Lessons We Learned Designing and Building the Chandra Telescope

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&
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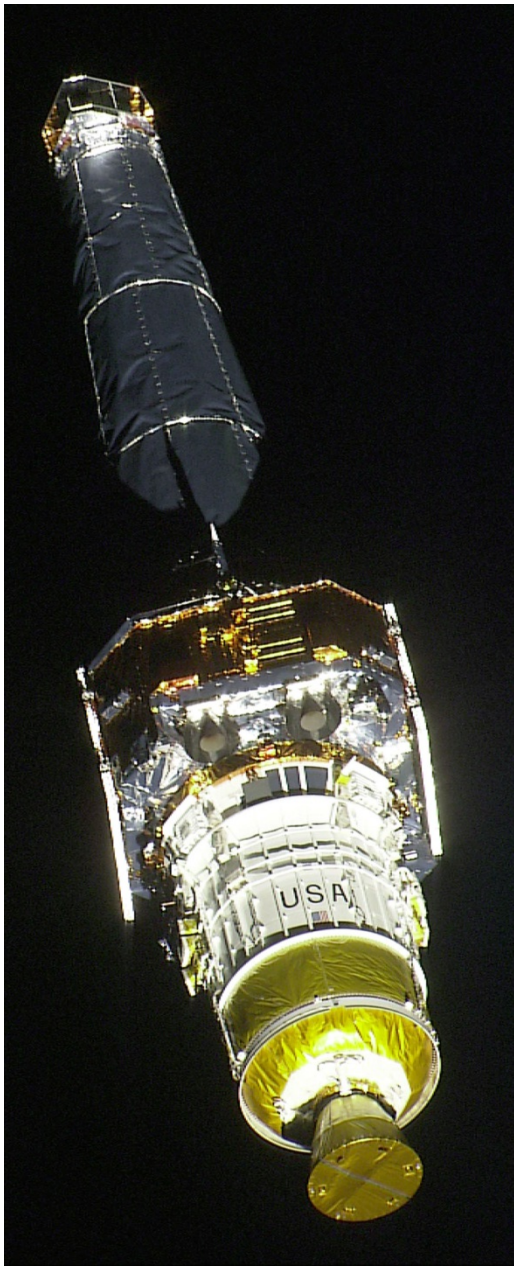
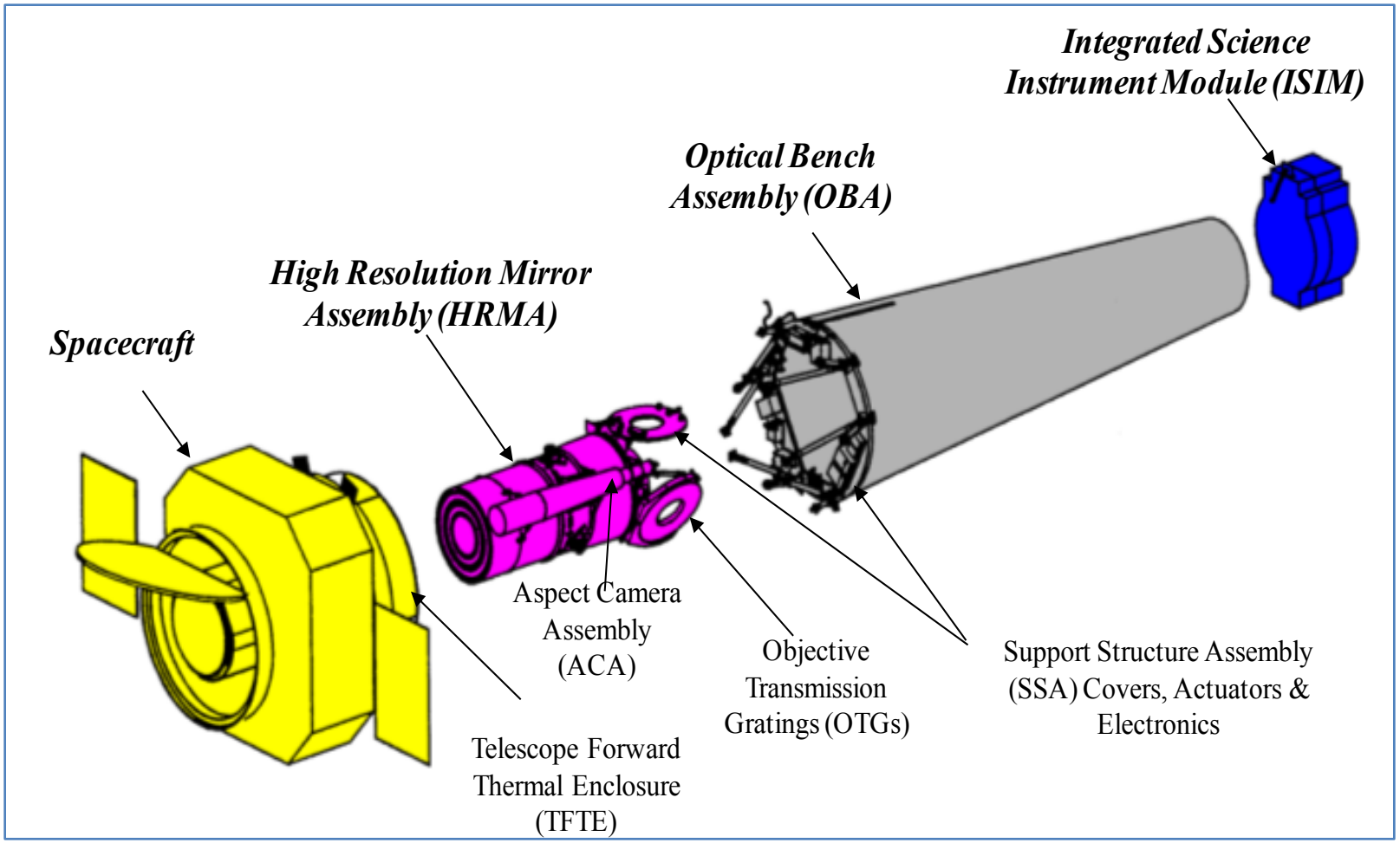
Overview of Talk

