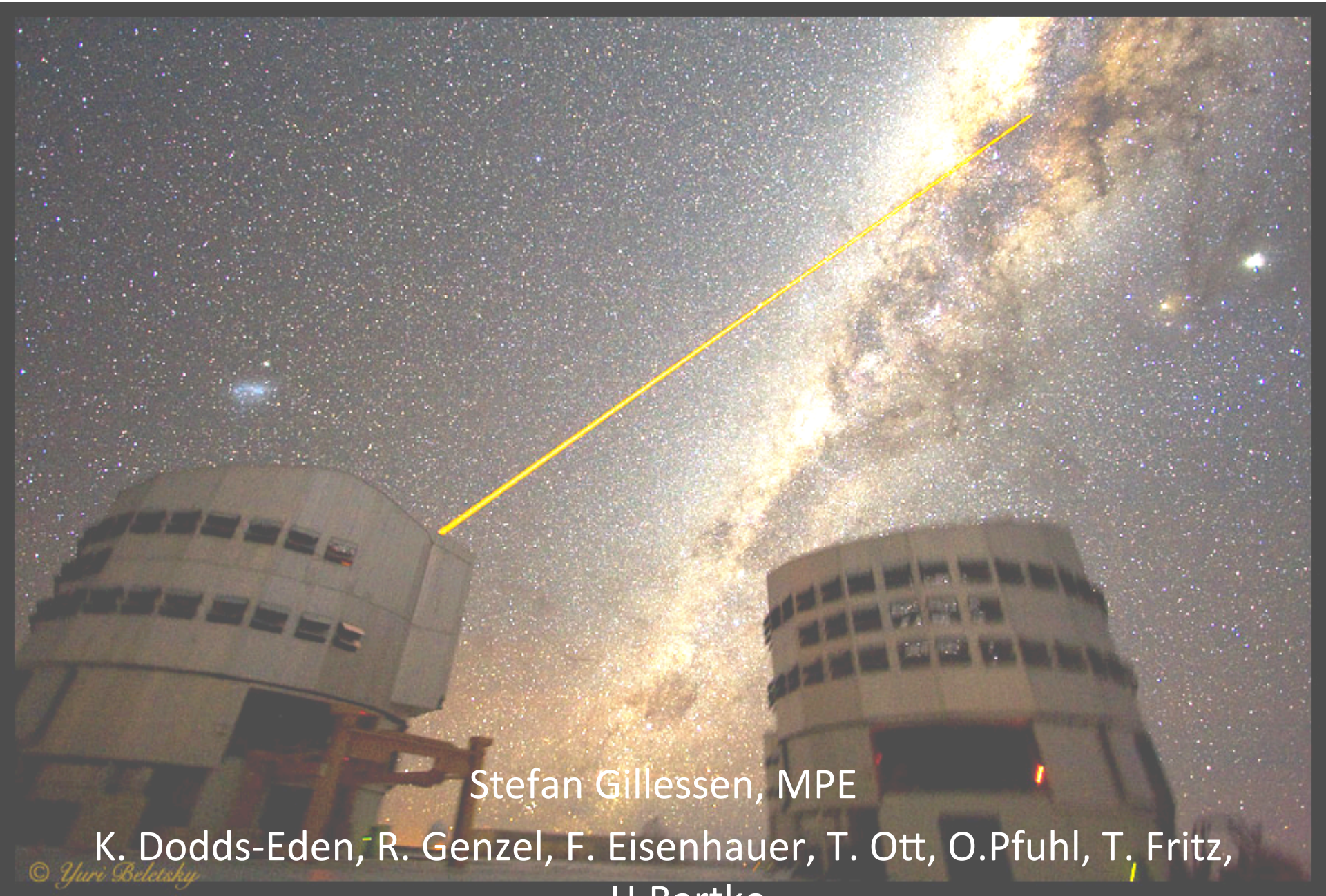
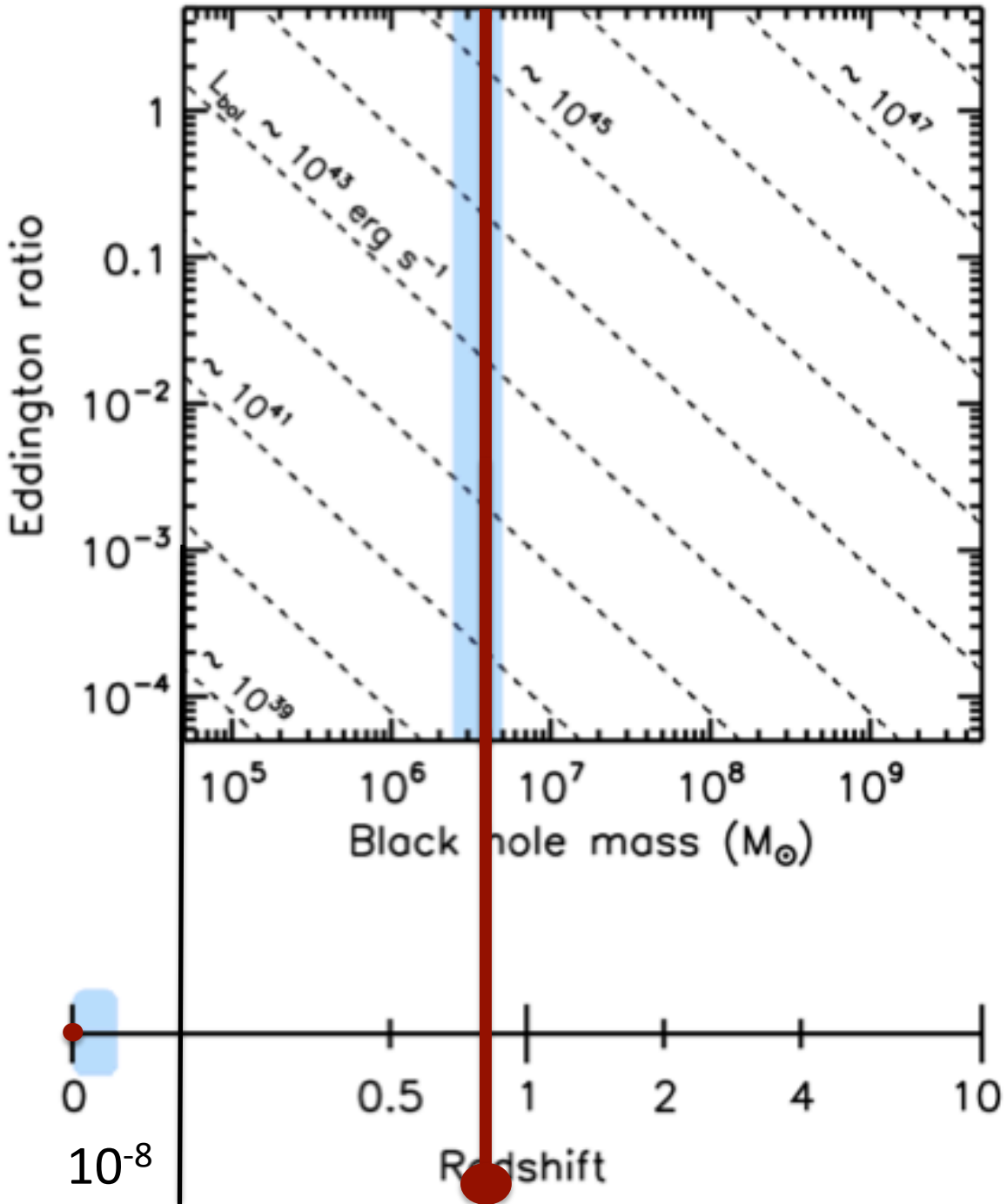
Flaring in Sgr A*



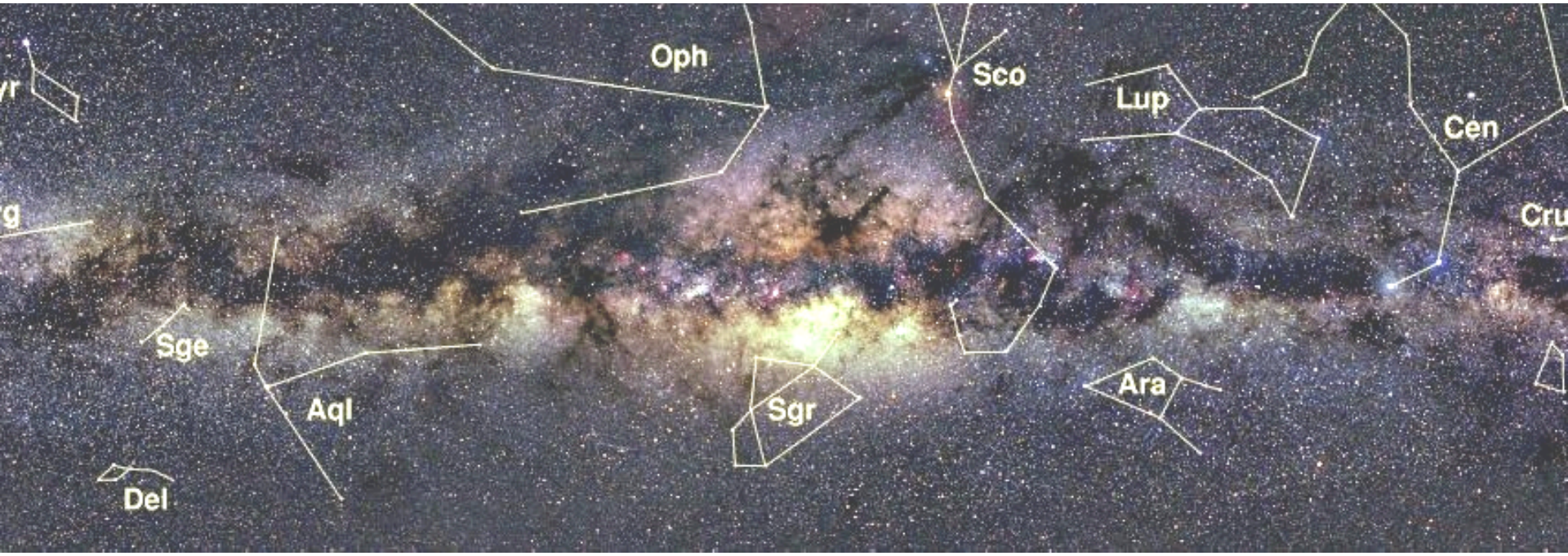
Stefan Gillessen, MPE

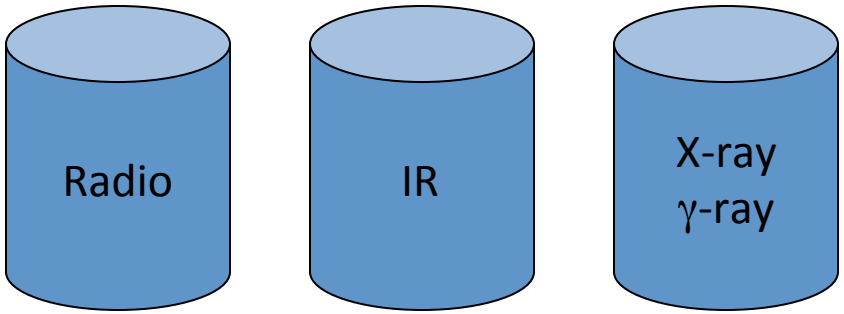
K. Dodds-Eden, R. Genzel, F. Eisenhauer, T. Ott, O.Pfuhl, T. Fritz,
H. Bartko


Eddington ratio
1
0.1
10^{-2}
10^{-3}
10^{-4}
$L_{bol} \sim 10^{43}$ erg s^{-1}
$\sim 10^{45}$
$\sim 10^{47}$
$\sim 10^{41}$
$\sim 10^{39}$
10^5
10^6
10^7
10^8
10^9
Black hole mass ($M_\odot$)
0
0.5
1
2
4
10
10^{-8}
Redshift

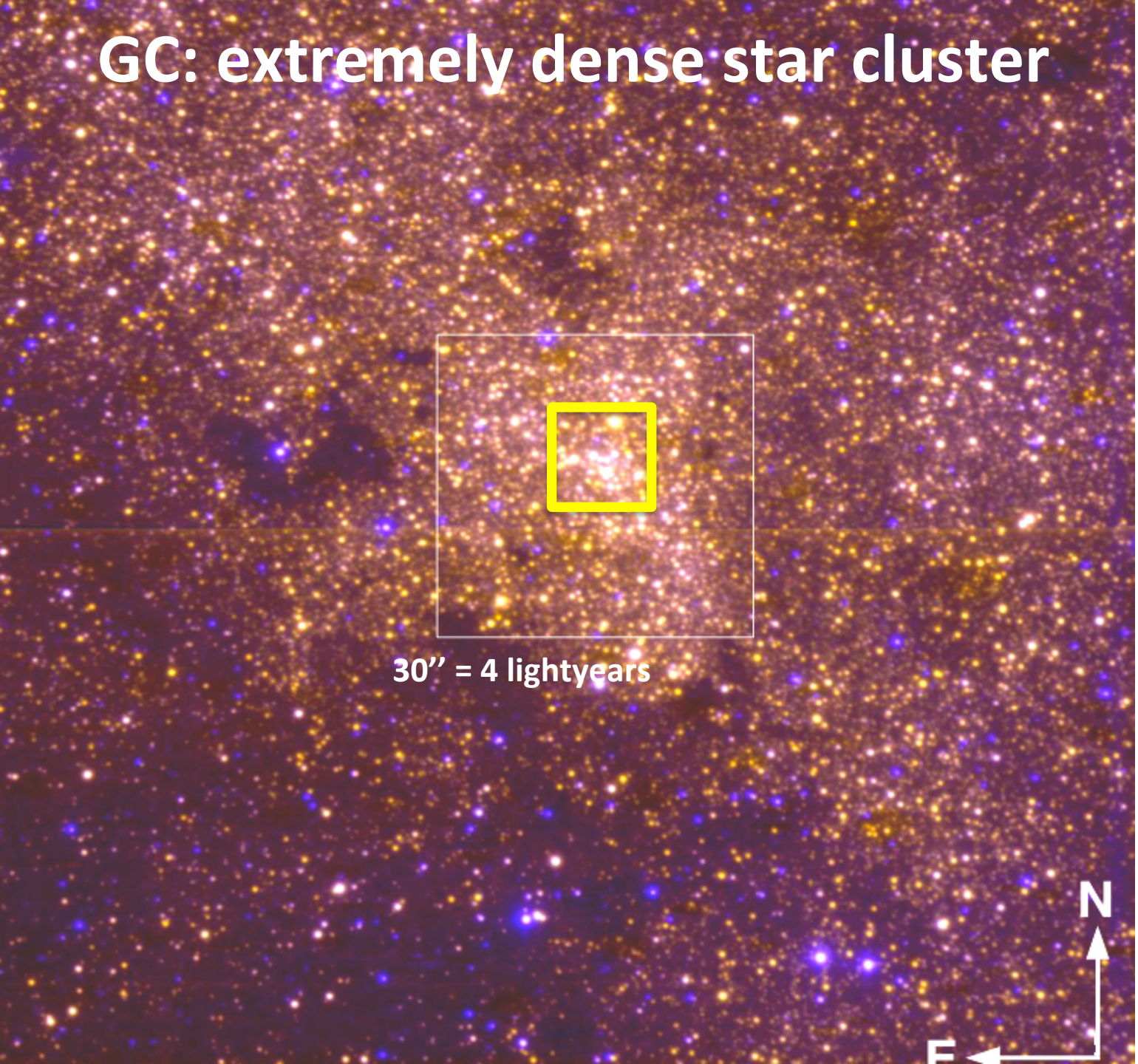
Where are we?

