Confronting MHD accretion theory with observations of Sgr A*

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MPE Garching

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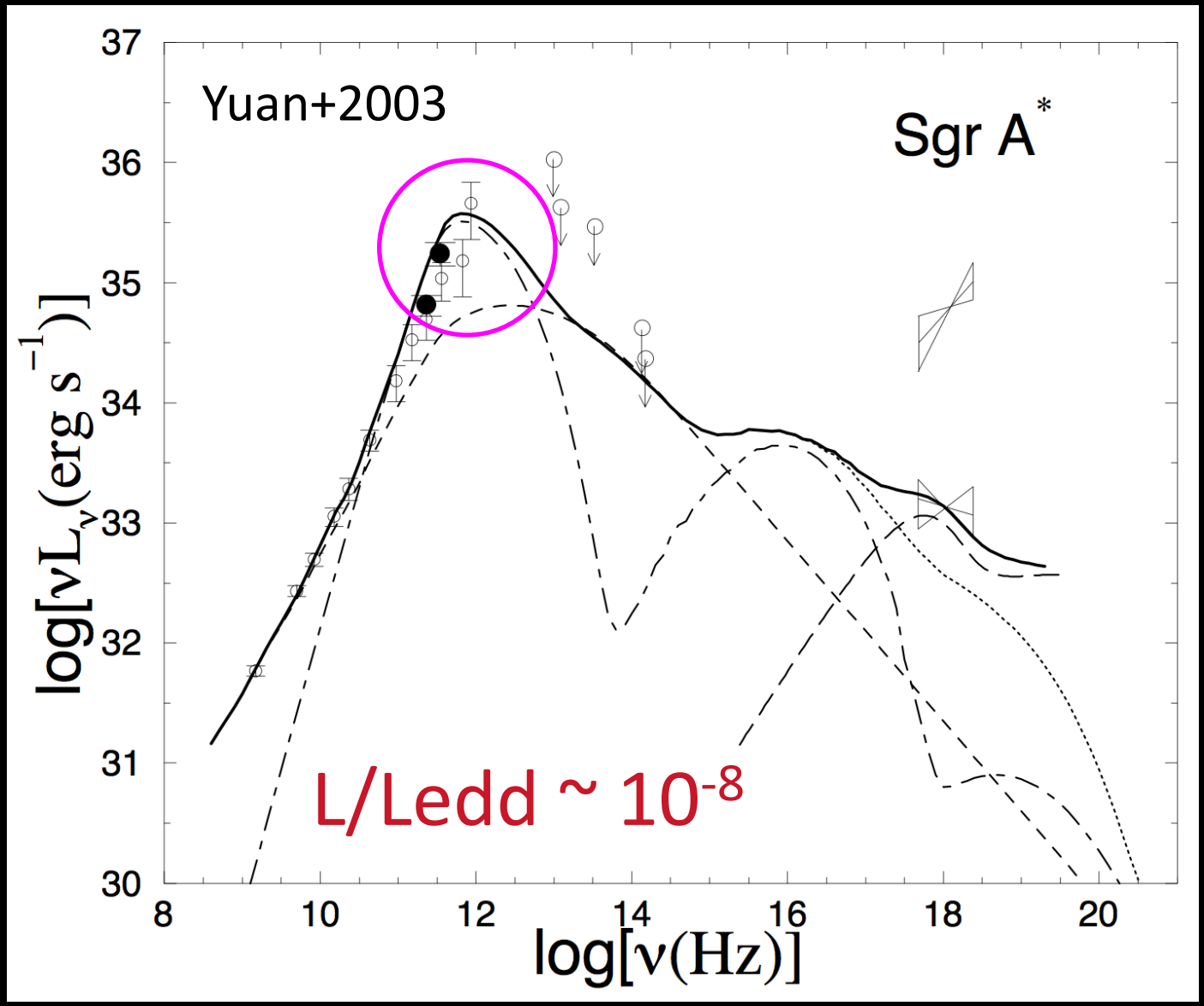
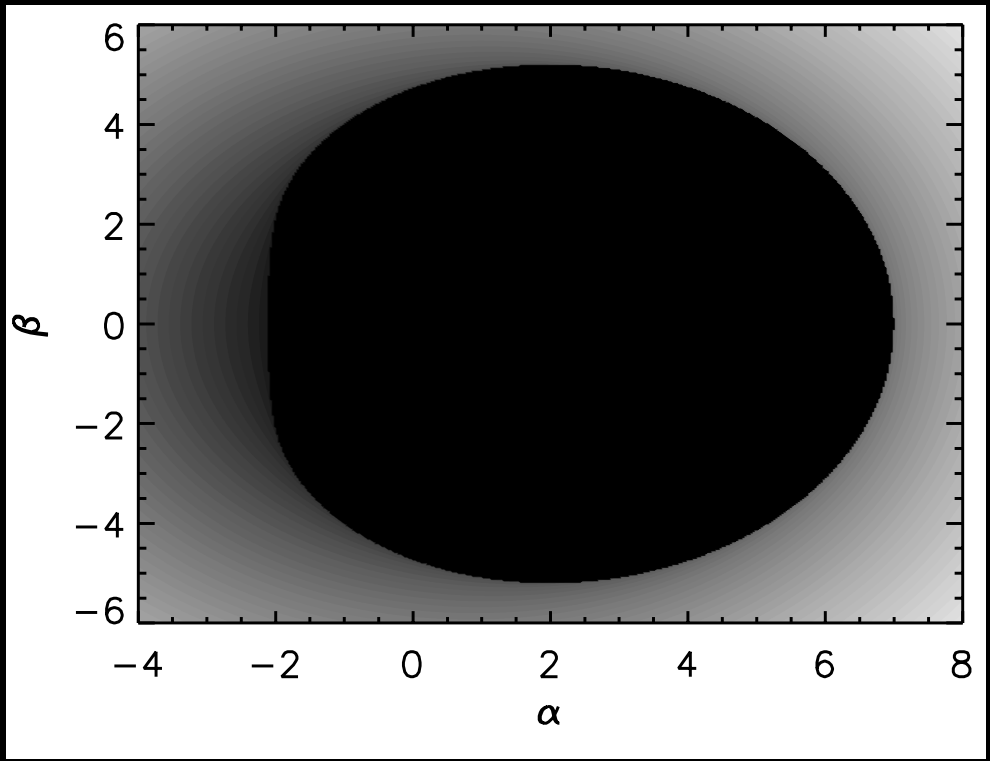
Sgr A*: an ordinary black hole

