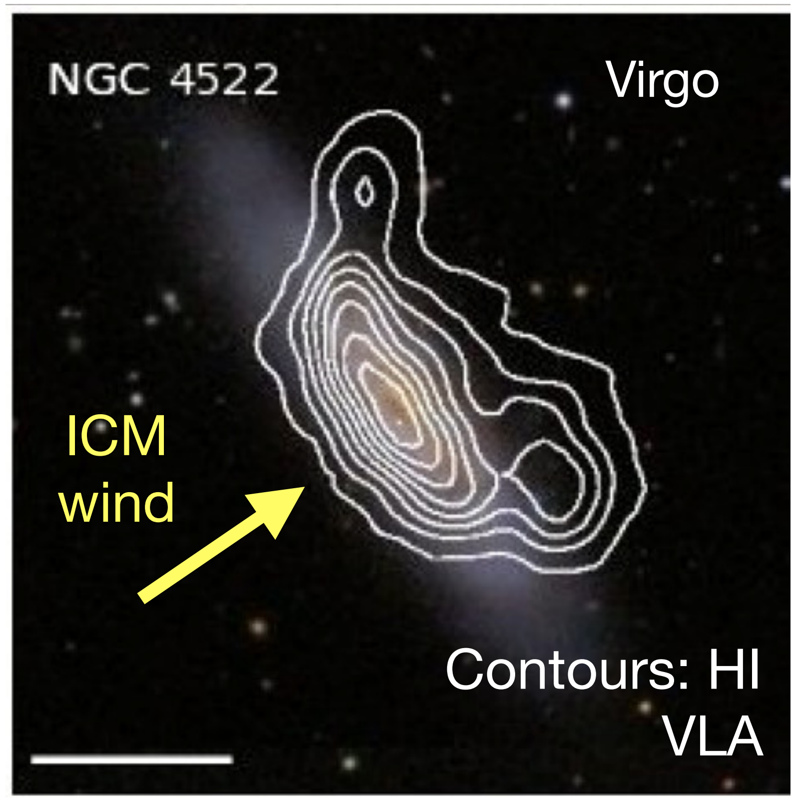
Environment Workshop 2021

The impact of ram pressure stripping on galaxies with varying gas fraction

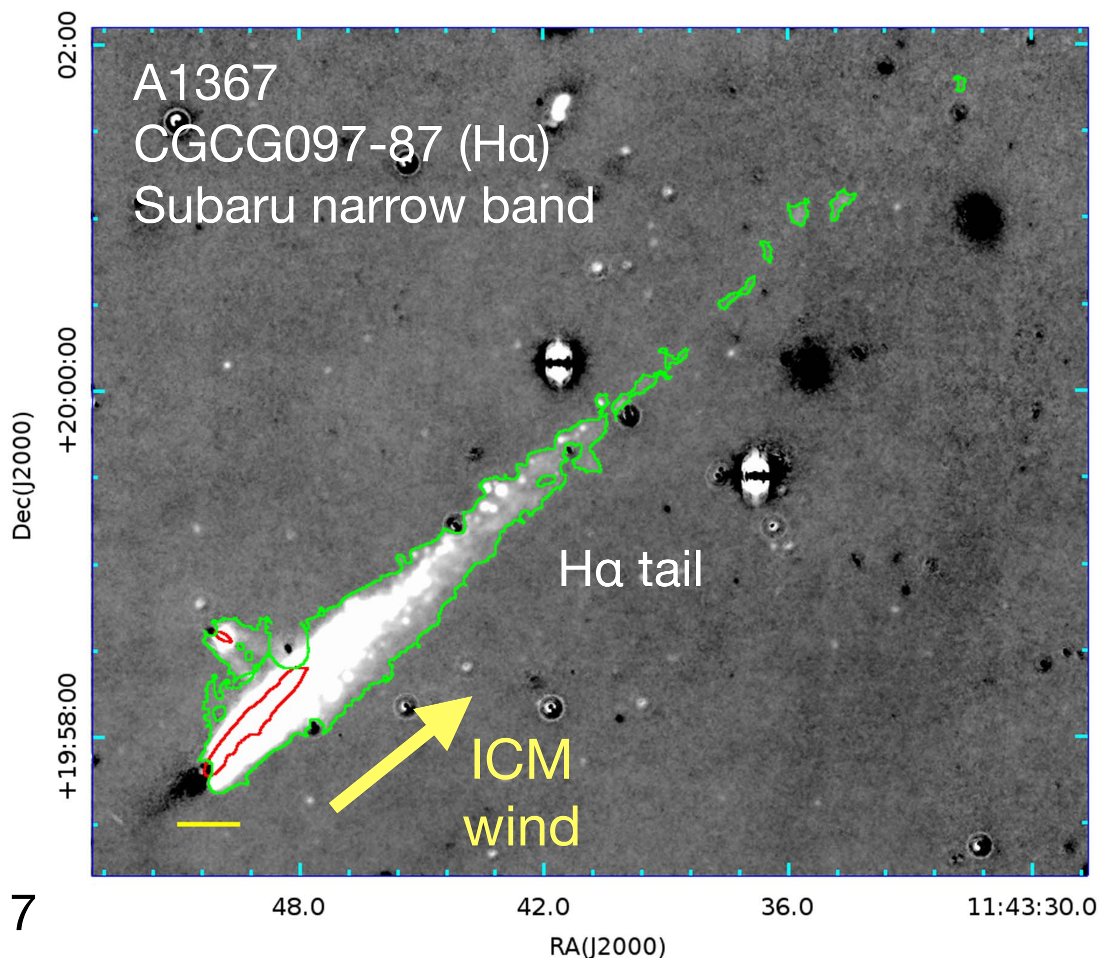
Jaehyun Lee (KIAS)

with Taysun Kimm (Yonsei) Haley Katz (Oxford) Joakim Rosdahl (Lyon)
Julien Devriendt (Oxford) Adrianne Slyz (Oxford)

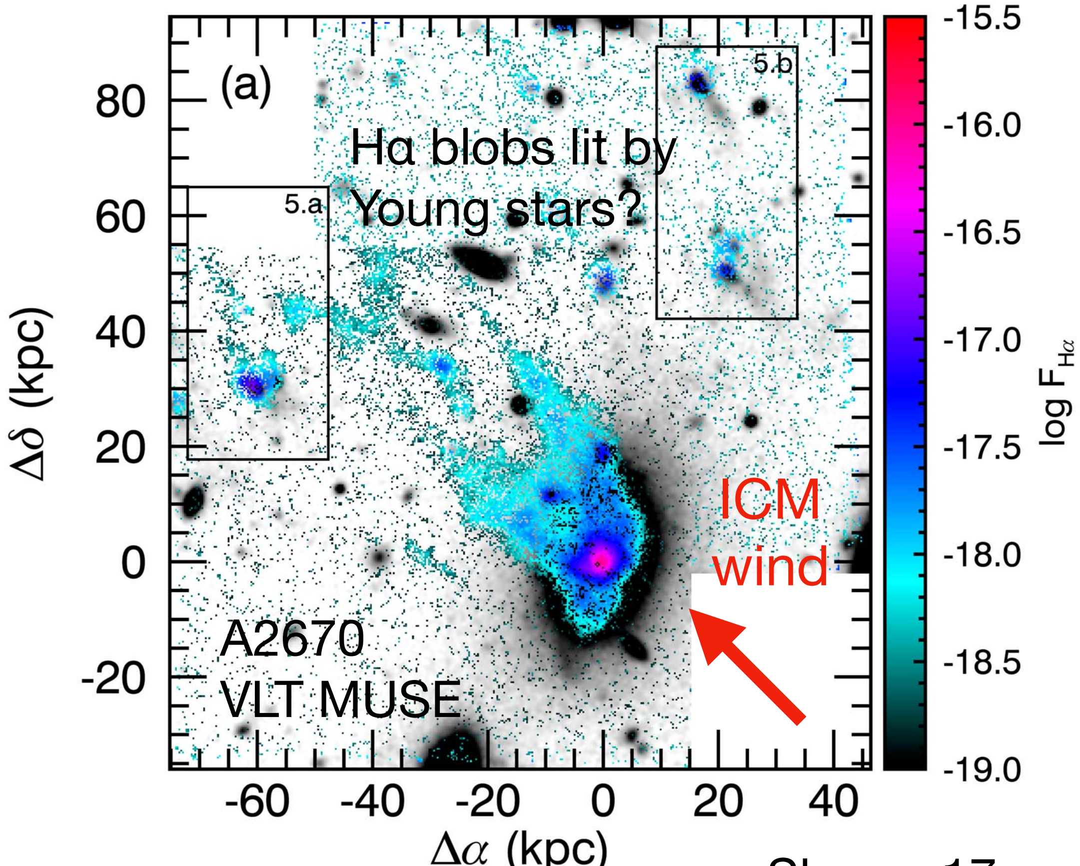
- Ram pressure stripping
  - Hydrodynamical process which can directly blow gas away from galaxies
    $$P_{\rm ram} \sim \rho_{\rm ICM} v^2$$
  - More effective in denser environments
  - Young stars are detected in the wakes of some ram pressure stripped galaxies