The GC is highly obscured



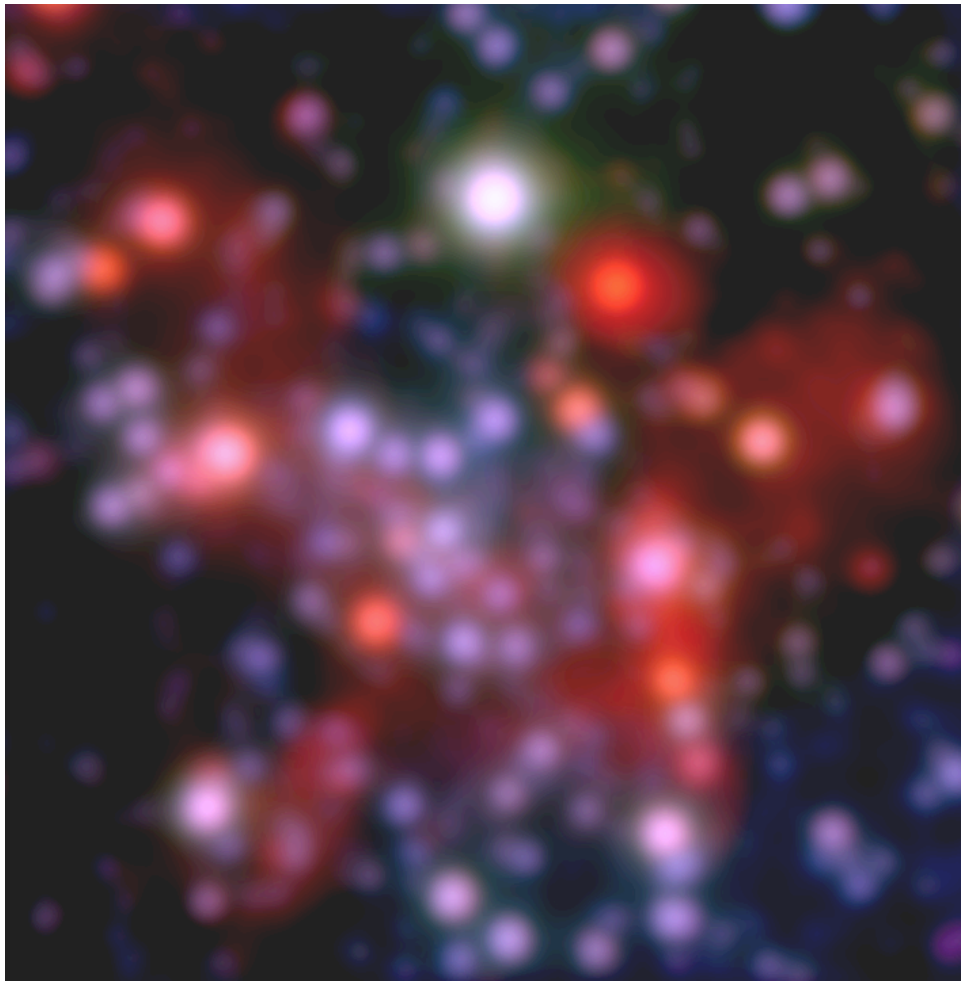


GC: extremely dense star cluster

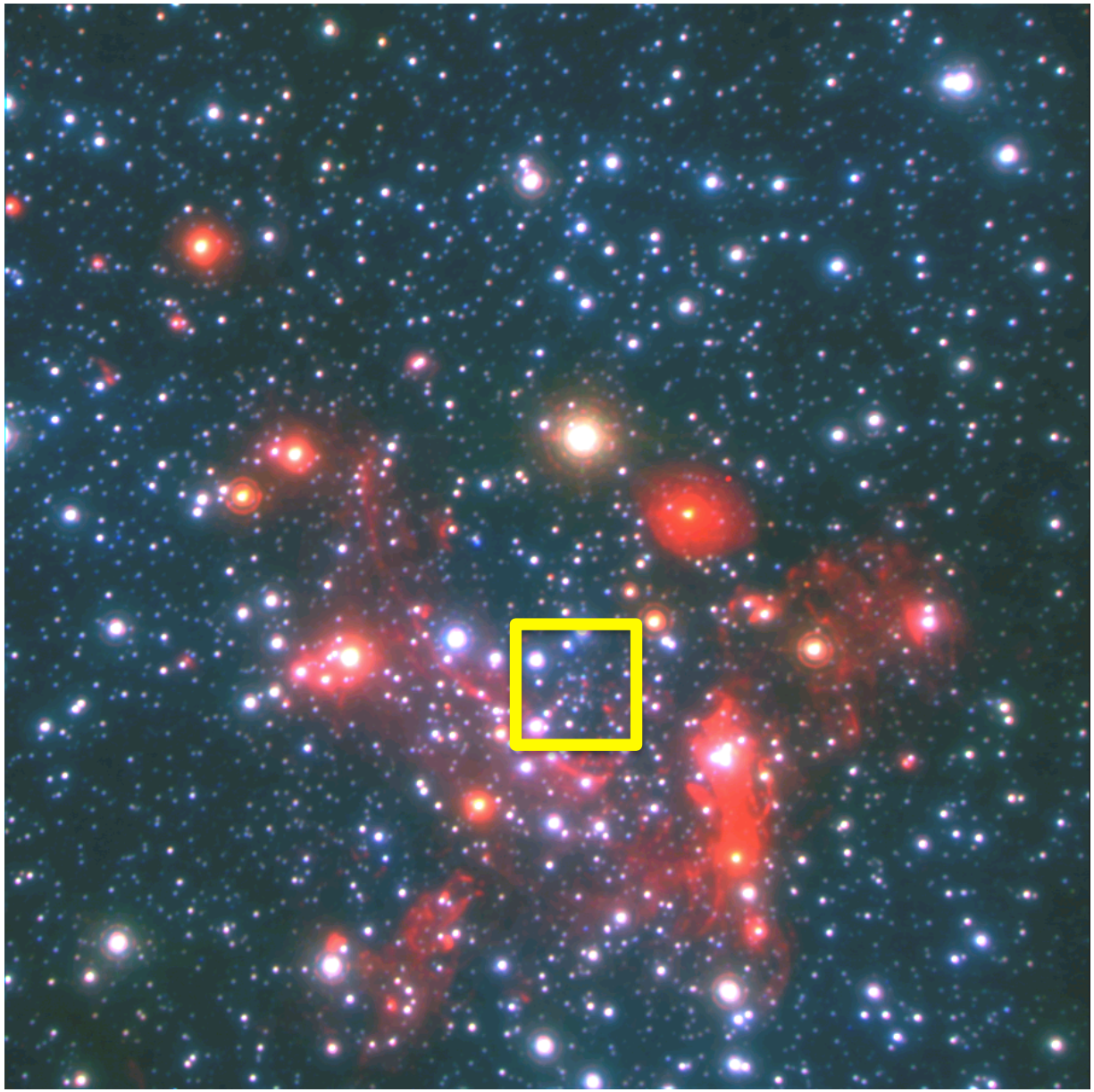


Schödel+ 2006
(ISAAC, VLT)

