How much does halo red-giant mass loss contribute to the gas falling toward the Milky Way disk?

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1950s: high-velocity Ca II gas at high latitudes (optical)

1960s: high-velocity H I gas at high latitudes (21 cm)

1970s: no gas in globular clusters (GCs)

but GC red giants loose mass!

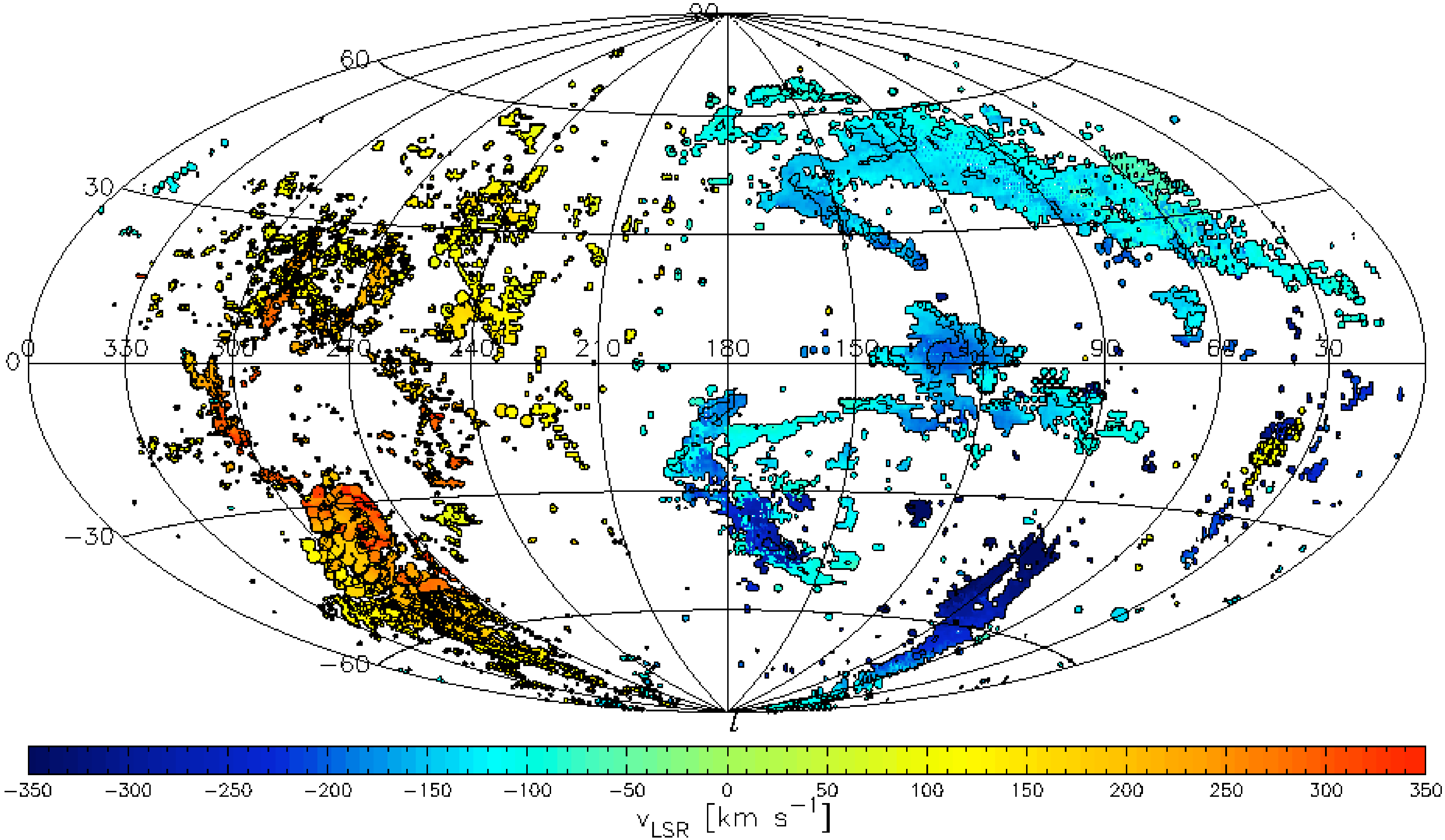
gas swept out during passage of cluster through MW disk?

1978-1984: detection of ubiquitous hot halo gas

renewed discussion of origin of gas

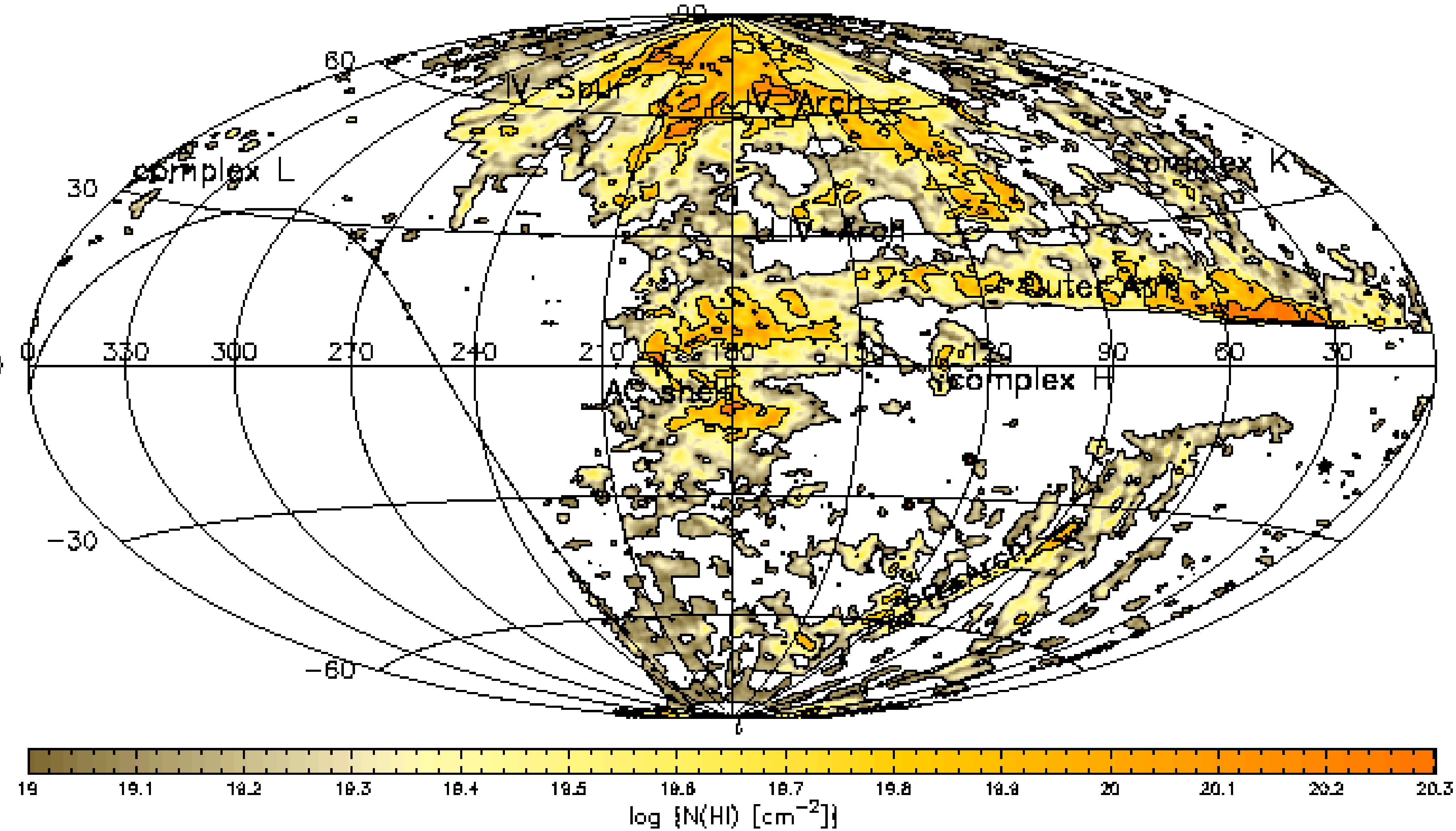
for more on history see Wakker, de Boer, & van Woerden
in ‘High-Velocity Clouds’, 2004, Wakker, van Woerden, Schwarz, & de Boer (eds.); ASSL 312

