Studying Star Formation Using High-Resolution Numerical Simulations of Galaxy Formation

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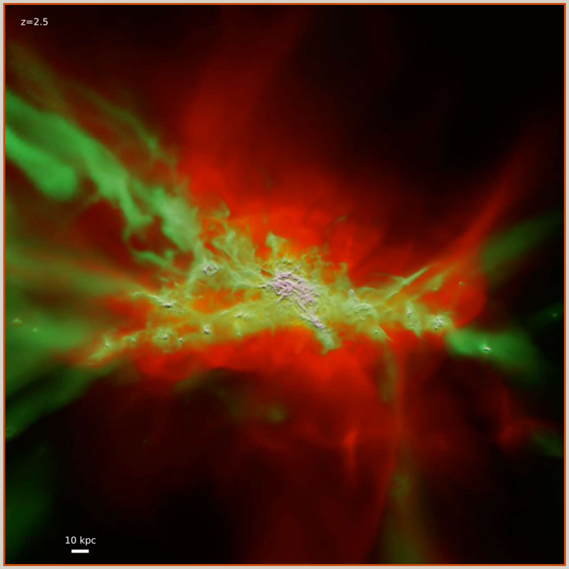
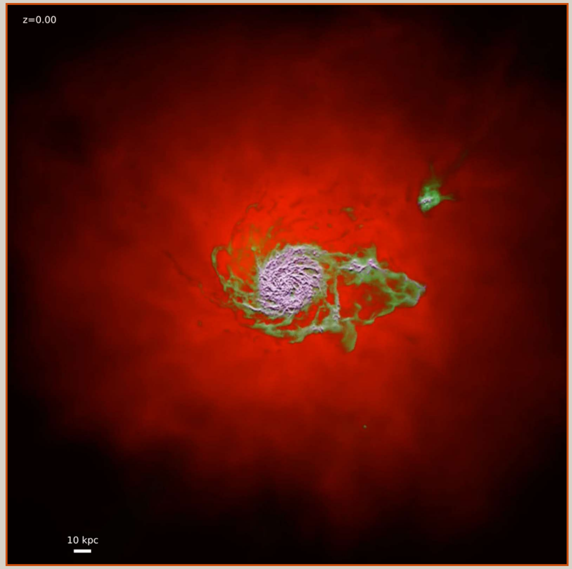
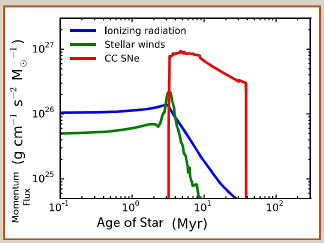
A Tale of Two Modes of Star Formation and Two Galaxy Morphologies



- Our simulations use a version of the publicly available gravity + magnetohydrodynamic code GIZMO in meshless finite mass (MFM) mode, a hydrodynamic solver that combines the advantages of grid based and SPH methods.
- The FIRE (Feedback in Realistic Environments) physics modules in GIZMO are specifically designed for galaxy formation simulations and include a detailed model for star formation in self-gravitating gas, gas cooling to T~10 K (enabling the formation of molecular clouds), and models for feedback from supernovae, stellar winds, and stellar radiation. This results in galaxies with realistic populations of stars with spatial distributions, ages, ambient properties, and that match the observationally-inferred star formation histories of galaxies
- The image on the left is of a simulation of a Milky Way-like galaxy, taken early in its life before it has fully formed. The gas is distributed around it chaotically and it periodically experiences violent bursts of star formation that evacuate its star-forming gas reservoir. The image on the right is the same galaxy, but after it has settled into a clearly recognizable, well ordered, disk that has a time steady star formation rate.
- This evolution from bursty star formation to time steady is a new prediction made by the suite of FIRE cosmological zoom-in simulations that helps explain observed galaxy stellar masses.



