Supermassive Black Hole Environment Imaging and Possible Wormhole Detections

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Millimetron Science Case

- Supermassive Relativistic Objects
- Water Trail and Life in the Universe
- Cosmology

Uniqueness of the Mmtron Project for SMRO

- Tera-Hertz frequency range
- Unprecedented Angular Resolution
- Unreachable before flux sensitivity

SVLBI: MM + EHT

wavelength range	angular resolution	flux sensitivity, 5σ
$\sim 750\mu$m–7 mm	~ 0.03–$0.3\ \mu$as	~ 1–20 mJy

SD

wavelength range	angular resolution	flux sensitivity, 5σ
~ 80–3000μm	$\gtrsim 5$ as	~ 0.1–1μJy

SMROs. Top priority targets

- Space-time geometry (Sgr A* & post-EHT M87*)
- Plasma physics and radiation around the horizon (Sgr A* & M87*)
- Wormholes

Space-time geometry with MM SVLBI

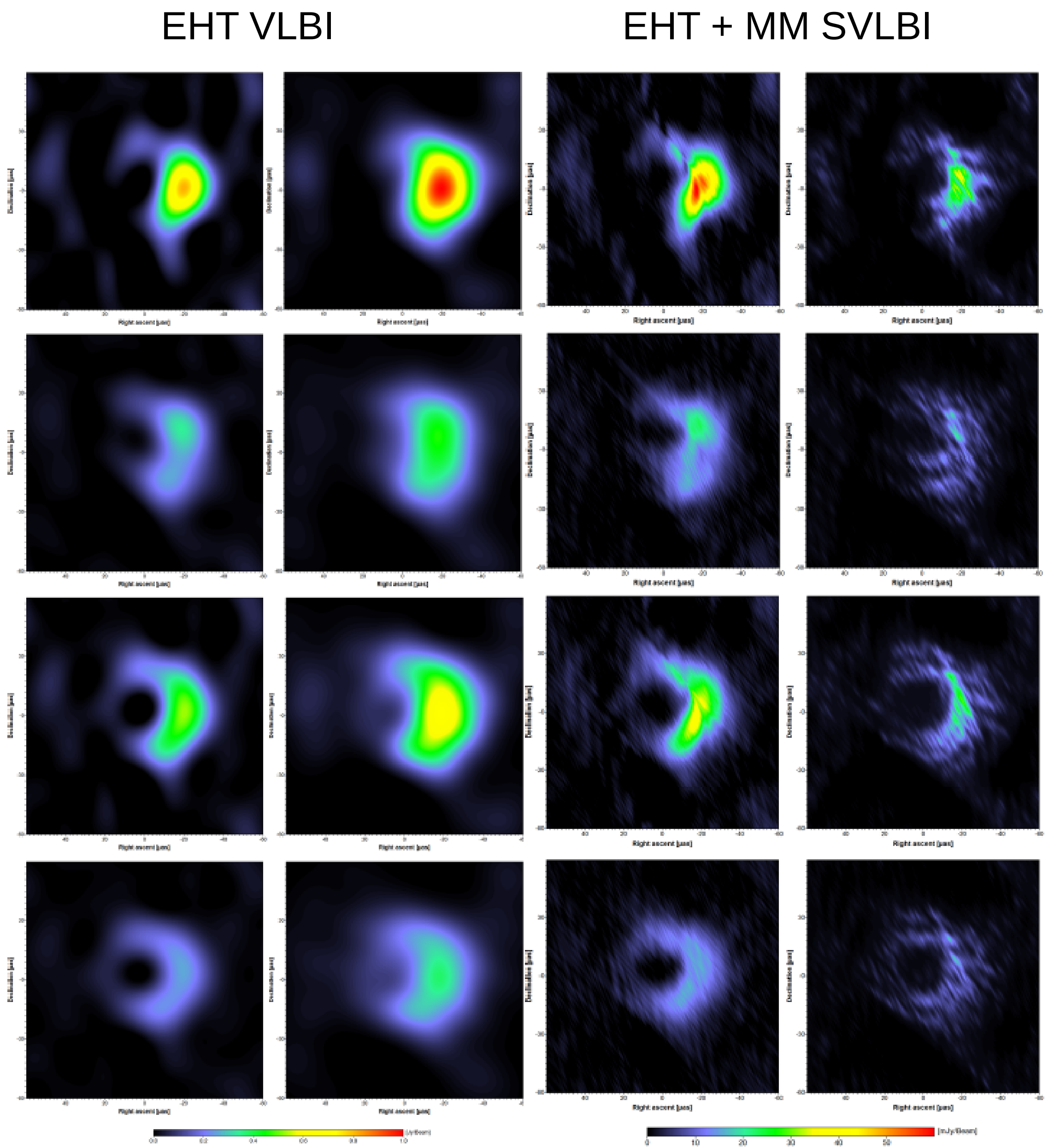
- Nearby SMBHs Sgr A* & M87*

Sgr A*	M87*
$M \simeq 4 \times 10^6 M_\odot$	$M \simeq 6 \times 10^9 M_\odot$
$\mathrm{R_S} \simeq 4.3(-2)$ au	$R_\mathrm{S} \simeq 62$ au
$\theta_\mathrm{S} \simeq 10\mu$as	$\theta_\mathrm{S} \simeq 8\mu$as
$L_{bol} \sim 10^{36}$ erg s^{-1}	$\sim 3 \times 10^{42}$ erg s^{-1}
$F_{470\ \mu\mathrm{m}} \sim 3$Jy	~ 0.43Jy

