Magneto hydrodynamic Phenomena in Galaxies, Accretion Disks and Star Forming Regions
銀河･降着円盤･星形成領域における磁気流体現象ワークショップ
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Spatially Resolved Radio QPO in SgrA*

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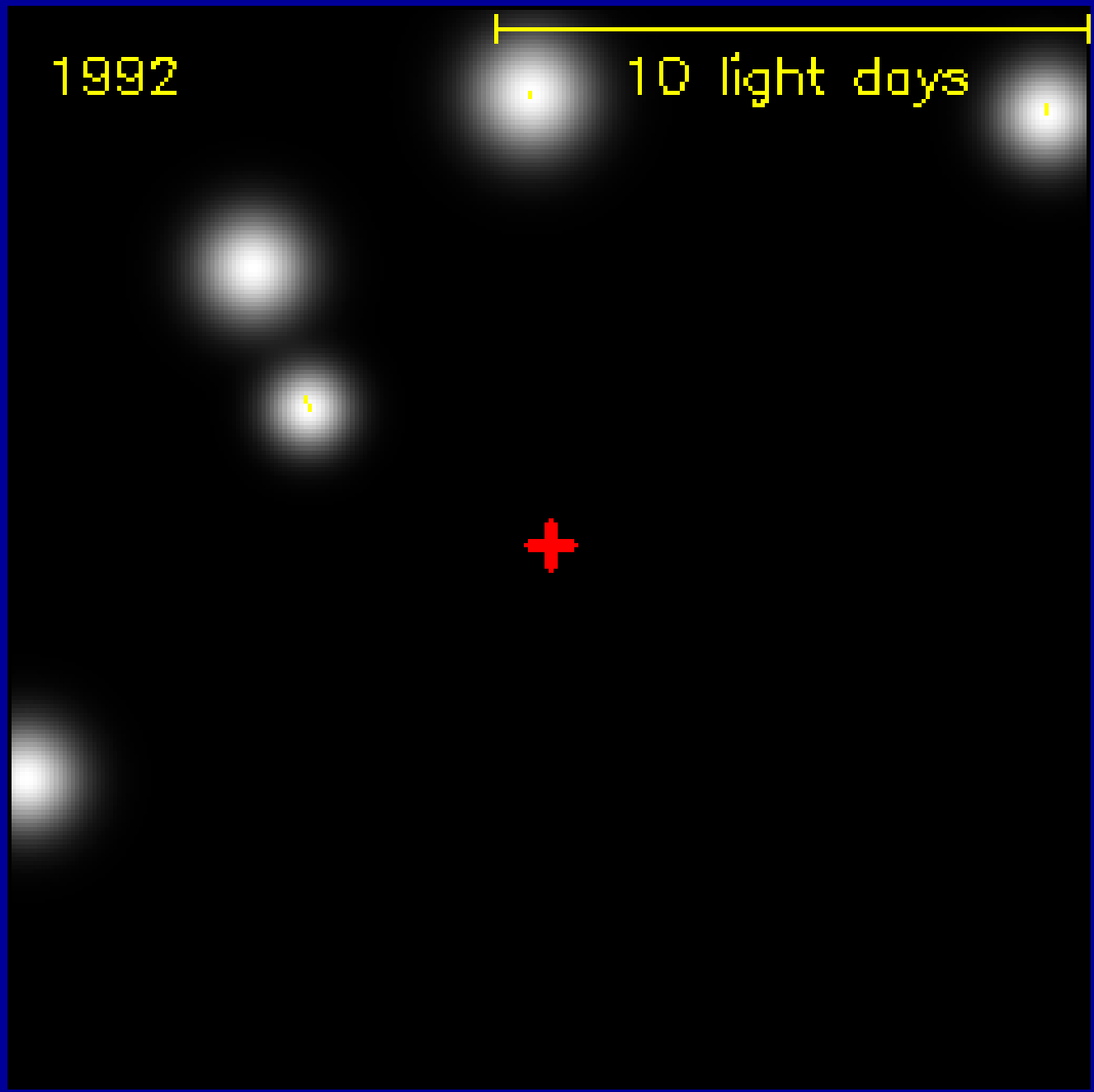
NAOJ

SgrA* is now the most convincing super massive black hole in the universe (Shen et al.05).

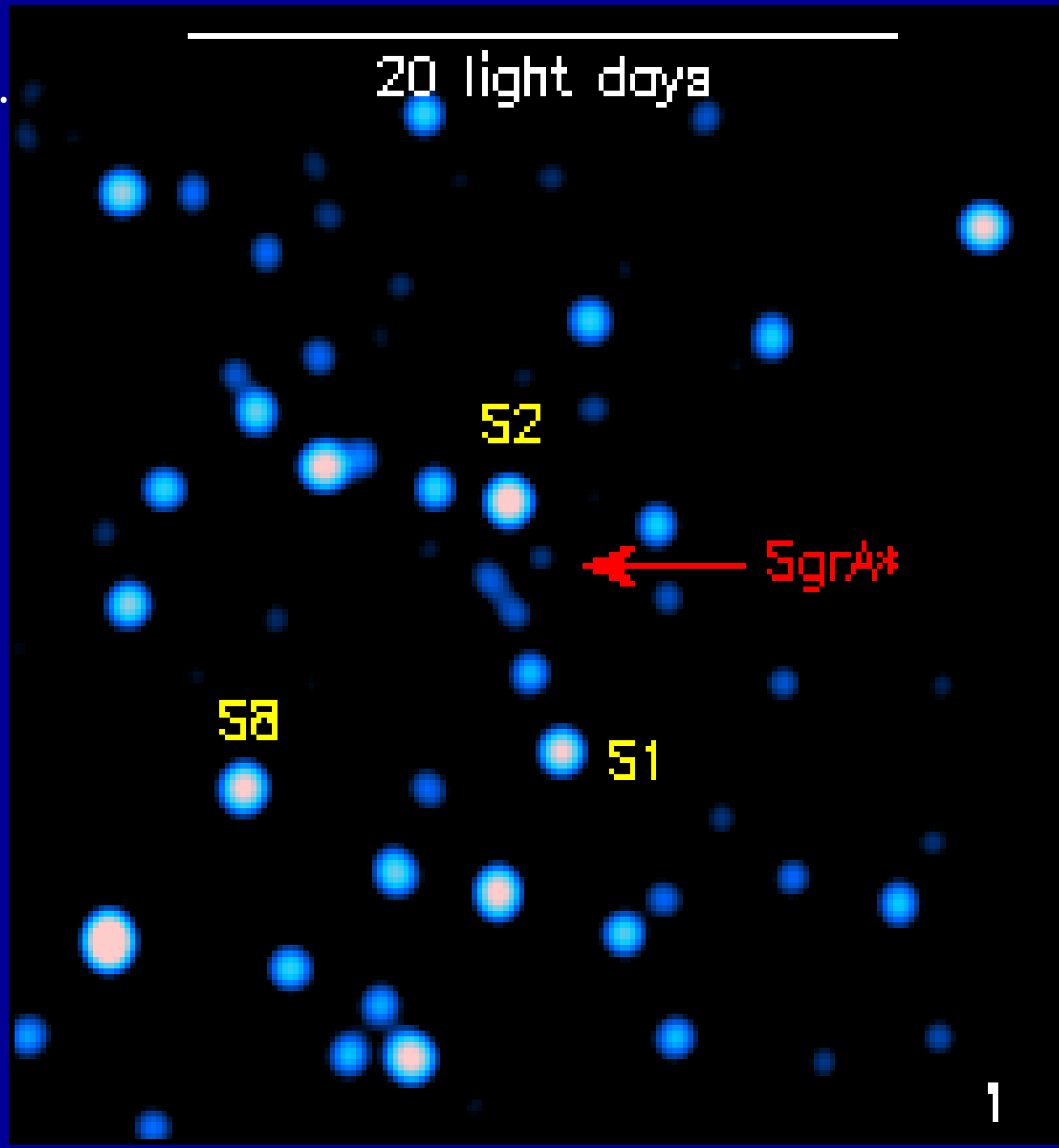
The mass $\sim 4*10^6$ Msun
The 1Rs $\sim$ 9.8 μas

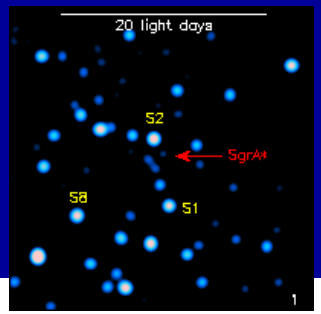
QPO P=16.8min is detected at IR and Xray at its short time flaring(IDV).

Motions of Stars around SgrA*
(Genzel et al03)



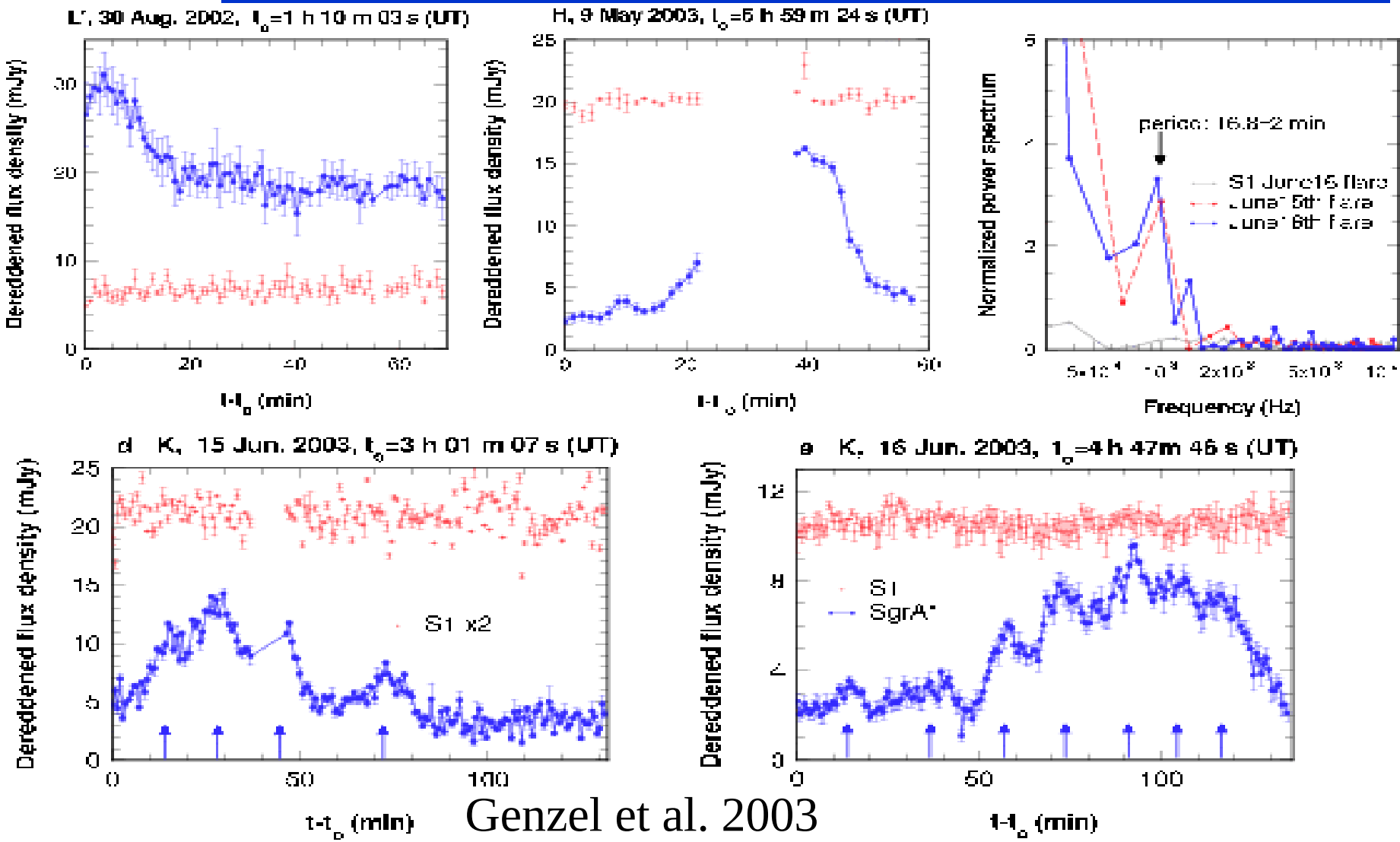
Detection of IR flaring.
(Genzel et al. 03)





Periodicity was also found from NIR flaring of SgrA*

P=16.8±2.0 min.(1008±120 sec.)



