Space Science in the Nineties and the AXAF Observatory

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- Major results from space astronomy
- Space science missions and their differences
- The AXAF mission
- AXAF science
- AXAF details
- AXAF dynamics
COBE

- Measured spectral shape of microwave background
- Measured temperature of background
- Measured anisotropy
- Active helium cryogen cooling - short life
- Sky survey
- Low spatial resolution
- Sun synchronous orbit.
HST Observations

- General purpose instruments - two cameras, two spectrographs.
- Automated scheduling, little experimenter involvement
- Nasty pointing constraints
- Articulated solar panels, more flexible than ROSAT

Results from Space Astronomy in the 1990s

- **Cosmology and Galaxies:**
  - Microwave Background spectrum and anisotropy measured (COBE)
  - Gamma Ray Burst theory disproved (CGRO)
  - Tentative detection of helium intergalactic medium (HST)
  - High redshift galaxy morphology (HST)
  - Evidence for substructure and continuing formation in clusters of galaxies (ROSAT)

- **Quasars:**
  - Gamma Ray Quasars discovered (CGRO)
  - Optical jets and conical flows in quasars imaged (HST)
  - X-ray absorbing material in quasars studied (ROSAT, ASCA)
  - High redshift quasars detected in X-rays (ROSAT)
• **Stellar Astronomy:**
  • Distances to nearby stars measured (Hipparcos)
  • Superluminal galactic binary systems (Granat, CGRO)
  • Annihilation source near Galactic Center located (Granat)
  • EUV sources cataloged (ROSAT, EUVE)
  • Discovery of supersoft X-ray stellar sources (ROSAT)
  • Detection of gamma rays from old radio pulsars (ROSAT, CGRO)
  • X-ray spectra of Type I and II supernova remnants different (ASCA)
  • Light echo in SN1987A imaged (HST)
What are the differences between satellite instruments?

• Focussing optics or bare detectors
• Wavelength or energy range - IR, UV, etc. Different technology used for different wavebands.
• Spatial Resolution (how sharp a picture?)
• Spatial Field of View (how large a piece of sky?)
• Spectral Resolution (can it tell photons of different energies apart?)
• Spectral Field of View (bandwidth)
• Sensitivity
• Pointing Accuracy
• Lifetime
• Orbit (hence operating efficiency, background, etc.)
• Scan or Point
What are the differences between satellites?

- Spinning or 3-axis pointing (older satellites spun around a fixed axis, precession let them eventually see different parts of the sky)
- Fixed or movable solar arrays (fixed arrays mean the spacecraft has to point near the plane perpendicular to the solar-satellite vector)
- Equatorial or polar orbit (equatorial allows higher mass, if low enough also less radiation; polar allows sun-synchronous operation).
- Low or high orbit (low orbit has higher radiation, atmospheric drag, and more Earth occultation; high orbit has slower precession and no refurbishment opportunity)
- Propulsion to raise orbit?
- Other consumables (proportional counter gas, attitude control gas, liquid helium coolant)
What are the differences in operation?

• PI mission vs. GO mission

PI = Principal Investigator. One of the people responsible for building the satellite. Nowadays often referred to as IPIs (Instrument PIs).

GO = Guest Observer. Someone who just want to use the satellite. (Confusingly, the GO is the PI on his or her own grant, which is different from being a PI on the mission).

A ‘PI mission’ is one in which the PIs get all the observing time. A ‘GO mission’ is one in which the GOs get most of the time. The PIs are guaranteed some fraction of the time (and are GTOs, Guaranteed Time Observers) as a reward for the decades of work invested in building it.

The first GO missions were IUE and Einstein. Nowadays all big missions are GO missions (ASCA, AXAF, HST) but some smaller ones (COBE, Alexis) are PI missions.

• Sky Survey vs. Observatory

Some missions scan the whole sky, cataloging every source they can see. Other missions are pointed at specific targets which are already known to be there (because they were discovered in a sky survey).
Who launches astronomy satellites?

There are three main players:

- NASA, the US National Aeronautics and Space Administration
- ESA, the European Space Agency,
- ISAS, the Japanese Institute of Space and Astronautical Sciences.

There are a number of other agencies which occasionally launch astronomy satellites:

- The US Air Force and the US Navy
- IKI (The Institute for Space Exploration of the Russian Academy of Sciences)
- The Indian Space Research Organization
- Individual European nations (Italy; Germany; Denmark; formerly, England and France)
- Argentina and Israel also have plans.

