Angular momentum and exponential disks

European Research Council

Established by the European Commission

Jakob Herpich
MPIA, Heidelberg, Germany

Exponential Disks Workshop, Lowell Observatory

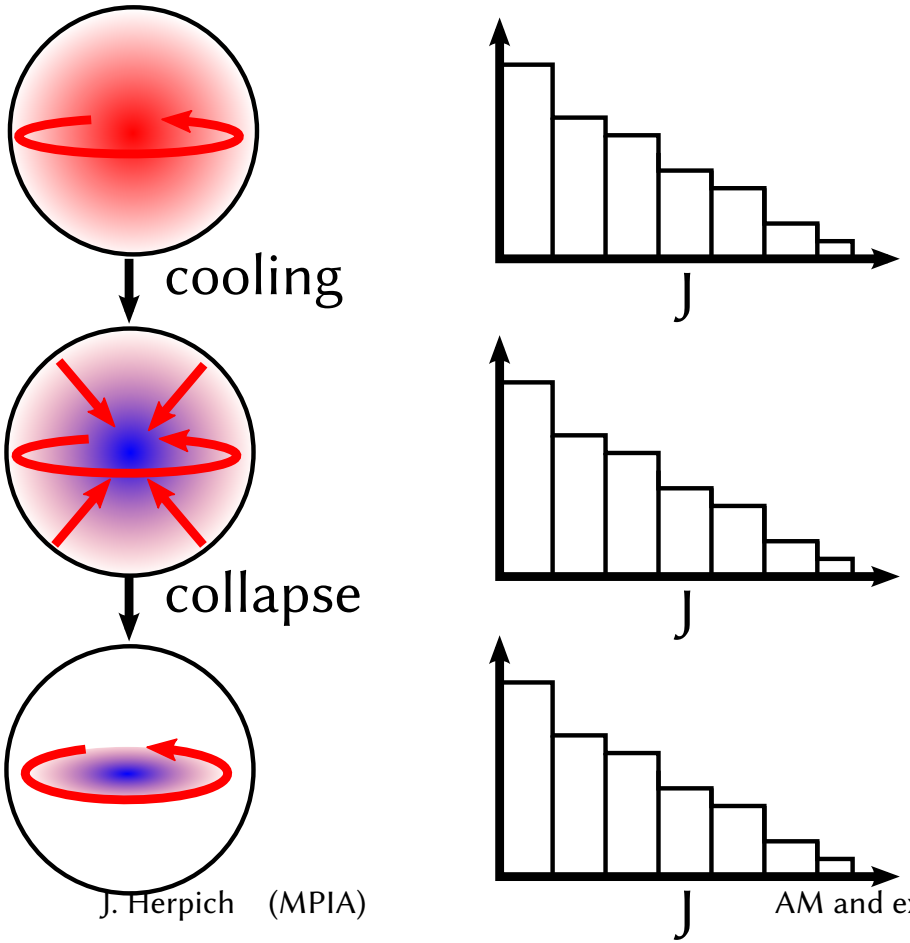
October 6, 2014

Collaborators: Greg Stinson, Aura Obreja, Aaron Dutton, Hans-Walter Rix

How to form exponentials

Analytical Models

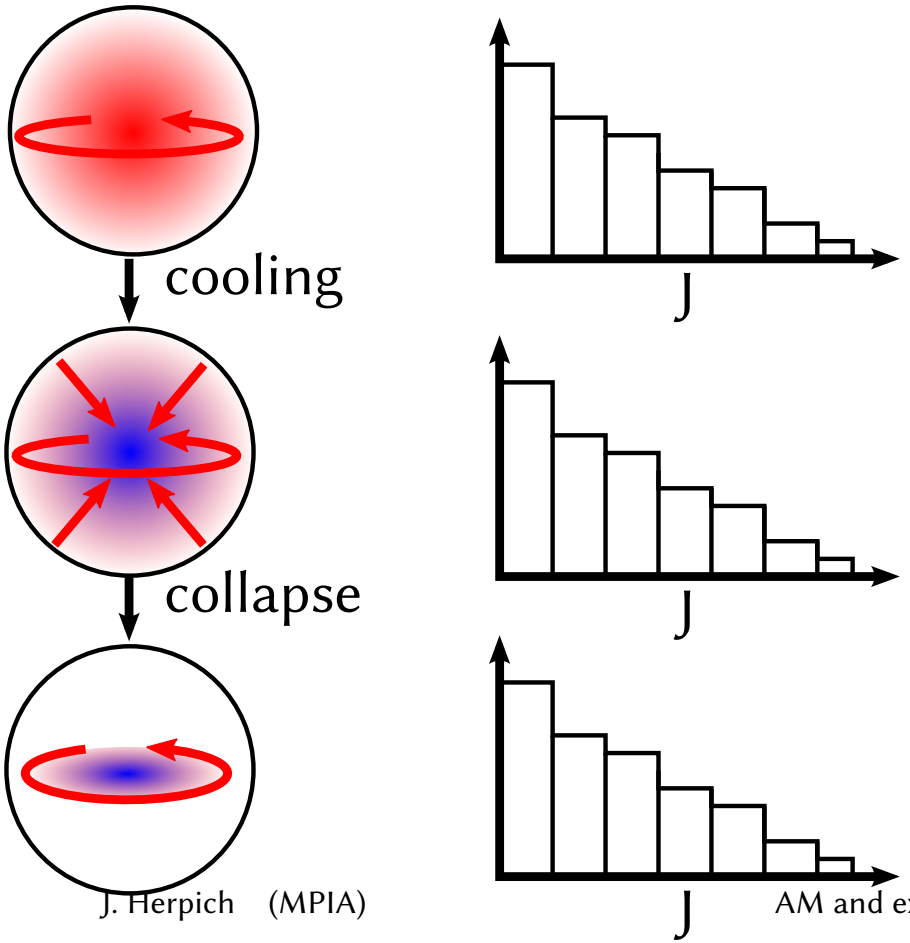
- Numerous analytical models (e. g. Mestel 1963, Fall & Efstathiou 1980, Dalcanton+ 1997)
- Common assumption: Angular momentum distribution conserved

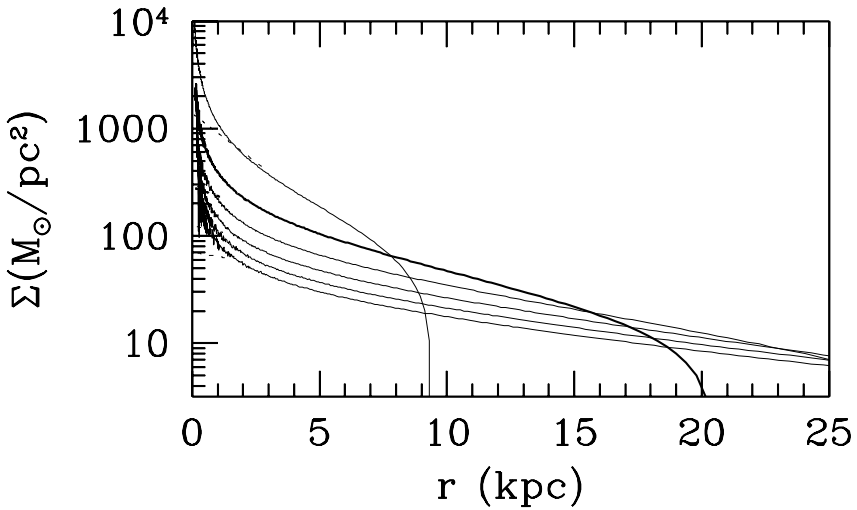


How to form exponentials

Analytical Models

- Numerous analytical models (e. g. Mestel 1963, Fall & Efstathiou 1980, Dalcanton+ 1997)
- Common assumption: Angular momentum distribution conserved

