THE DEVELOPMENT OF X-RAY ASTRONOMY

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Presented at Symposium

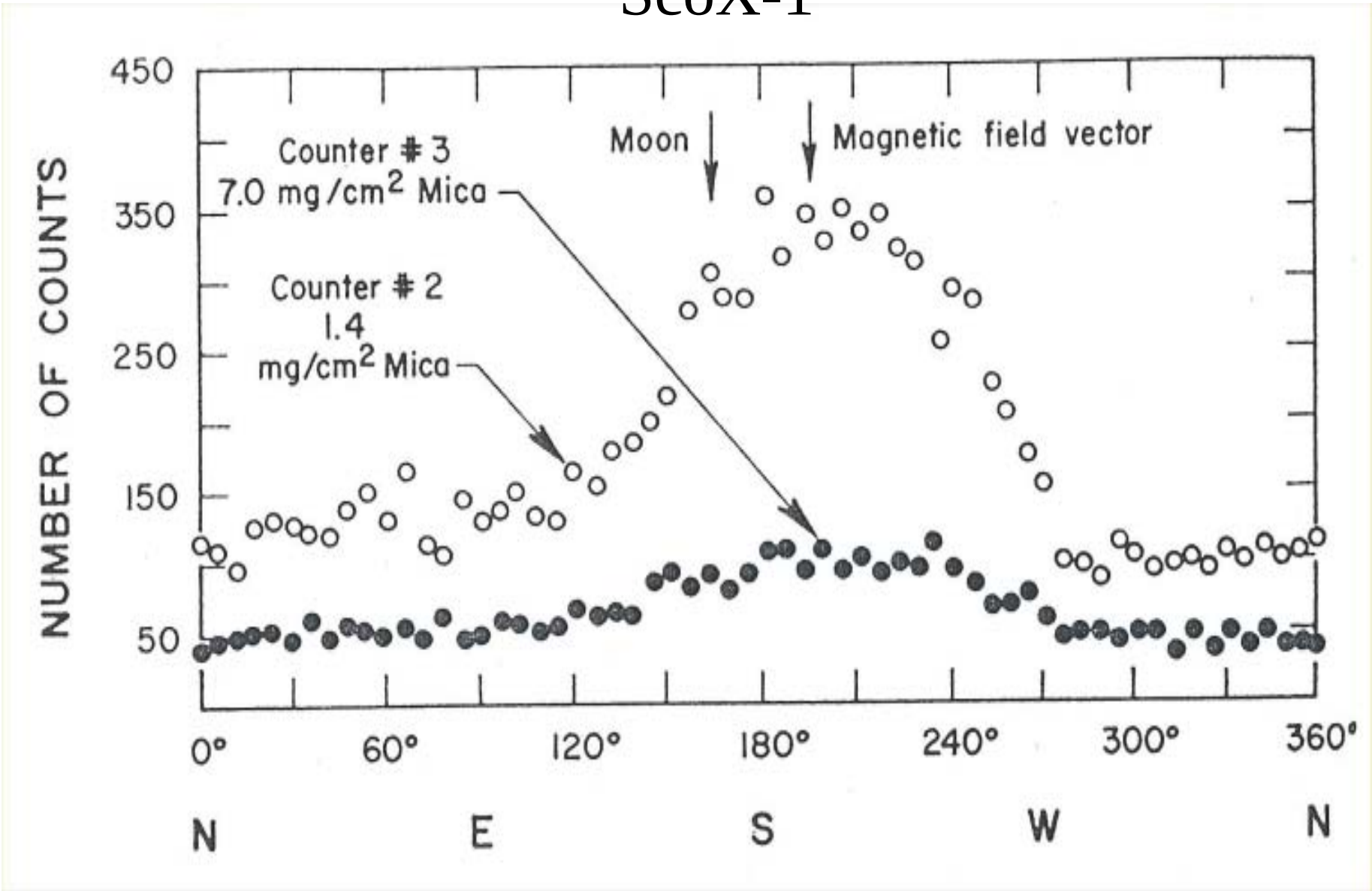
FOUR YEARS OF CHANDRA OBSERVATIONS

September 16, 2003

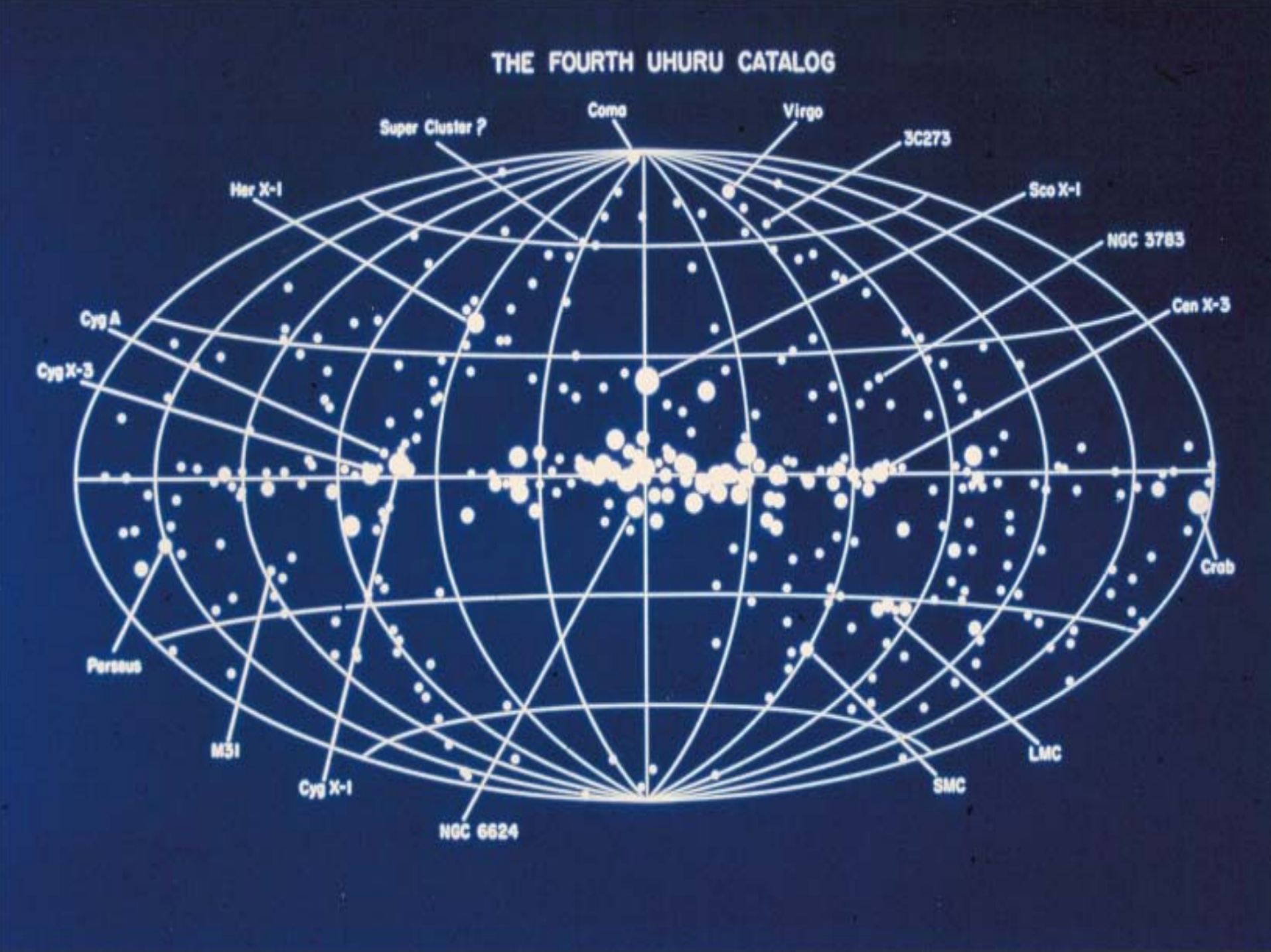
GIACCONI, CLARK, ROSSI (1960)

SUN	< 20 Å	CORONAL EMISSION	~ 10^6 CM^{-2} S^{-1}
SUN AT 8 LIGHT YEARS	< 20 Å	CORONAL EMISSION	2.5 x 10^{-4} CM^{-2} S^{-1}
SIRIUS IF $L_X \sim L_{OPT}$	< 20 Å	? NO CONVECTIVE ZONE	0.25 CM^{-2} S^{-1}
FLARE STARS	< 20 Å	SUNLIKE FLARE?	?
PECULIAR A STARS	< 20 Å	B ~ 10^4 GAUSS LARGE B PARTICLE ACCELERATION	?
CRAB NEBULA	< 25 Å	SYNCHROTRON E_E ? 10^{13} eV IN B = 10^{-4} GAUSS LIFETIMES?	?
MOON	< 23 Å	FLUORESCENCE	0.4 CM^{-2} S^{-1}
MOON	~ 20 Å	IMPACT FROM SOLAR WIND ELECTRONS Φ_ε = 0-10^{13} CM^{-2} S^{-1}	0-1.6 x 10^3 CM^{-2} S^{-1}
SCO X-1	2-8 Å	?	28 ± 1.2 CM^{-2} S^{-1}

ScoX-1


NUMBER OF COUNTS
450
350
250
150
50
Counter # 3
7.0 mg/cm² Mica
Counter # 2
1.4
mg/cm² Mica
Moon
Magnetic field vector
0°
60°
120°
180°
240°
300°
360°
N
E
S
W
N

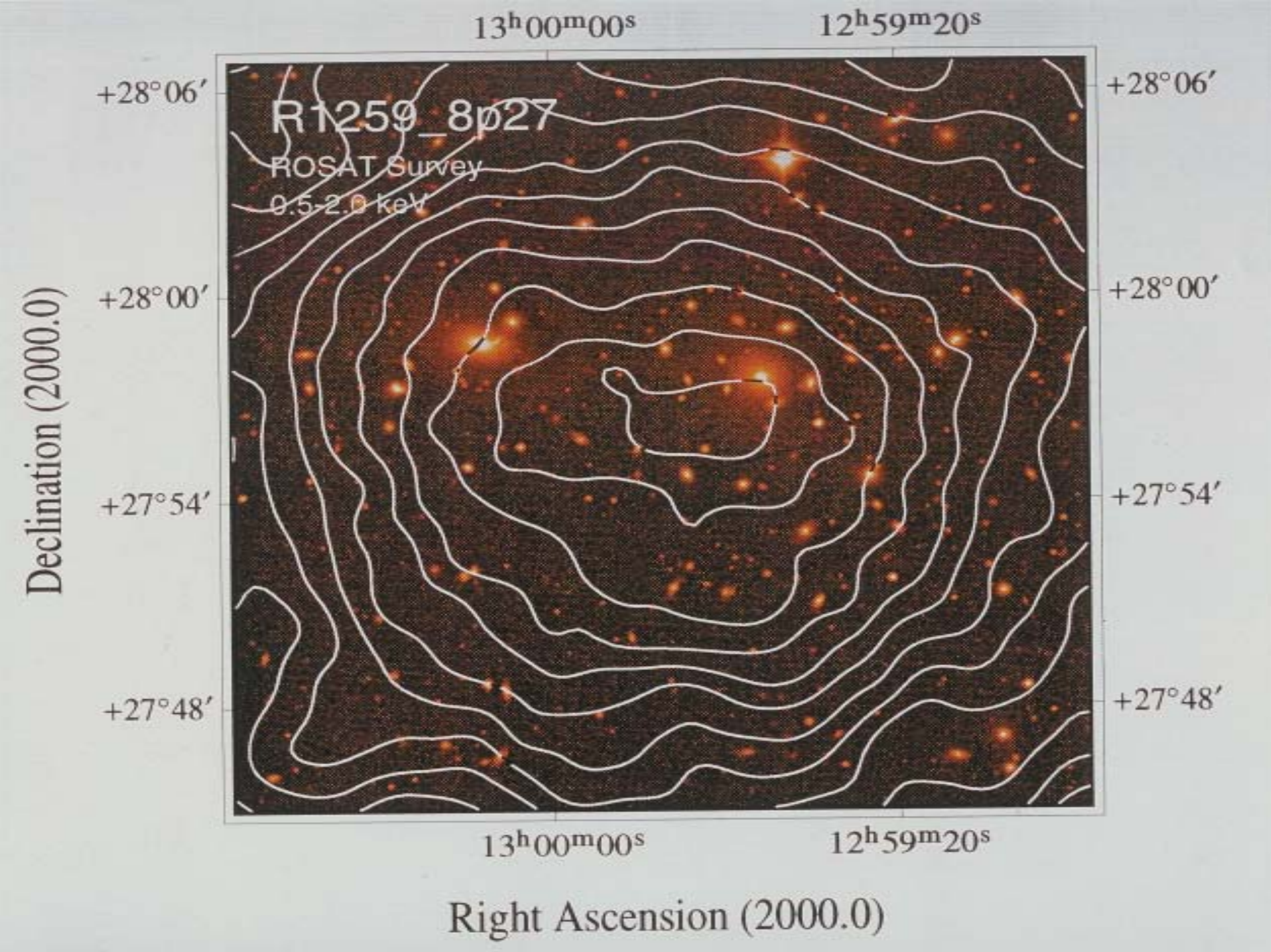
UHURU satellite (artist's image)