- Overview of main lessons learned
- A very brief historical overview
- Some of our lessons learned
- Summary

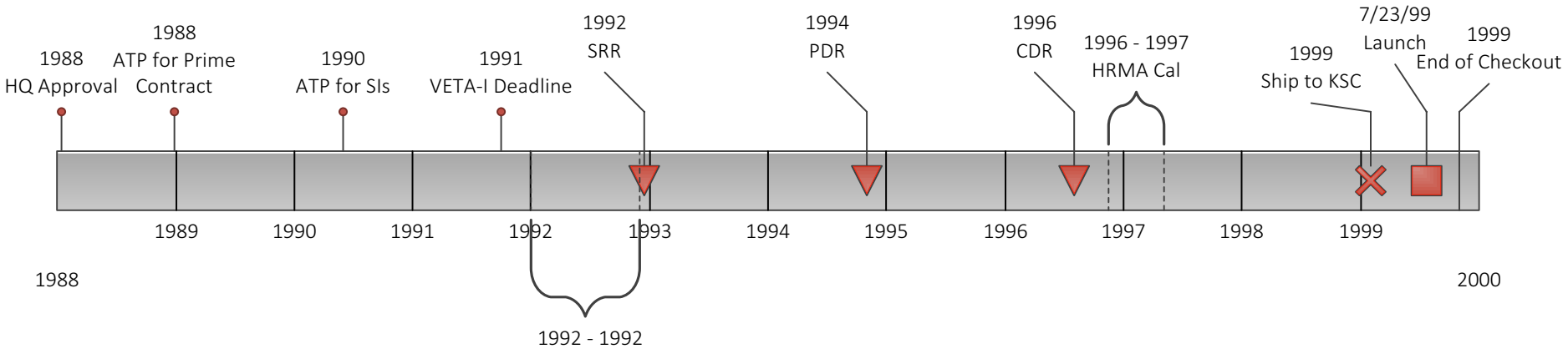


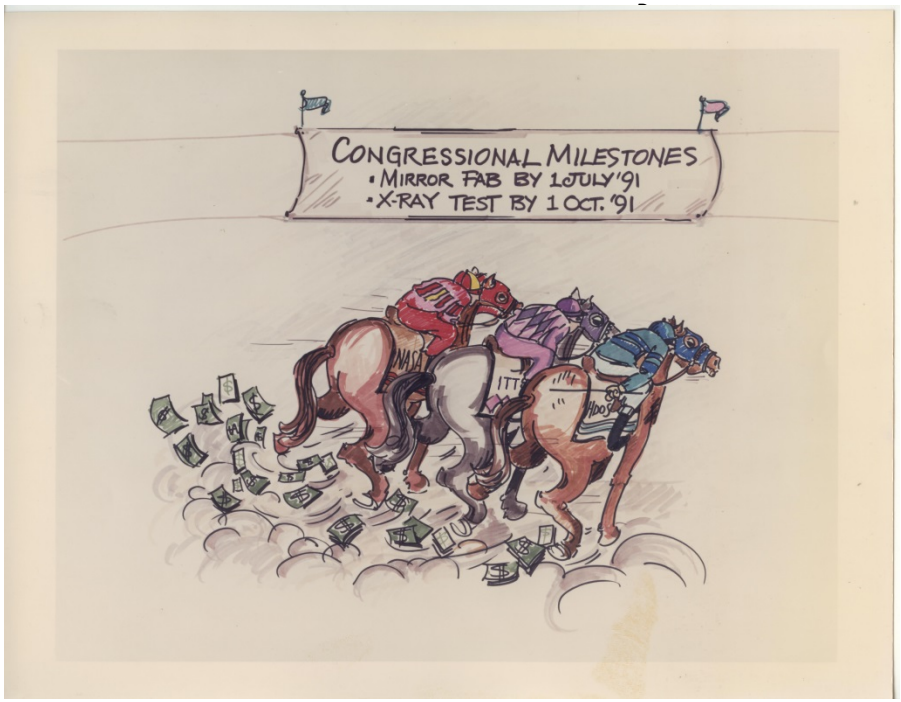
- Build a solid team—face to face, keep that team together throughout the program.
- Understand the details---there is no such thing as a “simple” interface or material property, requirements too!
