Feeding and accretion in low luminosity AGNs

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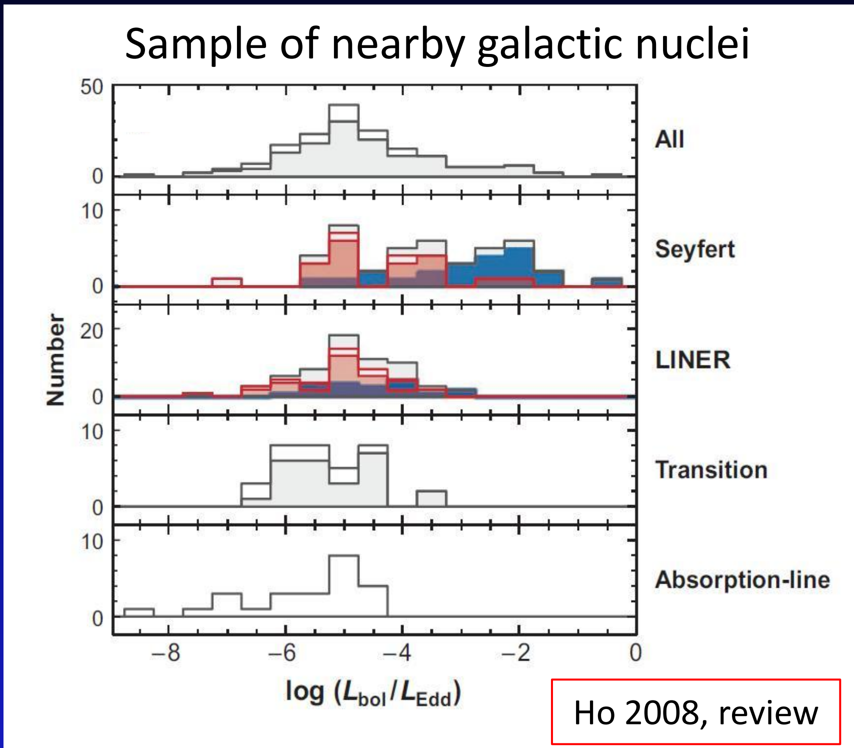
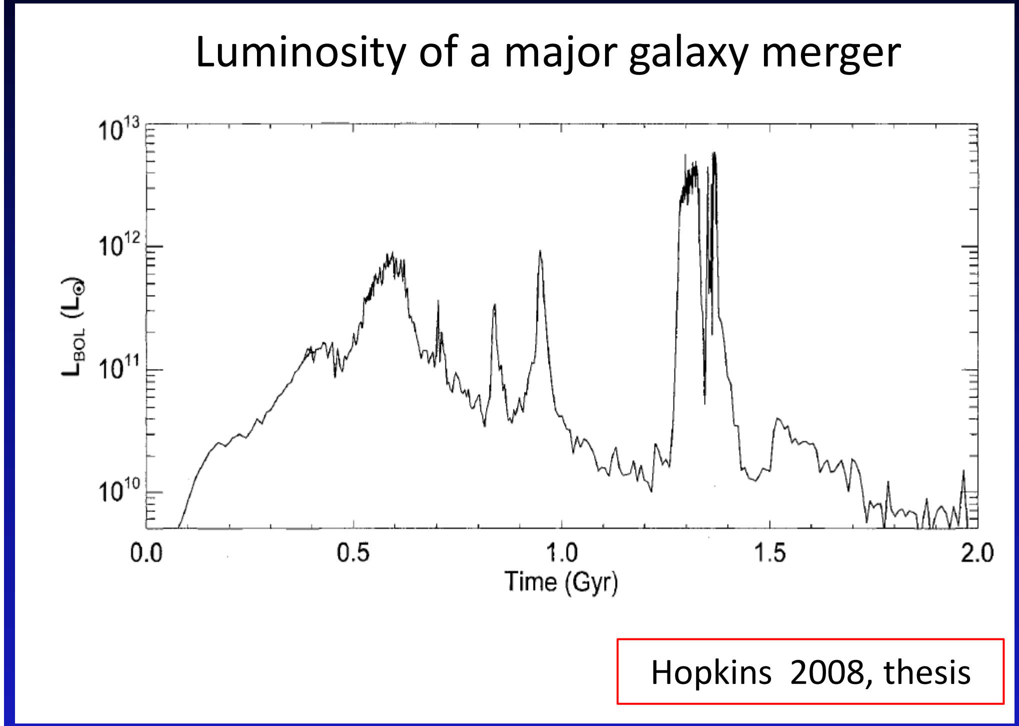
Typical AGN is not active





L_{bol} – total luminosity

L_{Edd} – Eddington luminosity
(theoretical maximum AGN luminosity)

An AGN shines at Eddington luminosity
for only a short time
(mergers don't happen all the time)

Typical AGN has
$L_{bol}/L_{edd} \sim 10^{-5}$

lower L_{bol} objects may still be missed ← Sgr A* has $L_{bol}/L_{edd} \sim 10^{-8}$

