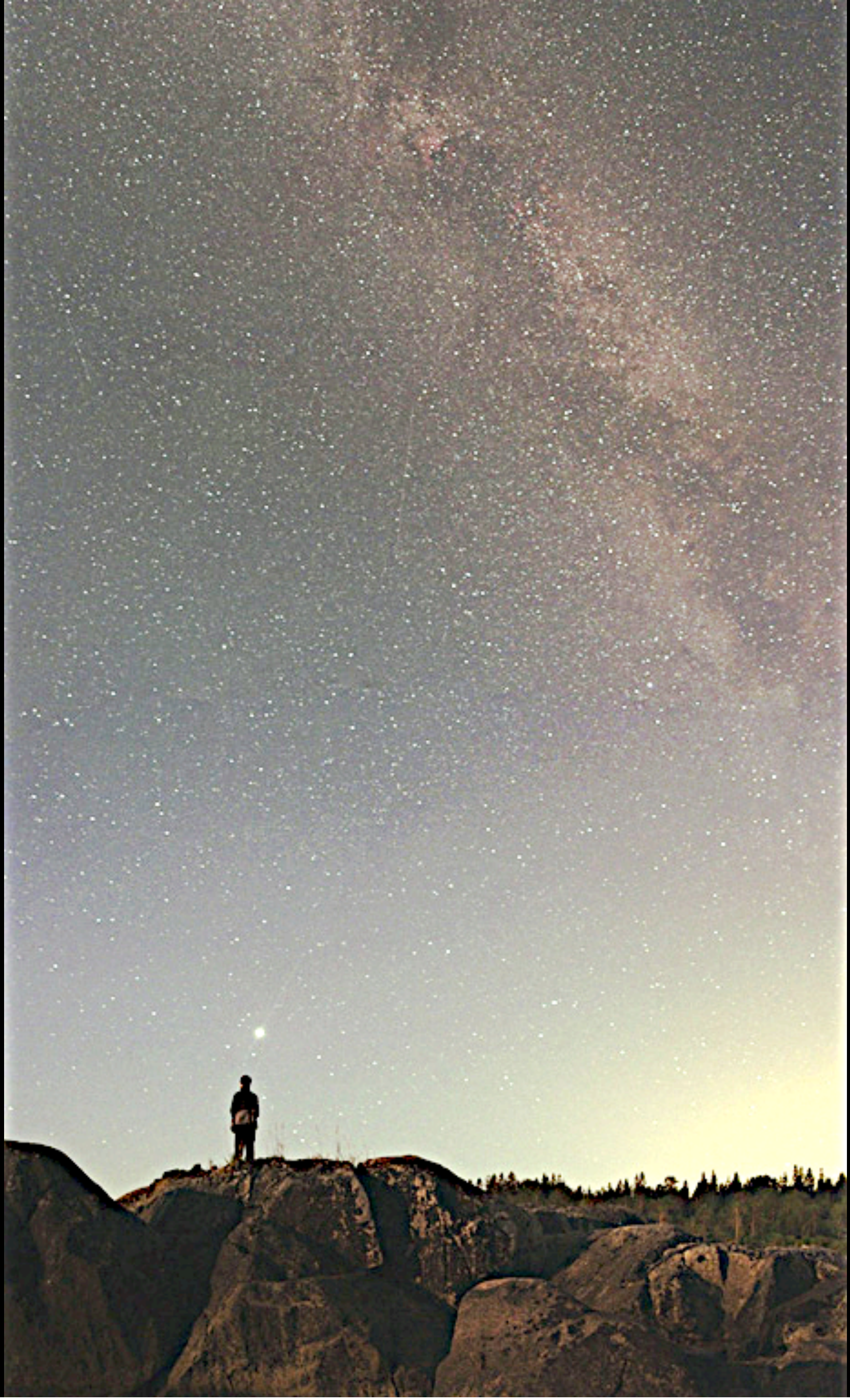
Near-field cosmology: now and in the Gaia era

Lennart recently gave a talk about Gaia - this talk will put the achievements of Gaia into a wider context of contemporary astrophysics

Sofia Feltzing



Per-Magnus Hedén
http://www.clearskies.se
www.twanight.org

Island Universes

- René Descartes, 1636
- Emmanuel Kant, 1755
  - Flatness is because they rotate
- Johann Lambert, 1761
- These were purely theoretical cosmologies that lacked observational confirmation

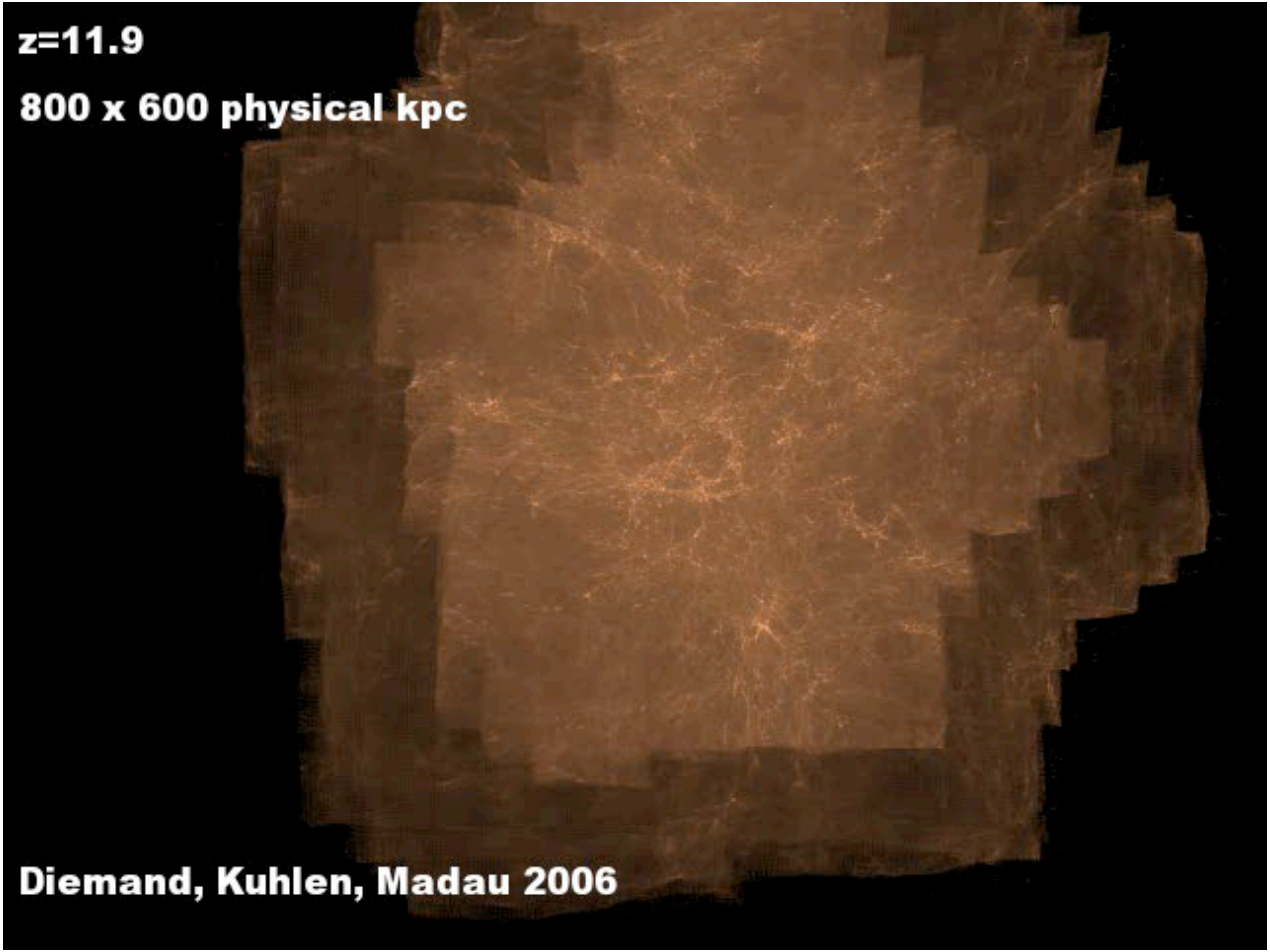
måndag den 8 november 2010

Observational progress Early 1900's

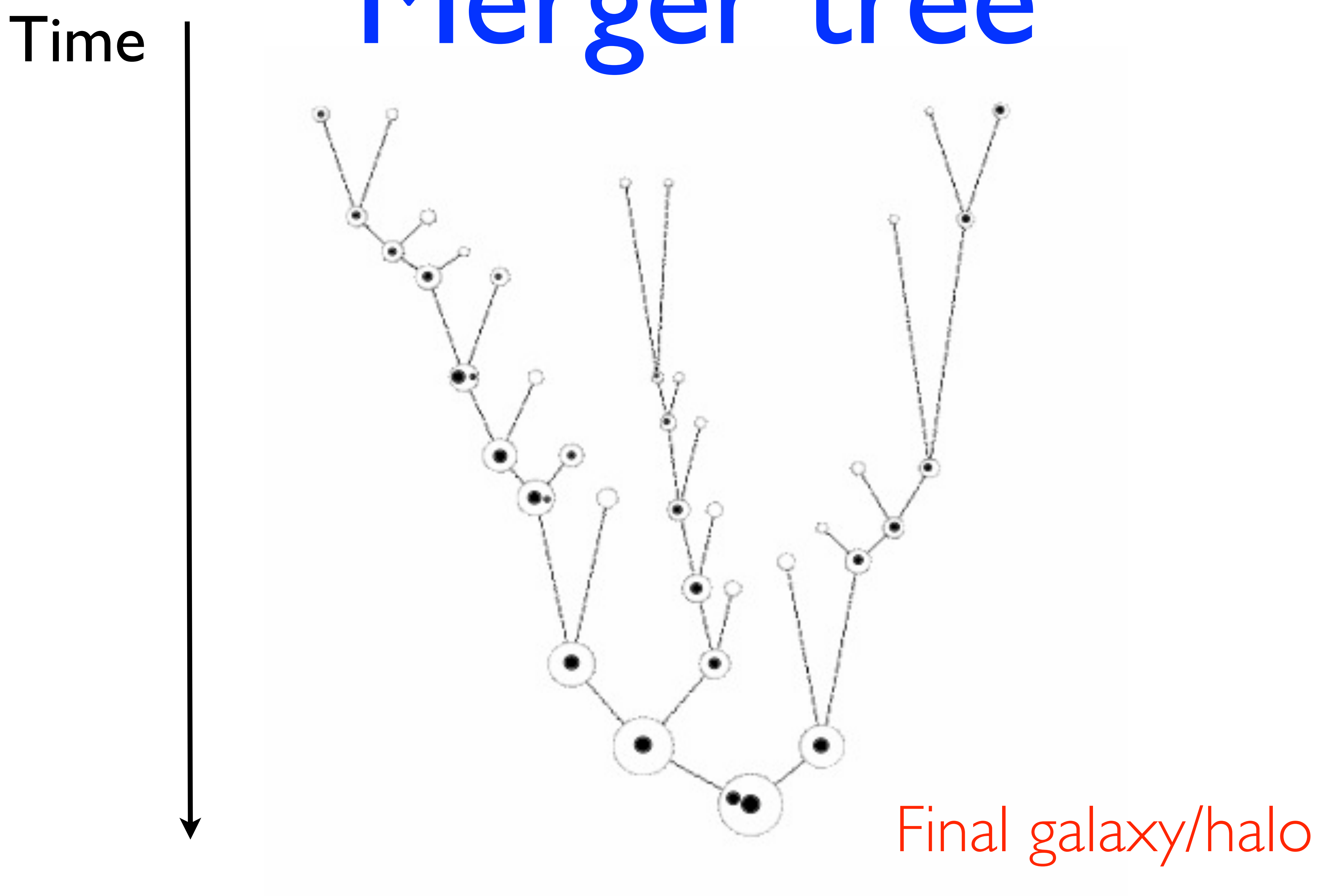
- The universe grows – not only the Milky Way
- Harlow Shapley moves the Sun to the outskirts of the Milky Way
- Henrietta Lewitt finds the cepheid P-L relation
- Edwin Hubble finds that the universe expands

