The Event Horizon Explorer

More Than Two, the Black Hole Demography Science Goal

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NG Space VLBI workshop
ASTRON/JIVE
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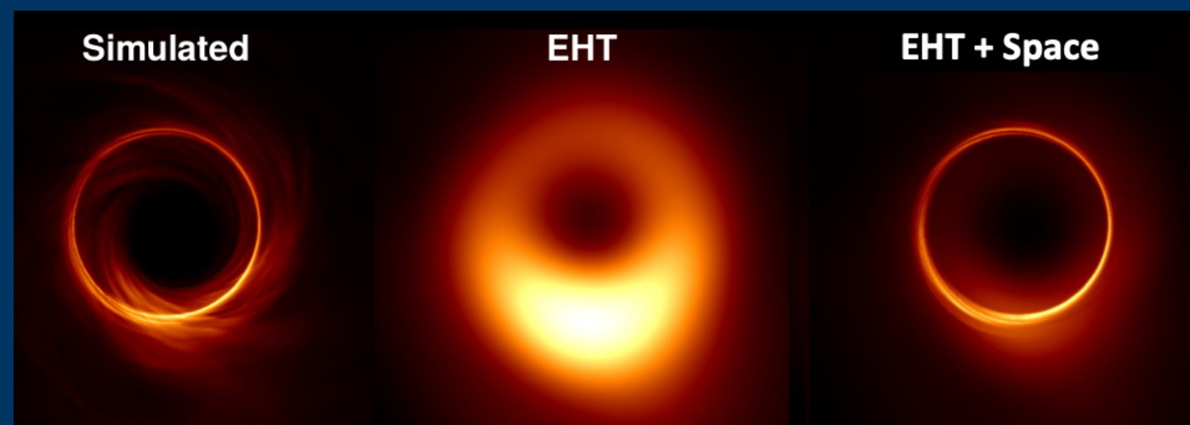
EHE Science Objectives:

* Precision Black Hole Measurements



Credit: Michael Johnson (CfA)

Peter Galison's and Freek Roelofs' talk

* Black Hole Accretion and Jets

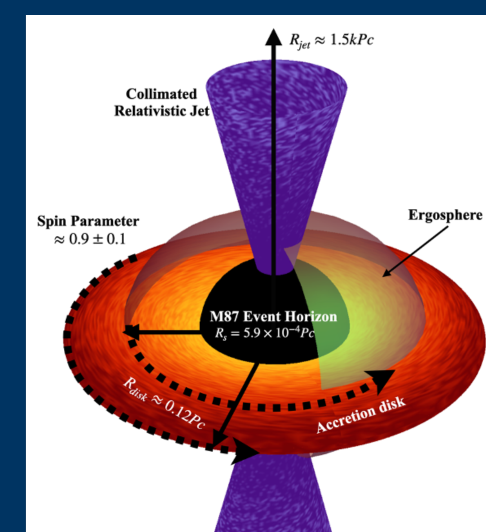


Image credit: Ronald Gamble, NASA/GSFC UMD – College Park / CRESST

*** Black Hole Formation and Demography**

EHE Science Objectives:

* Black Hole Formation and Demographics

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* Black Hole Formation and Demographics

I. More single shadows

What could we learn?

How many could we detect?

II. More *than* single shadows

I. More single shadows?
What could we learn?

*Horizon-scale census of nearby black holes

*Mass measurement calibration (~10% on M/D)
— Mass or cosmology constraint

*SBH mass function constraint, possibly its evolution

*Accretion rate constraints from measured SED and BH mass

*SBH growth mechanisms from measured BHMF evolution and accretion rates

*Spin distributions

I. More single shadows
How many?

Toward determining the number of observable supermassive black hole shadows

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Following Pesce et al; ApJ, 923, 26 (2020)

I. More single shadows

How many?

Count BHs and require:

— Resolvable ($\theta_r < \theta_{\mathrm{shdw}}$)

— Bright ($S_\nu > \mathrm{SNR}\ \sigma_\nu$)

— Optically thin emission at horizon

Ingredients:

— SMBH mass function

— SED(BH mass, Accretion rate)

— Accretion rate distribution

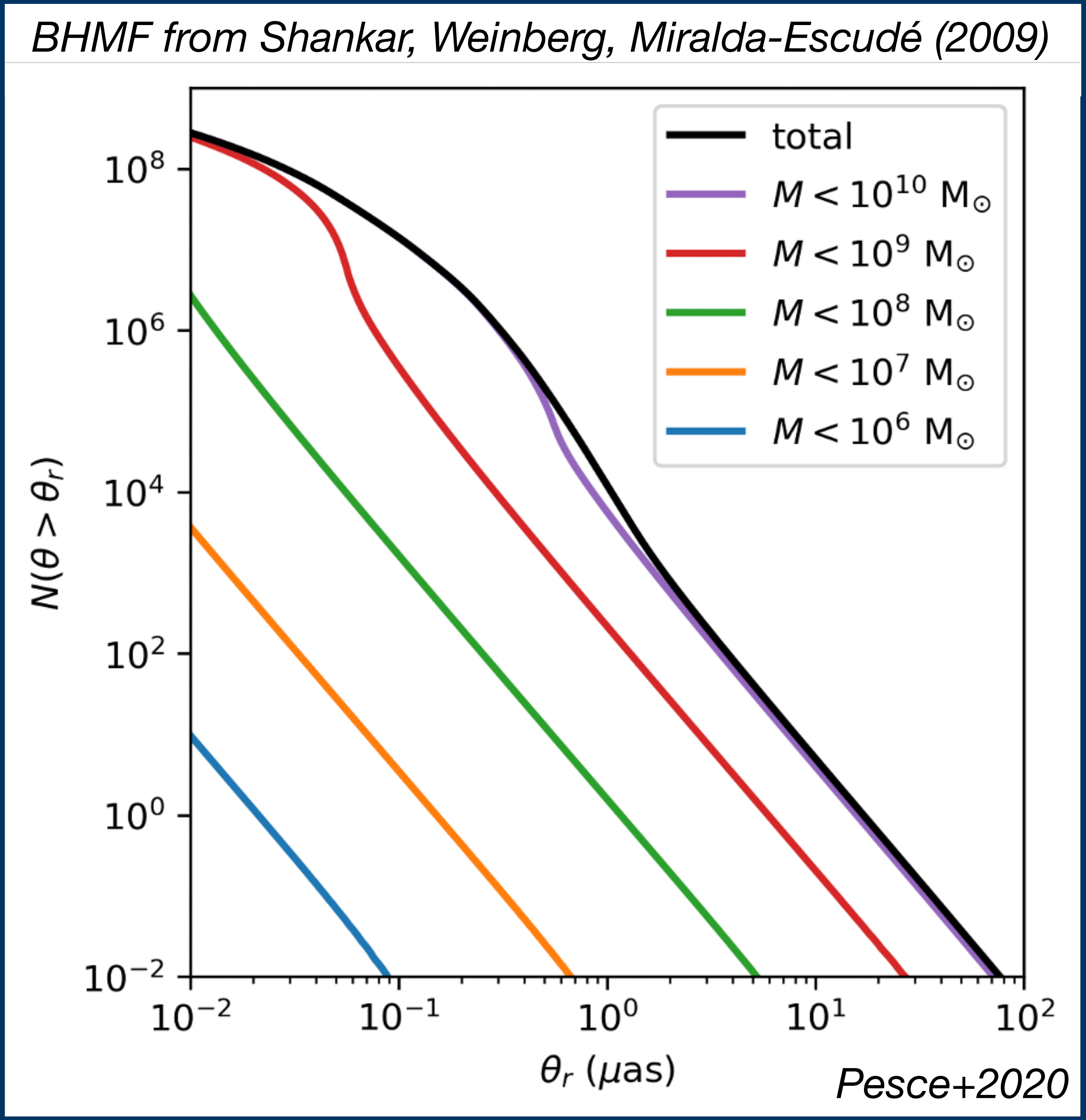
Following Pesce et al; ApJ, 923, 26 (2020)

