

Reflections on the Development of The Advanced CCD Imaging Spectrometer

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MIT Kavli Institute for Astrophysics and Space Research

On behalf of

Gordon P. Garmire, ACIS Instrument Principal
Investigator

Pennsylvania State University
& The ACIS Tribe



Overview

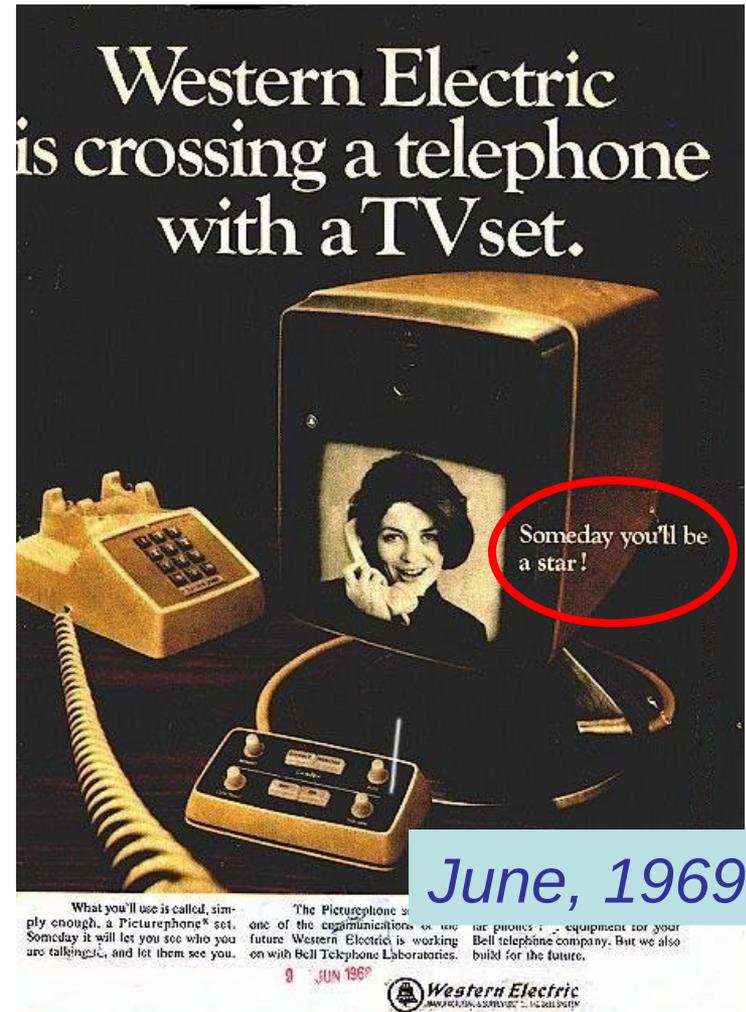
- “Historical” context & initial ACIS concept
- Great (& not-so-great) moments in ACIS Development
- Science Highlights & Surprises

Overview

- “Historical” context & initial ACIS concept
- Great (& not-so-great) moments in ACIS Development*
- The Future (for ACIS & the rest of us)
NB: A very incomplete & biased account!

Prehistory

- 1970: Boyle & Smith (Bell Labs) invent the CCD for use in 'Picturephones'
- 1973: Fairchild produces 1st commercial CCD (CCD201, 0.01 Mpix)



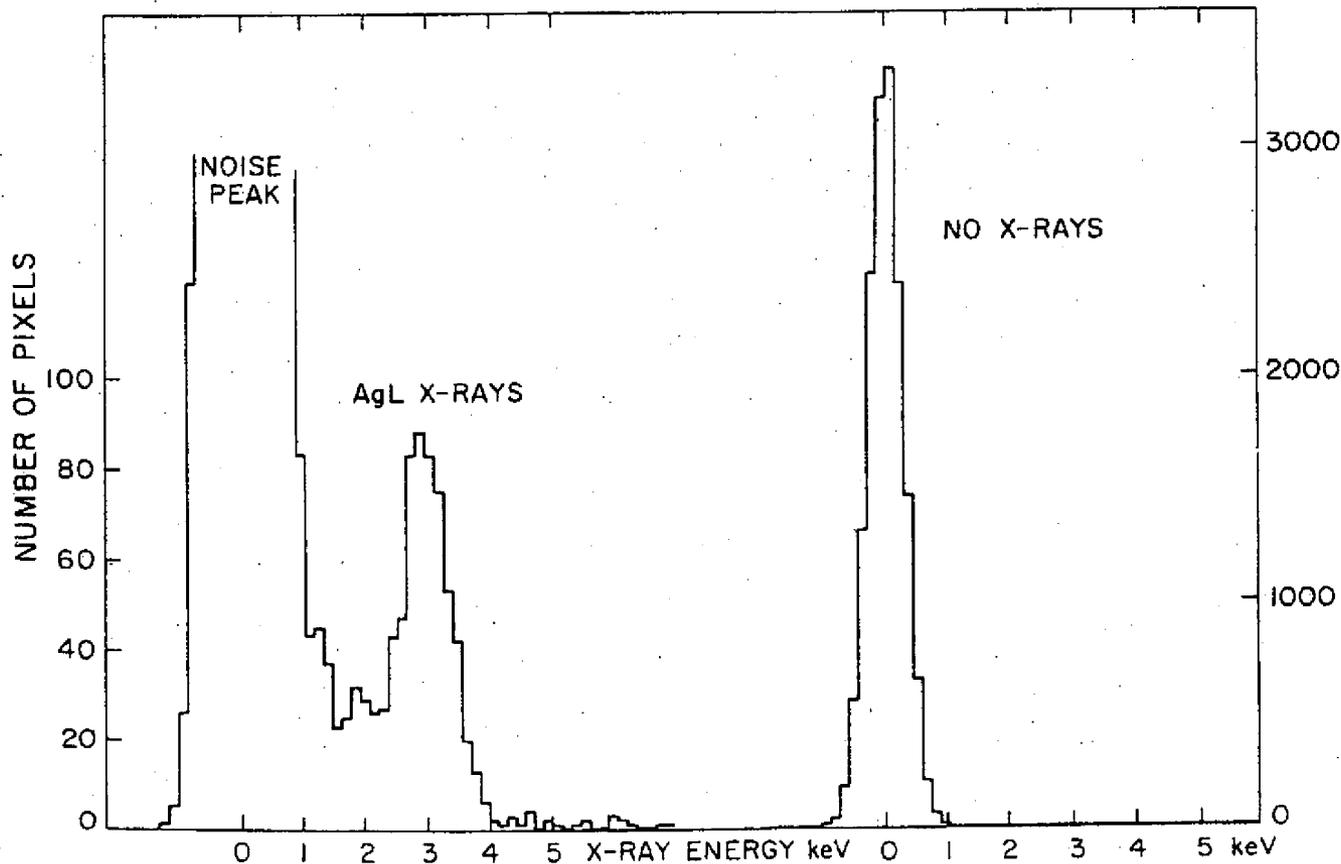
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MWB for Gordon Garmire