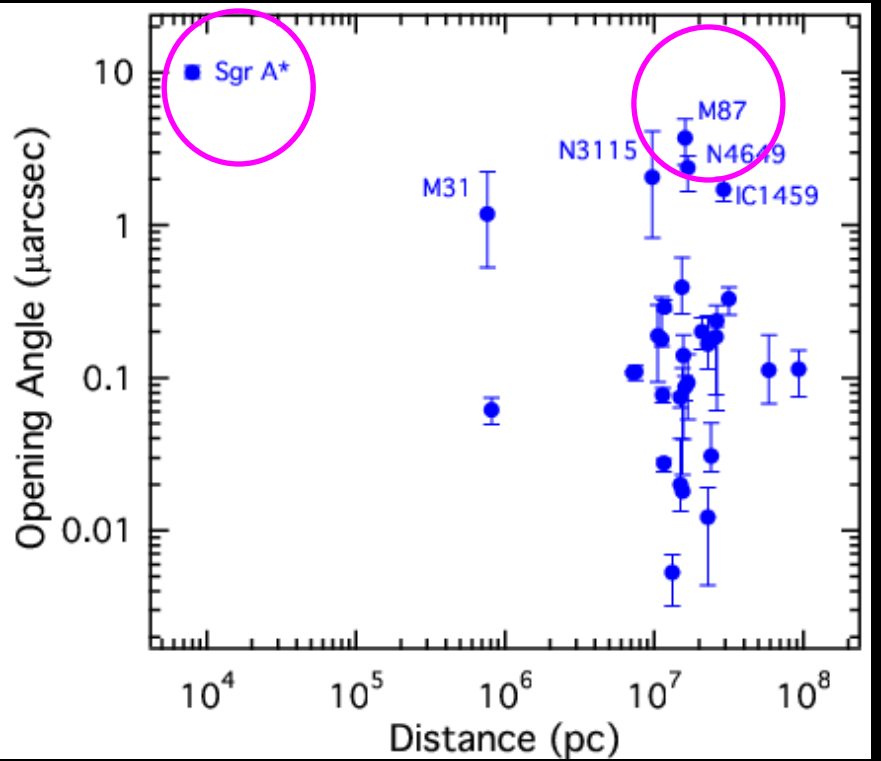


Resolving the event horizon of Sgr A*

- Known M/D: shadow θ ~ 50 μas
- mm: λ/θ ~ 10^4 km, NIR: 10 km



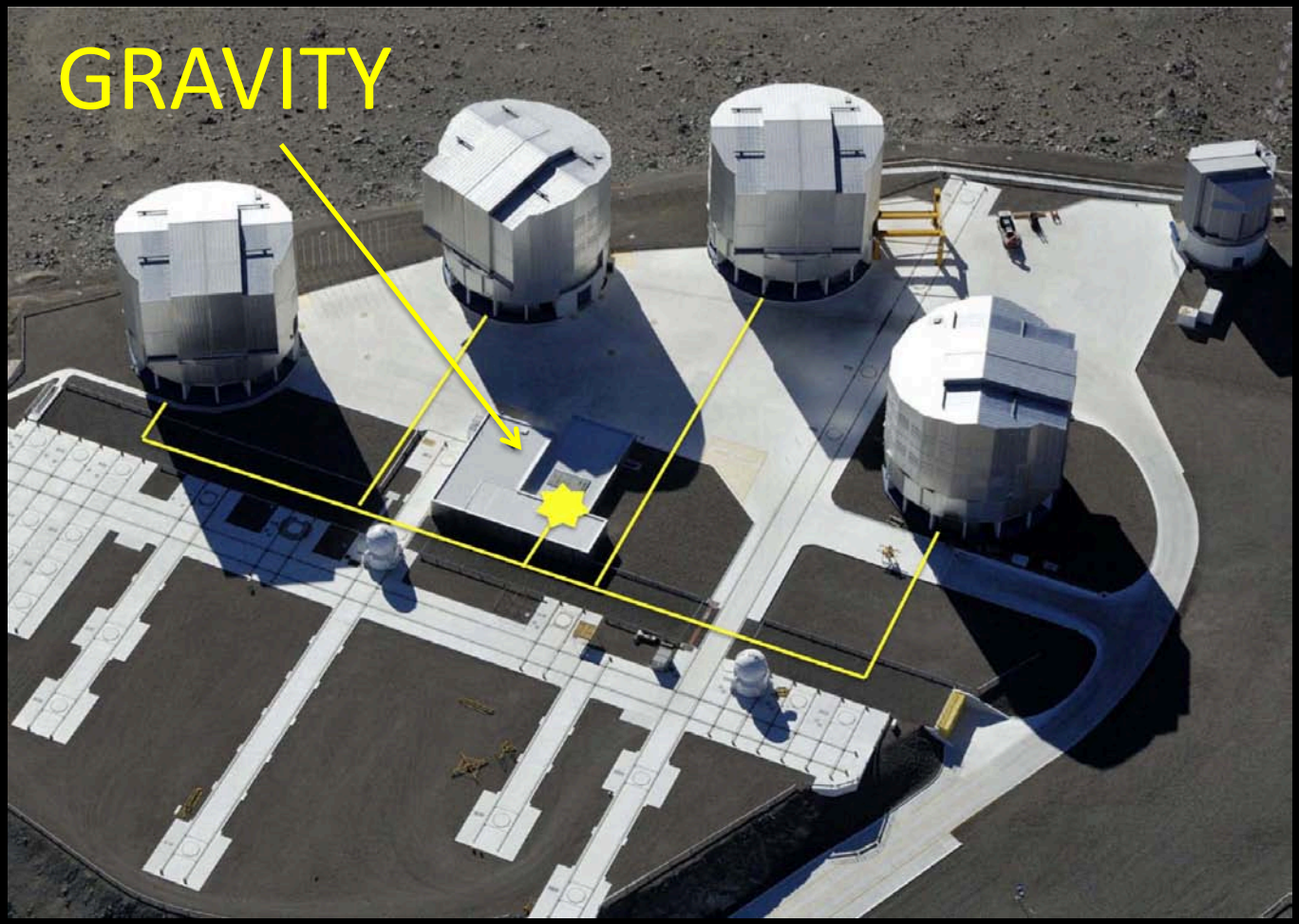
Bardeen 1973, Falcke+2000



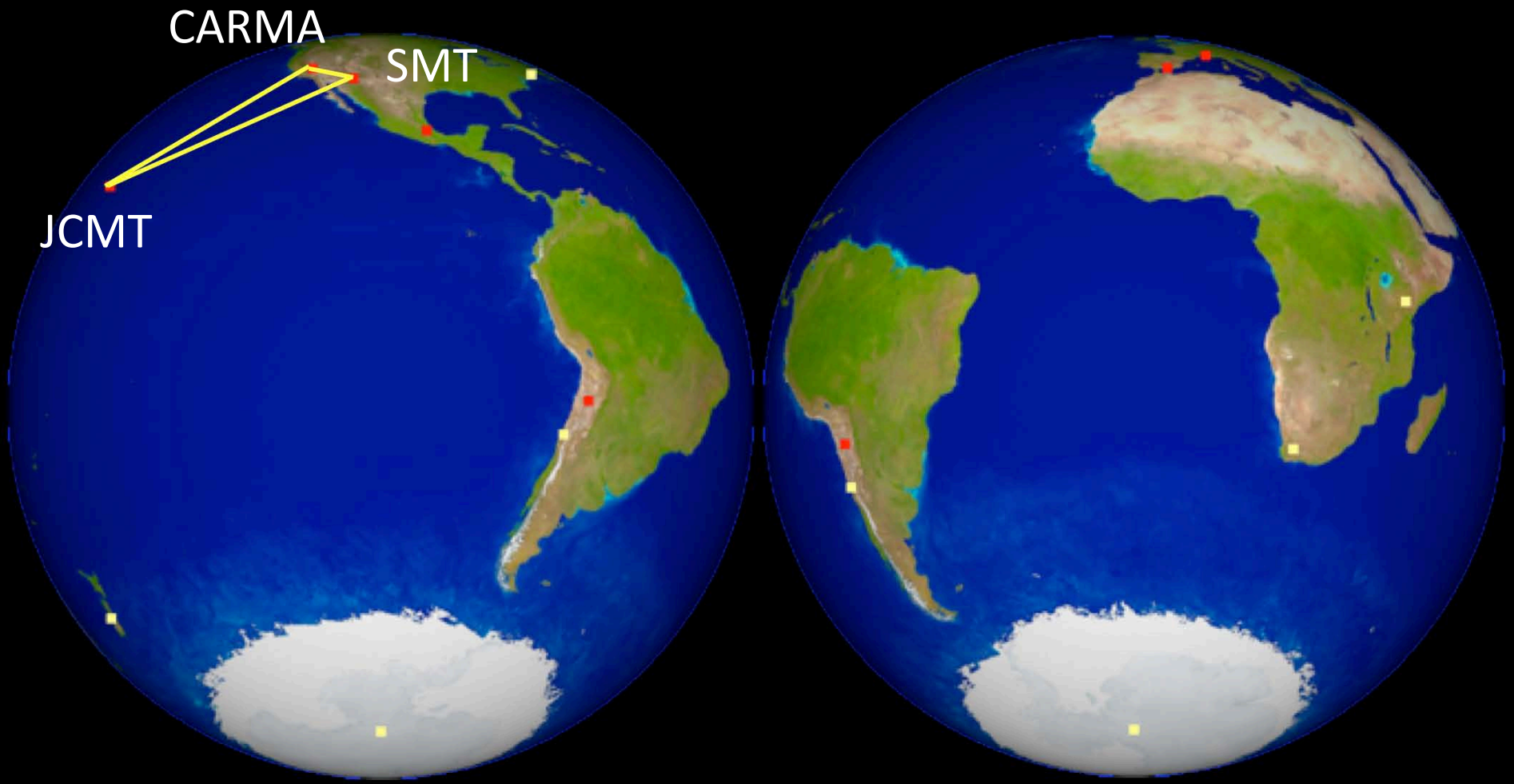
Psaltis 2008

VLTI GRAVITY

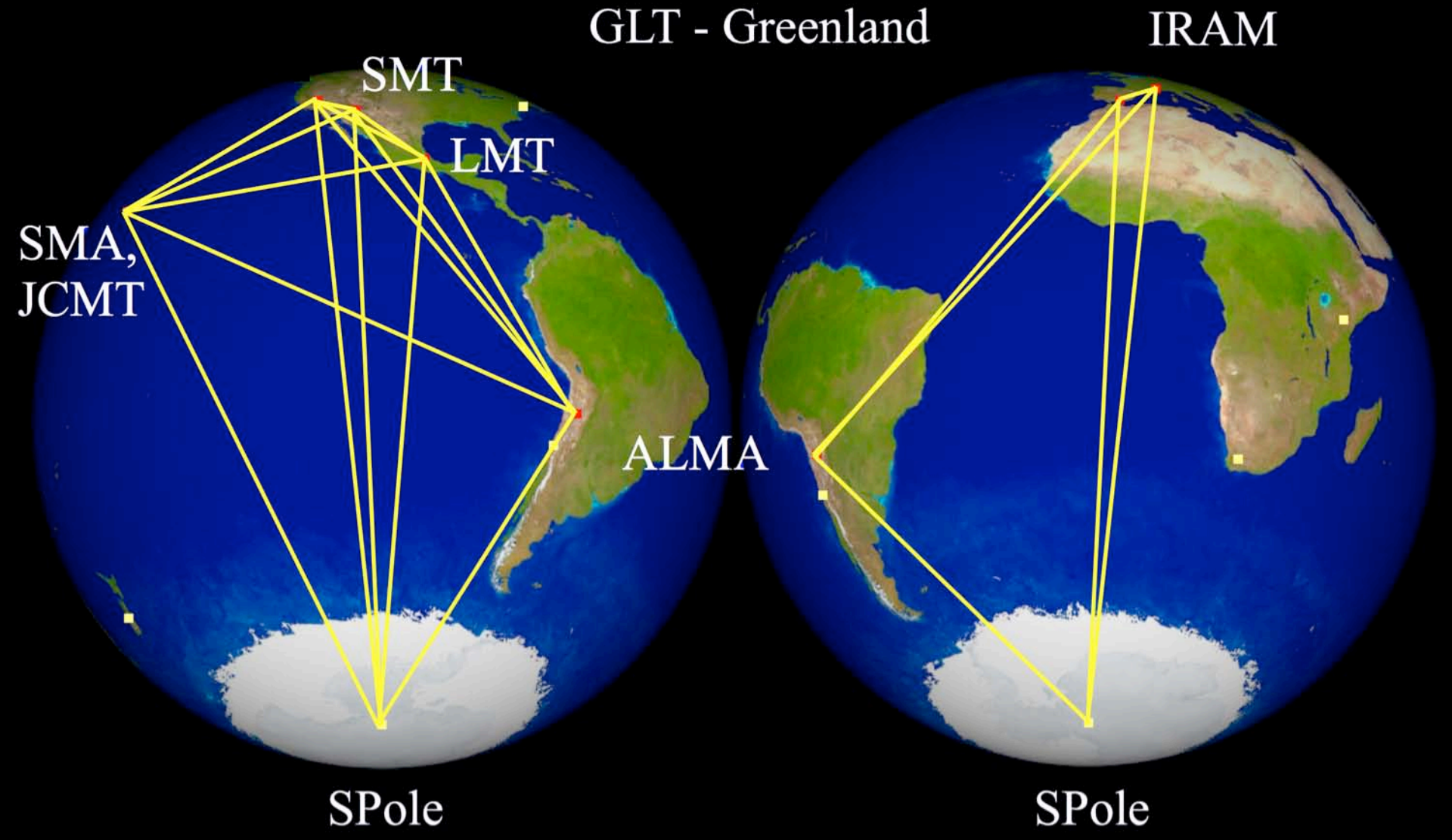
- 10-100 μas IR astrometry (Eisenhauer+2017)
- GR effects in stellar orbits, Sgr A* flares



