The Center of the Milky Way

Stellar Dynamics
Star Formation/Young Stars
Variable emission from Sgr A*

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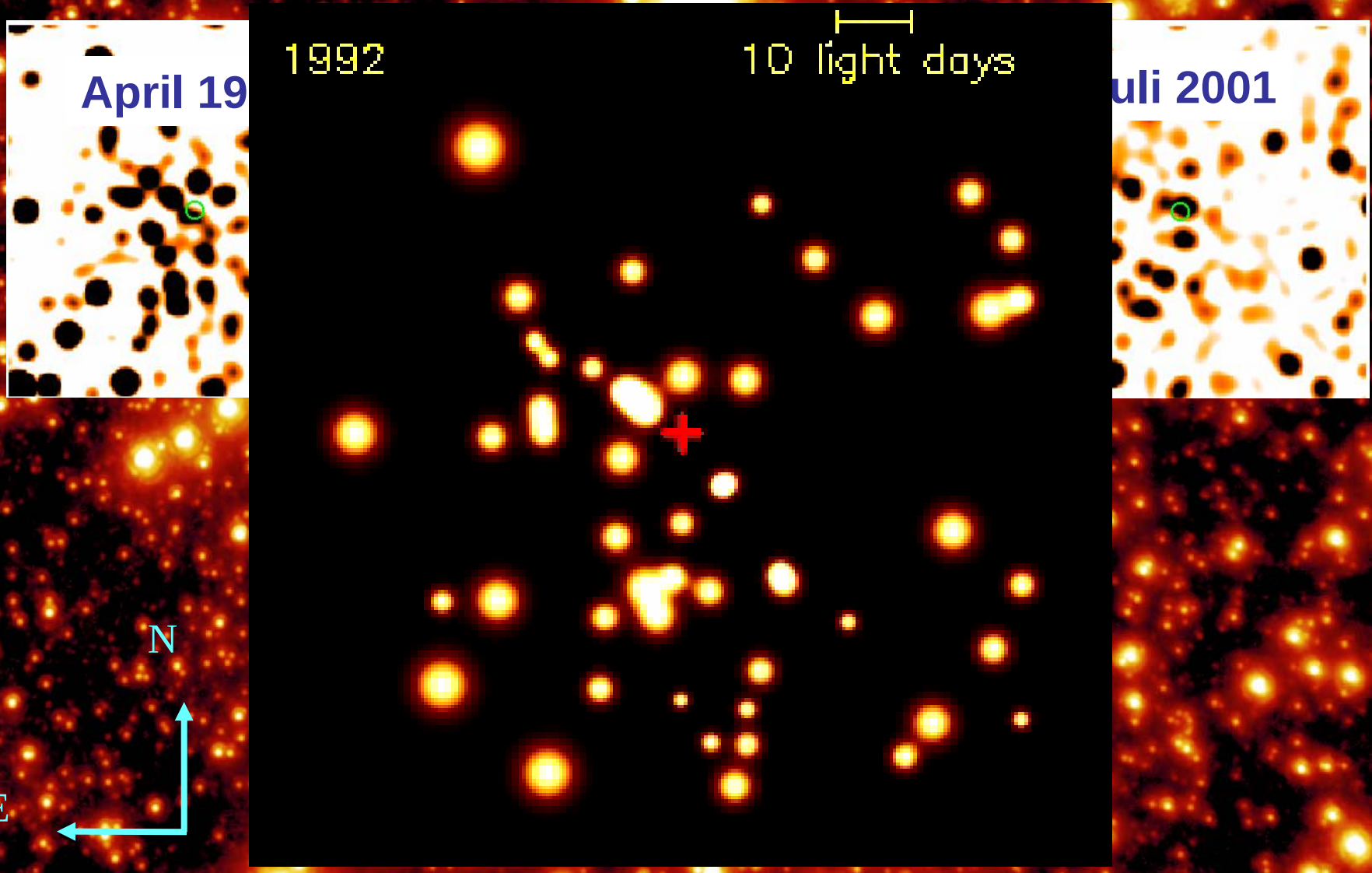
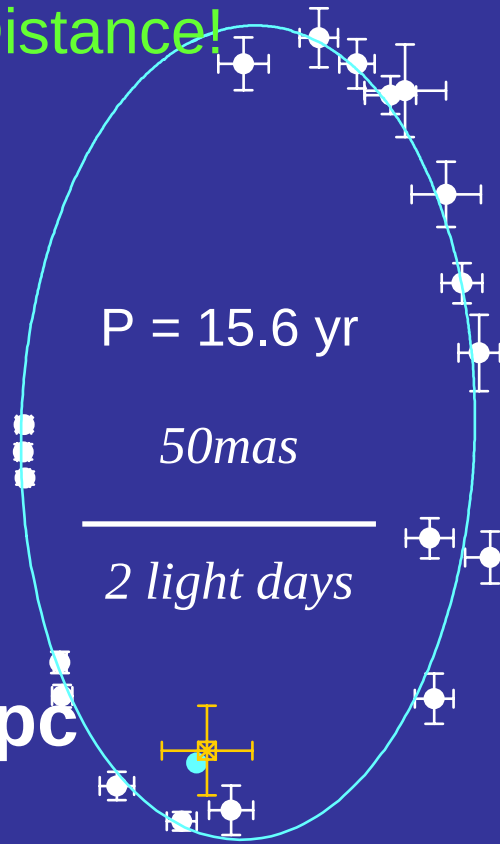
Proper Motions of Stars near Sgr A*



e.g. Eckart & Genzel (1996); Ghez et al. (1998); Genzel et al. (2000); Eckart et al. (2002); Schödel et al. (2003)

The orbit of S2

proper motion data + spectroscopic line of sight velocity
➔ Orbital Elements + BH Mass/Location + GC Distance!

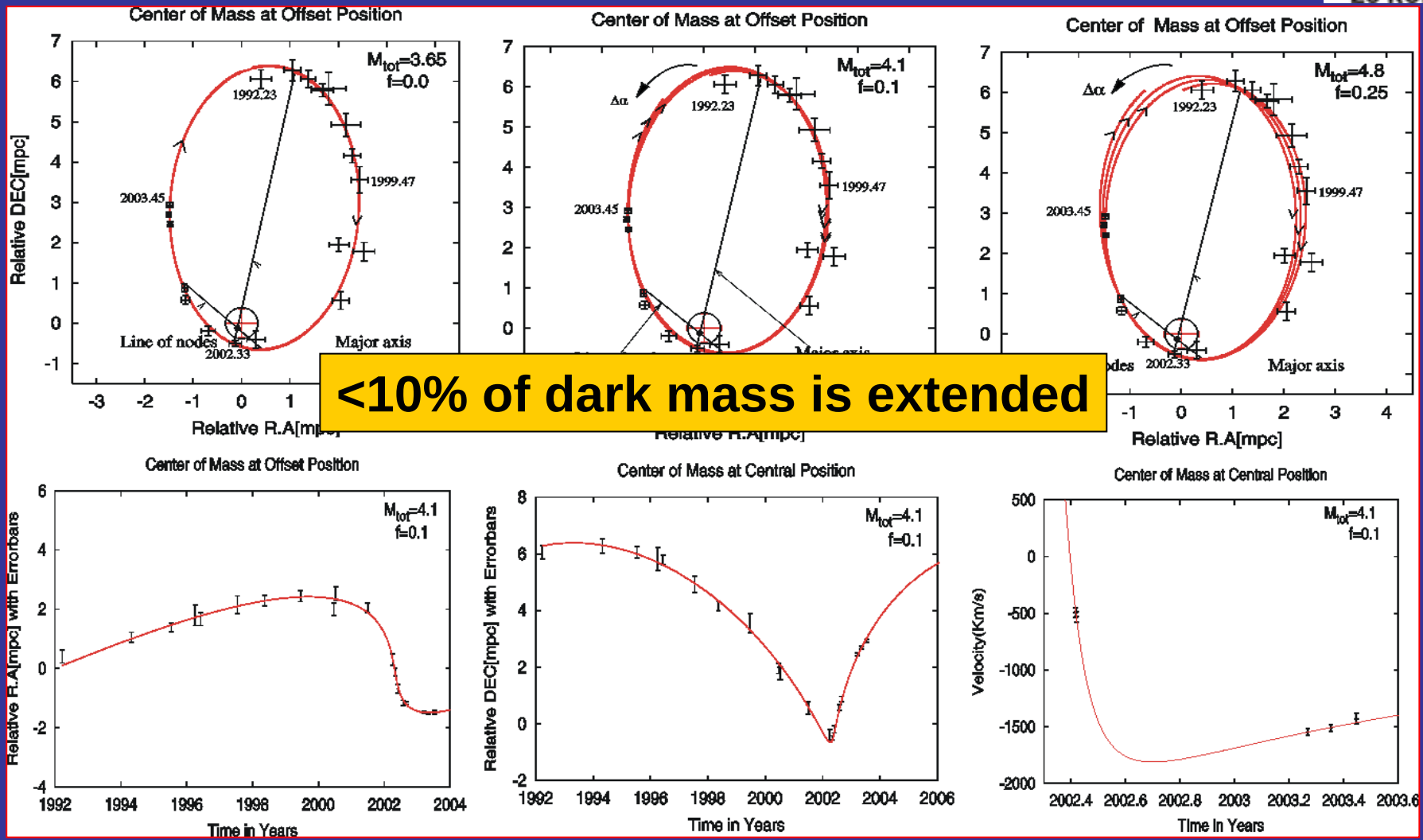


1. **$M_0 = 3.6 \pm 0.6 \times 10^6 M_{sol}$**
2. **$R_0 = 7.9 \pm 0.4$ kpc → 1st direct measurement**
3. **Center of attraction within < 0.16 mpc of formal radio position of Sgr A***
4. **Closest approach to Sgr A*: 0.55 mpc or 15.6 lh**

Schödel et al. (2002, 2003); Ghez et al. (2003); Eisenhauer et al. (2003)

Weighing the central cusp

Non-Keplerian orbit fitting:

