

Title: A Newly Refurbished Hubble Space Telescope: Discoveries Unbound

Date: Feb 10, 2010 02:00 PM

URL: <http://pirsa.org/10020025>

Abstract: Last May, NASA astronauts performed a challenging and flawless Space Shuttle servicing mission to the orbiting Hubble Space Telescope. With science instruments repaired on board and incredible new ones installed, the observatory is more powerful now than ever before. I will show the dramatic highlights of the mission, and present some of the first results from the refurbished telescope. The sensitivity and multi-wavelength capabilities are revealing the highest redshift galaxies ever seen as well as details of the cosmic web of intergalactic medium, large scale structure formation, and stellar evolution. Studies of dark matter, dark energy, and exoplanet atmospheres add to the profound contributions to astrophysics that Hubble is making, at the new apex of its capabilities.

A Refurbished
HUBBLE SPACE TELESCOPE
Discoveries Unbound!



Jennifer Wiseman

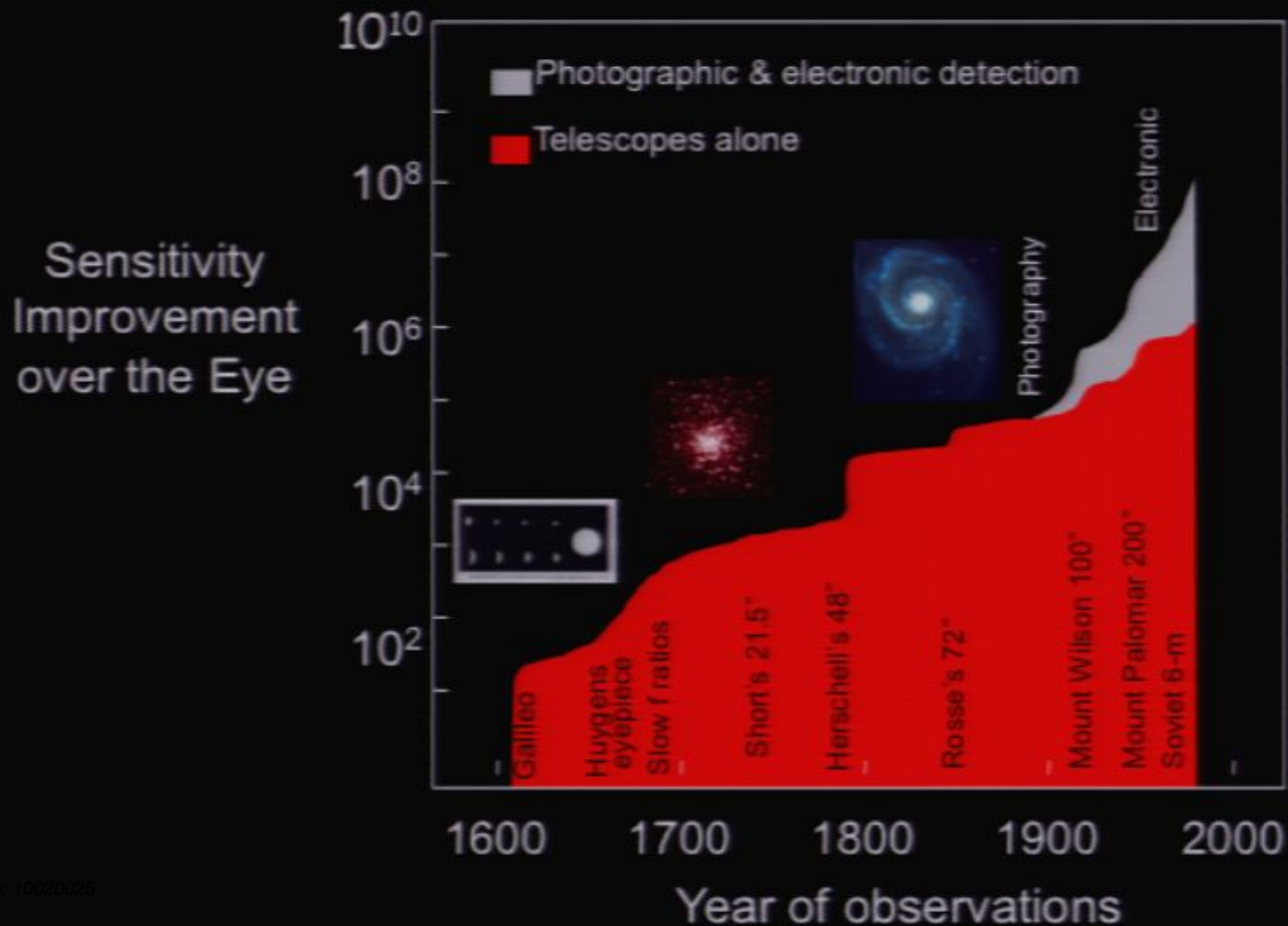
A Refurbished
HUBBLE SPACE TELESCOPE
Discoveries Unbound!



Jennifer Wiseman

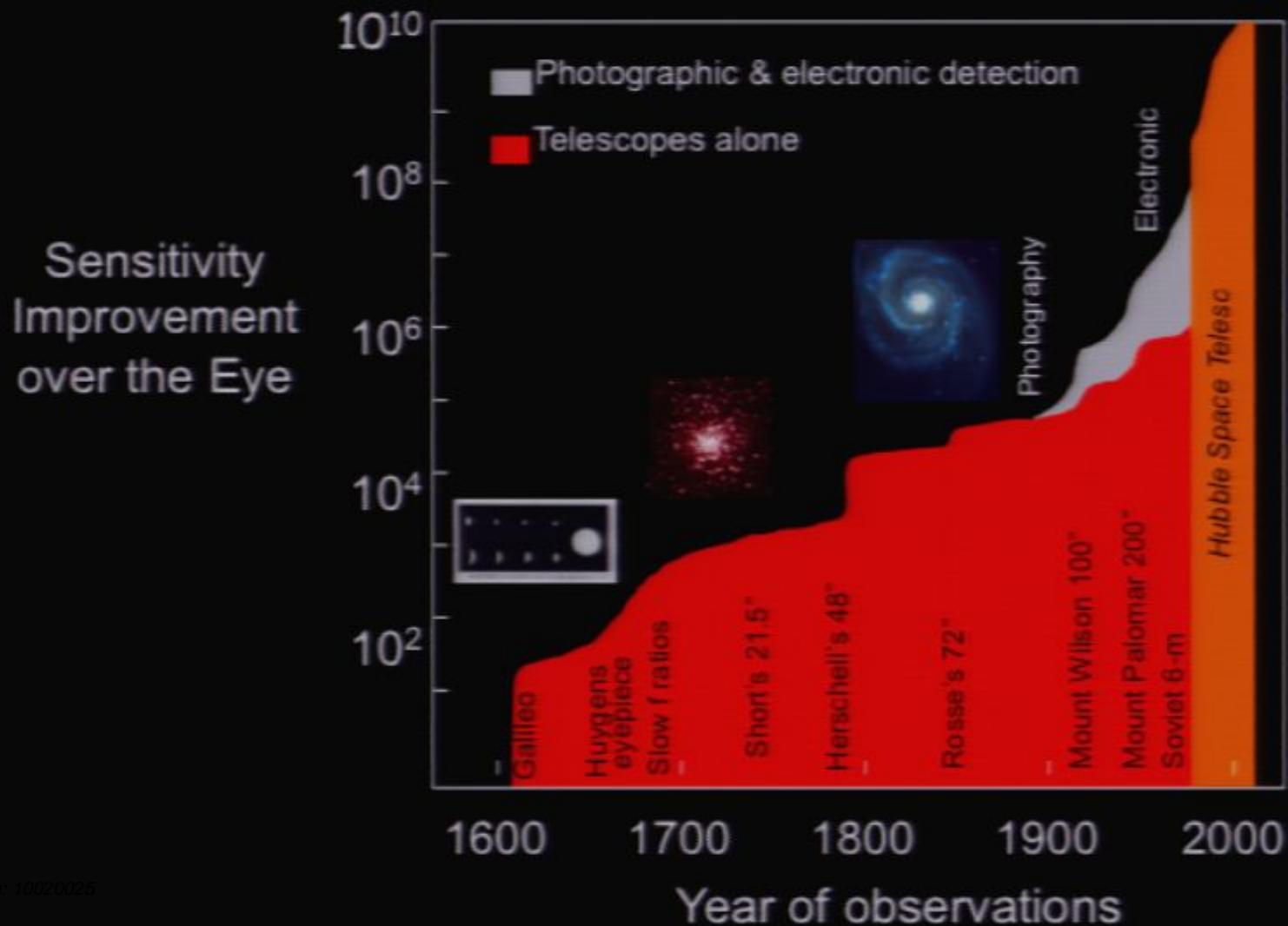
Search & Discovery

After Fig. 3.10 in *Cosmic Discovery*, M. Harwit



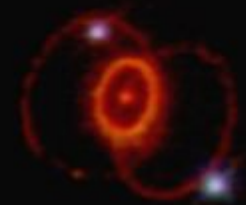
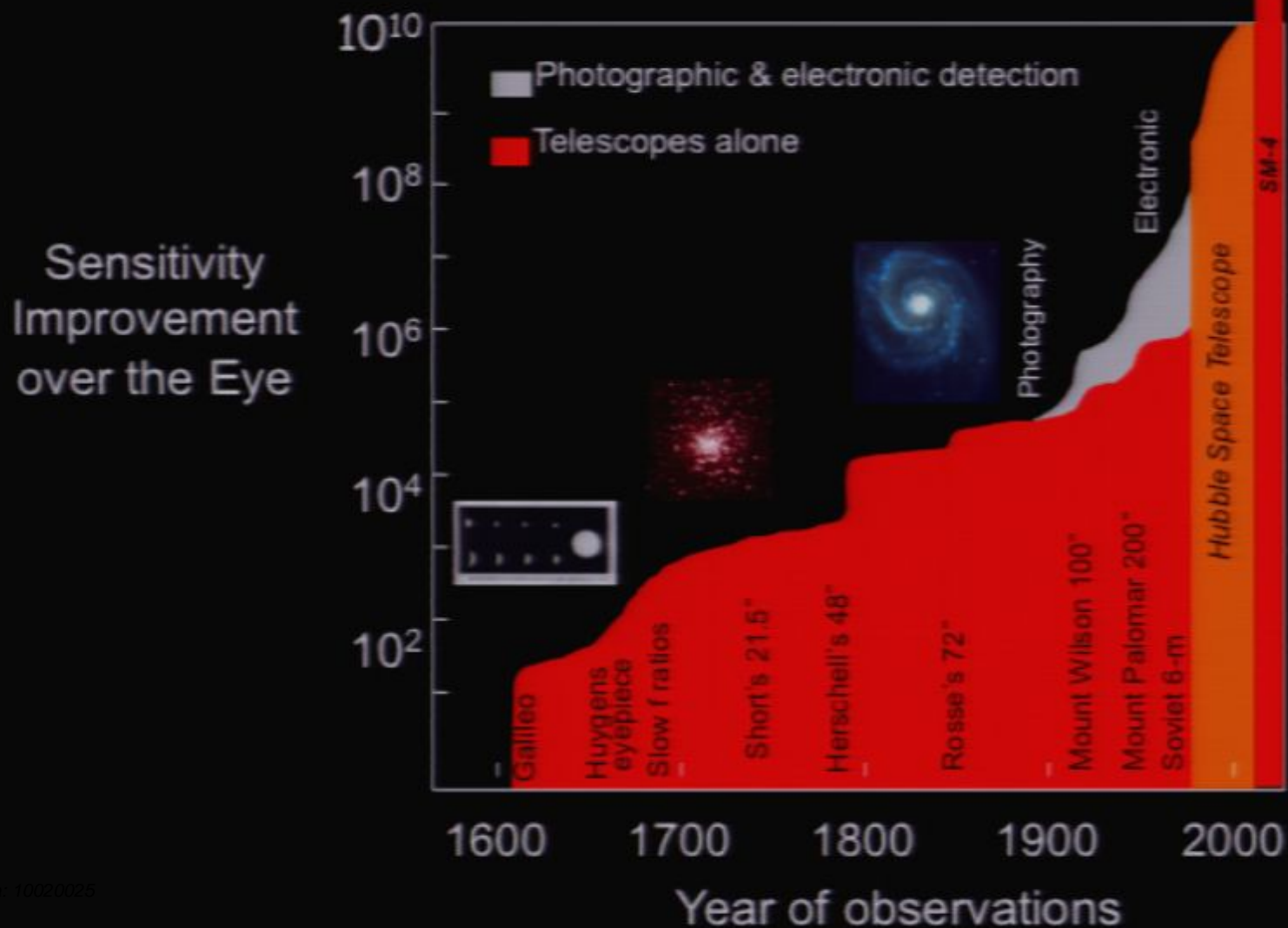
Search & Discovery

After Fig. 3.10 in *Cosmic Discovery*, M. Harwit



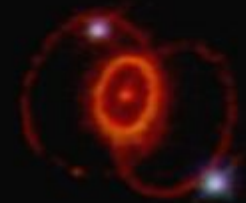
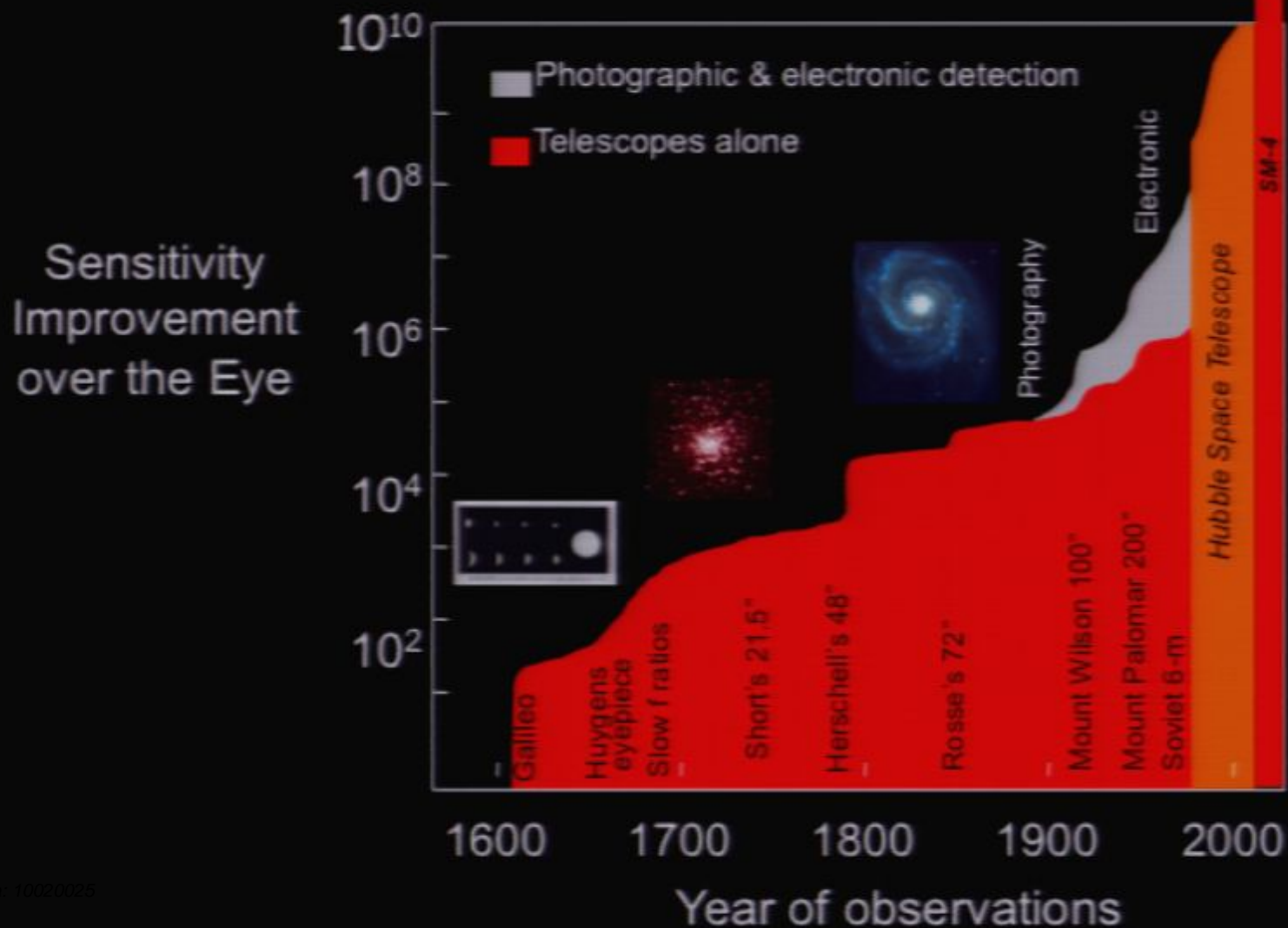
Search & Discovery

After Fig. 3.10 in *Cosmic Discovery*, M. Harwit



Search & Discovery

After Fig. 3.10 in *Cosmic Discovery*, M. Harwit



Sagittarius Star Cloud



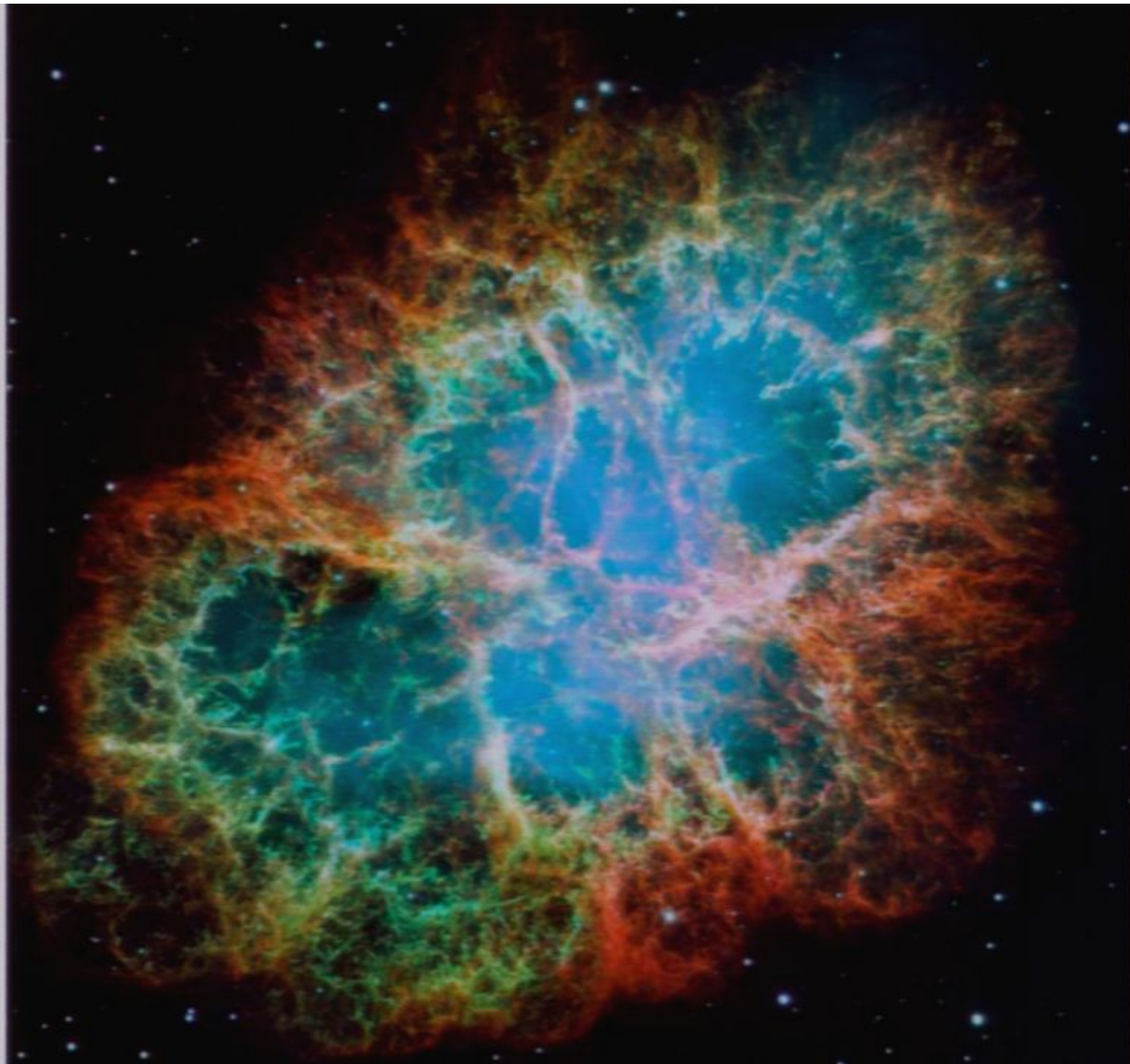
Orion Nebula • M42

HST • ACS/WFC



NASA, ESA, M. Robberto (STScI), and the HST Orion Nebula Team

STScI-PRC06-01a



Spiral Galaxy NGC 1309



Hubble
Heritage

NASA, ESA, The Hubble Heritage Team (STScI/AURA), and A. Riess (STScI)
Hubble Space Telescope ACS - STScI-PRC06-07

Hubble Ultra Deep Field

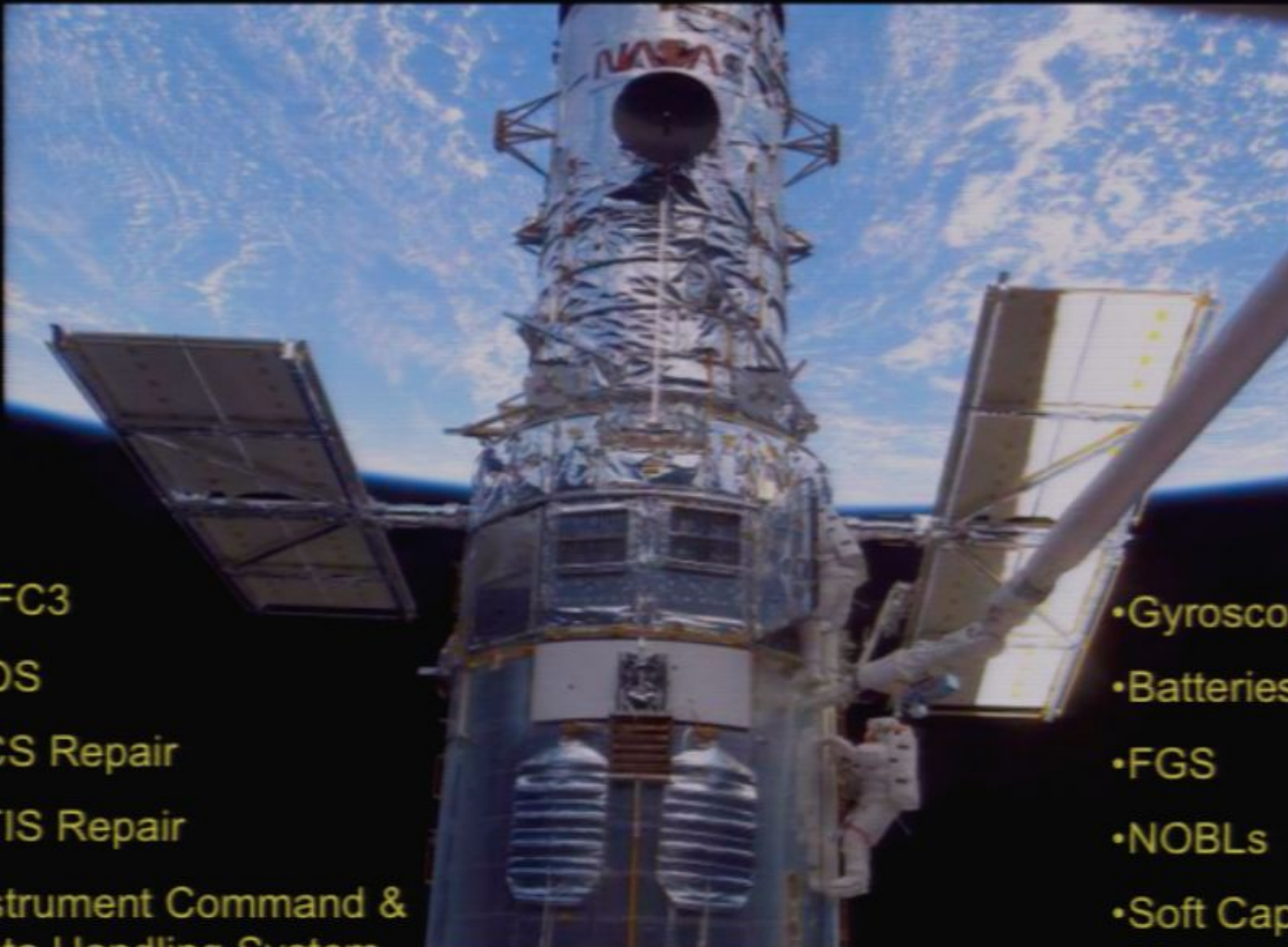
HST • ACS



NASA, ESA, S. Beckwith (STScI) and The HUDF Team

STScI-PRC04-07a

SM4 Mission Overview



- WFC3
- COS
- ACS Repair
- STIS Repair
- Instrument Command & Data Handling System

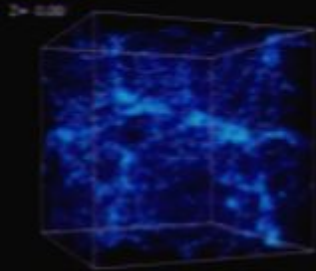
- Gyroscopes
- Batteries
- FGS
- NOBLs
- Soft Capture Mechanism

MISSION GOAL: *When the astronauts leave Hubble for the last time, it will be at the apex of its capabilities - better than it has ever been before.*

**WFC3 + ACS + NICMOS =
Most powerful imaging ever**

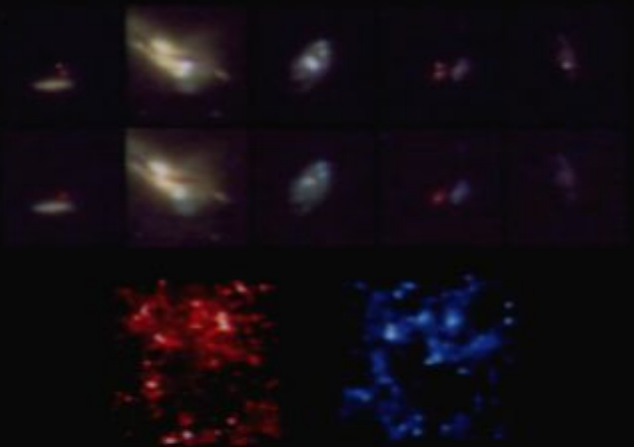
**COS + STIS = Full set of
tools for astrophysics**

The architecture of the universe



The mysteries of dark matter and dark energy

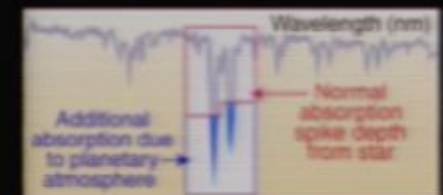
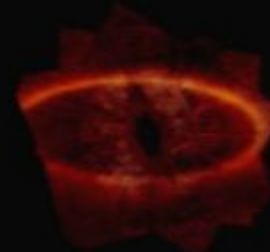
The life story of galaxies



