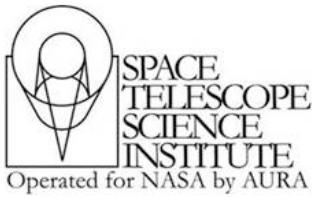


On-Orbit Verification of the *Hubble Space Telescope* Advanced Camera for Surveys Repair

David Golimowski
Space Telescope Science Institute
15 October 2009

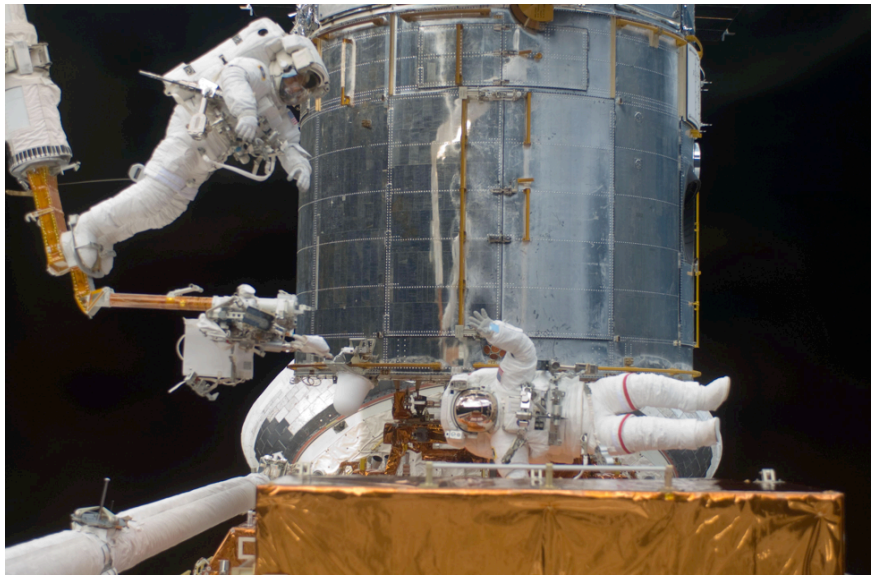
SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

In Memoriam

Rodger Doxsey
Head of HST Mission Office
Space Telescope Science Institute
(1947-2009)

HST Servicing Mission 4

- STS-125: NASA's 5th servicing mission to HST (11-24 May 2009)
- 2 new instruments (WFC3, COS)
- 2 repaired instruments (ACS, STIS)
- Many other components replaced (SIC&DH, gyros, batteries, etc.)
- ACS-R hardware successfully installed on 16 May 2009 during EVA-3
- WFC and SBC passed Aliveness and Functional Tests; HRC not recovered

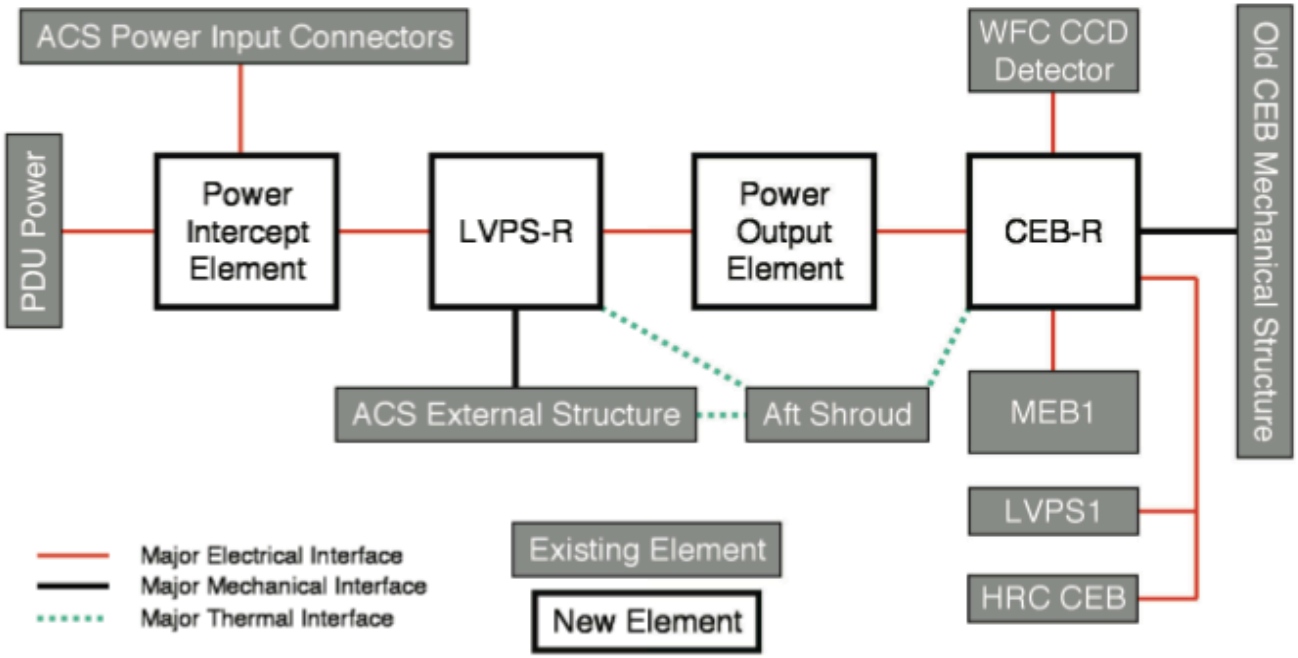


STS-125 astronauts Drew Feustel and John Grunsfeld during EVA-3

The ACS Repair (ACS-R)

Four major components of ACS-R:

- **CCD Electronics Box Replacement (CEB-R)**
- **Low Voltage Power Supply Replacement (LVPS-R)**
- **Power Intercept Element (PIE)**
- **Power Output Element (POE)**



