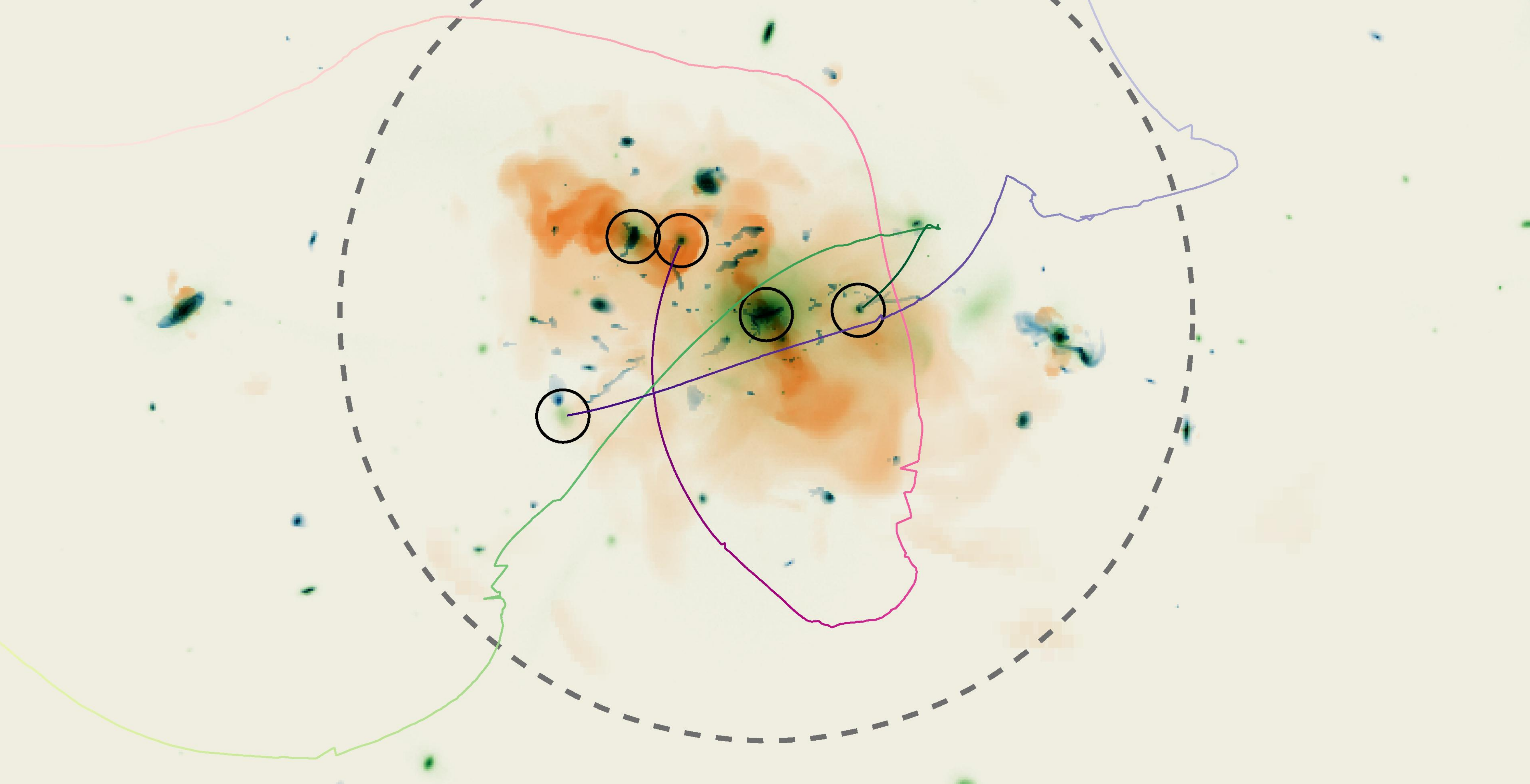
NewHorizon:

On the origin of star formation quenching of group galaxies

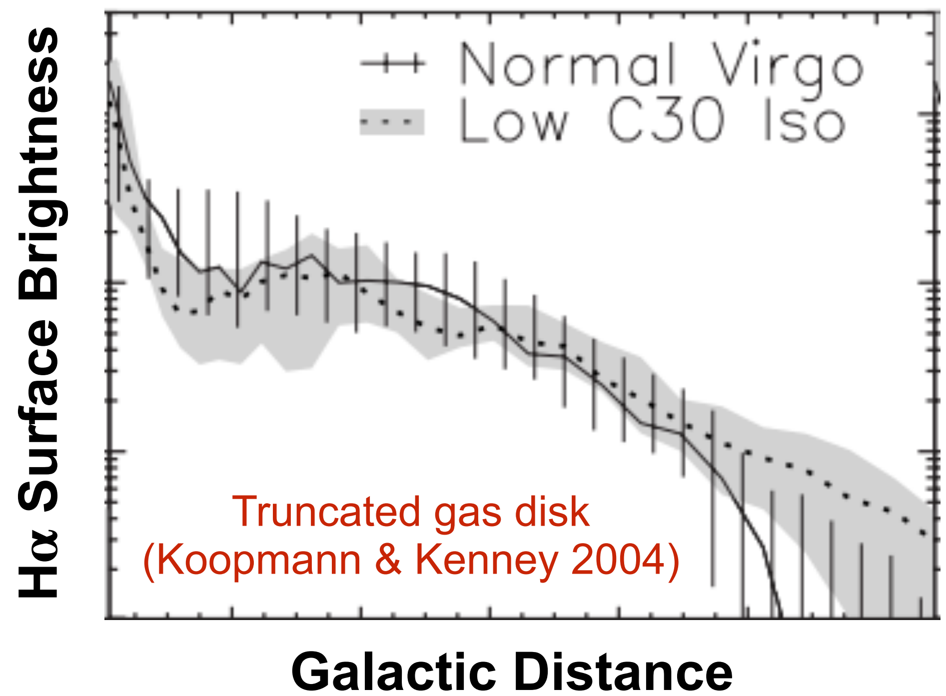


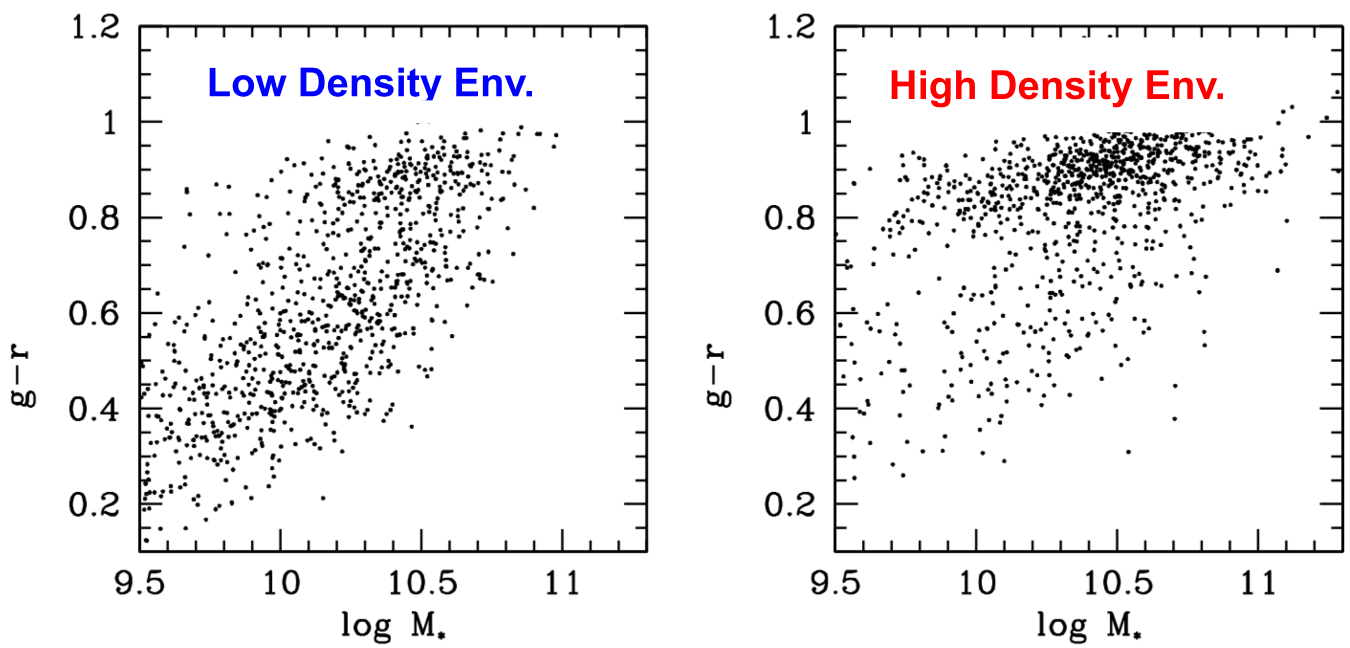
Jinsu Rhee (Yonsei)

Sukyoung K. Yi (Yonsei) and the NewHorizon team

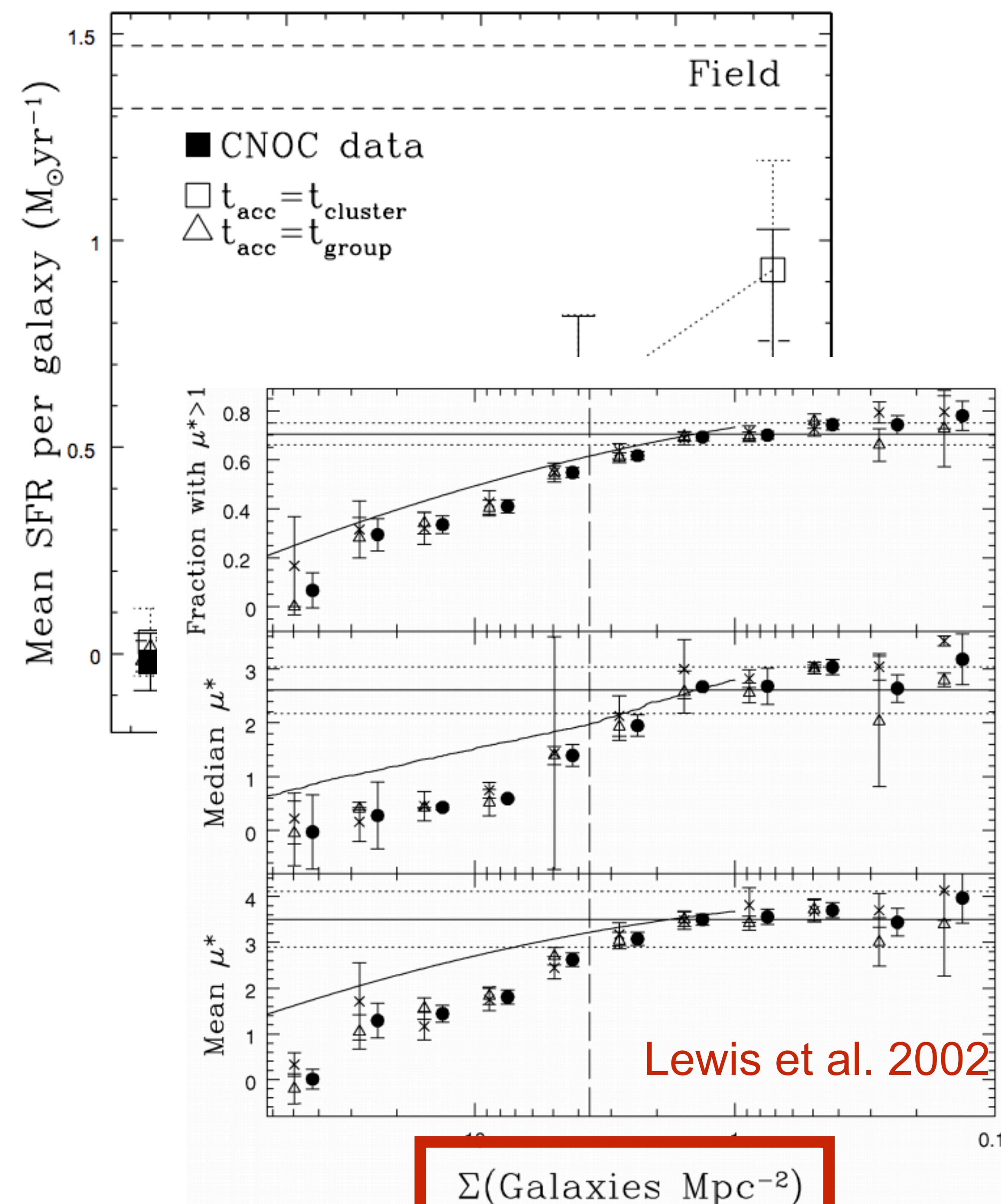
Quenching in dense env-

Environmental effects seen from large-scale surveys



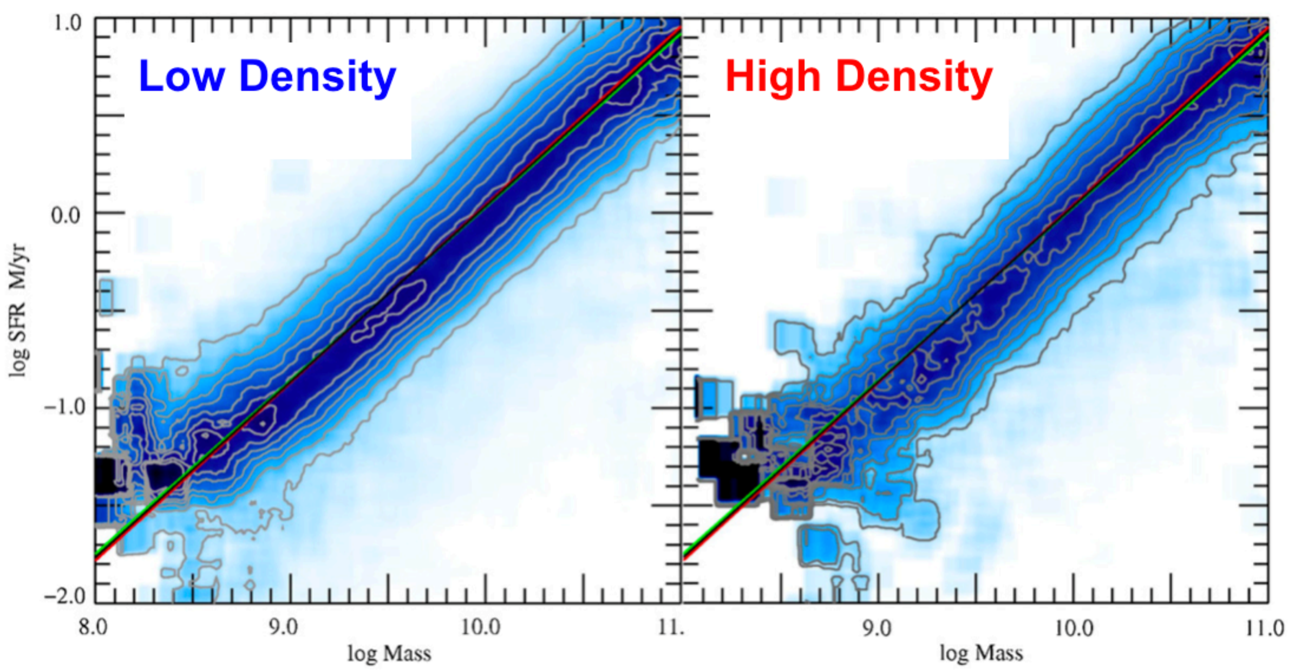


Kauffmann et al. 2004



Quenching in dense env-

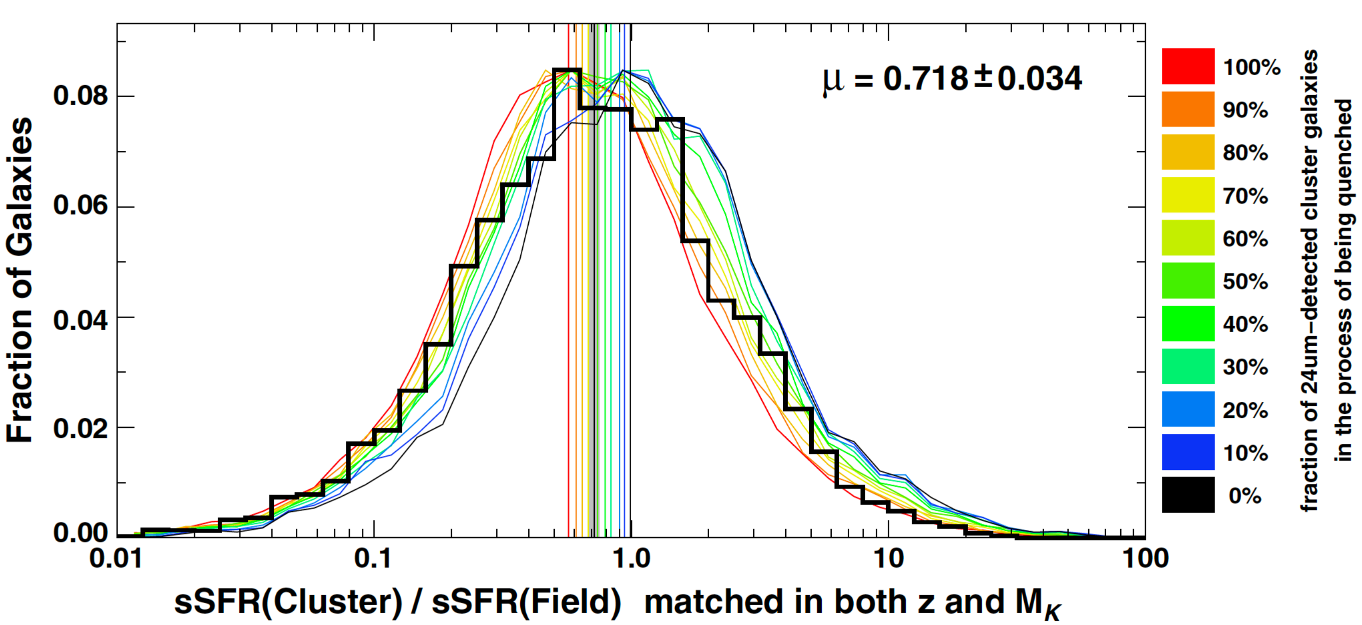
Star formation Quenching Timescale



Instantaneous quenching Scenario

(e.g., Peng et al. 2010)

- Main sequence of star-forming galaxies
- No galaxies with the suppressed SFR seen



Slow quenching Scenario

(e.g., Haines et al. 2013)

- Suppressed SFR indeed observed
- Quenching is slow enough to be observed

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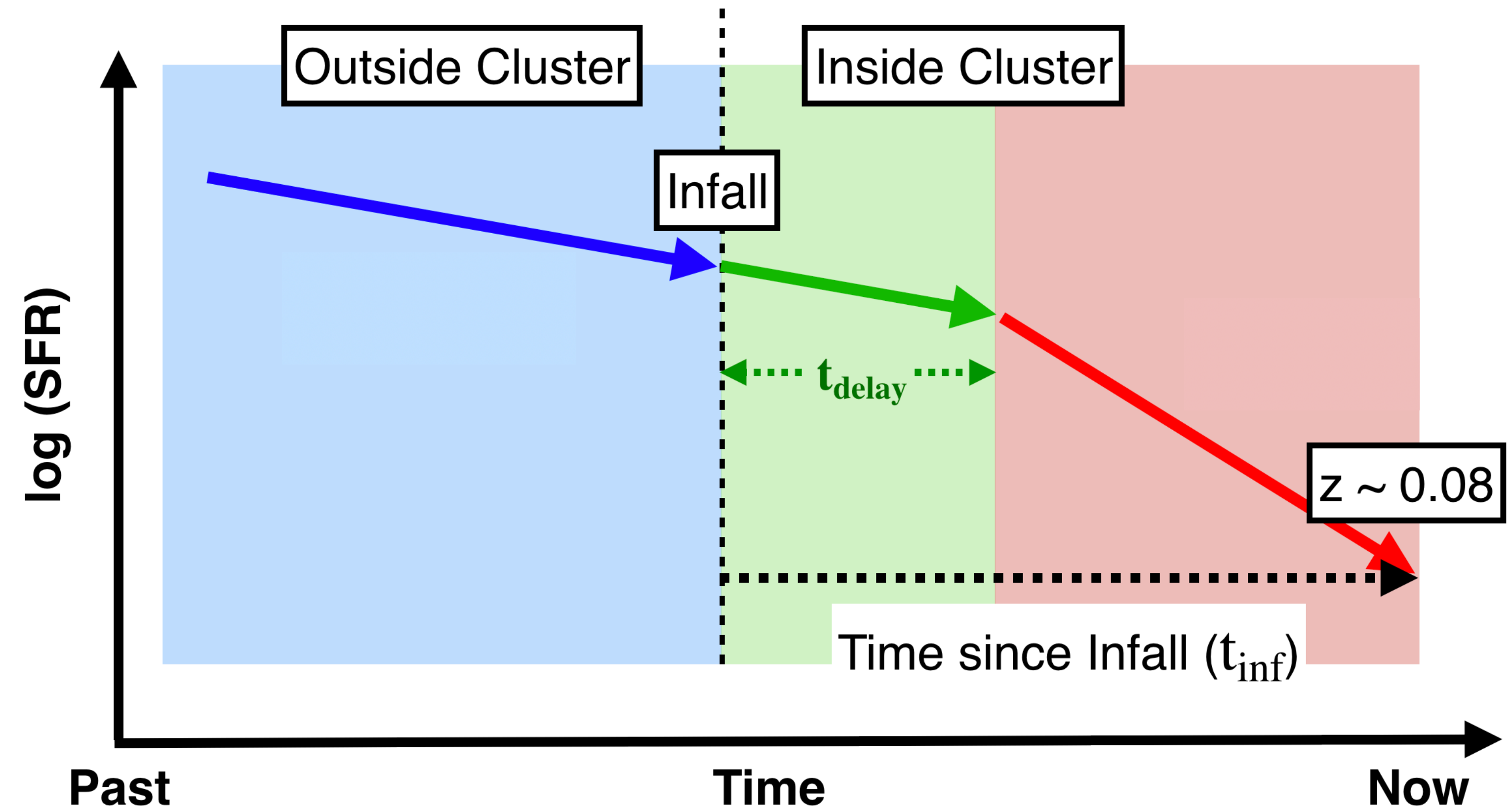
Quenching in dense env-

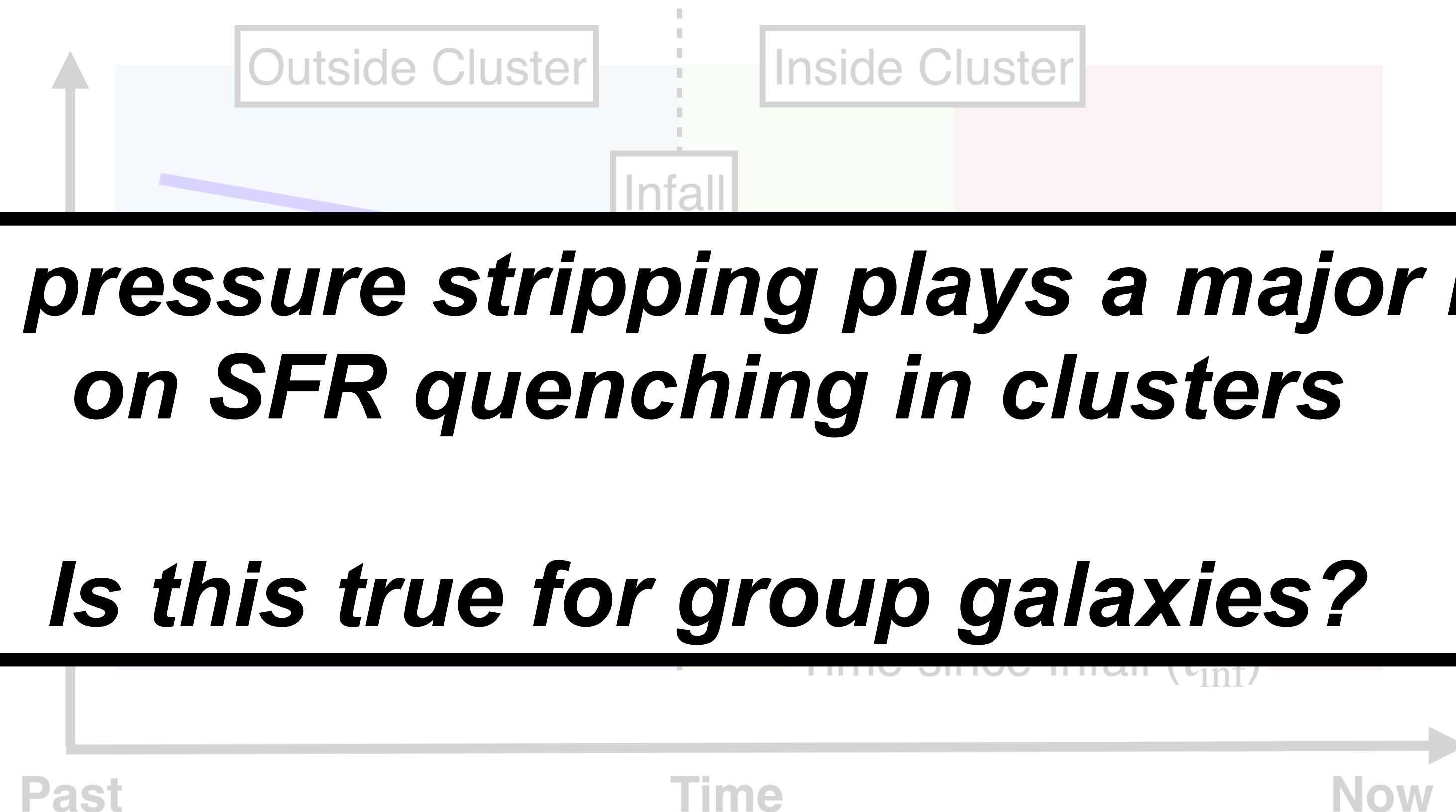
Delayed-then-rapid Quenching Scenario



- ✦ HI gas stripping during the first infalling
- ✦ Weak SF quenching before the first pericenter passage
- ✦ H_2 gas stripping after the pericenter passage
- ✦ Rapid SF quenching

Quenching in dense env-

Delayed-then-rapid Quenching Scenario



Ram pressure stripping plays a major role on SFR quenching in clusters

Is this true for group galaxies?

