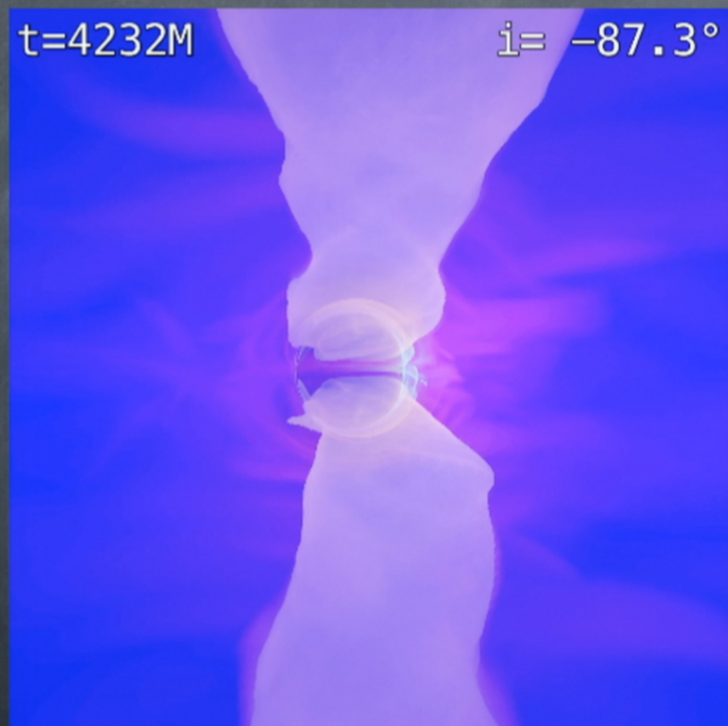
Title: GPU-accelerated Ray Tracing and a Null Hypothesis Test of GR with the EHT

Date: Nov 12, 2014 03:45 PM

URL: http://pirsa.org/14110121

Abstract: The Event Horizon Telescope will generate the first images of the black-hole shadows in Sgr A* and in M87. The observed photons will have originated in one of the strongest gravitational fields found in the Universe, encoding during their travel to the Earth the properties of the black-hole spacetimes. In this talk, I will discuss the prospect of performing a new null hypothesis test of GR with EHT observations of Sgr A* that does not depend on a prior knowledge of the properties of the accretion flow. I will address a a small number of outstanding questions related to the scattering screen towards the galactic center that need to be answered in order for this null hypothesis test to be performed. I will then use results from recent GPU-accelerated ray tracing calculations in conjunction with GRMHD simulations to argue that upcoming observations of Sgr A* with the EHT will be able to confirm the GR predictions for the size and shape of the black-hole shadow to an accuracy of better than 10%, in a model independent way.

A Null Hypothesis Test of GR with the Event Horizon Telescope



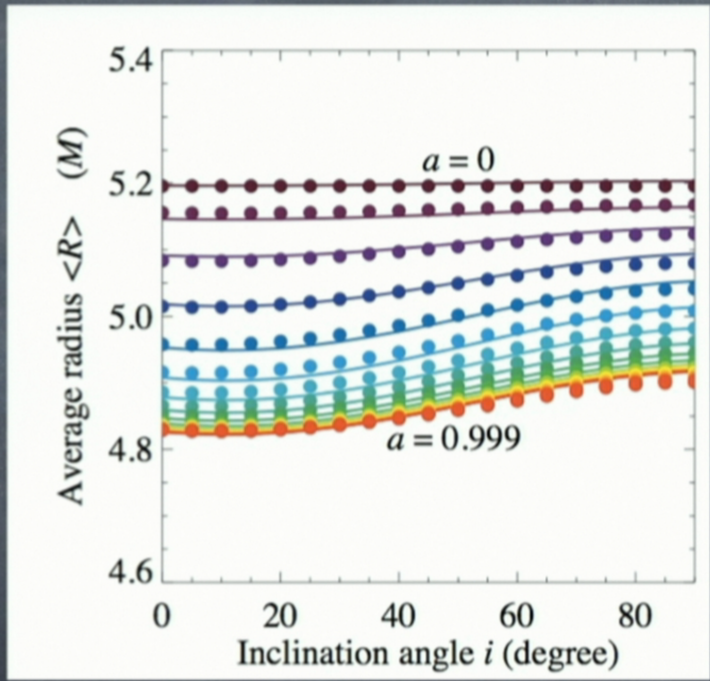
THE UNIVERSITY OF ARIZONA

Dimitrios Psaltis
Chi-Kwan Chan
Feryal Ozel
Dan Marrone

Ramesh Narayan
Olek Sadowski

arXiv: 1303.5057 ,1410.3492, 1411.1454

The opening angle of the black-hole shadow has a very weak dependence on black-hole spin or inclination.



±4% range!

A null hypothesis test: Does the image of Sgr A* have a shadow of the shape and size expected in GR?

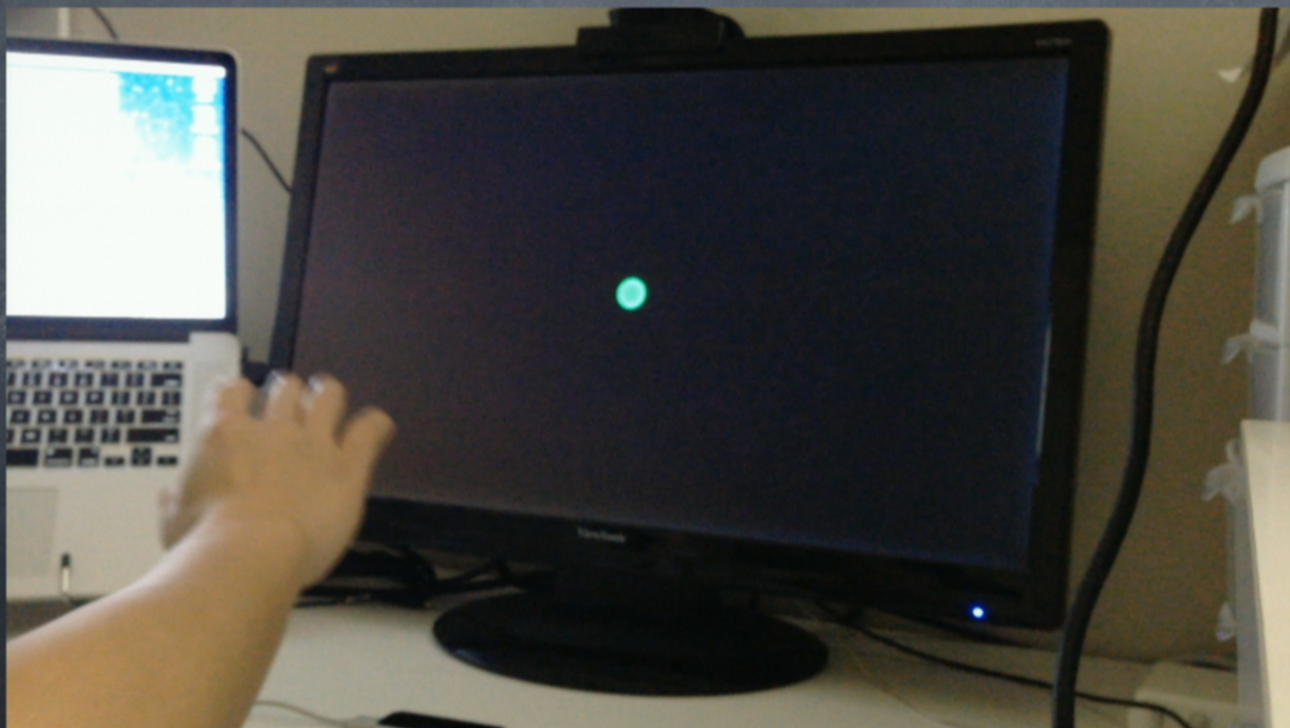
Challenge #1: Measure the properties of the shadow, without modeling the accretion flow