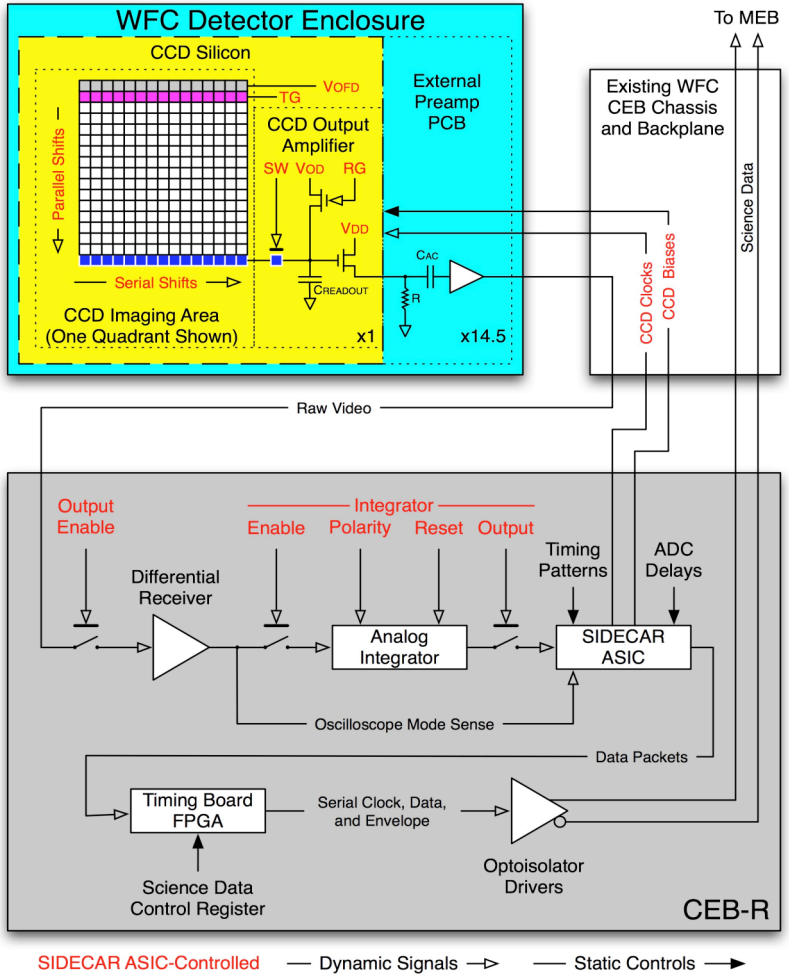
The CEB-R

Main CEB-R features:

- **Teledyne SIDECAR* ASIC** permits optimization of WFC performance via adjustment of CCD clocks, biases, and pixel transmission timing**
- **Built in oscilloscope mode (O-mode) that allows sensing of analog signal from each output amplifier**

* System for Image Digitization, Enhancement, Control, and Retrieval

** Application Specific Integrated Circuit



Sample O-scope Image

Reset Gate

DSI output B

Raw video B

Raw video A

WFC Optimization Campaign (1)

Ground testing:

- Ensured performance of CEB-R with spare WFC (2 butted 4096x2048 SITe CCDs), but not actual flight WFC ⇒ CCD performance highly variable
- Revealed non-ideal transient settling behavior in external preamp
  ⇒ Preamp not replaced by ACS-R, so behavior with CEB-R not verifiable
- Revealed noise dependence on timing of data transmission from CEB-R to MEB

On-orbit testing:

- To satisfy requirement that WFC perform at least as well as before, CEB-R must accommodate above uncertainties via flexible, programmable settings
- Need iterative campaign to optimize CCD read noise, gains, linearity, full well depth, CTE, cross-talk

WFC Optimization Campaign (2)

Strategy:

- Perform up to 8 iterations of comprehensive CCD performance tests and exploratory adjustments of bias voltages, clock rails, and data transmission timing via uplinked commands to ASIC
- Converge to optimal settings; truncate Optimization Campaign if possible
- Select default CDS mode (DSI or clamp-and-sample)
- Modify flight software and assembly code to conform to optimal settings

Tactics:

- In each iteration, summarize CCD performance and target specific conditions for optimization
- Start with pre-failure default CCD voltages and timing patterns as baseline, then vary appropriate values for targeted conditions
- Analyze both image data (STScI) and O-mode data (Teledyne and GSFC)
- Uplink new baseline voltages for next iteration

WFC Optimization Campaign (3)

Launch 5/12/2009					Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F
					28-May	29-May	30-May	31-May	1-Jun	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun	16-Jun	17-Jun	18-Jun	19-Jun	20-Jun	21-Jun	22-Jun	23-Jun	24-Jun	25-Jun	26-Jun	27-Jun	28-Jun	29-Jun	30-Jun	1-Jul	2-Jul	3-Jul
		day			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
		iteration			1						2					3					4								5				6			7				8
		Prop ID			11809						11810					11811		End BEA	CTE/Xtalk		11812								11814				11813	CTE		11815				11816
Test	Ref	Visit	images	GB																																					
Real time uplink	6.2																																							
O-scope internal signal	6.1.4	G	12	0.005	G						G					G					G								G				G			G				G
Performance check	6.1.3	A	234	1.29	A						A					A					A								A				A			A				A
Preamp settling	5.1	B	69	0.04	B																								B											
Clock feedthrough	5.2	C	18	0.007	C						C										C								C				C								
Bias voltages optimization	5.3	D	160	0.09	D											D													D							D				
Clock voltages optimization	5.3	E	27	0.96	E											E													E							E				
Science data transmission	5.6	F	51	0.03	F																F								F												
		Total Images			571						264					433					315								571				264				433				246
		Total Data Vol (GB)			2.42						1.3					2.35					1.33								2.42				1.3				2.35				1.3
		gigabits			19						10					19					11								19				10				19				10