Ingredients: SMBH mass function

Number density per SBH Mass

$$\Phi(M, z) = \frac{dN}{dM dV}$$

Provides number of resolvable shadows



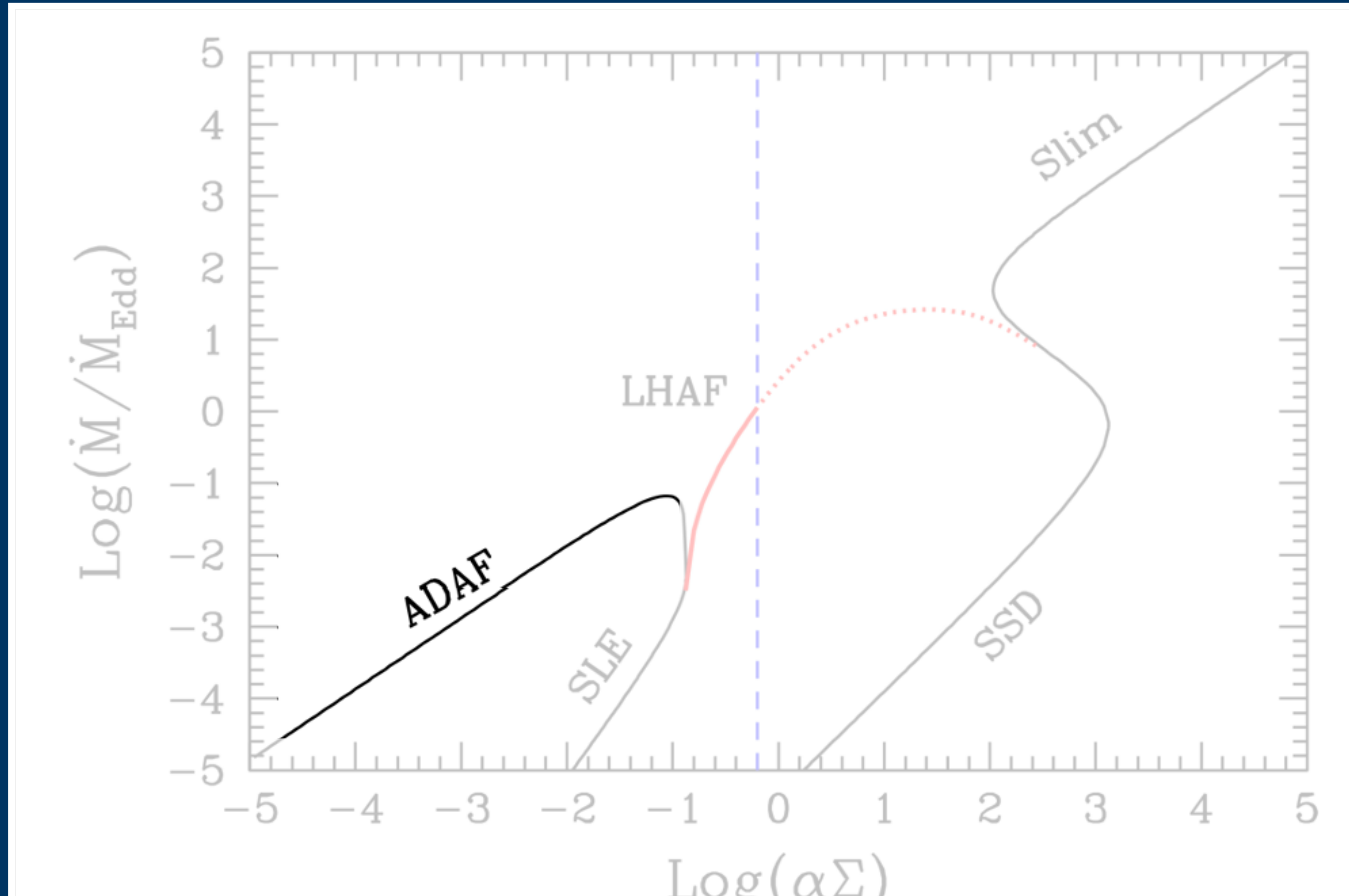
Following Pesce et al; ApJ, 923, 26 (2020)

Ingredients: Spectral Energy Distribution (SED)

*Assume advection dominated accretion flows (ADAFs).

*Observationally motivated for low accretion rate systems.

