JGRG21 @仙台

2011/09/29

Oscillation phenomena in the Disk around the Massive Black Hole Sagittarius A*

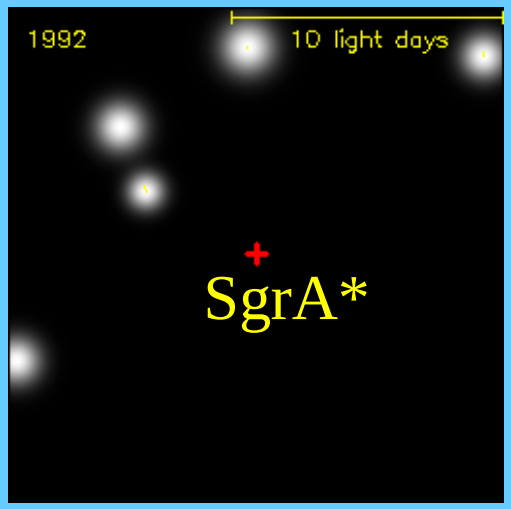
M. Miyoshi(NAOJ),
Z.-Q. Shen(SHAO),
T. Oyama(NAOJ),
R. Takahashi (Tomakonai Nat. College),
& Y. Kato(NAOJ)

Space-Time around a Black Hole

- Accretion Disk is in the Space-Time.
- The Behavior of Accretion Disk is governed by the Space-Time.
- Therefore, we can investigate the Metric of BH from the Oscillations of the Accretion Disk.

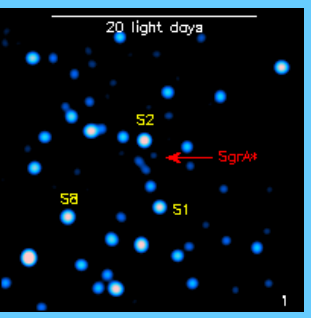
SgrA*
The most convincing Black Hole today from Density Measurement.
Precise Mass Measurements $M \sim 4 \times 10^6 M_{sun}$
MBH at the Closest Distance ~8kpc
The Largest Apparent Schwarzschild Radius
Rs ~ 8-10 micro-arcseconds

Black Hole Shadow will be observed soon at SgrA* (Falcke, Melia et al 00)

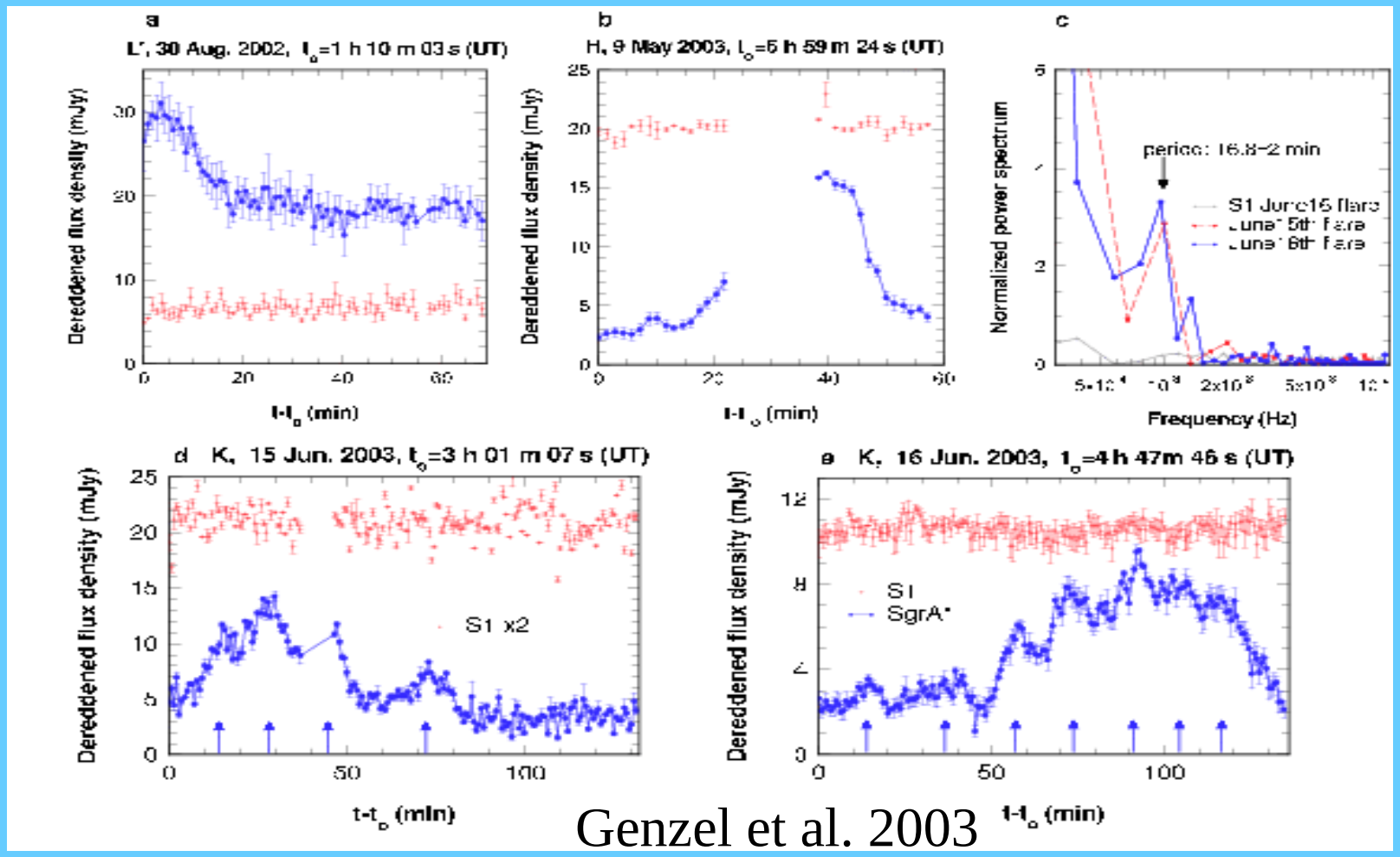


Motions of Stars at GC. NIR Observations (Genzel et al)

<u>Quasi Periodic Variation at Flare of IR&X-ray</u>
(Genzel03, Eckart06:Aschenbach04)
?Existence of Bright Blob Moving at the Last Stable Orbit ?
?Does the Period mean an Orbital Period?
→Precise Period Determination is important but difficult because the Flare is not so Frequent. Also because the Flare Duration is less than about 3 hours.

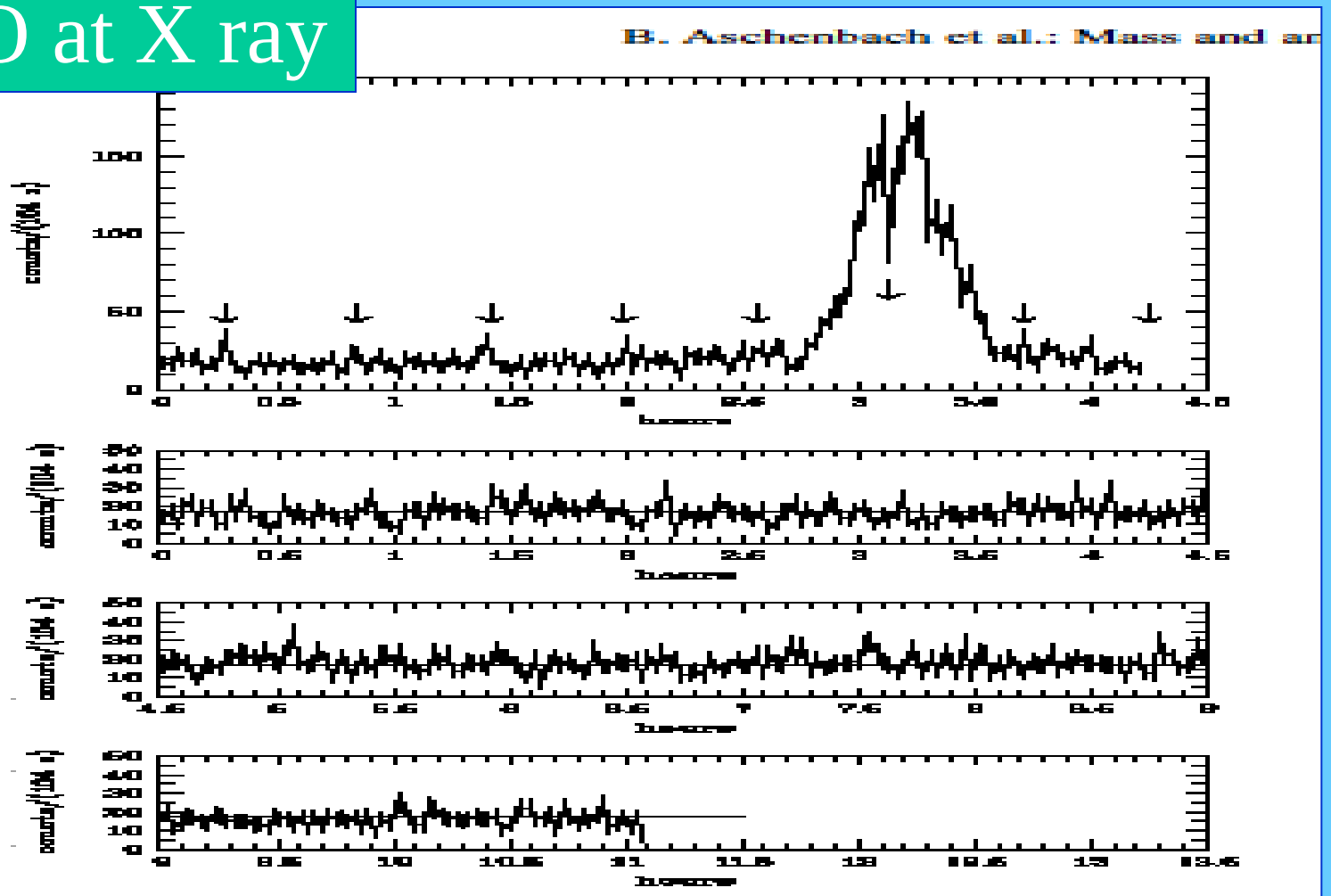


Periodicity was found during NIR flaring of SgrA* P=16.8±2.0 min.(Genzel 03) P=22 min.(Eckart et al 06)



Genzel et al. 2003

QPO at X ray



Periodicity is also found from X ray flare.

(analysis by Achenbach et al. 2004)

How about Radio Emission of SgrA*?

1) Constantly bright (high SNR).

2) Flare–ups are also detected.