Space-time geometry with EHT+MM

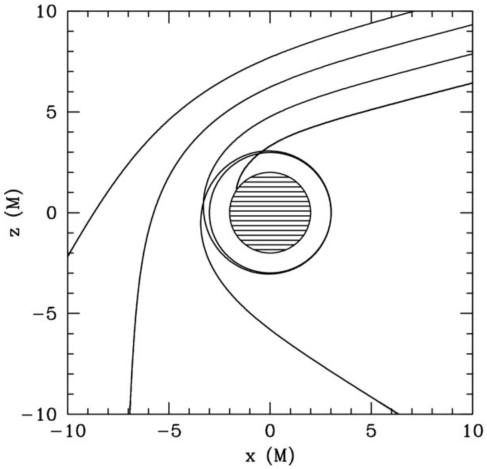
- **M87***

EHT + MM SVLBI, Andrianov + in prep 2019

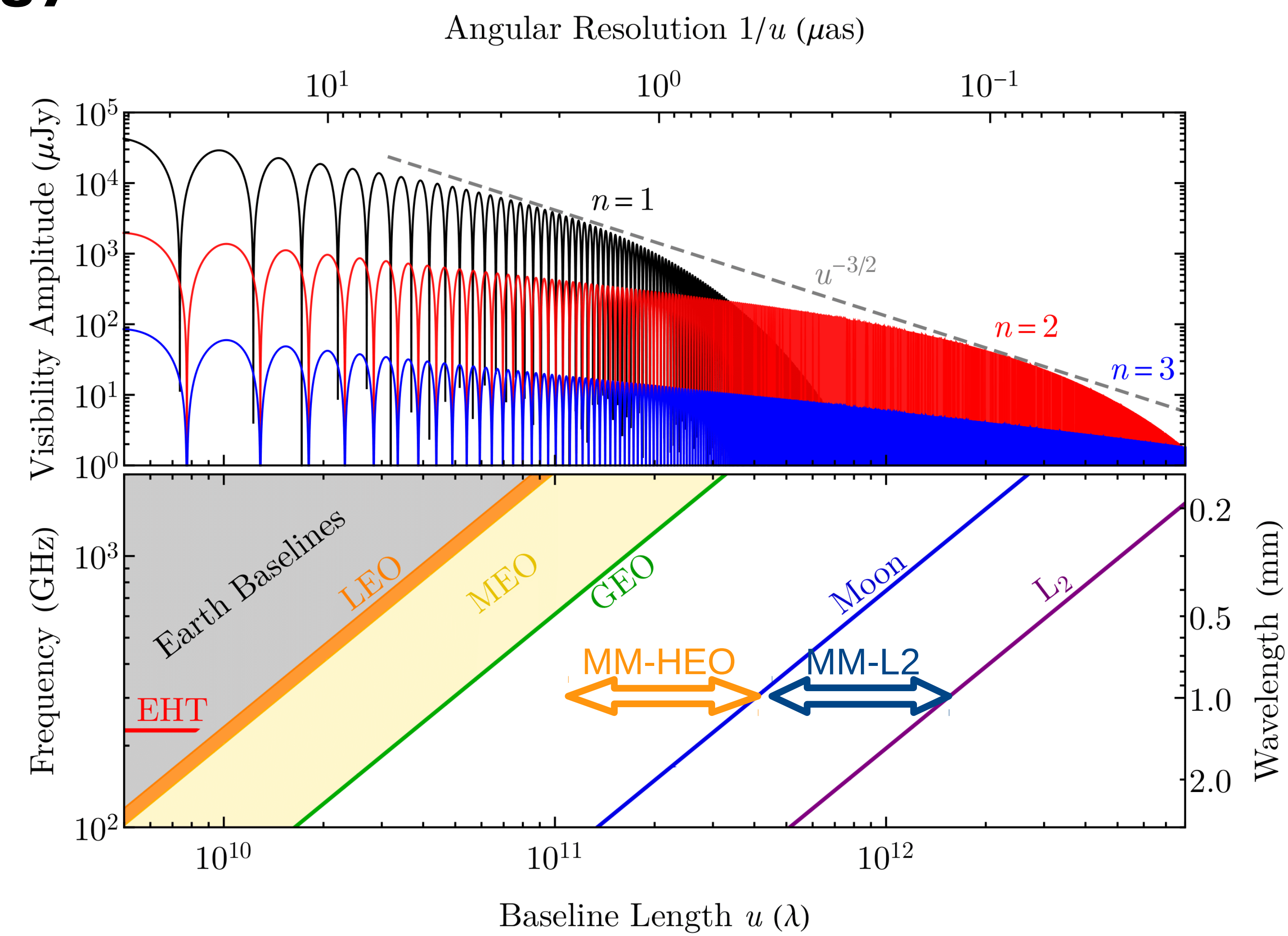


Space-time geometry with MM

- **Sgr A* & M87***



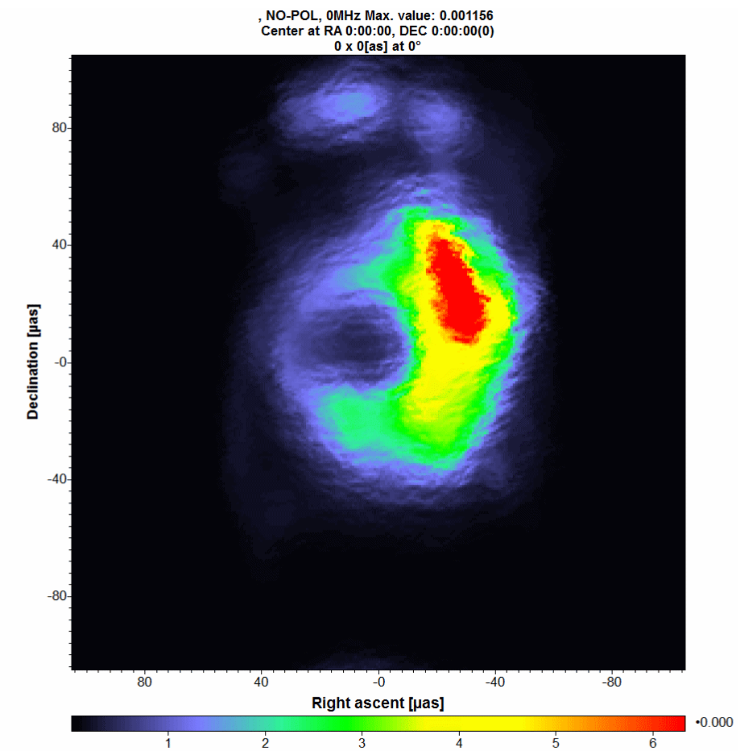
Johannsen & Psaltis 2010

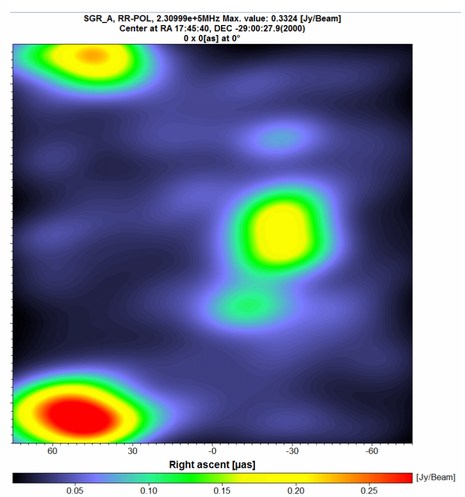


Johnson etal 2019

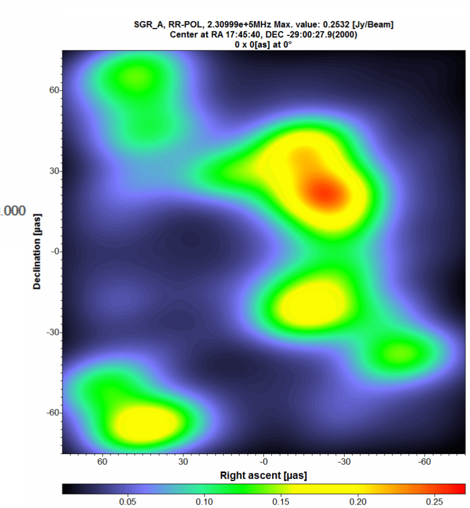
Short time scale domain

- Sgr A* dynamical imaging on Schwarzschild time scales





EHT, Moscibrodzka + 2014



EHT + MM, Andrianov + in prep, 2019, talk by Rudnitsky & Kostenko

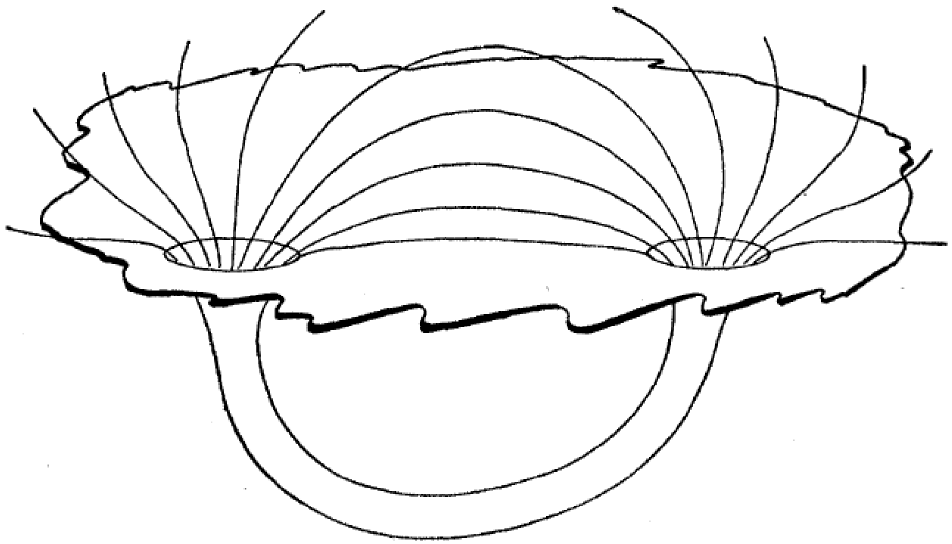
Flux sensitivity of *Millimetron is* sufficient to resolve 4 mins – sub-Schwarzschild scale!

Plasma & radiation near the shadow

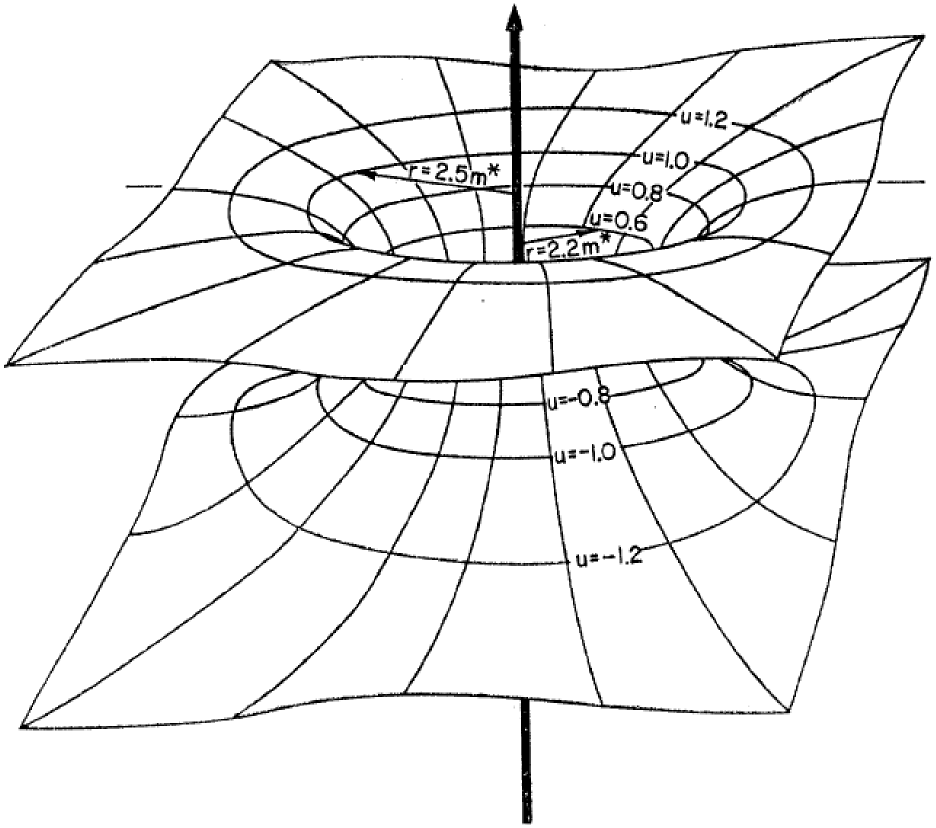
- Why the shadow is observed around M87* and not around Sgr A*?

