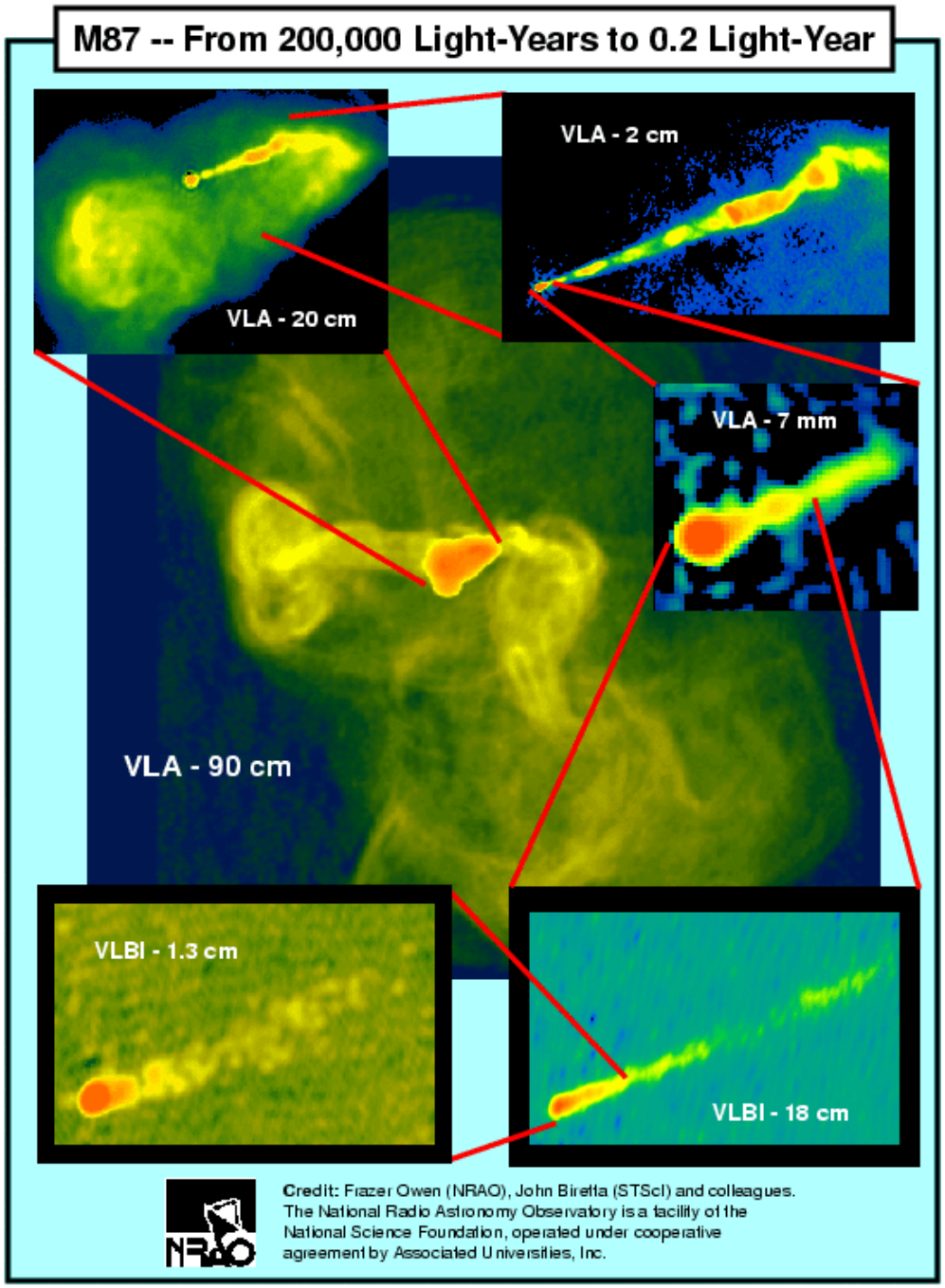
EUROPEAN VLBI NETWORK

The 7th European VLBI Network Symposium
on New Developments in VLBI Science and Technology
Toledo, Spain.
October 12-15, 2004

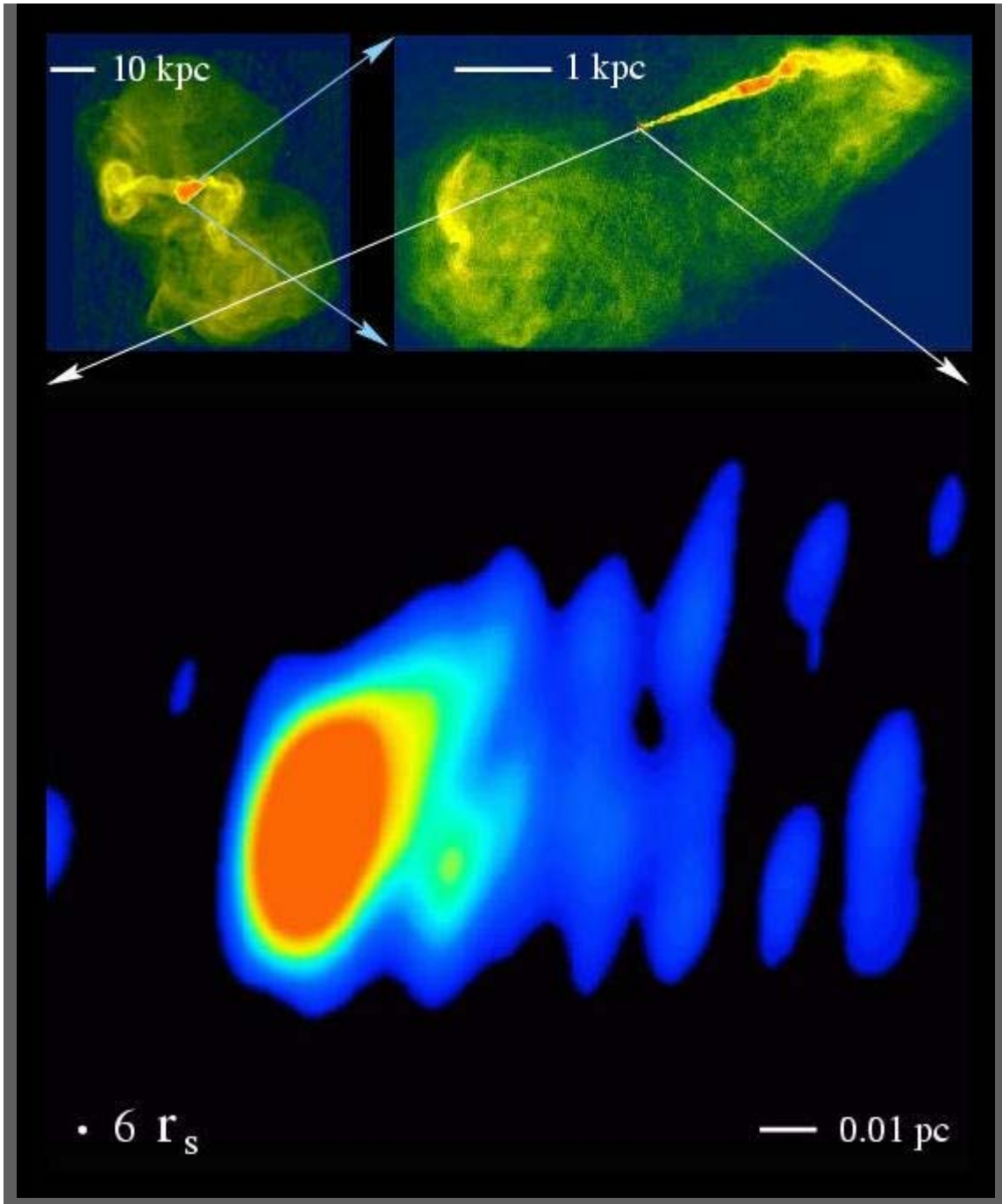
Title : An Approach Detecting the Event Horizon of SgrA*

Author : Makoto Miyoshi (National Astronomical Observatory, Japan)

Abstracts : Imaging the vicinity of black hole is one of the ultimate goals of VLBI astronomy. The closest massive black hole, SgrA*, located at Galactic center is the leading candidate for such observations. Combined with recent VLBI recording technique and sub-mm radio engineering, we now have the sufficient sensitivity for the observations. We here show performance simulations of sub-mm VLBI arrays for imaging SgrA*. An excellent image is obtained from a sub-mm VLBI array in the Southern hemisphere like the configuration of VLBA. We also note that even with a small array, we can estimate the shadow size and then the mass of black hole from visibility analysis. Now, if only constructing a sub-mm VLBI array in Southern hemisphere, we can unveil the black hole environments of SgrA*.

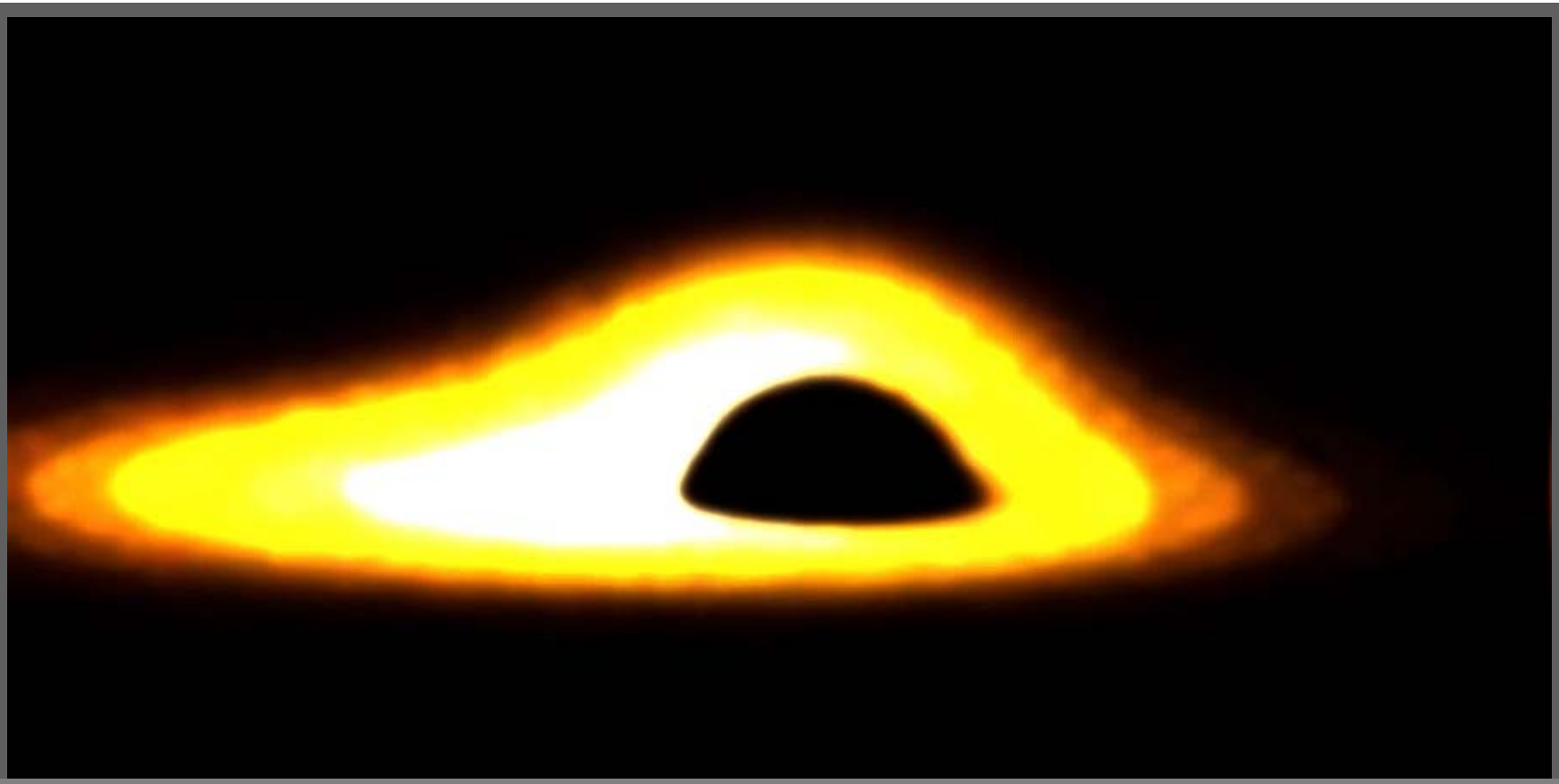


Radio Interferometer has been trying to resolve the central part of the monsters. Above all, VLBIs have the best instruments for investigating fine structures of the sources.



