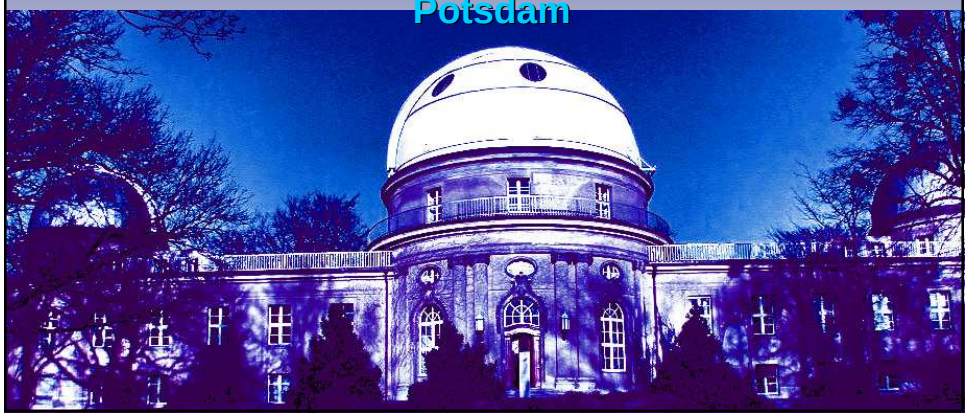
Galactic Archeology with RAVE

Matthias Steinmetz
Astrophysical Institute
Potsdam



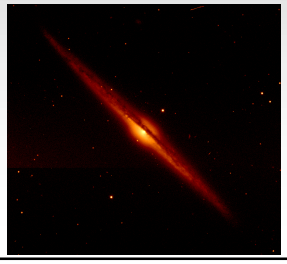
AIP

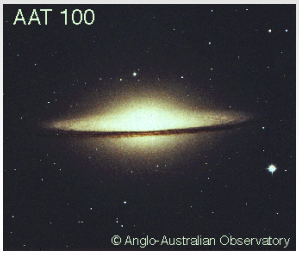
KITP lunch seminar

Dec 7th 2004

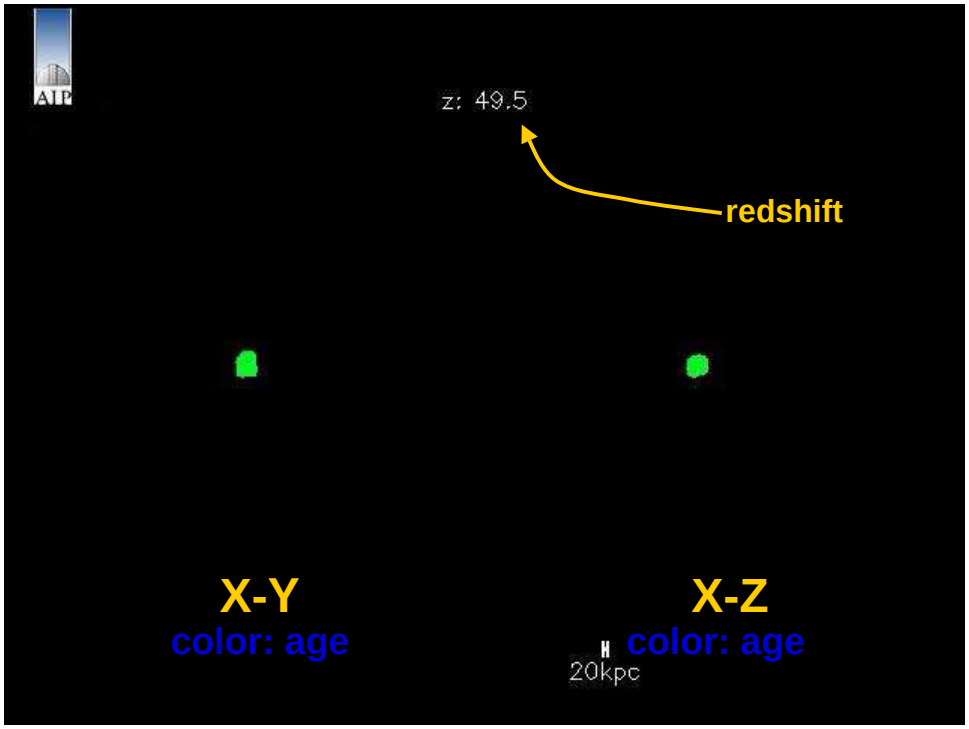
CDM and Galaxy Morphology

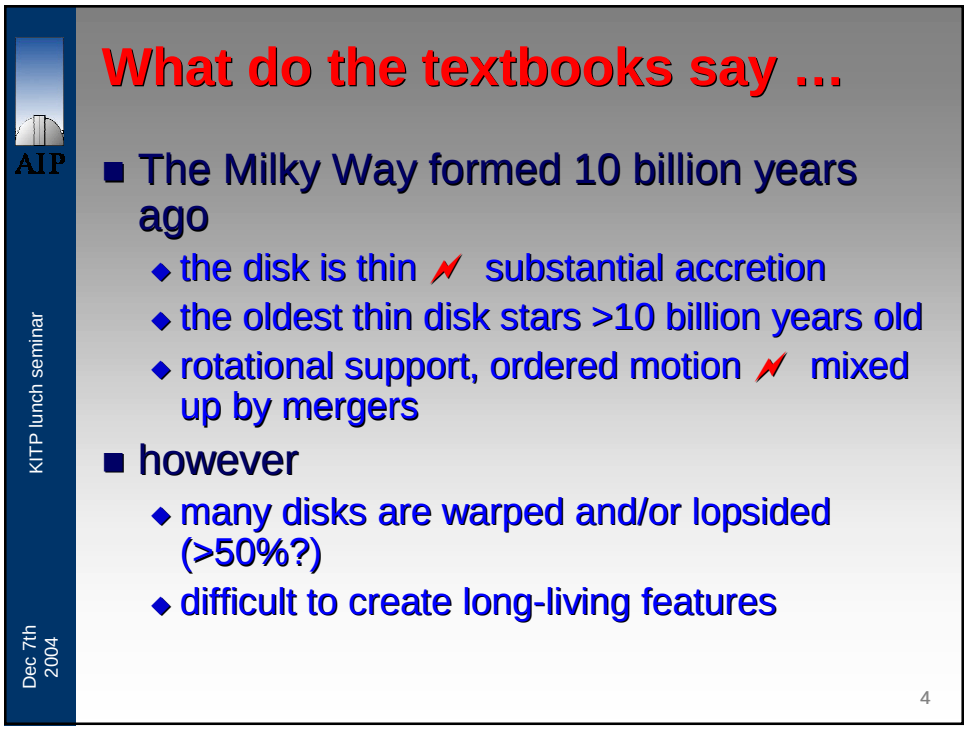
- The morphology of a galaxy is a transient, evolving feature dictated by the mass accretion history of its dark matter halo
  - most stars form in disks; spheroids result from subsequent mergers
  - disks result from smooth gas accretion; oldest disk stars are often used to date the last major merger event





2


AIP
z: 49.5
redshift
X-Y
color: age
X-Z
color: age
20kpc

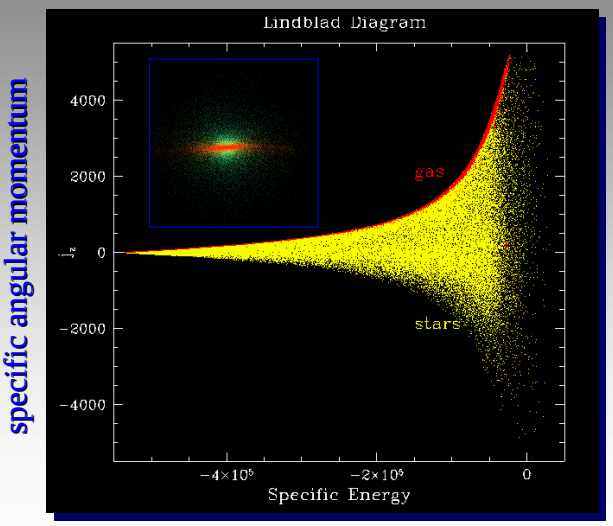

AIP
KITP lunch seminar
Dec 7th 2004
What do the textbooks say …
The Milky Way formed 10 billion years ago
the disk is thin ↯ substantial accretion
the oldest thin disk stars >10 billion years old
rotational support, ordered motion ↯ mixed up by mergers
however
many disks are warped and/or lopsided (>50%?)
difficult to create long-living features
4

