592. WE-Heraeus Seminar
“Reconstructing the Milky Way's History”

Accretion, radial flows and abundance gradients in spiral galaxies

Gabriele Pezzulli
(University of Bologna)
Filippo Fraternali
(Bologna, Groningen)

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Gas accretion onto star-forming discs

- Crucial for evolution of spirals
- Accretion profile $\dot{\Sigma}_{\rm acc}(t, R)$ unknown!
- 2 main routes :

"FORWARD" (from first principles)

- Hydro cosmo sims
- Sensible to detailed baryonic physics

SEE poster by
Maider Miranda

"BACKWARD" (phenomenological)

- From observed properties of galaxies
- Simple (empirical) prescriptions $\longrightarrow$ Simple (analytic) predictions

Structural evolution

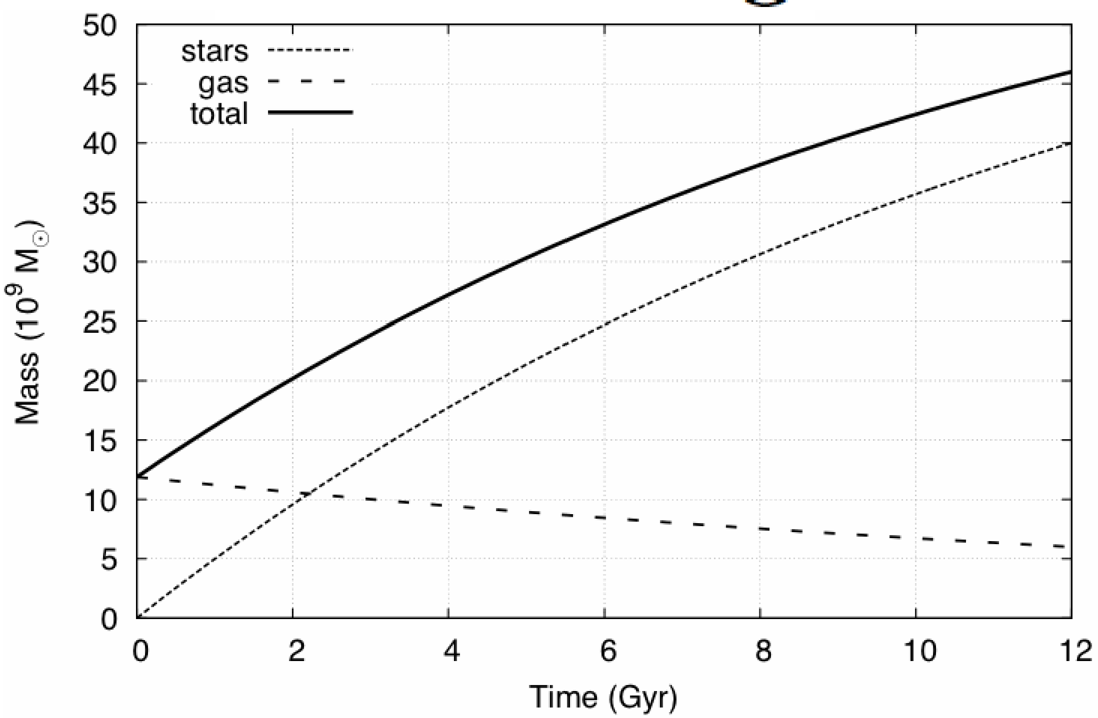
A basic toy model

- Exponential stellar disc
- Kennicutt-Schmidt law
- Exponential SFH

3 (observable) parameters: $R_\star \quad M_\star \quad M_\mathrm{g}$

MW-like example:

$$\begin{cases} R_\star &= 2.5\ \mathrm{kpc} \\ M_\star &= 4 \times 10^{10}\ \mathrm{M}_\odot \\ M_\mathrm{g} &= 6 \times 10^{9}\ \mathrm{M}_\odot \end{cases}$$



Can we infer $\dot{\Sigma}_{\mathrm{acc}}(t, R)$?