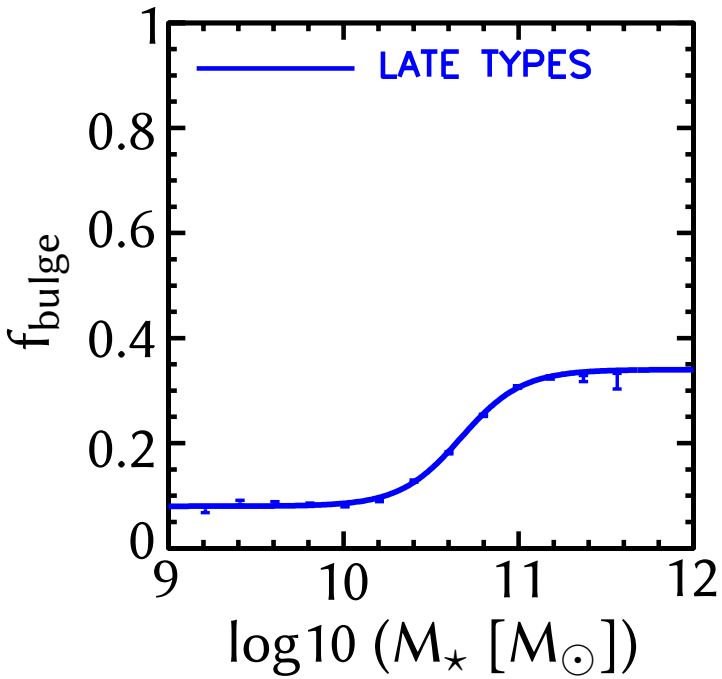




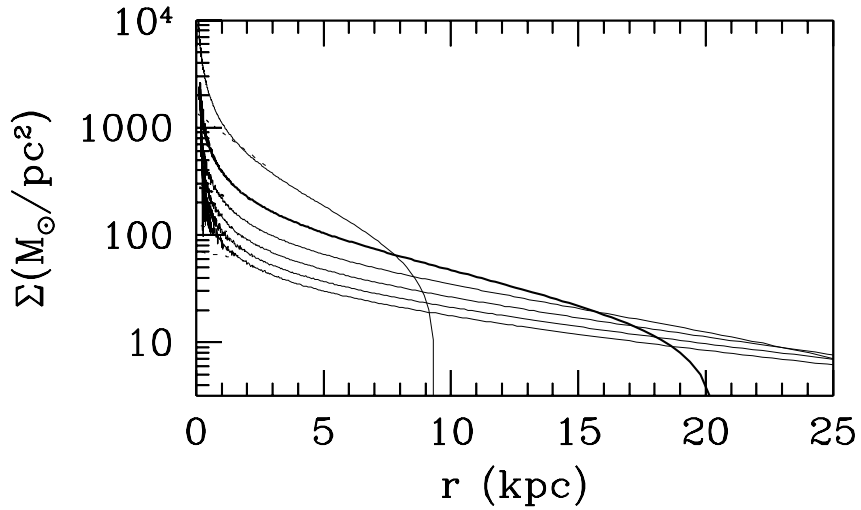
Dalcanton+ 1997

How to form exponentials 2

Bulges



Dutton+ 2011

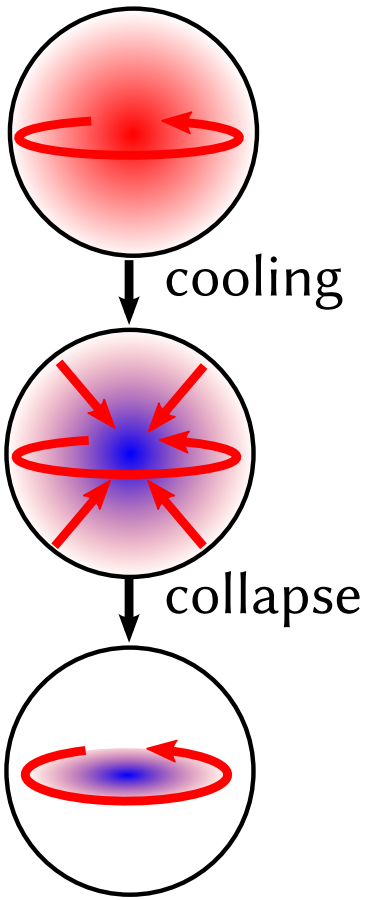


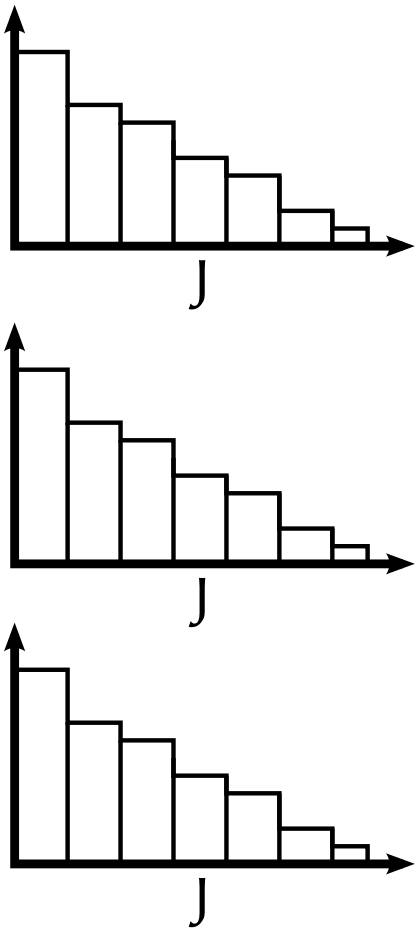
Dalcanton+ 1997

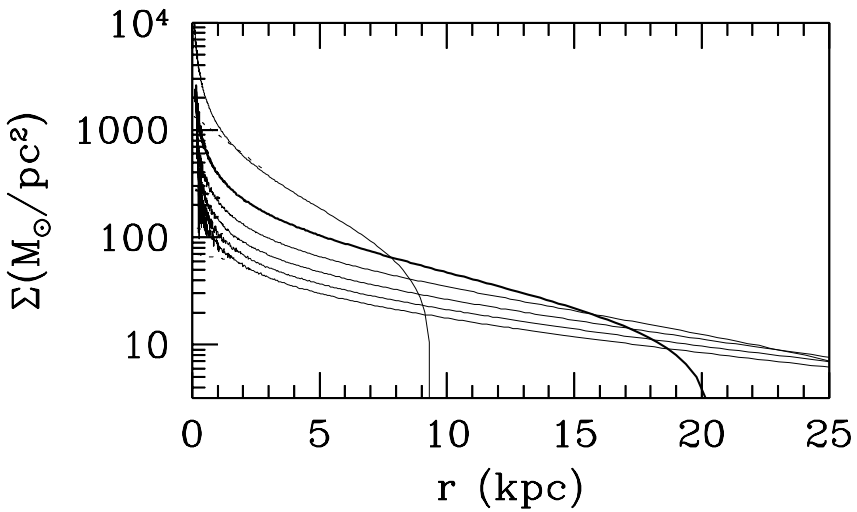
- Most spirals are bulgeless: ≈ 10 % for $M < 2 \times 10^{10} M_\odot$