AIP

KITP lunch seminar

Dec 7th 2004

Dynamical components of the simulated galaxy



specific angular momentum

binding energy

Abadi, Navarro, Steinmetz & Eke 2003

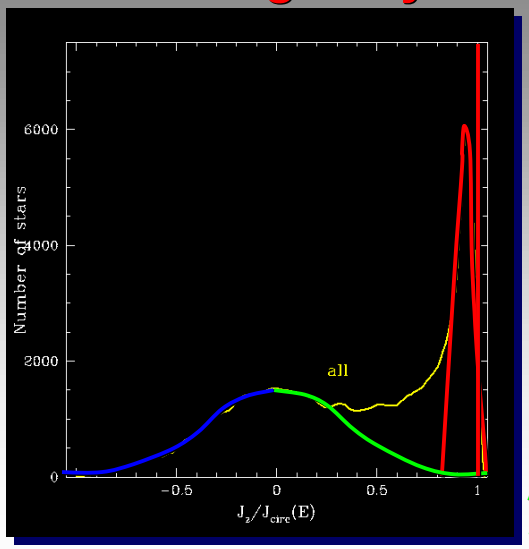
5

AIP

KITP lunch seminar

Dec 7th 2004

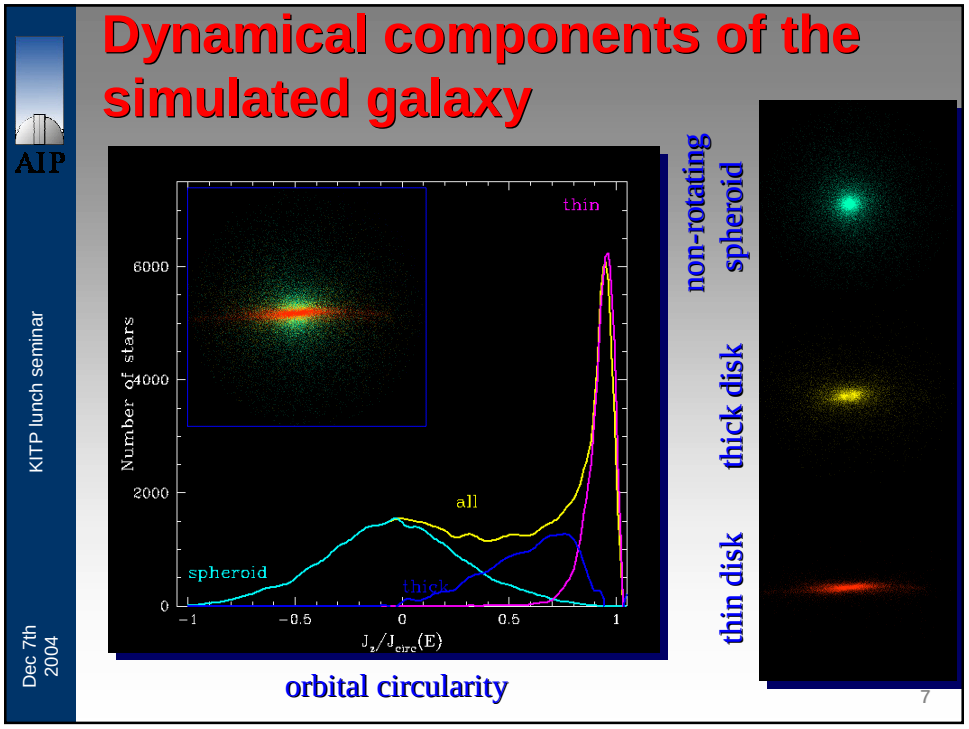
Dynamical components of the simulated galaxy

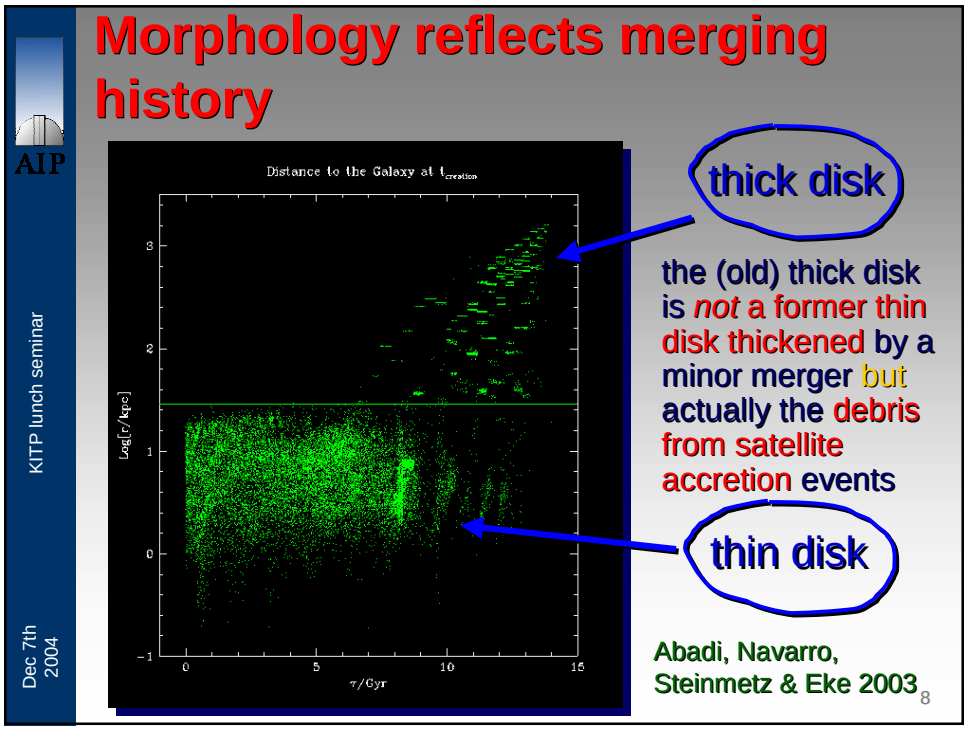


orbital circularity

Abadi, Navarro, Steinmetz & Eke 2003

6


Dynamical components of the simulated galaxy
AIP
KITP lunch seminar
Dec 7th 2004
thin
all
spheroid
thick
Number of stars
6000
4000
2000
0
−1
−0.5
0
0.5
1
$J_z/J_{circ}(E)$
orbital circularity
non-rotating spheroid
thick disk
thin disk
7


Morphology reflects merging history
AIP
KITP lunch seminar
Dec 7th 2004
Distance to the Galaxy at $t_{creation}$
Log[r/kpc]
τ/Gyr
thick disk
the (old) thick disk is *not* a former thin disk thickened by a minor merger but actually the debris from satellite accretion events
thin disk
Abadi, Navarro, Steinmetz & Eke 2003
8

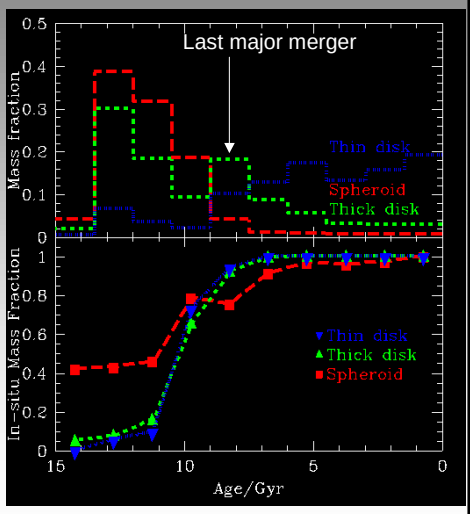
AIP

KITP lunch seminar

Dec 7th 2004

Age distribution per component (KIA3)