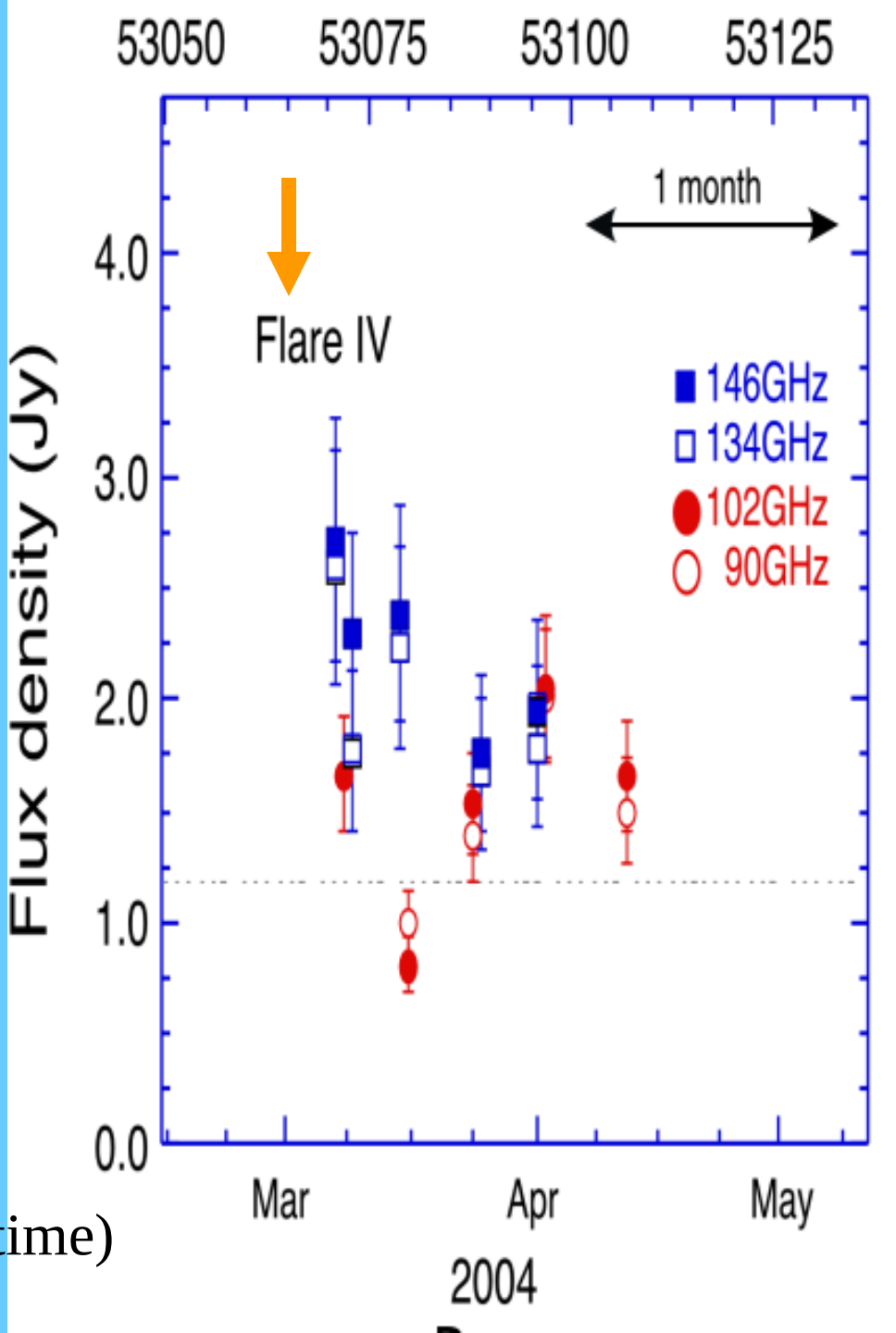
SgrA* Millimeter Flare at 6th March 2004

Flare IV in 2004
Maximum flux density
Mar 6, 2004
2.7±0.5 Jy at 146GHz
2.6±0.5 Jy at 134GHz

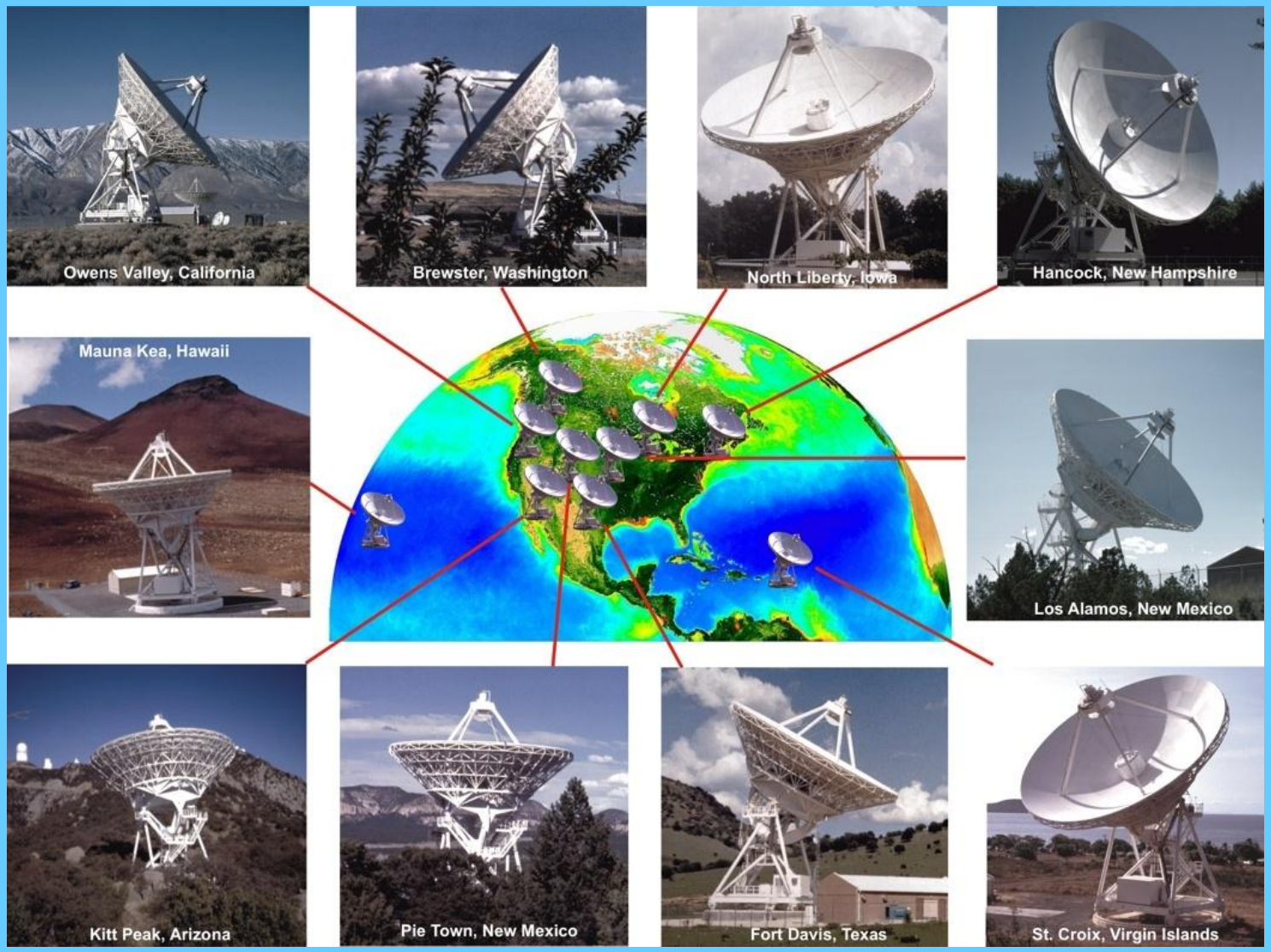
Our bservation:

VLBA obs at 43GHz Mar 8, 2004!
(512Mbps – highest sensitivity)

Unlike with X-ray & NIR,
We can observe SgrA*
for more than 7 hours.
(=horizon to horizon observational time)



