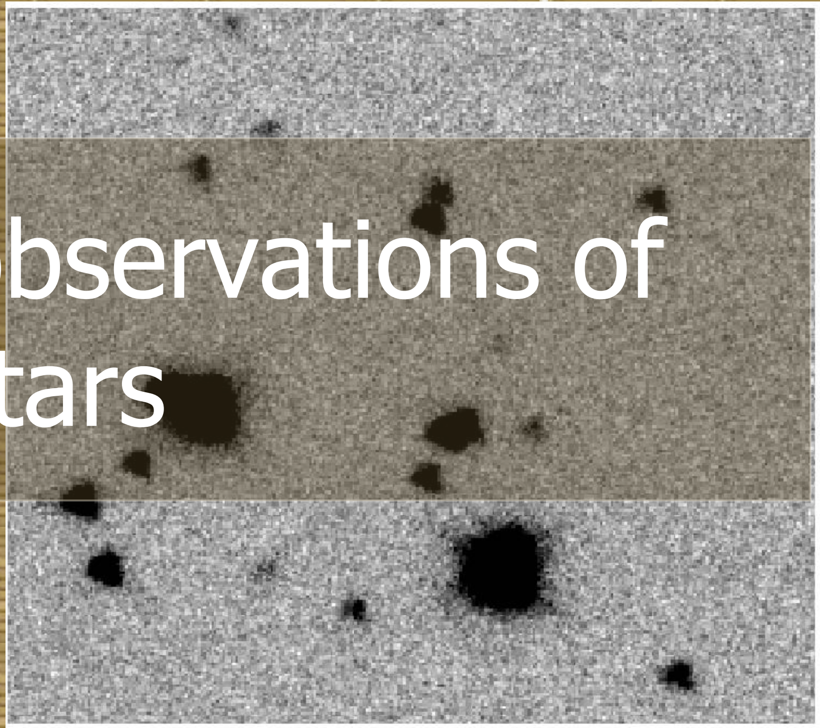
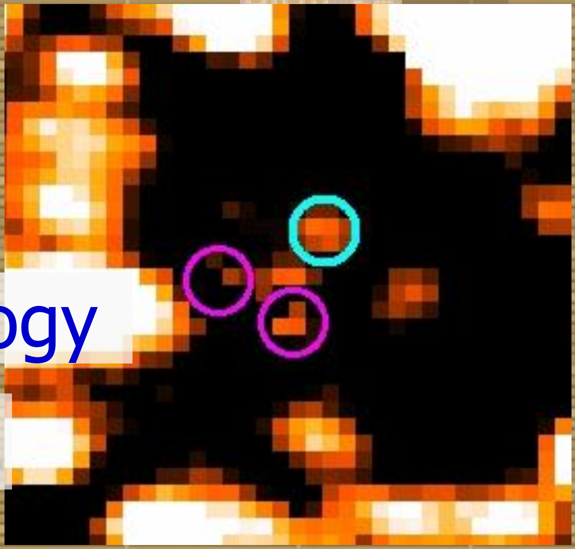


Infrared-Optical observations of magnetars

Mikio Morii

Tokyo Institute of Technology



2012.09.01 @ Rikkyo Univ.

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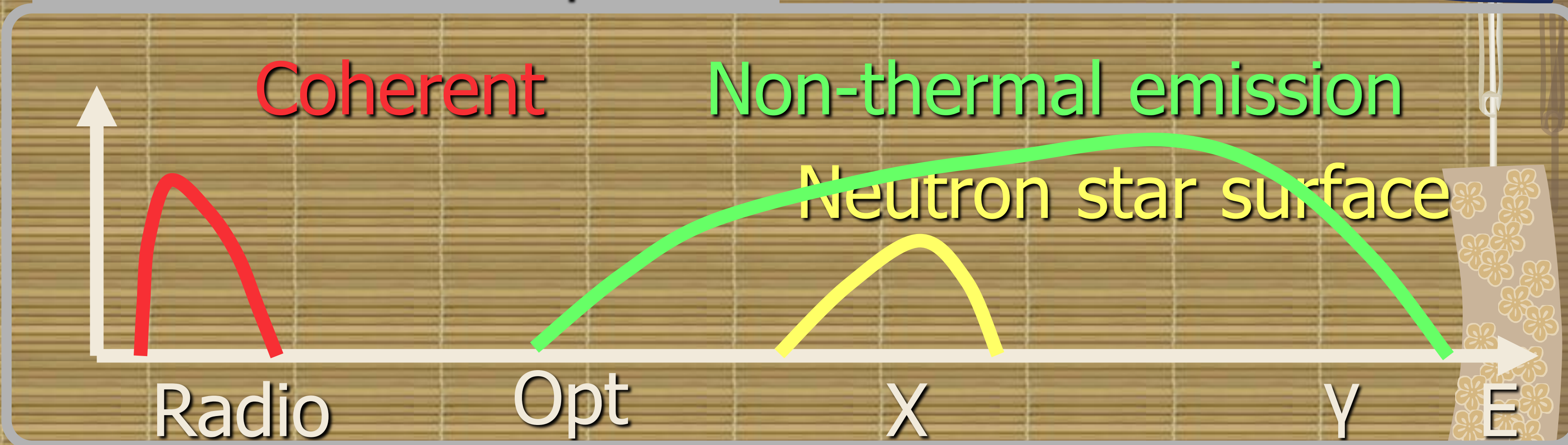
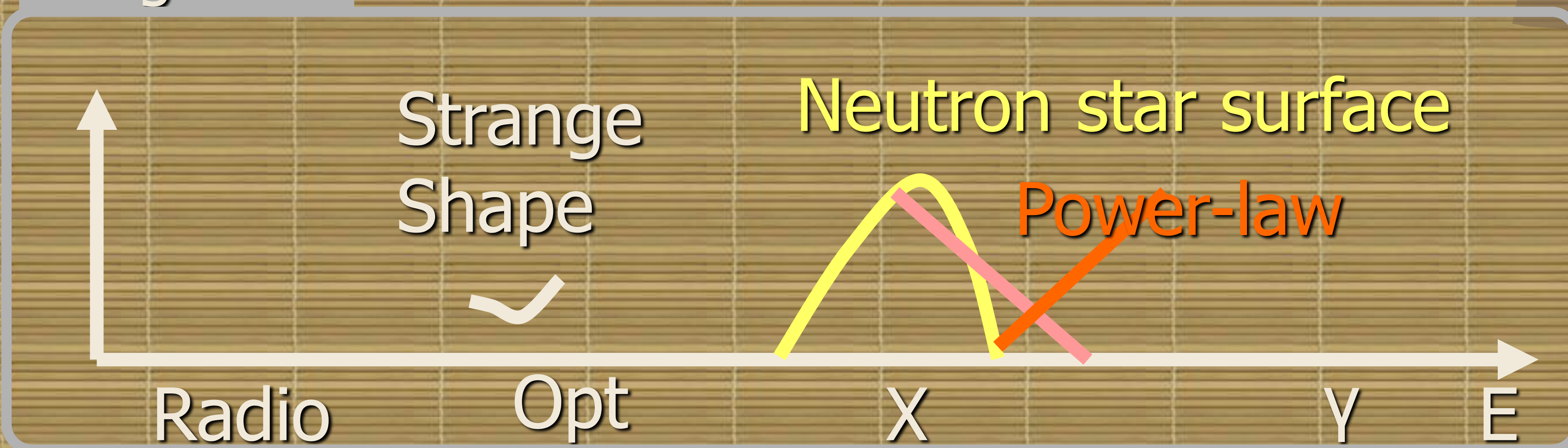
- Search for Near-Infrared Pulsation of the AXP 4U 0142+61
  - M. M., N. Kobayashi, N. Kawai, H. Terada, Y. T. Tanaka, S. Kitamoto, & N. Shibazaki
- AKARI observation of AXP 4U 0142+61 and 1E 2259+586
  - K. Kaneko, T. Kohmura, S. Ikeda, M. M., K. Asano, M. Shirahata, & N. Shibazaki

Broad band spectra

Rotation Powered pulsar



Magnetar



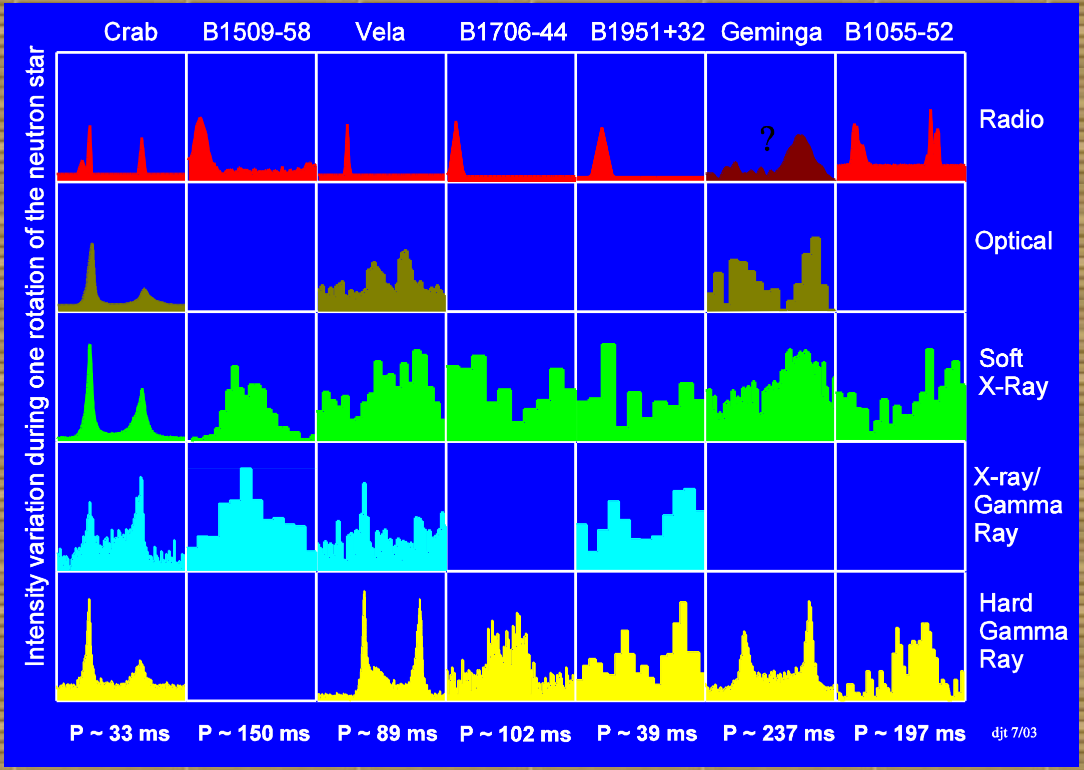
NIR and Optical Counterparts of Magnetars