- Magnetic field: topology and strength, RM, plasma beta;
- Determining the accretion rate from Bondi radius to ISCO – how and where the accretion flow is getting lost;
- Measurements flux variability, RM variations (turbulence: spectrum, scales);
- Acceleration of relativistic particles inside the accretion flow region;

Wormholes (Misner & Wheeler 1957)



A WH threaded by force field lines (e.g. magnetic) as drawn by John A. Wheeler 1955.



Einstein-Rosen bridge between two nearly Euclidean spaces as drawn by Fuller & Wheeler 1962.

Wormholes

- WH signatures (sufficient, not necessary)

  - Monopole magnetic field;
  - Luminous objects inside the throat (on the “shadow”): thermal emission from the very early Universe, thermal emission from a neighbor young universe, anomalous primordial chemical composition from other U;
  - Blueshifted emission inside the throat (on the “shadow”);
  - Twin images of the same object beside the WH and through it with different redshifts;
  - Short (less than the Schwatzschild’s) time and spatial variations;

WH **B**: a speculative example

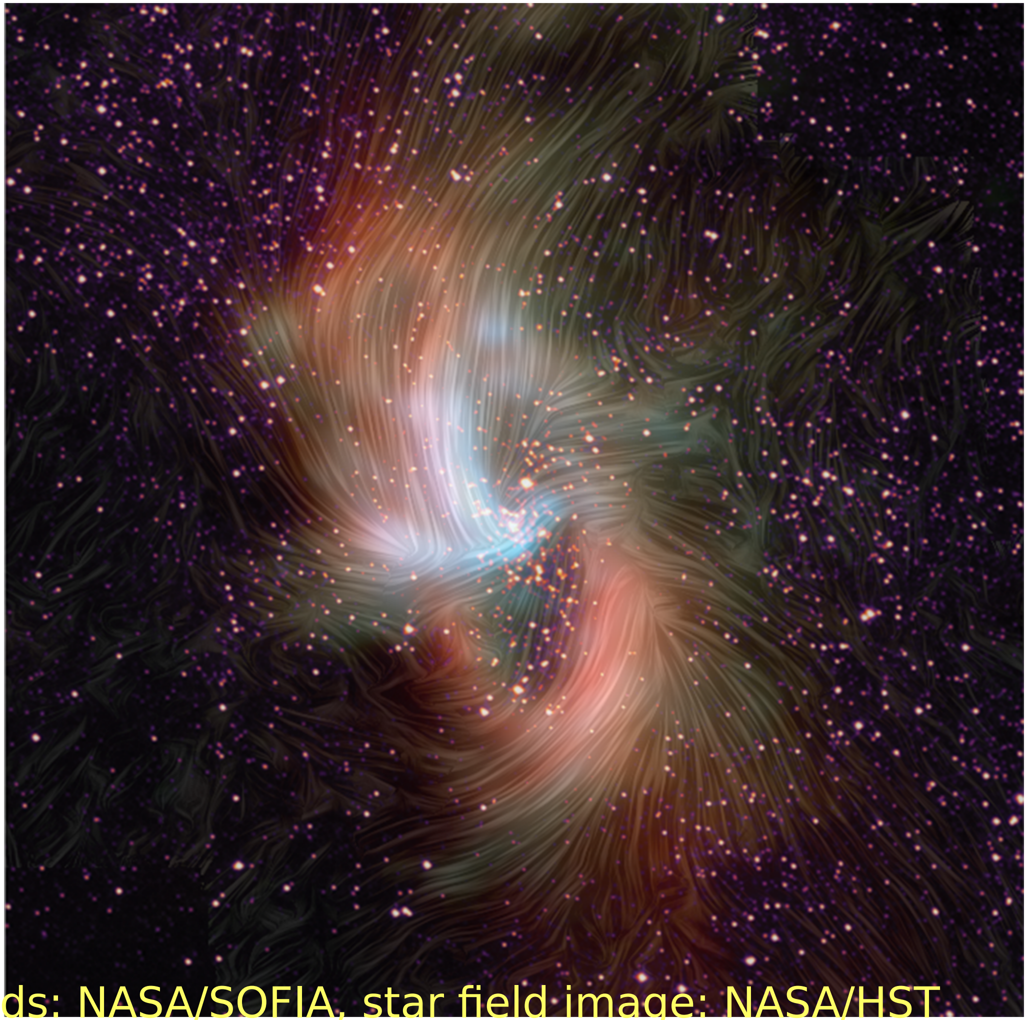
- WH monopole **B**: $$B \le \frac{1}{\sqrt{2}} \frac{c^4}{G^{3/2} M} \sim 2 \times 10^{10} \left(\frac{10^9 M_\odot}{M} \right) \ \mathrm{Gauss}$$

The dusty ~0.5 – 5 pc ring around SgrA*: B~1mG Dowell eta 2019, BAAS, 316.05.

Equipartition would result in unrealistic conditions with density $n \gtrsim 10^5 \ \mathrm{cm}^{-3}$ and optical depth $\tau_V \gtrsim 300$

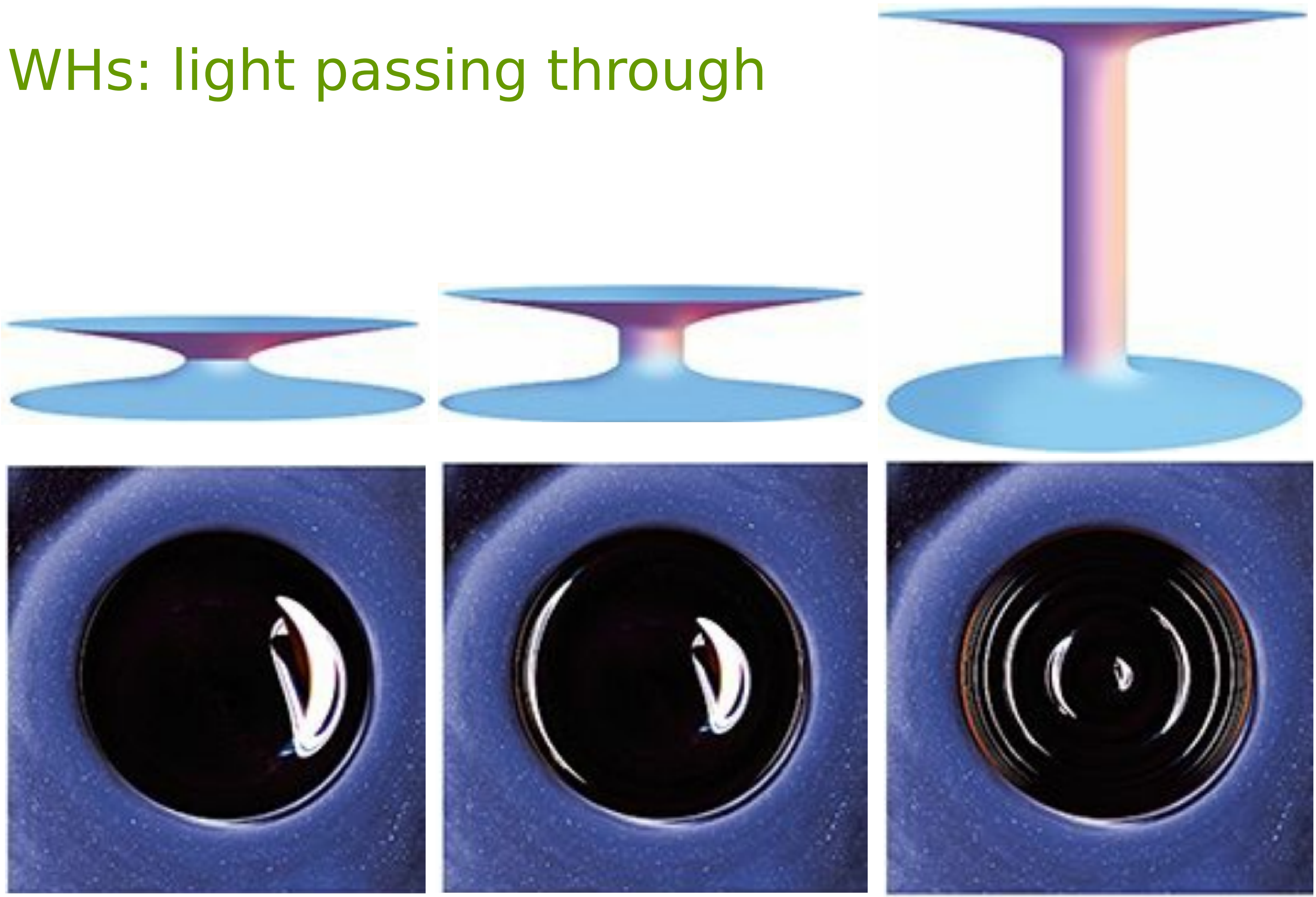
Conservation of flux would result at the BH horizon in:

$$B_\mathrm{S} \sim 1\mathrm{mG} \left(\frac{0.5\text{–}5 \ \mathrm{pc}}{0.1 \ \mathrm{au}} \right)^2 \sim 10^9\text{–}10^{11} \ \mathrm{G}$$



Credit: Galactic Center dust and magnetic fields: NASA/SOFIA, star field image: NASA/HST

WHs: light passing through



Credit: Thorne, The Science of Interstellar, 2014; Oliver, von Tunzelmann, Franklin, Thorne, AJP, 2015

WHs: light passing through

- If in Sgr A* and in M87*: angular resolution in SVLBI mode of MM–ALMA $\Delta\theta \sim 0.1\mu\text{as} \ll \theta_S$ is sufficient, provided such light emerges inside the shadow area. Light concentrates towards the throat edge.

Credit: Thorne, The Science of Interstellar, 2014; Oliver, von Tunzelmann, Franklin, Thorne, AJP, 2015

SMROs. Related targets: nearby and distant

- Nearby obscured SMBHs in galaxy mergers
- Obscured AGNs in ETGs
- Changing-look and binary AGNs
- SMBHs through cosmic times: BHs & Hosts coevolution, feedbacks, interrelations..

Obscured SMBHs in galaxy mergers

- Dust obscured SMBHs (Arp220 a prototype)