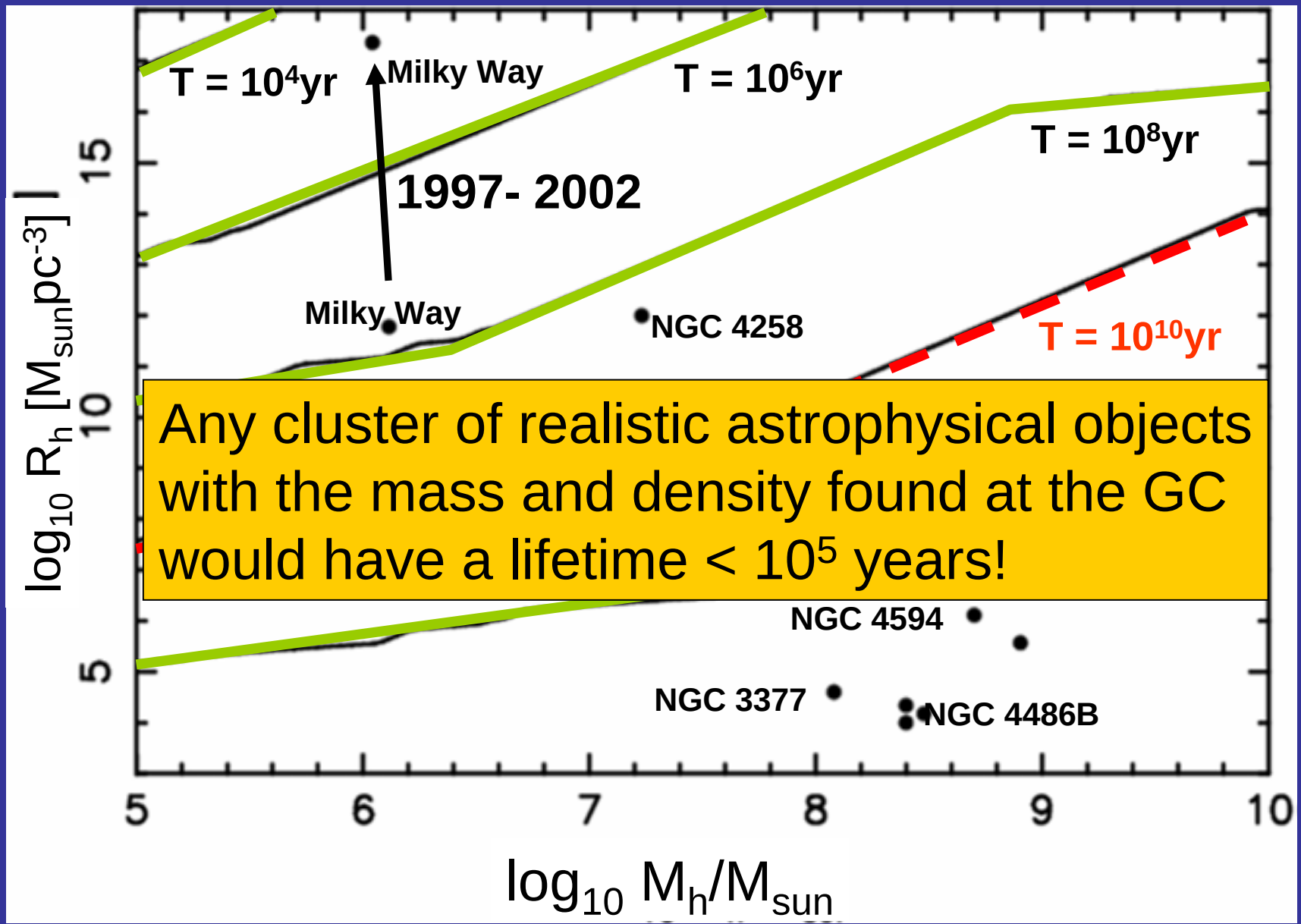


<10% of dark mass is extended

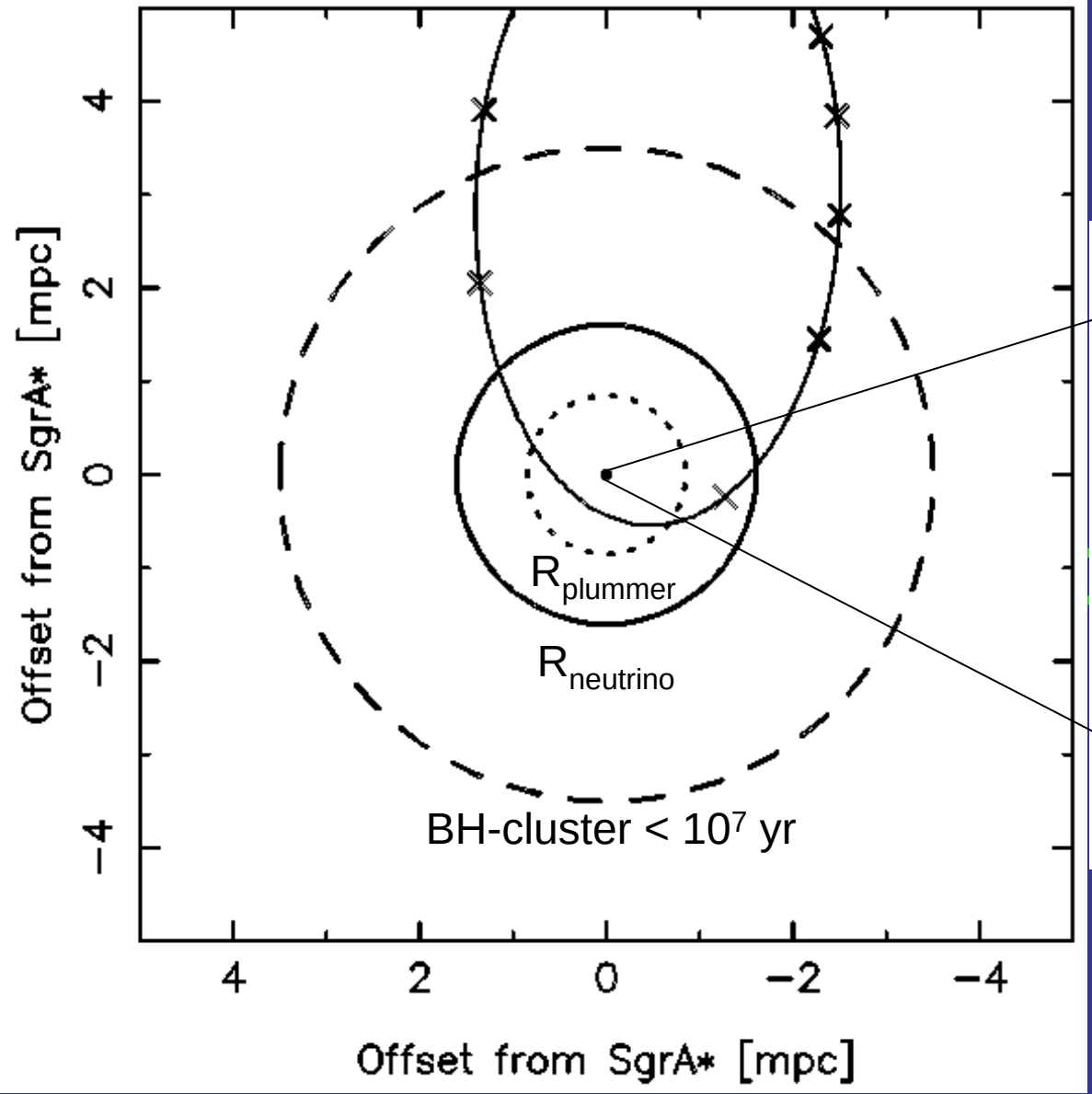
Mouawad et al., 2004, astro-ph/0402338

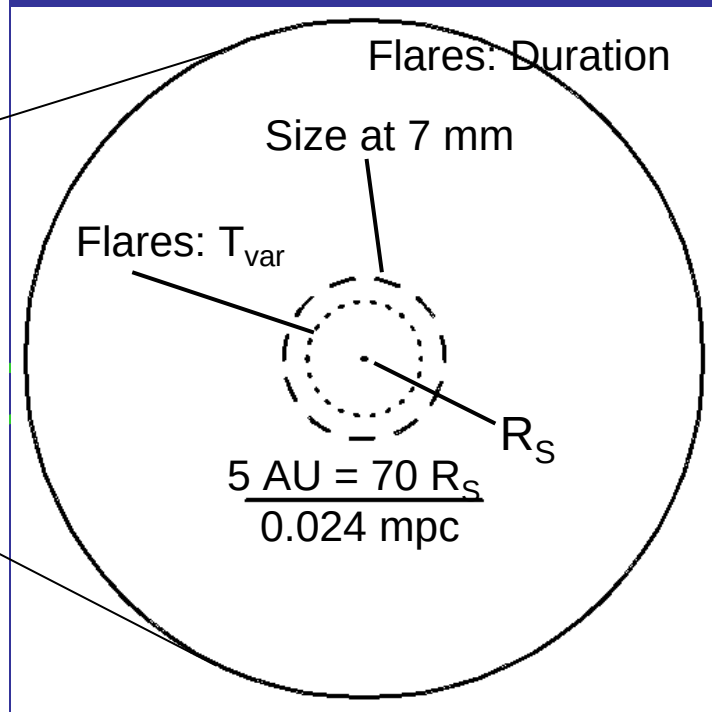
The Nature of SgrA*

Cluster of Dark Objects?



Based on Maoz 1998



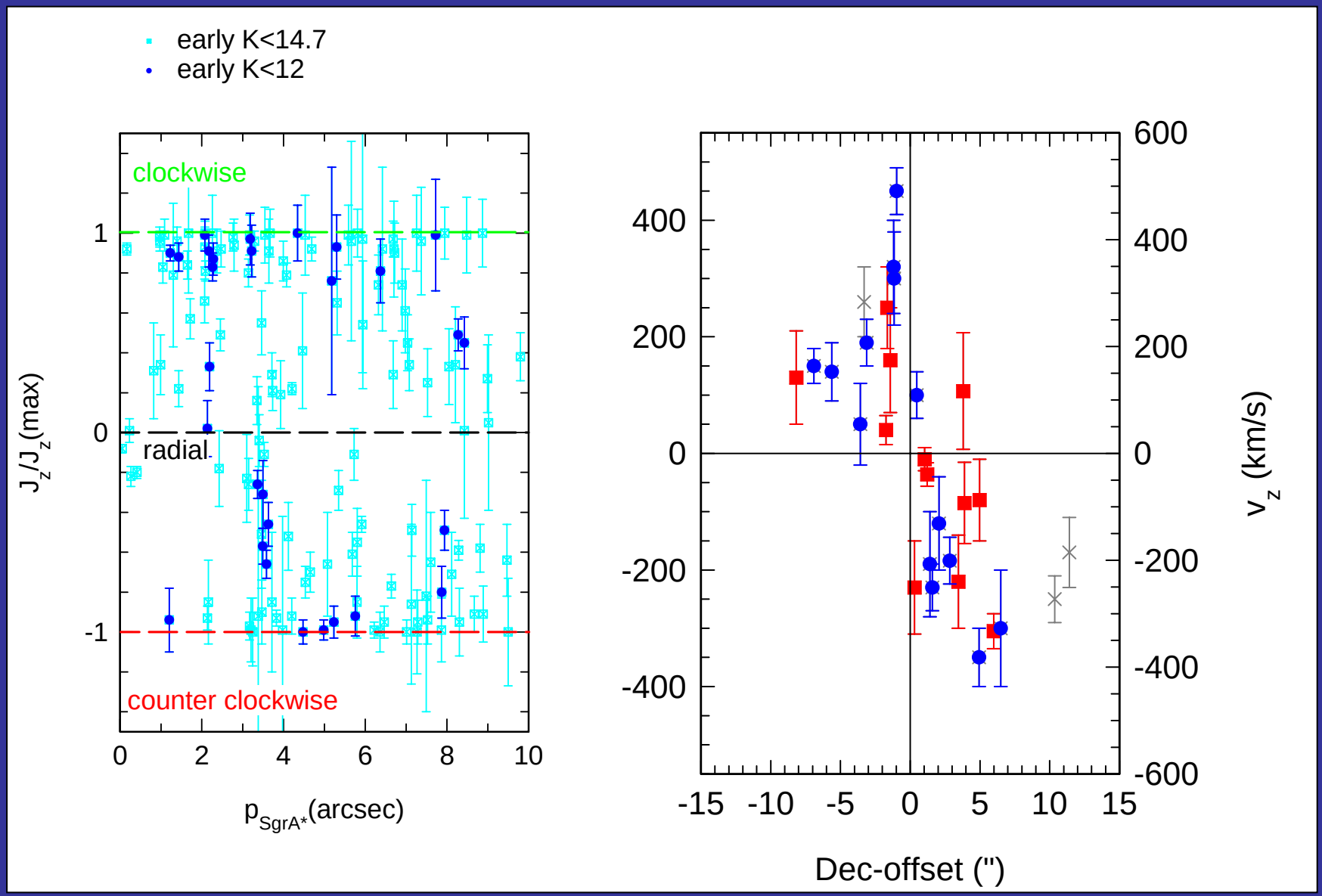


Any non BH Model:

Accretion of matter over life time of galaxy should eventually lead to collapse and BH formation!

