The Causal Connection Between Inflows, Outflows, and Disk Star Formation in ART Simulations

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What is the relationship between processes in the disk and in the CGM?

- Disk:
  - Star formation
  - Feedback
- CGM:
  - Flow of gas due to accretion and outflow
  - Ram pressure and tidal stripping
- Steidel et al. 2010: observed cause and effect relationship between SF in disk and gas mass in CGM

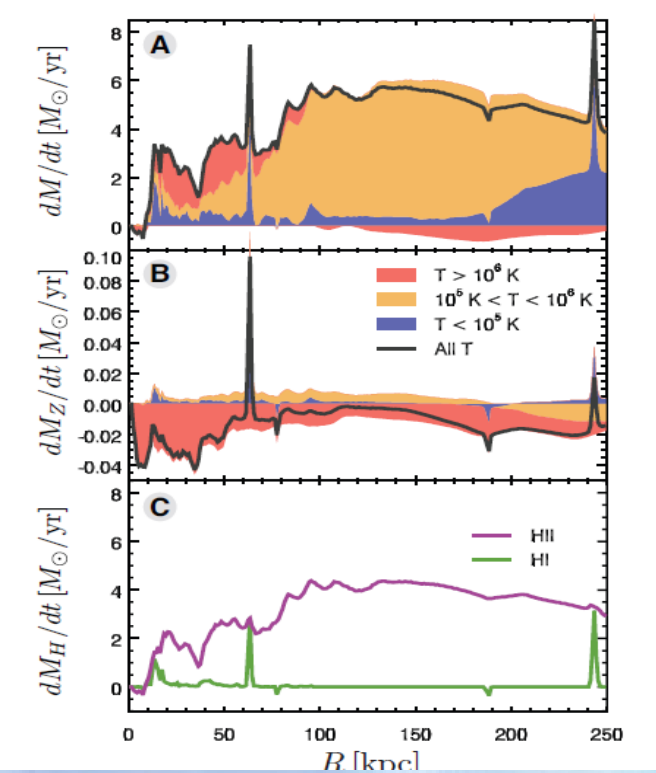
Mass Flux Through High Redshift Galaxies Simulated with ART

Ceverino & Klypin (2009), Kravtsov et al. (1997),Kravtsov (1999,2003)

- ART Code:
  - Hydrodynamic AMR code
  - High-resolution (30-70 pc) cosmological simulation of MW progenitor between 2<z<4
    - ($10^{10.7} < M_{vir} < 10^{11.2}$ M_{sol})
  - Thermal feedback due to SNII and SNIa, stellar winds
  - No AGN
- Define Simulated Galaxy Components:
  - Central cylindrical region representing the disk
  - All baryons outside of disk region out to 2 R_{vir} considered to be part of CGM
- Calculate the SFR in the disk
- Calculate the mass flux of inflowing/outflowing baryons and dark matter through spherically symmetric shells in the halo
  - Gas in different temperature ranges as probed by ionic tracers in absorption line studies

Mass Flux

- Joung et al. 2012 studied gas accretion by calculating the mass flux of gas through the CGM of a simulated MW-mass galaxy at z=0 (a single snapshot in time)



$$\dot{M}(R) = \sum_{i=1}^{n(R)} \frac{M_i \, \boldsymbol{V_i} \cdot (-\hat{r}_i)}{dR}$$

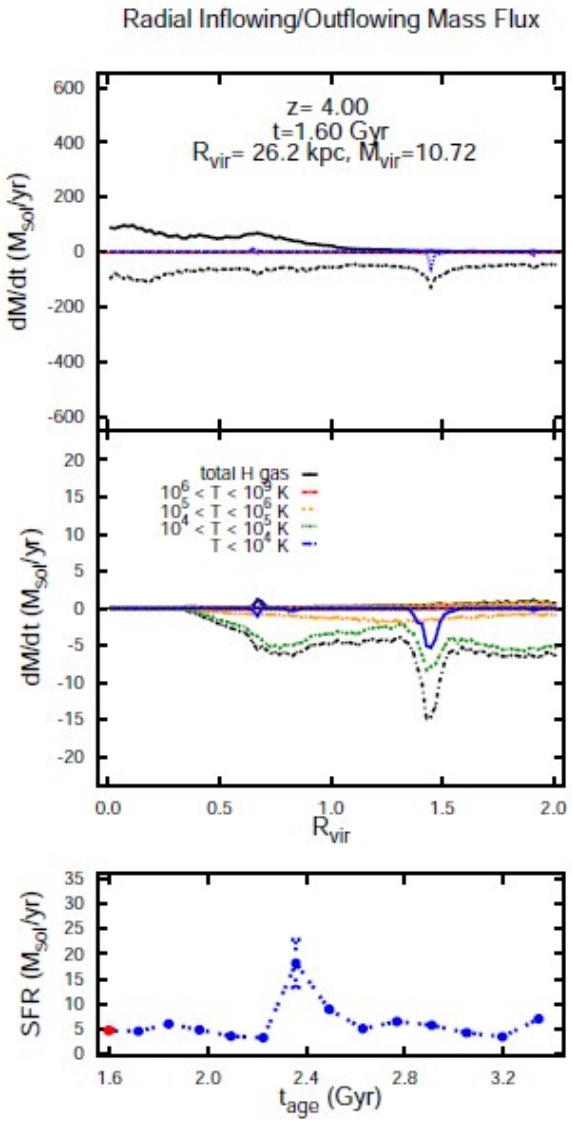
Peek (2008)

- Expanding on this idea:
  - How does the flow of material through the CGM affect star formation in the disk?
  - How does star formation in the disk affect the flow of material through the CGM?