Galaxy formation

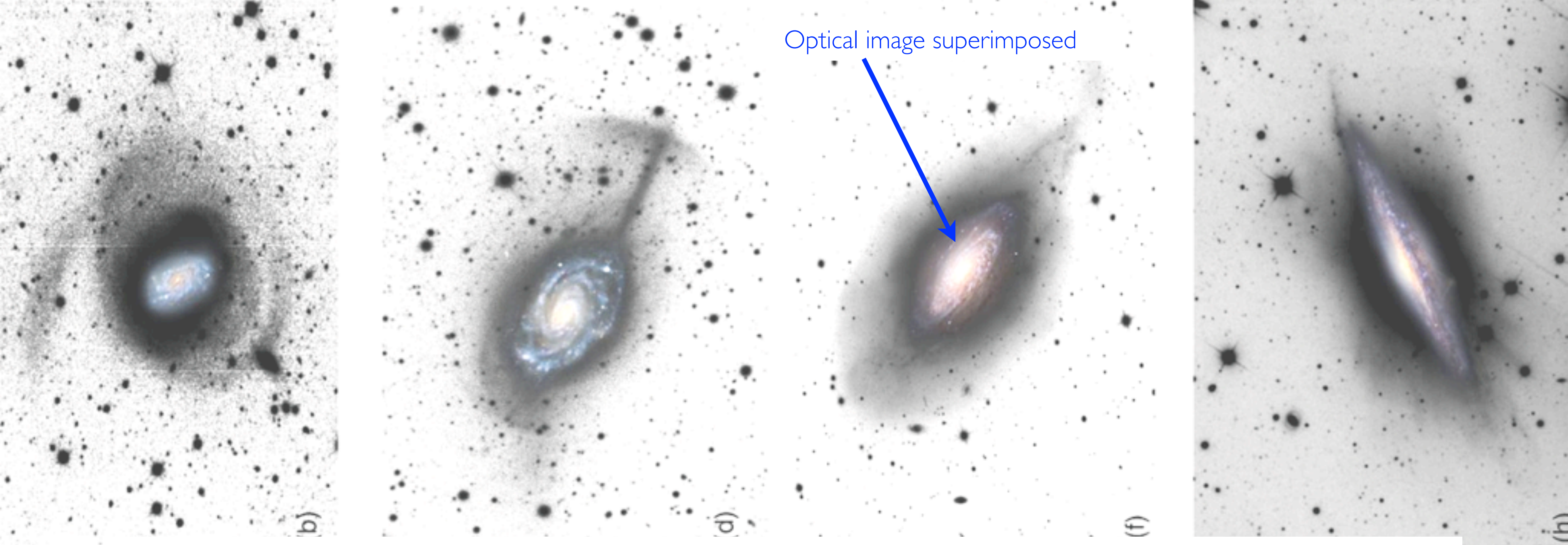
- Galaxy formation is believed to be initiated by cold dark matter (CDM)
- Simulations suggest that galaxies grow through a sequence of infall events
- Most accreted objects are so small nothing happens
- Others create mild perturbations
- A handful of events involve an object that causes a major convulsion


z=11.9
800 x 600 physical kpc
Diemand, Kuhlen, Madau 2006

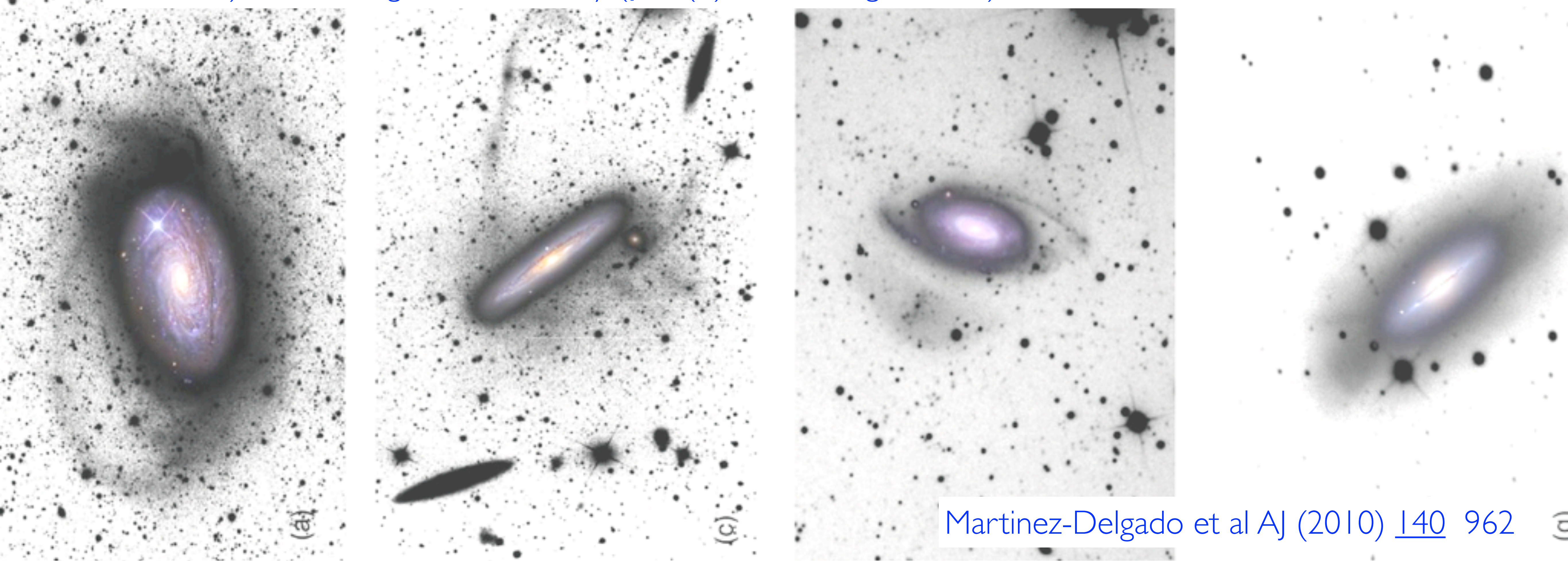
Merger tree



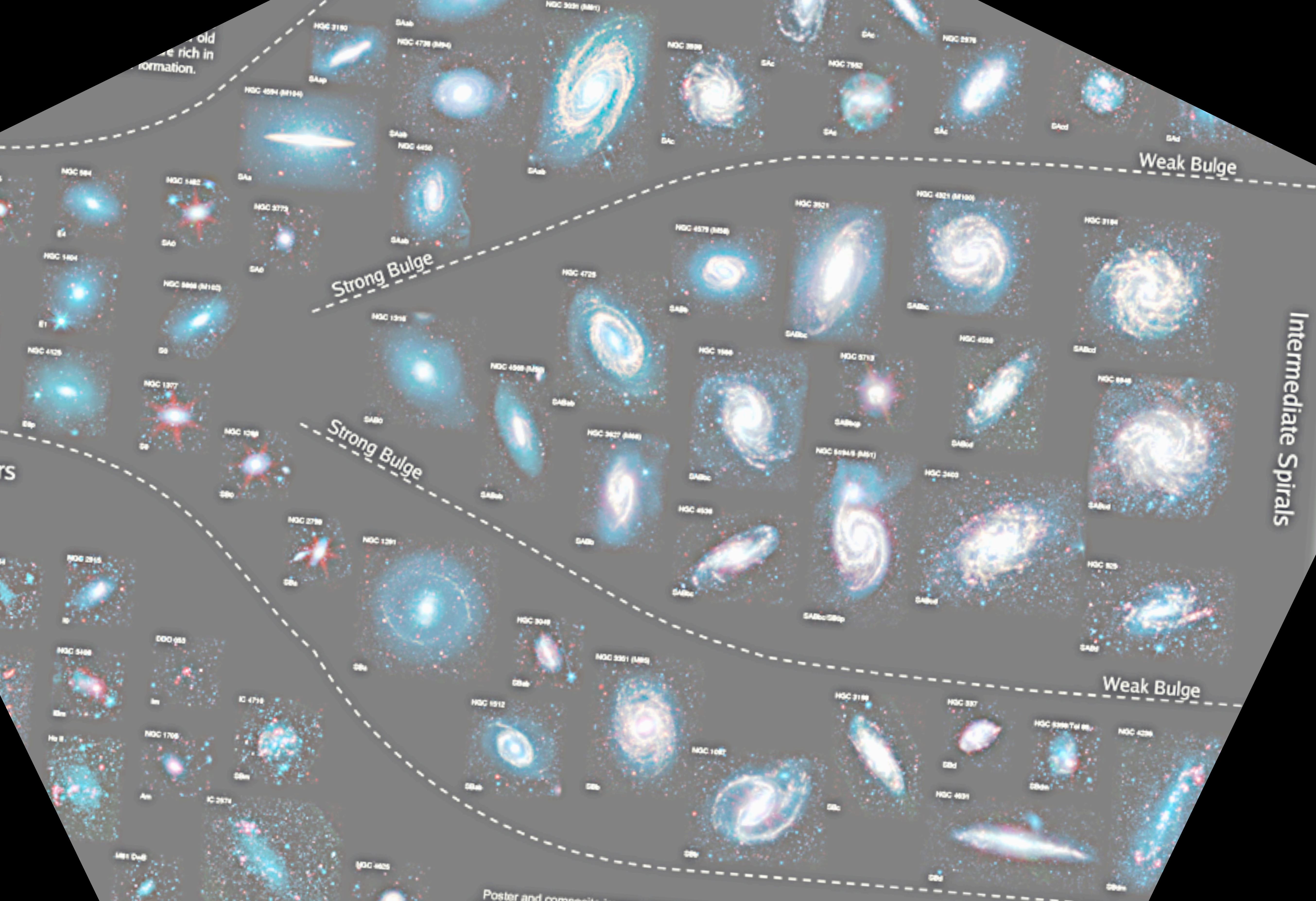
Credit: Marta Volonteri, Milky Way sized galaxy



Ultra deep, wide field imaging of eight isolated spirals in the Local Volume. Small robotic telescopes (D = 0.1-0.5 m). Surface brightness sensitivity (**μ**lim(V) ~ 28.5 mag arcsec^{-2}). FoVs ~10-30 x ~10-30 arcmin.



Martinez-Delgado et al AJ (2010) 140 962


Weak Bulge
Strong Bulge
Intermediate Spirals
Strong Bulge
Weak Bulge
Poster and composite images

- Observations of high-redshift objects allows us to see galaxies forming. There are two limitations
  (i) the observed objects are faint and subtend small angles on the sky, hard to get detailed information
  (ii) hard to relate a given object at high redshift to the objects we study nearby
- The aim of near-field cosmology is to answer some of these questions by studying nearby galaxies, especially our own, for archaeological evidence of their history

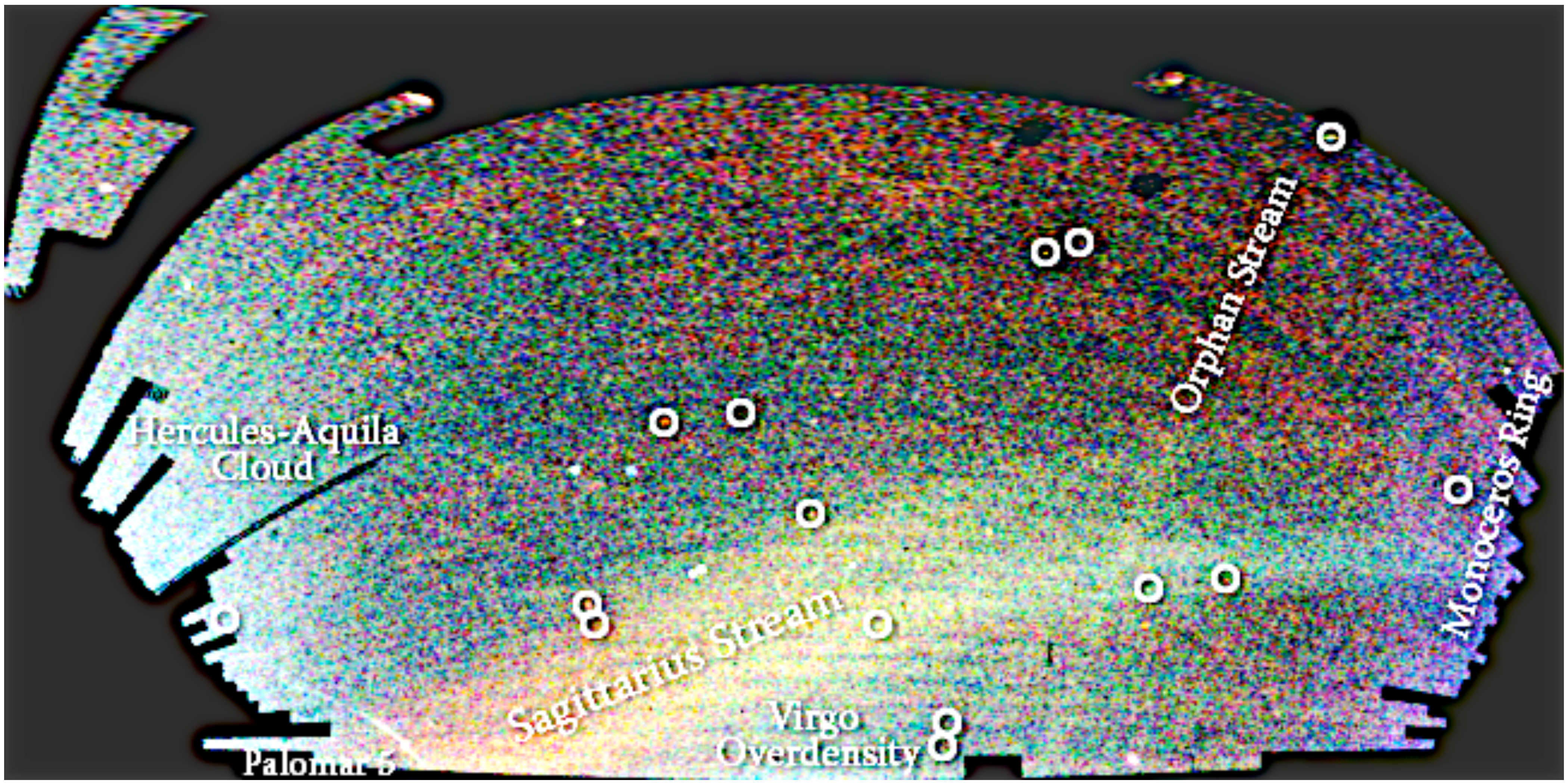
Stars tell us about the past

Stars record the past in two ways

- in their ages and elemental abundances
- in their orbits

- Provide observational constraints that any model of galaxy formation must fulfill
- We work with the Milky Way as this is the galaxy that can be studied in most detail