- ✦ HI gas stripping during the first infalling
- ✦ Weak SF quenching before the first pericenter passage
- ✦ H_2 gas stripping after the pericenter passage
- ✦ Rapid SF quenching

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NewHorizon Simulation (Dubois et al. 2021)

- RAMSES (AMR, Teyssier 2002)
- 80M CoreHours
- A follow-up Zoom-in Simulation of HorizonAGN (Dubois et al. 2016)
- 10 Mpc/h of radius
- **DM+hydro**: baryon prescription included
  (Gas Cooling/Heating, SF, AGN/SN FB, …)
- Spatial resolution: **dx=34 pc**
- DM particle resolution: dm=1e6 $M_\odot$
- Stellar mass resolution: dm_*=1e4 $M_\odot$

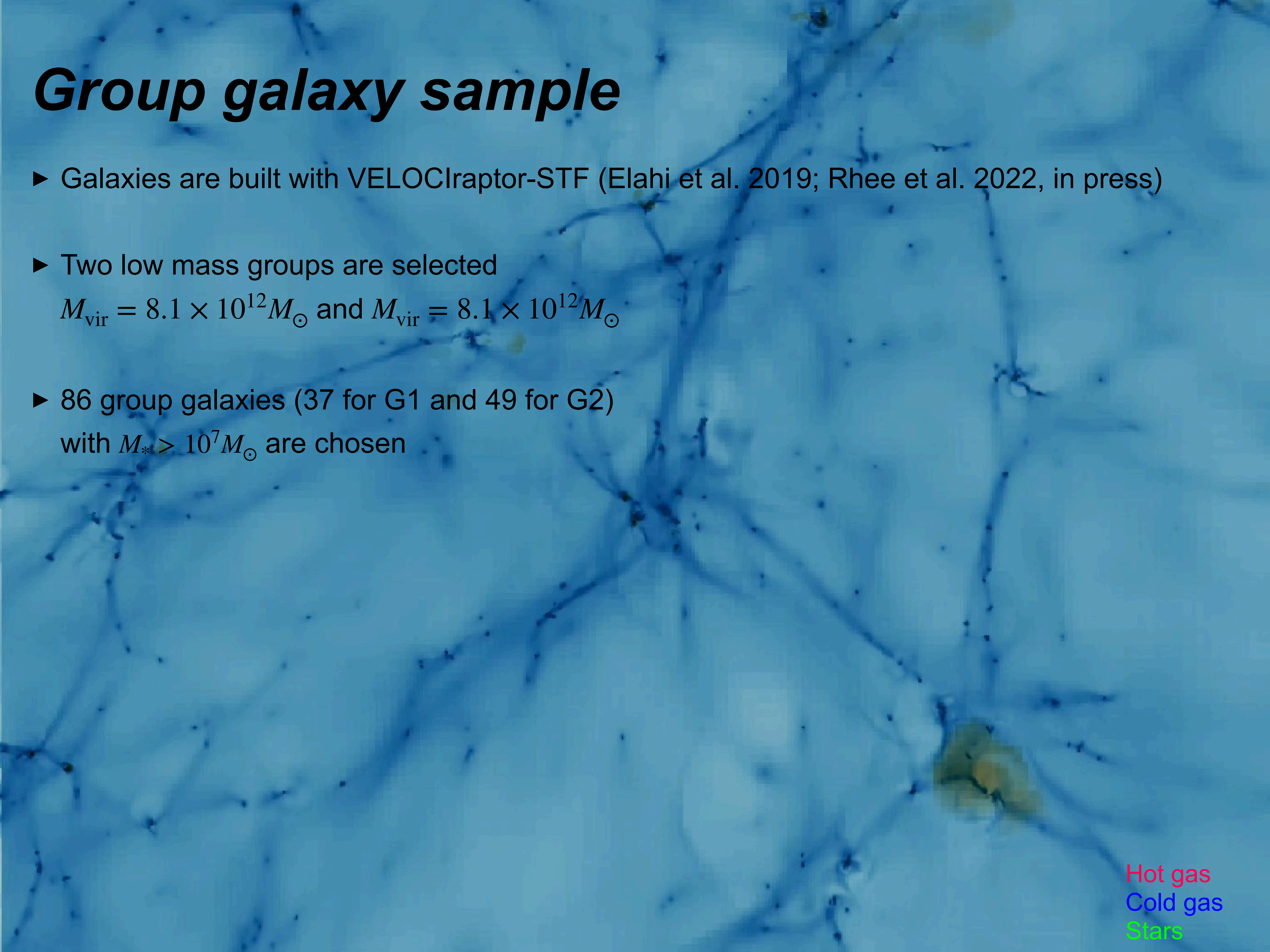
Hot gas temperature
Star mass density
DM mass density

Group galaxy sample

- Galaxies are built with VELOCIraptor-STF (Elahi et al. 2019; Rhee et al. 2022, in press)

- Two low mass groups are selected
  $M_{\rm vir} = 8.1 \times 10^{12} M_\odot$ and $M_{\rm vir} = 8.1 \times 10^{12} M_\odot$

- 86 group galaxies (37 for G1 and 49 for G2)
  with $M_* > 10^7 M_\odot$ are chosen



Quenching in Group Env-

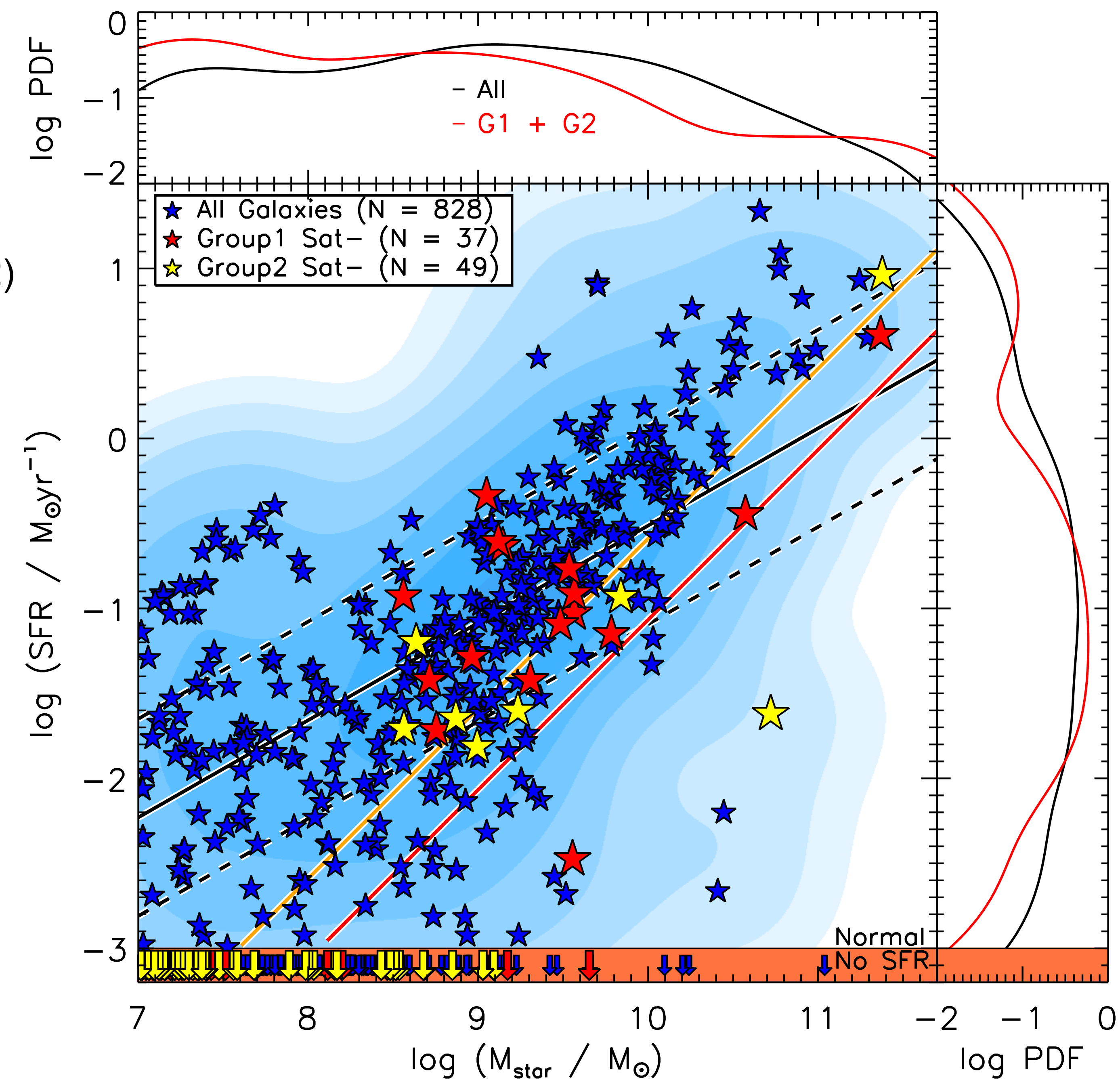
SFR of the sample galaxies

- Galaxies are classified based on their birthrate ($b := \text{sSFR} \times t_H$)

  Star-forming : $b > 0.3$ (e.g., Franx+08, Lotz+19, Park+22)

  Quenched : $b < 0.1$ (yields sSFR ~ 10^{-11} yr^{-1})

  Intermediate : $0.3 > b > 0.1$



Quenching in Group Env-

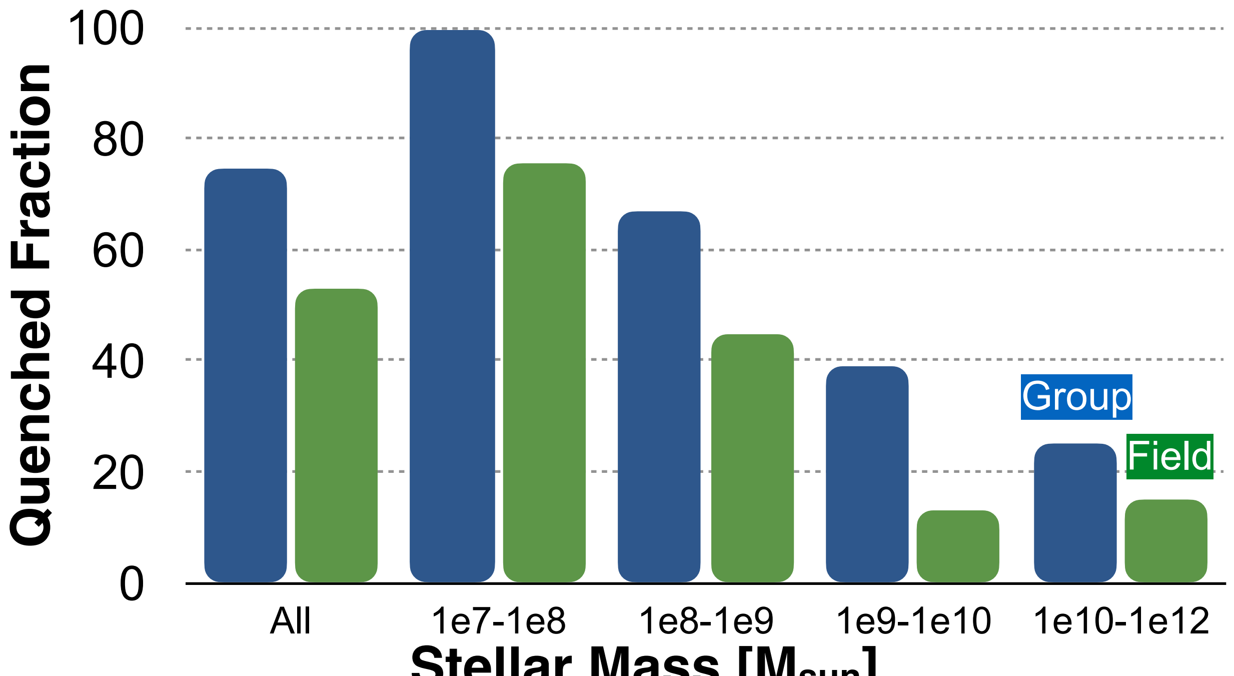
SFR of the sample galaxies

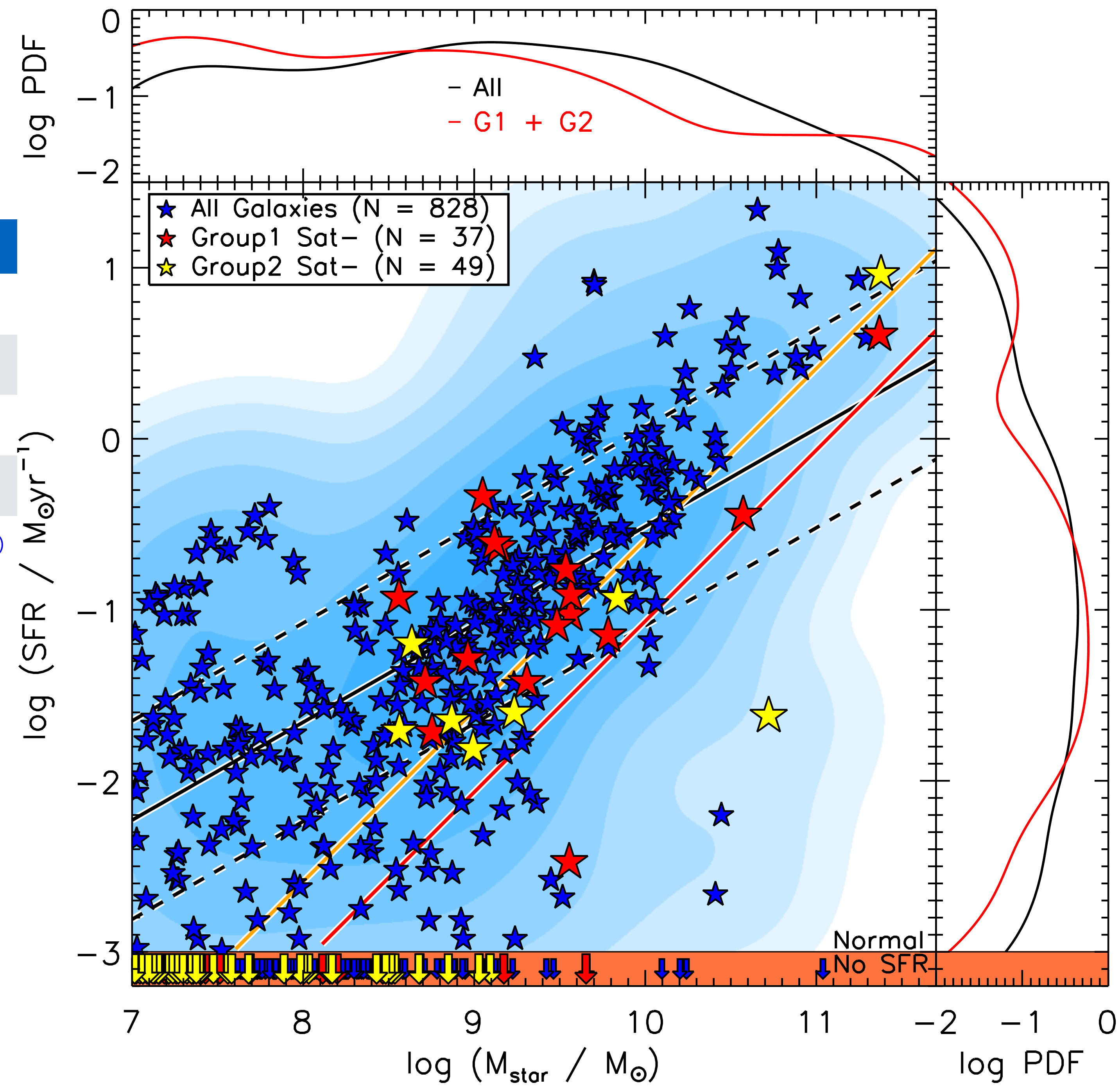
- Numbers

  Group galaxies are quenched more

	All	1e7-1e8	1e8-1e9	1e9-1e10	1e10-1e12
SFing	14 (302)	0 (87)	7 (78)	6 (98)	1 (39)
Intermediate	8 (47)	0 (8)	1 (16)	5 (16)	2 (7)
Quenched	64 (393)	40 (291)	16 (77)	7 (17)	1 (8)
Total	86 (742)	40 (386)	24 (171)	18 (131)	4 (54)
f_q	74.4% (53.0%)	100% (75.4%)	66.7% (45.0%)	38.9% (13.0%)	25.0% (14.8%)

(): field values





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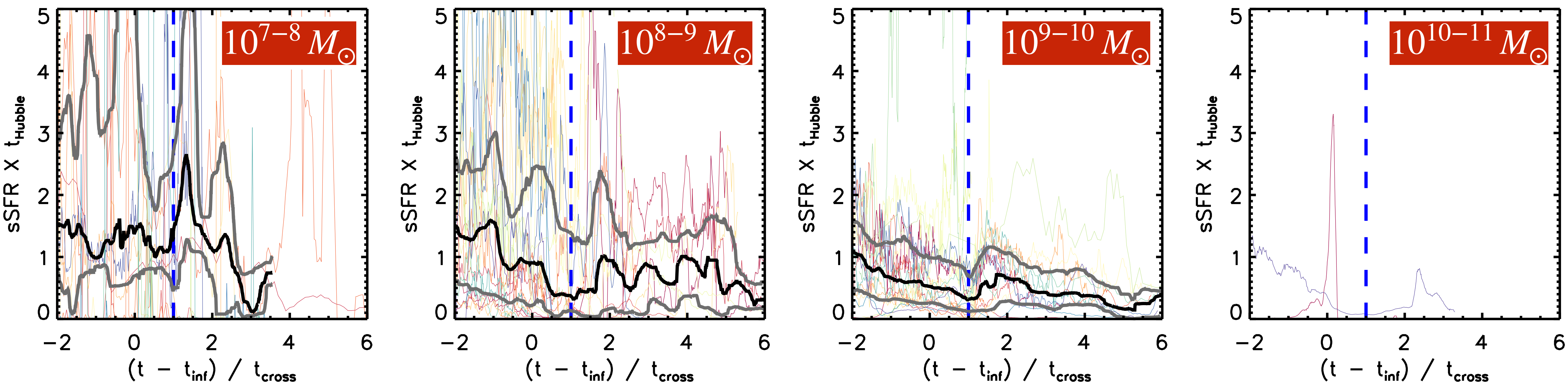
Quenching in Group Env-

Orbit-related quenching?

- Average SFH

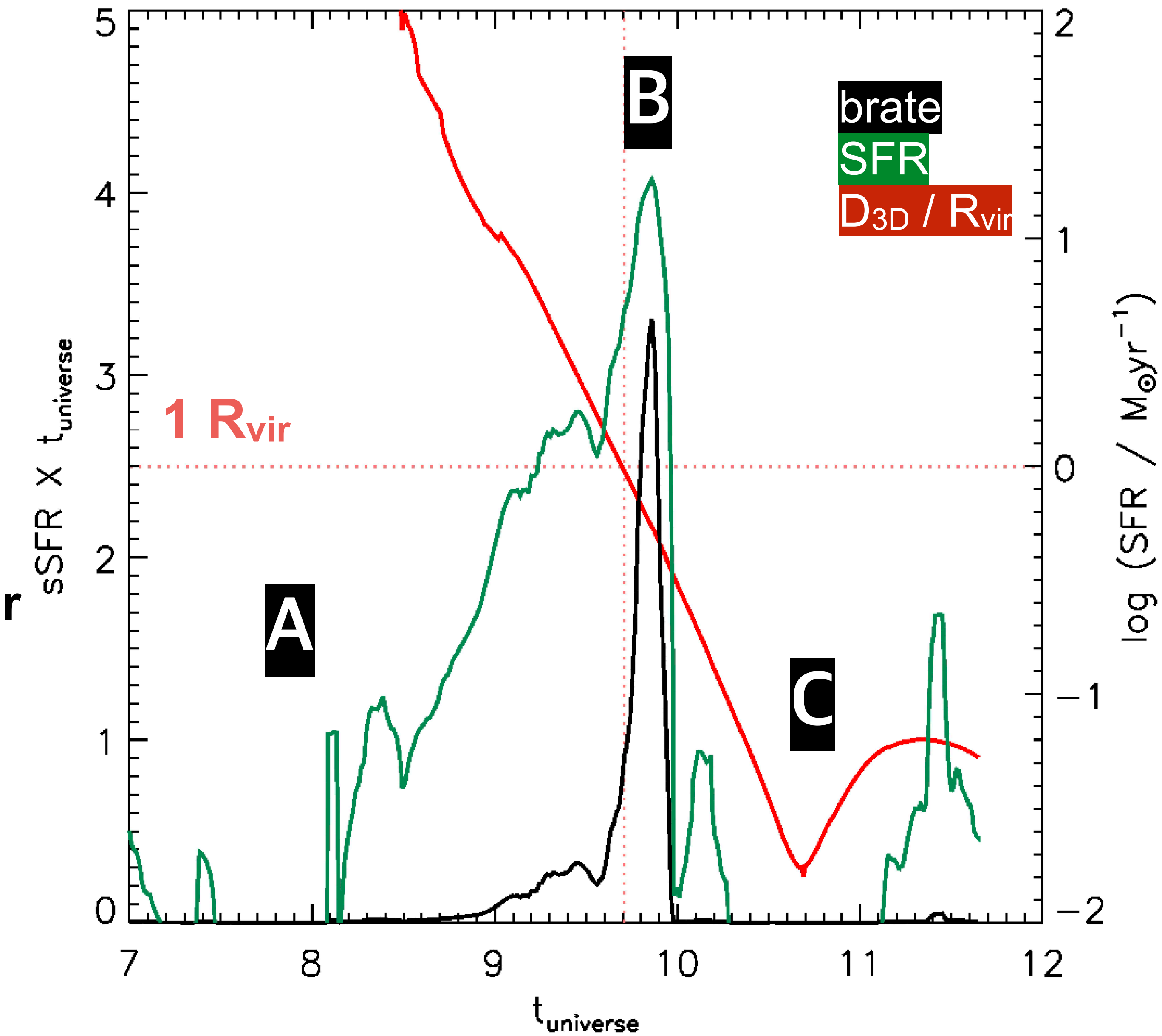


- Orbit-related periodicity of SFR is seen
- Decreasing with approaching peri-centers and increasing with receding
- Low mass galaxies are totally quenched while other galaxies are periodic

Quenching in Group Env-

Physical origin of Quenching (ID = 0013)

- **Galaxy ID=13 ($M_* = 5.2 \times 10^{10}\, M_\odot$)**
- **(A) SFR increases prior to infall**
- **(B) SFR rapidly quenched**
- **(C) SFR decreases further at the pericenter**



Data Building- Gas Prop.