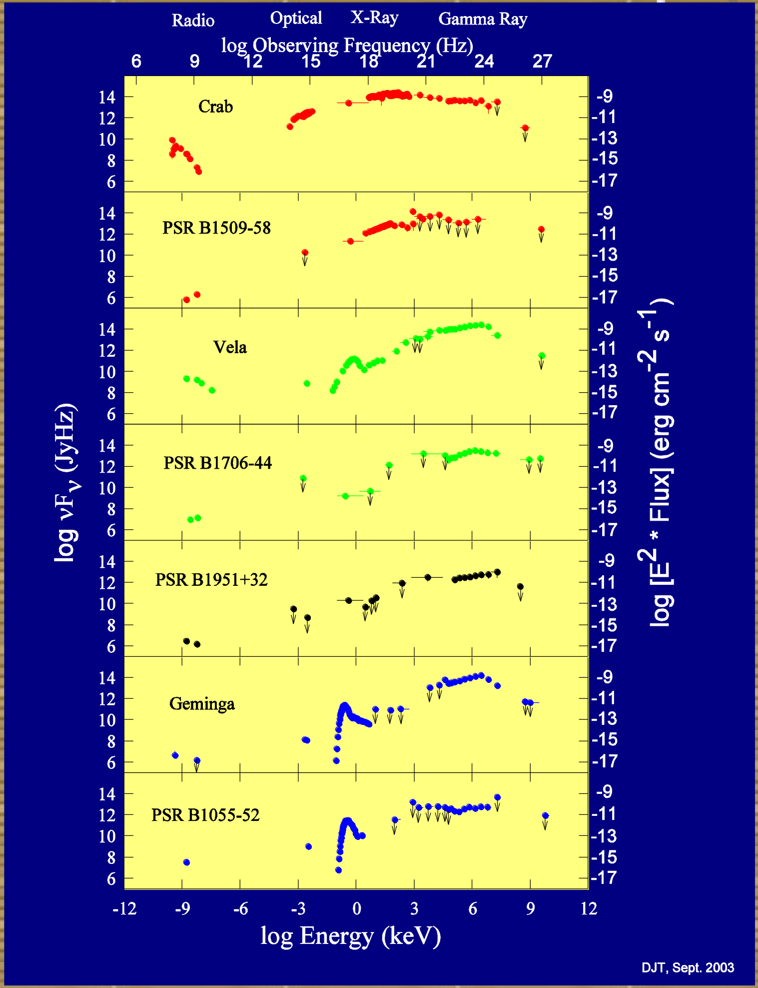
AXPs & SGRs	Flux (erg/cm²/sec) @ 2 – 10 keV	K	H	J	I	R	V	B	
4U 0142+61	10×10^{-11}	19.9(1)	20.6(1)	22.1(1)	24.0(1)	25.6(2)	25.3(1)	>27.2	Pulse (opt), variable
1E 2259+586	3×10^{-11}	~ 20	----	----	-----	-----	-----	----	variable
1RXS J170849.0-400910	4×10^{-11}	17.5	18.9	20.9(1)	----	----	----	----	
1E 1048.1-5937	0.7×10^{-11}	19.4(3)	20.8(3)	21.7(3)	----	----	----	----	variable
1E 1841-045	1×10^{-11}	----	----	----	----	----	----	----	
XTE J1810-197 (transient)	4×10^{-11}	20.8	----	----	----	----	----	----	variable
SGR 1806-20	1×10^{-11}	~20	----	----	---	---	----	----	variable
SGR 1900+14	$< =1 \times 10^{-11}$	----	----	----	----	---	---	----	

IR/optical emission is very rare.

~2000 Rotation-powered

A few

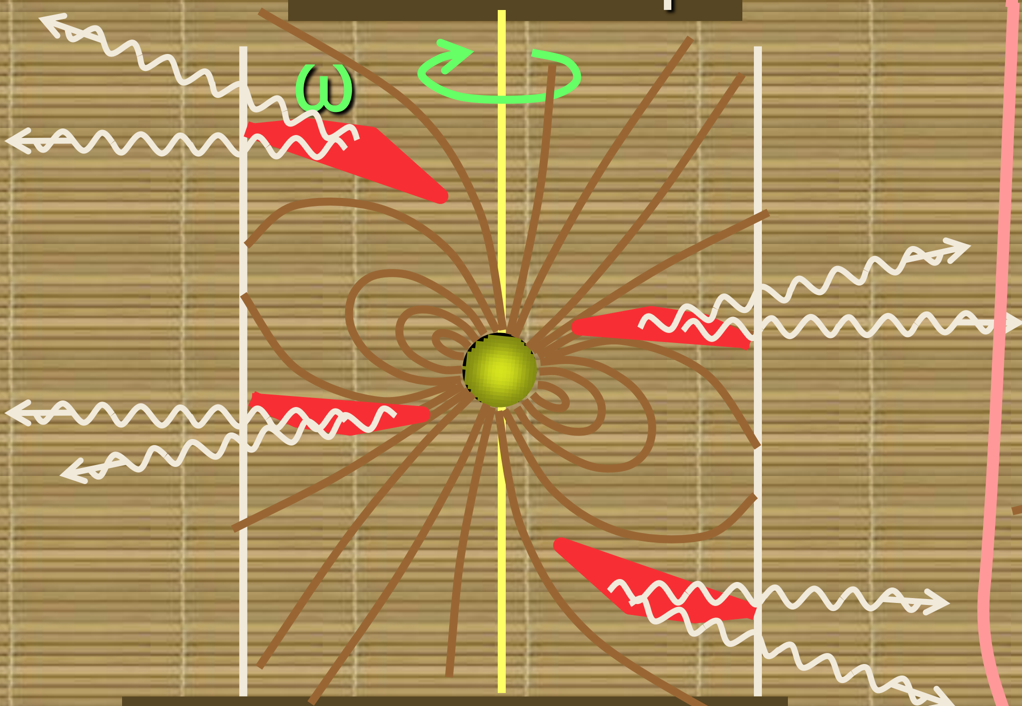




D.J. Thompson (2003)

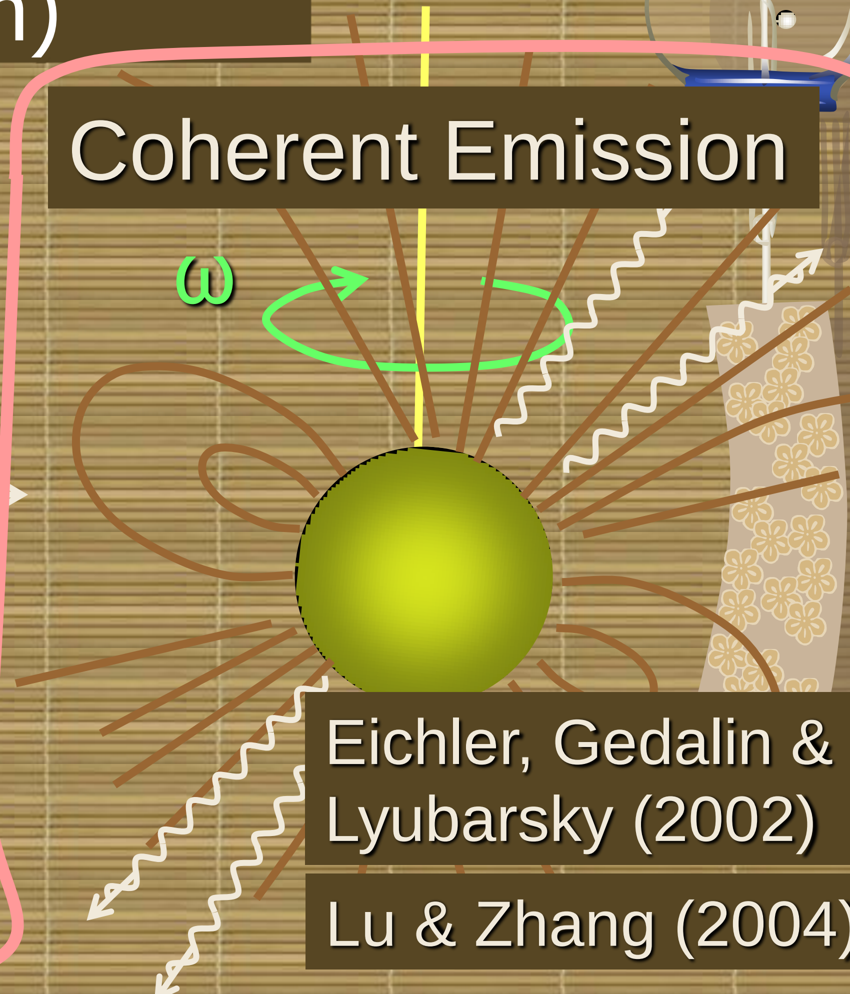
IR/optical Emission Mechanism (Magnetospheroc emission)

