Curriculum Vitae

Michael Y. Grudić

Theoretical Astrophysicist

Flatiron Institute
162 5th Ave
New York, NY 10010, USA

mgrudic@flatironinstitute.org
(626) 484-9037
https://mikegrudic.github.io
https://github.com/mikegrudic

Professional Experience

Associate Research Scientist – Software, Flatiron Institute, New York, NY *Sept 2024-present*
NASA Hubble Fellow, Carnegie Observatories, Pasadena, CA *Sept 2021-Aug 2024*
CIERA Postdoctoral Fellow, Northwestern University, Evanston, IL *Sept 2019-Aug 2021*

Research Interests

Theoretical astrophysics ∘ Numerical simulations ∘ HPC ∘ Star and galaxy formation ∘ Star clusters: origins, demographics, dynamics, IMF ∘ Stellar feedback ∘ Software ∘ Interstellar medium: physics, chemistry, observations

Education

Ph.D. in Physics *2014-2019*
California Institute of Technology (Caltech), Pasadena, CA
Dissertation: *The Role of Stellar Feedback in Star Cluster Formation*, advised by Dr. Philip F. Hopkins

B.Sc. (Honours) in Physics and Applied Mathematics *2009-2014*
Memorial University of Newfoundland (MUN), St. Johns, NL, Canada
Dissertation: *Gravitational Scattering in the Relativistic Kepler Problem*, advised by Dr. John Lewis

Computational and Software Skills

- 14 years' experience designing, testing, optimizing, debugging software for astronomy and physics
- Programming languages: C, C++, Fortran, Python, Lua, Julia, Wolfram Language
- High-performance computing, incl. parallel programming: MPI, OpenMP, numba, JAX
- Version control: git
- Profiling/optimization: gprof, Intel VTune
- Documentation: TeX, Sphinx, autodoc

Selected Software Contributions

GIZMO - N-body and radiation magnetohydrodynamics simulation code (major contributor, 2015-present)
meshoid - Package for efficient analysis, grid deposition, and visualization of meshless/unstructured data
pytreegrav - Package for optimized gravity calculations and tree-based spatial algorithms
MakeCloud - Script for turbulent initial conditions for GMC simulations
ISMulator - Interactive data app for experiments with ISM cooling and heating physics

Competitive Computing Awards

Frontera LRAC: *STARFORGE: Simulating star formation with realistic physics and feedback* – 60M CPU-h to date (PI) *2021-2023*
Frontera Pathways: *Exploring the Physical Ingredients of Star Formation with Simulations* – 14M CPU-h (PI) *2020-2021*
XSEDE AST190018: *Simulating the Life of a GMC* – 28M CPU-h (co-PI) *2020-2021*

Academic Honors

Caltech Robert F. Christy Prize for Outstanding Doctoral Thesis in Theoretical Physics *2019*
Caltech James A. Cullen Memorial Fellowship for Excellence in Physics *2017*
MUN Medals for Excellence in both Physics and Applied Mathematics majors *2014*
Lou Visentin Award *2014*
NSERC Undergraduate Summer Research Award *2011-2013*
MUN Faculty of Science Deans Book Prize (Physics) *2013*
Dr. S. W. Brekon Scholarship in Physics *2012-2013*
MUN Faculty of Science Dean's List *2011-2013*

