

ESA-ESO Galaxy WG Open questions

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ESA-ESO Working Groups

Report No.4 Galactic Populations, Chemistry and Dynamics June 2008

ESA-ESO Working Groups

Report No.2 Galactic Populations, Chemistry and Dynamics



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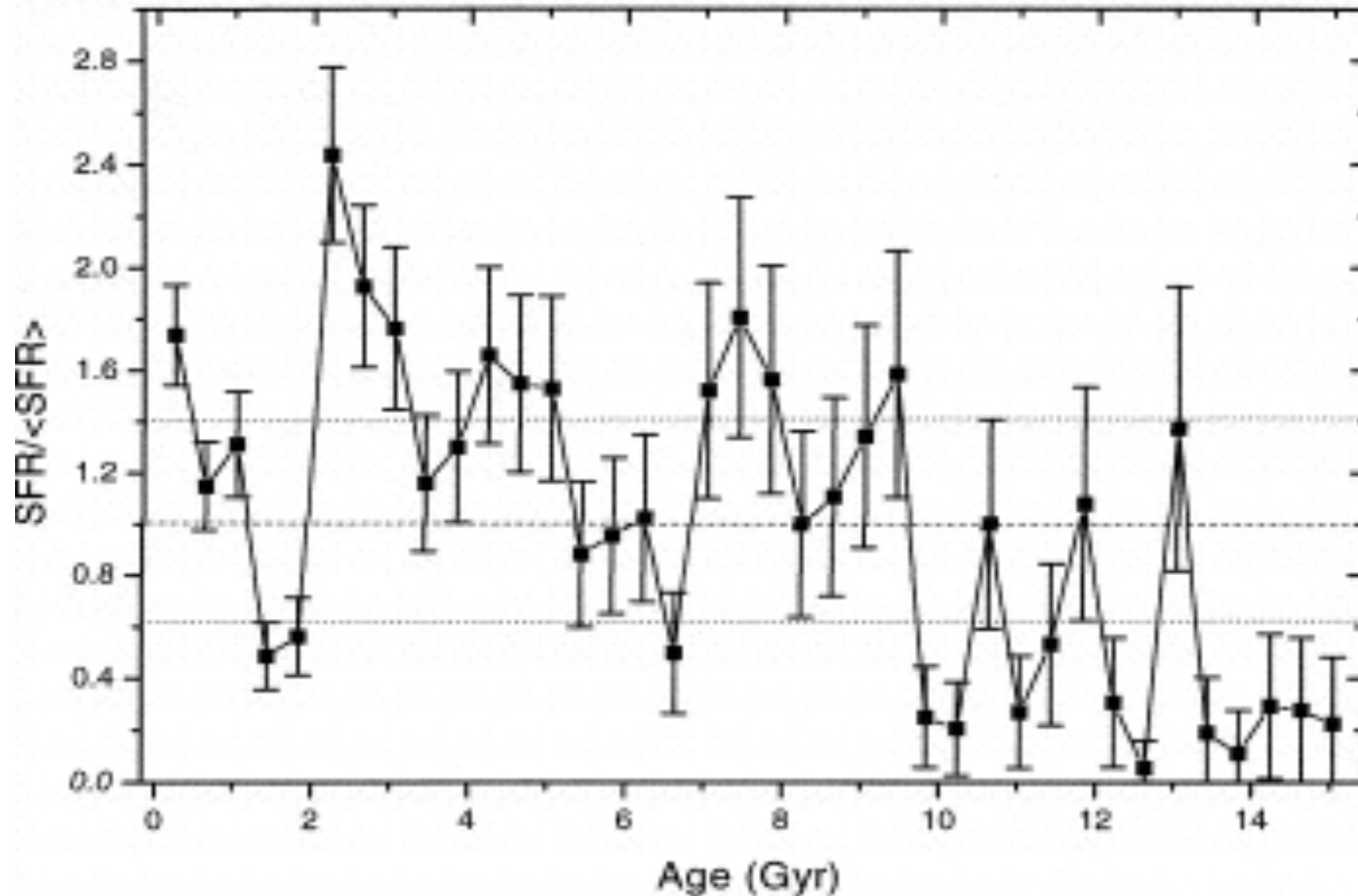
Global top questions

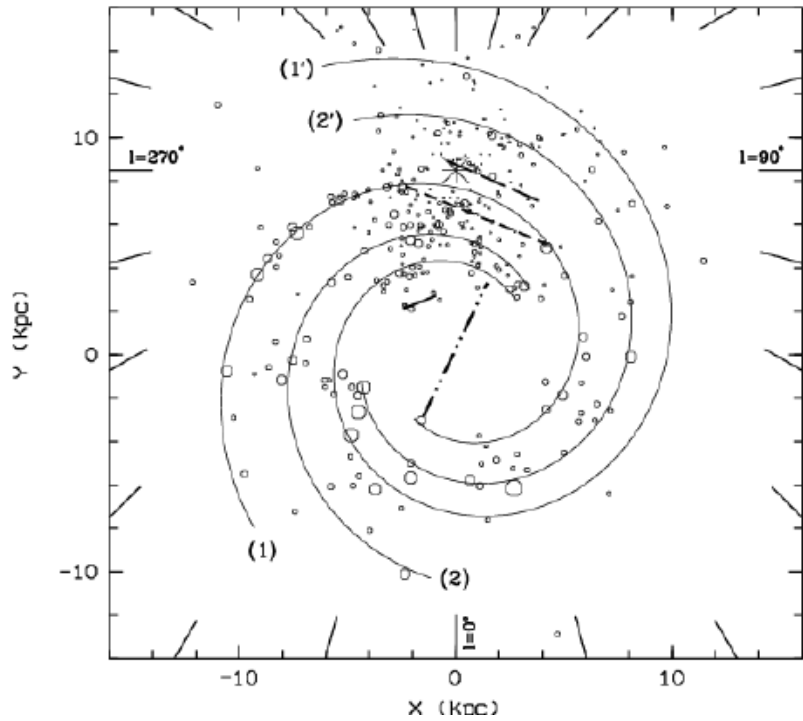
1. Which stars form and have been formed where?

- Star formation history of the inner disk
- Location and number of spiral arms
- Extent of the outer disk (and properties of the populations)
- Star formation in the bulge (a different IMF?)

- Which stars formed "in-situ" in comparison to accreted?
- How does this fraction change for the various components (how important was accretion?)
- How do the dynamics of the Galaxy (disk/spiral arms/bar) affect star formation, and how important is radial migration?

star formation history in galactic thin disk from SN: roughly uniform,
with episodic star bursts for ages < 10 Gyr,
but lower for ages > 10 Gyr