Outer Gap



Ertan & Cheng (2003)

Coherent Emission



Eichler, Gedalin & Lyubarsky (2002)

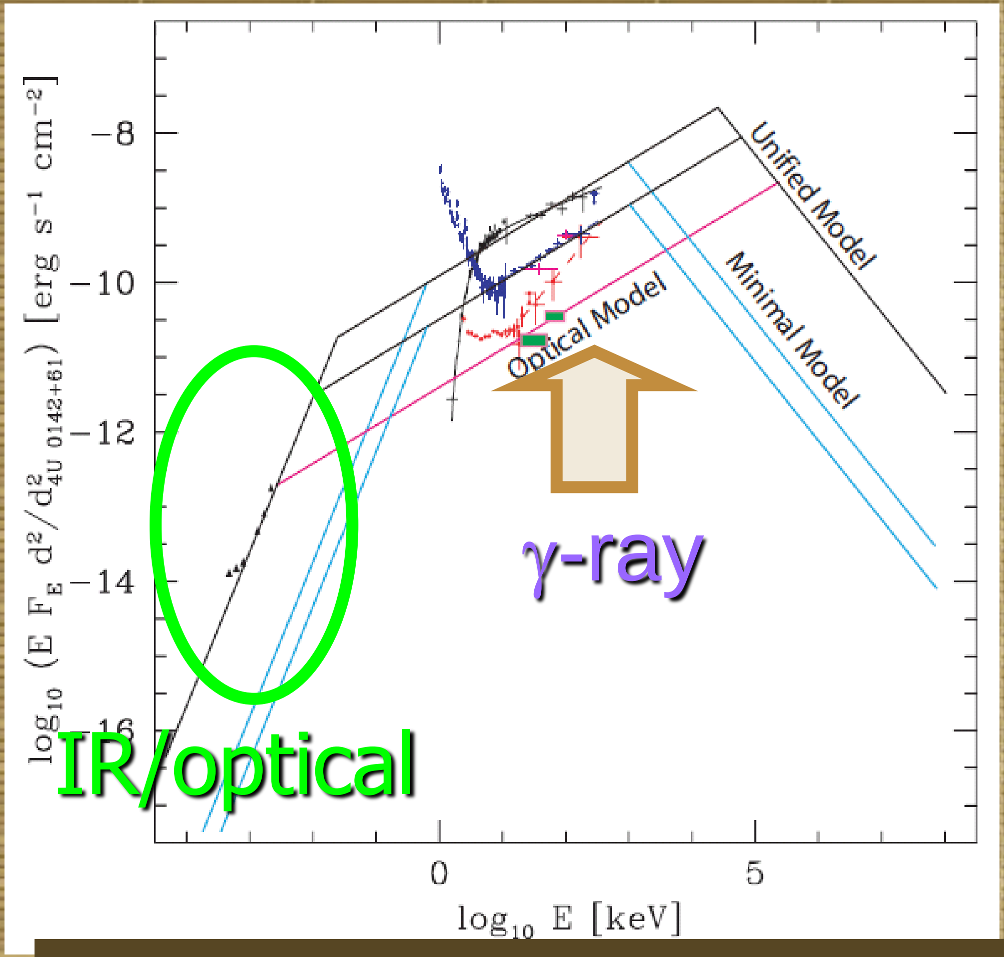
Lu & Zhang (2004)

Radio emission mechanism of rotation-powered pulsars was applied to magnetars.

Shifted to IR/optical region by strong magnetic field

Exotic IR/optical emission model

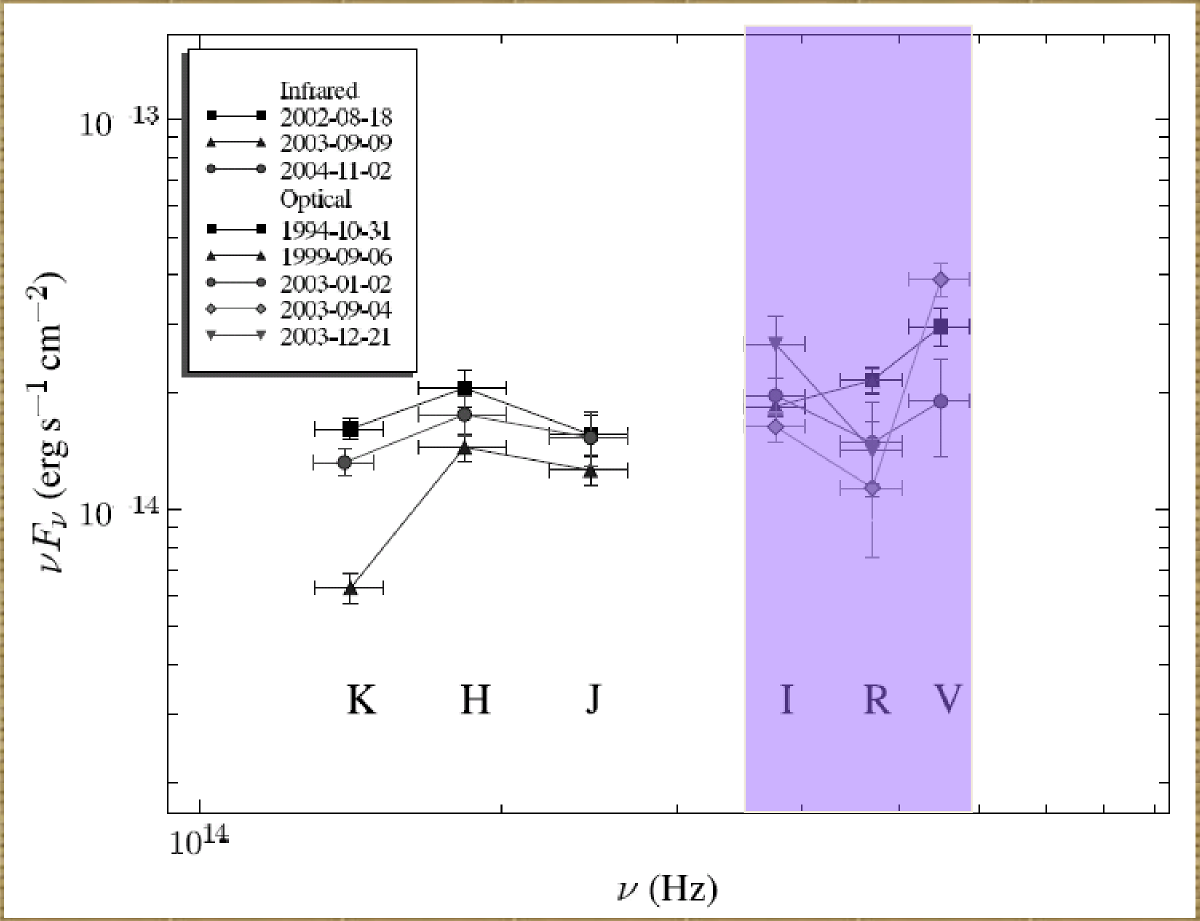
QED (Quantum Electrodynamics) model



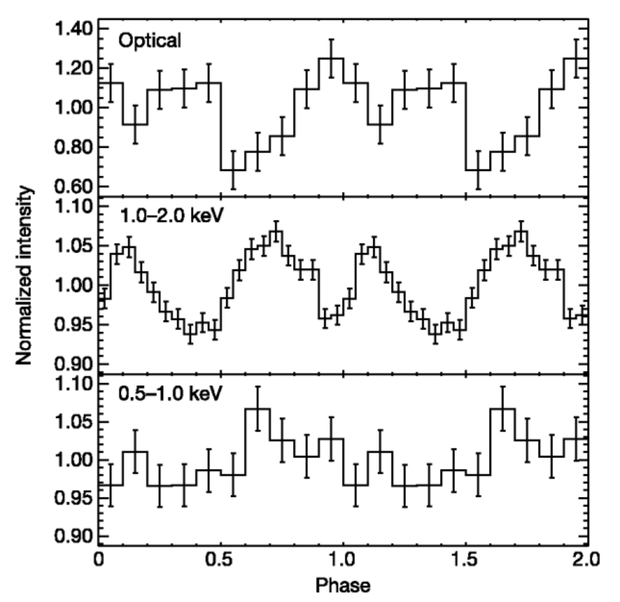
Heyl & Hernquist (2005)