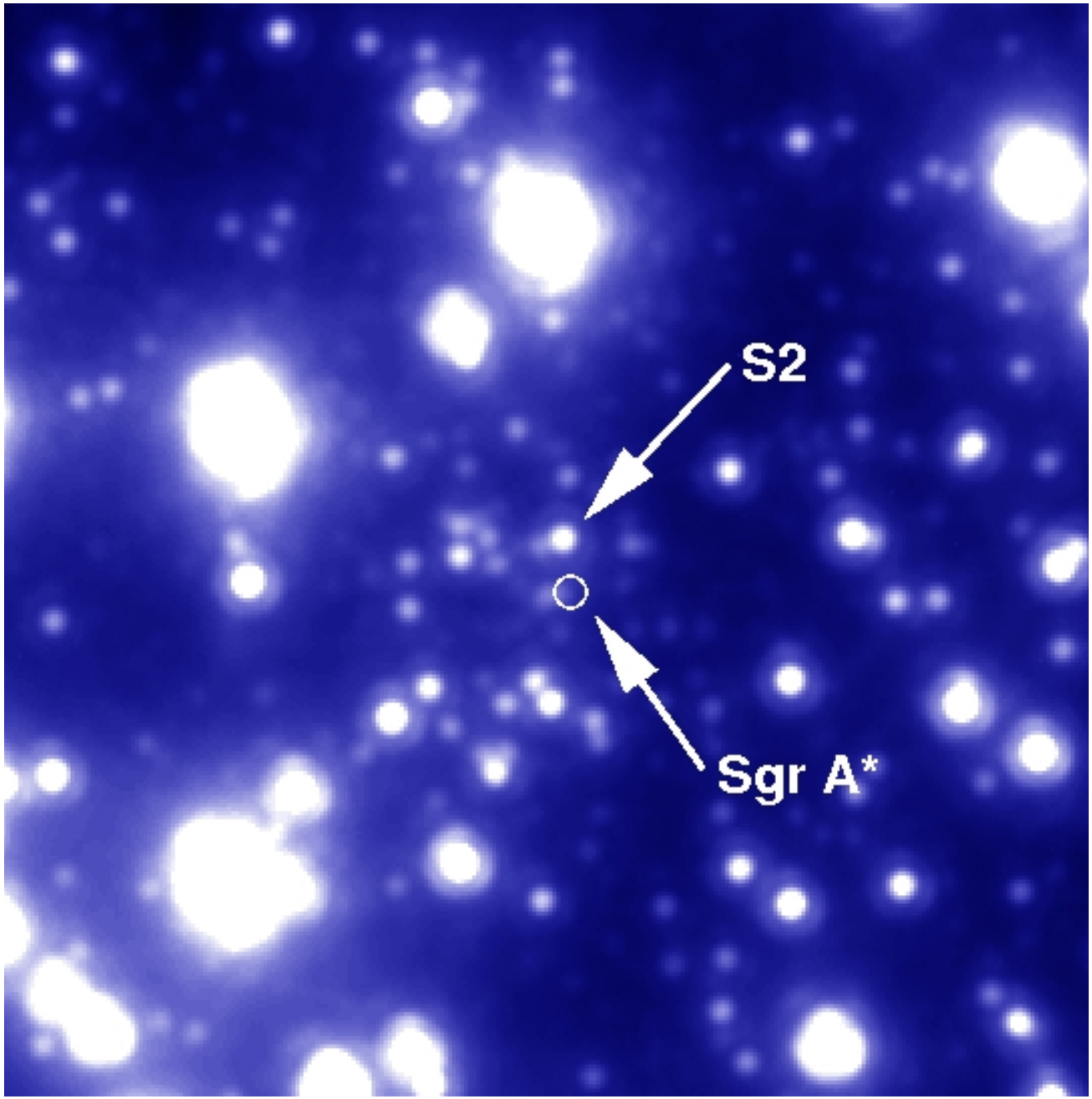
The central 20’’: Seeing limited



Adaptive Optics

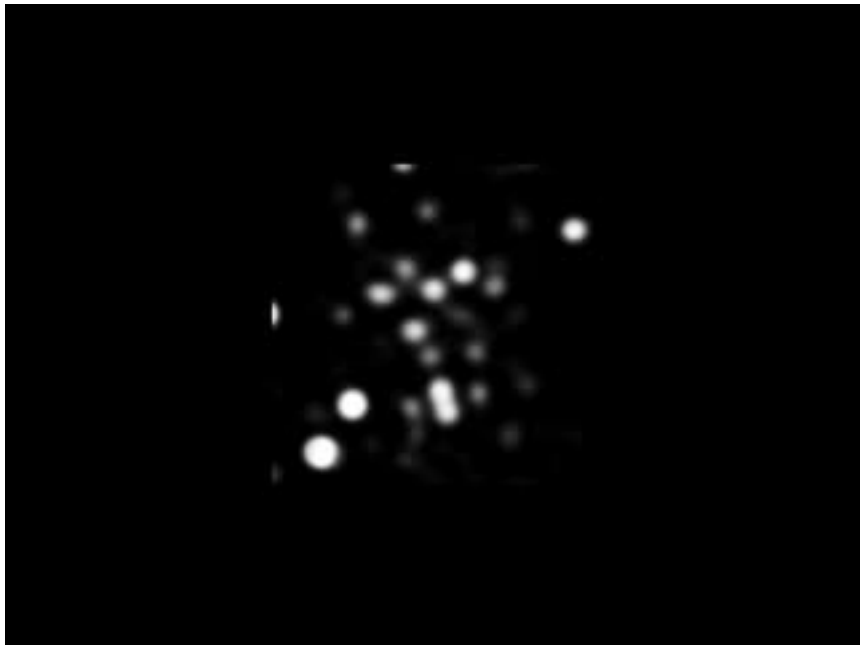


NACO,
HKL color composite

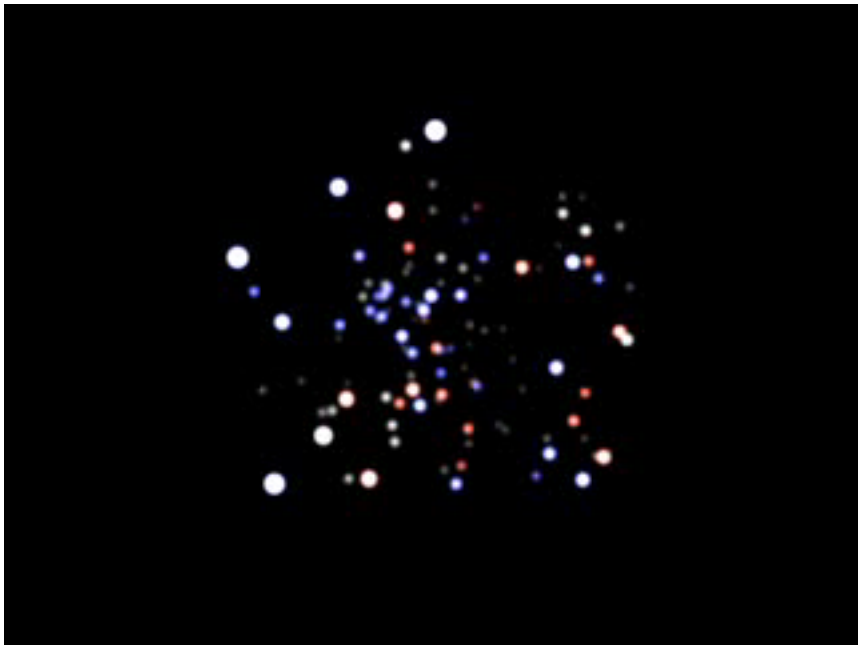


Diffraction-limited images

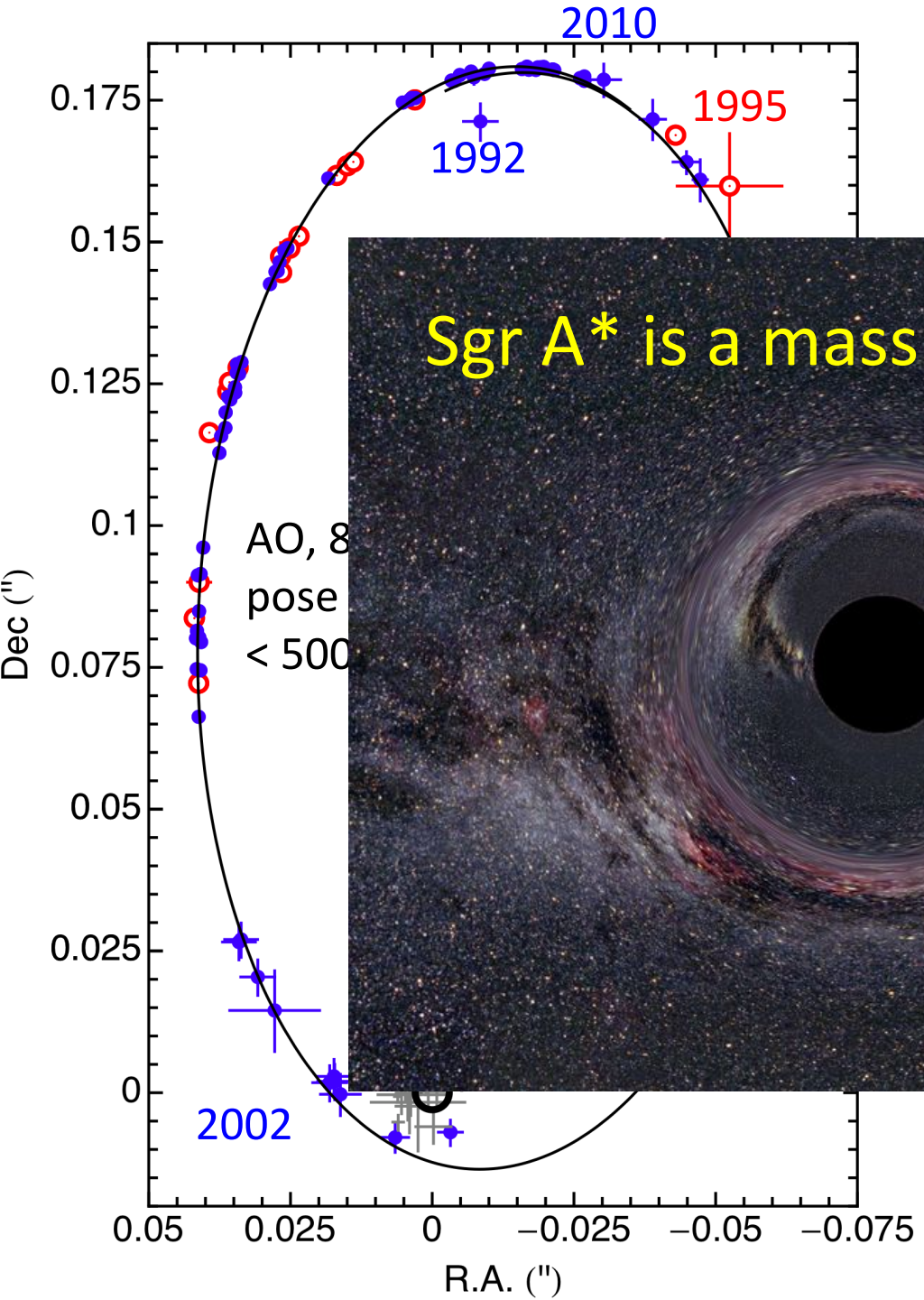
Stars move on Keplerian orbits



Real Data (!)



Model



VLT & Keck data suitably combined

, 707, 114)

Sgr A* is a massive black hole

AO, 8
pose
< 500

5 x 10^6 $M_\odot$

R_0 0 kpc

Sgr A* should be bright - but is not

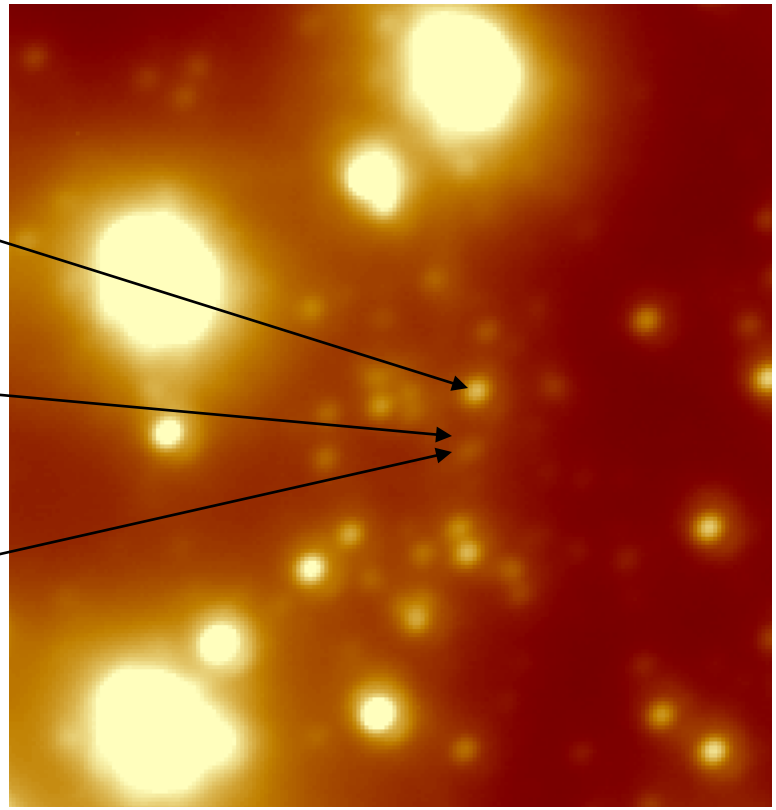
Limit: Eddington luminosity

radiation pressure = gravitation

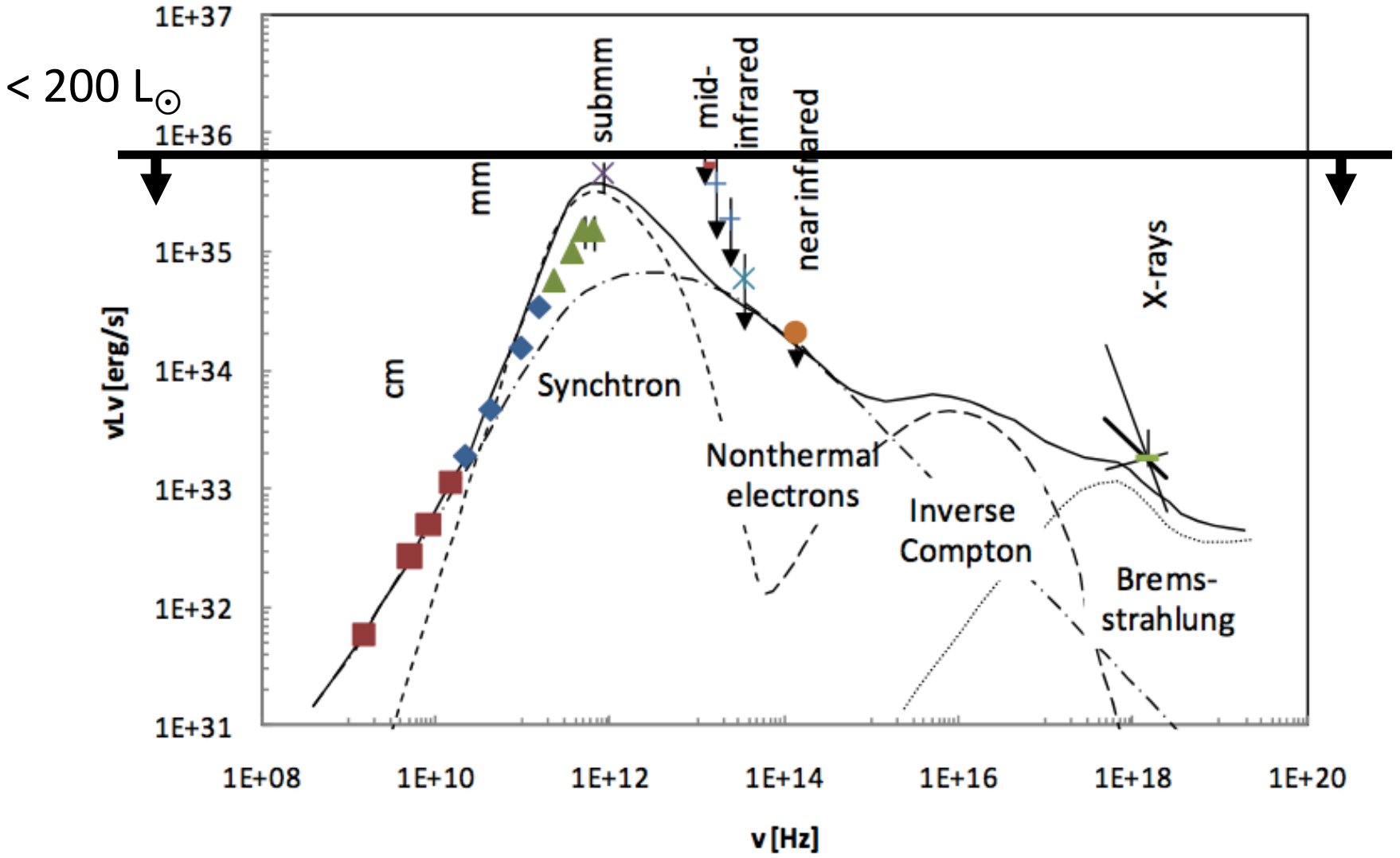
$$L_{Edd} = \frac{4\pi G m_p c}{\sigma_T} M$$

$L = \eta \times 5 \times 10^{44}$ erg/s

$= \eta \times 10^{11} L_{\odot}$



Sgr A* is dim at all wavelengths:
$\eta \sim 10^{-8}$



Radiatively Inefficient Accrection Flow

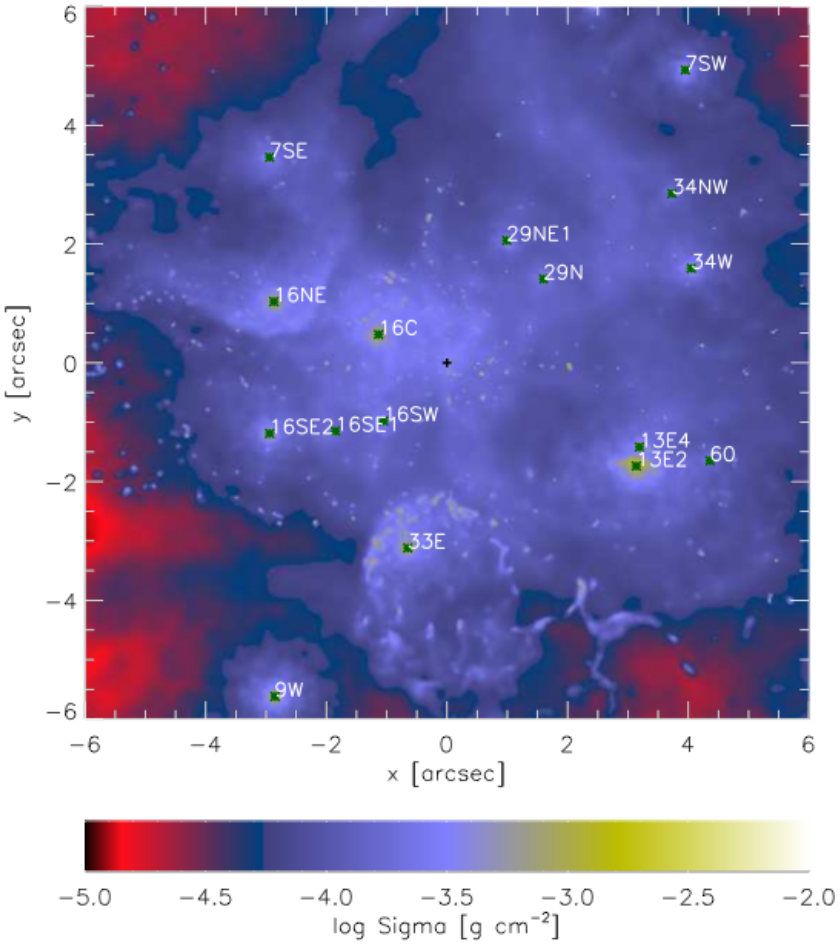
low L/L_{Edd} is a combination of:

- low accretion rate at Bondi radius
- low efficiency angular momentum transport
- low efficiency energy transfer protons to electrons
- most of the gas arriving at a few R_s ejected back out

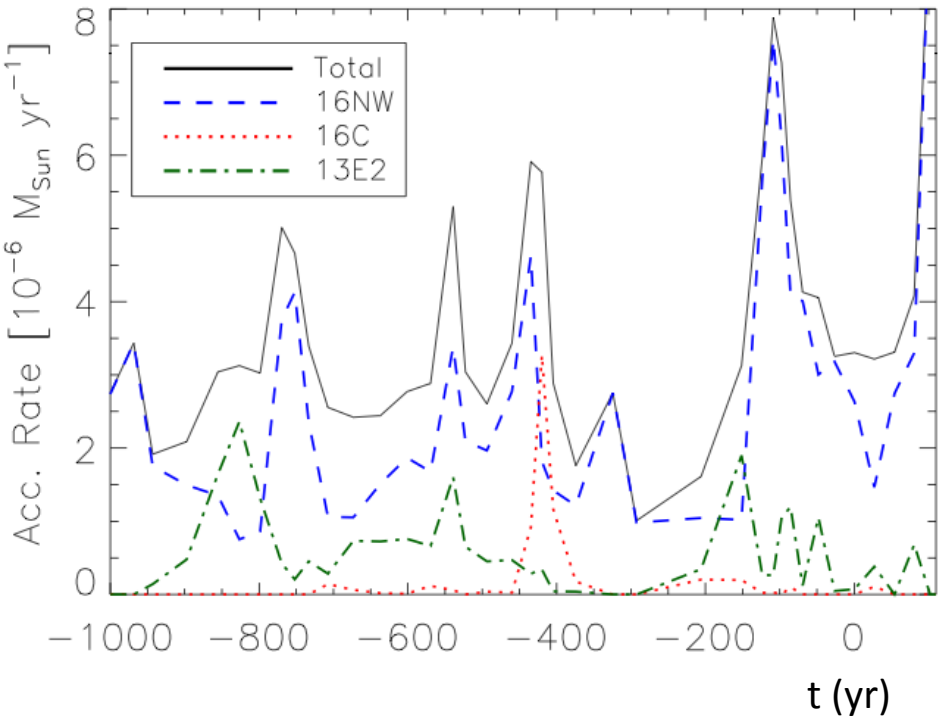
Cuadra et al. 2006, Bower et al. 2005, Marrone et al. 2006, Revnitsev et al. 2005, Begelman, Blandford, De Villers, Hawley, Krolik, Liu, Narayan, Quataert, Melia, Markoff, Rees, Stone, Yuan 1995-2006