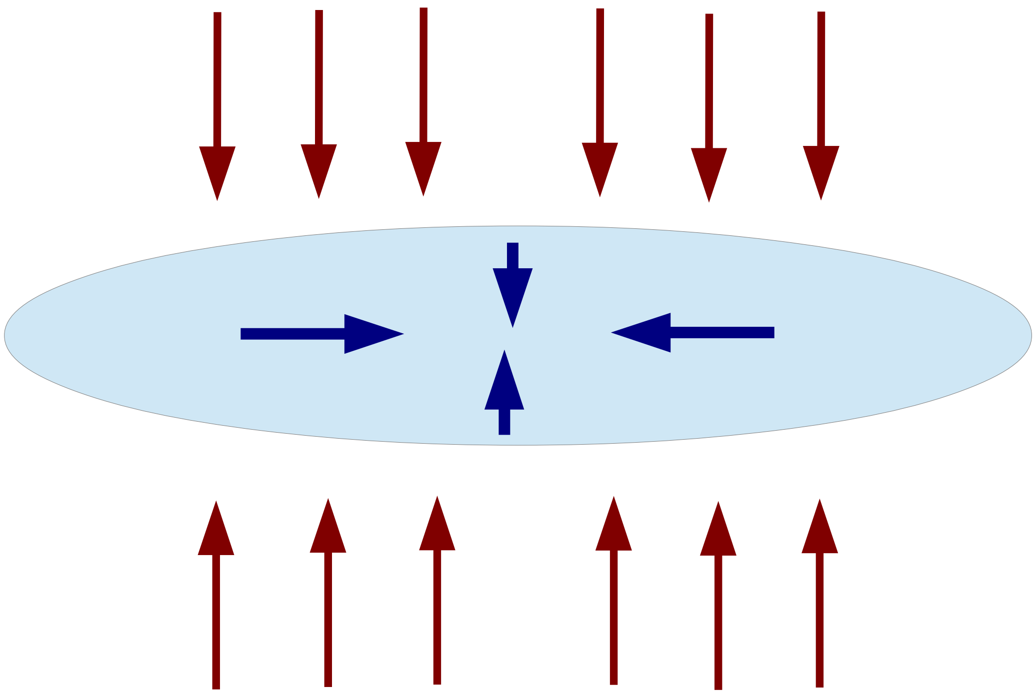
Effective accretion

$$\boxed{\dot{\Sigma}_{\mathrm{eff}}(t,R) := \frac{\partial \Sigma_{\mathrm{g}}}{\partial t}(t,R) + \frac{\partial \Sigma_{\star}}{\partial t}(t,R)}$$

The gas "need" of annulus R at time t

Conservation of mass:

$$\boxed{\underline{\dot{\Sigma}_{\mathrm{eff}}} = \underline{\dot{\Sigma}_{\mathrm{acc}}} - \frac{1}{\underline{2\pi R}}\frac{\partial \mu}{\underline{\partial R}}}$$

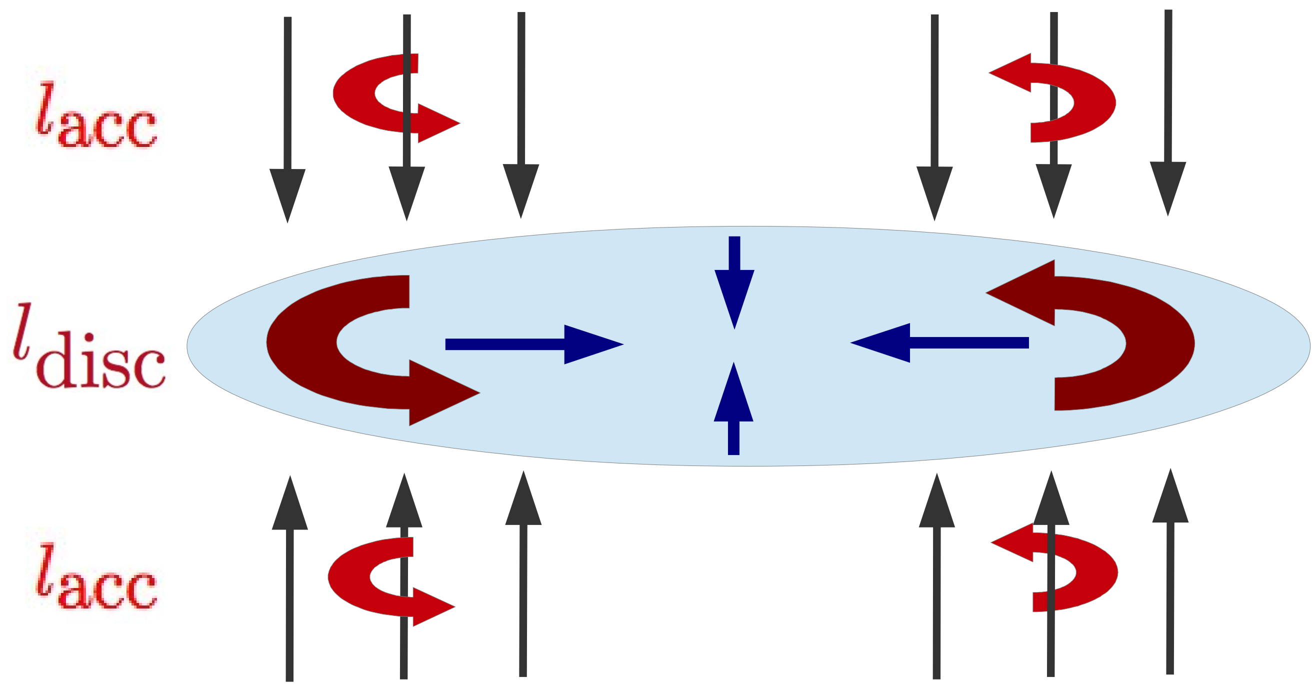


Two components:

- Direct accretion (from IGM)
- Radial mass flux (within the disc)

$$\boxed{\mu := 2\pi R \Sigma_{\mathrm{g}} u^{R}}$$

Angular momentum and radial flows



$$\boxed{l_{\mathrm{acc}} < l_{\mathrm{disc}} \longrightarrow \mu < 0}$$

Mayor & Vigroux (1981); Lacey & Fall (1985)

