Pixel Arrays in X-ray Astronomy and Related Fields

G.W. Fraser

Space Research Centre, Department of Physics and Astronomy,
University of Leicester, Leicester LE1 7RH (gwf@star.le.ac.uk)

1. Current projects and design drivers
2. Laboratory imaging XRF (using CCDs)
3. Planetary imaging XRF (using GaAs pixel arrays)

The University of Leicester Space Research Centre

INDUSTRIAL COLLABORATORS

Photonis SAS
EADS Astrium
Honeywell Inc.
AMPTEK
Lablogic
Silson
Nova Scientific Inc

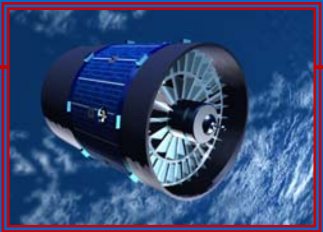
E2V Ltd.
Photek
RMD Inc.
Metorex
Severn Science
Bayer
JMAR

Oxford Instruments
Walker Precision Engineering
SIRA
Gresham Scientific Instruments
JRA Technology
El Mul
Hamamatsu

Imaging in the University of Leicester Space Research Centre (I)

Project	Detector	Scientific Driver(s)
XMM-EPIC	Open electrode CCD	ΔE, 0.1-10 keV QE, Bi, Rad
AXAF HRC	Low noise MCP	A, Δx, 0.1-10 keV QE, Bi
Swift XRT	Open electrode CCD	ΔE, 0.1-10 keV QE, Bi, T, Rad
Lobster-ISS	Microwell PC	A, 0.1- 4 keV QE, Bi
XEUS NF	TES	ΔE, 0.1-6 keV QE
XEUS WF	MOS or pn CCD	ΔE, 0.1- 6 keV QE, N
XEUS HE	Hybrid CCD/CZT	1-100 keV QE
J-PEX	Small pore MCP	Δx, 60 eV QE
BepiColombo	GaAs pixel array	ΔE, 0.5-10 keV QE, T, Rad
XIF	linear TES array	ΔE, Δx

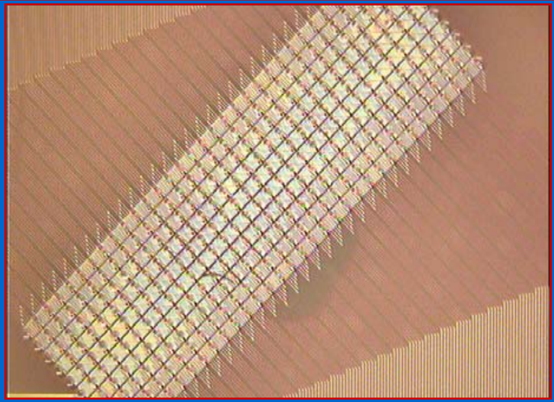
$$(D.E_{max})/8kf = 1$$



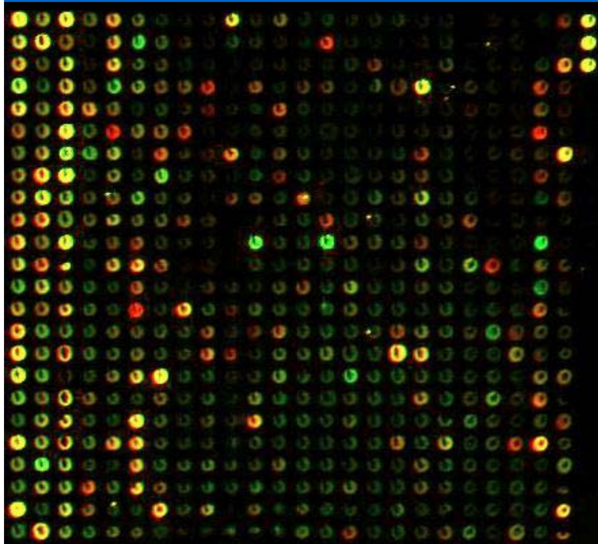
University of Leicester

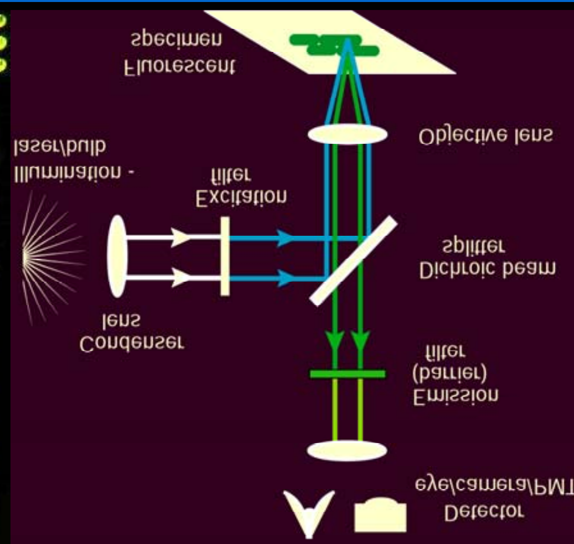
Imaging in the University of Leicester Space Research Centre (II)

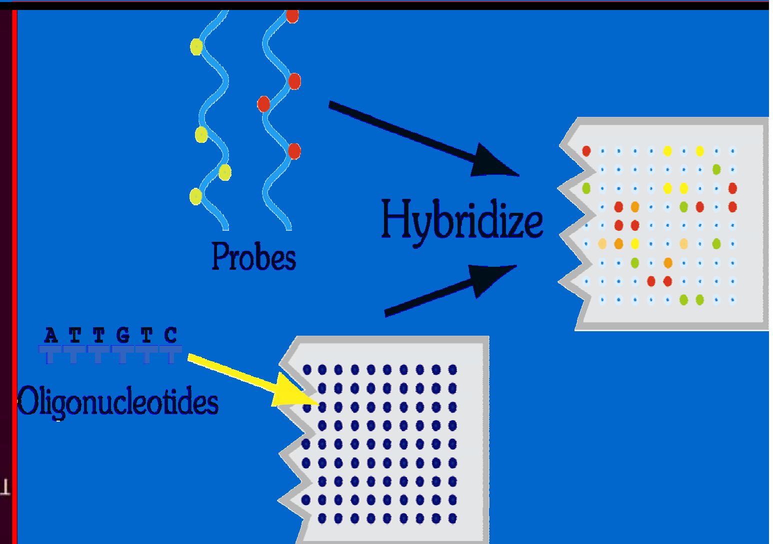
Project	Detector	Scientific Driver(s)
TEARES	Bulk Conductivity MCP	format, N, electron QE
Auroral Imager	Spherical slump MCP	format, 10 eV QE
Fast neutron	Si MCP + a-Si pixel array	neutron QE, A
Thermal neutron	borated MCP	neutron QE, Δx
Imaging XRF	CCD	ΔE, 0.1-6 keV QE
HRGI	Gadox+CCD	10-150 keV QE
Biofluorescence	STJ array	ΔE, 2 eV QE, Bi



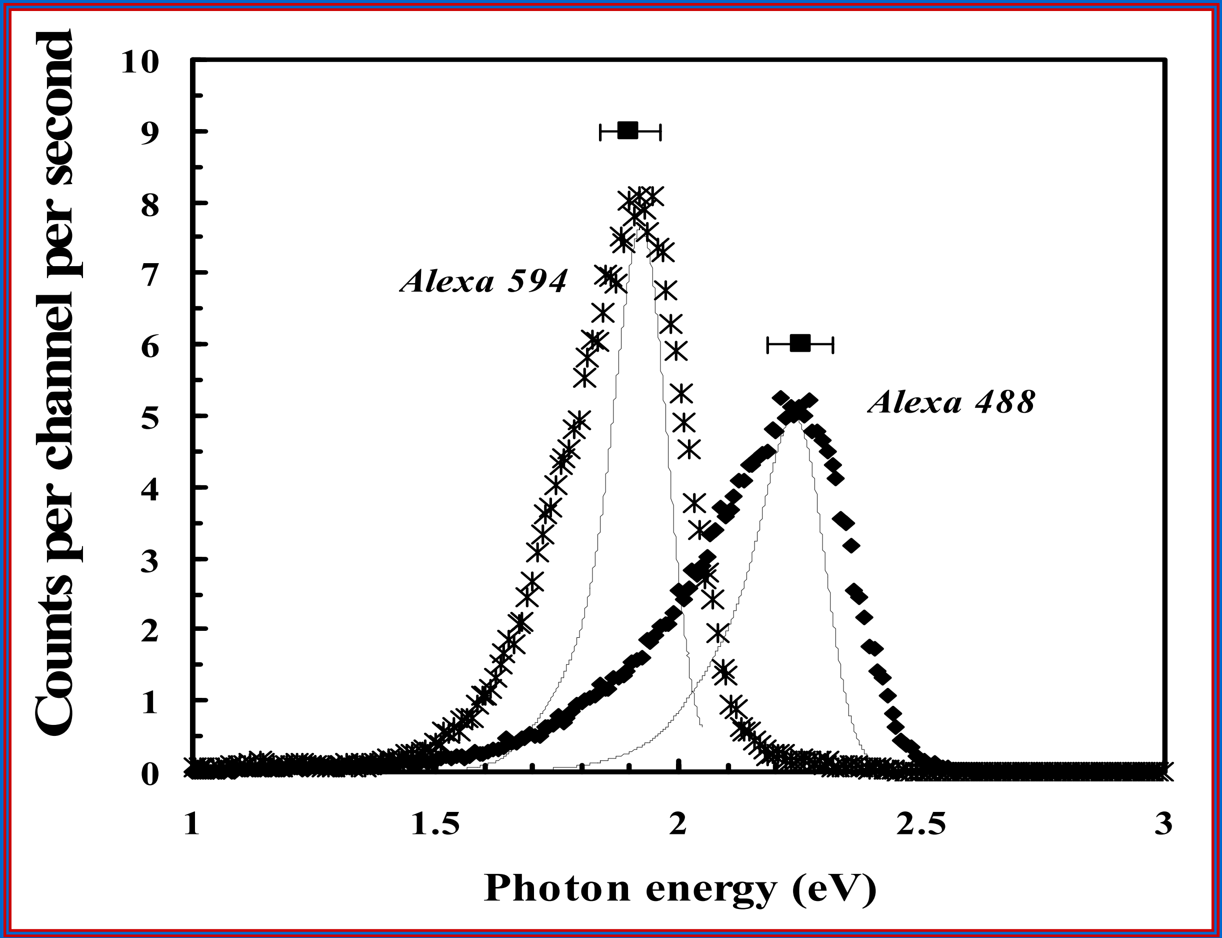
Detection of Optical Fluorescence using Superconducting Tunnel Junctions (STJs)







A microarray or *gene chip* is a 2D array of ~100 µm x 100 µm hybridisation cells on a silicon, glass, plastic or nylon membrane. Readout is usually by optical fluorescence An important goal in the life sciences is to perform many parallel tests for gene expression using multiple fluorochrome *probes* - molecules which fluoresce in particular bands of the optical spectrum. The state of the art is three simultaneous probes, but there are severe problems with current readout technology based on sequential pass band filters and PMTs (semi-quantitative, sequential, insensitive). What is required is a *wavelength resolving, non-dispersive photon counting detector of optical photons.*



The detection of multiple fluorescent labels using superconducting tunnel junction detectors

G.W. Fraser*, J.S. Heslop-Harrison†, T. Schwarzacher†, A.D.Holland*, P. Verhoeve‡ and A. Peacock‡