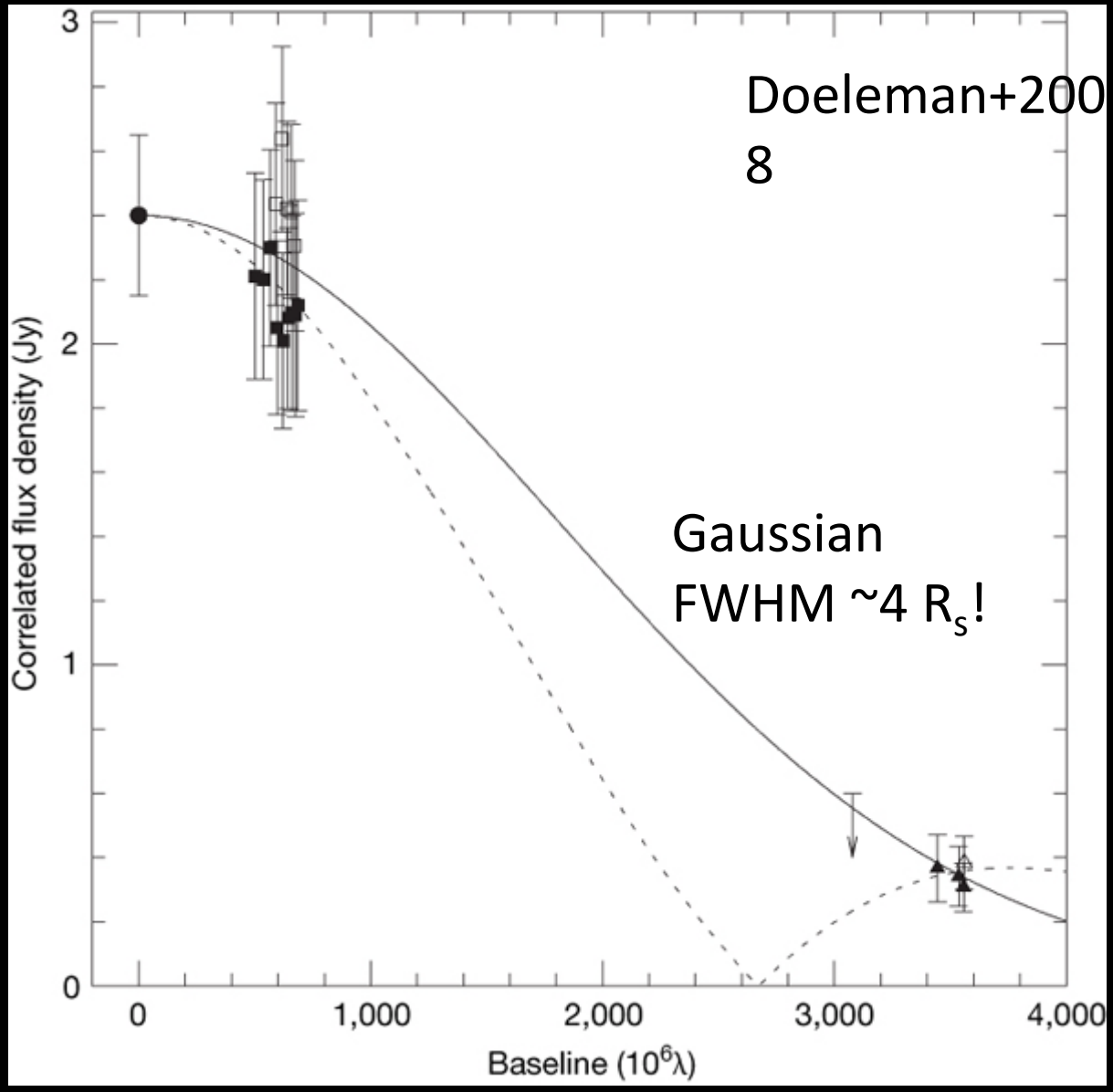
Event Horizon Telescope 2007



Event Horizon Telescope 2017



Event horizon scale emission

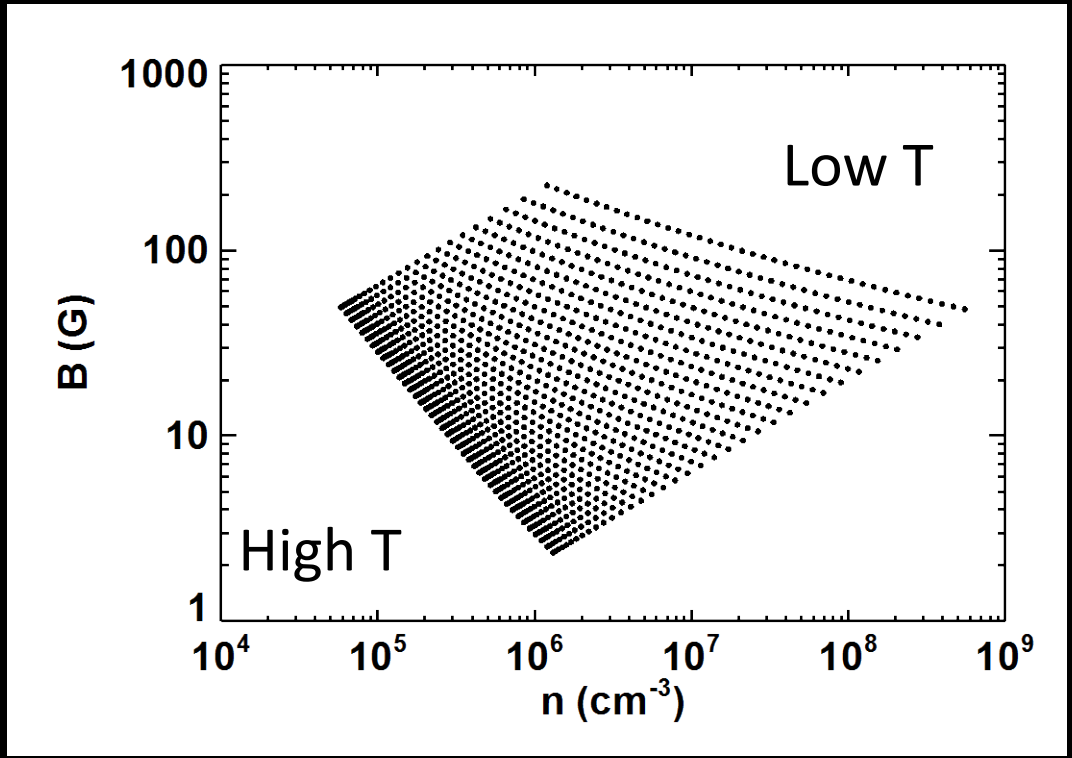


Sgr A* submm plasma parameters

- Know F_ν, θ, D, M

$$T_b = \frac{c^2 I_\nu}{2k\nu^2} \simeq 6 \times 10^{10} \mathrm{K}$$

cf. $T_i \approx T_{vir} \approx 10^{12}$ K



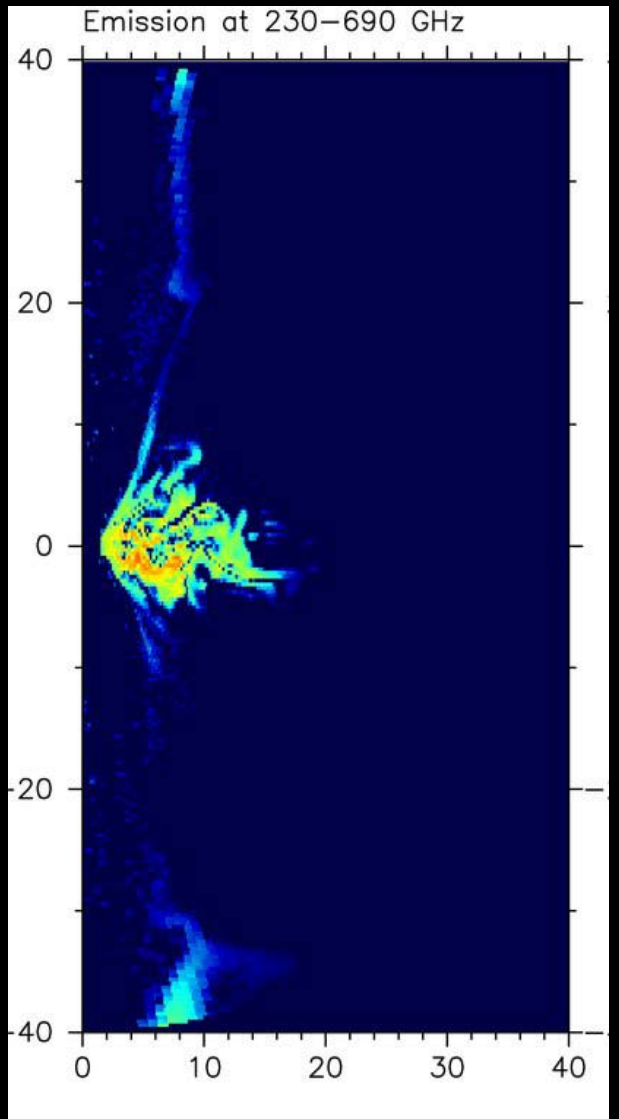
- One zone model (n,B,T,R): solutions for $T > T_b$, β

GRMHD models of Sgr A*

- Self-consistent accretion, field geometry, variability
- Cooling is negligible (Moscibrodzka+2011, Dibi+2012, Drappeau+2013)

- Not perfect…
  - collisionless plasma
  - electron models: assume constant T_p/T_e

Moscibrodzka+2009



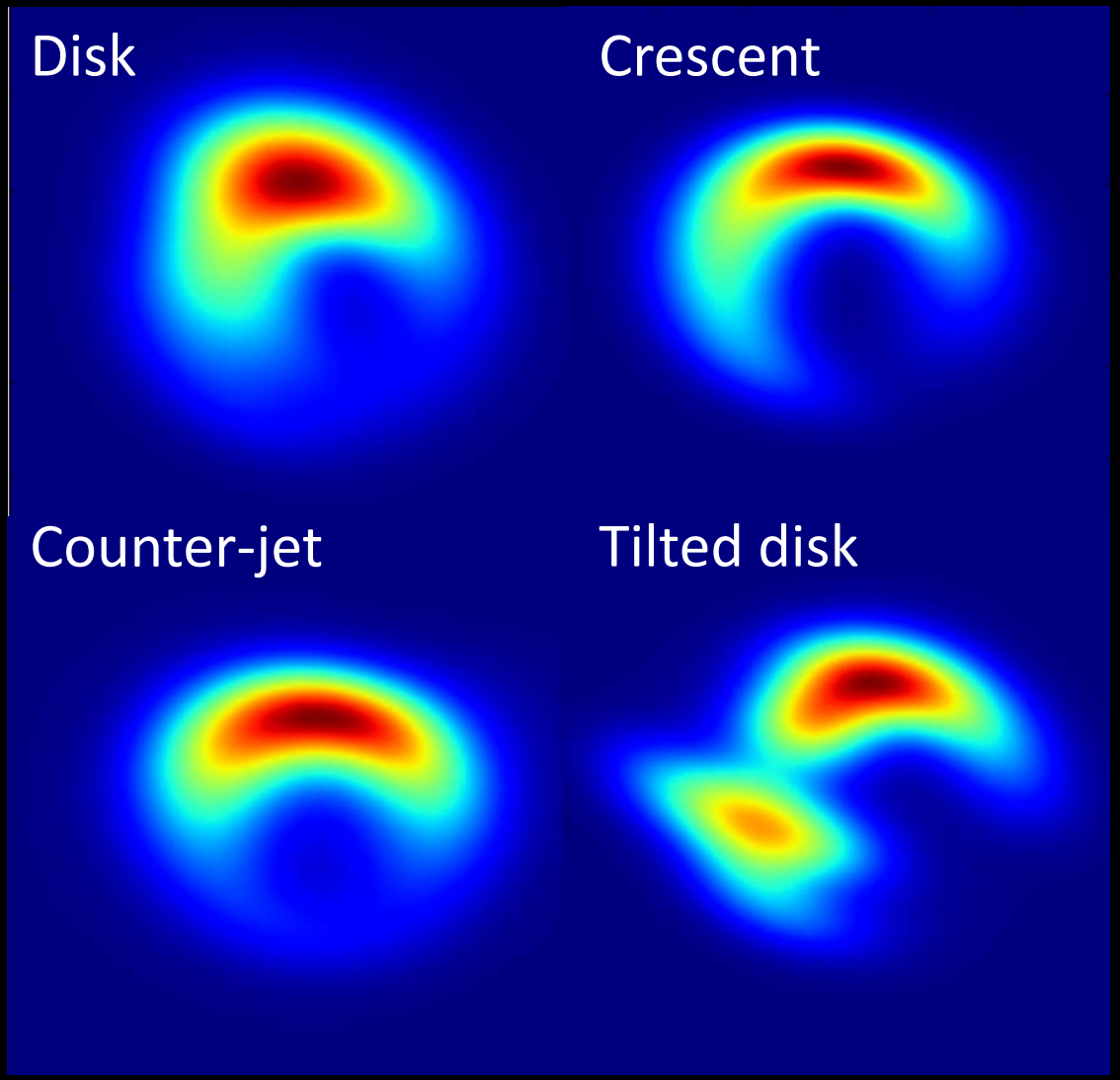
Sgr A* Disk Images

Dexter et al. (ord (2009)

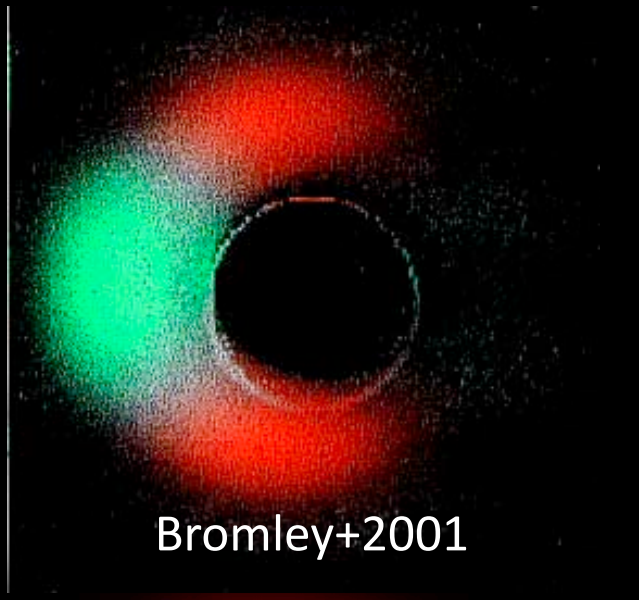
Crescent images

- Wide range of viable models: crescent images
- Rel. effects dominate if emission radius is small