Time Sequence:
14 Snapshots 2<z<4

Outflowing components: $+v_r$

Inflowing components: $-v_r$



Black: DM
Blue: Stars

CGM Gas

Star Formation Rate

Time Sequence:
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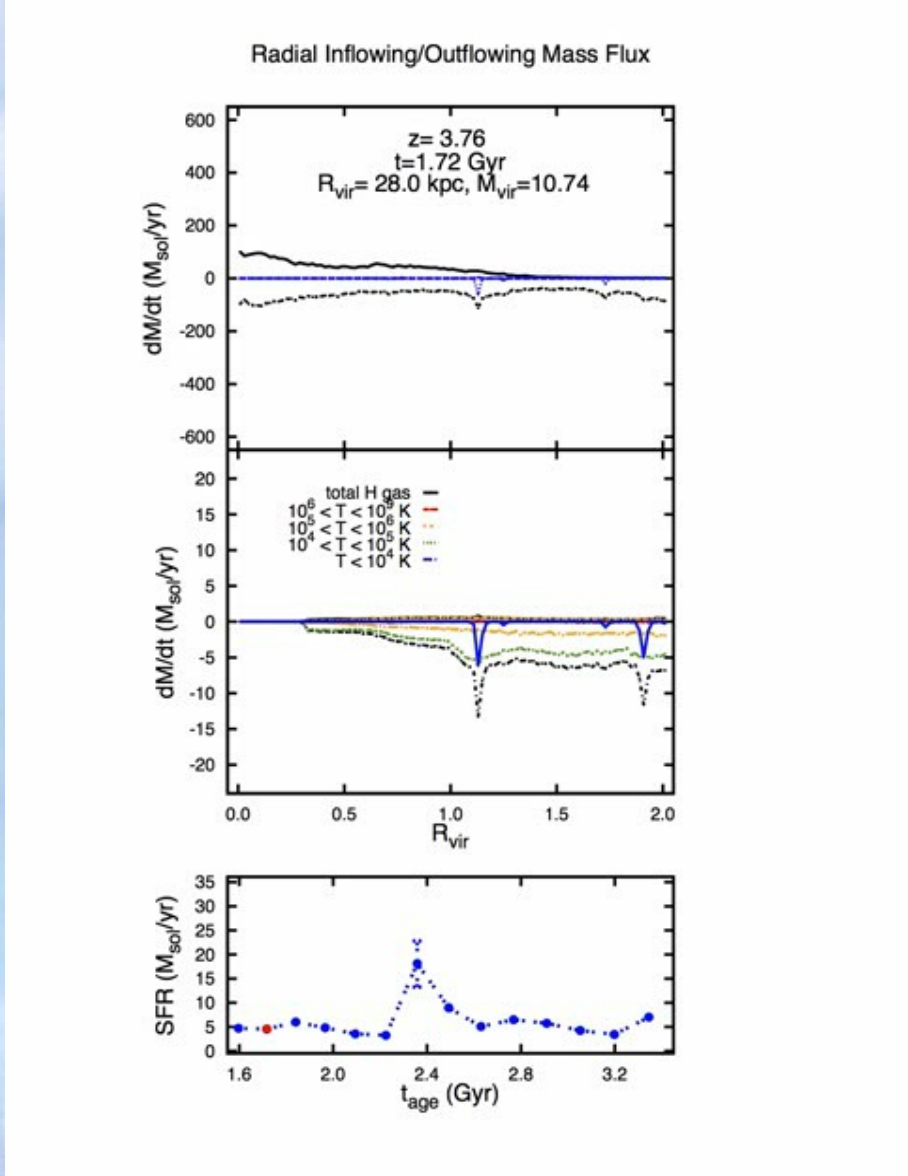

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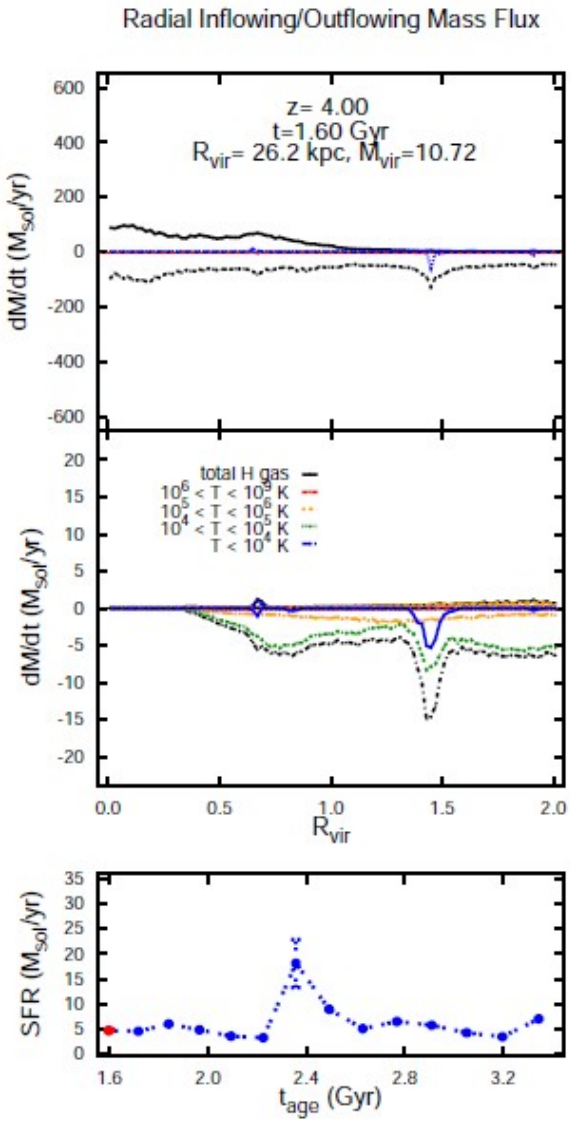

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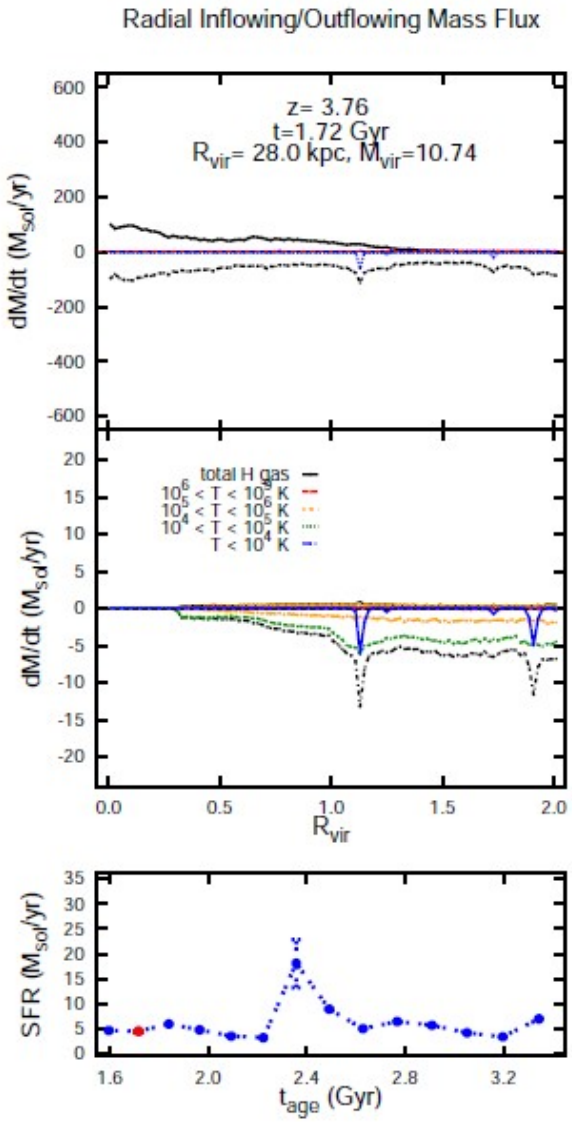

