

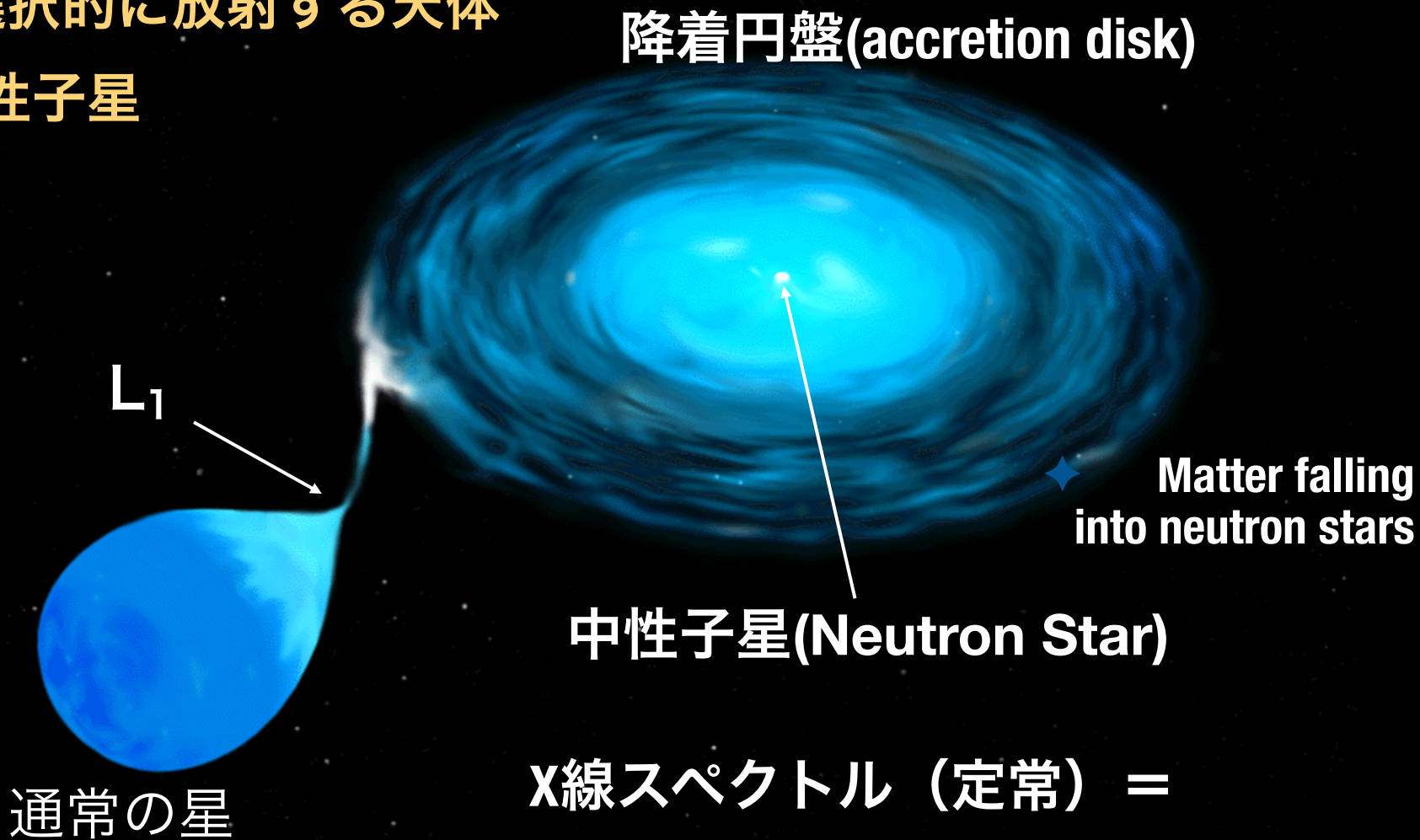
# 宇宙X線観測による 中性子星研究の新展開 計画研究C01

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*S. Sasaki*

# 1. X線天文学と中性子星の関わり

X線を選択的に放射する天体  
→ 中性子星



X線スペクトル (定常) =  
降着円盤(BB)+中性子星表面(BB)  
+ (パワーロー成分)

## 2. Constraints on M/R can be made in a variety of ways



### 本研究のテーマ

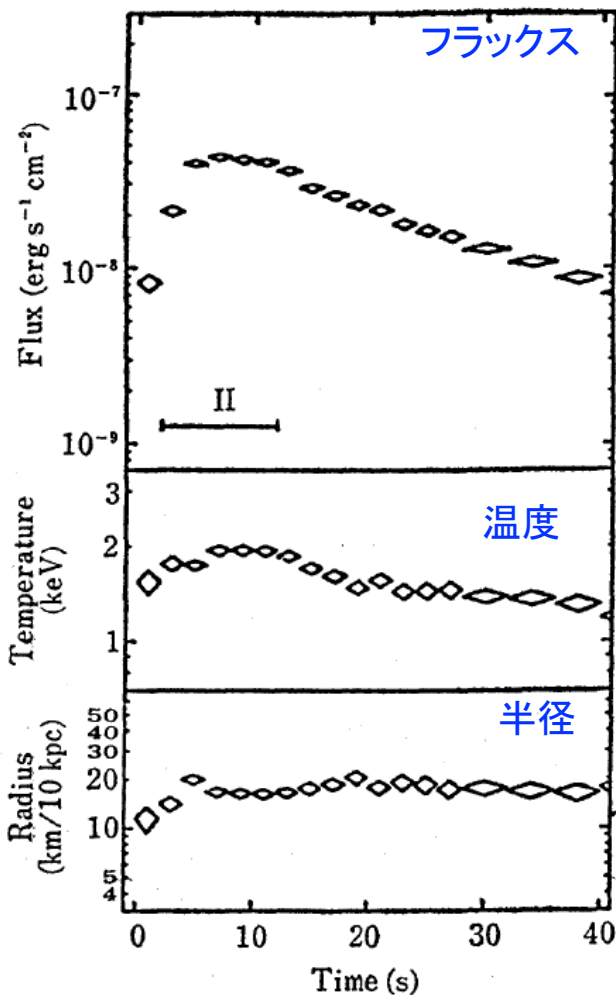
- 1) redshift of any narrow lines emitted from the photosphere of the NS (High Resolution)
- 2) redshift of the broad iron line from reflection from the accretion disc as the inner edge of the disc is an upper limit on the size of the NS (High Resolution + Broad Band)
- 3) detailed pulse profile modeling of accreting millisecond pulsars and burst oscillations (Broad Band)
- 4) a direct measure of the radius from the luminosity and temperature of thermal radiation from the NS surface cooling after accretion has stopped (Broad Band)
- 5) Maybe More...

