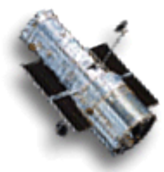
Hubble Space Telescope

STUC Meeting – April 2012

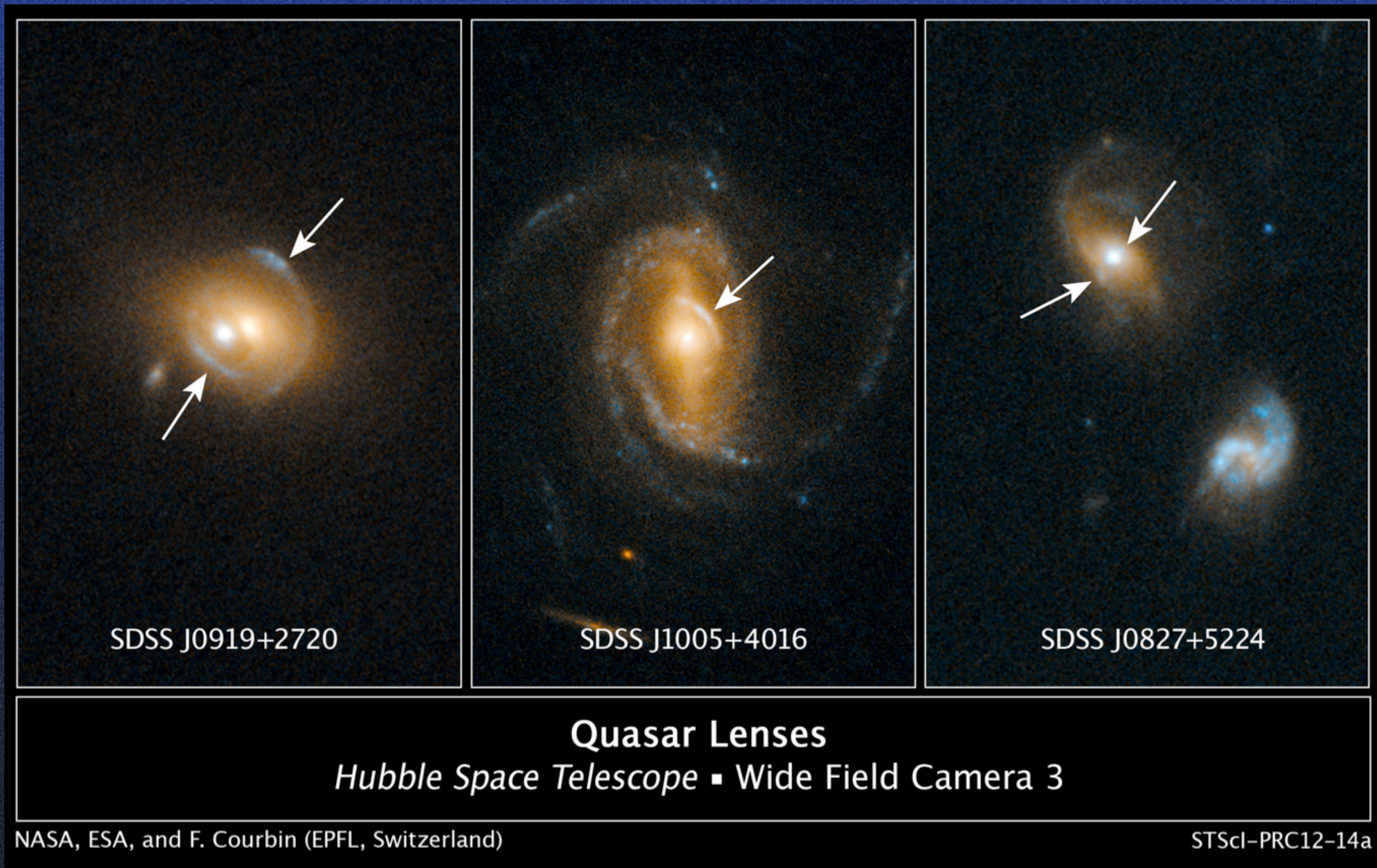
K. Sembach

Hubble Space Telescope
Powers of 10

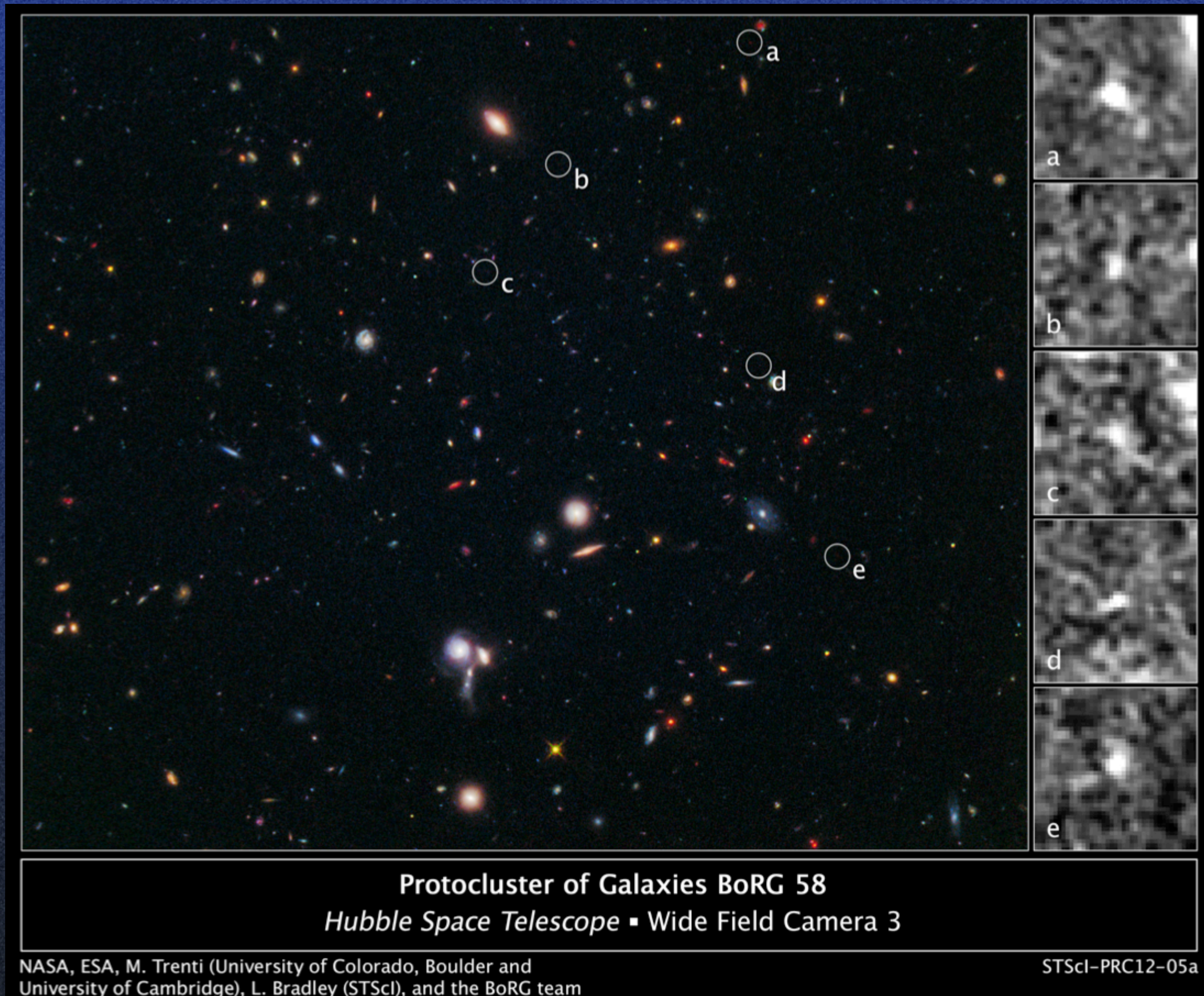


1,000,000	Observations
100,000	Citations received in past two years
10,000	Refereed papers
1,000	Proposals received each year
100	Graduate students supported each year
10	Redshift of most distant galaxy candidate
1	Nobel prize

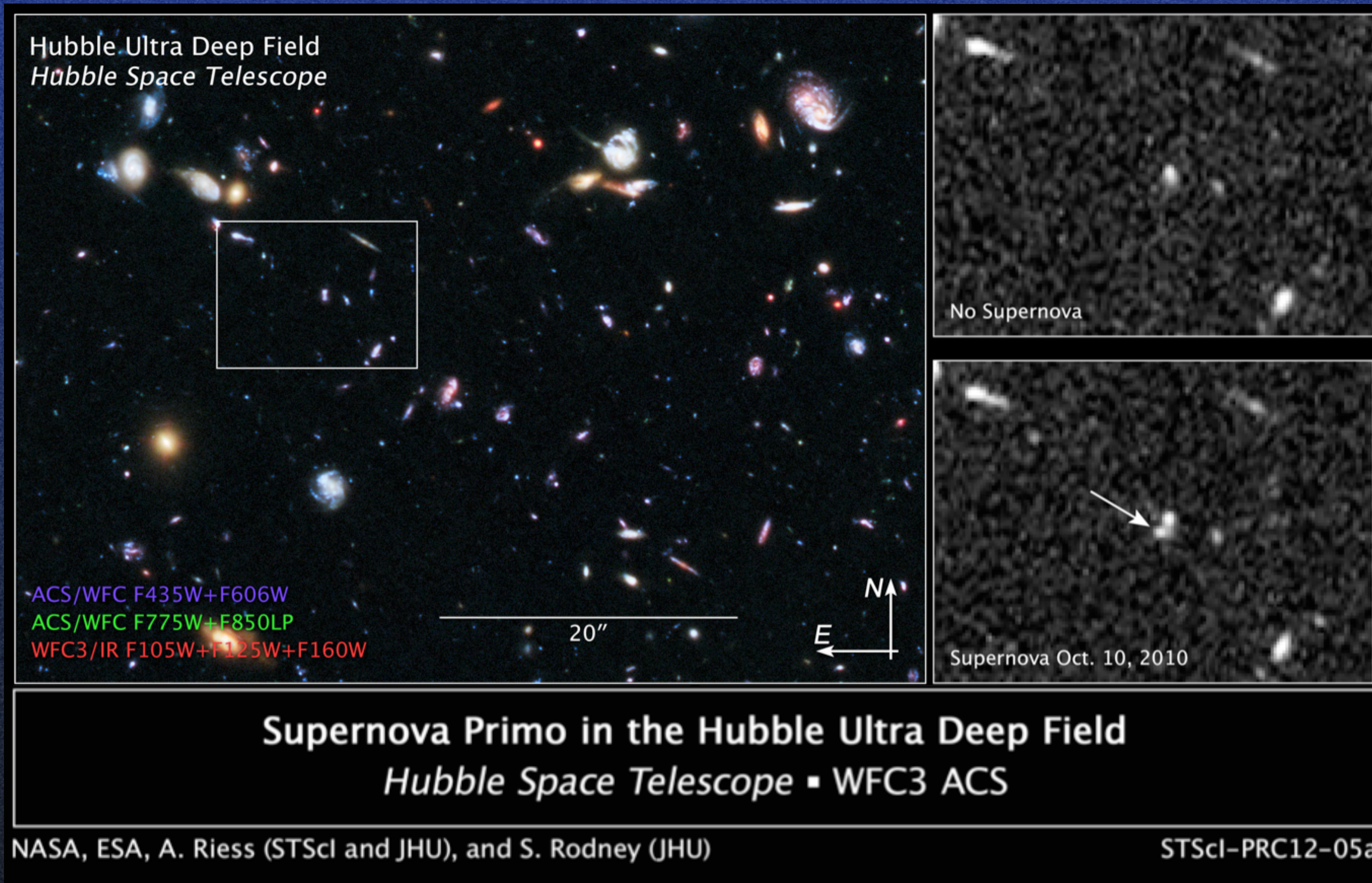
Astronomers Using Hubble Discover Quasars Acting as Gravitational Lenses



