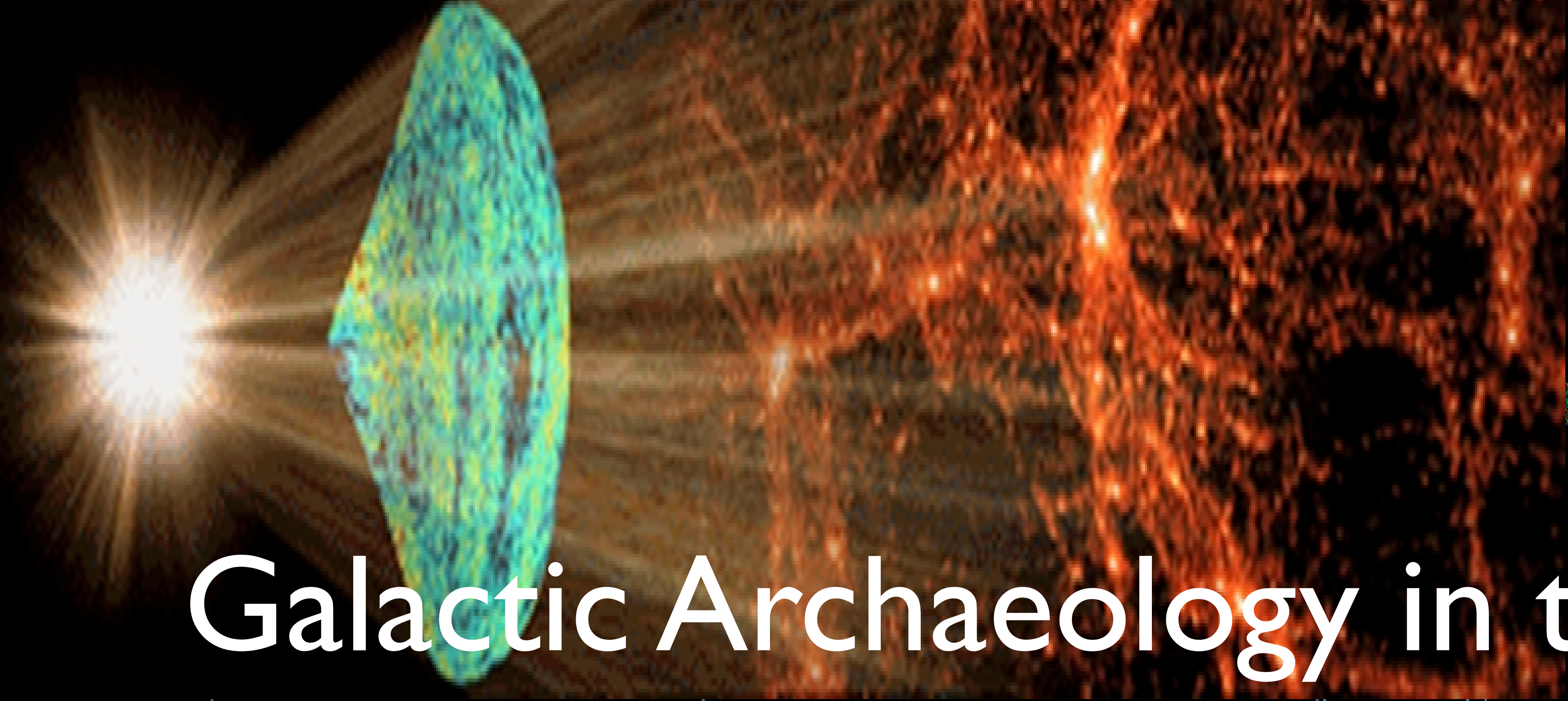
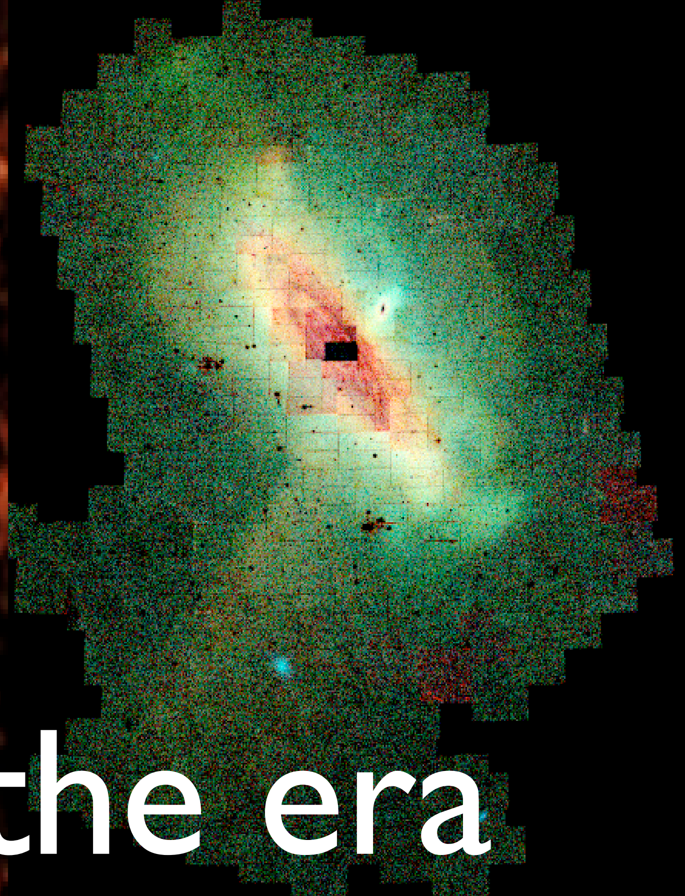
