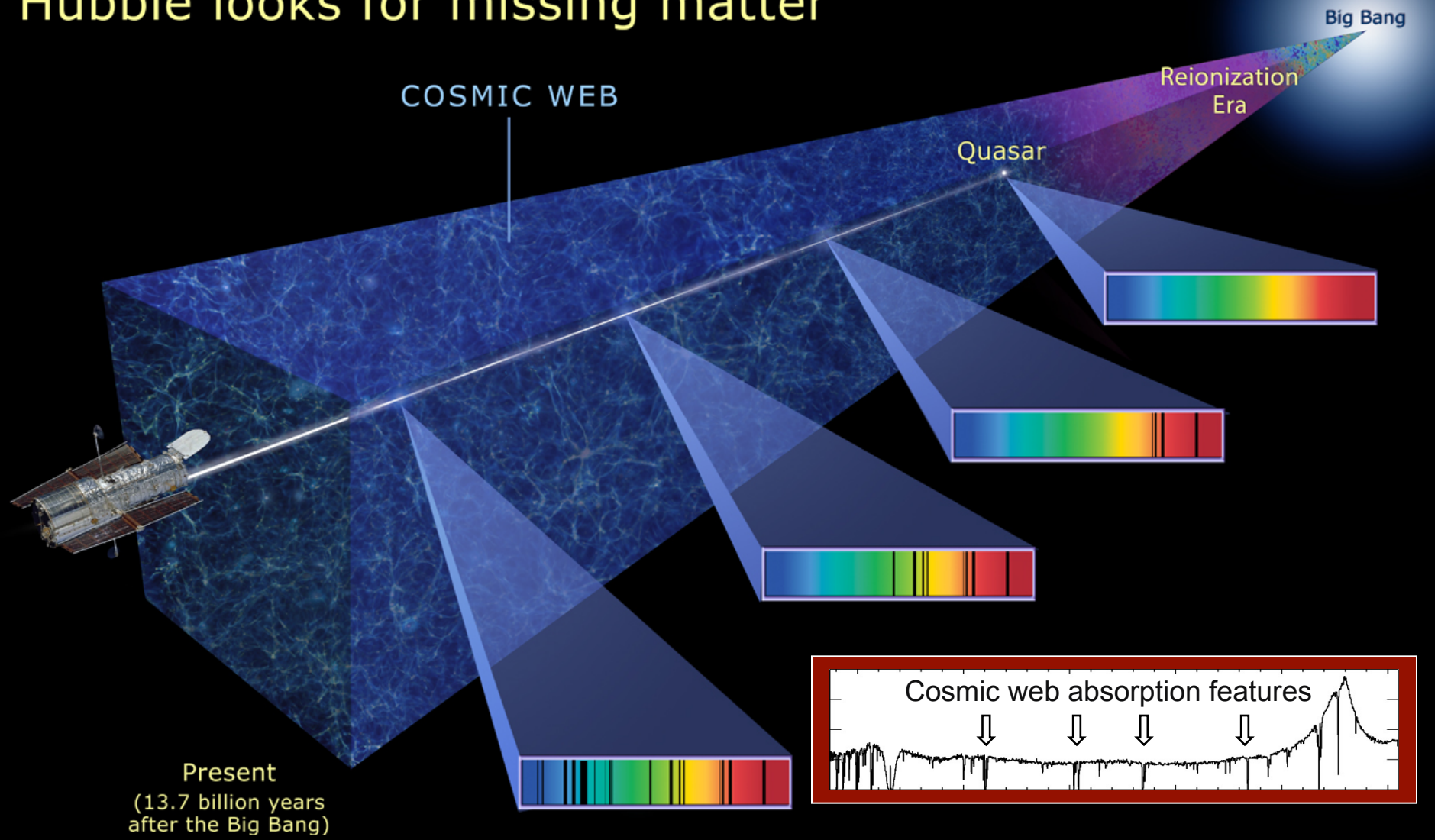





Most of the matter in the Universe is located in intergalactic space outside galaxies.

Normal matter in the cosmic web of intergalactic gas traces the distribution of dark matter.

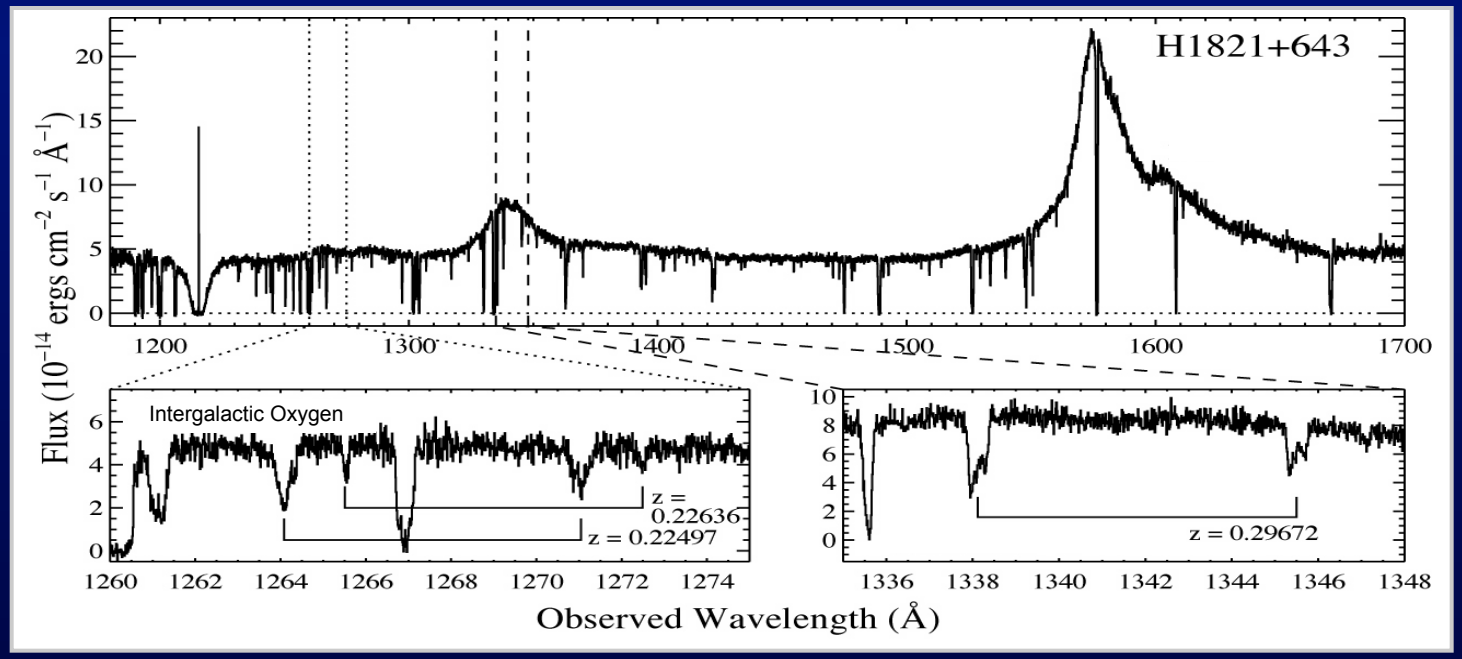
# Hubble looks for missing matter




In just a few weeks of observing time, Hubble's new Cosmic Origins Spectrograph has probed more of the cosmic web than all previous Hubble spectrographs combined.

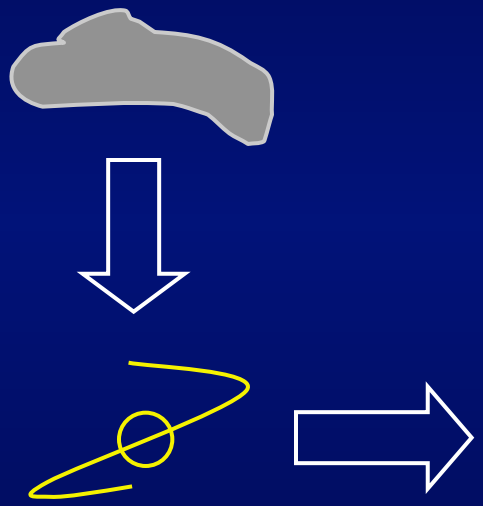
# Hubble Spectra Contain Information

- What is it? Chemical composition
- What state? Molecular/atomic/ionic
- Hot hot? Temperature
- How much? Quantity
- How fast? Velocity
- Where is it? Location (redshift)



# COS Is Exploring Galactic Outflows

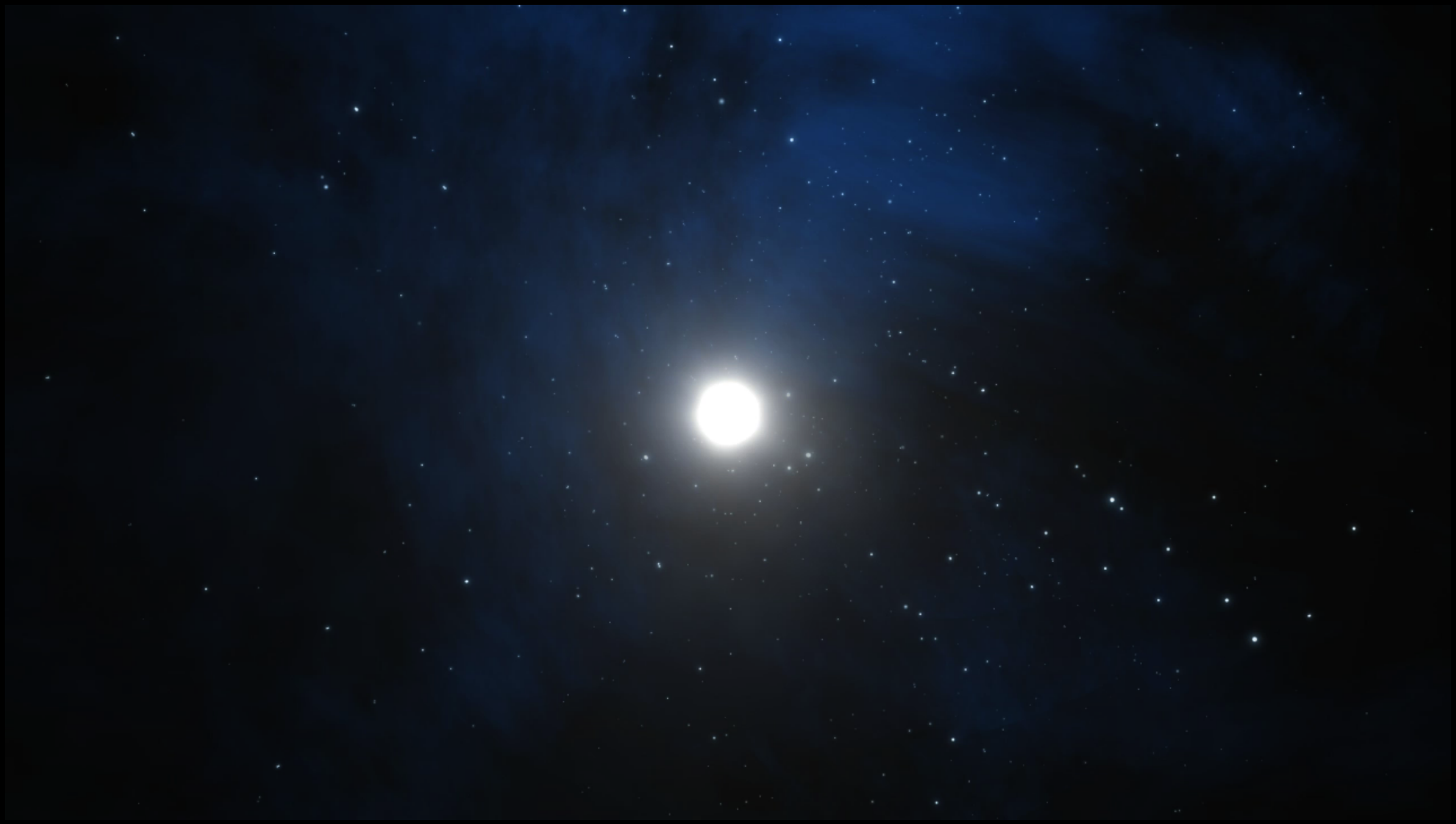
Galaxies accrete intergalactic matter...