Field of streams



Near
Far

Dec (ca 0-60°)

RA (ca 240-110°)

This SDSS map shows the richness of structure present in the Milky Way halo

Vasily Belokurov

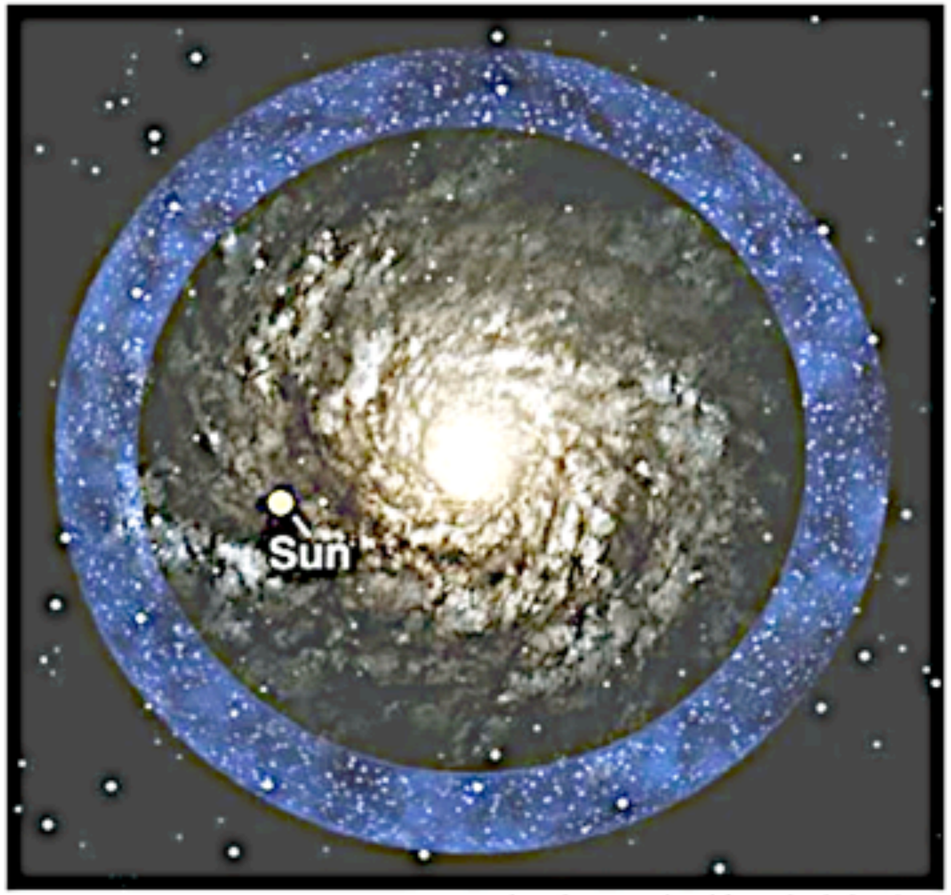
The Monoceros Ring, new dSph-Galaxies and other oddities in and around the Milky Way

Silke Möser
milky-way@gmx.de

The Monoceros Ring

What is it?

- A proposed ring of stars surrounding our Milky Way galaxy
- Wraps around the galactic disk at distances between 14 and 21 kpc from the galactic centre, suggesting that the ring is maybe wrapped around the Milky Way several times (Conn et al. 2007)
- 3.6e8 - 9e9 (Yanny et al. 2003) or 2e7 - 1e9 (Ibata et al. 2003) stars
- 2.7e7 - 5e8 (Yanny et al. 2003) solar masses
- Stars are very dispersed (Ibata et al. 2003)
- Stars are bluer than those in the Milky Way's thick disk and have lower initial metallicity. (Yanny et al. 2003)



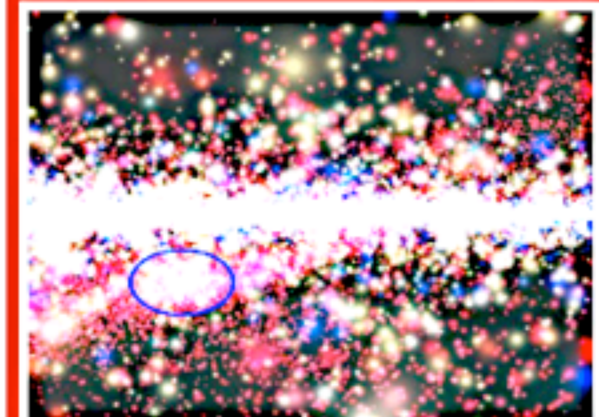
www.solstation.com/x-objects/gal-ring.htm

How was it discovered?

- **2003:** Two teams of astronomers - Yanni et al. (2003) and Ibata et al. (2003) - first announced the discovery of a vast ring of stars, which they had found via an overdensity of colour selected F-stars, around the Milky Way galaxy. Combined, the two teams had found patches of stars spanning about one-sixth of the Milky Way's circumference.
- **2004 - 2007:** Subsequent surveys extended the detections of the ring. Evidences of the ring were found an both sides of the galactic plane at distances to the galactic centre varying from 14 to 21 kpc. Combined with non-detections of the ring in other fields this suggests a very complex structure. (Conn et al. 2005, Conn et al. 2007)

How did it form?

The Canis Major Dwarf Galaxy



The Canis Major dwarf galaxy below the Milky Way disk
http://astro.u-strasbg.fr/images_ri/image3_big_nocap.jpg

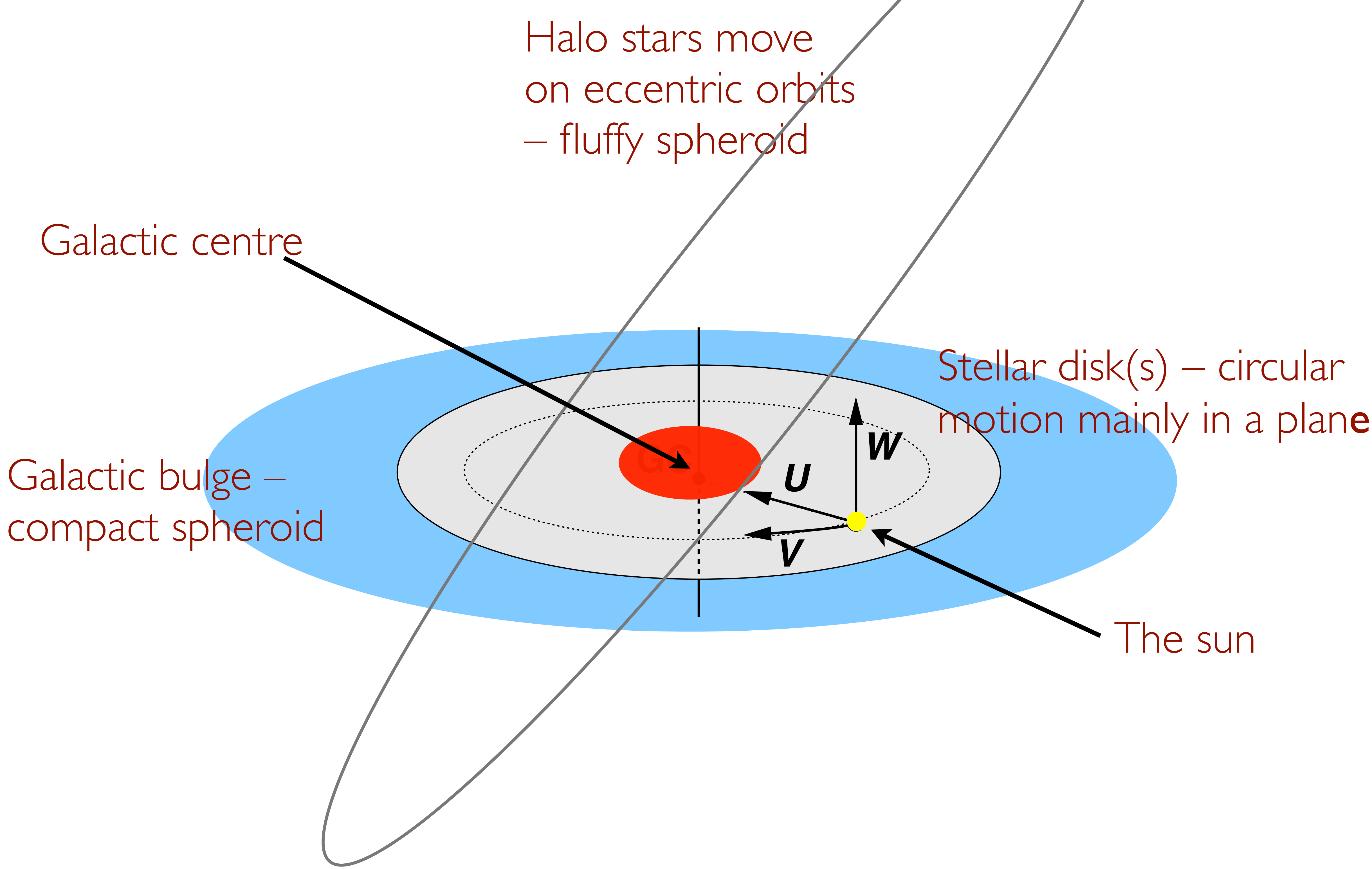
The Canis Major dwarf galaxy, discovered in 2003, is an irregular galaxy and is momentarily the closest known other galaxy to our location in the Milky Way, being located 7.7 kpc away from our sun.

It is a satellite galaxy orbiting the Milky Way. Due to the gravitational forces exerted by the Milky Way (and its dark matter halo) it is slowly pulled apart.