*Quick computation via (modified) procedure from Mahadevan+1997



Yuan & Narayan (2014)

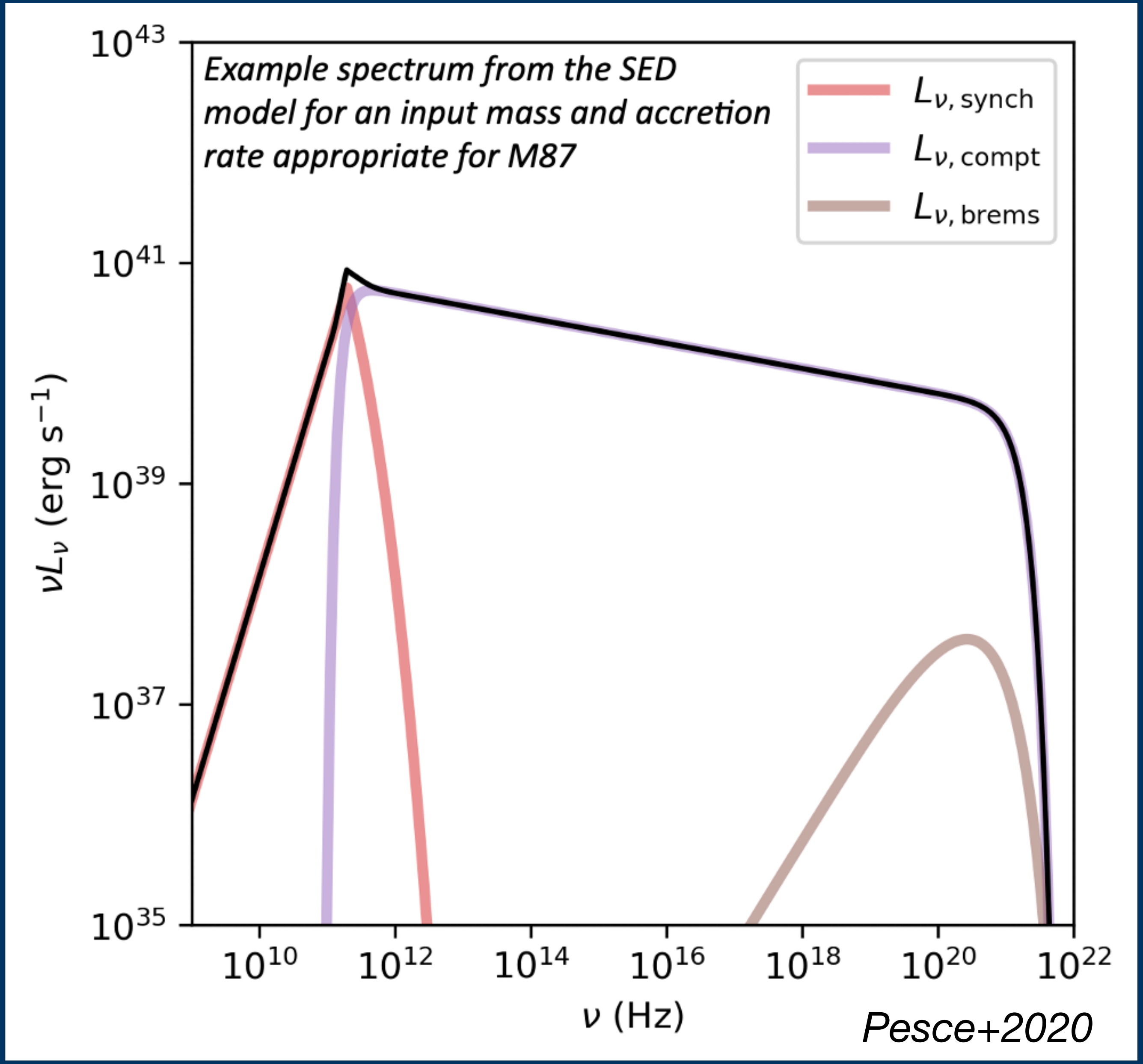
Following Pesce et al; ApJ, 923, 26 (2020)

Ingredients: Spectral Energy Distribution (SED)

Requires specification of mass, accretion rate and frequency

$$\nu L_\nu(M, \dot{M})$$

Provides specific flux at desired frequency and the optical depth to synchrotron self-absorption



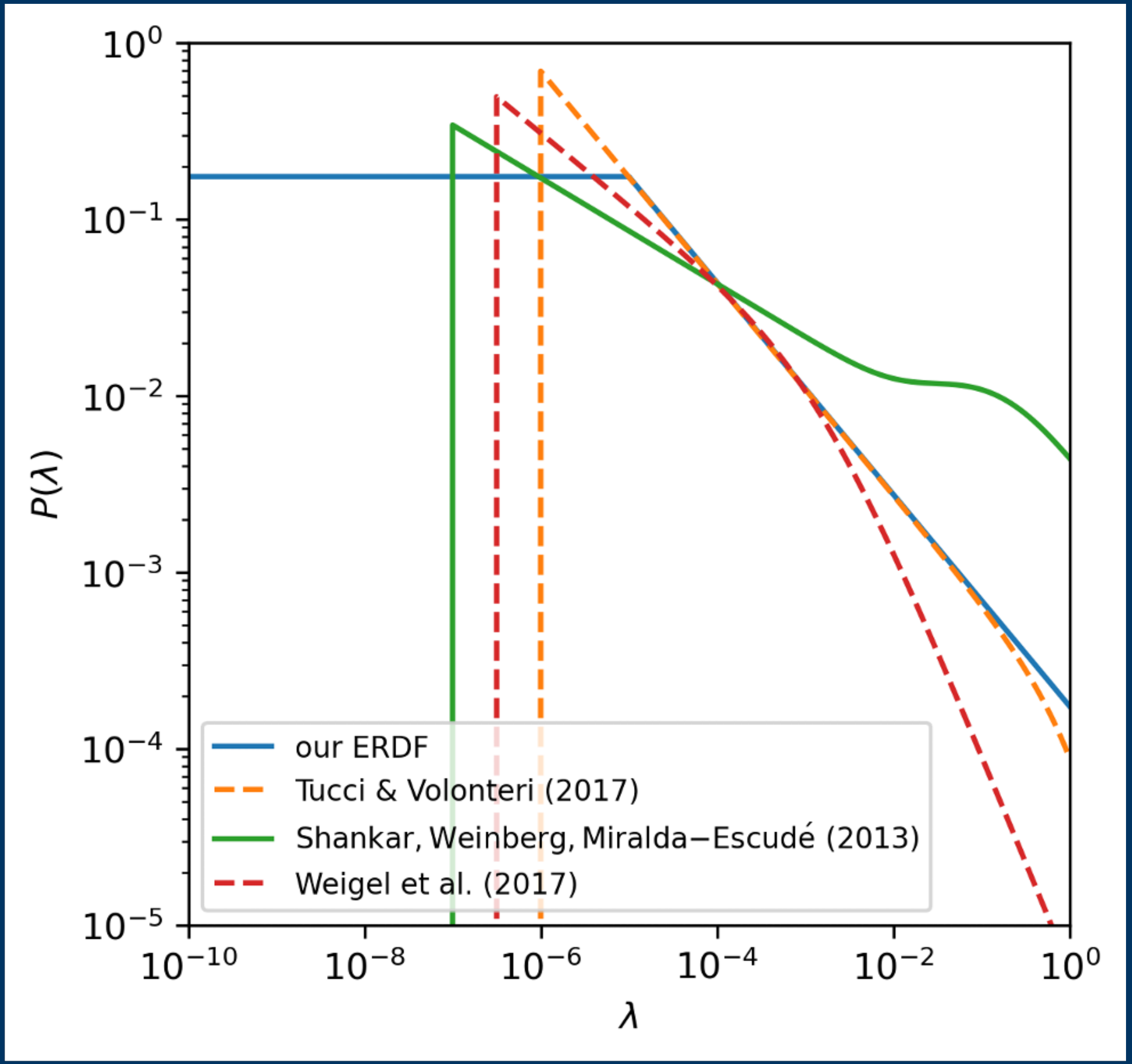
Following Pesce et al; ApJ, 923, 26 (2020)