Sky in H I 21 cm - velocities deviating from normal disk rotation



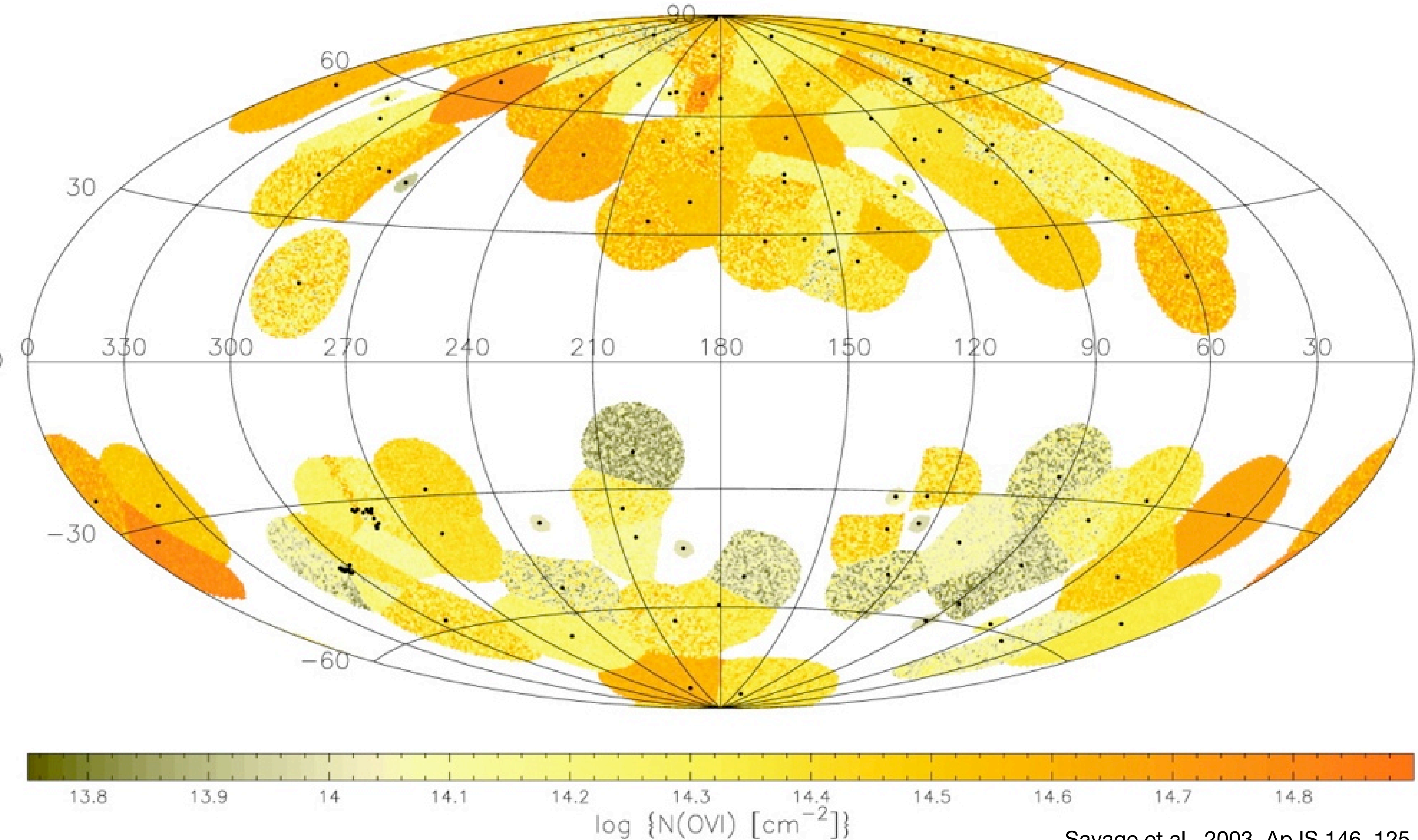
Wakker, 2004, in ‘High-Velocity Clouds’; ASSL 312, p.25

Sky with intermediate-velocity gas (negative velocities)



Wakker, 2004, in 'High-Velocity Clouds', ASSL 312, p.25

Sky in O VI absorption

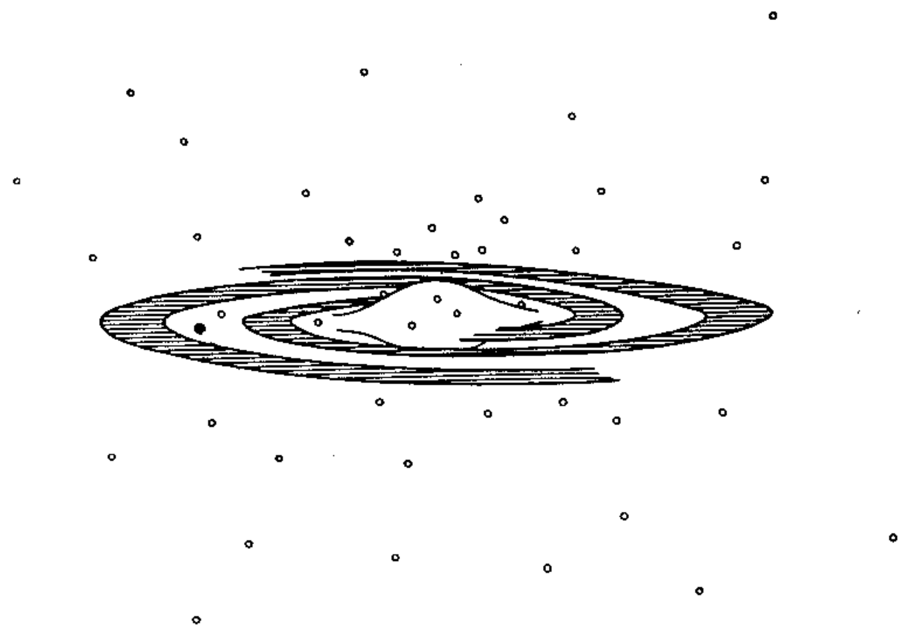


Savage et al., 2003, ApJS 146, 125

Ideas about the origin of the halo clouds (1)

= Infall from Intergalactic Space

- should have high (negative) velocity
- should be 'pristine'
- unknown rate



= Galactic Fountain (Shapiro & Field, 1976, ApJ; Bregman 1980, ApJ)

- cannot reach high into the halo
- should have metallicity like disk gas
- rate difficult to estimate

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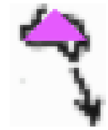

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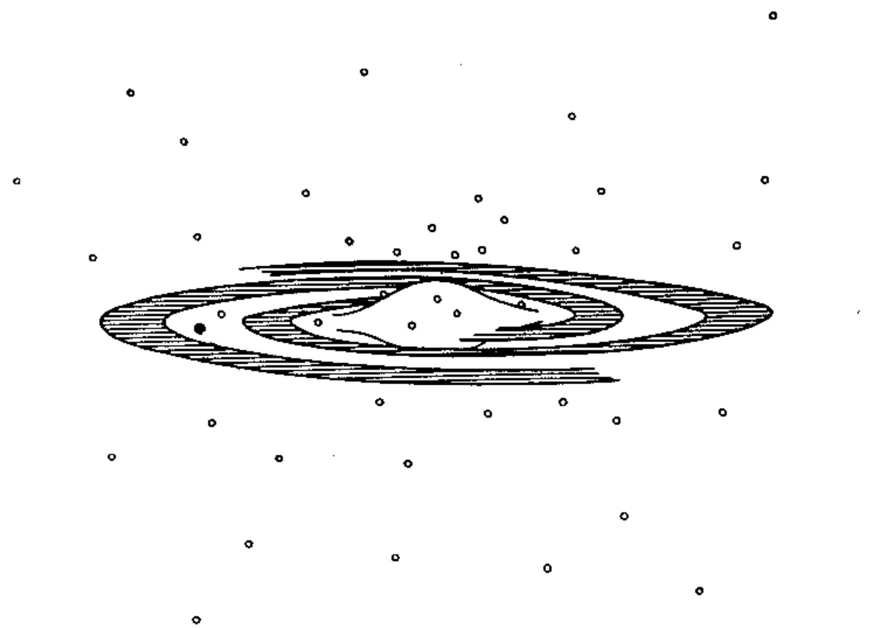

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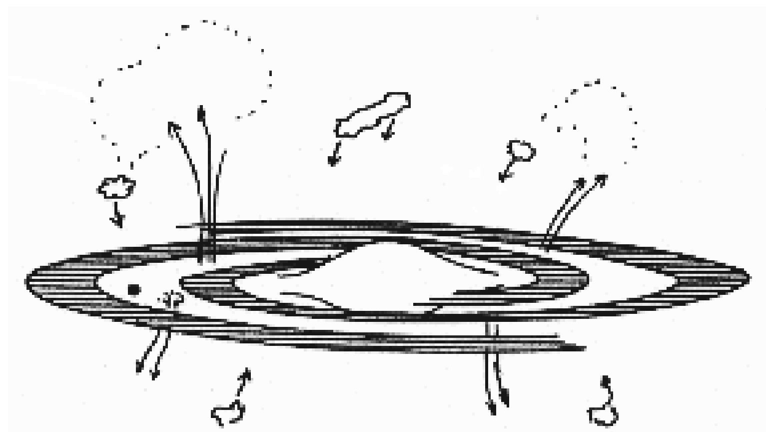
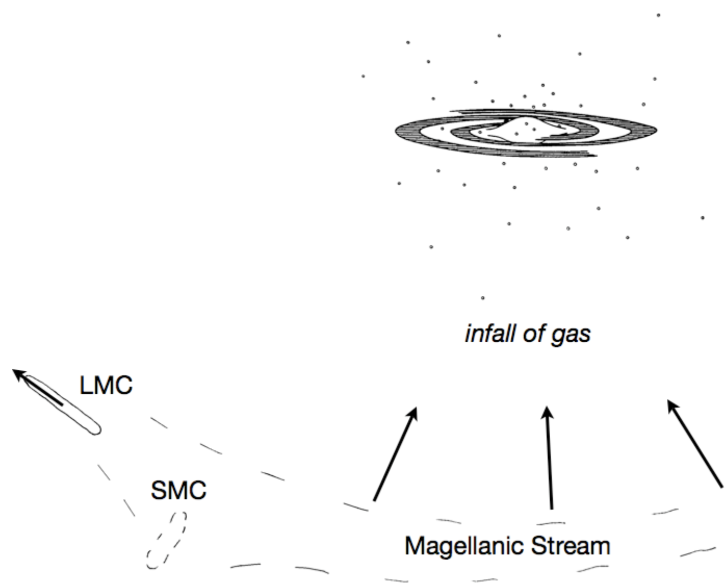