Galaxy Gas components (ISM vs. CGM vs. IGM)

▸ **Based on mechanical energy and metallicity**

> Cell bound-ness: $E_{\mathrm{tot}} = u + k + \phi = \frac{p/\rho}{\gamma - 1} + \frac{1}{2}v^2 + \phi$

> Gas components

ISM - bound gas

IGM - unbound low metallicity gas

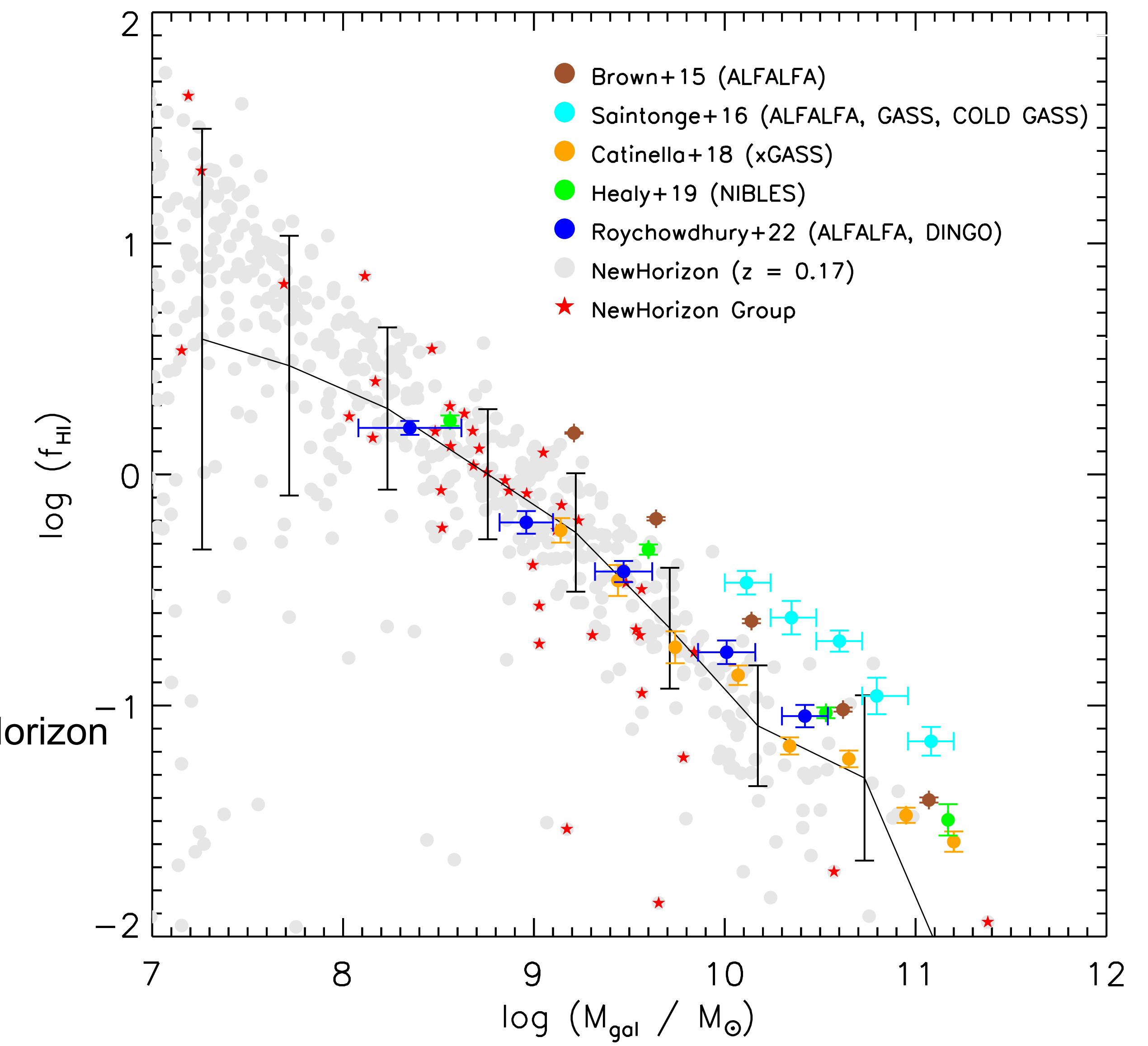
CGM - unbound high (similar to ISM) metallicity gas

> Gas phase

Cold or **hot** based on ρ and T (Torrey et al. 2012)

Dense ($n_{\mathrm{H}} > 10\,\mathrm{cm}^{-3}$)

* $n_{\mathrm{H}} > 10\,\mathrm{cm}^{-3}$ is one of the necessary conditions for SF in NewHorizon



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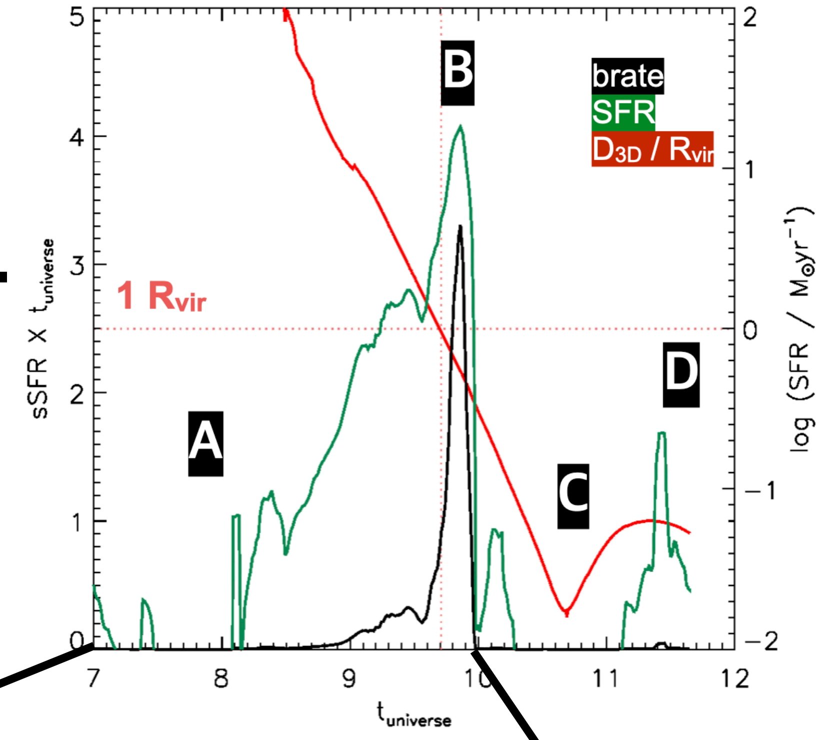
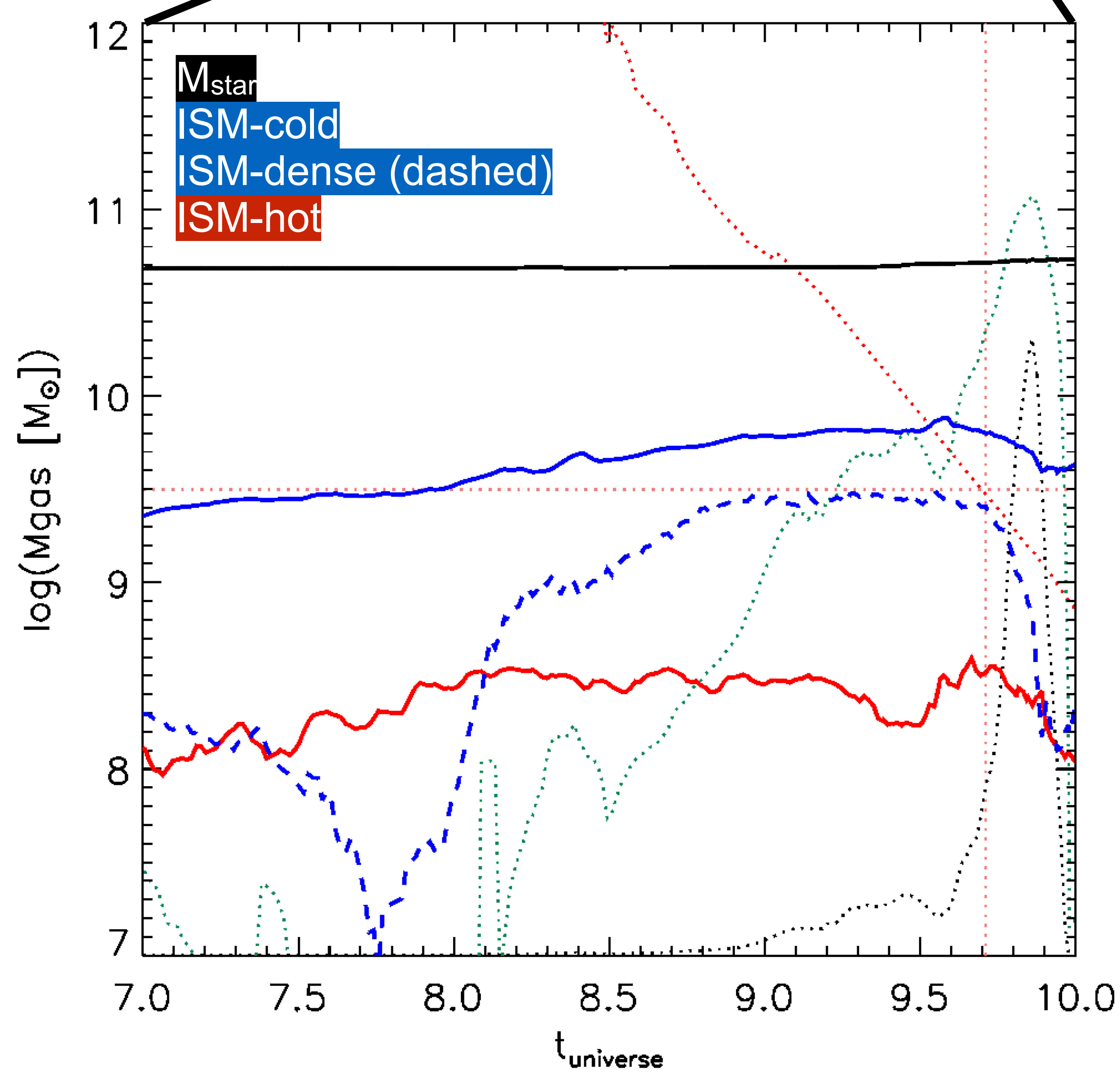
Analysis: Quenc

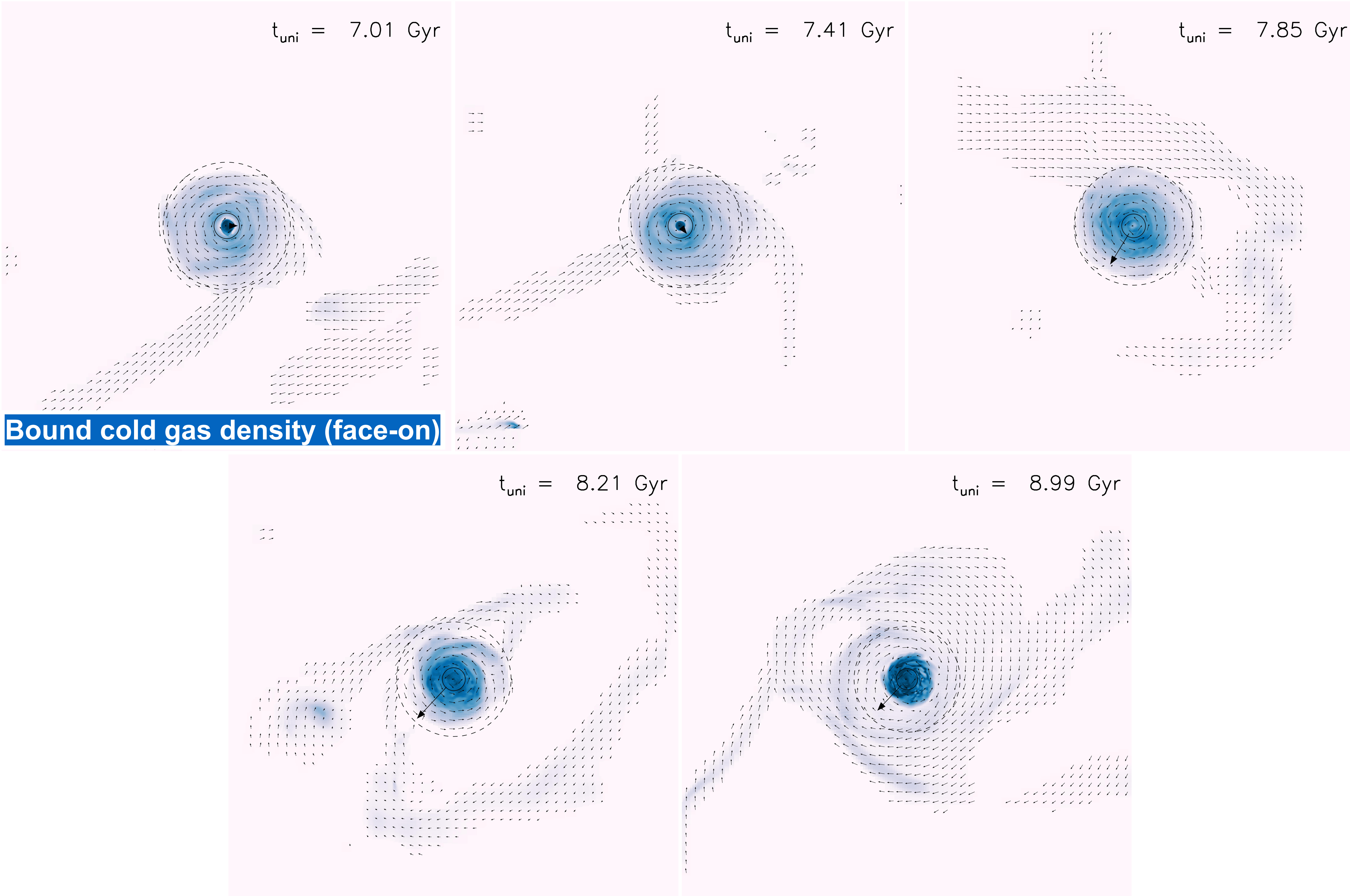
Physical origin of Quenching (ID = 0013)

- **(A) SFR increases prior to infall**
  > Cold ISM gas increase (7 - 9.5 Gyr)





Cold gas accretion drives the increase of the cold ISM gas mass



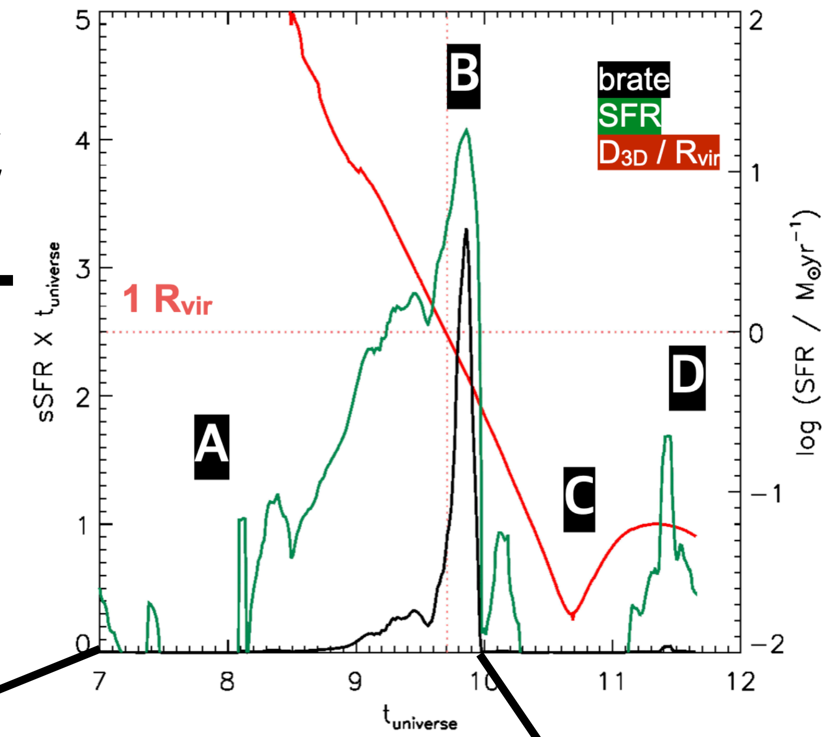
Analysis: Quenc

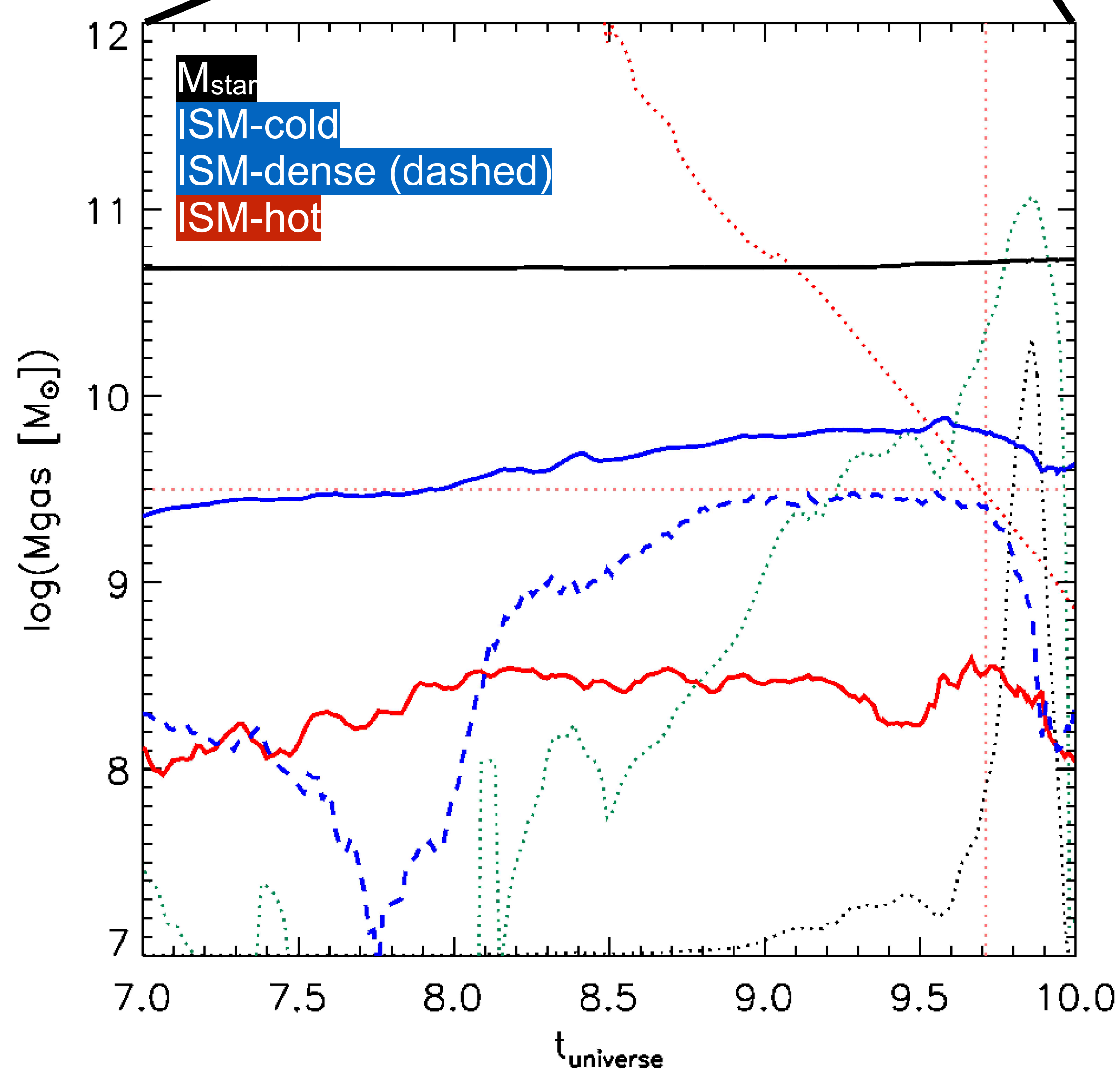
Physical origin of Quenching (ID = 0013)

- **(A) SFR increases prior to infall**

  > Cold ISM gas increases (7 - 9.5 Gyr)

  Continuous cold gas inflow





Analysis: Quenc

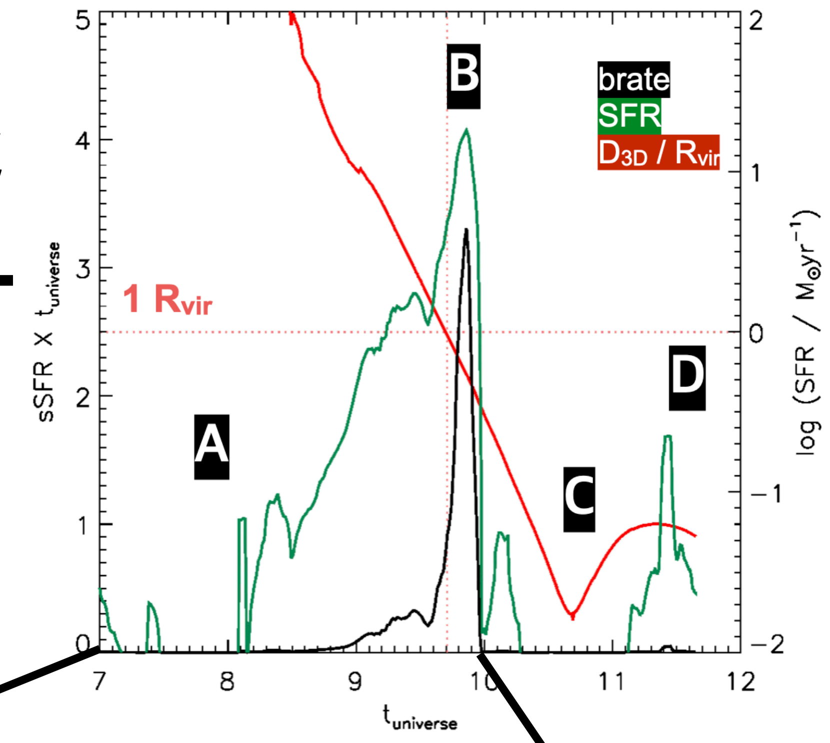
Physical origin of Quenching (ID = 0013)