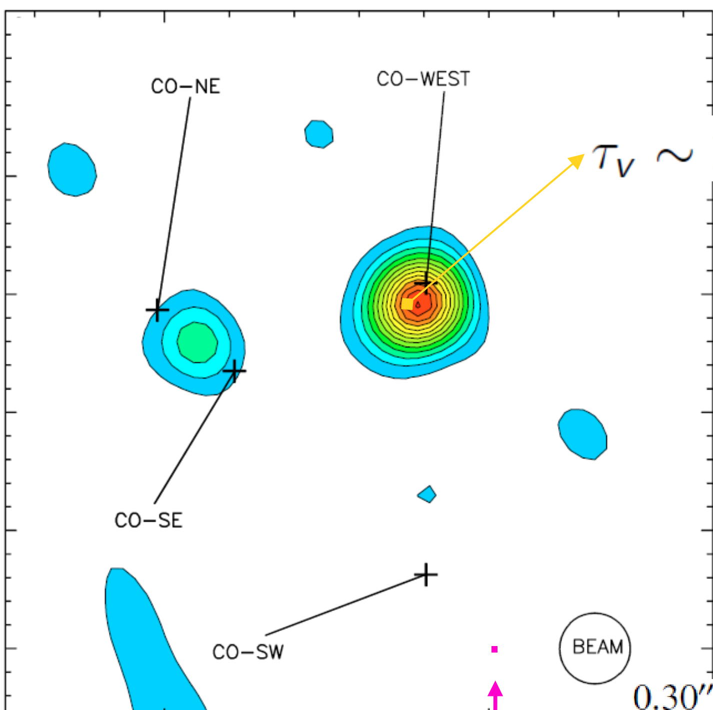
Downes & Eckart 2007

Ricci etal 2017

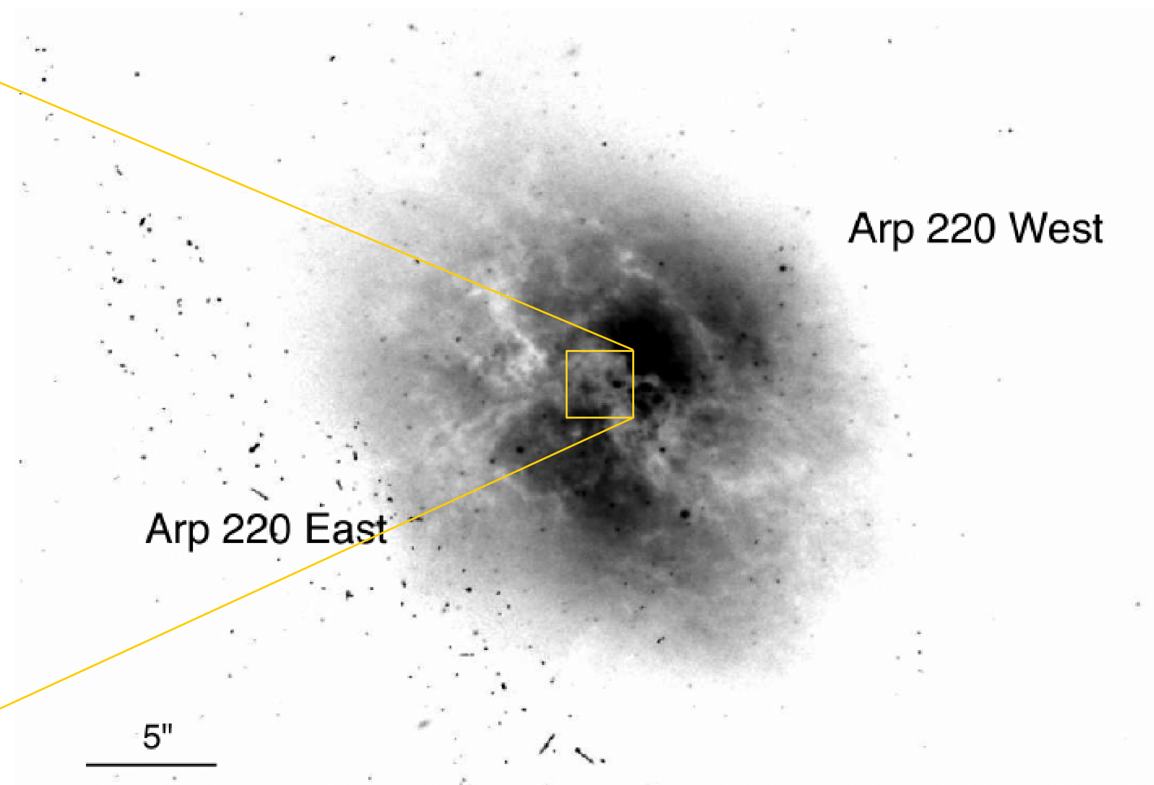
$F_\nu(1\text{mm}) \sim 100$ mJy

IRAS 15327+2340

D=87 Mpc



$\tau_V \sim 10^5$

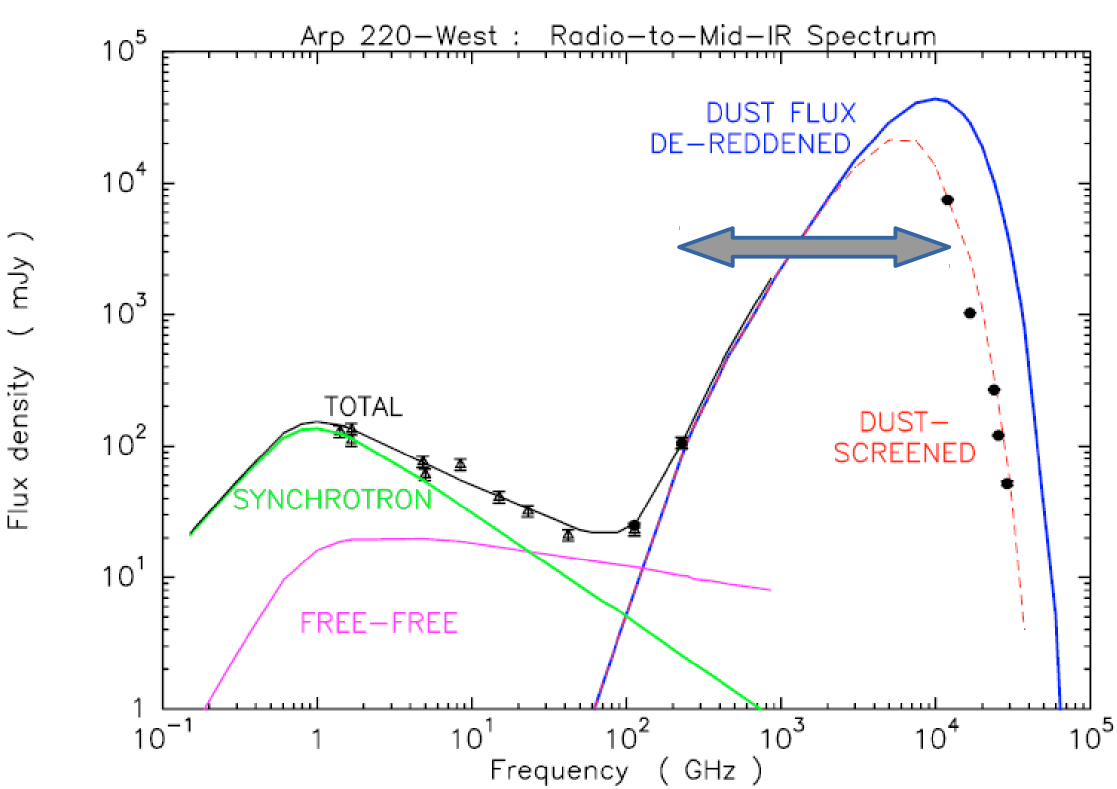


SVLBI MM+ALMA beam $\sim 0.1\mu$as (5×10^{-5} pc at Arp 220)

Obscured SMBHs in galaxy mergers

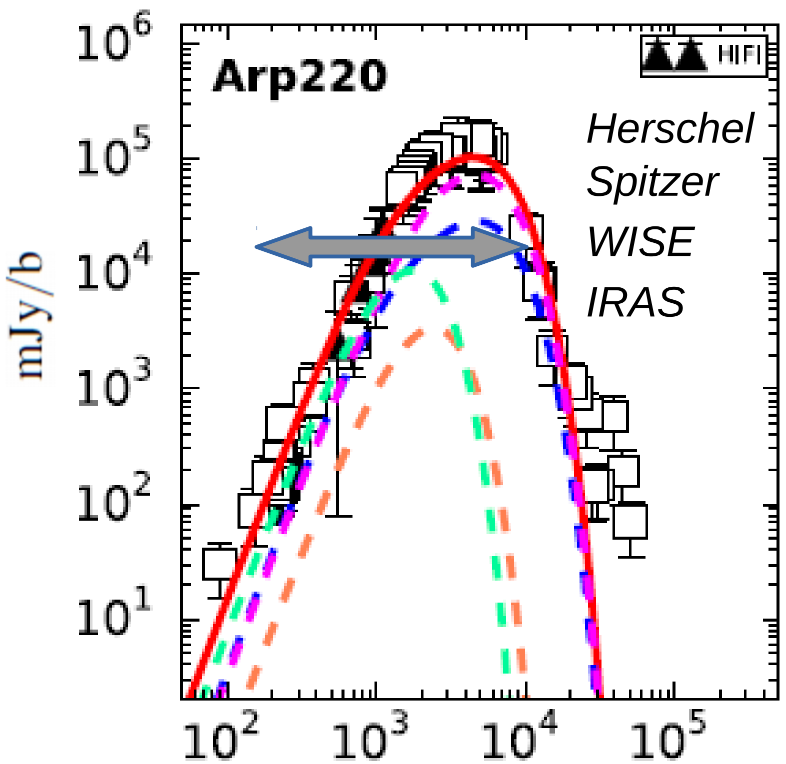
- Arp220 – what does it look like without MM

Downes & Eckart 2007



VLBI analysis without THz

L Liu etal 2017



THz analysis without VLBI

Obscured SMBHs in galaxy mergers

- Tentative candidates

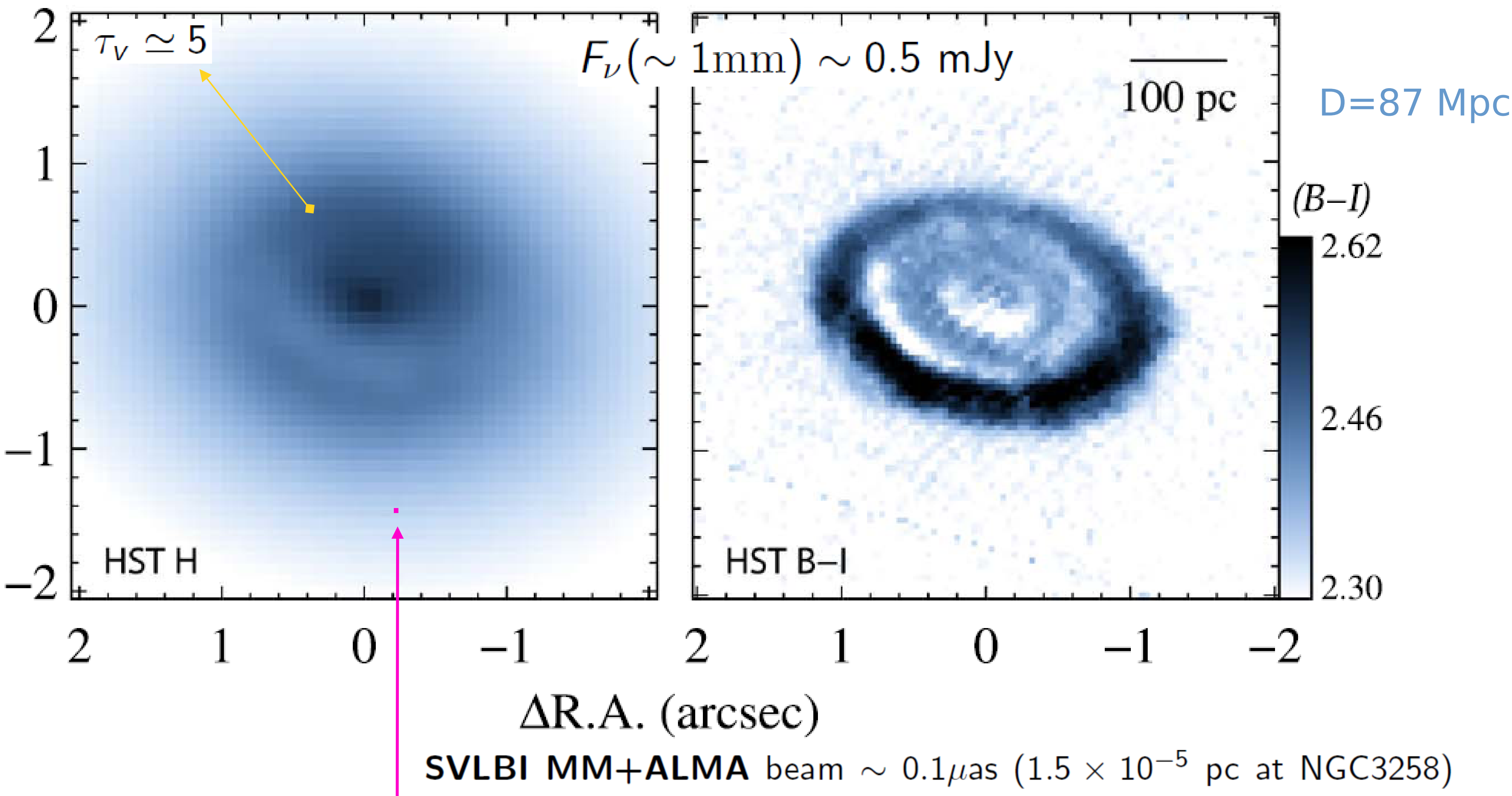
IC 860	NGC4418	NGC 5101	Mrk 273	Mrk 231
$\simeq$ 60 Mpc	33	170	166	184
2e11$L_\odot$	1e11	$\sim$1e12	1.5e12	3.4e12
$\sim 1 - 50$ mJy	$\simeq$0.1 Jy	~ 3 Jy	$\sim 0.3 - 1$ Jy	$\sim 0.3 - 1$Jy

All these candidates are of M87* class sources and are good for MM + ALMA VLBI with AU resolution.

