Galactic Center S cluster as a reservoir of strong-gravity probes

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Author: **Michal Zajaček**

In collaboration with: **Andreas Eckart**, **Florian Peissker**, and **Basel Ali**

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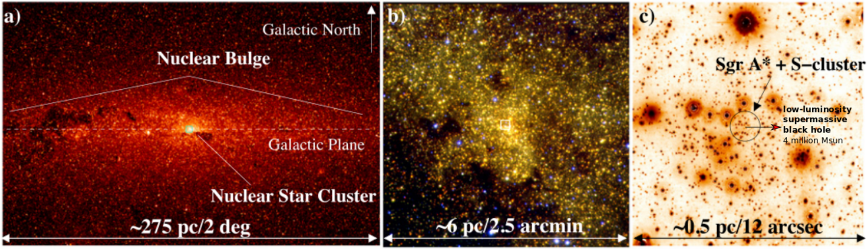
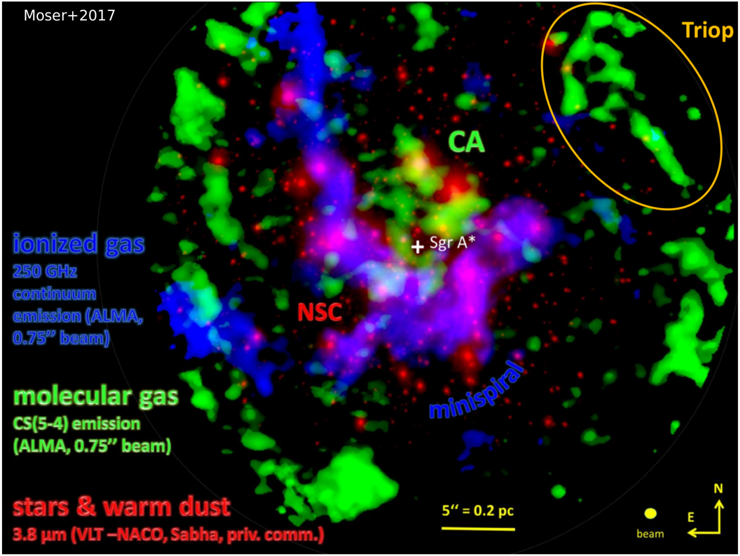
Approaching the Galactic center



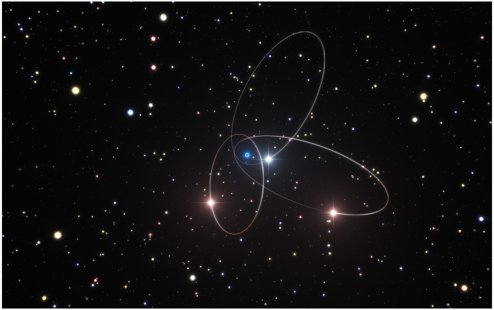
- zoom-in towards the compact radio source (Sgr A*) – NIR wavelengths (Schödel+14): (a) Spitzer/IRAC, (b) ISAAC multicolor, (c) NACO/VLT
- **Nuclear Star Cluster**: one of the densest clusters in the Galaxy $\Longleftrightarrow$ **(super)massive black hole (SMBH)** of $4 \times 10^6\,M_{\odot}$ (Eckart+17, Genzel+10)
- enables monitoring individual objects as well as study cluster properties as a whole

Approaching the Galactic center – a unique laboratory



- the inner 1 pc: unique laboratory – a mutual interaction of stars, gas and dust in the potential of the SMBH