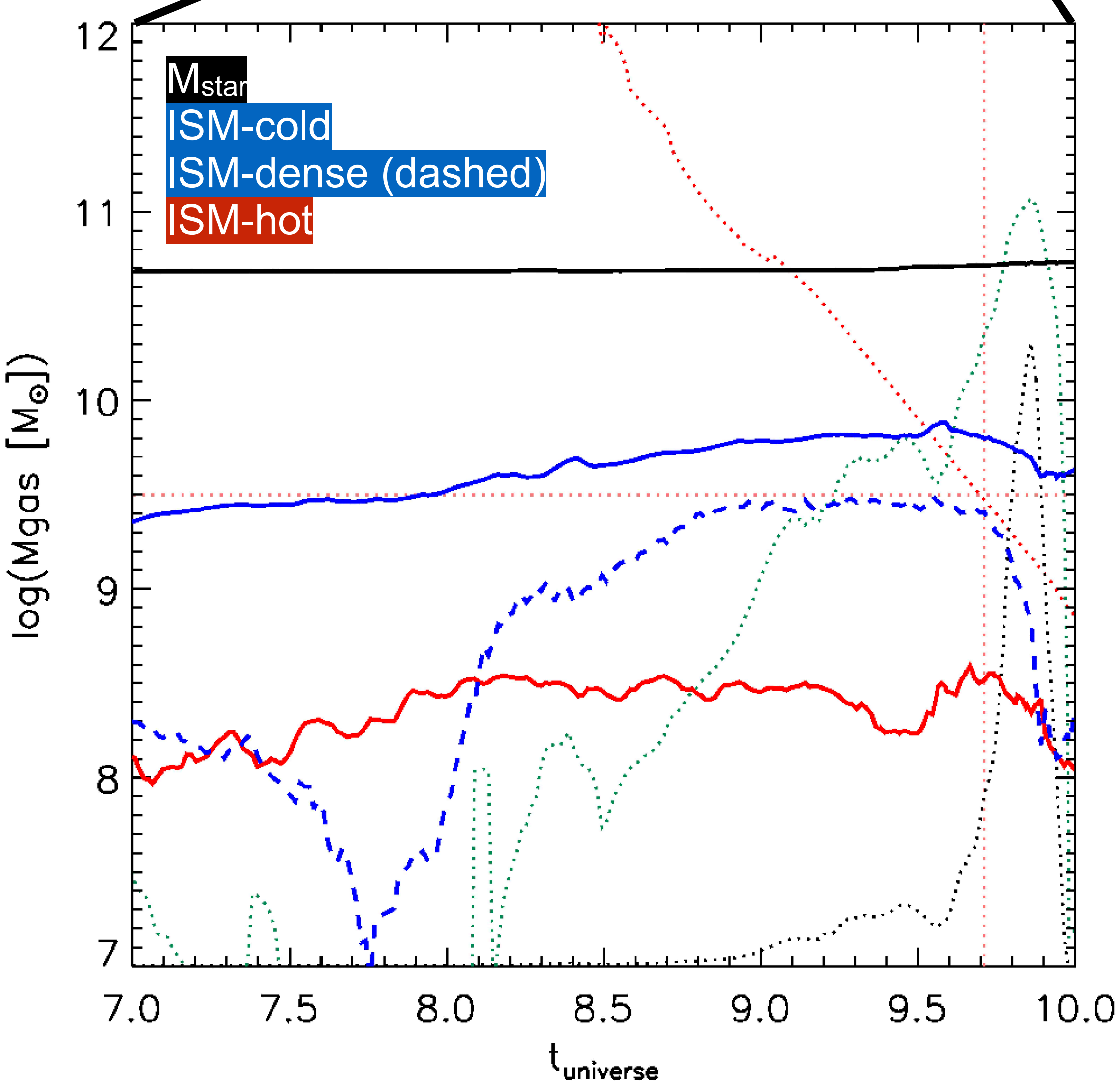
- **(A) SFR increases prior to infall**

  > Cold ISM gas increases (7 - 9.5 Gyr)

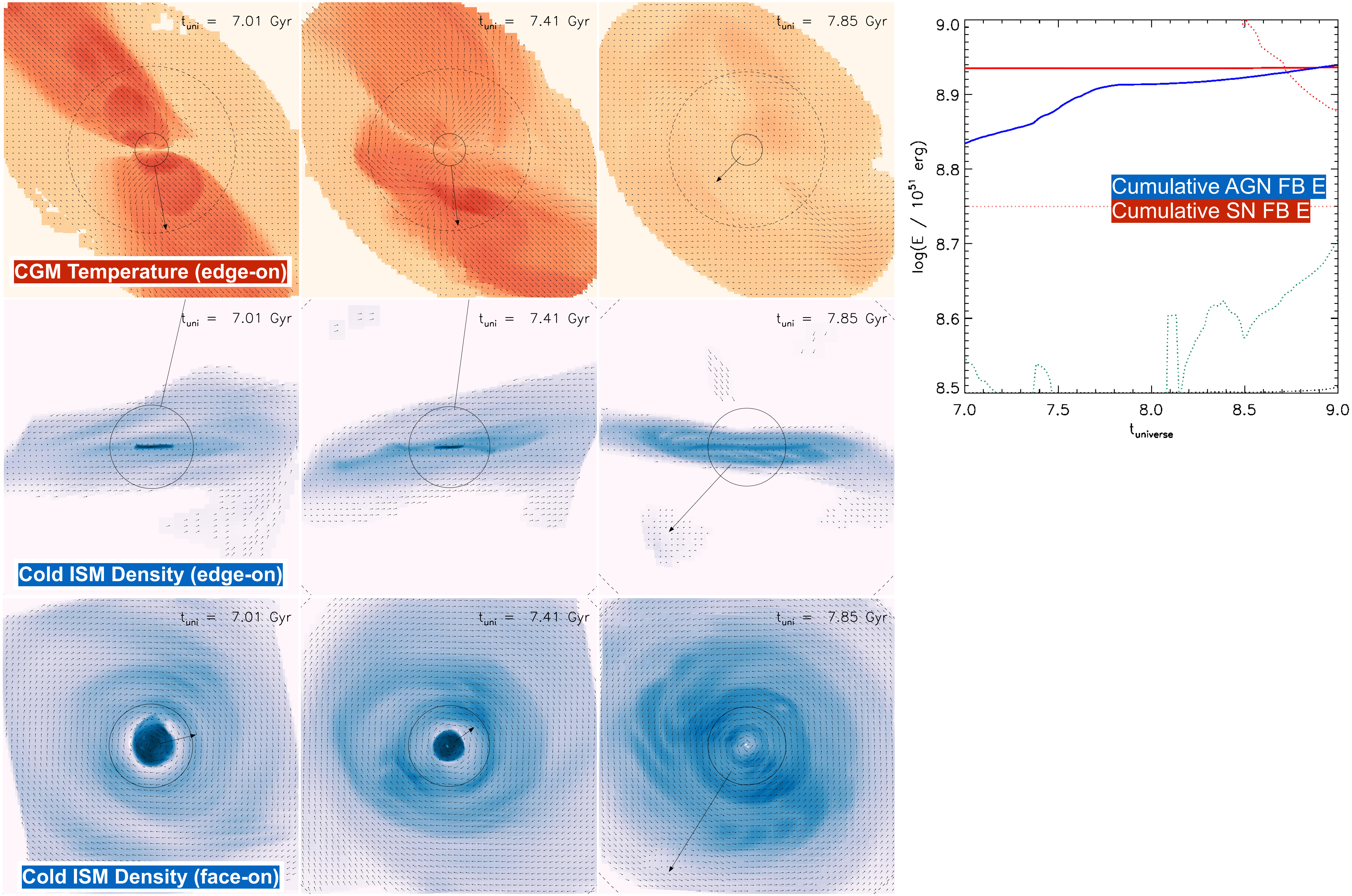
  Continuous cold gas inflow

  > Dense ISM decreases (T < 7.8 Gyr) and increases (T > 7.8 Gyr)





AGN feedback seems to destroy a dense ISM gas disk



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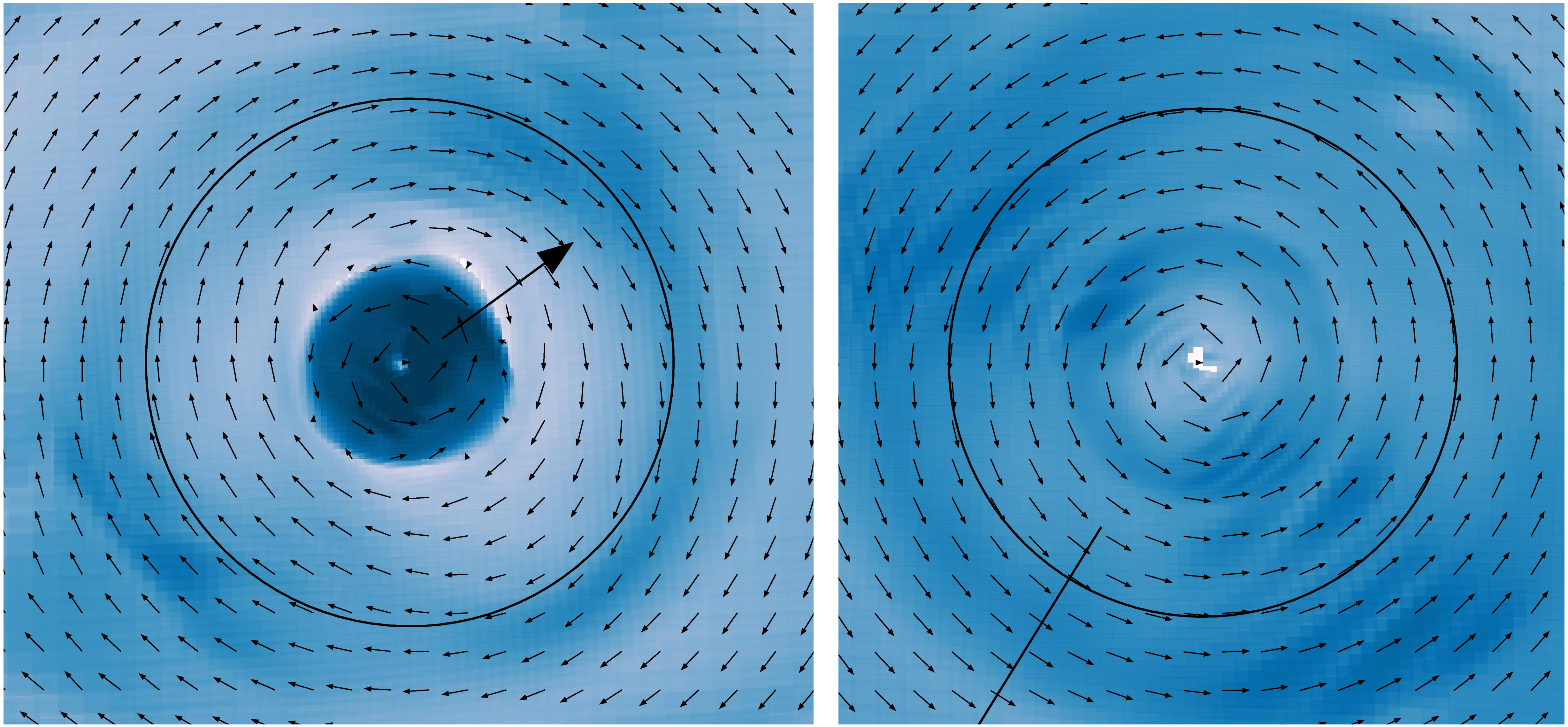
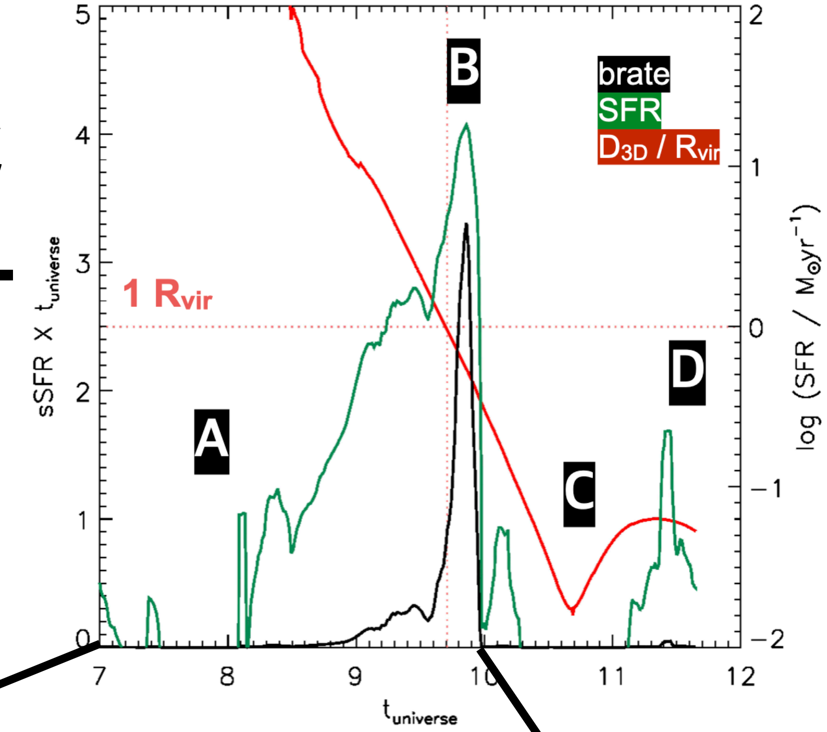


Analysis: Quenc



Physical origin of Quenching (ID = 0013)

- **(A) SFR increases prior to infall**

  > Cold ISM gas increases (7 - 9.5 Gyr)

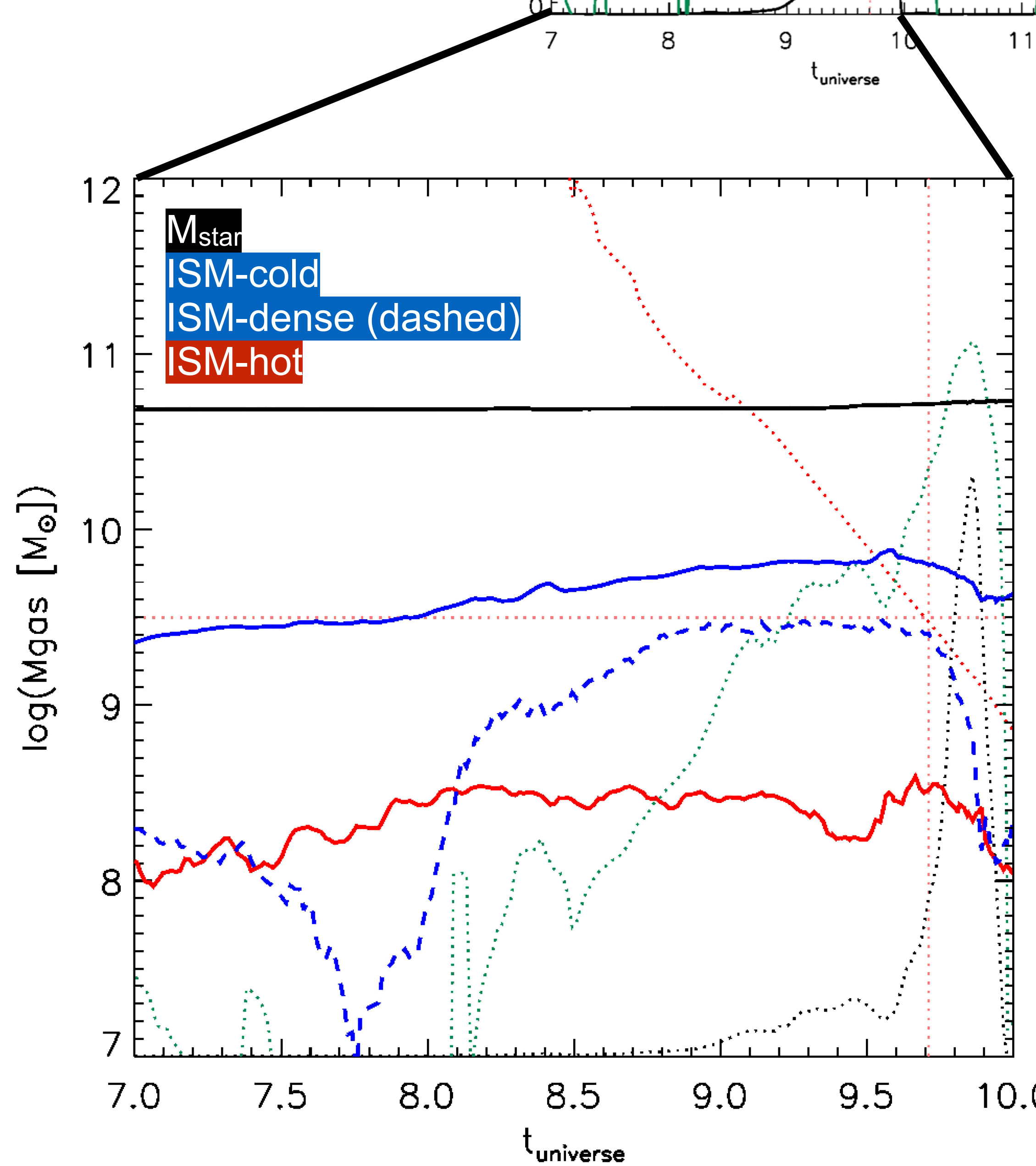
  Continuous cold gas inflow

  > Dense ISM decreases (T < 7.8 Gyr) and increases (T > 7.8 Gyr)

  AGN outflow seems to destroy (or kinematically heat) dense ISM gas disk

  After AGN feedback terminates, dense gas disk formed again.

  Seems to gain angular momentum by accreted gas (Coherent rotation)



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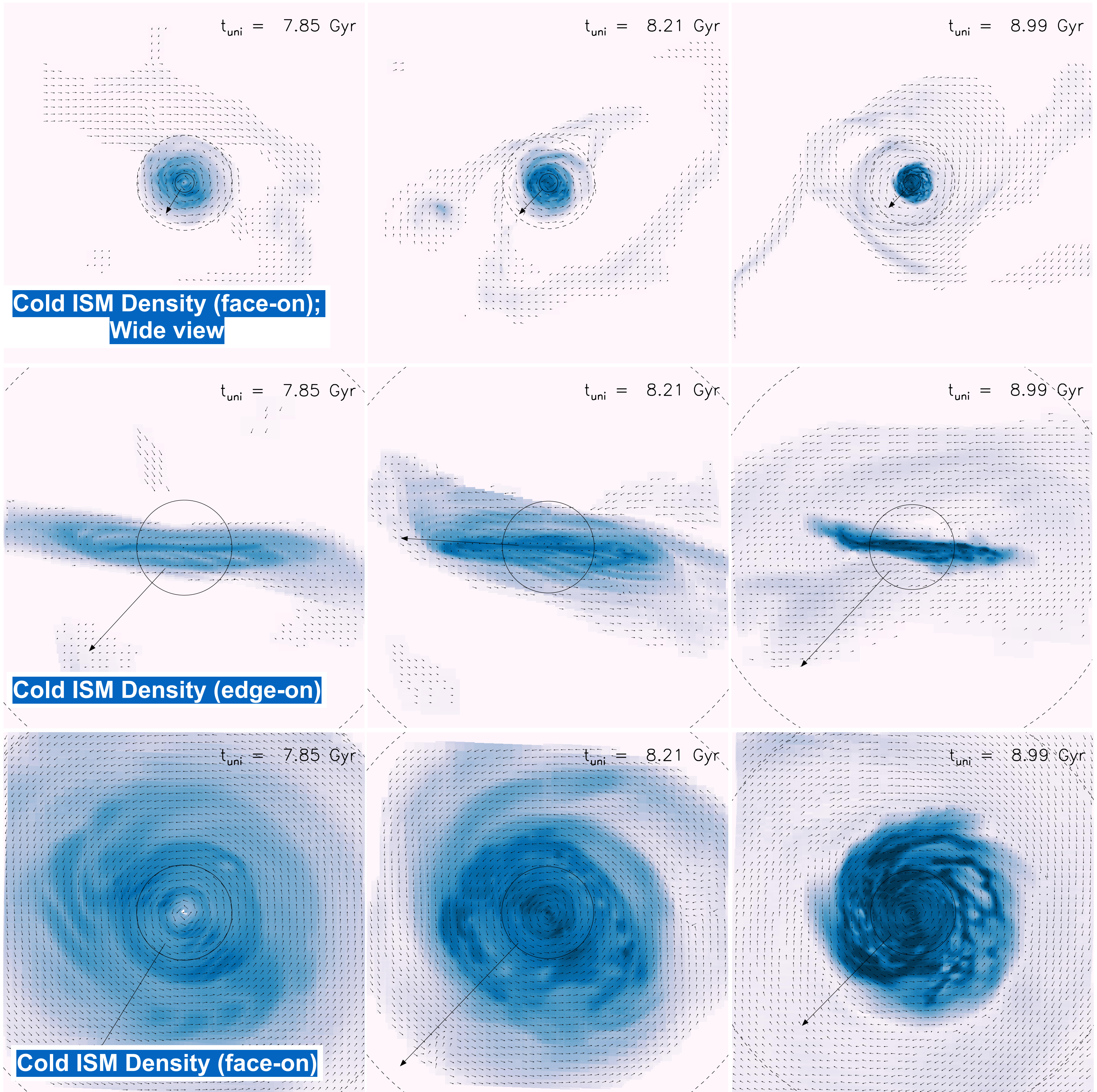
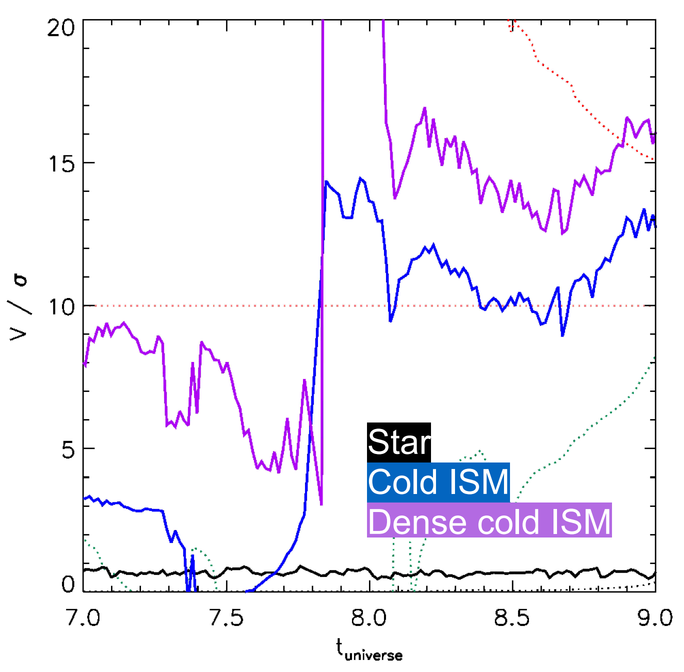
Dense ISM gas disk is quickly reformed





