Gas accretion and radial flows onto Milky Way-type galaxies:

Chemical Evolution Models in the light of cosmological simulations

Sebastián E. Nuza

in collaboration with

Emanuele Spitoni, Cecilia Scannapieco, Cristina Chiappini,
Ivan Minchev, Marie Martig, Robert Grand, Pablo Illing, et al.

Institute for Astronomy and Space Physics

IAFE (CONICET/UBA)

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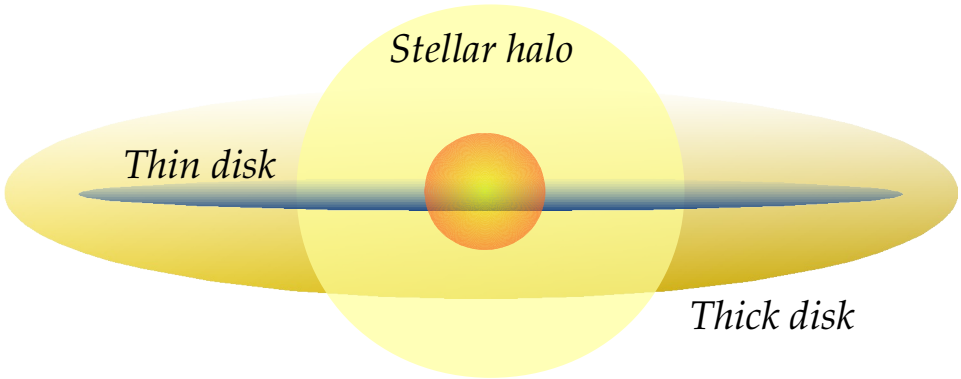
Motivation: Chemical Evolution Models (CEMs)



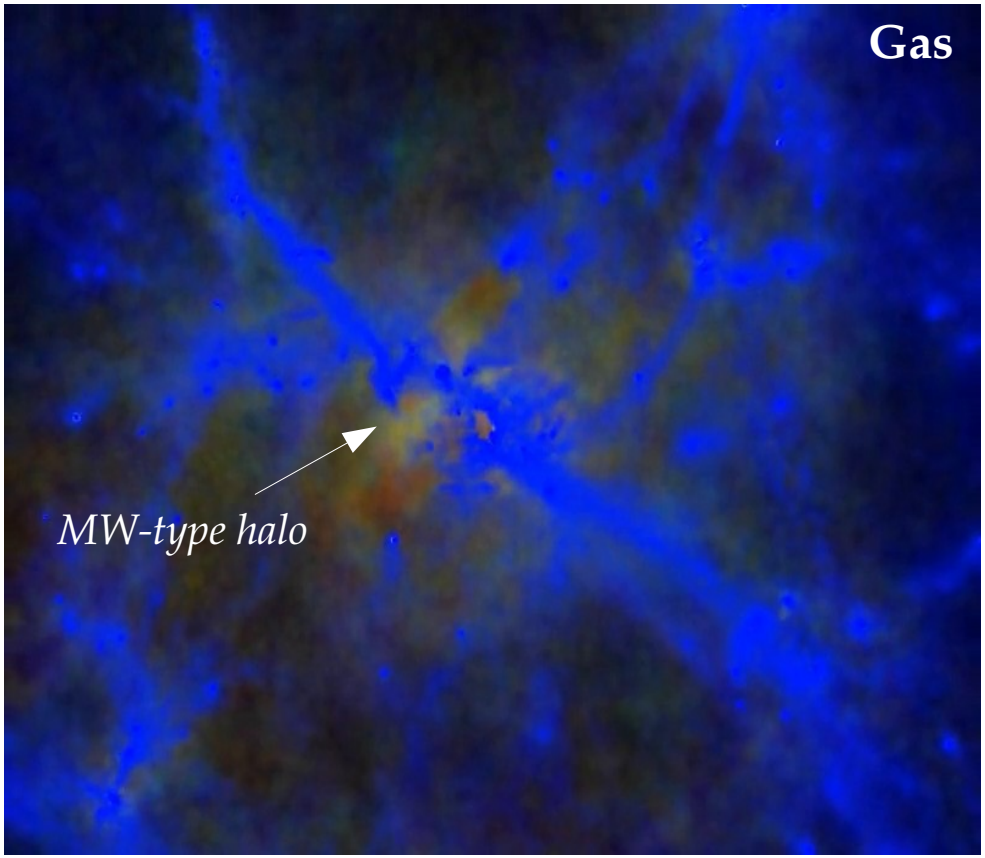
- Compute chemical abundances of stars in galaxies; specially the **Milky Way**
- Simplifying assumptions (gas flows, SFR, stellar nucleosynthesis,…)
- Model each galaxy component separately
- Solve a set of integer-differential equations
- No dynamics involved in classical CEMs
- Highly idealized

Evolution of gas enrichment:

$$
\begin{aligned}
\dot{G}_i(r,t) &= -\psi(r,t)X_i(r,t) \\
&+ \int_{M_L}^{M_{Bm}} \psi(r,t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)\,\mathrm{d}m + A_{\mathrm{Ia}} \int_{M_{Bm}}^{M_{BM}} \phi(M_B) \\
&\times \left[\int_{\mu_m}^{0.5} f(\mu)\psi(r,t-\tau_{m2})Q_{mi}^{\mathrm{SNIa}}(t-\tau_{m2})\,\mathrm{d}\mu\right]\mathrm{d}M_B \\
&+(1-A_{\mathrm{Ia}}) \int_{M_{Bm}}^{M_{BM}} \psi(r,t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)\,\mathrm{d}m \\
&+ \int_{M_{BM}}^{M_U} \psi(r,t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)\,\mathrm{d}m \\
&+ X_{A_i}A(r,t), \qquad (1)
\end{aligned}
$$

Cosmological evolution

- Gas accretion is a key process in ΛCDM
  - Brings fresh, uncontaminated gas
  - Affects metallicity patterns
  - It impacts star formation
- The gas accretion process is very complex
  - Depends on time, not isotropic
  - Different accretion channels: mergers, filamentary, smooth
  - Significant variations among different galaxies
- Outflows can also be important



Blue: cold gas
Yellow/Red: hot gas

Outline

- **Introduction**
  - Main assumptions in CEMs
- **Simulations & analysis**
  - The need for a MW analogue
  - Simulated MW-like galaxies
  - Calculation of gas fluxes onto the disc
- **Results (Nuza+19)**
  - Gas accretion rate vs. time
  - Accretion timescale vs. galactic radius
  - Radial flows in MW analogues (preliminary...)
  - Impact on CEM predictions (preliminary...)
- **Summary**

Motivation: CEM assumptions

- **Gas accretion** is a key ingredient in **chemodynamical models (CEMs)**, as it sets the efficiency of star formation as a function of time and radius
- Usual assumptions for the **gas accretion law** for different **galaxy components:**
  - *Decreasing function of time (exponential, gaussian, …)*

$$A(r,t) = a(r)\mathrm{e}^{-t/\tau_{\mathrm{H}}(r)} + b(r)\mathrm{e}^{-(t-t_{\mathrm{max}})/\tau_{\mathrm{D}}(r)}$$

$\propto$ gas accretion rate

(e.g. Chiappini+01)

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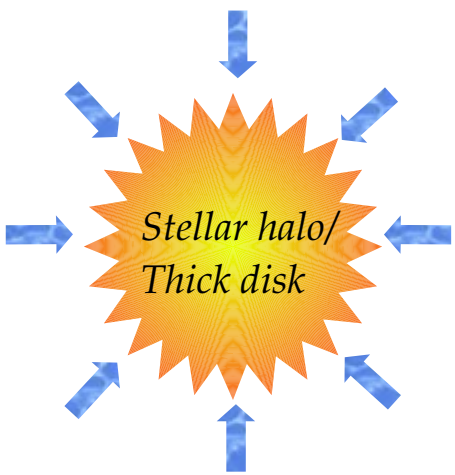
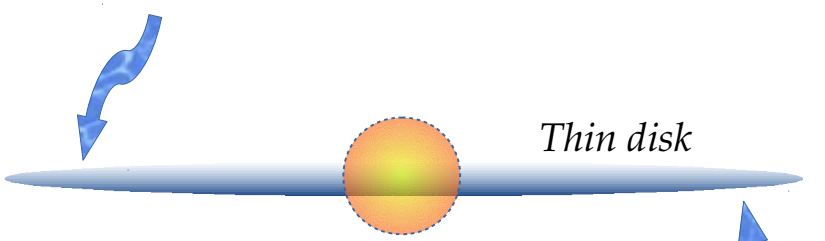