Use GRMHD simulations to explore a large range of possibilities and investigate the rate of false-positive identifications of the shadow

Challenge #1: Measure the properties of the shadow, without modeling the accretion flow

Use GRMHD simulations to explore a large range of possibilities and investigate the rate of false-positive identifications of the shadow

GR Ray Tracing with GPUs: A Game Changer



Challenge #1: Measure the properties of the shadow, without modeling the accretion flow

Use GRMHD simulations to explore a large range of possibilities and investigate the rate of false-positive identifications of the shadow

GR Ray Tracing with GPUs: A Game Changer

A special purpose supercomputer: computer gaming on steroids

67x2 NVIDIA GPUs

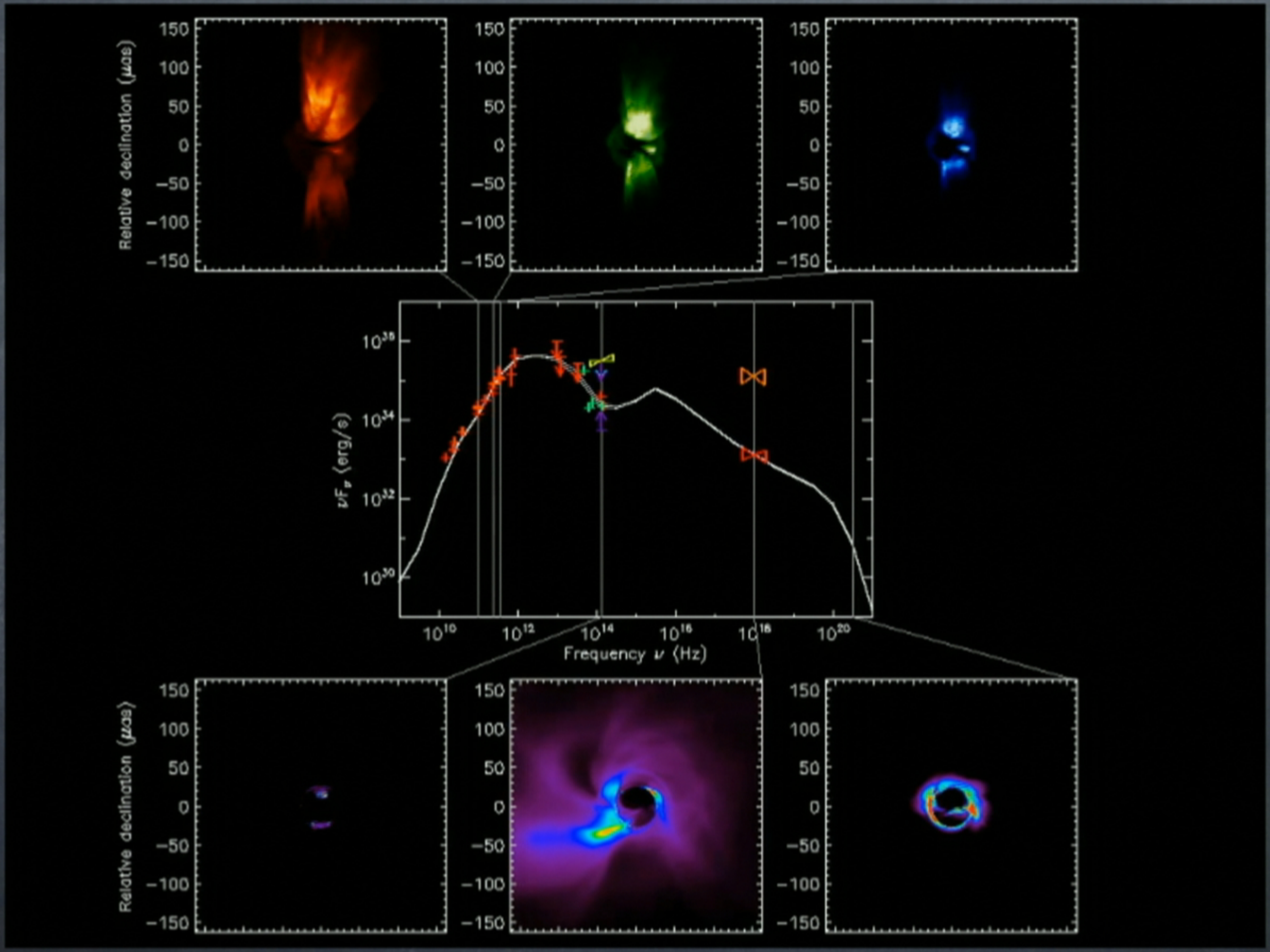
$1.8M (NSF MRI grant)

The Green500 List

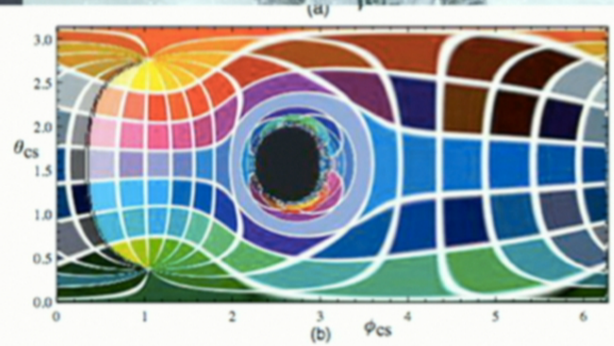
Listed below are the November 2013 The Green500's energy-efficient supercomputers ranked from 1 to 10.