G: O-scope internal signal: Verify O-scope traces are synced with clocks

A: Performance summary: read noise, dark current, gains, full well, CTE (EPER and hot pixels), cross talk, bias drift (DSI and C&S; full speed & half speed)

B: Preamp settling: Vary V_{RG}; check noise, gain, and full well

C: Clock feedthrough: Vary summing well and serial clock high rails; check O-mode

D: Bias voltages: Vary V_{OD}, V_{DD}, V_{LG}; check noise, gain, and full well

E: Clock voltages: Vary serial and parallel clocks; check noise, gain, full well, CTE

F: Science data transmission: Vary timing and size of bit packets between CEB-R and MEB; check noise

Optimization Campaign Family

PI: Ed Cheng (Conceptual Analytics)

STScI: George Chapman, Marco Chiaberge, Tyler Desjardins, Tracy Ellis, David Golimowski, Norman Grogin, Pey-Lian Lim, Ray Lucas, Aparna Maybhate, Max Mutchler, Merle Reinhart, Marco Sirianni (ESA/ESTEC), Linda Smith, Anatoly Suchkov, Alan Welty, Tom Wheeler

GSFC: Steve Arslanian, Kevin Boyce, Darryl Dye, Olivia Lupie, Kathleen Mil, Barbara Scott, Beverly Serrano, Augustyn Waczynski, Erin Wilson

Teledyne: Markus Loose (Markury Scientific), Raphael Ricardo

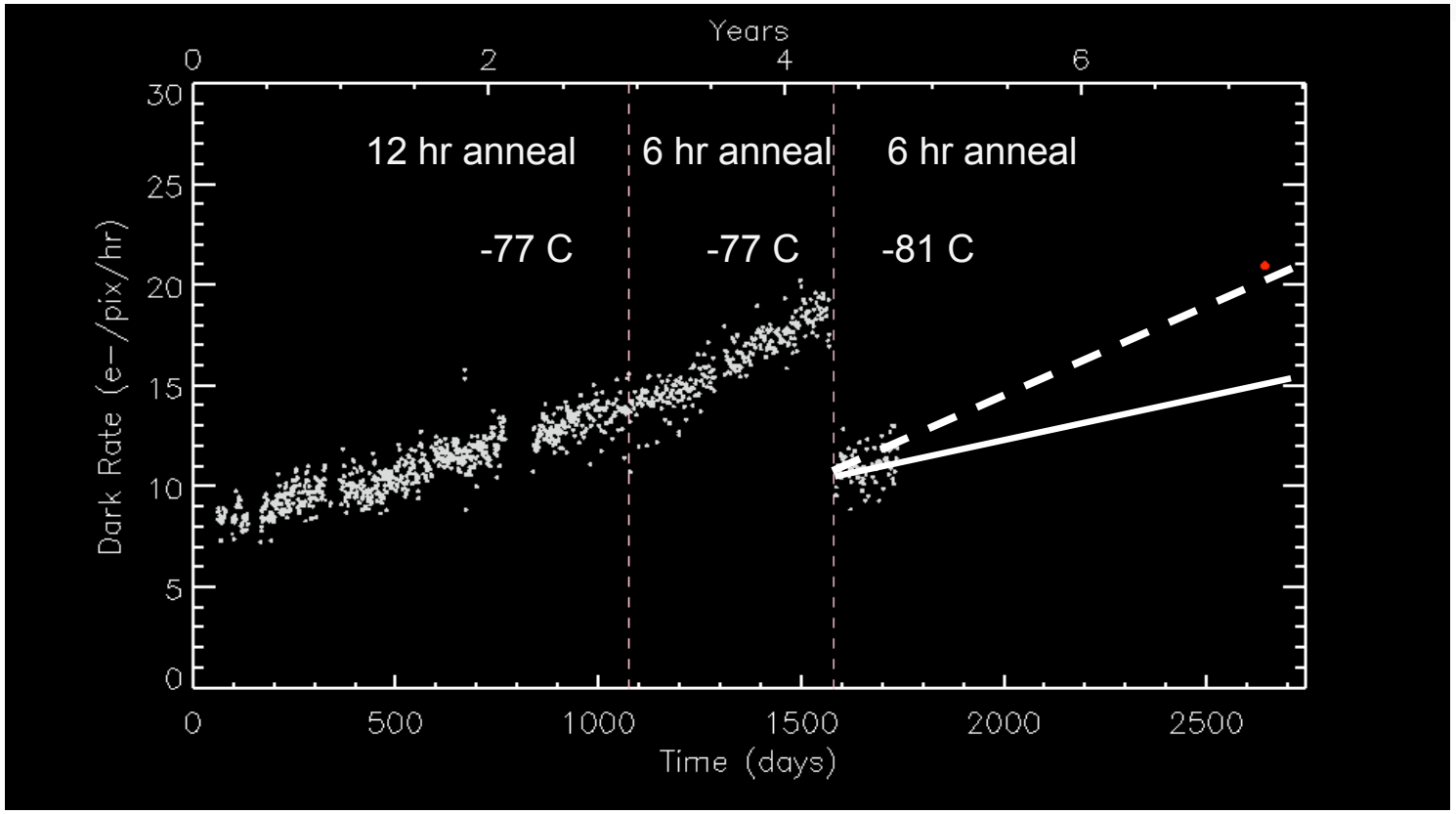
WFC Performance Summary

Metric	January 2007 (measured)	May 2009* (projected)	Problematic*	Post SM4 (measured)
Read noise (e-; gain = 2)	C&S: 5.5	DSI: 4.0	10	DSI: 3.9-4.7 C&S: 4.4-5.7
Dark current (e-/pix/hr)	10.7	15	100	20-25
Hot pixels (%)	0.68	1.1	1.5	1.1
Full well depth (e^-)	84,000	84,000	40,000	> 80,000
Non-linearity (%)	< 0.1	< 0.1	0.5	< 0.2 (exp time > 2 s)
CTE (1620 e^-)	0.999949	0.999921	0.9999	0.99989
Cross-talk (50ke^- source)	$4x10^{-5}$	$4x10^{-5}$	$4x10^{-4}$	$(5\pm4)x10^{-5}$
Bias shift** (%)	0.02	< 0.1	< 0.2	0.02-0.30 (*before* correction)

* Projected and problematic values from Gilliland et al. 2008 (TIR ACS 2008-04) .