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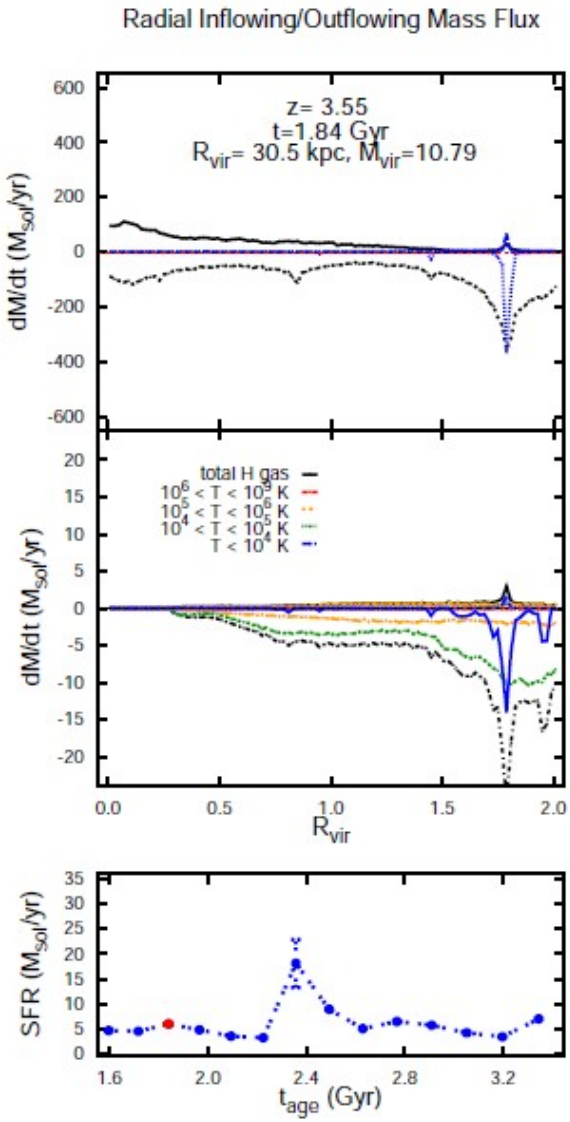

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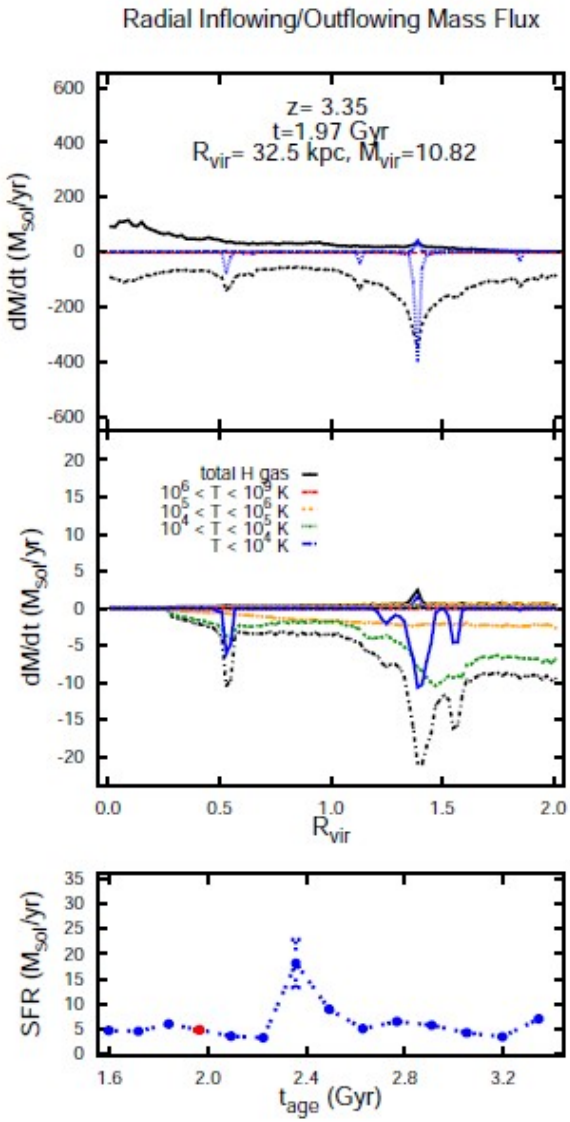

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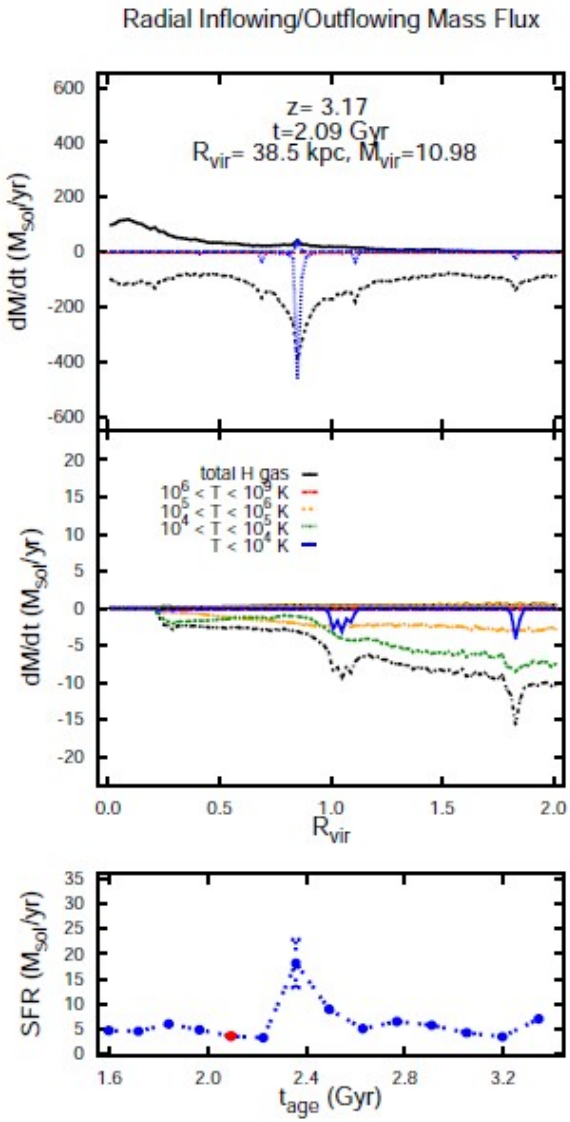