Green500 Rank	MFLOPS/W	Site*	Computer*	Total Power (kW)
1	4,503.17	GSIC Center, Tokyo Institute of Technology	TSUBAME-KFC - LX 1U-4GPU/104Re-1G Cluster, Intel Xeon E5-2620v2 6C 2.100GHz, Infiniband FDR, NVIDIA K20x	27.78
2	3,631.86	Cambridge University	Wilkes - Dell T620 Cluster, Intel Xeon E5-2630v2 6C 2.600GHz, Infiniband FDR, NVIDIA K20	52.62
3	3,517.84	Center for Computational Sciences, University of Tsukuba	HA-PACS TCA - Cray 3623G4-SM Cluster, Intel Xeon E5-2680v2 10C 2.800GHz, Infiniband QDR, NVIDIA K20x	78.77
4	3,185.91	Swiss National Supercomputing Centre (CSCS)	Piz Daint - Cray XC30, Xeon E5-2670 8C 2.600GHz, Aries interconnect , NVIDIA K20x Level 3 measurement data available	1,753.66
5	3,130.95	ROMEO HPC Center - Champagne-Ardenne	romeo - Bull R421-E3 Cluster, Intel Xeon E5-2650v2 8C 2.600GHz, Infiniband FDR, NVIDIA K20x	81.41
6	3,068.71	GSIC Center, Tokyo Institute of Technology	TSUBAME 2.5 - Cluster Platform SL390s G7, Xeon X5670 6C 2.930GHz, Infiniband QDR, NVIDIA K20x	922.54
7	2,702.16	University of Arizona	iDataPlex DX360M4, Intel Xeon E5-2650v2 8C 2.600GHz, Infiniband FDR14, NVIDIA K20x	53.62
8	2,629.10	Max-Planck-Gesellschaft MPI/IPP	iDataPlex DX360M4, Intel Xeon E5-2680v2 10C 2.800GHz, Infiniband, NVIDIA K20x	269.94
9	2,629.10	Financial Institution	iDataPlex DX360M4, Intel Xeon E5-2680v2 10C 2.800GHz, Infiniband, NVIDIA K20x	55.62
10	2,358.69	CSIRO	CSIRO GPU Cluster - Nitro G16 3GPU, Xeon E5-2650 8C 2.000GHz, Infiniband FDR, Nvidia K20m	71.01

Black Hole Rendering with GPUs in the Arizona Cluster



MATTHEW McCONAUGHEY
ANNE HATHAWAY
JESSICA CHASTAIN
MICHAEL CAINE
THE END OF EARTH WILL NOT BE THE END OF US.
INTERSTELLAR
IN THEATRES AND IMAX
EVERYWHERE
NOVEMBER 7



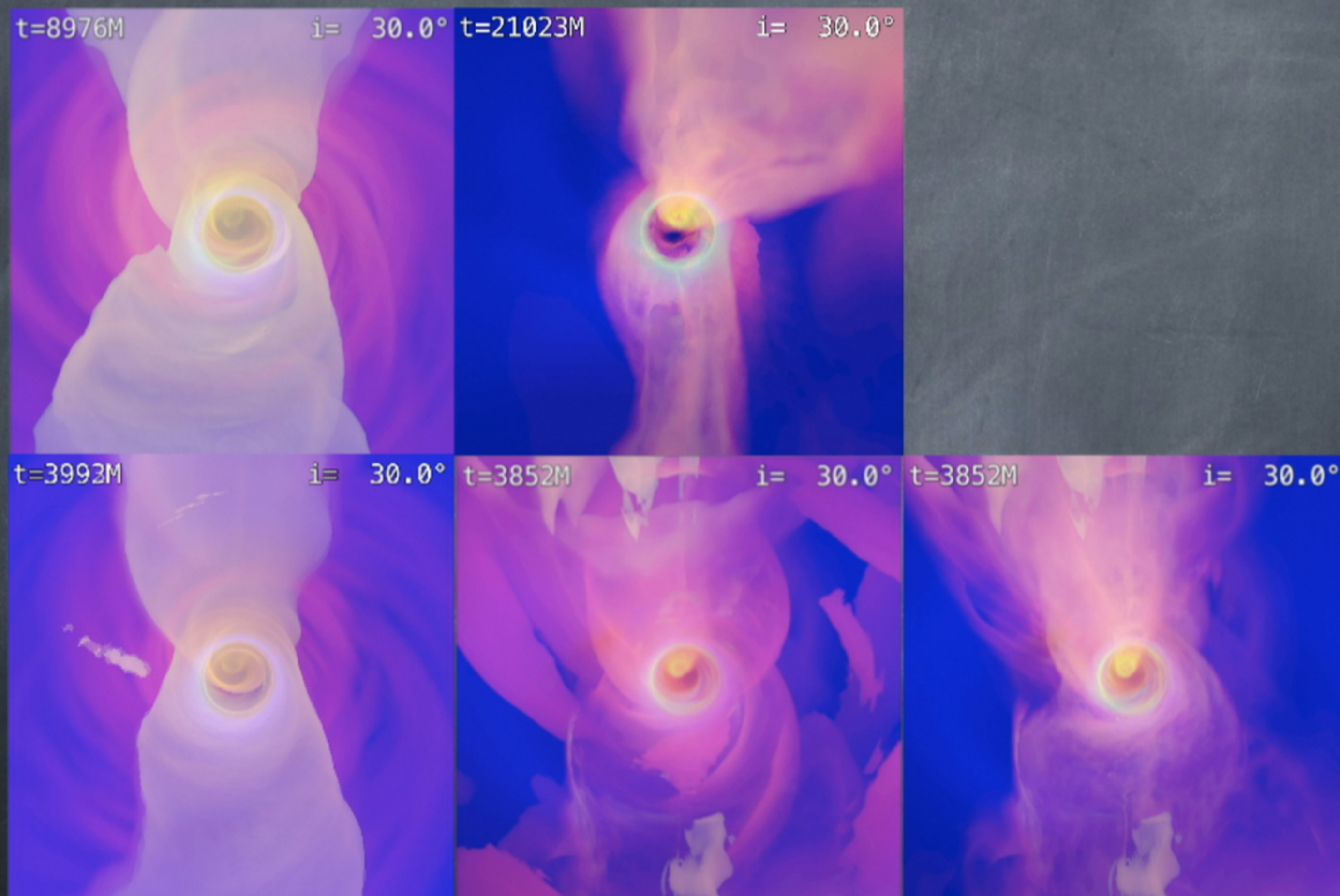
McConaughey explores another world in Interstellar (top). Thorne's diagram of how a black hole distorts light.