- Understand the risks and attack the big ones as early as possible.
- Practice all challenging or new processes, procedures, facilities and teams off the critical path
- Test completely as early and completely as possible, after all “An ounce of prevention is worth a pound of cure.”

Chandra's Anatomy



Chandra Timeline





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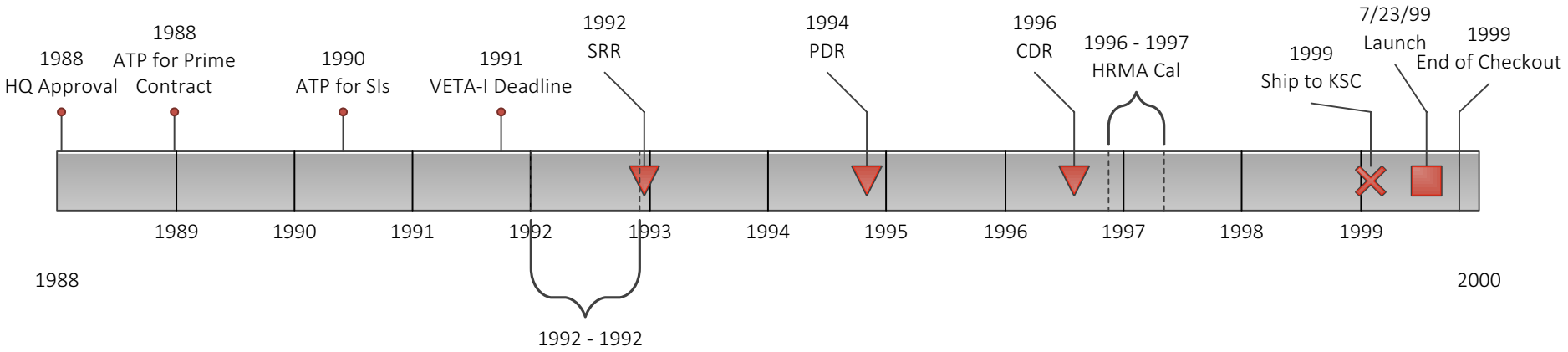