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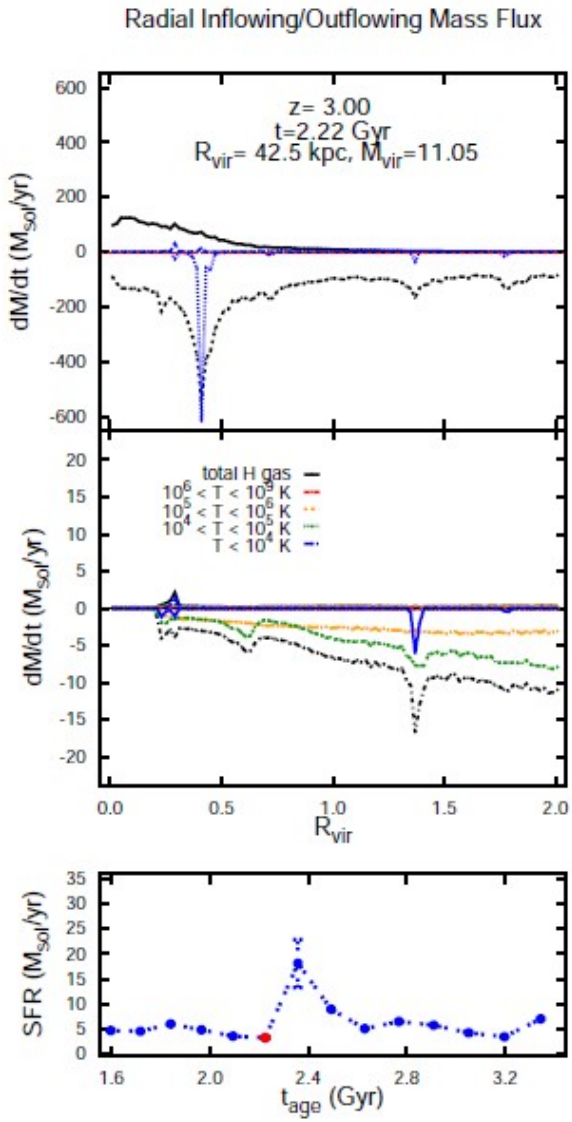

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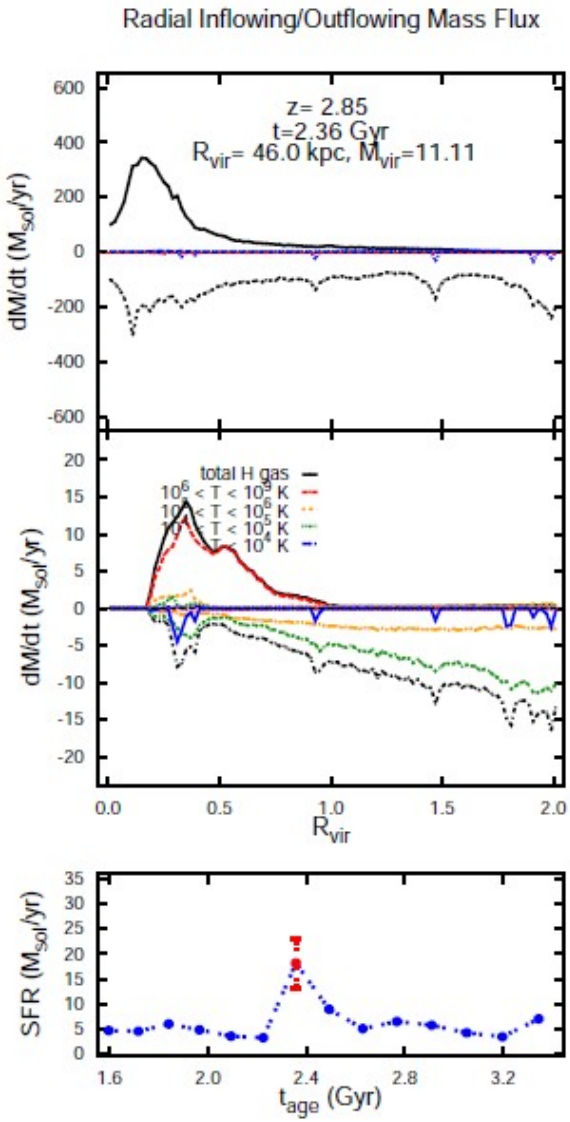

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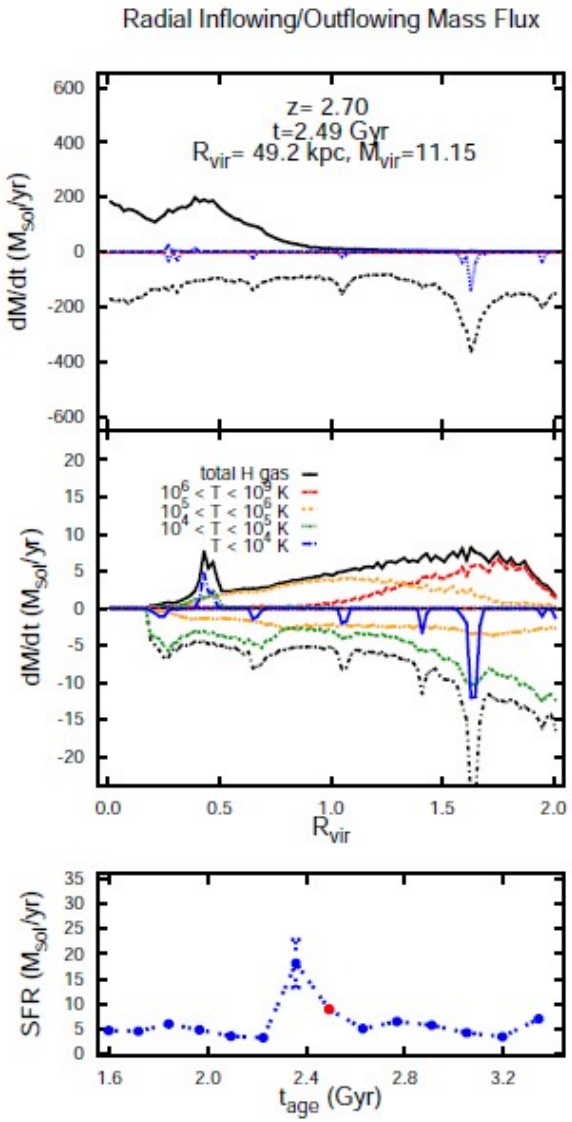