The birth and death of stars

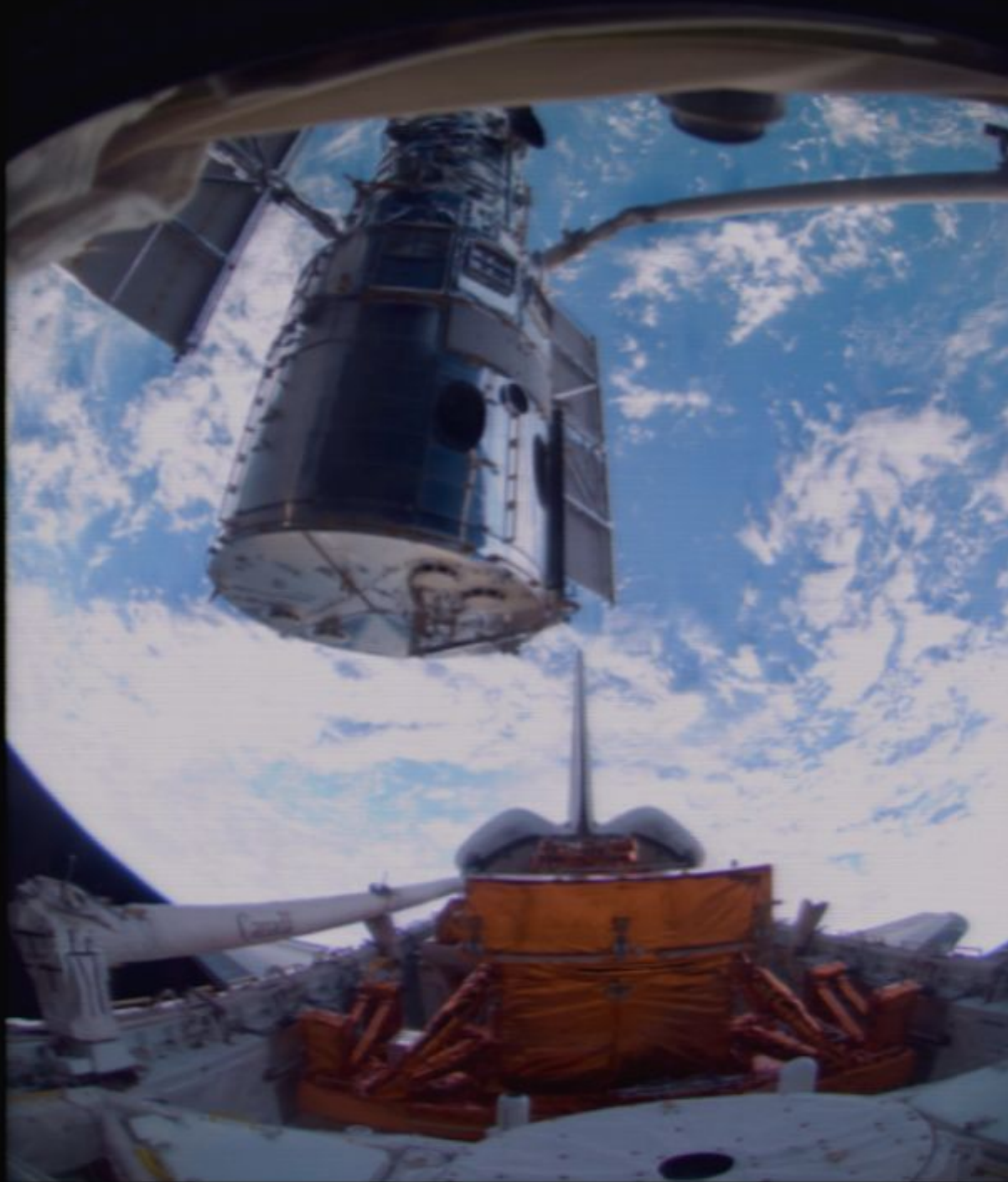


Recipes for building planets

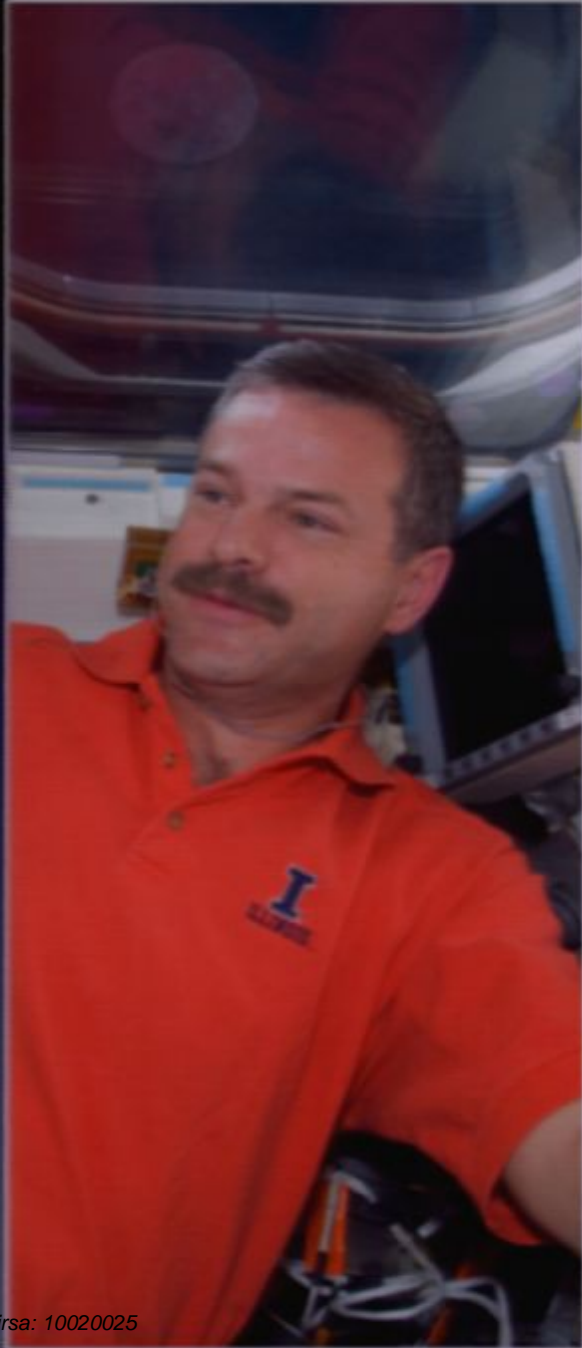


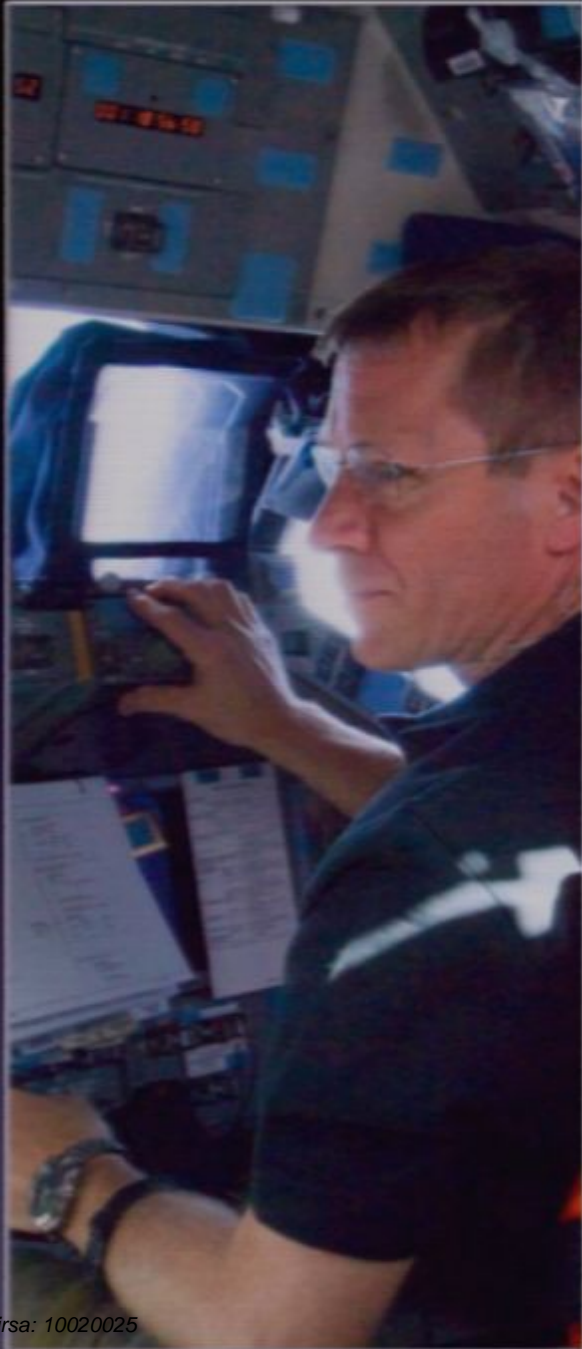






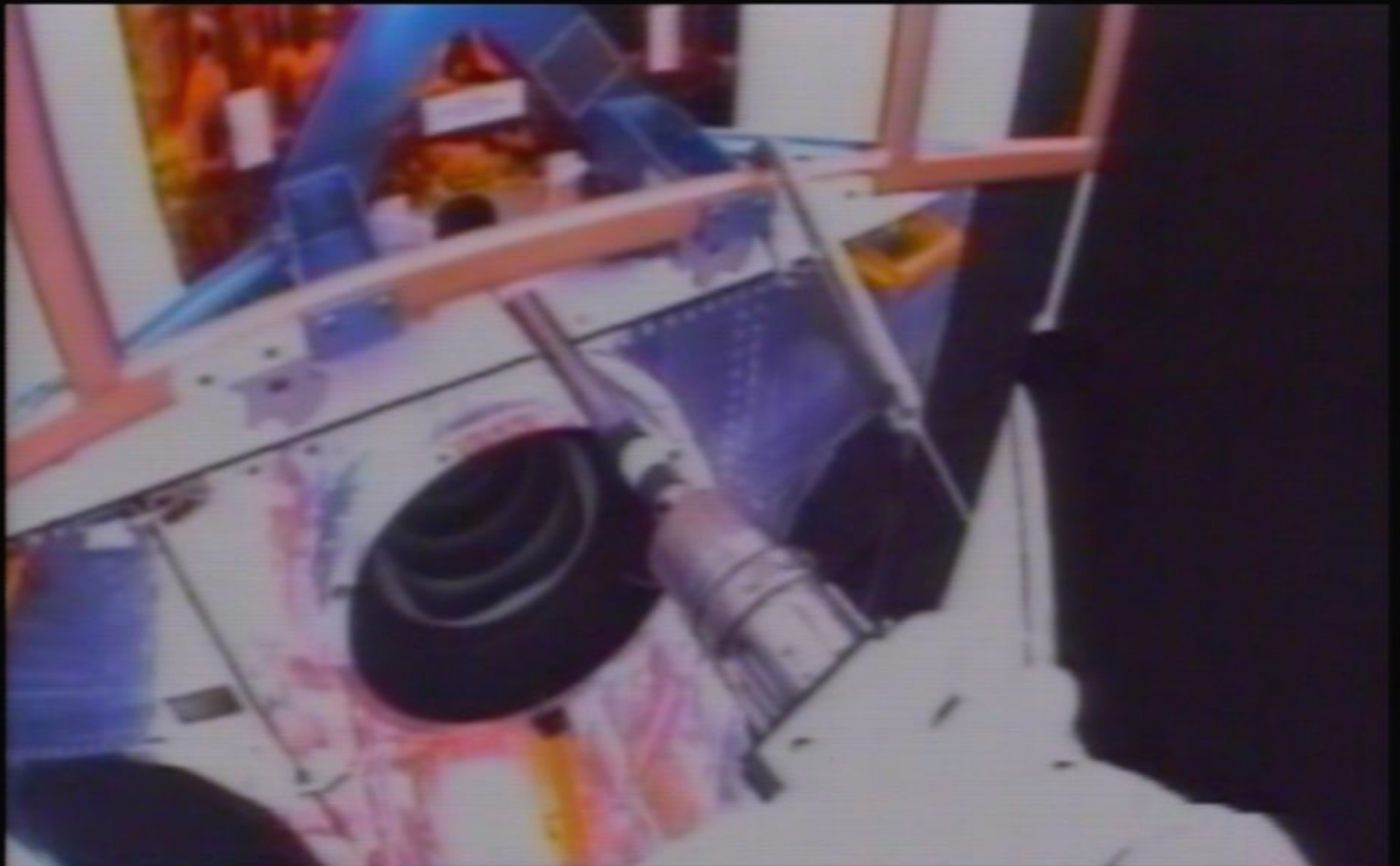




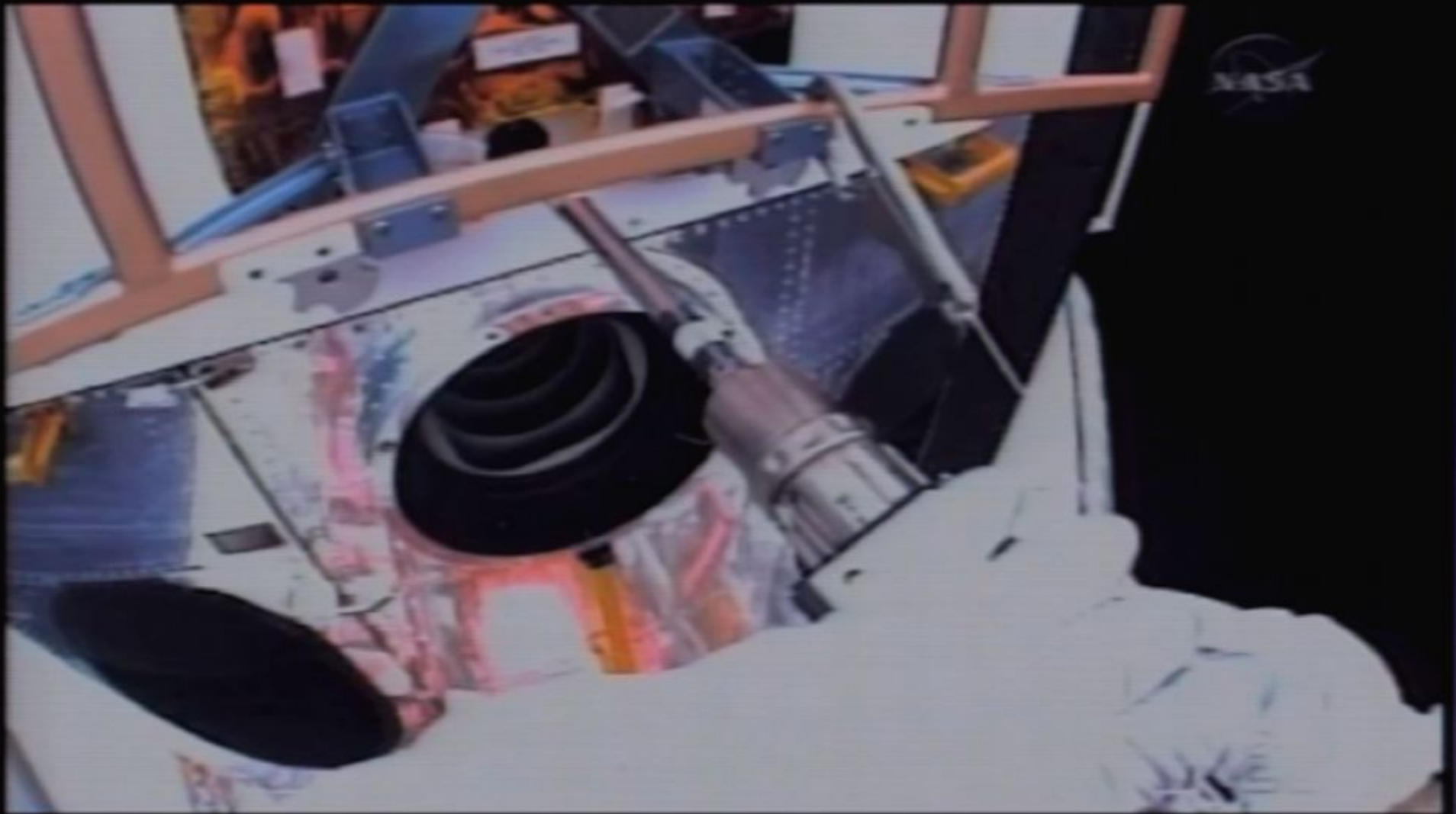




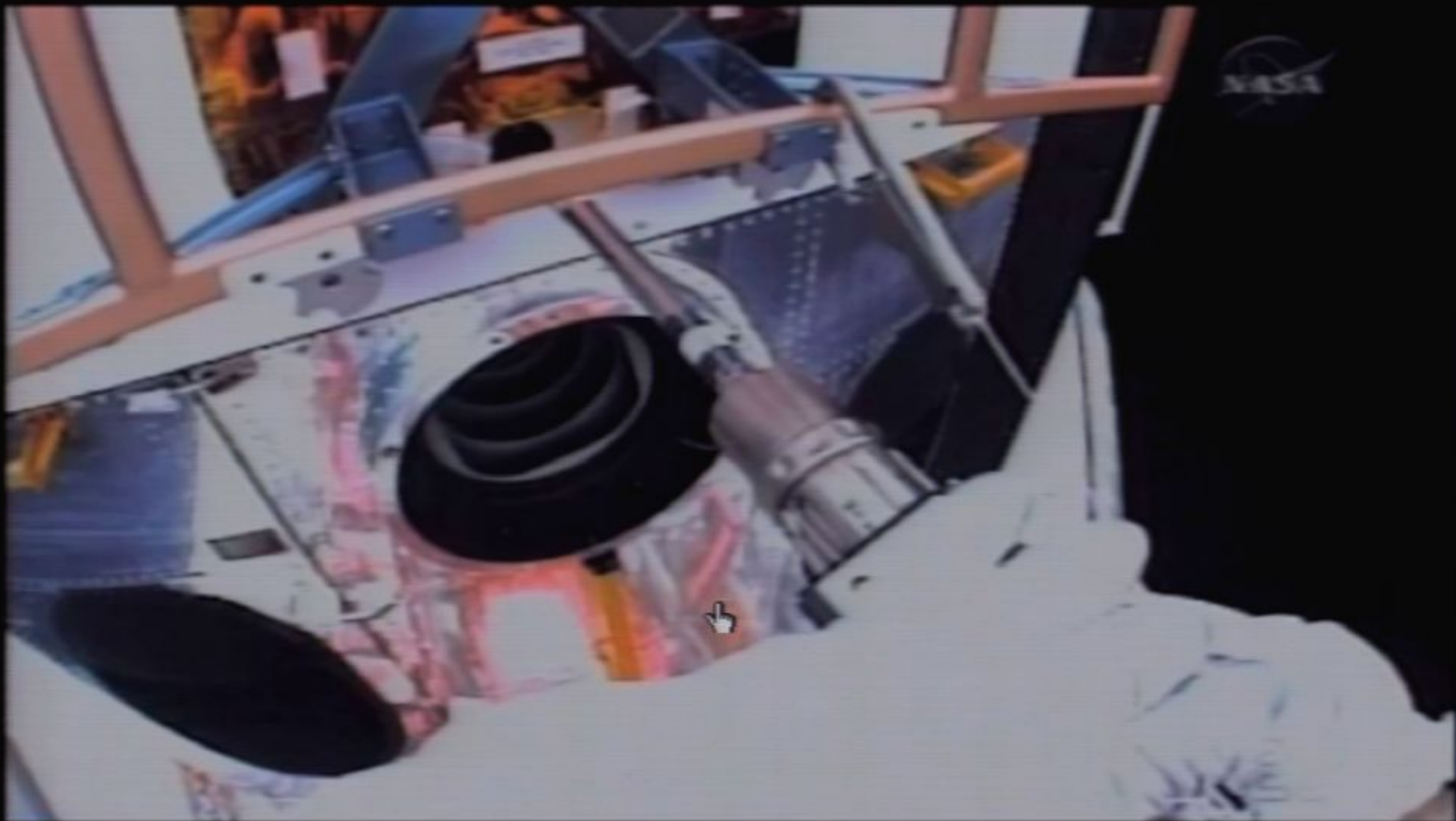
Wide Field Camera 3 Installation

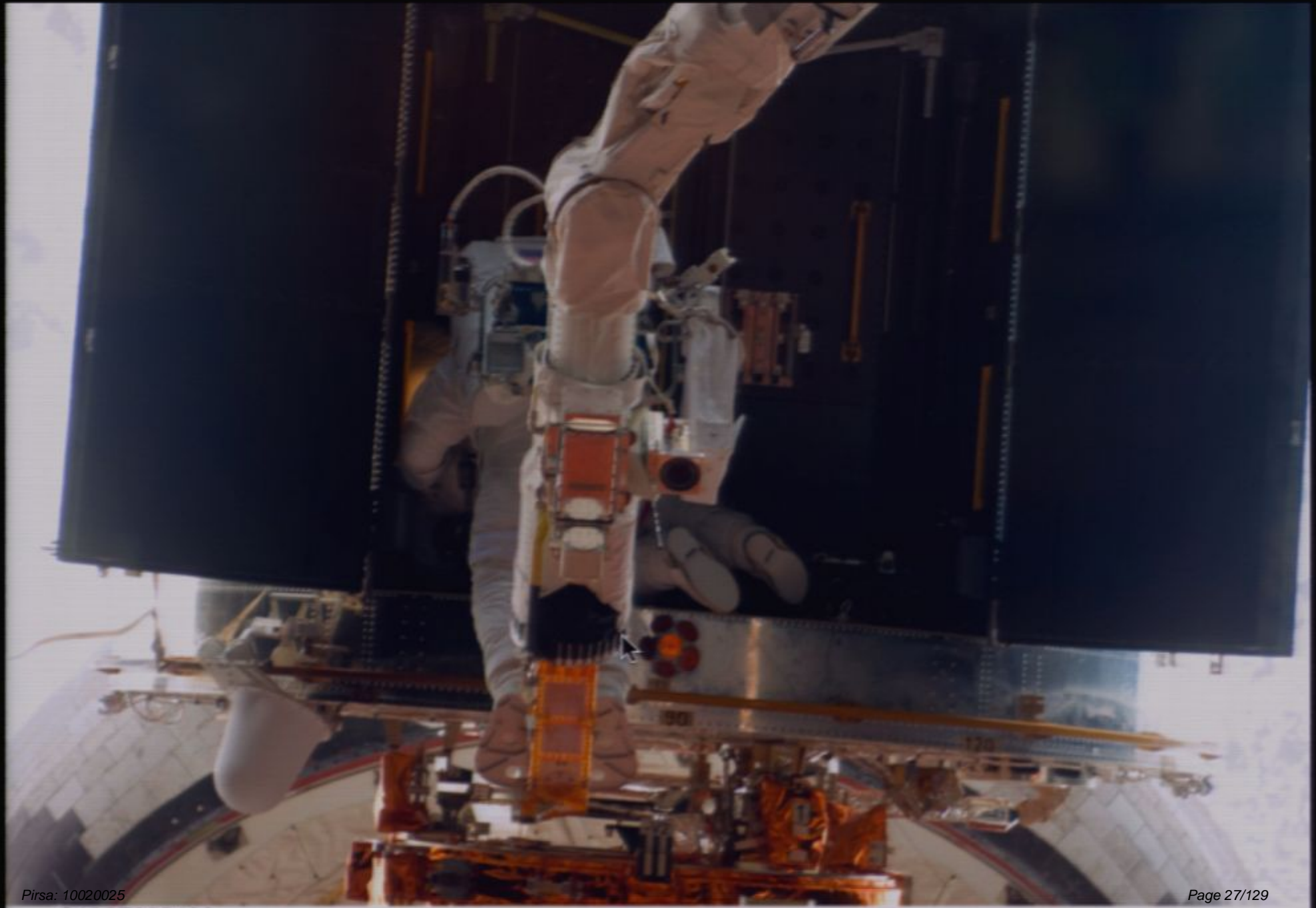


#31 ALC ??? PAN +000.0 FOC 000.5
OTH GAM ??? TLT +000.0 ZOOM 2.462 TM
GMT 000:00:00:00 AUTO 0db







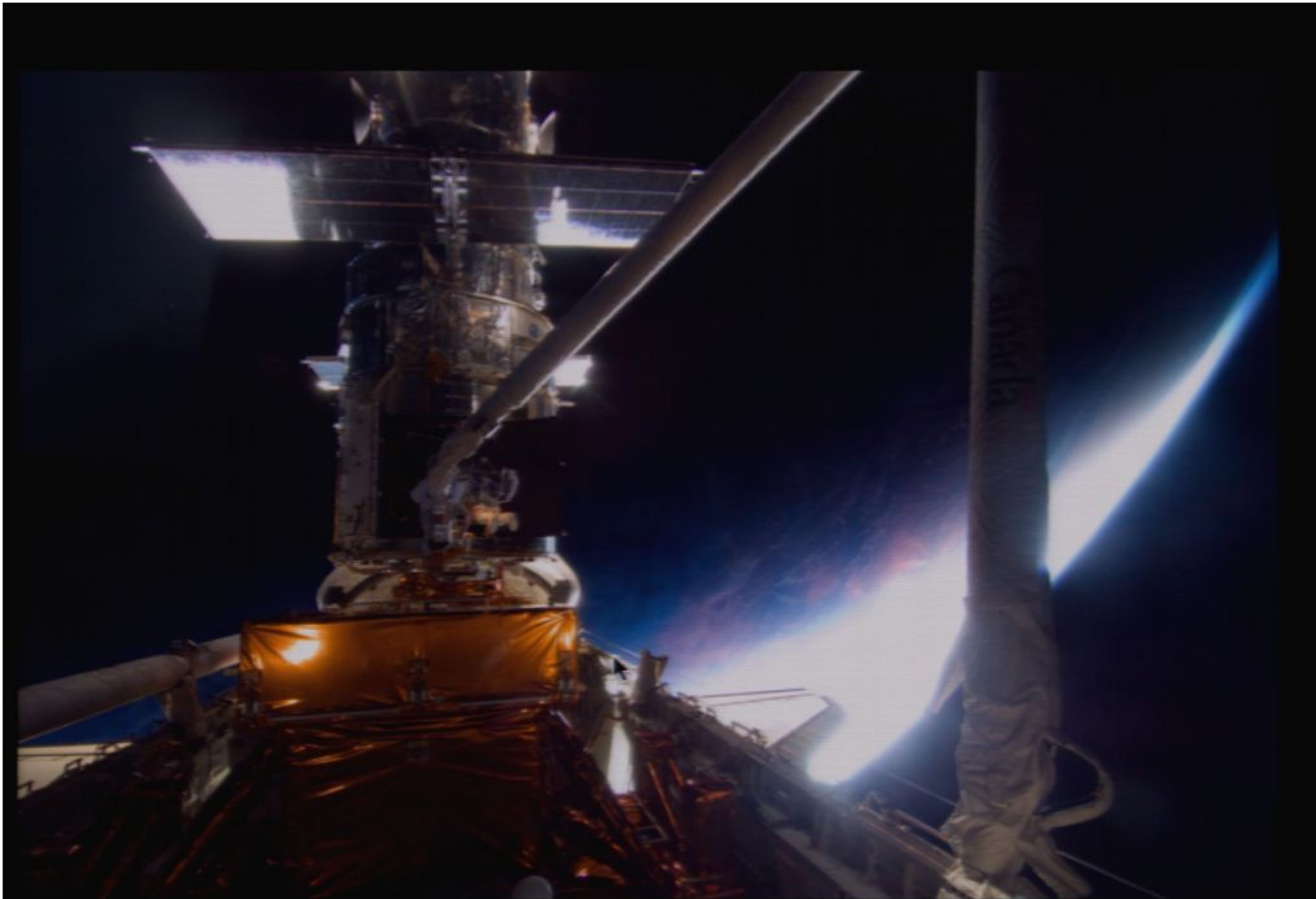




RMS ALC AV PAN +001.6 FOC 078.0
CTV GAM BLK TLT -024.8 ZOOM 24.11 T/M
GMT 136:15:28:21 AUTO ALC SHOF SUN 0db

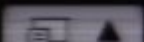
Advanced Camera for Surveys Repair





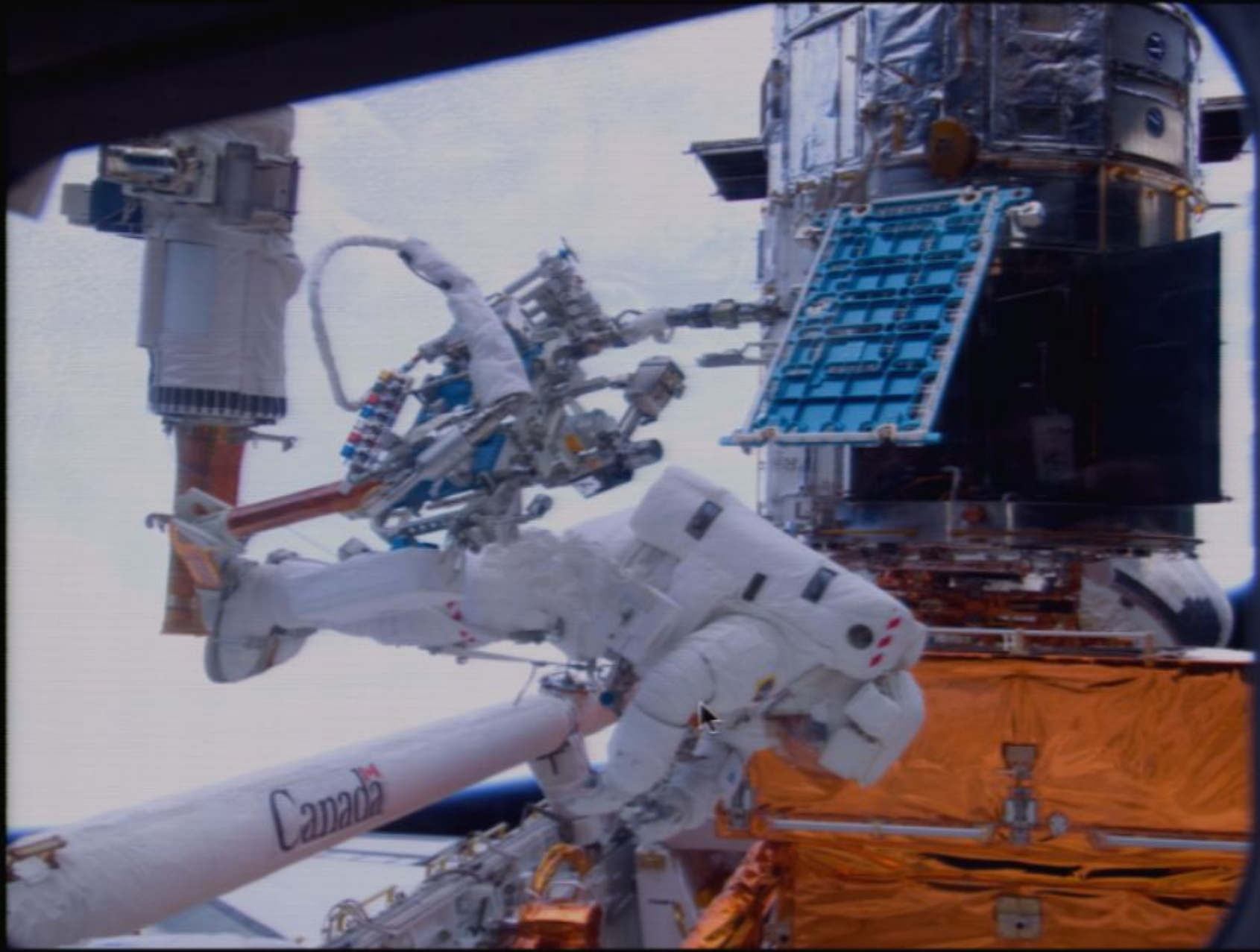


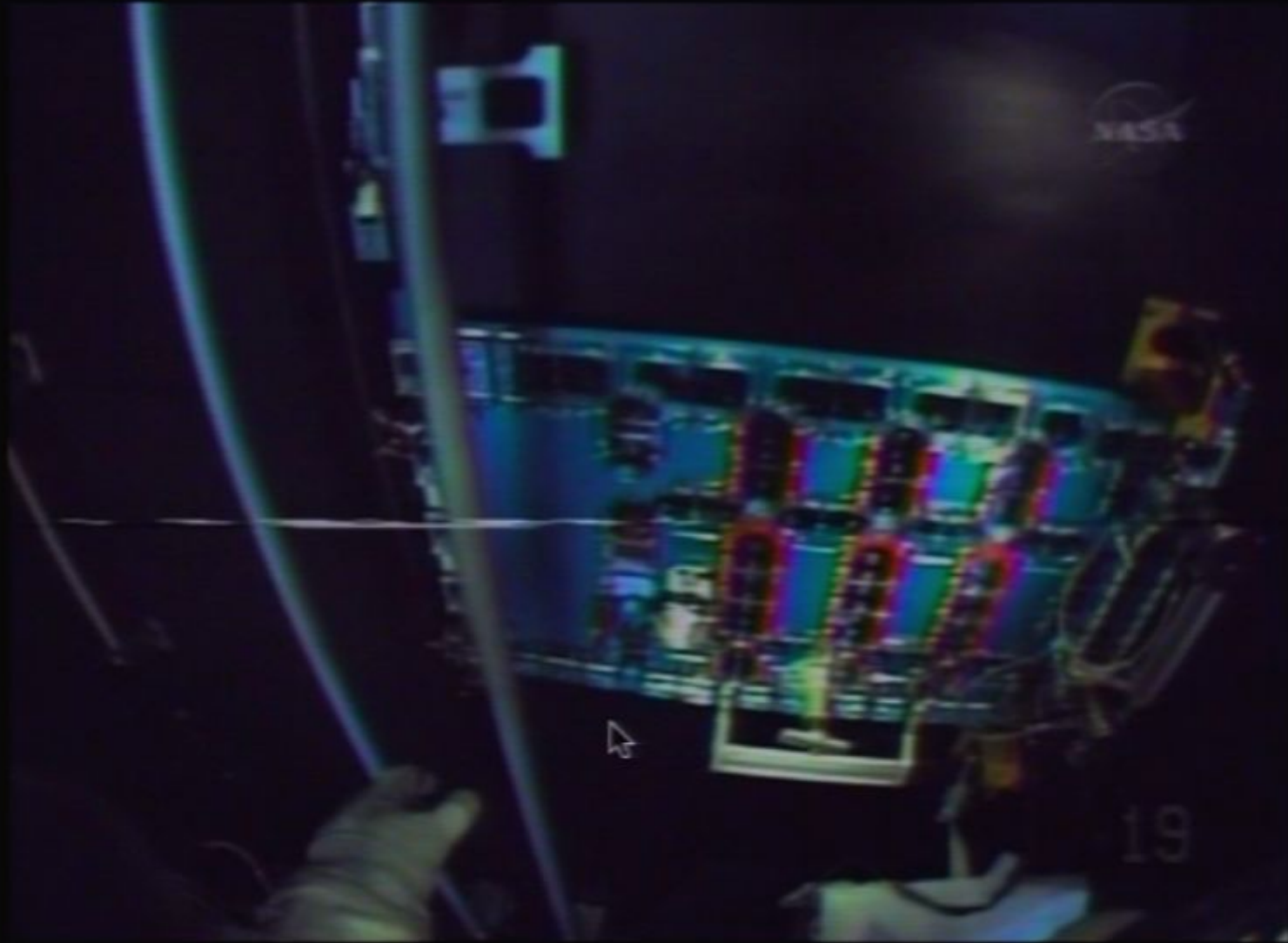




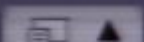
Space Telescope Imaging Spectrograph Repair