Spectrum of AXP 4U 0142+61

Magnetospheric emission



Optical pulse

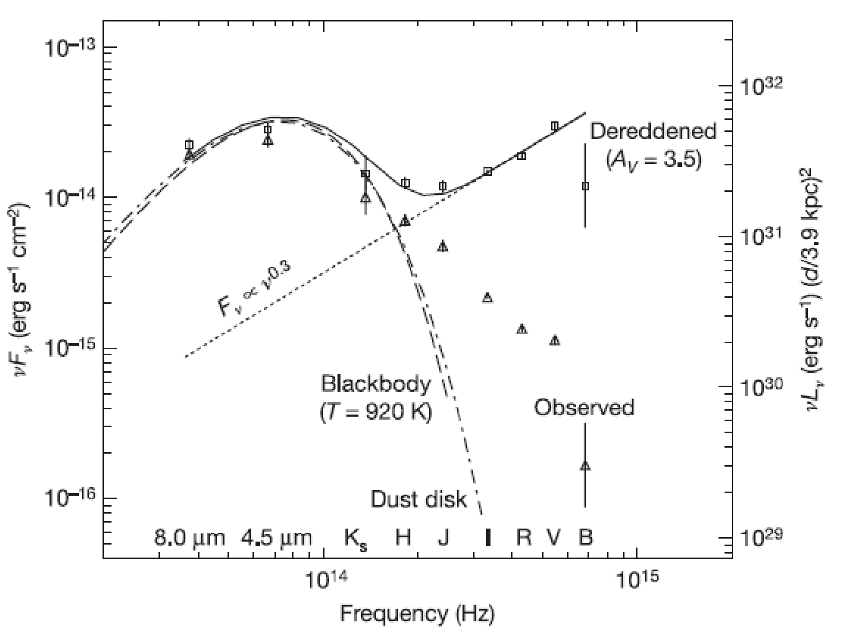


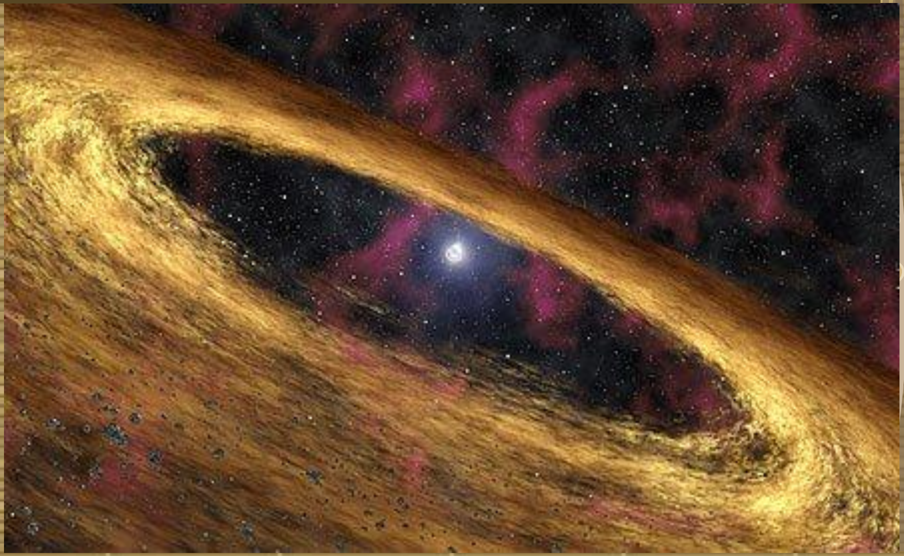
Kern & Martin 2002

Durant & Kerkwijk 2006, ApJ

Dust Disk around 4U 0142+61

Wang, Chakrabarty & Kaplan (2006) showed mid-infrared excess with Spitzer

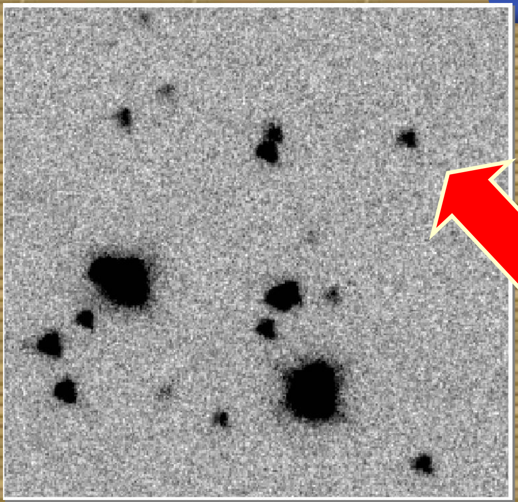




They explained IR excess component as dust disk around a neutron star. Such disk was formed by fall-back of supernova ejecta. They suggested planet formation around young neutron stars.

Our Observation: NIR Pulse search

Target: 4U 0142+61



P = 8.7 sec

K = 19.7 mag

Obs. date：2004.07.31

Detector: Subaru/IRCS

Band：   K' band

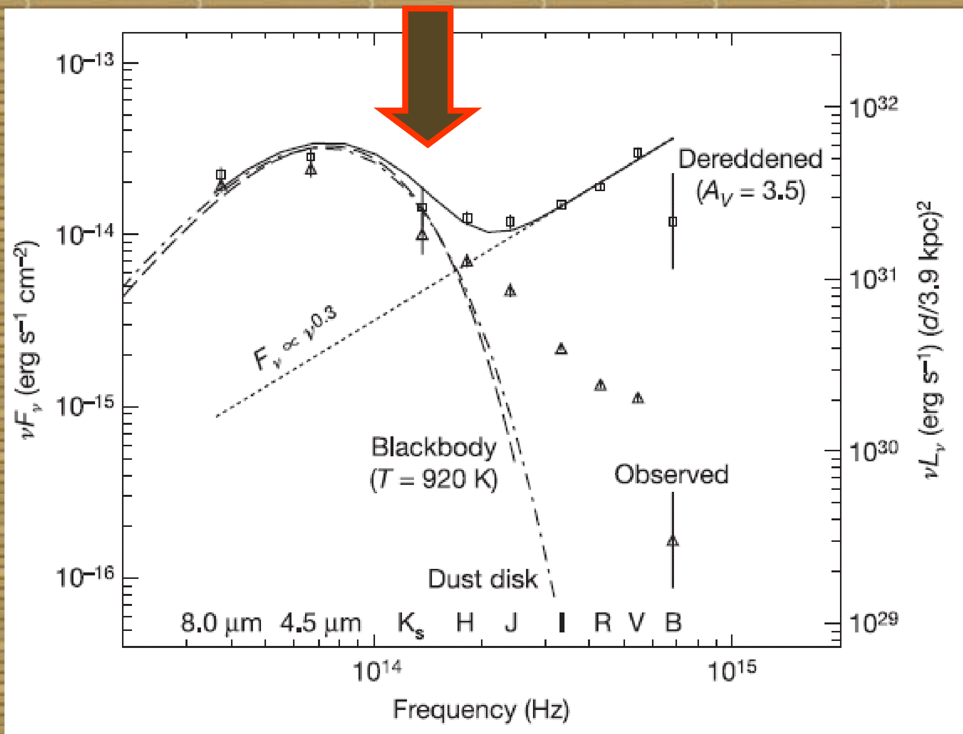
2.4 hours observation

Total Exposure：

0.8 sec x 5400 frames = 1.2 hours

Pulse search in K band is important.

Pulse search for K band

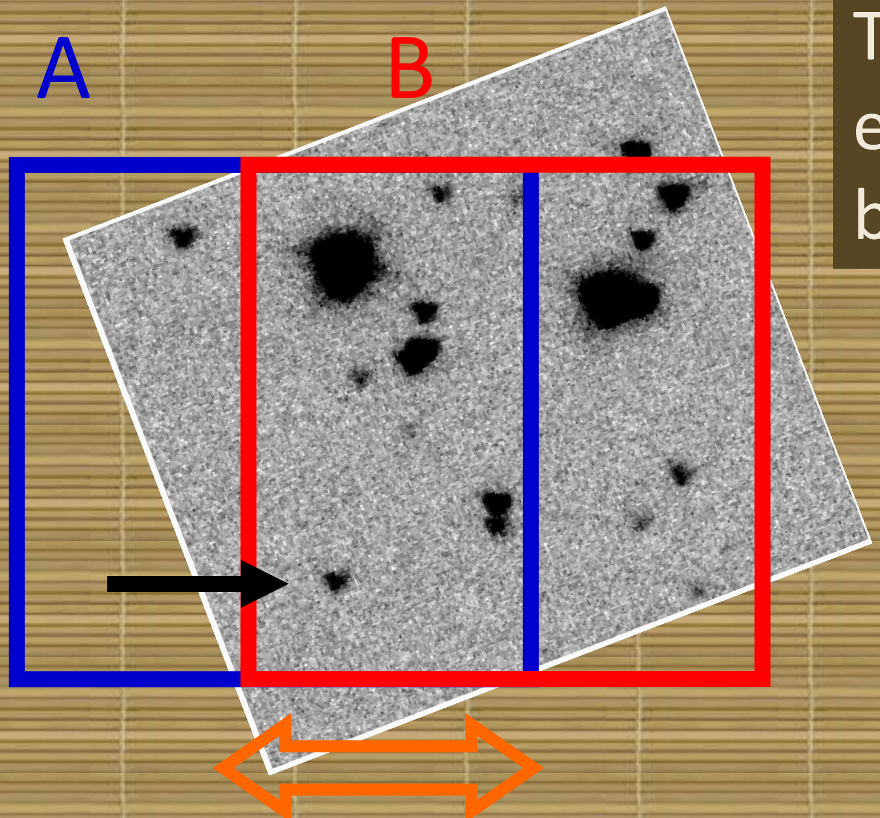


If dust disk model is correct, most of K band emission must come from dust disk.

By measuring pulse fraction, constraint on disk model is possible.

If pulse fraction is large, the model must be reconsidered.

