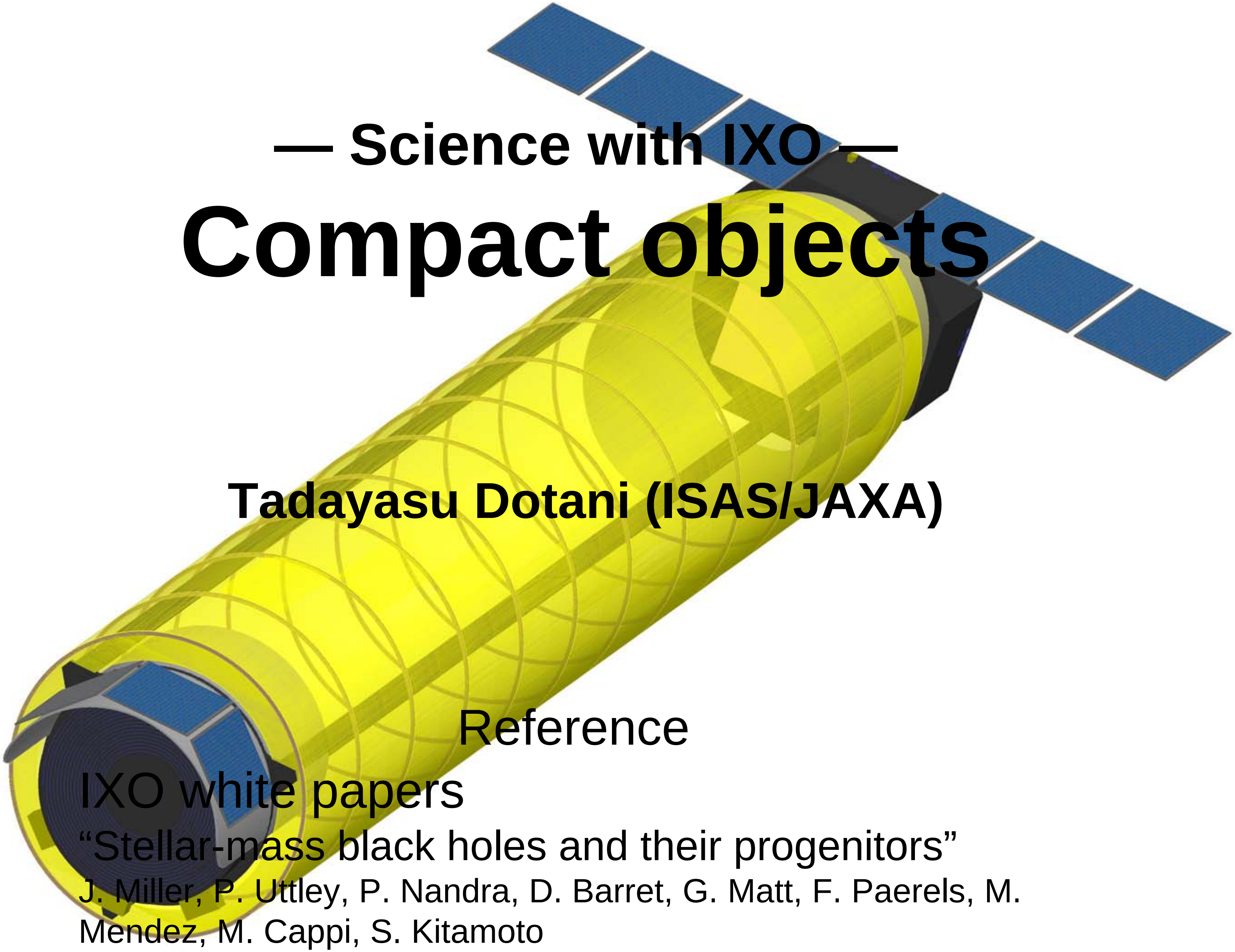


— Science with IXO —

Compact objects

Tadayasu Dotani (ISAS/JAXA)

Reference

IXO white papers

“Stellar-mass black holes and their progenitors”

J. Miller, P. Uttley, P. Nandra, D. Barret, G. Matt, F. Paerels, M. Mendez, M. Cappi, S. Kitamoto

Spin of the stellar-mass black hole

Spin of the stellar-mass BH cannot change largely during the life time.

⇒ **BH spin is determined at birth**

(1) Low-mass companion

Mass of the companion is too small.