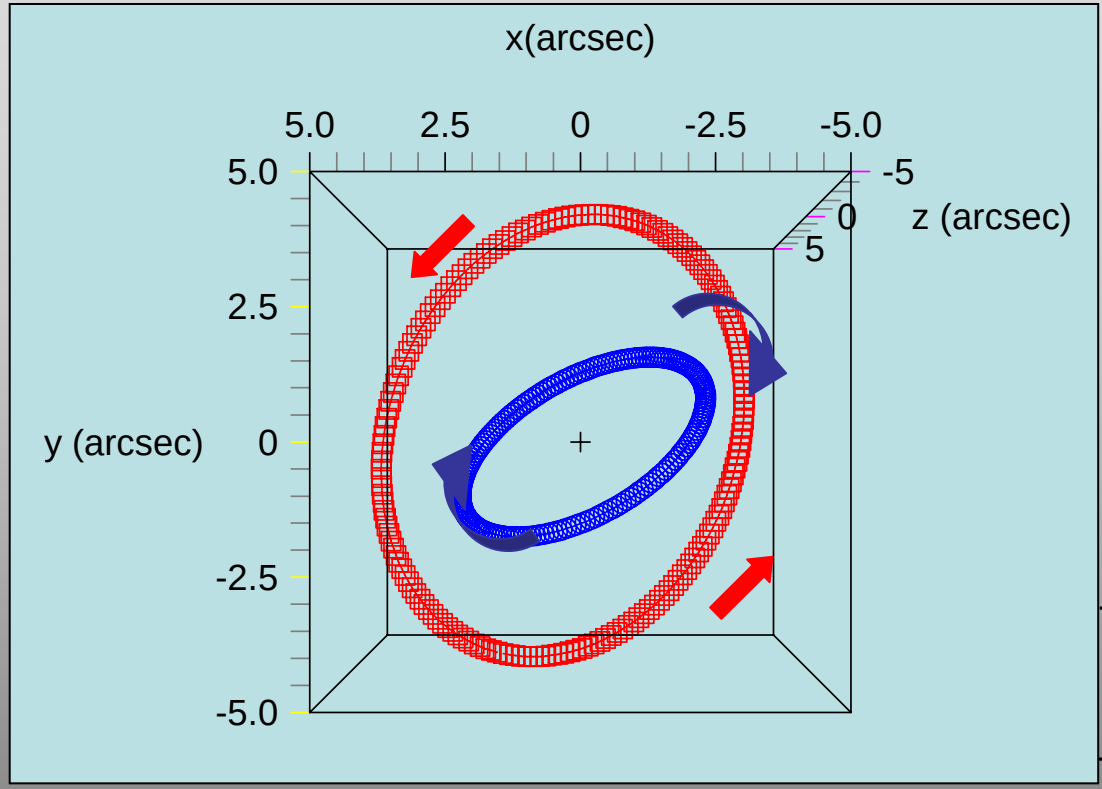
Stellar Dynamics near SgrA*: Evidence for recent star formation

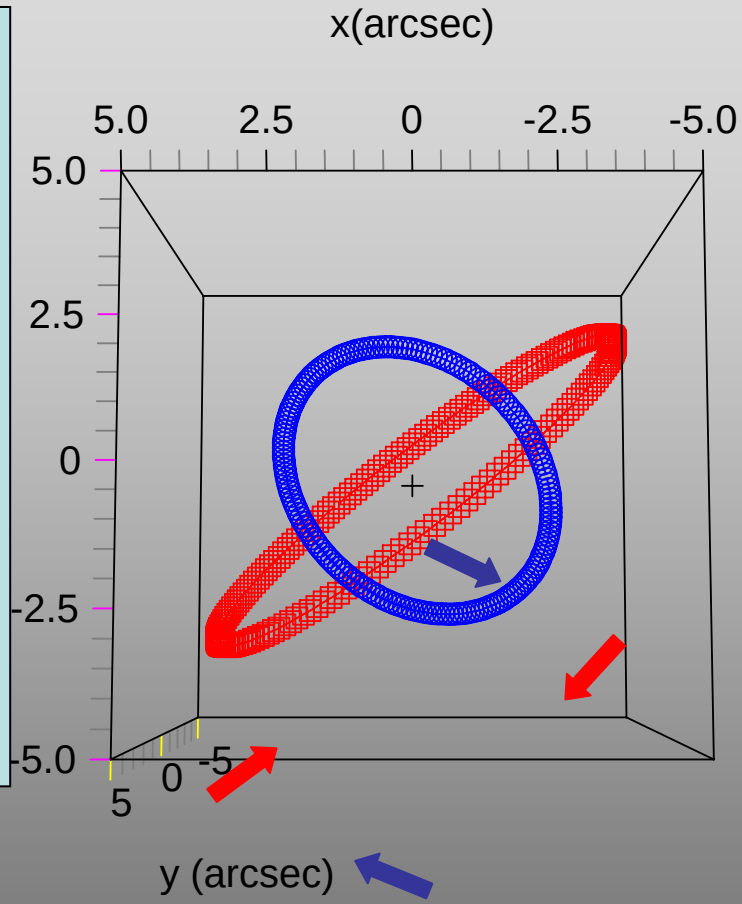
Overall rotation of early type stars



Genzel et al. 2003, Ap.J. , Ott et al. 2004 (1000 proper motions, 200 3Dvels)

Rotating disks of early type stars

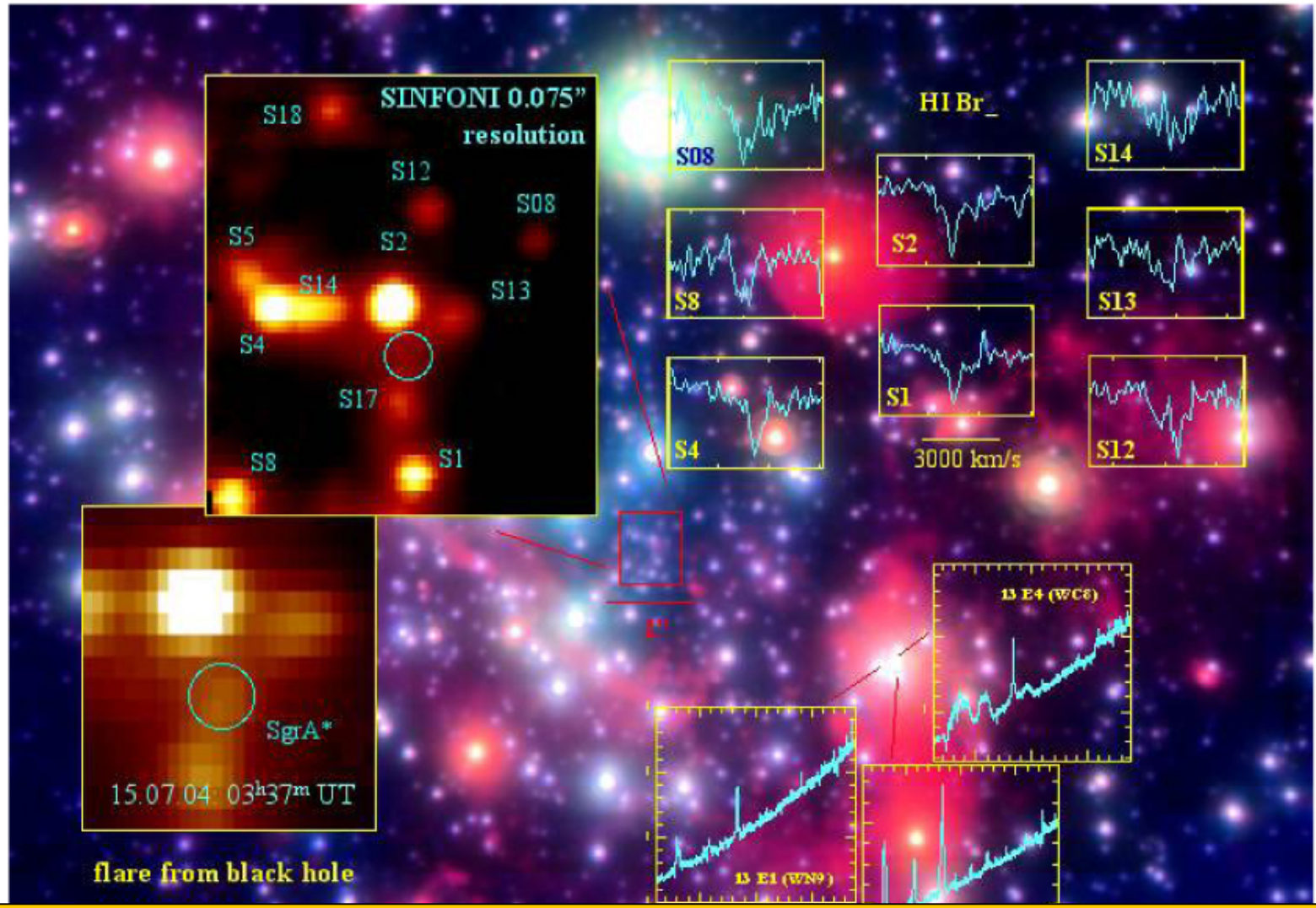




SPIFFI spectroscopy:
The two disks have *very similar short-lived stellar populations* (LBV, Wolf-Rayet…)

➔ ***Coeval formation***

Genzel et al. 2003, Ap.J. 2003 (astro-ph 0305423)
Levin & Beloorodov, Ap.J. 2003



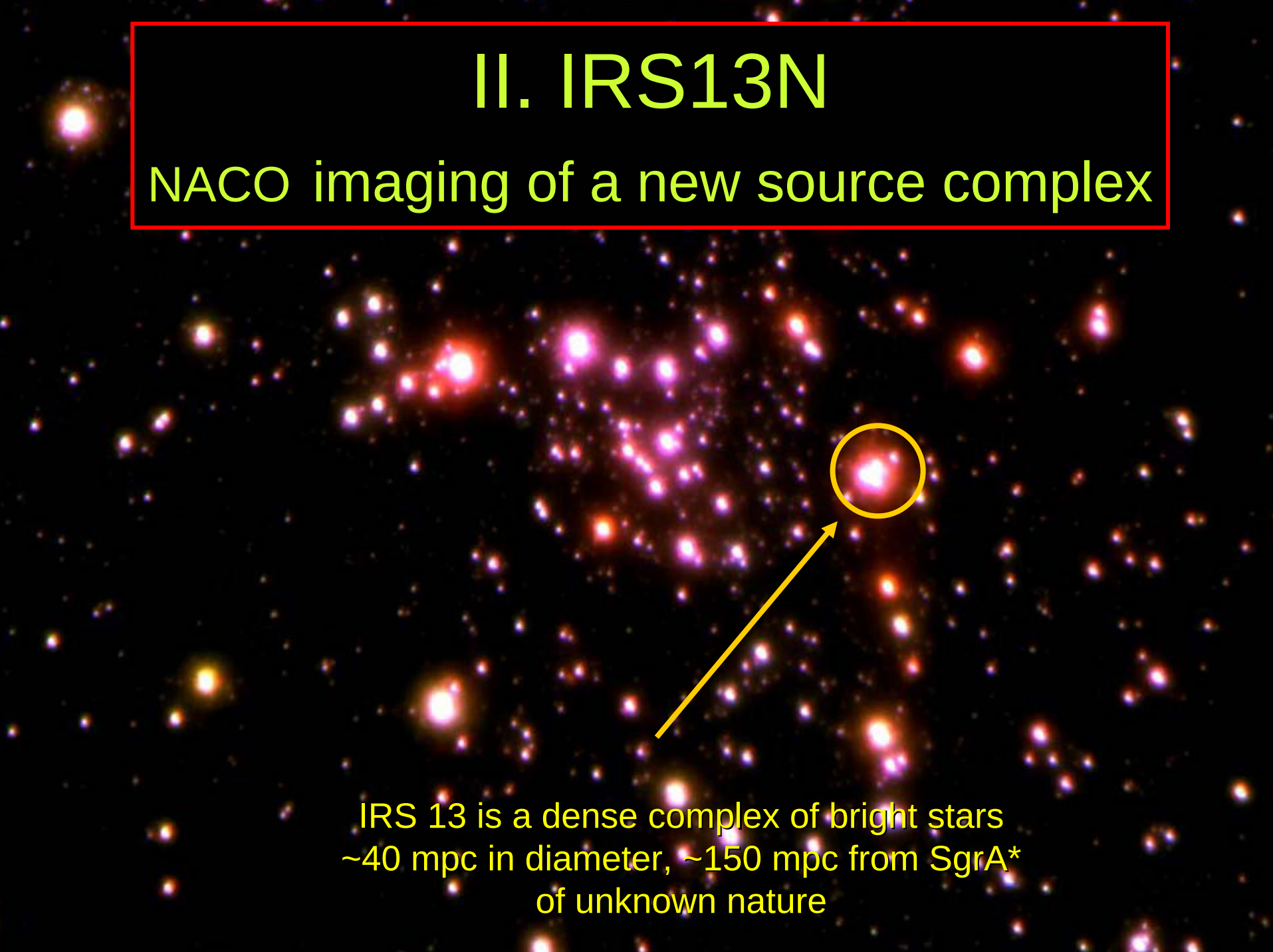
Many stars near SgrA* are indeed OB main sequence stars!!!