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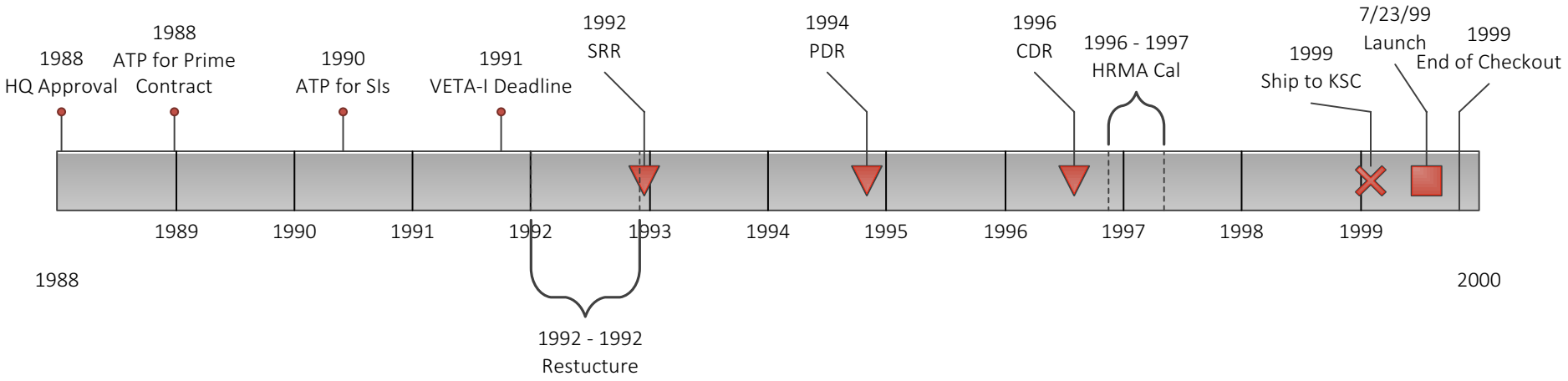
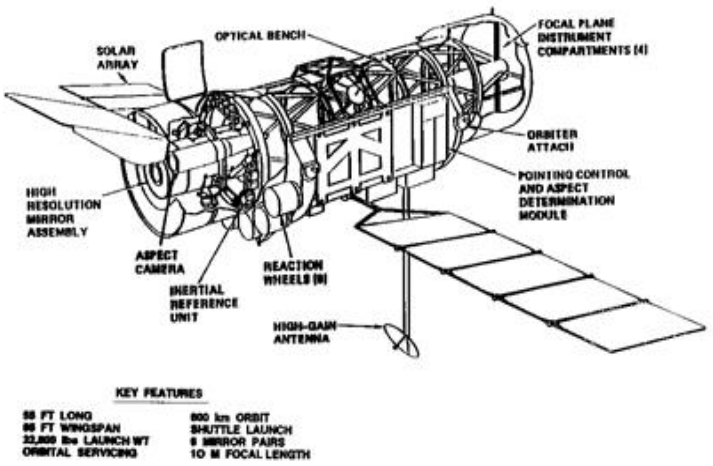
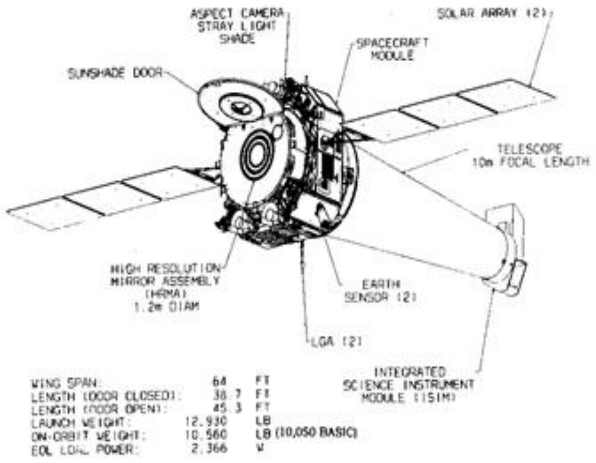