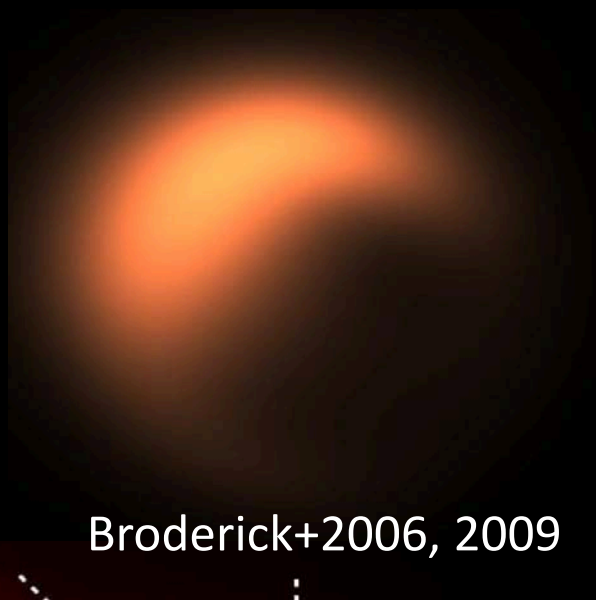
Dexter+2010, 2012, 2013; Kamruddin & Dexter 2013



Crescent Images

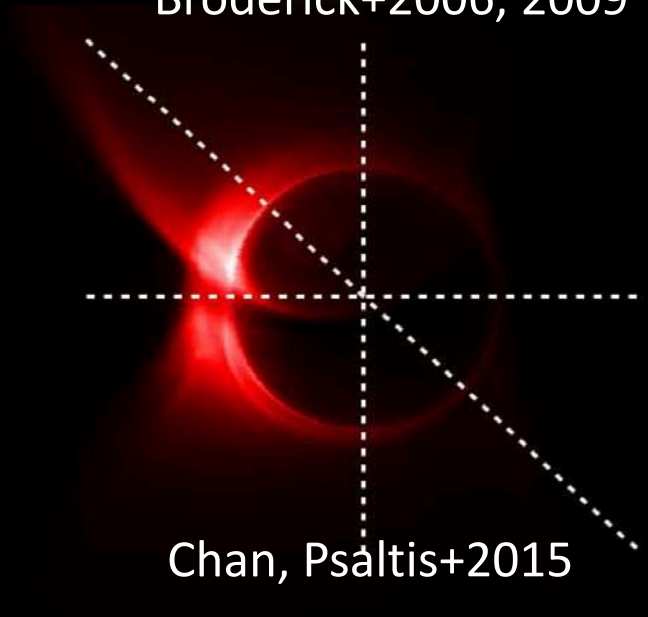


Bromley+2001



Broderick+2006, 2009

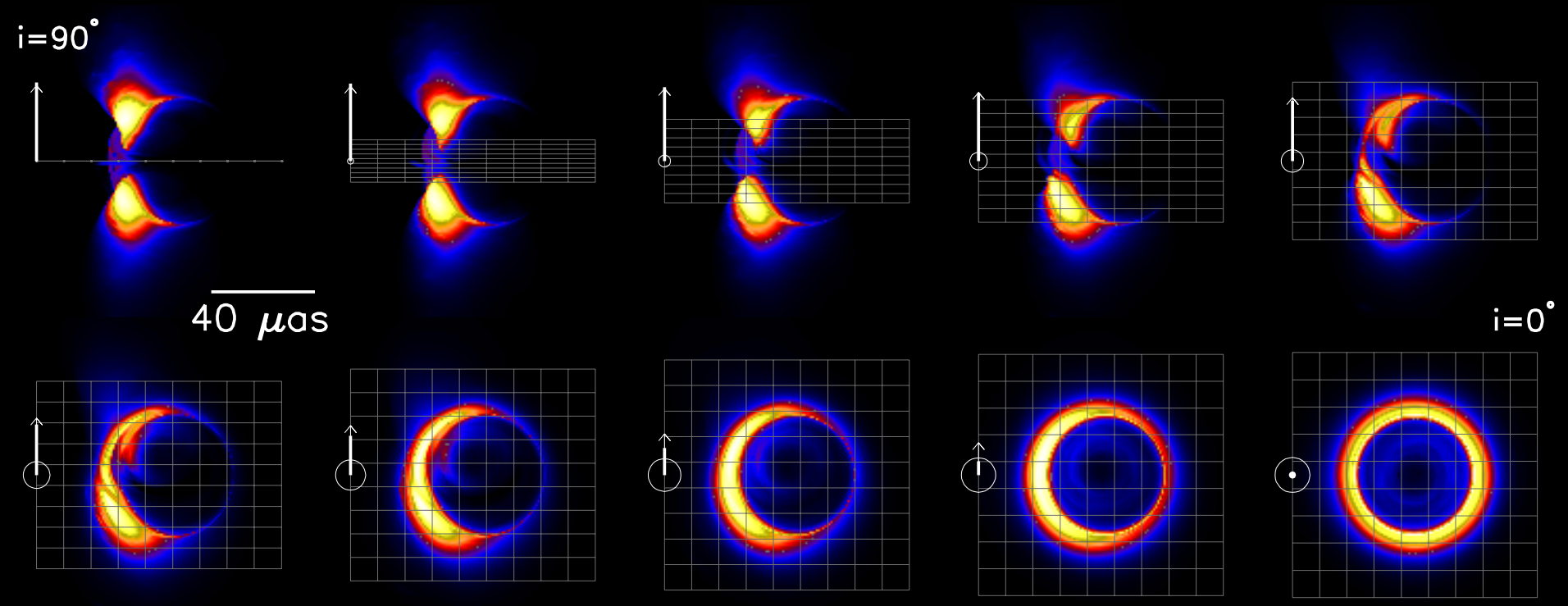
Moscibrodzka+2014



Chan, Psaltis+2015

Crescent images from counter-jets

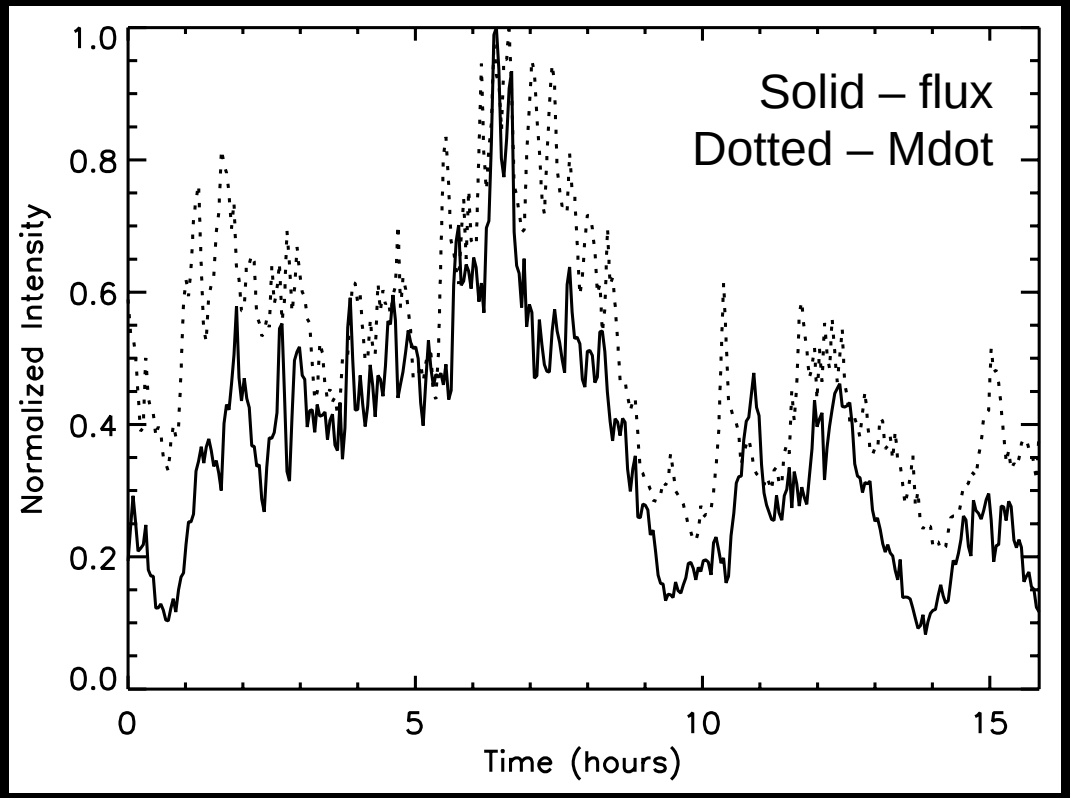
- Low inclination (e.g. M87): light bending hides forward jet and lenses counter-jet



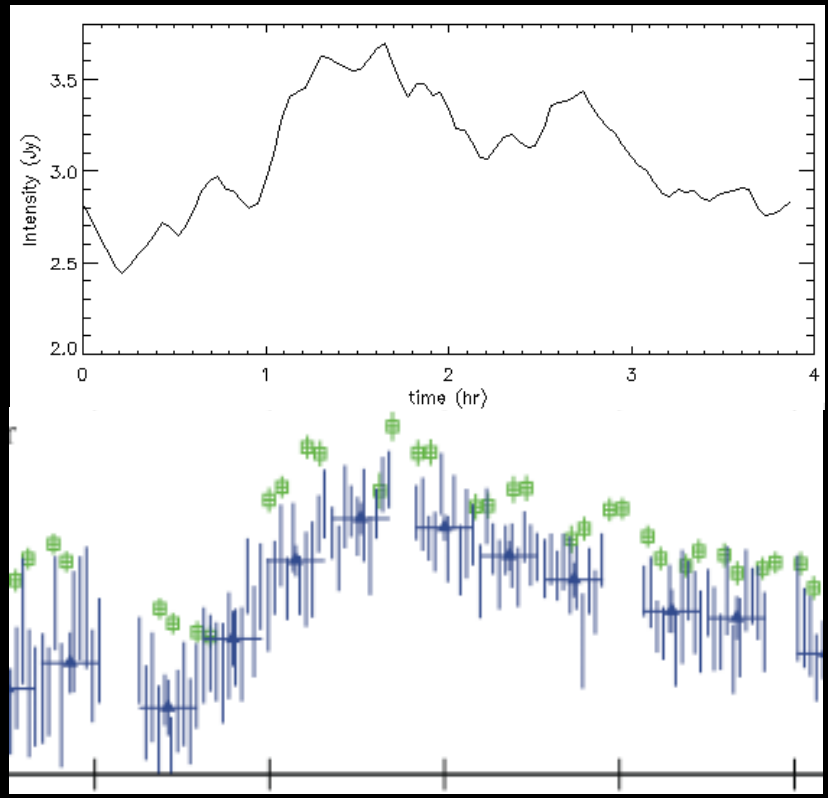
Dexter+2012

Sgr A* variability from the MRI

- submm light curve correlated with accretion rate, from MRI fluctuations in n, B