The nucleus of M87 (VLA,VLBA. This is one of the highest resolution VLBI maps.

But, the true face of central massive black hole cannot be seen.

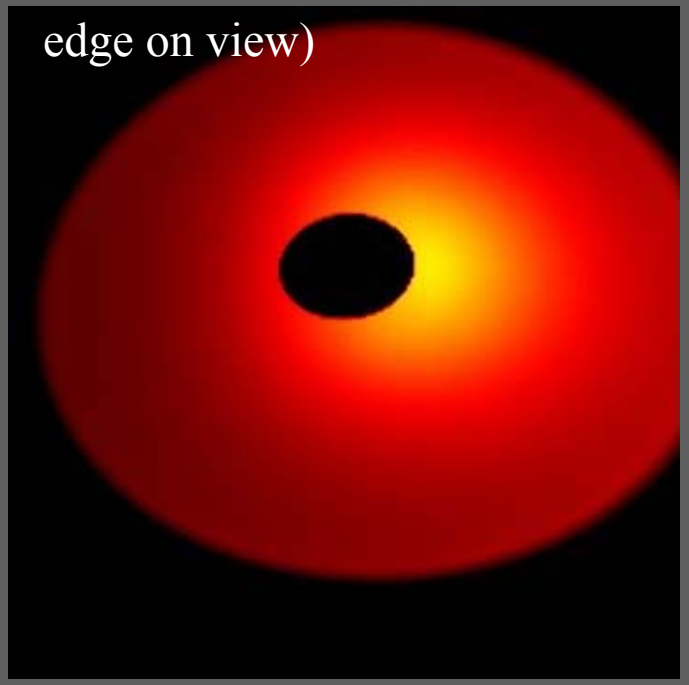


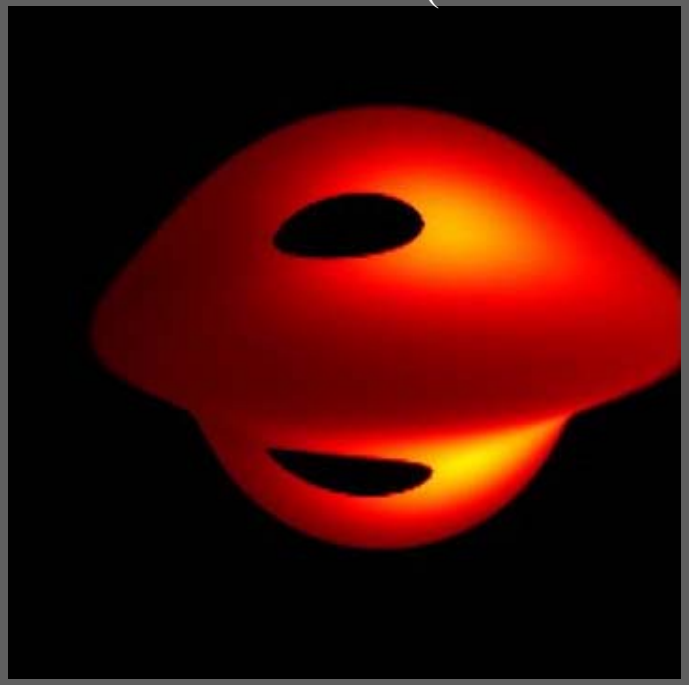
A simulation of the appearance of black hole with accretion disk (Fukue et al 1989). Light from the other side is bended by the black hole gravity, and then we can see opposite side. At the center ‘black hole ‘ can be seen from where no light come towards us. . . h ttp://quasar.cc.osaka-kyoiku.ac.jp/~fukue/

. . . G H .

SgrA*

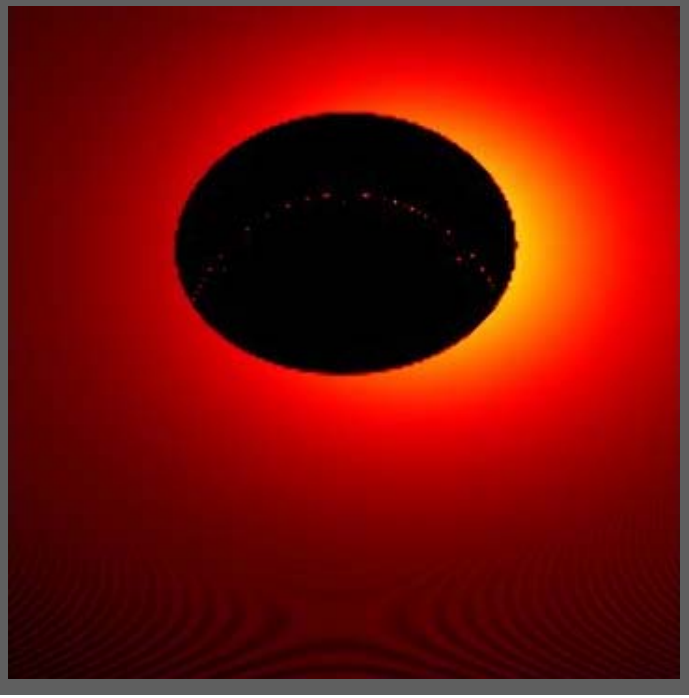
i . . . ° . . . . . i . . . ° (almost edge on view)

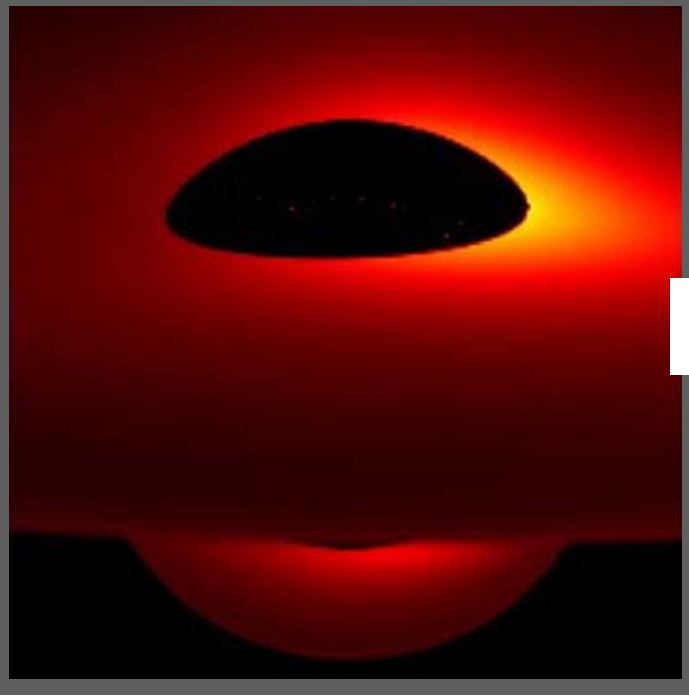




Kerr

ADAF. H=1) .
Axis
symmetric



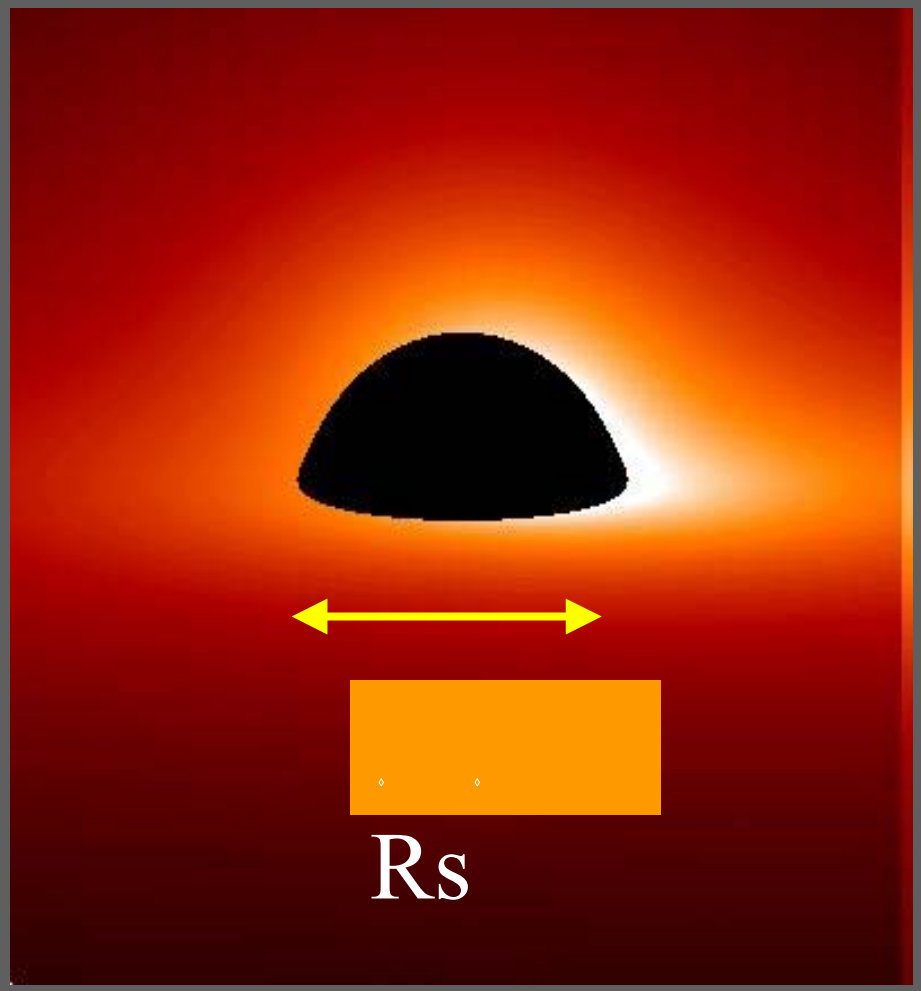


Schwarzschild
ADAF
(H=1)
Axis symmetric

Takahashi
et al (04?)

12Rs

So we must check.
How small are the black holes?



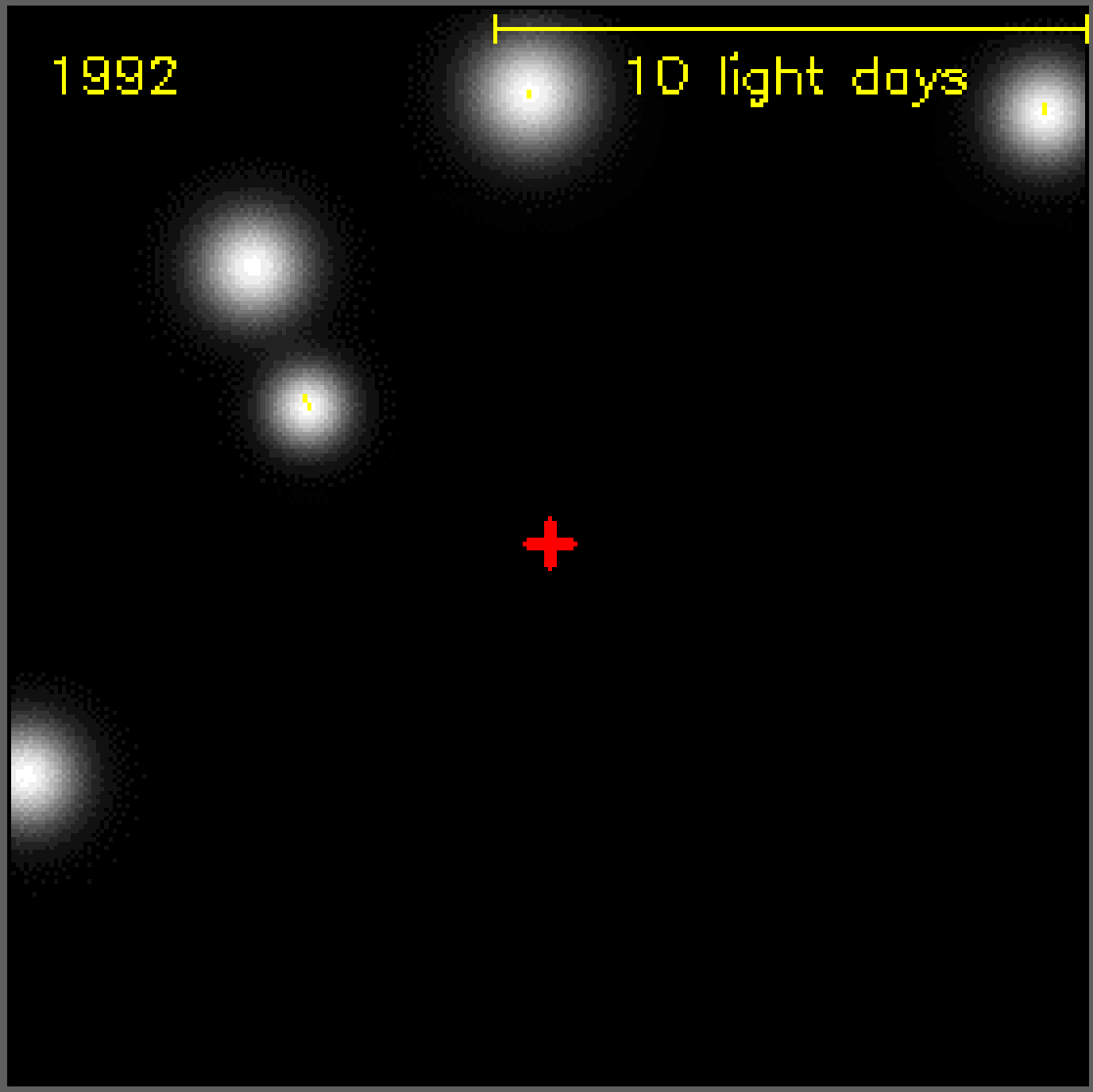
Takahashi & Mineshige (2004?)