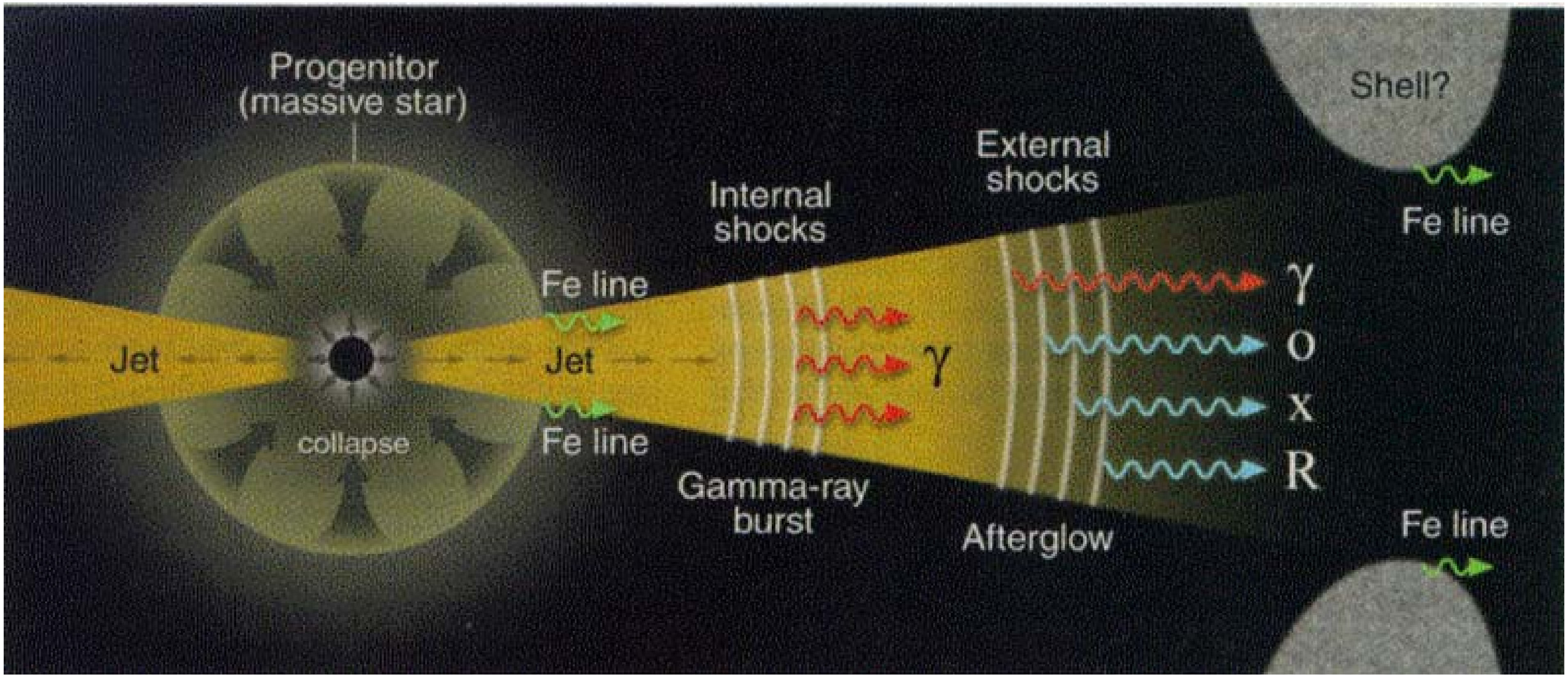
(2) High-mass companion

Companion is too short-lived to transfer significant mass.

Eddignton accretion rate $$\dot{M} = 2.3\times10^{-7}\left(\frac{M}{10M_{\rm sun}}\right)M_{\rm sun}/{\rm yr}$$

Initial spin of the BHs

- What is the nature of the hyper-nova and the central engine of the GRBs?



Spin of the first BHs

- What is the spin distribution of the first black holes in the universe?

	Available potential energy
Schwarzschild BH	~6%
Extreme Kerr BH	~50%

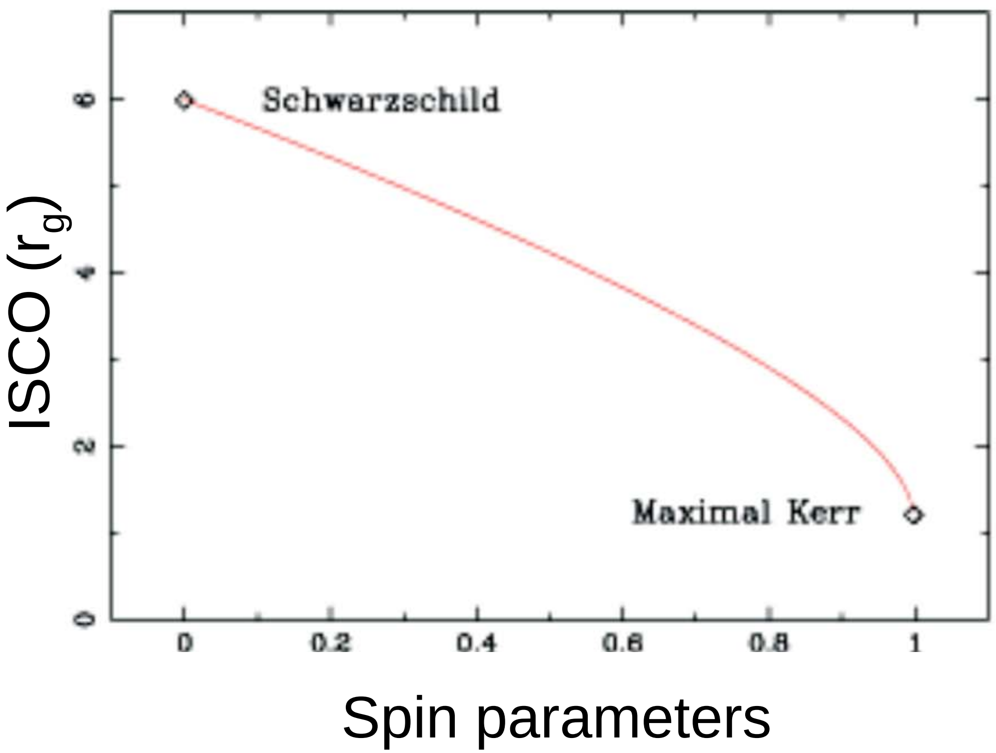
Kerr BH can supply an order of magnitude larger ionizing radiation, which can affect the star formation in early galaxies.