Genzel et al. 2003

QPO at X ray too.

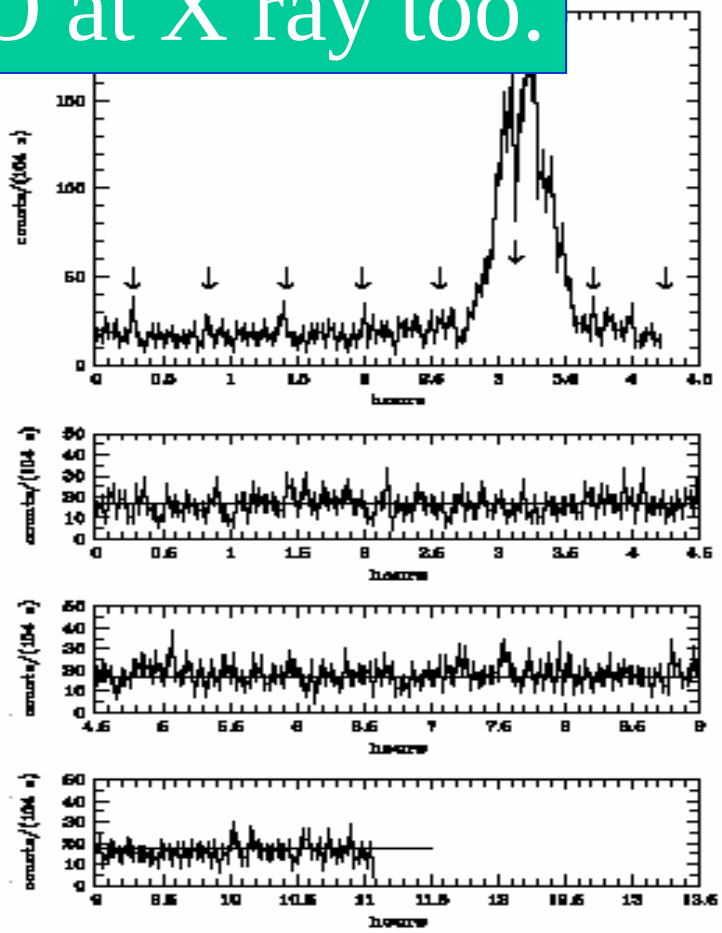


Fig. 1. EPIC light curves (MOS 1+MOS 2+PN) of the *XMM-Newton* observation of October 3, 2002 (*upper panel*, Fig. 1a) and the February 26, 2002 observation (*lower three panels*, Fig. 1b). Error bars indicate 1σ uncertainties. The horizontal line in the lower three panels corresponds to the mean count rate level. Arrows mark peaks associated with a 2178 s periodic signal.

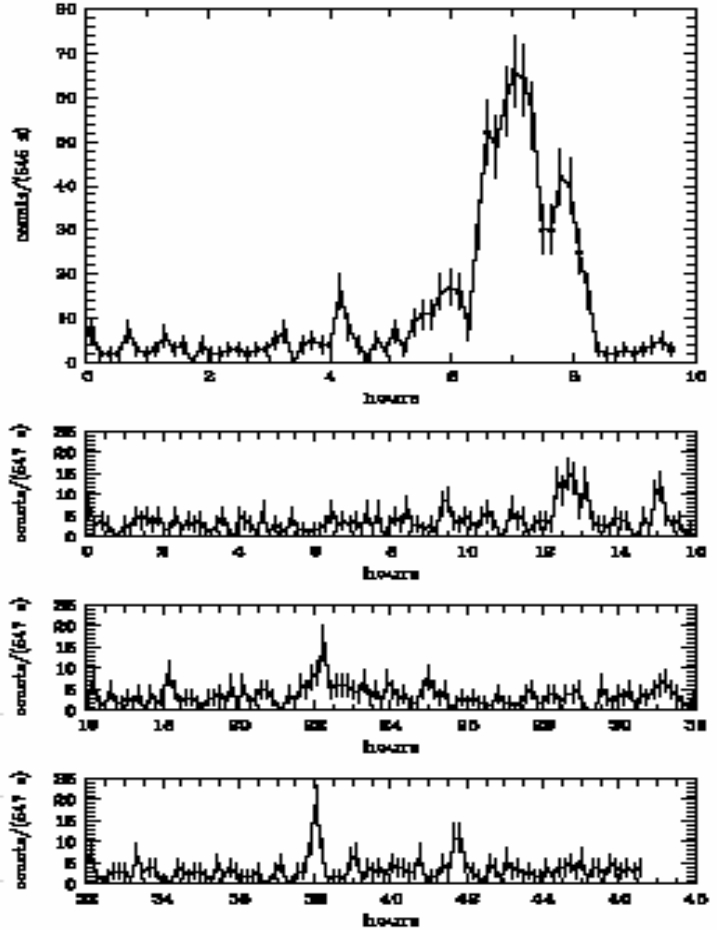
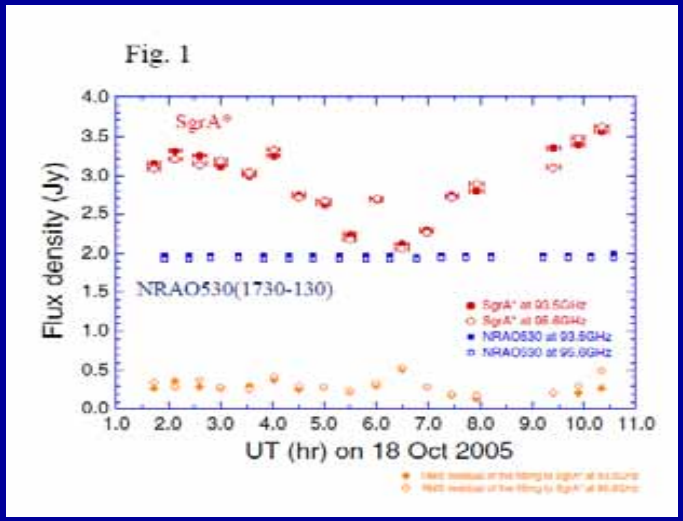


Fig. 2. ACIS-I light curves of the *Chandra* observation of October 26, 2000 (*upper panel*, Fig. 2a) and the May 25, 2002 observation (*lower three panels*, Fig. 2b). Error bars indicate 1σ uncertainties.

Periodicity is also found from X ray flare. P~100 s, 219 s, 700 s, **1150** s, and 2250 s (analysis by Aschenbach et al 2004)



New detection of SgrA* flaring (IDV) by Miyazaki in this October using the AT.

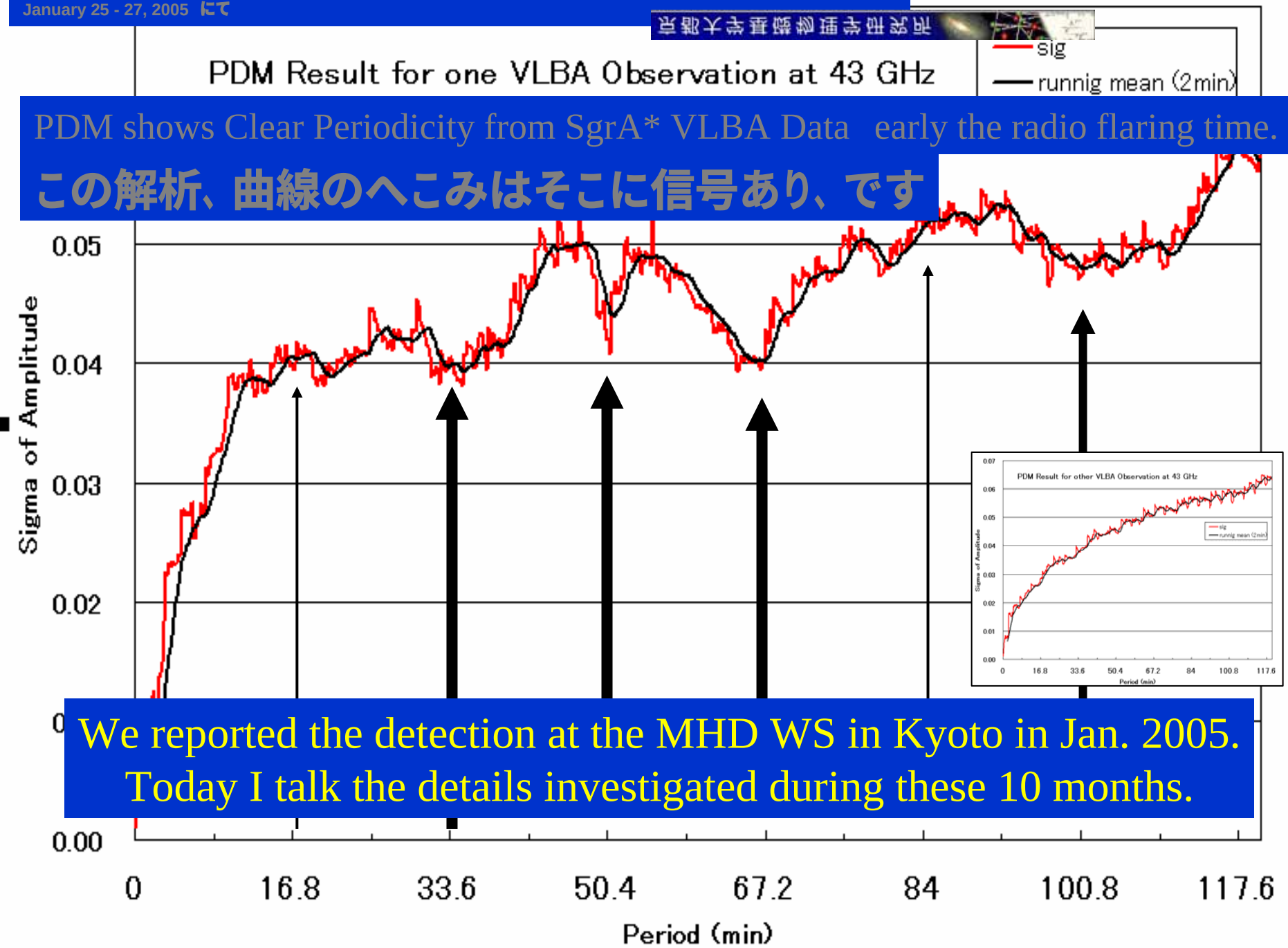
- At millimeter wave we have also detected short time flaring (ex. Miyazaki et al.04), we can expect to detect similar kinds of QPO in radio too!

- Following the idea we have been checking the data of SgrA* obtained VLBA since the end of 2001.
- We detected the spatially resolved QPO from the VLBA data taken at 8th March 2004 at 43GHz.

(1.5 days after the millimeter wave short time flare.)