Eisenhauer et al. in preparation

SINFONI Observations of the Galactic Centre Region

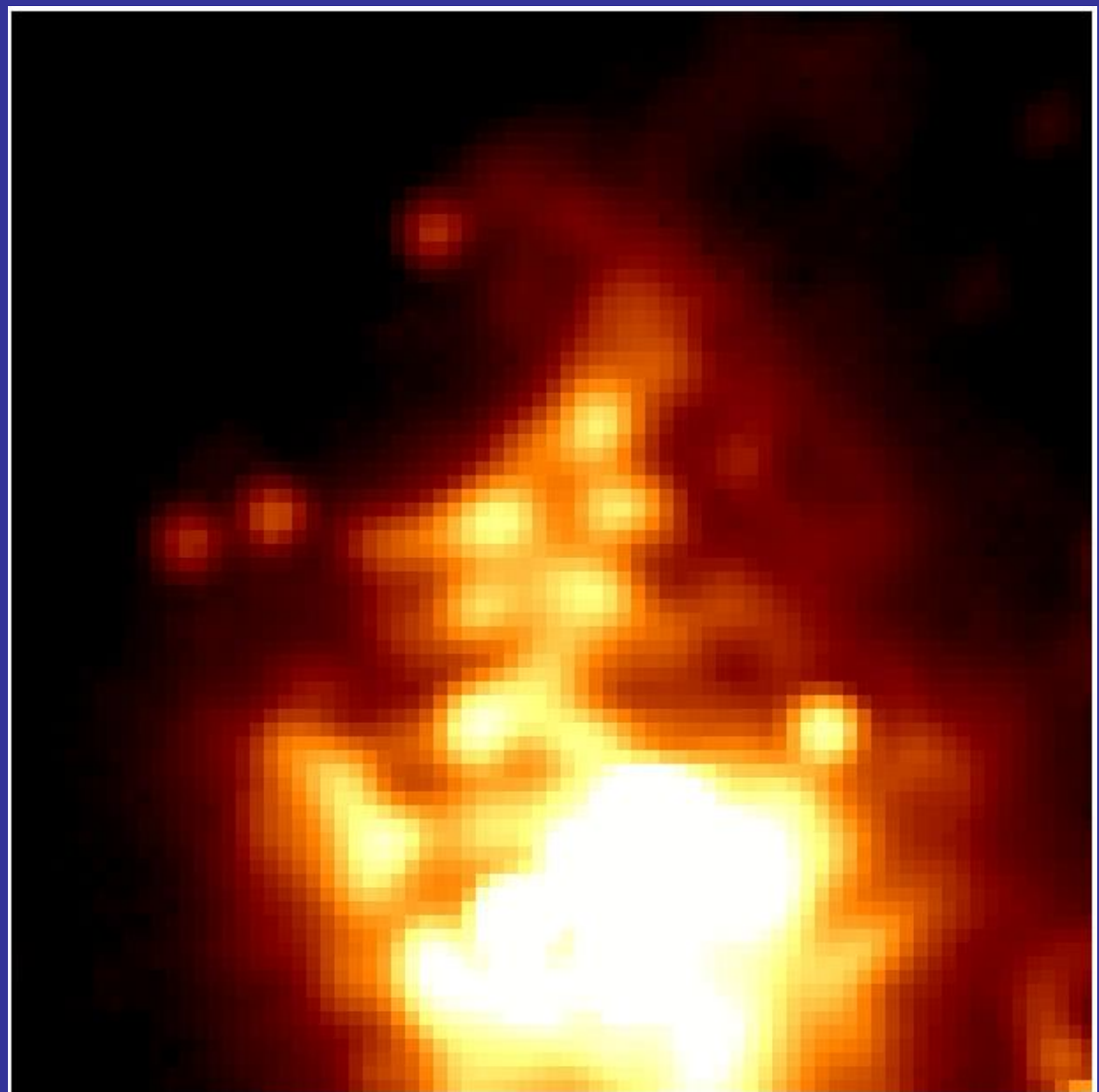
II. IRS13N

NACO imaging of a new source complex



IRS 13 is a dense complex of bright stars
~40 mpc in diameter, ~150 mpc from SgrA*
of unknown nature

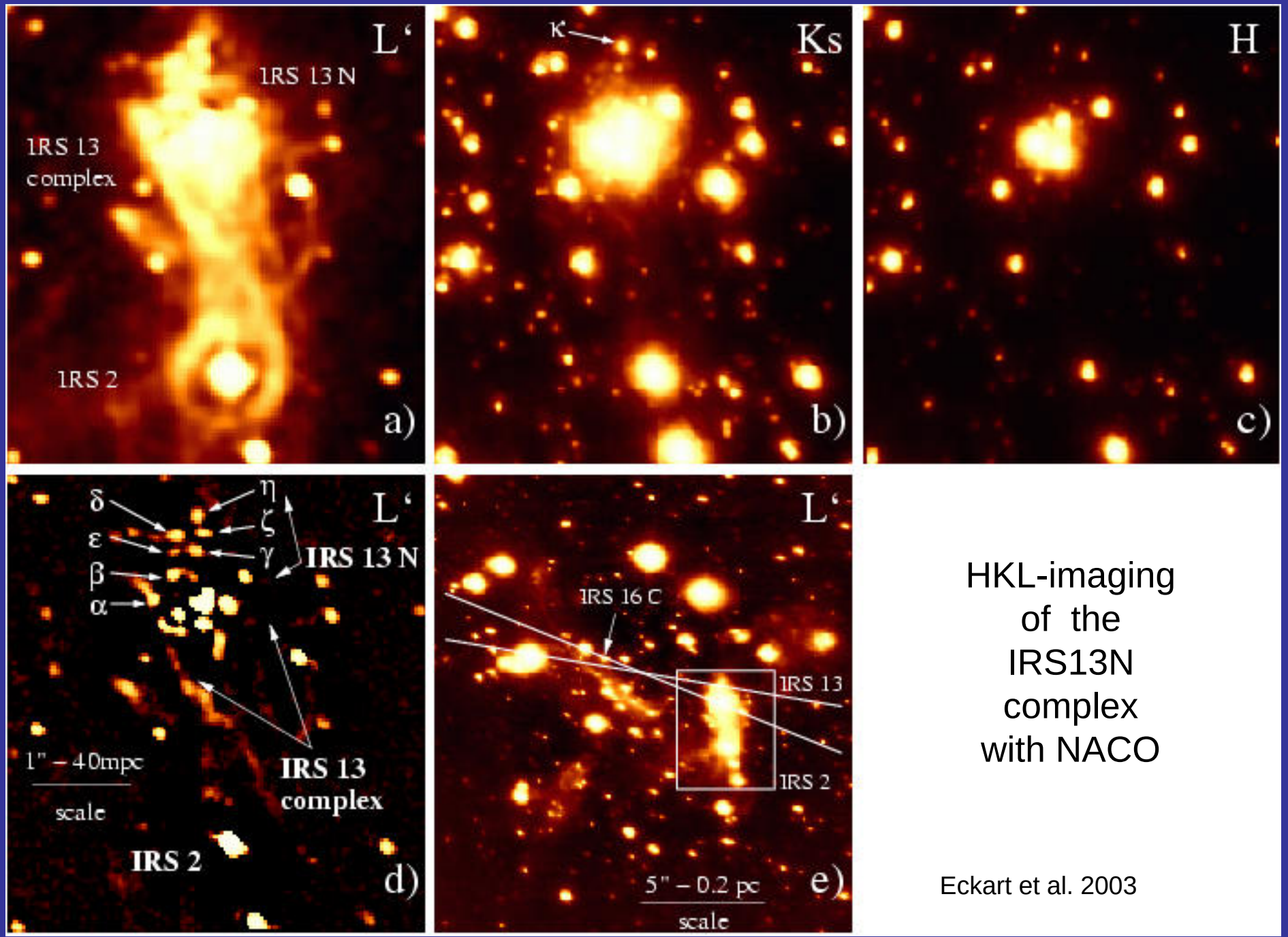
NACO L-band Adaptive Optics



NIR
3.8 μm

science
verification
data

500mas
23 light days



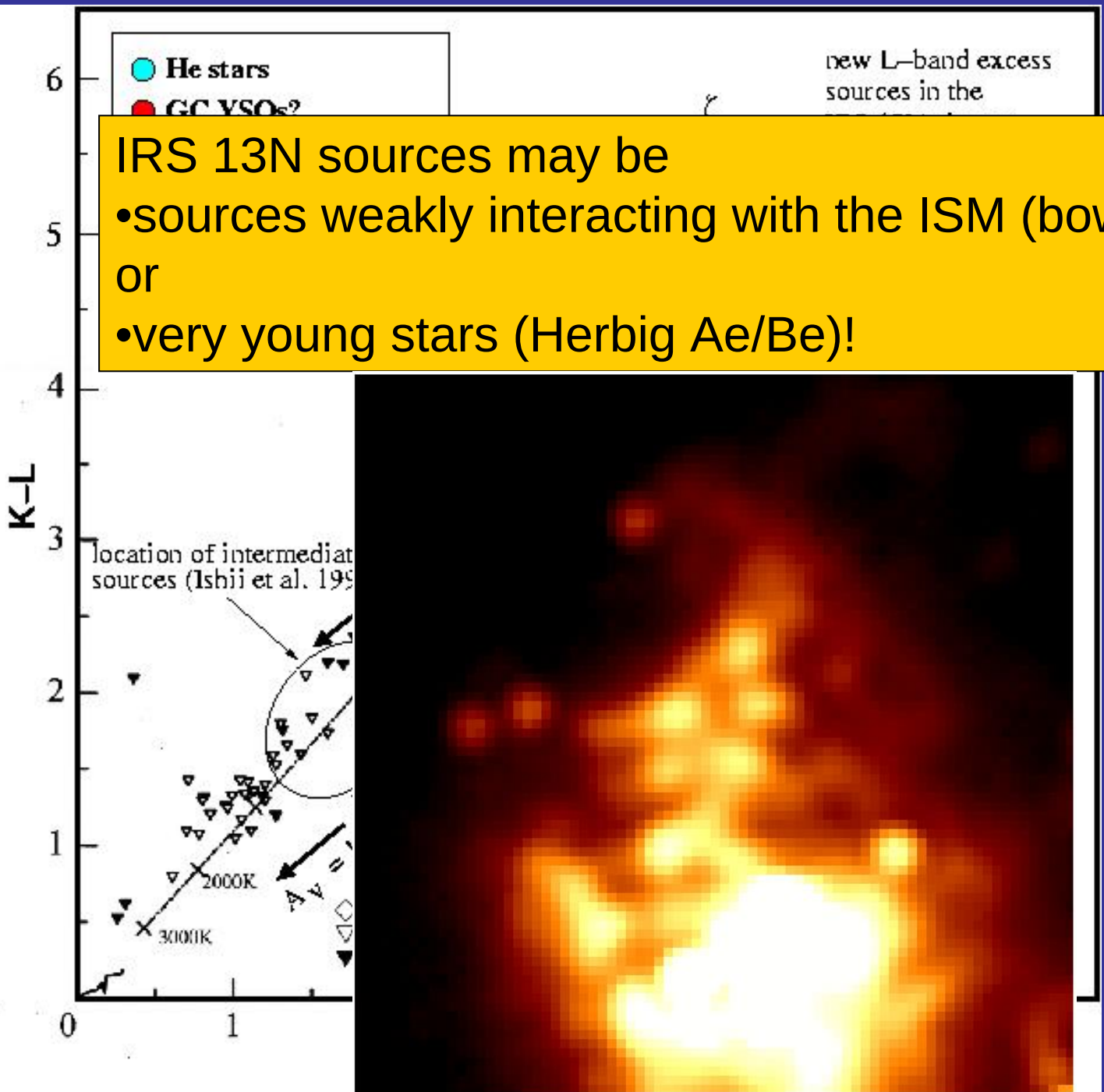
HKL-imaging of the IRS13N complex with NACO

Eckart et al. 2003

HKL-colors of sources

IRS 13N sources may be
- sources weakly interacting with the ISM (bow shocks)

or
- very young stars (Herbig Ae/Be)!