Subaru/IRCS: Observation details



Two point dithering (**A**, **B**), each frame contains the bright stars.

alignment

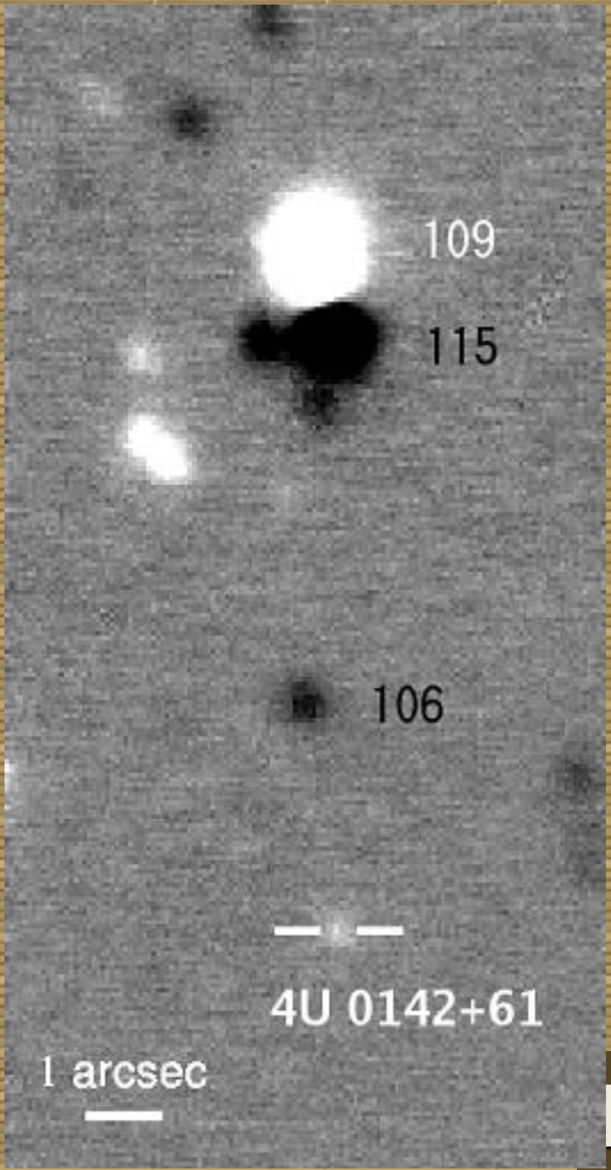
A:300, B:300, ...

Continuous 0.8s short exposures.

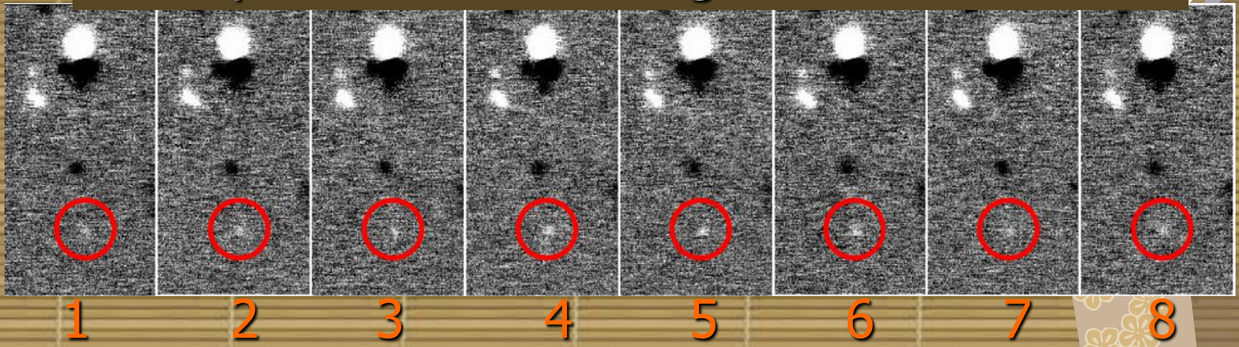
A – B, B – A frame: sky background subtraction.
→Combine frames with reference to the two bright stars.

Result

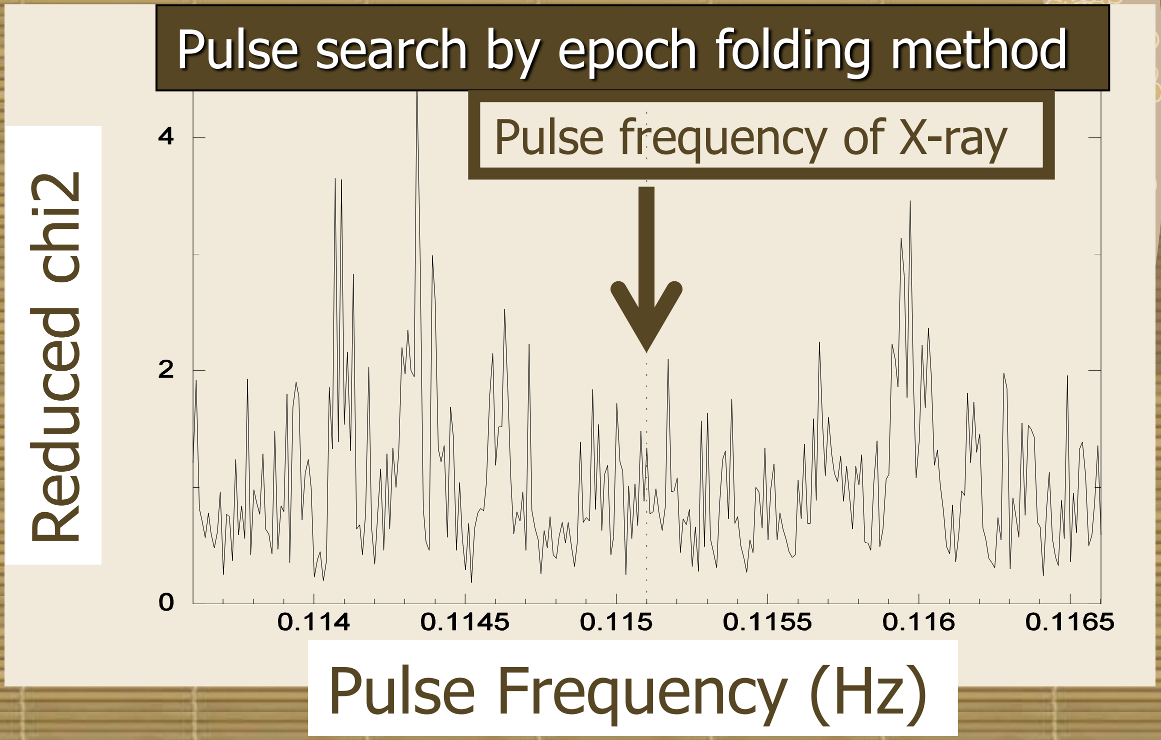
Phase-averaged



Pulse phase-resolved images of 4U 0142+61



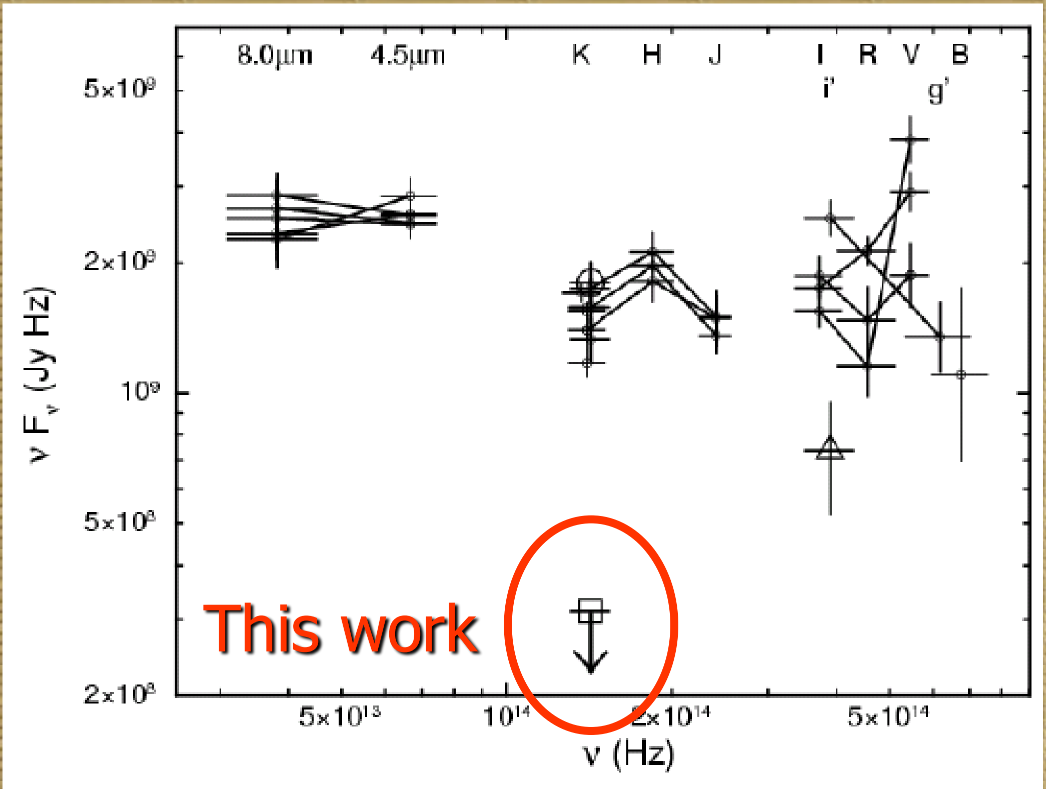
Pulse search by epoch folding method



Pulse Fraction < 17% (90%C.L.)

SED: νF_ν (Jy Hz)

Un-absorbed flux (A_V= 3.5)



Limit for the slope of the power-law function

$F_\nu \propto \nu^\alpha$ (Jy)

$\alpha > -0.87$ (90%C.L.)