Solar physics in space

I won’t cover this topic, nor will I touch on planetary astronomy.
HST Instruments

- HSP High Speed Photometer (removed 1993)
- WF/PC Wide Field/Planetary Camera (removed 1993)
- FOC Faint Object Camera
- FOS Faint Object Spectrograph
- GHRS Goddard High Resolution Spectrograph
- COSTAR Corrective Optics Space Telescope Axial Replacement (in 1993)
- WF/PC II Wide Field/Planetary Camera II (in 1993)
- STIS Space Telescope Imaging Spectrograph (due 1997)
- NIC Near Infrared Camera (due 1997)
- HACE Hubble Advanced Camera for Exploration (due 2000)
# The Space Observatories

## Great Observatories

<table>
<thead>
<tr>
<th>Mission</th>
<th>Name</th>
<th>Year</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>HST</td>
<td>Hubble Space Telescope</td>
<td>1990</td>
<td>Optical/UV</td>
</tr>
<tr>
<td>CGRO</td>
<td>Compton Gamma Ray Observatory</td>
<td>1991</td>
<td>Gamma ray</td>
</tr>
<tr>
<td>SIRTF</td>
<td>Space Infrared Telescope Facility</td>
<td>2001?</td>
<td>IR</td>
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</table>

## Pretty Good Observatories

<table>
<thead>
<tr>
<th>Mission</th>
<th>Name</th>
<th>Year</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>COBE</td>
<td>Cosmic Background Explorer</td>
<td>1989</td>
<td>Microwave, Submm</td>
</tr>
<tr>
<td>Hipparcos</td>
<td></td>
<td>1989</td>
<td>Optical</td>
</tr>
<tr>
<td>ROSAT</td>
<td>Rontgensatellit</td>
<td>1990</td>
<td>Soft X-ray, EUV</td>
</tr>
<tr>
<td>EUVE</td>
<td>Extreme Ultraviolet Explorer</td>
<td>1992</td>
<td>EUV</td>
</tr>
<tr>
<td>ASCA</td>
<td>Asuka</td>
<td>1993</td>
<td>X-ray</td>
</tr>
<tr>
<td>SOHO</td>
<td>Solar Heliospheric Observatory</td>
<td>1995</td>
<td>Solar UV, X-ray</td>
</tr>
<tr>
<td>XTE</td>
<td>X-ray Timing Explorer</td>
<td>1995</td>
<td>X-ray</td>
</tr>
<tr>
<td>ISO</td>
<td>The Infrared Space Observatory</td>
<td>1995</td>
<td>IR</td>
</tr>
<tr>
<td>VSOP</td>
<td>VLBI Space Observatory Project</td>
<td>1996</td>
<td>Radio</td>
</tr>
<tr>
<td>SRG</td>
<td>Spektr Rontgen-Gamma</td>
<td>1997?</td>
<td>X-ray</td>
</tr>
<tr>
<td>XMM</td>
<td>X-ray Mirror Mission</td>
<td>1999</td>
<td>X-ray</td>
</tr>
<tr>
<td>Integral</td>
<td></td>
<td>2000?</td>
<td>Gamma ray</td>
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## Smaller Missions