L=10e2-10e4 L_{sol}
M=2-8 M_{sol}

Eckart et al. 2004

*Variable Emission from SgrA**

Dynamical Model for Accretion

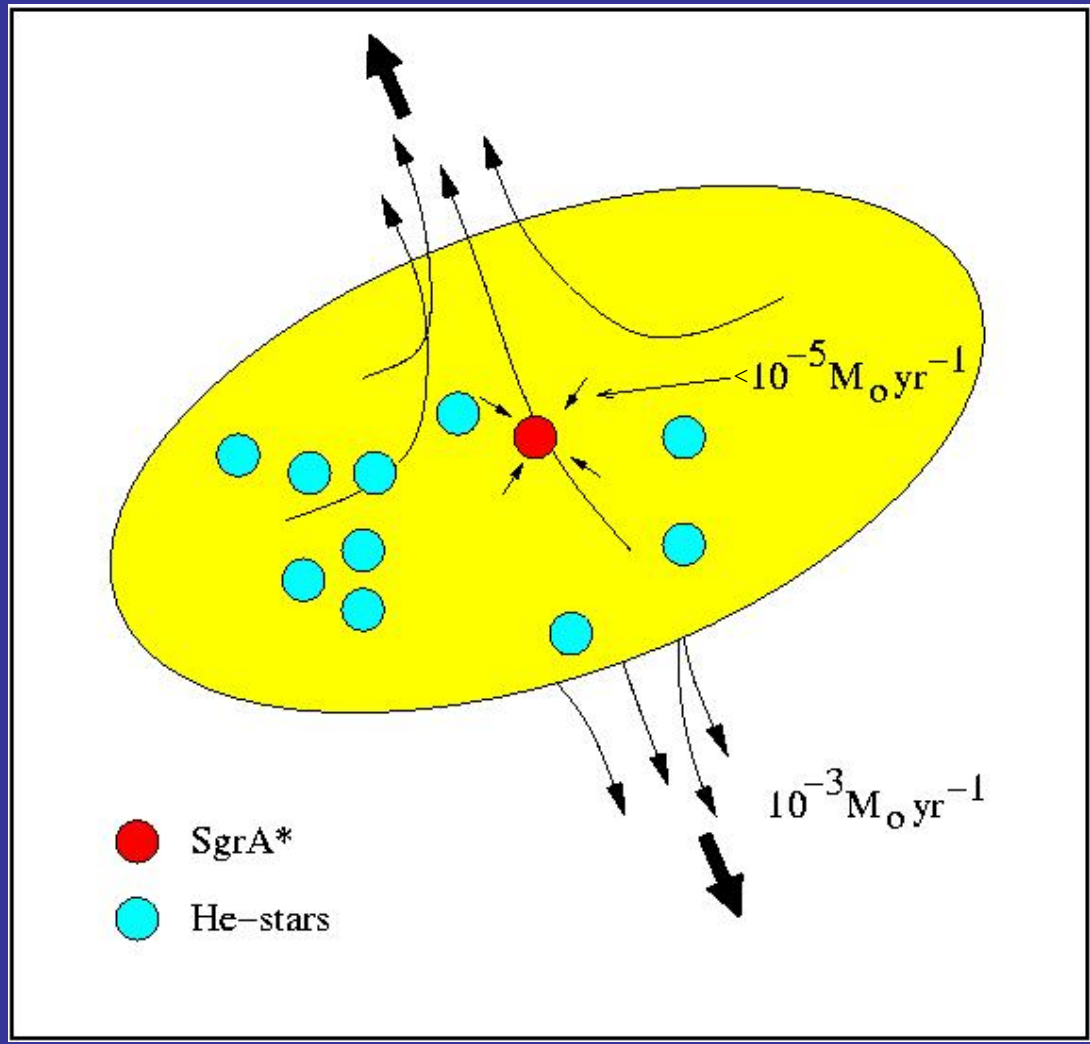
Ineraction between the ‘starburst’ and the black hole

Massloss from stars $10^{-3} M_o yr^{-1}$

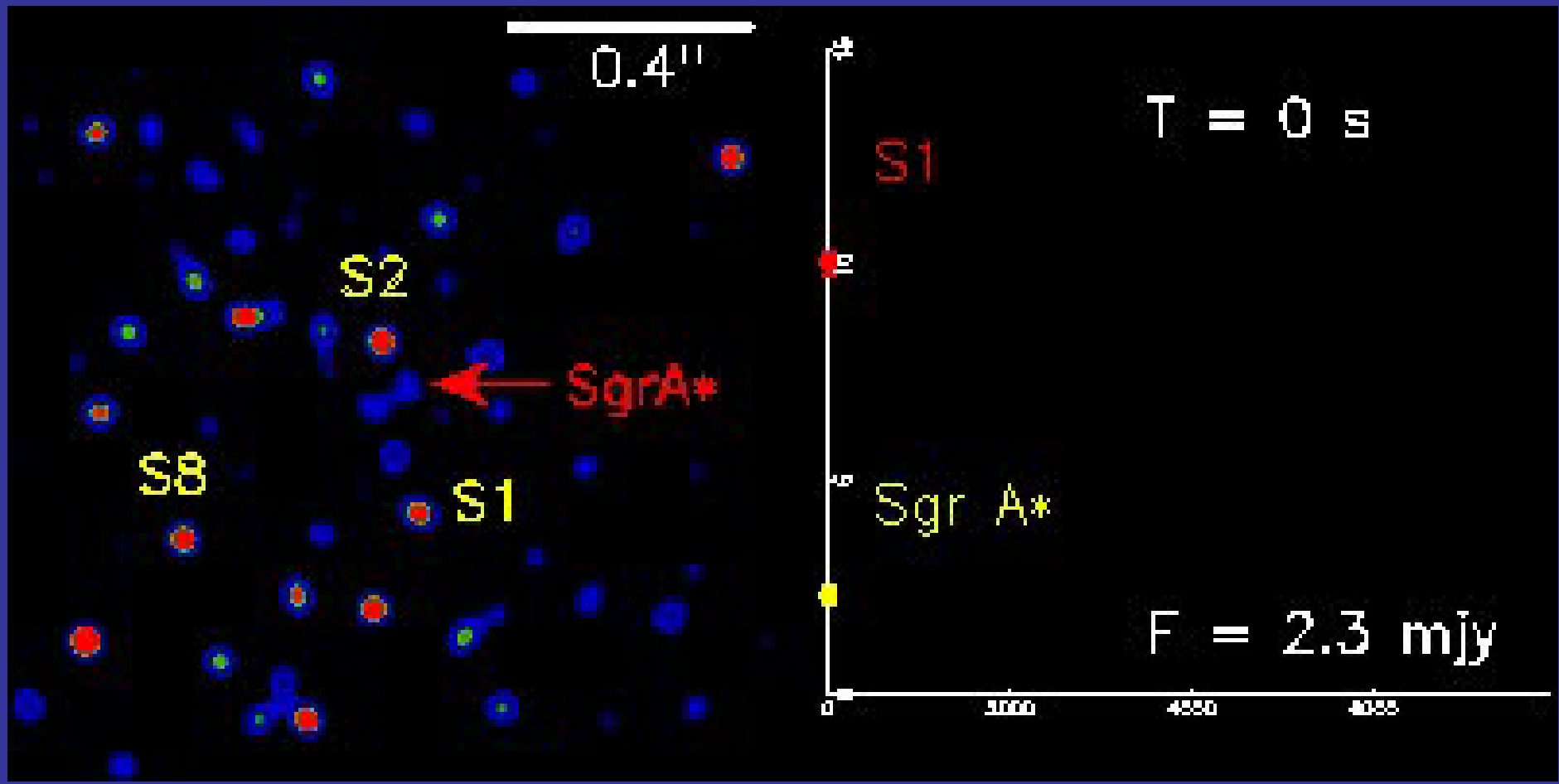
radiation efficiency
of SgrA* $\approx 10^{-8}$

Bower et al. 2003:
RM of linear polarized
flux rules out large
accretion rates

Quataert 2003:
hydrodynamic calculations show
that all the mass gets blown away
in a central wind.
Available for accretion: $10^{-5} M_o yr^{-1}$



SgrA* NIR flares!



NACO/VLT, 16.6.2003, 2 µm

SgrA* NIR flares!

- Detected at 1.7 + 2.2 μm (VLT); 3.8 μm (VLT+Keck)
- Similar to X-ray flares (Baganoff et al., 2001)
- position within < 10 mas (0.4 mpc) from Sgr A*
- Frequency: 3 - 6/day!
- Factors 1.5 (3.8 μm) to 6 (1.7 μm)
- Time scales ➔ origin <10 R_S of 3.6×10^6 M_{sol} BH!

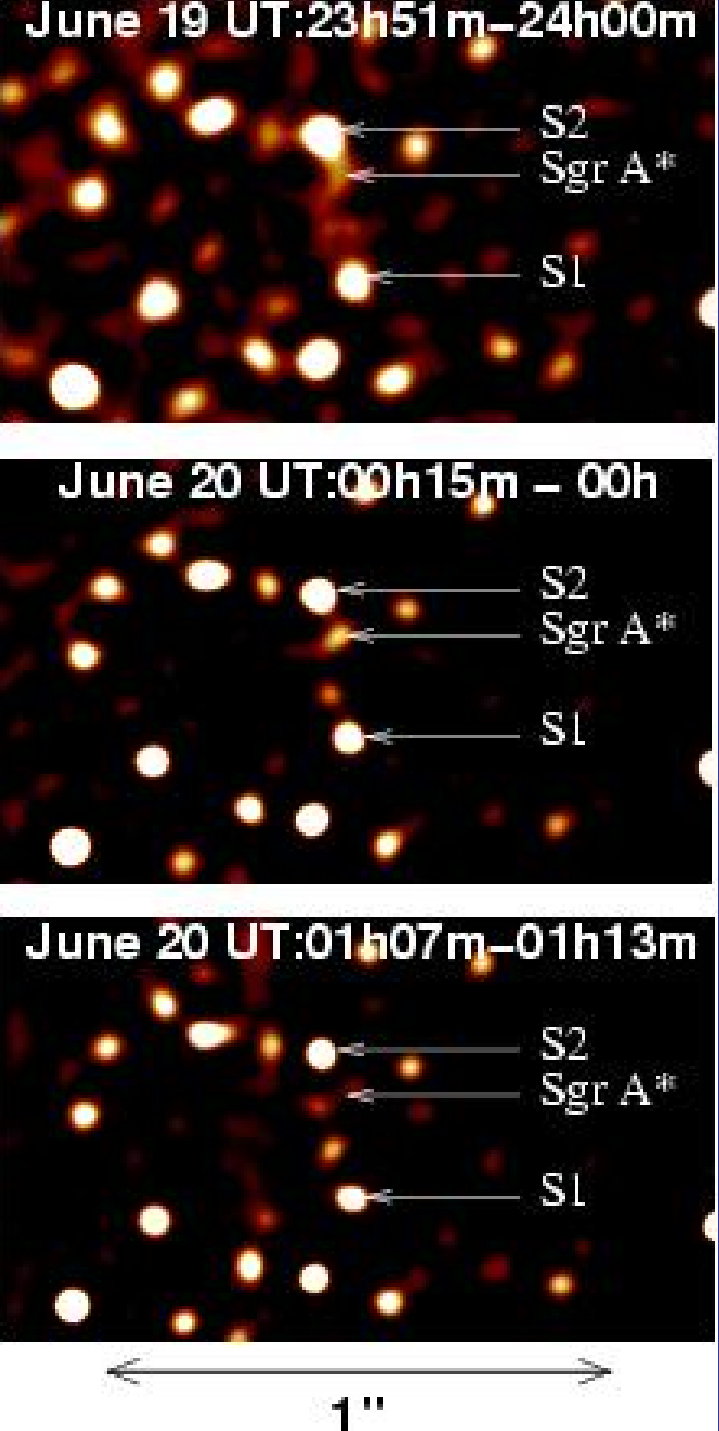
Radio to X-ray Spectrum of Sgr A*

To understand the accretion and emission mechanisms simultaneous multi-wavelength observations are necessary.