- Spheroid and thick disk are old
- Thin disk is young
- 15% of the stars in the thin disk predate the last major merger event.
- Most of the old disk stars are not formed in-situ, rather they are the tidal debris from disrupted satellites



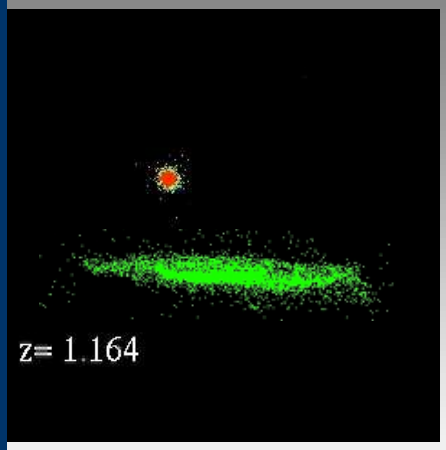
9

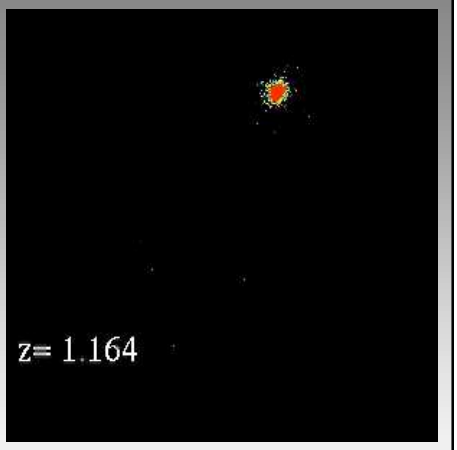
AIP

KITP lunch seminar

Dec 7th 2004

One progenitor of the old thin disk





40 kpc

thin disk
thick disk
spheroid

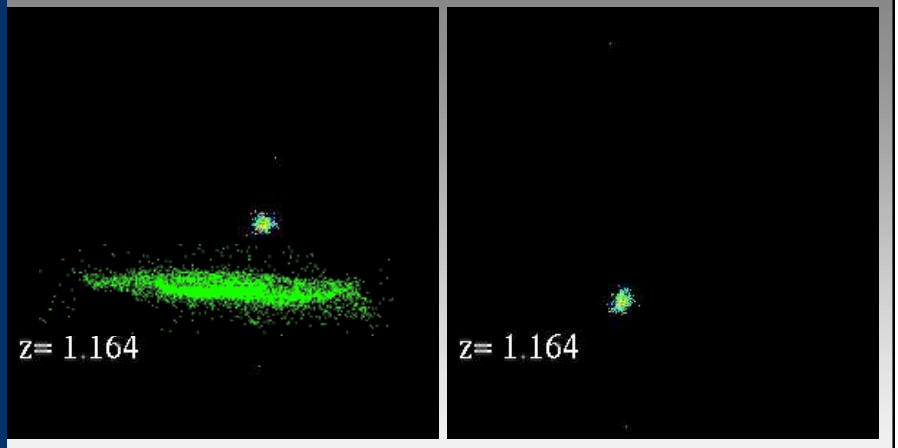
10

AIP

KITP lunch seminar

Dec 7th 2004

One progenitor of the stellar halo



40 kpc

thin disk
thick disk
spheroid

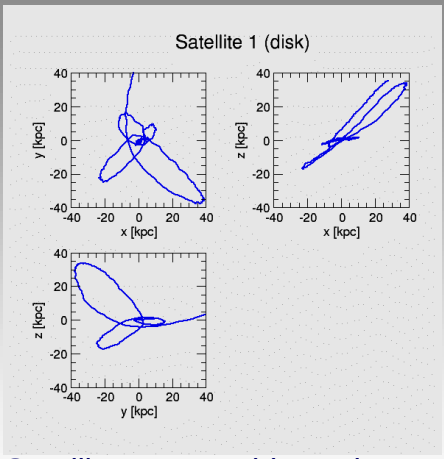
11

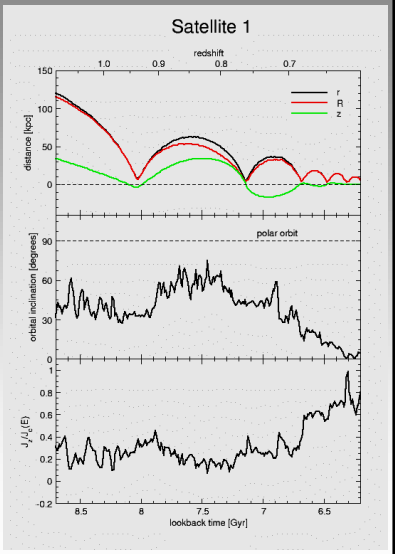
AIP

KITP lunch seminar

Dec 7th 2004

Satellite on roughly coplanar orbit





Satellites on roughly coplanar orbits are brought into the plane and circularized by dynamical friction