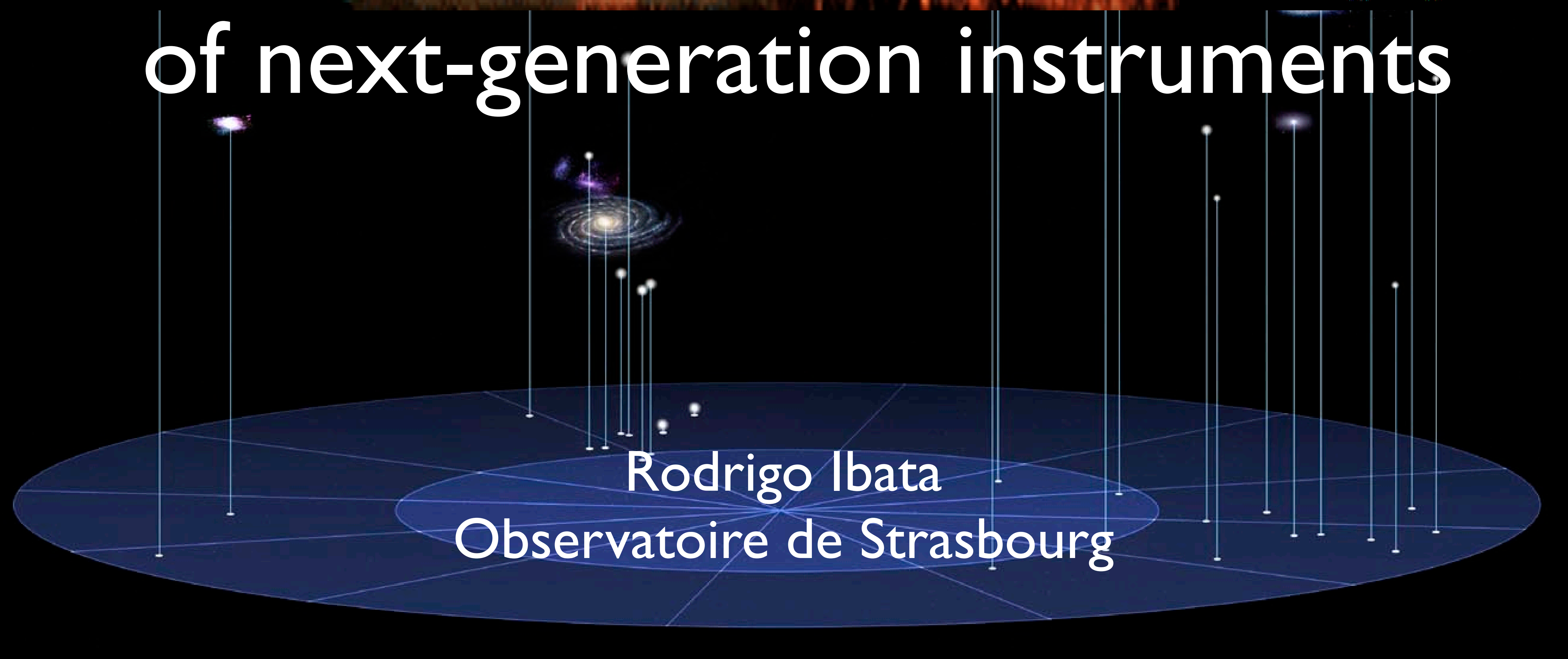
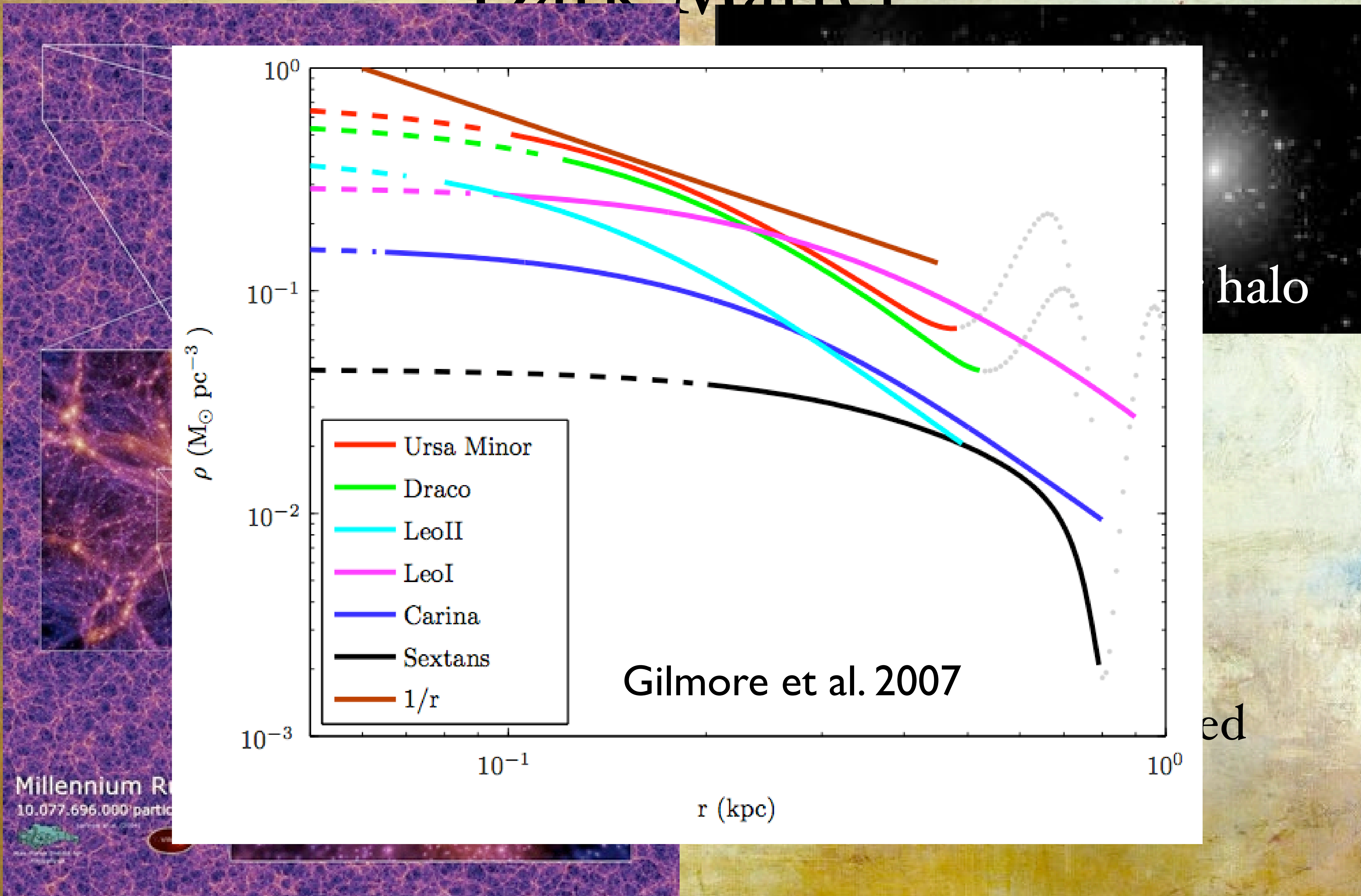