# 3. 中性子星表面での重力赤方偏移

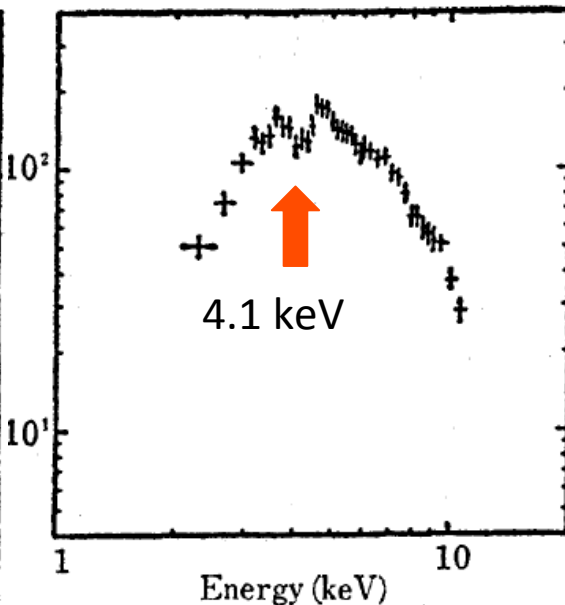
## ● Redshift of Absorption Line

### 過去の観測例

4U 1608-52



Nakamura+1988



X線バースト（中性子星表面での核融合反応の暴走）中には、鉄イオンを始めとする重元素による吸収線が見られる事がある。

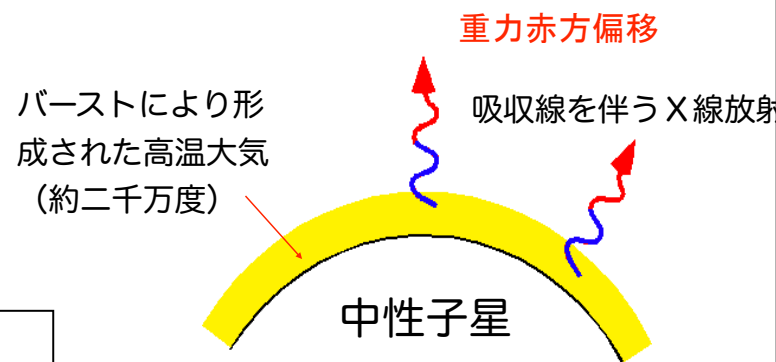


中性子星表面からの放射は、非常に大きな重力赤方偏移を受けるはず。これを正確に測定できれば、半径（と質量）に対する強い制限になる。

Other absorption features

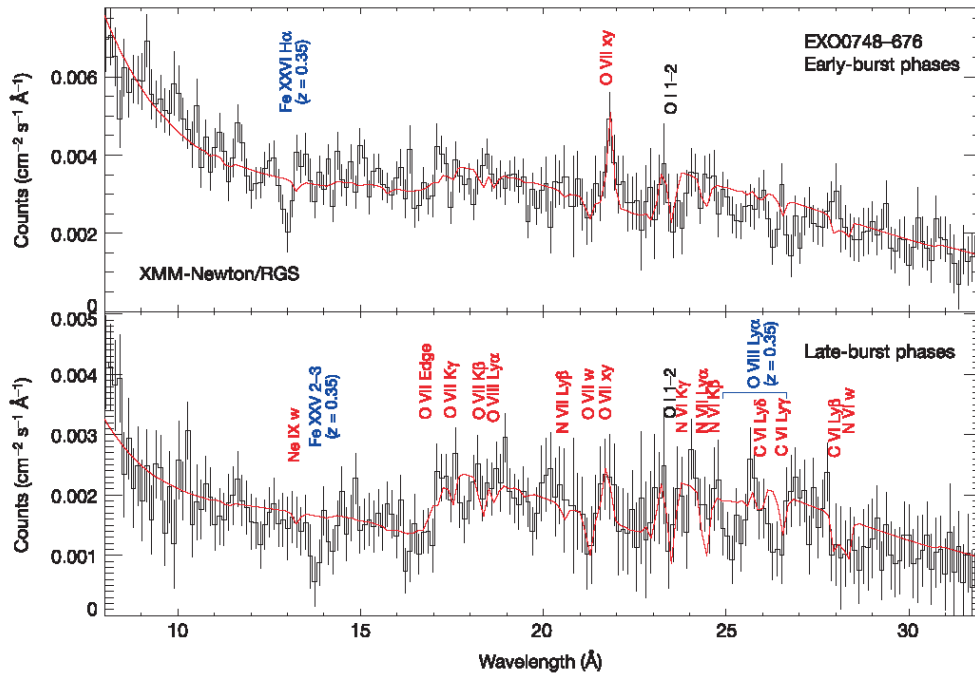
4U1636-536 (Waki+1984)

EXO1747-214 (Magnier+1989)



蛍光比例計数管（「てんま」）による観測：実はこれ以降、高い分解能と高い計数率を併せ持つ検出器はない。

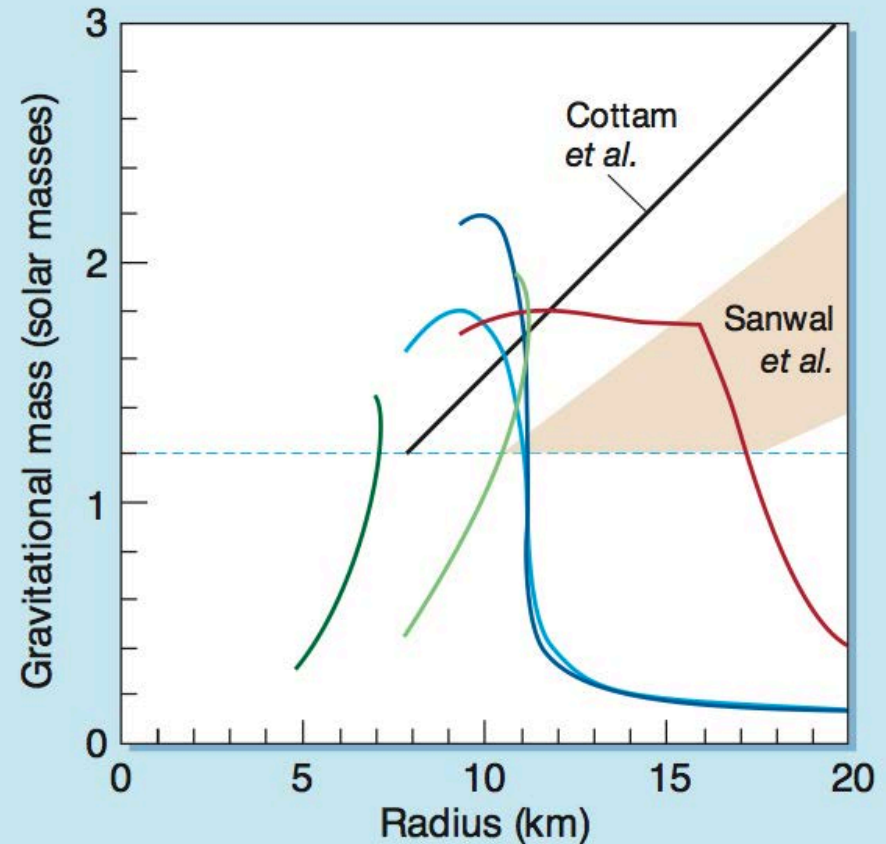
### 3. 中性子星表面での重力赤方偏移



Cottam et al. Nature, 420, 51 (2002)