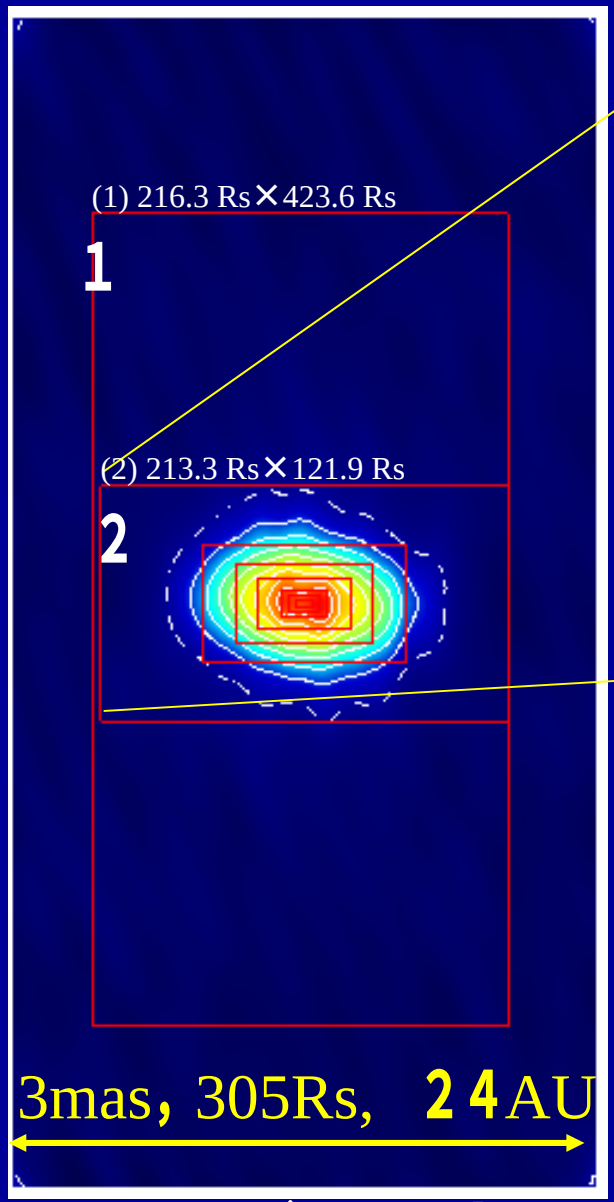
PDM shows Clear Periodicity from SgrA* VLBA Data early the radio flaring time.

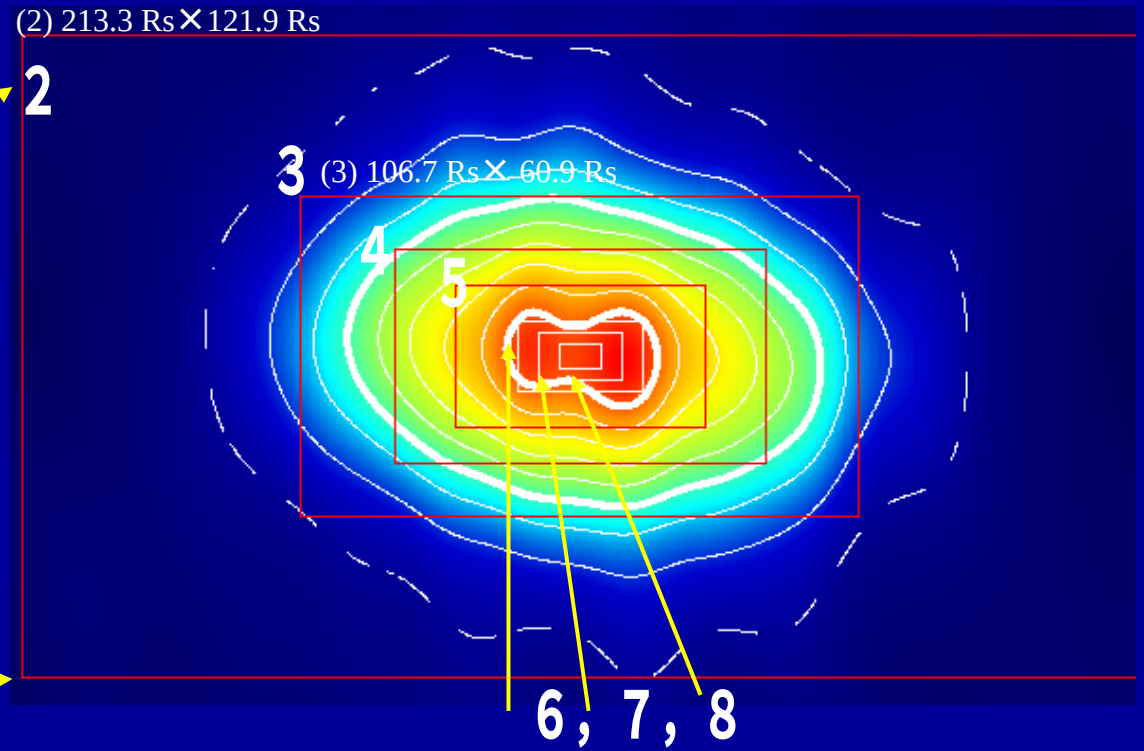
この解析、曲線のへこみはそこに信号あり、です



We reported the detection at the MHD WS in Kyoto in Jan. 2005.
Today I talk the details investigated during these 10 months.

VLBI gives us high spatial resolution(～0.1mas) .
So we can investigate the differences of QPOs between small regions in the SgrA* image.
First, we check whether the QPOs are concentrated at the center or ubiquitous around the whole disk?

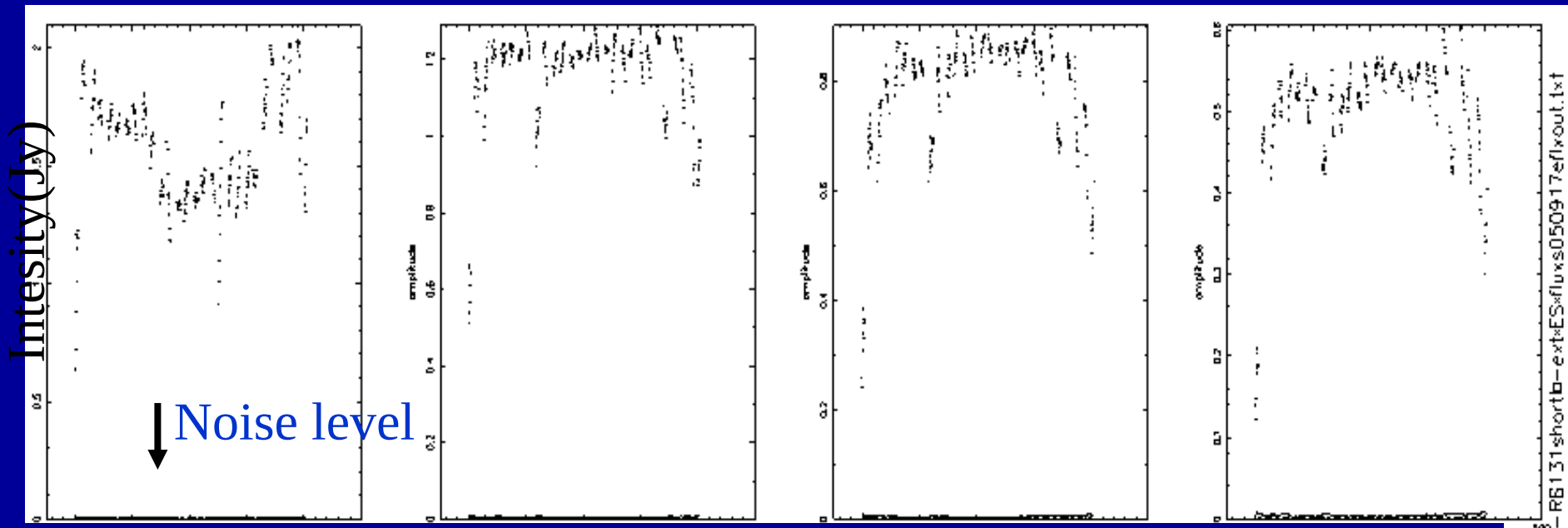




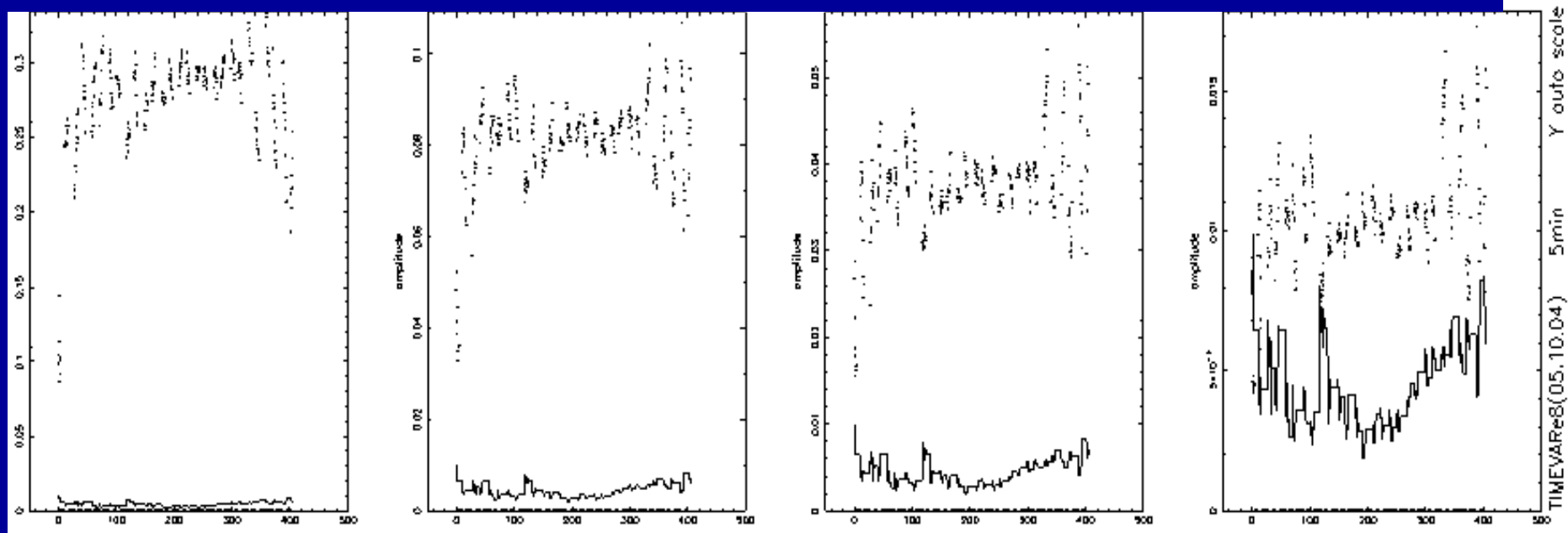
(1) 216.3 Rs×423.6 Rs
(2) 213.3 Rs×121.9 Rs
(3) 106.7 Rs× 60.9 Rs
(4)　71.3 Rs× 40.8 Rs
(5)　47.5 Rs× 26.8 Rs
(6)　23.8 Rs× 13.4 Rs
(7)　15.8 Rs×　9.0 Rs
(8)　7.9 Rs ×　4.5 Rs

assumption；D_{GC}=8kpc,$M_{SgrA*}=4.0\times10^{6}M_{\odot}$

(1) 216.3 Rs×423.6 Rs (2) 213.3 Rs×121.9 Rs (3) 106.7 Rs×60.9 Rs (4) 71.3 Rs×40.8 Rs



(5) 47.5 Rs× 26.8 Rs (6) 23.8 Rs× 13.4 Rs (7) 15.8 Rs× 9.0 Rs (8) 7.9 Rs × 4.5 Rs



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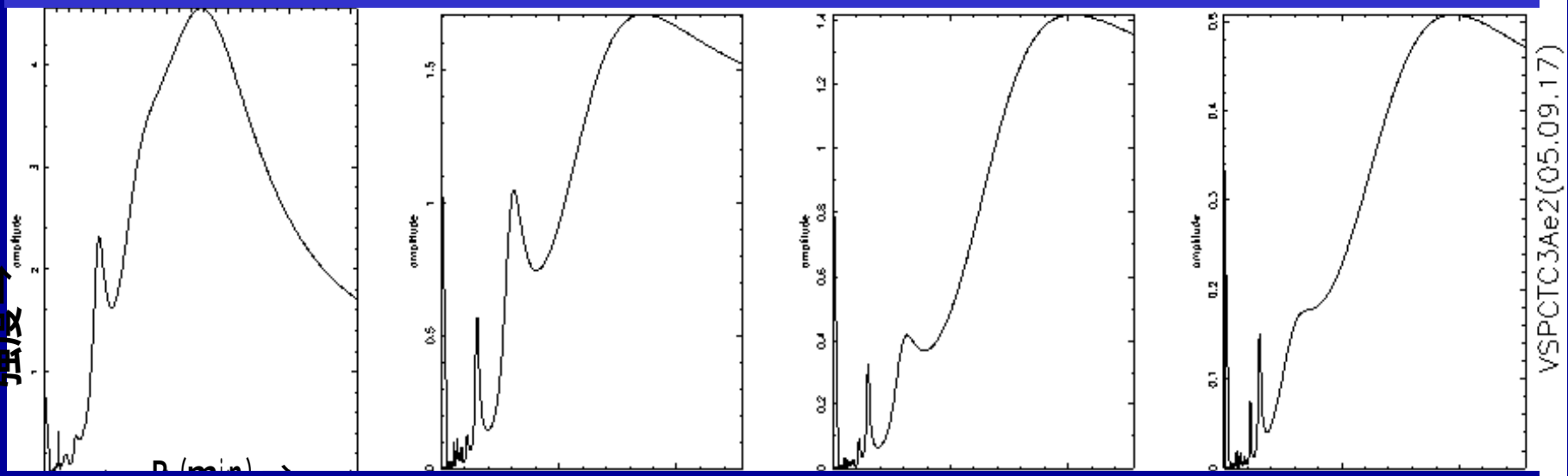