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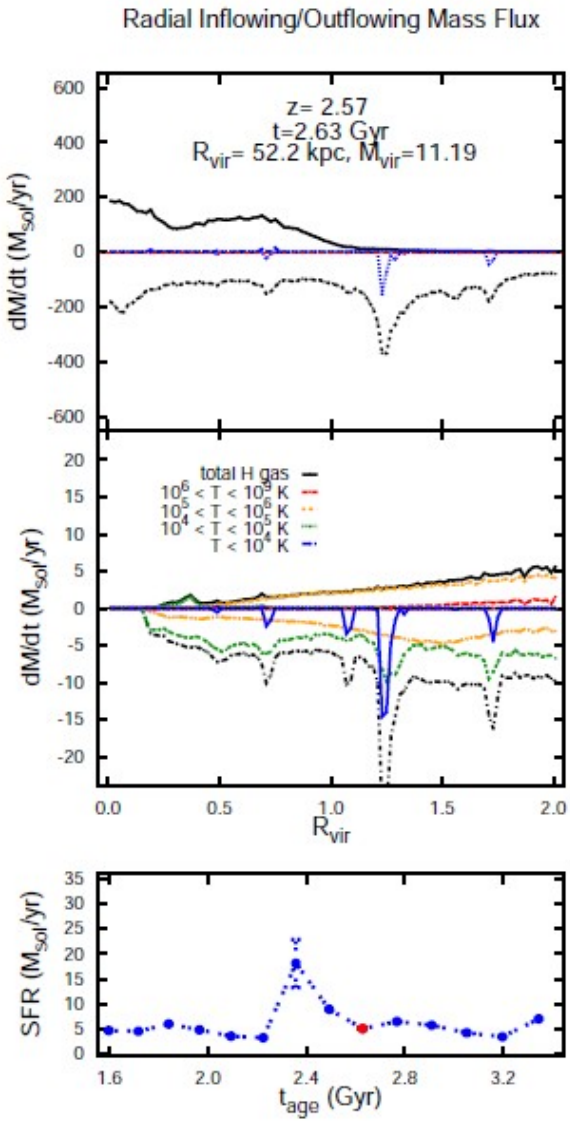

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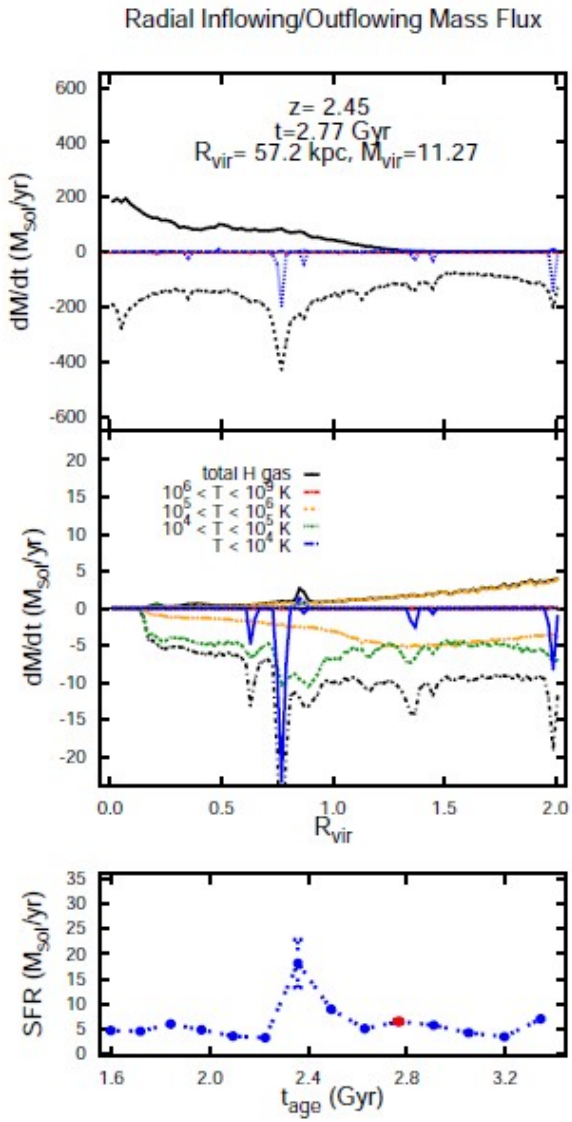

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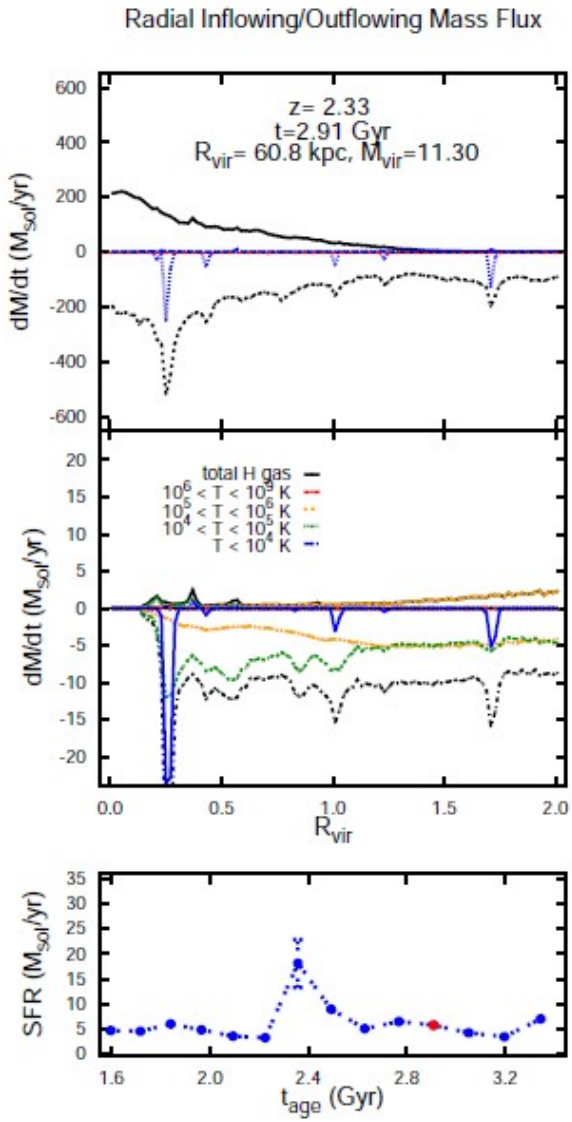