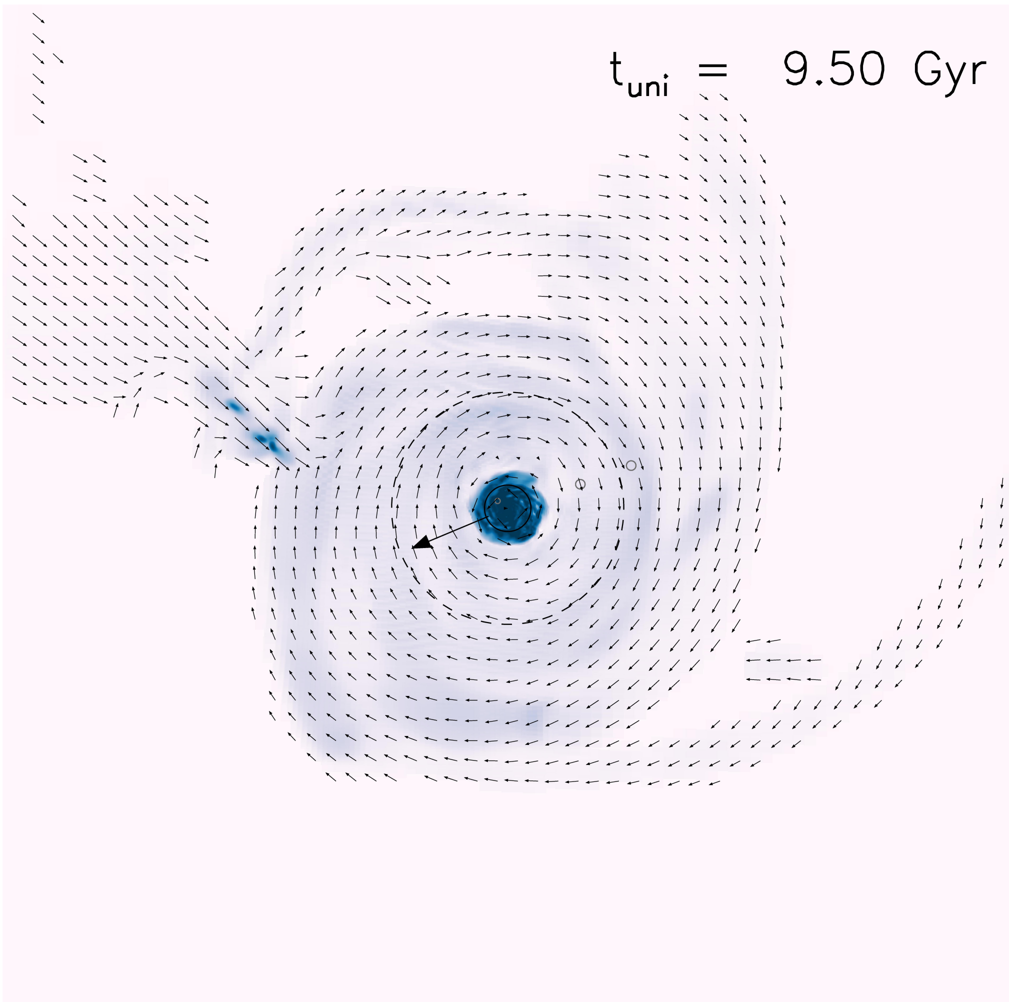
Analysis: Quenc

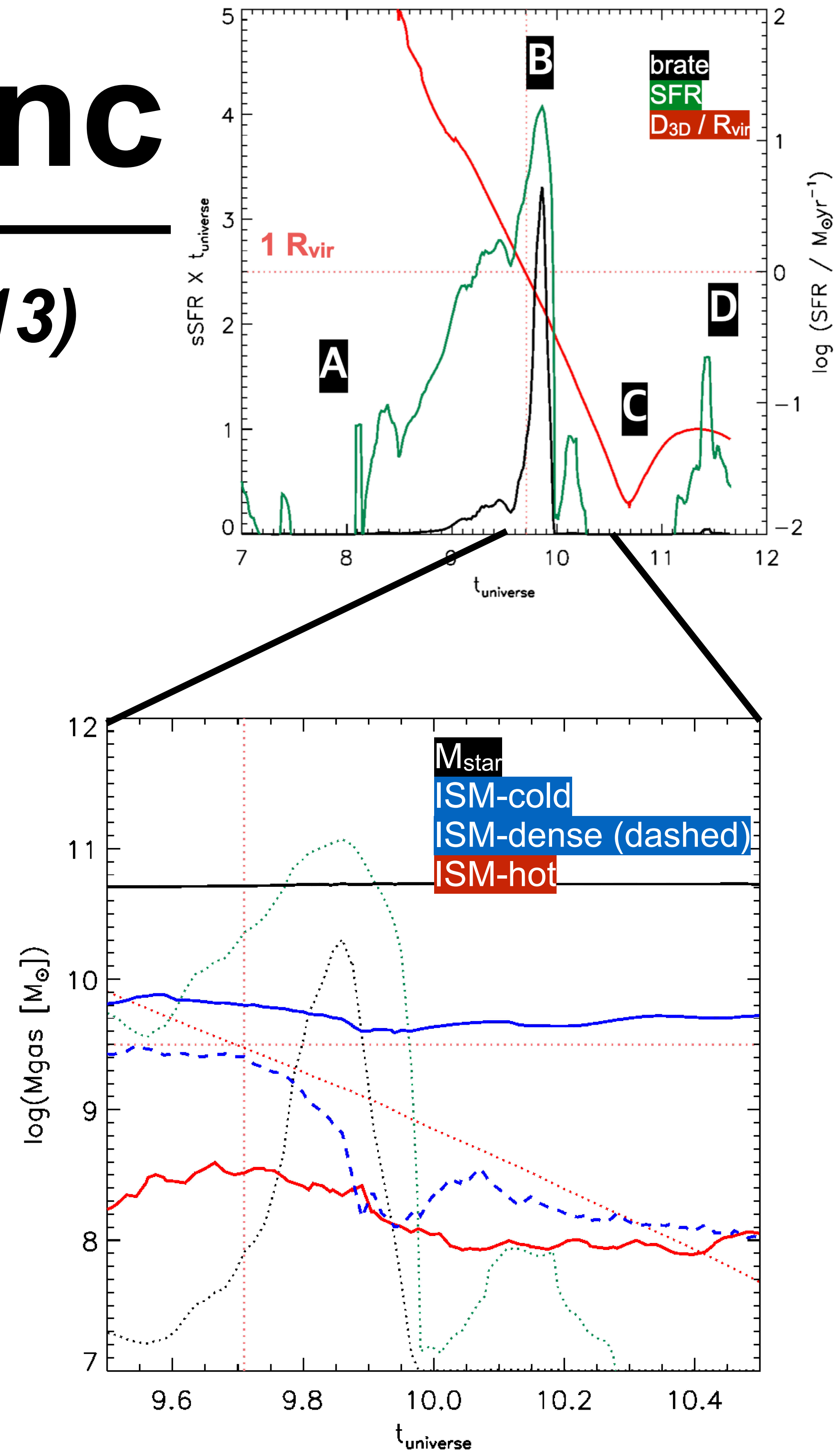
Physical origin of Quenching (ID = 0013)

- **(B) SFR rapidly quenched**

  > SFR bursts (9.5 - 9.8 Gyr)

  Wet merger





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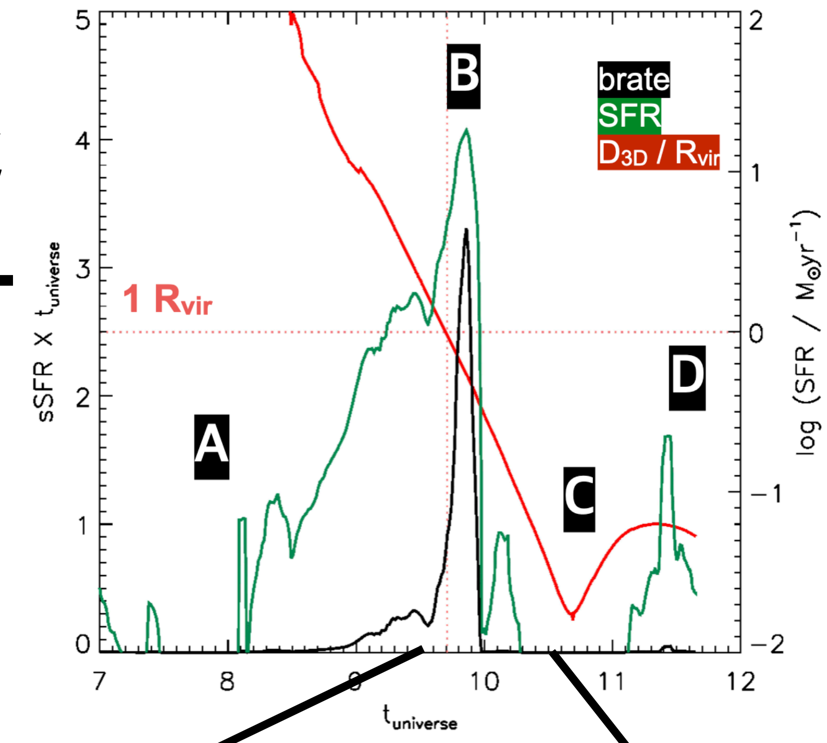
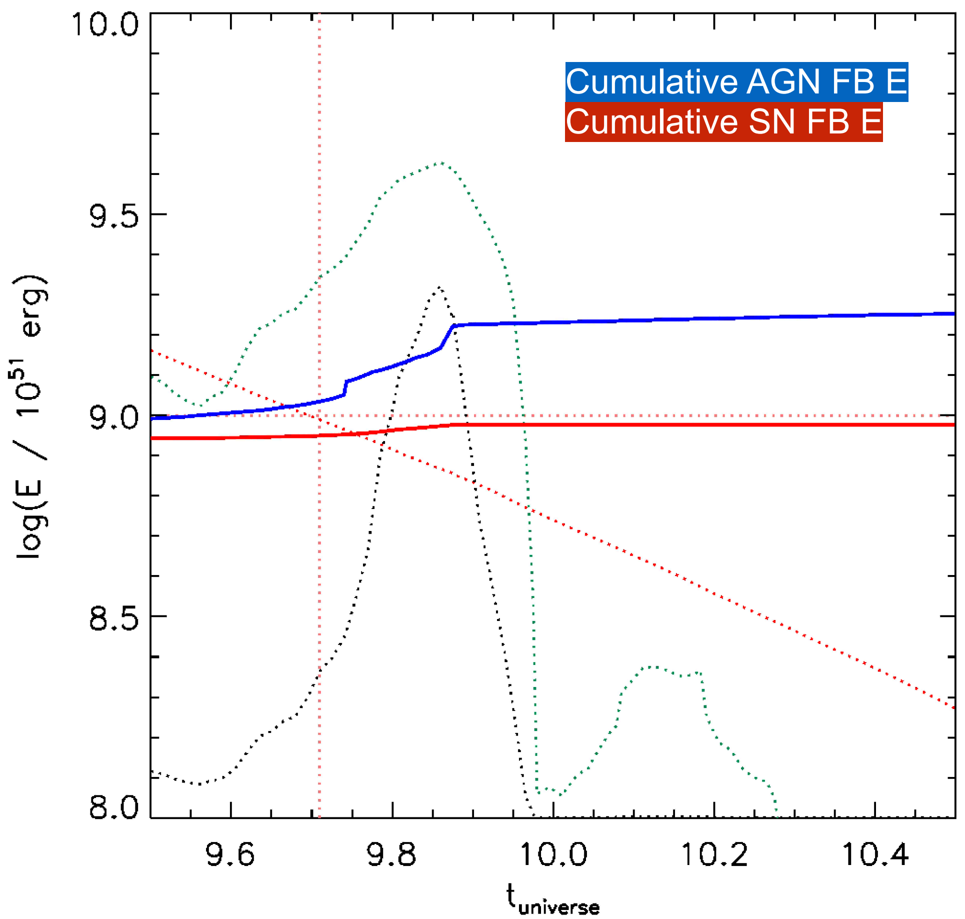
Analysis: Quenc

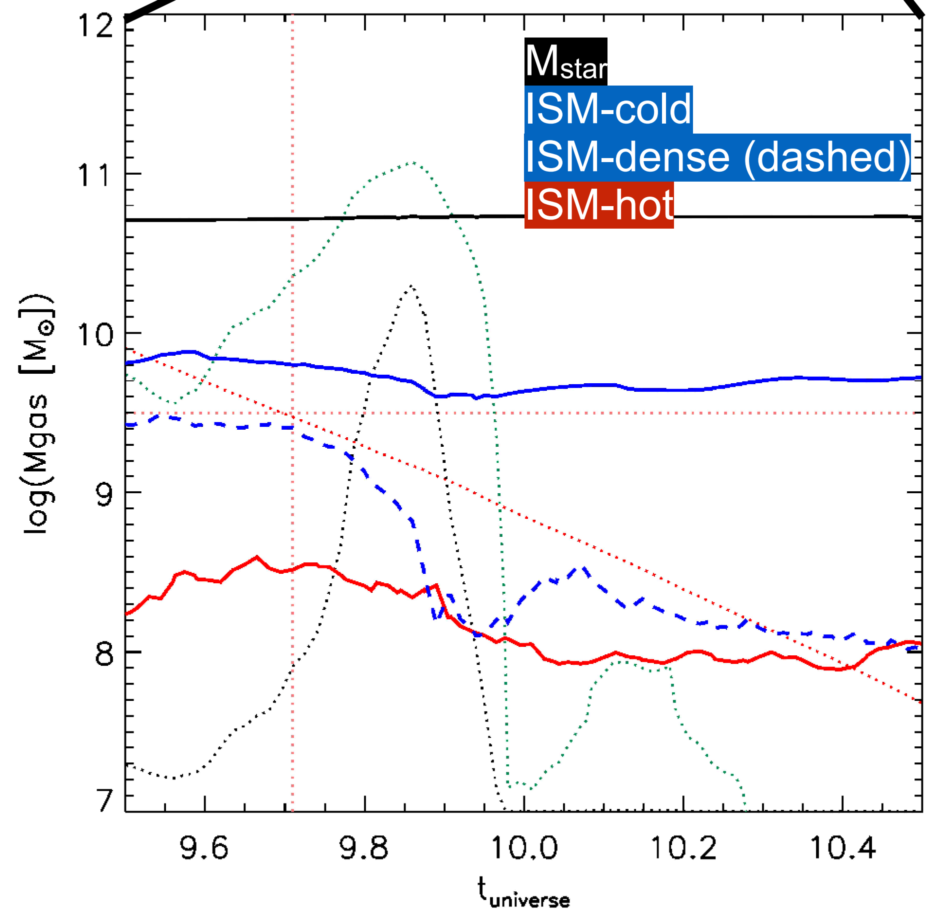
Physical origin of Quenching (ID = 0013)

- **(B) SFR rapidly quenched**
  > SFR bursts (9.5 - 9.8 Gyr)
  Wet merger

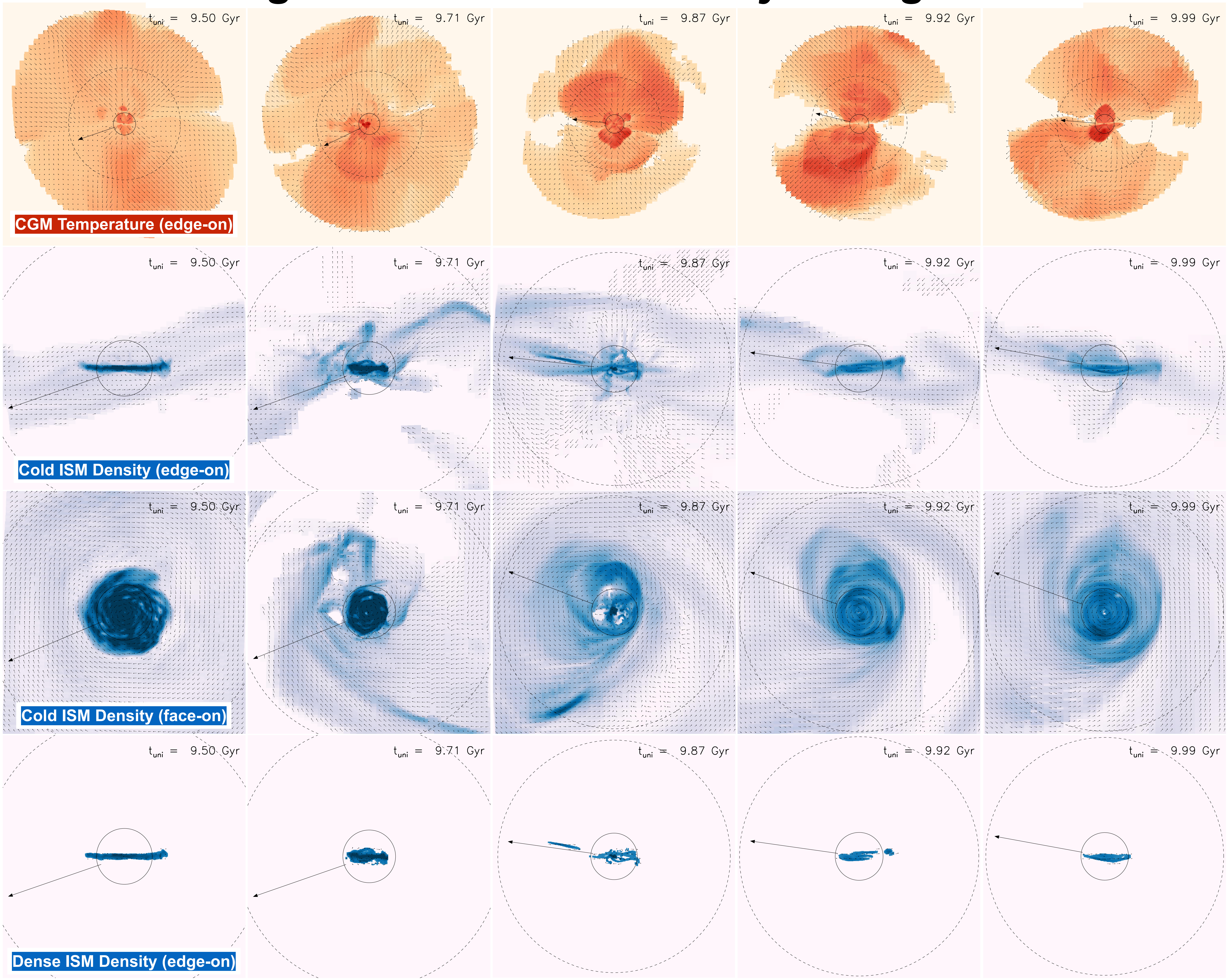
  > Dense ISM gas decreases (9.5 - 9.8 Gyr)
  AGN triggered at the same epoch



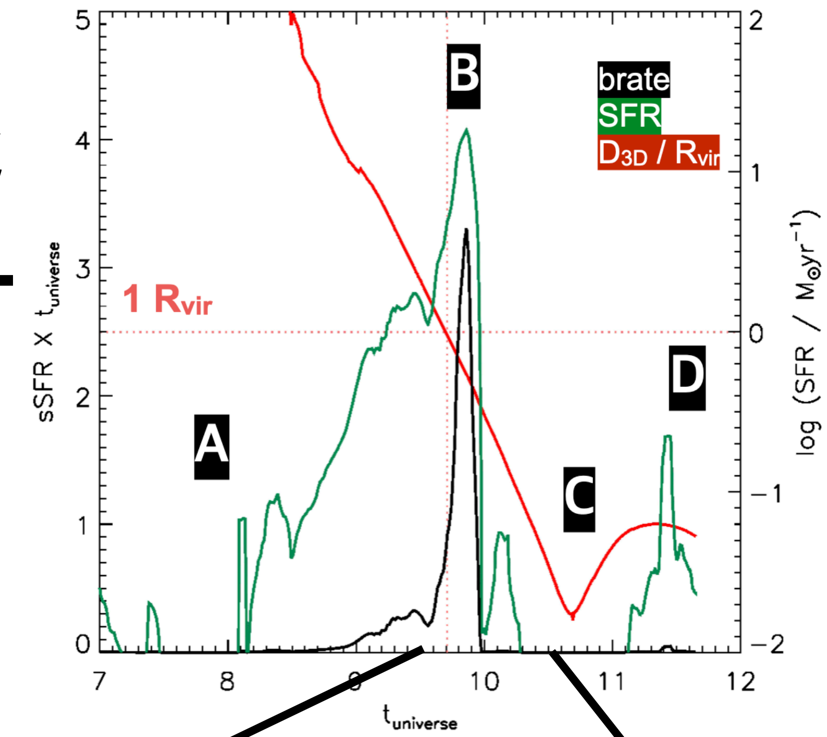




Strong AGN feedback destroys the gas disk



Analysis: Quenc



Physical origin of Quenching (ID = 0013)

- **(B) SFR rapidly quenched**

  > SFR bursts (9.5 - 9.8 Gyr)

  Wet merger

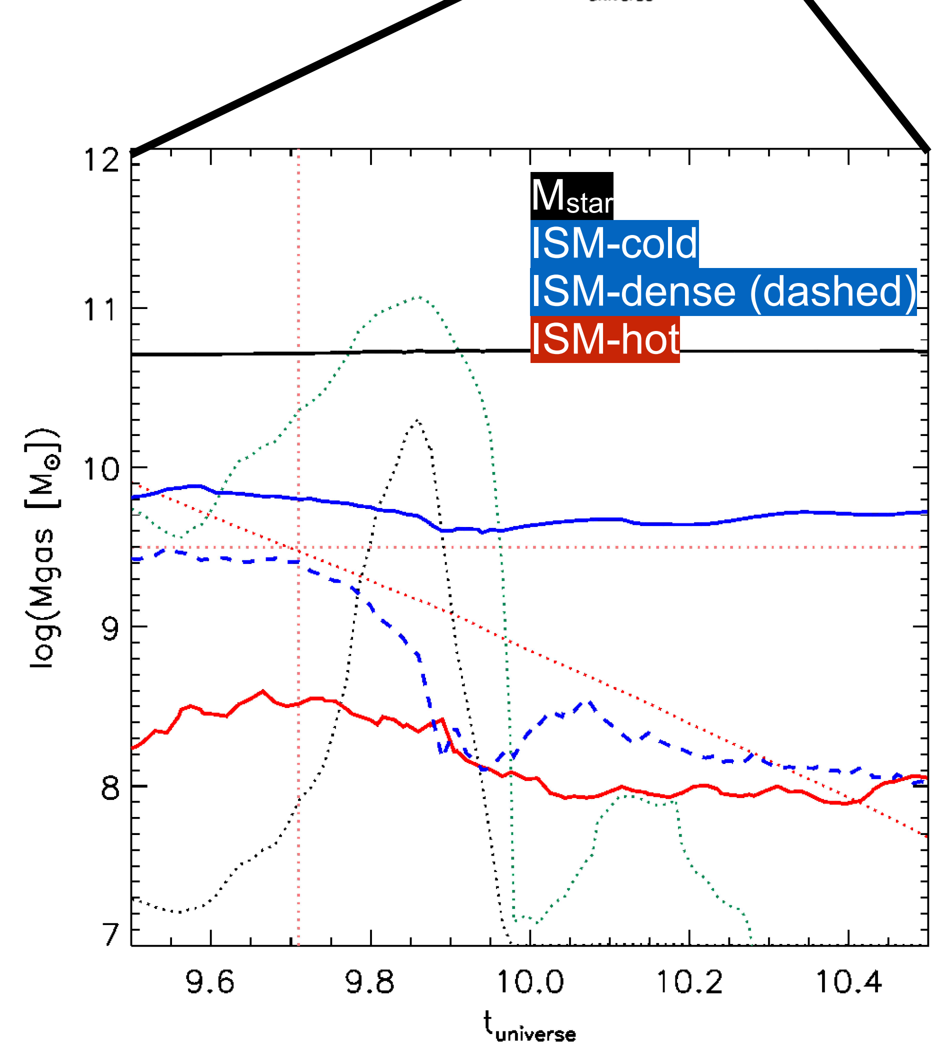
  > Dense ISM gas decreases (9.5 - 9.8 Gyr)