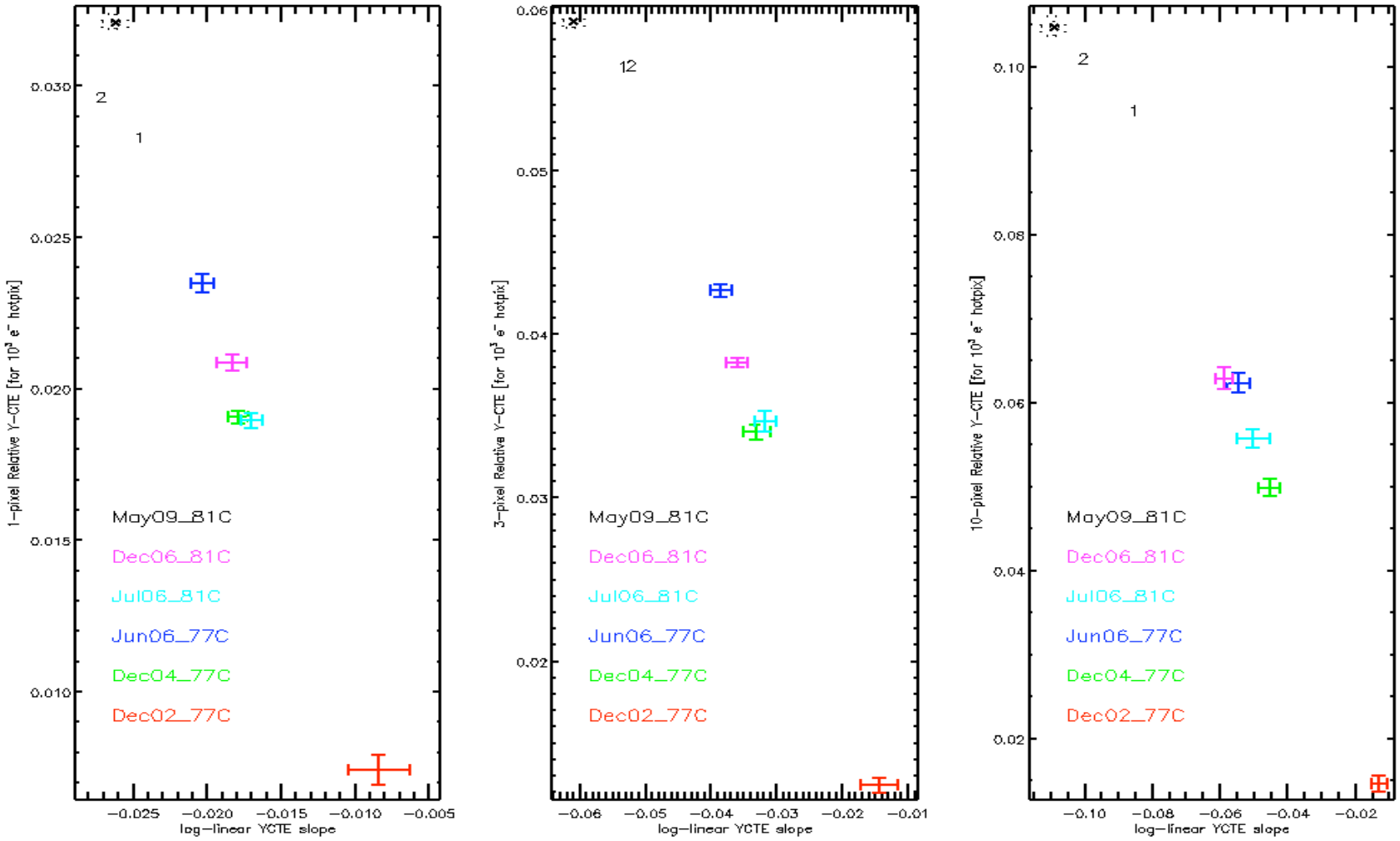
**Residual bias shift *after* analytical correction of signal-dependent effect.