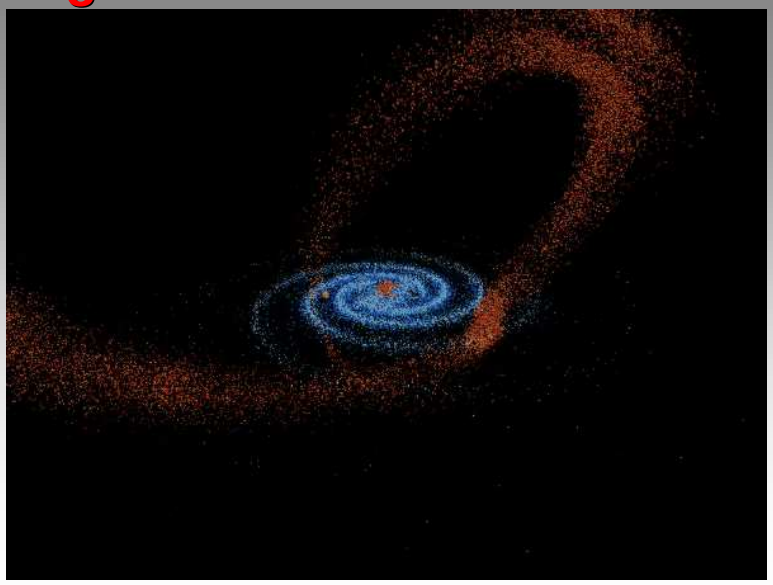
12

AIP

KITP lunch seminar

Dec 7th 2004

Sagittarius Dwarf



Majewski et al. 2003

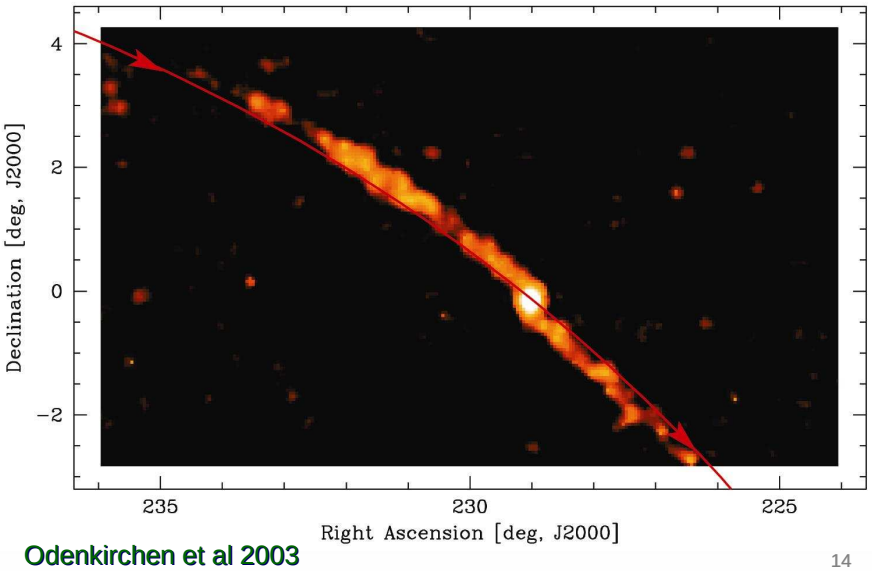
13

AIP

KITP lunch seminar

Dec 7th 2004

Pal 5



Odenkirchen et al 2003

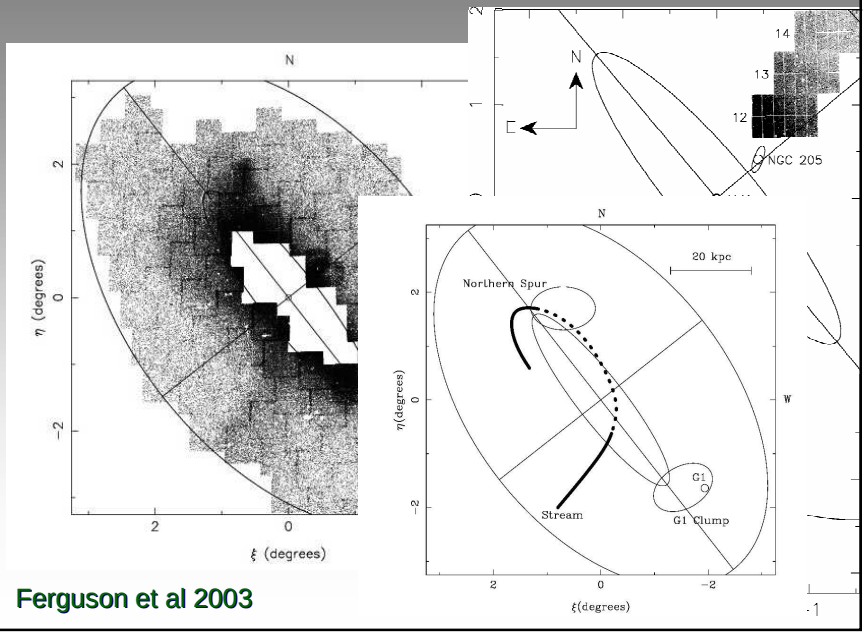
14

AIP

KITP lunch seminar

Dec 7th 2004

Tidal streams in M31



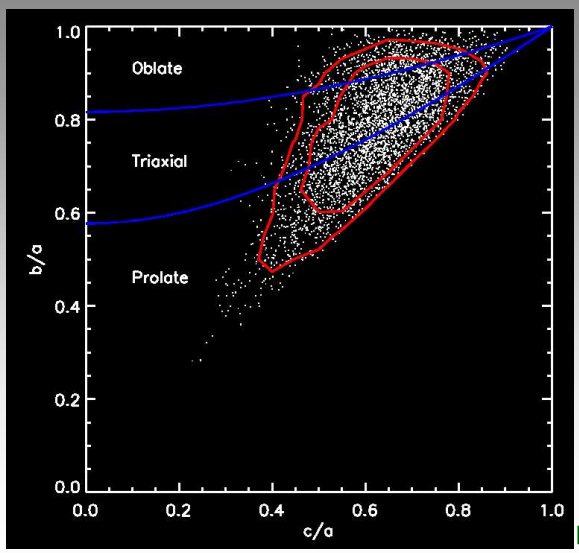
Ferguson et al 2003

AIP

KITP lunch seminar

Dec 7th 2004

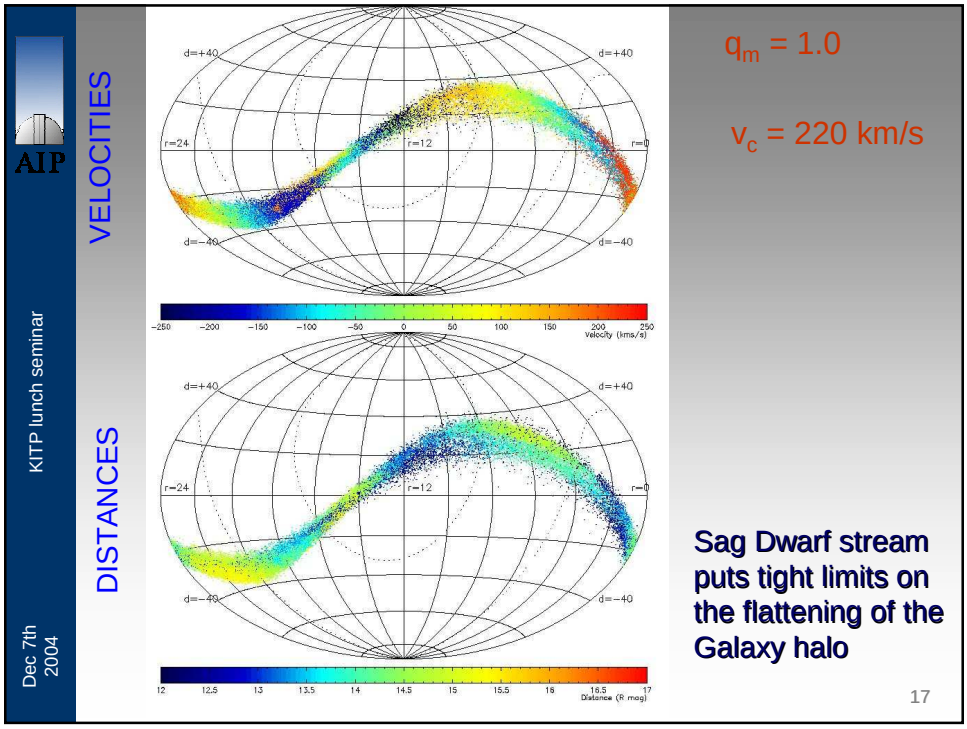
Shapes of Dark Matter Halos

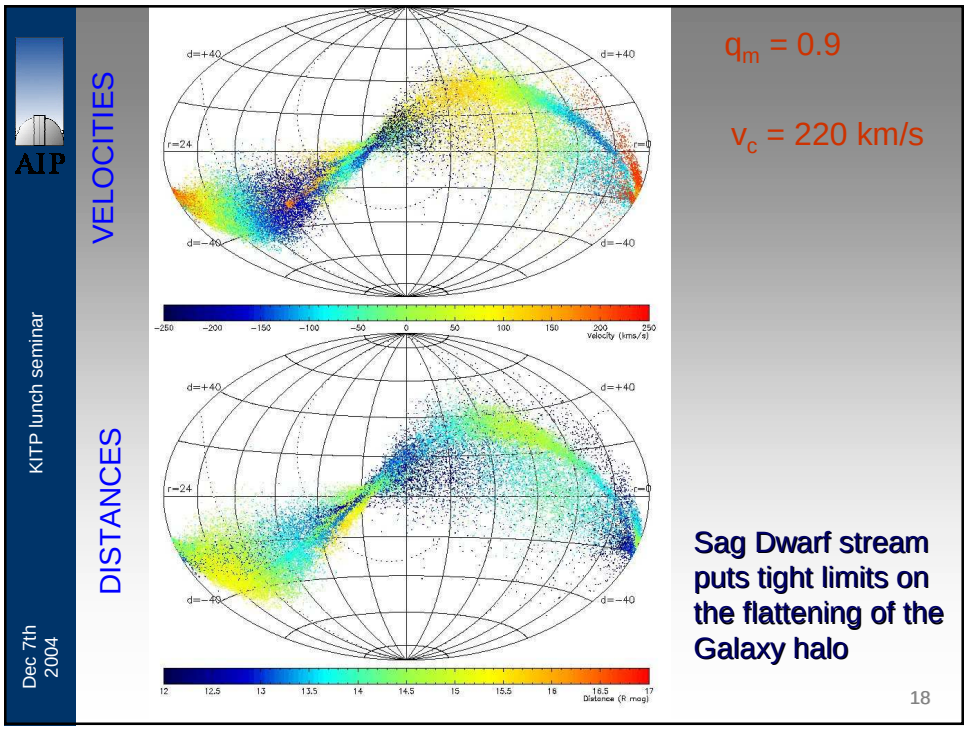


- Mostly prolate or triaxial

Bailin & Steinmetz 2004

16


AIP
KITP lunch seminar
Dec 7th 2004
VELOCITIES
DISTANCES
d=+40
d=−40
r=24
r=12
r=0
Velocity (kms/s)
Distance (R mag)
q_m = 1.0
v_c = 220 km/s
Sag Dwarf stream puts tight limits on the flattening of the Galaxy halo
17