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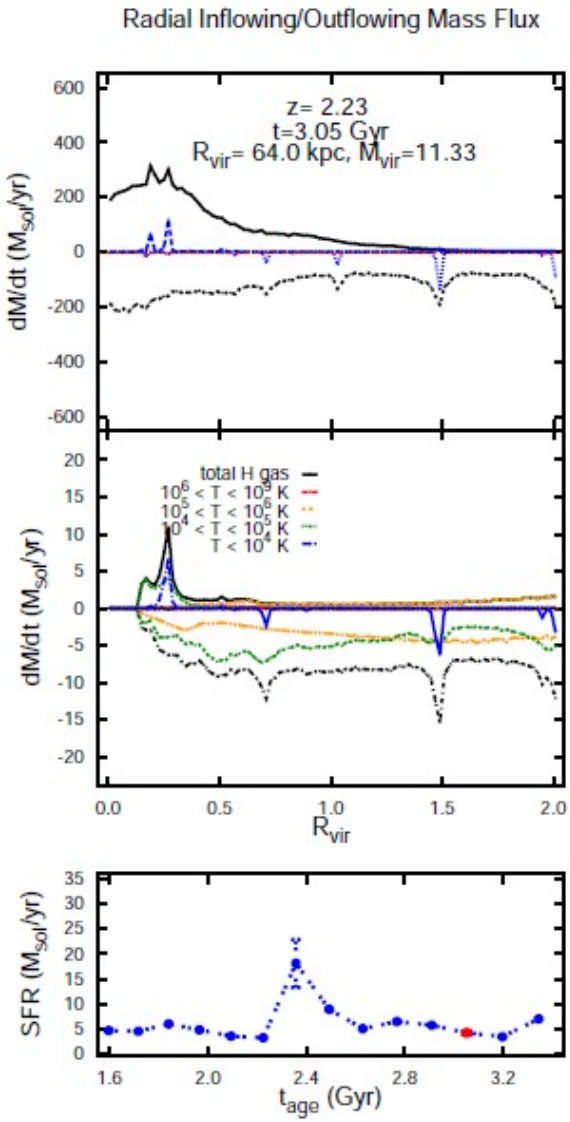

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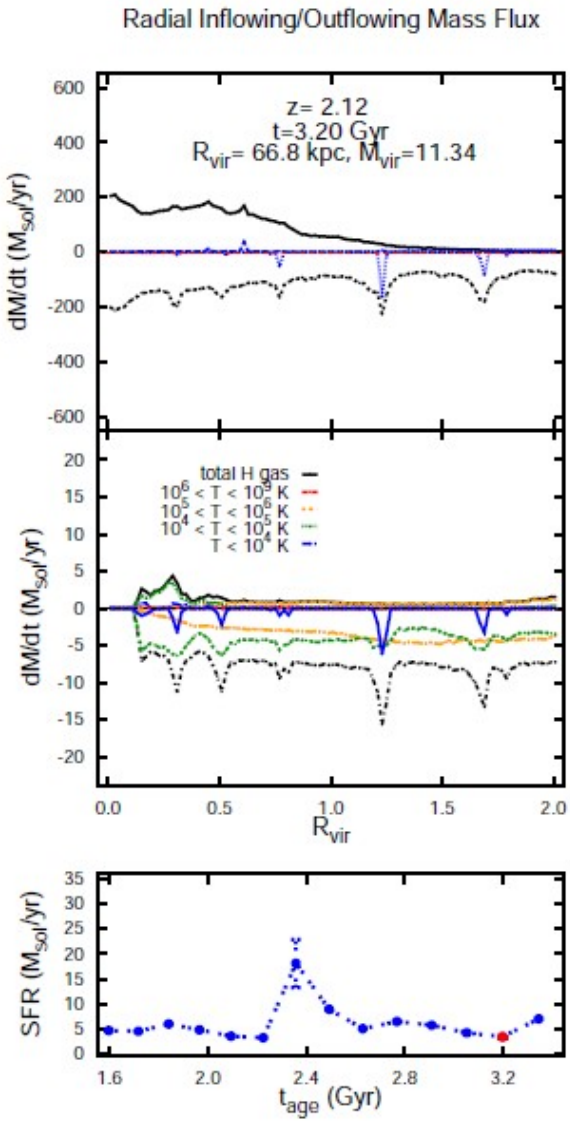