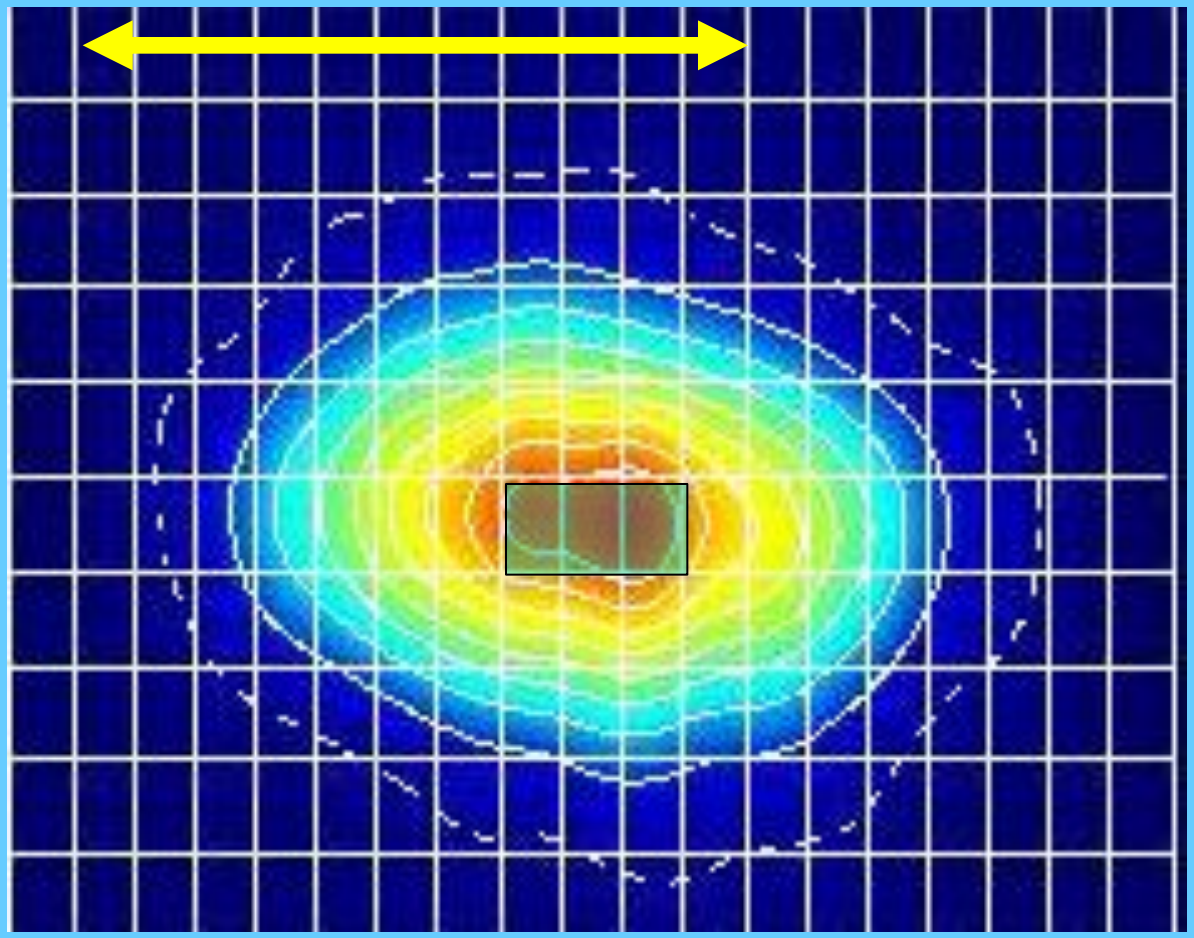
Very Long Baseline Array（VLBA） D=8600km



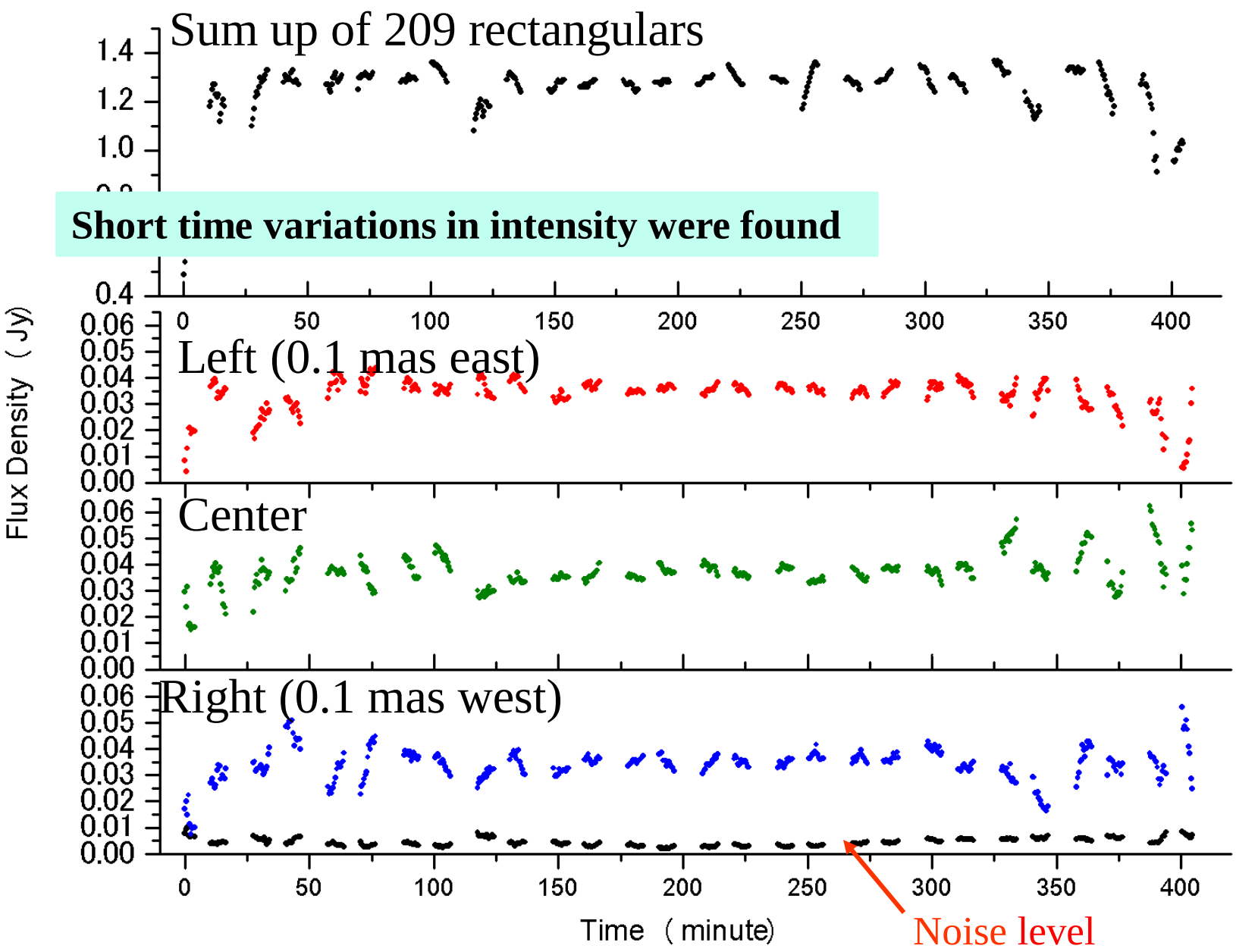
25m-Dish
10 stations
8600km
in extent

SgrA* Radio Image at 43GHz by VLBA.

1 mas = 8 au @8kpc = 100 Rs for SgrA*



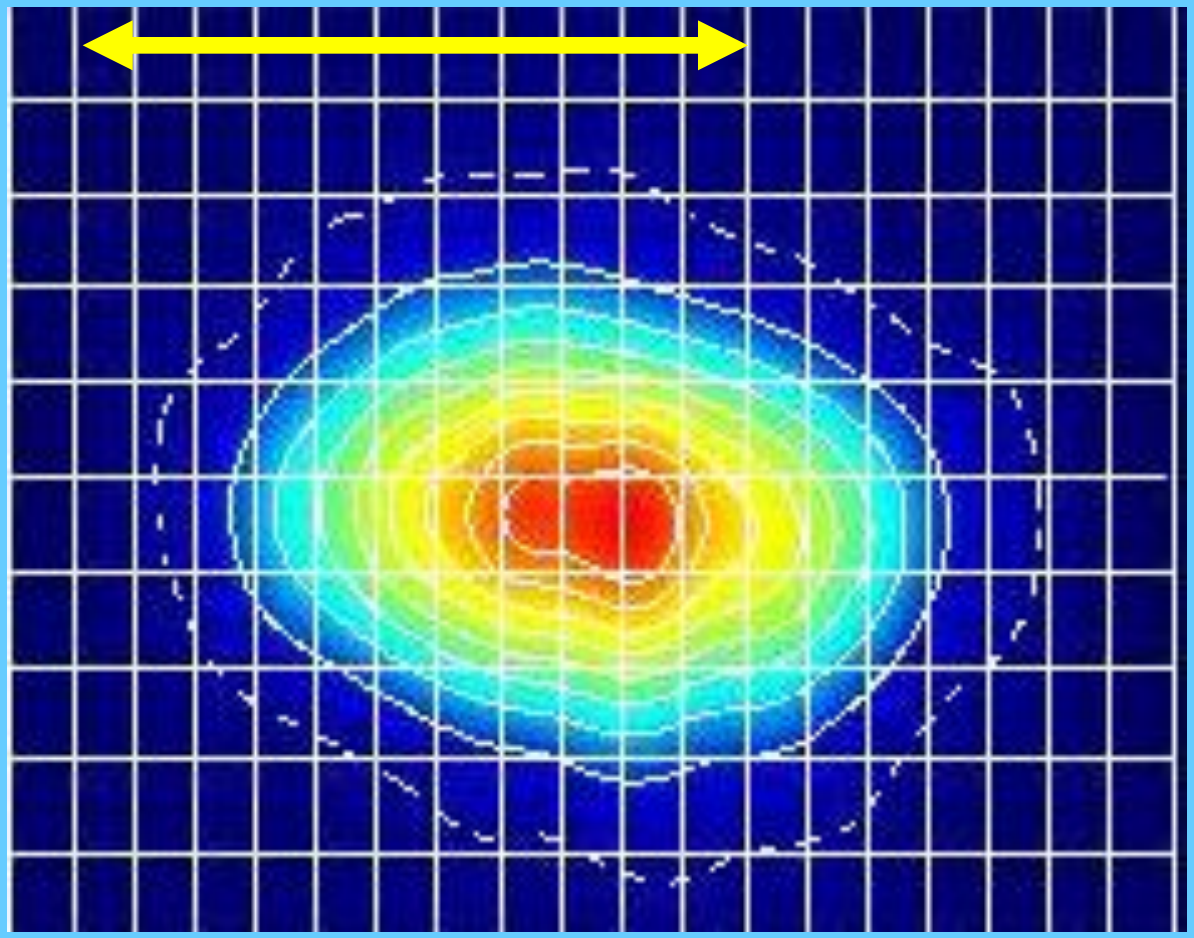
We investigated the time variations of intensities in respective cells.



Time variations of flux densities in the central 3 rectangulars, & sum-up

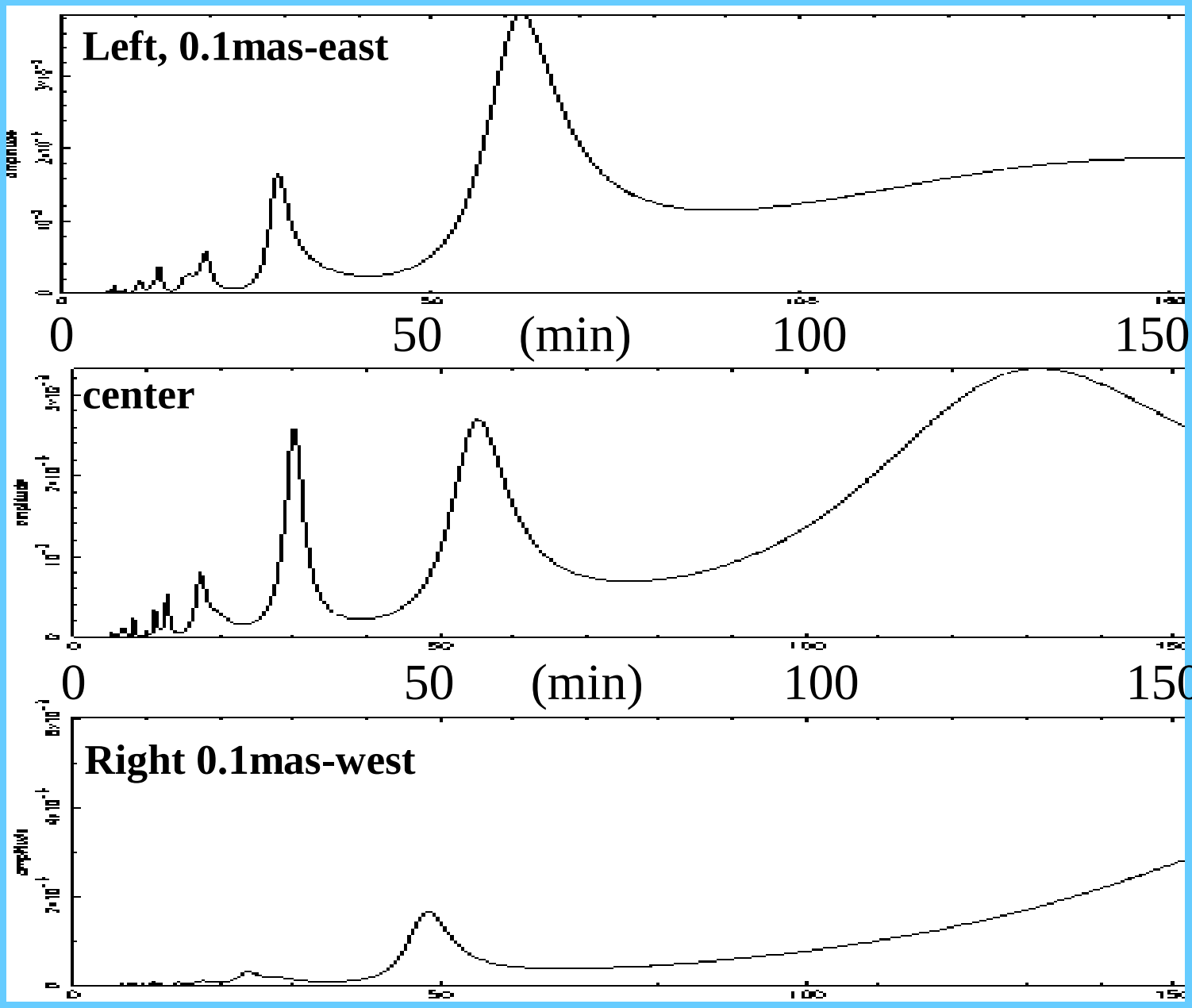
SgrA* Radio Image at 43GHz by VLBA.