Ideas about the origin of the halo clouds (2)

= Gas from Dwarf galaxies

- range in velocities possible
- metallicity like dwarf galaxy
- rate unknown



(Fig. from de Boer, 1998, in `The Magellanic Clouds and other Dwarf Galaxies')

= Gas from Red Giants

- generated inside potential well
- metallicity like RG stars
- rate can be calculated

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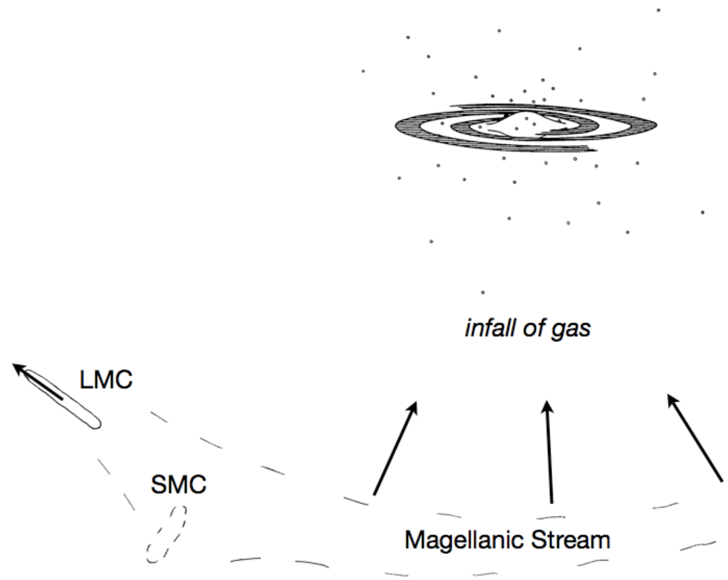

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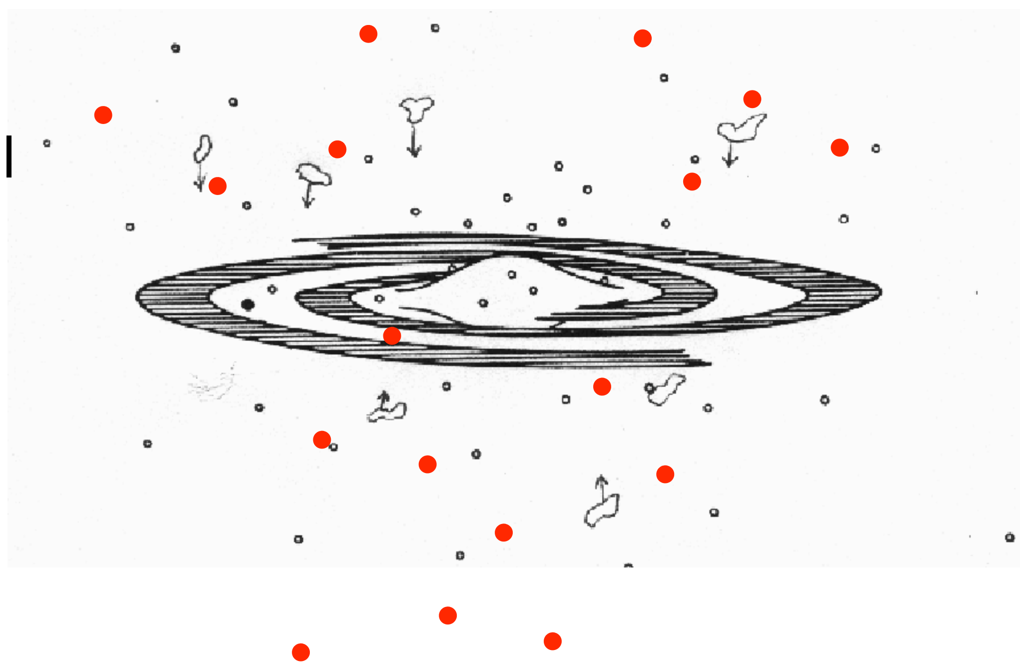


Calculating the halo RG mass loss

(de Boer, 2004, A&A 419, 527)

Input/Data needed

= RG mass loss rate
- rate is variable
- average mass lost is M_{RG} - M_{HB} $\simeq$ 0.3 $M_{\odot}$

= spatial distribution of RGs

- essentially unknown
- distance determination very unreliable due to large range in luminosity for small colour range
- distances from spectroscopy not available (expensive)

Calculating the halo RG mass loss

solution for spatial distribution question:

= use as proxy HB stars
- evolutionary state after RG
- spatial distribution must be the same
- distances easy

= spatial distribution of HB stars

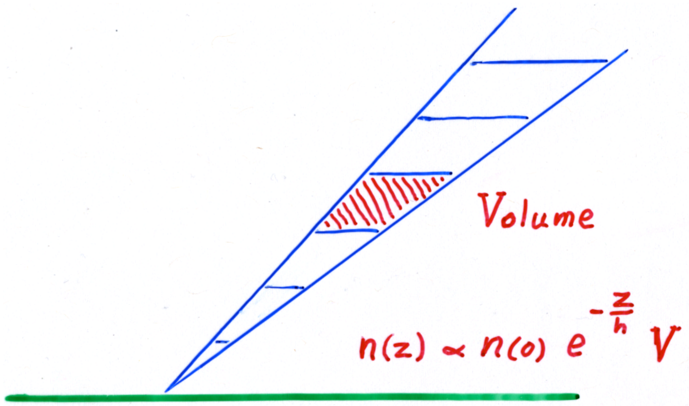
- photometry + Balmer line spectroscopy
- $T_{\rm eff}$, log g, $E(B-V)$, L and thus distance
- originally using sdB stars (de Boer et al., 1997, A&A 327, 587)
- also $v_{\rm rad}$ and p.m. can be obtained

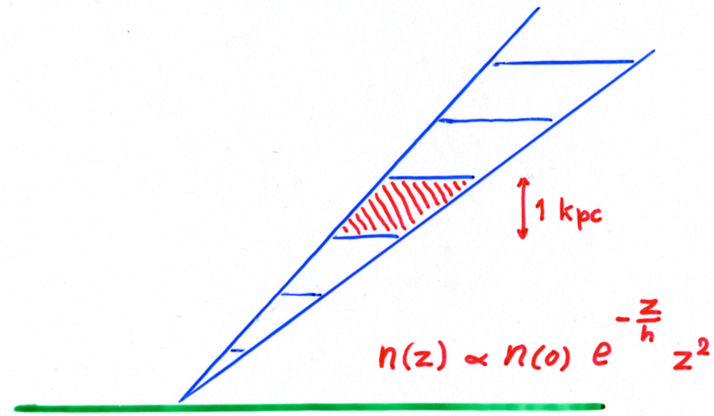
= sample selection ?

