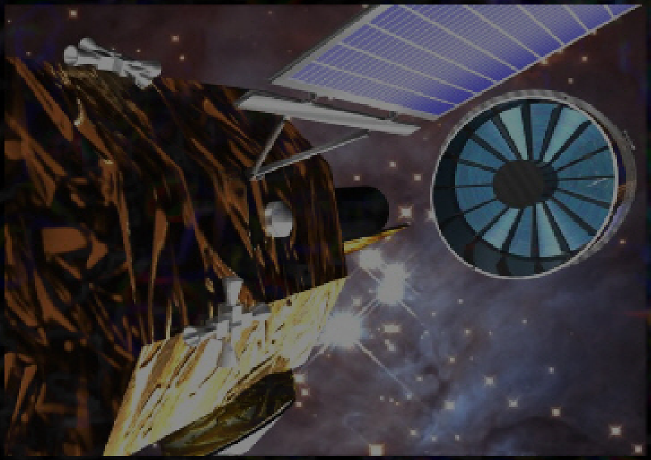
Future Optical & X-ray Facilities for Pulsar Studies

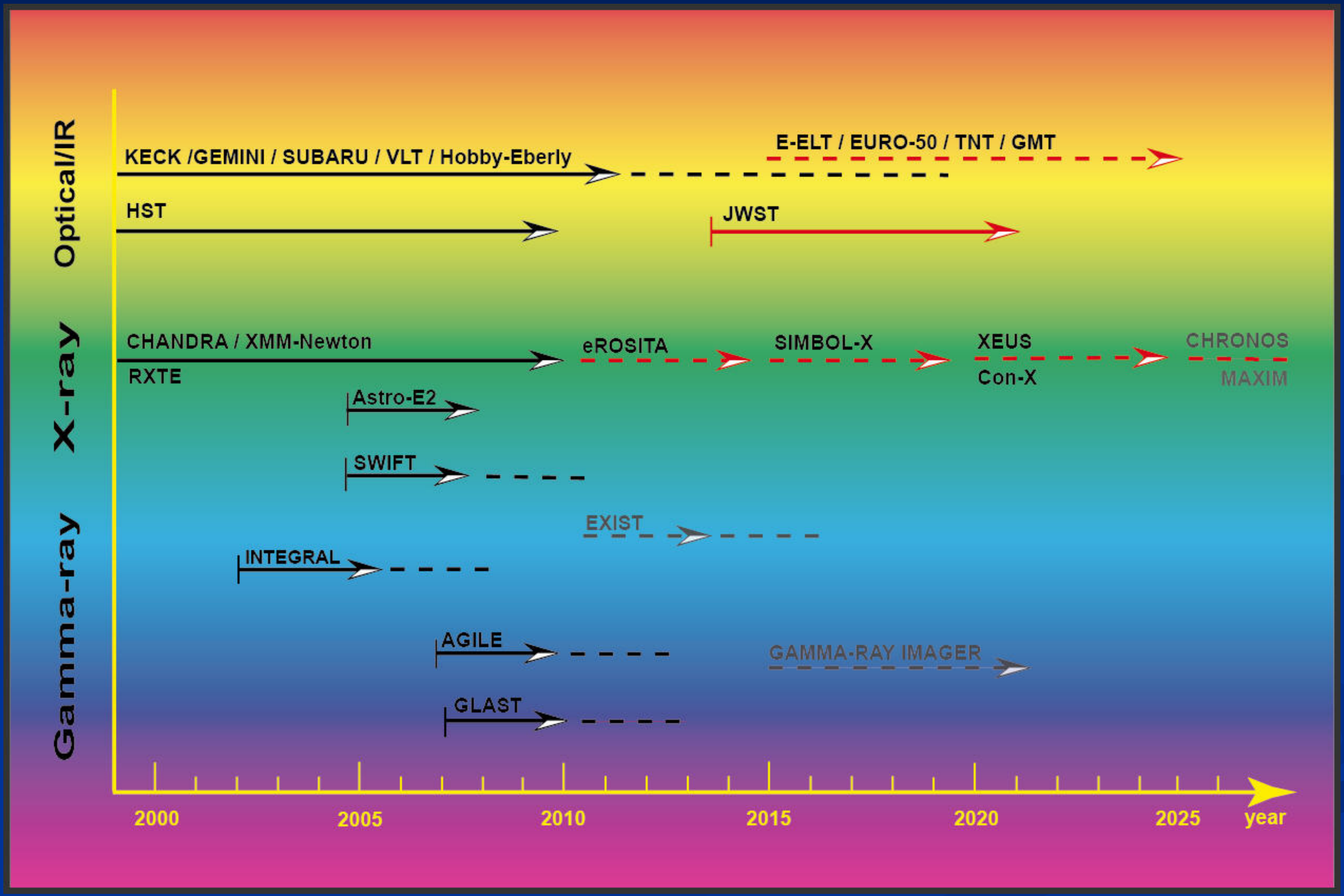


With input from: R. Mignani, P. Predehl, L. Strüder, N. Meidinger, G. Hasinger and A. Parmar

Werner Becker

Max-Planck Institut für extraterr. Physik

Observatories and mission timelines



Future optical facilities

Summary of Pulsars detected at optical wavebands

PSR	Age Log(yrs)	Mag	Tim	Spec	Pol	Photometry
Crab	3.1	16.6	P	Yes	Yes	UV+UBVRI+JHK
1509-58	3.19	25.7			Yes	R
0540-69	3.22	22	P	Yes	Yes	UBVRI
Vela	4.05	23.6	P	Yes	Yes	UV+UBVRI+JH
0656+14	5.05	25	P			UV+UBVRI+JHK
Geminga	5.53	25.5	P	Yes		UV+UBVRI+JH
1055-52	5.73	24.9				U
1929+10	6.49	25.6				UV+U
0950+08	7.24	26				U+BVI
PSRJ0437-4715	9.2					UV
RXJ1856-3754	>6.0?	25.6		Yes		UV+UBV
RXJ0720-3125	6.4	26 .2				UV+UBV-broad,R
RXJ1308.6+2127	>6.0?	28.6				V-broad
RXJ1605.3+3249	>6.0?	26.8				V-broad,R

14 neutron stars detected at optical wavebands (10 radio pulsars)

Pulsar's spin down flux density at Earth

For rotation-powered pulsars (magnetic braking model):

$$\dot{E} = 4\pi^2 \, I \, \dot{P} \, P^{-3}$$ ← spin down energy

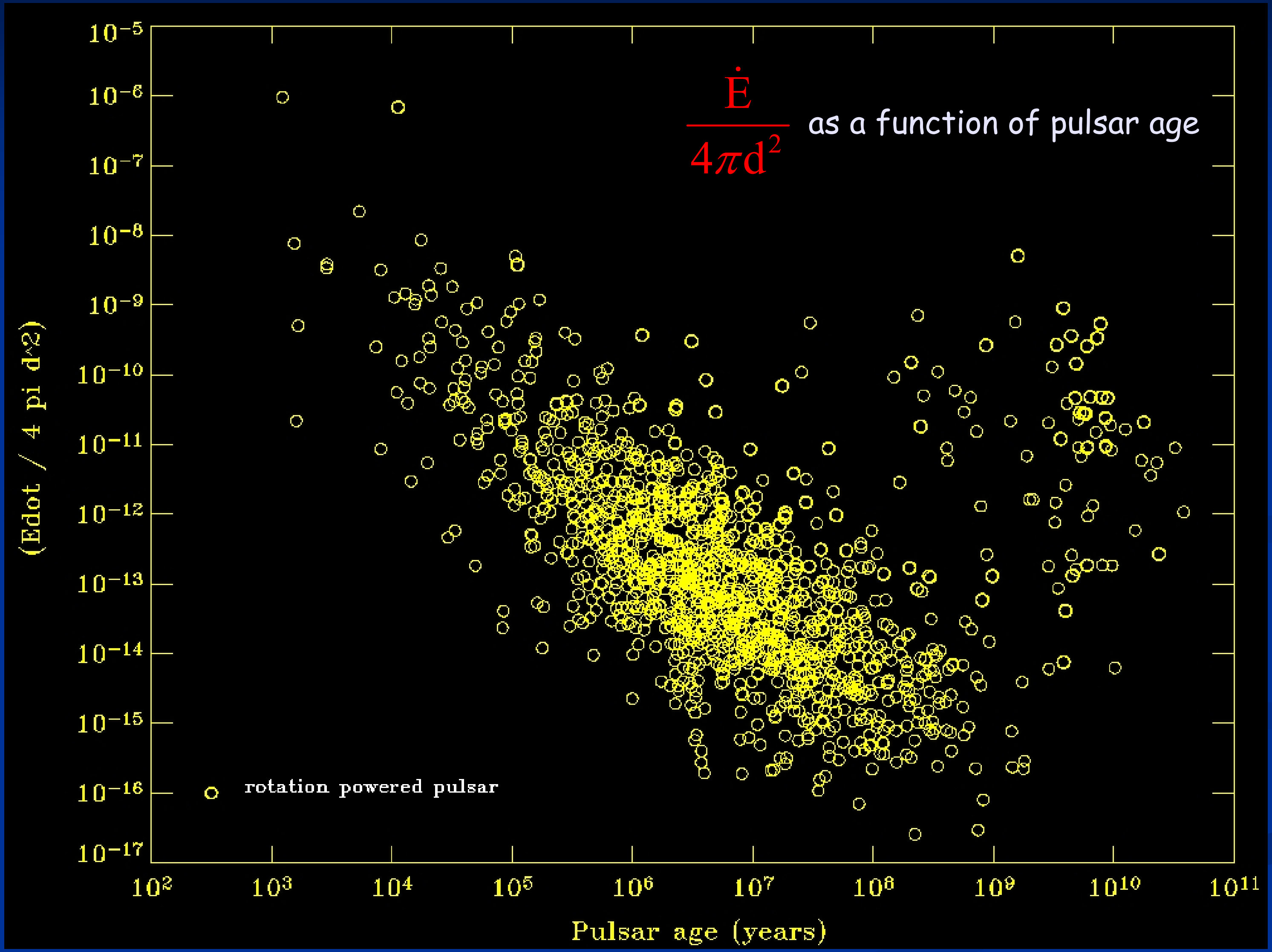
$$DM \rightarrow d$$ ← electron density model: (Cordes and Lazio 2002)

$$\frac{\dot{E}}{4\pi d^2}$$ ← spin down flux density at earth

← vital measure for detecting a pulsar

$$\tau = \frac{P}{2\dot{P}}$$ ← spin down age

Spin down flux density as a function of pulsar age



Estimate of the interstellar column absorption

The neutral hydrogen column density ....

$$N_H \sim DM \times pc \times 10$$

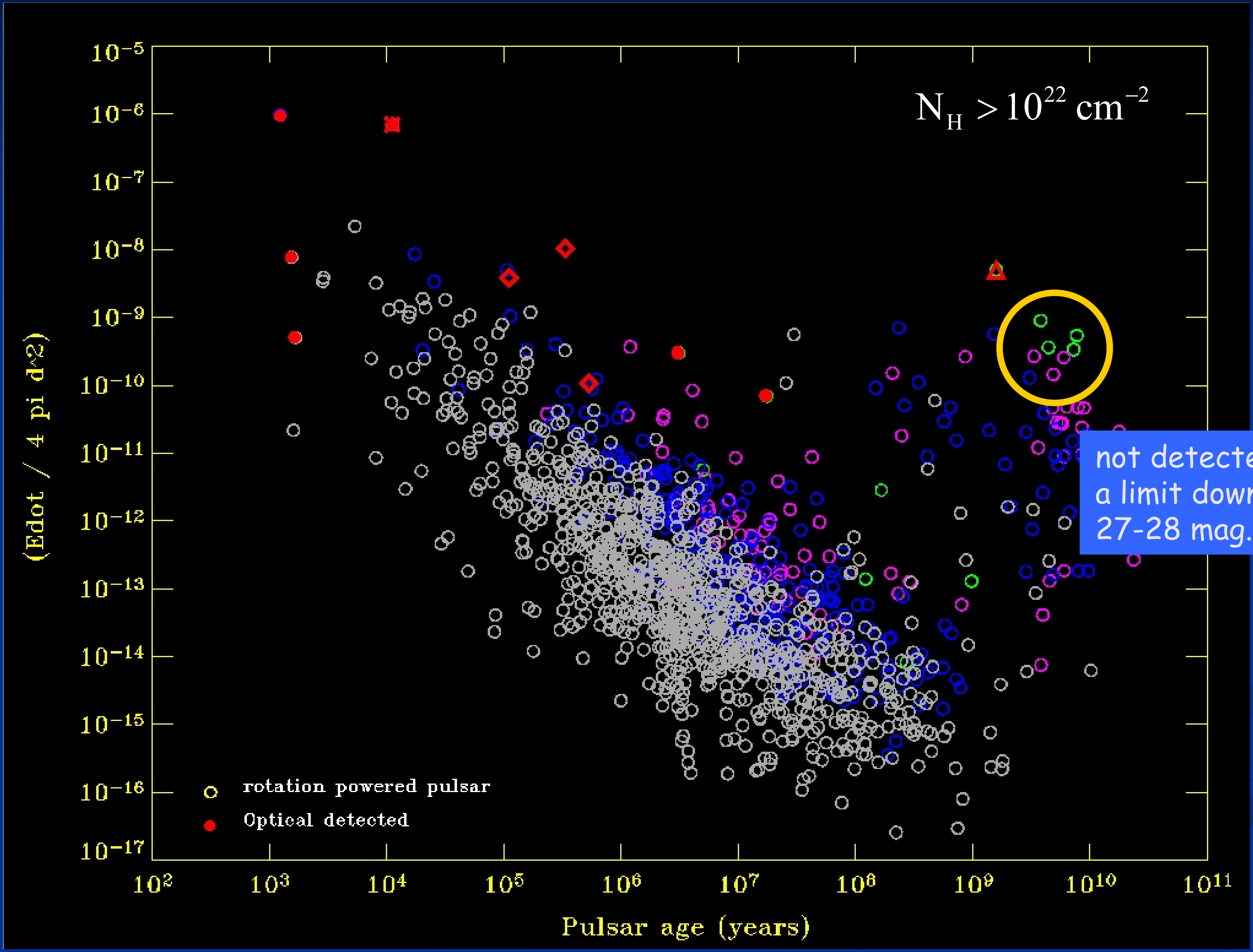
10 free electrons per H Atom

1 pc = 3.085 10^18 cm

Radio dispersion measure

………… provides an estimate for the interstellar column absorption

Radio Pulsars detected at optical wavebands

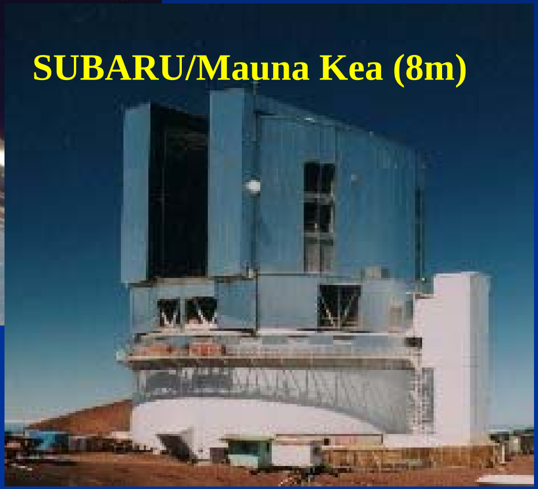


not detected with a limit down to 27-28 mag.