It is probably the progenitor of the Monoceros ring, which is thought to be the stream of its tidal debris. (Martin et al., 2003)

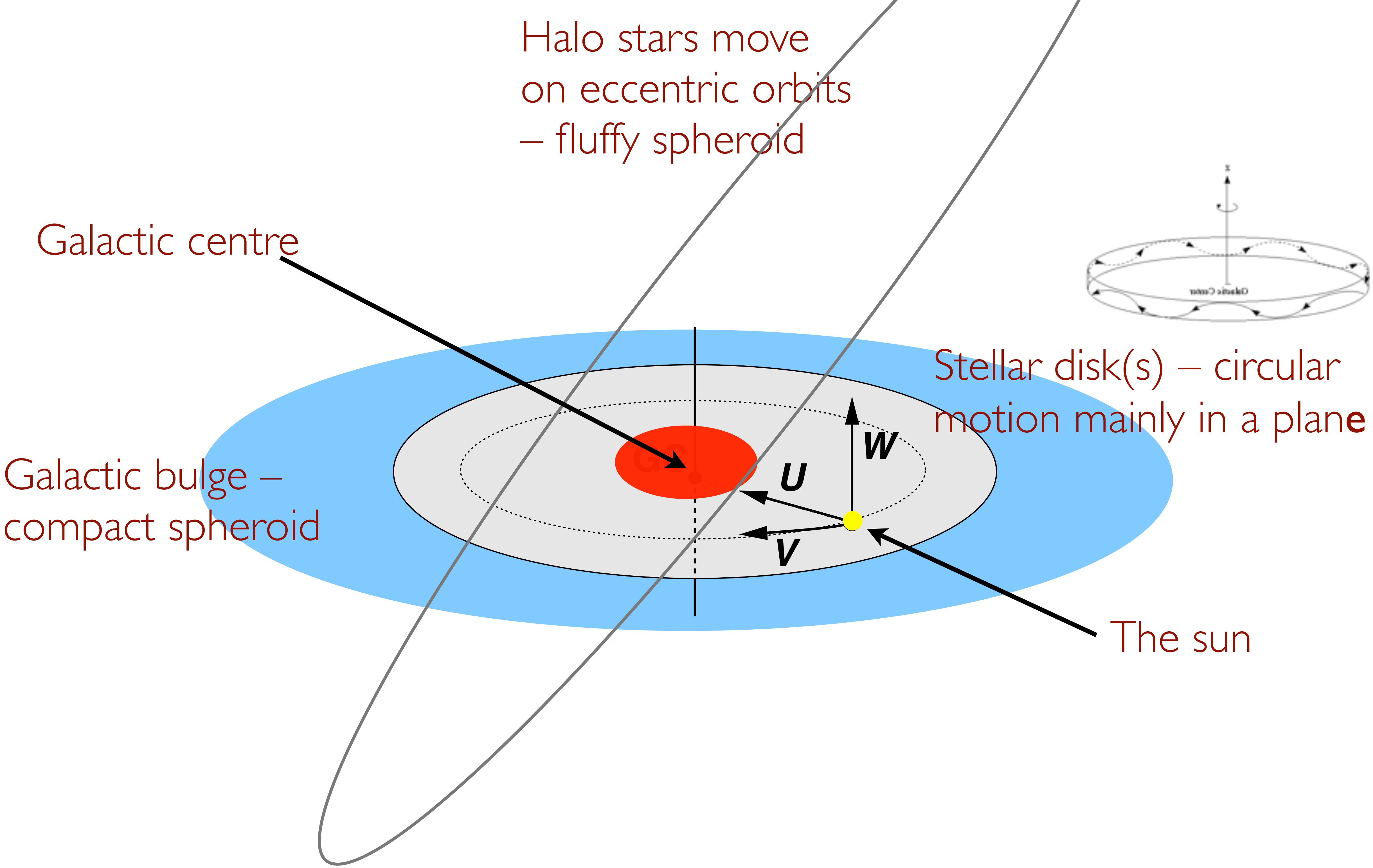
The stream of the Canis Major dwarf galaxy (in red) wrapped around the Milky Way (in blue)
http://astro.u-strasbg.fr/images_ri/image1sun_big_nocap.jpg

How stars move in the Milky Way



Dark matter halo

How stars move in the Milky Way



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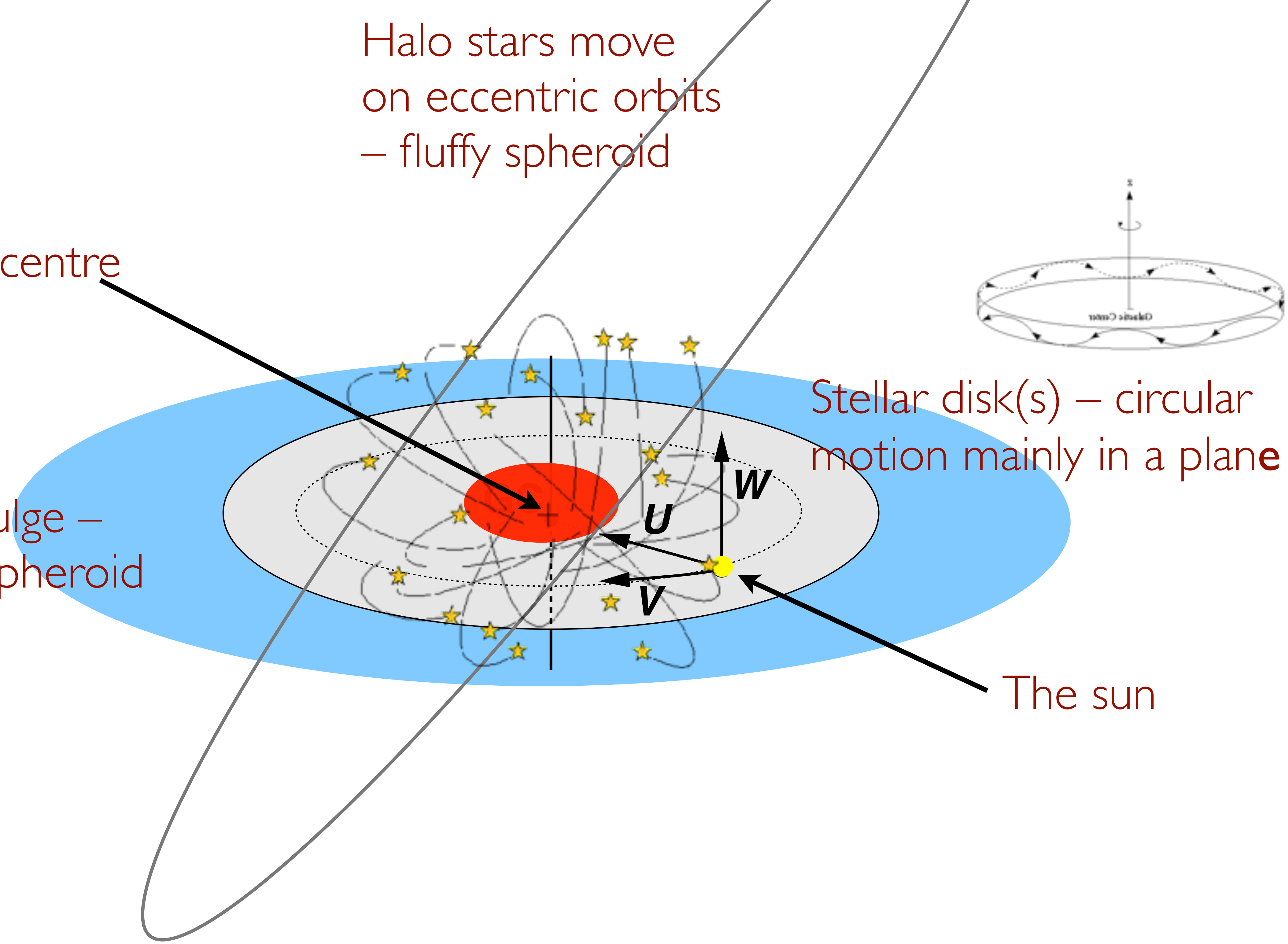
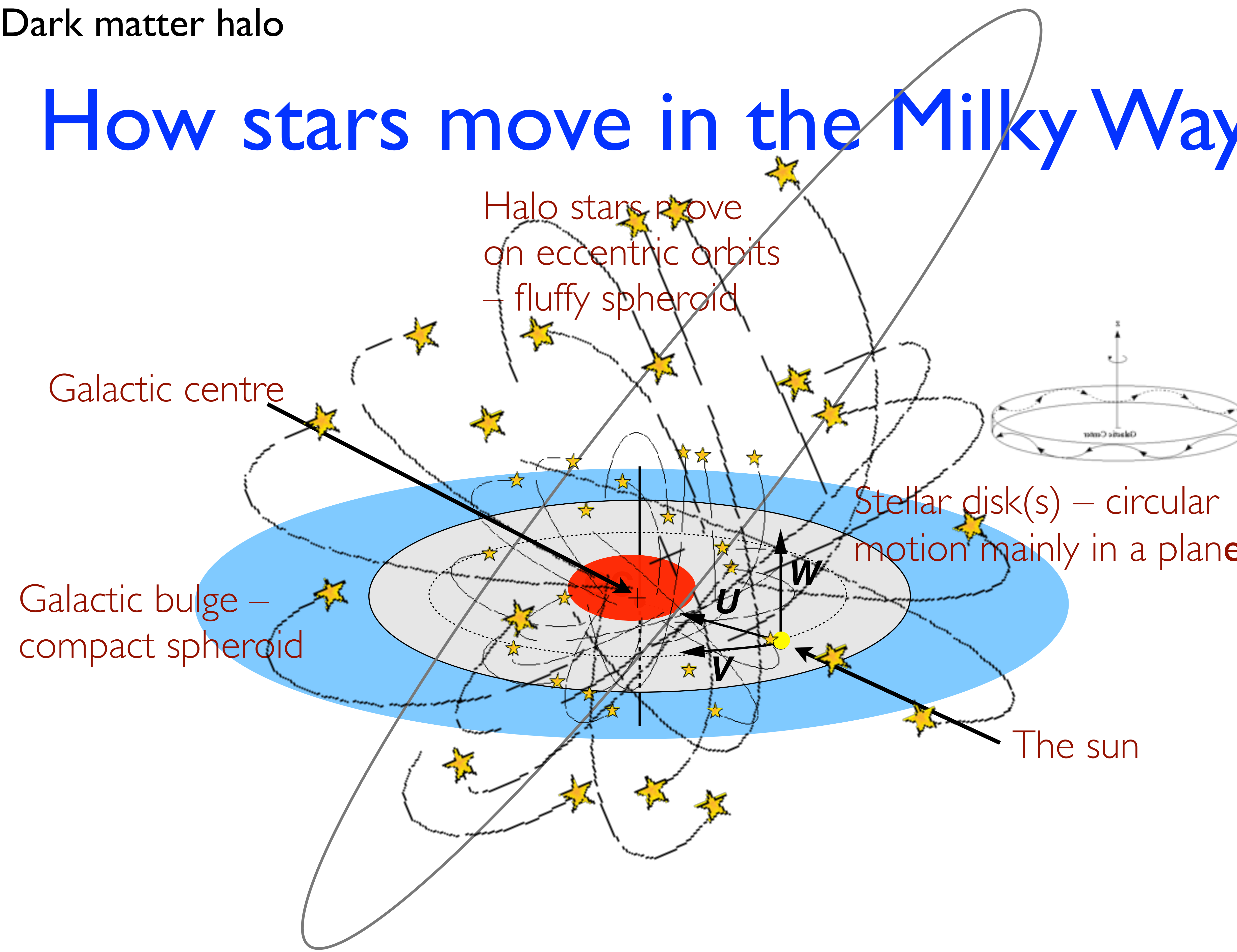