Accretion on Sgr A* is variable on 100 yr timescale

winds from known stars

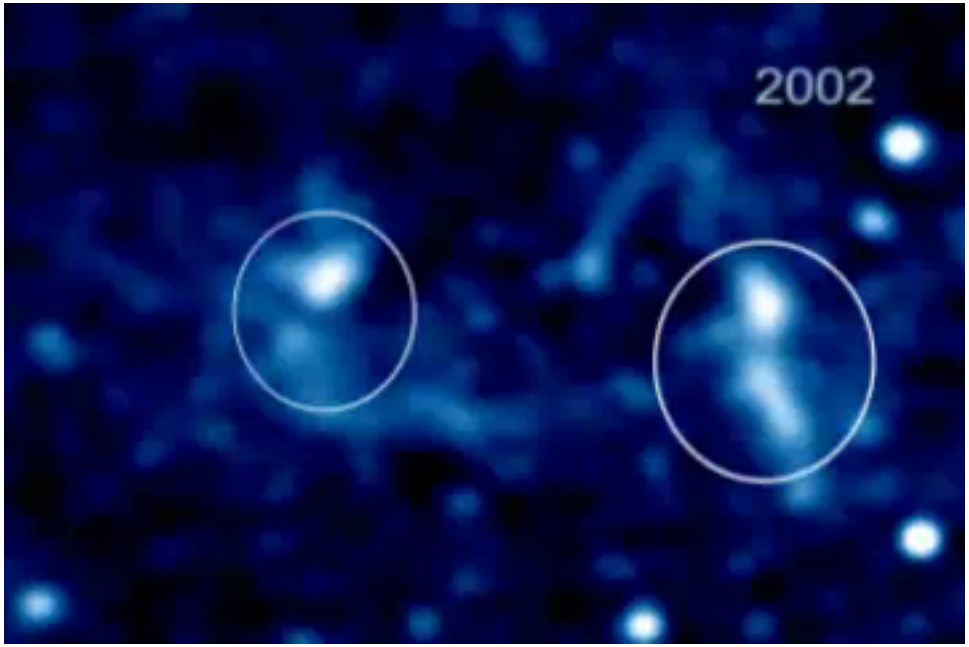


accretion rate



Cuadra+ 2008

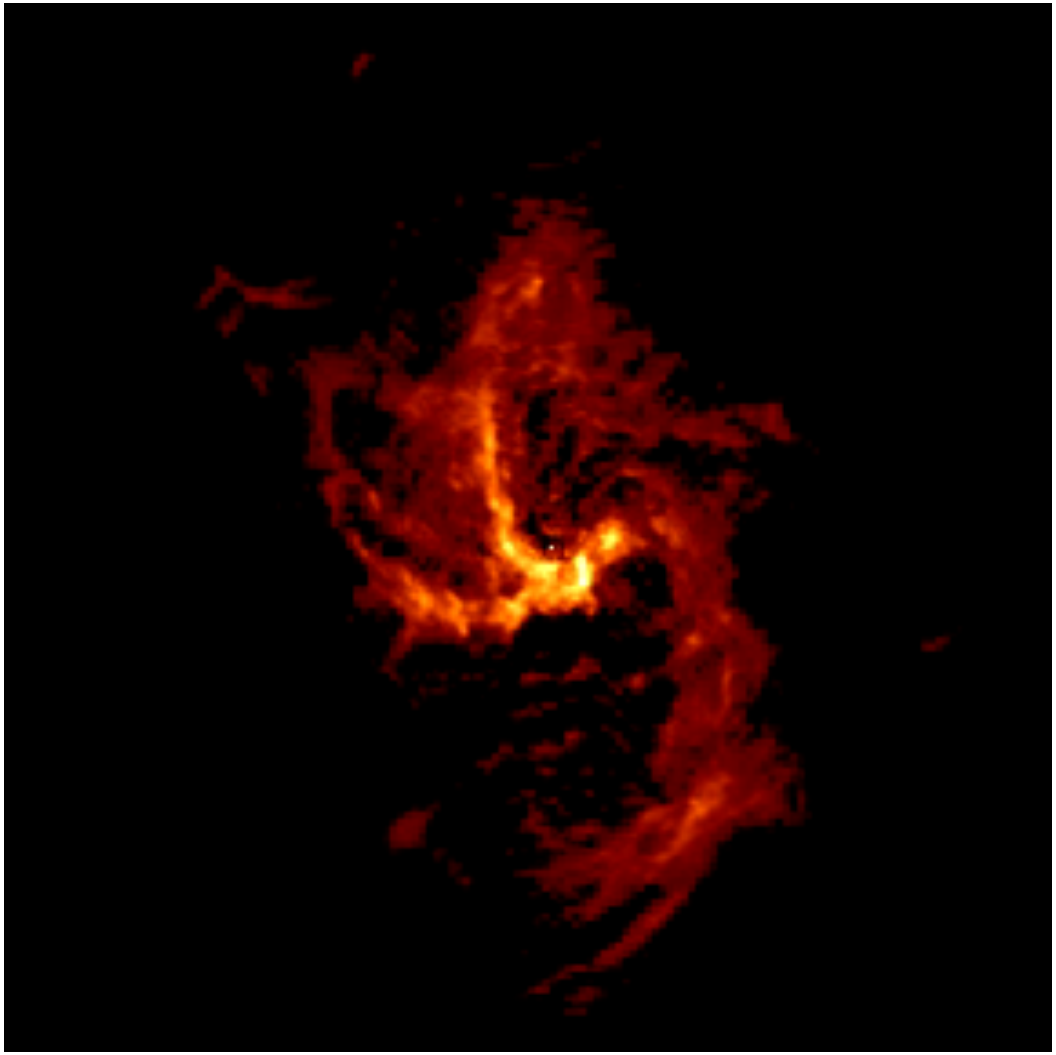
Maybe hints of higher activity in the past are seen as X-ray echos

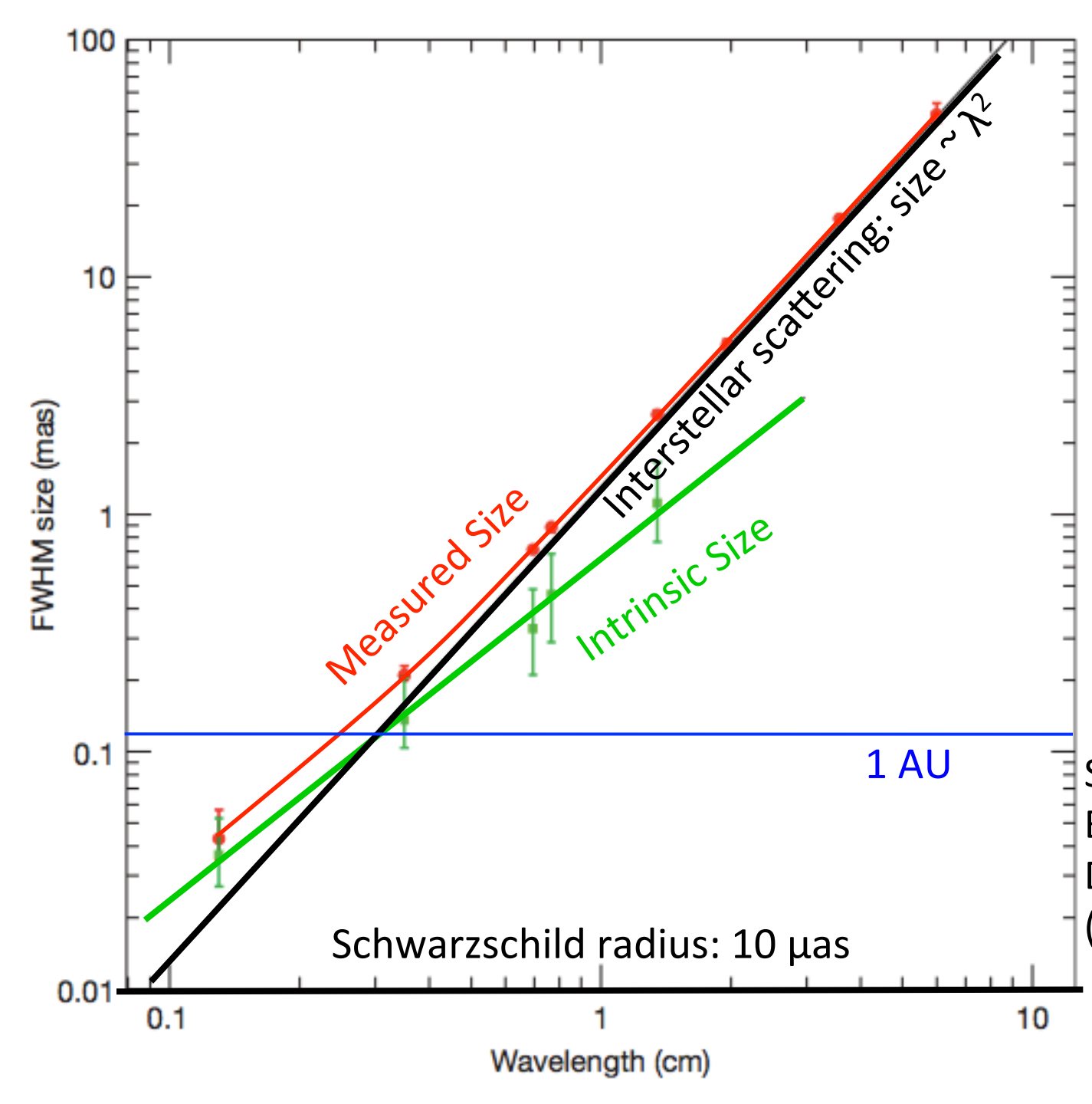


t = 300 yrs

Muno et al.
2007
Ponti et al. 2010

Sgr A* is a bright & extremely small radio source



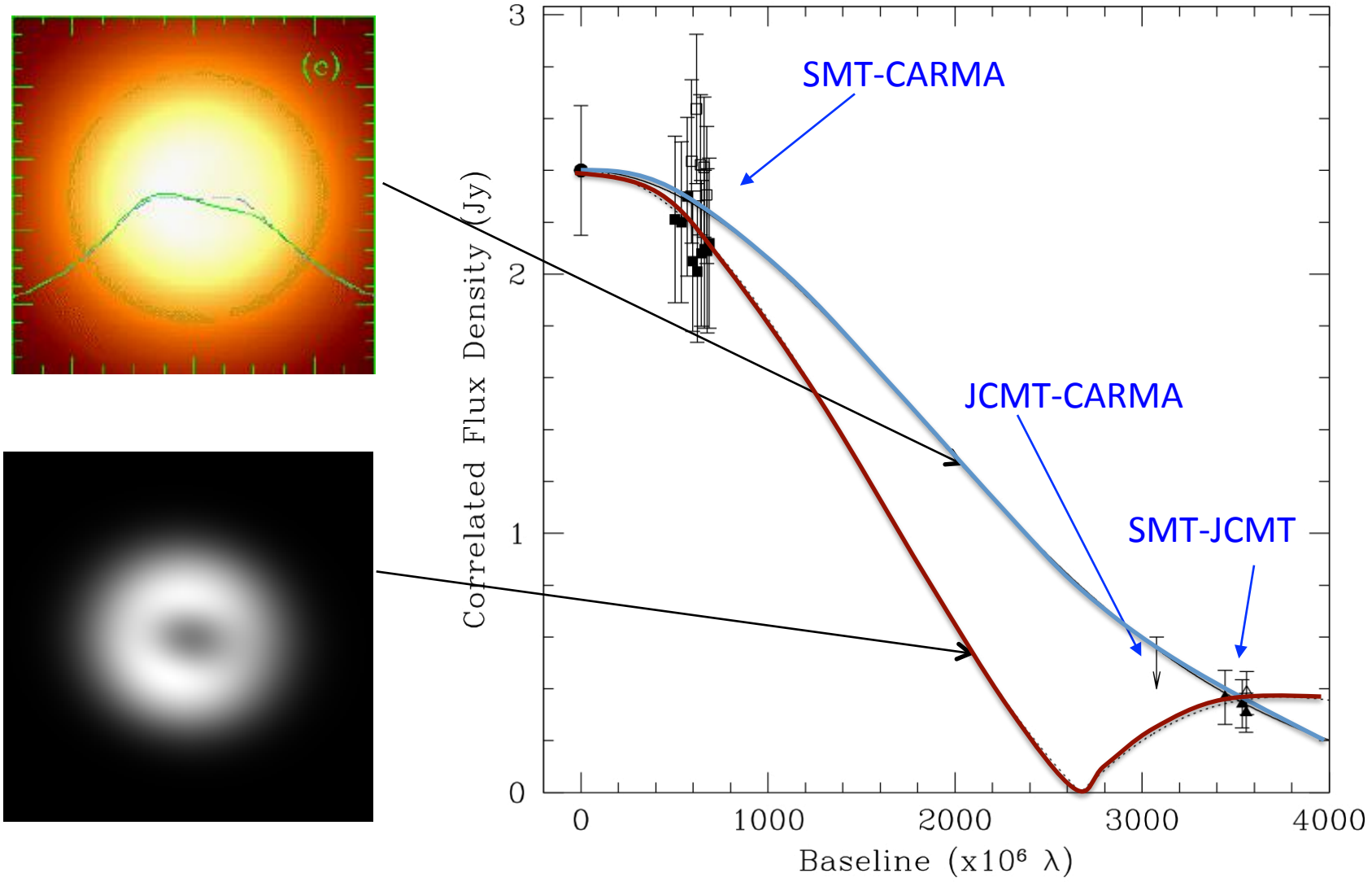


r < 1AU

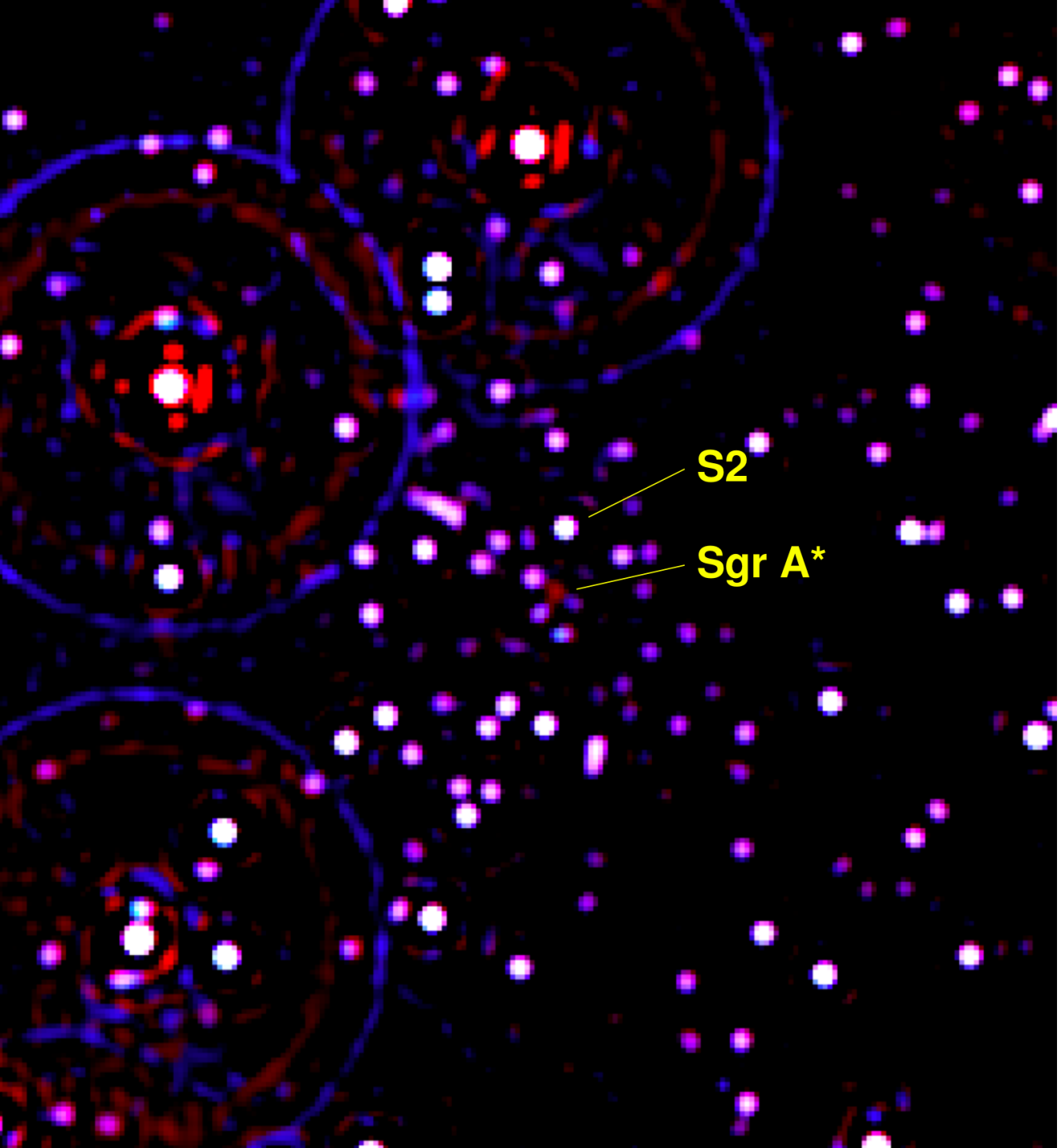
r = 3.7 R_S

Shen et al. 2005
Bower et al. 2006
Doeleman et al. 2008
(VLBI)