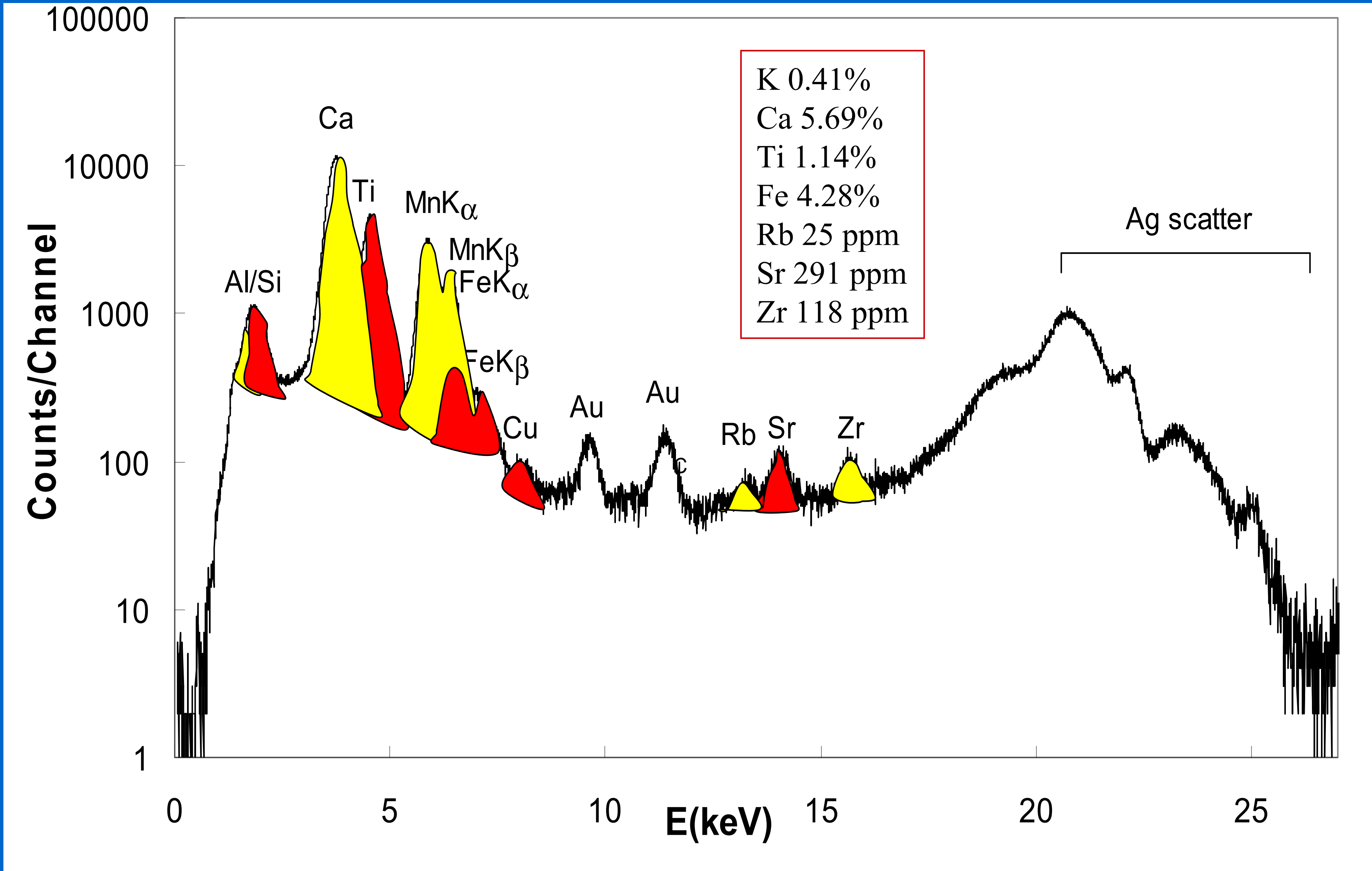
*(*Space Research Centre, Department of Physics and Astronomy and Department of Biology†, University of Leicester, Leicester LE1 7RH, UK. ‡ Science Payloads Technology Division SCI-ST , Research and Scientific Support Department , Postbus 299, ESA/ESTEC, 2200 AG Noordwjik, The Netherlands.)*

University of Leicester

IWORID Glasgow, 26th July 2004

Planetary X-rays I : The Beagle 2 XRS

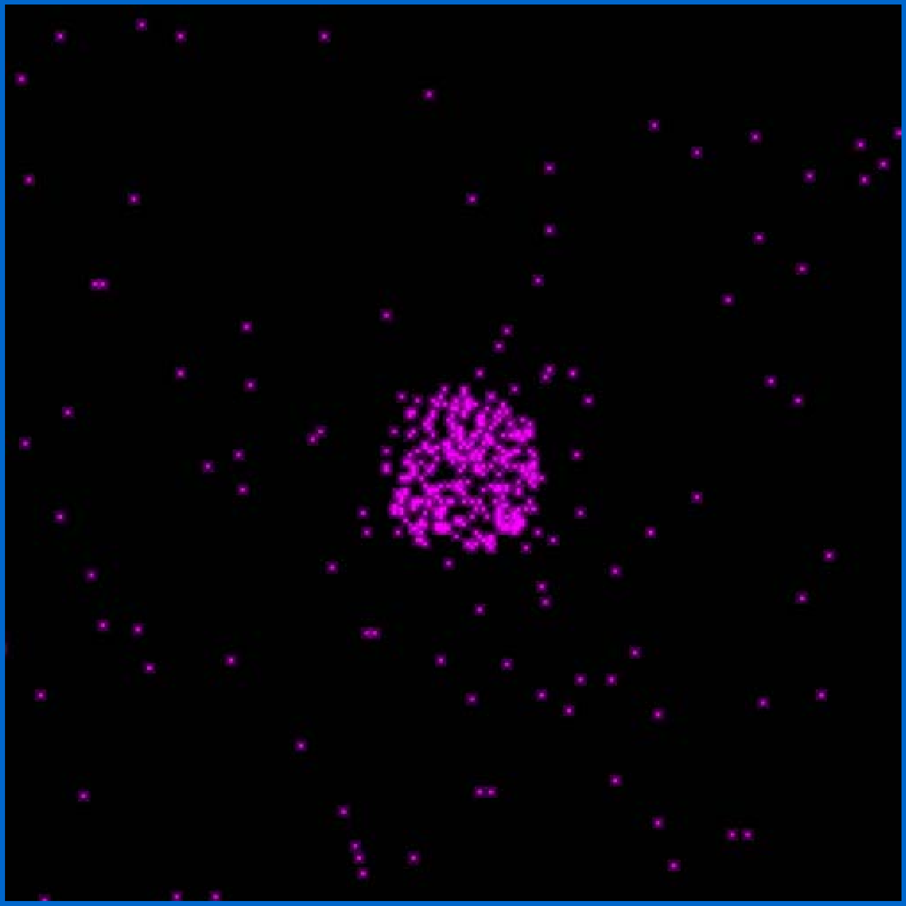
- Determine major element abundances : Mg, Al, Si, K, Ca, Ti, Fe
- Determine trace (ppm) elemental abundances up to niobium (Z = 41)
- Measure potassium content for K/Ar dating of Martian rocks.



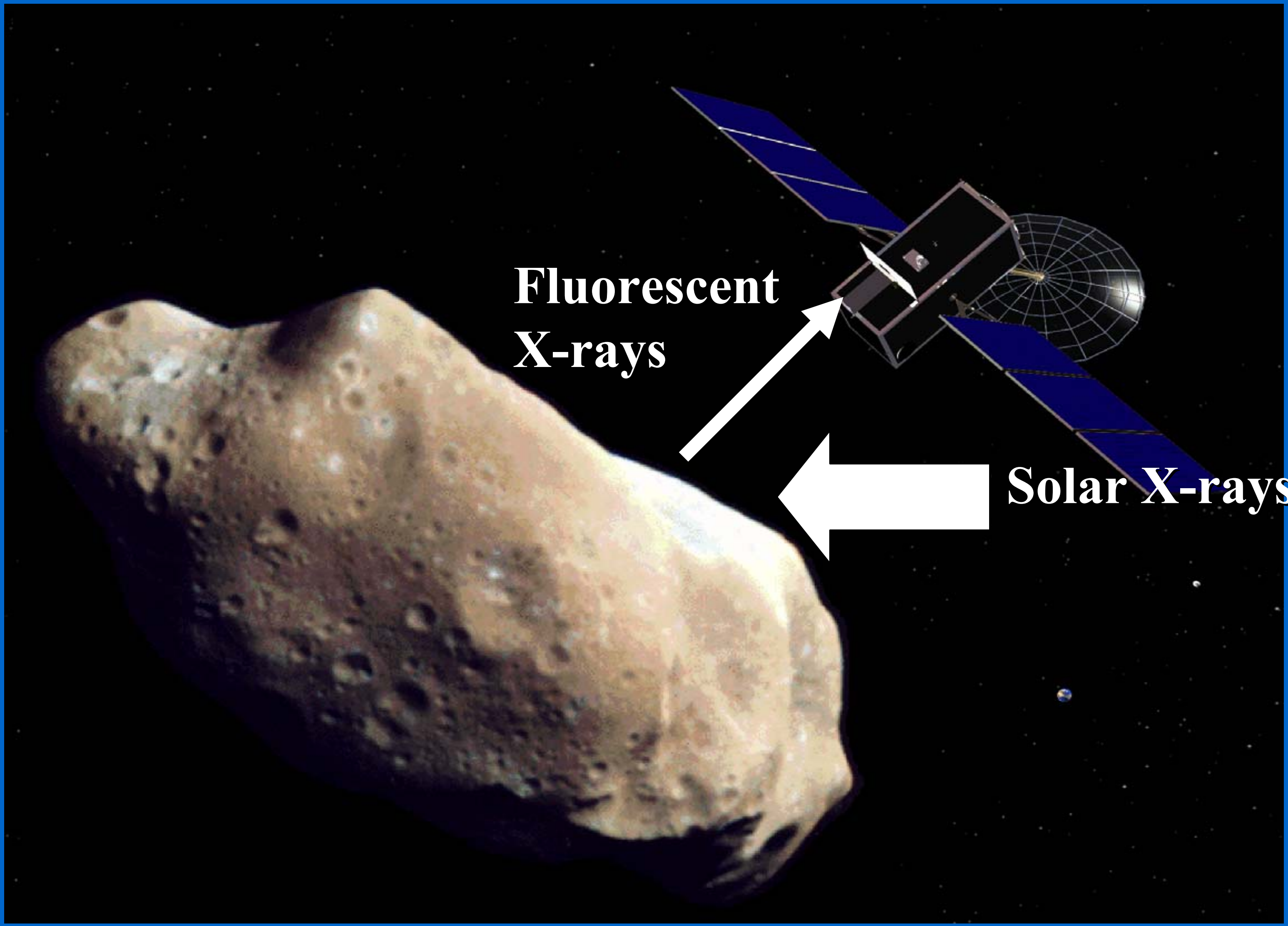
100000
10000
1000
100
10
1
Counts/Channel
0
5
10
15
20
25
E(keV)
Al/Si
Ca
Ti
MnKα
MnKβ
FeKα
FeKβ
Cu
Au
Au
Rb
Sr
Zr
Ag scatter
K 0.41%
Ca 5.69%
Ti 1.14%
Fe 4.28%
Rb 25 ppm
Sr 291 ppm
Zr 118 ppm

Planetary X-rays II

The power of an imaging telescope in planetary XRF :
Mars as seen by *Chandra ACIS* - (K.Dennerl, 2003)