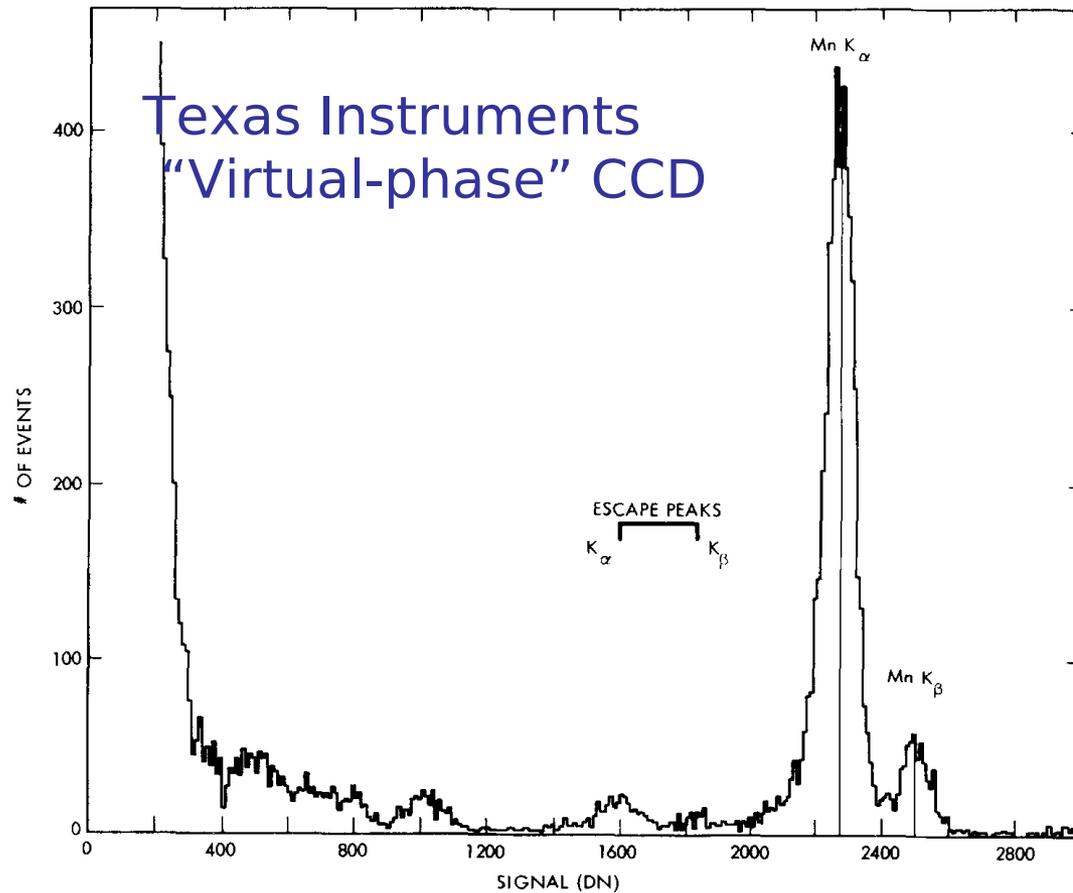
Early X-ray CCD Spectrum

Griffiths, Murray, Schwartz & Zombeck, 1980, SAO



Early X-ray CCD Spectra

Stern, Liewer & Janesick, 1983, JPL/Caltech



A Proposal for CCD Imaging Spectroscopy on AXAF

This joint proposal is submitted by the

Department of Astronomy
The Pennsylvania State University

Center for Space Research
Massachusetts Institute of Technology

Jet Propulsion Laboratory
California Institute of Technology

Gordon P. Garmire

Gordon P. Garmire
Principal Investigator
Department of Astronomy
The Pennsylvania State University
University Park, PA 16802
(814) 865-0418

In Response to:

A0-OSSA-3-83

Submitted:
17 February 1984

Original ACIS Co- Investigators 1984

George Ricker, Dep. PI

Hale Bradt

David Burrows

Claude Canizares

George Clark

Stewart Collins

Eric Feigelson

Jeffery McClintock

Albert Metzger

James Morrison

John Nousek

Saul Rappaport

Guenther Riegler

Richard Sherman

Wallace Sargent

Daniel Weedman

Original ACIS Focal Plane (1984 Proposal)

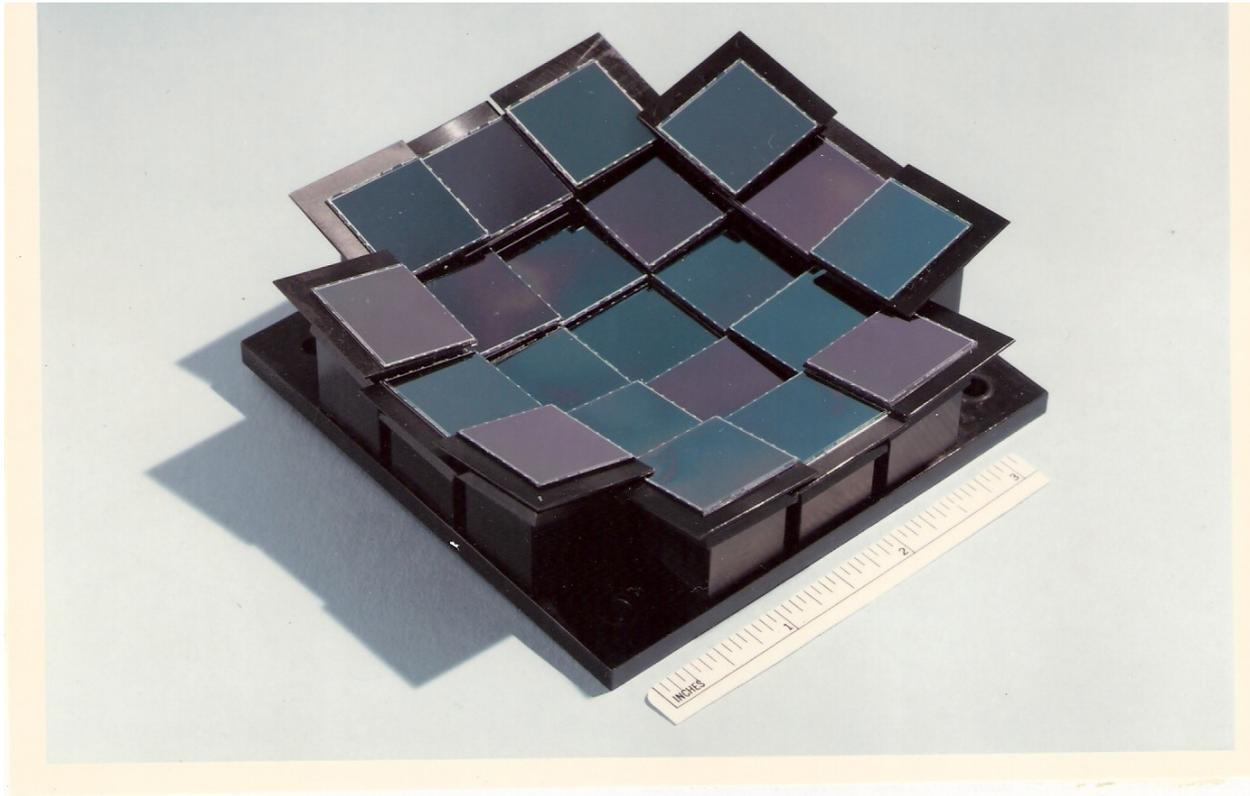


Fig. 4.7-1 A mechanical mock-up of the proposed ACIS focal plane detector array. The 1024 CCDs shown in the picture have the approximate ACIS CCD dimensions; but, unlike ACIS, there is circuitry along all four edges of the chips. As shown, the curvature of the AXAF focal surface permits a horizontal offset between adjacent CCDs which facilitates the device mounting and the wire bonding that is necessary to drive and read the CCDs.