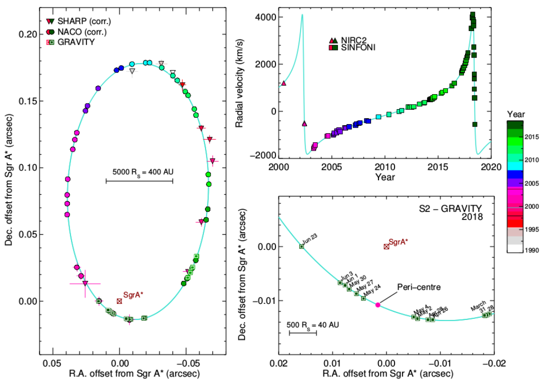
Looking for new strong-gravity probes



Credit: ESO/M. Parsa/L. Calçada
Parsa+ ApJ 845, 2017

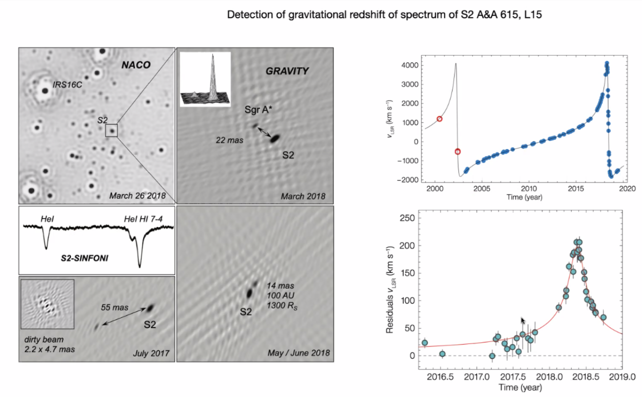
S2 star: successful measurements by GRAVITY

S2 orbit with the period of 16.05 years (Gravity Collaboration, 2018)



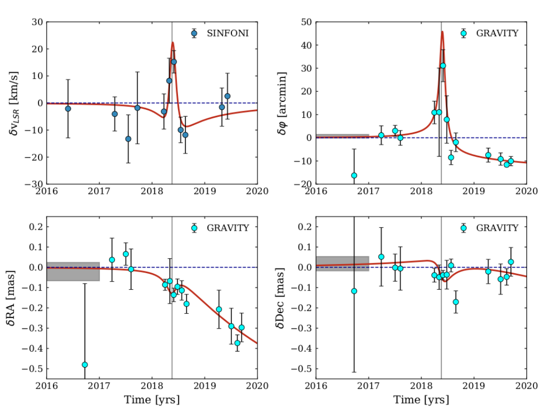
S2 star: successful measurements by GRAVITY

Detection of gravitational redshift (Gravity Collaboration, 2018)



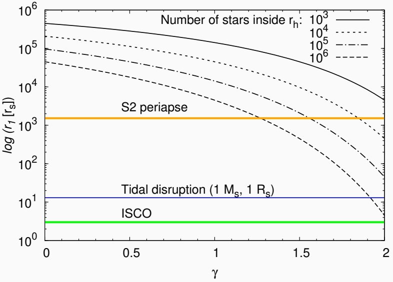
S2 star: successful measurements by GRAVITY

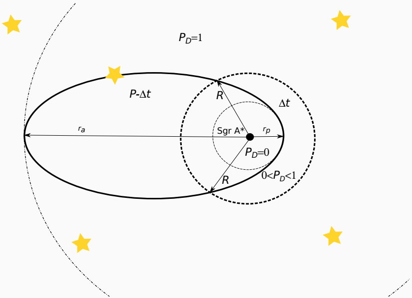
Detection of Schwarzschild precession (Gravity Collaboration, 2020)



Are there any stars inside S2 star orbit?

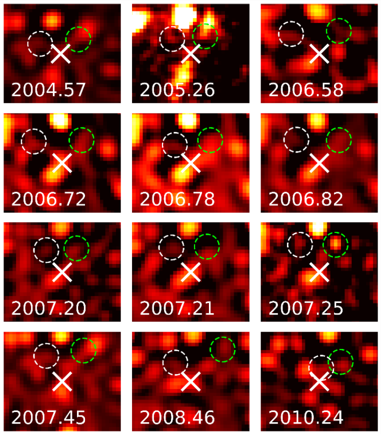
Generally, the region inside 1500 Schwarzschild radii is expected to be sparse (Zajacek & Tursunov, 2018) according to $r_1 = r_\mathrm{h} N_\mathrm{h}^{-\frac{1}{3-\gamma}}$