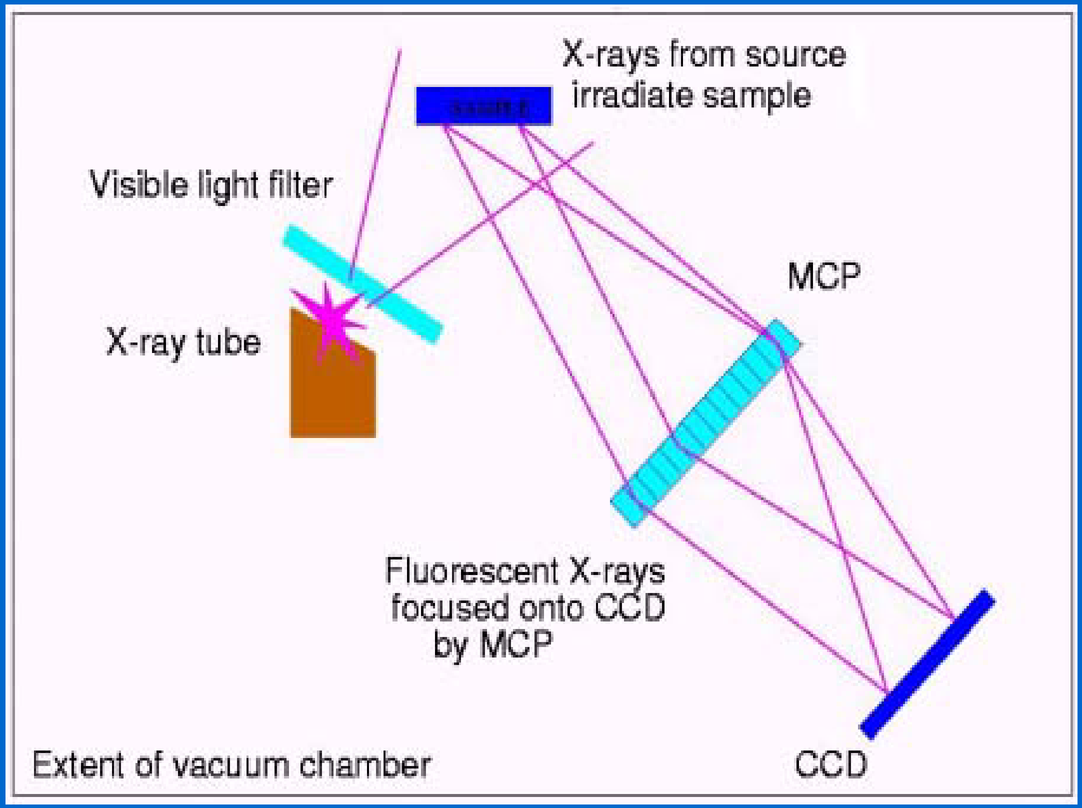
Planetary X-rays III : IXRF - X-ray Remote Sensing

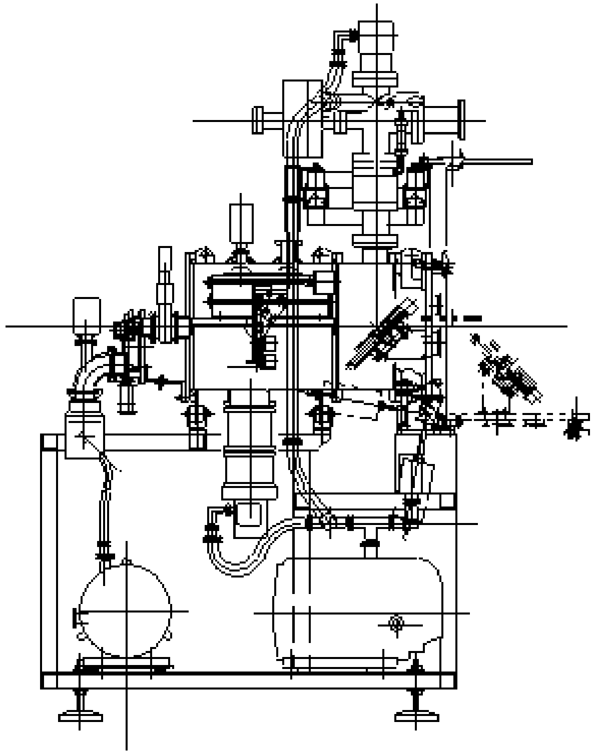


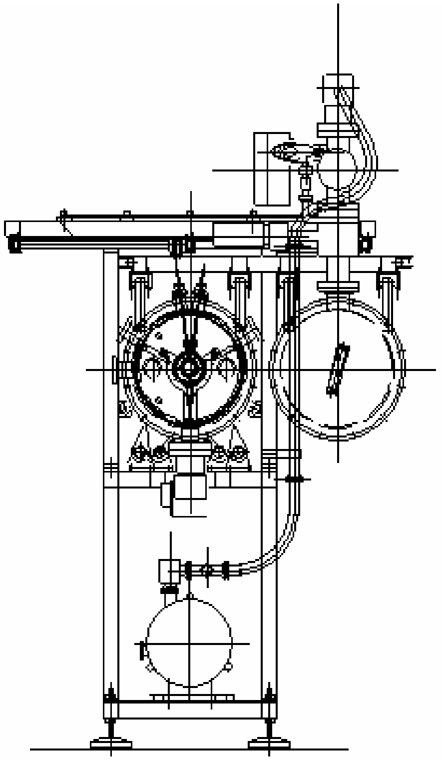
University of Leicester

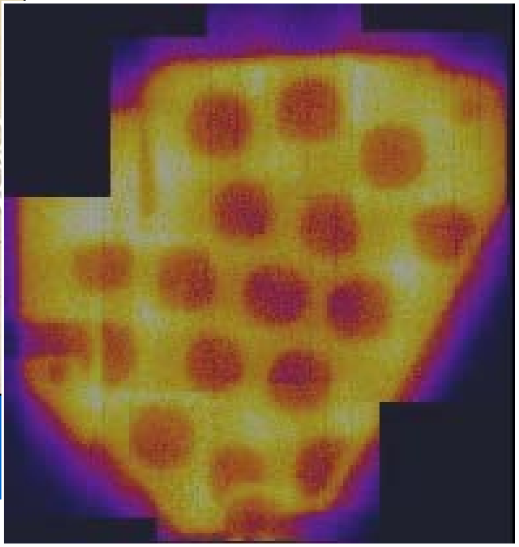
Laboratory Imaging X-ray Fluorescence using MCP optics and X-ray CCDs

- Combination of MCP optic and X-ray CCD to permit imaging X-ray fluorescence with "no moving parts"
- Proof of principle - A.P. Martin et al., X-ray Spectrometry 28 (1999) 64.
- Position resolution on the detector of ~250 µm
- Magnification possible
- ***Scale invariant***









IXRFS Lab System

G.J. Price et al.,

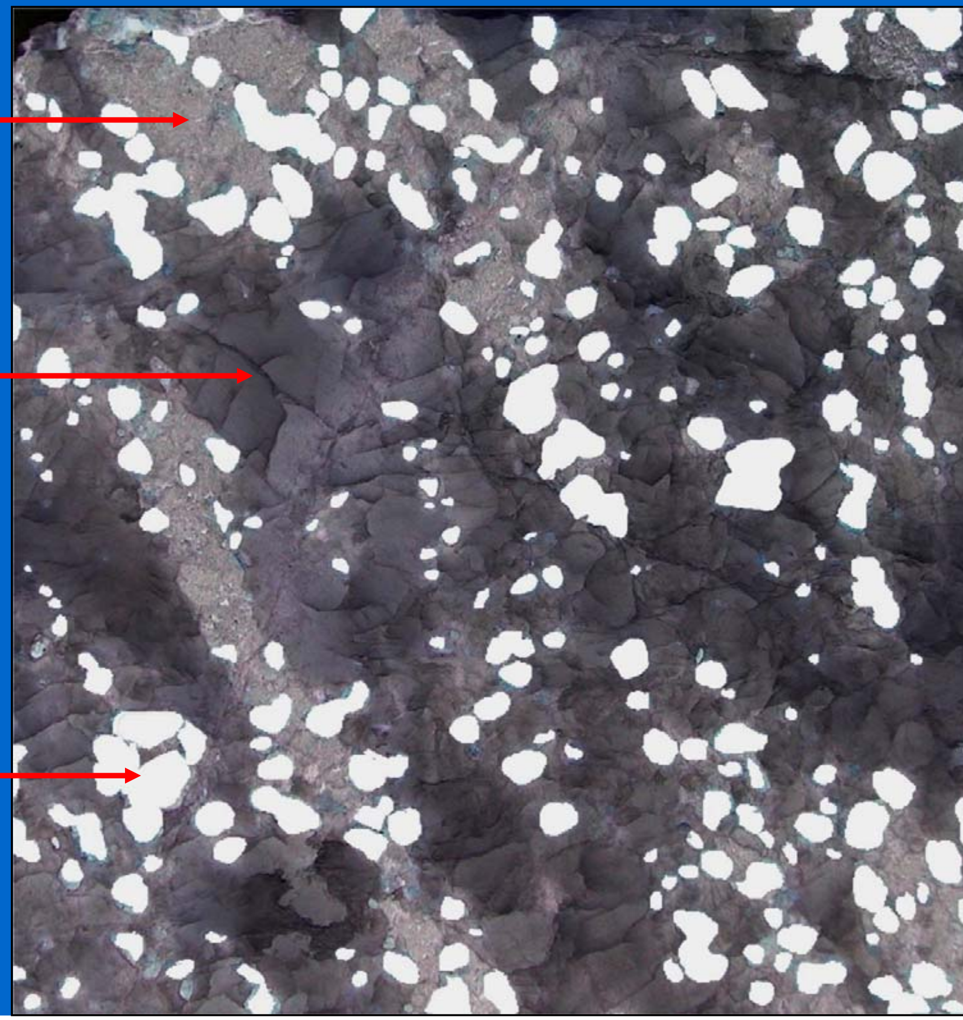
Rev.Sci.Instr. (2004) in press

Garnetiferous Anorthosite (Bergen, Norway)

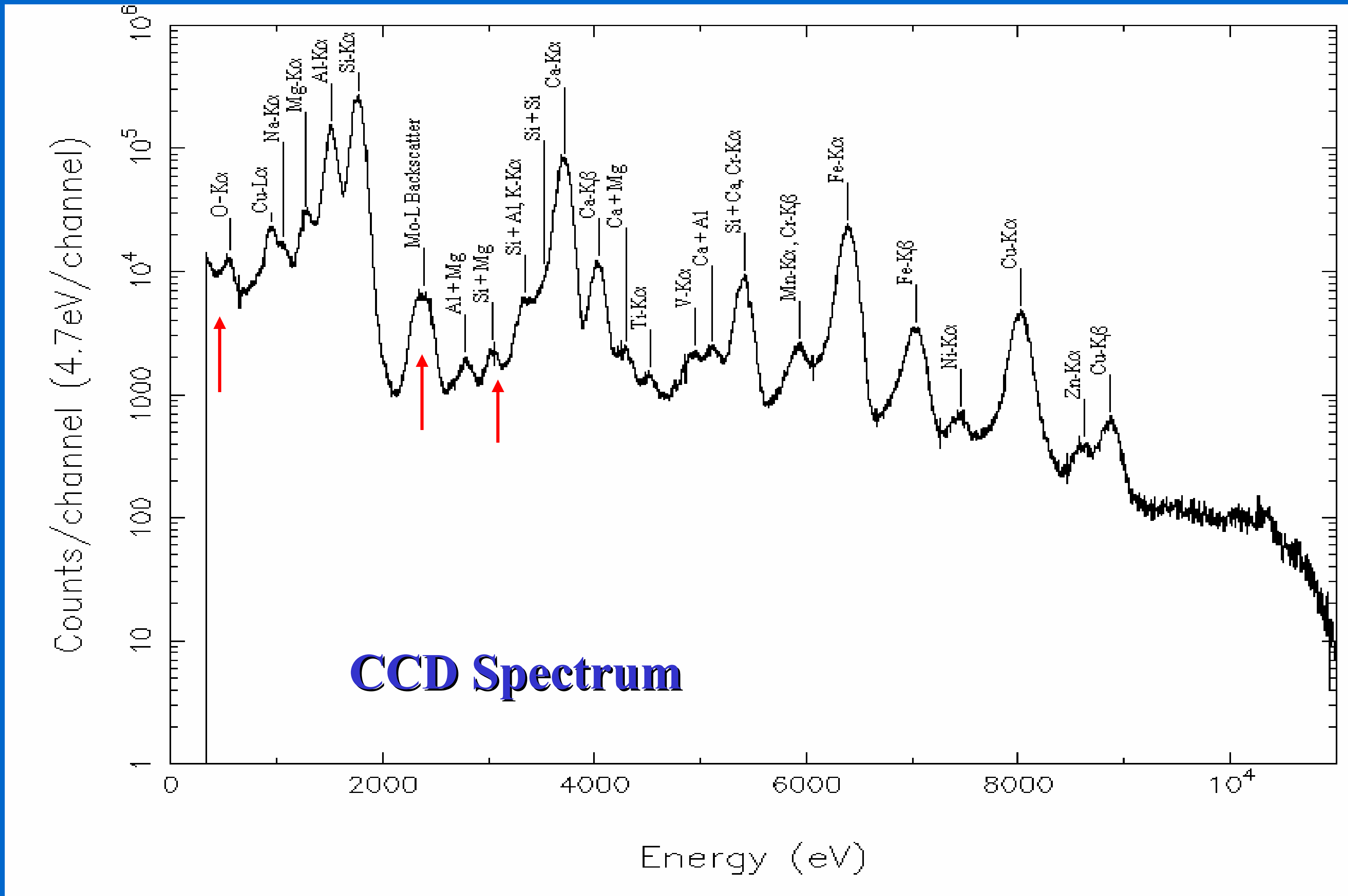
TBD
High relief
Pleochroic (lt blue-lt brown)
Birefringent