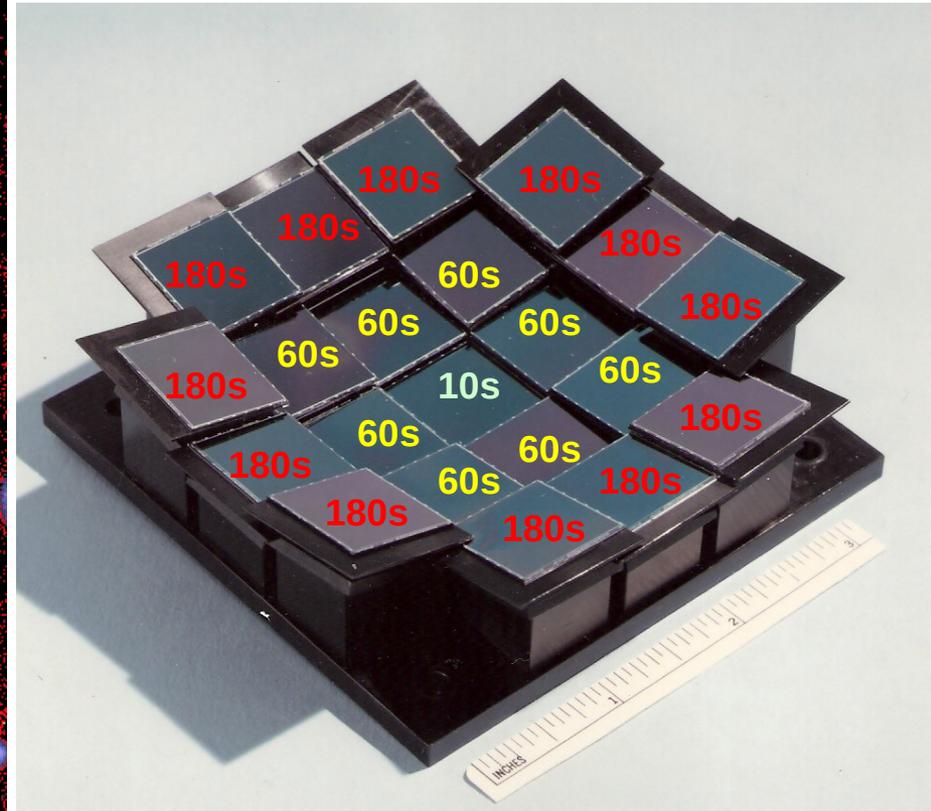
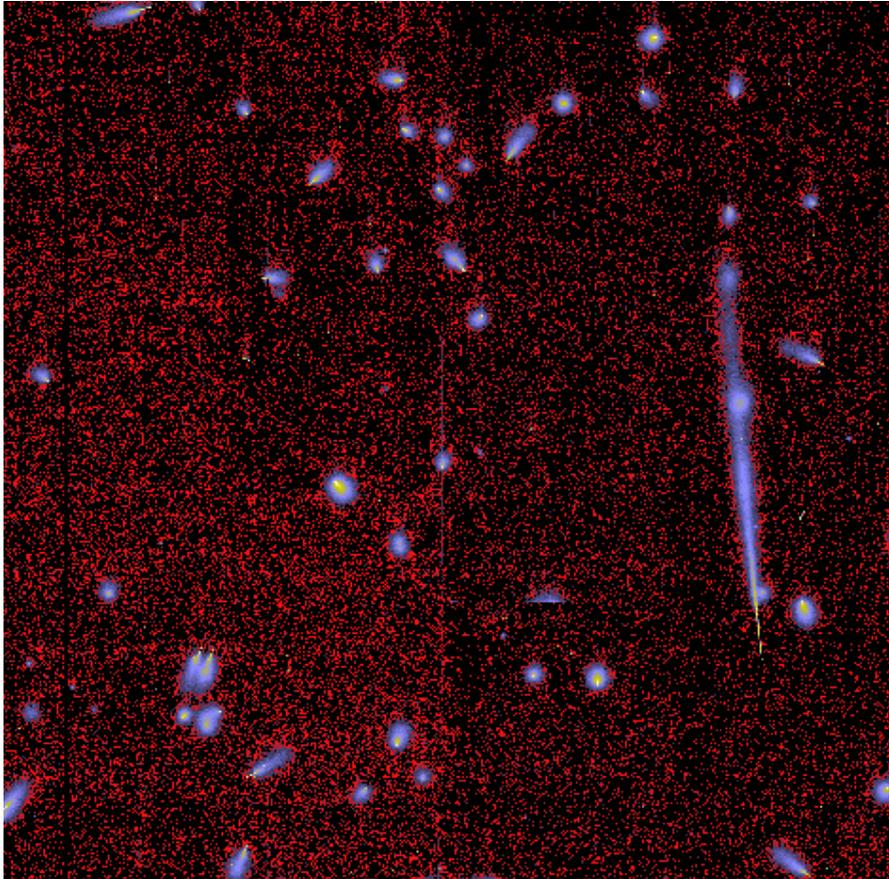
1984 ACIS Peculiarities

The 1984 ACIS:

- Had 21 imaging CCDs -- & 1 spare (JPL!)
- Had a huge FOV, much of which would have been useless
- Had a mechanical shutter that by now would have completed ~ 70 million cycles
- Was approved as a 5-chip, grating readout instrument only

Original ACIS Focal Plane

ACIS Flight Data (1 fr/3s)



Animation: B. LaMarr/C. Grant

Assessment

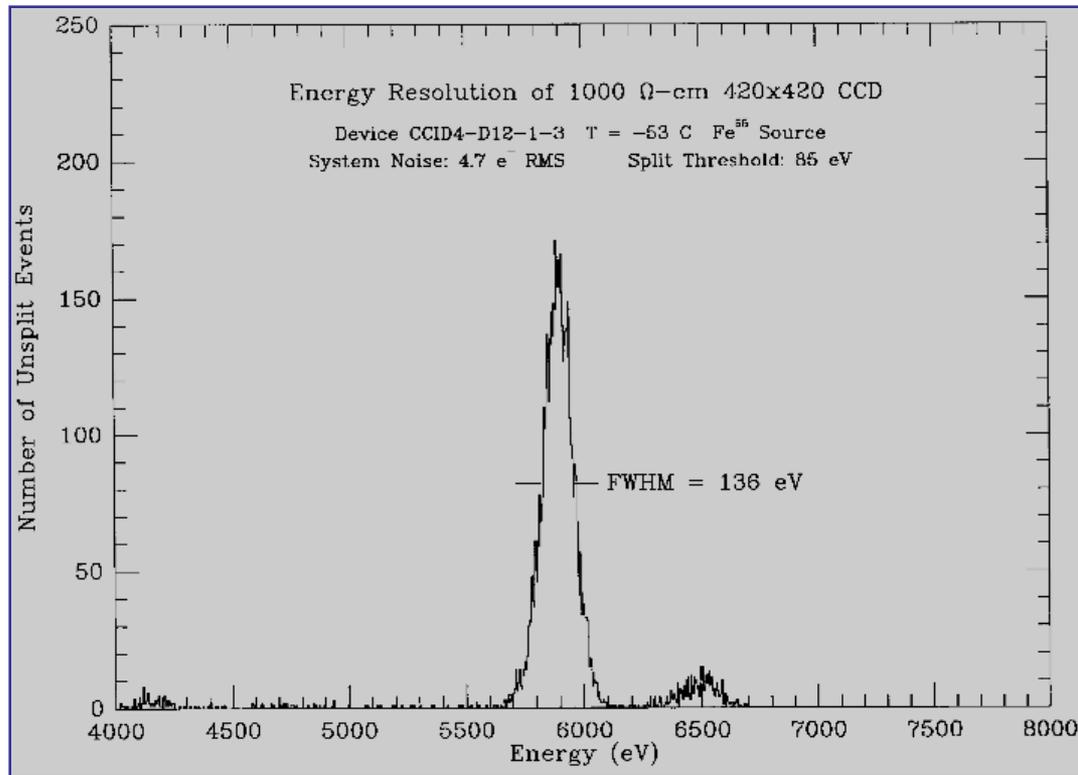
In 1984:

- The ACIS instrument concept was sound.
- Power & mass were *over*-estimated compared to final flight instrument
- ACIS scientific capabilities were (generally) correctly understood.
- The CCD technology was not ready.

Finding CCDs for ACIS

- Originally-proposed 'virtual phase' devices looked promising...
 - Less dead layer opacity, better soft QE
 - Electronics apparently simpler than multi-phase
- But were just too cranky, and never worked to expectations.
- By 1986, TI was giving up and alternate vendors (Ford, Thompson) were consulted.

MIT/Lincoln CCDs



- George Ricker encountered Barry Burke of MIT/LL & learned of LL CCDs developed for space surveillance.
- First X-ray detection achieved Oct. '87 at MIT CSR
- Much lower noise, excellent resolution, *no fuss*

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ACIS Flight Focal Plane



- Completion date: 19 days before ACIS arrived at XRCCF
- ~3 months behind schedule due to 'flexprint' woes

- Flight 'paddle' was 4th ACIS focal plane
- 100+ ACIS CCDs were characterized at MIT
- 30+ ACIS CCDs were 'fully' calibrated at MIT (some twice @ $12 \text{ days} + 10^7$ photons/device)