First successful simultaneous observation of NIR/X-ray flare and quasi-quiescent emission in 2003

Eckart, Baganoff, Morris, Schödel et al. 2004, A&A, in press

Simultaneous NIR / X-ray Measurements June 2003 Chandra data



NACO DDT Observations

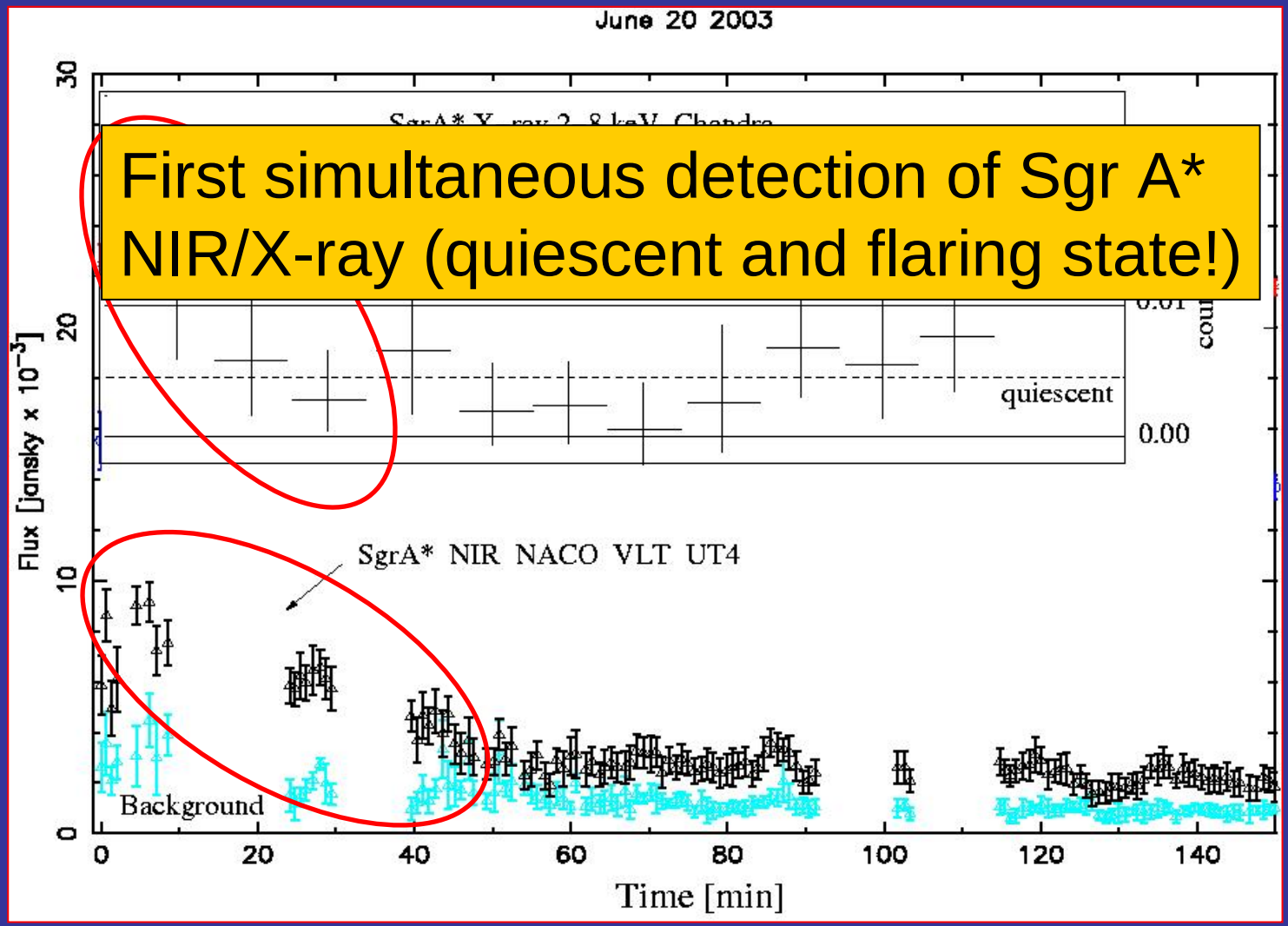
DDT time on June 19, 2003
NACO VLT UT4
AO locked on IRS7 (NIR)
Ks filter science observations
zenith seeing 0.8‘‘
Strehl ~20%

NIR source to within about 10mas at the dynamical position of SgrA*

Observations in parallel to Chandra measurements of SgrA*

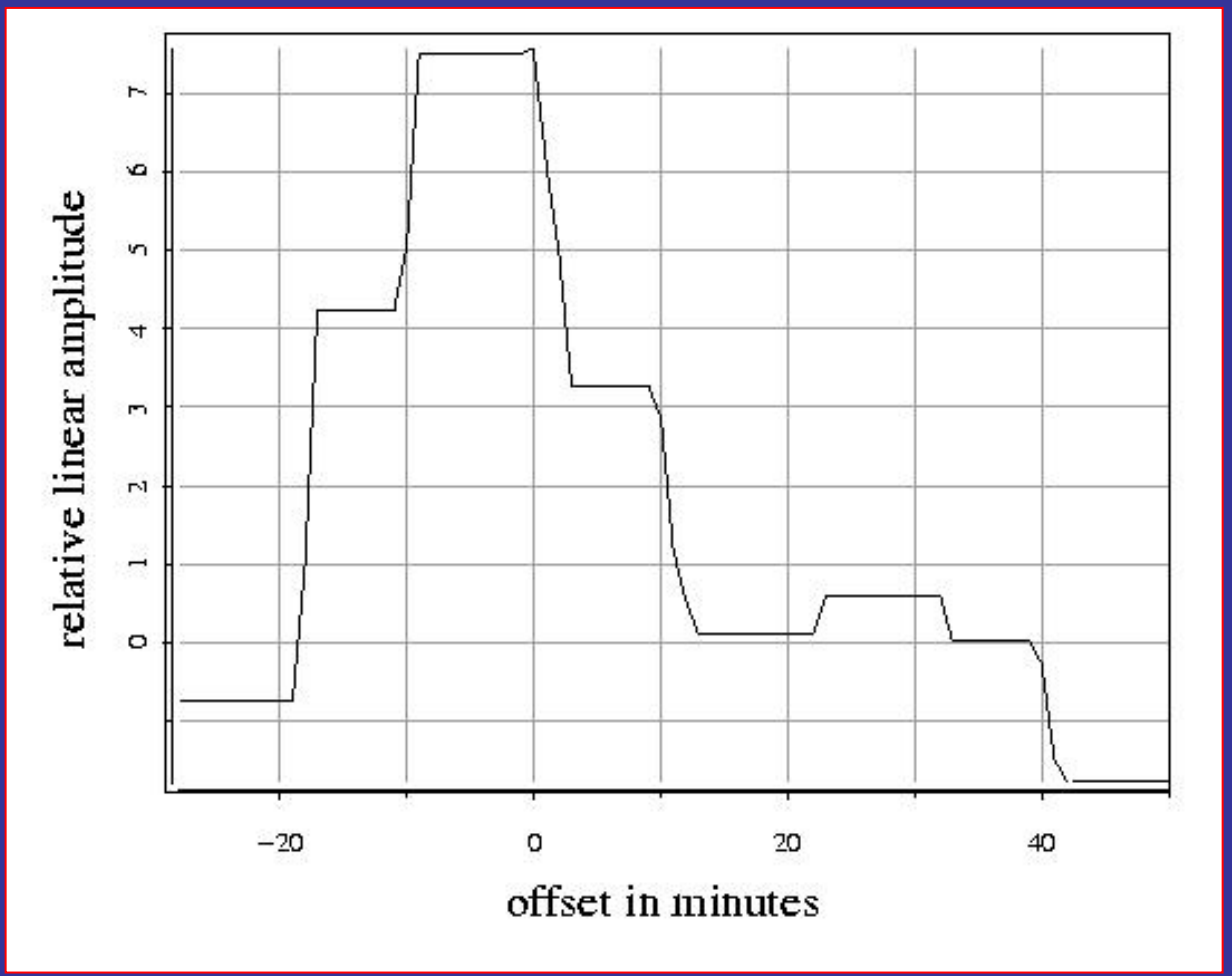
Eckart, Baganoff, Morris, Bautz,
Brandt, Garmire, Genzel, Ott, Ricker,
Straubmeier, Viehmann, Schödel,
Bower, and Goldston A&A in press