AIP
KITP lunch seminar
Dec 7th 2004
VELOCITIES
DISTANCES
d=+40
d=−40
r=24
r=0
Velocity (kms/s)
Distance (R mag)
q_m = 0.9
v_c = 220 km/s
Sag Dwarf stream puts tight limits on the flattening of the Galaxy halo
18

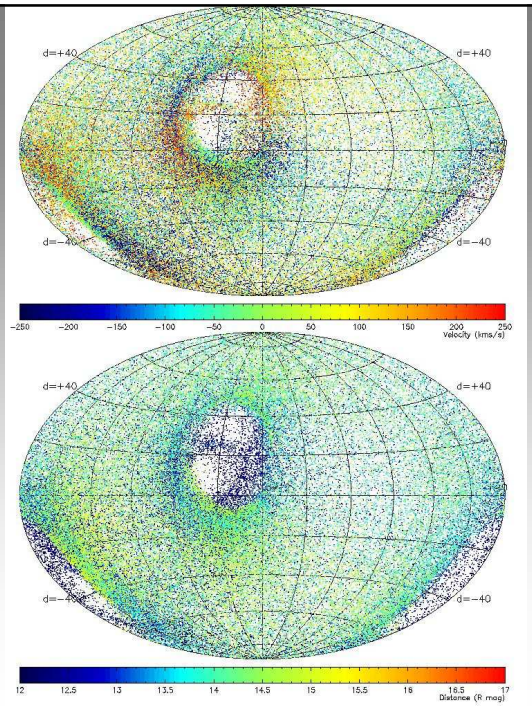
AIP

KITP lunch seminar

Dec 7th 2004

VELOCITIES

DISTANCES



$q_m = 0.7$

$v_c = 220$ km/s

Sag Dwarf stream puts tight limits on the flattening of the Galaxy halo

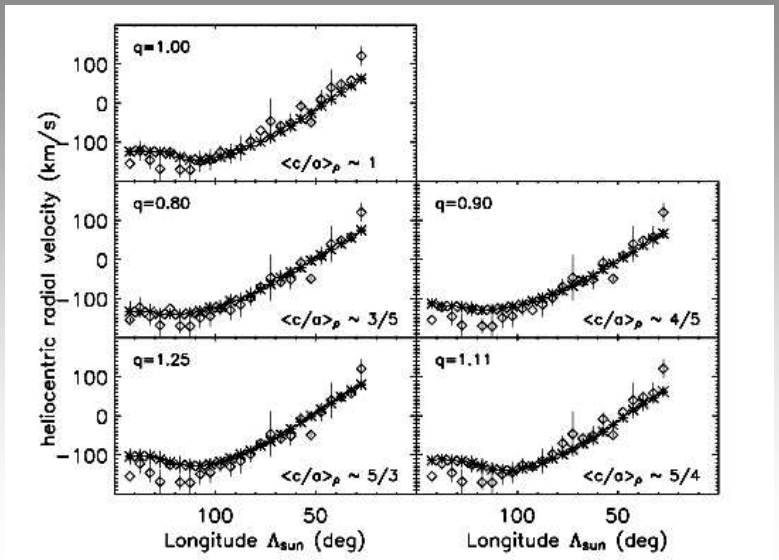
19

AIP

KITP lunch seminar

Dec 7th 2004

Stars stripped within last 2 Gyr



Helmi 2004

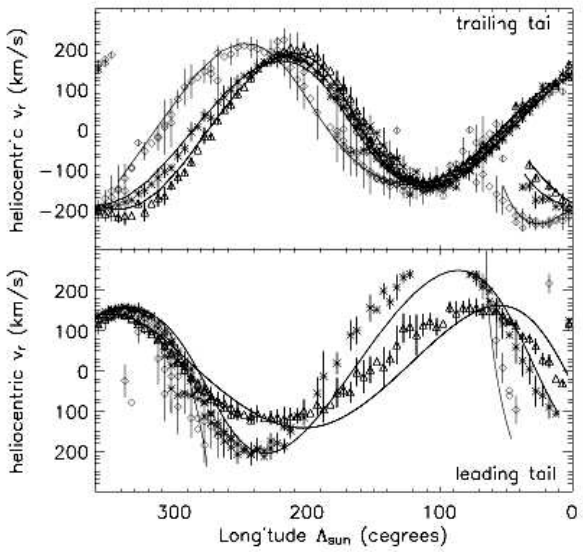
20

AIP

KITP lunch seminar

Dec 7th 2004

Stars stripped within last ~4 Gyr



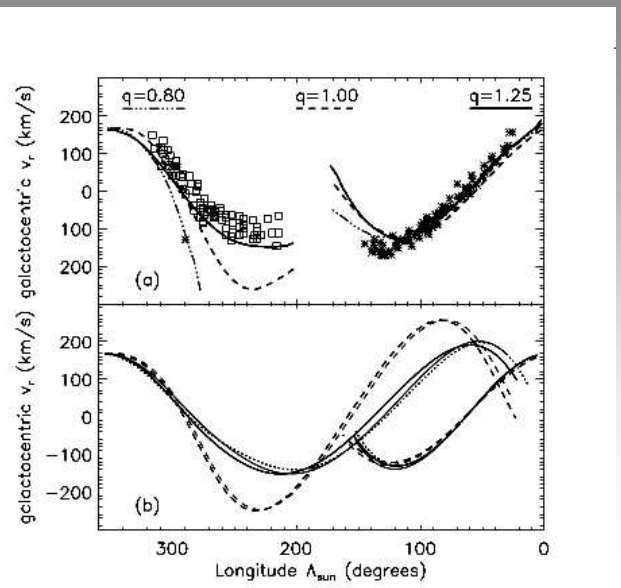
Helmi 2004 21

AIP

KITP lunch seminar

Dec 7th 2004

Stars stripped within last ~4 Gyr



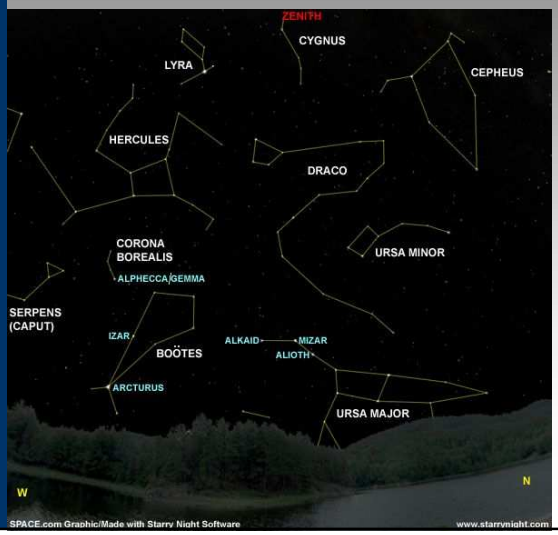
Helmi 2004 22

AIP

KITP lunch seminar

Dec 7th 2004

Are there further examples of accretion onto the Milky Way disk?