How to form exponentials 3

Reducing Bulges



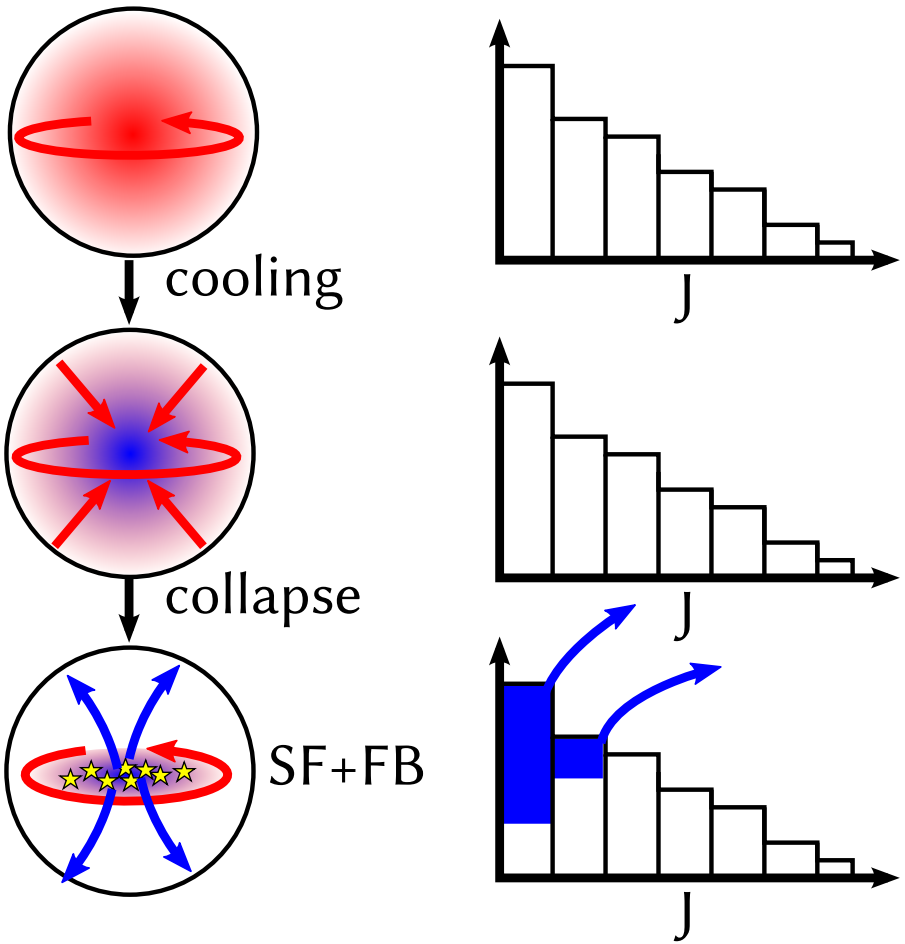


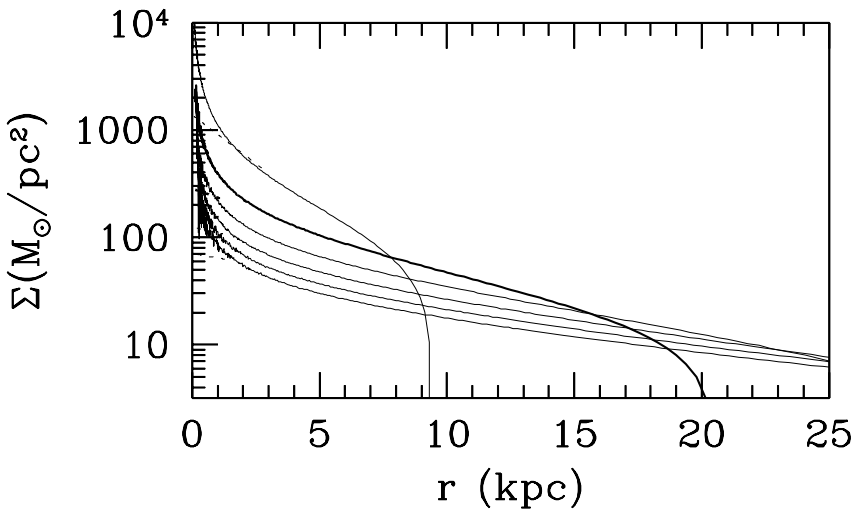


How to form exponentials 3

Reducing Bulges

- Dutton 2009: Remove low AM material via feedback

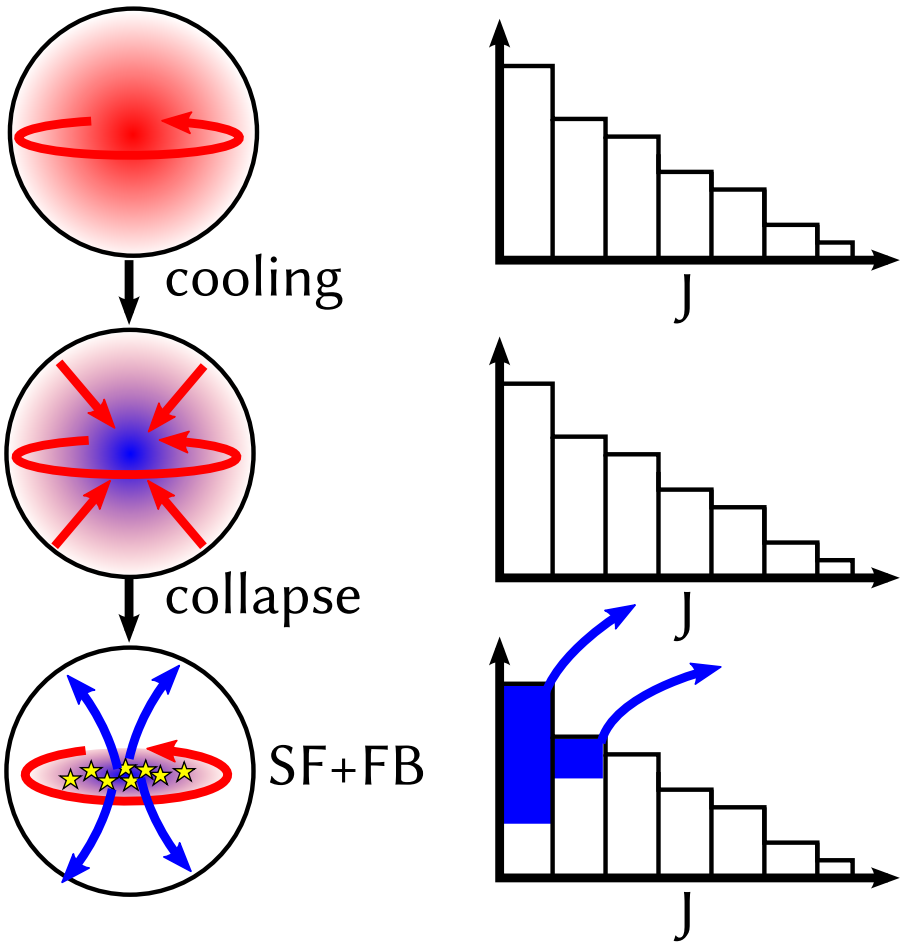


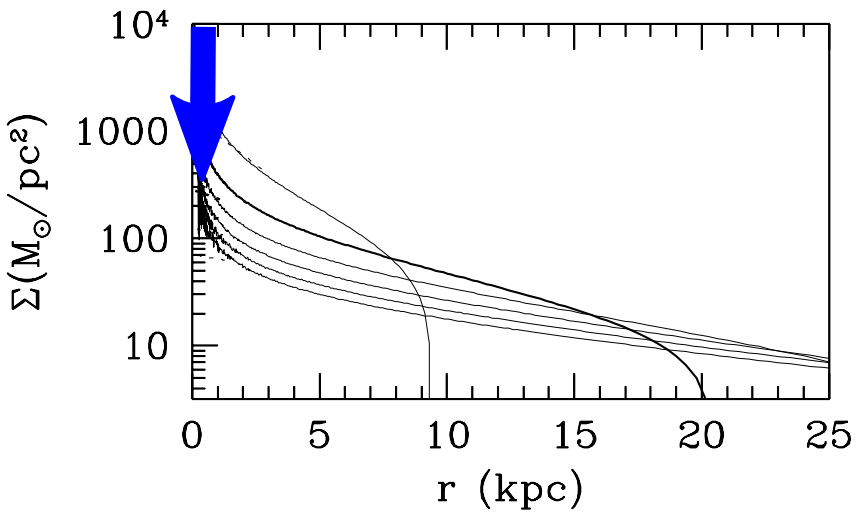


How to form exponentials 3

Reducing Bulges

- Dutton 2009: Remove low AM material via feedback



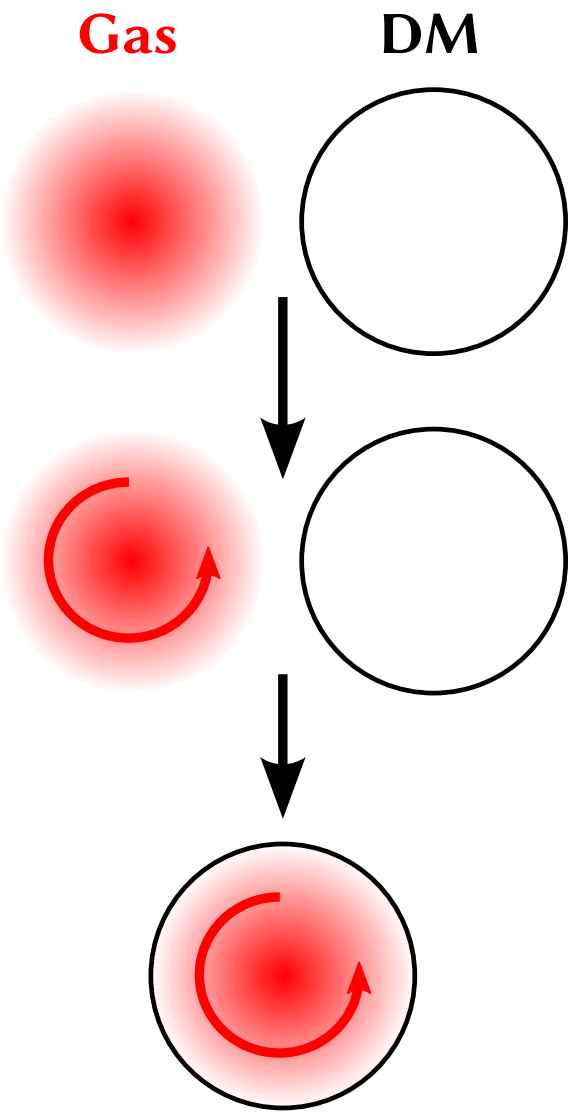


→ bulge reduced

This Work

- Test analytic models in hydrodynamic simulations
- Initial conditions based on analytic models (Dutton 2009)

Initial Conditions



1. DM halo: dynamic equilibrium
2. Gas sphere: hydrostatic equilibrium
3. Spin up gas (DM not rotating)
4. Combine gas + DM

Herpich+ (in prep.)

Initial Conditions

- 10^{12} $M_\odot$ NFW halo
- Bullock+2001 angular momentum profile $M(< j)$
- $\lambda = 0.04, \mu = 1.3, f_{\mathrm{gas}} = 0.1$