Current optical facilities


NTT/La Silla (3.5m)


HST (2.4m)


SUBARU/Mauna Kea (8m)


GEMINI-N/Mauna Kea (8m)


GEMINI-S/Cerro Pachon (8m)


ESO-VLT/Paranal

(4x8m)


Kecks/Mauna Kea

2x10m

The road to today's Large Telescopes

- Breakdown in the telescope concepts at the beginning of the 80s
  - Single-Mounted Arrays

    small mirrors mounted on the same structure
  - Segmented mirrors (e.g. Keck):

    primary mirror made of small assembled mirror units
  - Adaptive Optics (e.g. VLT):

    active mirror supports makes monolithic mirrors

    thinner and lighter
  - Arrays of Telescopes (e.g. VLTI):

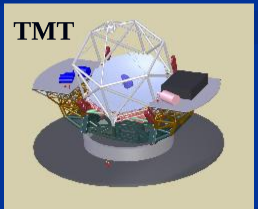
    interferometry-based array of multiple telescopes
- Advent of generation of (>) 8m class telescopes:

  VLT (8m), GEMINI (8m), KECK (10m), SUBARU (8m) , VLTI (16m) ...

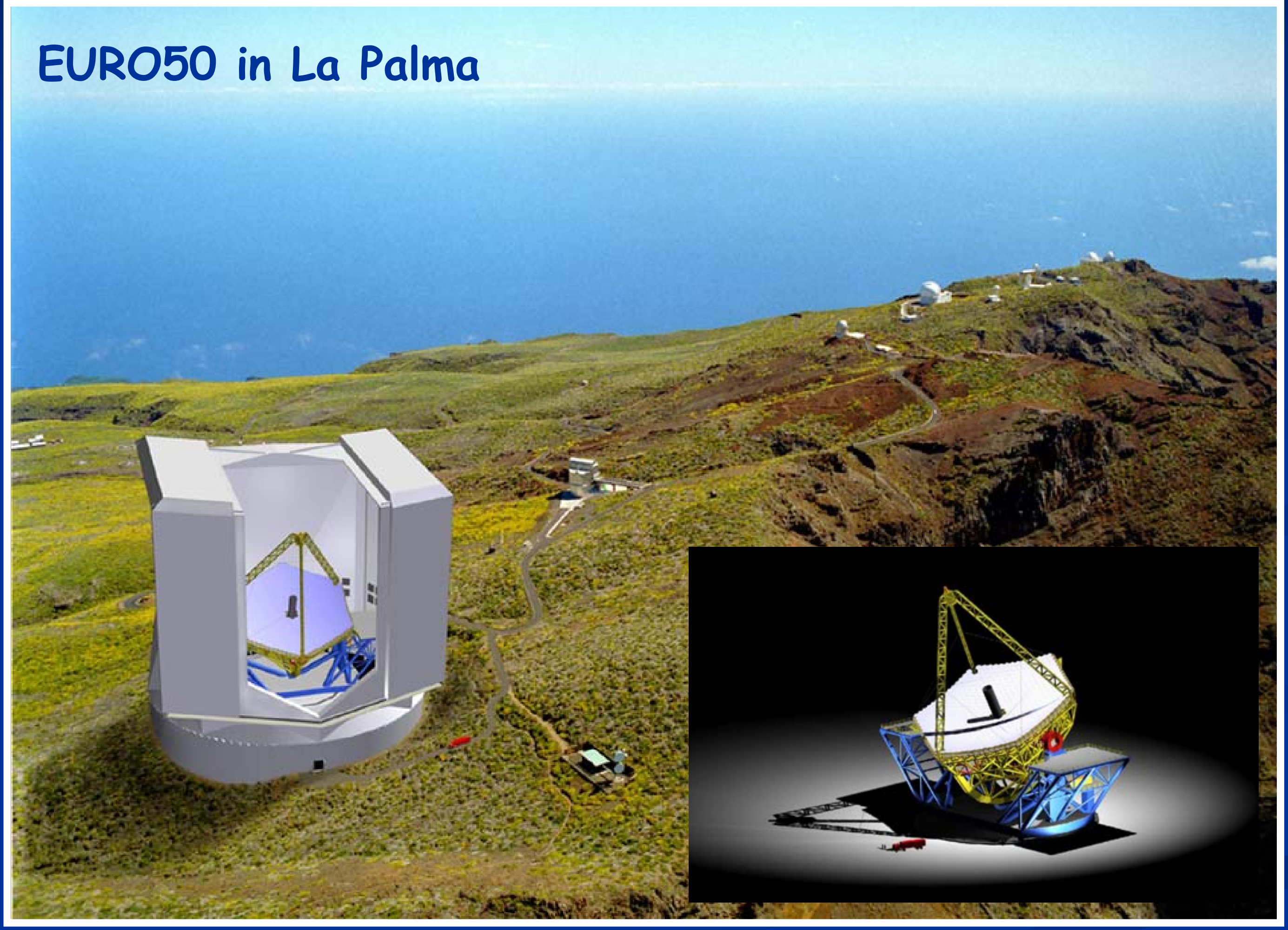
The road to future X-Large Telescopes

- Paradigm to minimize weight/diameter: small + thin mirrors
  - From e.g. KECK: → segmented mirror technology
  - From e.g. VLT: → active and adaptive optics technology
  - From e.g. Hobby-Eberly: → Low-cost structures/optics

- Many conceptual studies in progress, e.g.:
  - Giant Magellan Telescope - GMT (24.5m – US / Australia)
  - Thirty Meter Telescope - TMT (30 m – US / Canada)
  - Maximum Aperture Telescope - MAXAT (30-50m, AURA)
  - EURO50 (50m, Europe)
  - ~~Overwhelmingly Large Telescope "OWL" (100 m / ESO-Garching)~~
  - European Extremely Large Telescope "E-ELT (30 – 60 m / ESO-Garching)



The road to future X-Large Telescopes



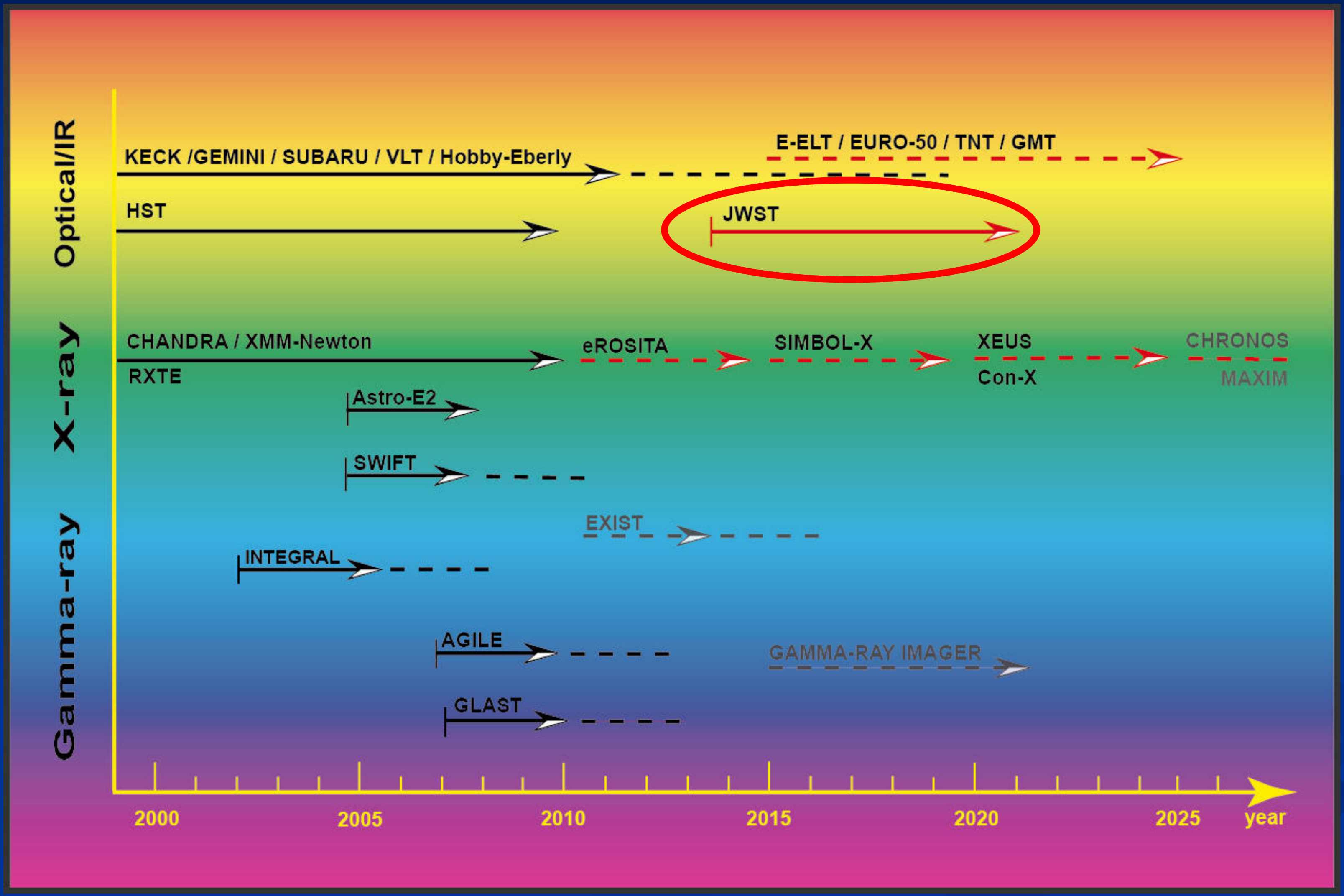
Proposed by scientists in Finland, Ireland, Spain, Sweden and United Kingdom

Pulsars are still challenging for ELTs

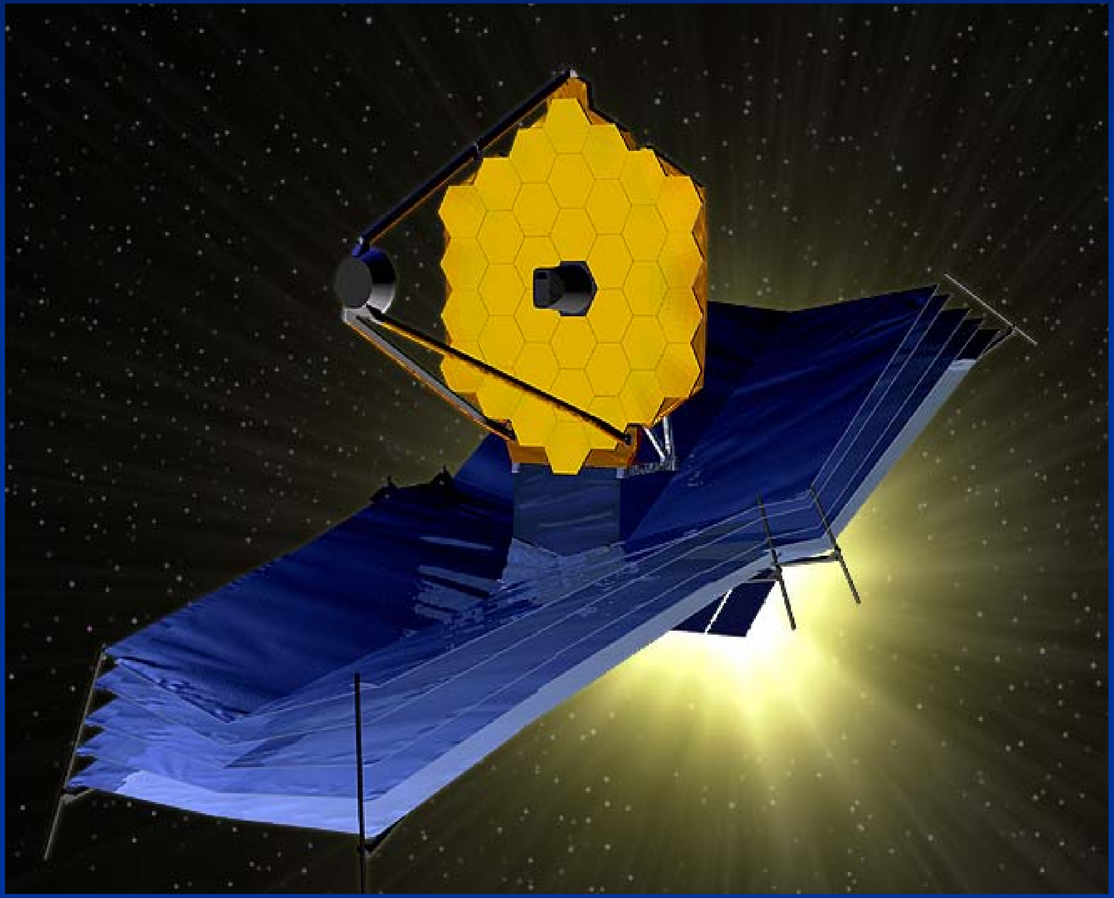
- About 4h of observing in phase with the pulsar's period will be required to build up a 300 bin pulse profile of a V=26 mag pulsar resembling the Crab
- Time-resolved spectroscopy, even at low resolution, will still be a substantial challenge:
  - e.g., spectra at 300 points around the cycle can be accumulated on a CCD by in phase charge transfer, but it will require roughly a week for a S/N ~ 5 and R~100

What follows the HST ?

