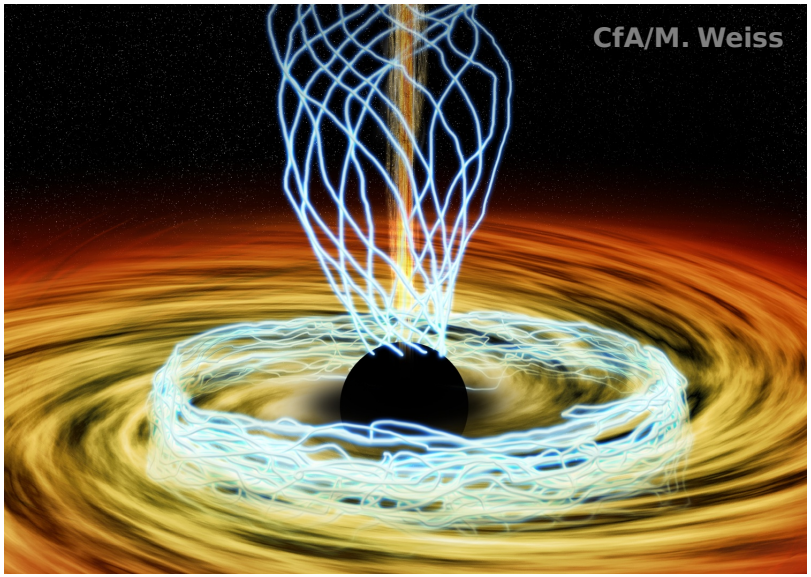
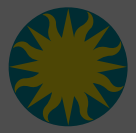
Smithsonian Astrophysical Observatory

Resolving Magnetic Fields near the Event Horizon of a Black Hole

Michael Johnson (CfA)



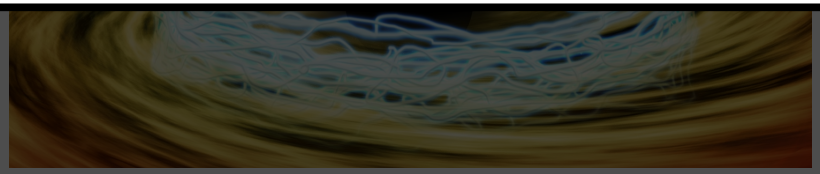
Blazars through Sharp Multi-Wavelength Eyes
May 31, 2016



Smithsonian Astrophysical Observatory

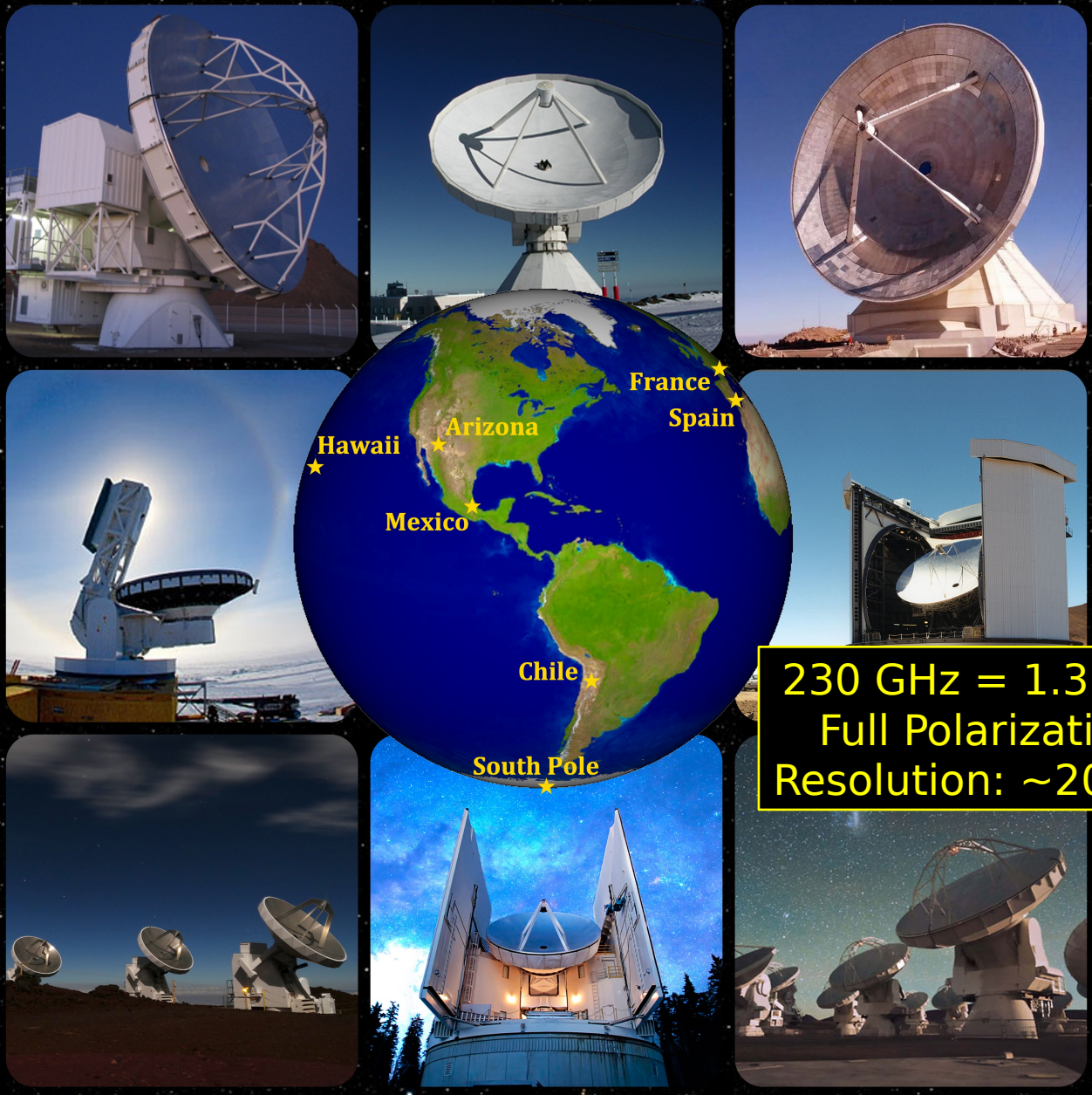
Resolved Magnetic-Field Structure and Variability Near the Event Horizon of Sagittarius A*

Michael D. Johnson*, Vincent L. Fish, Sheperd S. Doeleman, Daniel P. Marrone, Richard L. Plambeck, John F. C. Wardle, Kazunori Akiyama, Keiichi Asada, Christopher Beaudoin, Lindy Blackburn, Ray Blundell, Geoffrey C. Bower, Christiaan Brinkerink, Avery E. Broderick, Roger Cappallo, Andrew A. Chael, Geoffrey B. Crew, Jason Dexter, Matt Dexter, Robert Freund, Per Friberg, Roman Gold, Mark A. Gurwell, Paul T. P. Ho, Mareki Honma, Makoto Inoue, Michael Kosowsky, Thomas P. Krichbaum, James Lamb, Abraham Loeb, Ru-Sen Lu, David MacMahon, Jonathan C. McKinney, James M. Moran, Ramesh Narayan, Rurik A. Primiani, Dimitrios Psaltis, Alan E. E. Rogers, Katherine Rosenfeld, Jason SooHoo, Remo P. J. Tilanus, Michael Titus, Laura Vertatschitsch, Jonathan Weintroub, Melvyn Wright, Ken H. Young, J. Anton Zensus, and Lucy M. Ziurys



