DISK-CORONA GAS CYCLE IN SIMULATED MILKY WAY-LIKE GALAXIES

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James Wadsley
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Rok Roskar

Life cycle of gas in galaxies, ASTRON, 2015
GAS ACCRETION ONTO HALOS

Cold vs hot mode of gas accretion (e.g., Keres+05,09)
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High redshift
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Low redshift

Coronae in MW like galaxies:

- $T \sim T_{vir}$ (few $10^6$ K)
- Extended hundreds of kph
- Low metallicity

see Fukugita & Peebles 2006
GAS ACCRETION ONTO HALOS

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Transition at \( z \sim 2 \)

The MW corona had fed our Galaxy continuously in the last 10 Gyr!

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IS THERE A CORONA AROUND THE MW?
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See Gurtina Besla’s talk
SIMULATION SETUP

Code: GASOLINE (SPH; Wadsley+04)
SIMULATION SETUP

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DM halo
- NFW
- $r_{200} = 200$ kpc
- $M_{\text{vir}} = 10^{12}$ Mo
- $m_{\text{DM}} = 10^6$ Mo
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Hot gas
- 10% of $M_{\text{tot}}$
- No metals
- hydro equilibrium
- $\lambda = 0.065$
- $m_{\text{gas}} = 1.4\times10^5$ Mo
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Radiative cooling (Shen+10)
- \( \rho, T \) and \( Z \) dependent
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Star formation (Stinson+06)
- $n > 0.1$ cm$^{-3}$
- $T < 15000$ K
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- Miller-Scalo IMF
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**Stellar feedback (Stinson+06)**
- SN feedback (thermal, blast-wave)
- \( E_{\text{SN}} \) as a free parameter
- stellar winds (\( \sim 25\% \))
FACE-ON MAPS

cold gas

stars

10 kpc

log(N(H,HI,cm^{-2})

log(Σ([M/Σ(pc)]))
<table>
<thead>
<tr>
<th></th>
<th>F80</th>
<th>F40</th>
<th>F10</th>
<th>F2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>2.9x10^9</td>
<td>2.5x10^9</td>
<td>2.4x10^9</td>
<td>2.5x10^9</td>
</tr>
<tr>
<td>Mo</td>
<td>5.8x10^10</td>
<td>5.9x10^10</td>
<td>6.1x10^10</td>
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**FACE-ON MAPS**

- **Cold Gas**
  - F80: 2.9x10^9 Mo
  - F40: 2.5x10^9 Mo
  - F10: 2.4x10^9 Mo
  - F2.5: 2.5x10^9 Mo

- **Stars**
  - 5.8x10^10 Mo
  - 5.9x10^10 Mo
  - 6.1x10^10 Mo
  - 6.2x10^10 Mo
MASS DISTRIBUTION AND KINEMATICS

- Surface density ($M_{\odot} \cdot pc^{-2}$)
  - F80: 10^{-5}
  - F40: 10^{-4}
  - F10: 10^{-3}
  - F2.5: 10^{-2}

- Rotation velocity (km/s)
  - F80: 10^0
  - F40: 10^5
  - F10: 10^10
  - F2.5: 10^15

- Radius [kpc]
  - F80: 0, 5, 10, 15
  - F40: 0, 5, 10, 15
  - F10: 0, 5, 10, 15
  - F2.5: 0, 5, 10, 15

- Milky Way
  - Sofue et al. (2009), rescaled
MASS DISTRIBUTION AND KINEMATICS

- Surface density (\(M_\odot\cdot pc^{-2}\))
- Rotation velocity (km/s)
- Lookback time [Gyr]

STAR FORMATION HISTORY

- Aumer and Binney 2009
- Fraternali and Tomassetti 2012

- SFR [\(M_\odot/yr\)]
MASS DISTRIBUTION AND KINEMATICS

STAR FORMATION HISTORY

Aumer and Binney 2009
Fraternali and Tomassetti 2012

SFR\text{SIM} \sim 4 \text{ M}_\odot/\text{yr}
SFR_{\text{MW}} \sim 2-3 \text{ M}_\odot/\text{yr}
**MASS DISTRIBUTION AND KINEMATICS**

- Surface density (M\textsubscript{☉} pc\textsuperscript{-2})
- Rotation velocity (km/s)
- Radius [kpc]

