Imaging Sgr A* to constrain its properties

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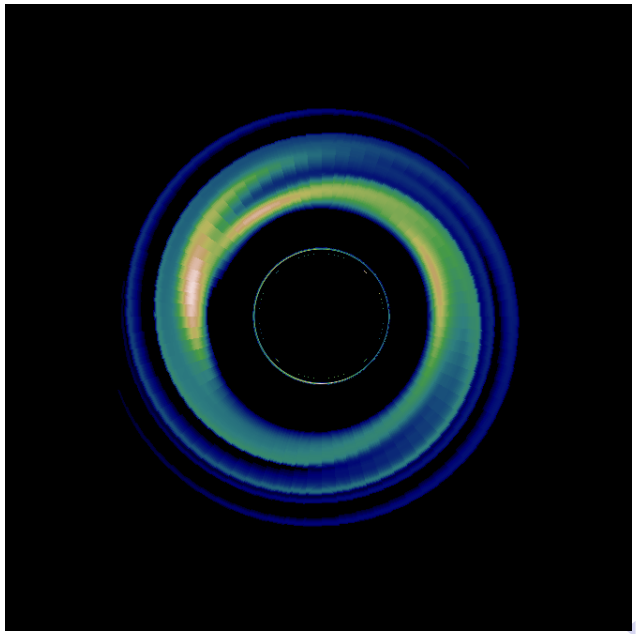
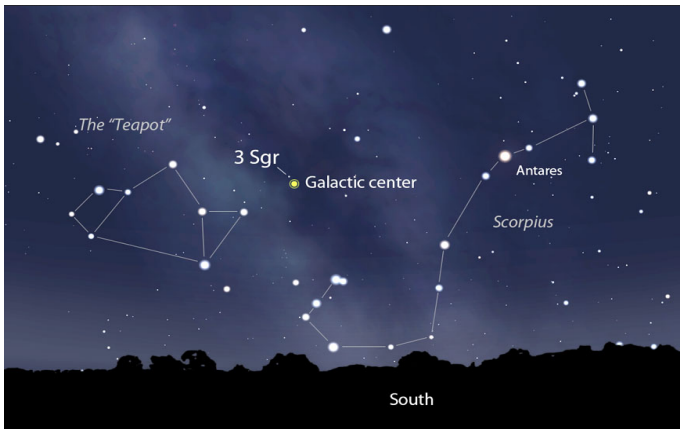
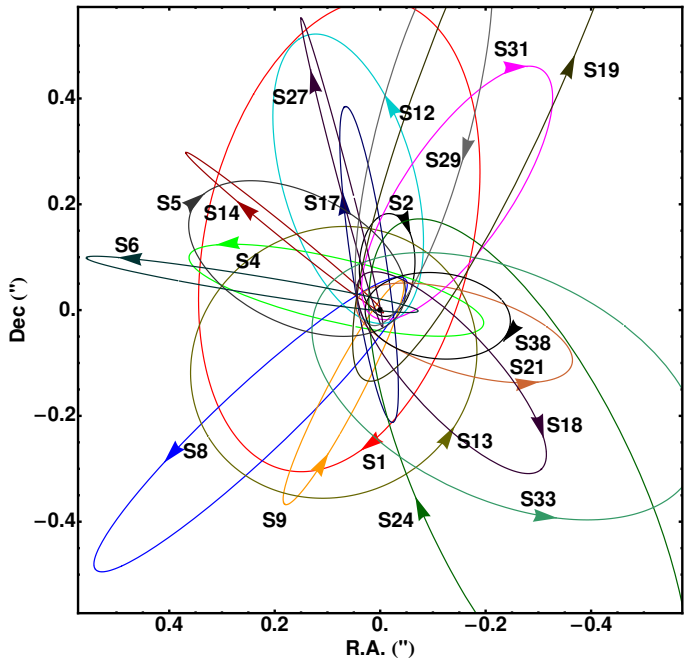