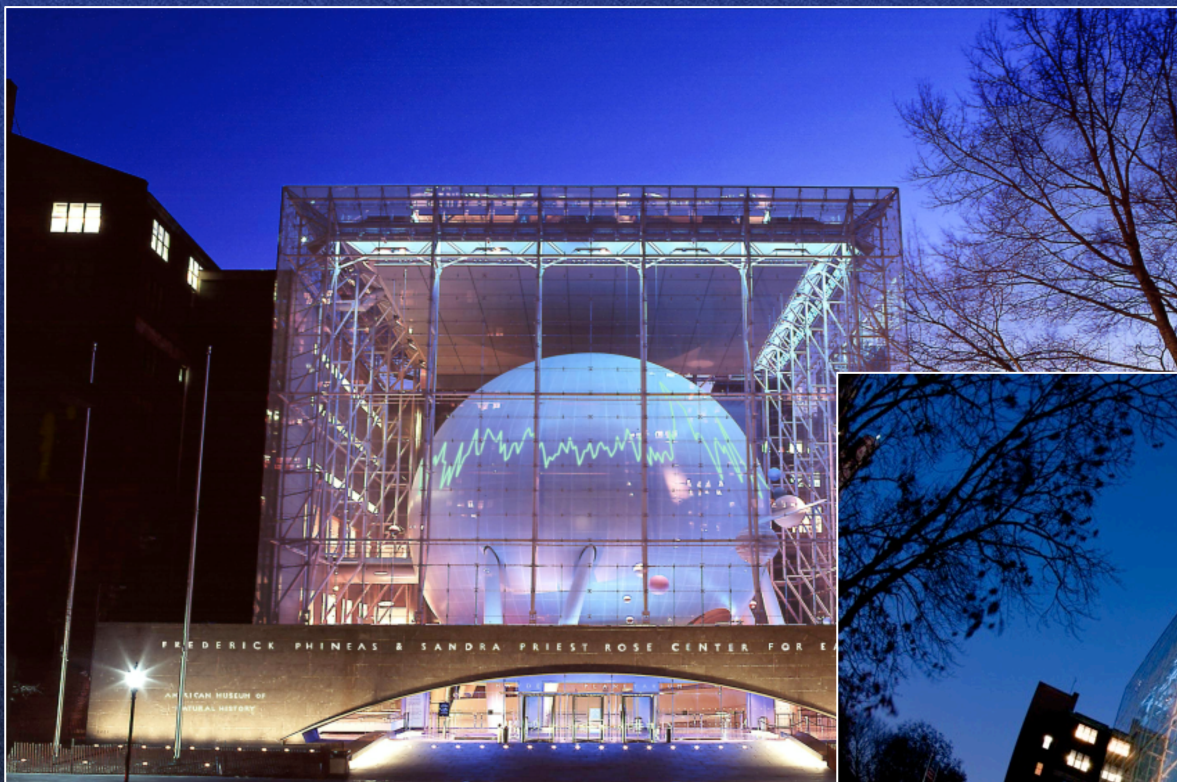
Hubble Pinpoints Farthest Protocluster of Galaxies Ever Seen



Hubble Breaks New Ground with Distant Supernova Discovery



Art Meets Science



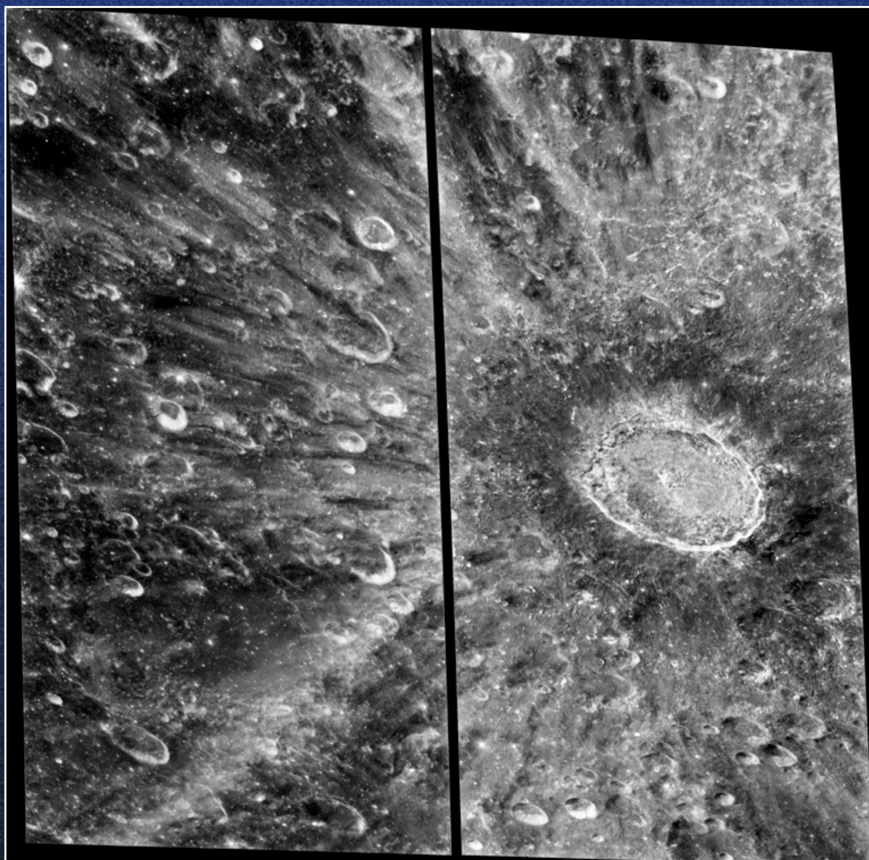
From the Distant Past

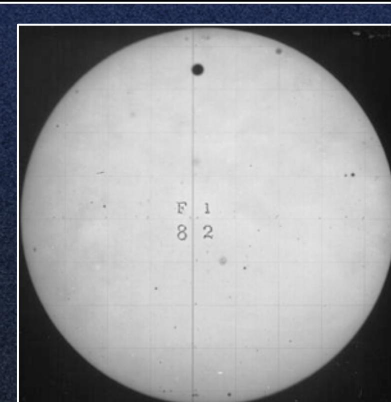
From the Distant Past

Artist Tim Otto Roth in front of AMNH

Hubble Shoots the Moon

"Venus Observed as an Extrasolar Planet"
Program 12537 (PI =D. Ehrenreich - Université de Grenoble)
Preparation for June 6, 2012 transit of Venus across the Sun





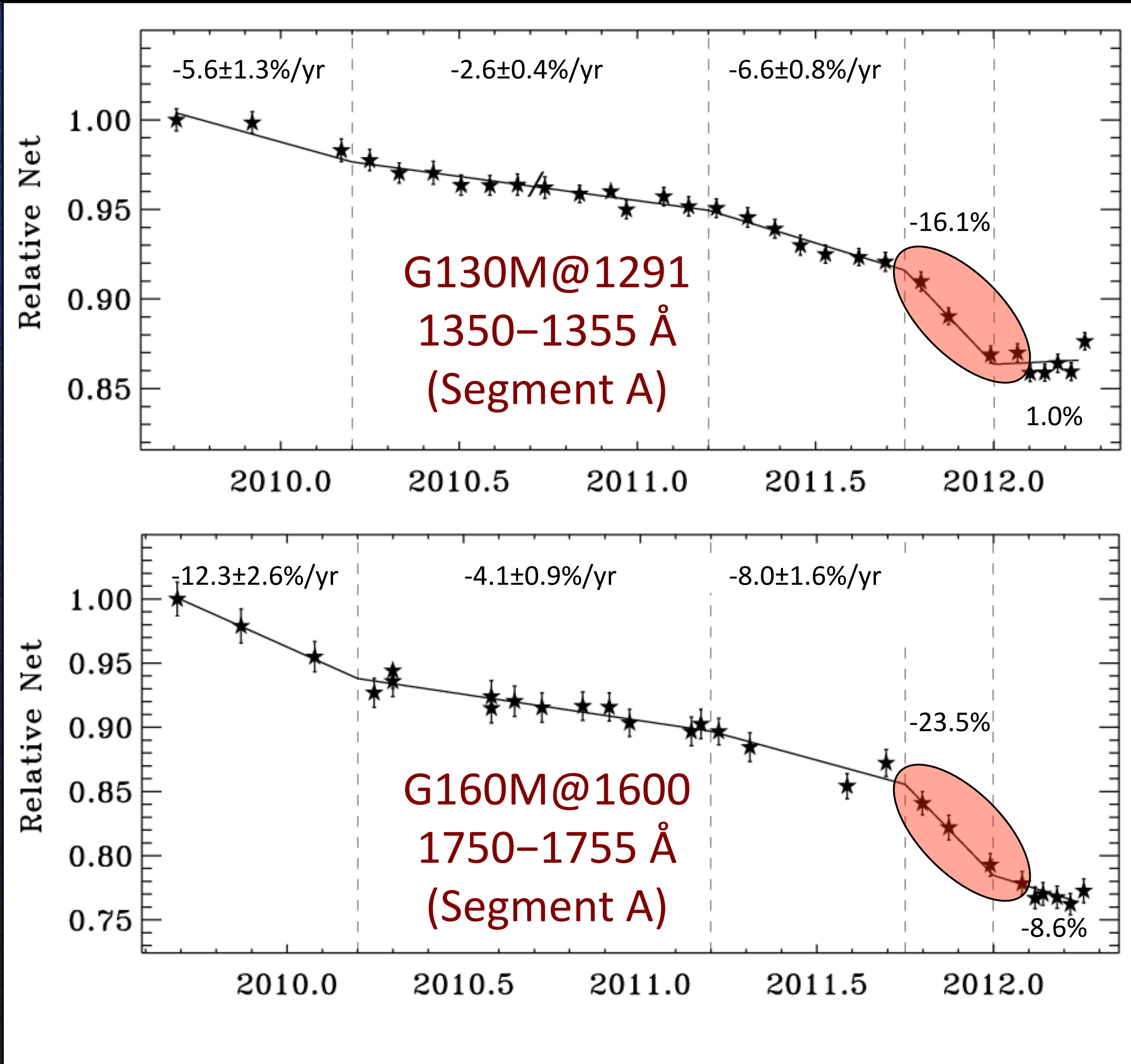
WFC3/UVIS F280N image of Tycho (60 s)
Scale: ~75m/pix => 154 km x 154 km

Happy 22nd Birthday!