Ingredients: Accretion rate distribution

Needed to evaluate the SED

$$\nu L_\nu(M, \dot{M})$$

Uncertain low-Eddington tail



$$\dot{M}/\dot{M}_{\rm Edd}$$

Following Pesce et al; ApJ, 923, 26 (2020)

Number of resolvable shadows

Mass function +
+ Accretion rate dist.
+ SED
+ Sensitivity σ_ν
+ Resolution θ_r

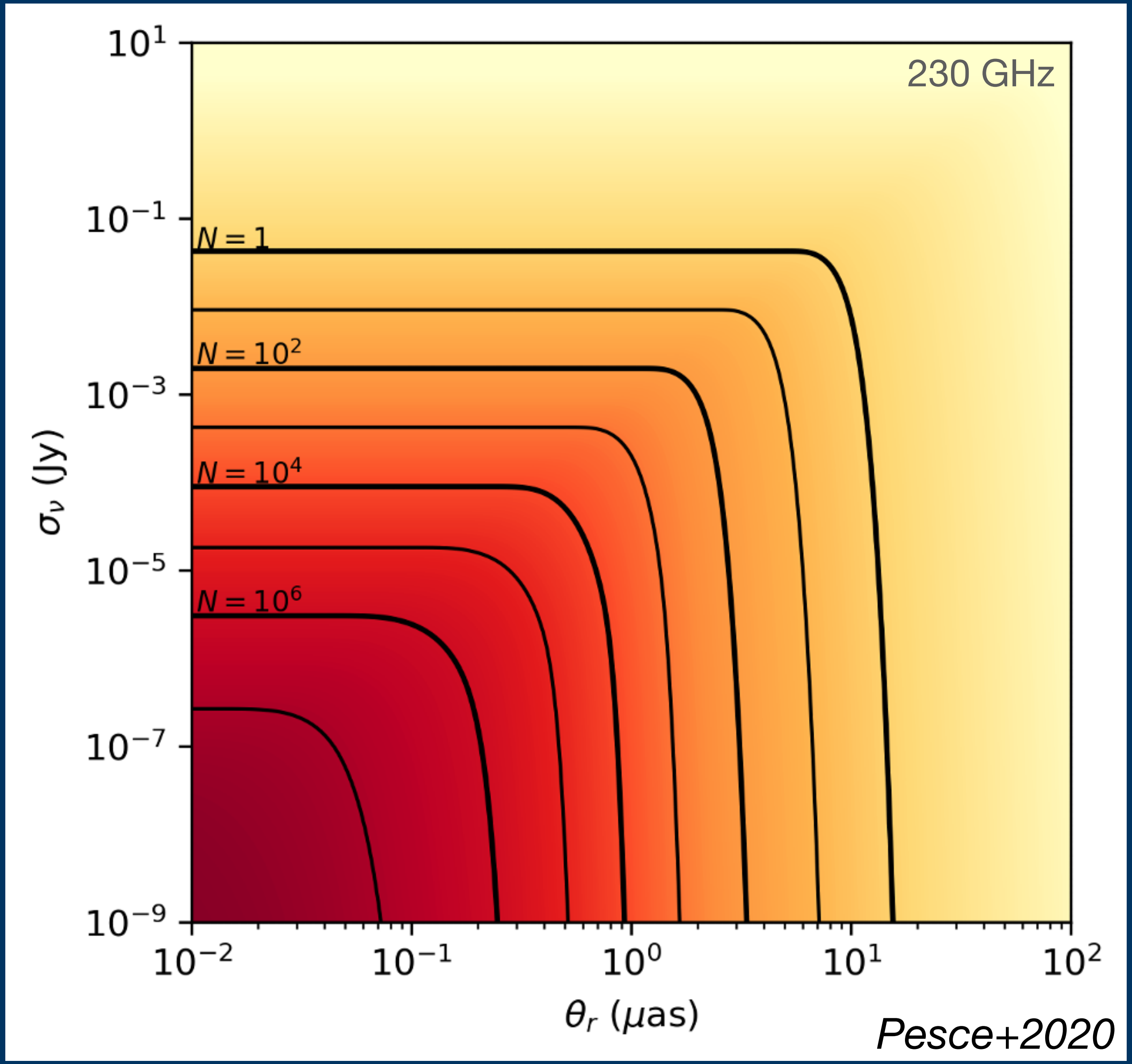
—>

Number of SMBHs with:

