The Galactic Center: From the Black Hole to the Minispiral

Jim Moran
Harvard-Smithsonian Center for Astrophysics

Institut d'Astrophysique de Paris and Observatoire de Paris
October 8, 2010

The Galactic Center on Three Size Scales

1. Circumnuclear (molecular) Disk (CND) and Minispiral (ionized streamers)
   120 arcs / 5 pc
   Zhao, Blundell, Downes, Schuster, Marrone
2. Black hole accretion envelope (100 R_s)
   1 mas / 0.3 micro pc
   Marrone, Munoz, Rao
3. SgrA* radio source
   37 microarcseconds / 0.01 microparsec
   Doeleman et al.

Submillimeter Valley, Mauna Kea, HI

CSO
10 m single dish
(79 m^2)

JCMT
15 m single dish
(177 m^2)

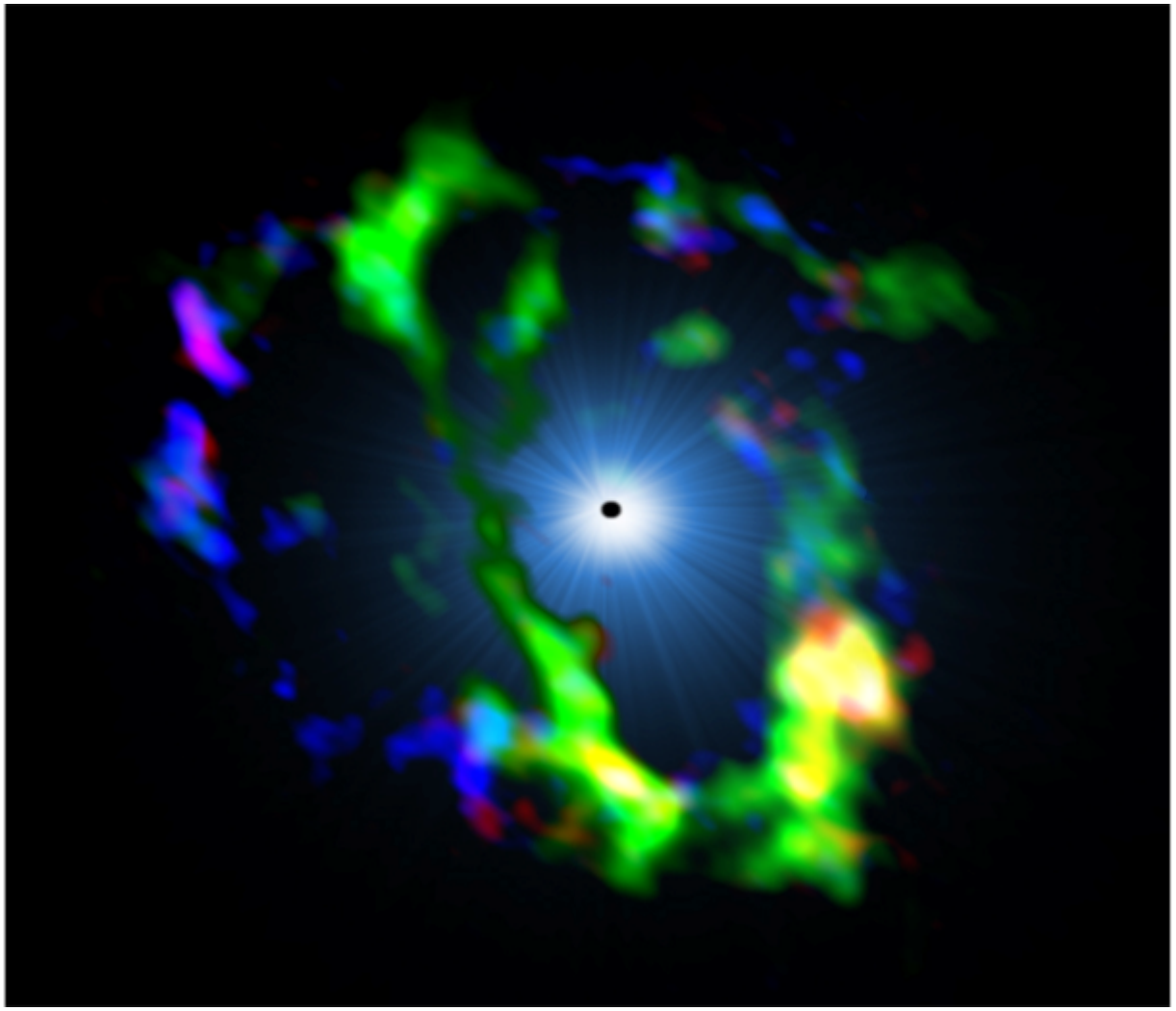
SMA
eight 6 m dishes
(compact configuration)
(226 m^2)

(aggregate area 482 m^2
equivalent of 25 m aperture)