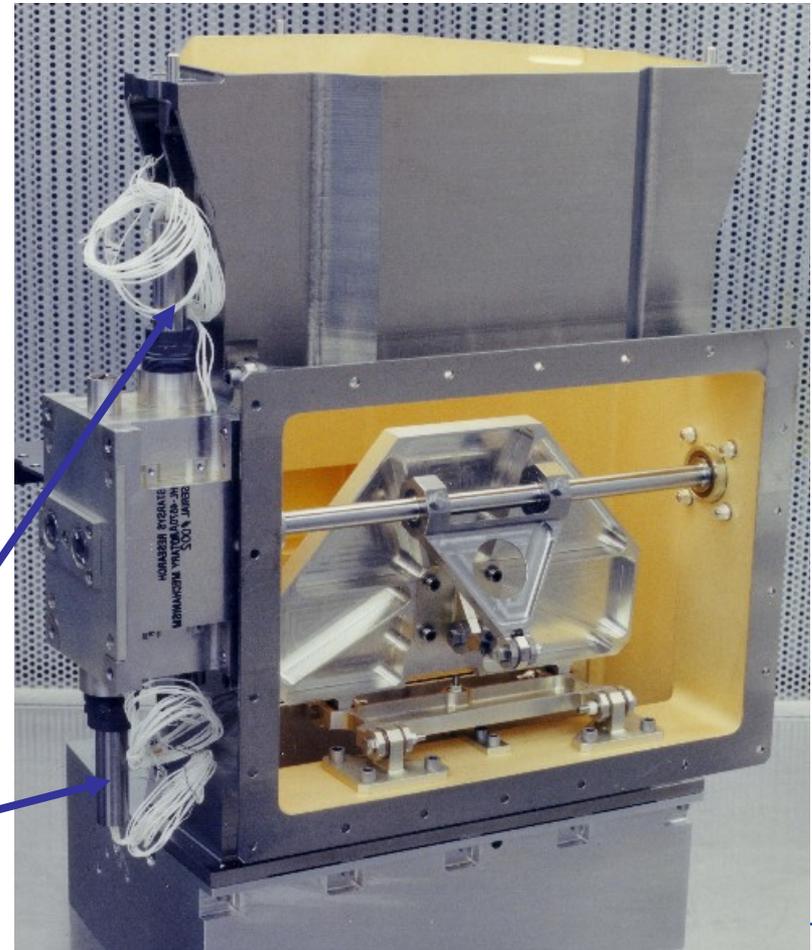
The ACIS Door Caper

- ACIS detectors were to launch under vacuum.
- A massive door & mechanism were required.



The ACIS Door Caper

- ACIS door design was excellent, but it relied on paraffin actuators with self-destructive tendencies
- Door actuators

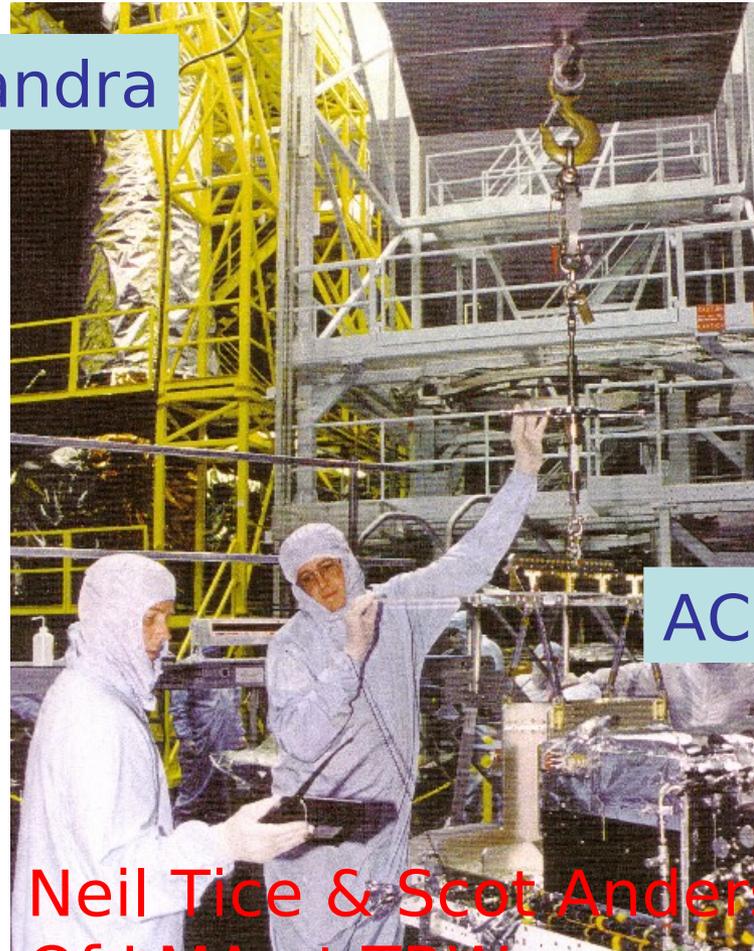


The ACIS Door Caper

On June 18, 1998,
after opening
flawlessly

253 times on dev. unit,
23 times on flight unit,
during 'final' ground
test at TRW TV,

Chandra



ACIS

Neil Tice & Scot Anderson
Of LMA at TRW

The ACIS door didn't
open

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Why didn't the door open?

Despite heroic sleuthing, no one knows to this day. Neil Tice thinks it may have to do with 'blocking'. Another save for "Test as you fly"



All's well in the end

Andy Northrup

CXC, 8 August 1999

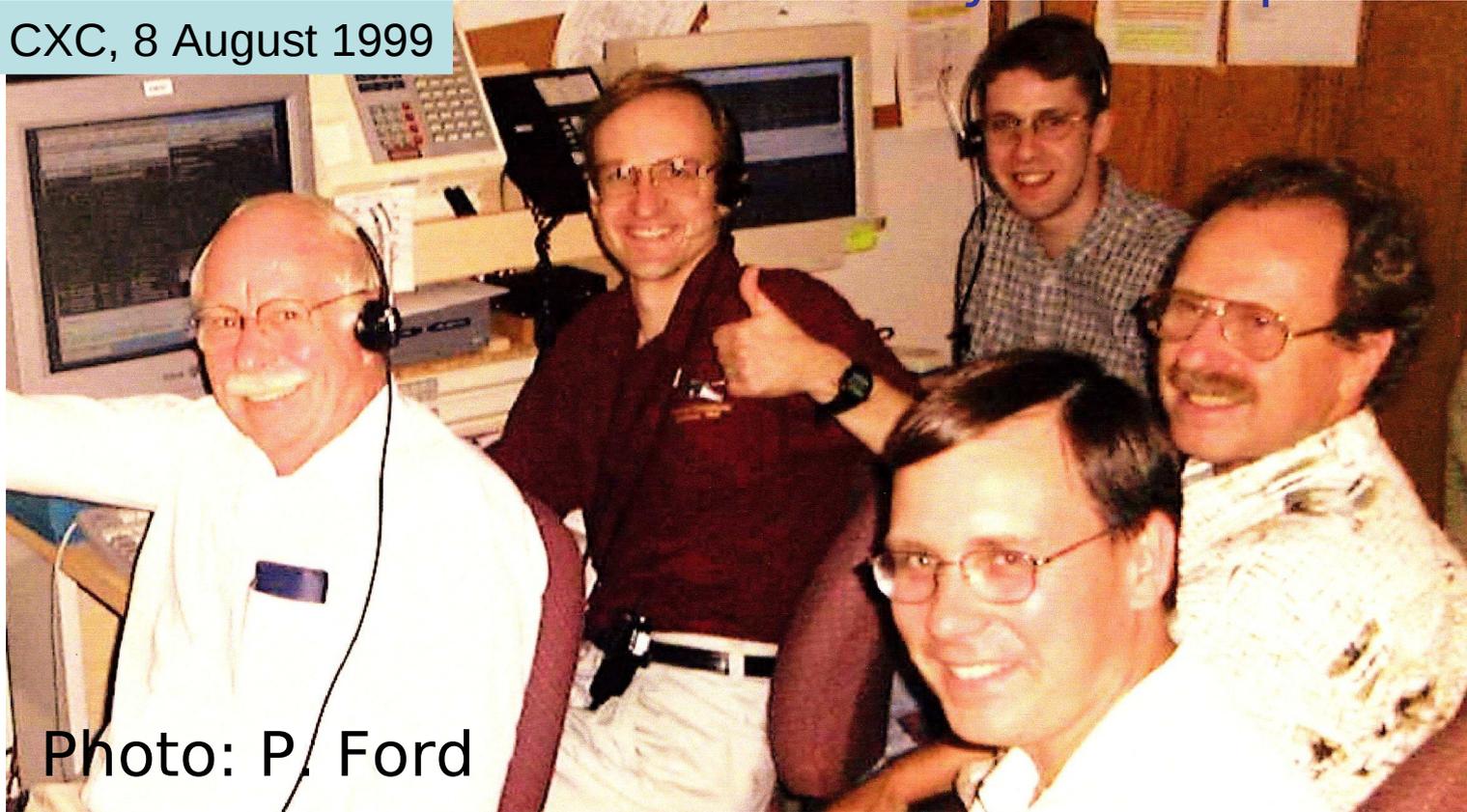


Photo: P. Ford

Ed
Boughan

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Paul
Plucinsky

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Gordon

Yes, I'm a little relieved," said Gordon Garmire,
the ACIS principal investigator.

"Actually, I feel really good!"

