教育部補助大專校院延攬國際頂尖人才
年度績效報告（擇一）

學校名稱及聘任系所：國立台灣大學物理系	學門領域： 理 學
學者姓名：薛熙于	□玉山學者　■玉山青年學者

Yushan Fellow Program Performance Report

Assessment of effectiveness of tangible work (The implementation results can be presented cumulatively, including the annual performance report of the second year, which can include the results of the first year and the second year)

Main points of assessment	The anticipated goals	Concrete work achievements or results	Supporting documents
1. Chief content of the Yushan (Young) Fellows' research work and overview of full research process.	1. Investigate the true nature of dark matter. 2. Develop high-performance tools for astrophysical simulations and data analysis.	1. Since 2018, we have published 11 papers related to the study of fuzzy dark matter or simulation tool development on top journals, including two papers on Physical Review Letters. 2. We have significantly extended the capability of our own code *GAMER* and applied it to various important applications, such as fuzzy dark matter, AGN jets with special relativity, core-collapse supernovae, and first star formation. 3. We have developed an in-situ analysis tool, *libyt*, for analyzing large simulations on-the-fly with a very high temporal resolution.	
2. The link between Yushan (Young) Fellows' future research topics and the university's development and the anticipated benefits (including Higher Education SPROUT Project): (1)Fellows' research plan and goals (2)The link between scholars' research content and the university's development (3)Specific work performance or achievements, please include the mid-term progress report of the particular research plan	1. Fuzzy Dark Matter (FDM): We will constrain the fuzzy dark matter model by comparing high-resolution numerical simulations, theoretical predictions, and observational data. 2. Code Development: We will continue the development of astrophysical simulation tools, including our GPU-accelerated adaptive mesh code *GAMER* and the in-situ analysis tool *libyt*. We will make the tools publicly available. 3. Papers: We plan to submit 1-2 papers per year on top journals.	1. Our pioneering high-resolution FDM simulations reveal, for the first time, that soliton is not static but exhibits a confined random walk at the base of the halo potential. This finding has a profound impact in that (i) it puts all previous studies assuming a static soliton in question, and (ii) it leads to new challenges against FDM, for example, the tidal disruption and heating of nuclear star clusters. 2. We have successfully constructed the world's first three-dimensional Milky Way-sized FDM halo with a particle mass	

Main points of assessment	The anticipated goals	Concrete work achievements or results	Supporting documents
(4)Anticipated goals (including qualitative or quantitative working performance or results) ※ If there is a quantitative work achievements, please fill out "Quantitative Assessment Form"		of (2-8)*10^{-23} eV and a halo virial mass of 10^{12} M⊙, an order of magnitude more massive than the previous most massive FDM halos in the literature. This task is extremely computationally expensive and is achieved by taking advantage of both mesh refinement and GPU acceleration using 32 V100 GPUs on the Taiwania II supercomputer at the National Center for High-performance Computing (NCHC). We have also managed to simulate the evolution of this halo, especially the random motion of its central solitonic core, over the age of the universe using GAMER. We demonstrate that the soliton random motion will lead prominent displacement and relative velocity between the central stellar object and the halo center-of-mass, which can be used to constrain the FDM particle mass. 3. We have demonstrated from both numerical simulations and theoretical analysis that, irrespective of the FDM particle mass, the gravitational heating from soliton oscillations on a central star cluster is inefficient and adiabatic since the oscillation timescale is substantially longer than the characteristic timescale of a star cluster. We have also shown that density oscillation is an intrinsic property of solitons that persists even after significant tidal stripping of an ambient halo. However, if the tidal field is strong enough such that the corresponding tidal radius is only a factor of few larger than	