How stars move in the Milky Way



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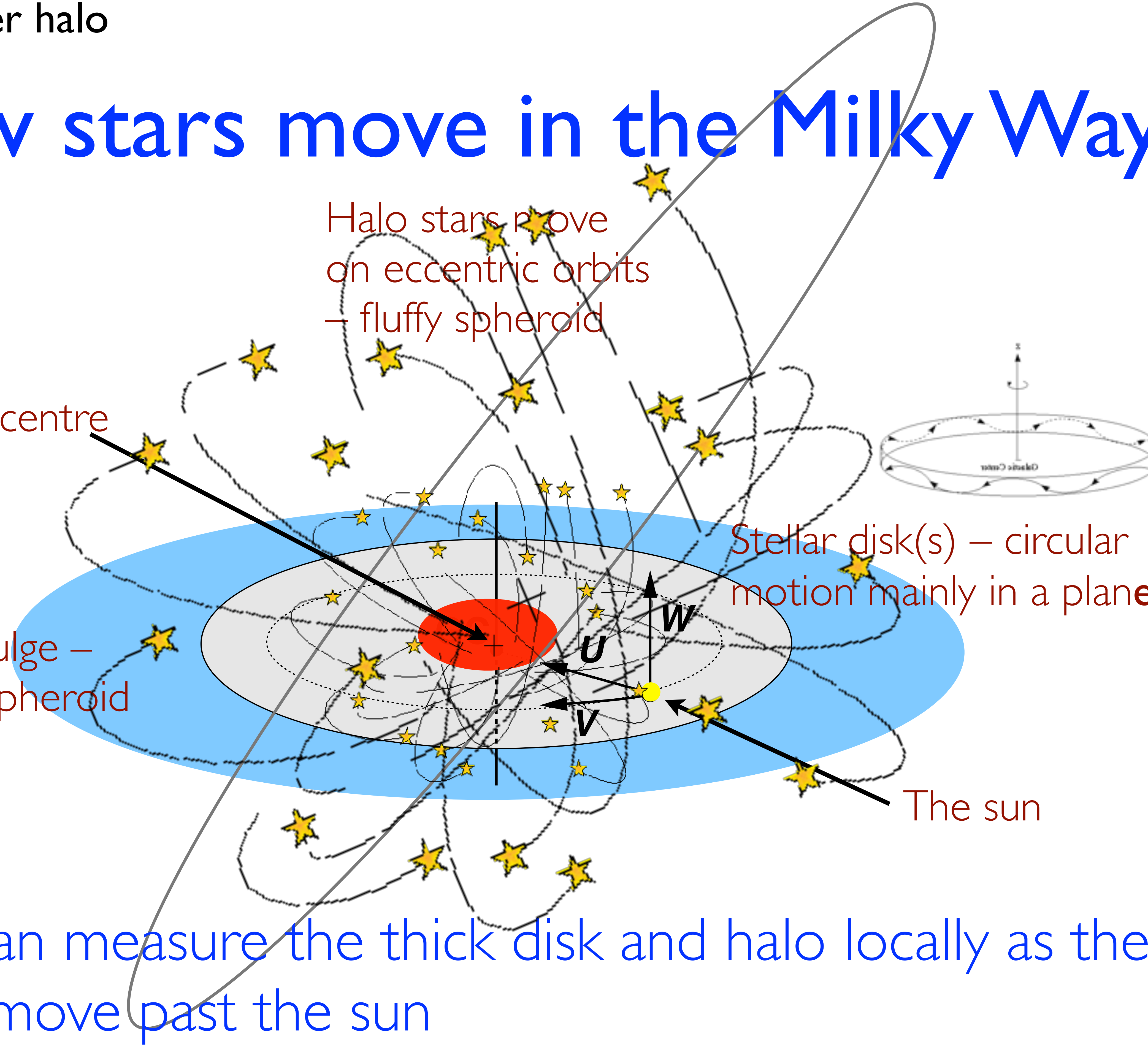
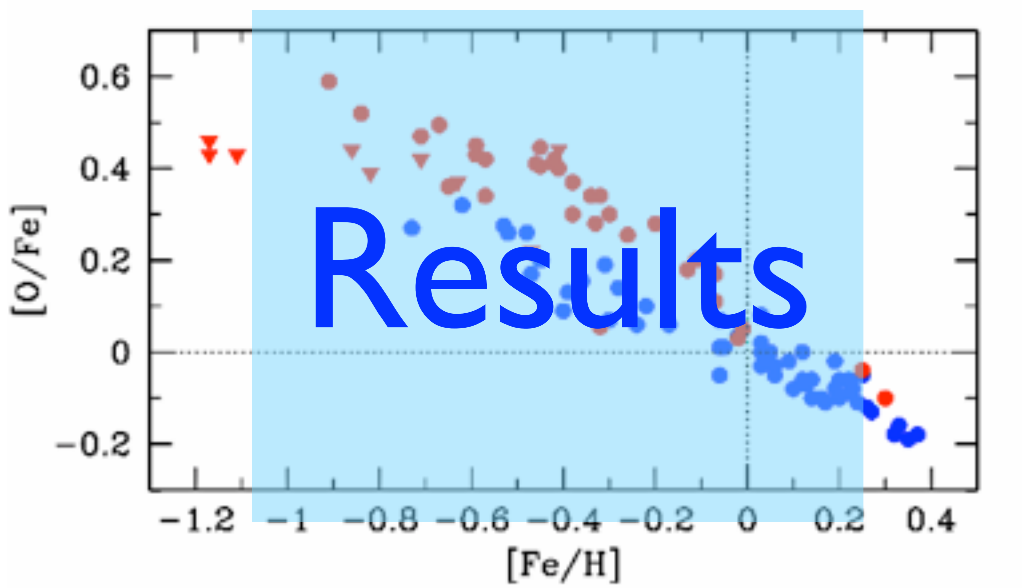
How stars move in the Milky Way

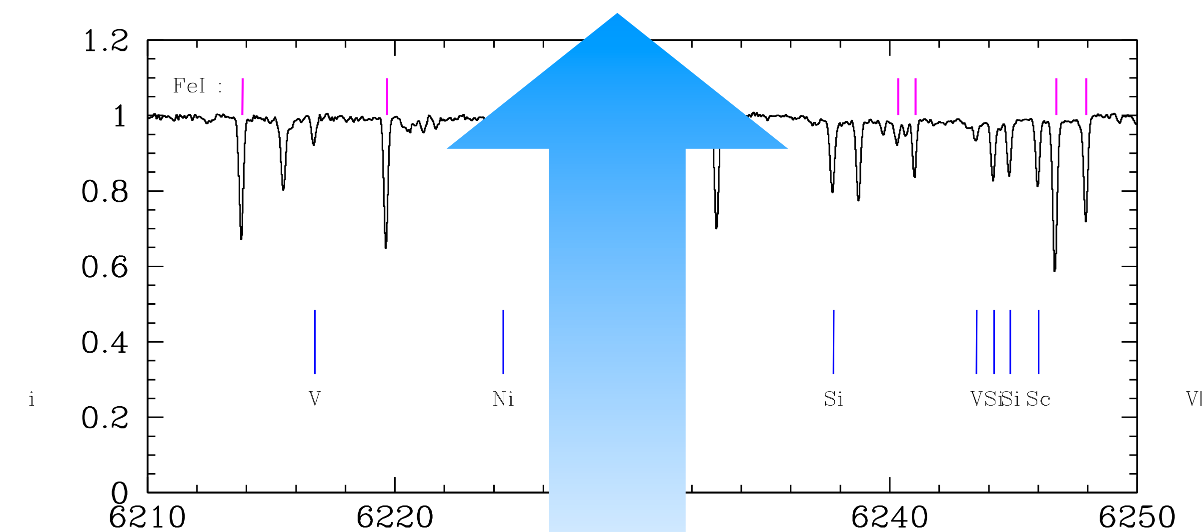


We can measure the thick disk and halo locally as the stars move past the sun

Abundances

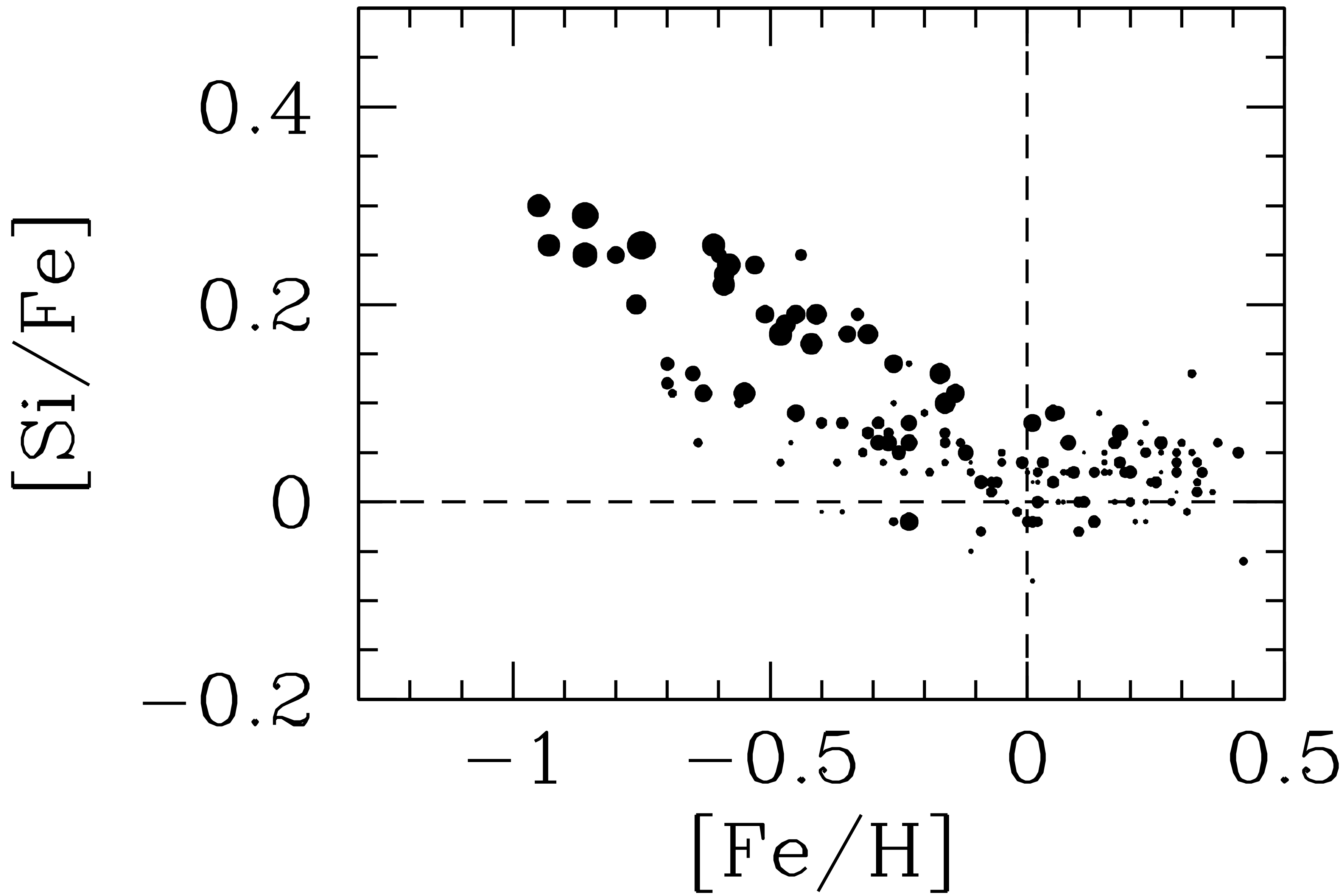
Measure line-strengths and turn into elemental abundances





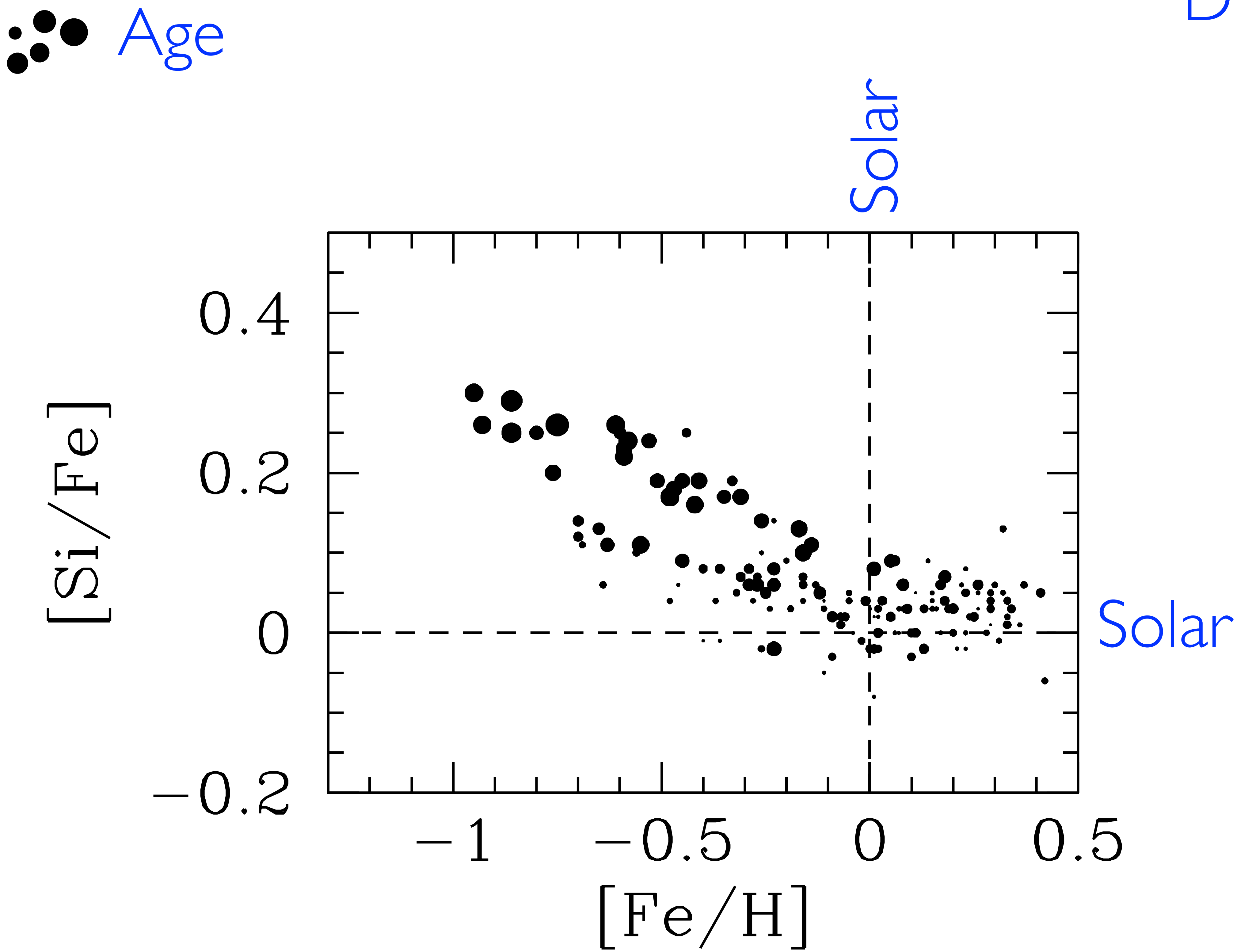
Select stars

Observe at the telescope



Bensby et al. 2010, in prep.