© Leigh Hilbert 2006


Left
Rear
Right
Rear

Nine-Field Mosaic Image of Circumnuclear Disk in Galactic Center



CN

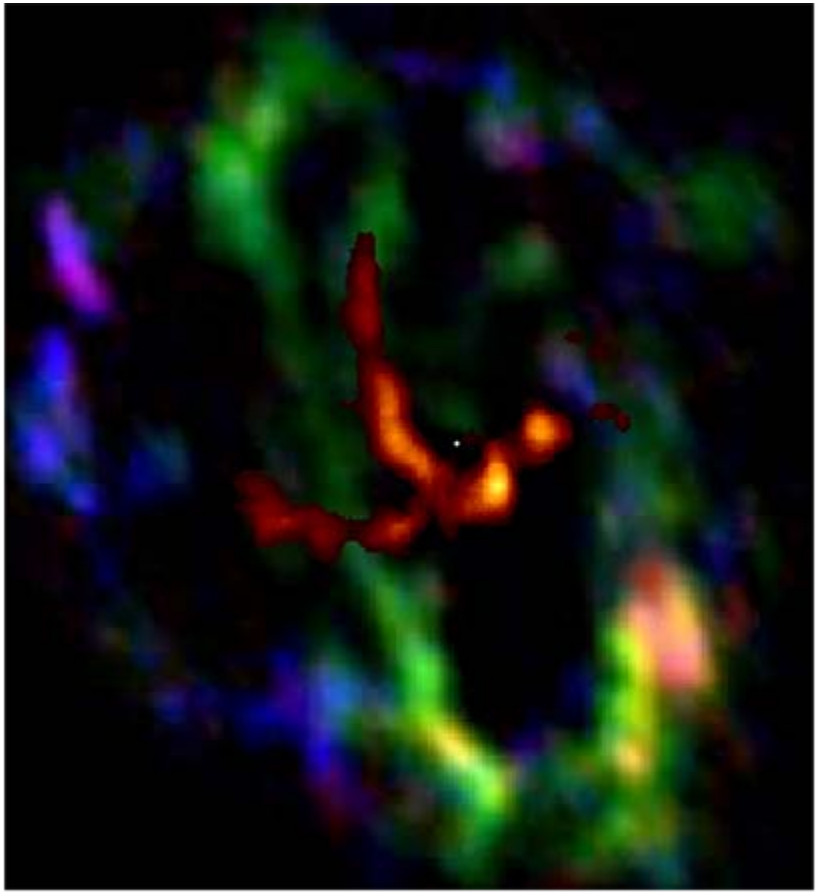
H_2CO

SiO

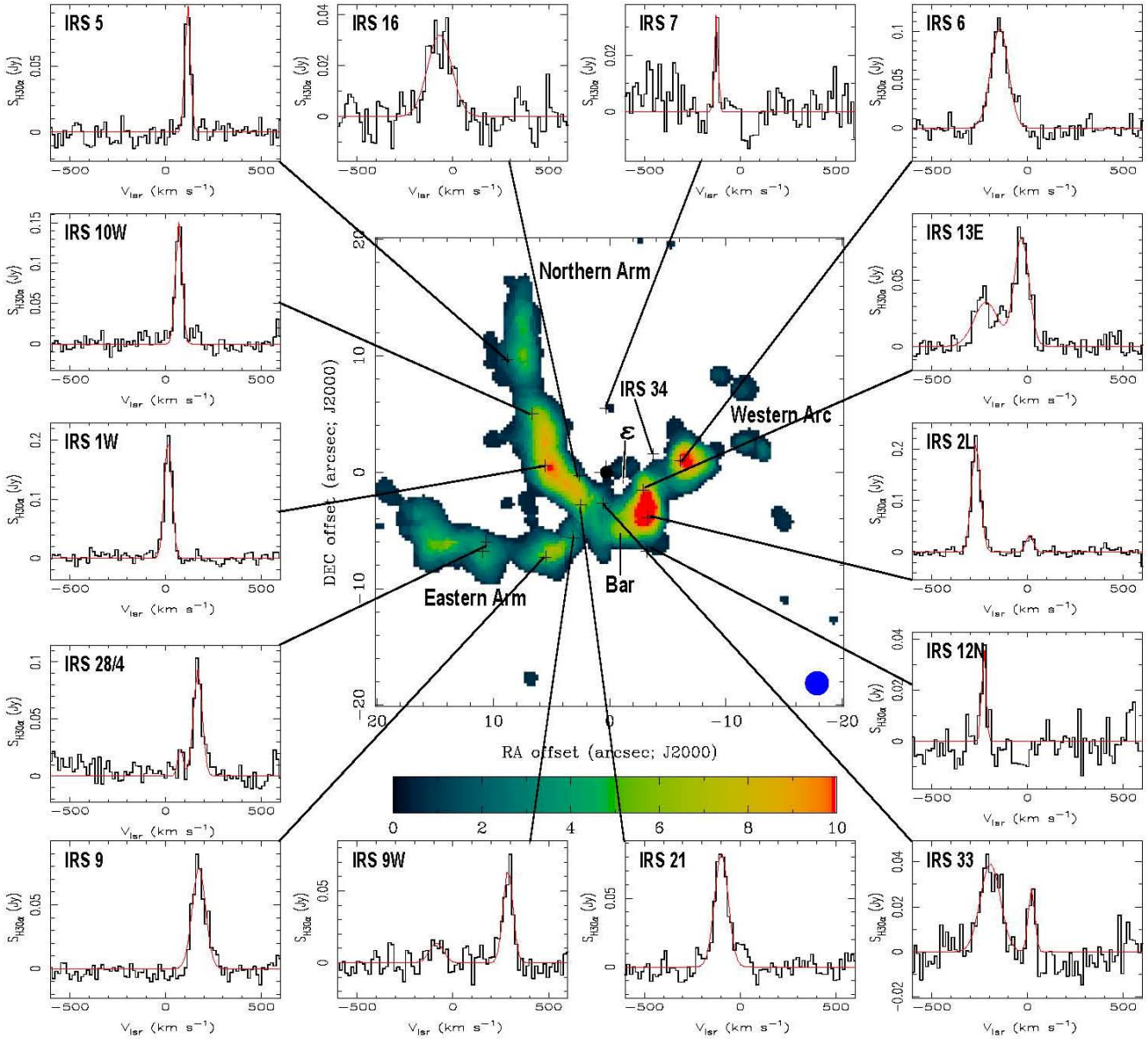
SMA Data
Sergio Martin Ruiz

5 arcmin field
3 arcs resolution
1.3 mm
wavelength

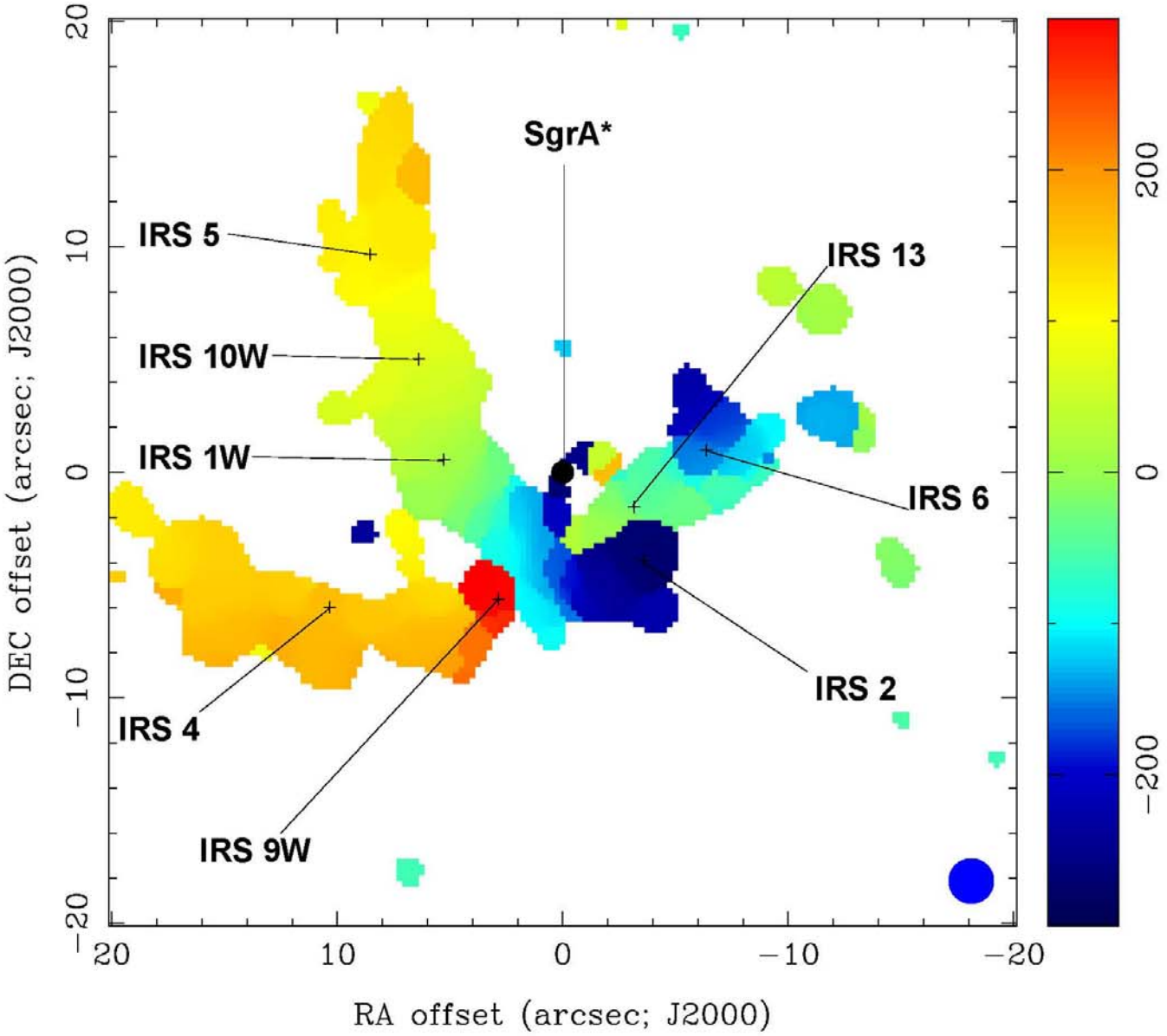
Galactic Center CND with 230 GHz Continuum from Ionized Minispiral



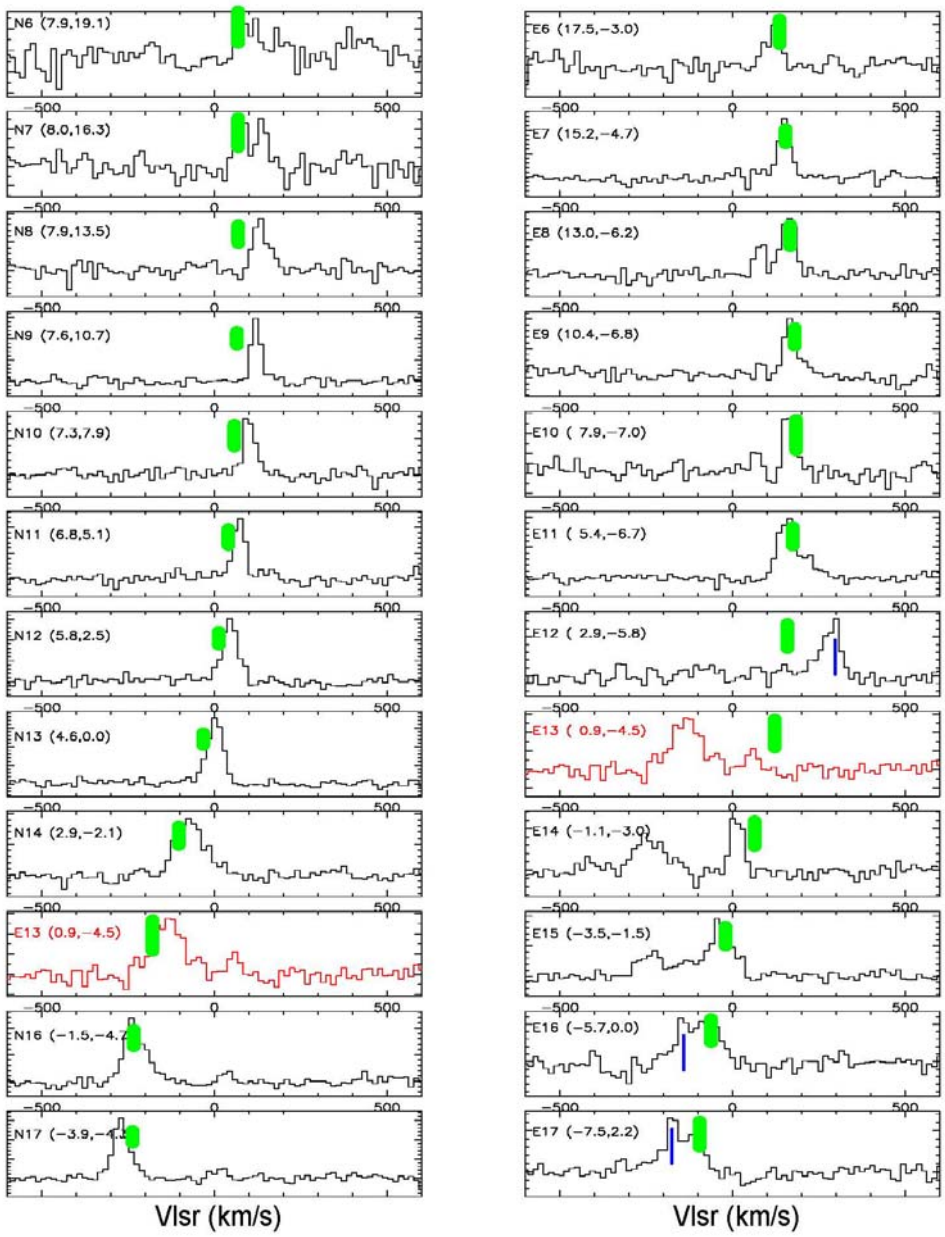
H30α Recombination Line at Prominent Locations



Velocity Distribution of Gas Traced by H30α Emission

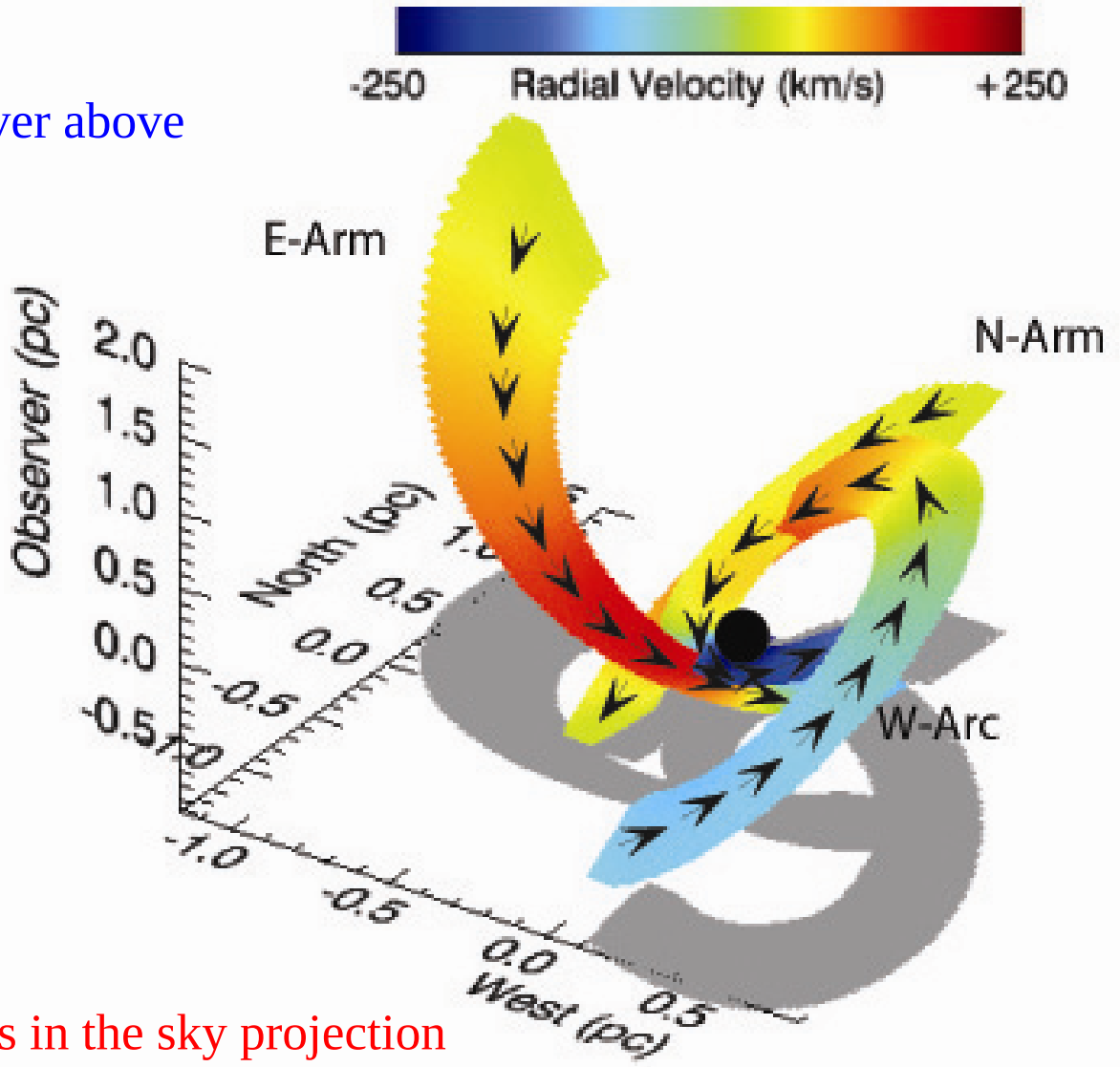


Keplerian Radial Velocity Model



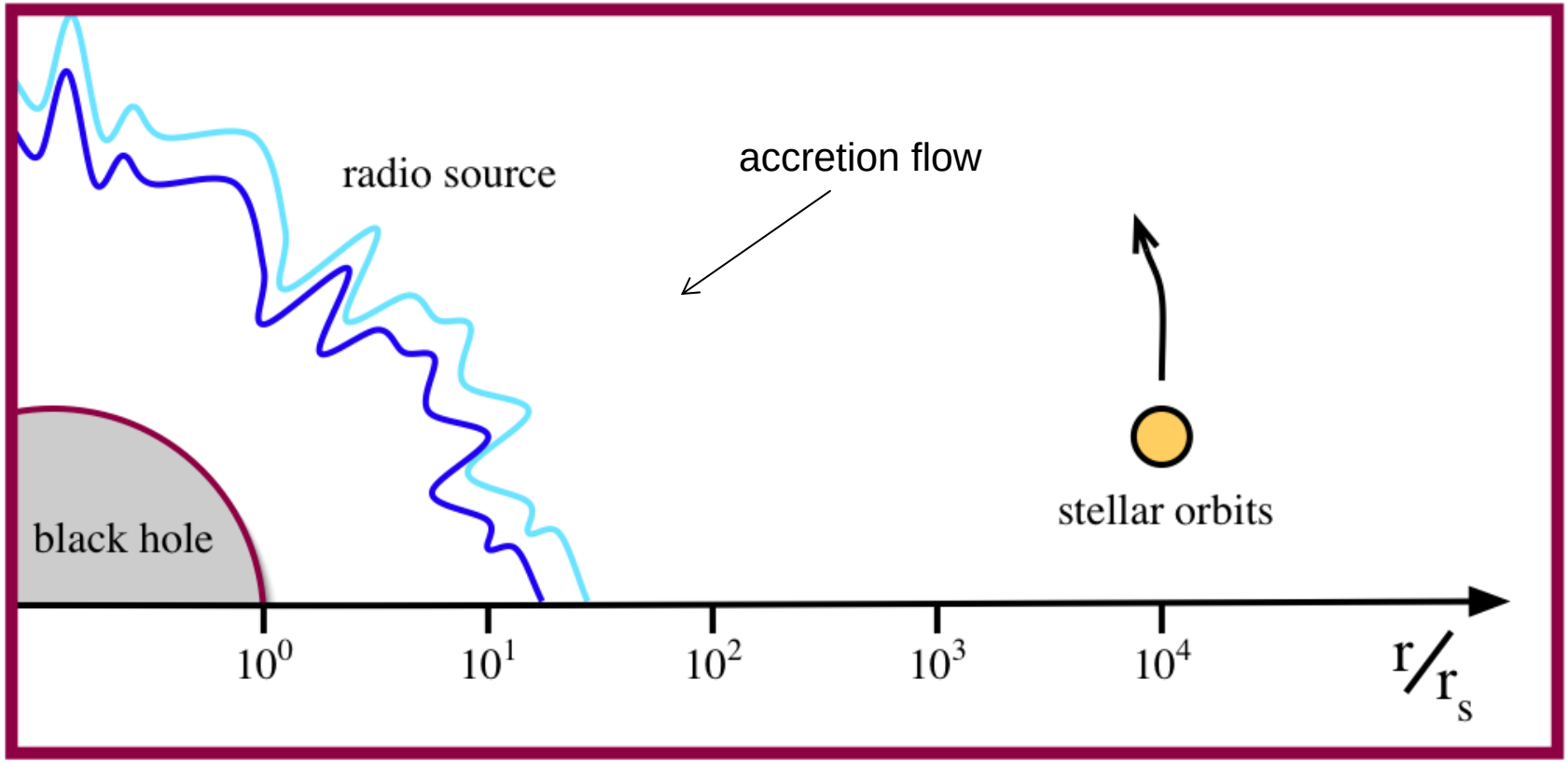
Three-Dimensional Geometry of Minispiral Arms