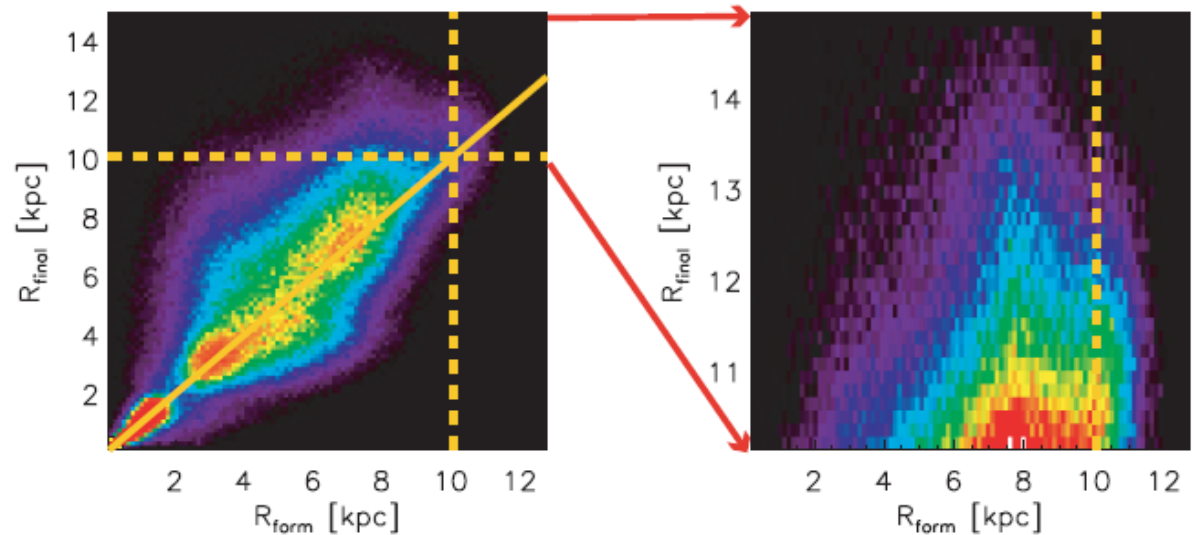




- Latest proposal 4 spiral arms
- Unclear whether CO/stellar arms coincide
- Outer spiral structure? Edge to thin disk?
- The other side of the Galaxy...

- Simulations show that stars do not remain at the birth location (radius) but radially migrate;
- this can erase correlations, such as age-metallicity;
- this takes some time, so in the outskirts there are some very old stars (but the disk formed inside-out)

...



Roskar et al. 2008

Global top questions

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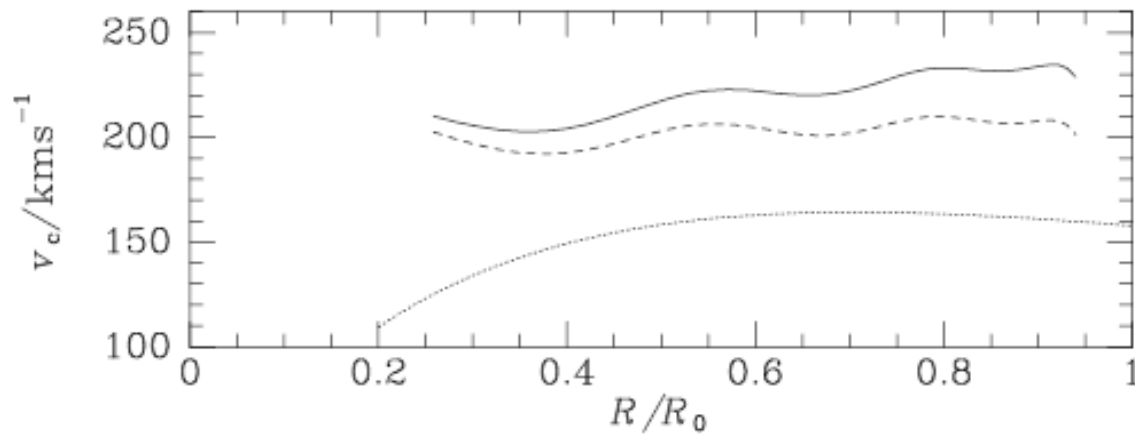
Tools:

- Photometric surveys (multi-colour, and infrared)
- Astrometric surveys (visual and infrared)
- Spectroscopic surveys for radial velocities and chemical abundances

Global top questions

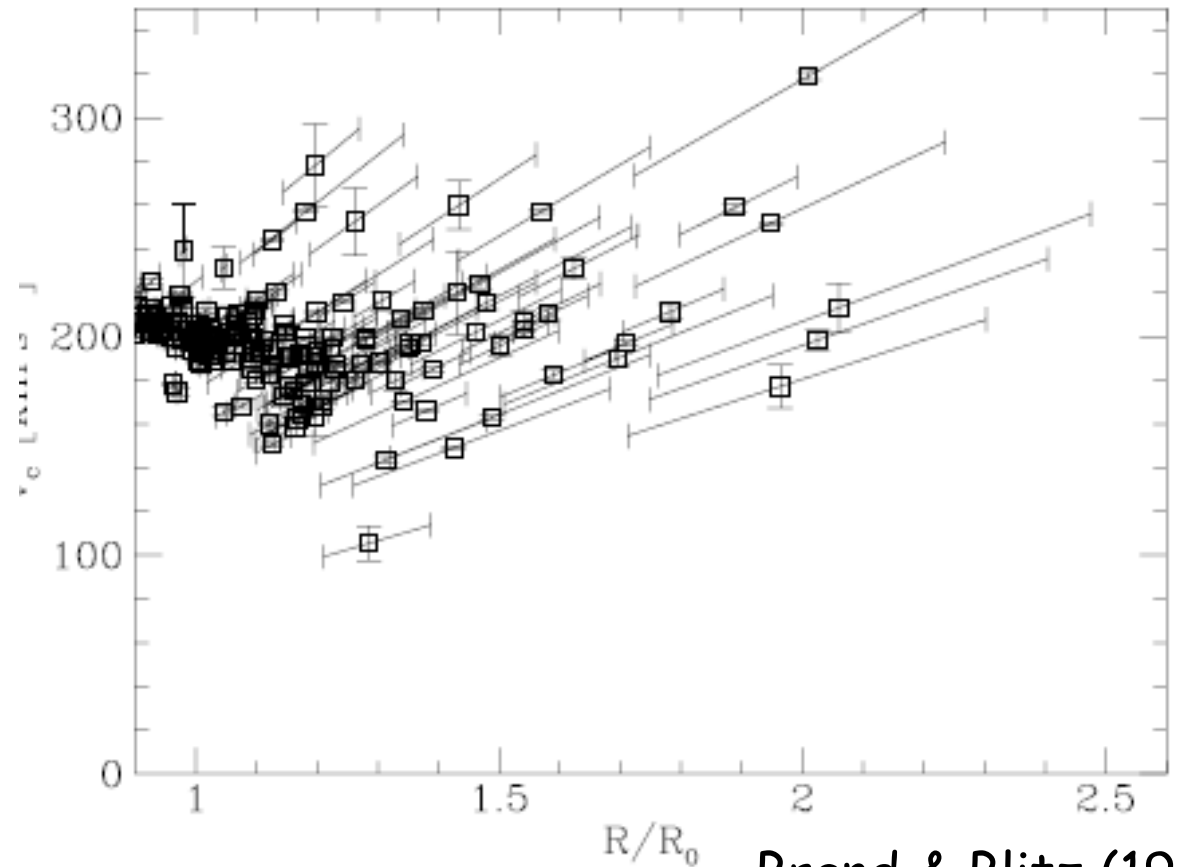
2. What is the mass distribution throughout the Galaxy?

- How much dark-matter is there in the Galactic disk?
- What is the distribution of mass (rotation curve) beyond the Solar circle?
- How is the dark matter distributed in the Galaxy?
 - What is the shape of the dark matter halo? What is the
 - density profile of the DM?
 - How is the DM distributed (smooth, in streams, clumps)?
 - Is the gravitational potential consistent with CDM or do we need to
 - modify "gravity"?