WFC Dark Current History

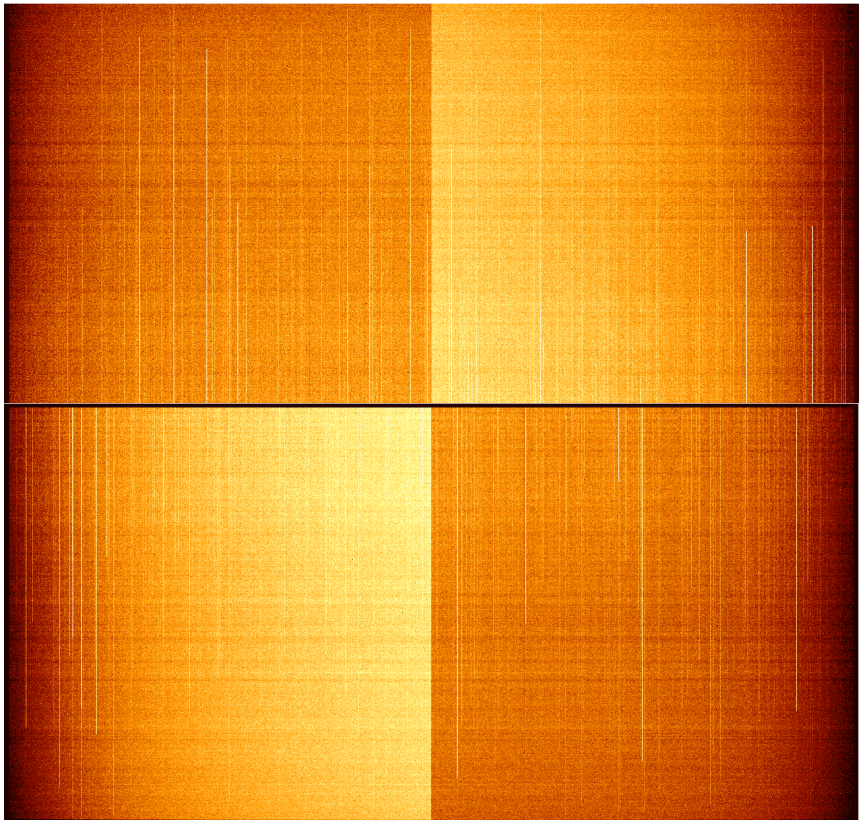


(See poster 7-B by M. Mutchler on space radiation effects on WFC CCDs)

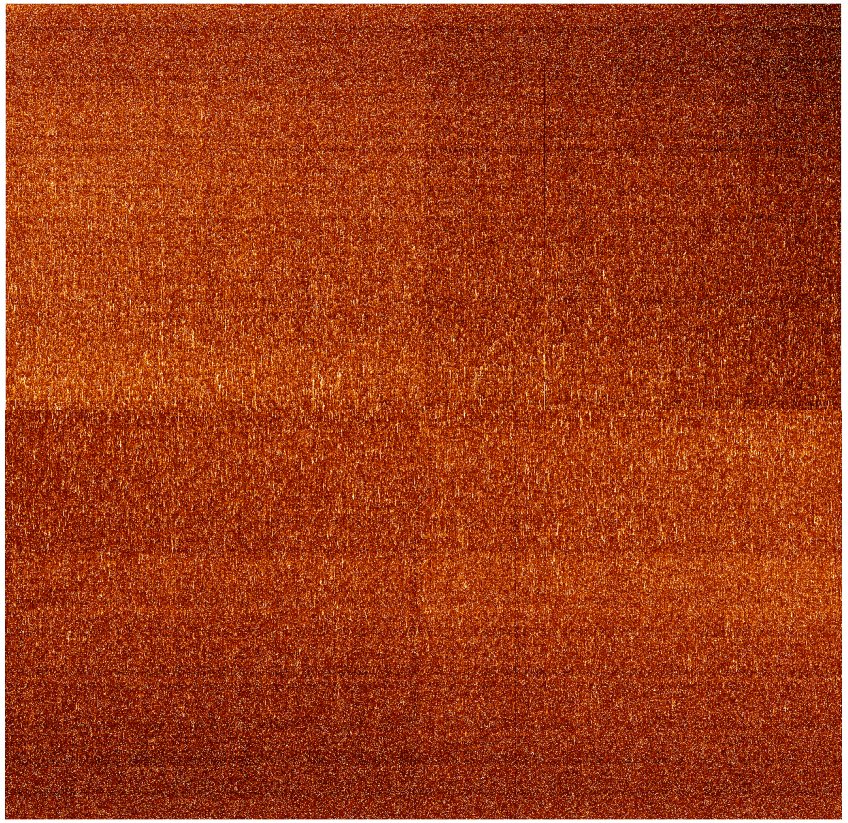
WFC CTE History



WFC Bias and Dark Frames



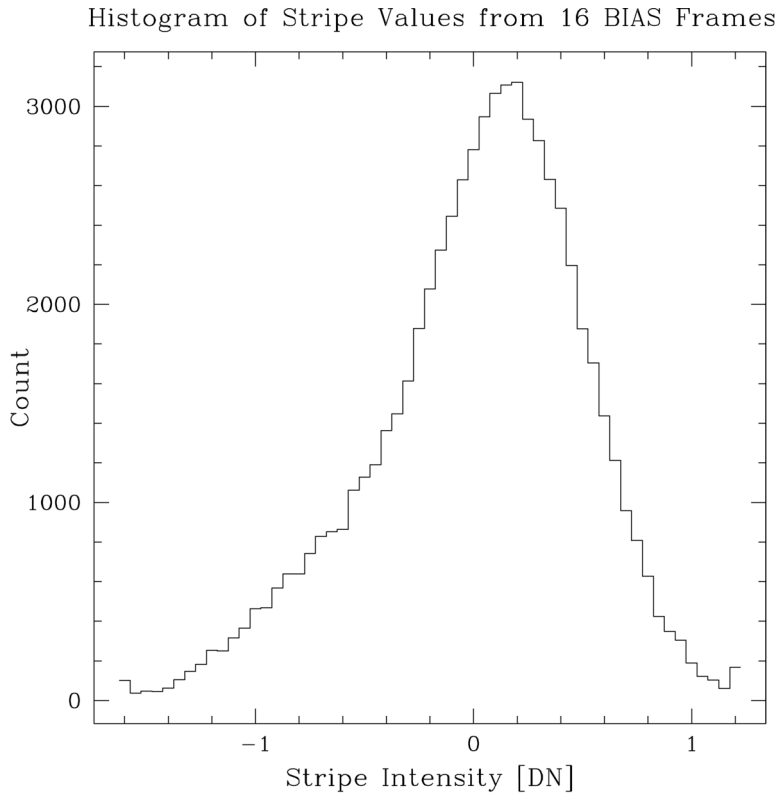
Superbias - 1 full anneal cycle
(DSI; 34 frames)



