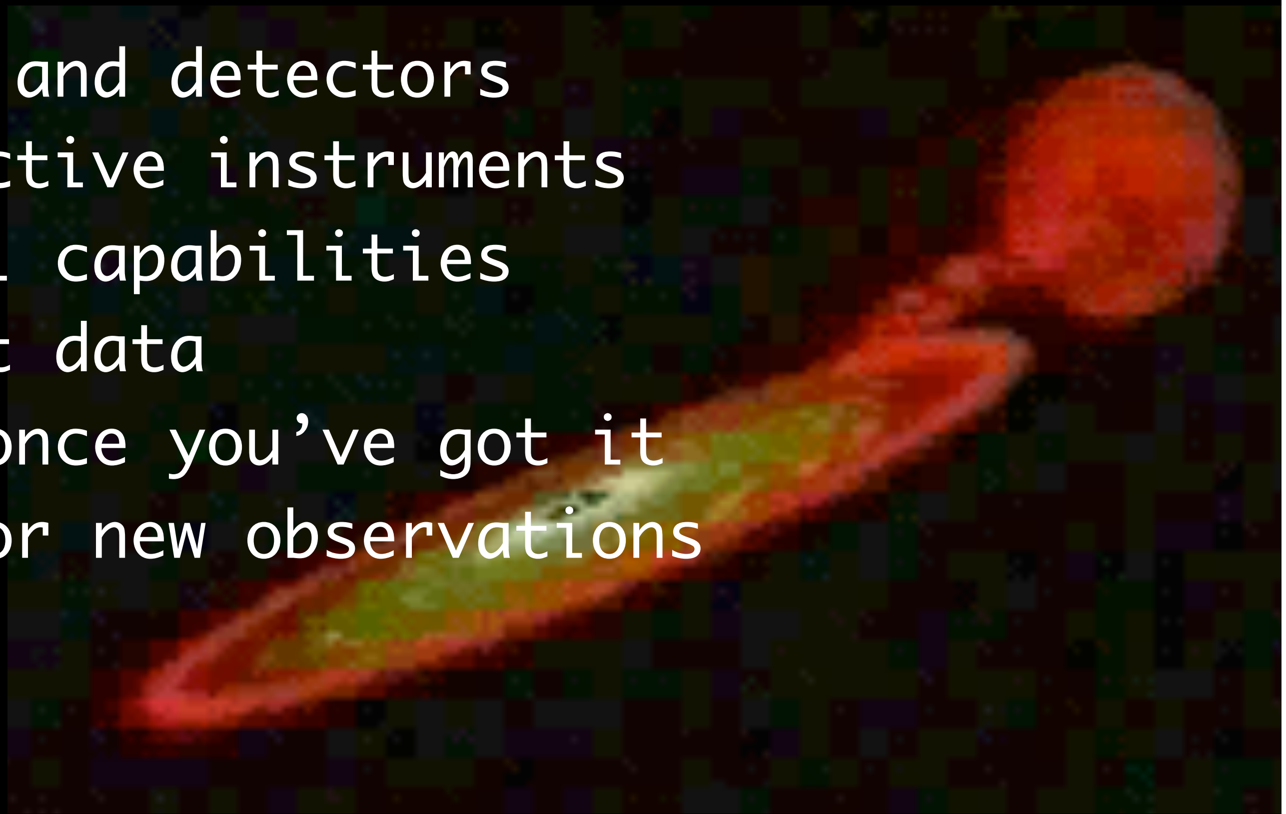
High-energy observing & data analysis

- Motivation
- Instruments and detectors
- Currently active instruments
- Instrumental capabilities
- Where to get data
- What to do once you’ve got it
- Proposing for new observations