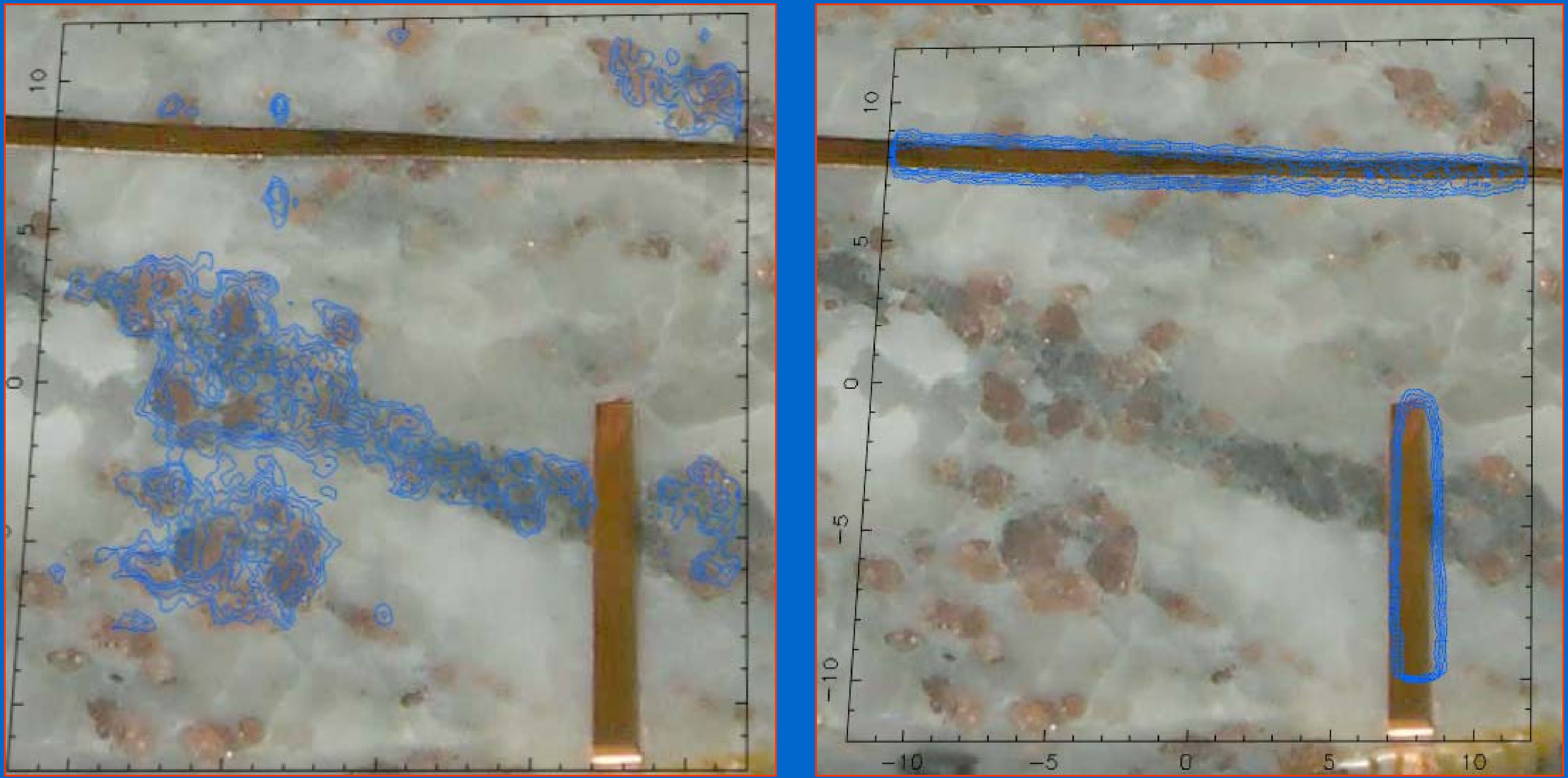
Plagioclase
Microcline (KAlSi3O8)
and Albite (NaAlSi3O8)

Garnet
Almandine (Fe3(2+)Al2SiO12)?
with Pyrope (Mg3Al2Si3O12)?

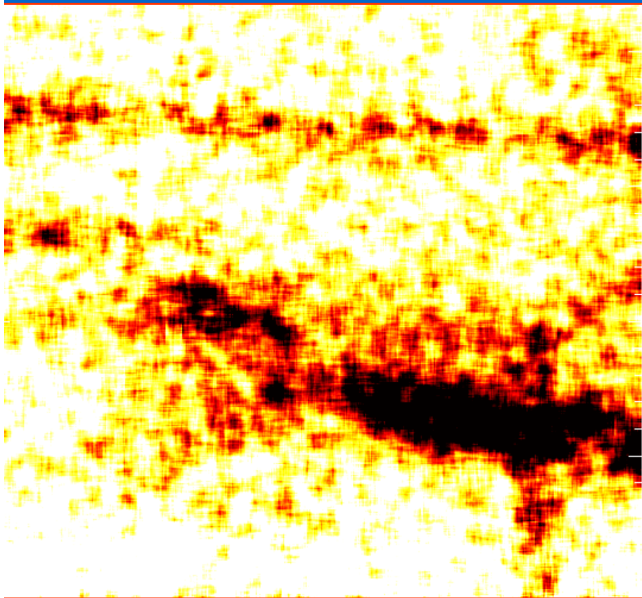


1 cm

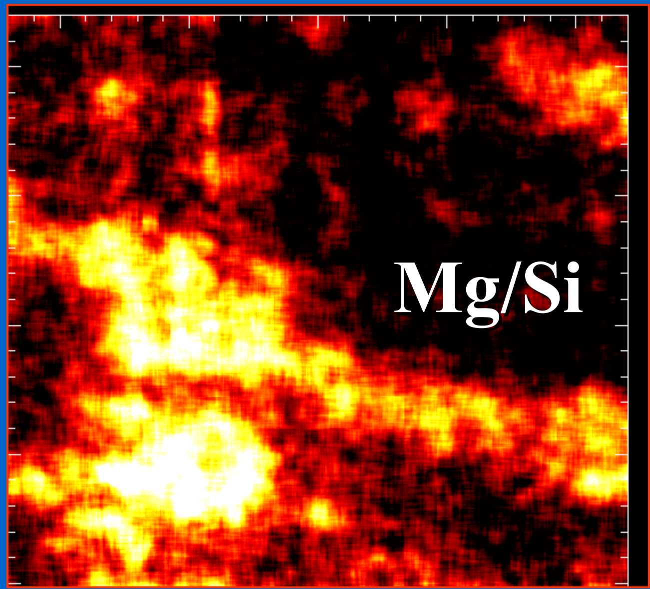

CCD Spectrum
Counts/channel (4.7eV/channel)
Energy (eV)
1
10
100
1000
10^4
10^5
10^6
0
2000
4000
6000
8000
10^4
O-Kα
Cu-Lα
Na-Kα
Mg-Kα
Al-Kα
Si-Kα
Mo-L Backscatter
Al + Mg
Si + Mg
Si + Al, K-Kα
Si + Si
Ca-Kα
Ca-Kβ
Ca + Mg
Ti-Kα
V-Kα
Ca + Al
Si + Ca, Cr-Kα
Mn-Kα , Cr-Kβ
Fe-Kα
Fe-Kβ
Ni-Kα
Cu-Kα
Zn-Kα
Cu-Kβ