Blazars through Sharp Multi-Wavelength Eyes
May 31, 2016

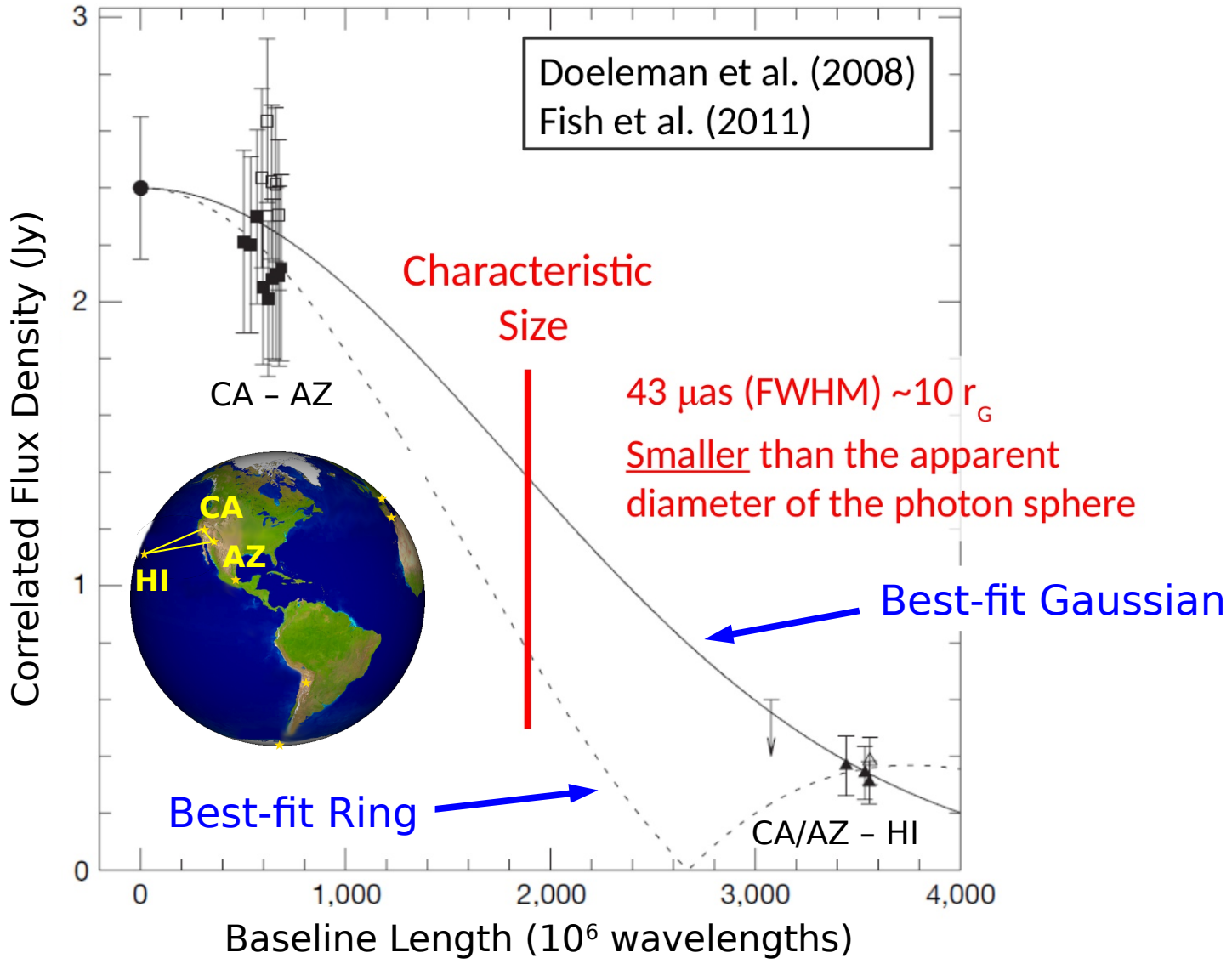
The Event Horizon Telescope



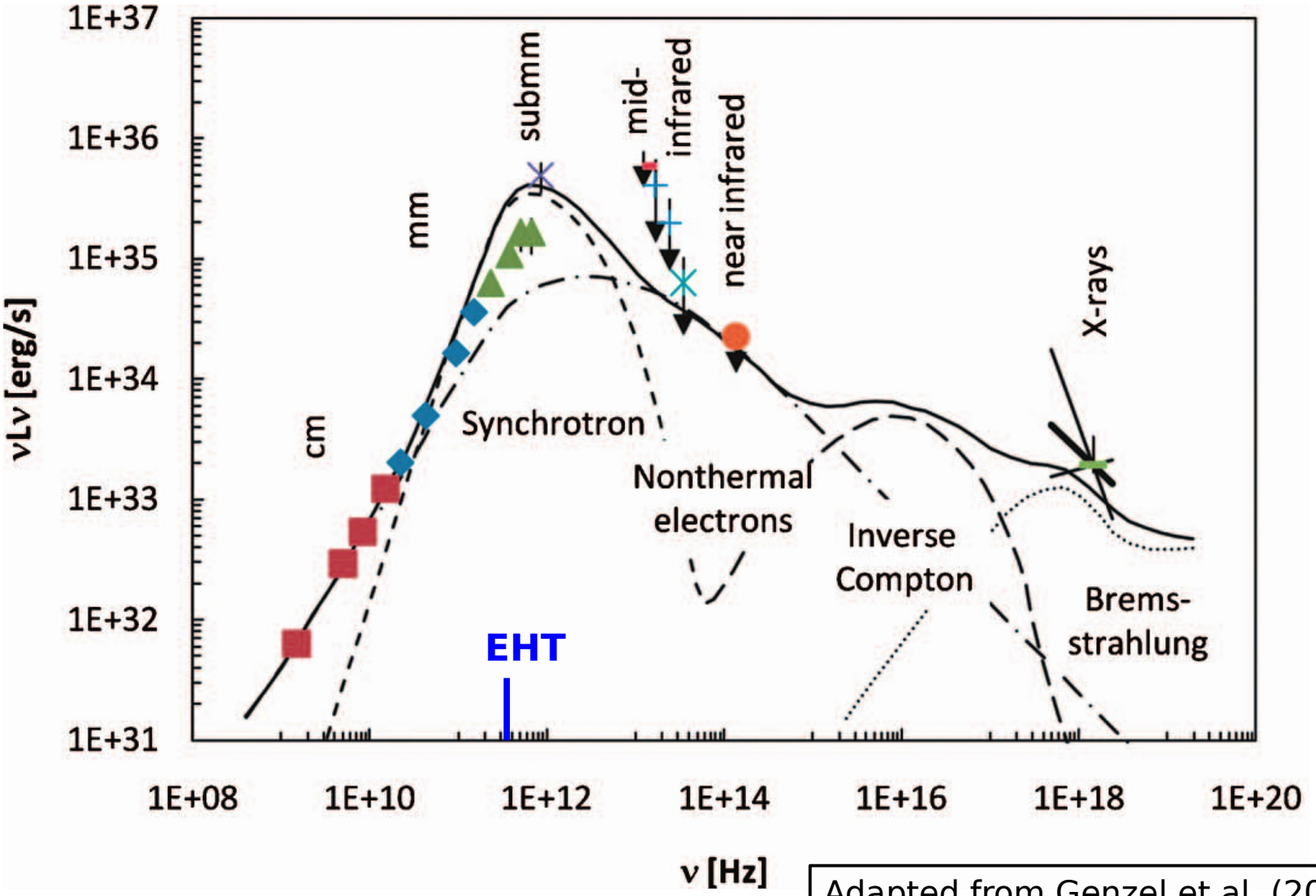
230 GHz = 1.3 mm
Full Polarization
Resolution: ~20 μas

Image Credit: APEX, IRAM, G. Narayanan, J. McMahon, JCMT/JAC, S. Hostler, D. Harvey, ESO/C. Malin