その後、この結果は疑問視。

However, the recent detection of 552 Hz oscillations at 15% rms amplitude revealed the spin frequency of the neutron star and brought into question the consistency of such a rapid spin with the narrow width of the absorption lines (Lin et al. 2010).



#### 問題点

1. 一時、45 Hzという報告があったが、その後、スピン周期が552 Hzと判明。  
Galloway et al. 2010, ApJ, 711, L148
2. より長時間の追観測で確認できず。  
Cottam et al. 2008, ApJ, 672, 504

### 3. 中性子星表面での重力赤方偏移

#### 現時点の認識 (XMM-Newton衛星他)

X線バースト中の確実な吸収線の観測はない。

#### バースト中の吸収線を観測するには

##### 1. バースト中の吸収線

$$\delta E / E \leq 1\%$$

- 非常に精度の高い観測が可能：

##### 2. エネルギー分解能の高い望遠鏡が必要。かつ、バースト中に観測できないといけない (パイルアップしない)。

- ASTRO-H (2014年打上予定) 搭載のマイクロカロリメータ。

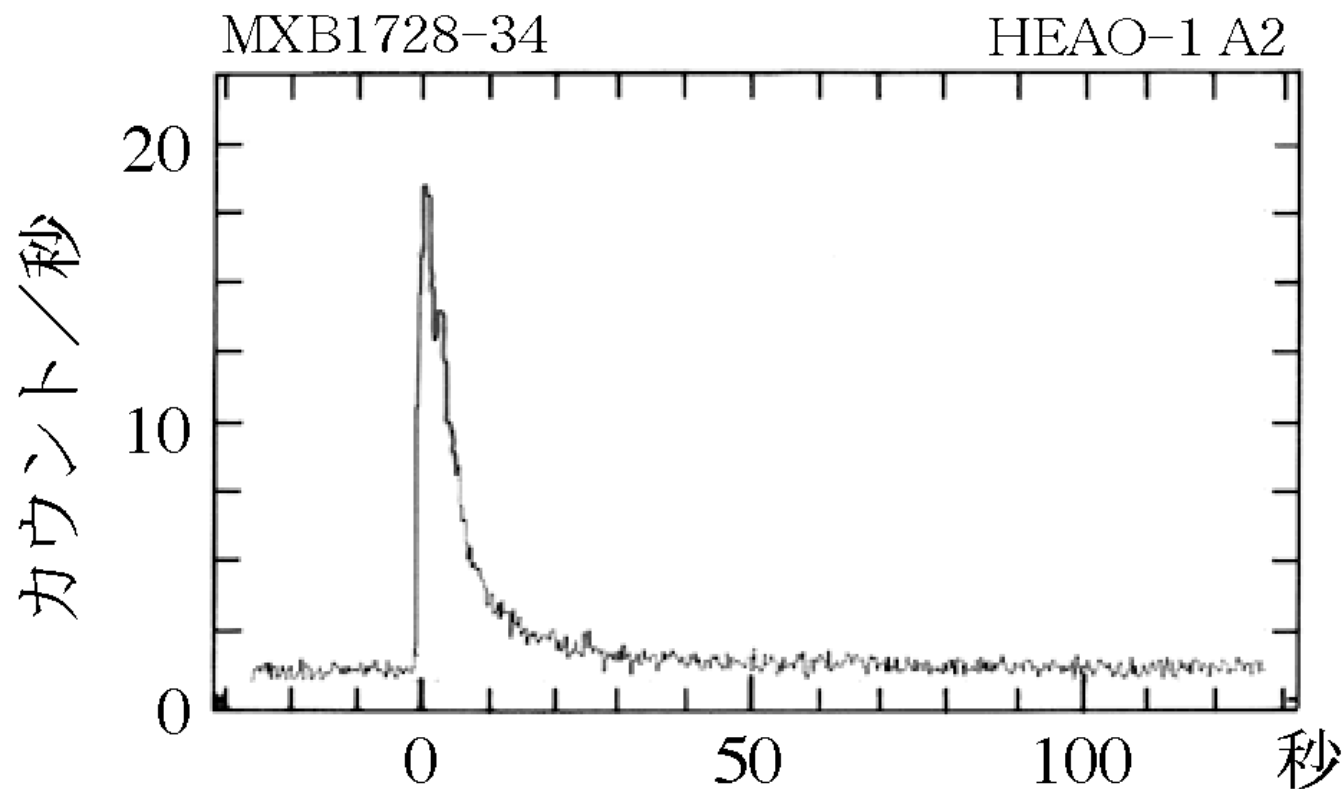
##### 3. 吸収線が「なまらない」ターゲットの選定が必要

### 3. 中性子星表面での重力赤方偏移

#### X線バースト

- 中性子星表面でのHe燃焼 ( $3\alpha \rightarrow {}^{12}\text{C}$ ) の暴走。
- 典型的なtime scaleは10秒から数十秒で、数時間に1回。
- 最大光度は、エディントン限界（輻射圧と重力：安定に輻射できるリミット） ( $\sim 10^{38}$  erg/sec)
- 70天体以上がバースト源(Burst sources) として知られている。