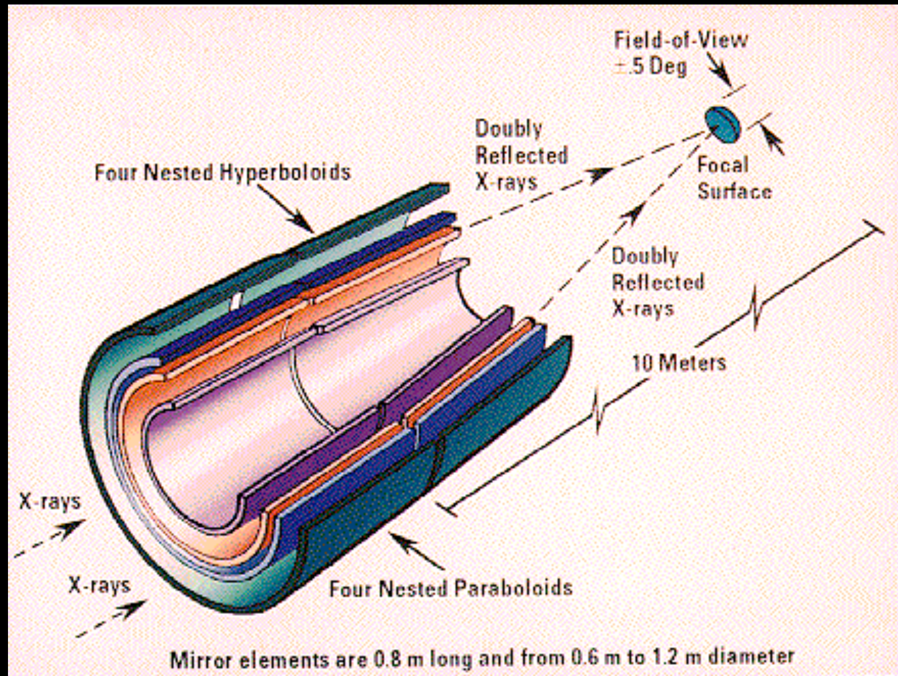
Why high energies?

- Objects which are very hot (millions of degrees) or which have non-thermal (e.g. synchrotron) spectra emit X- & γ-rays
- For example, neutron stars, black holes, white dwarfs, coronae of young stars, galaxies & clusters, AGN, jets, pulsar wind nebulae, SNRs etc.
- X-ray band is particularly informative; includes the K- and L-shell electronic transitions of all the post-big bang elements
- As in other bands, instrumentalists are continually pushing the boundaries -> (occasionally) dramatic increases in capabilities

Instruments and detector types

CCD (*Chandra, XMM*)

- Typically uses (grazing incidence) focussing X-ray optics to produce an image of the source in the detector plane
- Can use reflection/ transmission gratings to disperse the spectrum for best resolving power

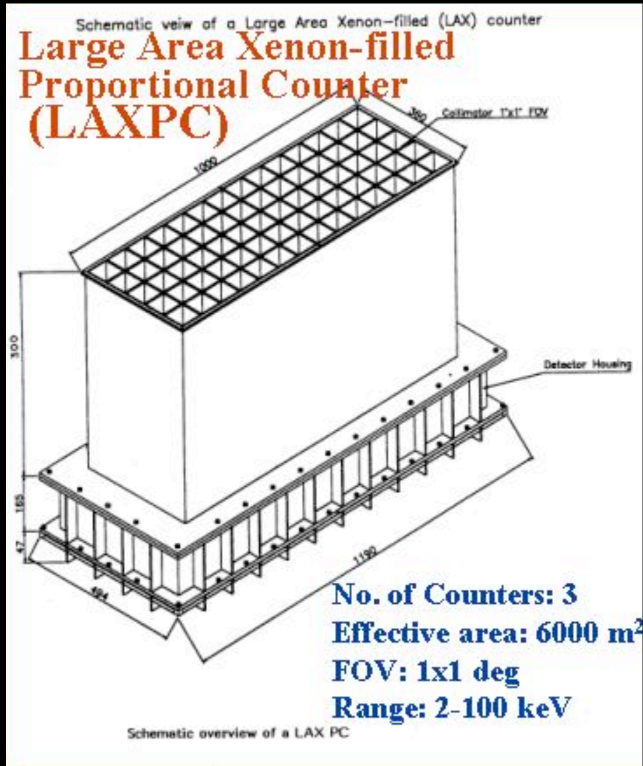


- Effective area limited by size of mirrors; typical sensitivity 0.5-10 keV
- Throughput limited by restriction to 1 photon per pixel per frame. Dithering helps. Otherwise you get pileup
- Also telemetry limitations, typically

