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XMM-Newton observations of Galactic globular clusters

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XMM-Newton

Cameras:
2 x MOS (0.1-12.0 keV)
1 x pn (0.1-15.0 keV)
2 x RGS (0.33-2.5 keV)
1 x OM (optical/UV)

Collecting area = 4650cm^2 @ 1.5 keV

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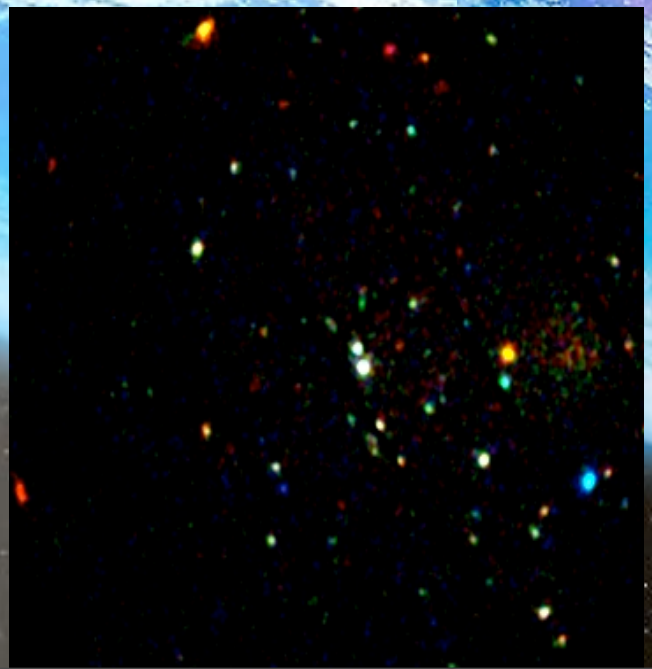

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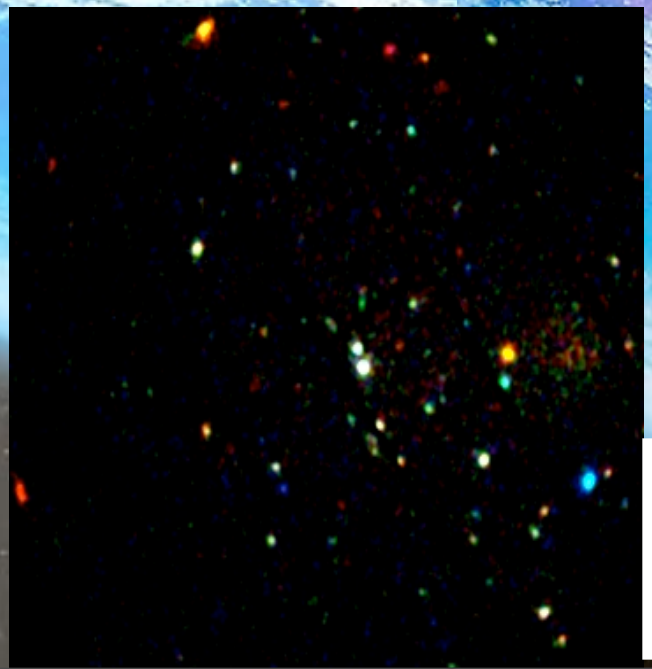

0.5-1.0 keV
1.0-2.0 keV
2.0-4.5 keV

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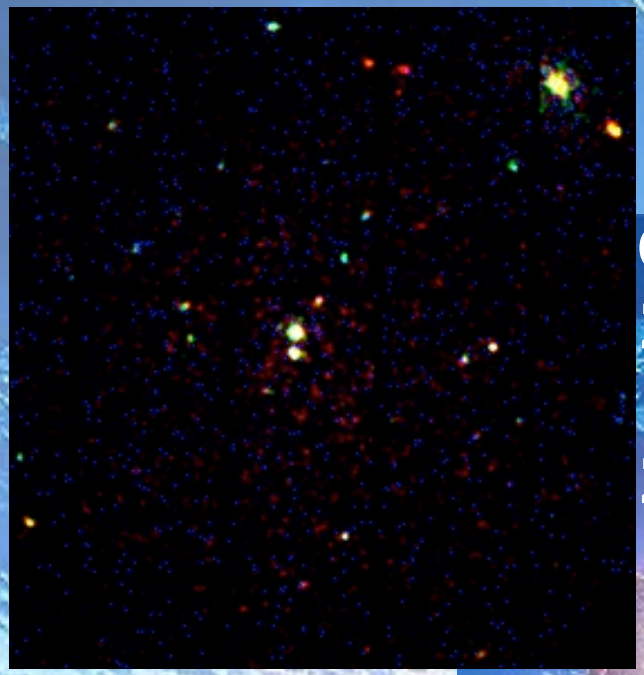

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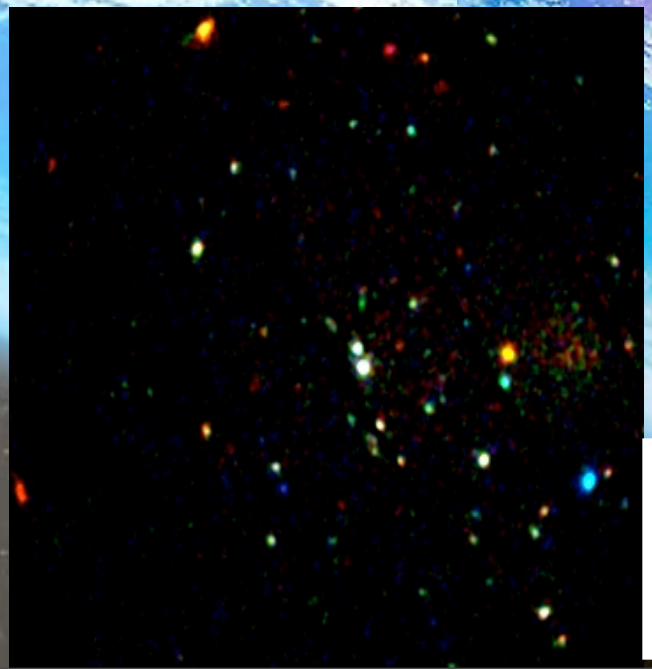

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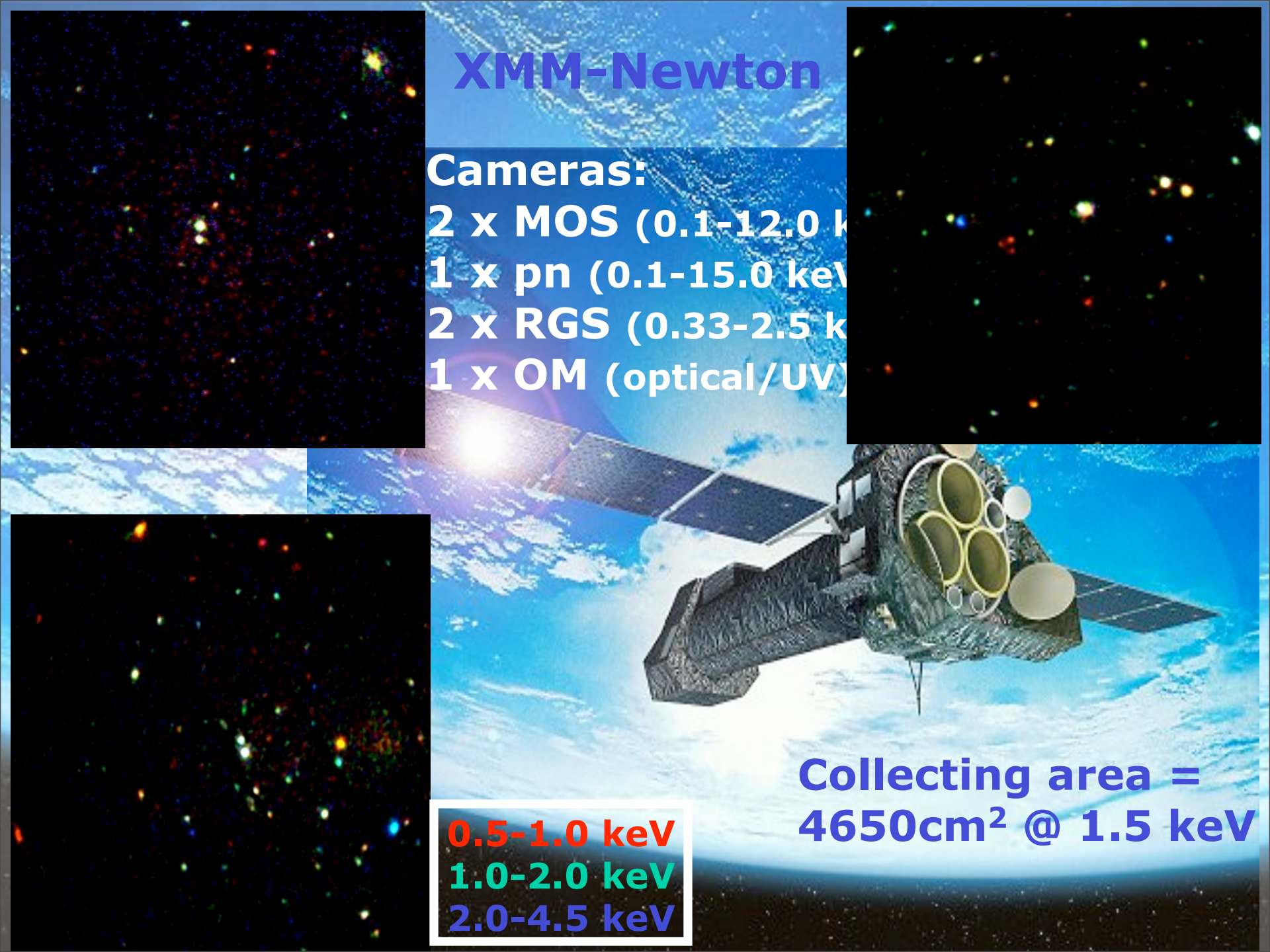
XMM-Newton
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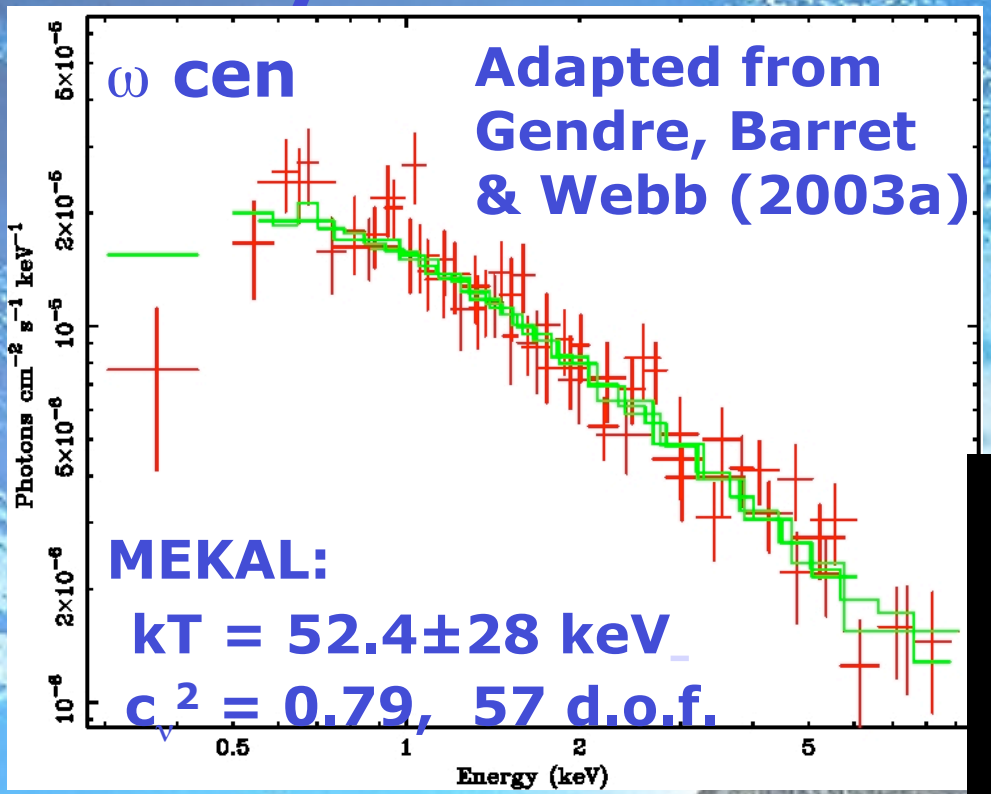
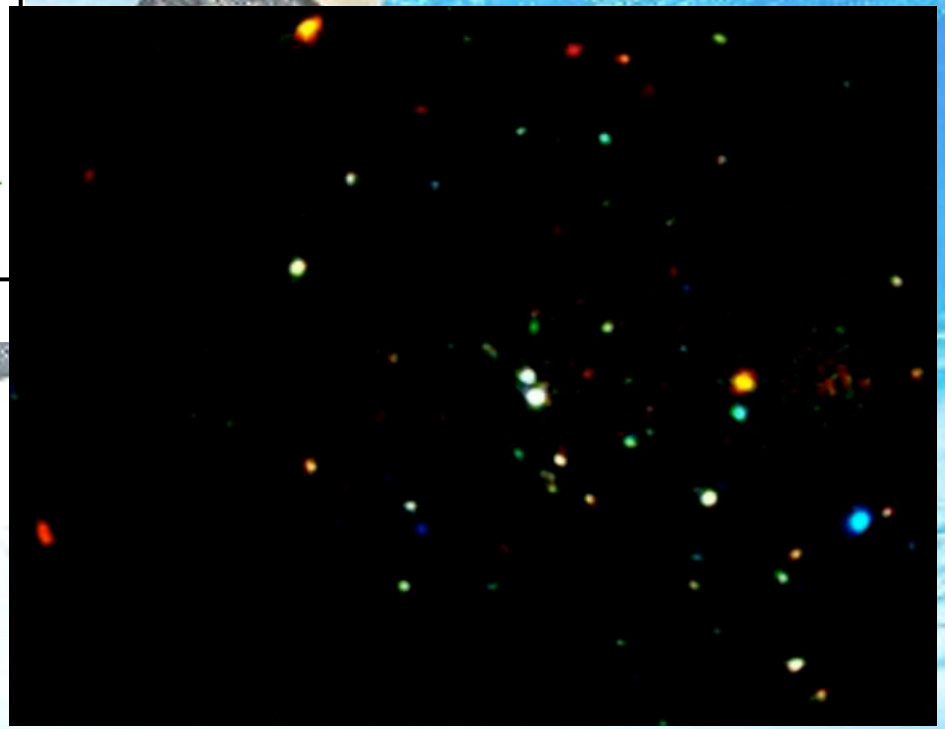
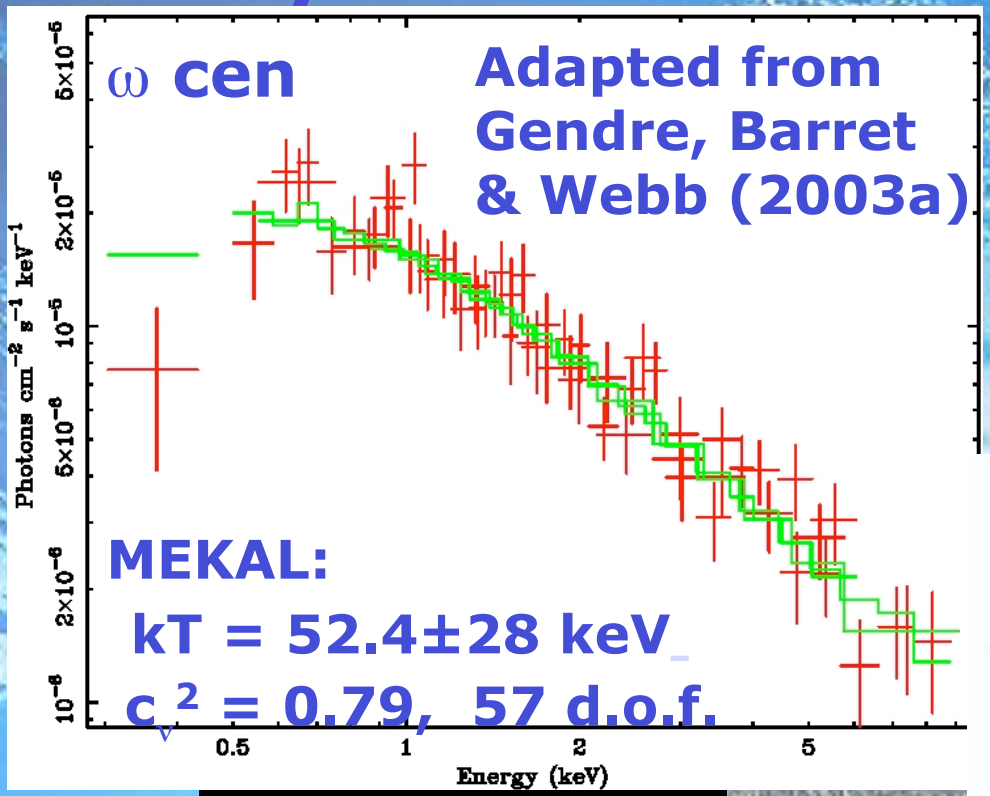
Cataclysmic variables

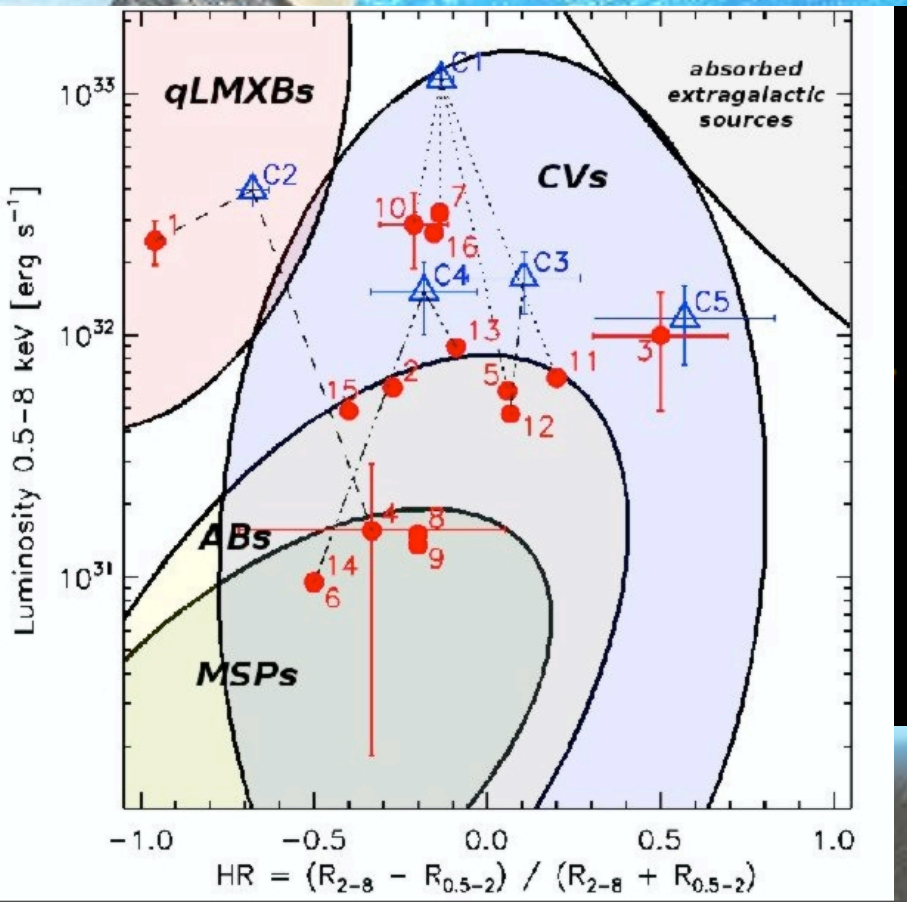
Cataclysmic variables





Cataclysmic variables





Where are the cataclysmic variable outbursts?

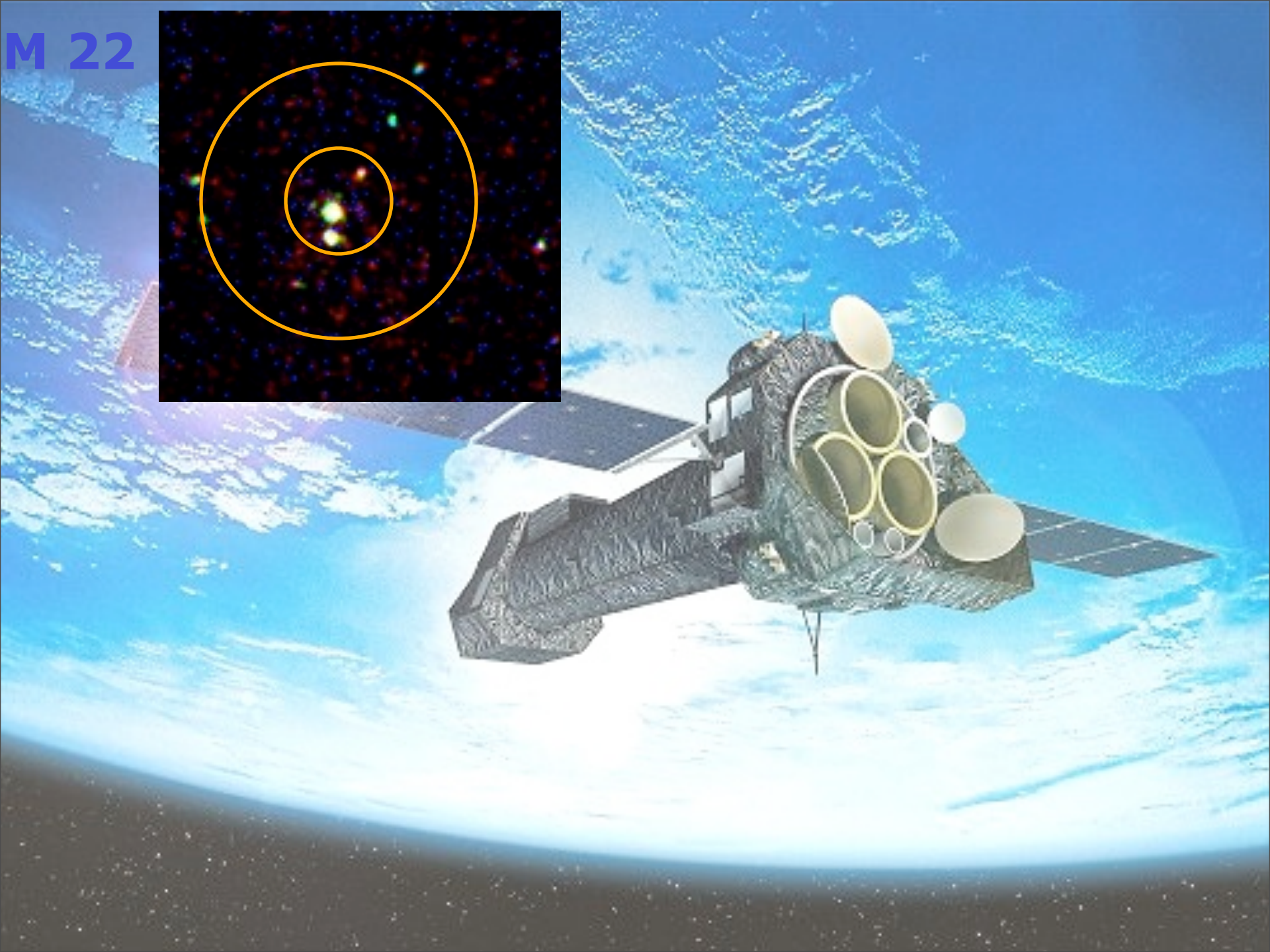
- Many field cataclysmic variables (CVs) show frequent outbursts

- Few outbursts observed from globular cluster CVs

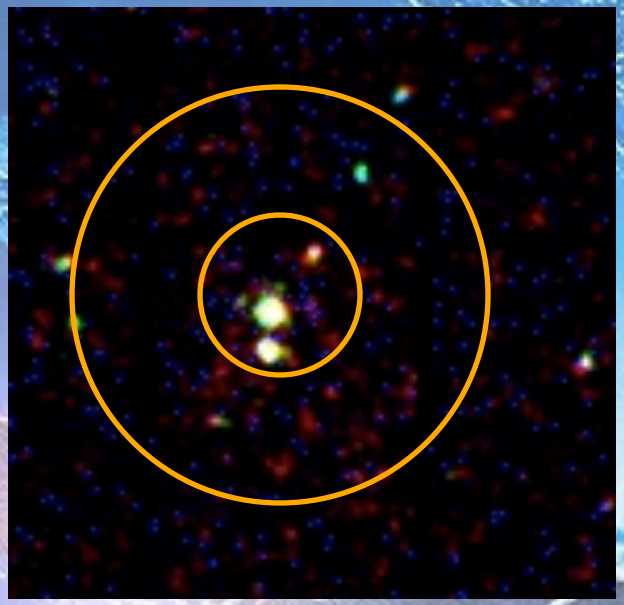
- Are the majority magnetic? (Grindlay et al. 1995)
  - evidence suggests that many are, but is this a selection effect?