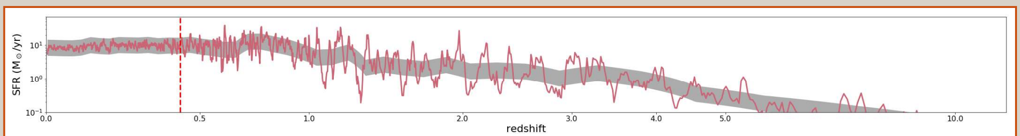
Self Regulation Through Stellar Feedback



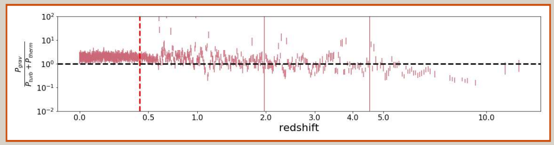
- Over the course of their lives stars return energy to their surroundings, suppressing further star formation through a set of processes known as "stellar feedback." The figure to the left quantifies the relative strengths of each stellar feedback process over a star's life.
- Supernovae contribute the most momentum to their surroundings by a factor of 10, making them the most important process in regulating star formation. However, because supernovae are limited by the minimum age of the youngest stars to die they cannot respond to bursts of star formation that occur in periods of time shorter than 4 Myr.
- When this occurs, the result is that "too many" stars form in this interim period before supernovae can kick in and the ensuing supernova overshoots the equilibrium, completely evacuating the star-forming gas reservoir with powerful "galactic winds," leading to periodic bursts.

Settling Down From a History of Bursty Star Formation

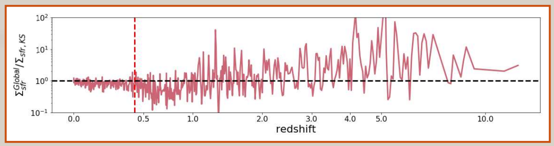
- We deem star formation to be "bursty" when the star formation rate changes by a factor of 3 within 500 Myr, denoted in the star formation history below by a gray band. The red dashed line is the identified "end" of bursty star formation.
- Bursts of star formation can also be driven by mergers of galaxies, meaning that the star formation rate may exit the gray band after the end of bursty star formation for some period of time.



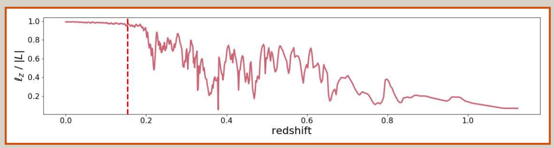
The Quest for Equilibrium



- Pressure balance is achieved between the weight of the gas disk and the turbulent/thermal support generated by stellar feedback.



- Star formation at a given gas surface density is enhanced before eventually reaching a steady state at the observed Kennicutt-Schmidt level.



- The end of bursty star formation coincides with transition to a stable disk.

References

C.-A. Faucher-Giguère, E. Quataert, and P. F. Hopkins, Monthly Notices of the Royal Astronomical Society 433, 1970 (2013). | P. Torrey, P. F. Hopkins, C.-A. Faucher-Giguère, M. Vogelsberger, E. Quataert, D. Kereš, and N. Murray, arXiv eprint 000 (2016). | P. F. Hopkins, A. Wetzel, D. Kers, C.-A. Faucher-Giguère, E. Quataert, M. Boylan-Kolchin, N. Murray, C. C. Hayward, S. Garrison-Kimmel, C. Hummels, R. Feldmann, P. Torrey, X. Ma, D. Anglés-Alcázar, K.-Y. Su, M. Orr, D. Schmitz, I. Escala, R. Sanderson, M. Y. Grudic, Z. Hafen, J.-H. Kim, A. Fitts, J. S. Bullock, C. Wheeler, T. K. Chan, O. D. Elbert, and D. Narayanan, Mon. Not. R. Astron. Soc 000, 0 (2017). | R. C. Kennicutt, Jr., The Astrophysical Journal 498, 541 (1998). | C. F. McKee and J. P. Ostriker, The Astrophysical Journal 218, 21 (1977). | C.-A. Faucher-Giguère, Mon. Not. R. Astron. Soc 000, 0 (2017). D. Martizzi, D. Fielding, C.-A. Faucher-Giguère, and E. Quataert, Monthly Notices of the Royal Astronomical Society 459, 2311 (2016). | D. Fielding, E. Quataert, D. Martizzi, and C.-A. Faucher-Giguère, (2017) C.-G. | Kim, W.-T. Kim, and E. C. Ostriker, The Astrophysical Journal 743, 25 (2011)

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