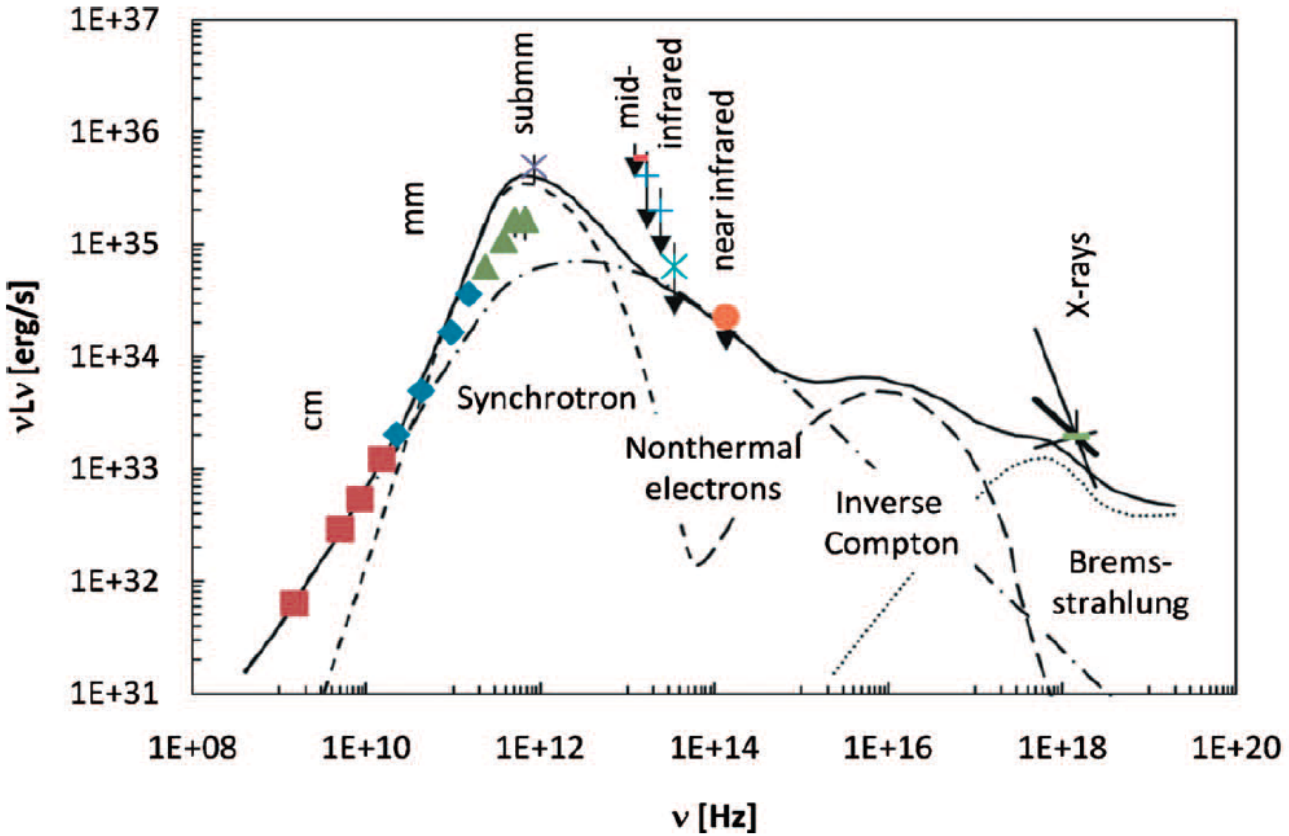
Credit : Stellarium, Bob King



S-stars cluster (Gillessen+09): size = **1" ≈ 0.05 pc**

Sgr A*: big mass in small region, SMBH

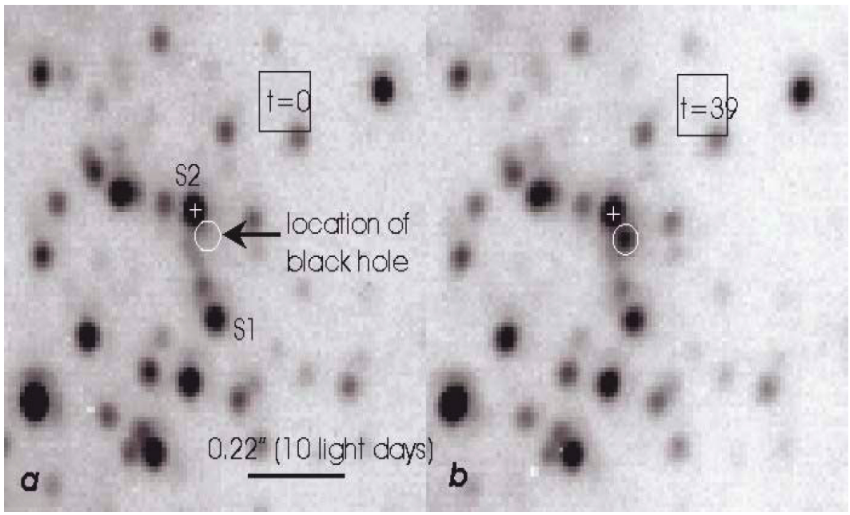
- Astrometric measurements of close stars → central mass
- Sgr A* mass is **$4.3\,10^6 M_\odot$**,
  S2 at perimelanophrear at **100 AU** from Sgr A*,
  $\theta_{\mathrm{app,Sch}} \approx$ **50 μas**



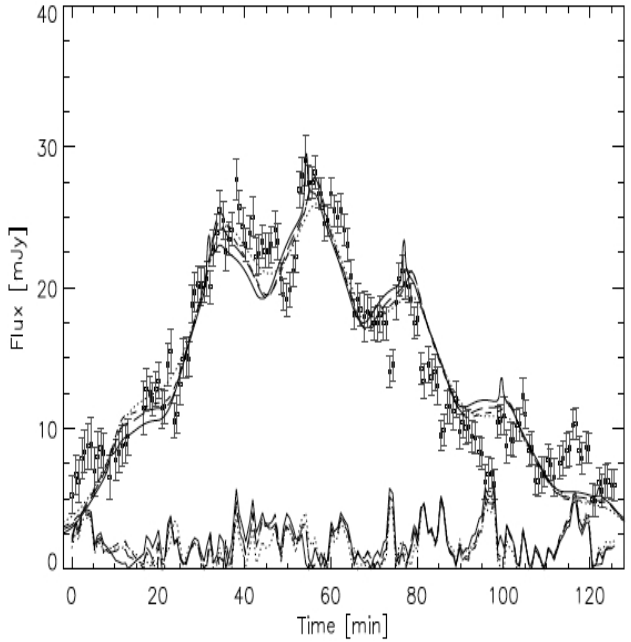
Genzel+10