Instruments and detector types

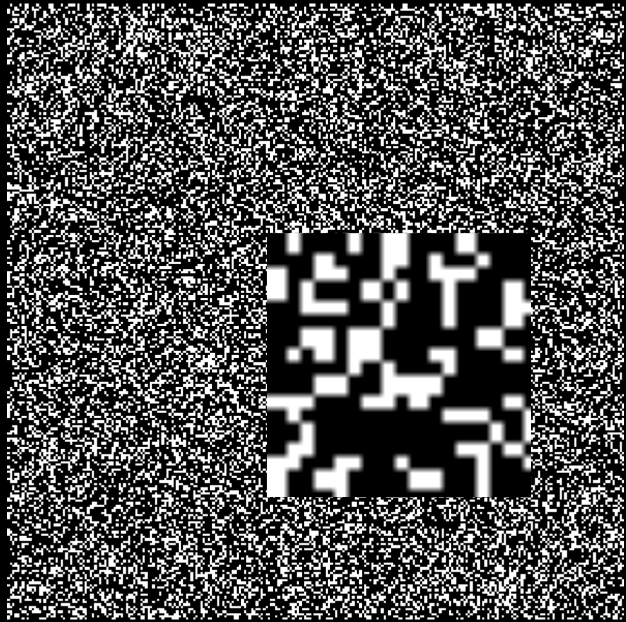
Proportional counter (*RXTE)*

- Array of wires with high PD within a gas-filled volume generates an electron cascade when an X-ray photon arrives
- Typically uses mechanical collimators, sometimes also can coarsely determine position from determining exactly which wire was activated



- Large effective area but poor (or no) spatial and spectral resolution
- High background rates must be modelled
- Can achieve very high timing resolution (down to 1μs)
- No pileup but a less significant problem of deadtime

Instruments and detector types



Coded mask imaging (IBIS, JEM-X)

- X-rays illuminate a detector through a mask which allows reconstruction of the source position

Solid state detectors (IBIS, HEXTE)

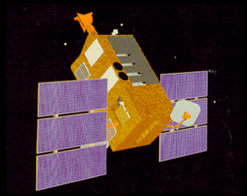
- CdTe, CsI, NaI etc.

Many other types!

All-sky monitors (ASM, JEM-X)

- Regularly scan the sky to provide up-to-date status of variable and/or transient objects, particularly important for binaries which are highly variable

Present-day instruments

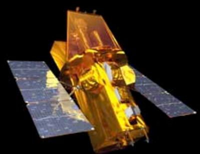


RXTE, launched 1995 (NASA) large effective area and very high timing resolution but no imaging capability; PCA [2-60 keV] & HEXTE [15-250 keV]; plus all-sky monitor

Chandra, launched 1999 (NASA), small effective area but very high (~1”) spatial and spectral resolution (courtesy transmission gratings) [0.5-10 keV]

XMM-Newton, launched 1999 (ESA), moderate effective area, spatial and spectral resolution (reflection gratings) + optical monitor [0.5-10 keV]

INTEGRAL, launched 2002 (ESA), primarily *gamma-ray* instrument but also wide-field X-ray and optical capability [4 keV - 10 MeV]



Swift, launched Nov 2004 (NASA), dedicated to prompt GRB followup but also transients; BAT [15-150 keV], XRT [0.3-10 keV], UVOT [170-650 nm] swift.gsfc.nasa.gov

ASTRO-E2/Suzaku, launched 2005 (JAXA-US), high-res spectrometer XRS failed shortly after launch, XIS imager [0.4-10 keV]/HXD [10-700 keV]

