Properties and Detection of Light: X-ray

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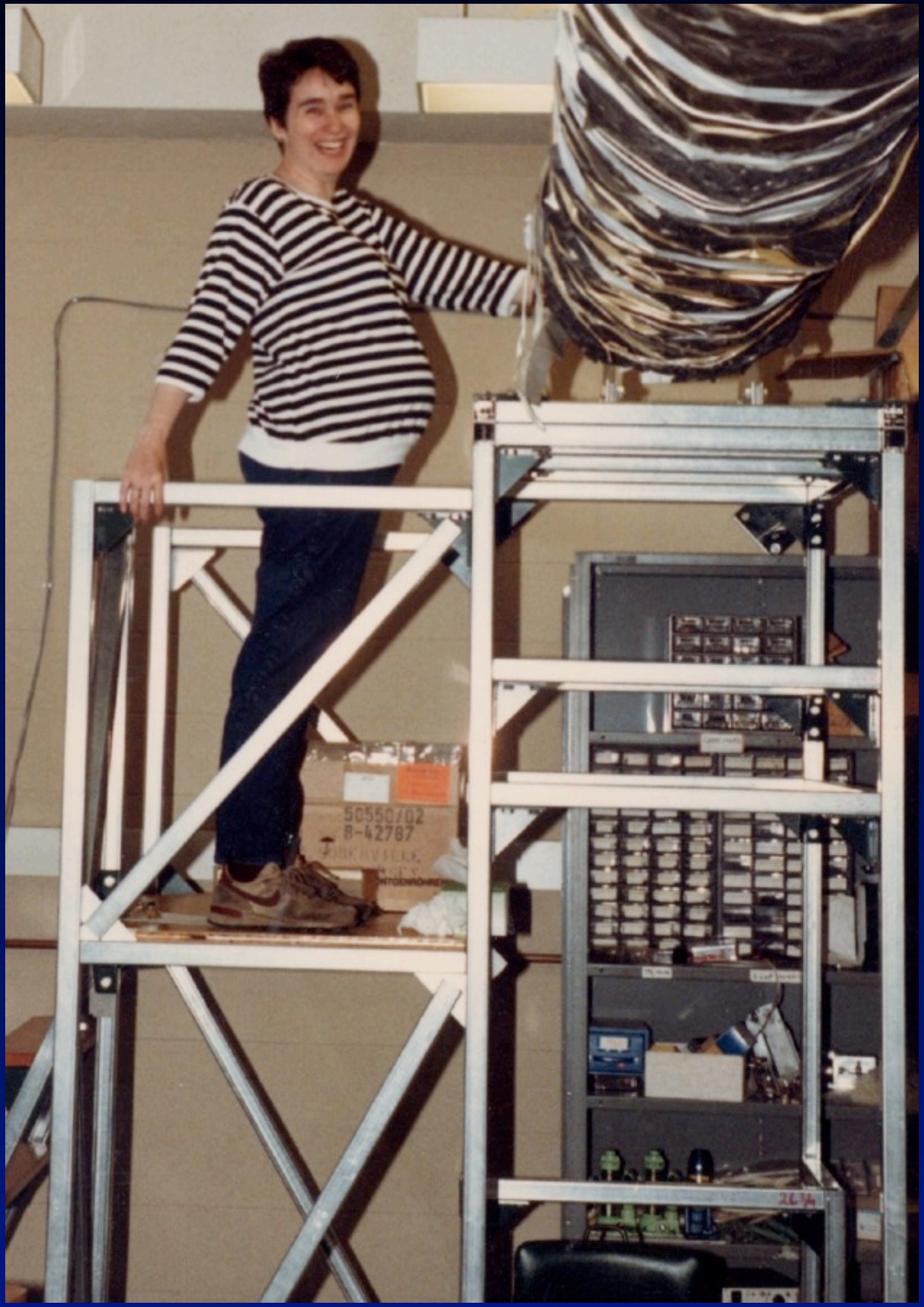
Space Telescope Science Institute

Dunlap Institute Summer School
July 9, 2019

Contents

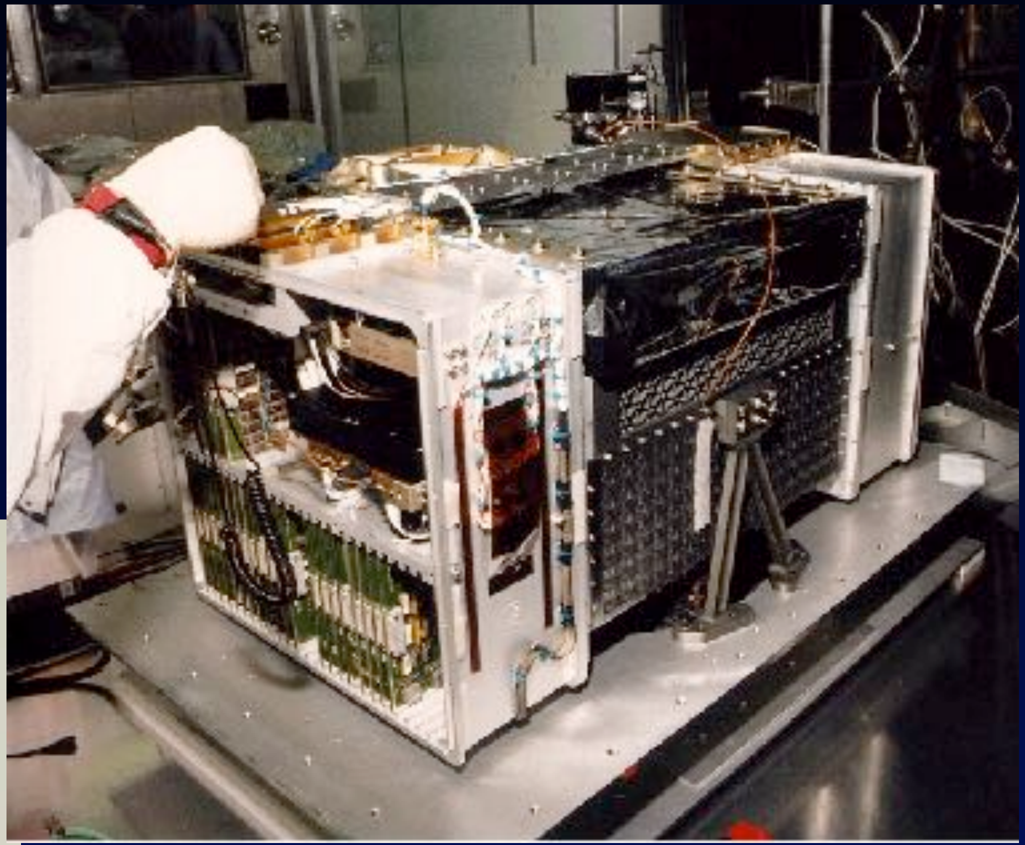


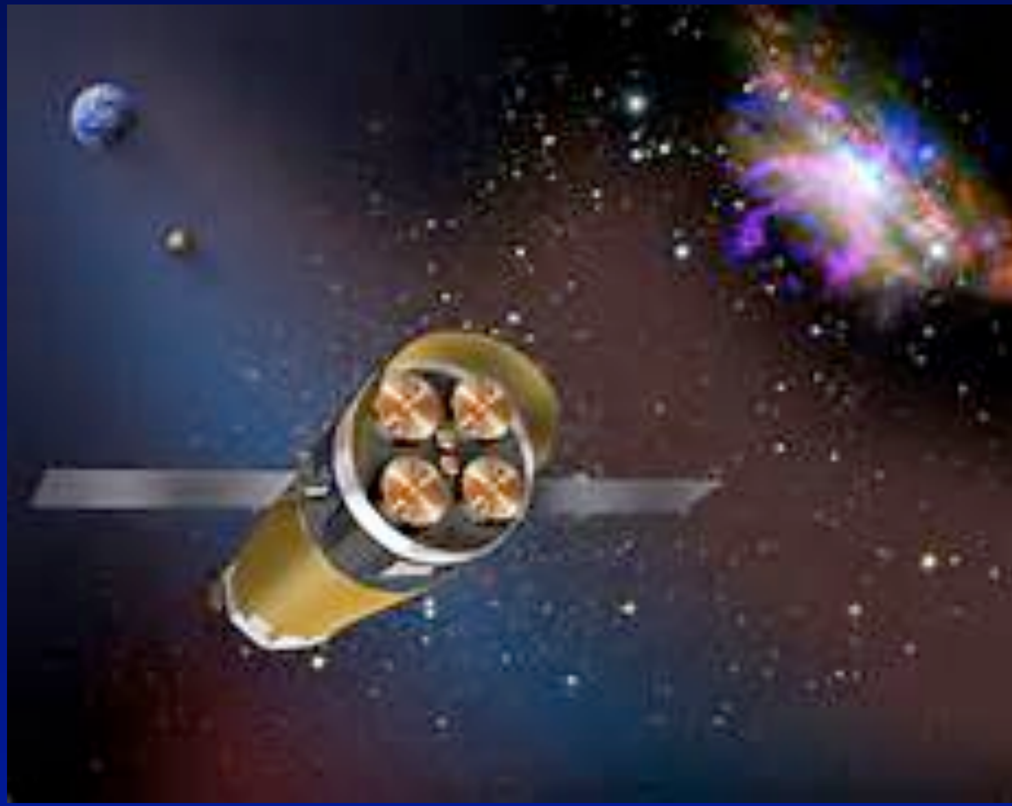
Physics major at MIT

Army brat, ~ a dozen schools before college. Lived in Asia and Europe.