Chung+09

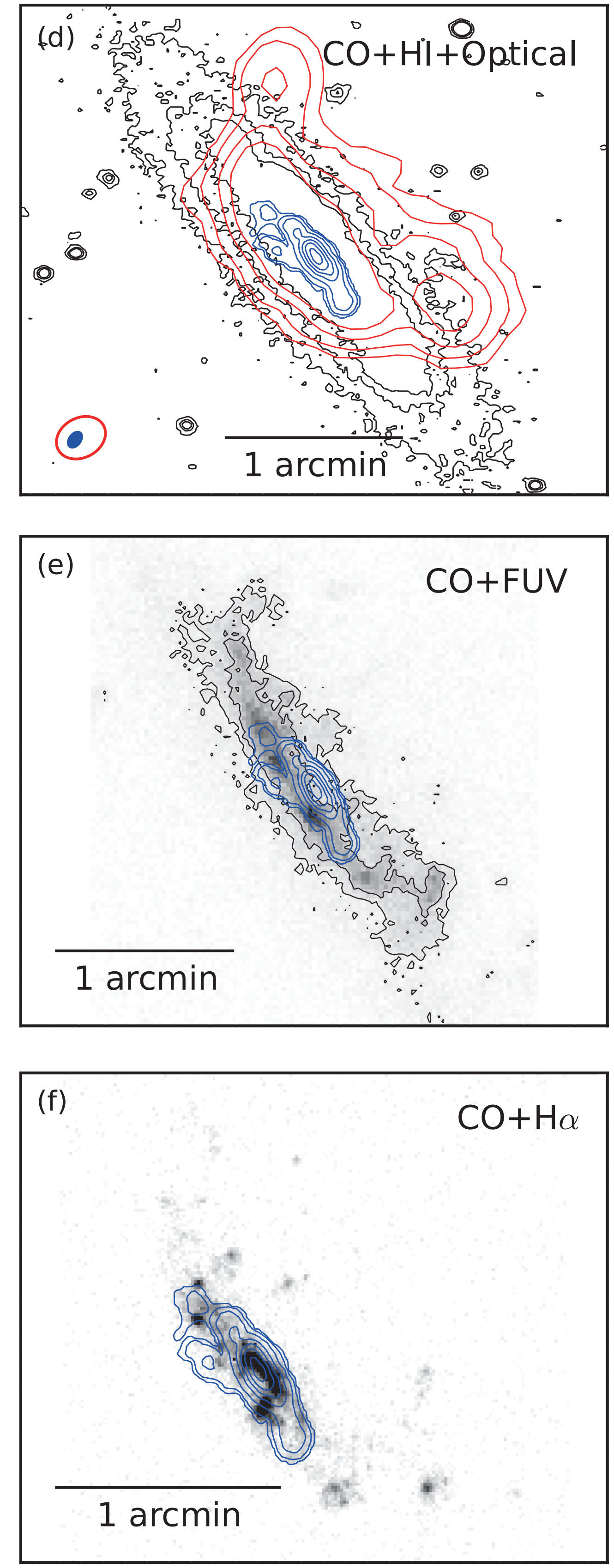


Yagi+17



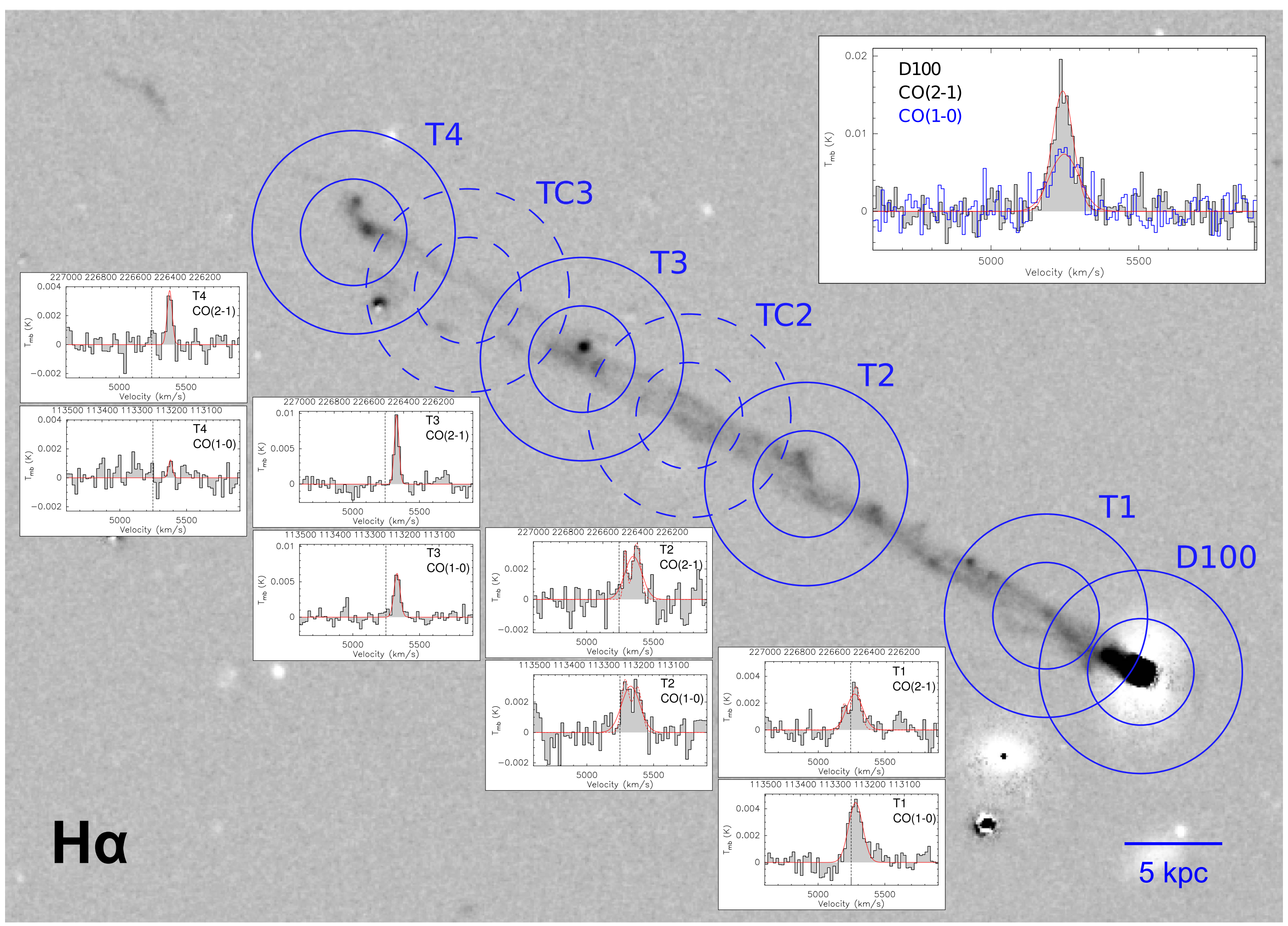
Sheen+17

- Effects of ram pressure on multi-phase disks
  - Ram pressure features are evident in HI, but it is not the case in CO
  - CO is concentrated more than FUV (t_*<100Myr)
  - A strong correlation is seen between CO and Hα (t_*<20Myr)
    - The molecular disk has shrunk for the last a few hundred Myr?

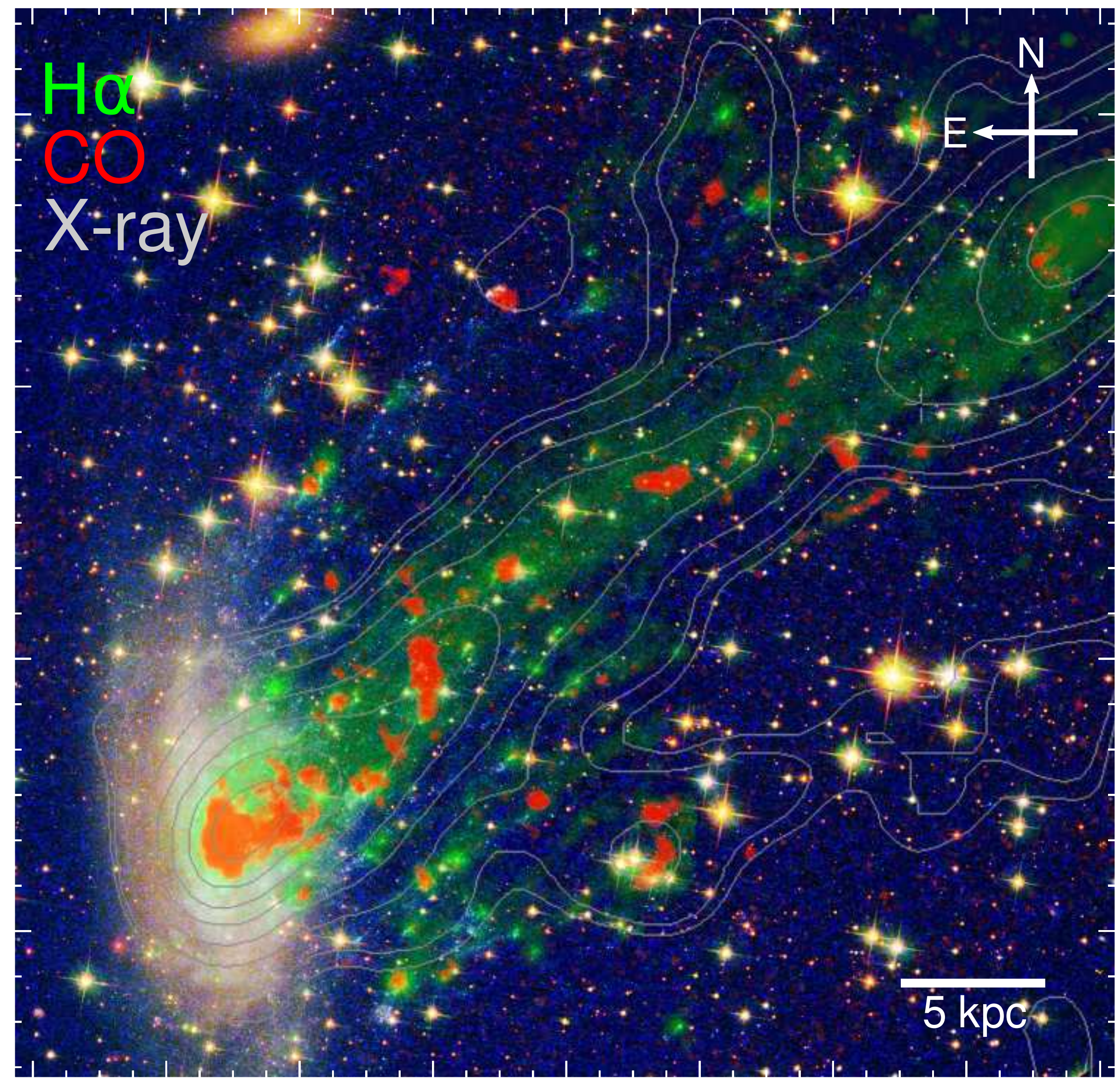


NGC4522 Lee+17

- So far, only two galaxies are confirmed to have molecular-rich tails
  - In the tails, $M_{H_2} \sim 10^9 M_\odot$, bright in Hα and X-ray, but HI deficit
  - Weak SF activities in the tails ($\sim 10^{-3} M_\odot$/yr)



D100 in Coma cluster
Jachym+17

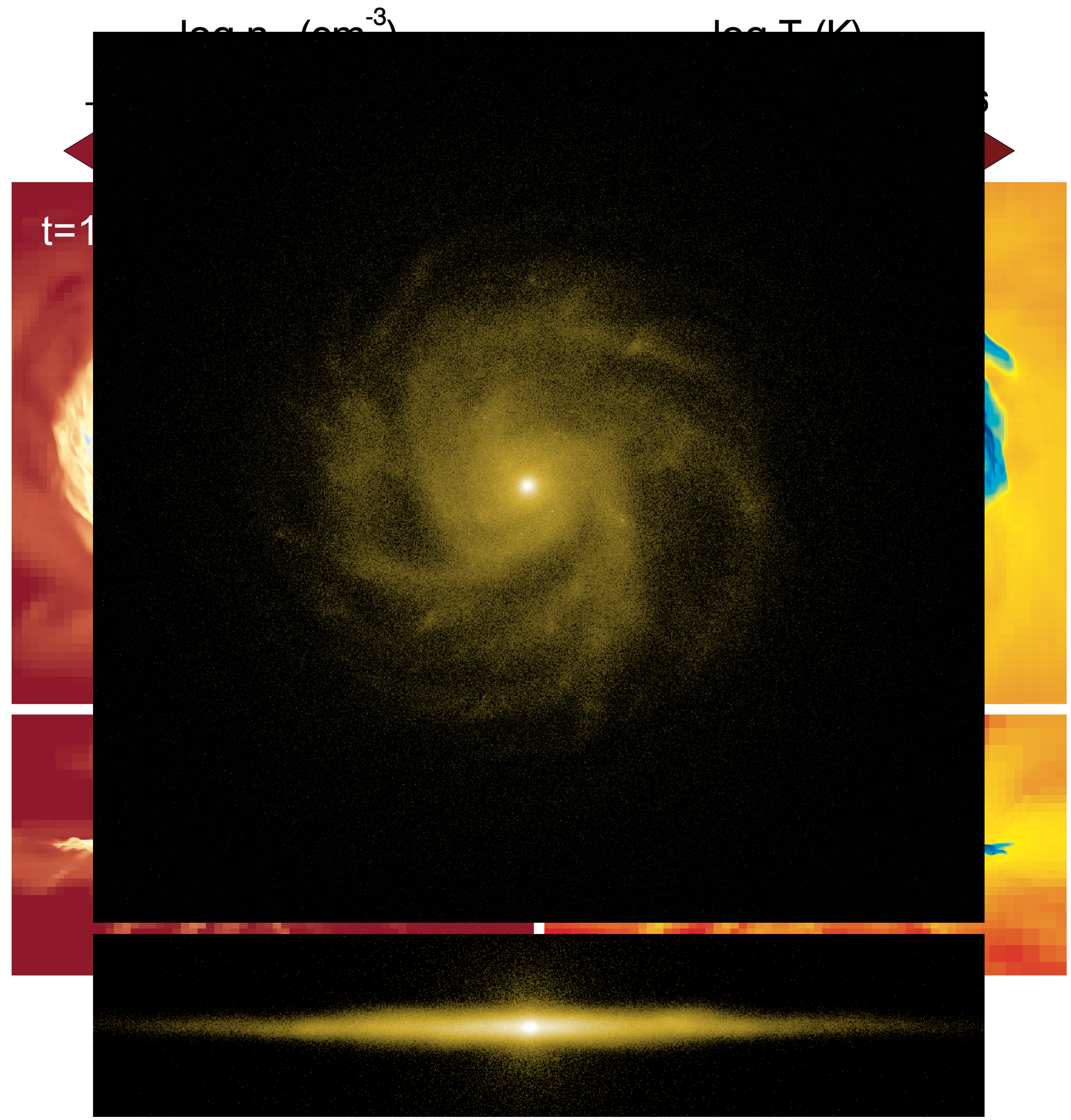


EOS137-001 in Norma cluster
Jachym+19

- Key questions
    - How does ram pressure affect multi-phase gas clouds?
        - Is molecular clouds hardly stripped? or just under detection limit?
    - How does ram pressure affect star formation activities?
        - How does ram pressure regulate SF in disks?
        - What are the essential conditions for star formation in RPS tails?