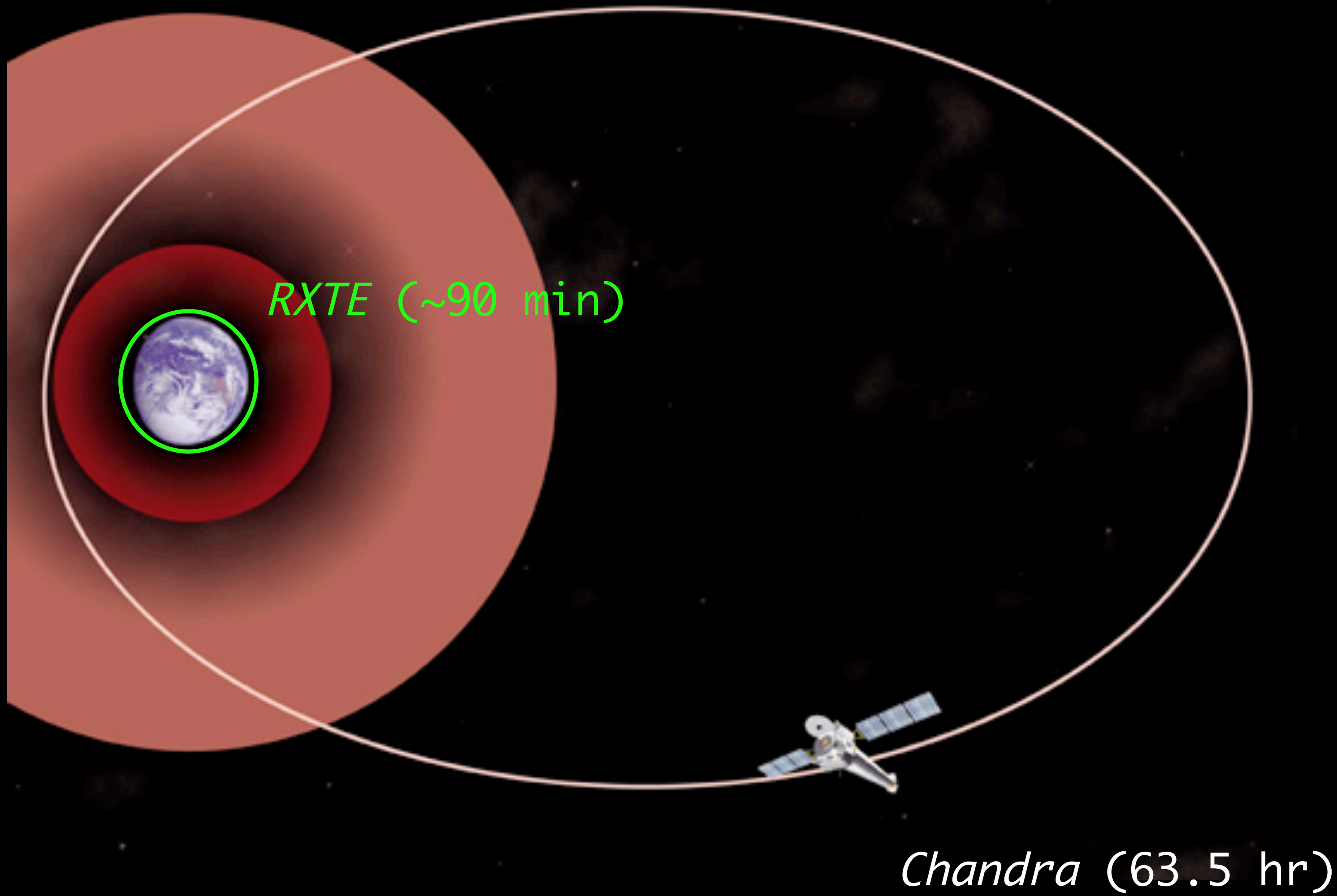
Fermi, formerly GLAST, launched June 2008, GBM [>8keV] & LAT [30 MeV-300 GeV], about which you will hear everything shortly!