* Flux > σ_ν

* Shadow > θ_r

* Optically thin emission



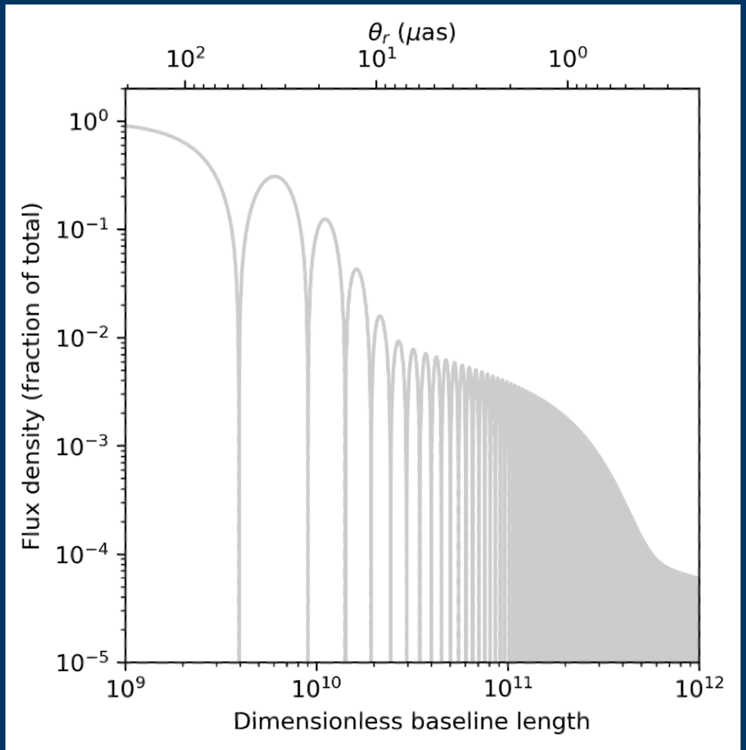
Following Pesce et al; ApJ, 923, 26 (2020)

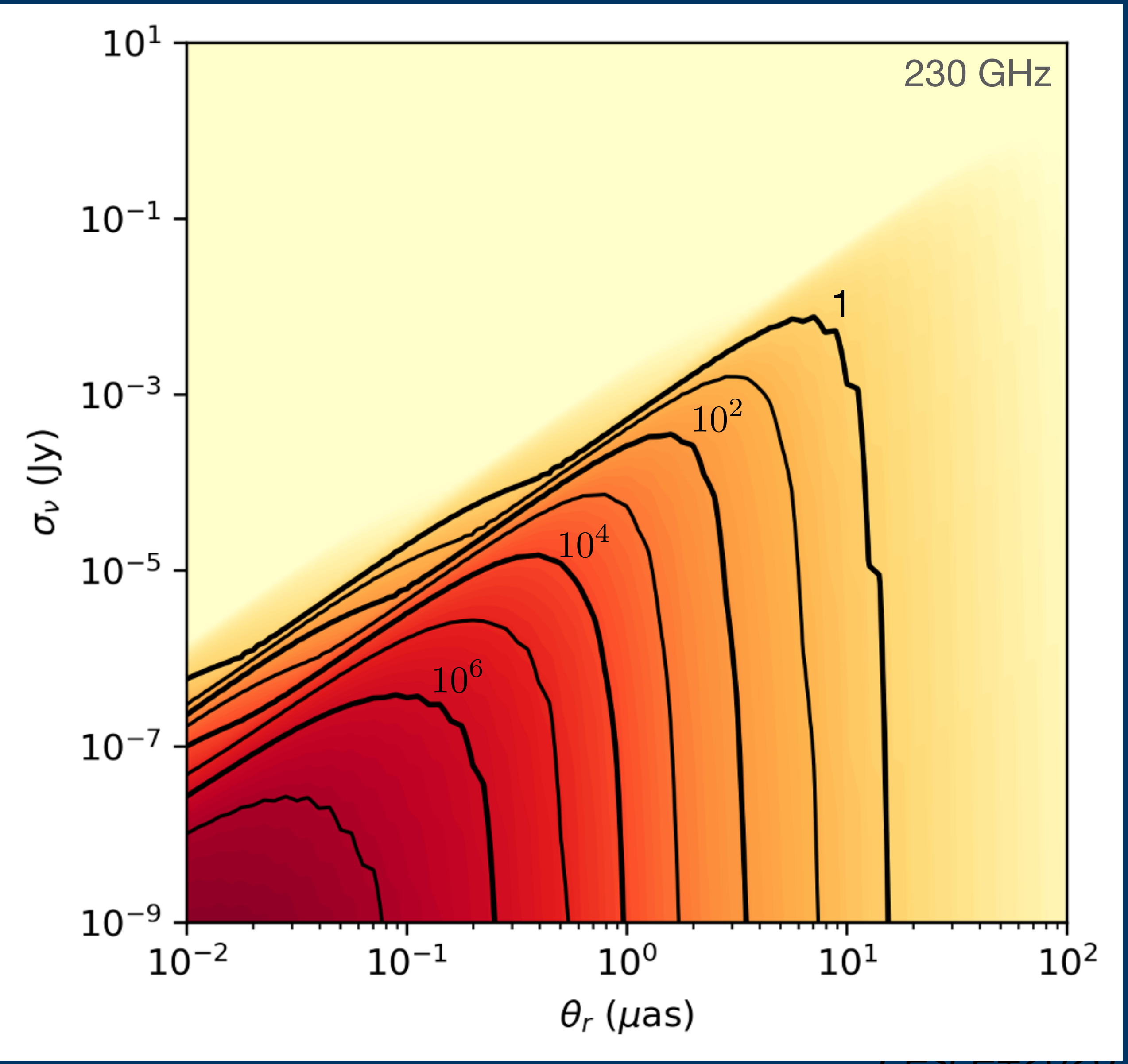
Number of resolvable shadows
…on a single baseline

One very long baseline can act like single base-line array

Longer baselines see lower flux density

$$S_\nu(1/\theta_r) = \mathrm{SNR}\ \sigma_\nu$$





Following Pesce et al; ApJ, 923, 26 (2020)