HOT accretion
(hydrostatic equilibrium)

$$\frac{l_{\mathrm{acc}}}{l_{\mathrm{disc}}} = \sqrt{1 - \delta \frac{T}{T_{\mathrm{vir}}}}$$

$$\left(\delta := -\frac{\partial \ln \rho}{\partial \ln R}\right)$$

COLD accretion
(independent particles)

$$\frac{< l_{\mathrm{acc}} >}{l_{\mathrm{disc}}} < 1$$

The flux decomposition problem

$$\underbrace{\dot{\Sigma}_{\rm eff}}_{\text{Local ``need''}} = \underbrace{\dot{\Sigma}_{\rm acc}}_{\text{Direct accretion}} - \underbrace{\frac{1}{2\pi R}\frac{\partial \mu}{\partial R}}_{\text{Radial flow}}$$

Solve as a function of angular momentum!

Previous work:

- **Pitts & Tayler (1989)**
  analytic solutions in special cases
- **Bilitewski & Schönrich (2012)**
  discretized equations
  in the Schönrich & Binney (2009) model

The general analytic solution

Dimensionless parameter: $\boxed{\alpha := \frac{l_{\rm disc} - l_{\rm acc}}{R\,\partial l_{\rm disc}/\partial R}}$ (Pezzulli & Fraternali, in prep.)

E.g. $V_{\rm disc} = const \rightarrow \alpha = 1 - \frac{V_{\rm acc}}{V_{\rm disc}}$

$\alpha = 0 \rightarrow$ Corotation

$\alpha = 1 \rightarrow$ No rotation

Key equations: $\boxed{\mu = -2\pi R^2 \alpha \dot{\Sigma}_{\rm acc}}$ + continuity

Explicit solution:

$$\mu(t,R) = \frac{1}{h(t,R)}\left(\mu_0 - 2\pi\int_{R_0}^{R} R' h(t,R')\dot{\Sigma}_{\rm eff}(t,R')dR'\right)$$

Structure

$$h(t,R) = \exp\left\{\int_{R_0}^{R}\frac{dR'}{R'\alpha(t,R')}\right\}$$

Angular momentum

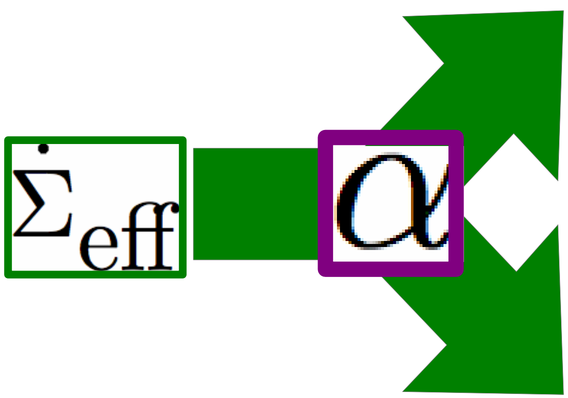
Furthermore, IF:

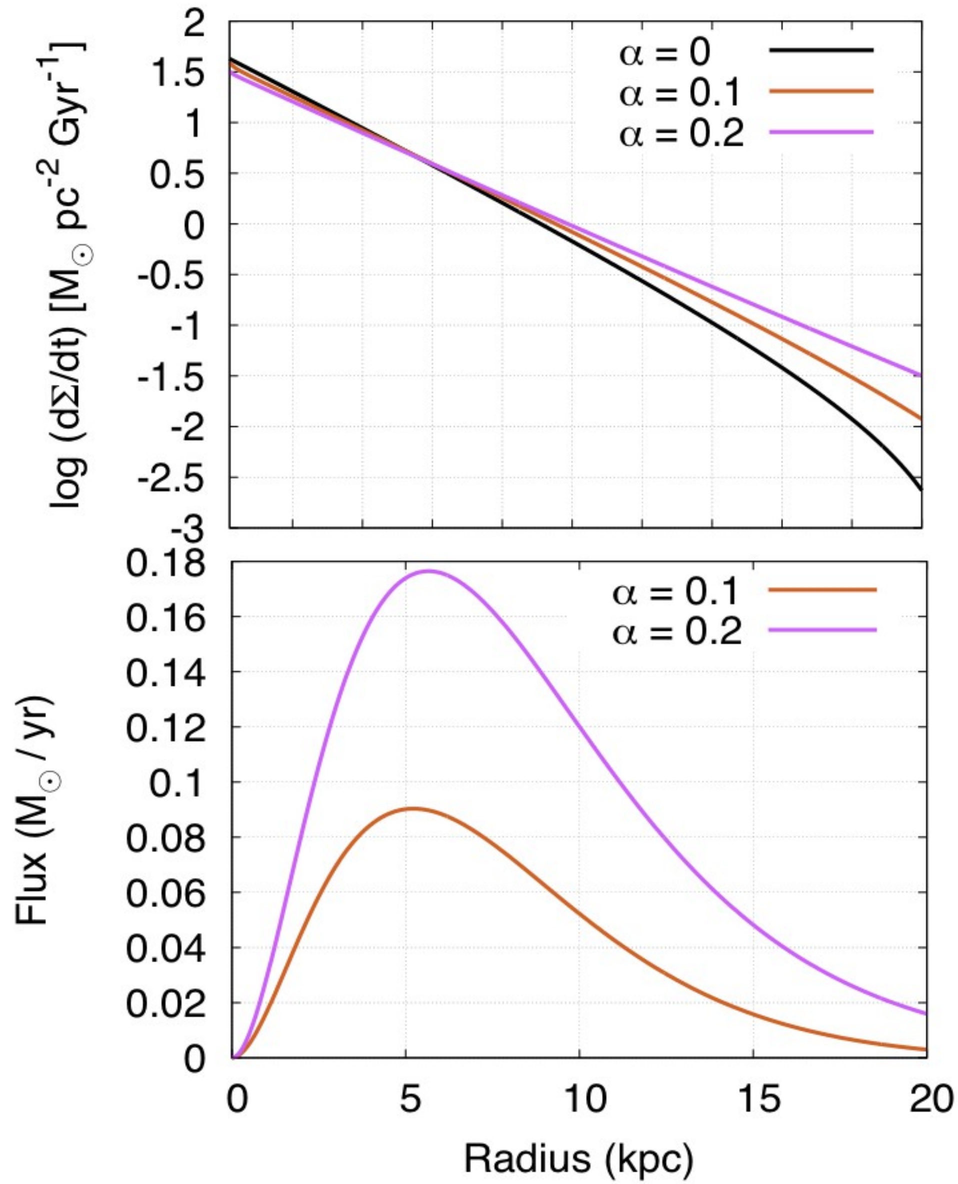
- $\alpha = \alpha(t)$
- $\dot{\Sigma}_{\rm eff}$ analyitic in R