Rapid/Violent

(*older* stellar populations)



Long duration/Smooth

(*younger* stellar populations)

(e.g. Chiappini+01)

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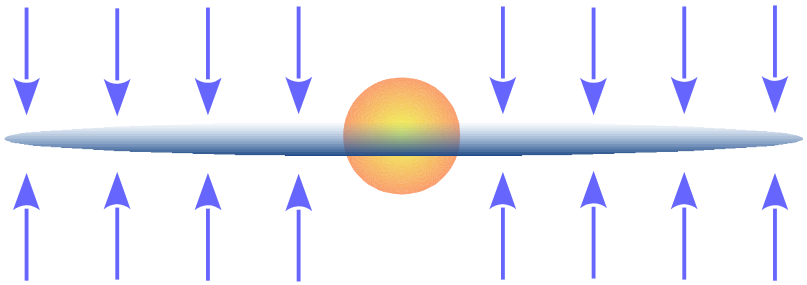
  - *The disc forms from the **inside-out**: radially-growing disks*



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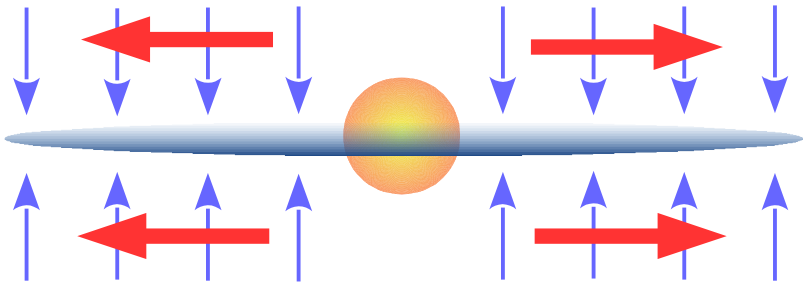

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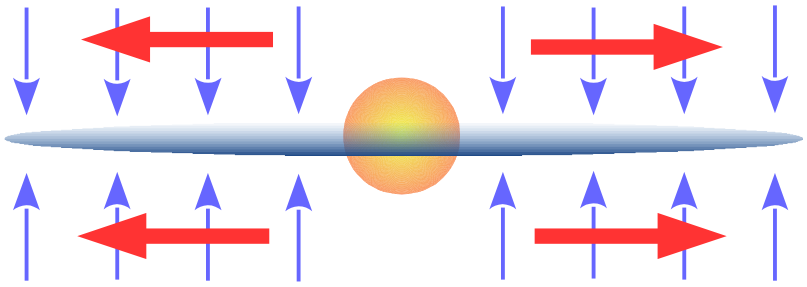

$$\tau_{\mathrm{D}} = 1.033r\ (\mathrm{kpc}) - 1.267\ \mathrm{Gyr}$$

(e.g. Chiappini+01)

Motivation: CEM assumptions

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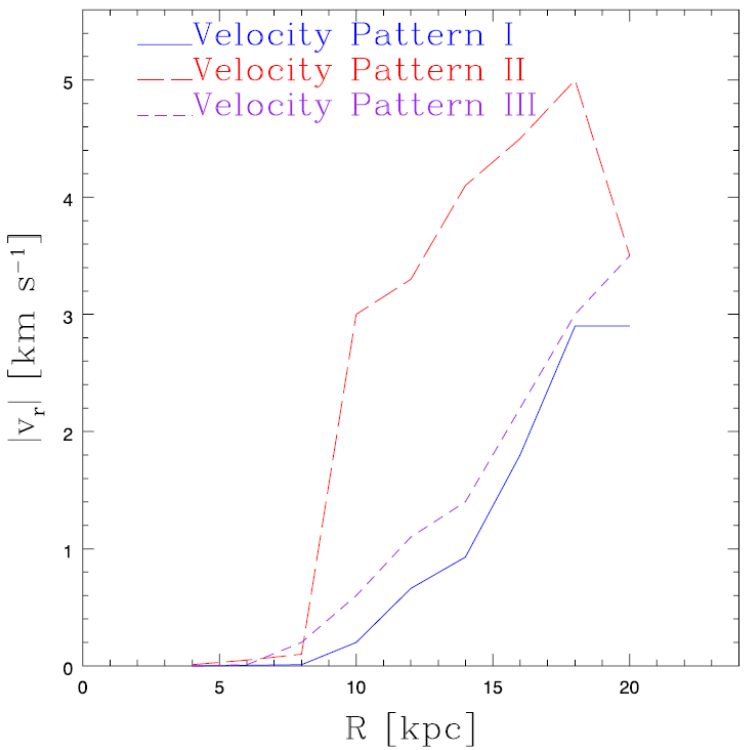
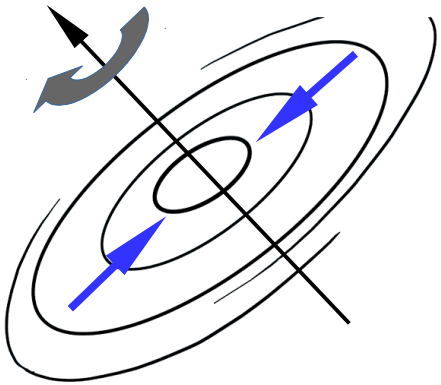
  - *CEMs including **radial flows** use **ad-hoc** velocity profiles*



(e.g., Spitoni & Matteucci+11; Mott+13,...)

<u>Radial gas flows across the disk are expected from physical considerations</u>

If the infalling material has lower specific angular momentum than circular motions in the disk, mixing with disk gas induces a net radial inflow (e.g., Biliwetski & Schönrich 2012).



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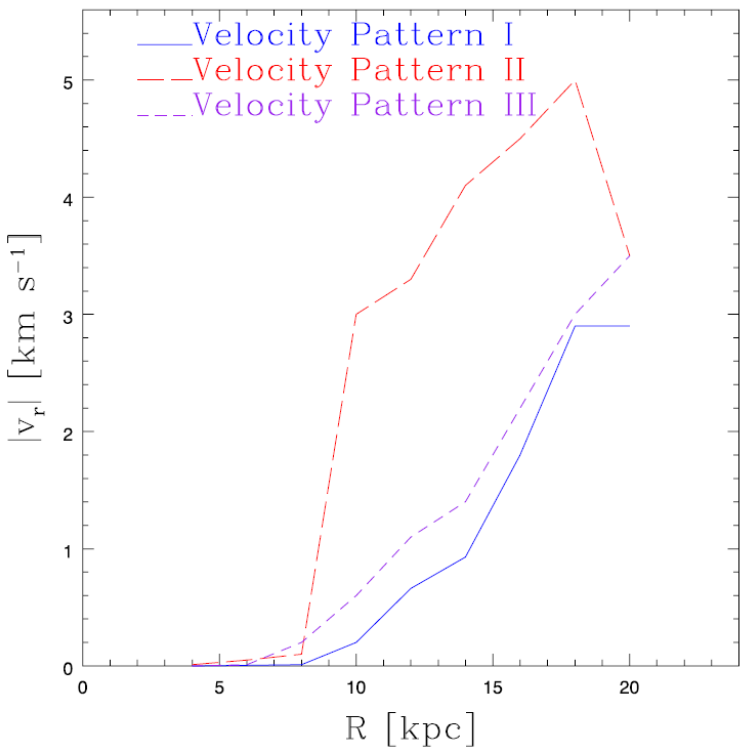