- RAMSES-RT
  - Developed by Teyssier 02; Rosdahl+13; Rosdahl & Teyssier 15
  - Updated by Katz+17; Kimm+17, 18
    - H_2 formation and dissociation
    - Star formation based on thermo-turbulent model
      - SFE can vary, depending on the turbulent condition of ISM
    - Mechanical SN feedback

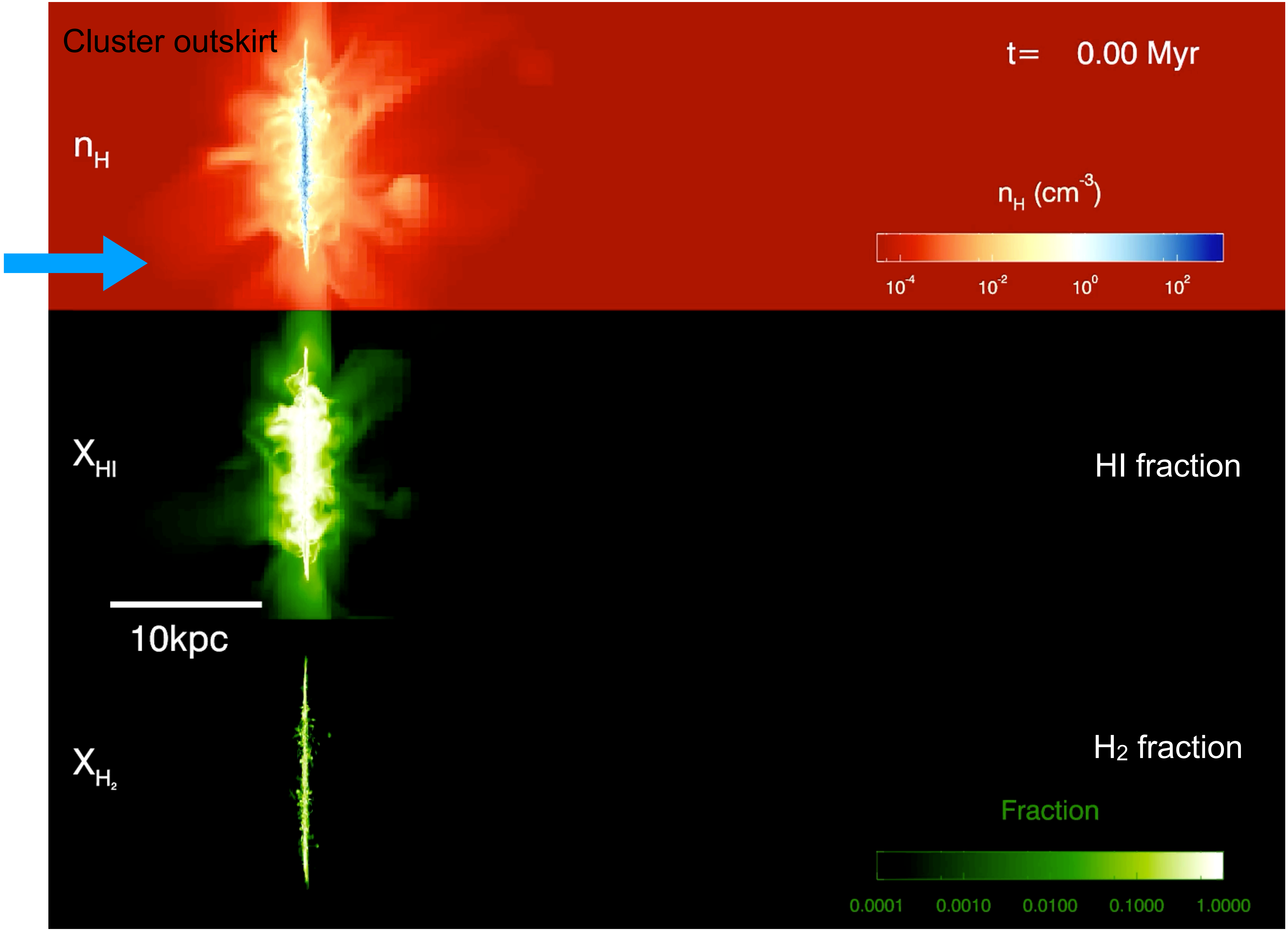
- Simulation setup
    - Wind-tunnel experiments for a galaxy
    - IC generated by Rosdahl+15 using MakeDisk (Springel+05)
    - Box size: 300kpc on a side
    - M_{halo}~$10^{11}M_{\odot}$, R_{vir}=89 kpc
    - Cell resolution down to 18pc
    - $M_{\star}$~$2.1 \times 10^{9} M_{\odot}$ ($R_{1/2}$~2.4kpc)
    - Gas content before arrival of winds
        - f_{cold}~$0.32 = M_{cold}/(M_{cold}+M_{\star})$
        - M_{HI}~$7 \times 10^{8} M_{\odot}$, M_{H_2}~$3 \times 10^{8} M_{\odot}$
        - $R_{1/2,cold}$ ~3 kpc



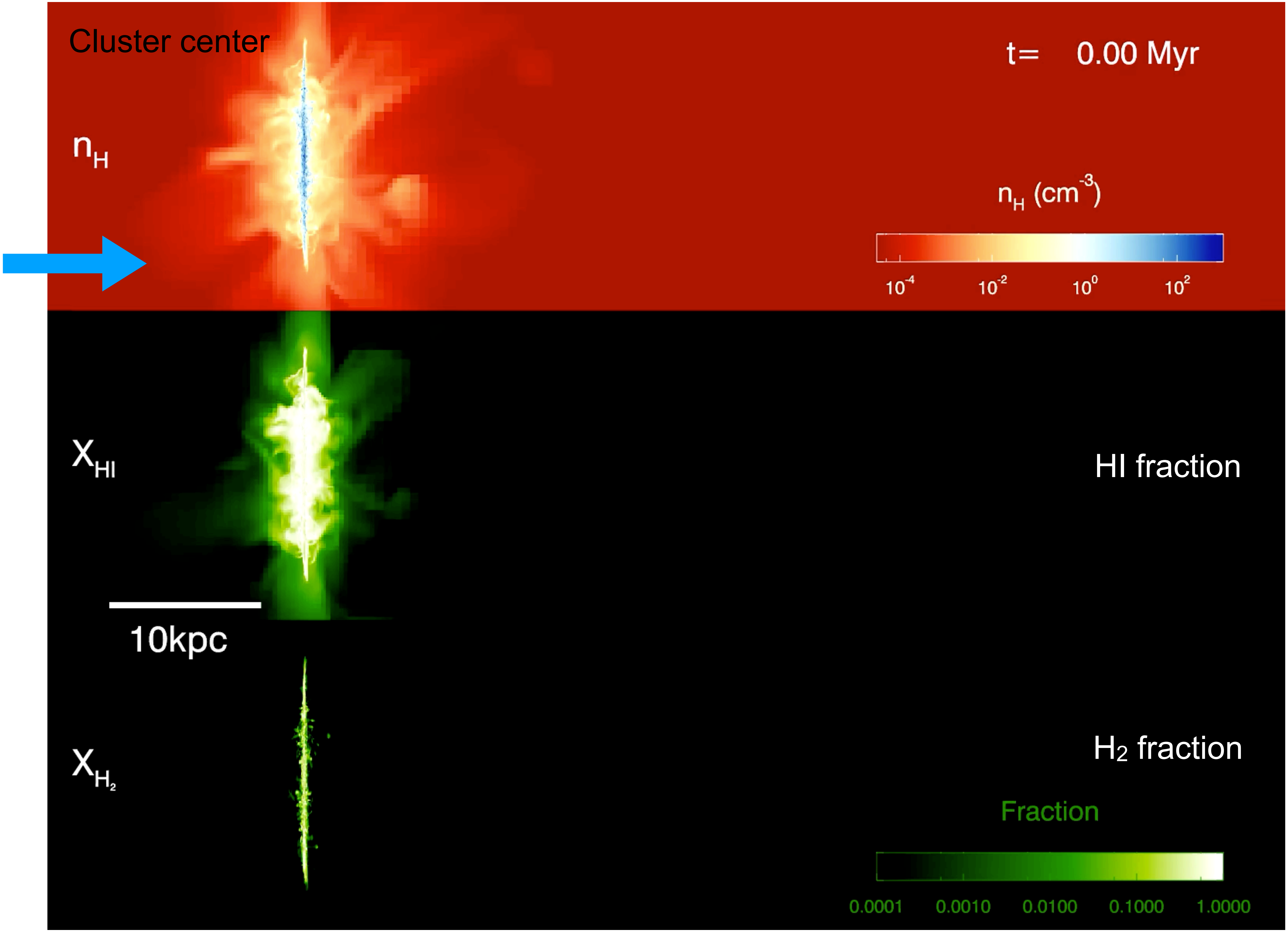
- Suite of Simulations
  - No wind (control sample) - an analogue of an isolated environment
  - With winds - mimicking cluster environments
    - Cluster outskirts
      - P_{ram}/k_B~$5x10^4 cm^{-3}$K, n_H~$10^{-4} cm^{-3}$, v_{wind}=1,000km s^{-1}, T_{ICM} ~10^7K
        - Face-on, Edge-on
    - Cluster center
      - P_{ram}/k_B~$5x10^5 cm^{-3}$K, n_H~$10^{-3} cm^{-3}$, v_{wind}=1,000km s^{-1}
        - Face-on with winds of T_{ICM} ~10^7K

          + gas rich case (new results in this talk!)
        - Face-on with winds of T_{ICM} ~10^6K

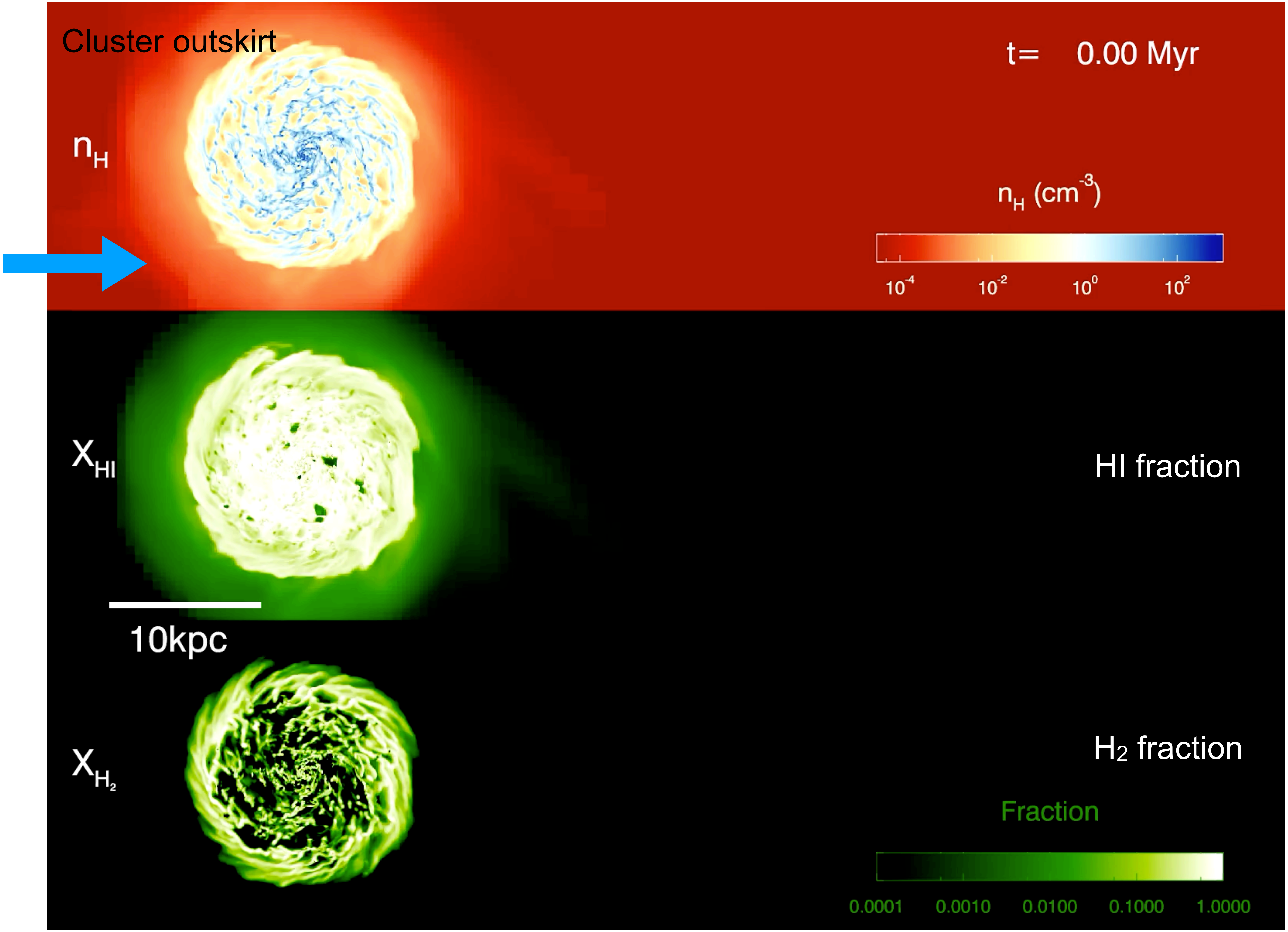
- FaceWind ($n_H \sim 10^{-4}$, $P_{ram}/k_B \sim 5 \times 10^4 cm^{-3}K$, $v_{wind} = 10^3 km\ s^{-1}$)