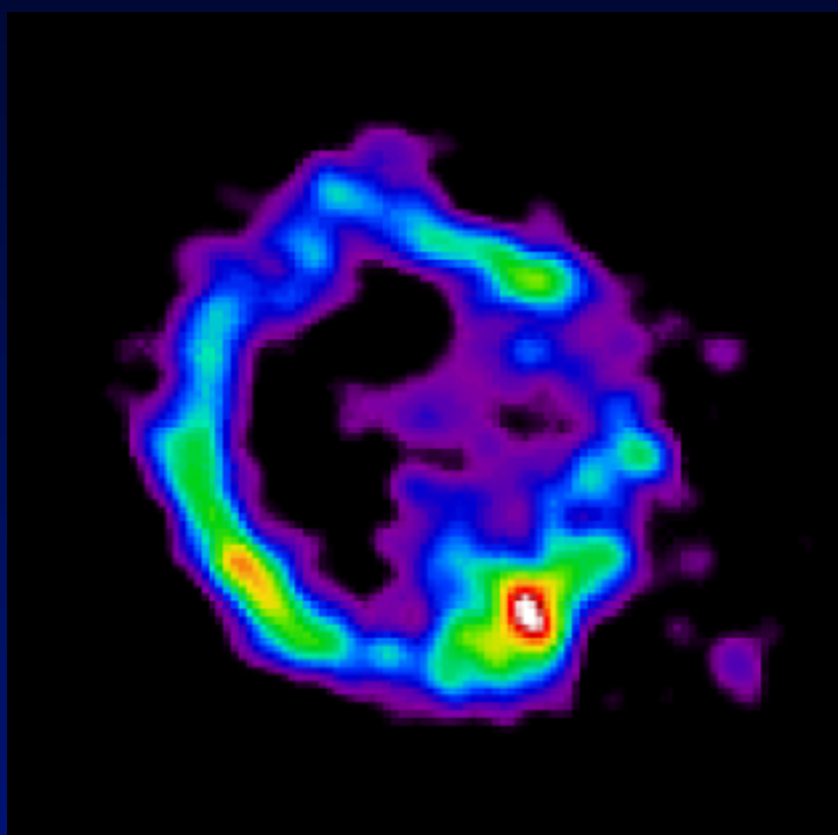
Peace Corps - teaching math and physics

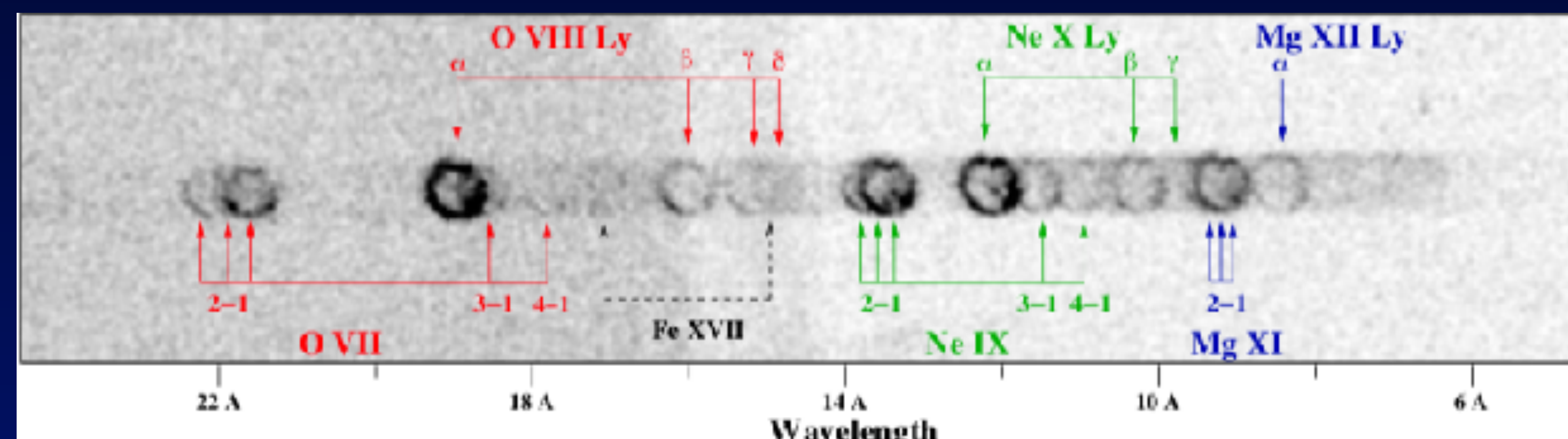
NASA X-ray instruments



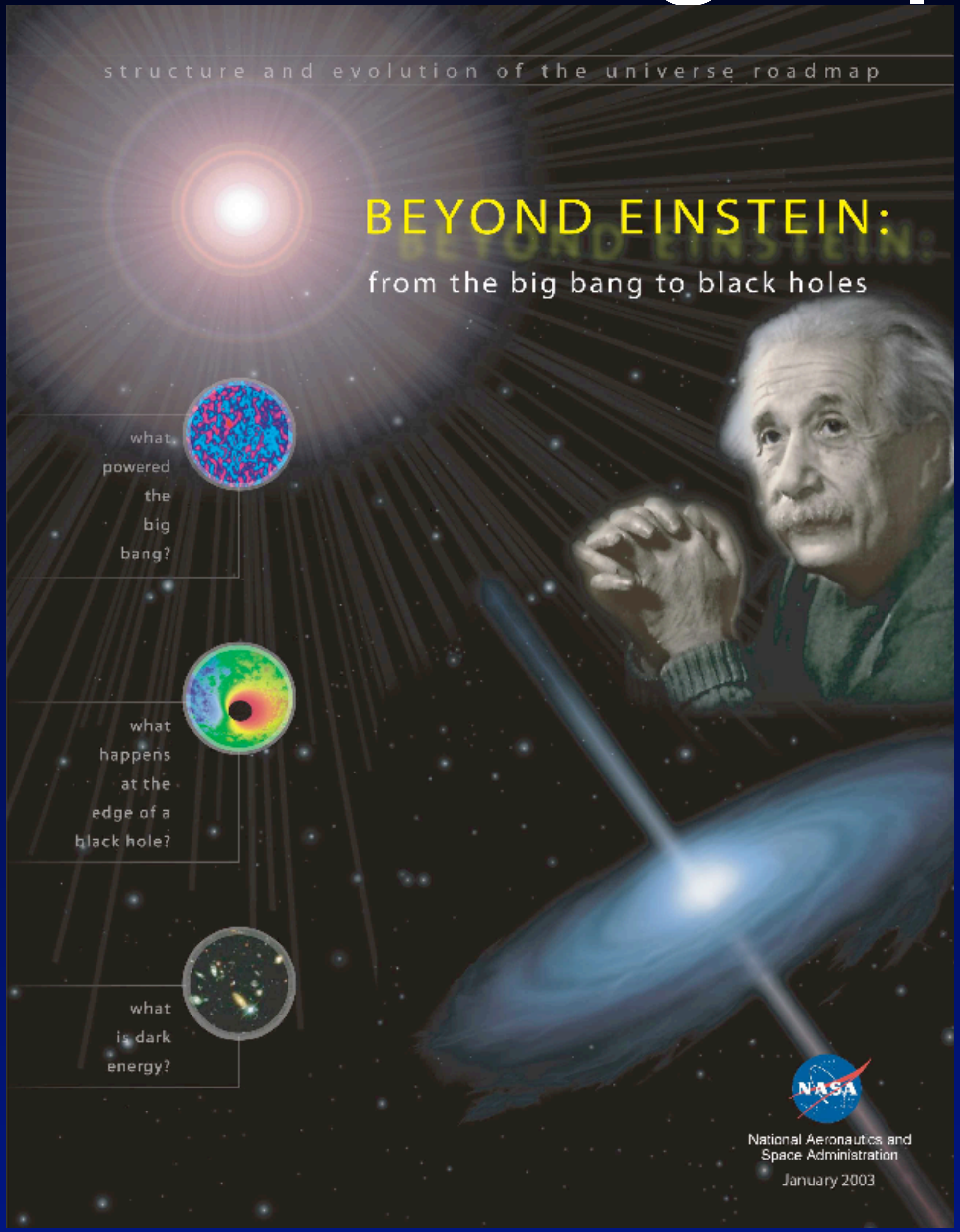


Astronomy - Supernova Remnants & X-ray Spectroscopy



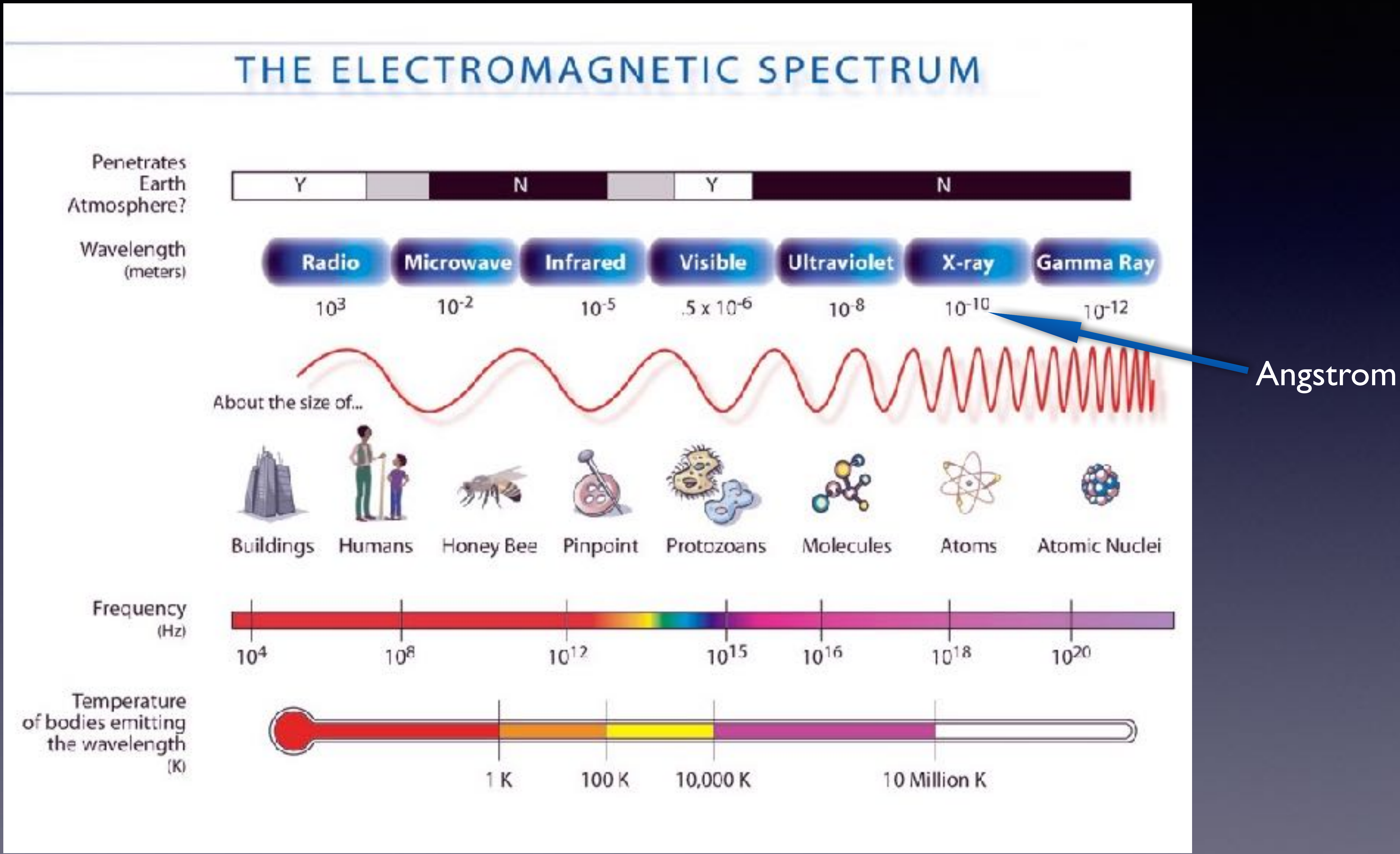


Strategic planning for NASA



STScI- going from blue jeans to suits

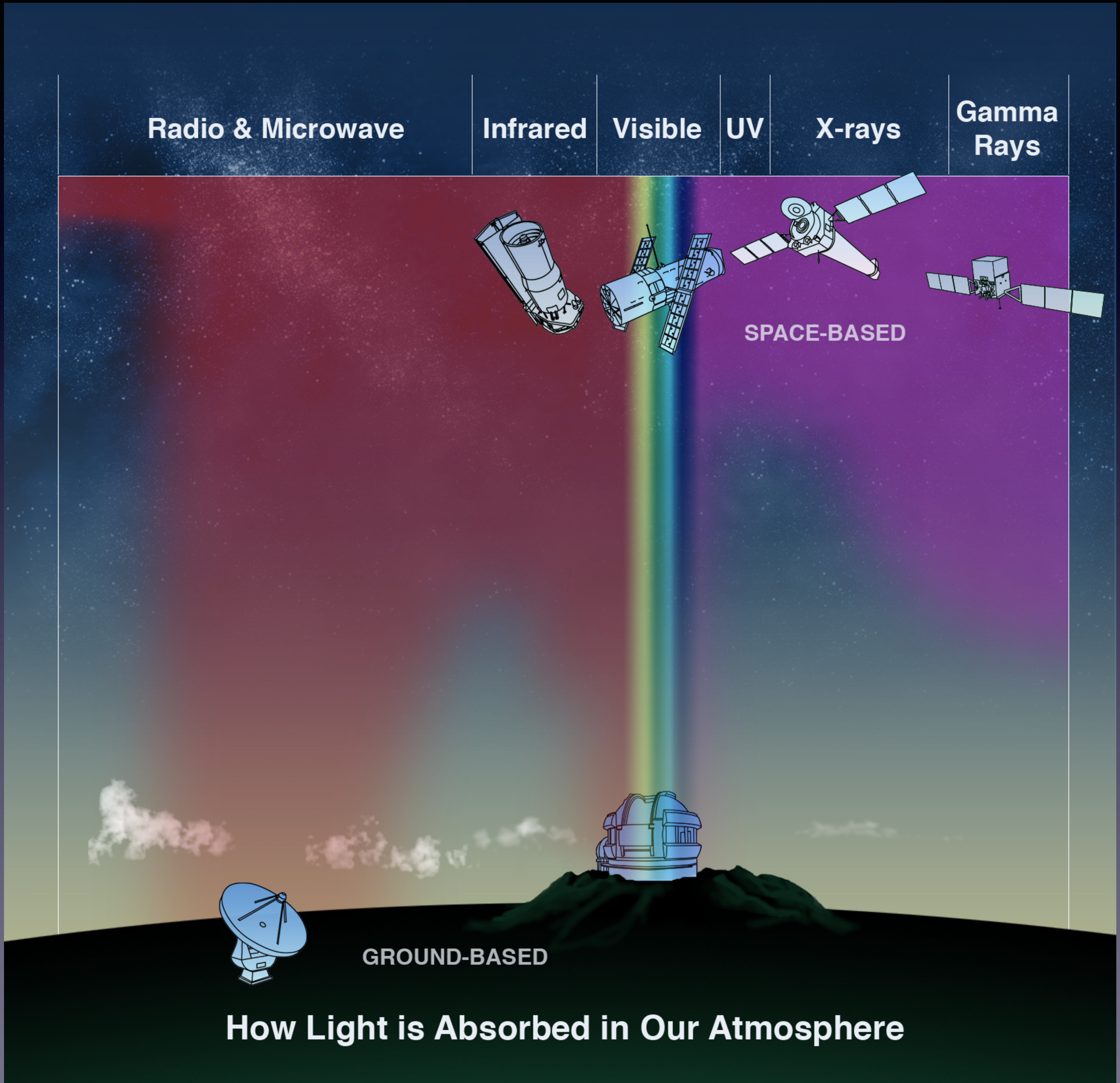
Electromagnetic Spectrum



$E = h\nu = hc/\lambda$

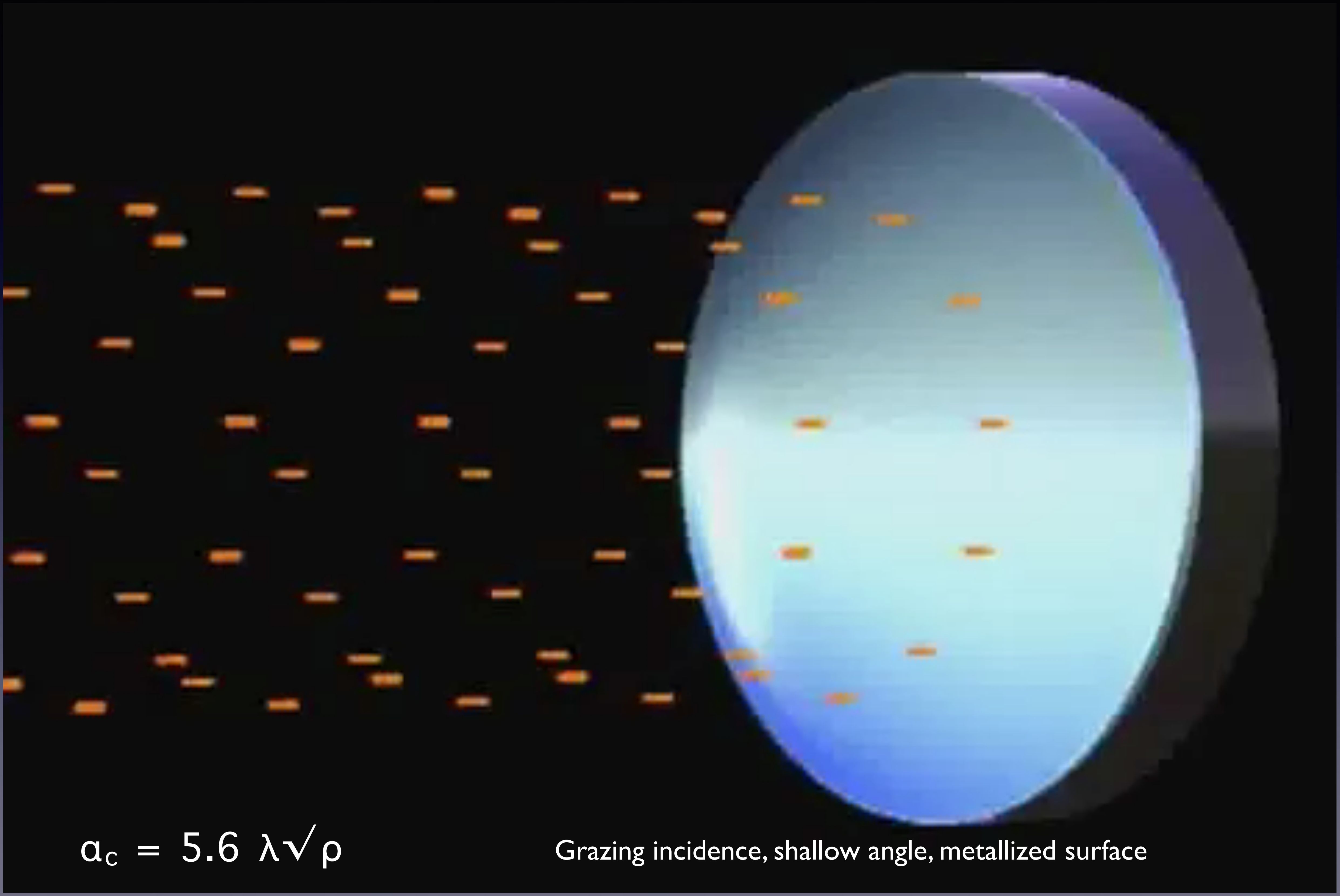
Chandra: ~1- 10Å (1-12 keV)

Atmospheric Absorption

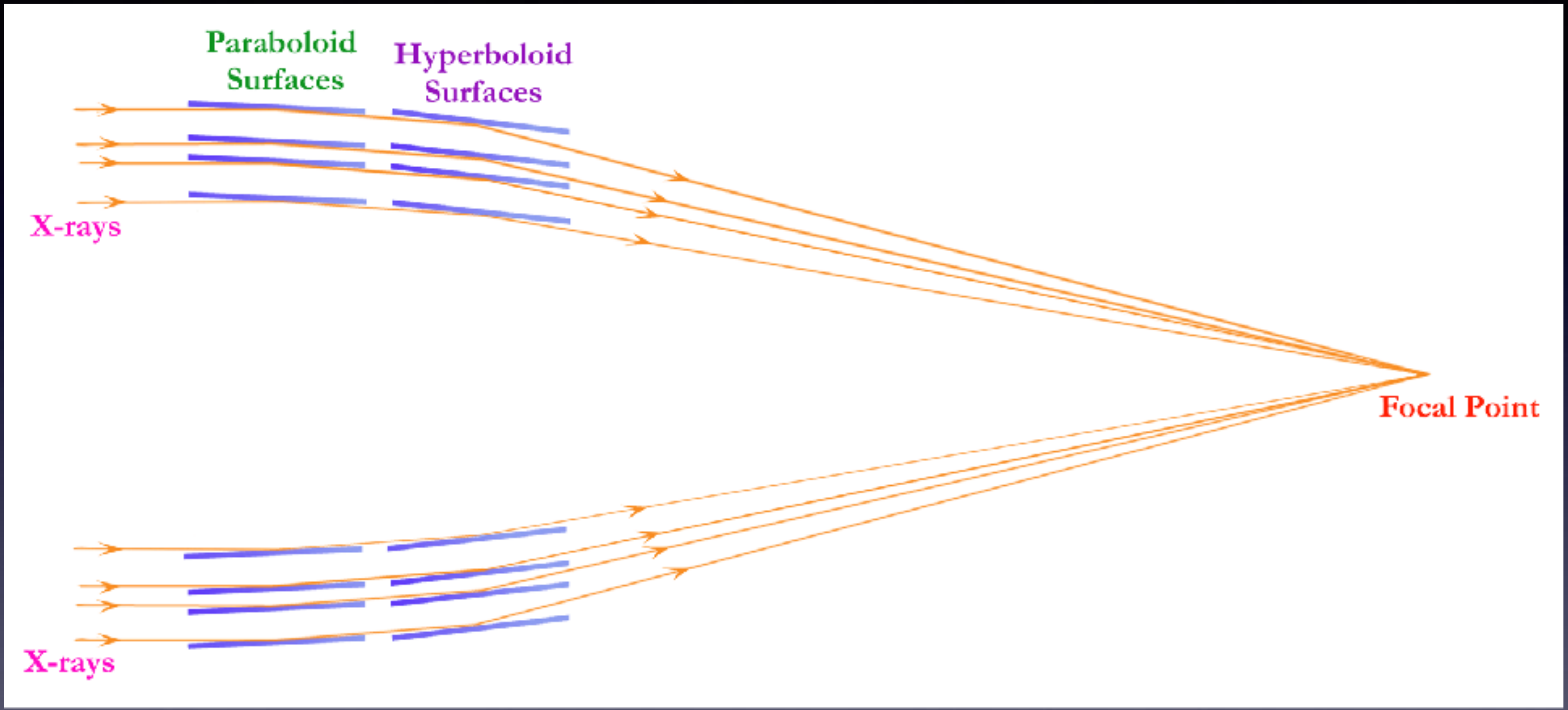


X-ray are observed from space

X-Ray Optics


$\alpha_c = 5.6\ \lambda\sqrt{\rho}$
Grazing incidence, shallow angle, metallized surface