Galactic Archaeology in the era of next-generation instruments



Rodrigo Ibata
Observatoire de Strasbourg

Dark Matter:



halo

ed

Galaxy formation:
The big questions

- How did the Milky Way build up?
- How are galaxies in general built up?
- What was the role of accretion vs in-situ growth in the formation of the halo, disk, bulge?
- What was the detailed chemical enrichment history?

Formation history of the Galaxy?

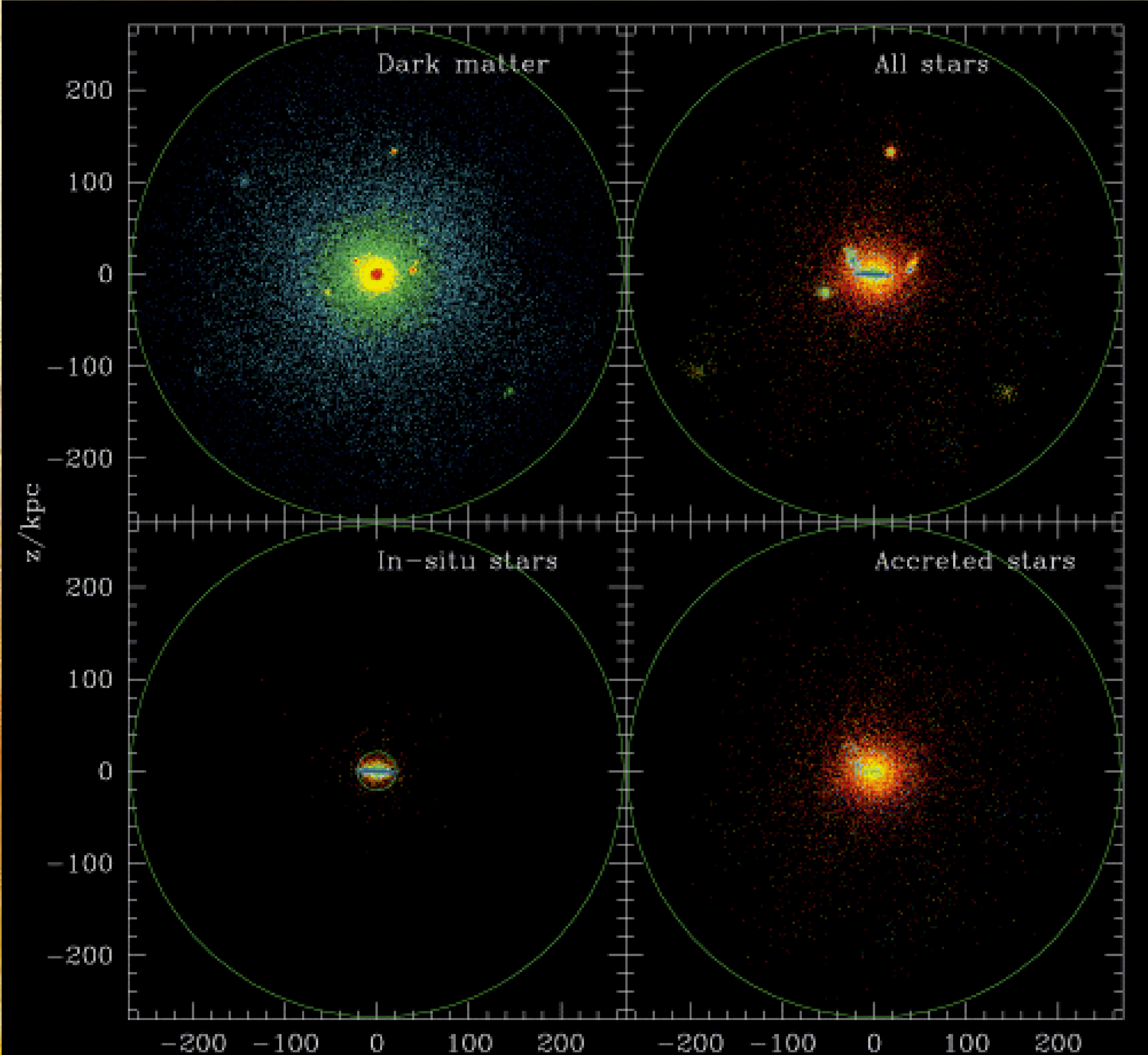
- >90% of the old thin disk (>10 Gyrs) are due to satellite accretion events
- The thin disk contains a significant number of old stars (10% are older than 10 Gyrs)
- The (old) thick disk is debris from satellite accretion events
- Only ~50% of spheroid stars are due to satellite accretions

Abadi, Navarro, Steinmetz & Eke 2003

How can we test these predictions?
Need high mass-resolution studies of galaxies:
covering disk, thick disk and spheroid....