本研究のテーマ  
バースト中の吸収線  
広範囲のスペクトル



## 4. 光度曲線からのアプローチ



### 本研究の発展テーマ

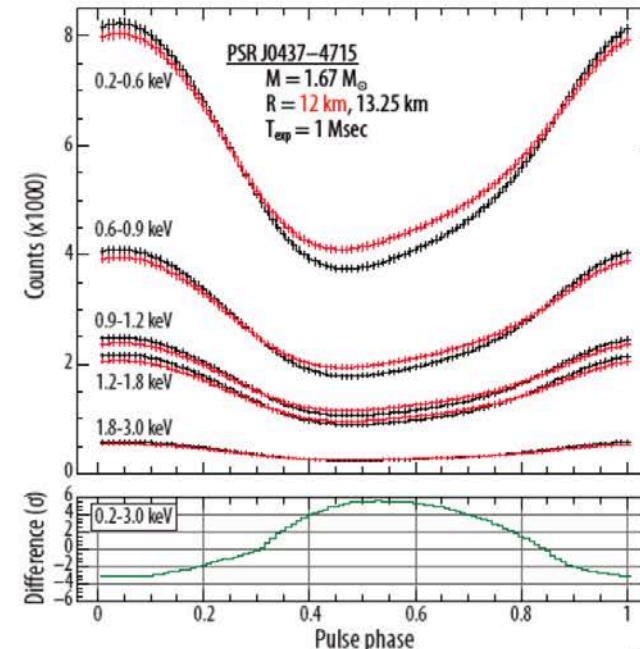
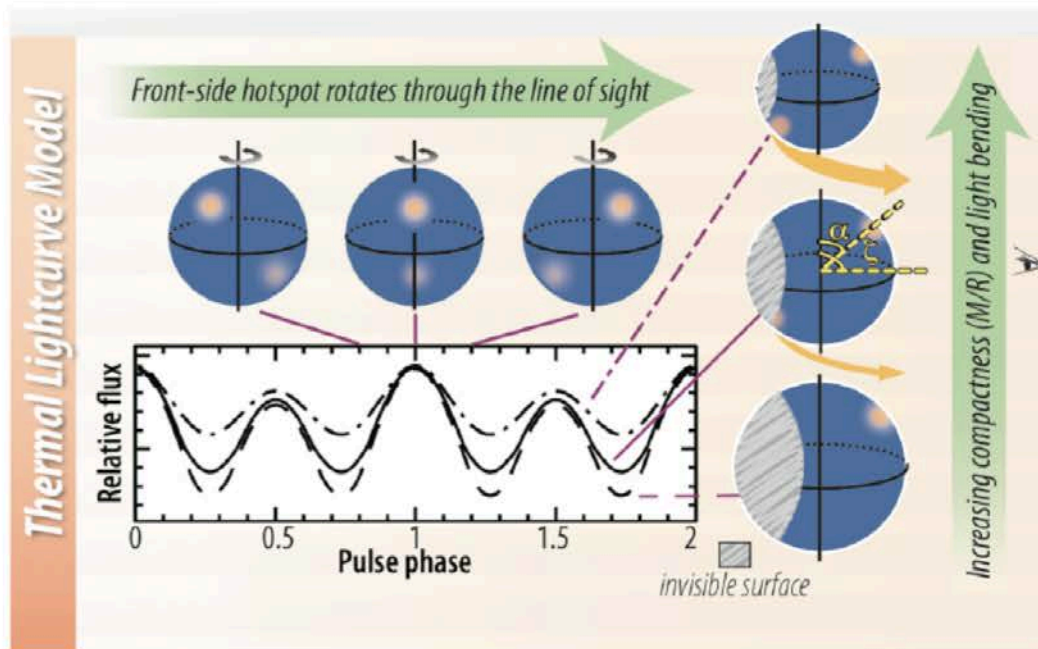


Figure 4. (Left) A distant observer sees X-ray intensity grow and fall as hot-spots on a neutron star surface spin through the line of sight. The far-side spot becomes more visible for smaller stars through gravitational light-bending, which depends on  $M/R$ ; thus, depth of modulation constrains compactness. (Right) Two sets of simulated NICER lightcurves, for stellar radii differing by  $\pm 5\%$ , show measurable differences in several energy bands for a 1 Msec exposure: 4–6 $\sigma$  differences per phase bin pinpoint the star's radius.

K. C. Gendreau et al. SPIE (2012)



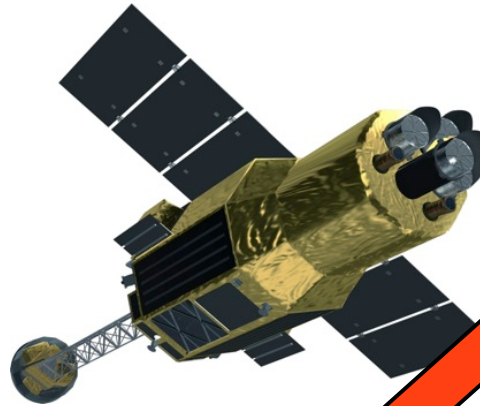
# Road map in 20 years for the study of neutron star with X-ray satellites

高橋, 渡辺(ISAS)が共同研究者



## ASTRO-H

超高分解能分光  
(Ultra High Energy  
Resolution)観測  
ワイドバンド観測



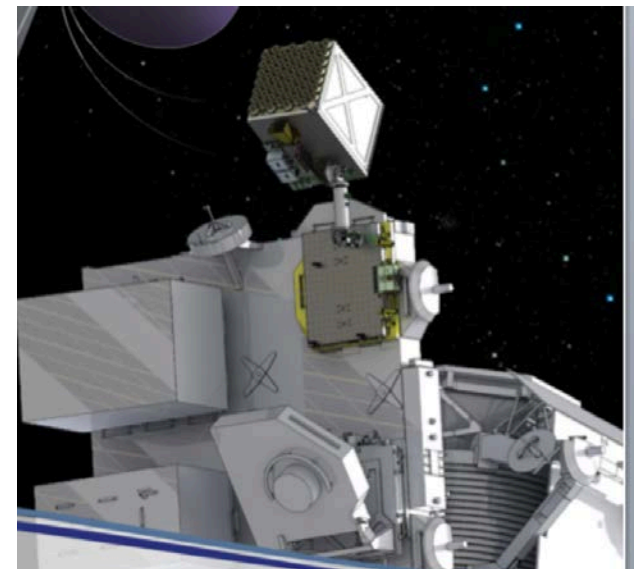
**(2015)**

超大面積

## LOFT提案

**(2020年代前半)**

高橋, 堂谷(ISAS)が共同研究者

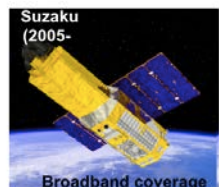
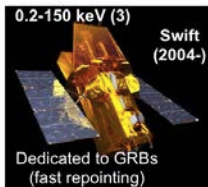
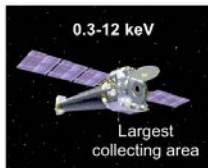


