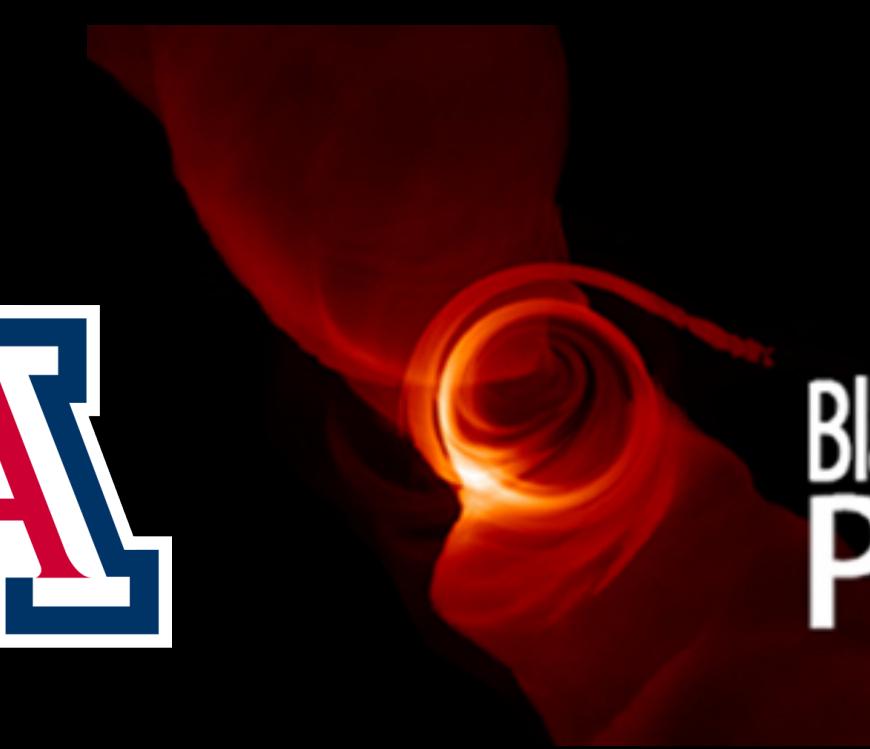
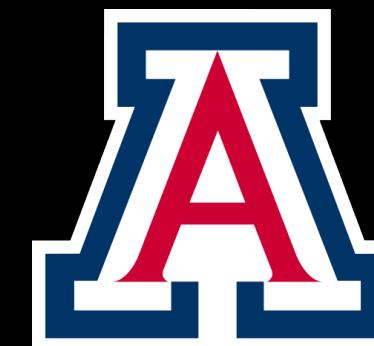


Decoding Black Hole Images

How OSG and Simulations Were Used to
Understand Black Holes

Chi-kwan "CK" CHAN
University of Arizona, EHT Collaboration

July 10th, 2023
Throughput Computing 2023



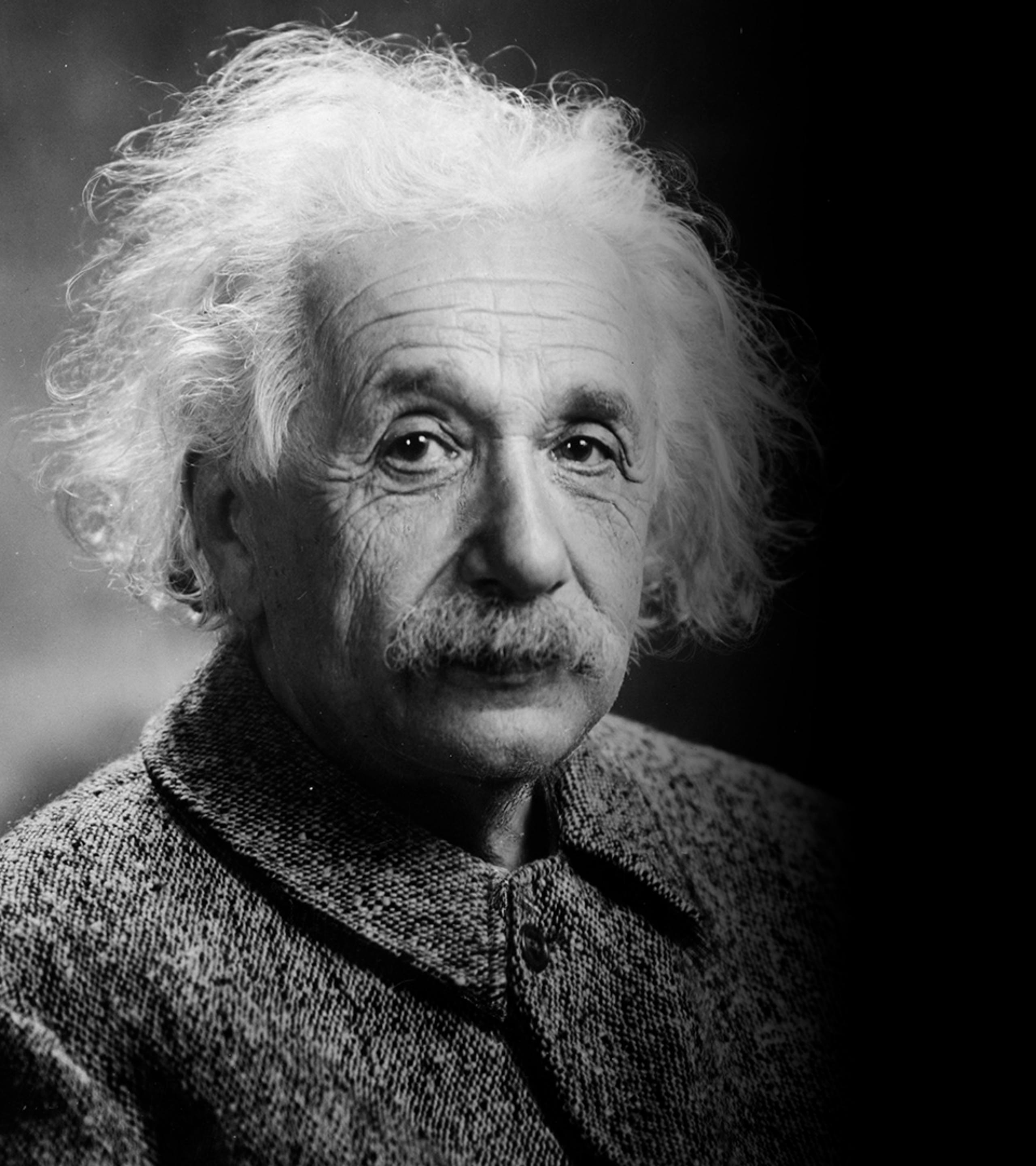
Black Hole
PIRE



Event Horizon Telescope

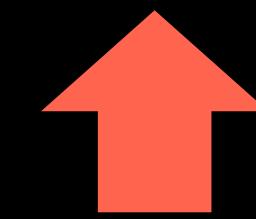
Optical light



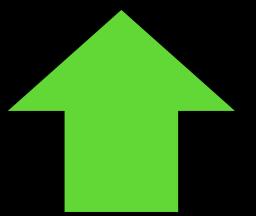
A black and white portrait of Albert Einstein, showing him from the chest up. He has his characteristic wild, grey hair and a full, grey beard. He is looking slightly to the right of the camera with a thoughtful expression.