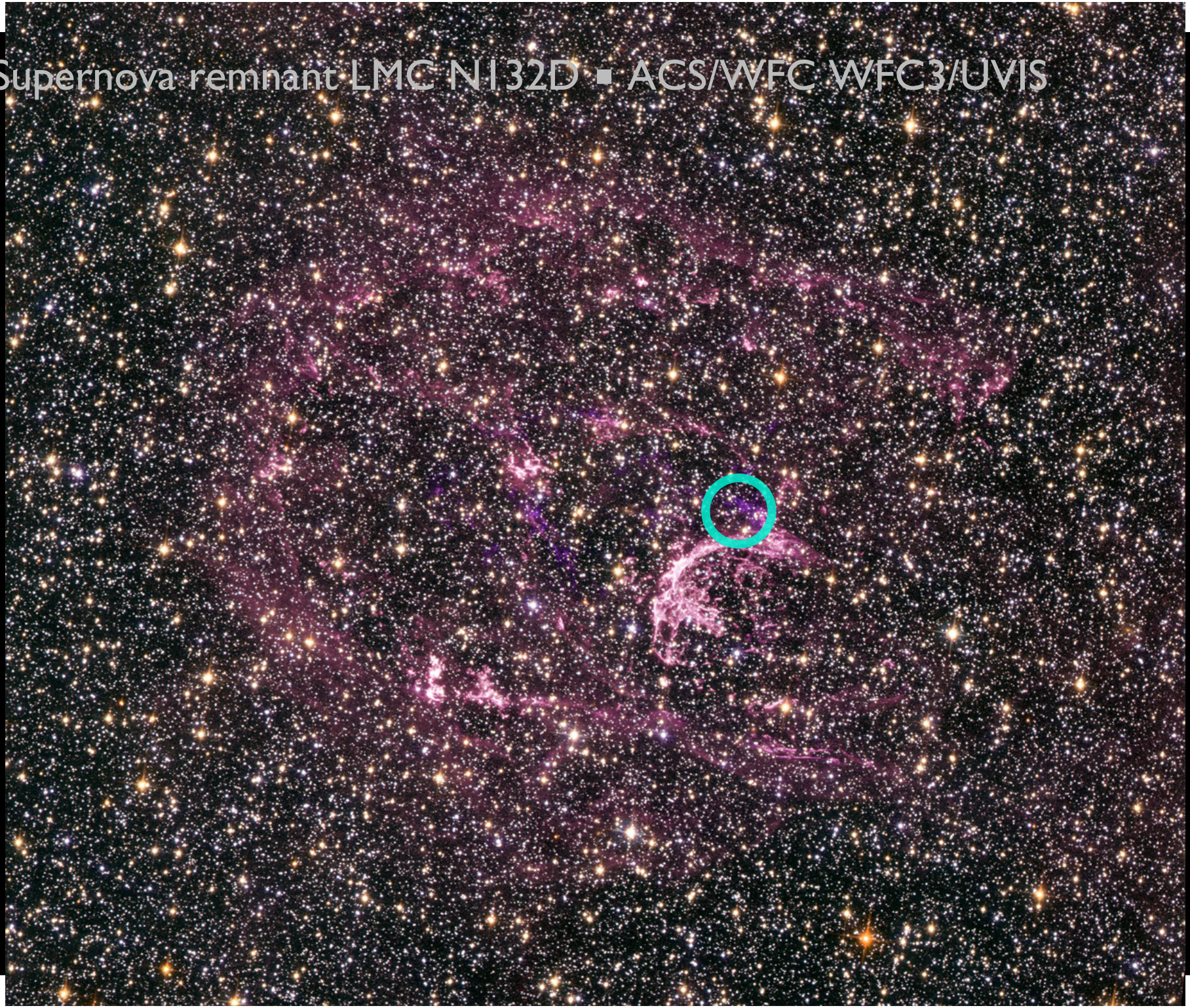


Credit: X-ray: NASA / CXC / JHU / D.Strickland;
Optical: NASA / ESA / STScI / AURA / The Hubble Heritage Team;
IR: NASA / JPL-Caltech / Univ. of AZ /C. Engelbracht

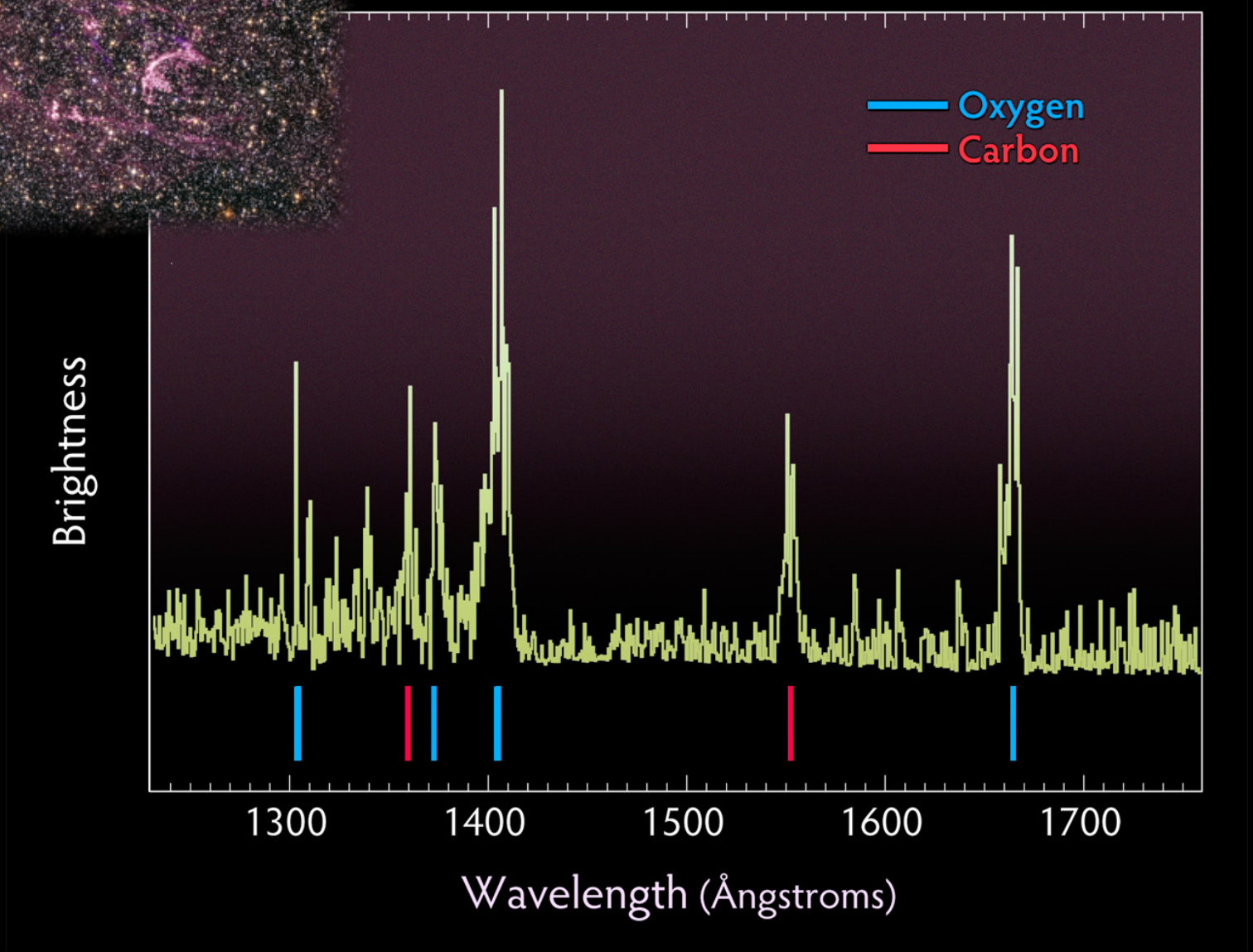
... then expel dust, gas, and heavy elements back into the intergalactic medium.

# a supernova



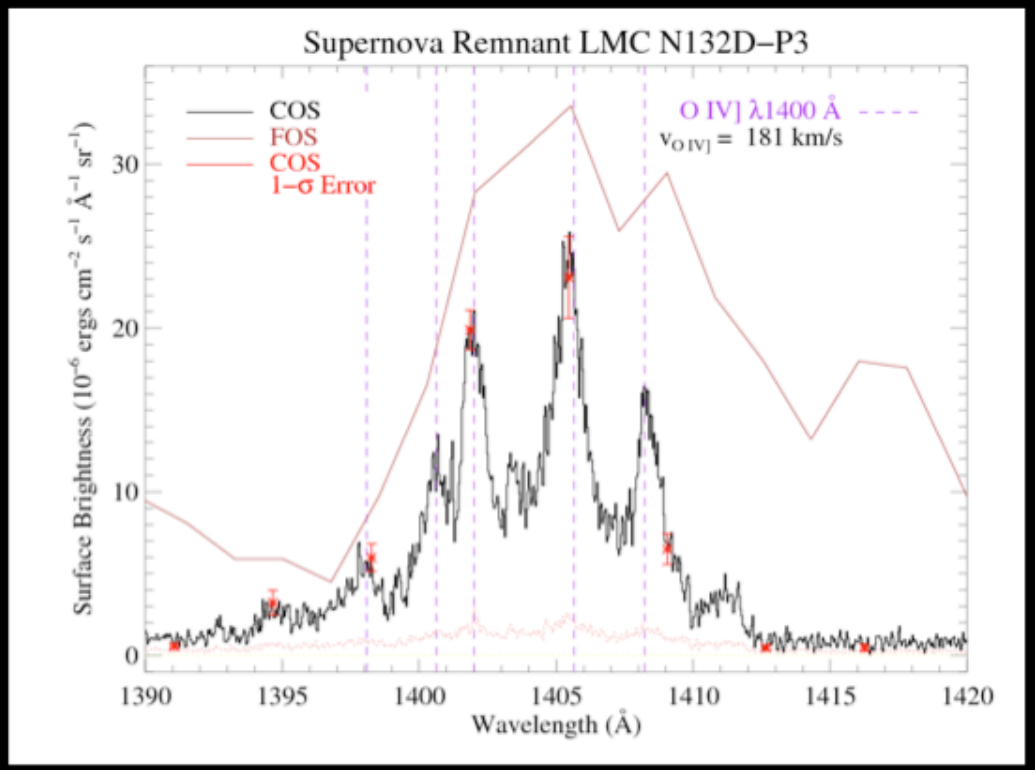

Supernova remnant LMC N132D ▪ ACS/WFC WFC3/UVIS

# probing the tattered remains of supernova remnant N132D



# N132D: Comparison with Previous Results

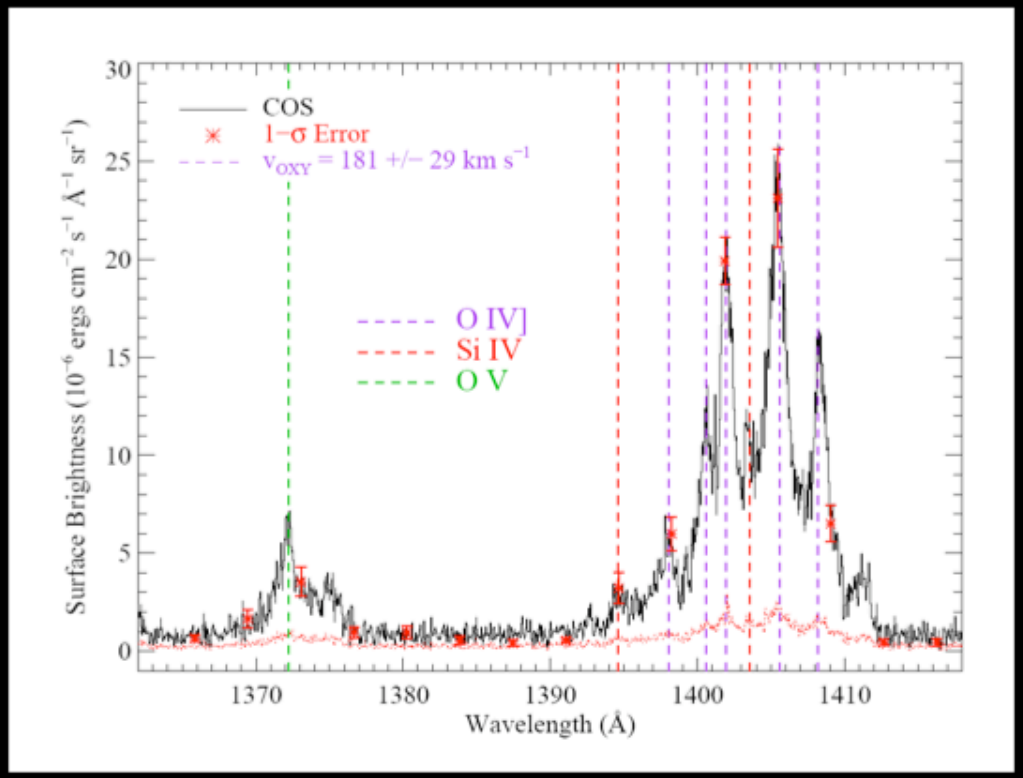
- N132D. 11503: 08/10&31/2009
  - Multiple ionization states of oxygen. C II, C IV, Si IV, He II




•Blair et al. (2000) used non-detection of Si and He to determine the mass of the progenitor and the classification as a Type 1b SN.