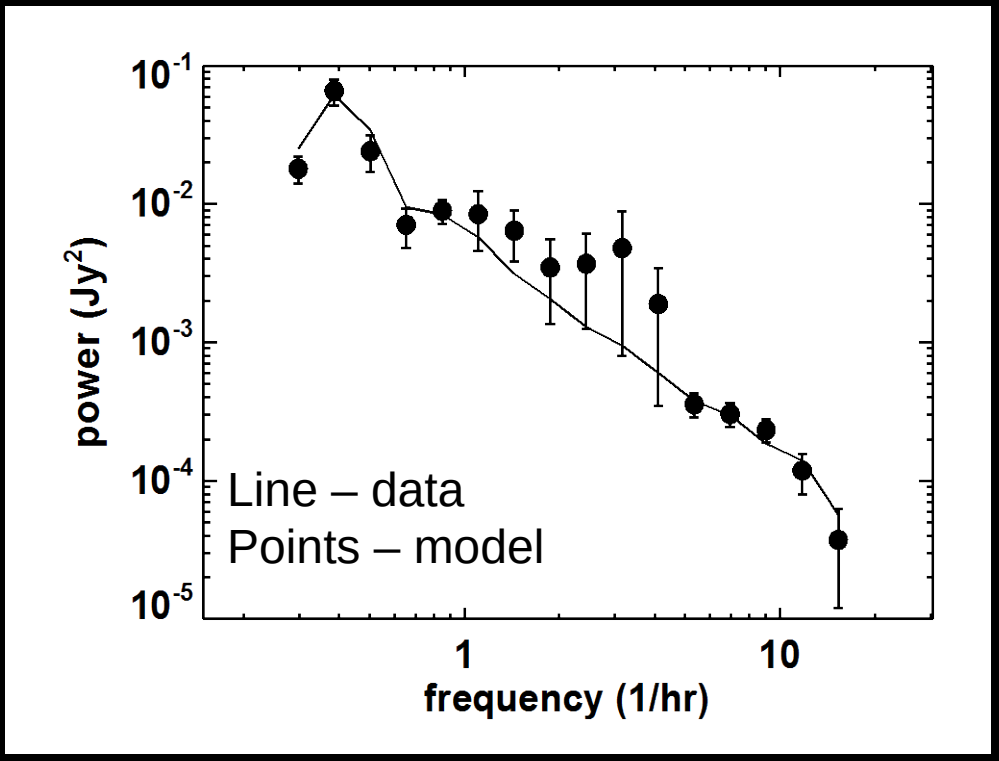
Dexter+2010

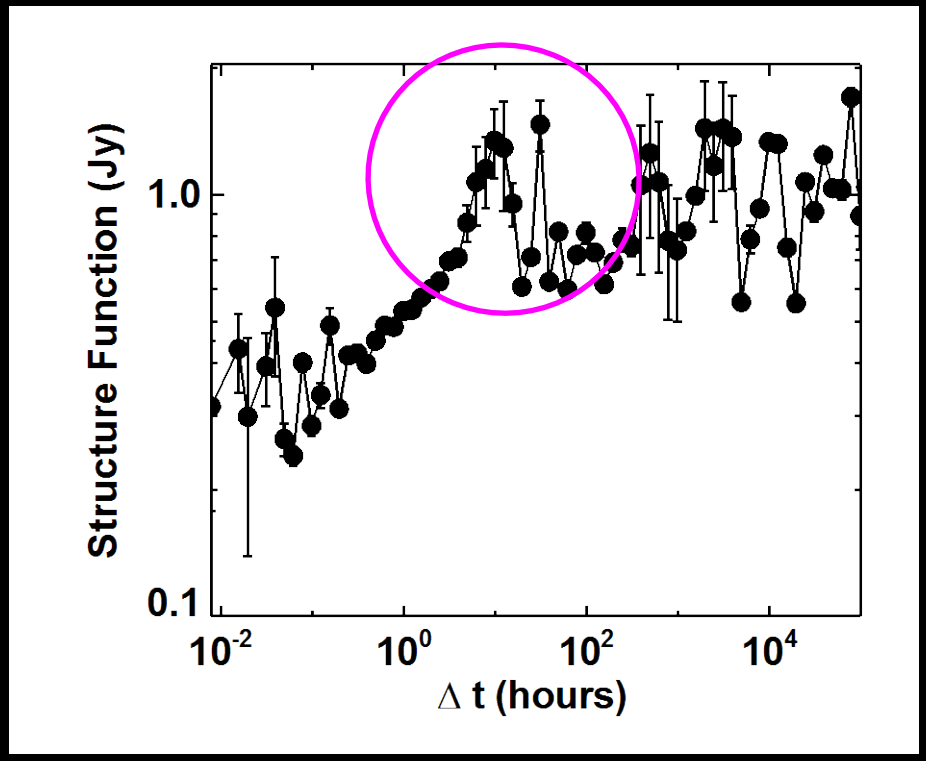


Marrone+2008

Quantitative comparisons

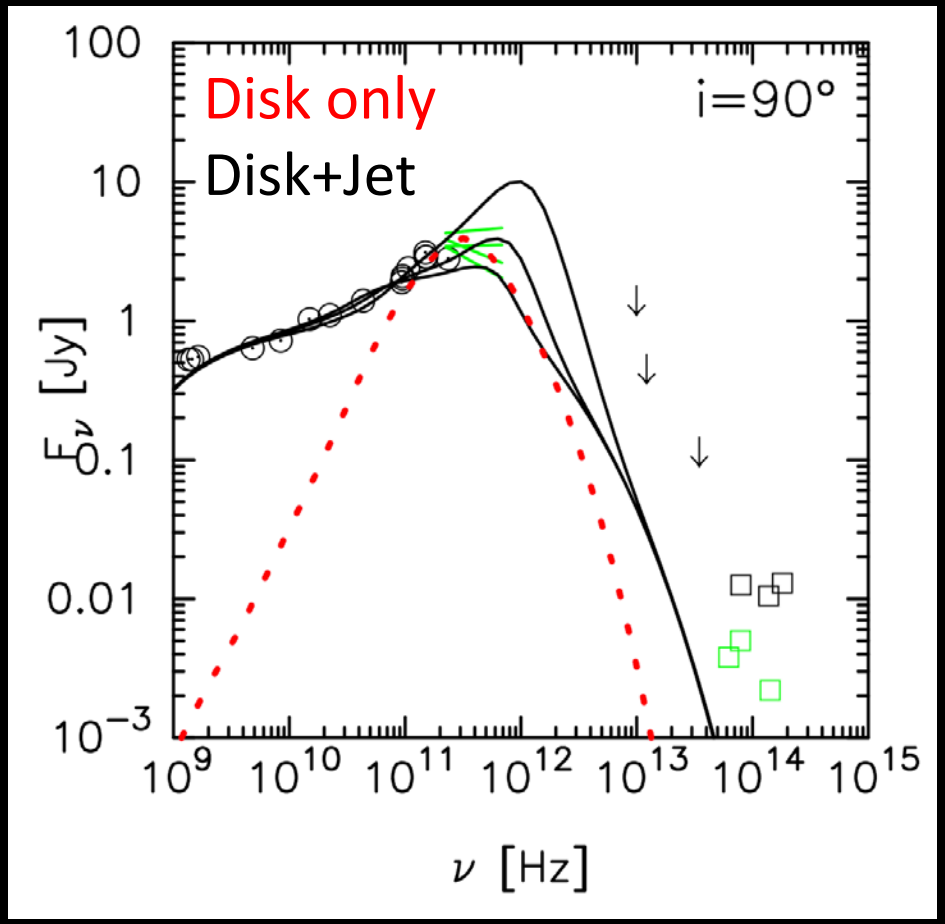
- Power law index 2.3+/-0.3 (Stone+2016)
- Relaxation time ~8 hours (Dexter+2014)