Shadow Size of Black Holes

. . Rs

	Mass (Msun)	D (kpc)	Rs (m)	Rs (au)	(μ as)	Shadow Size (μ as)
StellarBH@pc	1.00E+00	0.001	2.95E+03	1.97E-08	0.02	0.10
M82	1.00E+06	3700	2.95E+09	1.97E-02	0.01	0.03
SgrA*@GC	2.60E+06	8	7.67E+09	5.11E-02	6.39	31.96
SgrA*@GC	3.70E+06	8	1.09E+10	7.28E-02	9.10	45.48
M31	3.50E+07	800	1.03E+11	6.88E-01	0.86	4.30
NGC4258	3.90E+07	7200	1.15E+11	7.67E-01	0.11	0.53
M87	3.20E+09	16100	9.44E+12	6.29E+01	3.91	19.54

SgrA*, central massive black hole at our galactic center . has the biggest apparent size Rs=6μ .
.) .



Motions of
Stars at GC
(Genzel et al))

For Black Hole observations

- The most promising source is SgrA*.

VLBI images of the SgrA* from 5GHz to 43GHz (Lo et al '99)

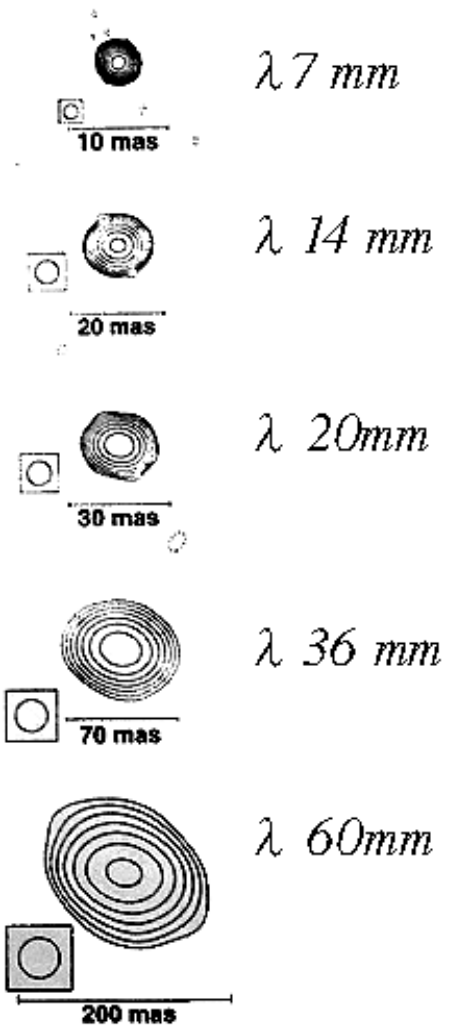
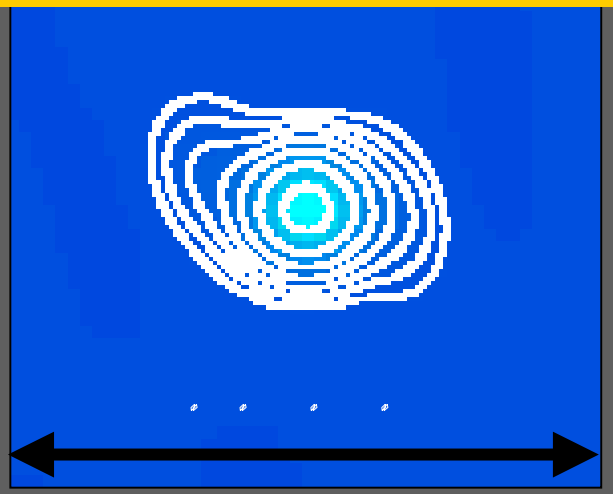
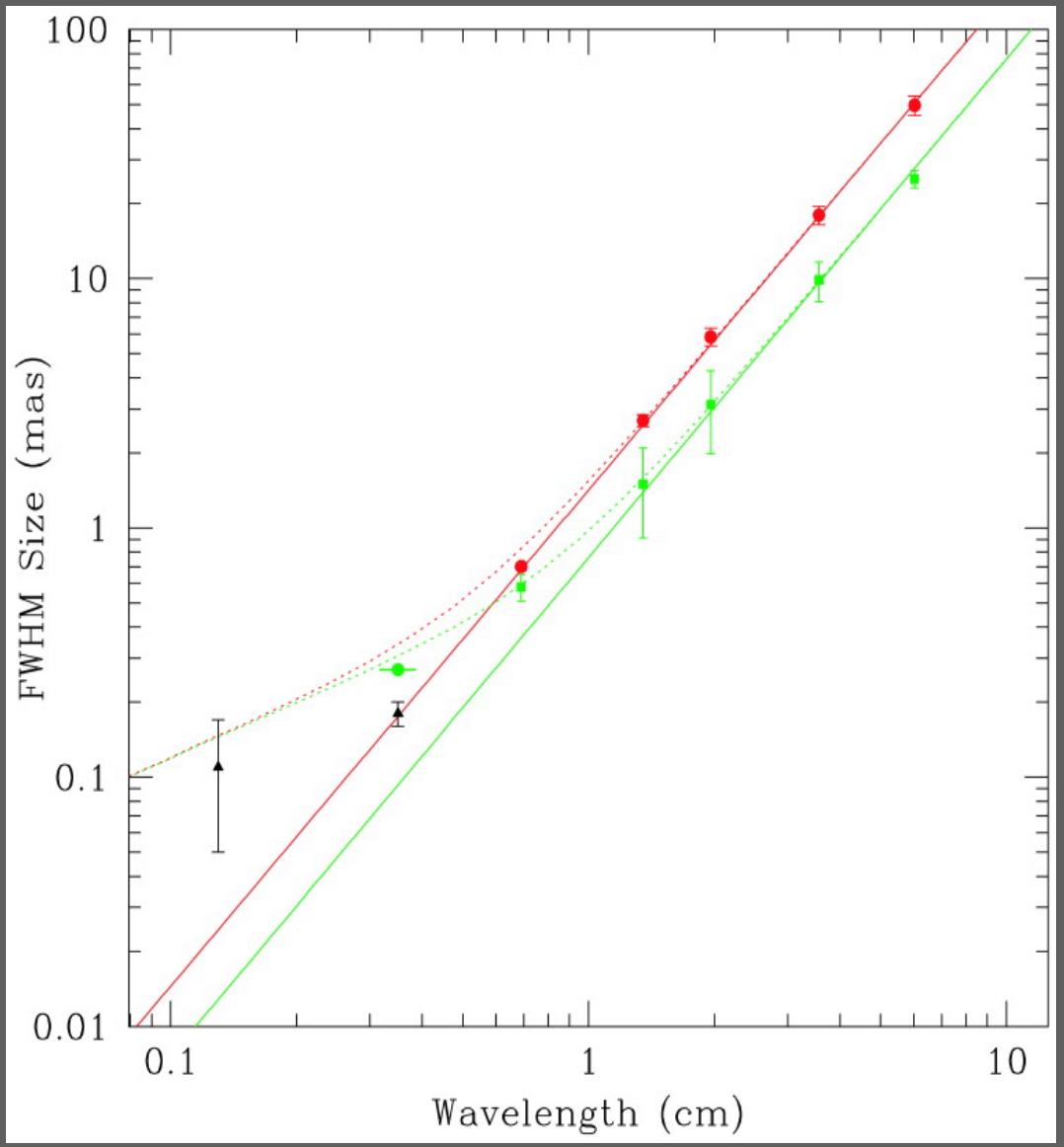


Figure 3. VLBA images of Sgr A* at wavelengths 6.0, 3.6, 2.0, 1.35 cm and 7 mm made with DIFMAP. These images are smoothed to a circular beam of FWHM = 2.62 $\lambda_{cm}^{1.5}$ mas as shown on the left-bottom corner on each image. At 7 mm, FWHM beam = 1.5 mas ~ mean synthesis beam size; and at 6 cm 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).

The intrinsic image is blurred and broadened because of scattering effect by circum-nuclear plasma.



VLBA,86GH. (3.5mm. Shen et al. (200. or later)



Apparent Size of SgrA*

Free from Scattering Effects by Plasma

λ

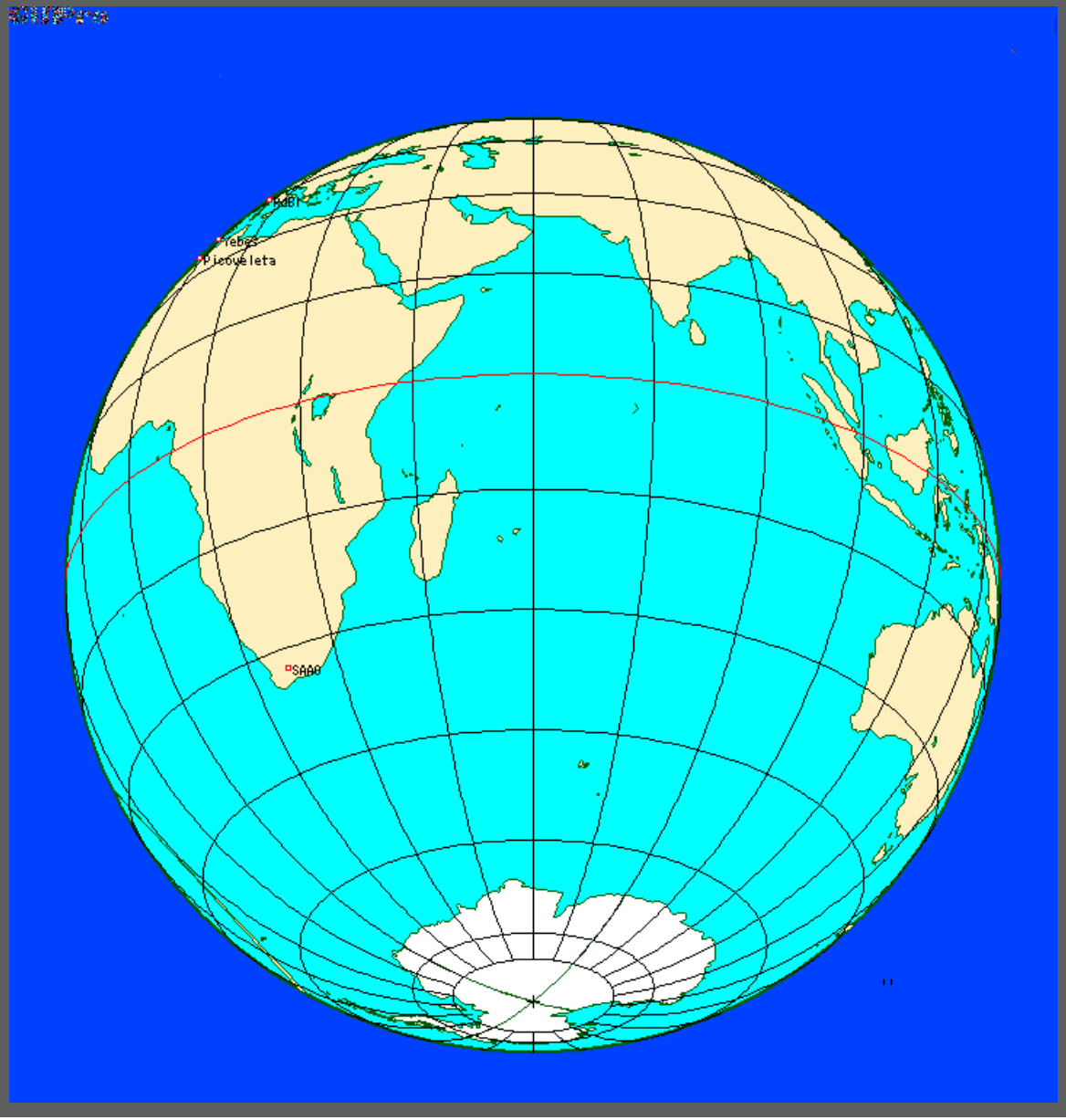
At sub-mm wave length !