Observer above



Gray image is in the sky projection

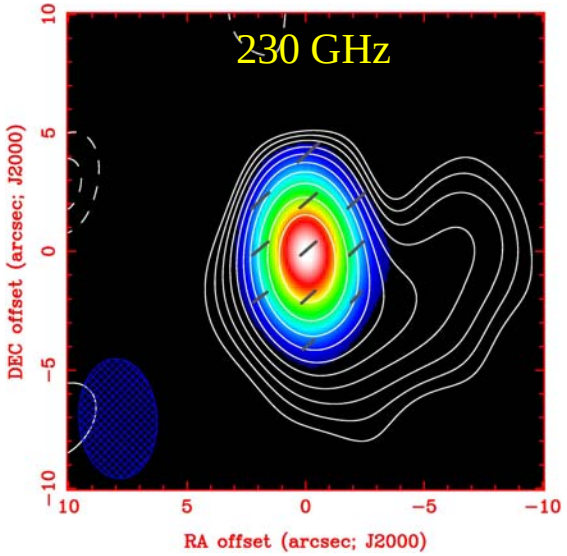
Some Scales in the Galactic Center

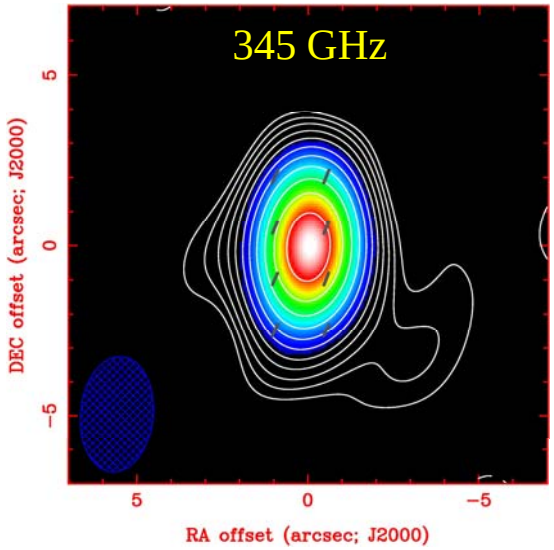


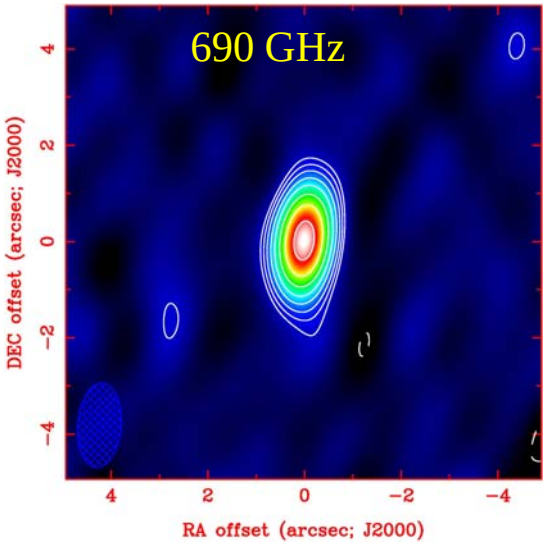
$r_s = 1.3 \times 10^{12}$cm (for 4.3×10^6 solar masses) $= 10\mu$as at 8.3 kpc

A Hungry Black Hole

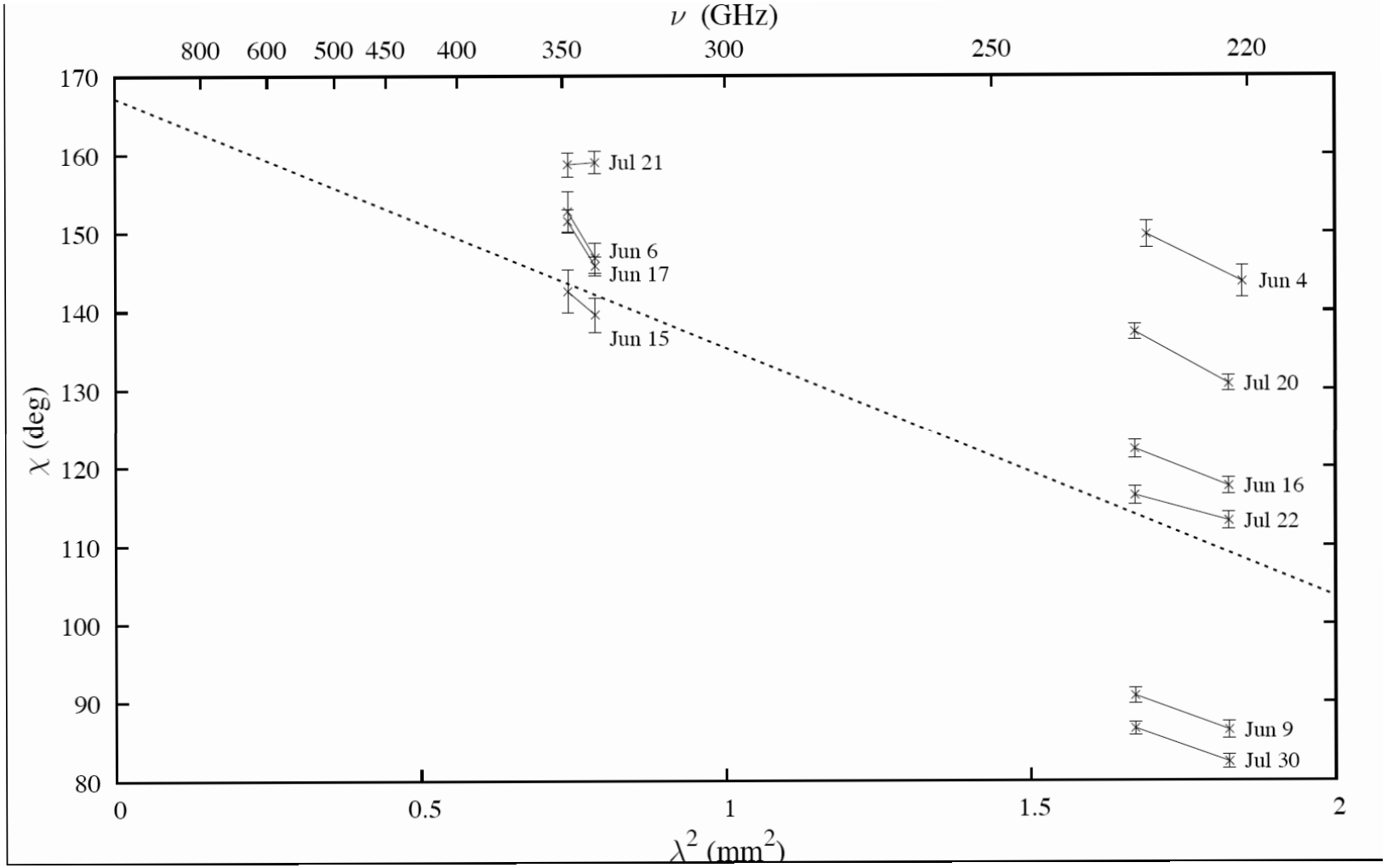
Polarization Images at Various Wavelengths from the SMA







2005 SMA Measurements of Faraday Rotation in Sgr A*



Accretion Rate and Faraday Rotation

$$\chi(\lambda,t) = \chi_0(t) + \lambda^2 RM(t)$$

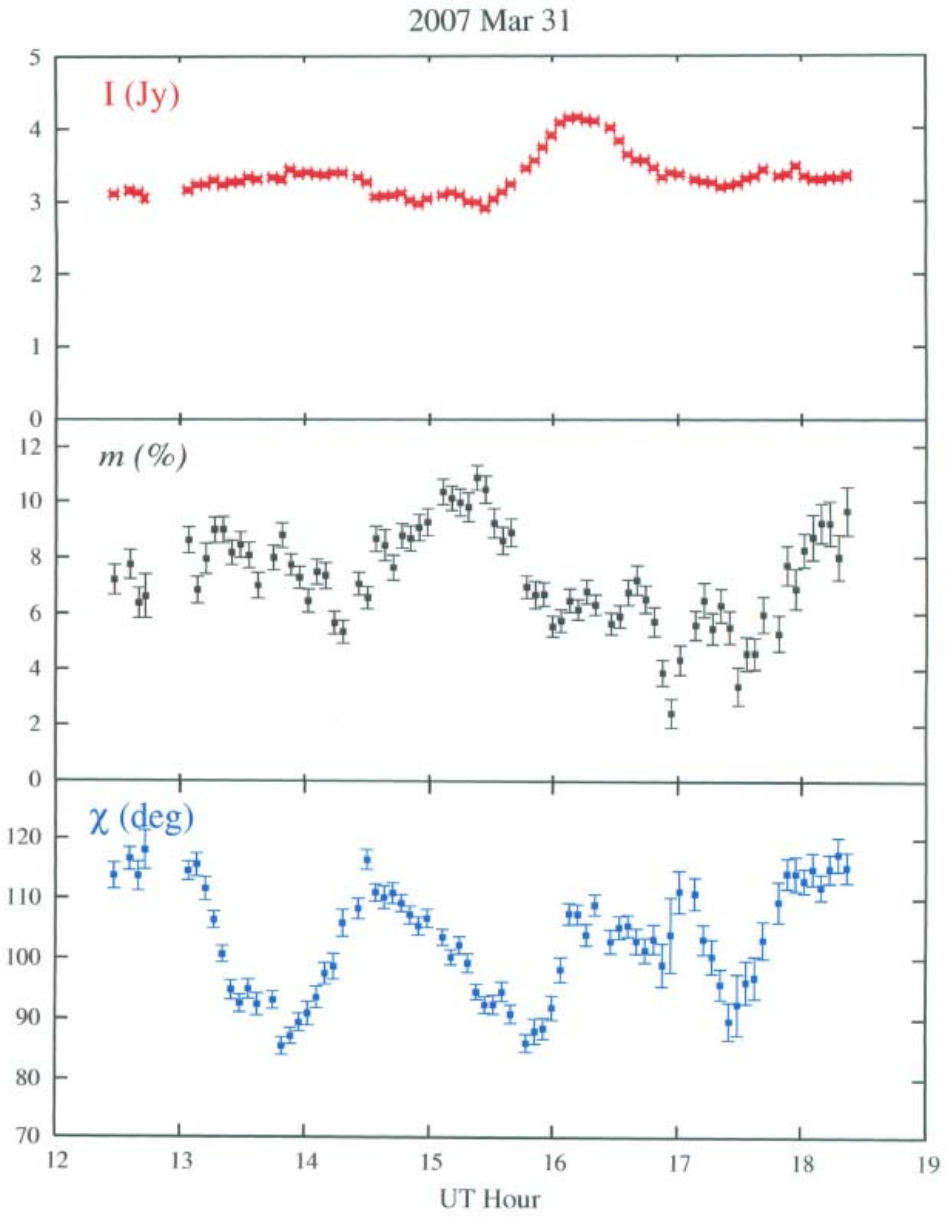
$$RM = 8.1 \times 10^5 \int n_e \overline{B} \cdot \overline{dl}$$