• We detect Si co-spatial with the O-rich knot, however the C is <u>not</u> at the velocity of the O components

# N132D: COS Results

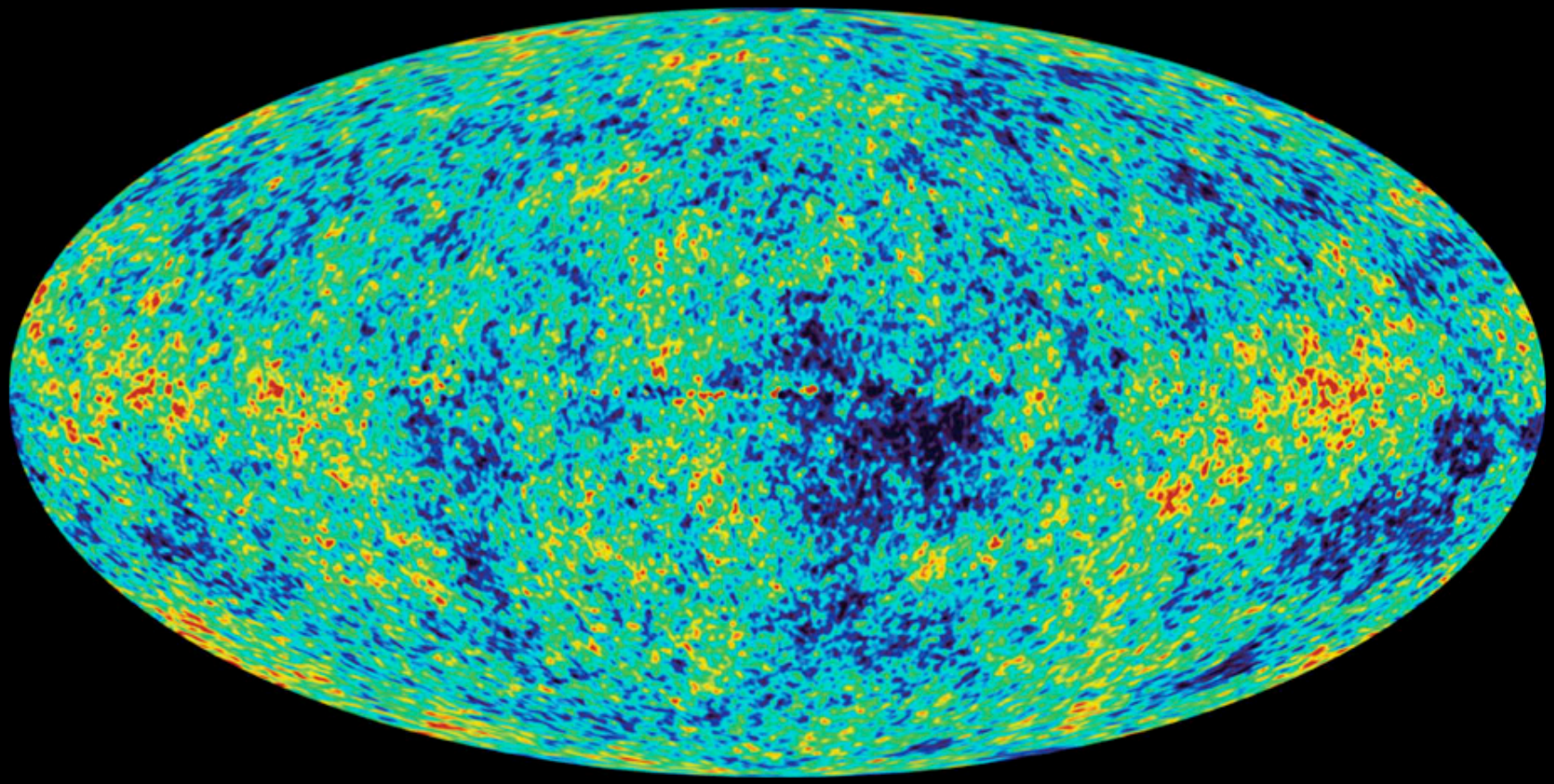


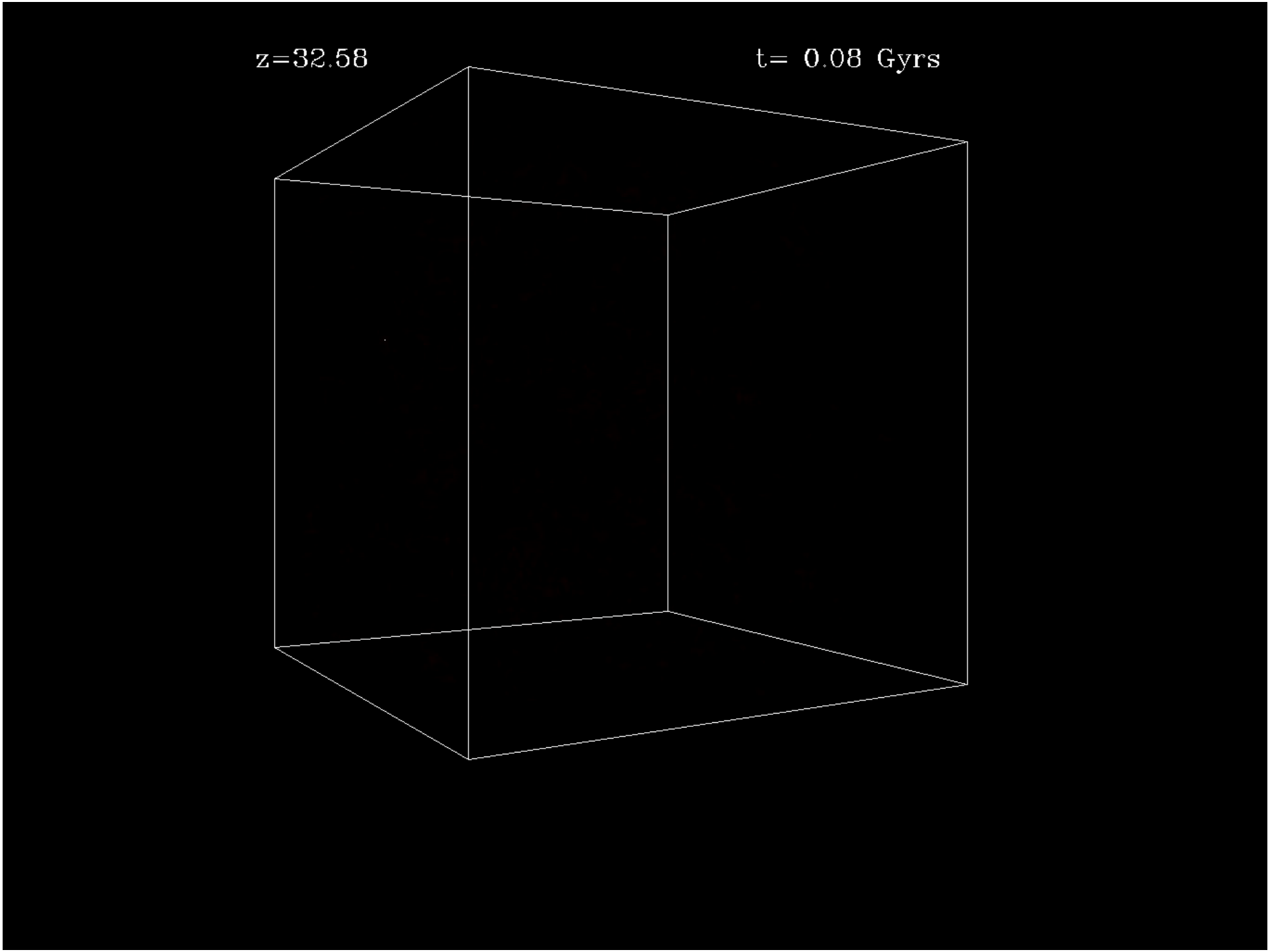

- We use the line-strengths and a model of oxygen-rich shocks to constrain the abundance ratios N(Si)/N(O) ≈ $10^{-2}$ and N(C)/N(O) < $10^{-2}$

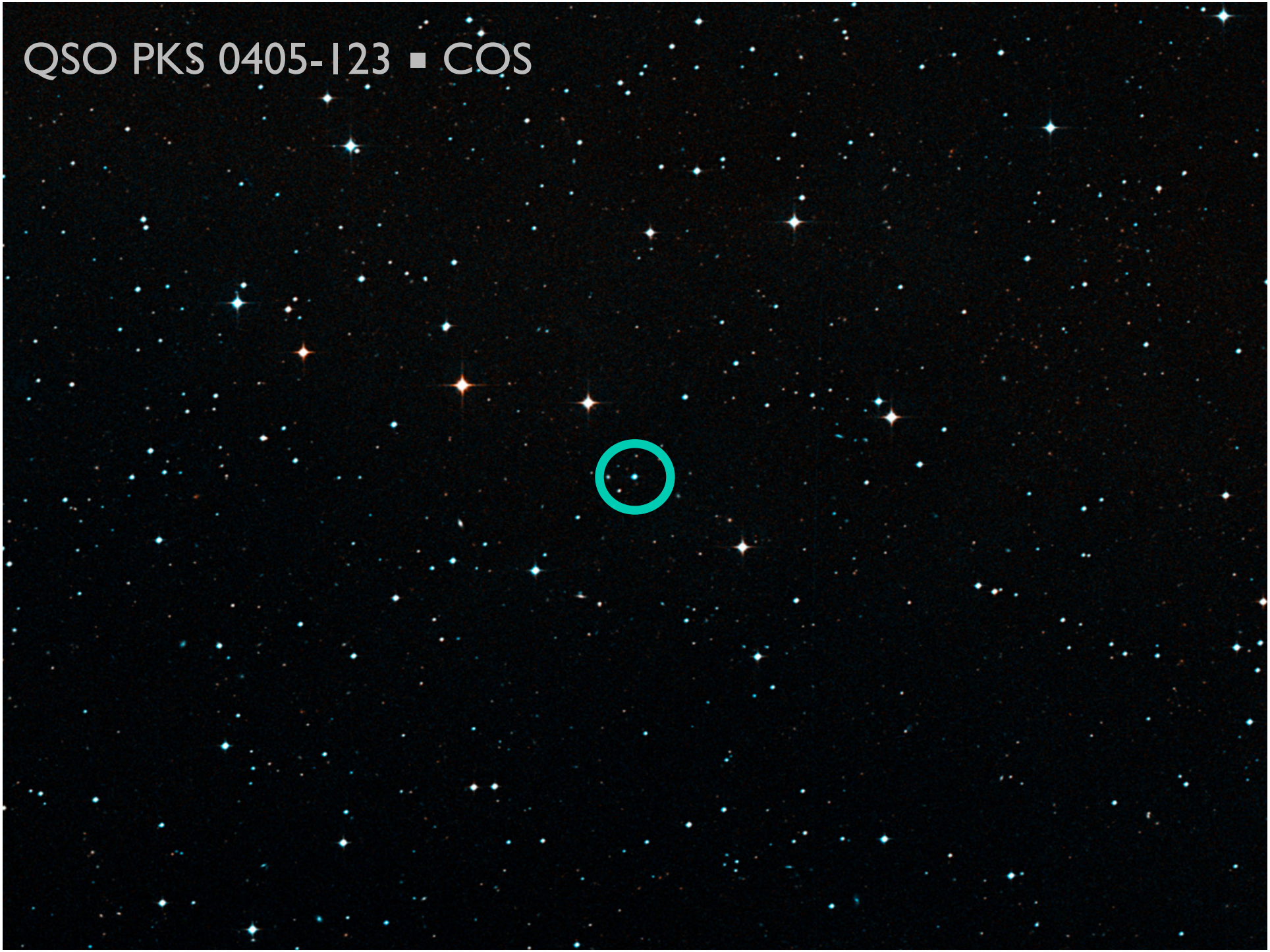
- Applying the results of core-collapse supernova models (Woosley et al 1993, Nomoto et al. 1997, and Umeda & Nomoto 2008), we determine a progenitor mass:

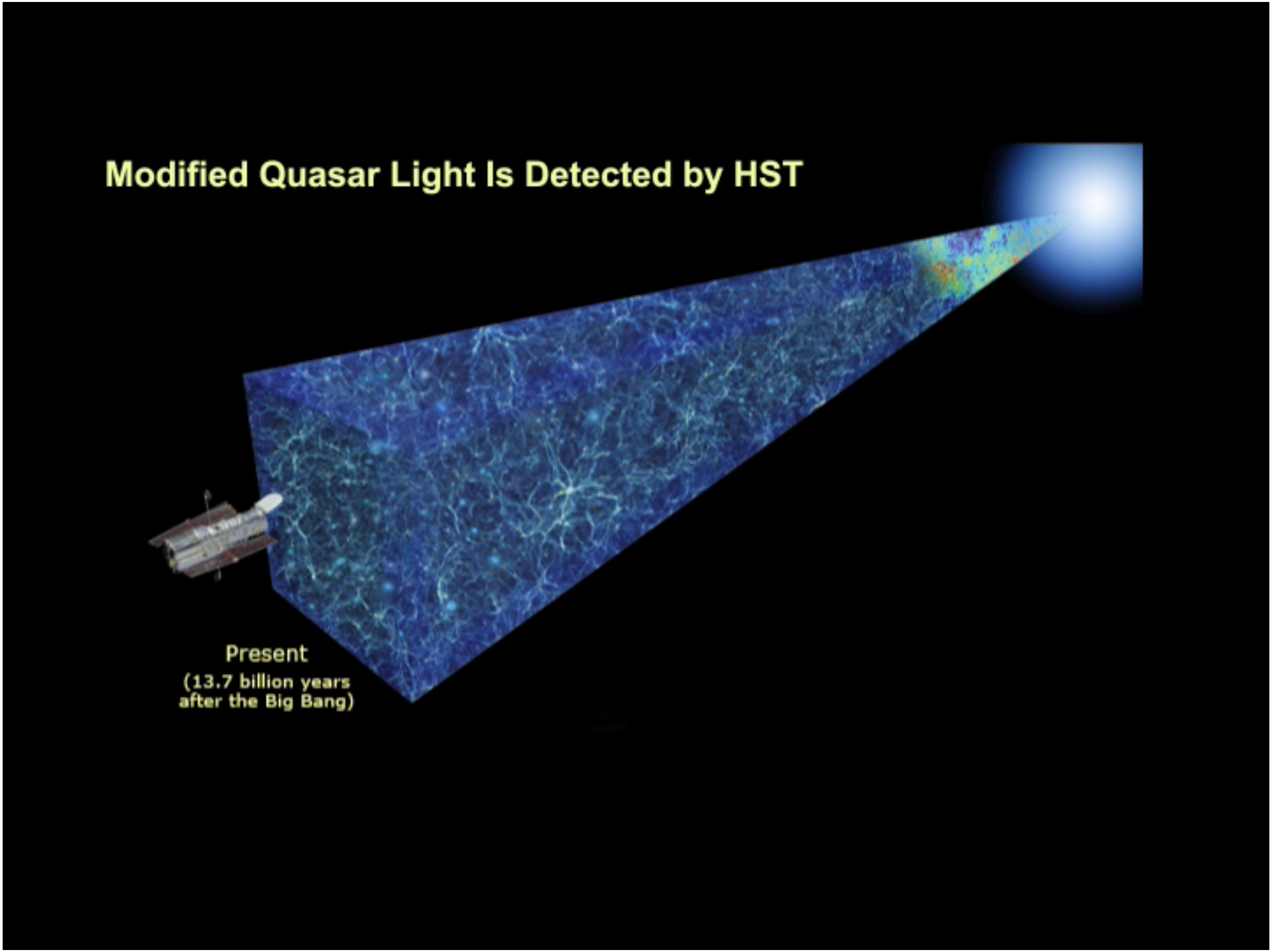
$M_* = 50 +/- 25\ M_\odot$

# WMAP VIEW OF COSMIC MICROWAVE BACKGROUND



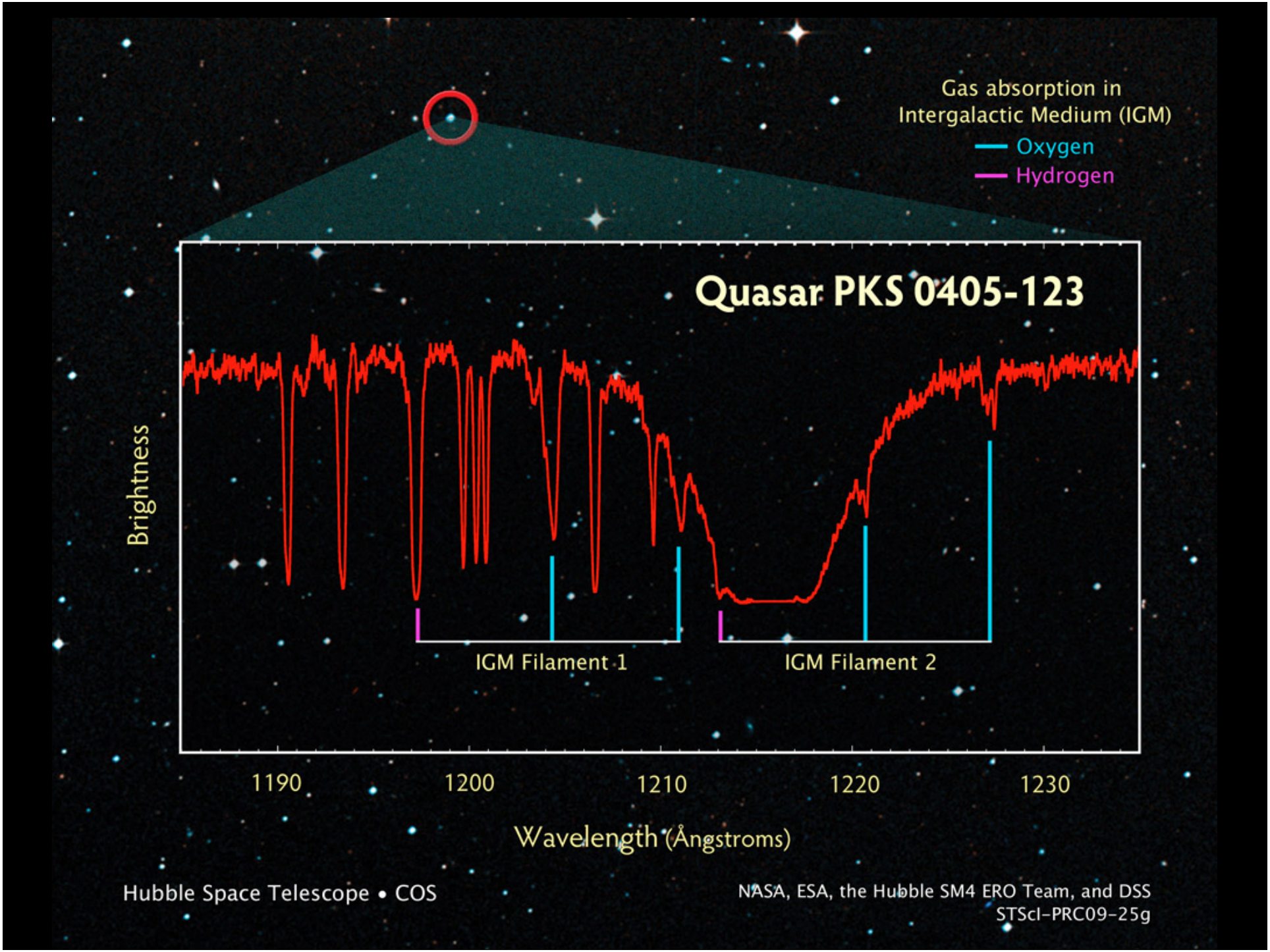

z=32.58
t= 0.08 Gyrs

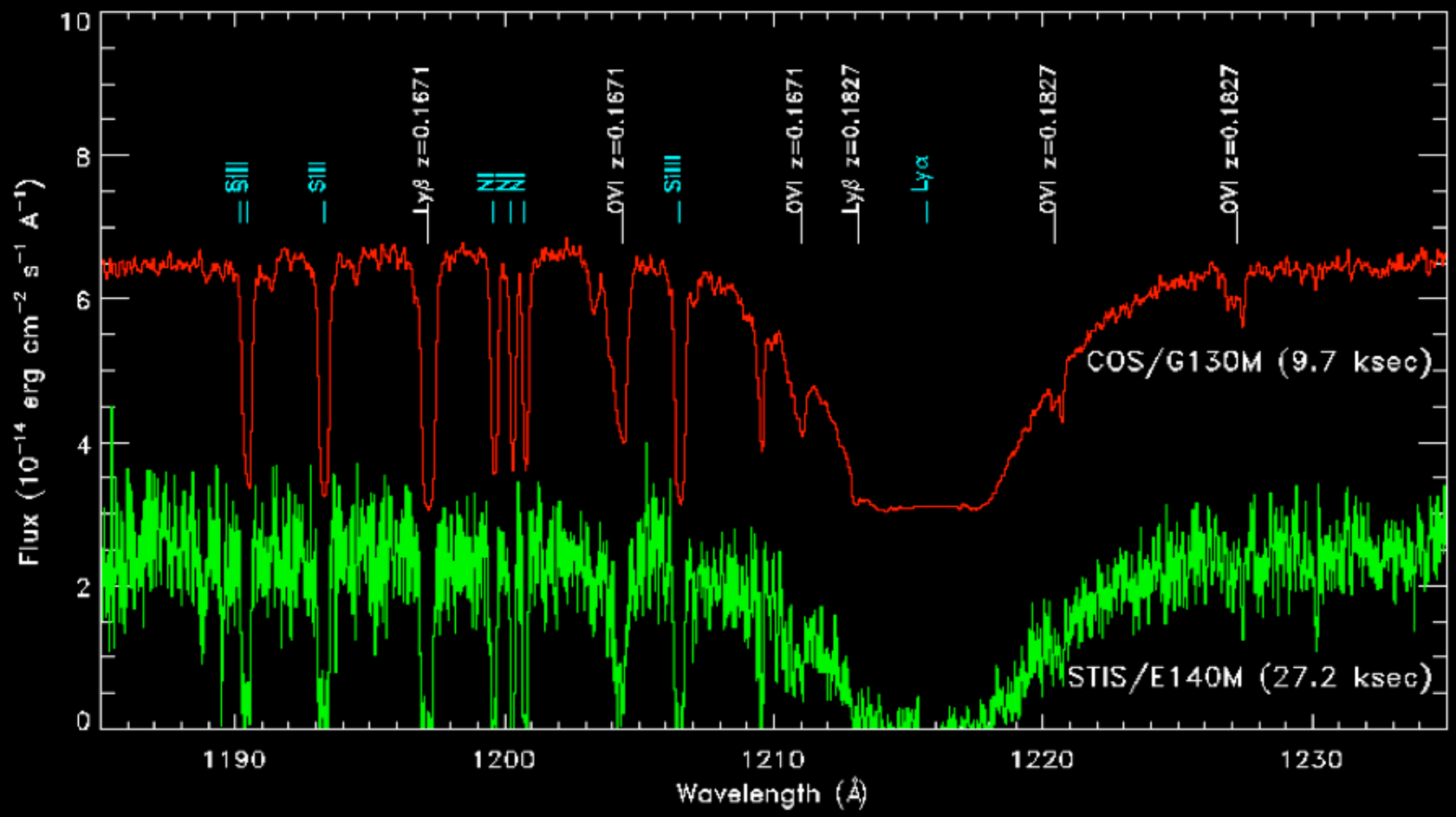

QSO PKS 0405-123 ▪ COS


Modified Quasar Light Is Detected by HST
Present
(13.7 billion years
after the Big Bang)