Sample selection difficult

most surveys did not reach deep

- scale height studies need ‘complete’ samples





- scale heights of sdBs so found reach from 200 to 700 pc (for refs see de Boer et al., 1997, A&A 327, 577)

- past samples not deep and not ‘statistically complete’

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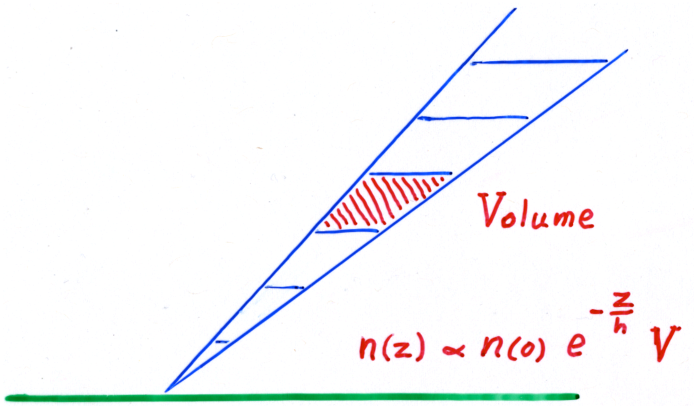
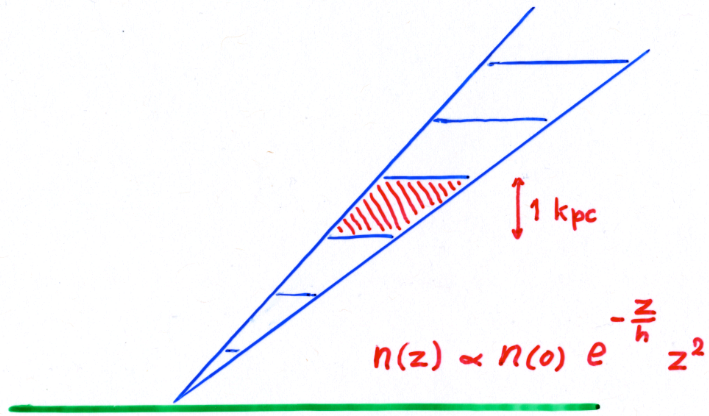




- scale heights of sdBs so found reach from 200 to 700 pc (for refs see de Boer et al., 1997, A&A 327, 577)

- past samples not deep and not ‘statistically complete’

other possibility: use calculated orbits

Orbits

Having

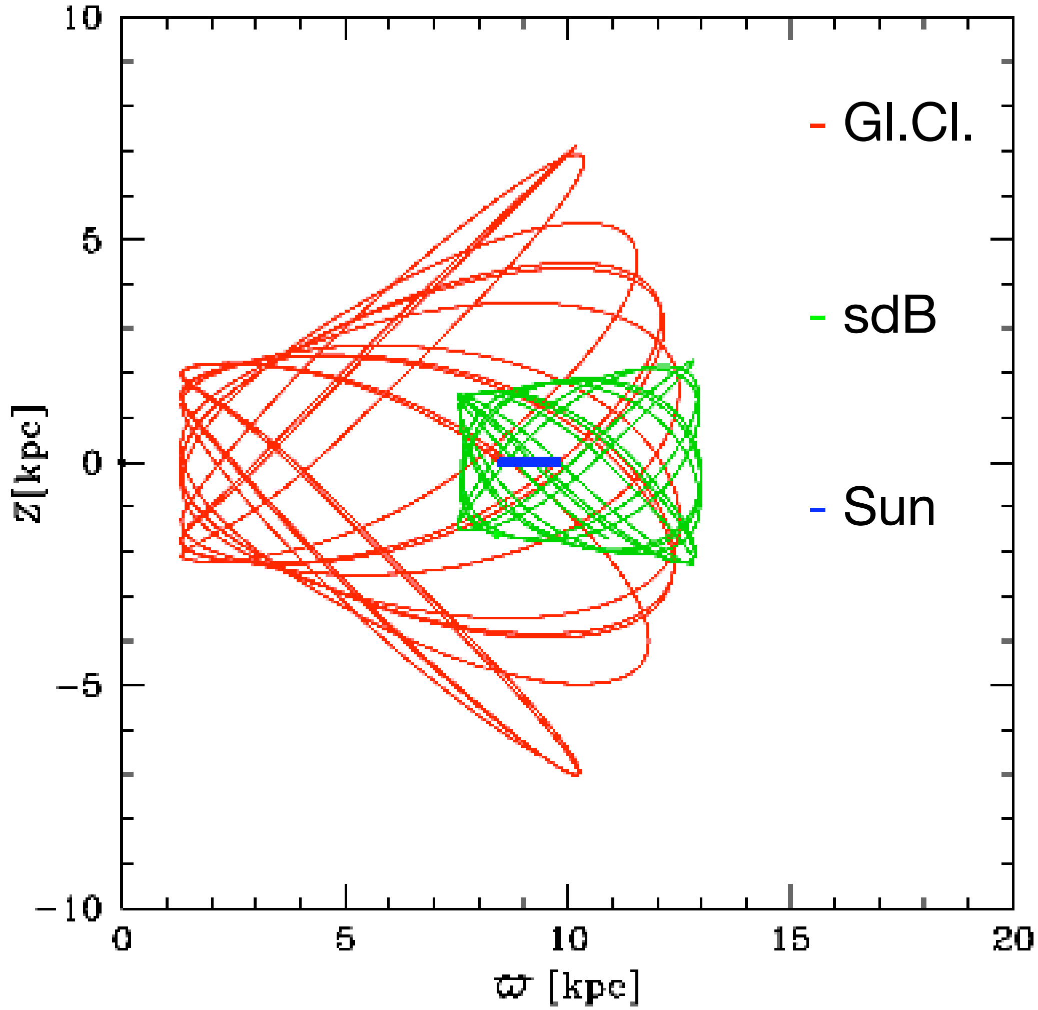
$d + v_{rad}$ + p.m.

allows determination of space velocity

Mass model from Allen & Santillan (1991)

Orbit calculator from Odenkirchen & Brosche (1992)

Plot in meridional section



41 sdB stars

 1997 A&A 327, 587

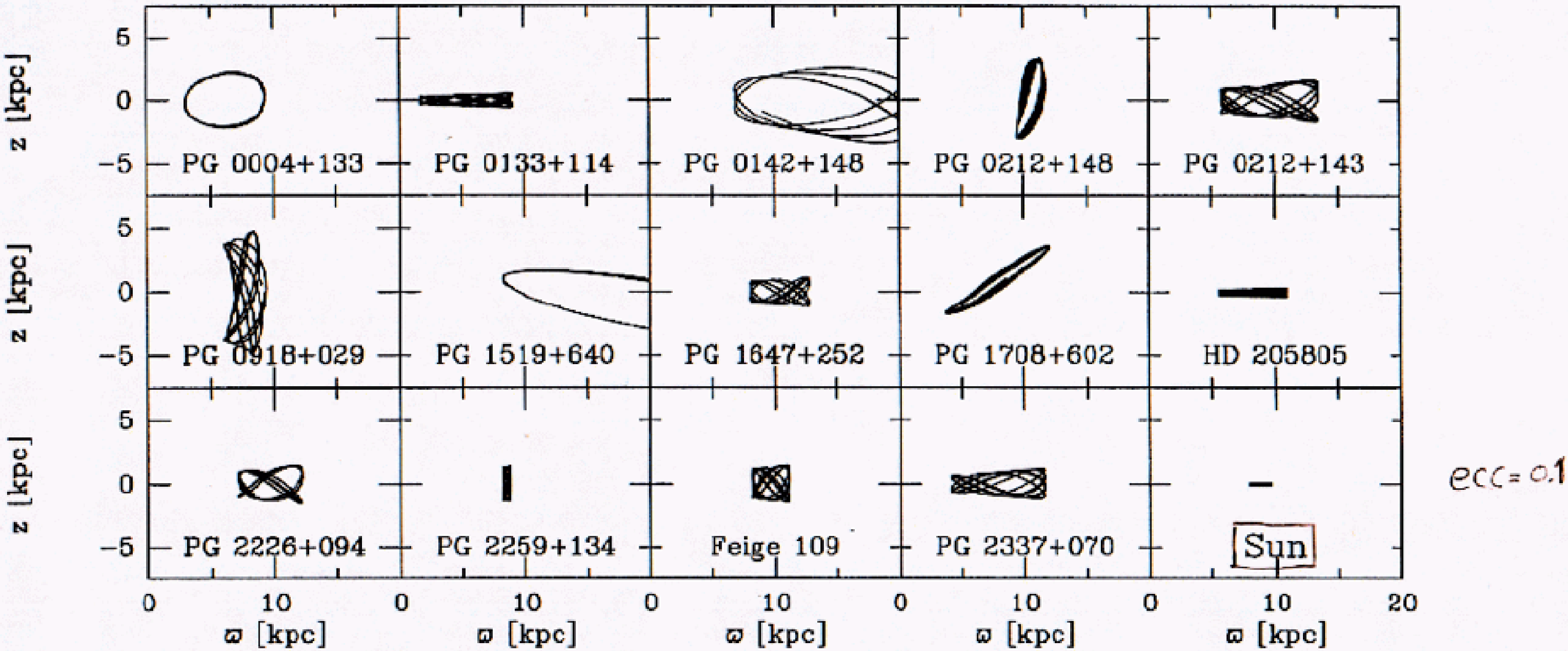


Fig. 1. For several stars the orbits are shown to demonstrate the variety in shape. The diagram shows the meridional cut, i.e., the plane through the rotation axis of the galaxy rotating along with the motion of the star. Plotted is the motion of the star in that plane in vertical distance z and galactocentric distance ϖ. All orbits were calculated backward over 1 Gyr in steps of 1 Myr. For comparison we have added the orbit of the Sun

