Life circle of Triple Supermassive Black Hole in NGC 6240

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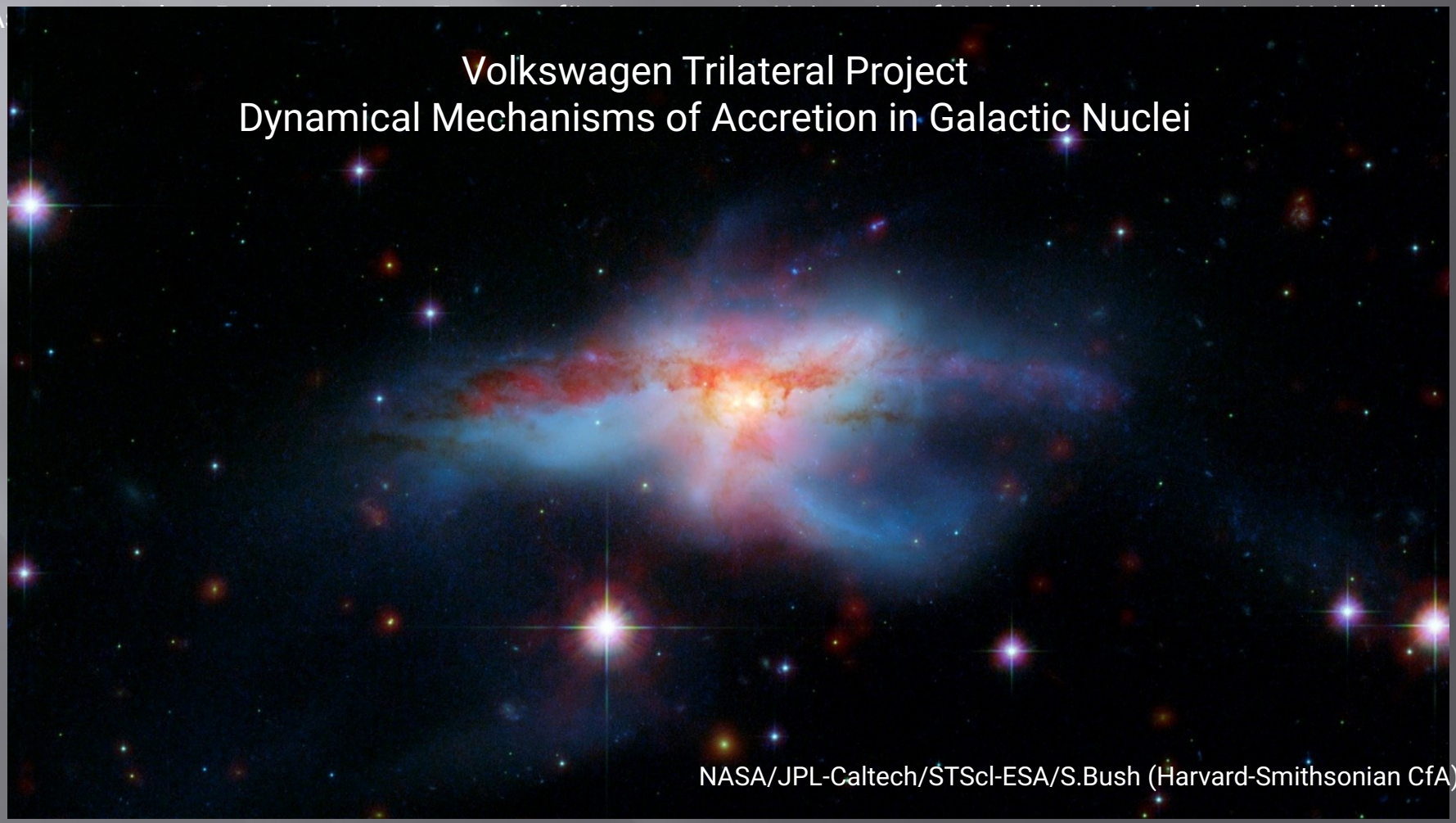
[3]A

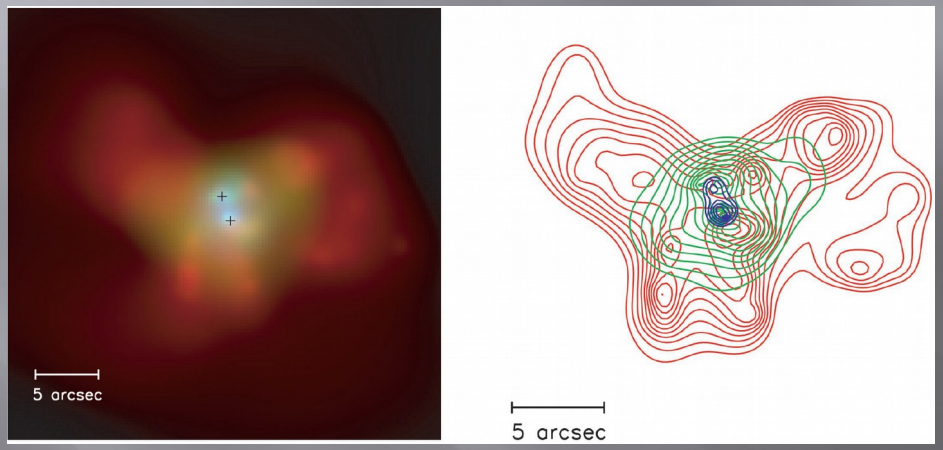


NGC 6240: observations

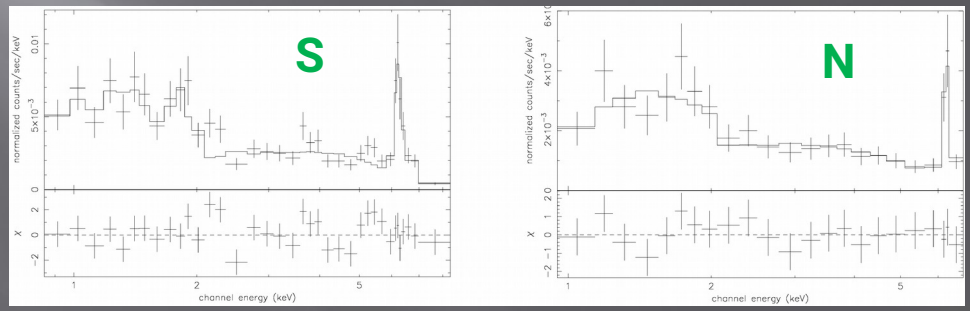
Discovery of a Binary Active Galactic Nucleus in the Ultraluminous Infrared Galaxy NGC 6240 Using Chandra

S. **Komossa** , V. Burwitz , G. Hasinger , P. Predehl , J. S. Kaastra , and Y. Ikebe

The Astrophysical Journal, 582:L15-L19, 2003



Multi-colour image of NGC 6240. Red=soft (0.5-1.5 keV), green = medium (1.5-5 keV) and blue = hard (5-8 keV) X-ray band. The right image shows contour plots, using the same colour coding.