Invited Scientific Presentations

KITP Conference: Cosmic Dawn Revealed by JWST, Santa Barbara, CA – Conference talk *2024*
The Feedback-Driven Matter Cycle in Galaxies, Heidelberg, Germany – Conference talk *2024*
Alpbach workshop on clouds, star clusters, and black holes, Alpbach, Austria – Conference talk *2024*
Gravitational waves: a new ear on the chemistry of galaxies, Leiden, Netherlands – Review *2024*
Cosmic Threads: Interlinking the Stellar IMF from Star-birth to Galaxies, Sexten, Italy – Conference talk *2024*
NOIRlab Journal Club, NOIRlab (virtual) – Journal club *2024*
Los Alamos Astrophysics Distinguished Seminar Series, Los Alamos, NM – Seminar *2024*
Berkeley TAC Seminar, Berkeley, CA – Seminar *2024*
University of Toledo Astronomy Colloquium, Toledo, OH – Colloquium *2024*
Topics in Star Cluster Dynamics and Evolution, N. Copernicus Astro. Ctr., Warsaw, Poland – Conference talk *2024*
University of Maryland Cosmology Talk, University of Maryland (virtual) – Seminar *2023*
Bash Symposium, Austin, TX – Review *2023*
Flatiron Institute CCA Galaxy Formation Meeting, New York, NY – Seminar *2023*
Columbia University Astronomy Colloquium, New York, NY – Colloquium *2023*
Santa Cruz Galaxy Workshop, UC Santa Cruz, Santa Cruz, CA – Conference talk *2023*
SF Clumps and Clustered Starbursts Across Cosmic Time, MIAPbP, Garching, Germany – Review *2022*
Harvard-Smithsonian Center for Astrophysics Seminar, Harvard University (virtual) – Seminar *2022*
University of São Paulo Institute of Astronomy Seminar, São Paulo University (virtual) – Seminar *2021*
Los Alamos Astrophysics Seminar, Los Alamos National Laboratory (virtual) – Seminar *2021*
236th AAS Meeting (virtual) – Conference talk *2020*
Princeton SFIR Seminar, Princeton, NJ – Seminar *2018*
MIT Astrophysics Brown Bag Lunch, Cambridge, MA – Seminar *2018*
MPA Cosmology Seminar, Garching, Germany – Seminar *2018*
Formation of Globular Clusters at High and Low Redshift, Sexten, Italy – Keynote *2018*
Multi-scale Physics of SF & Feedback During Galaxy Formation, Heidelberg, Germany – Conference talk *2018*
UT Austin Theory Seminar, Austin, TX – Seminar *2018*
CITA Seminar, Toronto, ON, Canada – Seminar *2017*

Outreach

Active in astronomy outreach since 2012, incl. outreach programs at University of Toronto, Caltech, Northwestern University, and Carnegie Observatories, and collaboration with Mannheim Planetarium and University of Arizona. **Activities:** ∘ Public lectures (speaking and volunteering), including Astronomy On Tap ∘ Public observing sessions, sidewalk astronomy ∘ Special events for transits, eclipses ∘ Presentations to K-12 students about astronomy and careers in STEM ∘ Planetarium and multi-media audiovisual presentations using simulation renderings

Academic Service

- Frequent referee for peer-reviewed journals including MNRAS(L), ApJ(L), A&A Letters, Nature Astronomy, and Journal of Open Source Software.
- Invited reviewer for grant programs: NSF AAG, NASA FINESST.

Publications (click for NASA ADS list)

In Review

[1] Fitz Axen, M., Offner, S., Hopkins, P. F., Krumholz, M. R., and **Grudic, M. Y.** "Suppressed Cosmic Ray Energy Densities in Molecular Clouds From Streaming Instability-Regulated Transport." *arXiv e-prints*, arXiv:2407.17597, July 2024.

[2] Hopkins, P. F., **Grudic, M. Y.**, Kremer, K., Offner, S. S. R., Guszejnov, D., and Rosen, A. L. "FORGE'd in FIRE III: The IMF in Quasar Accretion Disks from STARFORGE." *arXiv e-prints*, arXiv:2404.08046, April 2024.

[3] Khullar, S., Matzner, C. D., Murray, N., **Grudić, M. Y.**, Guszejnov, D., Wetzel, A., and Hopkins, P. F. "Playing with FIRE: A Galactic Feedback-Halting Experiment Challenges Star Formation Rate Theories." *arXiv e-prints*, arXiv:2406.18526, June 2024.

[4] Soliman, N. H., Hopkins, P. F., and **Grudić, M. Y.** "Thermodynamics of Giant Molecular Clouds: The Effects of Dust Grain Size." *arXiv e-prints*, arXiv:2407.09343, July 2024.

[5] **Grudić, M. Y.** and Hopkins, P. F. "The opacity limit." *arXiv e-prints*, arXiv:2308.16268, August 2023.

Student Project Research Notes

[1] Lue, A., Guszejnov, D., Offner, S. S. R., and **Grudić, M. Y.** "Evolution of the Gas Density in a Simulated Star-forming Cloud with Stellar Feedback." *Research Notes of the American Astronomical Society*, 5, 10, 225, October 2021.