Sgr A* with the EHT

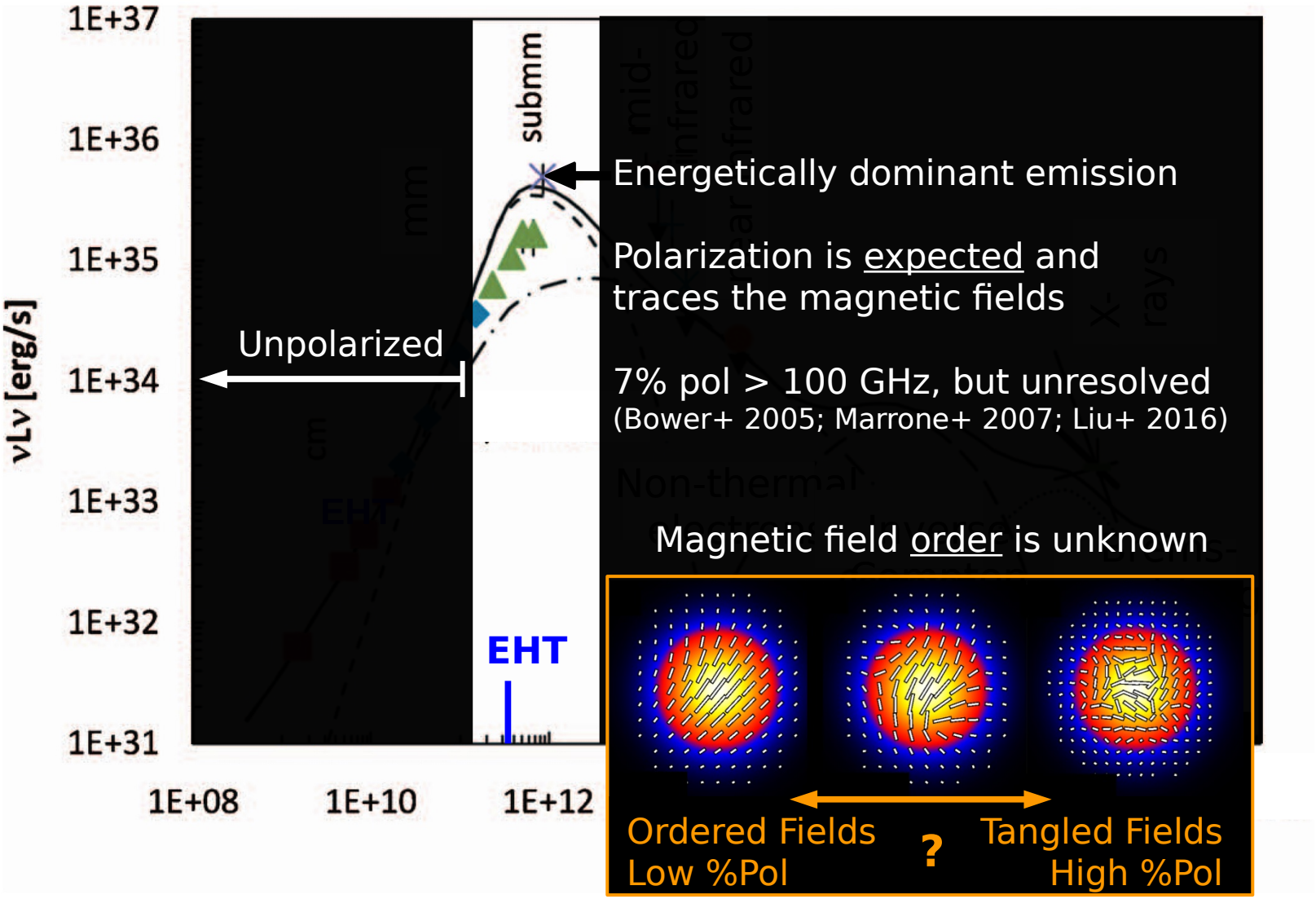


The SED of Sgr A*

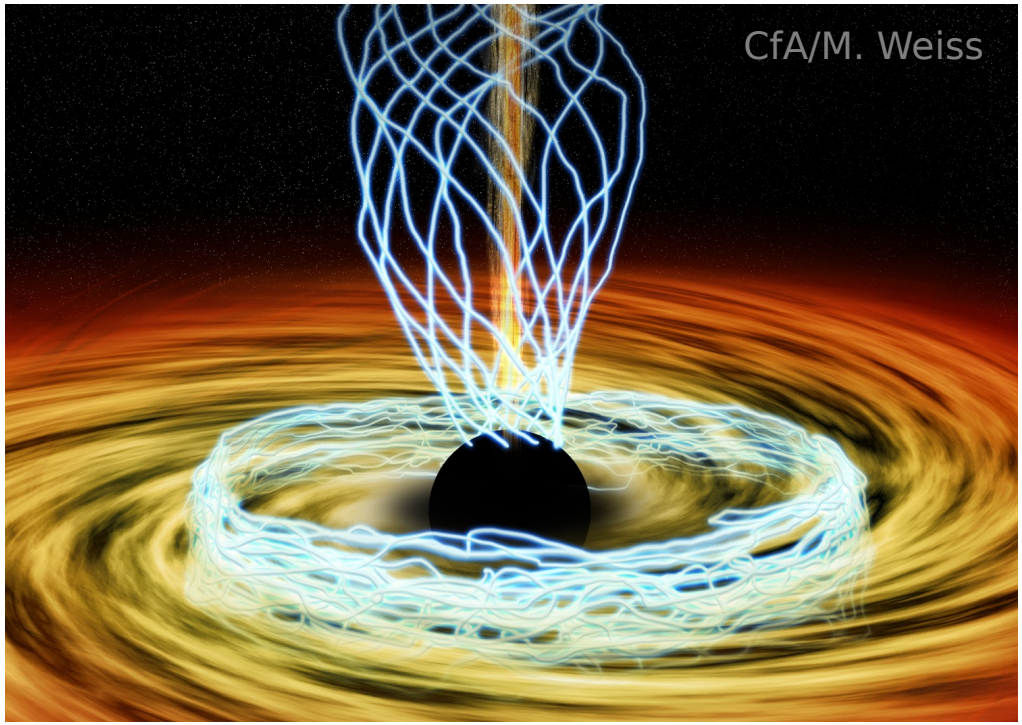


Adapted from Genzel et al. (2010)

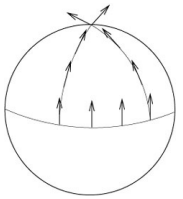
The SED of Sgr A*



Why Study Polarization?

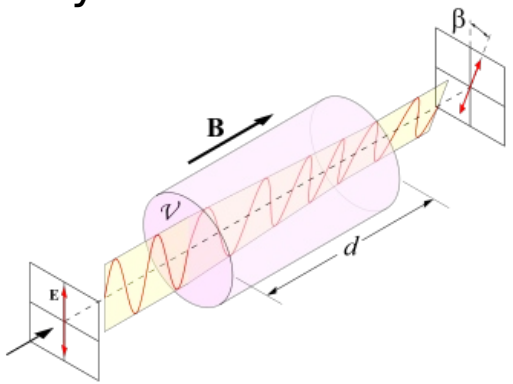


Strong Gravity:
- Parallel Transport
- Relativistic Aberration



BH Accretion and Outflow:
- Field morphology
- Turbulence

Global Accretion:
- Faraday rotation & conversion



The accretion rate of Sgr A* was not determined until submillimeter polarization was detected!

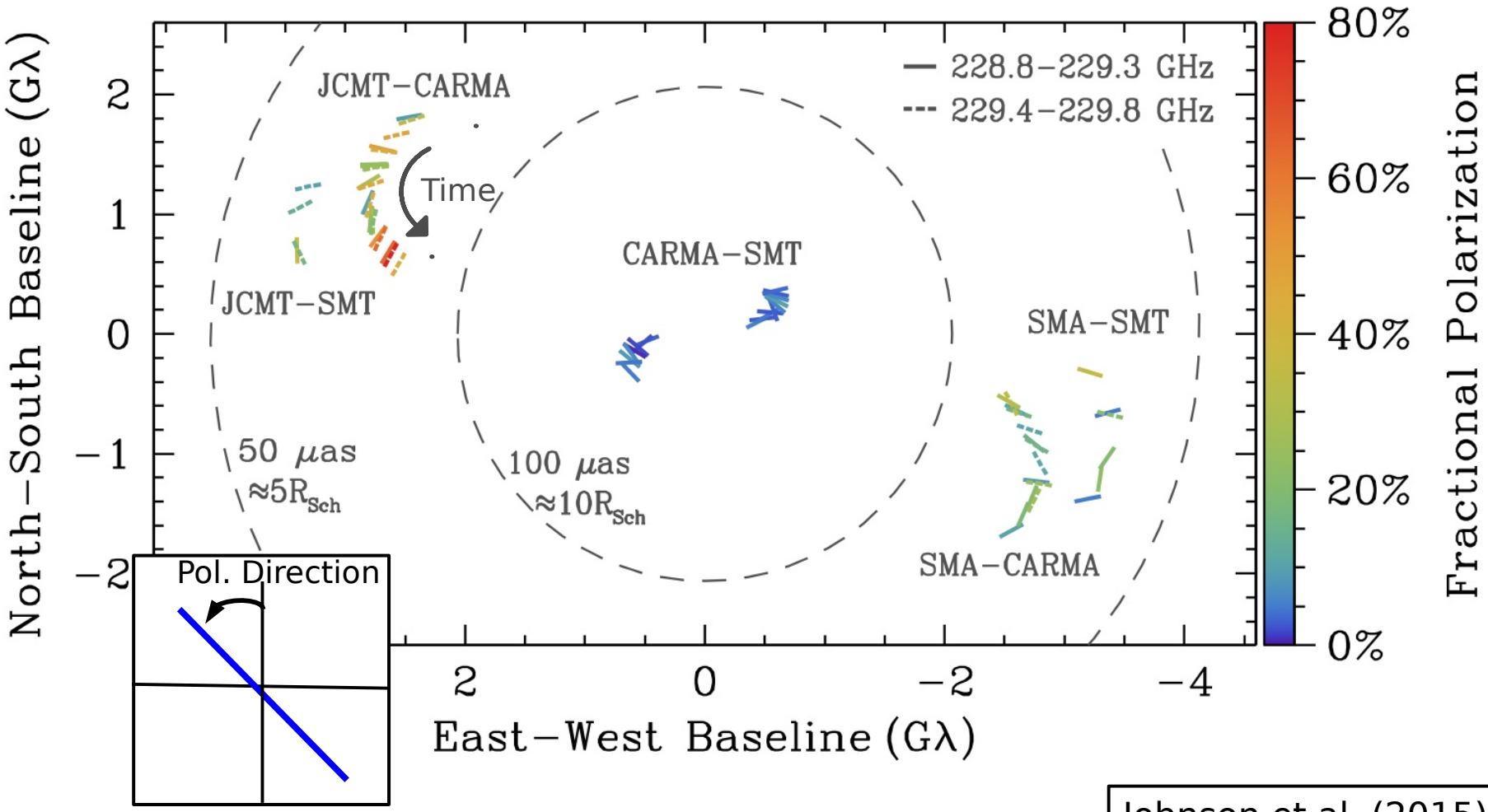
(Aitken et al. 2000; Marrone et al. 2007)

Polarimetry with the EHT

Image Credit: APEX, IRAM, G. Narayanan, J. McMahon, JCMT/JAC, S. Hostler, D. Harvey, ESO/C. Malin