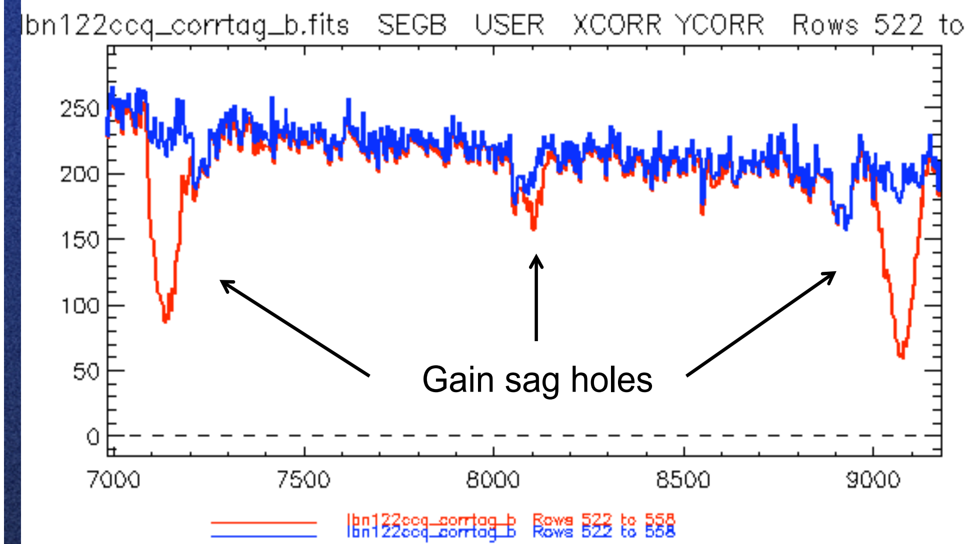
Surprise!

COS Sensitivity

- FUV sensitivity has been decreasing since launch - still excellent.
- Decreasing sensitivity was expected, but the rate is faster than expected.
  - Cause is unknown
  - Internal outgassing
  - External, Earth atmosphere



Mitigating COS Gain Sag Effects



Blue ➔ PHA=[2,30] **Red** ➔ PHA=[4,30]
G160M/1577 data from program 12424, obtained on Dec 22nd 2010.

Short-term solutions

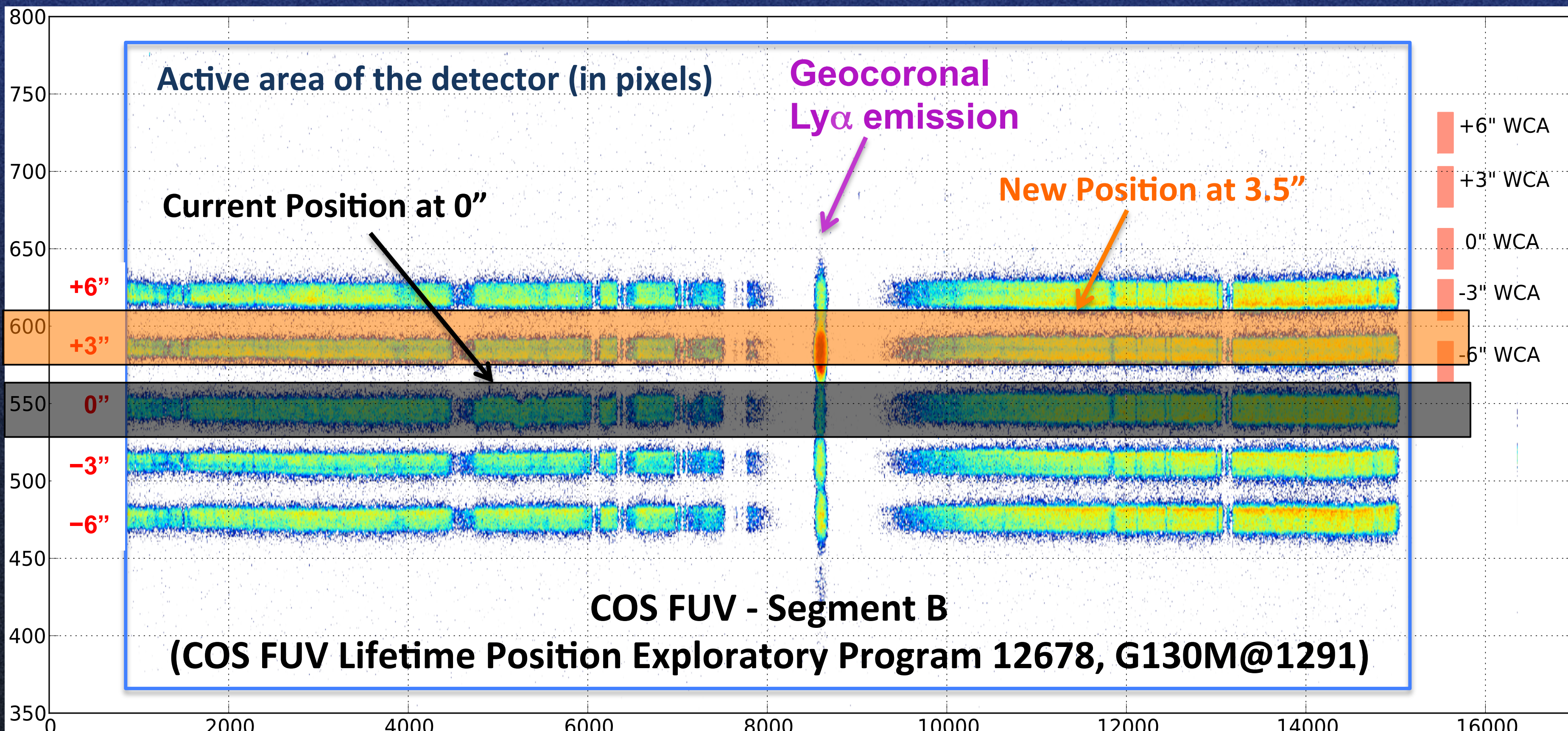
- Increase high voltage to restore gain
  - No more headroom
- Use of all FP-POS positions per setting recommended starting from Cycle 19
  - mitigates effects of gain-sag holes from geocoronal Lyα on data
  - spreads additional Lyα damage on detector and delays onset of new holes

Long-term solutions

- Gain-sag map to flag and reject gain-sagged regions when combining multiple FP-POS positions
- Move to a new "lifetime" position on the detector
  - COS aperture is shifted to project spectra onto pristine part of detector

Moving to a New COS Lifetime Position

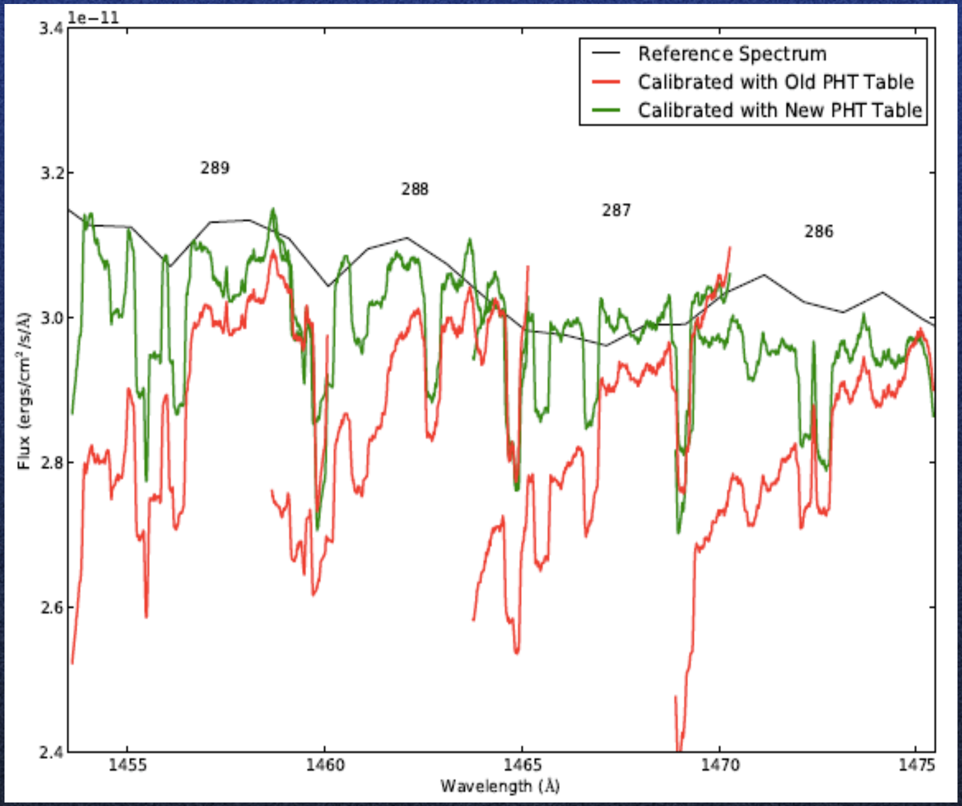
- New position located at +3.5” in cross-dispersion direction
  - Resolution at new position only 7-10% degraded compared to current position
- Science operations at new position currently planned for early July 2012
- Additional calibration to be performed in parallel with science over summer 2012



Post-SM4 STIS Echelle Absolute Flux Calibration

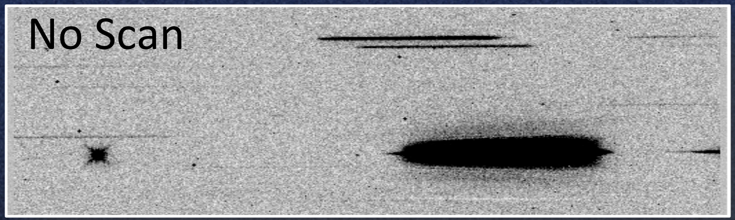
- Flux calibration of echelle settings
  - Wavelength-dependent decline of sensitivity with time (similarly to other STIS modes)
  - Time-dependent shift of blaze function (in addition to spatial dependence)
- New baseline for sensitivity of all echelle settings taken after SM4
- Current accuracy of echelle absolute flux calibration is ~ 5%
- Temporal evolution of blaze shift is noticeable in some settings
  - to be characterized soon