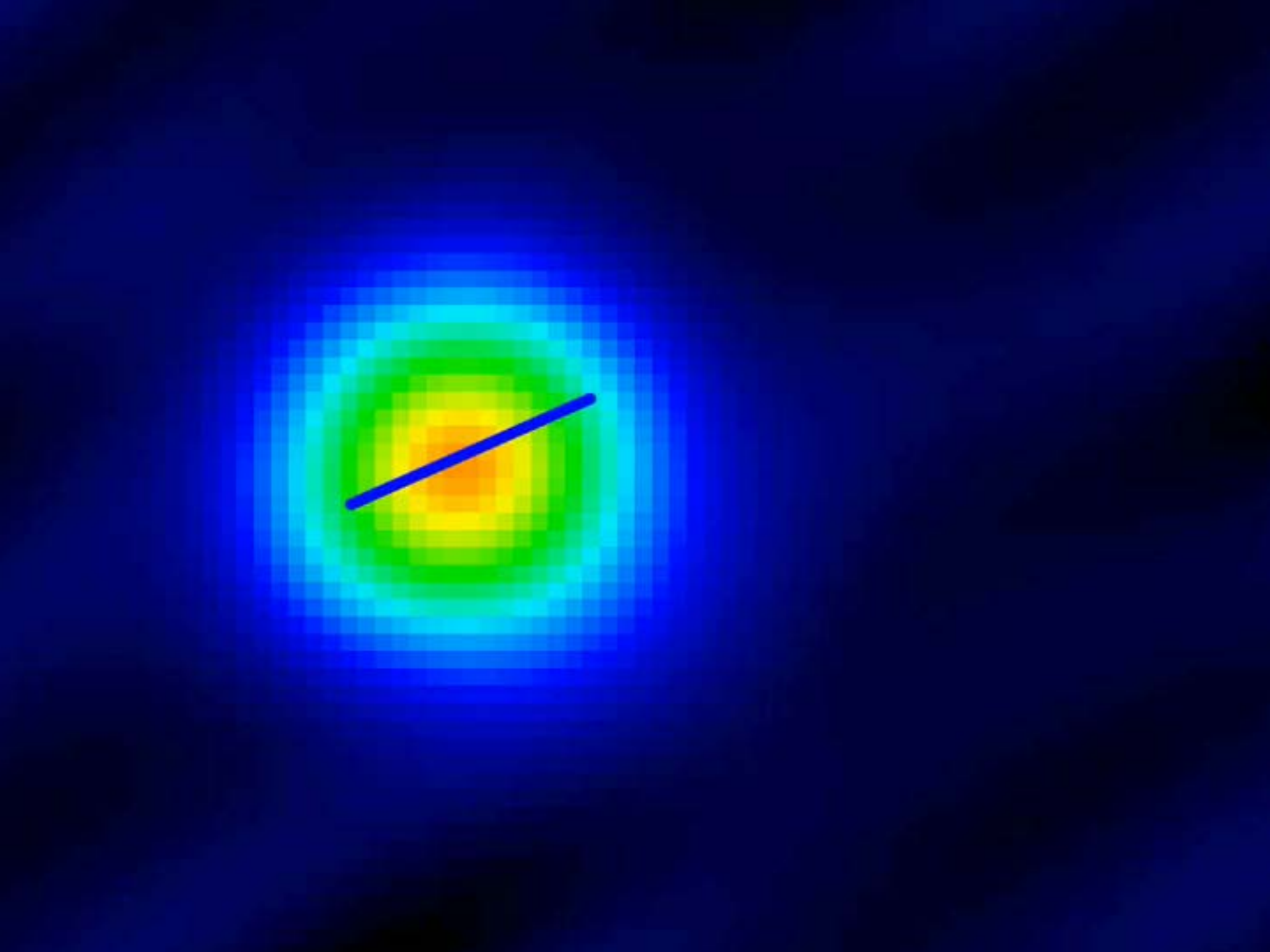
$RM = -5.1 \times 10^5$ rad/m^2

Assumptions
- equipartition
- density power law
- inner radius cutoff of Faraday screen

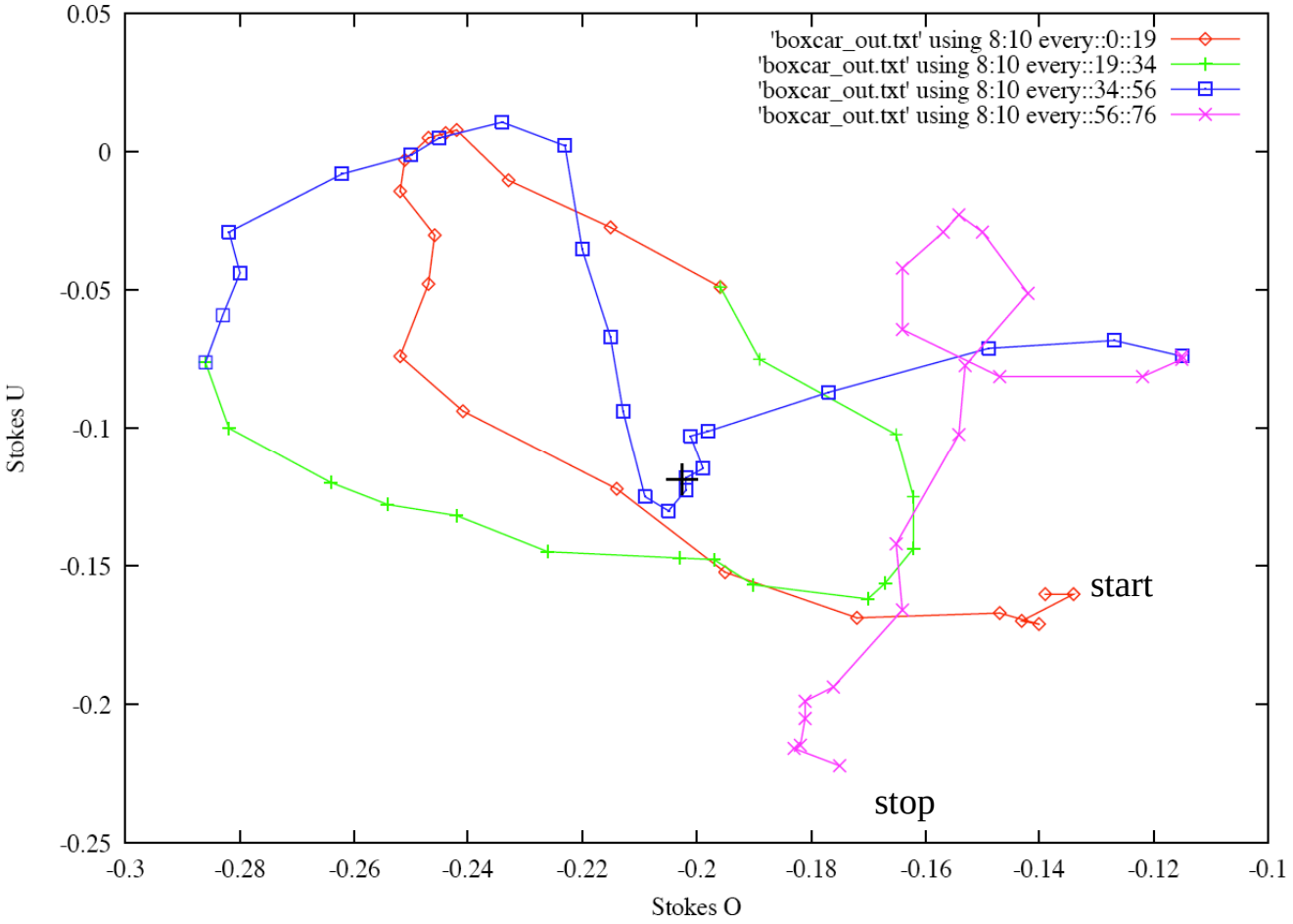
Accretion rate = 10^{-9}–10^{-7} M_{Sun}/yr

Polarization of Sgr A* at 230 GHz (1.3 mm) (SMA)

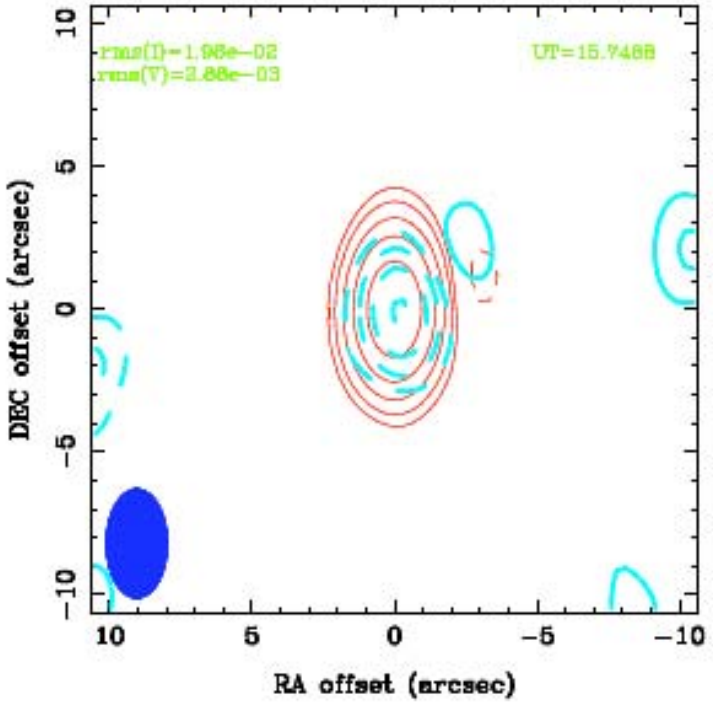




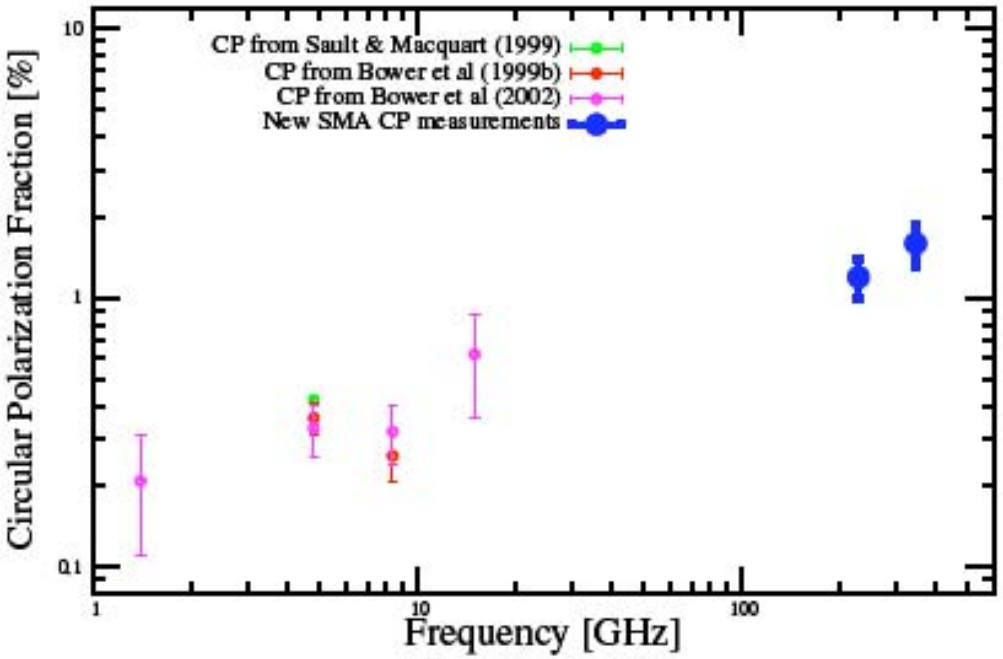
Polarization Track for 3/31/07 Observation of SgrA*