Sgr A* **quiescent** spectrum: not so clear

- Radiatively inefficient accretion flow (**RIAF**)
- **Jet**
- **Torus**-like accretion flow [→ this talk!]



Genzel+03



Hamaus+09

Sgr A* **flares**: really unclear

- Sphere of gas orbiting around Sgr A*
- Jet / blob
- MHD instability
- ...

Question marks at Sgr A*

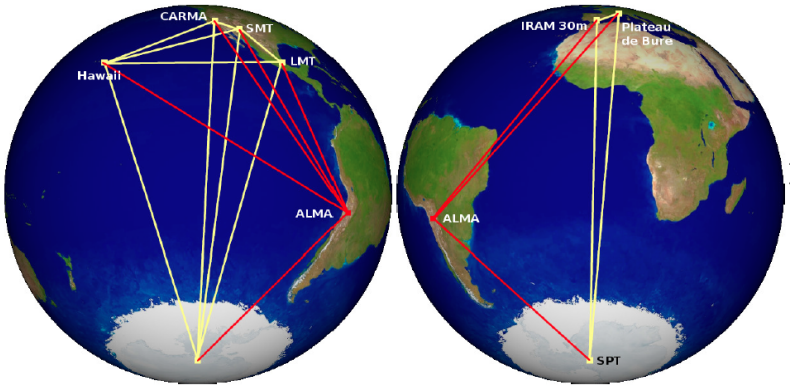
- **Quiescent** model of Sgr A* is not so clear (**geometry?**)
- **Flare** model is really **not clear**