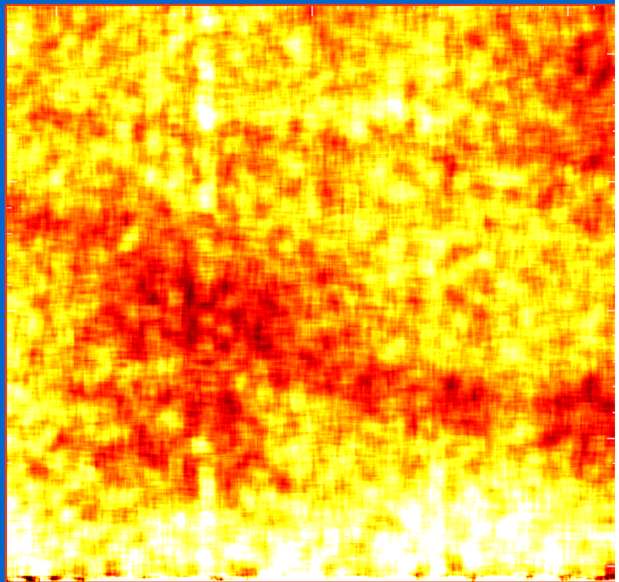
Overlaid Optical and X-ray Images



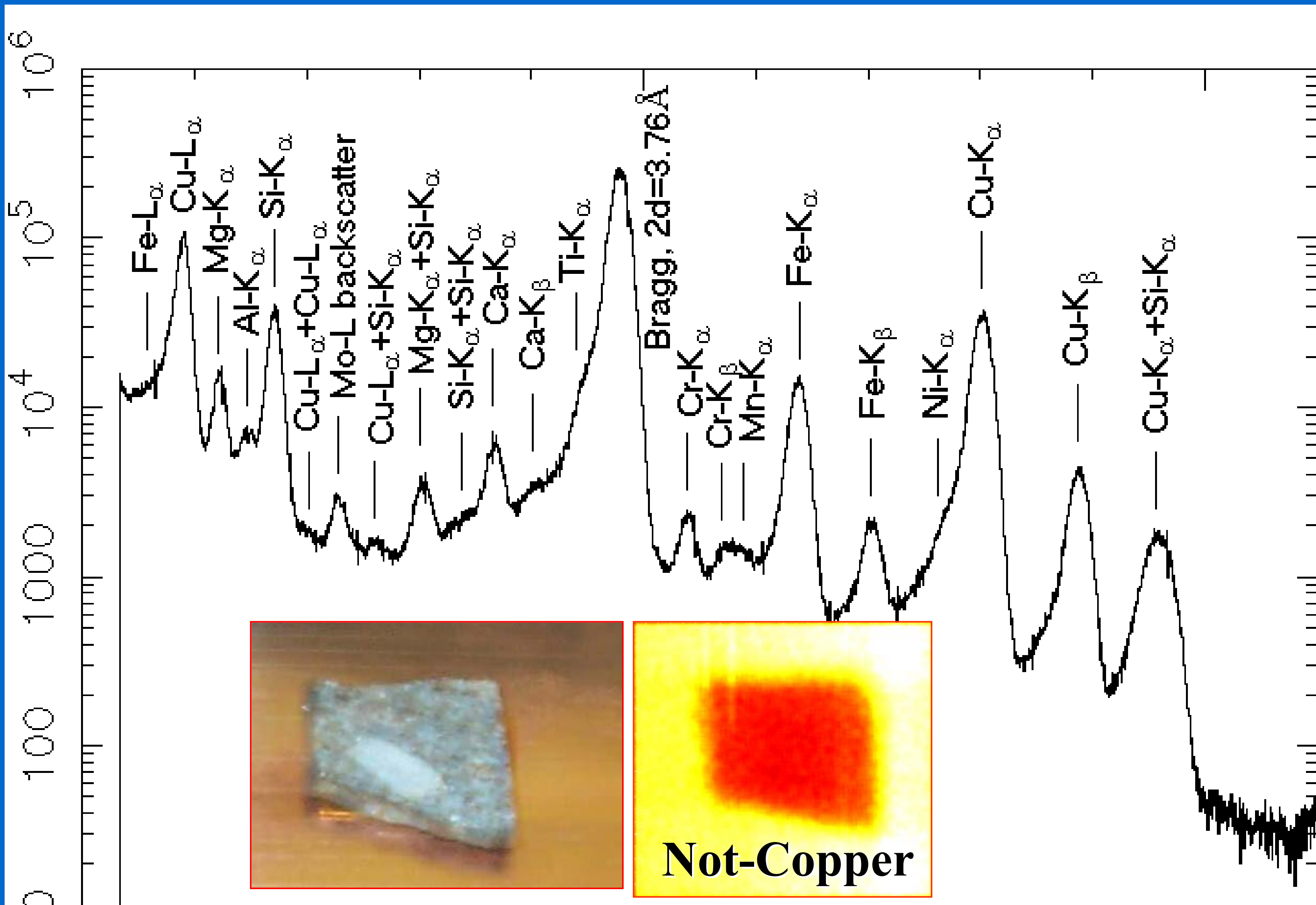
Al/Si



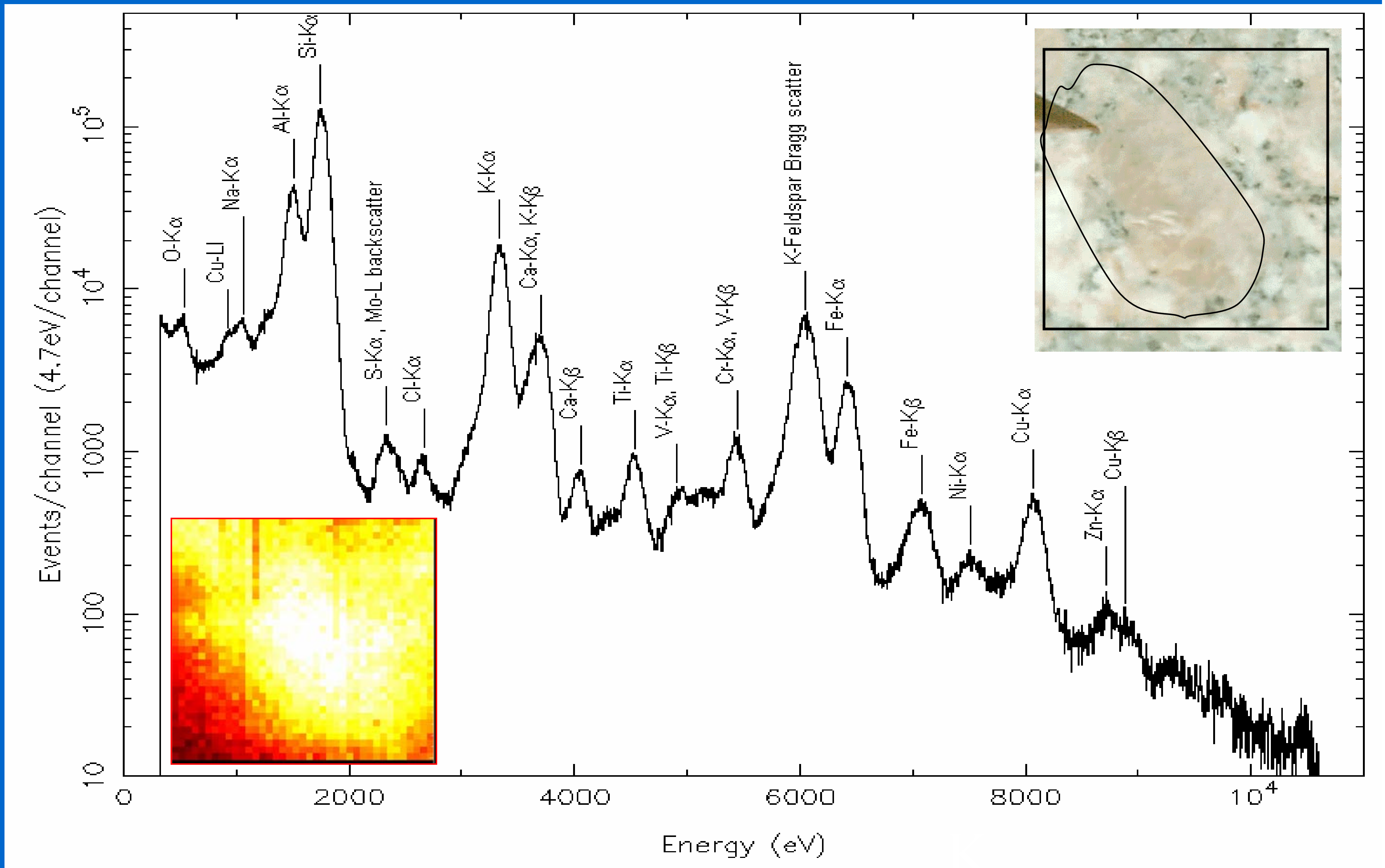
Na/Ca



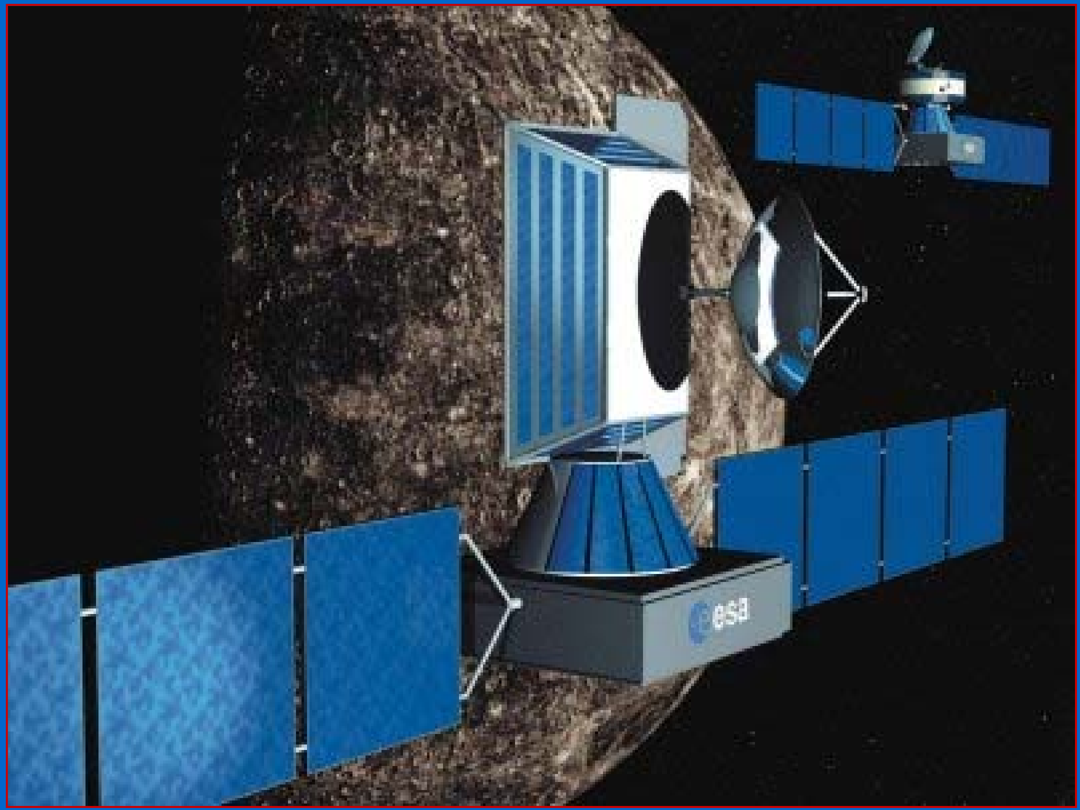
Element ratios



10^6
10^5
10^4
1000
100
Fe-Lα
Cu-Lα
Mg-Kα
Al-Kα
Si-Kα
Cu-Lα+Cu-Lα
Mo-L backscatter
Cu-Lα+Si-Kα
Mg-Kα+Si-Kα
Si-Kα+Si-Kα
Ca-Kα
Ca-Kβ
Ti-Kα
Bragg, 2d=3.76Å
Cr-Kα
Cr-Kβ
Mn-Kα
Fe-Kα
Fe-Kβ
Ni-Kα
Cu-Kα
Cu-Kβ
Cu-Kα+Si-Kα
Not-Copper



Events/channel (4.7eV/channel)
10
100
1000
10⁴
10⁵
0
2000
4000
6000
8000
10⁴
Energy (eV)
O-Kα
Cu-Ll
Na-Kα
Al-Kα
Si-Kα
S-Kα, Mo-L backscatter
Cl-Kα
K-Kα
Ca-Kα, K-Kβ
Ca-Kβ
Ti-Kα
V-Kα, Ti-Kβ
Cr-Kα, V-Kβ
K-Feldspar Bragg scatter
Fe-Kα
Fe-Kβ
Ni-Kα
Cu-Kα
Zn-Kα
Cu-Kβ



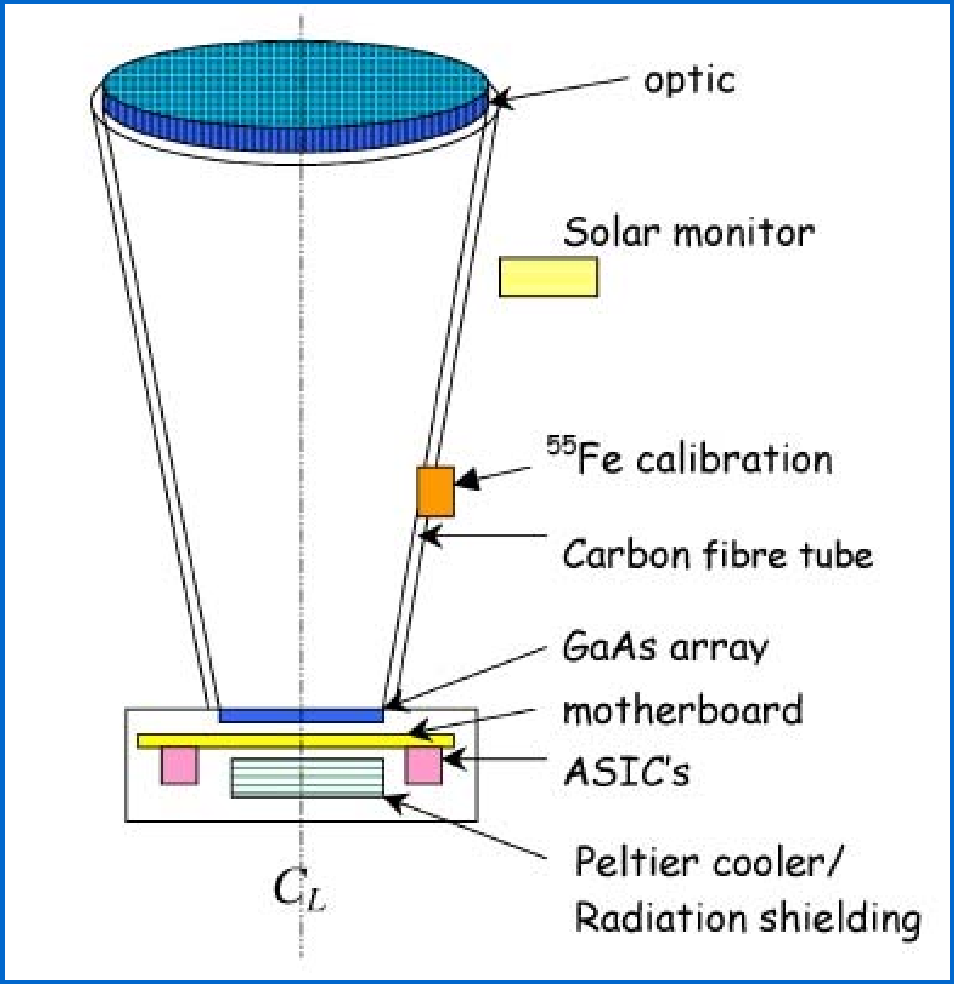
A Future Opportunity for Planetary IXRF: ESA BepiColombo to Mercury (2016)