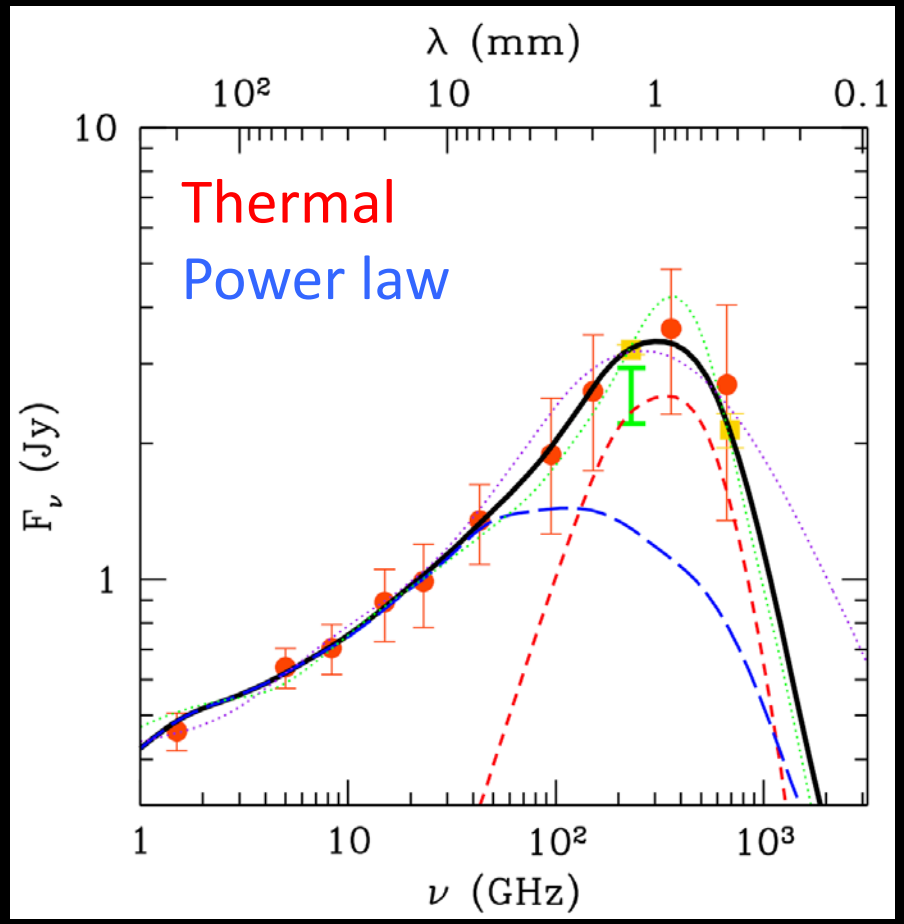


Radio: jet or non-thermal e-

Moscibrodzka & Falcke 2013

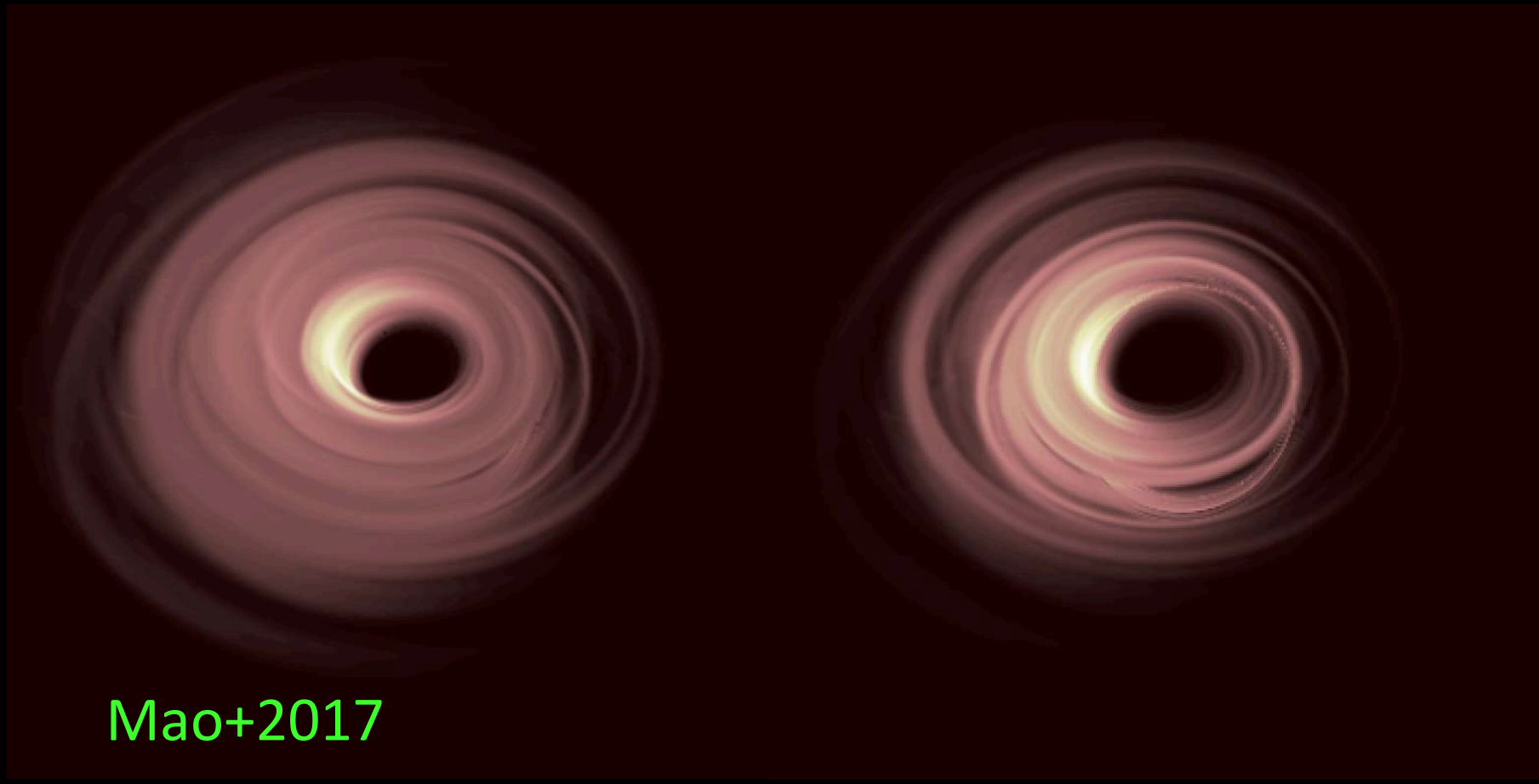


Broderick+2011



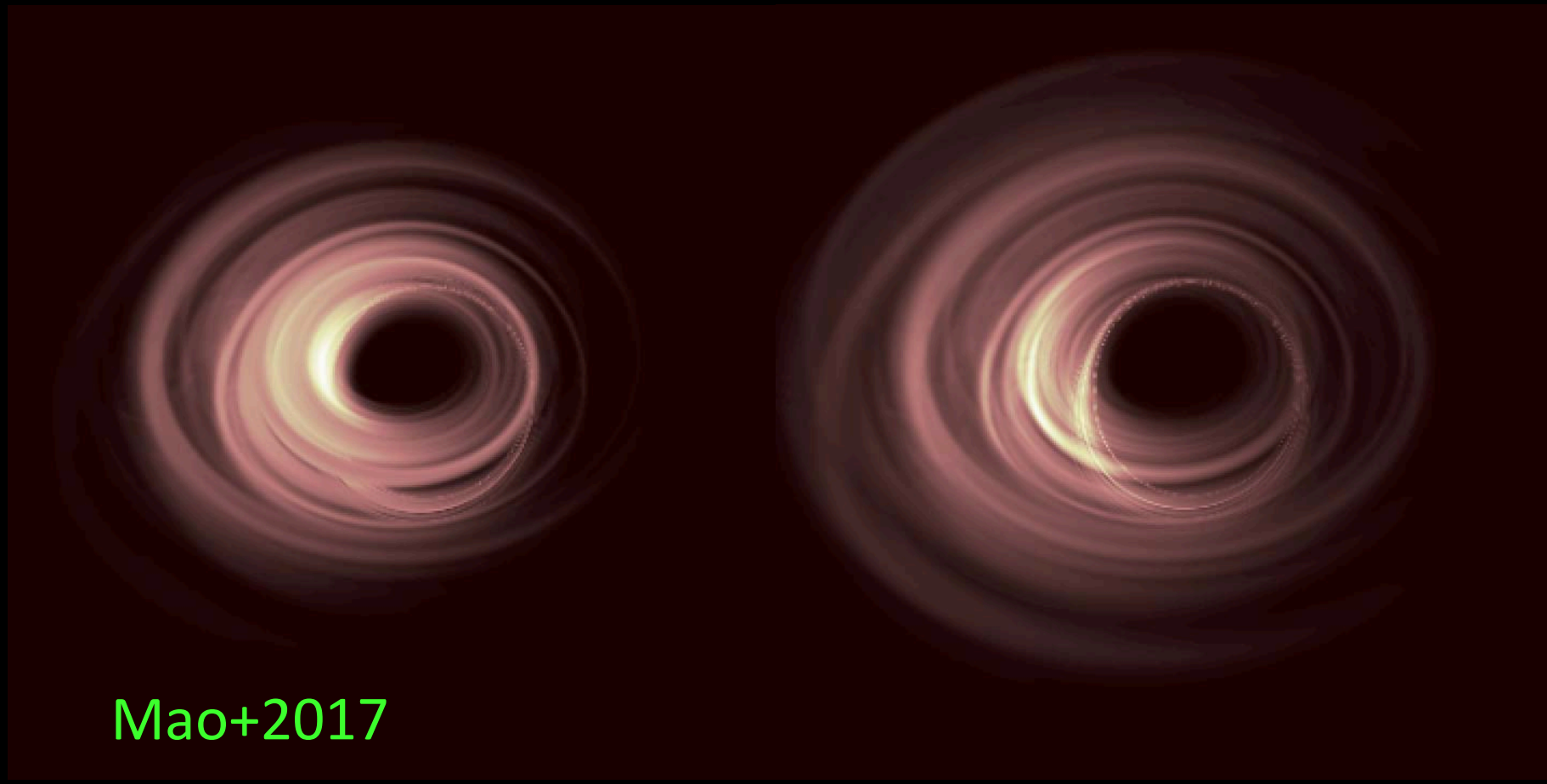
Minimum image size when $T \sim T_b$

- Opt. depth lower at higher T, size decreases



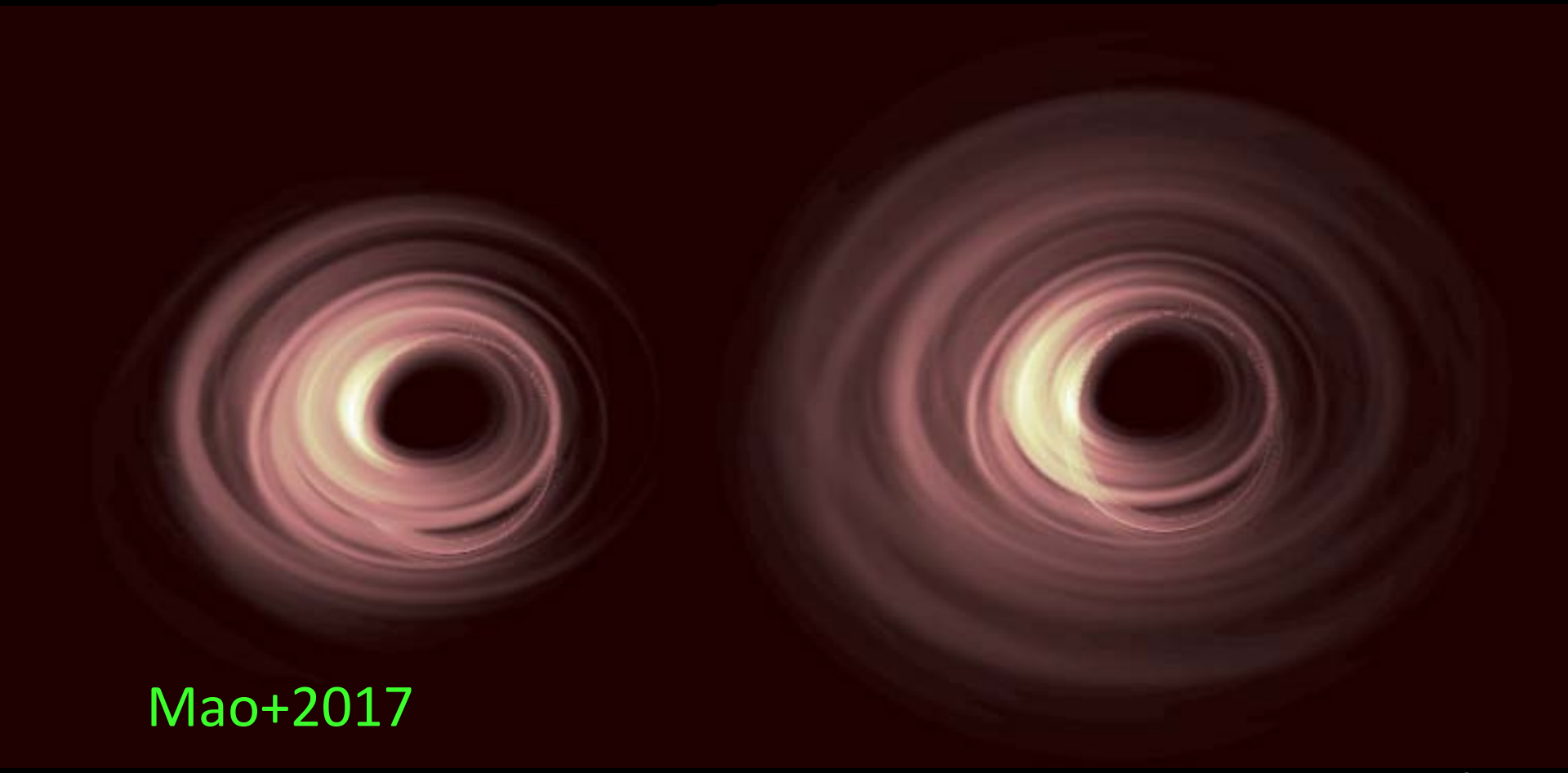
Minimum image size when $T \sim T_b$

- Opt. thin, emission out to ~ $r(v=v_c)$



Extended “halo” from high energy e-

