TPIVb initial readings & preparation

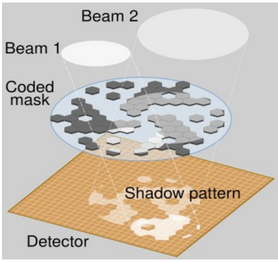
INTEGRAL

Integral is ESA's International Gamma-Ray Astrophysics Laboratory. It studies explosions, radiation, formation of elements, black holes, etc.

- Observes in gamma rays, X-rays and visible light.
- Principal targets are gamma-ray bursts, supernovae and black holes.

IBIS: Imager on Board the Integral Satellite

- Coded-aperture instrument
- 12' FWHM
- 15 keV – 10 MeV
- 29.1° * 29.4° full FOV
- 8.3° * 8° fully coded FOV
- Aperture-mask 3.2m above detector plane
- Two detector planes separated by 90mm:



	ISGRI (top)	PICsIT (bottom)
Collecting area (cm^2)	2600	3000
Sensitivity range (keV)	15 - 1000	100 – 10 000
Max effective area (keV)	20 - 100	200 – 400 (single) 500 – 10 000 (multiple)
# modules	8	8
# pixels	16384	4096
Pixel materials	CdTe	CsI
Pixels / module	64 * 32	32 * 16
Pixel size (mm^3)	4 * 4 * 2	9 * 9 * 30

JEM-X: Joint European X-ray Monitor

- Makes observations simultaneously with main gamma-ray instruments
- Arcminute angular resolution
- 3 – 35 keV energy band
- Photon detection system: two high-pressure imaging microstrip gas chambers
- Each detector views the sky through its coded-aperture mask 3.2m above detection plane

HIGH-ENERGY EMISSION FROM PLANETS (articles)

Discovery Of X-Rays From Venus With Chandra

Abstract: first X-ray observation of Venus in 2001 using Chandra. Venus is detected as a half-lit crescent which agrees well with the expected **fluorescent** scattering of solar X-rays in the planetary atmosphere. The radiation is observed at discrete energies, mainly at 0.53 keV (O–Kα).
Evidence for temporal variability of the X-ray flux found at 2.6 σ level with a time scale of minutes.

Introduction: Venus is similar to a comet with a carbon and oxygen rich atmosphere, absence of a strong magnetic field and its proximity to the sun. Dissociative recombination of O_2^+ in the Venus ionosphere leads to a hot oxygen exosphere out to over 4000 km, resembling a cometary coma.
Venus is a challenging object as it is close to the sun (a maximum separation of 47.8 degrees as seen from Earth). The detectors on Chandra are also sensitive to optical light which needs to be suppressed using blocking filters without attenuating the X-rays. No need for continuous tracking as Venus moved across the sky with a proper motion of 2.6'/hour and the CCDs read out every 3.2s. Observations done in soft (0.2-1.5 keV) and hard (1.5-10.0 keV) energy ranges.

Results: the X-ray image of Venus shows the expected crescent morphology. The striking difference is the pronounced limb brightening (edge). The surface brightness decreases with distance from r = 16.5" on both day and night sides in the soft band. The corresponding distributions in the hard band are flat => not caused by inhomogeneities in sensitivity => possibly extended X-ray halo around Venus.

Data shows X-ray spectrum of Venus is very soft. Observations also done with LETG which shows that most of the flux comes from O–Kα fluorescence. Line energies determined by accumulating all photons with E < 1.5 keV within a circle of r = 16.5" around Venus along solar direction to get intensity profile perpendicular to solar direction. This profile, which shows a characteristic central dip due to the effect of limb brightening, was then smoothed with a cubic spline function and used as a template for the spectral fit. Comparing X-ray flux to optical flux shows that there is only one X-ray photon among $5 * 10^{11}$ optical photons showcasing the challenge of observing Venus in X-rays.

While there is practically no variation of the optical flux from Venus on time scales of hours and less, the X–ray flux shows indications for pronounced variability on time scales of minutes. We expect this to be due to variability of solar flux, but observations don't show a clear correlation. This may be related to the fact that solar X–rays are predominantly emitted from localized regions and that Venus saw a solar hemisphere which was rotated by 48.0° (LETG/ACIS–S) and 46.5° (ACIS–
I) from the solar hemisphere facing Earth. Differences from the broad band solar X–ray flux may also arise due to the fact that the X–ray flux from Venus responds very sensitively to variability of the solar flux in a narrow spectral range just above the K edges.

Venus was also modelled to compare with observations. The model depended on the composition and density structure of the Venus atmosphere, the photoabsorption cross sections and fluorescence efficiencies of the major atmospheric constituents, and the incident solar spectrum.

Conclusion: The Chandra observation clearly shows that Venus is an X–ray source. From the X–ray spectrum and morphology we conclude that fluorescent scattering of solar X–rays is the main process for this radiation, which is dominated by the Kα emission lines from C, N, and O, plus some possible contribution from the C 1s → π? transition in CO2 and CO. By modelling the X–ray appearance of Venus due to fluorescence, we have demonstrated that the amount of limb brightening depends sensitively on the properties of the Venus atmosphere at heights above 110 km.

Discovery Of Diffuse Hard X-Ray Emission Around Jupiter With Suzaku

Abstract: Discovery of diffuse hard (1 – 5 keV) X-ray emission around Jupiter using Suzaku. Emission is distributed over ~ 16 * 8 Jovian radius and spatially associated with radiation belts and Io Plasma Torus (IPT). Flat power-law spectrum. Seems to be diffuse => non-thermal electrons in radiation belts / IPT (not synchrotron or bremsstrahlung). 160 ks observation.