THE FOURTH UHURU CATALOG
Super Cluster ?
Coma
Virgo
3C273
Her X-1
Sco X-1
NGC 3783
Cen X-3
Cyg A
Cyg X-3
Crab
Perseus
M31
Cyg X-1
NGC 6624
SMC
LMC

Hercules X-1 artist concept

THE DISCOVERY OF X-RAY BINARY SYSTEMS

- EXISTENCE OF BINARY STELLAR SYSTEMS CONTAINING A NEUTRON STAR OR A BLACK HOLE
- EXISTENCE OF BLACK HOLES OF STELLAR MASS
- MEASURE OF THE MASS, RADIUS, MOMENT OF INERTIA AND EQUATION OF STATE FOR NEUTRON STARS (DENSITY 10^{15} GR/CM^3)
- A NEW SOURCE OF ENERGY DUE TO GRAVITATIONAL INFALL (100 TIMES MORE EFFICIENT PER NUCLEON THAN FUSION)
- A MODEL (GENERALLY ACCEPTED) FOR THE NUCLEUS OF ACTIVE GALAXIES AND QUASARS


13h00m00s
12h59m20s
+28°06′
+28°00′
+27°54′
+27°48′
R1259_8p27
ROSAT Survey
0.5-2.0 keV
Declination (2000.0)
Right Ascension (2000.0)