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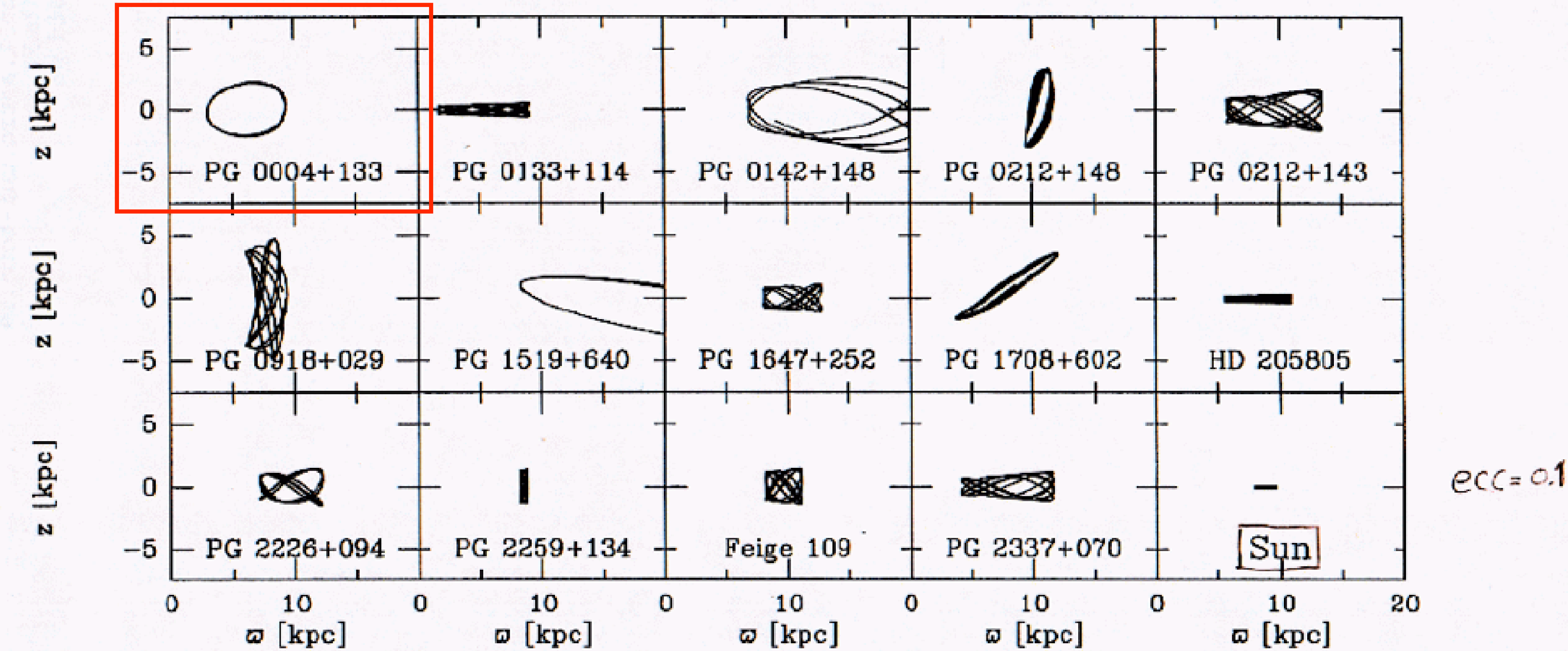

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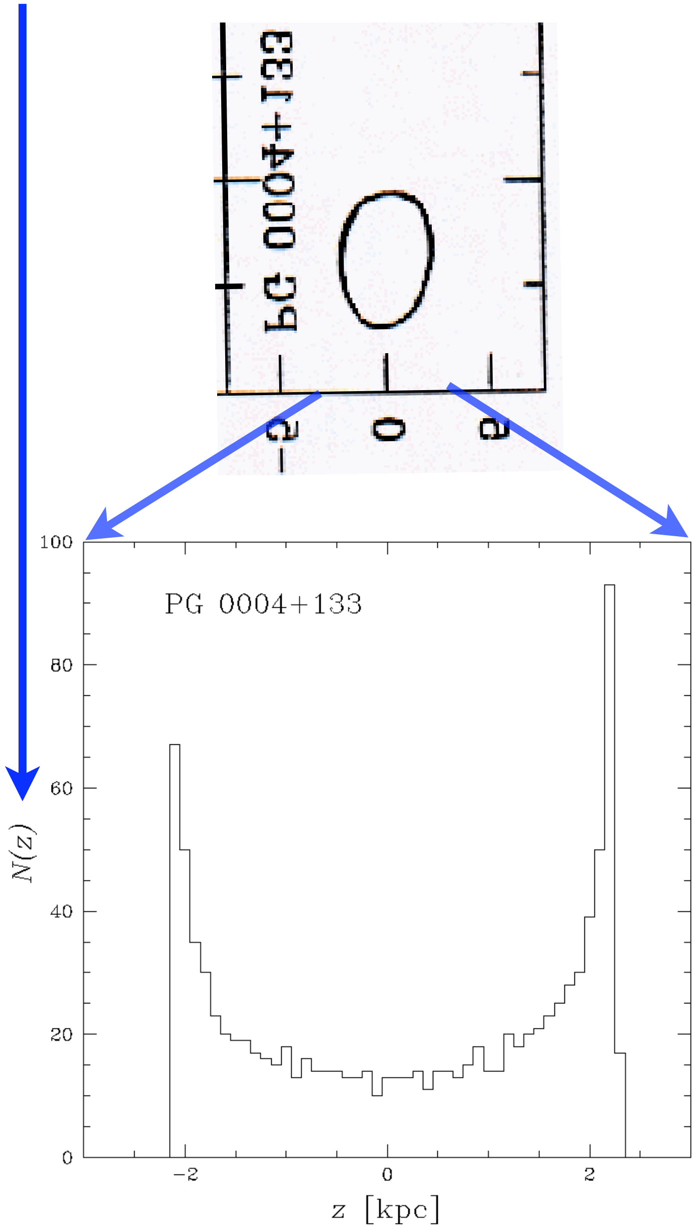
$N(z)$ = probability of finding a star at z