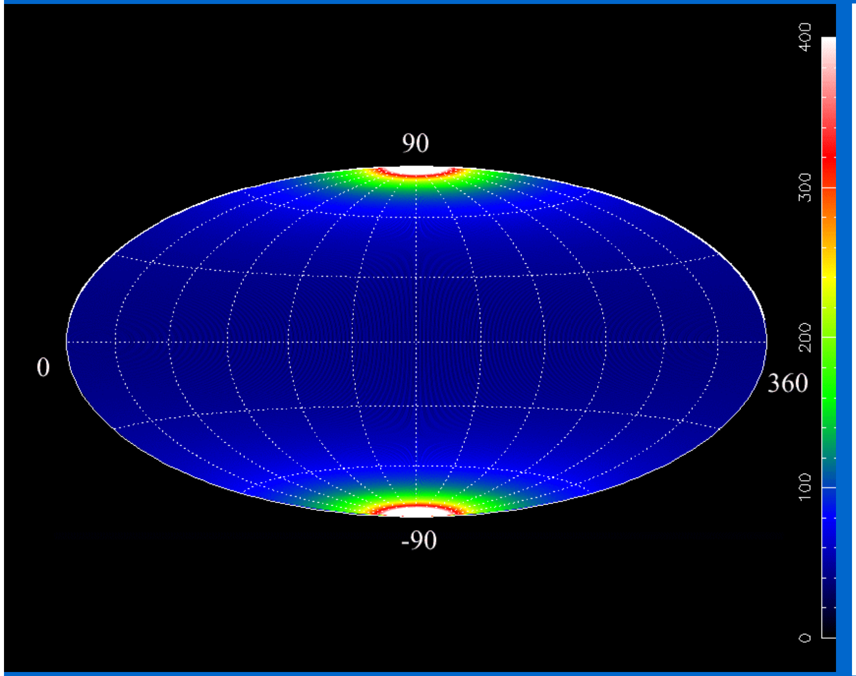
University of Leicester

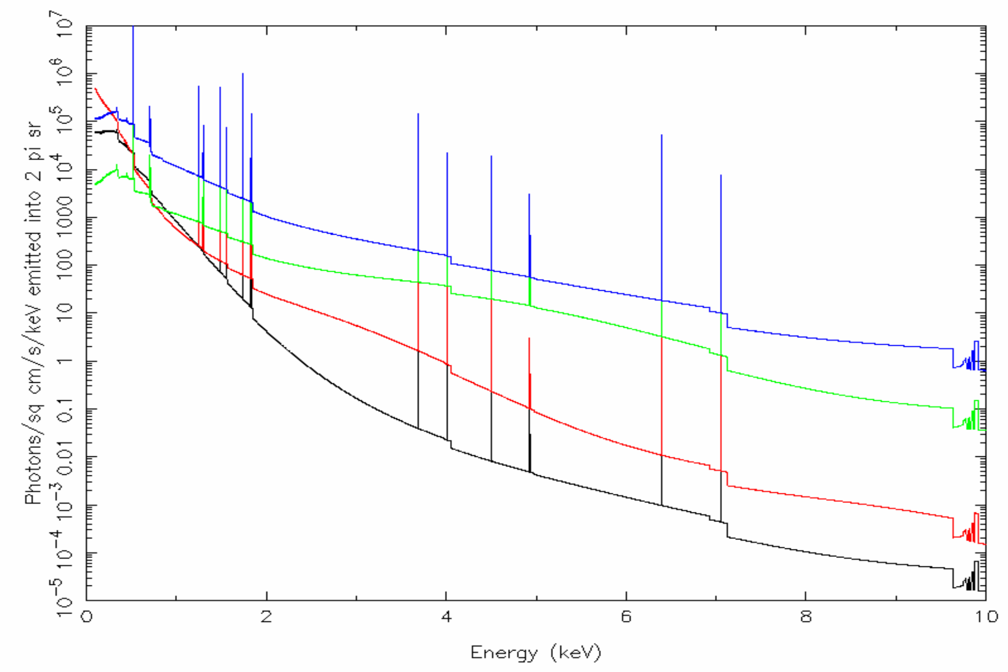
IWORID Glasgow, 26th July 2004

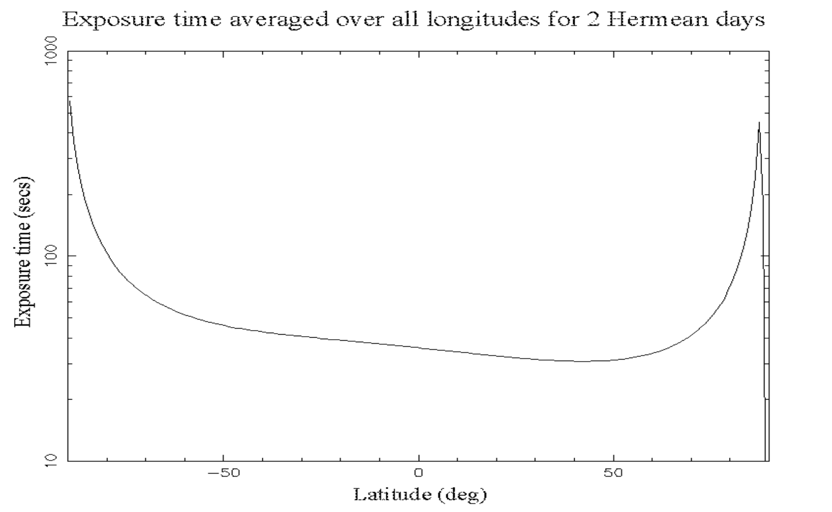
MIXS-T

- low mass Wolter Type 1 optic based on microchannel plates. One metre focal length (A_{eff} ~100 cm^2).
- GaAs pixel array
- Radiation hard solar monitor
- Use of optic allows use of small focal plane with resultant advantages in shielding, cooling









MIXS Mission Issues :

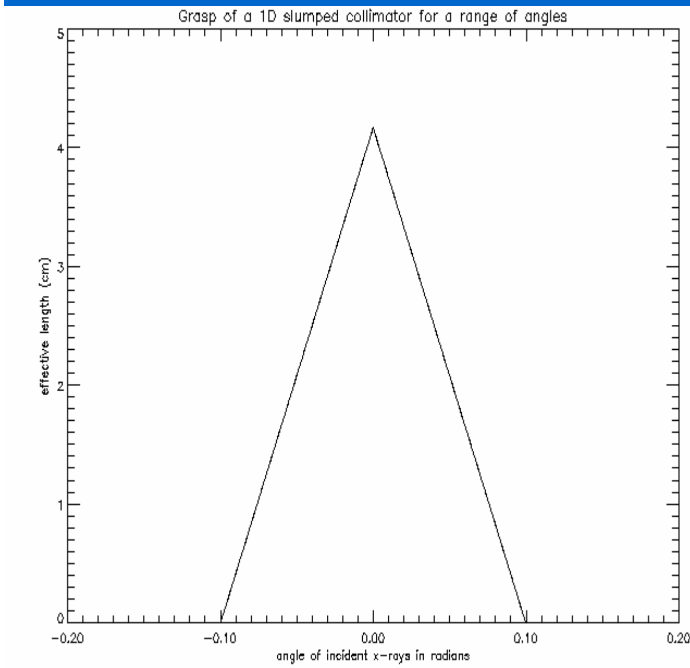
•Exposure maps (2 Hermean days/ 117 Earth days)

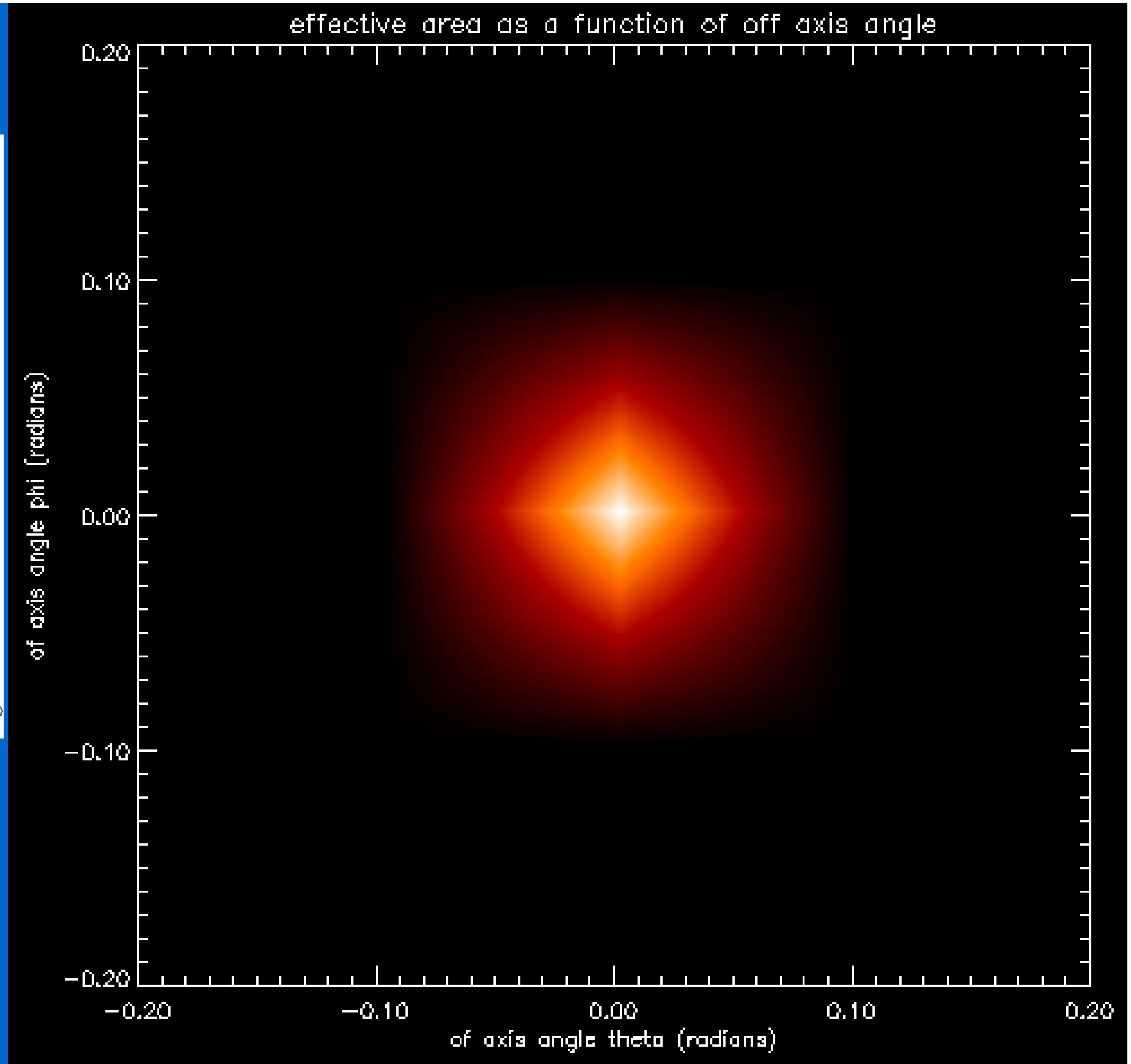
• Expected X-ray fluxes as functions of solar flare state (Quiet, B-flare, C-flare, M-flare)

MIXS-T

Requirements :
Radiation Tolerance, Warm Operation, 200 eV Energy Resolution, Spectroscopy down to 0.5 keV

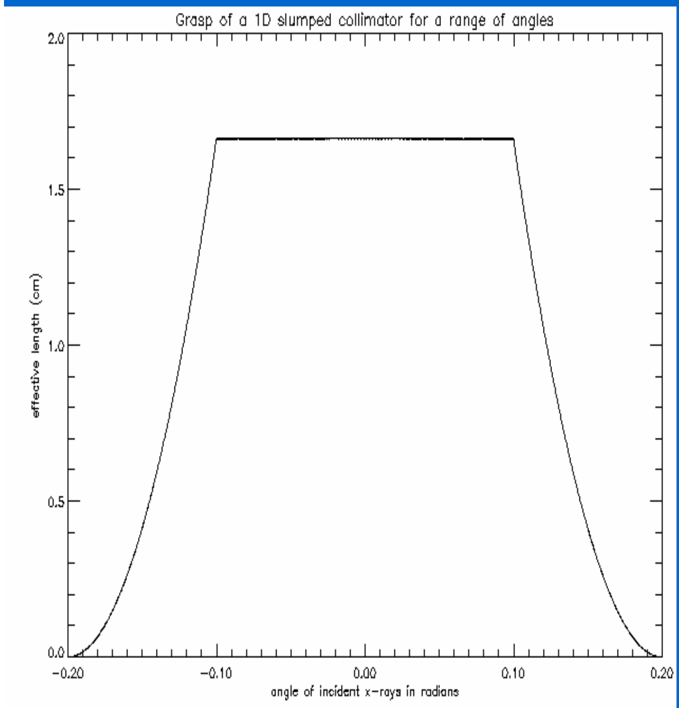
Bandpass	1-10 keV (elemental range Na to Fe)
Basic surface "pixel"	7 x 7 sq.km
Optic type	Wolter Type 1.
Focal length	1 metre
Optic technology	Radially packed square-pore microchannel plate
Field-of-view	~2 degrees FWZM
On axis angular resolution	2 arcminutes FWHM (1.1 arcminute already measured on prototypes)
Diameter	21 cm
Optic mass	0.5 kg
Focal plane detector	Pixellated GaAs array, flip-chip bump-bonded to custom ASIC chip
Operating temperature	-10 degrees C or higher
Radiation tolerance	High compared to silicon : 200 krad on single pixel GaAs measured (for times 2 increase in leakage current). For comparison, the maximum tolerable dose for an X-ray CCD is ~1 krad.
Energy resolution	257 eV at 5.9 keV at –3 deg.C ; 219 eV at – 30 deg. C