THE DISCOVERY OF X-RAY EMISSION FROM CLUSTERS OF GALAXIES

- **EXISTENCE OF GAS**

  $T = 10^7 – 10^8$ K

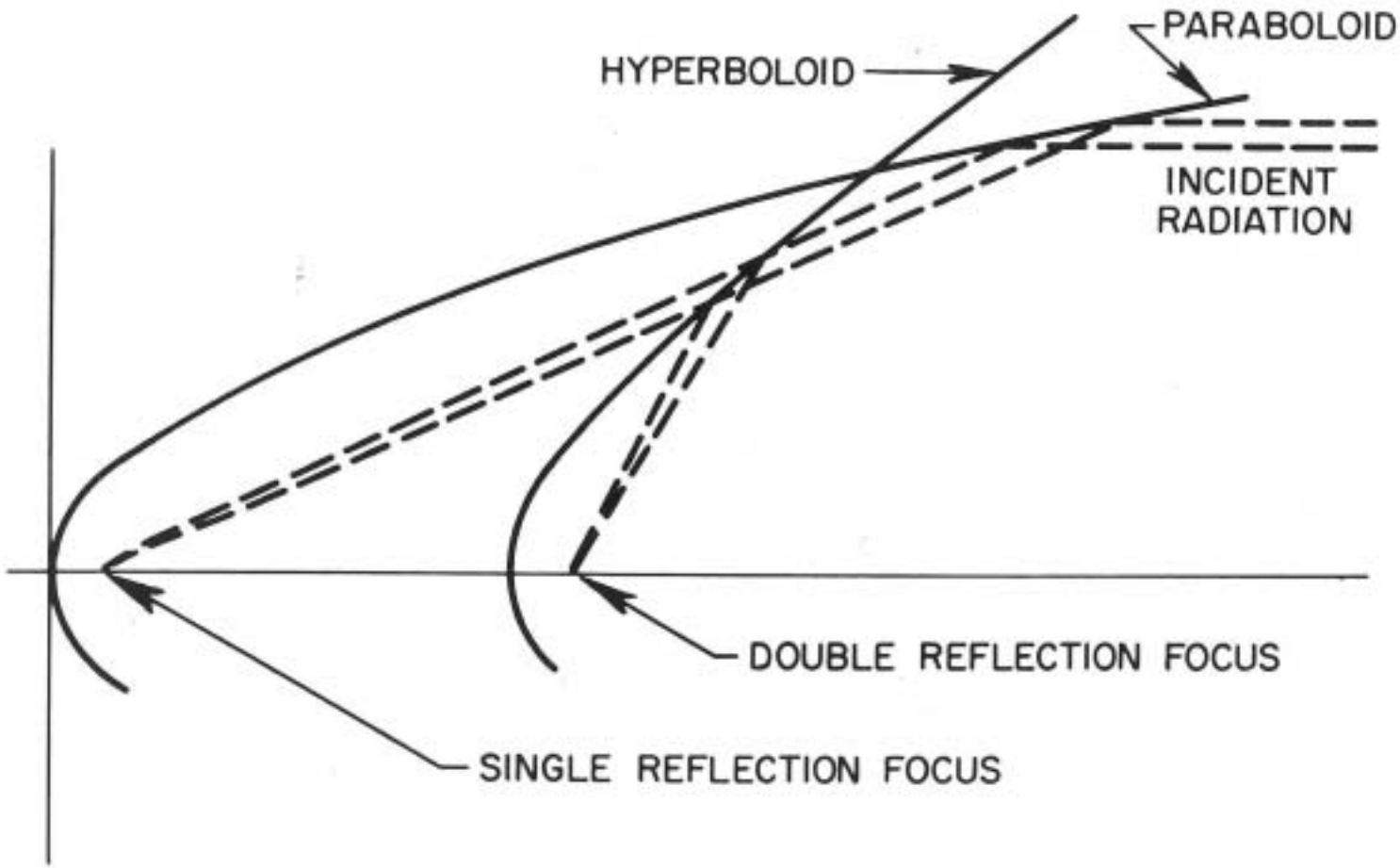
  $L_X = 10^{42} – 10^{45}$ ERG S^{-1}

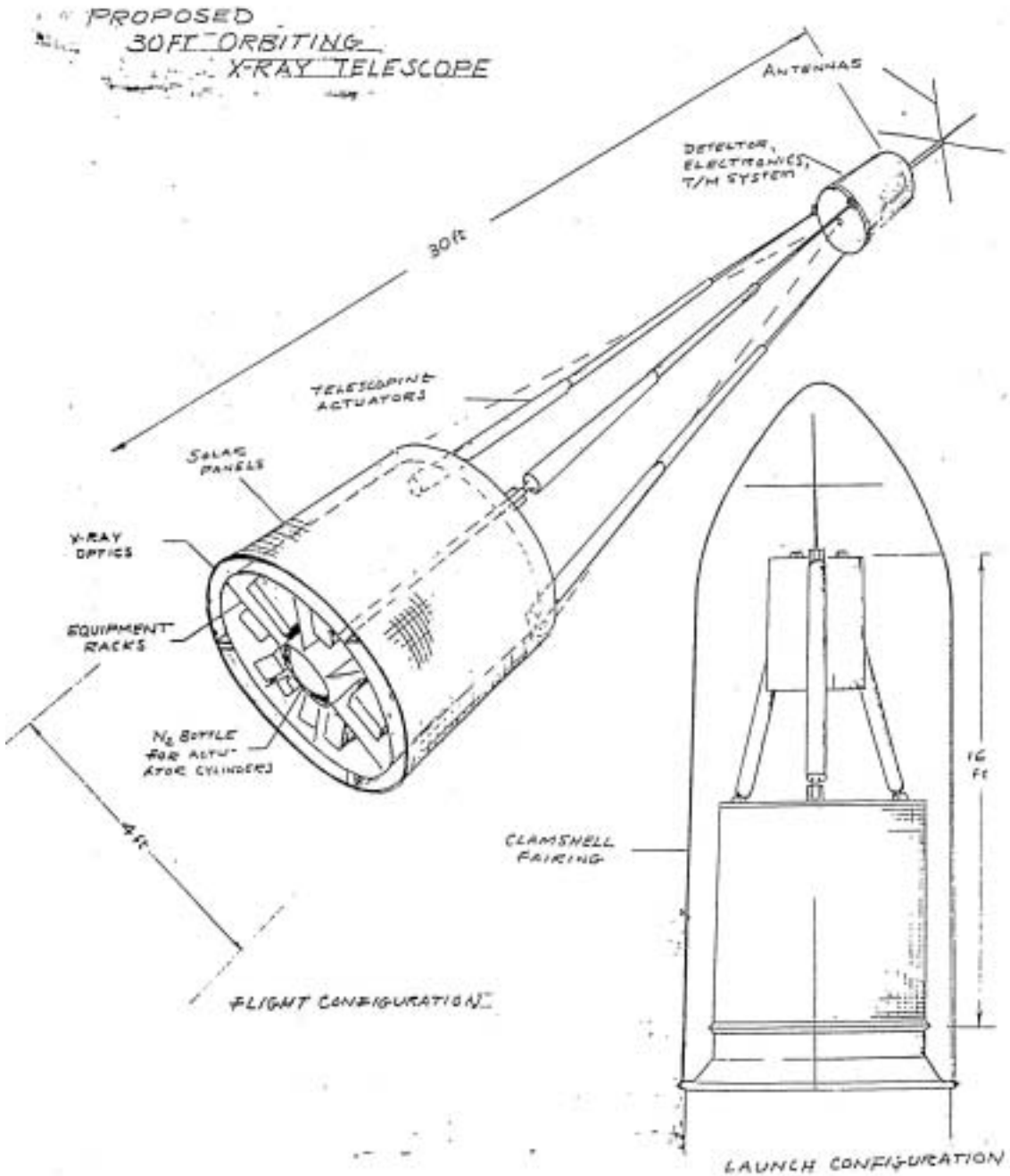
  DENISITY $10^{-2} – 10^{-3}$ CM^{-3}

  MASS IN GAS ~ MASS IN GALAXIES

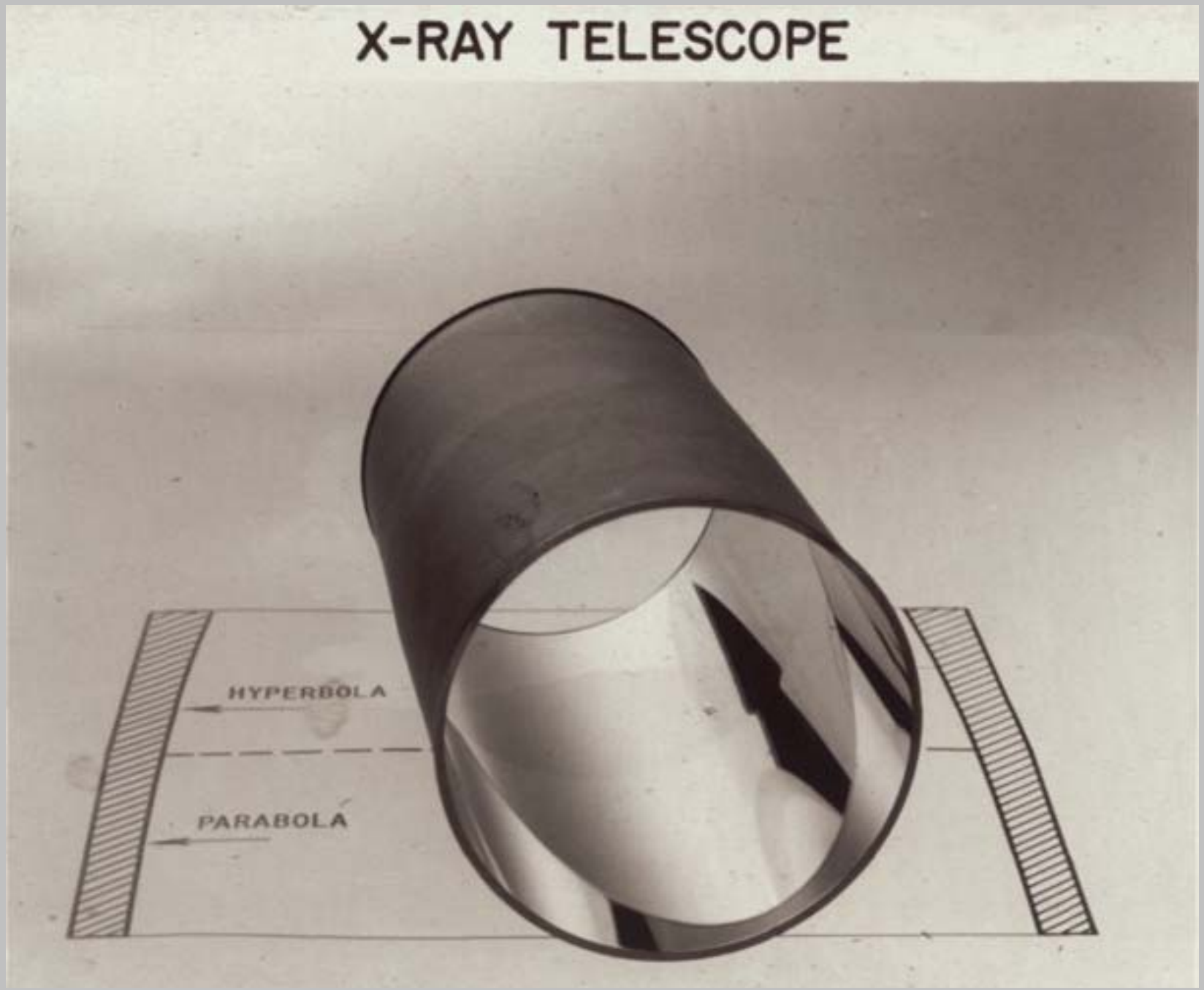
- **STRUCTURE AND DISTRIBUTION OF MASS IN CLUSTERS**
- **MANY CLUSTERS NOW FORMING – SUBSTRUCTURES = A YOUNG UNIVERSE**
- **TRACERS OF LARGE SCALE STRUCTURE**
- **FORMATION, EVOLUTION AND DYNAMIC DEVELOPMENT OF CLUSTERS; SPECTRUM OF INITIAL FLUCTUATIONS; CHEMICAL EVOLUTION**
- **H_O THROUGH SUNAYEV-ZELDOVICH EFFECT (INVERSE COMPTON ON 3K RADIATION)**

FOCUSSING X-RAY TELESCOPE

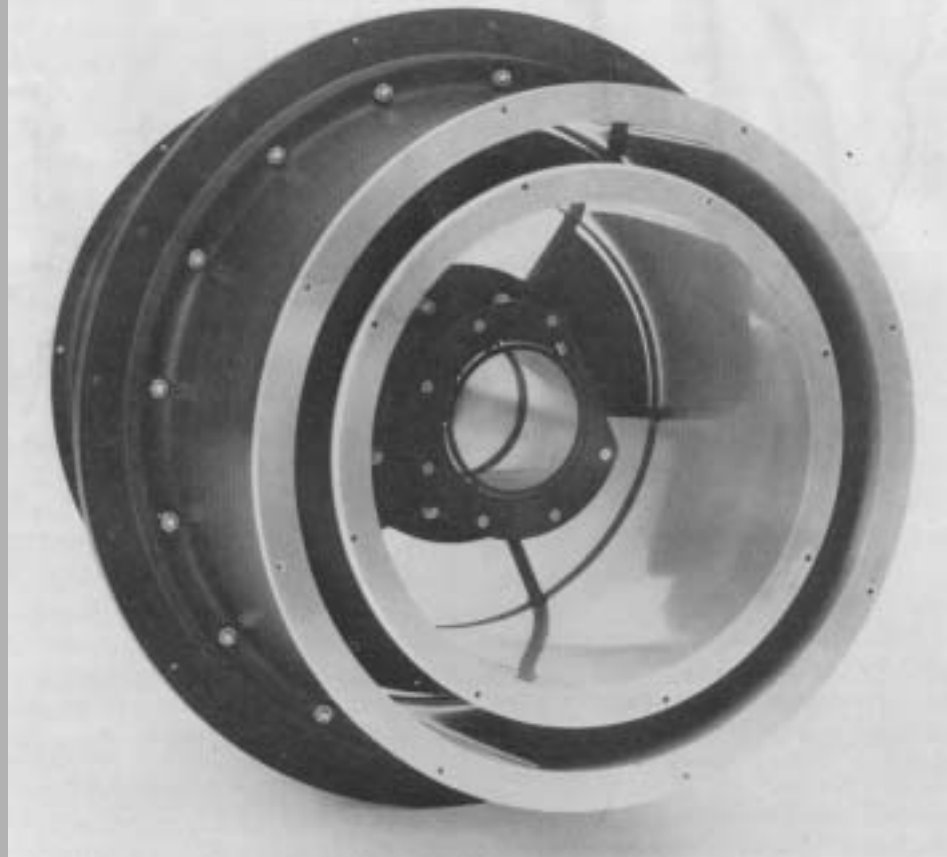



PROPOSED
30 FT ORBITING
X-RAY TELESCOPE
ANTENNAS
DETECTOR, ELECTRONICS, T/M SYSTEM
30 ft
TELESCOPING ACTUATORS
SOLAR PANELS
X-RAY OPTICS
EQUIPMENT RACKS
N_2 BOTTLE FOR ALTITUDE CYLINDERS
4 ft
FLIGHT CONFIGURATION
CLAMSHELL FAIRING
LAUNCH CONFIGURATION