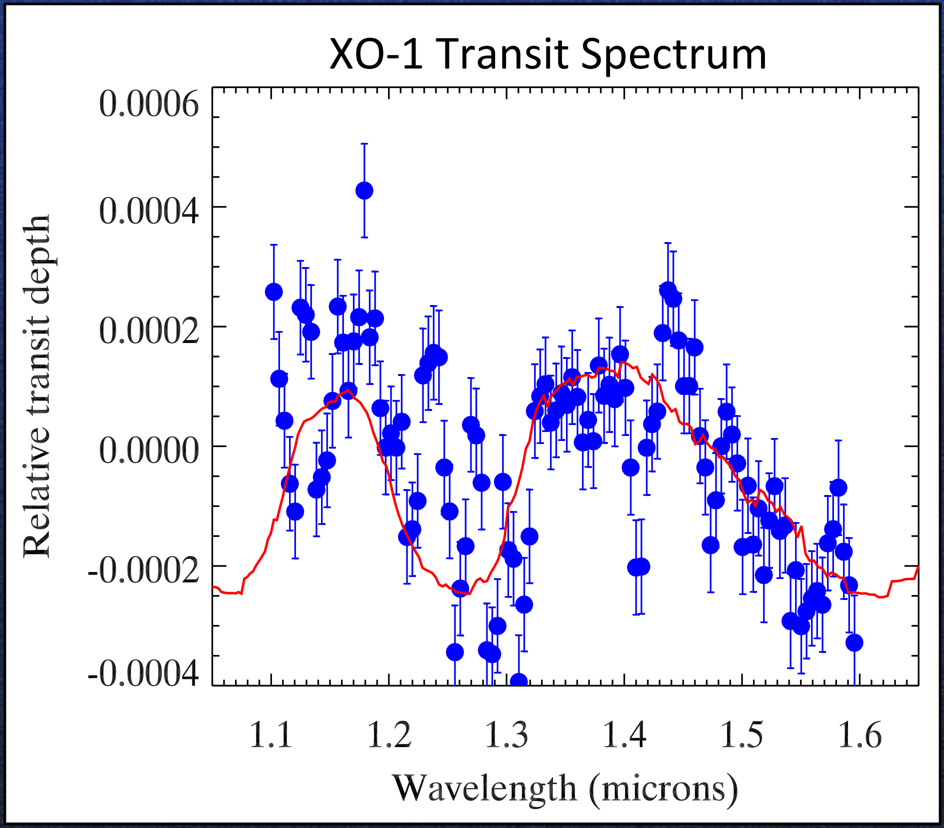
Observations of standard star BD 28D4211 in a few selected orders of E140H @ 1416 Å (Jun 10, 2010)



Spatial Scanning Enables High-Precision WFC3 Photometry and Spectroscopy

- Controlled motion of HST during WFC3 imaging or spectroscopy exposures
- Developed to extend exoplanet science capabilities
- Observations of bright targets that would otherwise saturate detector
- High-precision photometry
  - Averages over many pixels
  - More photons per exposure
  - Less overhead

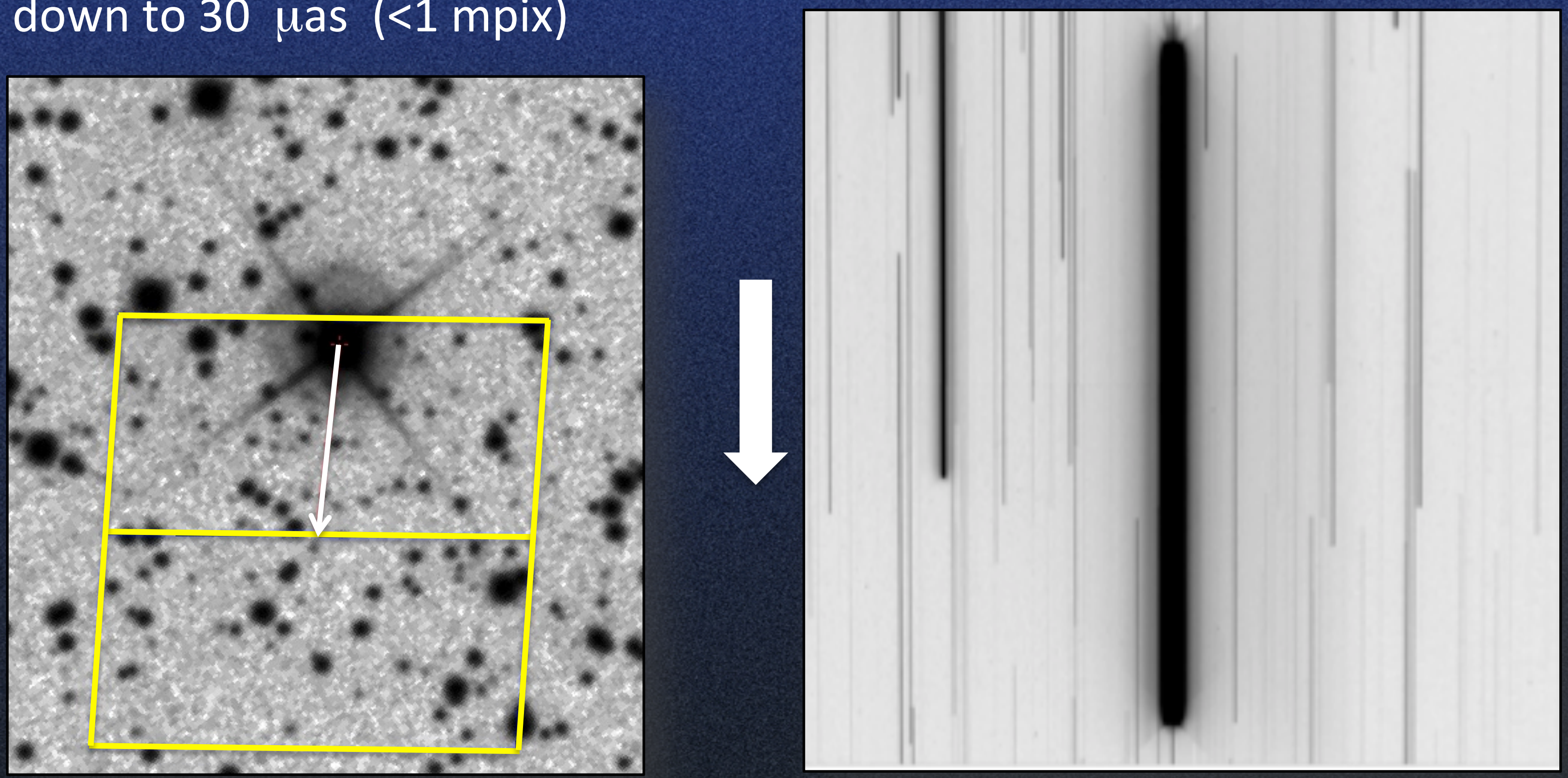




- Exoplanet atmosphere spectroscopy (e.g., Deming et al.)

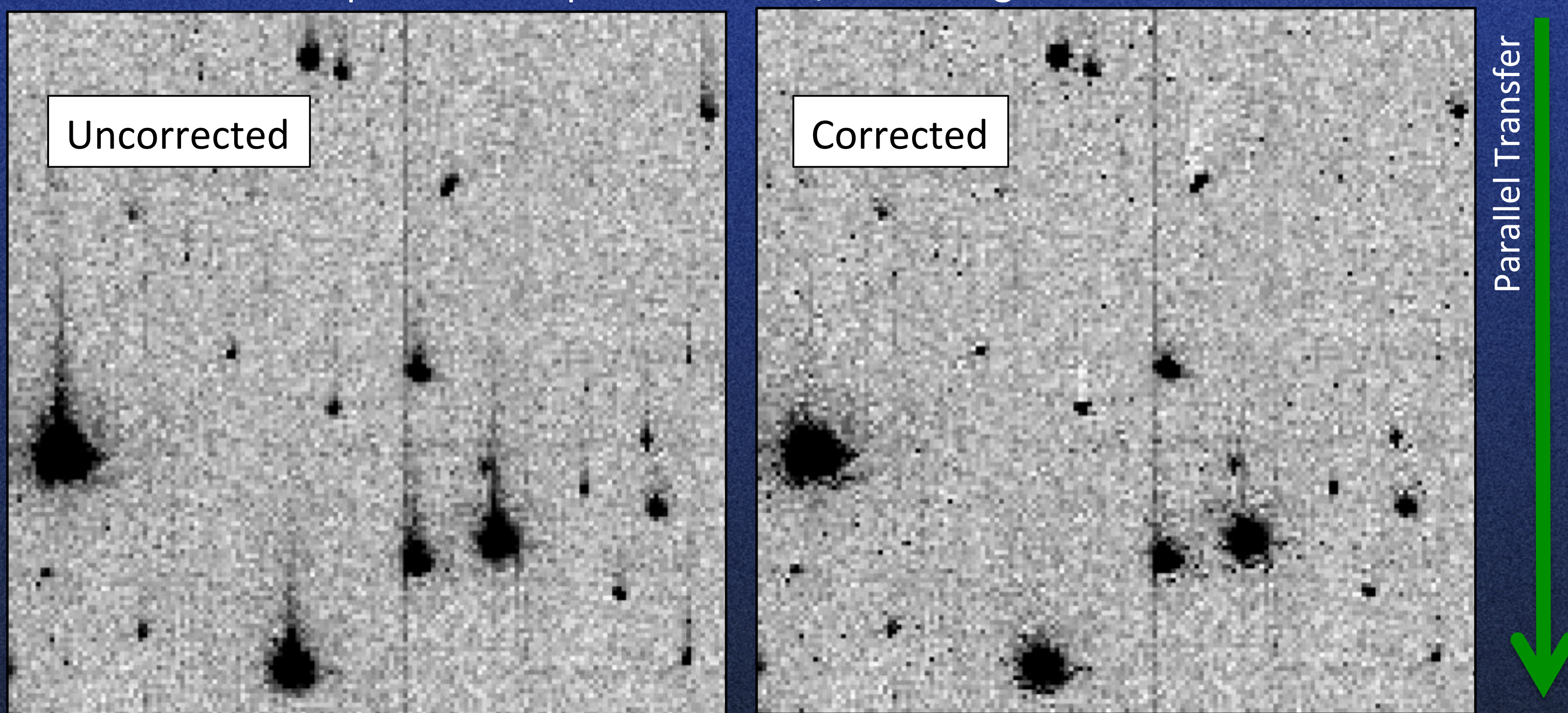
Spatial Scanning Also Enables High-Precision Relative Astrometry