<table>
<thead>
<tr>
<th>Mission</th>
<th>Name</th>
<th>Year</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-35</td>
<td>Astro 1/BBXRT</td>
<td>1990</td>
<td>UV, X-ray</td>
</tr>
<tr>
<td>P89-1B</td>
<td>Alexis</td>
<td>1993</td>
<td>X-ray/EUV</td>
</tr>
<tr>
<td>Instrument</td>
<td>Description</td>
<td>Year(s)</td>
<td>Domain</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------------------------------------------------</td>
<td>---------</td>
<td>----------------</td>
</tr>
<tr>
<td>DXS</td>
<td>Diffuse X-ray Spectrometer</td>
<td>1993</td>
<td>X-ray</td>
</tr>
<tr>
<td>ORFEUS</td>
<td>Orbiting... Far/EUV Spectrometer</td>
<td>1993</td>
<td>UV, EUV</td>
</tr>
<tr>
<td>SPTN-201</td>
<td>Spartan 201</td>
<td>1993-95</td>
<td>Solar UV</td>
</tr>
<tr>
<td>AUOS-SM</td>
<td>Koronas</td>
<td>1994</td>
<td>Solar UV, X</td>
</tr>
<tr>
<td>STS-67</td>
<td>Astro 2</td>
<td>1995</td>
<td>UV</td>
</tr>
<tr>
<td>SFU/IRTS</td>
<td>IR Telescope In Space</td>
<td>1995</td>
<td>IR</td>
</tr>
<tr>
<td>IEH</td>
<td>International EUV Hitchhiker</td>
<td>1995</td>
<td>EUV</td>
</tr>
<tr>
<td>HETE</td>
<td>High Energy Transient Experiment</td>
<td>1995</td>
<td>X-ray</td>
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<tr>
<td>SAC-B</td>
<td>Argentine satellite</td>
<td>1995</td>
<td>X-ray</td>
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<tr>
<td>SWAS</td>
<td>Submillimeter Wave Astronomy Satellite</td>
<td>1995</td>
<td>Submm</td>
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<tr>
<td>TRACE</td>
<td>Transition Region and Coronal Explorer</td>
<td>1997</td>
<td>Solar UV</td>
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<tr>
<td>WIRE</td>
<td>Wide Field Infrared Explorer</td>
<td>1998</td>
<td>IR</td>
</tr>
<tr>
<td>FUSE</td>
<td>Far Ultraviolet Spectroscopic Explorer</td>
<td>1998</td>
<td>EUV</td>
</tr>
<tr>
<td></td>
<td><strong>Still Going...</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VGR-2</td>
<td>Voyager 2</td>
<td>1977</td>
<td>UV</td>
</tr>
<tr>
<td>IUE</td>
<td>International Ultraviolet Explorer</td>
<td>1978</td>
<td>UV</td>
</tr>
<tr>
<td>1A</td>
<td>Granat</td>
<td>1989</td>
<td>Hard X-ray</td>
</tr>
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</table>
X-ray missions for the new millenium

A new generation of X-ray observatories:

- AXAF (NASA, 1998)
- XMM (ESA, 1999)
- Spektr-RG (RKA, 1998?)

- XMM emphasizes collecting area and spectroscopy
- AXAF emphasizes angular resolution
## History of X-ray astronomy

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Area (1 keV)</th>
<th>Area (6 keV)</th>
<th>Spatial</th>
<th>Spectral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uhuru</td>
<td></td>
<td></td>
<td>1 degree</td>
<td>1</td>
</tr>
<tr>
<td>Einstein/IPC</td>
<td></td>
<td></td>
<td>1 arcmin</td>
<td>2</td>
</tr>
<tr>
<td>Rosat/HRI</td>
<td>100</td>
<td>0</td>
<td>5 arcsec</td>
<td>-</td>
</tr>
<tr>
<td>Rosat/PSPC</td>
<td>220</td>
<td>0</td>
<td>30 arcsec</td>
<td>5</td>
</tr>
<tr>
<td>ASCA/SIS</td>
<td>160</td>
<td>100</td>
<td>10 arcmin</td>
<td>50</td>
</tr>
<tr>
<td>XTE/PCA</td>
<td>0</td>
<td>6000</td>
<td>1 degree</td>
<td>5</td>
</tr>
<tr>
<td>AXAF/ACIS</td>
<td>650</td>
<td>350</td>
<td>0.5 arcsec</td>
<td>50</td>
</tr>
</tbody>
</table>
Science goals of AXAF

- Community facility like HST, ROSAT; participation by non-X-ray-astronomers encouraged.

- High resolution spatially resolved X-ray spectroscopy for:
  - Evolution of quasars to high redshift
  - Evolution of clusters of galaxies
  - Structure and physics in low redshift clusters
  - Abundance and plasma conditions versus position in supernova remnants
  - Faint X-ray sources and the background
  - Detailed transmission grating spectroscopy of galactic binary sources.
Who? The AXAF Project:

• Management: NASA Marshall Space Flight Center, Alabama
• Science Center: AXAF Science Center
  – Headquarters at SAO, Cambridge MA and MIT, Cambridge MA
  – Software Beta Test sites at Chicago, Stanford, Hawaii
  – ASC Director: Harvey Tananbaum, SAO
  – User Support Group: Fred Seward, Andrea Prestwich, Eric Schlegel, Nancy Evans
• Mission Support Team: SAO
• Instrument teams:
  – ACIS: MIT/Penn State
  – HRC: SAO
  – HETG: MIT
  – LETG: Utrecht
• Industrial Contractors:
  – Spacecraft: TRW
  – Aspect camera: Ball
  – Upper Stage: Boeing
When?

- Mirror manufacture: Done!
- Instrument assembly and calibration: Now!
- Mirror coating: Completed Feb 1996
- Mirror assembly: Soon!
- Telescope calibration: Jul 1996- Feb 1997
- PROPOSALS: *** Fall 1997 ***
- Launch: Summer 1998
- Lifetime: At least 5 years
What?