Circular Polarization of Sgr A*



(red) Stokes I
(blue) Stokes V

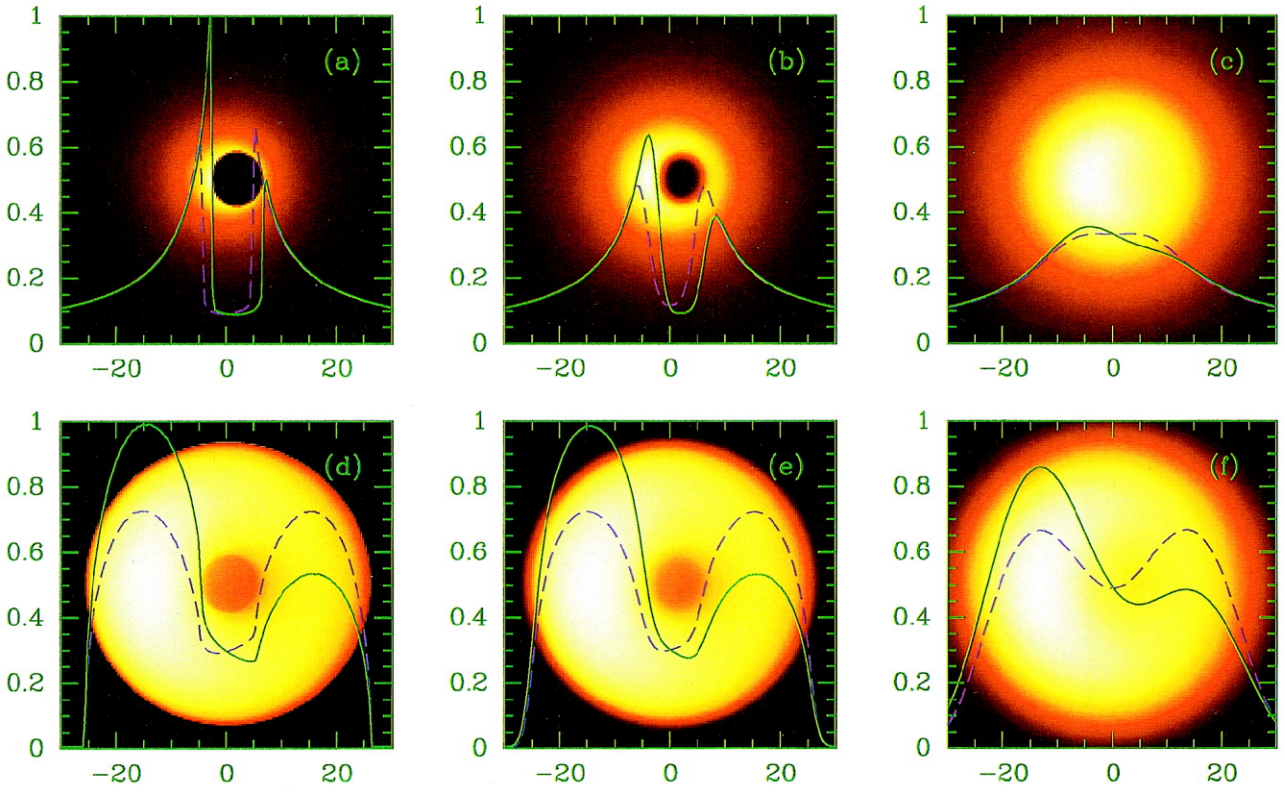


Fractional Circular Polarization
vs. Frequency

Emission Models for SgrA*

Free Fall onto Rotating BH

Orbiting Gas and Nonrotating BH



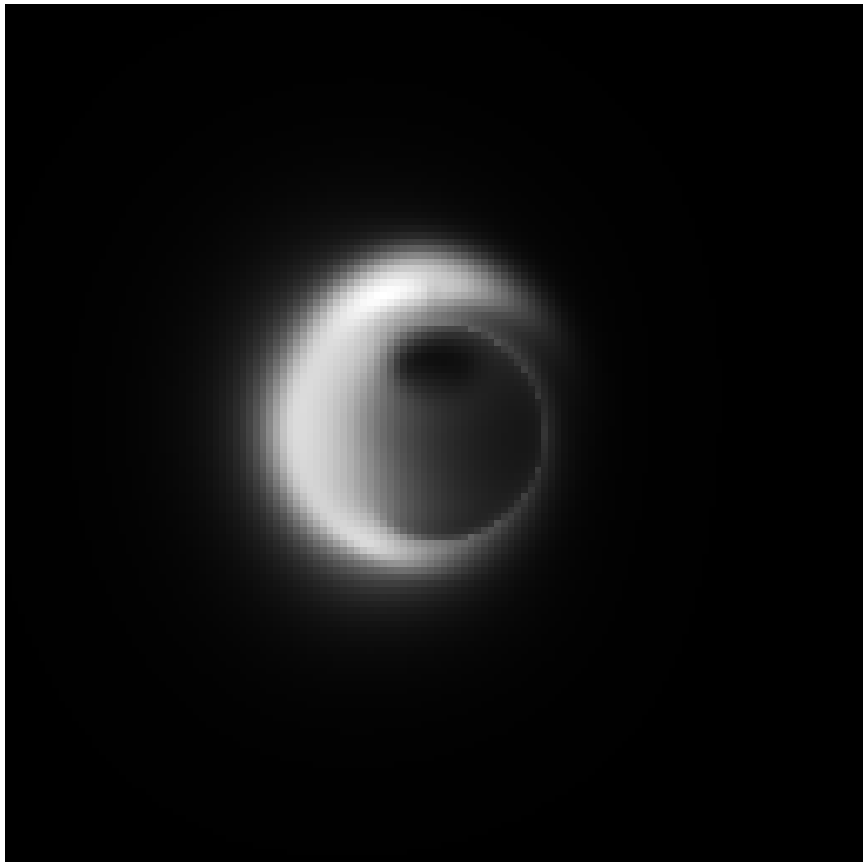
GR Code | 0.6mm VLBI | 1.3mm VLBI

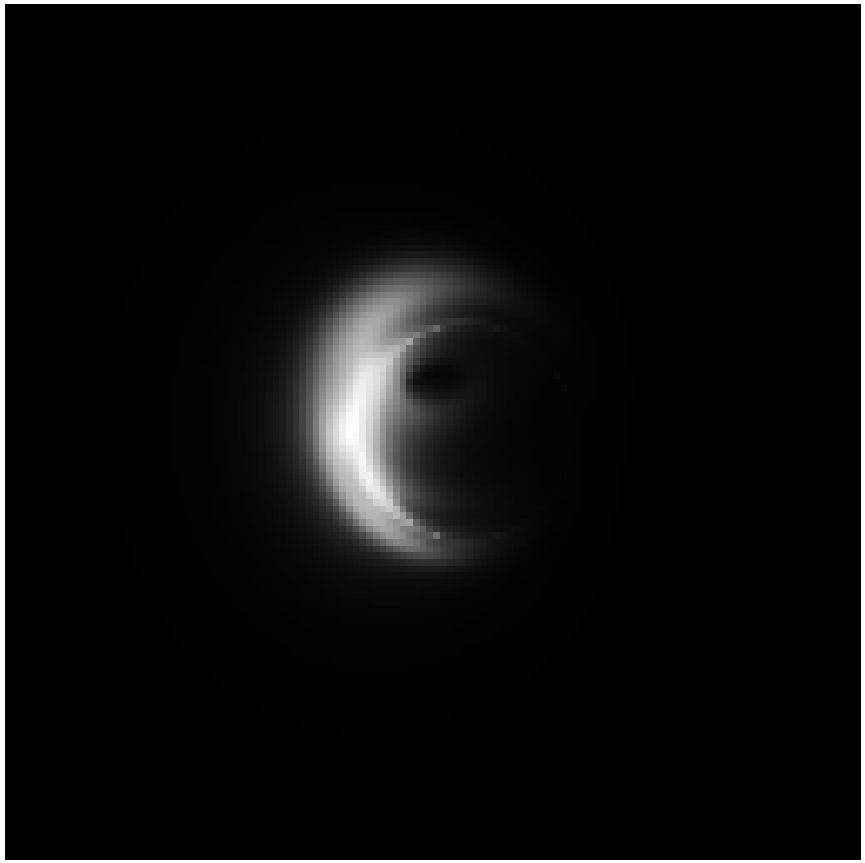
Falcke et al.

Hot Spot Models (P = 27 min)