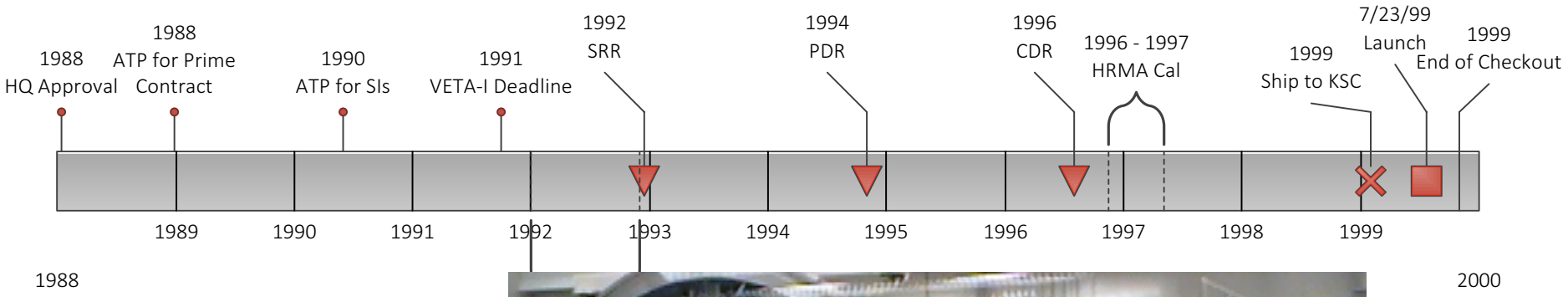


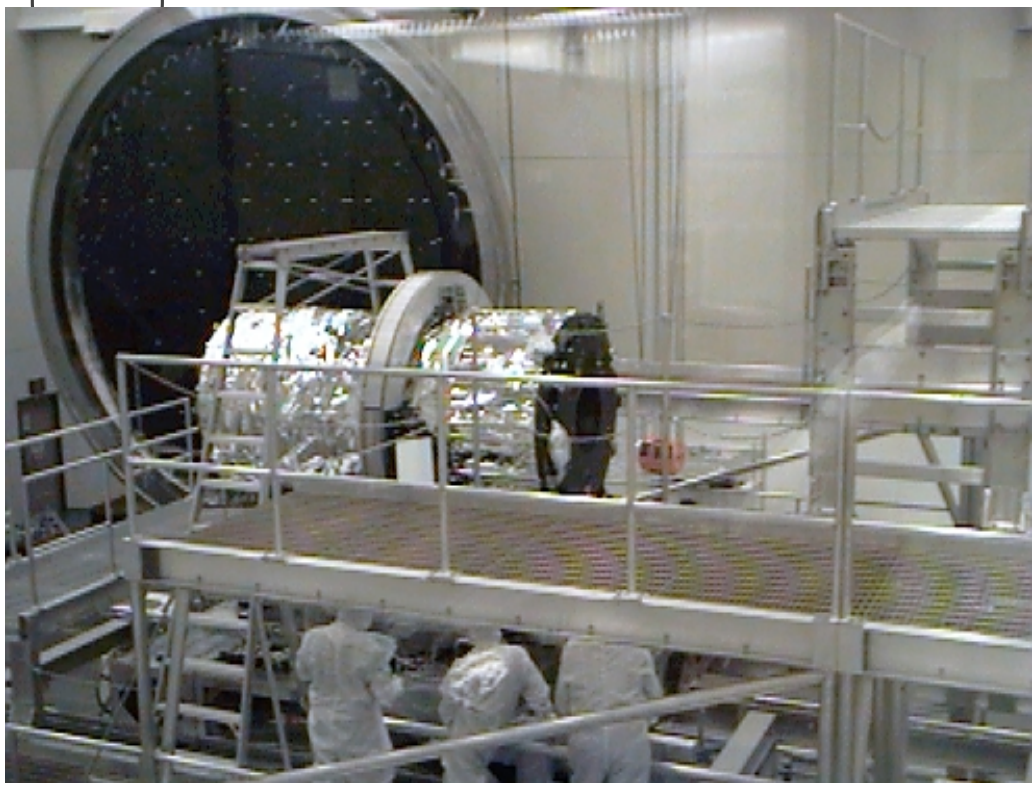
Original Mission Concept



Flight Mission Concept

Chandra Timeline





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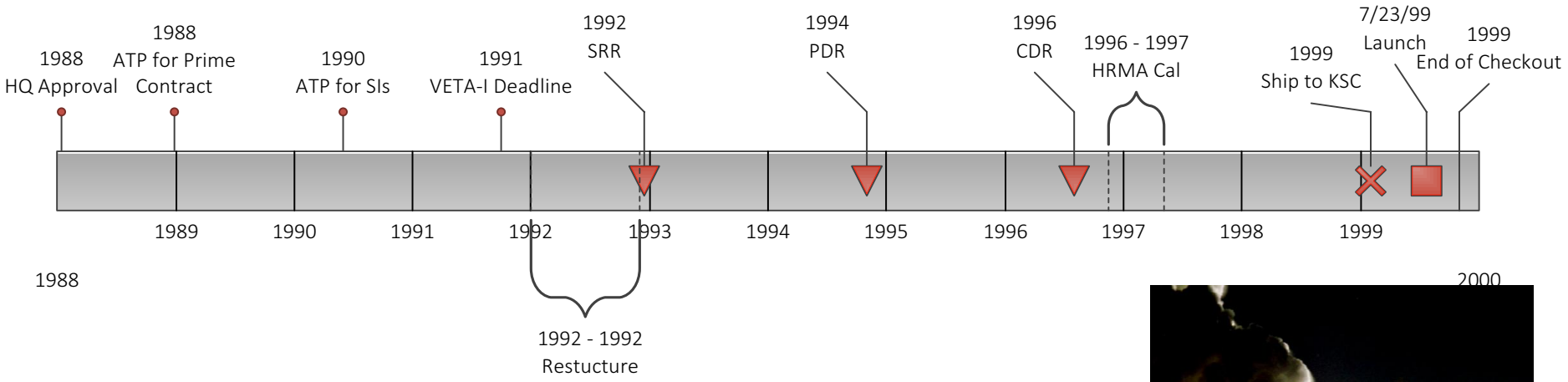


Team

- Most key positions were held by the same people over the course of the entire program
- VETA-I veterans formed the core of the team
- After program reformulation, the team emerged truly badgeless with the single goal of executing the science driven design
  - ~1,000 cm^2 of collecting area
  - 0.5 arcsec imagery

Details: Moisture in the Glue

- The mirrors are supported by invar pads that are epoxied to the outside diameter of the mirror.
- Test and analysis of the epoxy showed that over seasonal humidity cycles the strain in the adhesive markedly changed.
- Requirement to control humidity to be dry during the bonding operation.
- This dry condition assured us of proper on orbit performance
- A method also had to be found to remove excess water from the epoxy's resin component,
  - A molecular sieve was identified
  - Absorbs water and only water from the neat epoxy resin

- Lesson is to make sure to know how material properties can affect performance, no matter how small the property change is

Dealing with Risk: Tale of Two VETAs

- Verification Engineering Test Article-I (VETA-I) addressed the major risk on the program-mirror development
  - Provided early check out of XRCF, x-ray calibration procedures and facility interfaces
- The VETA-I experience allowed the argument for rehearsals for flight calibration
  - Not in baseline plan for program
  - Rehearsals enabled a successful calibration yielding better scientific return

