Cold Clouds in the Hot Winds and Halos of Galaxies

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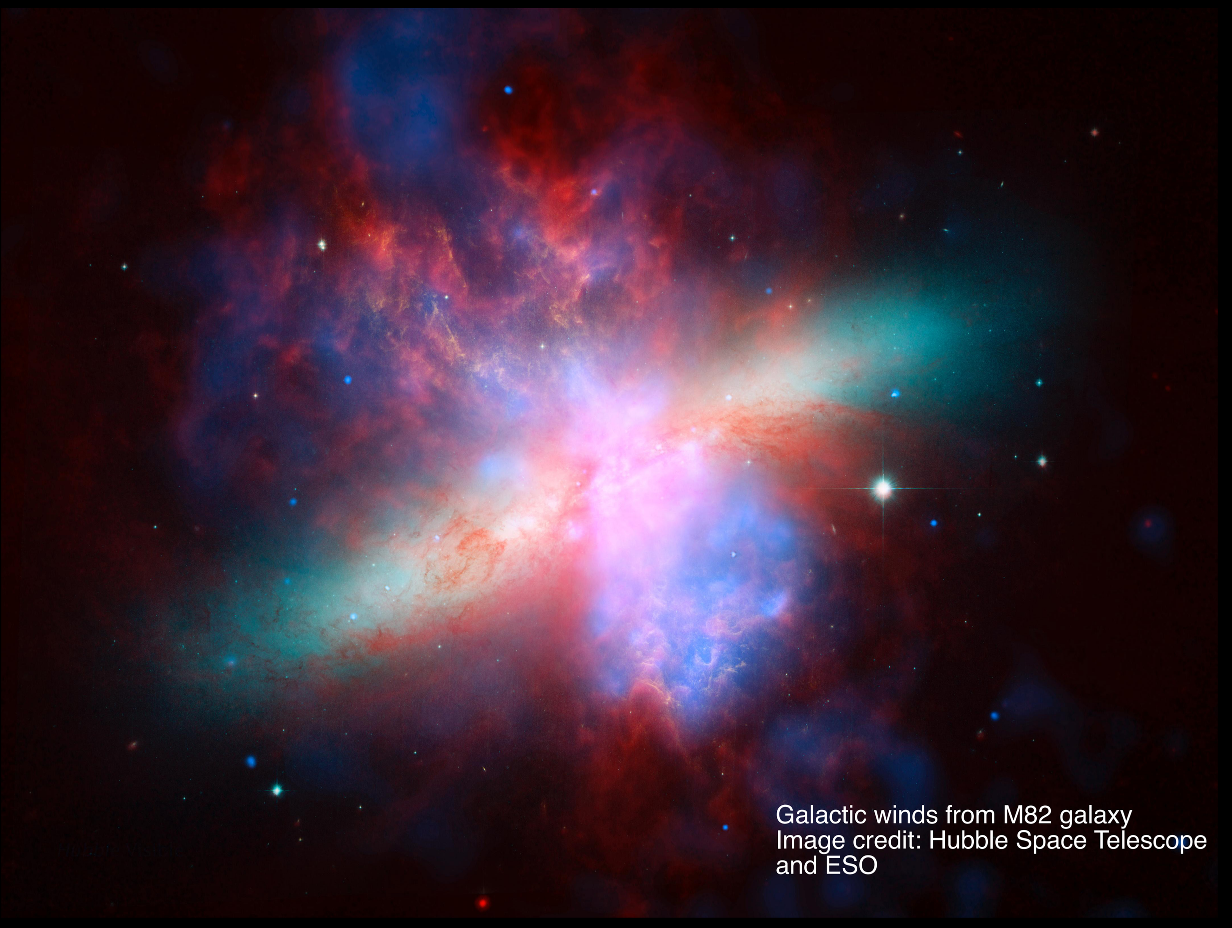
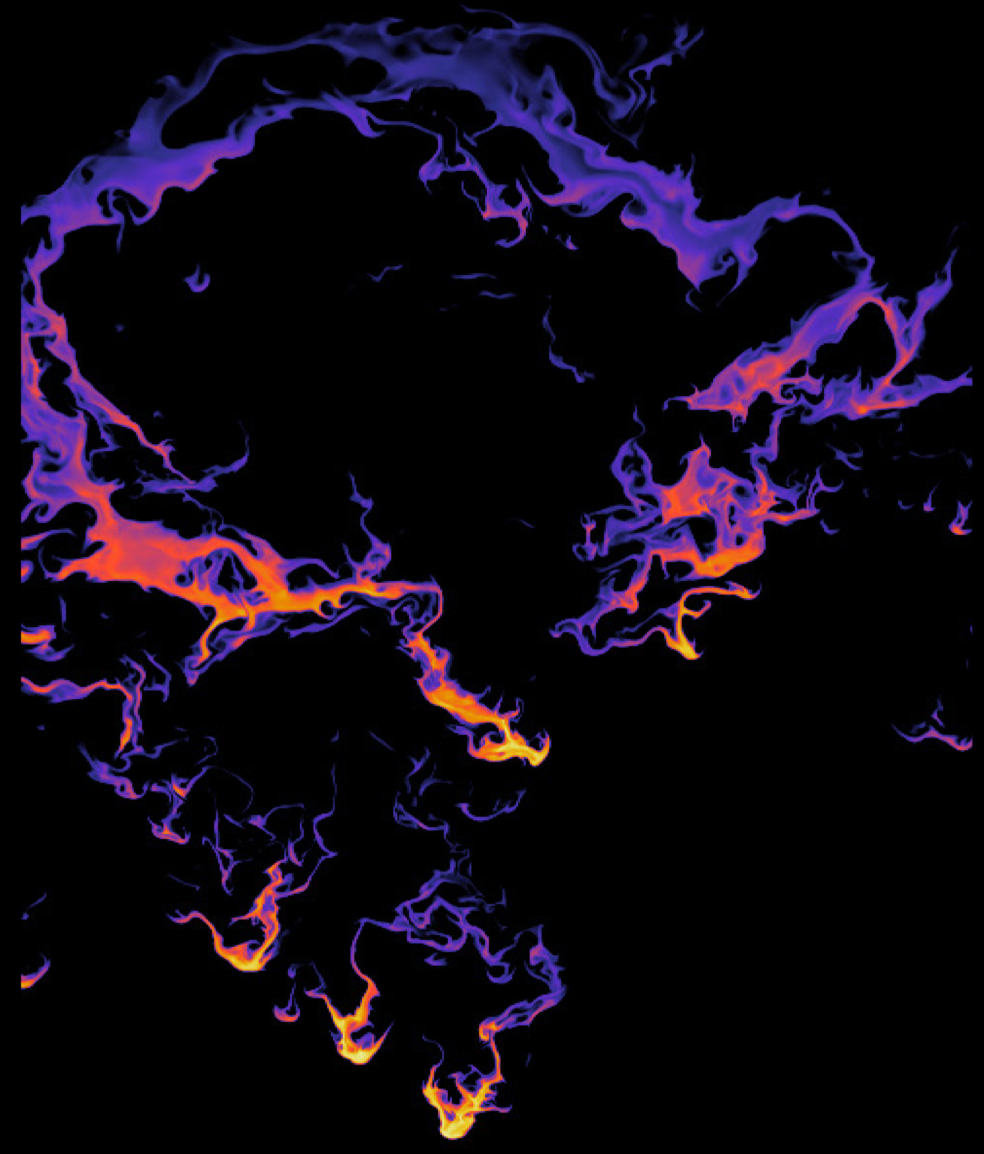
ABSTRACT: Multi-wavelength imaging observations of galactic winds indicate that outflowing materials are multi-phase and dynamic. Small, dense and cold gas clumps are entrained and accelerated by the hot wind. At the same time, spectroscopy of background quasars reveals multi-phase gas in absorption, with consistent cloud sizes as small as 0.3 to ~500 light years across (e.g., Crighton et al 2015). The fate of these cold clouds is vital for the growth of galaxies since they are a large fraction of the baryon budget for future star formation. Is it then natural to ask: what is the nature of these cold clouds? Will they evaporate and mix with the hot ambient gas? How does radiative cooling play a role? Will magnetic fields suppress thermal conduction and allow the clouds to travel high in galactic latitude and rain back down?