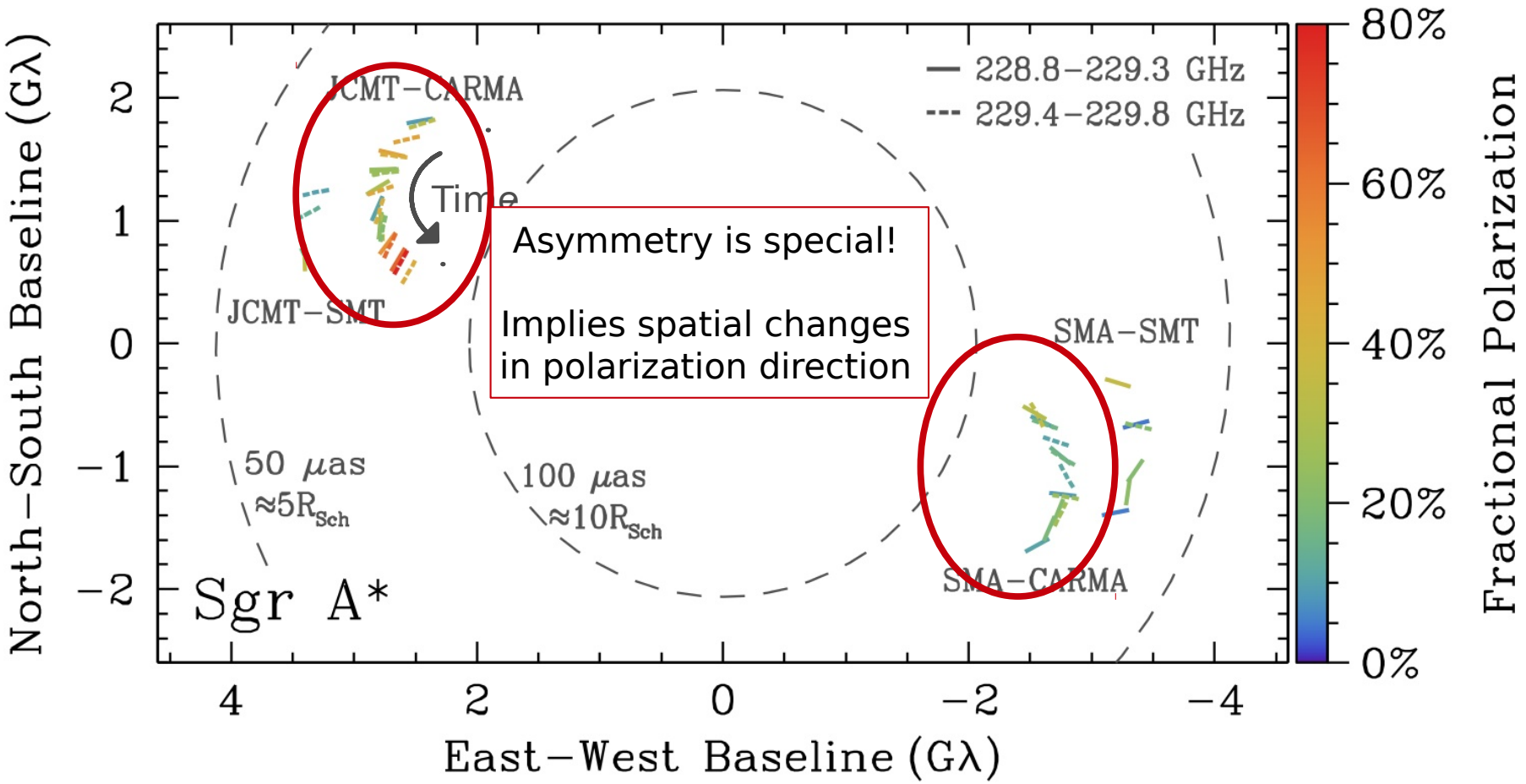
Resolving Sgr A* with the EHT

First polarimetric VLBI at 230 GHz
First resolved polarization of Sgr A* at any wavelength

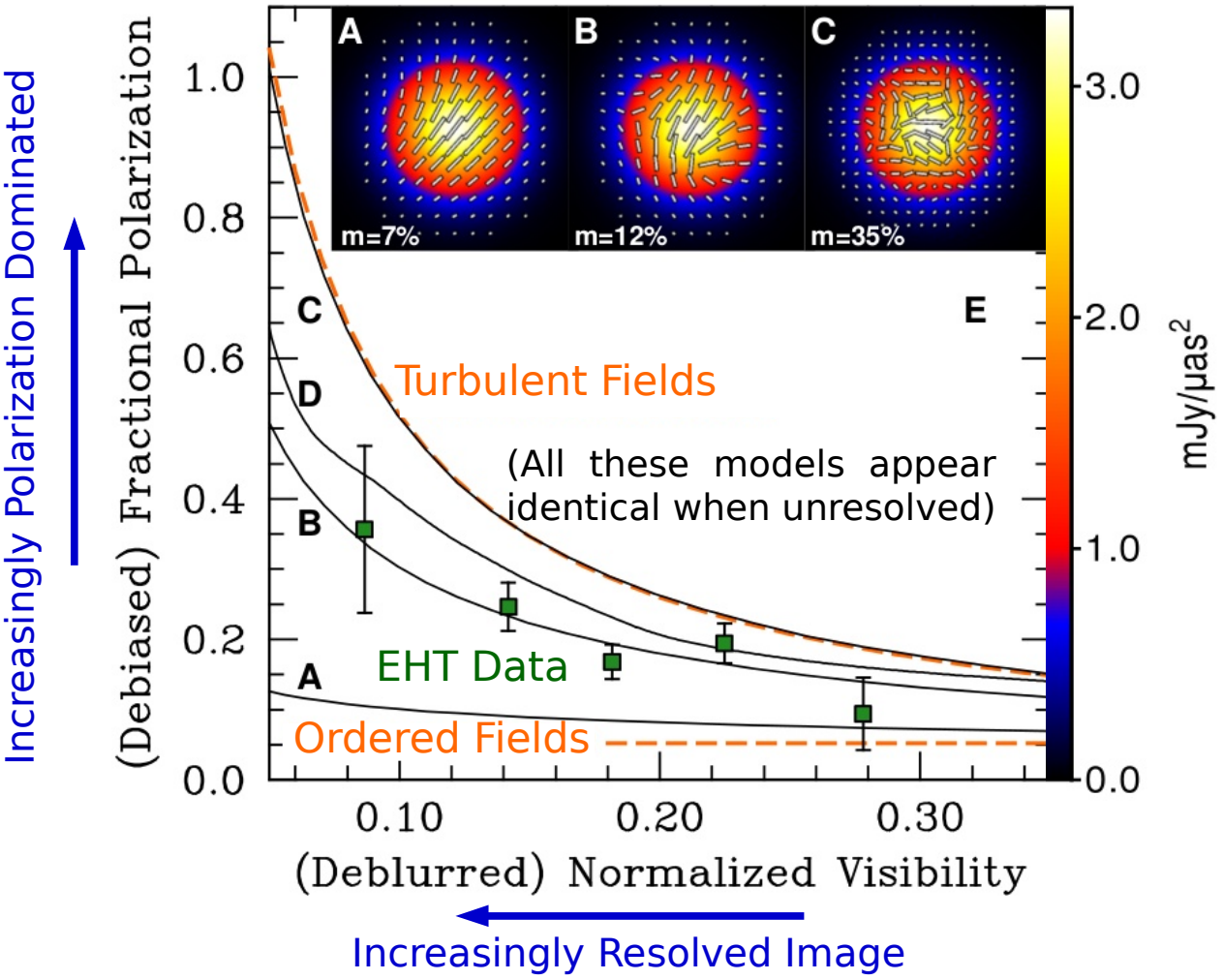


Johnson et al. (2015)

Resolving Sgr A* with the EHT



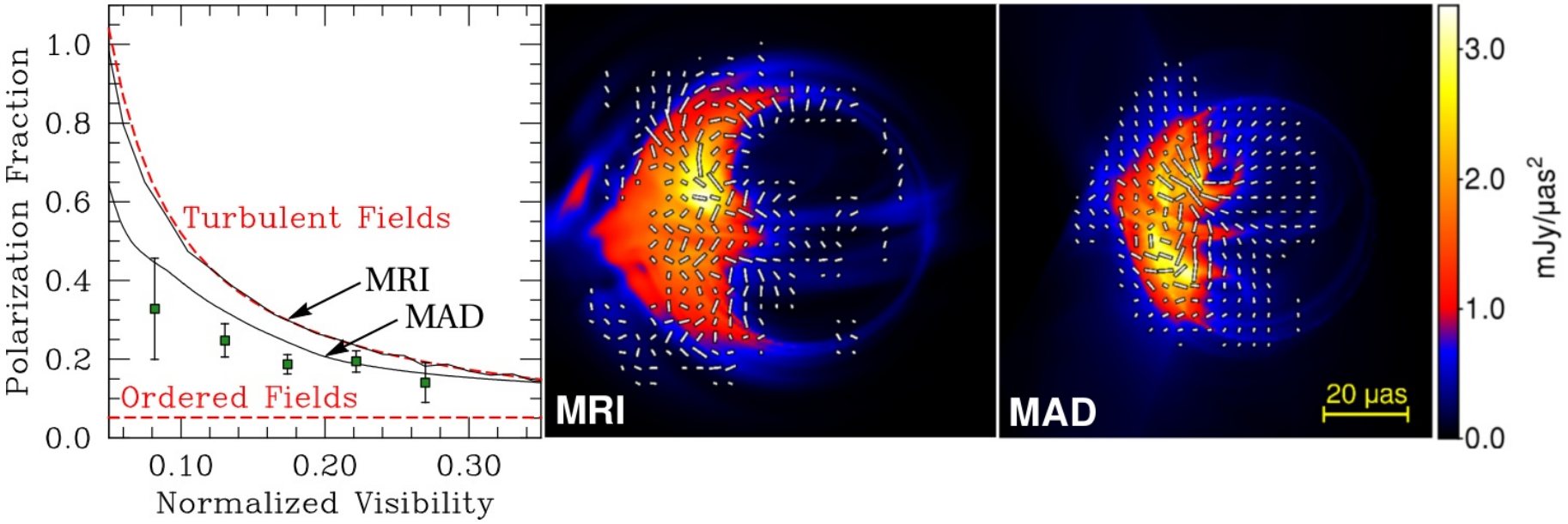
Ordered Fields Near the Horizon



Johnson et al. (2015)