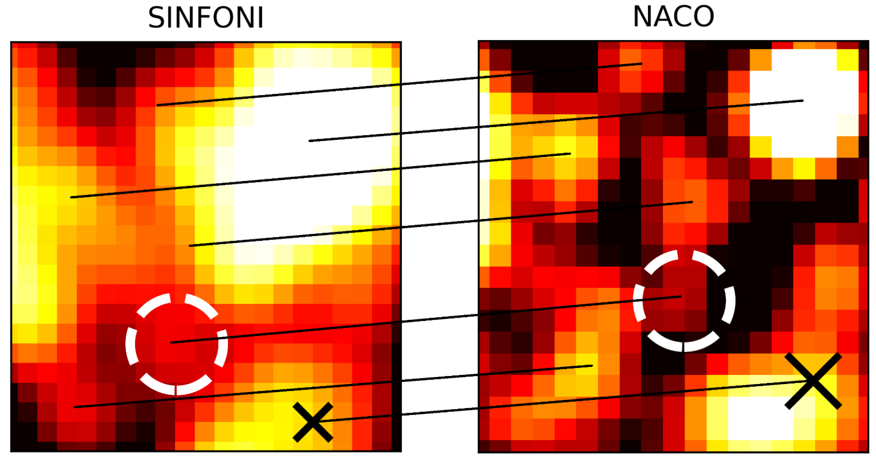
S4711 and friends

Discovery of S4711 (white circle) with the orbital period of only $\sim 7.6\,\mathrm{yr}$ in NACO K_s-band images (Peissker+2020 ab). S62 has a period of $\sim 9.9\,\mathrm{yr}$ (green circle). Size of every image is $0.44'' \times 0.37''$



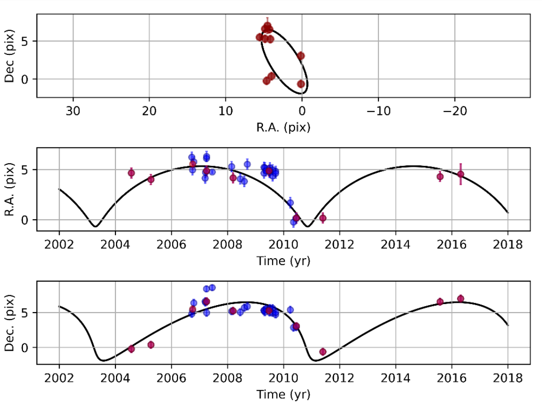
S4711 and friends

Detection of S4711 in both NACO and SINFONI high-pass filtered images in 2007

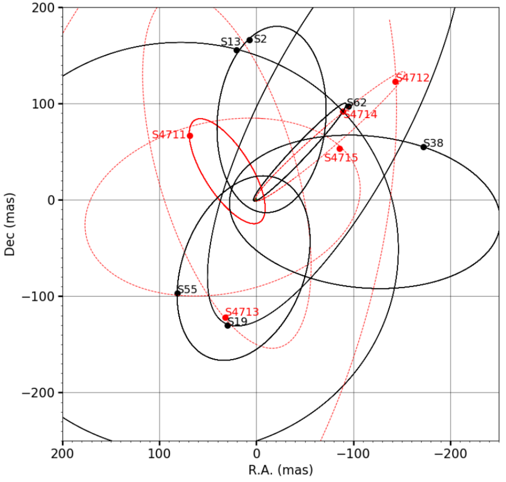


S4711 and friends

Orbital solution for S4711

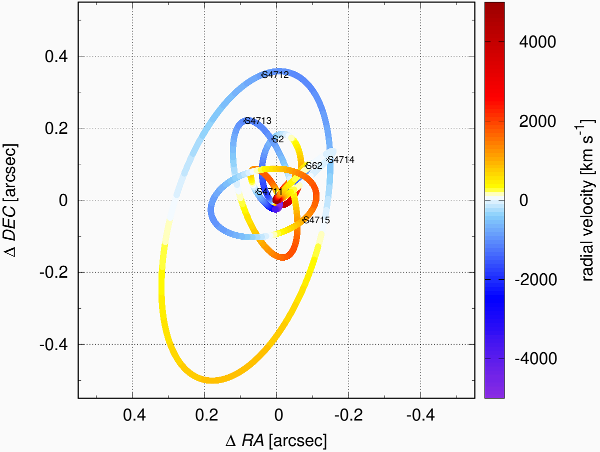


Orbits for S4711-S4715



S4711 and friends

Orbits for S4711-S4715 with colour-coded radial velocities: **red** Doppler-redshifted (away from the observer), **blue** Doppler-blueshifted (towards the observer)