[2] Piperno, E., Guszejnov, D., Offner, S. S. R., and **Grudić, M. Y.** "Comparing Methods to Identify GMCs in Simulated Galaxies." *Research Notes of the American Astronomical Society*, 4, 1, 14, January 2020.

Refereed Articles

[1] Bruel, T., Rodriguez, C. L., Lamberts, A., **Grudić, M. Y.**, Hafen, Z., and Feldmann, R. "Great Balls of FIRE. III. Modelling black hole mergers from massive star clusters in simulations of galaxies." A&A, 686, A106, June 2024.

[2] Crowe, S., Fedriani, R., Tan, J. C., Whittle, M., Zhang, Y., Garatti, A. C. o., Farias, J. P., Gautam, A., Telkamp, Z., Rothberg, B., **Grudic, M. Y.**, Andersen, M., Cosentino, G., Garcia-Lopez, R., Rosero, V., Tanaka, K., Pinna, E., Rossi, F., Miller, D., Agapito, G., Plantet, C., Ghose, E., Christou, J., Power, J., Puglisi, A., Briguglio, R., Brusa, G., Taylor, G., Zhang, X., Mazzoni, T., Bonaglia, M., Esposito, S., and Veillet, C. "Near-infrared observations of outflows and young stellar objects in the massive star-forming region AFGL 5180." A&A, 682, A2, February 2024.

[3] Farias, J. P., Offner, S. S. R., **Grudić, M. Y.**, Guszejnov, D., Rosen, A. L., and STARFORGE Team. "Stellar populations in STARFORGE: the origin and evolution of star clusters and associations." MNRAS, 527, 3, January 2024.

[4] Hennebelle, P. and **Grudić, M. Y.** "The physical origin of the stellar initial mass function." *Annual Review of Astronomy and Astrophysics*, 62, 2024.

[5] Hopkins, P. F., **Grudić, M. Y.**, Su, K.-Y., Wellons, S., Angles-Alcazar, D., Steinwandel, U. P., Guszejnov, D., Murray, N., Faucher-Giguere, C.-A., Quataert, E., and Keres, D. "FORGE'd in FIRE: Resolving the End of Star Formation and Structure of AGN Accretion Disks from Cosmological Initial Conditions." *The Open Journal of Astrophysics*, 7, 18, March 2024.

[6] Hopkins, P. F., Squire, J., Su, K.-Y., Steinwandel, U. P., Kremer, K., Shi, Y., **Grudić, M. Y.**, Wellons, S., Faucher-Giguere, C.-A., Angles-Alcazar, D., Murray, N., and Quataert, E. "FORGE'd in FIRE II: The Formation of Magnetically-Dominated Quasar Accretion Disks from Cosmological Initial Conditions." *The Open Journal of Astrophysics*, 7, 19, March 2024.

[7] Khullar, S., Matzner, C. D., Murray, N., **Grudić, M. Y.**, Guszejnov, D., Wetzel, A., and Hopkins, P. F. "Playing with FIRE: A Galactic Feedback-Halting Experiment Challenges Star Formation Rate Theories." *arXiv e-prints*, arXiv:2406.18526, June 2024.

[8] Foley, M. M., Goodman, A., Zucker, C., Forbes, J. C., Konietzka, R., Swiggum, C., Alves, J., Bally, J., Soler, J. D., Großschedl, J. E., Bialy, S., **Grudić, M. Y.**, Leike, R., and Enßlin, T. "A 3D View of Orion. I. Barnard's Loop." ApJ, 947, 2, 66, April 2023.

[9] **Grudić, M. Y.**, Hafen, Z., Rodriguez, C. L., Guszejnov, D., Lamberts, A., Wetzel, A., Boylan-Kolchin, M., and Faucher-Giguère, C.-A. "Great balls of FIRE - I. The formation of star clusters across cosmic time in a Milky Way-mass galaxy." MNRAS, 519, 1, February 2023.

[10] **Grudić, M. Y.** and Hopkins, P. F. "The opacity limit." *arXiv e-prints*, arXiv:2308.16268, August 2023.

