Internal & external feedback in dwarf galaxies

The halo-to-galaxy mapping for low mass systems

Mark Wilkinson

*with: **Claire Cashmore**, S. Nayakshin, C. Power, G. Lewis, A. Robotham, G. Wynn*

University of Leicester

Internal & external feedback in dwarf galaxies

The halo-to-galaxy mapping for low mass systems

Mark Wilkinson

*with: **Claire Cashmore**, S. Nayakshin, C. Power, G. Lewis, A. Robotham, G. Wynn*

University *of* Leicester

Non-linearity in halo occupation probability

- Tensions between abundance and structure of sub-haloes in simulations and Local Group dSphs:
  - "Too big to fail" *(e.g. Boylan-Kolchin et al., 2012)*
  - "Gap" in mass between dSphs and Magellanic Clouds?
- Suggests mapping may depend on additional parameters and/or be stochastic *(c.f. talks by Maccio, Bullock)*

Q: Are there likely sources of stochasticity?

Conclusions

- Sources of stochasticity in halo-galaxy mapping:
  - supernova regulation of star formation at low SFR
  - external AGN outflows as star formation regulators
- Rotation curves of low-mass galaxies (e.g. M33) can provide constraints on physical properties of haloes
- High-resolution simulations of SN feedback in dSphs
  - impact of SN feedback determined by small number statistics

Feedback in low-mass haloes

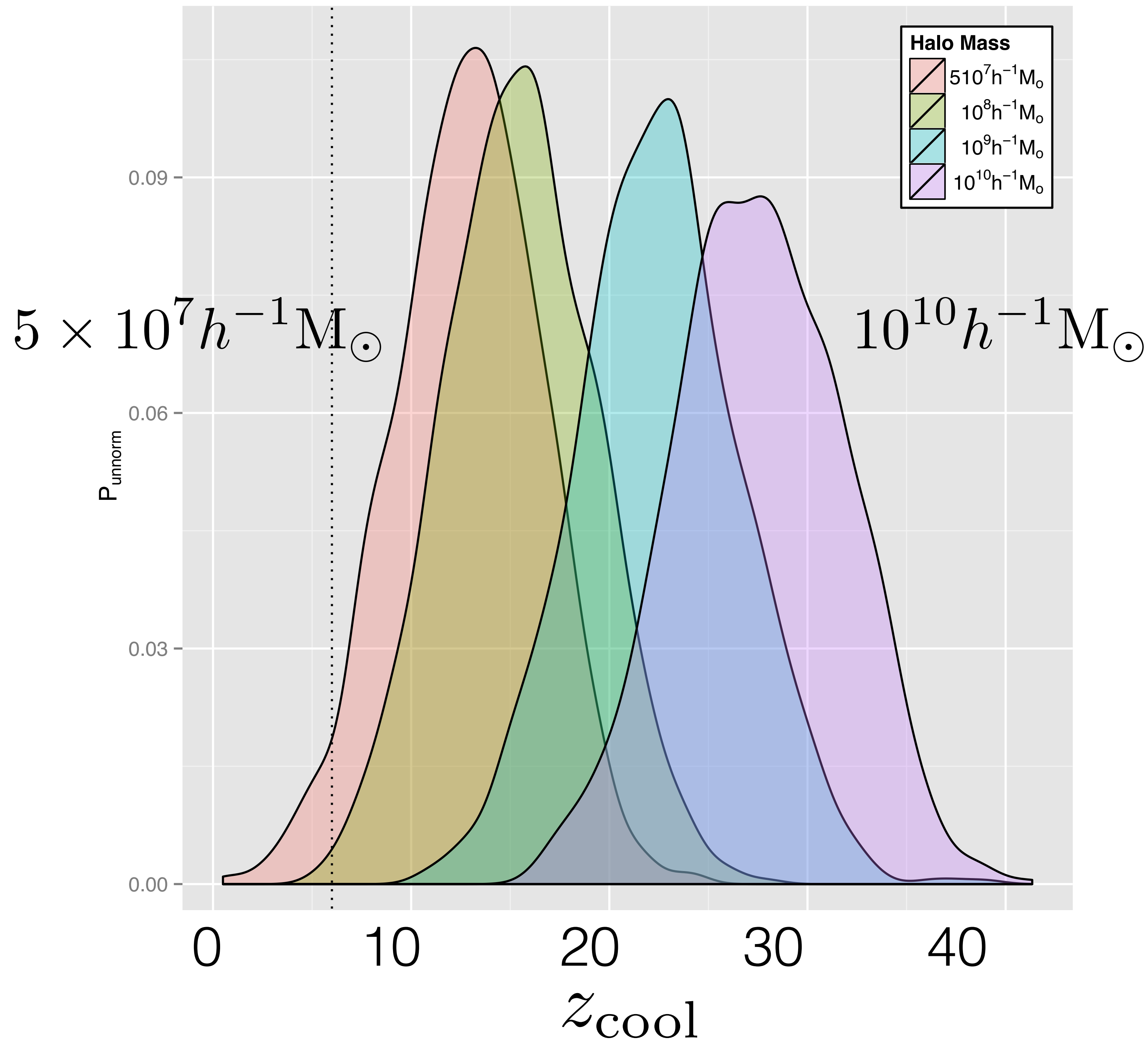
Power et al., submitted

- Simple physical model to explain scatter in galaxy properties
- Assume universal baryon fraction in a DM halo
- Gas forms diffuse disk via atomic or molecular hydrogen cooling
- Assume gas settles into disk on dynamical timescale
- Up to 0.2% stars have masses $> 8\,\mathrm{M}_\odot$
- Massive stars can evolve and expel gas before low-mass stars form