S4711 and friends

Orbital parameters:

- a - semimajor axis
- e - eccentricity
- i - orbital inclination
- ω - argument of periastron
- Ω - longitude of the ascending node
- t_{closest} - time of peribothron

Source	a [mpc]	e	i [°]	ω [°]	Ω [°]	t_{closest} [years]	t_{period} [years]
S62	3.588 ± 0.02	0.976 ± 0.01	72.76 ± 5.15	42.62 ± 2.29	122.61 ± 4.01	2003.33 ± 0.02	9.9 ± 0.3
S4711	3.002 ± 0.06	0.768 ± 0.030	114.71 ± 2.92	131.59 ± 3.09	20.10 ± 3.72	2010.85 ± 0.06	7.6 ± 0.3
S4712	18.038 ± 0.099	0.364 ± 0.032	117.28 ± 1.31	238.08 ± 3.43	166.38 ± 3.20	2007.12 ± 0.08	112.0 ± 2.9
S4713	8.016 ± 0.379	0.351 ± 0.059	111.07 ± 1.66	301.97 ± 8.02	195.06 ± 5.15	2000.03 ± 0.22	33.2 ± 2.5
S4714	4.079 ± 0.012	0.985 ± 0.011	127.70 ± 0.28	357.25 ± 0.80	129.28 ± 0.63	2017.29 ± 0.02	12.0 ± 0.3
S4715	5.756 ± 0.439	0.247 ± 0.040	129.80 ± 3.72	359.99 ± 5.38	282.15 ± 2.92	2008.05 ± 0.30	20.2 ± 2.4

S4711 and friends

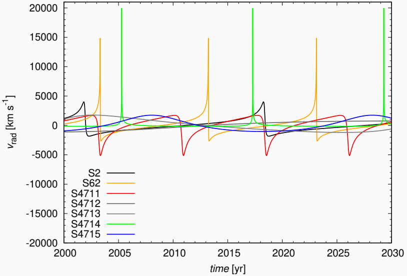
General relativistic effects:

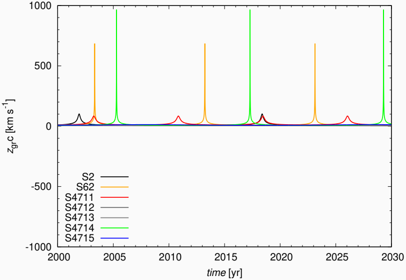
- relativistic parameter: $\Gamma = r_\mathrm{s}/r_\mathrm{p}$, $r_\mathrm{p} = a(1-e)$
- Schwarzschild precession: $\delta\phi = \frac{6\pi GM}{c^2 a(1-e^2)} = \frac{3\pi\Gamma}{1+e}$
- gravitational redshift: $z_\mathrm{gr} = \left(1 - \frac{r_\mathrm{s}}{r}\right)^{-1/2} - 1$
- Lense-Thirring (LT) precession (spin towards the observer): $\dot{\Omega}_\mathrm{LT} = \frac{2G^2M^2\chi}{c^3a^3(1-e^2)^{3/2}} = \Gamma^2 \frac{\chi c}{2r_\mathrm{a}}\sqrt{\frac{1-e}{1+e}}$
- detailed studies about LT precession and S4711-S4715 stars: Fragione & Loeb (2020), Iorio (2020)