- FaceWind10 ($n_H \sim 10^{-3}$, $P_{ram}/k_B \sim 5 \times 10^5 cm^{-3} K$, $v_{wind} = 10^3 km\ s^{-1}$)



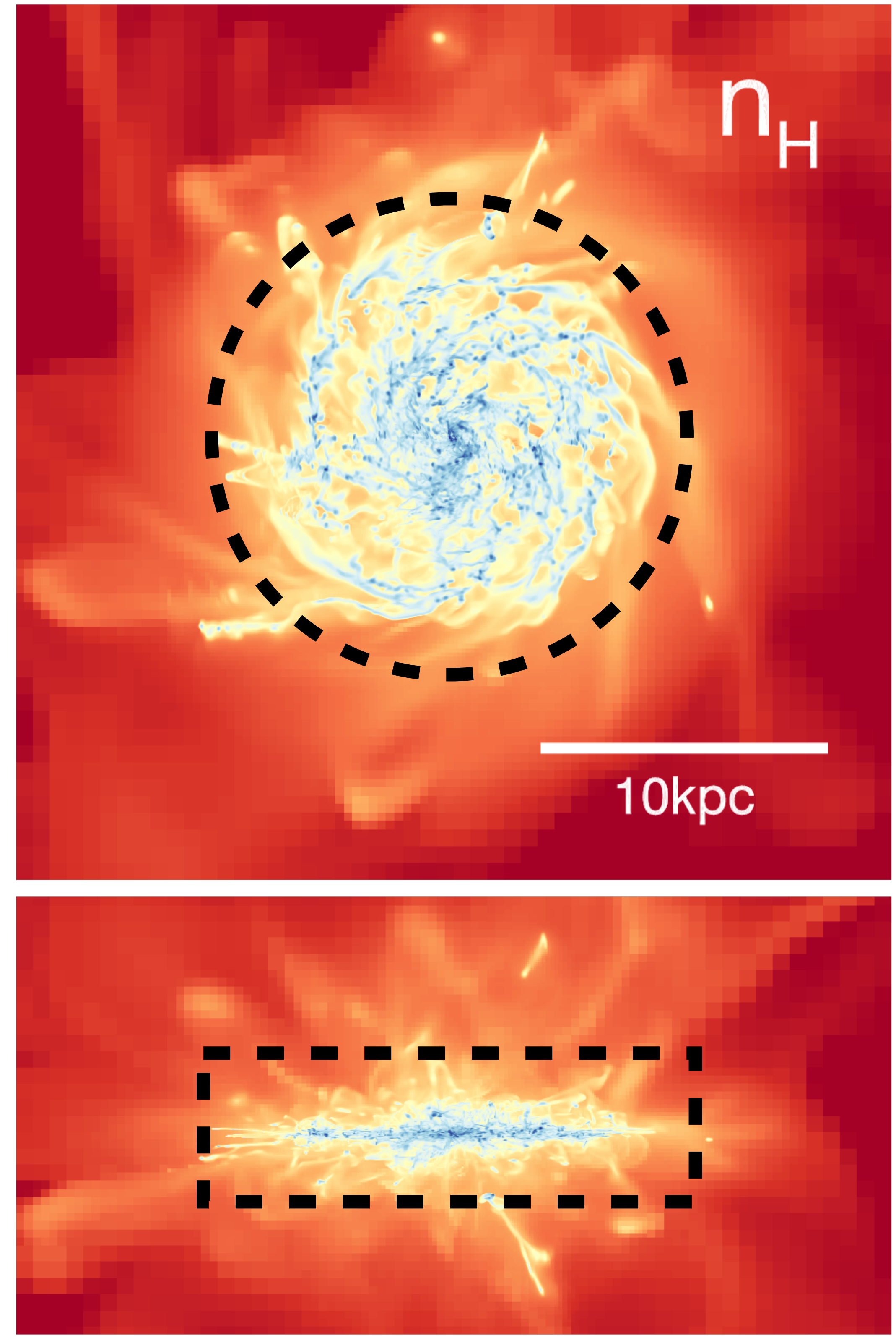
- EdgeWind (n_H~10^{-4}, P_{ram}/k_B~$5x10^4 cm^{-3}K$, $v_{wind}=10^3 km\ s^{-1}$)



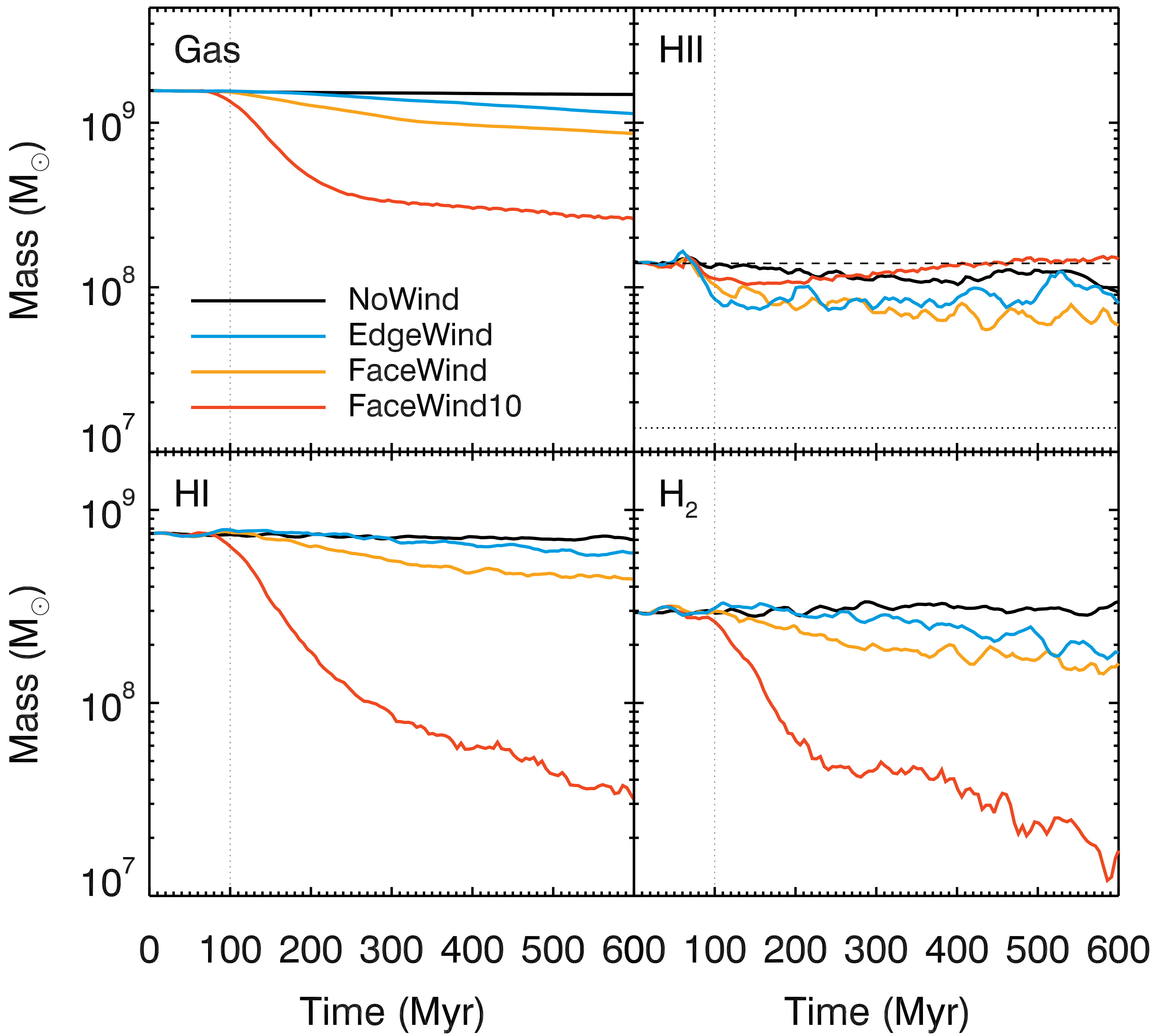
- Disk components

  - Gas content located inside a cylindrical volume of h=±3kpc and r=10kpc (~3$R_{1/2}$ of HI+H_2) are defined as the gaseous disk

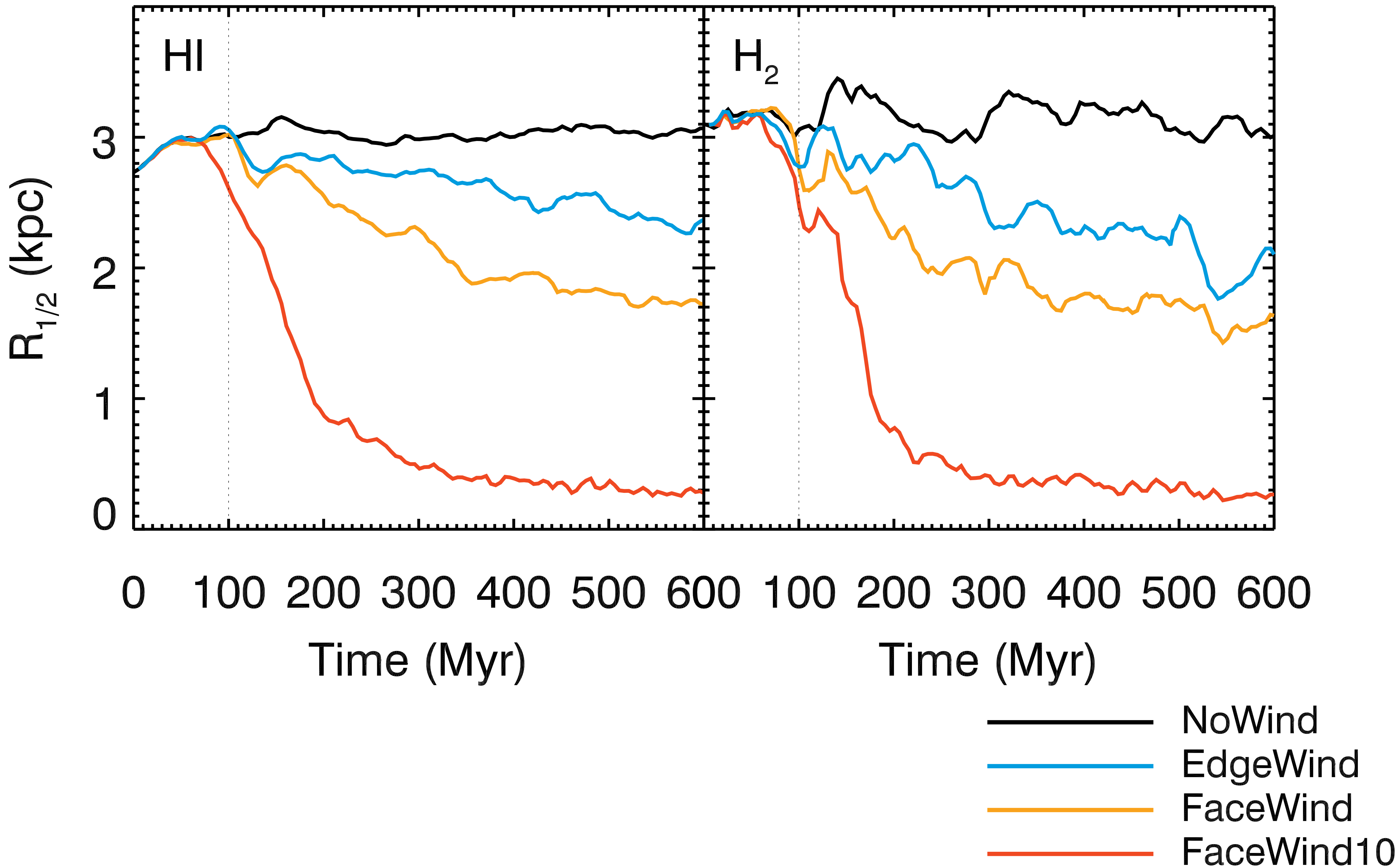
  - More than 99.9% of cold gas (HI and H_2) is initially located inside the cylinder