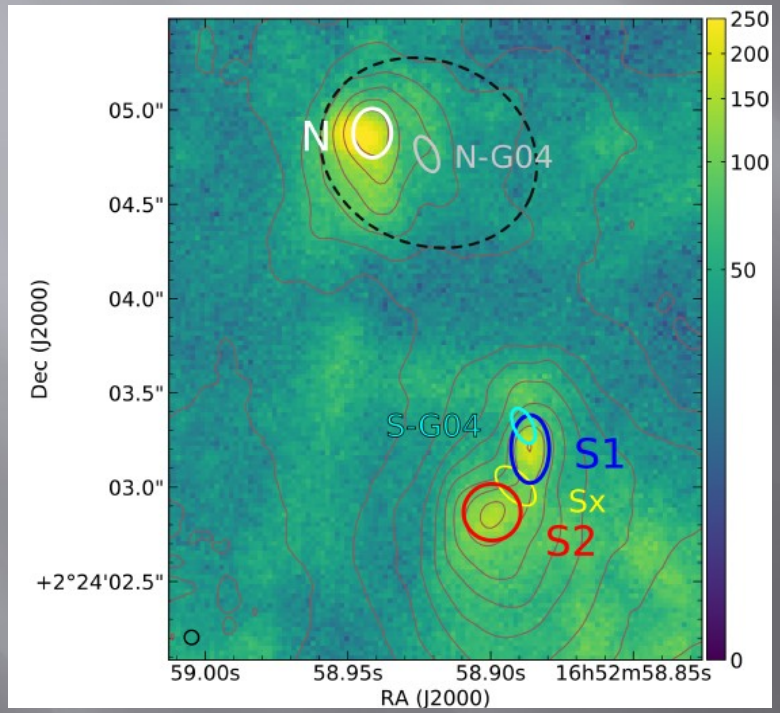
X-ray spectrum of southern nucleus (left) and the northern nucleus (right) of NGC 6240. A model consisting of thermal emission plus an absorbed power law and two Gaussian emission lines was fitted to the data. The lower panel of each figure shows the residuals.

NGC 6240: observations

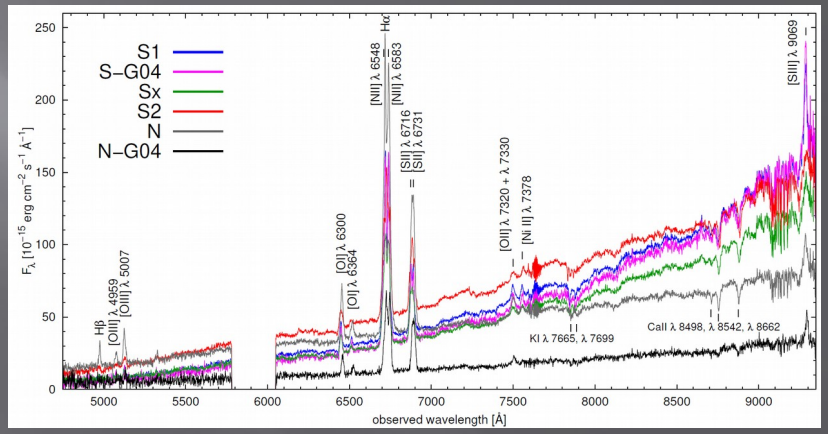
NGC 6240: A triple nucleus system in the advanced or final state of merging

W. Kollatschny, P. M. Weilbacher, M. W. Ochmann, D. Chelouche, A. Monreal-Ibero, R. Bacon and T. Contini

A&A **Vol.** 633, Jan. 2020



I-band contour levels are overlaid. Spectra were extracted at the three locations corresponding to the peaks of maximum intensity in the I-band map (N, S1, S2, indicated by circles or ellipses)