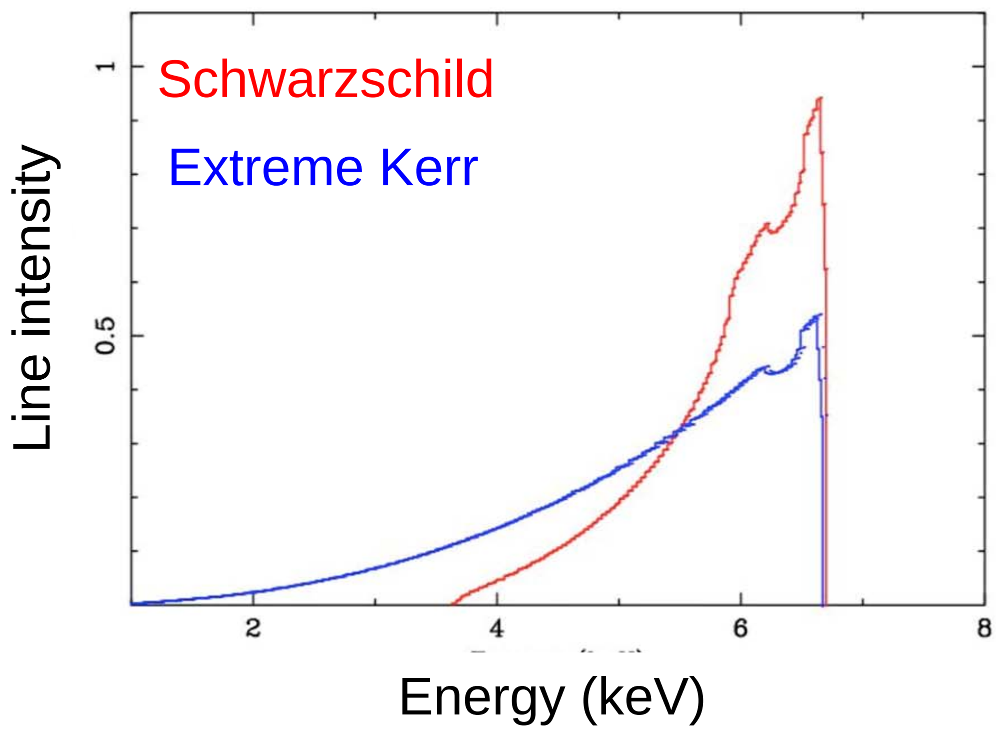
How to measure the BH spin

(1) Relativistic disk line

It is critical to model the underlying continuum correctly.

→ Hard X-ray capability is important.