Constraining the Field Strength

Comparisons with GRMHD simulations indicate strong near-horizon fields

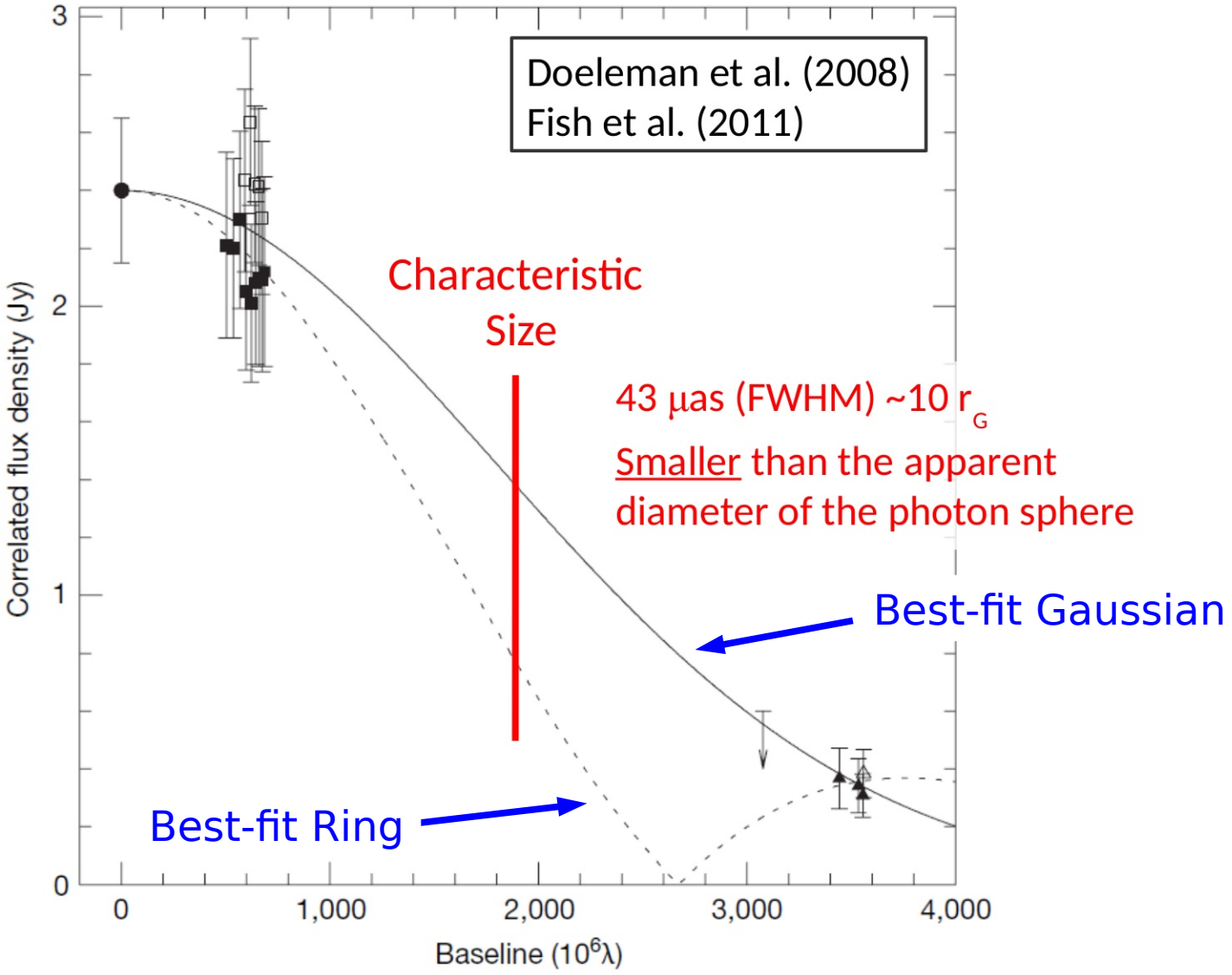


MRI: Classic turbulent accretion disk (Balbus & Hawley 1998)

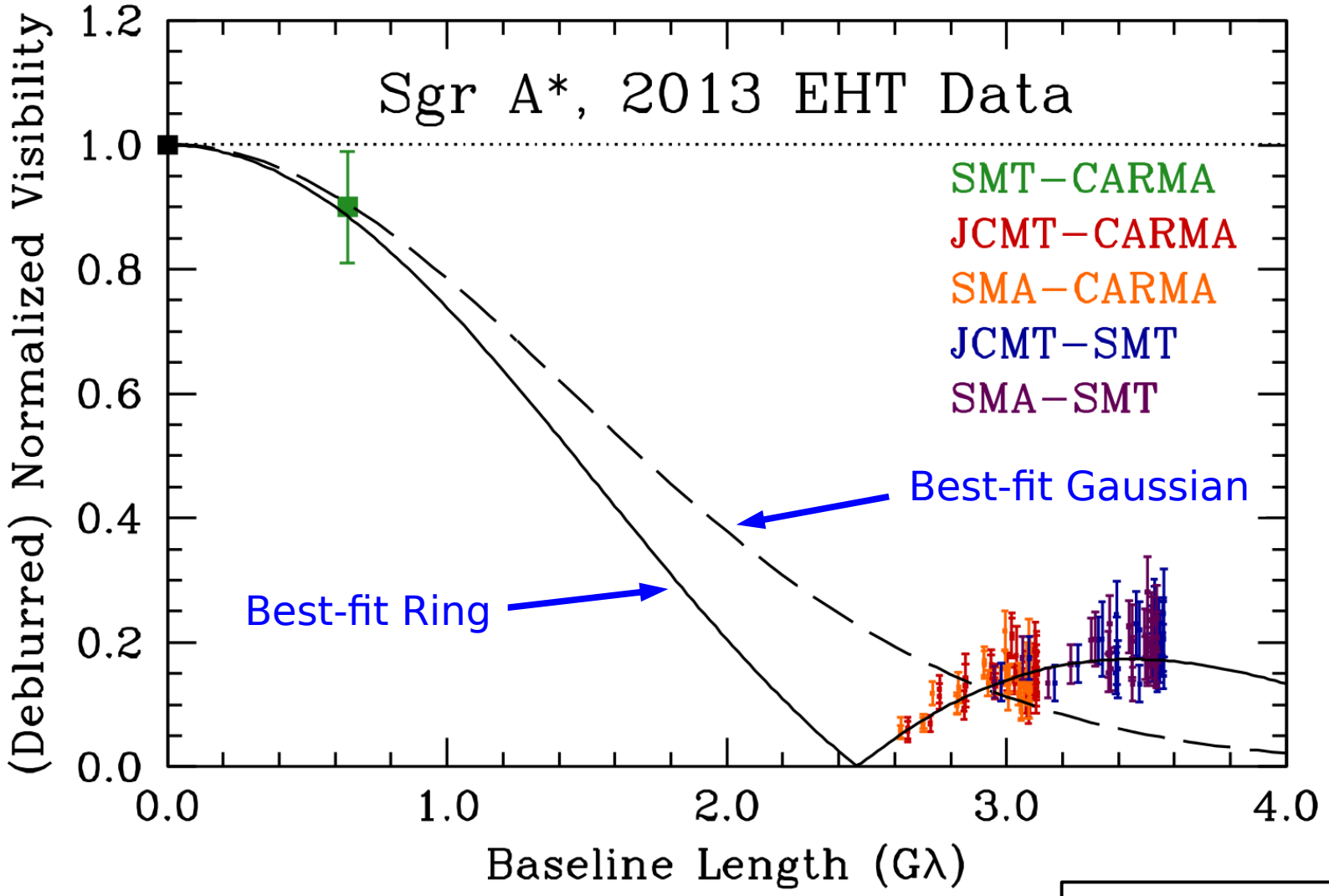
MAD: “Magnetically-Arrested Disk” with strong fields (Narayan et al. 2003)

See Gold et al. (2016)

Geometry of Sgr A*: 2008

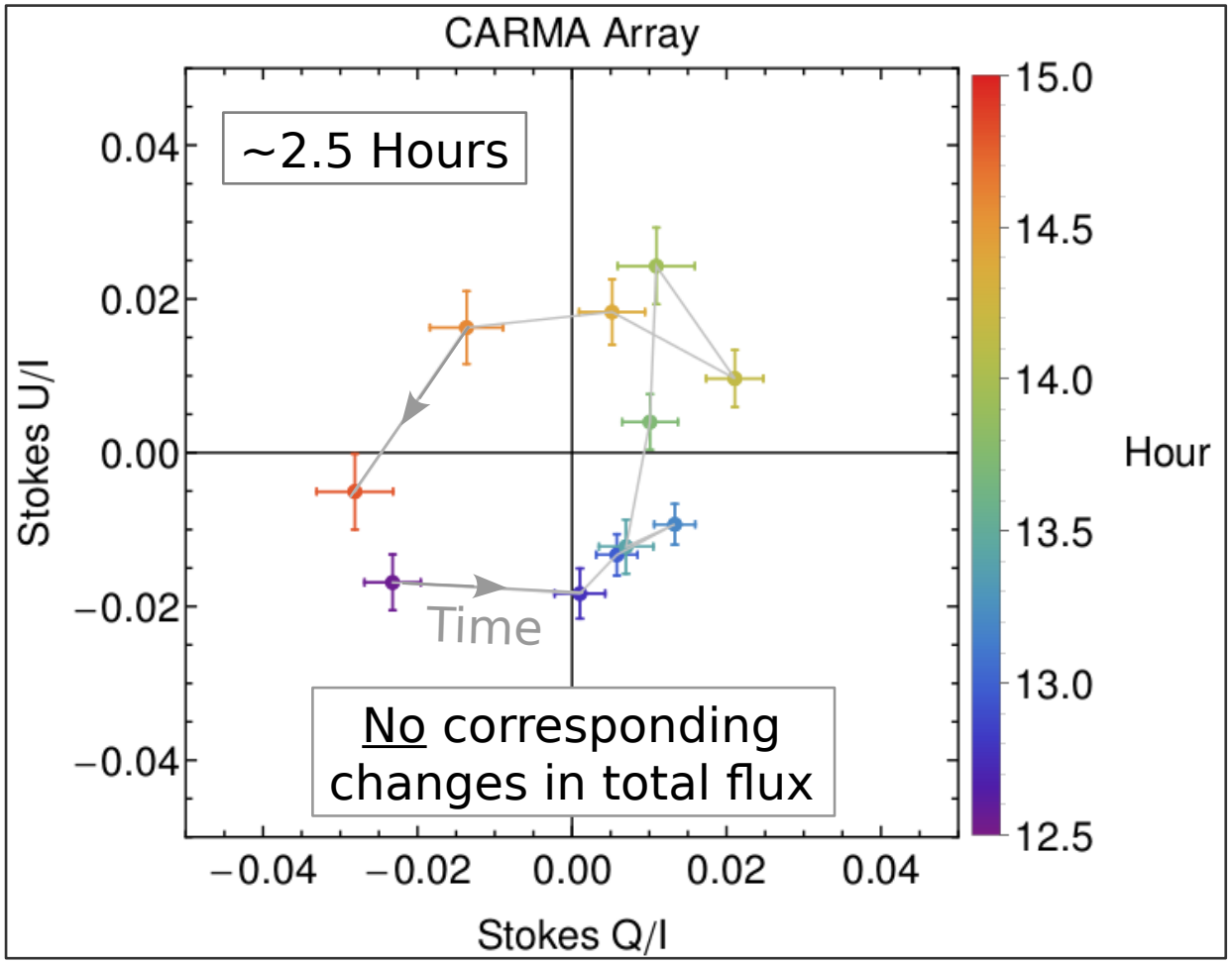


Geometry of Sgr A*: 2013



Johnson et al. (2015)