Not yet imaging – but a size measurement



Falcke et al. 2000, Gammie et al. , Broderick et al., ..., Doeleman et al. 2008

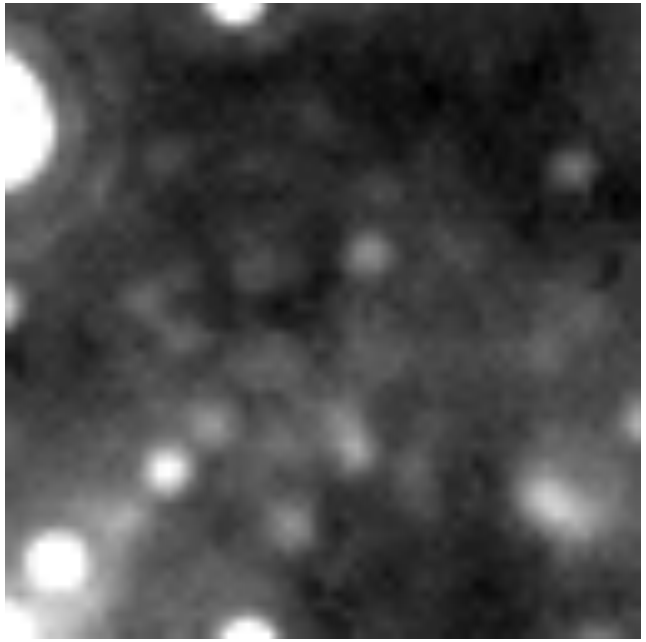


Sometimes, SgrA* shines up in the NIR

- Typically one flare per night
- Lasts ~ 90 min
- Much redder than the stars

Genzel et al. 2003,
Eisenhauer et al. 2005
Gillessen et al. 2006,
Hornstein et al. 2007

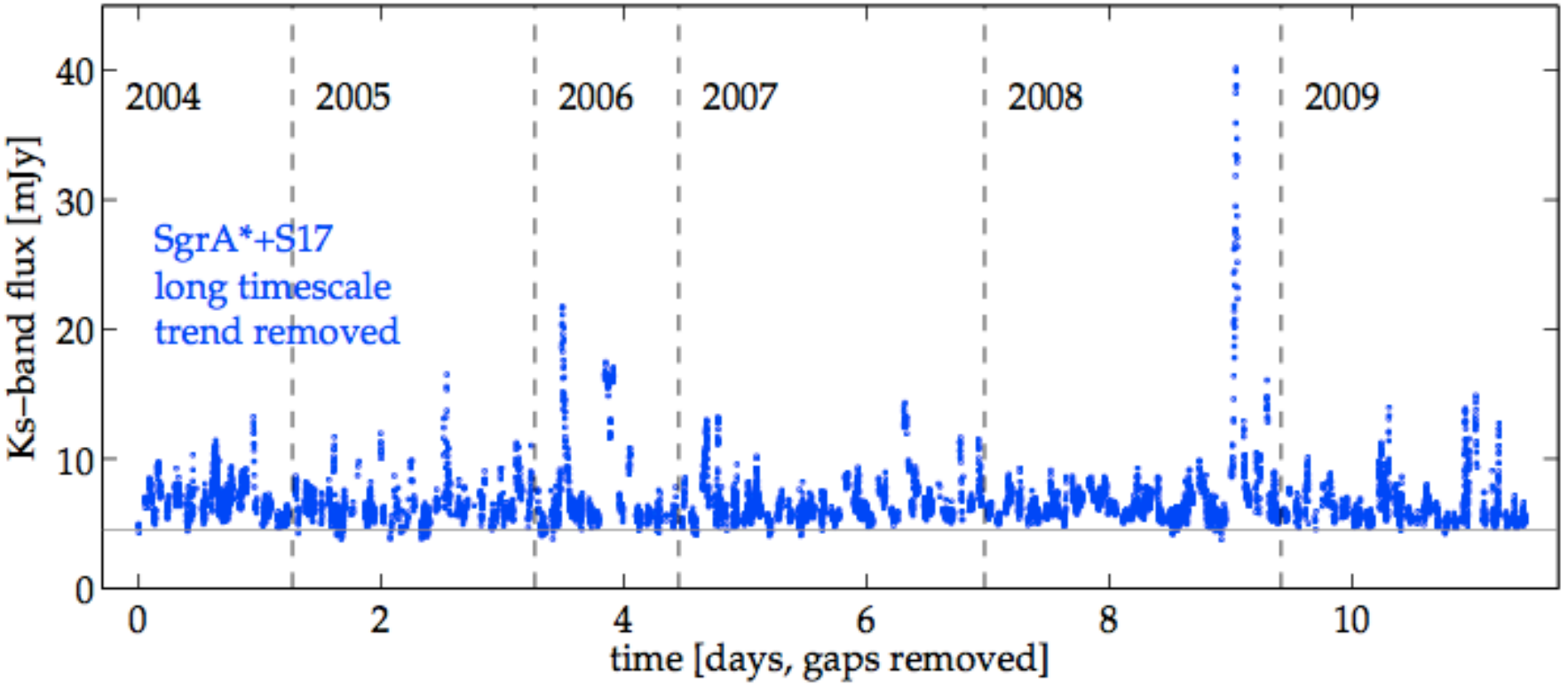
Flares are highly variable



90 min of data

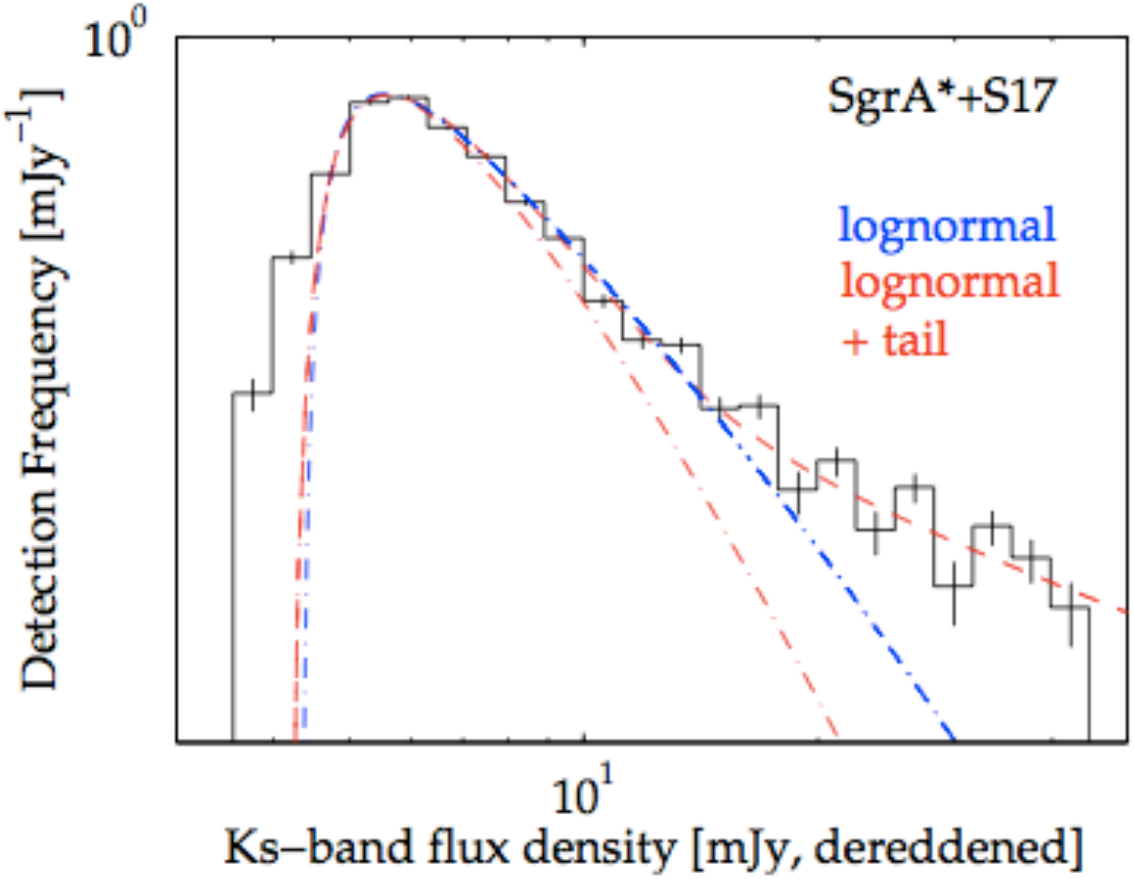
April 4, 2007
NACO, L-band

Sgr A* is a source that undergoes bursts



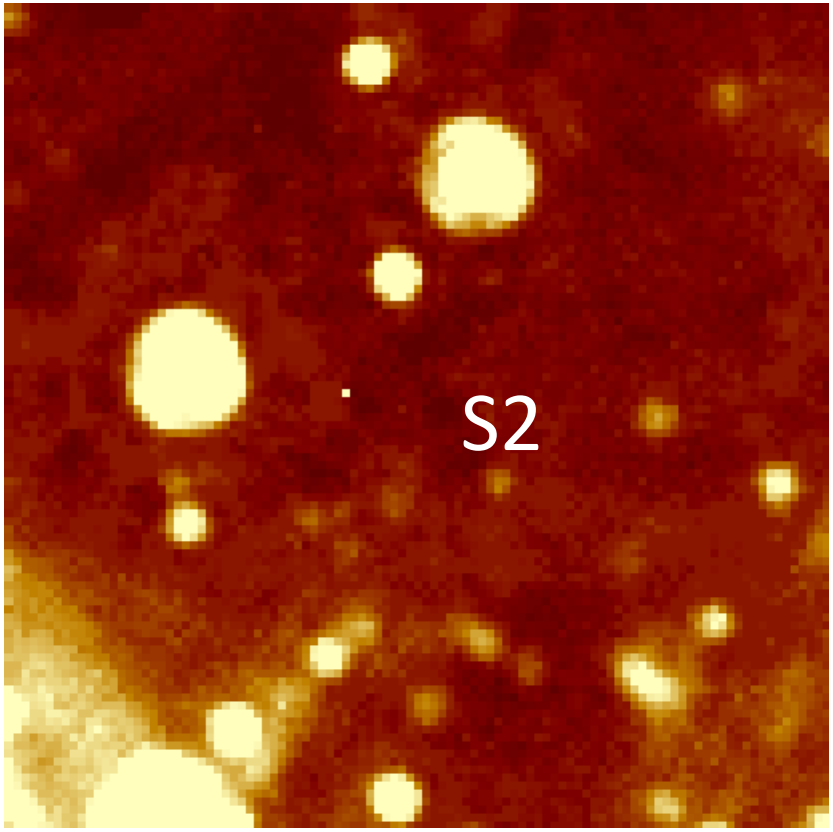
Dodds-Eden et al. in prep.

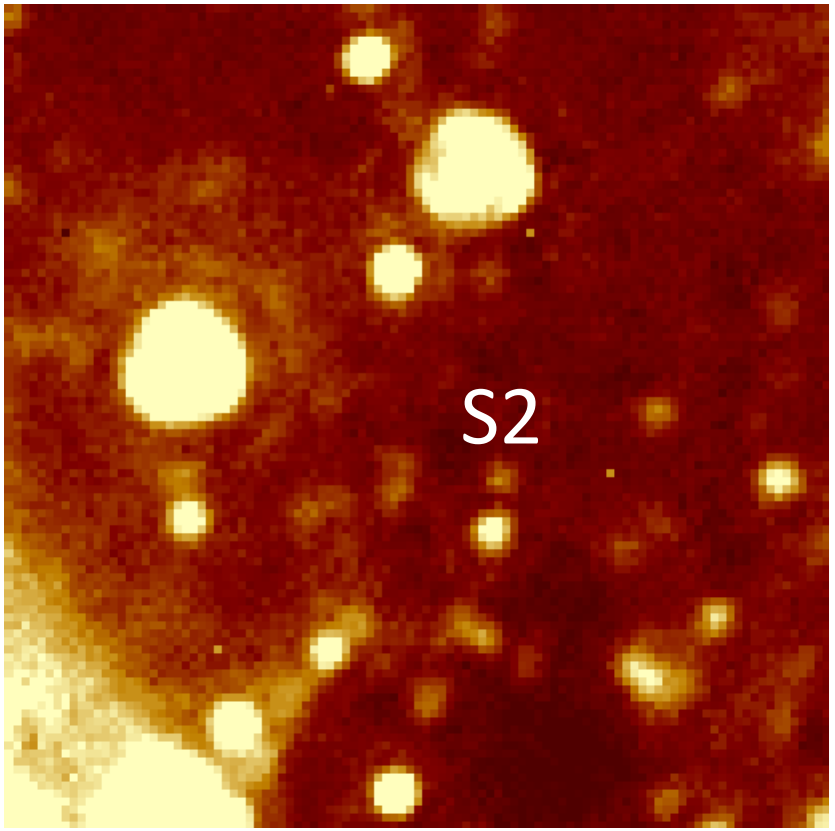
Continuous variability & a tail of flares



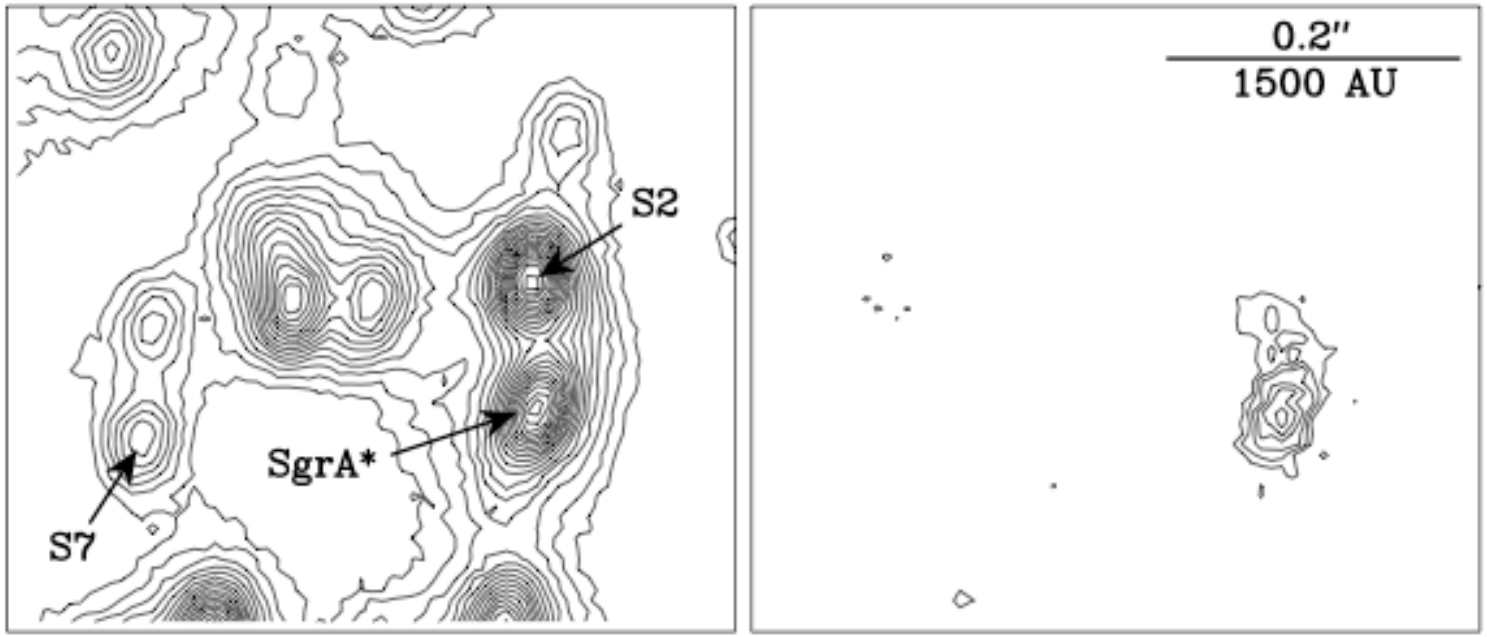
Dodds-Eden et al. in prep.

