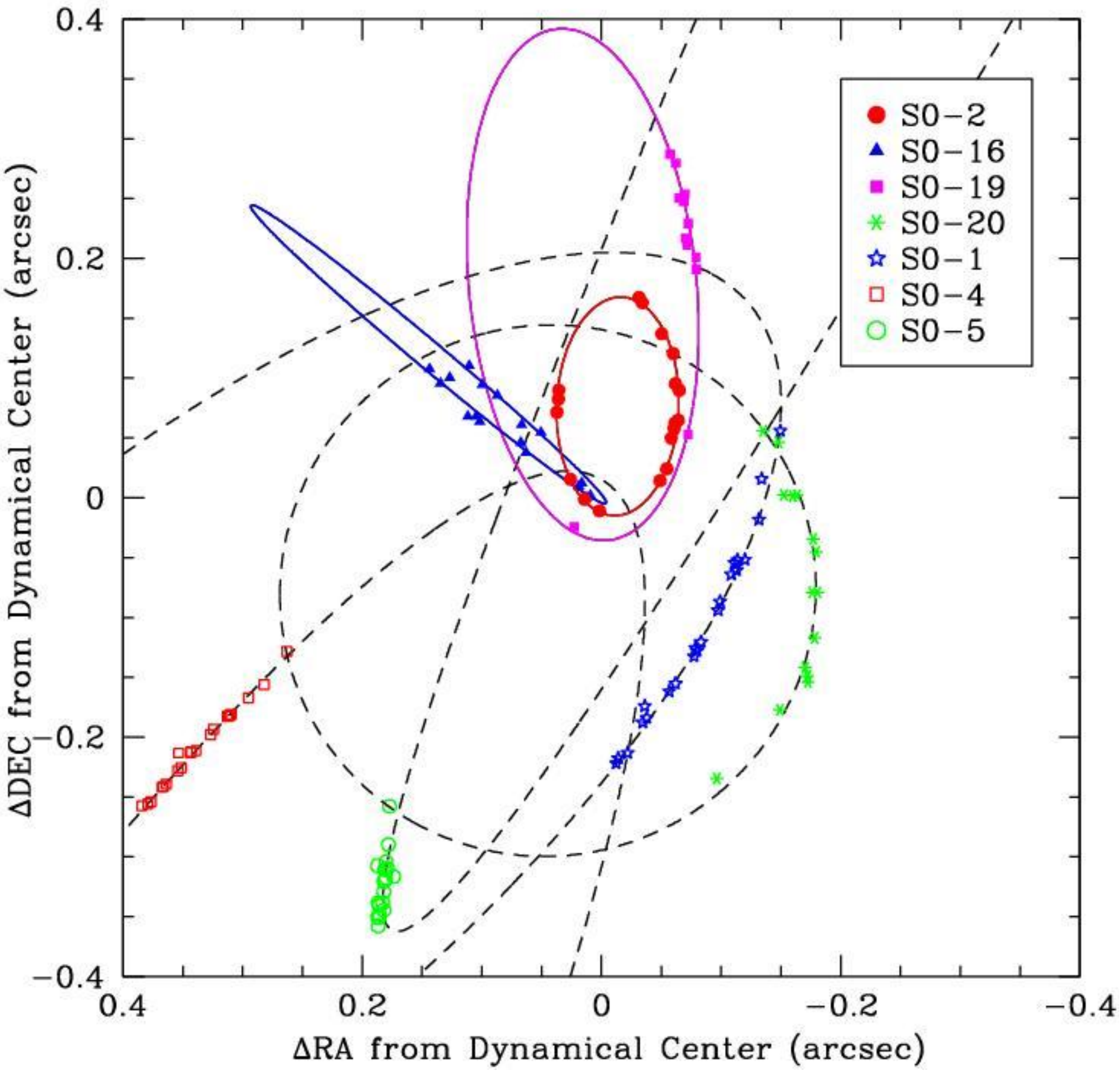
Population of BHs in the Galaxy and in the MCs

INVENTORY OF GALACTIC BHs

- 1 SUPERMASSIVE BH (Sgr A*)
- (zero ÷ few tens ?) of

  INTERMEDIATE MASS BHs
- $10^7 \div 10^8$ STELLAR MASS BHs


S0-2
S0-16
S0-19
S0-20
S0-1
S0-4
S0-5
0.4
0.2
0
−0.2
−0.4
ΔDEC from Dynamical Center (arcsec)
0.4
0.2
0
−0.2
−0.4
ΔRA from Dynamical Center (arcsec)

