Stars in Early-Type Galaxies and Cooling Flows

Joel Bregman

University of Michigan

Mass Loss From PN/AGB Stars in Ellipticals

- Motivations
 - Mass loss from stars becomes thermalized by shocks
 - T equivalent to velocity dispersion of the stars
 - Maybe the true situation is more complex (it is)
- Will this solve the metals problem?
 - Mass loss from AGB stars (about solar metallicity) plus Type Ia supernovae, the metallicity should be 3-5 times solar.
 - X-ray gas: the observed metallicities are 0.1-2 times solar (typically solar).
 - Solution: Not all stellar mass loss may become hot (preference against higher metallicity gas?)
 - Parriott and Bregman (2008); Bregman and Parriott (2009)
- Note: we actually see the collective mass loss from AGB stars
 - Athey et al. (2002)



- Bow shock: both ISM and stellar mass loss heated
- PN mass loss ends at 5,000 yr
- Expansion unimpeded until the momentum flux from ambient flow becomes comparable to the momentum flow of the expanding stellar mass loss.





Flow of ambient material past the stellar mass loss excites Kelvin-Helmholtz and Rayleigh-Taylor instabilities. Significant gas parcels are torn away from the stellar mass shell and flow quickly downstream.



Gaseous filaments are cooler than the ambient material and leave the grid at a velocity of about 200 km/s, about 60% of the ambient flow. About 40% of the stellar mass loss is in these extended filaments and the remainder is in the cooler, denser wake.

Summary and Results 1

- At least 30% of the PN gas flowing off the grid is too cool to become part of the ambient flow (it may be up to 80% for some cases).
- During the lower mass loss stage (giant and AGB), only about 20% of the mass loss remains cool.
- Higher metallicity gas should preferentially remain cool.
 - Not a strong enough effect to solve the metallicity problem
- The interaction heats the ambient gas.
- Much of the gas is heated to 5x10⁵ K before cooling down. This could be responsible for OVI emission.
- Cooled gas at 10⁴ K could account for some of the optical emission line luminosity.
- Limitations of calculation
 - Gas not given a chance to sink downward
 - 2D instead of 3D
 - Grid should be larger to follow wake better
 - Feel free to improve on this calculation

Thermal Properties of Hot Gas in an Elliptical

- For no inflow, outflow, or radiative losses
 - Gas density increases steadily as stellar mass loss add gas to system
 - $\frac{\partial \rho}{\partial t} = \alpha \rho_*$
 - lpha is the specific stellar mass loss rate; ho_* is the stellar density
 - Thermalization of gas shed from stars is about the virial temperature

•
$$\rho \frac{d\varepsilon}{dt} = -\alpha \rho_*(\varepsilon_0 - \varepsilon)$$

- ε is the thermal gas energy (think T); ε_o is the energy the gas comes in with from AGB stars
- ε approaches ε_o over time (T approaches the virial temperature)
- Gas sits in hydrostatic equilibrium: density increases with time, T does not; $T = T_*$
- Add radiative losses
 - As density increases, radiative losses increase

•
$$\rho \frac{d\varepsilon}{dt} = \frac{\rho^2 \Lambda(T)}{m_p^2} - \alpha \rho_*(\varepsilon_0 - \varepsilon)$$

- When cooling time becomes less than Hubble time, gas cools (runs away)
- Classic cooling flow scenario

Can Stellar Heating Defeat Cooling Flows?