The circular velocity is larger than expected on the basis of the estimated mass and extent of the disk

The rotation curve is poorly known for the outer disk (need better distances!)



Brand & Blitz (1993)

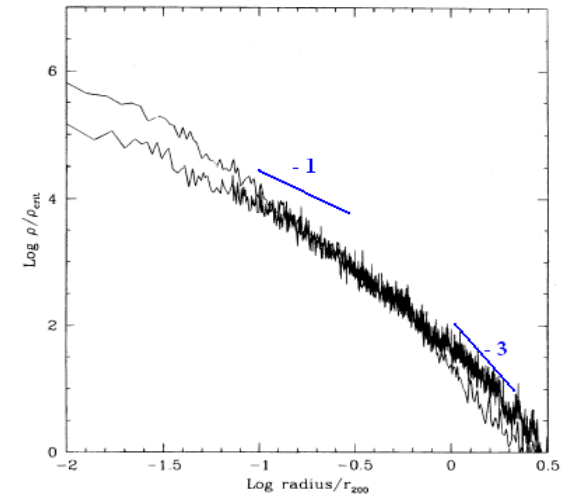
Dark-matter: predictions

Numerical simulations of the formation of dark matter halos make very definite predictions on

density profile:

à la Navarro, Frenk & White (NFW)

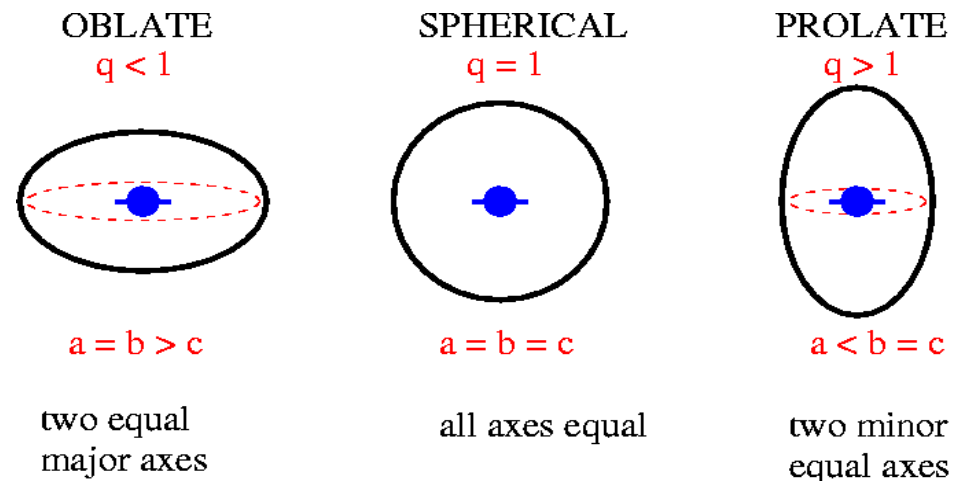
$$\rho(r) = \rho_0 r_s^3 / [r (r + r_s)^2]$$



• halo shapes:

oblate, prolate or triaxial (rarely spherical)

mean minor/major axis ratio $\langle q \rangle \sim 0.8$
(Bullock 2002)





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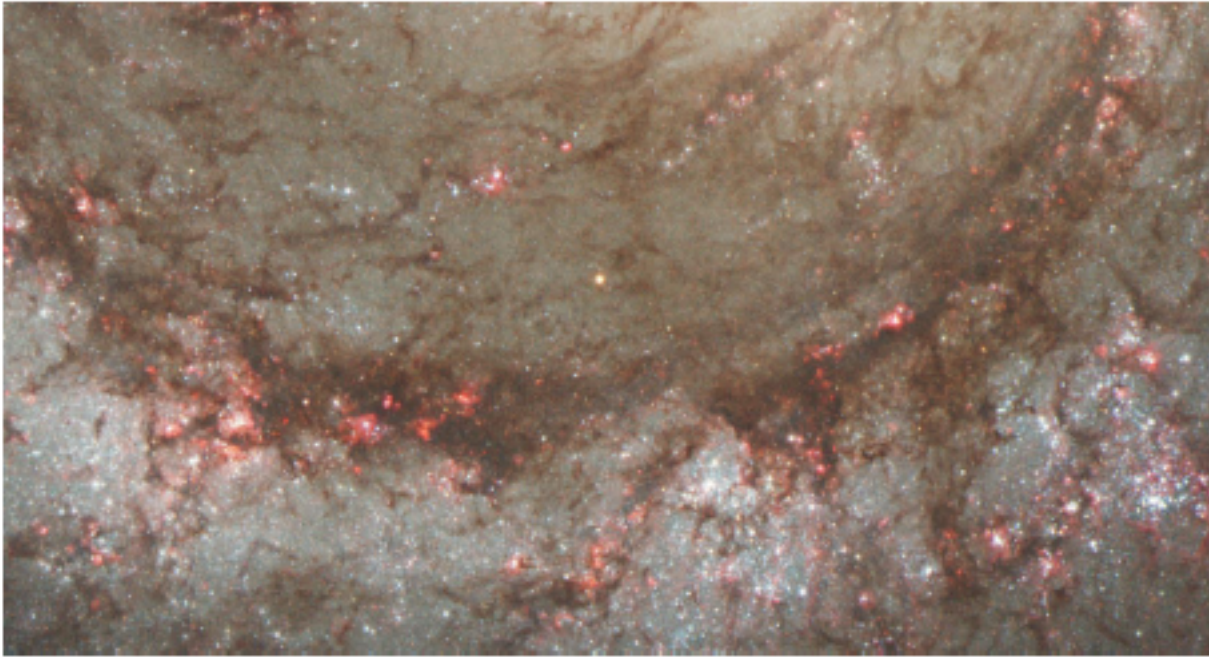
Tools:

- Kinematic surveys (astrometry+distances and radial velocity)
- Dynamical models

Global top questions

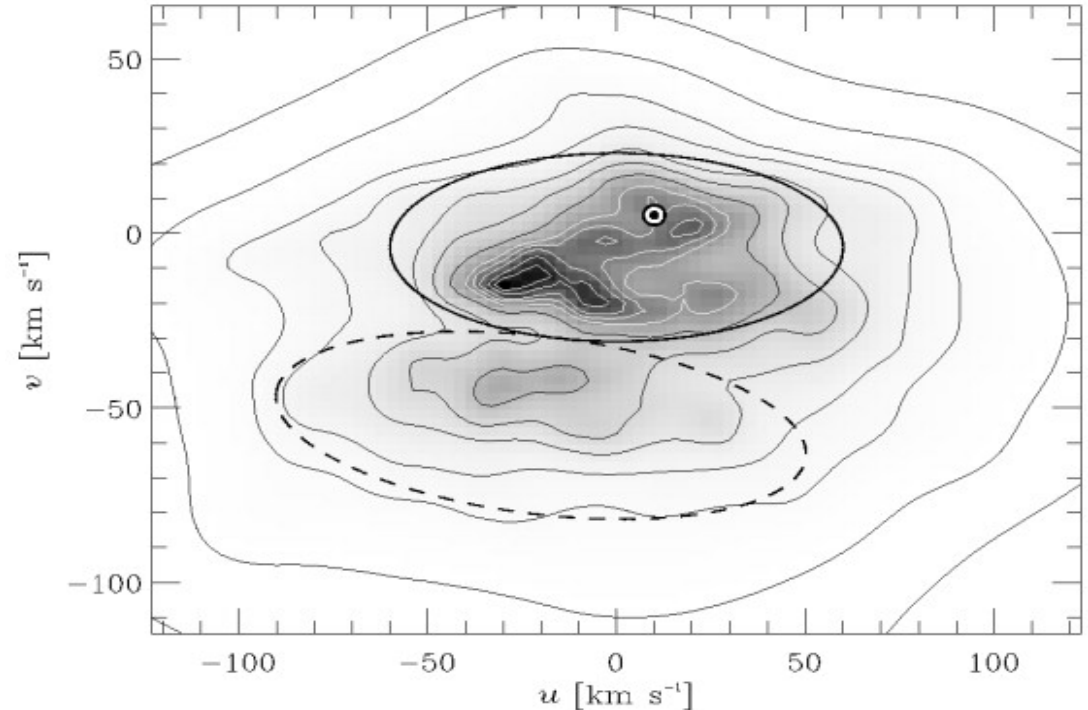
3. What is the spiral structure of our Galaxy?