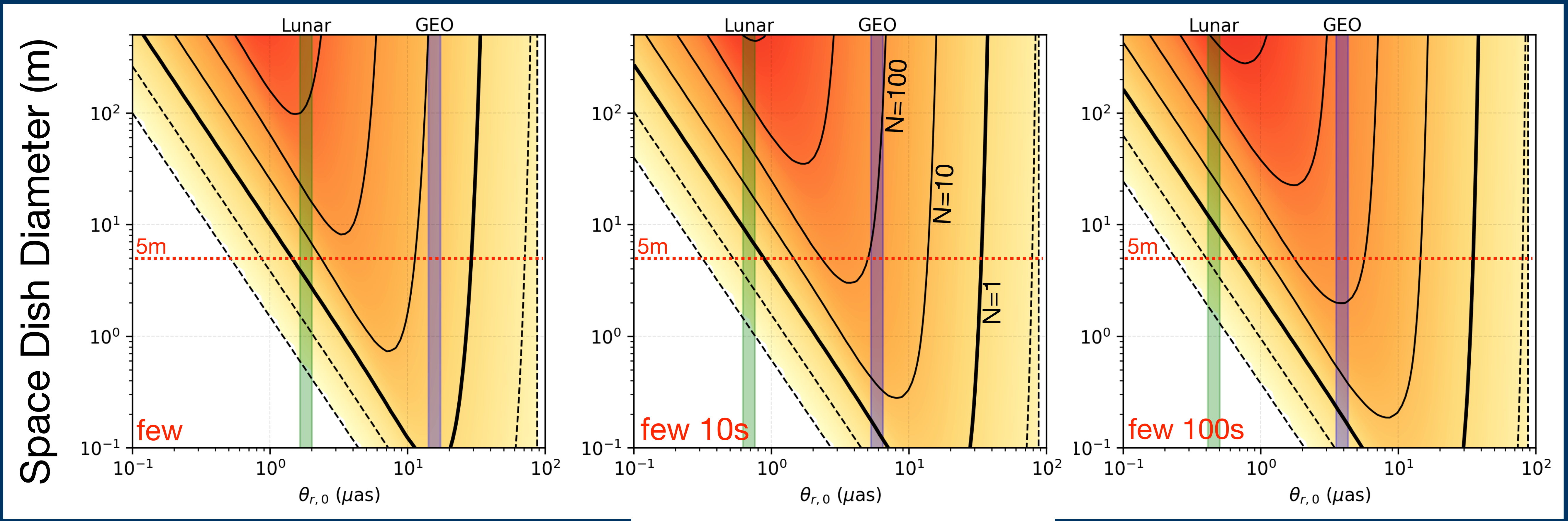
Number of resolvable shadows
… for possible EHE mission

Based on calculation by M. Johnson

$$\sigma_{\rm G-S} = 0.1\,{\rm mJy} \times \left(\frac{\theta}{6\,\mu{\rm as}}\right)^{-1} \left(\frac{\Delta t}{100\,{\rm s}}\right)^{-1/2} \left(\frac{D}{5\,{\rm m}}\right)^{-1} \left(\frac{D_{\rm gnd}}{50\,{\rm m}}\right)^{-1} \eta_{\rm sys}$$

100s integration, SNR=5 $S_\nu(1/\theta_r) = {\rm SNR}\ \sigma_\nu$

86 GHz, 100m Ground Dish | 230 GHz, 50m Ground Dish | 345 GHz, 50m Ground Dish



From Dom Pesce EHE science Study

Spatial Resolution

Can we do better? Larger dish? Receiver/transmitter properties?

I. More single shadows?

What could we learn?

*Horizon-scale census of nearby black holes — *(>10's promising)*
— Jet connection?

*Mass or cosmology calibration (10% M/D) — *(SNR dependent; z<0.1)*

*SBH mass function constraint, possibly its evolution?
(Via anchoring in nearby BH measurements)

*Accretion rate constraints from SED and BH mass? (For 10's)

*SBH growth mechanisms from measured BHMF evolution and accretion rates?

*Spin distributions?

*You tell me — let's talk!

Science Objectives:

* Black Hole Formation and Demographics

I. More single shadows

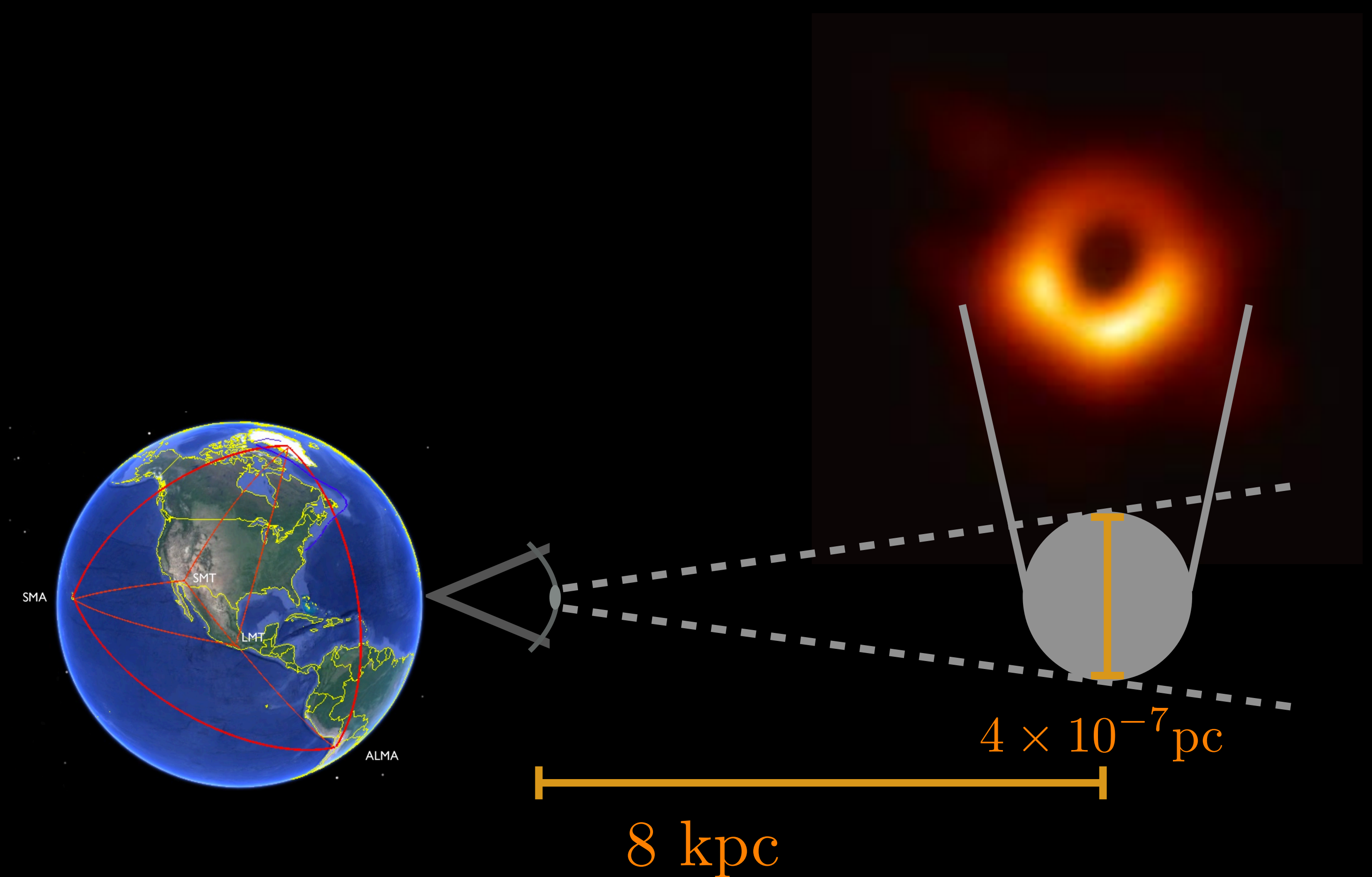
What could we learn?