From orbits (astrometry & spectroscopy) :

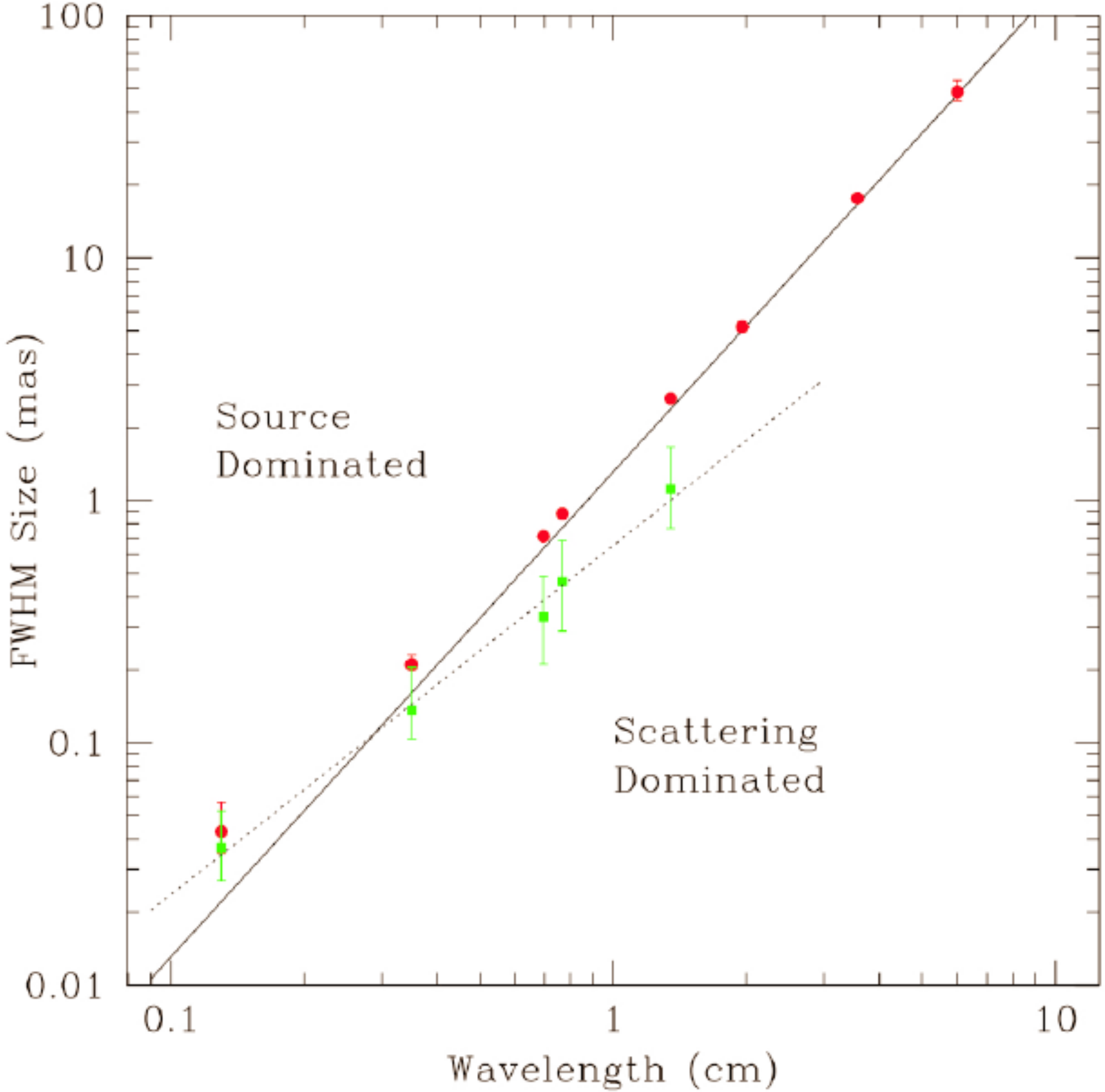
$M_{BH} = (4.5 \pm 0.4) \times 10^6 M_{SUN}$

$D = 8.4 \pm 0.4$ kpc

Star S0-16 approaches the focus of the orbit to a distance of ~ 45 A.U. (~ 6 light hours or ~ 600 R_S)

VLBI observations at 1.3 mm (Doeleman et al., 2008) permitted us to see (for the first time) the structures on the scale of the event horizon!