  AGN triggered at the same epoch

  AGN outflows destroy a gas disk

  But, the cold ISM gas component is not fully removed

  Disk settled quickly



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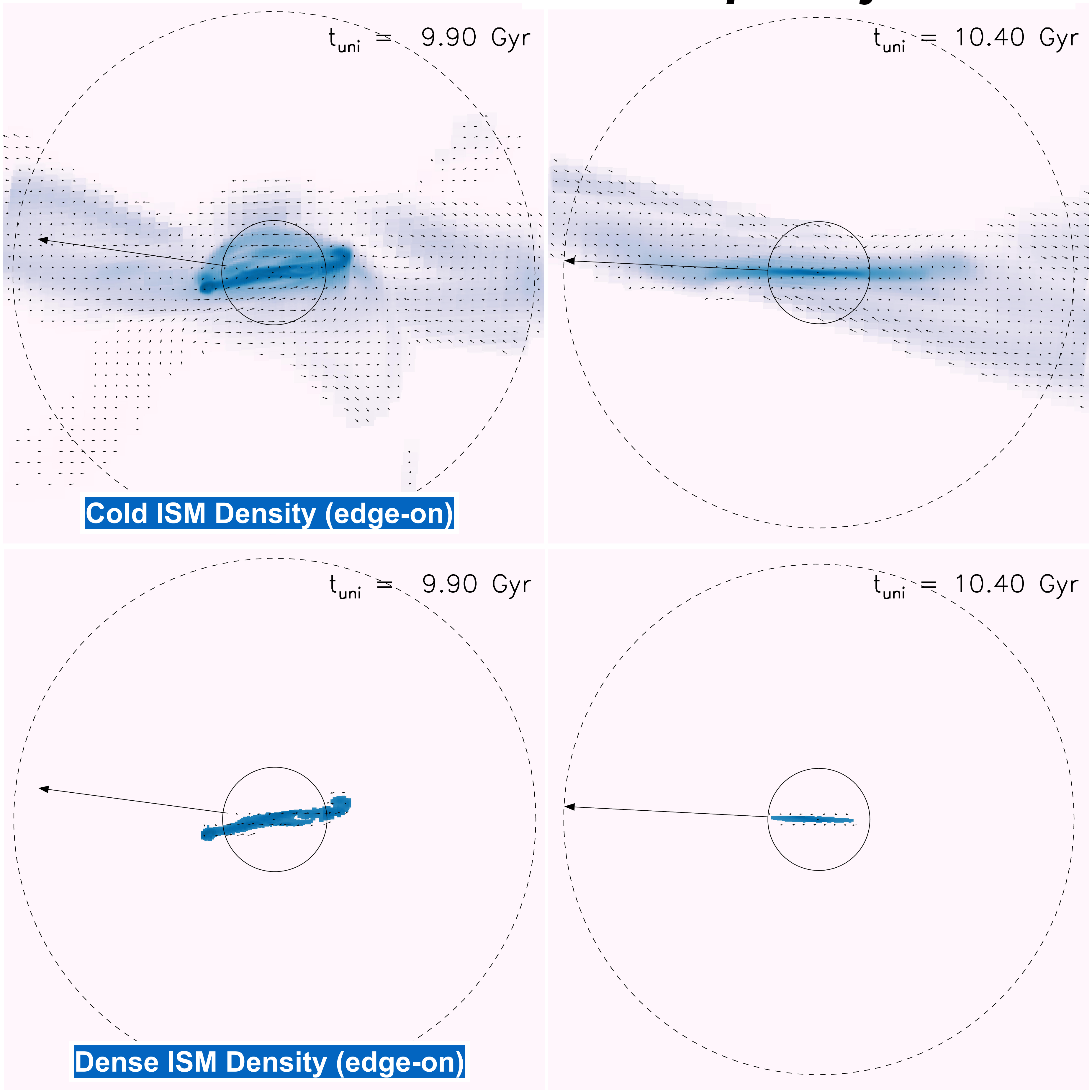
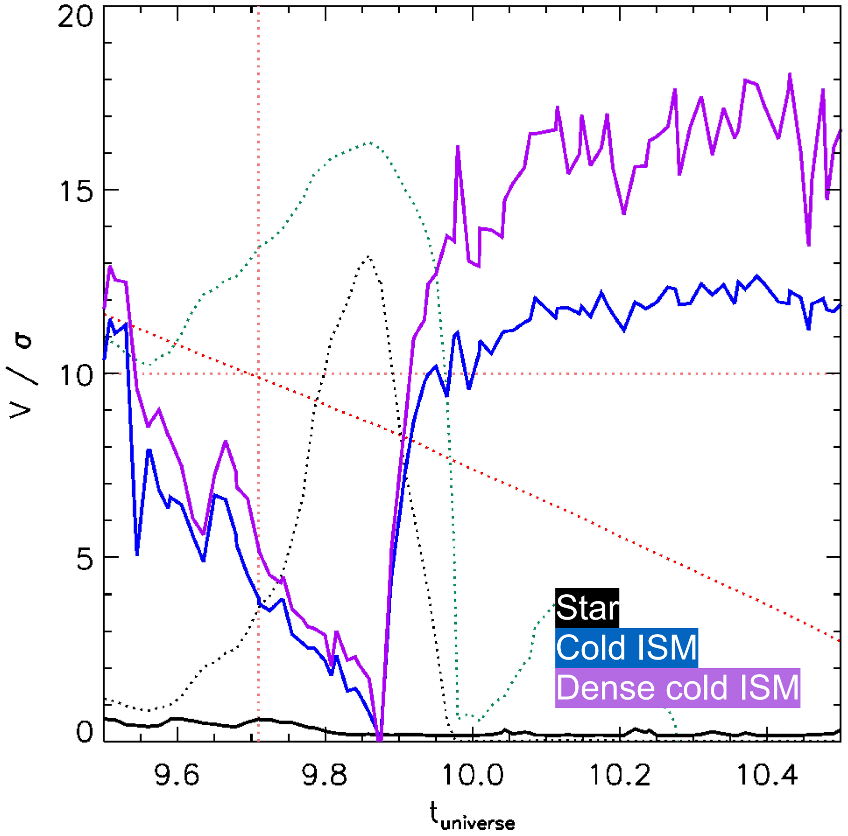
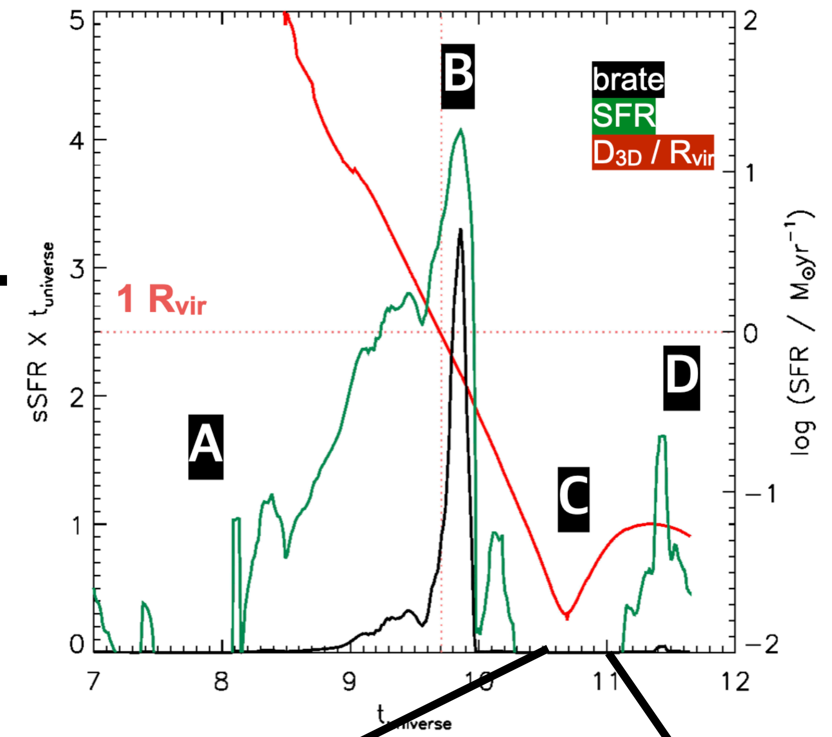
Disk is quickly settled



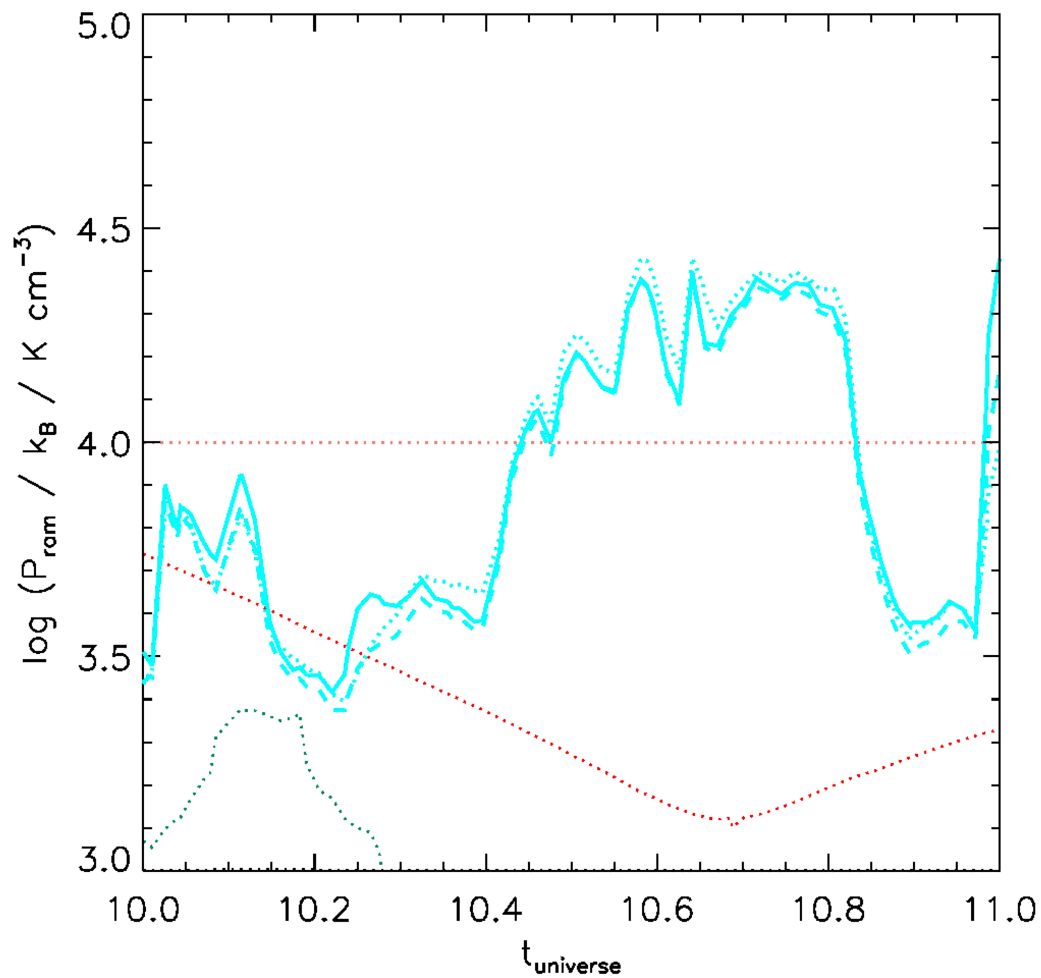


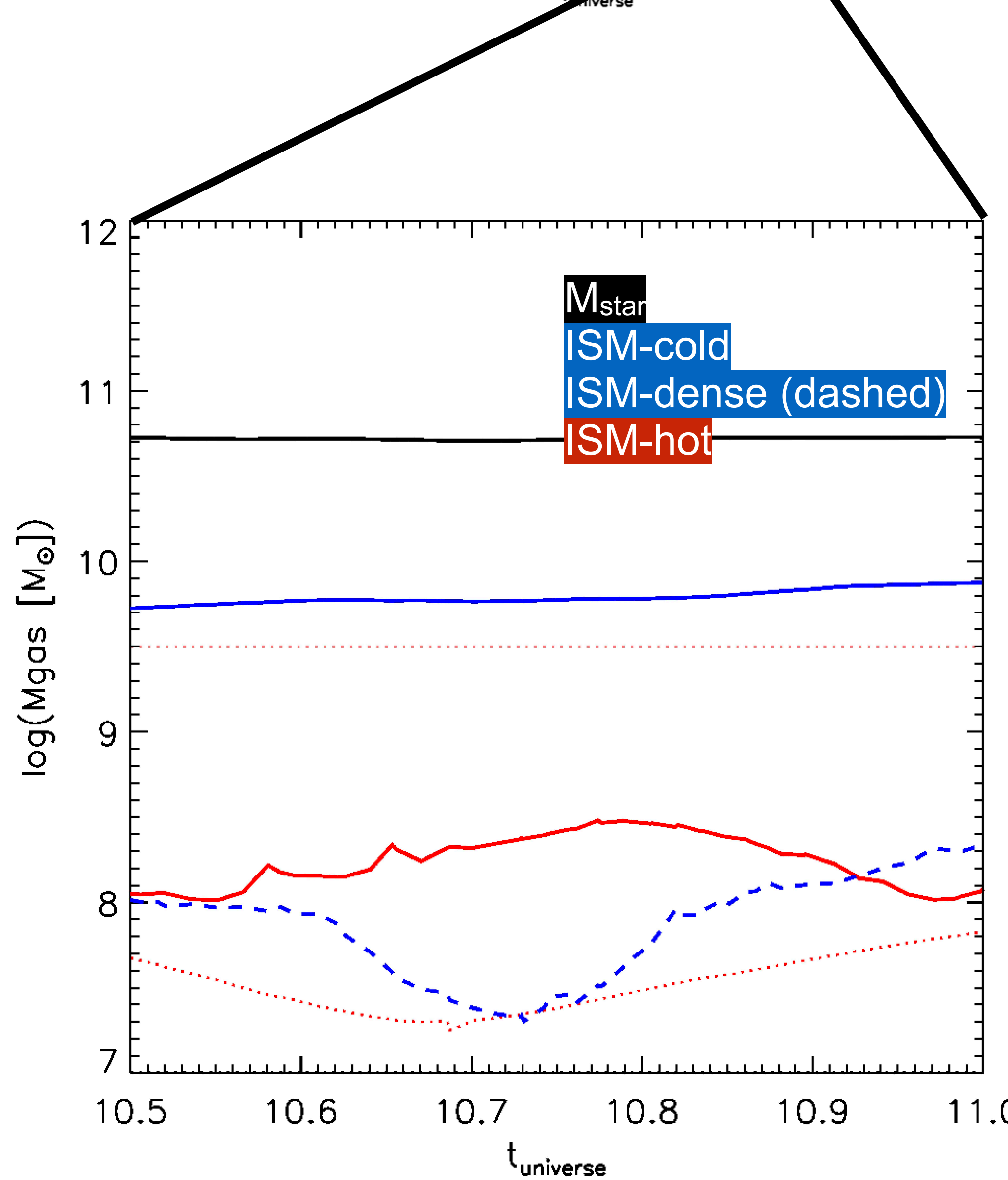
Analysis: Quenc

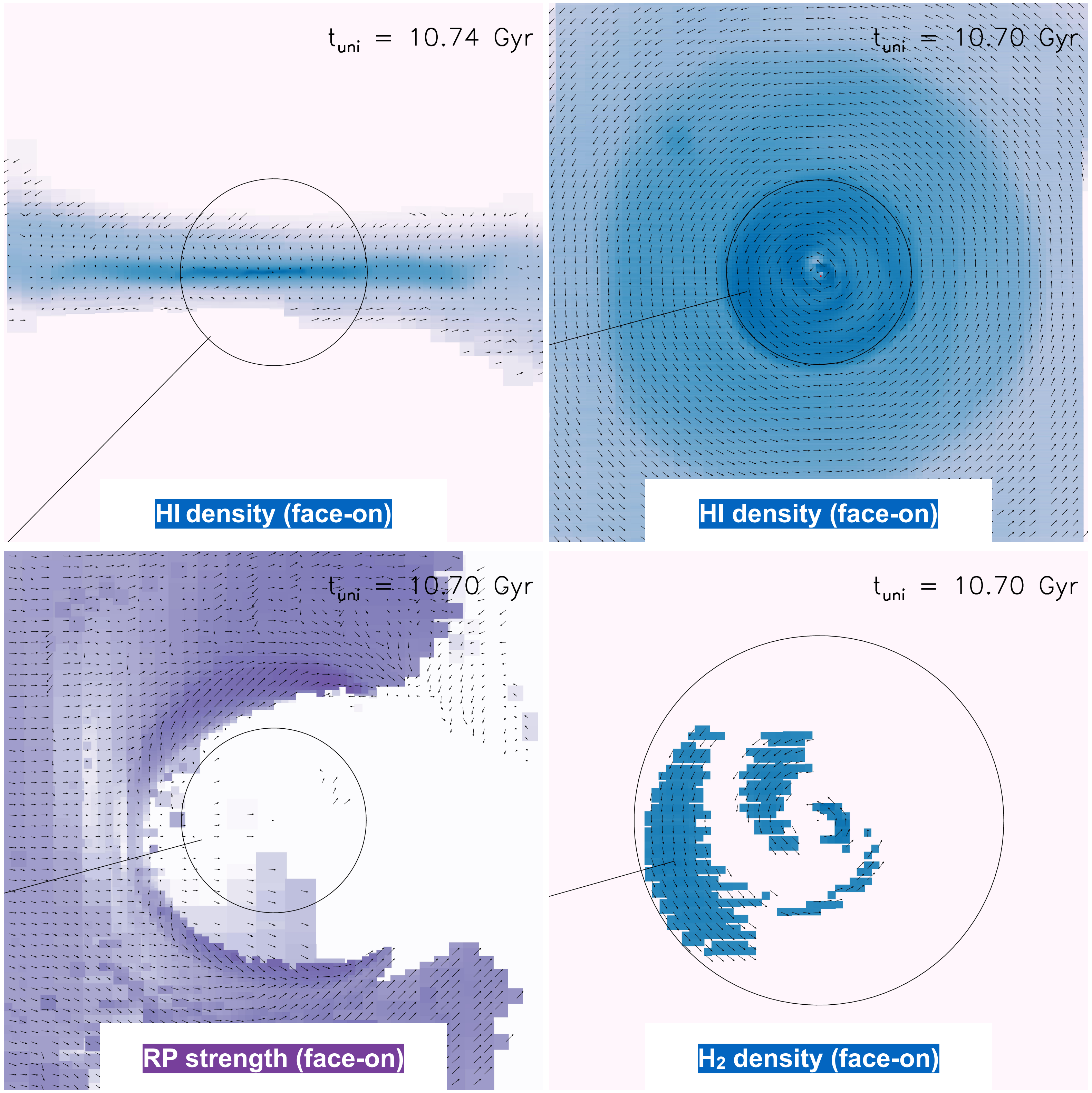
Physical origin of Quenching (ID = 0013)



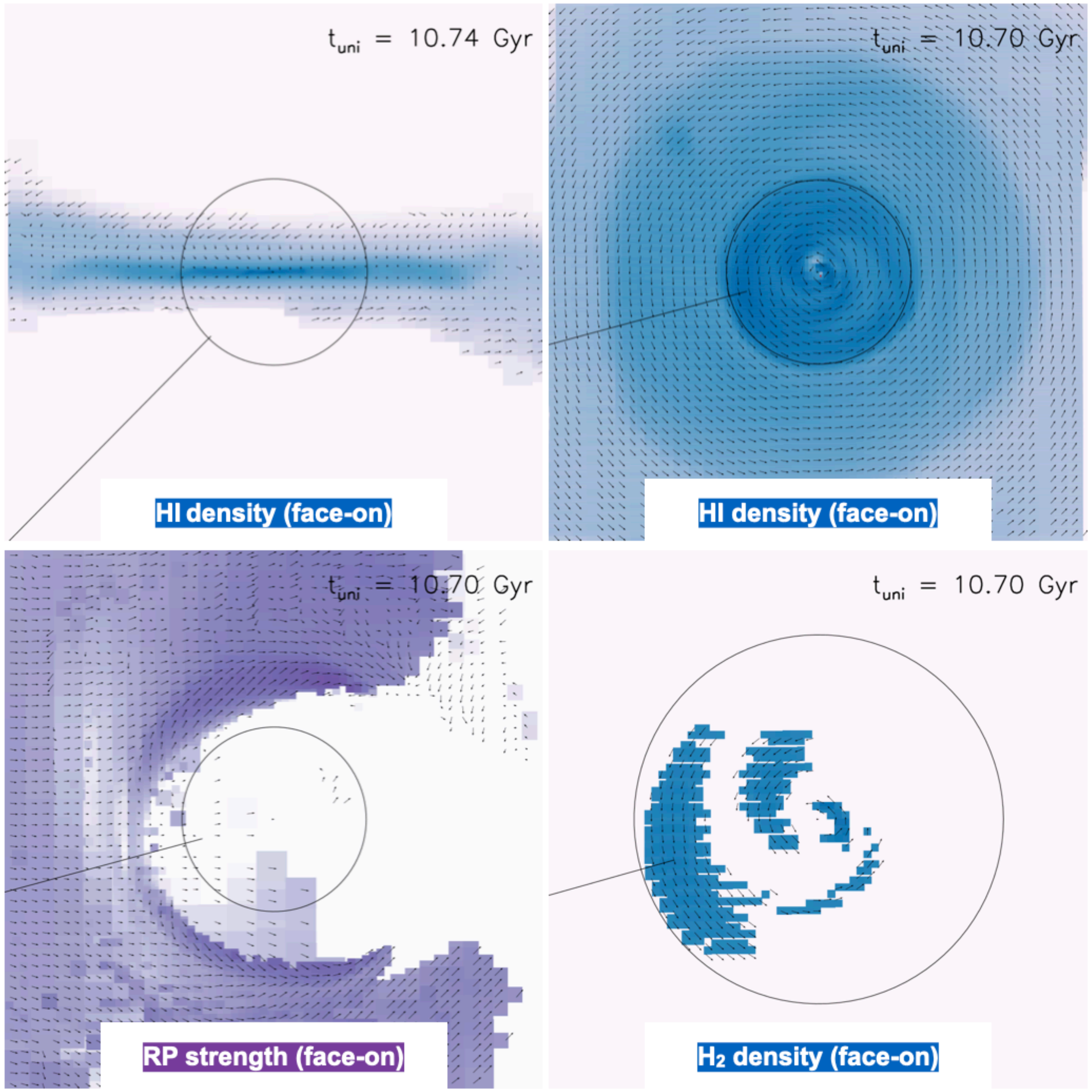
- **(C) SFR decreases further at the peri-center**
  - \> Dense ISM drops at the same epoch
  - Dense ISM gas disk shrinks and gets asymmetric
  - \> RP gets stronger





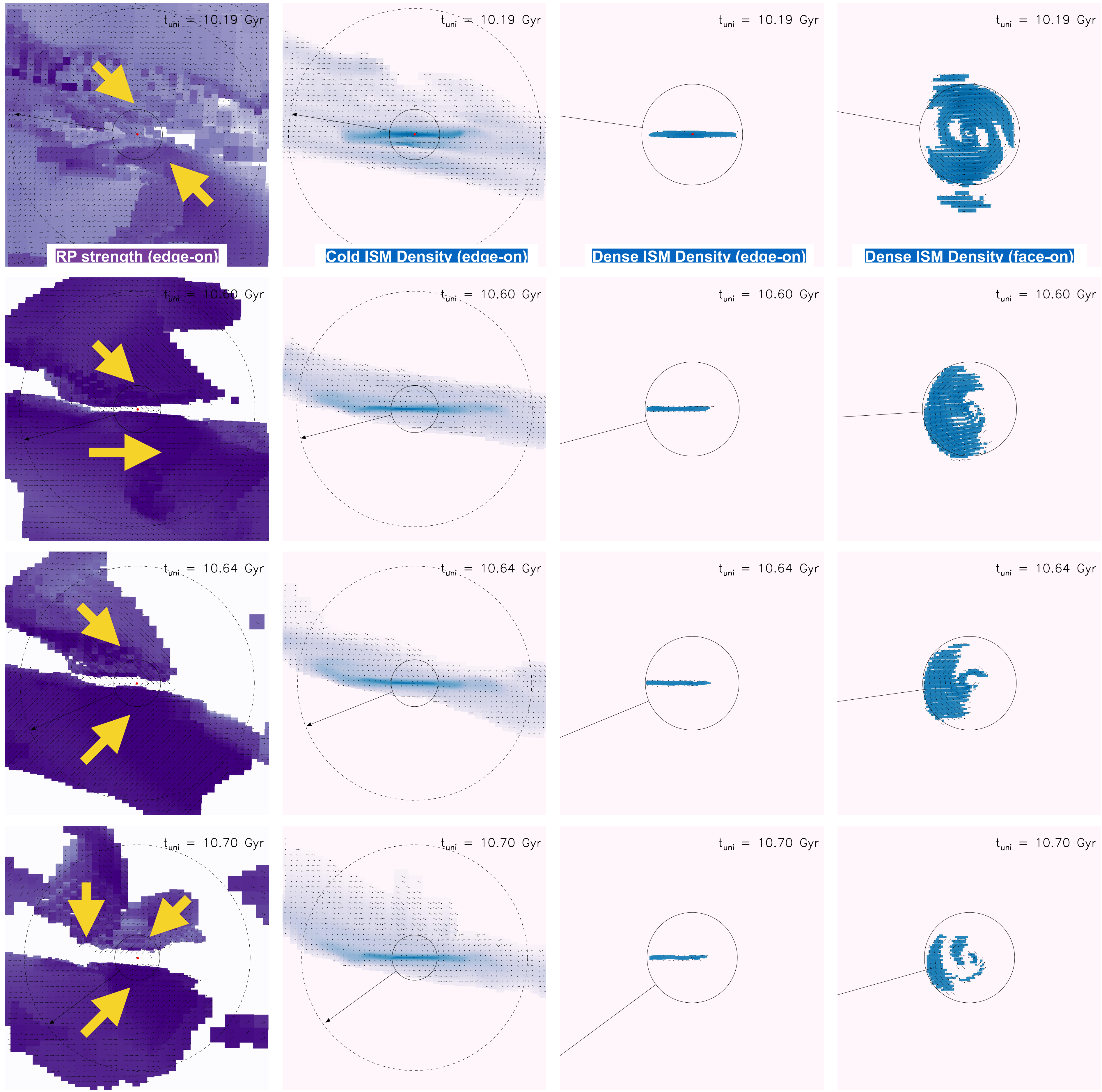


t_{uni} = 10.74 Gyr
HI density (face-on)
t_{uni} = 10.70 Gyr
HI density (face-on)
t_{uni} = 10.70 Gyr
RP strength (face-on)
t_{uni} = 10.70 Gyr
H_2 density (face-on)