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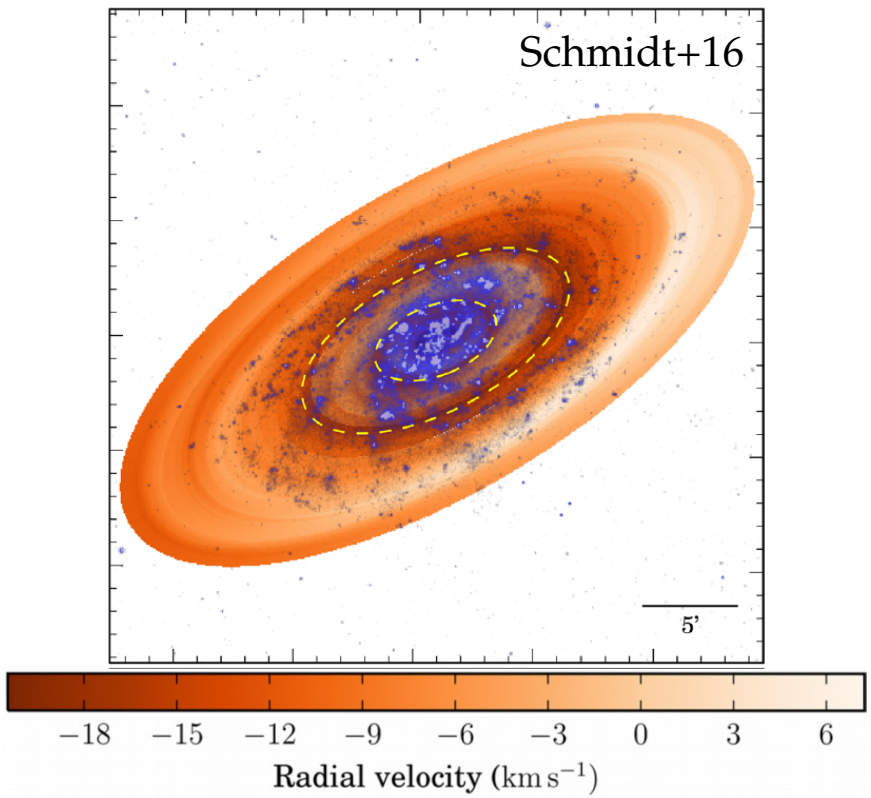
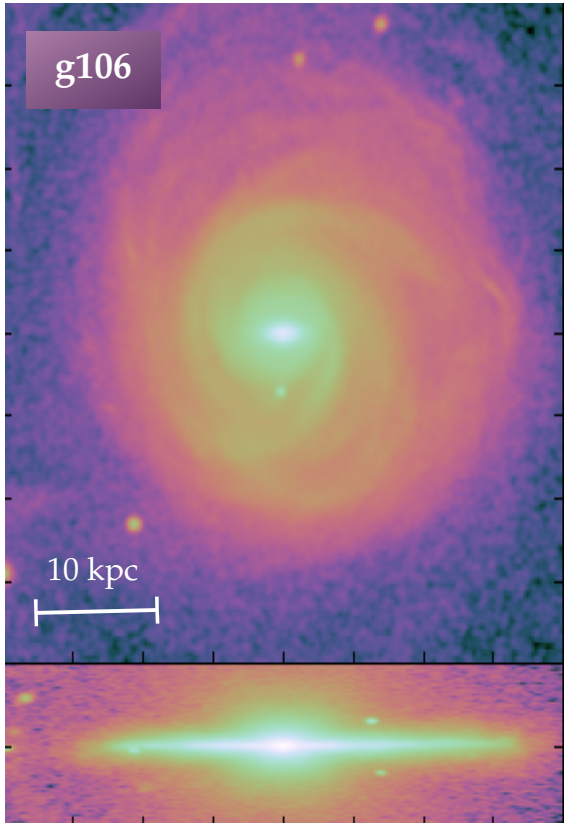


The simulated Milky Way-type galaxies

Stellar distribution

Martig



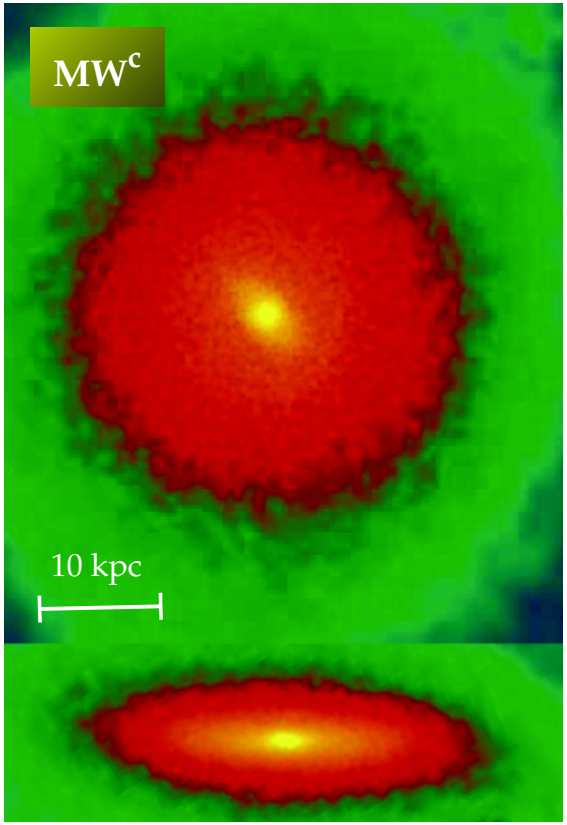
$m_{gas} = 1.5 \times 10^4\ h^{-1}\,M_\odot$

$m_{DM} = 3.5 \times 10^4\ h^{-1}\,M_\odot$

$\epsilon_g \sim 150$ pc

Martig+12
Minchev+13,14

CLUES



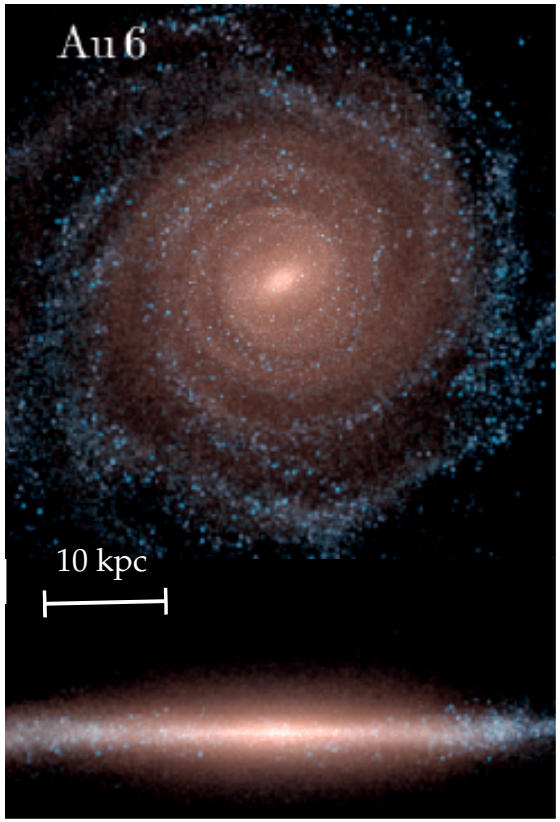
$m_{gas} = 3.9 \times 10^5\ h^{-1}\,M_\odot$