1 mas = 8 au @8kpc = 100 Rs for SgrA*



The 43GHz image is scattered and broadened by surrounding plasma, but partially retains information of the intrinsic figure.

Periods Spectra of the Central 3 cells by MEM



peaks

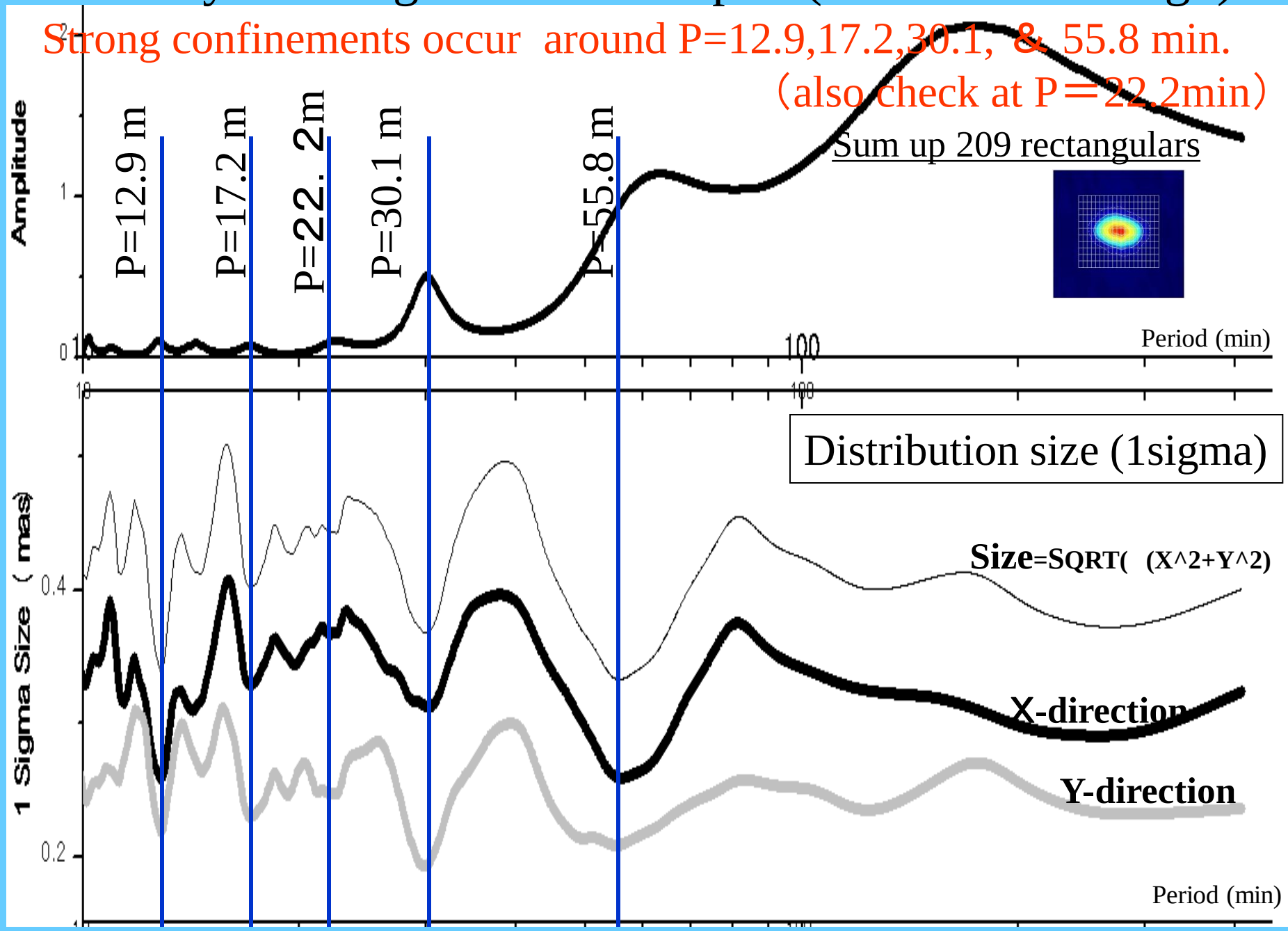
62. 2
29. 3
19. 4
17. 0

(131. 6)
55. 3
30. 2
17. 3
12. 8

(224. 8)
48. 4
23. 8
17. 7
14. 3

Periodicity is strong at the central part (where SNR is high).

Strong confinements occur around P=12.9,17.2,30.1, & 55.8 min.
（also check at P＝22.2min）



Not only intensity variations,

We found Periodic Structure Change Patterns with the 4 Periods:

1) We searched periodic structure change by SMI method(Miyoshi 2008).

2) We found characteristic change patterns of the 4 periods.

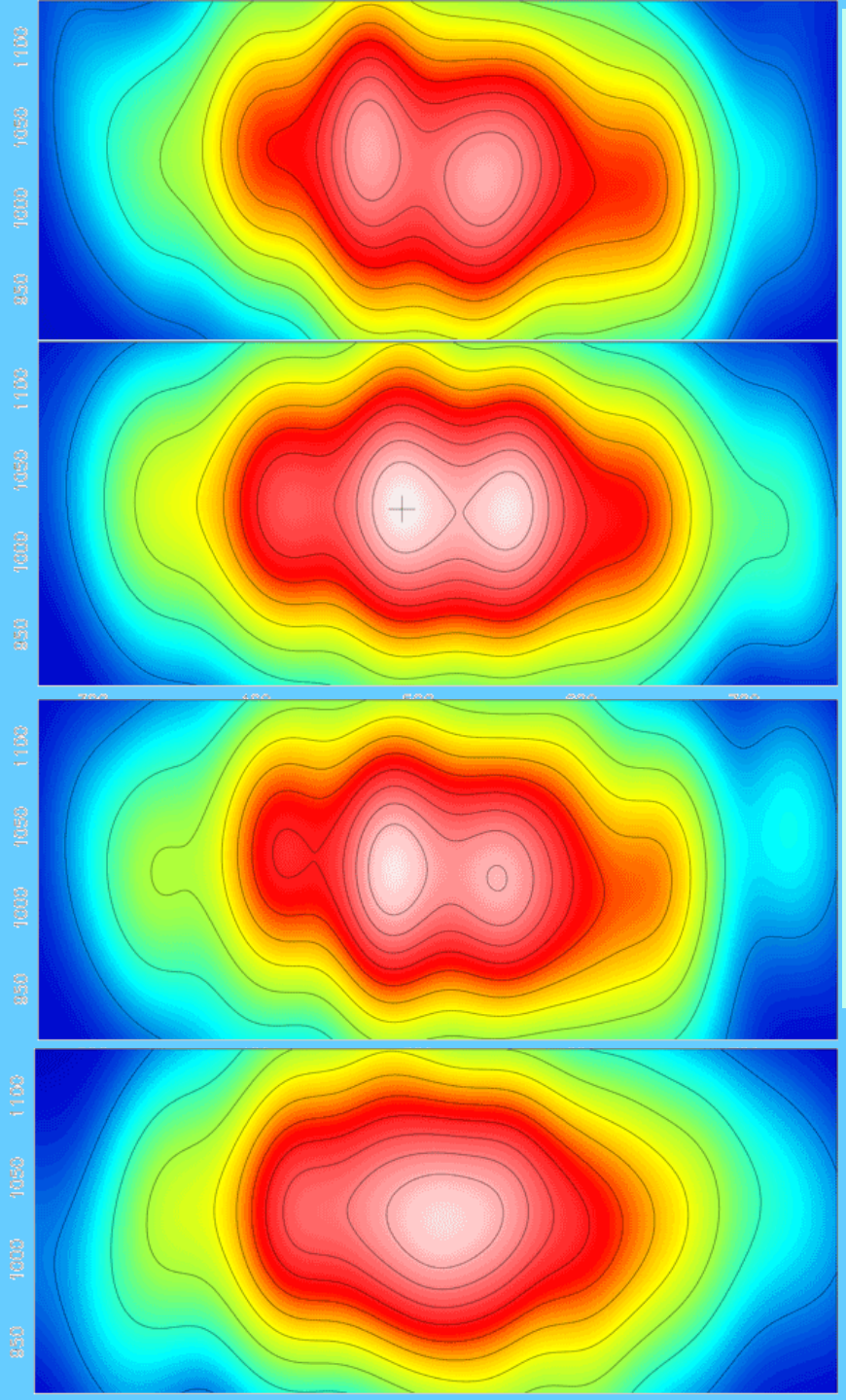
(P=16.8, 22.2, 31.4, &56.4 min. ~ 3:4:6:10 roughly)

P=16.8min
m=1

P=22.2min
m=1
(counter
rotation)