Obscured SMBHs in ETGs

- Dust obscured SMBHs (e.g., ETG NGC3258)

Bizelle etal 2019



SVLBI MM+ALMA beam $\sim 0.1\mu$as $(1.5 \times 10^{-5}$ pc at NGC3258)

Obscured SMBHs in ETGs

- Nearby dust obscured ETG SMBHs candidates

NGC1332	NGC4374	NGC6861	IC 4296
$\simeq$ 23 Mpc	16	$\simeq$40	50
$F_\nu(236\ \mathrm{GHz}) \simeq$ 8mJy	130	23	$\simeq$210

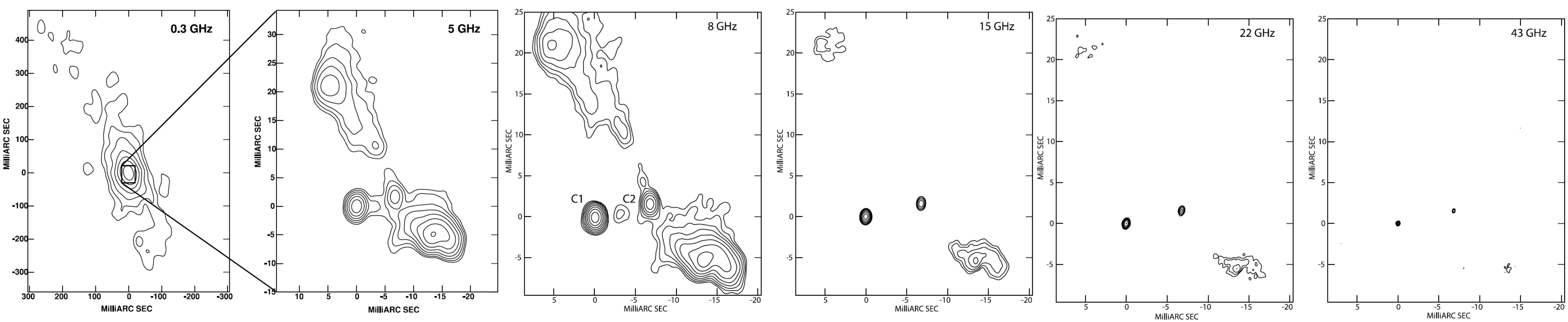
Changing-look & binary AGNs

- Binary AGNs: 0402+379

- They should apparently copiously present, but only few detected → as a rule only one component is active;

- Need pc and sub-pc resolution;

0.3 GHz | 5 GHz | 8 GHz | 15 GHz | 22 GHz | 43 GHz



Rodriguez + 2006

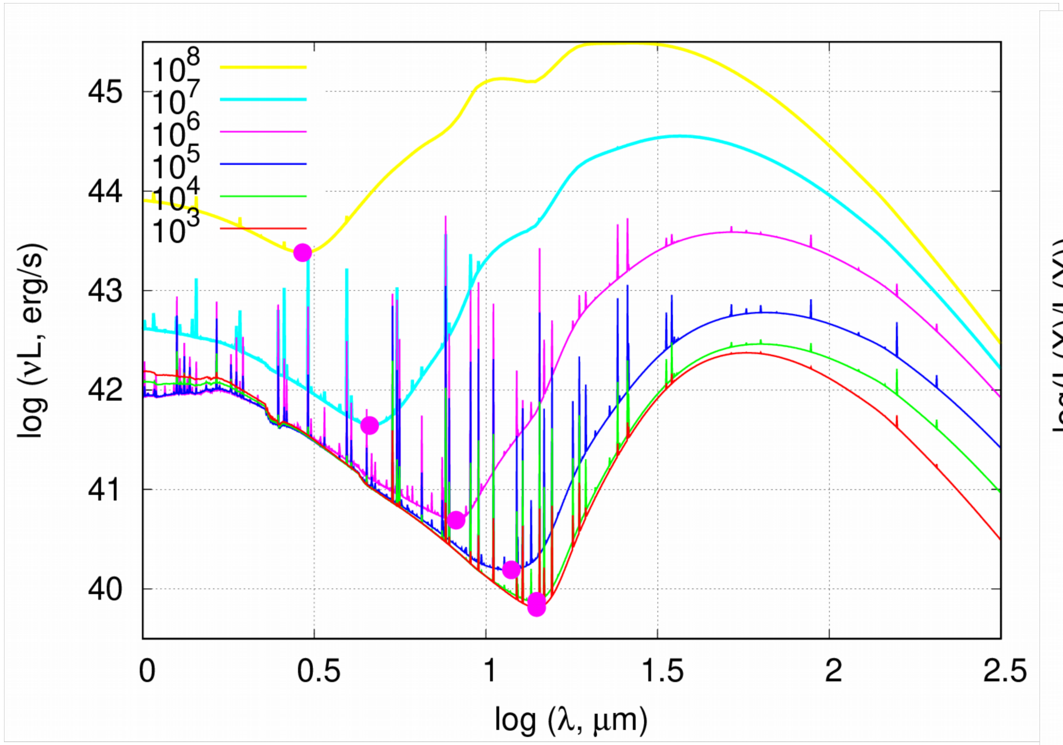
Orbiting BHs with $\sum M_i \sim (1-2) \times 10^8 M_\odot$