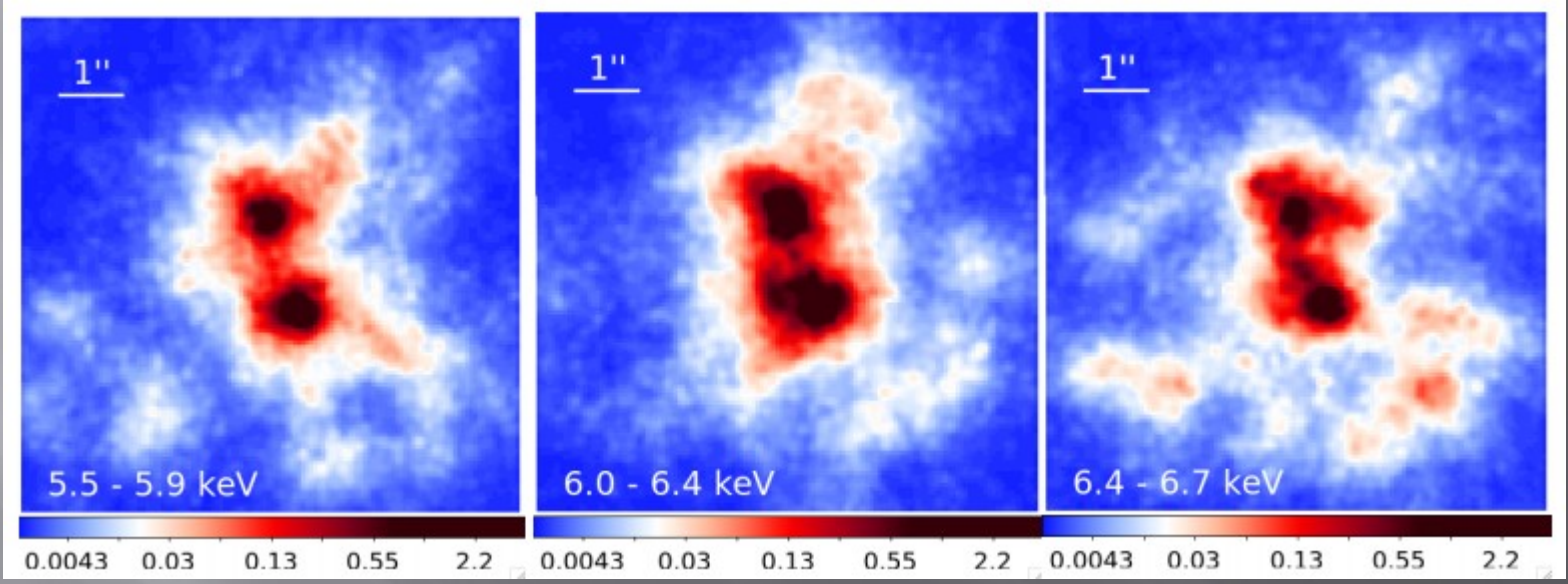
Spectra of the northern N (gray) and southern S1 (blue) and S2 (red) emission regions, of the northern N-G04 (black) and southern S-G04 (pink) MERLIN and VLBA radio positions, and the region Sx between the southern components (green)

NGC 6240: observations

Revisiting the complex nuclear region of NGC 6240 with Chandra

G. Fabbiano, A. Paggi, M. Karovska , M. Elvis , E. Nardini, J. Wang

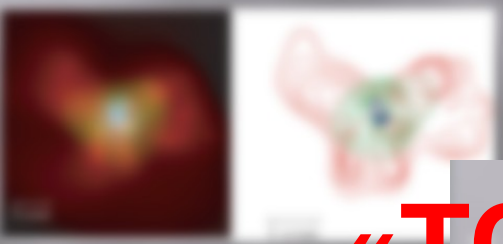
The Astrophysical Journal, Vol. 902, Iss.1, 15 pp.



EMC2 reconstruction (200 iterations) of the X-ray emission in the central ~1 kpc of NGC 6240 , in the hard 5.5-5.9 keV observed continuum, 6.0-6.4 keV (redshifted Fe I Ka) and 6.4-6.7 keV (redshifted Fe XXV) energy bands. N is to the top and E to the left in all the panels. The color scale is logarithmic in units of counts per image pixel (1/8 of the

"We do not find strong evidence of X-ray emission associated with the 3rd nucleus proposed by Kollatschny et al. (2020), although this region is associated with the SE excess, and a possible clump of Fe I Ka emission is suggested in this area by the EMC2 reconstruction."

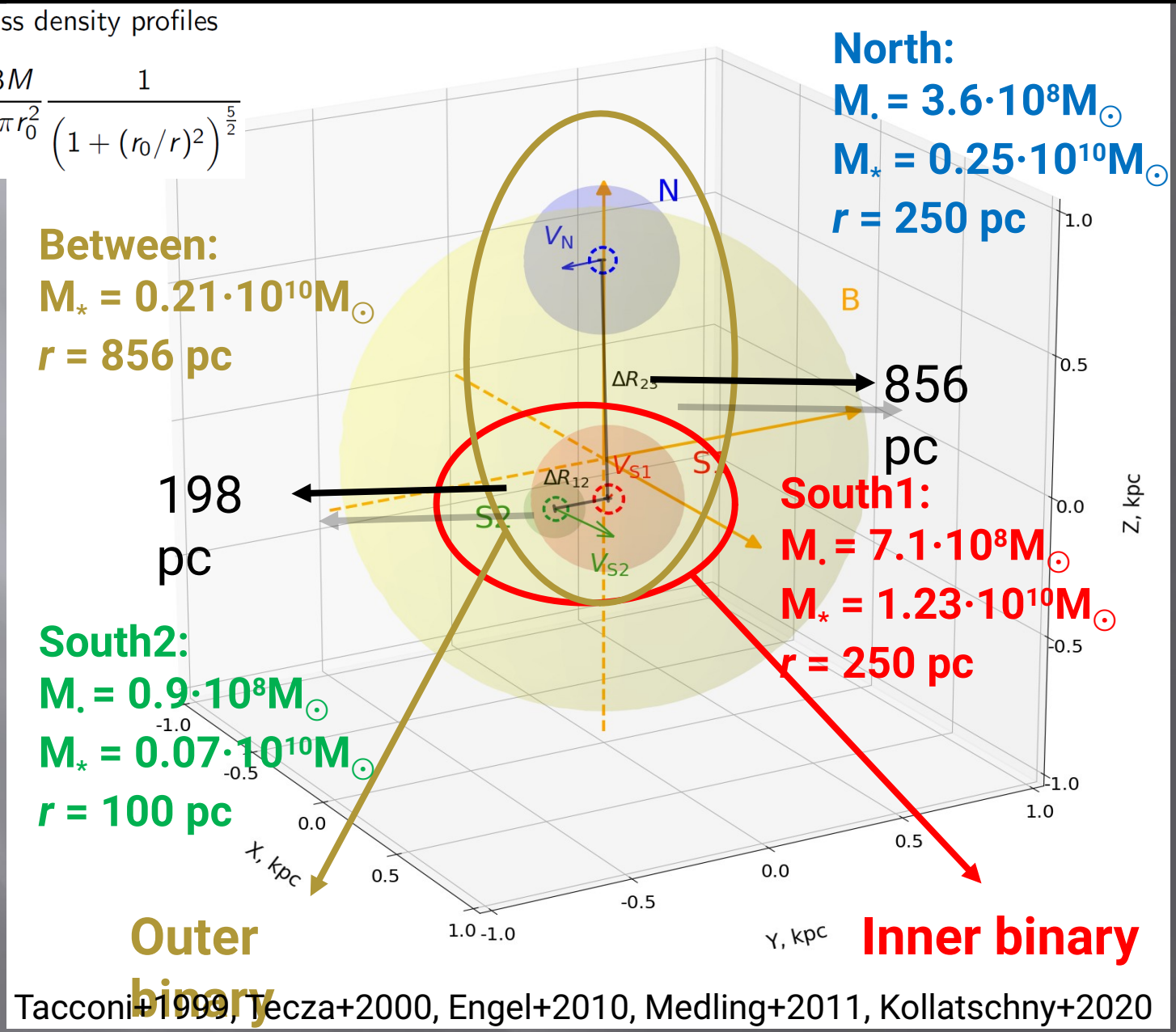
«TO BE OR NOT TO BE» - THE QUESTION IS OPEN AND REQUIRES FURTHER STUDY!