CXC, 8 August 1999

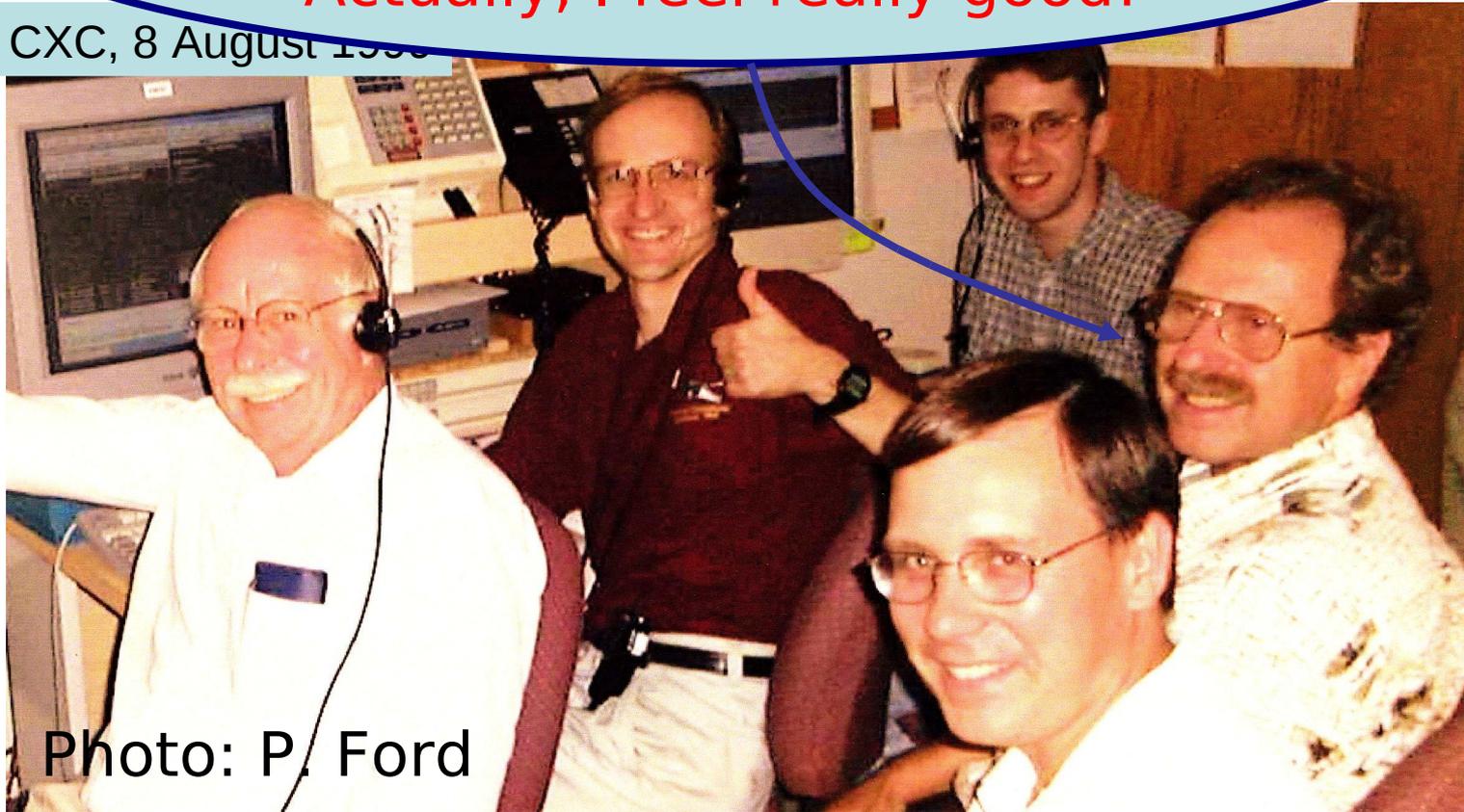


Photo: P. Ford

Ed
Boughan

Paul
Plucinsky

Gordon

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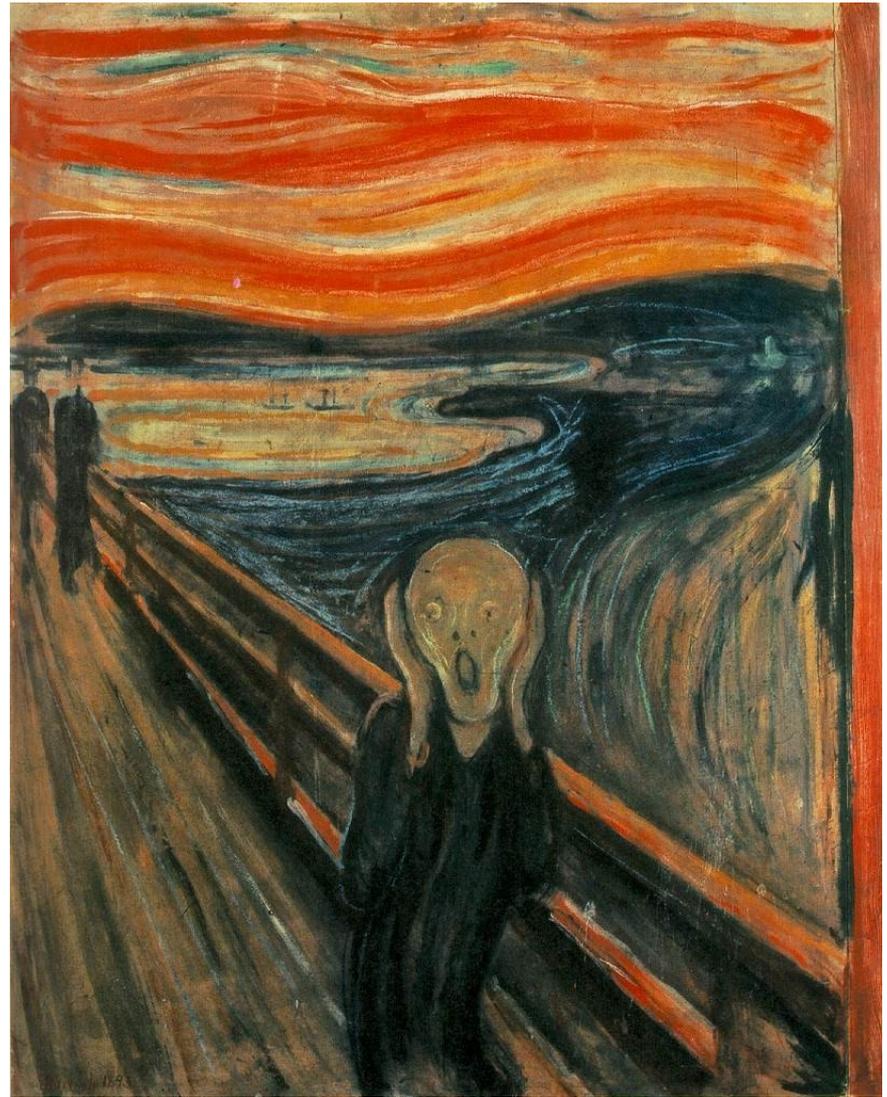


Crisis

After ACIS door opened on 8 August
1999:

- 12 August: HRMA/sunshade opened (Leon X-1)
- 19 August: Cas-A observation
- 20 August-8 Sept: SIM, HETG, HRC Checkout
- 8 September: 1st CTI measurement with ACIS calibration source showed trouble

There followed
two weeks
of angst &
confusion...



<http://www.ibiblio.org/wm/paint/auth/munch>

Resolution

- Martin Weiskopf 'clarified' (very colorfully) role of rad belts, no later than 17 September (3 orbits after discovery)
- Bronislaw Dichter (AFRL) proposed mechanism at LL meeting on 23 September: Rutherford scattering allows HRMA to focus soft protons on ACIS detectors.
- Gordon Garmire made proton scattering measurements to test this idea.

Recovery

- Steve O'dell led development of Chandra radiation model to predict effects of solar weather & ensure safe ops.
- CXO SOT (Schwartz/Plucinsky et al.) implemented essential monitors & procedures.
- Leisa Townsley & team developed the CTI corrector ground processing algorithm which greatly improved science from the FI detectors.

ACIS Development Team

Penn State

Gordon Garmire, IPI

John Nousek, Lead Co-I
Pat Broos
David Burrows
George Chartas
Eric Feigelson
Audrey Garmire
Scott Koch
George Pavlov
Leisa Townsley
Eric Cocklin
Catherine Grant
Kaori Nishikida

+SAO & MSFC!