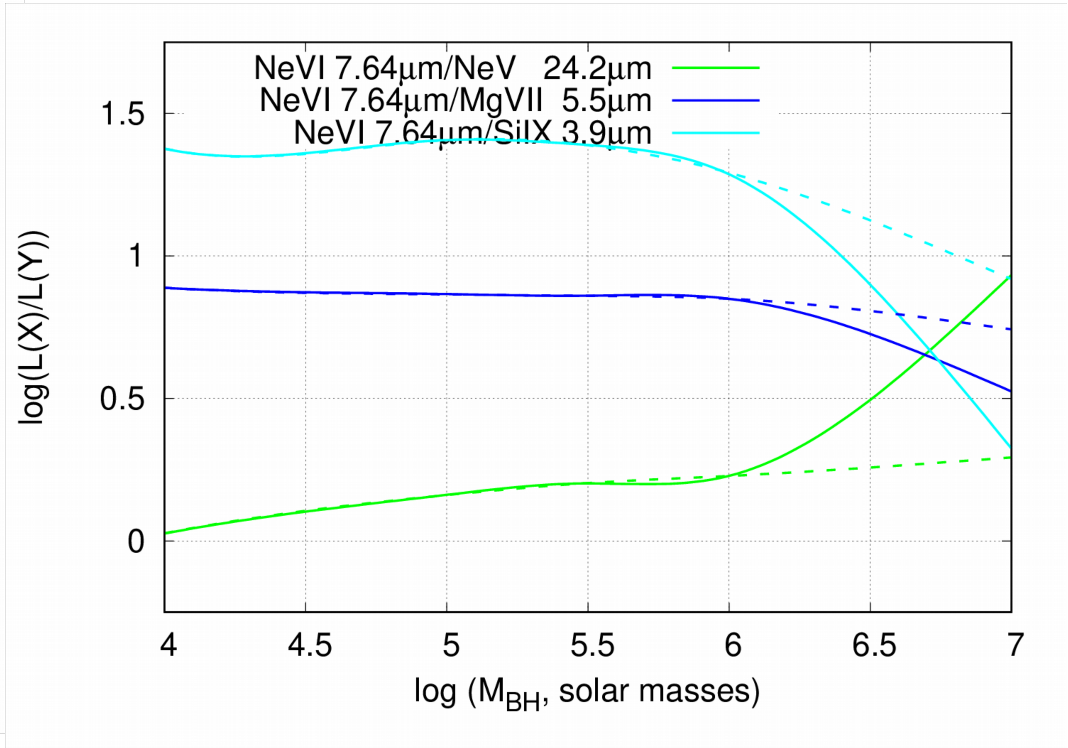
Flux $\sim$ 1 mJy

SMBHs & Host interplay in a distant U

- Probe of SMBHs-Hosts coevolution with Single Dish MM – an example

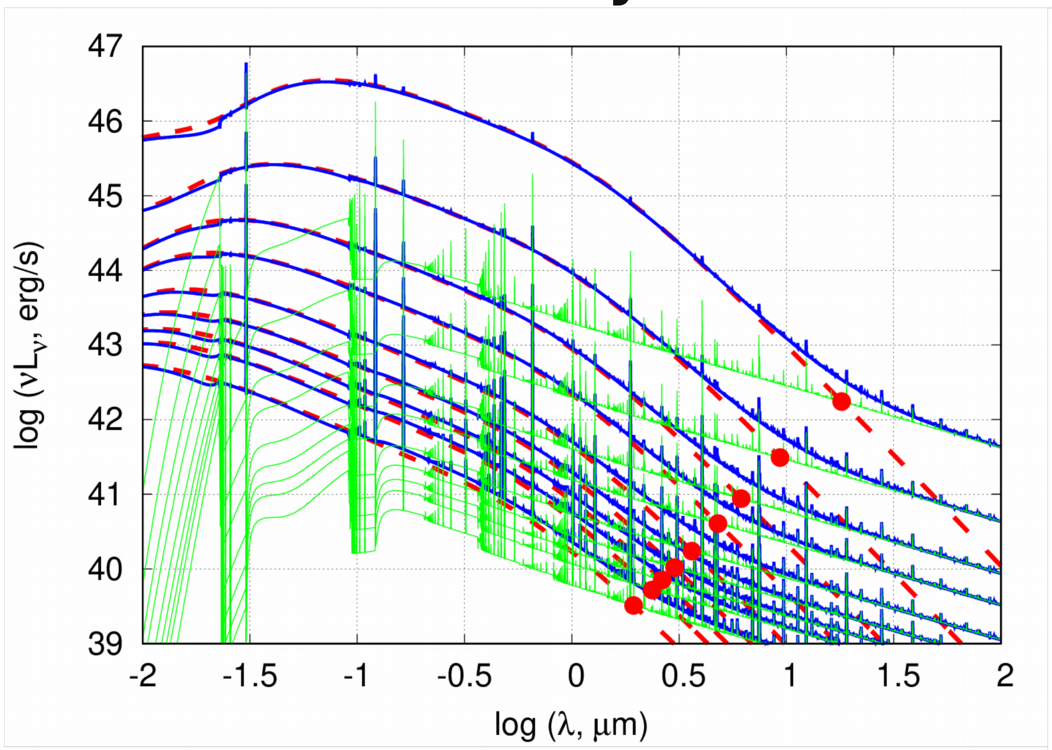
Vasiliev & YuS, in prep 2019

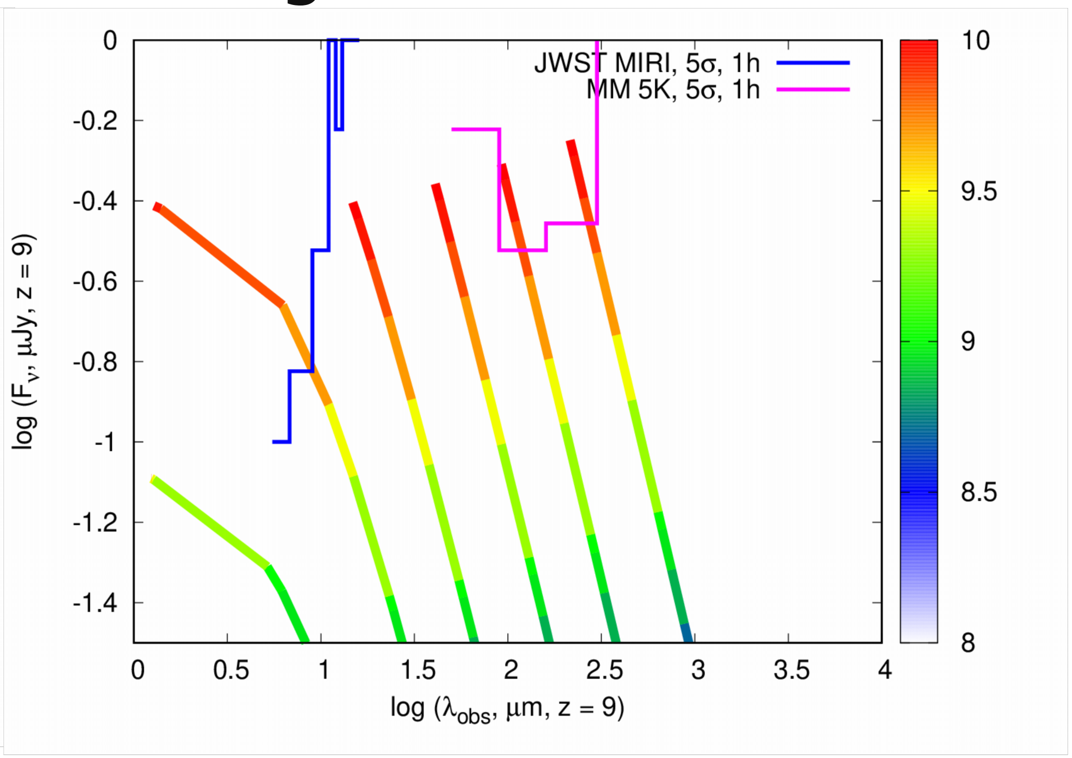




SMBHs monsters in a very distant Universe

- The first Gyr of the U with Single Dish MM





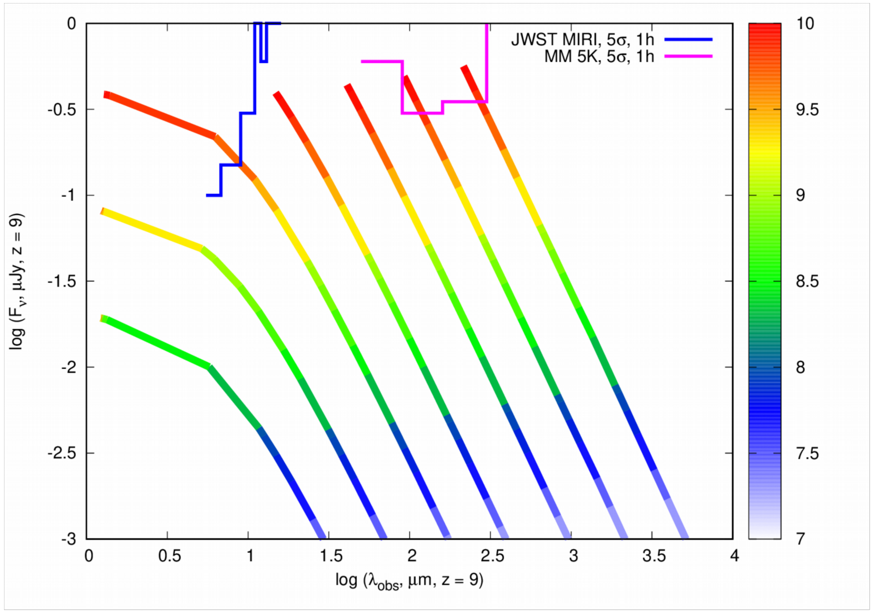
Left: Red are the SEDs of BH (10^5 at $z \simeq 16$ to $10^{8.7} M_\odot$ at $z \simeq 7$ upwards), blue is nebular emission of gas, green are the sum; $M_\bullet = 0.002 M_{gas}$
Right: The wide-band ($R = 100$) flux at the kink λ_k emitted at $z = 9$ for BH masses: $10^5 \rightarrow 10^8 M_\odot$ rightwards; color is the log(gas mass): Vasiliev & YuS 2019

SMBHs in a distant Universe with MM

- Prospective to search BH "monsters" beyond *z>10*

$$\text{JWST FoV } (2' \times 2') \Rightarrow \Delta N_{\bullet} \geq 0.12\text{–}4: \text{ at least 1 in 5 random pointings,}$$