Einstein's Field Equation

$$G_{\mu\nu} = \kappa T_{\mu\nu}$$



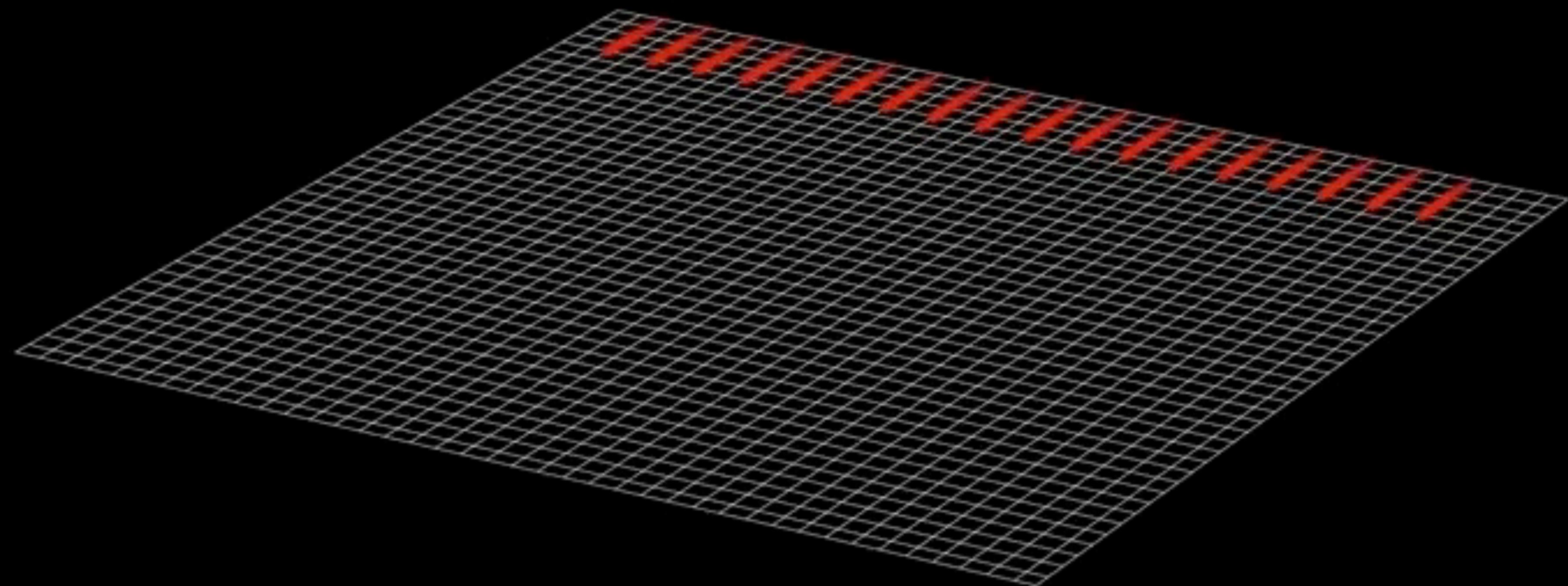
**Spacetime
Curvature**



**Matter/Energy
Density**

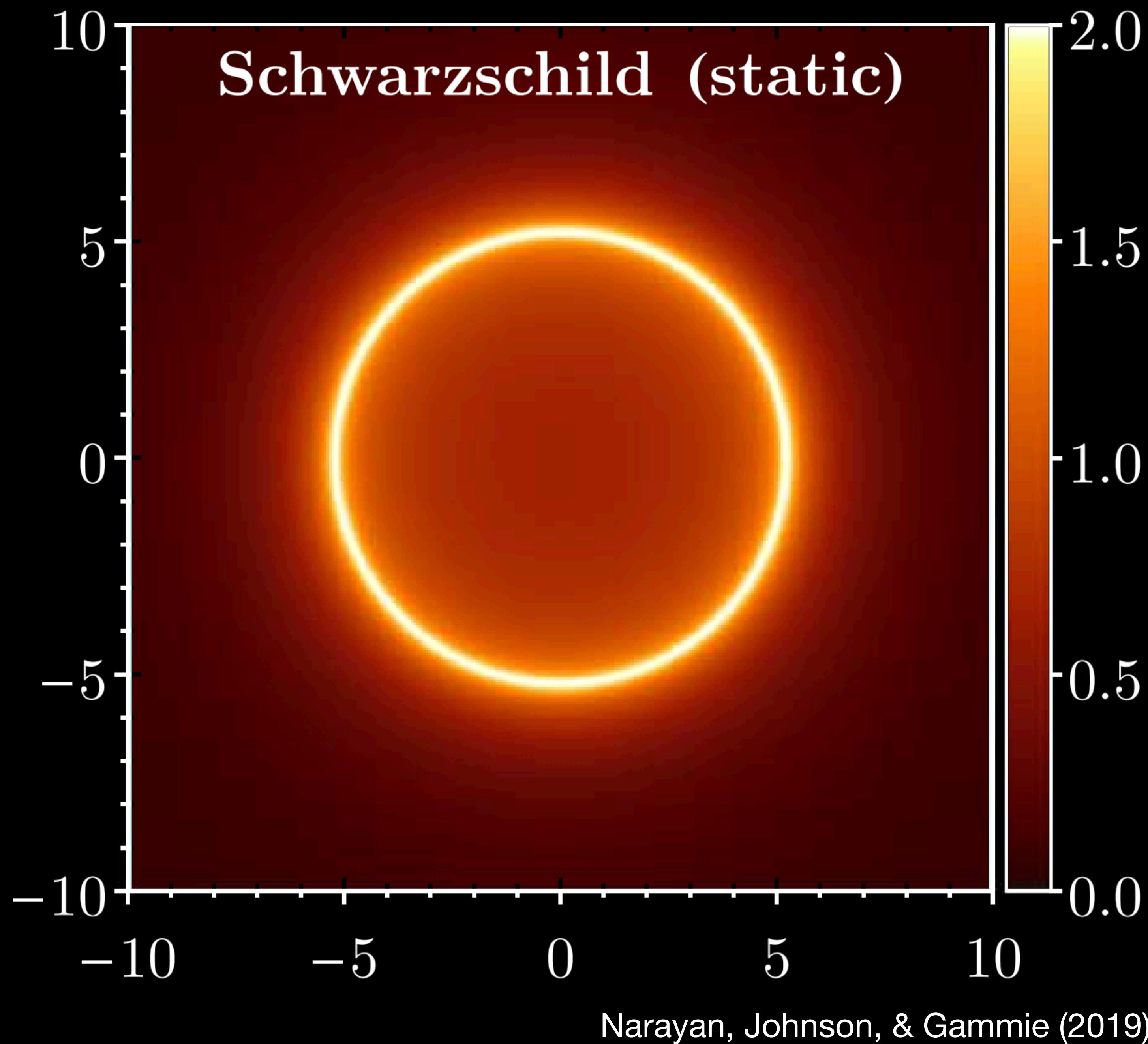
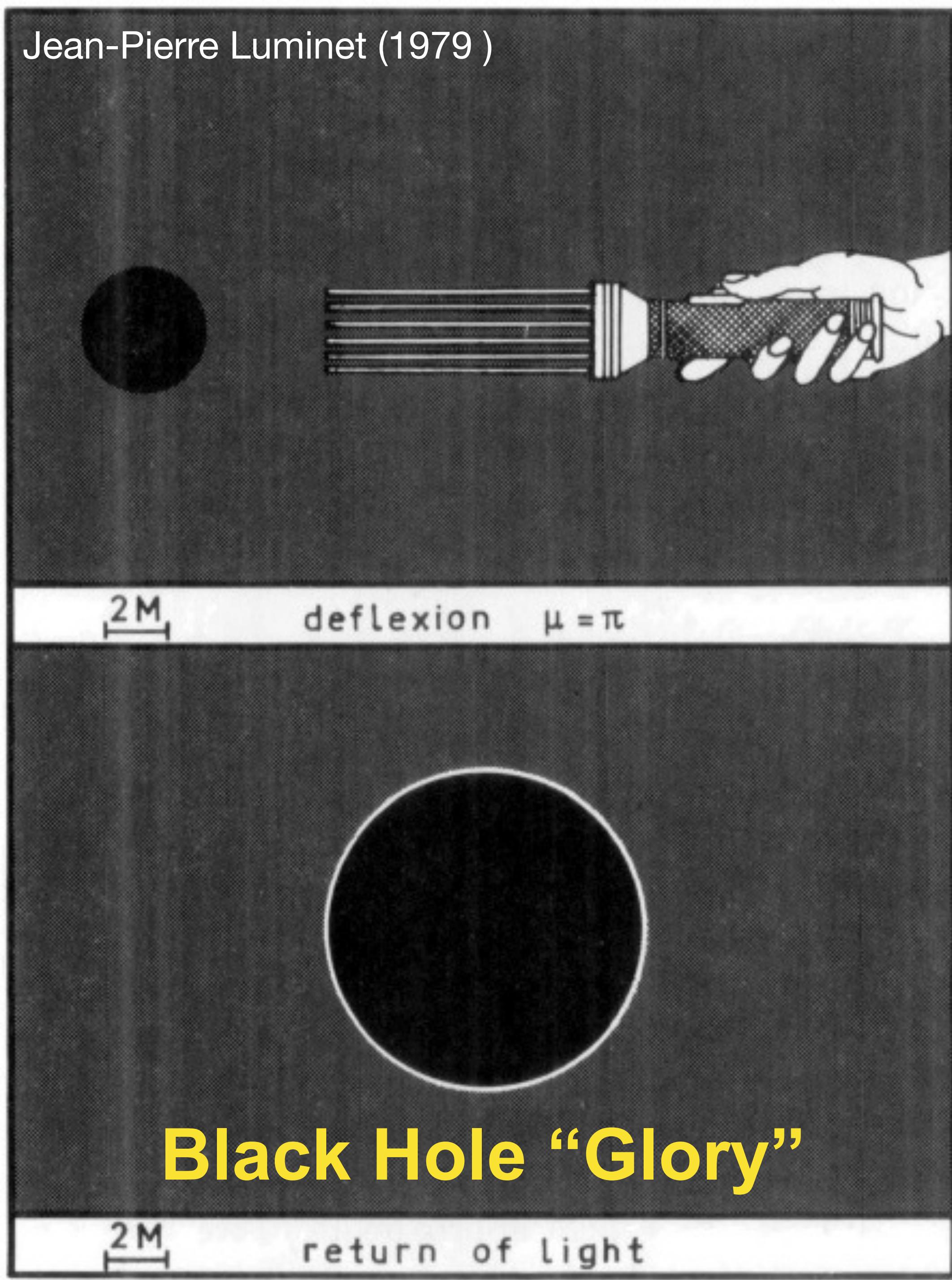
Spacetime tells matter how to move;
matter tells spacetime how to curve.