Older missions

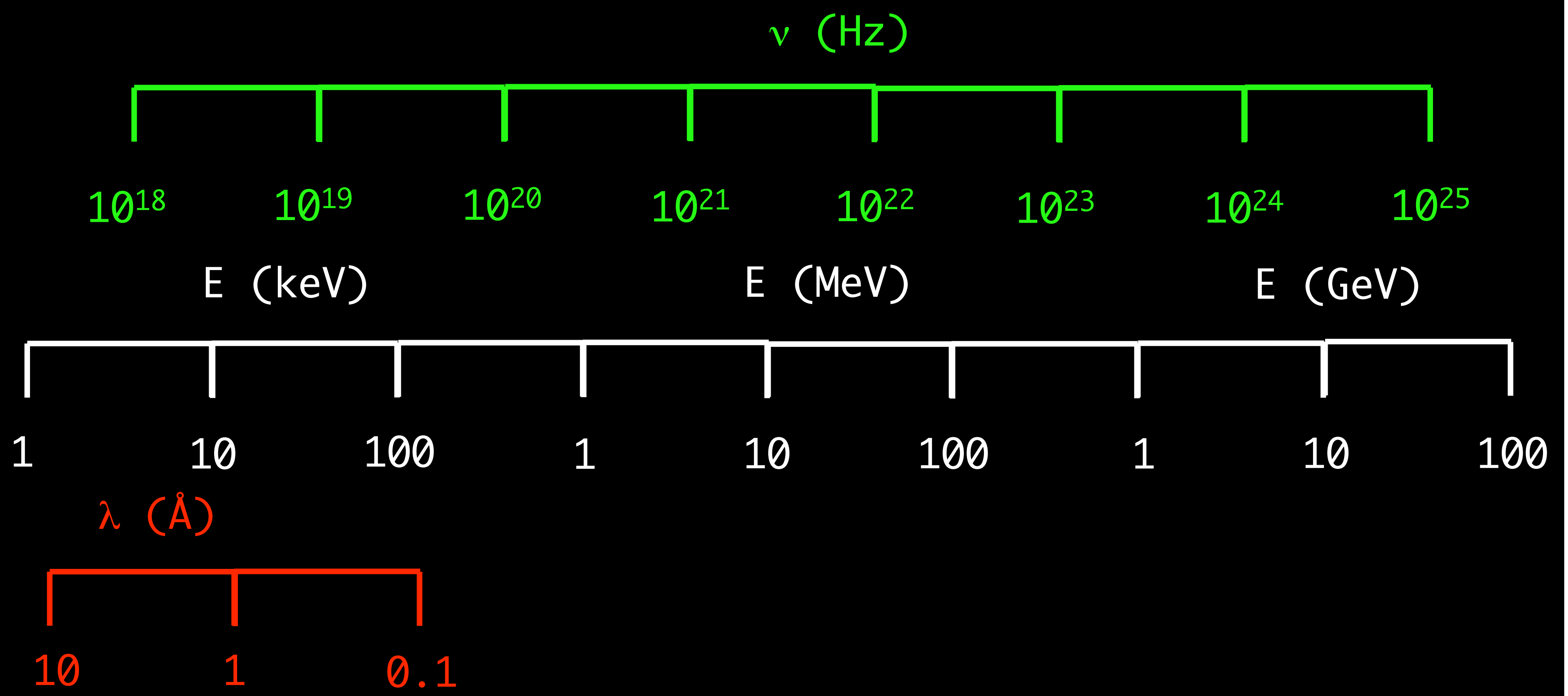
- Archive also contains data from past missions including *ROSAT*, *ASCA*, *BeppoSAX*; "Full Browse" option allows you to search missions going right back to *Uhuru* (1970-73)! *Don't rule out these missions when looking for archival data!*
- Dedicated support facilities at HEASARC http://heasarc.gsfc.nasa.gov
- For individual missions try