Observatories and mission timelines

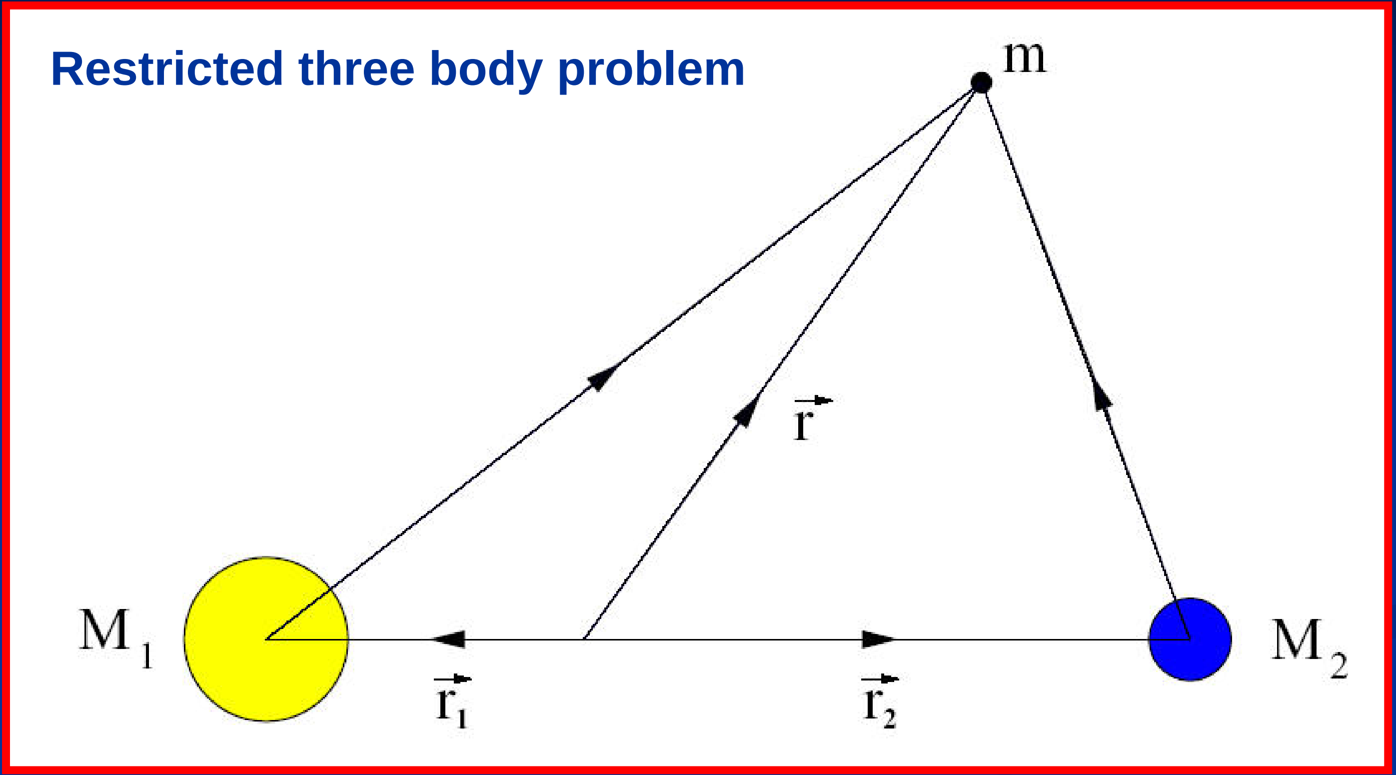


James-Webb Space Telescope



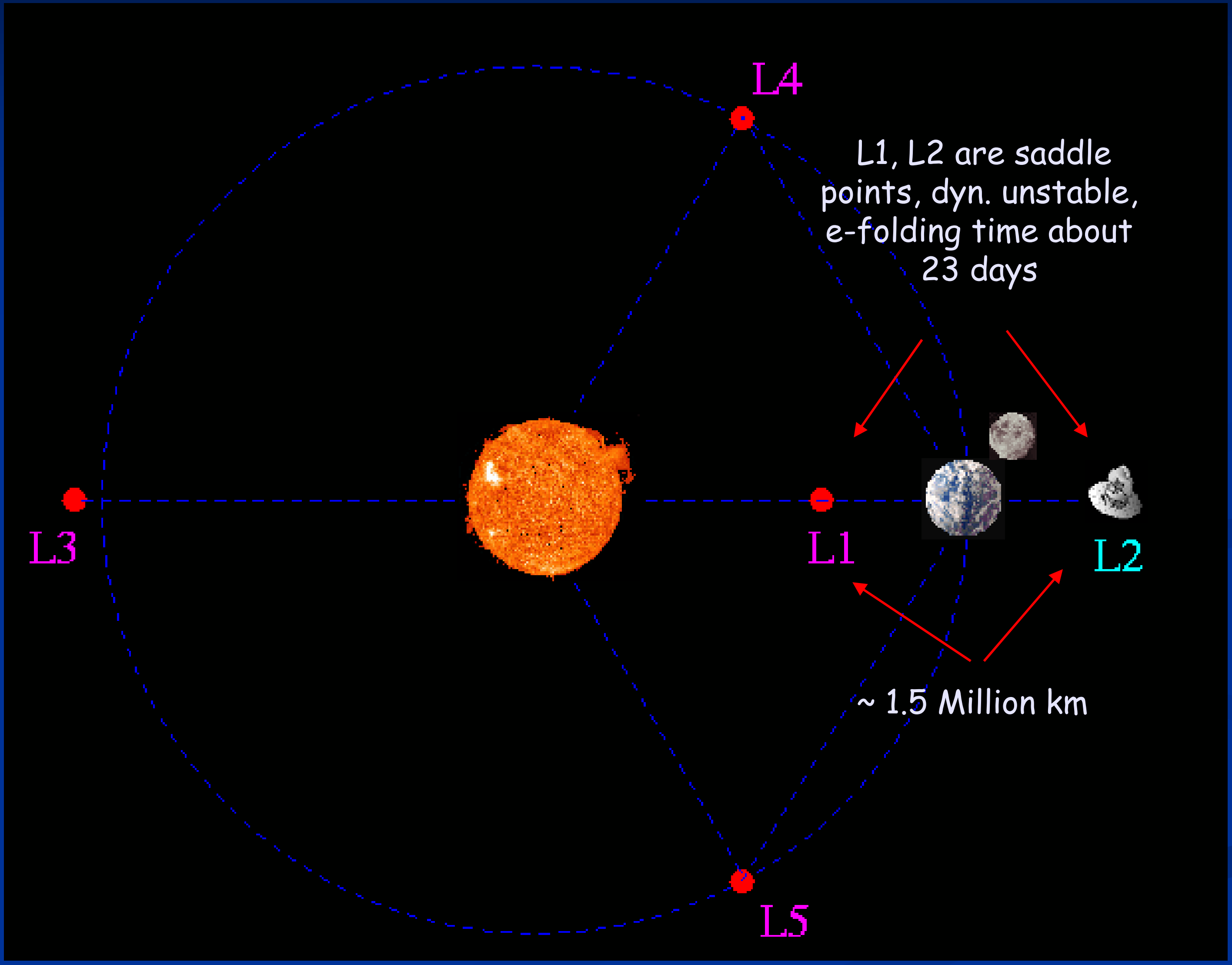
- Launch Date: summer **2013**
- Aperture: **6.5 m** – segmented (18) mirror
- Expected lifetime: **> 5 years**
- **NIRCAM:** Near-IR and Visible Camera
  6000 - 50,000 Å
  2.3 x 2.3 arcmin FOV
- **NIRSPEC**: Multi-Object Spectrograph
  10,000 -- 50,000 Å
  3 x 3 arcmin FOV
- **MIRI:** Mid-IR Camera and spectr.
  5,000 -- 28,000 Å
  2 x 2 arcmin FOV
- Orbit: **L2, 1.5 M km** apogee

The 5 Lagrange equilibrium points

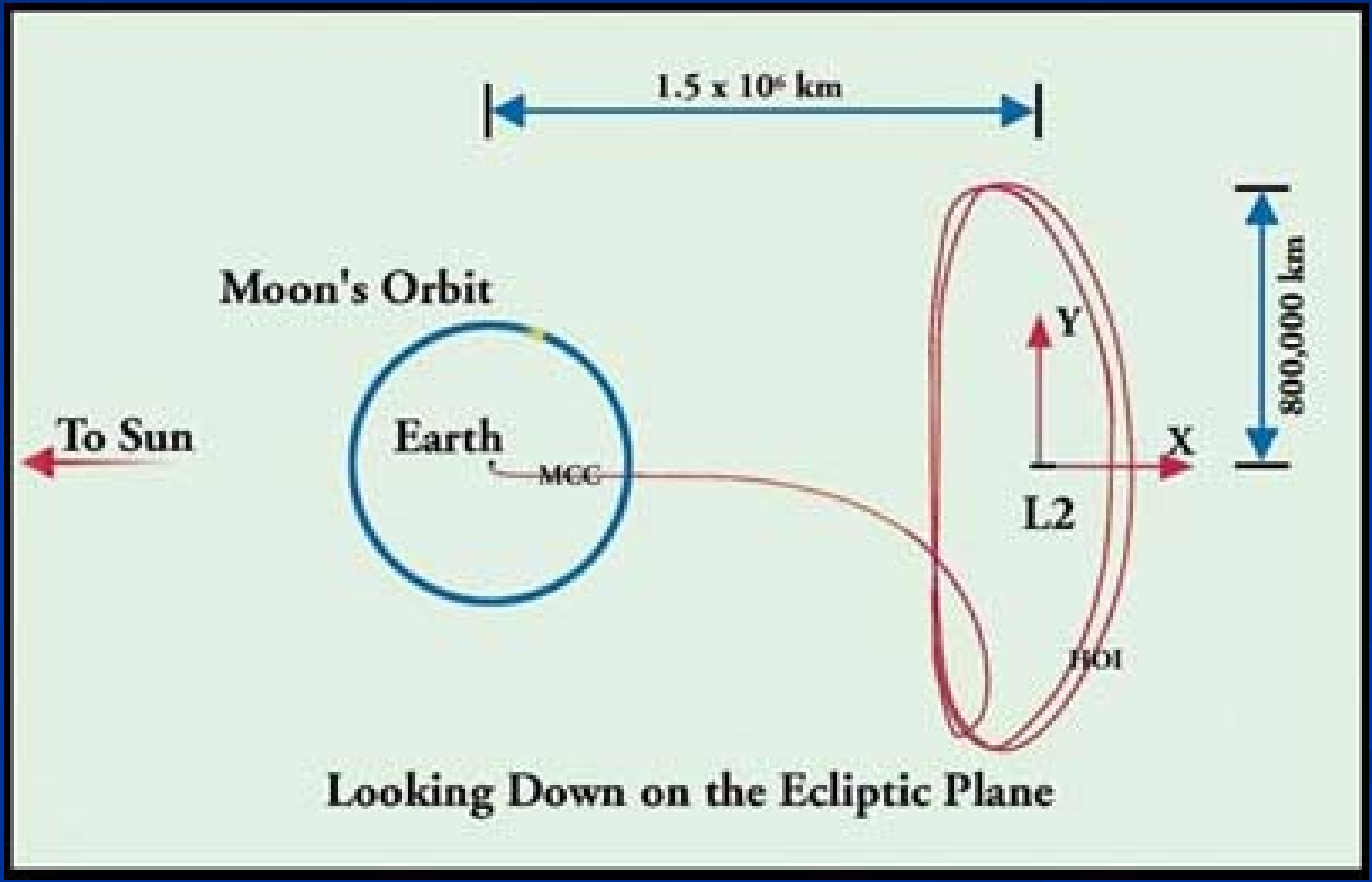


$$\vec{F} = -\frac{GM_1 m}{|\vec{r} - \vec{r_1}|^3}(\vec{r} - \vec{r_1}) - \frac{GM_2 m}{|\vec{r} - \vec{r_2}|^3}(\vec{r} - \vec{r_2})$$

Lagrange points for the Earth-Sun System: L1 - L5



The L2 Orbit


1.5 x 10⁶ km
Moon's Orbit
Y
800,000 km
To Sun
Earth
X
MCC
L2
HOI
Looking Down on the Ecliptic Plane

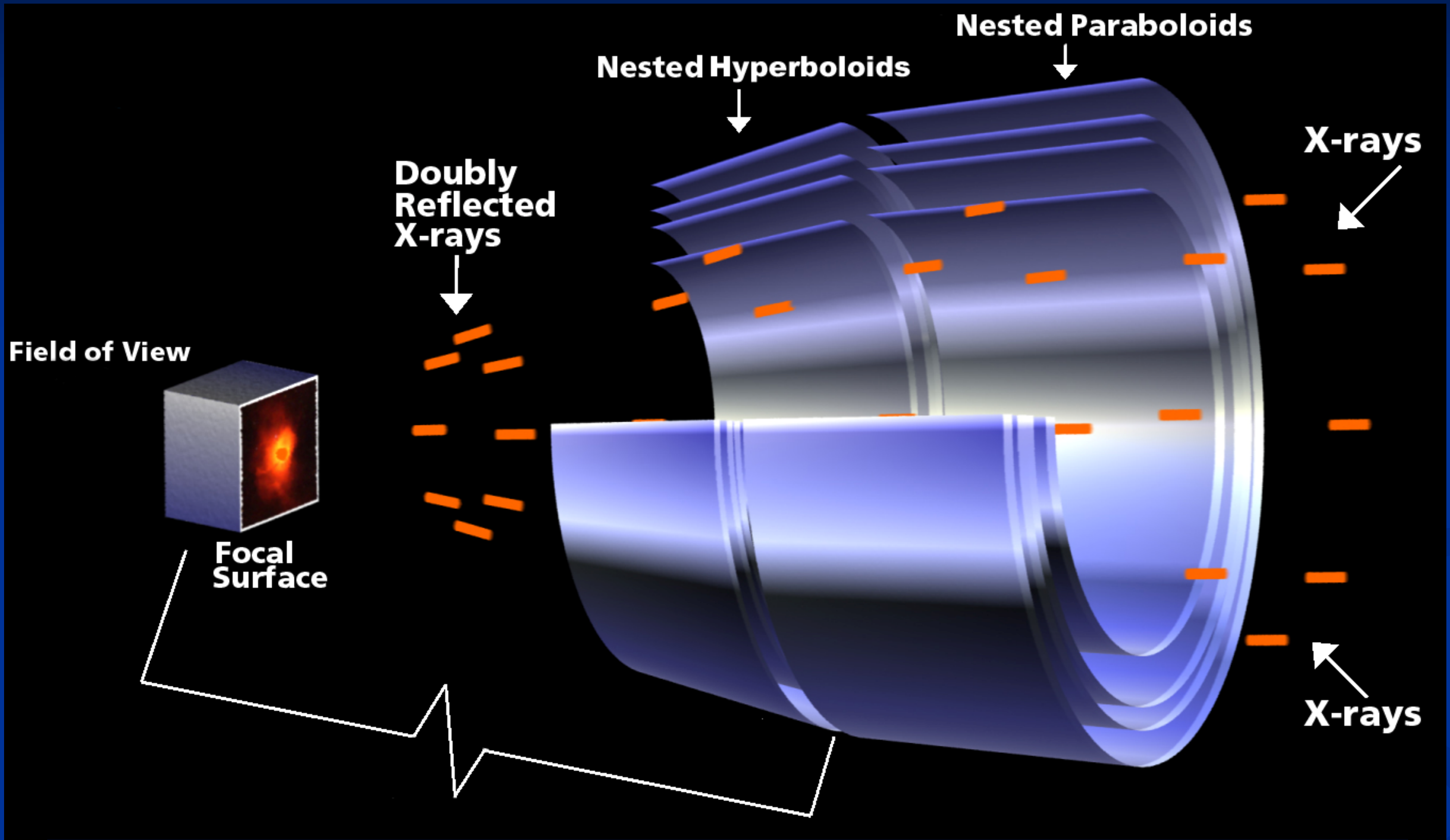
Future X-ray facilities

Summary of rot. powered pulsars detected at X

- With EINSTEIN & EXOSAT: 7 radio pulsars detected in X-rays
- With ROSAT, ASCA & BSAX: 33 radio pulsars detected in X-rays
- After ~7 yrs with XMM & Chandra: 78 radio pulsars detected in X-rays