230 GHz, ISM scattered

Models: Broderick & Loeb

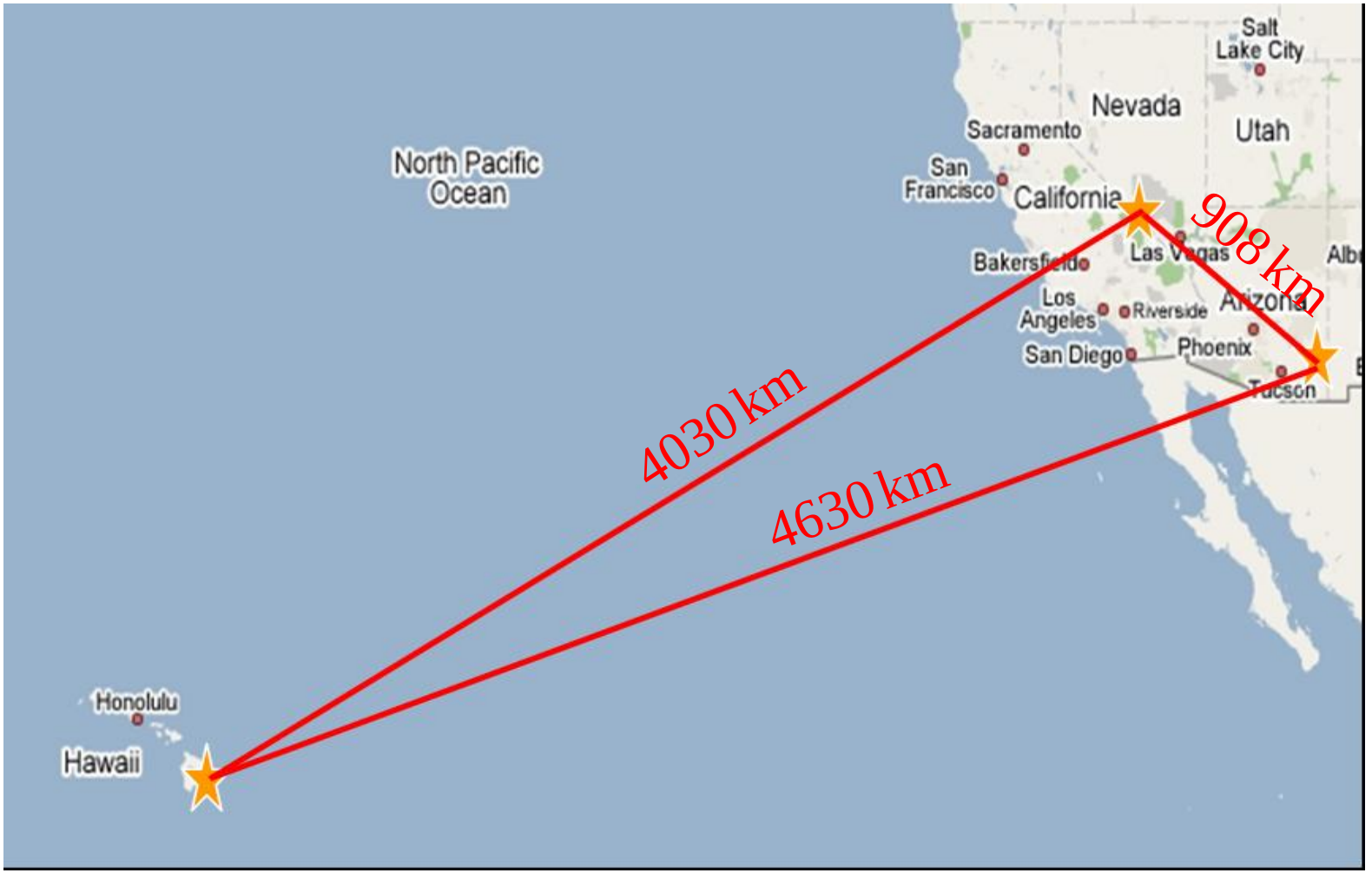




Spin = 0, orbit = ISCO

Spin = 0.9, orbit = 2.5 x ISCO

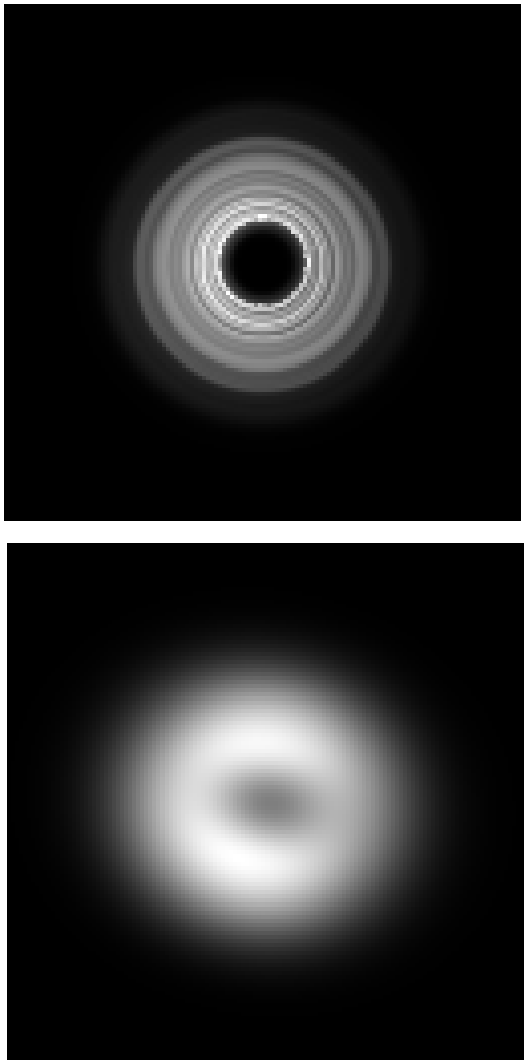
1.3mmλ Observations of SgrA*

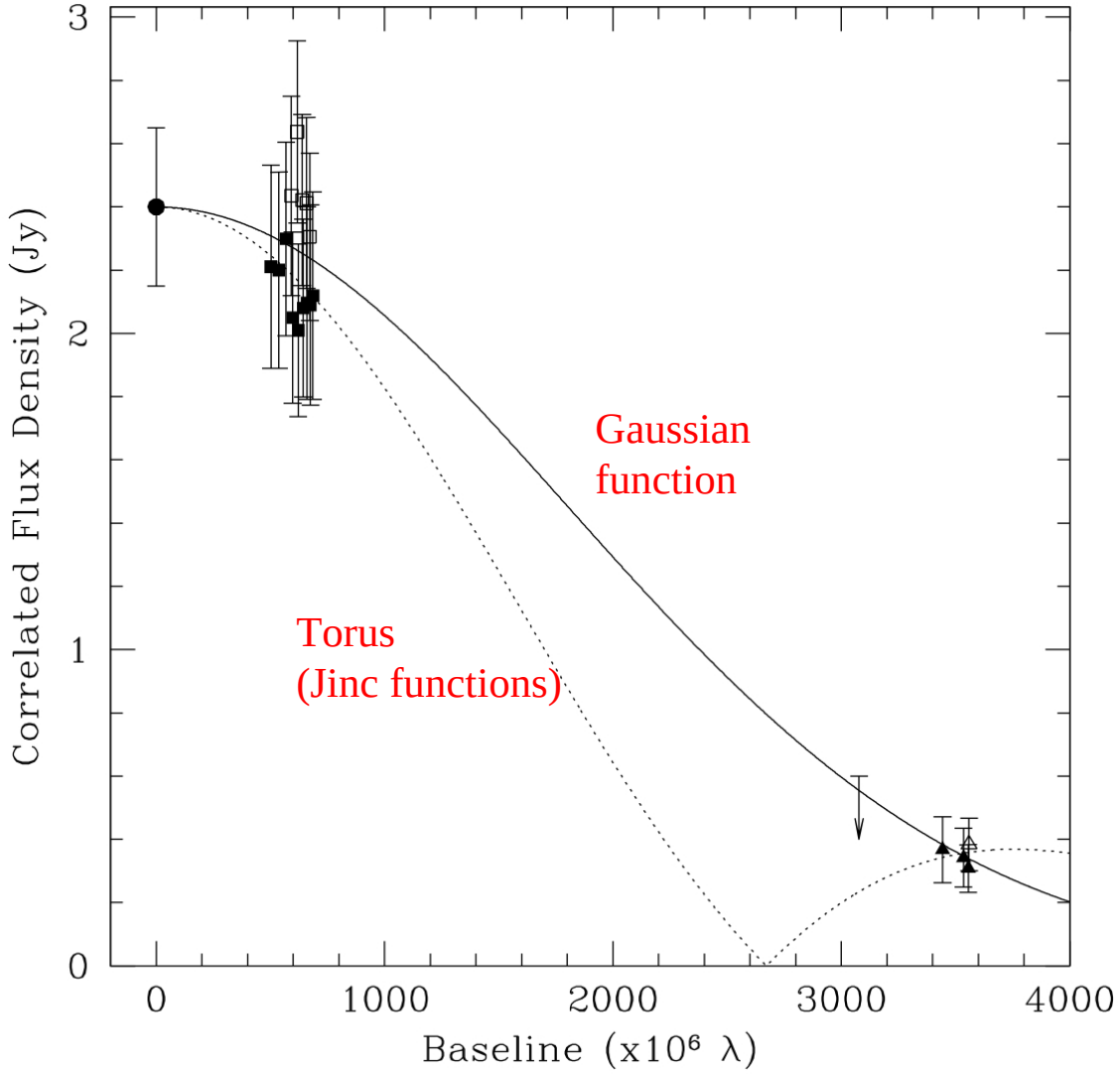


VLBI program led by a large consortium led by Shep Doeleman, MIT/Haystack

Fits to Visibility Data

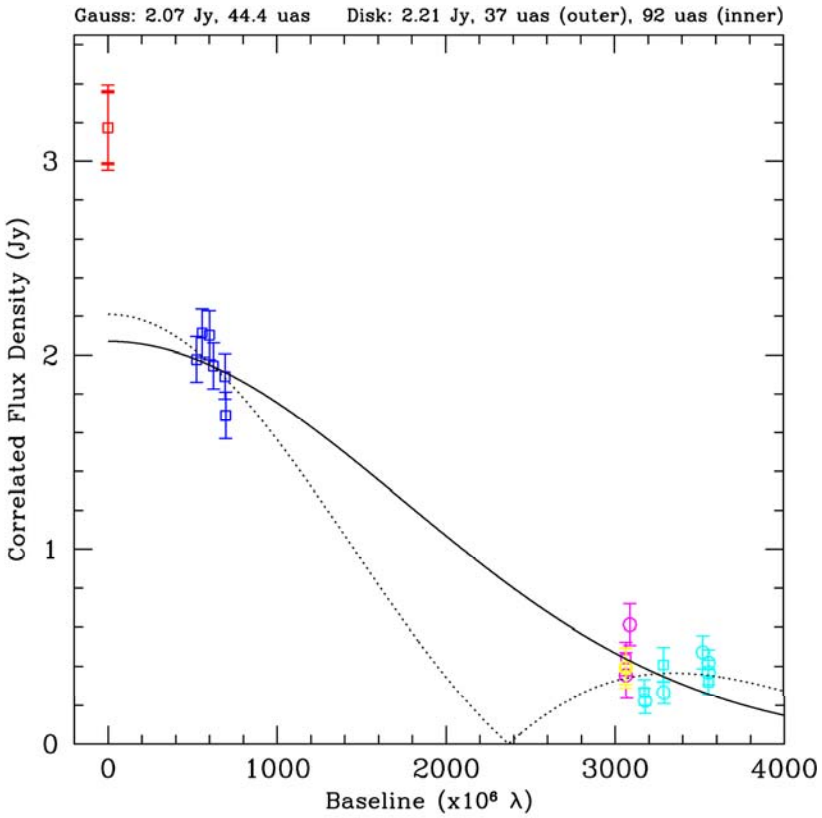
14 Rsch (140μas)

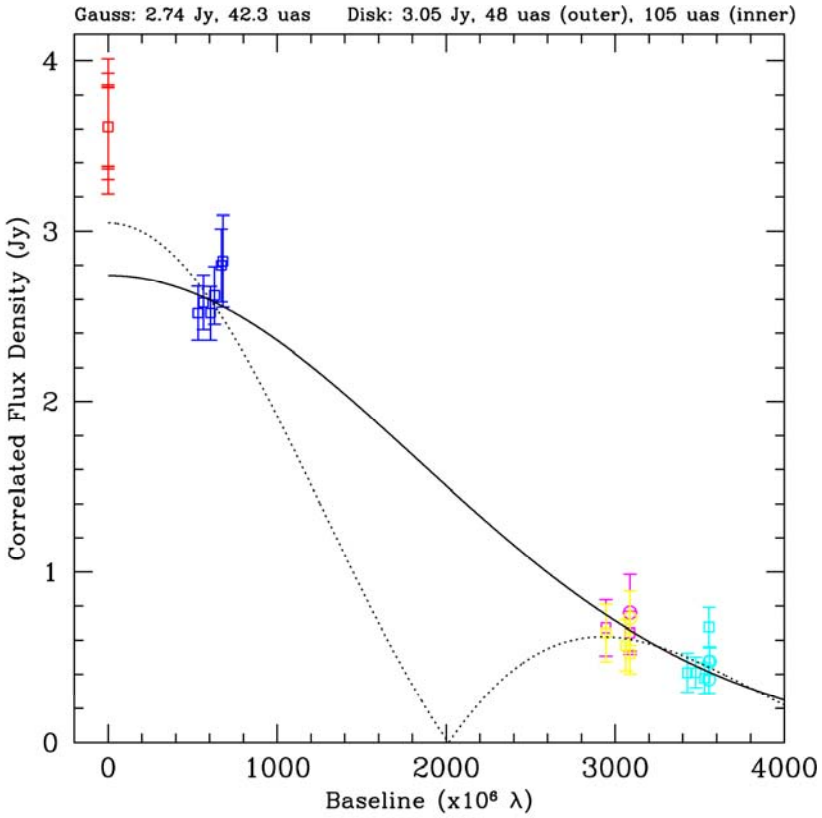




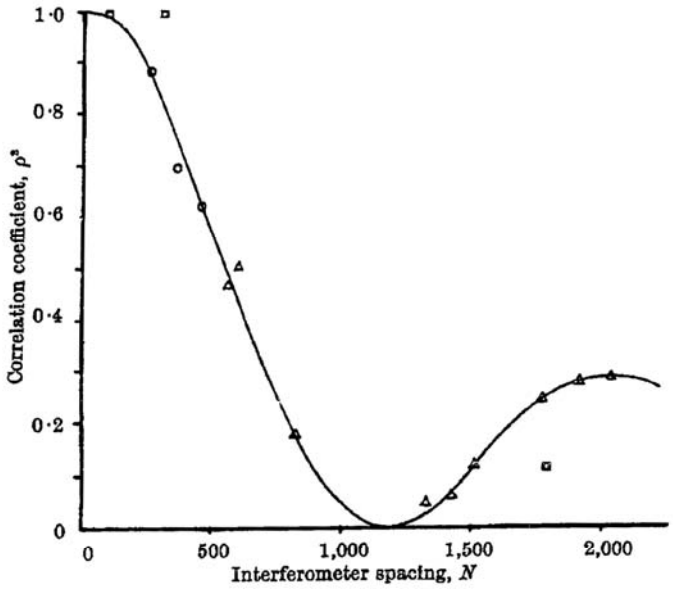
Gammie et al.

Days 96 and 97 (2009)

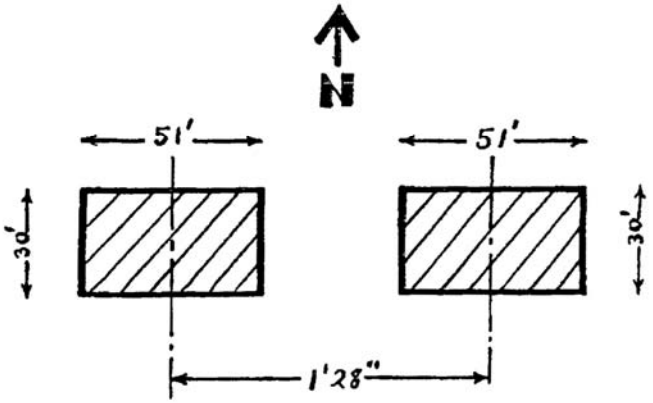




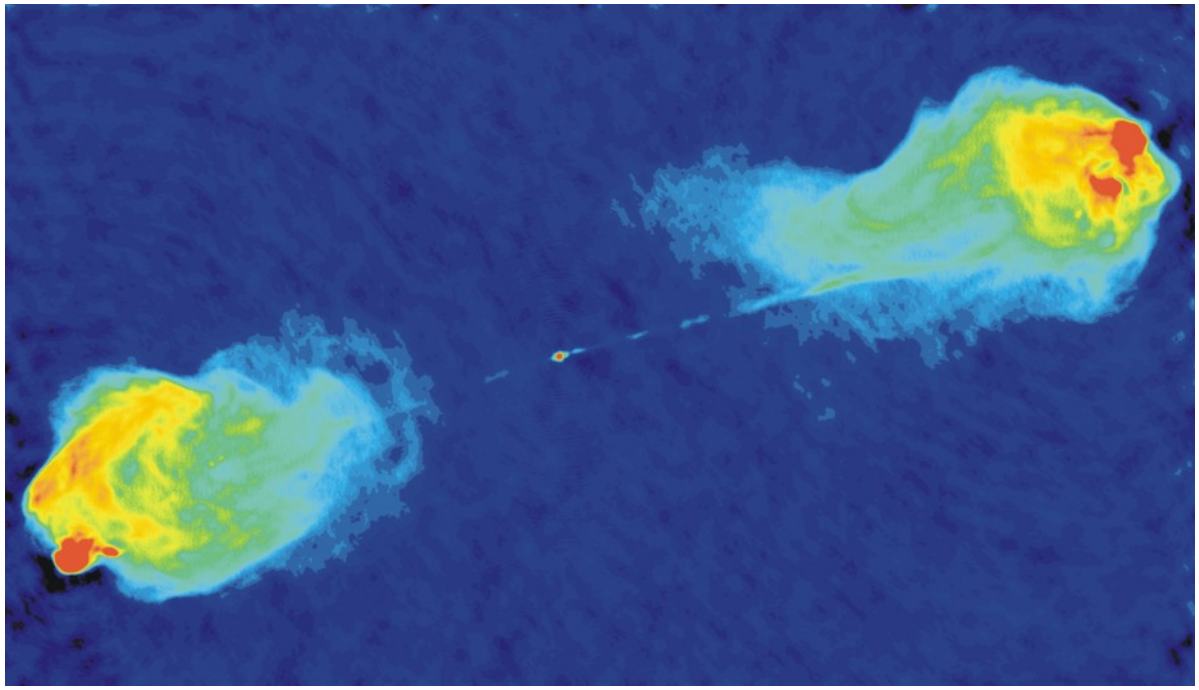
Observations of Cygnus A with the Jodrell Bank Intensity Interferometer at 125 MHz before 1952 by Jennison and das Gupta