- Assumption: j_z increases with R

Initial Conditions

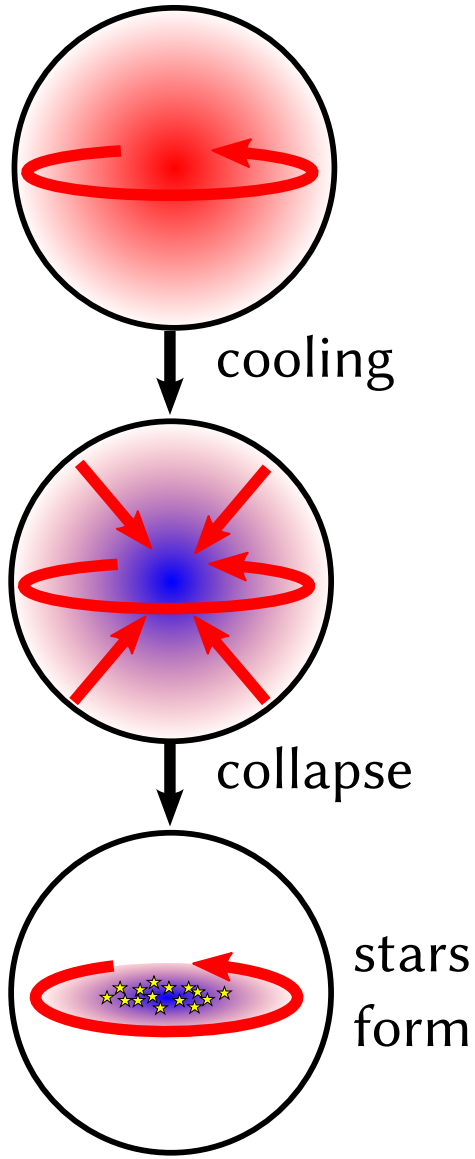
- 10^{12} $M_\odot$ NFW halo
- Bullock+2001 angular momentum profile $M(< j)$
- $\lambda = 0.04, \mu = 1.3, f_{\mathrm{gas}} = 0.1$
- Assumption: j_z increases with R
- Code will be public (pynbody)

Simulation Code: ChaNGa

- Parallel NBody + SPH code (gravity + hydrodynamics)
- Chemical Enrichment (e. g. Stinson+ 2012)
- Metal Cooling
- Stochastic Star Formation (Stinson+ 2006)
- SN Feedback (Stinson+ 2006)
- Stellar Winds (Stinson+ 2013)
- Forming realistic galaxies (Stinson+ 2013)

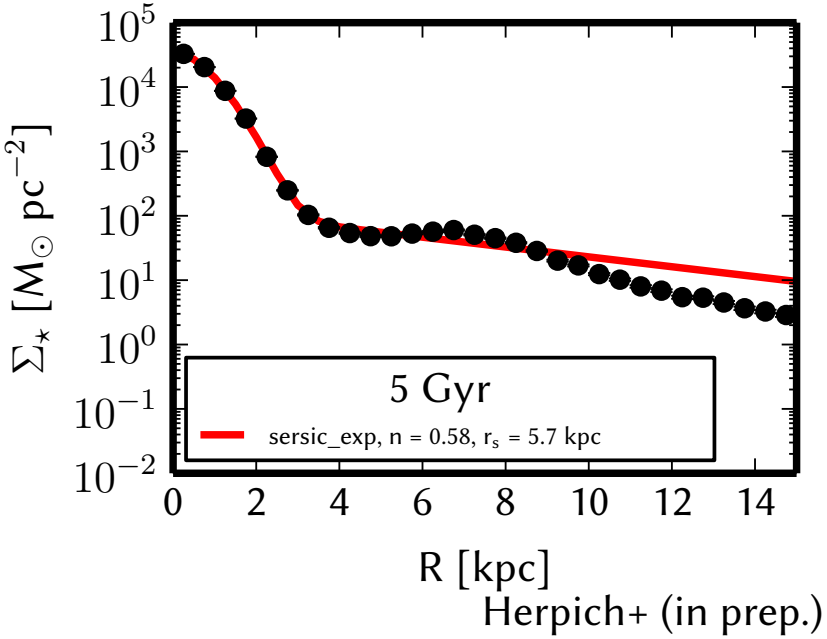
Simulation Code: ChaNGa

- Parallel NBody + SPH code (gravity + hydrodynamics)
- Chemical Enrichment (e. g. Stinson+ 2012)
- Metal Cooling
- Stochastic Star Formation (Stinson+ 2006)
- SN Feedback (Stinson+ 2006)
- Stellar Winds (Stinson+ 2013)
- Forming realistic galaxies (Stinson+ 2013)



Herpich+ (in prep.)