- How many spiral arms?
- What are the dynamics of the arms?
- How does it affect star formation and the dynamics of the disk?
- How far do the arms extend in the outer regions?



Star formation is associated (always) with spiral arms
Is this a dynamical relation?

Many substructures appear to be induced by the spiral arms... can they also be responsible for substructures in the thick disk (or even halo?)



Global top questions

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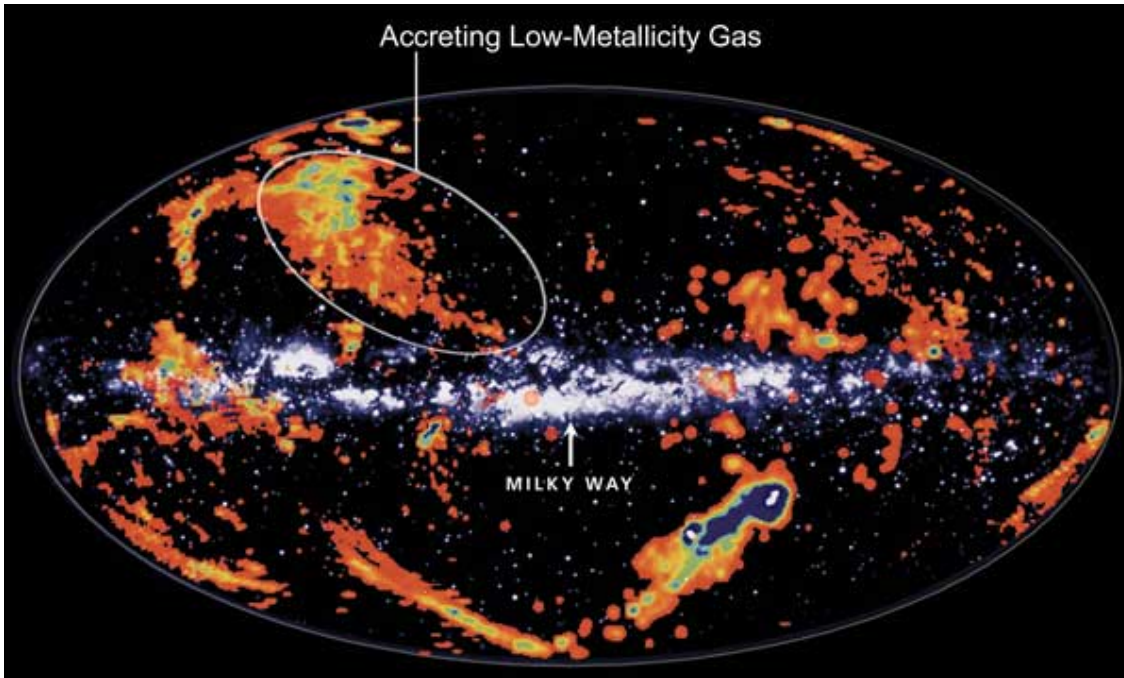
Tools

- Gas velocity field (radio observations)
- Extinction map
- Infrared surveys of the Galactic plane
- Distances and kinematics of stars in the plane
- Dynamical models

Global top questions

4. How is mass cycled through the Galaxy?

- What is the current rate of accretion of gas? How has it varied in time? What is the chemical composition of this gas? What is its origin? What is the role of high-velocity clouds?
- How does the distribution of accreted gas compare to that already present in the disk (and associated to star formation)? Is there a flow of gas in the disk? What drives it?
- How are the heavy elements produced in SN carried? What fraction ends up in extra-planar HI gas? What in winds that leave the Galaxy? How did this change with time?
- Is there a "cooling flow"? Is there a hot gas reservoir?
- What drives the intense star formation in the centre of the bulge?

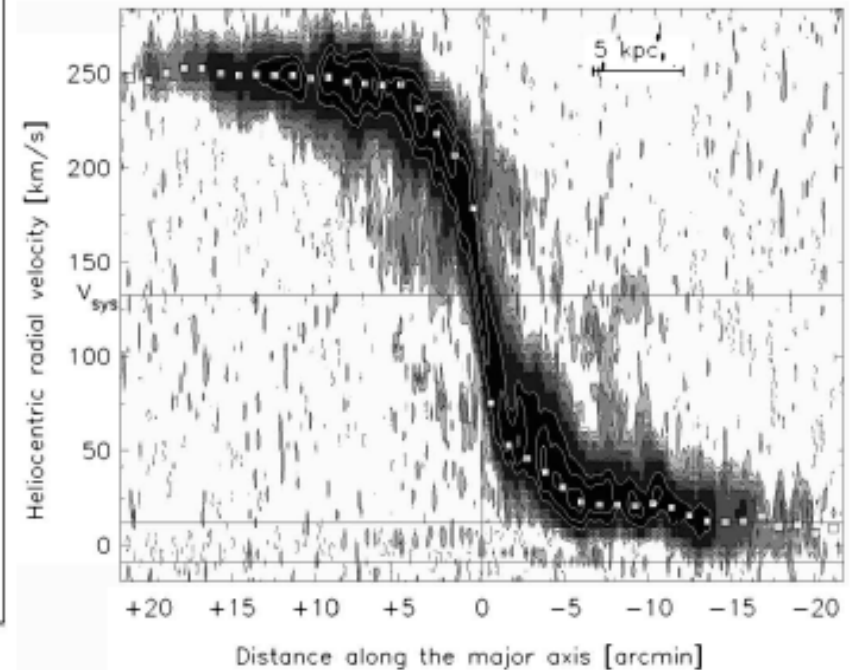
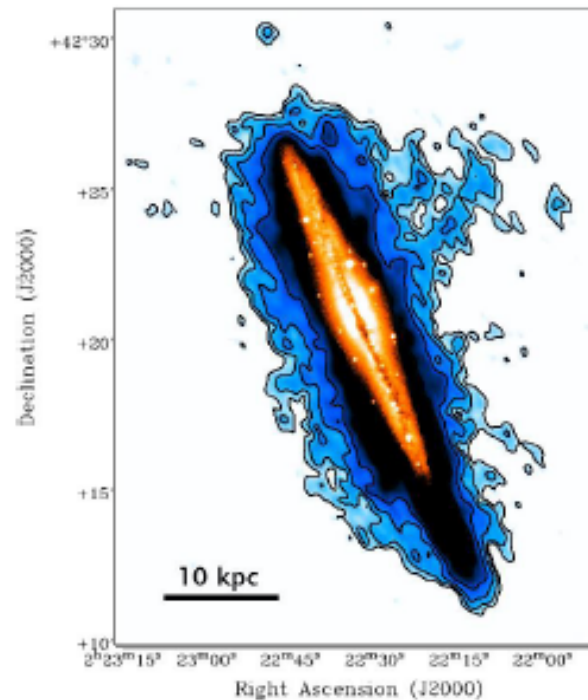