To study these questions, we run a series of high-resolution MHD simulations (Δx ~ 1 light year) on the interaction of hot galactic winds with an initially turbulent medium. We systematically implement additional physics that might play a relevant role in the fate of the cold clouds: radiative cooling, thermal conduction and magnetic fields.

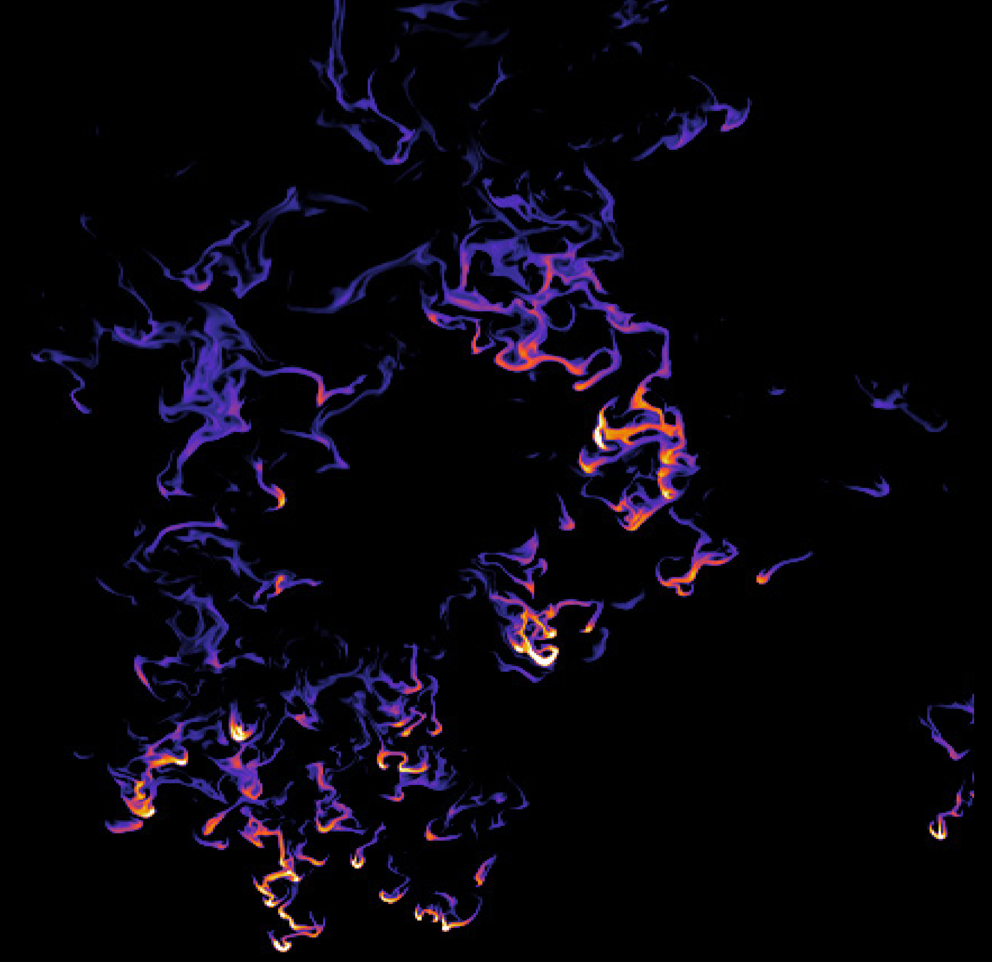


Galactic winds from M82 galaxy
Image credit: Hubble Space Telescope and ESO

Adiabatic: A fiducial run with a hot wind at 10^7 K pushing from below on a turbulent cold cloud at 10^4 - 10^5K. The color represents the density of the cold clumps.