- John Wheeler

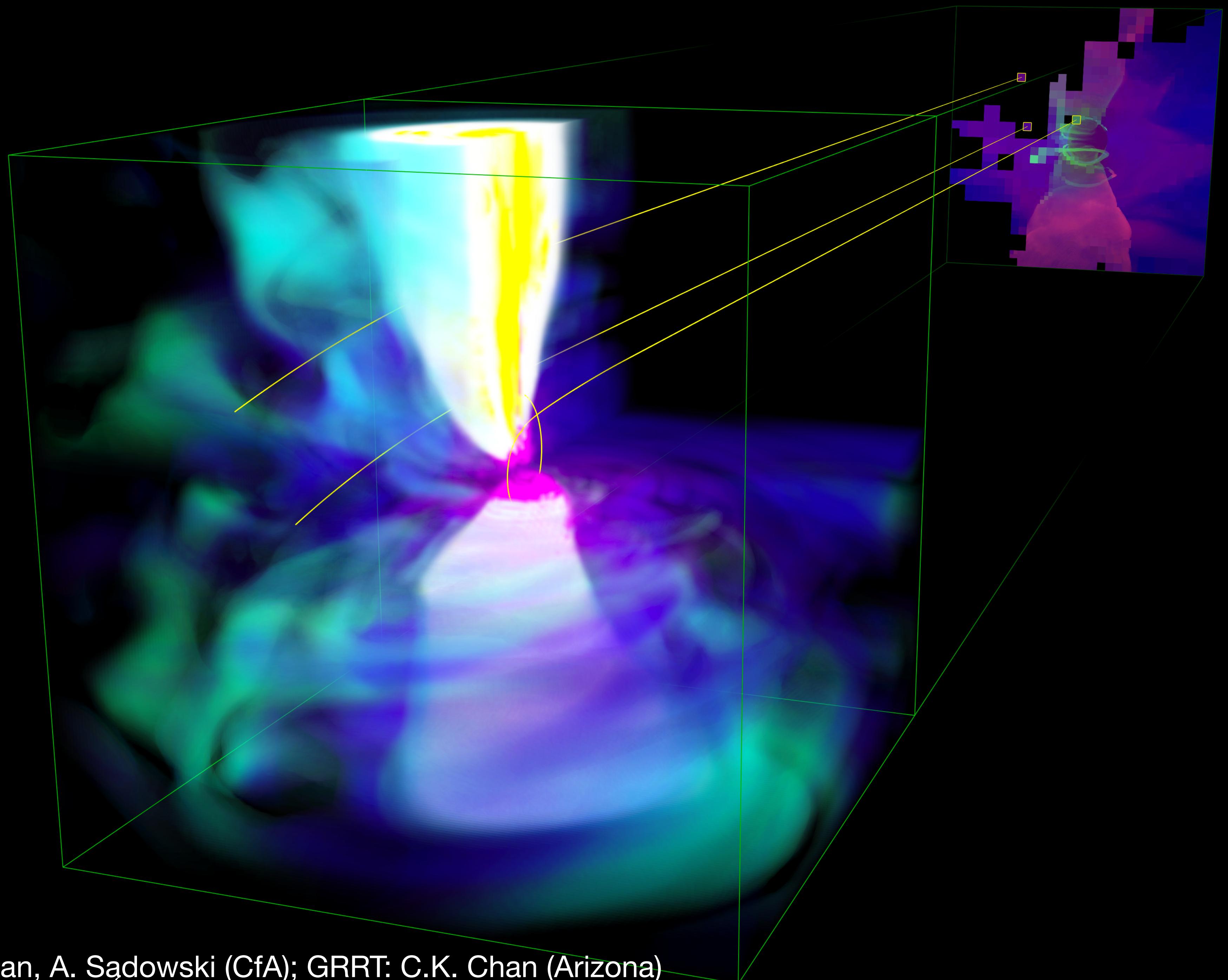


Credit: D. Psaltis

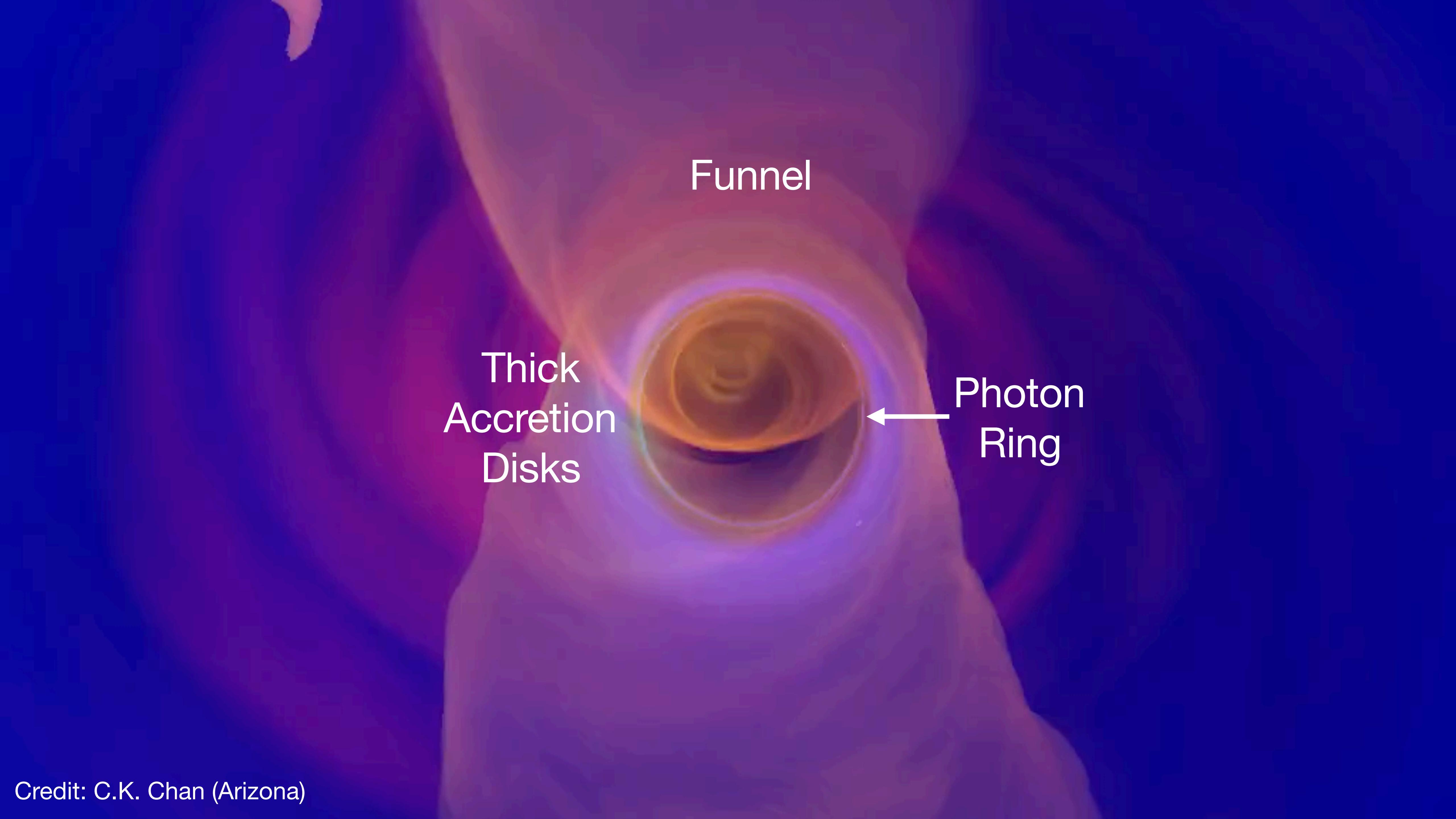
Jean-Pierre Luminet (1979)



Narayan, Johnson, & Gammie (2019)



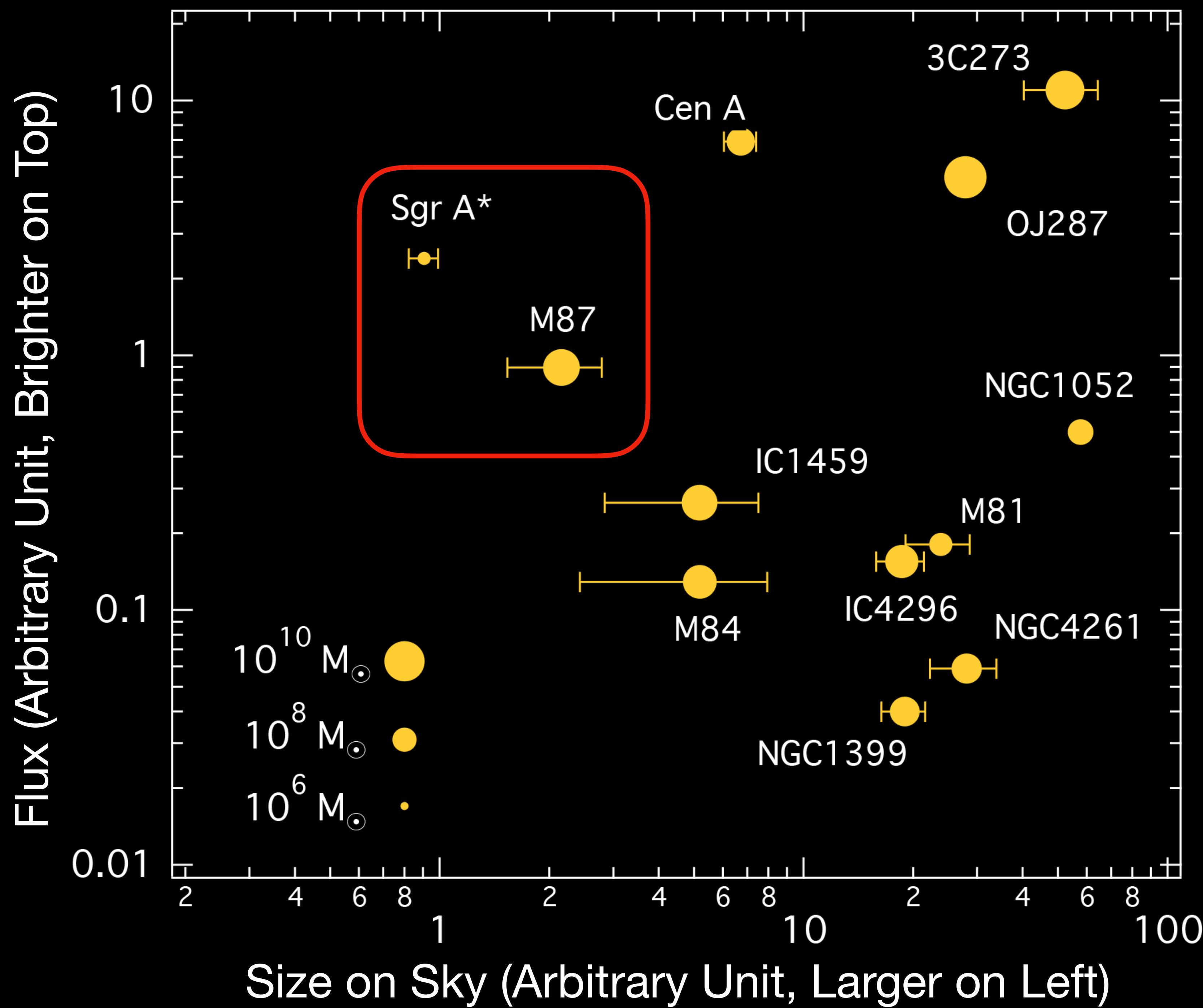
GRMHD: R. Narayan, A. Sadowski (CfA); GRRT: C.K. Chan (Arizona)