High velocity clouds: HI at high latitude and with (relatively) large radial velocities

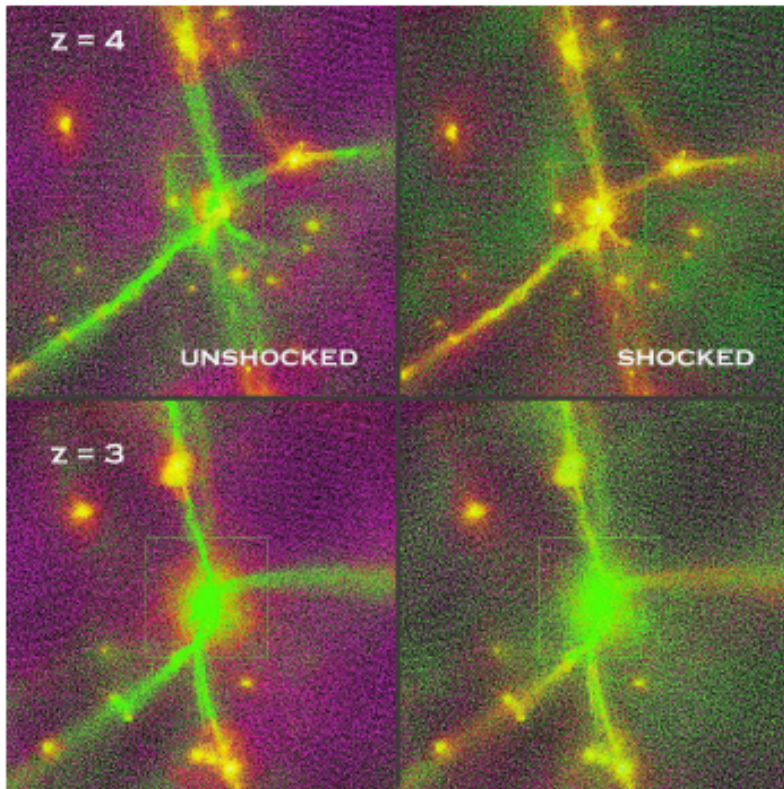
Unknown distances...

Wakker et al. 2008

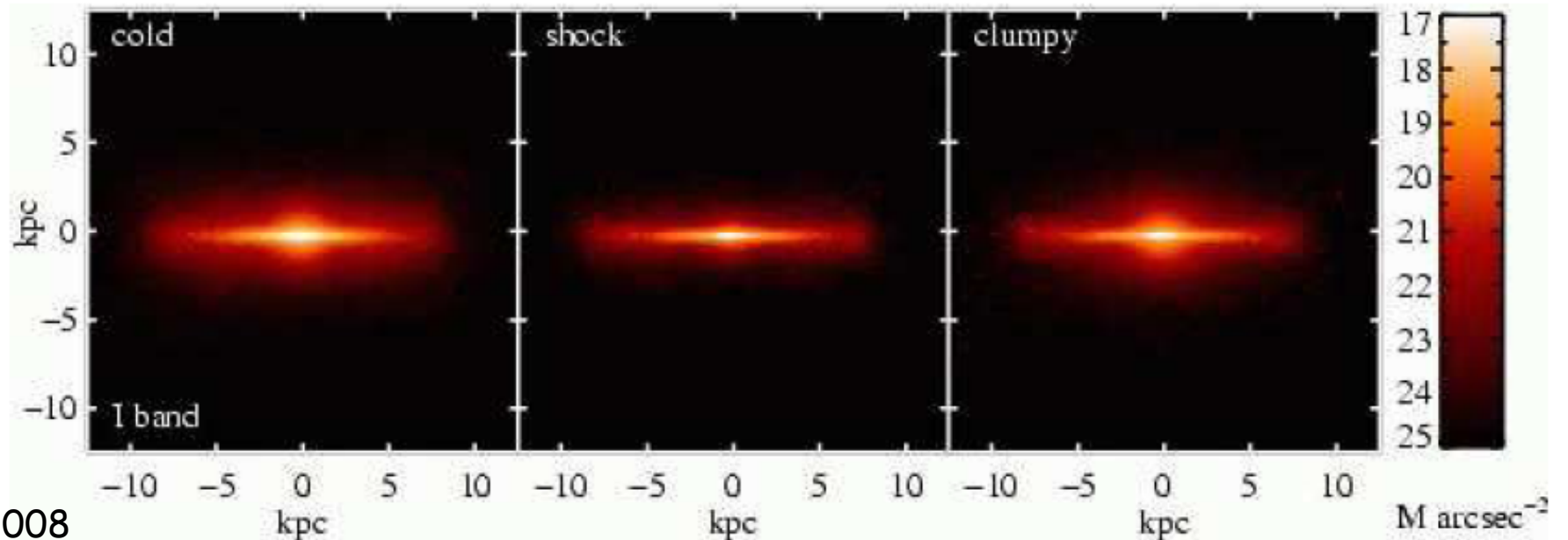
In other galaxies, HVC are not far out in the halo ... origin?



Fraternali 2008



- Until recently models predicted cold gas resulted from the cooling of gas in a hot halo
- More recently, the cold gas deposited in a disk like the MW is predicted to come also from direct cold flows
- Some of the gas may also accrete in clumps



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Tools:

- Hot gas expected to be very diffuse: soft X-ray and UV
- Nature of HVC (distances and masses) <- halo stars spectra (absorption)

Global top questions

5. How universal is the initial mass function?

- Does the shape of the IMF vary with environment?
- Was the IMF different at high-redshift?