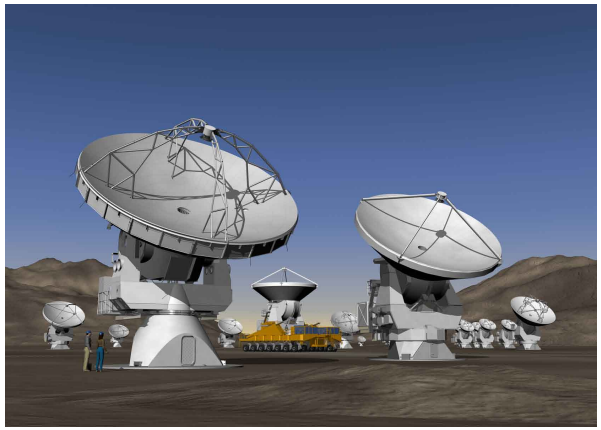
New instruments

- At a scale of $\approx$ **10 μas**!
- Quiescent state: $\rightarrow$ detailed "**picture**"

  $\rightarrow$ *Event Horizon Telescope*
- Flaring state: $\rightarrow$ quick (few min) **dynamical monitoring**

  $\rightarrow$ *GRAVITY* (next talk)





Event Horizon Telescope (2008-2020)

Quiescent state imaging

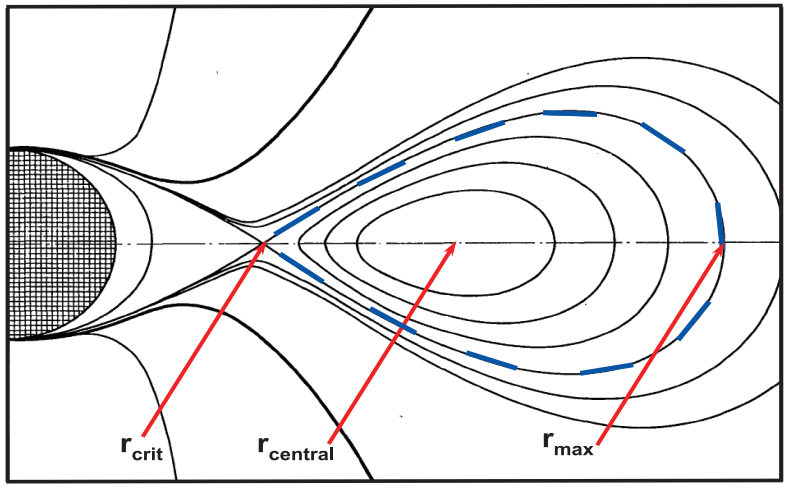
- EHT: **15 μas** resolution (mm; 10^{11} Hz)

→ Doeleman+08, *Nature, 455, 78*; Doeleman+09, *Astro2010 White Paper*

My goal

- Analytic accretion model:
  torus model for Sgr A*
- Interest: close-future **EHT** data, **100%-controled** model
- Why analytic? Very **quick computation**: first-order idea
- Higher order: GRMHD