- Tidal relicts are most easily identified in samples of stars that minimize the contribution of the young thin disk:
  - metal poor stars
  - stars above or below the Galactic plane
  - stars at large Galactocentric distances

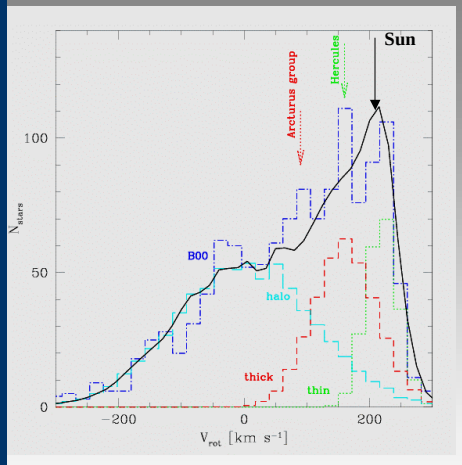
23

AIP

KITP lunch seminar

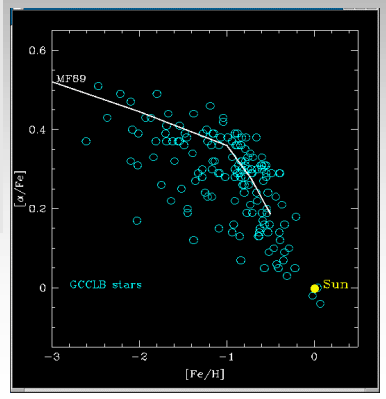
Dec 7th 2004

Metal-Poor Stars near the Sun



The rotation speed distribution of metal-poor stars and the three "canonical" components of the Milky Way

- They are less rotationally-supported than stars like the Sun
- They are enhanced in α-elements relative to the Sun.



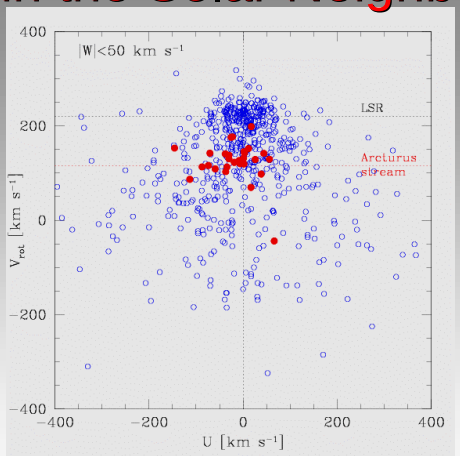
24

AIP

KITP lunch seminar

Dec 7th 2004

Dynamical Substructure in the Solar Neighborhood



Open circles: metal-poor stars of Beers et al 2000

Filled circles: Eggen's Arcturus group candidates

Arcturus

- a metal-poor, [Fe/H]~-0.6, presumably old star
- on an disk-like orbit confined to within ~ 1 kpc of the Galactic plane
- with negligible radial velocity (near apocenter)
- lagging the LSR rotation speed by ~110 km/s

Navarro, Helmi & Freeman 2003

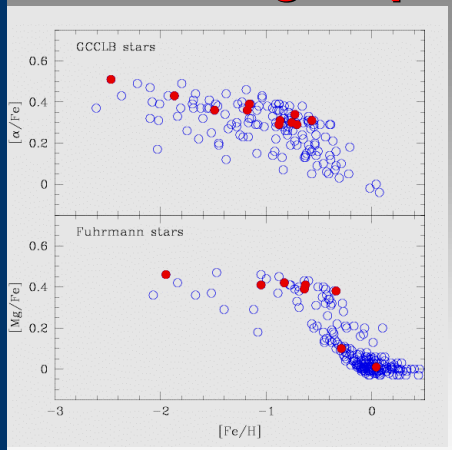
25

AIP

KITP lunch seminar

Dec 7th 2004

Chemical abundance of Arcturus group candidates



Stars in the Arcturus group are fairly metal-poor, and trace a tight relation in the [α/Fe] vs [Fe/H] plane, as expected for a population of stars that self-enriched to a metallicity of about 1/3 solar.

Open circles: Gratton et al 2003 and Fuhrmann 2003 samples

Filled circles: stars with J_z comparable to Arcturus

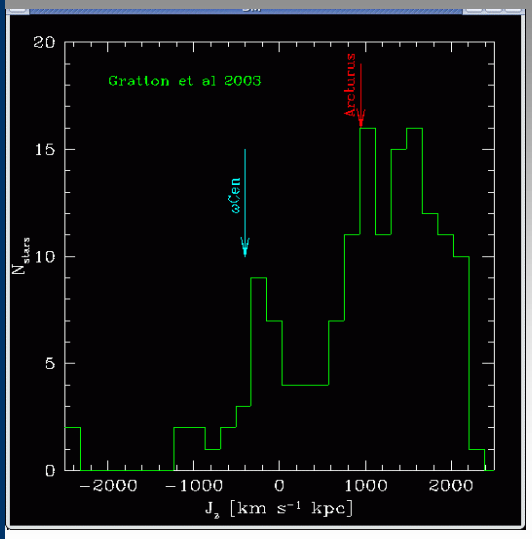
26

AIP

KITP lunch seminar

Dec 7th 2004

More Substructures in the Solar Neighbourhood?



- The Beers et al catalog shows another possible "excess" of stars at slightly retrograde, very eccentric orbits.
- This peak has been associated with the unusual globular cluster ωCen, which might have been the nucleus of a disrupted dwarf galaxy.

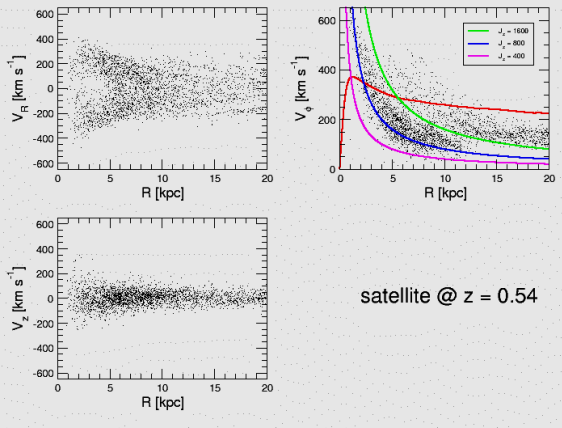
27

AIP

KITP lunch seminar

Dec 7th 2004

Dynamical properties of disk debris on eccentric orbits



satellite @ z = 0.54

The satellite stars split into groups of similar angular momentum and binding energy at each pericentric passage.

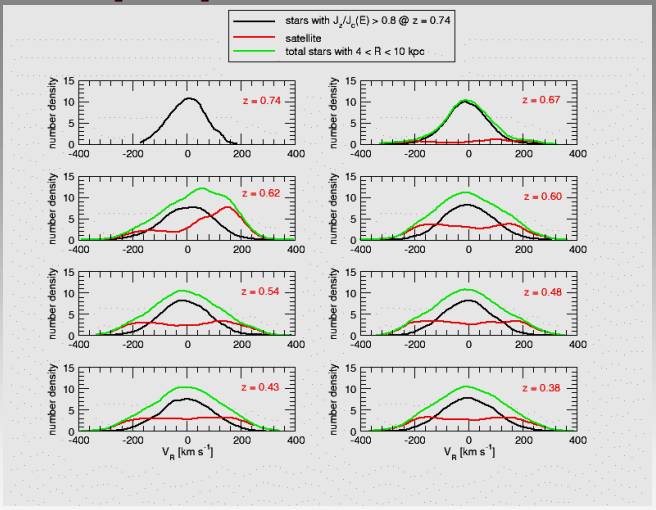
Meza, Navarro, Abadi & MS 2004 28

AIP

KITP lunch seminar

Dec 7th 2004

Dynamical properties of disk debris



- Debris stars are expected to show as a symmetric excess of stars with large galactocentric radial velocities, if observed from a radius between the apocenter and pericenter of their orbit.