Initial physical model

Plummer mass density profiles

$$\rho(r) = \frac{3M}{4\pi r_0^2} \frac{1}{\left(1 + (r_0/r)^2\right)^{\frac{5}{2}}}$$



Tacconi+1999, Tecza+2000, Engel+2010, Medling+2011, Kollatschny+2020

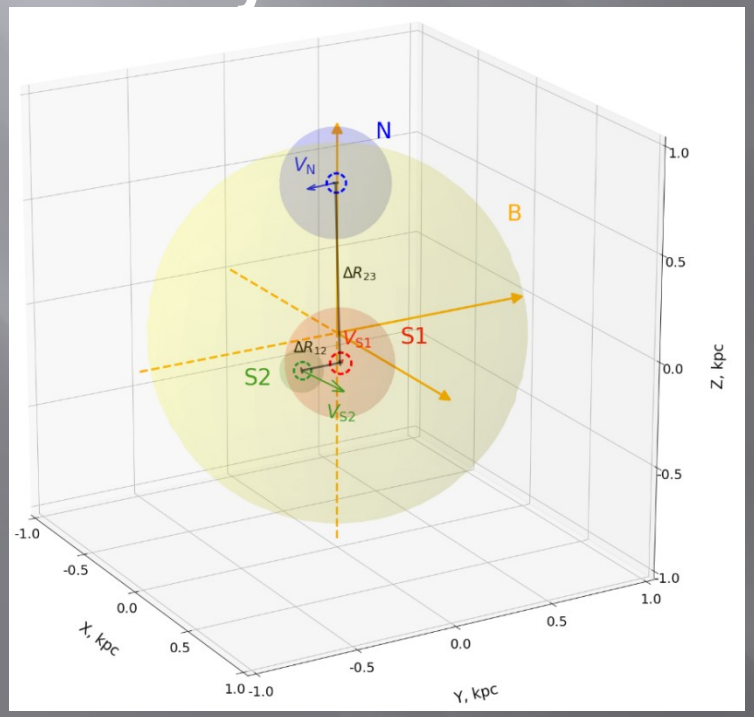
N-body code and set of models

- For simulations we used the publicity available **φ-GPU code**† with the blocked hierarchical individual time step scheme and a 4th-order Hermite integration of the equation of motions for all particles (Berczik+2011, Khan+2011)
- Acceleration for *i* particle:

$$\boldsymbol{a}_i = -\sum_{j=1,\, j\neq i}^{N} \frac{G m_j}{(r_{ij}^2 + \varepsilon_{ij}^2)^{3/2}} \boldsymbol{r}_{ij},$$

where **softening** is $\varepsilon_{BH}=0$ for BHs and $\varepsilon_{p}=10^{-4}$ for all another particles.