  http://[mission_name].gsfc.nasa.gov

Satellite orbits



Units



$E\ (keV) = 12.3984/\lambda\ (Å)$

Instrument capabilities

Instrument	Energy range (keV)	Effective area (cm^2)	Spectral resolution	Spatial resolution
Chandra ACIS-I/S, HRC; LETG, HETG	0.1-10	ACIS: 110 @ 0.5 keV 600 @ 1.5 keV	HEG: 0.012Å MEG: 0.023Å E/ΔE~1000	~0.5"
XMM-Newton EPIC MOS/pn, RGS, OM	EPIC:0.15-15 RGS:0.3-2.5	300/800 @ 1keV 150 @ 15Å	E/ΔE~20-50 150-800	~6"
INTEGRAL SPI, IBIS, JEM-X, OMC	15-10^4 3-35	500+2600/3000 500	2 keV @ 1.3 MeV 1.3 keV @ 10 keV	~12' ~3'
Suzaku XIS, HXD	XIS:0.2-12 HXD:10-600	400 @ 1.5keV 300 @ 120keV	50eV @ 1keV 3keV 10-30keV	~1.8'
RXTE PCA, HEXTE, ASM	PCA 2-60 HEXTE 15-250 ASM 2-12	6500 8x225 100	~18% <9kev @60keV 3 channels	N/A; FOV 1° ~1'

Where to get data

HEASARC archive:
http://heasarc.gsfc.nasa.gov

- Data becomes public & enters the archive after a proprietary period of (typically) 1 year
- Can search data from many X-ray missions, in addition to FUSE, HST etc.
- Basic search by name/ coordinates or more complex queries, batch etc.

What will you get?

- Basic form is simply a list of events, with time, detector position, and energy; you can do anything you want with them (essentially)
- May also have columns for dispersion order, CCD ID etc.

xray

	time	x	y	pha	pi	energy	tg_m	tg_part
	s	pixel	pixel					
1	1.134210594243385E+08	3.8690908E+03	4.5024653E+03	357	121	1.7600293E+03	INDEF	99
2	1.134210594243385E+08	3.9348687E+03	3.8977085E+03	724	230	3.3517656E+03	INDEF	99
3	1.134210594243385E+08	3.9210662E+03	4.2532021E+03	1025	340	4.9536719E+03	INDEF	99
4	1.134210594243385E+08	3.9447605E+03	4.1287632E+03	1161	387	5.6488745E+03	INDEF	99
5	1.134210594243385E+08	3.9195654E+03	4.5692563E+03	1102	363	5.2908916E+03	INDEF	99
6	1.134210594243385E+08	3.9930525E+03	3.9078657E+03	878	277	4.0316406E+03	INDEF	99
7	1.134210594243385E+08	3.9979885E+03	3.9457102E+03	877	277	4.0339299E+03	INDEF	99
8	1.134210594243385E+08	3.9231311E+03	4.7795977E+03	1090	343	4.9949204E+03	INDEF	1
9	1.134210594243385E+08	3.9756477E+03	4.2443428E+03	556	190	2.7660706E+03	INDEF	99
10	1.134210594243385E+08	3.9985703E+03	4.0474626E+03	867	276	4.0227734E+03	INDEF	99
11	1.134210594243385E+08	3.9660554E+03	4.4820557E+03	849	280	4.0735564E+03	INDEF	99
12	1.134210594243385E+08	3.9397822E+03	4.8829980E+03	660	212	3.0882512E+03	1	1
13	1.134210594243385E+08	4.0303113E+03	3.9597051E+03	96	36	5.1212341E+02	INDEF	99
14	1.134210594243385E+08	3.9680408E+03	4.6040396E+03	367	126	1.8343530E+03	INDEF	1
15	1.134210594243385E+08	4.0064827E+03	4.2125703E+03	714	241	3.5166091E+03	INDEF	99
16	1.134210594243385E+08	3.9492776E+03	4.8338657E+03	669	215	3.1316624E+03	1	1
17	1.134210594243385E+08	3.9864619E+03	4.4768149E+03	431	145	2.1147842E+03	INDEF	1
18	1.134210594243385E+08	3.9526814E+03	4.8257979E+03	691	222	3.2311777E+03	1	1
19	1.134210594243385E+08	3.9580474E+03	4.7860527E+03	722	231	3.3628411E+03	1	1

More?[Yes]

Data processing

"Standard Products" (images, lightcurves, spectra) available as part of the archival data package may be sufficient for your analysis needs