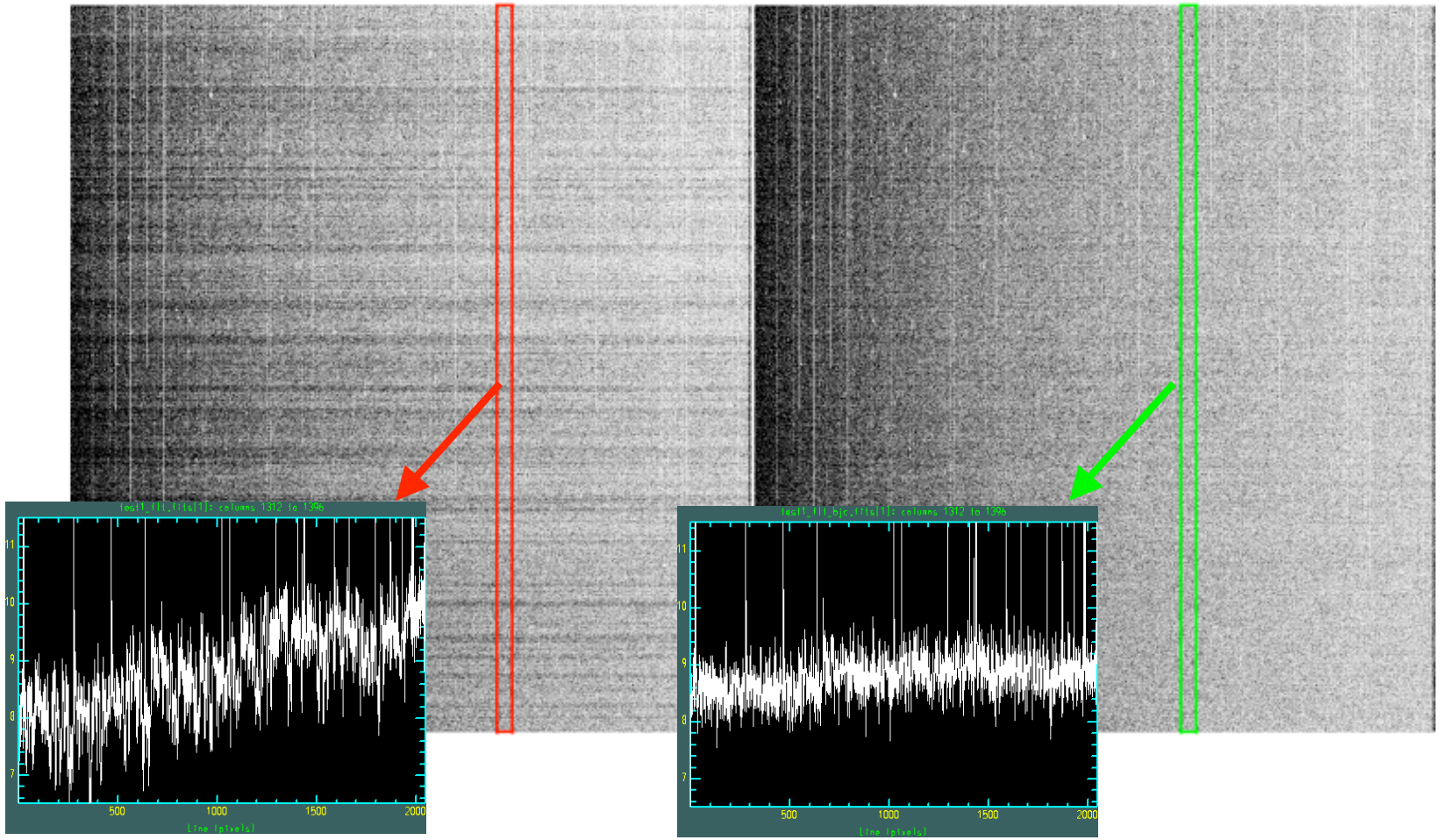
Superdark - 1/2 anneal cycle
(DSI; 24 frames)

Bias Stripe Effect

- Caused by 1/f noise (1 mHz to 1 Hz) on ASIC bias reference voltage after CDS
- Appears in both DSI and C&S frames
- Stripes have peak-to-peak variations of ~2 DN; negligible contribution to read noise
- Noise is correlated; may affect photometry of the faintest sources
- STScI developing algorithms to remove effect



Bias Stripe Removal

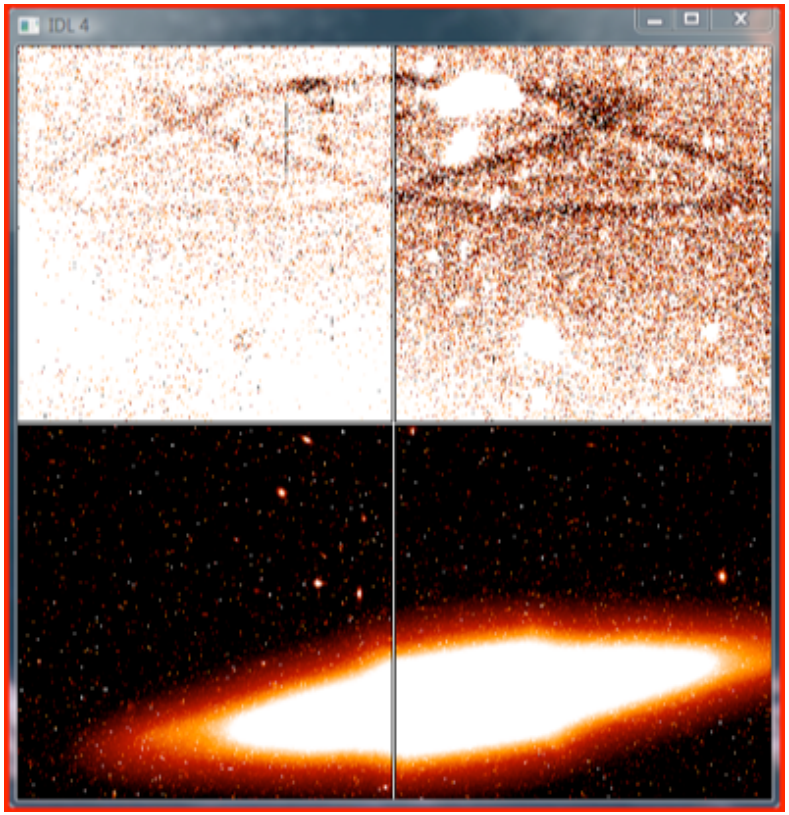


(before)