X-Ray Optics

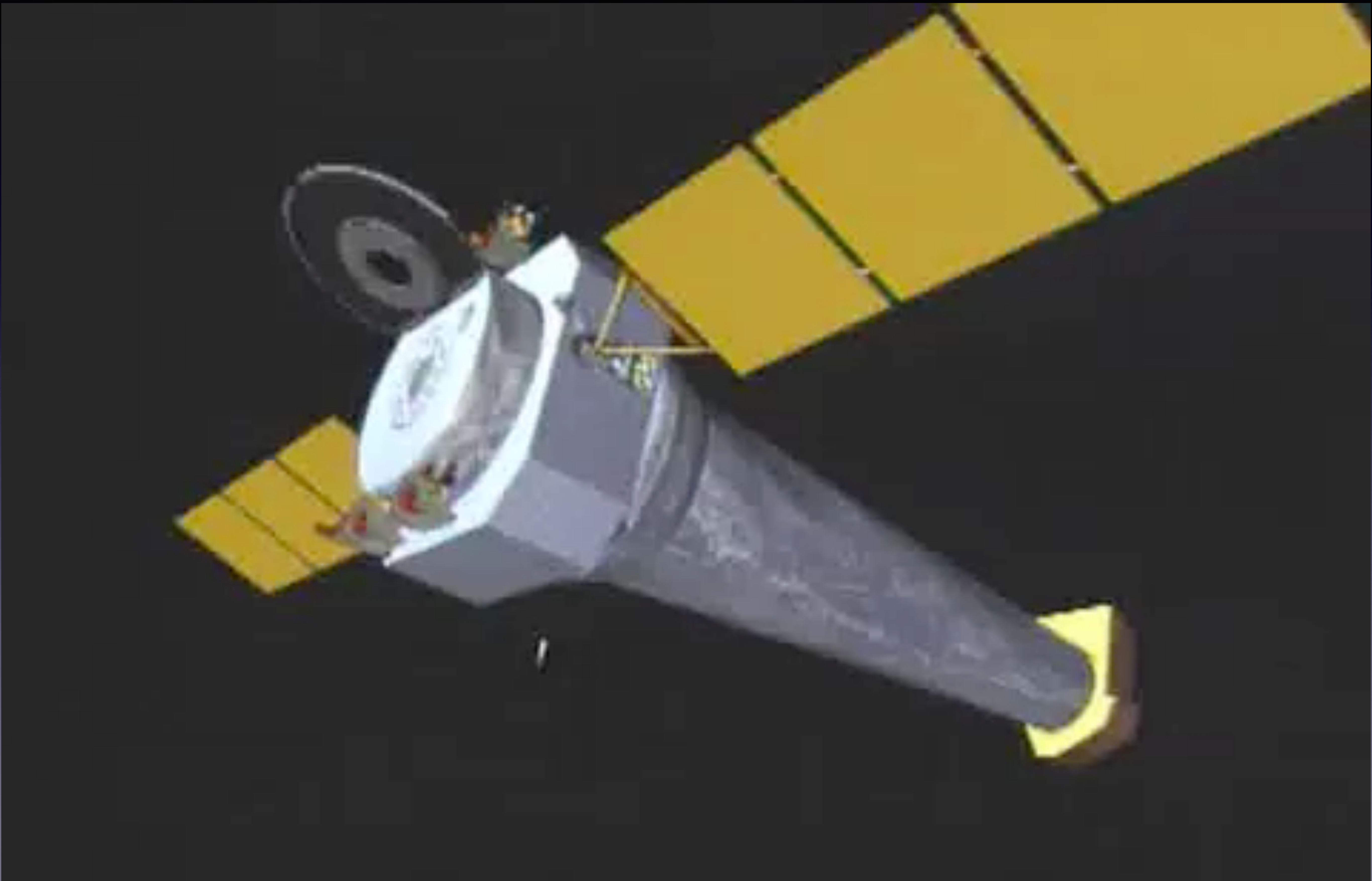


Nest shells to increase collecting area

Insert gratings in light path to disperse spectrum

Place X-ray detectors at focal plane

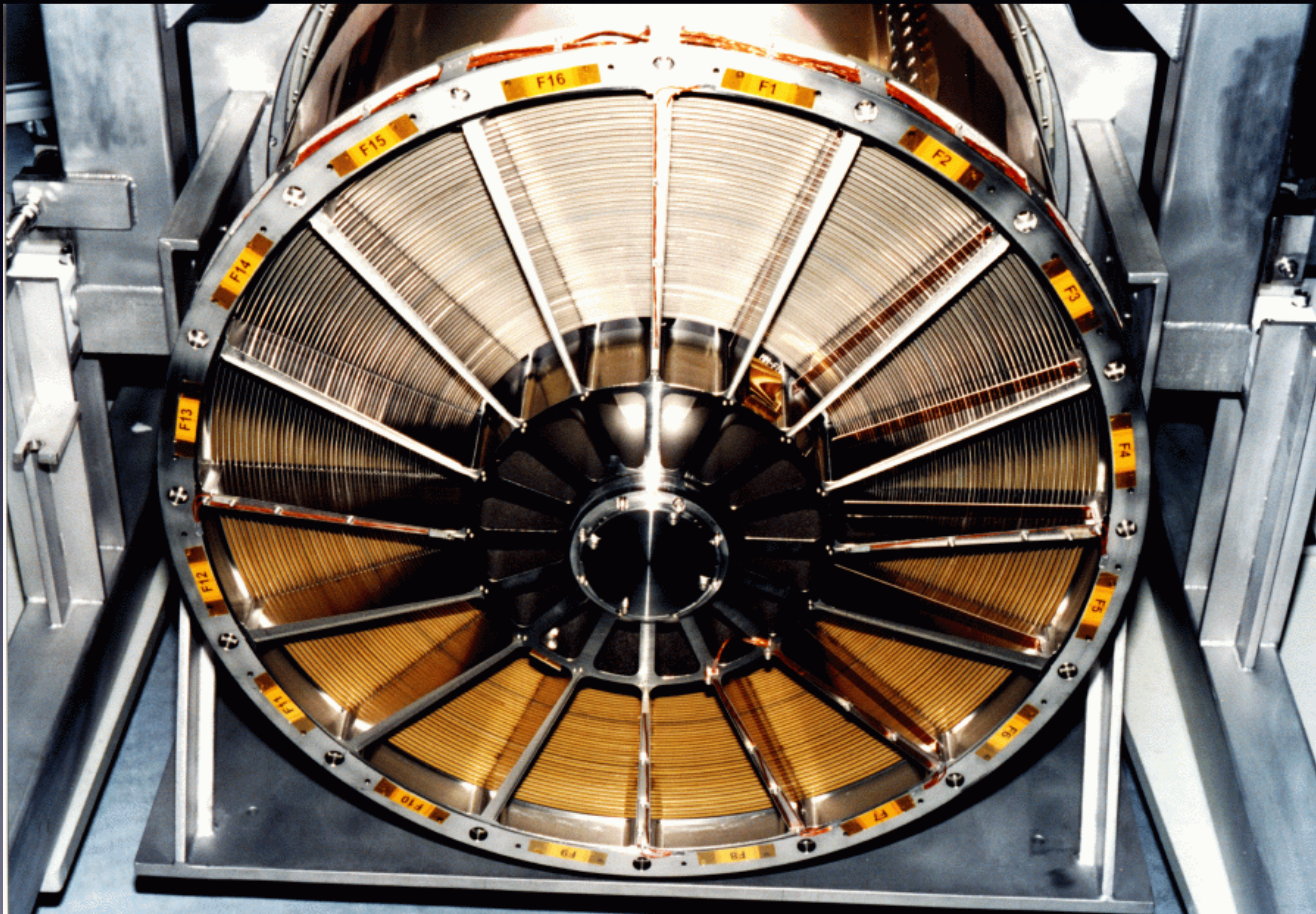
Chandra Lightpath



Chandra Mirror Assembly

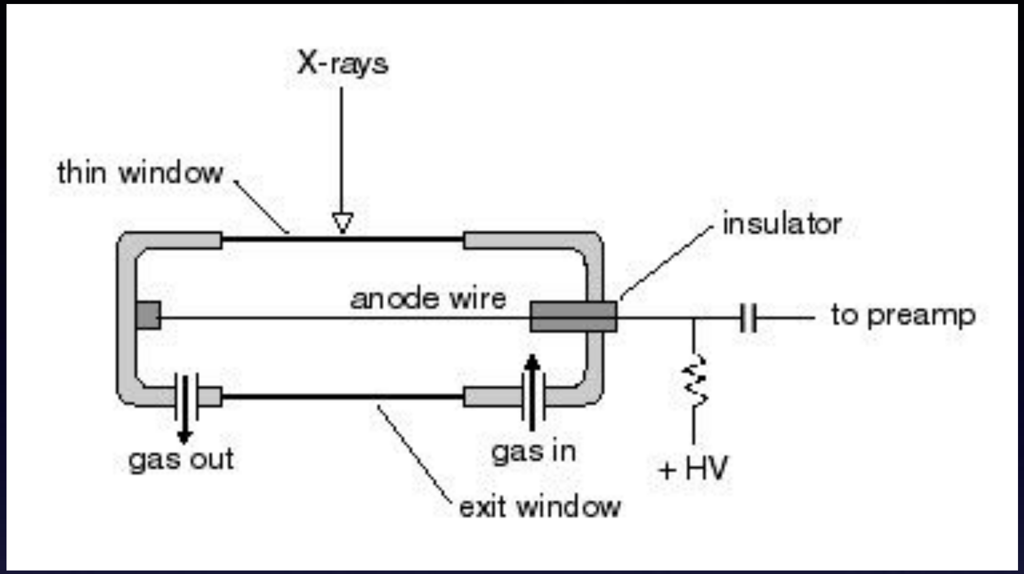
Imaging Resolution

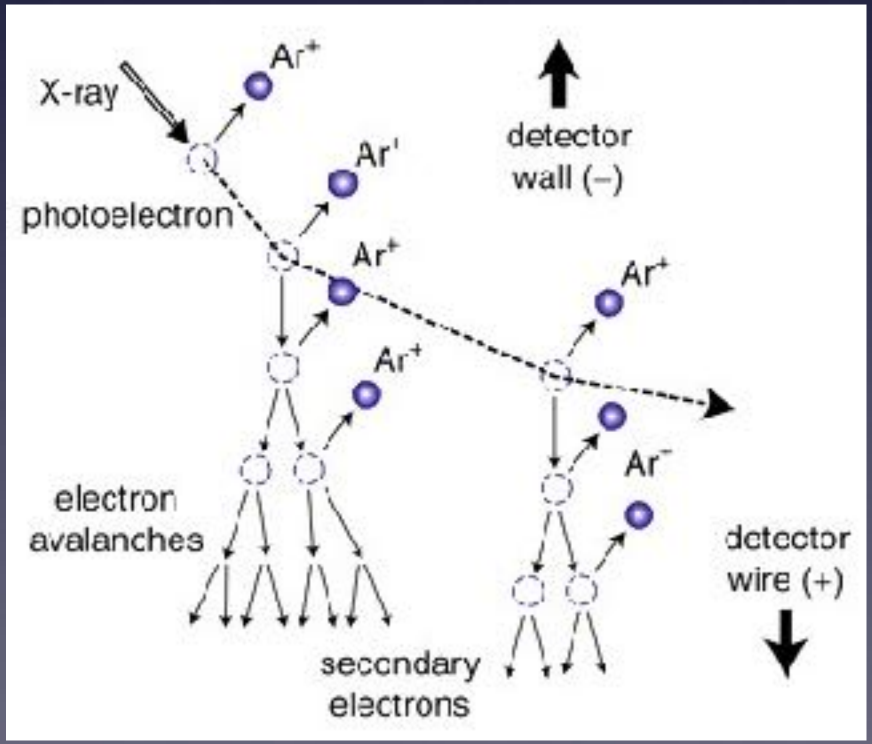
XMM-Newton Mirrors



Proportional Counter

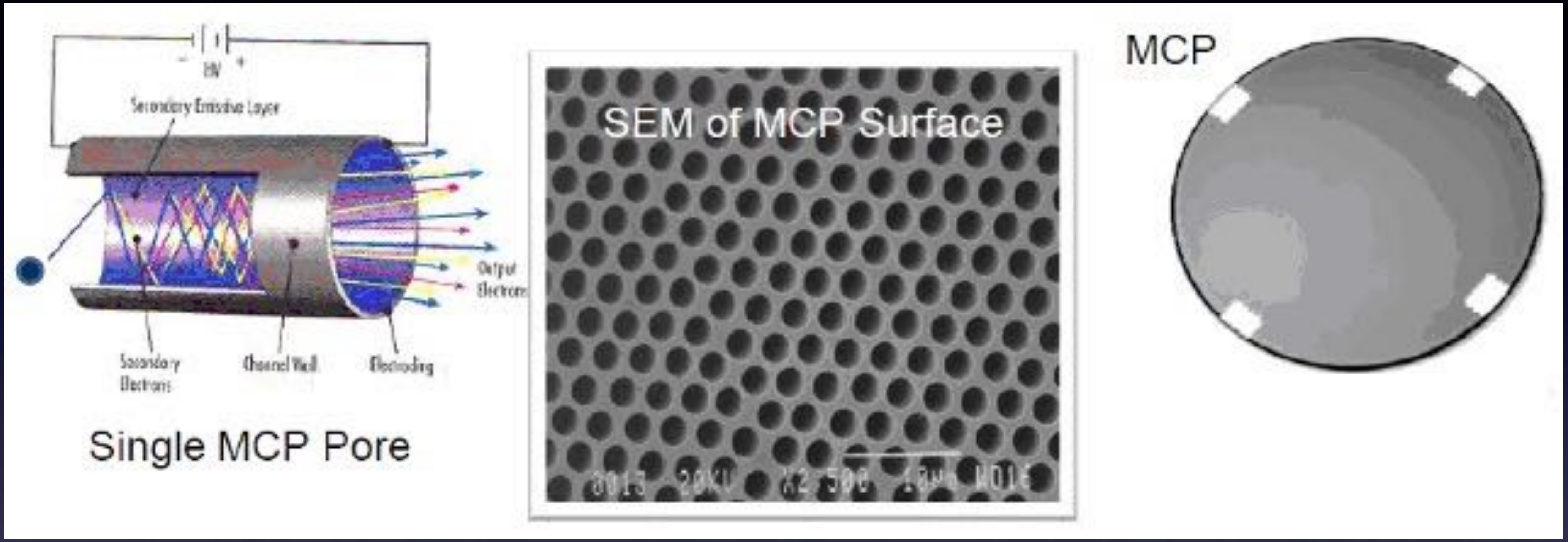
- An X−ray interacts with an atom of the proportional counter gas.
- Charge is generated; (electrons and positive ions separated).
- The charge multiplies, proportional to the incident X−ray energy.
- The charge is collected, measured, digitized and telemetered.



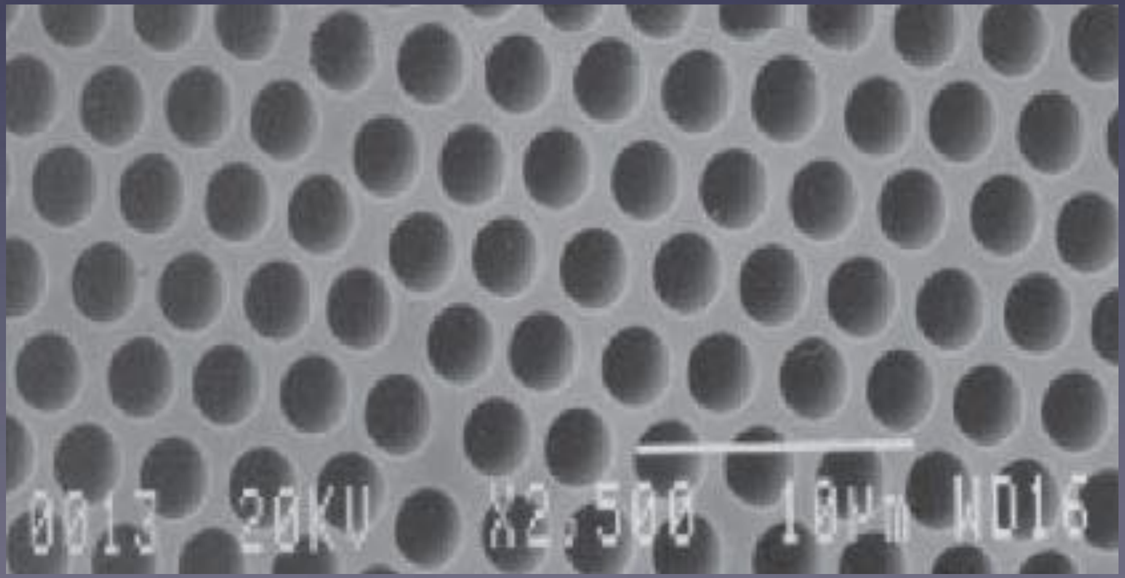


ENGS 168, engineering.dartmouth.edu; http://www.astro.psu.edu/~neil/astro485/xrayschool/schwartz-prop_counters.pdf
also: Northern Arizona University, Electron Microprobe Lab, Detection of Signals

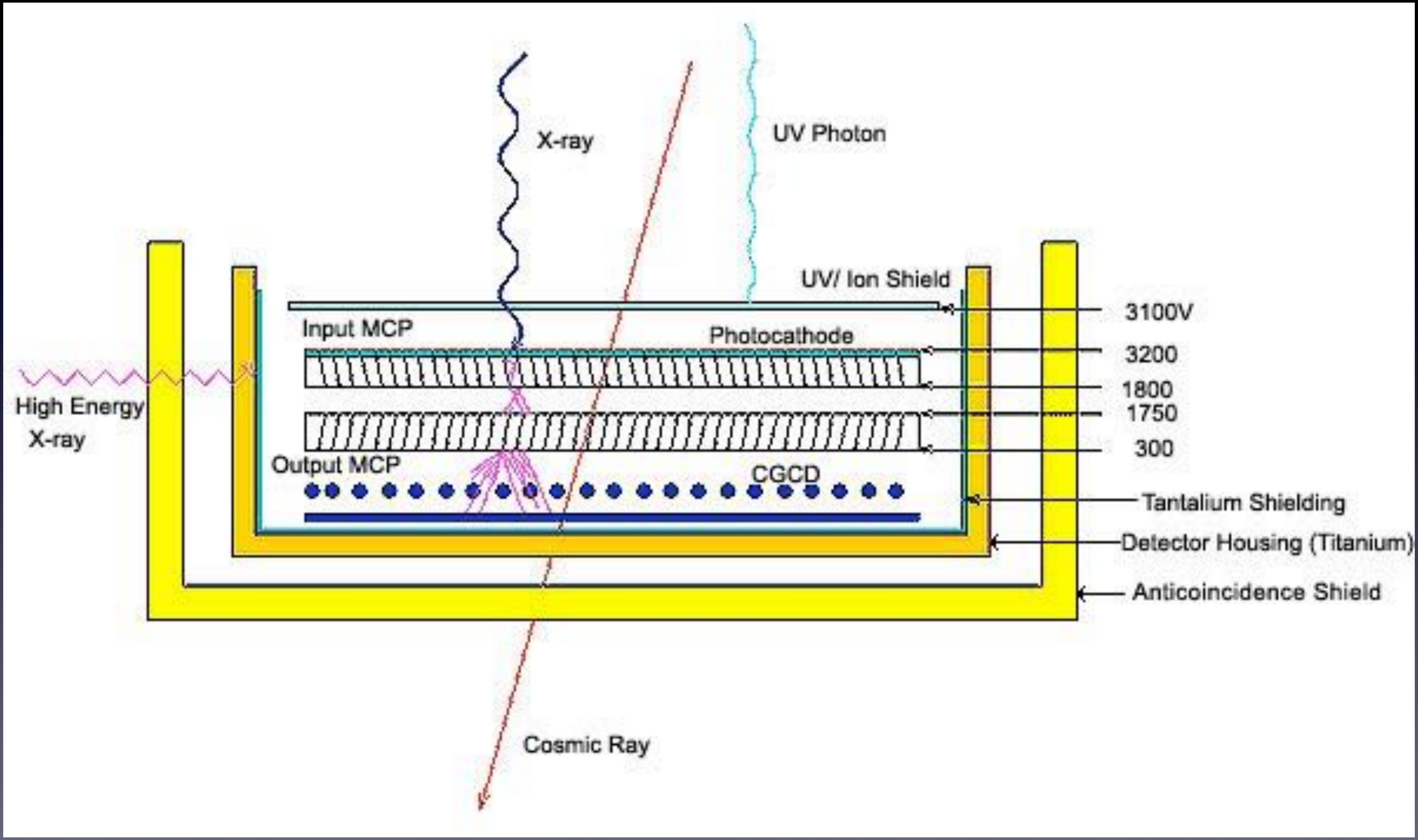
Microchannel Plate (MCP)



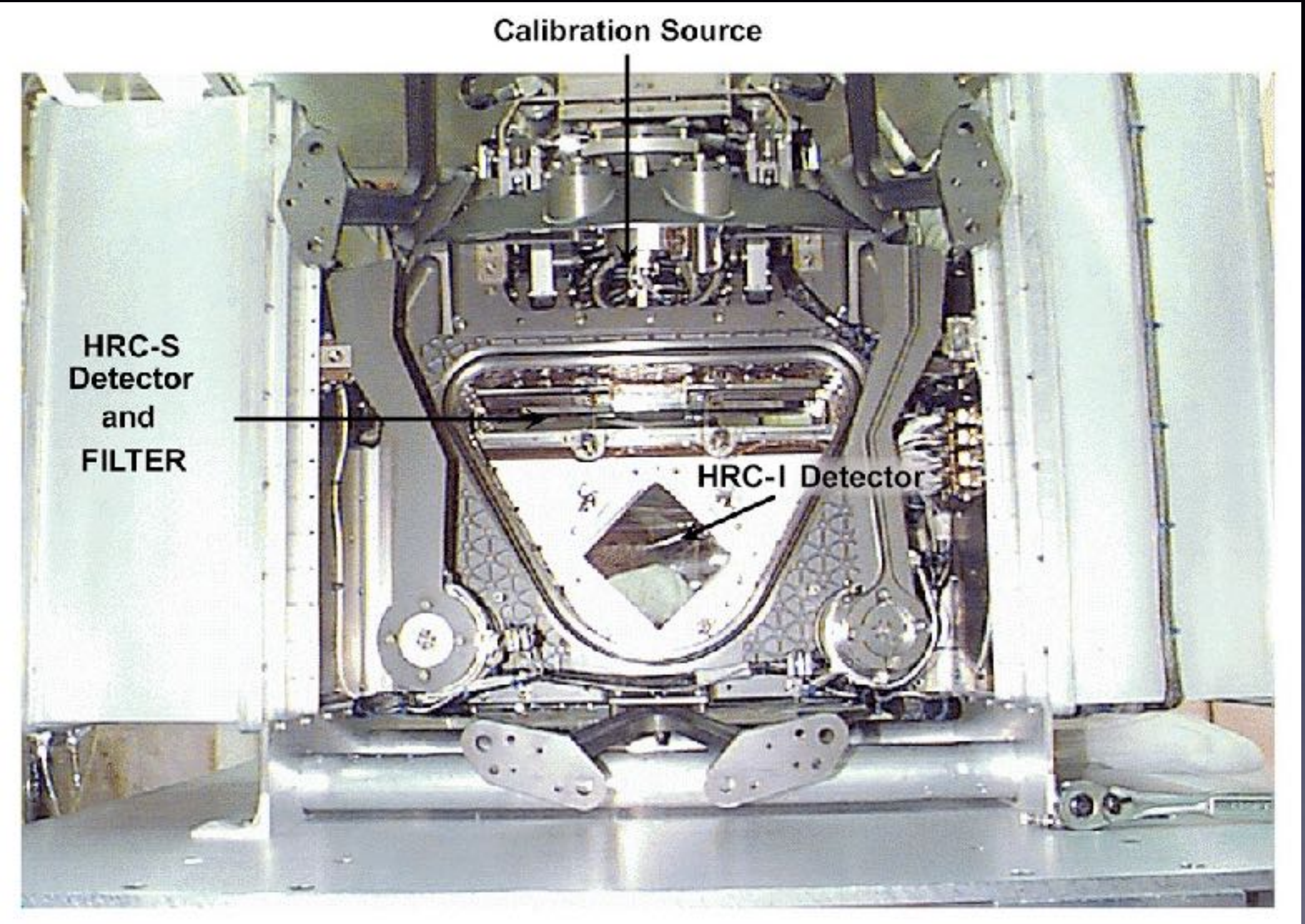
www.azooptics.com



Microchannel Plate (MCP)

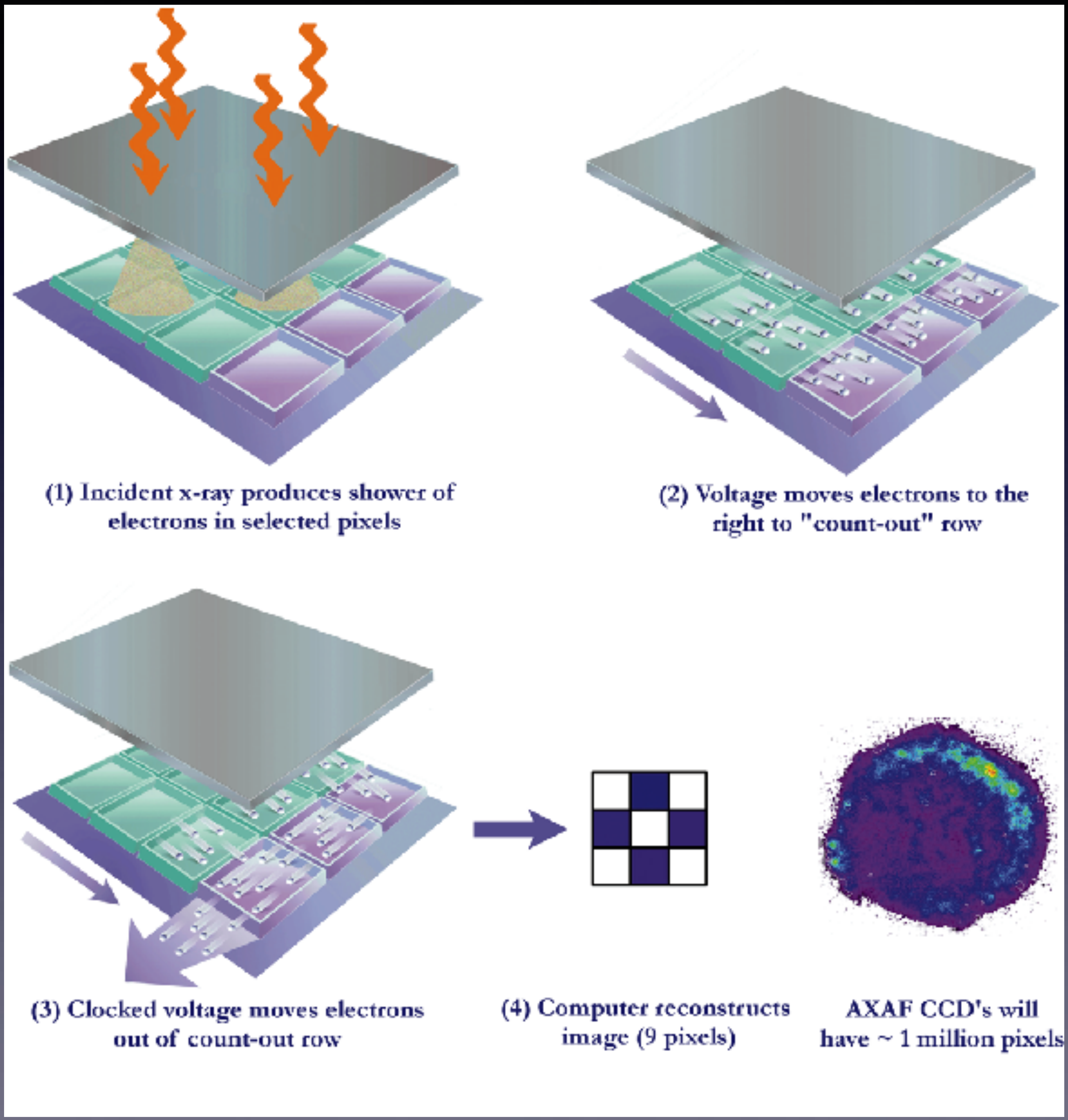


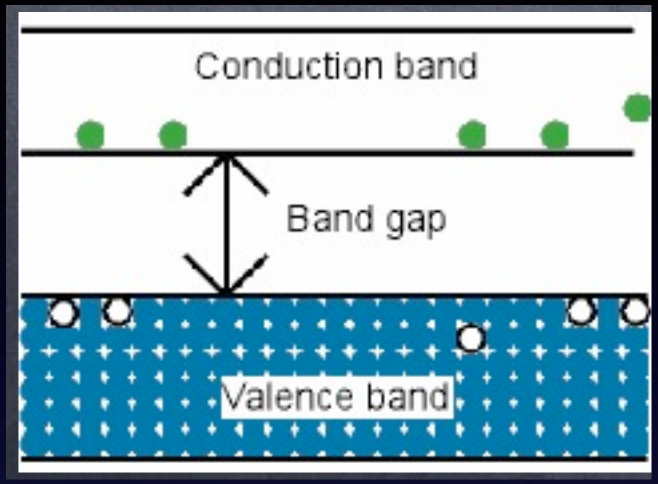
Microchannel Plate (MCP)