$m_{DM} = 2.0 \times 10^5\ h^{-1}\,M_\odot$

$\epsilon_g \sim 500$ pc

Nuza+14
Scannapieco+15

Auriga



$m_{gas} = 5.0 \times 10^4\ h^{-1}\,M_\odot$

$m_{DM} = 3.0 \times 10^5\ h^{-1}\,M_\odot$

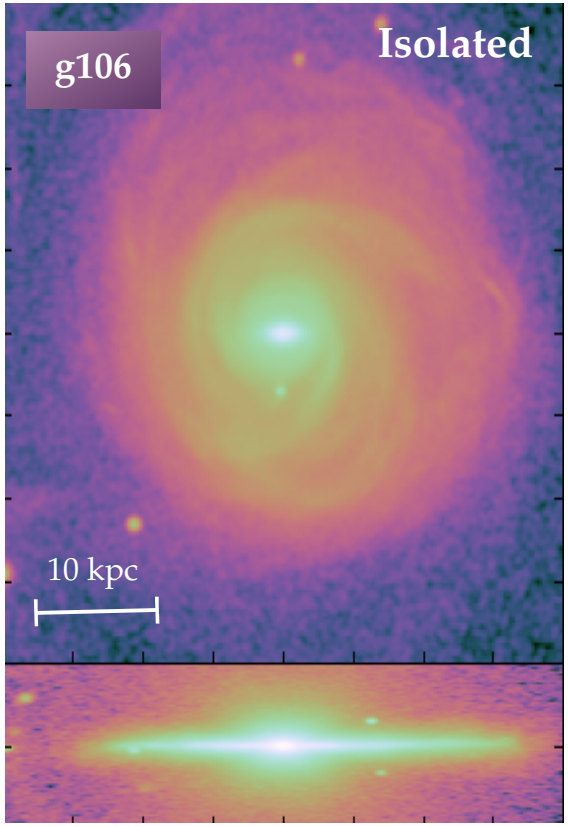
$\epsilon_g \sim 369$ pc

Grand+17

The simulated Milky Way-type galaxies

Stellar distribution

Martig

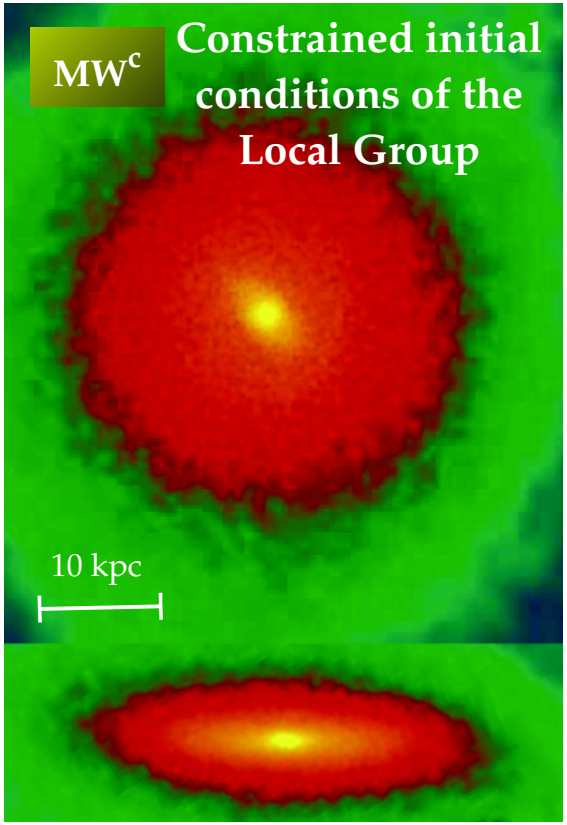


- *Semi cosmological*
- *High resolution*

Sticky particle model
(Bornaud & Combes 02, 03)

Martig+12, Minchev+13,14

CLUES

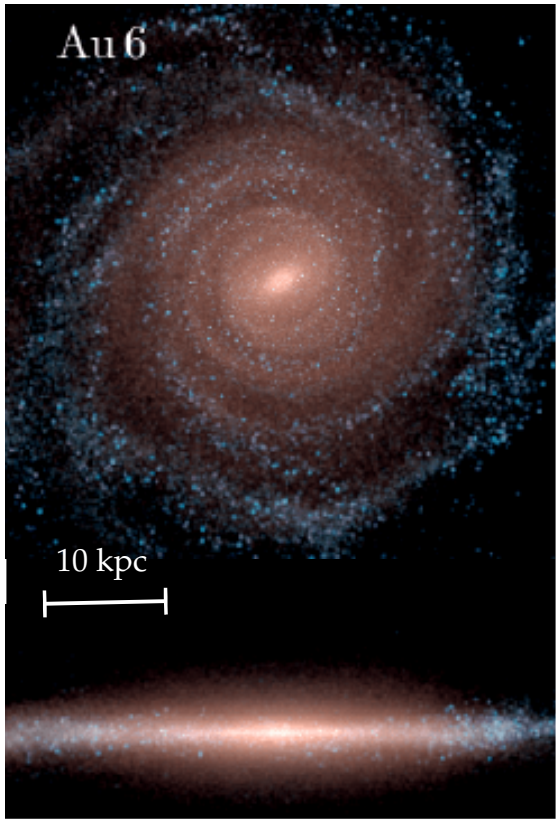


- *Fully cosmological*
- *Medium resolution*

GADGET-3 code
(Springel+08)

Nuza+14, Scannapieco+15

Auriga



- *Fully cosmological*
- *High resolution*

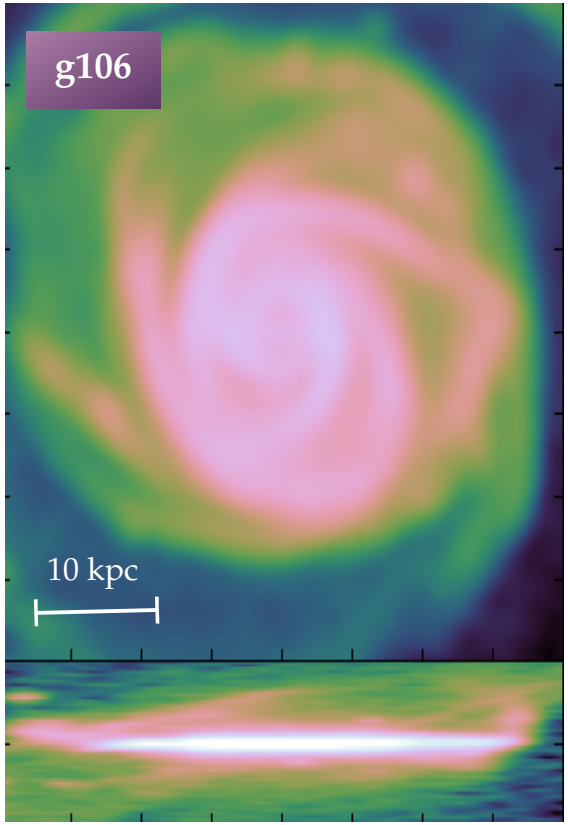
AREPO code
(Springel 10)

Grand+17

The simulated Milky Way-type galaxies

Gas distribution

Martig



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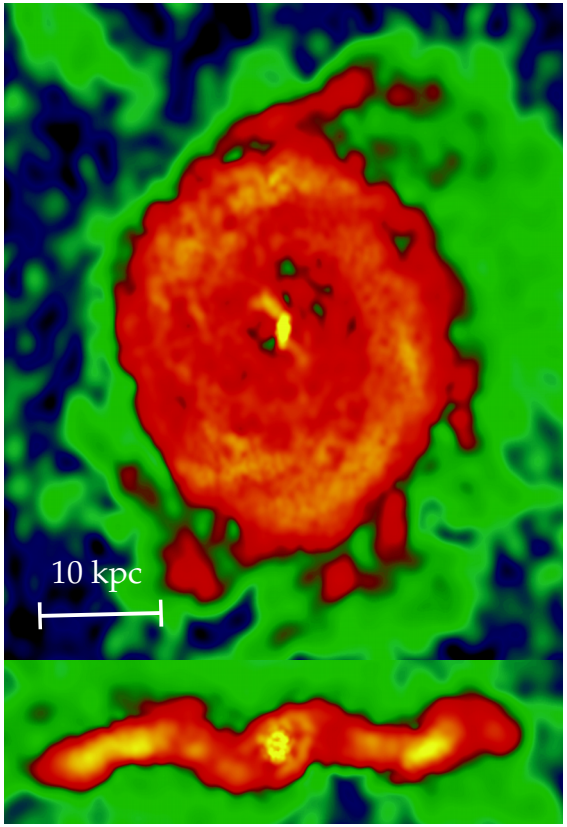