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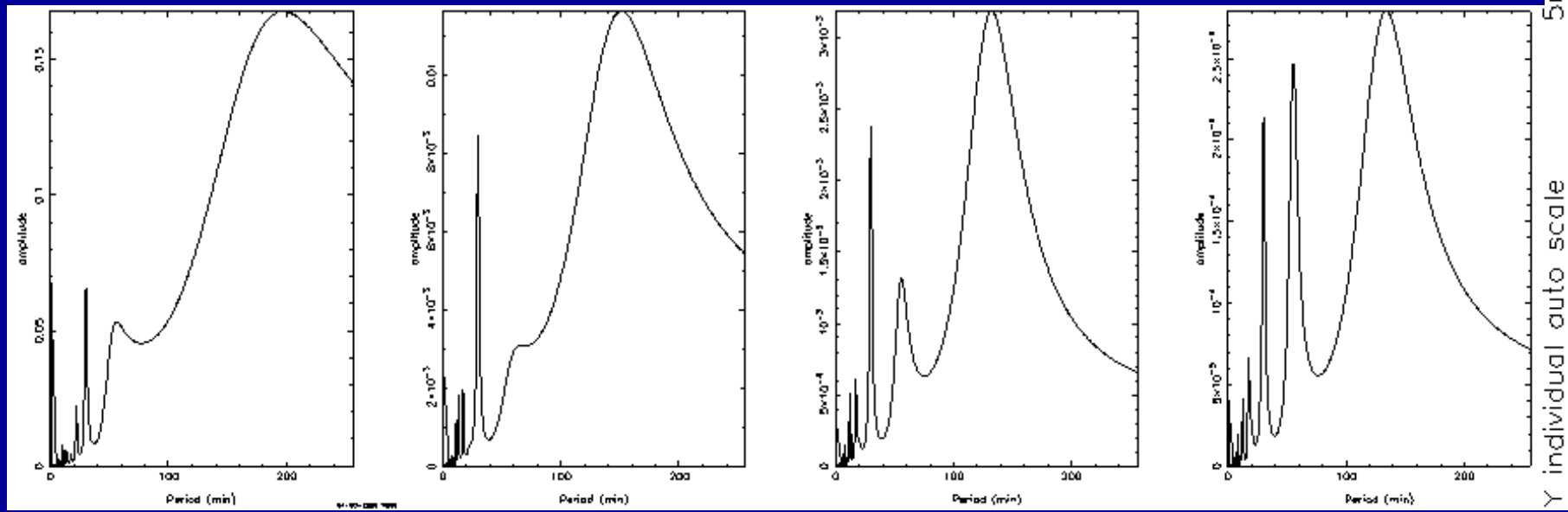
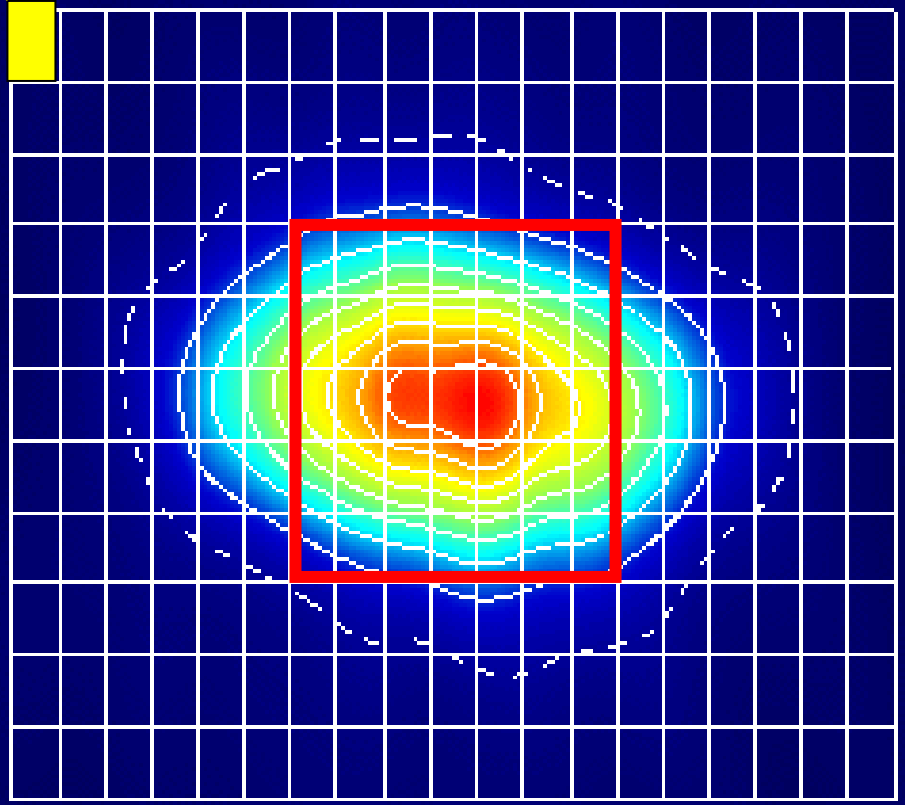


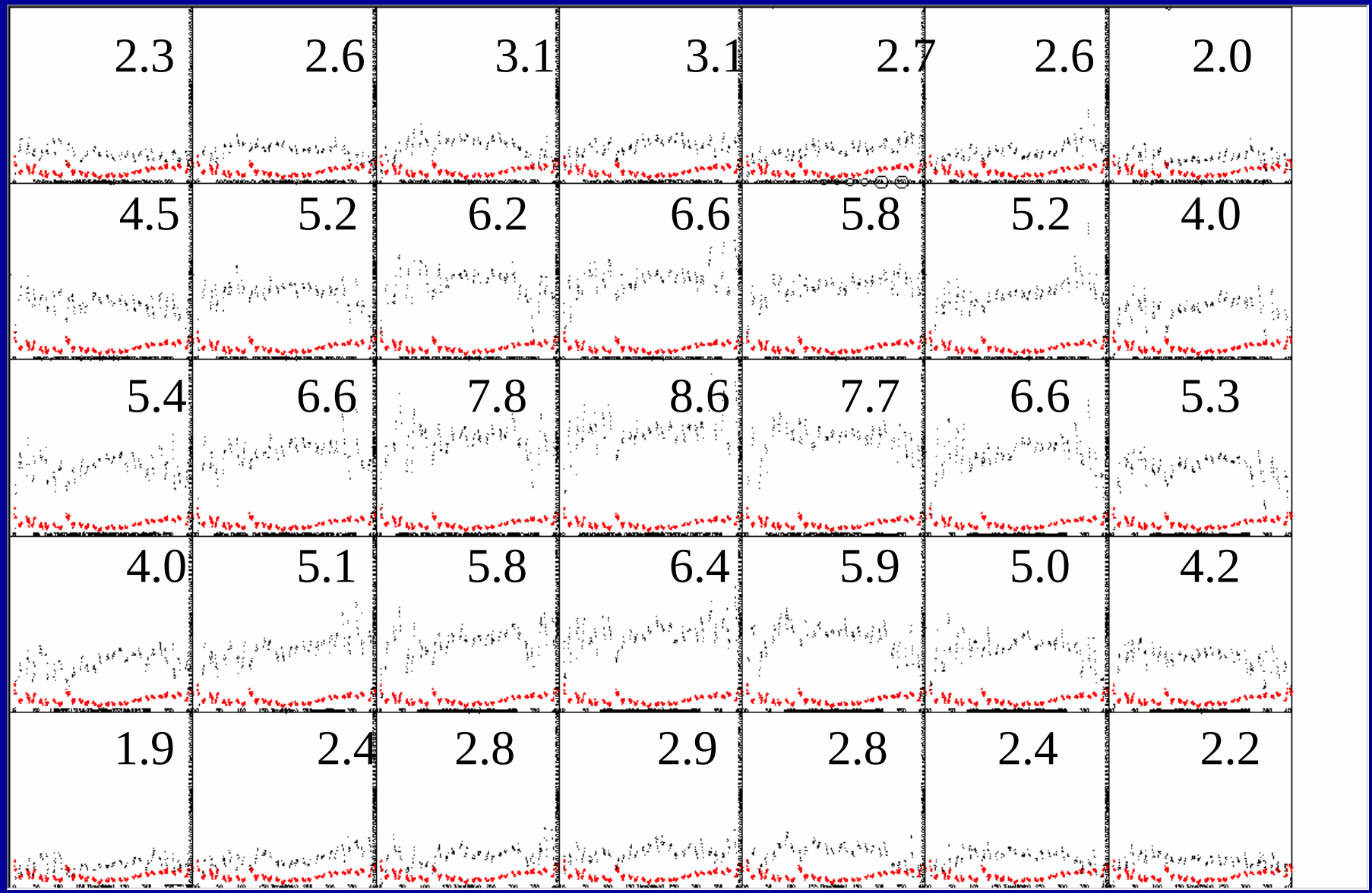
QPO spectra become very spiky as the region limited to the center.