$$t_{\rm PMS} \simeq 10^7 \left(\frac{M}{M_\odot}\right)^{-2.5} \mathrm{yr}$$

Assembly histories of low-mass haloes

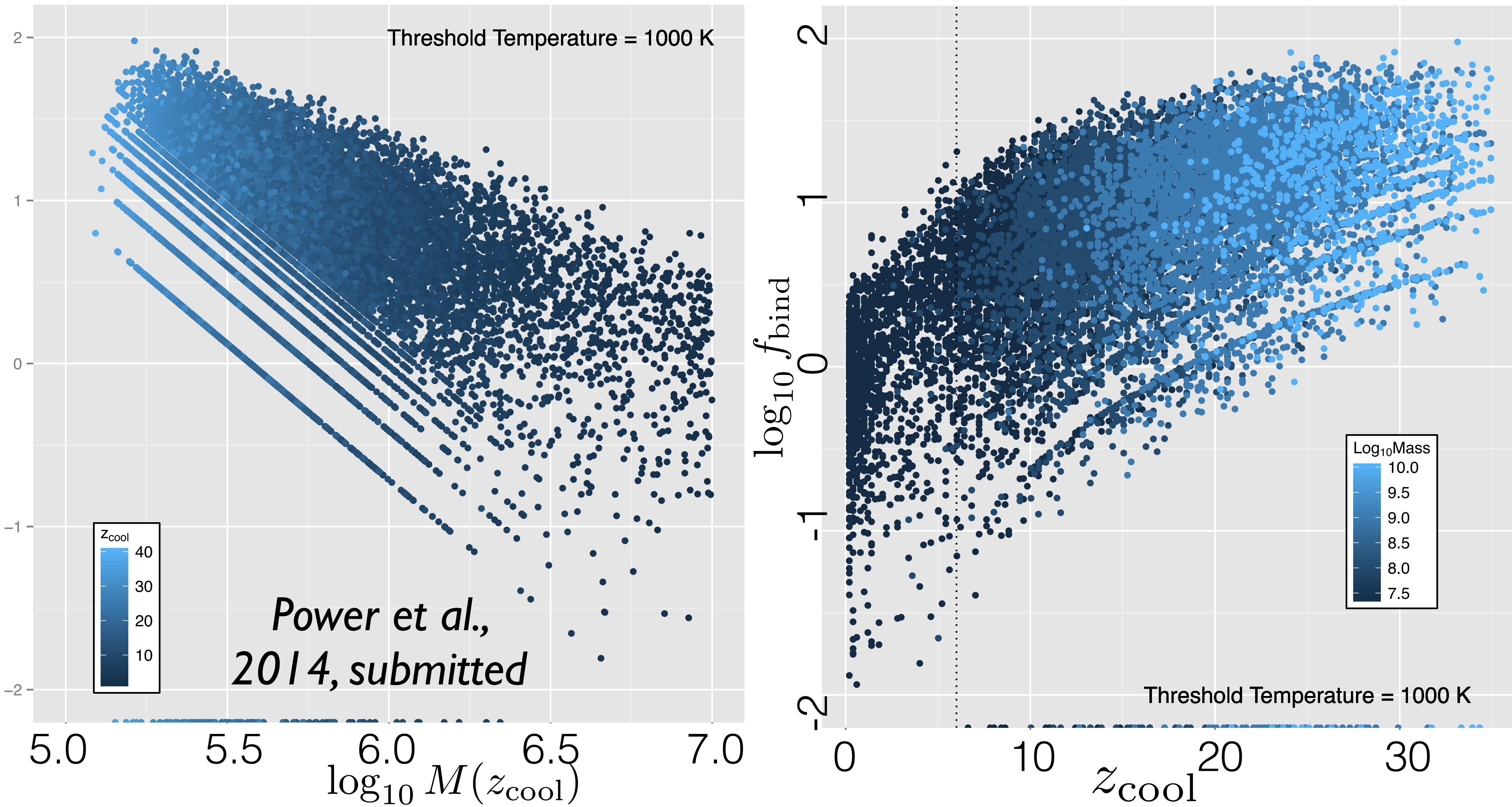
- Monte Carlo merger trees *(Parkinson et al., 2008)*