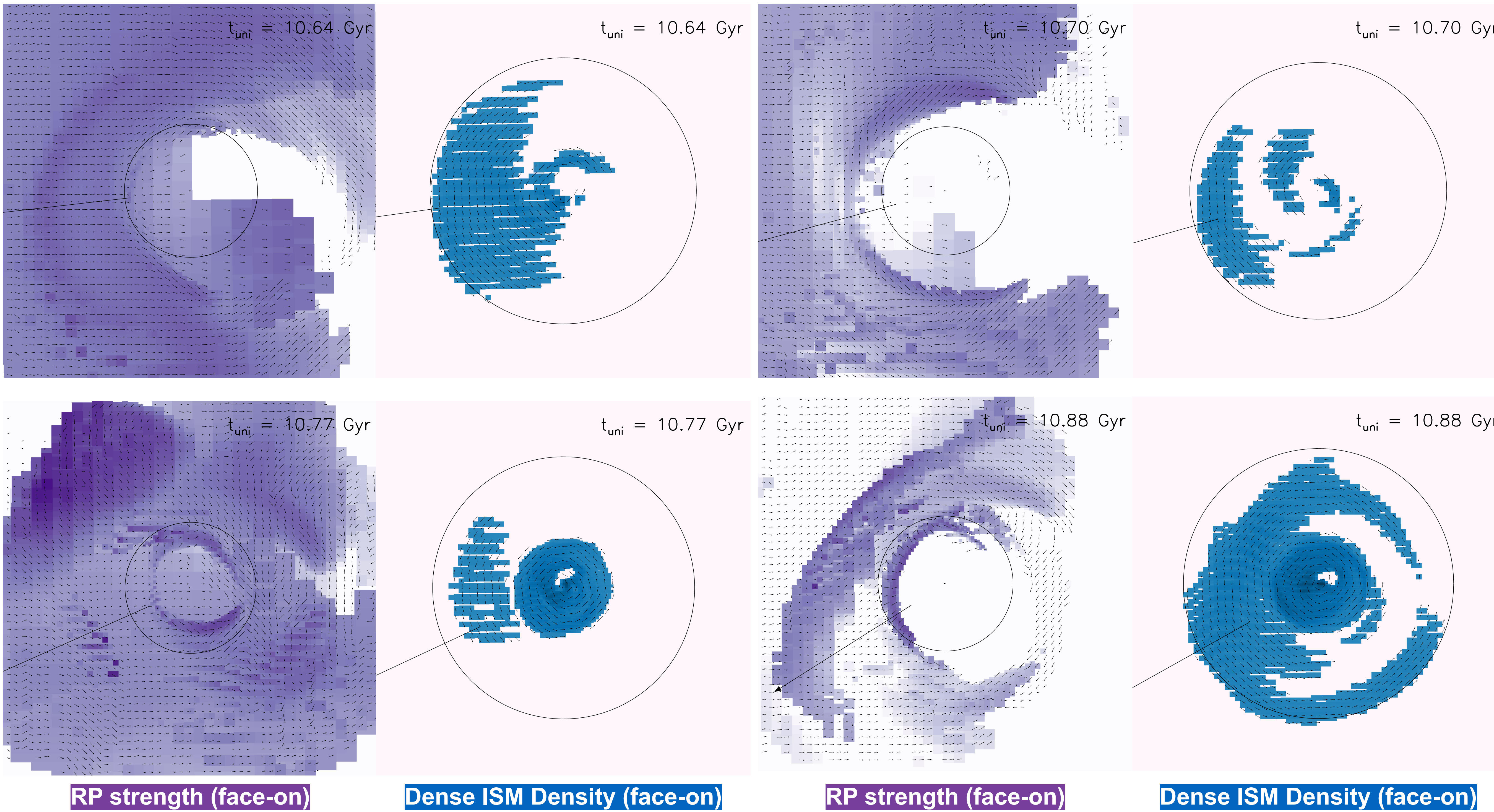


t_uni = 10.74 Gyr
HI density (face-on)
t_uni = 10.70 Gyr
HI density (face-on)
t_uni = 10.70 Gyr
RP strength (face-on)
t_uni = 10.70 Gyr
H2 density (face-on)

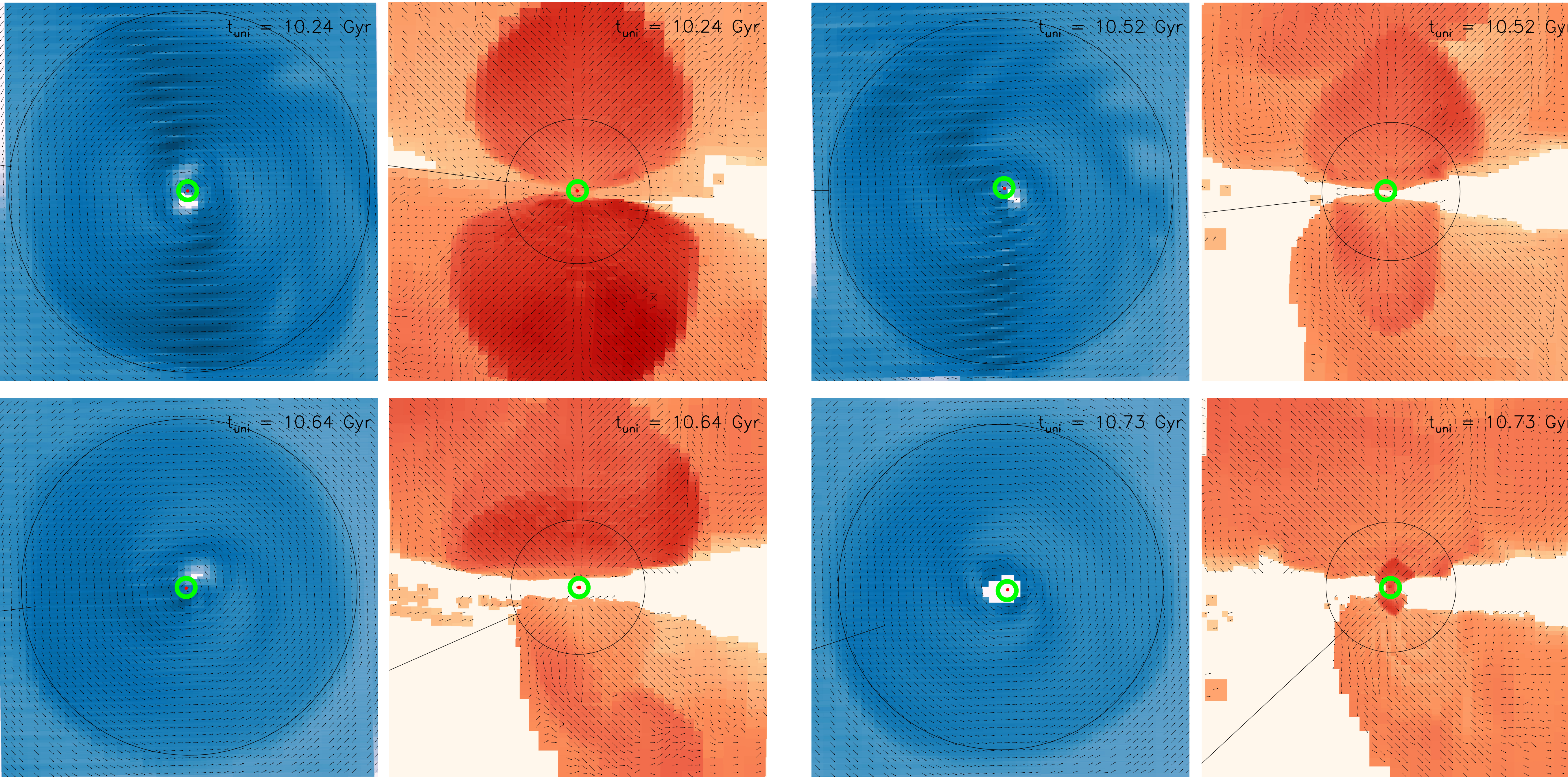
HI distorted & Dense ISM gas disk shrinks & asymmetric



Asymmetric distribution of the dense ISM component

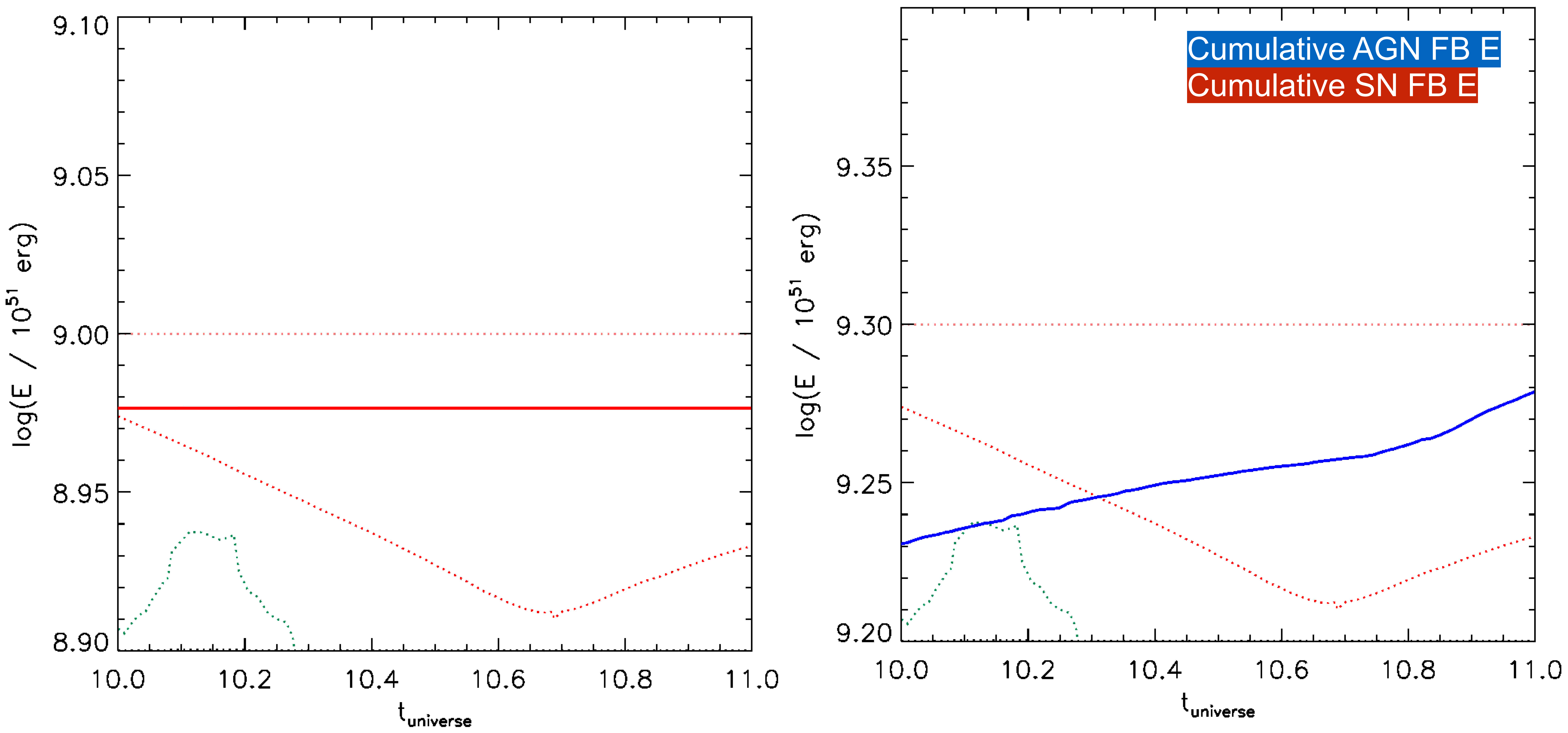


Strong Feedback affects gas disks?



Cold ISM density (face-on) | CGM temperature (edge-on) | Cold ISM density (face-on) | CGM temperature (edge-on)

AGN originated Feedback



Analysis: Quenc

Physical origin of Quenching (ID = 0013)

- **(C) SFR decreases further at the peri-center**

  > RP gets stronger

  > Dense ISM drops at the same epoch

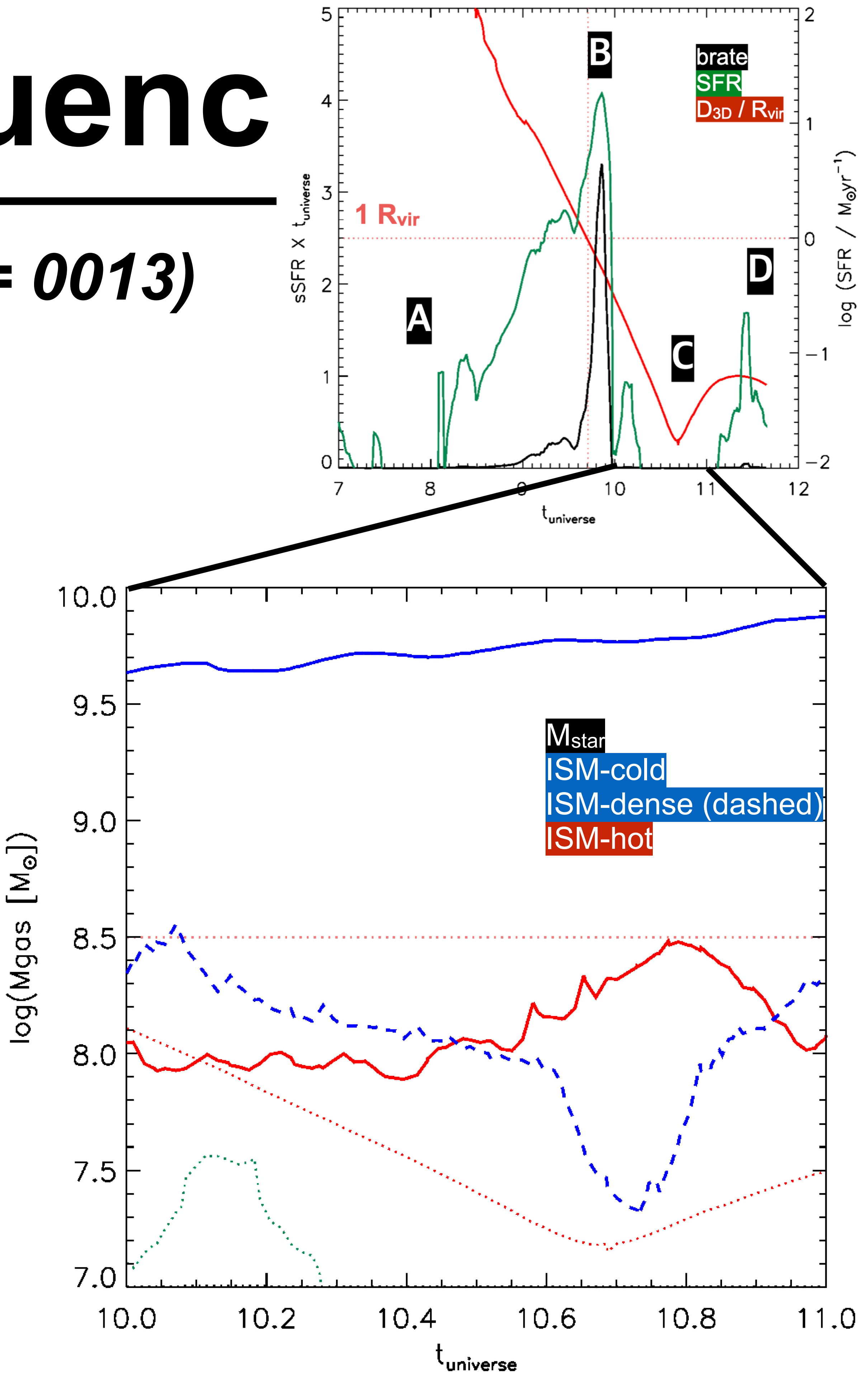
  Dense ISM gas disk shrinks and gets asymmetric

  An HI disk distortion is seen

  Somehow, AGN triggered and
  seems to destroy dense ISM gas disk

  Dense ISM still exists (or formed) at the front side

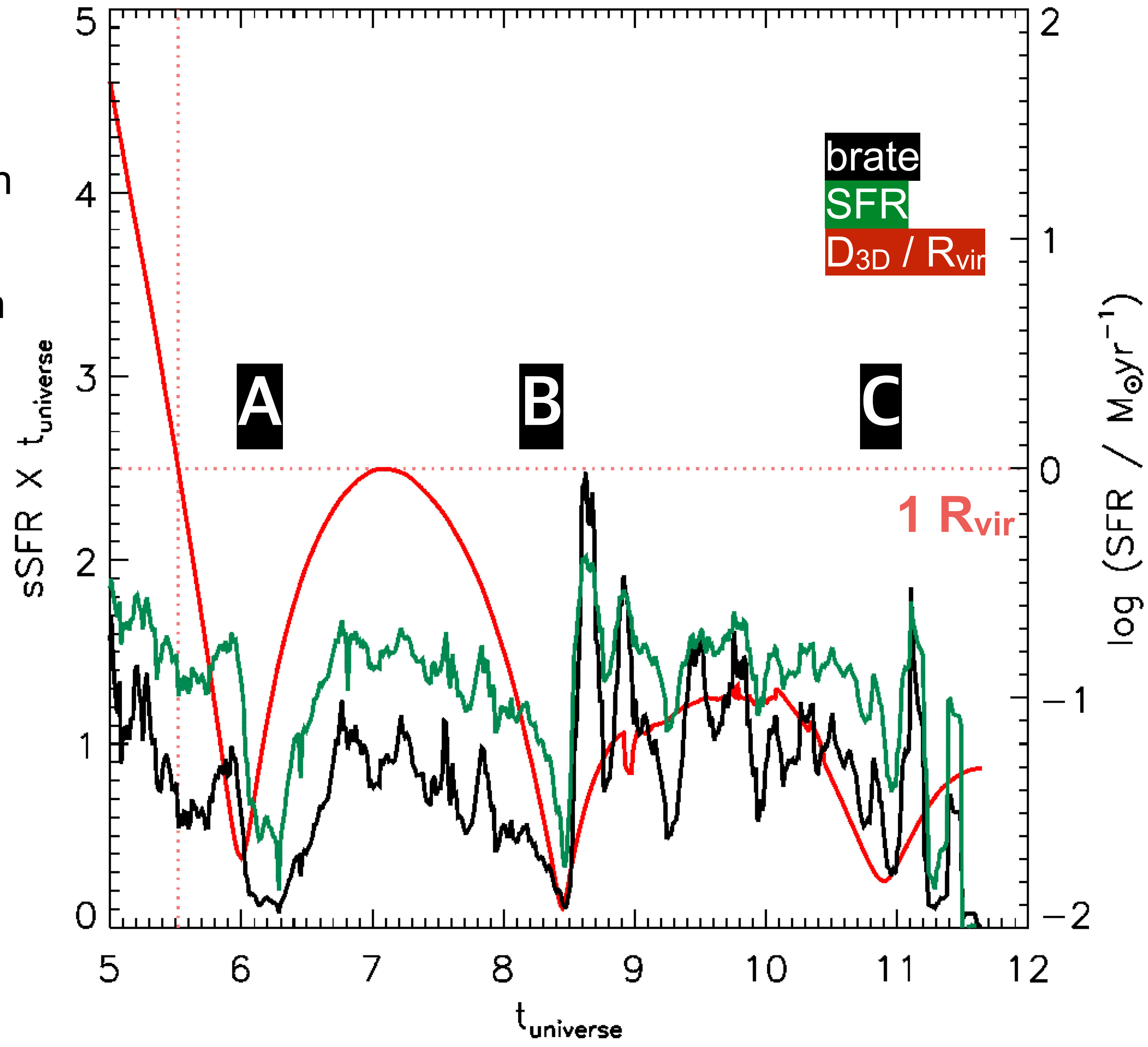
  RP triggers AGN!?



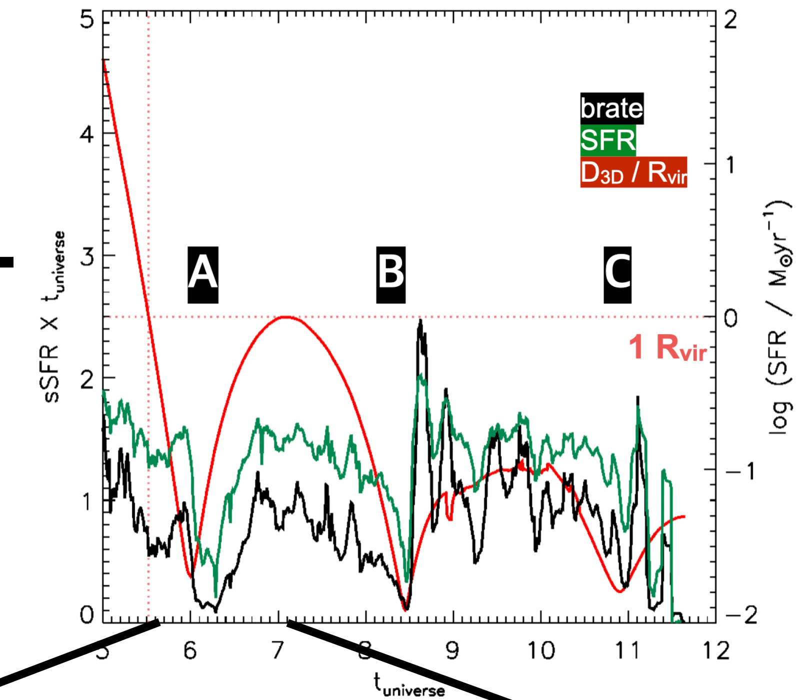
Analysis: Quenching

Physical origin of Quenching (ID = 0162)

- Galaxy ID=162 ($M_* = 1.5 \times 10^9\, M_\odot$)
- Clearly show an orbit-related quenching pattern
- Drops around peri-centers and increases again



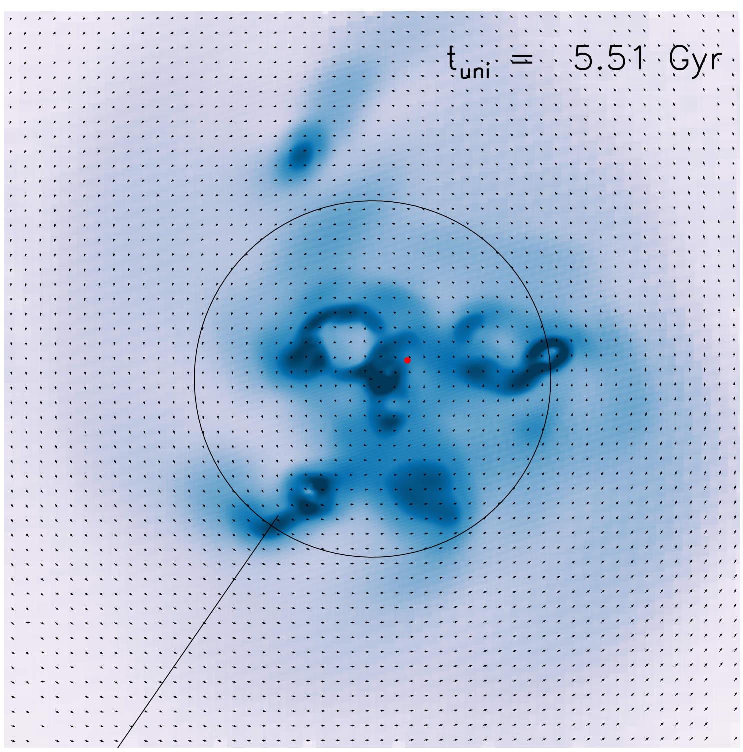
Analysis: Quenc



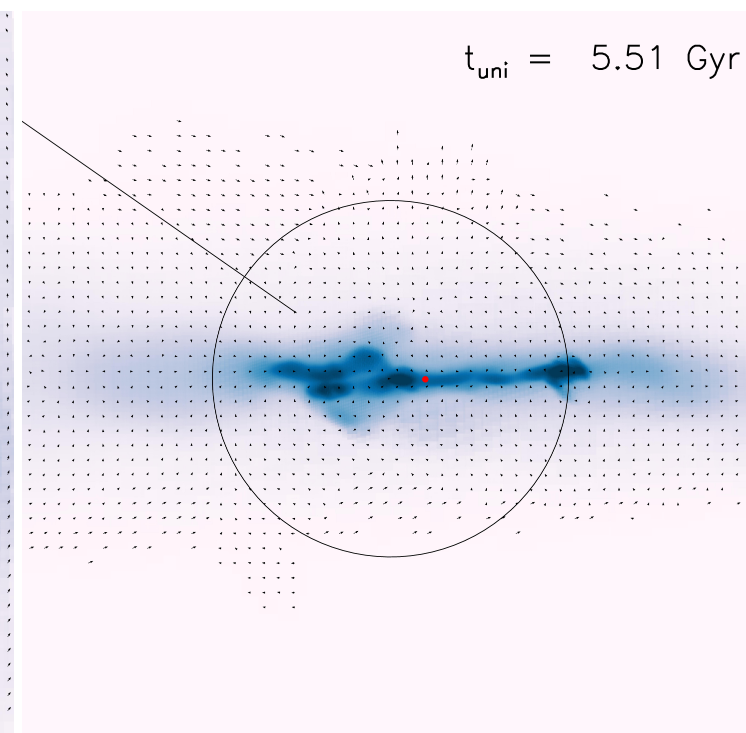
Physical origin of Quenching (ID = 0162)