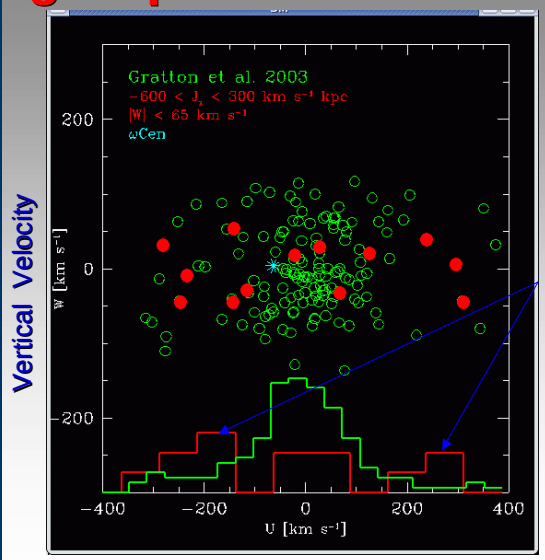
29

AIP

KITP lunch seminar

Dec 7th 2004

Dynamical properties of ωCen group candidates



Stars confined to the disk and with similar angular momentum as **ωCen** appear to have an excess of large galactocentric radial velocities.

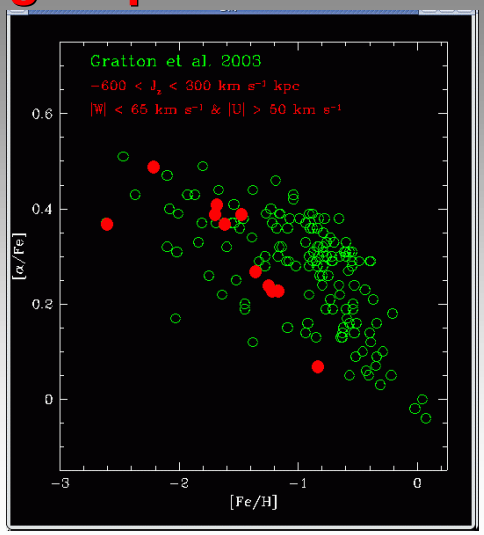
30

AIP

KITP lunch seminar

Dec 7th 2004

Chemical abundance of ωCen group candidates



Open circles: Gratton et al 2003 sample
Filled circles: stars with J_z comparable to ωCen

- Stars in the ωCen group are fairly metal-poor, and trace a tight relation in the [α/Fe] vs [Fe/H] plane, as expected for a population of stars that self-enriched to a metallicity of about 1/5 solar on a longer timescale than the Arcturus group.
- It may be that *all* metal poor disk stars have been contributed by various accretion events!

31

AIP

KITP lunch seminar

Dec 7th 2004

What do we need?

- 6-d coordinates for millions of stars
  - positions on the sky (α,δ) → catalogues
  - distances → parallaxes
    → astrometry from space (SIM, GAIA)
  - proper motions on celestial sphere
    → astrometry from space or 100yr baselines
  - radial velocities
    → spectra; fringe benefit: abundances
- How to analyze these data sets?
- What can we learn from 5-d or 4-d projections ?

32

AIP

KITP lunch seminar

Dec 7th 2004

What do we have?

33

AIP

KITP lunch seminar

Dec 7th 2004

Main Project

- 50 million stars, magnitude limited survey down to V=16 (I=15)
  - 26 million thin disk stars
  - 9 million thick disk stars
  - 2 million bulge stars
  - 1 million halo stars
  - 12 million giants out to 50kpc from the Sun
- all-sky survey
  30 min exposures ⇒ 22000 objects per night
- Ca-triplet (8400-8750Å) at R=10000
- radial velocities to 1 km/s
- [Fe/H] to 0.1 dex,[α/H] (V<15)
- Pathfinder for GAIA

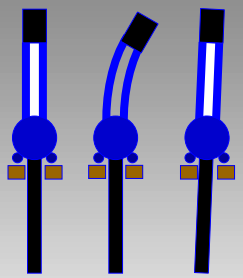
34

AIP

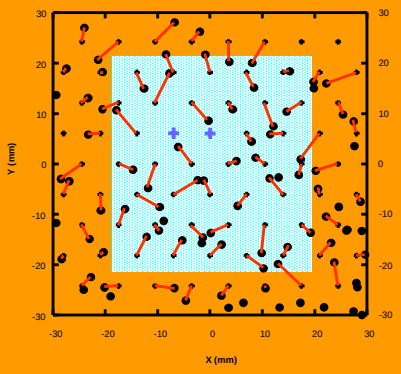
KITP lunch seminar

Dec 7th 2004

UKCHDNA



BALL SPINE PRINCIPLE



Example of fibre allocation to randomly scattered targets

- I_{AB}=15.5; R=10^4; S/N=30 in 1200s
- 5 min reconfiguration time
- 2250 spines ⇒ 25000 spectra per night