So we can expect observe the intrinsic image at mm-, sub-mm wave length.

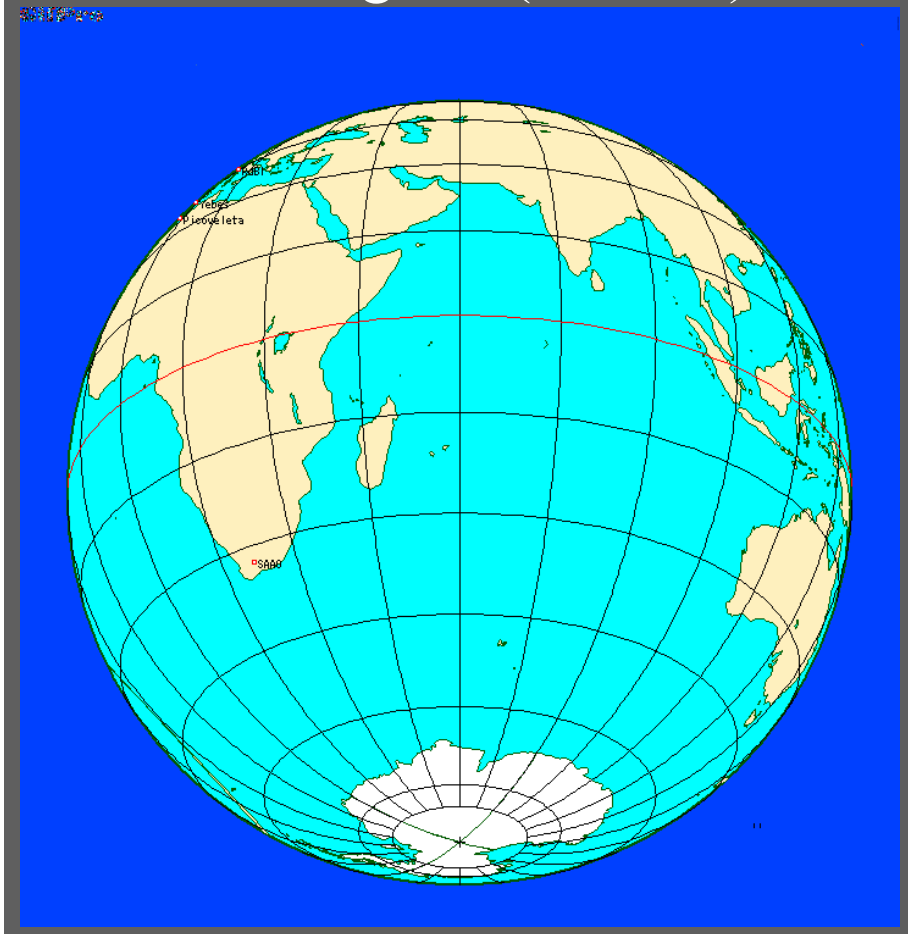
For Black Hole observations

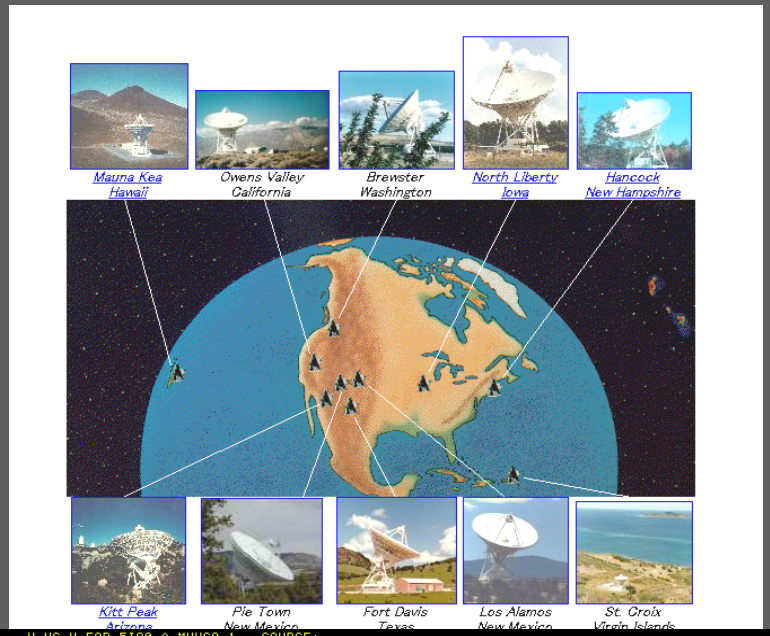
- The most promising source is SgrA*.
- We need sub-millimeter VLBI observations.

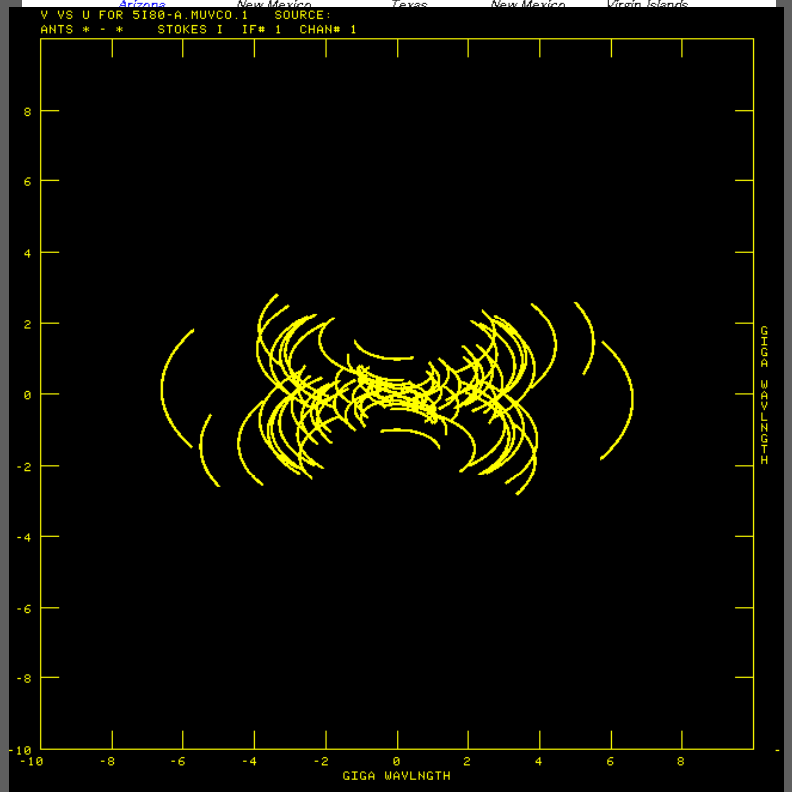
The Earth Rotation seen from SgrA* (δ=-30°)



The Earth Rotation seen from SgrA* (δ=-30°)

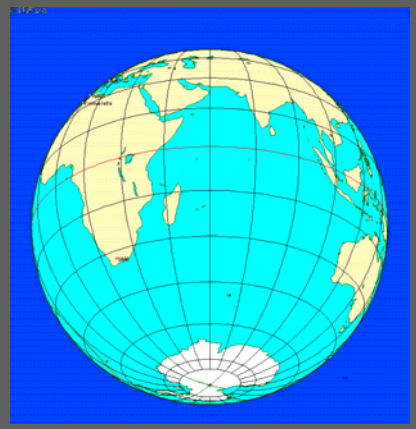


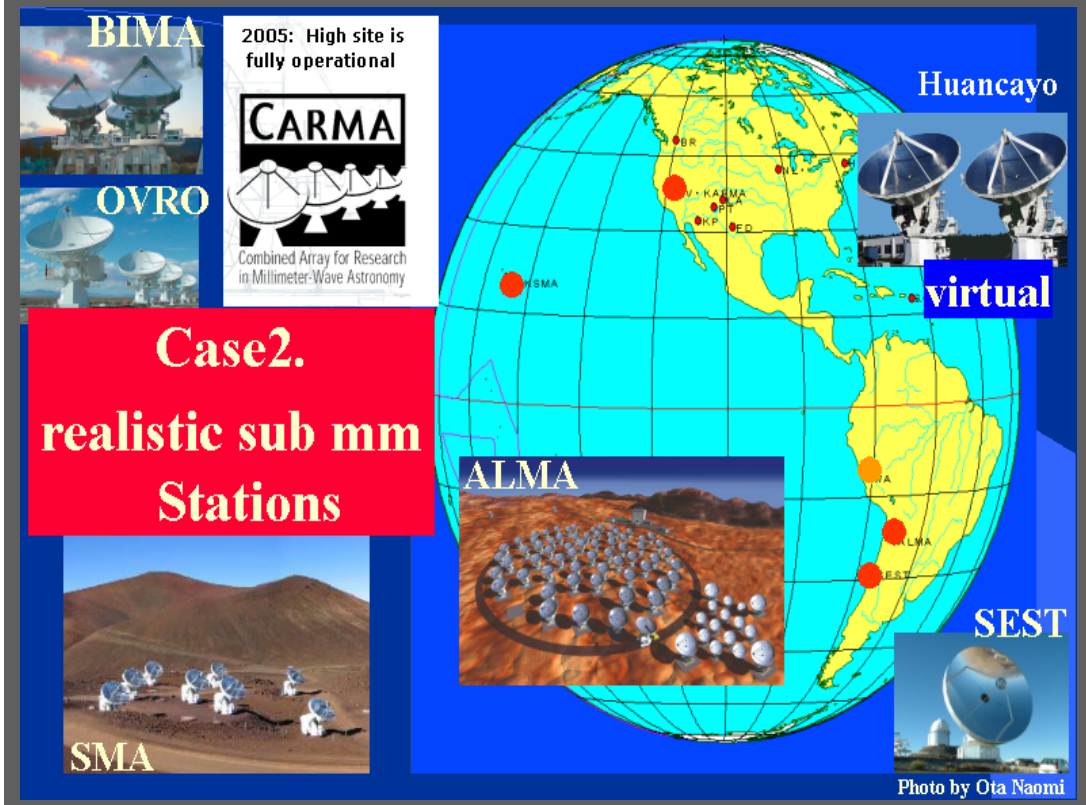




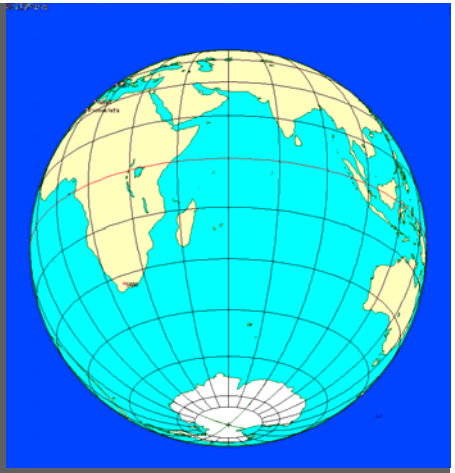
The uv coverage of VLBA seems poor for SgrA*.