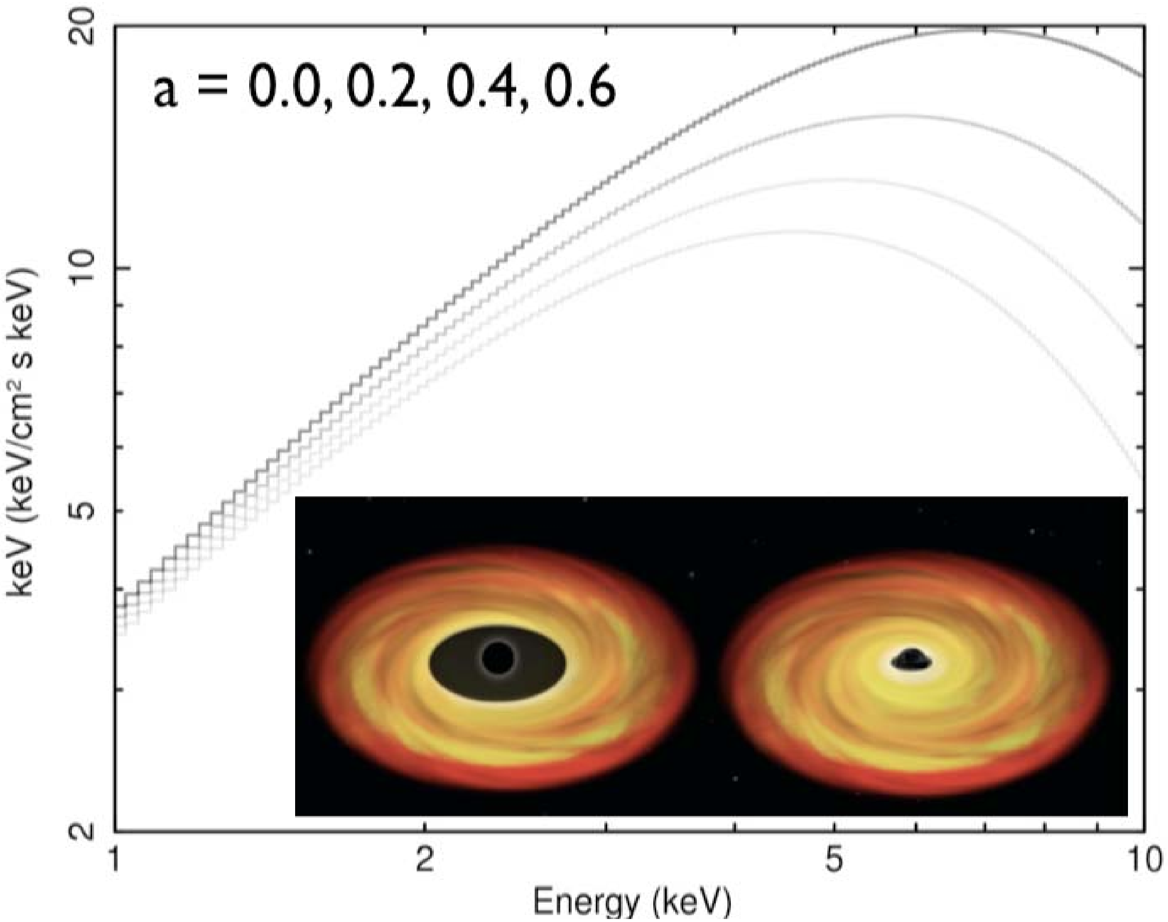




(2) Continuum emission from the accretion disk

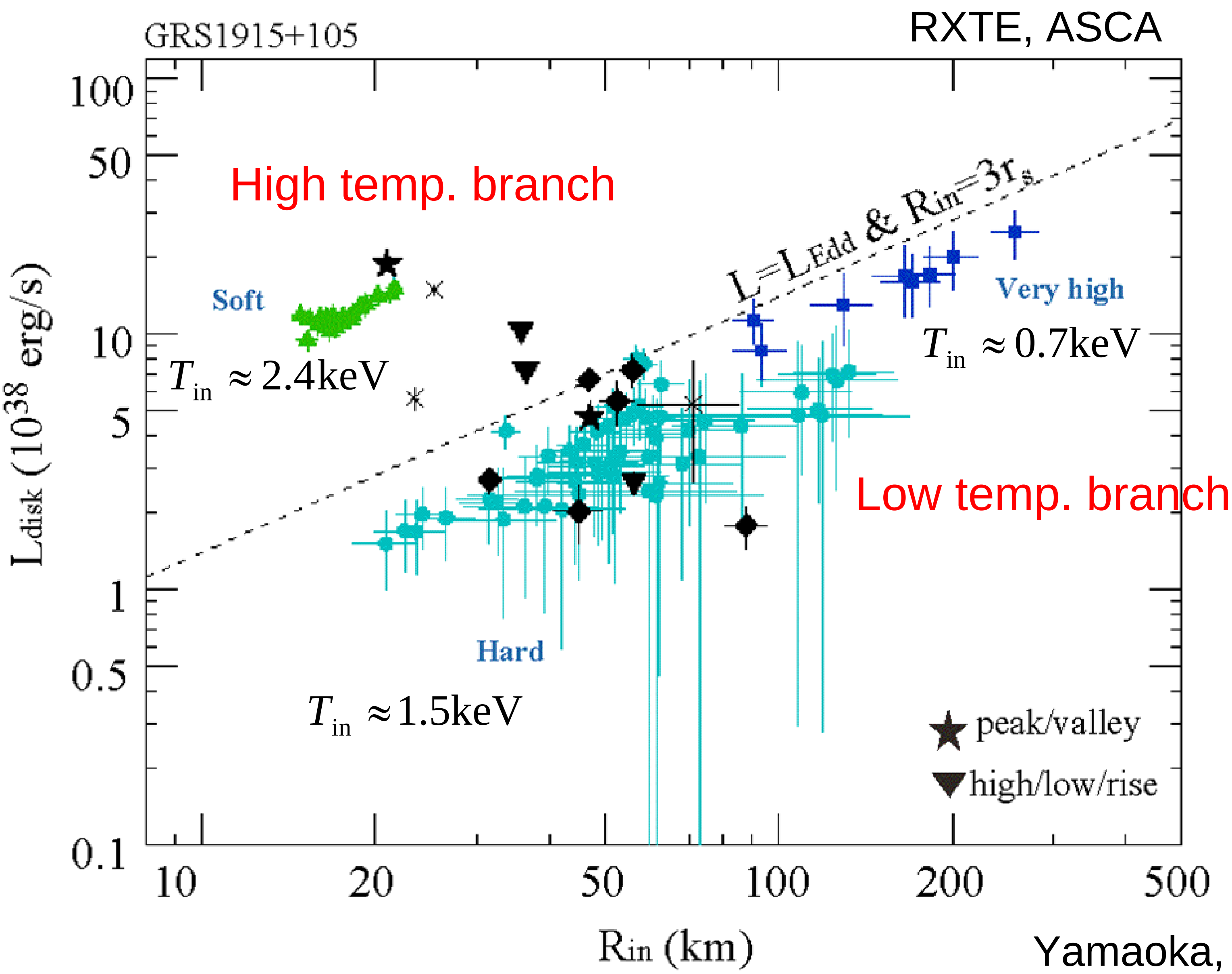
Higher spin ⇨ Harder, brighter thermal emission from the accretion disk.