VETA-II Simulated the HRMA

- VETA-II added to program as risk reduction activity
- VETA-II mounted P1/H1 to the flight tolerances using the flight handling hardware and alignment metrology
  - Hundreds of lessons learned resulted from VETA-II
    - Affecting handling procedures, support equipment, metrology hardware, and alignment and metrology processes

VETA-II as recently discovered at MSFC. Dr H. Jones, Jr is visible at right

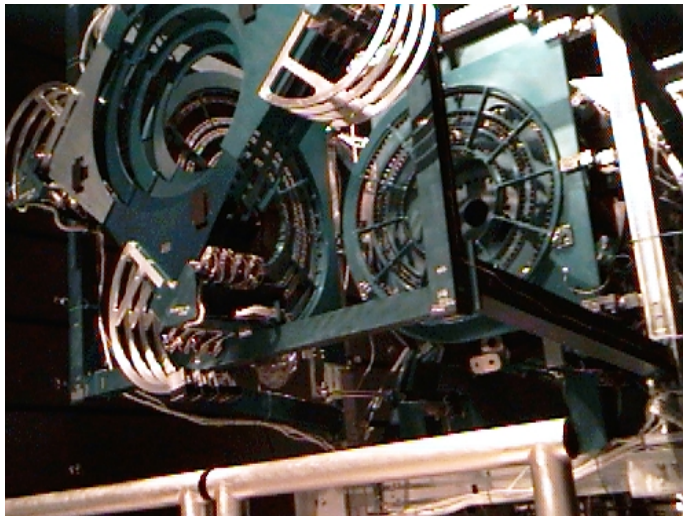
- Lessons learned from VETA-II enabled the installation of the flight mirrors to complete 1 month ahead of schedule
- VETA-II was always “on the chopping block” to save budget in tight moments

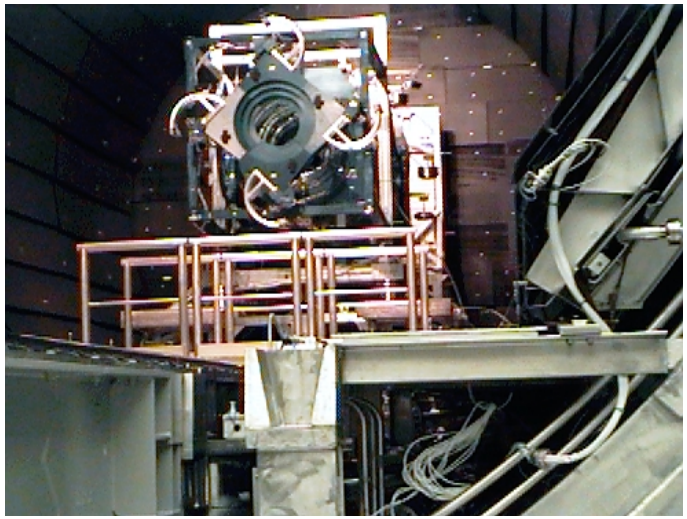
Practice Makes Perfect

- VETA-I test efficiency was about 1-3%
  - Necessary flight calibration was not feasible in the allotted time
- A series of rehearsal tests, were conducted, form May 1996 to late November 1996
- Could entire new test procedure from the science database of requested measurements in 30 minutes
  - React to what was being learned in near real-time
- Final average efficiency for x-ray calibration was 48.8% for all test phases
  - The efficiency for the non-flight detector, HXDS, was significantly lower than for calibration with the flight detectors.
  - Lesson rehearsals pay off, but we would have even better served with more attention to requirements on data collection speed

Test Completely

- The ground support equipment for use at XRCF did not get tested in a vacuum
  - Cost and schedule
- The GSE was designed well and checked out in Rochester and appeared to be working as designed
  - Vacuum testing at XRCF after integration of the flight hardware surfaced issues
- Early vacuum testing would have identified problems and corrected them off the critical path of the program, which was x-ray calibration
- Early system debugging would have identified these issues and they would have been solved off the critical path





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