横0.1mas（10Rs)縦0.15mas（15Rs)のグリッド

３５（＝７×５）grids at the center

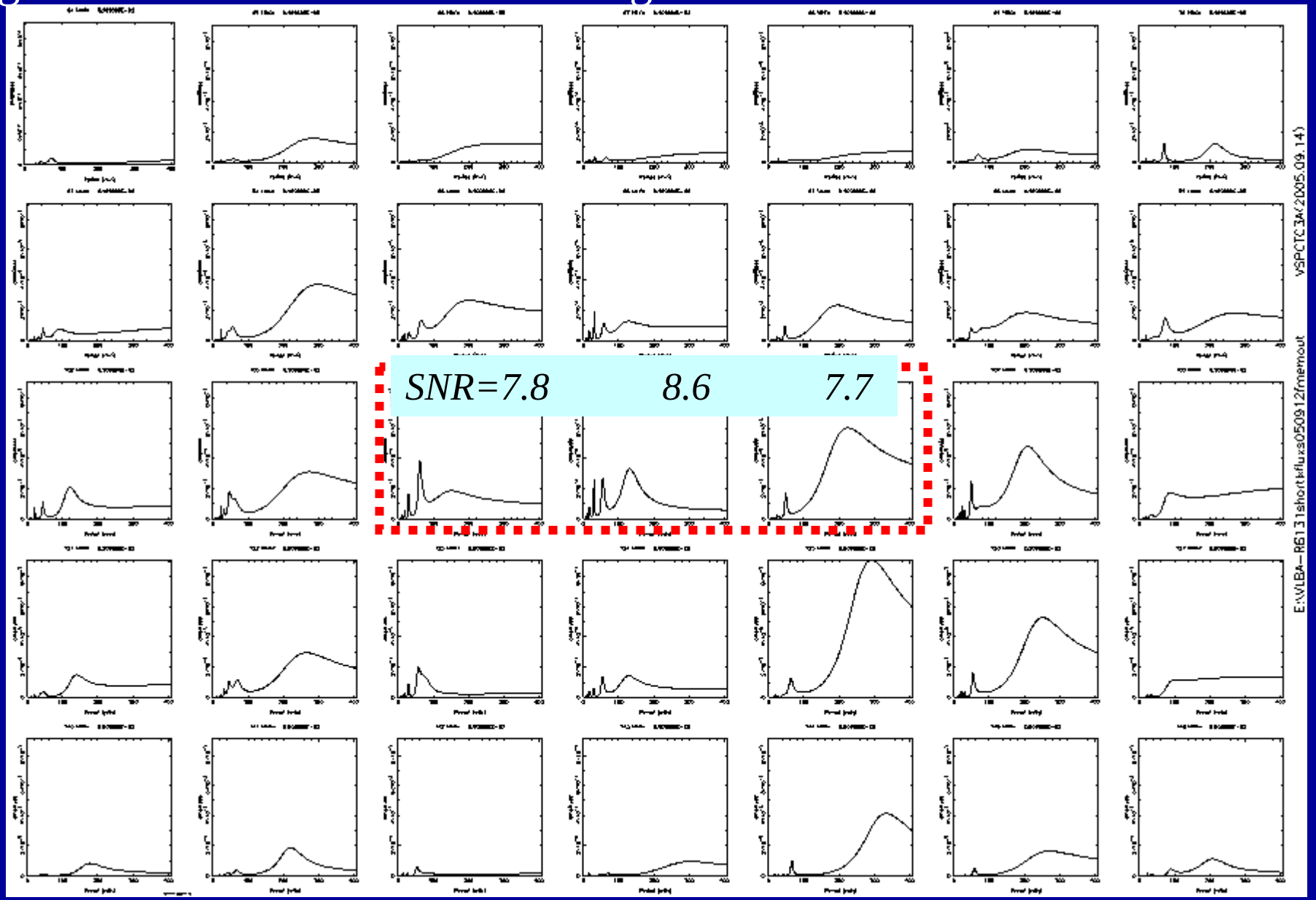


Then we check the spatial distributions of the QPOS.

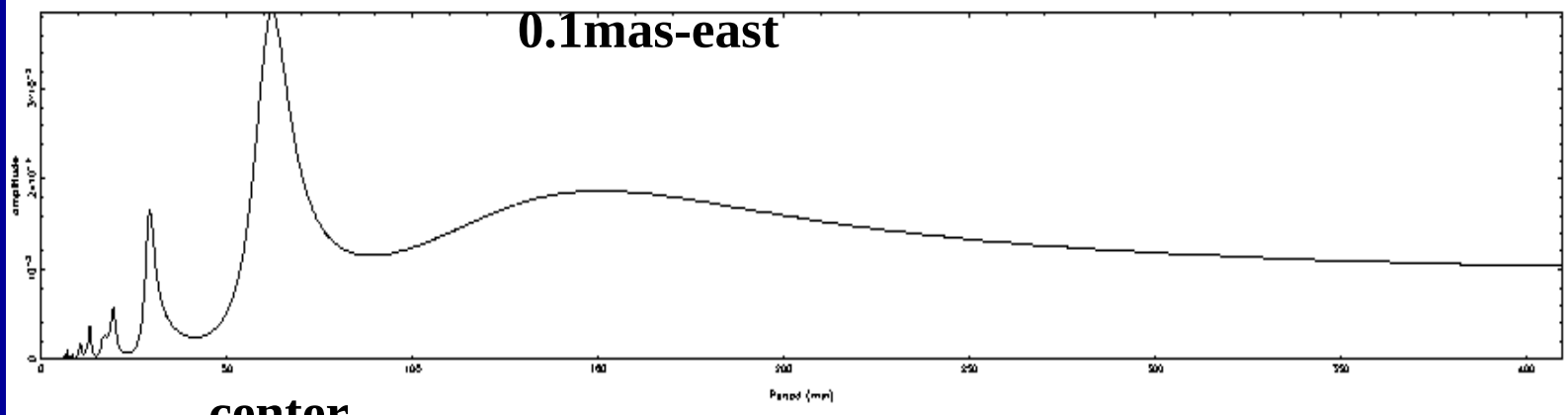


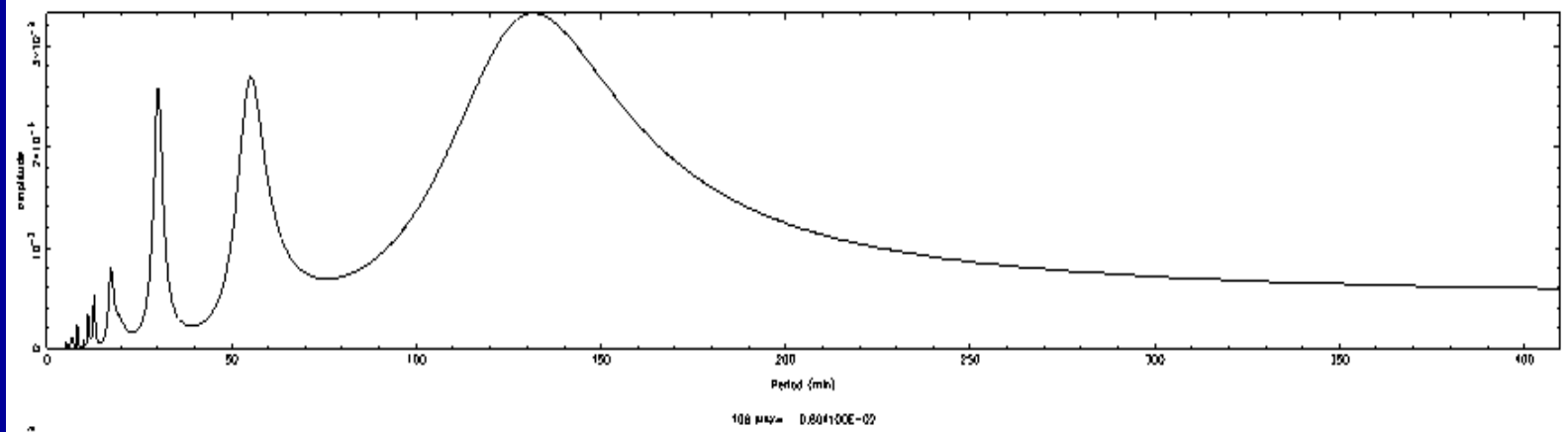
Time variations of intensity in the grids (The denoted numbers are SNRs)

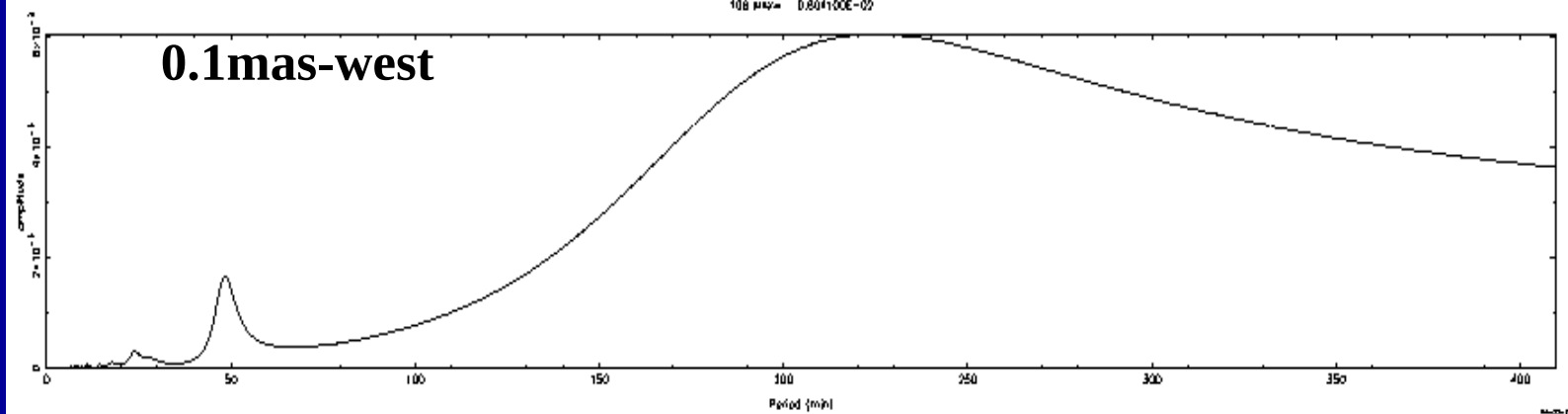
Every grids show something. Here we look carefully at the central 3 grids because those of SNR are higher than 7.



P=17; common all around the disk(?), come from outer edge of disk?
The strongest peak; large difference in periods.