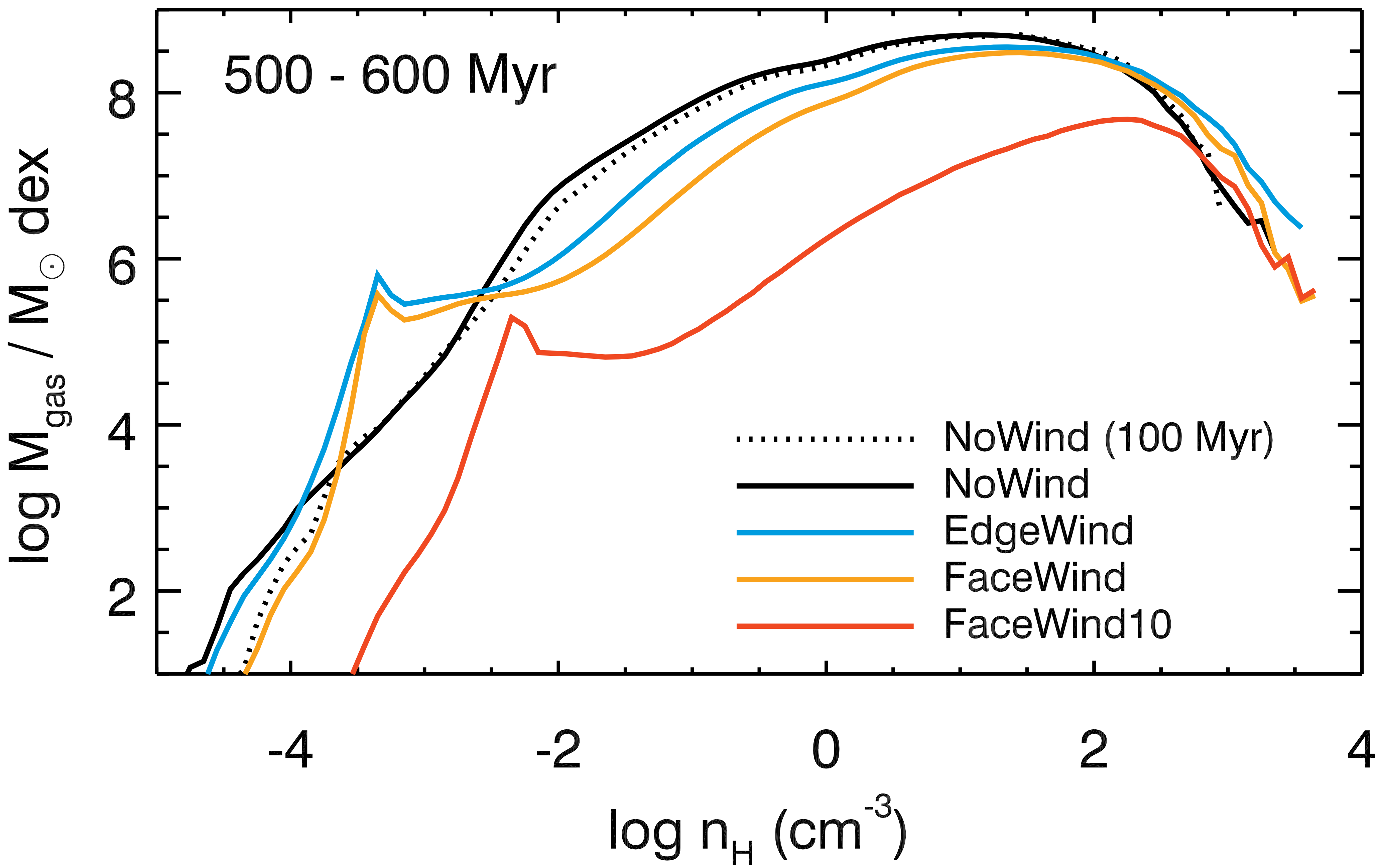
- Impact of RPS on the gaseous disk - mass
  - Mass loss is larger with stronger winds



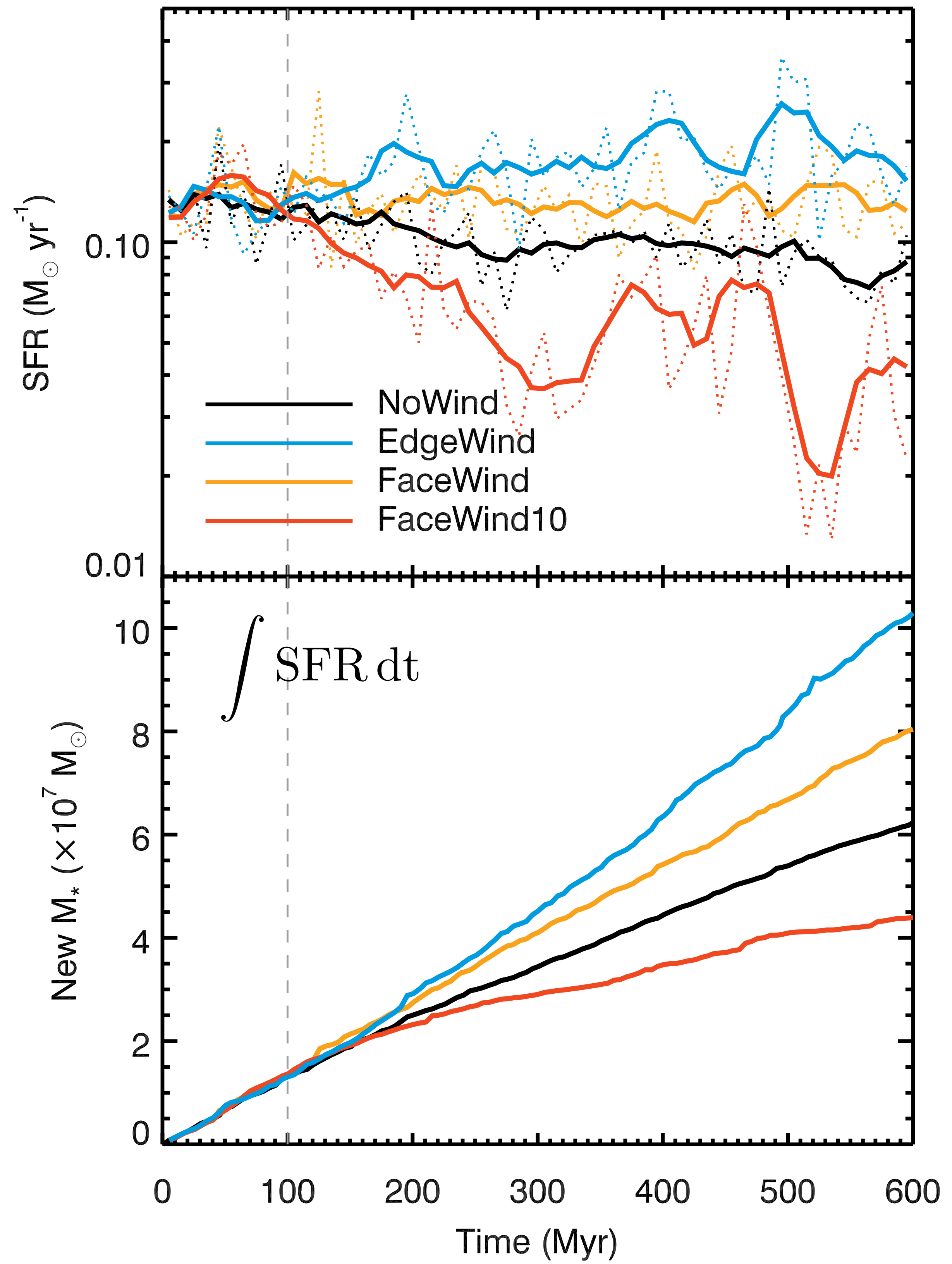
- Impact of RPS on the gaseous disk - size ($R_{1/2}$)
    - Gaseous disk shrinks/is truncated more with stronger winds



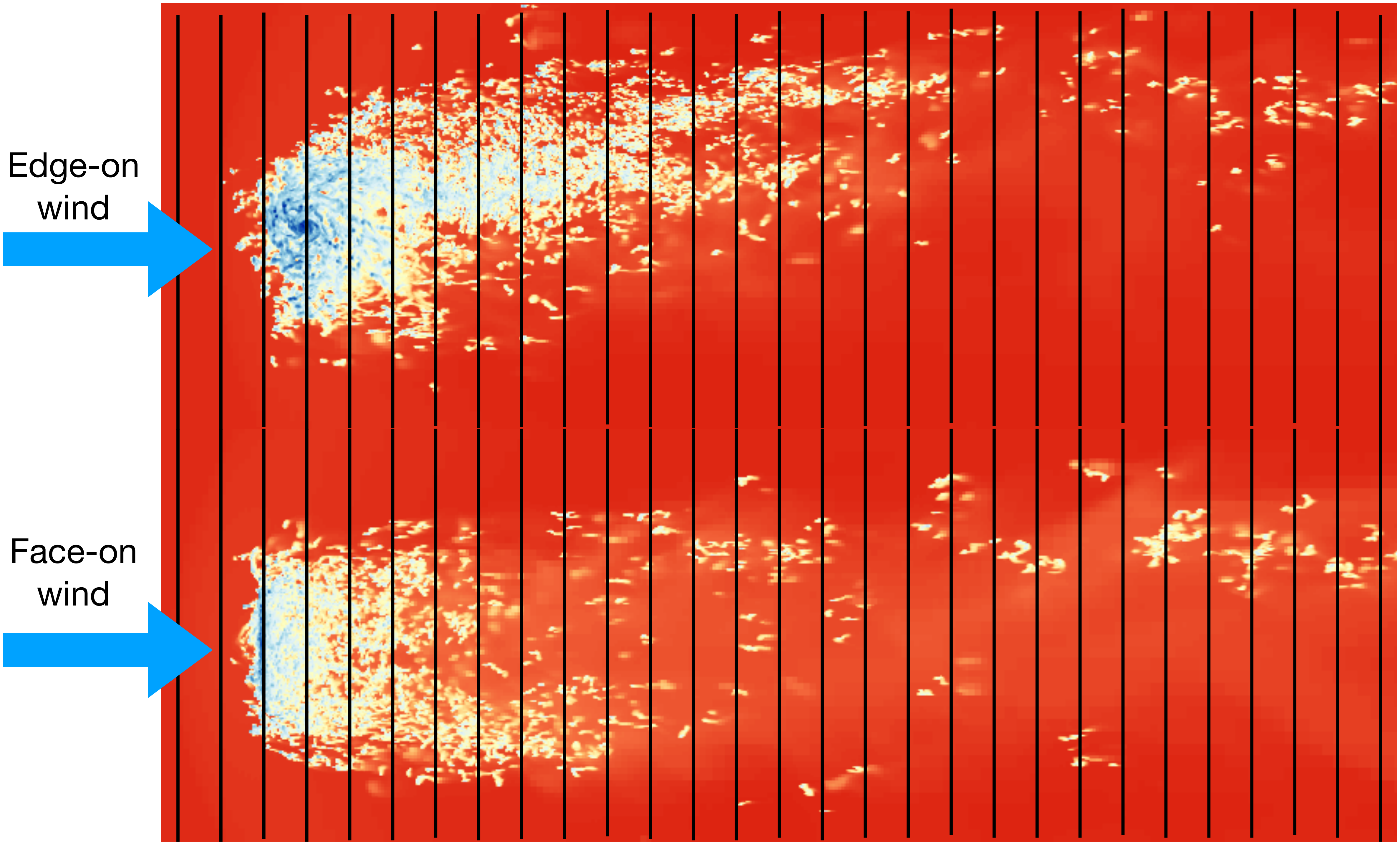
- Cloud density function
  - ICM winds blow a significant amount of low density gas away from the galaxy
  - In contrast, the amount of dense clouds rather increases with mild RP