Looking into the HRC Vacuum Housing

Charge Coupled Device





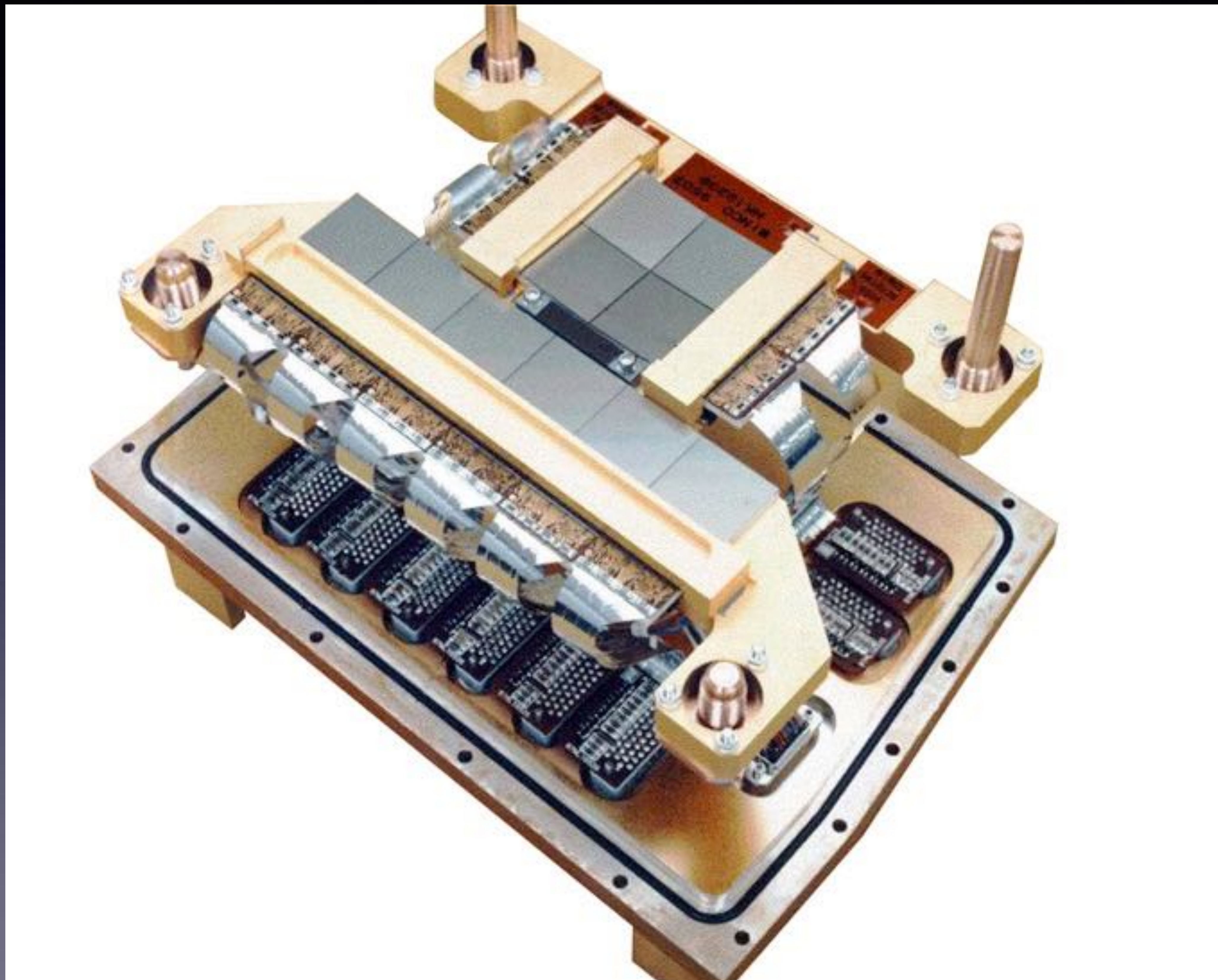
Photon absorbed by silicon, and a valence electron is bumped up to conduction band.

Electrons are trapped in potential wells until pixels are read out by charge transfer. Rows are transferred across the chip and the last row is clocked out pixel-by-pixel.

See also Tesla Jeltema's ASTR27 lectures at http://scipp.ucsc.edu/~tesla/

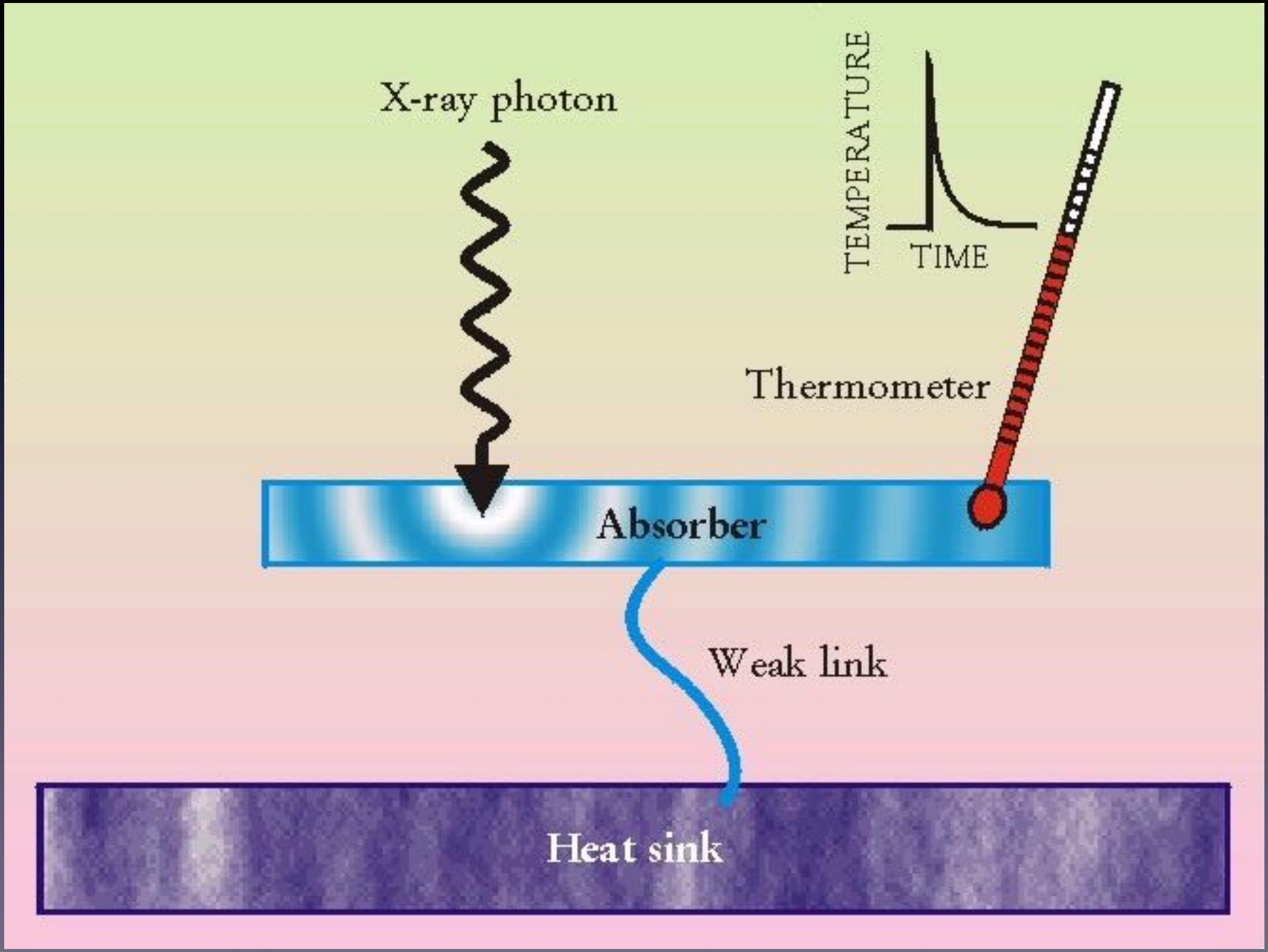
X-Ray spectroscopy Lab

Charge Couple Device (CCD)



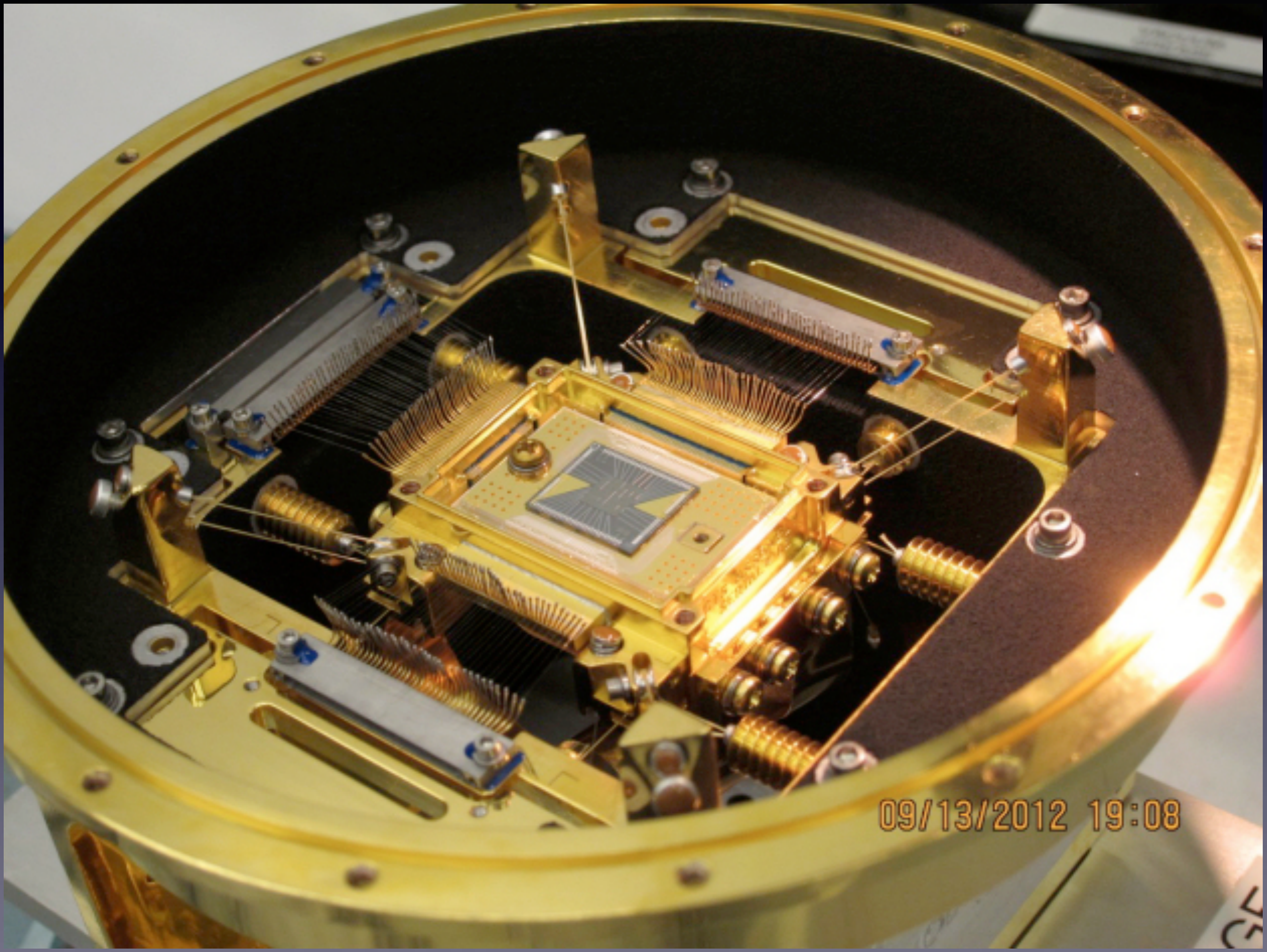
CCD Imaging Spectroscopy

Microcalorimeter

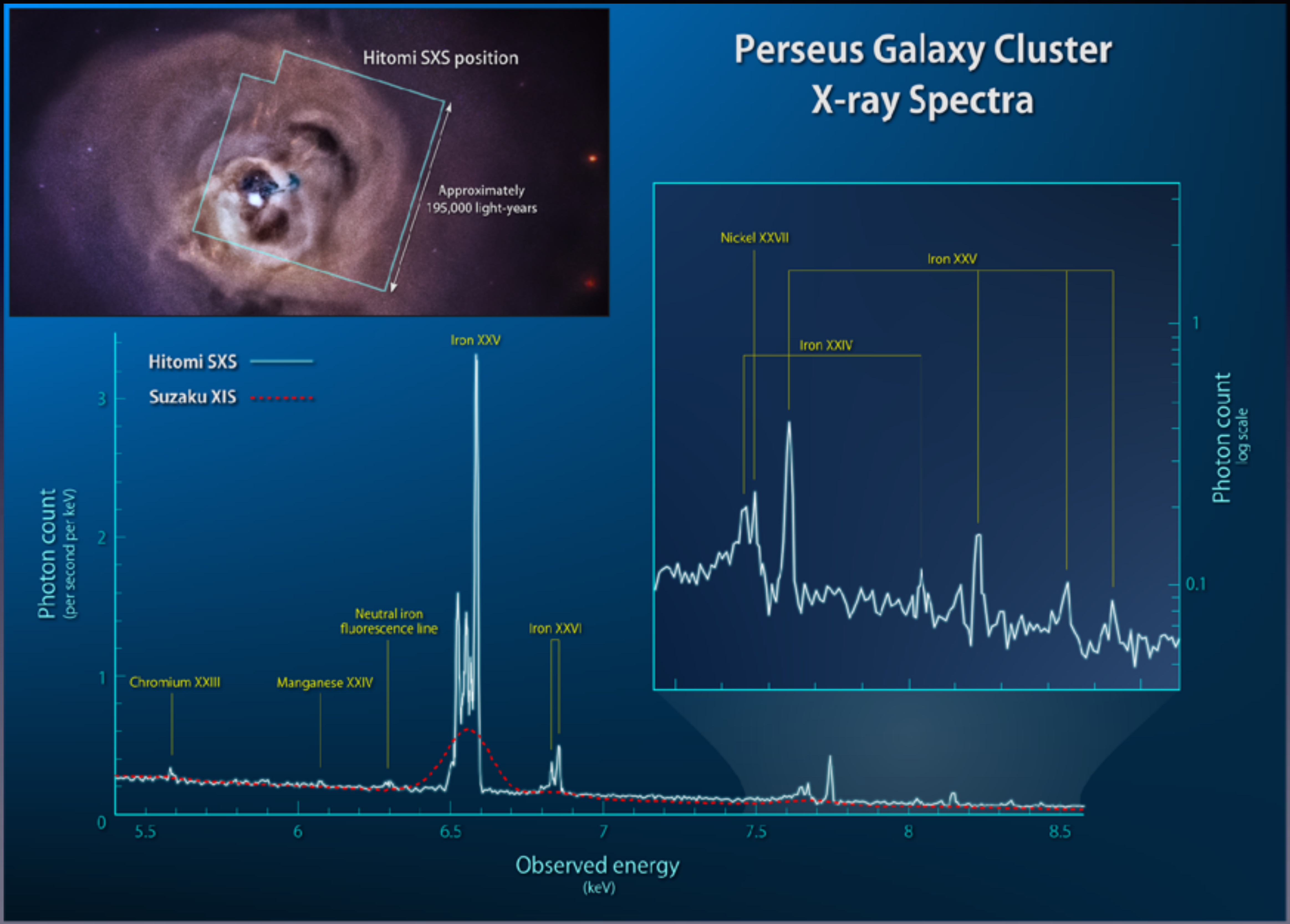


See also paper by F. Scott Porter, http//www.issibern.ch/forads/sr-009-28.pdf

Microcalorimeter

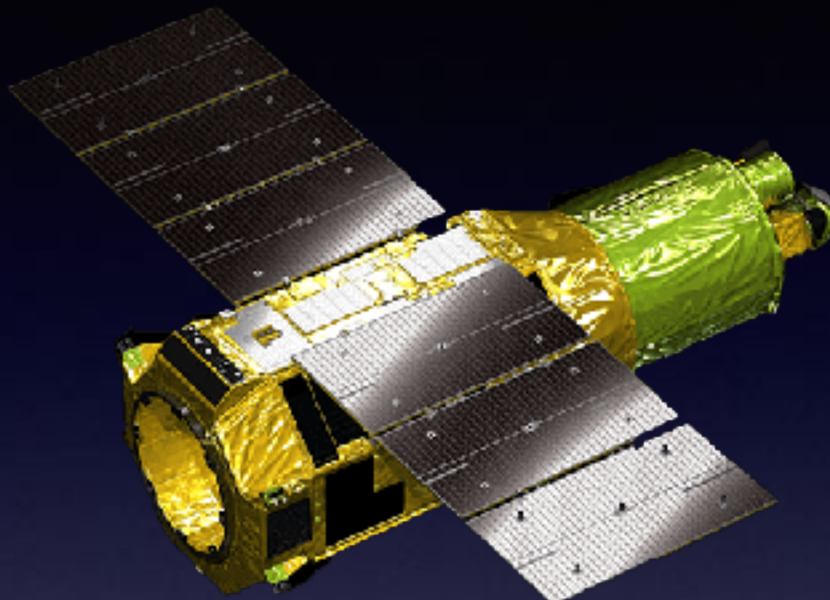


Hitomi's calorimeter spectrum



Hitomi Soft X-Ray Spectrometer

XRISM: X-Ray Imaging and Spectroscopy Mission (formerly XARM)



- JAXA/NASA mission ~2121 with X-ray Calorimeter (Resolve) & a CCD imager (Xtend).
- Canadian Light Source to be used for characterization & calibration of filters

Colibrì
Taking the pulse of neutron stars and black holes

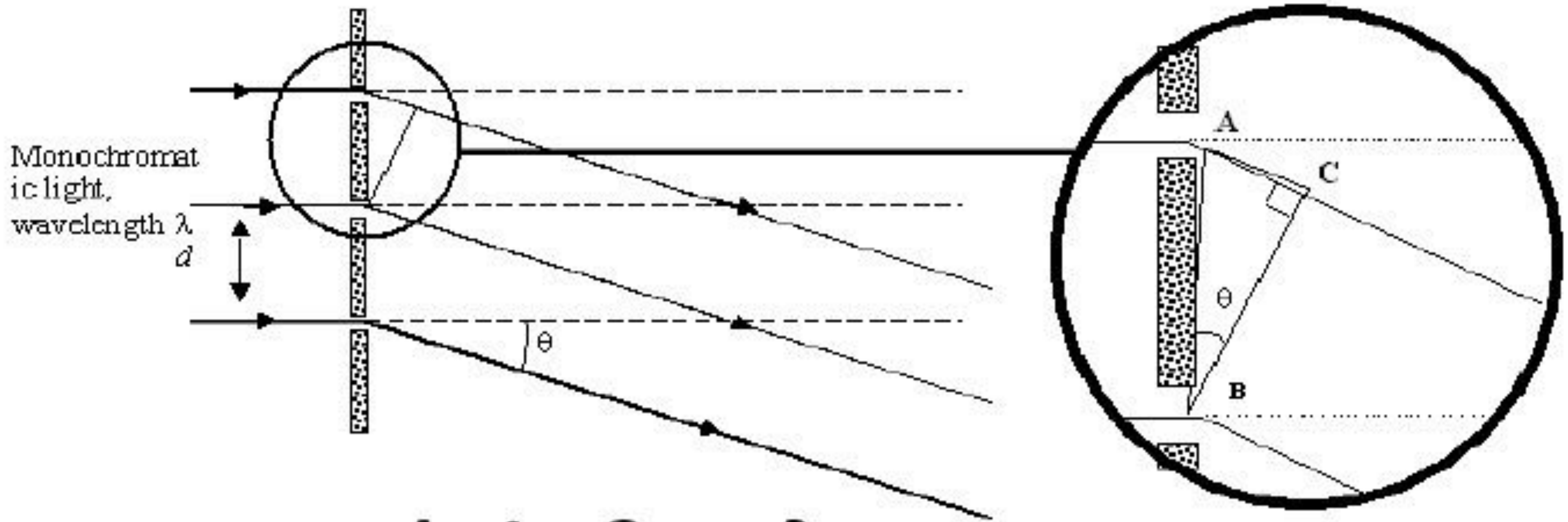
- Canadian scientists:

  Luigi Gallo (science team)

  Brian McNamara (Resolve

X-Ray Gratings

Diffraction Grating Equation



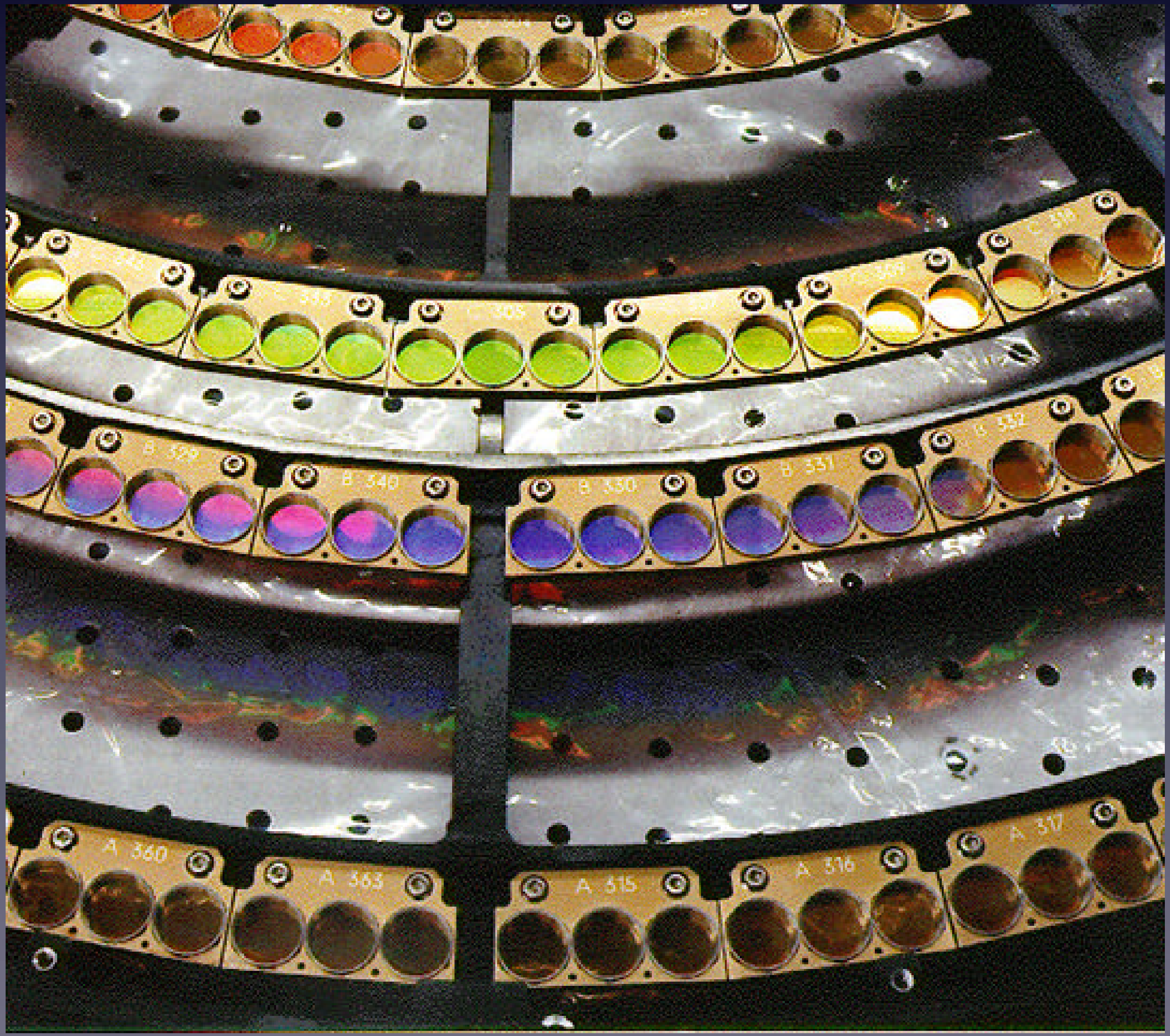
$$d \sin \theta = n\lambda$$

d = distance between the slits
Θ = angle to maxima
n = integer number to next bright fringe
λ = wavelength of light

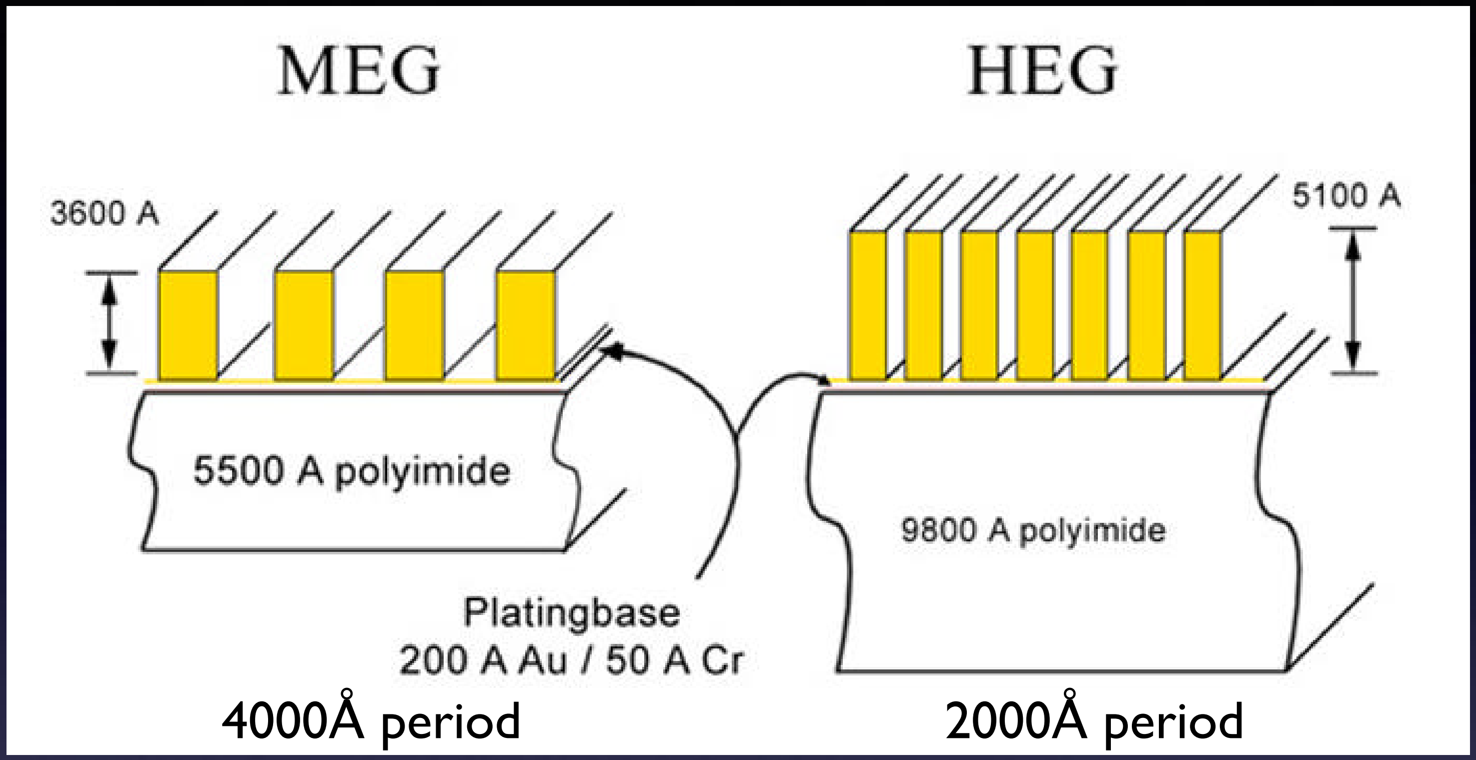
Number of slits per metre
N = 1/d

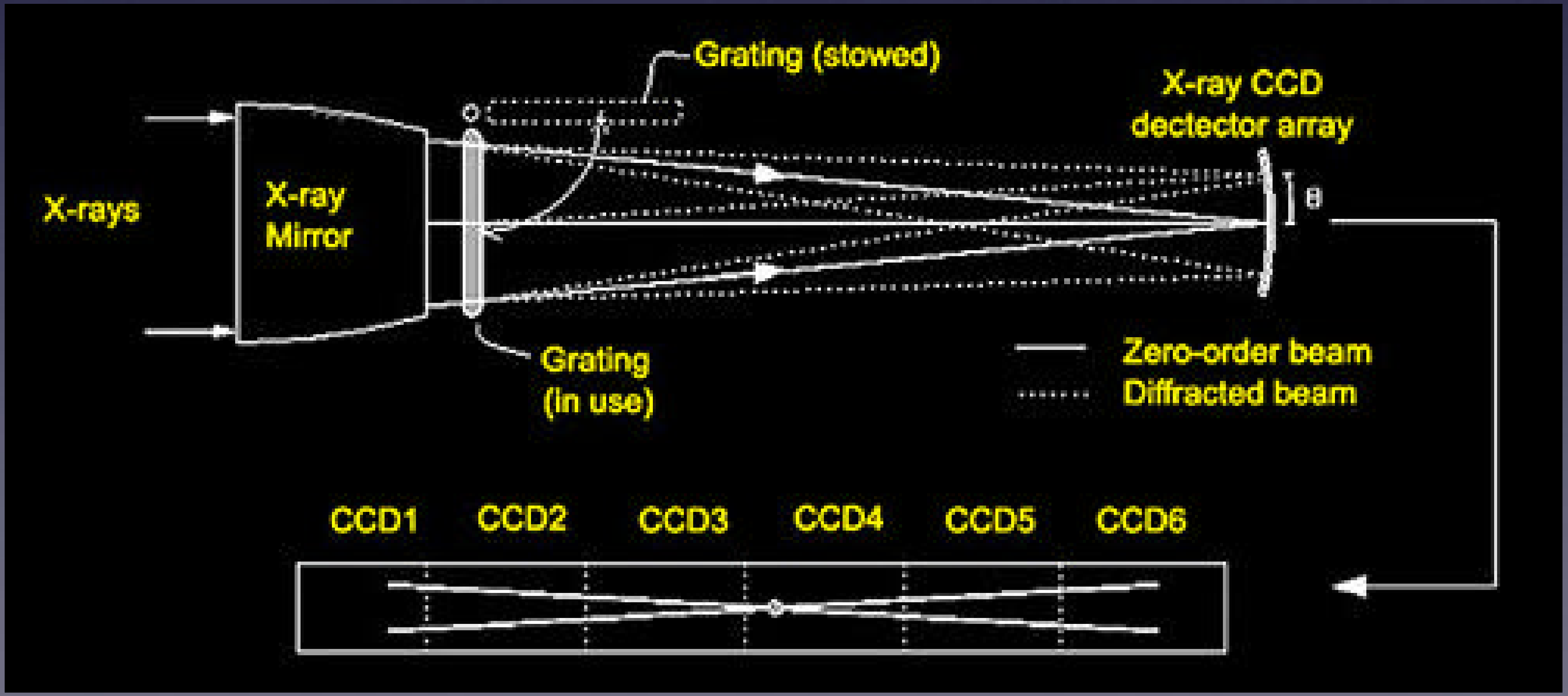
Sin θ can never be greater than 1, so there is a limit to the number of spectra that can be obtained.