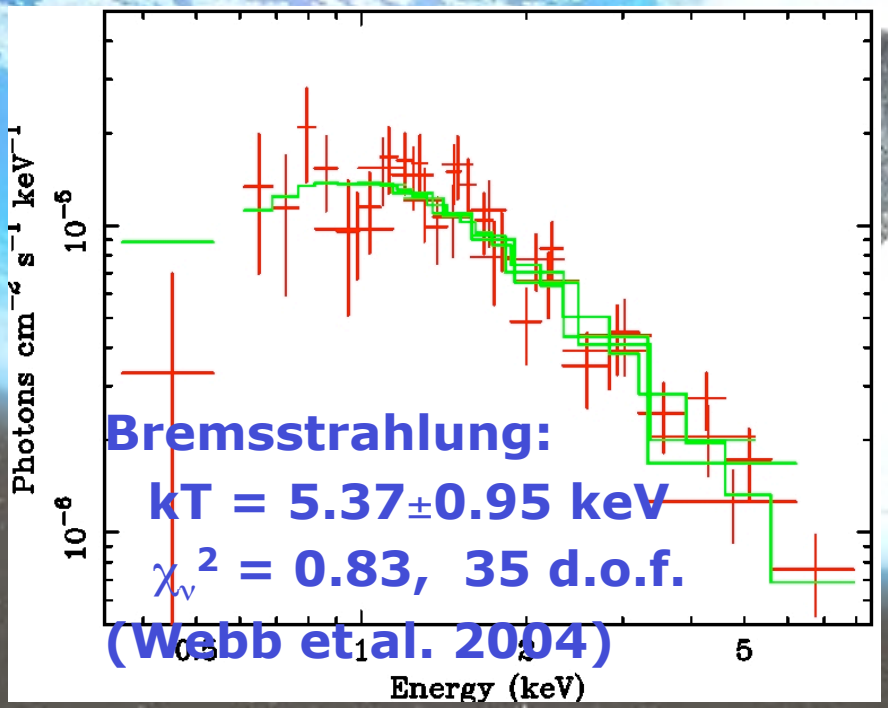
- Likely to be due to moderate magnetic fields + low mass transfer rates (Dobrotka et al. 2006)/ more massive white dwarfs (Ivanova et al. 2006)
  - are GC CVs different to those in the field?

- ... recent observations of M 22 have shown 4 outbursts from one CV and 2 from another (Bond et al. 2005, Pietrukowicz et al. 2006) ...


M 22

M 22





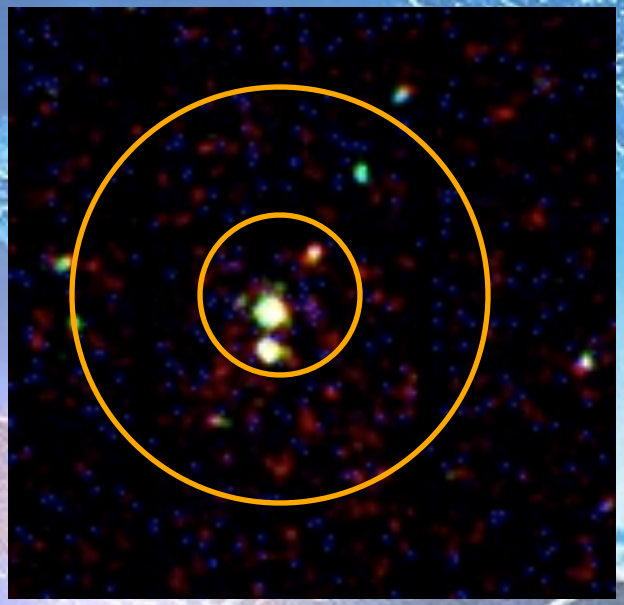
Bremsstrahlung:

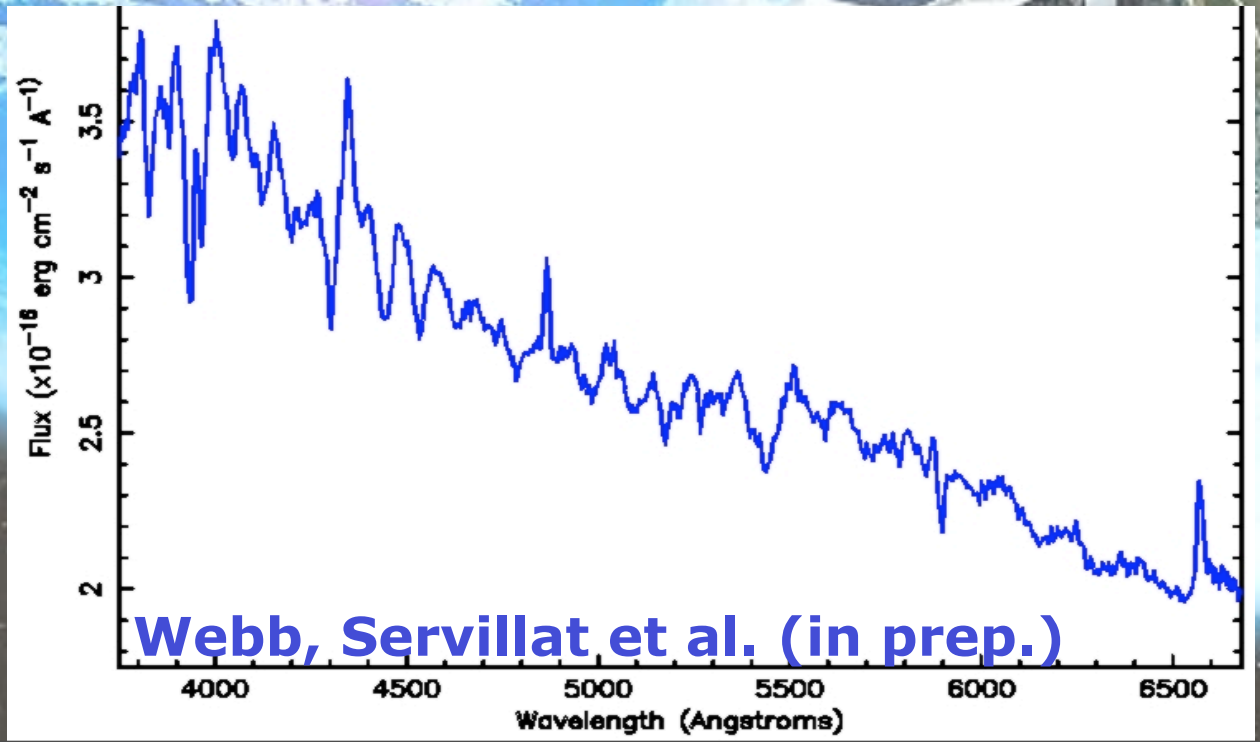
kT = 5.37±0.95 keV

χ_ν^2 = 0.83, 35 d.o.f.

(Webb et al. 2004)

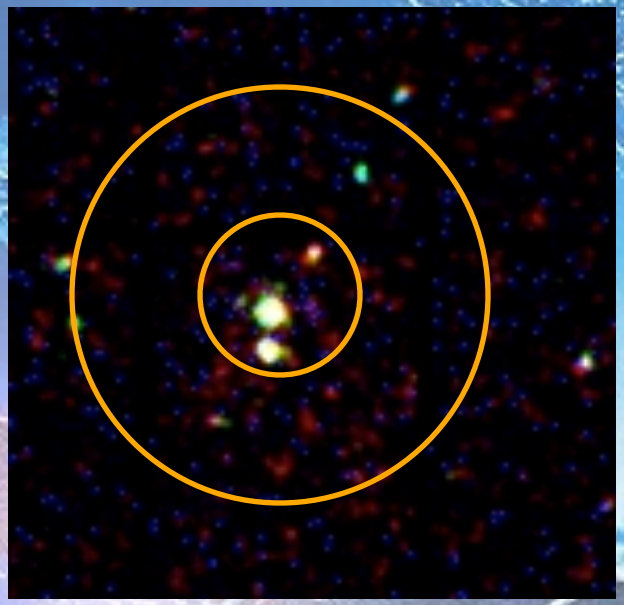
M 22

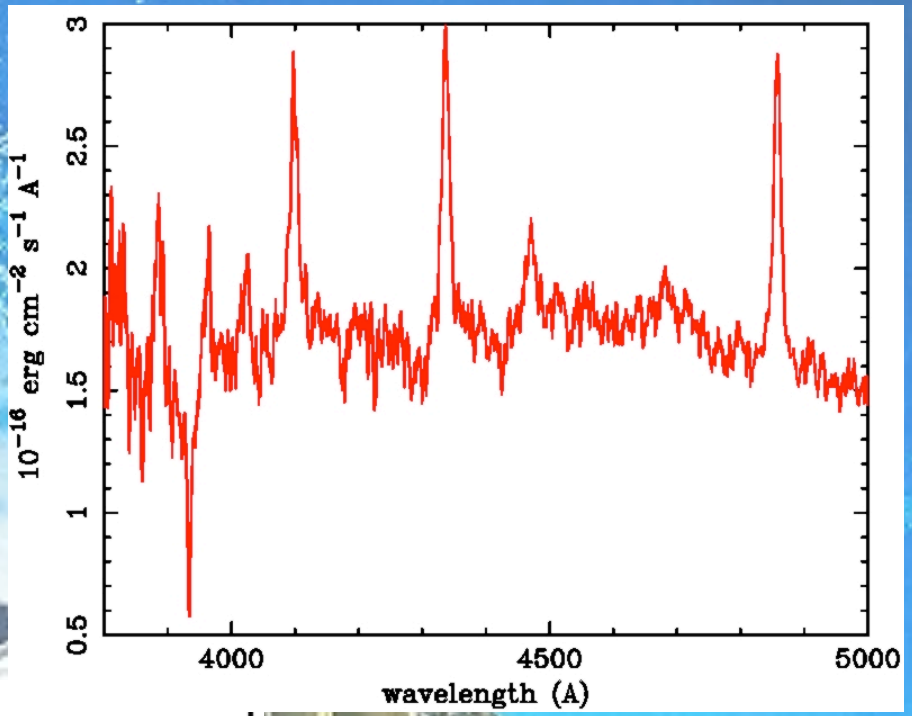


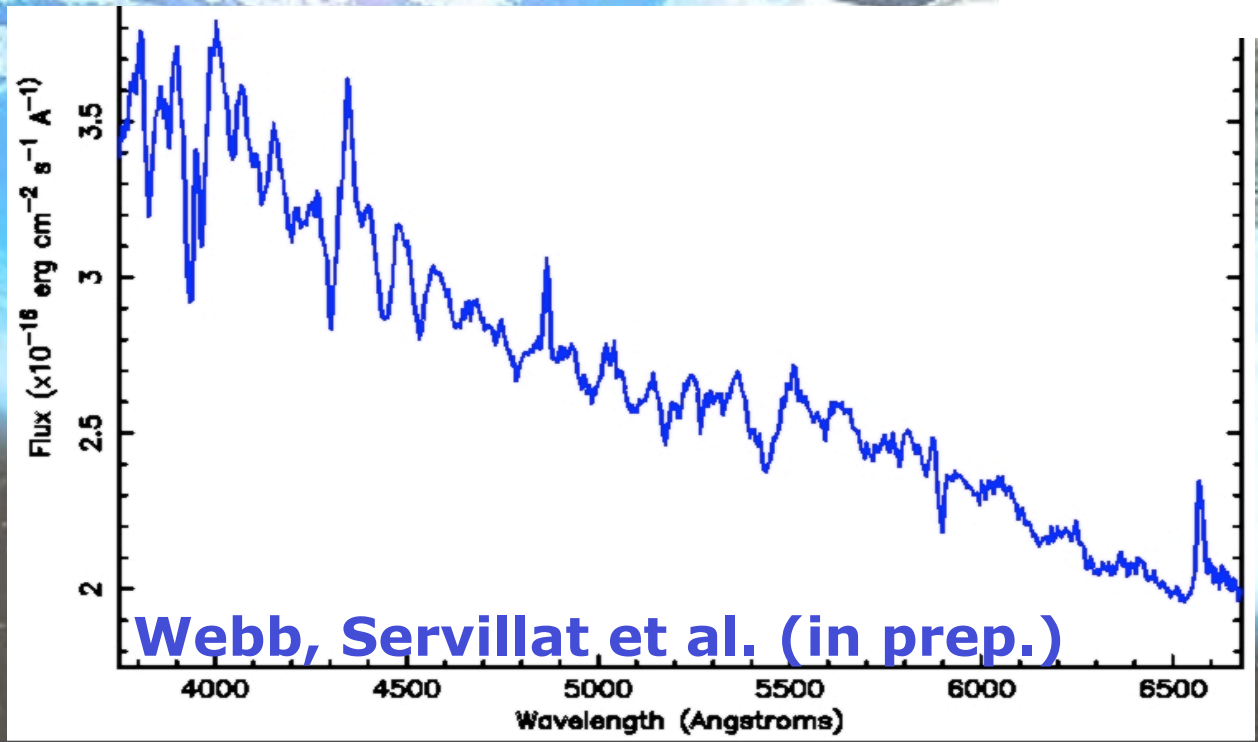


Webb, Servillat et al. (in prep.)

M 22







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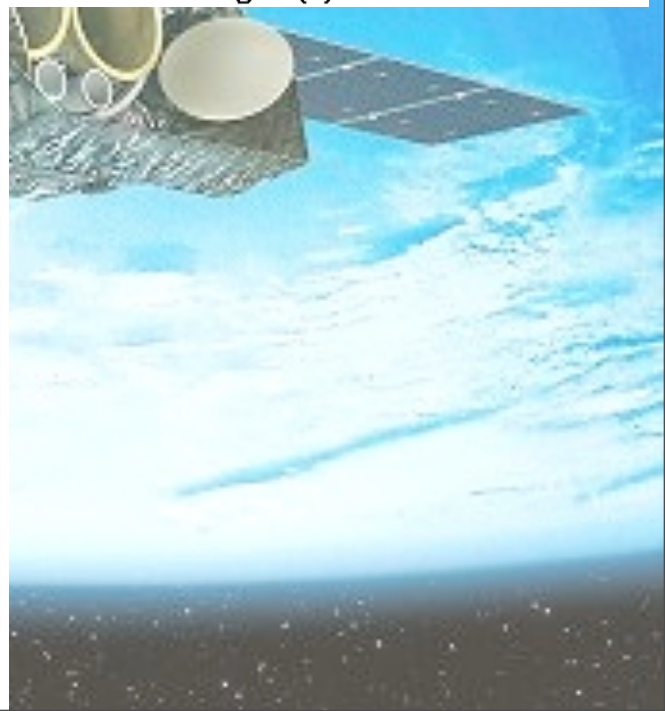

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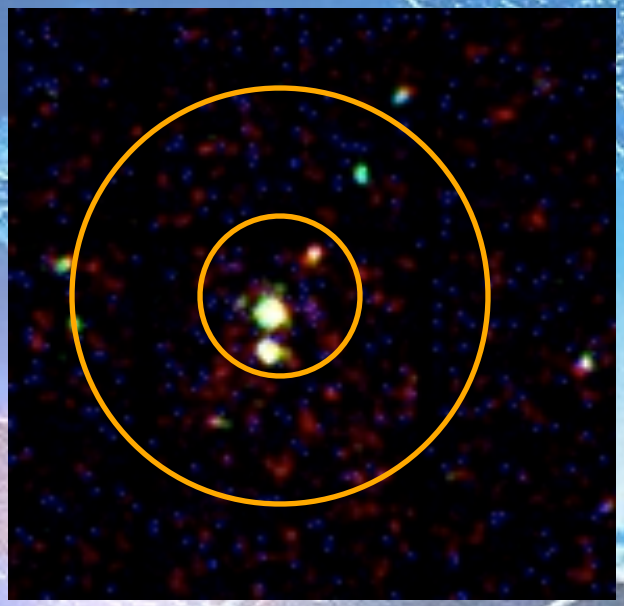

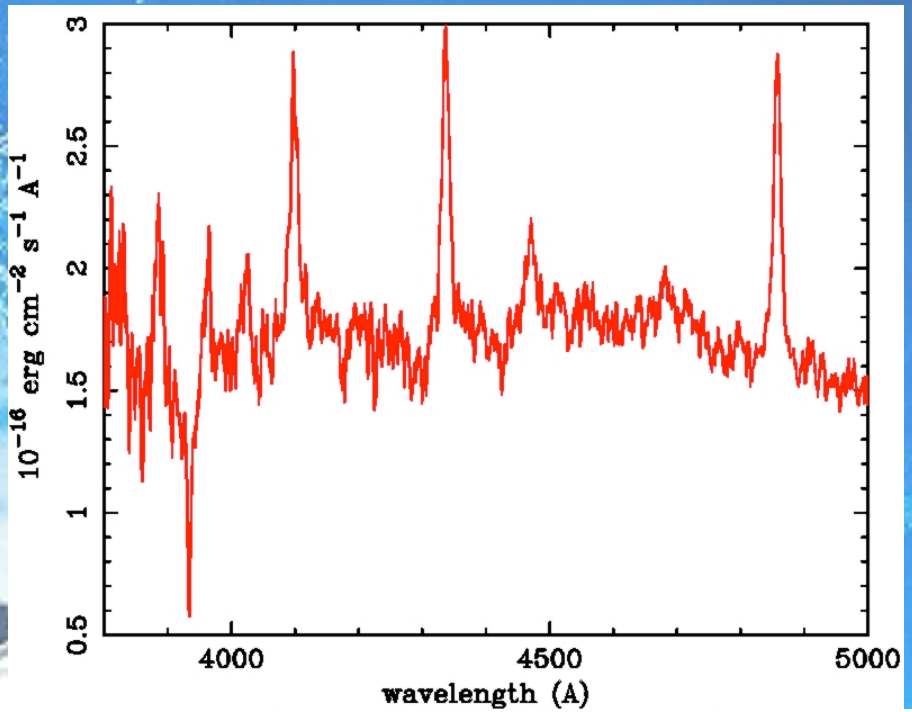

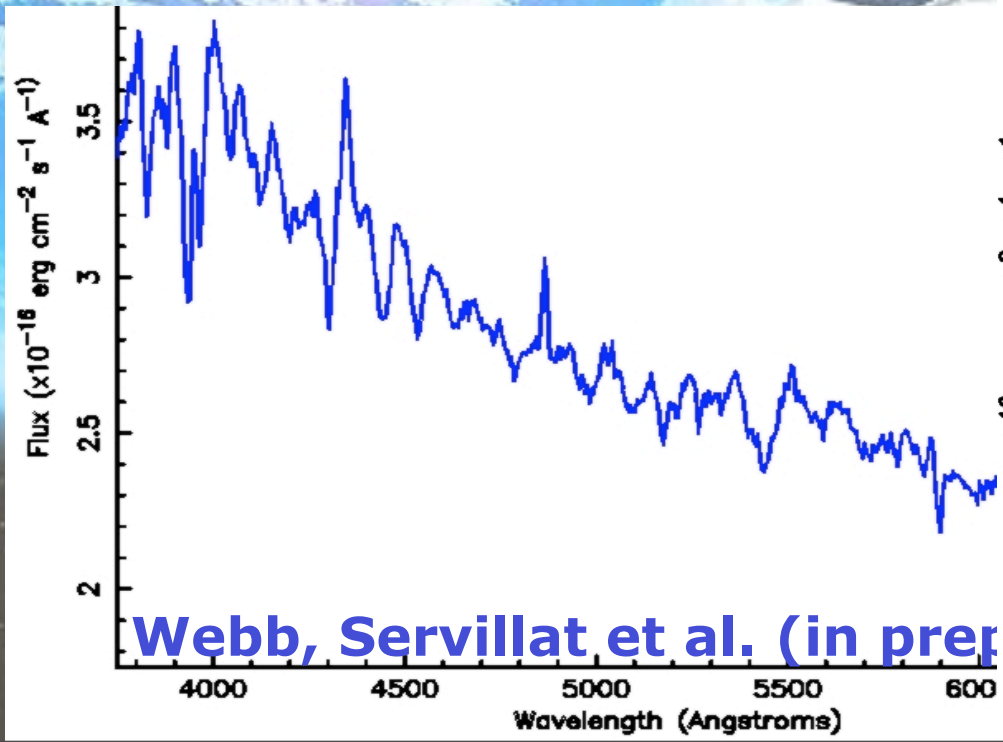

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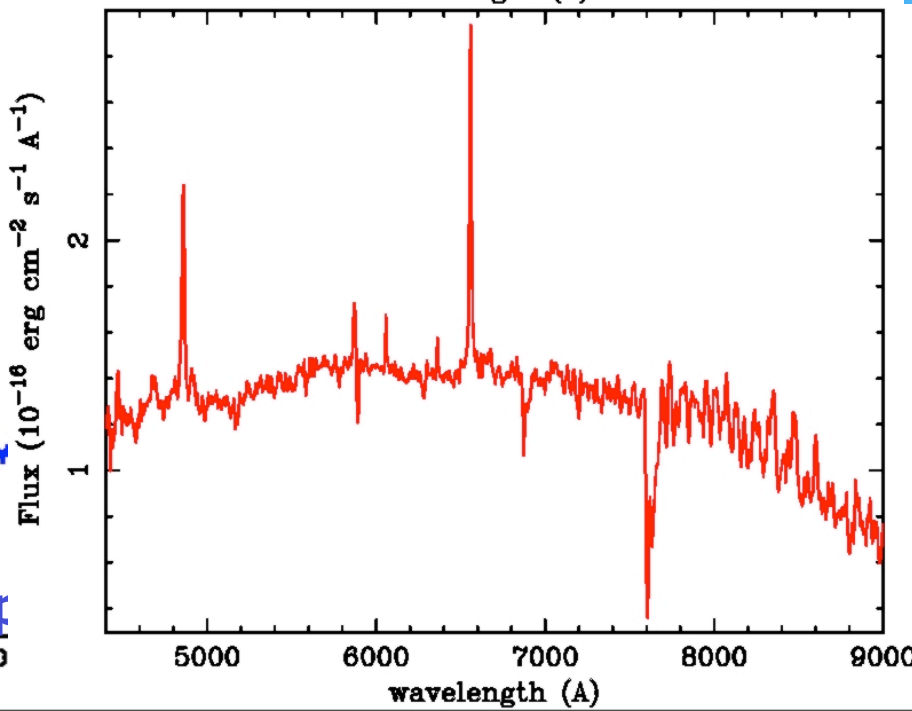