The measured size (major-axis) of Sgr A* is 37^{+16}_{-10} μas



Doeleman et al., 2008

A gas cloud on a collision course with Sgr A*

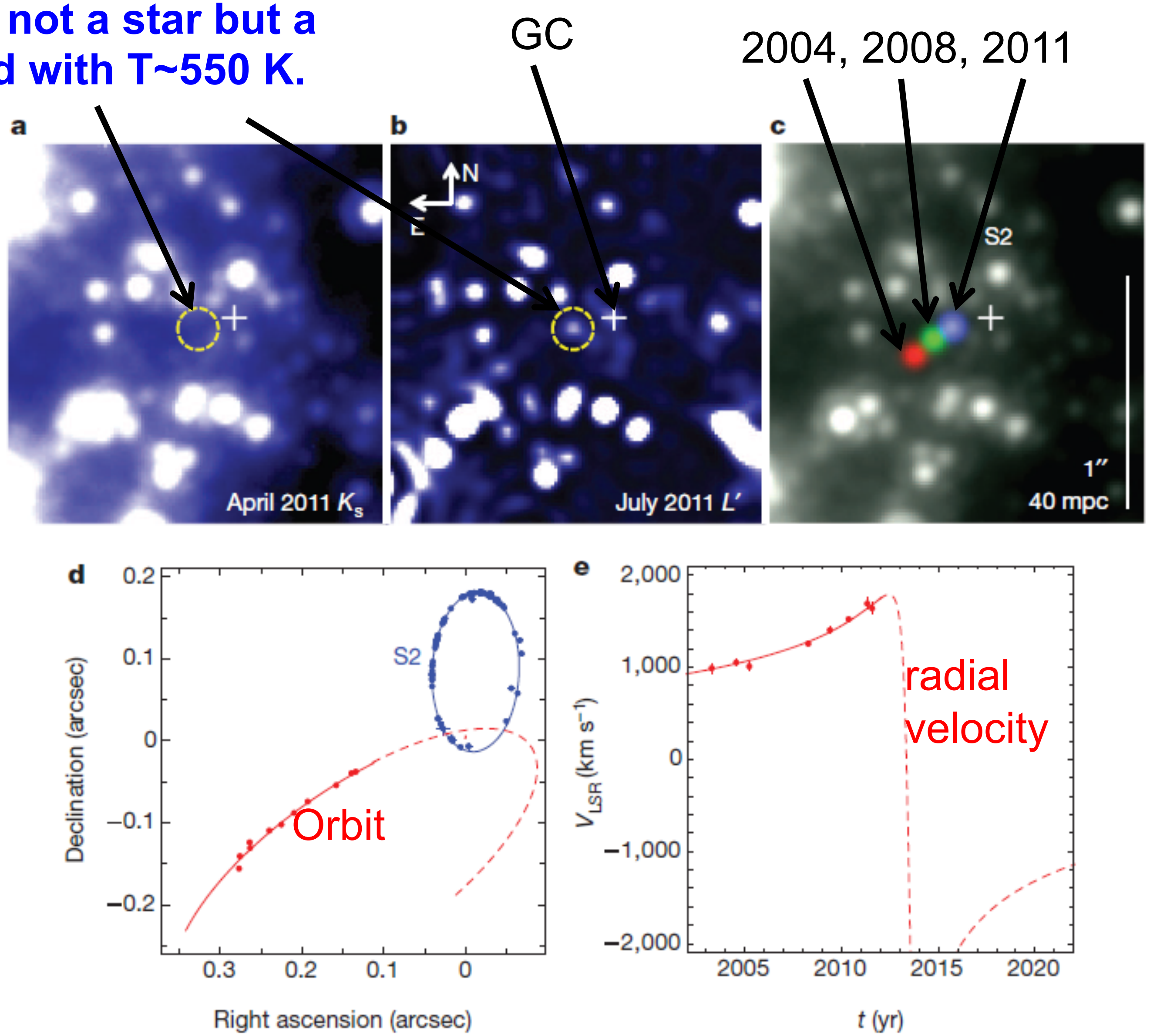
- $M \approx 3M_E \approx 1.7\text{x}10^{28}$ g.
- $T \approx 550$ K.
- e ≈ 0.94 ± 0.01.
- Pericentre distance from the black hole:
  ≈ 3140 ± 240 R_S.
- Period ≈ 137 ± 11 yr.
- The predicted X-ray luminosity in mid 2013 of $L \sim 10^{34}$ erg/s, about 10 times brighter than now.