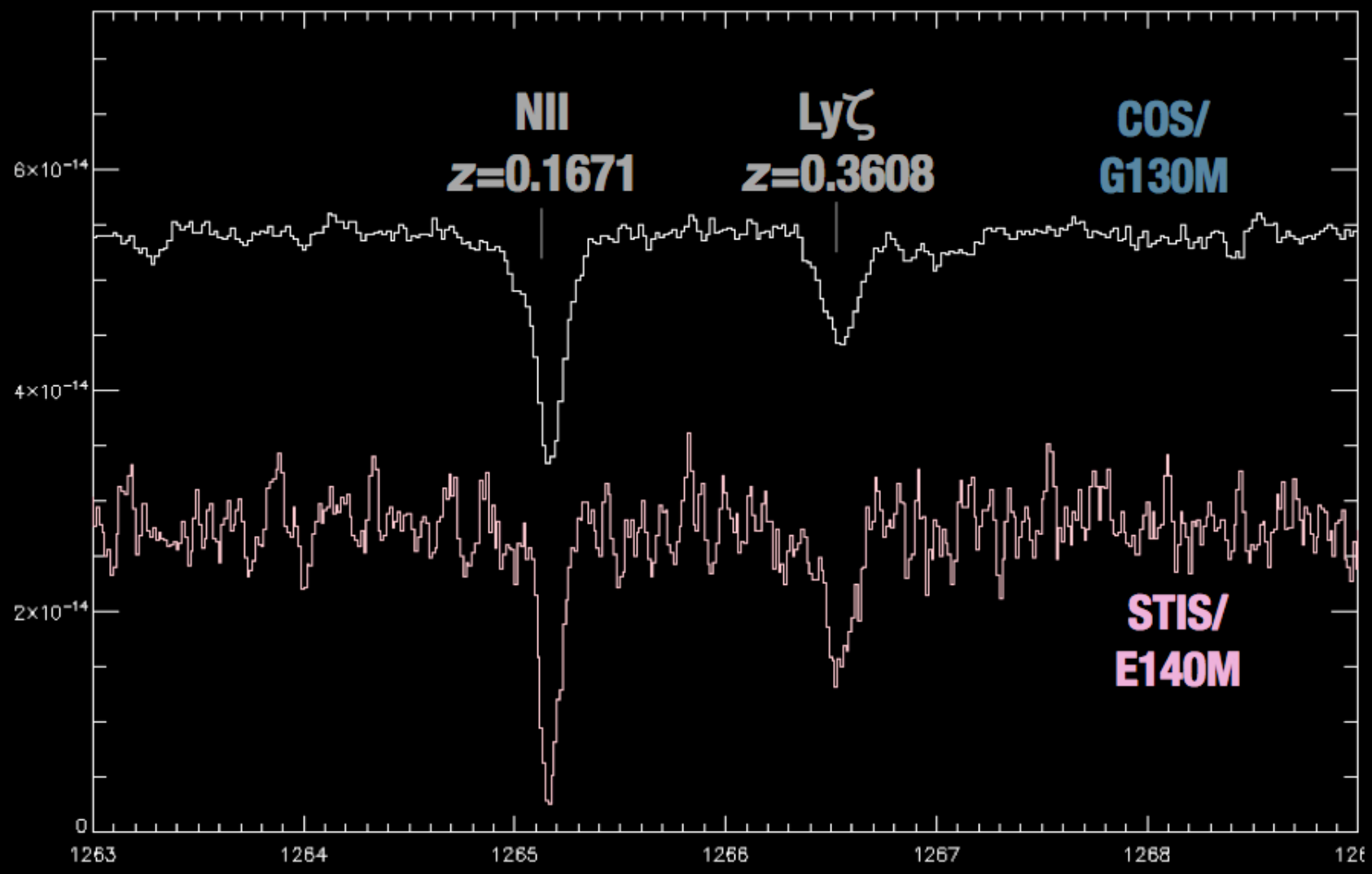
# PKS 0405-12 Overview

- Well-studied, bright QSO, z=0.573
- Rich in IGM Ly$\alpha$/metal ion lines
- Observed by every generation of HST far-UV spectrograph: FOS, GHRS, STIS, and now COS, as well as HUT, FUSE
  - FUSE: 150 ksec → **S/N=5-10** per 20 km $s^{-1}$ resel
  - STIS/E140M: 27 ksec → **S/N≈12** per 7 km $s^{-1}$ resel
  - COS: 17 ksec (7 orbits) → **S/N≈50** per 15 km $s^{-1}$ resel


Gas absorption in
Intergalactic Medium (IGM)
Oxygen
Hydrogen
Quasar PKS 0405-123
Brightness
IGM Filament 1
IGM Filament 2
1190
1200
1210
1220
1230
Wavelength (Ångstroms)
Hubble Space Telescope • COS
NASA, ESA, the Hubble SM4 ERO Team, and DSS
STScI-PRC09-25g




Courtesy Charles Danforth and the COS Science Team



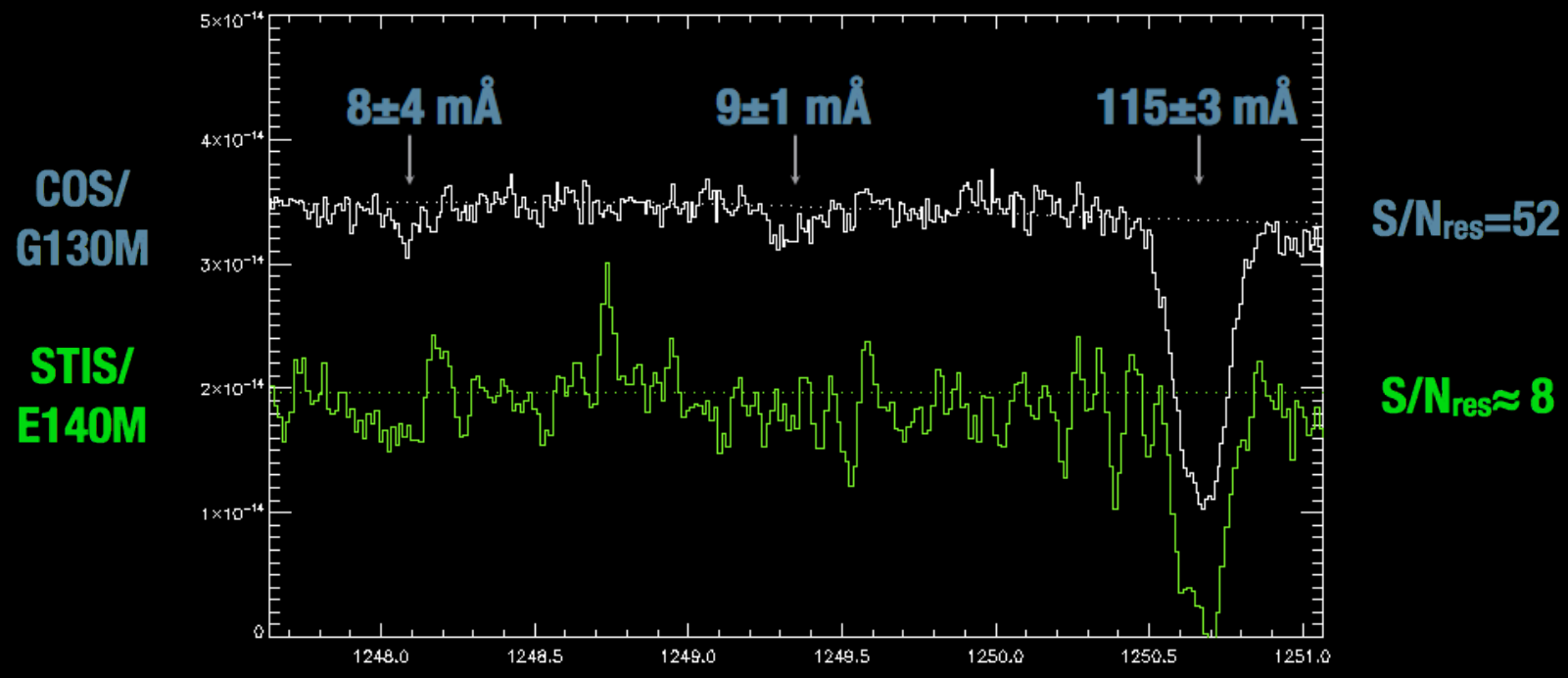

Courtesy Charles Danforth and the COS Science Team

# PKS 0405-12: Weak Lines

- Can we see the weak features?

$$W_{\min} \approx \frac{(SL)\ \lambda}{R\ (S/N)}$$

$$W_{\min} \approx \frac{(4\sigma)\ 1300\text{Å}}{(2 \times 10^4)\ (50)} = 5\,\text{mÅ}$$




Courtesy Charles Danforth and the COS Science Team

# An Illustrative Problem

- Significant fraction of FUV lines cannot be identified with current line lists

- Either lines are missing or *f*-values are highly inaccurate

- Problem seen in stellar spectra covering a wide range in effective temperature

- Likely due to transitions to highly-excited levels, especially in iron-group ions

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# VERY HIGH RESOLUTION ULTRAVIOLET SPECTROSCOPY OF A CHEMICALLY PECULIAR STAR: RESULTS OF THE $\chi$ LUPI PATHFINDER PROJECT

DAVID S. LECKRONE[1]
Laboratory for Astronomy and Solar Physics, Goddard Space Flight Center, Code 680, Greenbelt, MD 20771; dleckrone@hst.nasa.gov
CHARLES R. PROFFITT[2,3] AND GLENN M. WAHLGREN[2,4]
Science Programs, Computer Sciences Corporation, Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218; proffitt@figaro.gsfc.nasa.gov, spek_glenn@garbo.lucas.lu.se
AND
SVENERIC G. JOHANSSON[5] AND TOMAS BRAGE
Department of Physics, University of Lund, Box 118, S-221 00 Lund, Sweden; spek_sej@garbo.lucas.lu.se, brage@kurslab.fysik.lu.se
*Received 1998 September 28; accepted 1998 November 20*