X-Ray Gratings

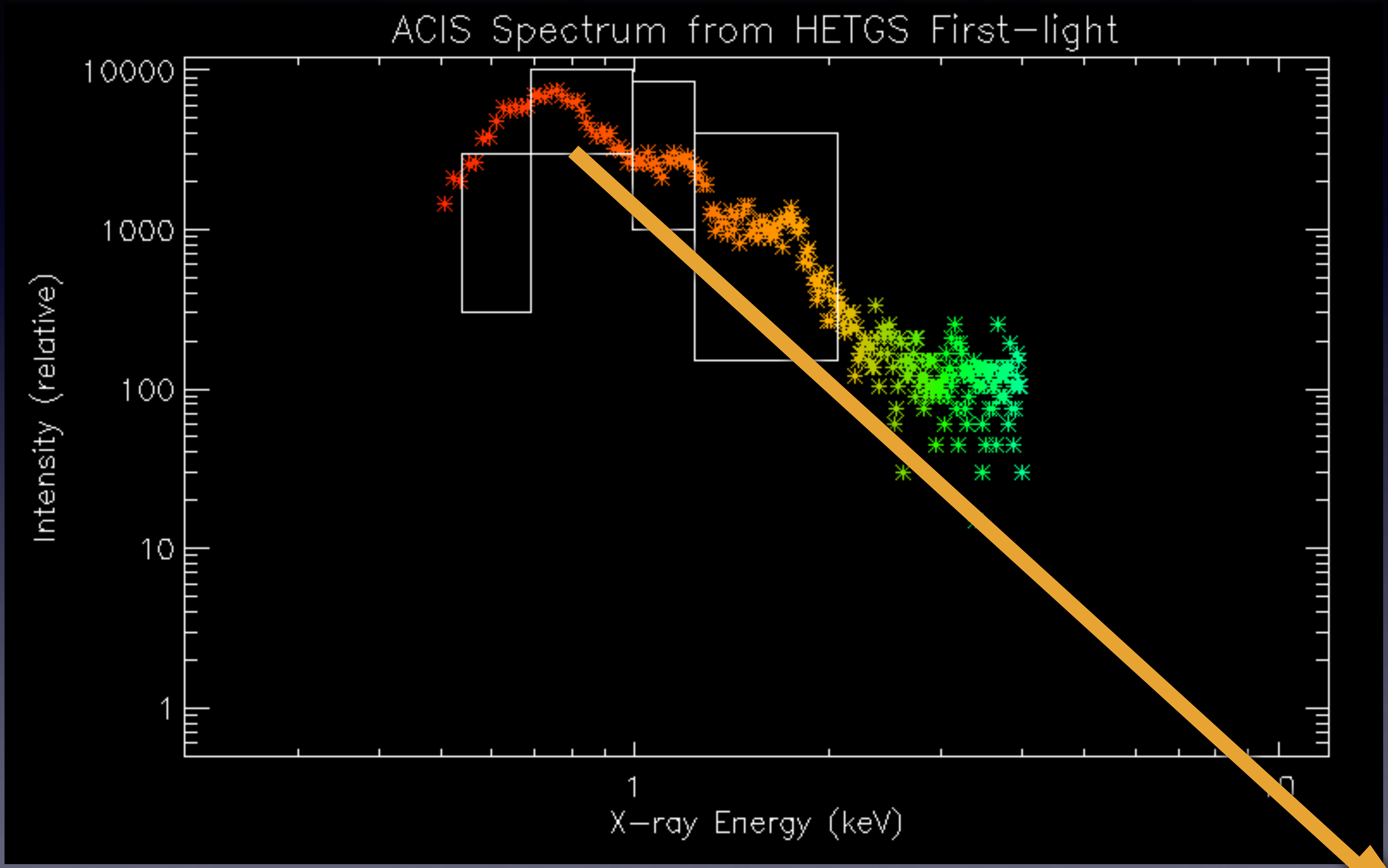


X-Ray Gratings

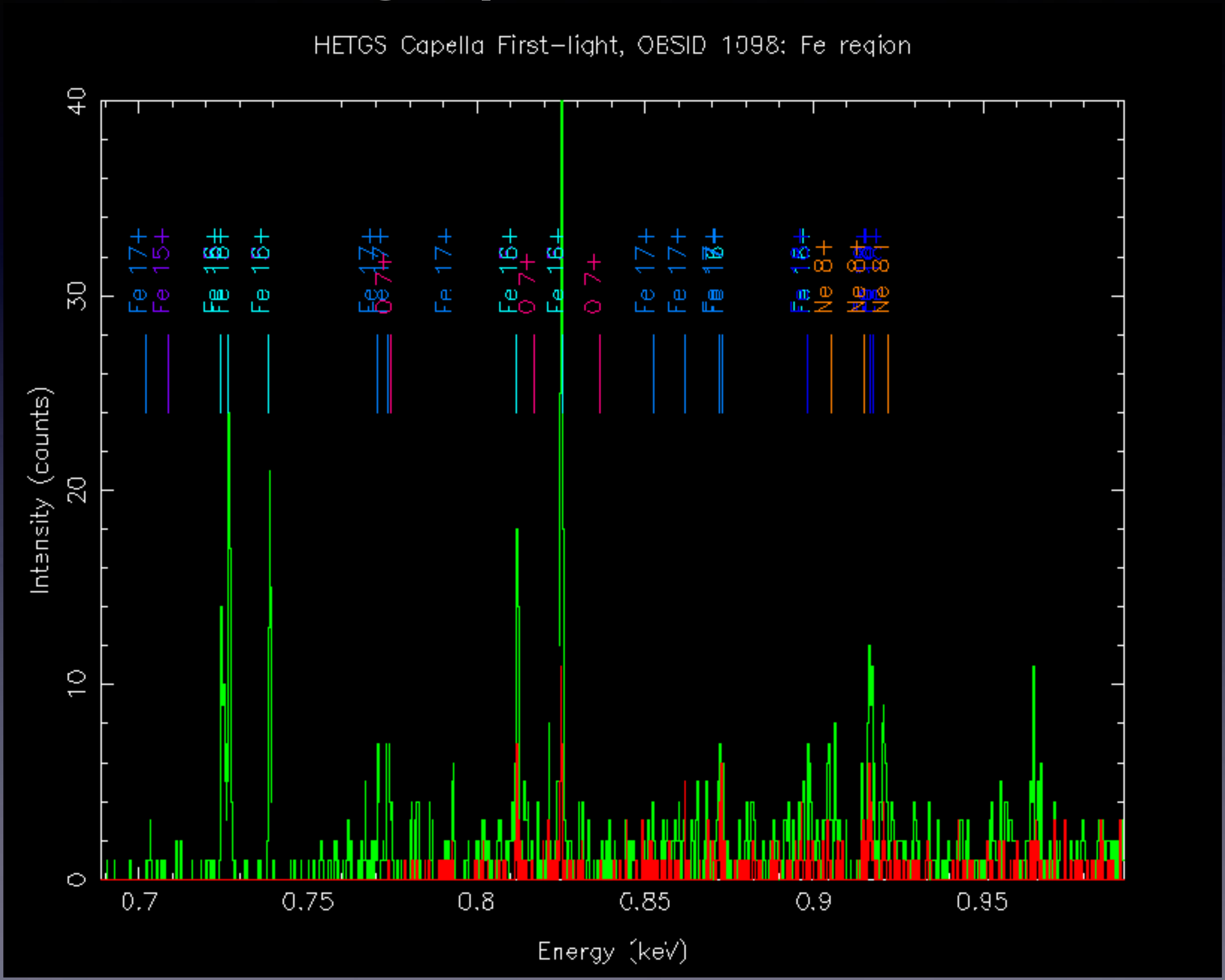




CCD and Grating Spectroscopy

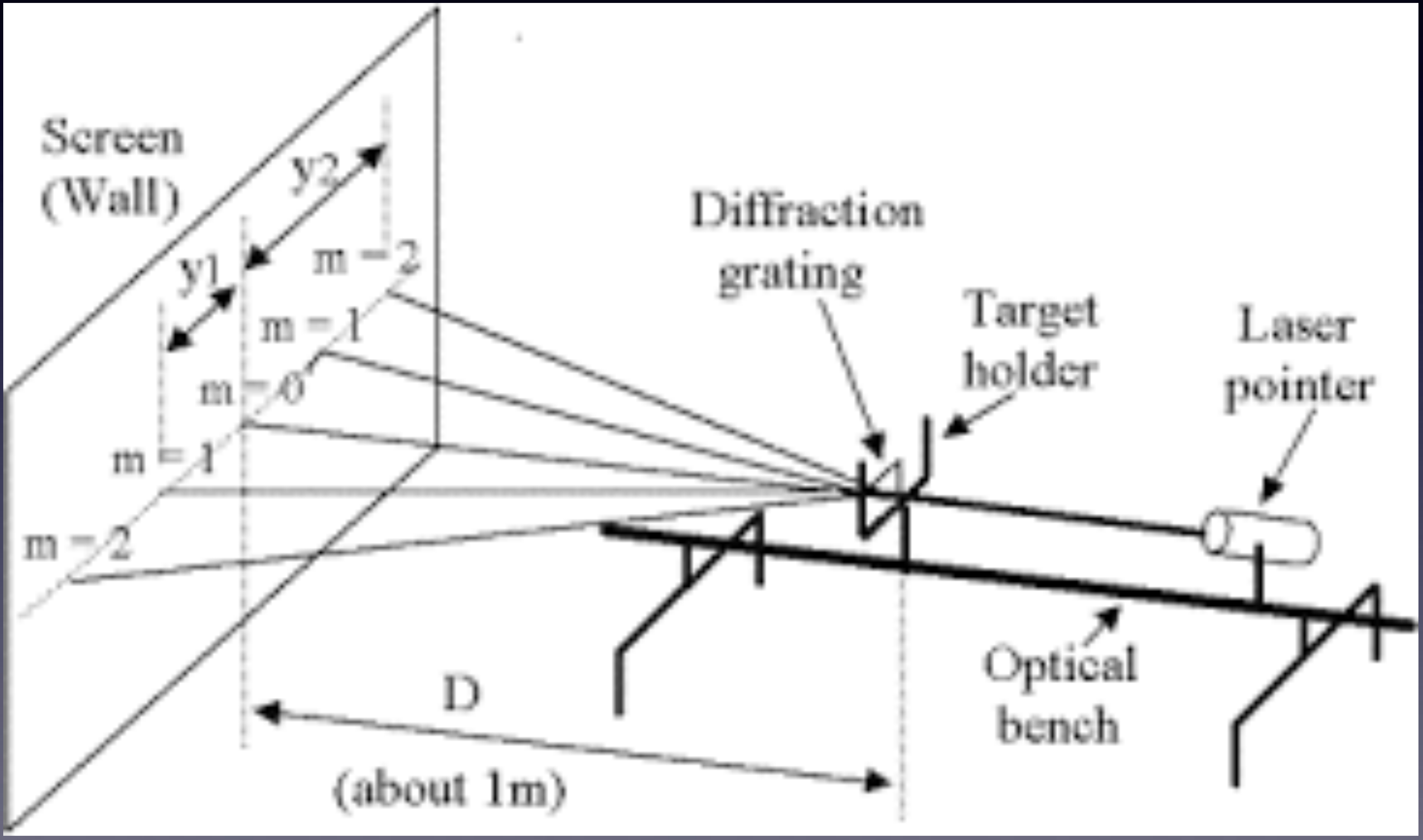


Grating Spectrometer

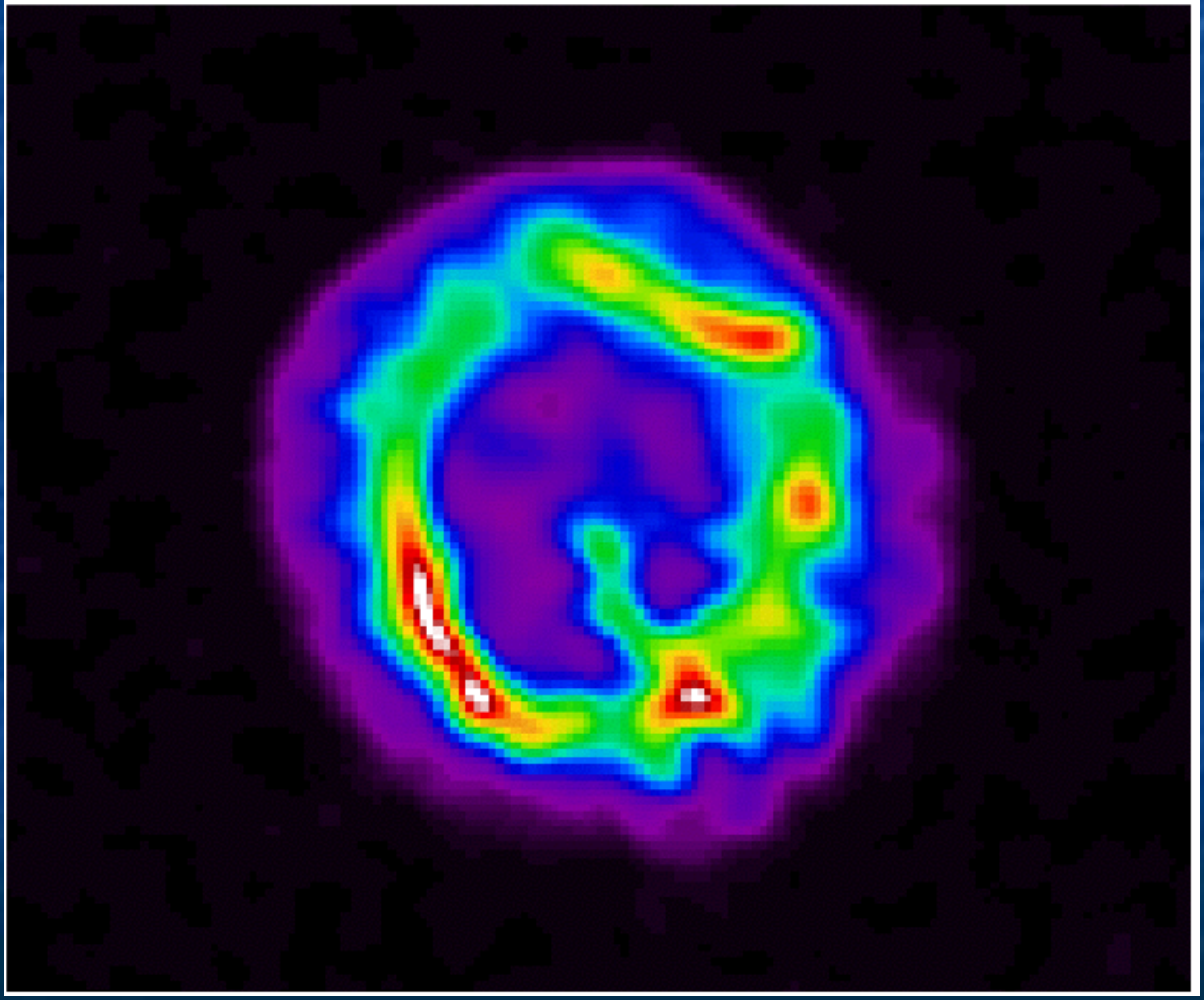


Naked-eye X-Ray Astronomy

Practice with gratings and laser pointers



Supernova Remnant: 1E0102-7219



- ~1000 years
- SMC
- Blast wave
- Reverse shock

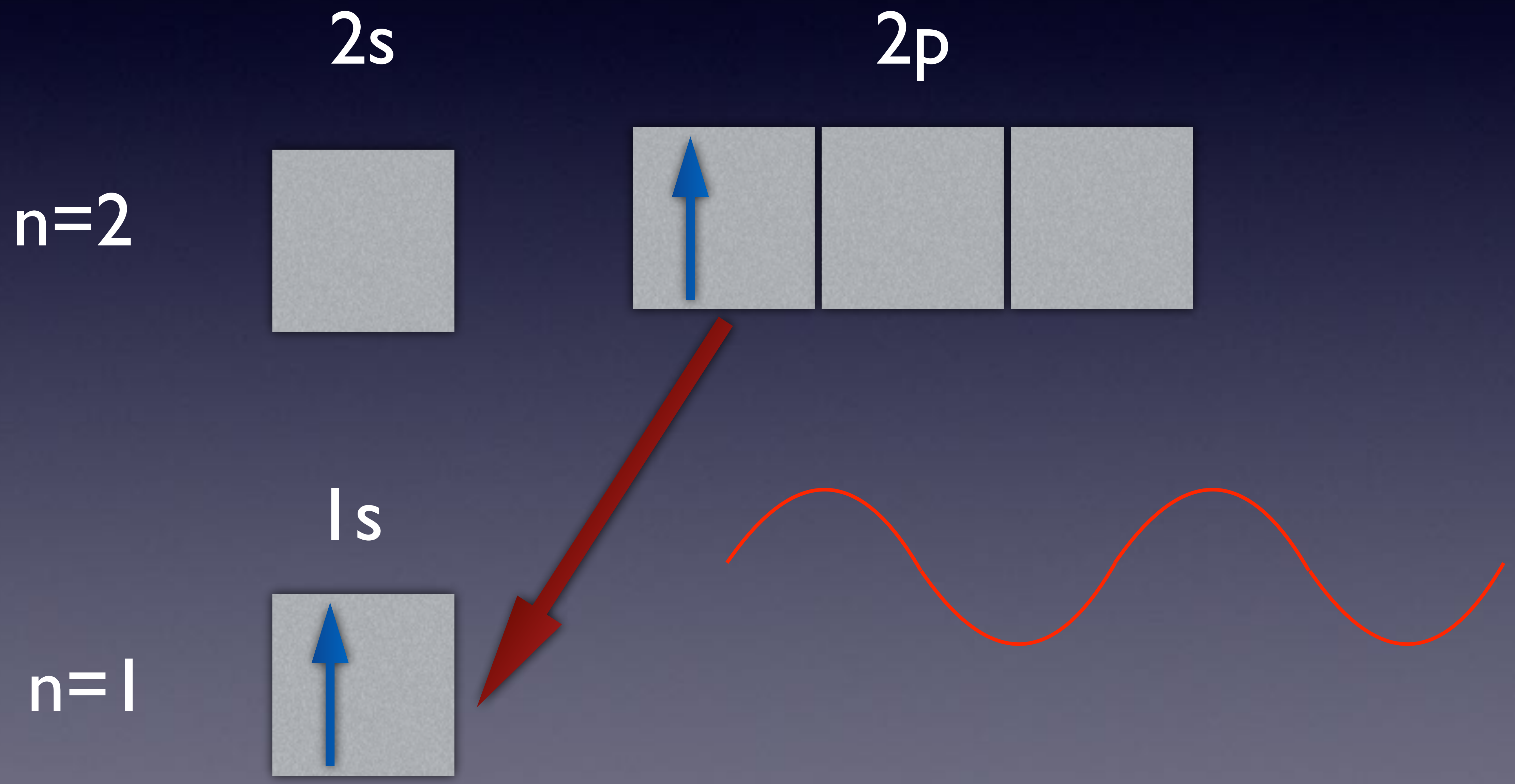
A.C. Fredericks, C.R. Canizares, D. Dewey, J.C. Houck (MIT)

Flanagan, et al. ApJ 605,230 (2004)

n=2 to n=1 transitions

H-like: Lyman alpha

He-like: triplet (Resonance, Forbidden, Intercombination)

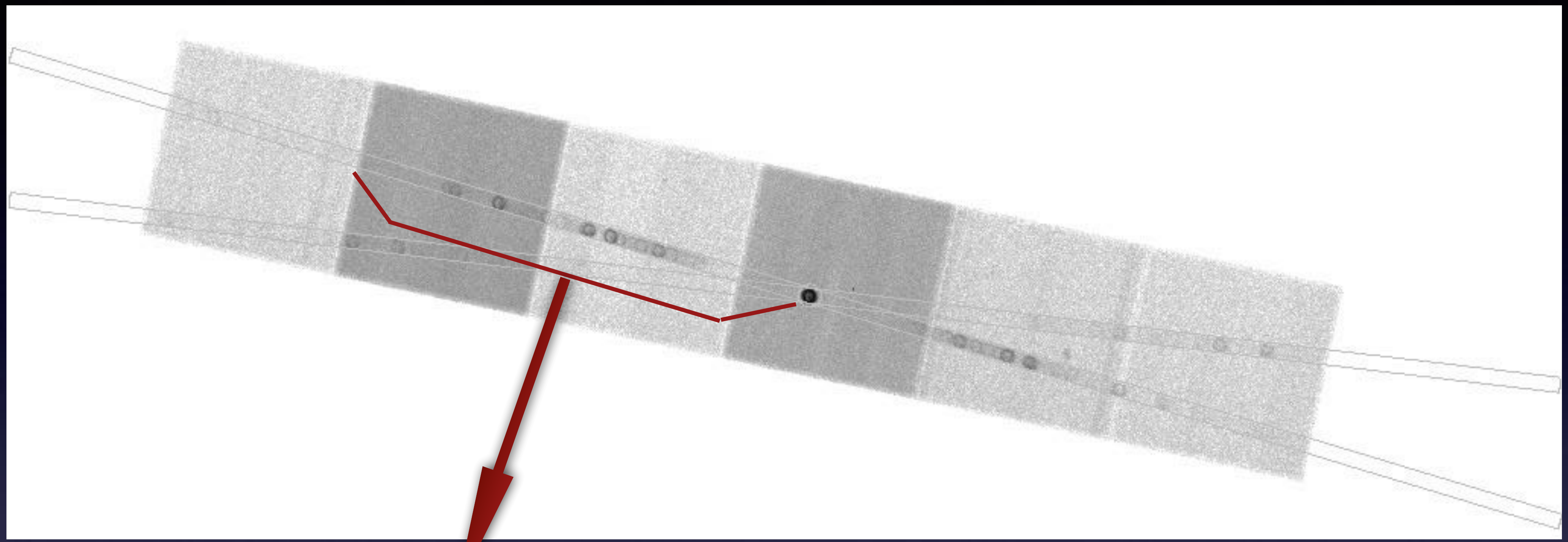


Prominent X-ray lines in supernova remnants

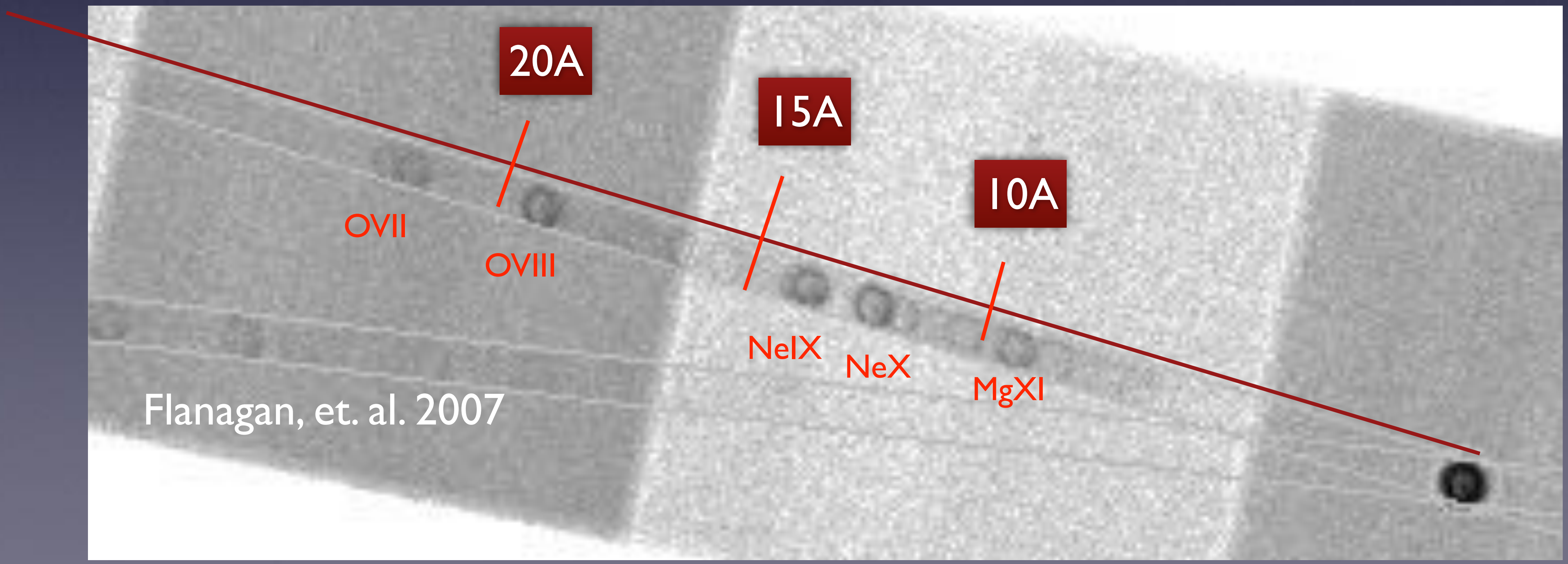
ion	line	wavelength	energy (eV)
Si IX	C4	55.356	224.4
Si X/XI	B6C	50.69	244.6
Si X/XI	B6A	50.53	245.4
Si X/XI	BE8	49.22	251.9
N VII	Ly α	24.78	500.3
O VII	For	22.1	561
O VII	IC	21.8	568.7
O VII	Res	21.6	574
O VIII	Ly α	18.97	653.6
O VII	1s-3p	18.63	665.6
O VII	1s-4p	17.77	697.7
O VII	1s-5p	17.42	711.7
Fe XVII	Ne8b	17.1	725.1
Fe XVII	Ne8a	17.054	727
Fe XVII	Ne7	16.787	738.6
O VIII	Ly β	16.01	774.4
Fe XVII	Ne6	15.458	802.1
Fe XVII	Ne4	15.262	812.4
O VIII	Ly γ	15.18	816.8
Fe XVII	Ne5	15.013	825.9

ion	line	wavelength	energy (eV)
O VIII	Ly δ	14.82	836.6
Fe XVIII	F2I	14.536	853
Fe XVIII	F2G	14.426	859.5
Ne IX	For	13.7	905
Ne IX	IC	13.55	915
Ne IX	Res	13.44	922.5
Fe XX	N1A	12.846	965.2
Fe XX	N1B	12.827	966.6
Fe XX	N1C	12.812	967.7
Fe XVII	Ne1b	12.263	1011
Ne X	Ly α	12.13	1022.1
Fe XVII	Ne1a	12.122	1022.8
Ne IX	1s-3p	11.56	1072.5
Ne IX	1s-4p	11	1127.1
Ne X	Ly β	10.24	1210.8
Mg XI	For	9.31	1331.7
Mg XI	IC	9.23	1343.3
Mg XI	Res	9.17	1352.1
Mg XII	Ly α	8.42	1472.5
Si XIII	triplet	6.65	1864.4