Gillesen et al. 2012, Burkert et al. 2012

The observations:

Courtesy A. Zdziarski

Detection in *L* but not in *K* shows it is not a star but a dusty cloud with T~550 K.



Cloud evolution simulations (Burkert et al. 2012)

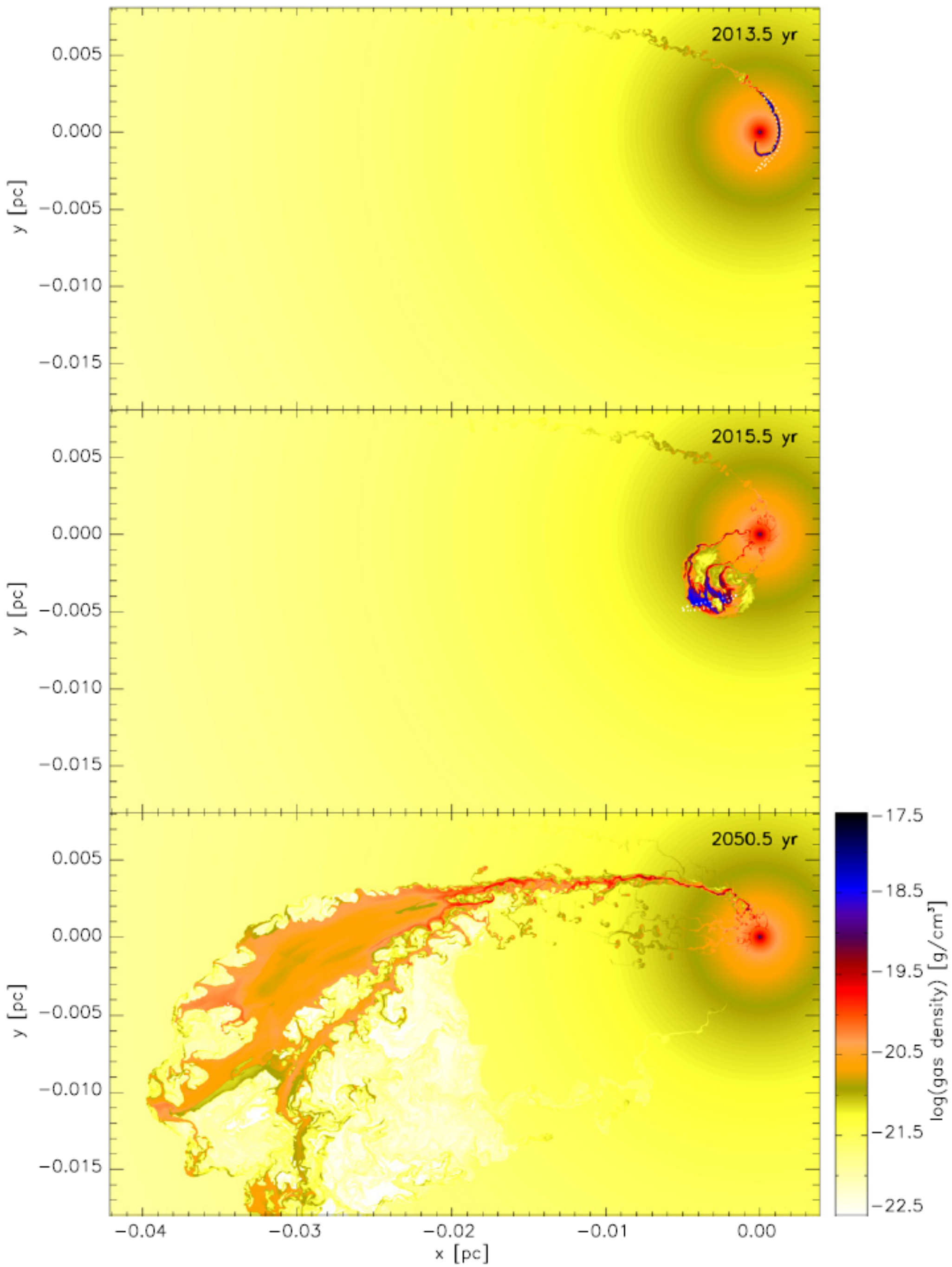
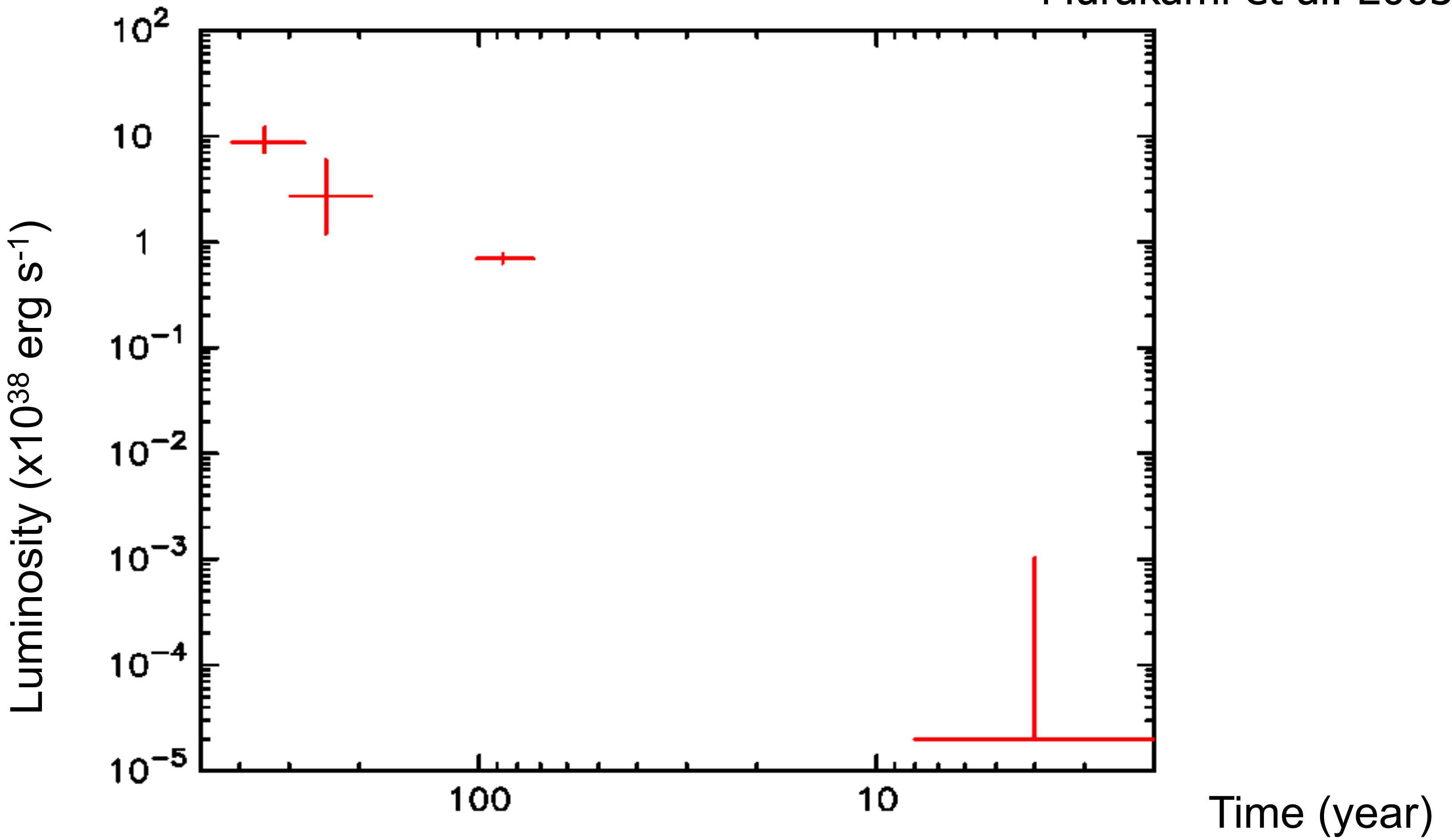


Figure 6. Late phases of the evolution of model CC01. In the year 2050, the cloud has broken up into a long filament that feeds Sgr A*.