Mass of the BH and the accretion geometry need to be known to apply this method.



GRS1915+105: disk parameters

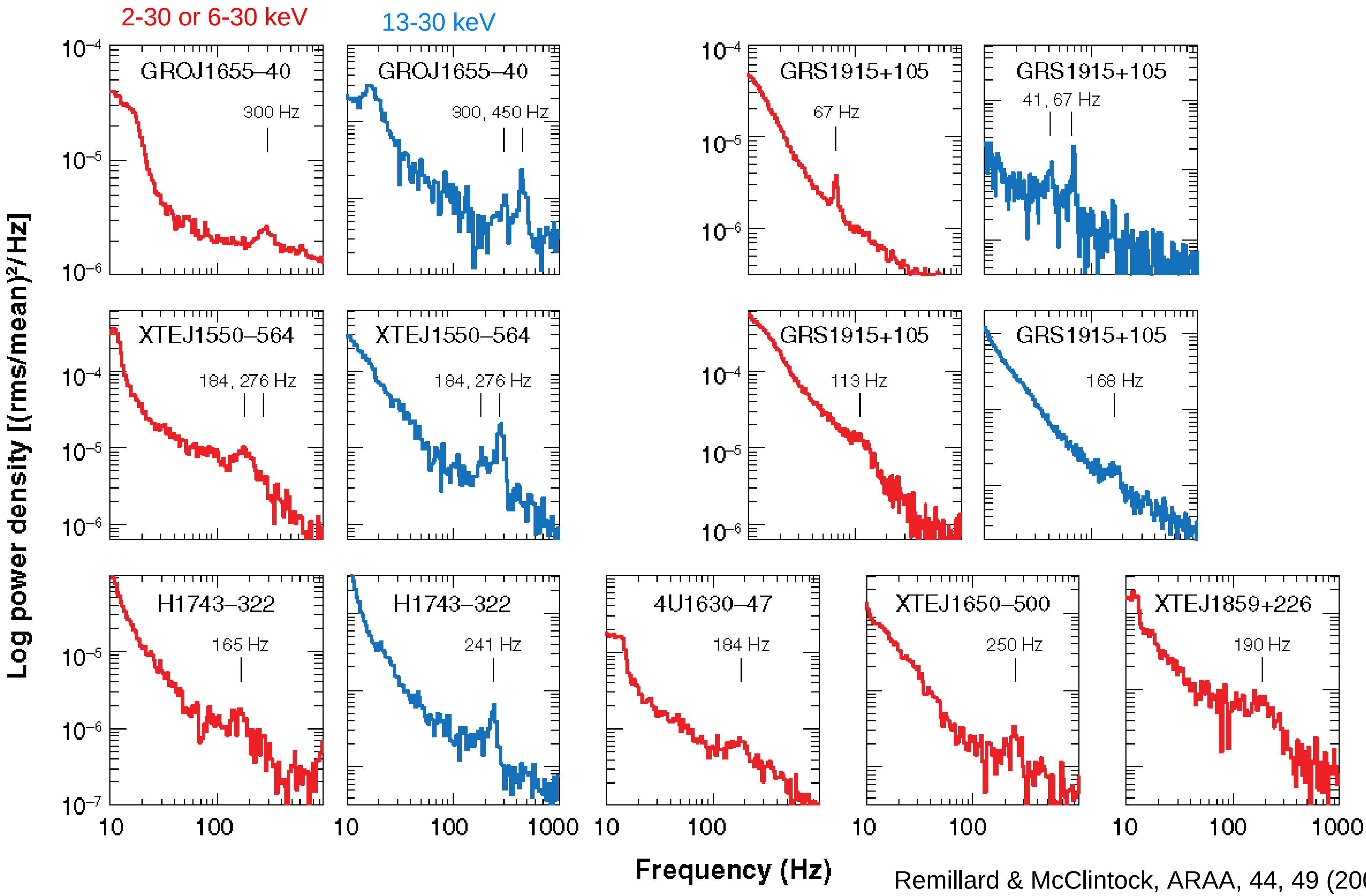
Model: multi-color disk (or p-free disk) + broken power law (E_{break} = 7 keV fix)



Yamaoka, PhD thesis

(3) High-frequency QPOs

Two peaks sometimes appear in 2:3 frequency ratio.