Power et al., 2014, submitted

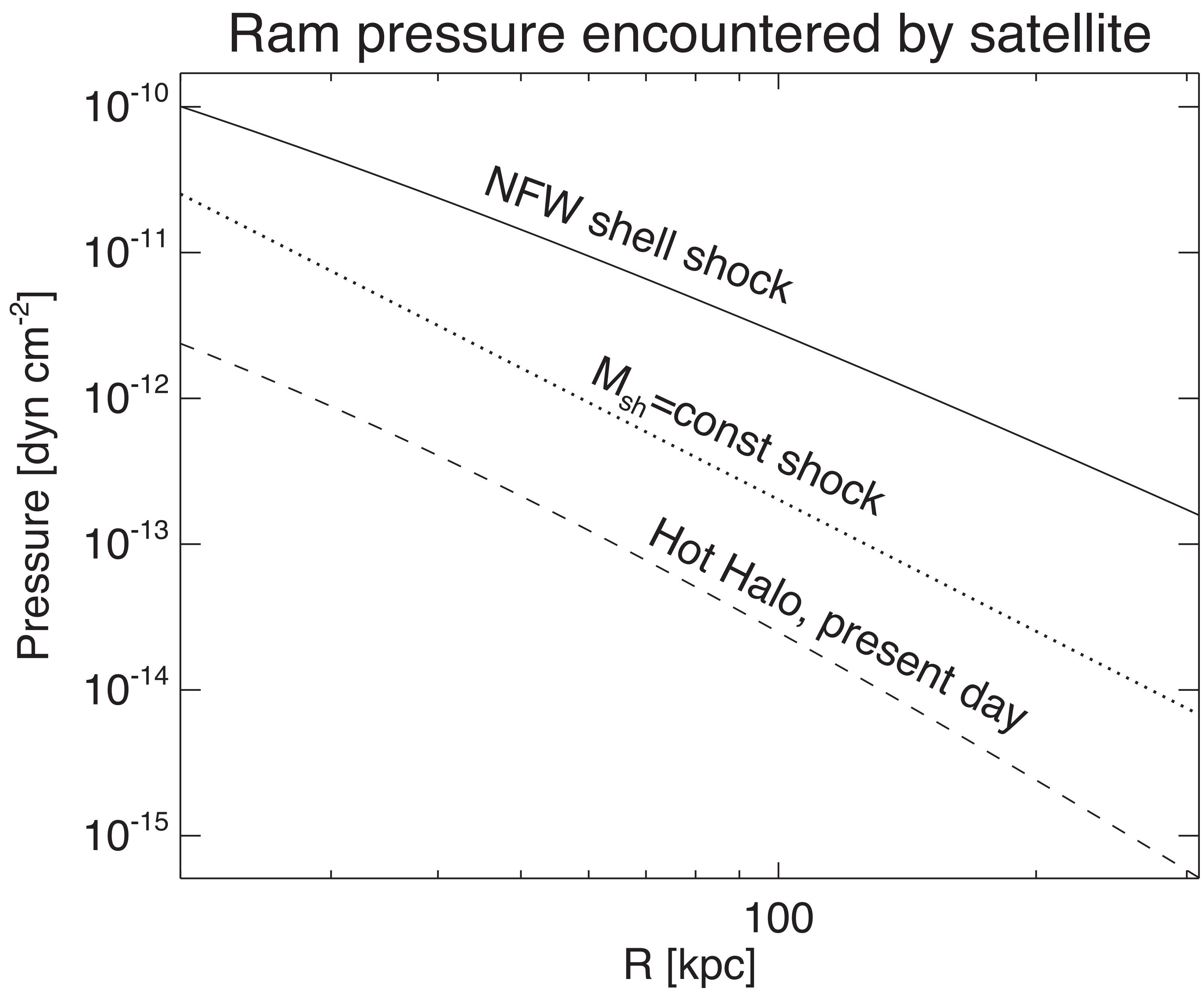
- More massive haloes support cooling earlier
- Bias of low-mass haloes to over-dense regions increases $z_{\rm cool}$

Feedback in low-mass haloes



- Haloes $> 10^9\,\mathrm{M}_\odot$ form from lower mass objects that lose gas
  - may re-accrete gas at lower z
- Haloes $< 10^8\,\mathrm{M}_\odot$ reach $M_{\rm cool}$ too late to accrete

External AGN outflows and dSph formation



Nayakshin & Wilkinson, 2013

Outflows during formation of black hole could have significantly affected dSph satellites