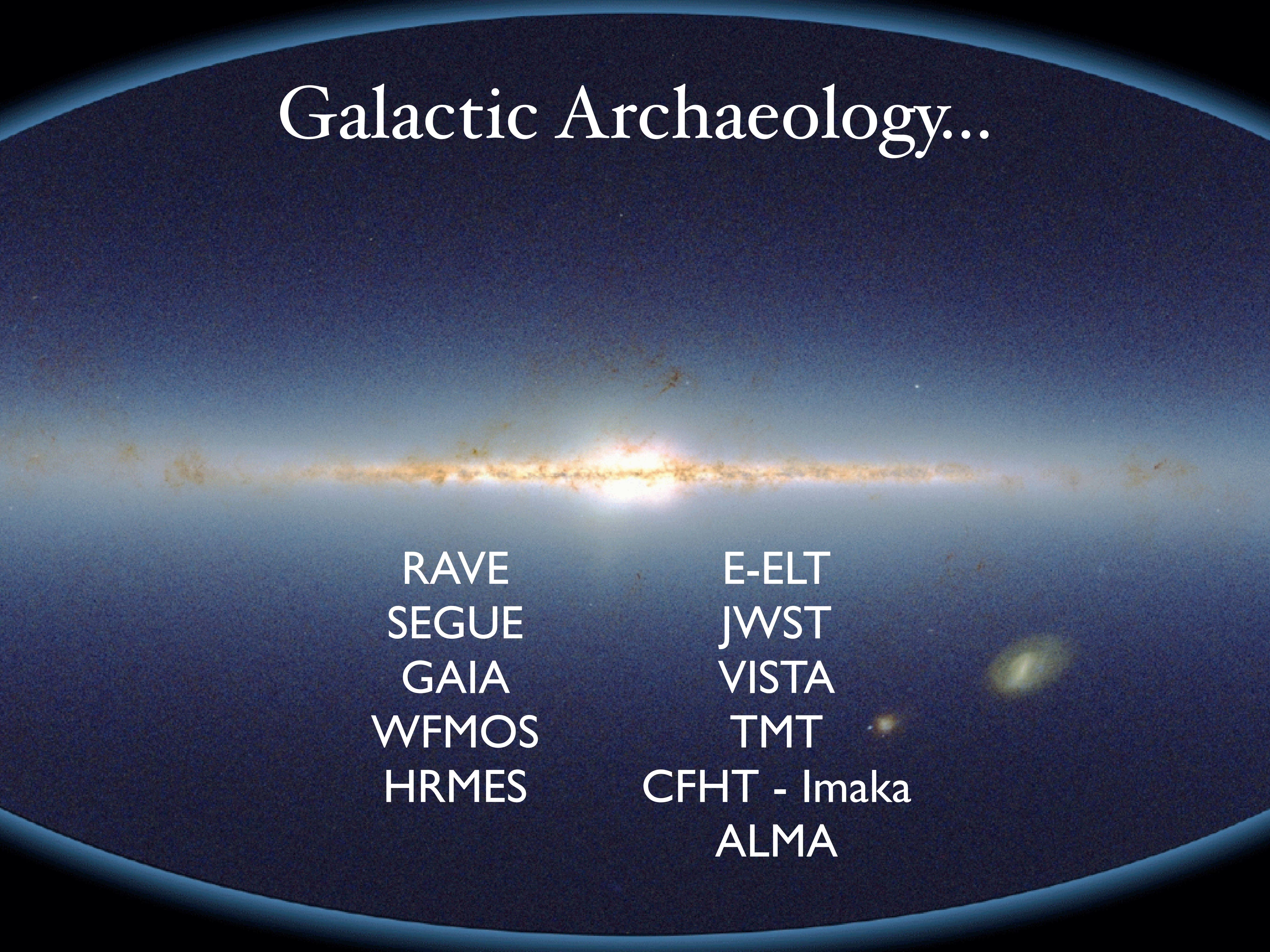
How do halos form?

- Stochastic process of complex multiple accretions for metal-rich component
- How did the metal-poor component form?
- Just beginning to be explored in detail
- Hernquist profile (slope=-4 exterior to 50kpc), h_S=15kpc



Abadi et al. 2006

Galactic Archaeology...



RAVE
SEGUE
GAIA
WFMOS
HRMES

E-ELT
JWST
VISTA
TMT
CFHT - Imaka
ALMA

The Ghosts of Galaxies Past

Strangely moving stars may be the remnants of past galaxies devoured by our Milky Way