Physical model

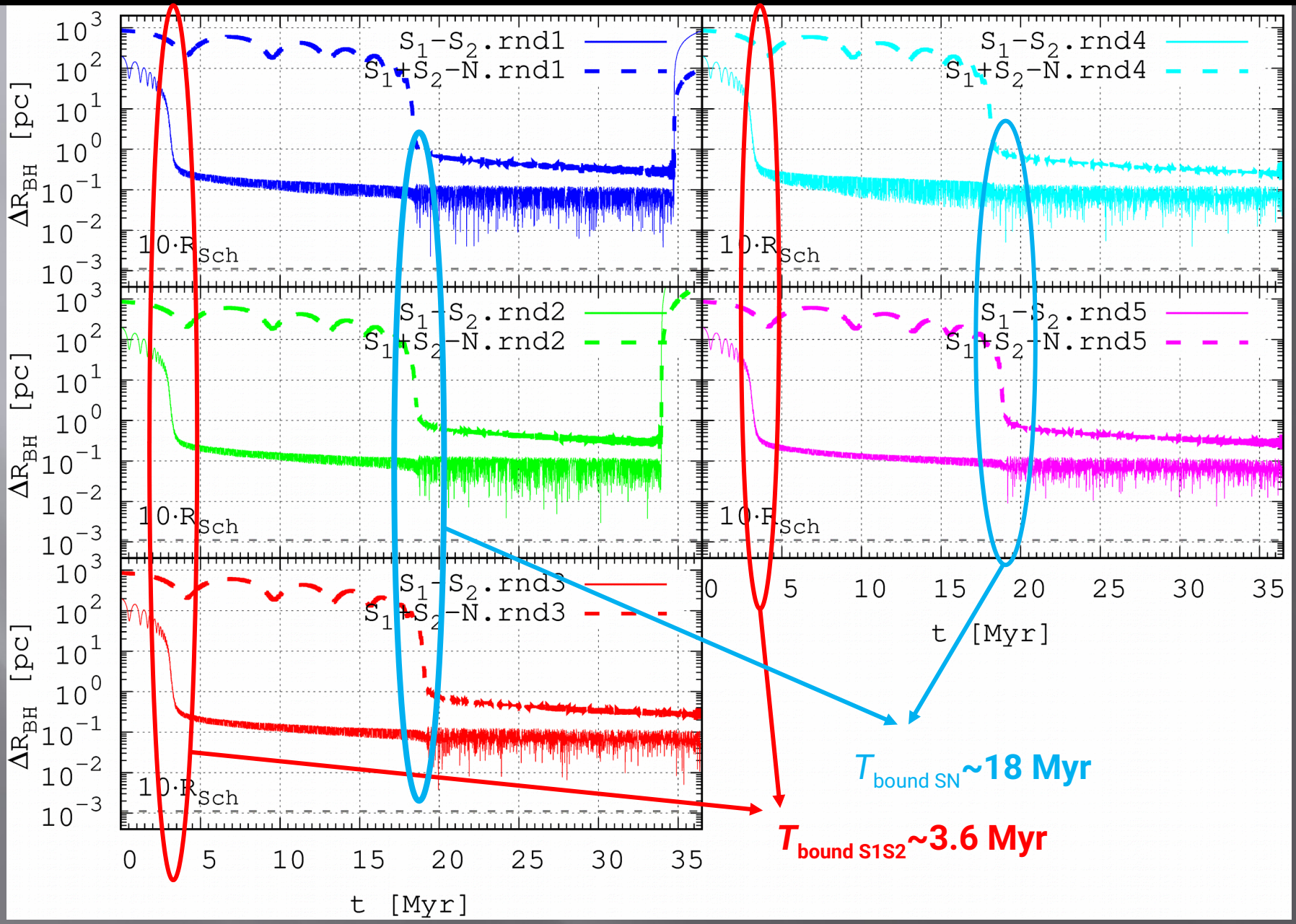


Numerical models

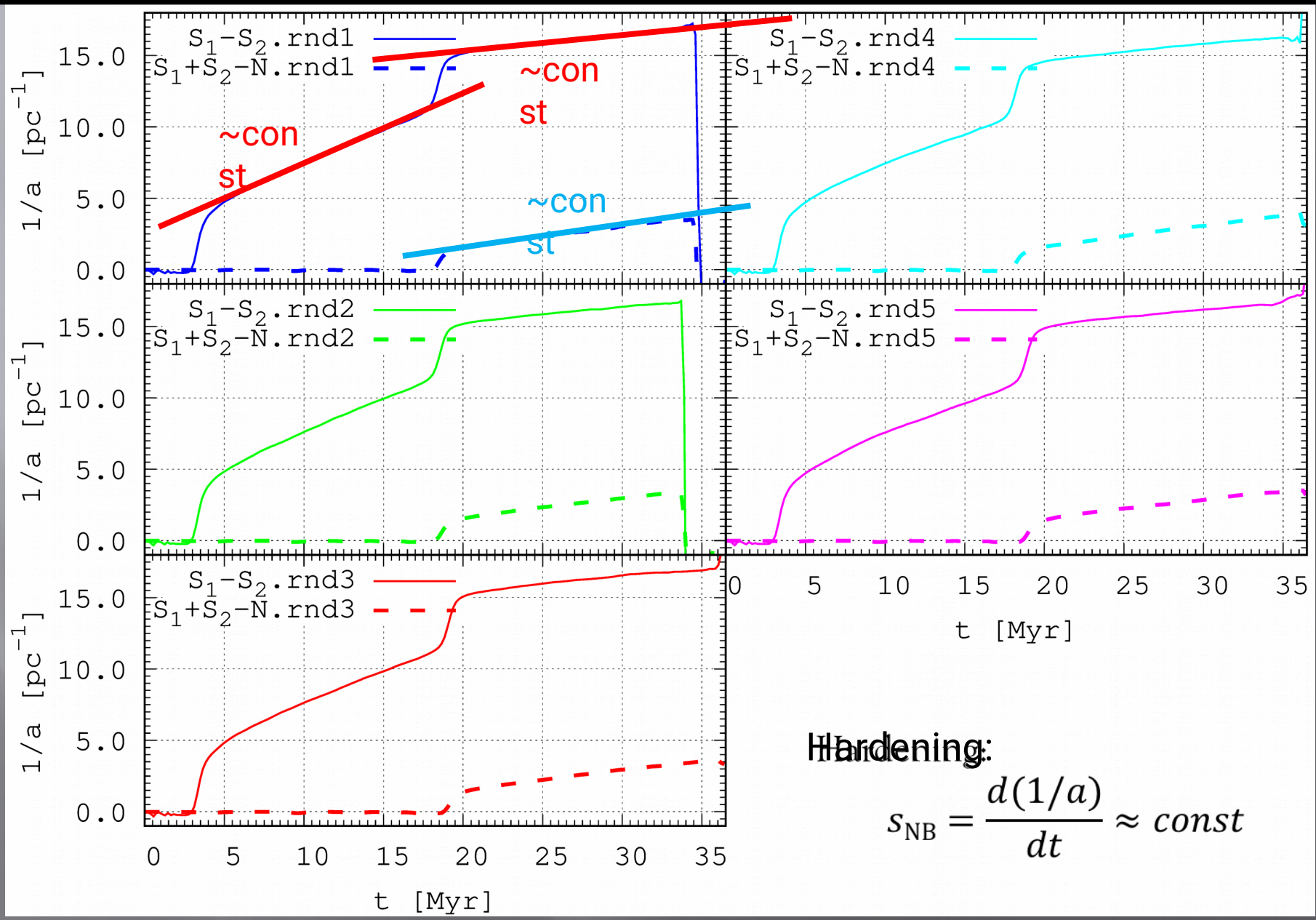
N, number of particles	Randomisation
67.5k	rnd 1, 2, 3, 4, 5
135k	rnd 1, 2, 3, 4, 5
270k	rnd 1, 2, 3, 4, 5
540k	rnd 1, 2, 3, 4, 5
4 variants x 5 randomization = **20 numerical sets**	