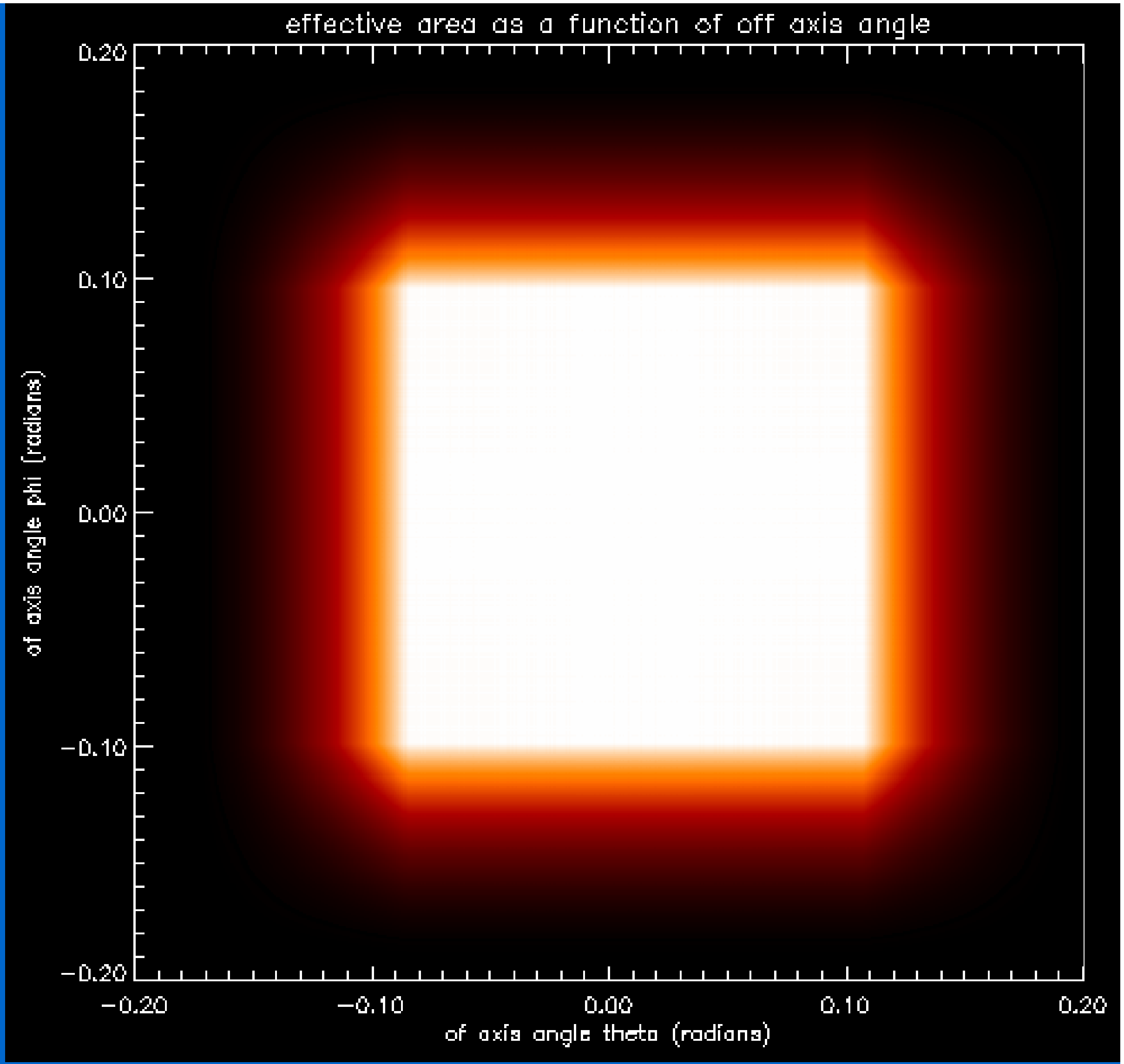




Planar Collimator
(L/D =10:1)