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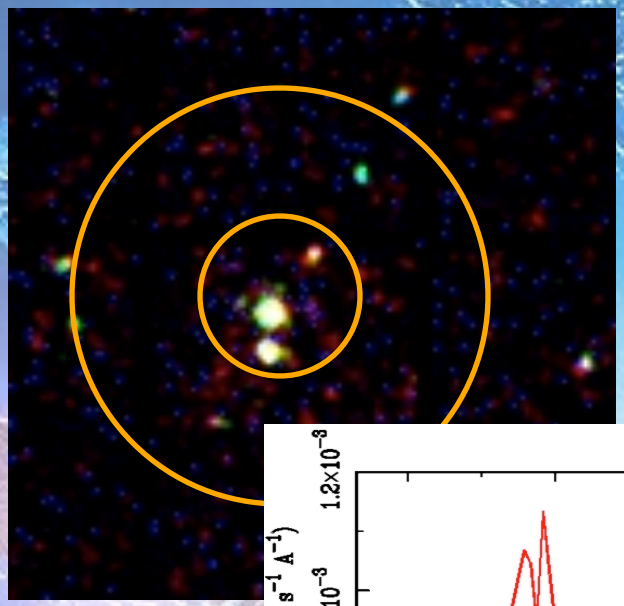

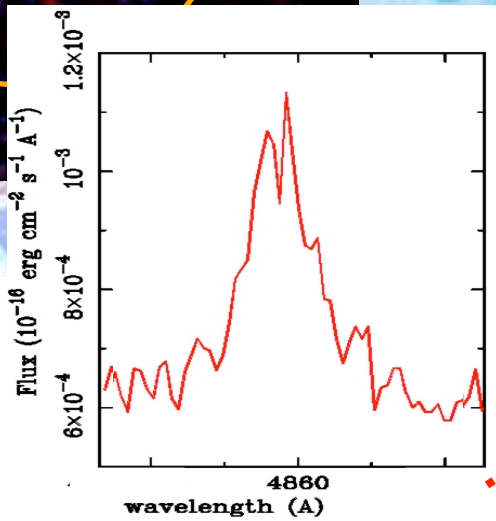

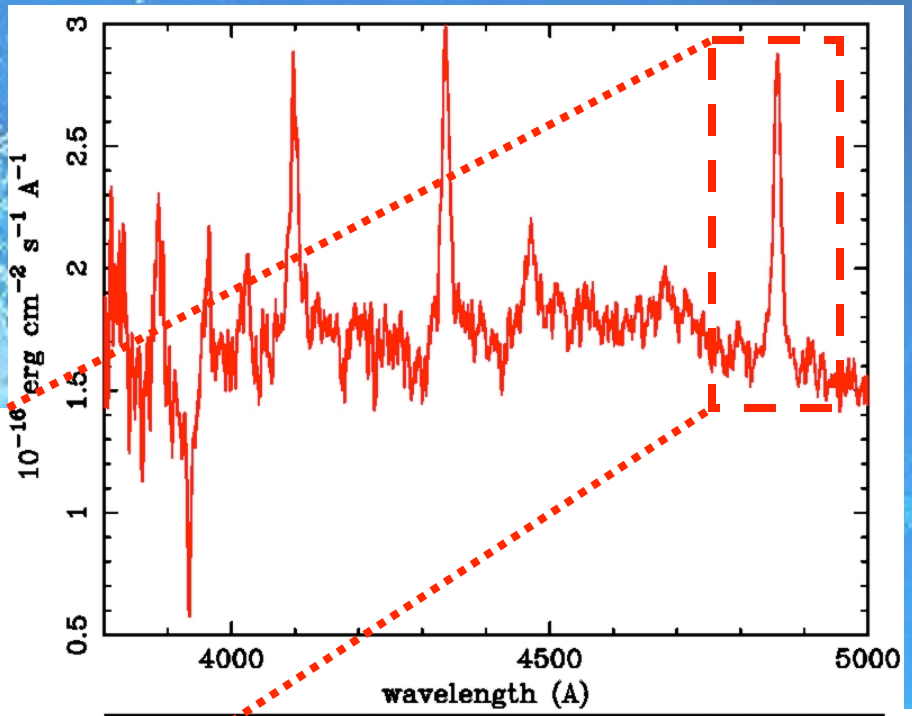

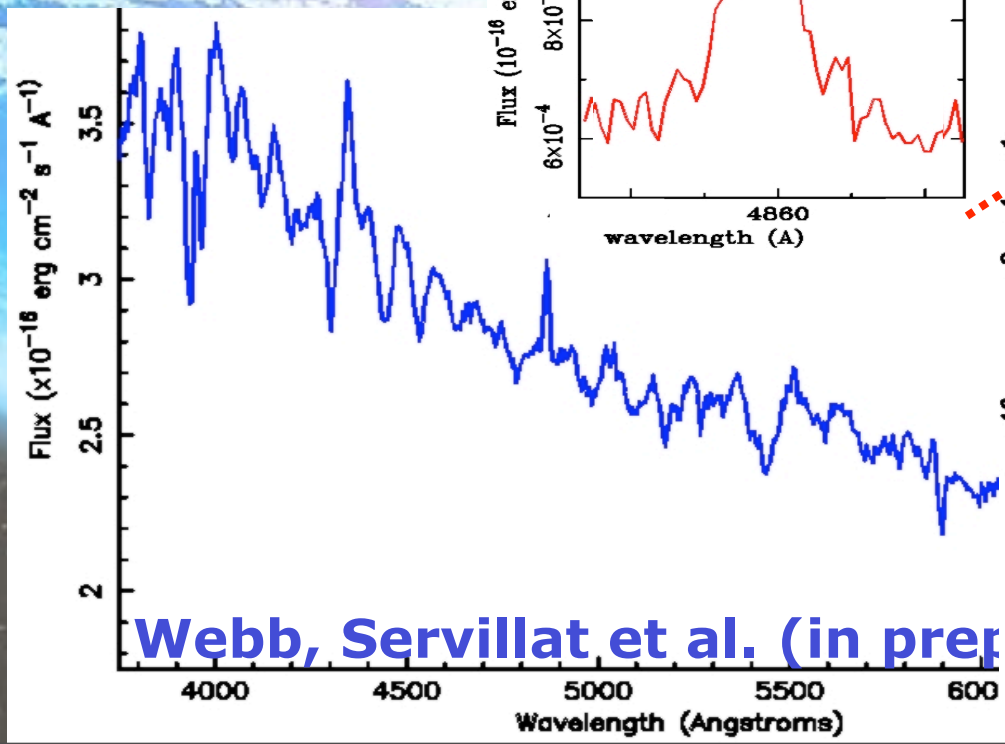

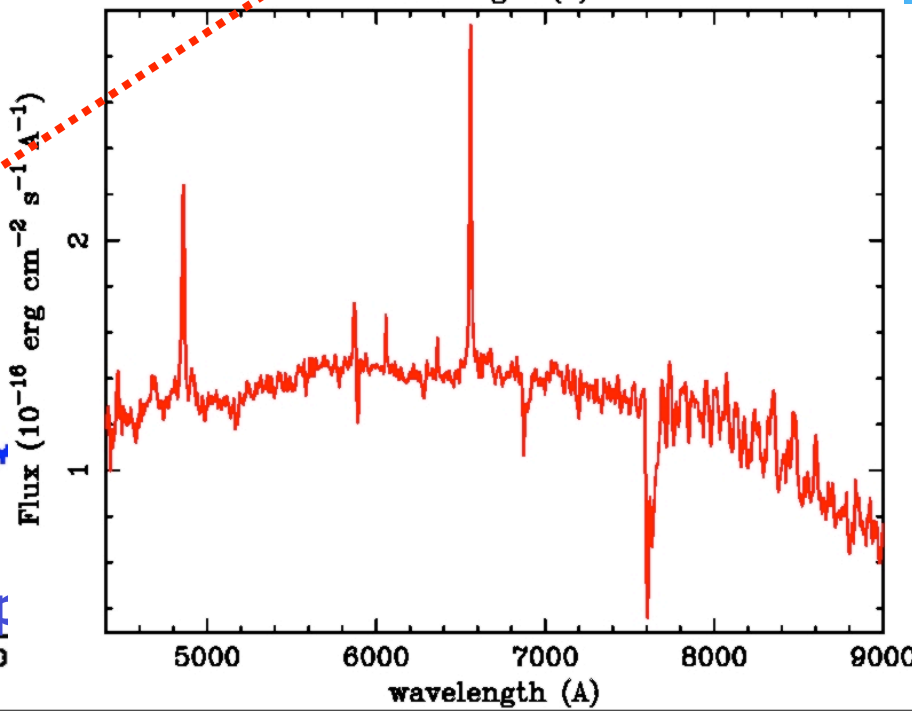

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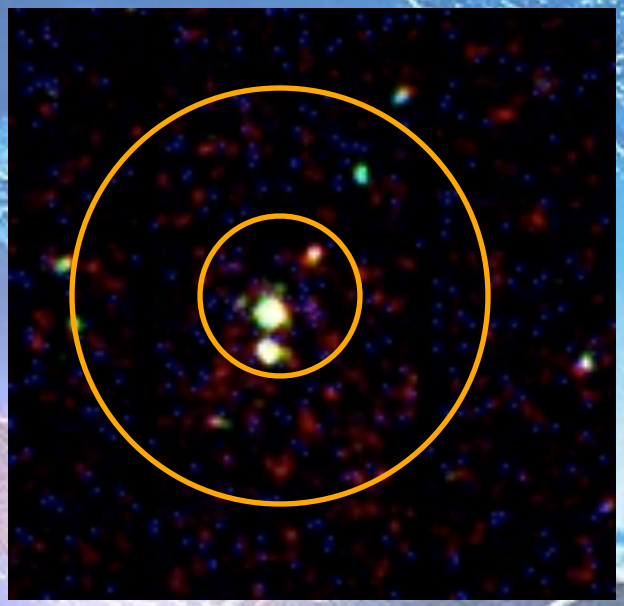

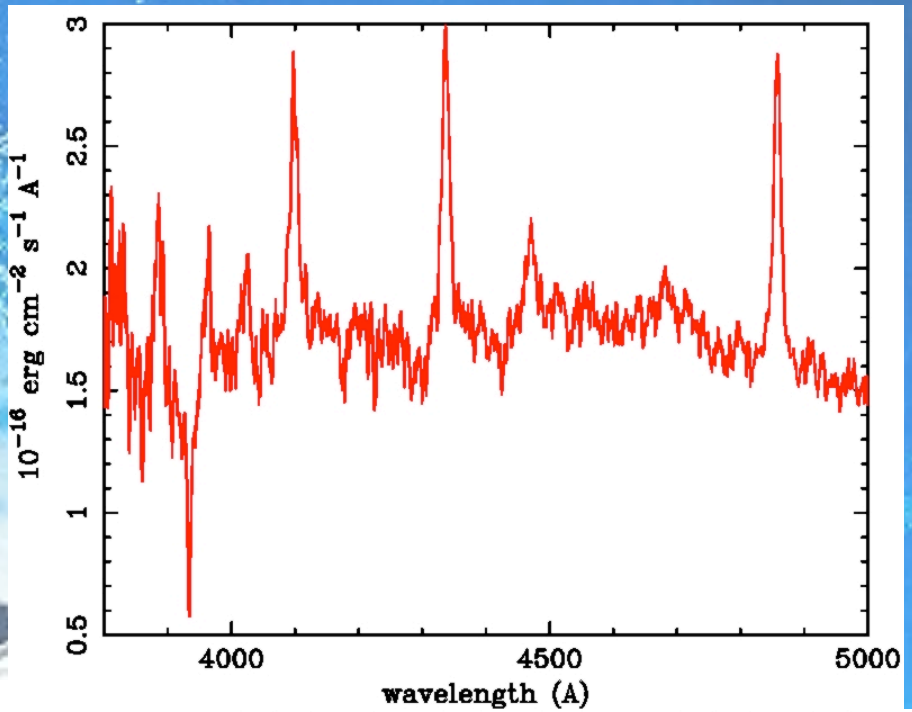

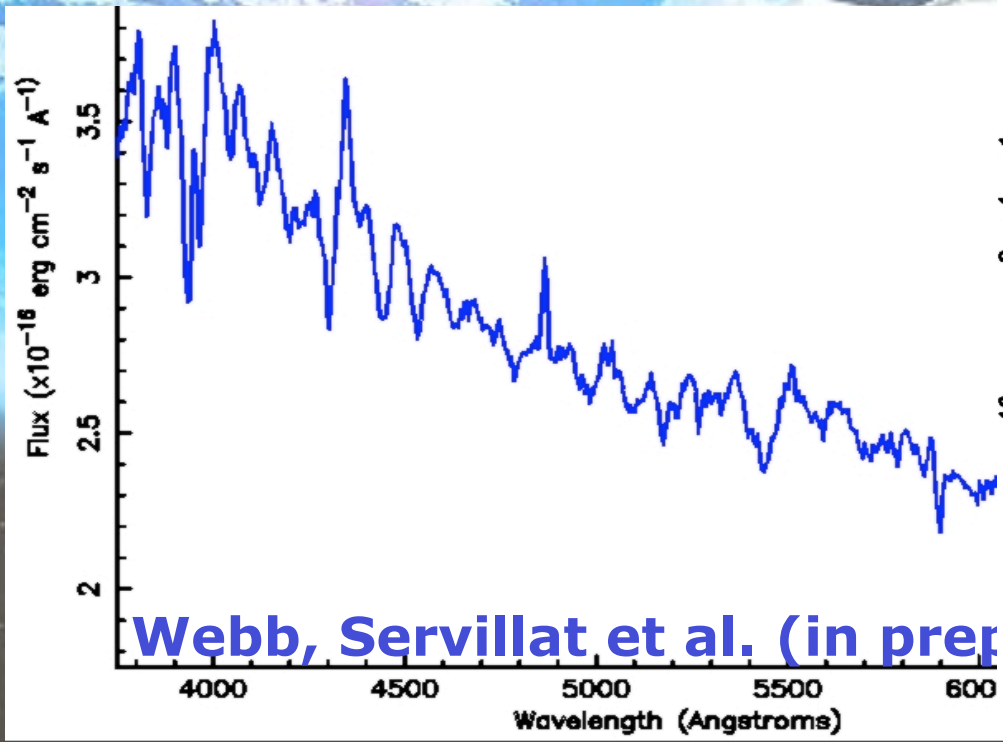

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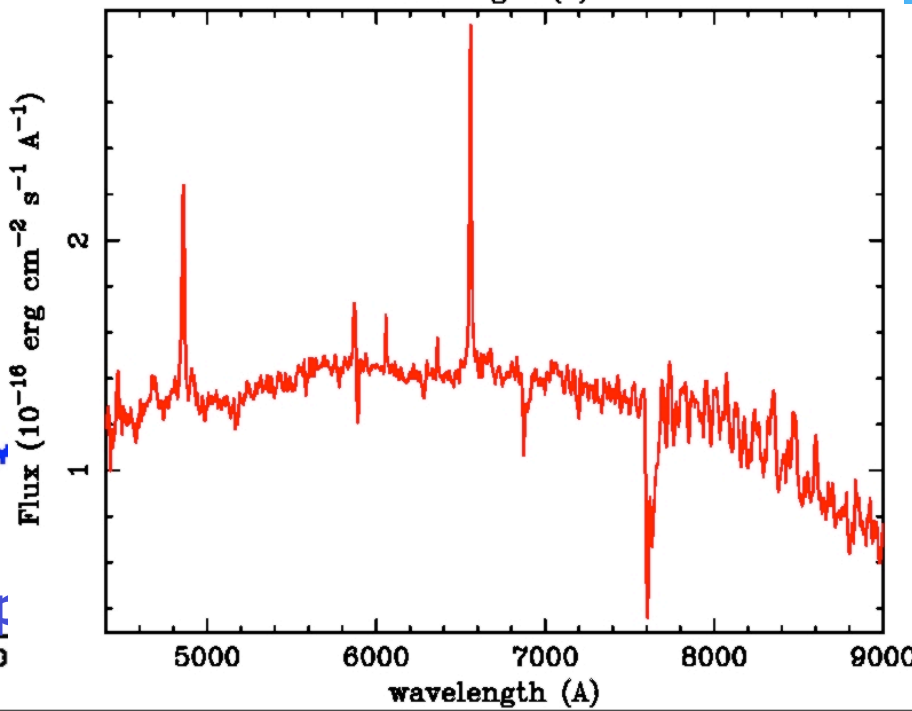

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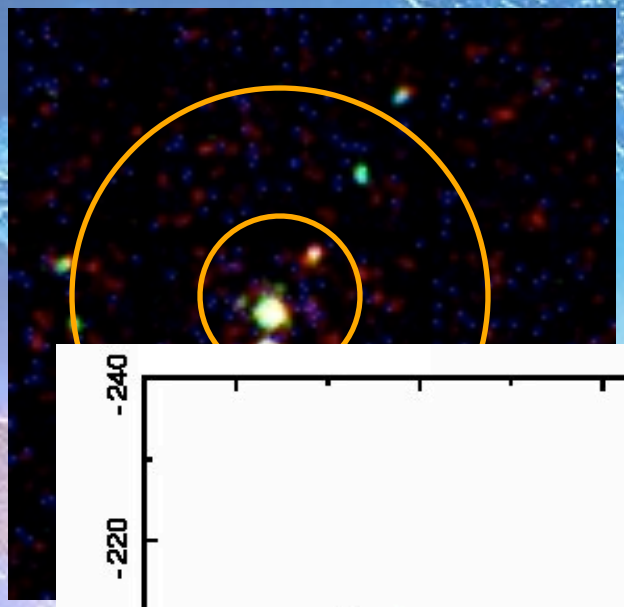
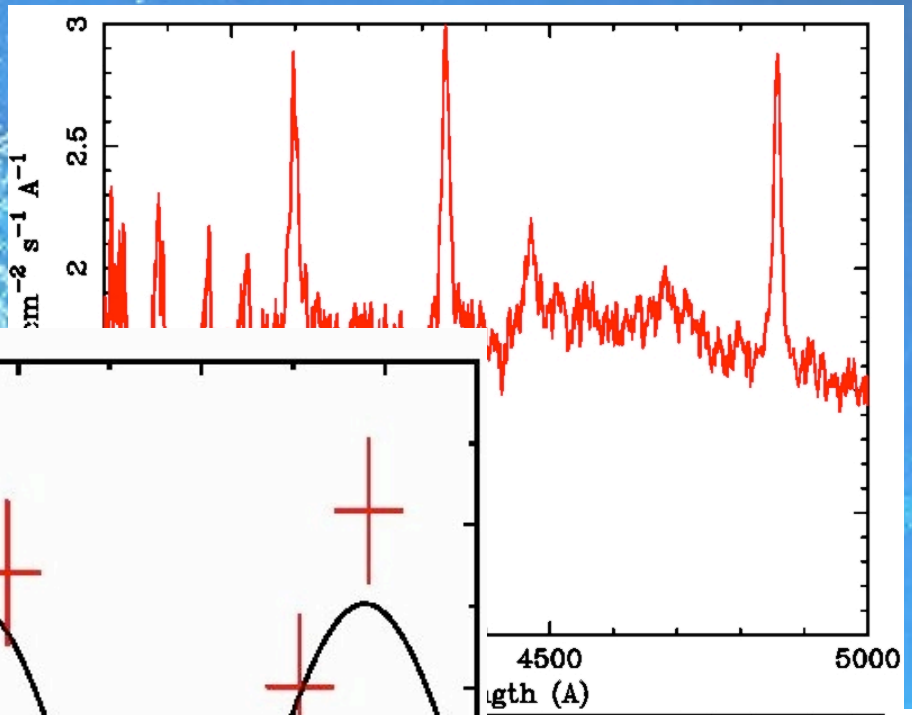
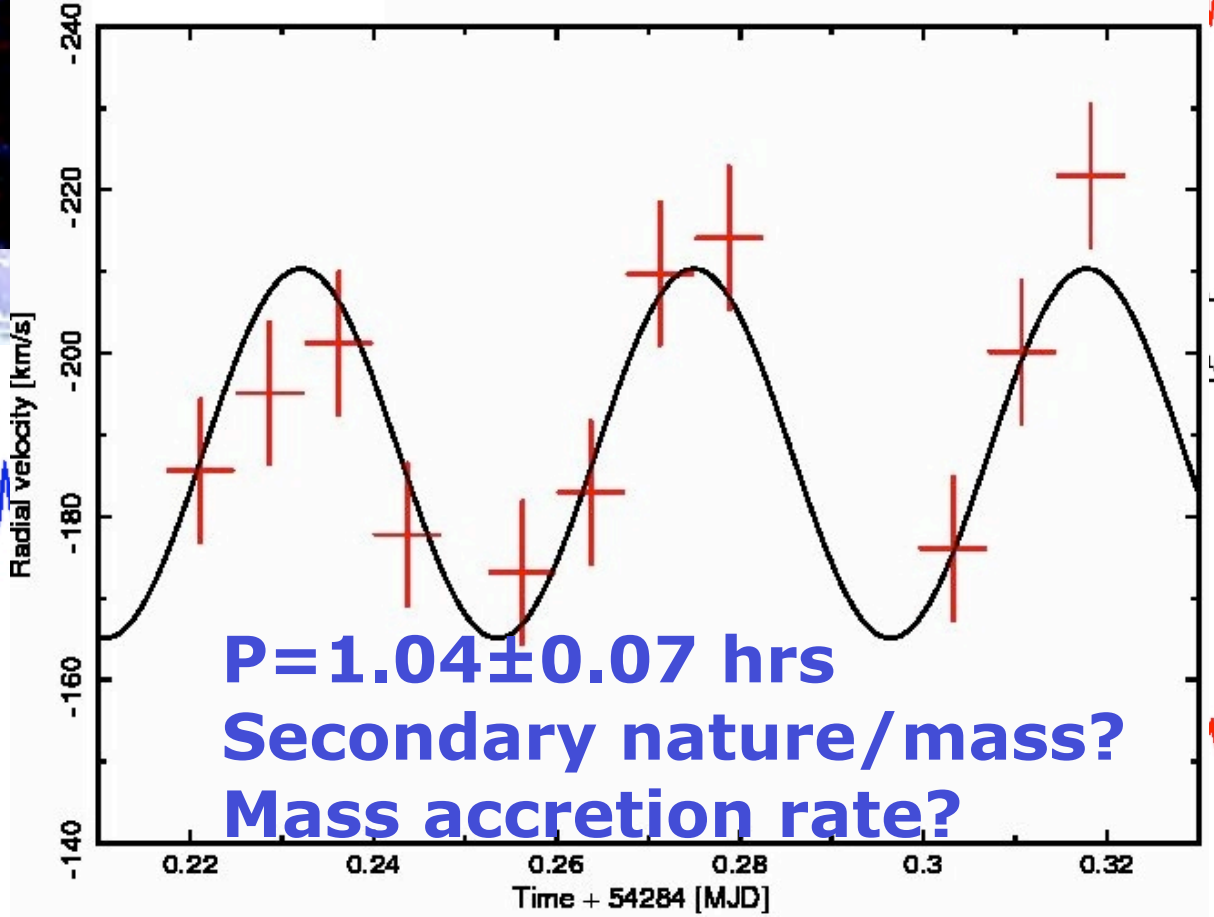
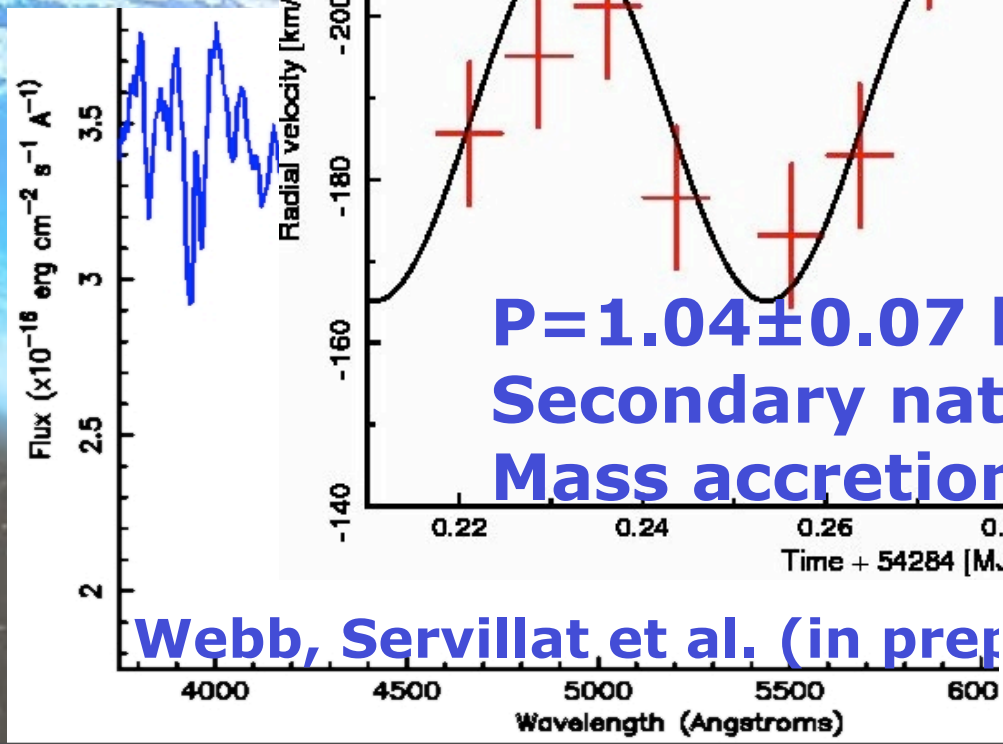
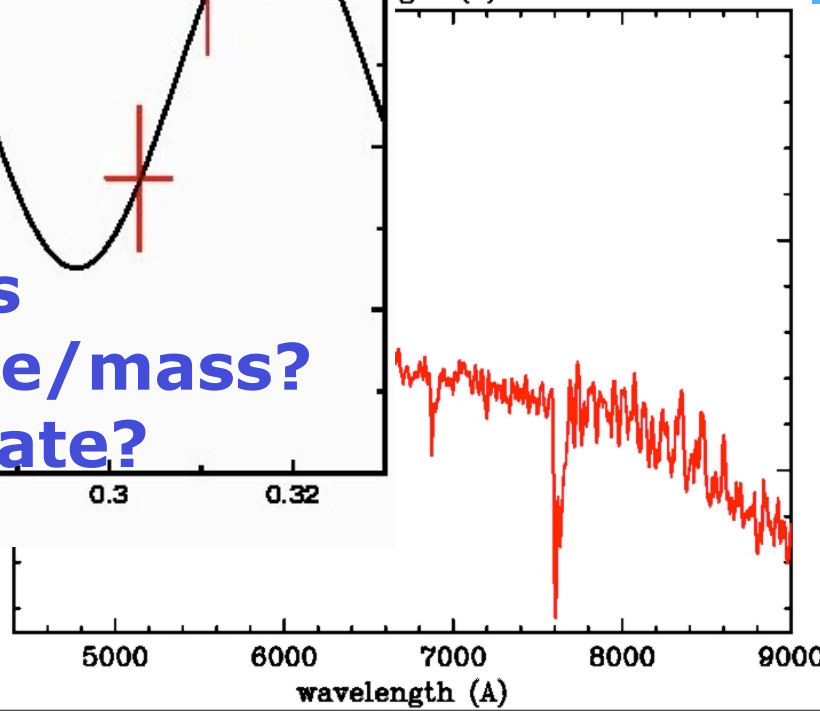






P=1.04±0.07 hrs
Secondary nature/mass?
Mass accretion rate?