MIT CSR (MKI)

George Ricker, Dep. IPI

Bill Mayer, Manager
Mark Bautz, Proj. Sci.
Claude Canizares
Steve Jones
Steve Kissel
Gregory Prigozhin
Herb Manning
Fred Baganoff
Takashi Isobe
Hale Bradt
George Clark
Saul Rappaport
John Doty
Robert Goeke
Ed Boughan
Rick Foster
Peter Ford

Jim Francis
Gordon Gong
Dorothy Gordon
Phil Gray
Pete Tappan
Brian Klatt
Matt Smith
Eric Kintner
Demitrios
Athens
Beverly LaMarr
Mike Pivovarovff
Mike Doucette
Fred Kasperian
Dan Hanlon
Fred Miller
Jim O' Connor
Ann Davis
Bob Blozie
Ellen Sen

MIT Lincoln

Bernie Kosicki
Barry Burke
Jim Gregory
Al Pillsbury

Lockheed-Martin

Lloyd Oldham
Neil Tice
Scott Anderson
Ed Sedivy
Larry Campbell

JPL/Caltech

S. Andy Collins
Steve Pravdo
Albert Metzger
Wallace Sargent

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Orion's First Decade
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Gordon's favorites:

- Ten days on Orion
- SN1987A
- The Crab and Vela pulsar nebulae
- RCW103 and its 6.7 hour pulsar
- Sgr A* and vicinity

Gordon's favorites:

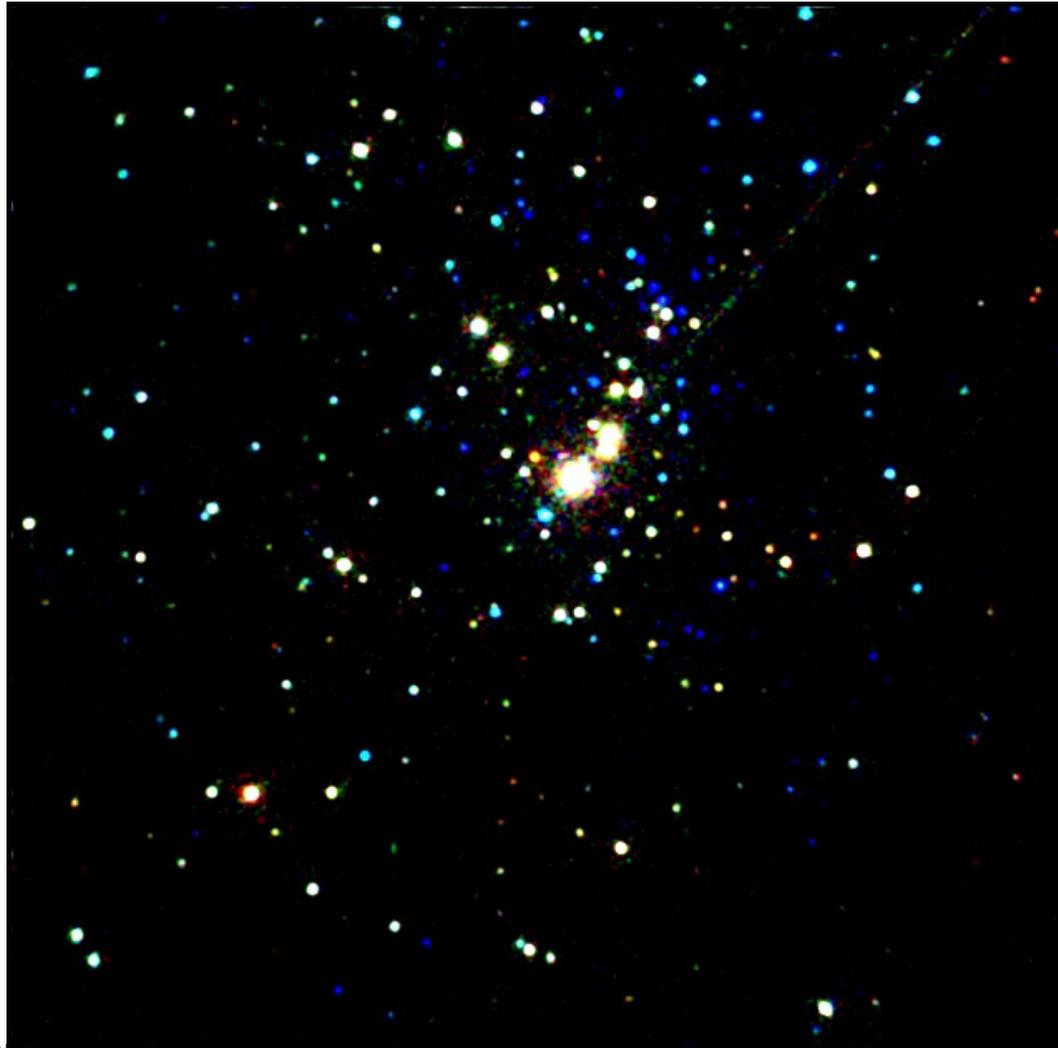
- Ten days on Orion
- SN1987A
- The Crab and Vela pulsar nebulae
- RCW103 and its 6.7 hour pulsar
- Sgr A* and vicinity

And one of mine:

- Feedback to 1 Mpc

Ten Days on the Orion Nebula

E. Feigelson et al.



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Ten Days on the Orion

Nebula
E. Feigelson, K. Getman, et al./CXC; EDF this AM



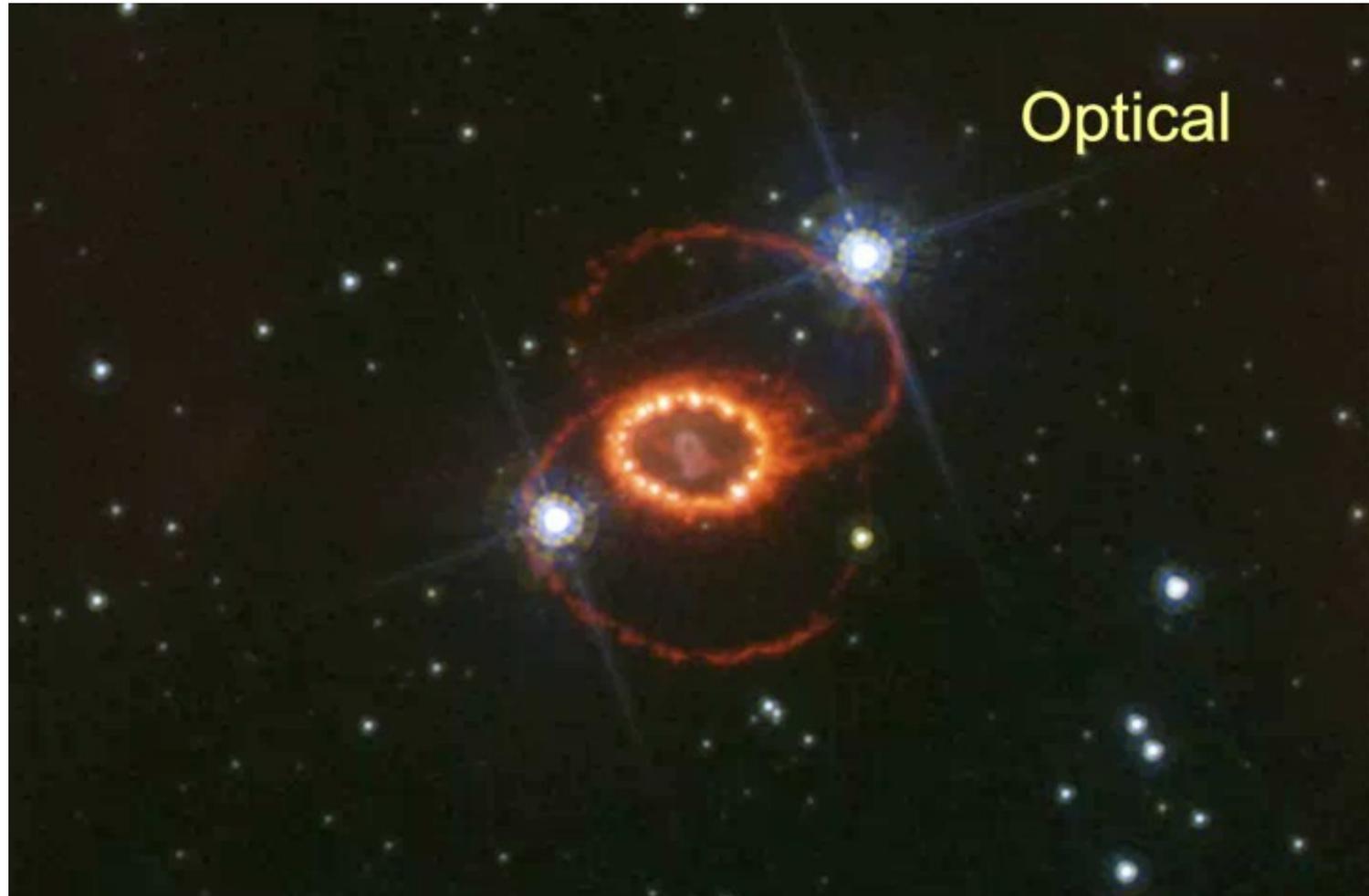
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SN1987A