Star	r_p [AU]	r_a [AU]	v_p [km/s] (% of c)	$\Gamma[10^{-4}]$	$z_\mathrm{gr}c$ [km s^{-1}]	$\delta\phi$ [arcmin]	$\dot{\Omega}_\mathrm{LT}$ [arcsec yr^{-1}]
S62	17.8 ± 7.4	1462.4 ± 11.0	20124 ± 4244 (6.7 ± 1.4)	46	685.5 ± 288.6	74.7 ± 31.0	5.1 ± 3.2
S4711	143.7 ± 18.8	1094.7 ± 28.7	6693 ± 494 (2.2 ± 0.2)	5.6	84.5 ± 11.8	10.3 ± 1.3	0.34 ± 0.07
S4712	2366 ± 120	5075 ± 122	1449 ± 54 (0.48 ± 0.02)	0.34	5.1 ± 0.4	0.81 ± 0.05	$(5.1 \pm 0.5) \times 10^{-4}$
S4713	1073 ± 110	2234 ± 144	2141 ± 153 (0.71 ± 0.05)	0.75	11.3 ± 1.3	1.8 ± 0.1	$(5.8 \pm 1.1) \times 10^{-3}$
S4714	12.6 ± 9.3	1670 ± 10	23928 ± 8840 (8 ± 3)	64	966.1 ± 713.5	104.6 ± 76.3	7.0 ± 7.6
S4715	894 ± 83	1480 ± 122	2253 ± 129 (0.75 ± 0.04)	0.90	13.6 ± 1.4	2.4 ± 0.2	$(1.4 \pm 0.4) \times 10^{-2}$
S2	119.3 ± 0.3	1949.9 ± 2.8	7582 ± 8 (2.527 ± 0.003)	6.8	101.7 ± 5.0	11.7 ± 0.6	0.19 ± 0.02

S4711 and friends

Predicted pericenter/peribothron velocities up to the fraction of light speed



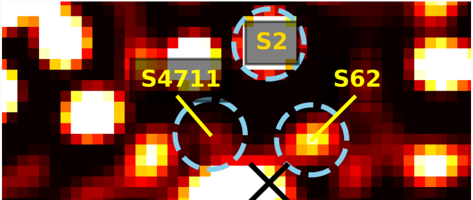


Source	Magnitude [mag_K]	Mass [$M_\odot$]
S62	16.1	6.1
S4711	18.4	2.2
S4712	18.4	2.2
S4713	18.5	2.1
S4714	17.7	2.0
S4715	17.8	2.8

Future monitoring with ELT/potentially GRAVITY needed!

Summary

- S62, S4711-S4715 are in projection at least for a fraction of their orbits inside S2 orbit
- S4711 shortest-period star around SMBH up to date (7.6 years)
- S4711 and S62 have periods of less than 10 years
- S4711, S4714 are predicted to have the relativistic parameter an order of magnitude larger than S2 star: their pericenter distances should reach $\sim 200\, r_\mathrm{s}$ in comparison with S2's pericenter distance of $\sim 1500\, r_\mathrm{s}$
- **S62, S4711, S4714: three new strong-gravity probes around SMBH $\rightarrow$ good prospects for studying Schwarzschild and LT precession with new instrumentation**



Summary

For more details, see the paper Peissker, Eckart,Zajacek+2020:

THE ASTROPHYSICAL JOURNAL

S62 and S4711: Indications of a Population of Faint Fast-moving Stars inside the S2 Orbit—S4711 on a 7.6 yr Orbit around Sgr A*

Florian Peißker[1], Andreas Eckart[1,2], Michal Zajaček[3,1], Basel Ali[1], and Marzieh Parsa[1]

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+ Article information

Abstract

We present high-pass filtered NACO and SINFONI images of the newly discovered stars S4711–S4715 between 2004 and 2016. Our deep *H*+*K*-band (SINFONI) and *K*-band (NACO) data show the S-cluster star S4711 on a highly eccentric trajectory around Sgr A* with an orbital period of 7.6 yr and a periapse distance of 144 au to the supermassive black hole (SMBH). S4711 is hereby the star with the shortest orbital period and the smallest mean distance to the SMBH during its orbit to date. The used high-pass filtered images are based on coadded data sets to improve the signal to noise. The spectroscopic SINFONI data let us determine detailed stellar properties of S4711 like the mass and the rotational velocity. The faint S-cluster star candidates, S4712–S4715, can be observed in a projected distance to Sgr A* of at least temporarily ≲120 mas. From these stars, S4714 is the most prominent, with an orbital period of 12 yr and an eccentricity of 0.985. The stars S4712–S4715 show similar properties, with magnitudes and stellar masses comparable to those of S4711. The MCMC simulations determine confidently precise uncertainties for the orbital elements of S62 and S4711–S4715. The presence of S4711 in addition to S55, S62, and the also newly found star S4714 implies a population of faint stars that can be found at distances to Sgr A* that are comparable to the size of our solar system. These short orbital time period stars in the dense cluster around the SMBH in the center of our Galaxy are perfect candidates to observe gravitational effects such as the periapse shift.