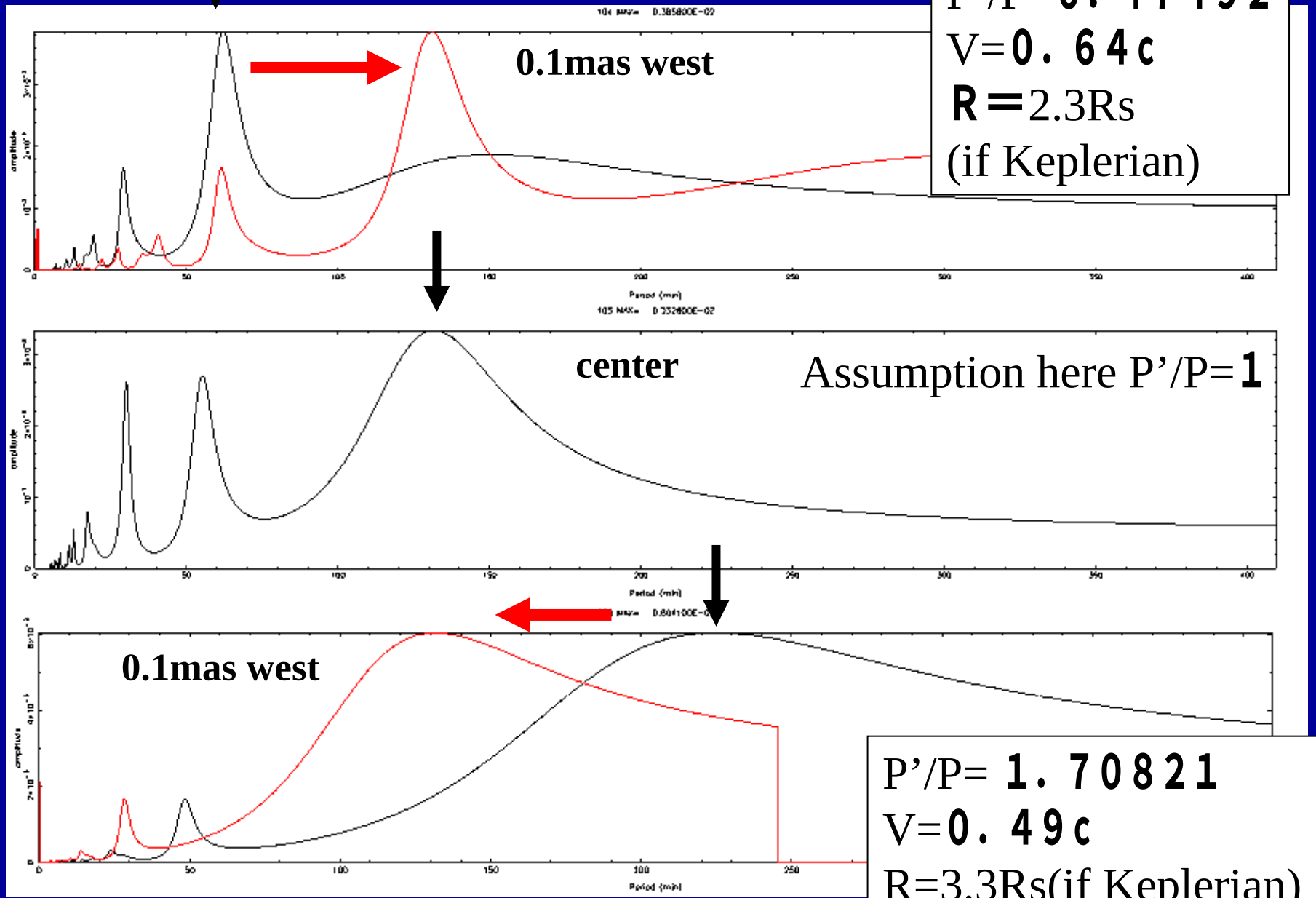


62.2
29.3
19.4
17.0

131.6
55.3
30.2
17.3
12.8

224.8
48.4
23.8
17.7
14.3

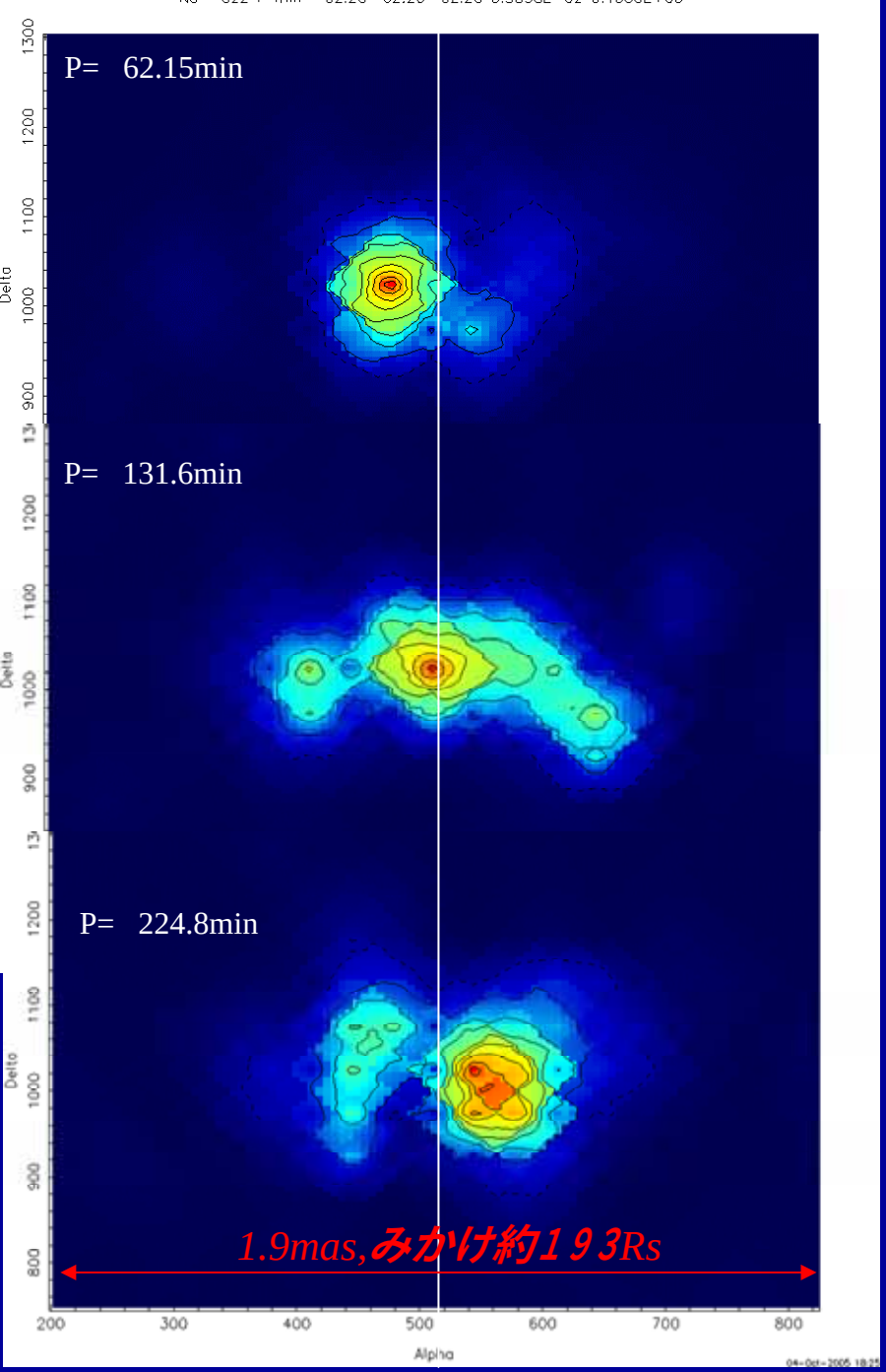
QPO Periods



P'/P=0.47492
V=0.64c
R=2.3Rs
(if Keplerian)

P'/P= 1.70821
V=0.49c
R=3.3Rs(if Keplerian)

黒線が観測された周期スペクトル、赤は伸縮させたもの



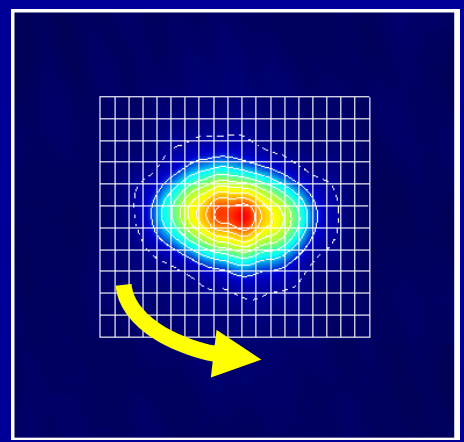
Intensity Maps of the Periods

P= 62.15min(上)

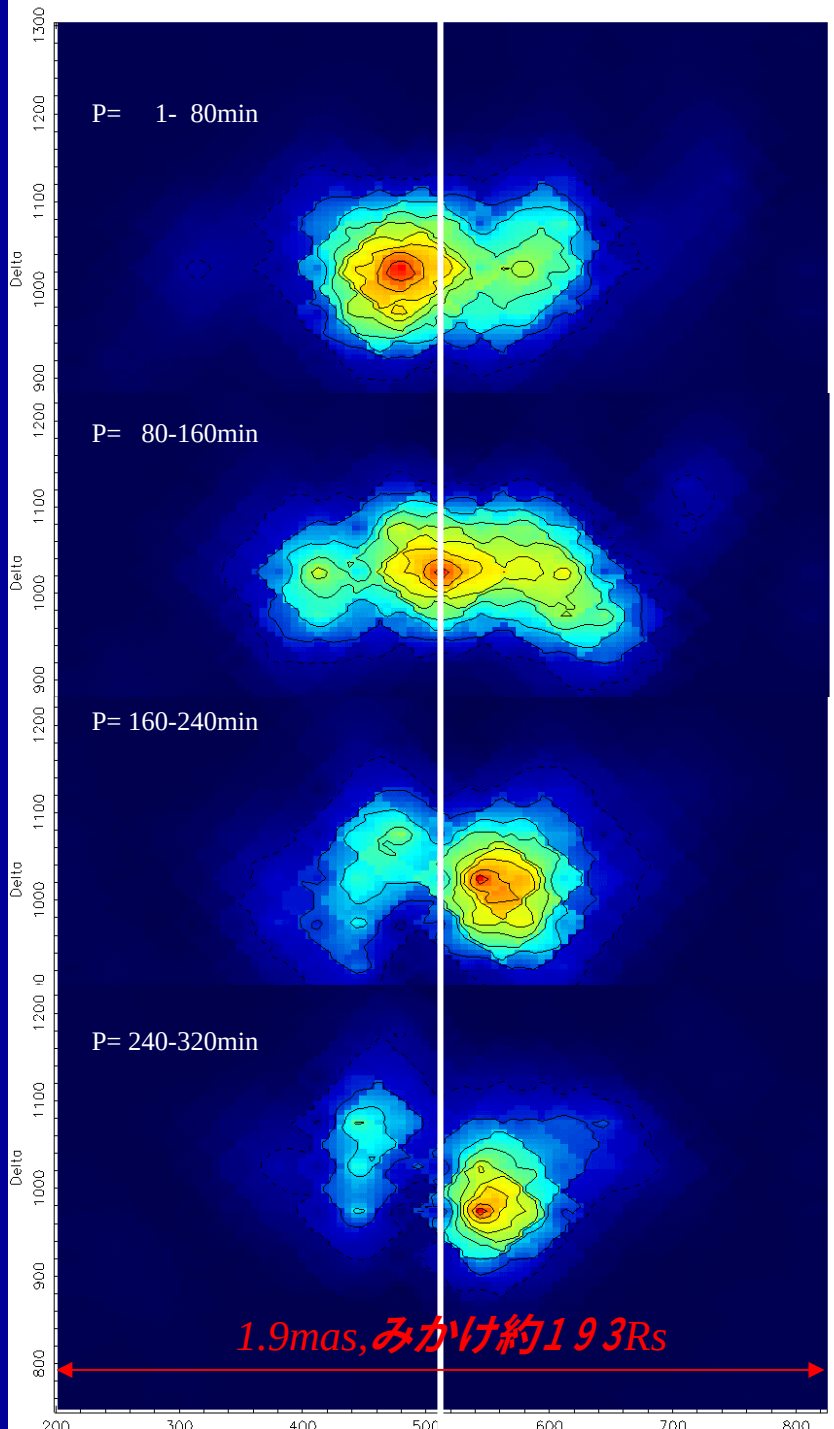
P=131.6min (中)

P=224.8min (下)

The Peak Position Moves Towards west as Periods Become long.



Rotation ?



Intensity Maps of rather wideband periods

(from the top)

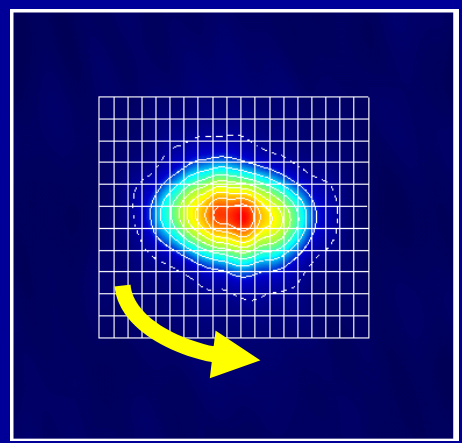
P= 1- 80min

P= 80-160min

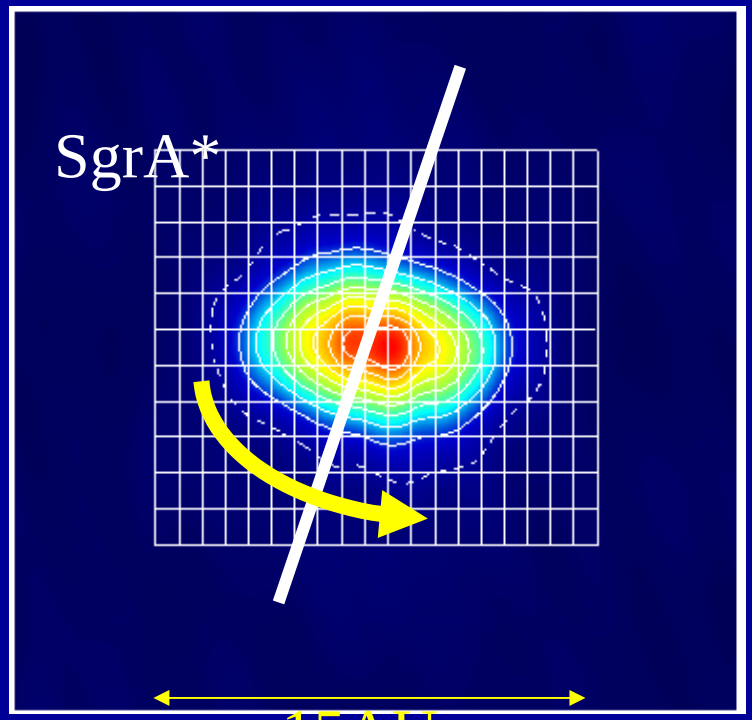
P= 160-240min

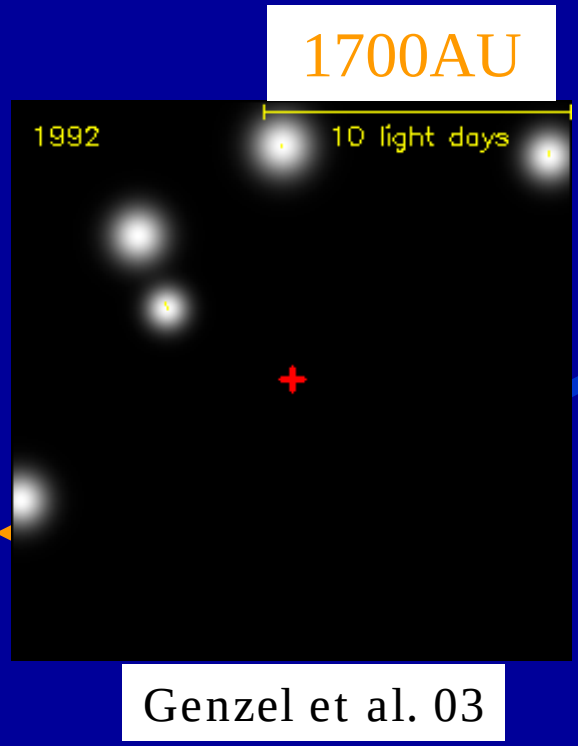
P= 240-320min

The Peak Position Moves Towards west as Periods Become long.