**STAR FORMATION HISTORY**

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*Note: The image contains graphs and data plots related to mass distribution, kinematics, and star formation history in the context of the Milky Way.*
MASS DISTRIBUTION AND KINEMATICS

STAR FORMATION HISTORY

Accretion rates in good agreement with cosmological simulations (e.g. Brook+14)

SFR$_{\text{SIM}} \sim 4$ Mo/yr
SFR$_{\text{MW}} \sim 2-3$ Mo-yr
The effect of feedback

The cold gas scale-height increases with feedback.
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EXTRA-PLANAR HI

\[ \frac{M_{\text{HI}(>1\text{kpc})}}{M_{\text{HI, tot}}} = 0.3 \] (see Marasco & Fraternali 2011)

\[ \frac{M_{\text{HI}(>1\text{kpc})}}{M_{\text{HI, tot}}} = 0.05 \] (Marasco et al. 2015)
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NGC 891
(Oosterloo et al. 2007)

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Simulation
(Marasco et al. 2015)

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(see Marasco & Fraternali 2011)
EXTRA-PLANAR HI: KINEMATICS

F80, velocity distribution at the disc-corona interface

![Graph showing velocity distribution](image-url)
EXTRA-PLANAR HI: KINEMATICS

F80, velocity distribution at the disc-corona interface

Velocity drop caused by hydrodynamical interaction with coronal gas (see Fraternali & Binney 2008)
CIRCUMGALACTIC MEDIUM

![Graph showing the relationship between logarithmic density (log(n[atoms/cm^3])) and temperature (log(temperature[K])) against distance from the centre (kpc). The graph is divided into radial and vertical views.](image)
CIRCUMGALACTIC MEDIUM

Distance from the centre [kpc] vs. log(n[atoms/cm³]) and log(temperature[K])

- Radial distribution
- Vertical distribution

Temperature intervals:
- log(T)<4.3 (cold)
- 4.3<log(T)<5.3 (warm)
- 5.3<log(T)<5.8 (hot)
- log(T)>5.8 (all gas)
CIRCUMGALACTIC MEDIUM

-7  -6  -5  -4  -3  -2  -1  0

4  4.5  5  5.5  6  6.5  7

log(T)<4.3 (cold)
4.3<log(T)<5.3 (warm)
5.3<log(T)<5.8 (hot)
log(T)>5.8
all gas

log(n[atoms/cm^3])

vertical

H I  C II  Si III  Mg II

Si III  Si IV  C IV

O VI

Si III  Si IV  C IV

O VI

Si III  Si IV  C IV

Si III  Si IV  C IV

Si III  Si IV  C IV

distance from the centre [kpc]

1  10  100  1000

log(temperature[K])

CIRCUMGALACTIC MEDIUM

-7
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-2
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log(n[atoms/cm^3])

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SiIII SiIV CIV
H I CII SiII MgII
radial

SiIII SiIV CIV

OVI

SiIII SiIV CIV

OVI

vertical

distance from the centre [kpc]
1
10
100
1000

4
4.5
5
5.5
6
6.5
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4
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CIRCUMGALACTIC MEDIUM

![Diagram showing the distribution of gas in different temperature regimes as a function of distance from the center of the galaxy. The diagram plots log(n[atoms/cm³]) on the y-axis and log(temperature[K]) on the x-axis. Different temperatures are indicated by color-coded regions: log(T)<4.3 (cold), 4.3<log(T)<5.3 (warm), 5.3<log(T)<5.8 (hot), log(T)>5.8 (all gas). The gas distribution is shown both radially and vertically.]

- Logarithmic temperature regimes:
  - Log(T)<4.3 (cold)
  - 4.3<log(T)<5.3 (warm)
  - 5.3<log(T)<5.8 (hot)
  - Log(T)>5.8 (all gas)

See Tumlinson+13, Werk+13,14.
CIRCUMGALACTIC MEDIUM

tentative conclusion:
cold-warm absorptions in the halo trace either late-type cold mode accretion or interaction with satellites

see Tumlinson+13, Werk+13,14
A model of pure hot-mode mass assembly predicts the following:

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CONCLUSIONS

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Future plan: larger feedback, interaction with satellites