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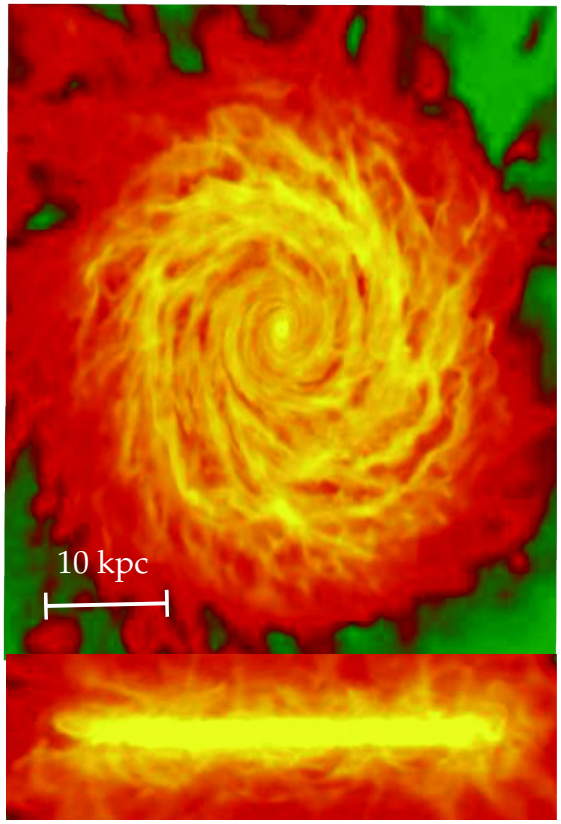
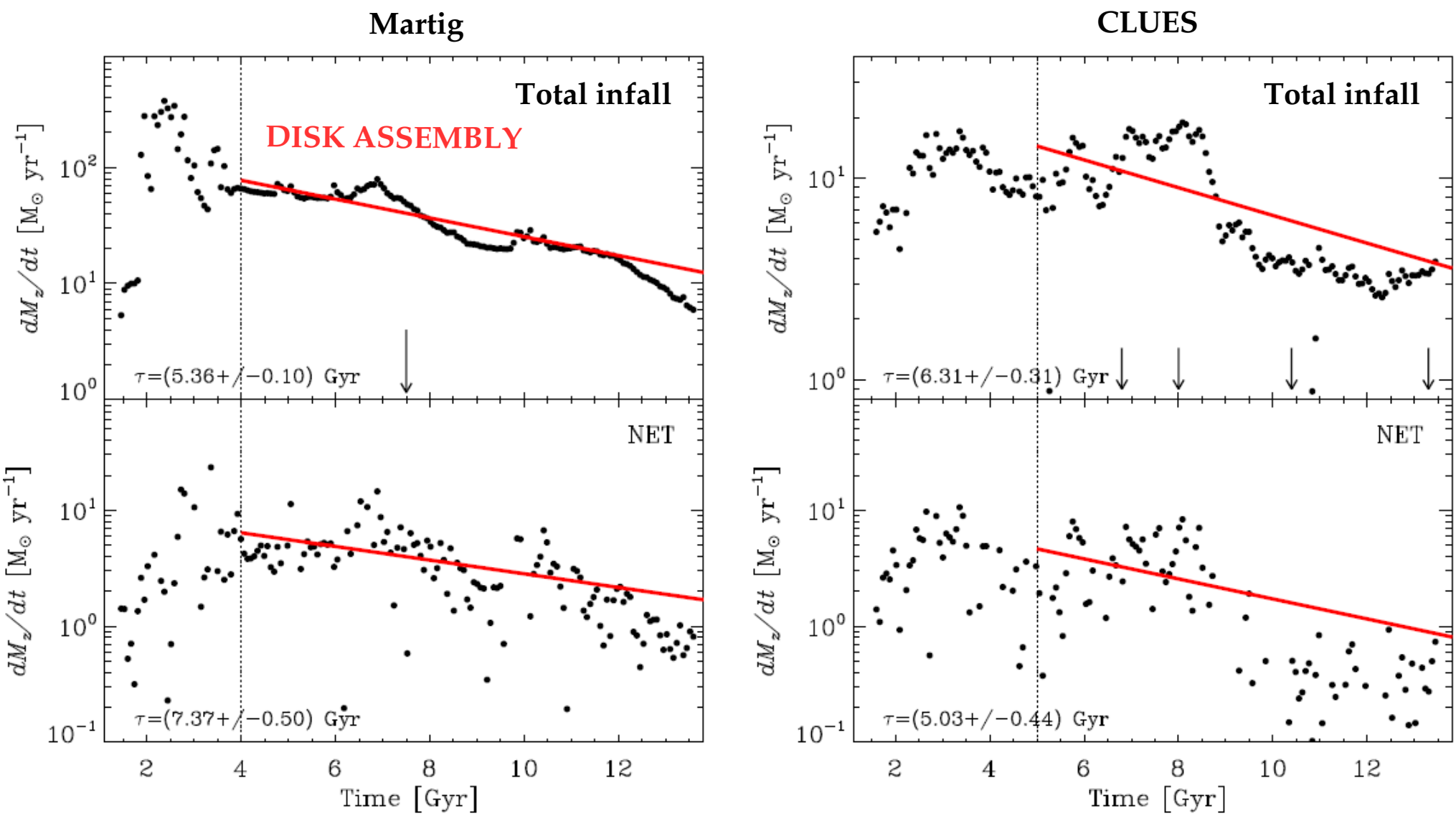


Results: 1) Gas accretion rate vs. cosmic time



Integrated over galaxy radius

Nuza+19

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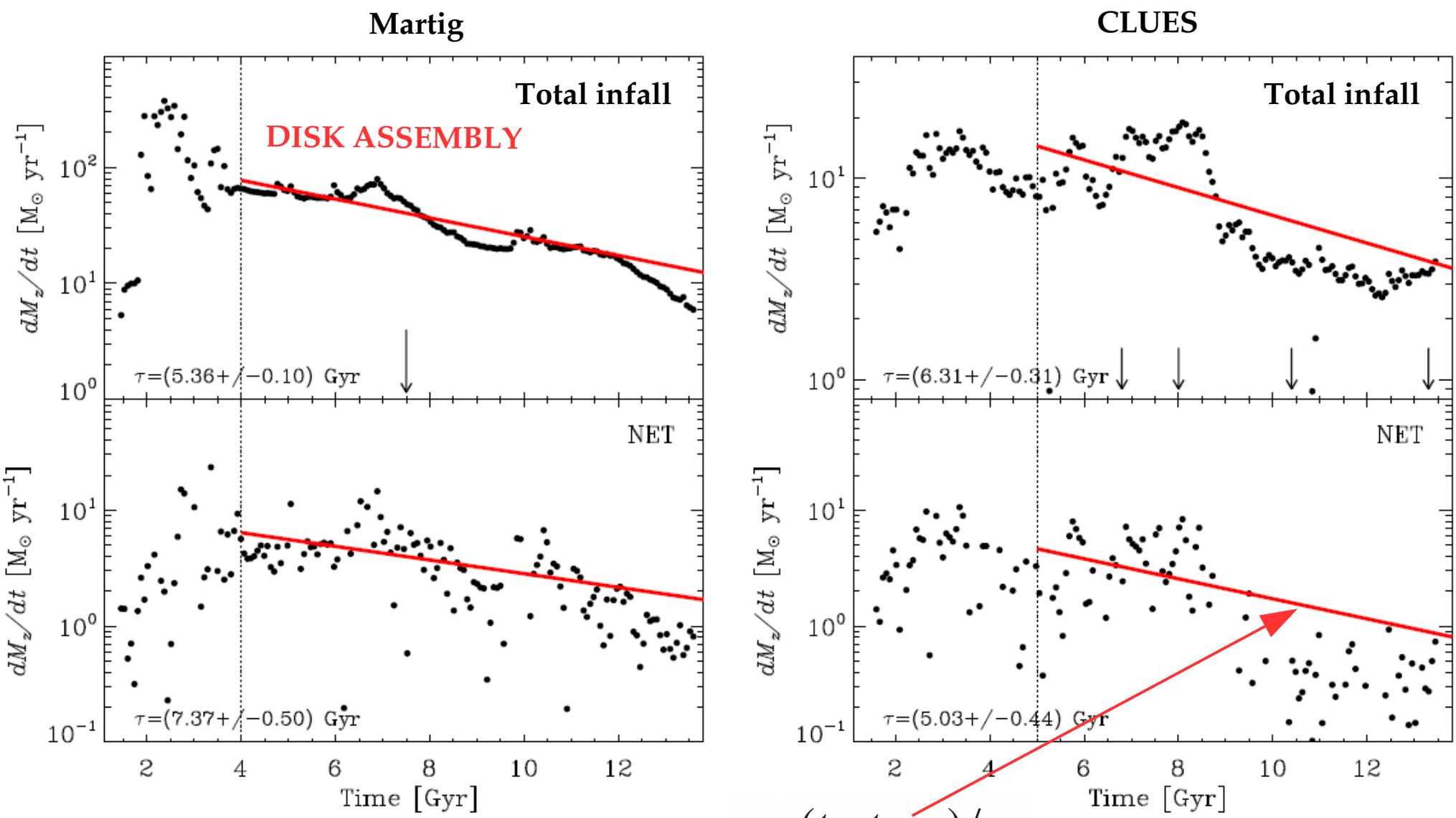
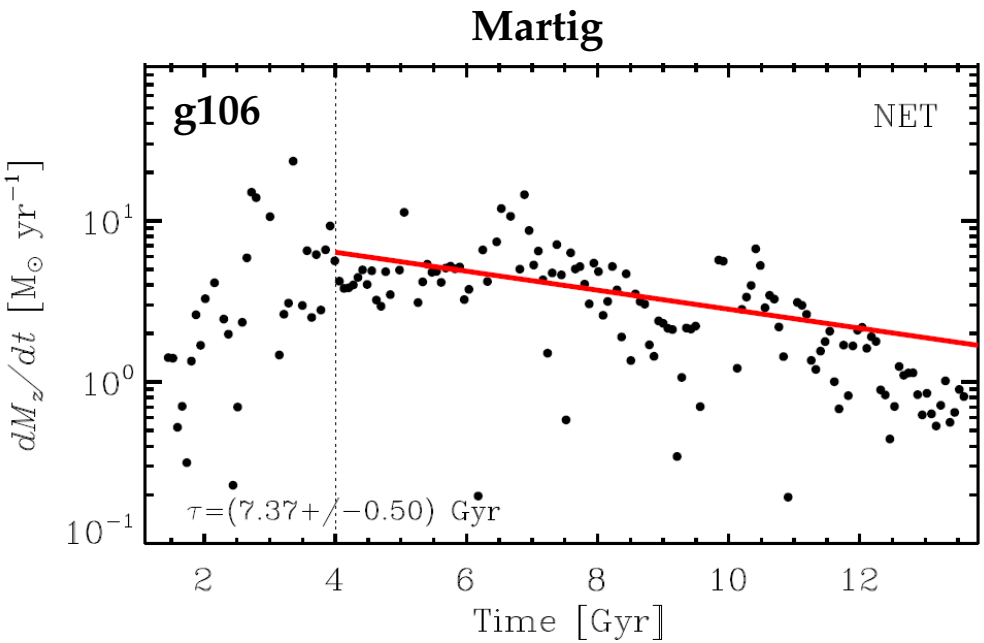
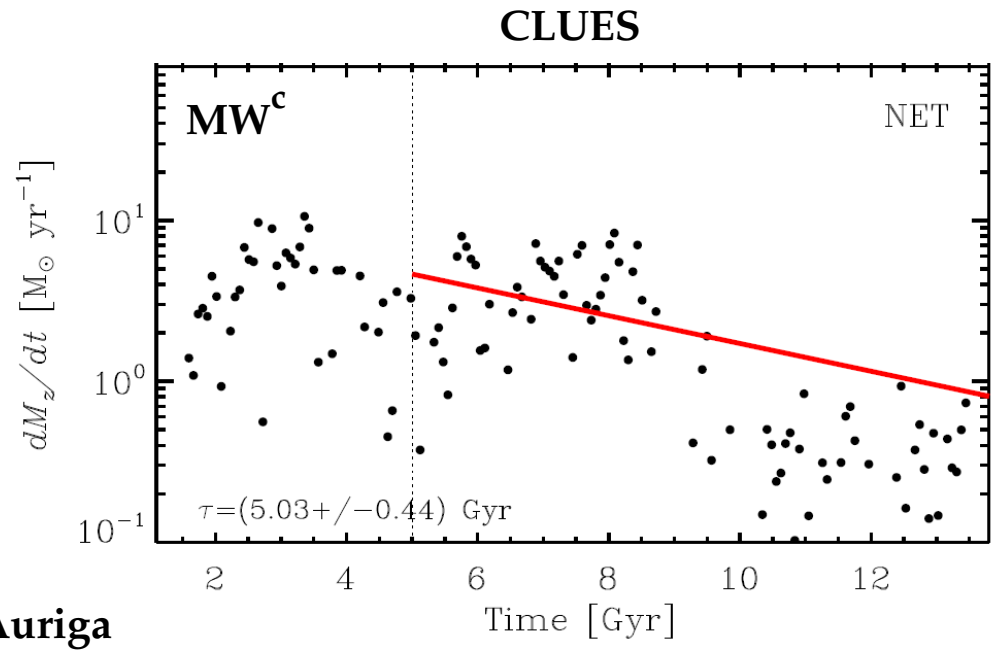