35

AIP

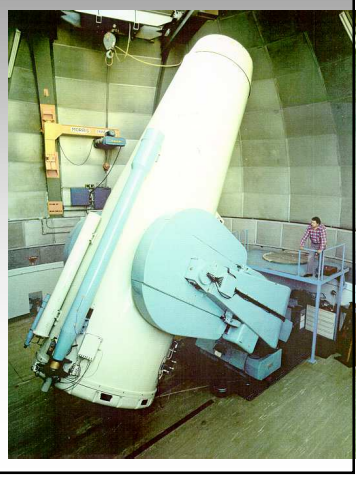
KITP lunch seminar

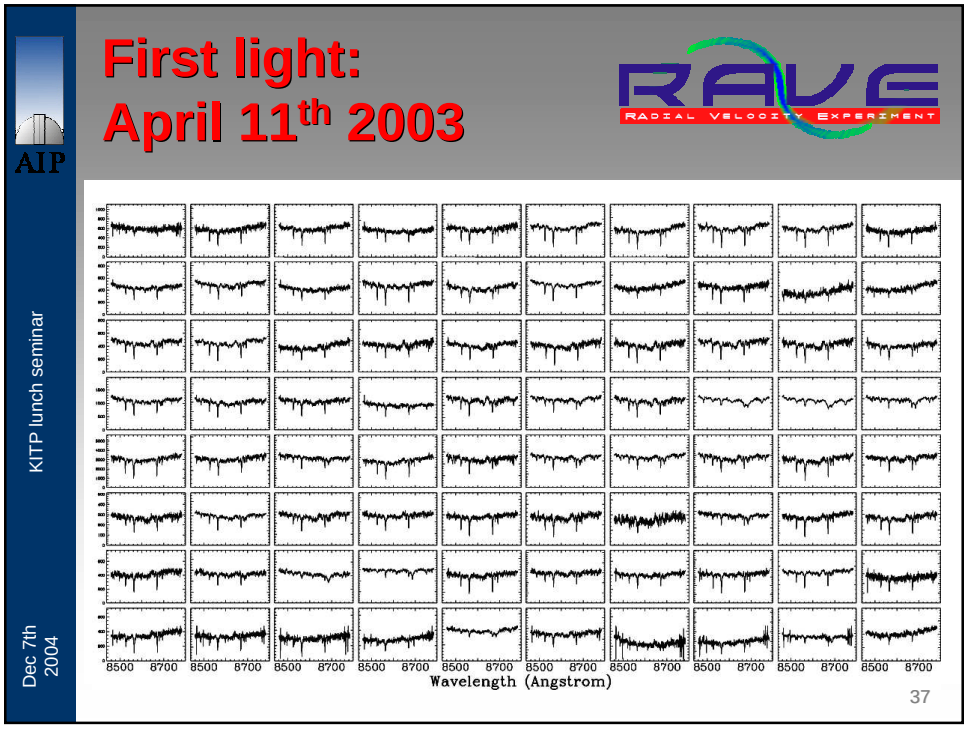
Dec 7th 2004

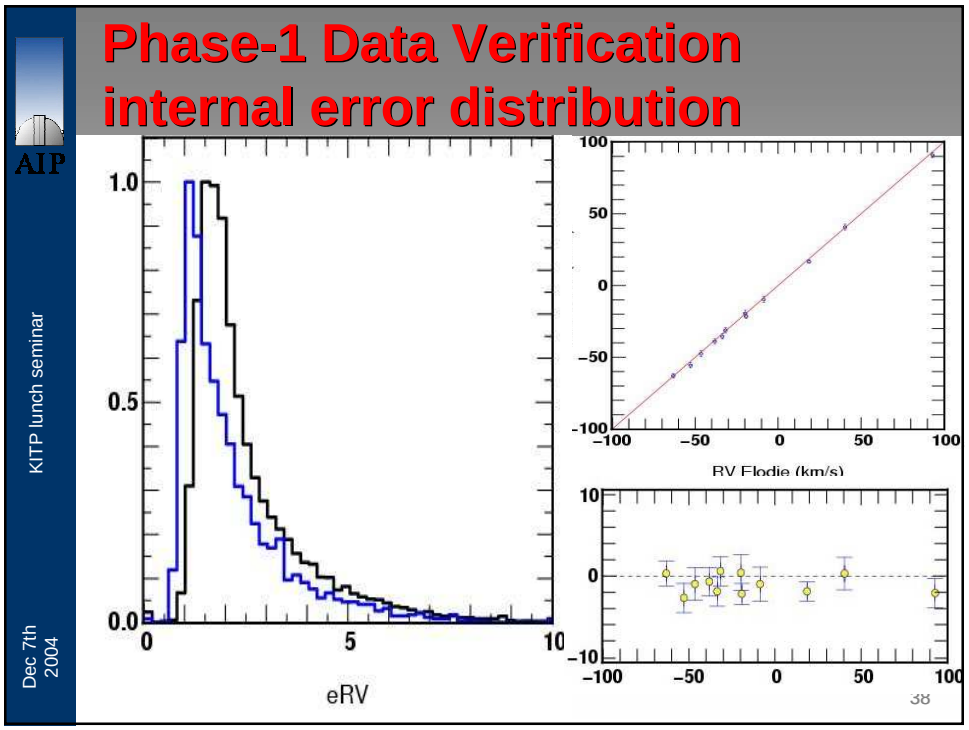
Pilot Project

RAVE Radial Velocity Experiment

- up to 279 nights of unscheduled bright-time at the 6dF (UK Schmidt) in 2003-2005
- 100 000 targeted stars 9<I<12, on the southern hemisphere
- no color selection
- ~120 fibres per field, 7" diameter
- Ca-triplet at 8400-8750Å at R=7000
- RVs to 2 km/s
- Data published via GAVO




First light:
April 11th 2003
RAVE
RADIAL VELOCITY EXPERIMENT
AIP
KITP lunch seminar
Dec 7th 2004
8500 8700 8500 8700 8500 8700 8500 8700 8500 8700 8500 8700 8500 8700 8500 8700 8500 8700 8500 8700
Wavelength (Angstrom)
37

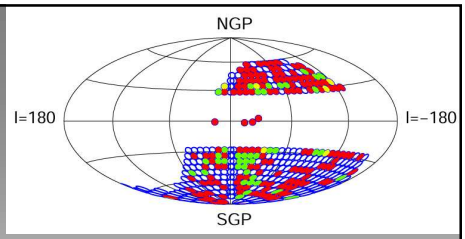

Phase-1 Data Verification
internal error distribution
AIP
KITP lunch seminar
Dec 7th 2004
1.0
0.5
0.0
0
5
10
eRV
100
50
0
−50
−100
−100 −50 0 50 100
RV Elodie (km/s)
10
0
−10
−100 −50 0 50 100
38

AIP

KITP lunch seminar

Dec 7th 2004

Current Status



- Phase I started on April 11th 2003 @ 7 nights/lunation
  - 4/11-12/31/2003 supported from AAO
  - 1/1/2004 – 6/30/2005 from several RAVE members
  - ~46000 spectra collected (as of 9/27/04)
  - expected: 70000 spectra by 6/2005
- Data analysis
  - RV pipeline finished
  - metallicity pipeline in progress
  - data verification in progress
- Data distribution
  - data base, VO interfaces in progress
  - internal data release v0.2 out
  - first public data release (2003 data) envisioned for mid 2005
  - critical path: sky subtraction/wavelength calibration

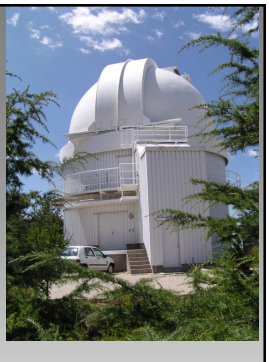
39

AIP

KITP lunch seminar

Dec 7th 2004

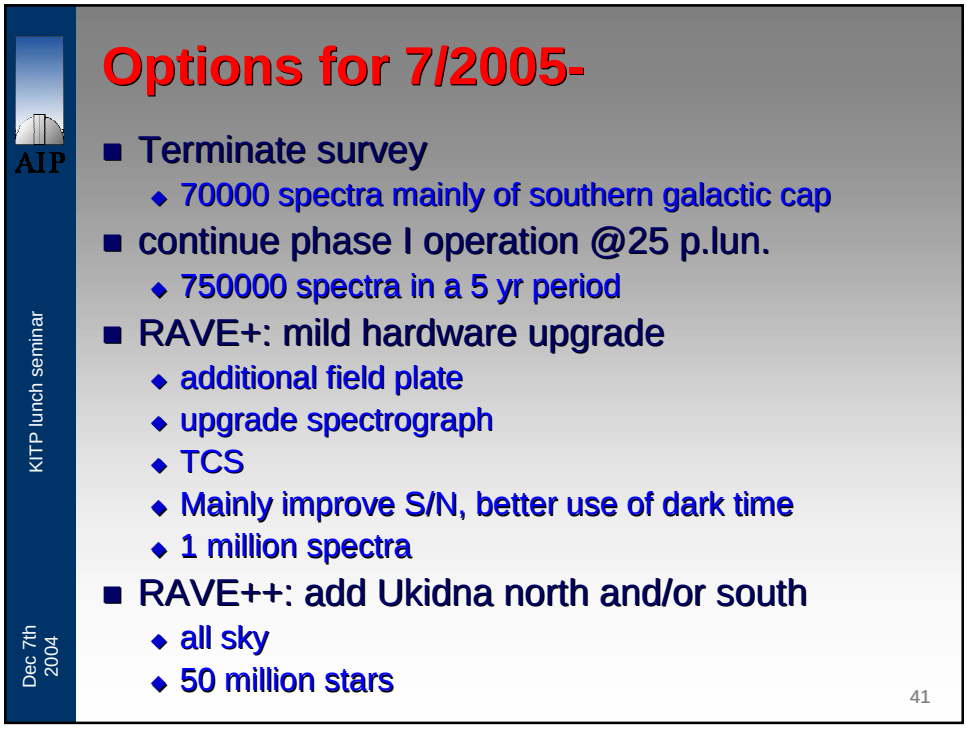
Current Status Phase II



- First steps towards phase II
  - Feasibility study Ukidna by AAO
  - Cost estimate spectrograph by AIP
  - Site visit Calar Alto (Spain) for RAVE-north
- However, funding/manpower to perform a design study Ukidna could not yet be secured
- Earliest commissioning of Ukidna: 2007

⇨ no data for at least 2 years !!!

40


AIP
KITP lunch seminar
Dec 7th 2004
Options for 7/2005-
Terminate survey
70000 spectra mainly of southern galactic cap
continue phase I operation @25 p.lun.
750000 spectra in a 5 yr period
RAVE+: mild hardware upgrade
additional field plate
upgrade spectrograph
TCS
Mainly improve S/N, better use of dark time
1 million spectra
RAVE++: add Ukidna north and/or south
all sky
50 million stars
41