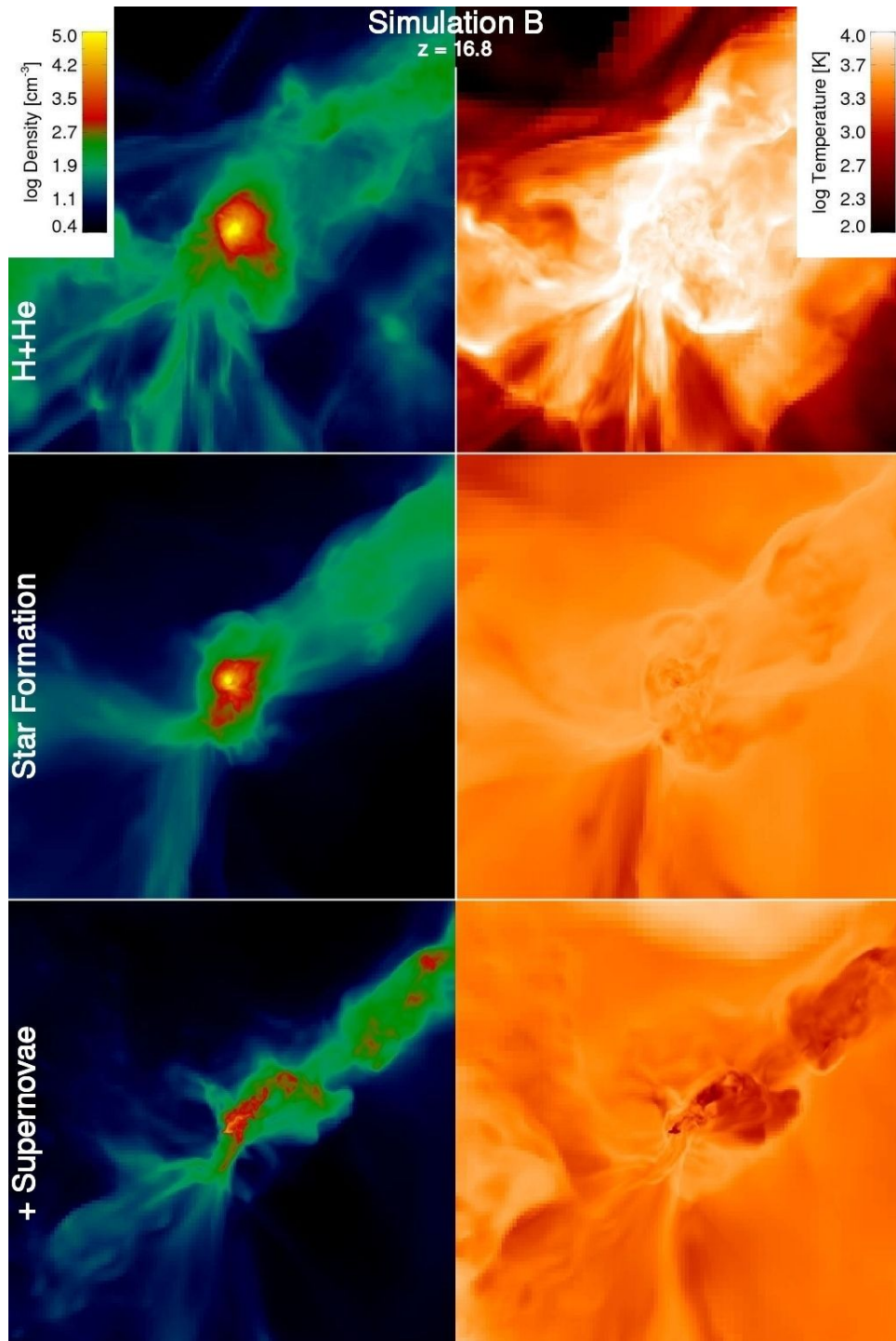
Tools

- Probe the IMF in different regions of the Galaxy
 - Dissolved clusters, star forming regions (distances; kinematics)
 - Ages; chemical compositions of stars
 - Well-calibrated mass-luminosity relation (many astrometric binary stars, from which the mass can be derived)
 - Infrared studies (for heavily obscured star forming regions)

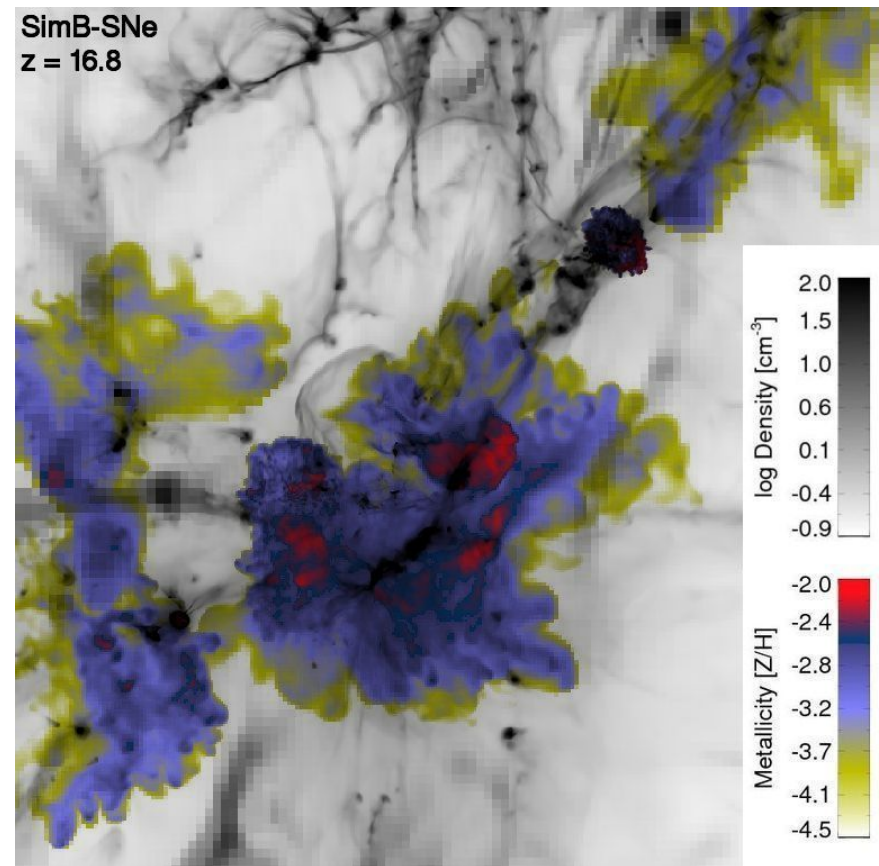
Global top questions

6. What is the impact of metal-free stars on Galaxy evolution?

- Metal-free stars: formed under a different IMF?
- What was the impact of the large UV flux? Local re-ionization?
- What fraction of the metals were retained and how have they been recycled in the Galaxy? Where are the second generation stars?
- Are there any in the Galaxy? Where?

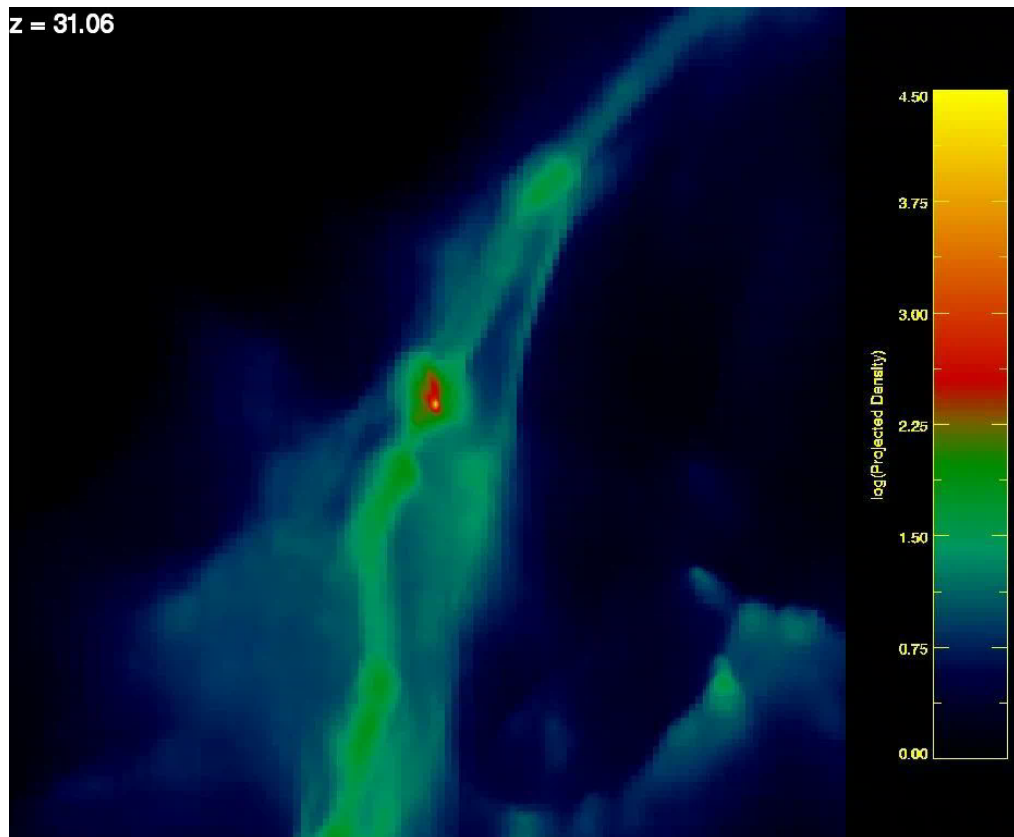


Very massive stars (such as believed Pop III stars) can strongly affect the medium around them (density, T , and metallicity)