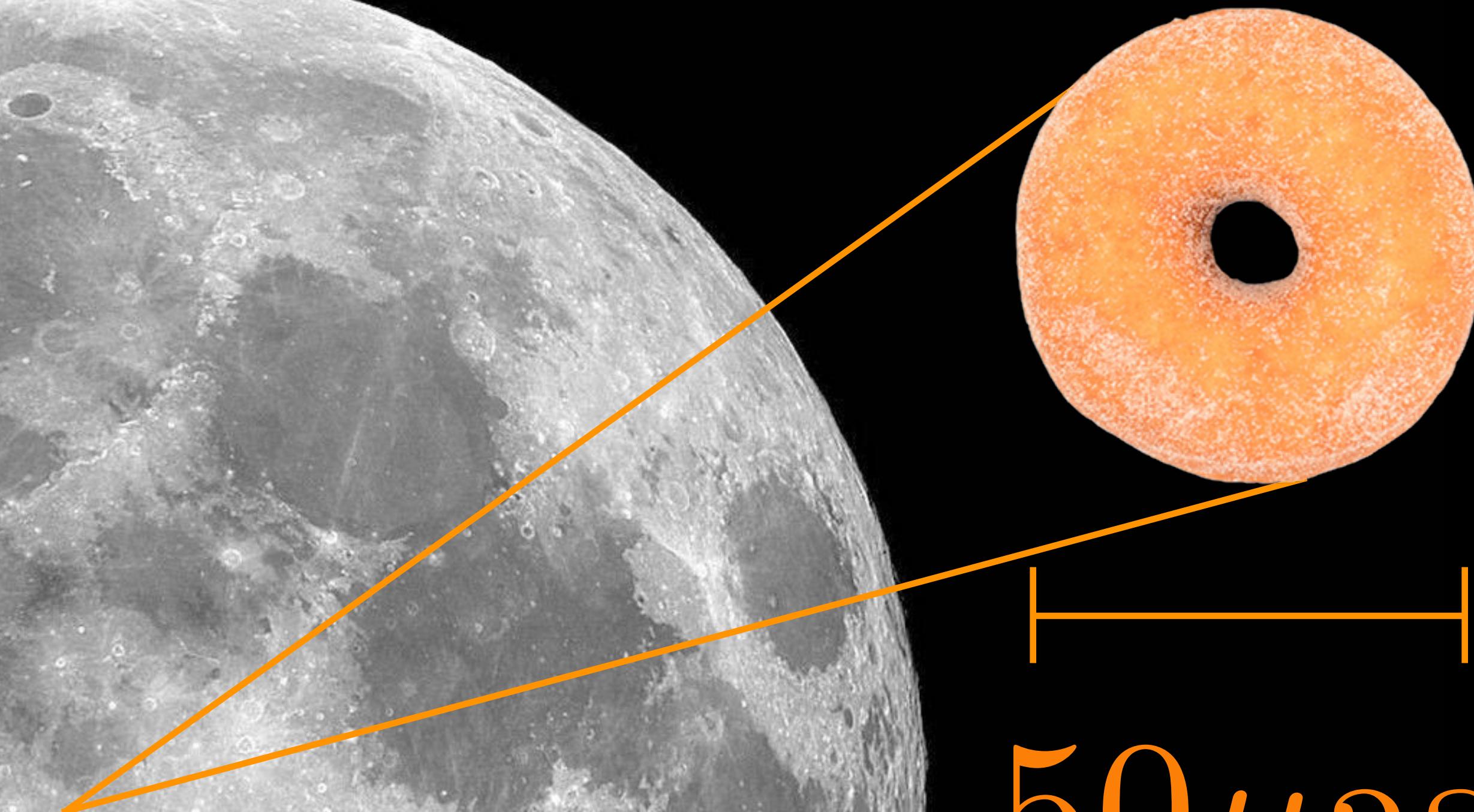
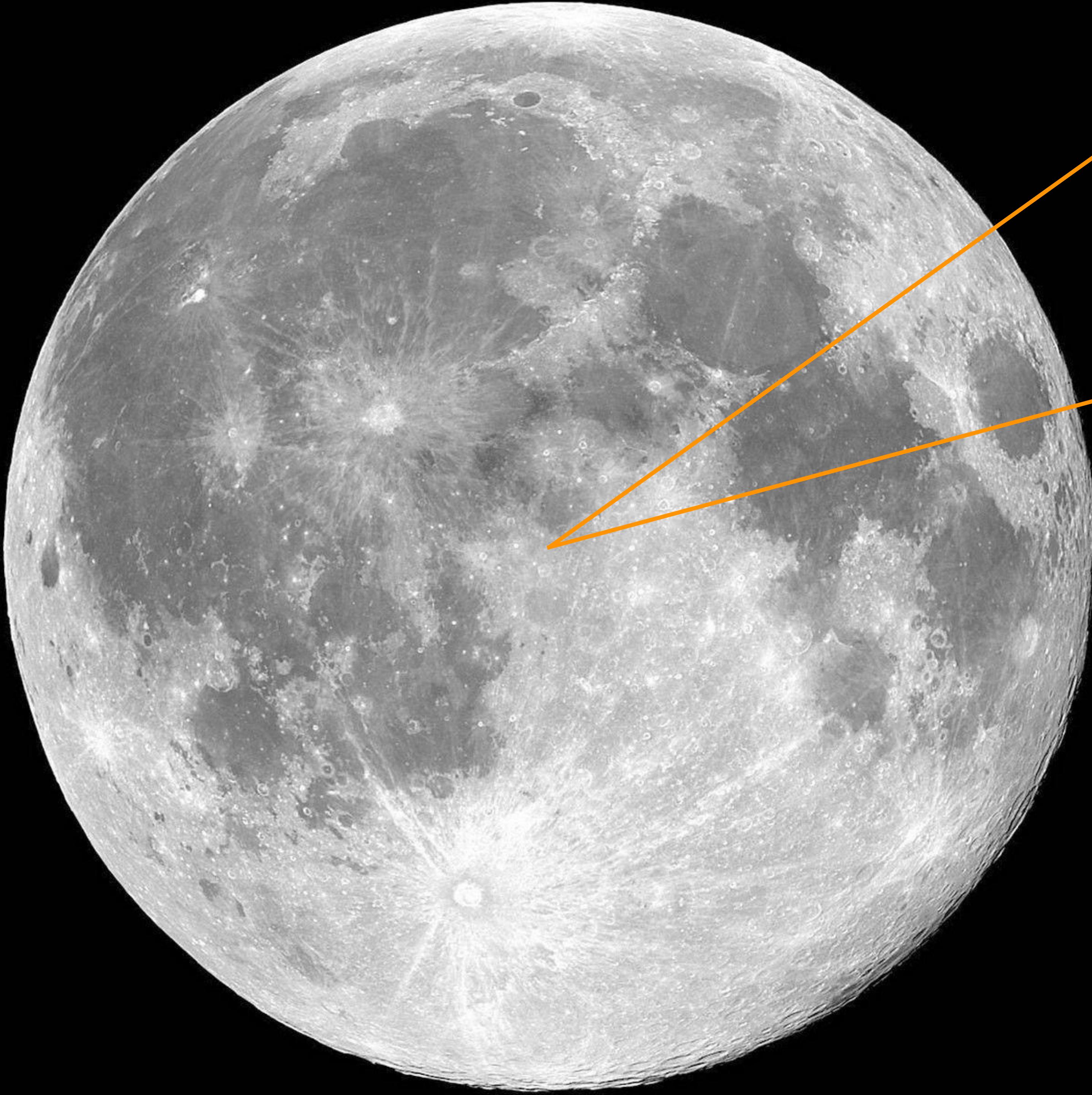
Thick
Accretion
Disks