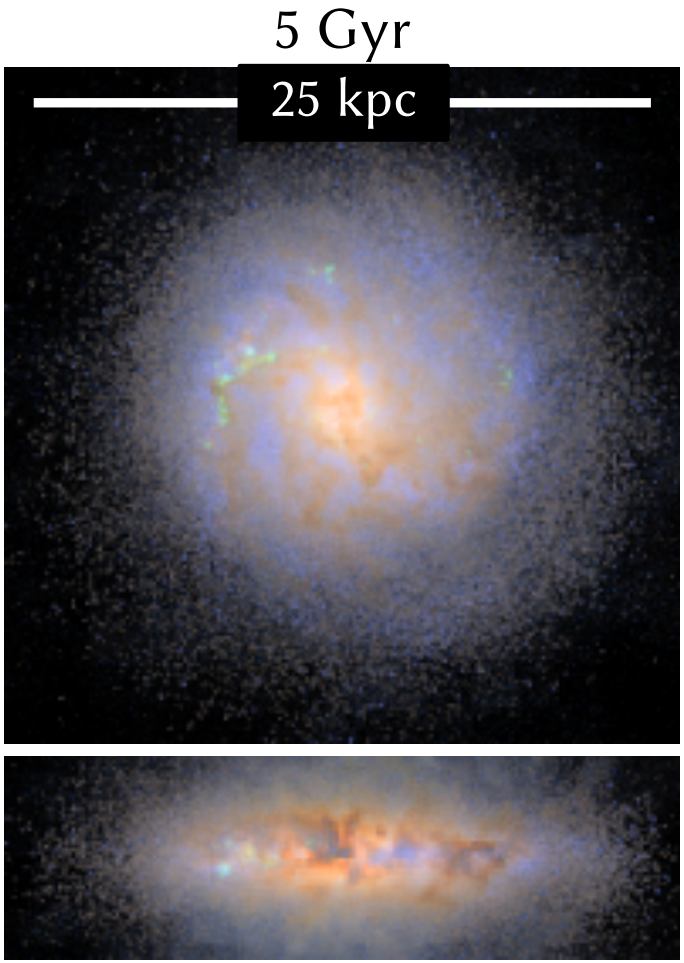
No Feedback

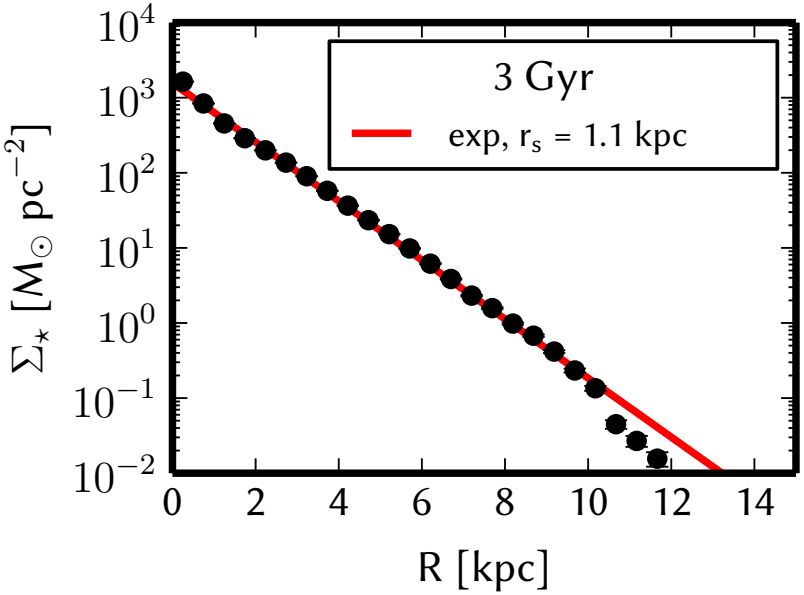


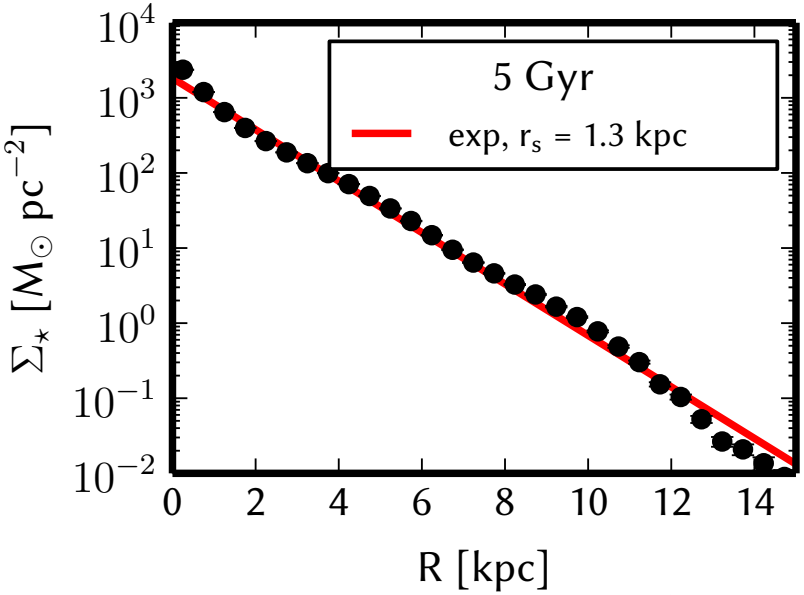
Herpich+ (in prep.)

- Massive Bulge
- Very extended disk component
- Numerical problems due to lack of FB

With Feedback



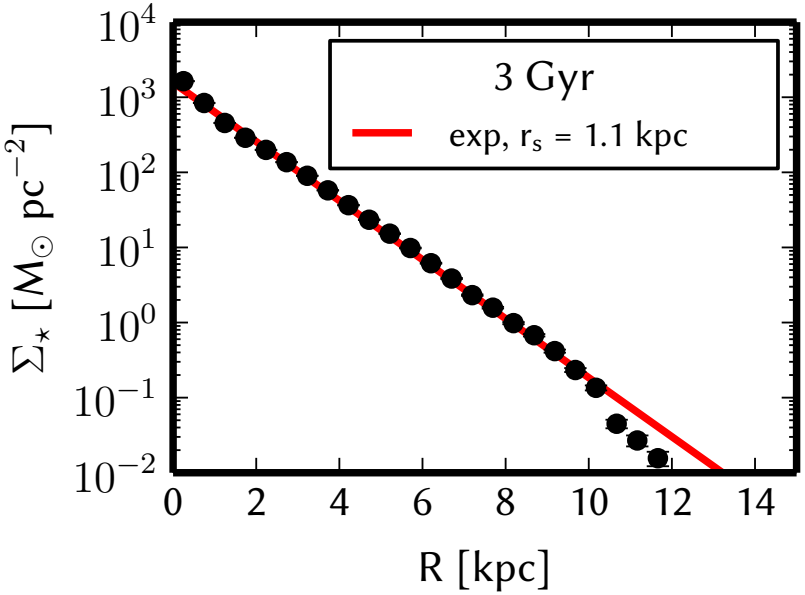


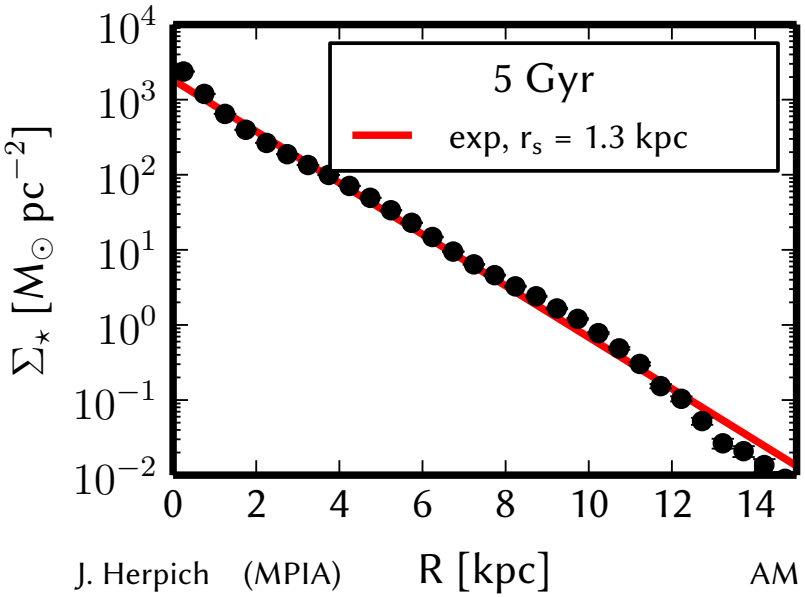


exponential within several r_s

Herpich+ (in prep.)