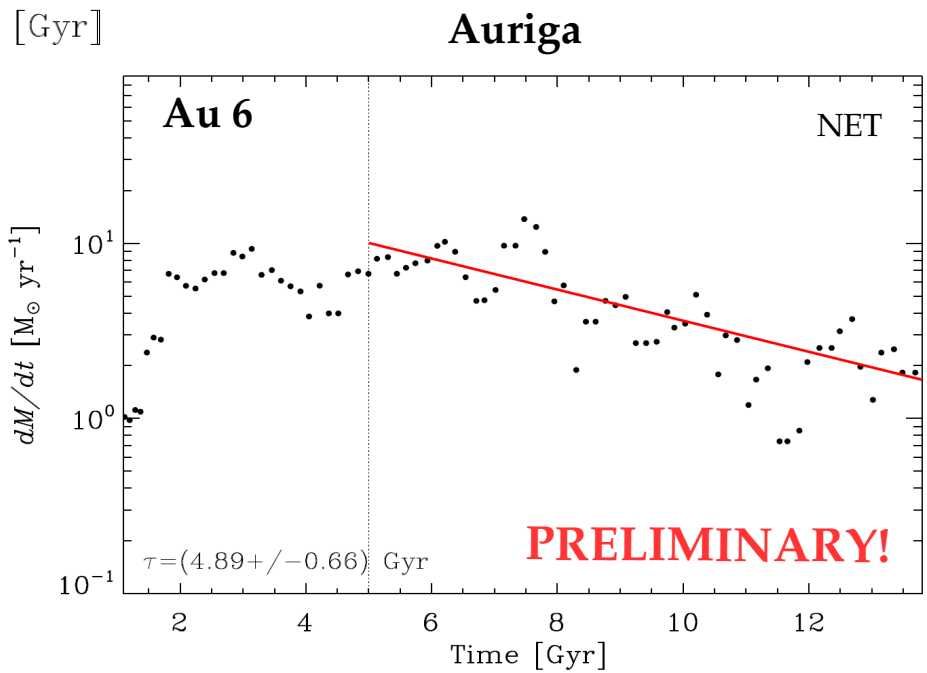
$$\frac{dM(t)}{dt} \propto e^{-(t-t_{\max})/\tau_D}$$

Nuza+19

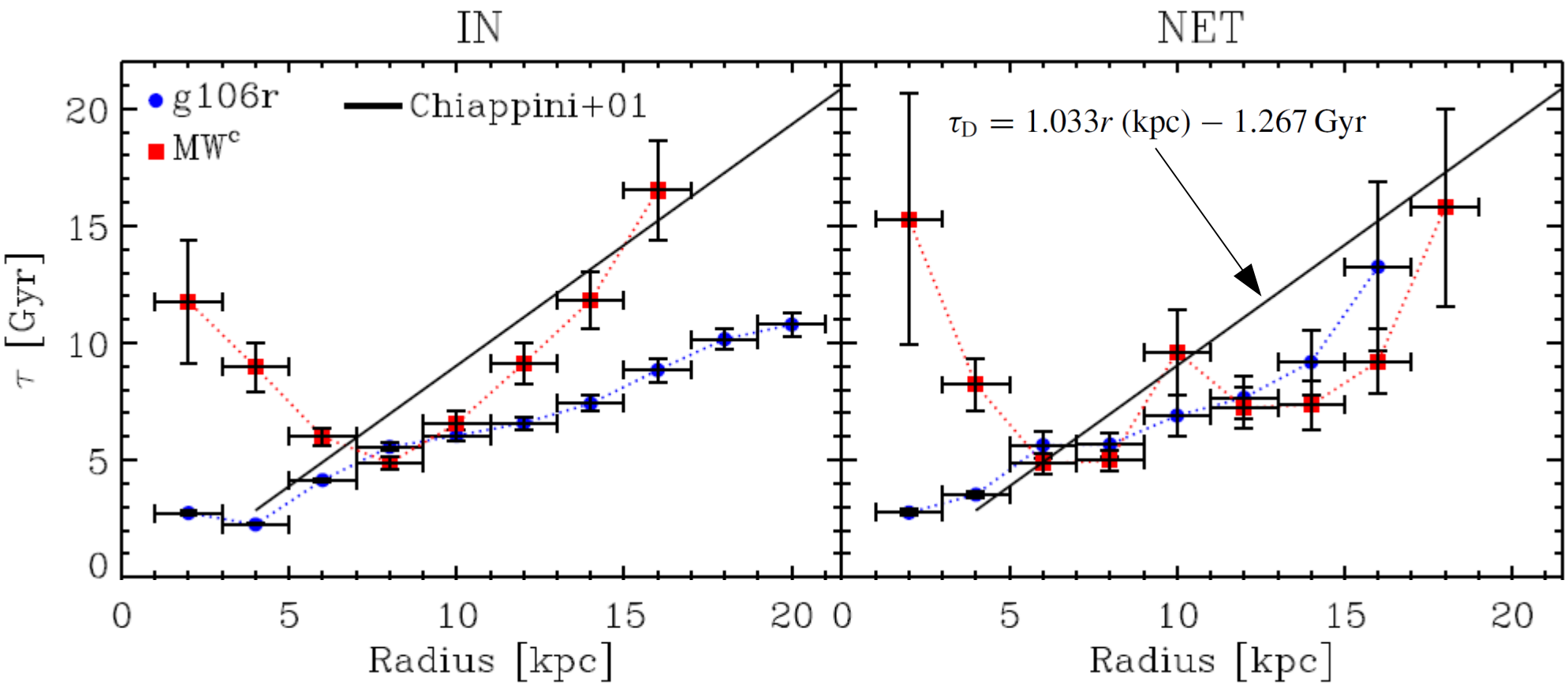
Results: 1) Gas accretion rate vs. cosmic time