Galactic Center Black Hole Sgr A*

Closest to us – easier to study

Keck-UCLA GC group

Monitoring of stellar orbits
=> black hole inside

Ghez et al. 2008; Gillessen et al. 2009

$M = 4.3 \cdot 10^6 M_{sun}$ $d = 8.3 kpc$

Dramatically underluminous

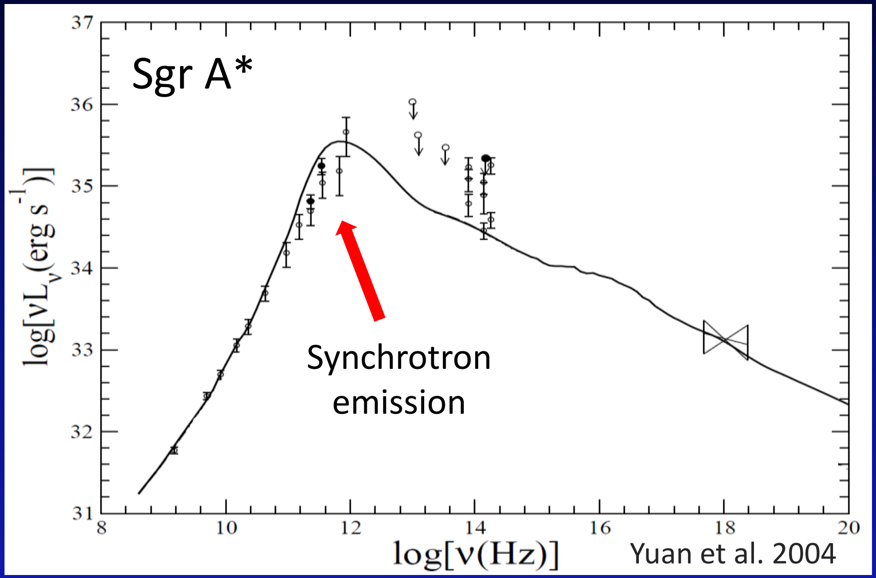
$L < 10^{-8} L_{Edd}$

Narayan et al. 1998

vs

Sub-mm flux from near the BH

Current quiescent SED



Electron T_e and magnetic field B increase steeply towards the BH

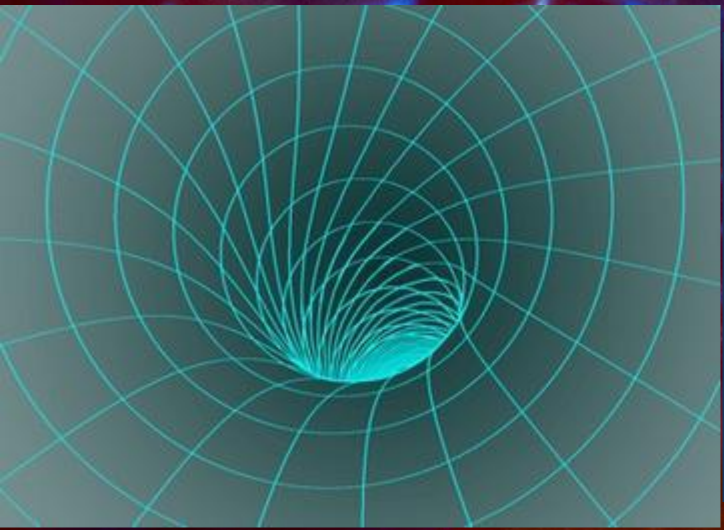
Synchrotron emissivity and peak ν rise closer to the BH

The synchrotron peak is produced near the event horizon

Study radiatively inefficient accretion flows onto the BH

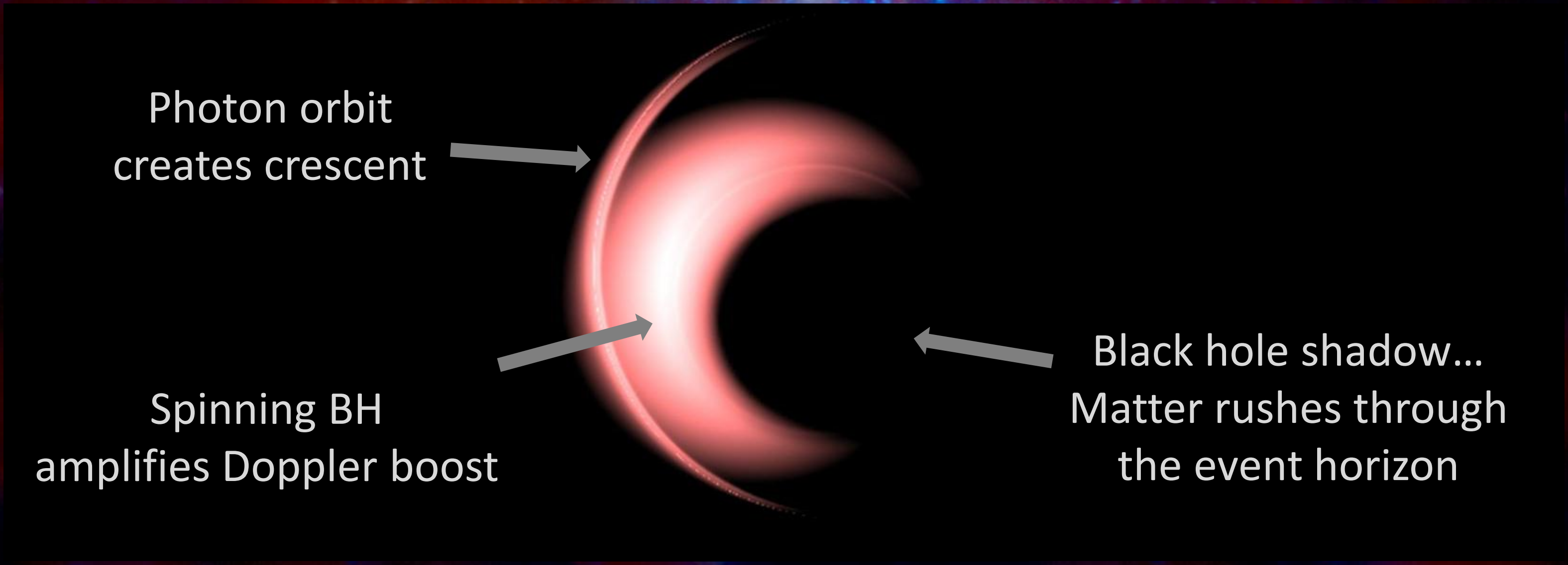
Can find BH spin a*,
Image flow near the BH