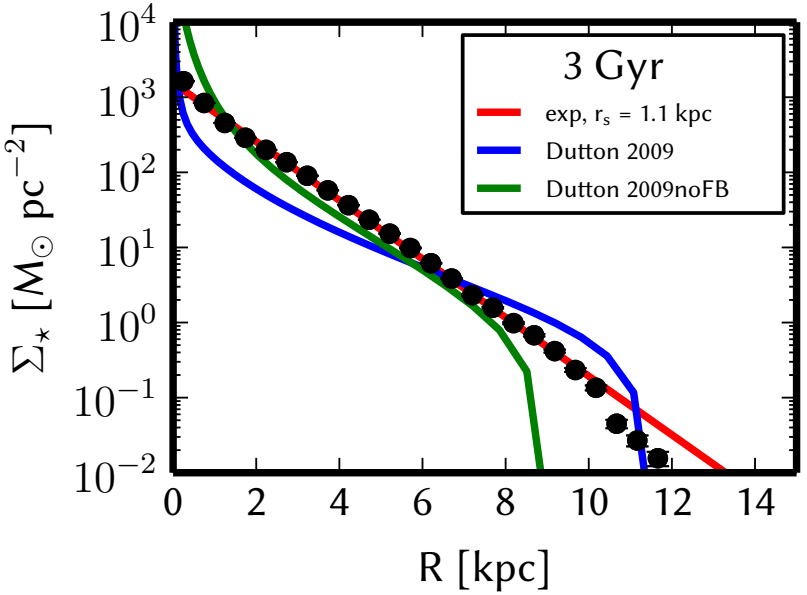
Compare with Analytic Models

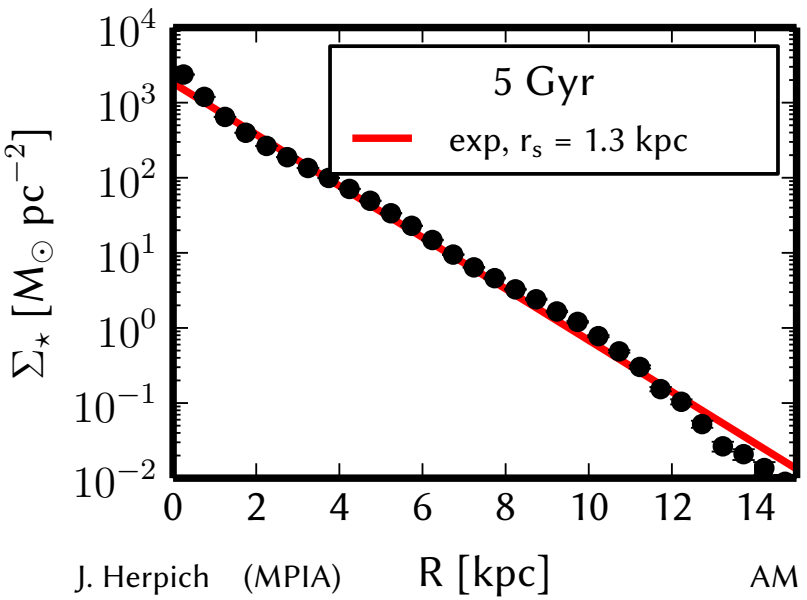




Herpich+ (in prep.)

Compare with Analytic Models



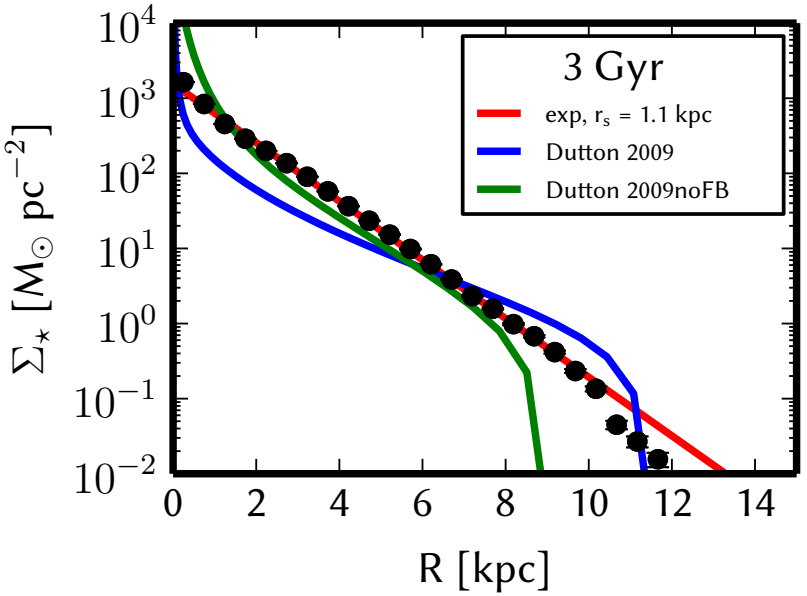


3 Gyr

- No FB model has same scale length
- Truncation radii agree

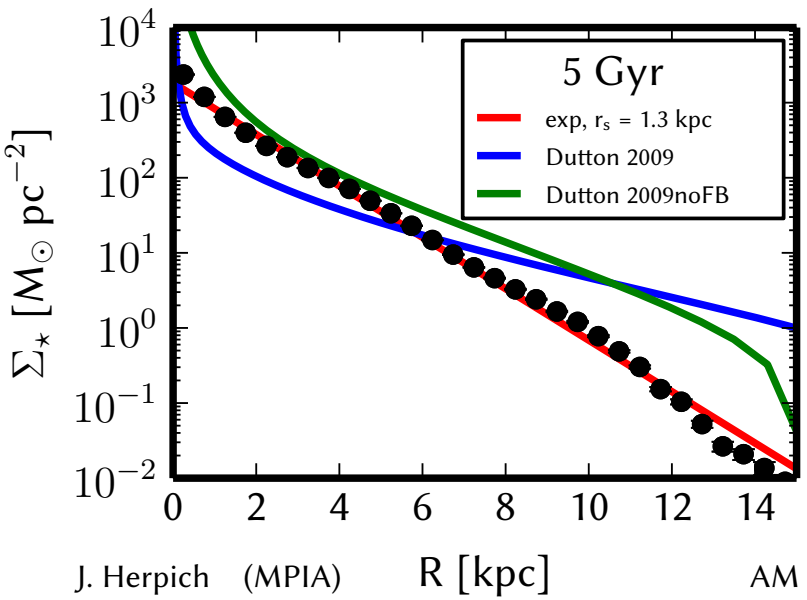
Herpich+ (in prep.)