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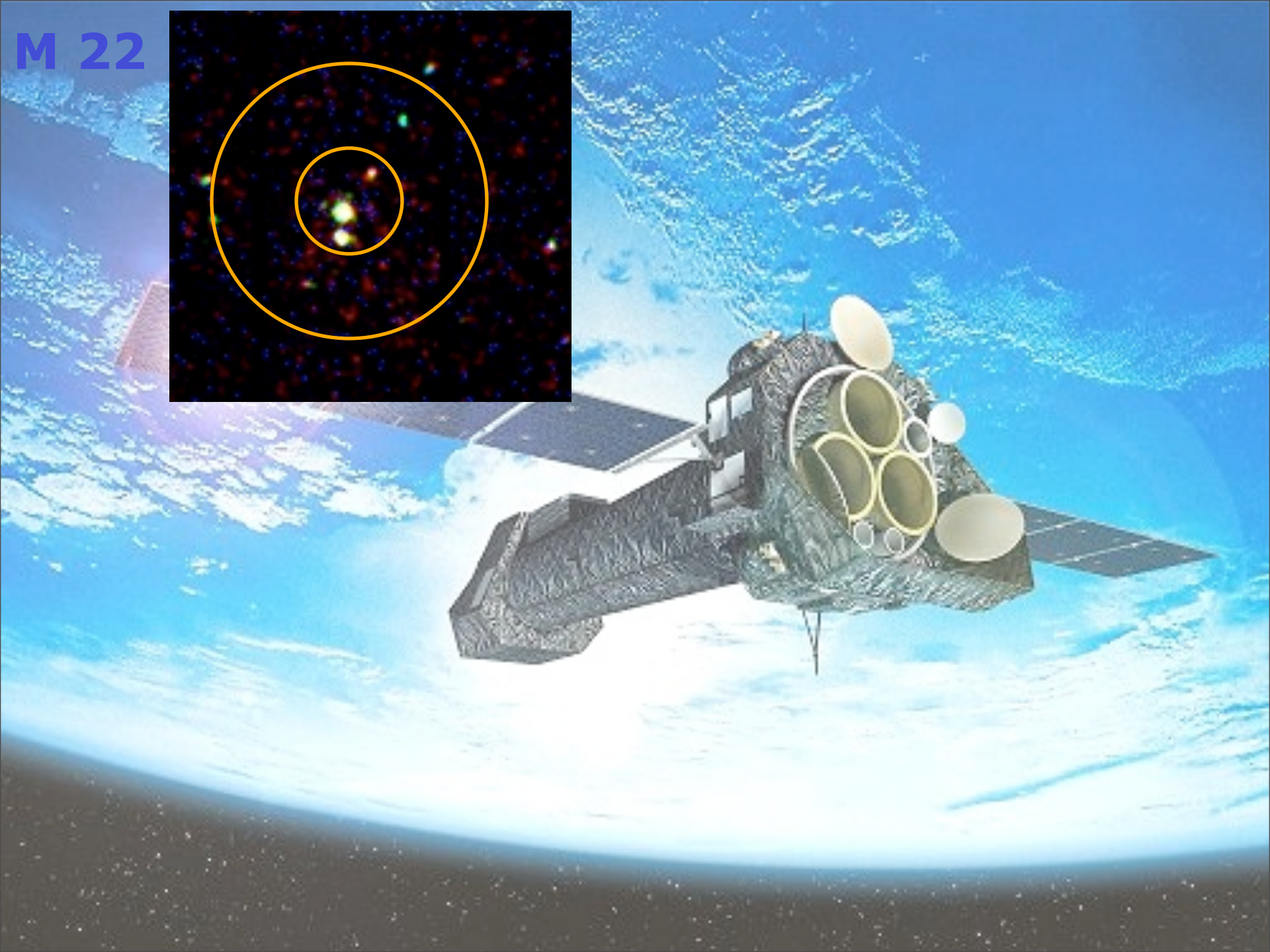
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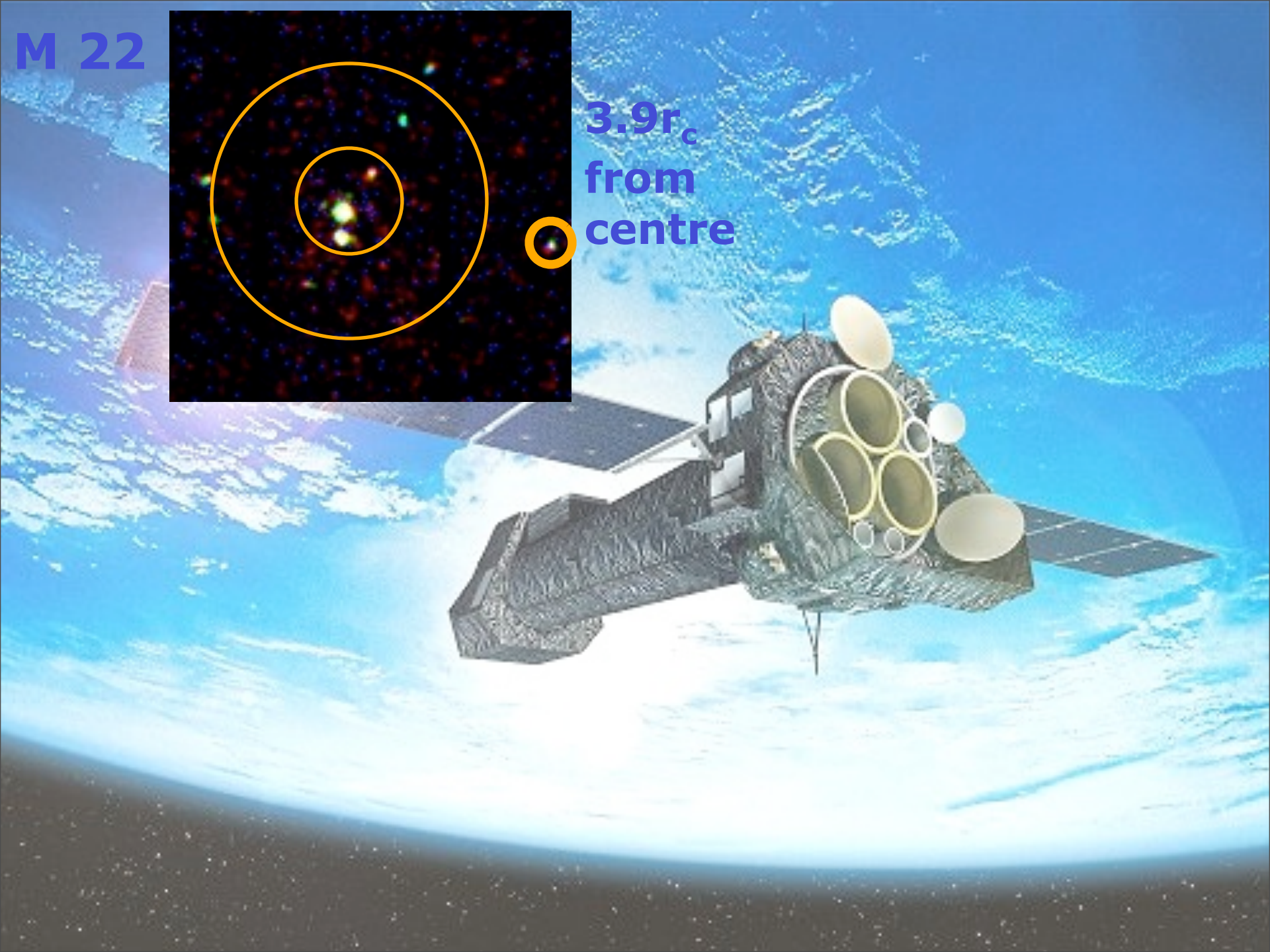
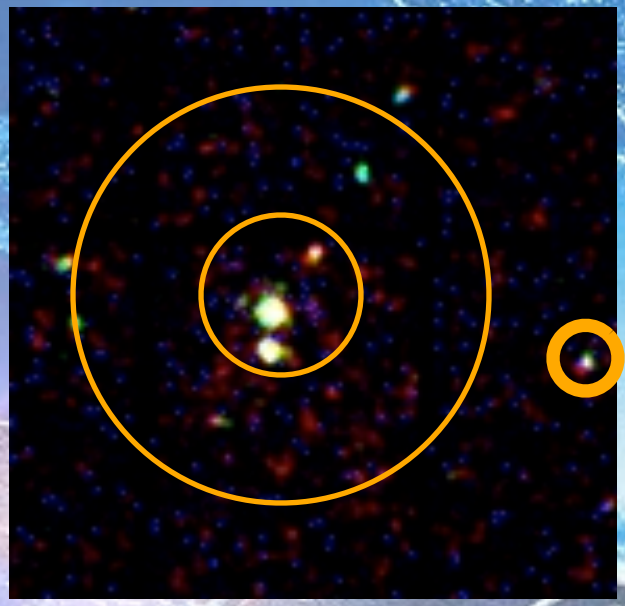
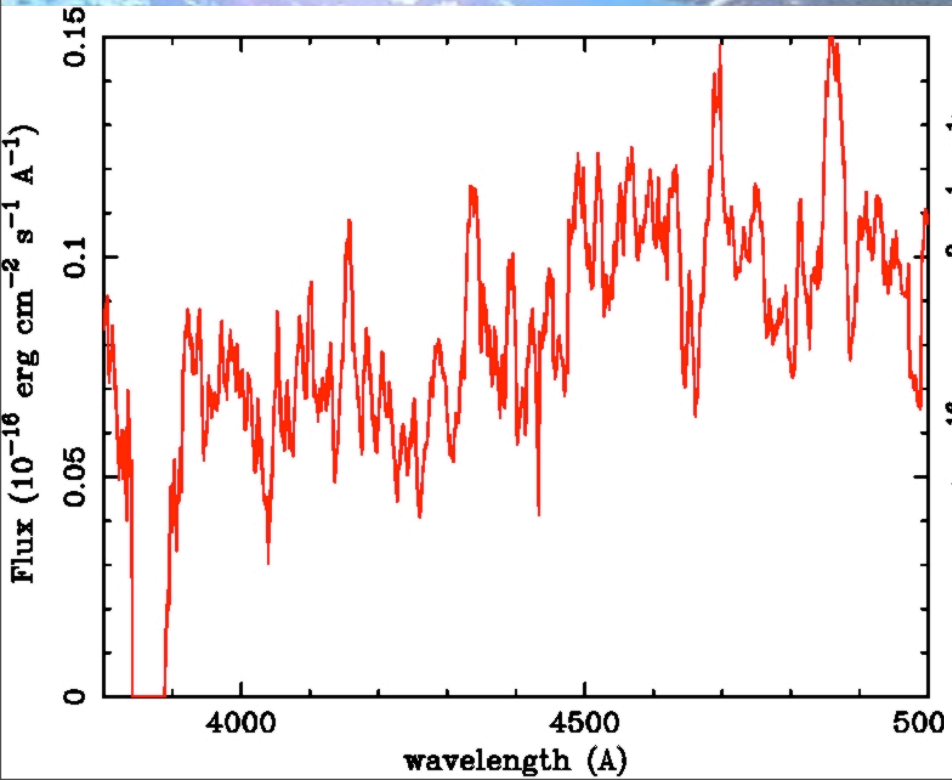
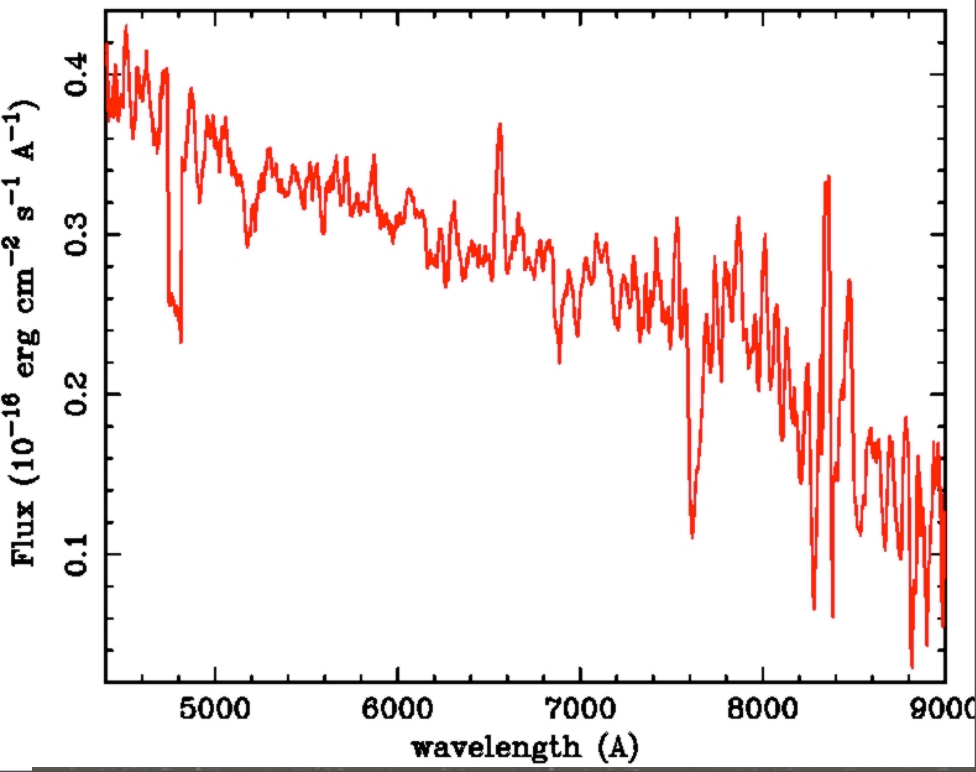

M 22
3.9r$_c$
from
centre

M 22



$3.9r_c$ from centre





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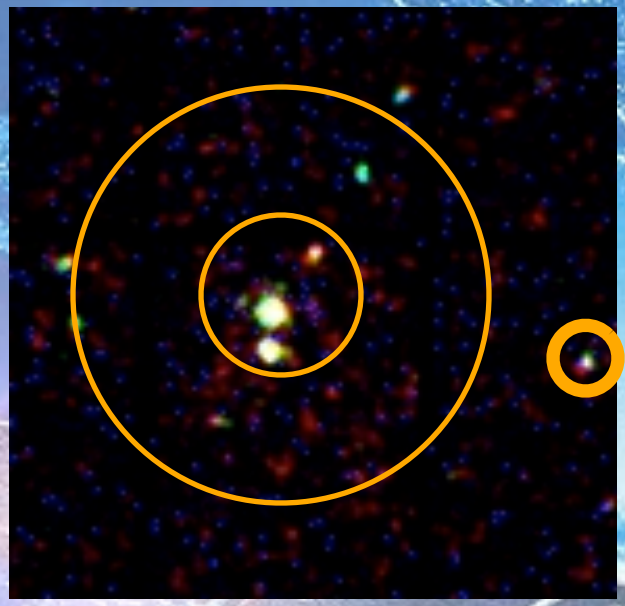
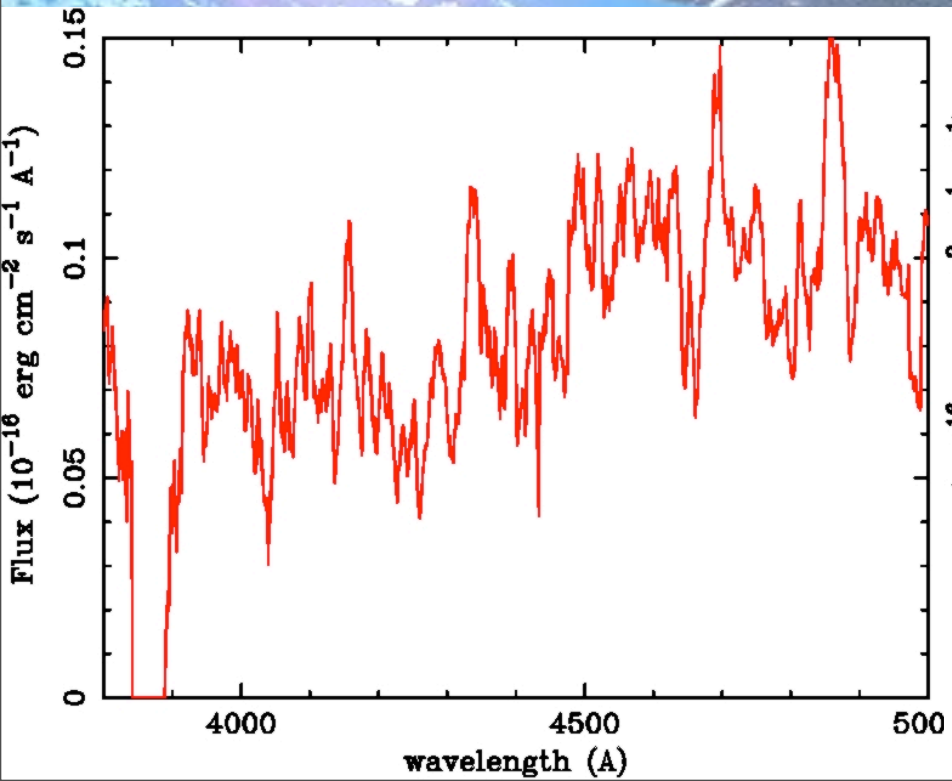
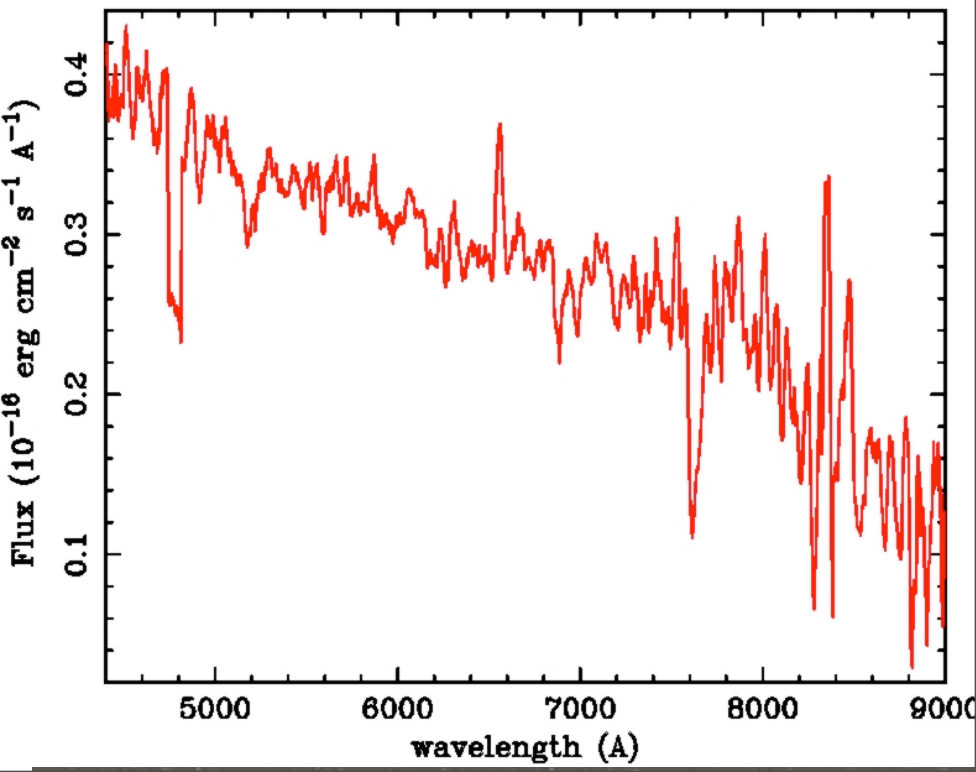
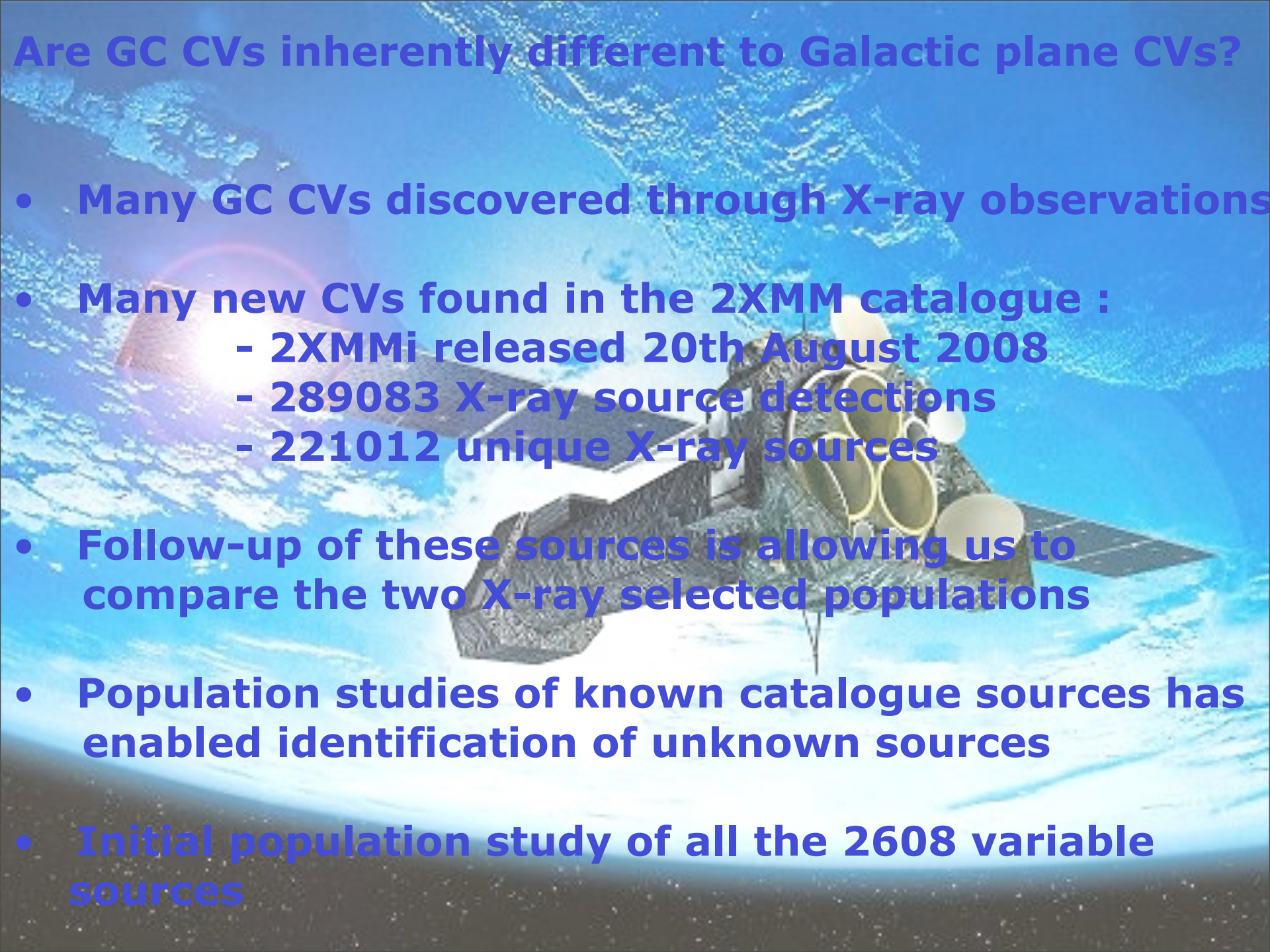


$3.9r_c$ from centre

Also UV and X-ray observations of NGC 2808 indicate two populations of CVs – estimates made to determine fractions of non-mag/mag. CVs (Servillat et al. 2008)







Are GC CVs inherently different to Galactic plane CVs?