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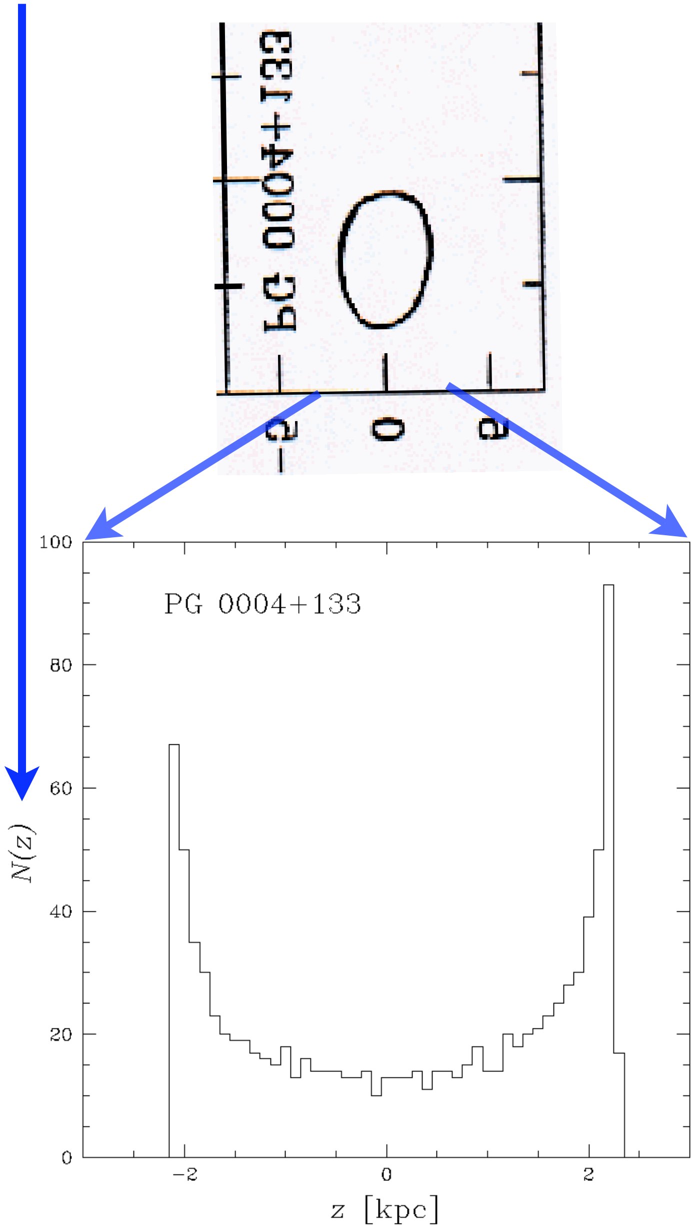
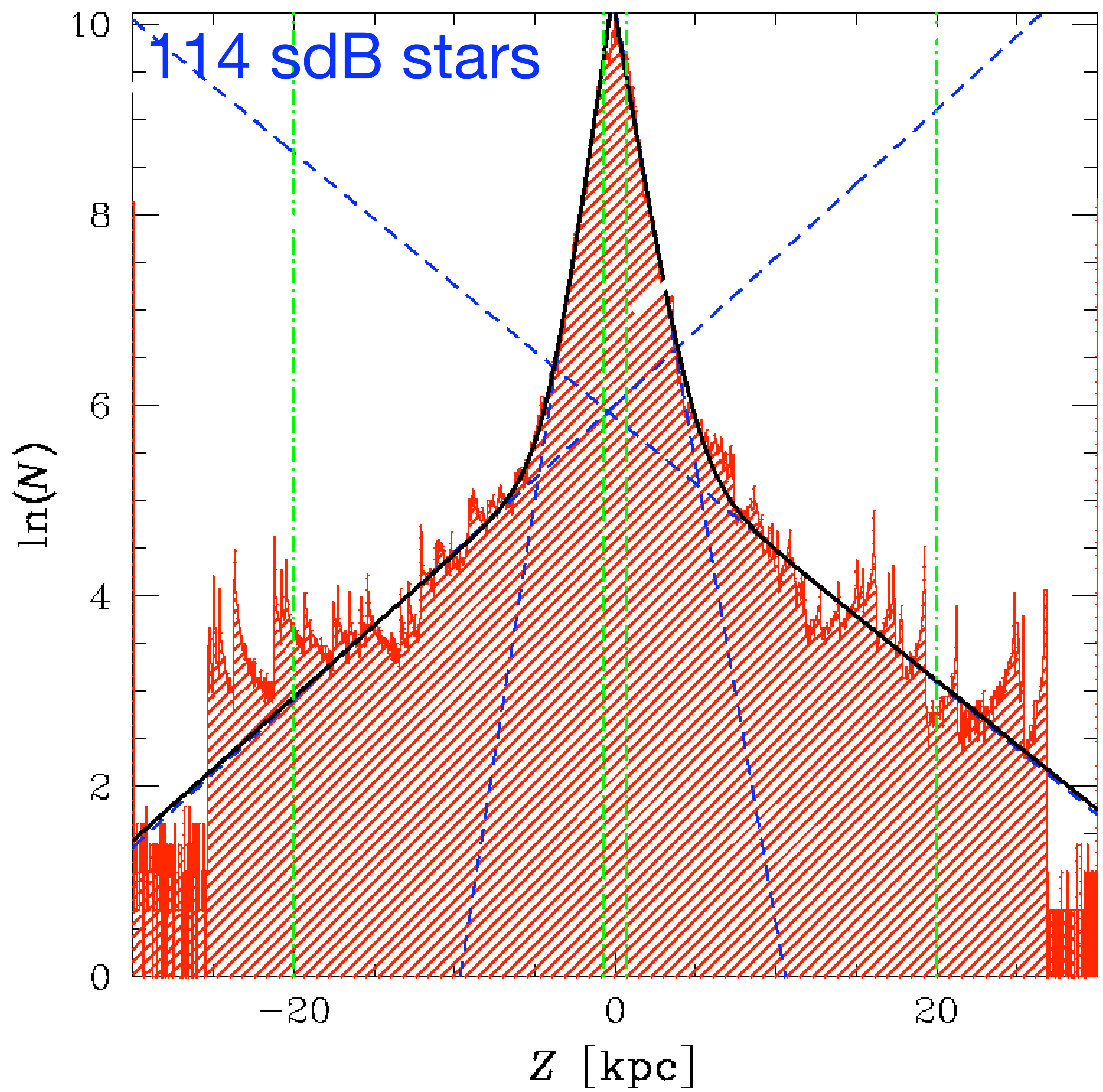


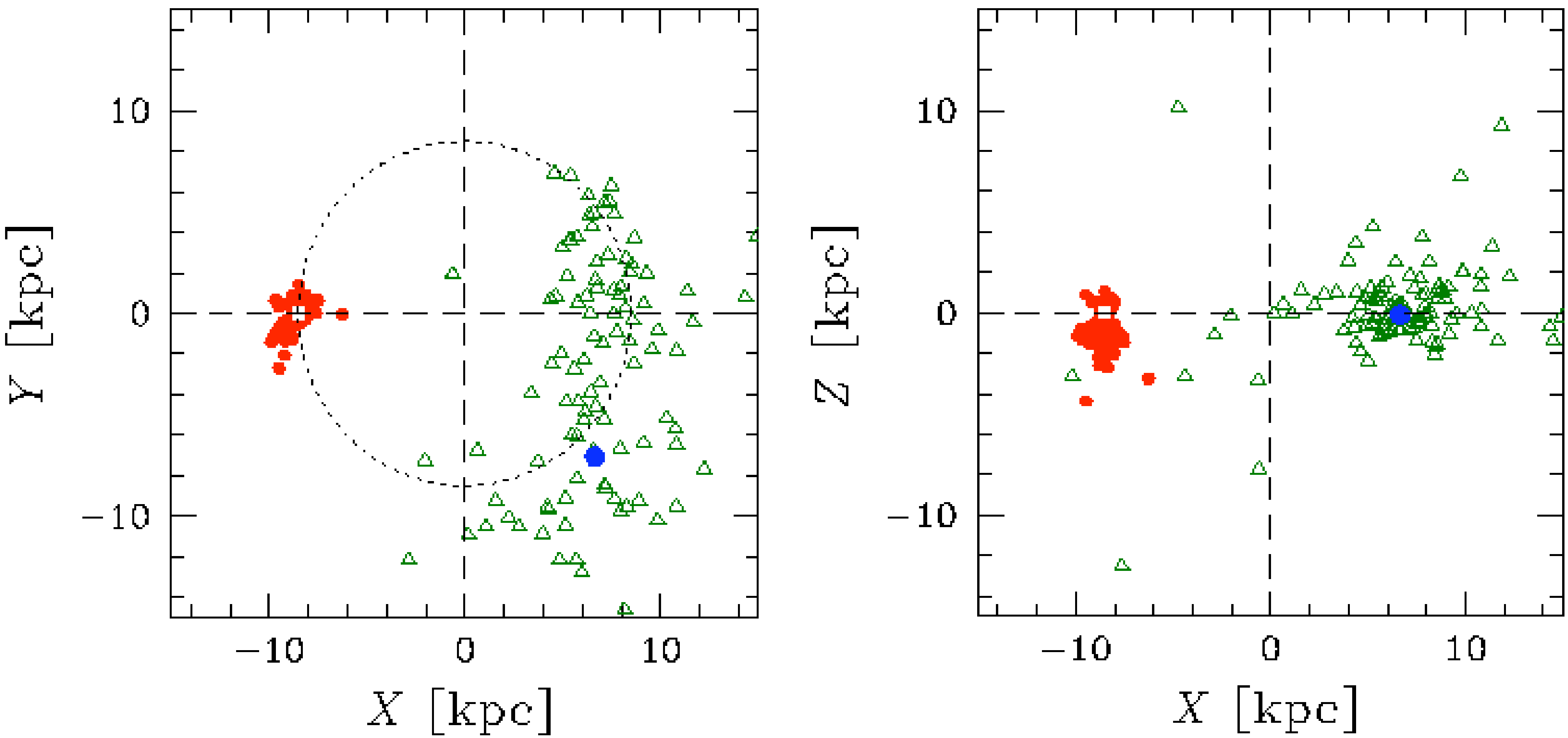
Probability of total sample



Altmann, Edelmann, de Boer, 2004, A&A 414, 181

Stars come from all locations in the Milky Way

Example of 114 sdB stars; now • , 100 Myr ago △ , Sun •



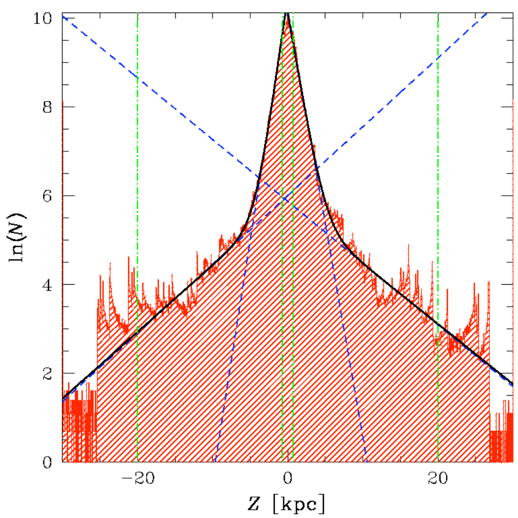
Altmann, Edelmann, de Boer, 2004 A&A

Distribution in *z* of HB stars from orbit statistics

for 811 stars orbits

mass model: Allen & Santillan (1991, RevMxAA 22, 255)
orbit code: Odenkirchen & Brosche (1992, AN 313, 69)