- WFC3/UVIS spatial scans provide root-N averaging over many samples of star-star separation
- Pilot project shows promise of improving parallax precision from 400 μas down to 30 μas (<1 mpix)

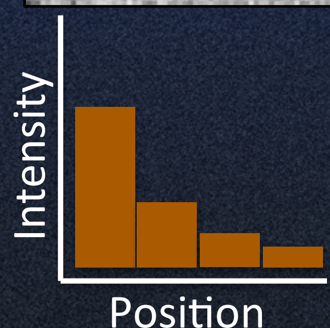


New Techniques
Turn Back the ACS CCD Aging Clock

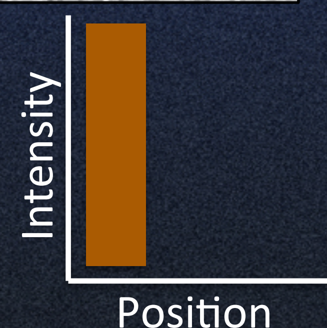
A portion of a post-SM4 ACS/WFC image of 47 Tuc



Anderson & Bedin 2010, PASP, 122, 1035

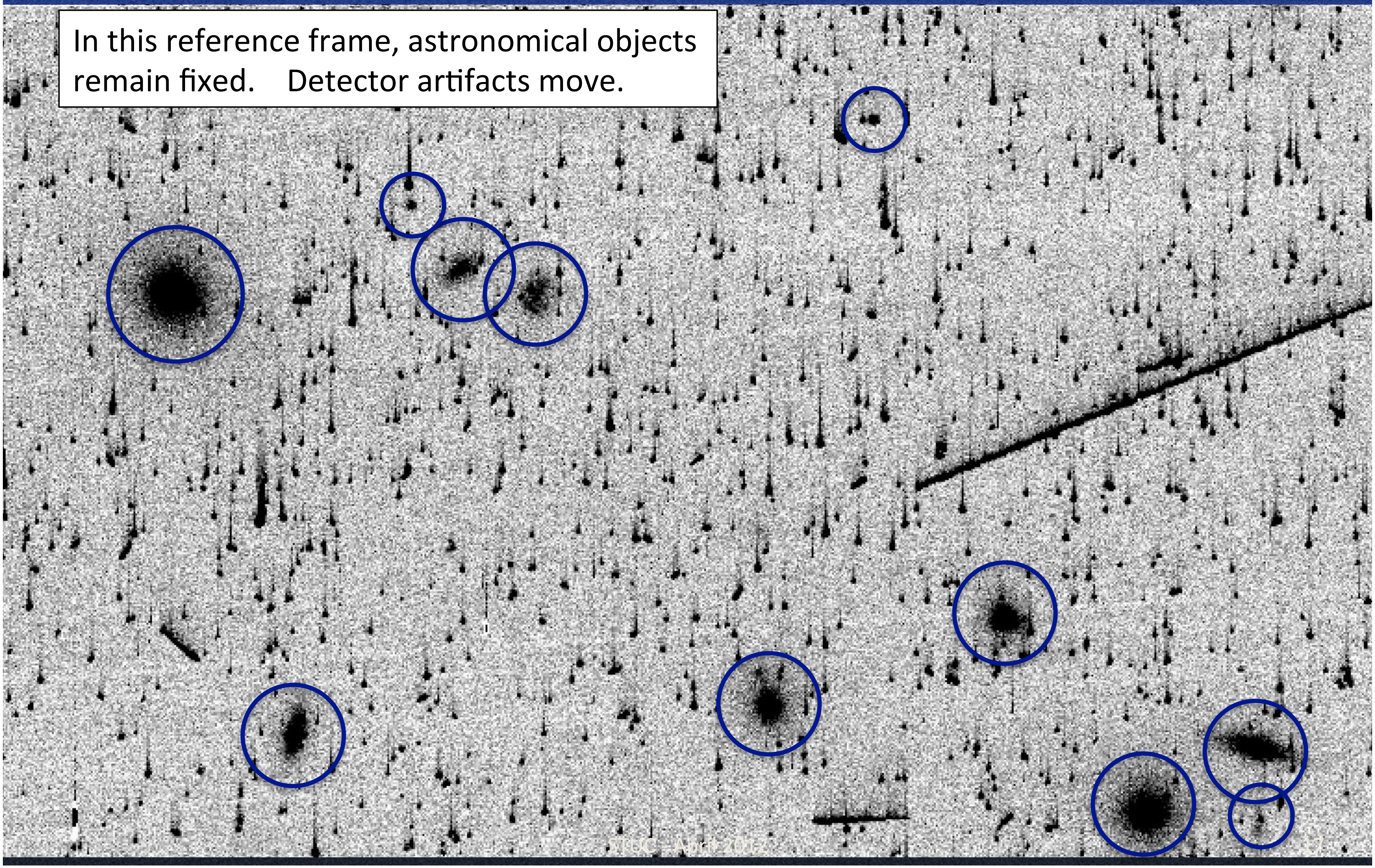


- Correction is ready for ACS calibration pipeline
- Archive will serve corrected images
- Application to other HST CCD cameras is planned

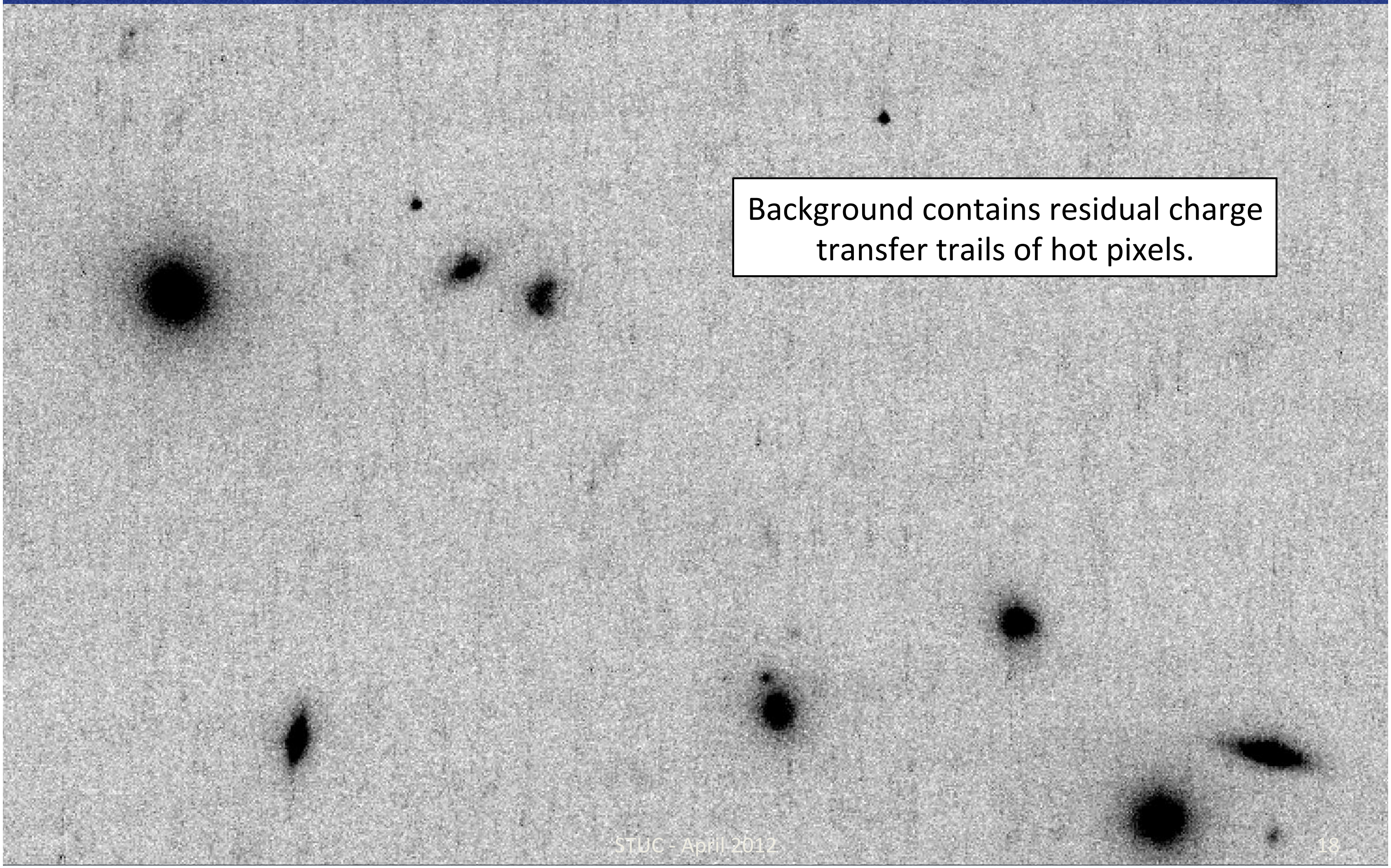


CTE Example – Extended Source
(Sequence of 6 dithered exposures)