- Many GC CVs discovered through X-ray observations

- Many new CVs found in the 2XMM catalogue :
  - 2XMMi released 20th August 2008
  - 289083 X-ray source detections
  - 221012 unique X-ray sources

- Follow-up of these sources is allowing us to compare the two X-ray selected populations

- Population studies of known catalogue sources has enabled identification of unknown sources

- Initial population study of all the 2608 variable sources

Variable sources in 2XMMi

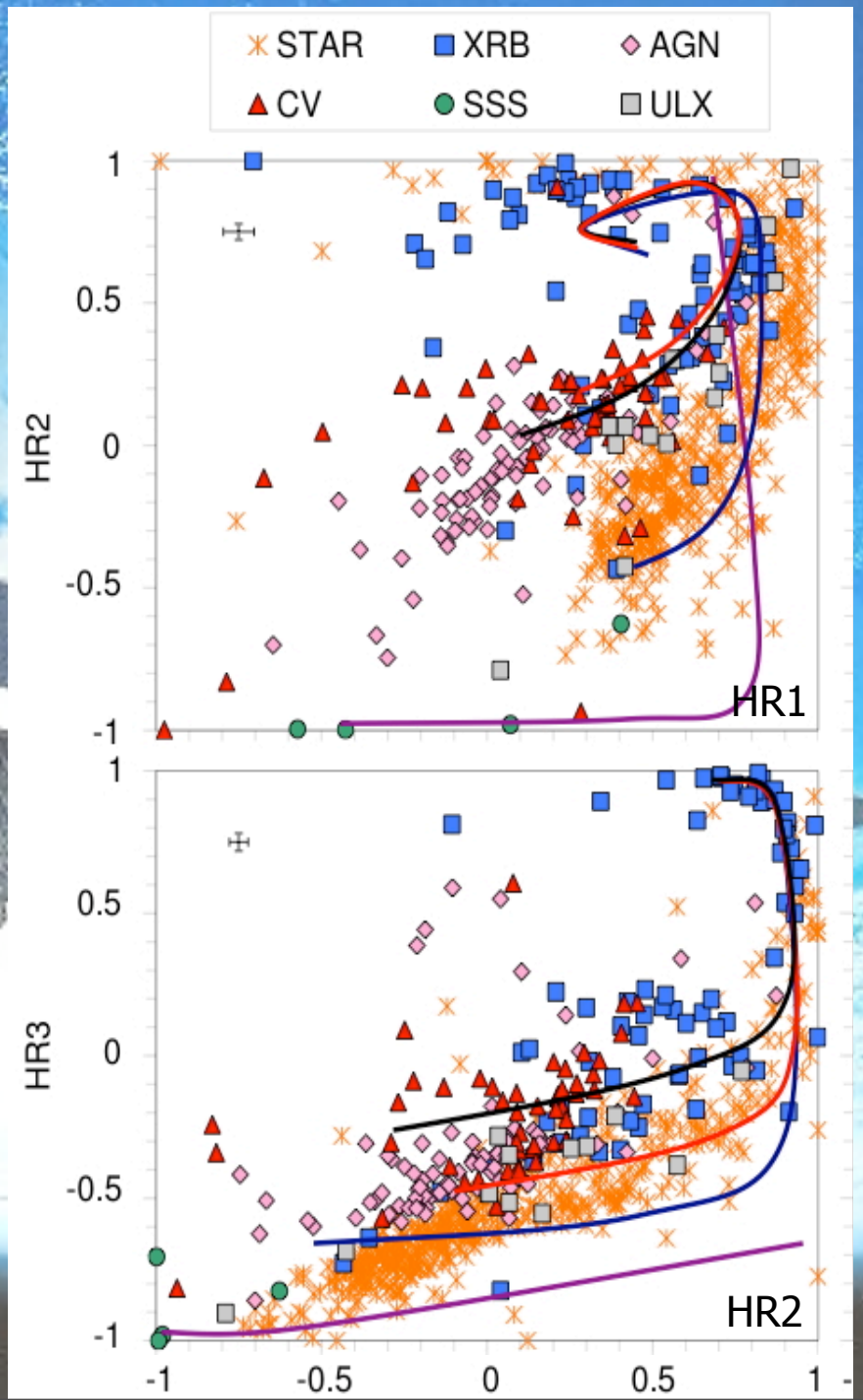
Band 1 = 0.2 – 0.5 keV
Band 2 = 0.5 – 1.0 keV
Band 3 = 1.0 – 2.0 keV
Band 4 = 2.0 – 4.5 keV
Band 5 = 4.5 – 12.0 keV

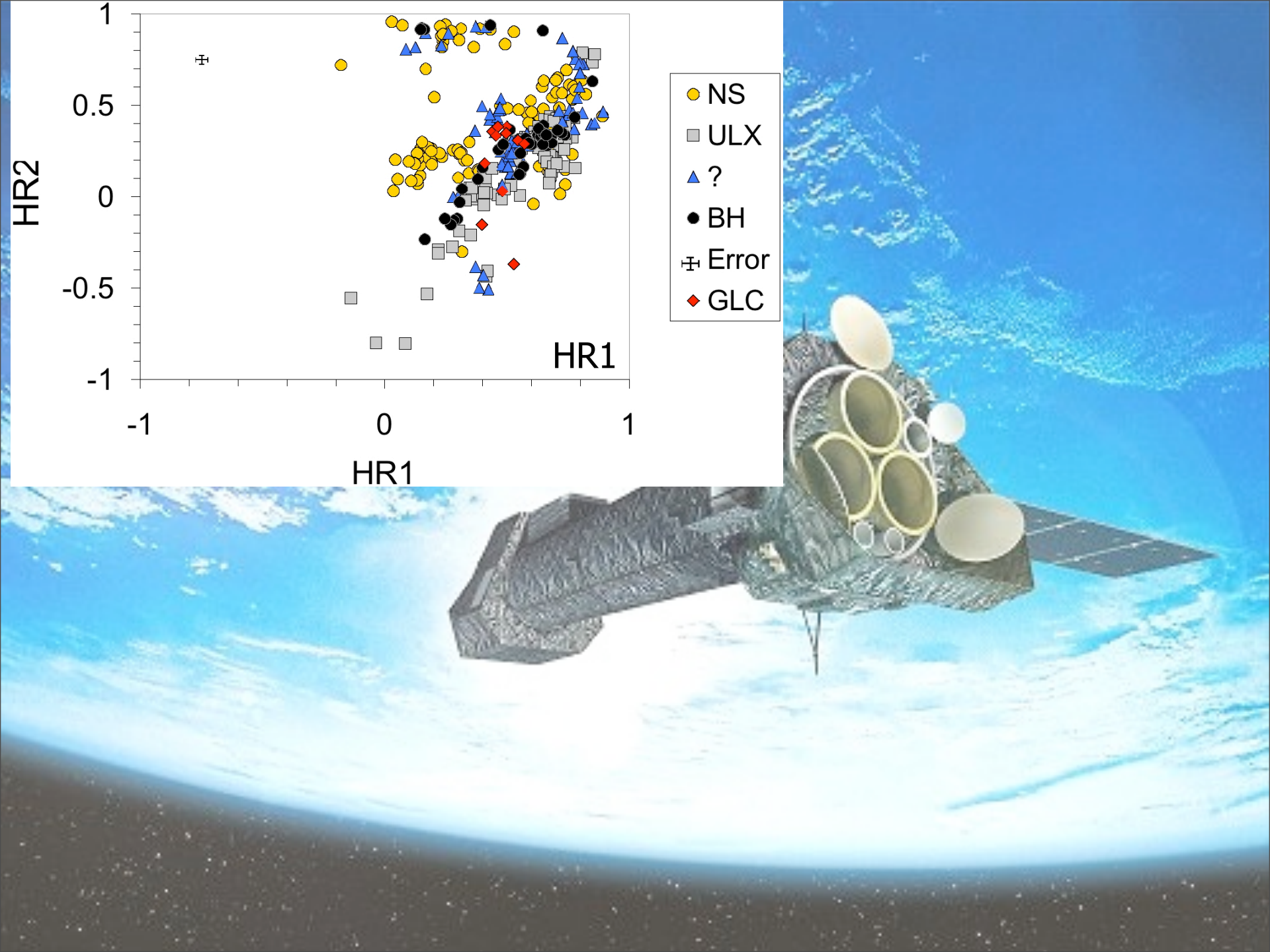
$$HR1 = \frac{\text{Band 2} - \text{Band 1}}{\text{Band 2} + \text{Band 1}}$$

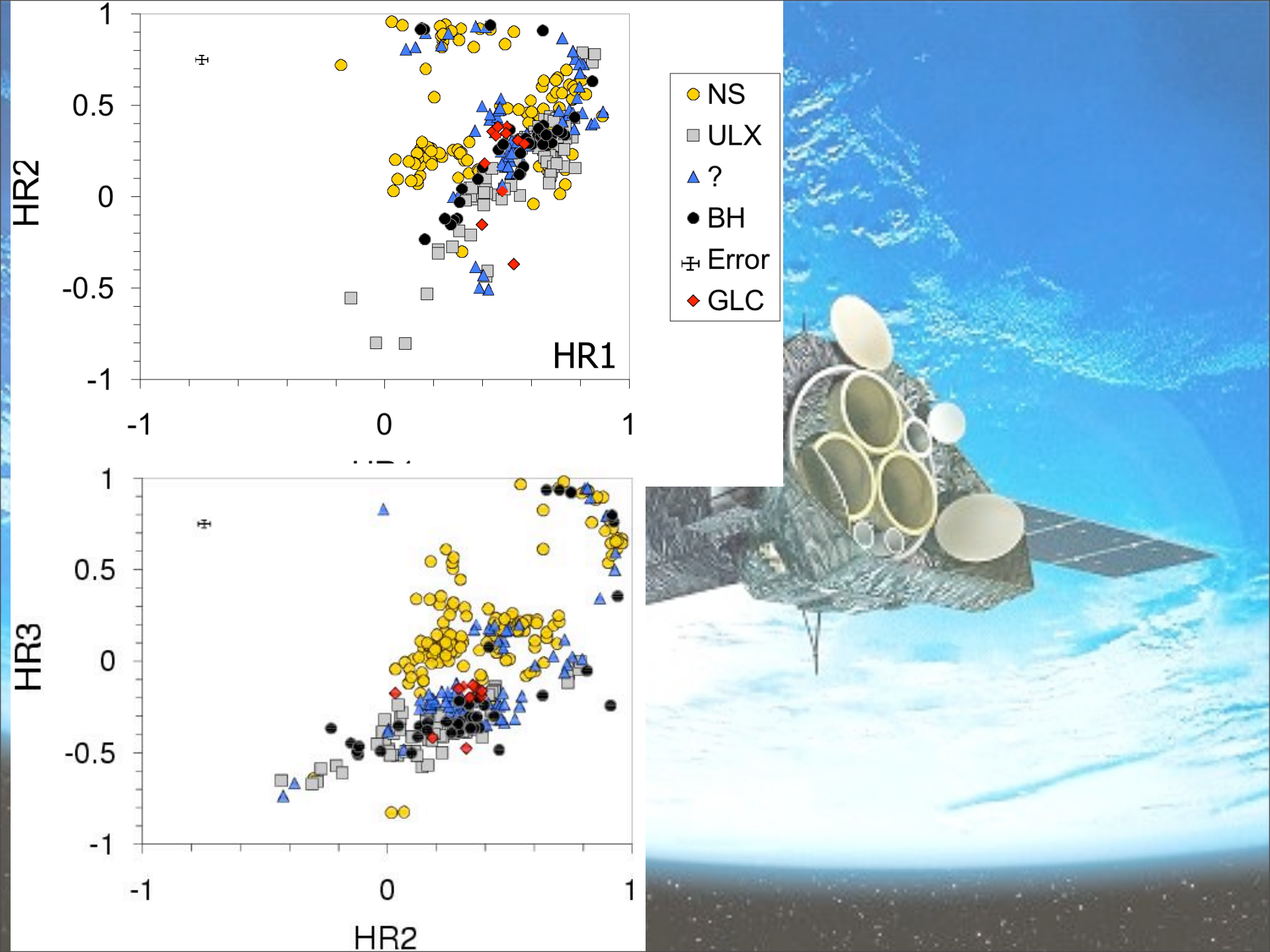
$$HR2 = \frac{\text{Band 3} - \text{Band 2}}{\text{Band 3} + \text{Band 2}}$$

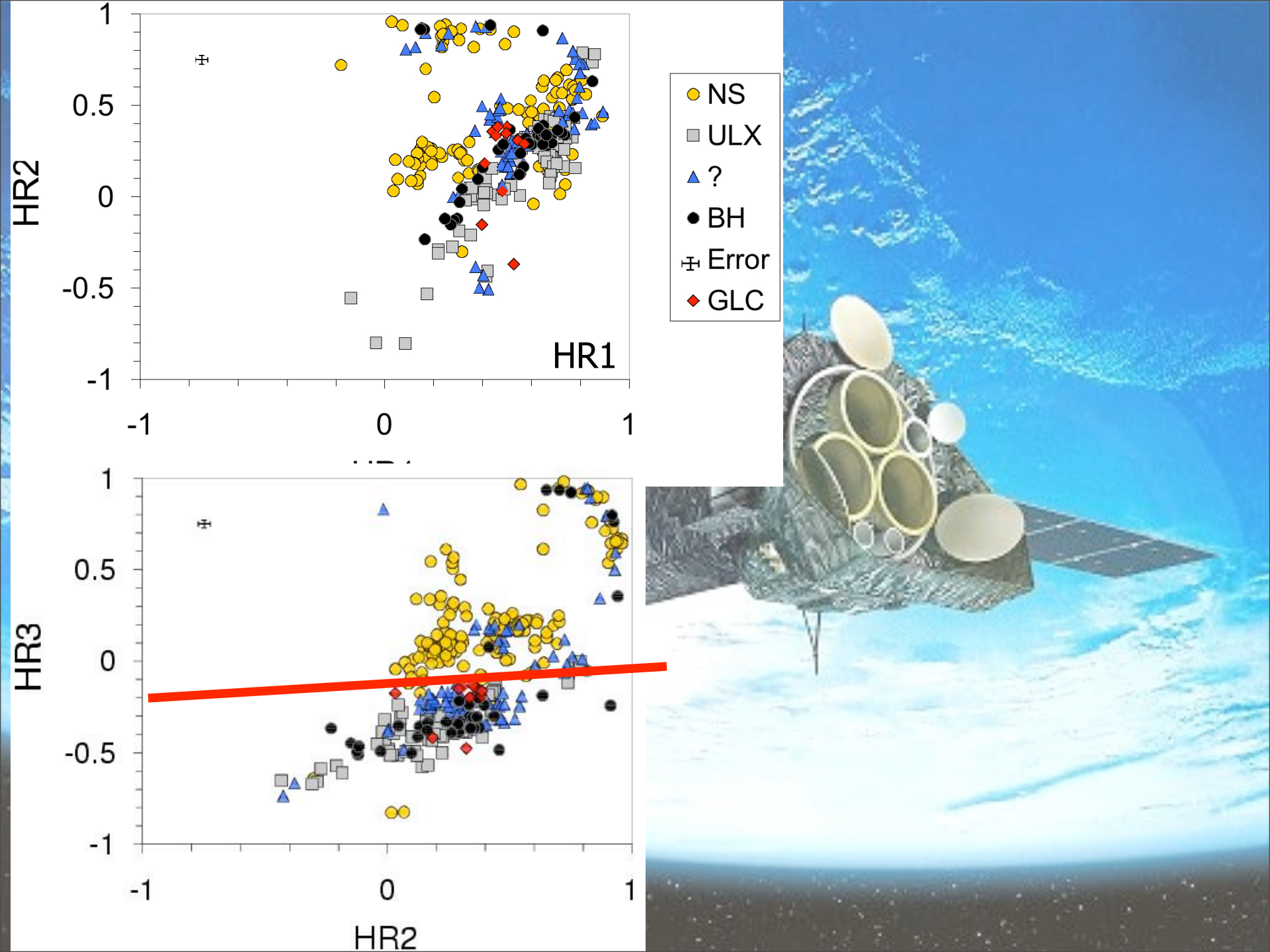
$$HR3 = \frac{\text{Band 4} - \text{Band 3}}{\text{Band 4} + \text{Band 3}}$$

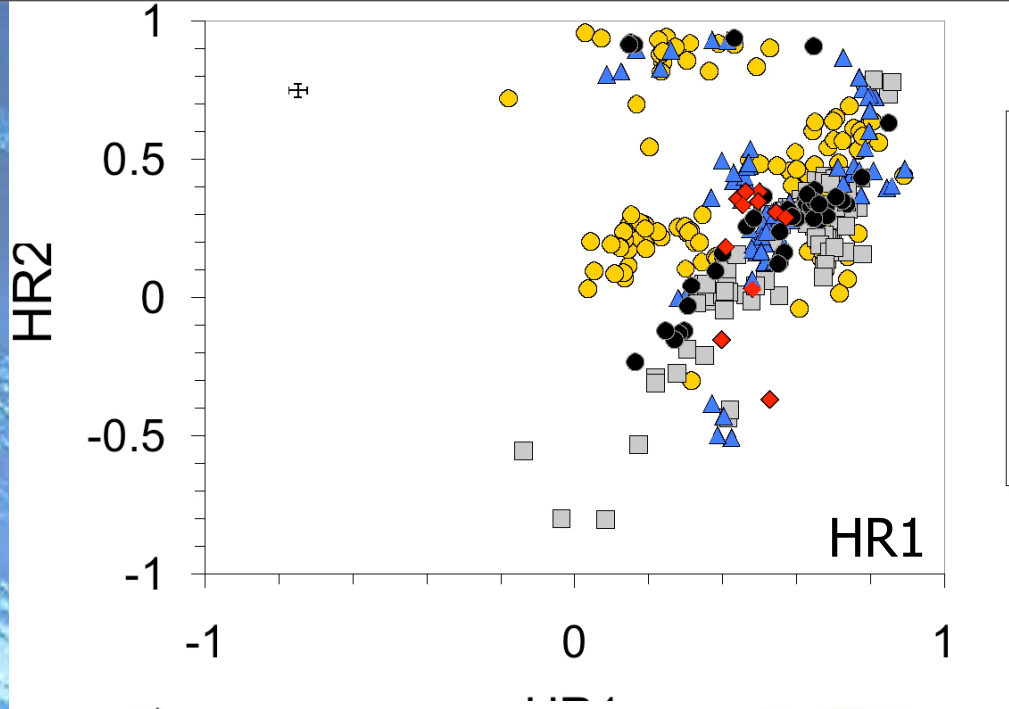
$$HR4 = \frac{\text{Band 5} - \text{Band 4}}{\text{Band 5} + \text{Band 4}}$$