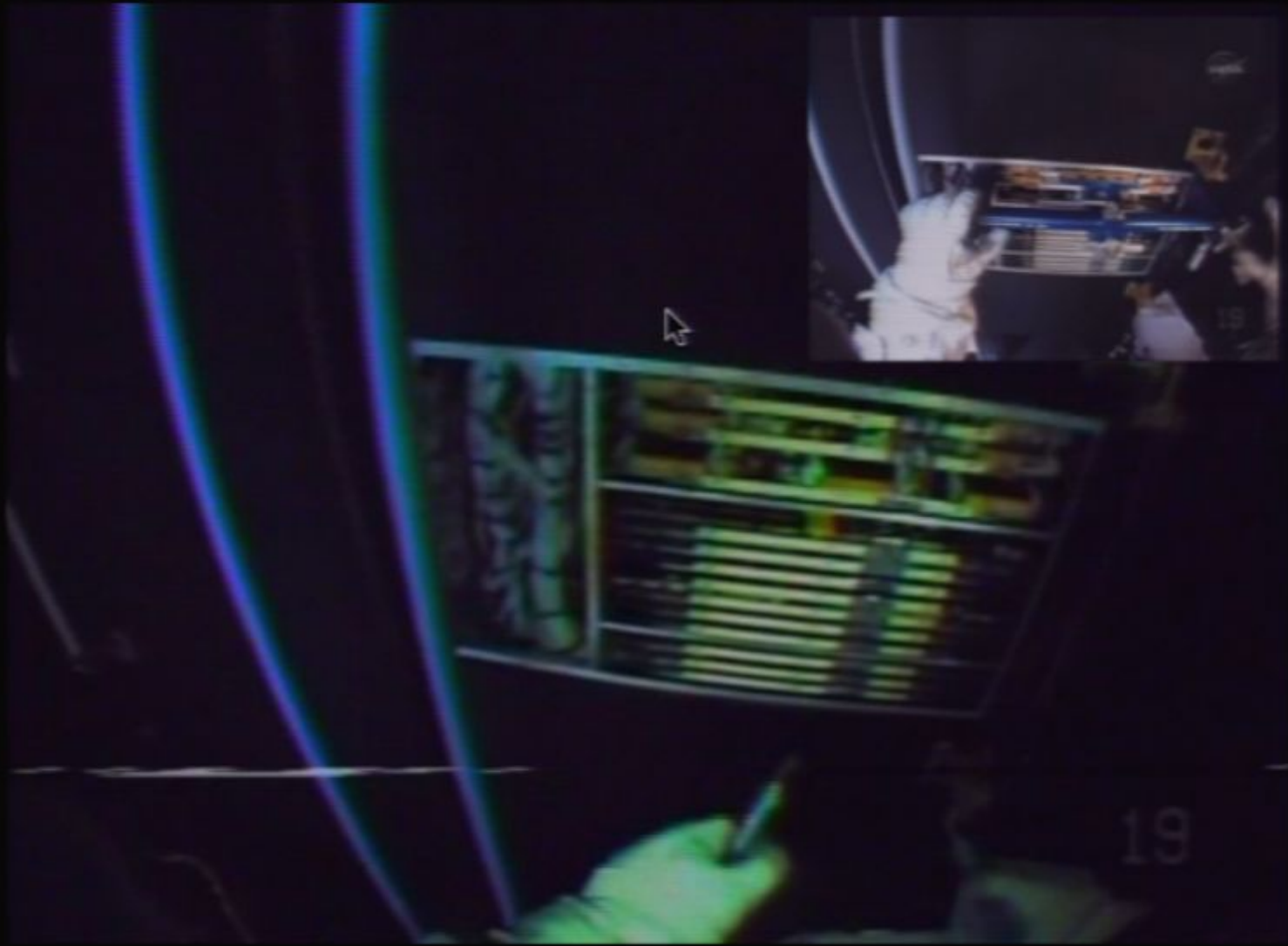


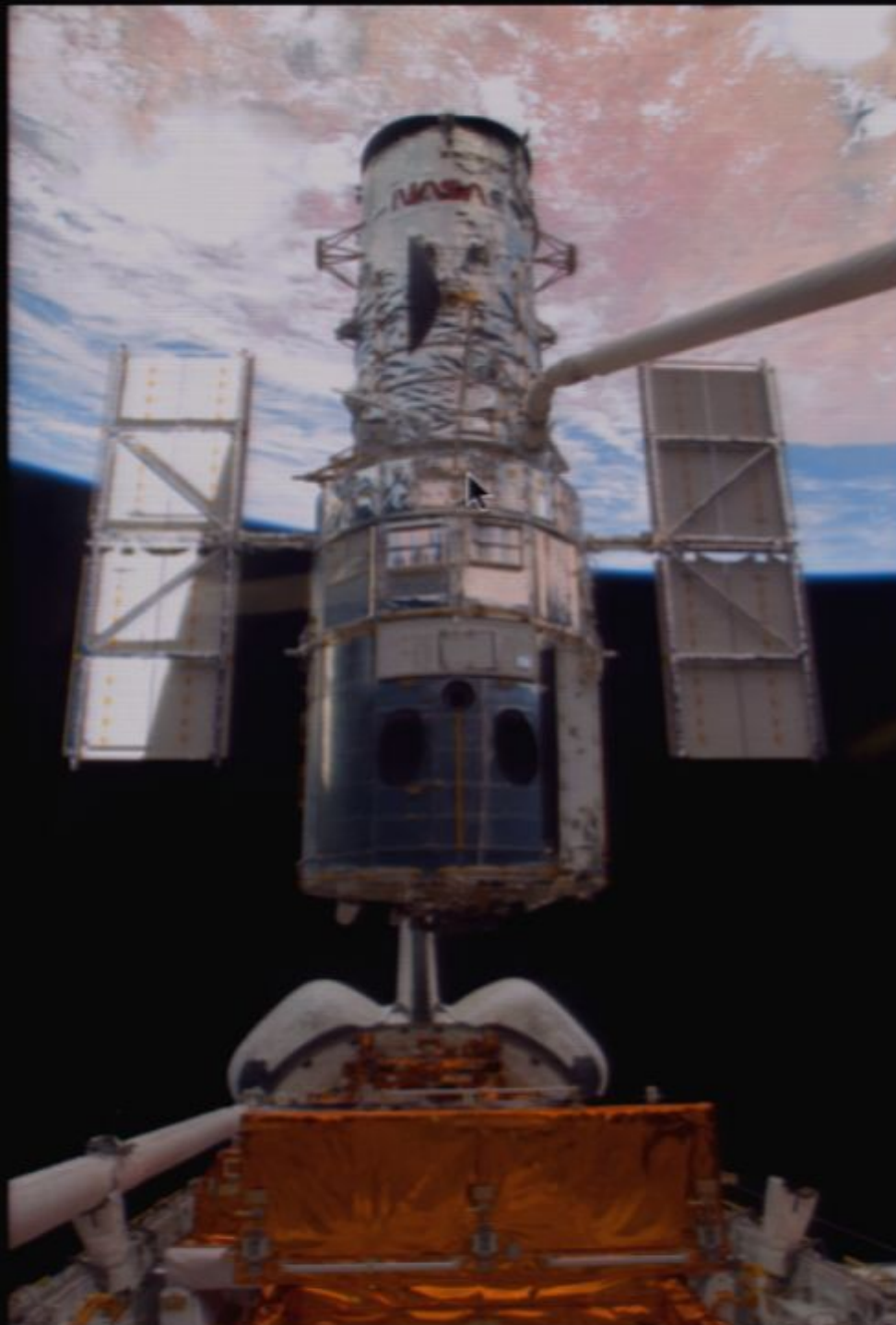


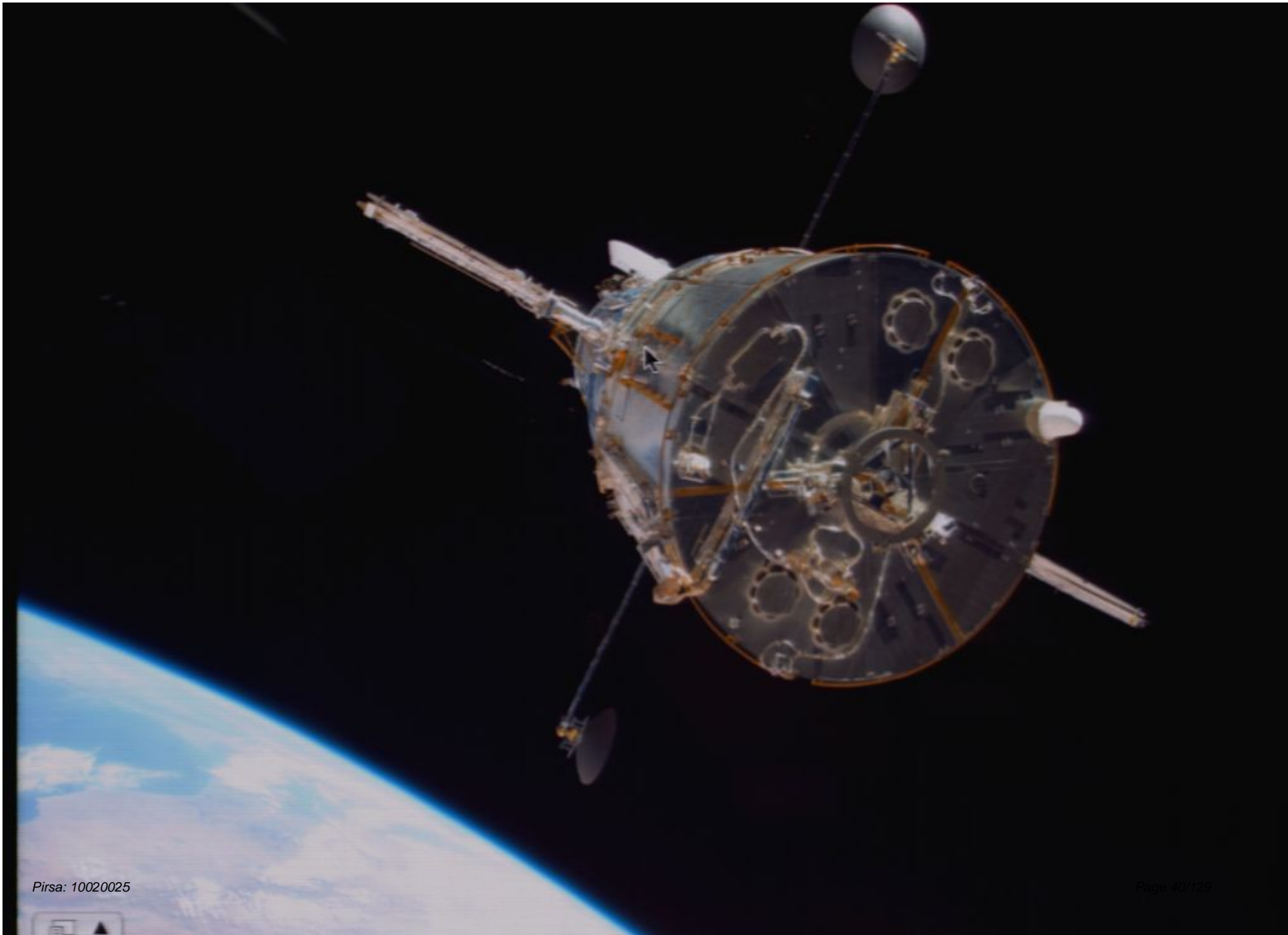


rewind...STIS repair





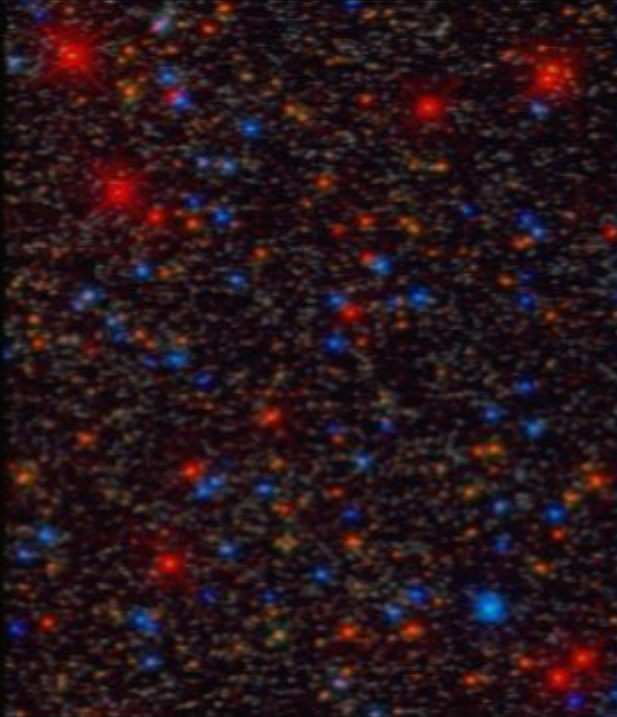










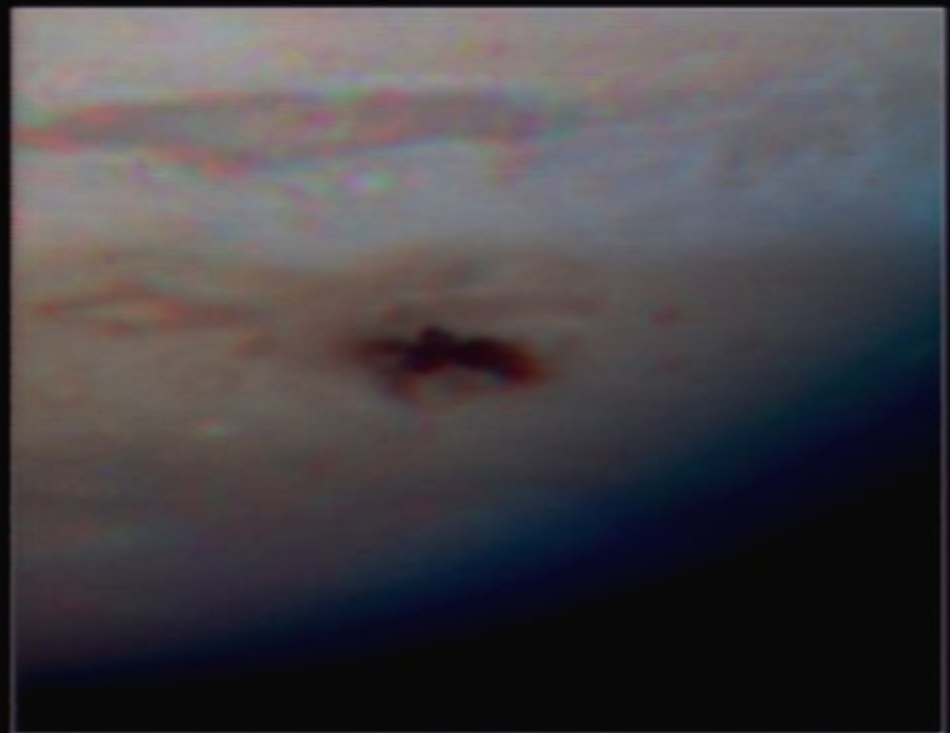
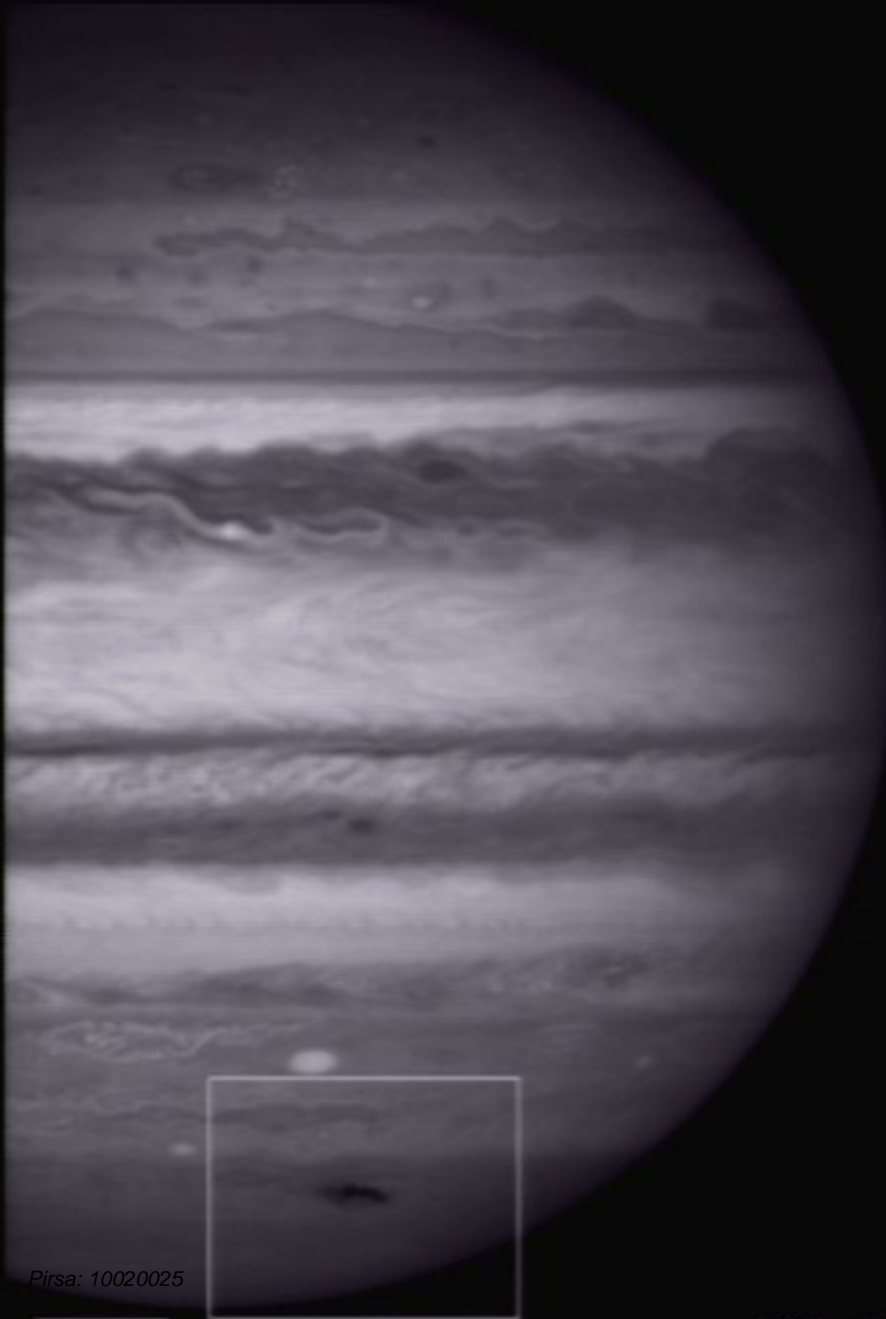


in 1994..



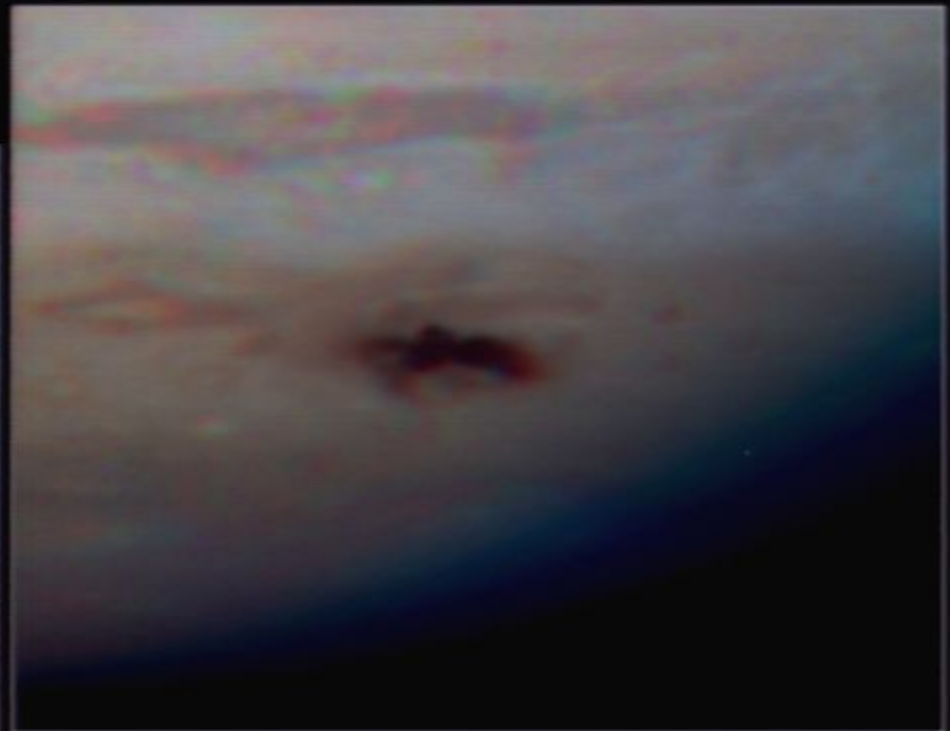
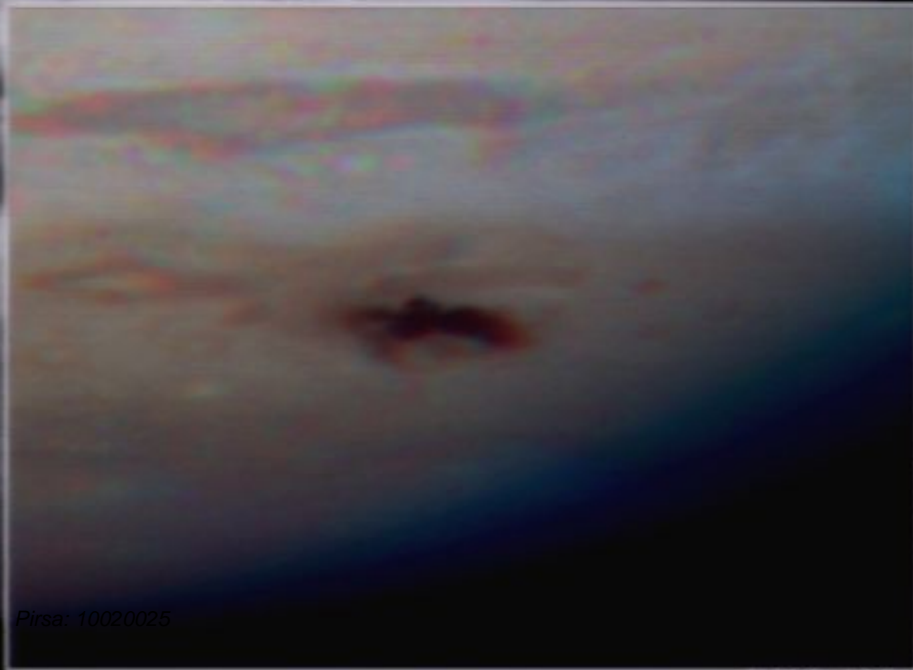
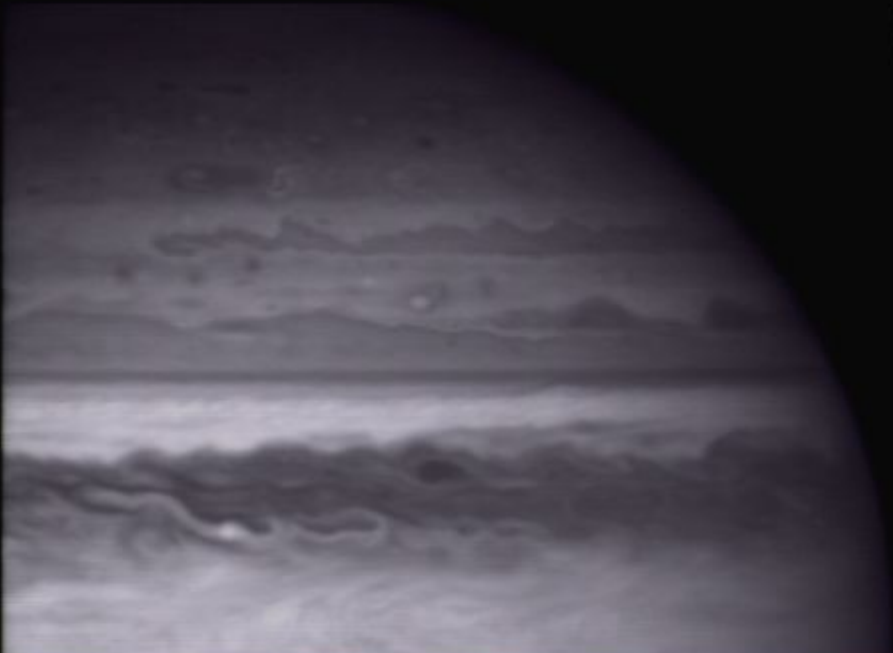
and again in 2009

Jupiter ■ July 23, 2009
Hubble Space Telescope
WFC3/UVIS



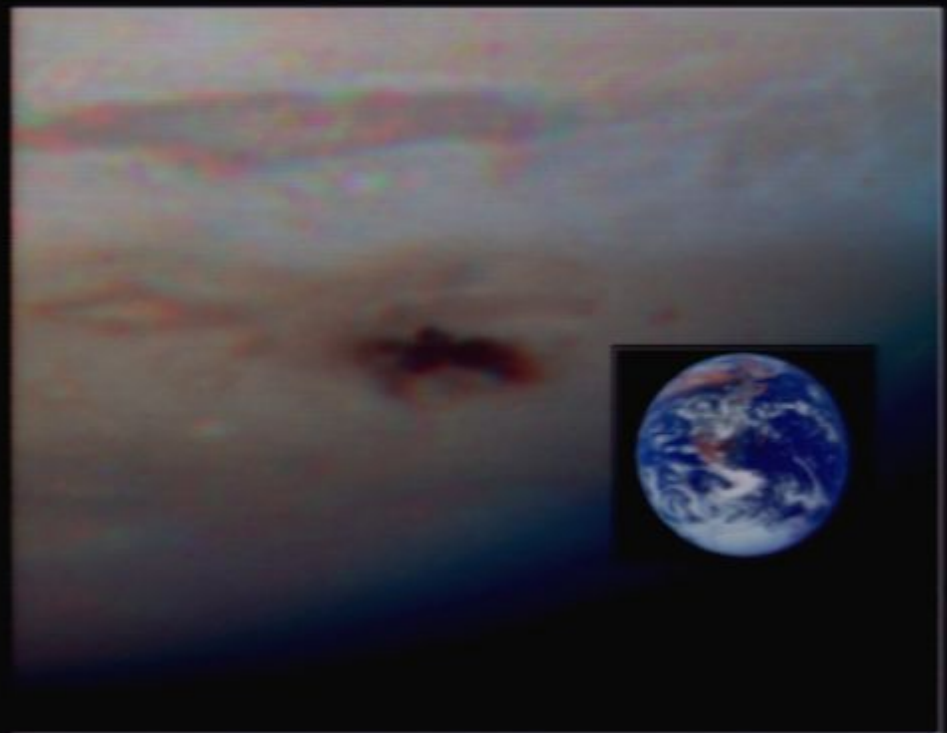
and again in 2009

Jupiter ■ July 23, 2009
Hubble Space Telescope
WFC3/UVIS



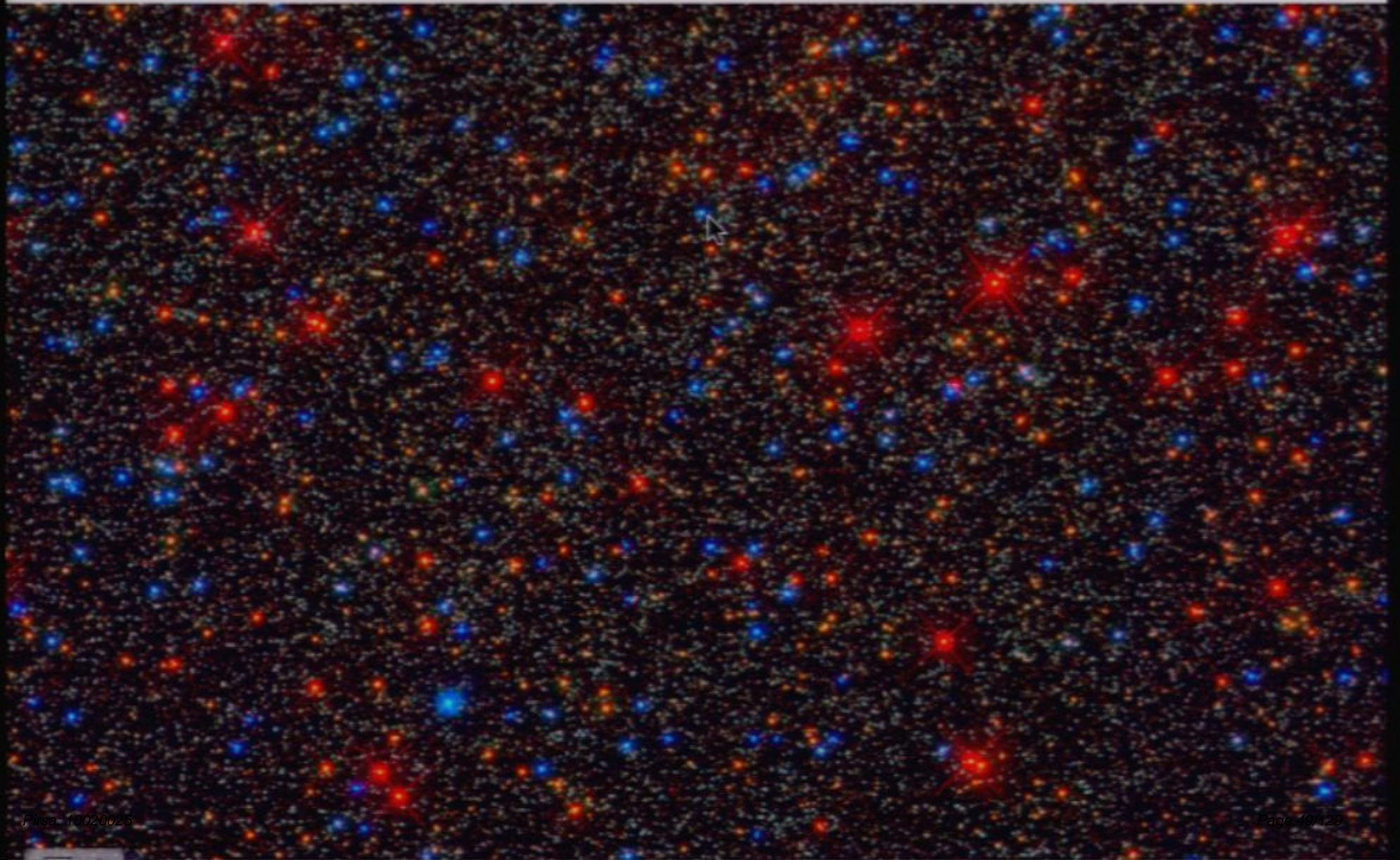
and again in 2009

Jupiter ■ July 23, 2009
Hubble Space Telescope
WFC3/UVIS



Omega Centauri Star Cluster

(credit: NASA, ESA, and the Hubble Early Release Observation Team)