Main points of assessment	The anticipated goals	Concrete work achievements or results	Supporting documents
		the soliton radius, it will quickly damp the FDM excited states responsible for soliton oscillations and thus greatly reduce the oscillation amplitude. 4. We have significantly extended the capability of GAMER, including magnetohydrodynamics, special-relativistic hydrodynamics (SRHD), nuclear equation of state, deleptonization, lightbulb scheme for neutrinos, FDM, and cold dark matter. We have applied the code to various astrophysical applications, such as merging galaxy clusters, AGN jets with SRHD, Fermi bubble with SRHD, core-collapse supernovae, and several FDM studies as mentioned previously. 5. We have finished the development of *libyt*, an in-situ analysis tool for astrophysical simulations. The code and user guide can be acessed at https://github.com/calab-ntu/libyt. We have successfully applied this tool to analyze (i) the entropy distribution and neutron star properties in core-collapse supernova simulations and (ii) the dynamics of quantum vortices (e.g., reconnection) in FDM halos. 6. We have published 11 papers on top journals since Aug. 2018, including two papers on Physical Review Letters.	
3. Support provided by the university and the project's original goals (please specify the type of support or funds provided by the university to assist in research, such as research equipment and funds, research	NTU core research project "Testing Wave Dark Matter ---- Observation, Theory, Simulation and Experiment": 1,200K TWD per year from 2019 to 2021.	We have utilized this fund to finish the construction of a 32-node GPU cluster.	

Main points of assessment	The anticipated goals	Concrete work achievements or results	Supporting documents
assistant personnel expenses, accommodation, relocation, children's education assistance, etc.)			
4. Yushan Fellows ' team cooperation (please list team members and cooperation methods) (Yushan Young Fellows don't need to fill in this)			
5. Yushan (Young) Fellow should aim to cooperate and exchange foreign academic resources, which should be linked to university development. It's suggested to make good use of these global academic network resources to assist the internationalization of the host university and promote international exchanges and cooperation, including teachers and students exchange activity between universities, international research collaborations, dual degree programs and so on.	1. Establishing concrete collaboration with leading research groups. 2. Student exchange.	1. We have been collaborating with Prof. Frank van den Bosch and Dr. Dhruba Dutta Chowdhury at Yale University and published one paper together on The Astrophysical Journal. 2. We have been collaborating with Prof. Jeremiah Ostriker at Columbia University on disk thickening induced by an oscillating granular halo. We will submit a paper later this year. 3. The former Master's student Barry Chiang has been visiting both Prof. Jeremiah Ostriker and Prof. Frank van den Bosch for the collaboration of various FDM projects. 4. The former Master's student Shin-Rong Tsai has been working as a research assistant at UIUC. 5. The former undergraduate student Huai-Hsuan Chiu has been admitted to a PhD program at Michigan university.	