新コンセプト大面積  
**NICER**  
**(2016)**

### X Ray Missions in Operations in 2010

At least one focusing instrument

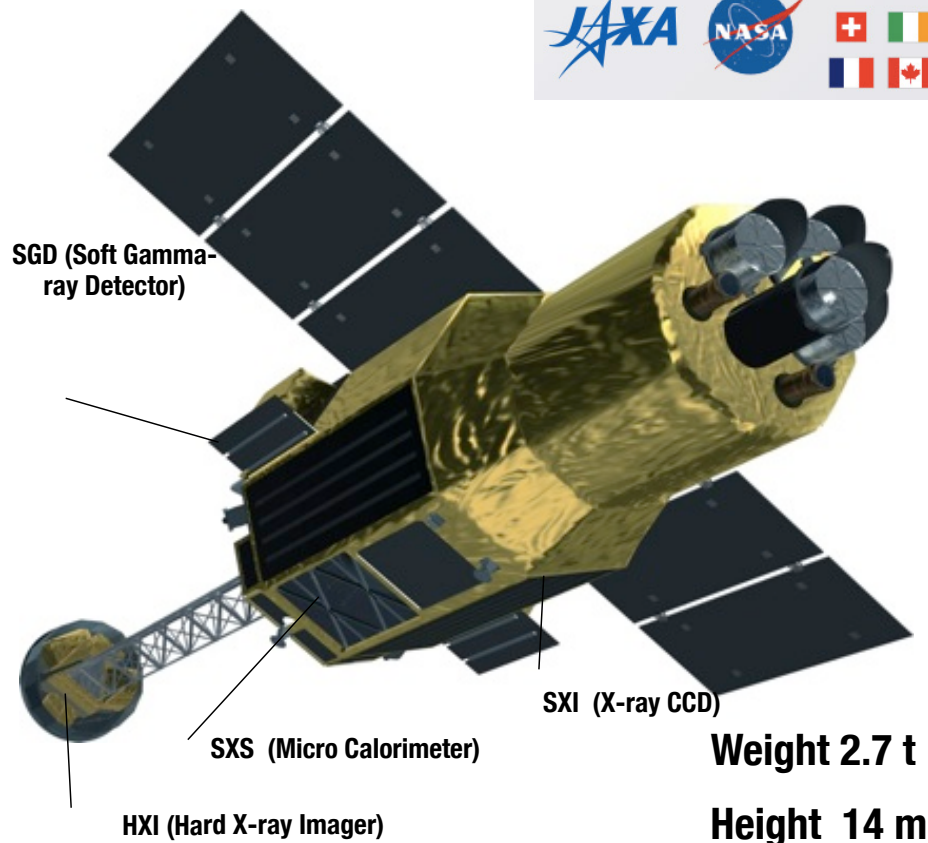
Non-focusing



## 5. ASTRO-H Mission



ASTRO-H is an international X-ray observatory, which is the 6th in the series of the X-ray observatories from Japan. More than 160 scientists from Japan/US/Europe/Canada.



- **Launch site:**  
Tanegashima Space Center, Japan
- **Launch vehicle:** JAXA H-IIA rocket
- **Orbit Altitude:** 550km
- **Orbit Type:** Approximate circular orbit
- **Orbit Inclination:** ~31 degrees
- **Orbit Period:** 96 minutes
- **Launch :** 2015

Science operations will be similar to those of Suzaku, with pointed observation of each target until the integrated observing time is accumulated, and then slewing to the next target.

# 5. ASTRO-H Mission



Cutting-edge Instruments

XRT



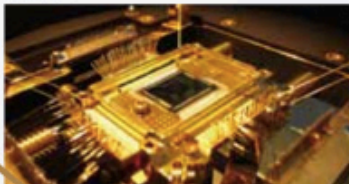
Close-up view of the aperture.

## Reflecting X-ray Telescopes (SXT/HXT)

This instrument focuses X-rays from celestial objects onto the detectors. Unlike the single lenses and mirrors usually used for visible light, this X-ray reflecting telescope is made up of over one thousand reflector-coated aluminum foils stacked into concentric circles.

## Soft X-ray Spectrometer (SXS)

Specialized detector elements are cooled down to near absolute zero (-273 degrees Celsius) using a series of refrigeration units. When an X-ray hits a detector element, its temperature slightly rises. This increase in "heat" is measured, and from this the energy of the incident X-ray can be estimated to a higher degree of accuracy than any achieved to date. Researchers from around the world have great expectations for this instrument, the centerpiece of ASTRO-H.



Close-up view of the main sensor part.

Micro Calorimeter

CCD



## Soft X-ray Imager (SXI)

This is a wide field-of-view X-ray camera using an array of four large-format X-ray CCD chips. It provide simultaneous imaging and spectroscopic data in the energy range of 0.5 keV to 12 keV. The detector will be placed in the main body of the satellite.

Si/CdTe Compton Camera



## Soft Gamma-ray Detector (SGD)

Many layers of semiconductor sensors are stacked to optimize the sensitivity of the gamma-ray spectrometer. Since gamma-rays have a higher penetrating power than X-rays, this instrument plays an important role investigating astronomical objects surrounded by dense gas.



X-ray sensor and signal-processing electronics

## Hard X-ray Imager (HXI)

This produces images of objects in the hard X-rays above 5 keV using a combination of silicon and cadmium telluride semi-conductors. Since this imaging telescope has a 12-meter focal length, this sensor will be placed at the end of a boom which will be extended in orbit.

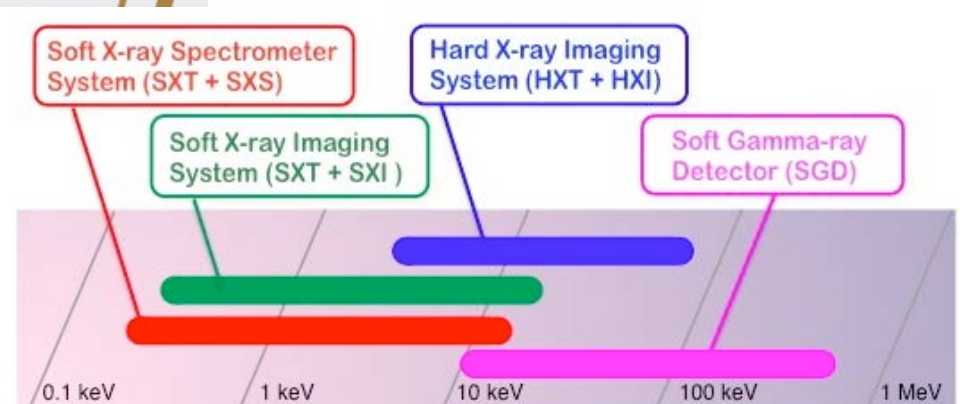
Si/CdTe Imager

## 1. High Resolution Spectroscopy by a micro-calorimeter array

ASTRO-H is the first mission to carry out high resolution spectroscopy of extended objects at Fe-K