Impact of external AGN outflow on satellites

Nayakshin & Wilkinson, 2013

- At large radii, ram pressure from outflow > restoring force from satellite

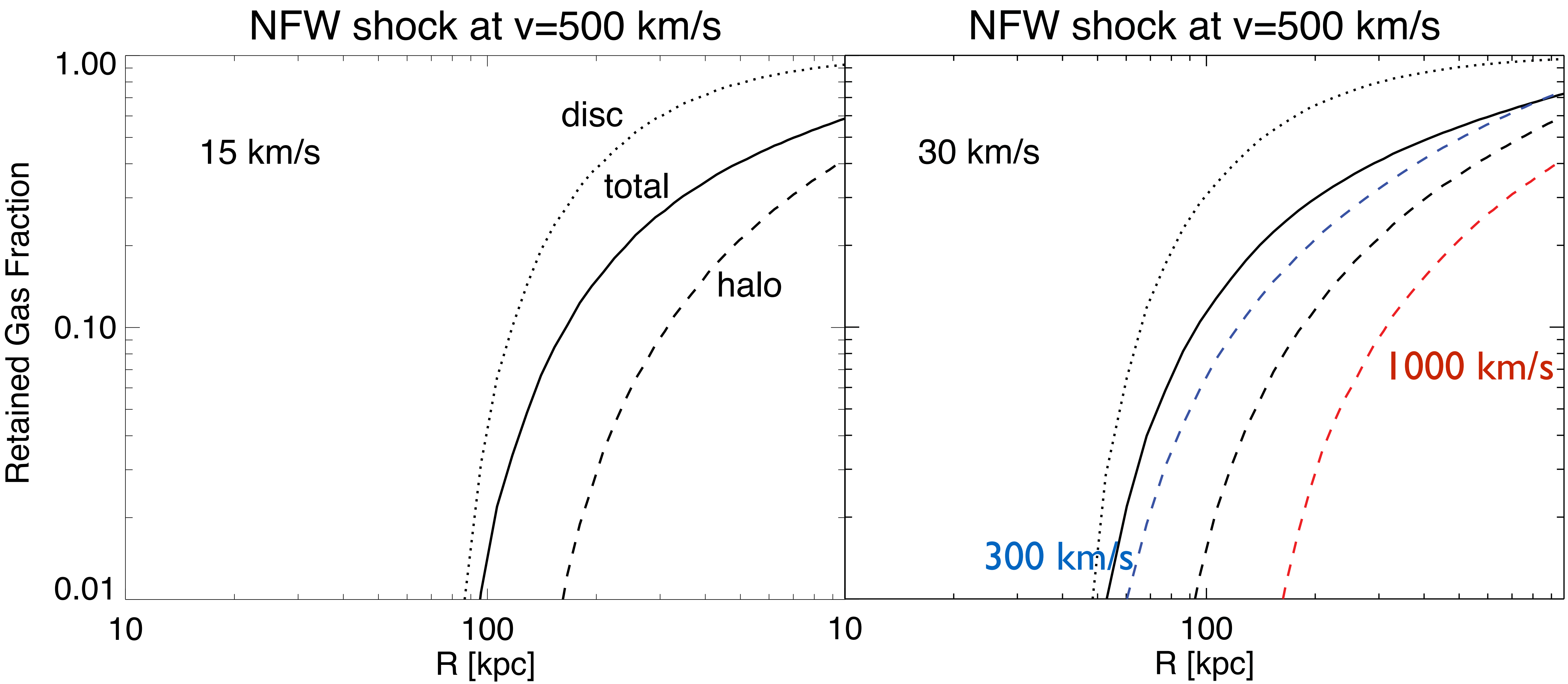
$$r_S = \left(\frac{8f_{\rm d}}{3f_g}\right)^{1/2} \frac{v_{\rm circ}^2 R}{V_{\rm circ} V_{\rm sh}} \approx 0.65\ {\rm kpc} \frac{v_{20}^2 R_{100}}{V_{200} V_{500}} \left(\frac{f_{\rm d}}{f_g}\right)^{1/2}$$

- Inside r_S, gas is compressed in regions where

$$P_{\rm sh} > P_{\rm disc} = 2\pi G \Sigma_{\rm d}(r) \Sigma_{\rm dg}(r) \frac{h}{2r}$$

- Inner edge for compression moves inwards over time
  - natural explanation for central concentration of later star formation

AGN outflows and dSph formation



Nayakshin & Wilkinson, 2013

- Outflow can remove gas from dSphs even at ~100kpc
- Removal depends on gas morphology within dSph
- May also trigger star cluster formation in satellite
- Impact depends on duty cycle of AGN and on satellite orbits