Spacetime distortions near the BH



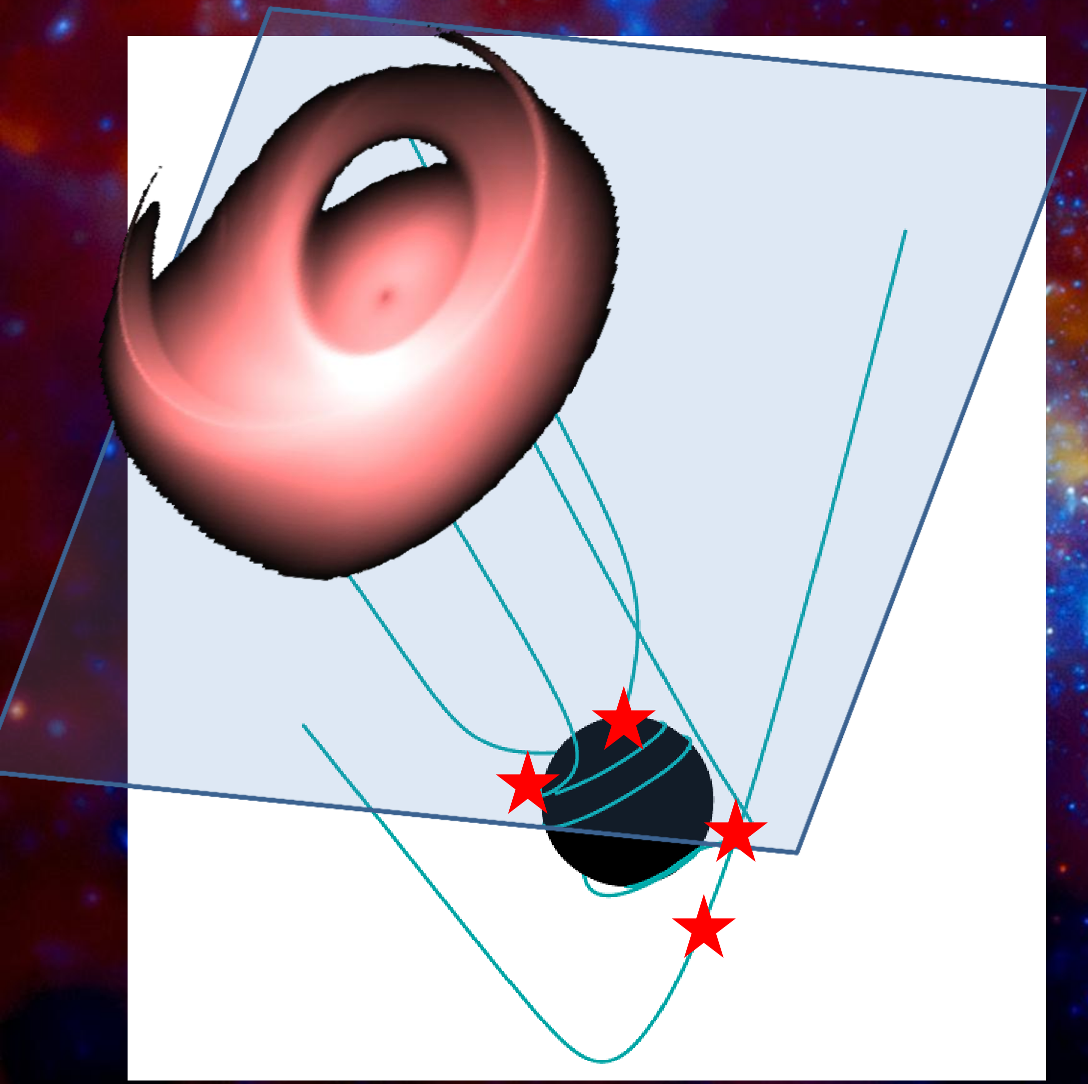
Black holes:

- ✓ Bend light rays (curved geodesics)
- ✓ Spin => extra Doppler boost
- ✓ Pull gas through the event horizon, so that it stops radiating out