## 2. Wide Band /High Sensitivity Observation

0.3 keV - 600 keV : Four Instruments including Hard X-ray Focusing optics

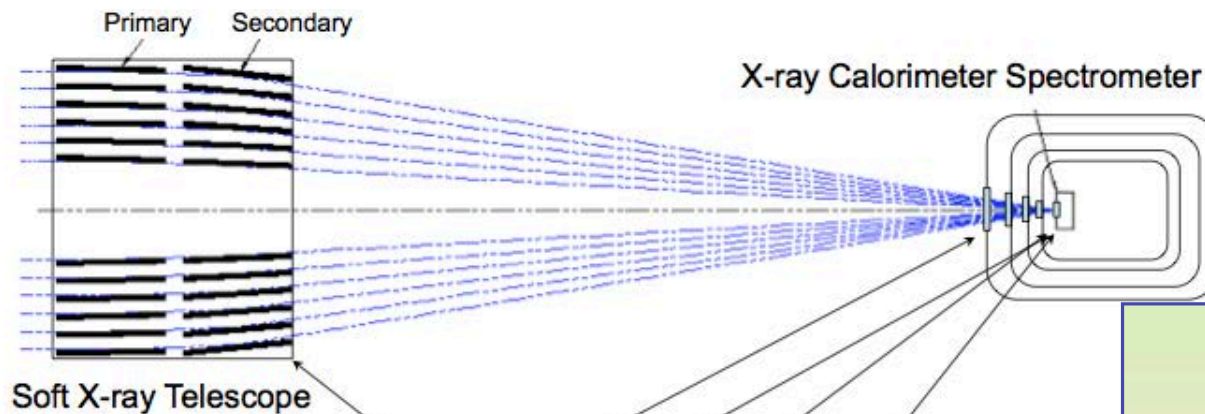


# 6. ASTRO-H Features --- High Resolution Spectroscopy ---



**- High Resolution Spectroscopy-  
by a micro calorimeter array**

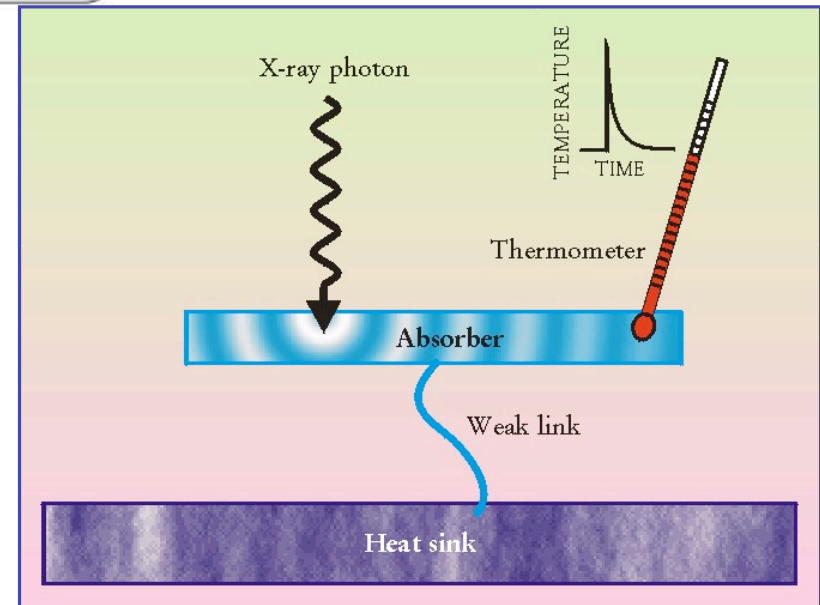
**Detector to be  
Operated at 50 mK  
Gain will be monitored  
by using a compact  
X-ray generator.**



$$A_{\text{eff}}(E) = A_{\text{XRT}}(E) * t(E) * \text{psf} * f_{\text{array}} * a(E)$$

t = transmission of blocking filters  
psf = x-ray image point spread function  
f<sub>array</sub> = geometric filling factor of array  
a = absorption efficiency of detector

SXS XCS (6 × 6 microcalorimeter array)	
Operating temperature	50 mK
Pixel size	814 μm × 814 μm
Pixel pitch	832 μm
Field of view	3'.05 × 3'.05
X-ray absorber	HgTe, 8 μm thickness