P=31.35min
m=3

P=56.35min
strong
variation
at the center

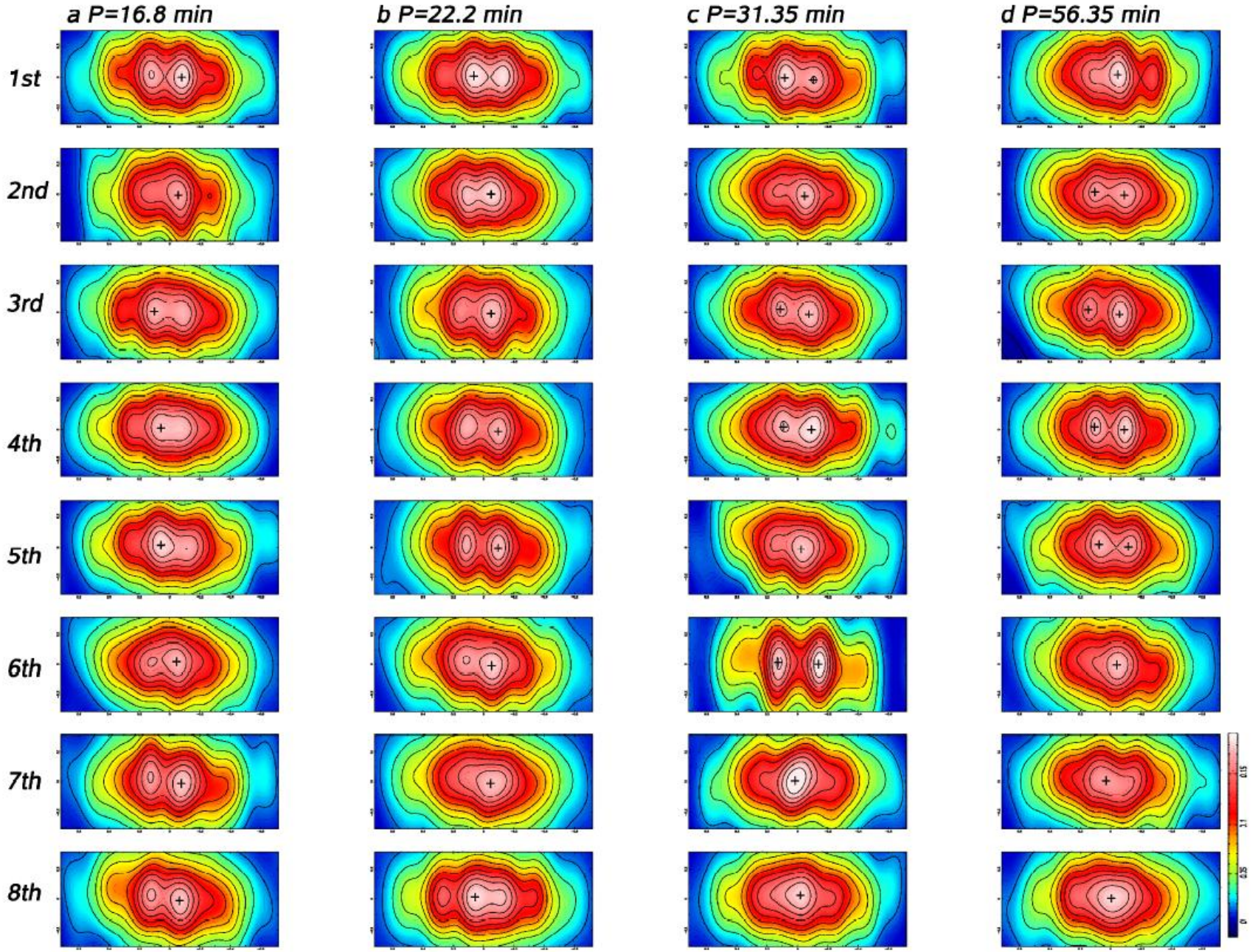


The 4 Periods show conspicuous change patterns.

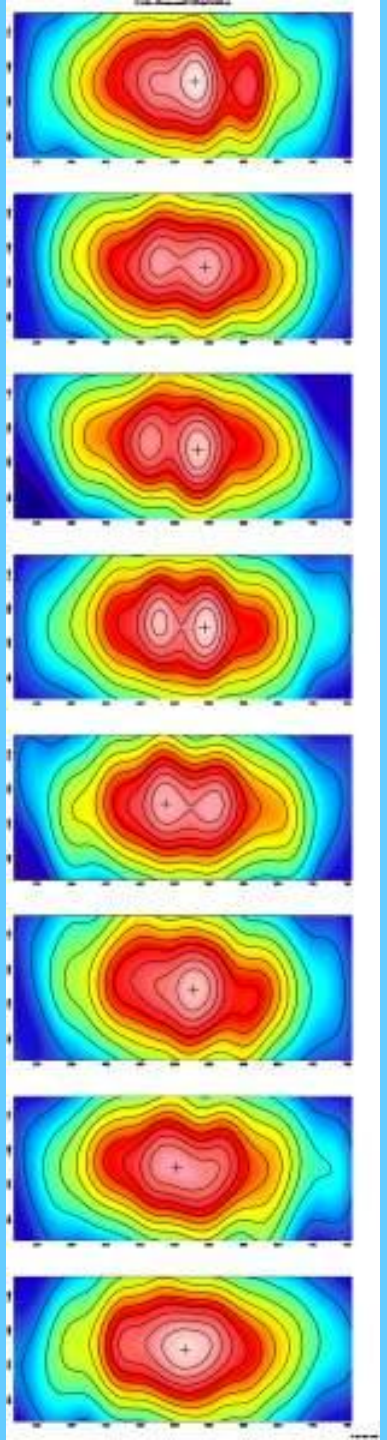
Periods Ratios 3:4:6:10

Disk Oscillation Theory tell us the BH is $M \sim 4 \times 10^6 M_{sun}$ spin~0.4

We found Periodic Structure Change Patterns with the 4 Periods



$P = 56.4 \text{ min}$



① 1 peak

② 2 peaks

③ 2 peaks

④ 2 peaks

⑤ 2 peaks

⑥ 1 peak

⑦ 1 peak

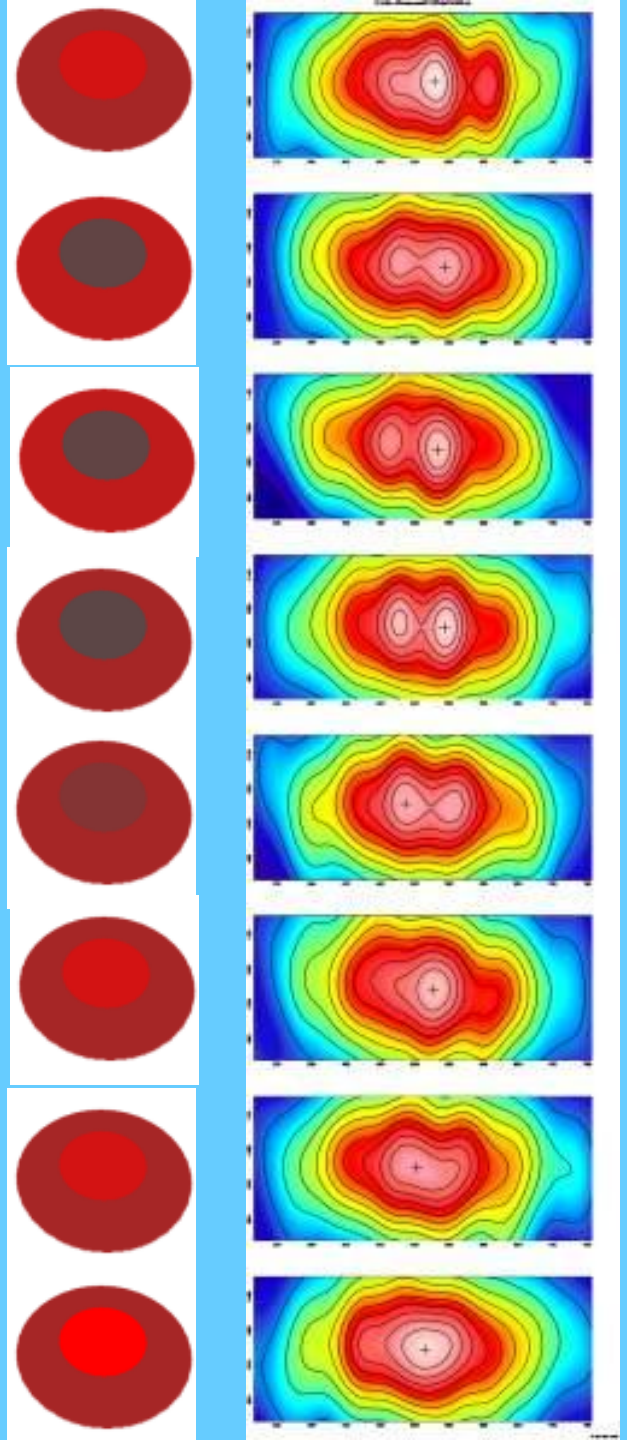
⑧ 1 peak

Periodic Structure
change pattern
of the P=56.4 min

2 peaks appear
during the half period.

「Realなピーク数変化」説は
は99.9%棄却できない。

1 peak appears during
the other half period.



① 1 peak

② 2 peaks

③ 2 peaks

④ 2 peaks

⑤ 2 peaks

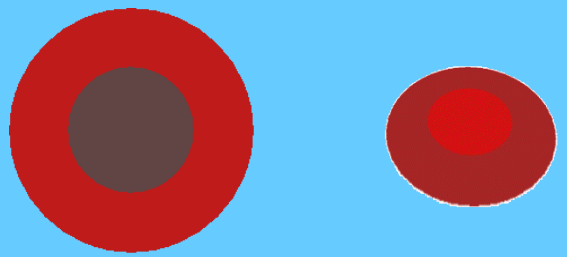
⑥ 1 peak

⑦ 1 peak

⑧ 1 peak

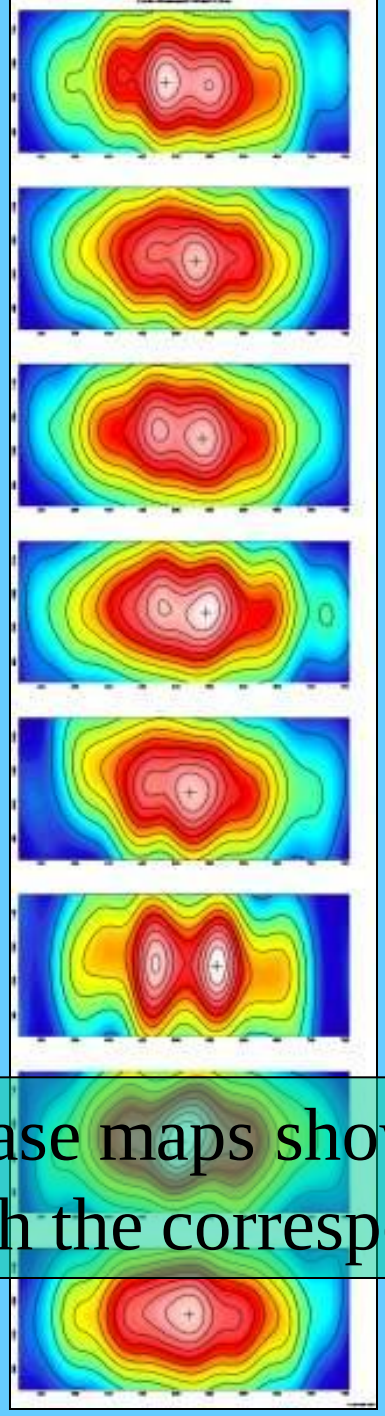
Periodic Structure change pattern of the P=56.4 min

This seems as if the central intensity of the period is larger than those of next outer radii. We observe the change with edge-on angle.