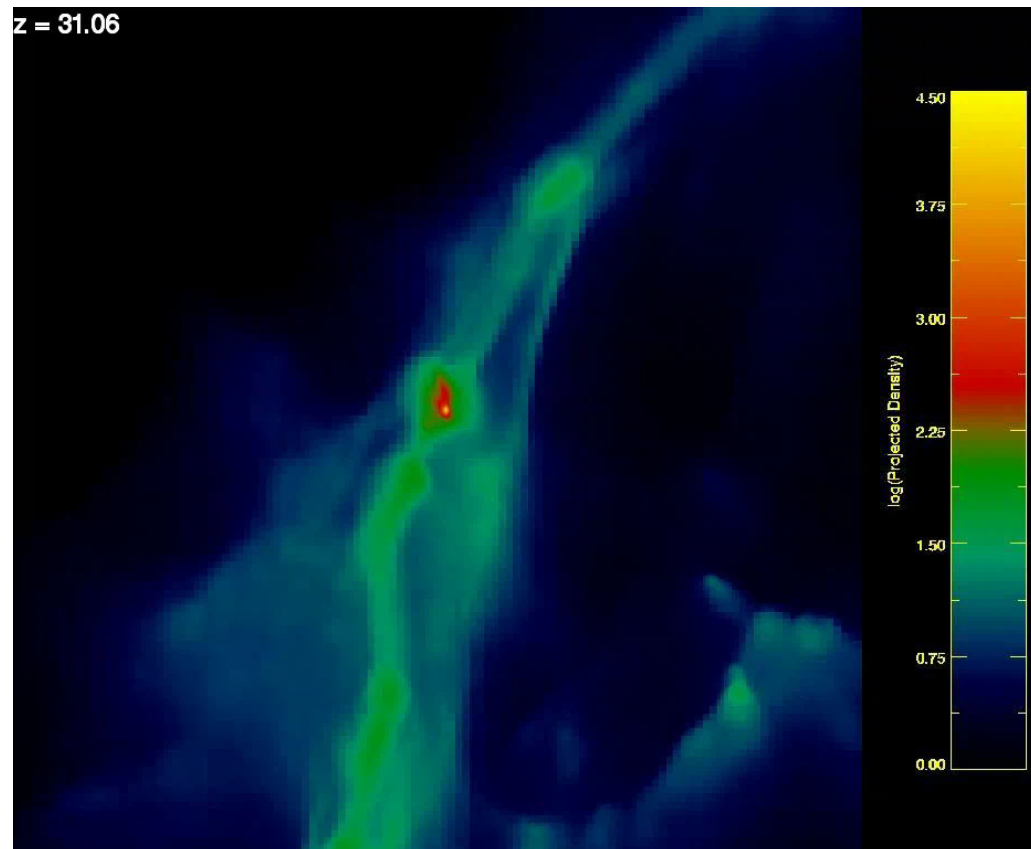


Wise & Abel 2008

$z = 31.06$



$z = 31.06$



Global top questions

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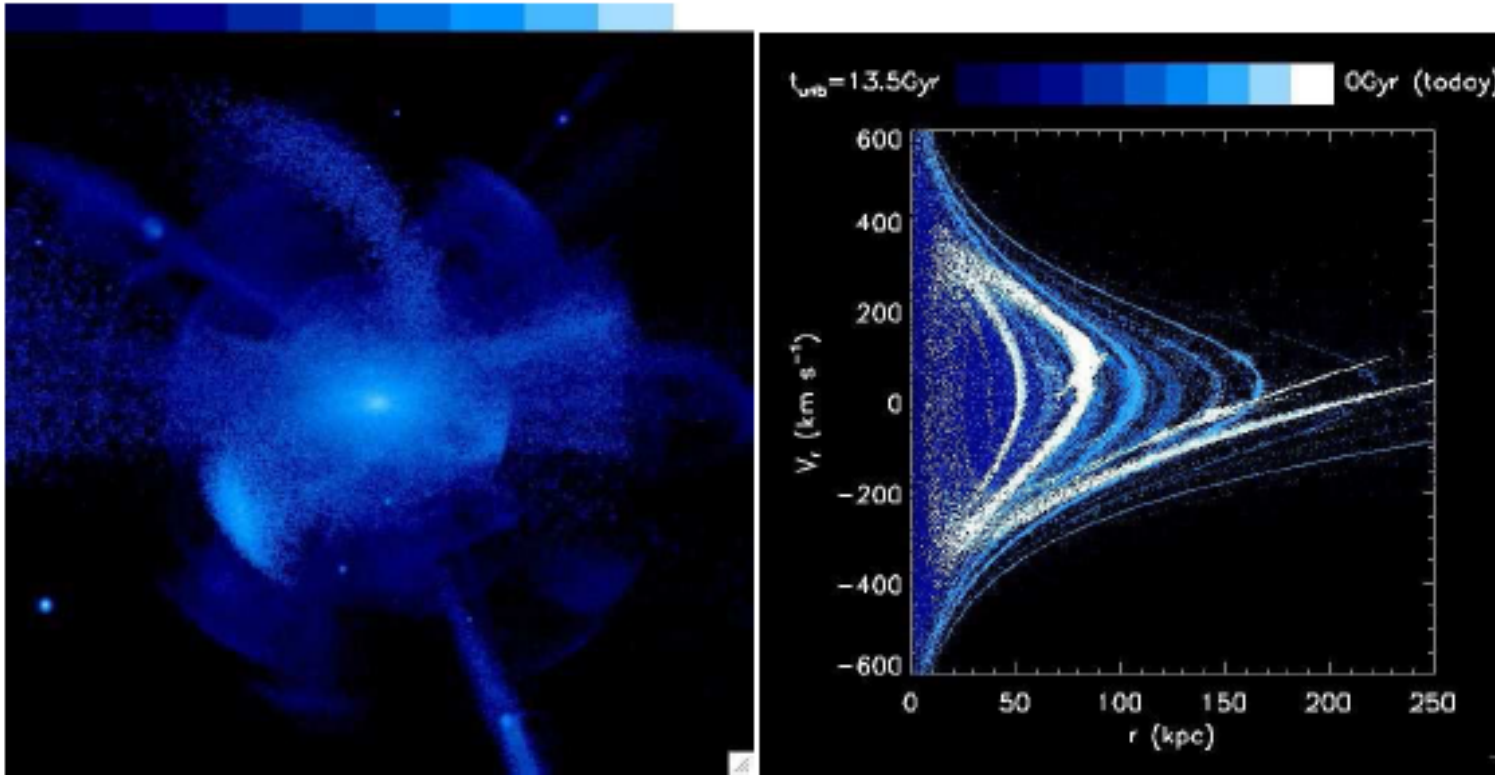
Tools

- Large low-res surveys to identify these (likely) very rare stars
- High-resolution spectroscopy
- Accurate ages for the oldest stars
- Stellar evolution models

Global top questions

7. What is the merging history of the Galaxy?

- How much substructure (from accretion) is there in the various Galactic components?
- What fraction of the mass is associated to substructure?
- What are the properties of the substructures? Dynamical age of the streams, stellar populations characteristics, mass of the progenitors?
- Is it possible to disentangle mergers with a significant amount of gas? How important were these in comparison?