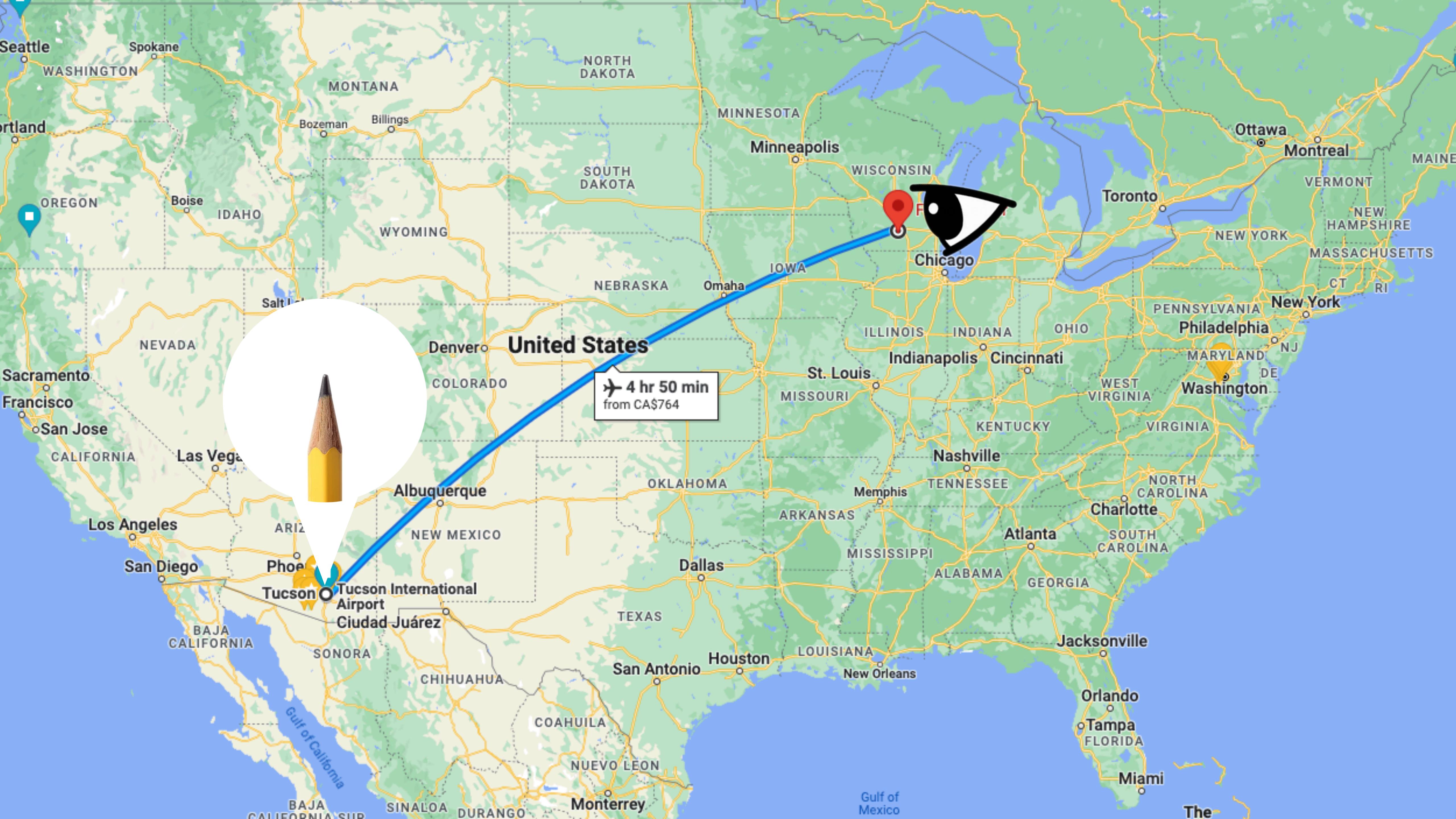
Funnel

Photon
Ring

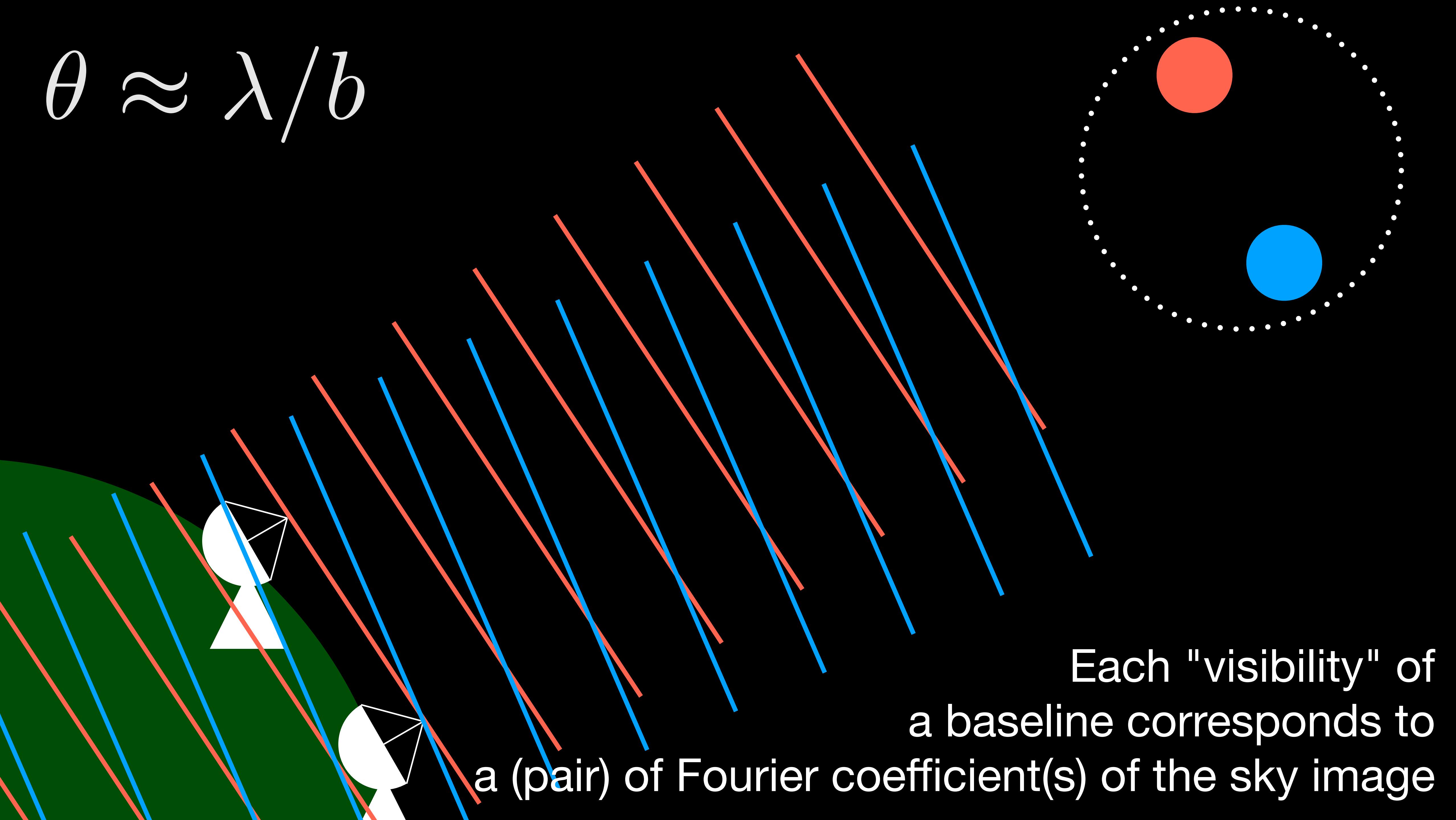


0.5°





$$\theta \approx \lambda/b$$



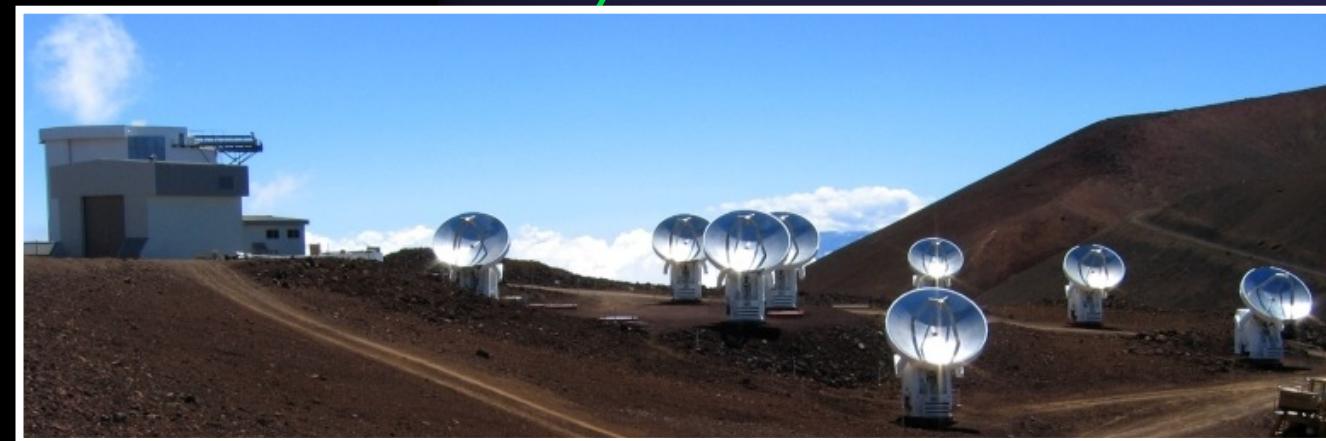
a (pair) of Fourier coefficient(s) of the sky image