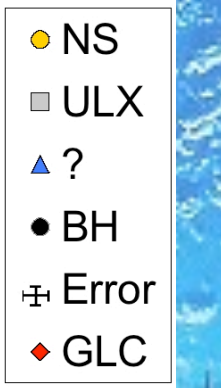


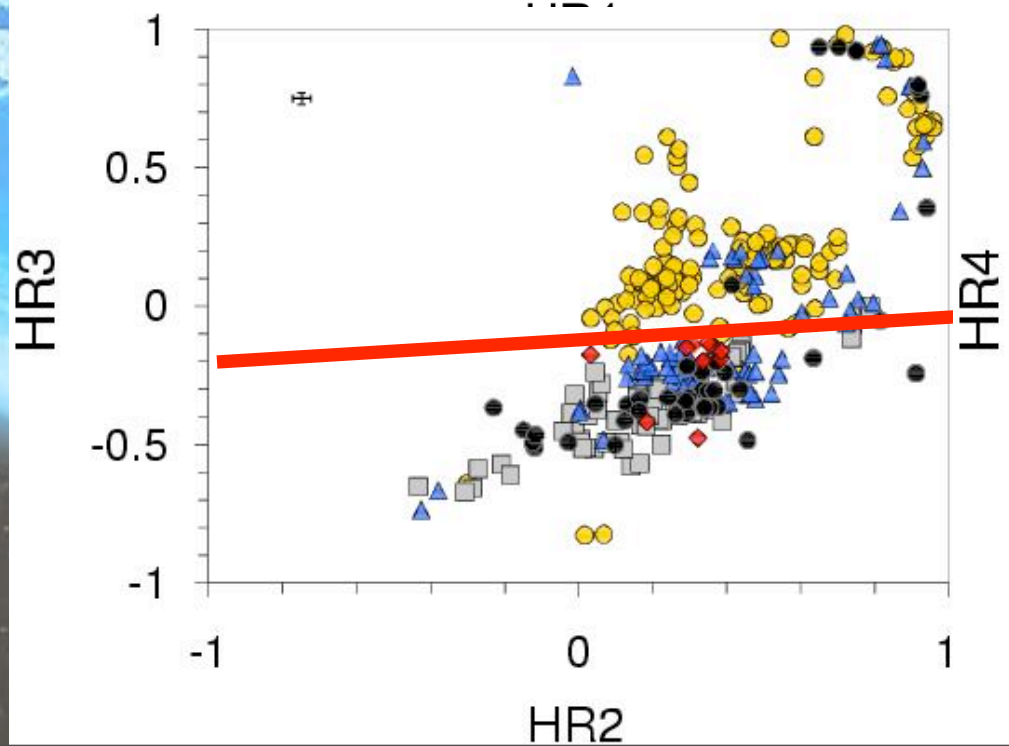

1
0.5
0
-0.5
-1
HR2
-1
0
1
HR1
HR1
NS
ULX
?
BH
Error
GLC

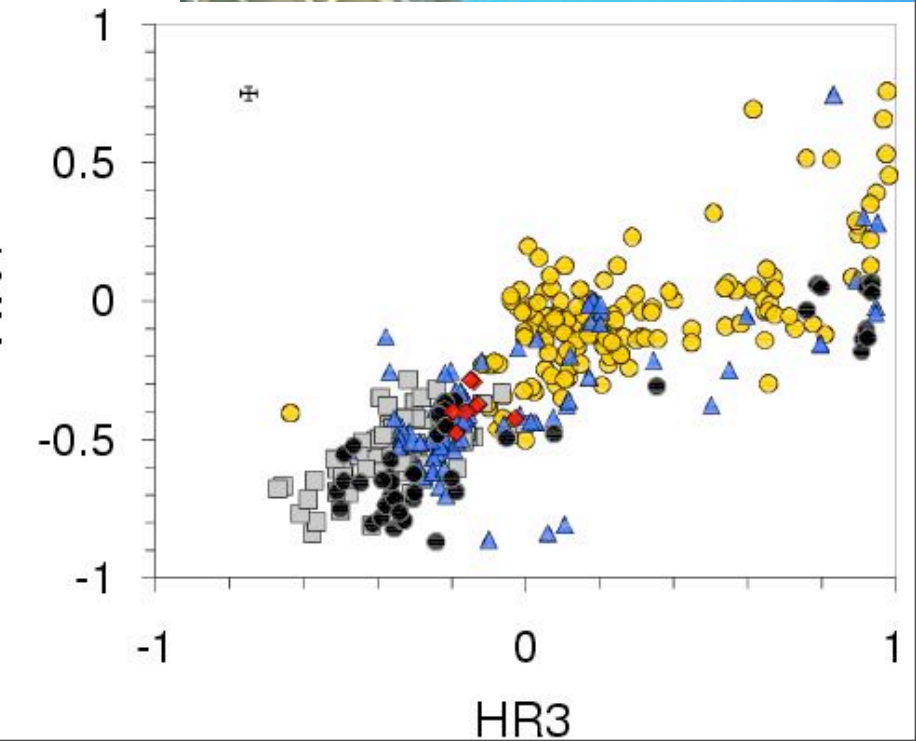

HR2
HR1
1
0.5
0
-0.5
-1
-1
0
1
NS
ULX
?
BH
Error
GLC
HR3
HR2
1
0.5
0
-0.5
-1
-1
0
1

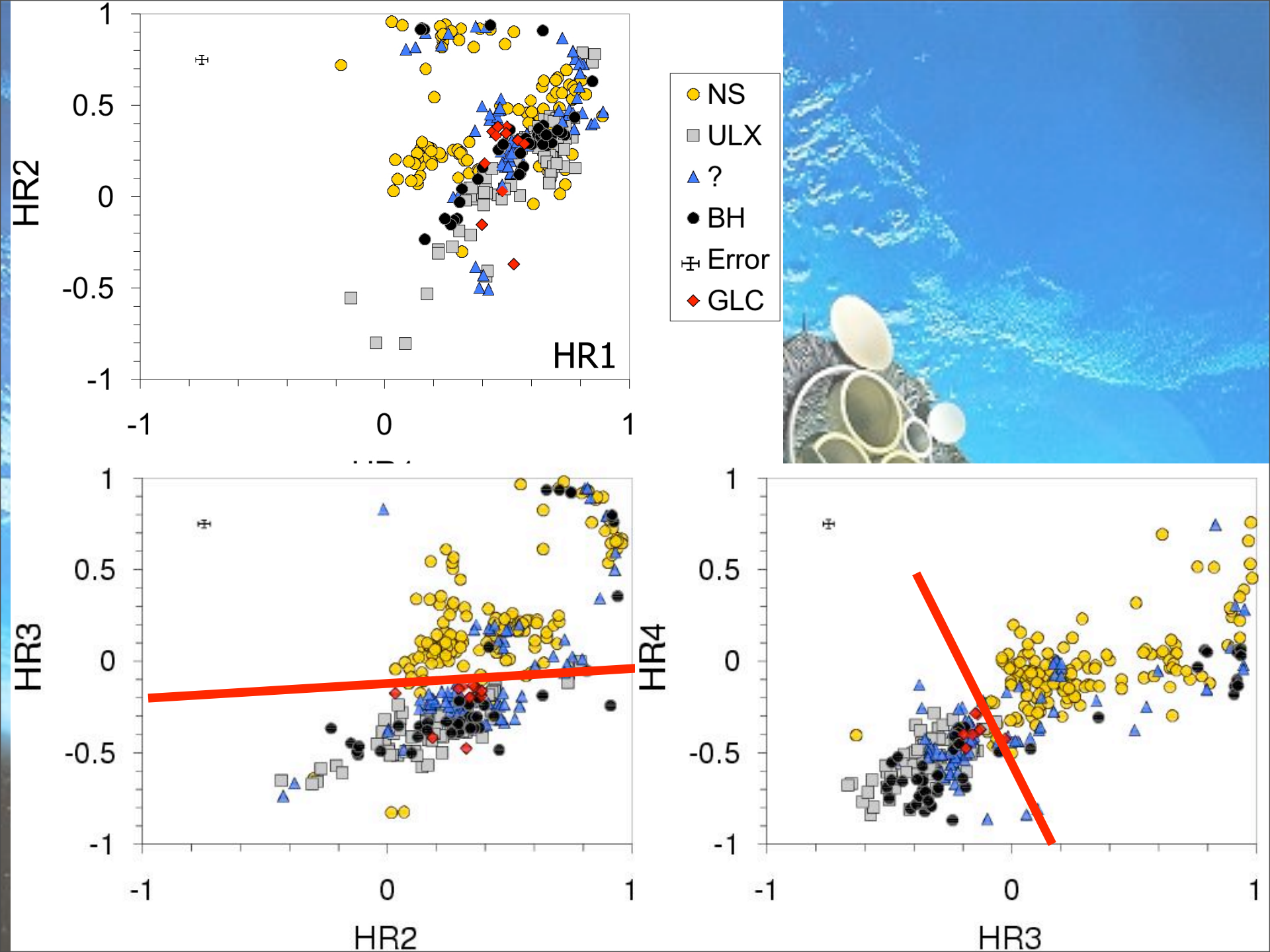

HR2
HR1
1
0.5
0
-0.5
-1
-1
0
1
NS
ULX
?
BH
Error
GLC
HR3
HR2
1
0.5
0
-0.5
-1
-1
0
1

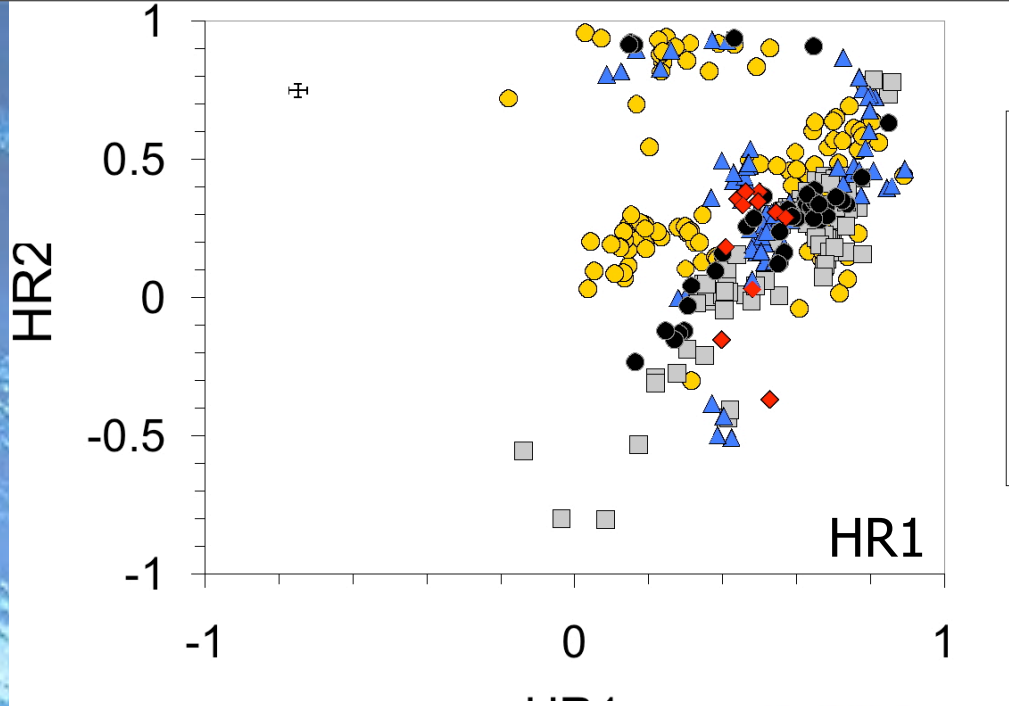

HR2
HR1
1
0.5
0
-0.5
-1
-1
0
1

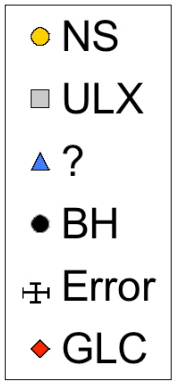

NS
ULX
?
BH
Error
GLC


HR3
HR2
1
0.5
0
-0.5
-1
-1
0
1


HR4
HR3
1
0.5
0
-0.5
-1
-1
0
1

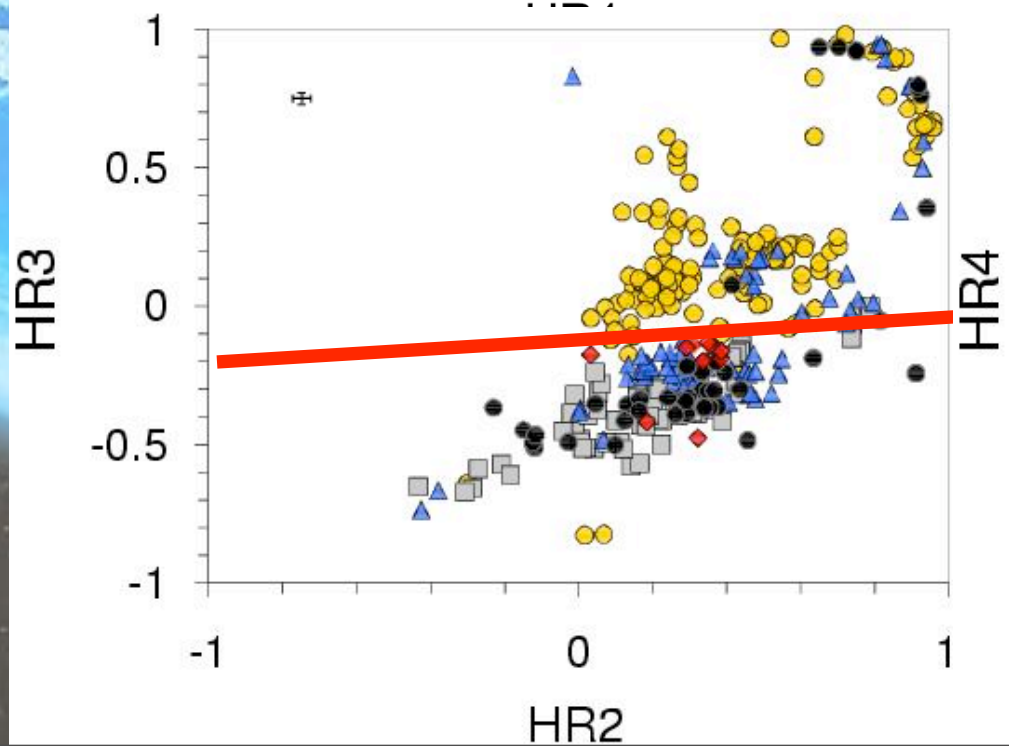

HR2
HR1
1
0.5
0
-0.5
-1
-1
0
1
NS
ULX
?
BH
Error
GLC
HR3
HR4
HR2
HR3

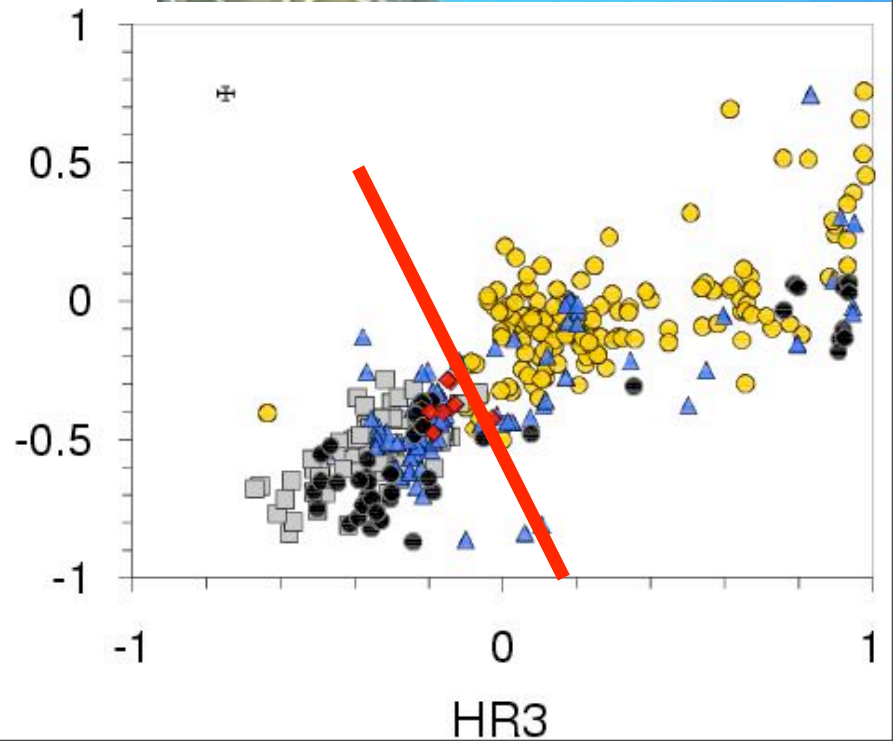




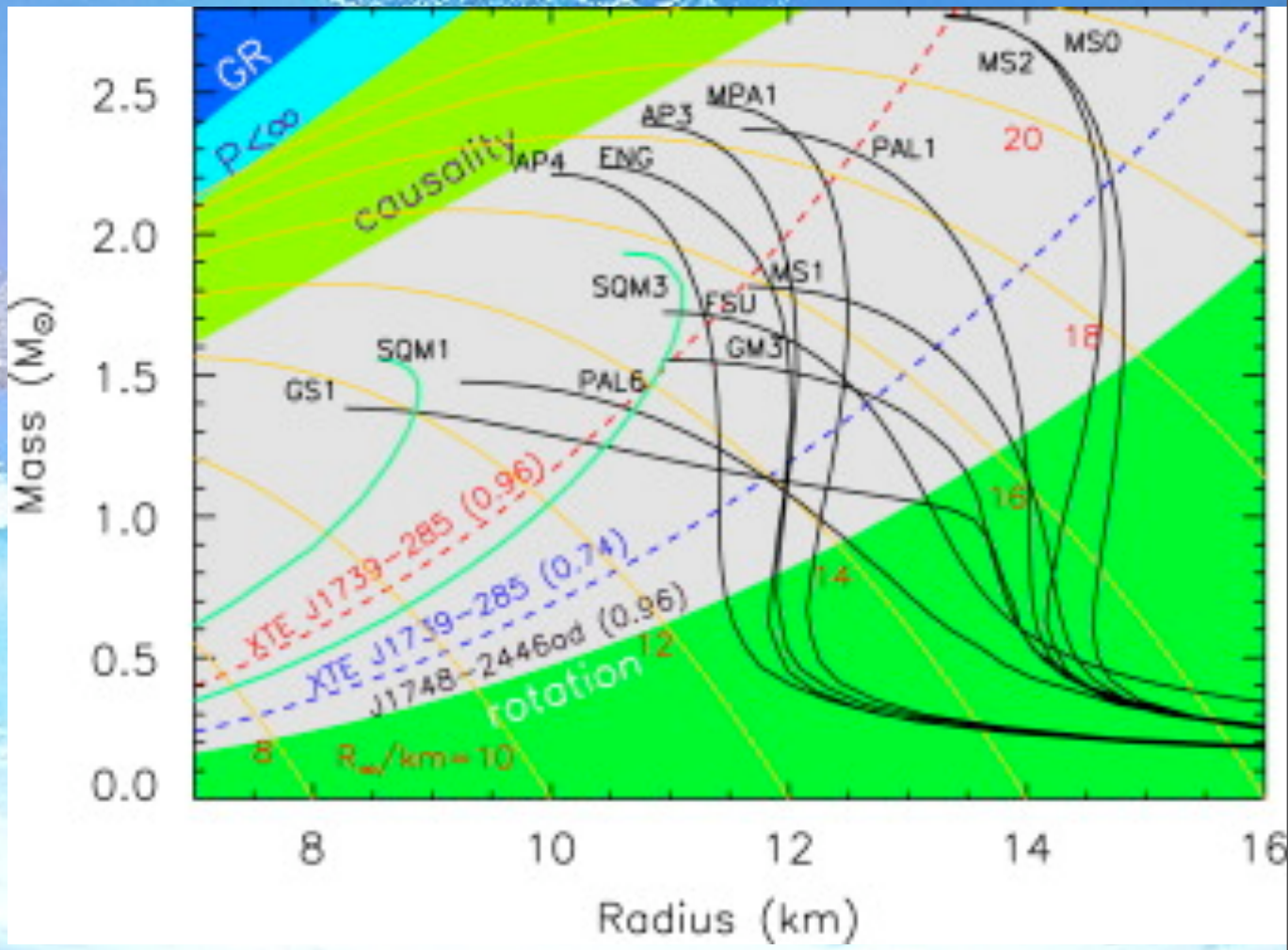
Four M 31 globular clusters observed several times

All fall in black hole region of diagrams





The equation of state



Lattimer & Prakash (2007)

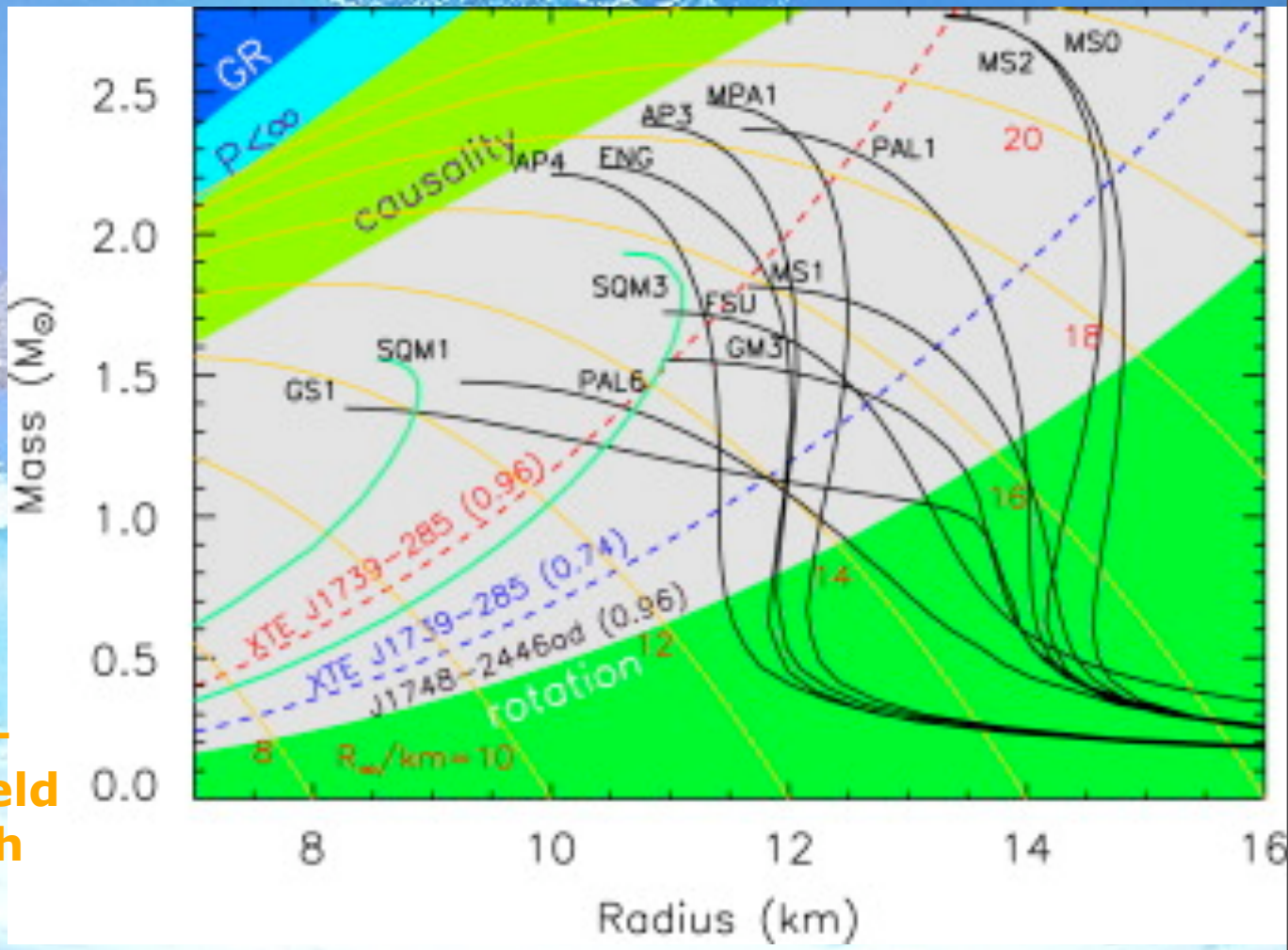
The equation of state

PAL –
Prakash, Ainsworth & Lattimer (1988)
Neutrons + protons using a schematic potential