GR polarized radiative transfer

Ray tracing



Procedure is outlined in

Shcherbakov, Huang 2010

Propagation effects of polarized radiation

Shcherbakov 2008

Implemented in C++, ran on a supercomputer

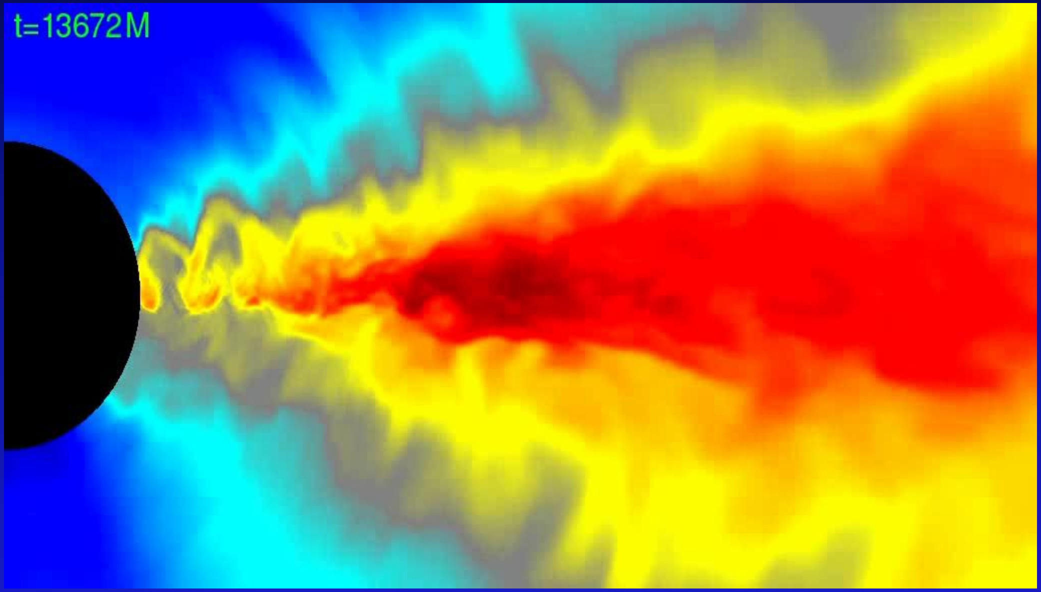
Code testing, application to Sgr A*

Shcherbakov et al. 2012

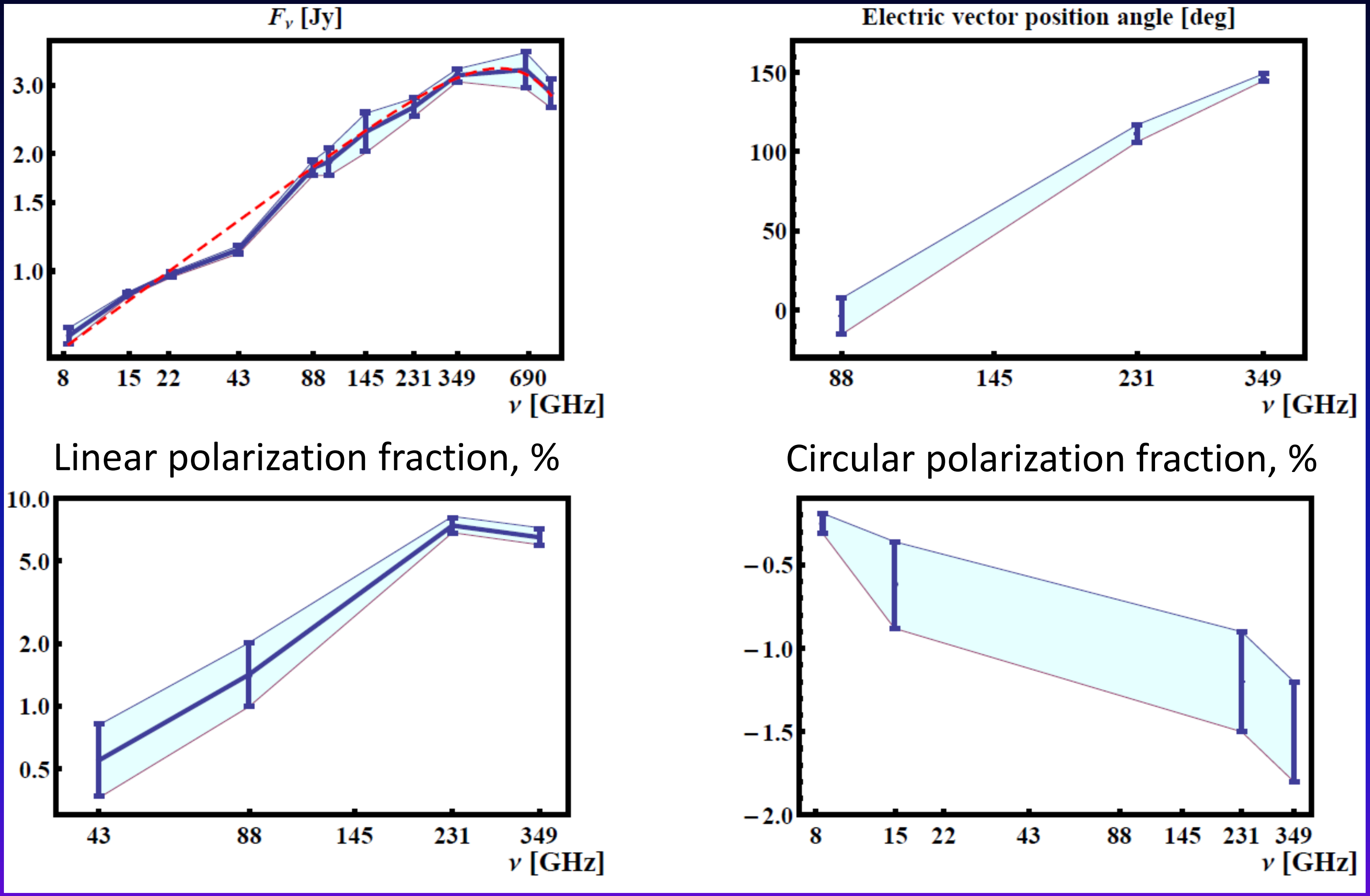
Modeling flow onto BH:
3D GRMHD simulations + thermal electrons

- Simulate BH accretion for a set of spins a*=0; 0.5; 0.7; 0.9; 0.98 without cooling
- Assume thermal electrons, (almost) constant ratio Tp/Te
- Perform fully self-consistent radiative transfer post-processing; find time-averaged spectrum
- Fit time-averaged observed spectrum
- Find best spin a*, inclination angle θ, ratio Tp/Te, accretion rate $\dot{M}$

similar to Penna et al. 2010



Mean polarized sub-mm spectrum



We fit: F_ν(87-857GHz) – 7 points; LP(87,230,349GHz); CP (230,349GHz)

Sgr A*: modeling results

1. No clear preference on spin value a* …
2. Spin inclination angle θ=55-70deg (closer to edge-on)
3. Electron temperature $Te=(3\text{-}4)\cdot 10^{10}$K near BH regardless of spin
4. Accretion rate
   from $7\cdot 10^{-8} M_{\odot}$ /yr for spin a*=0
   to $1.4\cdot 10^{-8} M_{\odot}$ /yr for spin a*=0.9

Accretion rate much below Bondi accretion rate ($10^{-3}\dot{M}_B$)!
Electrons are mildly relativistic

Problems with modeling

Numerical simulations:

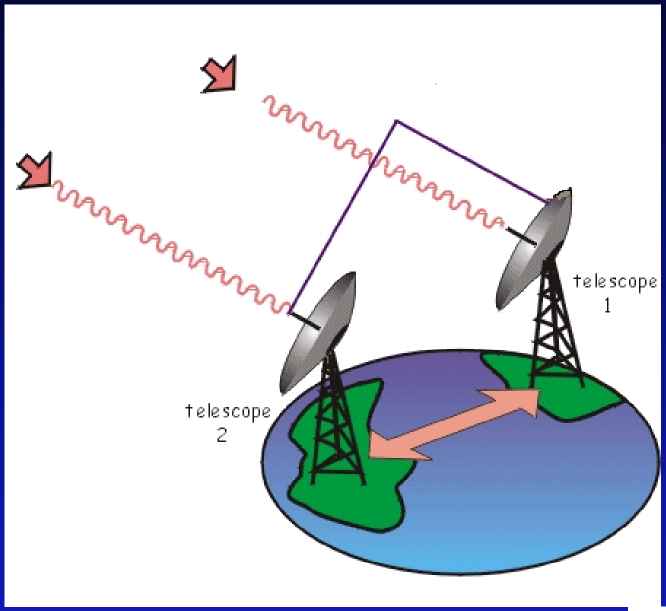
dependence on initial/boundary conditions;
outcome changes with resolution;
long-term time evolution not modeled.

Collisionless effects not treated:

heating/acceleration of electrons;
non-thermal distribution of e^-;
heat transfer/conduction.