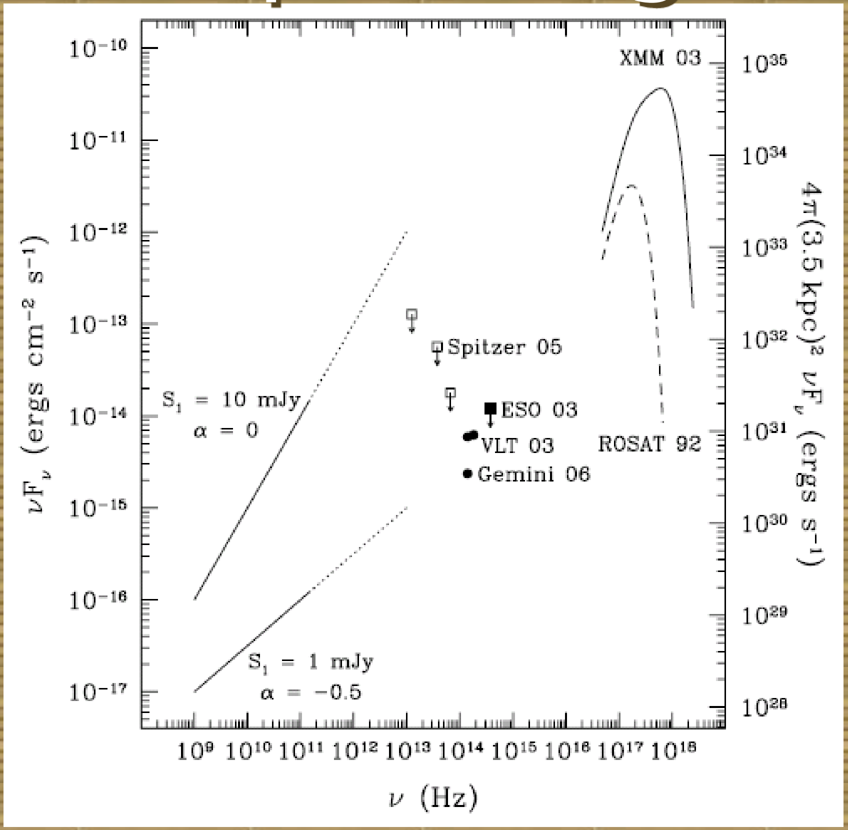
Limit is still weak to constrain the emission processes.

$\alpha = 0$ (QED, Heyl & Hernquist)

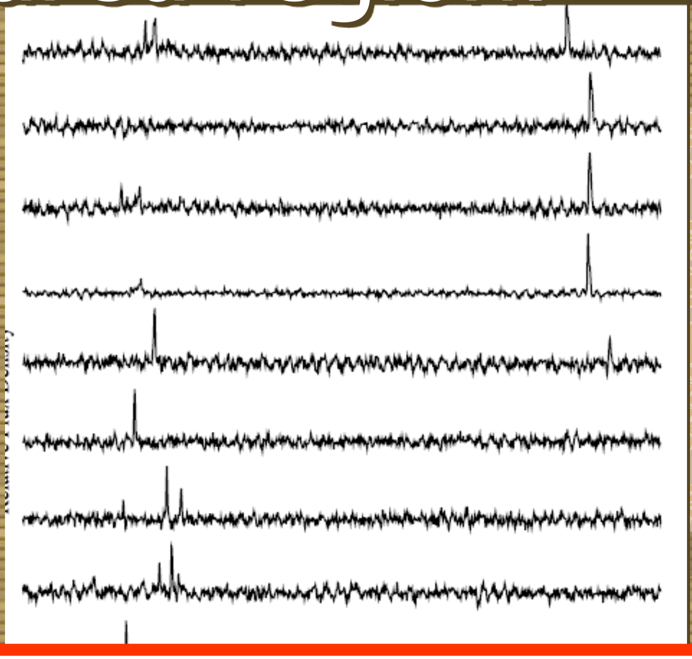
$\alpha \sim -0.5$ (Outer-gap, Ertan & Cheng 2004)

Dust Disk Model is also possible.

Nevertheless, there are a suggestion that the transient AXP, XTE J 1810-197 is pulsating in infrared region.



Spectrum of Transient AXP, XTE J1810-197



IR flux point is at the extrapolation of the radio transient pulsed spectrum.

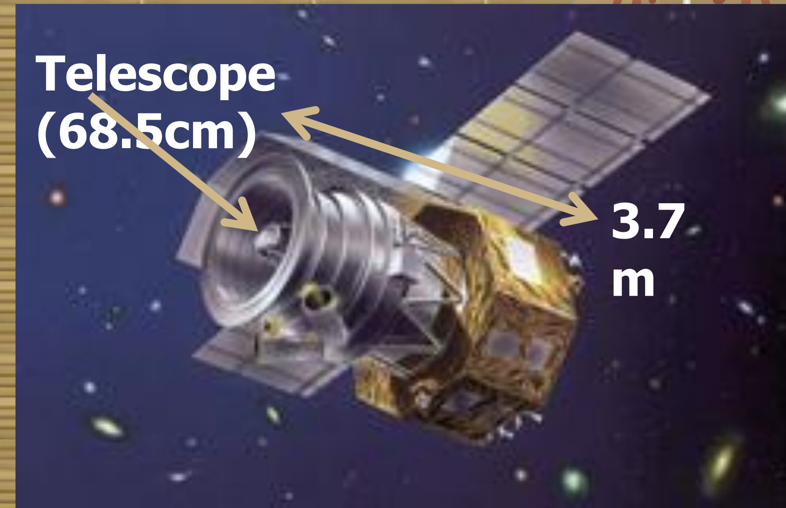
Camilo+, 2007, ApJ

Infrared Observation of 4U 0142+61 by AKARI satellite

K. Kaneko, T. Kohmura, S. Ikeda, M. M.,
K. Asano, M. Shirahata, & N. Shibazaki

Infrared astronomical satellite “AKARI”

- ✓ The second Japanese space mission for infrared astronomy.
- ✓ Launched on Feb. 21, 2006.
  (Mission completed in Nov. 24, 2011)
- ✓ Instruments:
  The Far-Infrared Surveyor (FIS).
  The Infrared Camera (IRC).



☐Our observation

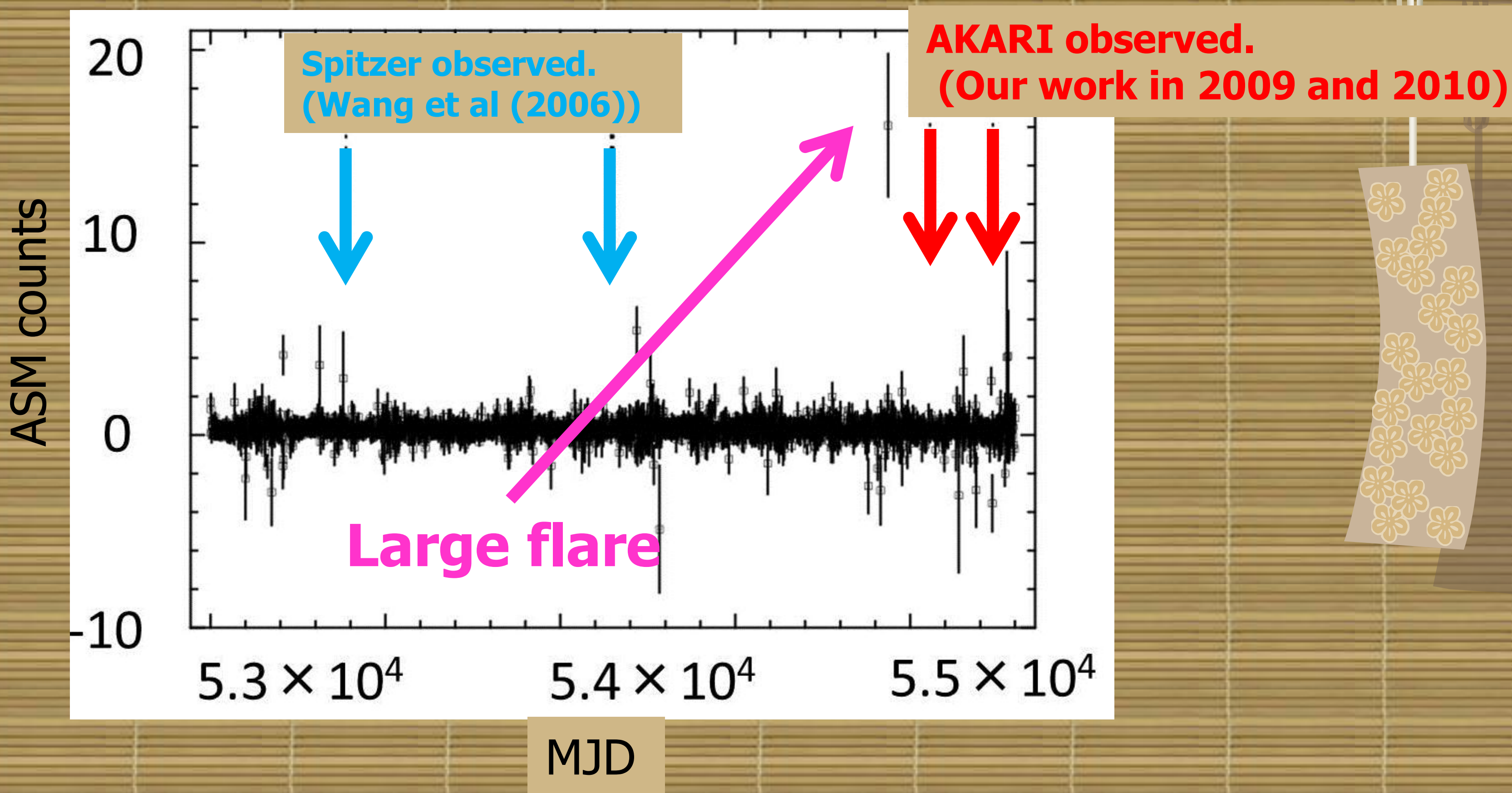
- ✓ We carried out imaging observations of 4U 0142+61 in the 2.43, 3.16 and 4.14μm bands by AKARI/IRC.