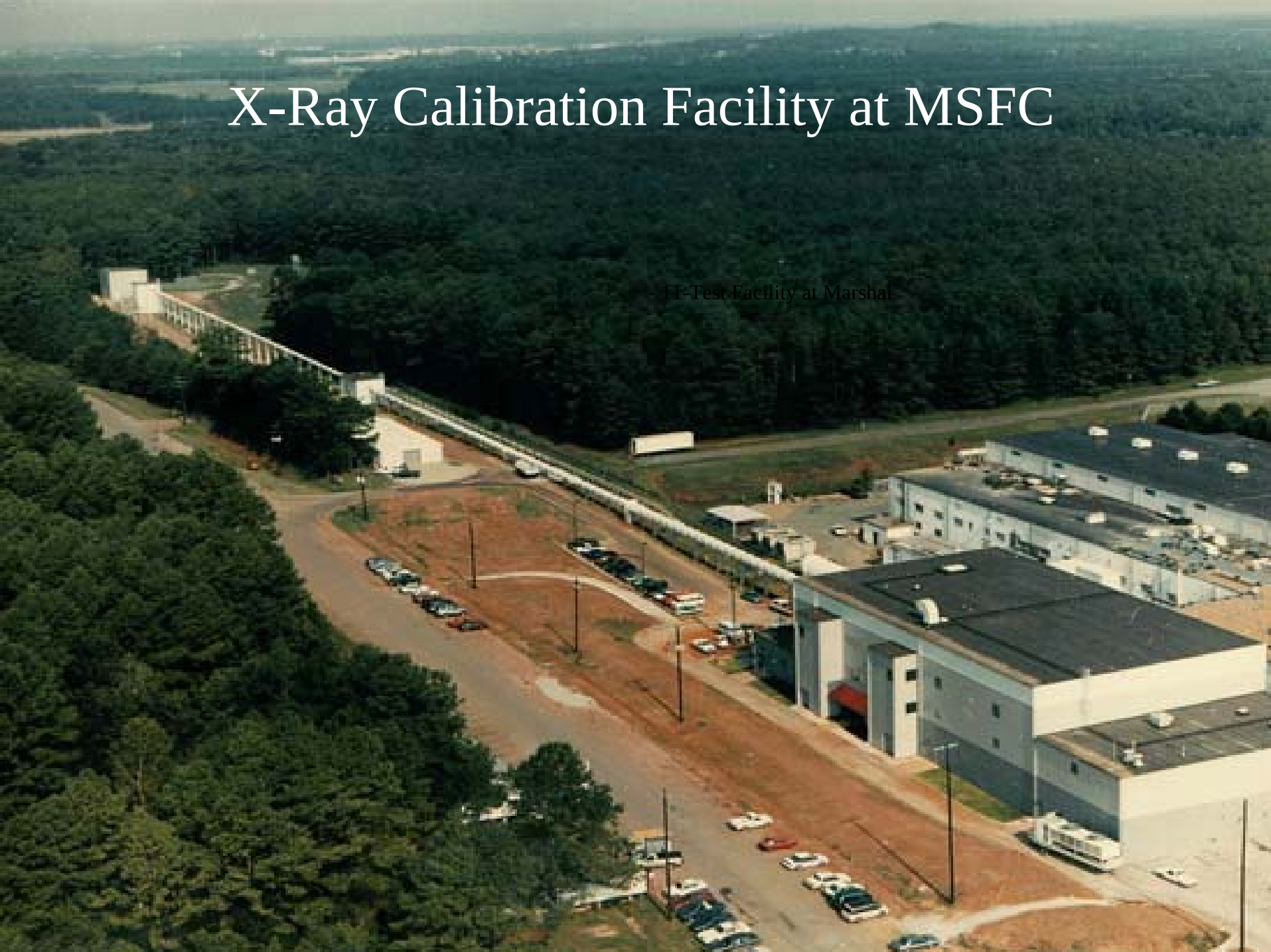
X-RAY TELESCOPE



So54 Sky Lab mirror

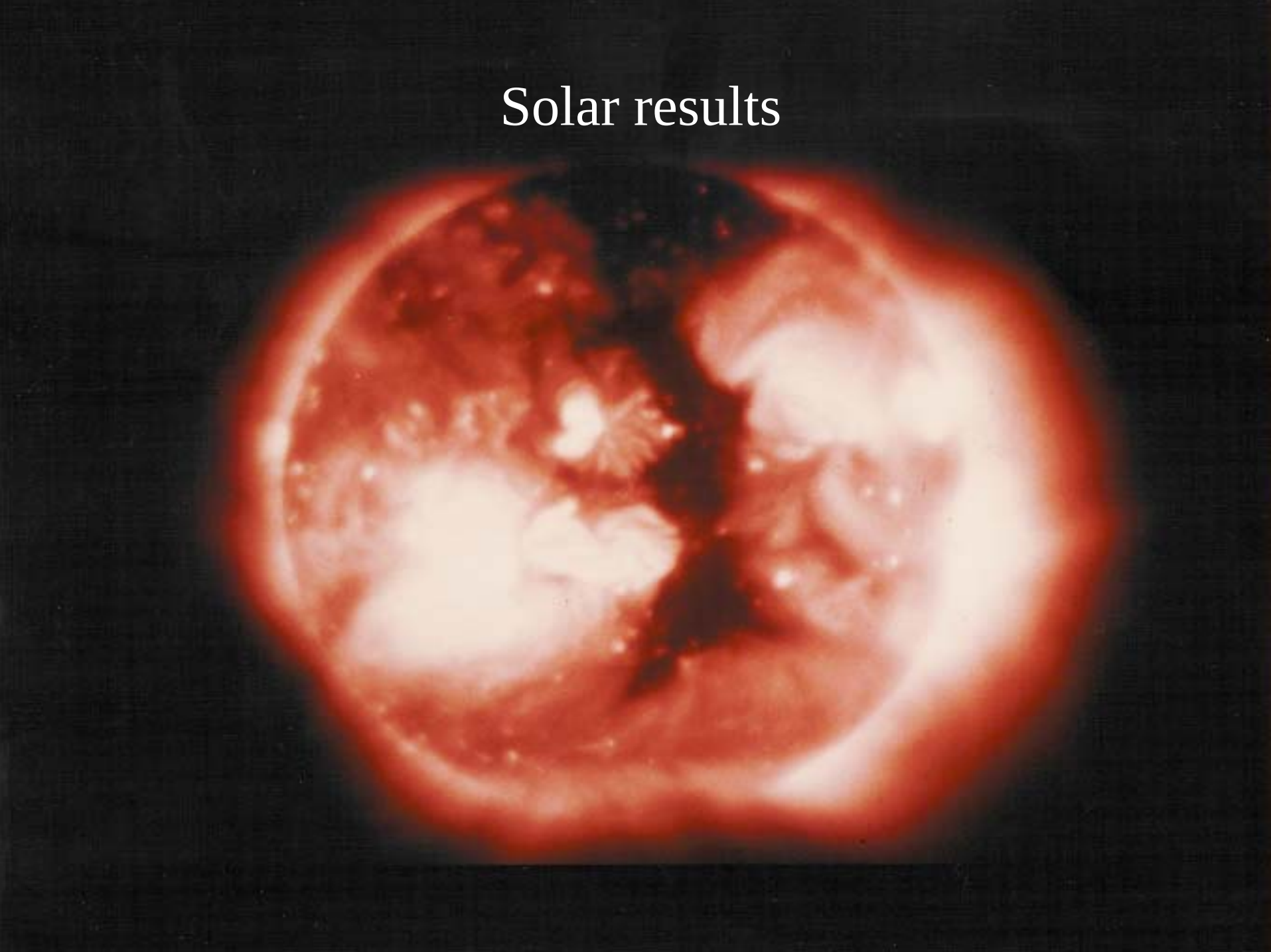


X-Ray Calibration Facility at MSFC

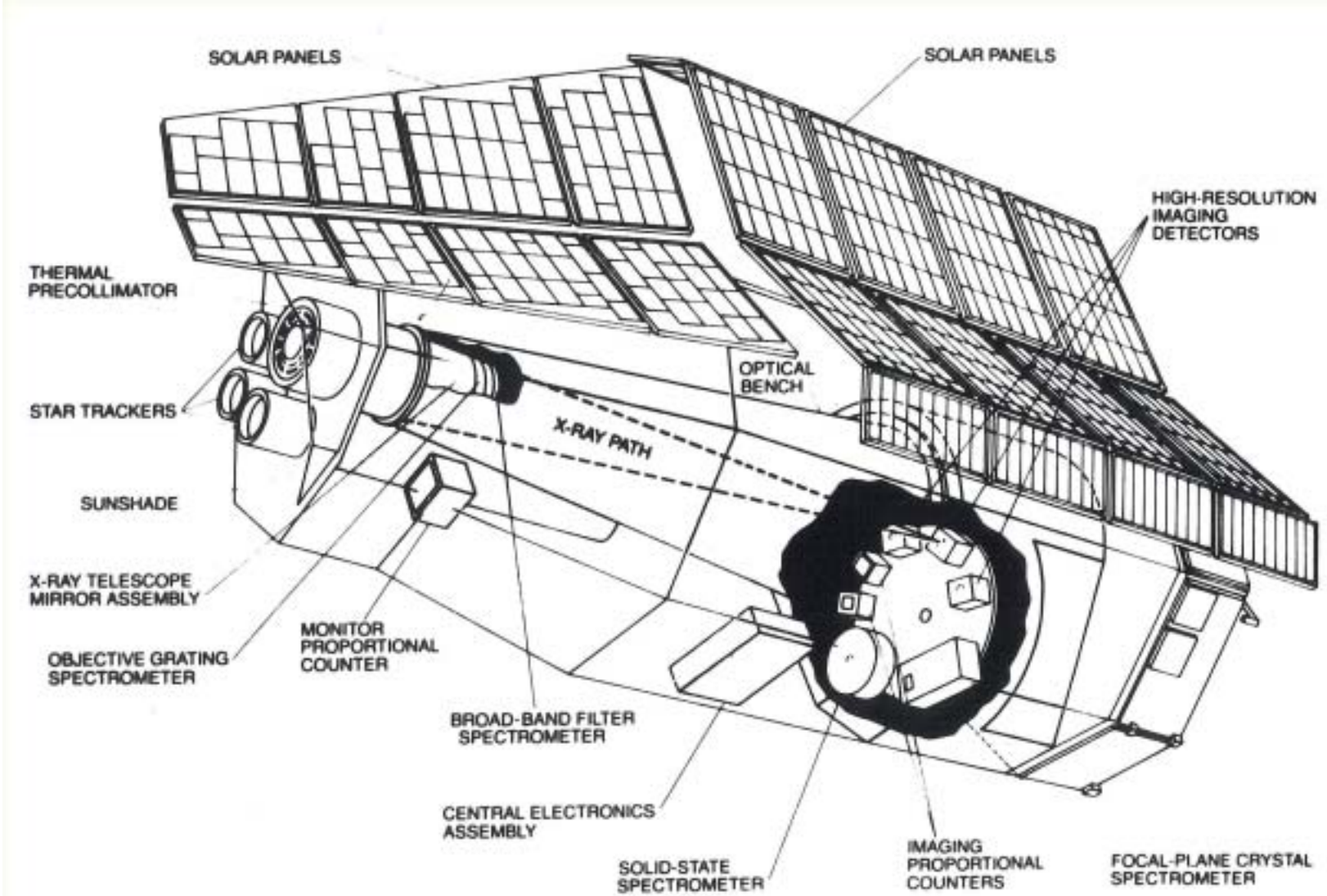


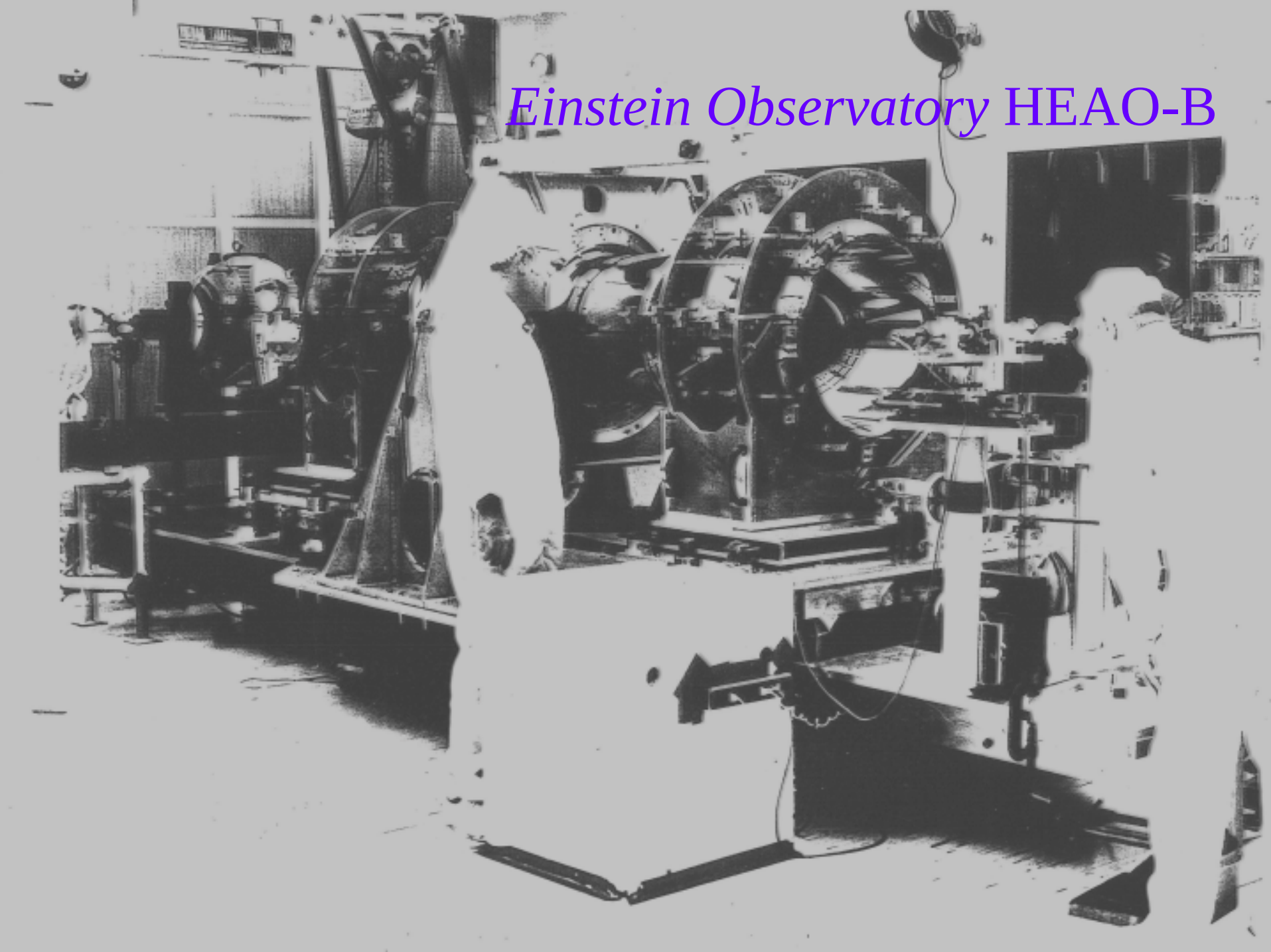
Sky Lab

Solar results



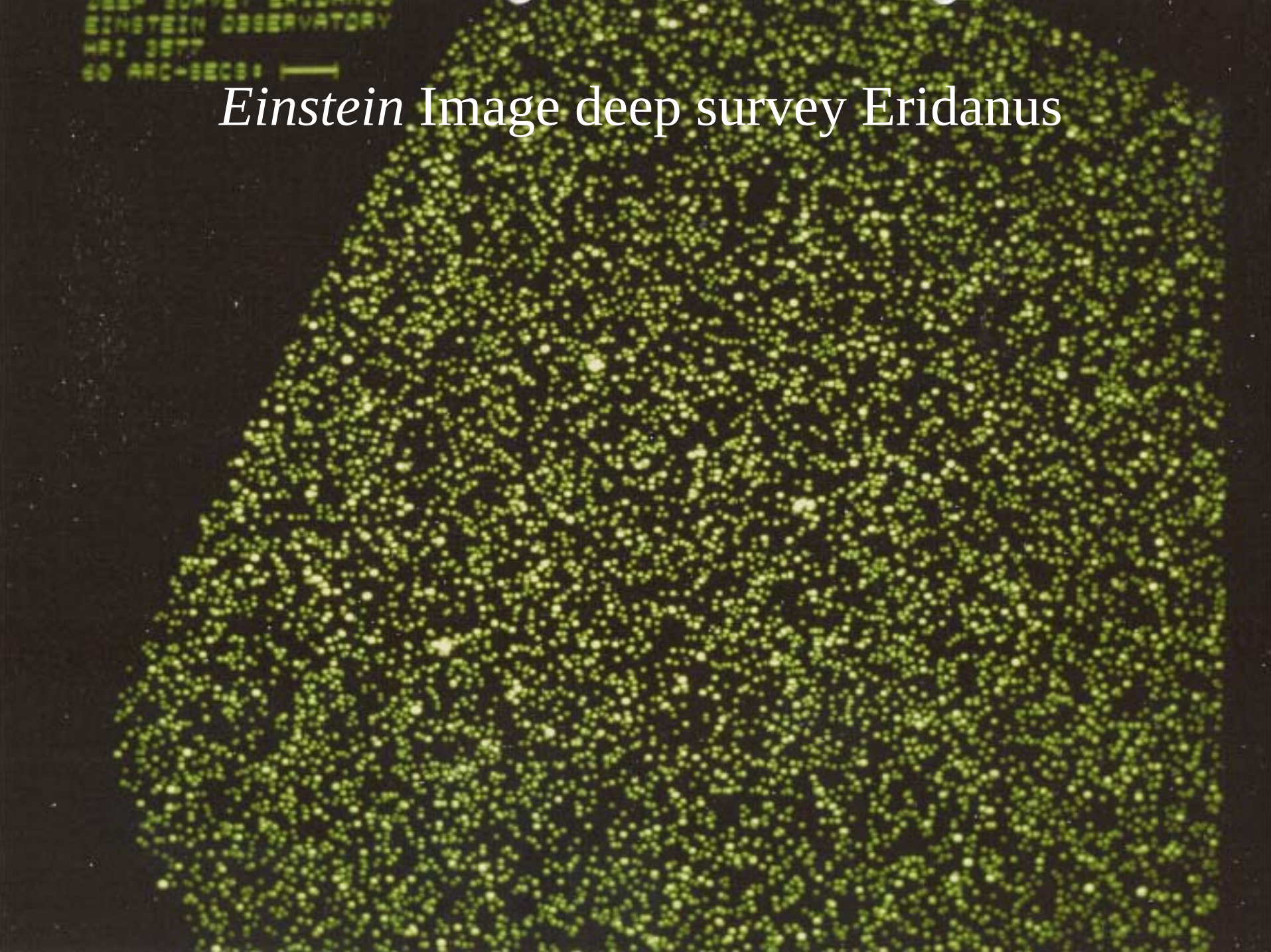
Einstein Observatory HEAO-B (schematic)




Einstein Observatory HEAO-B

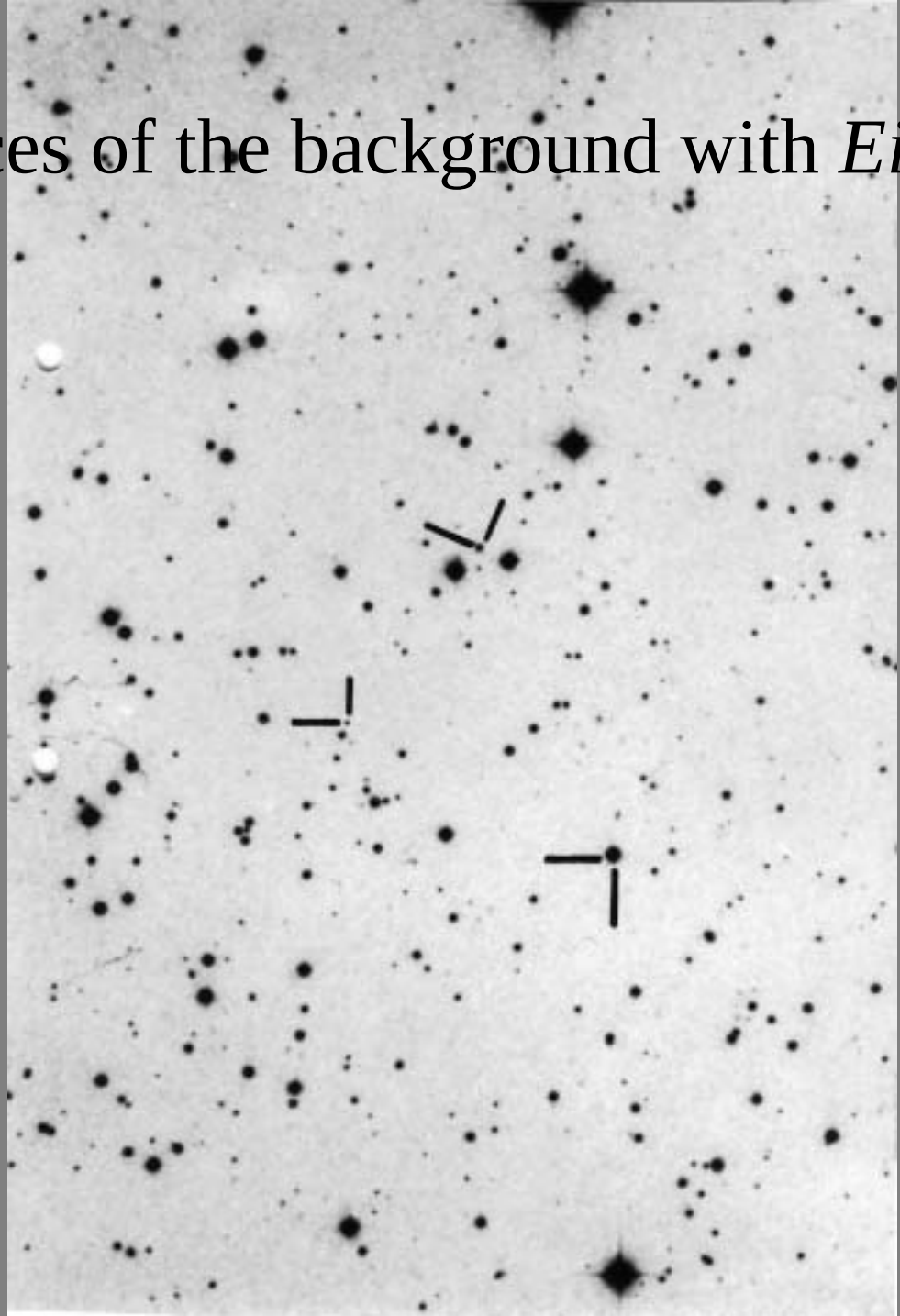