By Rodrigo Ibata and Brad Gibson

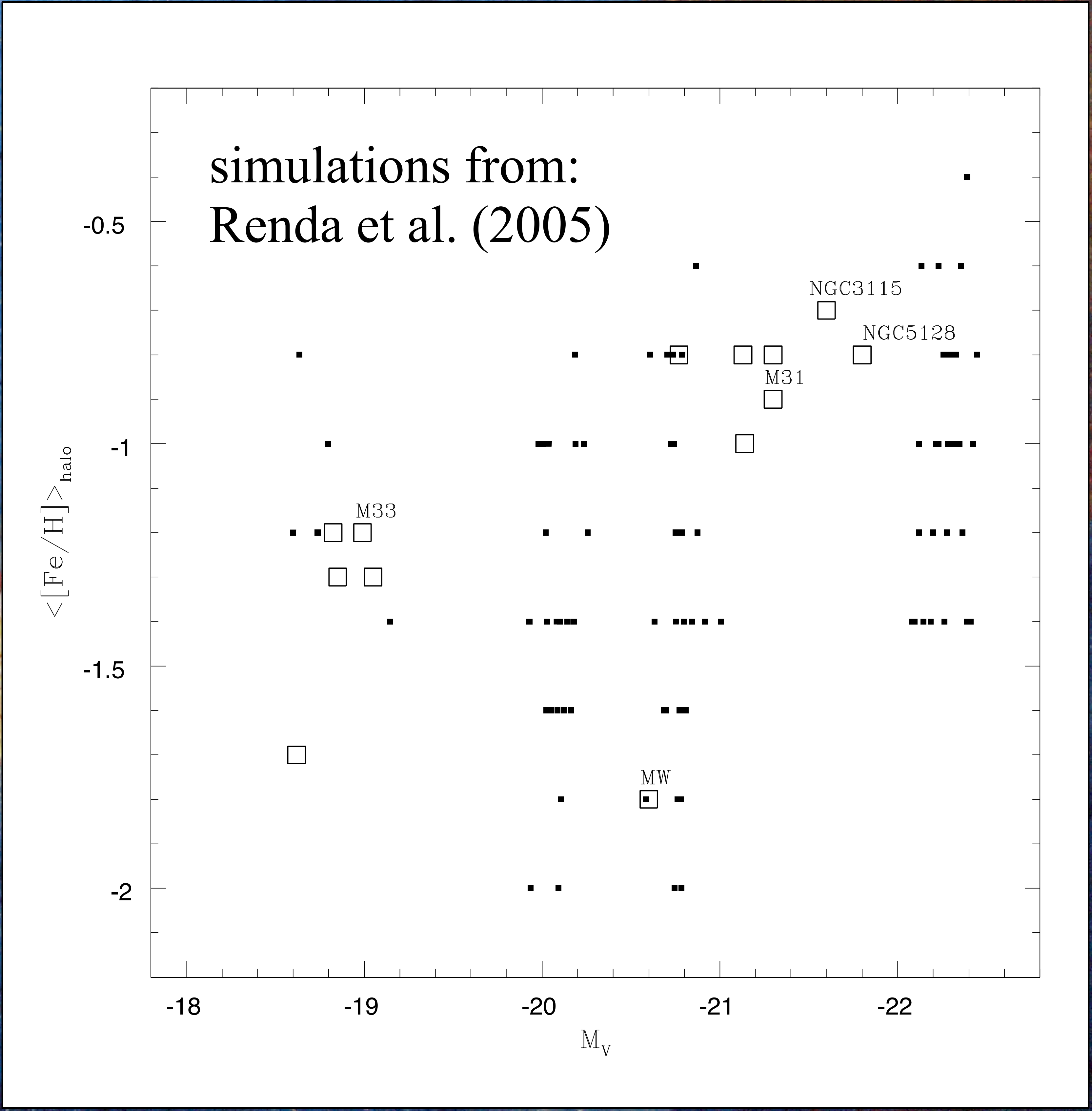
When you look up at the night sky, the stars that you see all reside in our own galaxy, the Milky Way. The nearest large galaxy to us, Andromeda, is more than two million light-years away, a distance 20 times the size of the main disk of our galaxy. With the unaided eye, you cannot make out its stars individually; they blend together into a faint fuzz. As far as our galaxy is concerned, those stars might as well inhabit a separate universe. Conversely, it is natural to think of the stars in our sky as native suns, born and bred within the confines of the Milky Way.

But then what do you make of Arcturus, the second brightest star in the northern sky? Arcturus moves in a subtly different way and has a slightly different chemical composition from that of most stars in the Milky Way; it shares its curious properties with a few other stellar mavericks scattered throughout the galaxy. The origin of these and other atypical stars has been a matter of heated debate since the 1960s. Did the gravity of our galaxy's spiral arms force them into oddball orbits, or are they immigrants, formed in regions beyond the Milky Way from material that was never part of it?

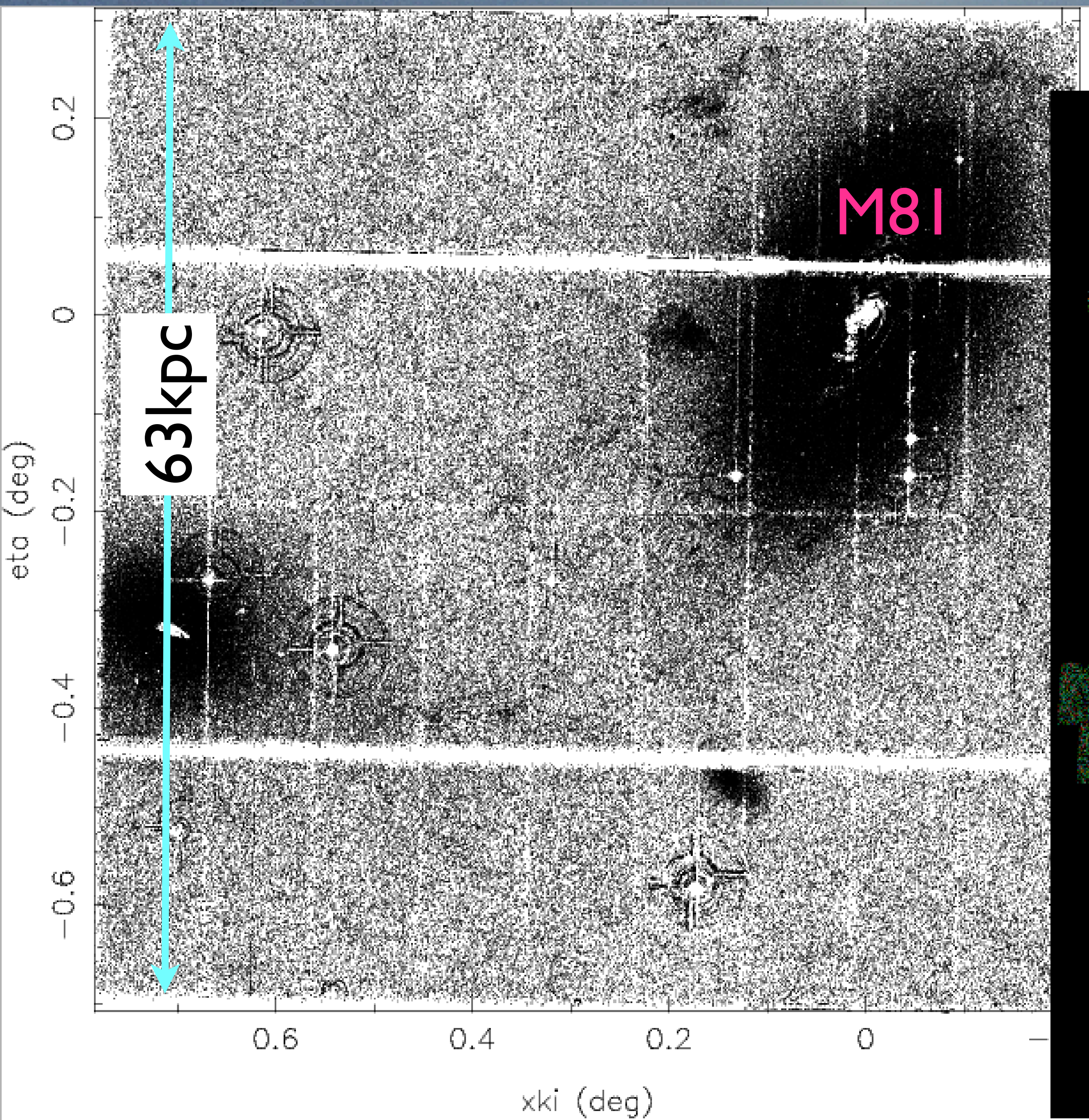
By applying sophisticated forensic techniques akin to those employed elsewhere in the sciences, astronomers have discovered in recent years that the answer is yes. Some galactic natives were indeed born in or pushed into peculiar orbits, but a surprisingly large number of the anomalies, including Arcturus, are genuine immigrants. A better metaphor than "immigrants" might be "kidnap victims" or "subject peoples," because astronomers think these stars were born into smaller galaxies that the Milky Way then captured, plundered and assimilated. Over time our galaxy may have vanquished hundreds of its neighbors. Their former inhabitants now intermingle with the Milky Way's na-