「Realなピーク数変化」説は
は99.9%棄却できない。

P=31.4 min.



① 2 peaks

② 1 peak

③ 2 peaks

④ 2 peaks

⑤ 1 peak

⑥ 2 peaks

⑦ 1 peak

⑧ 1 peak

Periodic Structure
change pattern
of the P=31.4 min

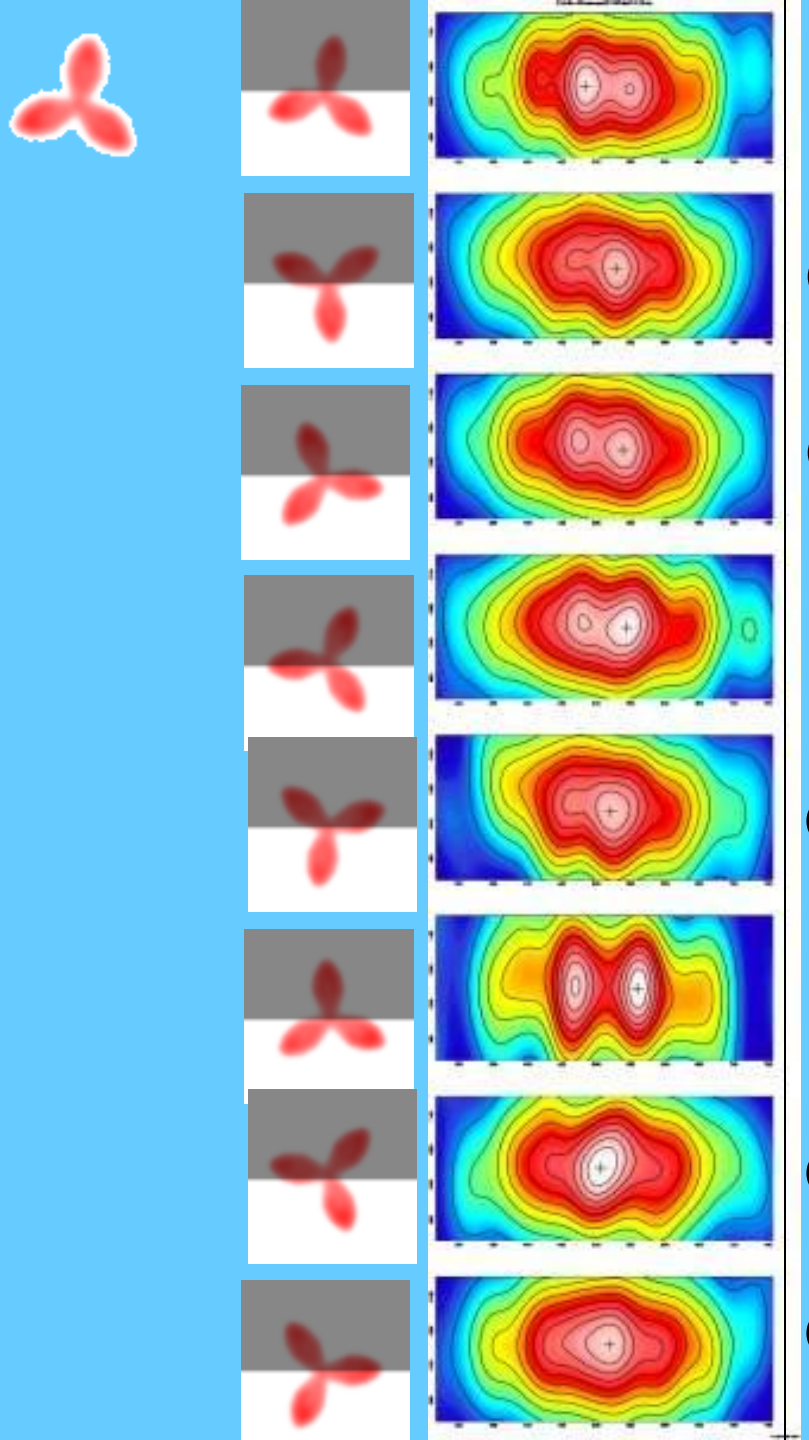
Opposite

Opposite

Opposite

Opposite

All Phase maps show different opposite peak number with the corresponding map half periods apart.



① 2 peaks

② 1 peaks

③ 2 peaks

④ 2 peaks

⑤ 1 peak

⑥ 2 peaks

⑦ 1 peak

⑧ 1 peak

Periodic Structure change pattern of the P=31.4 min

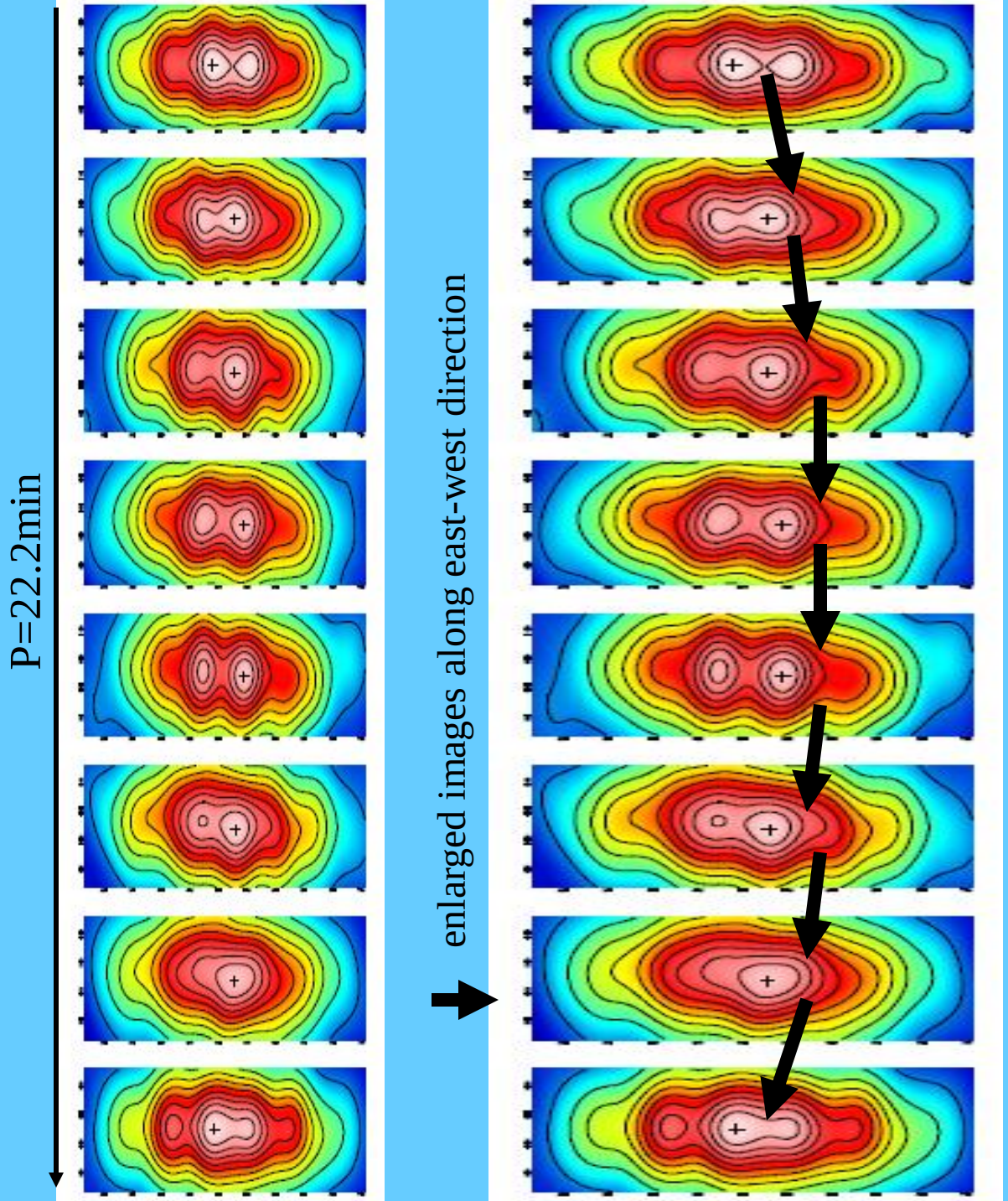
This can be explained with 3 bright arms model. We observe the pattern motion from edge-on angle. Far side is unseen.

