Space Science in the Nineties and the AXAF Observatory

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- Major results from space astronomy
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- The AXAF mission
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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		
HST	Hubble Space Telescope	1990	Optical/UV
CGRO	Compton Gamma Ray Observatory	1991	Gamma ray
AXAF	Advanced X-ray Astrophysics Facility	1998?	X-ray, Soft X
SIRTF	Space Infrared Telescope Facility	2001?	IR
	Pretty Good Observatories		
COBE	Cosmic Background Explorer	1989	Microwave, S
	Hipparcos	1989	Optical
ROSAT	Rontgensatellit	1990	Soft X-ray, E
EUVE	Extreme Ultraviolet Explorer	1992	EUV
ASCA	Asuka	1993	X-ray
SOHO	Solar Heliospheric Observatory	1995	Solar UV, X
XTE	X-ray Timing Explorer	1995	X-ray
ISO	The Infrared Space Observatory	1995	IR
VSOP	VLBI Space Observatory Project	1996	Radio
SRG	Spektr Rontgen-Gamma	1997?	X-ray
XMM	X-ray Mirror Mission	1999	X-ray
	Integral	2000?	Gamma ray
	Smaller Missions		
STS-35	Astro 1/BBXRT	1990	UV, X-ray
P89-1B	Alexis	1993	X-ray/EUV

DXS	Diffuse X-ray Spectrometer	1993	X-ray
ORFEUS	Orbiting... Far/EUV Spectrometer	1993	UV, EUV
SPTN-201	Spartan 201	1993-95	Solar UV
AUOS-SM	Koronas	1994	Solar UV,X
STS-67	Astro 2	1995	UV
SFU/IRTS	IR Telescope In Space	1995	IR
IEH	International EUV Hitchhiker	1995	EUV
HETE	High Energy Transient Experiment	1995	X-ray
SAC-B	Argentine satellite	1995	X-ray
SWAS	Submillimeter Wave Astronomy Satellite	1995	Submm
TRACE	Transition Region and Coronal Explorer	1997	Solar UV
WIRE	Wide Field Infrared Explorer	1998	IR
FUSE	Far Ultraviolet Spectroscopic Explorer	1998	EUV
	Still Going...		
VGR-2	Voyager 2	1977	UV
IUE	International Ultraviolet Explorer	1978	UV
1A	Granat	1989	Hard X-ray

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

Instrument	Area (1 keV)	Area (6 keV)	Spatial	Spectral
Uhuru			1 degree	1
Einstein/IPC			1 arcmin	2
Rosat/HRI	100	0	5 arcsec	-
Rosat/PSPC	220	0	30 arcsec	5
ASCA/SIS	160	100	10 arcmin	50
XTE/PCA	0	6000	1 degree	5
AXAF/ACIS	650	350	0.5 arcsec	50

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.