CELESTIAL OBJECTS OBSERVED WITH EINSTEIN

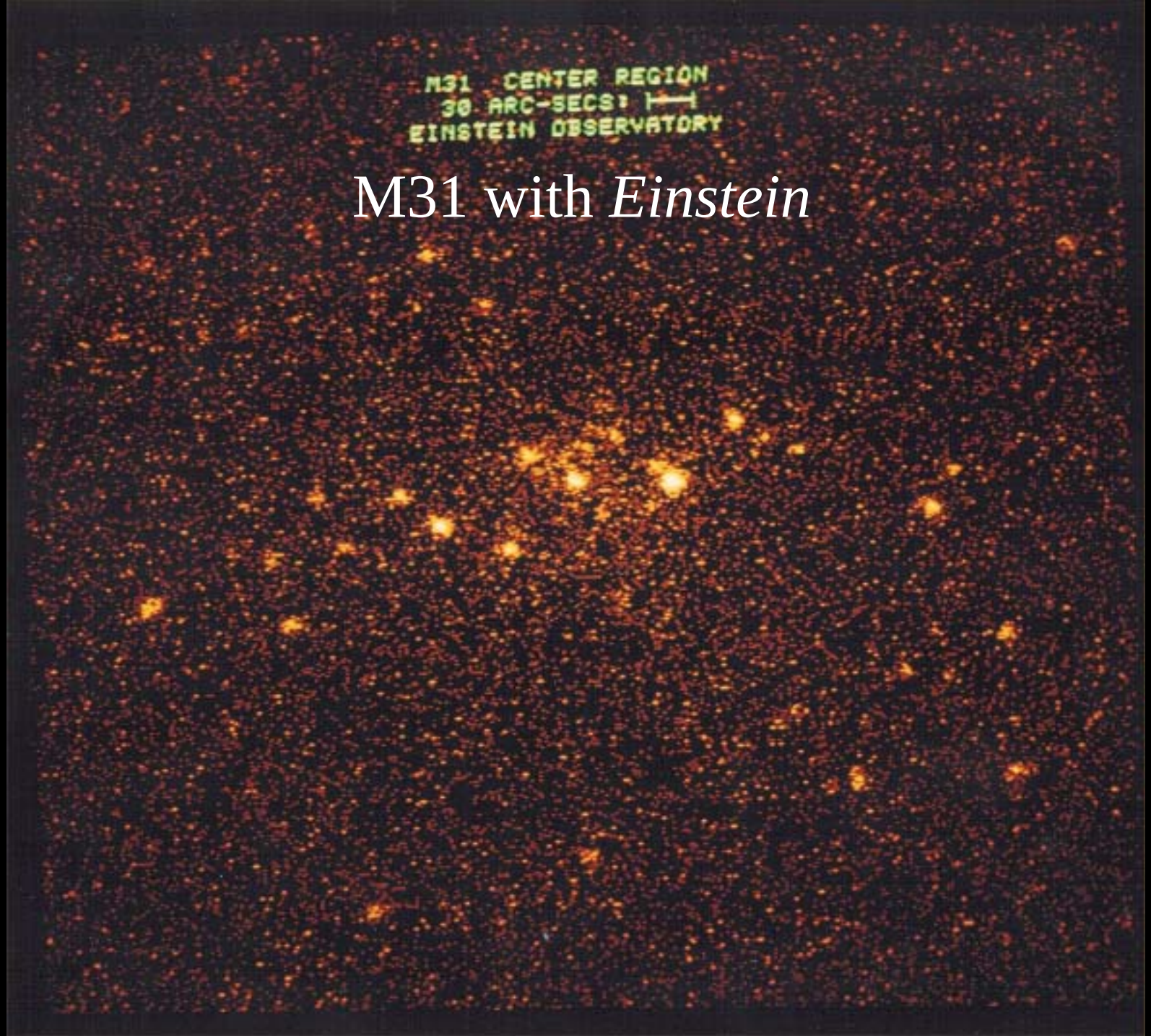
- **AURORA ON JUPITER**
- **X– RAY EMISSION FROM ALL TYPES OF MAIN SEQUENCE STARS**
- **NOVAS AND SUPERNOVAS**
- **PULSARS**
- **BINARY X–RAY SOURCES AND SUPERNOVAS IN EXTERNAL GALAXIES**
- **NORMAL GALAXIES**
- **NUCLEI OF ACTIVE GALAXIES**
- **QUASARS**
- **GROUPS AND CLUSTERS OF GALAXIES**
- **SOURCES OF THE EXTRAGALACTIC X–RAY BACKGROUND**