Time Variability of Sgr A*

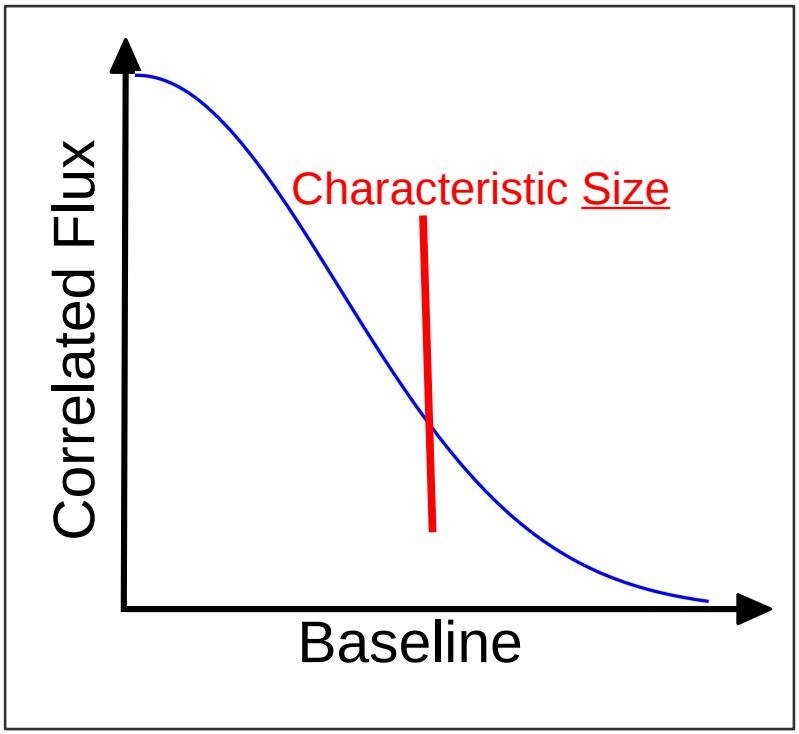


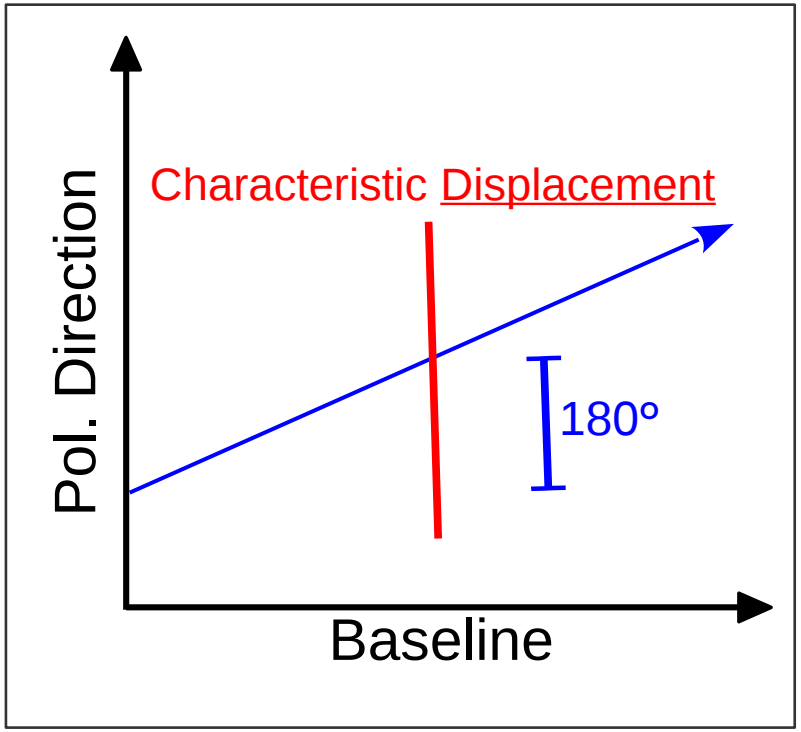
see also: Marrone et al. (2007), Fish et al. (2009)

Relative Offset of the Polarization Centroid

Model-independent morphology constraints via the polarization angle

An Analogy

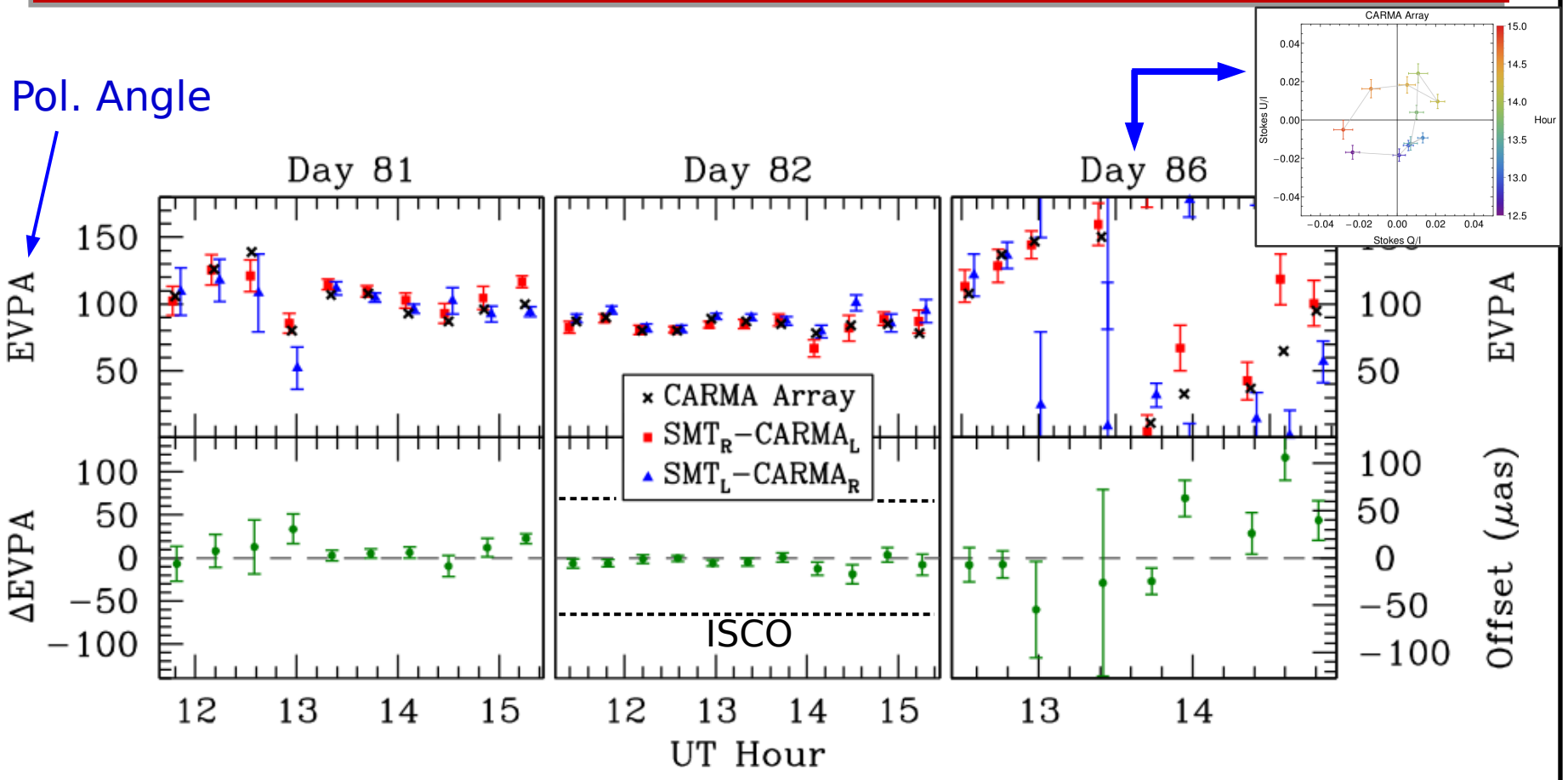




For a California-Arizona Baseline: 1 R_{Sch} offset <=> 10° in polarization direction

Johnson et al. (2014)