Carina Nebula





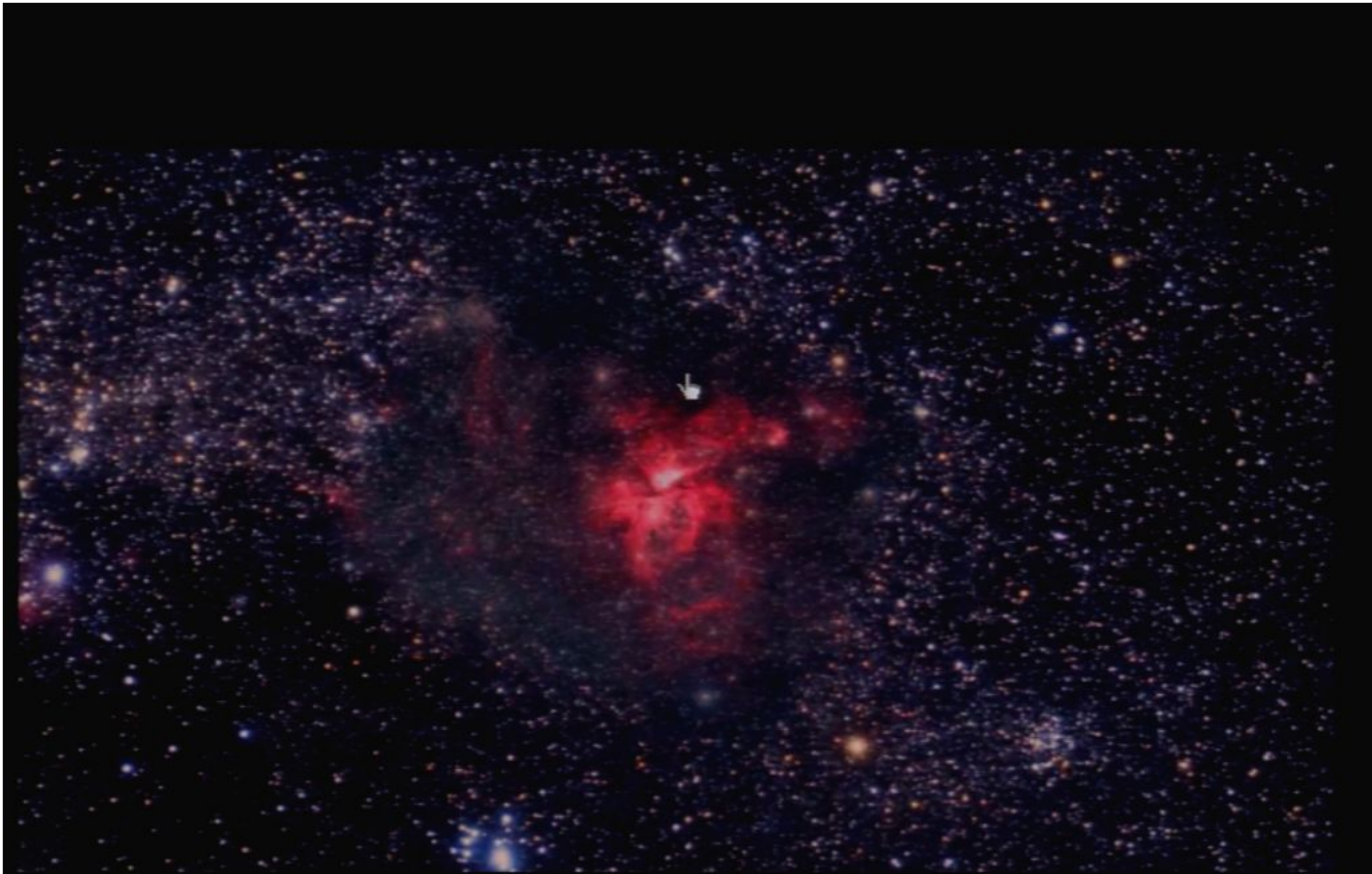


Centarus

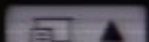
Crux

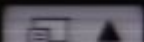
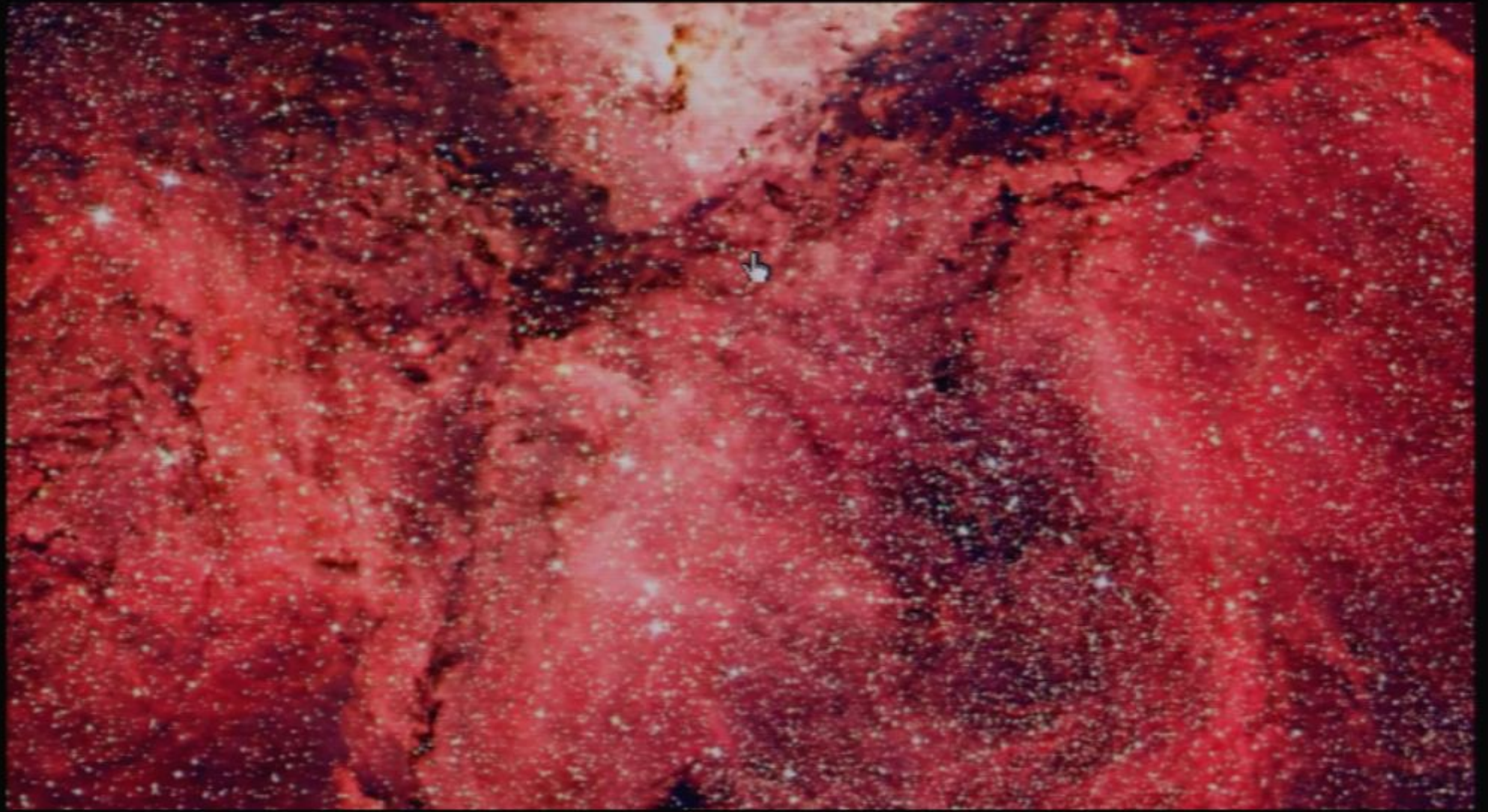
Carina

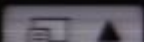


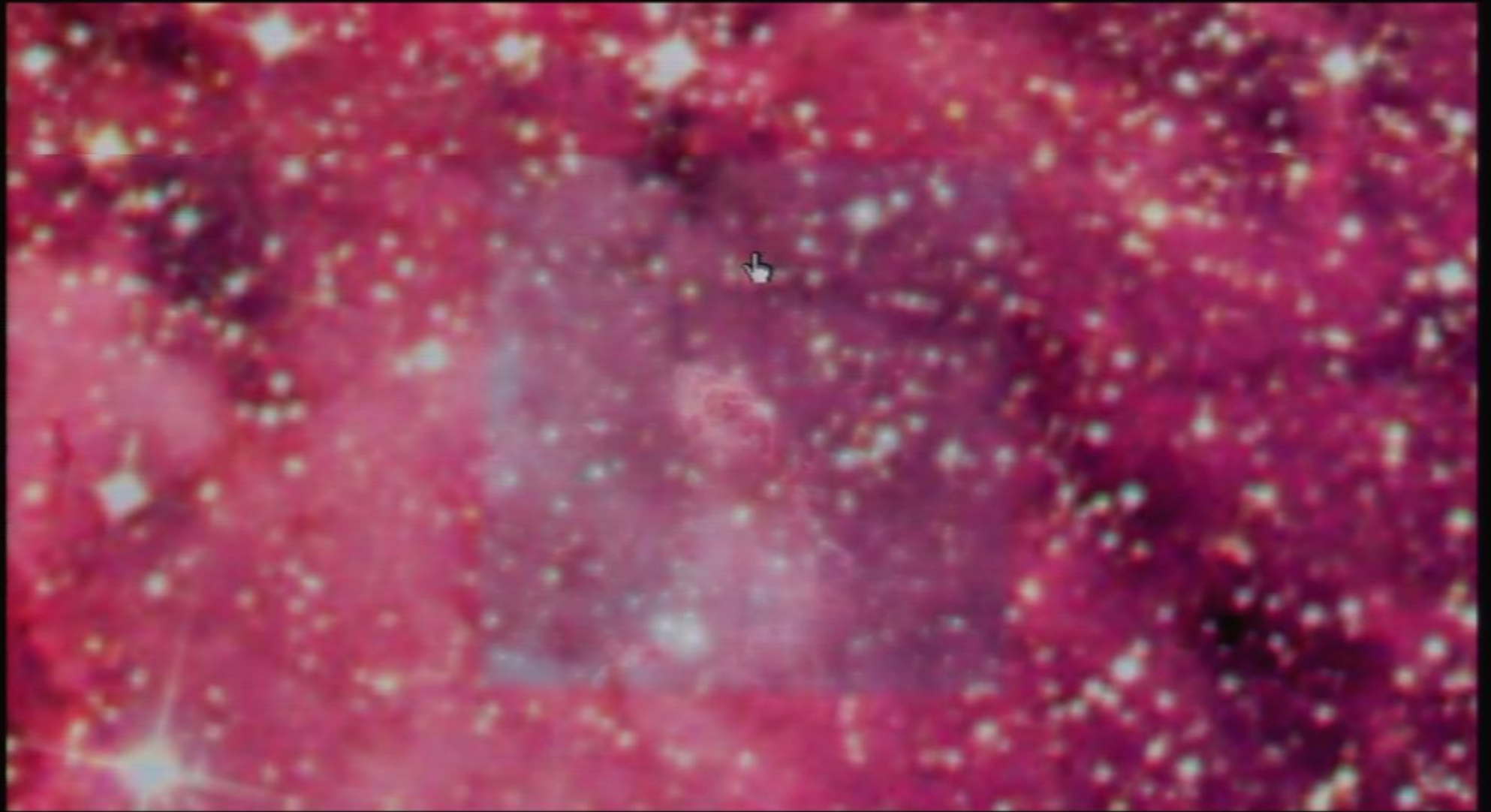






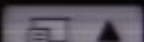


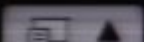












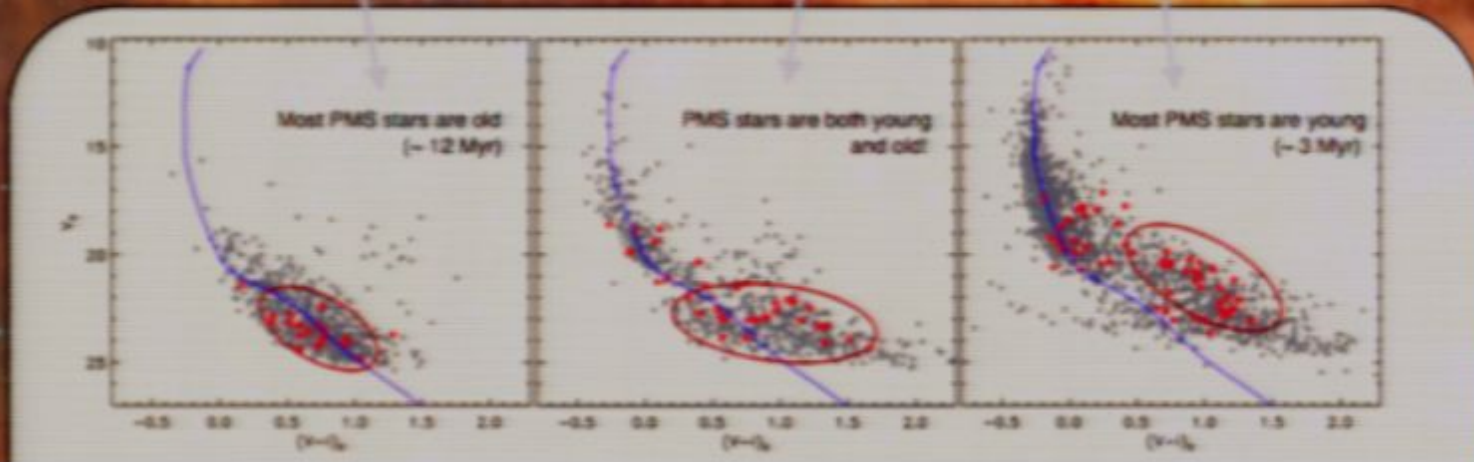
Carina Nebula ■ WFC3/UVIS

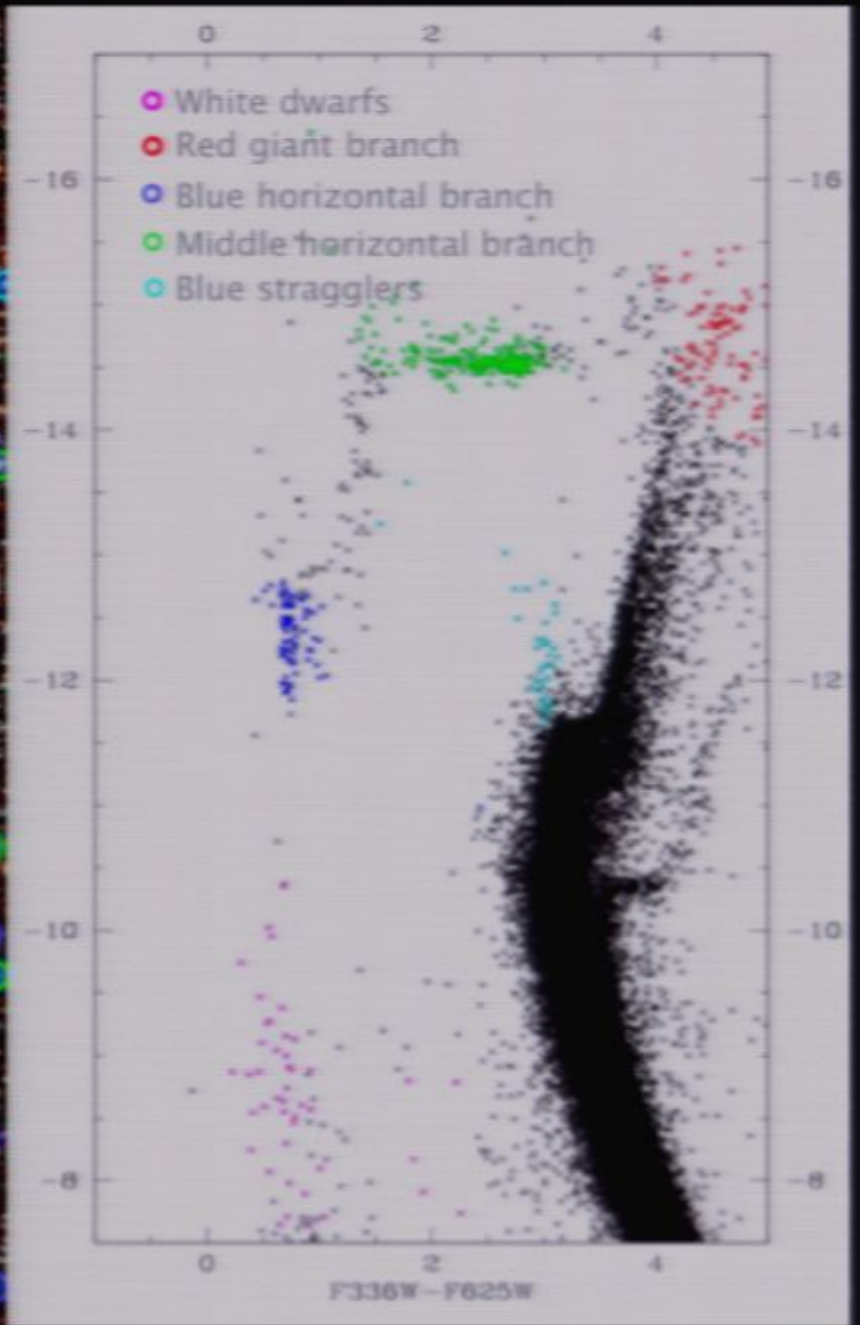
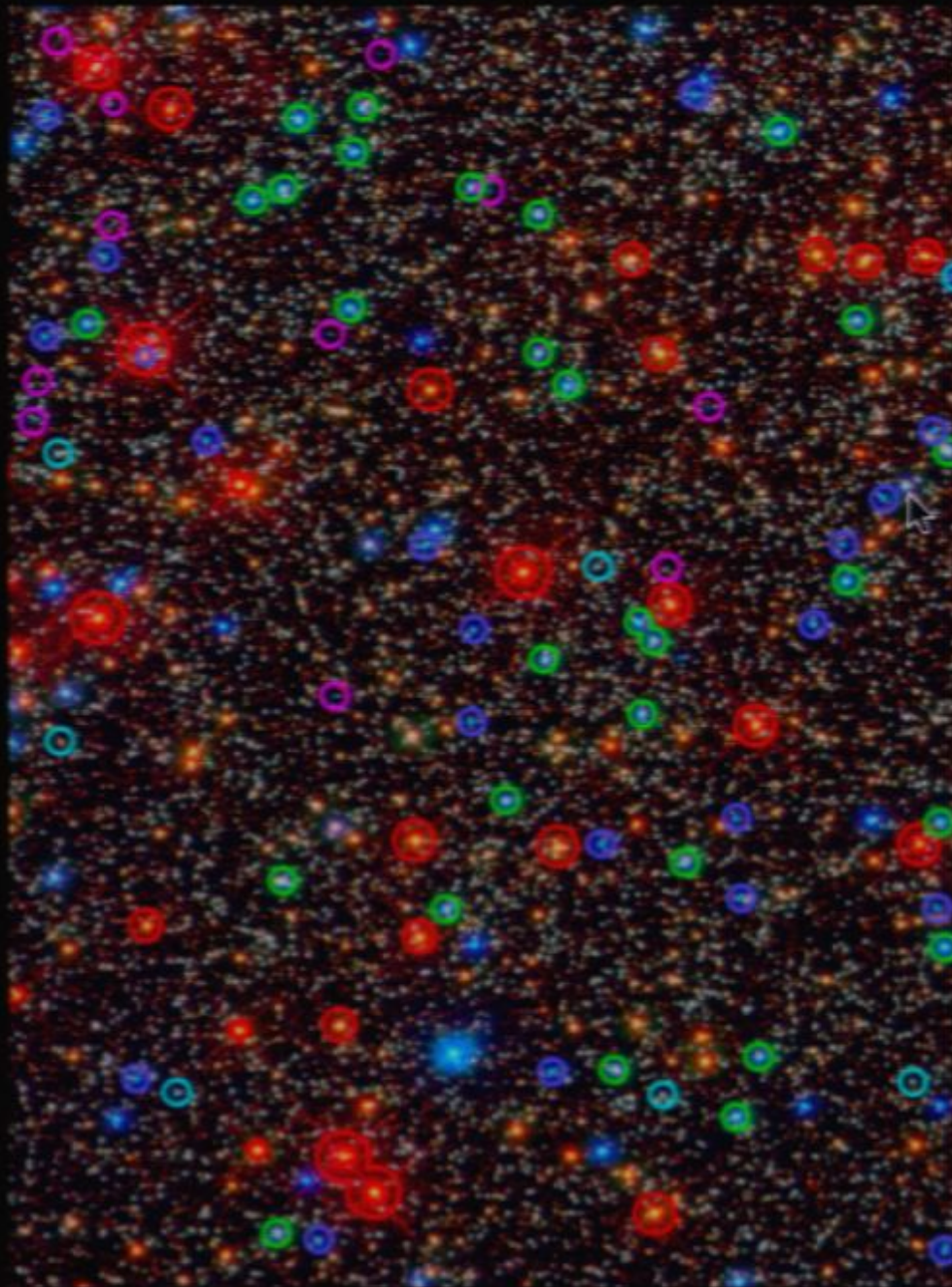


Carina Nebula ■ WFC3/IR

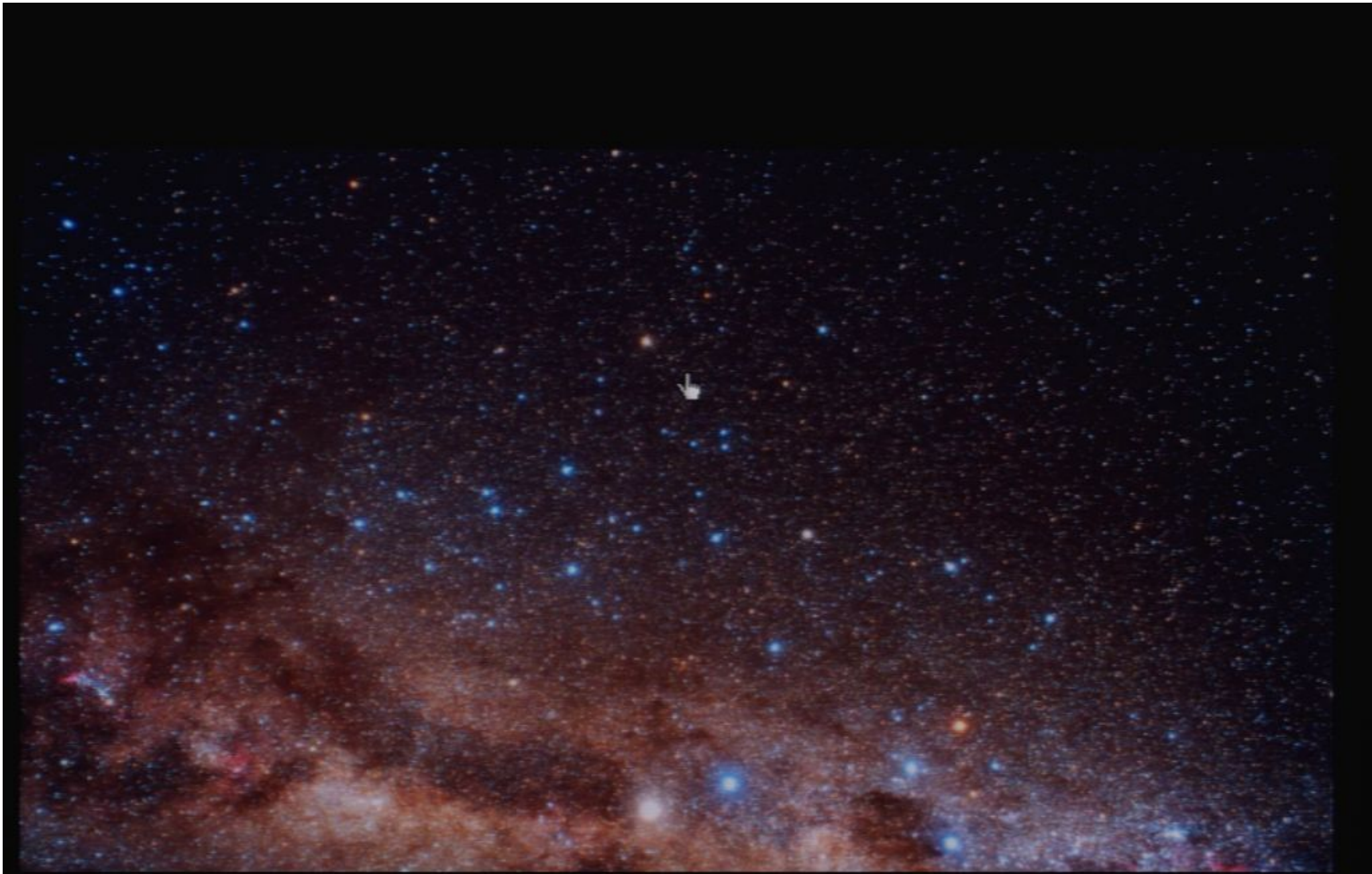


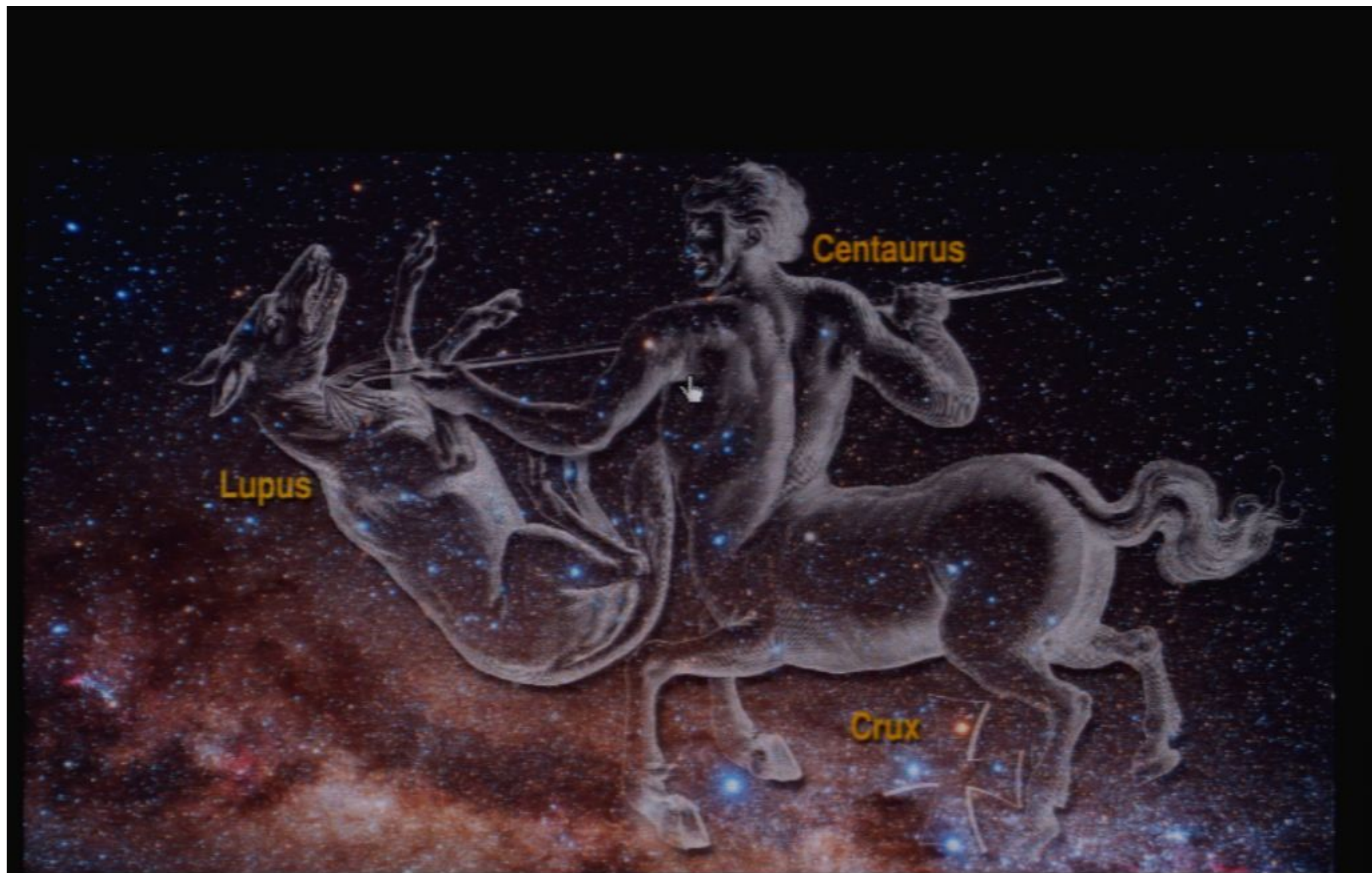
Pre-Main Sequence CMDs in 30 Dor











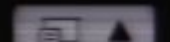




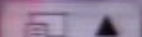












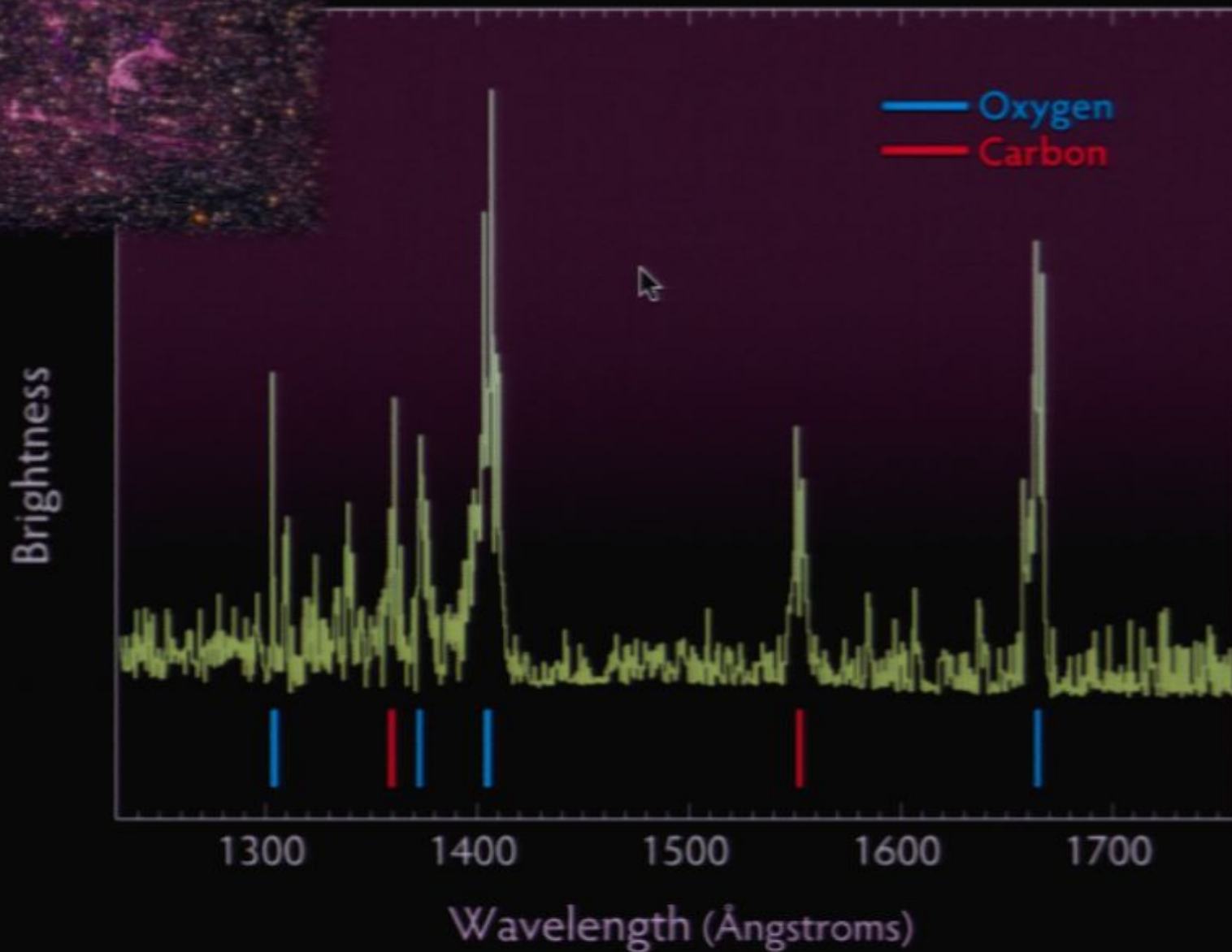
a supernova



Supernova remnant LMC N132D ■ ACS/WFC WFC3/UVIS



probing the tattered remains of supernova remnant N132D



30 Doradus (LMC)
WFC3/UVIS



M83 (Sc Spiral)



Gravity Bends Light



Gravitational Lens



M83 (Sc Spiral)