Compare with Analytic Models



3 Gyr

- No FB model has same scale length
- Truncation radii agree



5 Gyr

- Analytic discs grow faster

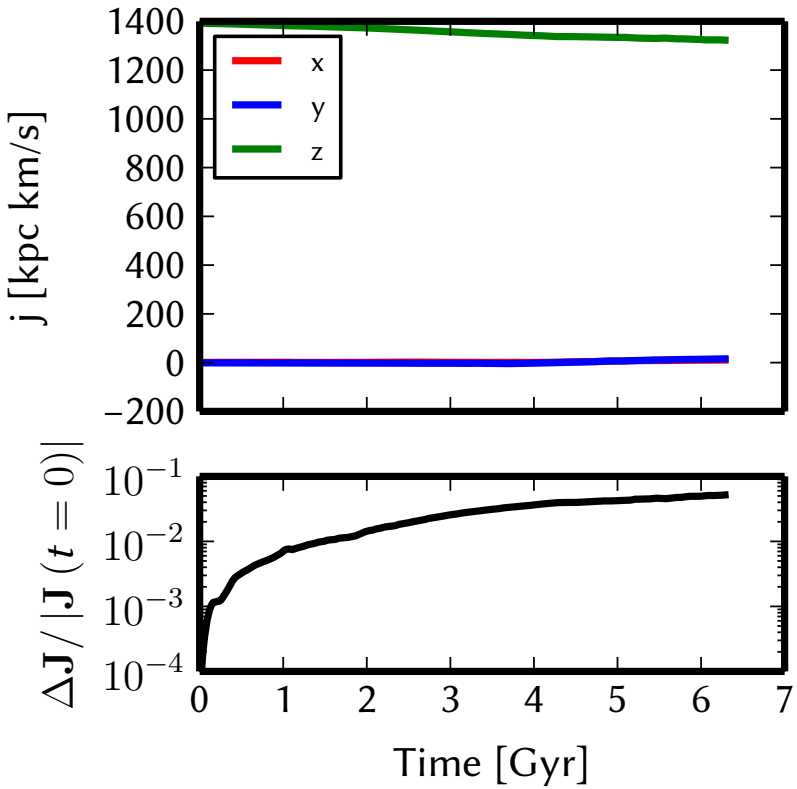
Simulation and analytic results show fair agreement

Herpich+ (in prep.)

Angular Momentum Conservation

Baryons

Global

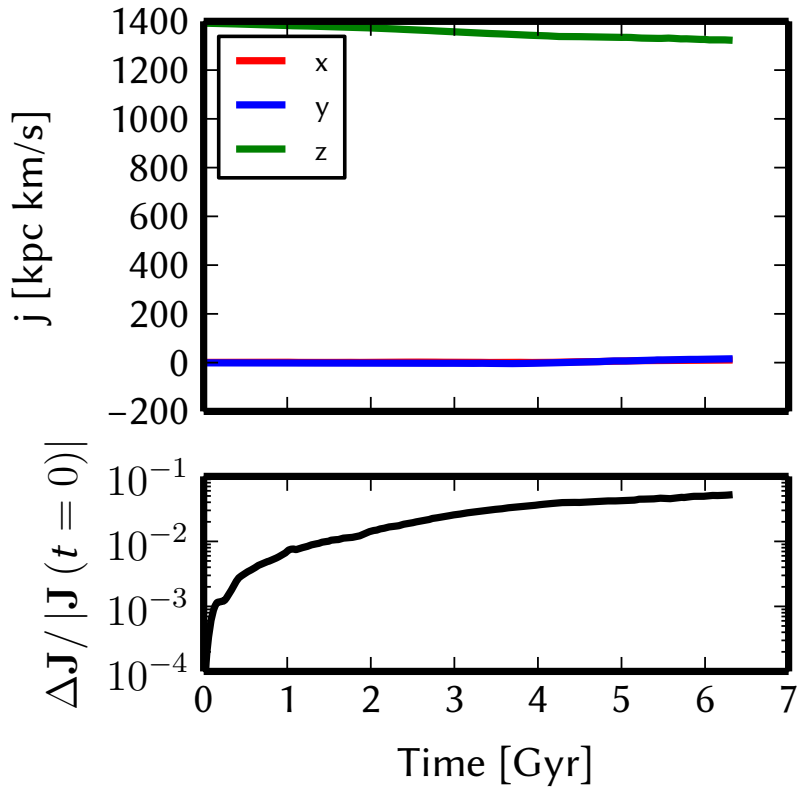


- Total AM conserved
- Little transfered to DM

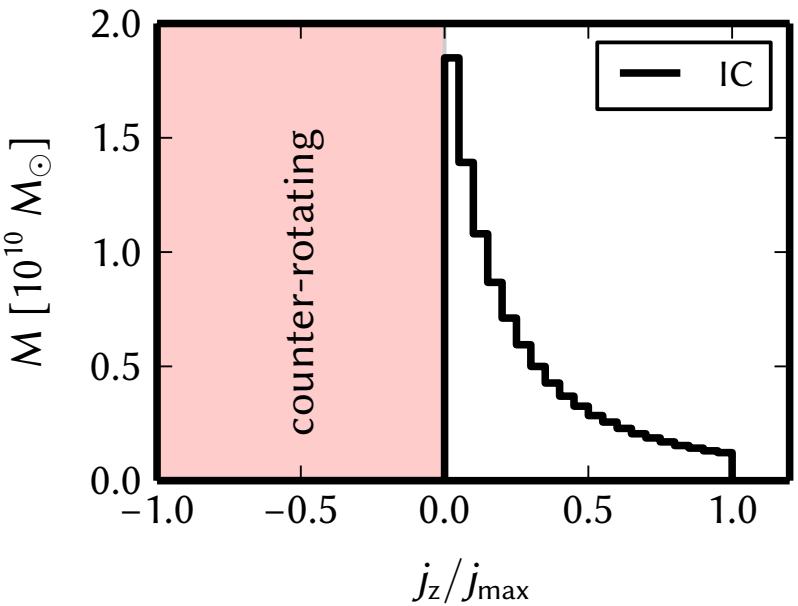
Angular Momentum Conservation

Baryons

Global



Distribution



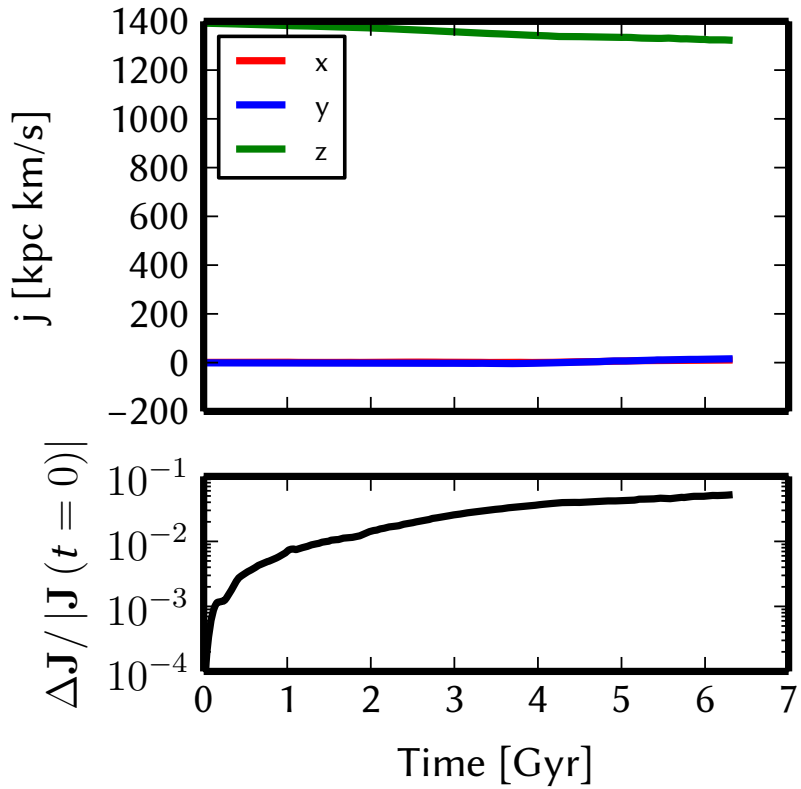
Herpich+ (in prep.)