Age τ	Pulsar category	ROSAT/ASCA	XMM/Chandra	Progress
$< 10^4$ yrs	Crab-like	5	9	+4
$10^4 - 10^5$ yrs	Vela-like	9	15	+6
$10^5 - 10^6$ yrs	Cooling NS	5	5	
$10^6 - 10^8$ yrs	Old & nearby	3	8	+5
	other	1	2	+1
$> 10^8$ yrs	ms-Pulsars	11	39	+28
	detected #	33	78	+45

Schematic of grazing incidence, X-ray mirrors

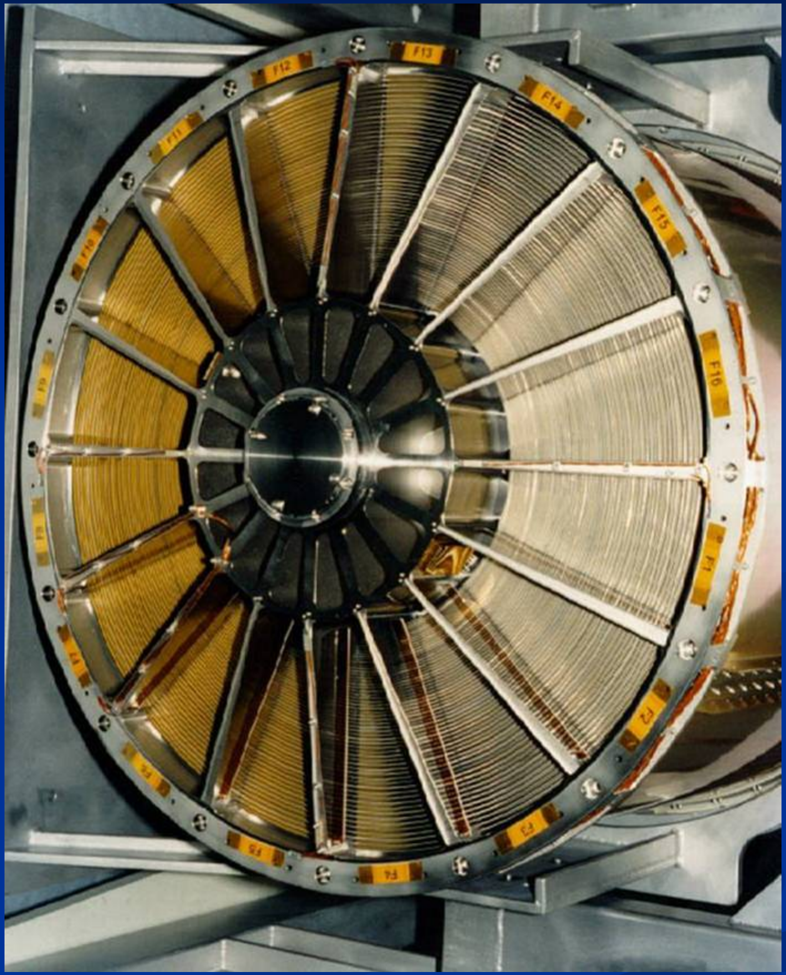


X-rays are focused by double reflection in a Wolter Type-I X-ray Telescope

X-ray Mirrors of current Missions

Chandra

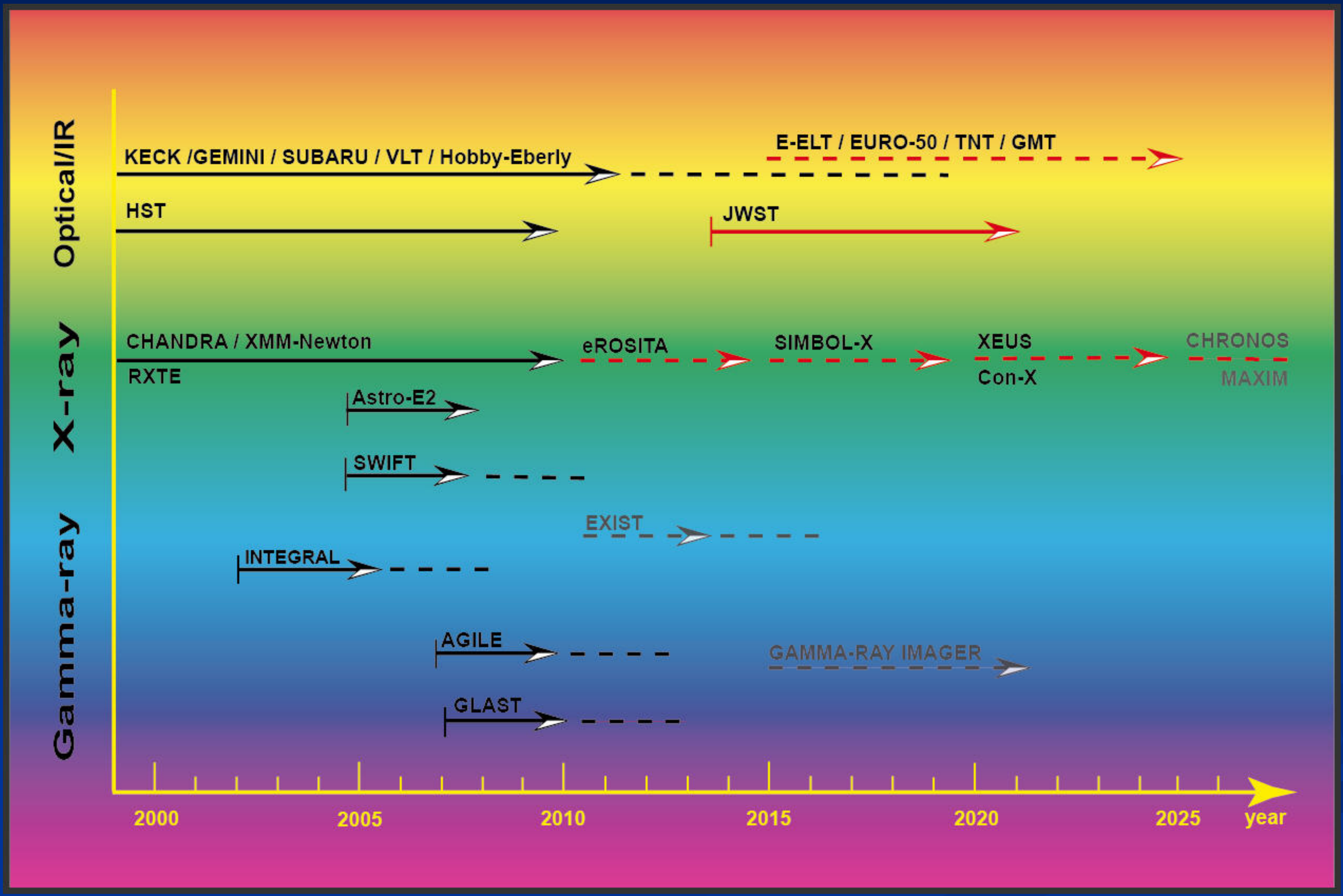
4 nested mirror shells



XMM-Newton

3 mirror modules with 58 nested mirror shells

Observatories and mission timelines

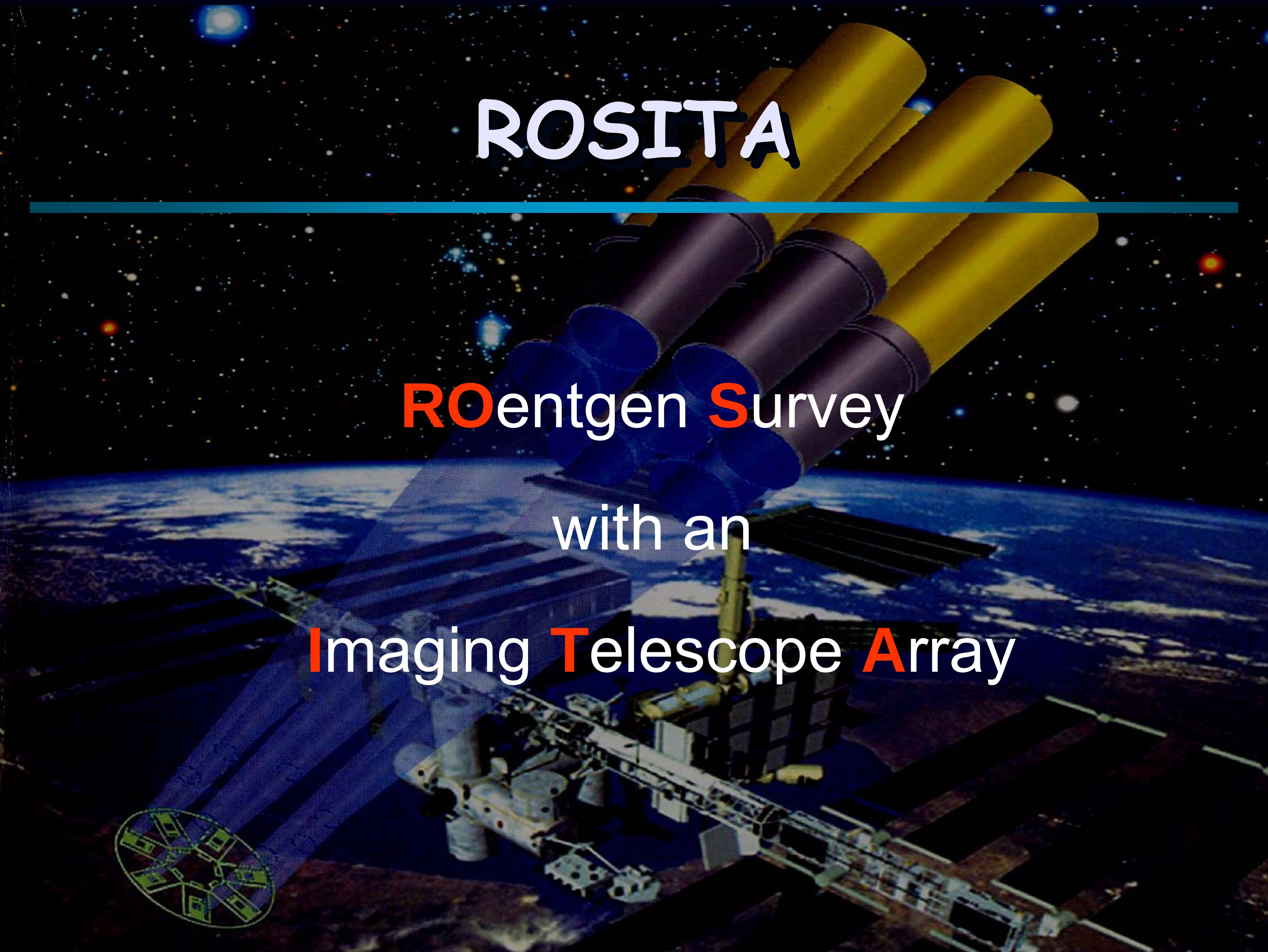


ROSITA

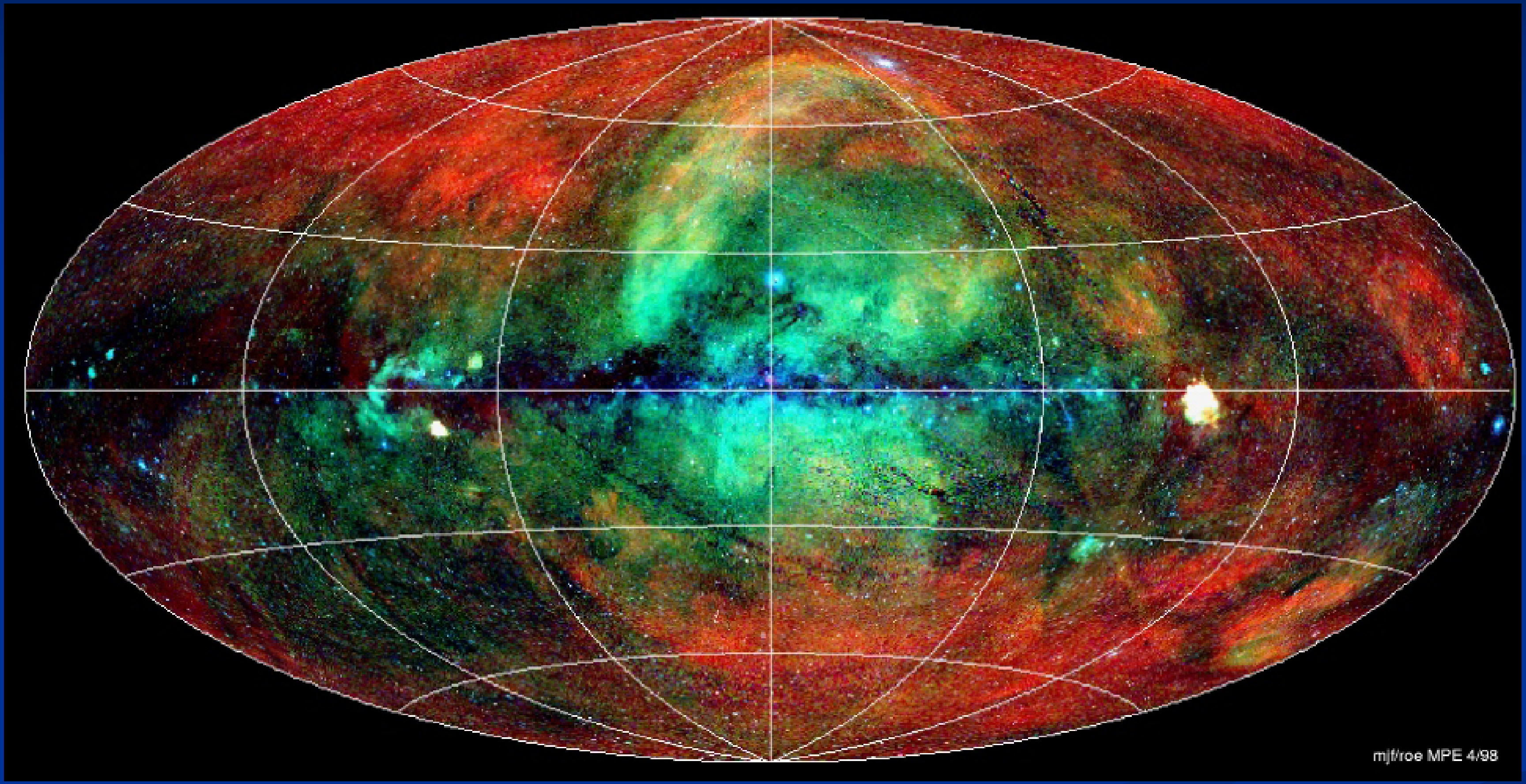
ROentgen Survey

with an

Imaging Telescope Array

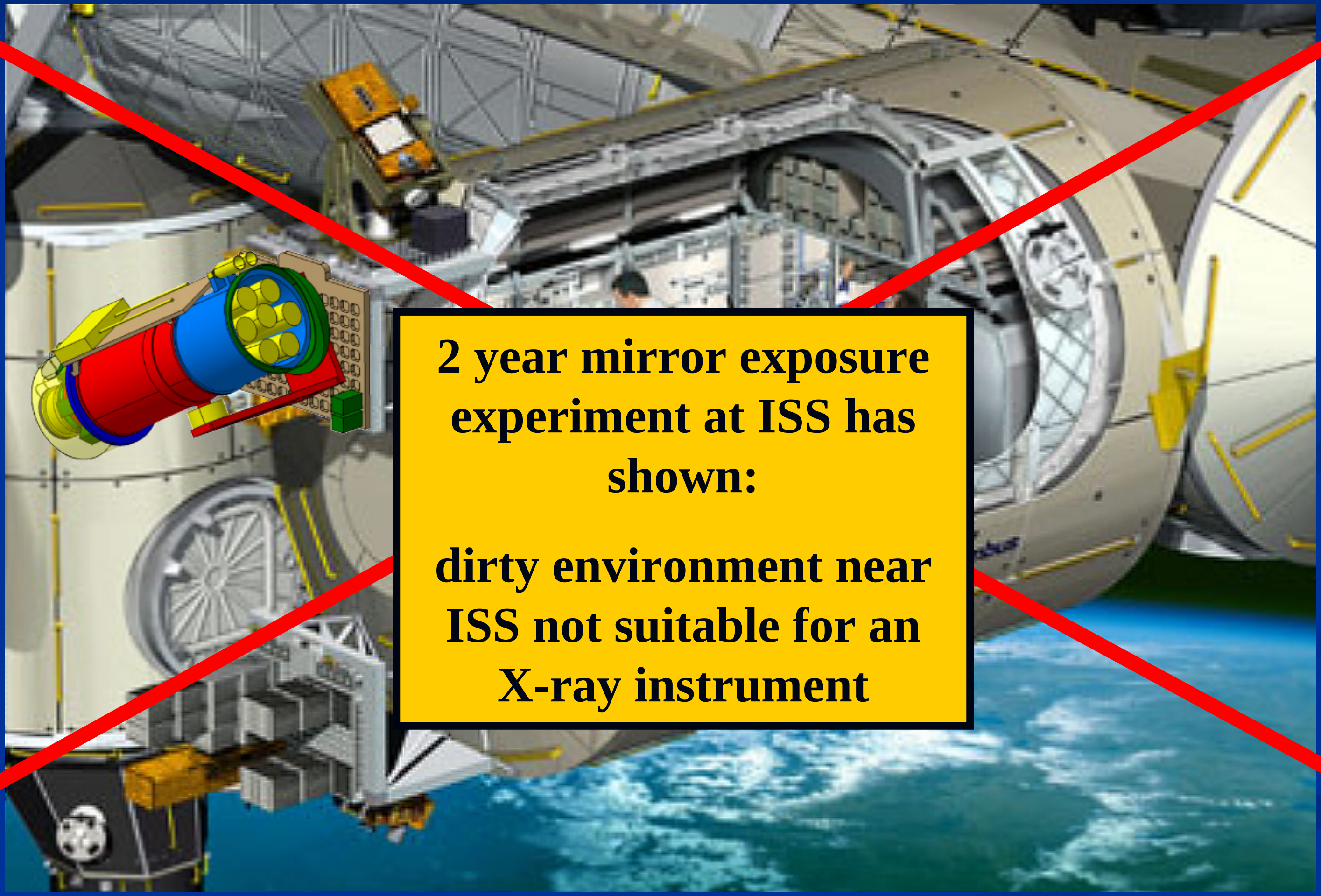


Basic Scientific Idea