Gravity Bends Light

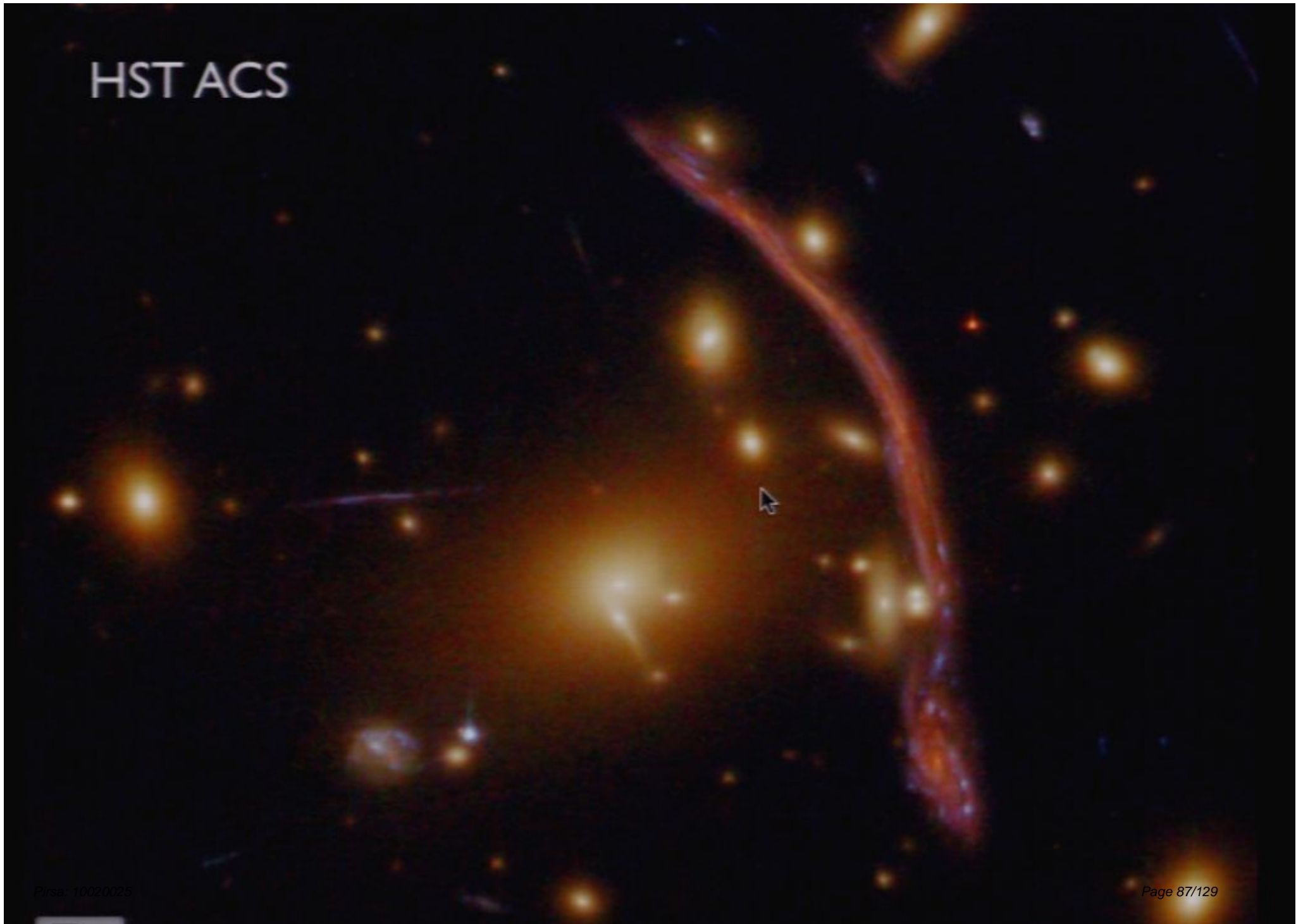


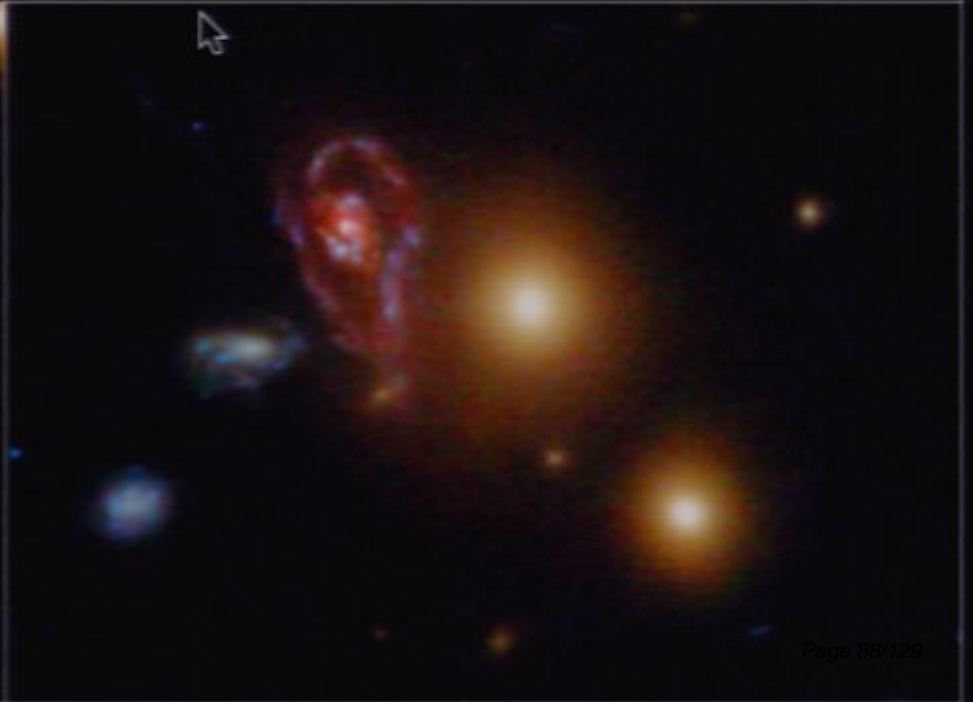
Gravitational Lens



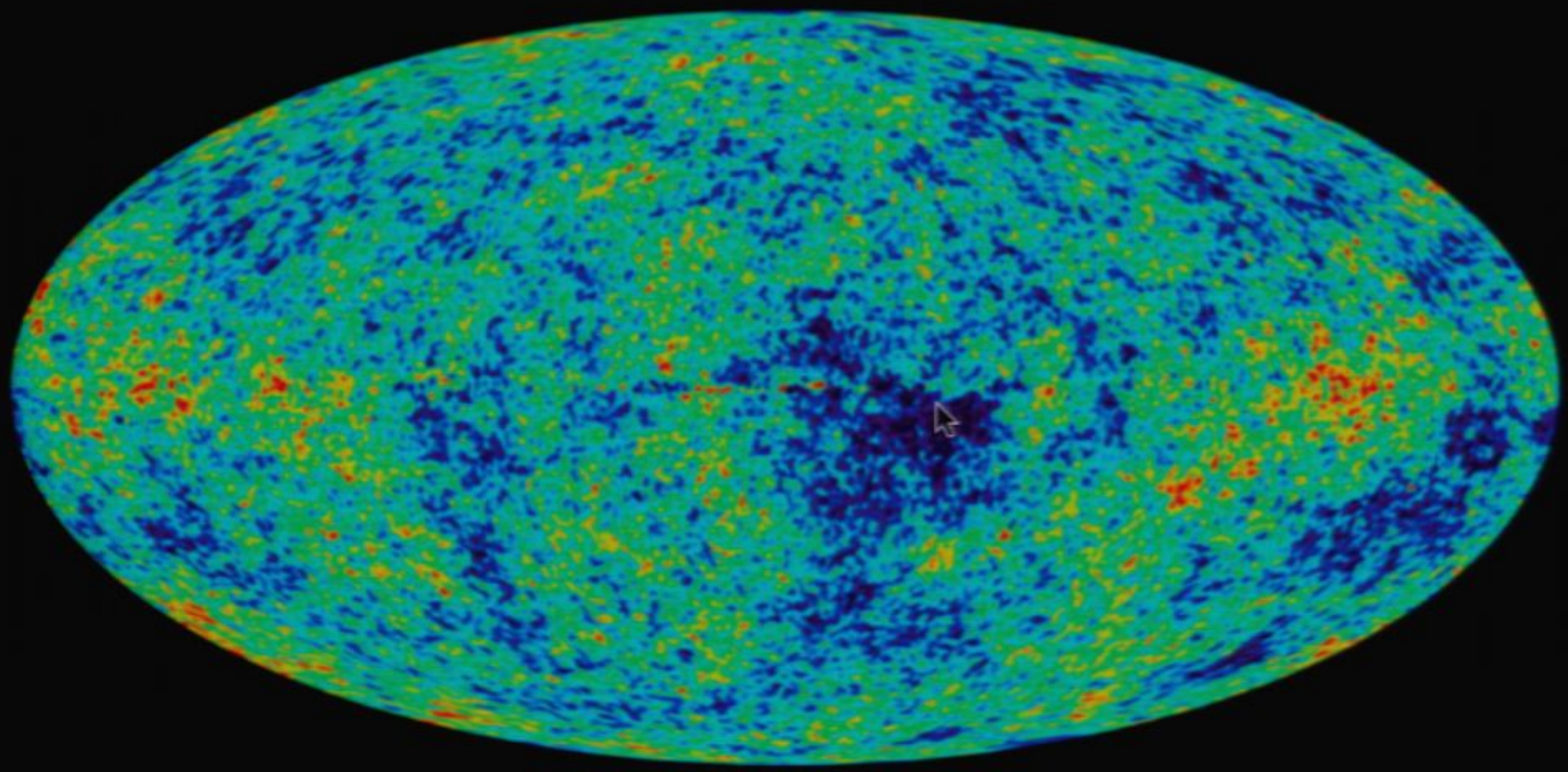


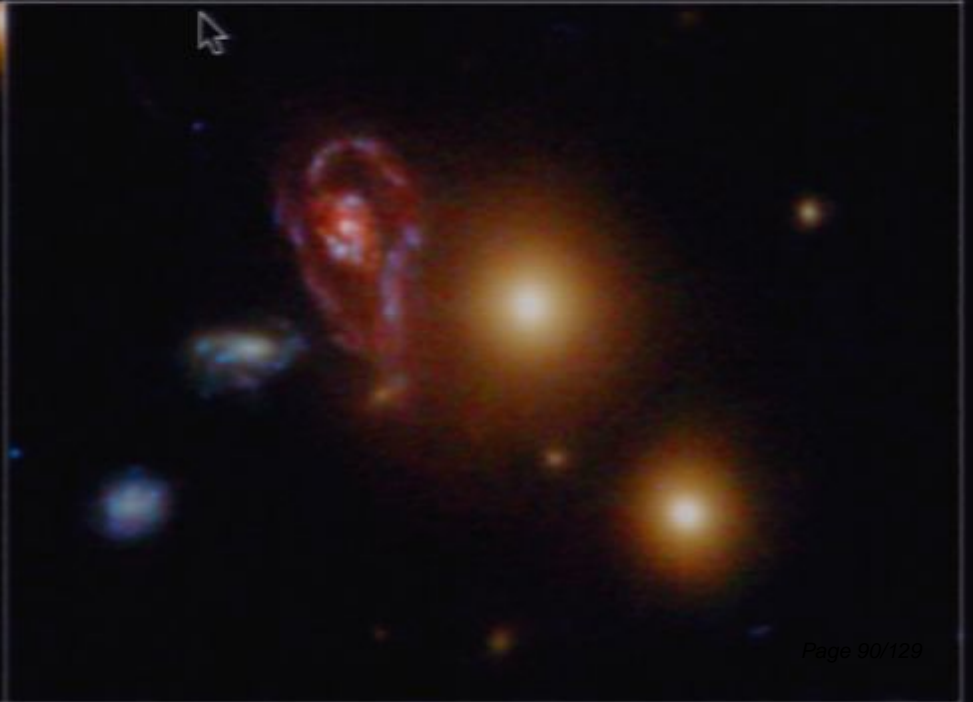
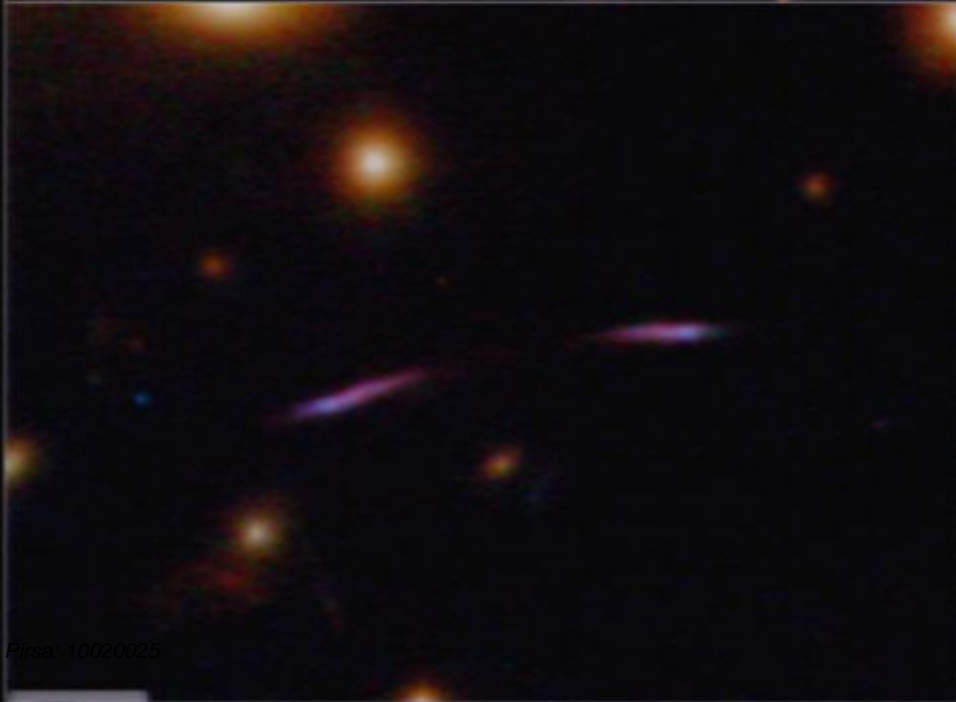
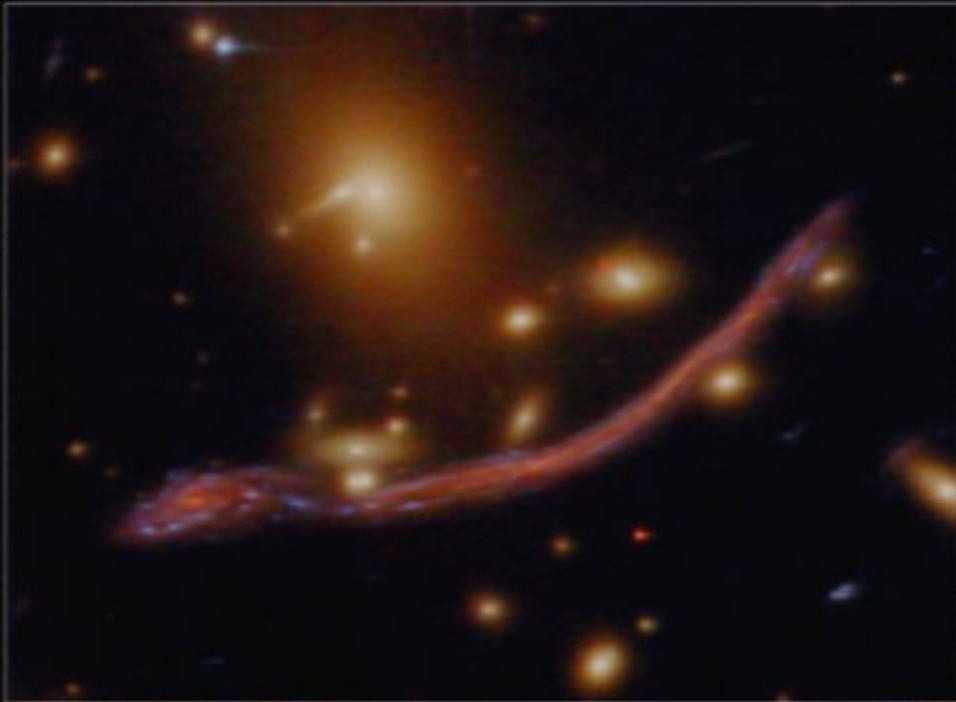
HST ACS



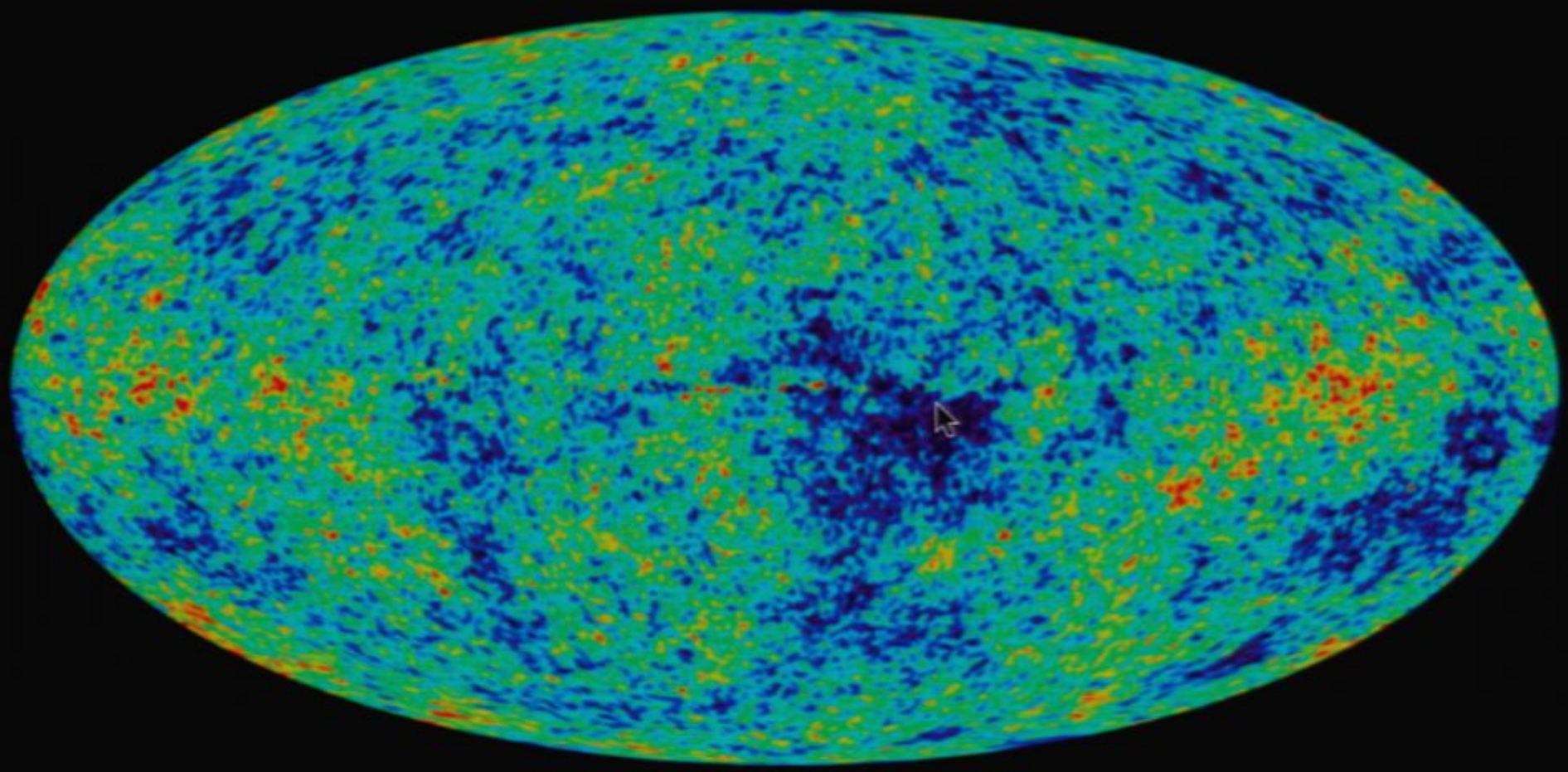


WMAP VIEW OF COSMIC MICROWAVE BACKGROUND



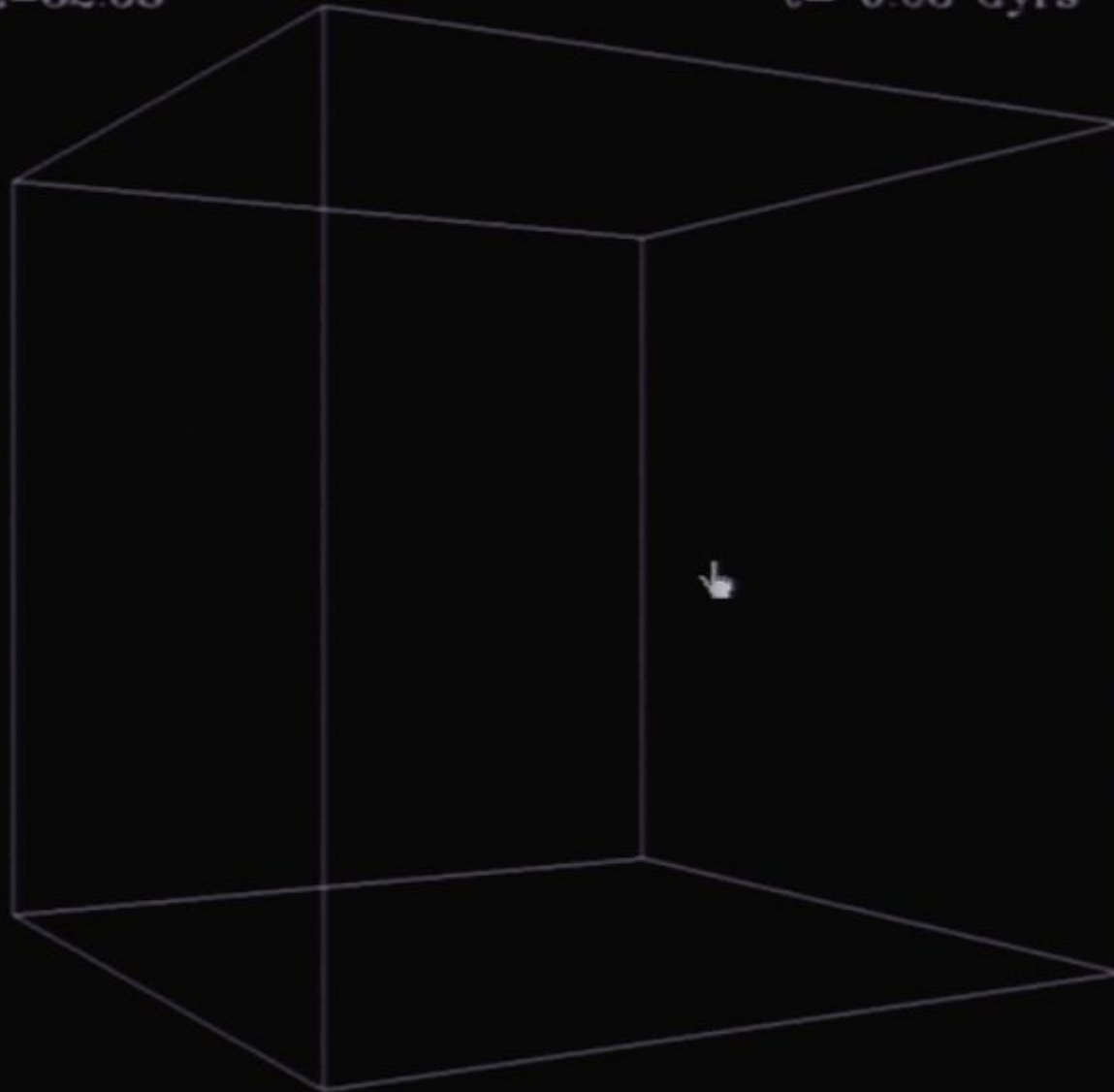


WMAP VIEW OF COSMIC MICROWAVE BACKGROUND



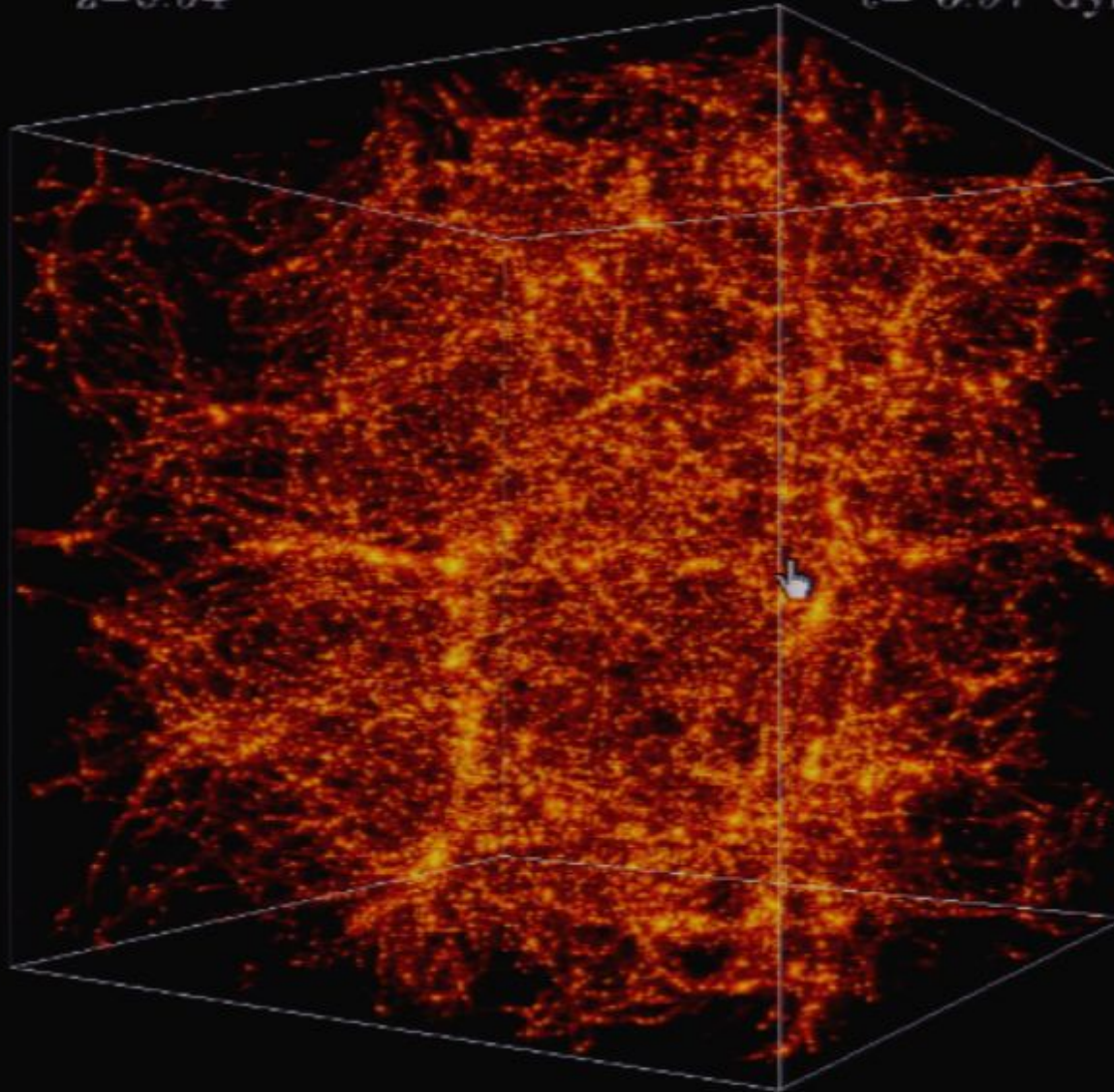
$z=32.58$

$t= 0.08$ Gyrs



$z=0.94$

$t= 5.97$ Gyrs



QSO PKS 0405-123 ■ COS

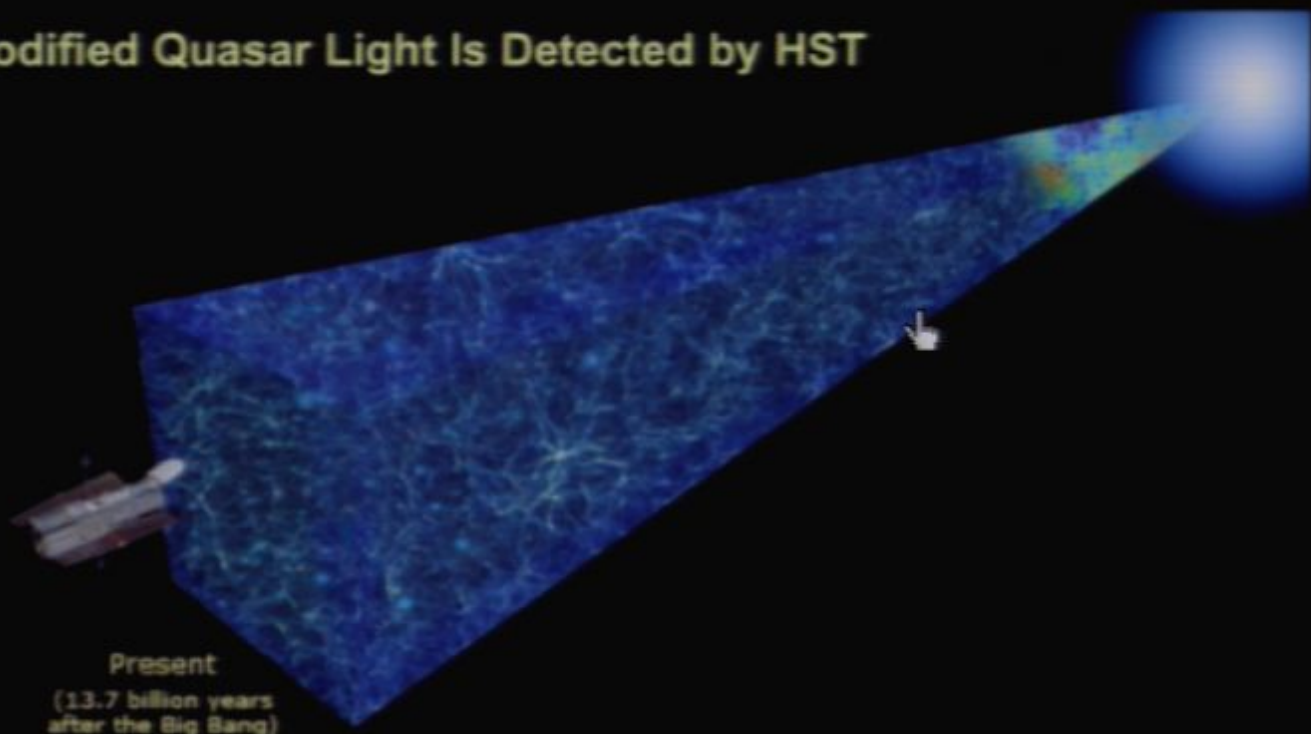


43



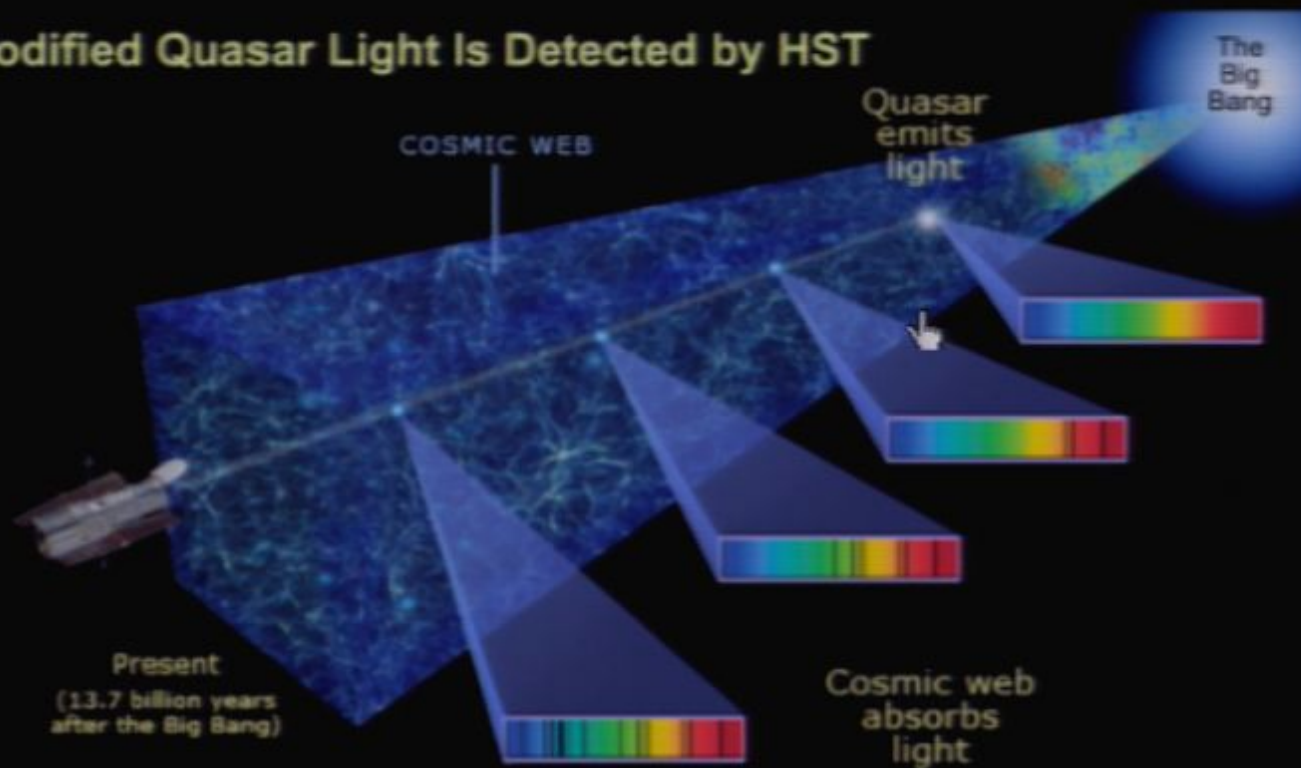
QSO PKS 0405-123 ■ COS

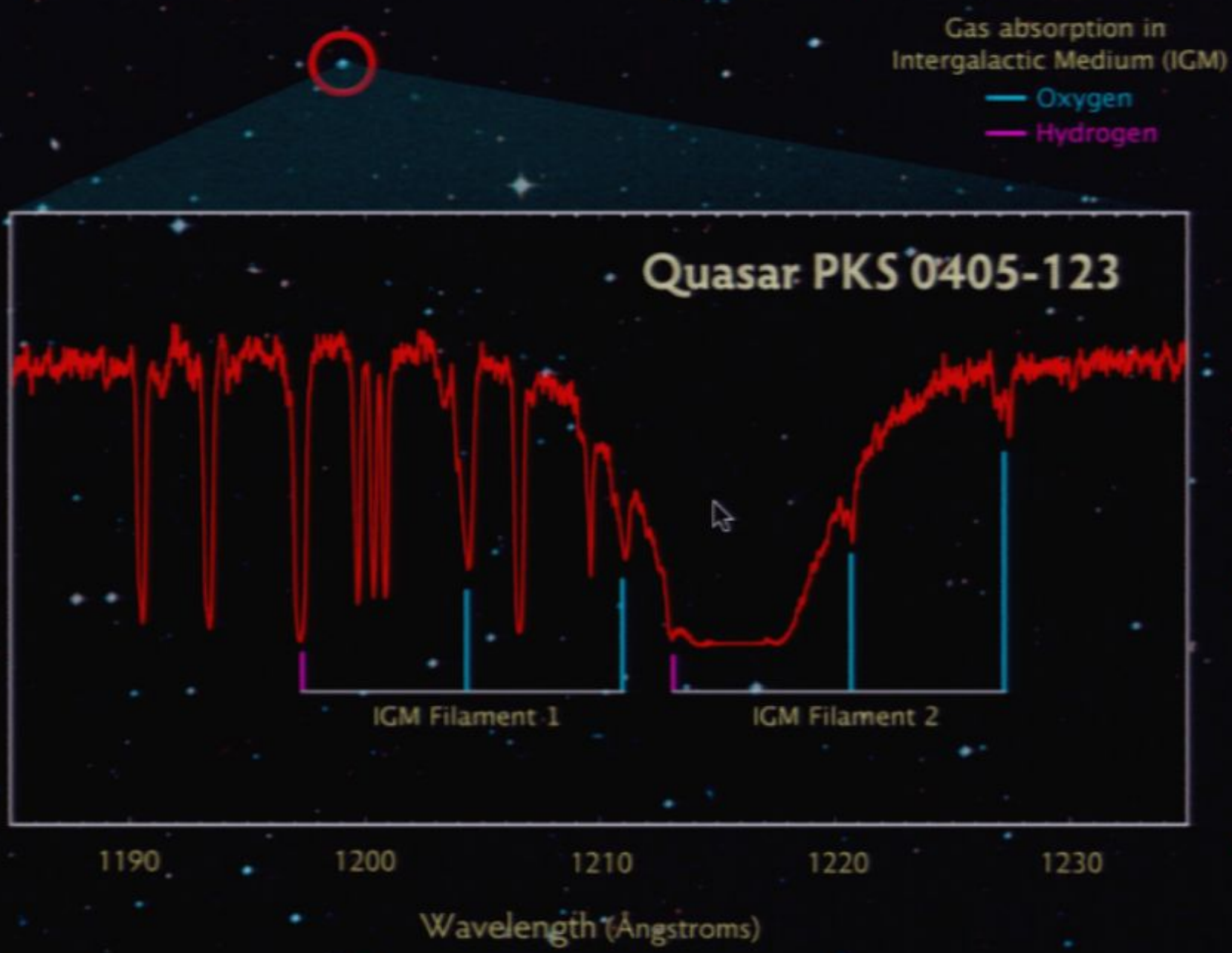
Modified Quasar Light Is Detected by HST