DIAGRAMS COURTESY OF KIP THORNE

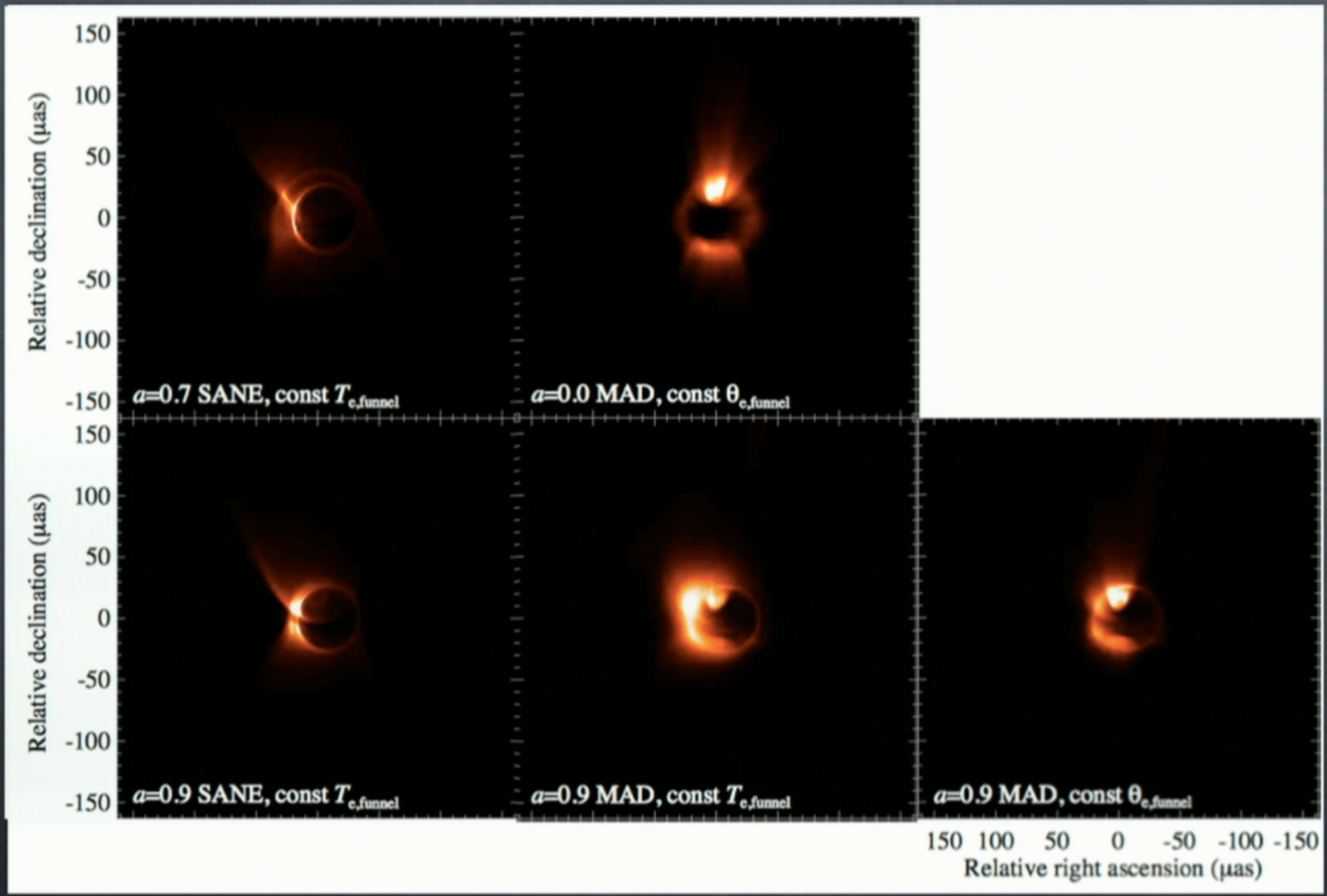
ray-tracing software makes the generally reasonable assumption that light is traveling along straight paths," says Eugénie von Tunzelmann, a CG supervisor at Double Negative. This was a whole other kind of physics. "We had to write a completely new renderer," she says.

Some individual frames took up to 100 hours to render, the computation overtaxed by the bendy bits of distortion caused by an Einsteinian effect called gravitational lensing. In the end the movie brushed up against 800 terabytes of data. "I thought we might cross the petabyte threshold on this one," von Tunzelmann says.

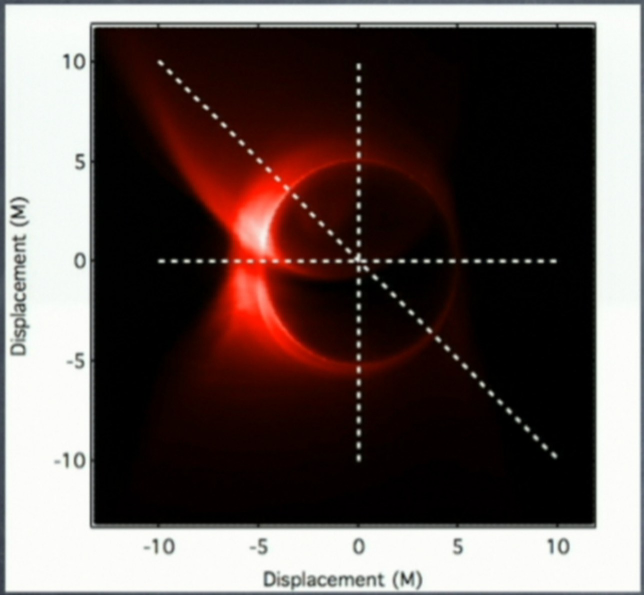
Black Hole Rendering with GPUs in the Arizona Cluster