Opposite

Opposite

m = 3

$P = 22.2 \text{ min}$

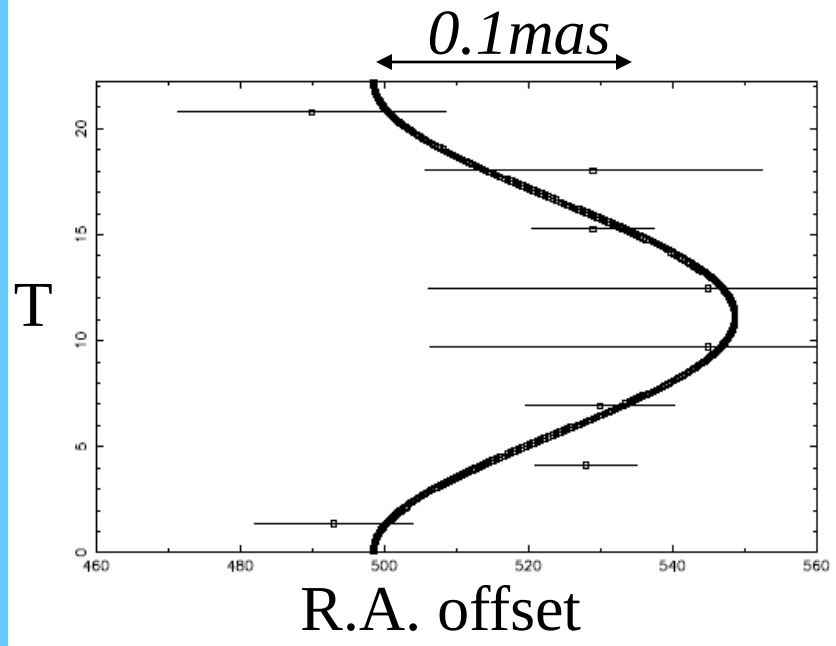


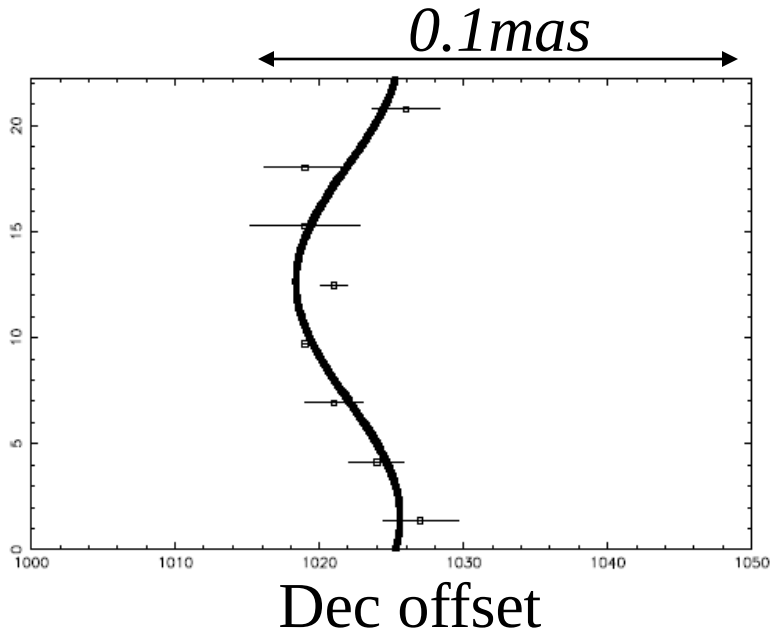
Periodic Structure
change pattern
of the P=22.2 min

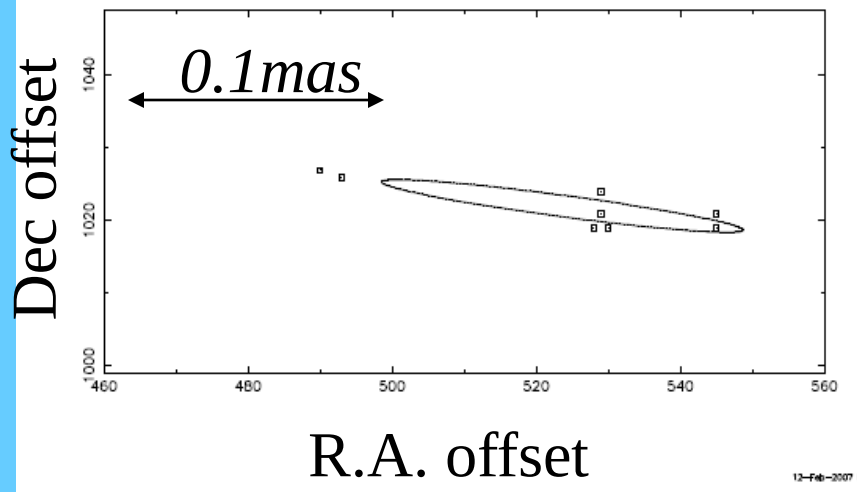
Peak is the cross in
the figure.
Peak position moves
along east-west
direction
with the period.

m = 1

Peak Position Shift in SMI maps. P=22.2min



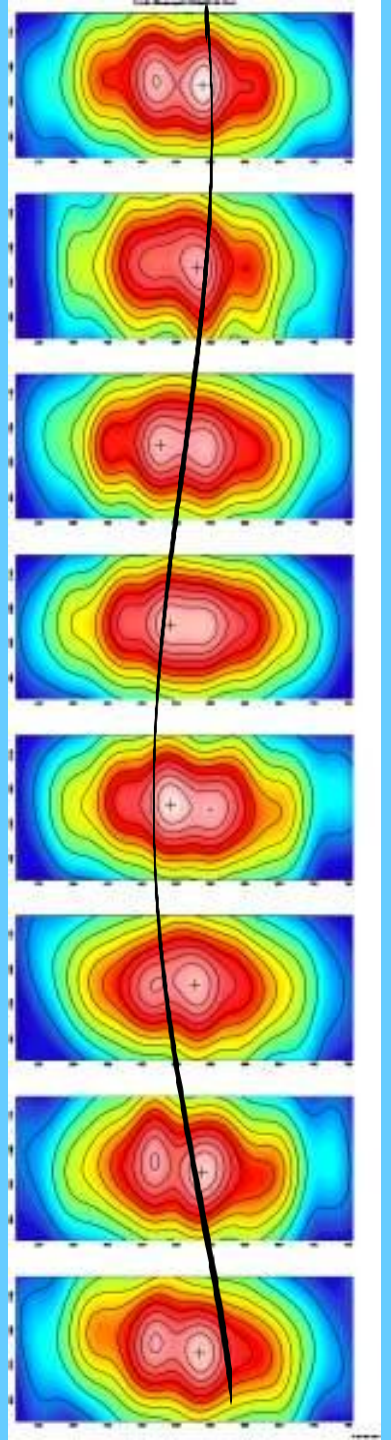




Deviation in R.A.＞that in Dec.
（If this is noise effect, the deviation should be larger in declination – direction of worse spatial resolution)

$P = 16.8 \text{ min}$

P=16.8min



① **Peak at right side**

② **Peak at center side**

③ **Peak at left side**

④ **Peak at left side**

⑤ **Peak at left side**

⑥ **Peak at center**

⑦ **Peak at right side**

⑧ **Peak at right side**

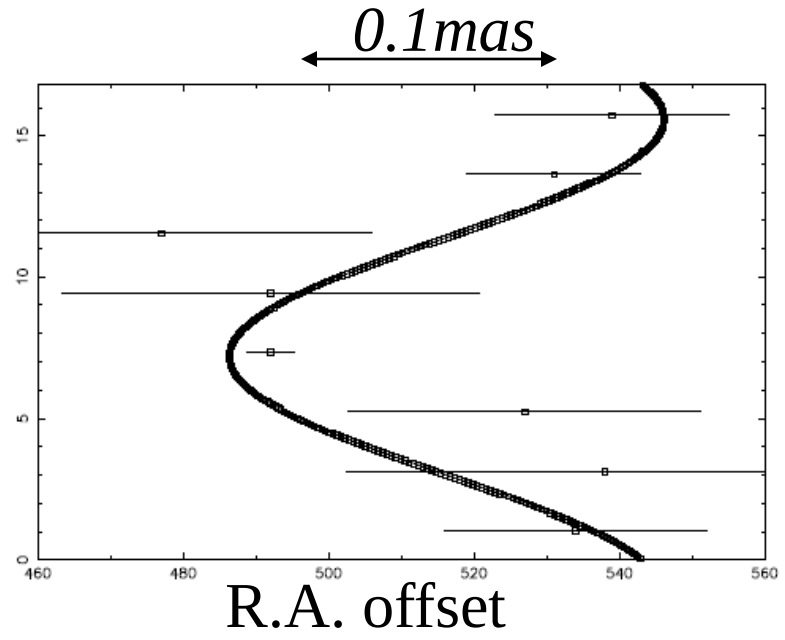
Periodic Structure change pattern of the P=16.8 min

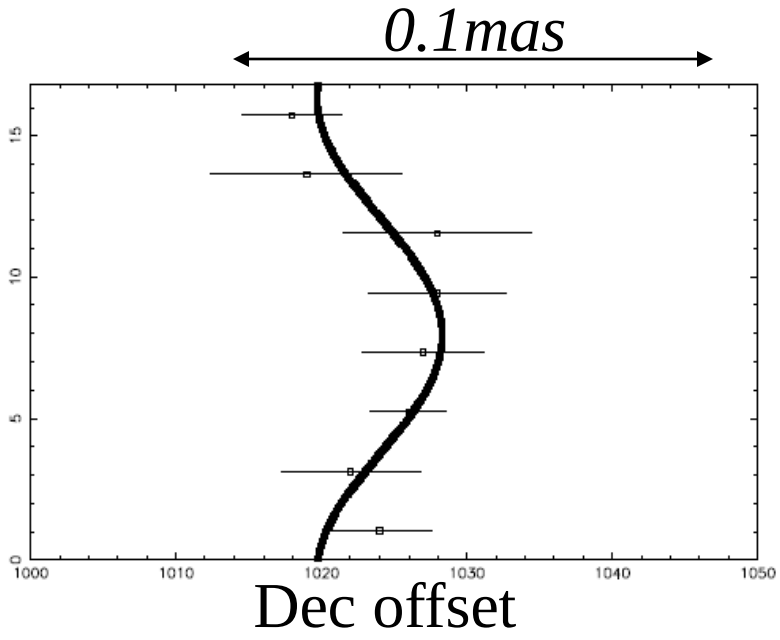
The peak position seems to move with the period.
This can be explained with one arm structure pattern rotating with the period.
And we observe it from edge-on .

m = 1

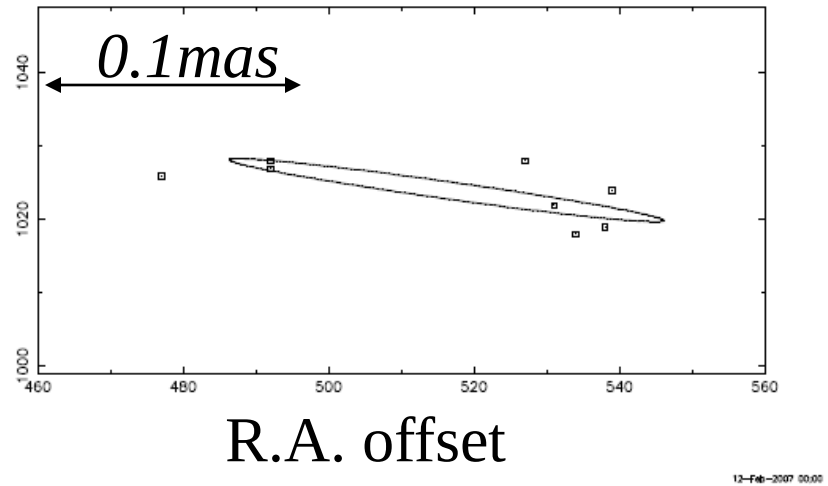
Peak Position Shift in SMI maps. P=16.8min

T





Dec offset



sinf1680B.out
sin fitting to the peak movement by sinf3.f
R.A. sinf.out P=16.80min with known error bar
par: 29.8641204 4.26669418 516.25
err: 11.3558106 0.380249284 8.03313451
chsq= 4.59033492
DEC. sinf.out P=16.8 min with error bar in DEC
par: −4.3059152 4.54583581 1024.
err: 15.9999646 3.71581252 11.3137085
chsq= 1.83305058

From disk oscillation observations, we can investigate space-time around black hole!

Conclusions.