114 sdB stars	217 RR Lyrae	480 RHB stars



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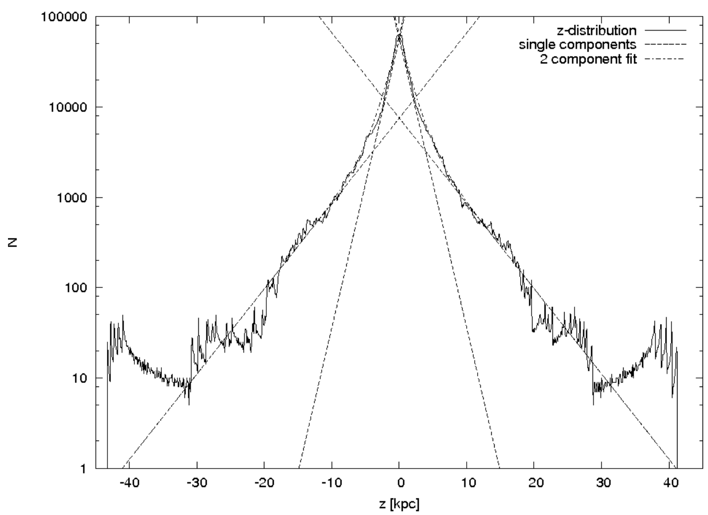
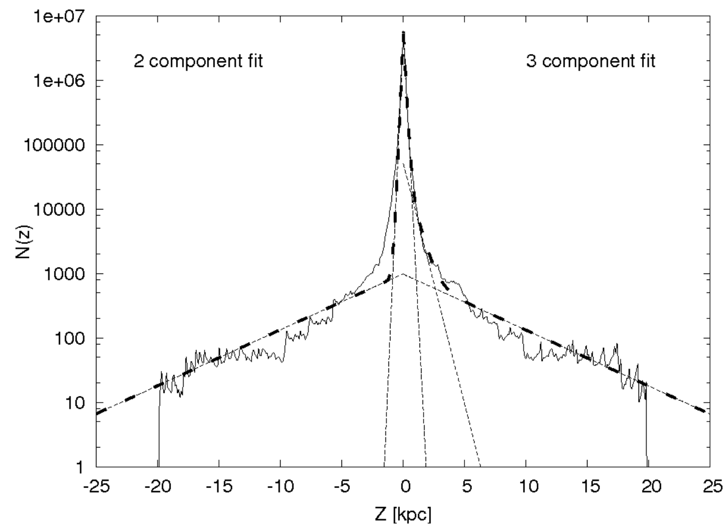


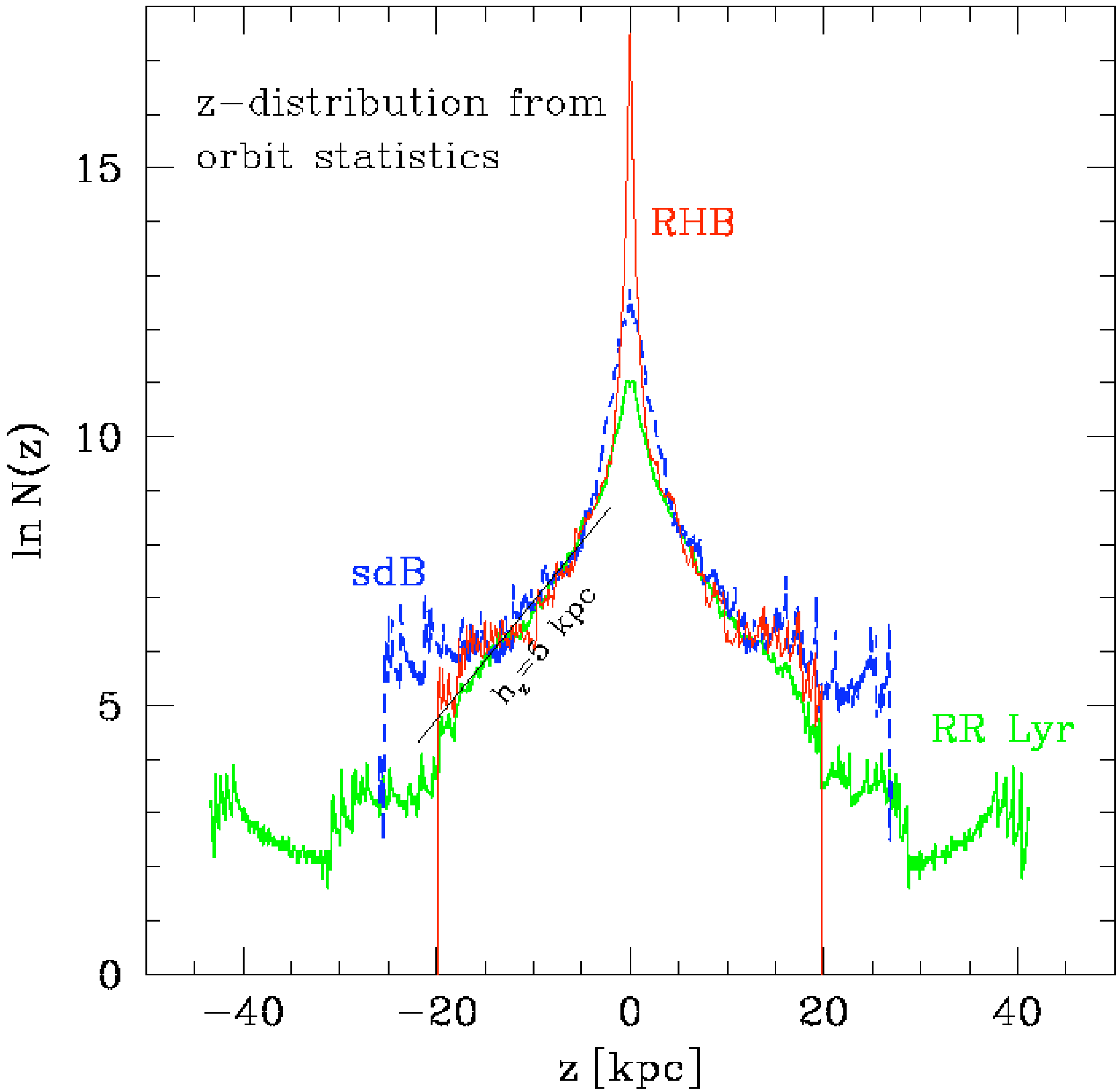
Maintz & de Boer
2005, A&A 442, 229



Kaempf & de Boer
2005, A&A 432, 879

Distribution in *z* of HB stars from orbit statistics

scaled to matching slopes at 3<|z|<20 kpc



disk component
$h_z \simeq 1$ kpc

halo component
$h_z \simeq 5$ kpc

N(disk)/*N*(halo)
differs between types!

Sample selection!

Sample selection effects

sdB: stars from PG, HS, HE

selected by V and spectroscopy

stars from all distances (but not very far)