HETG spectrum of E0102-72

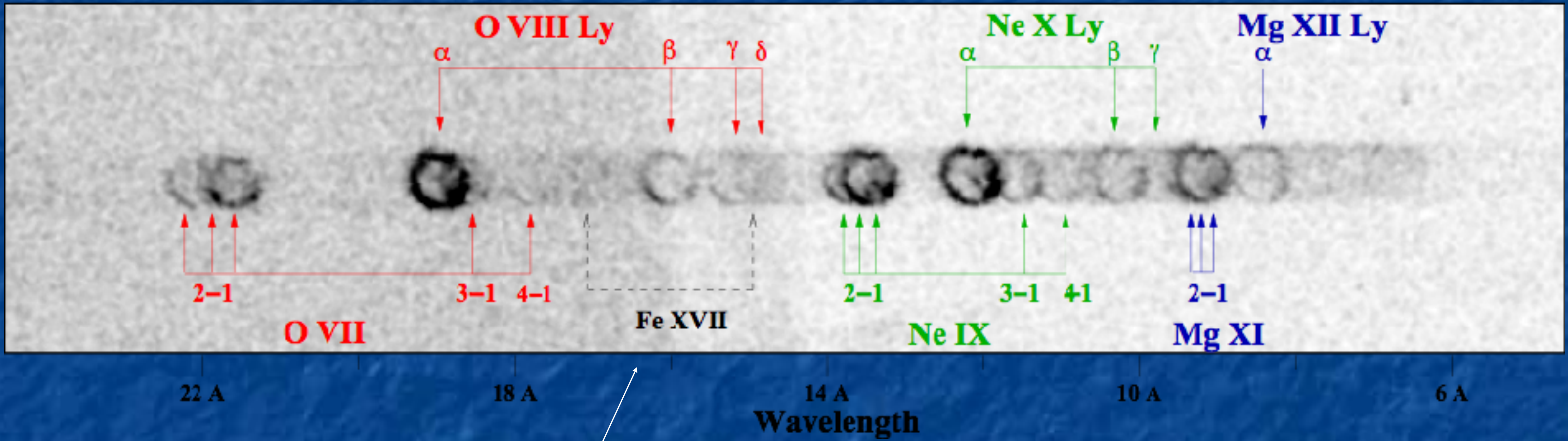


Flanagan, et. al. 2007



X-ray Lines in E0102-72

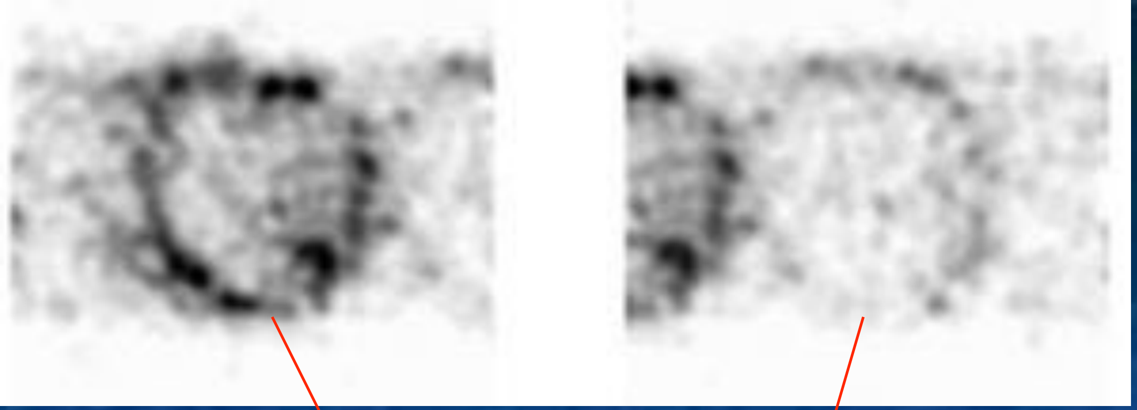
H-like and He-like O, Ne, Mg and Si provide diagnostic line ratios

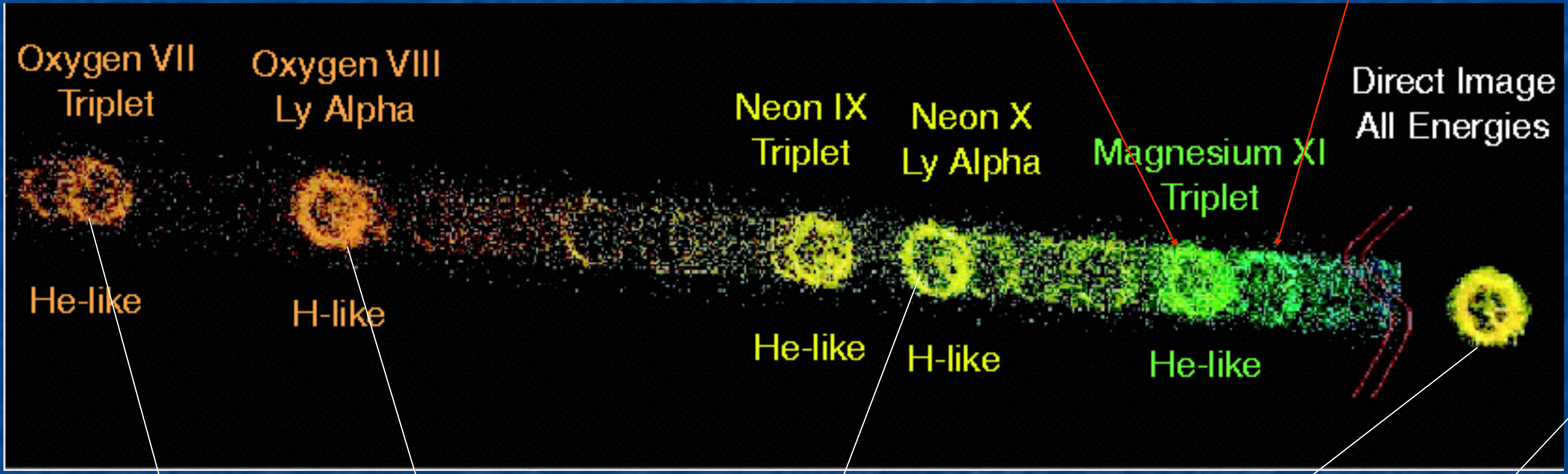


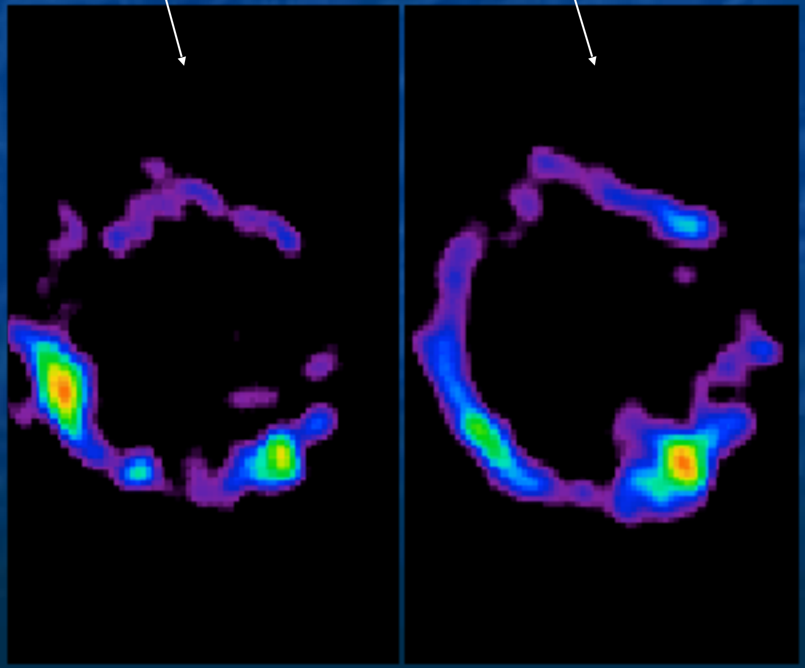
weak Fe

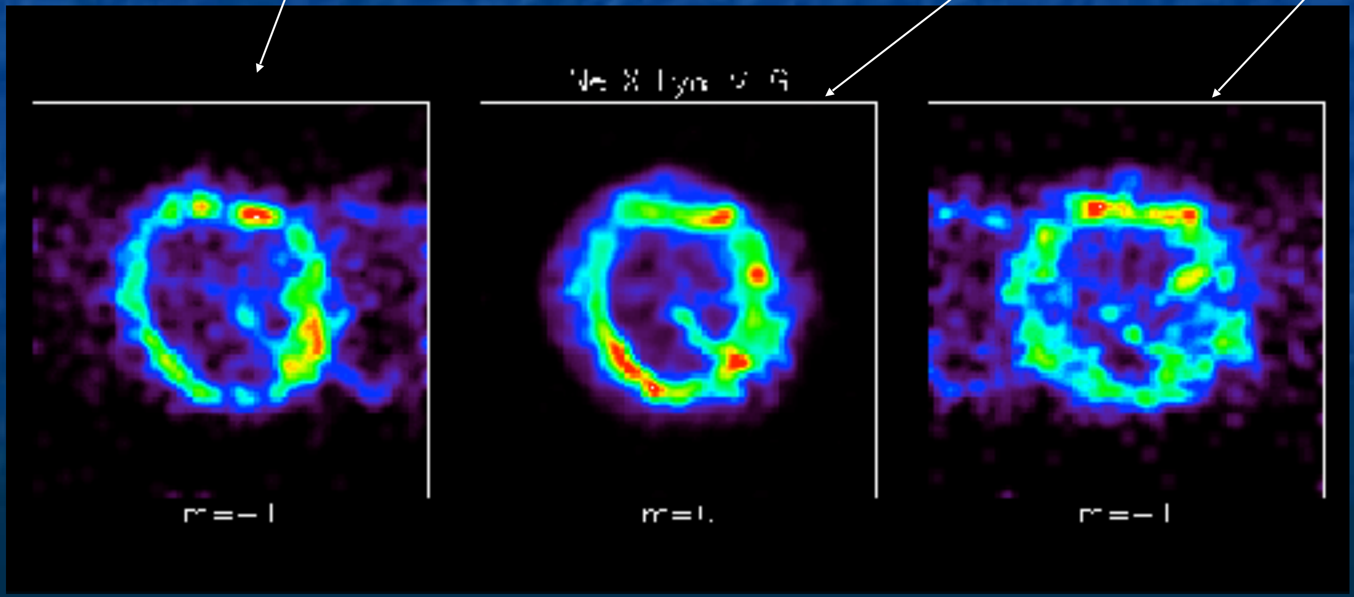
XMM_newton (Rasmussen et al 2001) detect also C, and lack of N.

Chandra HETGS Spe



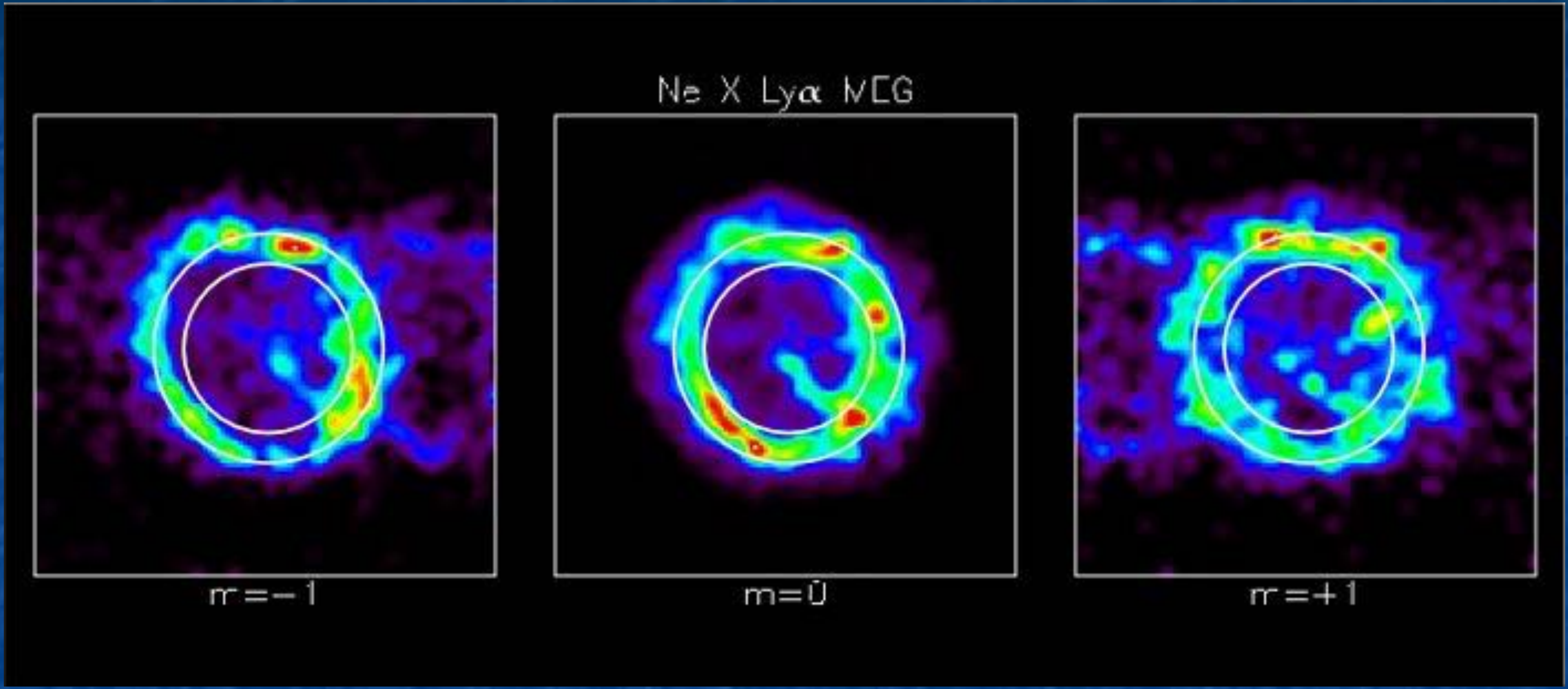


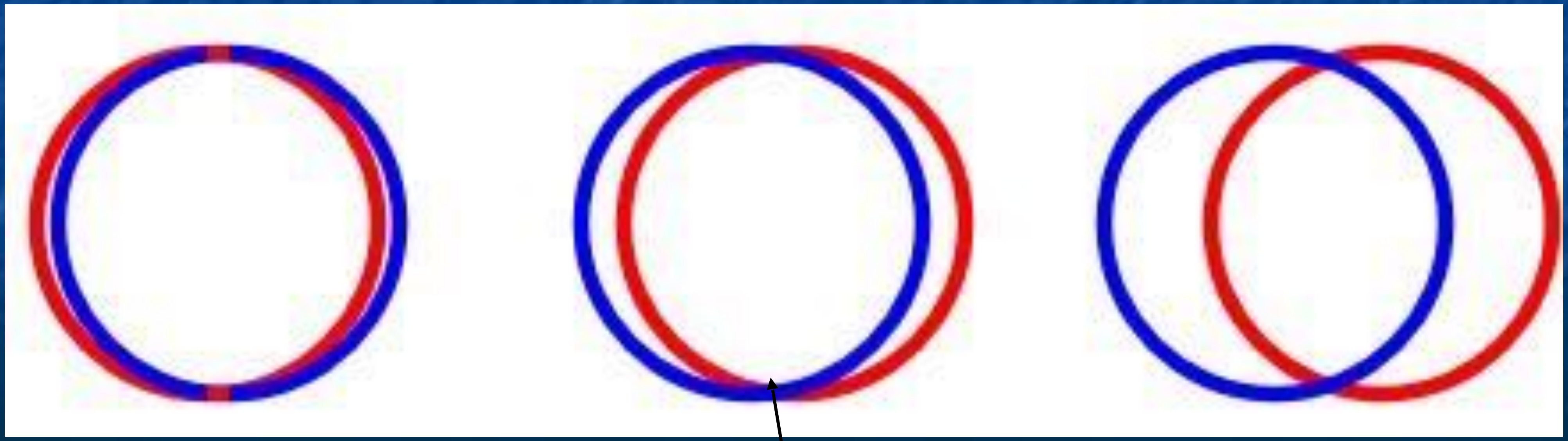




Flanagan et al. 2004

Doppler shifts distort dispersed rings and hint at 3D structure



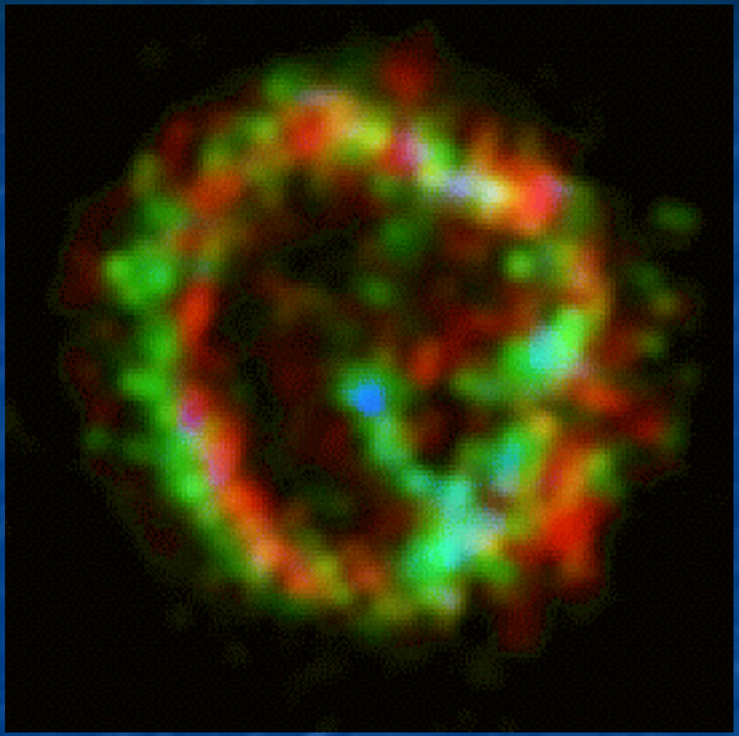


Leading (blue shifted) and trailing (red-shifted) edges of expanding cylinder

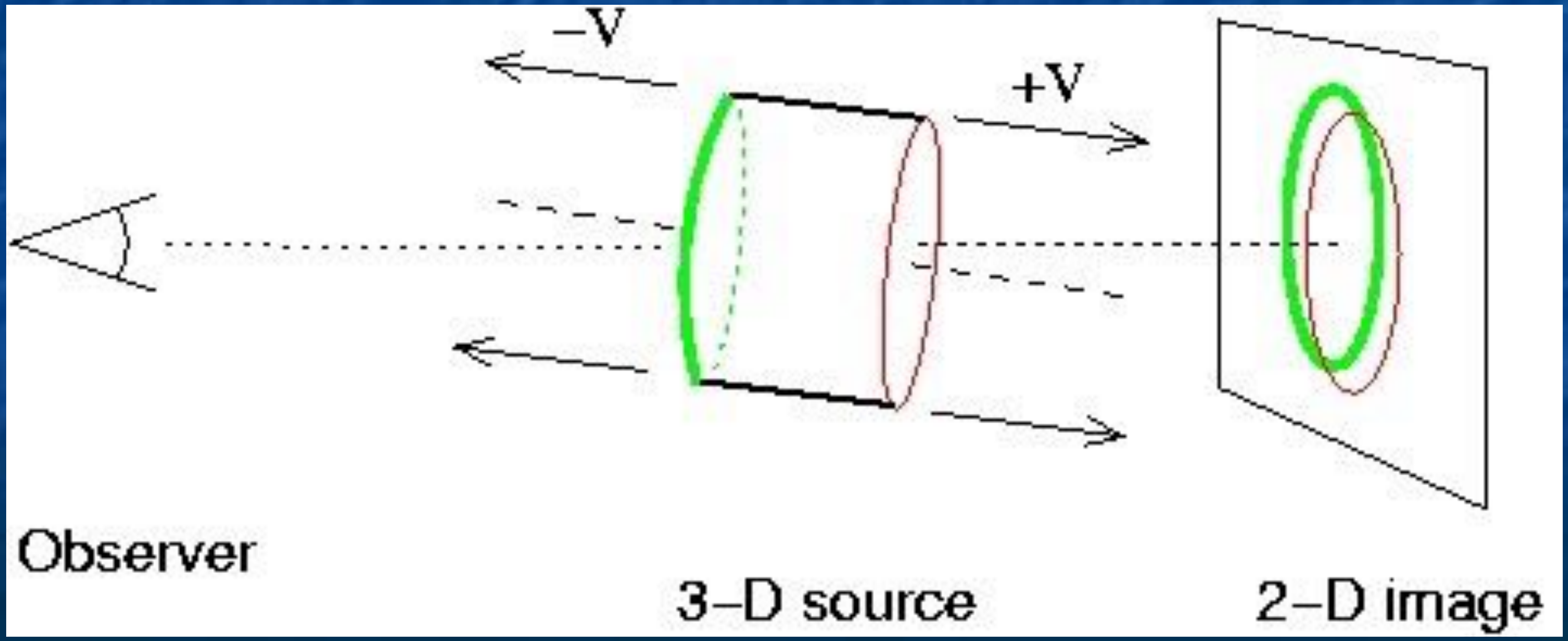
Color-velocity image results

Regions of red and blue shift appear as displaced rings.