Very Long Baseline Interferometry

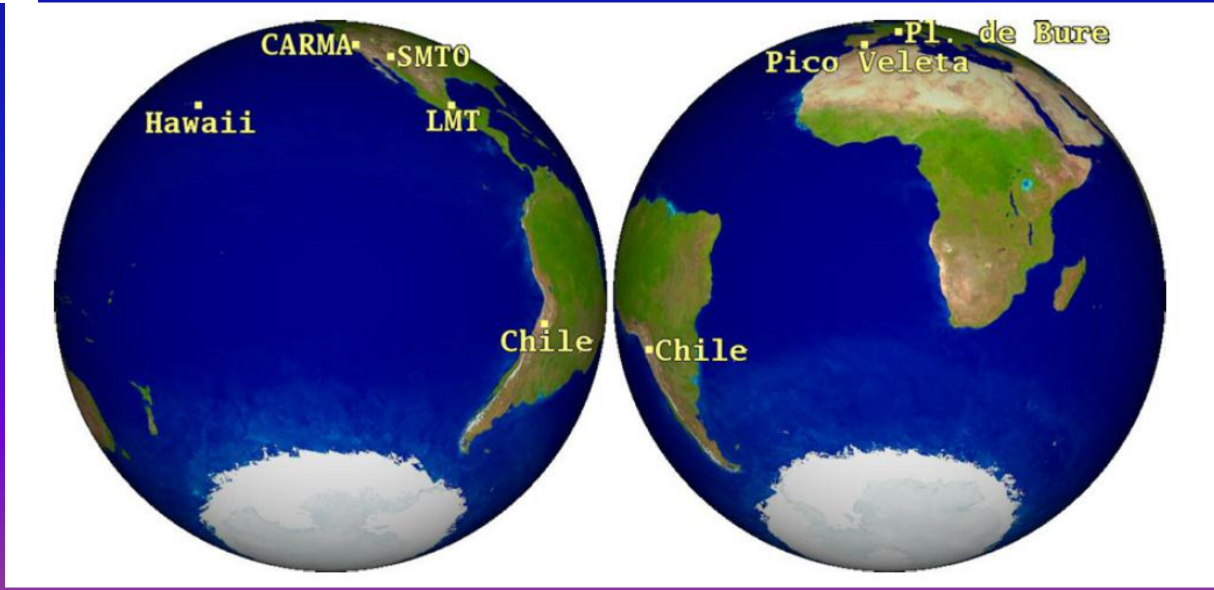
A pair of telescopes at different sites on Earth (or in space!)



VLBI

- ✓ Two telescopes 300-10.000km apart
- ✓ Observe separately, then data are correlated to find source size
- ✓ Usage of several telescopes allows us to reconstruct image

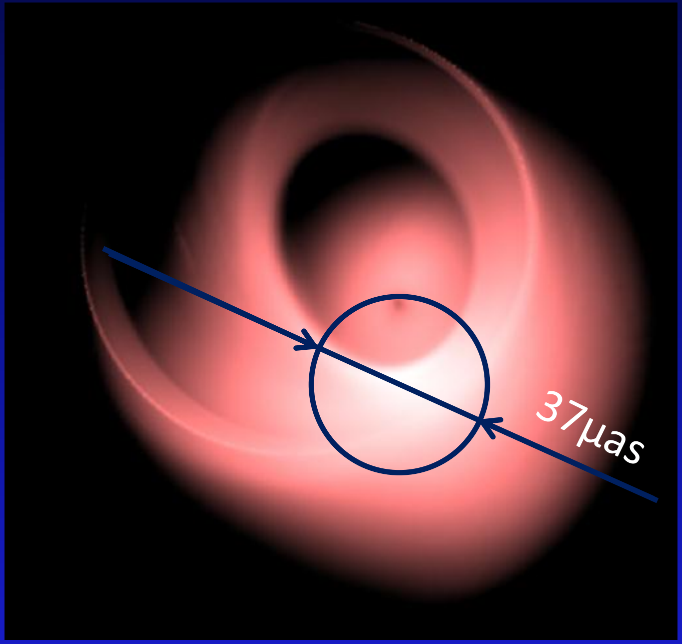
Doeleman et al. 2010



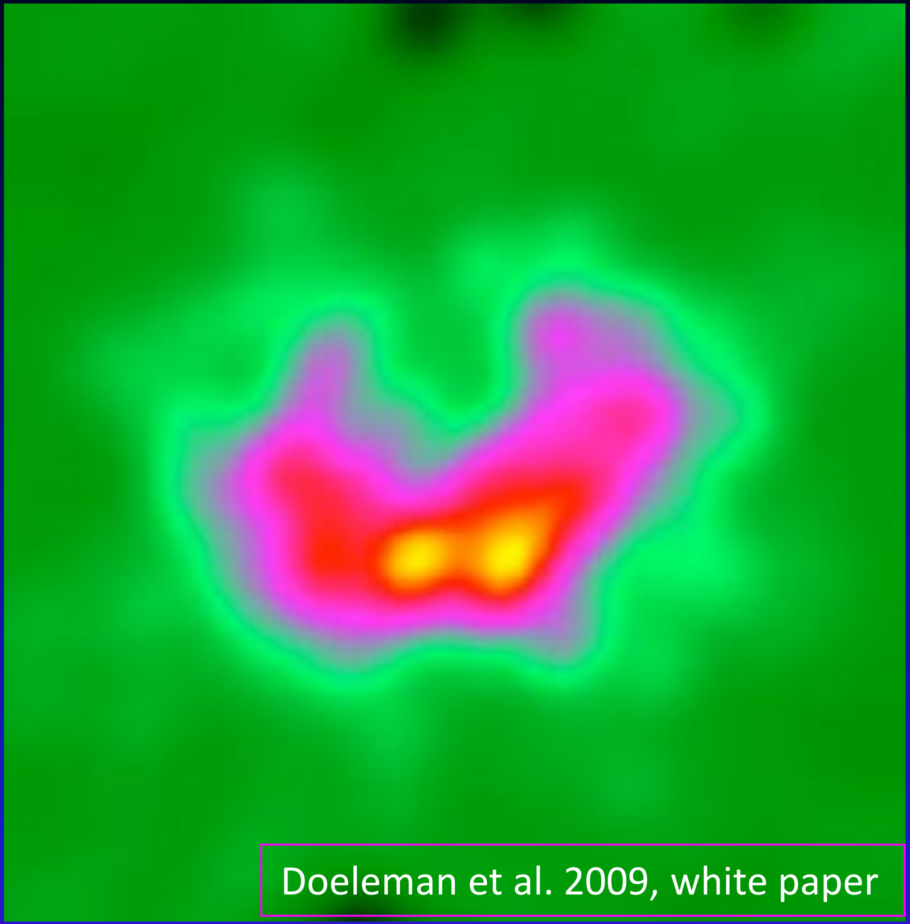
Telescopes in Hawaii, Arizona and California are operating in VLBI mode at 230 GHz now!