→ sample of all distances

RR Lyr: stars from literature

selected for good documentation and v_{rad}

predominantly distant

sizable fraction is retrograde

→ halo-dominated sample

RHB: stars from Hipparcos

selected for $\Delta\pi/\pi$ <30%

only nearby stars

→ disk-dominated sample

Distribution in *z* of HB stars from orbit statistics

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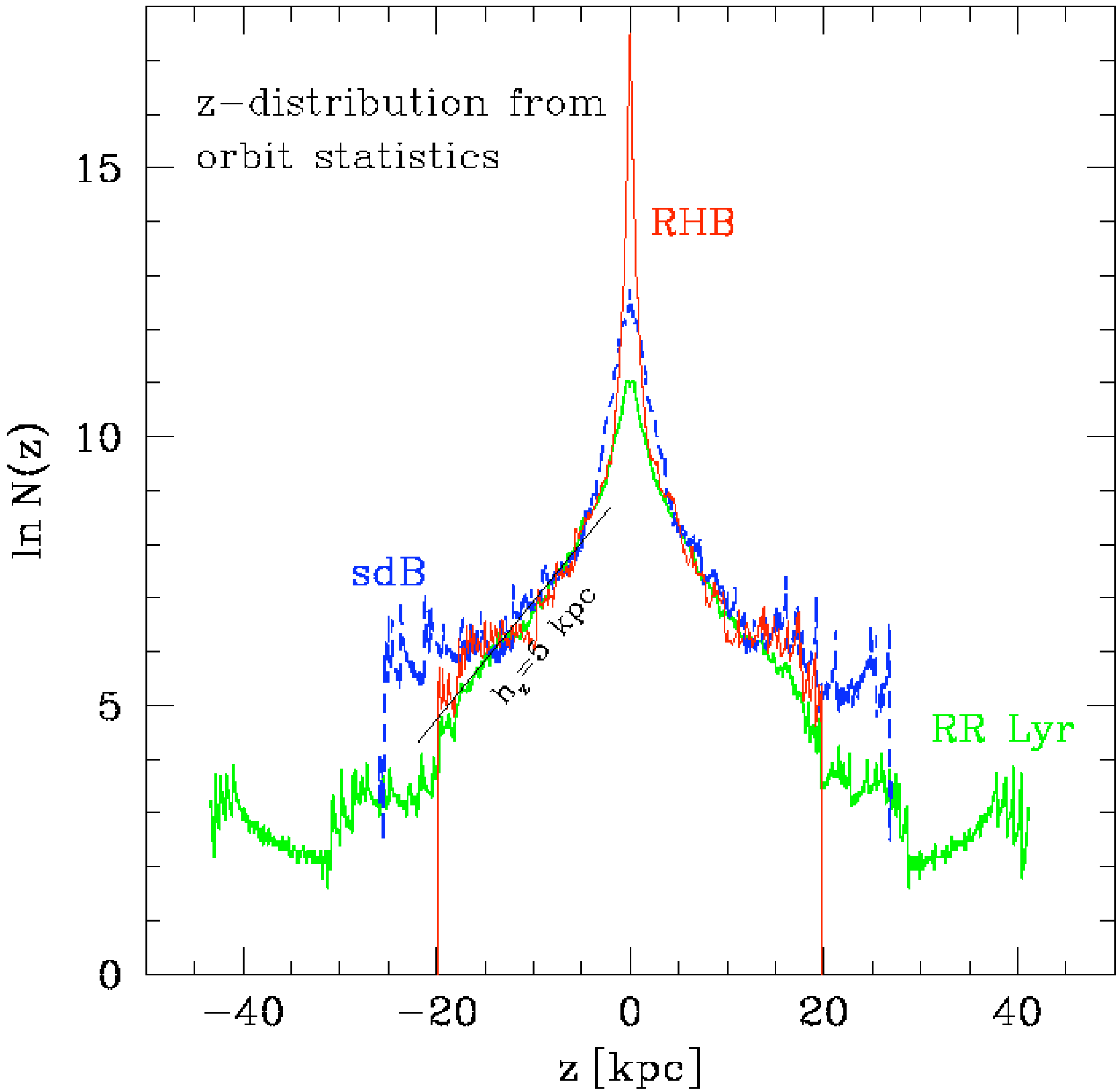

de Boer, 2007, in prep.

disk component
$h_z \simeq 1$ kpc

halo component
$h_z \simeq 5$ kpc

N(disk)/*N*(halo)
differs between types!

Sample selection!

Other mass models and other integrators?

used were Allen & Santillan + Odenkirchen & Brosche

later tests with Dehnen & Binney model and integrator

tests with RR Lyrae and RHB-stars

orbits individually different,
especially those reaching near the galactic centre

orbit statistics only marginally different

CONCLUSION
at the moment no effects to worry about

Calculating the mass lost by halo RGs

- mass lost per RG
- each HB star represents an RG having lost its 0.3 $M_{\odot}$
- set RG mass loss rate equal to M_{lost}/t_{HB}
- number of HBs in the halo (but use sdBs)
- ratio of sdBs to all HBs
- midplane volume density of sdBs
- integrate z-distribution

Calculating the infall rate due to mass lost by halo RGs

$$\dot{M}_{\rm RG\ halo} = \dot{M}_{\rm RG} \cdot N_{\rm RG\ halo} \quad (1)$$

$$N_{\rm RG\ halo} = N_{\rm HB\ halo} \quad \text{(each HB star was RG)} \quad (2)$$

$$f_{\rm all\ HB/sdB} = n_{\rm all\ HB}/n_{\rm sdB} \simeq 100 \quad (3)$$

$$n(z)_{\rm sdB} = n(0)_{\rm sdB}\ e^{-z/h_z} \quad (4)$$

$$N_{\rm sdB} = \int_{z_b}^{z_t} n(0)_{\rm sdB}\ e^{-z/h_z} dz = n(0)_{\rm sdB} h_z\ \mathbf{g} \quad (5)$$

$$n(0)_{\rm sdB\ halo} \simeq 4 \cdot 10^{-9}\ {\rm pc}^{-3},\ h_z \simeq 5\ {\rm kpc}$$

$$\mathbf{g} = 0.8 \text{ for halo sdBs } (z_b = 1\ {\rm kpc},\ z_t = \infty)$$

$$\overline{\dot{M}_{\rm one\ RG}} = \overline{M_{\rm lost}}\ /\ t_{\rm HB} \simeq 0.3/10^8\quad {\rm M}_\odot\ {\rm yr}^{-1} \quad (6)$$

$$\dot{M}_{\rm halo\,RGs} = N_{\rm sdB} \times f_{\rm all\,HB/sdB} \times \overline{\dot{M}_{\rm one\,RG}}\quad {\rm M}_\odot\ {\rm kpc}^{-2}\ {\rm yr}^{-1} \quad (7)$$

$$\dot{M}_{\rm RGs} = 2 \times n_{0\ \rm sdB} \times h_z \times \mathbf{g} \times f_{\rm all\ HB/sdB} \times \overline{M_{\rm lost}}/t_{\rm HB} \quad (8)$$

Result: $\dot{M}_{\rm total\ halo\ RGs} \simeq 1.4 \cdot 10^{-5}\ {\rm M}_\odot\ {\rm kpc}^{-2}\ {\rm yr}^{-1}$

Calculating the infall rate due to mass lost by halo RGs

from RGs in globular clusters

$$\dot{M}_{\rm Gl.Cls.} \simeq 4 \cdot 10^{-7}\ {\rm M}_\odot\ {\rm kpc}^{-2}\ {\rm yr}^{-1}$$

from RGs of the halo population at z>1 kpc (h_z = 5 kpc):

$$\dot{M}_{\rm total\ halo\ RGs} \simeq 1.4 \cdot 10^{-5}\ {\rm M}_\odot\ {\rm kpc}^{-2}\ {\rm yr}^{-1}$$

Stars of halo are metal poor, so this infall is metal poor

from RGs of the ‘thick disk’ population at 1<z<3 kpc (h_z = 1 kpc):

$$\dot{M}_{\rm total\ thick\ disk\ RGs} \simeq 5.4 \cdot 10^{-5}\ {\rm M}_\odot\ {\rm kpc}^{-2}\ {\rm yr}^{-1}$$

Stars of ‘thick disk’ are not very metal poor

total infall from RGs: $\dot{M}_{\rm total\ RG} \simeq 7 \cdot 10^{-5}\ {\rm M}_\odot\ {\rm kpc}^{-2}\ {\rm yr}^{-1}$

similar to what is observed (HI 21 cm)

(de Boer, 2004, A&A 419, 527)

Uncertainty of estimate is large

uncertainty in important parameters: 2-3

overall uncertainty: factor 10?

Infall due to mass lost by halo RGs

Total metal-poor infall on entire galactic disk from halo RGs:

$$\dot{M}_{\rm metal\ poor} \simeq 10^{-2}\ {\rm M_\odot\ yr^{-1}}$$

is of same oder as overall galactic SFR

Distance of infalling gas largely unknown

for a few clouds distance estimates 2-5 kpc

Is high-velocity gas far away?

Is intermediate velocity near? Thus galactic fountain?

What is needed to know and understand infall better?

if working with distribution of actual stars:

- better spatial distribution of RGs (or of some substitute)
- if substitute, better ratio N(RG)/N(substitute)
- better knowledge of midplane density of halo RGs or of substitute
- better mass loss estimates, or:
  better knowledge of RG mass function

concerning the gas

- chemical composition of infalling gas

if working with orbit statistics:

- distance, v_{rad}, p.m. for more stars
  in particular for more distant stars

Conclusions

- RG mass loss contributes to metal-poor infall
- stars now near Sun were widely dispersed
- vertical star distribution shows two 'populations'

  data from sdB-, RRLyr-, RHB- stars mutually consistent
  '(thick) disk' with scale height $h_z \simeq 1$ kpc
  'halo population' with $h_z \simeq 5$ kpc
- halo population sample has prograde and retrograde stars
- orbit results are mass-model and integrator independent

and further.....

- in RG winds normally dust is formed

  also in winds of metal-poor RGs....

- when halo gas cools and condenses to clouds....
- H_2 may form on the cool dust
- H_2 is seen in absorption in a few HVCs
- the infalling gas is (in part) very metal-poor

Questions

- RG mass loss rate and [M/H]?
- is number of HB stars (sdB, HBB, RHB) consistent with RGs?

*

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Halo Stars:

- subdwarf stars:
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- astrometry:
  Michael Geffert, Jacques Colin, Martin Altmann

- orbit calculations:
  Michael Geffert, Martin Altmann, Torsten Kaempf, Gisela Maintz

Halo Gas:

- spectroscopy IUE:
  Blair Savage, Willem Wamsteker, Giovanni Vladilo, Dominik Bomans, Adem Altan

- spectroscopy 21 cm:
  Esteban Bajaja, Peter Kalberla, Ulrich Schwarz

- spectroscopy ORFEUS and FUSE:
  Philipp Richter, Hartmut Bluhm, Ole Marggraf

- general:
  Blair Savage, Dietmar Lilienthal, Bart Wakker, Huug van Woerden