SQM –
Prakash, Cooke & Lattimer (1995)
Strange Quark Matter model

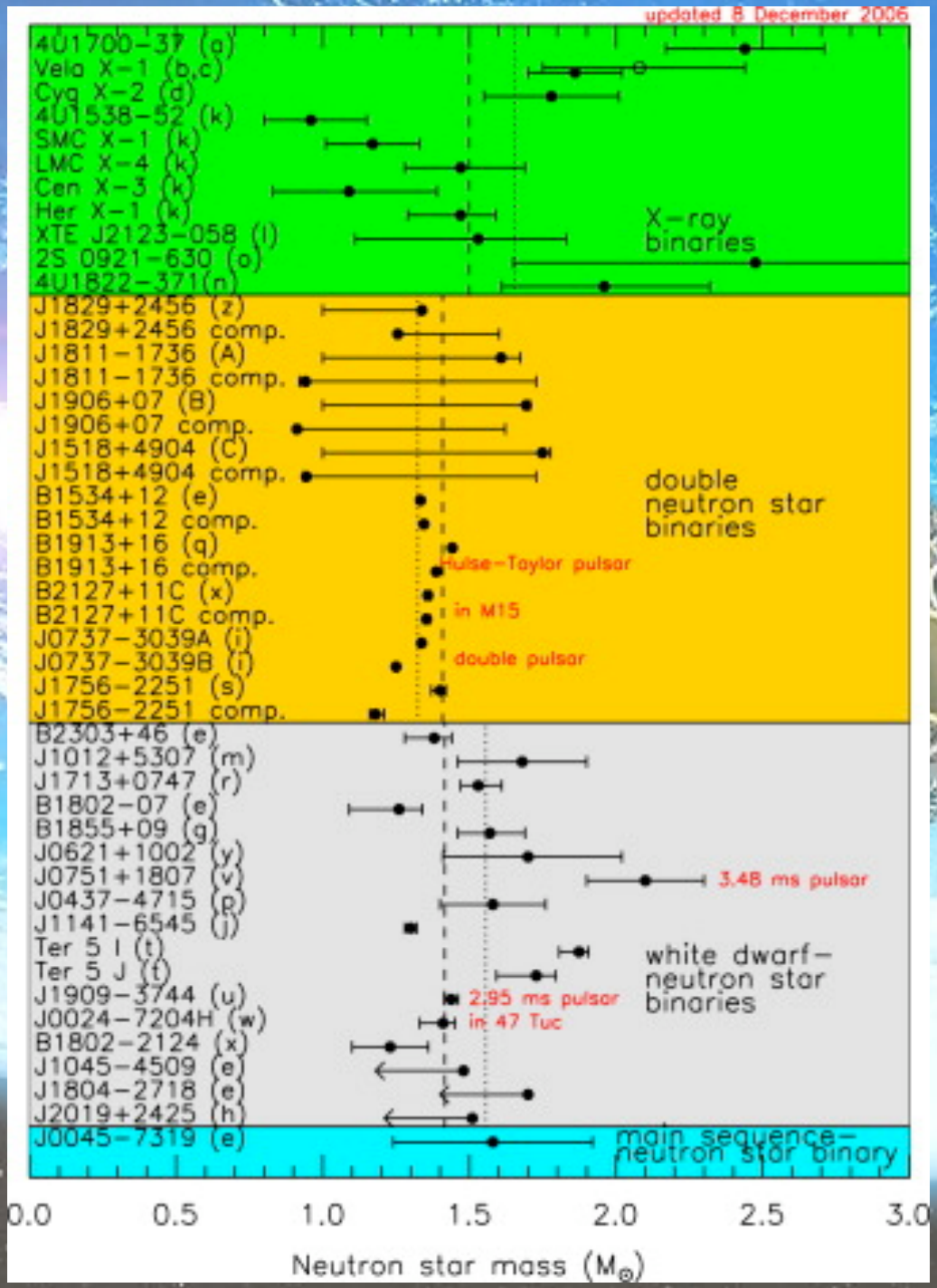
GM –
Glendenning & Moszkowski (1991)
Neutrons, protons + hyperons using a field theoretical approach

GS –
Glendenning & Schaffner-Bielich (1991)
Neutrons, protons + kaons using a field theoretical approach



Lattimer & Prakash (2007)

Masses



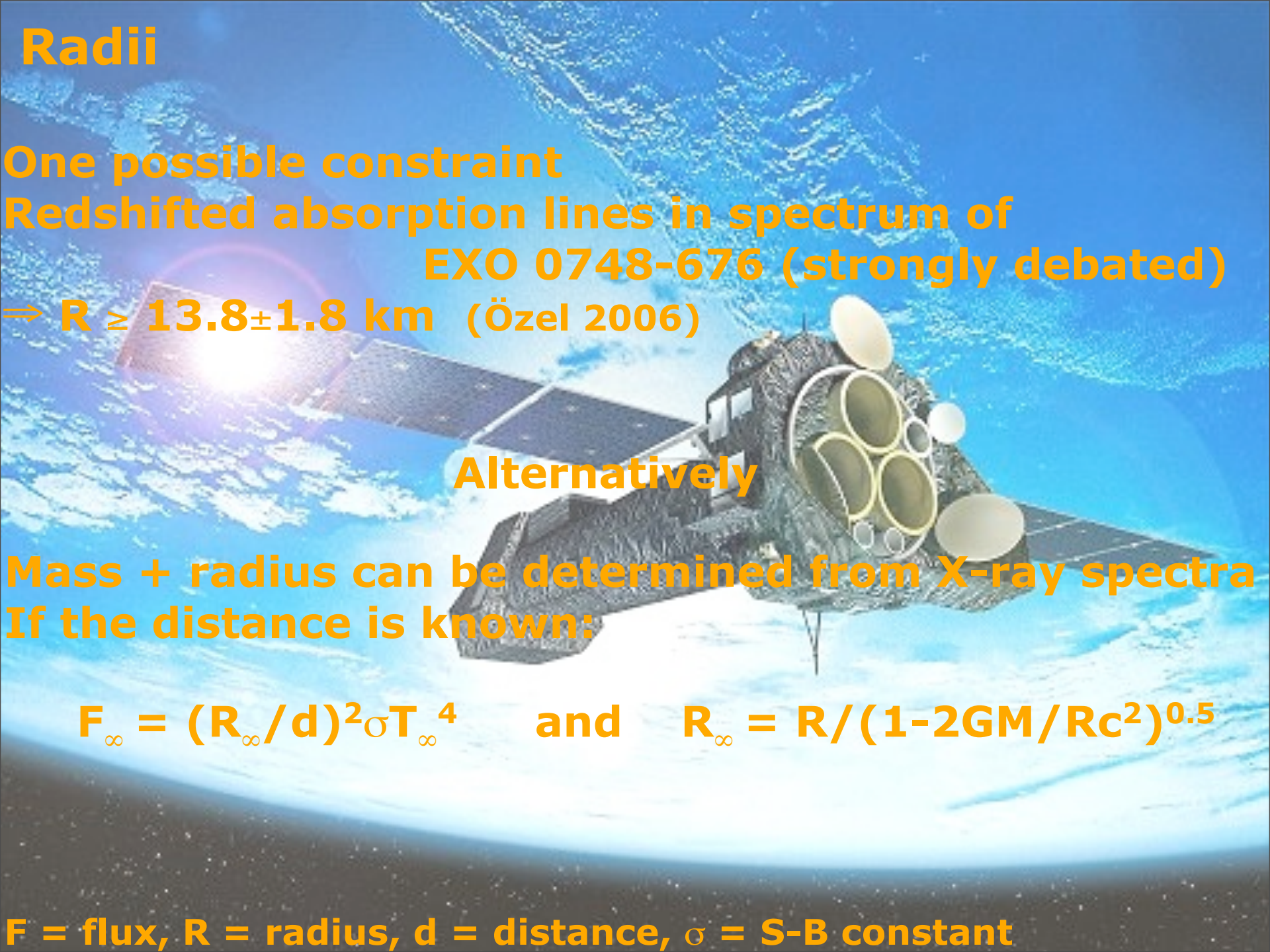
Lattimer & Prakash (2007)

Radii

One possible constraint
Redshifted absorption lines in spectrum of
EXO 0748-676 (strongly debated)

$\Rightarrow R \geq 13.8 \pm 1.8$ km (Özel 2006)

Radii



One possible constraint
Redshifted absorption lines in spectrum of
EXO 0748-676 (strongly debated)

$\Rightarrow R \geq 13.8 \pm 1.8$ km (Özel 2006)

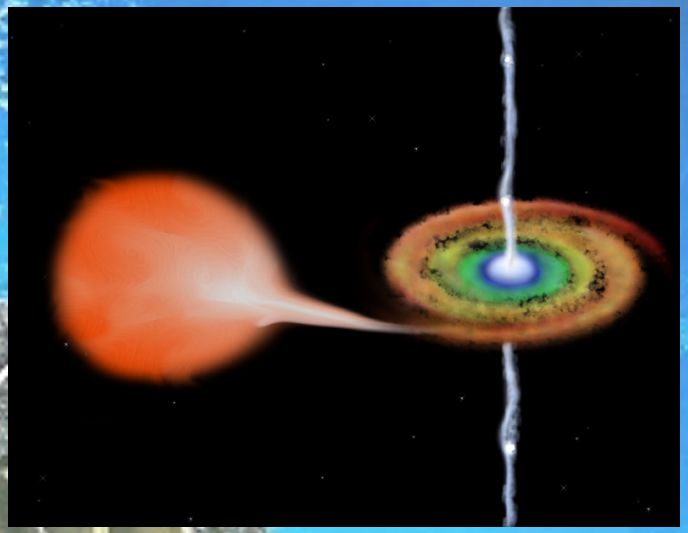
Alternatively

Mass + radius can be determined from X-ray spectra
If the distance is known:

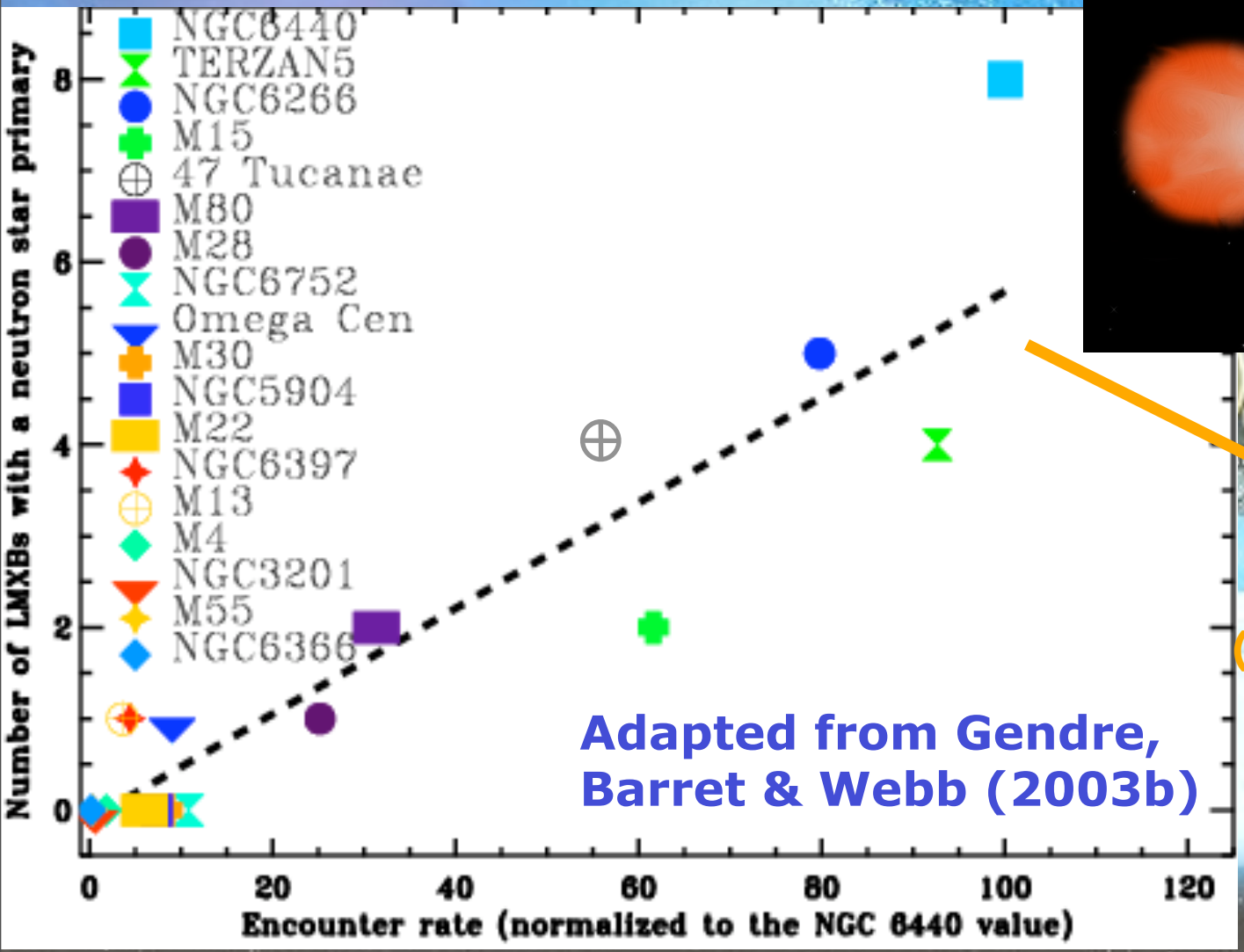
$$F_\infty = (R_\infty/d)^2 \sigma T_\infty^4 \quad \text{and} \quad R_\infty = R/(1-2GM/Rc^2)^{0.5}$$

F = flux, R = radius, d = distance, σ = S-B constant

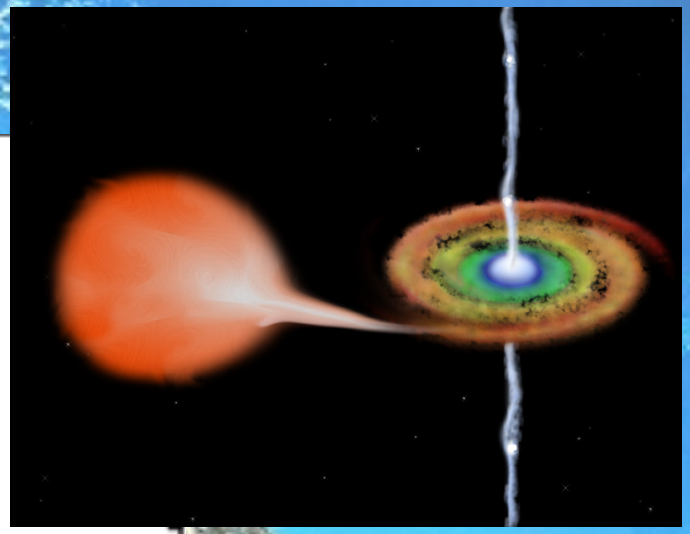
Quiescent neutron star low mass X-ray binaries (qNSLMXBs) in globular clusters



Quiescent neutron star low mass X-ray binaries (qNSLMXBs) in globular clusters



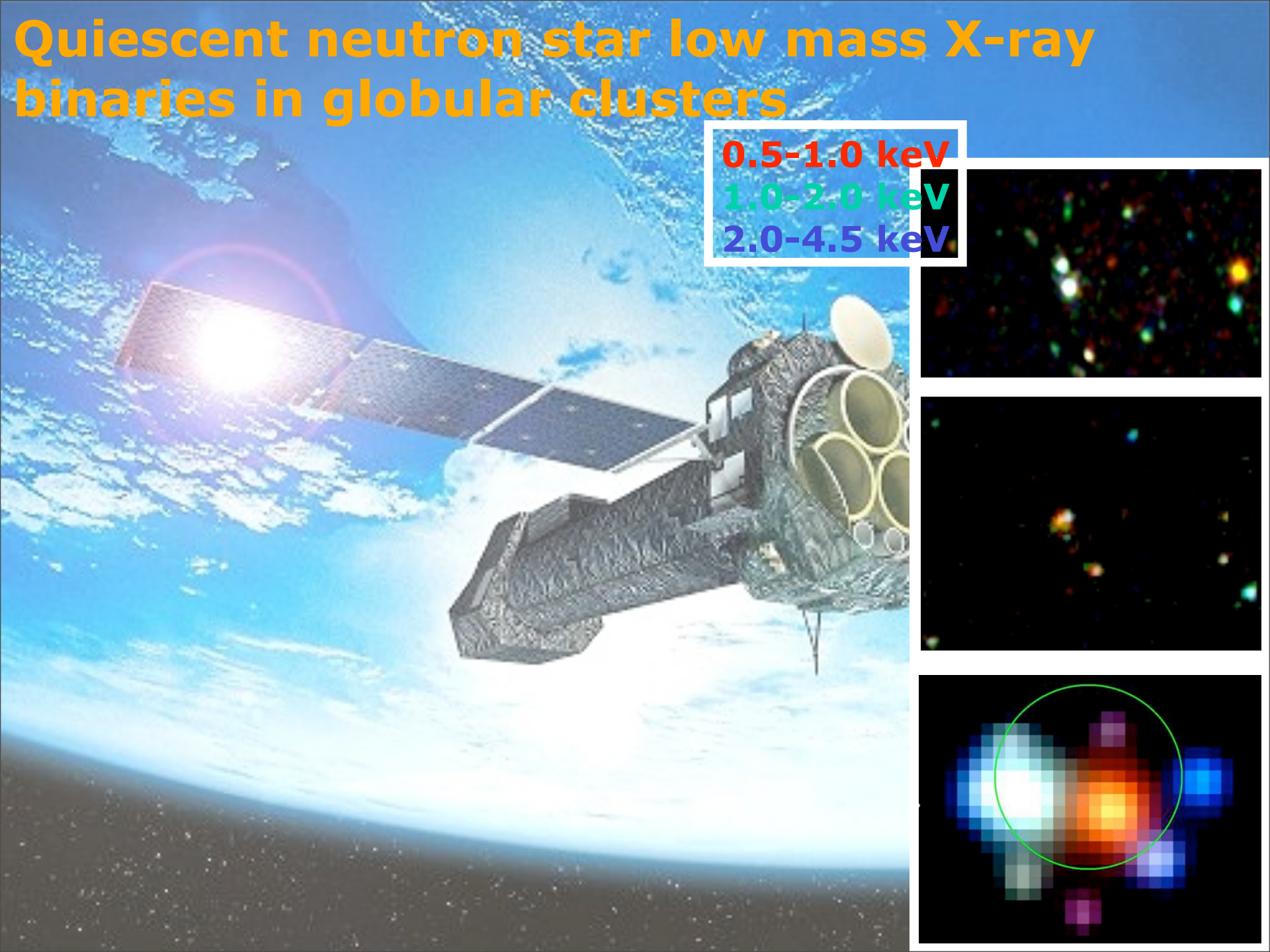
Adapted from Gendre, Barret & Webb (2003b)



~100 NSLMXBs in Galactic GCs (Pooley et al. 2003)

Constrain neutron star eq. of state

Quiescent neutron star low mass X-ray binaries in globular clusters



Quiescent neutron star low mass X-ray binaries in globular clusters

Distance well constrained

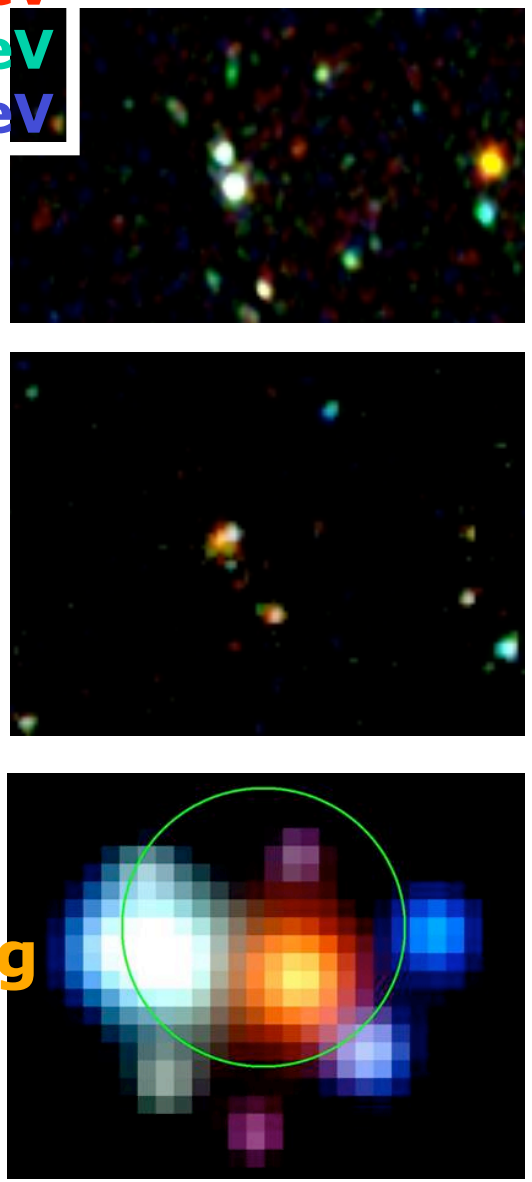
Very soft X-ray spectra, T~50eV

Approximate blackbody spectra

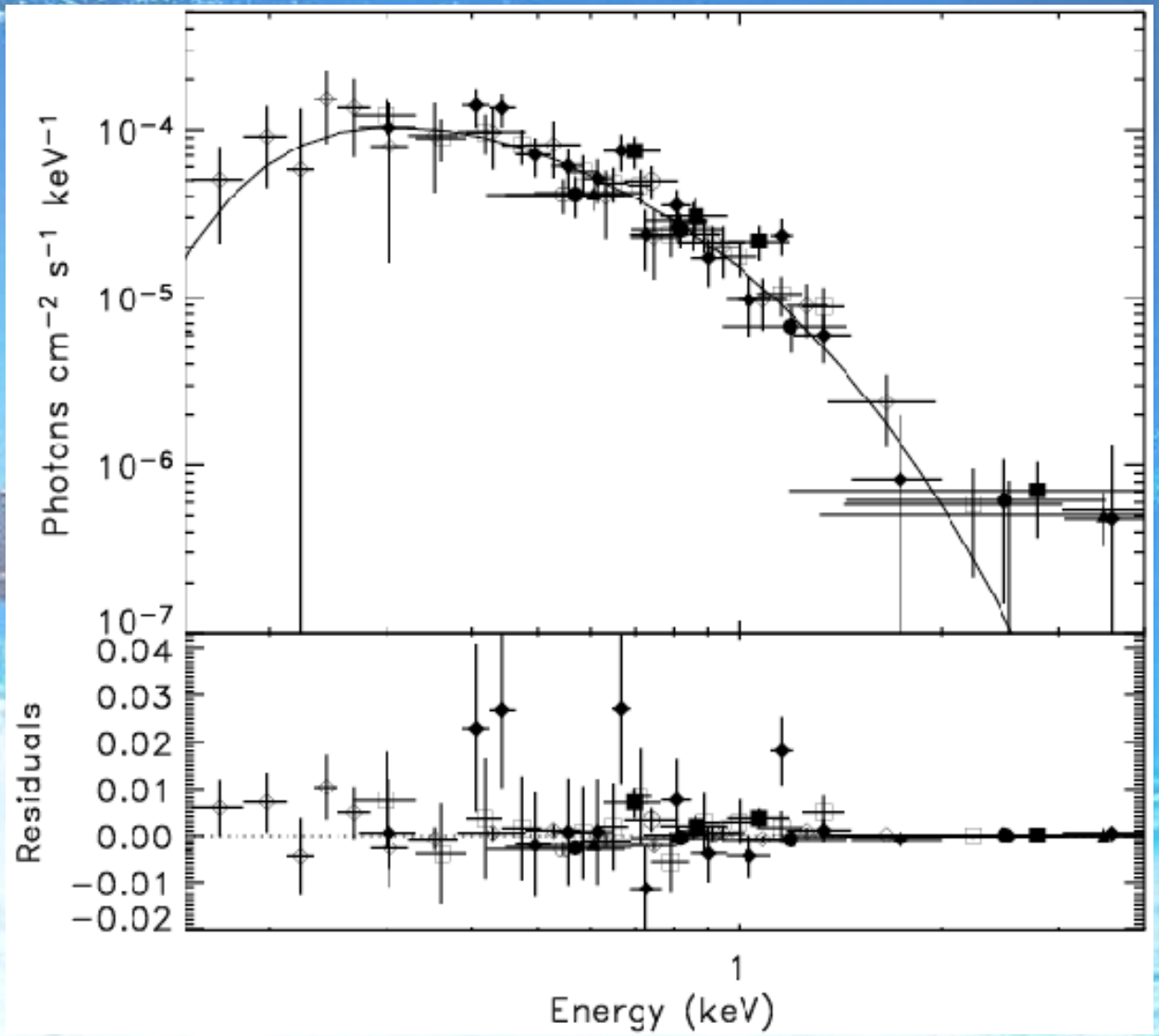
Hydrogen atmosphere models give more realistic radii

Recent improvements to H atmos. models include (among others) :
- variety of surface gravities
- opacity due to absorption/scattering
- self irradiation by photons from NS