High-resolution simulations of SN feedback in dSphs

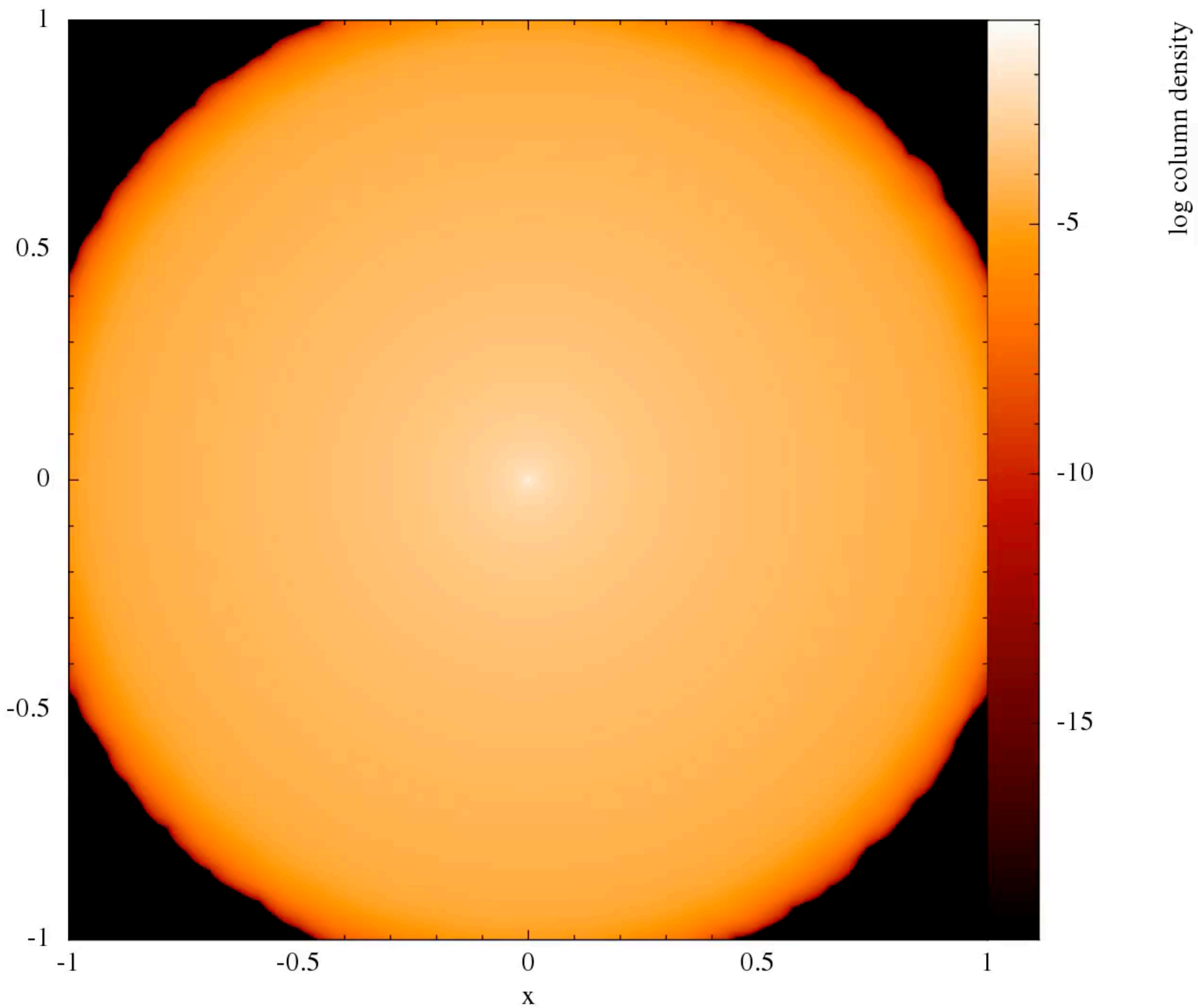
- Gadget-3 SPHS simulations with 5×10^5 gas particles and live dark matter halo of mass $10^9\,\mathrm{M}_\odot$
- Hernquist halo with spherical gas distribution
- SN events occur randomly in position and time, with average rate of 1 per Myr
- Each event injects either 10^{51} or 10^{52} ergs (equivalent to multiple SNe per "event")