The brightest flare observed so far





Sgr A* is the only strongly polarized source in the GC

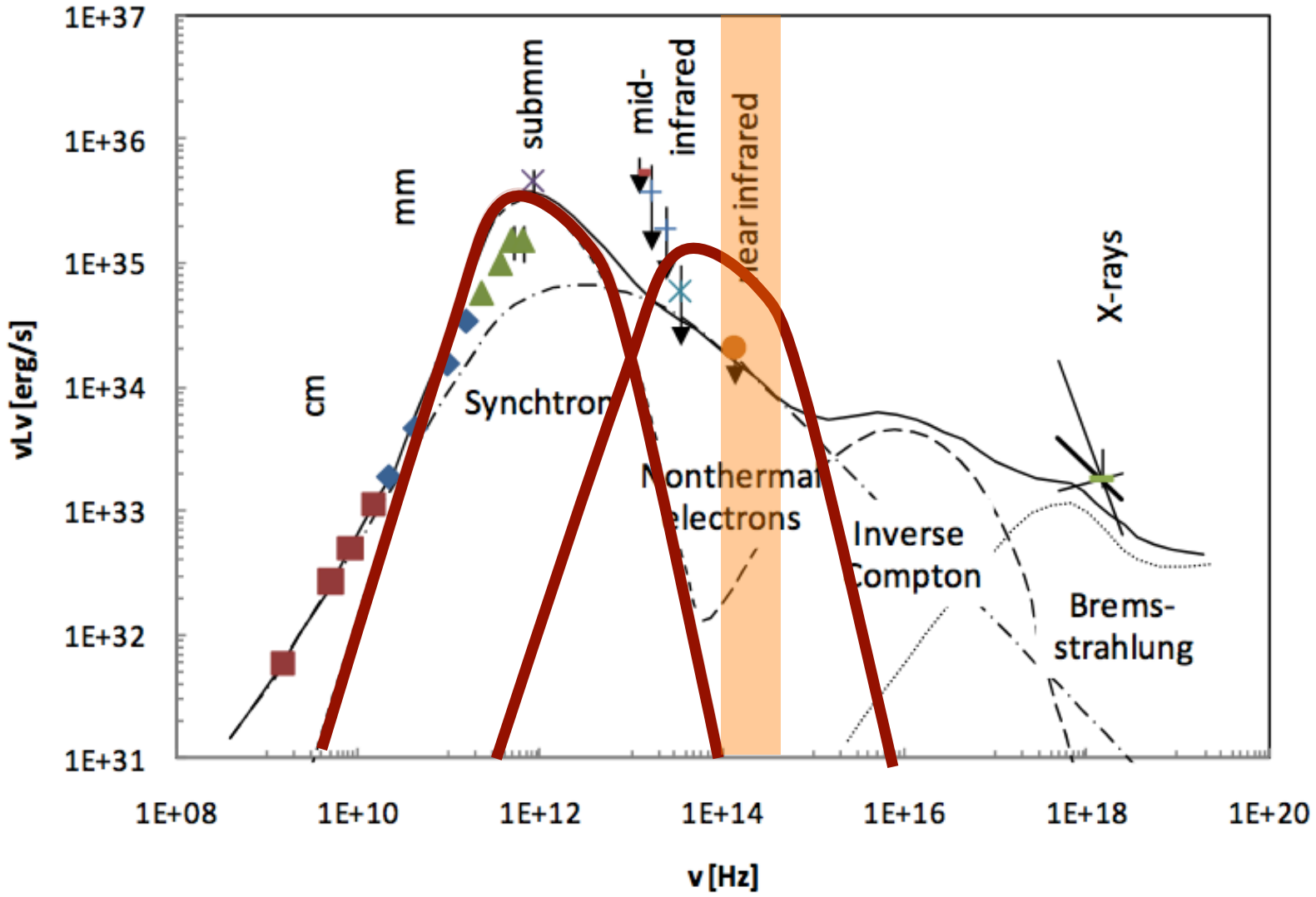


Sum of two polarizations

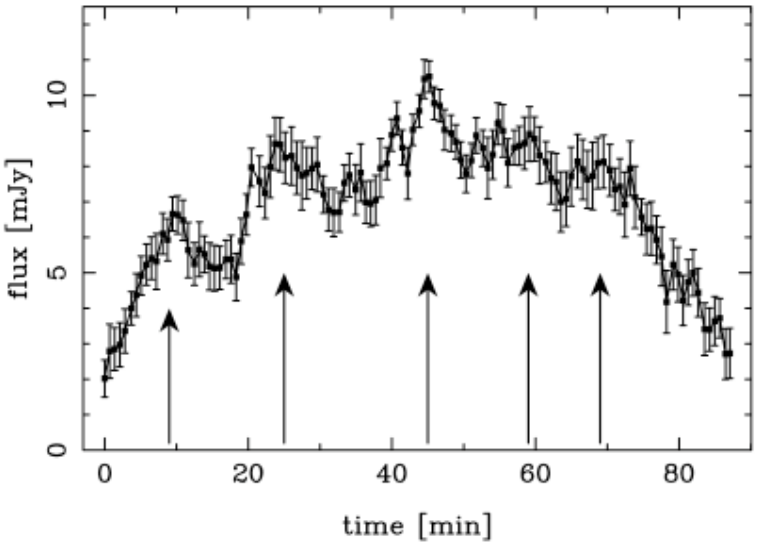
Difference of two polarizations

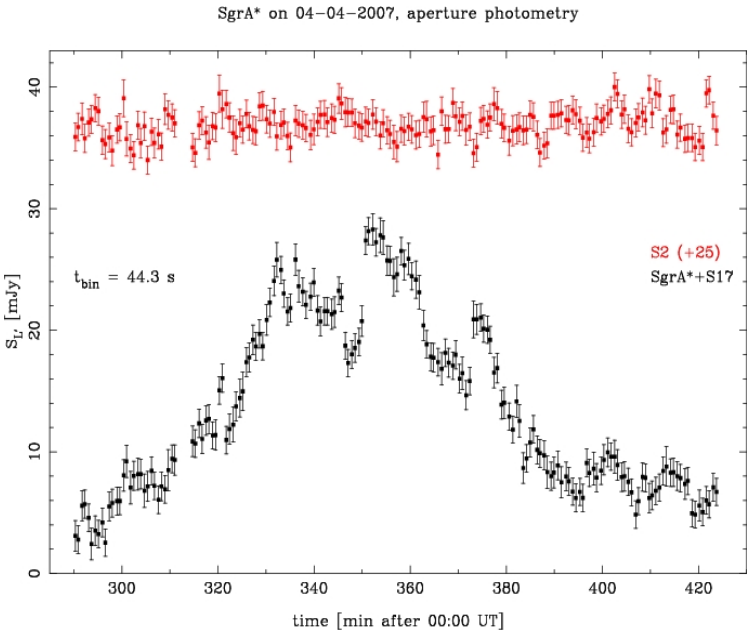
Trippe 2007

Flares are synchrotron emission of transiently heated electrons



Flares often are quasi-periodic





16.6.2003

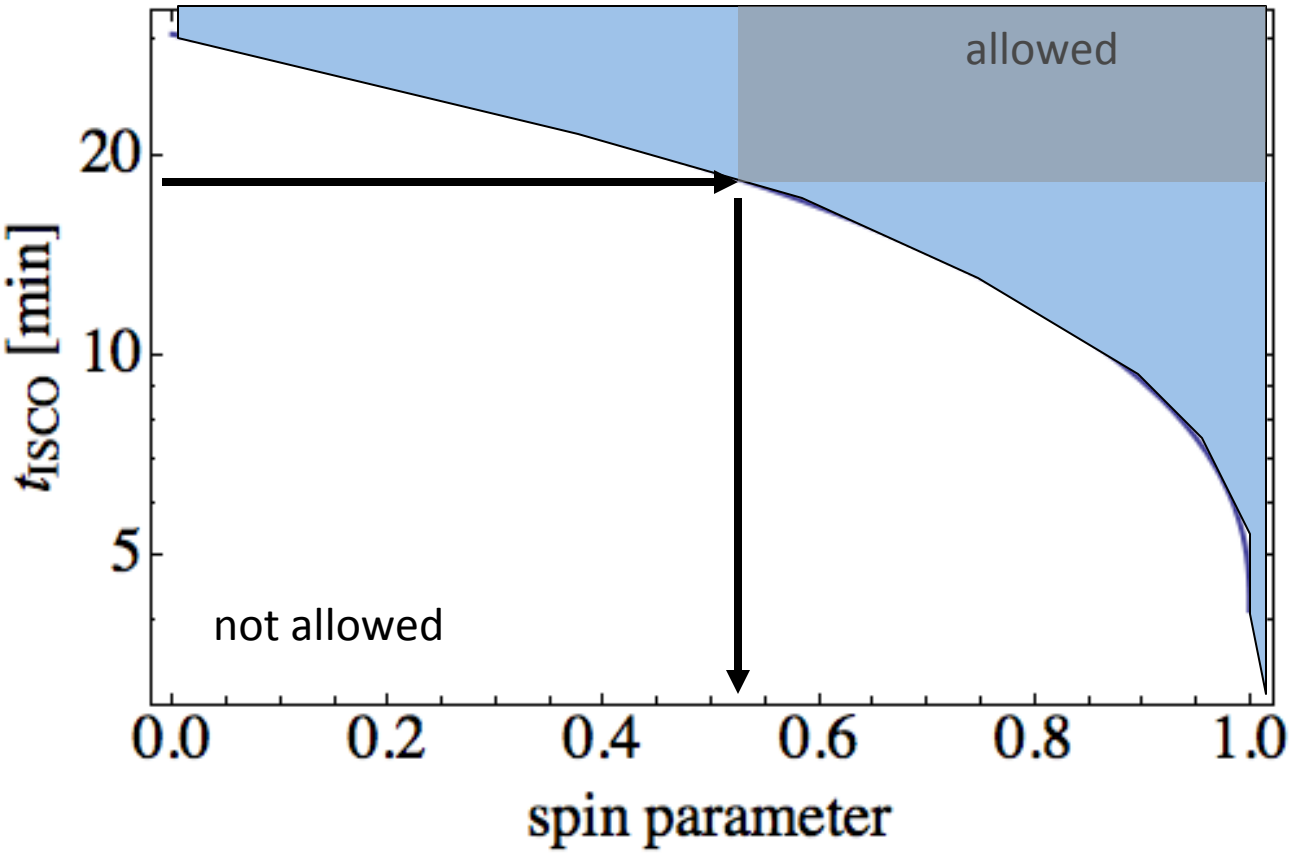
3.4.2007

Minute-timescale variability:
size < 2 light-min = 30 μas

Basic picture: Orbiting hot spot

Magnetic field winds up
Reconnection event
Energy from B heats electrons

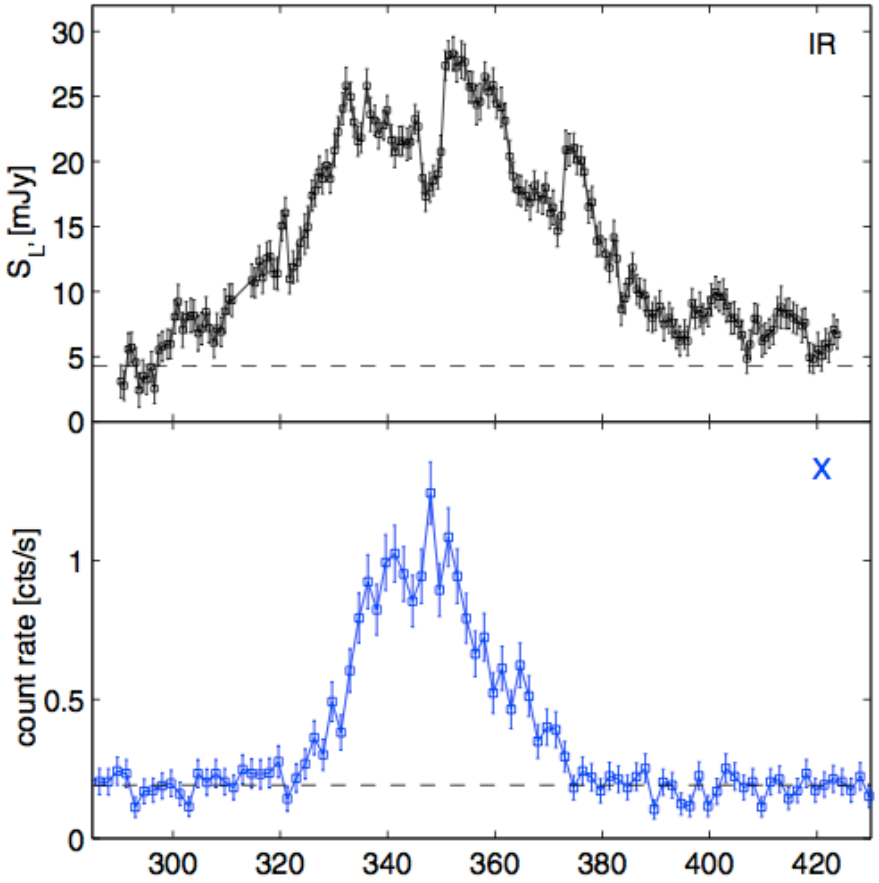
Sgr A* has spin parameter > 0.5 if QPO is due to orbital dynamics