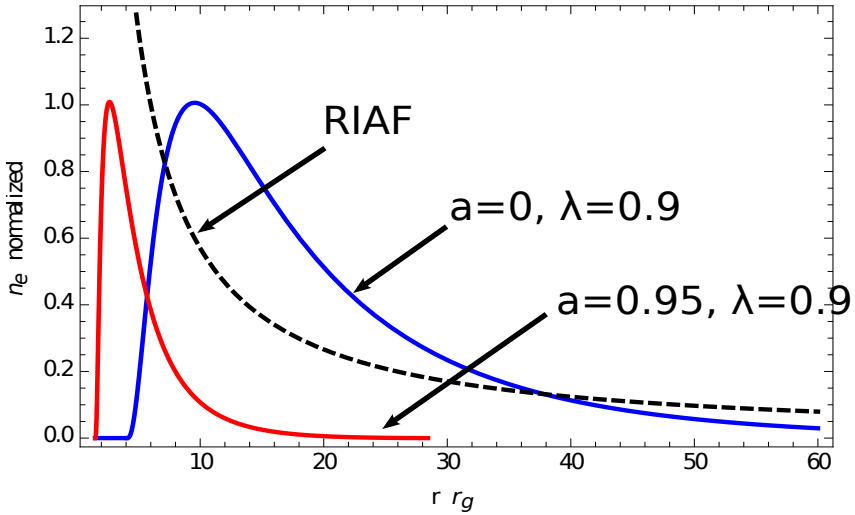
→ Vincent+15, *A&A, 574, A48*



Torus cross-section (Abramowicz+78)

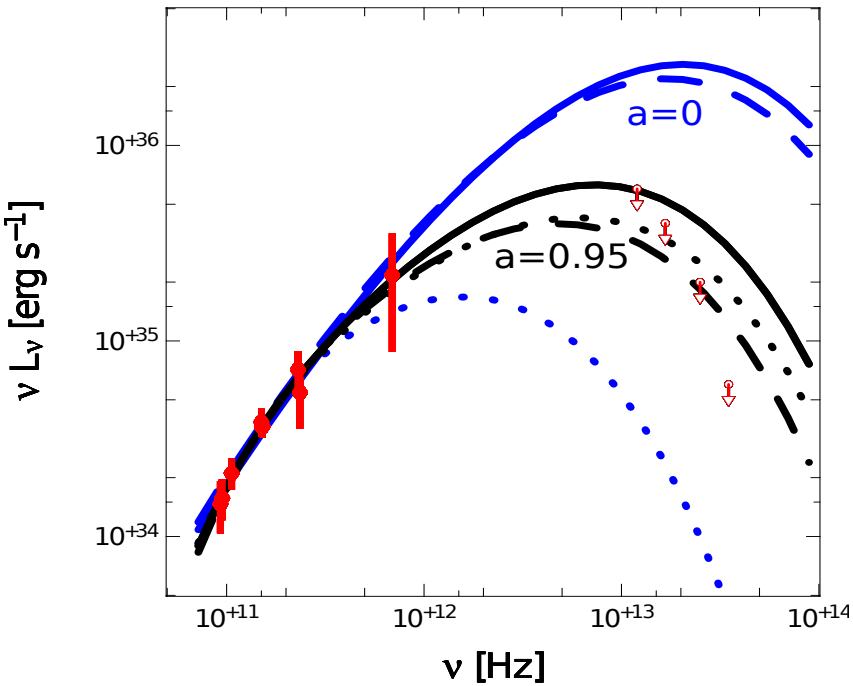
The recipe

- $\rightarrow$ stationary, axisymmetric
- $\rightarrow$ perfect fluid, constant ℓ, circular, polytropic
- $\nabla_\mu T^\mu_\nu = 0 \rightarrow p, \rho$ analytic expressions [Abramowicz+ 78]
- Magnetic field [Komissarov 06] + synchrotron [Wardziński & Zdziarski 00]
- $\rightarrow$ torus model $(a, i, \ell, n_c, T_c, \beta = 0.1, k = 5/3)$