1. 4 QPO periods (P=16.8,22.2, 31.2, & 56.4min) are detected. Clear periodic change patterns seen at these 4 periods. These mean disk oscillations.
2. We derive the mass and spin of SgrA* BH from disk oscillation Theory ($M \sim 4 \times 10^6 M_{sun}$ spin~0.4; Kato et al '10).
3. Radio images of SgrA* has some imprints of intrinsic structure at 43GHz (though scattered and broadened by circum-nuclear plasma).
4. SgrA* image is almost an edge-on accretion disk.

Space-Time around a Black Hole

- Accretion Disk is in the Space-Time.
- The Behavior of Accretion Disk is governed by the Space-Time.
- **Therefore, we can investigate the Metric of BH from the Oscillations of the Accretion Disk.**

おしまい。

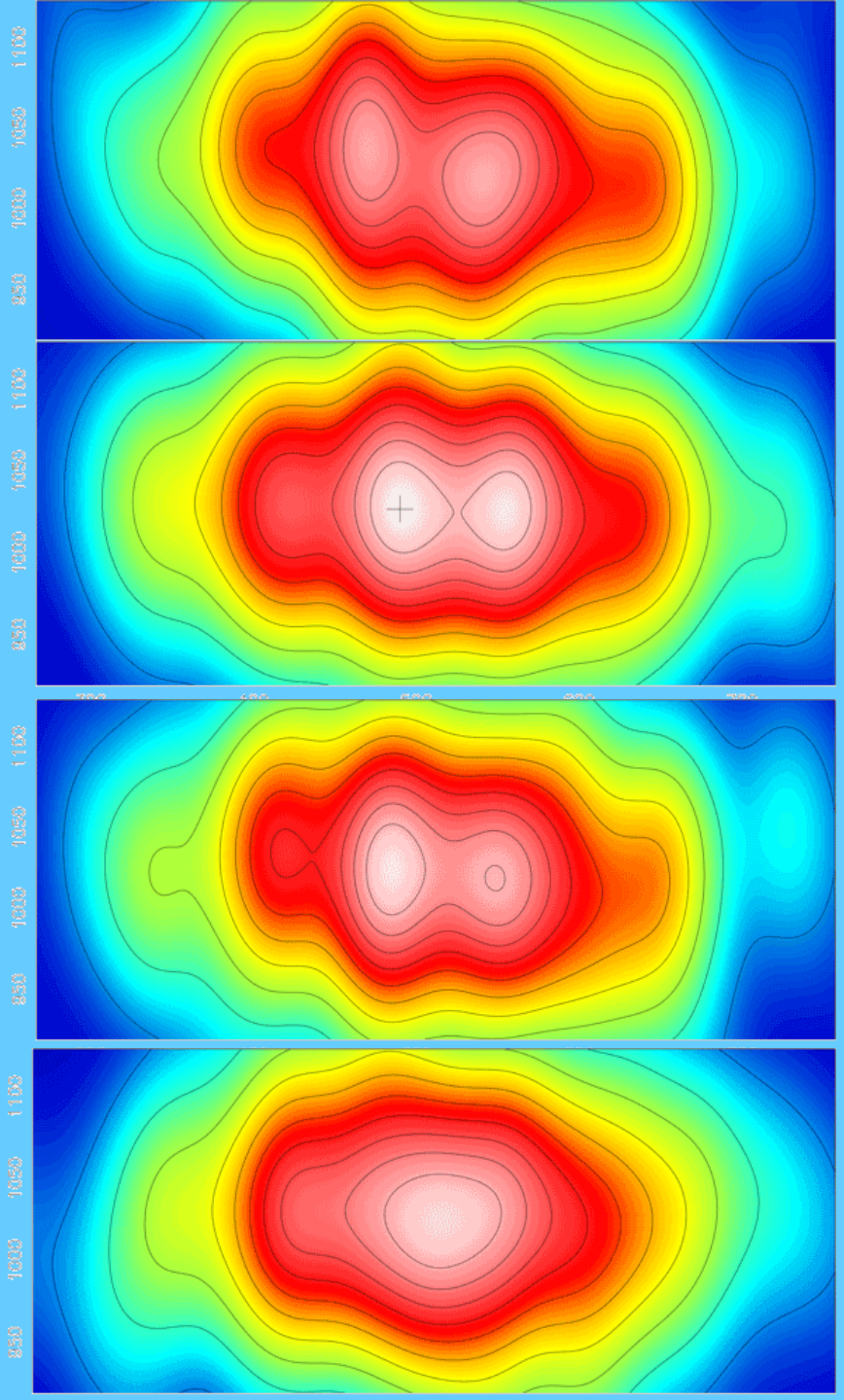
SMI(Ndiv=8)

P=16.8min

P=22.2min

P=31.4min

P=56.4min



A Comment:
All Accretion Disks should Rotate.
And Also Should Oscillate!
Not Everything Rotates,
But Everything Should Oscillate and Has The Modes of its Oscillation.

-Including The Sun,
The Earth,
and Your Hearts—

They seem in a **resonance.**

P=16.8, 22.2, 31.35, 56.35min

Roughly saying **３:４:６:１０**

（20:15:10:6 in frequency domain)

P=16.8 & 22.2 min; circular change pattern one-arm structure.
but counter-rotation to each other (m=1).

P=31.4 min; three-arms structure (m=3).

P=56.4 min; confined at the center.

Rough Relation from Disk Oscillation Theory:

$M(M_{sun}) \sim P(\mathrm{min}) \times 10^{-3}$ => then M SgrA*=$3.3 \times 10^{6} M_{sun}$！）

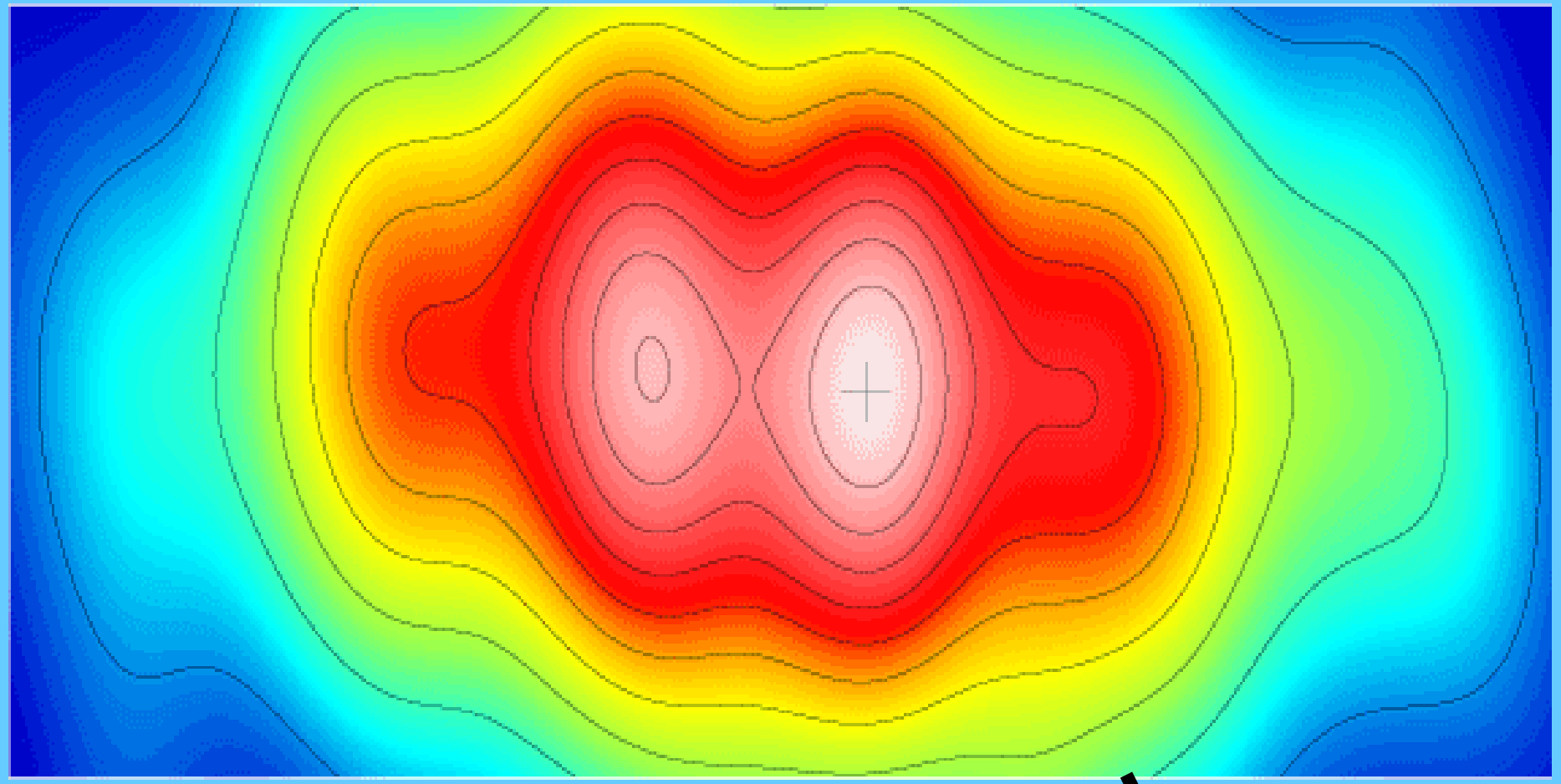
！Very good mass ! --Further investigation was done by Y. Kato 2009.

The motion changes are too rapid v > c, light velocity.

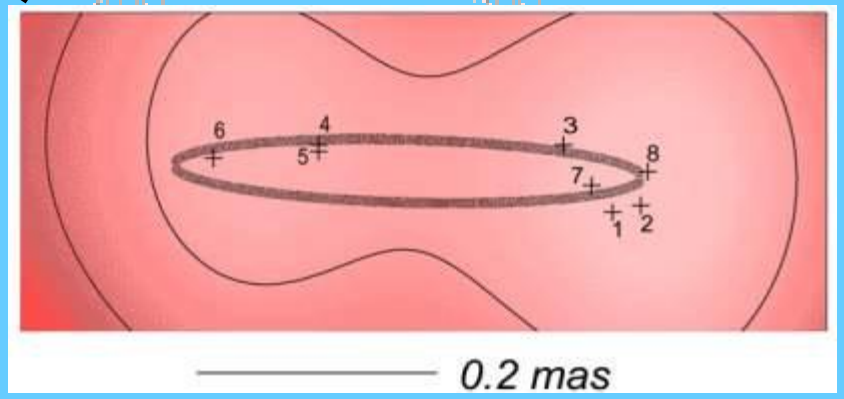
The changes are not real motion but pattern changes.

Or the image is magnified about 3times by scattering effect?

These should relate to **oscillations of accretion disk**!



P=16.80min



←Position shift of the peak