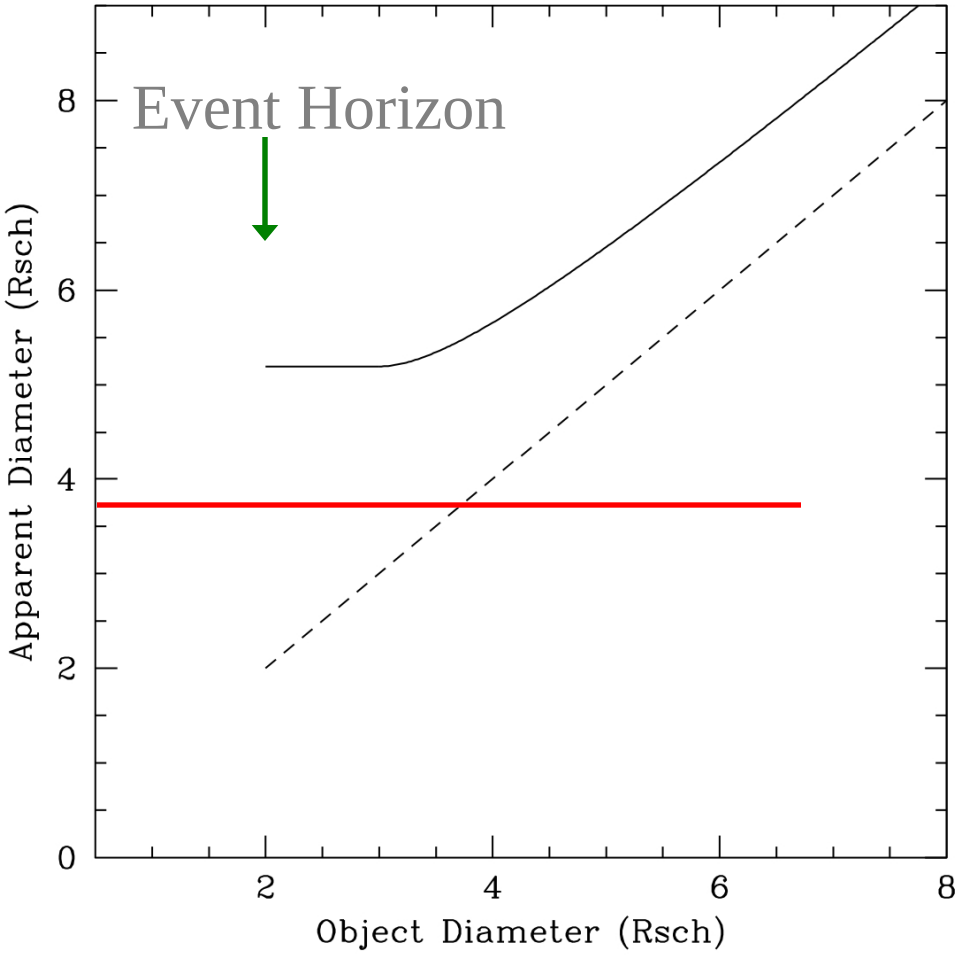
Preferred model!