To extend the ROSAT survey up to 15 keV

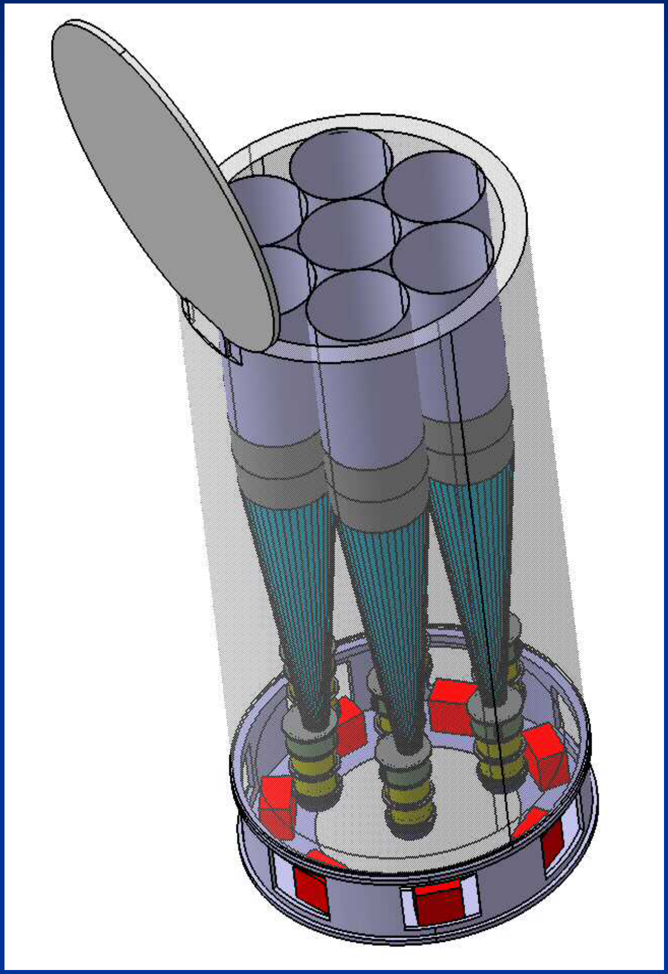
ROSITA design study



2 year mirror exposure experiment at ISS has shown:

dirty environment near ISS not suitable for an X-ray instrument

eROSITA: extended ROSITA



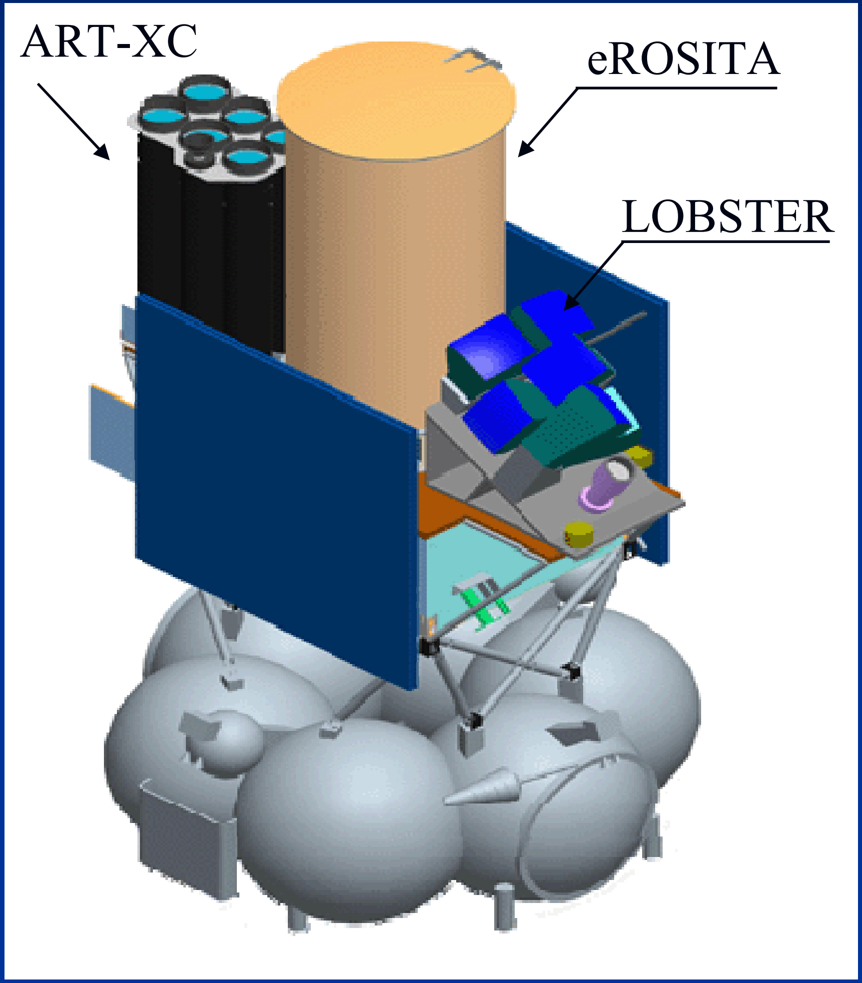
P.Predehl, et. al. 2006, (SPIE 6266-27)

= 7 X-ray telescopes, each with 54 mirror shells + advanced XMM pn-CCD detector -> mounted onto the Russian Spectrum-RG mission

All-Sky Survey + pointed

- 4 + 1 year mission time
- Energy range 0.2 - 12 keV
- FOV: 1 degree
- Sensitivity ~ (10 – 30) x ROSAT
- Temporal res. ~ 50 ms
- Spectral res. ~ 100
- Angular res. ~ 15" (20" survey)

eROSITA: extended ROSITA



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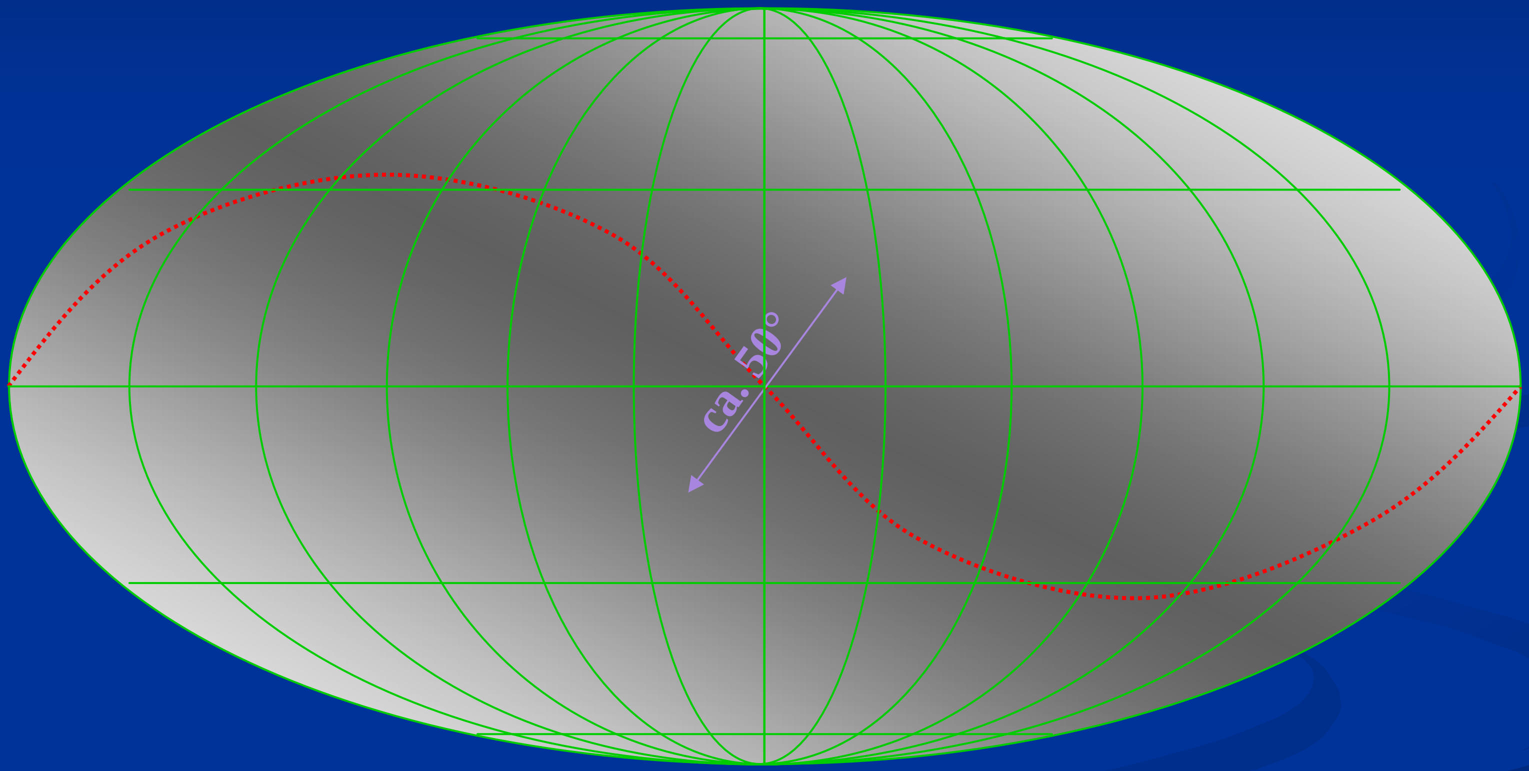
eROSITA: Schematic exposure map