- Total AM conserved
- Little transfered to DM

Angular Momentum Conservation

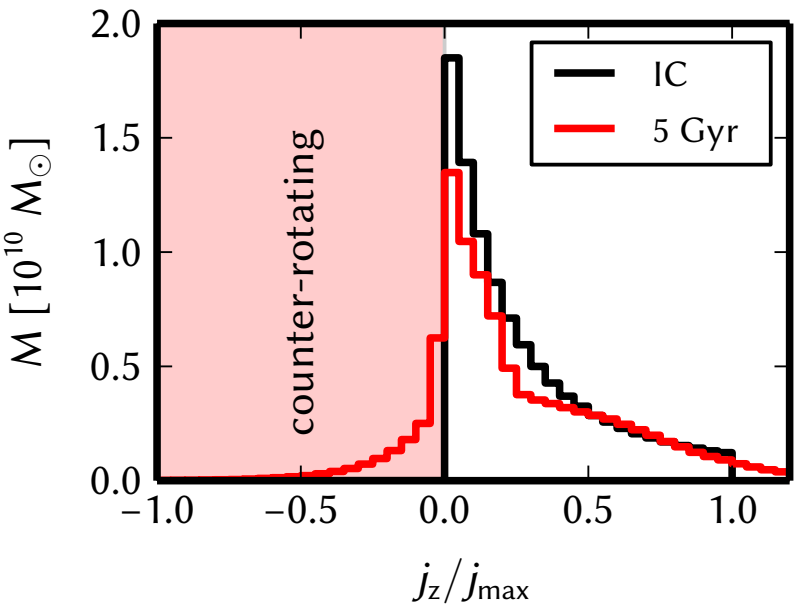
Baryons

Global



- Total AM conserved
- Little transfered to DM

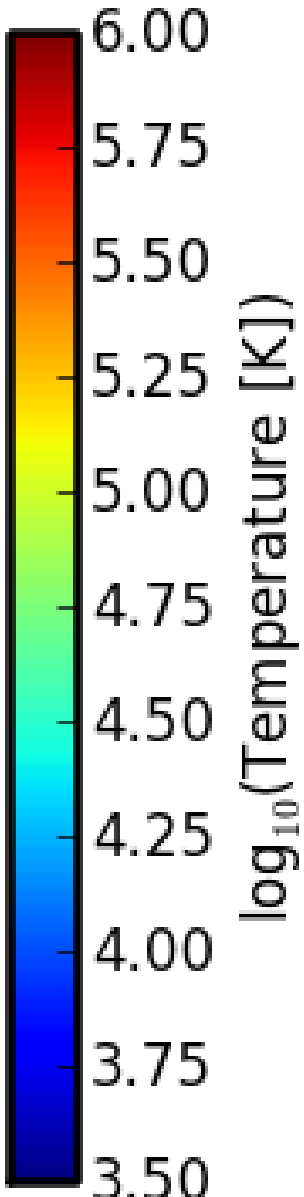
Distribution



Herpich+ (in prep.)

- Redistribution of low AM material

Movie



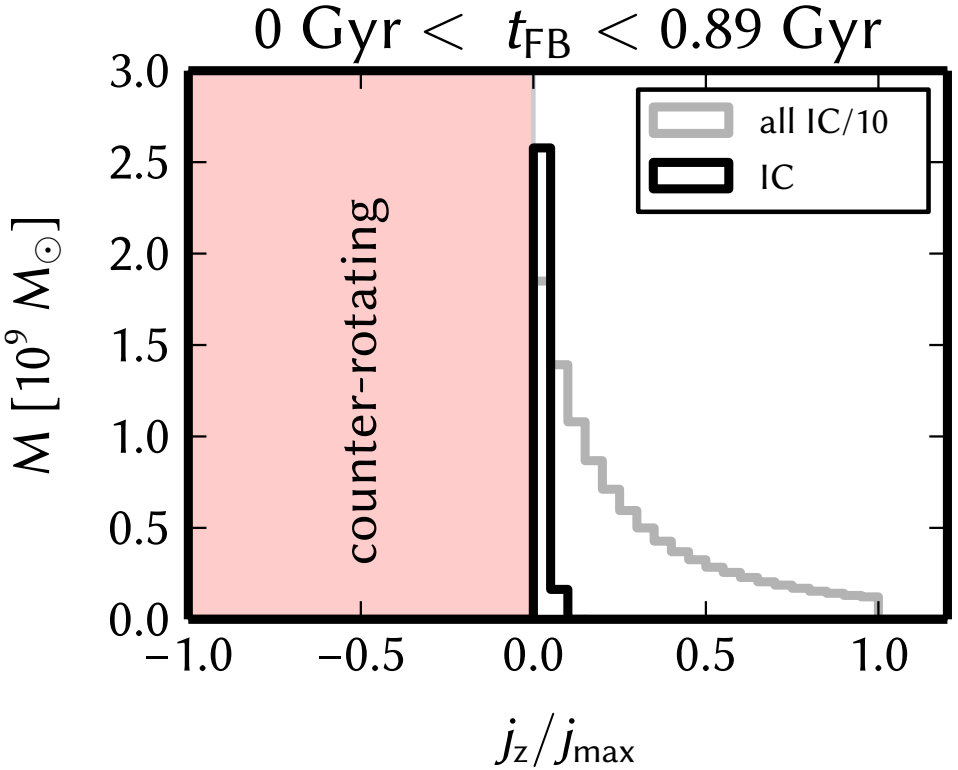
- Color: gas temperature
- Intensity: density

`http://www.mpia.de/~herpich/movies/l4_mu13_m12_c10_f1.mp4`

Angular Momentum Redistribution

Preliminary

Gas that received feedback



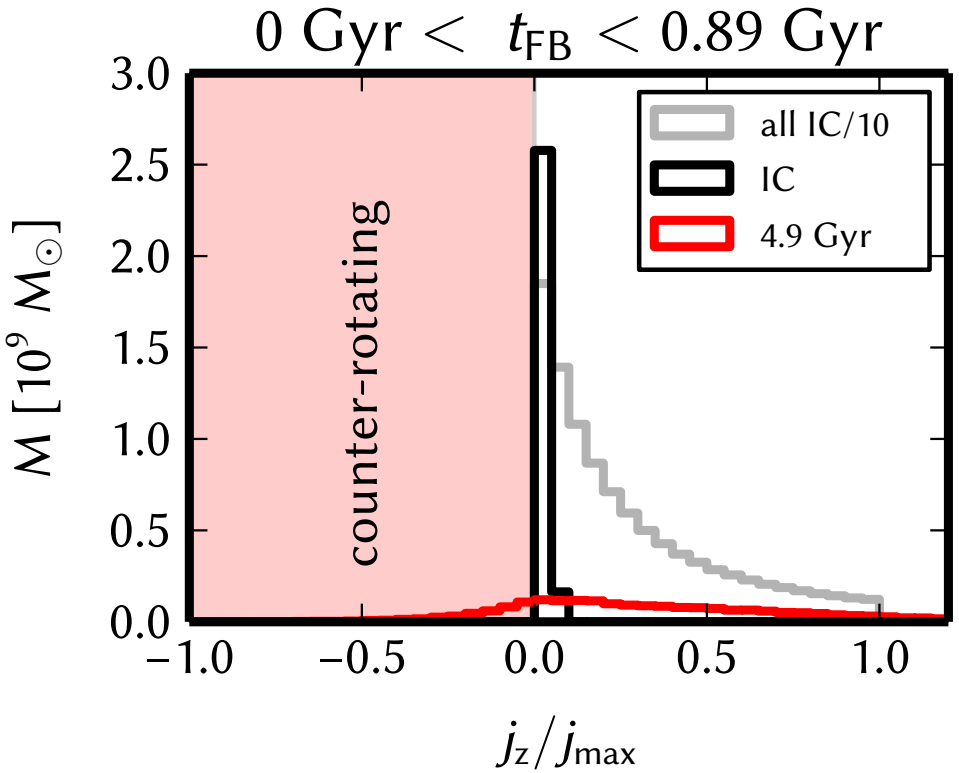
Herpich+ (in prep.)

Low AM gas removed by feedback

Angular Momentum Redistribution

Preliminary

Gas that received feedback



Herpich+ (in prep.)

Low AM gas removed by feedback

Take home

- Low angular momentum gas forms bulges
- Supernova feedback $\rightarrow$ less low angular momentum gas $\rightarrow$ pure exponentials
- IC code will be public