Thermal + Power law

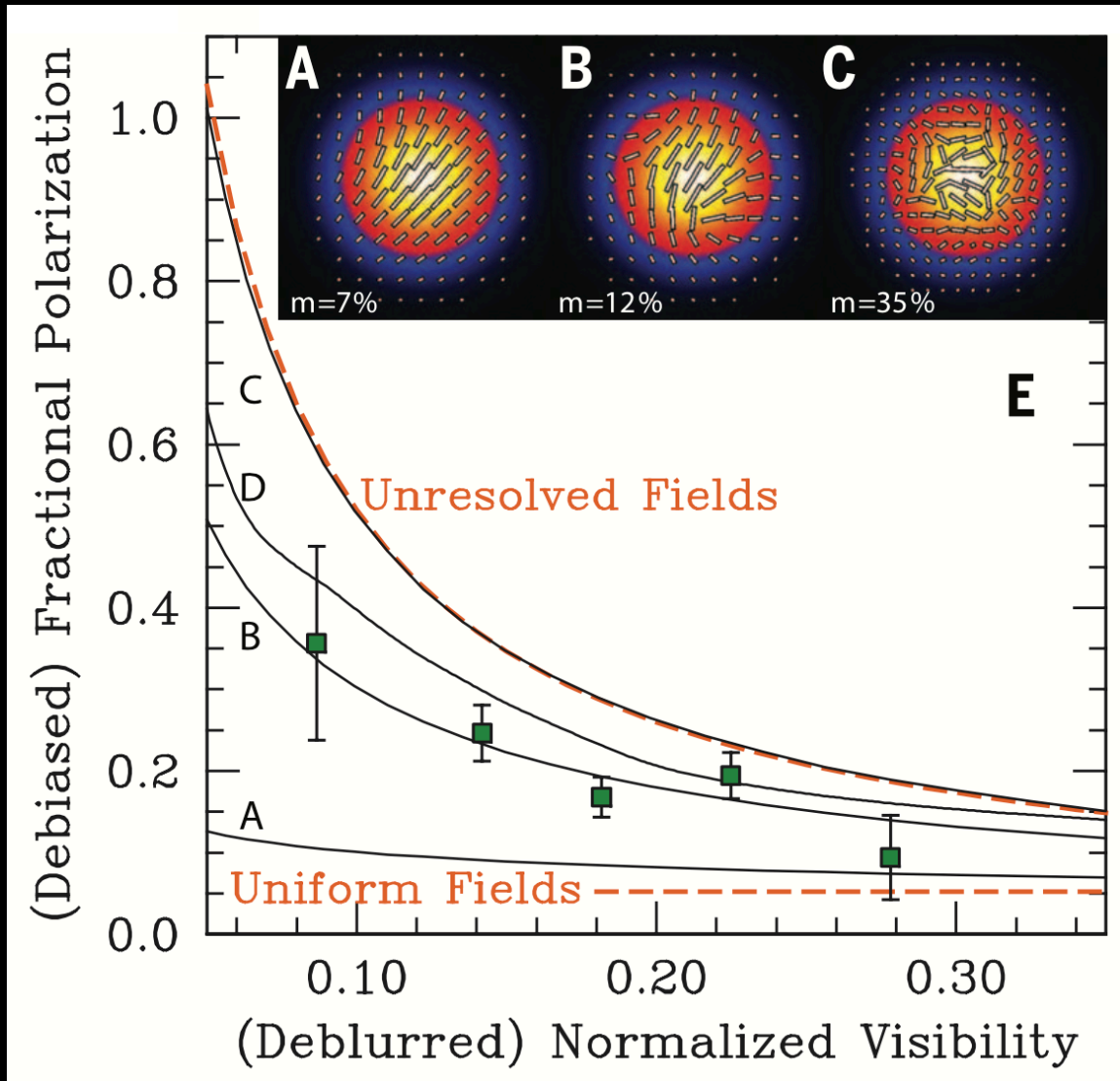


Mao+2017

EHT Sgr A* polarization

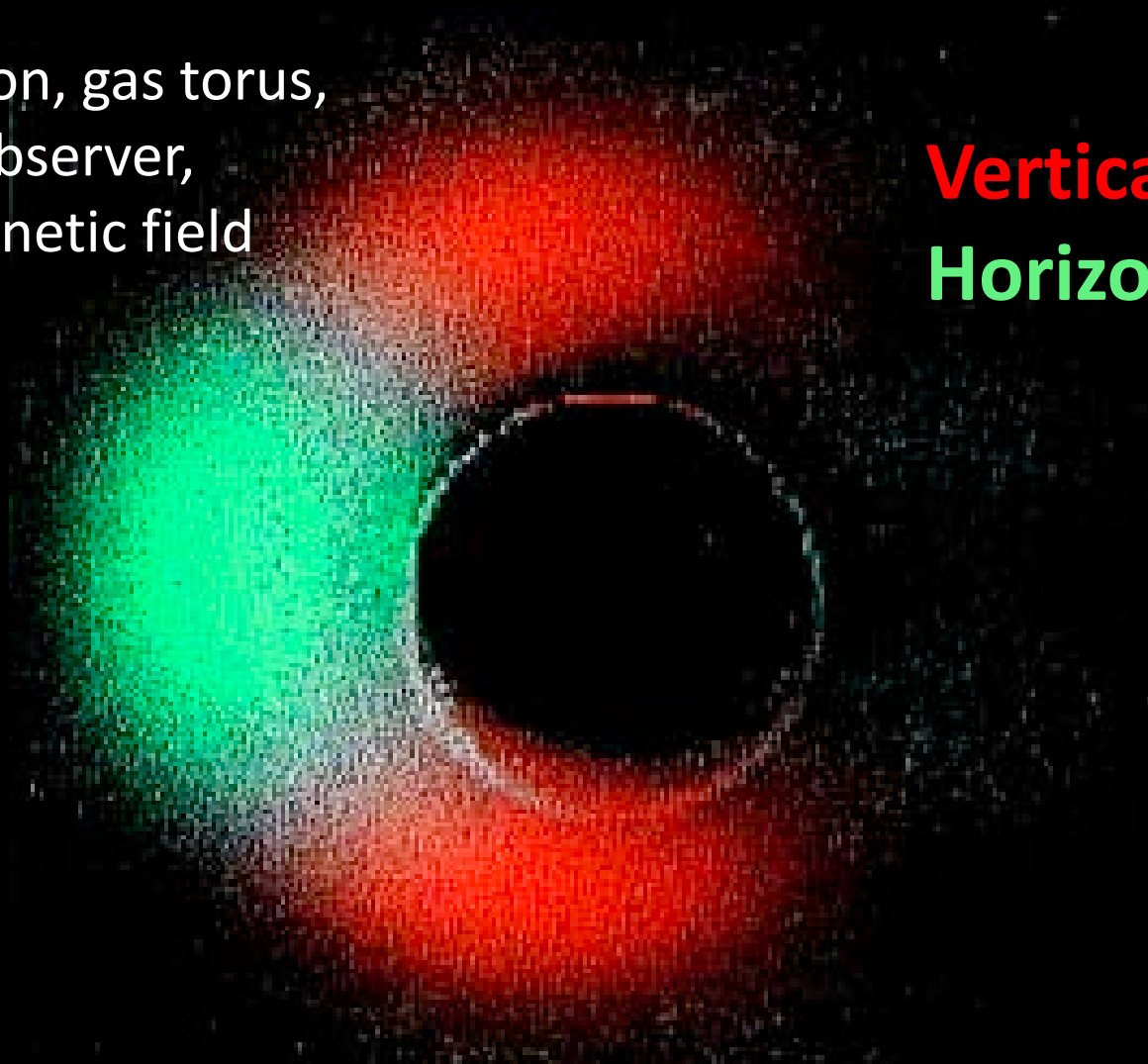
Johnson+2015

- Coherent polarization on ~few R_S scales
- Not tangled, not uniform



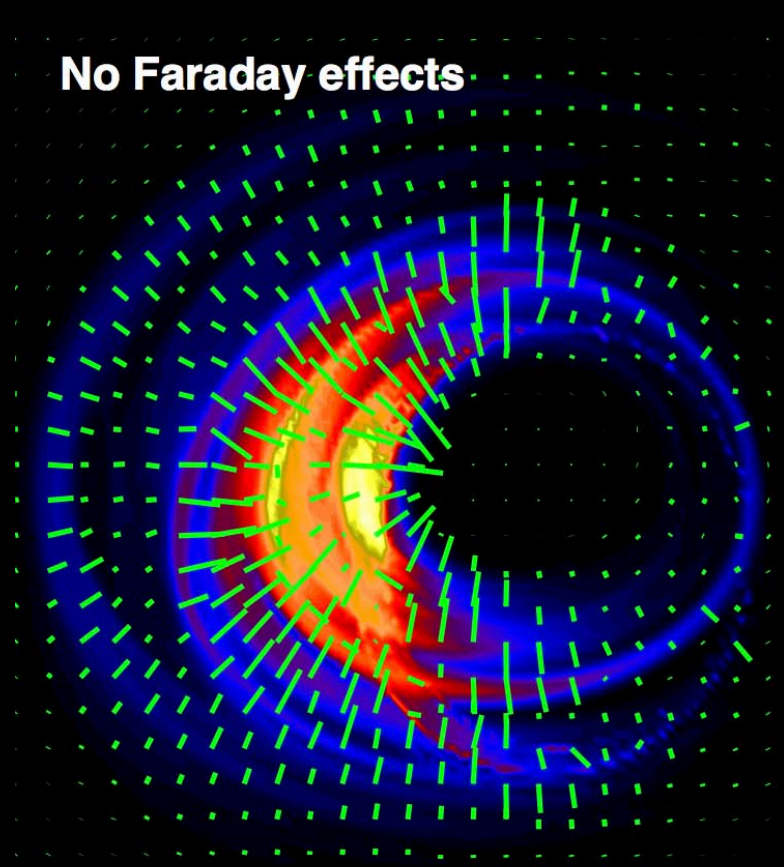
Polarized black hole images

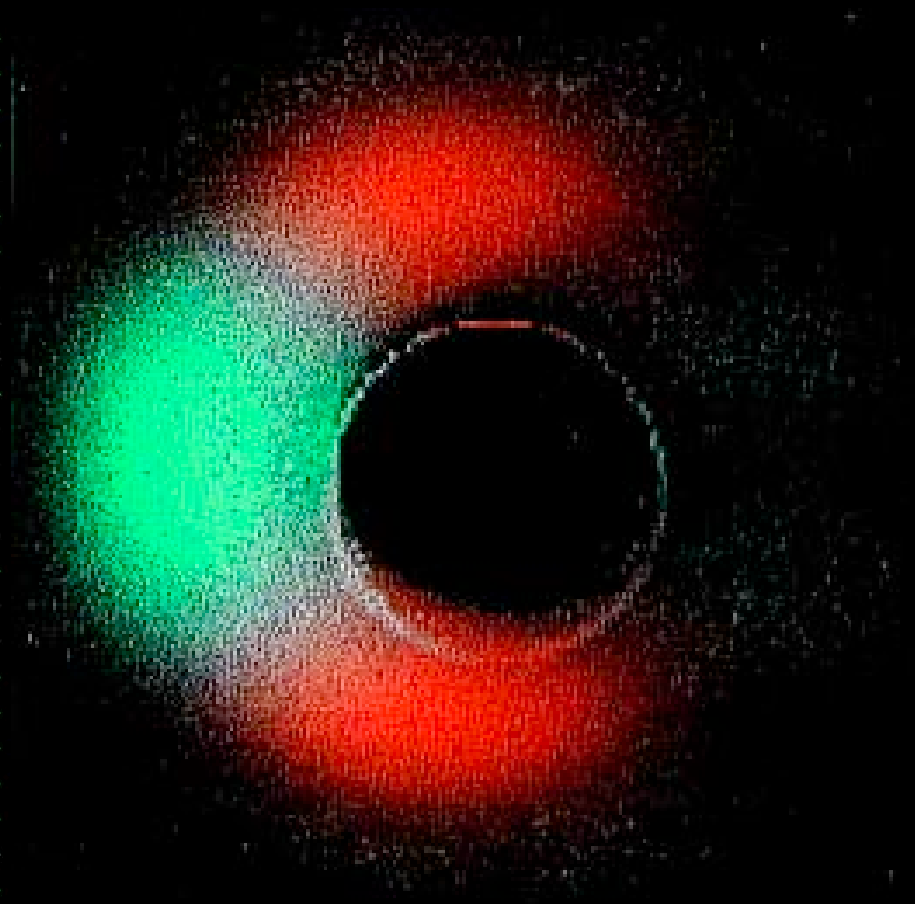
Orbital motion, gas torus,
inclined to observer,
toroidal magnetic field



Bromley, Melia & Liu (2001)