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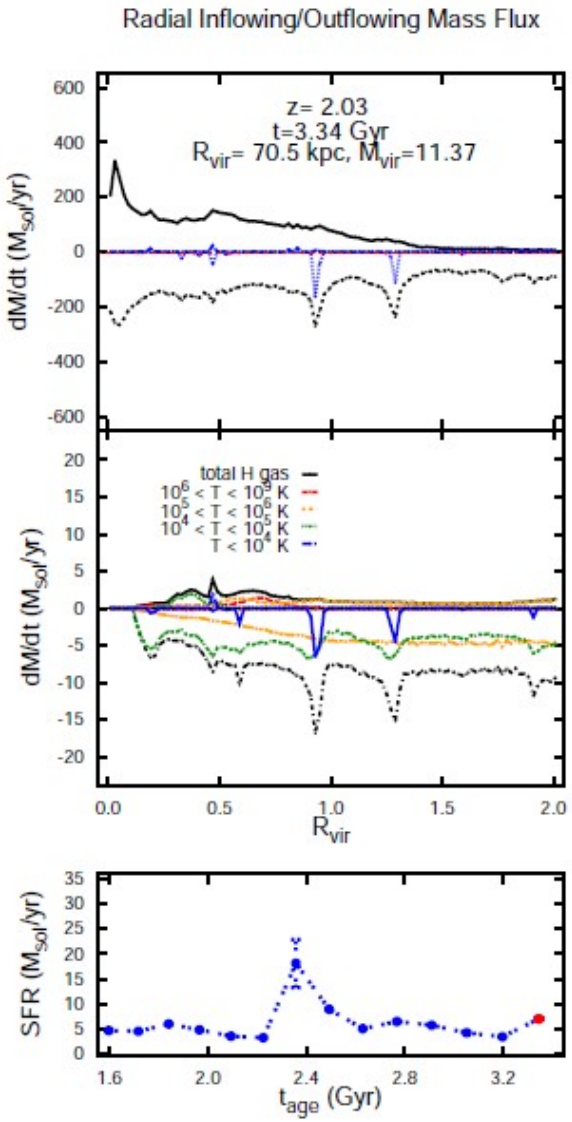
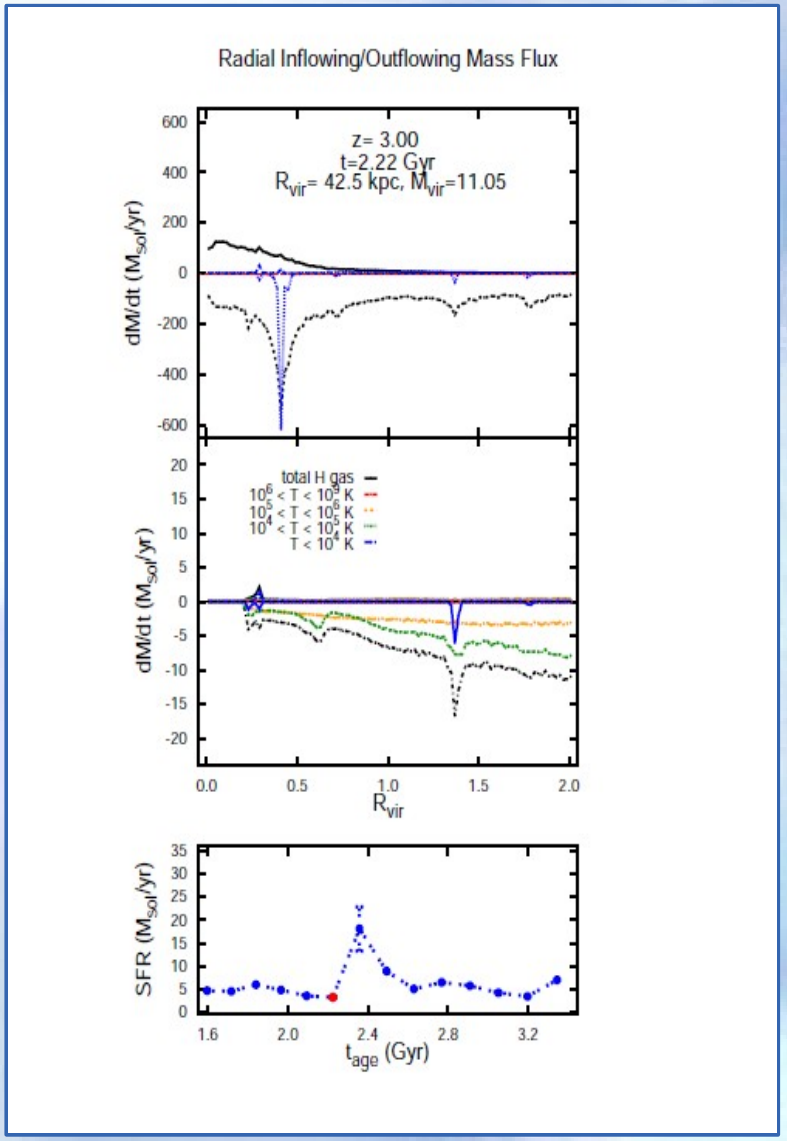
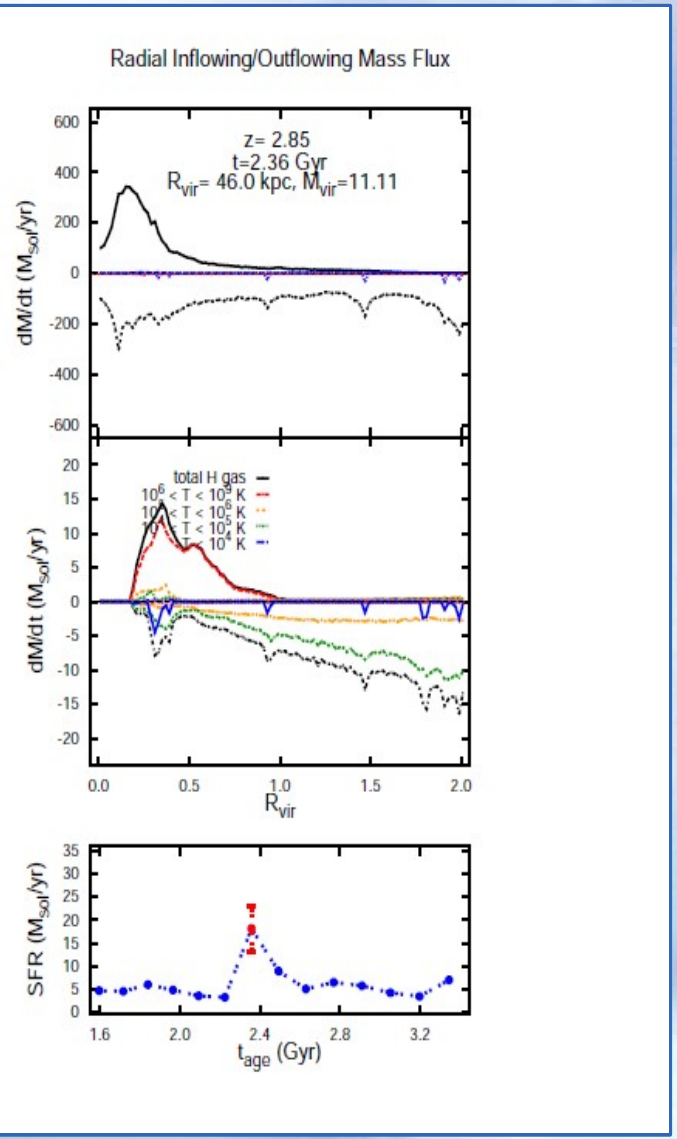