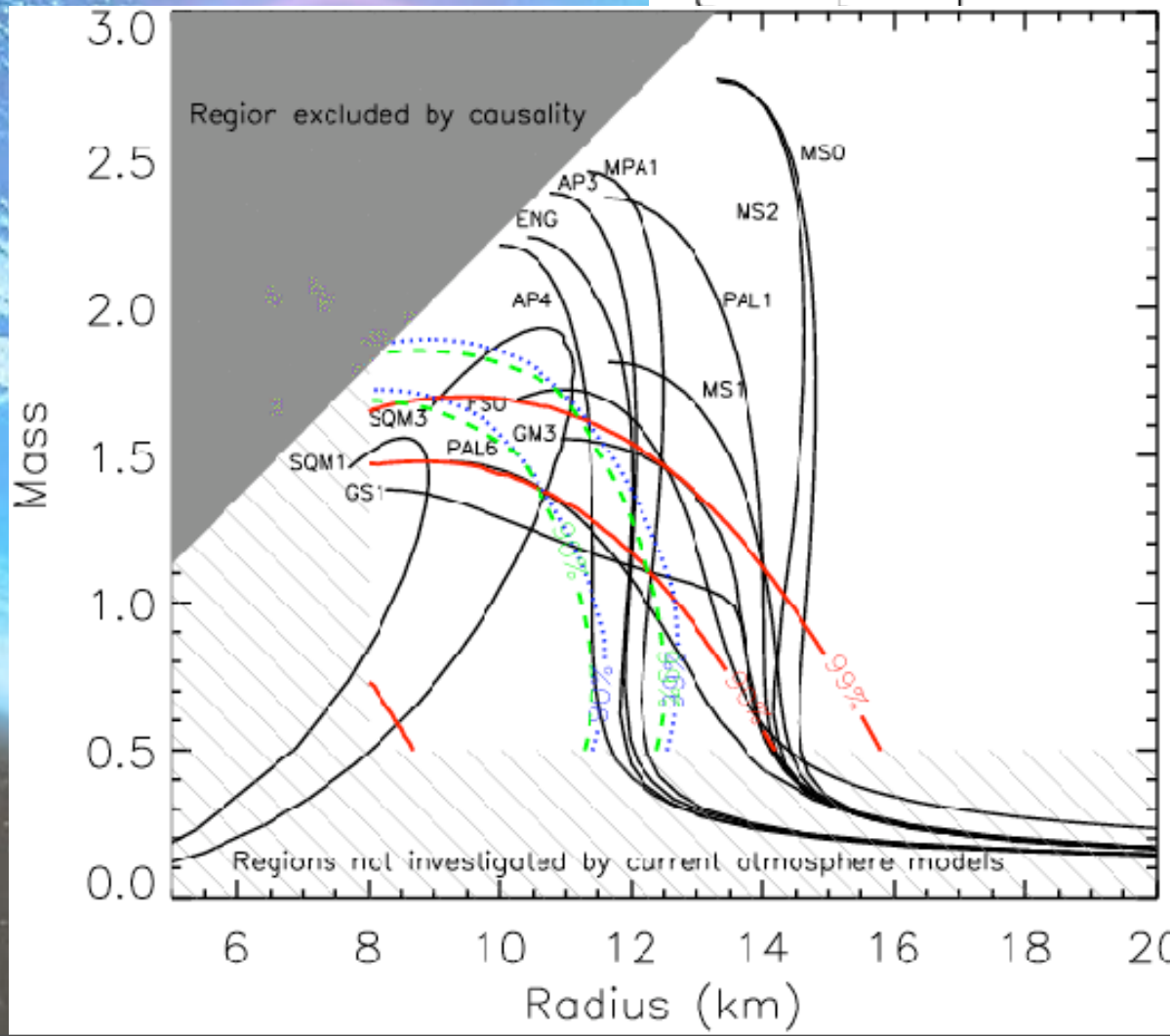
(Heinke et al. 2006, Zavlin et al. 1996)

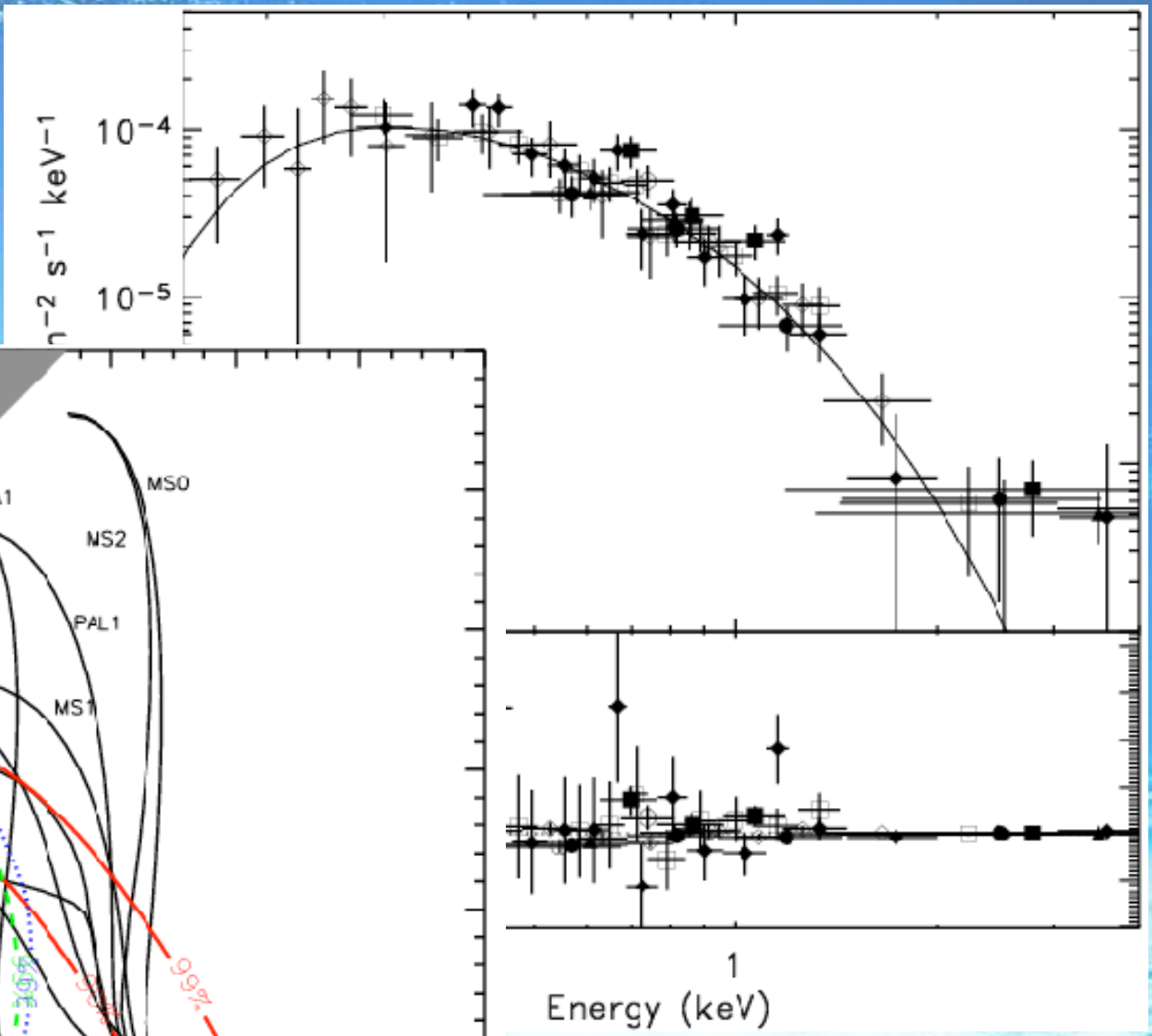


M 13


Photons cm^{-2} s^{-1} keV^{-1}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Residuals
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
1
Energy (keV)

M 13

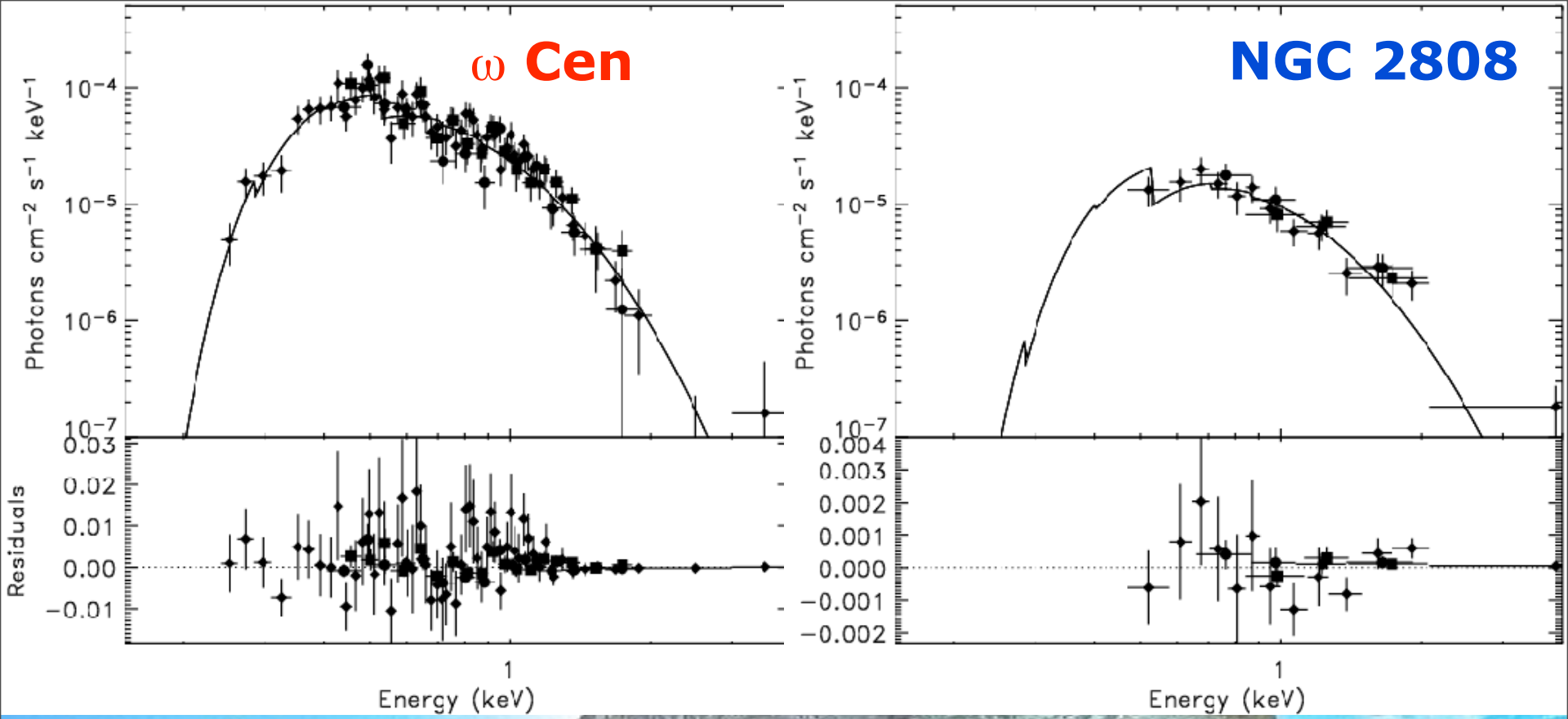


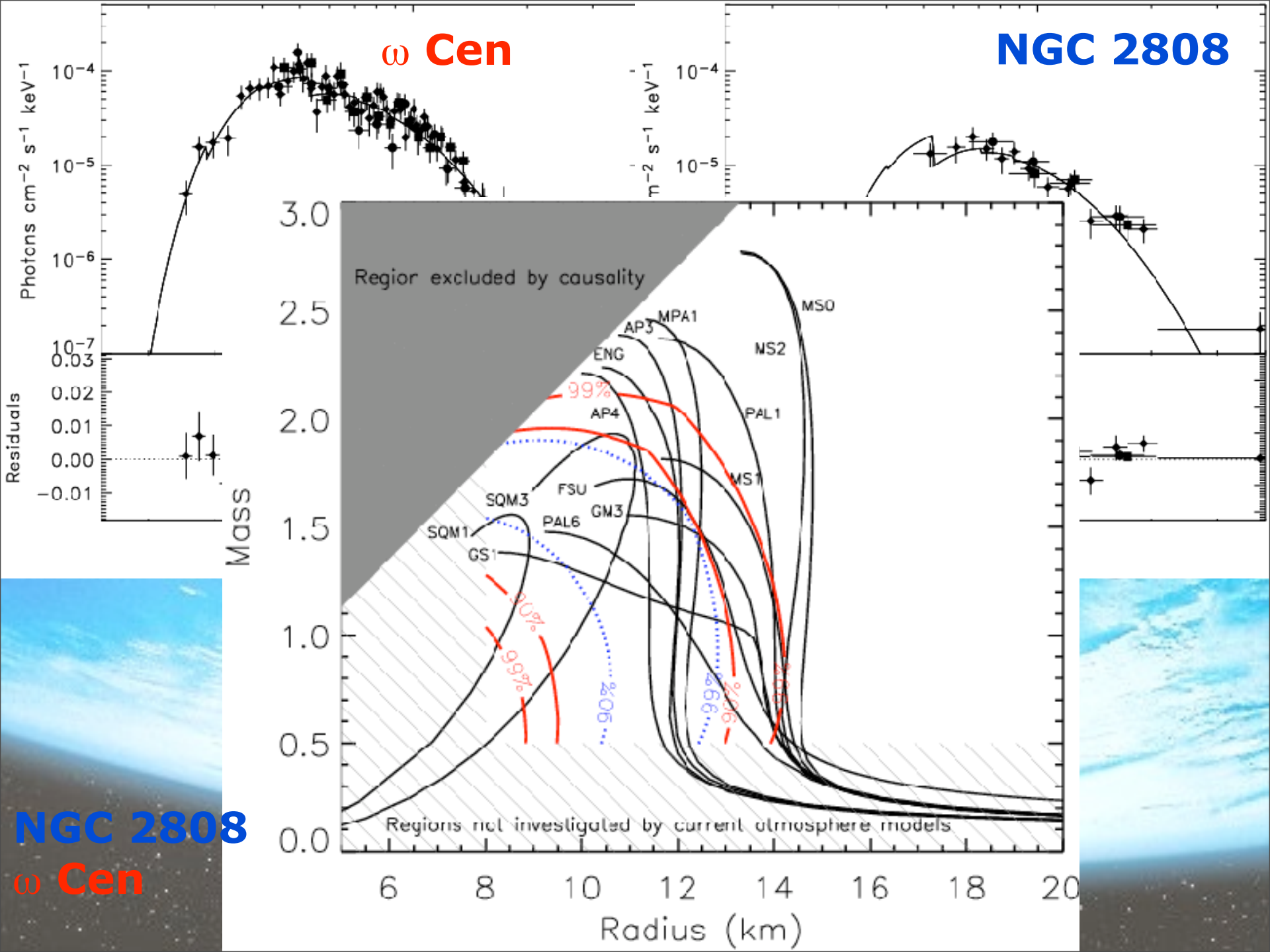


NSA – Zavlin et al (1996)

NSAGRAV - Zavlin et al (1996)

NSATMOS – Heinke et al. (2006)

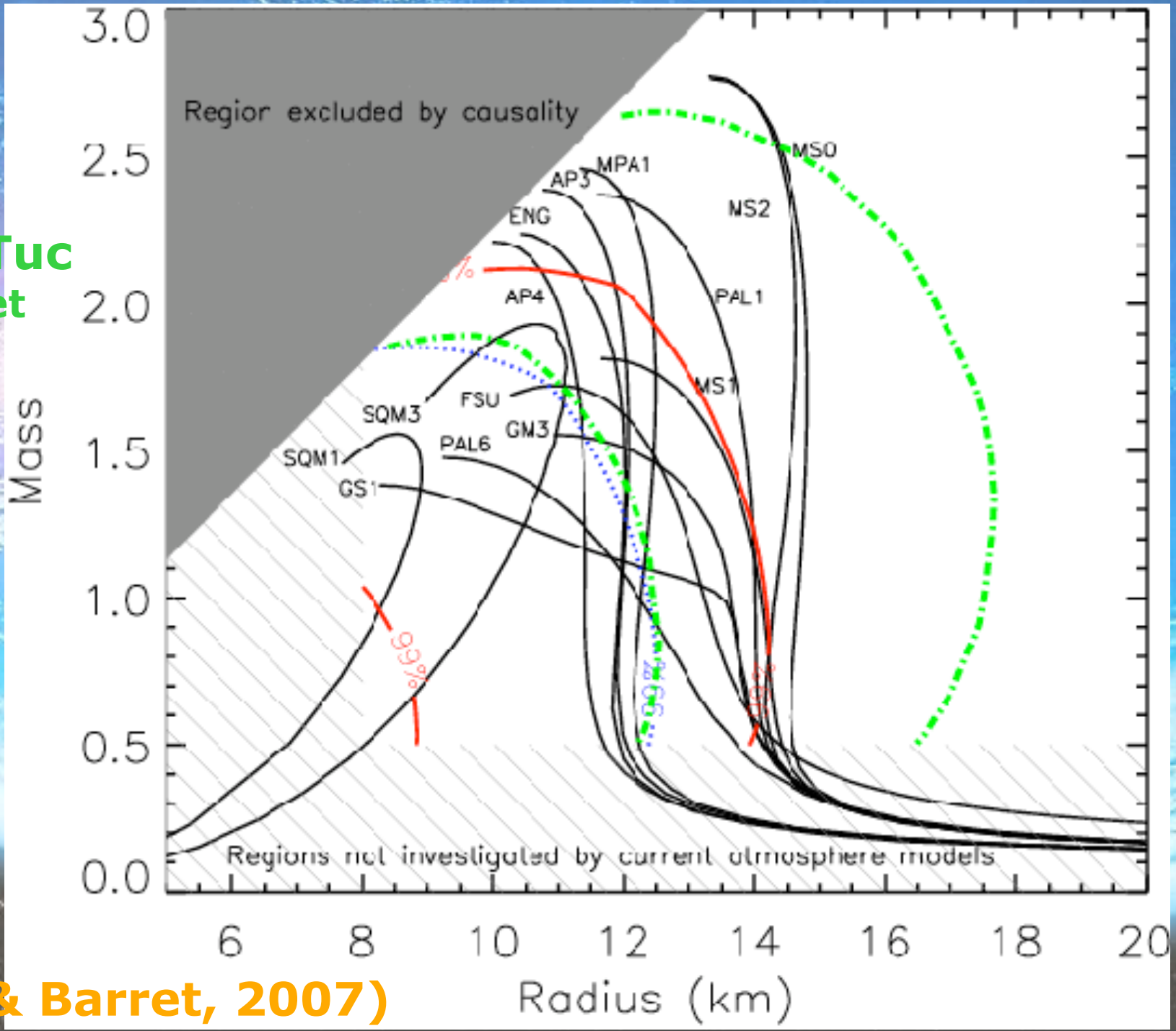

ω Cen
NGC 2808
Photons cm^{-2} s^{-1} keV^{-1}
Residuals
Energy (keV)


ω Cen
NGC 2808
Photons cm^{-2} s^{-1} keV^{-1}
Residuals
Region excluded by causality
MS0
MPA1
AP3
MS2
ENG
99%
AP4
PAL1
MS1
FSU
SQM3
GM3
PAL6
SQM1
GS1
90%
99%
90%
99%
90%
99%
Regions not investigated by current atmosphere models
Mass
Radius (km)
NGC 2808
ω Cen

M 13

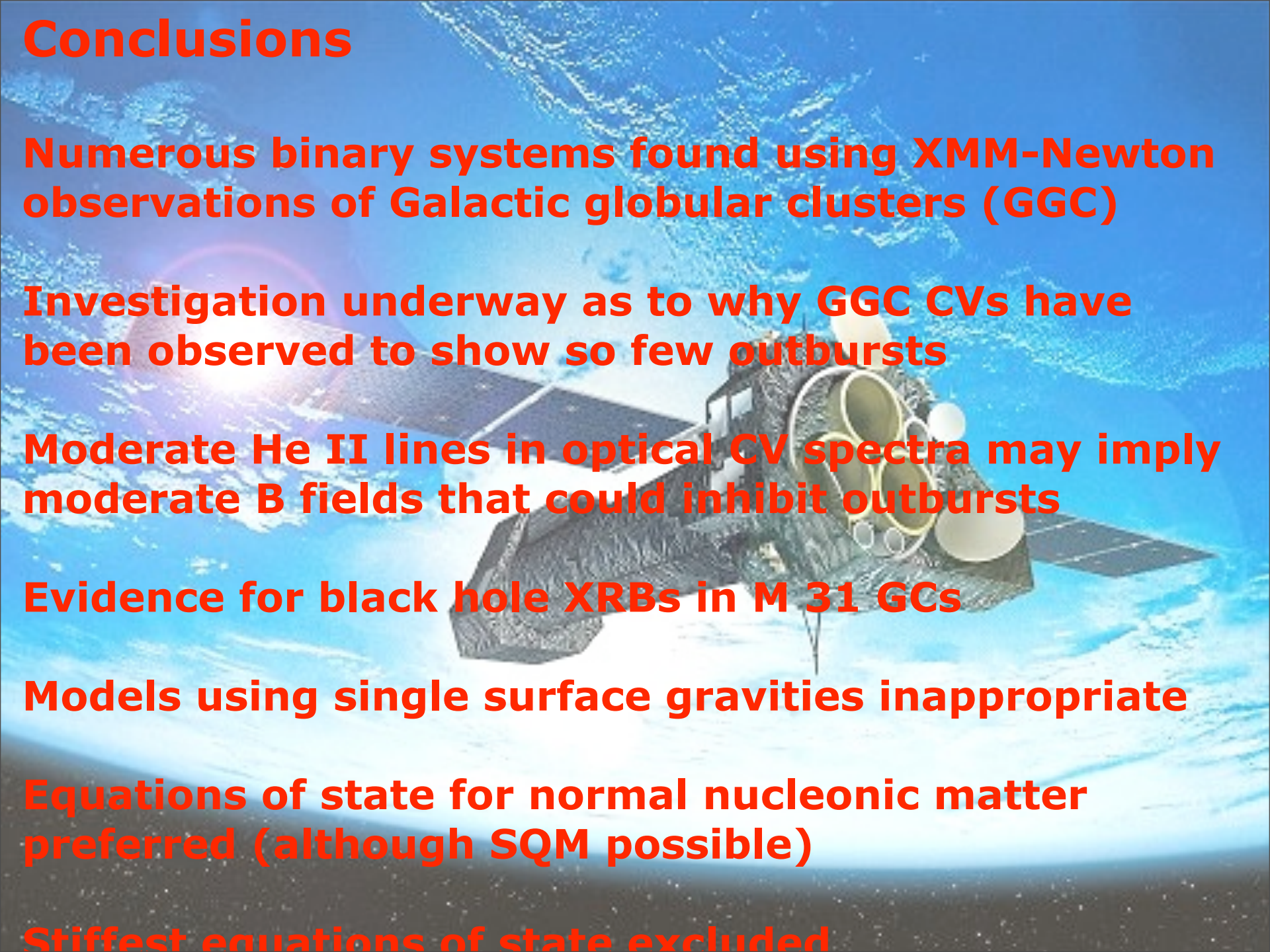
ω Cen

X7, 47 Tuc (Heinke et al. 2006)



(Webb & Barret, 2007)

Conclusions



Numerous binary systems found using XMM-Newton observations of Galactic globular clusters (GGC)

Investigation underway as to why GGC CVs have been observed to show so few outbursts

Moderate He II lines in optical CV spectra may imply moderate B fields that could inhibit outbursts

Evidence for black hole XRBs in M 31 GCs

Models using single surface gravities inappropriate

Equations of state for normal nucleonic matter preferred (although SQM possible)

Stiffest equations of state excluded