- **(A) First peri-center passage**
  - > Cold ISM mass is consistent (5.5 - 6.5 Gyr)

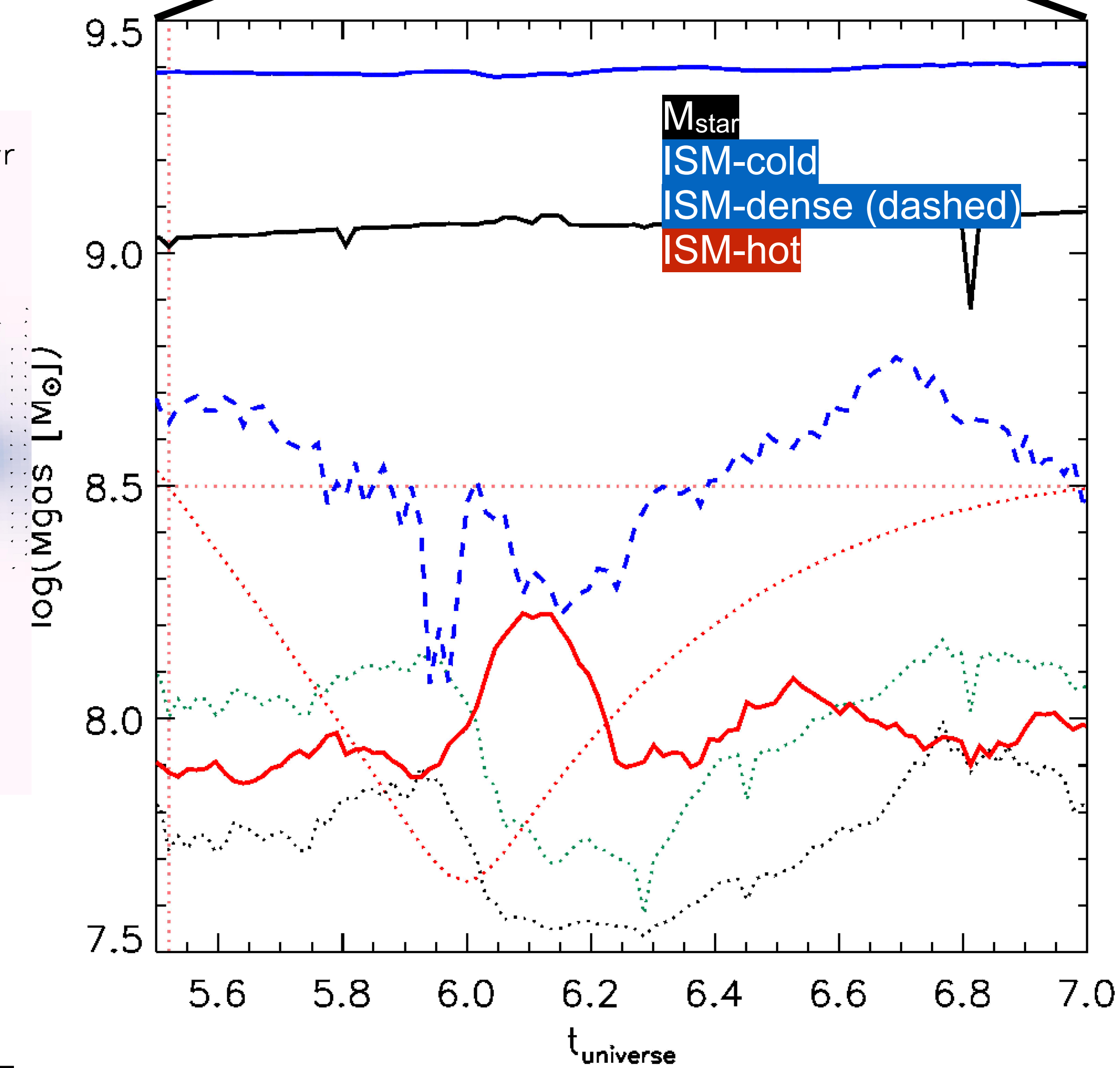
Cold gas disk exists (not arm-like but a group of blobs and weakly bound)



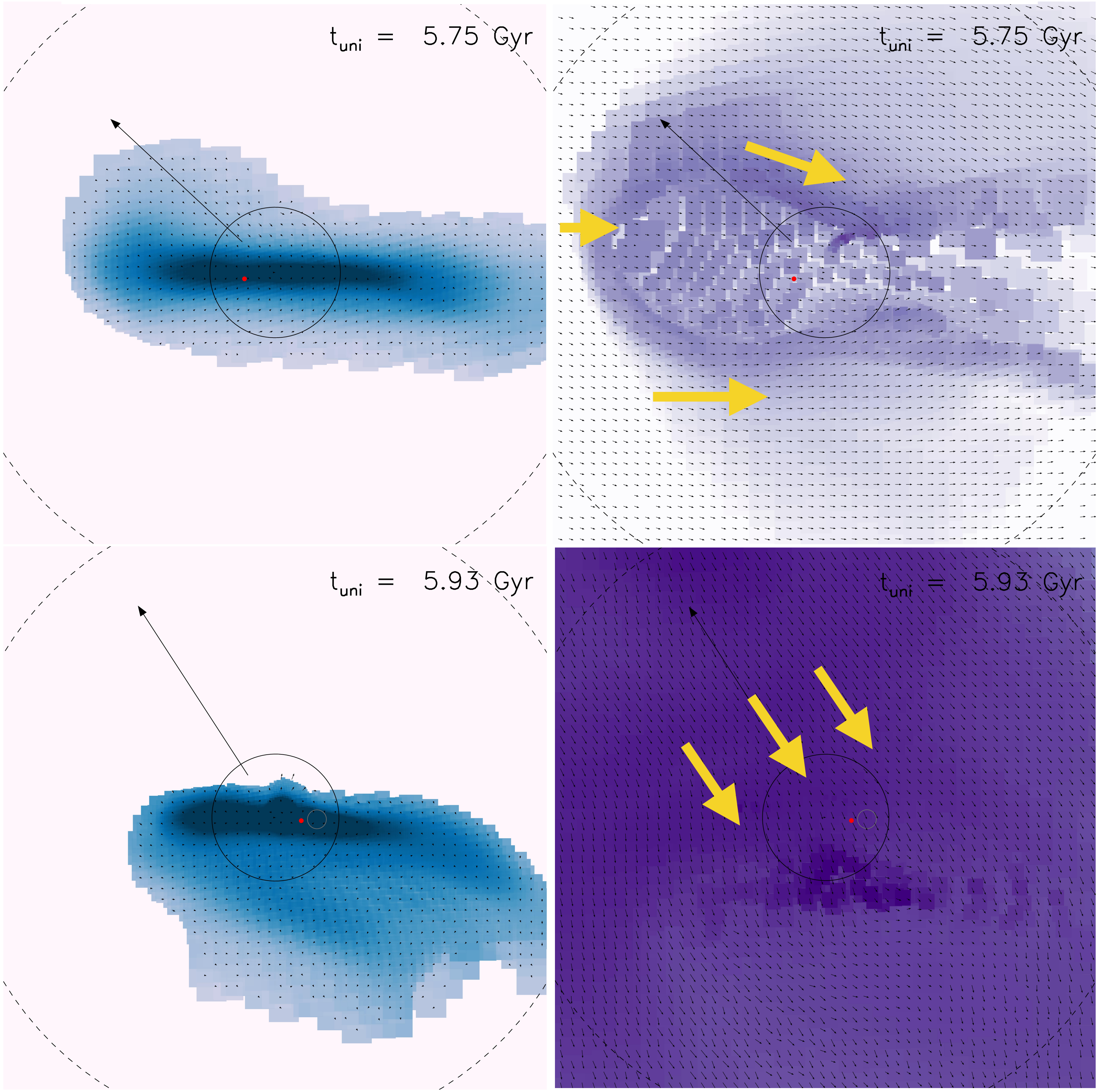
Cold ISM density (face-on)



Cold ISM density (edge-on)



Weak stripping (or disturbed) features



Analysis: Quenc

Physical origin of Quenching (ID = 0162)

- **(A) First peri-center passage**

  > Cold ISM mass is consistent (5.5 - 6.5 Gyr)

  Cold gas disk exists (not arm-like but a group of blobs and weakly bound)

  > Sudden Dense ISM drops at the peri-center passage

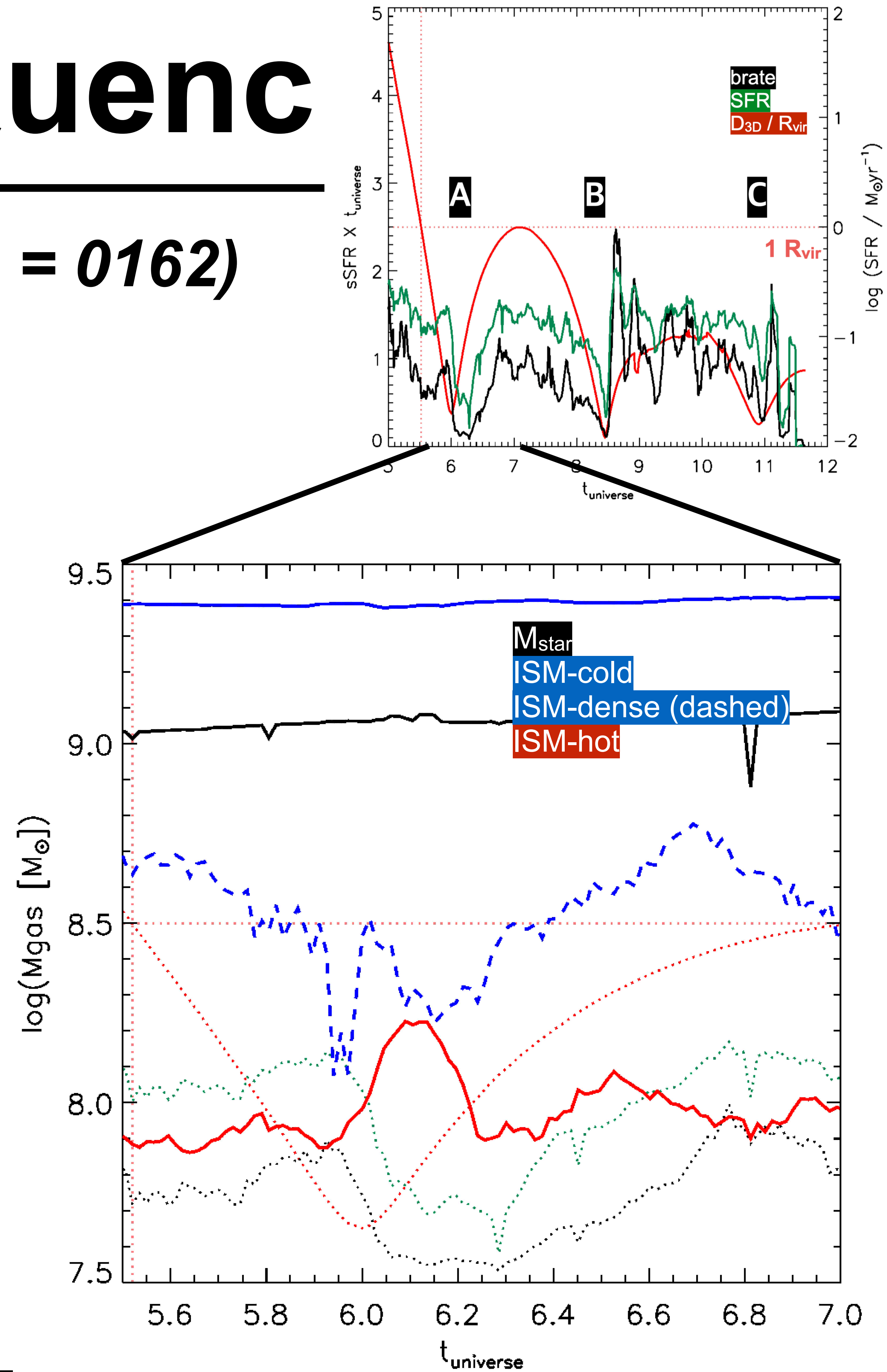
  Feedback-related? SN feedback destroys the central dense ISM blob

  RP only has only extended ISM gas stripped

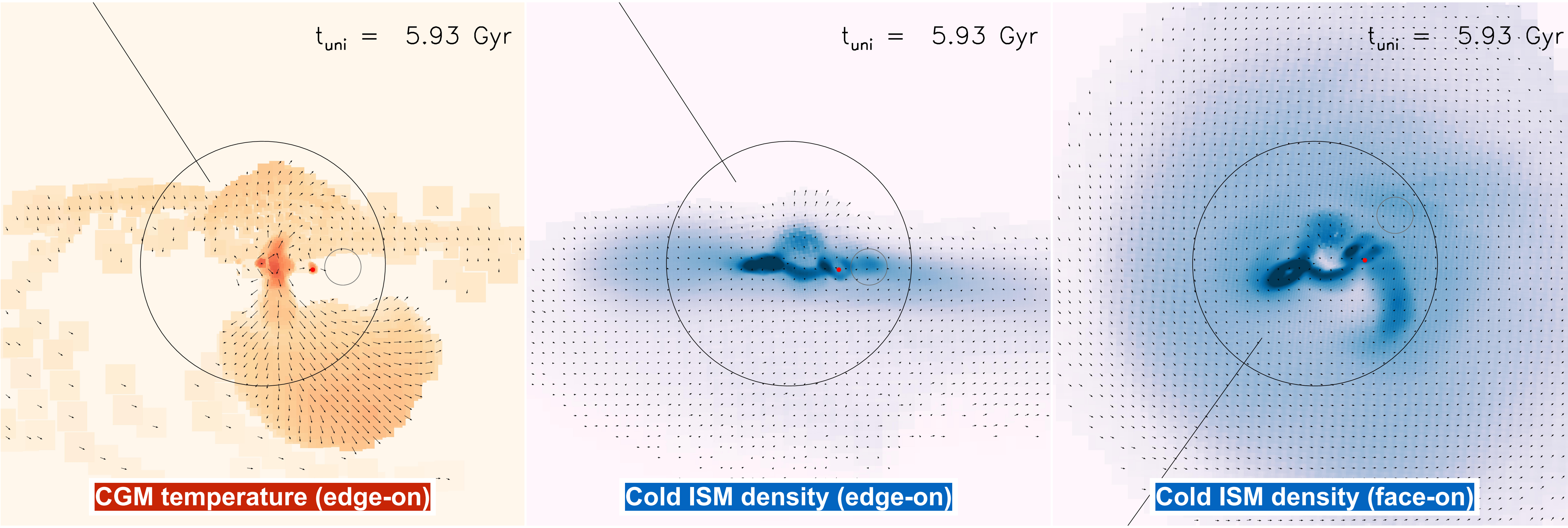
  > SFR quenched after the dense ISM drops

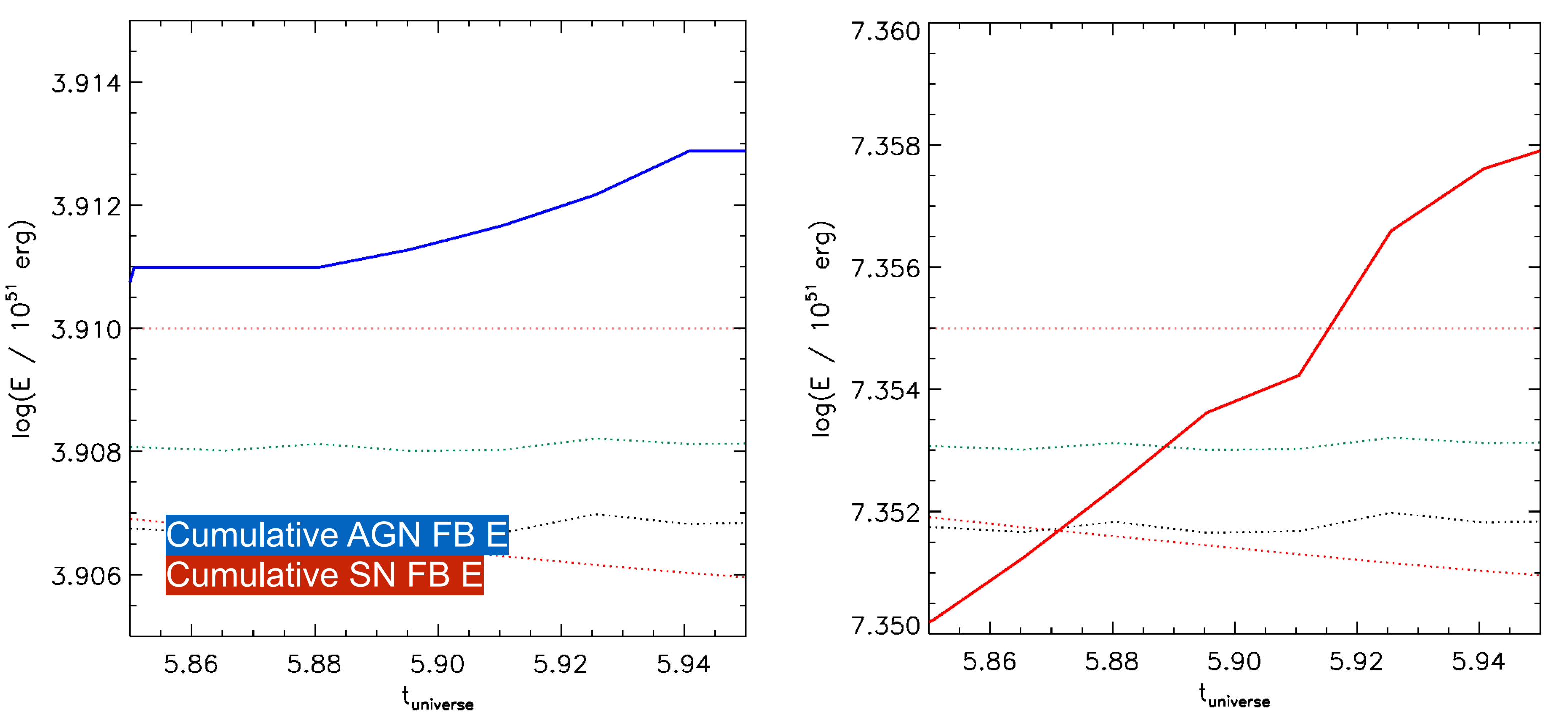
  delayed feature due to the time window of SFR measurement

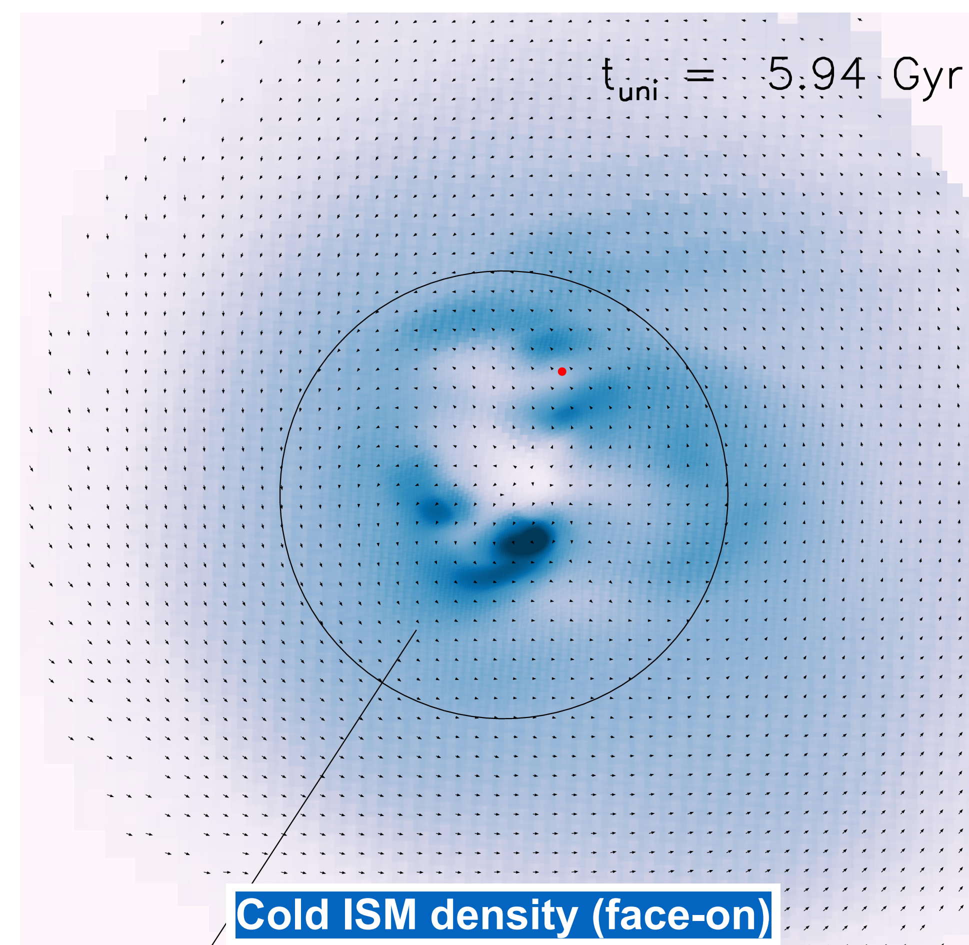
  Due to the reduction of dense ISM gas



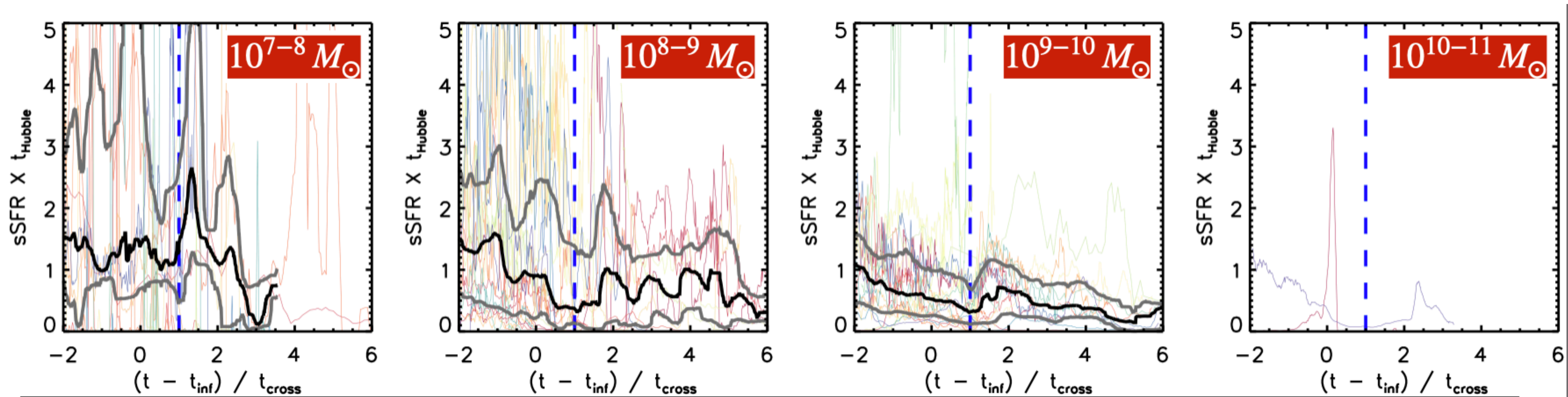
SN Feedback blows ISM gas







Conclusion



- Group galaxies are more quenched than their field counterpart
- SFH of group galaxies show **a orbit-related quenching feature**

  > **Increase prior to infall** - cold gas inflow

  > **Low SFR at the pericenter** - Feedback rather than RP

  > Show HI stripping feature but its total mass is not significantly changed

  > **Rejuvenation after the pericenter** - H_2 disk settling from the remained HI disk

- Dense ISM decrease seems to be originated from feedback events
- Feedback activity seems to be boosted when ram-pressure acts