[11] **Grudic, M. Y.**, Offner, S. S. R., Guszejnov, D., Faucher-Giguère, C.-A., and Hopkins, P. F. "Does God play dice with star clusters?" *The Open Journal of Astrophysics*, 6, 48, December 2023.

[12] Guszejnov, D., Raju, A. N., Offner, S. S. R., **Grudić, M. Y.**, Faucher-Giguère, C.-A., Hopkins, P. F., and Rosen, A. L. "Effects of the environment on the multiplicity properties of stars in the STARFORGE simulations." MNRAS, 518, 3, January 2023.

[13] Hopkins, P. F., Gurvich, A. B., Shen, X., Hafen, Z., **Grudić, M. Y.**, Kurinchi-Vendhan, S., Hayward, C. C., Jiang, F., Orr, M. E., Wetzel, A., Kereš, D., Stern, J., Faucher-Giguère, C.-A., Bullock, J., Wheeler, C., El-Badry, K., Loebman, S. R., Moreno, J., Boylan-Kolchin, M., and Quataert, E. "What causes the formation of discs and end of bursty star formation?" MNRAS, 525, 2, October 2023.

[14] Hopkins, P. F., Nadler, E. O., **Grudić, M. Y.**, Shen, X., Sands, I., and Jiang, F. "Novel conservative methods for adaptive force softening in collisionless and multi-species N-body simulations." MNRAS, August 2023.

[15] Hopkins, P. F., Wetzel, A., Wheeler, C., Sanderson, R., **Grudić, M. Y.**, Sameie, O., Boylan-Kolchin, M., Orr, M., Ma, X., Faucher-Giguère, C.-A., Kereš, D., Quataert, E., Su, K.-Y., Moreno, J., Feldmann, R., Bullock, J. S., Loebman, S. R., Anglés-Alcázar, D., Stern, J., Necib, L., Choban, C. R., and Hayward, C. C. "FIRE-3: updated stellar evolution models, yields, and microphysics and fitting functions for applications in galaxy simulations." MNRAS, 519, 2, February 2023.

[16] Millstone, S., Gutermuth, R., Offner, S. S. R., Pokhrel, R., and **Grudić, M. Y.** "Co-Evolution of Stars and Gas: Using Analysis of Synthetic Observations to Investigate the Star-Gas Correlation in STARFORGE." *arXiv e-prints, accepted for publication in ApJ*, arXiv:2310.11544, October 2023.

[17] Rodriguez, C. L., Hafen, Z., **Grudić, M. Y.**, Lamberts, A., Sharma, K., Faucher-Giguère, C.-A., and Wetzel, A. "Great balls of FIRE II: The evolution and destruction of star clusters across cosmic time in a Milky Way-mass galaxy." MNRAS, 521, 1, May 2023.

[18] Shi, Y., Kremer, K., **Grudić, M. Y.**, Gerling-Dunsmore, H. J., and Hopkins, P. F. "Hyper-Eddington black hole growth in star-forming molecular clouds and galactic nuclei: can it happen?" MNRAS, 518, 3, January 2023.

[19] Xu, D., Offner, S. S. R., Gutermuth, R., **Grudić, M. Y.**, Guszejnov, D., and Hopkins, P. F. "Predicting the Radiation Field of Molecular Clouds Using Denoising Diffusion Probabilistic Models." ApJ, 958, 1, 97, November 2023.

[20] **Grudić, M. Y.**, Guszejnov, D., Offner, S. S. R., Rosen, A. L., Raju, A. N., Faucher-Giguère, C.-A., and Hopkins, P. F. "The dynamics and outcome of star formation with jets, radiation, winds, and supernovae in concert." MNRAS, 512, 1, May 2022.

[21] Guszejnov, D., **Grudić, M. Y.**, Offner, S. S. R., Faucher-Giguère, C.-A., Hopkins, P. F., and Rosen, A. L. "Effects of the environment and feedback physics on the initial mass function of stars in the STARFORGE simulations." MNRAS, 515, 4, October 2022.

[22] Guszejnov, D., Markey, C., Offner, S. S. R., **Grudić, M. Y.**, Faucher-Giguère, C.-A., Rosen, A. L., and Hopkins, P. F. "Cluster assembly and the origin of mass segregation in the STARFORGE simulations." MNRAS, 515, 1, September 2022.