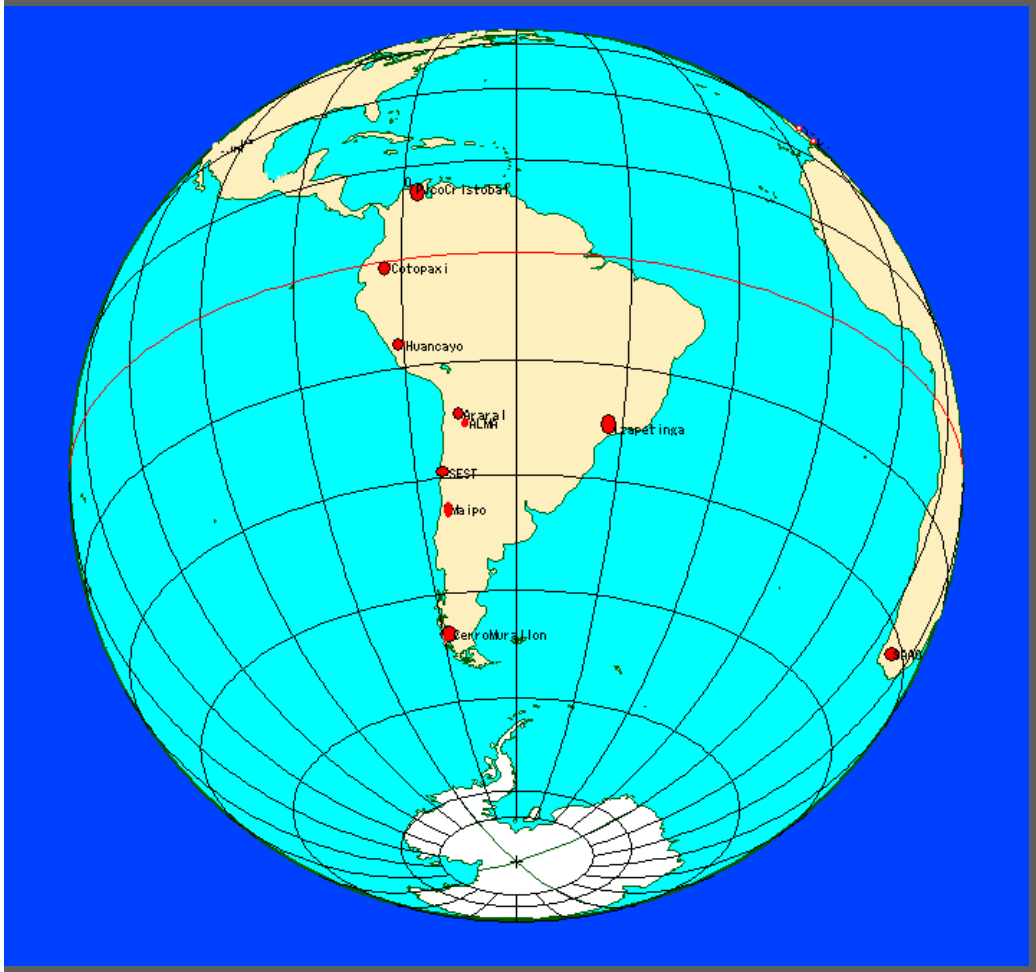
The coverage of a realistic sub-millimeter VLBI array is also poor.

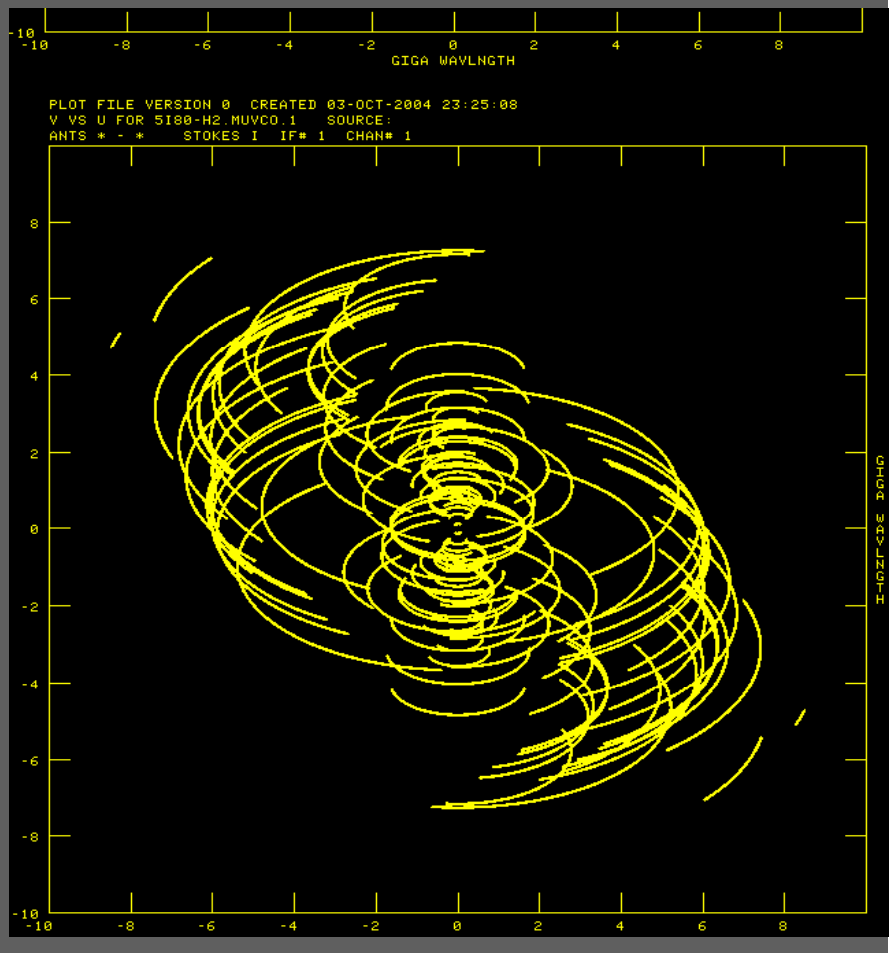




Virtual southern array (10 stations)
The uv coverage seems enough for SgrA* ?

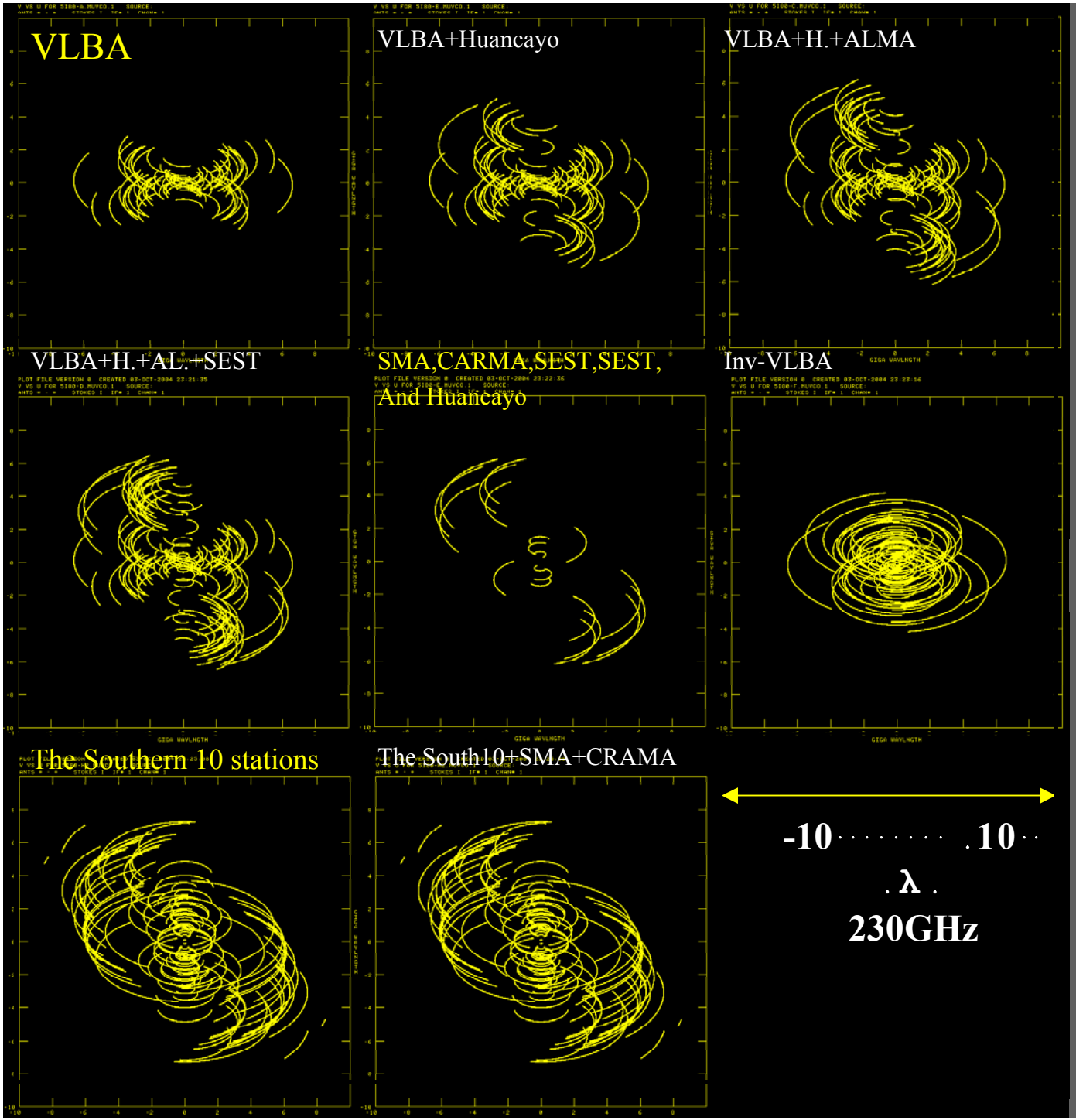




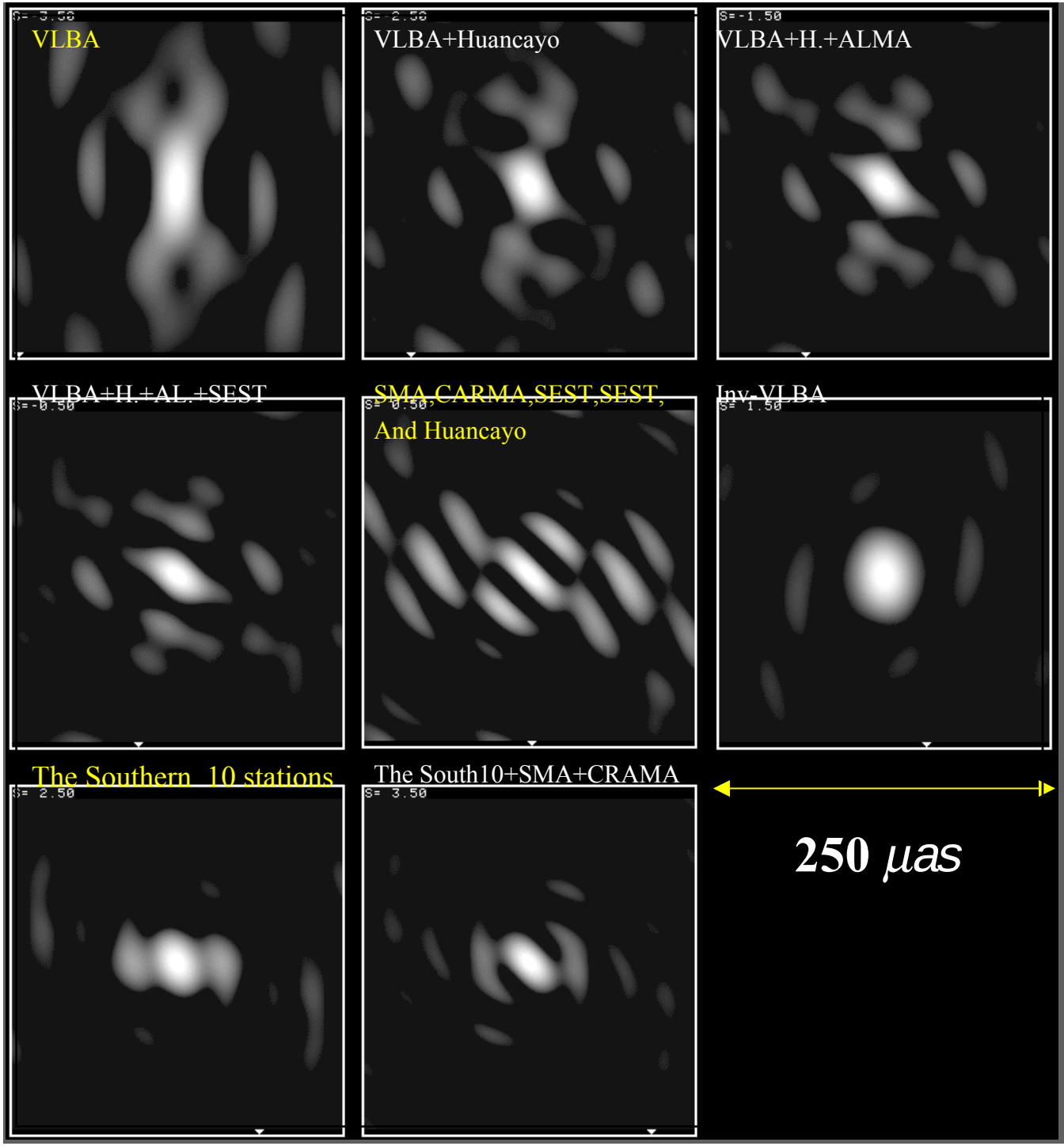


For BH observations

- The most promising source is SgrA*.
- We need sub-millimeter VLBI observations.
- We need the southern hemisphere array for good uv coverage.. L et's check .