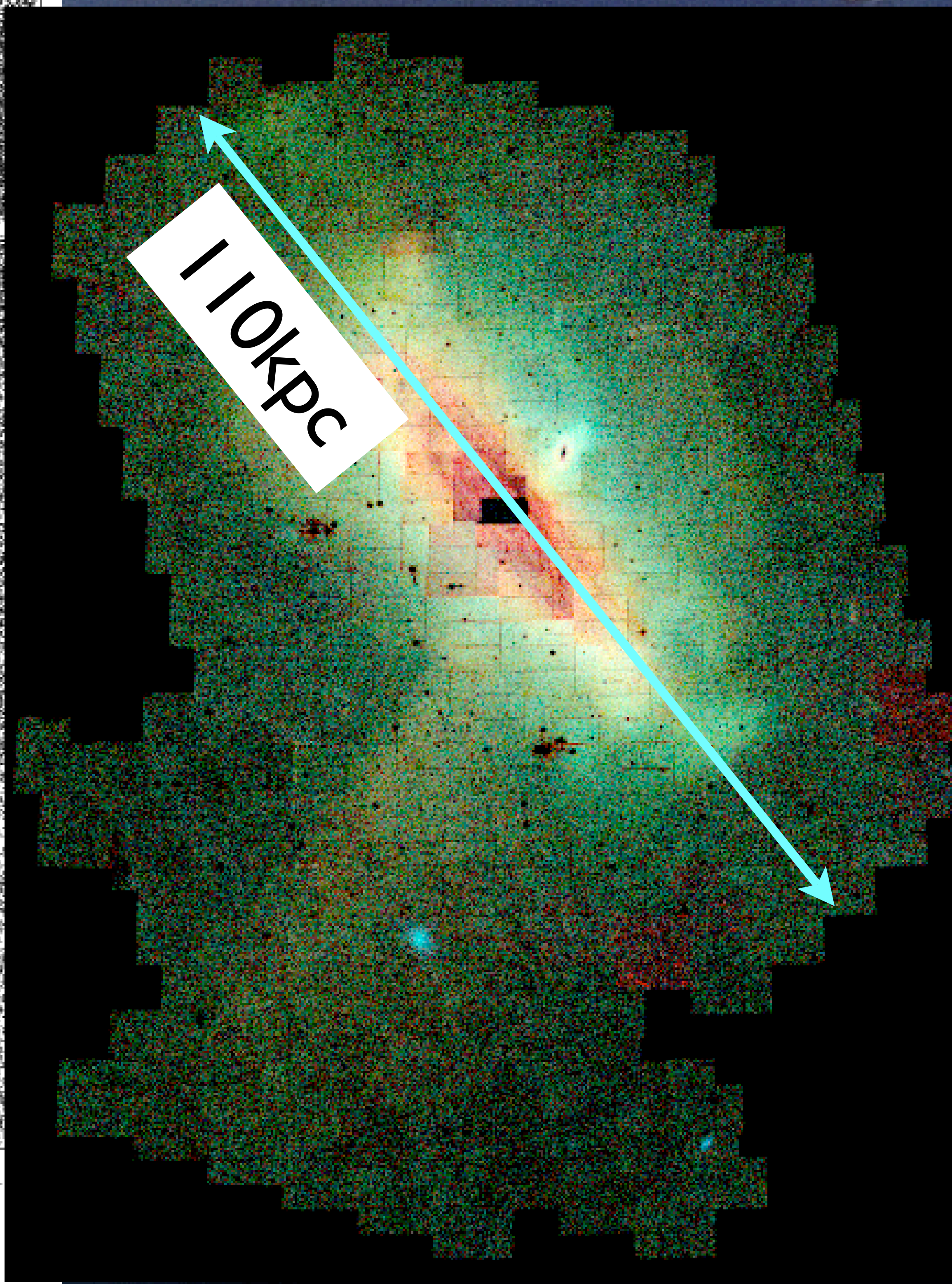
THEY GAVE THEIR LIVES TO BUILD THE M
galaxies have been ripped apart by ou
streams of stars that slowly mix into t
population. As we speak, the Milky Wa
dwarf galaxy, creating a stream (the w
completely surrounds the central disk

Stochastic nature of formation



Evolutionary sequence?