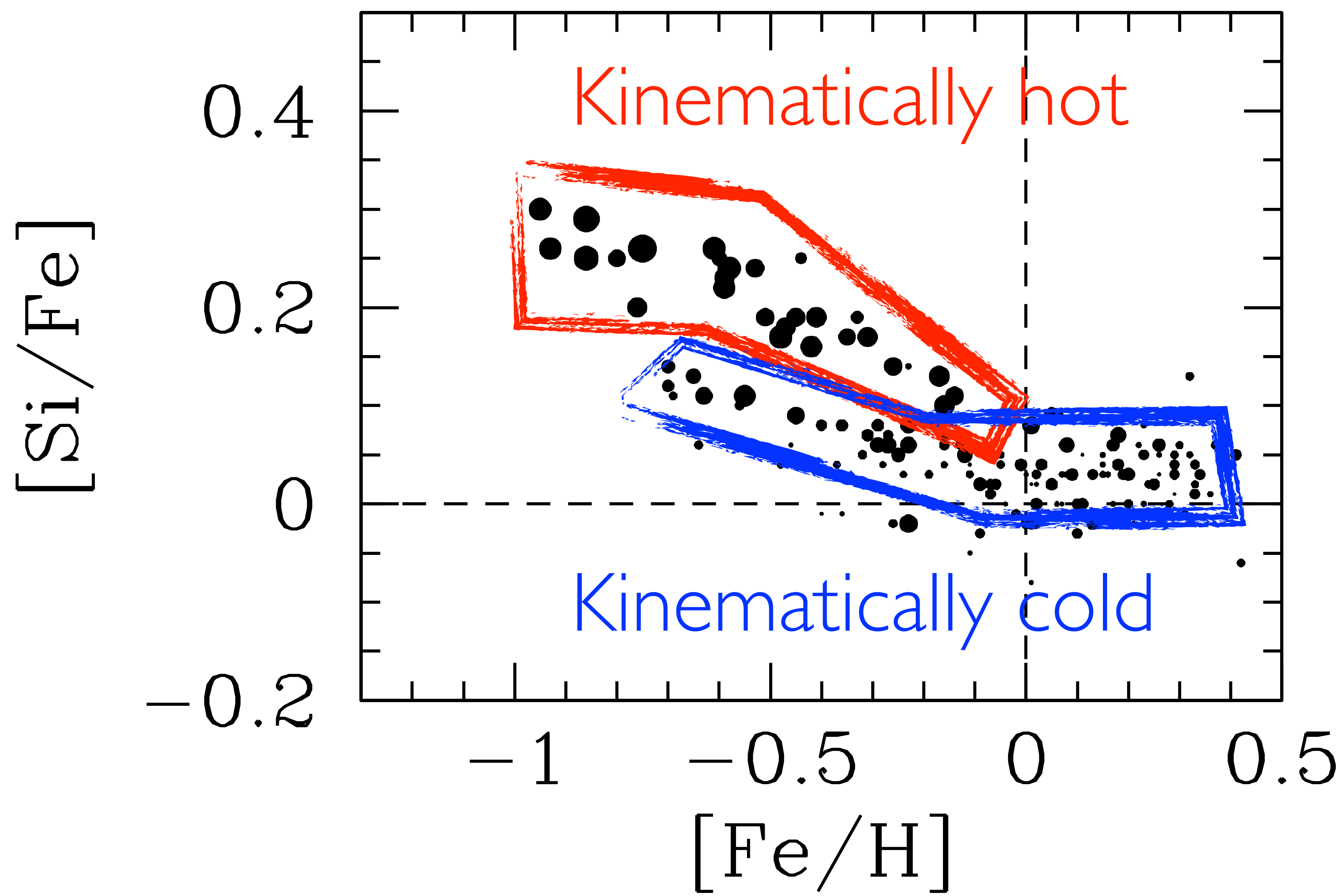
D < 50 pc



$[Fe/H] = \log(N_{Fe}/N_H)_{star} - \log(N_{Fe}/N_H)_{sun}$

Age

D < 50 pc



$[Fe/H]=\log(N_{Fe}/N_H)_{star} - \log(N_{Fe}/N_H)_{sun}$

Thick disk scenarios

- Monolithic collapse
- "Puff up"
- Accretion and disruption of satellites
- Disk heating by a minor merger
- Radial migration via resonant scattering
- In-situ formation during/after a gas-rich merger
- Gas-rich, turbulent, clumpy disk formation at high z

Dwarfs vs Giants

- Classical chemical analyses may be affected by systematic errors that would cause observed abundance differences between dwarfs and giants. For some elements, however, the abundance difference could be real.

Pace et al. 2010

Locally we see tight trends, whilst as a function of distance we do not know what is going on, especially in the old stellar populatons

÷

However, we can not efficiently select dwarf stars from other stars

Gaia

- Gaia will be the first survey that will provide 6D phase space (r, v) information together with photometry for very large, magnitude-limited samples of stars (in total a billion objects)

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A few examples of its impact on near-field cosmology, however, Gaia will have profound impact also in fields such as

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A few examples of its impact on near-field cosmology, however, Gaia will have profound impact also in fields such as

stellar astrophysics, exoplanets (~10^4), solar system, general relativity

- Distances + magnitudes and colours + kinematics
  - ★ spatially and kinematically resolved distributions (luminosity, ages, metallicity)
  - ★ history of star formation
  - ★ chemical enrichment history
- Number density and kinematics of tracer stars
  - ★ mapping the galactic potential (non-axisymmetric)
  - ★ distribution of (dark) matter
  - ★ disk dynamics (bar, spirals)
- Phase space (or E, L_z) structures in halo
  - ★ history of galactic mergers

LL, Gaia for all 2008

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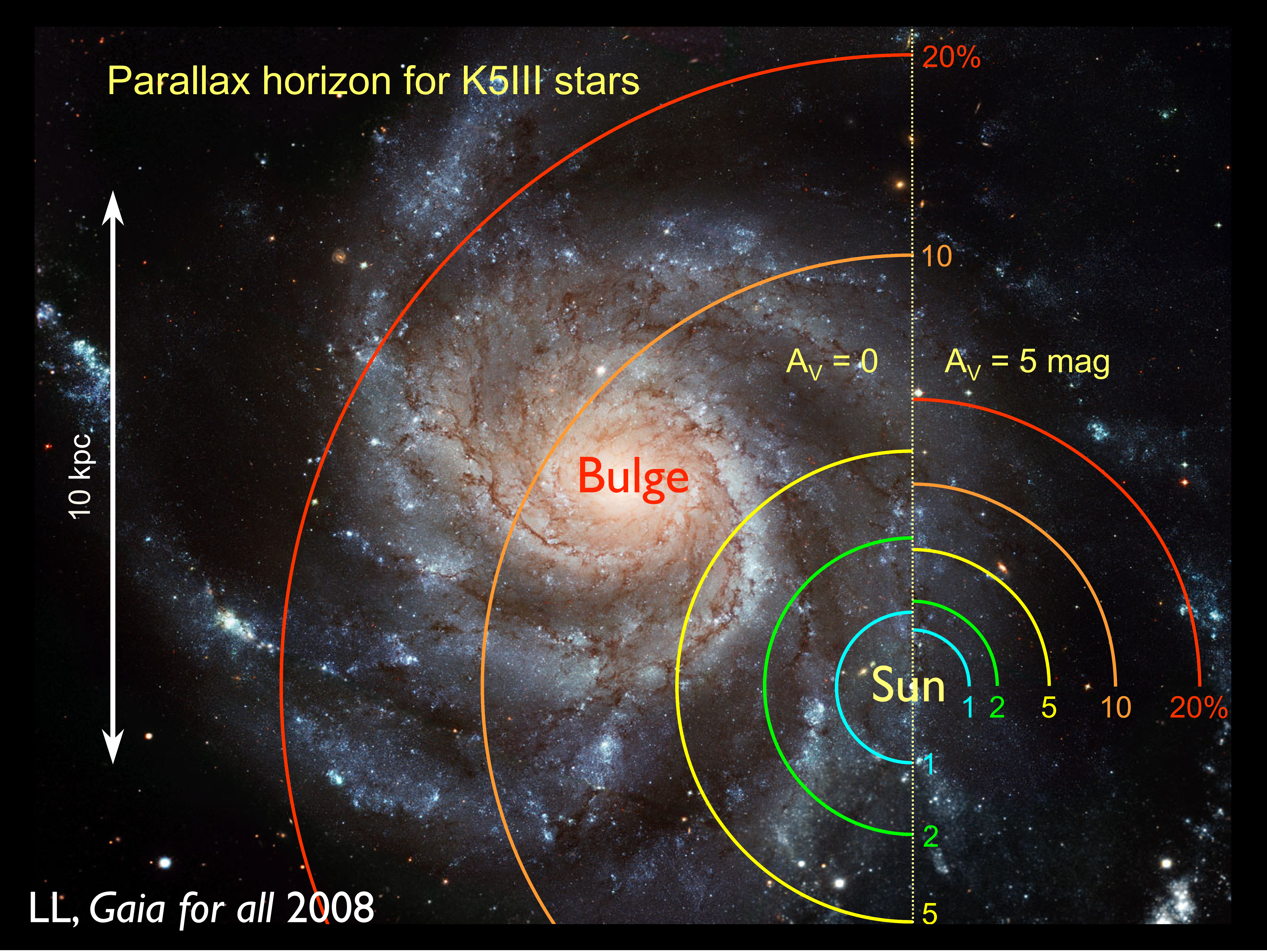
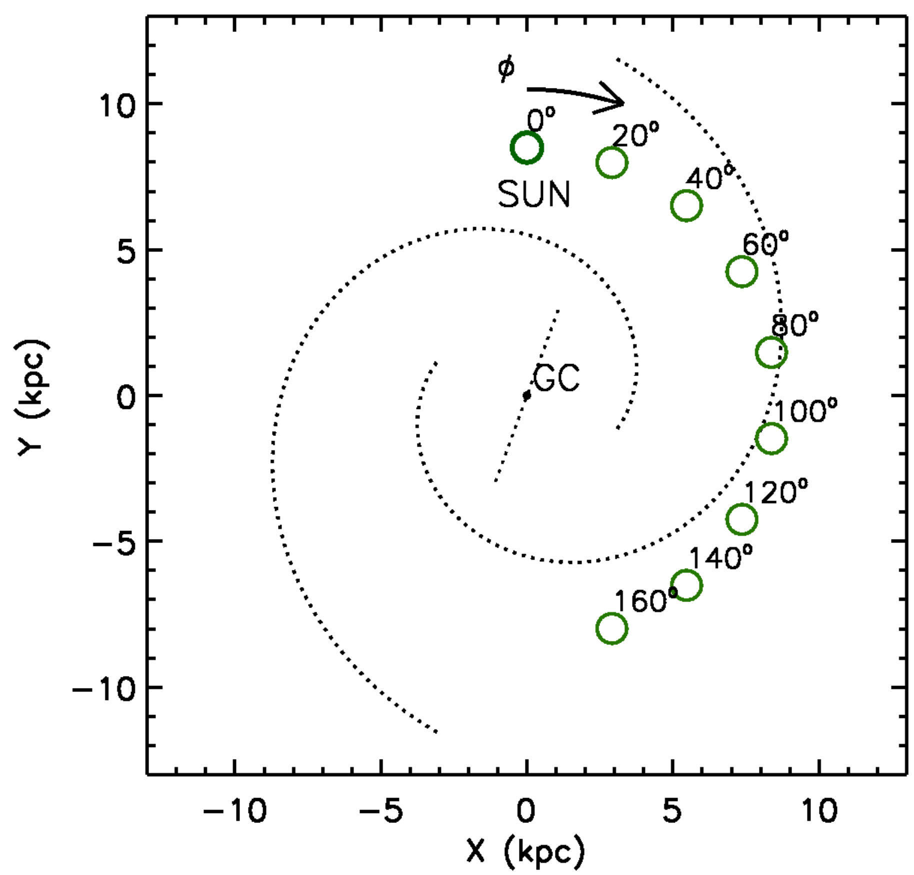
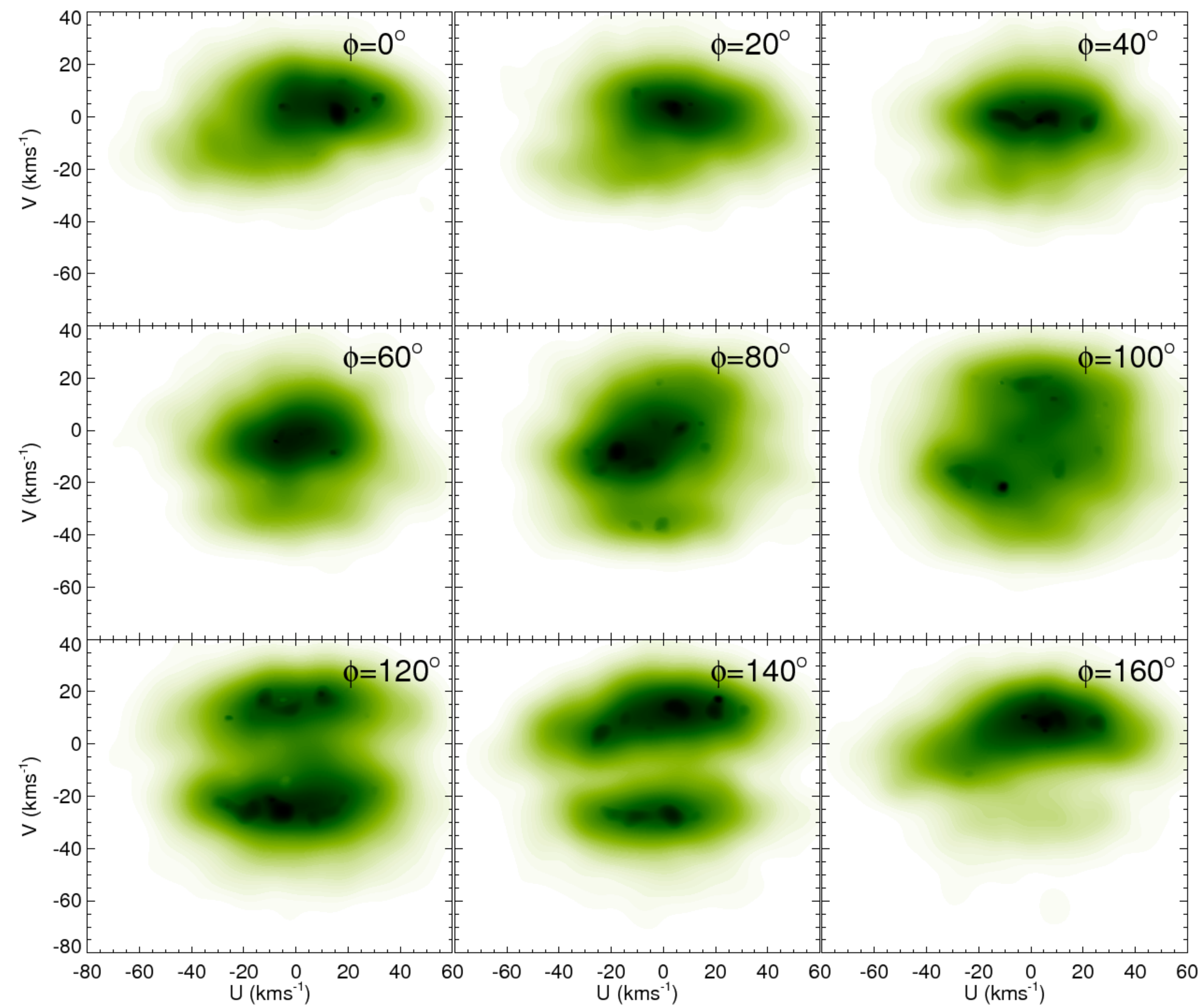
LL, Gaia for all 2008