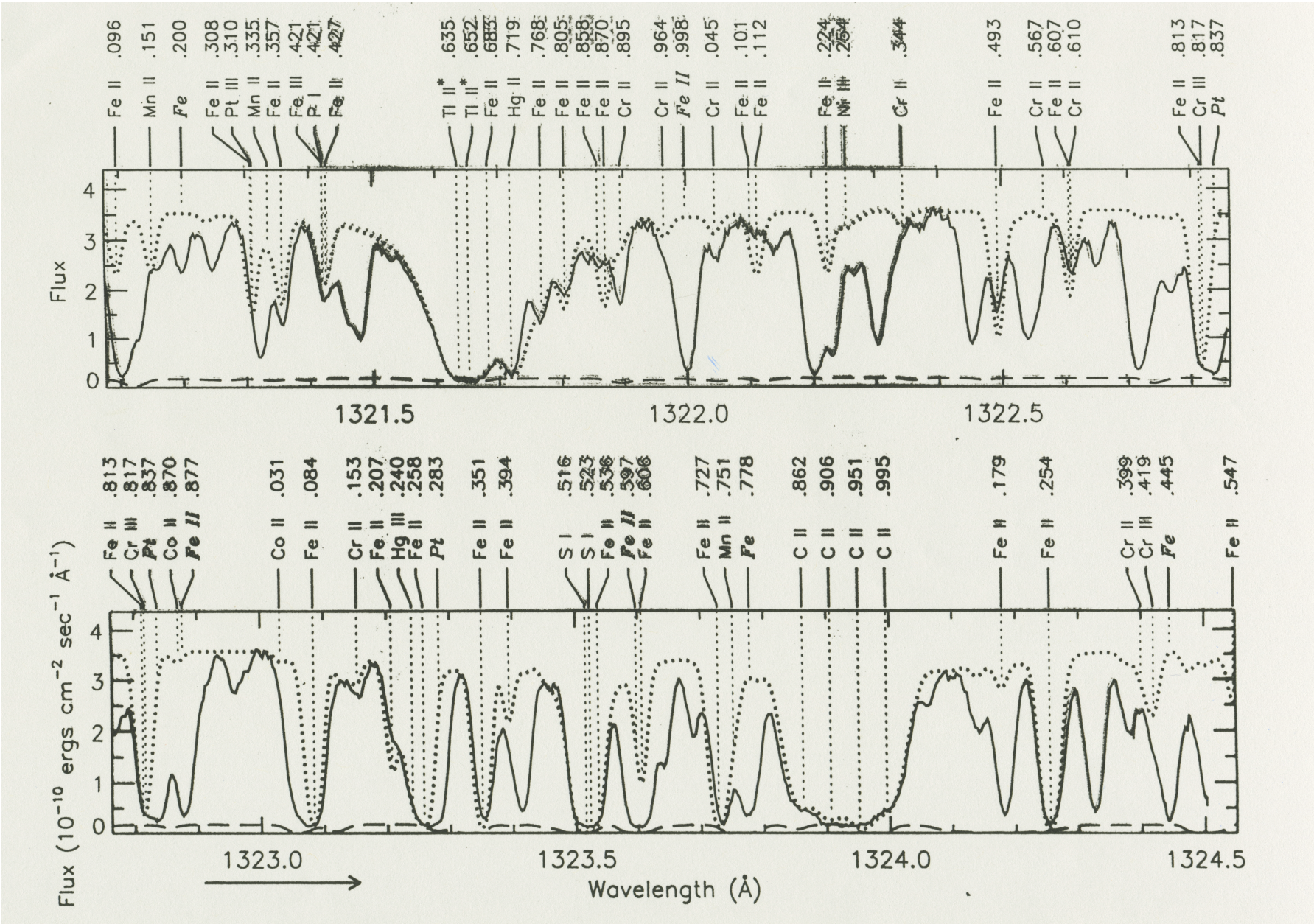
TABLE 6

STATISTICS OF LINE IDENTIFICATIONS VERSUS WAVELENGTH

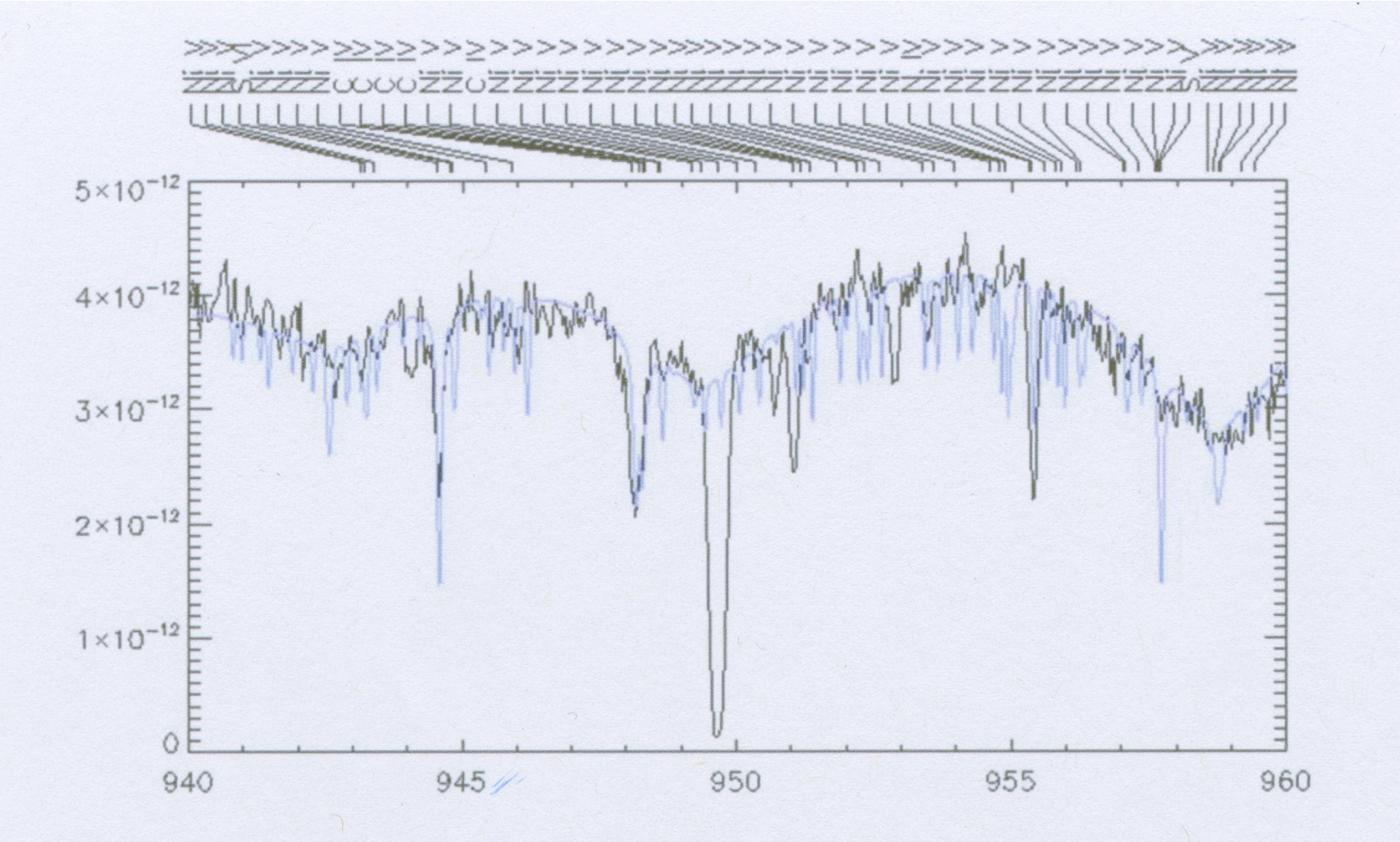
| $\lambda$ Range (Å) | $\langle\delta\lambda\rangle$[a] (Å) | ⟨Number of Lines⟩[b] | Firm ID[c] | Probable ID[d] | Total Unidentified[e] | Stronger Unidentified[f] |
|---|---|---|---|---|---|---|
| 2334–2688 ..... ⟨29, 34, 36⟩[g] | 14 | 105 | 57% | 36% | 7% | 3% |
| 1904–2160 ..... ⟨17, 18, 24⟩ | 11 | 112 | 44% | 36% | 20% | 7% |
| 1644–1873 ..... ⟨13, 14, 16⟩ | 10 | 112 | 36% | 42% | 22% | 13% |
| 1317–1543 ..... ⟨3, 9, 11⟩ | 8 | 133 | 30% | 31% | 39% | 28% |

[a] Average width of observed intervals.
[b] Average number of spectral features counted per interval.
[c] Observed feature closely matched by spectrum synthesis.
[d] Discrepancies between spectrum synthesis and observations probably reflect uncertainties of atomic data or issues with abundances as discussed in the text. Unmodeled features plausibly identified by wavelength from laboratory spectra.
[e] Substantial line opacity missing in spectrum synthesis; no plausible identification.
[f] Subset of unidentified features that are moderately strong and (in most cases) well resolved.
[g] Statistics are averages for three intervals denoted by their figure numbers in Paper II.

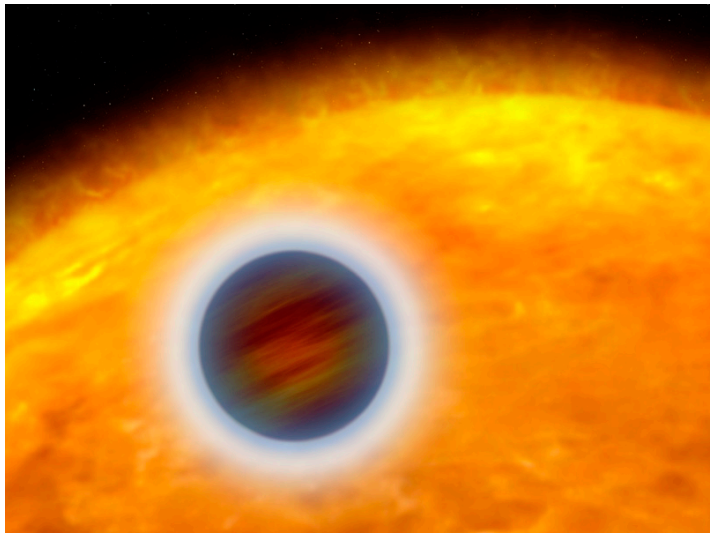
# Unidentified Lines and/or Inaccurate *f*-values in the FUV
chi Lupi, B9.5p, Teff=10,650 K (Leckrone, et al. 1999)



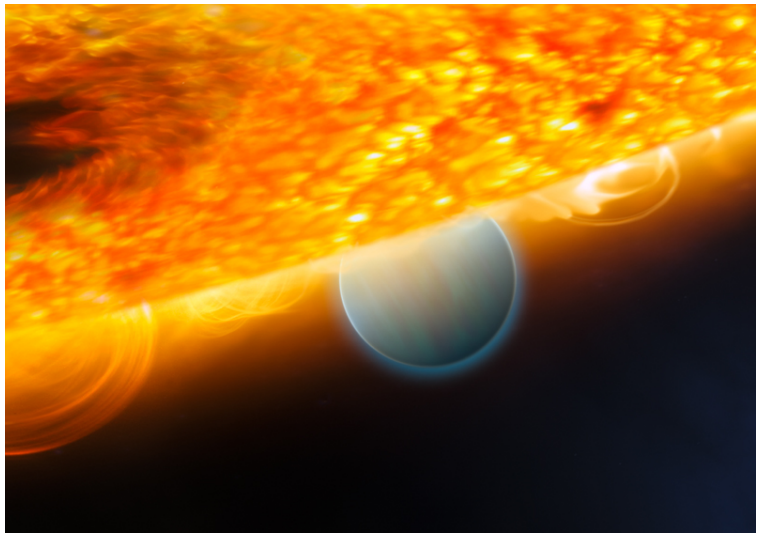
Unidentified Lines and/or Inaccurate *f*-values in the FUV
White Dwarf REJ0503-289, Teff = 70,000 K; FUSE observation
Barstow, et al. (includes “Kentucky” line database – www.pa.uky.edu/peter/atomic/)