Remillard & McClintock, ARAA, 44, 49 (2006)

High frequency QPOs

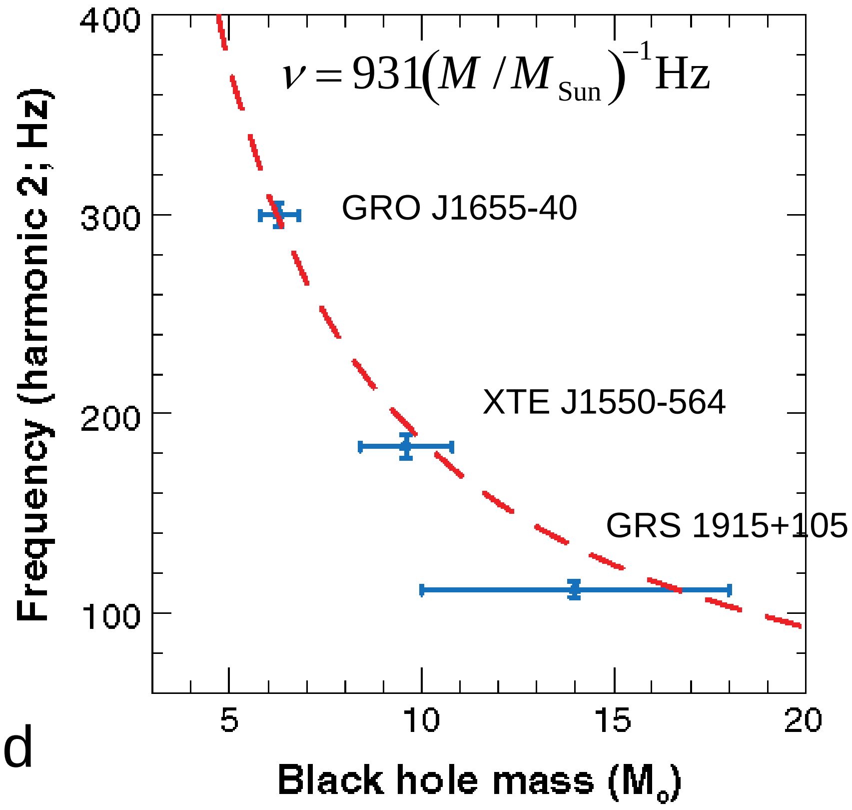
Orbital freq. in Kerr spacetime

$$\nu_\phi = \frac{\sqrt{GM/r^3}/2\pi}{1 + j(r_s/2r)^{3/2}} = \nu_k\left(1 + j(r_s/2r)^{3/2}\right)^{-1}$$

$j = Jc/GM^2$ Angular momentum parameter

Max. freq. at the ISCO.

$$\nu_{\rm ISCO} = \begin{cases} 219\left(\dfrac{M}{10M_{\rm Sun}}\right)^{-1} \text{Hz} & \text{schwarzschild} \\ 1611\left(\dfrac{M}{10M_{\rm Sun}}\right)^{-1} \text{Hz} & \text{Extreme Kerr} \end{cases}$$



Remillard & McClintock, ARAA, 44, 49 (2006)