See poster by Claire Cashmore

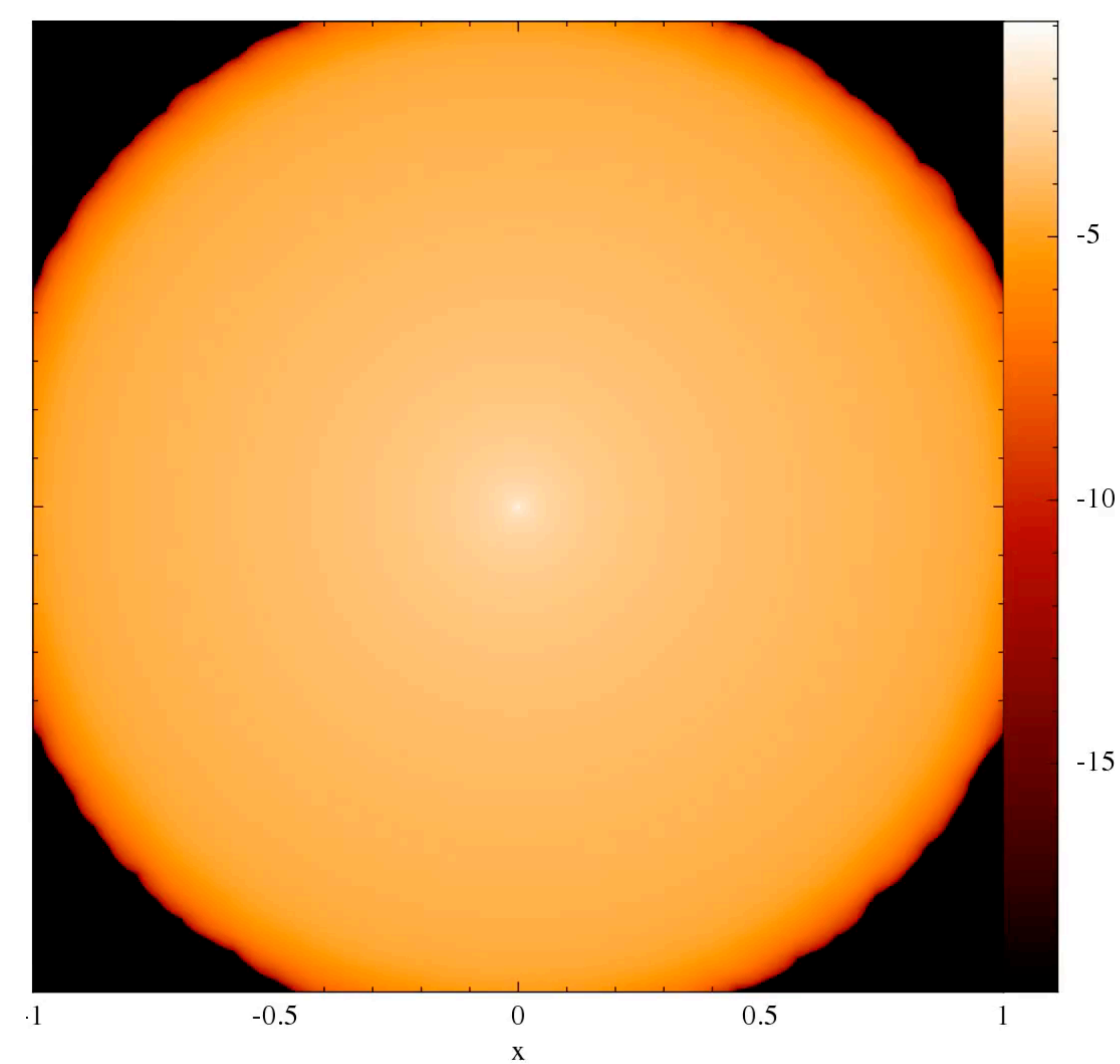
SN feedback in dSphs

Cashmore et al., in prep.