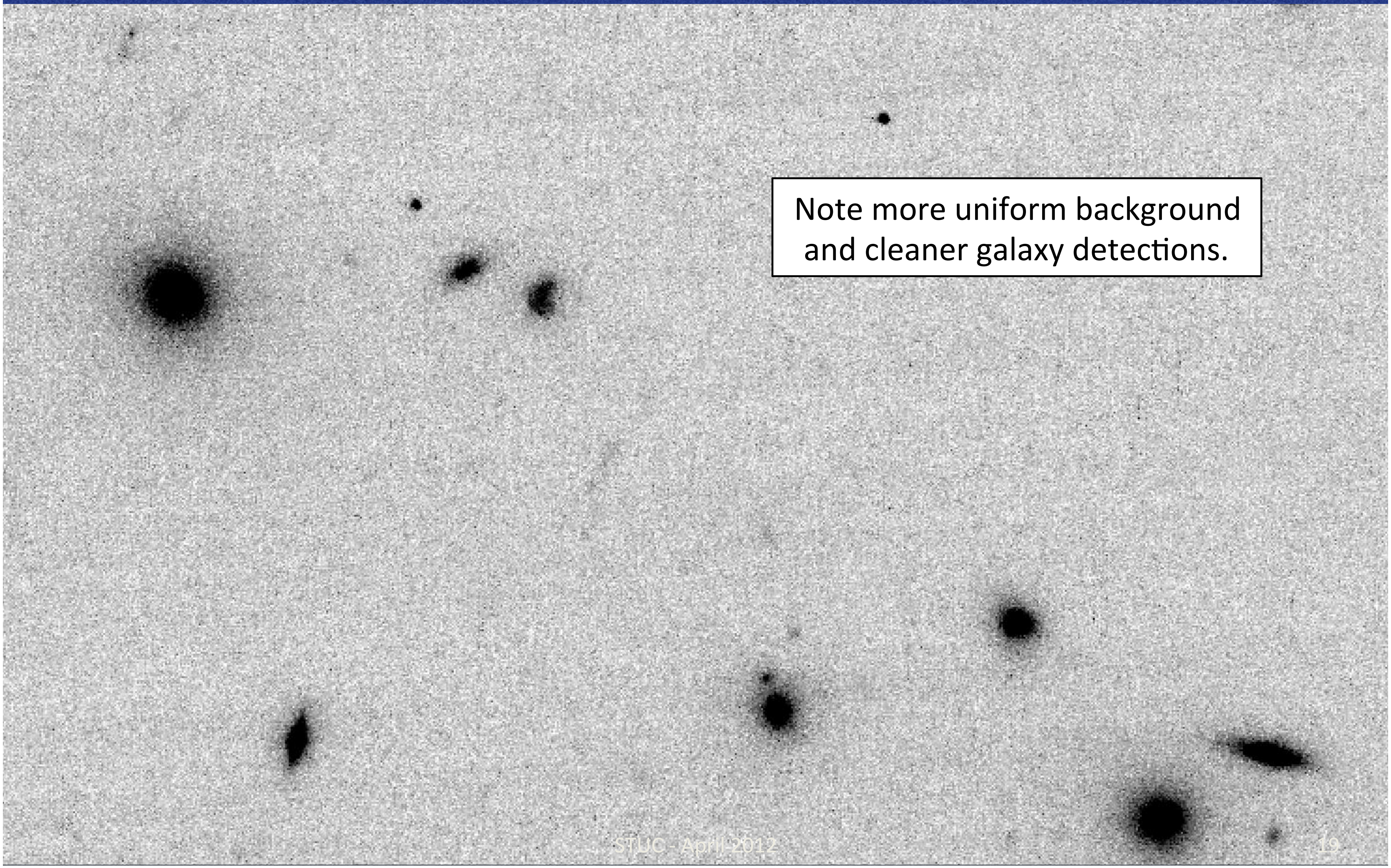
In this reference frame, astronomical objects remain fixed.   Detector artifacts move.



CTE Example – Extended Source
(No CTE correction, simple shift and add)



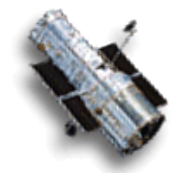
CTE Example – Extended Source
(CTE correction applied, simple shift and add)



Long Range Plan

MCT	Total alloc	Executed/scheduled by 4/15/12	Planned before 9/30/12	Planned 10/1/12+	Not in plan
Dalcanton	834	560	112	102	60 (C20)
Faber/Ferguson	750	480	86	67	117 (C20)
Postman	474	266	103	10	95 (C20)
Riess (ToO)	202	128	1	1	72
C18 Large/Treasury					
Ayres	146	143	0	0	Completed
Deming	115	110	0	5	Done in Oct
Tumlinson	129	128	0	0	Completed
Van Dokkum	248	244	0	2	Done in Dec
C19 Large/Treasury					
Brown	113	63	50	0	0
Ellis	128	0	128	0	Aug-Sep
Heckman	119	27	70	22	0
Sahu	64	16	40	8	0
Sing	124	14	54	56	0
Teplitz	90	18	72	0	0

NASA 2012 Senior Review

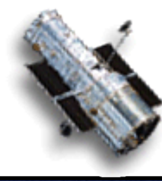


- NASA's Science Mission Directorate (SMD) periodically conducts comparative reviews of its operating missions to maximize the scientific return from these projects within finite resources. NASA uses the findings from these comparative reviews to define an overall implementation strategy and give programmatic direction to the missions and projects concerned for the next two fiscal years (FY13, FY14).

- The 2012 Senior Review assesed the scientific merits of nine astrophysics missions – Chandra, Fermi, Hubble, Kepler, Spitzer, and Swift and the U.S. components of participation in Suzaku, Planck, and XMM-Newton. Performance factors include scientific productivity, future scientific potential, data dissemination, technical status, and cost.

- Unlike past reviews, no mission ranking was provided by the committee.

NASA 2012 Senior Review Schedule



HST Senior Review Schedule	
Draft Call for Proposals	July 1, 2011
Call for Proposals	August 10, 2011
(Red Team Review)	December 8, 2011
EPO SR Proposal Due	December 15, 2011
SR Proposal Due	January 18, 2012
EPO Section Review	January 23-25, 2012
SR Committee Meets	February 28 – March 2, 2012
Final Report	March 30, 2012
Guidance to Project	April 3, 2012
Project Response	April 23, 2012

- HST had 60 minutes for oral presentation + 30 minutes for Q/A (Feb 28)
  - Wiseman, Mountain, Sembach, & Faber presented
  - Committee asked an additional 45 minutes of questions about budget

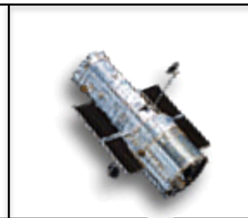
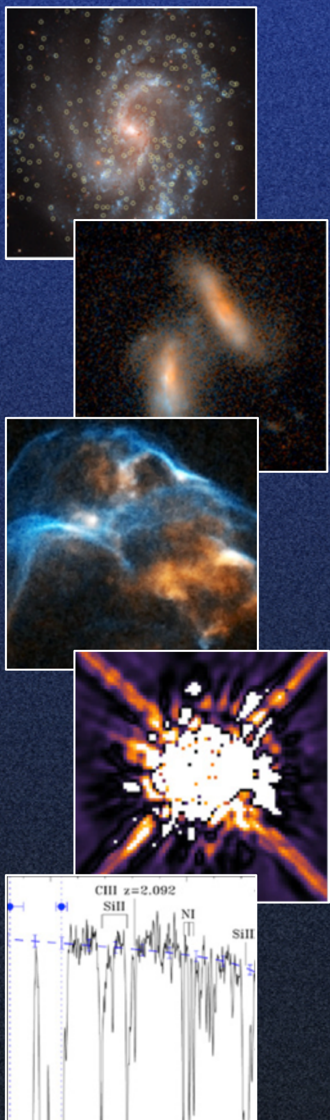
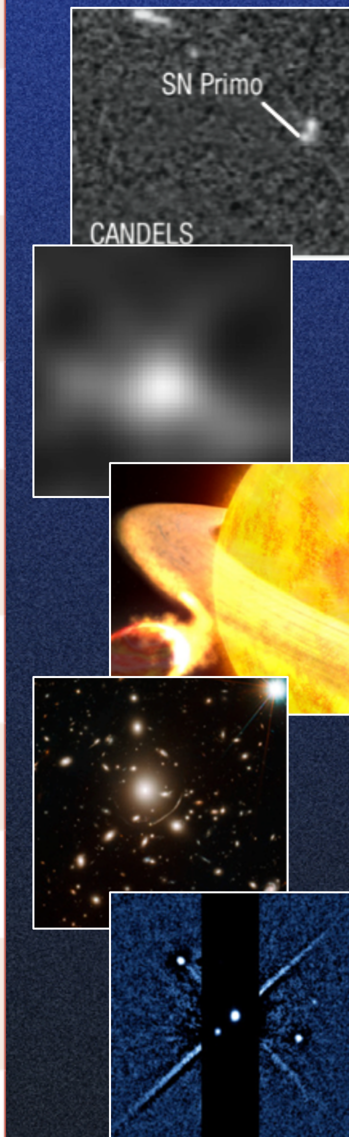
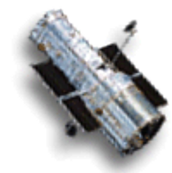


Table 1.2: Hubble Highlights and Science Goals		
SM1, SM2, SM3A	SM3B	SM4
1990-1999 Hubble 1st Decade	2000-2009 Hubble 2nd Decade	2010-2016 Hubble Goals
H_0 measured to 10% accuracy	H_0 measured to 3 % accuracy	Measure H_0 to 1 % accuracy
—	Dark energy is dominant (73%) component of the accelerating universe	Characterize SN Ia evolution at z > 1.5 to constrain dark energy equation of state
Merging galaxies are common at high z; cosmic SFR peaks at z~2 (HDF)	Detection of galaxies at z = 6-8 (UDF and HUDF09)	Measure cosmic variance at high-z in several deep fields
Mass of supermassive black hole in M87 is determined	Supermassive black holes exist in most galaxies	Detect isolated, stellar-mass black holes
Witness planetary disk formation (Orion proplyds)	First exoplanet atmospheric composition measurement; direct imaging of exoplanets	Measure water vapor in exoplanet atmospheres
Deep color magnitude diagrams for clusters/galaxies	Multiple stellar populations in globular clusters (ω Cen)	Map star-formation history of M31
Gravitational lenses used to test cosmology	First maps of dark matter in galaxy clusters	Map cluster DM and observe structure in high-z galaxies
Collisions still happen in the solar system (Comet SL-9)	Some KBOs are larger than Pluto (Is Pluto a planet?)	Two new Pluto moons discovered; maybe more
Lyα forest thins out rapidly at low redshift	Warm-hot IGM is significant baryon reservoir (O VI)	Find the "missing" baryons in the cosmic web
SN1987A ring structure and shock wave interaction	Long-duration GRBs arise predominantly in Irr galaxies	Witness next nearby SN explosion?