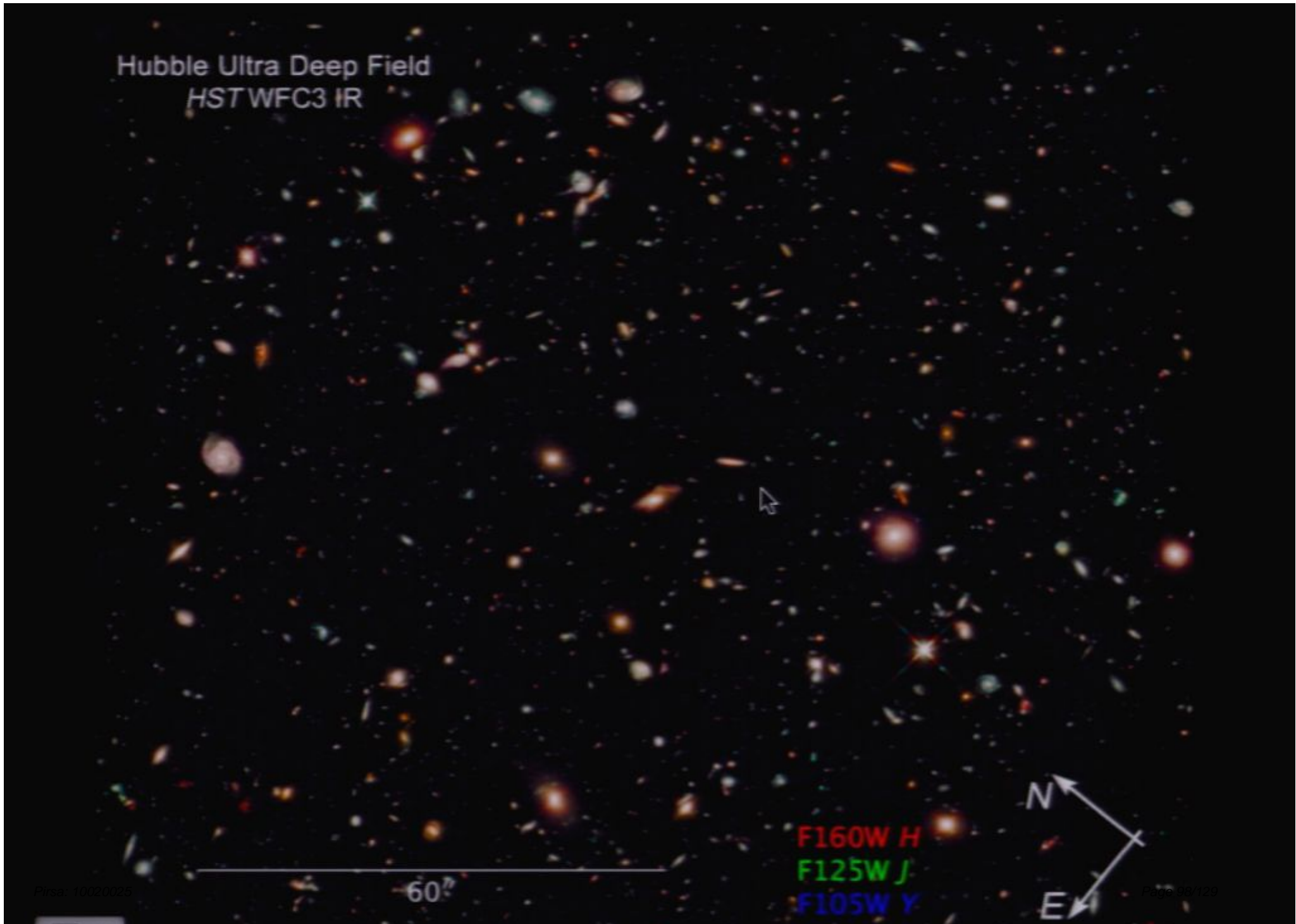
QSO PKS 0405-123 ■ COS

Modified Quasar Light Is Detected by HST





Hubble Ultra Deep Field
HST WFC3 IR



F160W H
F125W J
F105W Y

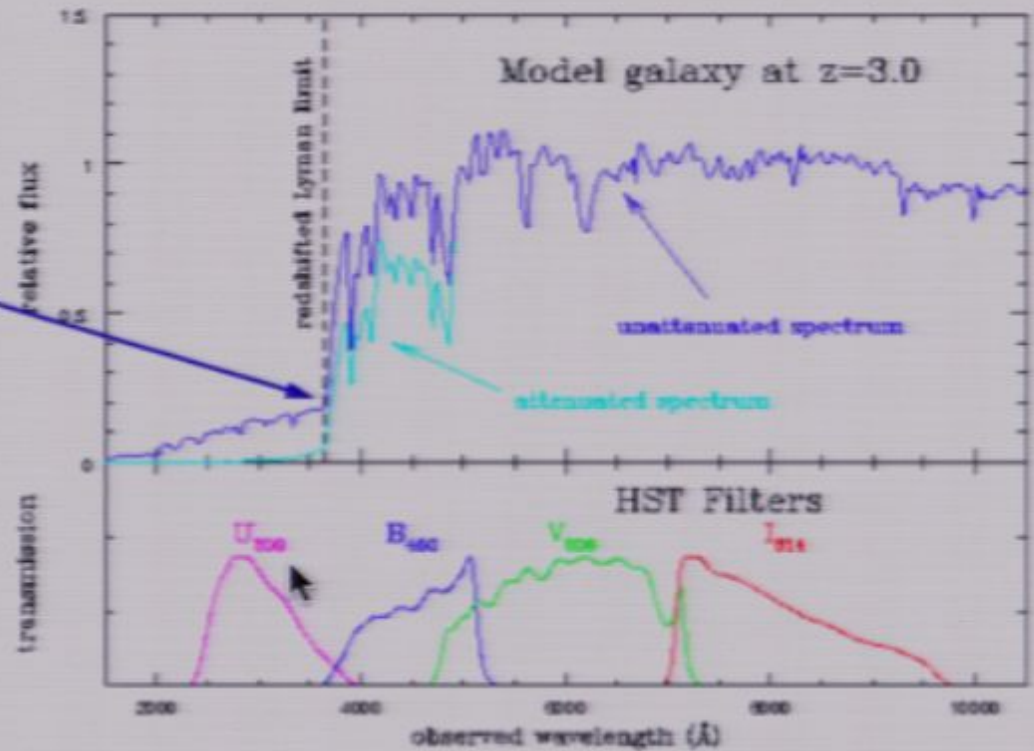


60"

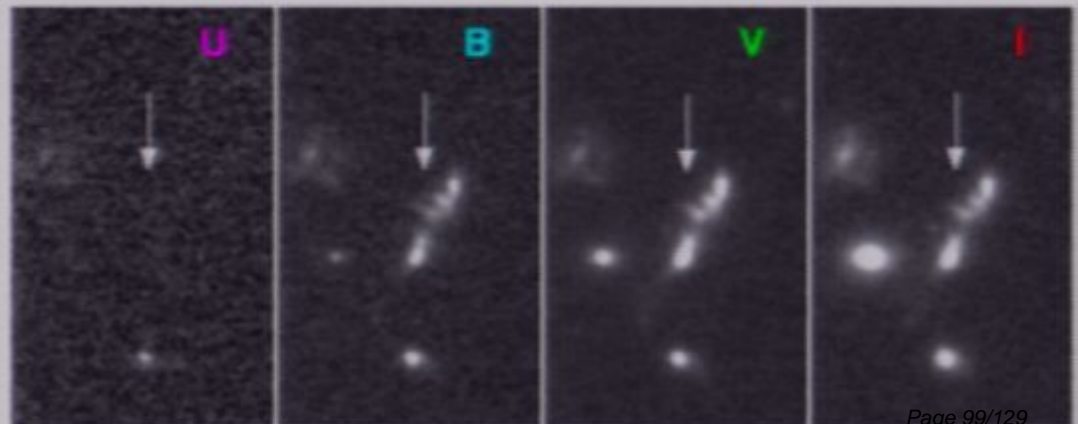


Lyman-Break Galaxies (LBG)

Hydrogen completely absorbs light shortward of $0.0912 \mu\text{m}$ in the rest frame



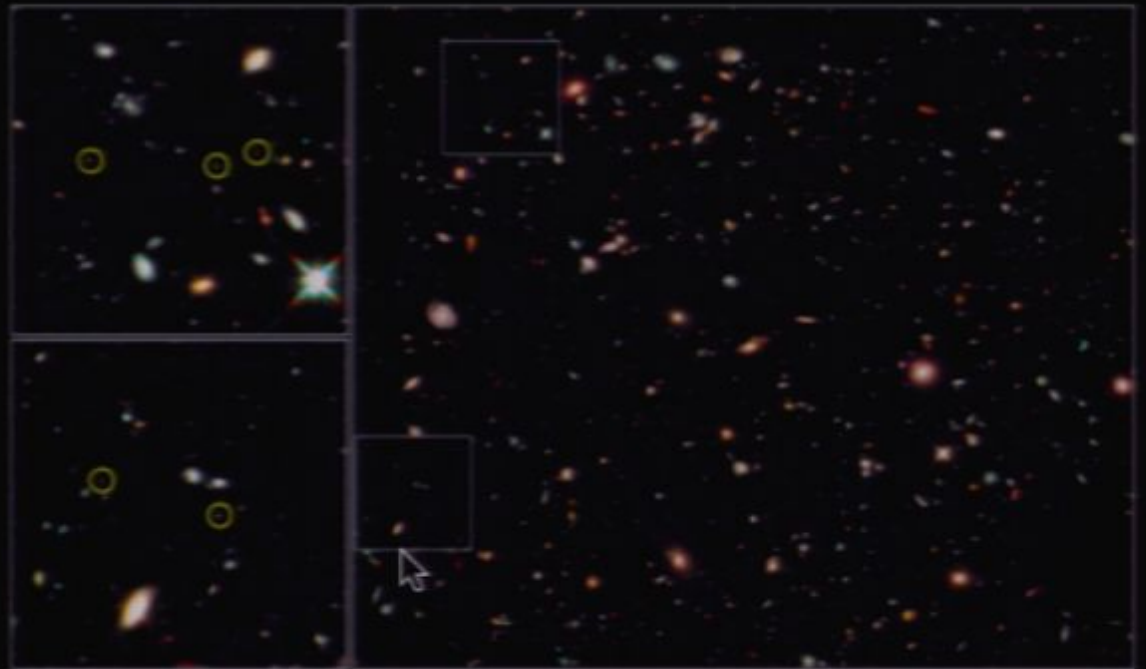
“Photometric redshifts” are derived from intensity ratios (colors) in broad filters



redshift vs age

galaxies at $z \sim 8$

z redshift	millions of years since the big bang
2	3300
3	2200
4	1600
5	1200
6	950
7	750
8	650
9	550
10	500
11	400



Hubble Ultra Deep Field - Infrared
Hubble Space Telescope - WFC3/IR

NASA, ESA, G. Illingworth (UCO/Lick Observatory and University of California, Santa Cruz), and the HUDF09 Team

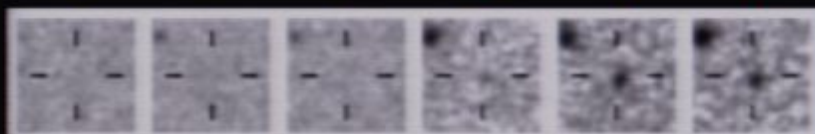
STScI-PRC10-02

these galaxies are really faint and only seen in the infrared

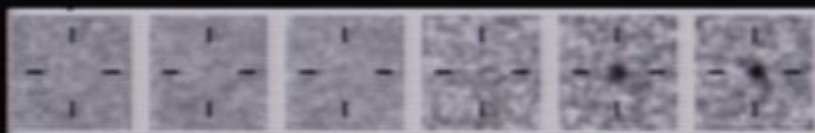
the highest redshift $z \sim 8$ galaxies

(Bouwens et al and Oesch et al papers)

ACS filters WFC3/IR
V i z Y J H



redshift
 $z \sim 8.4$

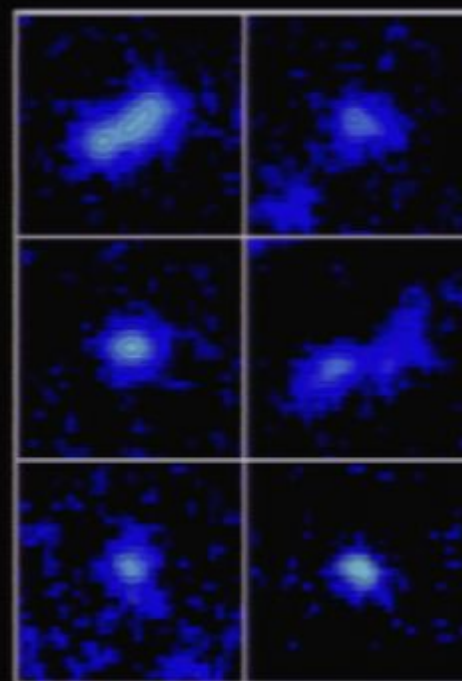


$z \sim 8.7$

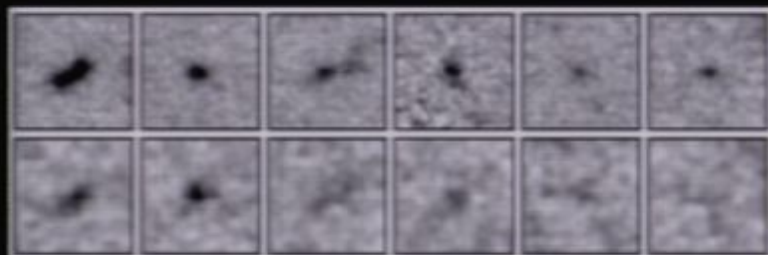
not detected

detected

redshift $z \sim 7$ galaxy images

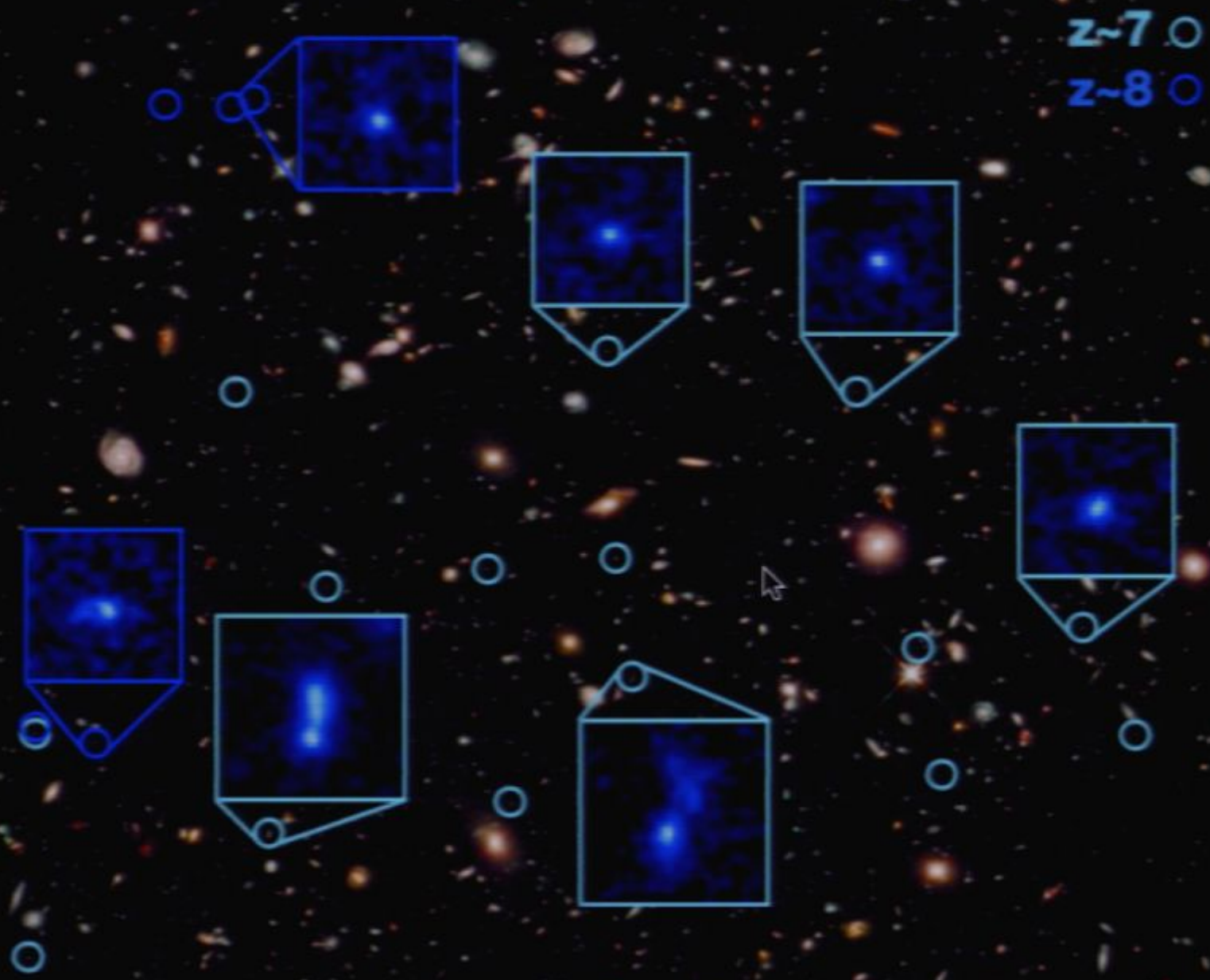


comparing the old and new Hubble infrared cameras



WFC3/IR

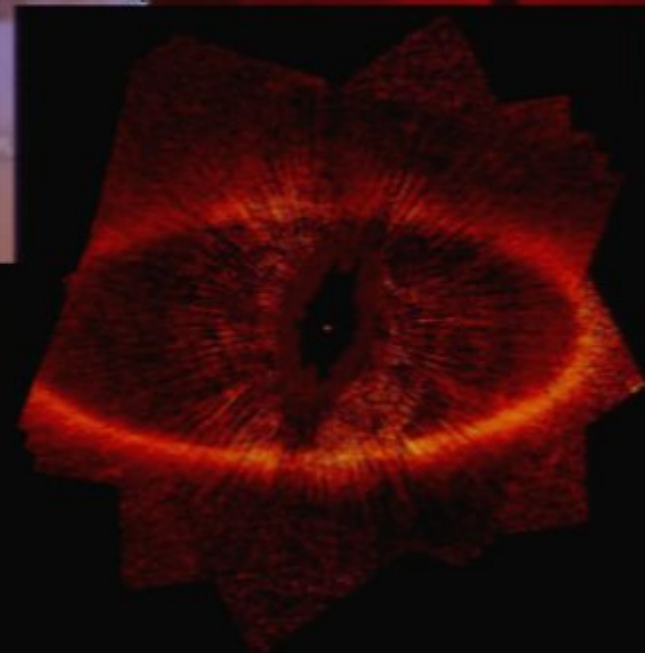
NICMOS



HUDF09 WFC3/IR Image with $z\sim 7$ and $z\sim 8$ Galaxies

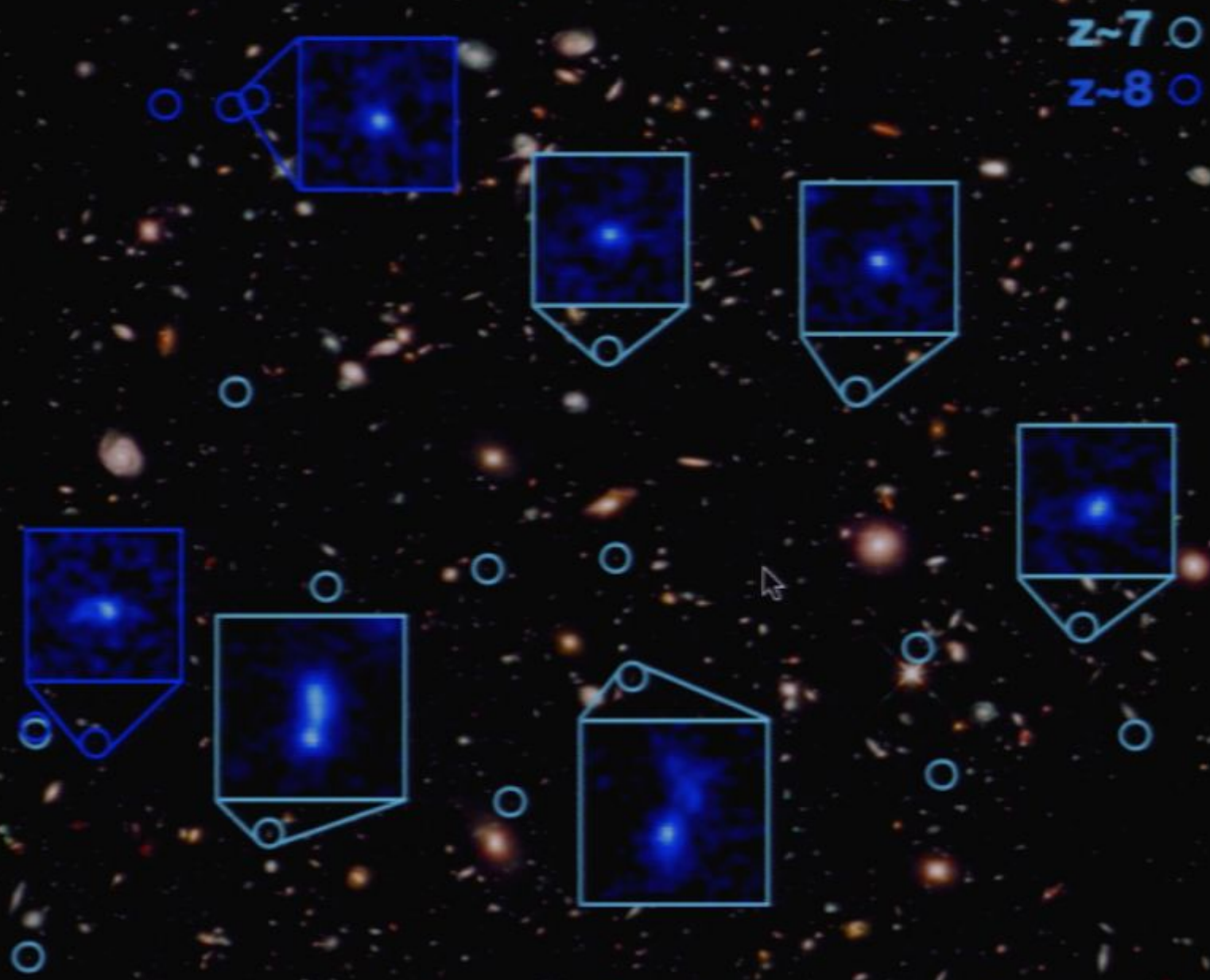
Credit: NASA, ESA, G. Illingworth, R. Bouwens (University of California, Santa Cruz), and the HUDF09 Team.





Planetary System Formation

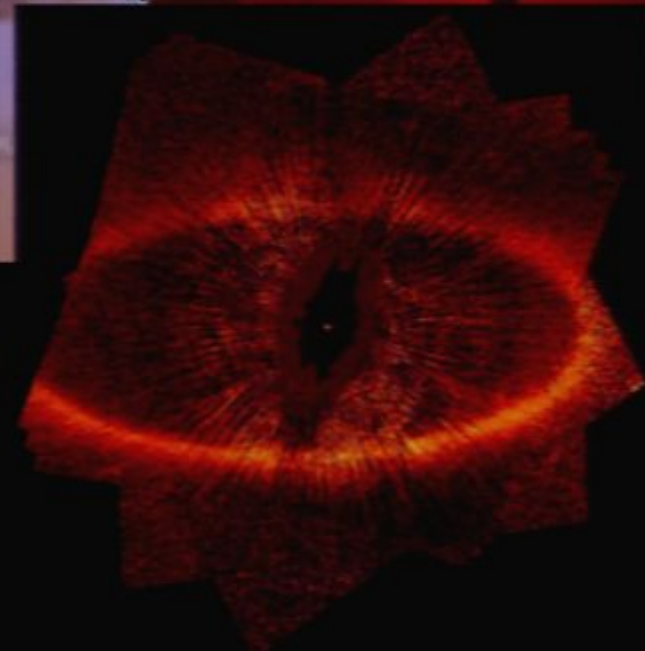




HUDF09 WFC3/IR Image with $z\sim 7$ and $z\sim 8$ Galaxies

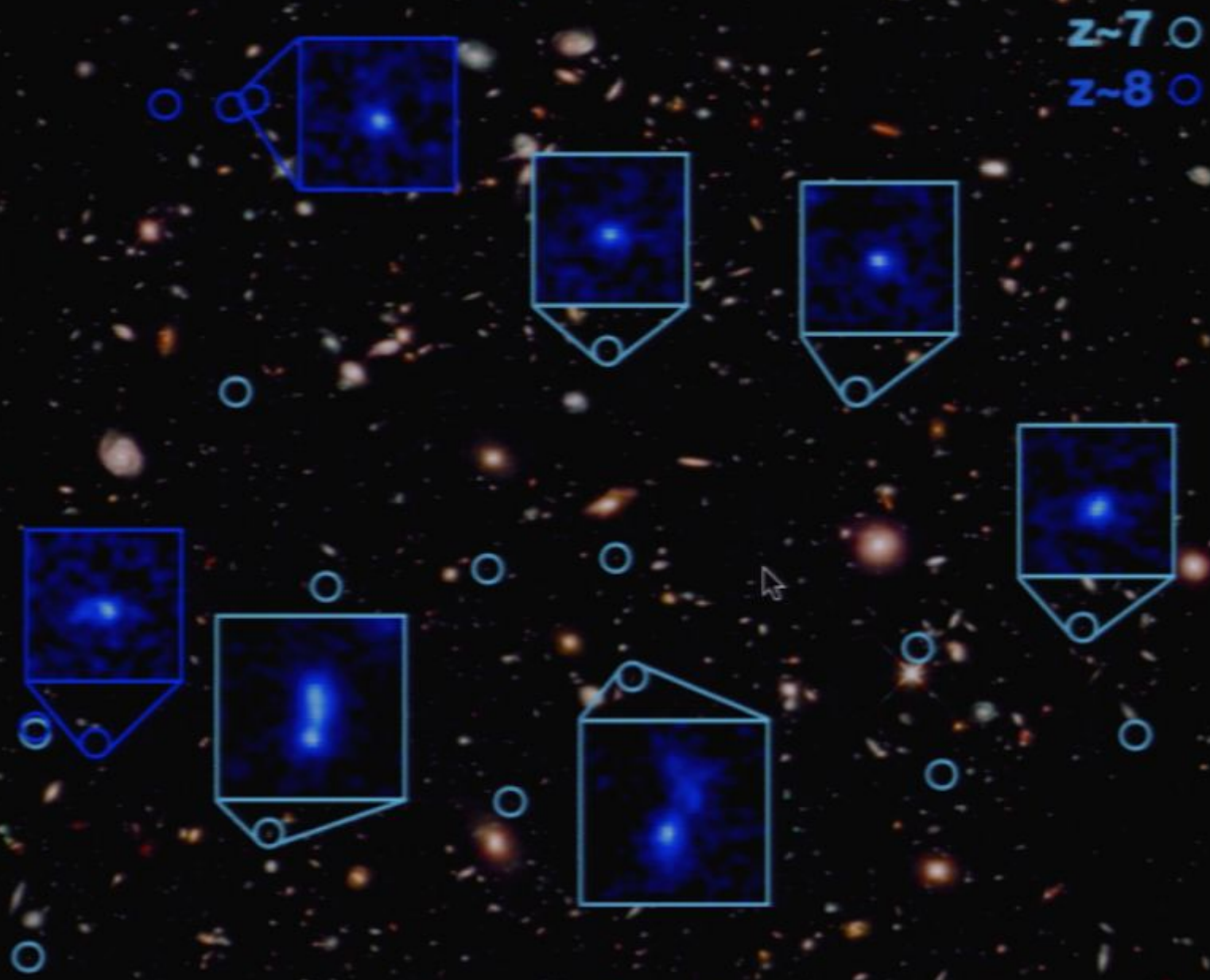
Credit: NASA, ESA, G. Illingworth, R. Bouwens (University of California, Santa Cruz), and the HUDF09 Team.