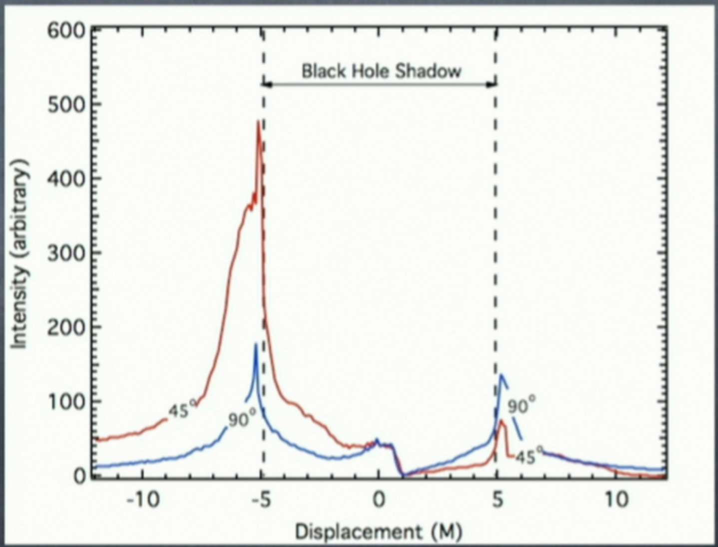


Black Hole Rendering with GPUs in the Arizona Cluster

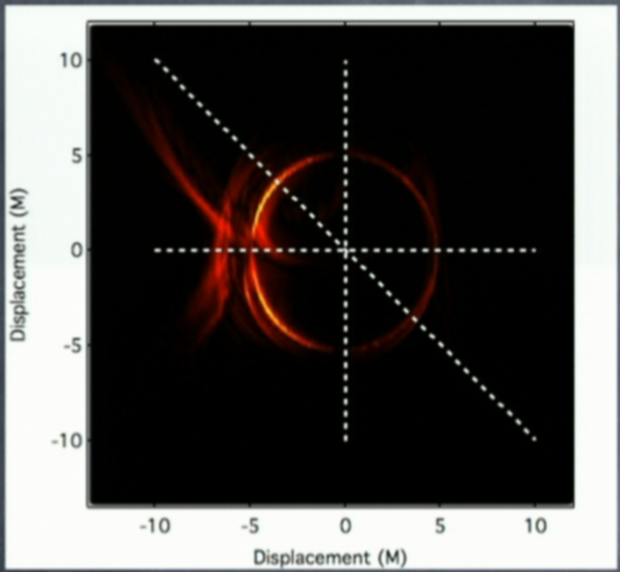


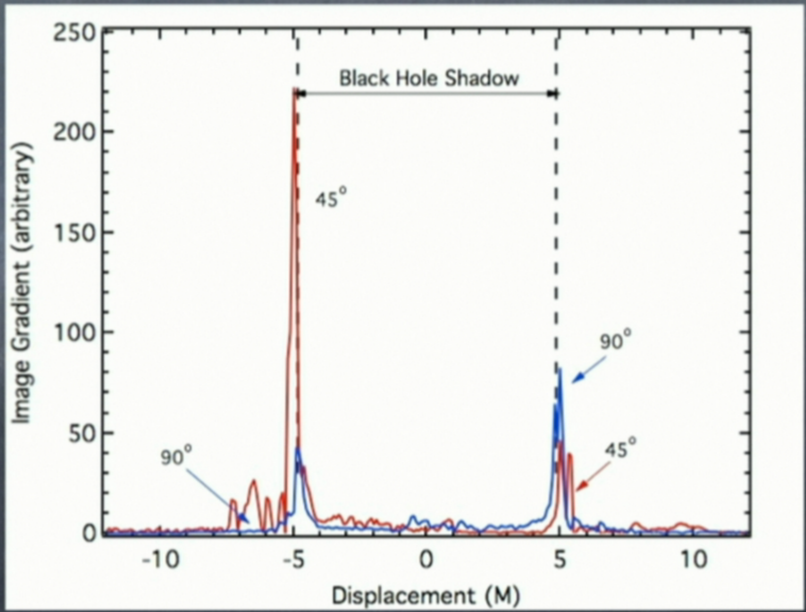
What is a characteristic, quantifiable property of the black-hole shadow?



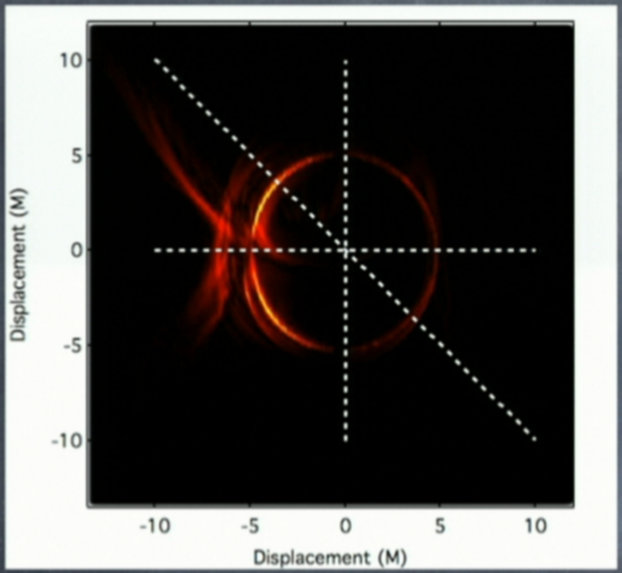


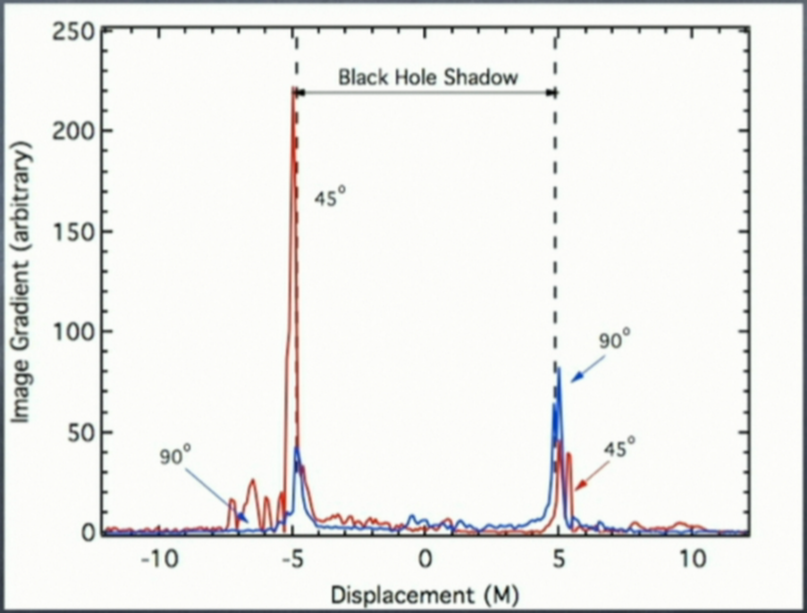
Edge Detection with a Gradient Magnitude





Edge Detection with a Gradient Magnitude





A formal definition of the Radon Transform for a Kerr Black-Hole Shadow, with appropriate definition of posterior Likelihood measures

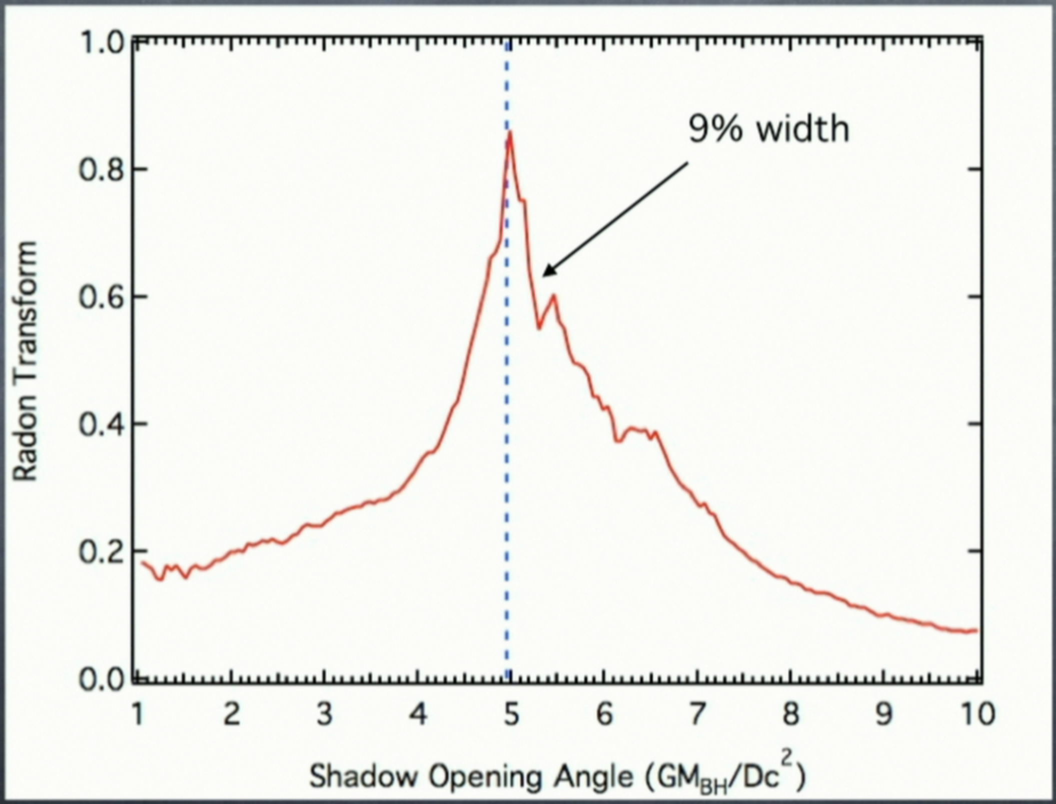
$$\alpha'(r) = -m \frac{\left[a^2(r+1) + (r-3)r^2\right] \csc\theta_o}{a(r-1)}$$