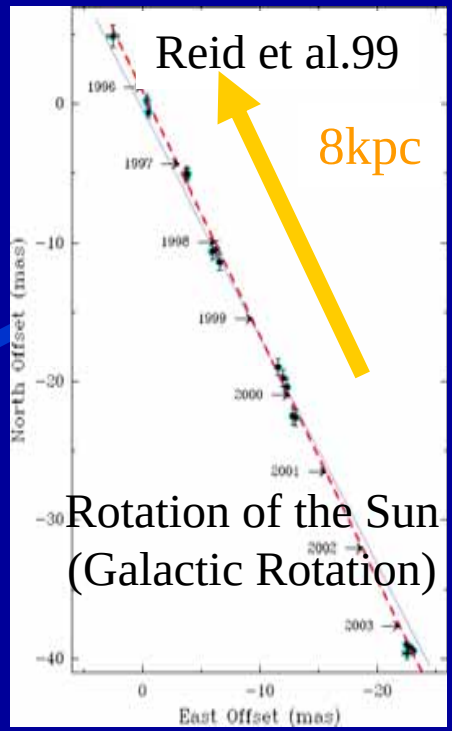


It must be due to Rotation!



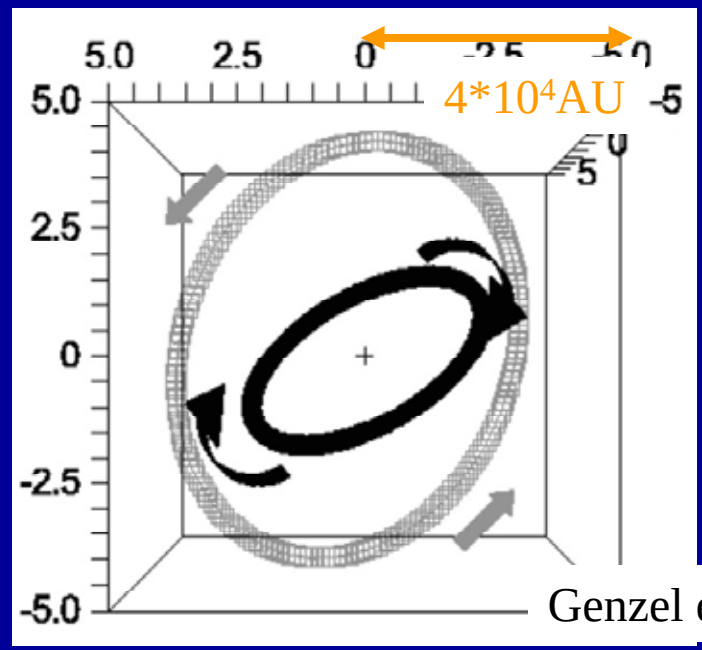


Genzel et al. 03



The Accretion Disk of SgrA*
Shows Counter-Rotation
Against the Galactic Rotation.

The Galactic Rotation
Becomes Random
At GC?!



Genzel et al.03

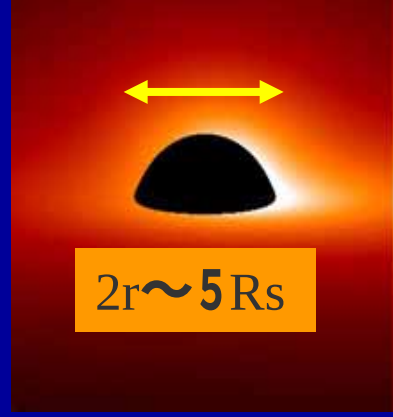
There is one thing to be discussed.
"The scale" seems inconsistent.

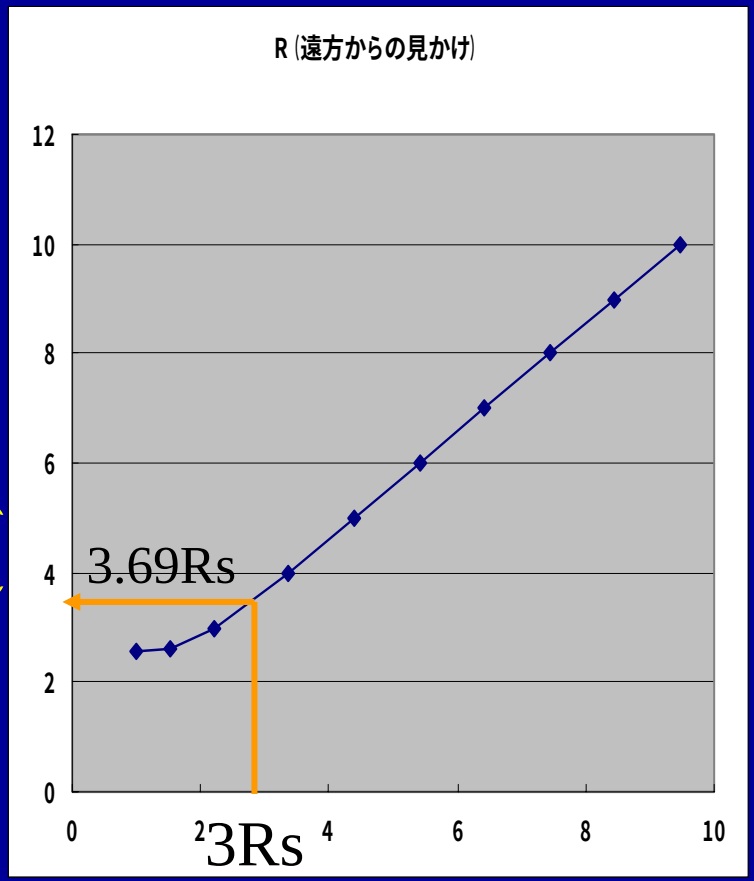
- From the velocity derived from the shift of spectra
  0.1 mas corresponds to ～3Rs （M=1.2 ×$10^7$$M_{sun}$ ！）
- From the distance (8kpc) and the mass of SgrA*(4×$10^6$$M_{sun}$)
  0.1 mas corresponds to ～10Rs

>The derived velocity is wrong?

---- Then check the possible theory to sit them well.
Something to change the scale of 0.1mas 10Rs to 3 Rs.

Self gravitational lensing effect of black hole will play an role of magnifying glass.





- Event horizon (r=1Rs) seems to be at r=2.5Rs from infinite direction.
- How about r～3Rs region? Magnifying ratio ～1.23 --insufficient to explain the scale problem--

Calculation by Takahashi R.

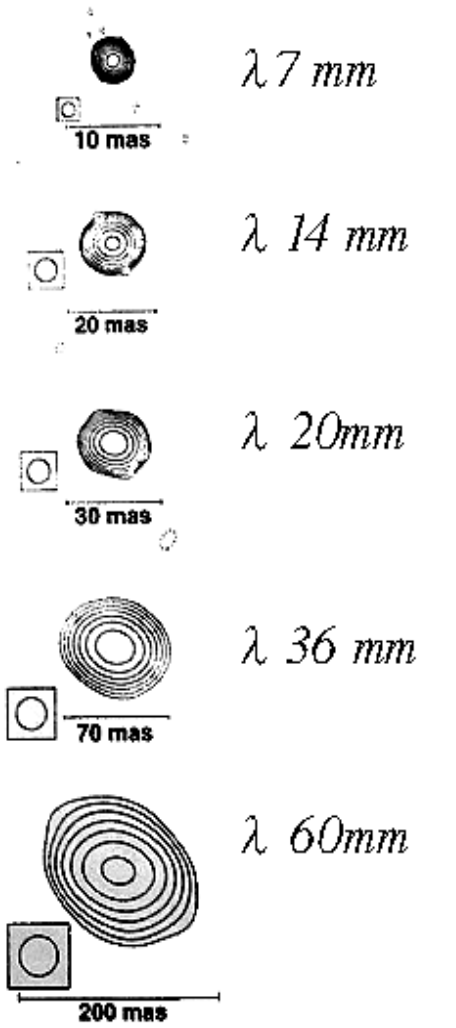


Figure 3. VLBA images of Sgr A* at wavelengths 6.0, 3.6, 2.0, 1.35 cm and 7 mm made with DIFMAP. These images are smoothed to a circular beam of FWHM = 2.62 $\lambda_{cm}^{1.5}$ mas as shown on the left-bottom corner on each image. At 7 mm, FWHM beam = 1.5 mas ~ mean synthesis beam size; and at 6 cm FWHM beam = 38 mas that is close to the mean scattering size at this wavelength. The contours are 2 mJy beam^{-1}× (-2, 2, 4, 8, 16, 32, 64, 128, 256).

VLBI images of the SgrA*(Lo et al.'99)

How the Scattering acts as magnifying glass on SgrA*?

The intrinsic image is obscured and broadened because of scattering effect by circum-nuclear or inter stellar plasma ($\propto \lambda^2$) .

Shen et al.(05), Bower et al(04) investgated the effect.

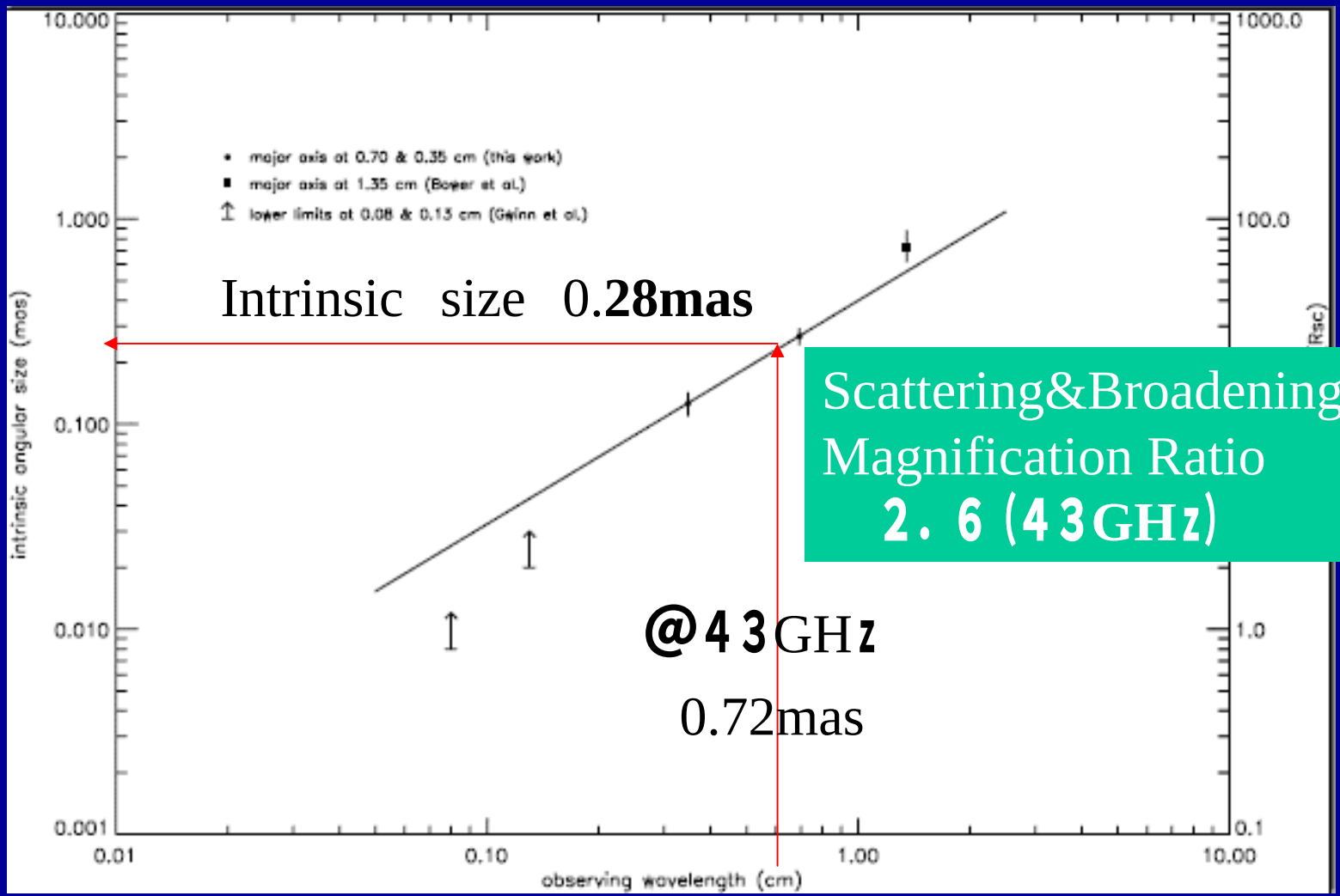
The ratio --2．6～3@43GHZ

The SgrA*の観測上の大きさと本来のサイズの関係

λobs2乗則にのって散乱が効き、大きく見える

From Shen et al. (Nature05) から。

Bower et al (Science 04) –similar result



Considering only the mass(400million solar mass) and distance (8kpc):