Chasing the BH shadow

37microarcsec size on Hawaii-Arizona baseline
Doeleman et al. 2008, Nature



Size of the image along certain axis – in general consistent with models of gas flow onto the black hole



Doeleman et al. 2009, white paper

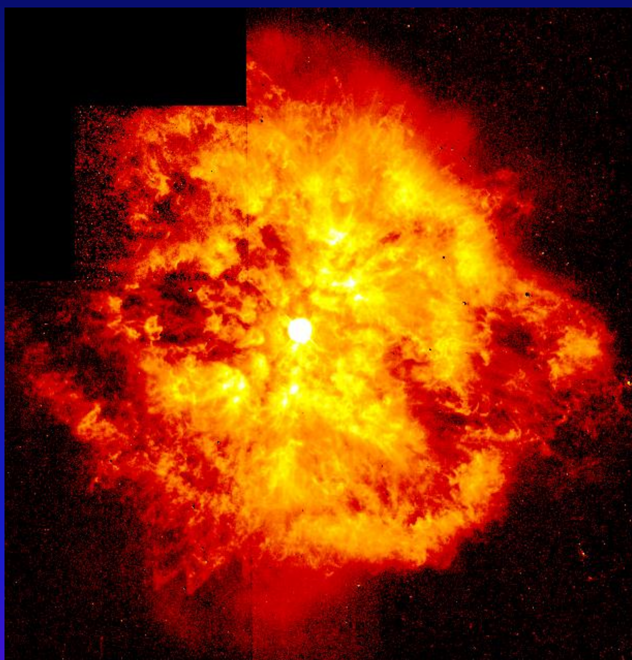
With 7 stations working (2014-2015) one can reconstruct the image

Event Horizon Telescope (EHT)

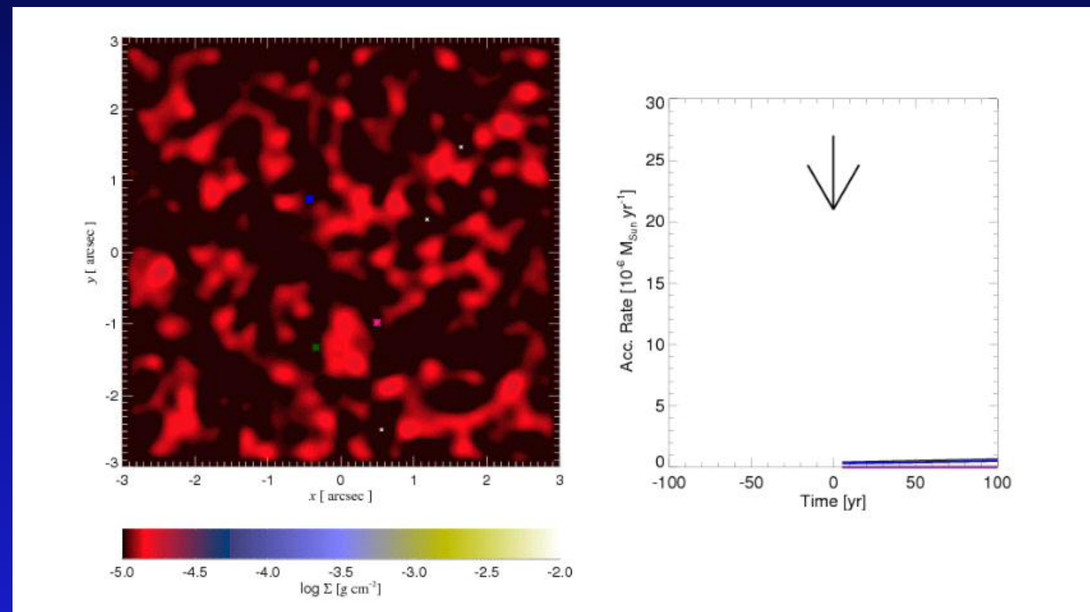
Will the accretion change over time?

Variable feeding by stellar winds/clouds

Wolf-Rayet star ~ $20M_{sun}$,
Stellar winds ~ $3M_{Earth}$ /yr



NASA, ESA (Hubble image)



Cuadra, Nayakshin et al. 2005

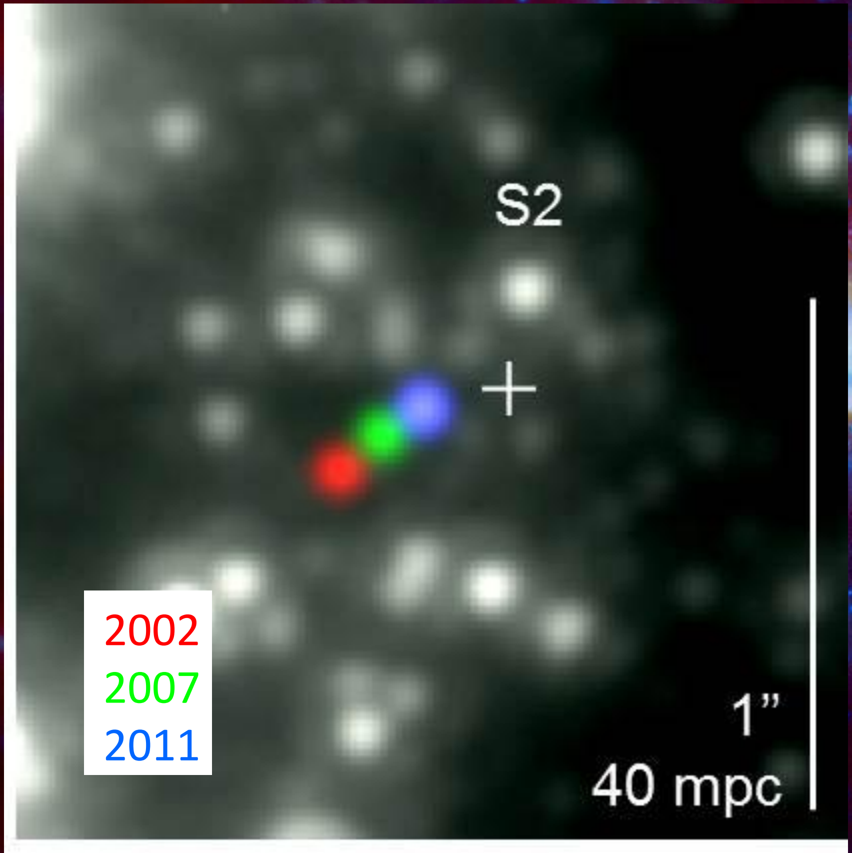
Stellar winds produce quickly changing accretion
Timescale ~10yrs