$$\beta'_\pm(r) = \pm m \frac{1}{a(r-1)} \left\{ a^4(r-1)^2 \cos^2\theta_o + a(r-1)\left[a^2(r+1) + (r-3)r^2\right] \cot^2\theta_o - r^3\left[(r-3)^2 r - 4a^2\right] \right\}^{1/2} .$$

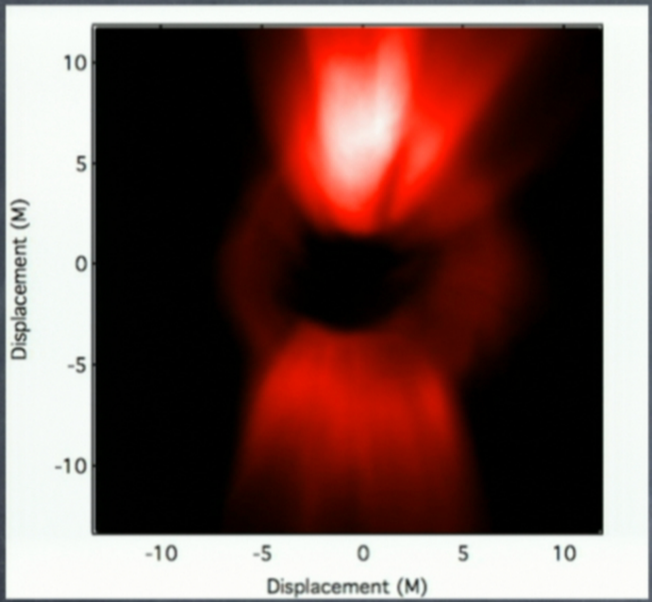
$$\mathcal{R}(\alpha_0, \beta_0, \phi, m, a) = C \int_{r_{\mathrm{ph}-}}^{r_{\mathrm{ph}+}} dr \frac{ds}{dr} \left\{ H\left[G(\alpha, \beta_+) - G_0\right] + H\left[G(\alpha, \beta_-) - G_0\right] \right\}$$

$$\frac{ds}{dr} = \frac{r\left(r^2 - 3r + 3\right) - a^2}{a(r-1)^2} \left\{ \frac{\left[a(r-1)\cot^2\theta_o - 2(r-3)r^2\right]^2}{a^4(r-1)^2\cos^2\theta_o + a(r-1)\left[a^2(r+1) + (r-3)r^2\right]\cot^2\theta_o - r^3\left[(r-3)^2 r - 4a^2\right]} + 4\csc^2\theta_o \right\}^{1/2}$$

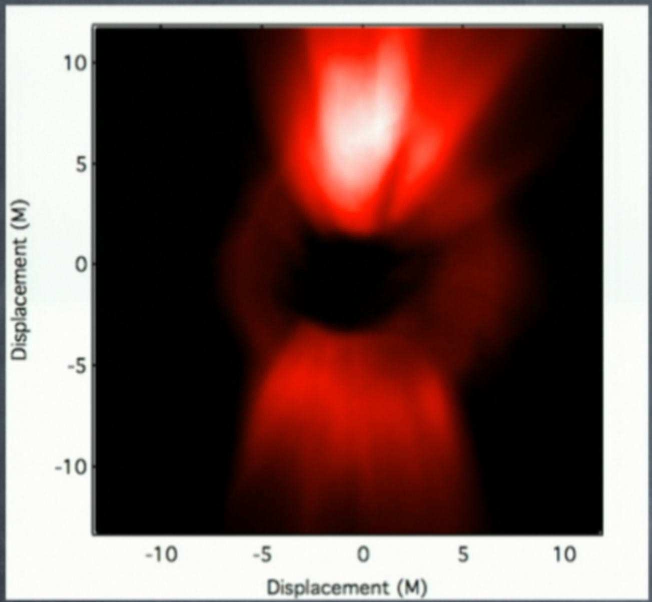
Radon Transform of a Simulated Gradient Image of a Black-Hole Accretion Flow

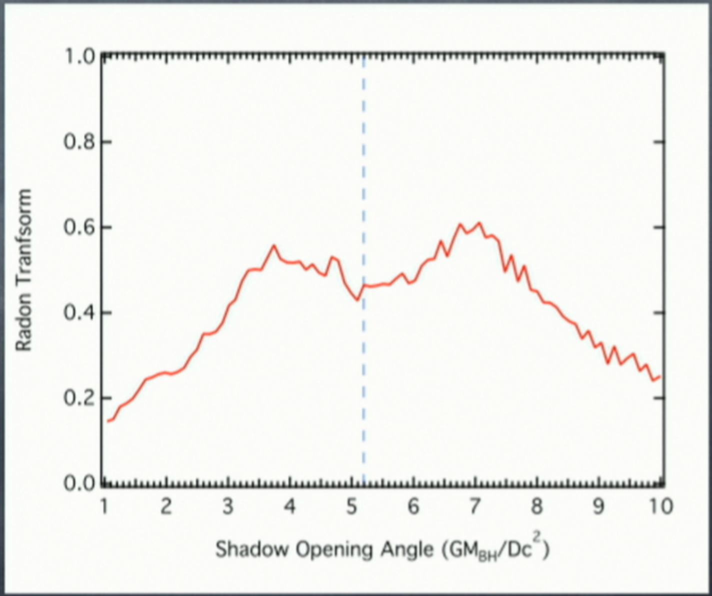


What if there is no visible shadow?