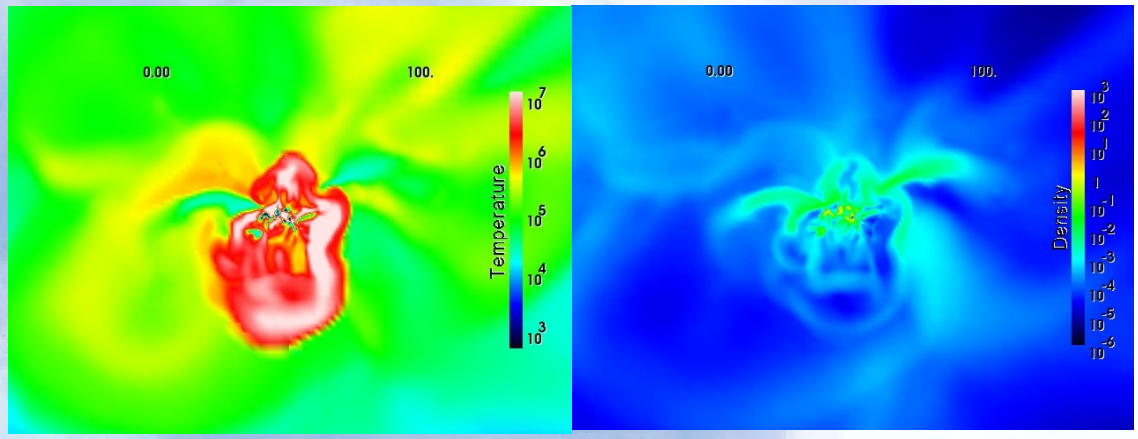
Starburst Event: Before...

- Satellite infalling at ~130 km/s



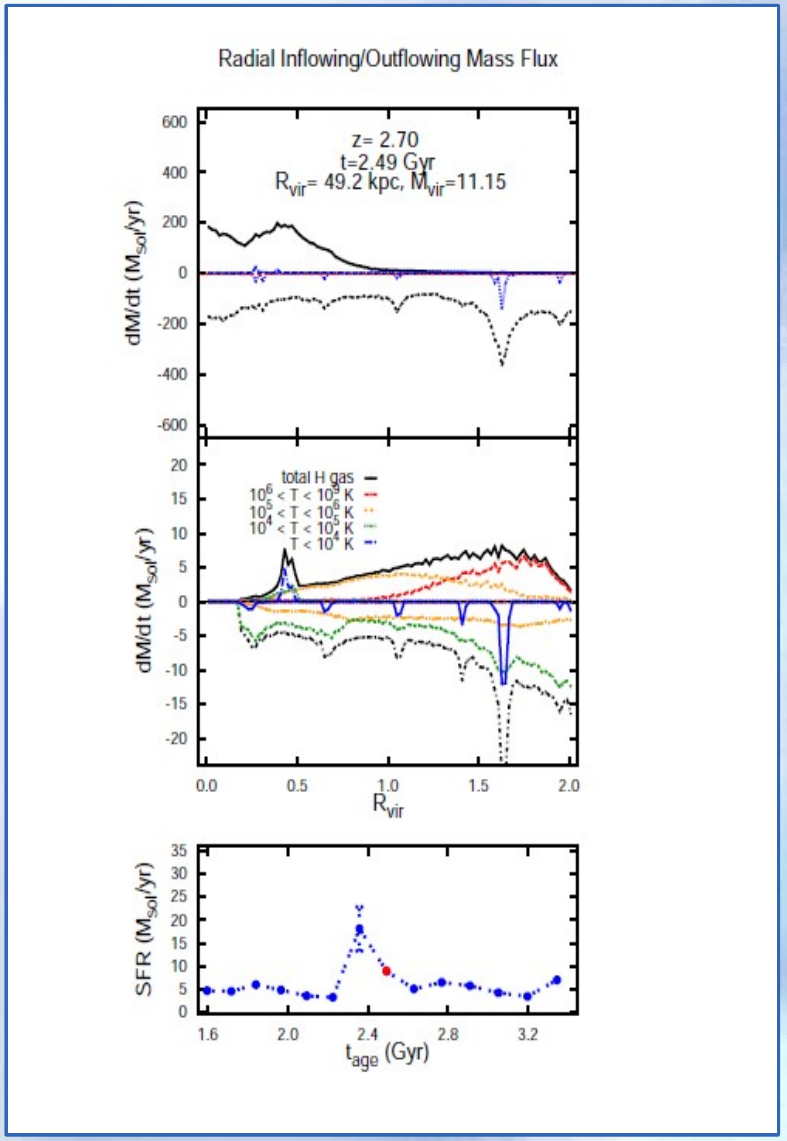
Starburst Event: During...





- Hot gas outflowing at ~400 km/s, well above v_{esc}
- Infall is not affected

Starburst Event: After...



- Hot outflow slows (~130 km/s) and disperses
- Infall still unaffected

Star Formation and Outflows: Diffuse Wind

- SFR consistent with predictions of Behroozi (2013) at z=2
- Wind composed entirely of hot gas—no cool gas seen
  - Steidel et al. 2010: low ionization absorption due to MgII, SiII,SiIII,SiIV, CIV, etc... tells us that there are outflows of cool gas.
- Wind speeds consistent with previous work by Ceverino & Klypin (2009) and with observations of outflow speeds in Lyman Break Galaxies (Steidel et al. 2010)
  - Wind achieves escape velocity, also consistent with with Steidel
- Outflow rate comparable (greater than or equal to) SFR (Pettini 2002, Steidel 2010)
- Inclusion of radiation pressure should reduce the amount of hot gas

Summary

- The time evolution of the mass accretion rate of gas enables a way to track and quantify the flow of gas through the CGM
- The time evolution of the mass accretion rate of dark matter and stars shows merging events that contribute to the buildup of the disk
- Cause and effect relationship can be seen
  - Diffuse outflowing wind follows a star formation event
  - However, can't discern what triggers the outflow
  - Dynamically induced?
- Hot, low density wind
  - Transports hot gas beyond 2 R_{vir}, in ~140 Myr
  - Does not disrupt the flow of infalling gas
  - Does not disrupt/strip infalling structures
- Next:
  - Quantify the mass loading factor, gas fractions, gas and stellar mass lost/gained by disk and satellites
  - Look at metallicity cuts
  - How will the inclusion of radiation pressure change the outflow?
-