History of activity of Sgr A*

Murakami et al. 2003



300 years ago milion times brighter!!

IMBHs

GLOBULAR CLUSTERS

Do some of them contain IMBHs ?

Some of them, possibly, yes.

Brightness profiles

→ r_c/r_h

clusters with **IMBHs** have expanded cores ($r_c/r_h > 0.1$)

Trenti (2006) considered a sample of 57 old globular clusters

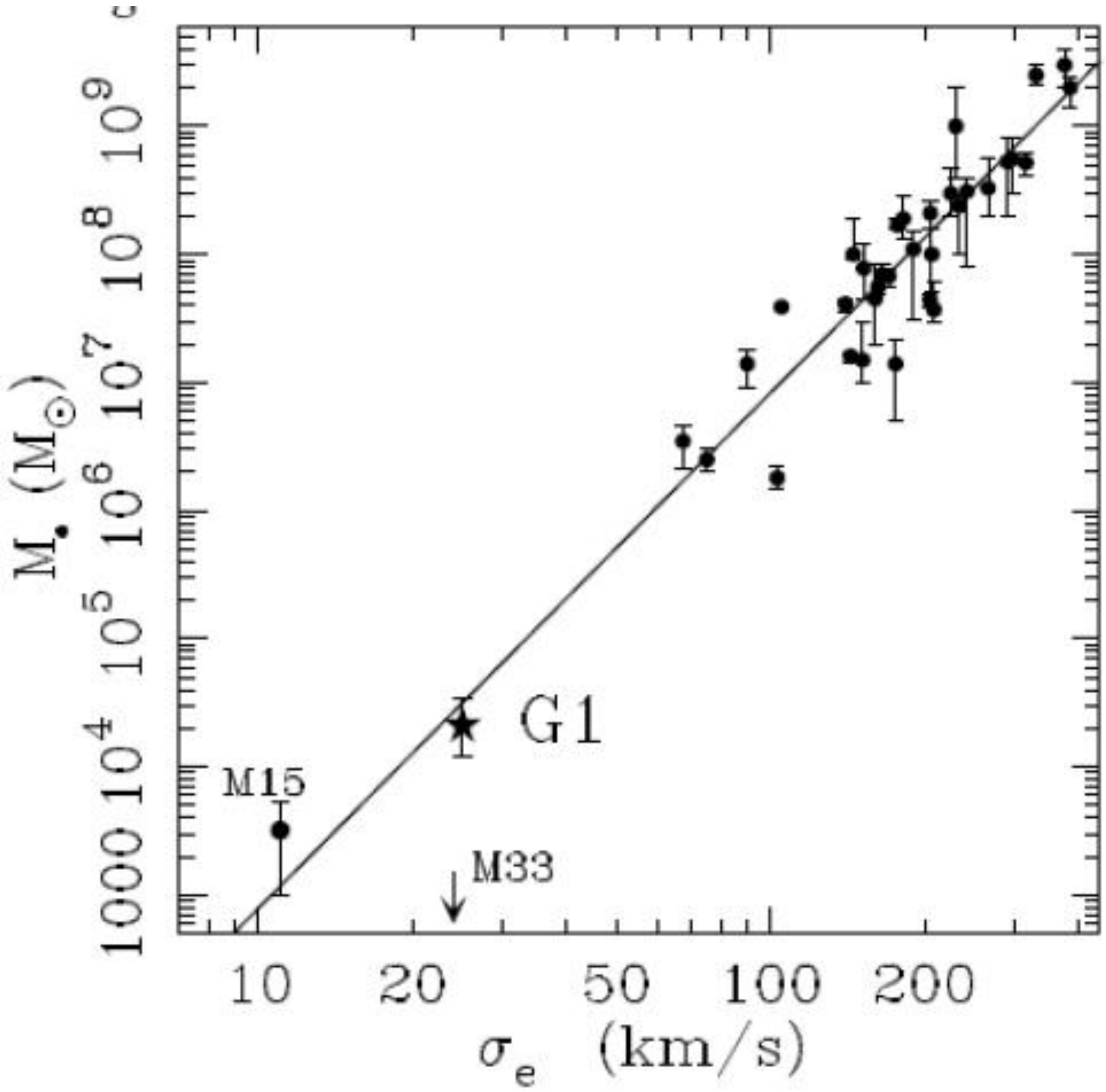
For at least half of them, he found $r_c/r_h \geq 0.2$

→ IMBHs necessary !