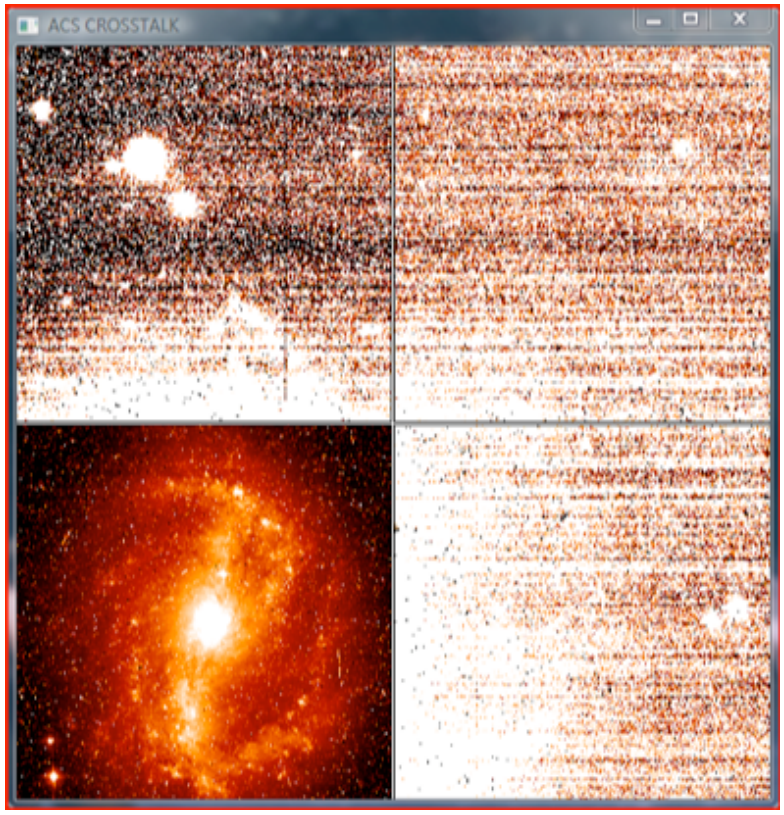
(after)

Cross Talk

NGC 4701 (pre-SM4)



NGC 6217 (post-SM4)

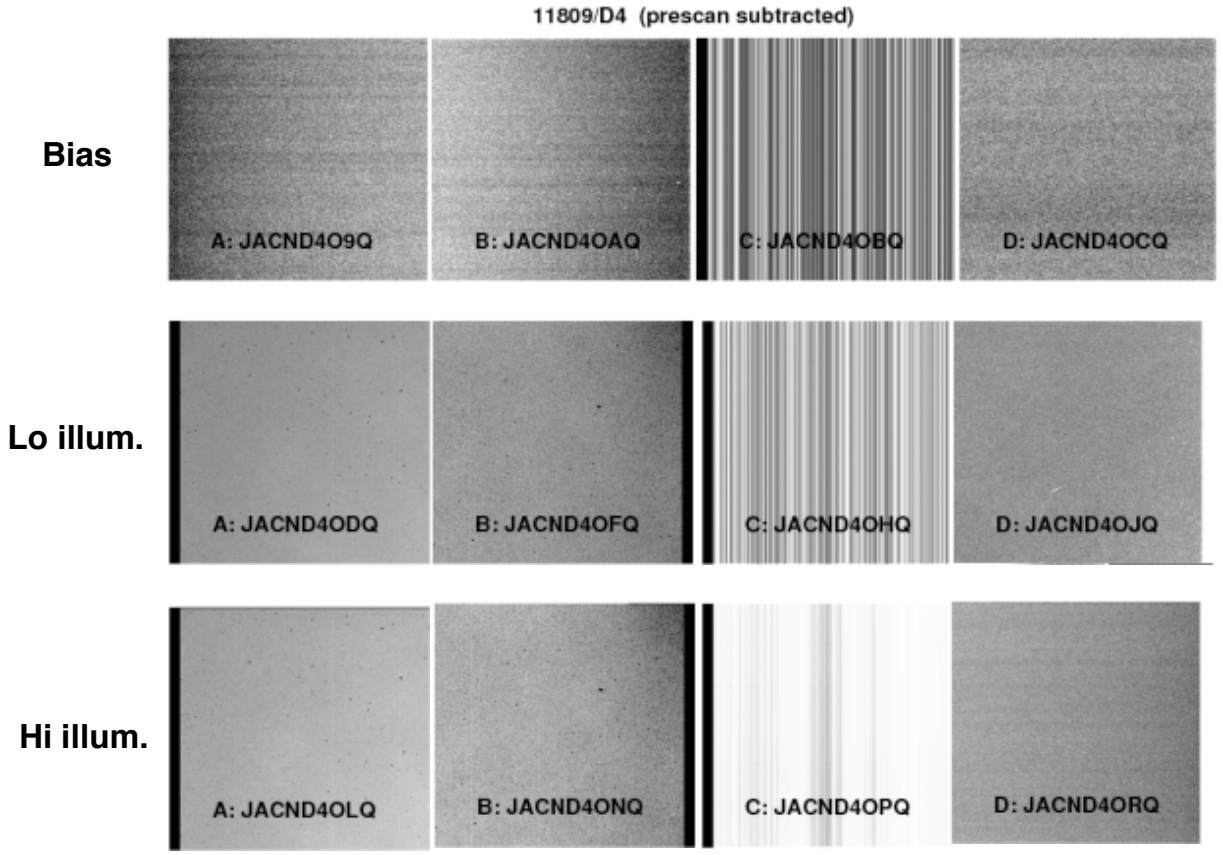


V_{OD} (Reset Drain) Anomaly

V_{DD}: +27 V (default)
V_{LG}: -3 V (default)