Parallax horizon for K5III stars
10 kpc
Bulge
Sun
A$_V$ = 0
A$_V$ = 5 mag
20%
10
5
2
1
1 2 5 10 20%
LL, *Gaia for all* 2008

Disk dynamics

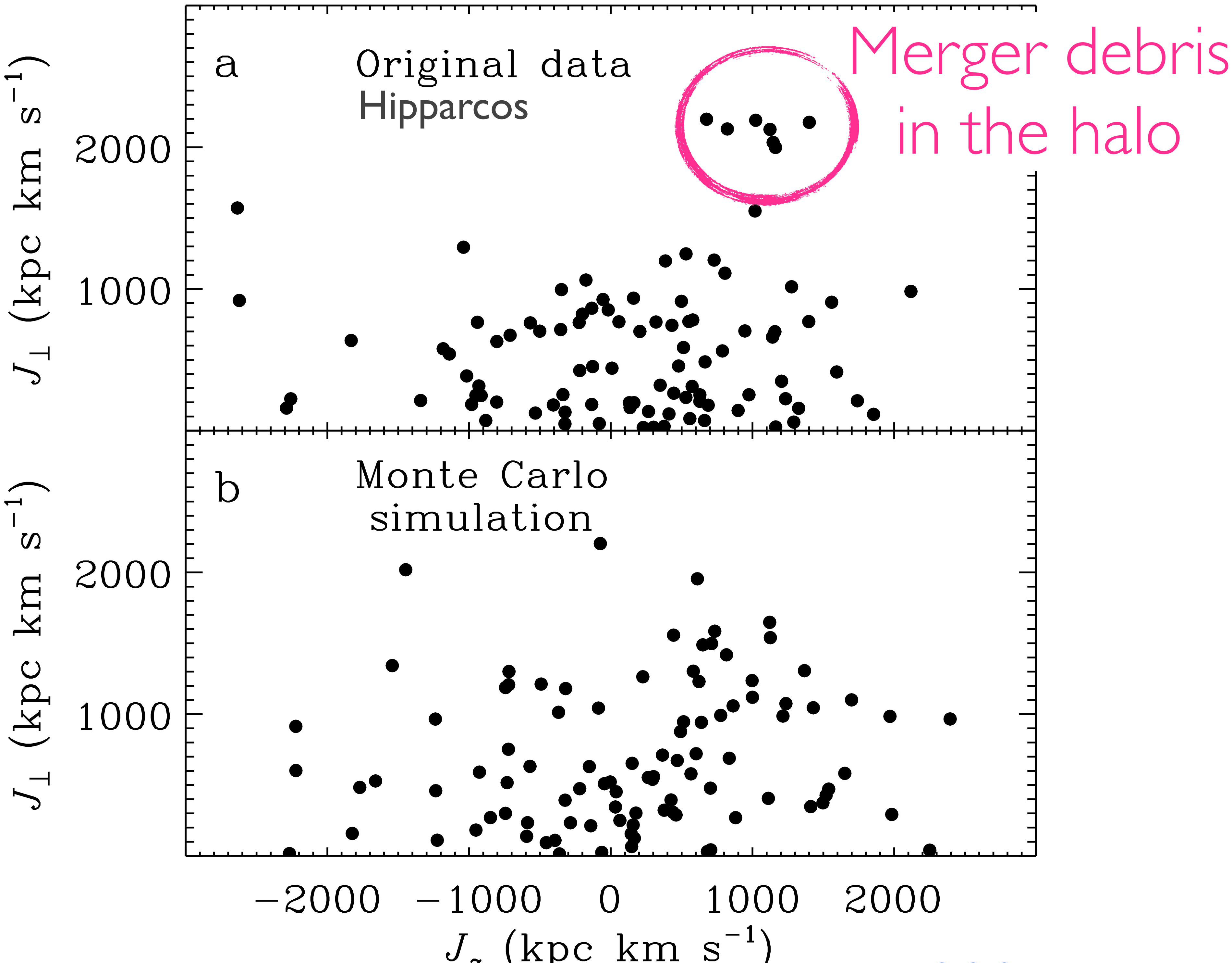




Bar and spiral arms
included in the model

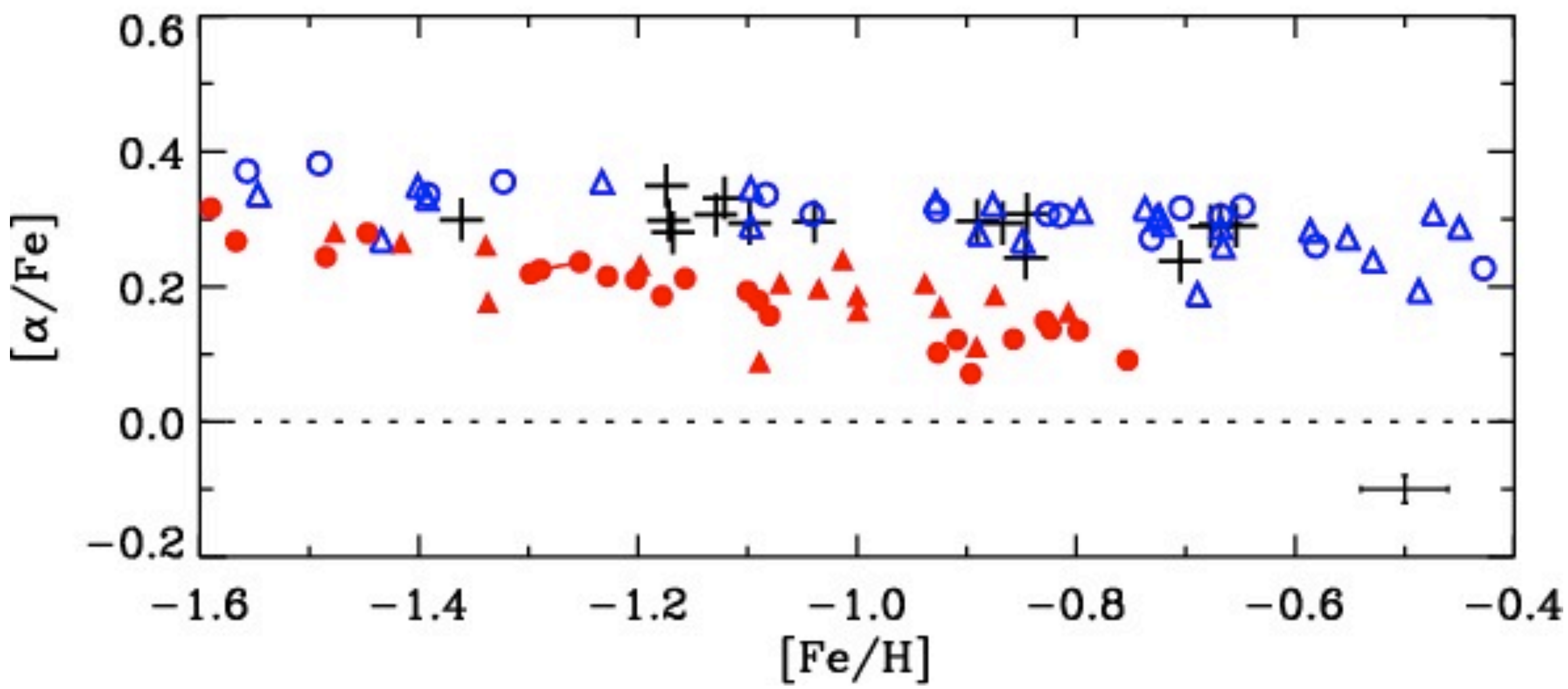
Antoja thesis

Galactic mergers



Helmi et al. 1999 Nature 402 53

Galactic mergers

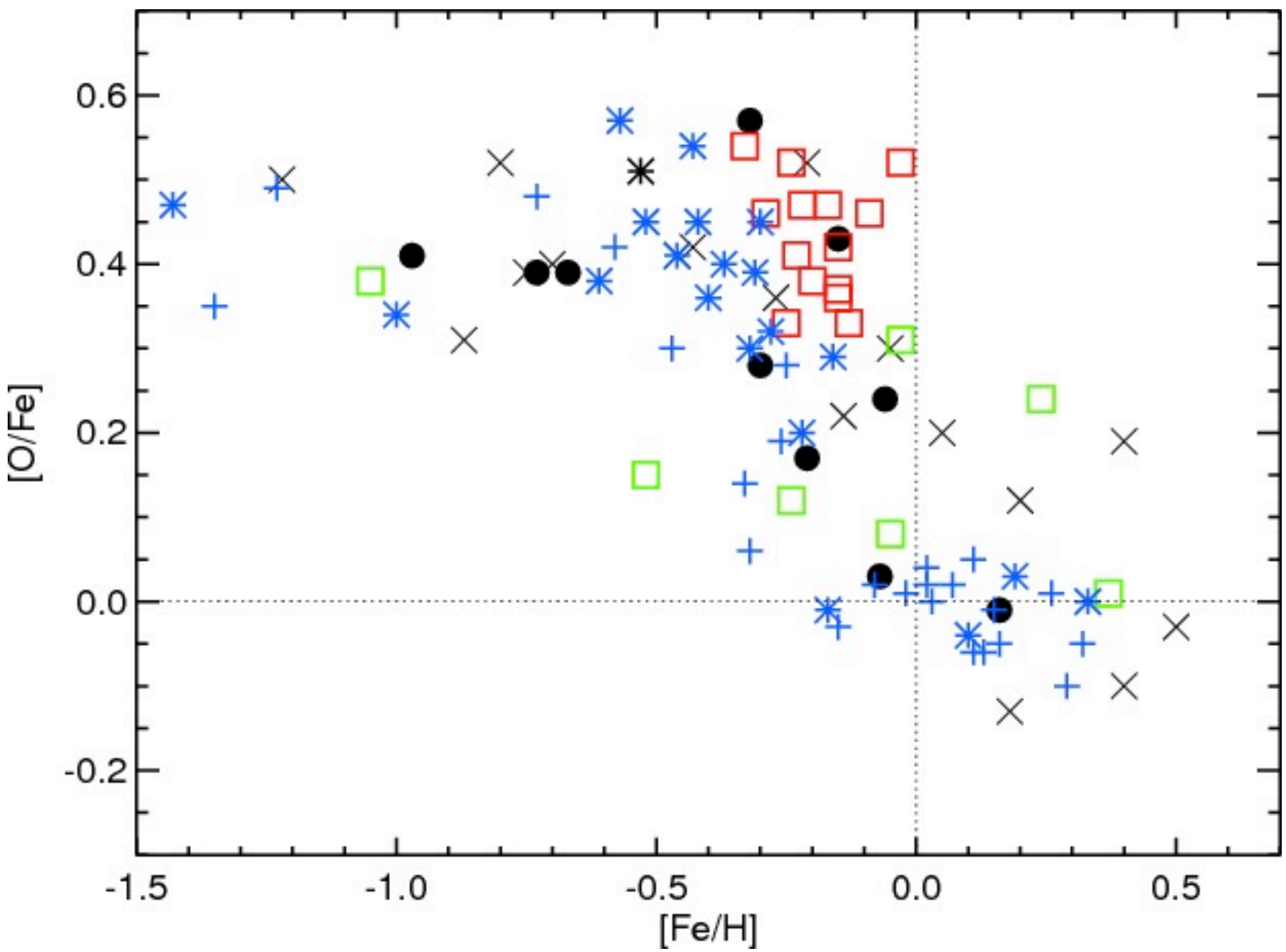


Nissen & Schuster (2010) A&A 511 L10

… but some things will still need an E-ELT

- Turn-off stars in the Bulge are inherently faint with V around 18-19
- For so faint stars we can not obtain spectra of sufficient S/N and R to do a detailed abundance analysis

Hence the bulge is studied with giants



Ryde et al. 2010 A&A 509 20

Potential problems

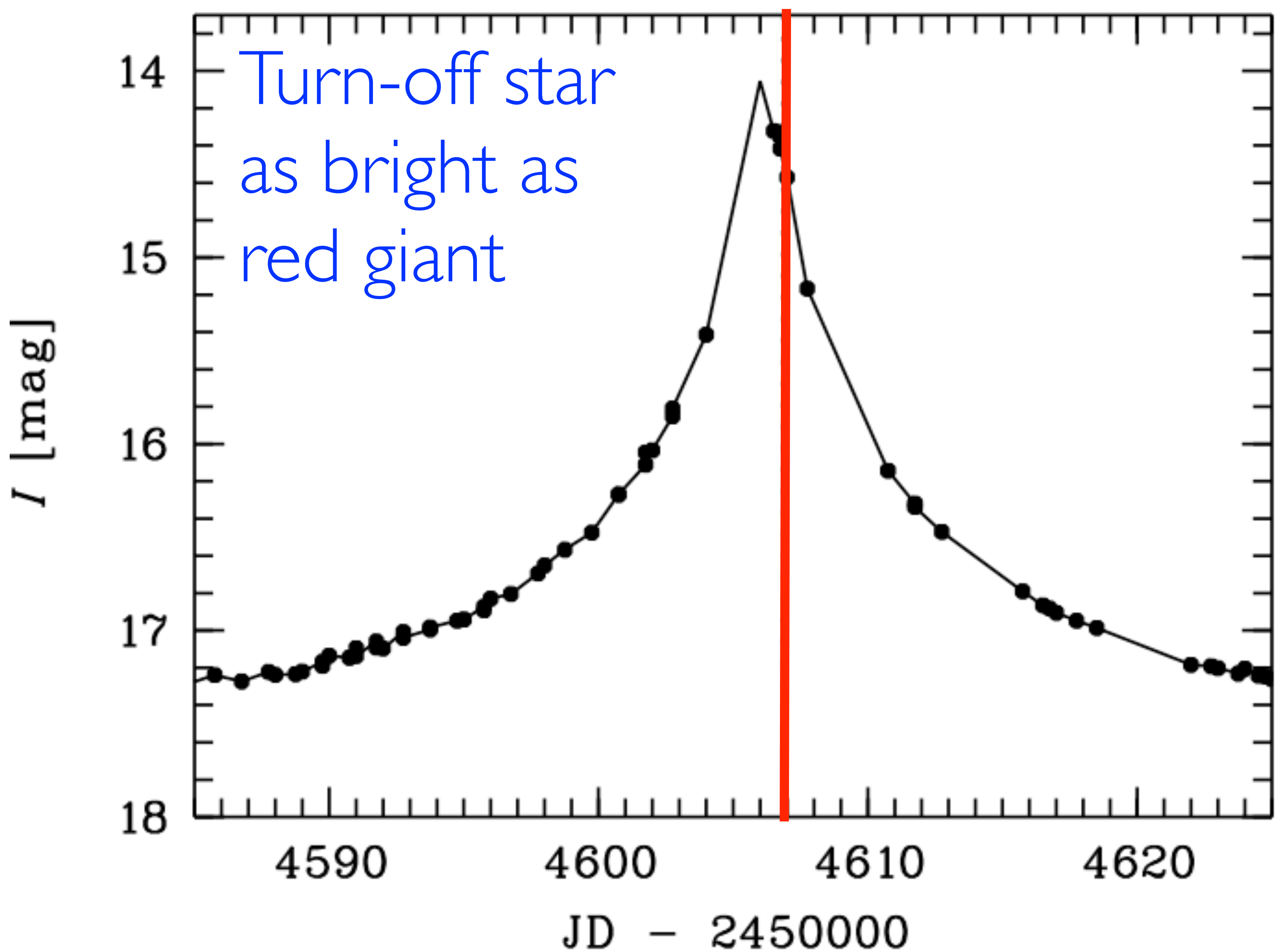
- Certain abundance signatures are erased
- We are uncertain about the stellar evolutionary paths at the very highest metallicities (these are likely to be present in the Bulge)