Velocity dispersion

correlates well with M_{BH}

(IMBH or SMBH)



Gebhardt et al., 2002

STRONGEST CANDIDATES

- [G1 $M_{BH} \sim 20\,000\ M_{SUN}$ Gebhardt et al., 2005]
- M15 $M_{BH} \sim 2\,000\ M_{SUN}$ Gerssen et al., 2003
- ω Cen $M_{BH} \sim 50\,000\ M_{SUN}$ Noyola et al., 2006

Situation became less favorable for IMBHs.

Recent analysis of the white dwarf (WD) populations in globular clusters suggest that WDs receive a kick of a few km/s shortly before they are born (Fregeau at al., 2009).

This effect increases both r_c/r_h and velocity dispersion.

As of now, no globular cluster requires an IMBH at its center (which does not mean that it does not have one).

NOTE: there are BHs in globular clusters but they are not IMBHs !

STELLAR MASS BHs

- Solitary BHs
- BHs in binaries
  - non-X-ray binaries
  - X-ray binaries

BH candidates from microlensing events

MACHO-96-BLG-5	$3 \div 16\ M_{SUN}$	Bennettet et al., 2002a
MACHO-98-BLG-6	$3 \div 13\ M_{SUN}$	Bennettet et al., 2002a
MACHO-99-BLG-22 = OGLE-1999-BUL-32	$\sim 100\ M_{SUN}$	Bennettet et al., 2002b
OGLE-SC5_2859	$7 \div 43\ M_{SUN}$	Smith, 2003

Some new candidates are investigated (including the use of HST)

BHs in non-X-ray binaries

- WR + unseen companion binaries
- V Pup

There are about twenty WR + unseen companion binaries

Most of them have high values of z-altitude over the Galactic plane, which might indicate that they survived SN explosion

If so, then unseen companions must be relativistic objects

In one of these binaries: CD-45°4482 the lower mass limit of the unseen companion (estimated from radial velocities of WR star) is 5.5 M_{SUN}.

Cherepashchuk, 1998

V Pup

Massive eclipsing binary P_{orb} =1^{d}45, 15.8 + 7.8 M_{SUN}

Cyclic orbital period oscillation indicates the presence of an unseen third body with mass ≥ 10.4 M_{SUN} orbiting the close pair in 5.47 years

Qian et al., 2008

How many BH X-ray binaries ?

- at present, we know **64** BHC binaries (**62** in MW and **2** in LMC)

8 are HMXBs (**6** in MW and **2** in LMC), **56** – LMXBs (all in MW)

- **23** BHCs have dynamical mass estimates (confirmed BHs) (**6** in HMXBs, **17** in LMXBs)

- **13** BHCs are microquasars (**4** in HMXBs, **9** in LMXBs)

STELLAR MASS BHs

- present range of masses ~ $4 \div 16\ M_{SUN}$
- present range of spins ~ $0 \div 0.99$

X-RAY SPECTRA

Zhang et al. (1997):	GRO J1655-40	$a^* = 0.93$
	GRS 1915+105	$a^* \approx 1.0$
Gierliński et al. (2001):	GRO J1655-40	$a^* = 0.68 \div 0.88$
McClintock et al. (2006, 2009):	LMC X-3	$a^* < 0.26$
	GRO J1655-40	$a^* = 0.65 \div 0.80$
	4U 1543-47	$a^* = 0.70 \div 0.85$
	LMC X-1	$a^* = 0.81 \div 0.94$
	GRS 1915+105	$a^* > 0.98$
Gou et al. (2011)	Cyg X-1	$a^* > 0.9$

SPECTRAL LINES

MODELING THE SHAPE OF Fe Kα LINE

Miller et al. (2004):	GX339-4	$a^* \geq 0.8 \div 0.9$
Miller et al. (2005):	GRO J1655-40	$a^* > 0.9$
	XTE J1550-564	$a^* > 0.9$
Miller et al. (2002):	XTE J1650-500	$a^* \approx 1.0$
Martocchia et al. (2002)	GRS 1915+105	small