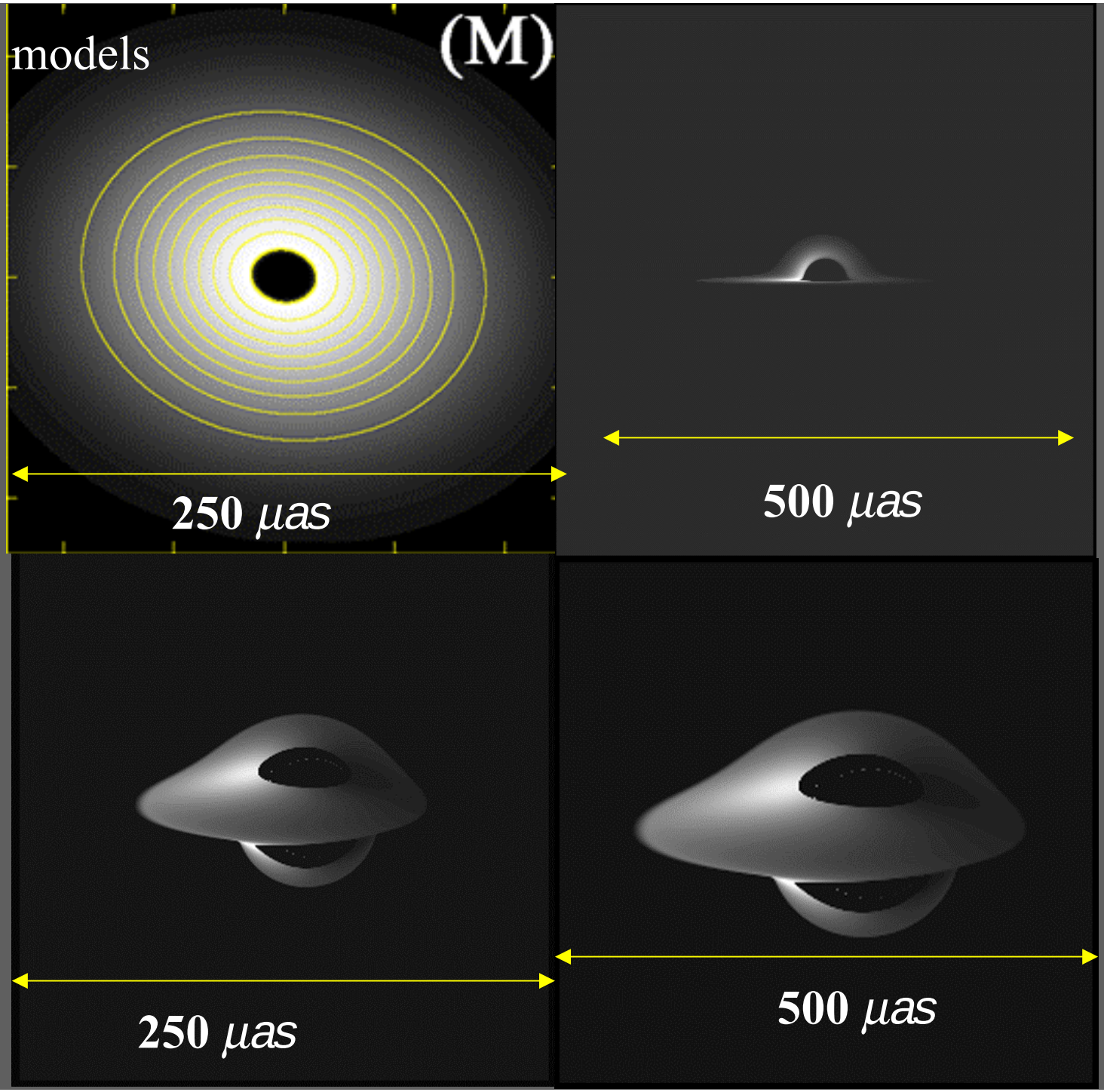


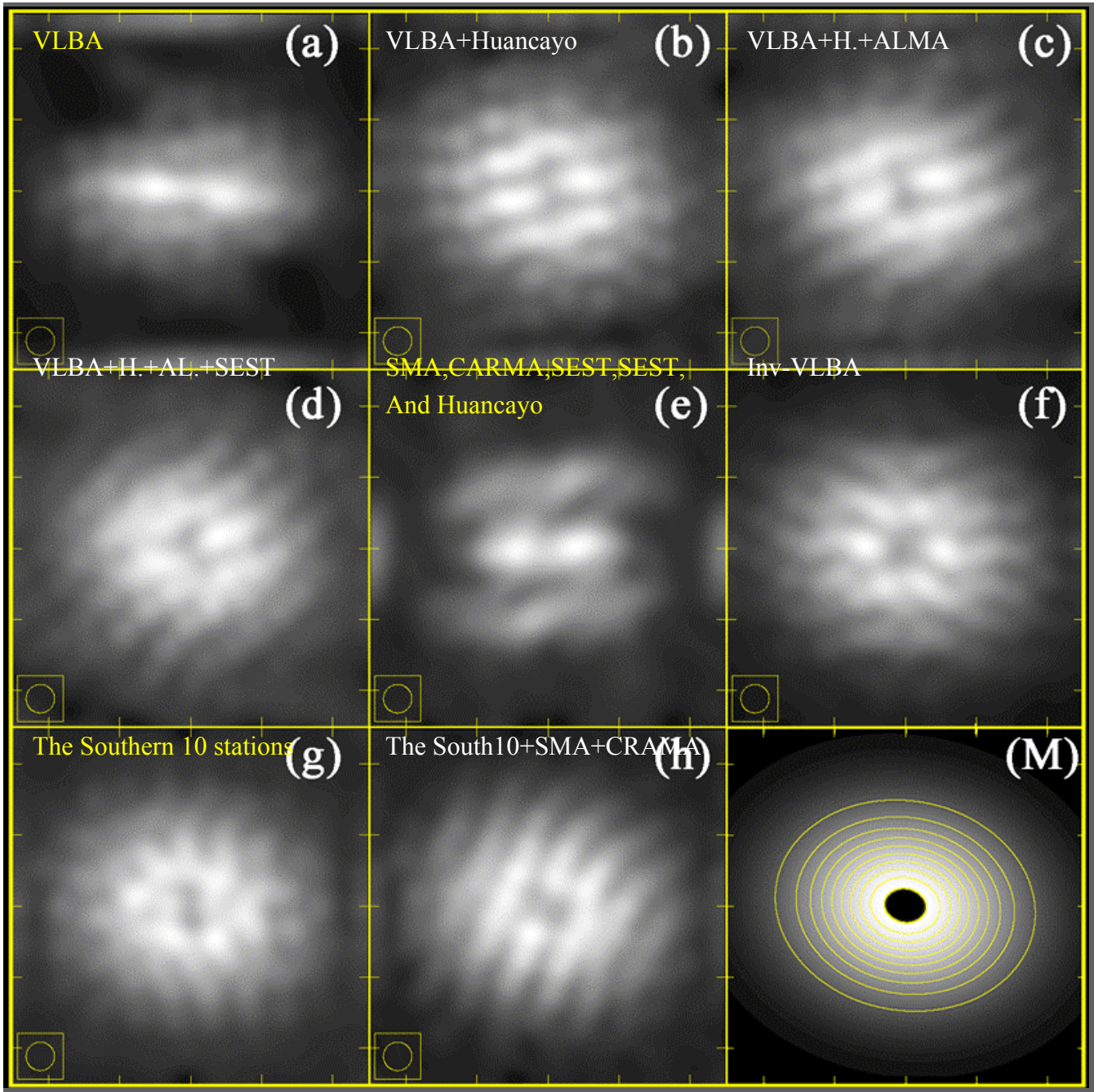
uv Cover
for SgrA*
(δ . . . °



Dirty Beams for SgrA* (δ ° 230GHz

Several image models





Clean simulations for each array -- 1

Model Image 1

Gaussian

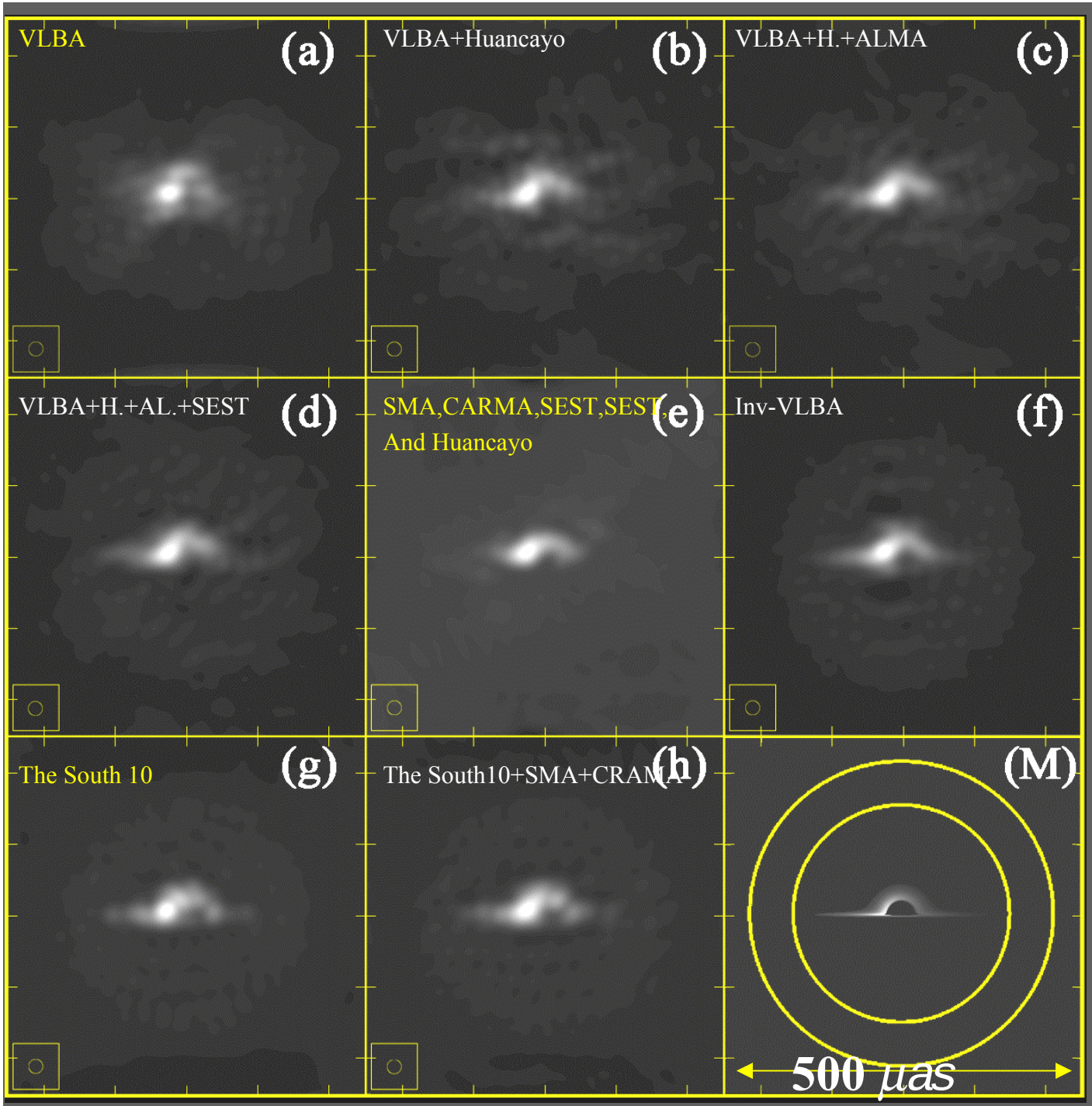
0.1×0.08mas,

PA=80.,f=3Jy

Black Hole Shadow

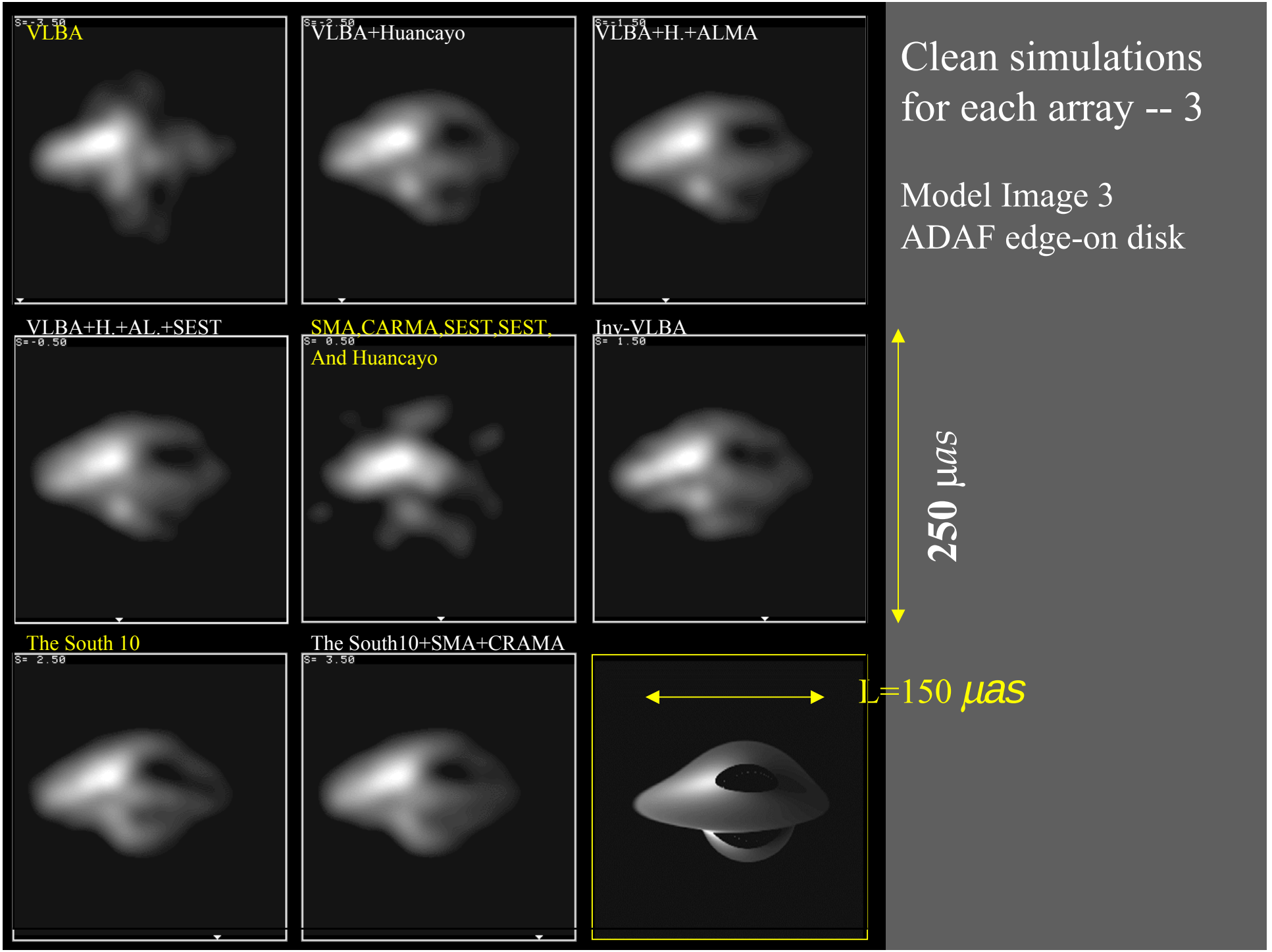
30×24μas . PA=80°

This image model is similar to that of Falcke et al (2000) .



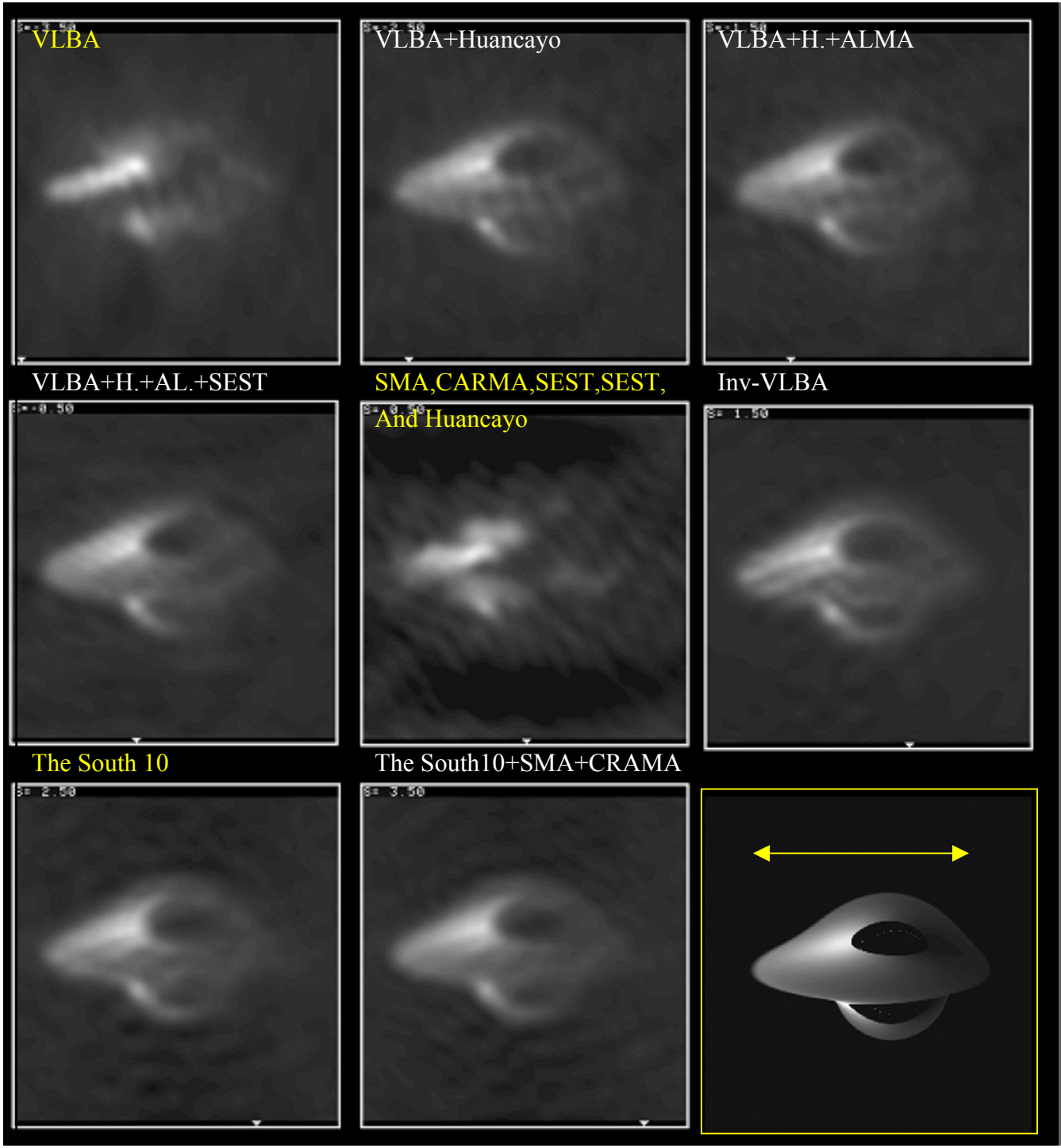
Clean simulations for each array -- 2

Model Image 2
Edge-on Standard disk + dim halo



Clean simulations for each array -- 3

Model Image 3
ADAF edge-on disk



Clean simulations for each array -- 4

Model Image 4
An ADAF edge-on disk (The larger one)

Results of uv simulations

- VLBA-only, small number (<5) of Array are insufficient to get real images.
- VLBA+α. s o uth),. a virtual Southern Array(10 stations) show good quality images.

!In these simulations, every station is assumed to be the same Tsys(=150K), and 12m-dish.

For BH observations

- The most promising source is SgrA*.
- We need sub-millimeter VLBI observations.