# TRANSITING EXOPLANETS (“HOT JUPITERS”)



PRIMARY ECLIPSE –
Spectroscopy/Photometry probe terminator region in absorption

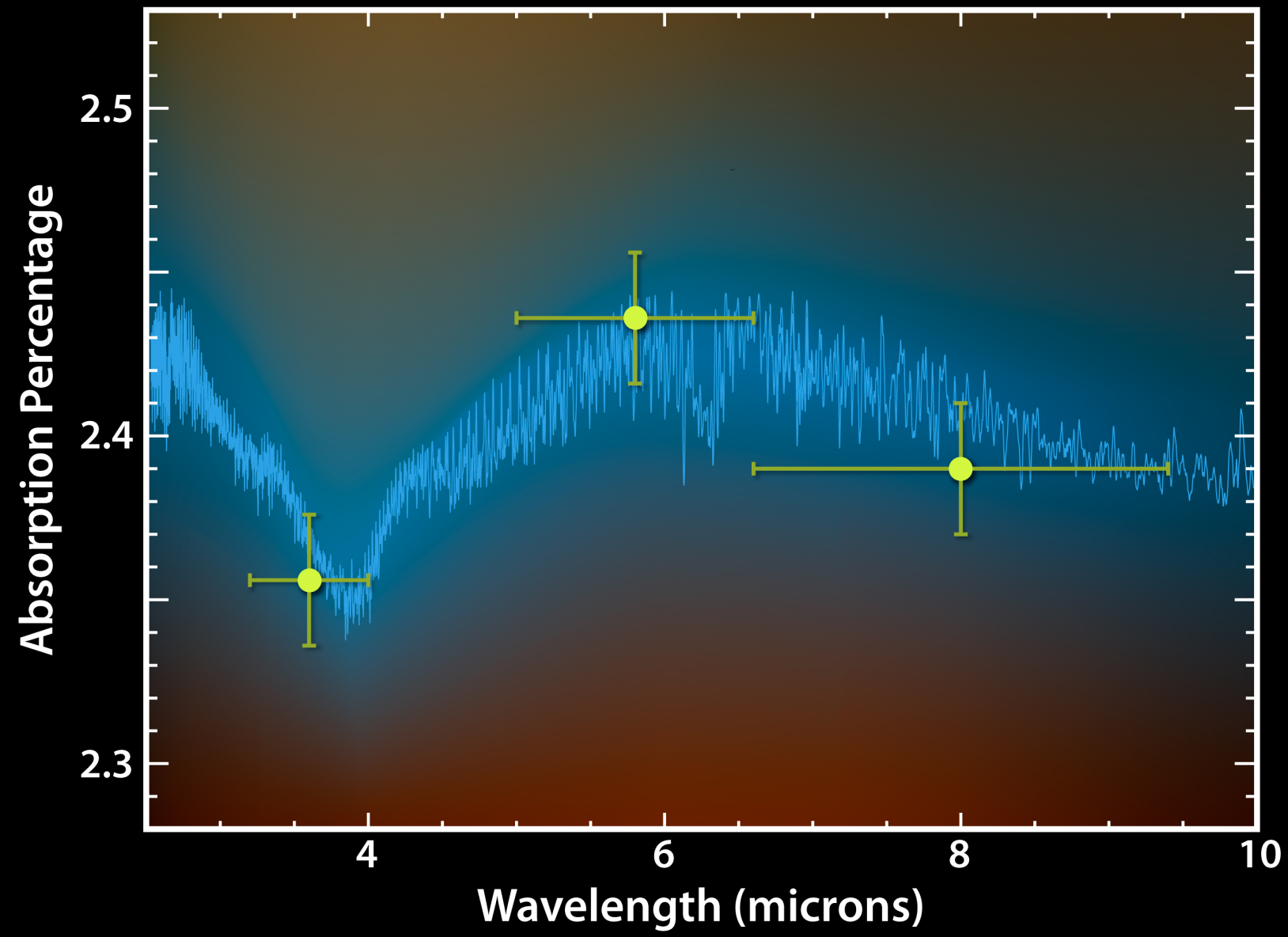


SECONDARY ECLIPSE –
Spectroscopy/Photometry probe dayside in emission/reflection

OBSERVATIONS WITH HUBBLE (NICMOS) AND SPITZER

- Enable identification of atmospheric molecular and atomic constituents
- Provide information about thermal profiles, dynamics of atmospheres
- At least four “hot Jupiters” observed to date
- Observed constituents include $CH_4$, $H_2O$, $CO_2$, CO

e.g. G. Tinelli, M. Swain, et al.



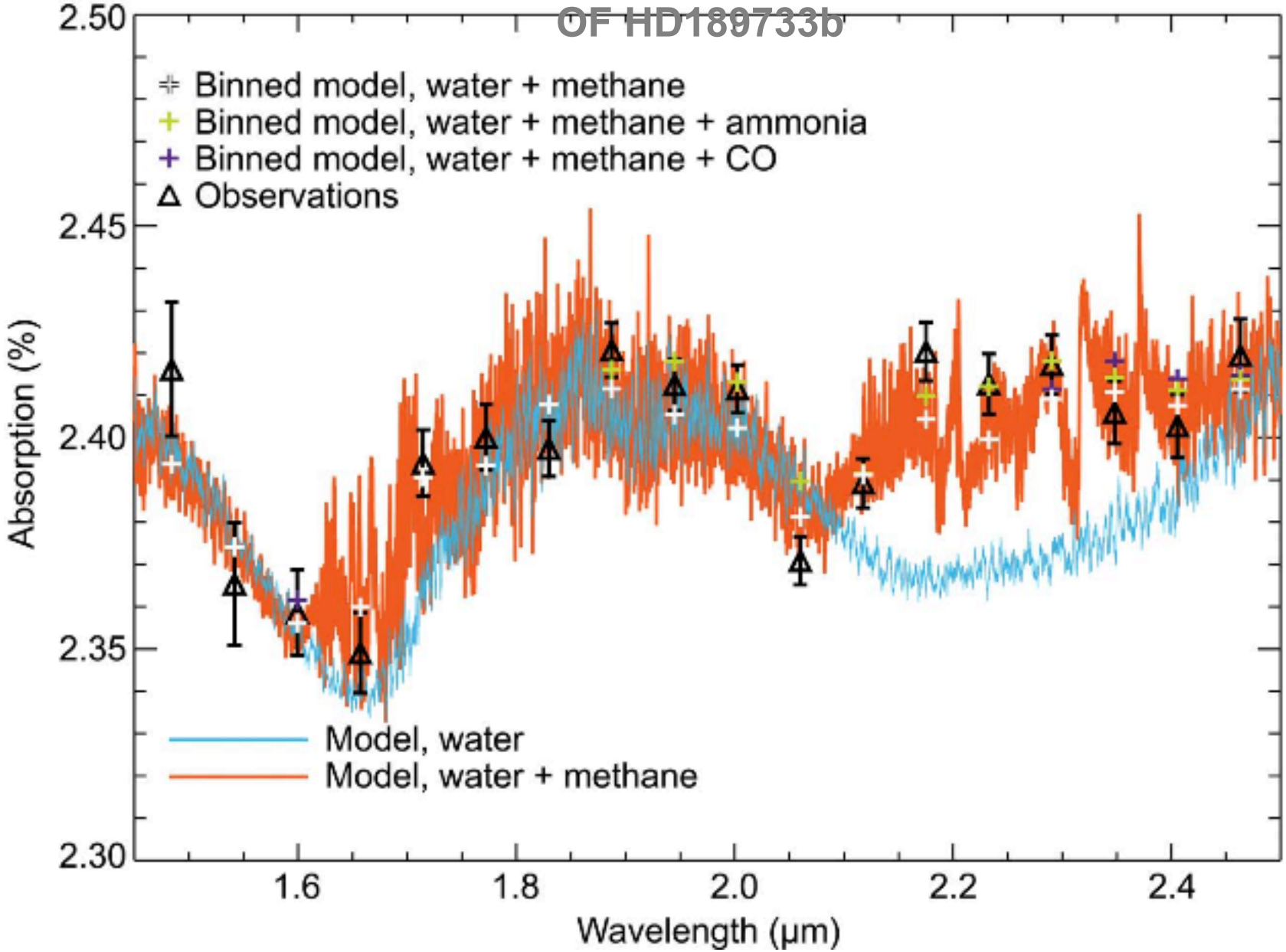

Water Signatures in Exoplanet HD189733b

Spitzer Space Telescope • IRAC

NASA / JPL-Caltech / G. Tinetti (Institute d'Astrophysique de Paris)