• The AXAF-I observatory is a single spacecraft (A companion AXAF-S was cancelled).

• Launch by Space Shuttle with IUS upper stage and GRO derived liquid propulsion system into high orbit

• Movable solar arrays allow wide area of sky to be observed.

• Four nested X-ray mirror pairs, hyperboloid and paraboloid, coated with Iridium

• Two transmission gratings

• Four focal plane detectors

What does a high orbit mean?

• 64 hour orbital period

• - Small part of sky obscured for long periods (30 deg region for two years at a time)

• - Don’t observe in radiation belt regions (10 hours of every 64)

• - Long observations possible (up to 54 hours uninterrupted viewing)
Imaging instruments: ACIS-I

The ACIS (AXAF CCD Imaging Spectrometer) has two components: ACIS-I and ACIS-S, with a total of ten 1024 x 1024 X-ray CCDs. The ACIS-I array has 4 CCDs arranged in a square. What does a CCD do for you? The first one flown was on ASCA.

- **Advantages:**
  - High Spectral Resolution in each pixel
  - Broad response (0.2-10 keV)
  - 16 x 16 arcmin FOV
  - Spatial resolution better than 2 arcsec even far off axis

- **Disadvantages**
  - Radiation degrades spectral resolution over time
  - Lower time resolution than proportional counters, since must read out the chip
  - No very soft X-ray response
  - Gaps between chips
**Imaging instruments: HRC-I**

The High Resolution Camera (HRC) imaging detector is a microchannel plate, a larger version of the HRI flown on Einstein and Rosat. “Pixels” run from 1 to 16384 - a big dataset!

0.5 arcsec FWHM on axis, degrades to 10 arcsec at 10 arcmin off axis. 30 arcsec FWHM over whole 32 x 32 arcmin field.

- **Advantages:**
  - Good spatial resolution on axis
  - Soft X-ray response
  - High time resolution
  - Wide area (32 x 32 arcmin)

- **Disadvantages:**
  - No spectral resolution
  - Lower sensitivity
  - Worse off axis spatial resolution
Transmission Gratings: HETG

The HETG will disperse the X-ray photons which then fall on one of the spectroscopic arrays, usually ACIS-S.

With ACIS-S we have two measures of the photon energy: the CCD pulse height and the dispersion angle. This helps to resolve the grating order confusion.

- Advantages:
  - High spectral resolution

- Disadvantages:
  - No soft X-rays
  - 10 times lower throughput than imagers
Transmission Gratings: LETG

The LETG disperses the X-ray photons onto the HRC-S spectroscopic array.

- Advantages:
  - High spectral resolution at low energies

- Disadvantages:
  - Order separation problems at higher energies.
Data Analysis

The AXAF Science Center will process the data and maintain a database of all the AXAF data. Data will be made available in FITS formats similar to those for ROSAT and ASCA data, so you can do basic analysis of the data with existing packages (IRAF/PROS, FTOOLS/XSELECT/XSPEC, MIDAS/EXSAS). We will also provide specialized analysis tools, which will be needed if you want to recalibrate or if you want to make full use of the information in the datafiles. We hope that this system will build on the existing ones and be nicer to use!

- Programs will work on either FITS or IRAF data formats, transparently; and in conjunction with either FTOOLS or IRAF programs.

- Emphasis on uniform, generic interface to data: spatial, spectral, temporal filtering, binning, manipulations will have unified syntax, which can be extended by user to manipulations on other parameters in data (e.g. phase, housekeeping).

- Emphasis on separating science algorithms from data format details - will provide simple subroutine library for C or Fortran programmers to access data at scientific object model level (as opposed to FITS record/keyword level).

- Emphasis on improved spatial analysis (weakest in current packages). Will collaborate with Keith Arnaud to integrate XSPEC for spectral analysis.
Calibration

The X-ray Calibration Facility in Huntsville, Alabama:

- Let’s make sure we can make in-focus pictures!
- Pump down entire mirror/instrument combination in huge vacuum bottle, with quarter-mile evacuated source tube
- Calibrate mirrors with special proportional counter detectors
- Mask off shells and quadrants
- Then calibrate instrument/mirror, instrument/grating combinations
- Tilt mirror to obtain off axis calibrations
- Move instruments to remain on mirror axis
- Dither HRC to avoid burning holes in it
- More than 1 Terabyte of data expected!
- Need to correct for 1-g sag of mirrors, finite distance of source, etc.