Einstein Image deep survey Eridanus

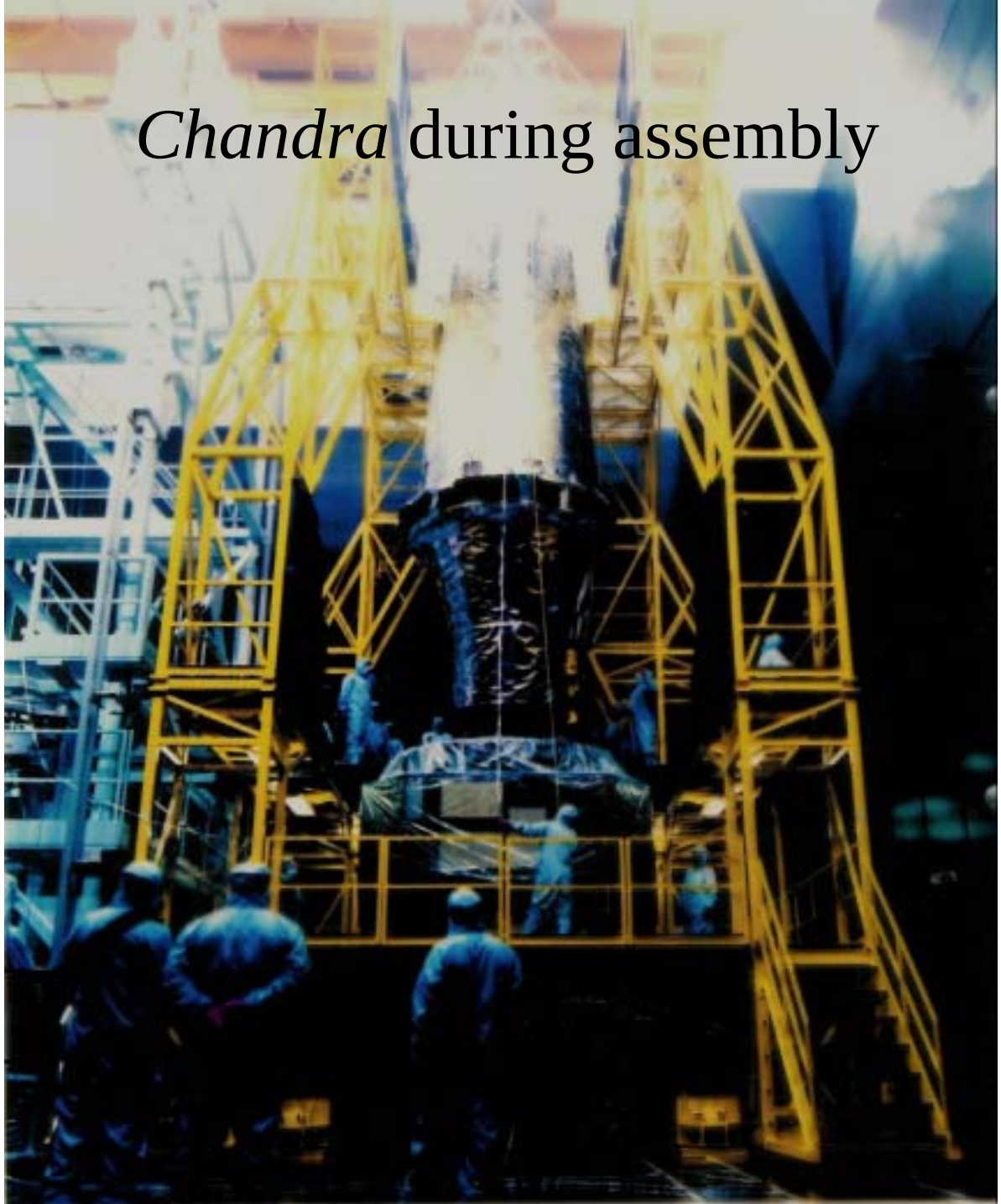
Sources of the background with *Einstein*