Tracking Dynamical Activity of Sgr A*

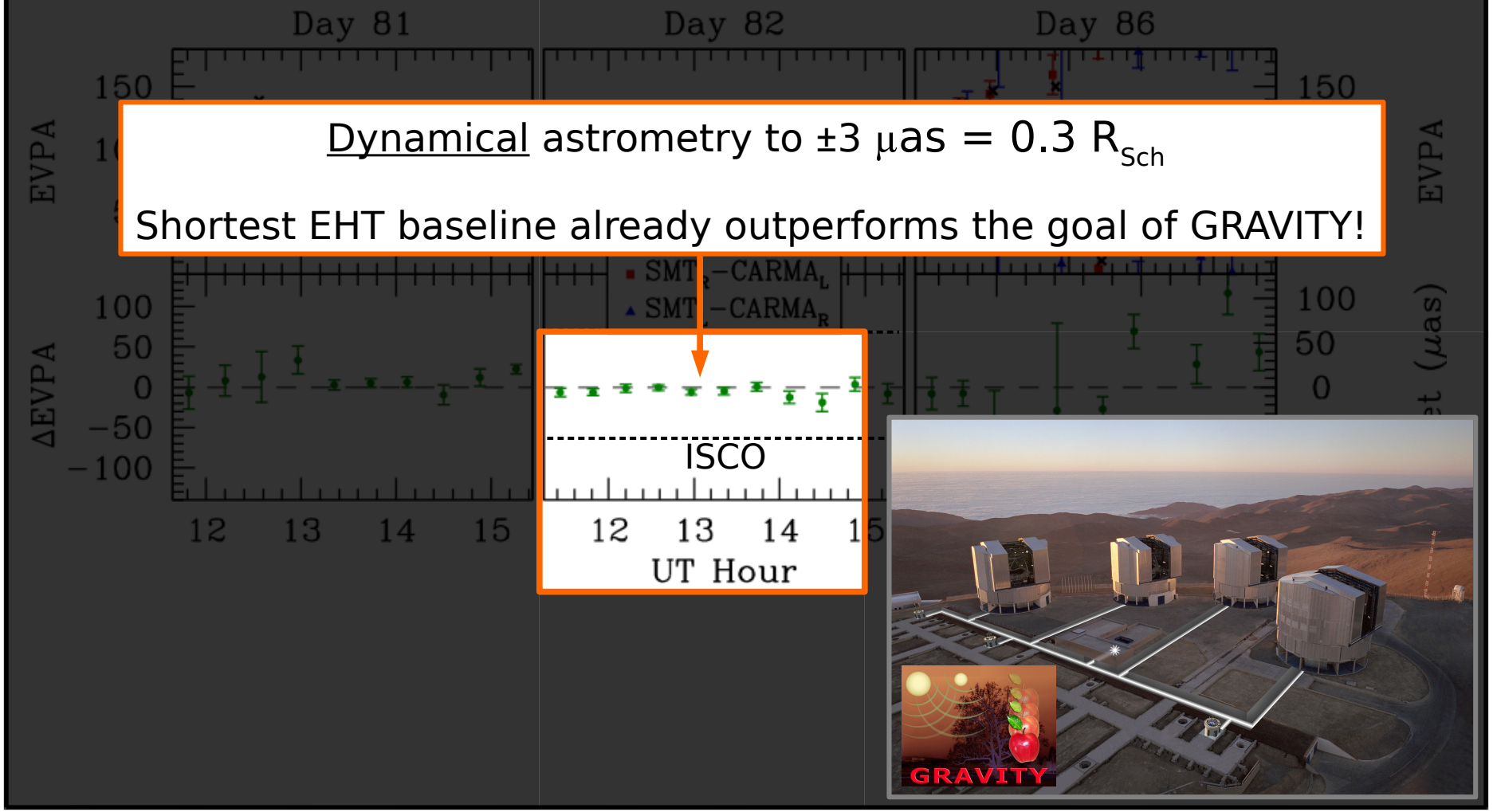


Johnson et al. (2015)

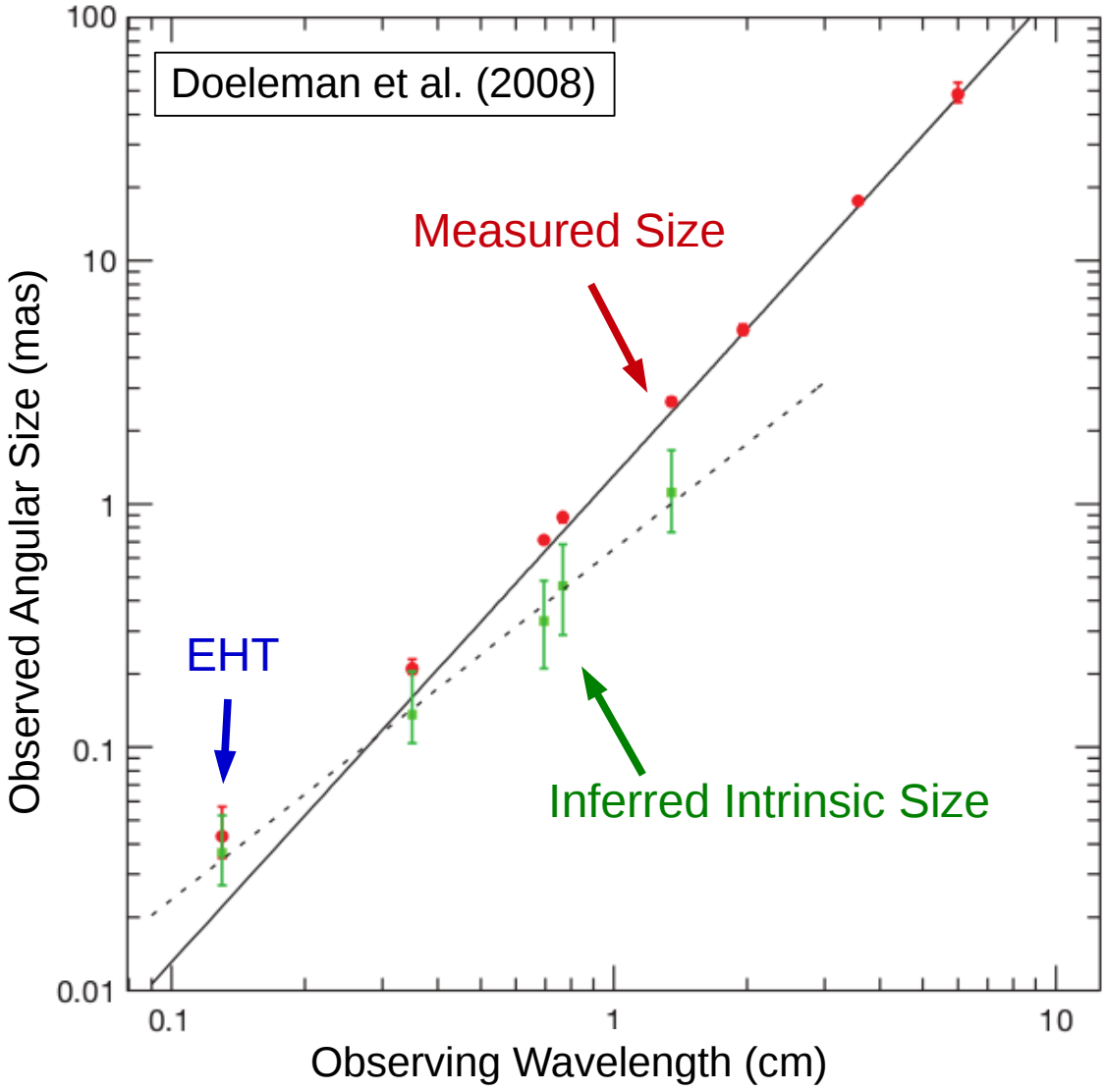
Tracking Dynamical Activity of Sgr A*

Dynamical astrometry to ±3 μas = 0.3 R_{Sch}

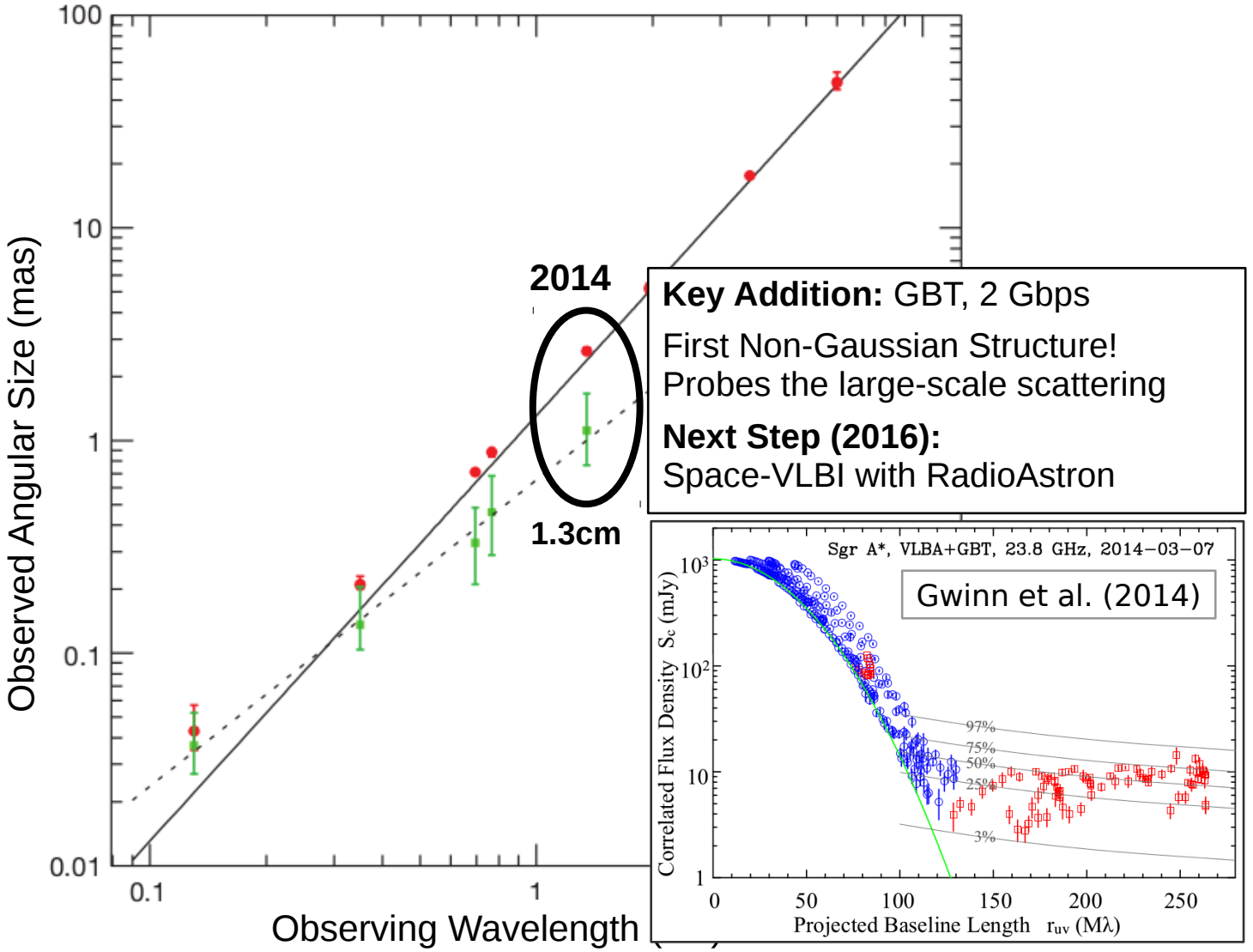
Shortest EHT baseline already outperforms the goal of GRAVITY!