D. Burrows et al./CXC; S. Park, Wednesday AM



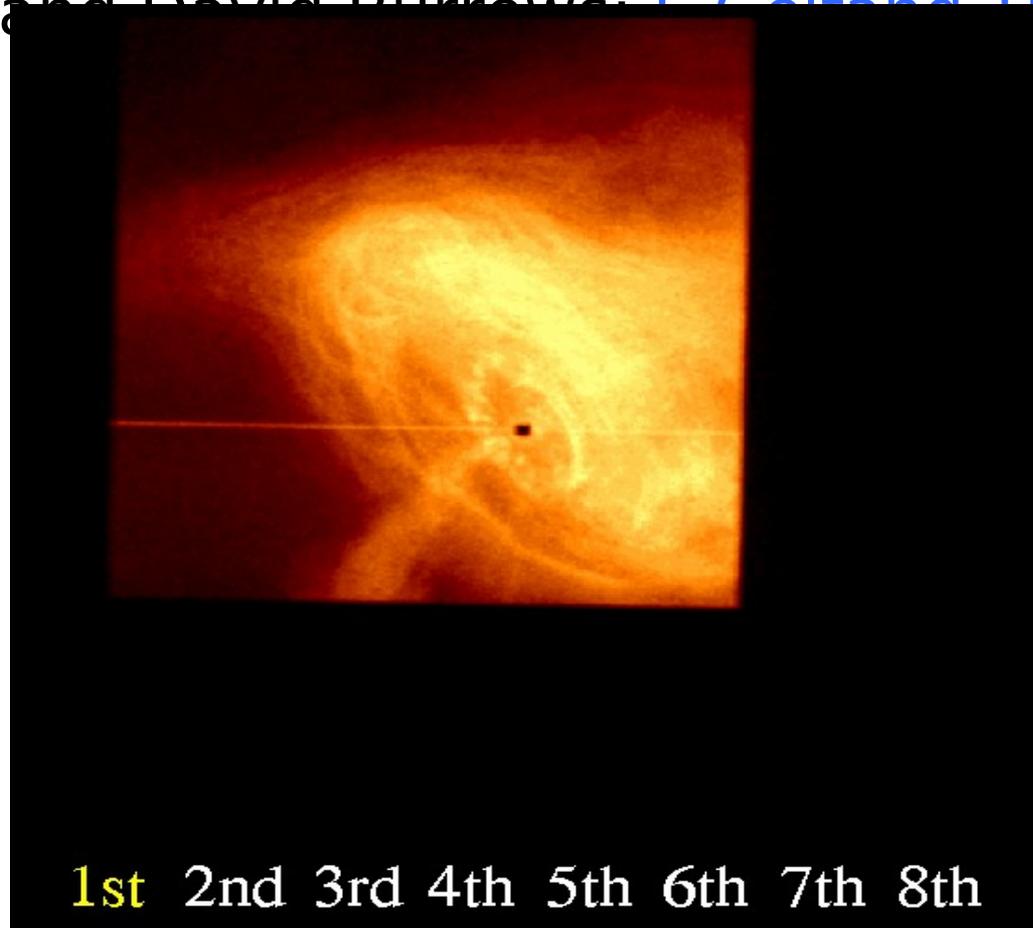
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The Crab Nebula and Pulsar

Koji Mori and David Burrows, [J. Geophys. Res.](#) **114**, G04101 (2009) [doi:10.1029/2008JG001181](#)



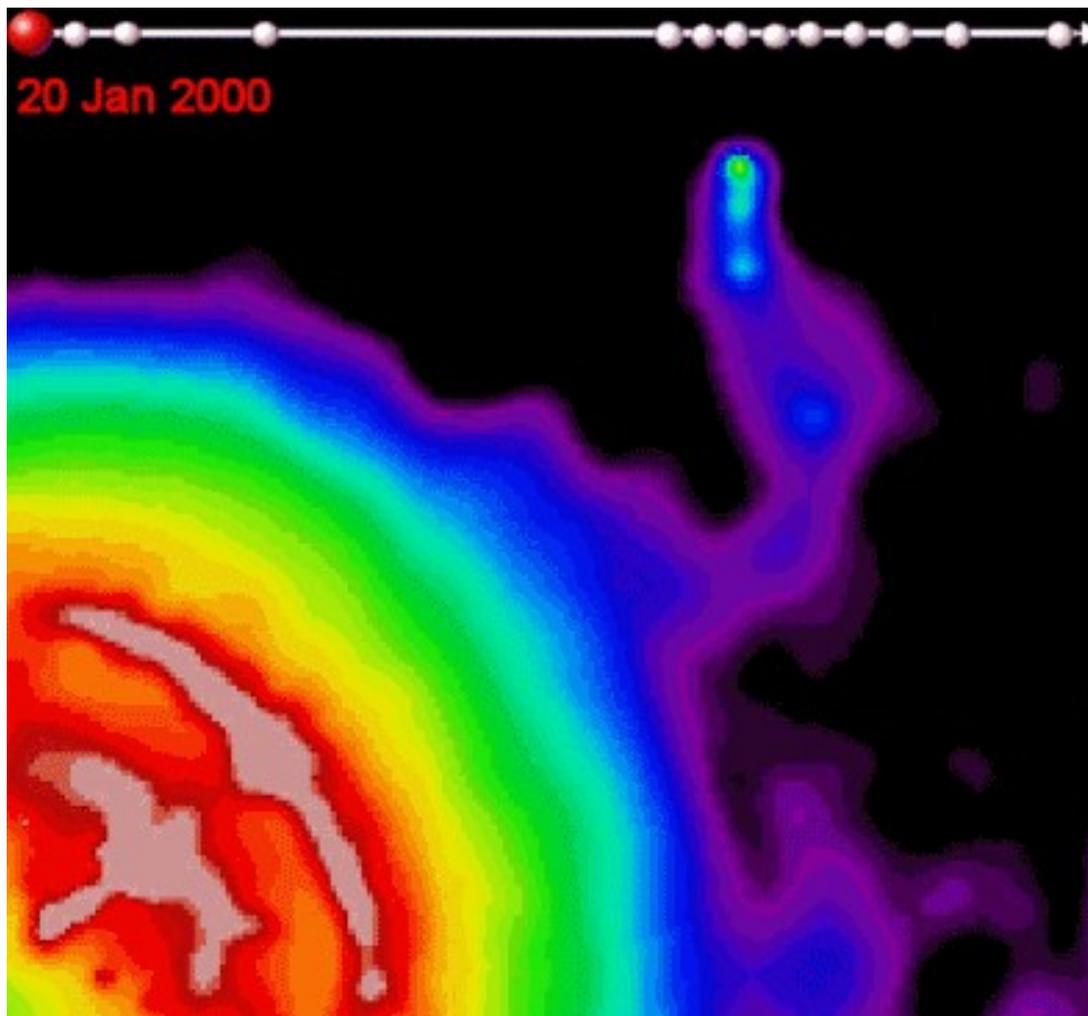
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Vela Pulsar and Nebula