How many could we detect?

II. More *than* single shadows

Binaries?

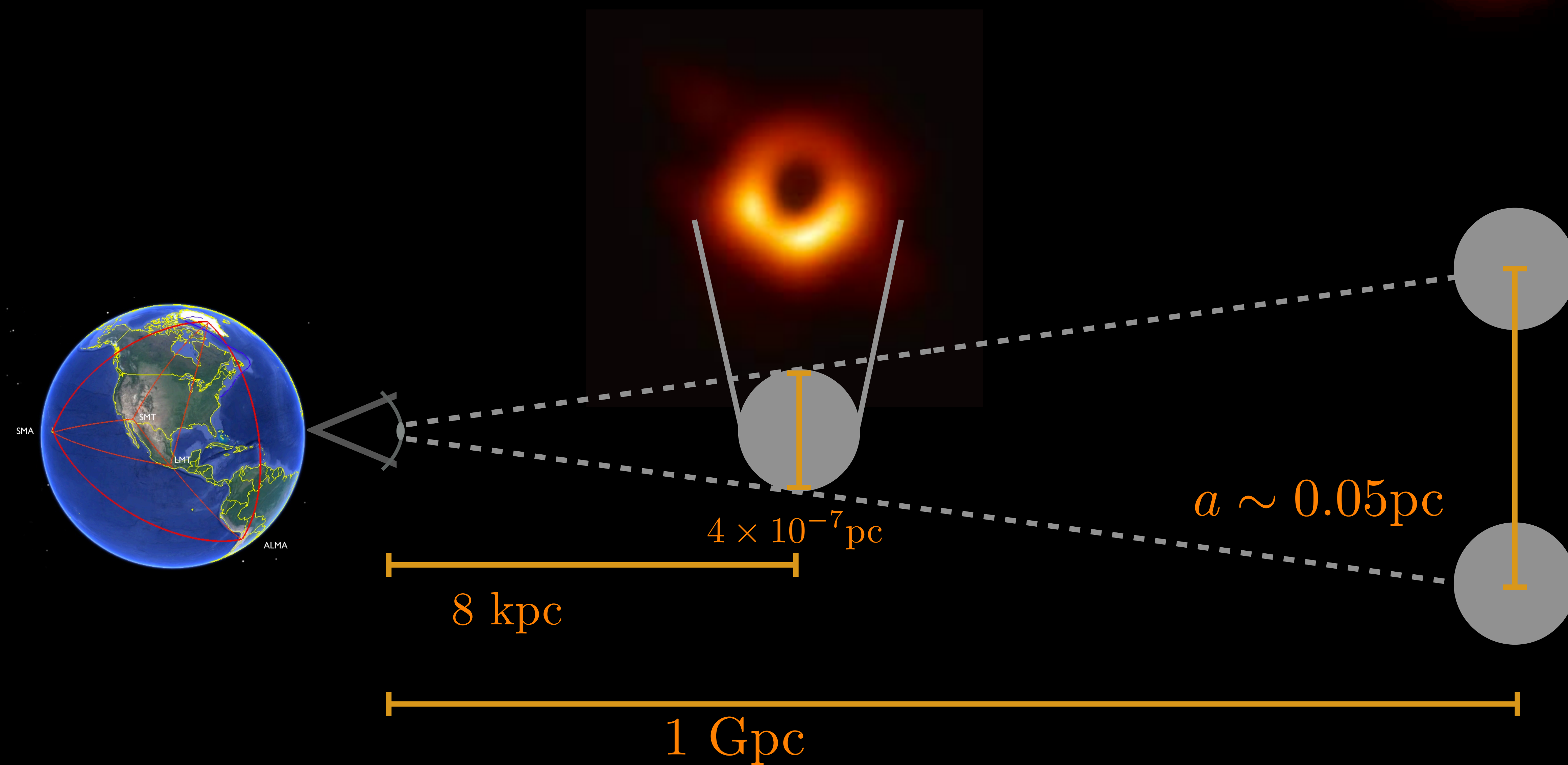
EVENT HORIZON TELESCOPE



FINAL PARSEC TELESCOPE?

*Definitive evidence for SBHBs beyond ‘final parsec’

*Also offers binary mass measurement assuming a cosmology
…or cosmology from a binary mass



D’Orazio & Loeb; *ApJ, 863,185 (2018)*

II. More *than* single shadows?

How many Super Massive Black Hole Binaries?