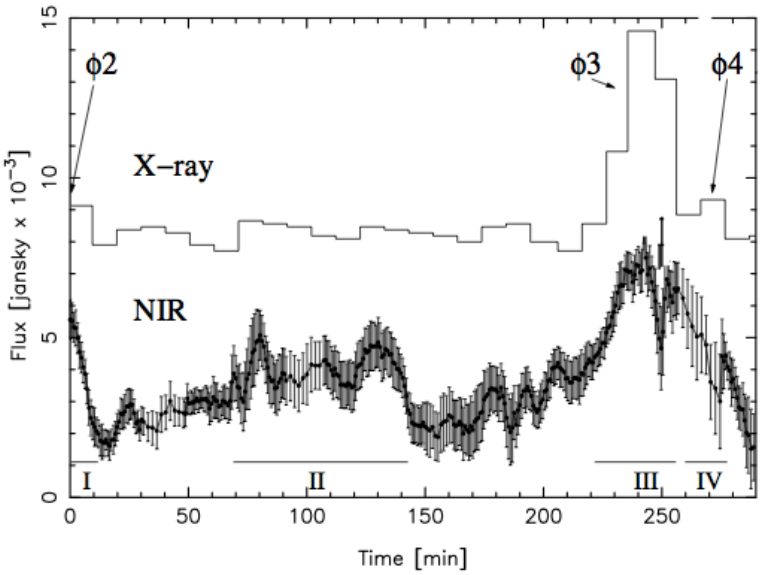
shortest QPO observed: 17min

Genzel+ 2003

Simultaneous X-ray flares happen on the same timescale

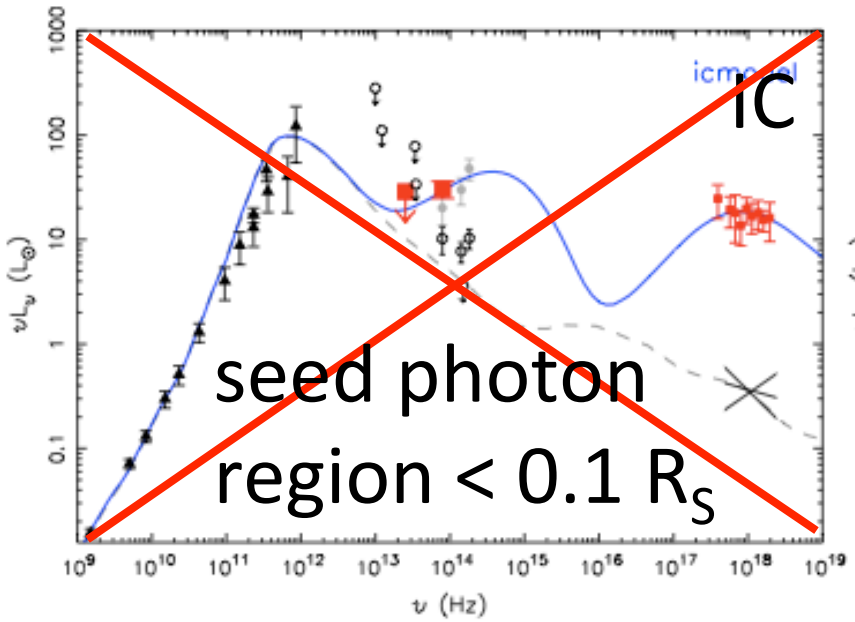


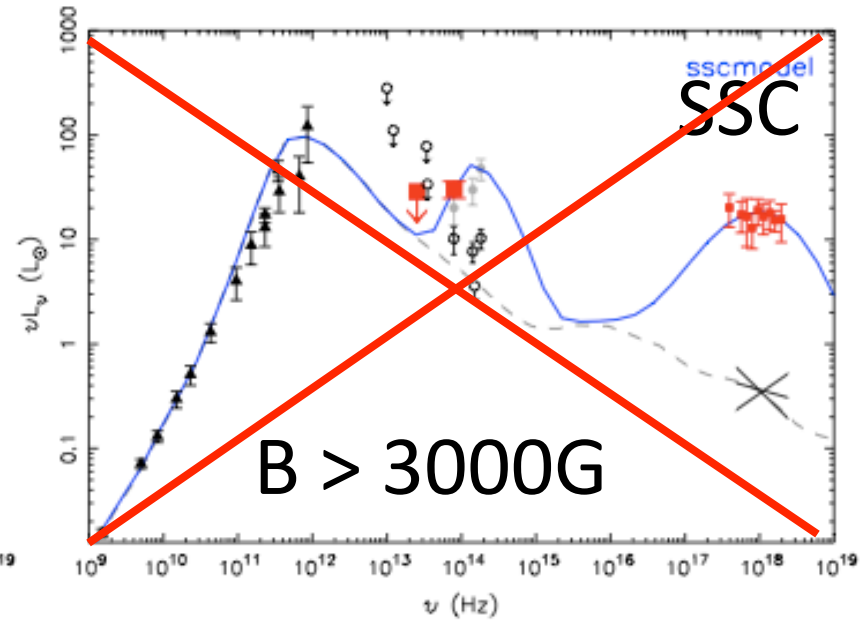
Dodds-Eden et al. 2009,
Porquet et al. 2009

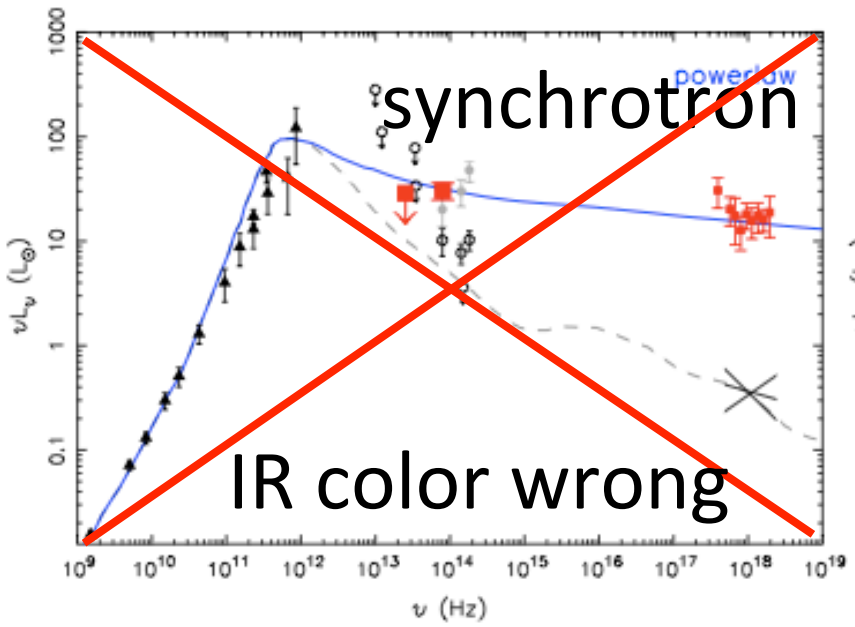


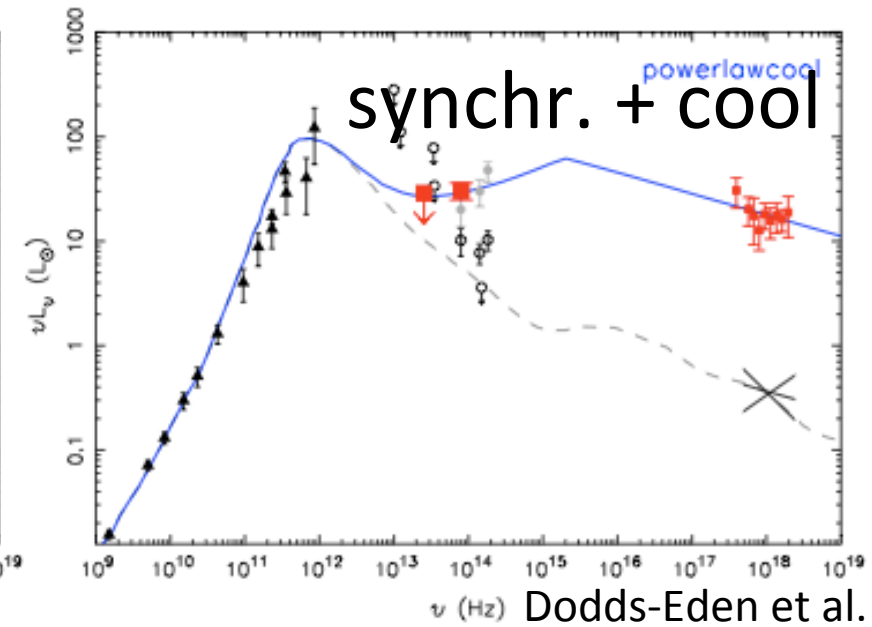
Eckart et al. 2006

X-ray origin is under discussion



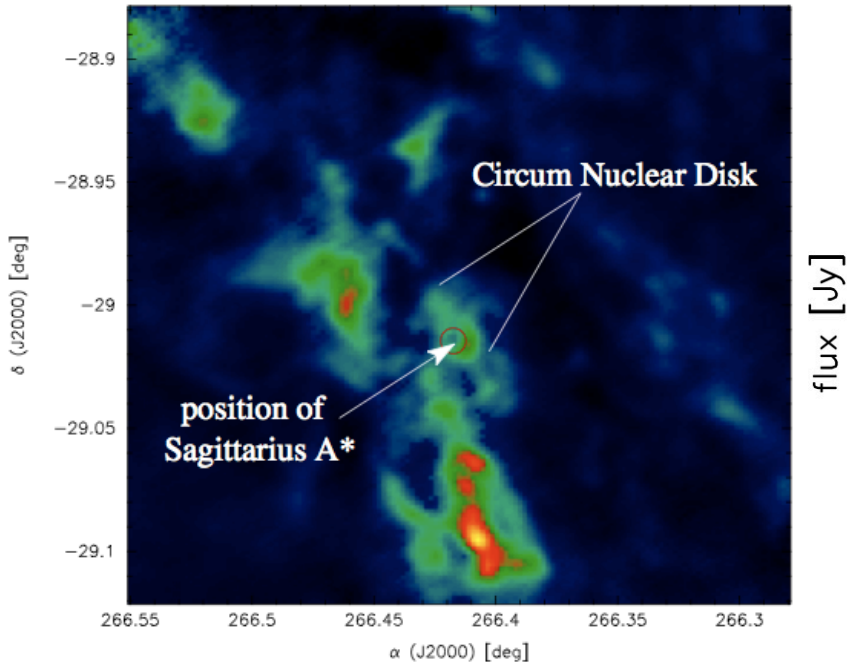




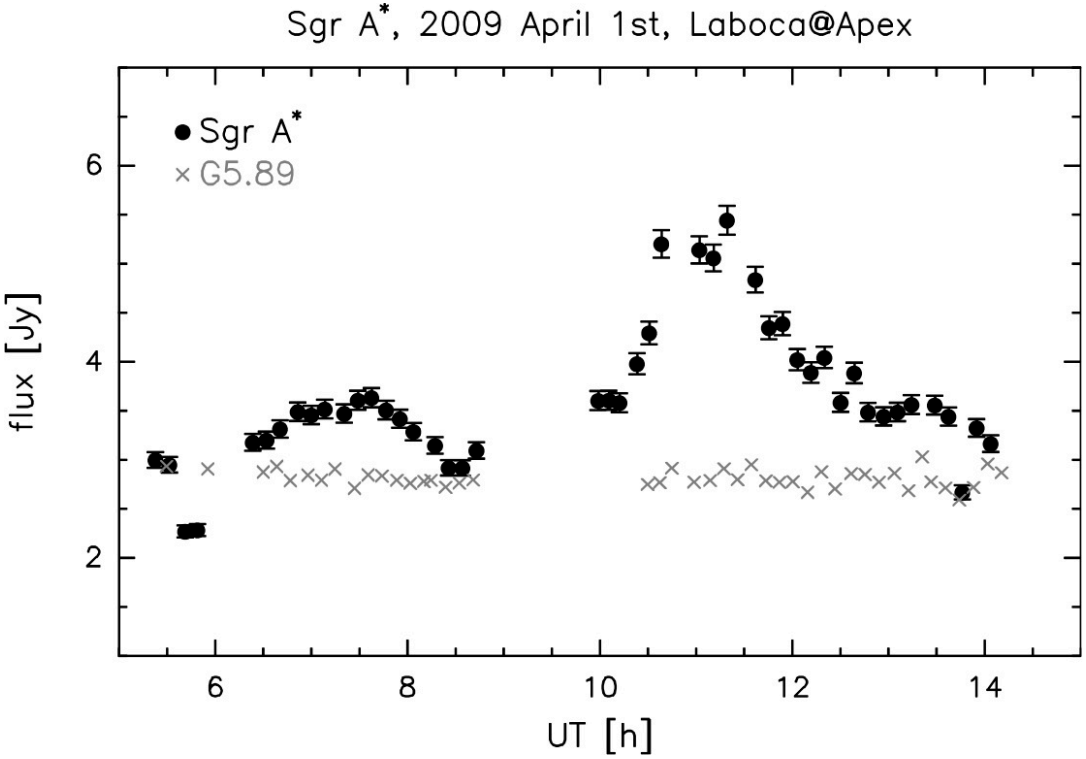


Dodds-Eden et al. 2009

To complicate the picture: submm flares

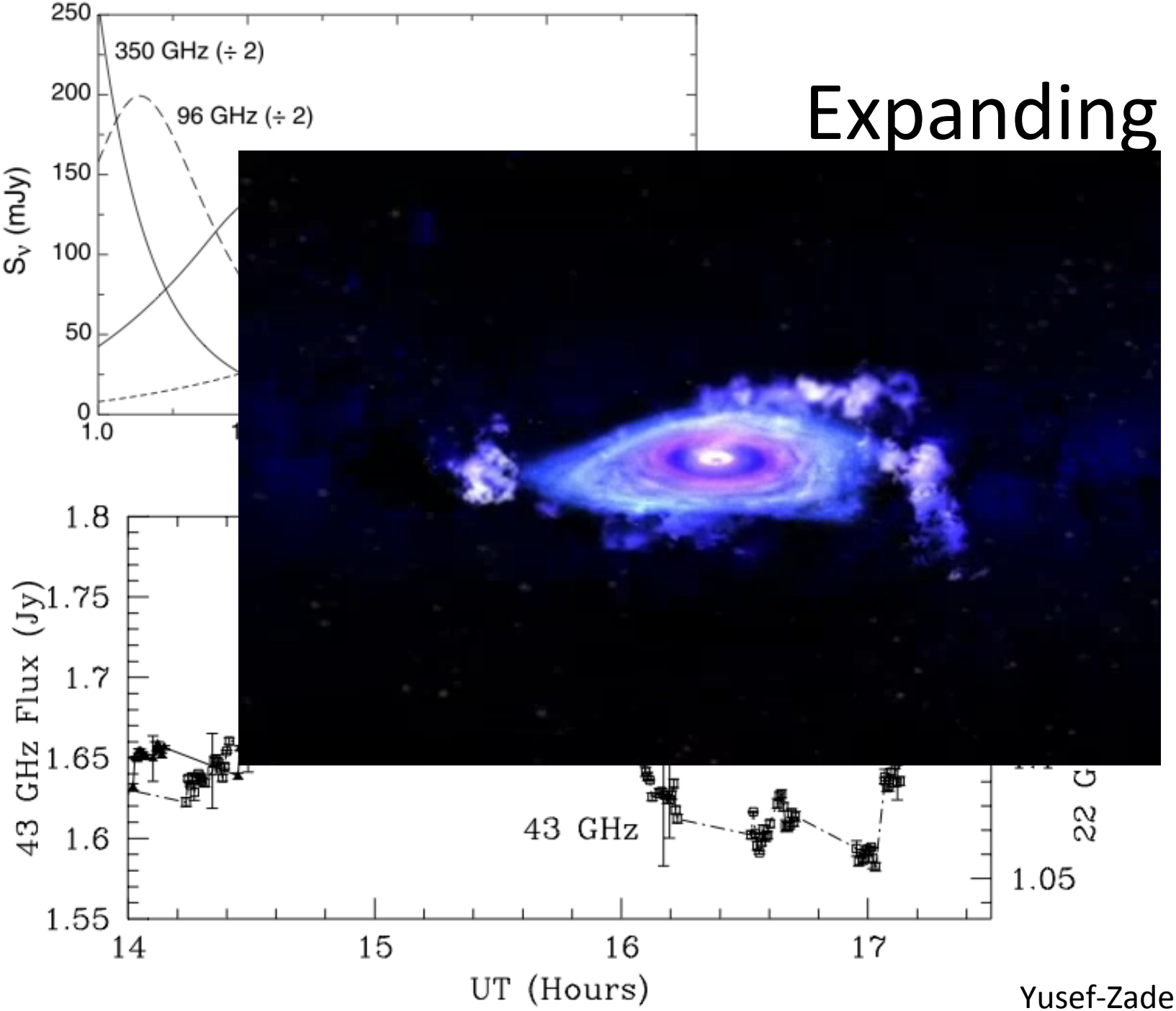


Eckart et al. 2008



Trap et al. in prep.