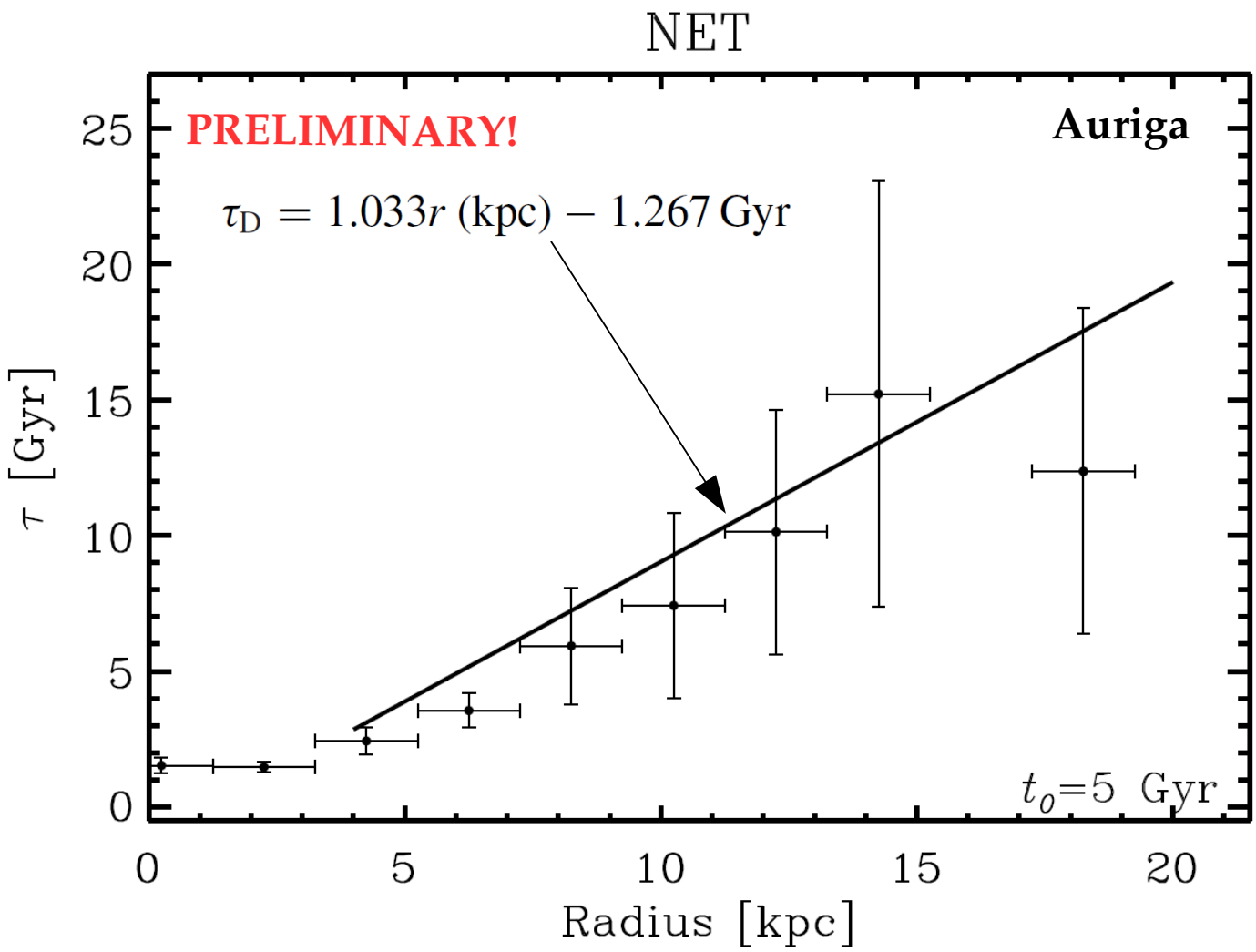
Results: 2) Accretion timescales onto the disk



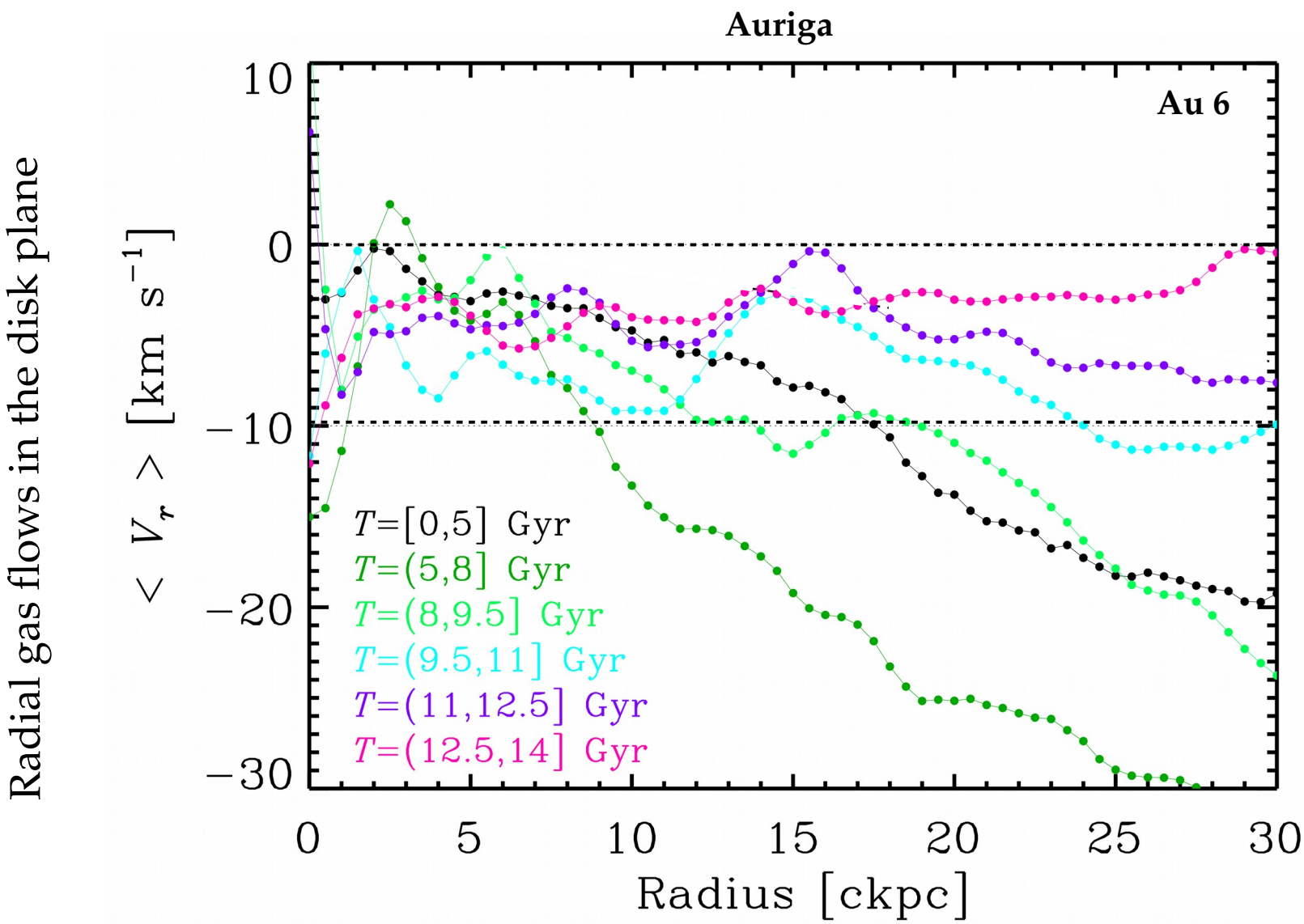
- Accretion timescales onto the disk increase towards larger radii
- Similar trend (but no detailed agreement) to the prescription of Chiappini+01 for $R > 4$ kpc
- Consistent with an **inside-out** scenario of disk formation

Nuza+19

Results: 2) Accretion timescales onto the disk



Results: 3) Radial flow velocities



- Test how this physically-motivated radial velocity profiles affect CEM predictions