Spherically slumped MCP Collimator (1) constant L/D=10:1



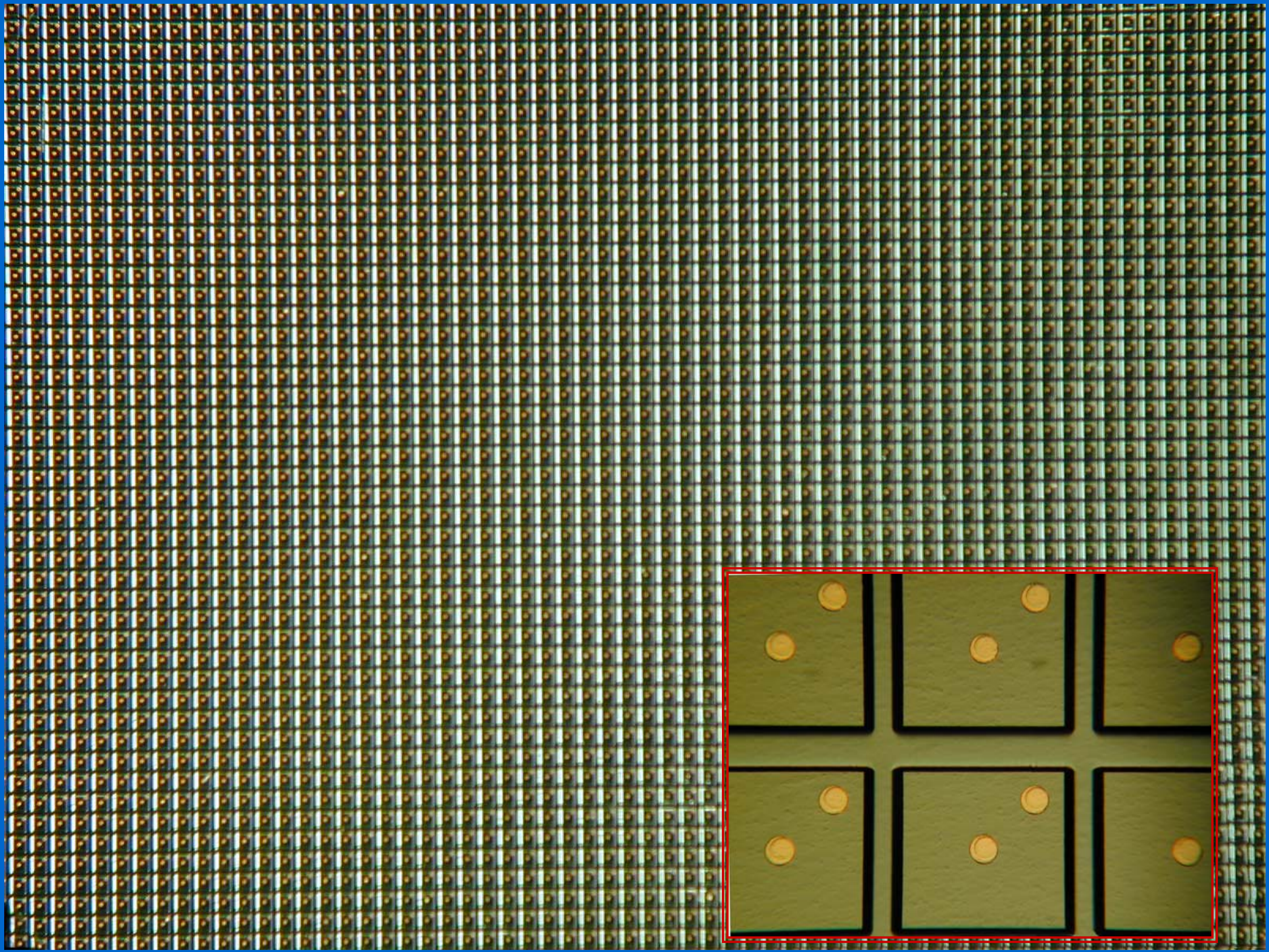


BepiColombo MIXS-C

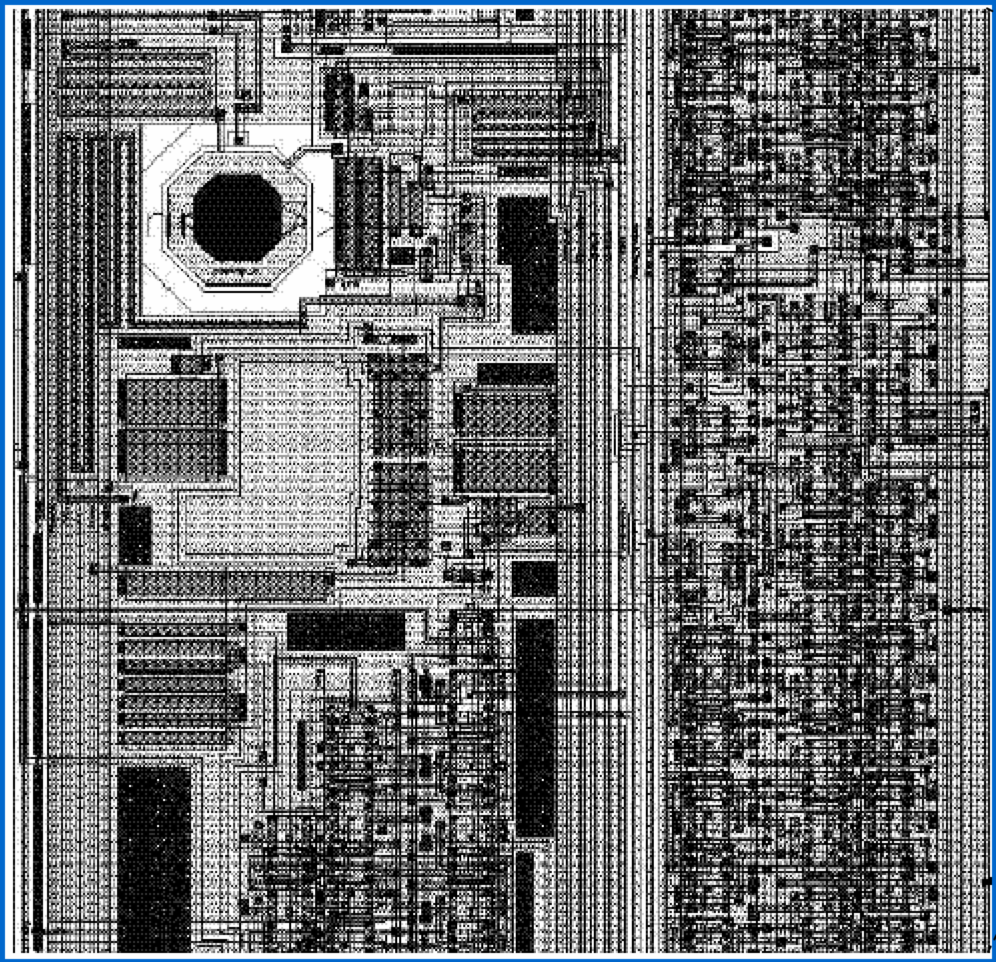
University of Leicester

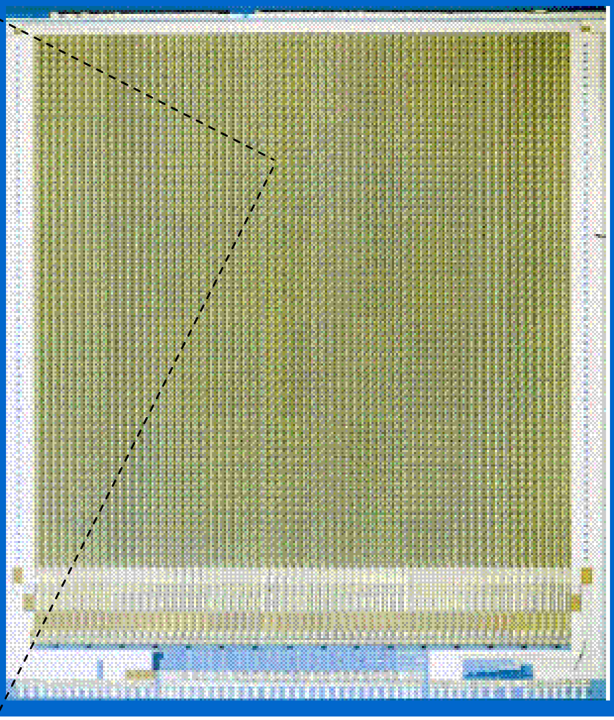
IWORID Glasgow, 26th July 2004

GaAs 64 x 64 Medipix I array



Medipix 1 ASIC - 1 micron technology





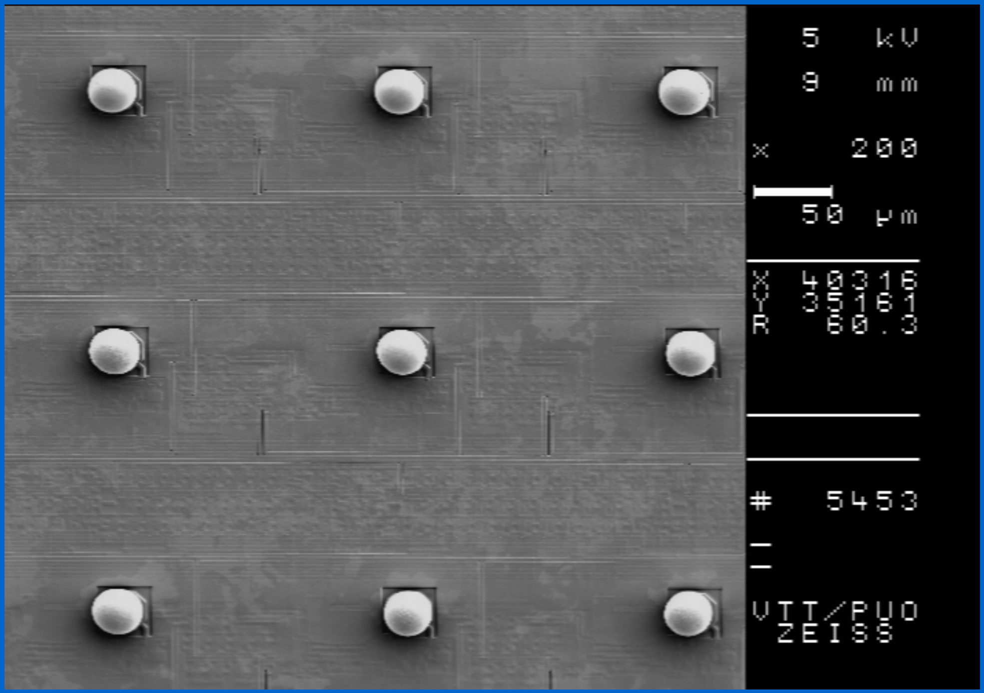
Medipix1 (1998)

4096 pixels 170 x 170 μm²

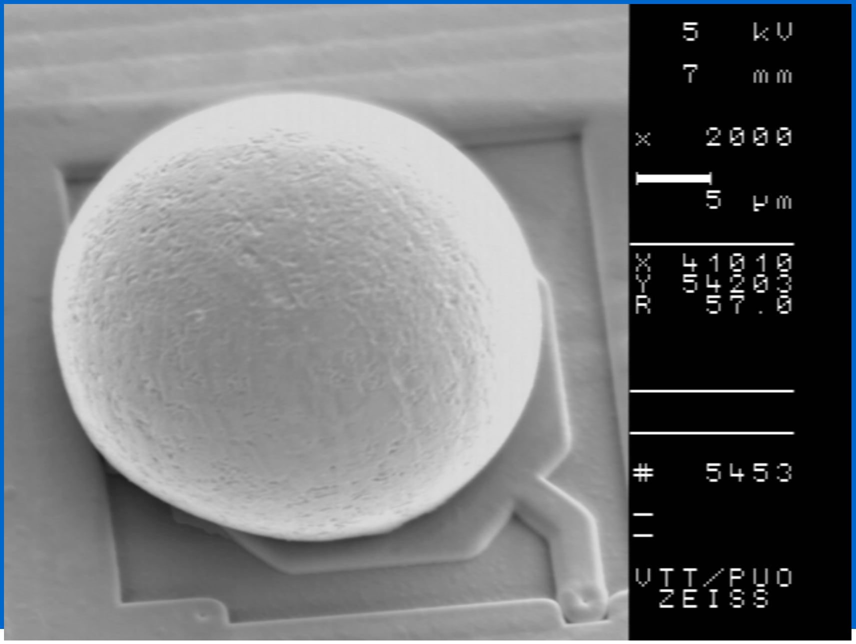
1.2 cm² sensitive area

1.6 x 10⁶ transistors

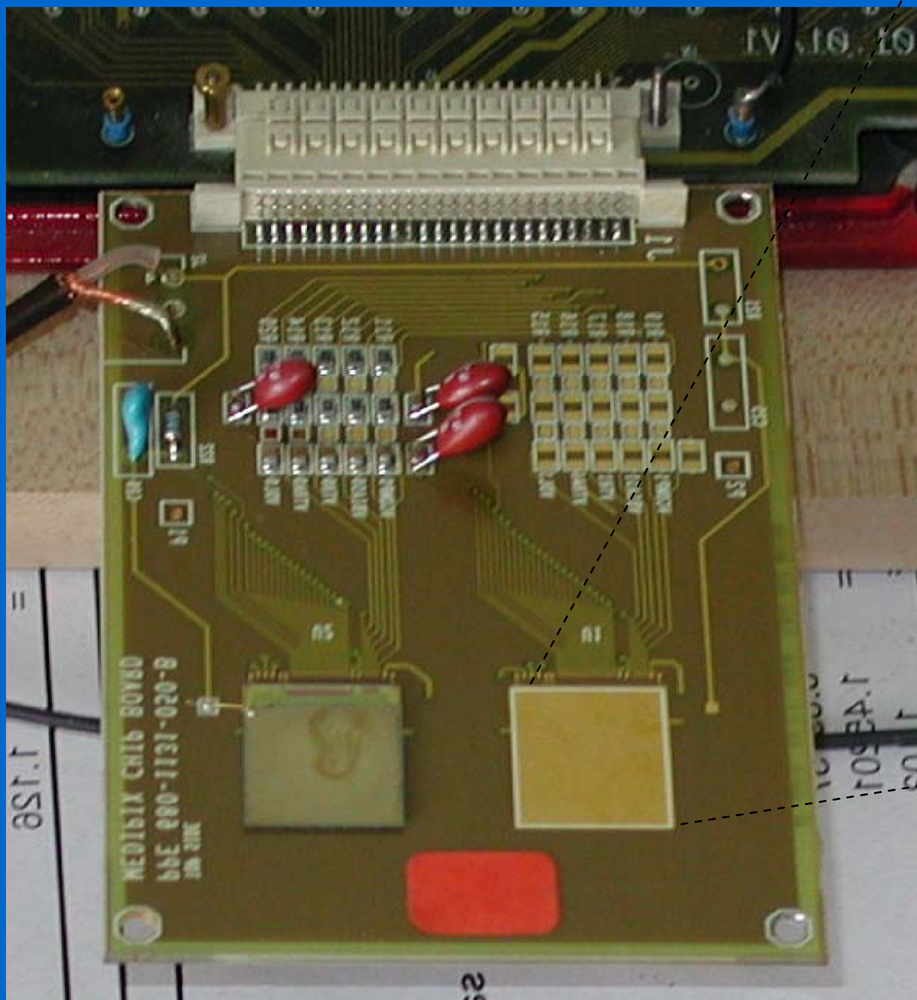
University *of* Leicester

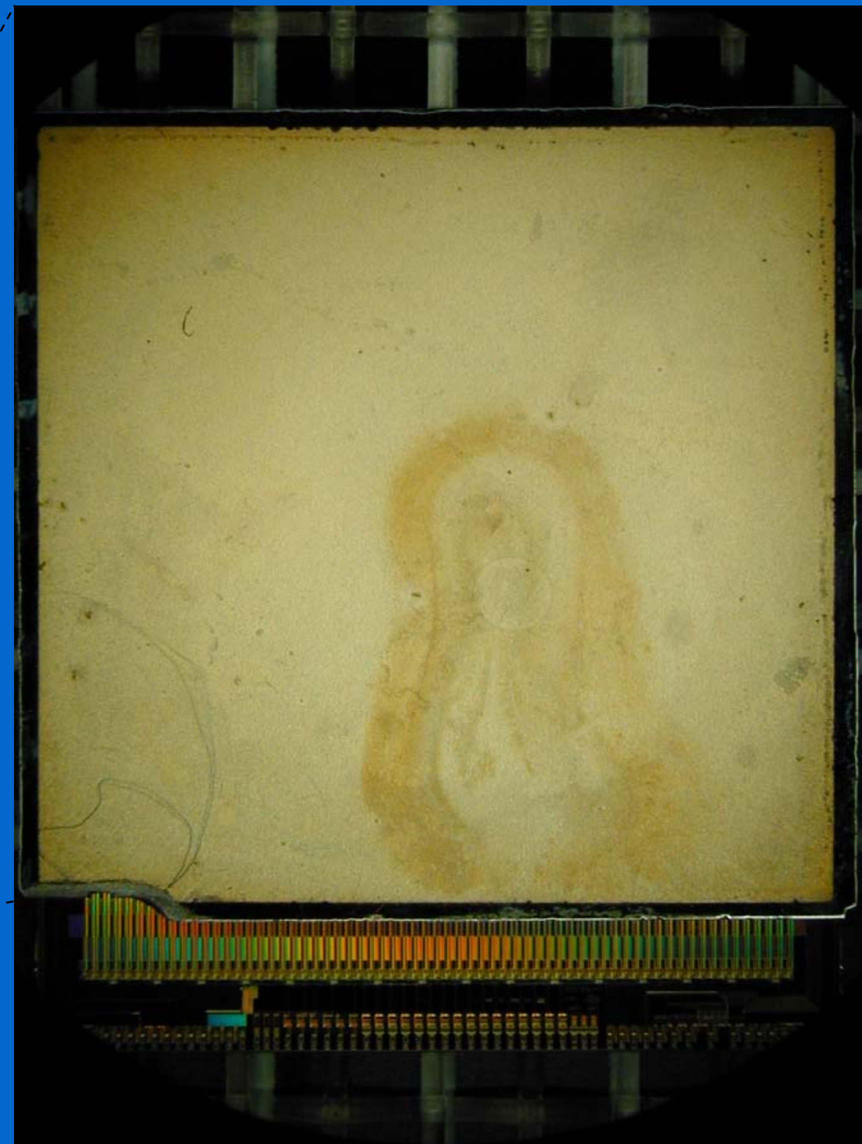


Medipix I ASIC
SnPb bumps



GaAs array flip-chip bump-bonded and mounted on the MUROS Multi-Purpose Readout System daughter board






4e+4
0


UL
ESA
5e+4
0


3e+4
1e+4
CSE
INOX
1
2
3
4
5
6

Thanks to

A.Owens, A. Peacock (Estec)

S. Dunkin, B. Maddison (RAL)

K. Muionenon, J. Huovelin (Helsinki)

J.Pearson, J. Carpenter, J.Nussey, G.Price, N. Bannister, G.Butcher, D. Talboys, P. Heslop-Harrison, T.Schwarzacher, J.Lees, D.Bassford, R.Ambrosi (Leicester)

A.Holland (Brunel)