$\rightarrow$ Solution analytic in R

Flux decomposition

$$\dot{\Sigma}_{\mathrm{eff}} = \dot{\Sigma}_{\mathrm{acc}} - \frac{1}{r}\frac{\partial \mu}{\partial r}$$





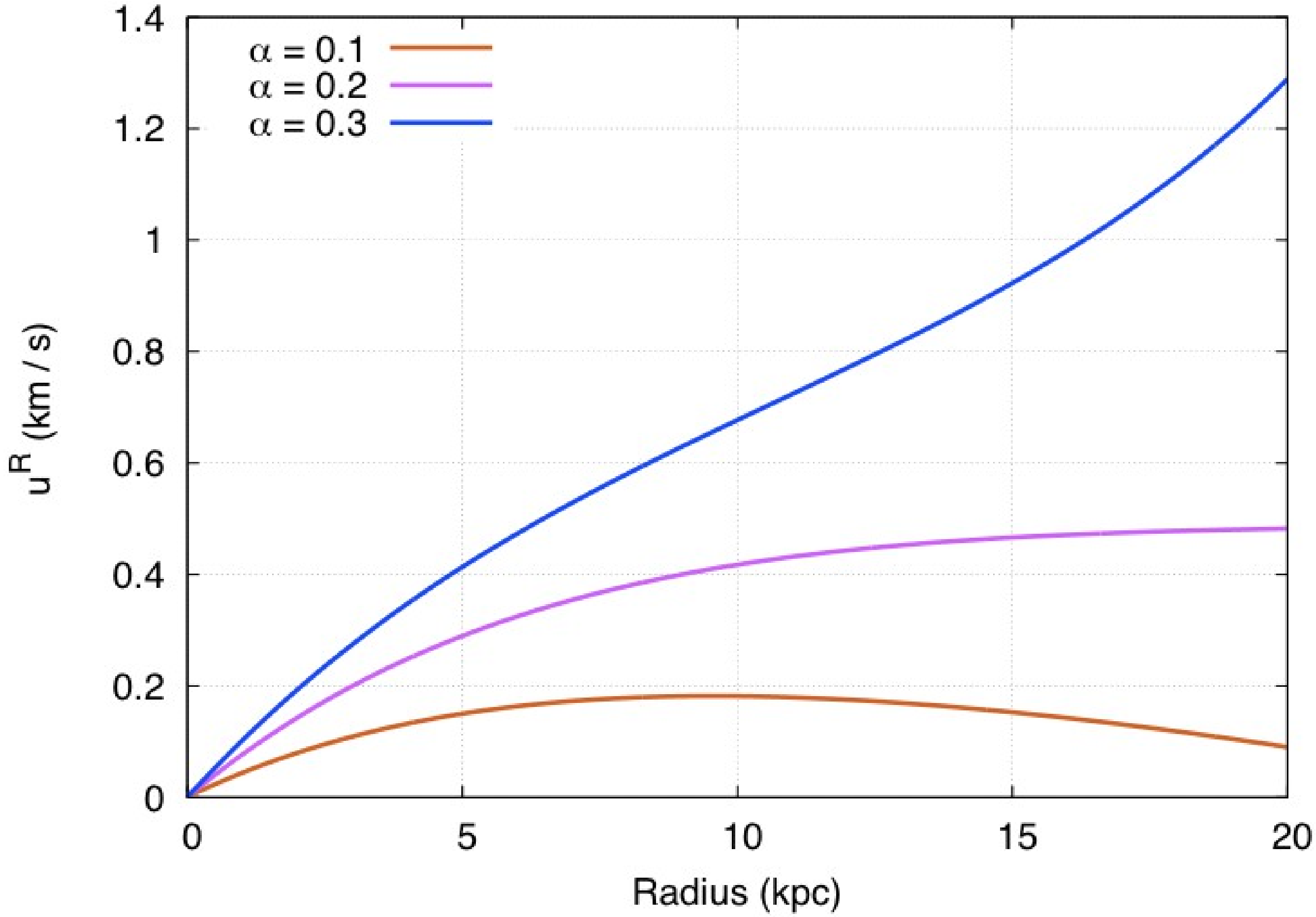
Accretion rate surface density

$$\boxed{\dot{\Sigma}_{\mathrm{acc}}}$$

Radial mass flux

$$\boxed{\mu := 2\pi R \Sigma_{\mathrm{g}} u^{R}}$$

Radial velocity



- Non trivial patterns

  Full calculation needed for consistency with AM conservation
- Too low for direct observation

  Need for an integrated signal: chemical evolution!

Chemical evolution

$$\frac{\partial \tilde{X}_i}{\partial t} + u^R \frac{\partial \tilde{X}_i}{\partial R} = \frac{\dot{\Sigma}_\star}{\Sigma_\mathrm{g}} - \tilde{X}_i \frac{\dot{\Sigma}_\mathrm{acc}}{\Sigma_\mathrm{g}}$$

CAVEAT:
Ok for α elements in the ISM

($\tilde{X}_i$ = <u>normalized</u> abundance by mass)

Linear equation!

1. <u>Characteristic</u> lines (integral curves of radial velocity)

$$\frac{dR}{dt} = u^R$$

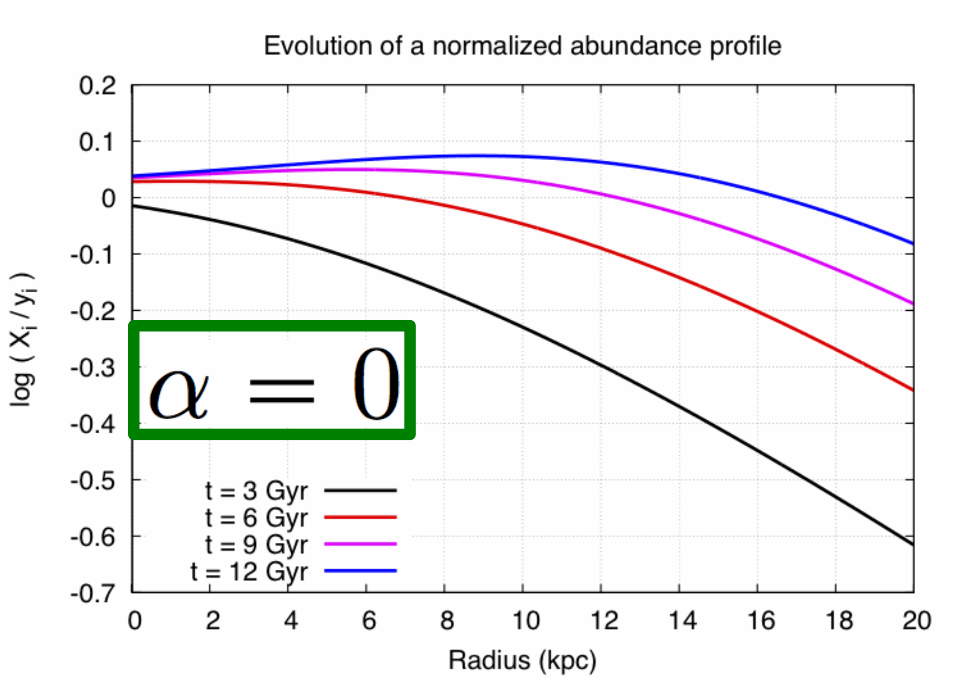
2. <u>Linear ODE</u> along characteristics

$$\sigma(t) = \int_0^t \frac{\dot{\Sigma}_\mathrm{acc}}{\Sigma_\mathrm{g}}(t')dt'$$