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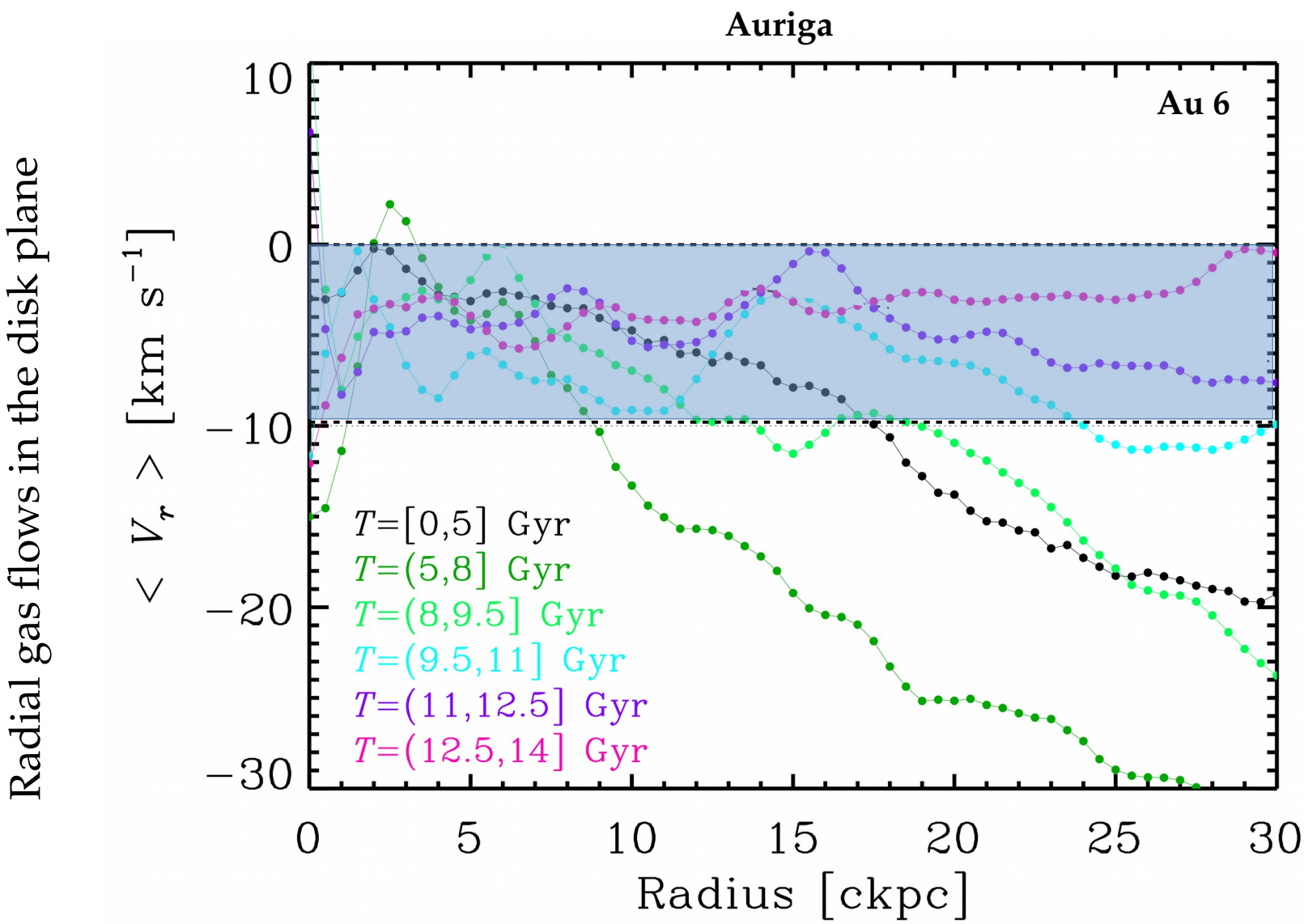
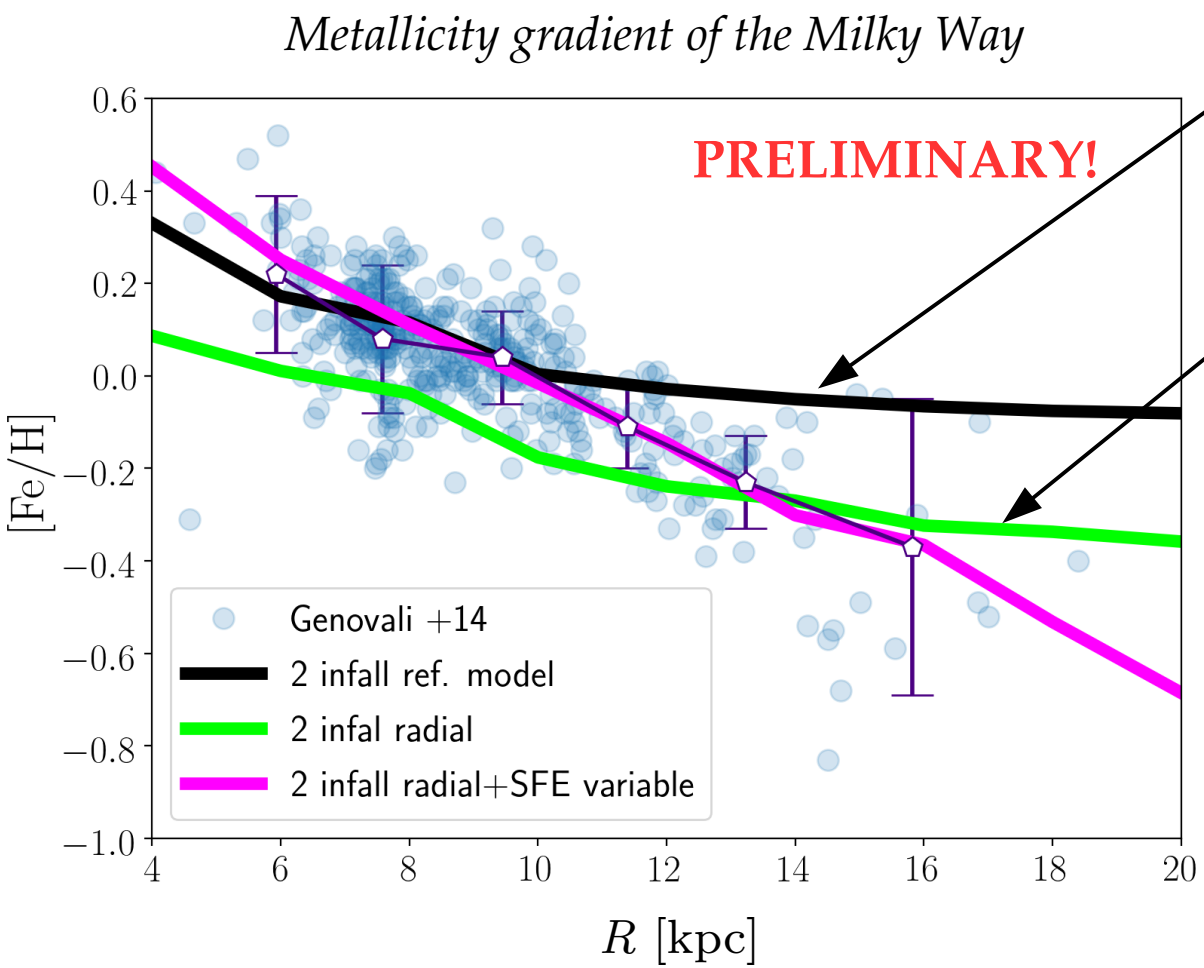


- Test how this physically-motivated radial velocity profiles affect CEM predictions

CEMs with time-dependent radial flows



Two-infall gas accretion law + **inside-out** formation

Two-infall gas accretion law + **inside-out** formation + **time-dependent** radial flows from MW-like simulations

- Significant change in the profile
- Must be always included in CEMs

Spitoni, Nuza+in prep.

Summary

- We tested **three sensible assumptions** of CEMs for the formation of the MW disc using simulations in a cosmological context:
  - *Exponential accretion of gas during disk assembly*
    - **On average**, gas fluxes exhibit a **smooth decline** in time
    - Typical disk assembly times in agreement with CEM assumptions
  - *Inside-out formation scenario*
    - Accretion timescales onto the disk increase towards larger radii
    - Similar trend as postulated in CEMs
    - The disk forms from the **inside-out**
  - *Radial gas flows*
    - Natural outcome of cosmological evolution of the Galaxy
    - Significant impact in CEM-derived chemical gradients
    - **Must be always** included in CEMs

Thanks!