First Simultaneous NIR/X-ray Flare



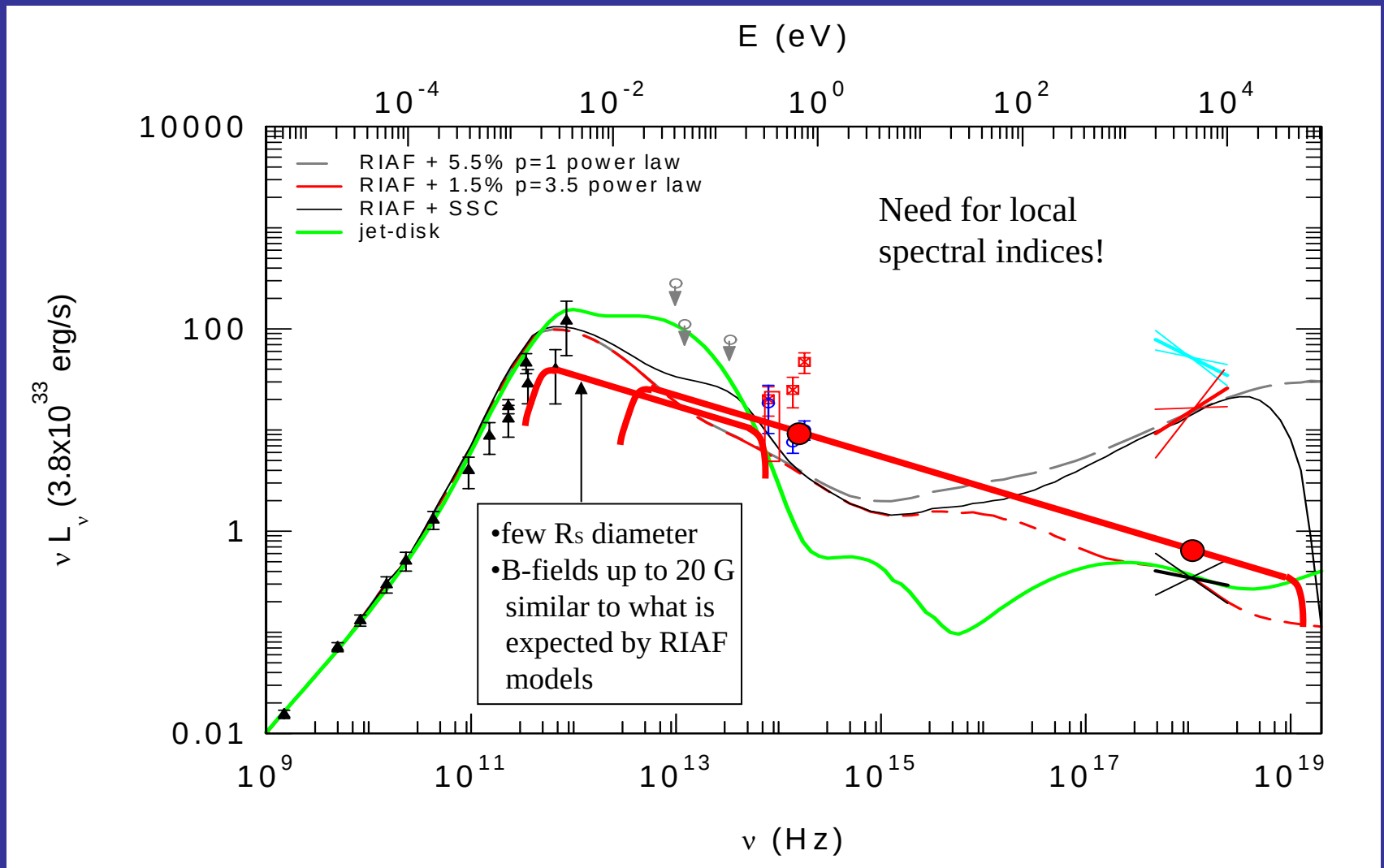
The NIR data started 0.38 minutes before the midpoint of the highest X-ray data point (10min bins).

Cross-Correlation of NIR/X-ray Data



Cross-correlation of NIR (40sec bins) and X-ray data (10min bins). This implies a delay of less than 10-15 minutes for the decaying part of the flare including the peak of the X-ray emission.

First simultaneous weak flare and models



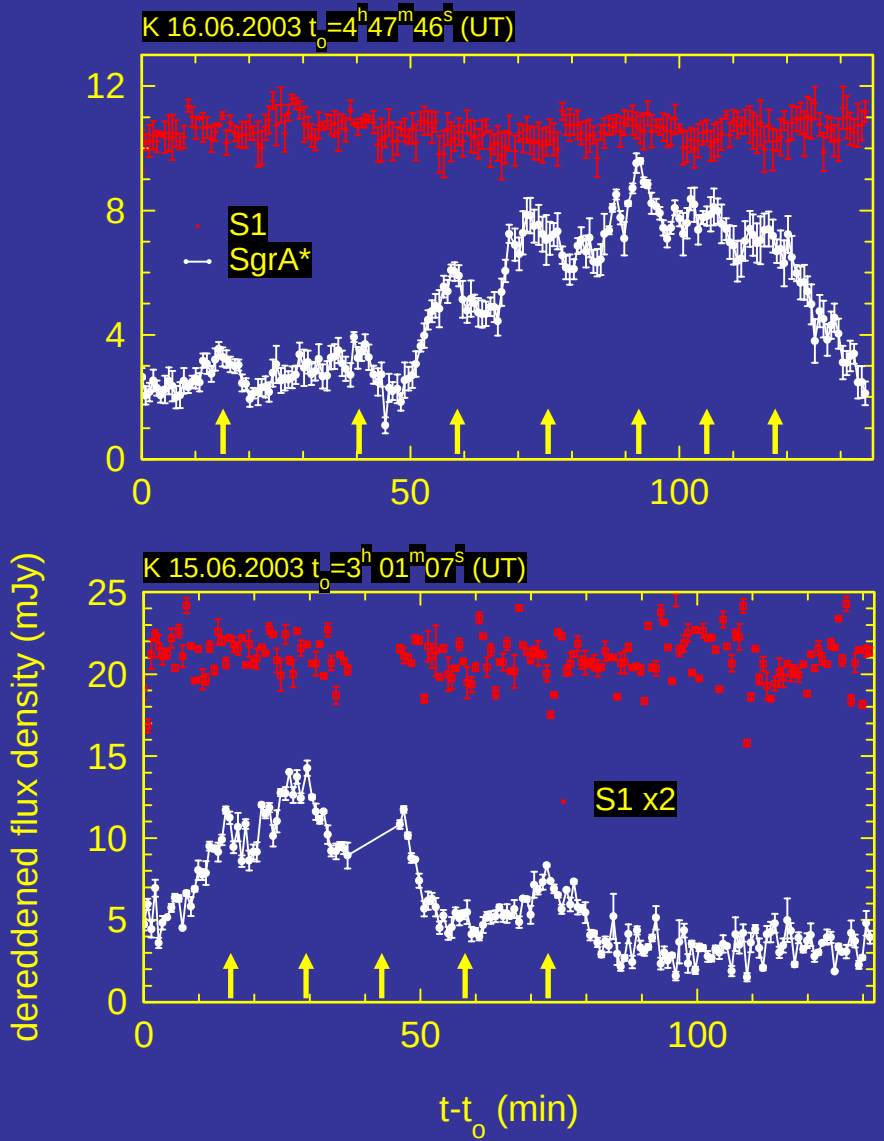
Radio: Zhao, Falcke, Bower, Aitken, et al. 1999-2003
X-ray: Baganoff et al. 2001, 2003, Goldwurm et al. 2003, Porquet et al. 2003,
NIR: Genzel et al. 2003, Ghez et al. 2003
models: Markoff, Falcke, Liu, Melia, Narayan, Quataert, Yuan et al. 1999-2001
SSC model after Marscher (1983) and Gould (1979)

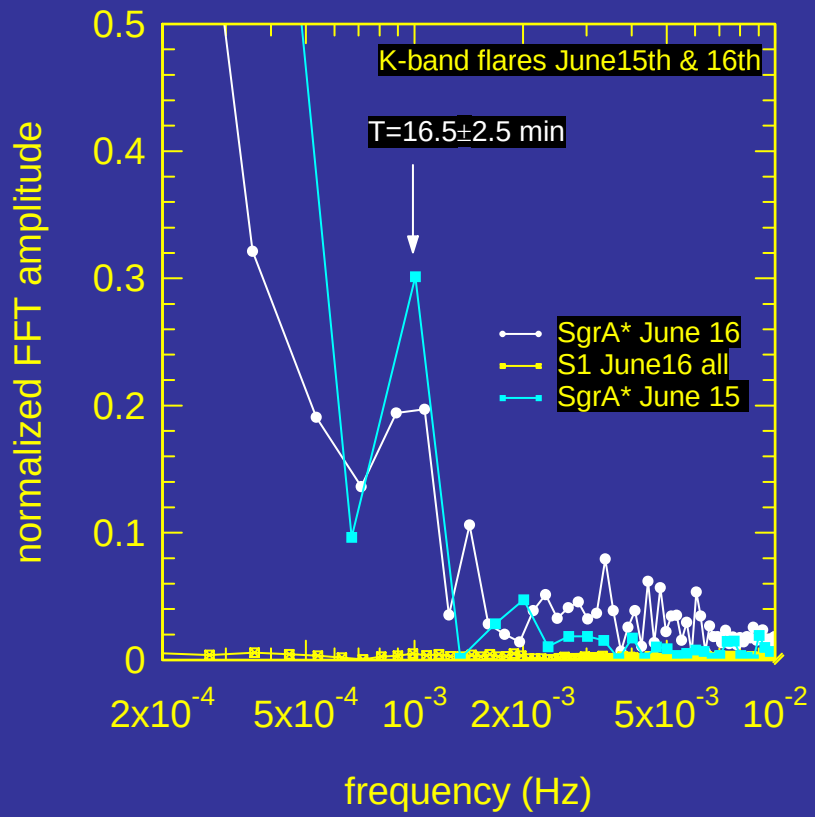
Data and model
Eckart, Baganoff, Morris et al. 2004

Fine Structure of the Flares

A Measurement of the Black Hole Spin?

NIR flares: quasi-periodicity





Genzel et al. 2003, Nature

Detection of Cyclic Accretion Disk Modes ?

Cyclic modes associated with accretion disks are well known QPO from (Nowak & Lehr 1998):

- Kepler orbital motion
- Lense-Thirring Precission
- vertical and ...
- radial epicyclic oscillation modes

They depend on the dimensionless spin parameter a=J/M and are of the order of a few 100Hz for 10 solar mass stellar BHs and about 0.6mHz for the GC MBH.

Aschenbach et al. (2004a,b) derive ~3.3 million solar masses and a~0.992 as possible solutions for the Galactic Center.

If emission is not associated with LSO then17min period may represend a lower frequency mde.

~4min static
~30min prograde
~60min retrograde
for 3.6x10**6Msol

Spin measurement of Sgr A*?

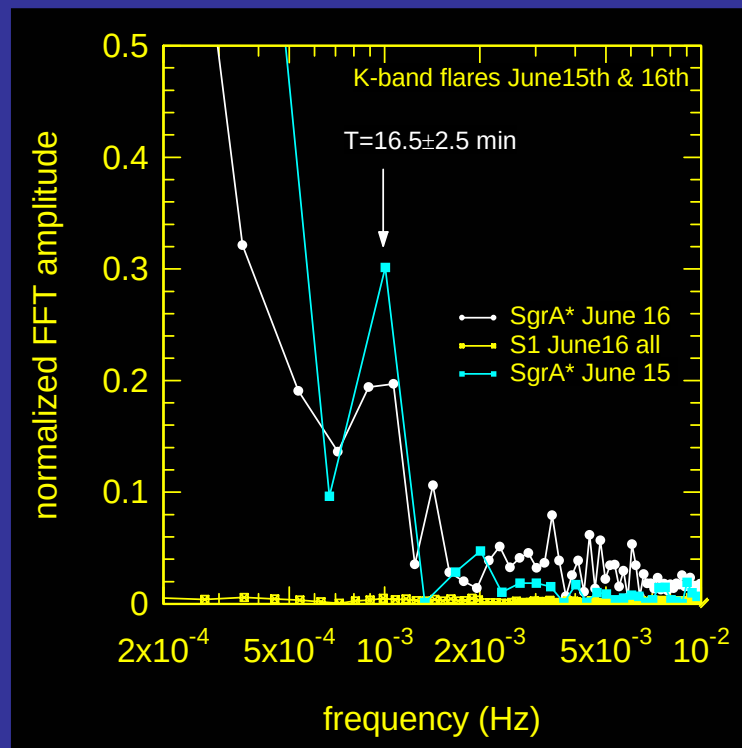
- Period at last stable orbit for 3.6 x10^6 M_{sol} non-rotation Schwarzschild BH: 27 min

- Orbital frequency is shortest one of all expected frequencies near a BH.

➔Interpretation of ~17 min quasi-periodicity:

Result from NIR flares: Emission from accreting matter on a prograde orbit near LSO of spinning (Kerr) BH at about half maximum spin.