† ftp://ftp.mao.kiev.ua/pub/berczik/phi-GPU/

540k models – evolution of separation ΔR_{BH}



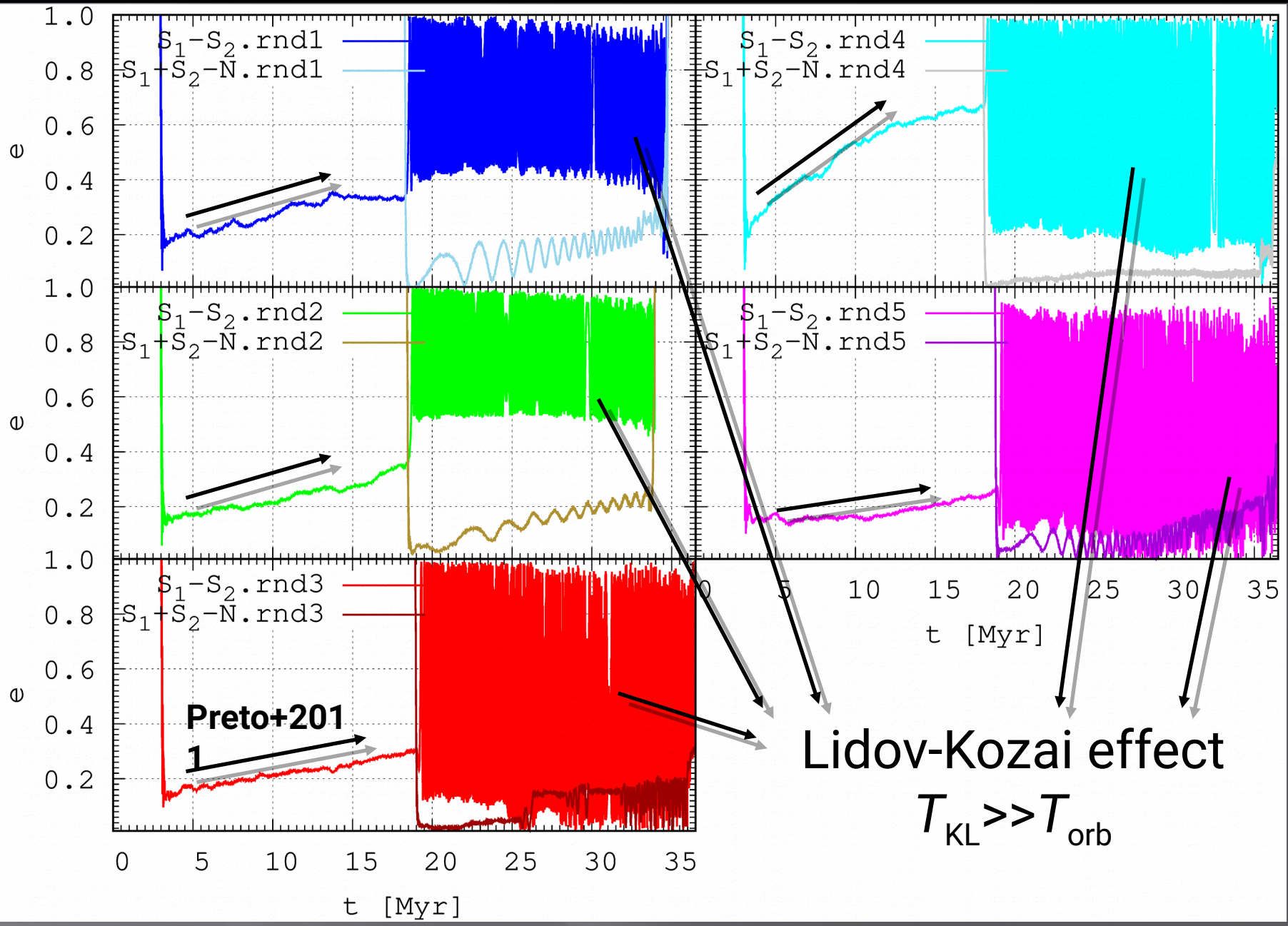
540k models – evolution of inverse semimajor axis 1/a



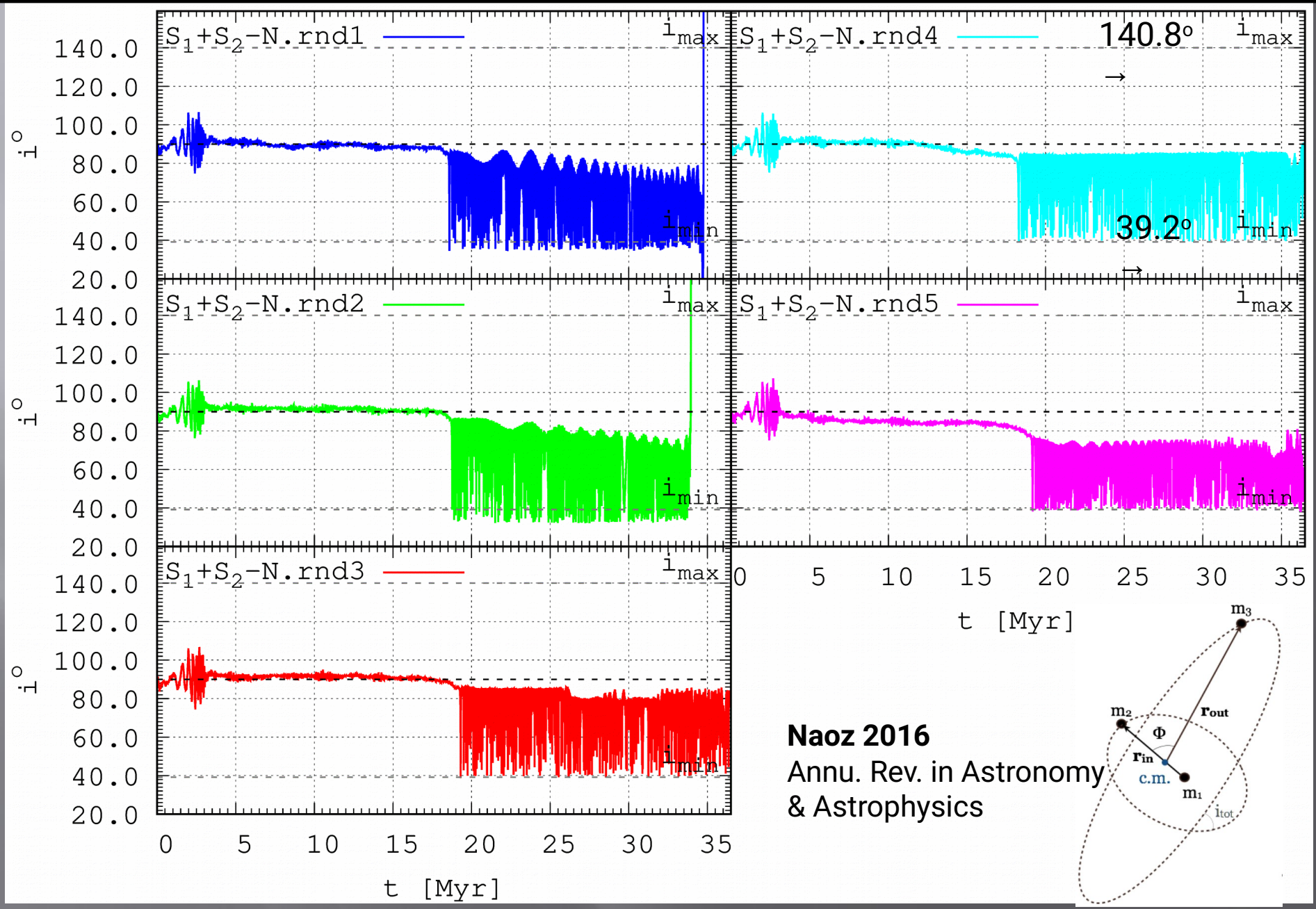
Hardening:

$$s_{\mathrm{NB}} = \frac{d(1/a)}{dt} \approx const$$

540k models – evolution of eccentricity e

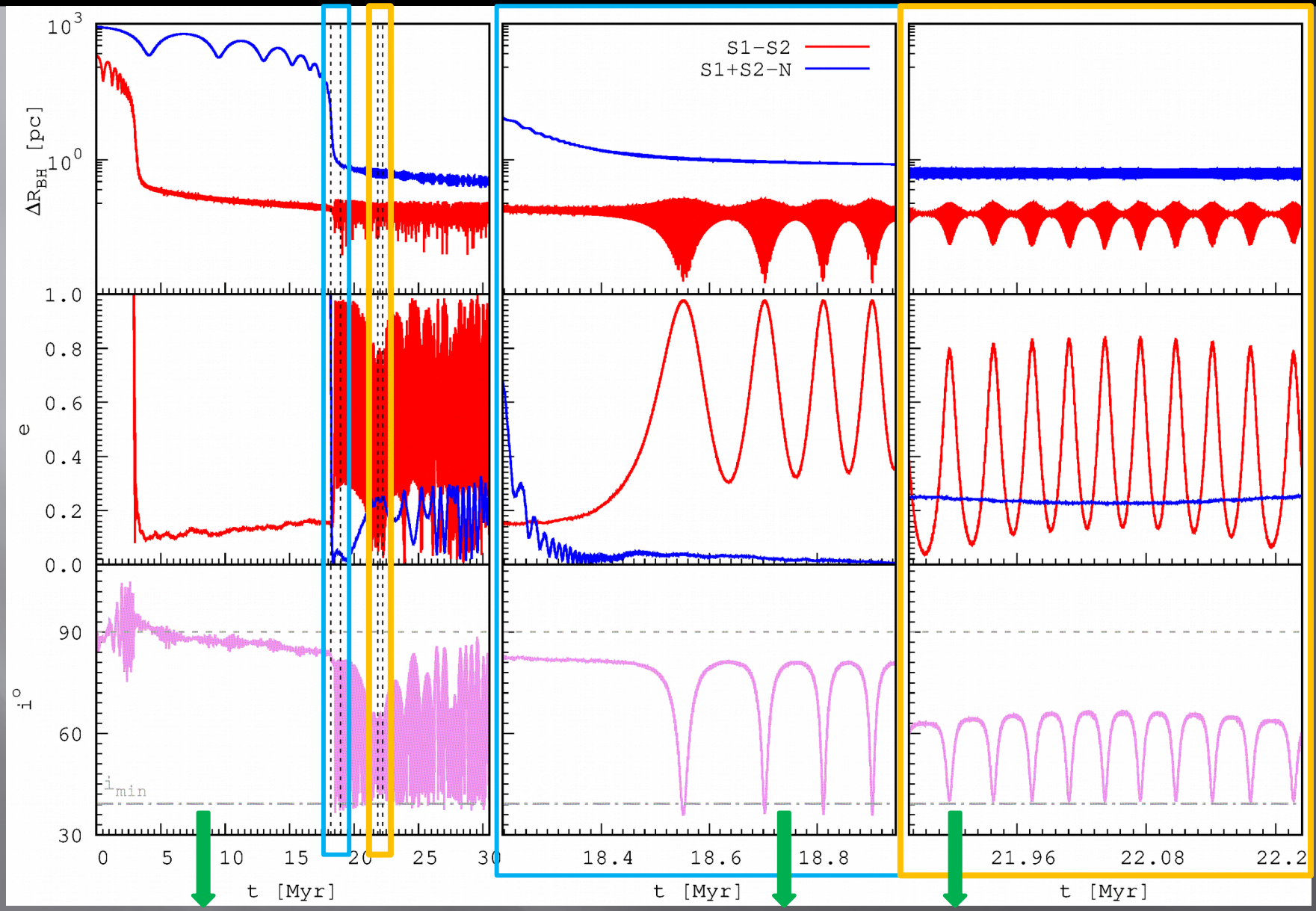


540k models – evolution of angle i



Naoz 2016
Annu. Rev. in Astronomy & Astrophysics

540k model – details at 18 Myr and 22 Myr



$\Delta t_{snap} \approx 46\,000$ yr

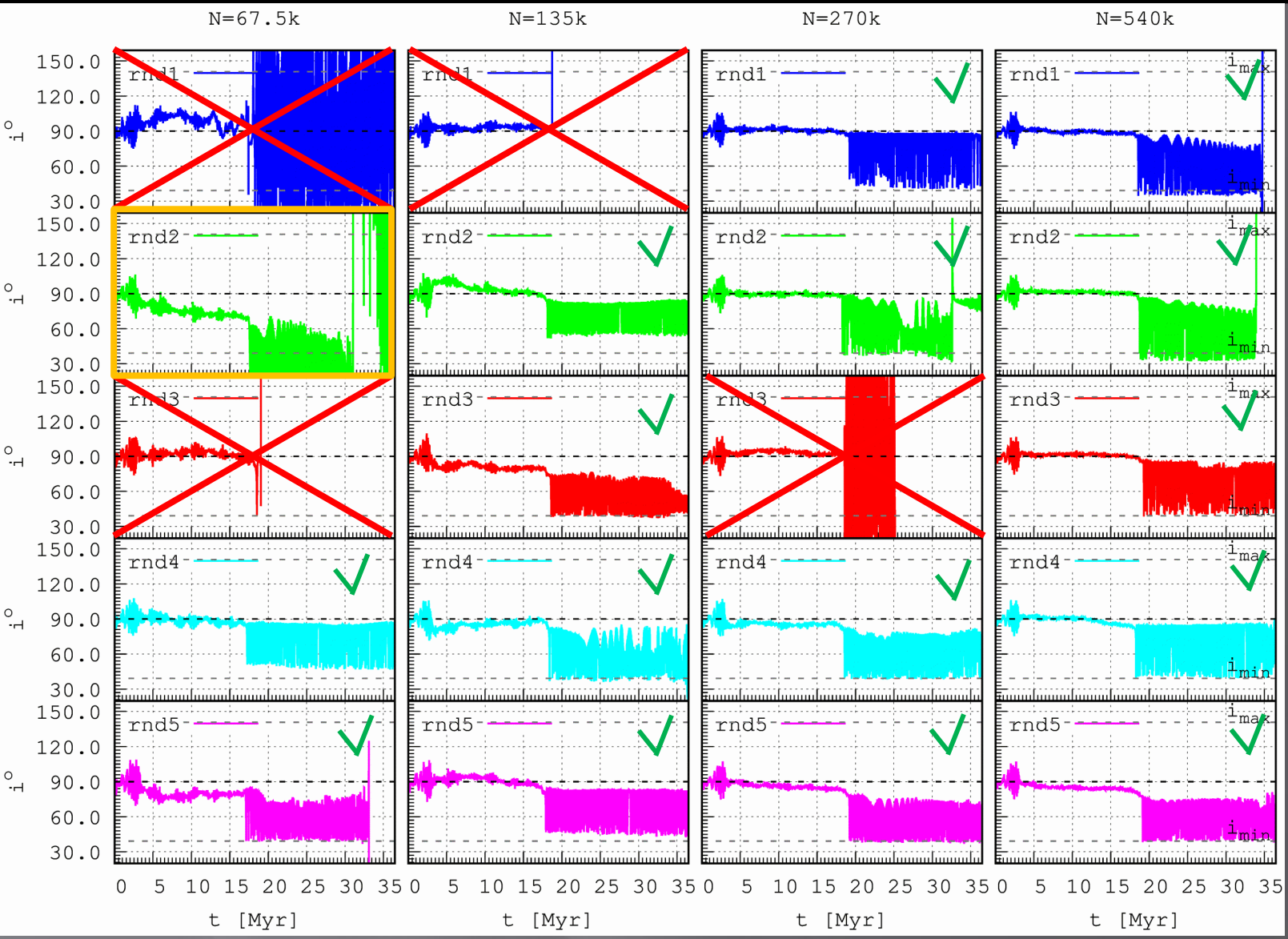
$\Delta t_{snap} \approx 5.6$ yr

Visualization of NGC 6240 evolution

Observation ➡ Simulation: bulge scale (±800/400 pc) ➡ Simulation: BH orbit scale (±1 pc)

Permanent link to the video
https://youtu.be/Jy919R6f61g

Set of numerical models



not formed triple system

formed nonhierarchical triple system

formed hierarchical triple system + Lidov-Kozai effect

~75 % of numerical models showed Lidov-Kozai

Conclusions

- We traced the dynamical evolution of rare triple SMBHs system at merging galaxy NGC 6240.
- Four numerical models with 67 500, 135 000, 270 000 and 540 000 particles with five sets of randomization were computed.
- We noticed the Lidov-Kozai mechanism in merging triple SMBH system in direct N-body simulations and showed global trending independence from the initial randomizations and number of particles.

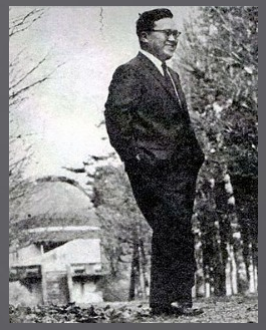
Future goals:

- Obtain the merging time for central BHs adding relativistic post-Newtonian terms.
- Analyze other initial system's configurations.