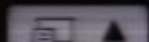
Planetary System Formation

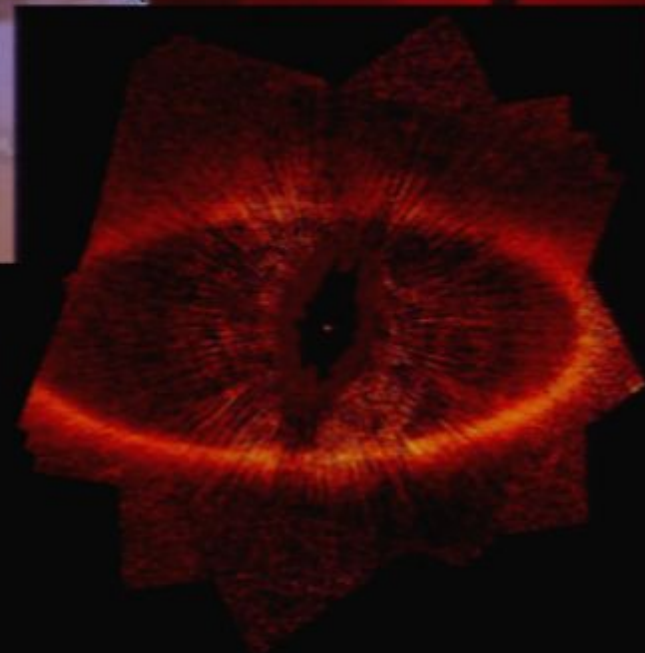




HUDF09 WFC3/IR Image with $z\sim 7$ and $z\sim 8$ Galaxies

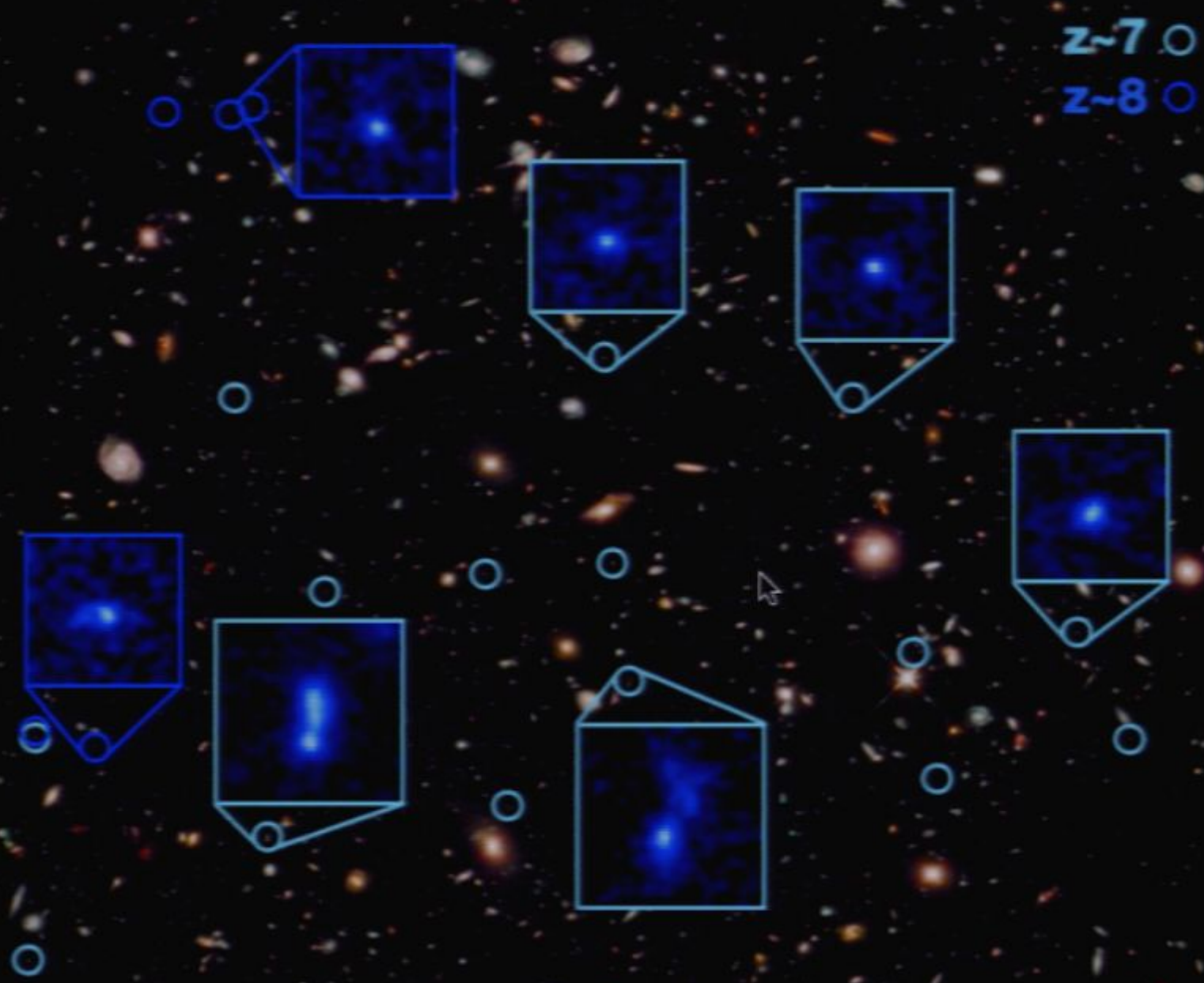
Credit: NASA, ESA, G. Illingworth, R. Bouwens (University of California, Santa Cruz), and the HUDF09 Team.





Planetary System Formation

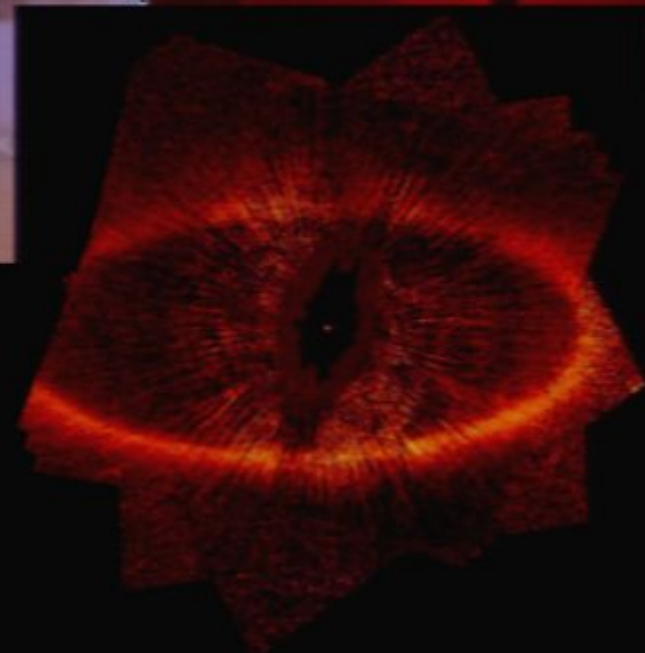




HUDF09 WFC3/IR Image with $z\sim 7$ and $z\sim 8$ Galaxies

Credit: NASA, ESA, G. Illingworth, R. Bouwens (University of California, Santa Cruz), and the HUDF09 Team.



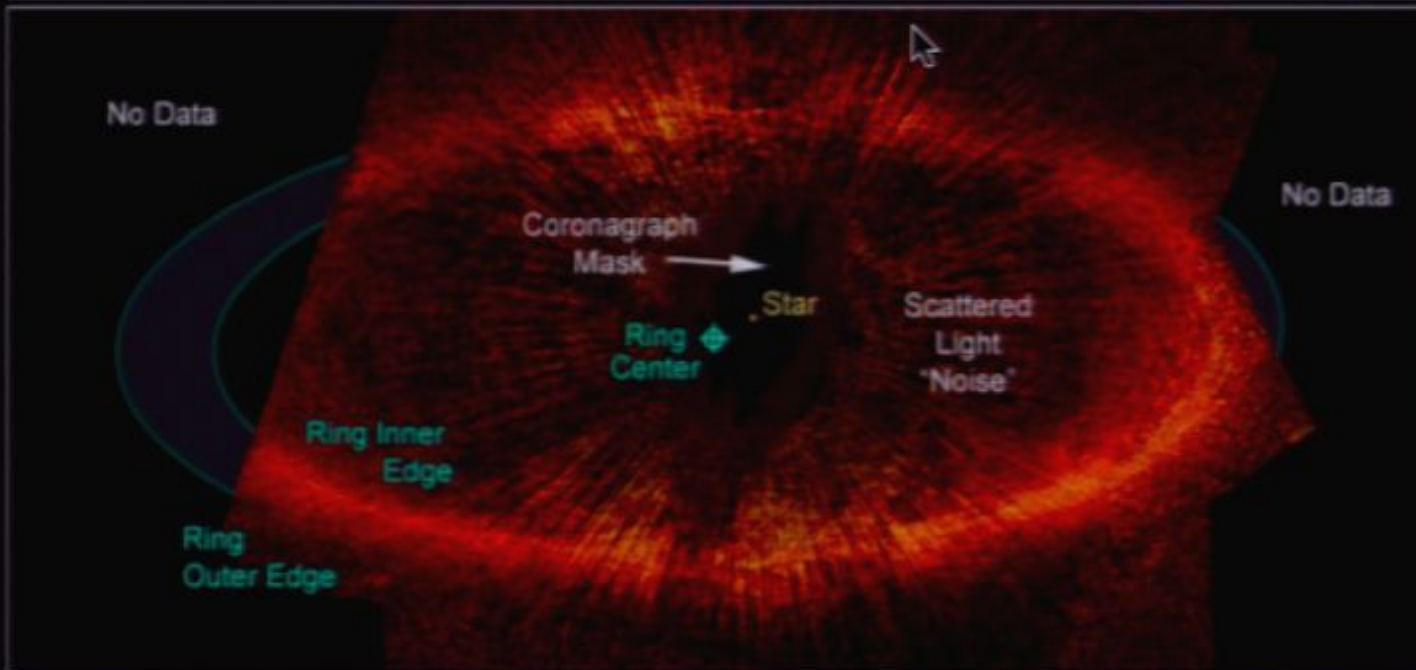
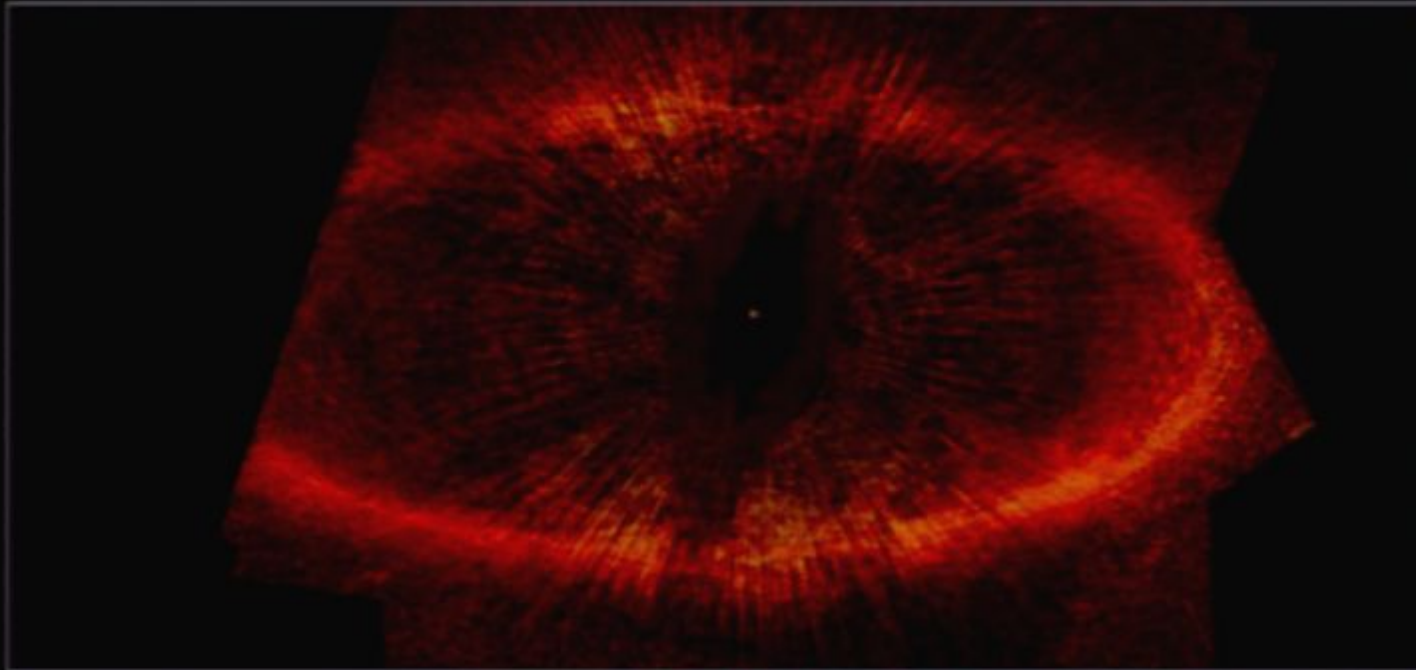


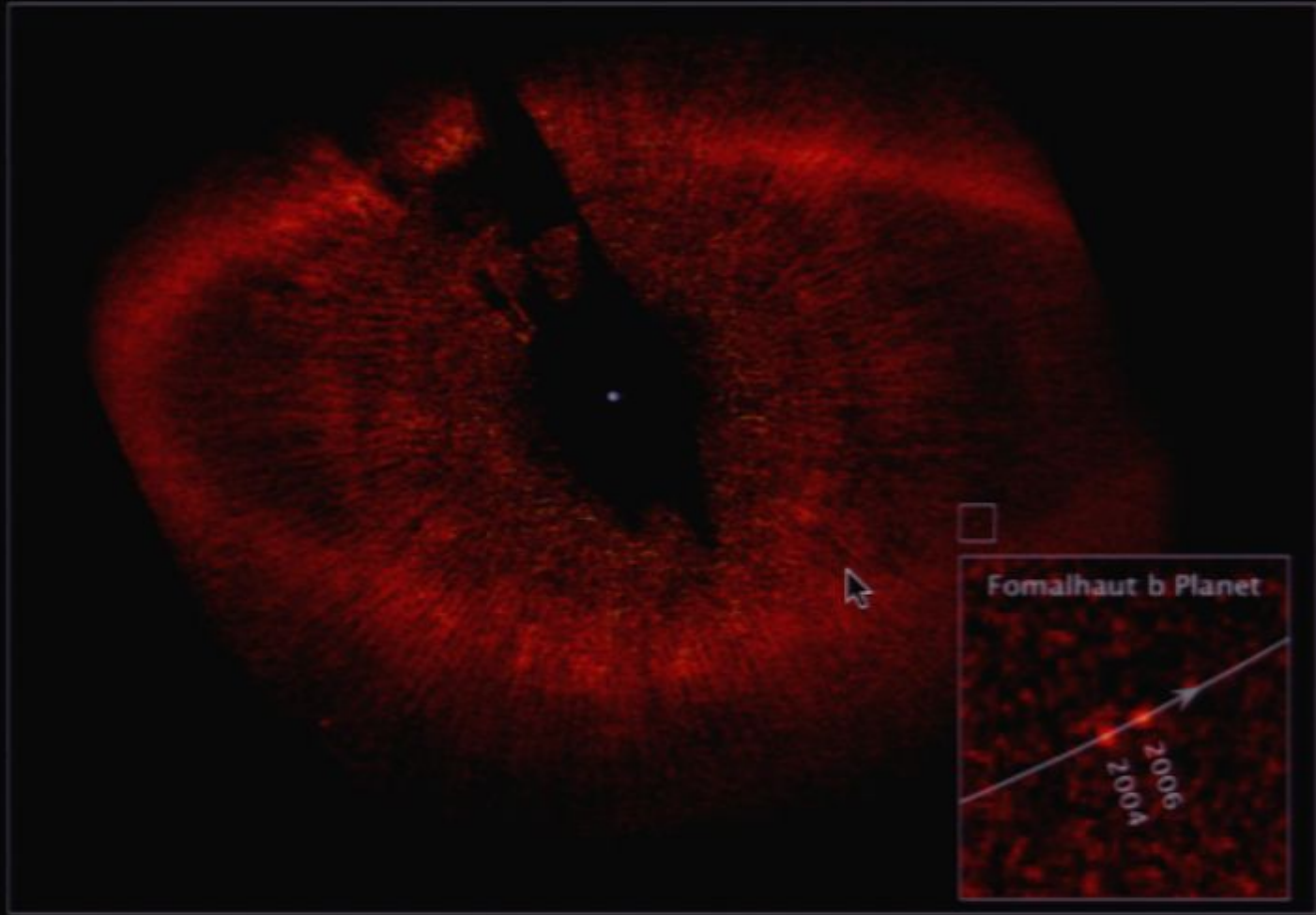
Planetary System Formation



Fomalhaut Debris Ring

Hubble Space Telescope • ACS HRC

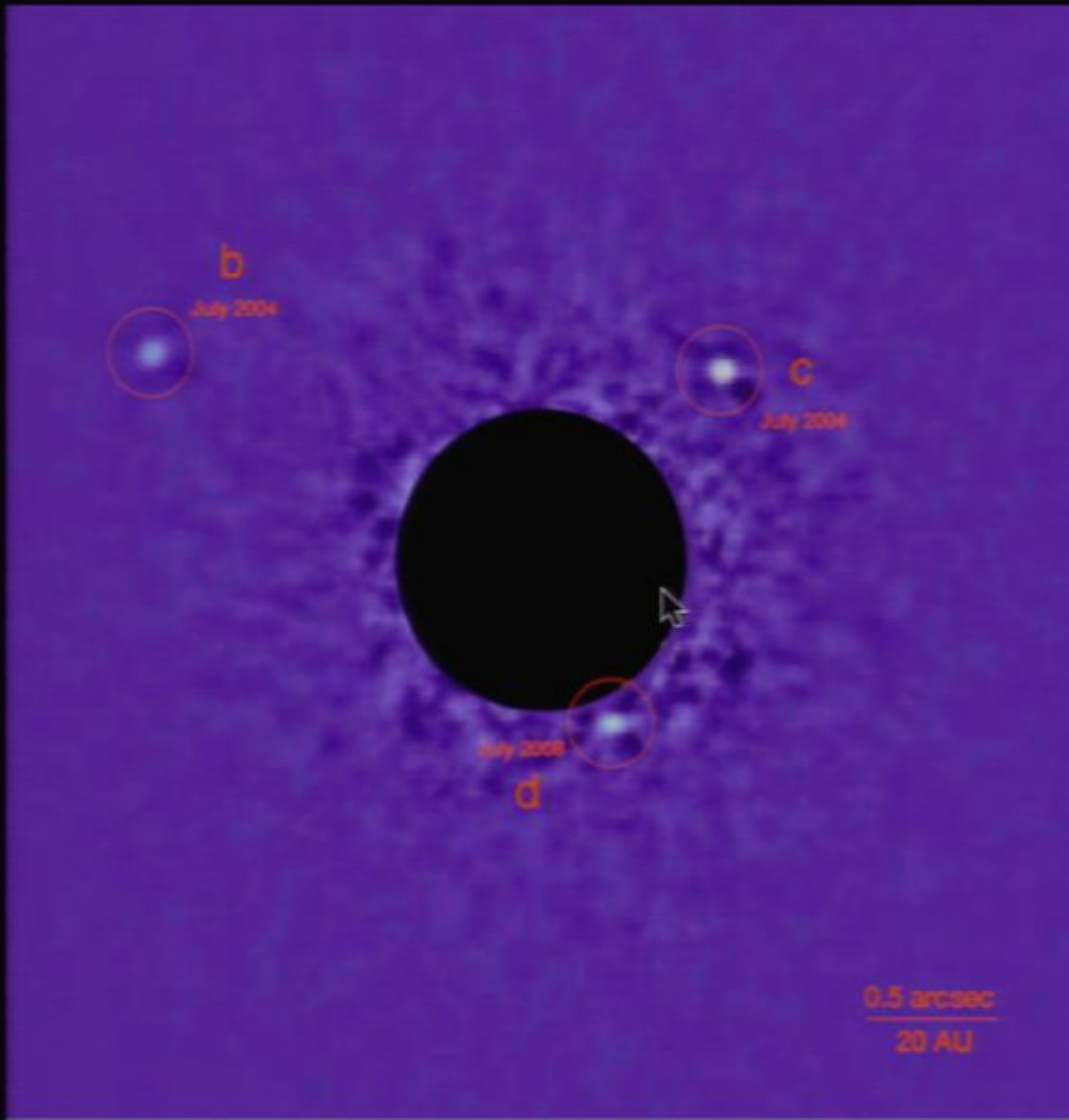




Fomalhaut System
Hubble Space Telescope • ACS/HRC

NASA, ESA, and P. Kalas (University of California, Berkeley)

STScI-PRC08-38a



Gemini Observatory / NRC / AURA / Christian Marois, et al.

Gemini Observatory Legacy Image



Forming Planetary Systems

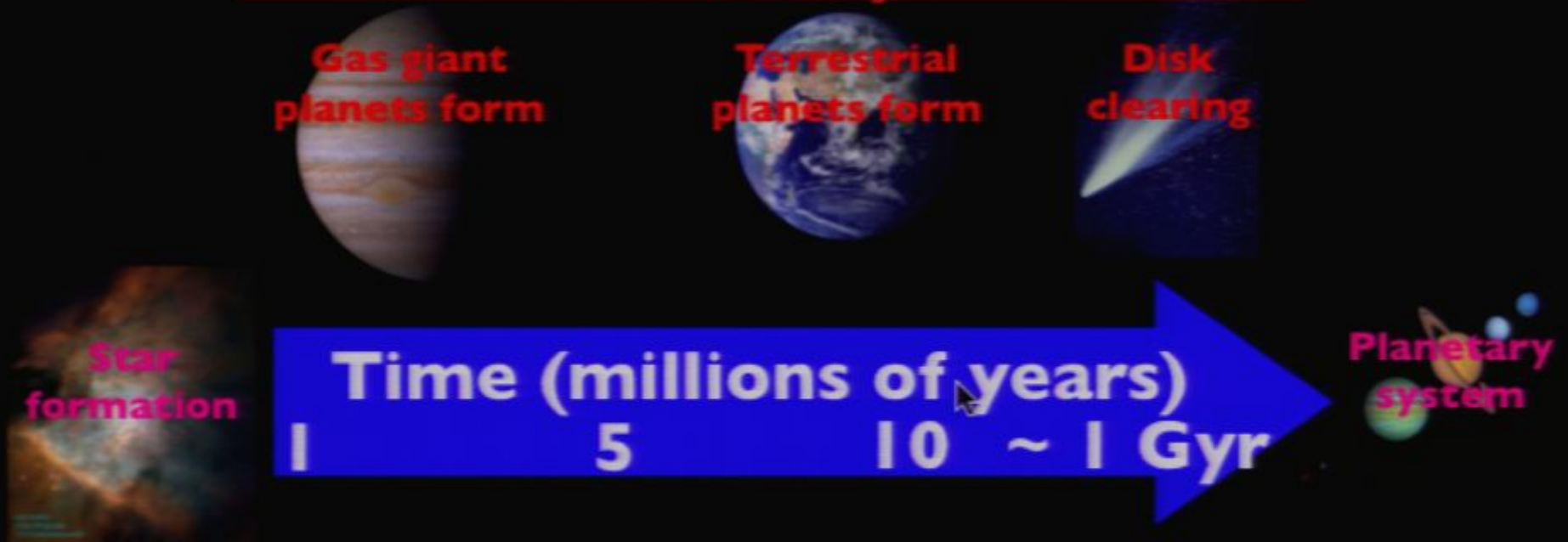


Forming Planetary Systems



Forming Planetary Systems

Theory



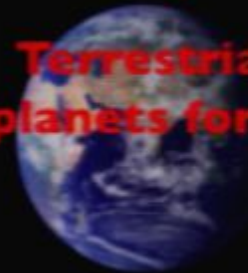
Forming Planetary Systems

Theory

Gas giant planets form



Terrestrial planets form



Disk clearing



Star formation



Time (millions of years)

1 5 10 ~ 1 Gyr

Planetary system



Primordial disk



Transitional disk



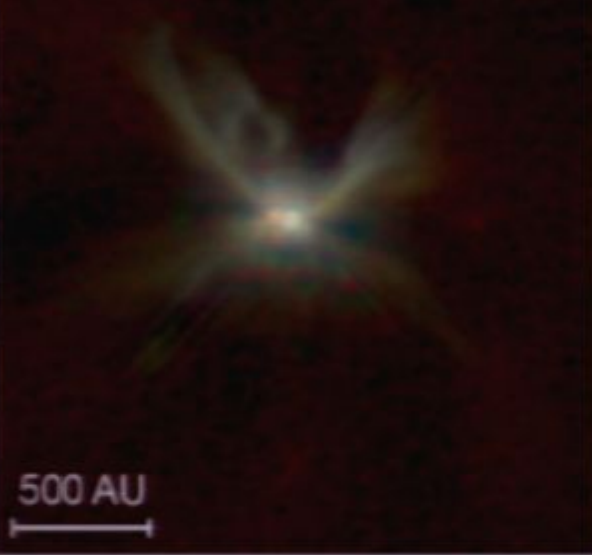
Debris disk



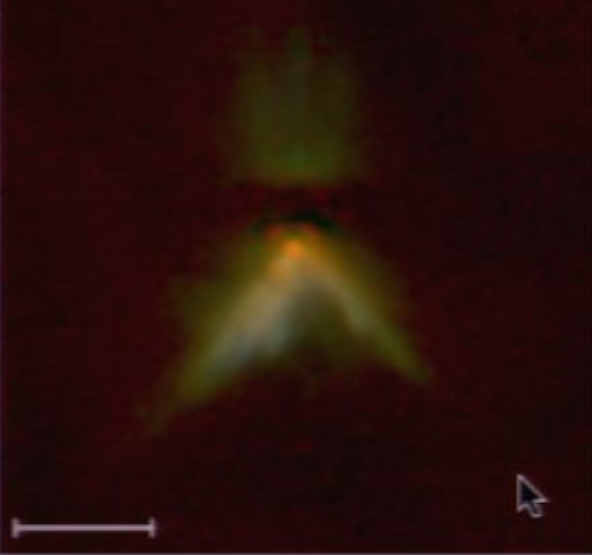
Observation

HST Images of Young Disks

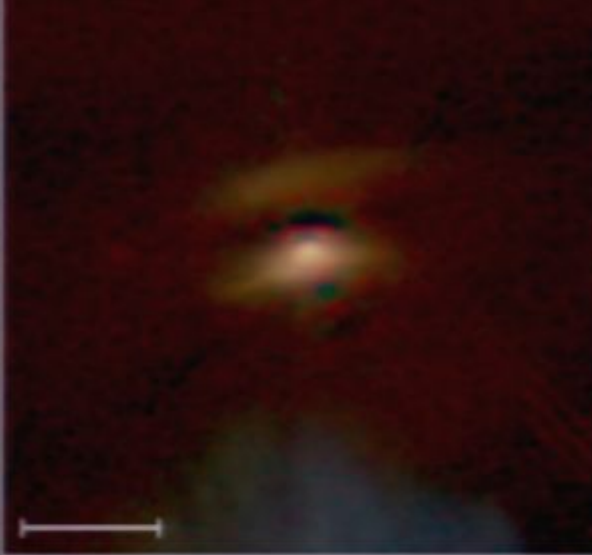
CoKu Tau1



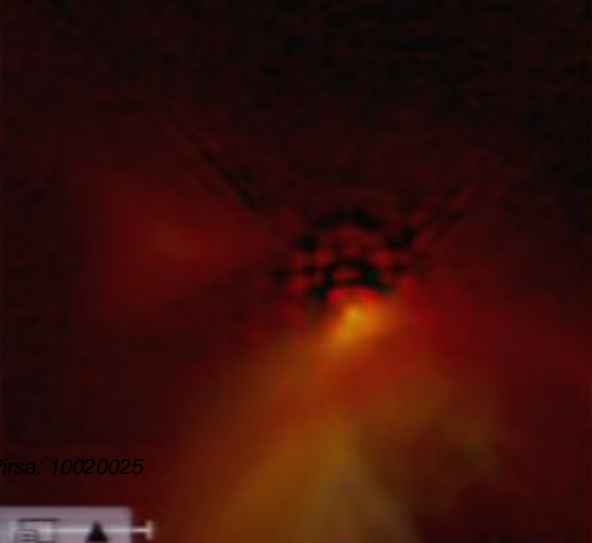
DG Tau B



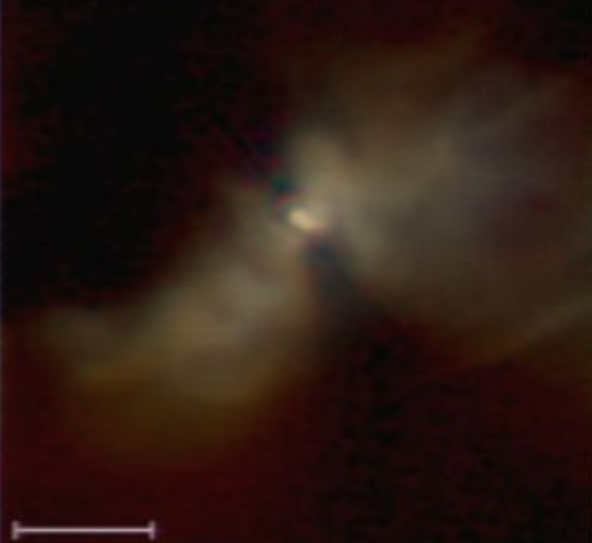
Haro 6-5B



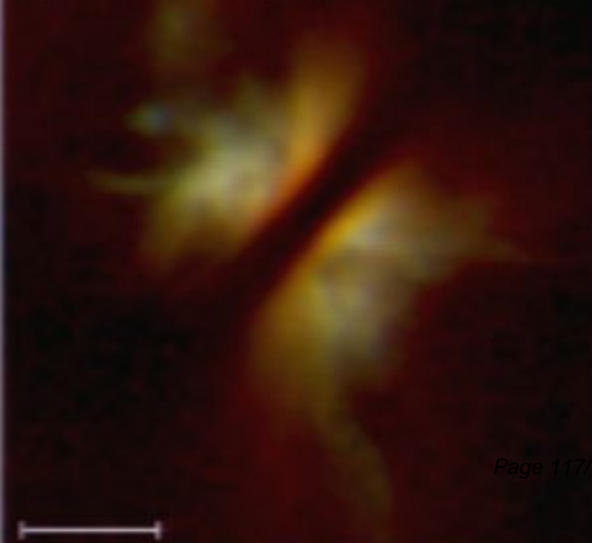
IRAS 04016+2610



IRAS 04248+2612

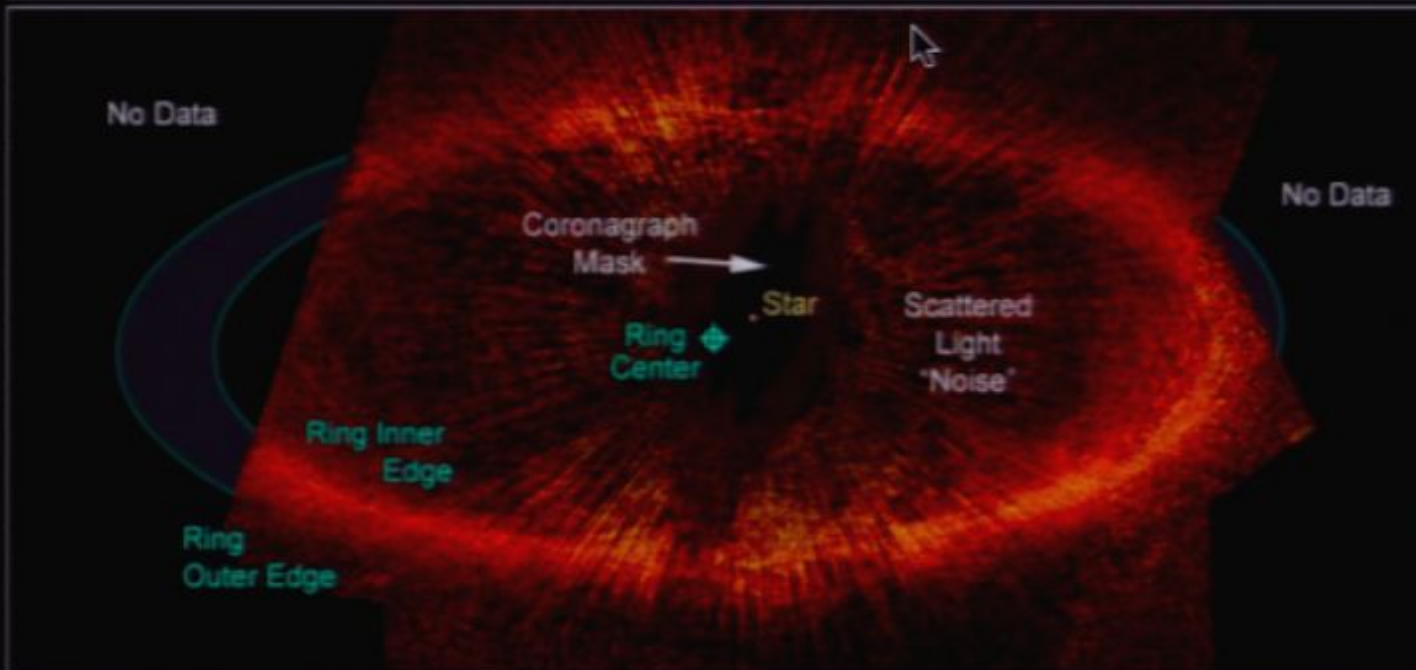
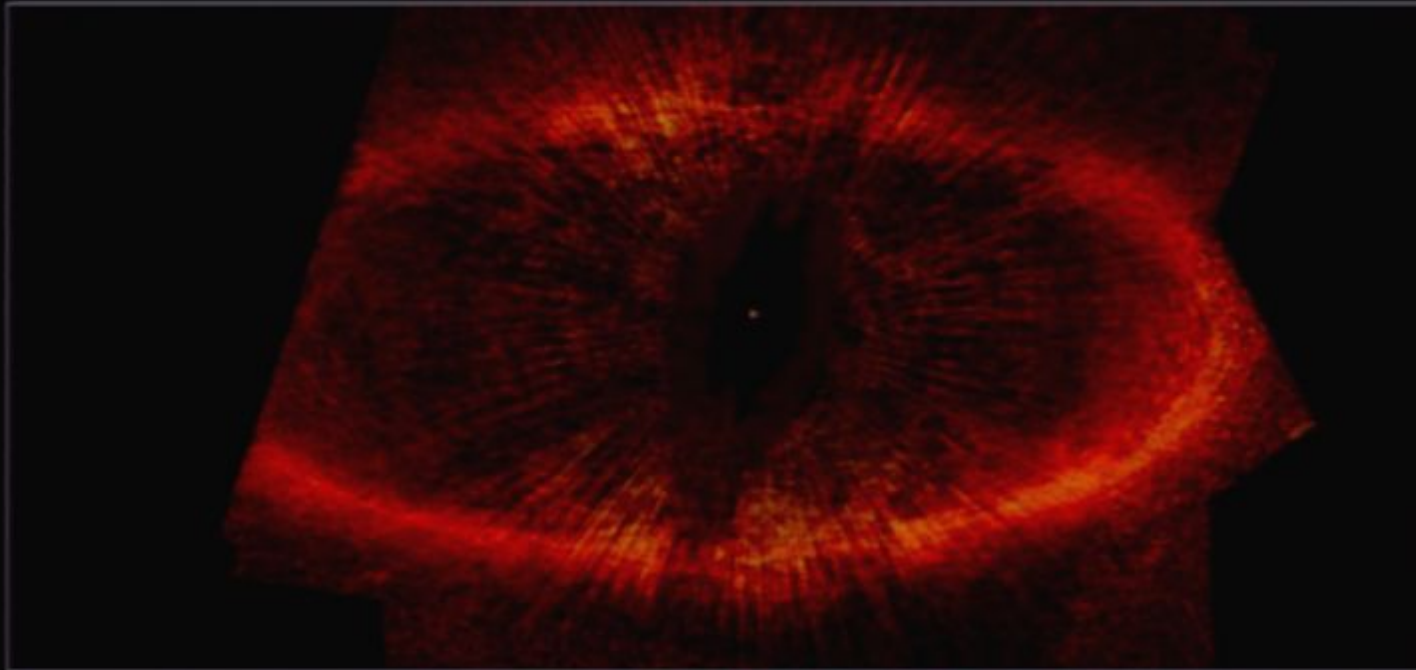