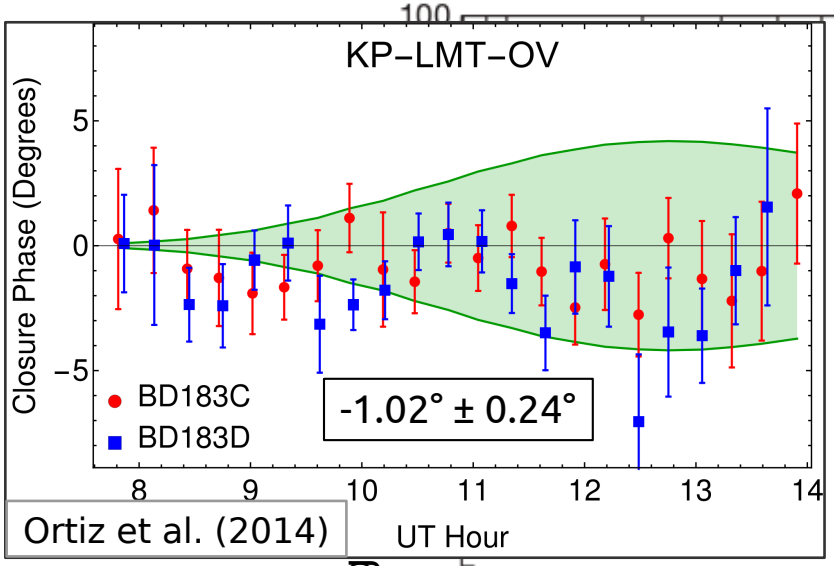
Sgr A*: Observed Size vs. Wavelength



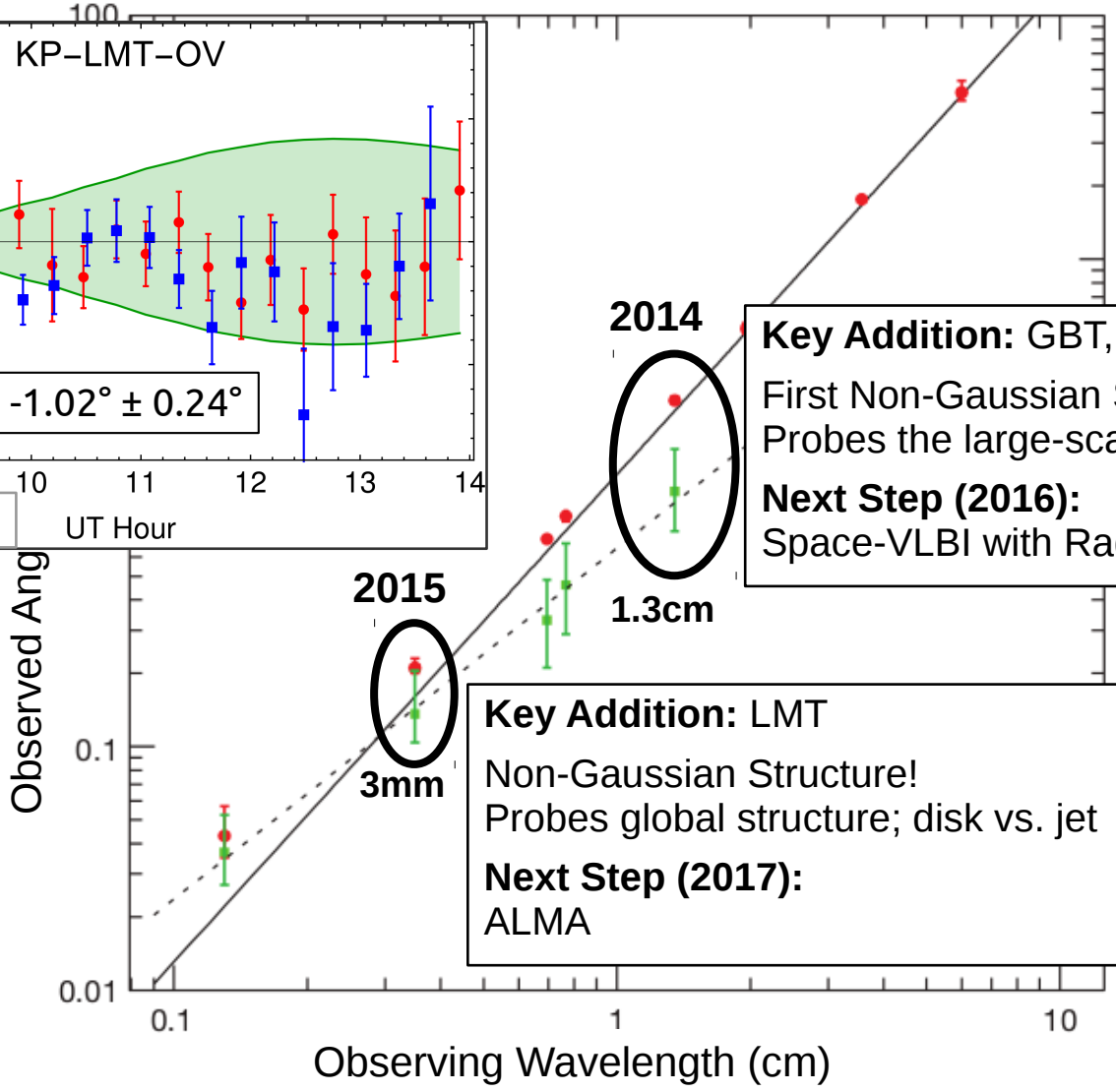
Sgr A*: Observed Size vs. Wavelength



Sgr A*: Observed Size vs. Wavelength



Ortiz et al. (2014)



Key Addition: GBT, 2 Gbps

First Non-Gaussian Structure!
Probes the large-scale scattering

Next Step (2016):
Space-VLBI with RadioAstron

Key Addition: LMT

Non-Gaussian Structure!
Probes global structure; disk vs. jet

Next Step (2017):
ALMA

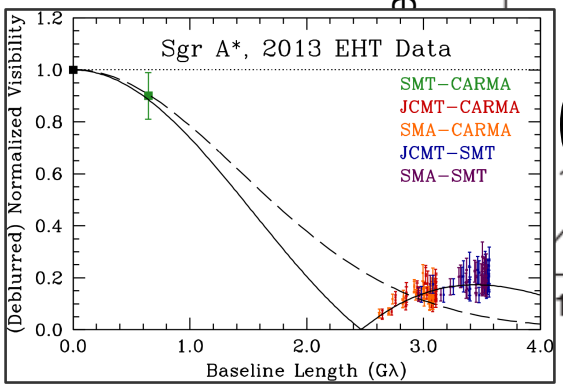
Sgr A*: Observed Size vs. Wavelength

Key Addition: Full Pol., 4 Gbps

Non-Gaussian Intrinsic Structure!
- Resolved polarization
- Resolved variability

Probes strong gravity & horizon-scale dynamical activity

Next Steps (2017-2018):
ALMA, LMT, SPT, PV, PdB
64 Gbps



100

1

10

Observing Wavelength (cm)

1.3mm

2015

3mm

2015

2014

1.3cm

Key Addition: GBT, 2 Gbps

First Non-Gaussian Structure!
Probes the large-scale scattering

Next Step (2016):
Space-VLBI with RadioAstron

Key Addition: LMT

Non-Gaussian Structure!
Probes global structure; disk vs. jet

Next Step (2017):
ALMA

Summary

Key Results from 2013 EHT Data:

- Discovery of ordered magnetic fields near the event horizon of Sgr A*
- Dominant variability in polarization but not in total flux
- Time-resolved astrometry of flares
- Non-Gaussian structure in the total flux (see also Fish et al. 2016)

In the next 1-2 years:

- Images of the black hole shadow and magnetic fields near Sgr A*
- Resolved trajectories of flaring regions
- Faraday rotation and circular polarization
- Other Targets: M87, 3C273, OJ287

See talk by John Wardle