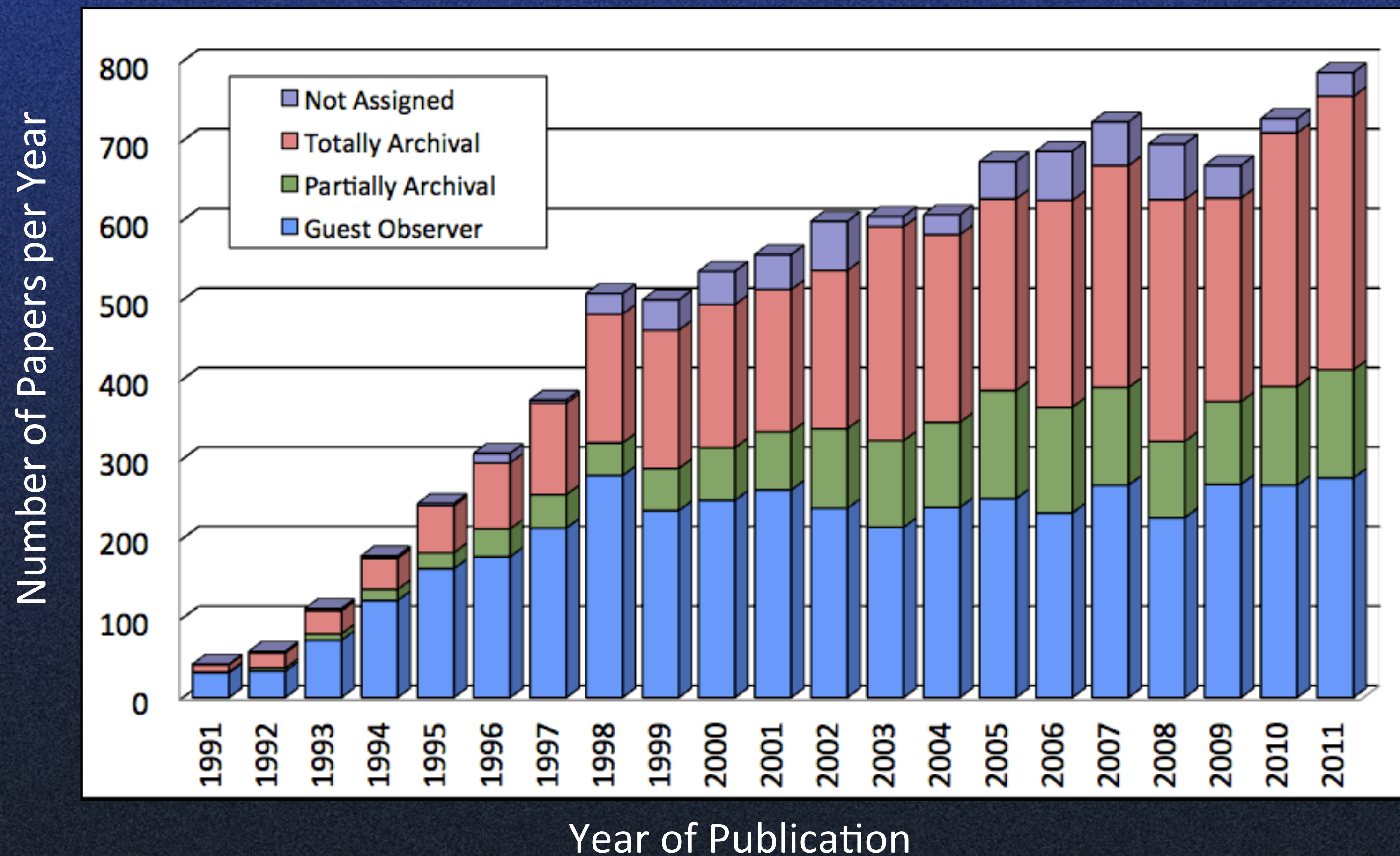




HST Scientific Output is Higher Than Ever

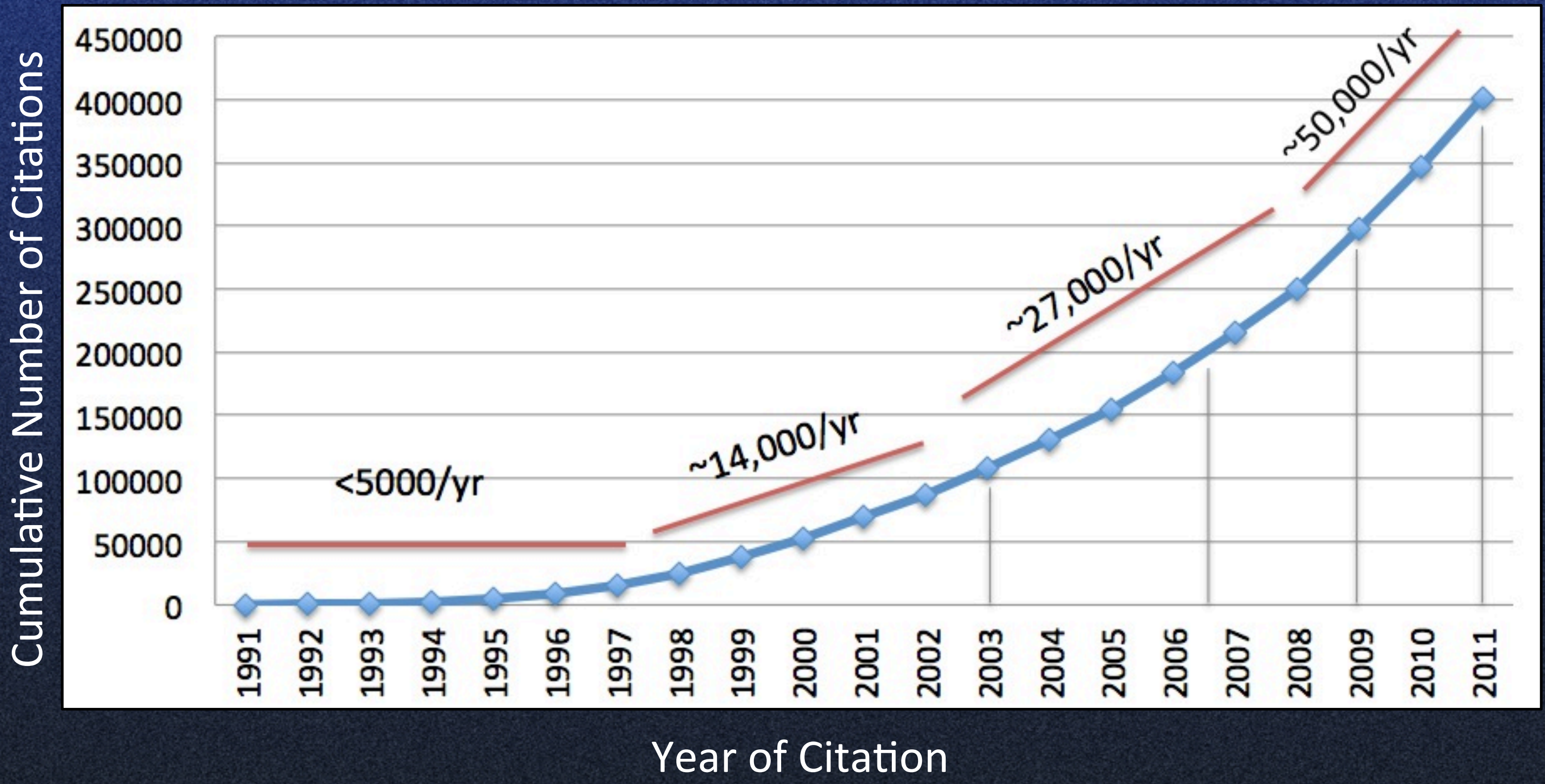


- 10,191 papers in refereed journals (1990-2011)
- 786 papers in 2011, 728 papers in 2010
- More than 11,100 individuals have (co)authored a Hubble paper



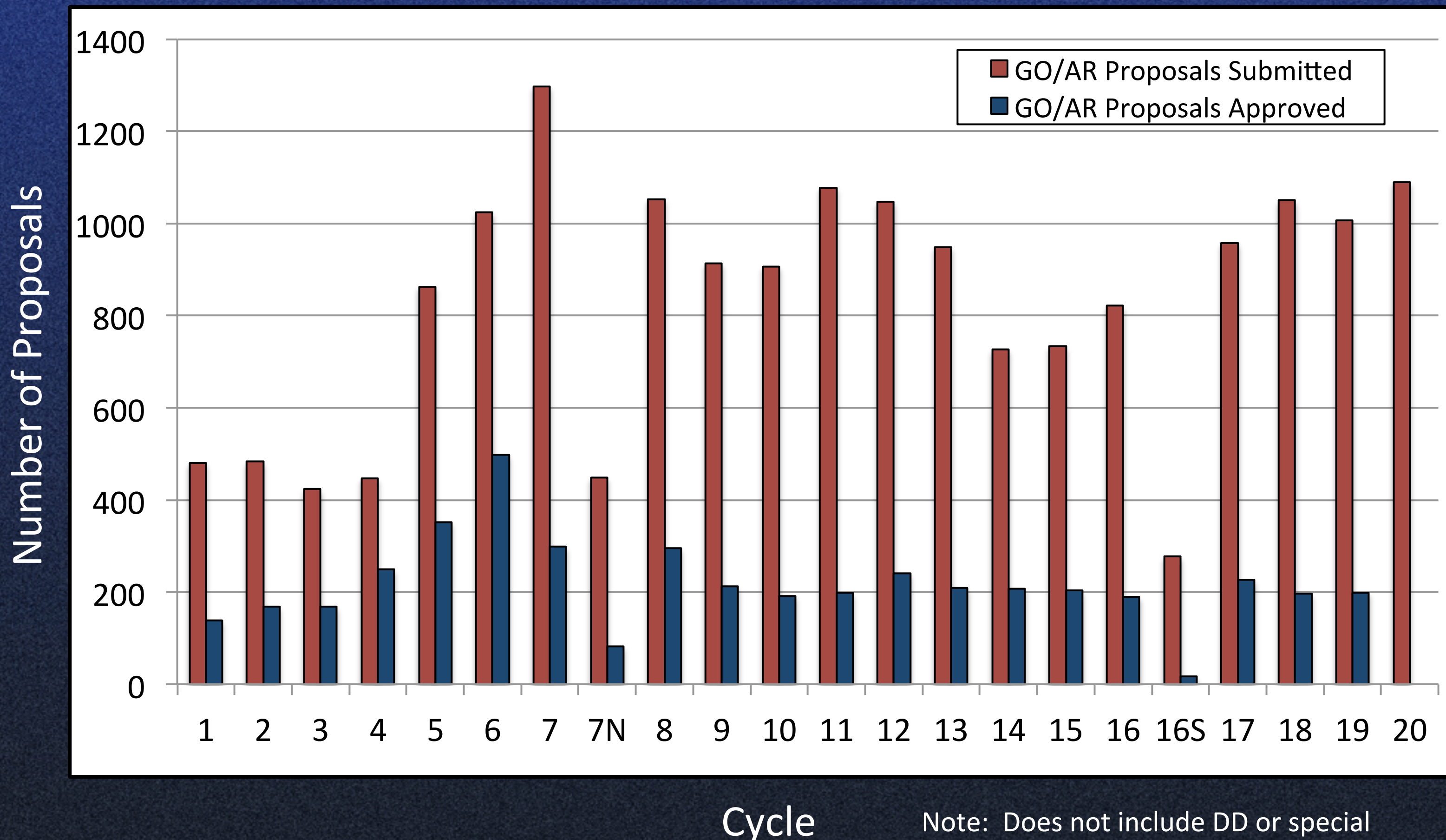
Citations to HST Publications are Increasing Exponentially