Date	Band [μm]	Exposure time [s]
2009/8/14	2.43	488.558
	3.16	888.288

- ✓ **3.16μm：First observation.**
  This band is difficult to be observed by Spitzer or terrestrial telescopes.
- ✓ 2.43μm： near K band, well observed with terrestrial telescopes.
- ✓ 4.14μm：Observed with Spitzer telescope. (Wang et al. (2006))

Observation detail

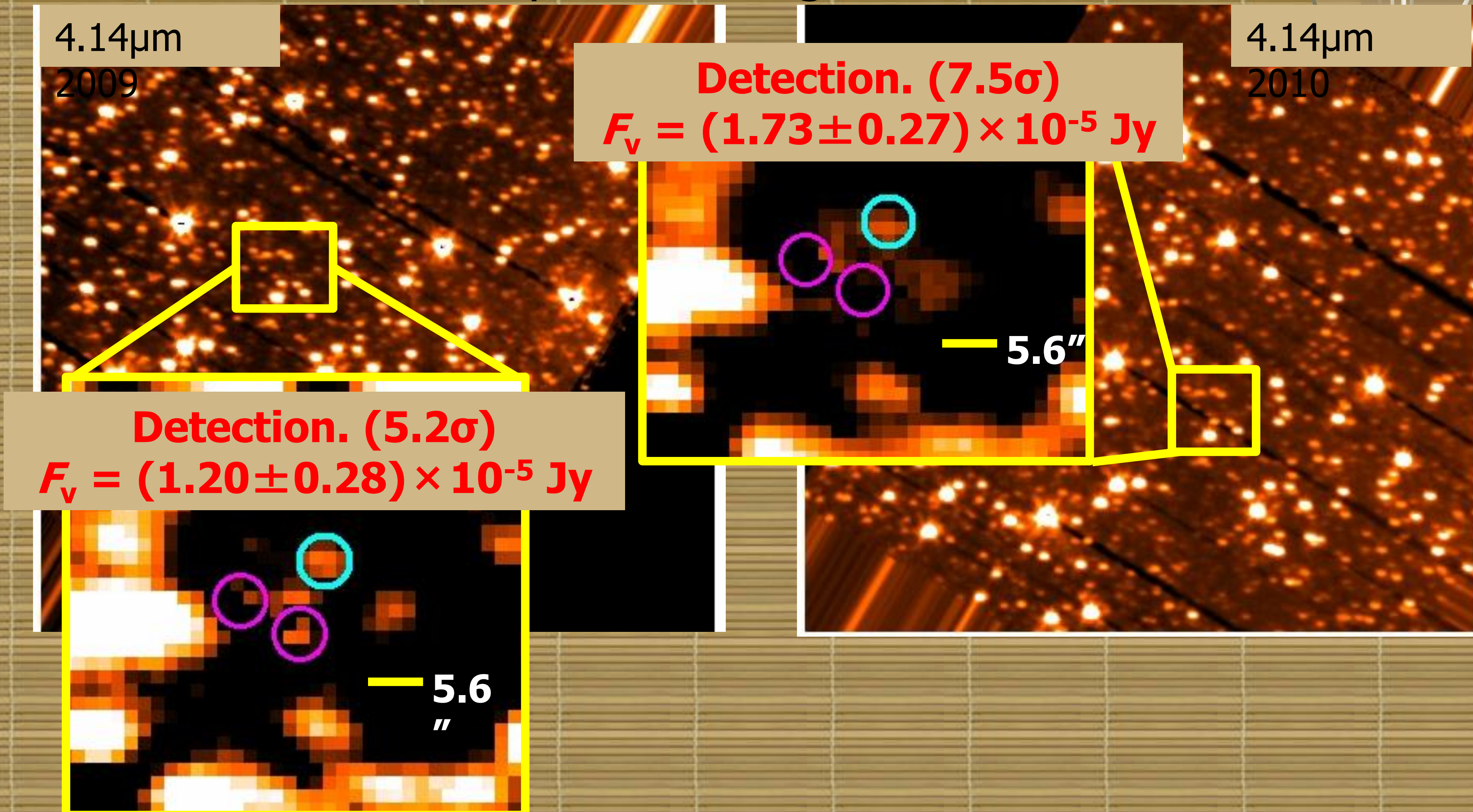
- X-ray light curve of 4U 0142+61



Before observation of AKARI, large flare occurred on 4U 0142+61.

Results

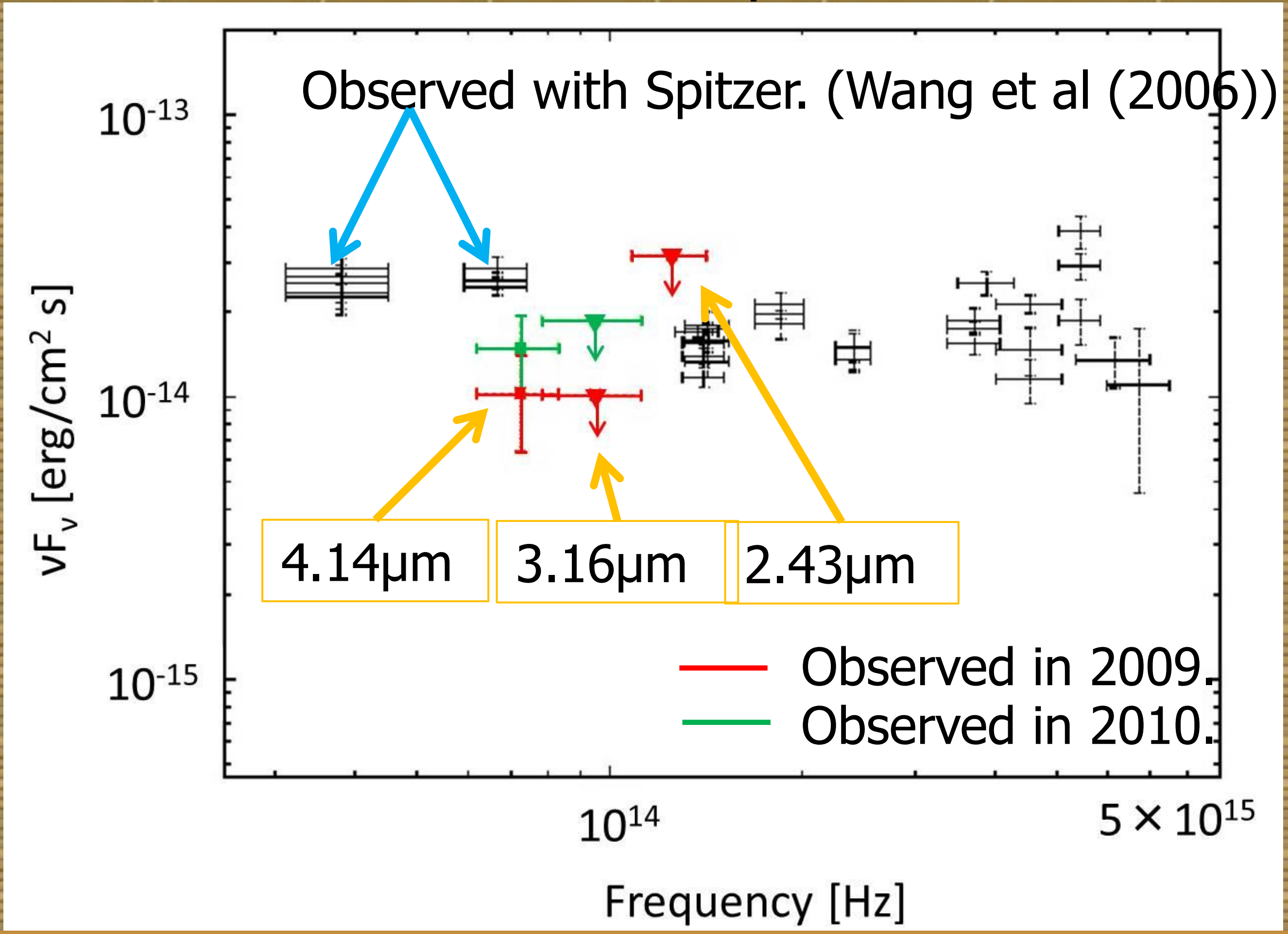
- Observation of 4.14μm wavelength in 2009 and 2010.



We detected 4U 0142+61 in 4.14μm band, significantly.