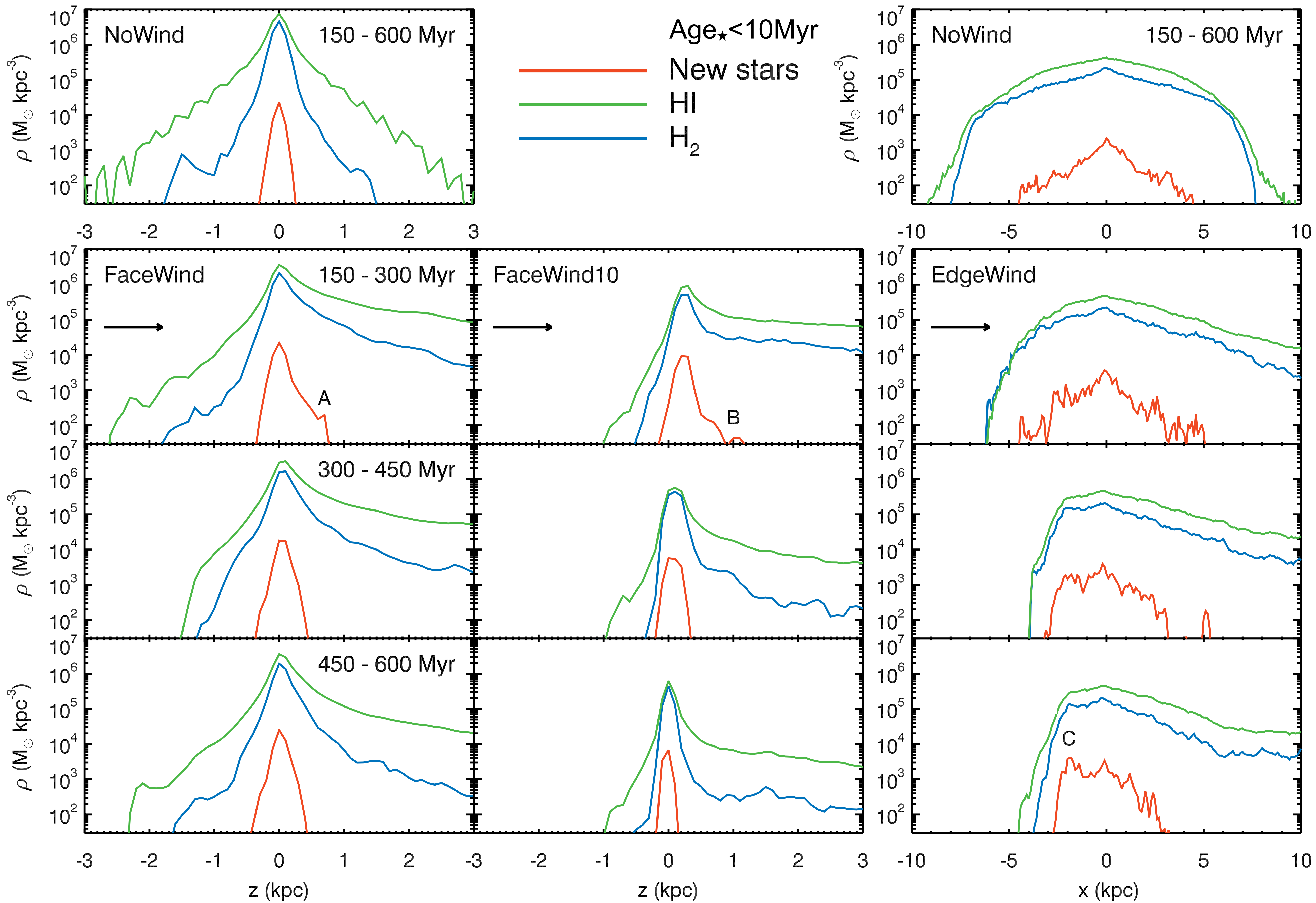
- Impact of RPS on SF in the disk
    - Moderate winds enhance the SF activity on the disk
    - SF is most strongly boosted by edge-on wind
    - SF is quickly suppressed by the strong wind



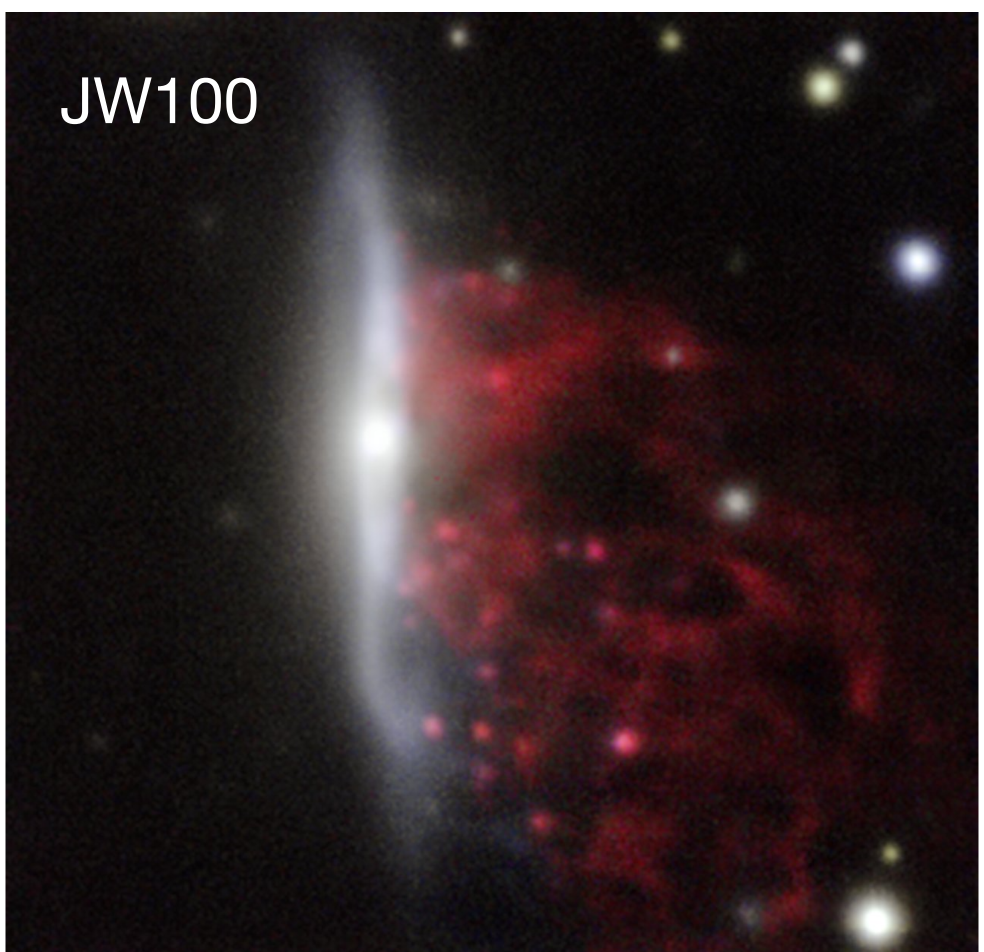
- Where stars form - slicing the galaxy perpendicular to the direction of winds



- Where stars form

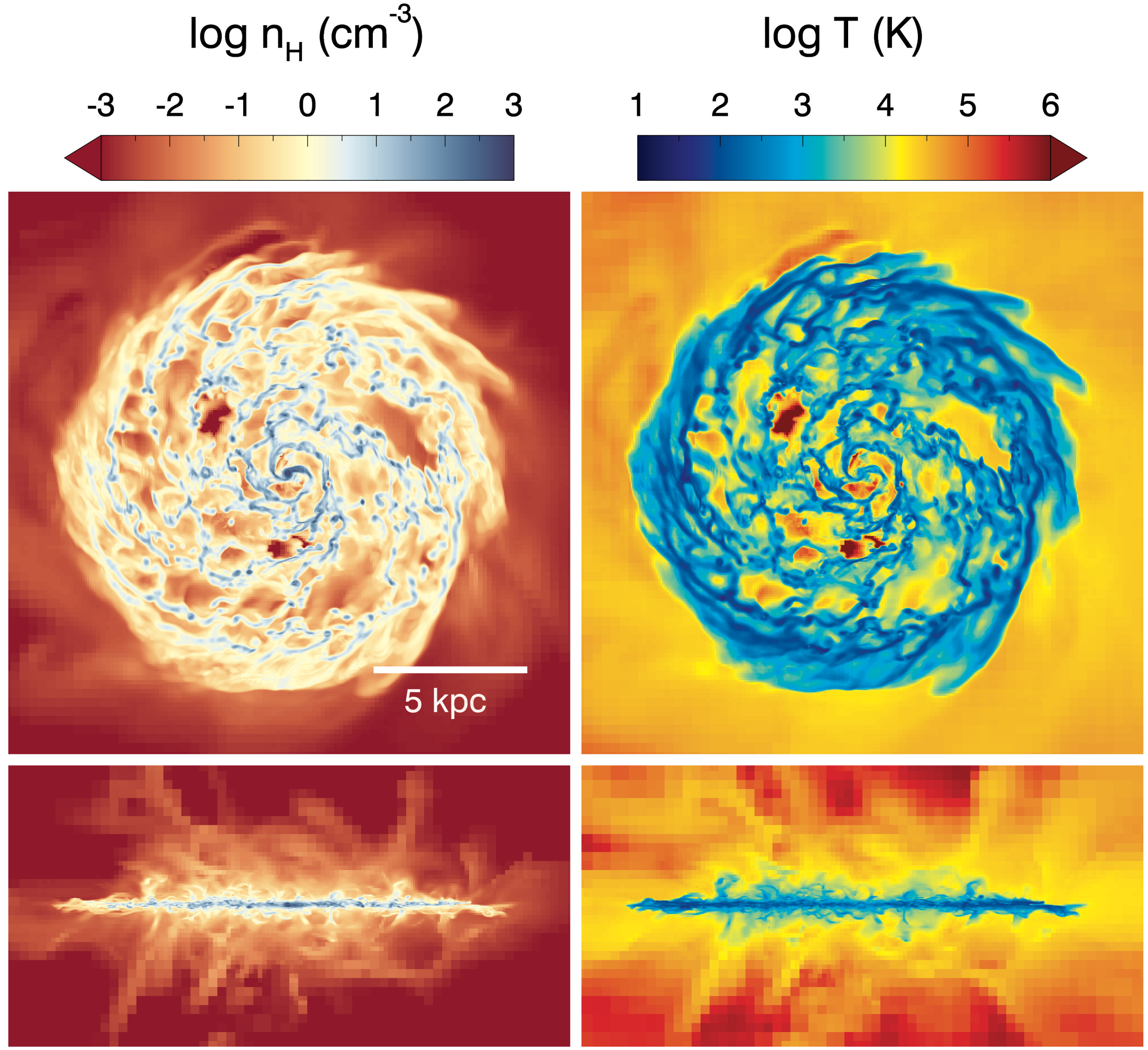


- SF signatures are detected in many RPS galaxies



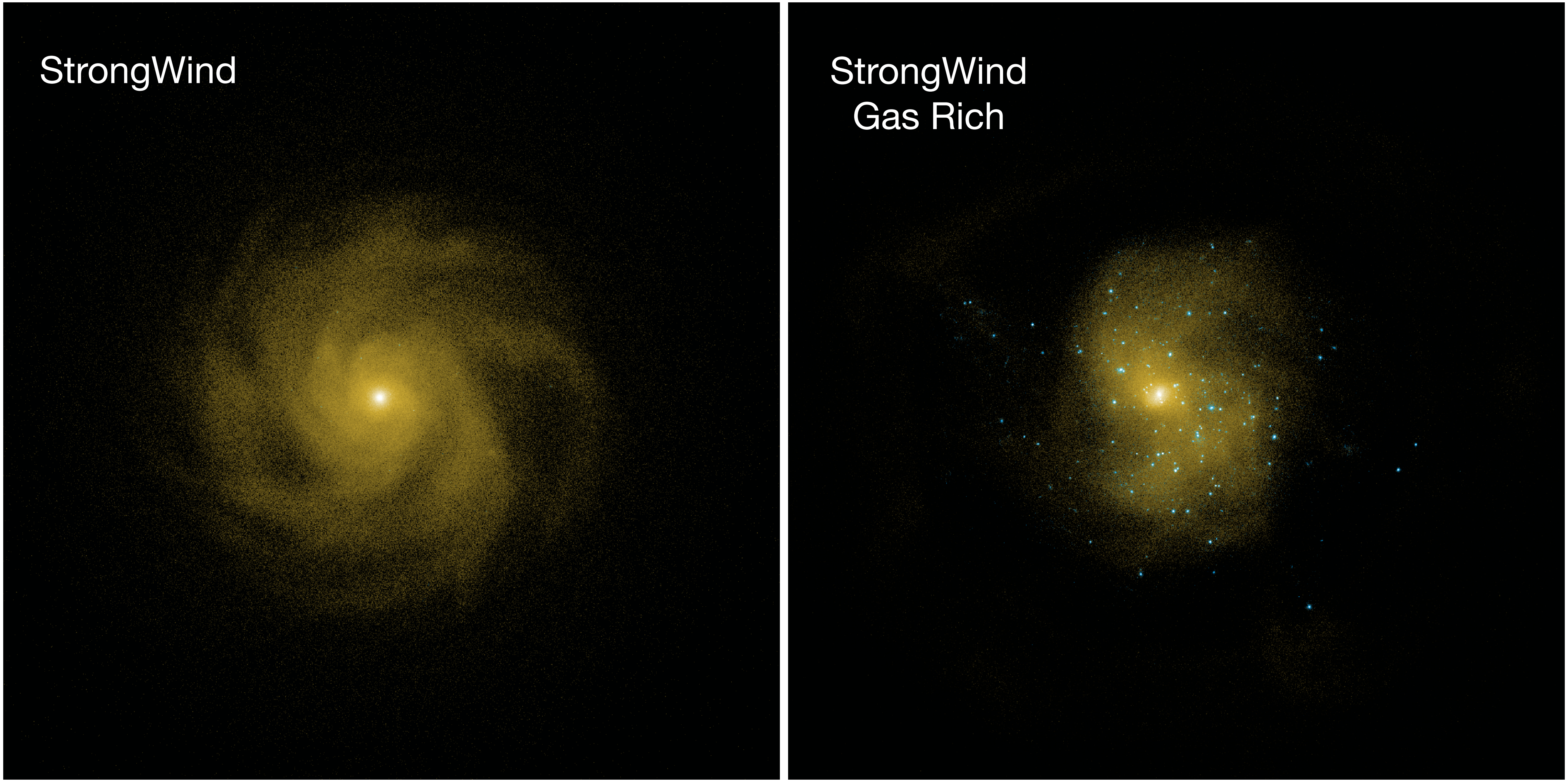
Optical+Hα MUSE/VLT
ESO/ GASP collaboration