Other methods

(4) X-ray polarimetry

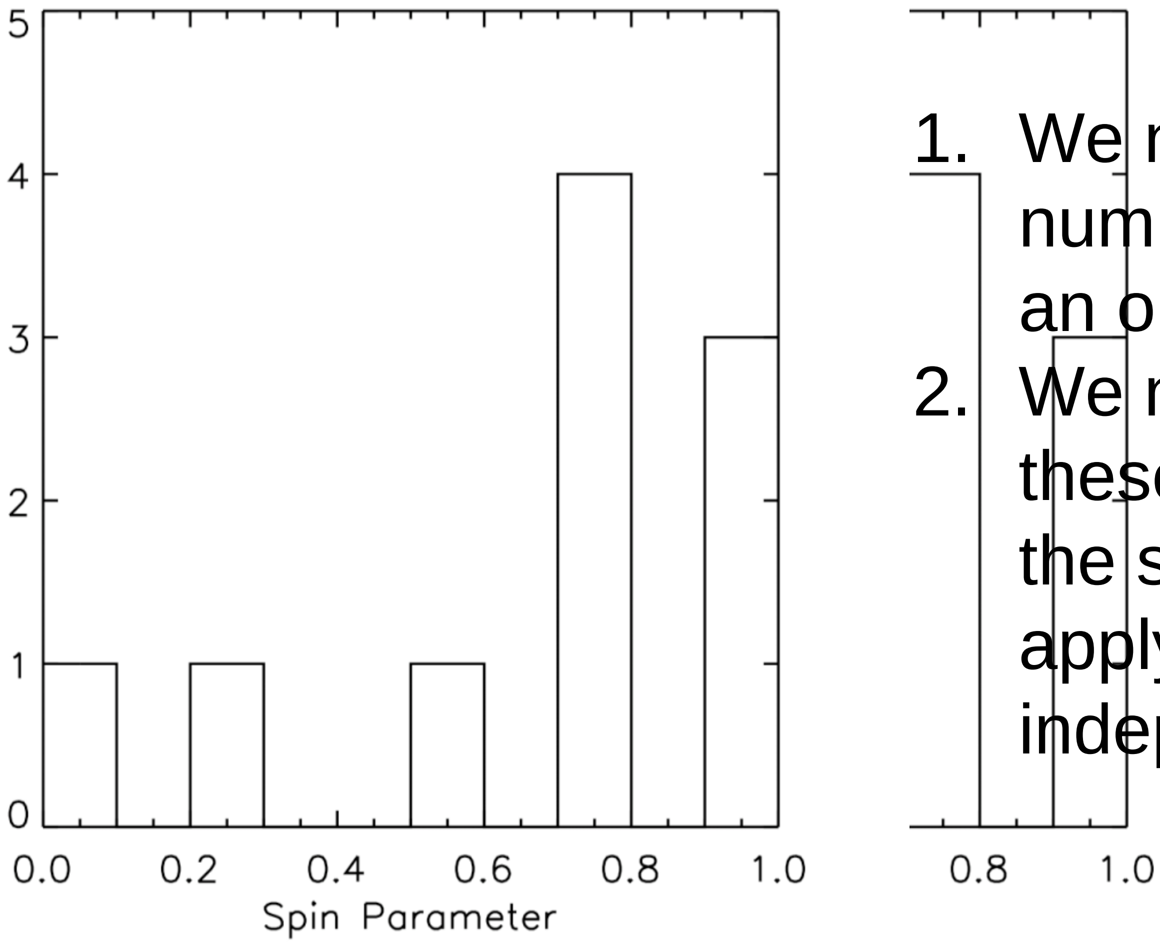
- Thermal emission from the accretion disk is expected to be polarized. Energy dependence of the polarization angle reflects the spin of the black hole.

(5) X-ray Reverberation

- Time lag between the hard X-ray continuum and the iron lines, which represents the light travel time, is expected to reflect the BH spin.

Spin measurement of BH binaries

Spin distribution of 10 stellar-mass BHs
measured by the relativistic iron line.



1. We need to increase the number of samples by an order of magnitude.
2. We need to confirm these measurements of the spin parameters applying various independent methods.

Miller et al. 2009, Reis et al. 2009, Blum et al. 2009

Number of observable BH binaries

- Milky Way Galaxy
  - 20 BHs and 20 BHCs are known.
  - ~1 X-ray nova / year is expected.
- Nearby galaxies
  - M31 (8 BHCs in the central region, 2 BHCs in GC), M33 X-7, IC10 X-1, NGC300 X-1, NGC4636 (2 BHCs) etc.
  - $a = 0.77 \pm 0.05$ is already estimated for M33 X-7.

Galaxy	Distance	Number of sources with >2E38 erg/s
NGC4194	39.5 Mpc	10
NGC7541	37.1	15
NGC1068	14.4	18
M51	8.4	13
Antenna	13.8	9
M100	16.8	11
NGC4945	3.7	4
M82	3.6	7
NGC4579	16.8	3
M74	8.8	2

Kaaret, Alonso-Herrero, 2008, ApJ, 682, 1020

IXO can measure the spin for BH binaries beyond ~10 Mpc

Comparison with the NS binaries

Calibration of the spin measuring methods

1. NS spin is inferred for 14 LMXBs from the burst oscillations.
2. Relativistic disk line was detected from 8 NS binaries.

The method of the relativistic disk line can be tested using the observations of the NS binaries with known spin.