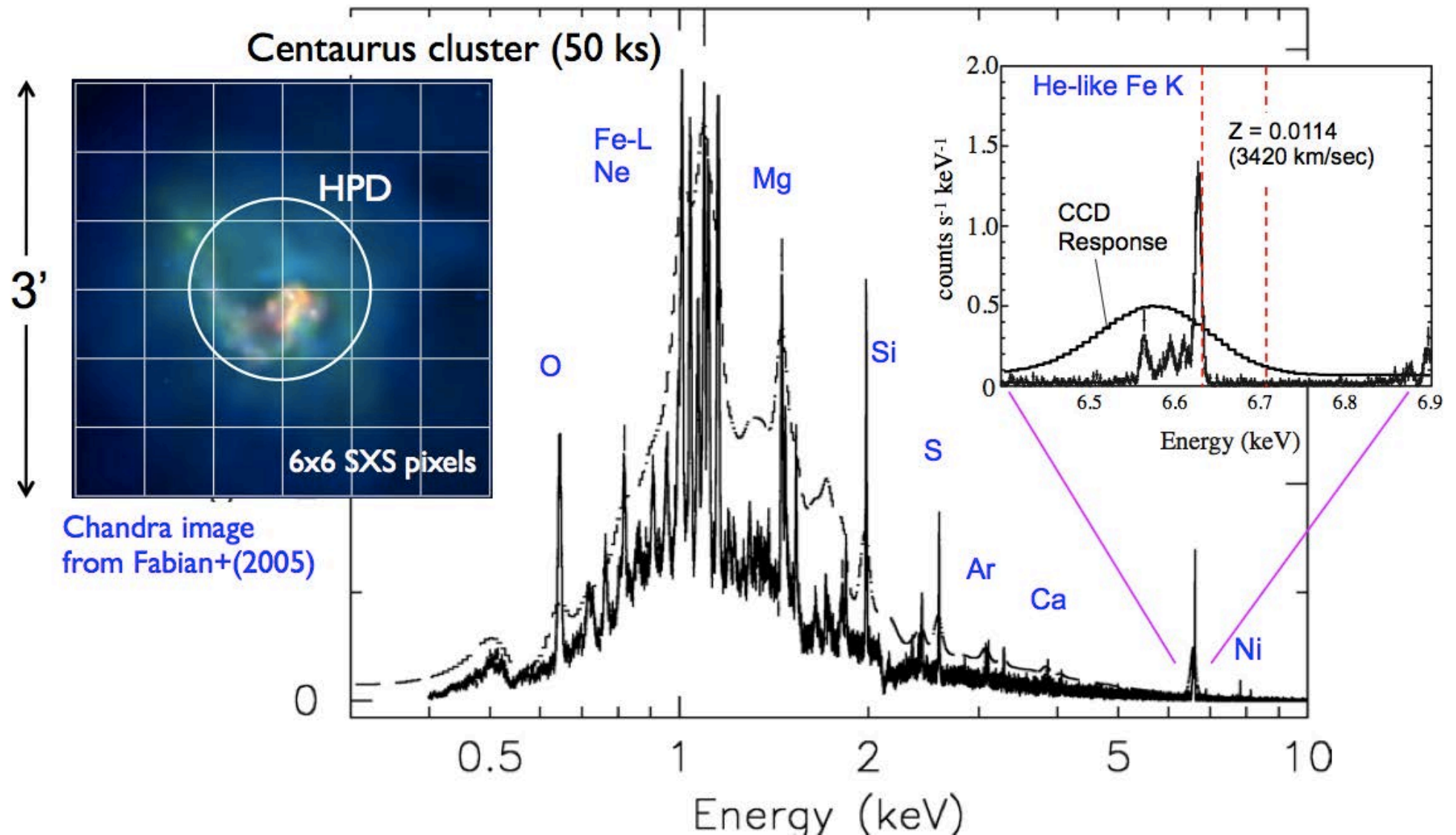


# 6. ASTRO-H Features --- High Resolution Spectroscopy ---



## High Resolution Spectroscopy by a micro-calorimeter array

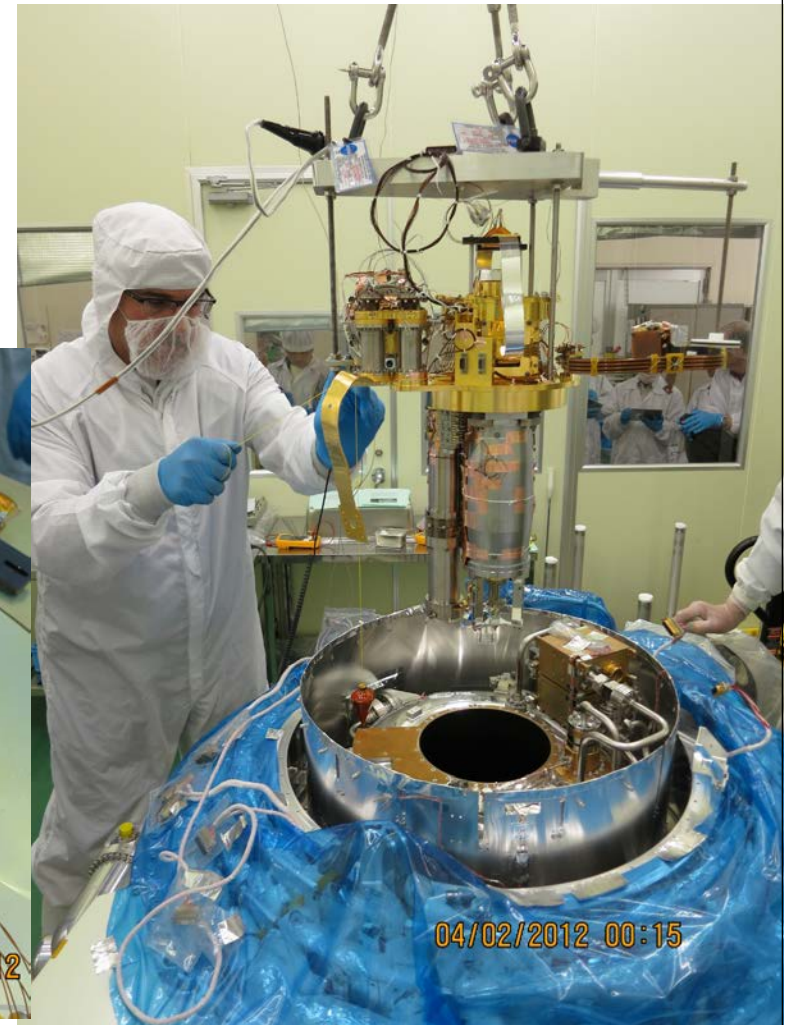
$<7$  eV (FWHM) @ 6 keV





## 6. ASTRO-H Features --- High Resolution Spectroscopy ---

- X-ray micro-calorimeter spectrometer with energy resolution better than 7 eV (FWHM)
- 6 x 6 array with 3' x 3' field of view
- Operated at 50 mK
  - Nominal expected liquid He lifetime 3.3 years



**SXS detector assembly**

T. Takahashi (X-ray Astronomy towards the next 50 years, Milano, 2012)

NASA/GSFC

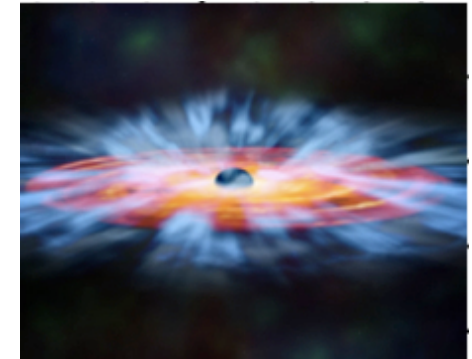
Sumitomo Heavy Industries, Ltd.  
**SXS dewar**  
JAXA