IRAS 04302+2247

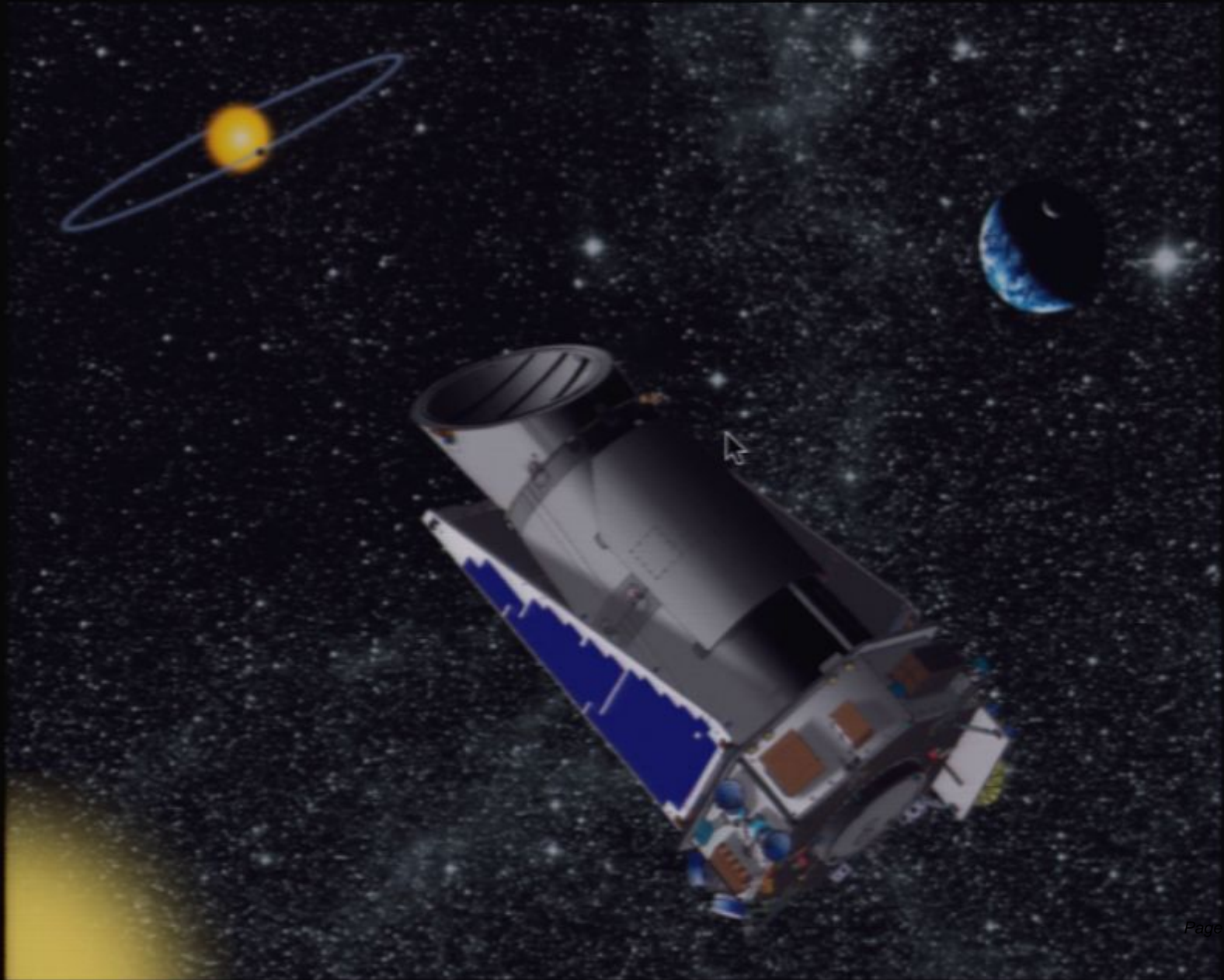


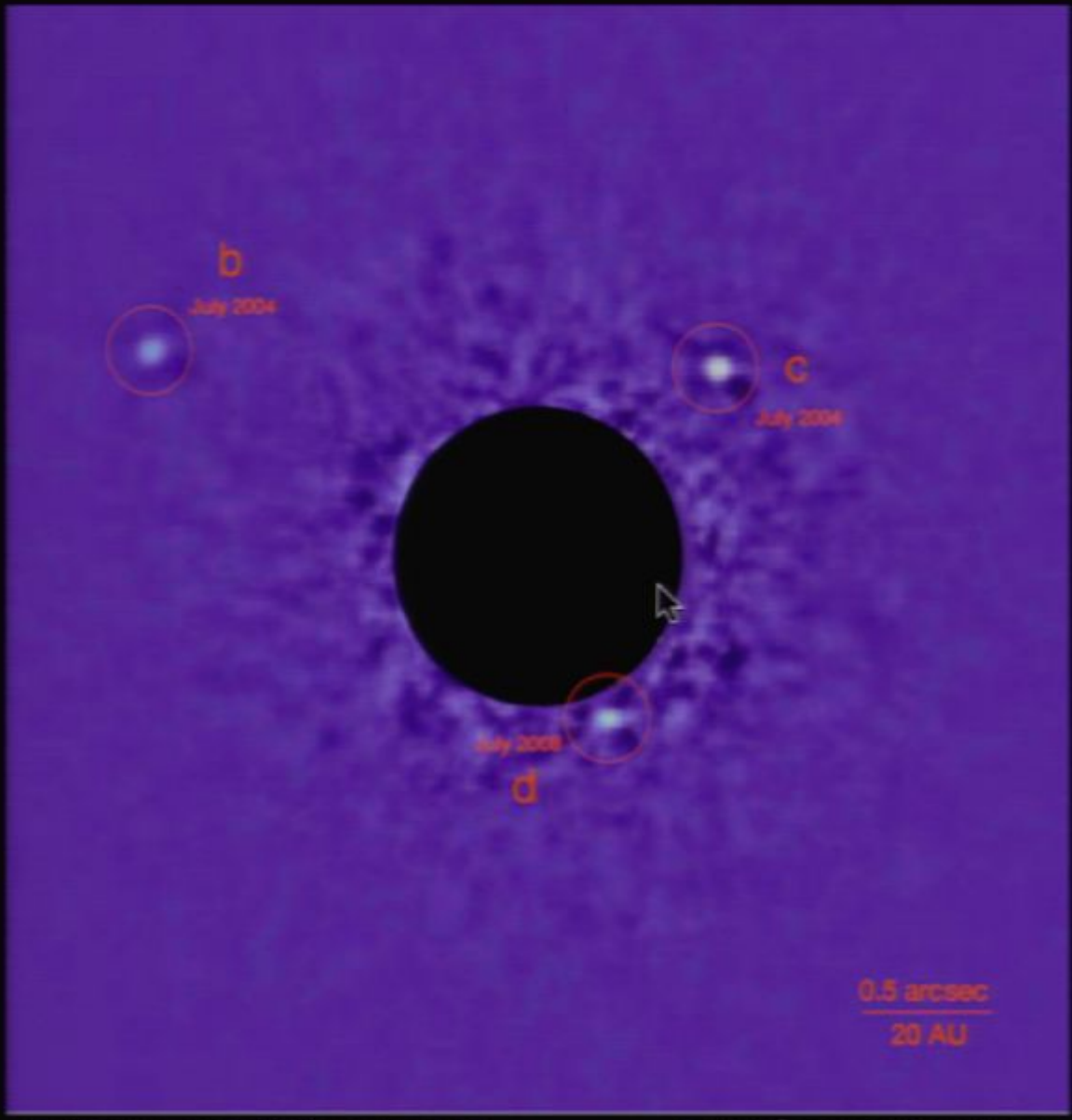
Fomalhaut Debris Ring

Hubble Space Telescope • ACS HRC



Kepler: A Space Telescope Finding Transiting Planets

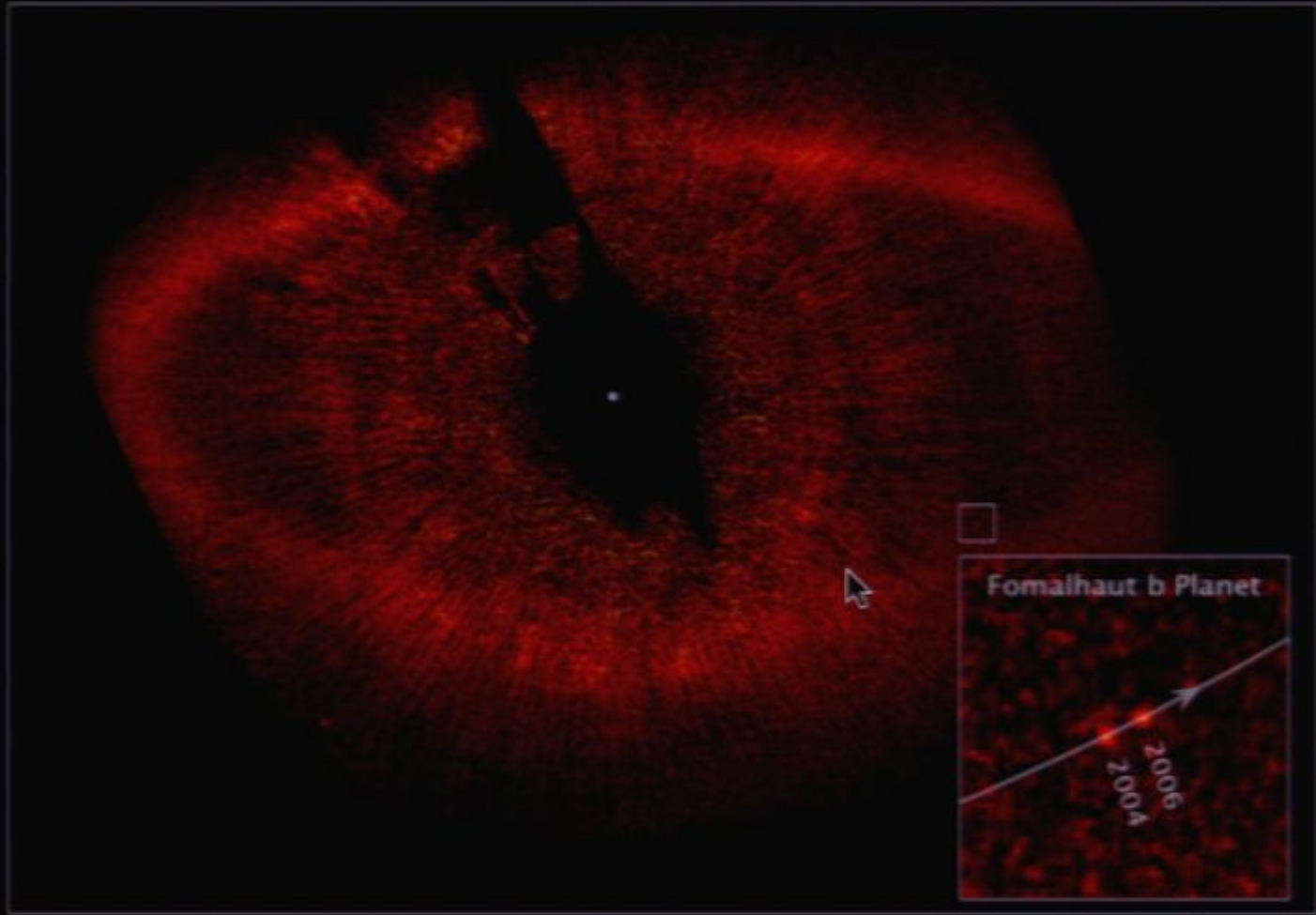




Gemini Observatory / NIRC / AURA / Christian Marois, et al.

Gemini Observatory Legacy Image



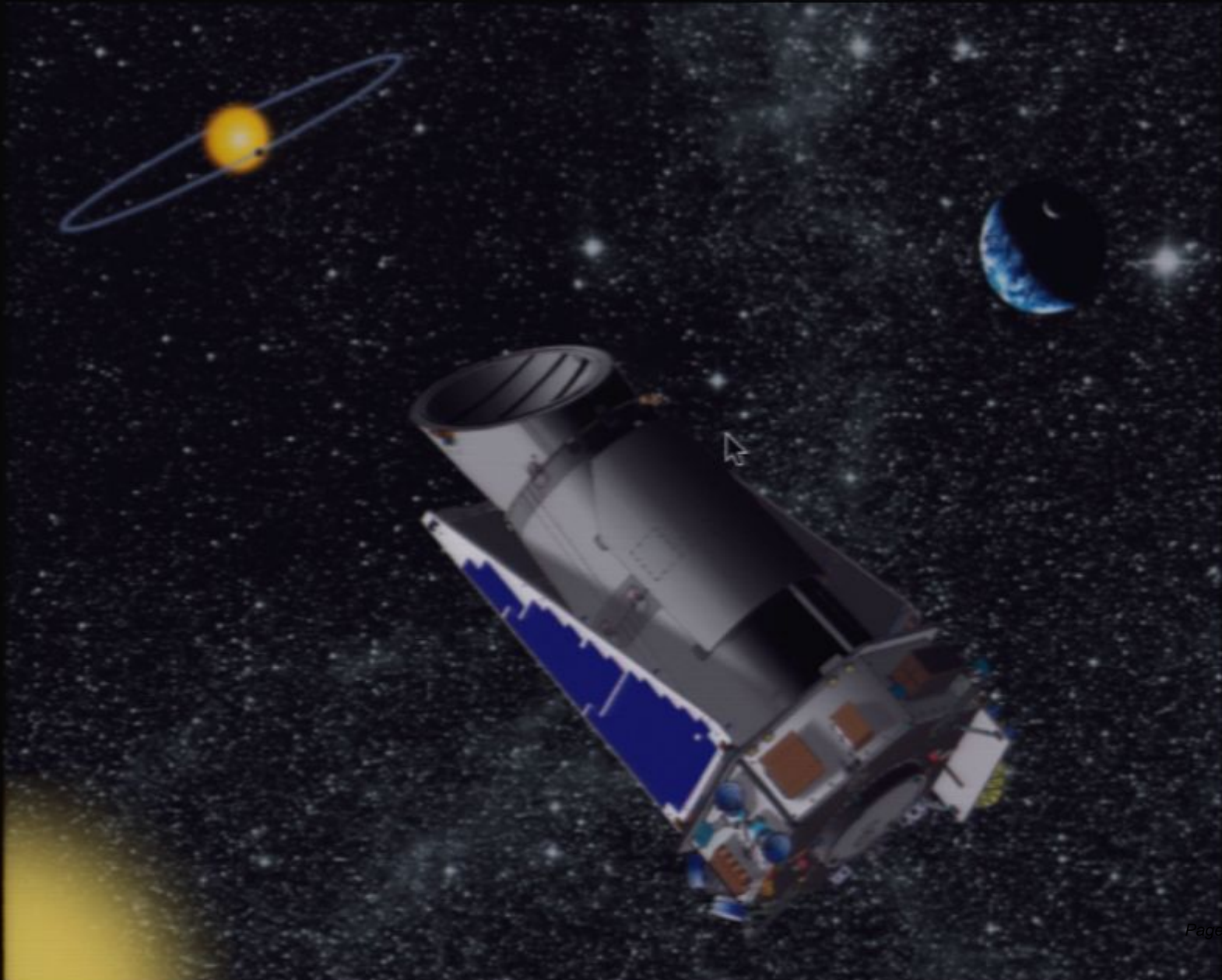


Fomalhaut System
Hubble Space Telescope • ACS/HRC

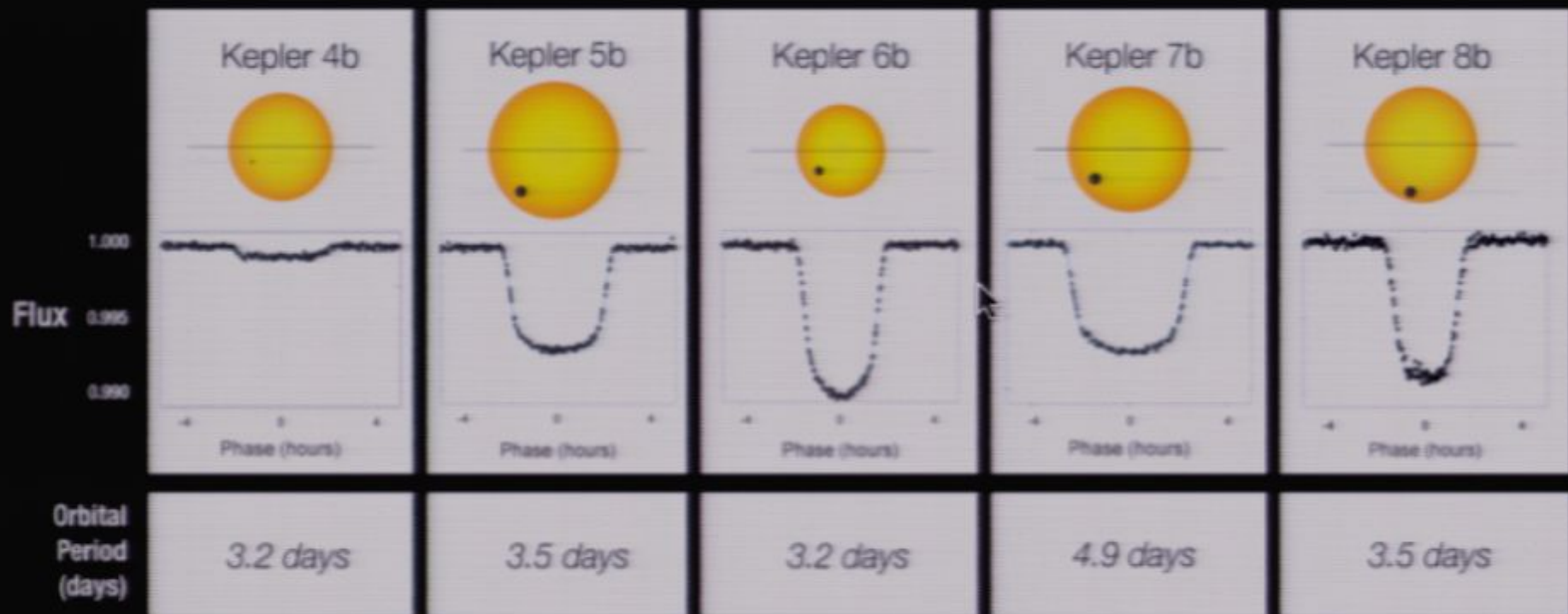
NASA, ESA, and P. Kalas (University of California, Berkeley)

STScI-PRC08-38a

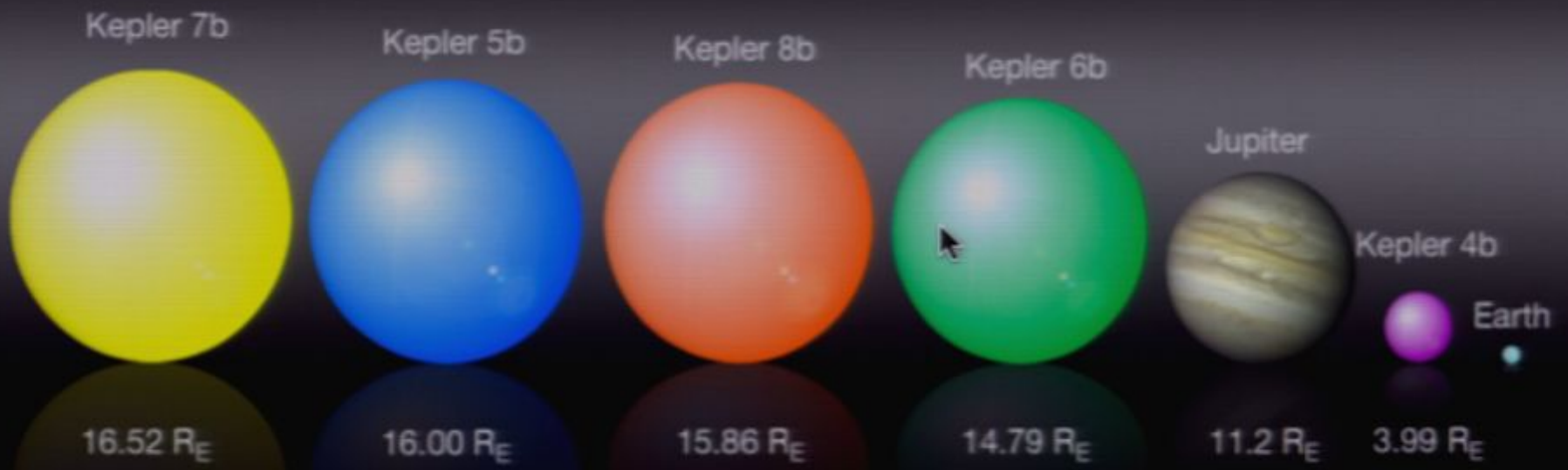
Kepler: A Space Telescope Finding Transiting Planets

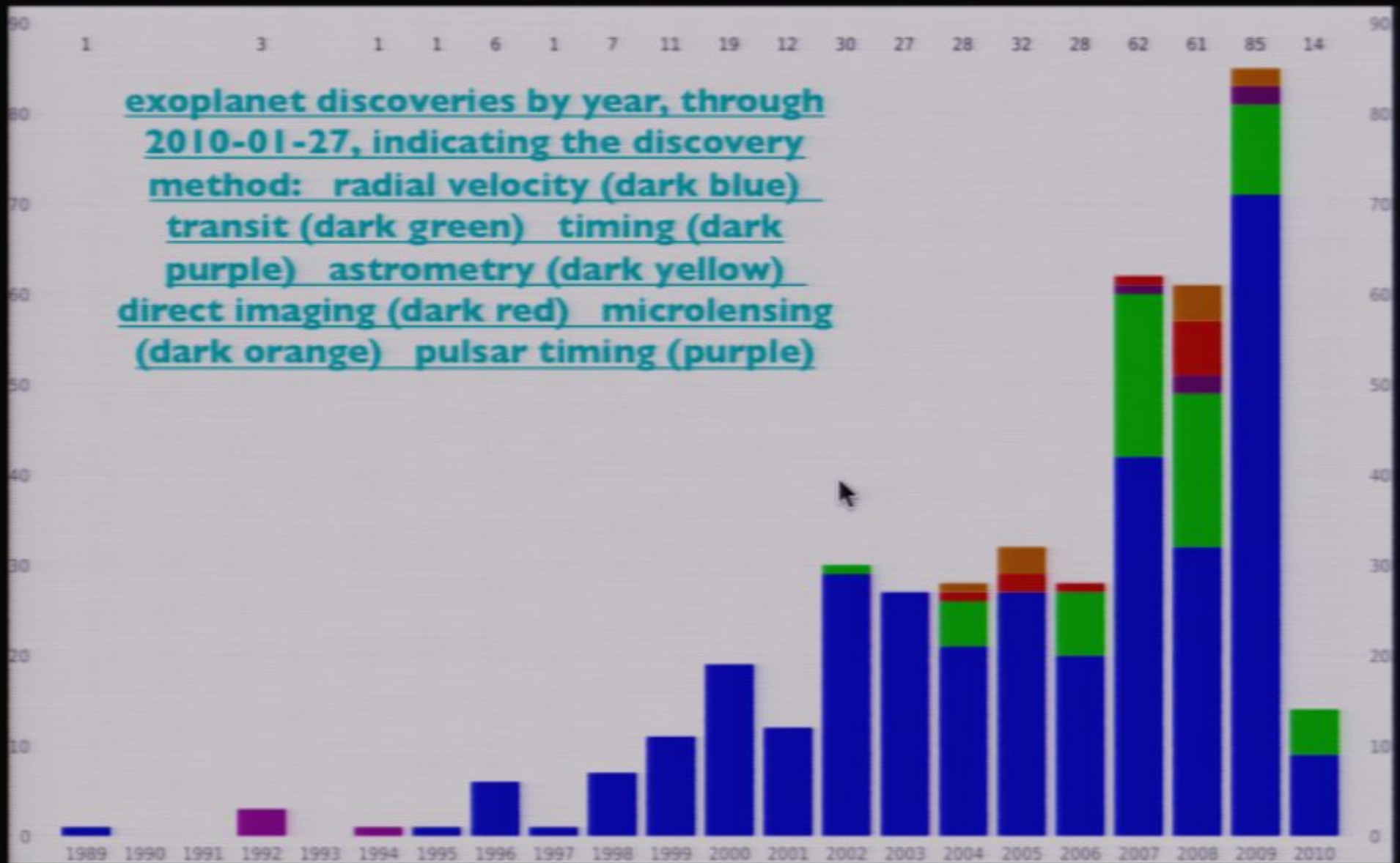


Transit Light Curves

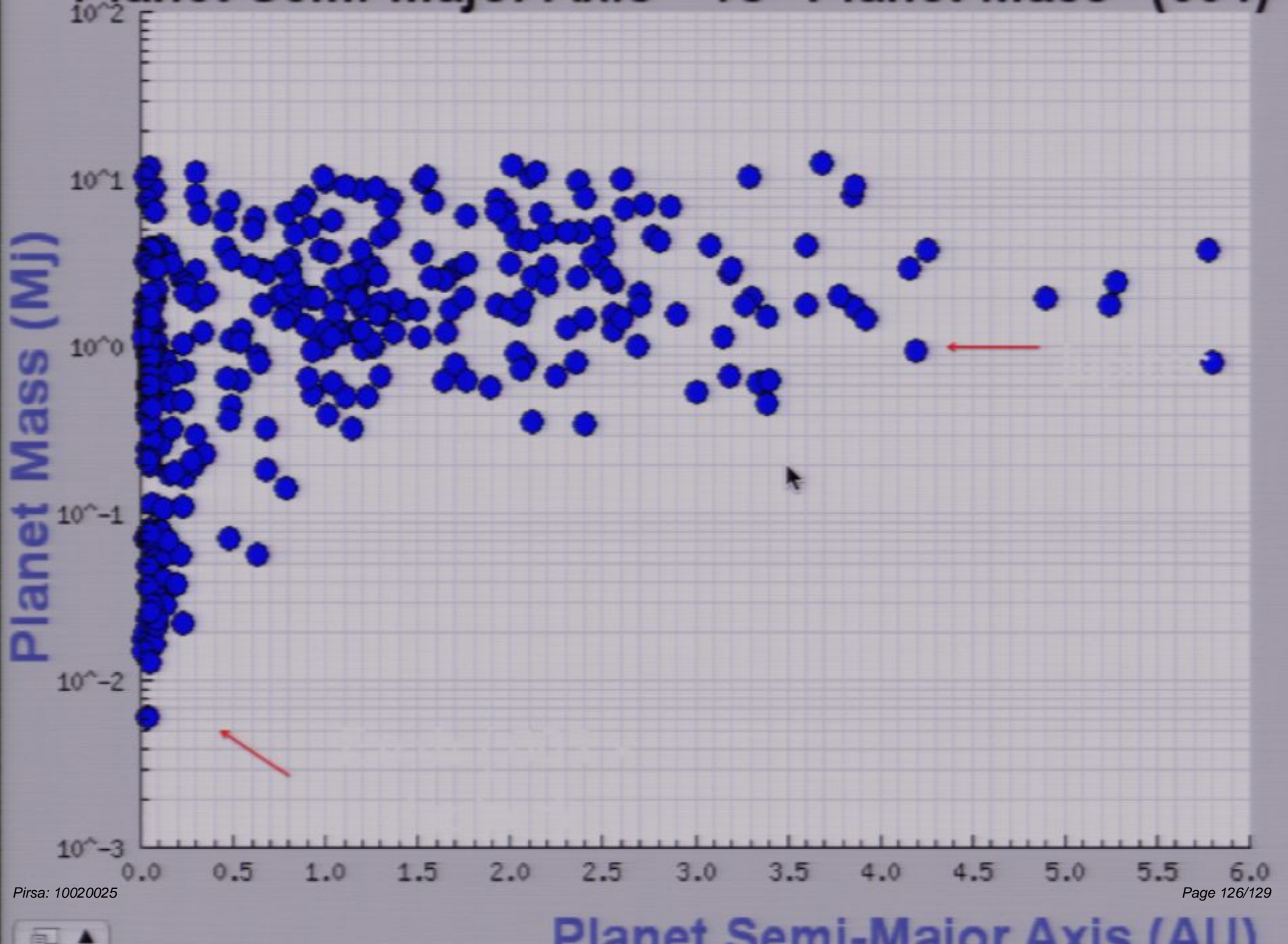


Planet Size





"Planet Semi-Major Axis" vs "Planet Mass" (354)



Methane Absorption by the Atmosphere of Extrasolar Planet 189733b

(Swain et al. 2008)

Starlight
filters through
planetary
atmosphere



Methane in the planet's
atmosphere absorbs starlight