- Gas rich run - Preliminary results
  - Same initial condition, but with gas content ~5 times more than the normal one
  - $M_\star$~2.1x$10^9 M_\odot$ ($R_{1/2}$~2.4kpc)
  - Gaseous disk is much more turbulent
  - Just before arrival of winds, f_{cold}~0.32 in the normal run vs. f_{cold}~0.44 in the gas rich run
    - Normal run: M_{HI}~7x$10^8 M_\odot$, M_{H2}~3x$10^8 M_\odot$, $R_{1/2}$ ~ 3 kpc
    - Gas rich run: M_{HI}~2x$10^9 M_\odot$, M_{H2}~4x$10^8 M_\odot$, $R_{1/2}$ ~ 4 kpc

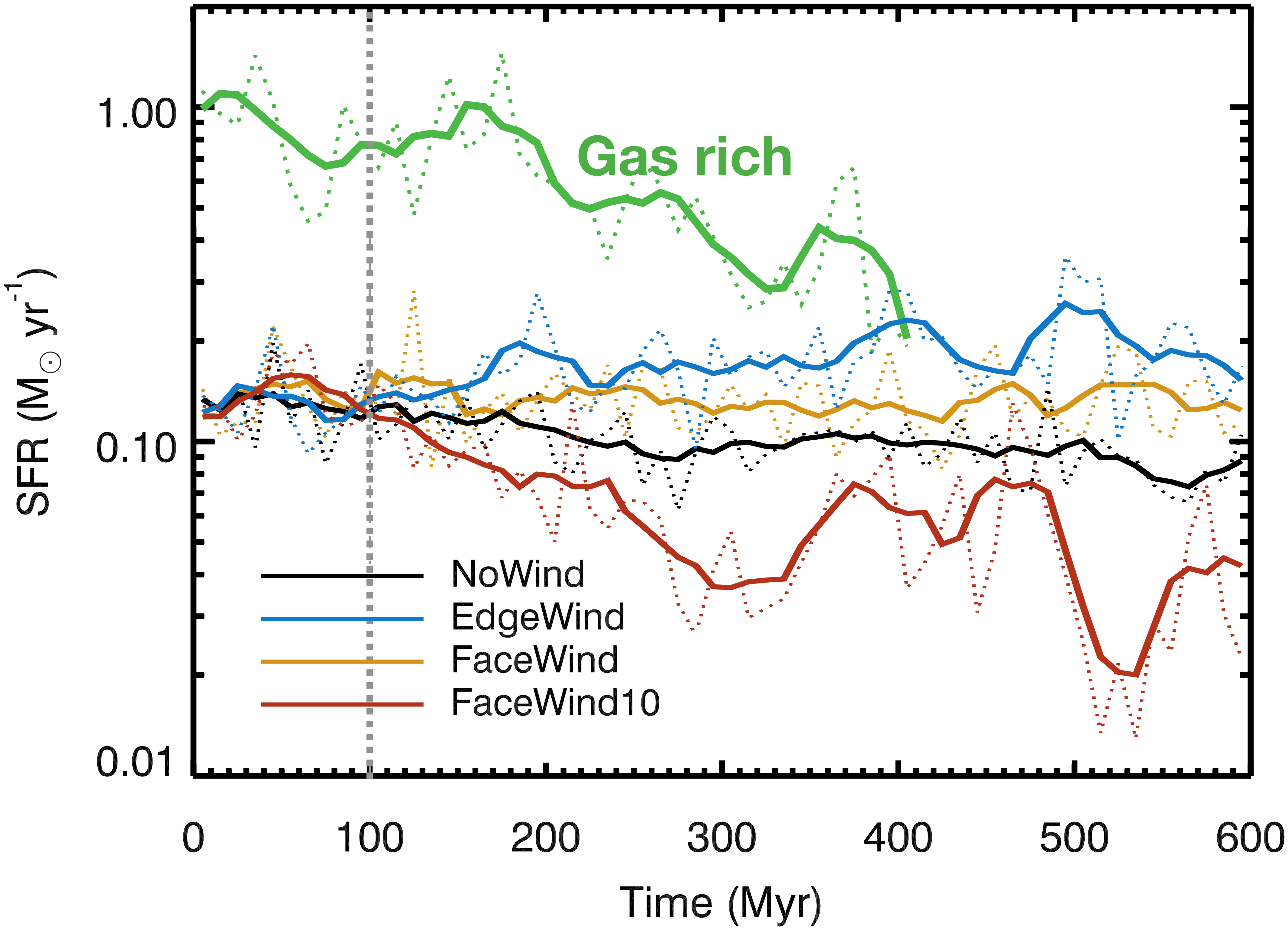


- Cluster center: P_{ram}/k_B~5x10^5cm^{-3}K, n_H~10^{-3} cm^{-3}, v_{wind}=1,000km s^{-1}, T_{ICM} ~10^7K

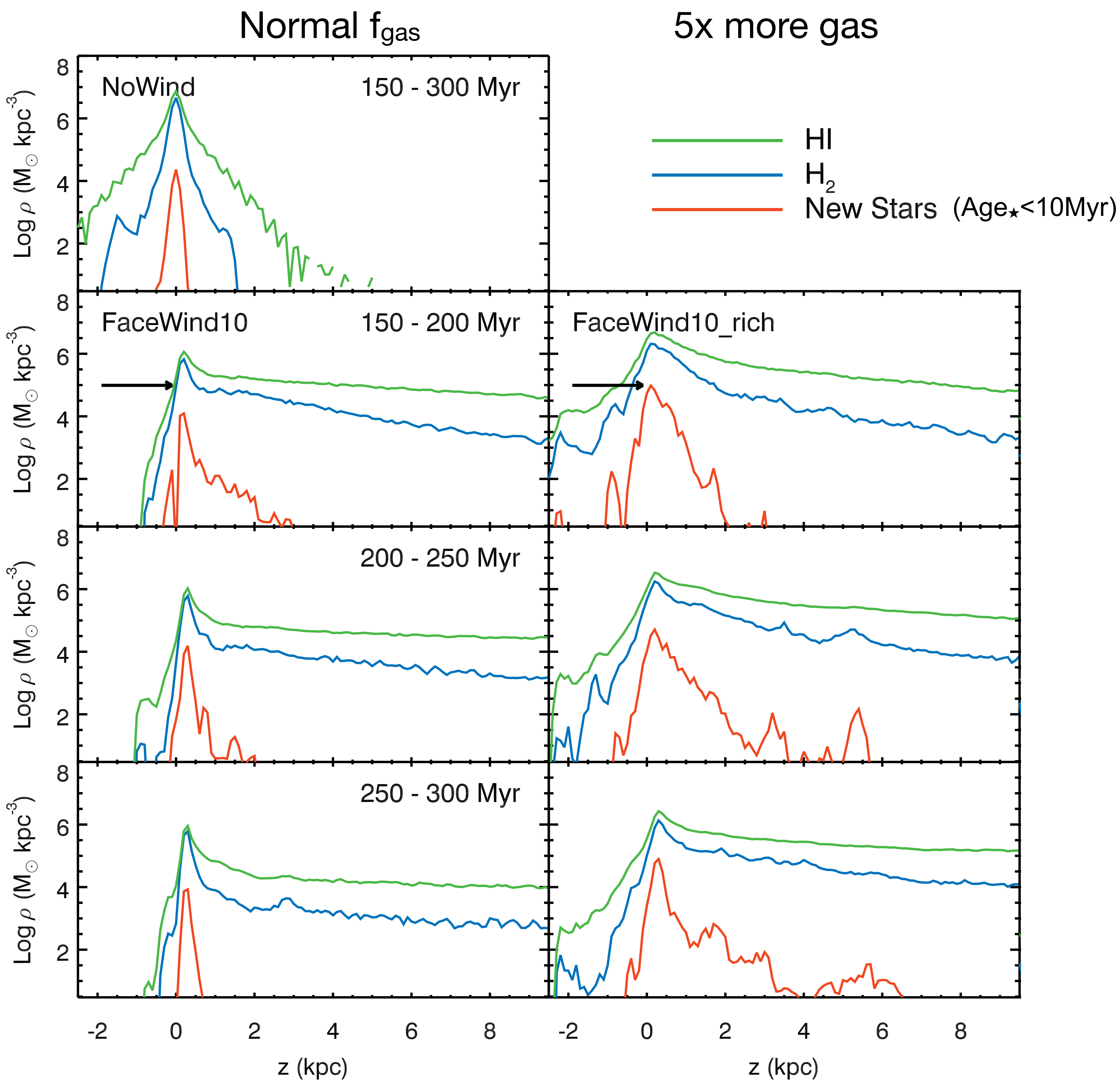
- Stellar distribution just before arrival of winds



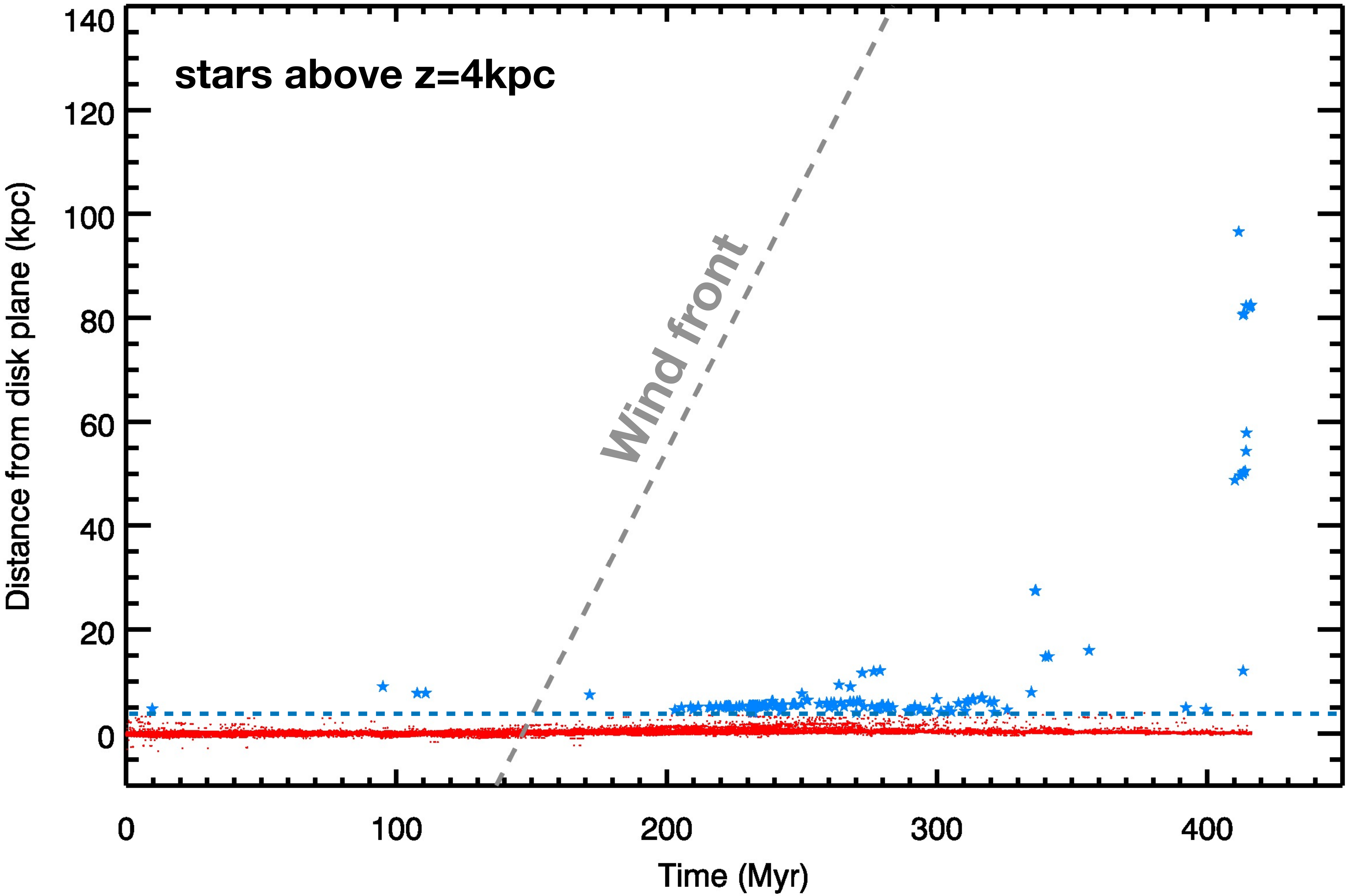
- SFR evolution - gas rich vs. normal cases