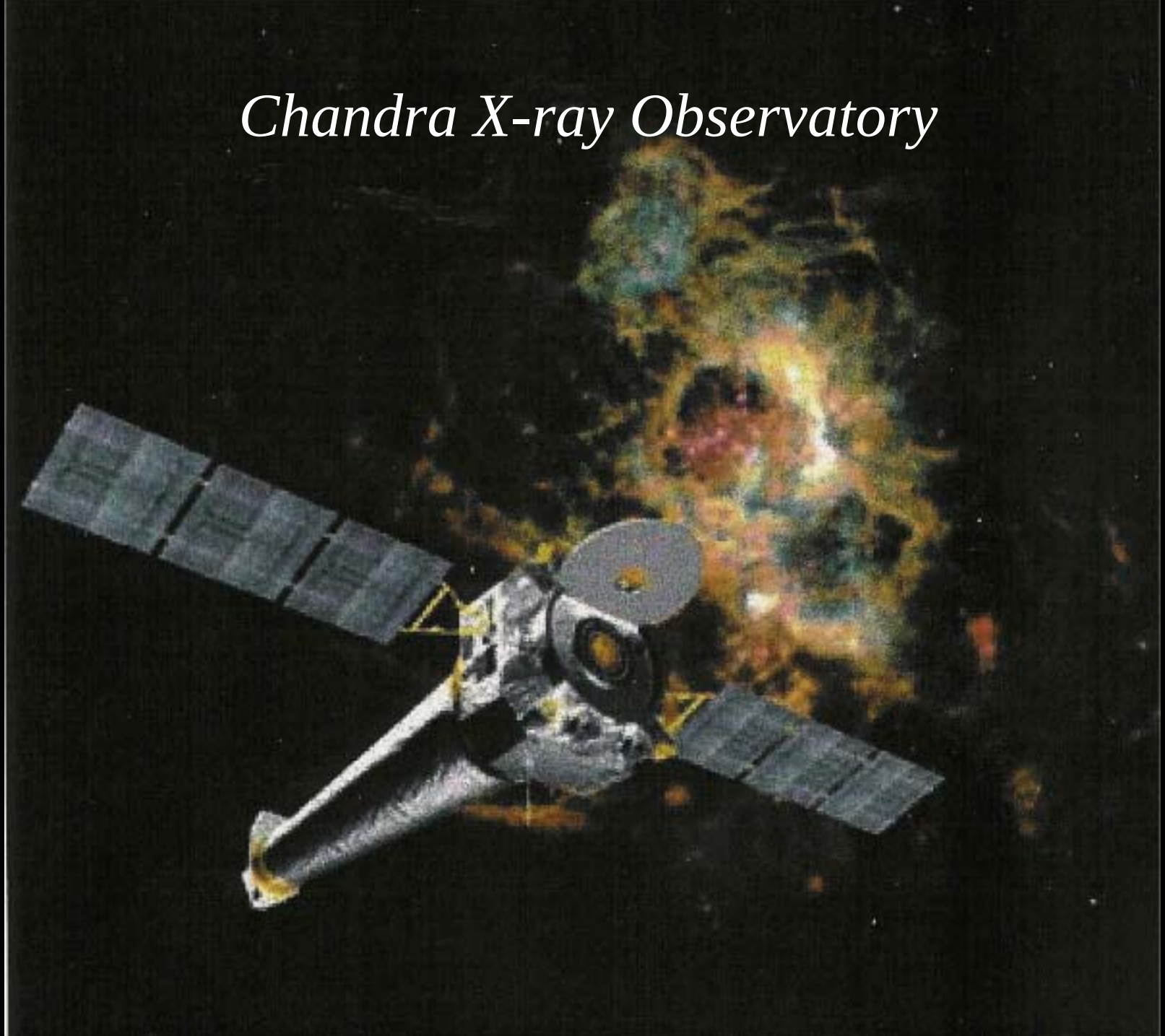


M31 with *Einstein*

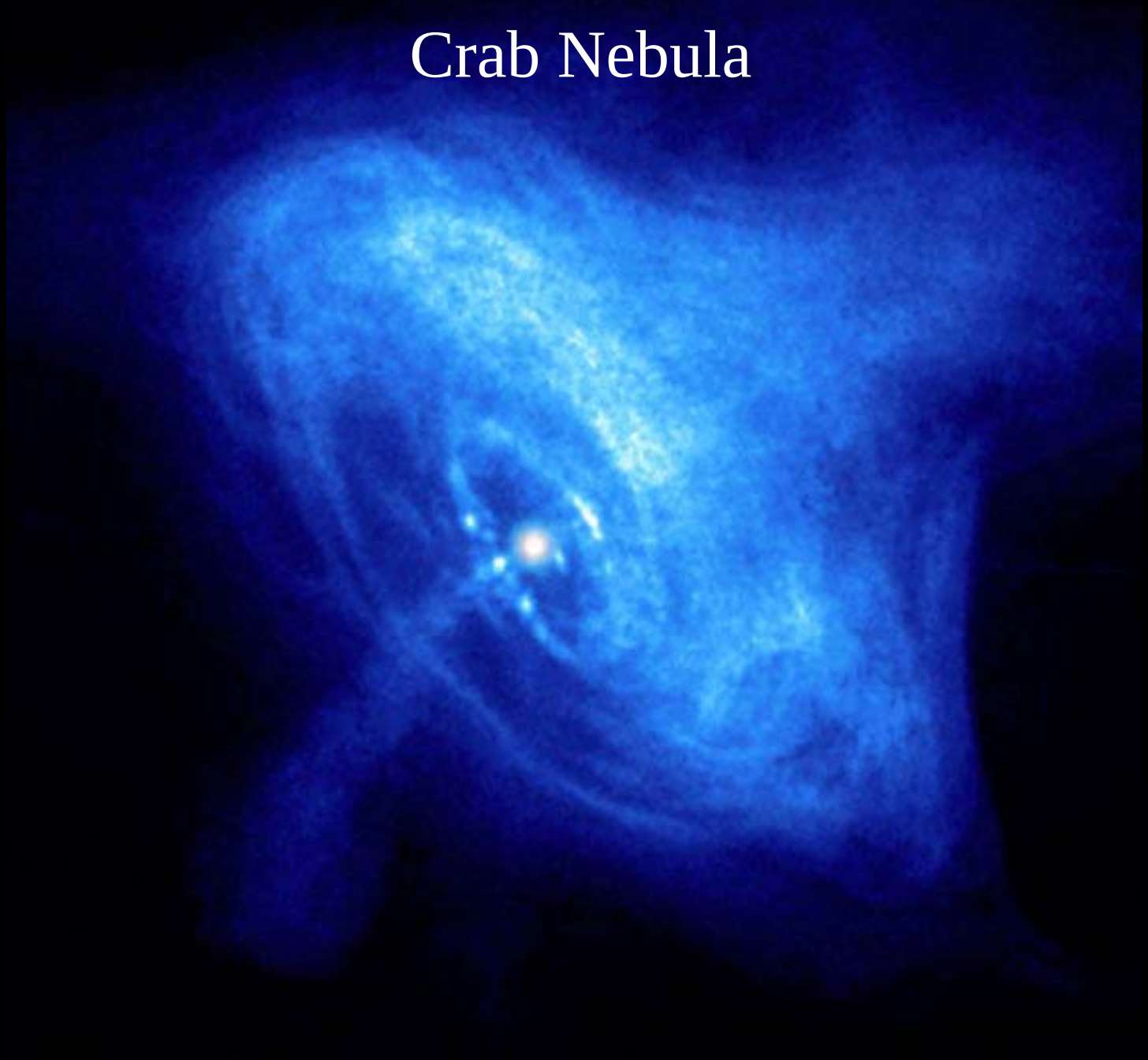
Chandra during assembly

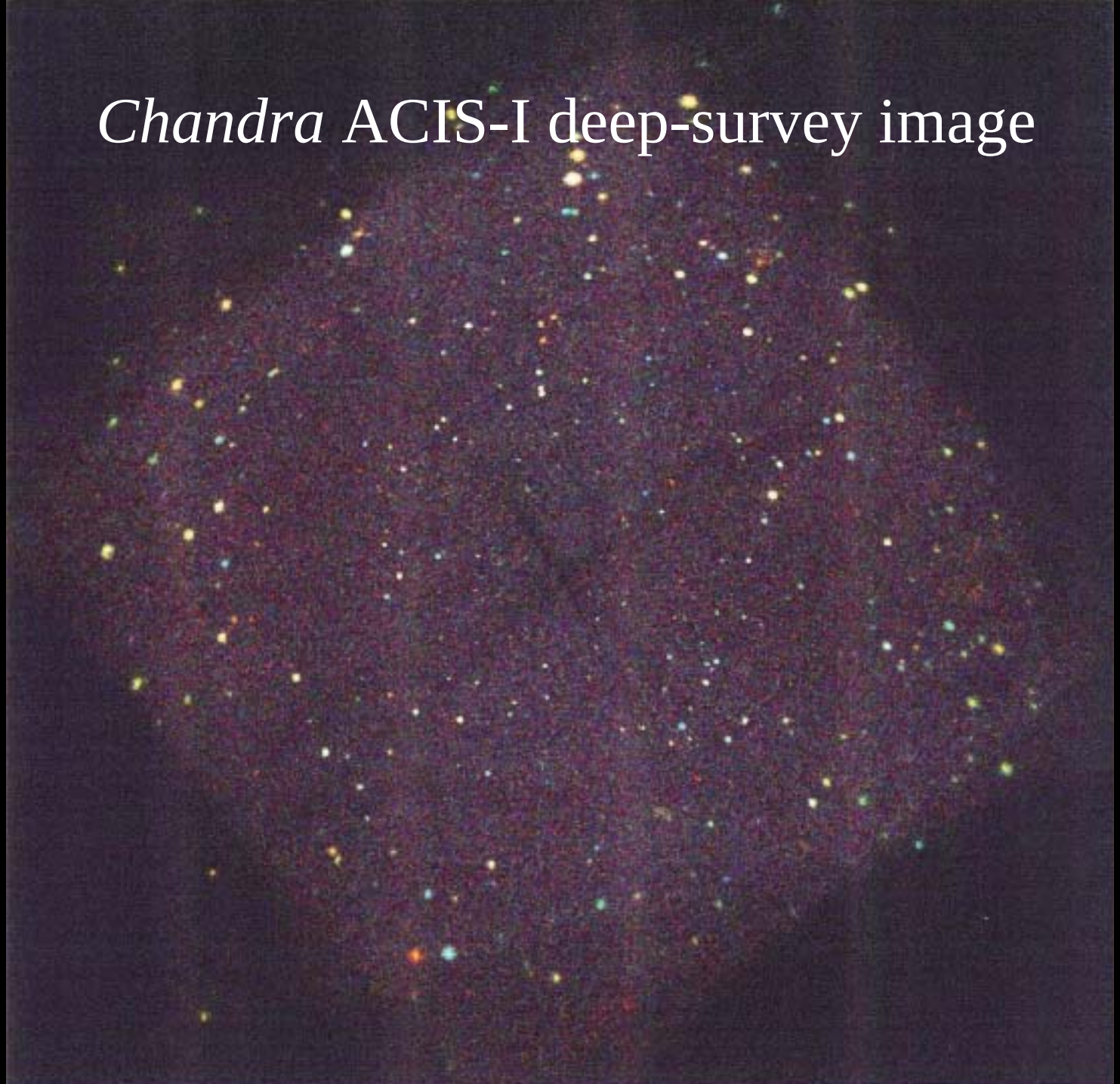


Chandra X-ray Observatory

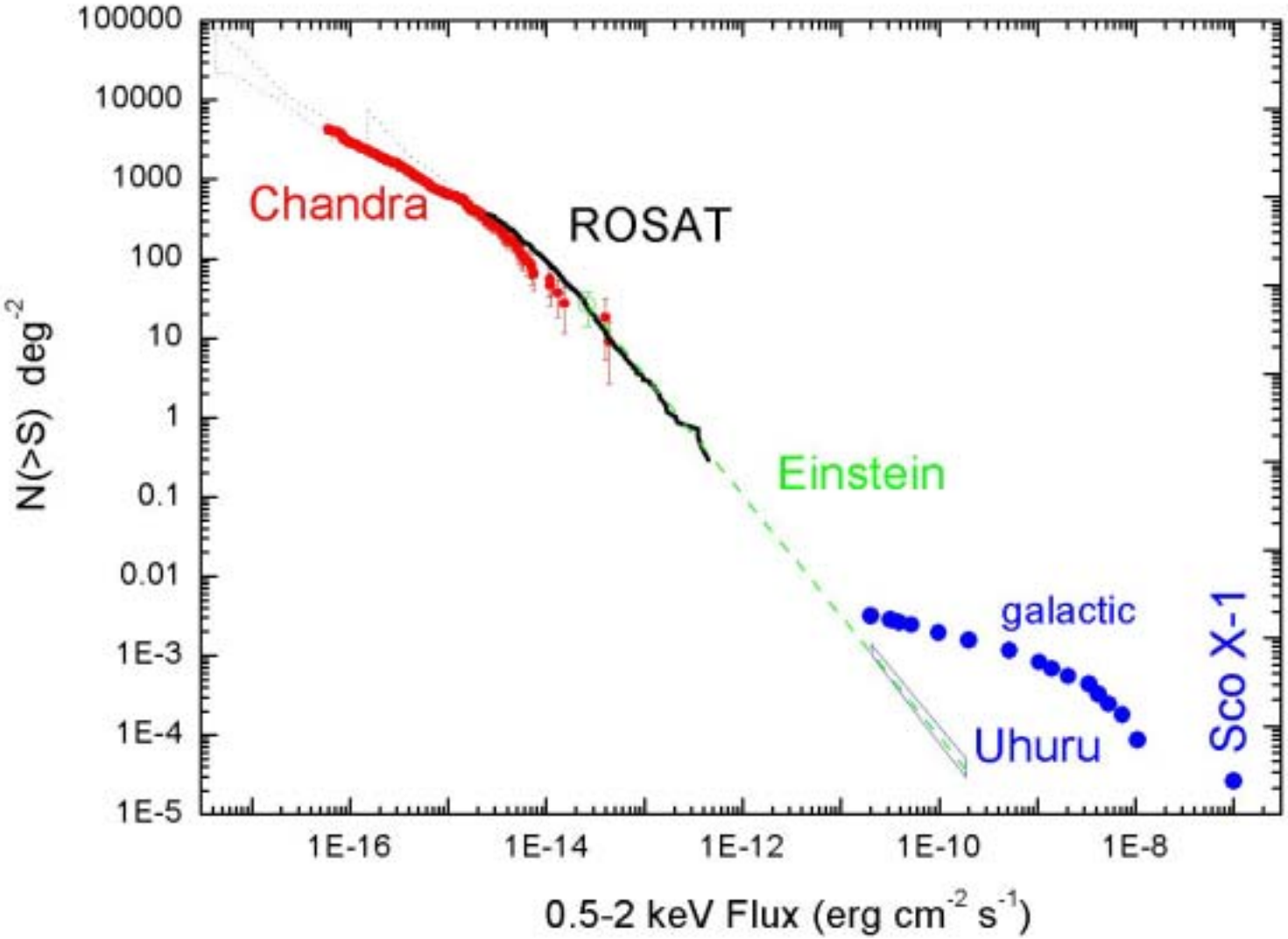


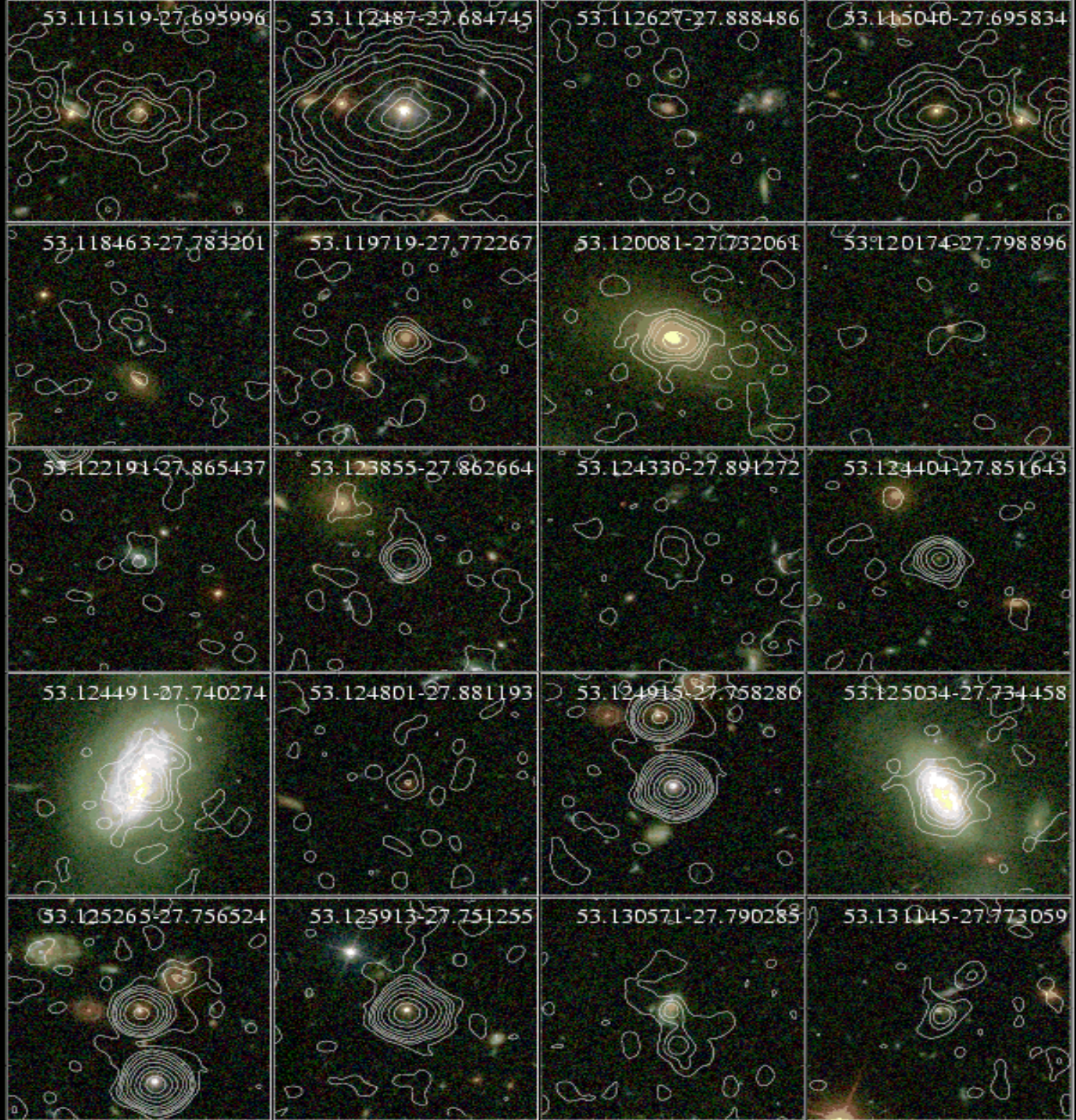
Crab Nebula




Chandra ACIS-I deep-survey image

Increase in sensitivity




53.111519-27.695996
53.112487-27.684745
53.112627-27.888486
53.115040-27.695834
53.118463-27.783201
53.119719-27.772267
53.120081-27.732061
53.120174-27.798896
53.122191-27.865437
53.123855-27.862664
53.124330-27.891272
53.124404-27.851643
53.124491-27.740274
53.124801-27.881193
53.124915-27.758280
53.125034-27.734458
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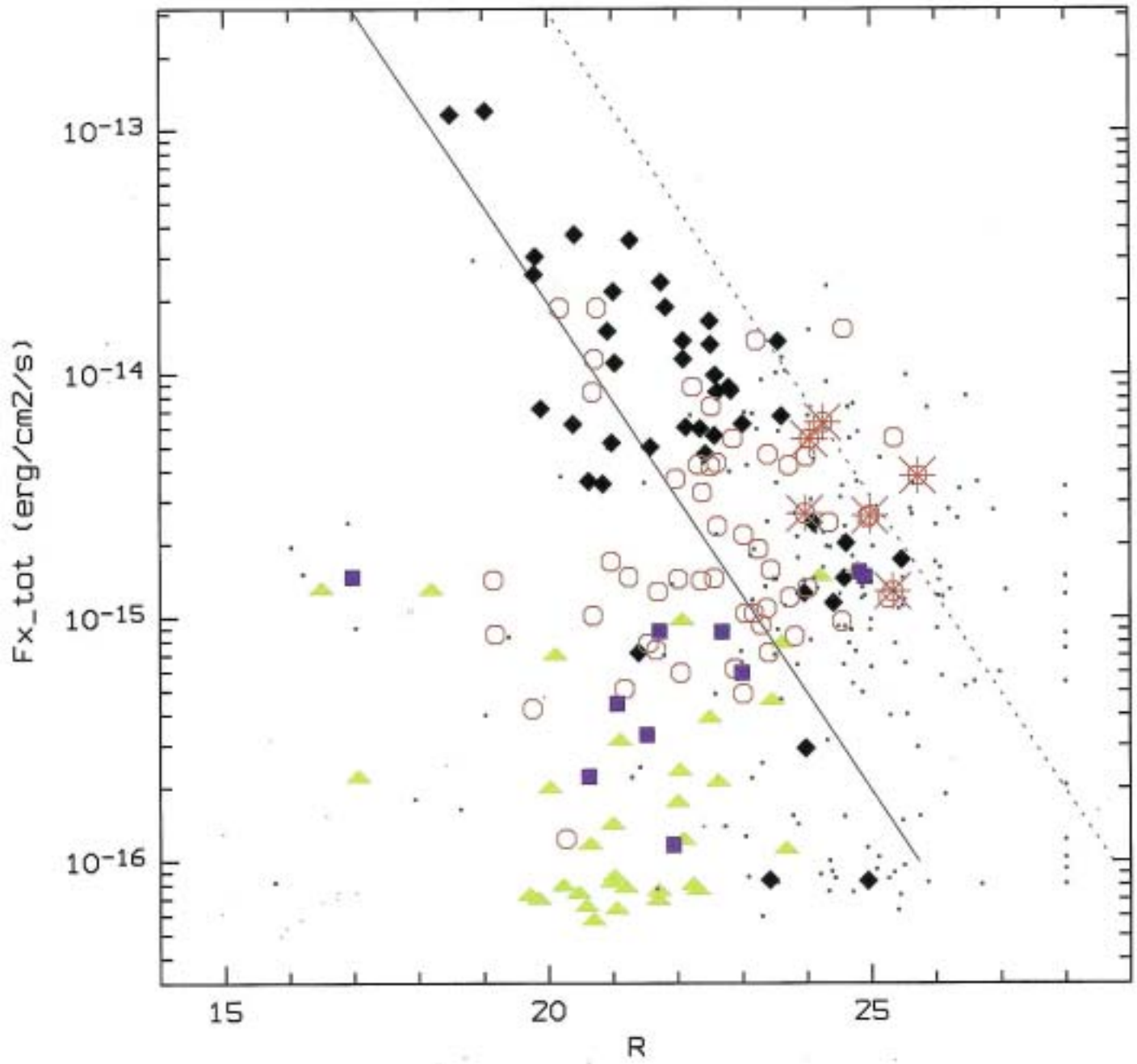
53.130571-27.790285
53.131145-27.773059


Fx_tot (erg/cm2/s)
10^-13
10^-14
10^-15
10^-16
15
20
25
R

THE X-RAY BACKGROUND (.5 – 10 KEV)

$ **> 95% XRB DUE TO SOURCES**

$ **XRB SPECTRUM = ? SPECTRA OF SOURCES**