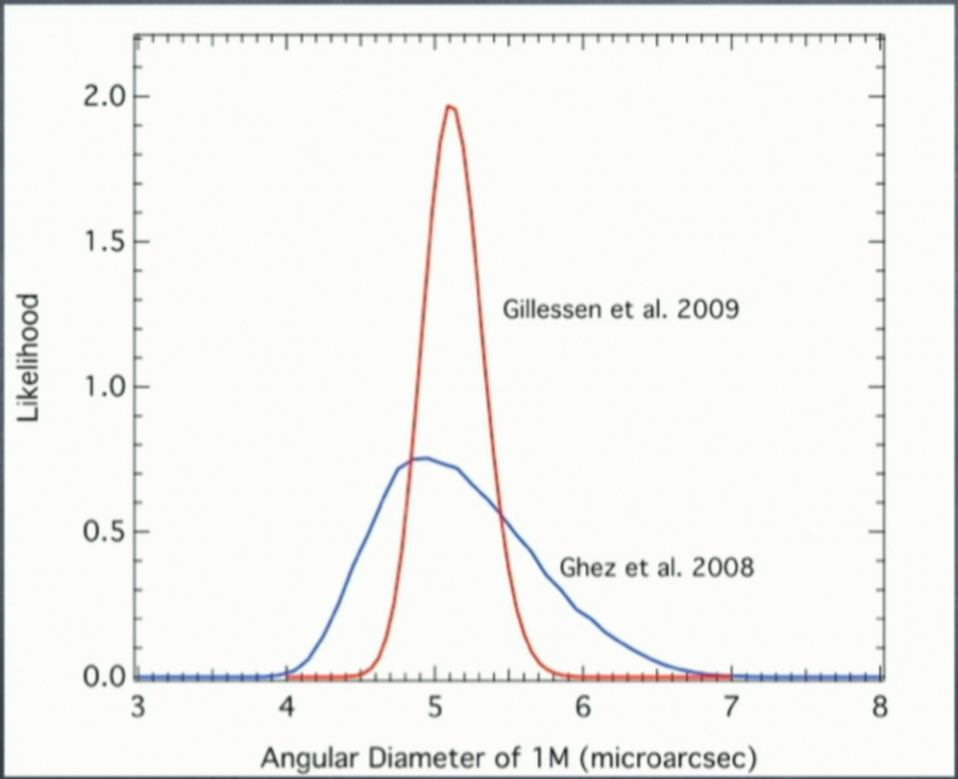


What if there is no visible shadow?



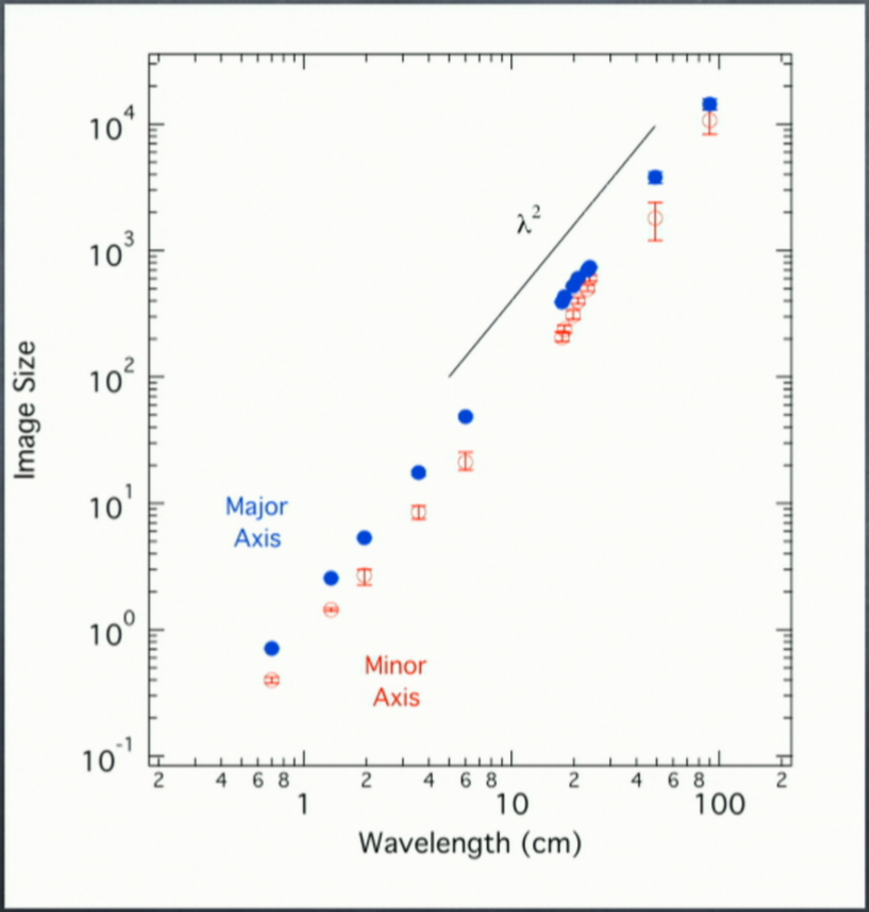


Challenge #2: What is the expected angular size of the black-hole shadow?

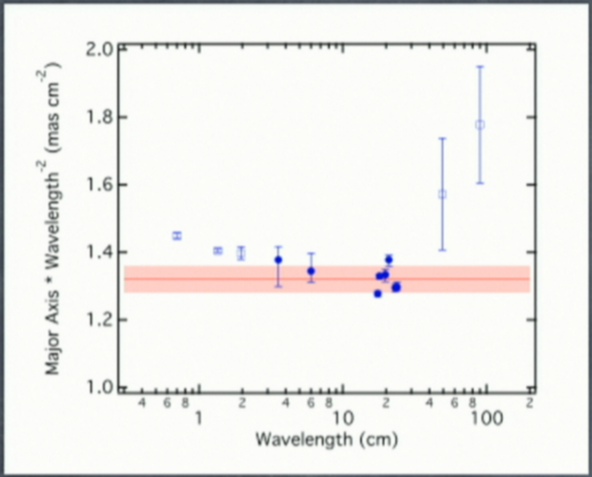


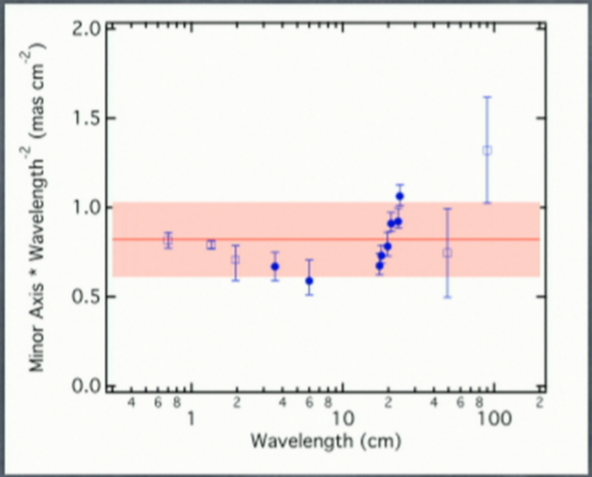
The angular size of the black-hole shadow is known to within 6%
M/D=5.19+-0.29 microarcsec

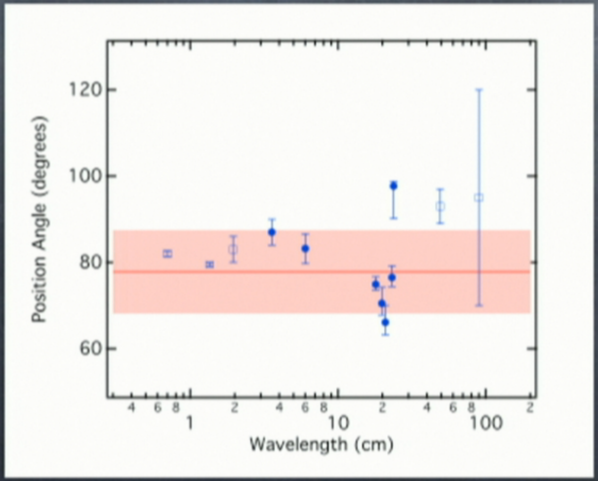
Challenge #3: How well do we know the properties of the scattering screen?