[23] Hopkins, P. F., Wellons, S., Anglés-Alcázar, D., Faucher-Giguère, C.-A., and **Grudić, M. Y.** "Why do black holes trace bulges (& central surface densities), instead of galaxies as a whole?" MNRAS, 510, 1, February 2022.

[24] Lane, H. B., **Grudić, M. Y.**, Guszejnov, D., Offner, S. S. R., Faucher-Giguère, C.-A., and Rosen, A. L. "Less wrong: a more realistic initial condition for simulations of turbulent molecular clouds." MNRAS, 510, 4, March 2022.

[25] **Grudić, M. Y.** "Accelerating self-gravitating hydrodynamics simulations with adaptive force updates." MNRAS, 507, 1, October 2021.

[26] **Grudić, M. Y.** and Gurvich, A. "pytreegrav: A fast Python gravity solver." *The Journal of Open Source Software*, 6, 68, 3675, December 2021.

[27] **Grudić, M. Y.**, Guszejnov, D., Hopkins, P. F., Offner, S. S. R., and Faucher-Giguère, C.-A. "STARFORGE: Towards a comprehensive numerical model of star cluster formation and feedback." MNRAS, 506, 2, September 2021.

[28] **Grudić, M. Y.**, Kruijssen, J. M. D., Faucher-Giguère, C.-A., Hopkins, P. F., Ma, X., Quataert, E., and Boylan-Kolchin, M. "A model for the formation of stellar associations and clusters from giant molecular clouds." MNRAS, 506, 3, September 2021.

[29] Guszejnov, D., **Grudić, M. Y.**, Hopkins, P. F., Offner, S. S. R., and Faucher-Giguère, C.-A. "STARFORGE: the effects of protostellar outflows on the IMF." MNRAS, 502, 3, April 2021.

[30] Shi, Y., **Grudić, M. Y.**, and Hopkins, P. F. "The mass budget for intermediate-mass black holes in dense star clusters." MNRAS, 505, 2, August 2021.

[31] **Grudić, M. Y.**, Boylan-Kolchin, M., Faucher-Giguère, C.-A., and Hopkins, P. F. "The universal acceleration scale from stellar feedback." MNRAS, 496, 1, July 2020.

[32] **Grudić, M. Y.** and Hopkins, P. F. "A general-purpose time-step criterion for simulations with gravity." MNRAS, 495, 4, July 2020.

[33] Gurvich, A. B., Faucher-Giguère, C.-A., Richings, A. J., Hopkins, P. F., **Grudić, M. Y.**, Hafen, Z., Wellons, S., Stern, J., Quataert, E., Chan, T. K., Orr, M. E., Kereš, D., Wetzel, A., Hayward, C. C., Loebman, S. R., and Murray, N. "Pressure balance in the multiphase ISM of cosmologically simulated disc galaxies." MNRAS, 498, 3, November 2020.

[34] Guszejnov, D., **Grudić, M. Y.**, Hopkins, P. F., Offner, S. S. R., and Faucher-Giguère, C.-A. "Can magnetized turbulence set the mass scale of stars?" MNRAS, 496, 4, August 2020.

[35] Guszejnov, D., **Grudić, M. Y.**, Offner, S. S. R., Boylan-Kolchin, M., Faucher-Giguère, C.-A., Wetzel, A., Benincasa, S. M., and Loebman, S. "Evolution of giant molecular clouds across cosmic time." MNRAS, 492, 1, February 2020.

[36] Hopkins, P. F., **Grudić, M. Y.**, Wetzel, A., Kereš, D., Faucher-Giguère, C.-A., Ma, X., Murray, N., and Butcher, N. "Radiative stellar feedback in galaxy formation: Methods and physics." MNRAS, 491, 3, January 2020.

[37] Ma, X., **Grudić, M. Y.**, Quataert, E., Hopkins, P. F., Faucher-Giguère, C.-A., Boylan-Kolchin, M., Wetzel, A., Kim, J.-h., Murray, N., and Kereš, D. "Self-consistent proto-globular cluster formation in cosmological simulations of high-redshift galaxies." MNRAS, 493, 3, April 2020.