Wind velocity up to 2000km/s

A cloud approaches Sgr A*… in 2013!

A dense cold cloud on its way to the GC

Gillessen et al. 2012, Nature



Position of the cloud in various epochs

The cloud

- ✓ Mass about $3M_{Earth}$
- ✓ Much cooler than surrounding gas – can't resist BH pull
- ✓ Parabolic trajectory reaches $4000R_g$ but a=0.5'' – semimajor axis

Might lead to substantial inflow:

Mass is 5% of mass inside $V=a^3$ volume

However, will likely accrete before spreading over V =>

1x-10x accretion rate by 2014?

Here is how it falls

A gas cloud on its way into the super-
massive black hole in the Galactic Centre

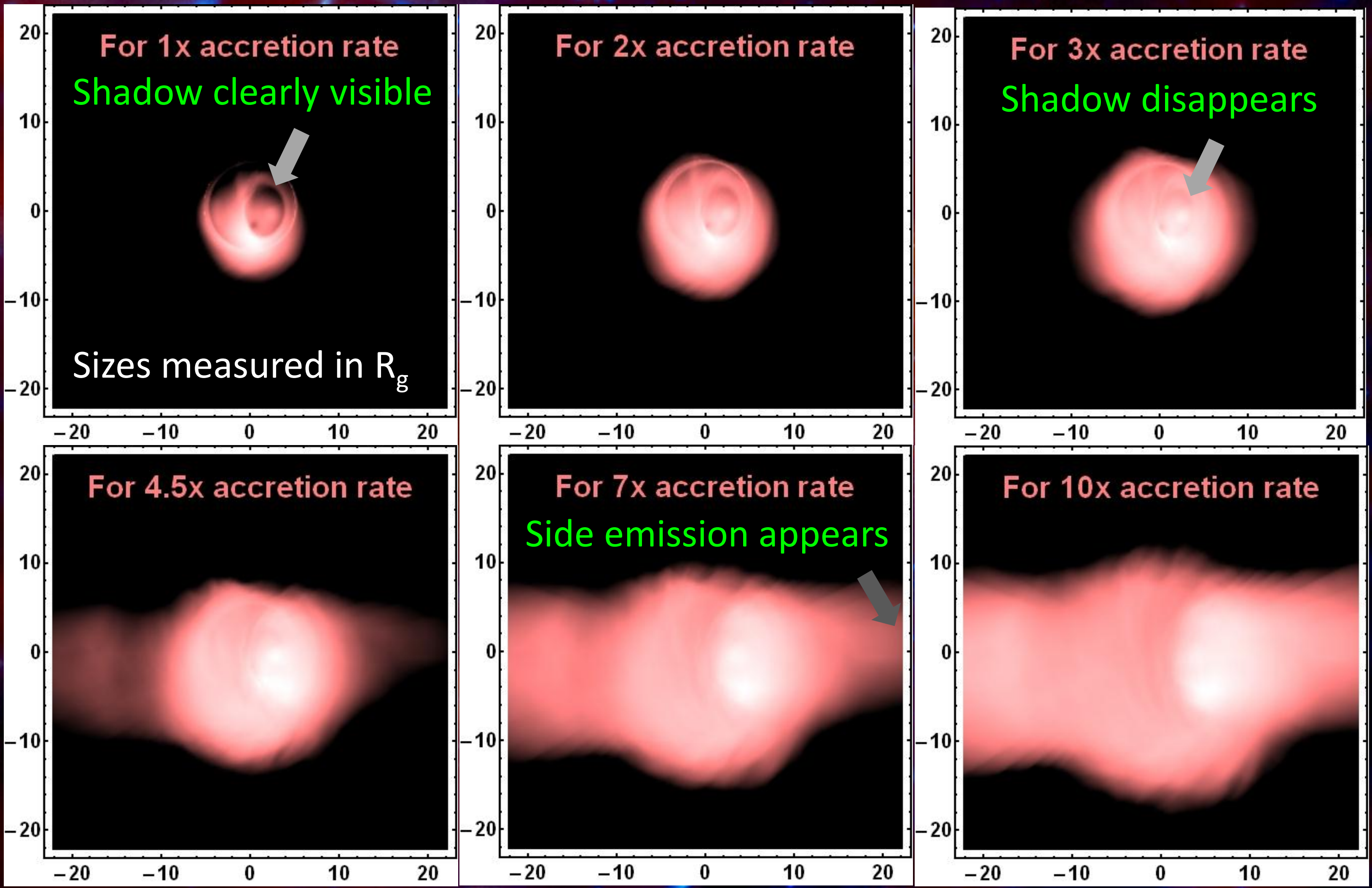
S. Gillessen, R. Genzel, T. Fritz, E. Quataert, C. Alig, A. Burkert, J.
Cuadra, F. Eisenhauer, O. Pfuhl, K. Dodds-Eden, C. Gammie, T. Ott
Nature, Dec. 2011

MPE

Simulation by: M. Schartmann, A. Burkert, C. Alig, S. Gillessen, R. Genzel
using PLUTO 3.1.1 (Mignone et al. 2007)

How will the BH shadow change?