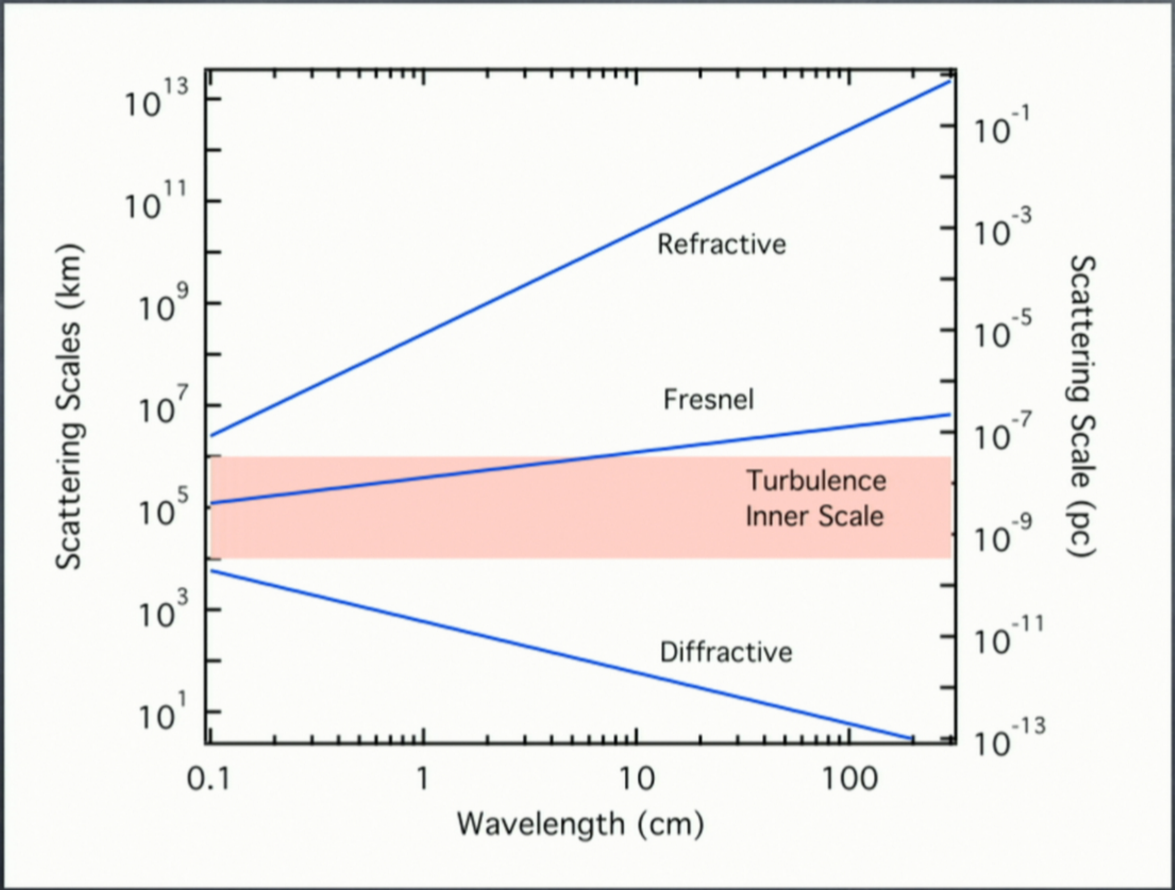
Challenge #3: How well do we know the properties of the scattering screen?



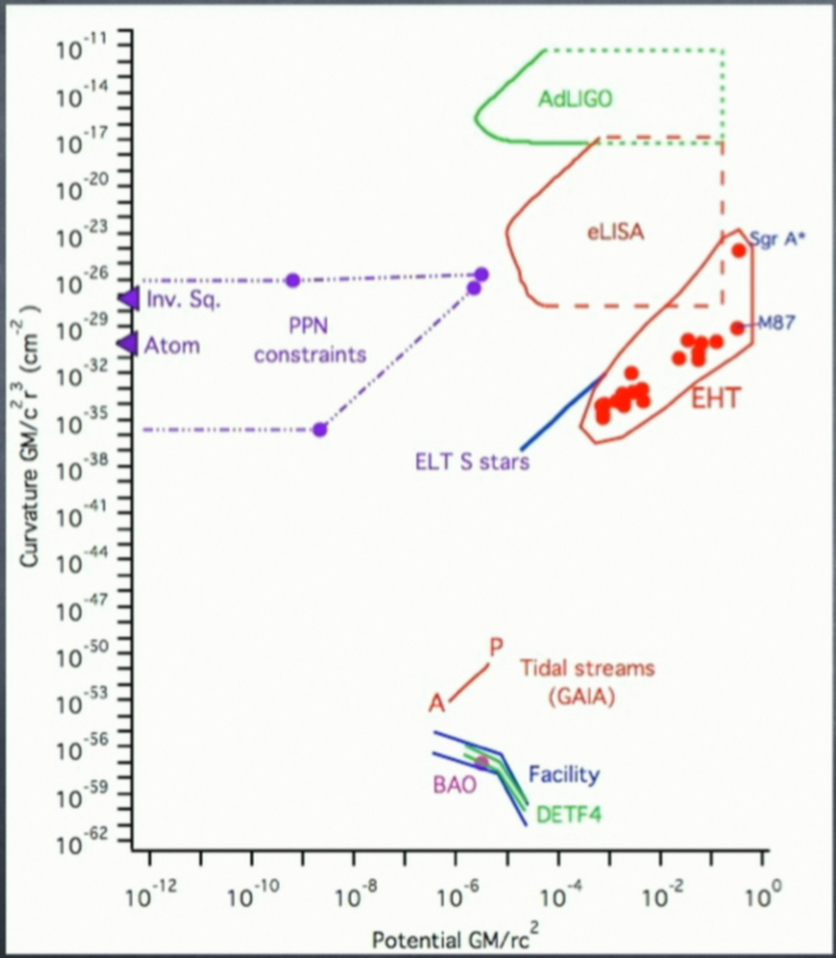




Length scales in the scattering screen towards Sgr A*



The EHT will probe an untested region of the parameter space of gravity



Baker, Psaltis, & Skordis 2014