Name	Spin (Hz)	Disk line
SAX J1808.4-3658	401	Yes
XTE J1814-338	314	
4U1608-52	619	
4U1636-53	582	Yes
4U1702-43	330	
4U1728-34	363	
KS1731-26	524	
SAX J1750.8-2900	601	
Aql X-1	549	
4U1915-05	272	
EXO0748-676	552	
MXB1659-298	567	
MXB1743-29	589	
SAX J1748.9-2021	410	
Cyg X-2		Yes
Ser X-1		Yes
4U1820-30		Yes
GX349+2		Yes
GX340+0		Yes
4U1705-44		Yes

Comparison with the rotation-powered pulsars

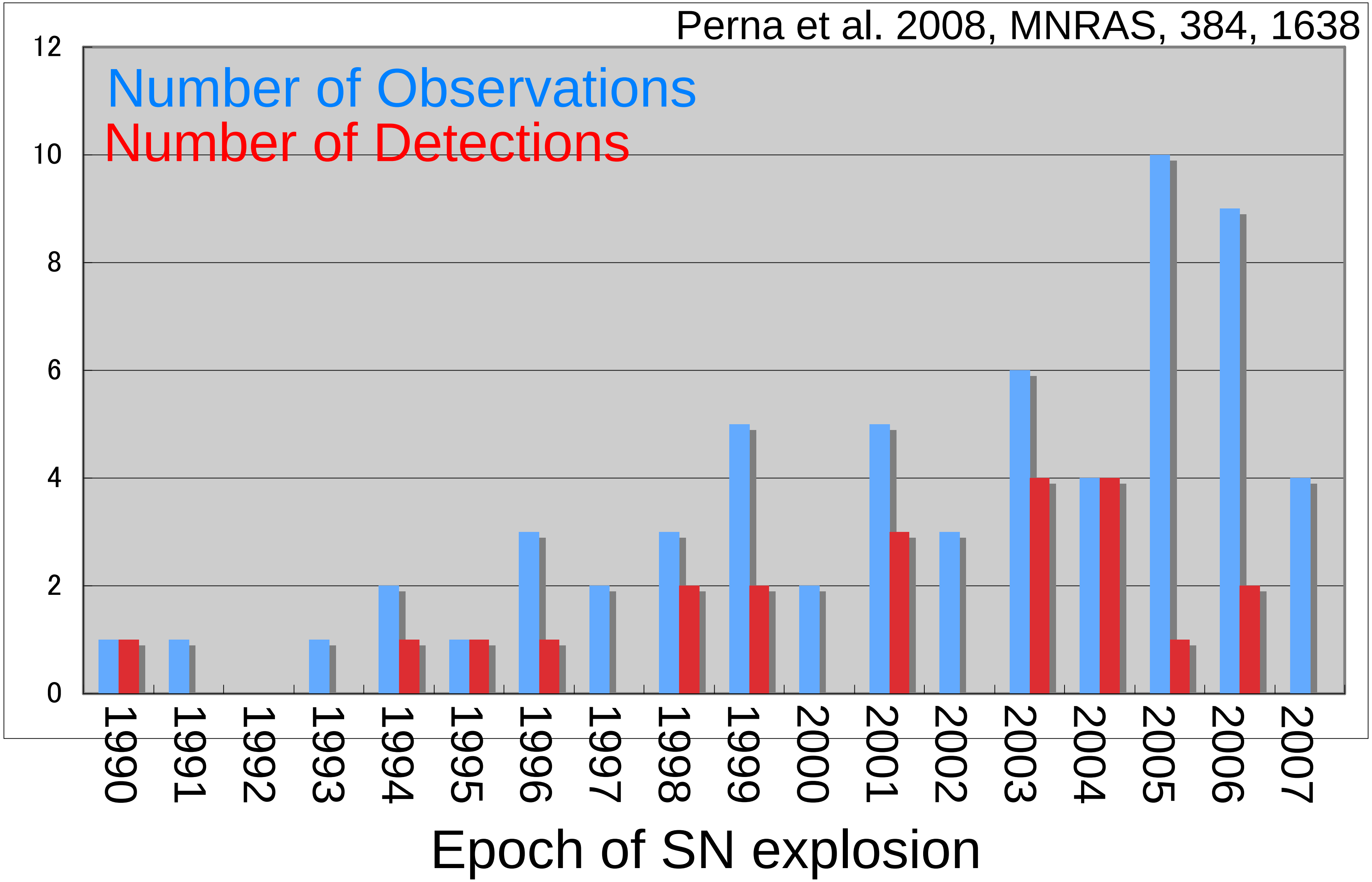
If the exact age of the pulsar (I.e「., historical SN) and the breaking index are known, we can estimate the initial spin of the pulsar.

	Current spin period	Year of explosion	Initial spin period
Crab	33ms	AD1054	19ms
G11.2-0.3 / PSR J1811-1925	64.7ms	AD386	62ms
3C58 / PSR J0205+6449	65.7ms	AD1181?	60ms?
G21.5-0.9 / PSR J1833-1034	61.8ms	BC48	(47ms)

IXO can search pulsars in the recent SNe in nearby galaxies.

Number of recent SNe observed in X-rays

Observations of recent (core-collapsed) SNe are searched in the archive data of Chandra, XMM-Newton and Swift.



Summary

- Spin measurement of the stellar mass BHs is important to study the nature of the initial BHs and the central engine of GRBs.
- IXO can measure the spin of BH binaries beyond ~10 Mpc.
- It is important to test the methods to measure the ┘ spin by comparing the data from the NS binaries with known spin.
- Measuring the initial spin of NS in SNe is important for comparison and can be done with IXO.