• AGB Heating

•
$$\rho \frac{d\varepsilon}{dt} = \frac{\rho^2 \Lambda(T)}{m_p^2} - \alpha \rho_*(\varepsilon_o - \varepsilon)$$

- Heating term never gets gas significantly above virial temperature
- Density eventually builds up and cooling wins
- Possible heating mechanisms
 - Supernovae
 - Conduction
 - AGNs
- Supernovae
 - Adds heat and metals but not much mass
 - Temperature of incoming gas: $T_o = (\alpha T_* + \alpha_{SN} T_{SN})/\alpha$

•
$$\varepsilon = \frac{3}{2} \frac{P}{\rho} = 3kT/2\mu m$$

- $\rho \frac{d\varepsilon}{dt} = \frac{\rho^2 \Lambda(T)}{m_p^2} \alpha \rho_*(\varepsilon_o \varepsilon)$
- T approaches T_o at radii where the cooling is < sound crossing time
- T_o can be large enough (> T_{escape}) to render gas unbound outside radius r_{crit} (cooling radius)

M60 (NGC 4649); X-Ray Image

Optical Image





- Low mass galaxies: $r_{crit} \approx 0$
 - Galactic wind from entire galaxy
 - Little detectable X-ray gas
- High mass galaxies: $r_{crit} > R_{25}$
 - Most of the gas is retained
 - Some can escape as a wind (if not a central galaxy)
 - X-ray bright
 - Cooling flow problem
- Central galaxies
 - Surrounded by very extensive pressure medium
 - Hard to have a wind (might have a breeze)

Do We Need to Prevent Cooling Flows?

- Suppose cooling gas forms into stars
 - Cooling rate of 0.1-1 Msun/yr in a healthy early-type galaxy (L_{*} and above)
 - For a normal IMF, star formation observed but generally pretty low
 - 10⁻⁴ Msun/yr
 - Maybe star formation mainly produces low mass stars
 - Some support for a low-mass weighted stellar mass distribution
 - Dynamical & spectral (Bell, this meeting)
 - Estimate from 1989 (Mathews) shows this is unlikely (need new estimate)
 - Some HI and CO
 - Not obvious that low mass star formation is occurring





Star formation in nearby E galaxies (Ford & JNB 2013) Classic "red and dead" galaxies Near L_{*} field galaxies: NGC 3379, NGC 4697 Central group (cooling flow gal): NGC 4636 Virgo galaxy: NGC 4474 (3C 274) Star formation rate of 10⁻⁴ Msun/yr over last 1-2 Gyr True for all four galaxies Recent drop in star formation? Assumes a normal IMF (only see massive stars)

2000

2000

Perhaps There is a Cooling Flow and Star Formation in Early-Type Galaxies

- Qualitative physics
 - Supernova heating drives a galactic wind (breeze) beyond R_{crit}
 - R_{crit} decreases a M_{gal} increases
 - Some fraction of the stellar mass remains cold
 - Source of small amounts of gas in early-type galaxies
 - More stellar mass retained as M_{gal} increases
- Stellar mass loss forms stars
 - Very small amount of high mass stars
 - Posit that most of the mass goes into low mass stars (Tooth Fairy alert)
 - Make 10¹⁰ Msun since z = 2
 - More massive galaxies appear to have heavier IMFs

- Don't need to have AGN heating to suppress star formation
- Don't have to worry why galaxies with underweight (or overweight) SMBHs look like those with average mass SMBHs (at fixed M_{*})
- Is there some way of detecting 0.3 Msun/yr of low mass star formation?
- In what volume can this star formation occur?
 - Not just in a very small central volume

Warming Flows

- System has sufficient thermal conduction
- Applies to centrals in richer groups and clusters of galaxies
- Relevant observations
 - Temperature drop into center to about 2 keV (from 4-6 keV, typically)
 - Cooling radius about 50-100 kpc (surrounded by infinite thermal bath)
- Central galaxy
 - Stellar mass loss becomes thermalized to 1 keV
 - Provides an inner boundary condition on temperature
- The flow
 - Heating exceeds cooling (mechanism not crucial)

- Conduction as the heating mechanism
 - Temperature rises as the gas flows outward
 - Very slow flow
- Virtues
 - Reproduces the T gradient in the center
 - Prevents (most) gas from cooling and forming stars
- Problems
 - Not obvious that this leads to the desired solution (most conduction models have failed)
 - Predicted central T a little lower than observed (ok in M87)
 - Doesn't work for isolated Es
- I hope this is the end of this talk -- Thanks for listening