500 SN events

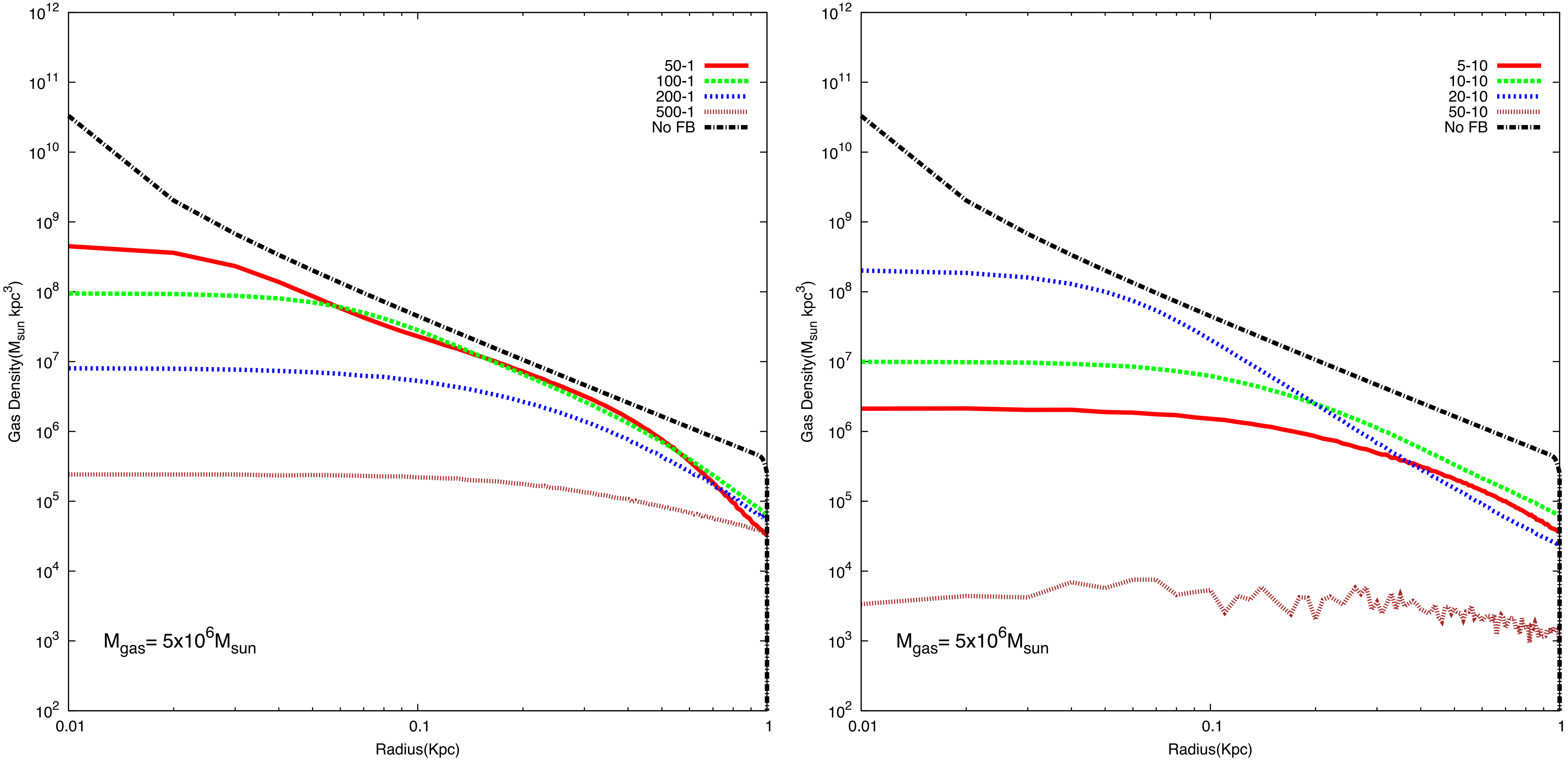


50 SN events



SN feedback in dSphs

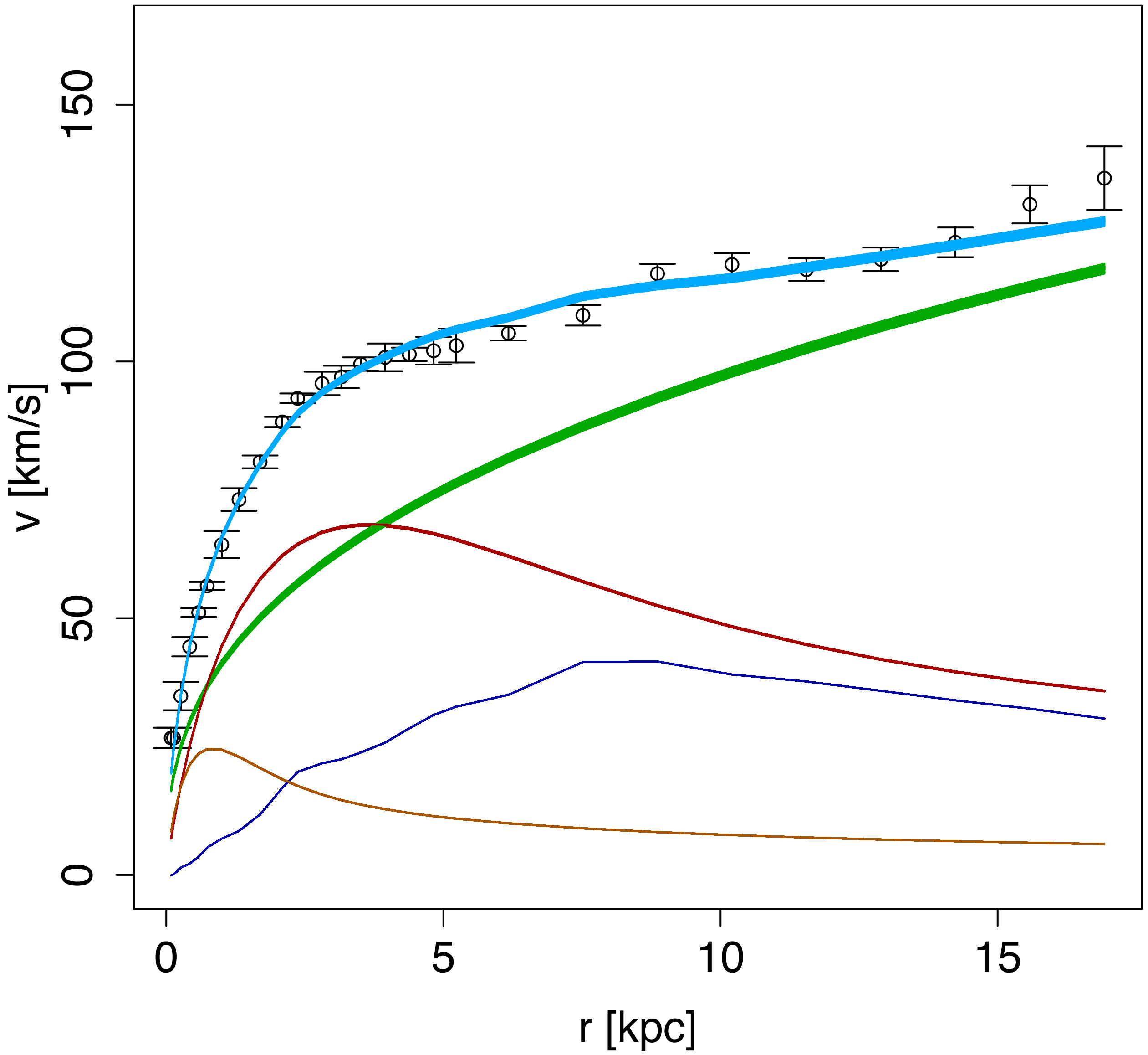
Cashmore et al., in prep.