G. Pavlov et al./CXC; Thurs. AM

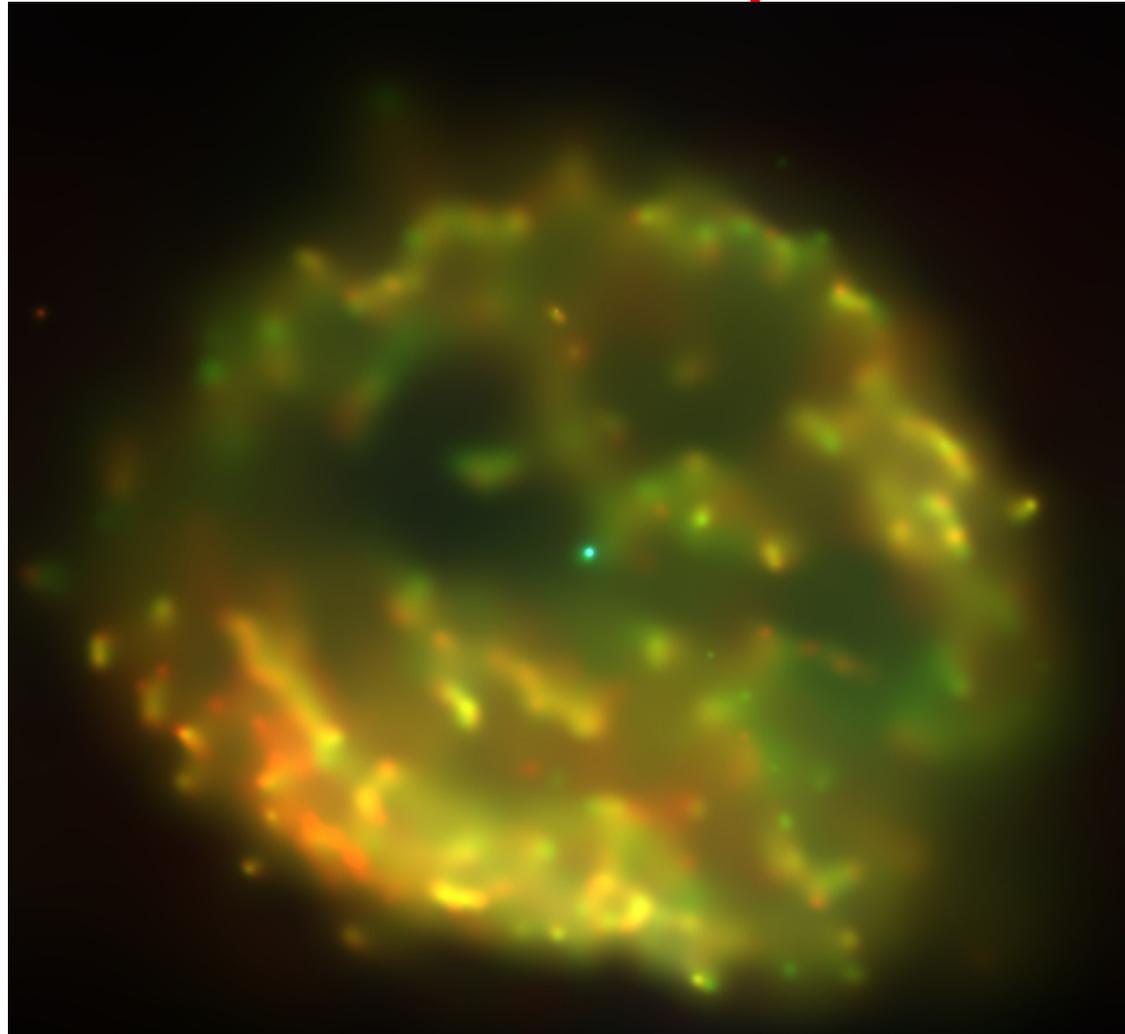


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The SNR RCW103 and its 6.67 Hr pulsar



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Sgr A* and Surroundings

F. Baganoff et al./CXC; S. Markoff Fri. AM



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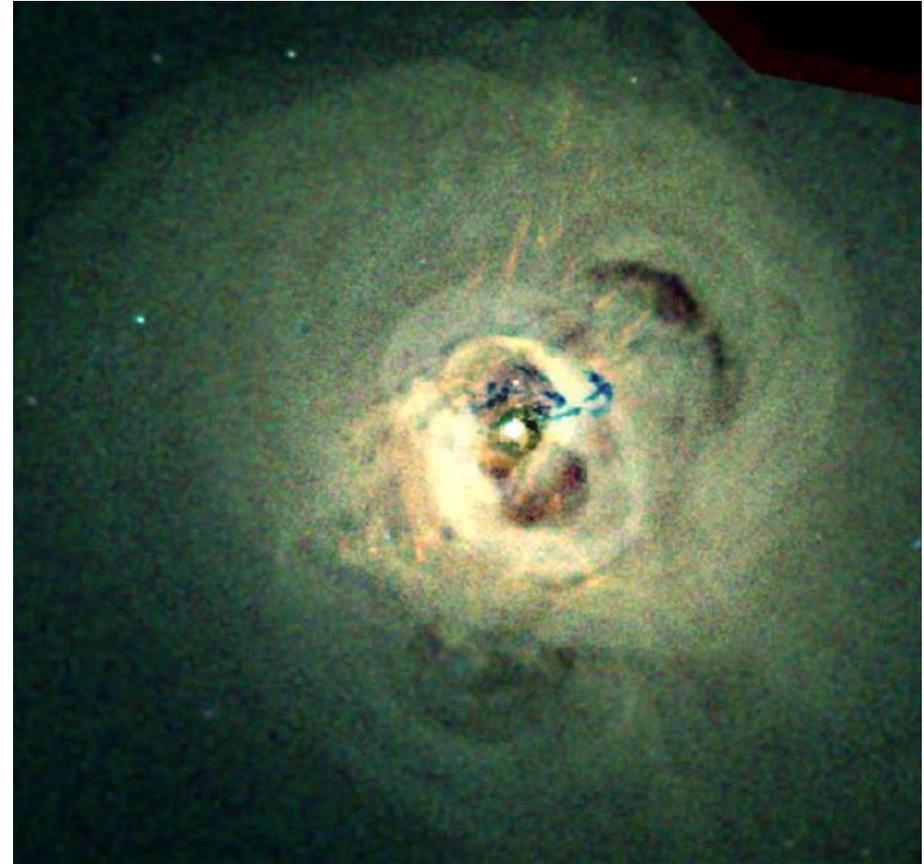
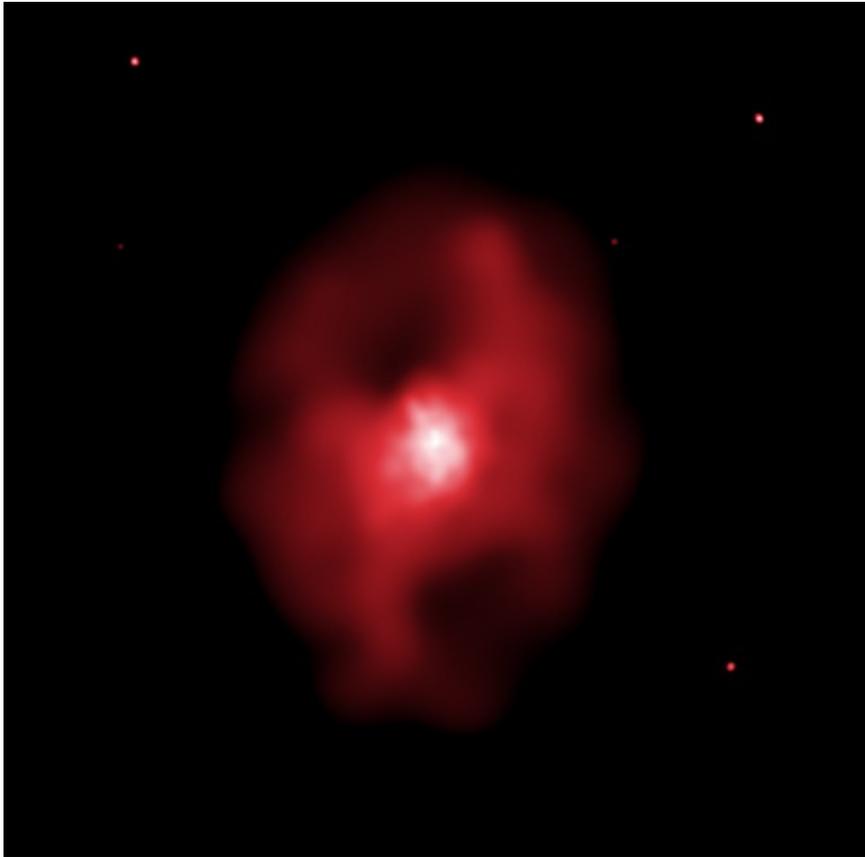


Feedback on Mpc Scales

Blanton, Gitti, Mittal, Wed AM

MS 0735, B. McNamara et al.

Perseus, A. Fabian et al.



We can't wait
for Chandra's next
decade!

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