- We need the southern hemisphere array for good uv coverage.

1. 10 stations, 8000km extent @230GHz
2. Present arrays located at northern hemisphere are not good for BH imaging of SgrA* imaging---great pity!!.

Sensitivity is already sufficient !

Seinsitibity for Continumm Sources . . . . GH . .

For example,

. D = ...

a.eff.. 70%

. Tsys= . . . K

(almost same as that ofALMA)

. B = ... MH .

. . other loss 30%)

. T = . . . sec

3σnoise .level 30mJy attainable

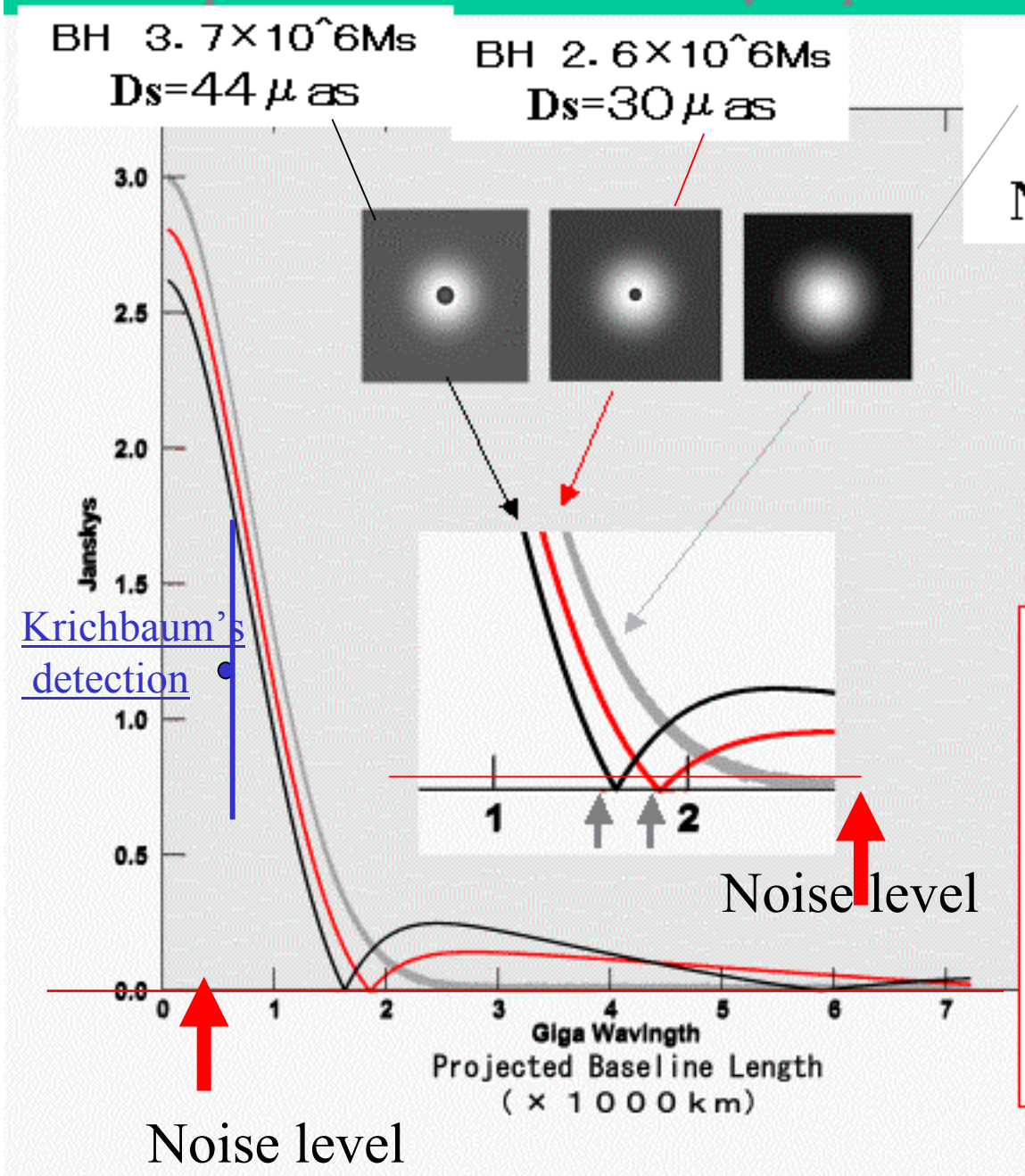
(Flux density of SgrA* at 230GHz is about 3 Jy)

D(m)	Eff	Tsys(K)	T(sec)	B(MHz)	3sigma(Jy)
10	0.6	200	10	1000	0.2029
10	0.6	200	10	10000	0.0642
12	0.6	200	10	10000	0.0446
12	0.7	150	100	10000	0.0091
15	0.7	150	100	10000	0.0058
12	0.7	150	100	1000	0.0287
12	0.7	150	50	20000	0.0091
12	0.7	450	100	10000	0.0272
12	0.6	450	100	10000	0.0317
12	0.6	450	50	20000	0.0317

•. Much Higher A/D sampler than 10-20GH .
. will come soon. So the sensitivity will not matter.

! Coherence time limitation due to atmosphere should be overcome with some technique --- Fast SW, Paired antenna, Self calibration, something else!