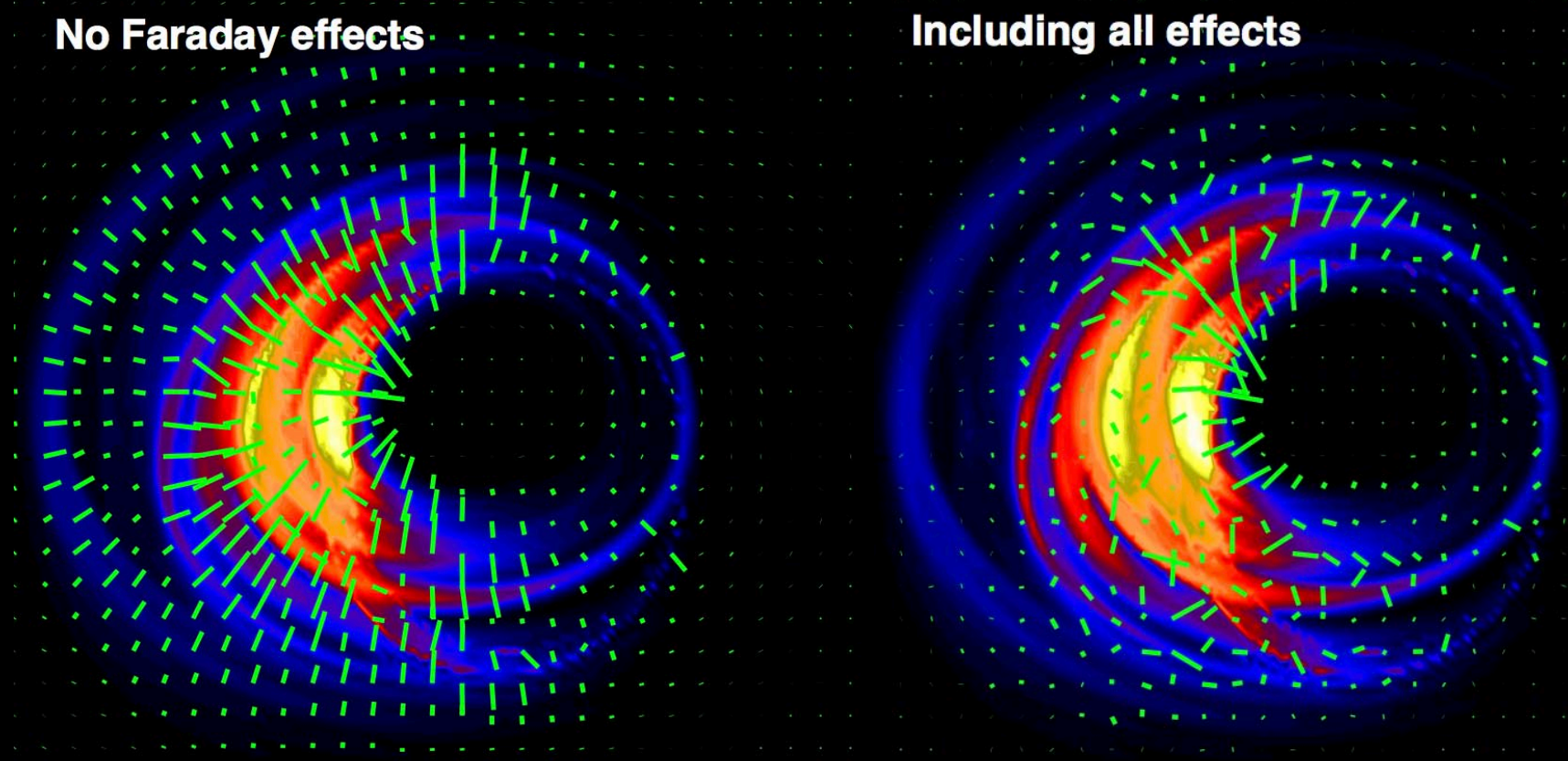
Field in GRMHD is not tangled





Internal Faraday effects can be strong

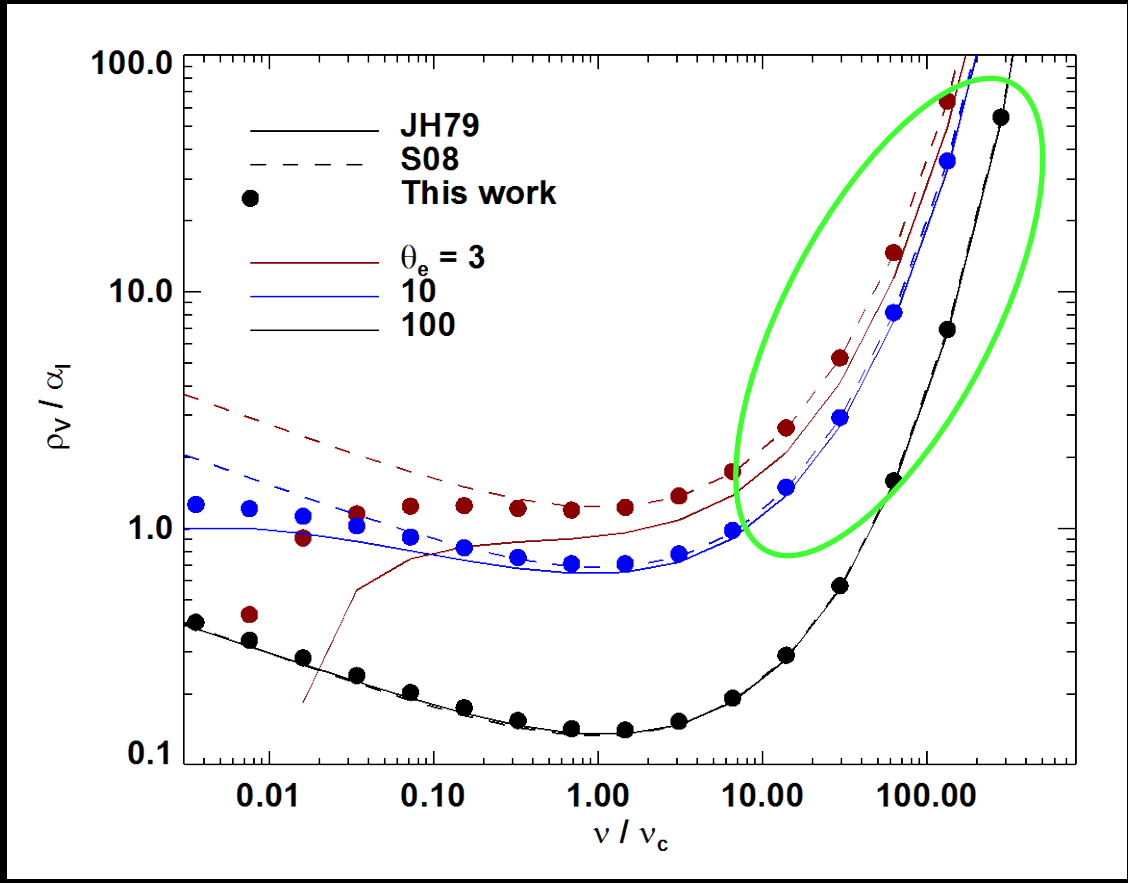
Dexter 2016



cf. Shcherbakov+2012, Gold+2016

Internal Faraday effects can be strong

- Sgr A* models:
  $\nu/\nu_c \sim 40$
  $(B / 30\ G)^{-1}$
  $(\theta_e / 10)^{-2}$
- $\tau \sim 1$, $\tau_{FR} \sim 1\text{-}100$!
- Larger for smaller B^2/n, θ_e

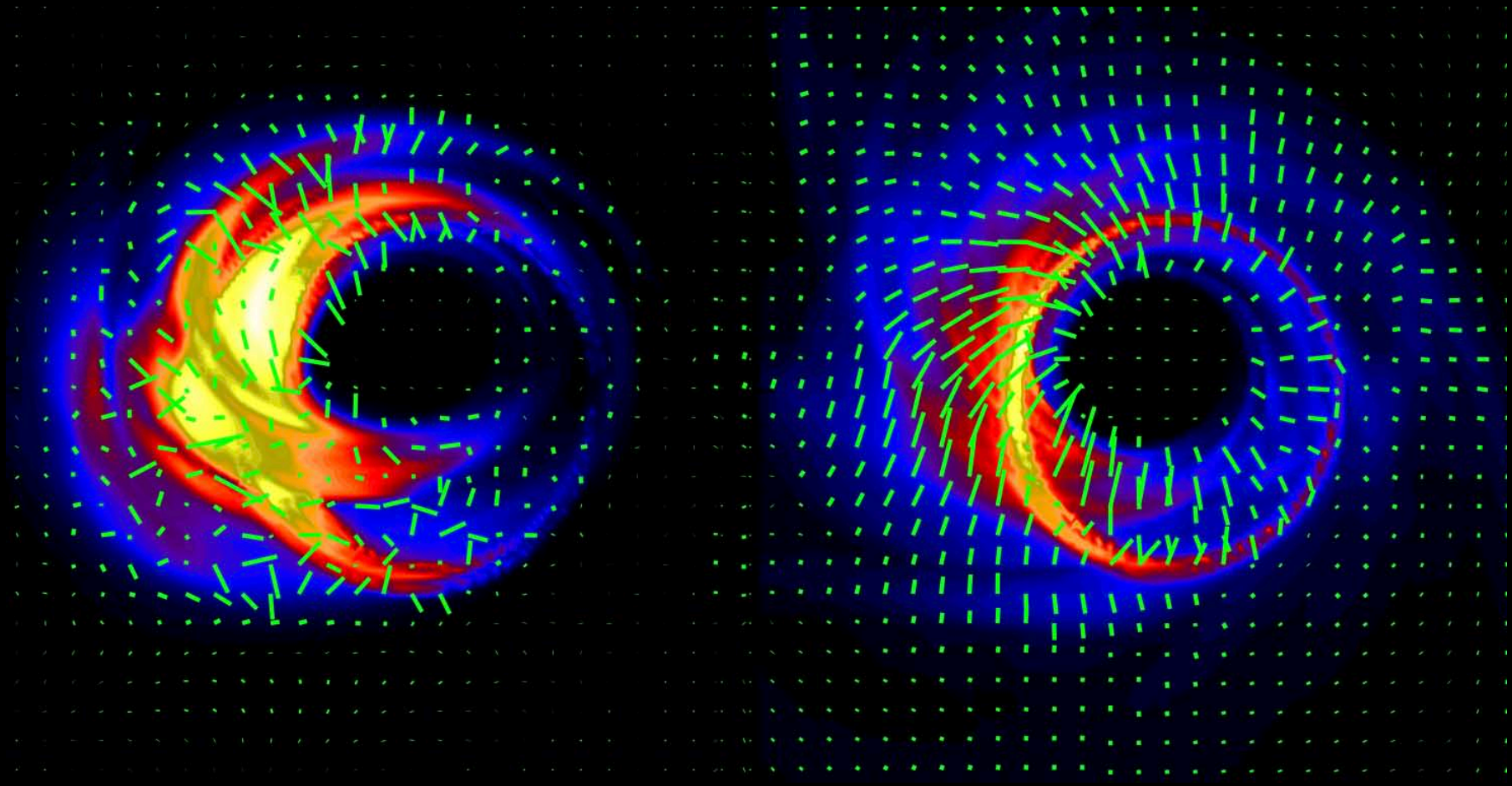


Dexter 2016, Jones & Hardee 1979, Shcherbakov 2008

Strength depends on model

Weak field, thinner disk

Strong field, thicker disk



FR scrambles pol

Weak FR, coherent pol

pol. constrains plasma parameters

A. Jimenez Rosales

Coherence limited by B direction

Johnson+2015

Scrambled by Faraday rotation

Summary

- Can now resolve event horizon scales (EHT and GRAVITY)
- First prediction for EHT: crescent images
- Link MHD with observables
  - MRI can explain Sgr A* submm var
  - extended “haloes” from high energy e-
  - pol. constraints on plasma properties