ideal scan geometry: scanning along gal. longitude circles

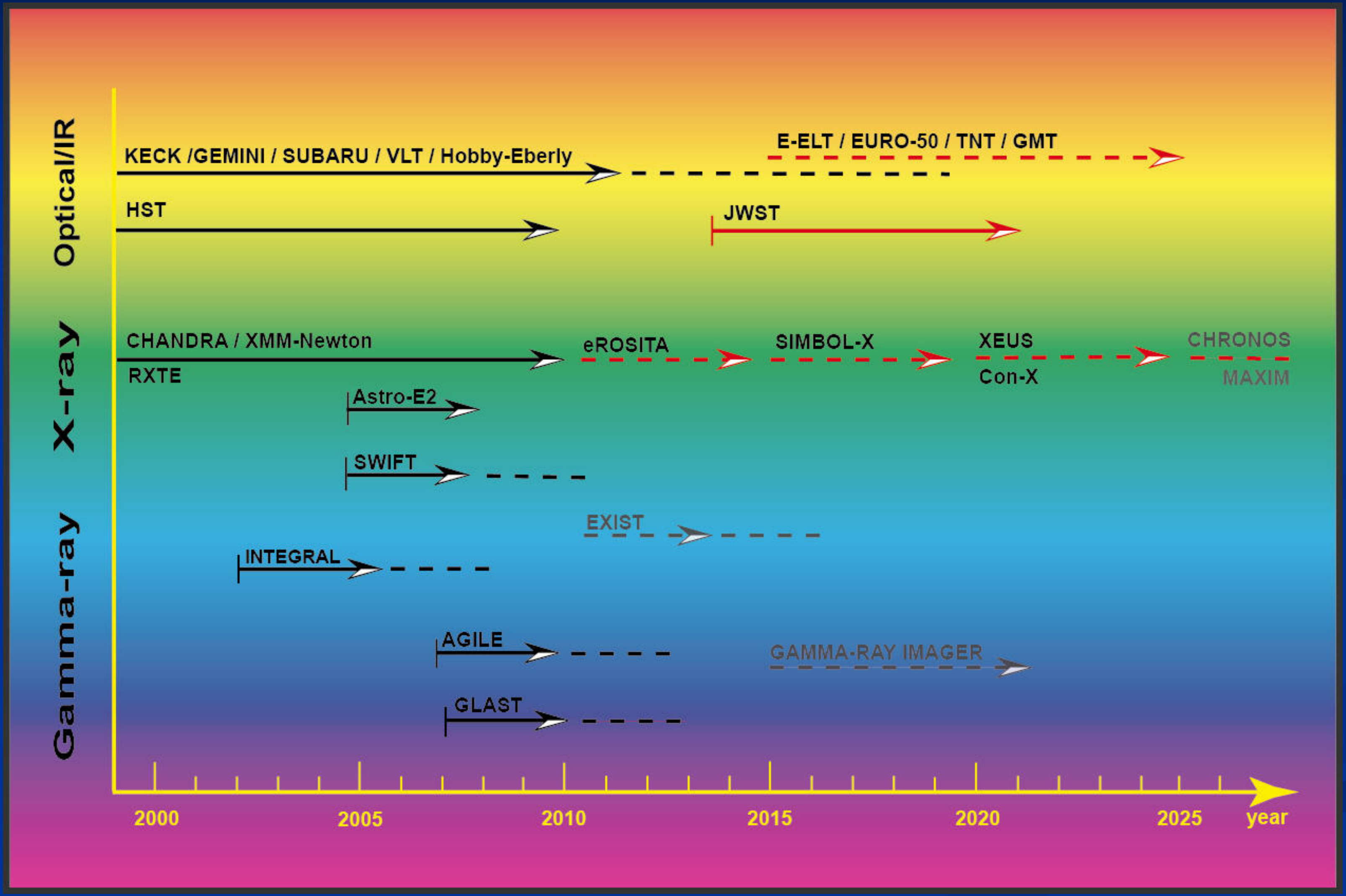
Average exposure ~ 1500 s



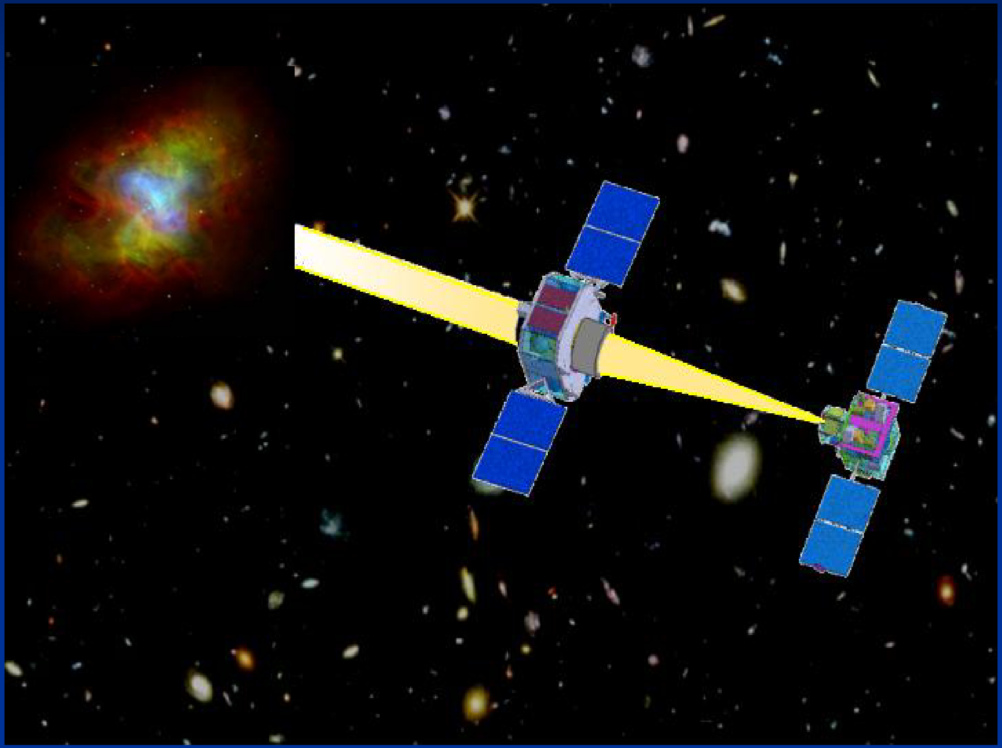
ecliptical coordinate system

galactic plane

Observatories and mission timelines



Simbol-X (0.5 – 70 keV)



A focusing telescope mission for hard X-ray astrophysics

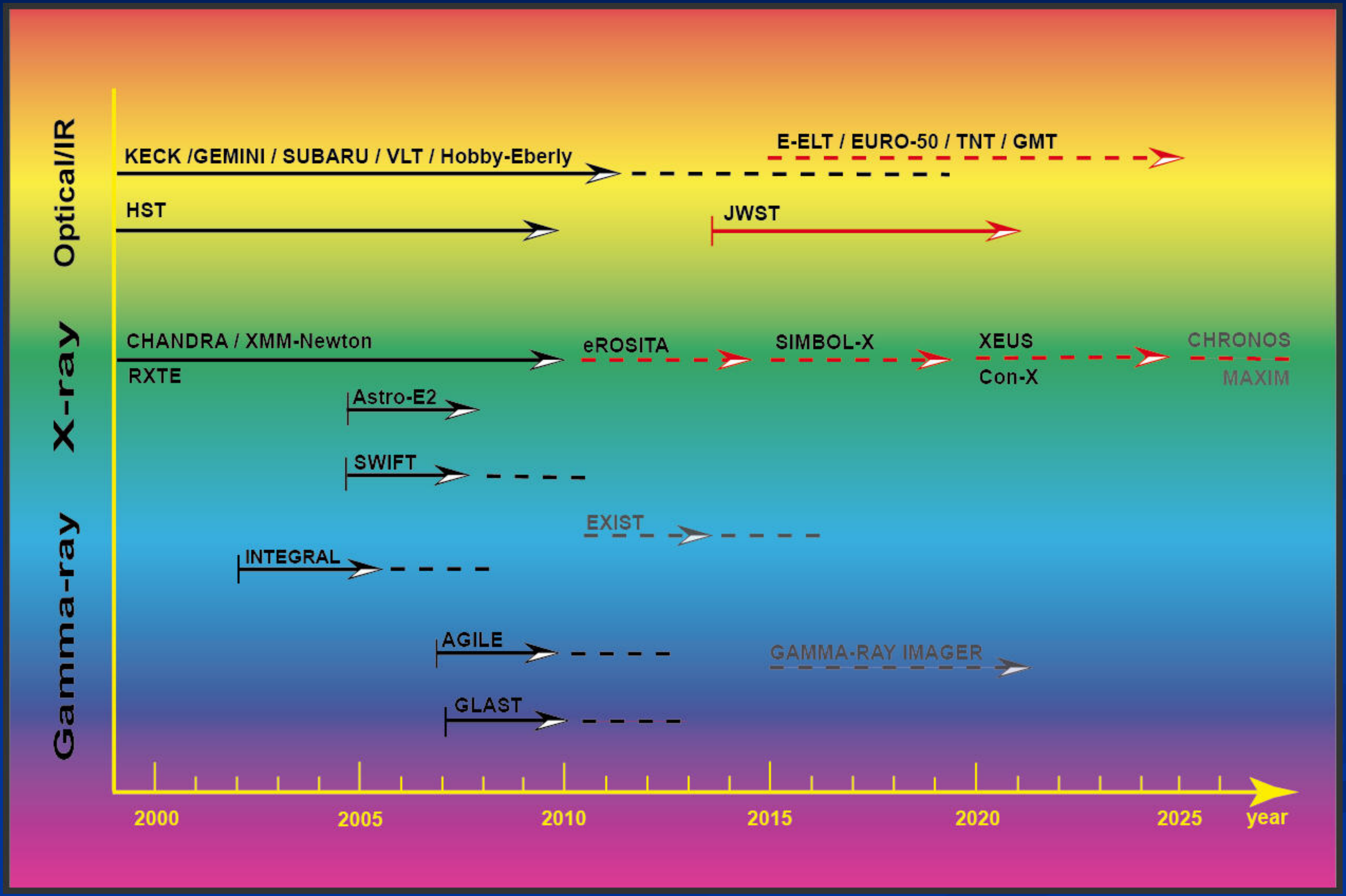
Pathfinder for a formation flight with a free-flying detector and mirror module

An astrophysics mission proposed to the „*Seminaire de Prospective*“ of CNES by a **French/Italian/German/UK** – Consortium

Simbol-X capabilities

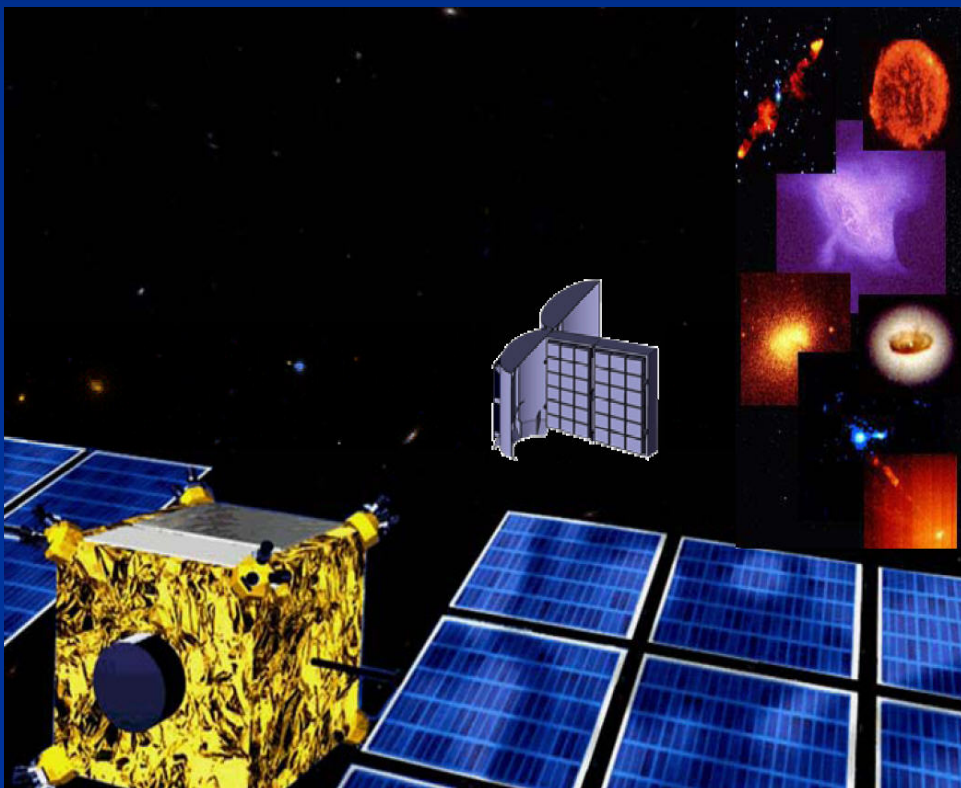
- Energy range 0.5 to 80 keV
- “XMM type” sensitivity up to 50 keV
- i.e. sensitivity more than 100 times better than IBIS on INTEGRAL with a “CCD type” spectral resolution up to ~ 20 keV
- a spectro-imaging capability with a < 30 arcsec angular resolution (HPD) on the full energy range

Observatories and mission timelines



XEUS

The X-Ray Evolving Universe Spectroscopy Mission



Joined ESA/JAXA mission

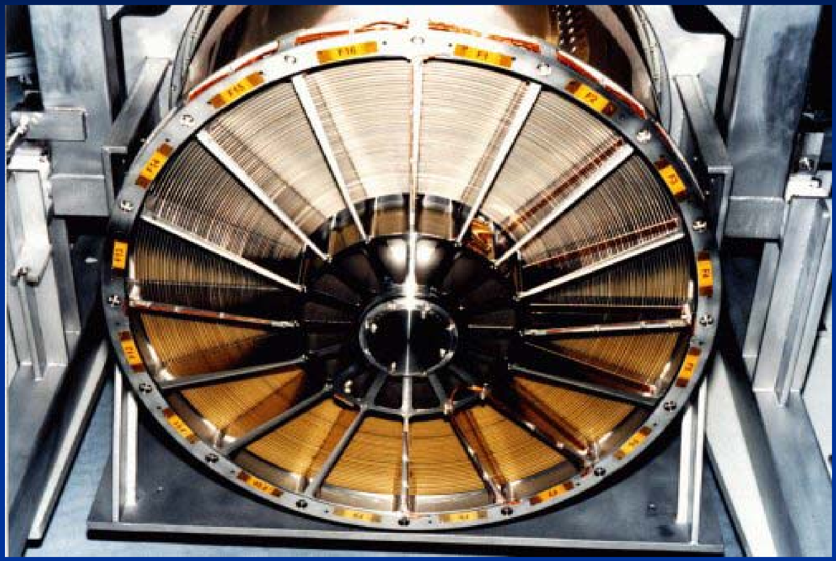
- ESA's potential follow-on mission to XMM
- Challenging satellite design with X-ray mirrors flying 35-50m ahead of the detector
- Effective area: 5 m^2 @ 1 keV (1 m^2 @ 6.5 keV)
- Limiting sensitivity: ~4 x 10^{-18} erg cm^{-2} s^{-1}
- Energy range: 0.1 – 40 keV (80 keV goal)
- FOV: 7′ x 7′ and 1.7′ x 1.7′
- Angular resolution: < 5″ (2″ goal) HPD
- Spectral resolution: 1 eV @ 0.5 keV
6 eV @ 6 keV
- Temporal resolution: < 5ms (< 5 us)
- **Possible launch date after ~2020+**

- **Increasing the sensitivity requires the development of novel lightweight compact X-ray optics!**

→ The mass of the mirror becomes a major driver in the mission design

→ Future applications have to archive good angular resolution and low mass while maintaining collecting area!