Expanding

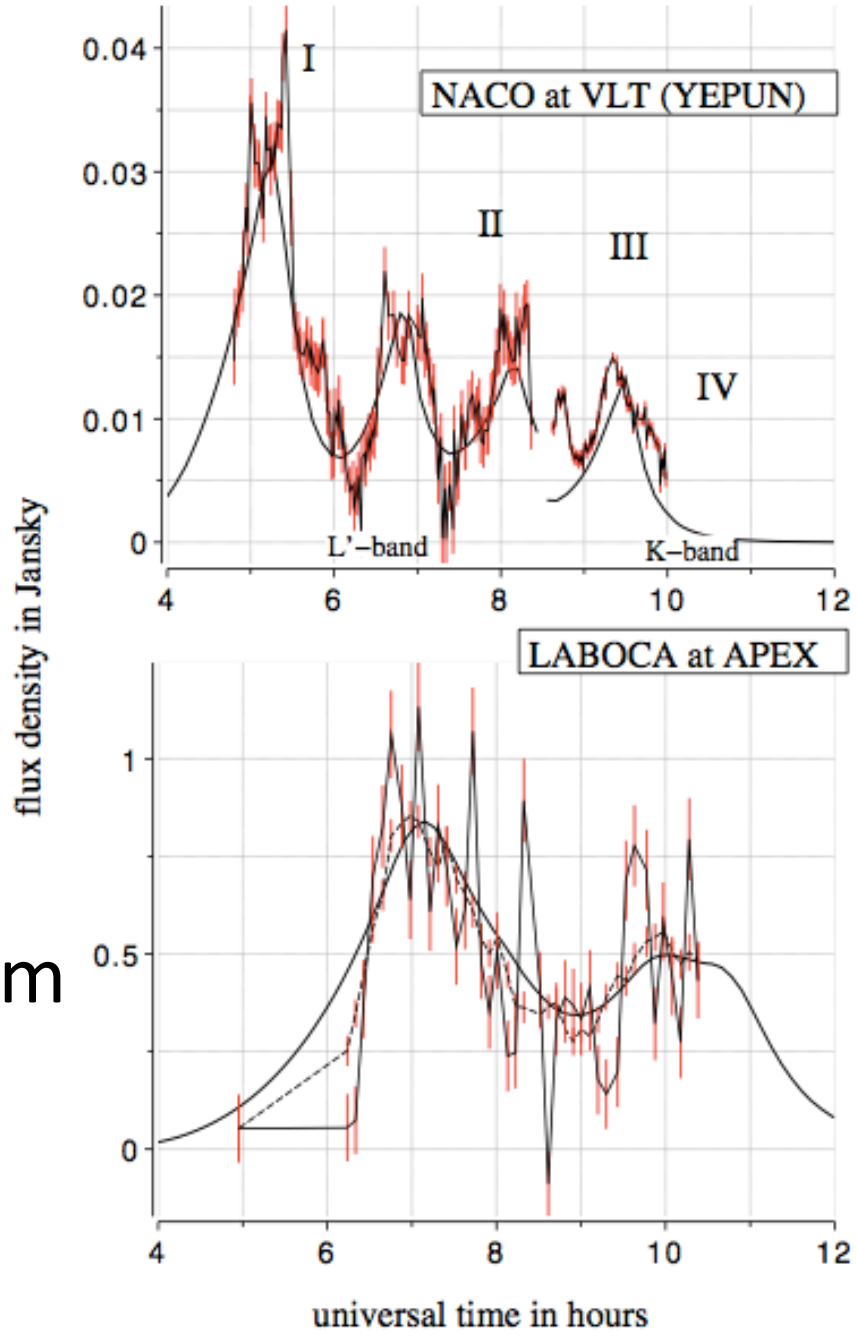


Yusef-Zadeh et al. 2006

Similar evidence for expanding hot spots from NIR and submm

NIR

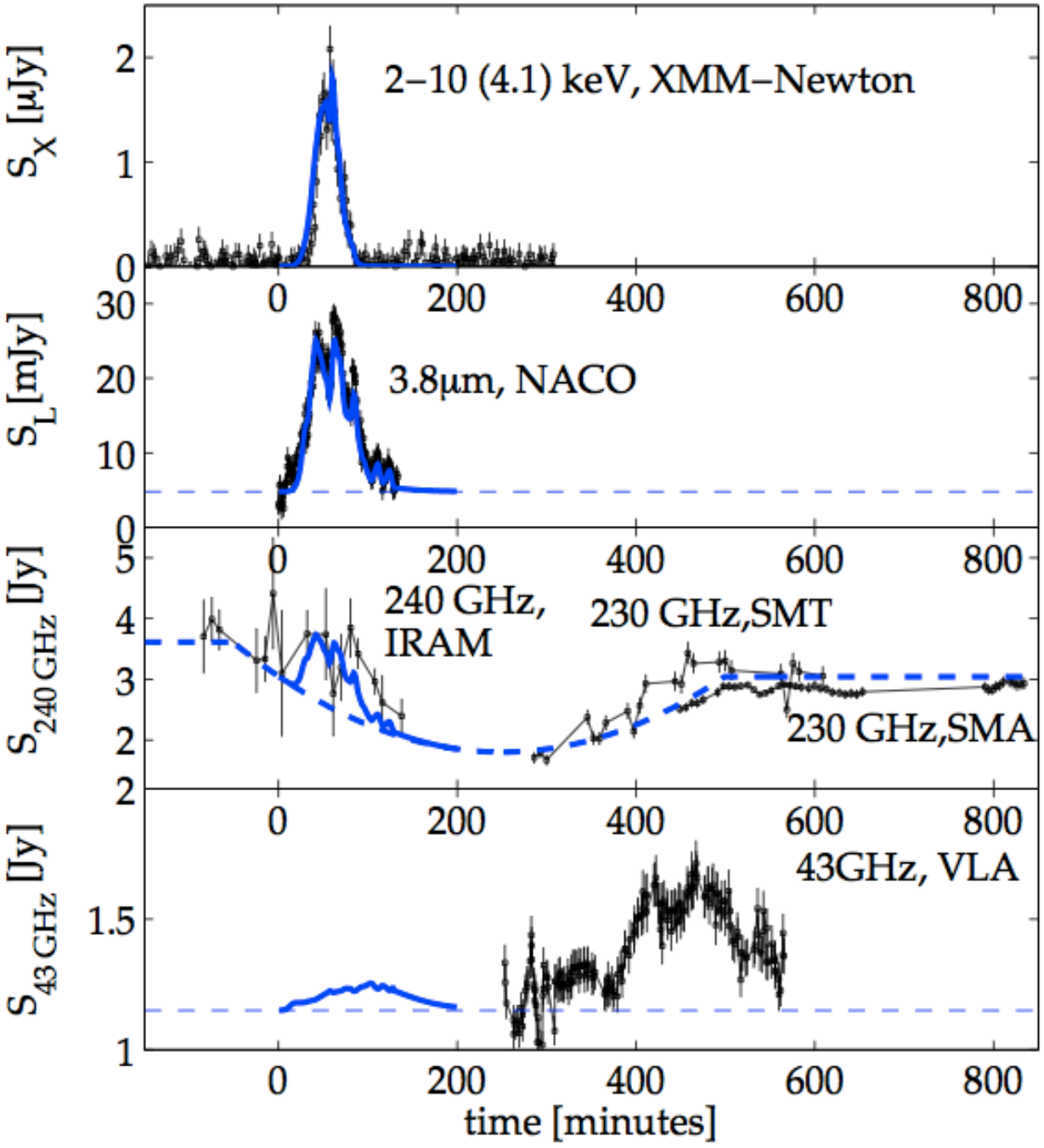
submm



fit NIR
&
predict submm

expansion speed << c

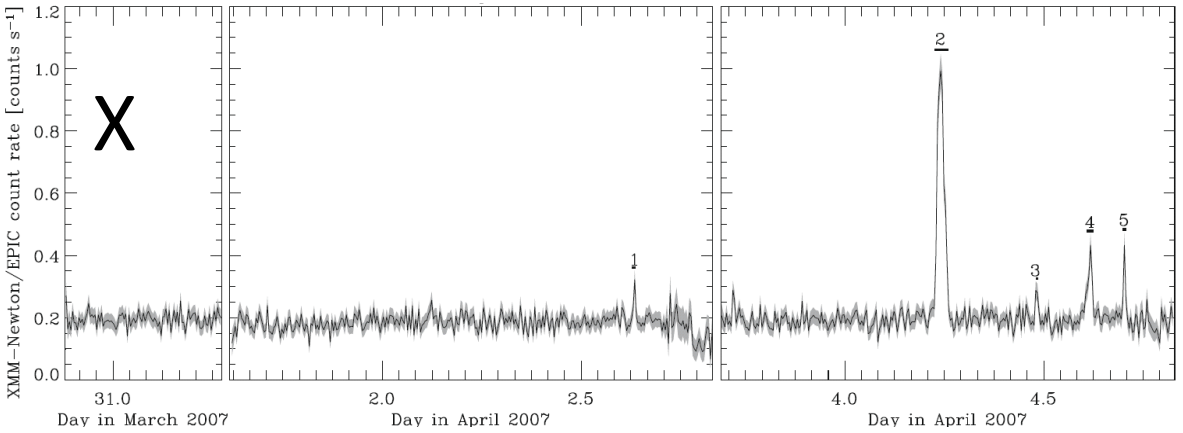
Eckart et al. 2008

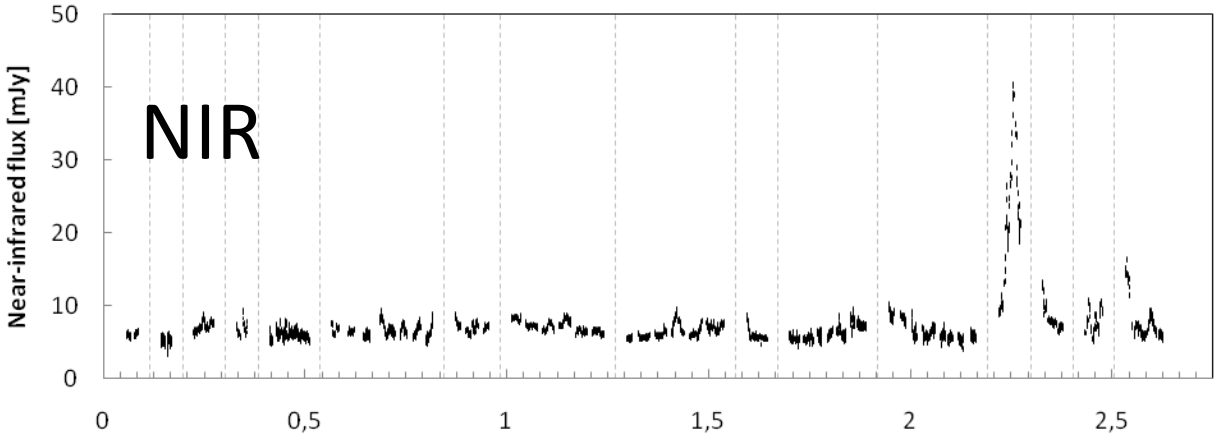


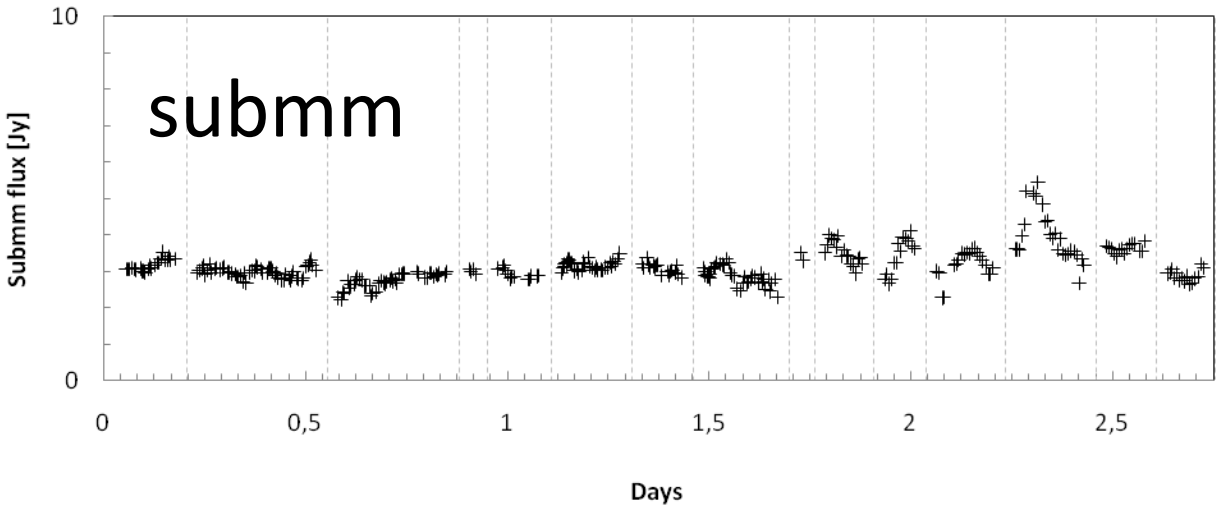
New idea: submm dips

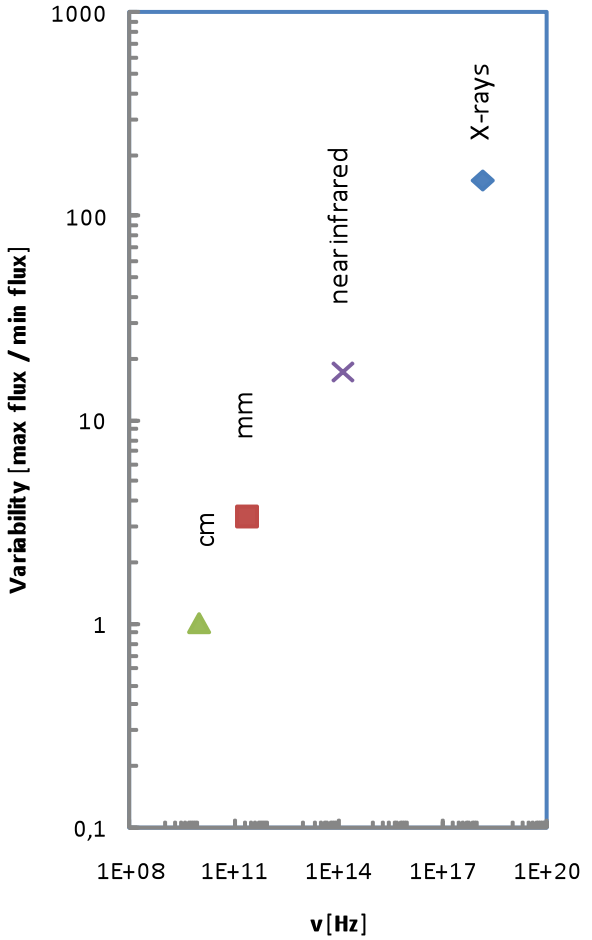
Energy for flares is from B^2

Dodds-Eden et al. submitted
arXiv/1005.0389









Emission is more bursty at shorter wavelengths

What we know and what not

- Sgr A* is a MBH
- Flares occur close to the event horizon
- Quiescent emission is snychrotron
- NIR flares are synchrotron

We know surprisingly little

- Quiescent emission: RIAF or Jet model ?
- Is Sgr A* in a typical state currently?
- What powers flares?
- Nature of X-ray flares?
- Nature of submm flares?
- Interplay?
- Dynamical effects important?