Each "visibility" of
a baseline corresponds to

Credit: D Marrone



SMA/JCMT



KP

LMT

SMT

APEX

ALMA

SPT



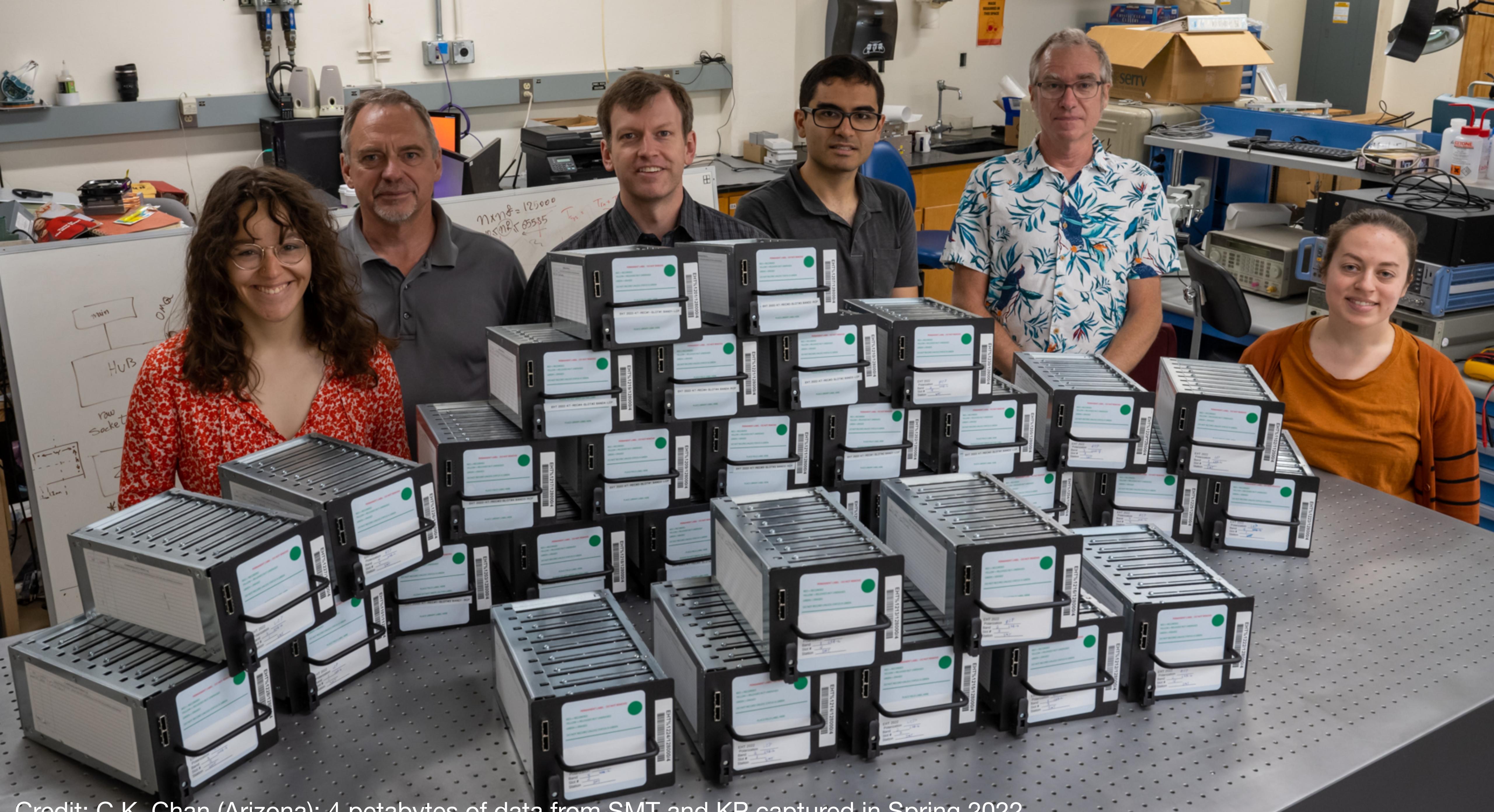
GLT

NOEMA

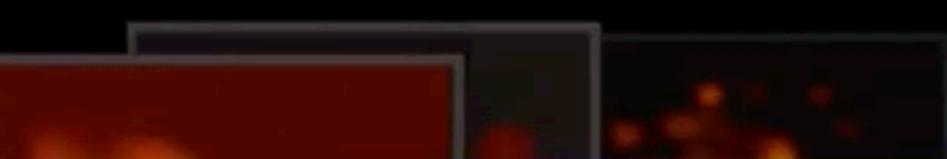
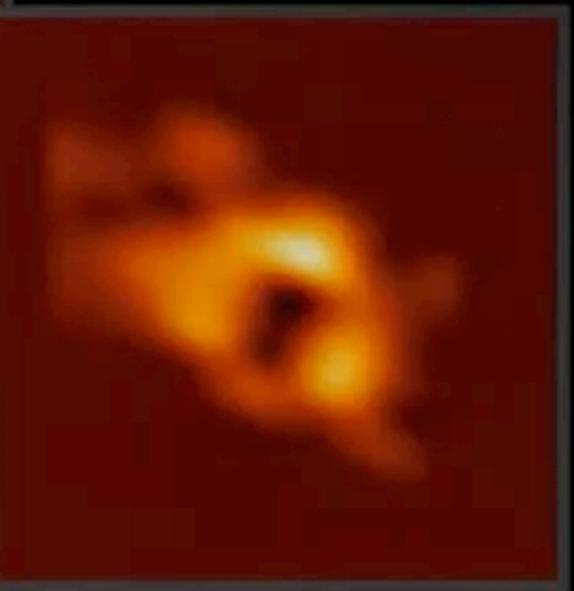
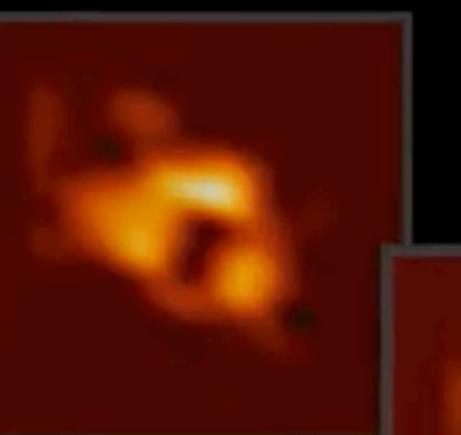
IRAM30m



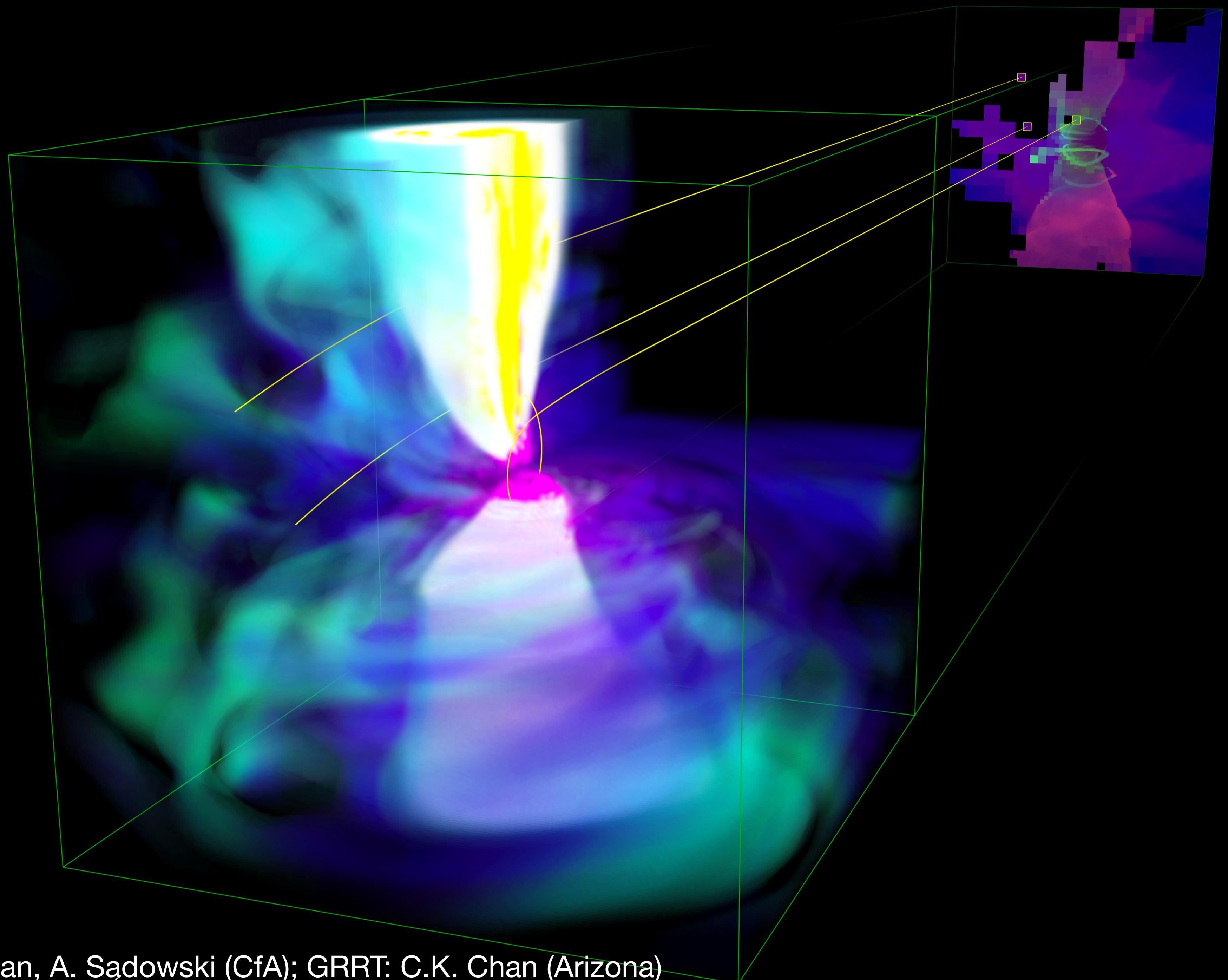
- 2017 Array
- 2018+ Array



Credit: C.K. Chan (Arizona); 4 petabytes of data from SMT and KP captured in Spring 2022



Credit: K. Bouman



GRMHD: R. Narayan, A. Sadowski (CfA); GRRT: C.K. Chan (Arizona)

Black Hole PIRE

github.com/orgs/bhpire/repositories

Overview Repositories 15 Projects Packages Teams

Find a repository... New repository

Type Language Sort

MARCH Private

Markov Chains for Horizons

● C 1 ★ 1 0 0 Updated on Feb 11

ipole-osg Public

A simple HTCondor setup for running `ipole` on the Open Science Grid

● Shell 2 ★ 0 0 0 Updated on Sep 8, 2022

igrmonty-osg Public

A simple HTCondor setup for running `igrmonty` on the Open Science Grid

● Shell 1 ★ 0 0 0 Updated on Sep 10, 2021

symba-osg Public

A Pegasus workflow for running SYMBA on the Open Science Grid

● Python 0 ★ 1 0 0 Updated on May 5, 2021

calsz-osg Public

A simple HTCondor setup for running `calsz` on the Open Science Grid

● Python 1 ★ 0 0 0 Updated on Apr 29, 2021

cvmfs-singularity-sync Public

Forked from opensciencegrid/cvmfs-singularity-sync

Scripts to synchronize Singularity images to a CVMFS repository.

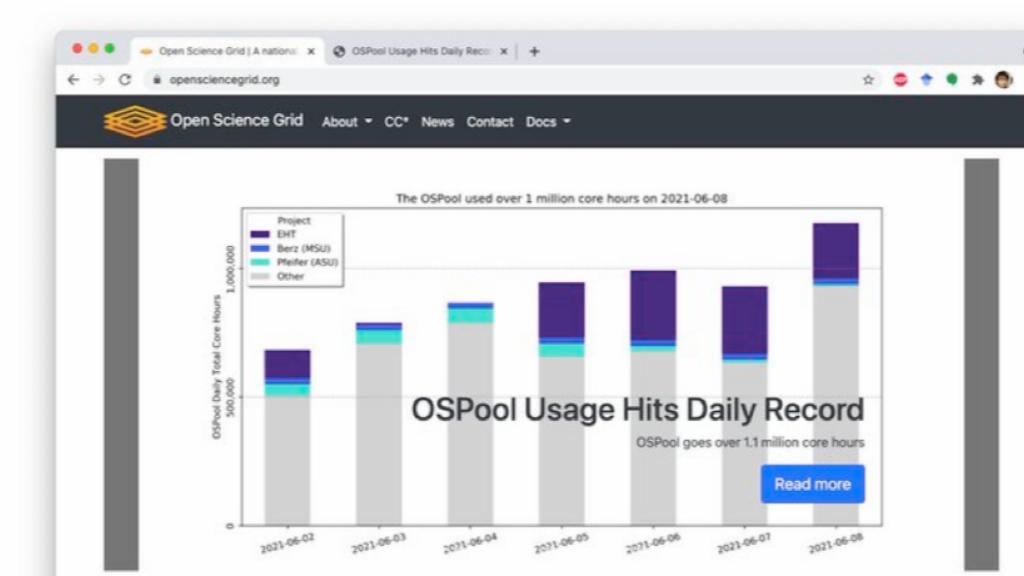
● Python Apache-2.0 134 ★ 0 0 0 Updated on Mar 12, 2020

11:07 11:07

◀ Chrome

Feryal Ozel
@feryal_ozel

Arizona @BHPIRE EHT team is the top user of the Open Science Grid in the entire country. Can you tell something is cooking? 😊