An Example of the relation of Visibility Amplitudes and Structure of SgrA＊ (230GHz)

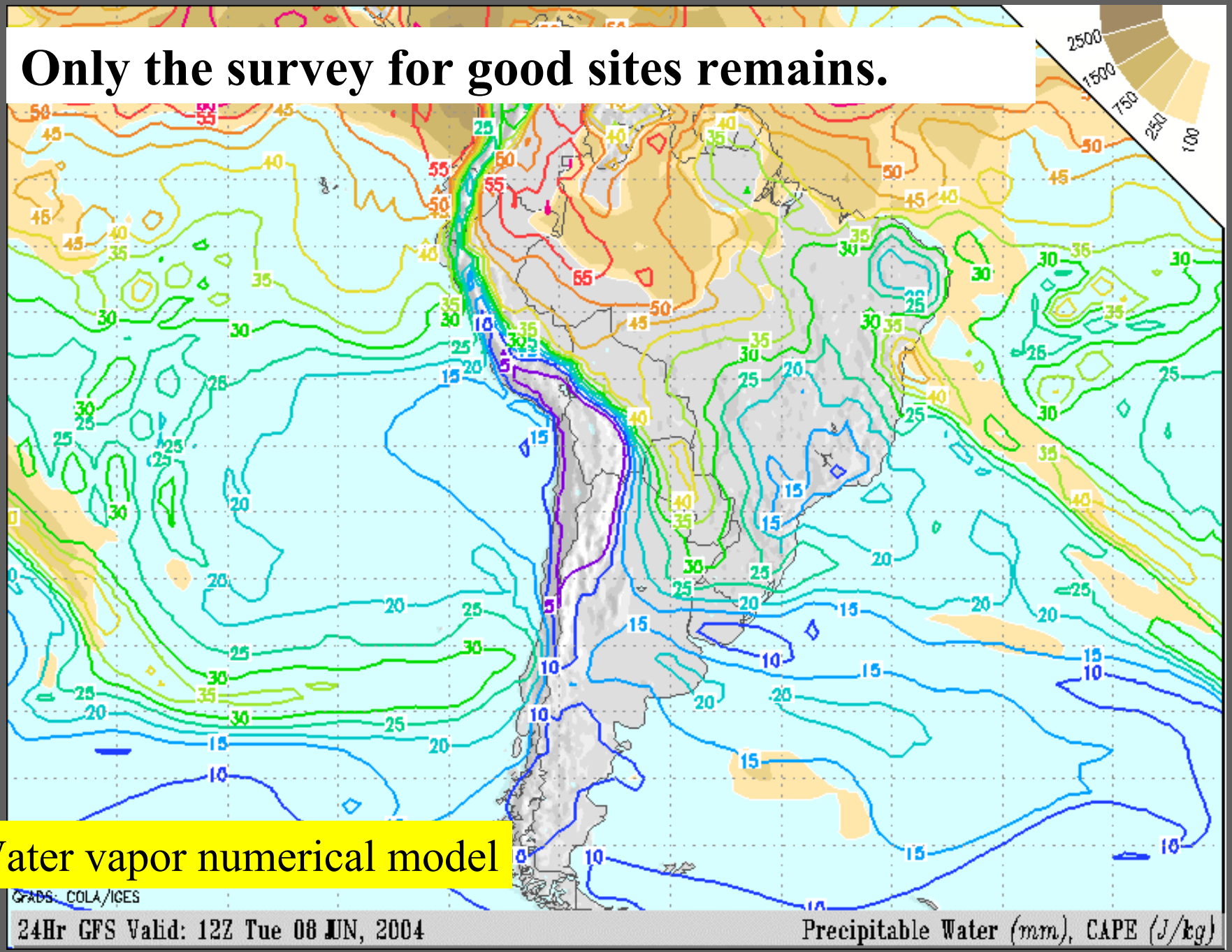


For BH observations by VLBI

- The most promising source is SgrA*.
- We need sub-millimeter VLBI observations.
- We need the southern hemisphere array for good uv coverage.

  10 stations, 8000km extent @230GHz.
- The required sensitivity is already attainable from the viewpoint of technology.
- We need good sites like that of ALMA for sub-millimeter VLBI array.

Only the survey for good sites remains.



Water vapor numerical model

For BH observations by VLBI

- The most promising source is SgrA*.
- We need sub-millimeter VLBI observations.
- We need the southern hemisphere array for good uv coverage for SgrA*.

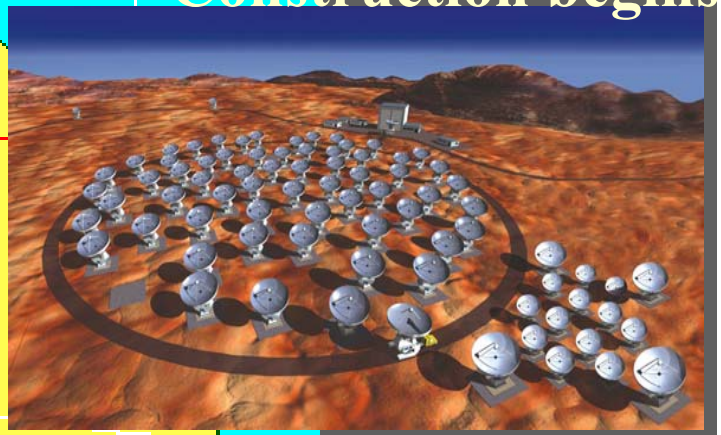
  10 stations, 8000km extent @230GHz.
- The required sensitivity is already attainable from the viewpoint of present technology.
- We need good sites like that of ALMA for sub-millimeter VLBI array.

Old 32m communication antenna

Huancayo

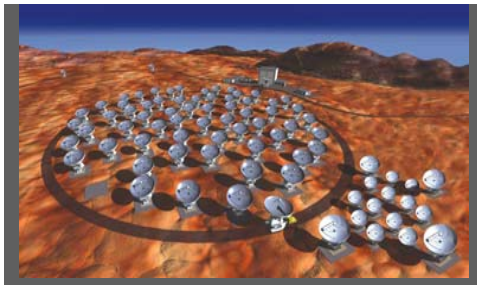
It is very serious situation for sub-mm VLBI if the SEST is really lost ！

Construction begins



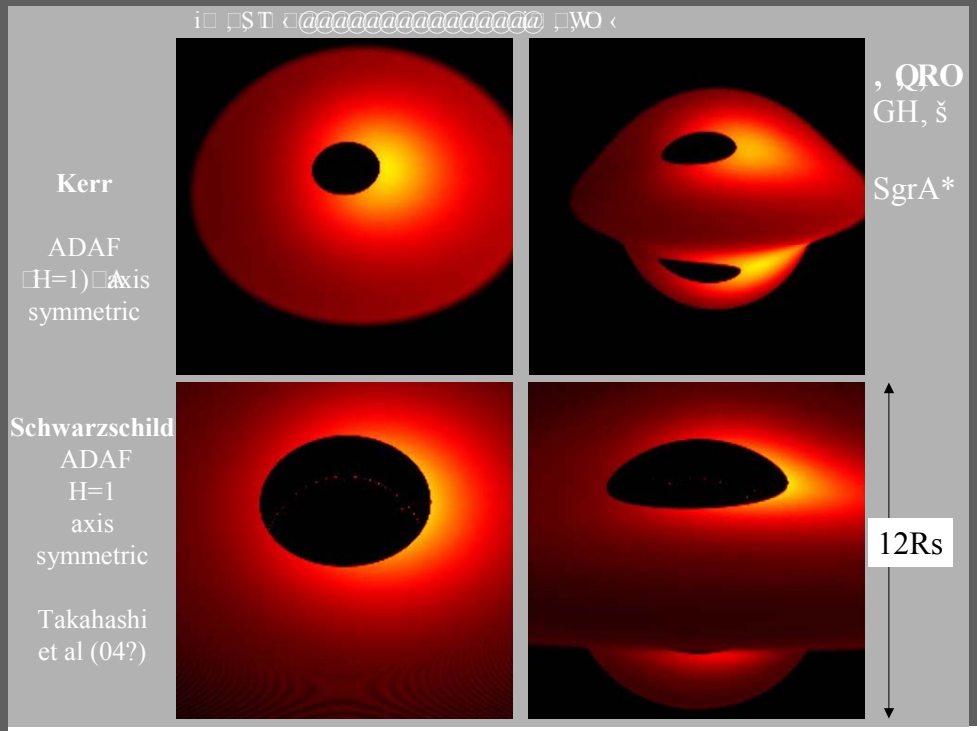
Since 1987

Photo by Ota Naomi



Conclusions

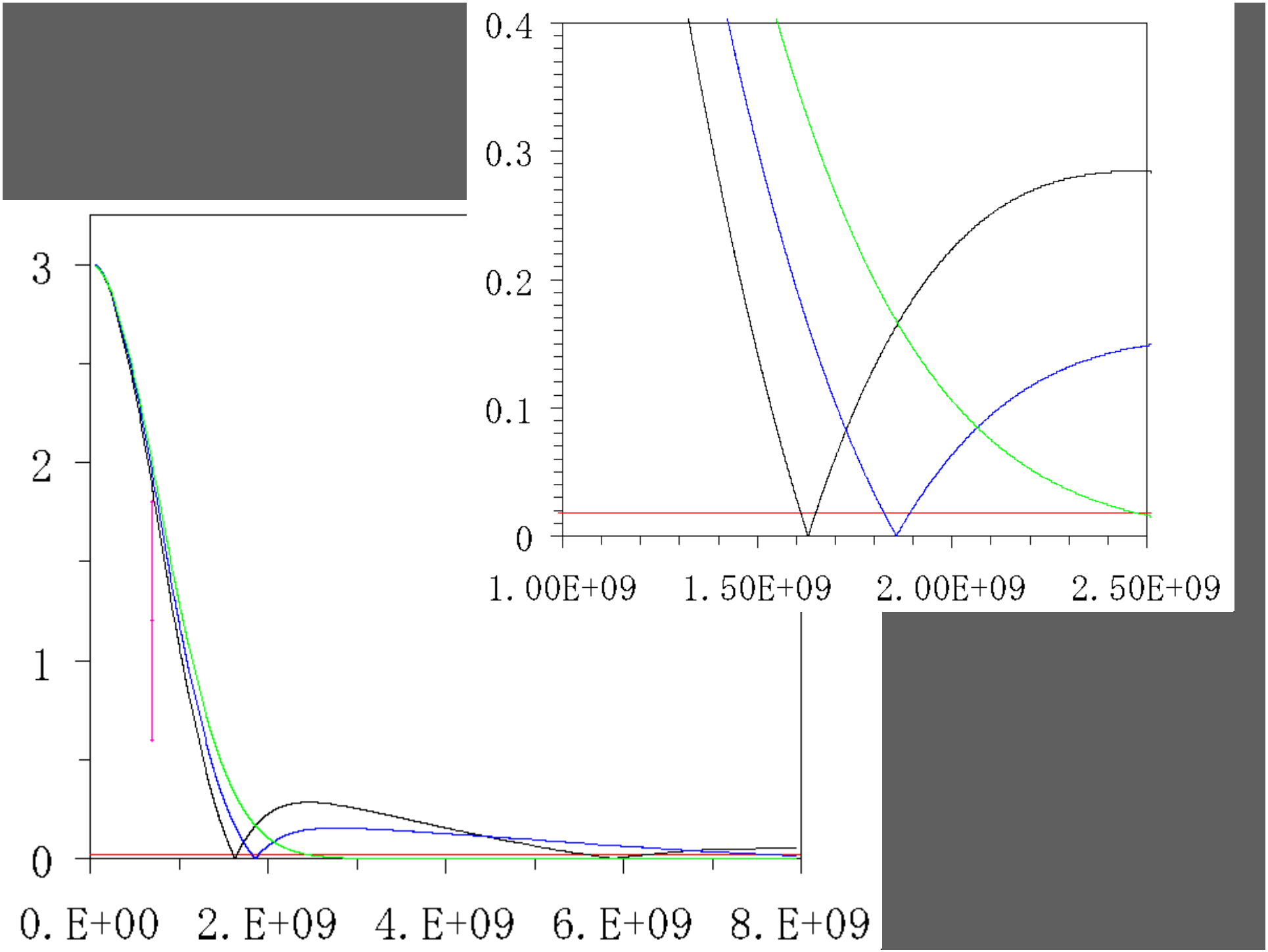
So Let's Start sub-mm VLBI at the Southern Hemisphere at once!



SgrA* image at 230GHz <u>from simulation</u>

(Takahashi et al. in preparations)

Thanks.


0.4
0.3
0.2
0.1
0
1.00E+09
1.50E+09
2.00E+09
2.50E+09
3
2
1
0
0. E+00
2. E+09
4. E+09
6. E+09
8. E+09