Density distribution

- Torus much more **compact**
- No far-distance contribution



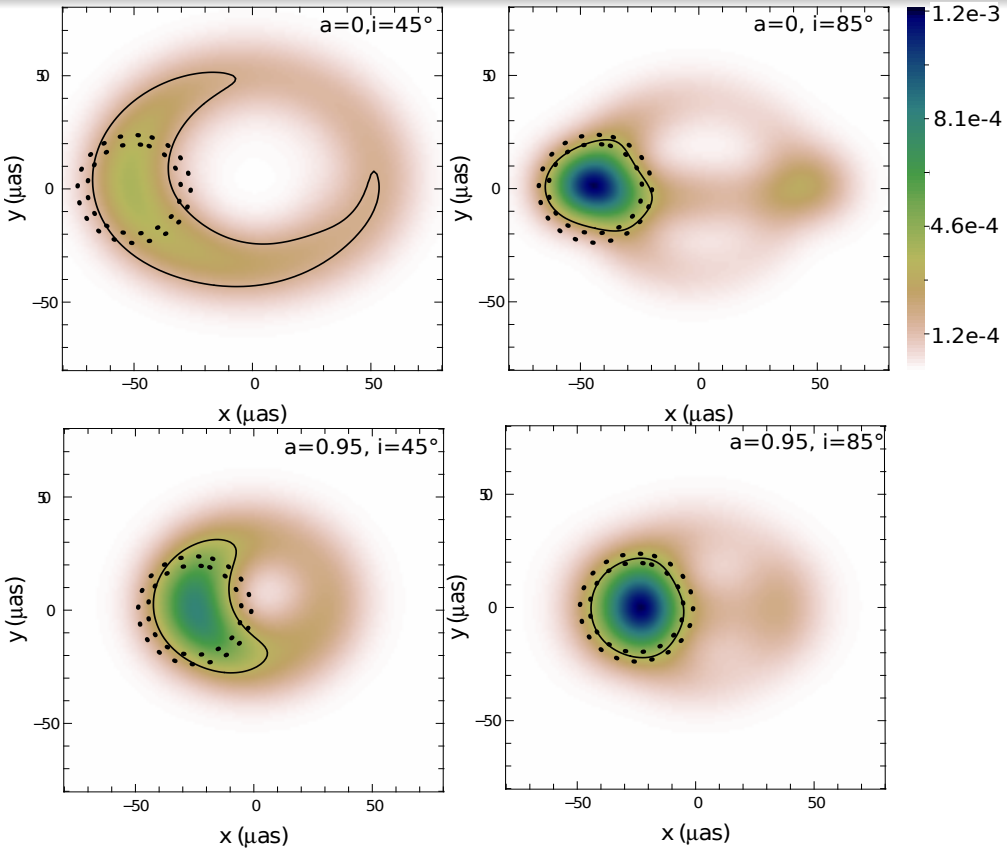
Millimeter spectral fitting

- Any (a, i) pair fits
- Probably constraints from mm-IR fits

(a,i)	λ	$r_{\rm out}\,(r_g)$	$n_c\,({\rm cm}^{-3})$	$T_c\,({\rm K})$	$\chi^2_{\rm red}$
$(0,5°)$	0.35	15	7.7×10^6	8.7×10^{11}	0.37
$(0,45°)$	0.33	15	8.4×10^6	7.5×10^{11}	0.37
$(0,85°)$	0.33	15	5.6×10^6	2.3×10^{11}	0.25
$(0.95,5°)$	0.75	11	1×10^7	4.2×10^{11}	0.21
$(0.95,45°)$	0.79	13	7×10^6	3.1×10^{11}	0.21
$(0.95,85°)$	0.85	20	3.5×10^6	3.1×10^{11}	0.21