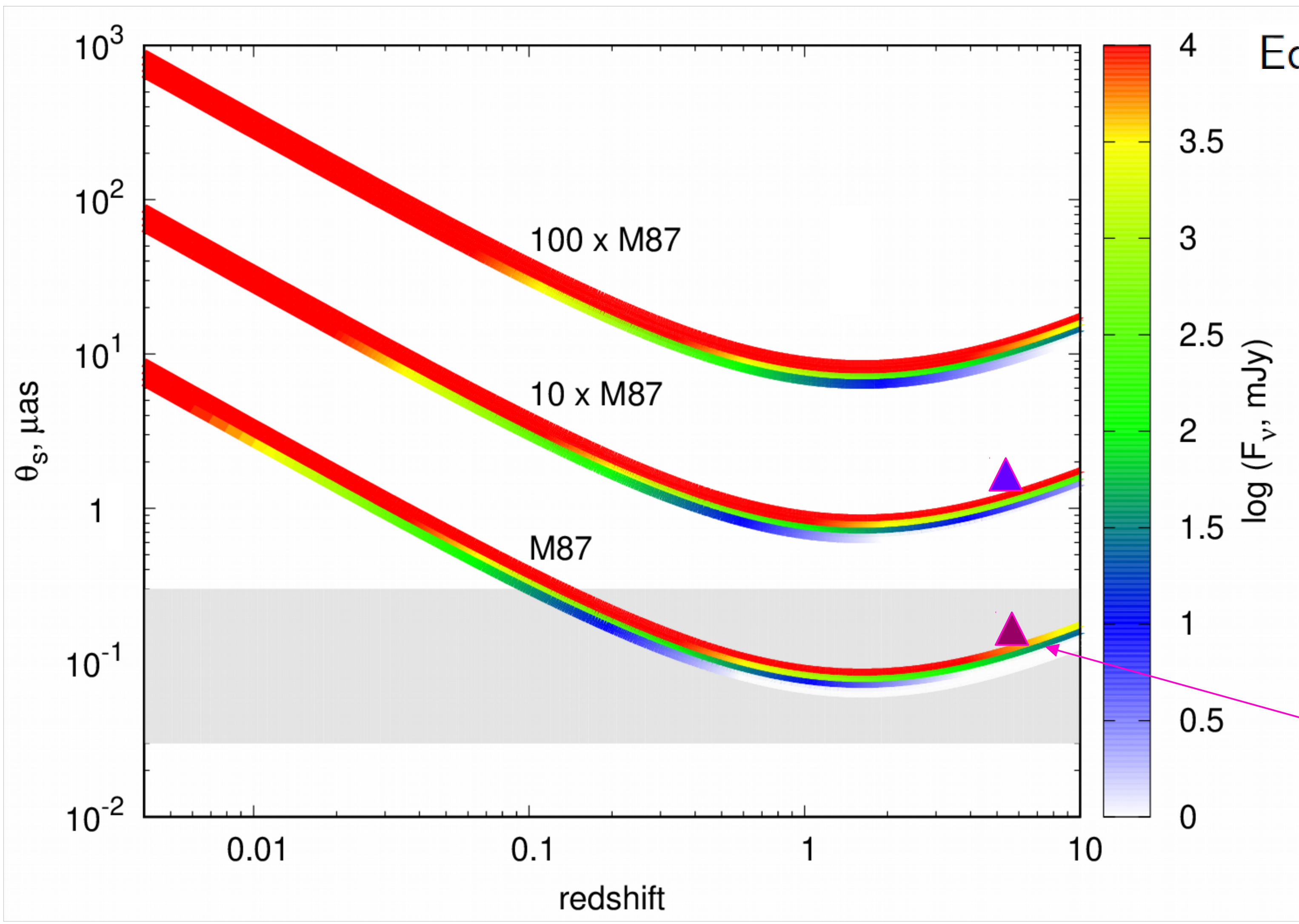
$$\text{MM FoV } (6' \times 6') \Rightarrow \Delta N_{\bullet} \geq 1 - 70: \text{ in 1 random pointing}$$

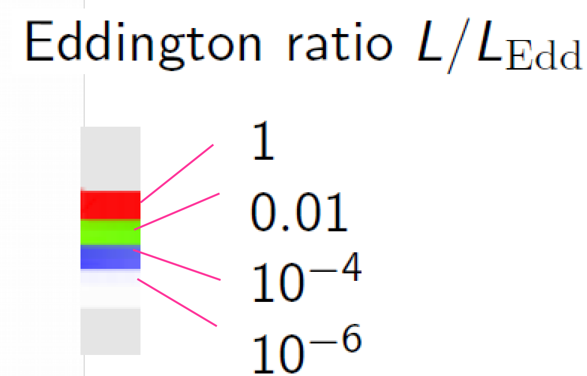


Vasiliev & YuS 2019

SMBHs through cosmic time with MMtron

- Distant SMBHs with MM + ALMA SVLBI





Up to 3 such BHs might fall into the MM FoV,
YuS & Vasiliev in prep

~30 M87 class BHs are known to present here..

SMBHs through cosmic time with MMtron

- Distant SMBHs with SVLBI: tentative list

M87* (z, $L/L_{\rm Edd}$) – all below θ_t	10×**M87*** – all might be sub-pc resolved
2QZ J002830.4-281706 (2.4, 0.62)	[HB89] 0329-385 (2.4, 0.18)
UM667 (3.1, 0.62)	TON618 (2.2, 0.14)
2QZ J023805.8-274337 (2.45, 0.68)	[HB89] 1246-057 (2.2, 0.41)
SDSS J02493.42-083454.4 (2.5, 0.25)	2QZ J222006.7-280324 (2.4, 0.53)
[HB89] 1318-113 (2.3, 0.61)	-
[HB89] 013-036 (2.4, 0.41)	-

Conclusions

"*Millimetron*" will mine THz "terra incognita" with an unprecedented sensitivity and angular resolution. Among the topics we expect new fundamental results are:

- Further understanding of the horizon region in M87*, in SgrA*, and unveil physics from ISCO to Bondi scales;
- Recognizing WH;
- 'SMBH – Host' synergy;
- Uncover obscured AGNs, changing-look and binary AGNs, including sub-pc scales of the neighbors;
- Probing structures and evolution of high-z BH "monsters".

Wormholes

- WH: monopole **B** as a possible observational signature:

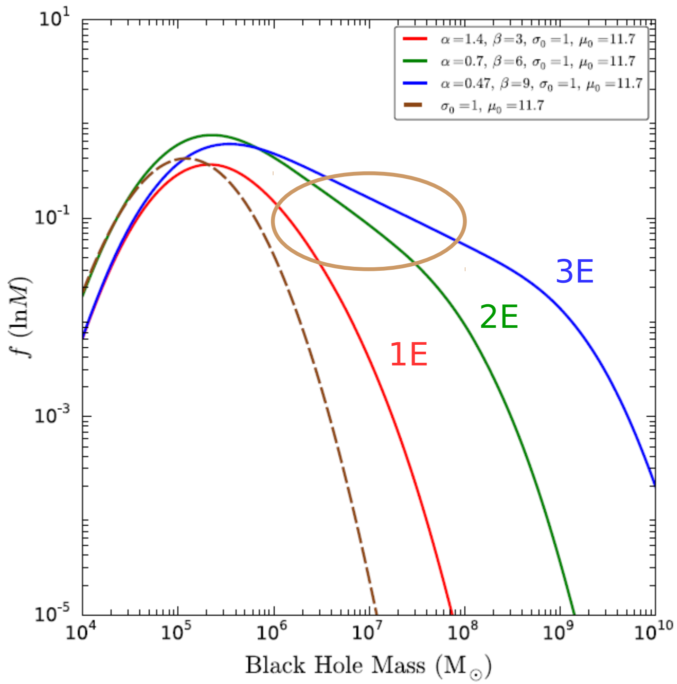
The upper limit on magnetic field at the throat

$$B \leq \frac{1}{\sqrt{2}} \frac{c^4}{G^{3/2} M} \sim 2 \times 10^{10} \left(\frac{10^9 M_\odot}{M} \right) \ \mathrm{Gauss}$$

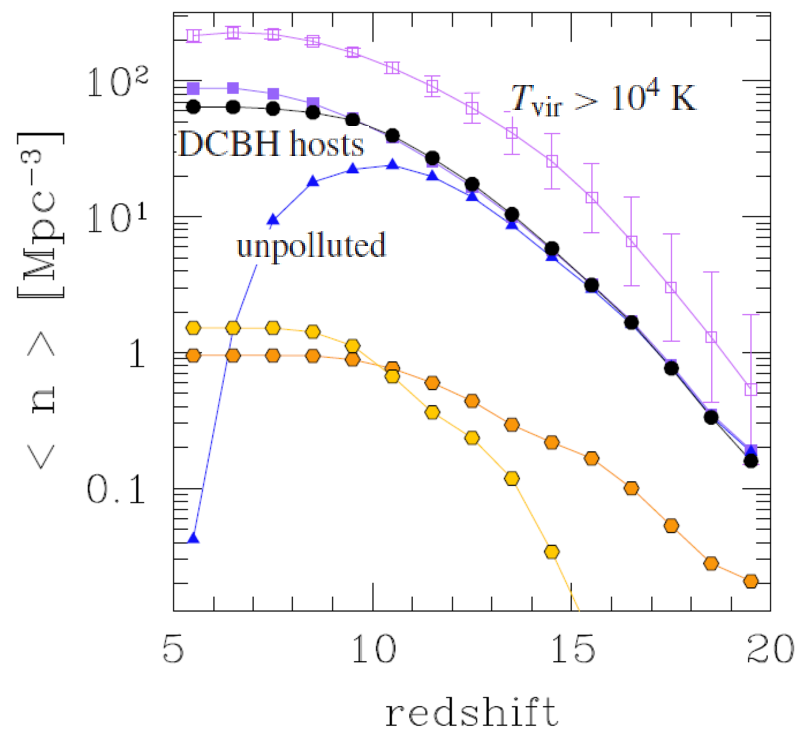
$$\text{Sgr A}^*\text{:} \ \ B \leq 5 \times 10^{12} \ \mathrm{Gauss}$$

SMBHs in a distant Universe with MM

- BH "monsters" in the first Gyr



Mass fraction of BH seeds by ~0.15 Gyr since BB; Basu & Das 2019



Comoving halos number density evolution; Ferrara etal 2014