3. Information on website **(Refer to: https://yushan.moe.gov.tw/TopTalent/EN/Project)**

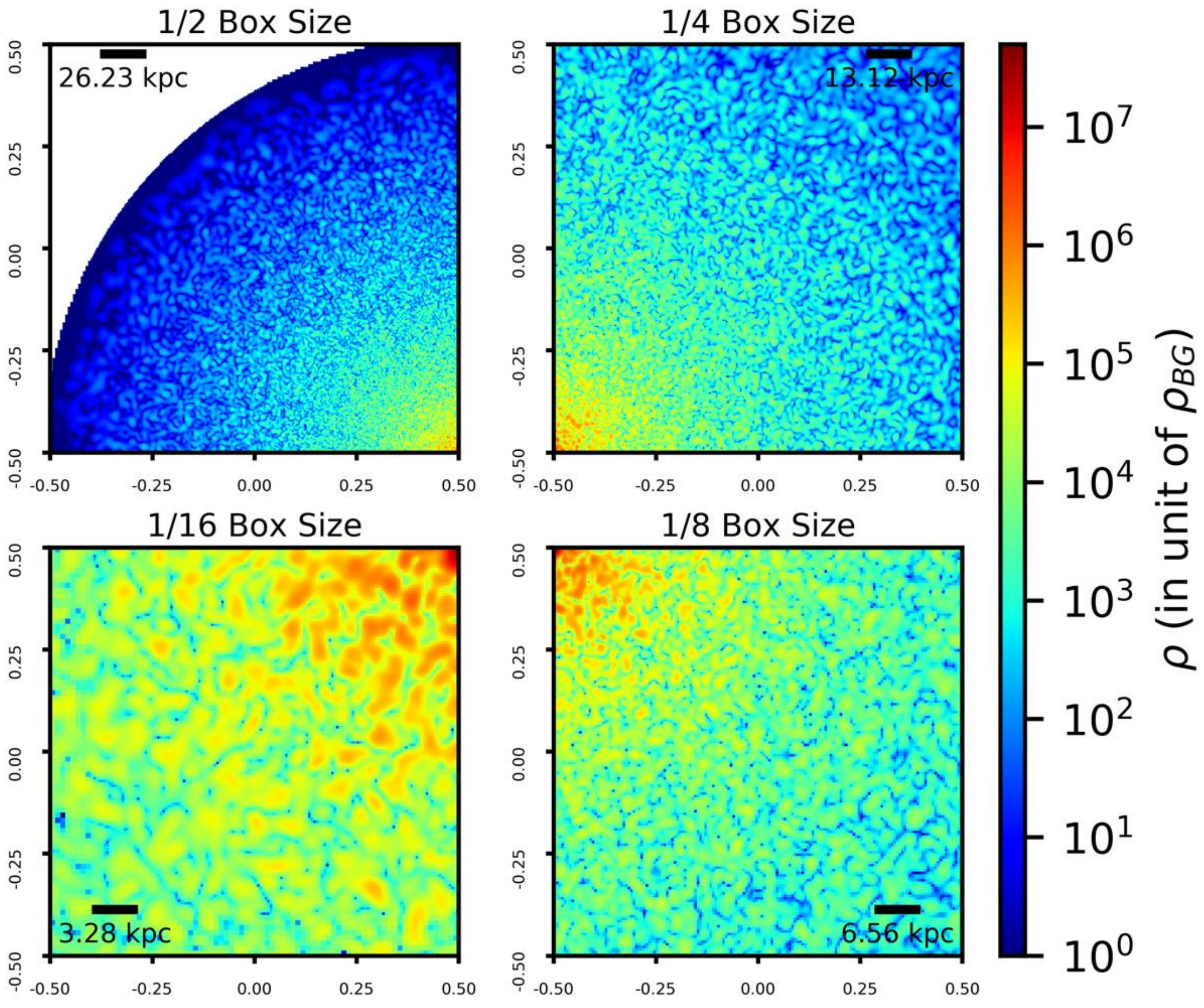
1) Title: Wave Dark Matter (Fill in the title of the article on the website)

2) Description of project results: (explain results' keywords)

Keyword: Dark Matter

Description: World's first three-dimensional Milky Way-sized fuzzy dark matter halo.

3) Photos of results (images) and description:



An analytically constructed, three-dimensional, Milky Way-sized fuzzy dark matter halo. Each panel shows a density slice with a different zoom factor, highlighting the large dynamic range, well-resolved granular structures, and a central soliton.

4) Explanation of results：

We have successfully constructed the world's first three-dimensional Milky Way-sized fuzzy dark matter (FDM) halo with an FDM particle mass of (2-8)*10^{-23} eV and a halo virial mass of 10^{12} $M_{\odot}$, an order of magnitude more massive than the previous most massive FDM halos in the literature. This task is extremely computationally expensive and is achieved by taking advantage of both mesh refinement and GPU acceleration using 32 V100 GPUs on the Taiwania II supercomputer at the National Center for High-performance Computing (NCHC). We have also successfully simulated the evolution of this halo, especially the random motion of its central solitonic core, over the age of the universe. These important breakthroughs pave the way for several follow-up projects to scrutinize the FDM scenario.

Appendix 1

Quantitative Assessment Form

Item		Results and concrete work performance	Explanation
1. Manpower training		Doctoral courses:____2________ Graduate courses:______8__________ Undergraduate courses:___10______ Doctoral students:______1________ persons Master's students:______8________ persons Undergraduate students:____8____ persons Others:___2_____ persons	
2. Papers and research works	Domestic	Journal papers:____________ Academic books and papers in books:______ Conference papers: ________ Technical reports:___________ Others:__________	
	Overseas	Journal papers:____11_______ Academic books and papers in books:______ Conference papers: ________ Technical reports:___________ Others:__________	
3. Keynote speaker		_______panels /sessions	
4. Patents（including patents pending）	Domestic	Quantity: ___________	
	Overseas	Quantity: ___________	
	☐ N/A		

5. Industry-Academia Cooperation	Number of partnered enterprises :________	
	Number of industry-academia research projects: ____________	
6. Technology licensing	Technology licensing cases: _________	
	Total technology licensing royalties （amount）NT$____________	
	☐ N/A	
7. Others		