Future instruments and missions

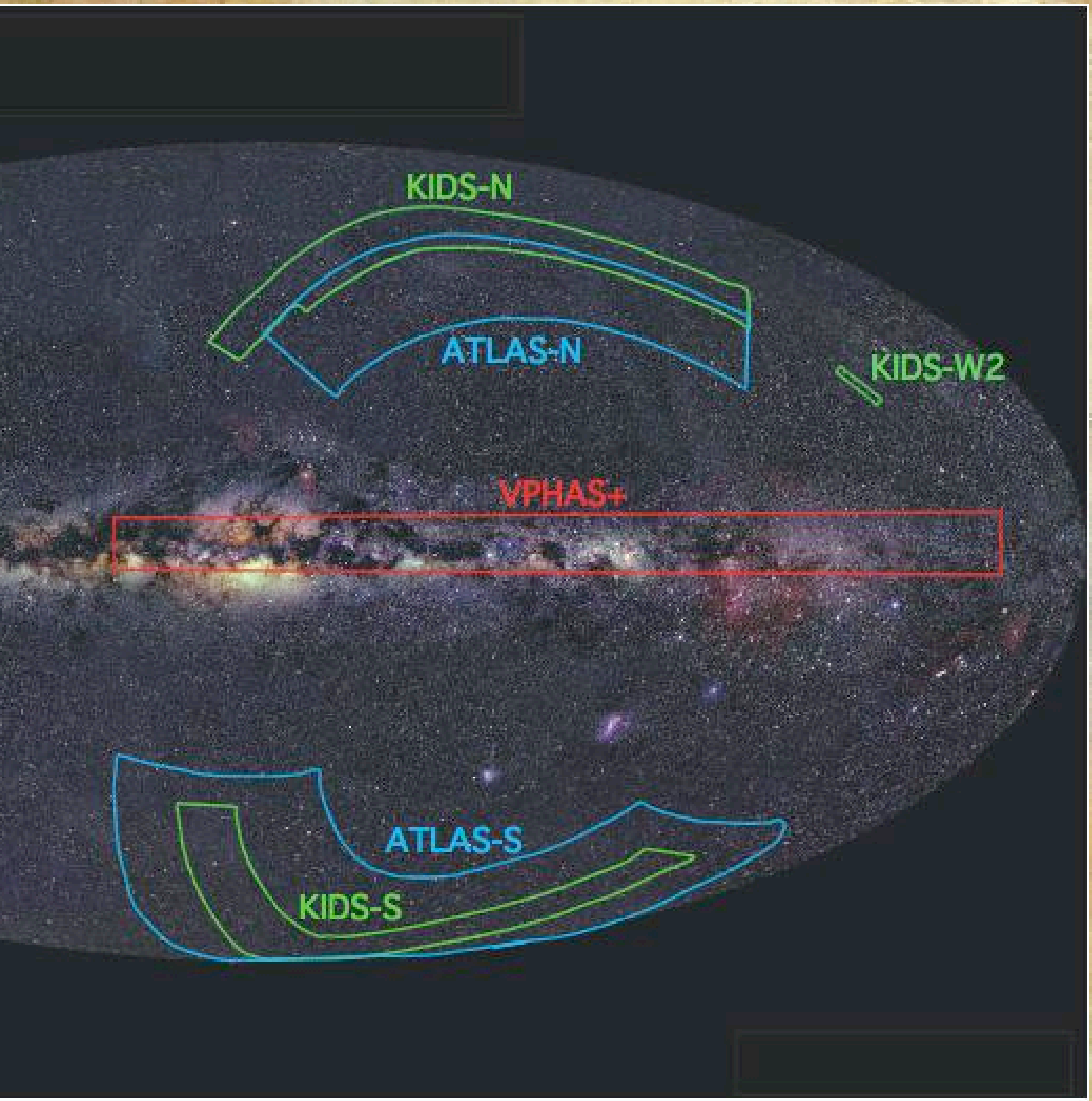
What are we trying to accomplish?

- We aim to identify the stars that formed in separate proto-galaxies, and determine when they were formed and when they were incorporated. This seems straightforward, but we need to measure positions, distances and 3-D velocities for vast numbers of stars.
- With the stars formed in-situ, e.g. in the disk, we aim to identify groups of common origin, formed out of separate star-forming regions. Since much of the dynamical information is lost, due to scattering, the way forward appears to be through chemical “fingerprinting” of stars.

Some upcoming instruments...

- Wide-field photometry
  - PanSTARRS, VISTA, VST, CFHT-Imaka, HyperSuprimeCam, LSST
- Deep photometry
  - JWST, E-ELT, CFHT NG-AO
- Wide-field astrometry
  - GAIA, LSST
- Deep astrometry
  - SIM, JWST, E-ELT
- High multiplexing spectroscopy
  - WFMOS, HRMES, APOGEE
- Deep spectroscopy
  - E-ELT, TMT

VLT Survey Telescope (VST)