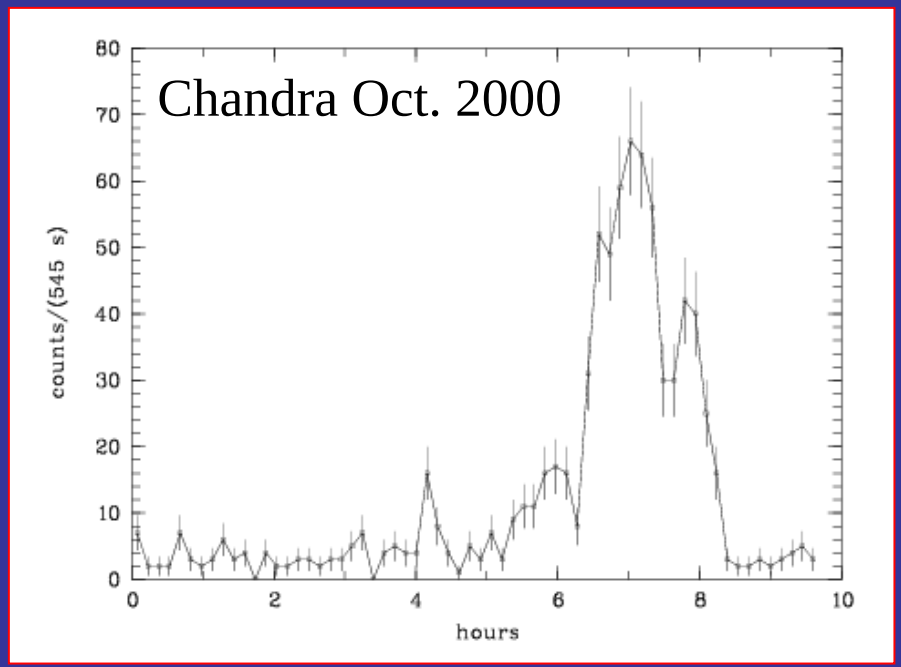
Genzel et al., NATURE 2003



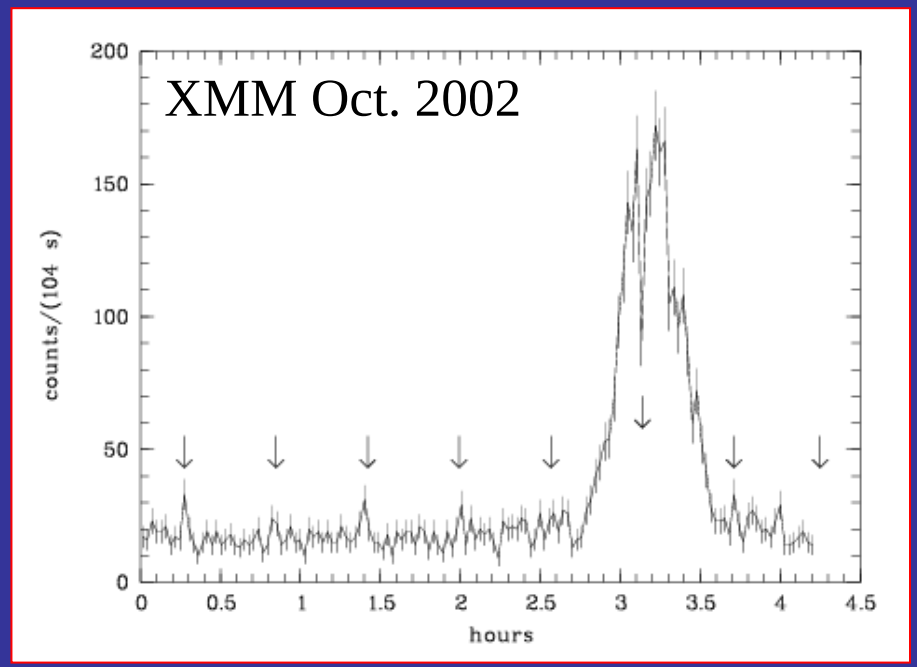
Melia et al. 2001, Bardeen, Press, Teukolsky 1972

Detection of Cyclic Accretion Disk Modes ?

Analysing the two strongest X-ray bursts Aschenbach et al. 2004 report the detection of cyclic modes associated with accretion disks.



Baganoff et al. 2001



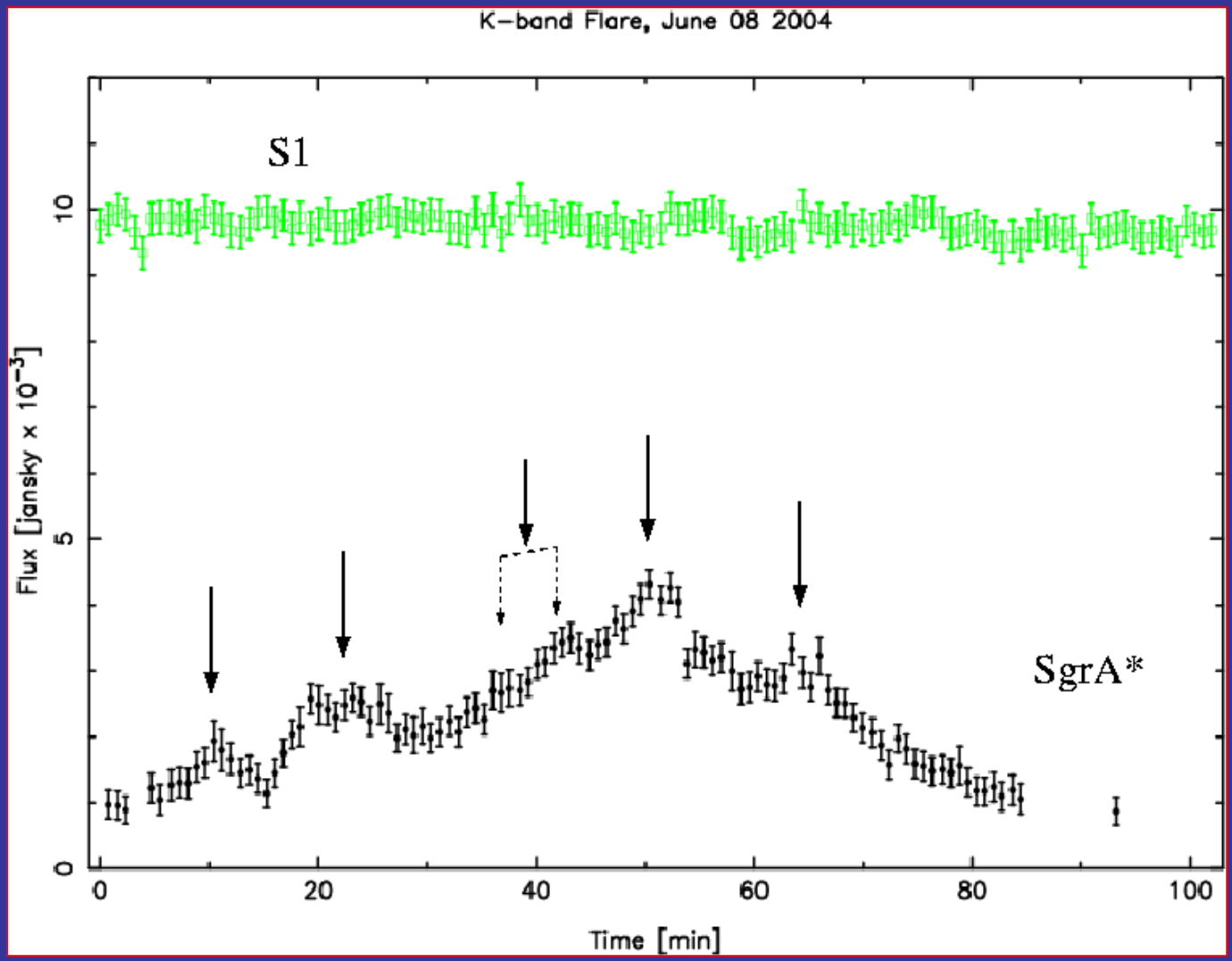
Porquet et al. 2003

July 2004 run

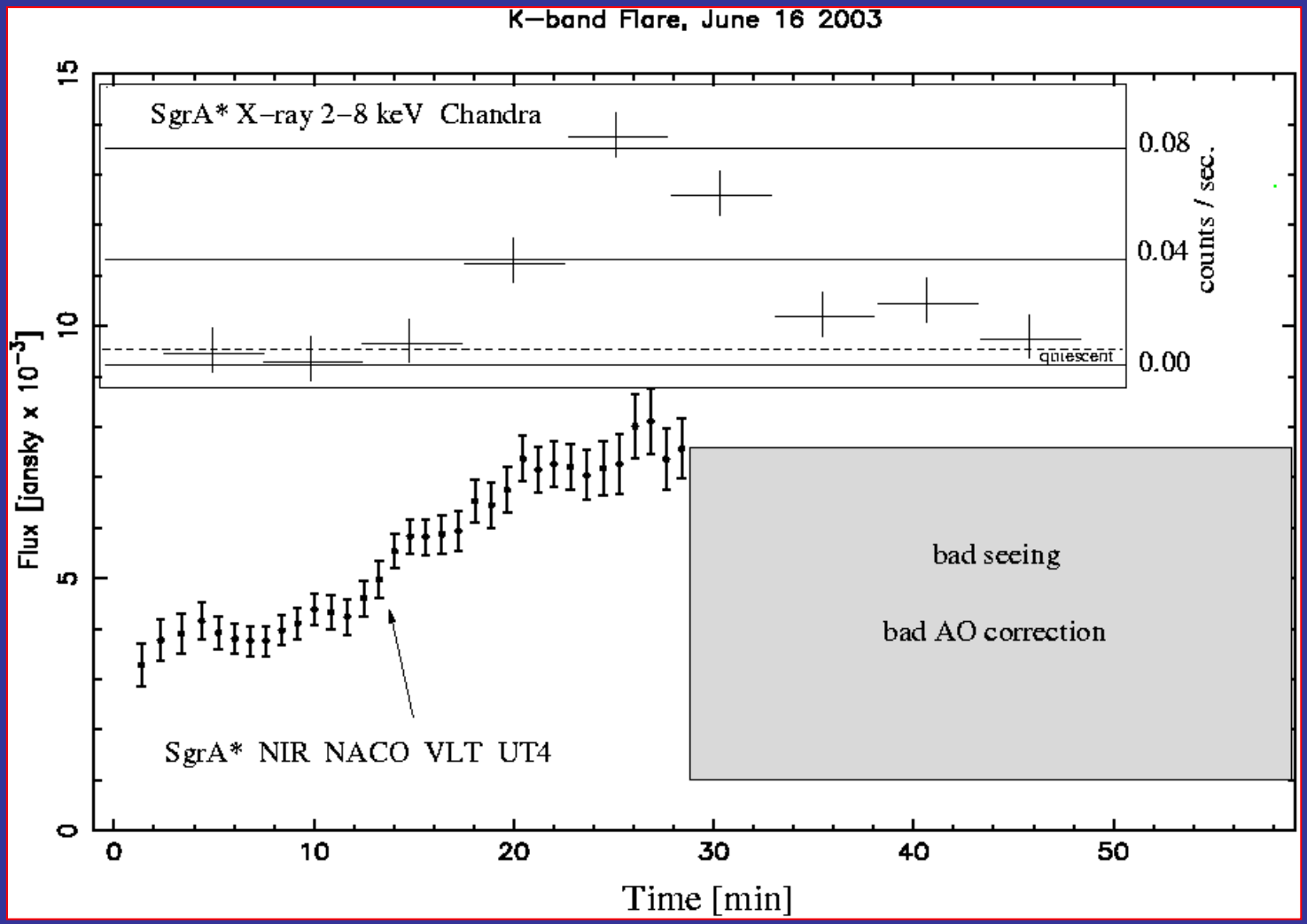
In collaboration with F. Baganoff (MIT), M. Morris (UCLA), R Genzel (MPE) and others

NIR/X-ray flare activity of SgrA* is a persistant feature!
A second simultaneous NIR/X-ray detection of a flare and
a further indication of flare fine structure.

New indications for persisting fine structure



July 2004: Detection of a Rising Flare Flank



X-ray flare: 07:07:03:12:20.0 - 07:07:03:54:12.8

07:07:03:00:55 - 07:07:04:00:00


to be continued...

2003/2004: Detection of Rising and Decaying Flare Flanks