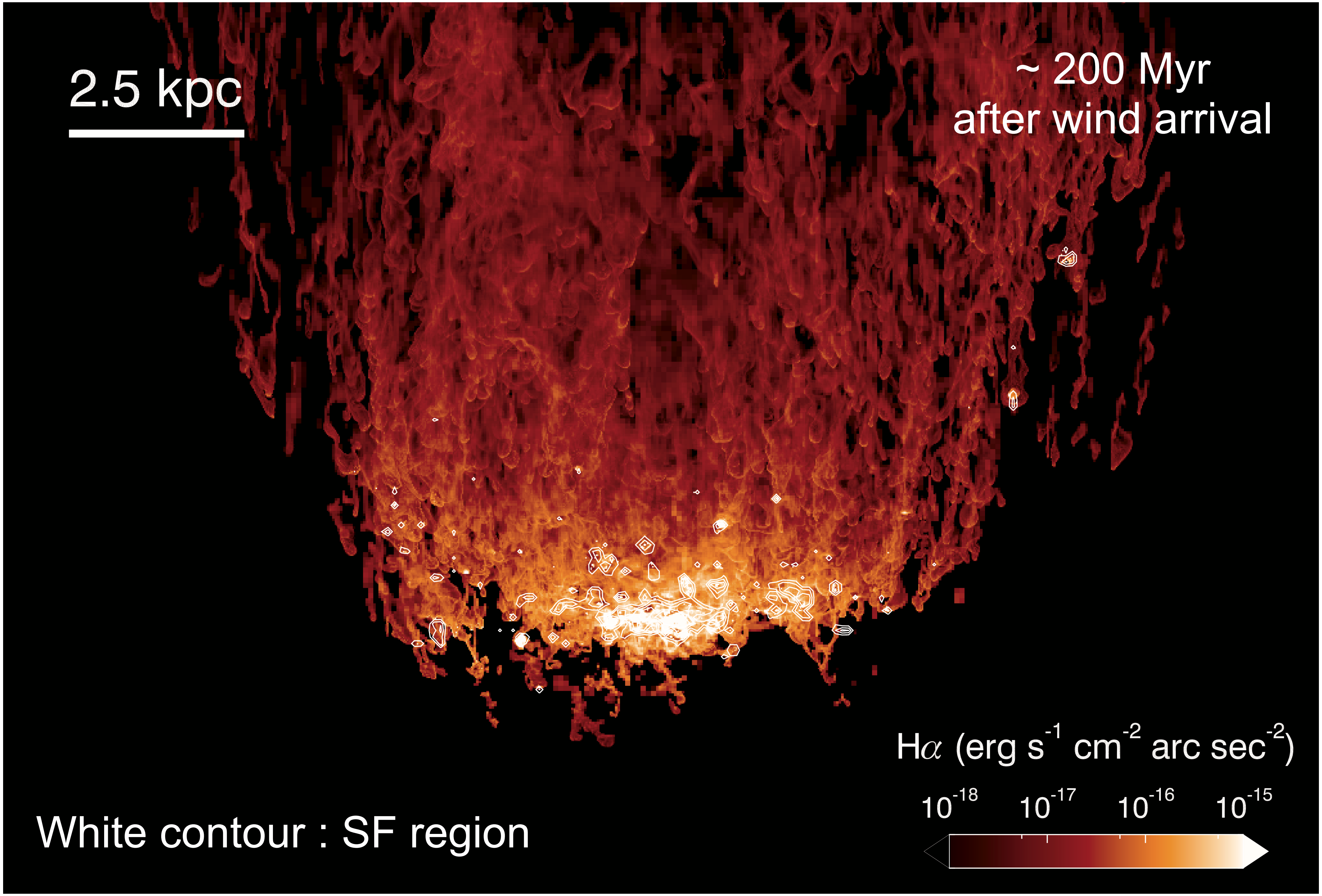
- SF is induced in the tail of the gas rich case



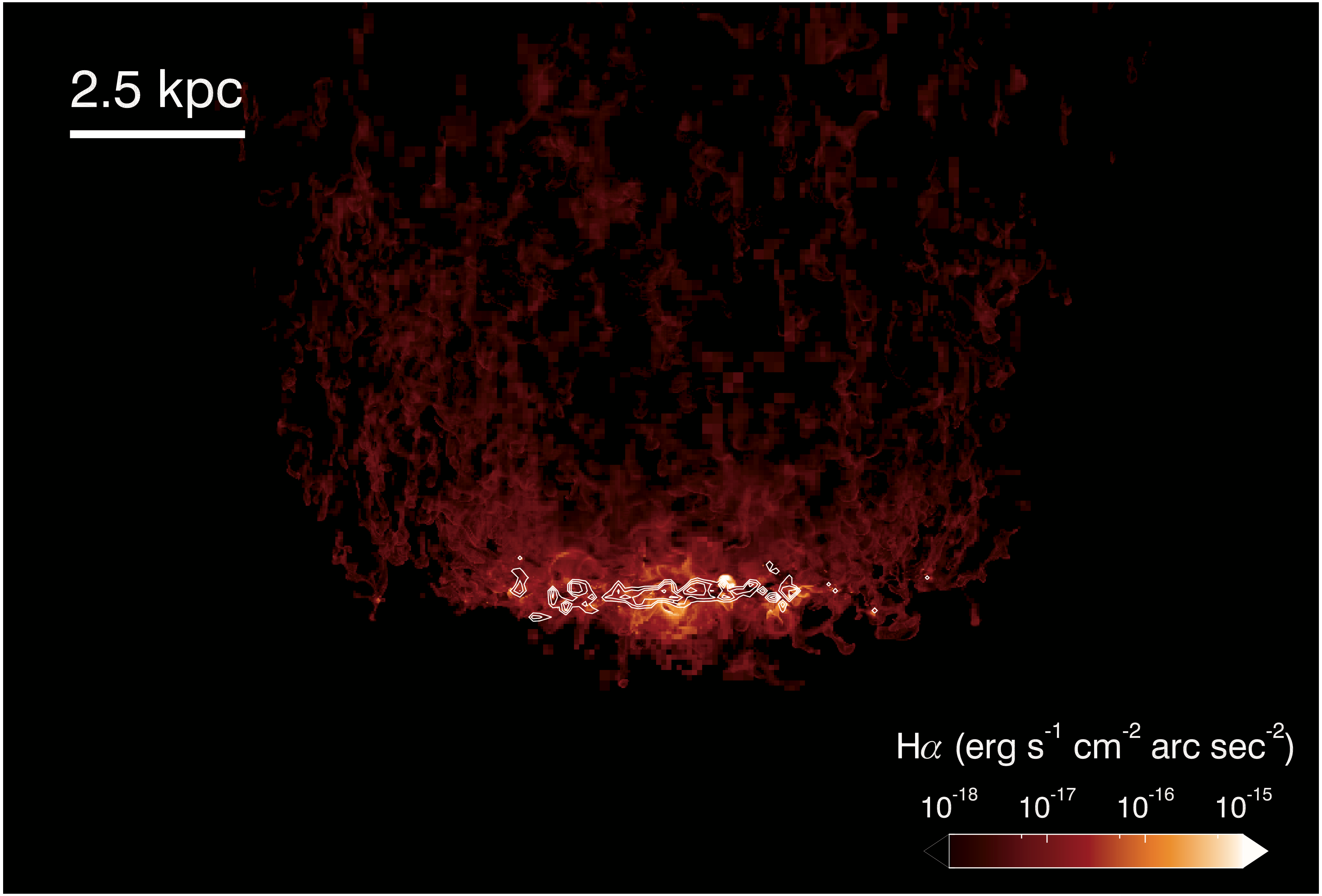
- How far can stars form?
  - SF is detected much more in the RPS tail with high gas fraction



- Hα emission map with dust extinction
  - Bright Hα regions well correlate with star-forming regions



- Hα emission map with dust extinction
  - Normal galaxy with a mild wind



- Comparable with observations?

A textbook-case: JO206
$M_\star \sim 8.5\times10^{10} M_\odot$
SFR ~ 7 $M_\odot$/yr

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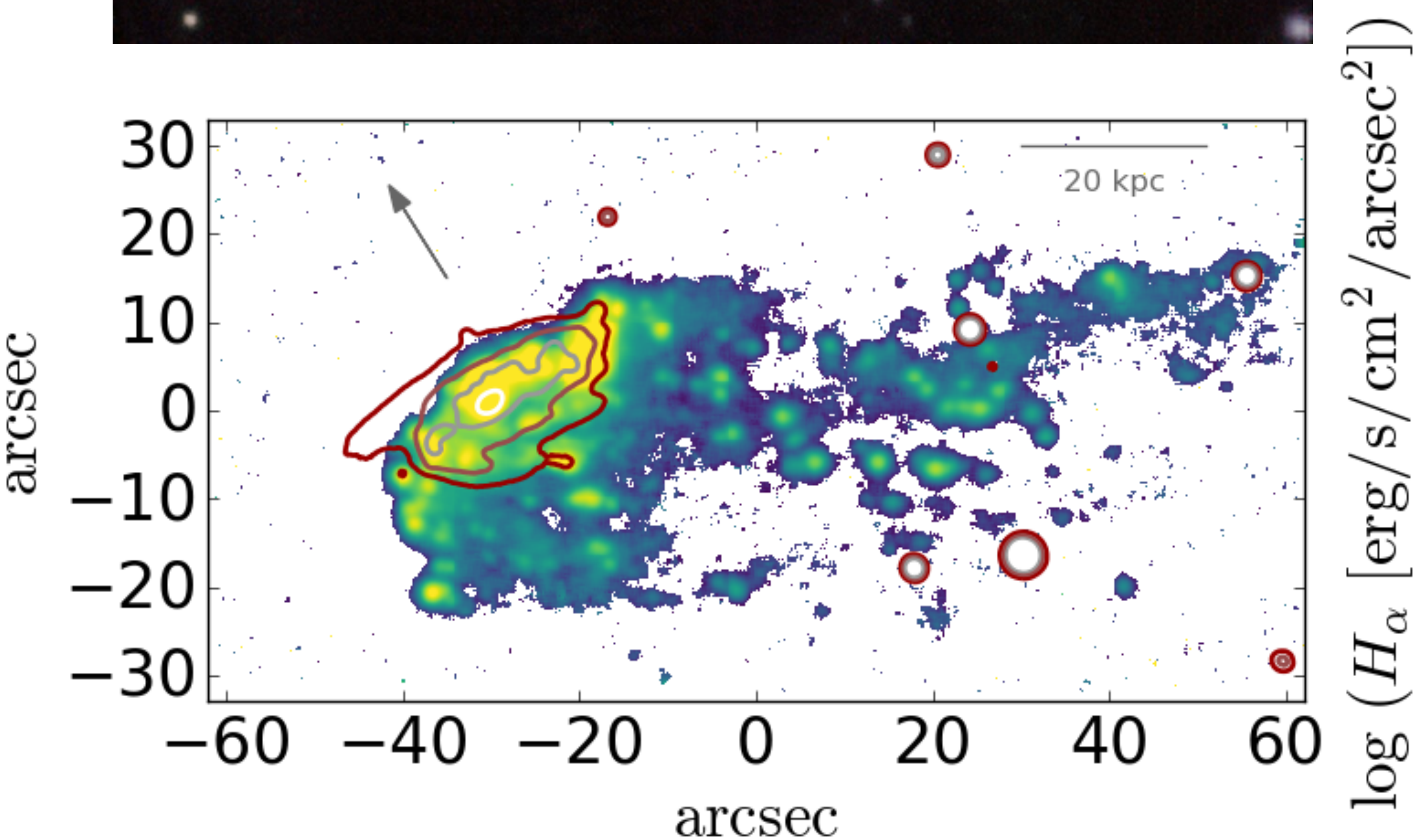

Poggianti+18

- Next step
  - Tracing gas content in the RPS tail
  - Tracing the origin of clouds forming stars in the RPS tail
    - Detached from the disk?
    - Collapsing in the tail?
- Future work
  - Resolution dependence?
  - RPS on massive galaxies?

- Summary
  - Moderate pam pressure can strip not only a significant amount of HI, but also H_2 in the outer part.
  - Mass loss and size decrease is more significant in the face-on wind run
  - Moderate ram pressure rather enhances SF in the disk
    - SF is boosted in the edge-on wind case, mainly at the interface between the ICM wind and gaseous disk
  - Many stars form in the ram pressure stripped tail of the gas rich galaxy, while it is negligible in the normal galaxy
    - The gas fraction seems to be one of primary parameters for tail SF.