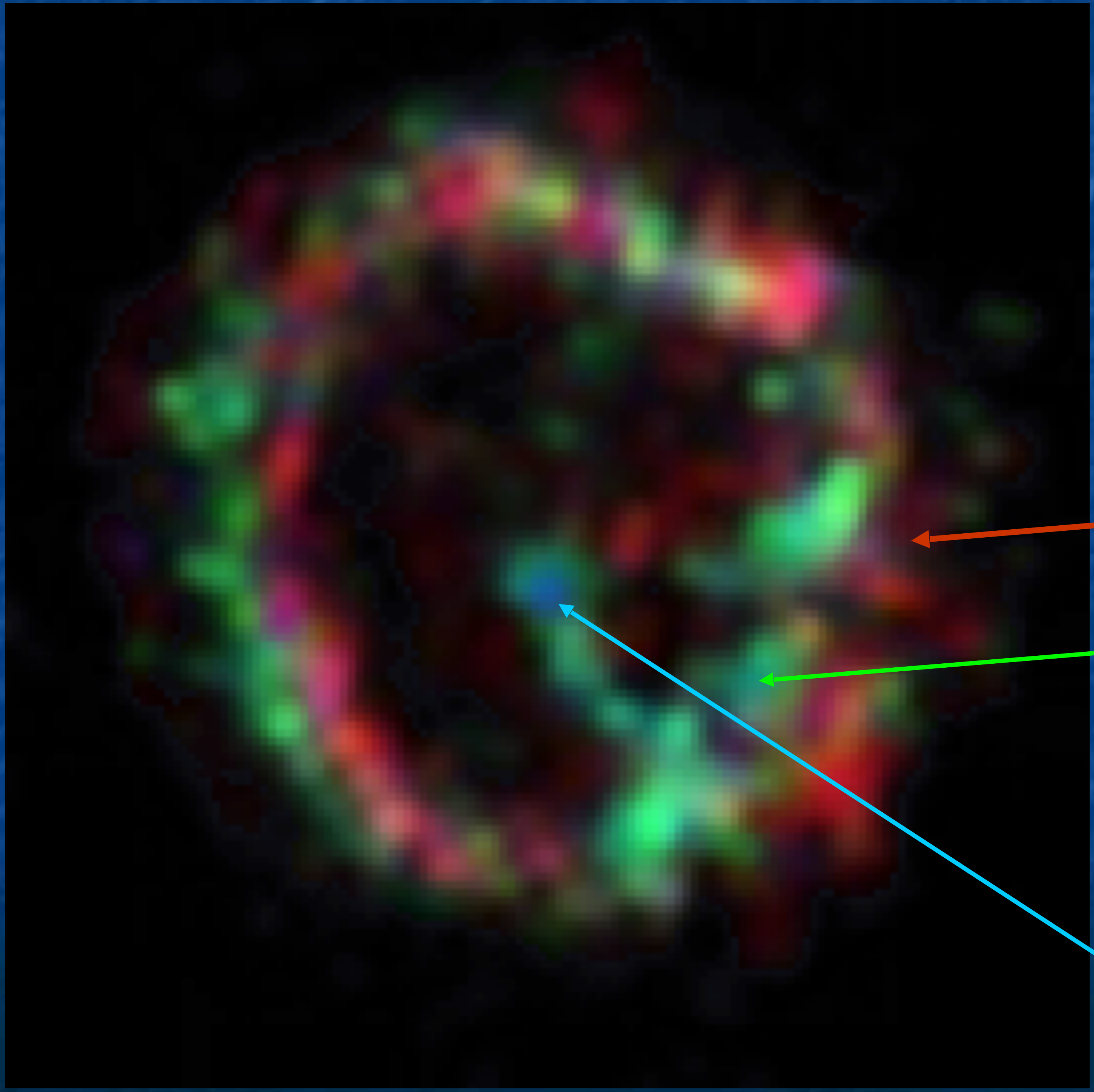
- Red: 900 and 1800 km/s
- Green: -900 km/s
- Blue: -1800 km/s



- Interpretation as cylinder viewed almost end-on



2-Dimensional Doppler Map of E0102



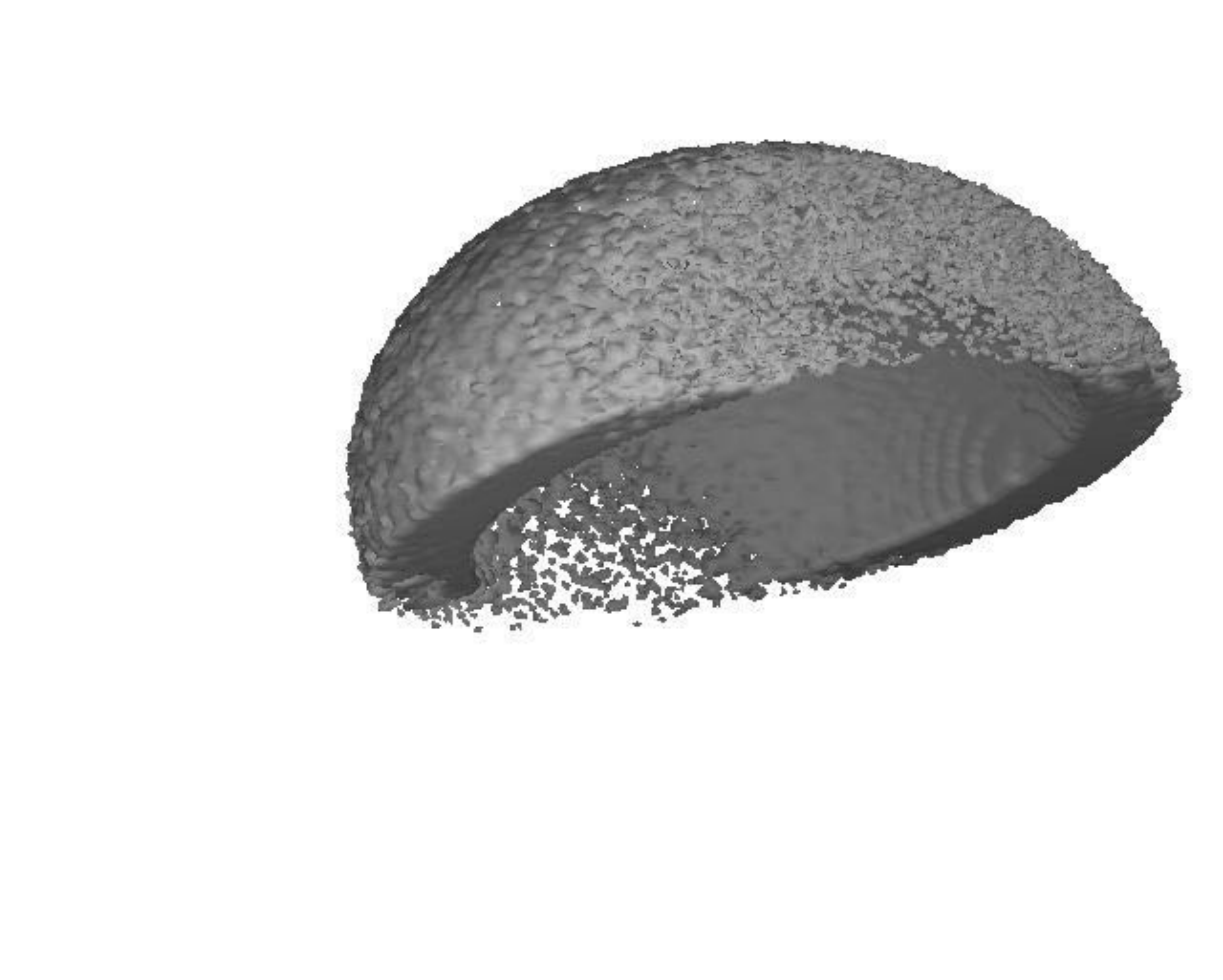
suggests tilted cylindrical distribution

+900, +1800 km/s

-900 km/s

-1800 km/s

3D Model



What have we discovered "by eye"?

- Identified elements - O, Ne, Mg, Si
- Identified different ionization states of these elements: He-like and H-like
- saw evidence for the reverse shock
- Identified Doppler shifts
- Hypothesize a barrel-shaped supernova remnant expanding at velocities ~1000km/s

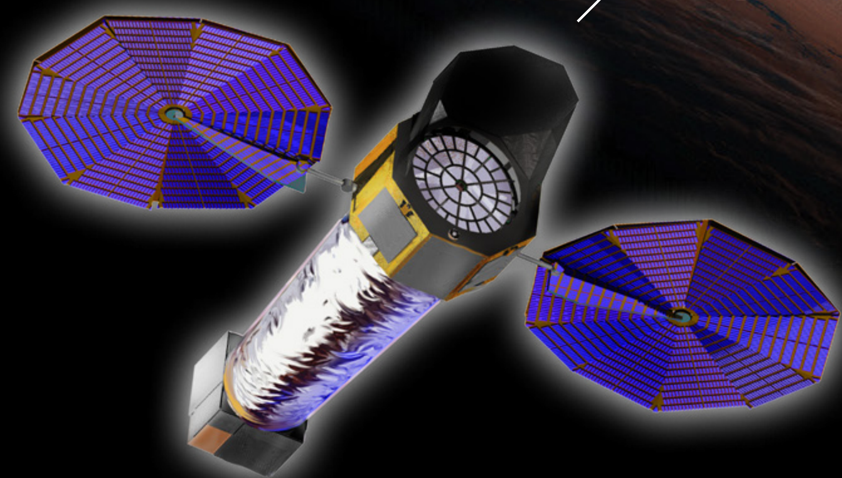
SO WHAT’S NEXT?


LYNX X-RAY OBSERVATORY

A NEW GREAT OBSERVATORY

X-RAY MIRROR ASSEMBLY

0.5'' Point-Spread Function,
stable over a 20 arcminute FoV

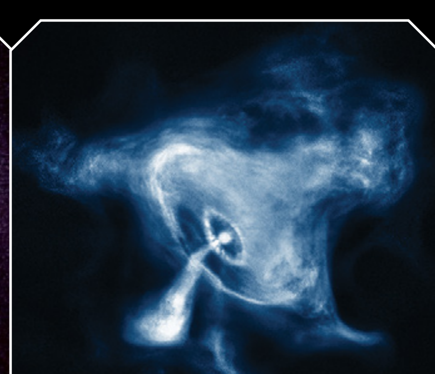


HIGH DEFINITION X-RAY IMAGER

LYNX X-RAY MICROCALORIMETER

X-RAY GRATINGS SPECTROMETER

EINSTEIN



CHANDRA

HIGH DEFINITION X-RAY IMAGER

Designed for exquisite imaging and wide surveys, the HDXI is an active pixel array covering a 20' x 20' field of view with subarcsecond imaging.

LYNX X-RAY MICROCALORIMETER

Spatially resolved 3 eV spectroscopy across a 5'×5' field of view, sampled with 1" pixels. Two subarrays optimized for finer imaging and higher spectral resolution.

X-RAY GRATINGS SPECTROMETER

Spectral resolving power of $R > 5000$ with ~4000 cm^2 of effective area across the critical X-ray emission and absorption lines of C, O, Mg, Ne, and Fe-L.

THE SCIENCE

Lynx is designed to pursue three science pillars.

There are ample resources for many other programs, including those unexpected today.

It will be a discovery platform for all.

WWW.HIDDENCOSMOS.ORG

The Ultimate Goal: Another "Living Earth"

Schoolchildren on Earth
already learn that there
are worlds orbiting other stars.

We aim for future generations to know,
with the same certainty,
that there is life on some of those worlds.

We are the first generation that can meet this lofty and ambitious goal, because we have the capability to identify Earths and search for signs of life there.

How will we do this?

Fainter

Revolutionary Technology

Farther

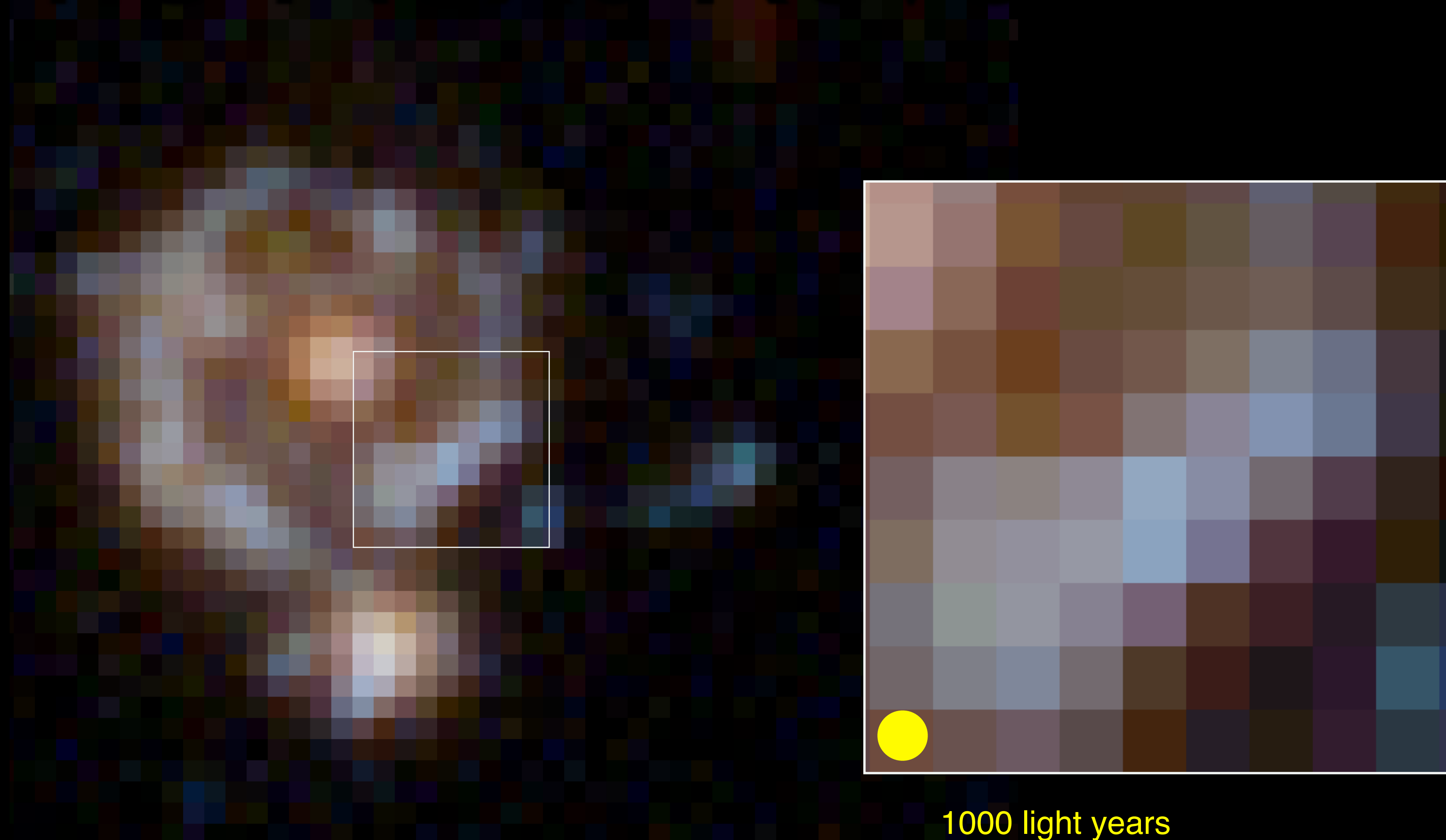
Brings

Rarer

Revolutionary Science

Finer

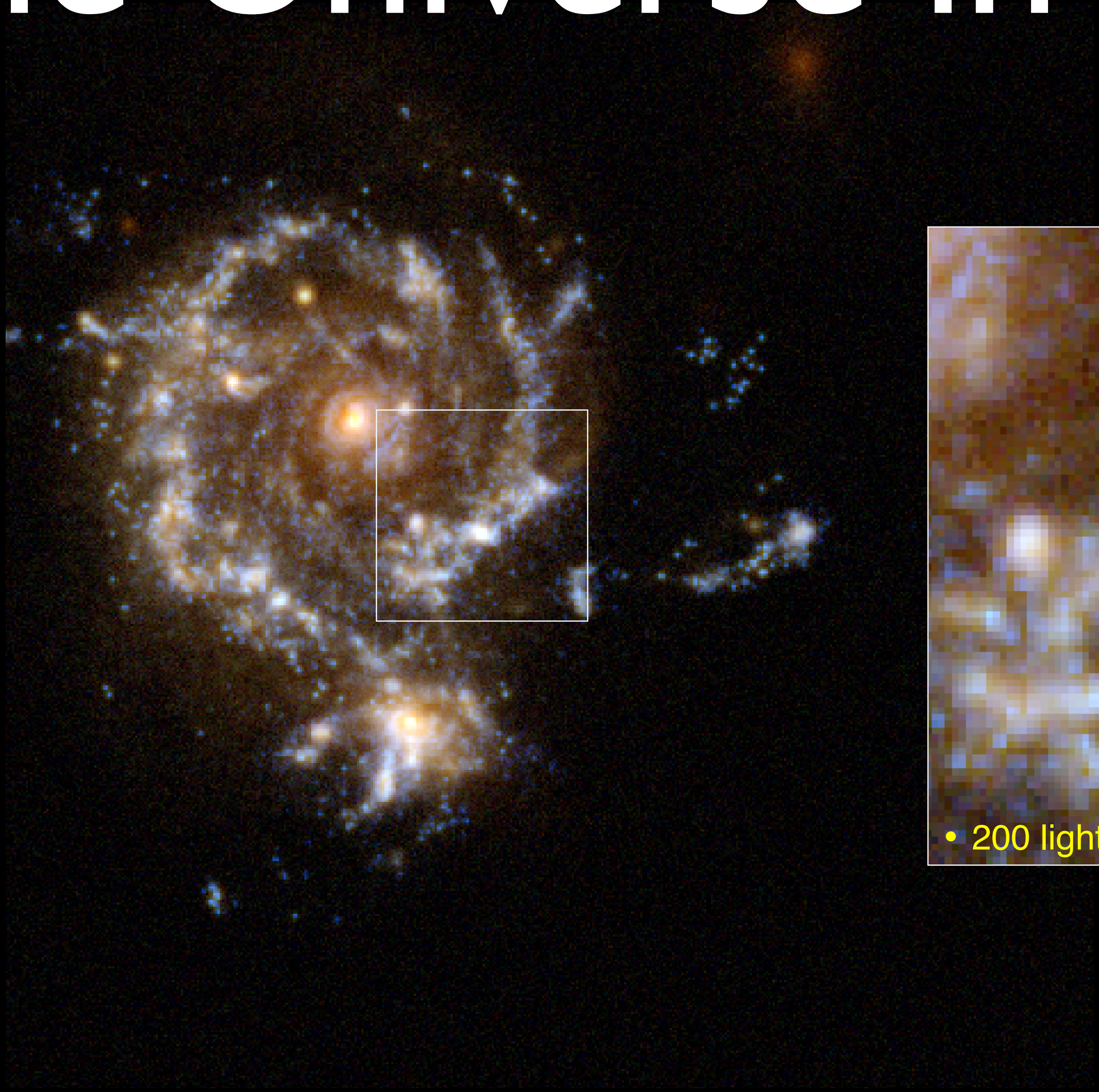
The Next Revolution

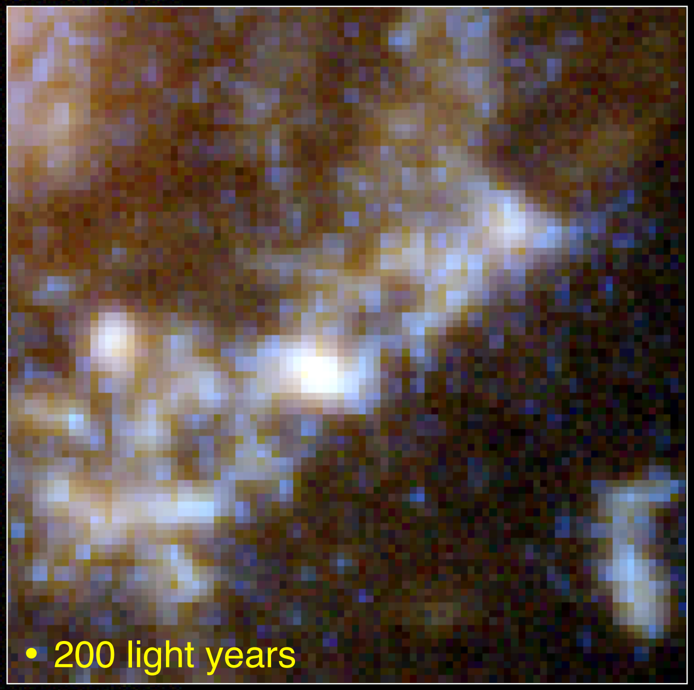


From Hubble to….

Image Credit: Ceverino/Moody/Snyder

…the Universe in High-Def





HDST

Image Credit: Ceverino/Moody/Snyder

~25 Days A Few Hours

Hubble HDST

What will HDST do?

What will HDST do?

size of Manhattan at the
orbit of Jupiter...

search for biosignatures

The High Definition Space Telescope

Are We Alone?

Concept for HDST (GSFC Conceptual Image Lab)

Courtesy of Chris Meaney, Honeywell Technology Solutions

What is it you plan to do
with your one wild and precious life?

Mary Oliver, *The Summer Day*