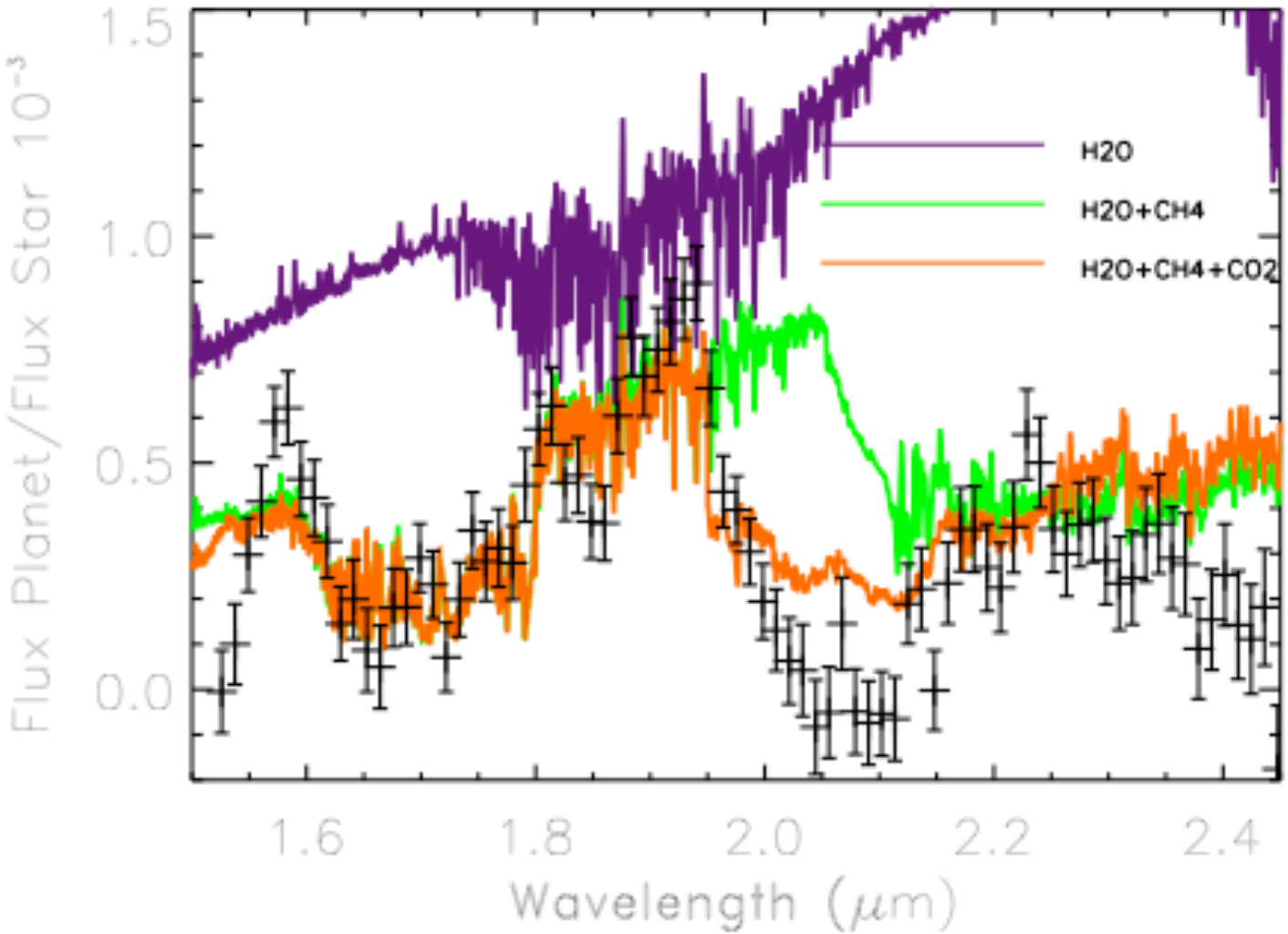
ssc2007-12a

# HUBBLE/NICMOS PRIMARY ECLIPSE SPECTROSCOPY OF HD189733b

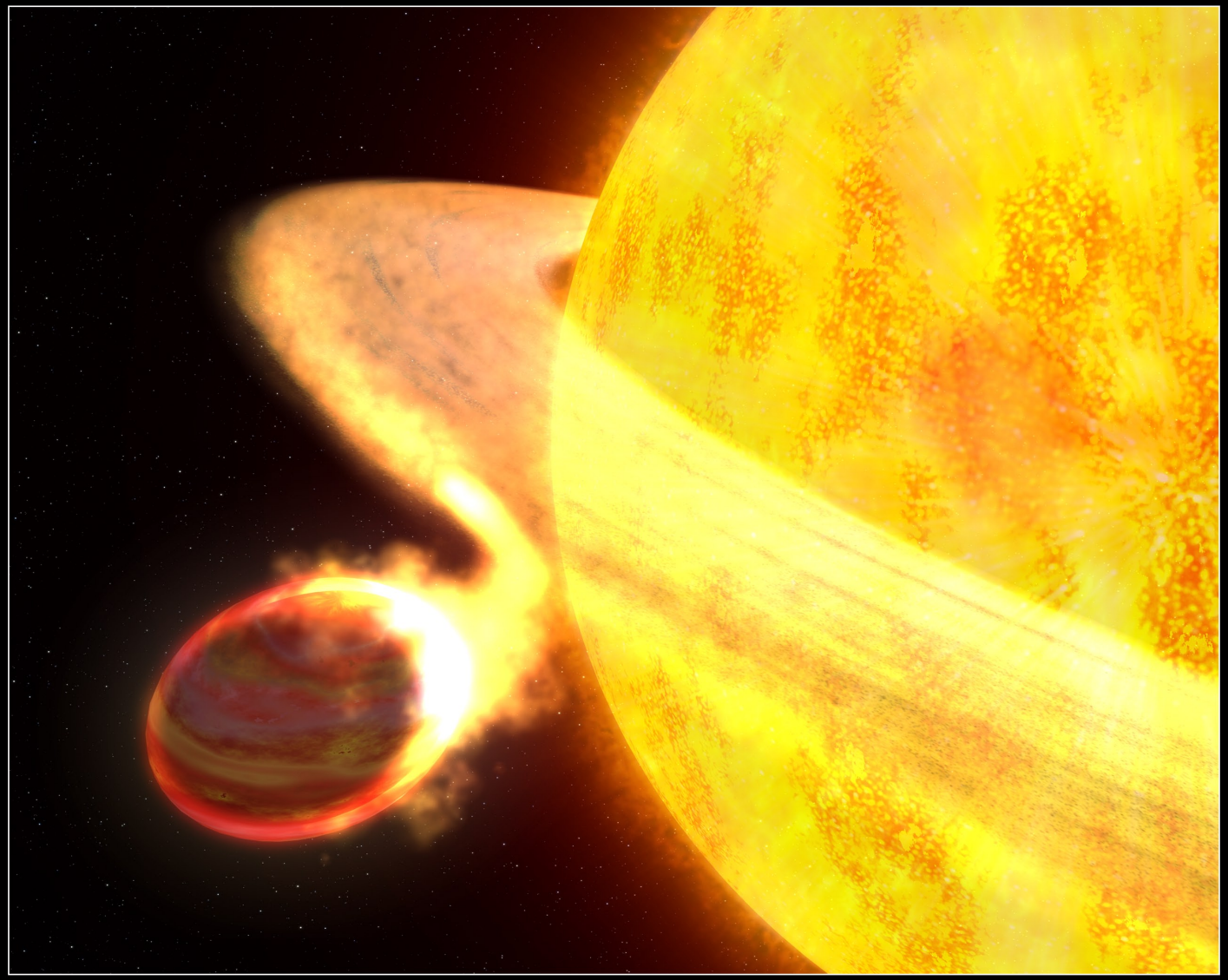



M. Swain, G. Vasisht, G. Tinetti 2008, *Nature*, **452**, pp. 329-331

## HUBBLE/NICMOS SECONDARY ECLIPSE SPECTROSCOPY OF HD209458b

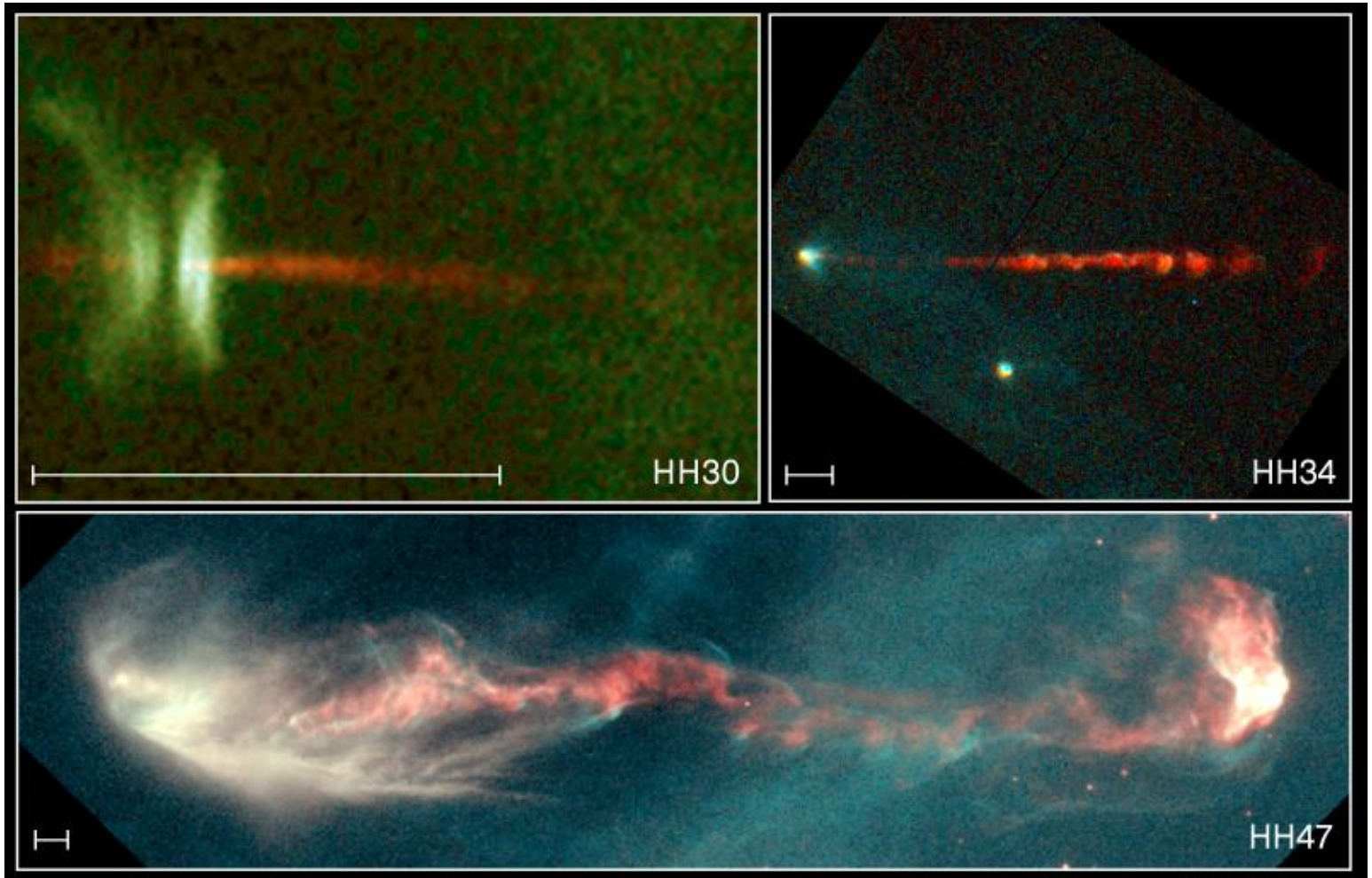



M.R. Swain, *et al.* 2009, ApJ, **704**, pp 1616-1621



**Artist's View of Extrasolar Planet WASP-12b**

NASA, ESA, and G. Bacon (STScI) ▪ STScI-PRC10-15




**Jets from Young Stars**

HST • WFPC2

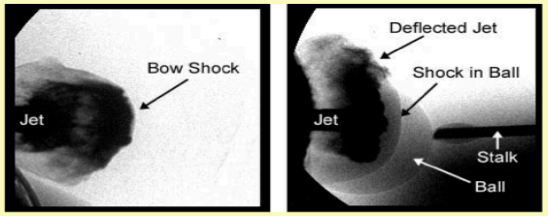
PRC95-24a · ST ScI OPO · June 6, 1995

C. Burrows (ST ScI), J. Hester (AZ State U.), J. Morse (ST ScI), NASA

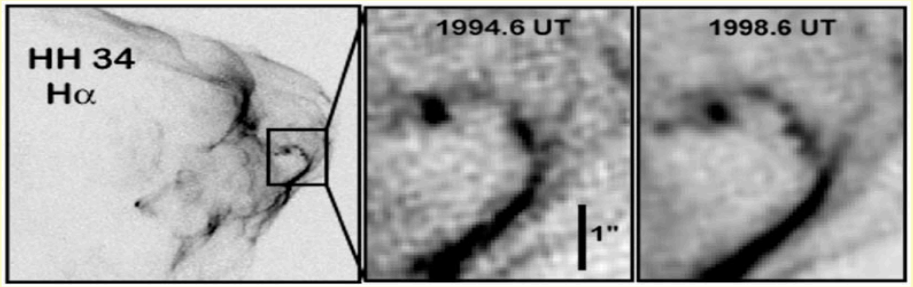
# Modeling and simulating jets

(Hartigan et al., Rice Univ.,
from Lab Astro presentation of R. Paul Drake, Univ. Michigan)

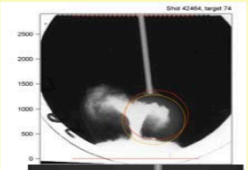
**Project led by Patrick Hartigan to study bow shocks and jets using experiments, simulations, and observations**



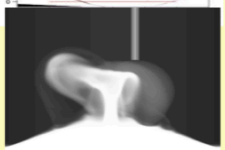

**Laser experiment of deflected jet and bow shock**




**Hubble Space Telescope project to obtain 3rd epoch to follow instabilities, clumps, and shear**

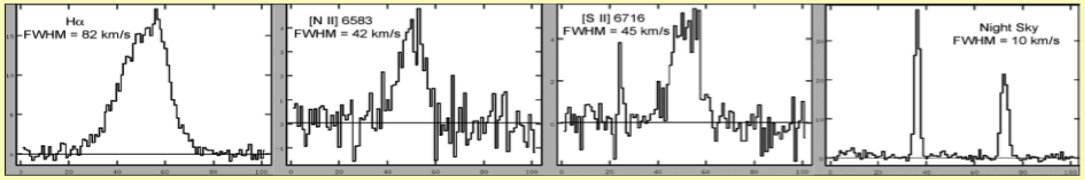


**Data**



**RAGE Code**

**Numerical Simulations**




**Kitt Peak 4-m spectral mapping to quantify supersonic turbulence in wake of a deflected jet**

# Summary

- Following last year's successful servicing, Hubble is more scientifically powerful and versatile than ever!

- Spectroscopy is particularly powerful, with STIS restored and the new Cosmic Origins Spectrograph
- Spectroscopy and related laboratory astrophysics are supporting studies of diverse sources including stellar atmospheres, supernova remnants, the IGM and Cosmic Web, astrophysical jets, and exoplanets
- Of particular need for laboratory astrophysics studies are the higher level atomic/ionic transition lines (identifications and f-values) for study of, e.g., stellar/ white dwarf atmospheres. Also needed are better models for exoplanet atmosphere transit spectra, such as in the infrared.
- With no more planned astronaut servicing, and no new space flagship UV-optical mission in development (though technology development is recommended), it is important to maximize the scientific return of HST (and its archive) in its remaining years, including relevant laboratory astrophysics