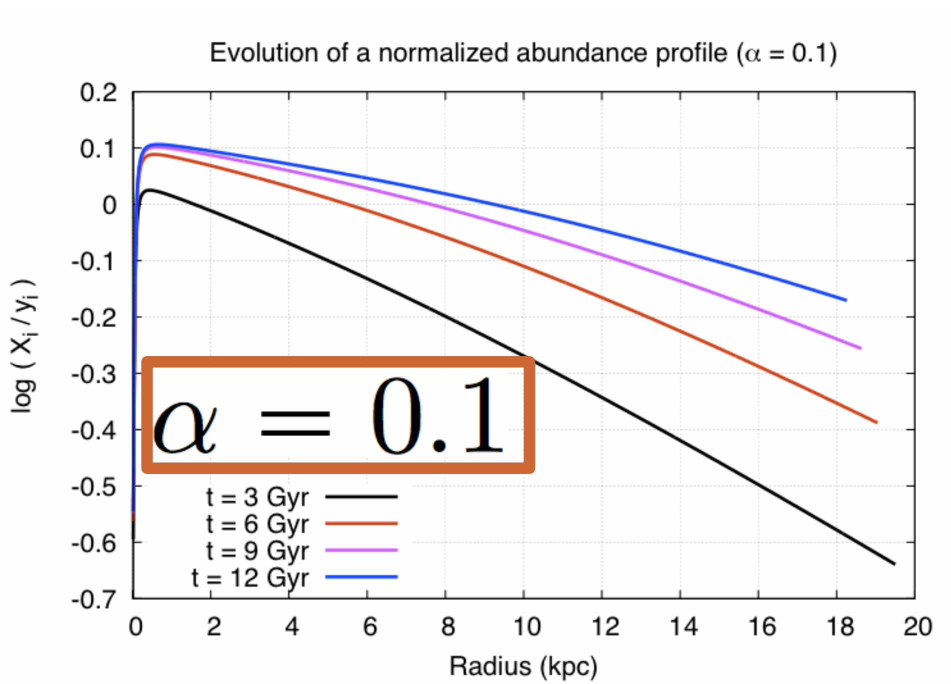
$$\boxed{\tilde{X}_i(t) = e^{-\sigma(t)} \int_0^t e^{\sigma(t')} \frac{\dot{\Sigma}_\star}{\Sigma_\mathrm{g}}(t')dt'}$$