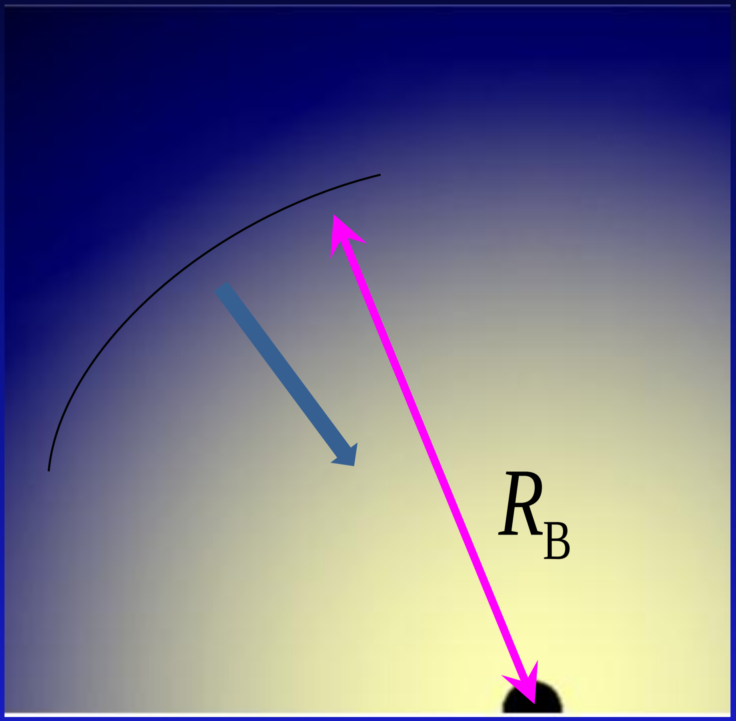
Accretion rate from the cloud may be 10x larger…



By the time the radio telescopes are ready, the shadow might disappear

How does matter get to the BH in LLAGNs?

Accretion from radius of BH gravitational influence (Bondi radius)



Three sources with very large R_B (T=0.3-1keV):

Milky Way : M_{BH}=4.3·$10^6 M_\odot$, d=8.3kpc, R_B=3.5''

Gillessen et al. 2009

M31 : M_{BH}=1.4·$10^8 M_\odot$, d=780kpc, R_B=4''

Bender et al. 2005

NGC3115 : M_{BH}=1.5·$10^9 M_\odot$, d=9Mpc, R_B=4.5''

Kormendy et al. 1996

Chandra X-ray visionary projects (XVP)
to directly probe gas near Bondi radius

3Ms grating observations of Sgr A* – underway
1Ms observations of NGC 3115 – almost done

Feeding by stellar winds?

Young nuclear star clusters produce enough winds to feed the BH

Specific mass loss rate
is lower with population age

$$\dot{f}_g \approx \frac{0.05}{age + 5Myr}$$

Jungwiert et al. 2001

Sgr A*: Paumard et al. 2006

$10^4 M_\odot$ star cluster, age 6Myr

$5 \cdot 10^{-4} M_\odot$/yr ejection rate
(consistent with directly observed mass loss)

BH accretes only ~$3 \cdot 10^{-8} M_\odot$/yr

M31*: Bender et al. 2005

$10^4 M_\odot$ star cluster, age 200Myr

$2 \cdot 10^{-5} M_\odot$/yr ejection rate

BH accretion rate $10^{-6} M_\odot$/yr –
if accretes similarly to Sgr A*

NGC3115*: Kormendy et al. 1996

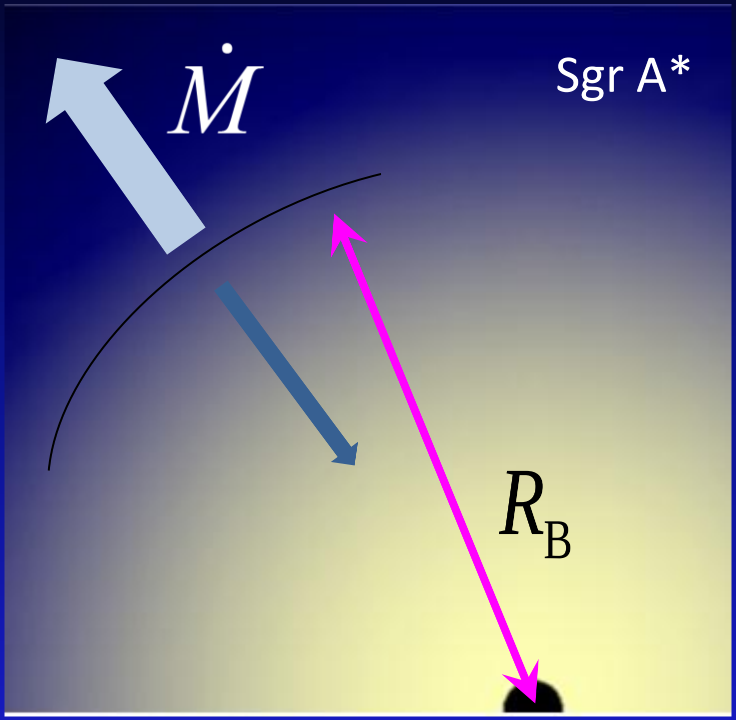
$5 \cdot 10^6 M_\odot$ star cluster, age ~1Gyr

$2 \cdot 10^{-4} M_\odot$/yr ejection rate

BH accretion rate $5 \cdot 10^{-5} M_\odot$/yr –
if accretes similarly to Sgr A*

BHs can be fed exclusively by stellar winds

Outflow from Bondi radius



Sgr A* may have transonic (fast) outflow

$$\dot{M} = 4\pi R_B{}^2 \rho c_s$$

$$\dot{M}_{out} = \dot{M}_{wind} = 5\cdot10^{-4} M_{\odot}/yr$$

n=100 cm^{-3}

consistent with X-ray observations

Baganoff et al. 2003; Shcherbakov & Baganoff 2010

M31 and NGC 3115 might have weaker outflows or stalling gas

Conclusions

- Low-Luminosity Active Galactic Nuclei (LLAGNs)
  produce synchrotron emission peak near the BH
  => can constrain flow near the BH + BH spin

- Imaging of synchrotron emission near the event horizon
  allows to catch a BH shadow (Event Horizon Telescope)

- Changes in accretion rate
  may complicate shadow observations

- Gas reaching the BH was likely ejected by stellar winds

- Gas might outflow from Bondi radius