Micro lensing events helps us to study the Bulge

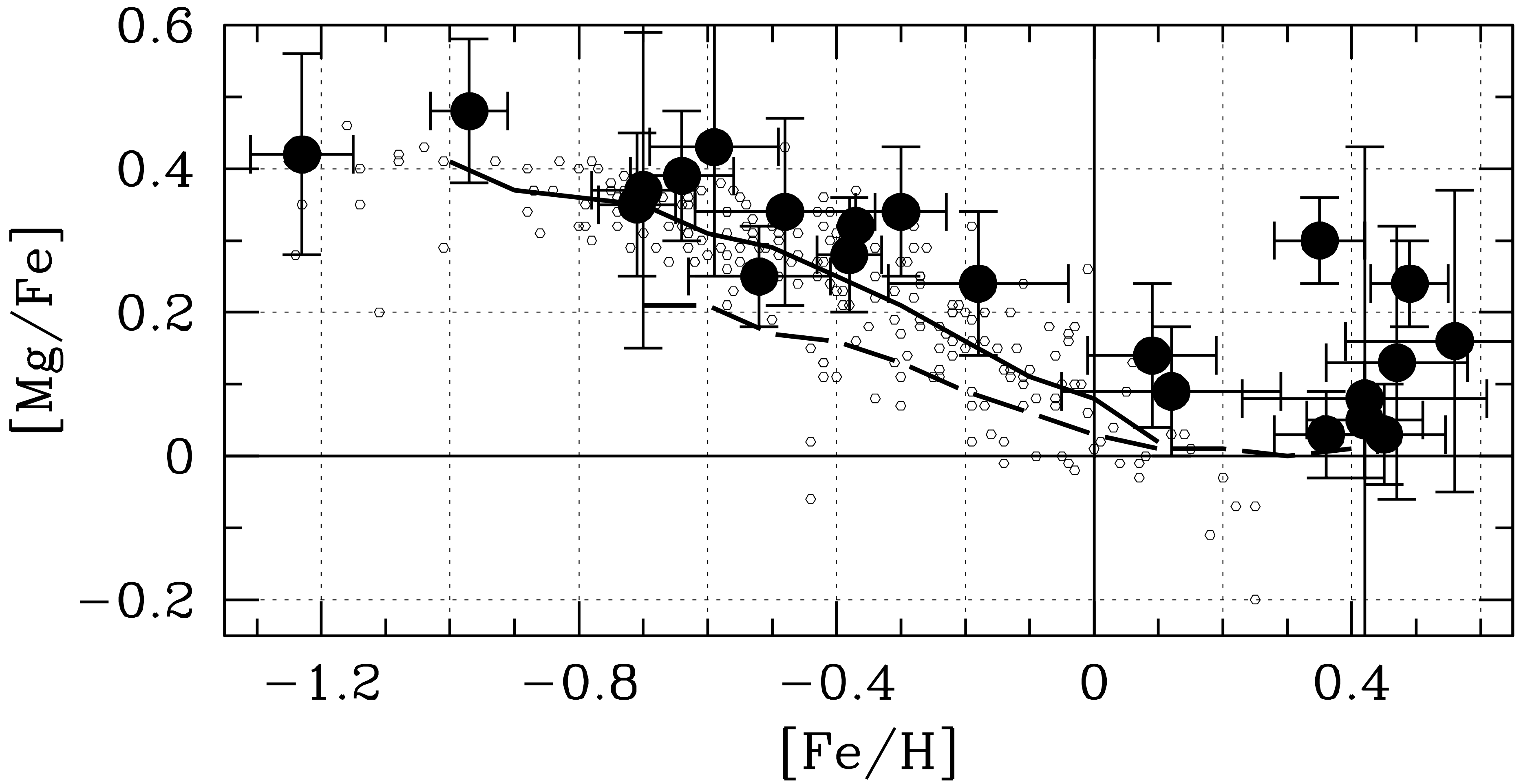
- Micro-lensing events give unique opportunities to obtain spectra of these stars
- OGLE & MOA
- We have 22 events resulting in high-res, high S/N data (Bensby et al 2010, and 2011 in prep.)

While we wait for the E-ELT
we have to be smart

OGLE-2008-BLG-209



Bulge with dwarfs



Bensby et al. 2010 in prep.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dSph galaxies
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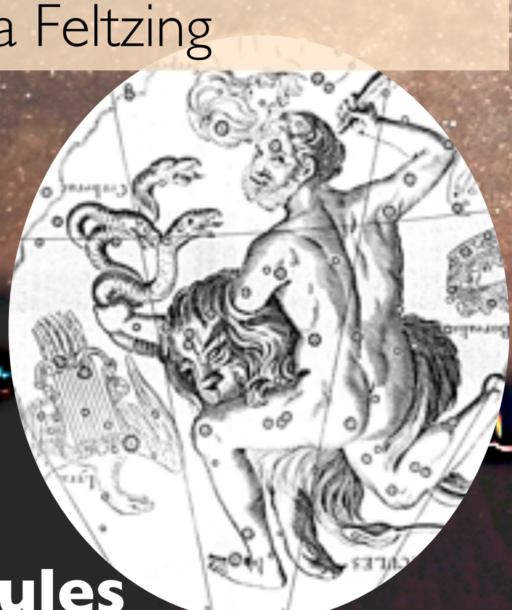

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Lund Spop

Stellar Evolution
Ross Church

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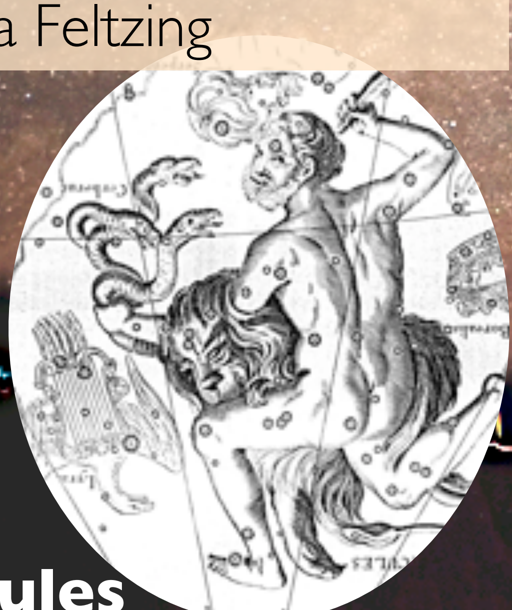

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ESO LoI spectrographs
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