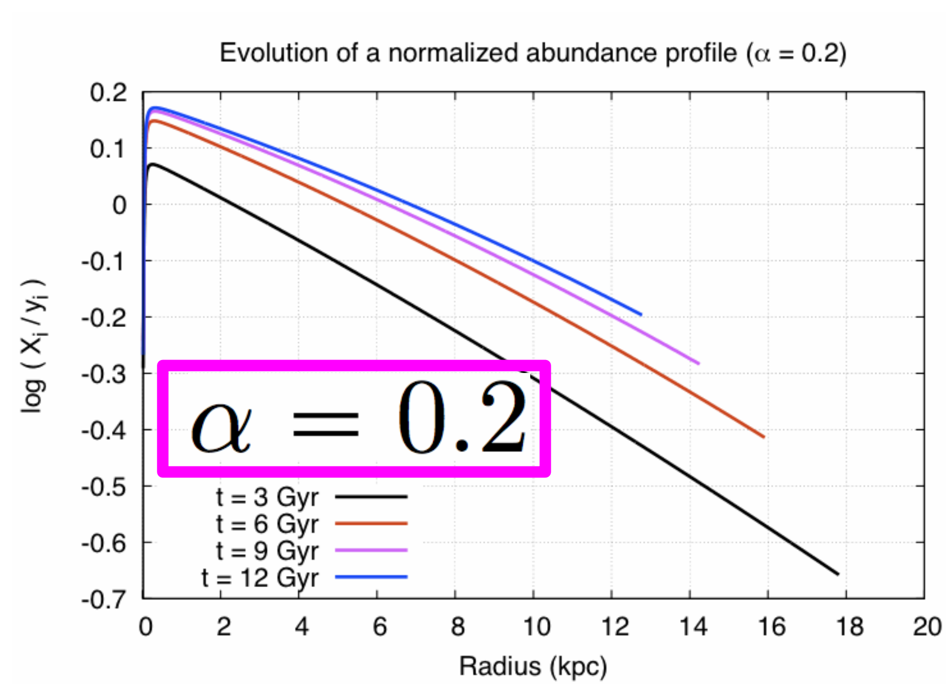
Explicit solution

Chemical evolution

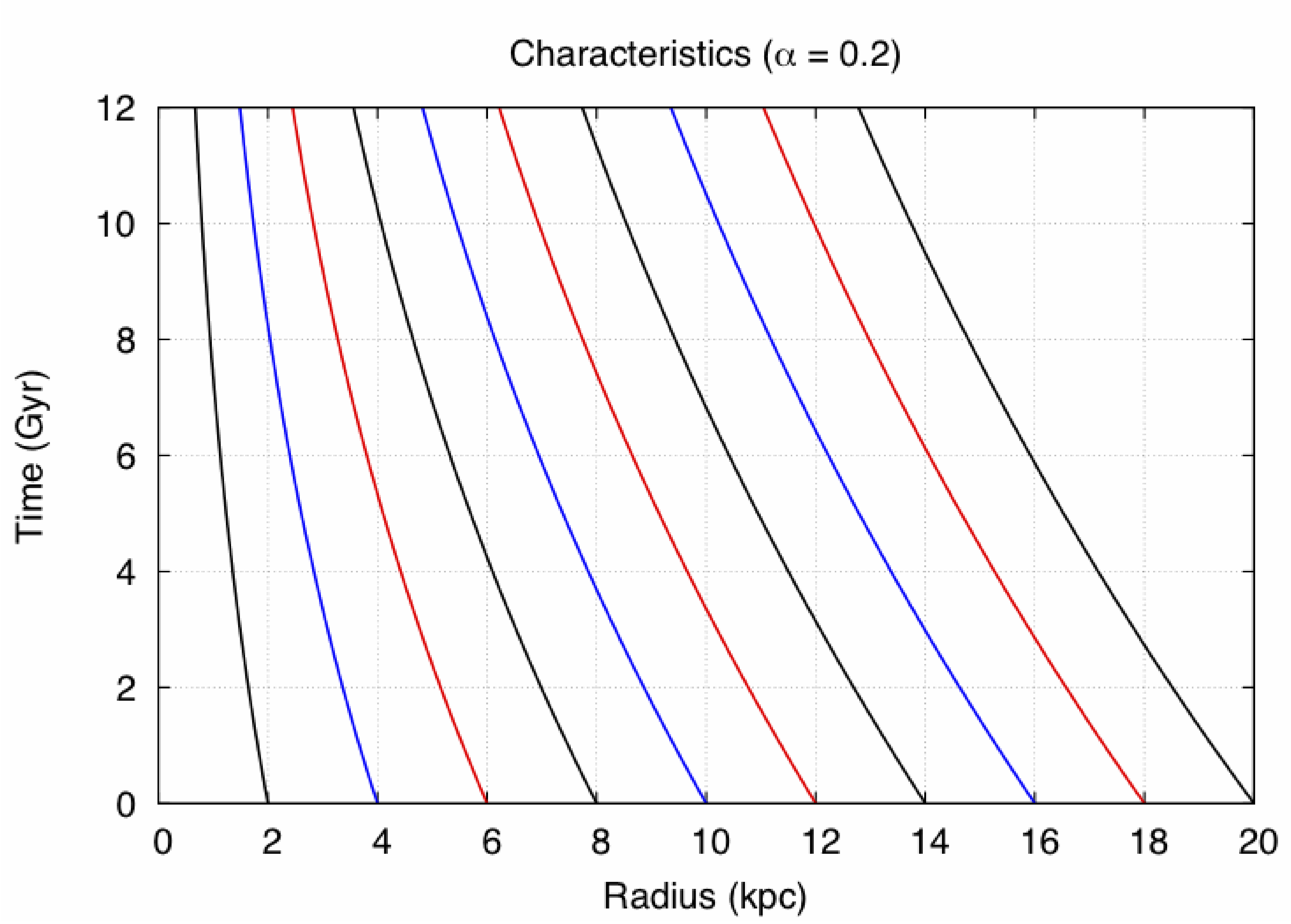


<u>Very sensitive</u> to angular momentum