Bullock & Johnston 2005

Global top questions

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Tools:

- Exploration of phase-space to find streams and substructures (velocities and distances; accurate); low-dim surveys for outer halo
- High-resolution spectroscopy for chemical abundances and photometry or ages, for stellar population properties
- Dynamical models to recover history

Global top questions

8. Is the Galaxy consistent with Λ CDM?

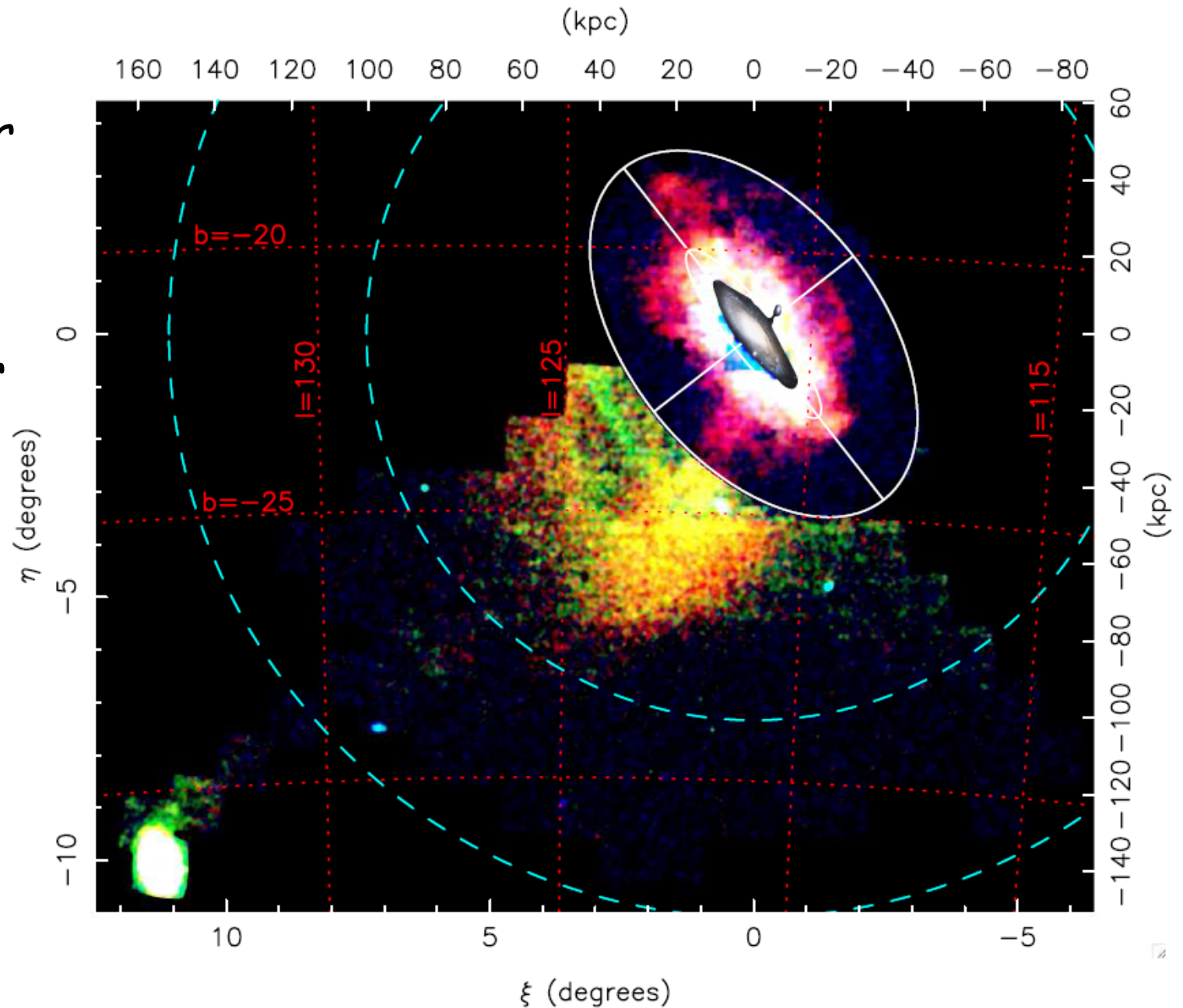
- Where are the missing baryons? How have they affected the evolution of MW?
- Is our Galaxy exceptionally quiescent? (merger history)
- What is the dark matter content and distribution of the MW? How has the mass/gravitational potential of the Galaxy changed in time?

M31 has a similar mass

A larger bulge
(hinting at major merger)

Lot of substructure
(metal-rich) in the halo

Is the MW
atypically
quiescent?



Ibata et al 2008

Global top questions

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Tools

- Studies of the hot halo via soft X-ray and UV; chemical abundances
- Cold baryons (H₂ clouds) -> dynamics
- Chemical abundances
- Tools for merging history
- Surveys of nearby galaxies to establish if MW is exceptional
- Streams in the halo to trace mass growth history (accurate kinematics)

More open questions

The central pc

Why is Sgr A* inert (so little activity)? Is it accreting matter? Does it drive a jet or outflow?

What are the structure, dynamics and history of the central cluster?

Are there any intermediate mass black holes?

Are there hypervelocity stars ejected from this region? How?

Why does the tidal field from Sgr A* not prevent star formation? What is the IMF in this region?

More open questions

The bar/bulge

Are there distinct bulge/bar populations? What is the orbital distribution? Does it break up into two “dynamical populations”?

What was the impact of the formation of the bulge on the chemical properties of the disk?

What is the star formation history?

What is the evidence of merging in the bulge?

More open questions

The thin disc

What is the relation between inner disk/bulge/bar/halo?

What is the extent of the (outer) disk (HI, dust, stars)?

What is the role of spiral density waves for star formation and cloud collapse?

What is the history of star formation across the thin disk, and how has the distribution of thin disk stars evolved in time?

Do all stars form in clusters? Why do the clusters not survive?

More open questions

The thick disc

How distinct is it from the thin disk? Does it share a common origin?

What was the star formation like?

How do the characteristics of the thick disk vary with position in the Galaxy?

How important was merging for this component?

More open questions

The stellar halo and the globular cluster system

How is the field component related to the dwarf satellites?

What fraction of the stars in the halo were accreted? Does the fraction vary with location?

When did the halo come into place?

How does our halo compare to that of M31 and other nearby spiral galaxies?

How do globular clusters relate to dwarf galaxies and to field stars?

What is the origin of the two populations of globulars?

How and where did the globular clusters form?

What fraction of the globular clusters have survived until the present day?

More open questions

The dark matter

What is the evidence for dark matter? Are there viable alternatives?

What is the distribution of dark matter? Shape, extent, density profile...

Is there evidence of substructures (dark satellites)?

What is the nature of dark matter?