- New observations for more precise definition of system's physical parameters.

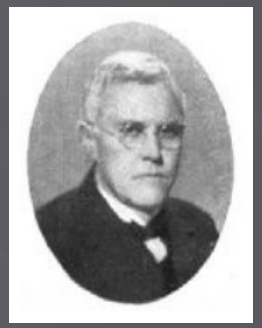
Post Scriptum

Лидов М. Л. Эволюция орбит искусственных спутников под воздействием гравитационных возмущений внешних тел // Искусственные спутники Земли – 1961. – Т. 8. – С. 5–45. , originally in Russian.

Lidov, M. L. (1962), The evolution of orbits of artificial satellites of planets under the action of gravitational perturbations of external bodies, Planetary and Space Science, 9, 719–759, [https://doi.org/10.1016/0032-0633(62)90129-0], an English translation of Lidov (1961).



Kozai, Y. (1962), Secular perturbations of asteroids with high inclination and eccentricity, The Astronomical Journal, 67, 591–598, [https://doi.org/10.1086/108790].



von Zeipel, H. (1910), Sur l'application des séries de M. Lindstedt à l'étude du mouvement des comètes périodiques, Astronomische Nachrichten, 183, 345–418, [https://doi.org/10.1002/asna.19091832202]. A full-text open access PDF file is available from ADS, https://ui.adsabs.harvard.edu/abs/1910AN....183..345V.

Takashi Ito and Katsuhito Ohtsuka (2019), The Lidov-Kozai Oscillation and Hugo von Zeipel, Monogr. Environ. Earth Planets, Vol. 7 (No. 1), pp. 1-113, [10.5047/meep.2019.00701.0001].

The prefix «VON ZEIPEL-LIDOV-KOZAI» should be used for designating this theoretical framework!