XEUS – New High Precision Pore Optics (ESA patent 499)



XMM-Newton nickel optics:
15”
900 kg m^{-2}

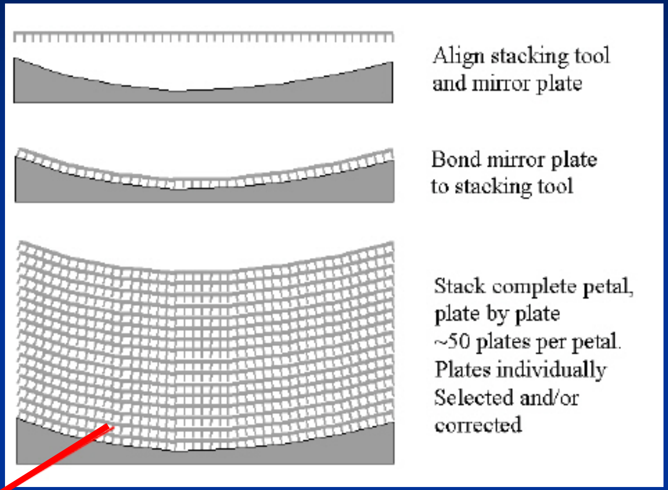
MCP/HPO optics:
30”
25 kg m^{-2}
XMM-Newton size: 4 kg

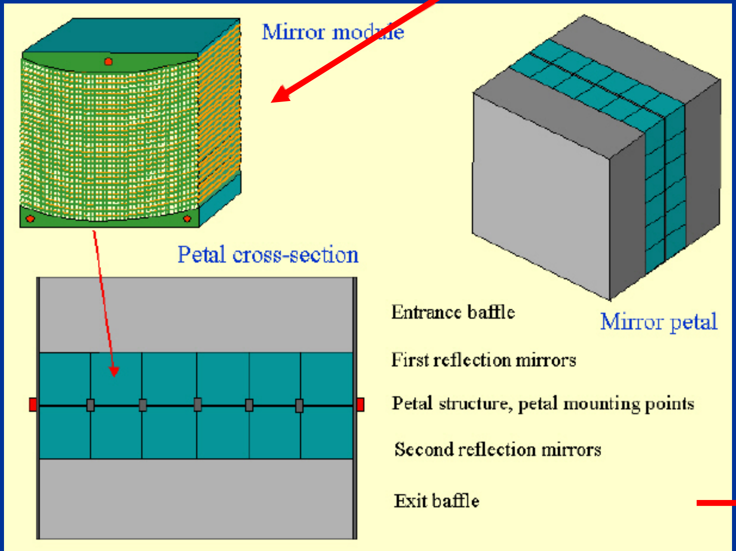
For the conical approximation to the Wolter-I geometry two reflections are required, and therefore also two MCPs in tandem

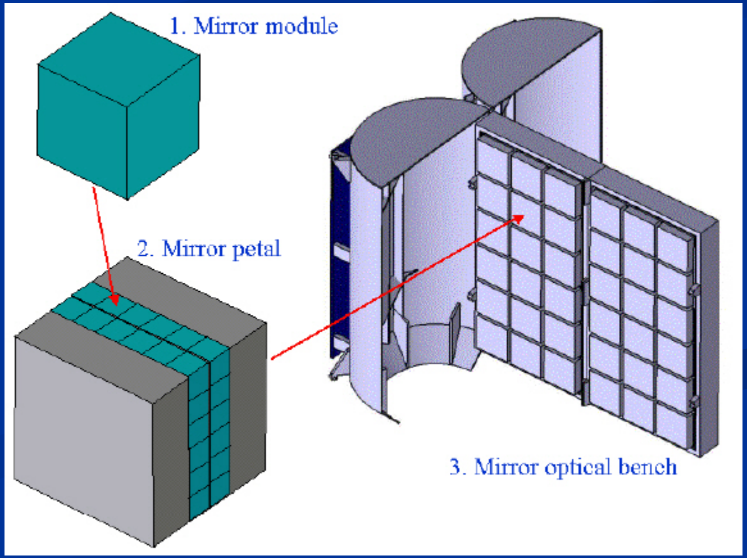
XEUS – Production of small Silicon HPO modules

Micromachining of Silicon

(ESA patent 499)



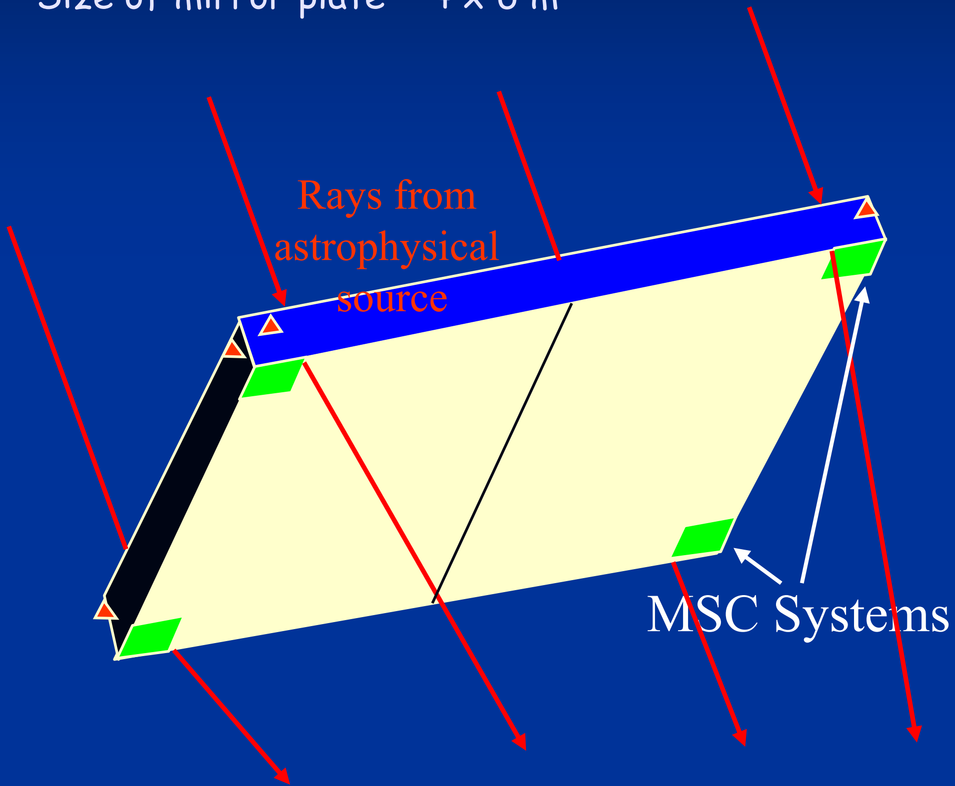




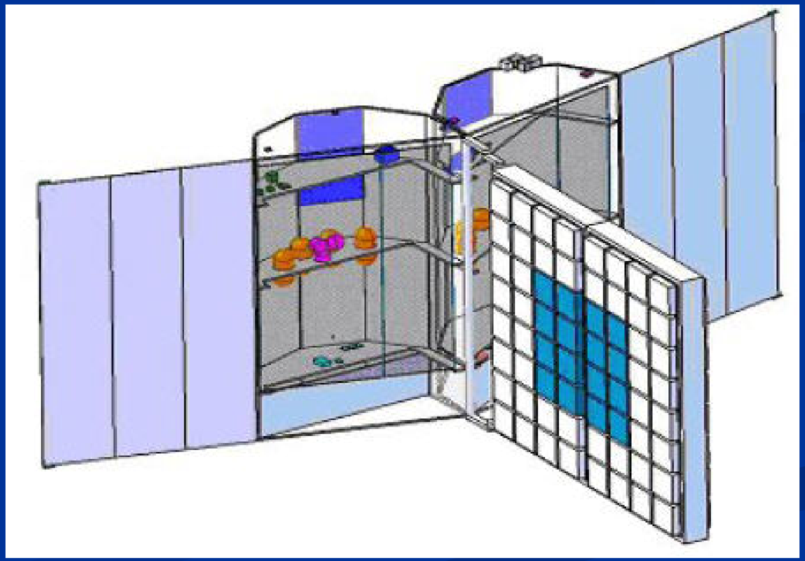
XEUS – New High Precision Pore Optics

Size of mirror plate ~ 4 x 6 m

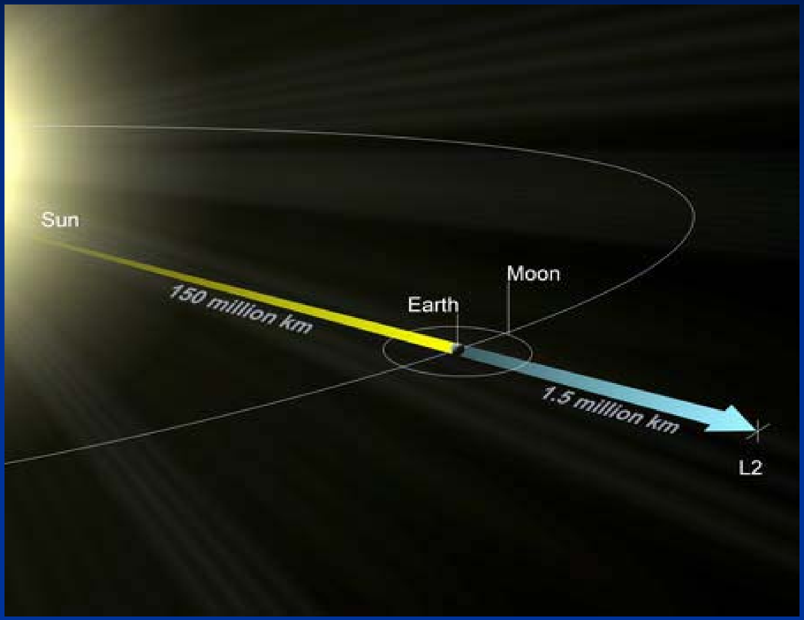
(ESA patent 499)

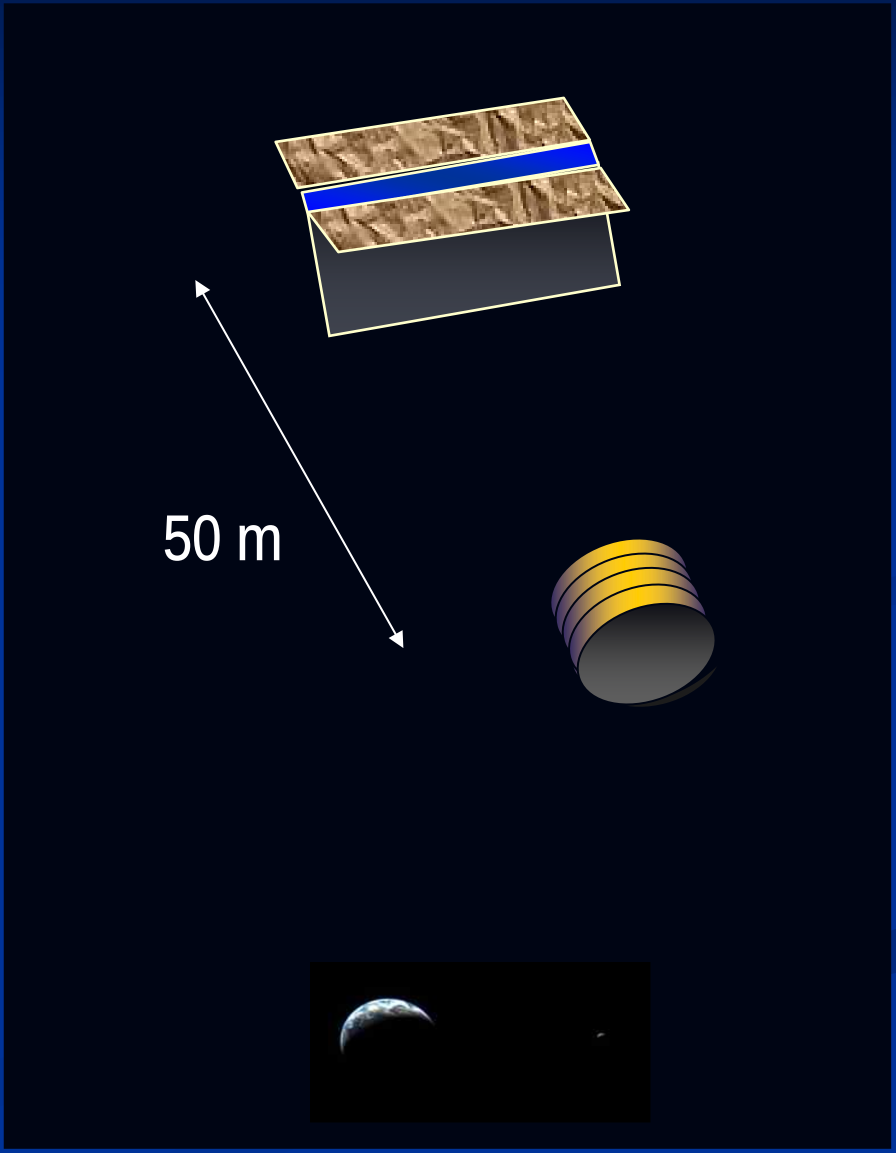


MSC is launched as a sort of „canister“ which unfolds later



XEUS – Current Mission Concept





1. Direct injection of MSC to **L2** with a modest rocket such as a Soyuz-Fregat or Ariane-5 to provide **5 m² mirror area**.

2. At L2 the DSC can be much smaller due to less fuel need and simpler orbit maneuvering

XEUS Instruments/Focal Plane

Wide field semiconductor and Narrow field cryogenic instruments:

Parameter	WFI	NFI1	NFI2
Detector type	Active Pixel DEPFET	STJ	TES
Energy range	0.1 – 30 keV	0.05 – 3 keV	0.5 – 7 keV
Field Coverage	5 arcmin	30 arcsec	32 arcsec
Number of pixels	1000 x 1000	48 x 48	32 x 32
Pixel size (arcsec)	0.3	0.6	1
Energy resolution	50 ev @ 1 keV	2 ev @ 1 keV	2 ev @ 1 keV
Energy resolution	100 ev @ 8 keV	5 ev @ 8 keV	5 ev @ 8 keV
Time resolution	< 5 ms	< 5 us	< 5 us
Count rate limit	200 – 1000 Hz/PSF	25000 Hz/PSF	250 Hz/PSF

XEUS: proposed ancillary instrumentation

- fast timing experiment

  based on a **silicon drift detector** to provide spectrally-resolved counting information for point-sources at 10^6 cts/s

- hard X-ray detector

  co-axially aligned with the on-axis imaging instrument. Proposed to be implemented as compound semiconductor detector pixel-array located behind the WFI