V_{OD}: +14 V (default +15V)

- Anomaly resembles charge injection
- Not reproduced in ground tests at GSFC; remains unexplained
- Similar effect from changes to V_{OFD} and V_{LG}
- **O.C. truncated after Iter 2 as precautionary measure**



Summary

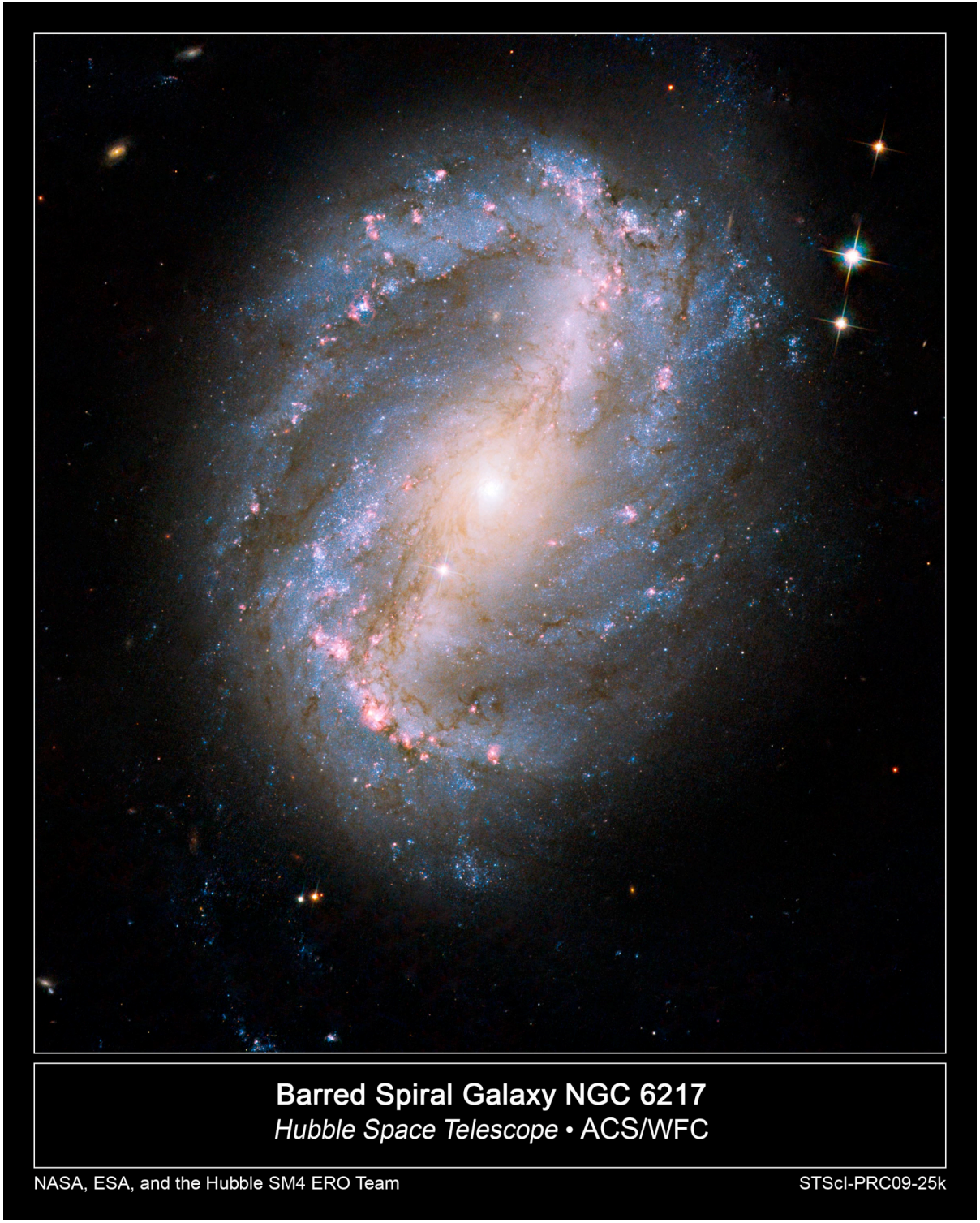
- Optimization Campaign began 28 May 2009; ended 3 June 2009 after Iter 2
  - ① Performance matched or exceeded projections and expectations
  - ② V_{OD} offsets of < -1 V produce anomalous behavior in amps C and D that mimics charge-injection but remains unexplained
  - ③ HST Mission Office and Project elect to proceed with WFC default configuration and continue "off-line" investigation of V_{OD} anomaly

- ASIC Dual-Slope Integrator selected as default CDS mode

- Bias gradient of 5-10 DN caused by **a slow drift of the bias reference voltage during and after the readout of each row of pixels; stable and removable**

- Low level (±2 DN) bias stripes caused by 1/f noise (1 mHz to 1 Hz) generated with ASIC during setting of bias voltage offset

- ACS enabled for science in mid-July 2009



Barred Spiral Galaxy NGC 6217

Hubble Space Telescope • ACS/WFC

NASA, ESA, and the Hubble SM4 ERO Team

STScI-PRC09-25k

Galaxy Cluster Abell 370
Hubble Space Telescope ▪ ACS/WFC

NASA, ESA, the Hubble SM4 ERO Team, and ST-ECF

STScI-PRC09-25h