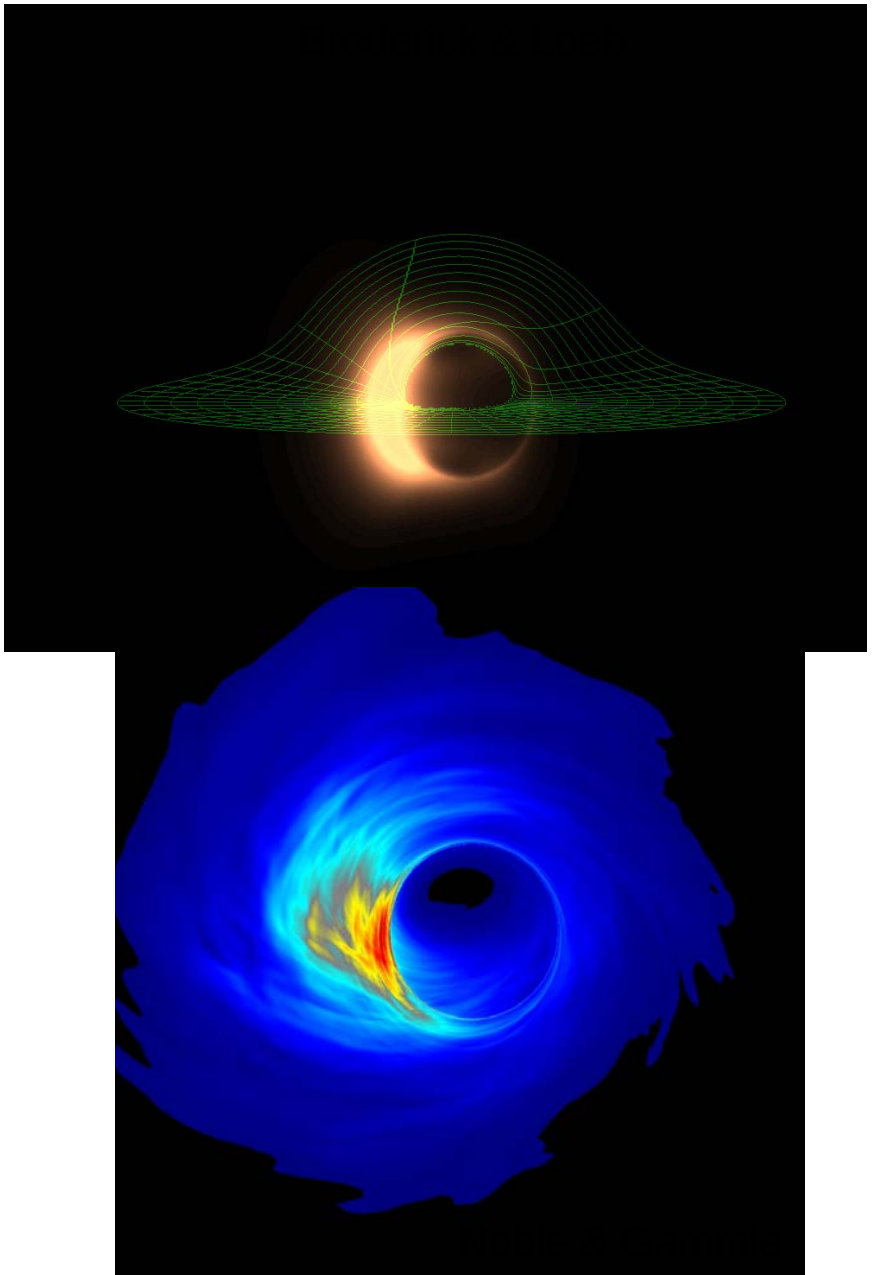


The Synchrotron Emission from Cygnus A Imaged with the VLA at 6 cm Wavelength

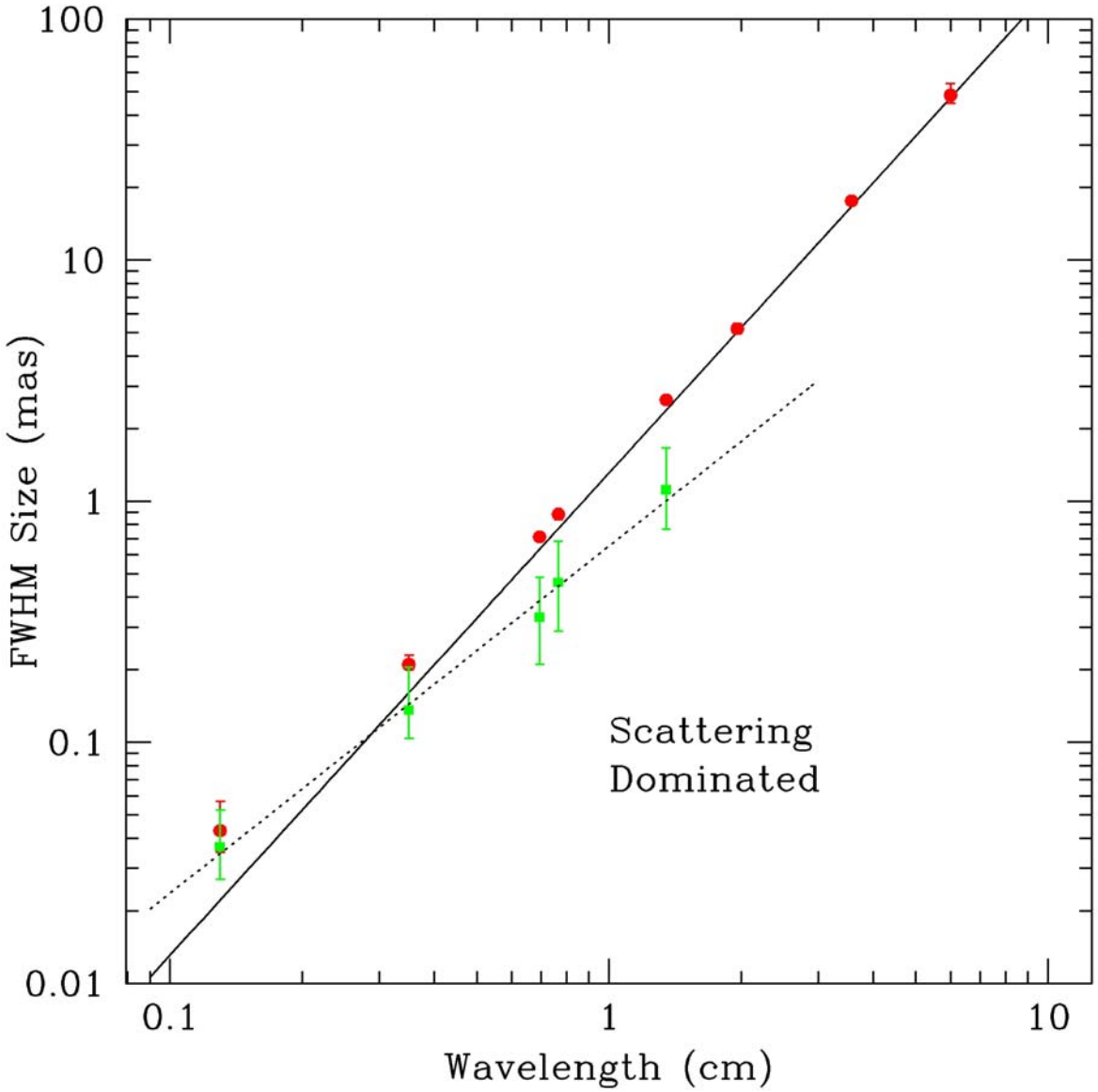


The Minimum Apparent Size





Seeing Through the Scattering

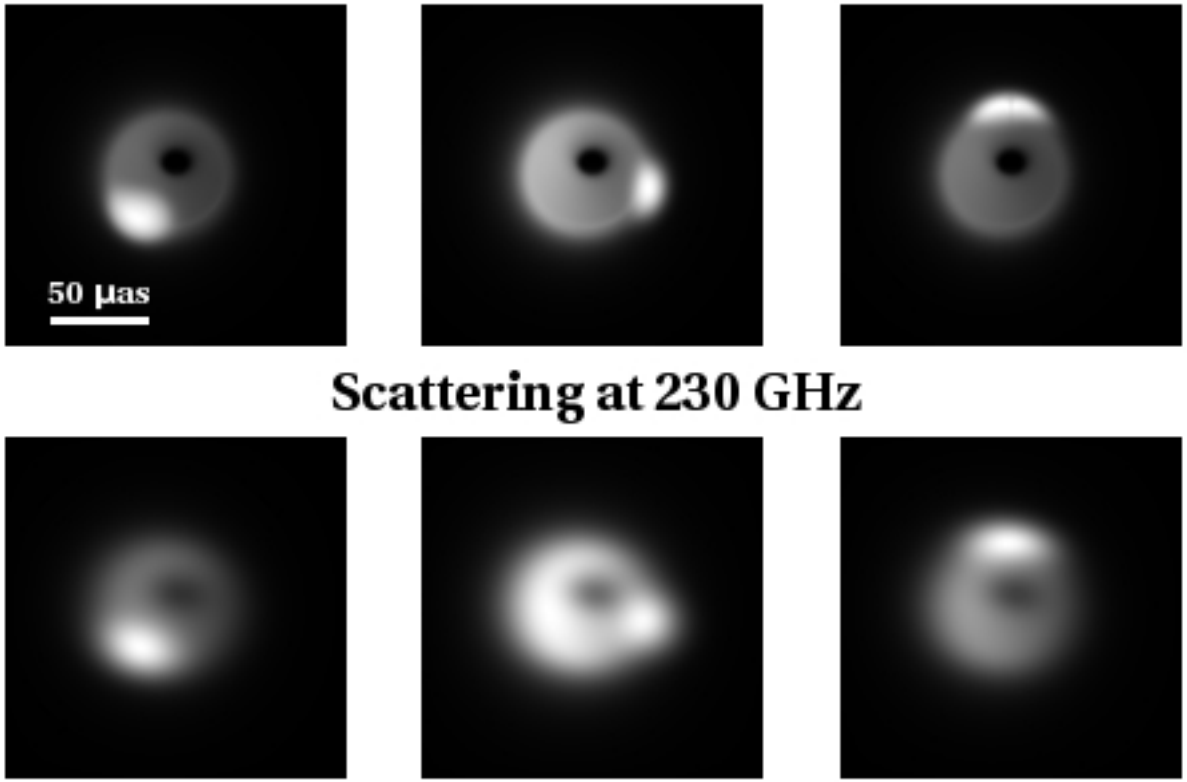


θ_{OBS} deviates from scattering for $\lambda < 1.35$ cm

$\theta_{INT} << \theta_{SCAT}$ for $\lambda > 1.3$ mm

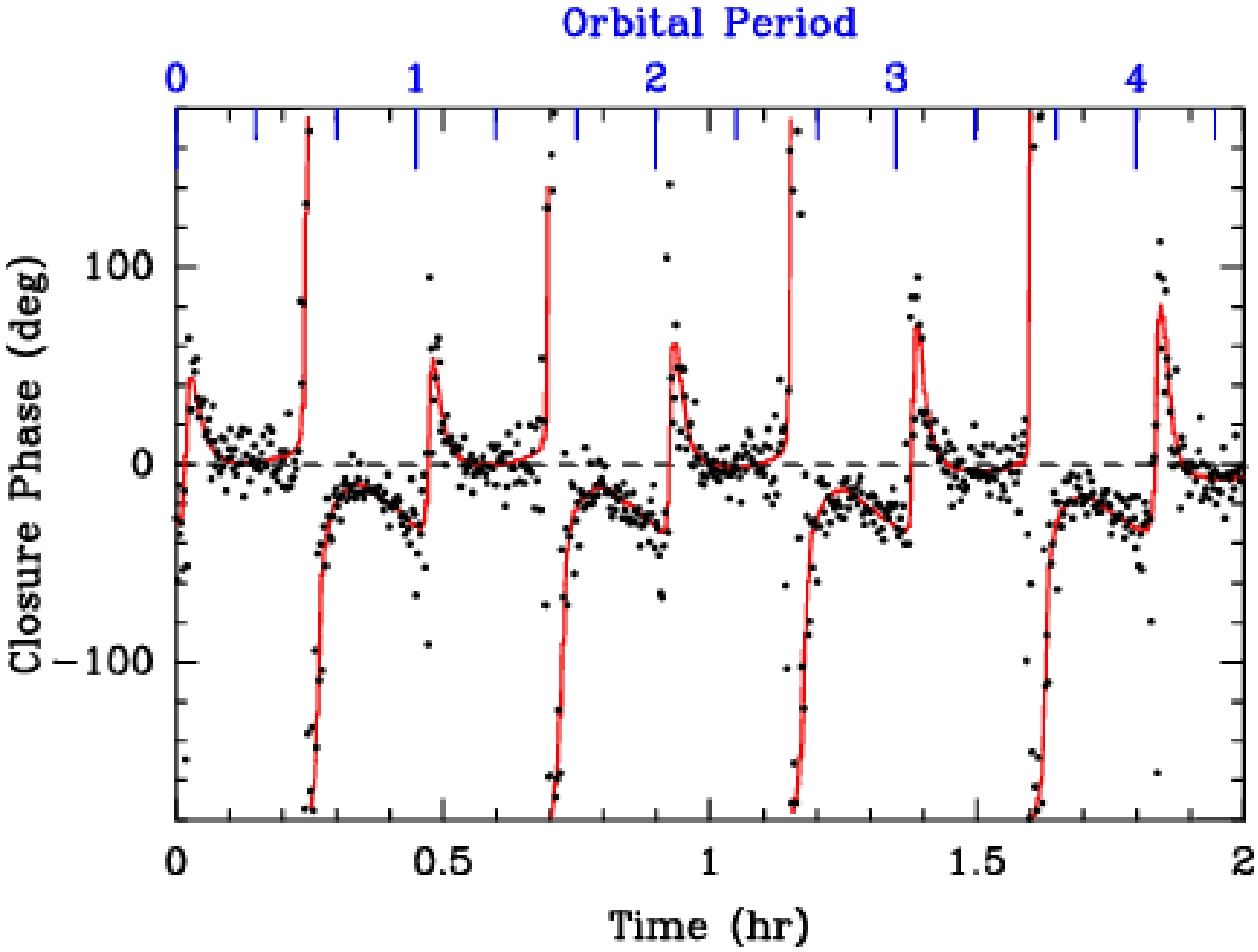
$\theta_{INT} \alpha \lambda^{1.4}$

Hot Spot Model (a = 0, i = 30)

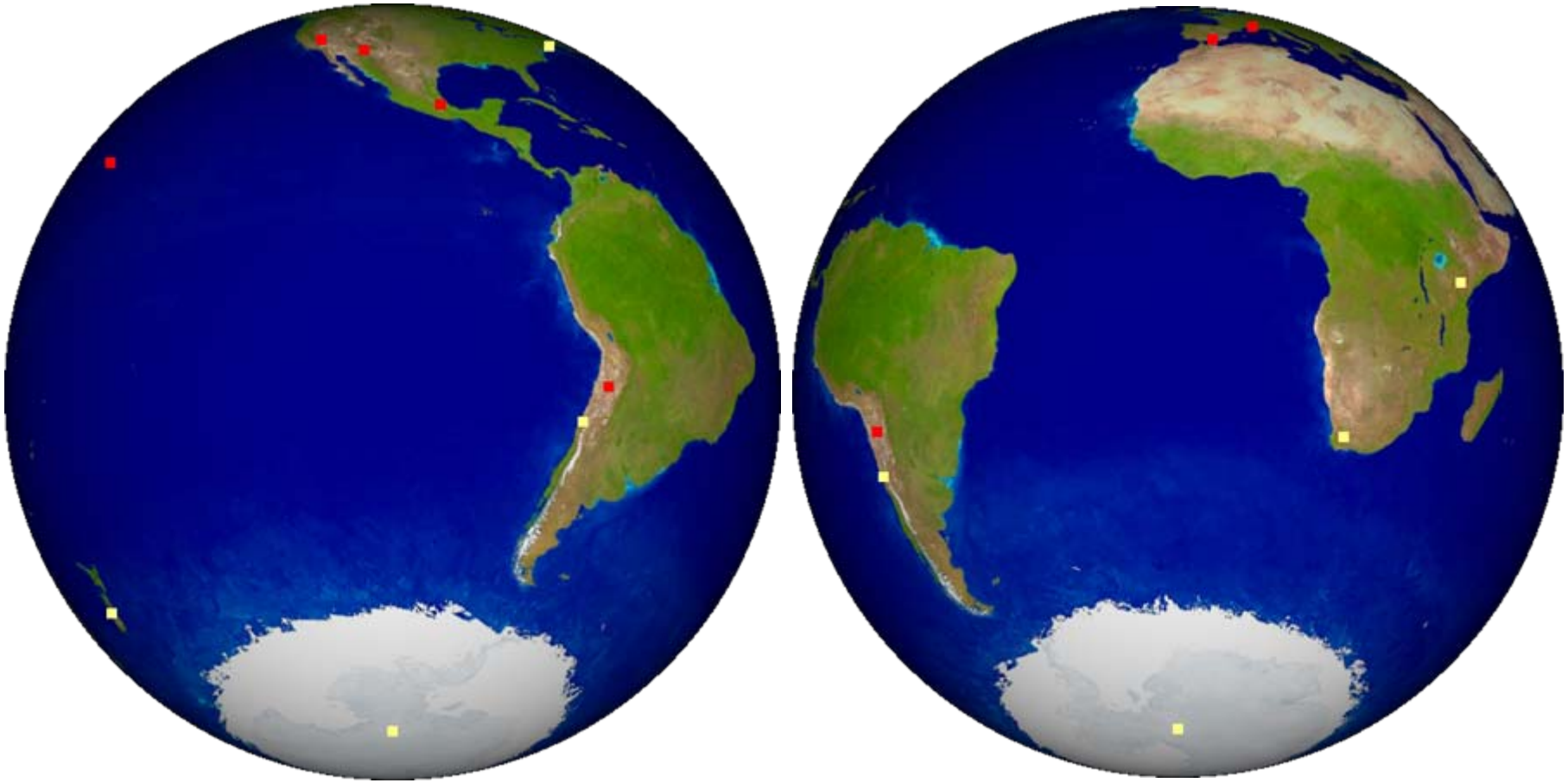


Simulation of Closure Phase for Hot Spot Model

SMTO–Hawaii–CARMA, 8 Gb/s, 230 GHz, 10 sec points



New (sub)mm VLBI Sites



Phase 1: 7 Telescopes (+ IRAM, PdB, LMT, Chile)
Phase 2: 10 Telescopes (+ Spole, SEST, Haystack)
Phase 3: 13 Telescopes (+ NZ, Africa)

EHT Phases

Phase I: 7-station 8Gb/s array

Phasing ALMA and CARMA

2010–2014

Phase II: 10-station 32Gb/s dual-pol array

Activate SEST, equip S.Pole

move to 0.8mm observations

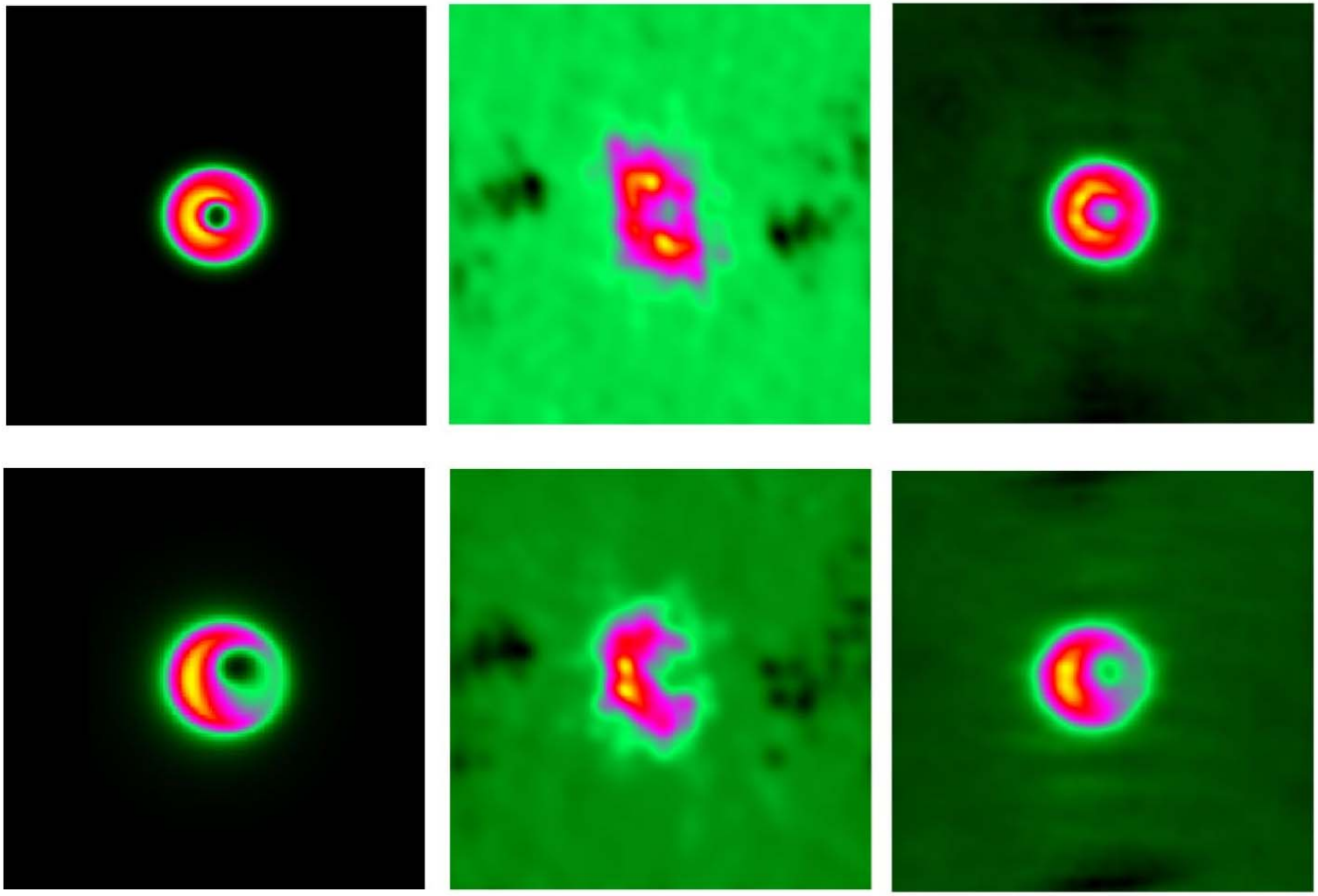
2015–2018

Phase III: 12-station array up to 64Gb/s

New dishes for optimal baseline coverage

2019–2024

Progression to an Image



GR Model

7 Stations

13 Stations