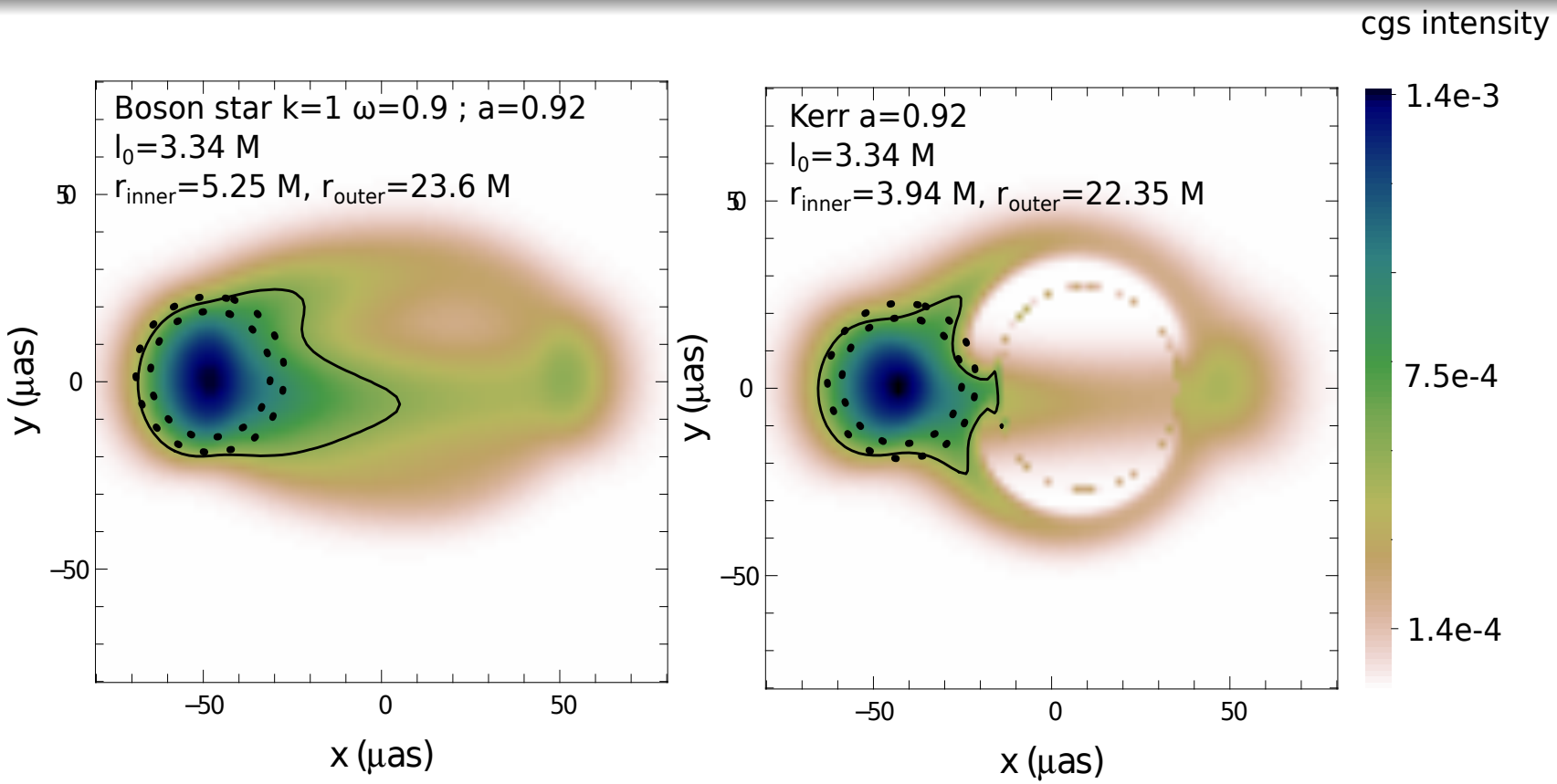
Millimeter spectral fitting

- Size of torus well constrained
- Very good fits for all parameters



Millimeter image constraints

- Kill some accretion flow models
- Constrain inclination
- Constrain spin
- Non-Kerr-BH compact objects?



Is Sgr A* a BH?

- Alternative: **boson star** (no event horizon, no singularity)
- Comparing images with Kerr
- BS: no projected photon ring ; shadow less clear
- **Preliminary!**

Conclusion

- Big motivation: **EHT** data coming this year
- Interest of analytic models:
  quick computation, rather simple
- Goal: (1) constrain accretion flow;
  (2) test the Kerr hypothesis??
- Future of torus model:
  (1) add a **jet**; (2) **image analysis** tools;
  (3) **full spectrum** (Comptonization)

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- Thanks for your attention!