5. Results

- Spectrum of 4U 0142+61: the previous data and our results



The flux in 4.14μm was reduced to be 64% of the previous flux obtained by Spitzer observation. (6.4σ)

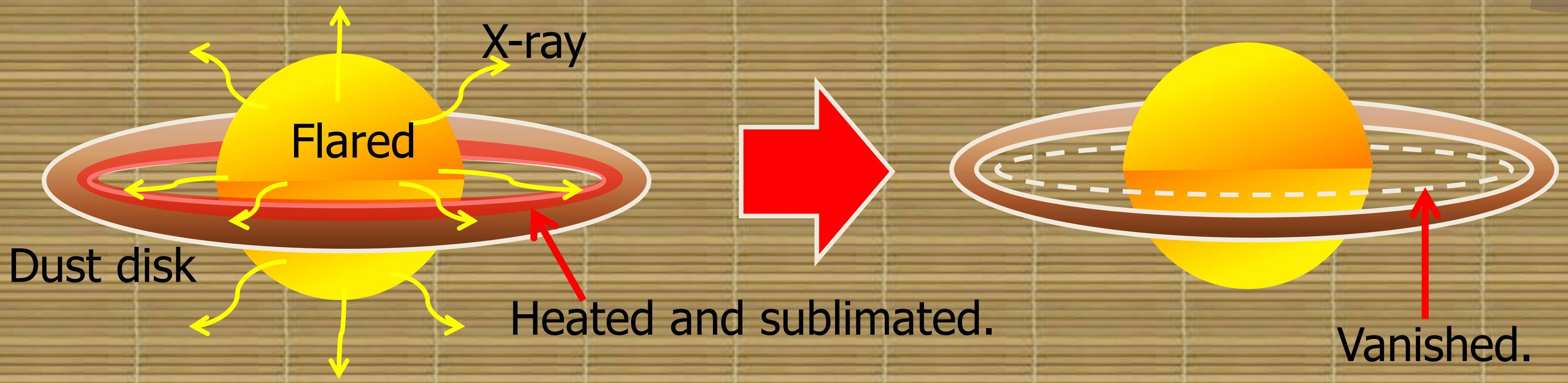
Our result suggests that MIR emission from Magnetar is variable.

Discussion

☐ Why did the infrared flux reduce?

- ✓ Before observations of AKARI, large flare occurred on 4U 0142+61.
- ✓ Assuming that "dust disk model" as infrared emission mechanism, dust disk was heated and sublimated by the flare. Therefore, we think that the inner radius of dust disk increased and infrared flux reduced.

We checked whether the infrared flux reduction can be explained by the increase of inner radius of the disk.



Discussion

Dust disk model

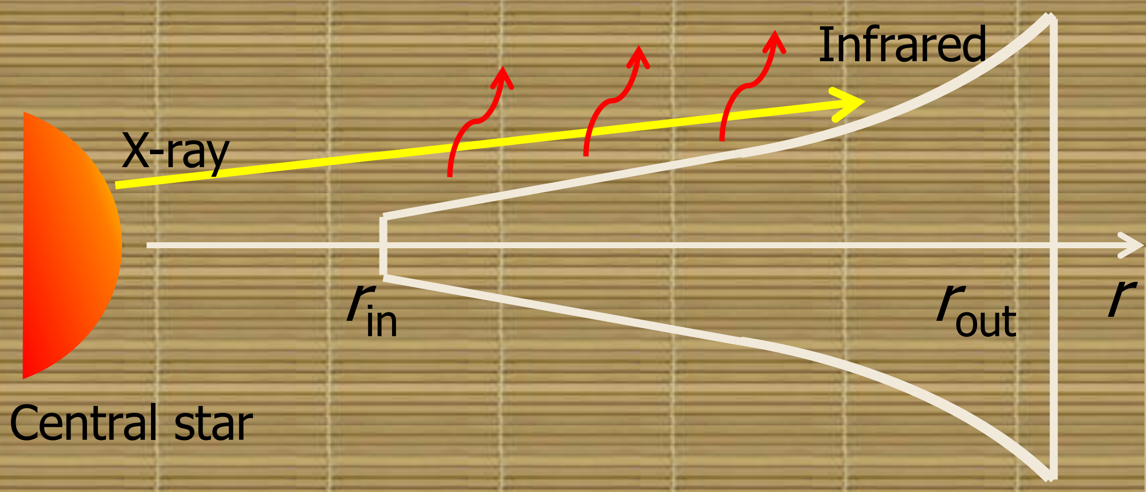
$$F_\nu(r) = \frac{2\pi \cos i}{d^2}\int_{r_{in}}^{r_{out}} B_\nu(r) r dr \qquad \left(B_\nu(r) = \frac{2h}{c^2}\frac{\nu^3}{\exp(h\nu/kT(r)) - 1} \text{ : Blackbody} \right)$$

$$T(r) = 5030[\mathrm{K}]\,(1-\eta_d)^{\frac{2}{7}}\left(\frac{d}{3.9kpc}\right)^{\frac{4}{7}}\left(\frac{r}{R_\odot}\right)^{-\frac{3}{7}}$$

(Wang et al. (2006))

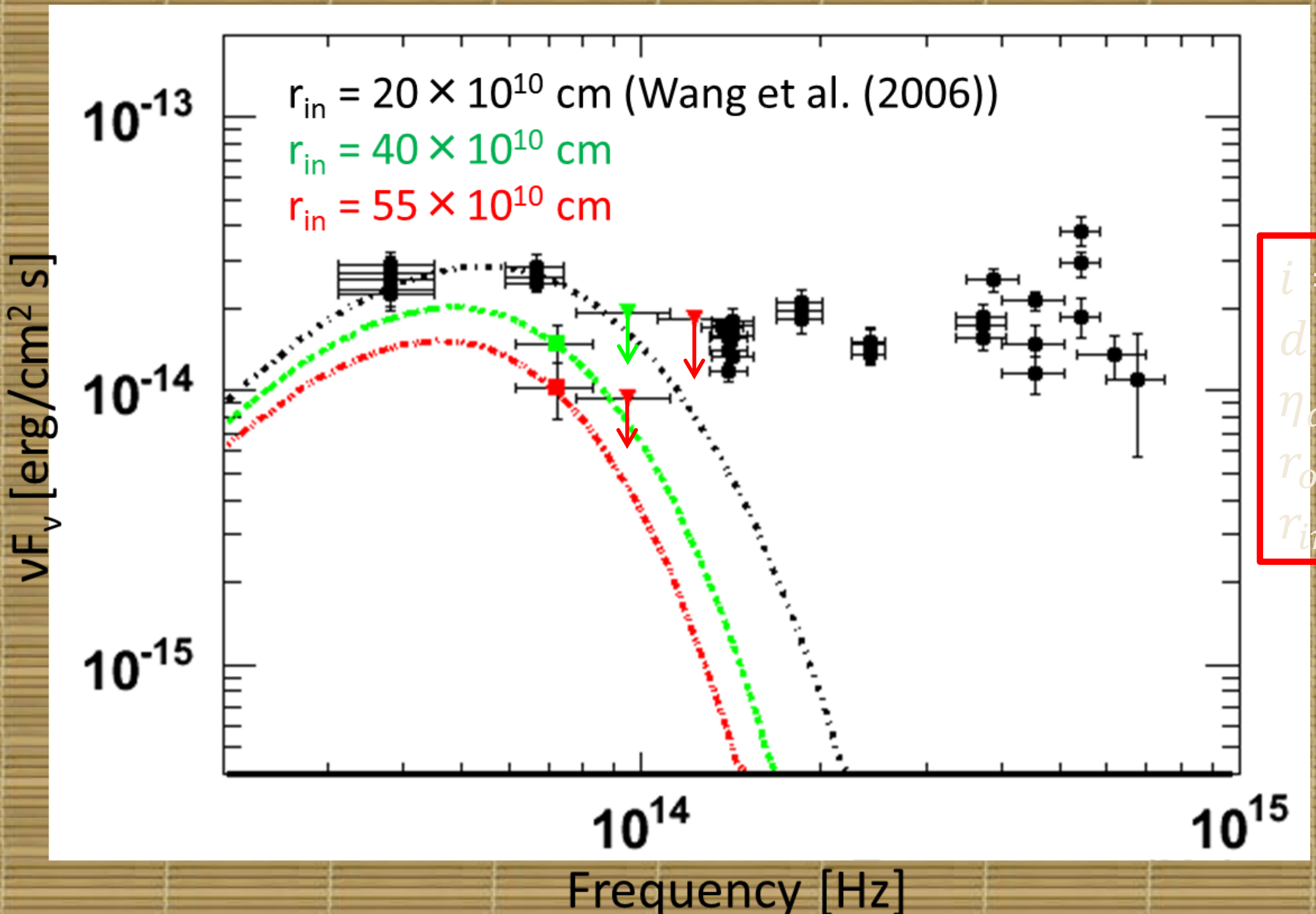
i: disk inclination angle, d: distance, η_d: X-ray albedo
r_{in}: disk inner radius, r_{out}: disk outer radius

Disk inner radius increases and infrared flux from dust disk reduces.



<u>We changed a value of disk inner radius and described the flux reduction as spectrum.</u>

Discussion



$i = 60$ deg
$d = 1.20 \times 10^{22}$ cm
$\eta_d = 0.975$
$r_{out} = 120 \times 10^{10}$ cm
r_{in} : Changed.

Summary

- Infrared Emission mechanism of magnetars are still open question.
- "Disk model " OR "Magnetospheric model"
- Spectrum of 4U 0142+61 is consisting of 2 components: "IR" excess component & "Optical" pulsating component.
- We searched for pulsation in near-infrared region.
- We obtained an upper limit of the pulse fraction: 17 % (90% C.L.) in K' band.

- ✓ We observed AXP 4U 0142+61 in the 2-4μm bands with "AKARI". **3μm band is first observation.**
- ✓ Detection in 4μm band. Upper limit for 2μm and 3μm bands.
- ✓ The flux of 4.14μm (in 2009) reduced to be 64% of that observed with Spitzer (in 2006).
- ✓ Infrared emission in 4 μm (dust disk dominant) is also variable.
- ✓ Our scenario: Magnetar flare → heating the dust disk → sublimation of the dust → vanishing inner disk region → reduced flux in MIR.
- ✓ We checked the spectrum according to this scenario. It is OK.
- ✓ **The infrared flux reduction can be explained by the increase of inner radius of the dust disk.**