[38] Rodriguez, C. L., Kremer, K., **Grudić, M. Y.**, Hafen, Z., Chatterjee, S., Fragione, G., Lamberts, A., Martinez, M. A. S., Rasio, F. A., Weatherford, N., and Ye, C. S. "GW190412 as a Third-generation Black Hole Merger from a Super Star Cluster." ApJ, 896, 1, L10, June 2020.

[39] Yu, S., Bullock, J. S., Wetzel, A., Sanderson, R. E., Graus, A. S., Boylan-Kolchin, M., Nierenberg, A. M., **Grudić, M. Y.**, Hopkins, P. F., Kereš, D., and Faucher-Giguère, C.-A. "Stars made in outflows may populate the stellar halo of the Milky Way." MNRAS, 494, 2, May 2020.

[40] **Grudić, M. Y.** and Hopkins, P. F. "The elephant in the room: the importance of the details of massive star formation in molecular clouds." MNRAS, 488, 2, September 2019.

[41] **Grudić, M. Y.**, Hopkins, P. F., Lee, E. J., Murray, N., Faucher-Giguère, C.-A., and Johnson, L. C. "On the nature of variations in the measured star formation efficiency of molecular clouds." MNRAS, 488, 2, September 2019.

[42] **Grudić, M. Y.**, Hopkins, P. F., Quataert, E., and Murray, N. "The maximum stellar surface density due to the failure of stellar feedback." MNRAS, 483, 4, March 2019.

[43] Hopkins, P. F. and **Grudić, M. Y.** "Numerical problems in coupling photon momentum (radiation pressure) to gas." MNRAS, 483, 3, March 2019.

[44] **Grudić, M. Y.**, Guszejnov, D., Hopkins, P. F., Lamberts, A., Boylan-Kolchin, M., Murray, N., and Schmitz, D. "From the top down and back up again: star cluster structure from hierarchical star formation." MNRAS, 481, 1, November 2018.

[45] **Grudić, M. Y.**, Hopkins, P. F., Faucher-Giguère, C.-A., Quataert, E., Murray, N., and Kereš, D. "When feedback fails: the scaling and saturation of star formation efficiency." MNRAS, 475, 3, April 2018.

[46] Guszejnov, D., Hopkins, P. F., and **Grudić, M. Y.** "Universal scaling relations in scale-free structure formation." MNRAS, 477, 4, July 2018.

[47] Guszejnov, D., Hopkins, P. F., **Grudić, M. Y.**, Krumholz, M. R., and Federrath, C. "Isothermal Fragmentation: Is there a low-mass cut-off?" MNRAS, 480, 1, October 2018.

[48] Hopkins, P. F., Wetzel, A., Kereš, D., Faucher-Giguère, C.-A., Quataert, E., Boylan-Kolchin, M., Murray, N., Hayward, C. C., Garrison-Kimmel, S., Hummels, C., Feldmann, R., Torrey, P., Ma, X., Anglés-Alcázar, D., Su, K.-Y., Orr, M., Schmitz, D., Escala, I., Sanderson, R., **Grudić, M. Y.**, Hafen, Z., Kim, J.-H., Fitts, A., Bullock, J. S., Wheeler, C., Chan, T. K., Elbert, O. D., and Narayanan, D. "FIRE-2 simulations: physics versus numerics in galaxy formation." MNRAS, 480, 1, October 2018.

[49] Kim, J.-h., Ma, X., **Grudić, M. Y.**, Hopkins, P. F., Hayward, C. C., Wetzel, A., Faucher-Giguère, C.-A., Kereš, D., Garrison-Kimmel, S., and Murray, N. "Formation of globular cluster candidates in merging proto-galaxies at high redshift: a view from the FIRE cosmological simulations." MNRAS, 474, 3, March 2018.

[50] Foucart, F., Buchman, L., Duez, M. D., **Grudić, M. Y.**, Kidder, L. E., MacDonald, I., Mroue, A., Pfeiffer, H. P., Scheel, M. A., and Szilagyi, B. "First direct comparison of nondisrupting neutron star-black hole and binary black hole merger simulations." Phys. Rev. D, 88, 6, 064017, September 2013.