Specific software packages required to analyse data from individual missions

- *Chandra* - CIAO
- *XMM-Newton* - SAS
- *RXTE* – HEASOFT
- *Fermi* – Fermi Science Tools

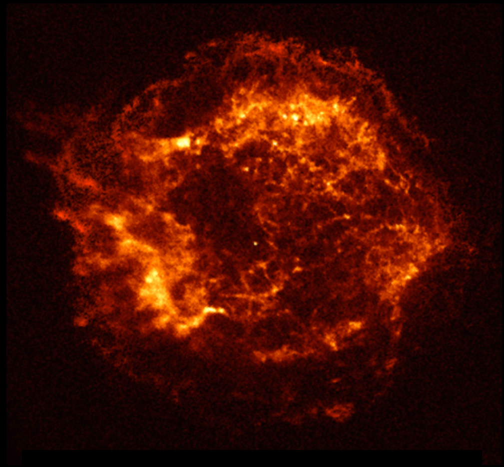
As well as the general-purpose Ftools, which operate on any FITS files

Data reduction recipes are provided, simply locate the one appropriate to your data and follow the instructions. Of course it's not that easy but there is help available!

What to do with it once you've got it

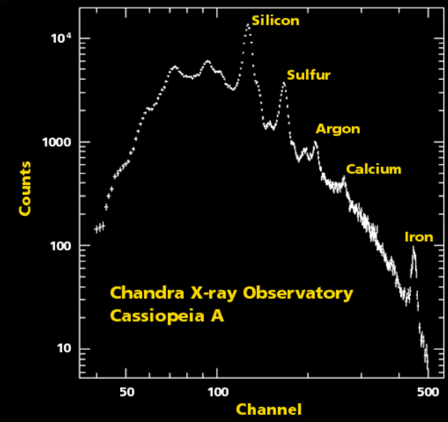
Imaging

- Create a histogram of events as a function of sky position. Source detection & localisation (celldetect, wavedetect). Spatially-resolved spectroscopy
- May need to worry about the shape of the point-spread function for extended sources? Subpixel imaging?



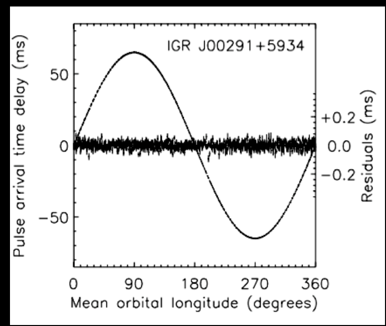
Spectroscopy

- Typically can't correct for the instrumental response, so fold a model through the response and fit to data
- Model choice, pileup, deadtime, background subtraction. Responses etc. change with time



Timing analysis

- Create a lightcurve by binning on arrival time. Barycentre correction
- Periodic and quasi-periodic signals - Fourier, Bayesian? Folding, pulse-phase spectroscopy



Proposing for new observations

Annual calls for proposals:

- November: Suzaku (AO-5 just last week!)
- February: *Fermi* (AO-3); *INTEGRAL* observations (AO-8; note 2-stage process)
- March *Chandra* (AO-12)
- July: *INTEGRAL* data rights proposals
- August *RXTE* (AO-*15*); no proprietary data
- October *XMM-Newton* (AO-10)

Proposals can be target-of-opportunity (TOO) contingent on some unexpected event (new transient outburst etc.)

Can submit unanticipated TOO (Director's Discretionary Time or DDT) any time (notably for *Swift*)

Writing successful proposals

- Missions are highly oversubscribed so a good science case is key!
- Choice of instrument depends upon your objective. High-resolution spectroscopy/imaging - *Chandra*. Brighter sources, lower resolution - *XMM-Newton*. High-res timing of very bright sources - *RXTE.*
- Make sure an observation that could answer your question has not already been done!

Proposal tools

- Basic tool to estimate source countrate is PIMMS. Define a source flux and spectral model, and get out the estimated countrate
- Can do more sophisticated simulations in Xspec, with real response matrices and more complicated models
- For *Chandra*, MARX software allows you to do ray-tracing to do a fully realistic simulation of the proposed observation

Happy observing!