0.1mas(EW)×0.15mas (NS)

＝＞9.7 Rs(E-W)× 16.2Rs(N-S)

magnification ratio：

1)self gravitational lensing effect at r =3Rs 1.23

2)scattered&broadening effect by intervening plasma 2.6～3

Total 1.23× 2.6～3 ＝ 3.12～3.7

Considering also the total magnification ratio 3.12～3.7

0.1mas(EW)×0.15mas (NS)

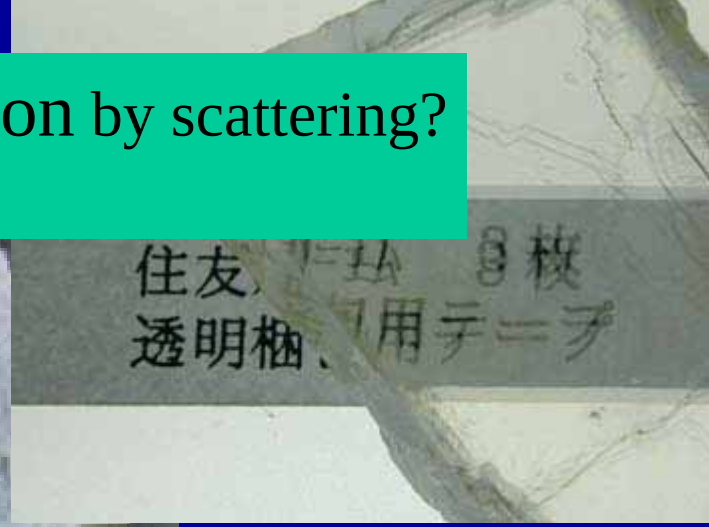
＝＞3.1-2.6 Rs(E-W)× 5.2-4.4Rs(N-S)

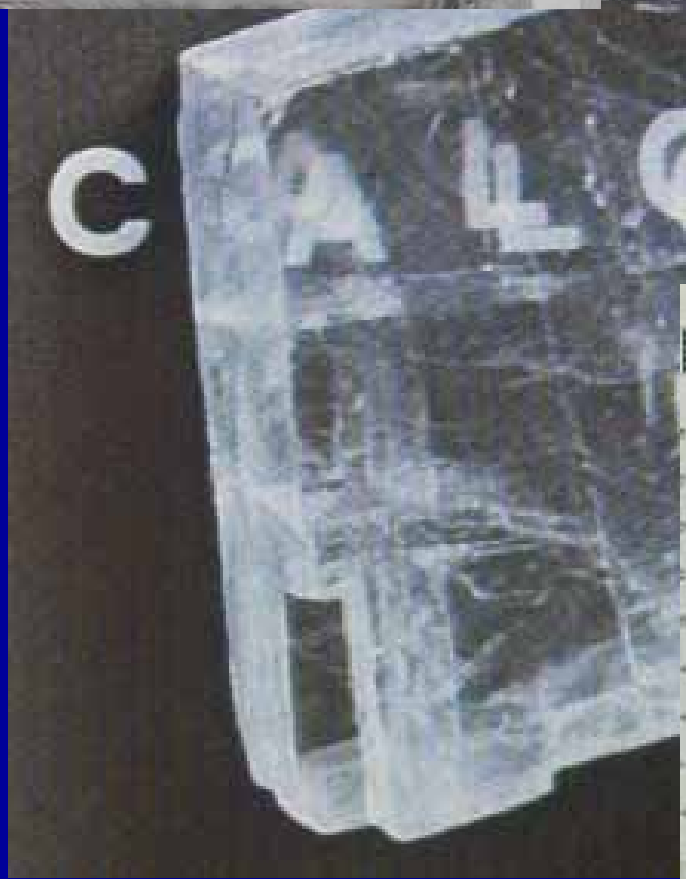
These two broadening effects give us the ～3Rs resolution!

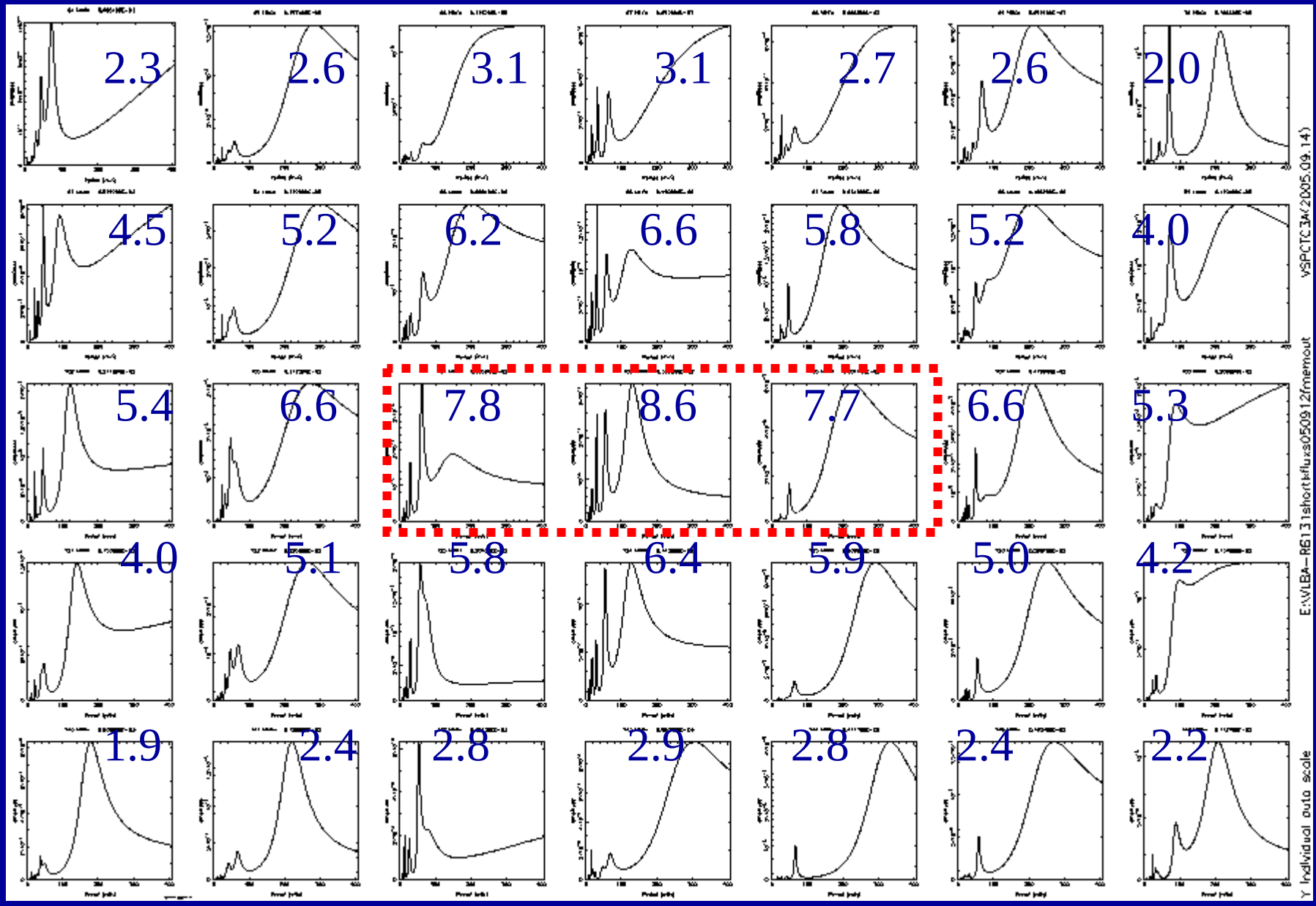
Does Thomson Scattering Really Work As Magnifying Glass on SgrA*?

double refraction by scattering?

複屈折もある？

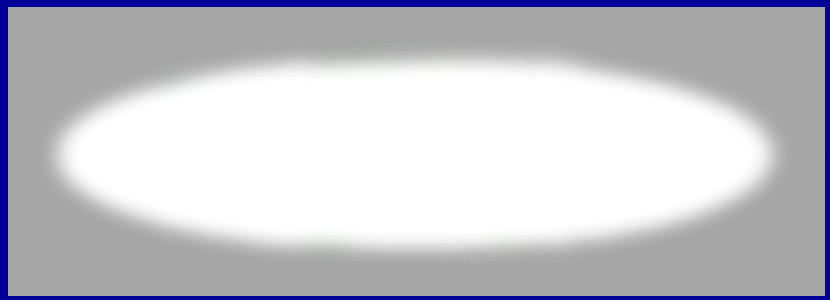




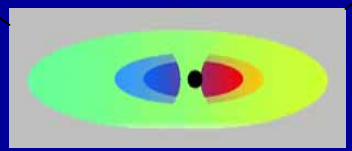


SNR & QPO spectra: The double refraction in plasma ?

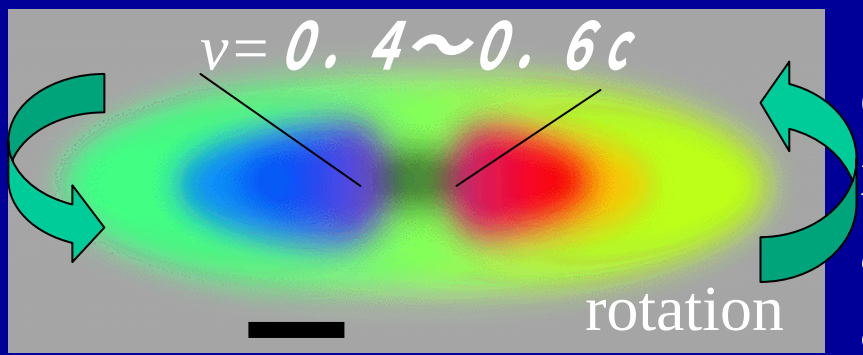
There exist plausible spectra on the quite low SNR data set(SNR<3)



✕**fully obscured**
No information on fine structure



◎**partially obscured**
with some information



Spatial resolution～3Rs

Future prospect

As the accepted theory says,.SgrA*is obscured by broadening and scattering below 1 mm wave length.

But there remain some pieces of information of the intrinsic structure!

Because The scattering effect and self gravitational lensing work as magnifier of SgrA*, we can get the spatial resolution detection the 3Rs.

VLBI observations of QPO in radio continuum will give us the chance to investigate the line of sight velocity and the structure of the inner accretion disk of SgrA*！