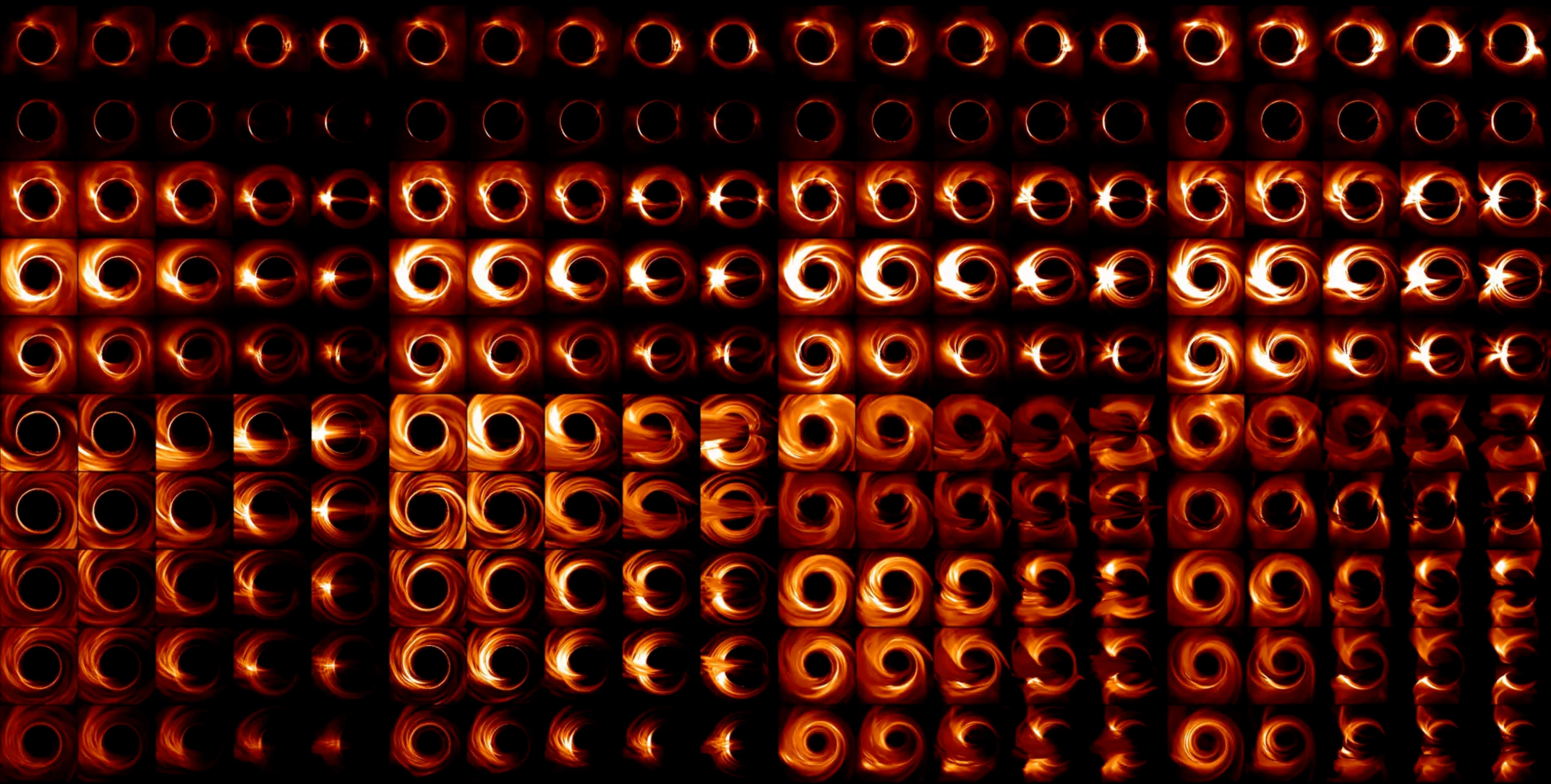
7:32 AM · 6/25/21 · Twitter for iPhone

Tweet your reply

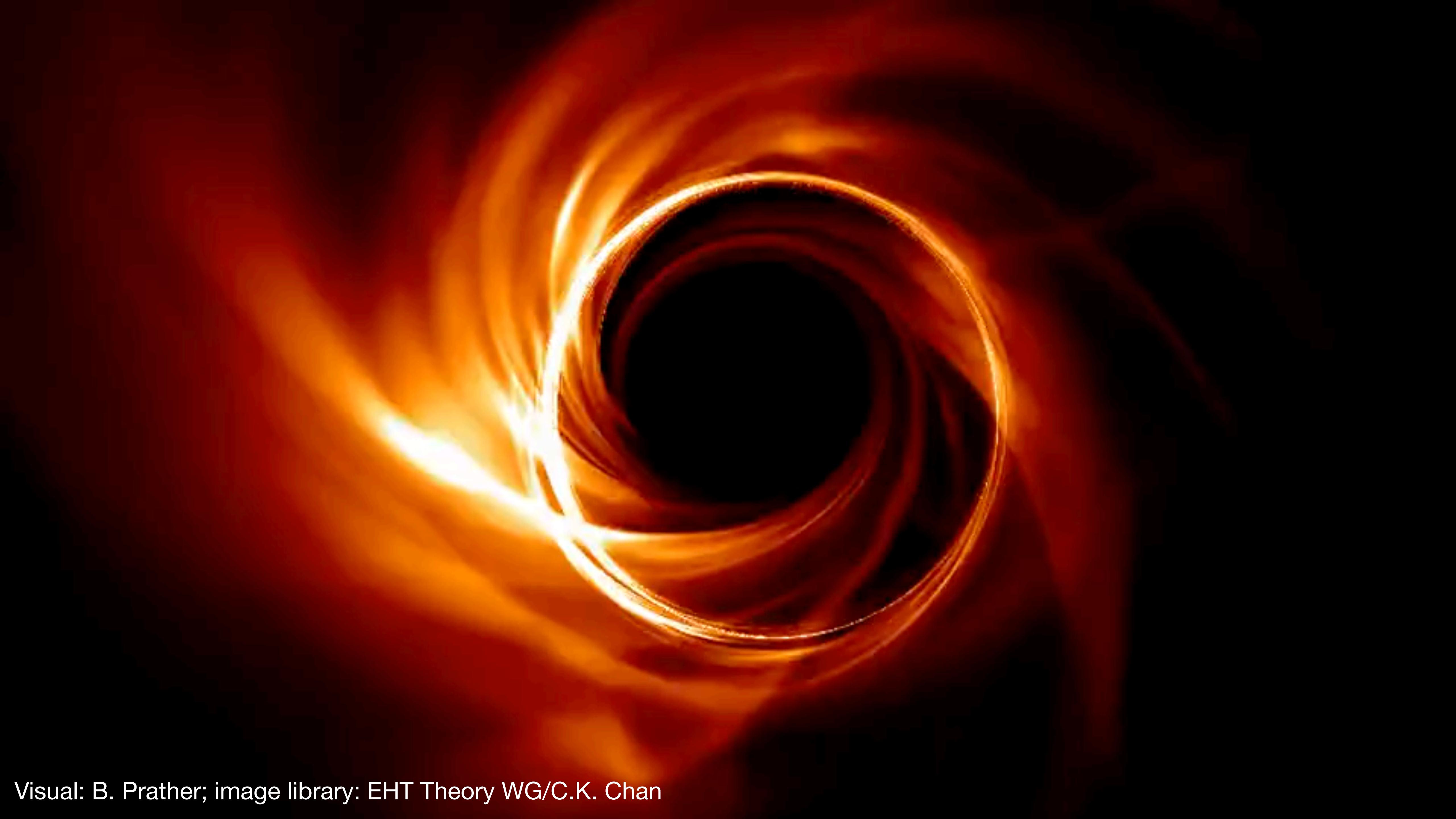
Home Search Microphone Bell Mail

MAD
 $R_{\text{high}} = 160$
 $a = +0.94$
 $i = 90$





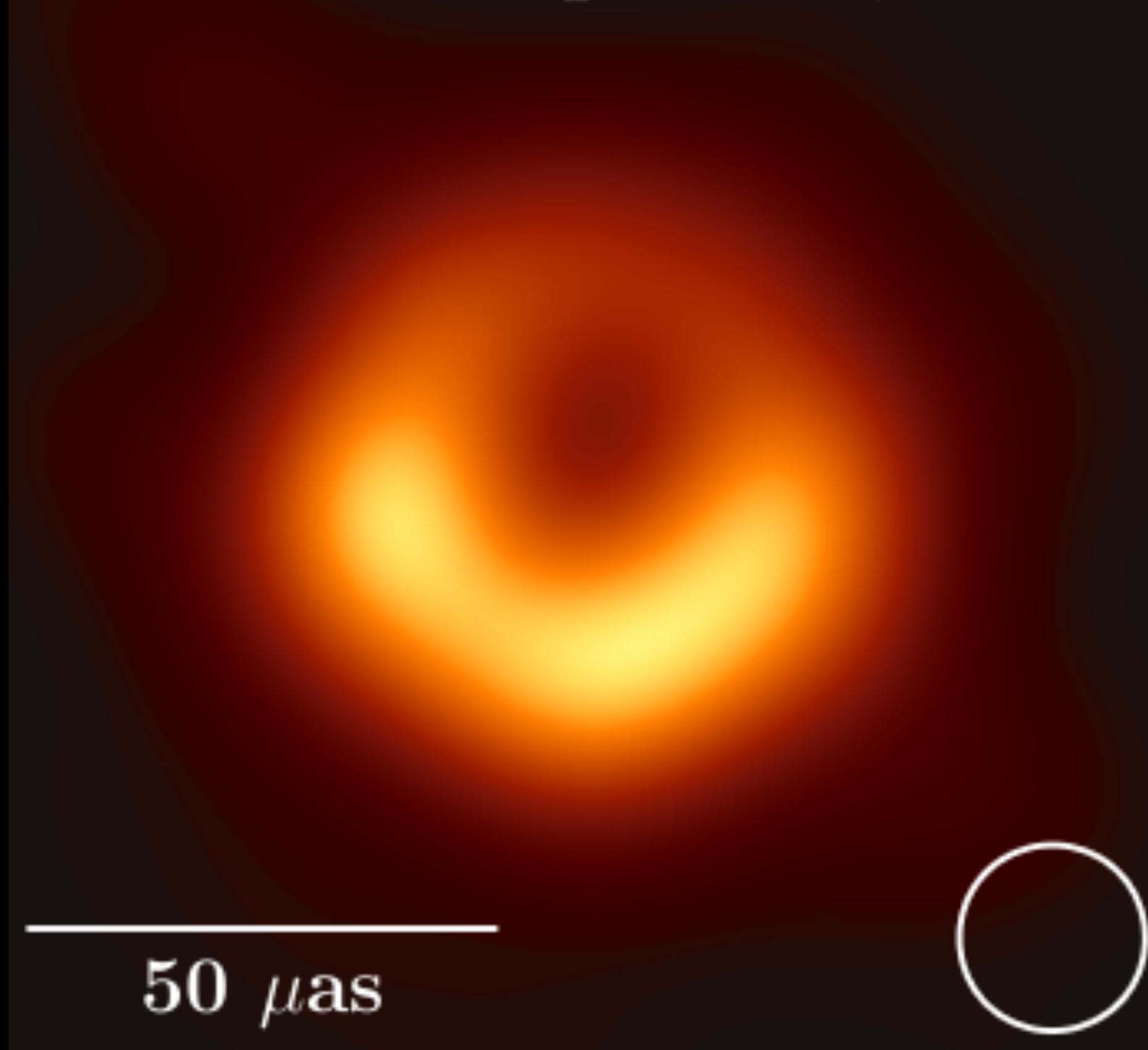
Visual: B. Prather; image library: EHT Theory WG/C.K. Chan