# 6. ASTRO-H Features --- High Resolution Spectroscopy ---

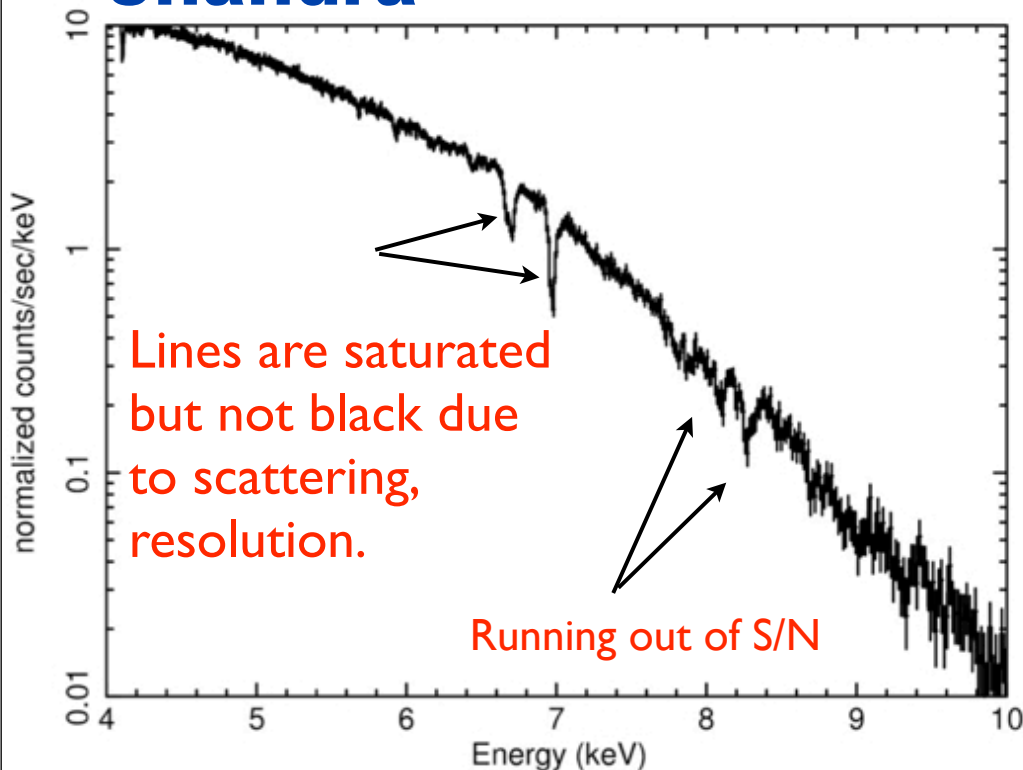


## GRO J1655-40

The superior resolution of SXS in the Fe K band enables the unambiguous detection of weak and narrow lines from a wind.

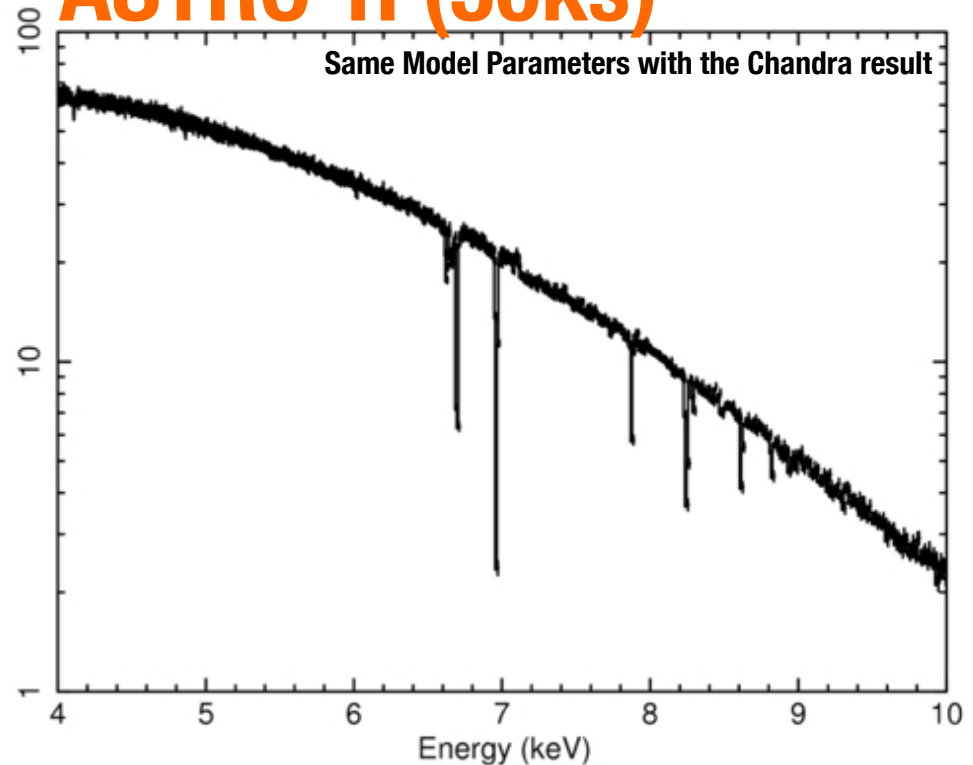


### Chandra



(Simulation by J. Miller)

### ASTRO-H (50ks)



ASTRO-H SXS can handle 250 cts/s

## 8. ASTRO-Hでの観測ターゲットの選定のための詳細研究



吸収線の中心エネルギーで決まるのは重力赤方偏移  
したがって半径と質量の比が求まる。

仮に、半径をSchwarzschild半径でnormalizeしたと  
すると、そのnormalized radiusは重力赤方偏移で一  
意に決まる。

$$\frac{E_{\text{obs}}}{E_{\text{lab}}} = \sqrt{1 - \frac{2GM_{\text{NS}}}{R_{\text{NS}}c^2}} \approx 0.6 - 0.9$$

**現在、低いSpin RateのLMXBの選定が進んでいる**

**ASTRO-H White Paper Task Force (辻本他)**



# まとめ (本計画班の研究内容)



新世代宇宙X線望遠鏡の革新的装置を用いた中性子星の直接観測と距離によらない中性子星半径の精密決定の試み

(1) 中性子星からのX線バースト

(2) 中性子星表面近くをケプラー運動するガスからの準周期的な X 線放射

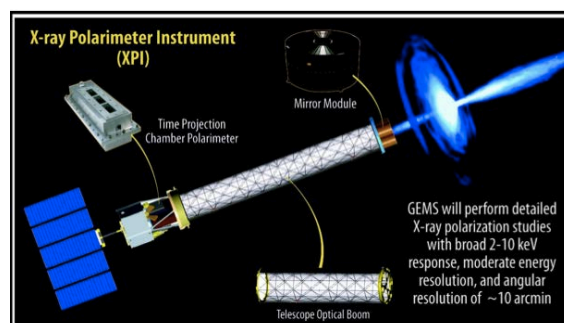
## ASTRO-Hで可能となる 新たな観測にむけて



1. 重元素の吸収線の重力赤方偏移
2. 広帯域スペクトルによる黒体放射スペクトルの分離と精密決定。そのための打ち上げ前キャリブレーション
3. 高レートへの対応 (FPGA、機上ソフトウェア、キャリブレーション)
4. ターゲットの選定 (予言のための理論計算を含む)

### 将来ミッションに向けた研究:

- 1) 吸収線やパルスプロファイルからMとRを同時に求める所に「日本」の理論研究を
- 2) 中性子星からの「バースト」中のスペクトルの特徴をとらえるためには、装置開発が必要  
(偏光X線観測、高計数率対応X線イメージャ)
- 3) 検出器の分野横断的開発 (ASIC、Si/CdTe他)
- 4) NICER, LOFTへの参加と貢献。**



May 16th  
Vibration Test