- >400,000 citations to refereed HST papers (1990-2011)
  - 27 papers have >500 citations; 200 papers have >200 citations
  - Typical paper more than 5 years old has 47 citations



HST Proposal Pressure is High

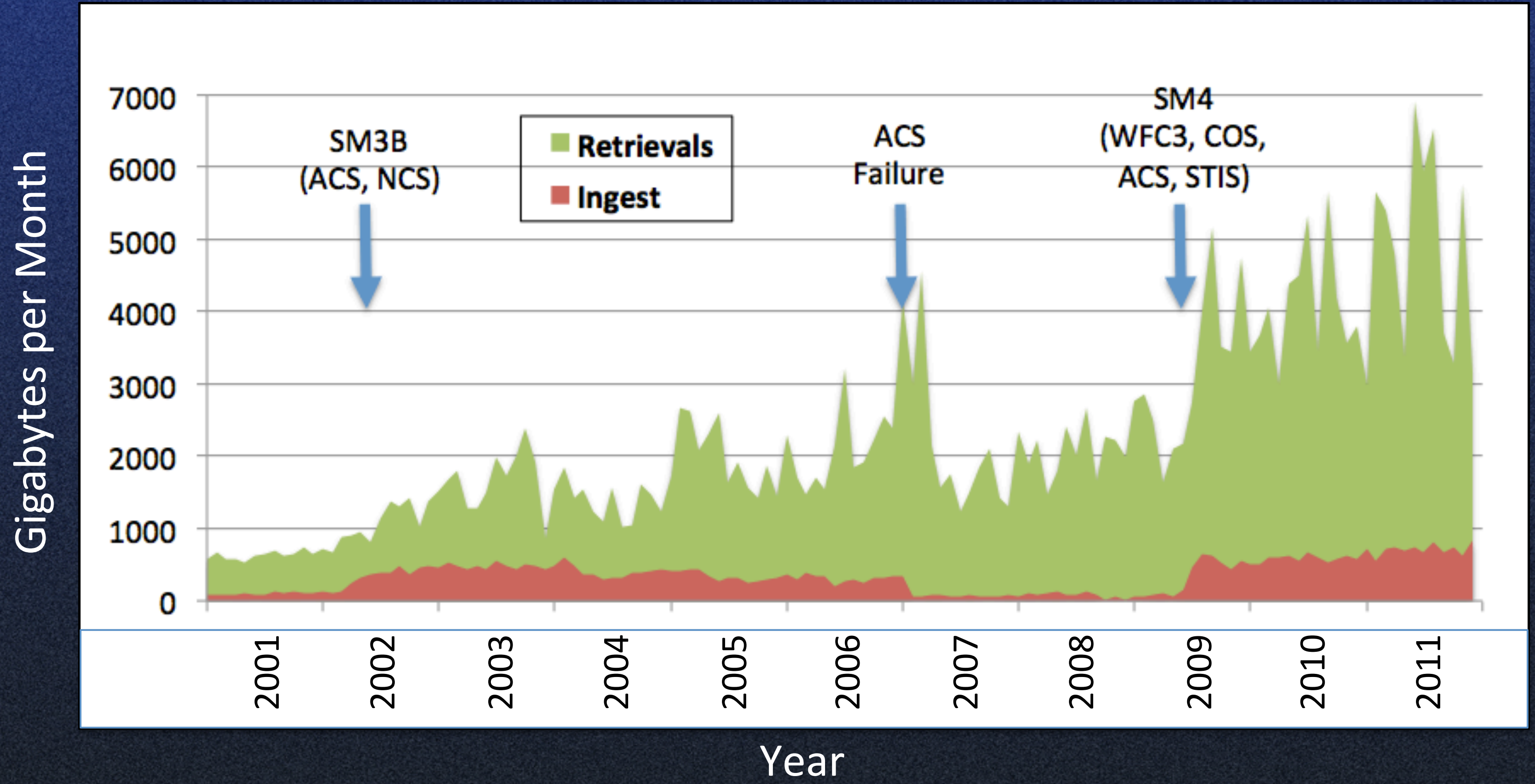
- In Cycle 20 (Feb. 24 deadline) there were 1090 proposals submitted
- >5000 investigators on approved programs in Cycles 1-20



Note: Does not include DD or special proposals

HST Archival Data Demand is Increasing

- HST archive size is ~60 TB at end of 2011
- HST archive retrievals doubled after Servicing Mission 4
- >10,000 registered archive users (85 countries, 49 states)

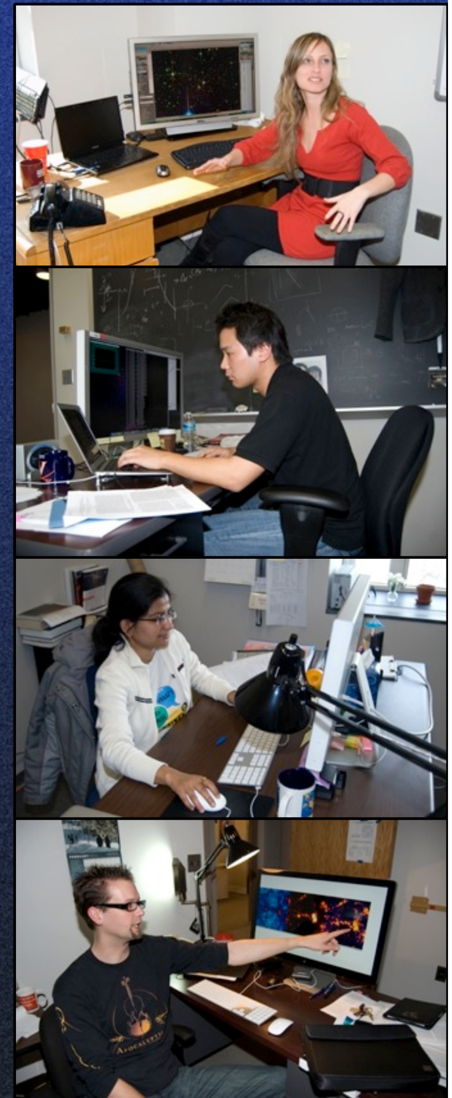


Hubble Supports Young Scientists

HST PhDs	
2011	≥33
2010	34
2009	36
2008	40
2007	30
2006	24

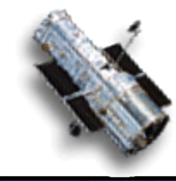
Hubble has trained multiple generations of postdocs and graduate students.

~430 PhD theses in U.S. and Canada



- 1750 FTE years of graduate student support
- 1500 FTE years of postdoc support
- 225 Hubble Fellowships between 1990 and 2008

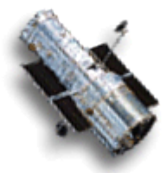
Science Vision Will Increase HST Science Productivity



Year	Cycle	Initiative	Status
FY12-13	19-20	Complete Multi-Cycle Treasury Programs	In progress, on schedule
FY14	21	Begin Ultra Deep Fields Observing Initiative	Planned
FY14	21	Begin UV Astrophysics Legacy Program	Planned
FY13-14	20-21	Create HST Source Catalog	Under study
FY13-14	20-21	Develop Enhanced Archival Products	Under study

- Each of these initiatives has the potential to significantly increase HST scientific productivity.
- Initiatives are (will be) conducted in combination with a broad, diverse observing program selected through the standard yearly call for proposals.

NASA 2012 Senior Review Results



MISSION	DISCOVERY SPACE	LONG TERM IMPACT	PUBLICATION/$	SYNERGY	CRITICAL CAPABILITY	HEALTH OF SCIENCE PROGRAM (RYG)
CHANDRA	9	9.5	7	9	9.5	G
FERMI	7.5	7.5	7	8	9	G
HST	9.5	9.5	7	9.5	10	G
KEPLER	9	9	7.5	8	9.5	G
PLANCK	7	10	6	8.5	9.5	G
SPITZER	9	8	6.5	9	9.5	G
SUZAKU	8	8	10	7.5	9	R
SWIFT	9	9	9.5	10	9.5	Y
XMM	8	9	9.5	9	9	R

Noted Weaknesses

- The SRC found the overguide request to provide a source catalog and enhanced data products were not well motivated in this proposal.

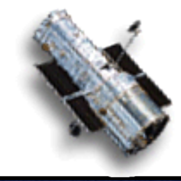
- Because HST has the possibility of operation into the next decade, operations and science systems costs are a significant concern. The committee found the budget justification for these costs to be obscure and inadequate.

- More transparency is required, both for the labor force and activities at GSFC as well as at STScI. The SRC questions whether all efficiencies in the program have been realized.

Overall Assessment (1/3)

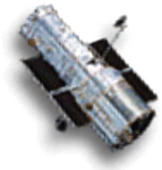
- HST provides excellent, cutting edge science at a total cost of about $95M per year, of which about $25M annually is GO funding. Continued high-impact scientific contributions over a wide range of fields are anticipated. Great care has gone into the allocation of observing time, the delivery of calibrated data products, along with software tools for use with the data sets. The HST team has been forward-looking in developing a variety of procedures that can extend the lifetime of the mission. Unfortunately, given the lack of budget detail, the SRC could not properly evaluate the need for the current and still large staff, nor could it evaluate the expressed need to reduce GO support in FY13.
  - It is unclear why the committee believes GO support needs to be reduced in FY13. This did not appear in the proposal, and it was not stated during the oral presentation or Q/A session.

Overall Assessment (2/3)



- To keep HST operating while maintaining the overall balance of NASA's astrophysics program it will be necessary to seek further cost reductions, even at the expense of some observing efficiency. The SRC strongly urges the HST team to consider all possible avenues, vigorously pursuing ways to accelerate cost reduction without compromising mission safety even if some science is not enabled.
  – An identical statement appears in the Chandra assessment (replace "HST "with "Chandra")
  – Similar statements appear in the assessments for other missions
    - Kepler: "A large fraction of the cost is for science operations, and the mission should consider carefully how they can reduce these and other costs in the extended phase. In the event of insufficient resources, NASA should consider all possible economies."
    - Fermi: " …develops a plan for decreasing the number of FTEs supporting instrument operations as the mission enters its extended phase."
  – Note: Decreasing observing efficiency is the worst way to save money…

Overall Assessment (3/3)



- The SRC applauds HST team efforts to improve lifetime probabilities for continued operation of all 4 instruments and the spacecraft. The SRC recommends that HST be reassessed by senior reviews on an ongoing basis as the mission components age.

- The SRC does not recommend that the proposed budget augmentations be funded.
  – These will be described in other presentations later today and tomorrow.

- The SRC recommends an extension through 2016 with review in 2014.
  – This same recommendation for extension was made for other missions – Chandra, Fermi, Kepler, Spitzer, Suzaku, Swift, XMM-Newton