SUMMARY OF SPIN DETERMINATIONS FROM Fe Kα LINE

Cyg X-1	a* = 0.05 (1)
4U 1543-475	a* = 0.3 (1)
SAX J1711.6-3808	a* = 0.2 ÷ 0.8
SWIFT J1753.5-0127	a* = 0.61 ÷ 0.87
XTE J1908+094	a* = 0.75 (9)
XTE J1550-564	a* = 0.76 (1)
XTE J1650-500	a* = 0.79 (1)
~~GX 339-4~~	~~a* = 0.94 (2)~~
GRO J1655-40	a* = 0.98 (1)
GRS 1915+105	a* = 0.56 (2)

Miller et al., 2009

Not all groups believe the precision of McC determinations

In particular, corrections for absorption introduce large uncertainty (C. Done)

Also modeling: different spectral models produce different results (Davis, Done & Blaes 2006)

BHs SPINS (stellar mass)

summary based on McC, Miller

(1) GRS 1915+105 probably has a rotation close to nearly maximal spin ($a^* > 0.98$, but Fe line gives 0.56)

(2) several other systems (GX 339-4, LMC X-1, GRO J1655-40, XTE J1650-500, XTE J1550-564, XTE J1908+094 and SWIFT J1753.5-0127 have large spins ($a^* \geq 0.65$)

(3) not all accreting black holes have large spins (robust (?) result $a^* < 0.26$ for LMC X-3)

(4) there are discrepancies between the results of two methods (Cyg X-1, GRS 1915+105)

Different populations in MW and in MCs

Population	Galaxy	LMC	SMC
Total mass (in M_{SMC} units)	100	10	1
HMXBs	118	26	83
Be XRBs	72	19	79
LMXBs	197	2	-
BHCs	62	2	-

In MCs (comparing with MW), we notice:

- lack of LMXBs
- relative surplus of HMXBs
- deficit of BHs

CONFIRMED BHs IN XRBs

Name	P_{orb}	Opt. Sp.	X-R	C	M_{BH}/M_{sun}
Cyg X-1	5^d6	O9.7 Iab	pers	μQ	16 ± 3
LMC X-3	1^d70	B3 V	pers		6 ÷ 9
LMC X-1	4^d22	O7-9 III	pers		10.9 ± 1.4
SS 433	13^d1	~ A7 Ib	pers	μQ	16 ± 3
LS 5039	3^d906	O7f V	pers	μQ	2.7 ÷ 5.0
XTE J1819-254	2^d817	B9 III	T	μQ	6.8 ÷ 7.4
GX 339-4	1^d76	F8-G2 III	RT	μQ	≥ 6
GRO J0422+32	5^h09	M2 V	T		4 ± 1
A 0620-00	7^h75	K4 V	RT		11 ± 2
GRS 1009-45	6^h96	K8 V	T		4.4 ÷ 4.7
XTE J1118+480	4^h1	K7-M0 V	T		8.5 ± 0.6
GS 1124-684	10^h4	K0-5 V	T		7.0 ± 0.6

CONFIRMED BHs IN XRBs (cont.)

Name	P_{orb}	Opt. Sp.	X-R	C	M_{BH}/M_{sun}
GS 1354-645	2^d54	G0-5 III	T		> 7.8 ± 0.5
4U 1543-47	1^d12	A2 V	RT		8.5 ÷ 10.4
XTE J1550-564	1^d55	K3 III	RT	μQ	10.5 ± 1.0
XTE J1650-500	7^h63	K4 V	T	μQ	4.0 ÷ 7.3
GRO J1655-40	2^d62	F3-6 IV	RT	μQ	6.3 ± 0.5
4U 1705-250	12^h54	K5 V	T		5.7 ÷ 7.9
GRO J1719-24	14^h7	M0-5 V	T		> 4.9
XTE J1859+226	9^h16	~ G5	T		8 ÷ 10
GRS 1915+105	33^d5	K-M III	RT	μQ	14 ± 4.4
GS 2000+25	8^h26	K5 V	T		7.1 ÷ 7.8
GS 2023+338	6^d46	K0 IV	RT		10.0 ÷ 13.4