Difference from single shadow estimates:

— Size: resolve optically thin emission on **scale of orbit** instead of horizon (min. orbital period for given mass)

— Timescale: observe over **orbital period (yrs) timescales** (max orbital period for all masses)

— Statistics: number density per orbit separation requires **binary formation/evolution** model

Extra/Different Ingredients:

— Binary orbital evolution model (assume simple gas + GW driven evolution)

— Flux from radio luminosity function scaled to ~300 GHz (not SED model) - optical depth from BK79 jet model

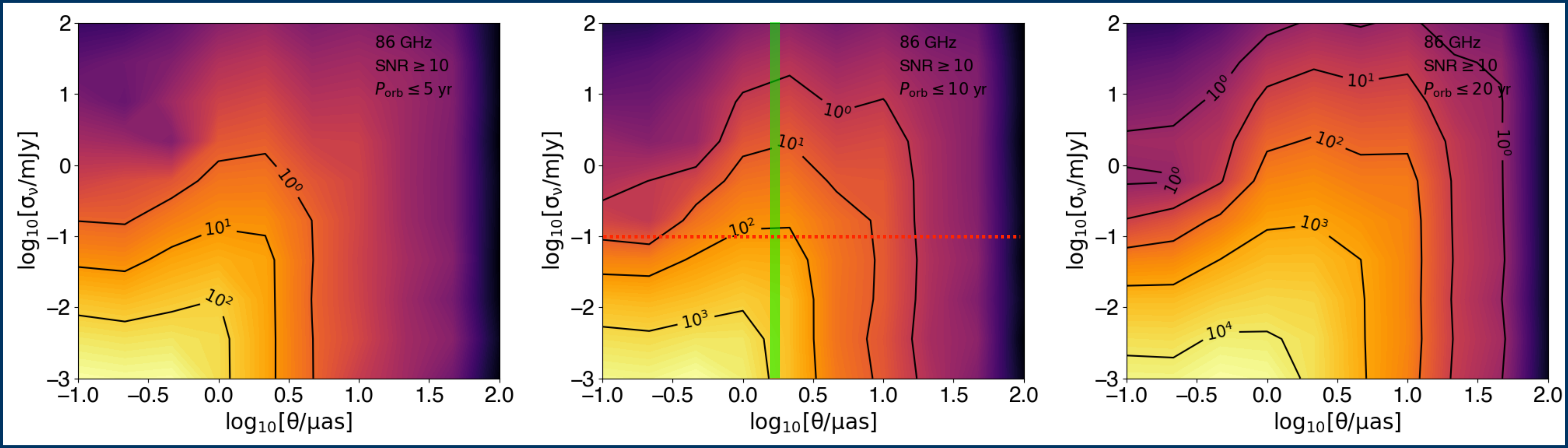
— Consistency with PTA GW background

D'Orazio & Loeb; *ApJ, 863,185 (2018); arXiv: 1712.02362*

II. More *than* single shadows?

Super Massive Black Hole Binaries (on single baseline)

~1-1000 resolvable orbits over all sky for EHE capabilities



From D'Orazio EHE science Study

How to observe?

— Need targets: OJ 287 (10-20 μas, ~Jy), PG 1302 (4 μas, ~Jy)
+ ~100 other SBHB candidates

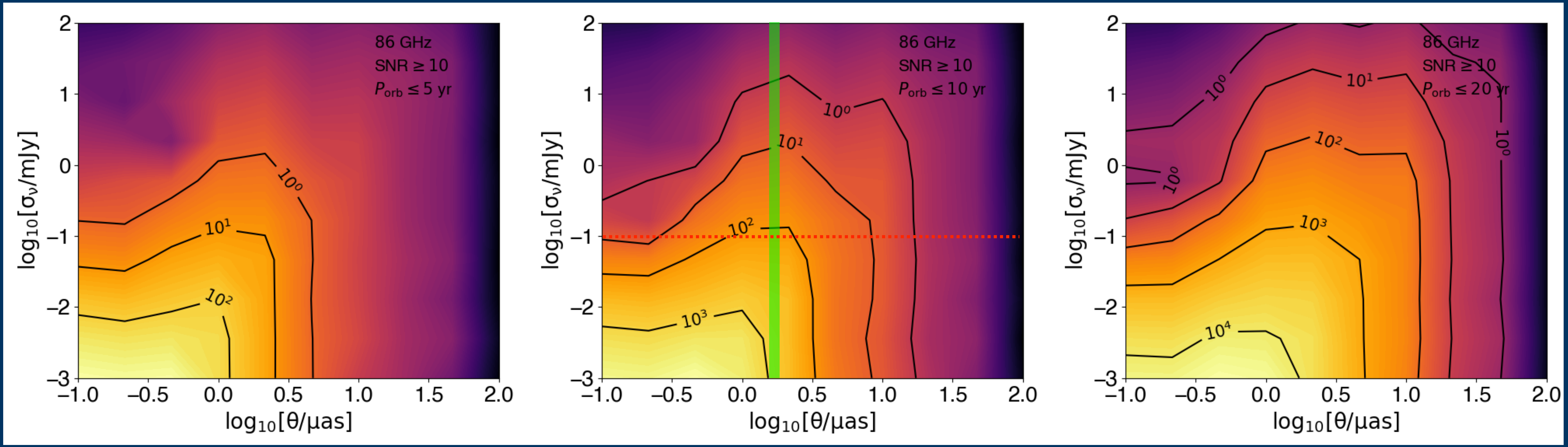
— Clusters of observation over course of binary orbit
- range of baseline orientations to detect double point source at different times over orbit

D'Orazio & Loeb; *ApJ, 863,185 (2018)*

II. More *than* single shadows?

Super Massive Black Hole Binaries (on single baseline)

~1-1000 resolvable orbits over all sky for EHE capabilities



From D'Orazio EHE science Study

Further modelling

— Binary emission at 86-345+ GHz?
Binary evolution and constraints from GW obs. (PTAs)

— One-one comparison with single shadow estimates desirable

D'Orazio & Loeb; *ApJ, 863,185 (2018)*

Summary

* ~10-1000 shadows resolvable with EHE-like mission

* Would extend EHT science to horizon-scale demography

* Exciting possibility of resolving SBH *Binary* orbits with links to gravitational wave science and cosmology

* Promising! — varying levels of uncertainty in population and detection modelling require further study