Introduction: Jupiter has high-energy electron Van Allen radiation belts with electrons ranging from energies of a few keV to 50 MeV. Theoretically: electrons energized by betatron acceleration via inward radial diffusion. The trapped electrons lose their energy through synchrotron radio emission, and some fraction is absorbed by Jovian moons and rings. Jupiter is the most luminous planet in solar system in X-rays. Emits X-rays from magnetic poles by charge exchange interaction with solar wind and magnetospheric heavy ions + bremsstrahlung emission. Optical loading from Jupiter problem, but negligible in this case.

Results: To search for emission from Jupiter, need to remove Suzaku's orbital motion and transform the data into Jupiter's co-moving frame using an ephemeris obtained from JPL. X-ray images without these corrections showed an extended emission detected in both the 0.2–1 keV and 1–5 keV bands along the path of Jupiter. Also point sources near Jupiter in hard band, but consistent with canonical cosmic X-ray background model. These were removed. The corrected results show hard X-rays extended over ~ 16 * 8 Jovian radius.

Distribution of the emission: projection profiles along horizontal axis. The hard X-ray emission is significantly extended more than the point-spread function. The overall profile seems to be well explained by a simulated model, being the sum of a point source and elliptical uniform emission. The emission is extended over a wide region (> 6 Rj). Excess on right of soft X-ray peak => emission from IPT. The hard X-rays are hence unlikely to originate only from a single point source or Jupiter. Furthermore, an artificial effect on the extended morphology due to the analysis can be excluded because of the different morphology from the soft X-ray image. An estimation gives a CCD background level as 1/10 of the auroral emission (so hard to detect). Can also be time variation if emission related to Jovian belts.

Spectrum analysed within 3' region, with 6' region as background. Flat continuum is obtained extending up to 5 keV and lines around 0.25 keV and 0.56 keV. Spectrum fitted with power-law plus 2 Gaussian models. Photon index of 1.4. The two lines seemed to correspond well with observations of Jupiter's auroral emission and are presumably a line complex from C^{5+} and ionized Mg, Si, S, and a Kα emission from O^{6+}, respectively. For the hard band, we get a flat continuum. The peak coincides with Jupiter, so some of the emissions likely originate from Jupiter. The spectrum is compared to aurora emission models. These are 2-3 times smaller than observed spectrum, so the observation is likely from a diffusion emission other than Jupiter.

Conclusion: Hard X-ray emission discovered around Jupiter, spatially associated with Jovian magnetospheric processes. But since images corrected for orbital motion, any faint background source on Jupiter's path can be seen as an extended emission. Considering symmetric projection profile, spatial distribution of background sources should be symmetric about Jupiter. Plausible case: emission is composed of Jupiter + single background source point. Excluding central part of Jupiter's orbit still yielded significant extended emission. The flat power-law continuum of the emission suggests a non-thermal mechanism. There are three candidates for the emission mechanism; synchrotron emission, bremsstrahlung emission, and inverse-Compton scattering. Synchrotron can be rejected as would need TeV electrons for emission at ~ 6 Rj. If TeV electrons exist, their Larmor radius would be too large and they would escape the radiation belts. Bremsstrahlung emission is possible, but we would expect a line around 2 keV (from in situ measurements, the plasma at r ~6 Rj is known to be mainly composed of heavy ions such as S+ and O+, we can estimate equivalent width of the S Kα line which should be resolved). Inverse Compton-scattering is the remaining possibility (scattering of solar light by ultra-relativistic
electrons in the radiation belts). The energy is consistent with this, so is the spectral shape. We can also look at electron density, which differs from empirical model by a factor of 7-50.

DATA ANALYSIS

Software: https://www.astro.unige.ch/mmoda/

API: https://oda-api.readthedocs.io/en/latest/

Article: An online data analysis system of *INTEGRAL* telescope

Notes from article:

- Use data after March 2023 (settings were continuously optimized before this)
- 17 years worth of data, 90% duty cycle (switched off at perigee of Earth radiation belts)
- The Online Data Analysis can be accessed online or through an API (oda_api)
- The front-end displays sky images, spectra, light curves and source catalogues in a virtual-desktop environment. Also allows post-analysis (fitting spectra, …)
- IBIS and JEM-X are coded-mask instruments that rely on a dithering pointing strategy with individual exposures called Science Windows (ScW) lasting 0.1–1 hour
- Default workflow: select data set, obtain a catalogue of detected sources by reconstructing an image and manipulate to extract spectra and light curves
- Minimum query: source name or sky coordinates, time interval
- Uses SIMBAD and NED databases
- Can also specify parameters specific to the instruments (ISGRI, JEM-X, …)
- Can specify detection threshold and many other parameters
- Limited to single requests based on no more than 50 science windows (if more are specified, only 50 are randomly selected)

After my reading, and initial testing:

- INTEGRAL provides us with 17+ years worth of data => can look for variability in X-ray emission from Jupiter on long timescales
- Looking at hard X-rays: compare to literature which suggests diffuse emission
  - Spectral analysis
- Search for small timescale emissions: flares, bursts, …

TO-DO:

- Need to look at more literature to see what has already been done and what is needed to be done, how can I contribute (ex: origin of diffuse hard X-rays).
- More playing around with API/ODA
- Try to find a science window where Jupiter was visible