Open Problems in Modern Astrophysics – Problem set 4. Autumn 2021

*The answers should be returned by **Friday (5.11) 4pm (16.00) in Moodle**, link through the official course homepage. The answers to the problem set will be discussed on Tuesday (9.11) at 12.15-14.00 in Room D123, Exactum.*

This problem set will contain **General** questions and questions based on the two papers: Oka, T., Tsujimoto, S., Iwata, Y. et al., 2017, Nature Astronomy, 1, 709: "Millimetre-wave emission from an intermediate-mass black hole candidate in the Milky Way"(**Paper 1**) Miller, J.M., Kaastra, J.S., Miller, M.V. et al, 2015, Nature, 526, 524: "Flows of X-ray gas reveal the disruption of a star by a massive black hole"(**Paper 2**)

1. **General question 1**

   (a) What three fundamental types of astrophysical black holes exist in the Universe, if we take the mass of the black hole as a dividing line. In what type of environments are these three types of black holes found and give also a rough estimate of their number in the Milky Way galaxy.

   (b) What is the Eddington limit for black hole accretion? Why does such a limit exist and is it possible to surpass this limit and accrete gas onto a black hole at Super-Eddington rates? In what circumstances could this be possible?

   (c) Explain briefly what is meant with two-body relaxation. Why is this process relevant close to the centre of the supermassive black hole in the Milky Way, but completely irrelevant in the Milky Way disc at the location of the Sun. What is meant by mass segregation, in which situations do we observe mass segregation?

2. **General question 2**

   (a) The merging of two supermassive black holes in a galaxy mergers proceeds through three phases, including the 1) dynamical friction phase, the 2) three-body scattering phase and 3) the gravitational wave emission phase. Explain briefly in words what is taking place in these different phases and why the concepts of loss-cone and the ”final-parsec problem” are important in this context.

   (b) Explain in what circumstances stars can be tidally disrupted close to supermassive black holes. Why can this disruption process be only observed around moderately massive supermassive black holes with $M_{\rm BH} \lesssim 10^8 M_\odot$? Is there a characteristic time dependence of the flux signal from tidal disruption events, if so, explain why?

   (c) What are hypervelocity stars (HVSs)? What are their mostly likely origin, how are they detected, approximately how many hypervelocity stars are currently known in the Milky Way and what is the ultimate fate of these stars?

3. Based on **Paper 1** answer the following questions:

   (a) In this paper, what exactly have the authors observed and using which instrument? What could the observed source potentially be and how has it ended up close to the Milky Way centre according to the authors of this paper?

   (b) Based on Figure 3. in the paper, how does the spectral energy distribution (SED) of this source compare with the SED of Sagittarius A*, which hosts the central supermassive black hole of the Milky Way. How luminous is the detected source currently and what does this mean for the accretion rate of the source?

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(c) The authors use numerical N-body simulations to support the claims made in the paper. Explain briefly how exactly the simulation supports the existence of an embedded massive point source. In particular study Figures 2. and 4. and explain what we can learn from them.

4. Based on **Paper 2** answer the following questions:

   (a) In this paper, what have the authors observed and how was the source detected? At what distance is the source and what does Figure 1. tell us about the most likely nature of this source?

   (b) What do the spectra in Figure 2. tell us about the source? Why is the absorption of blueshifted ionised gas important? What can be learned about the source based on its blackbody emission?

   (c) Why is it relevant that the spectra seem to indicate a phase of super-Eddington accretion? What is most probably causing such accretion? Are the gas flows expected to be smooth or clumpy? Are there any indications of an accretion disc and what is this telling us?