Visual: B. Prather; image library: EHT Theory WG/C.K. Chan

M87*

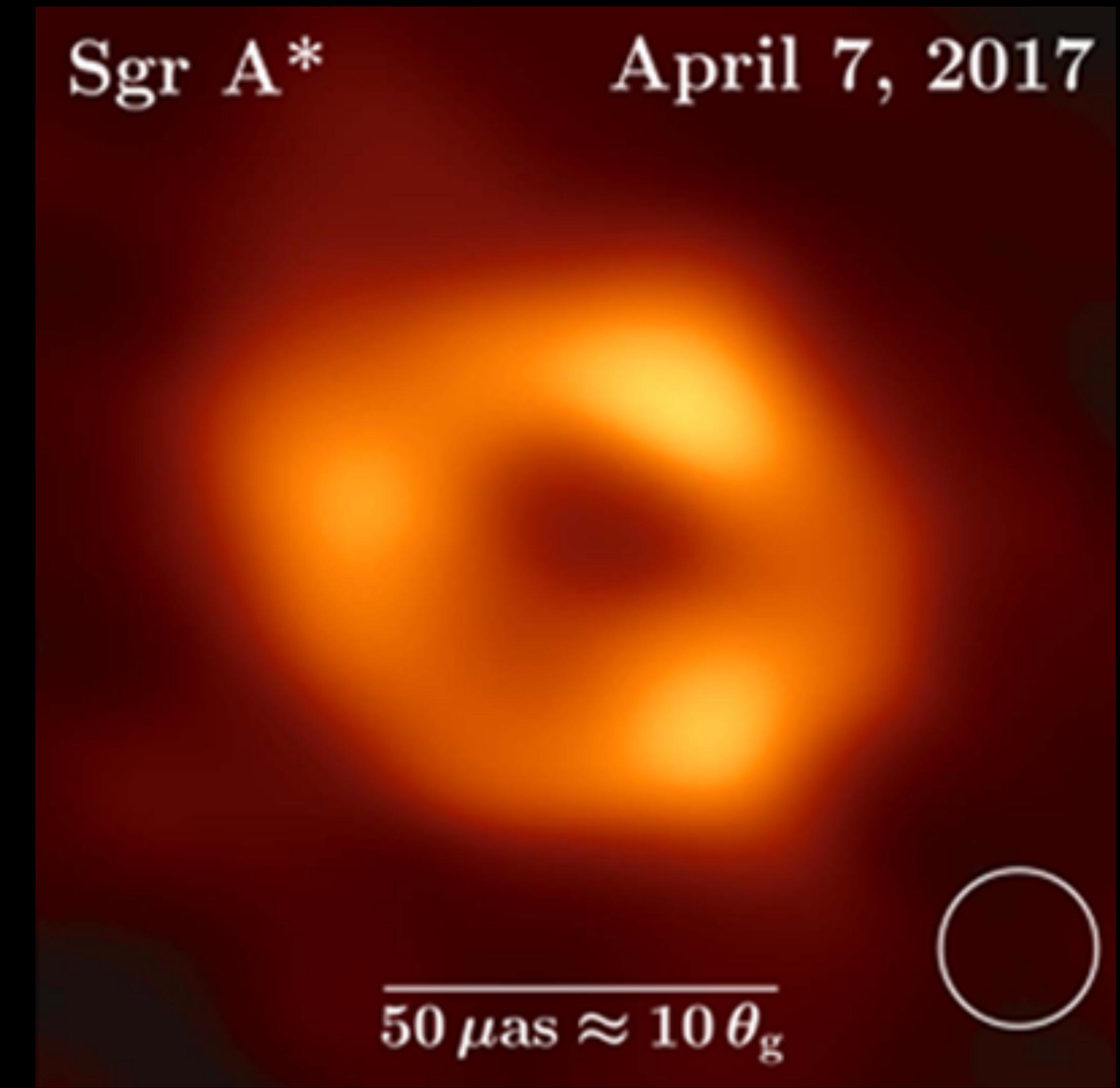
April 11, 2017



50 μ as

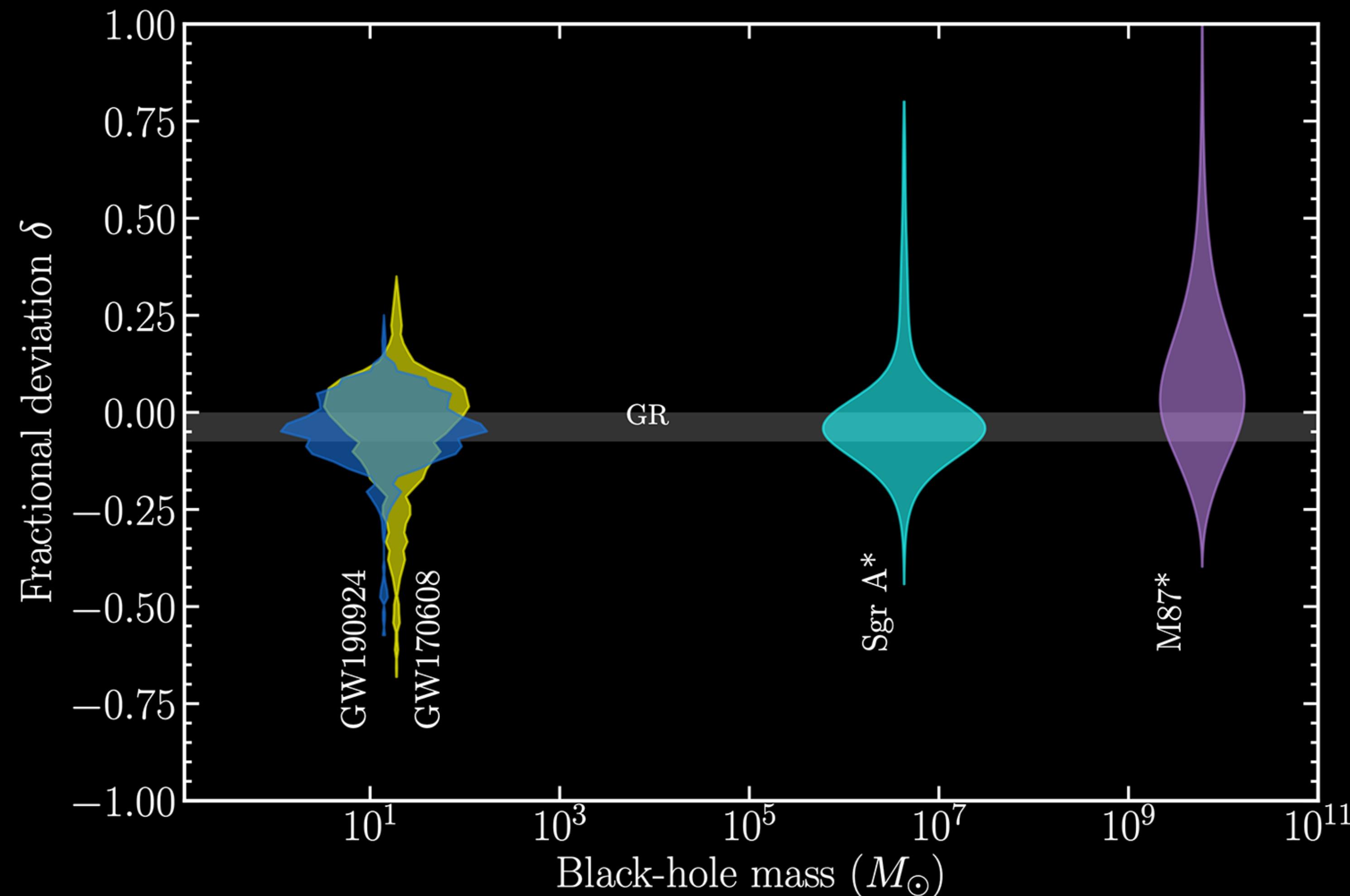
Sgr A*

April 7, 2017



$50 \mu\text{as} \approx 10 \theta_g$

No evidence for deviation from Kerr predictions across 8 orders of magnitude in black hole mass



- EHT captured the **first horizon scale images** of M87* and Sgr A*
- With OSG and black hole simulations, we decoded the images and learned that
 - Sgr A* is likely **two temperature**, **prograde**, **MAD**, and **face-on**
 - Sgr A* is **consistent** with a **Kerr** black hole; Einstein is right again even in extreme gravity!
 - Sgr A* is **less variable** than expected. Good for image reconstruction; **new astrophysics?**
- For **current collaboration** with OSG and Science Gateway
 - See **Rob Quick's talk** on Tuesday, 1:30pm