Characteristics and boundaries



Characteristics and boundaries

Domain shrinking

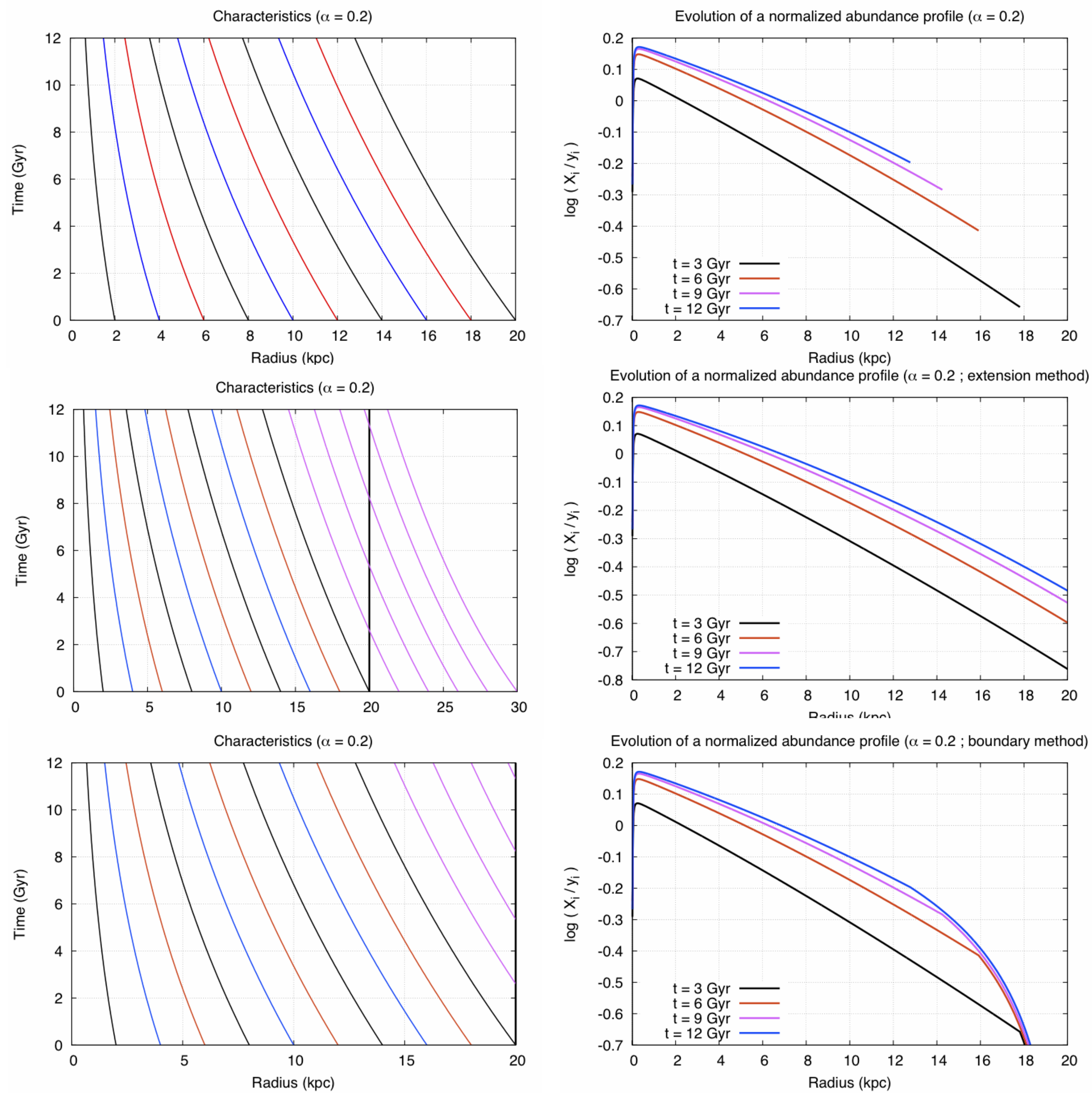
Possible solutions:

Consider more characteristics...

Conservative choice

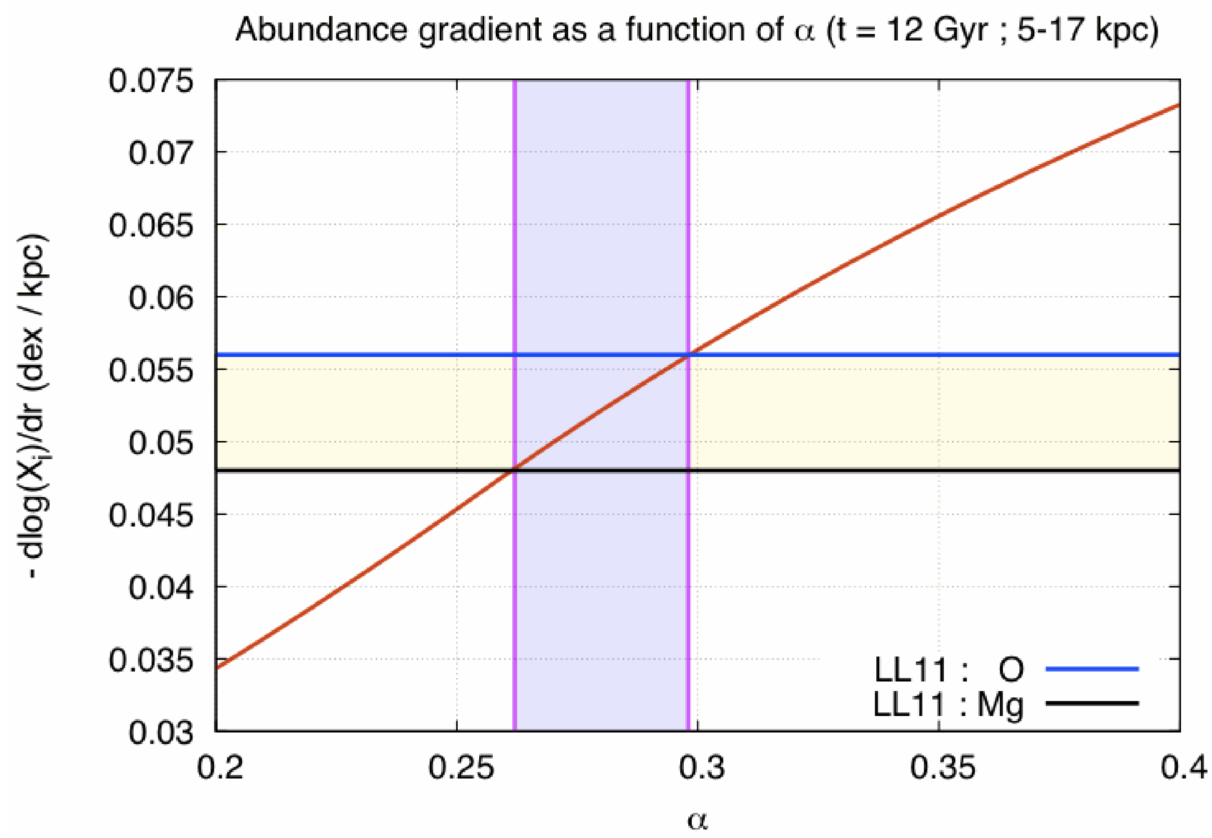
... or introduce an outer boundary (often implicit)

Artificially steep gradients



Comparison with observations

Gradients for α elements in Cepheids (Luck & Lambert 2011)



$\boxed{0.26 < \alpha < 0.30}$ → $\boxed{\frac{V_{\rm acc}}{V_{\rm disc}} \simeq 0.70 \div 0.74}$

cfr. Bilitewski & Schönrich (2012)

Summary

- Structural properties → <u>effective</u> accretion, BUT
- Decomposition (accretion + radial flows)
  depends on angular momentum
  <u>Can be solved analytically!</u>
- (Locally) low angular angular momentum implies:
  - enhanced outer accretion
  - steepening of gradients
- Impact of <u>boundary conditions</u> on <u>gradients</u>...
  under control with the <u>method of characteristics</u>

Thank you!