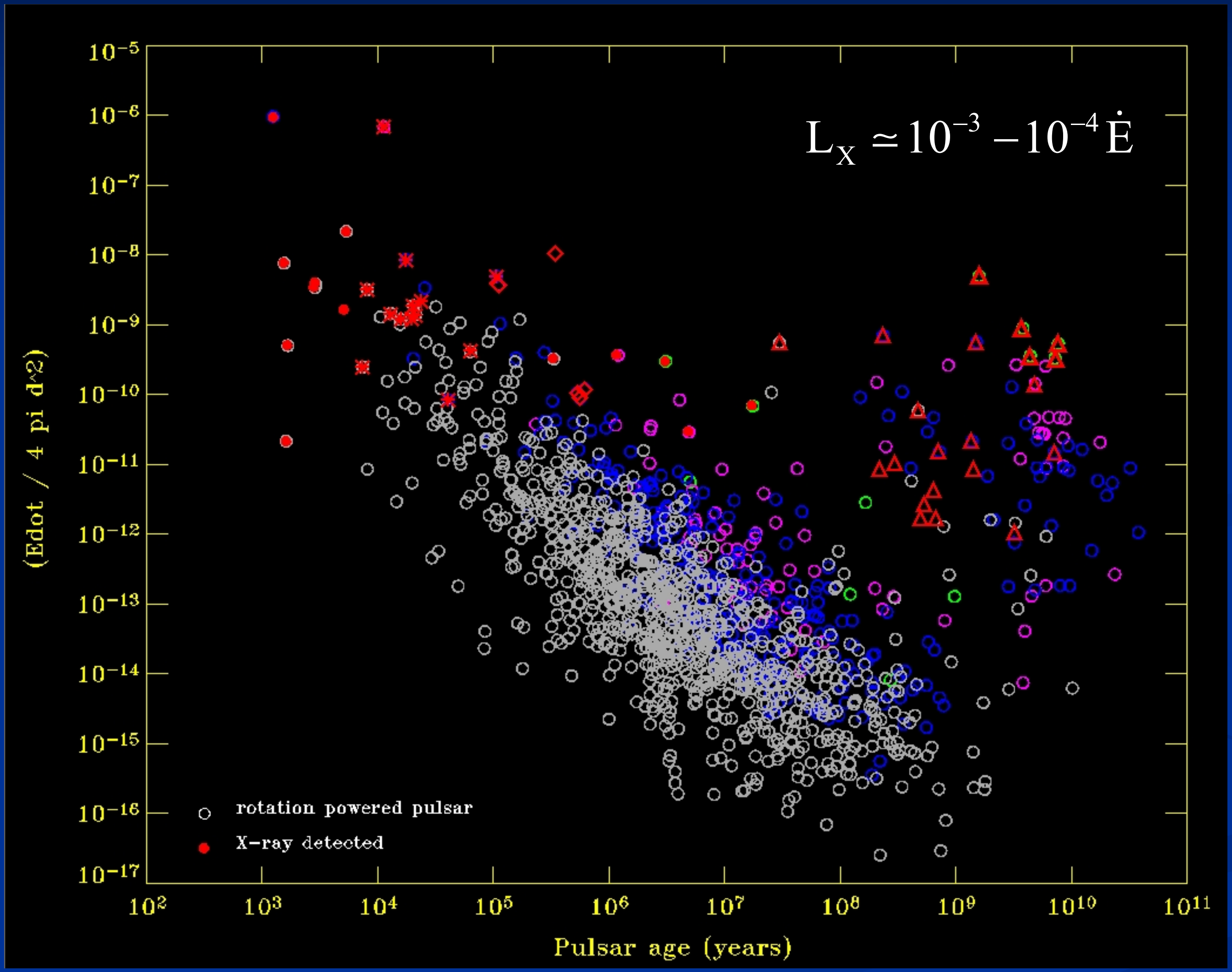
- enhanced wide-field instrument

  using an array of more conventional CCDs located around the on-axis imager

- polarization detector

  comprising a micro-well gas electron multiplier to sense the photoelectric polarization effect

Summary of rot. powered Pulsars detected at X



~ Limits:

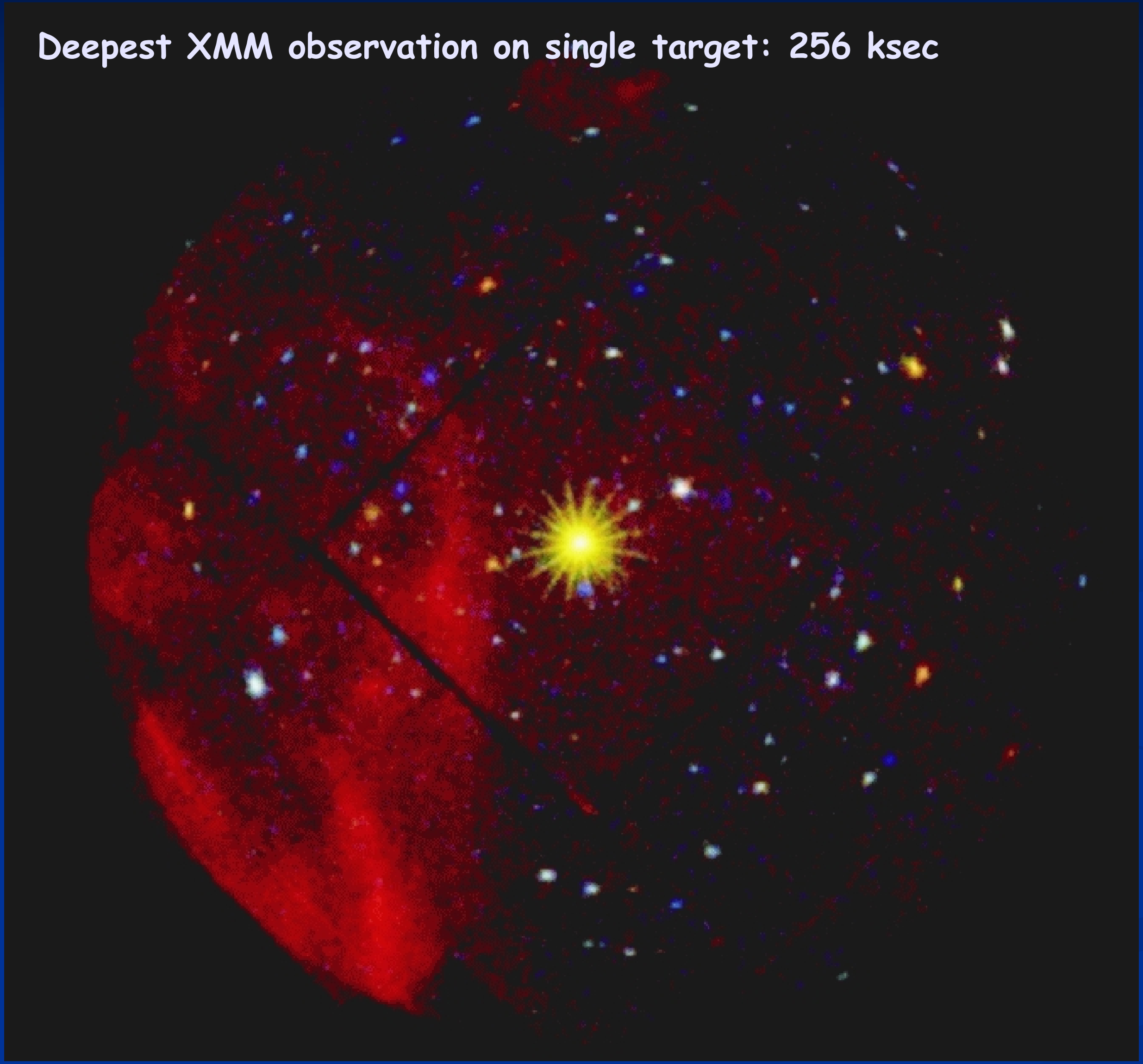
ROSAT

Chandra

XMM

XEUS

XEUS: Simulation of pulsar spectra



1E 1207-52 in G296.5+10.0

d= 2.2 kpc

age ~ 7 kyr

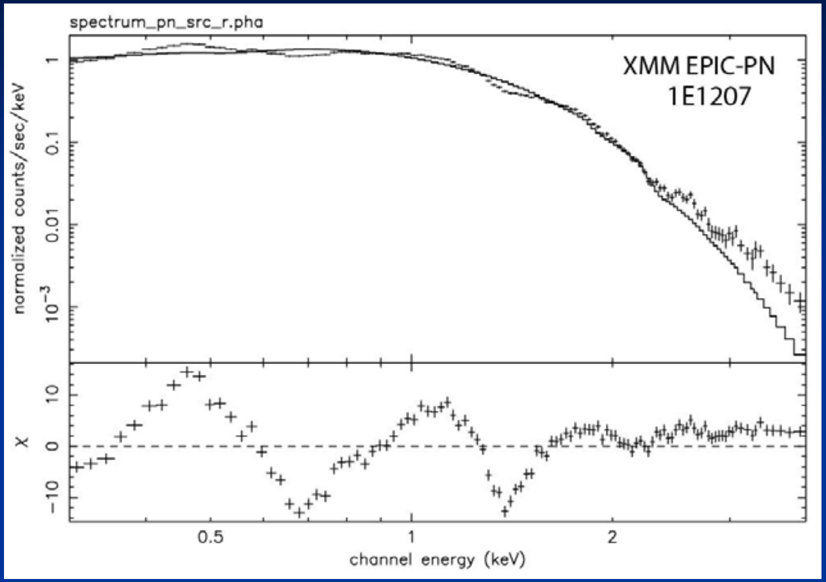
P = 424 ms

Zavlin et al. 2001

Mereghetti et al 2002

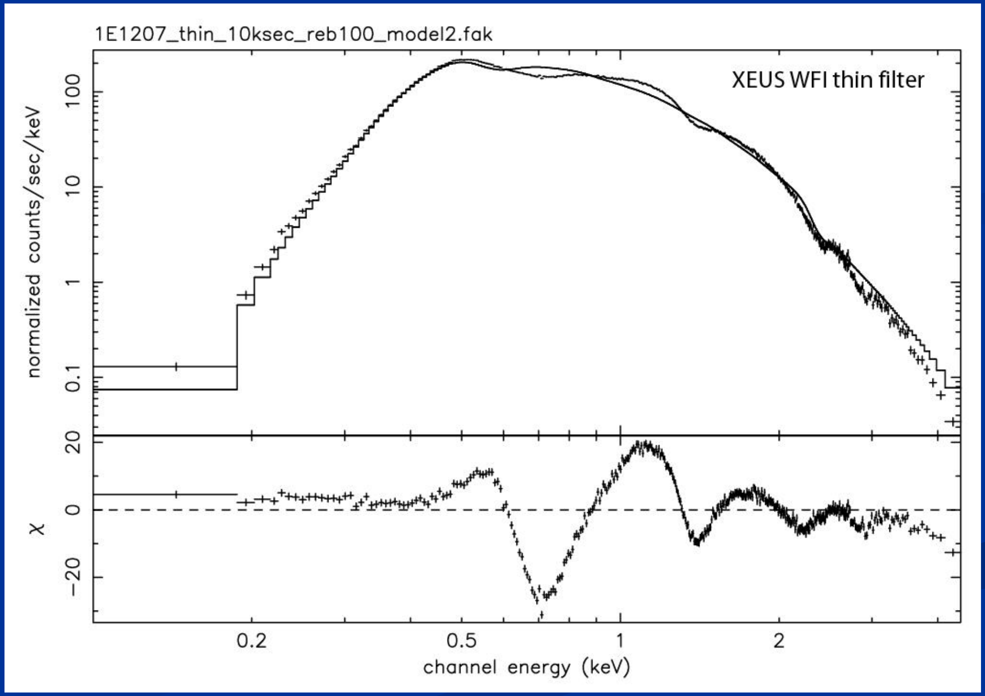
De Luca et al. 2004

XEUS: Simulation of spectra: 1E1207

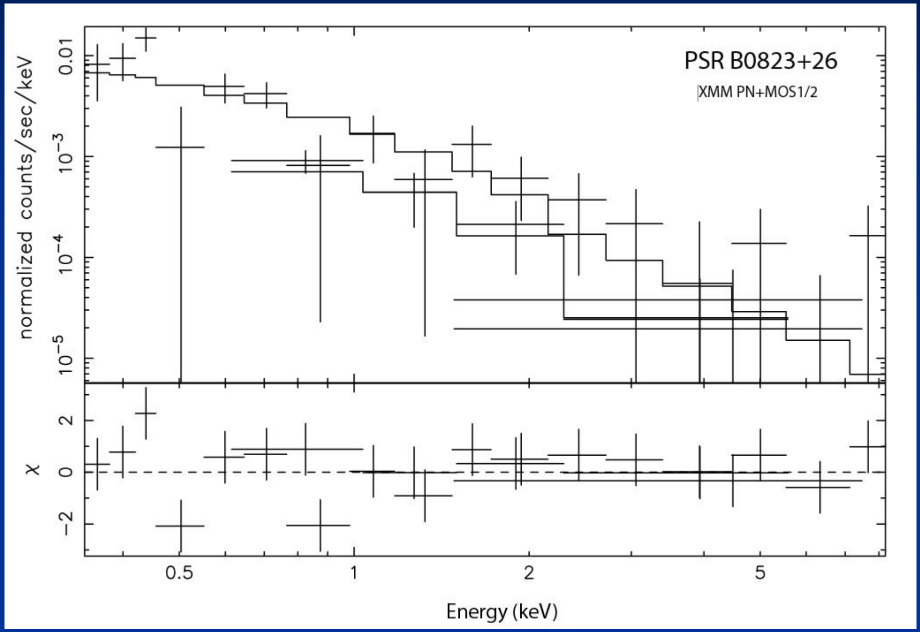


observed with XMM-Newton (thin filter, 256 ksec)

XEUS WFI (thin filter, 10 ksec)



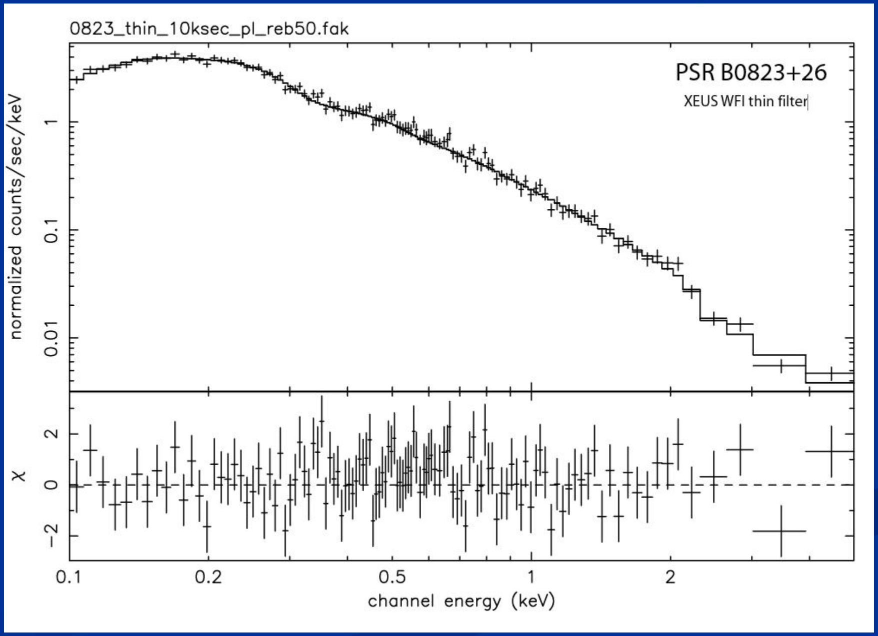
XEUS: Simulation of spectra: B0823+26



40 ksec XMM-Newton obs. of PSR B0823+26

(Becker, Weisskopf, Tennant et al. 2004)

XEUS WFI
(thin filter, 10 ksec)




Thank you
very much