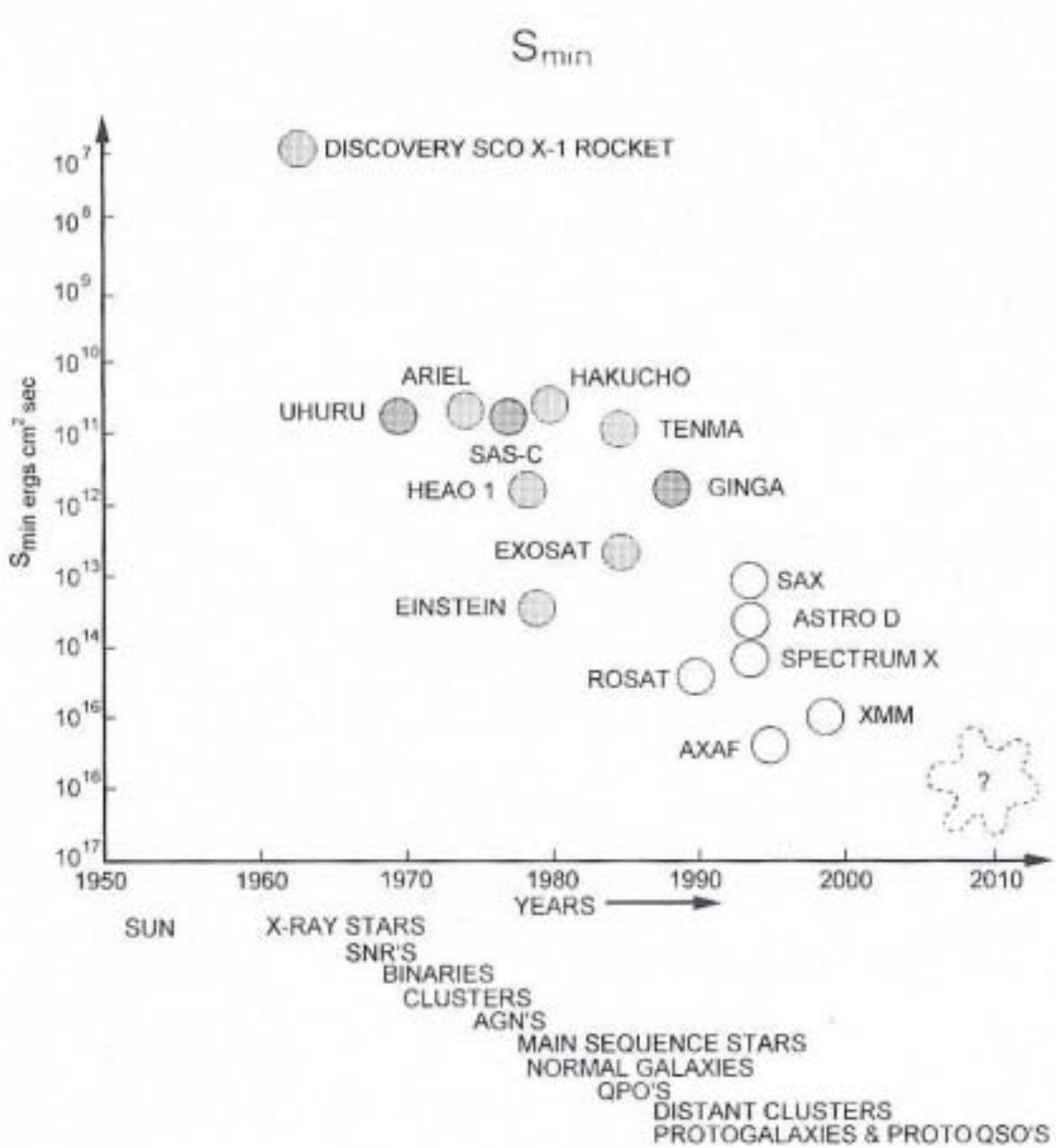
$ **SPECTRUM EVOLUTION**

$ **SOURCES: AGN TYPE I ($L = 10^{42} - 10^{45}$ $H \sim 0.5$)**
AGN TYPE II ($L = 10^{41} - 10^{44}$ $H > 0.0$)
GALAXIES ($L < 10^{42}$ $H \sim -1$)
CLUSTERS OF GALAXIES
UNIDENTIFIED ~ 10%

$ **SOURCE DENSITY 3000/SQ DEGREE**
(10^8 ALL SKY) AT $S = 5 \times 10^{-17}$ ERG CM^{-2} SEC^{-1}
HIGHEST DENSITY AGN'S (BH'S)

$ **1/3 OF SOURCE IN CDFS ARE IN SHEETS Z = 0.67, 0.73**
(LOW SIGMA) Z = 1.04, 1.62 AND 2.57

$ **DEEP SURVEYS STUDY EVOLUTION OF GALAXIES – AGN'S – CLUSTERS OF GALAXIES & LARGE STRUCTURES**


S_{min}
DISCOVERY SCO X-1 ROCKET
ARIEL
HAKUCHO
UHURU
TENMA
SAS-C
HEAO 1
GINGA
EXOSAT
SAX
EINSTEIN
ASTRO D
SPECTRUM X
ROSAT
XMM
AXAF
?
S_{min} ergs cm^2 sec
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{16}
10^{16}
10^{17}
1950
1960
1970
1980
1990
2000
2010
YEARS
SUN
X-RAY STARS
SNR'S
BINARIES
CLUSTERS
AGN'S
MAIN SEQUENCE STARS
NORMAL GALAXIES
QPO'S
DISTANT CLUSTERS
PROTOGALAXIES & PROTO QSO'S