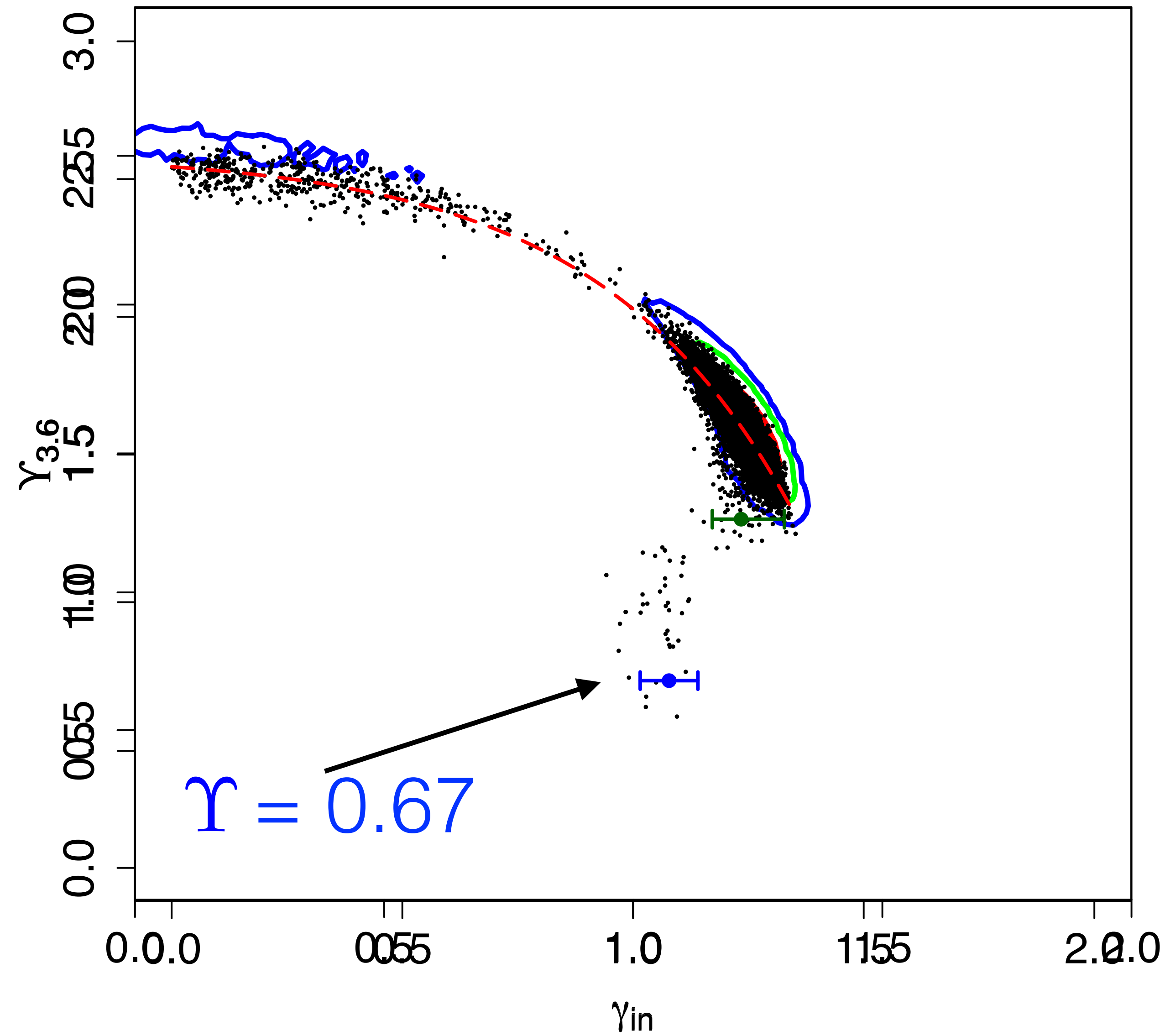


- Cumulative impact of larger events is greater than that of smaller events *of same combined energy*
- Feedback very sensitive to details of SN events

The halo profile of M33

Hague & Wilkinson, submitted, astro-ph:1408.4452





- MCMC analysis with 5 halo parameters
- Calculate halo slope at radius of inner data point and r_1
- Fixed M/L: NFW favoured - Free M/L: steeper halo
- Beware $\chi^2_{\rm red}$ comparisons across parameter space

Conclusions

- Stochasticity in outcomes of star formation in low-mass haloes may be key to resolution of the too big to fail & "gap" problems
- Outflows from AGN or starbursts in host galaxy can both remove gas and trigger star formation in satellites
- MCMC modelling of rotation curves is yielding physical properties of haloes which can be compared with simulations
- The impact of SN feedback in dSphs is affected by distribution of SNe in space and time (**see poster by Claire Cashmore**)