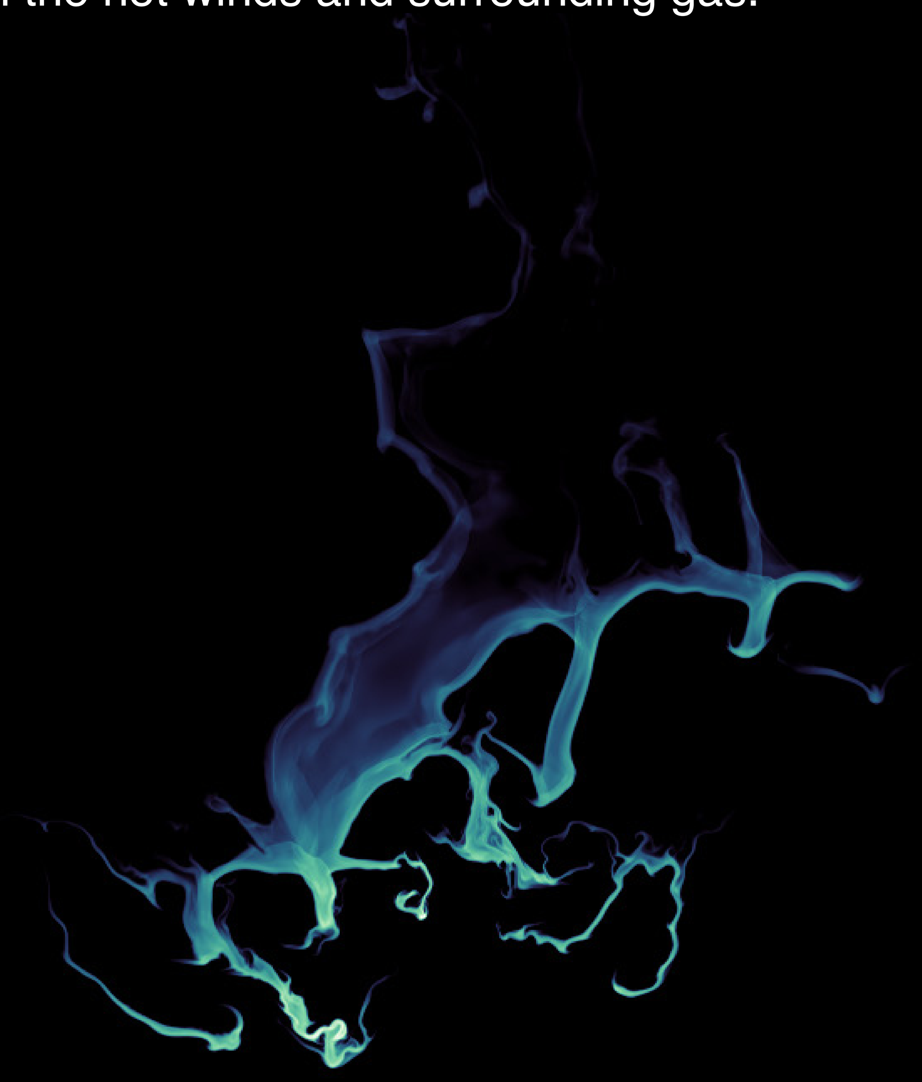


Cooling only: Simulations with radiative cooling introduce a spatial scale due to thermal instability (McCourt et al 2016). Cooling removes internal thermal pressure of clouds and leads to further collapse from compression of surrounding higher pressure gas. The runaway collapse stops when the the gas can thermally support itself. A comparison with the adiabatic run shows that the cloud sizes are much smaller.



Cooling + thermal conduction: The nature of the clouds changes drastically when thermal conduction is turned on. With large temperature differences between the cold clouds and the hot winds, thermal conduction is very efficient in transferring heat. The cold clouds in this simulation, shown in green, seem to be inconsistent with the morphologies of observed clouds (e.g., M87 outflows). The clouds quickly evaporate and completely mixes with the hot medium.

Cooling + Conduction + Magnetic Fields: Magnetic fields significantly suppress conduction. The left panel shows the density of the cold gas while the right shows the strength of the magnetic fields. The magnetic field is draped around the surface of the clouds protecting them from shear instabilities and thermal conduction. The size of the clouds is larger than those in the run with cooling only. This is because magnetic fields provide an additional form of pressure to counter the pressure from the hot winds and surrounding gas.



References:

1. McCourt et al. 2016, arXiv: 1610.01164
2. Crighton et al. 2015, MNRAS, V466, p18

Image credit: European Southern Observetory (ESO)