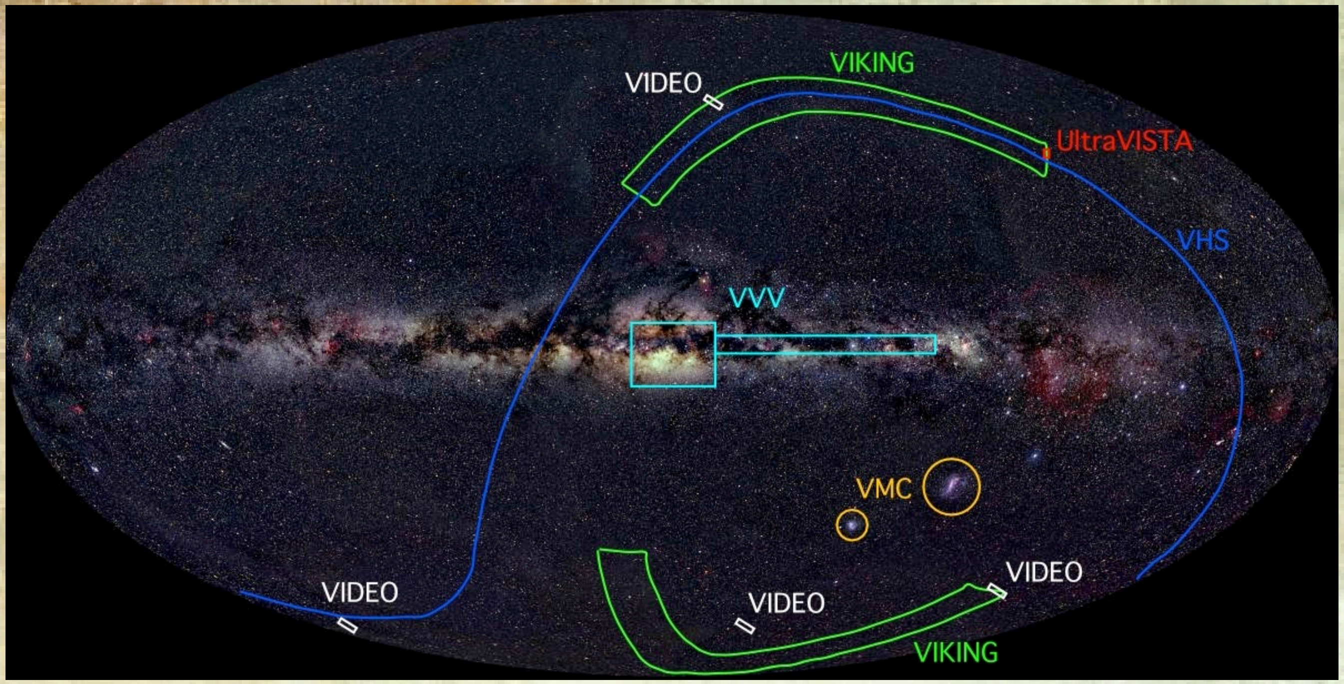


Survey	Area (deg^2)	Filters and Depth (mag (10σ, AB)
KIDS	1500	u'=24.8 g'=25.4 r'=25.2 i'=24.2
ATLAS	4500	u'=22.0 g'=22.2 r'=22.2 i'=21.3 z'=20.5
VPHAS+	1800	u'=21.8 g'=22.5 Hα=21.6 r'=22.5 i'=21.8

+ Dark Energy Survey (5000 deg^2)

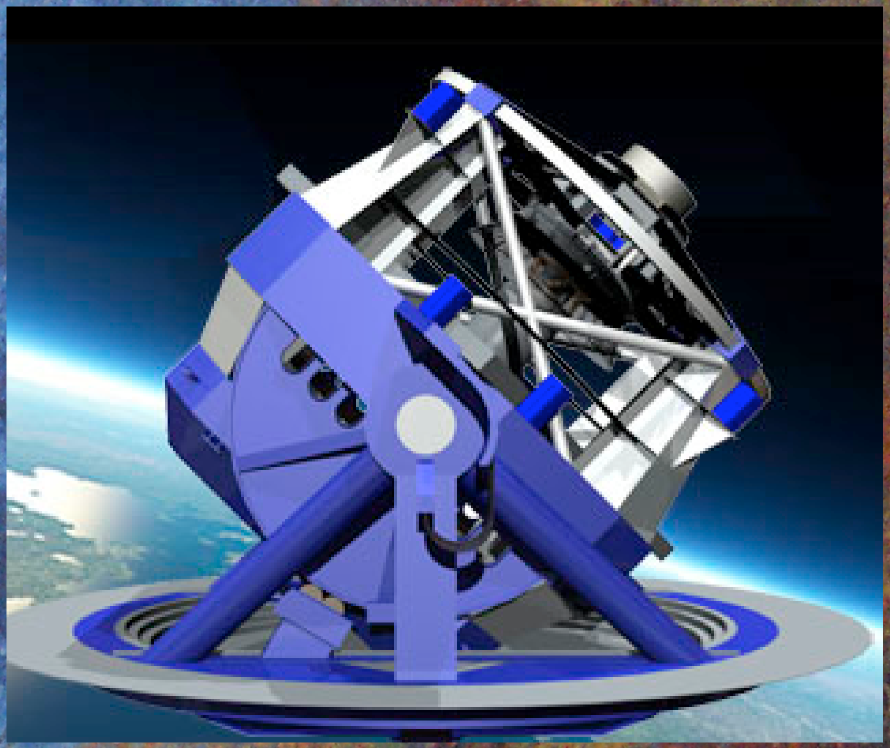
VISTA

(first light 2008)



Survey	Area (deg^2)	S/N depth	depth
Ultra-VISTA	0.73	5,AB	Y=26.7 J=26.6 H=26.1 K_s=25.6 NB=24.1
VIKING	1500	5,AB	Z=23.1 Y=22.3 J=22.1 H=21.5 K_s=21.2
VMC	184	10,Vega	Y=21.9 J=21.4 Ks=20.3
VVV	520	5,Vega	Z=21.9 Y=21.2 J=20.2 H=18.2 K_s=18.1
VHS	20000	5,AB	Y=21.2 Y=21.2 J=21.2 H=20.6 Ks=20.0
VIDEO	15	5,AB	Z=25.7 Y=24.6 J=24.5 H=24.0 K_s=23.5

LSST



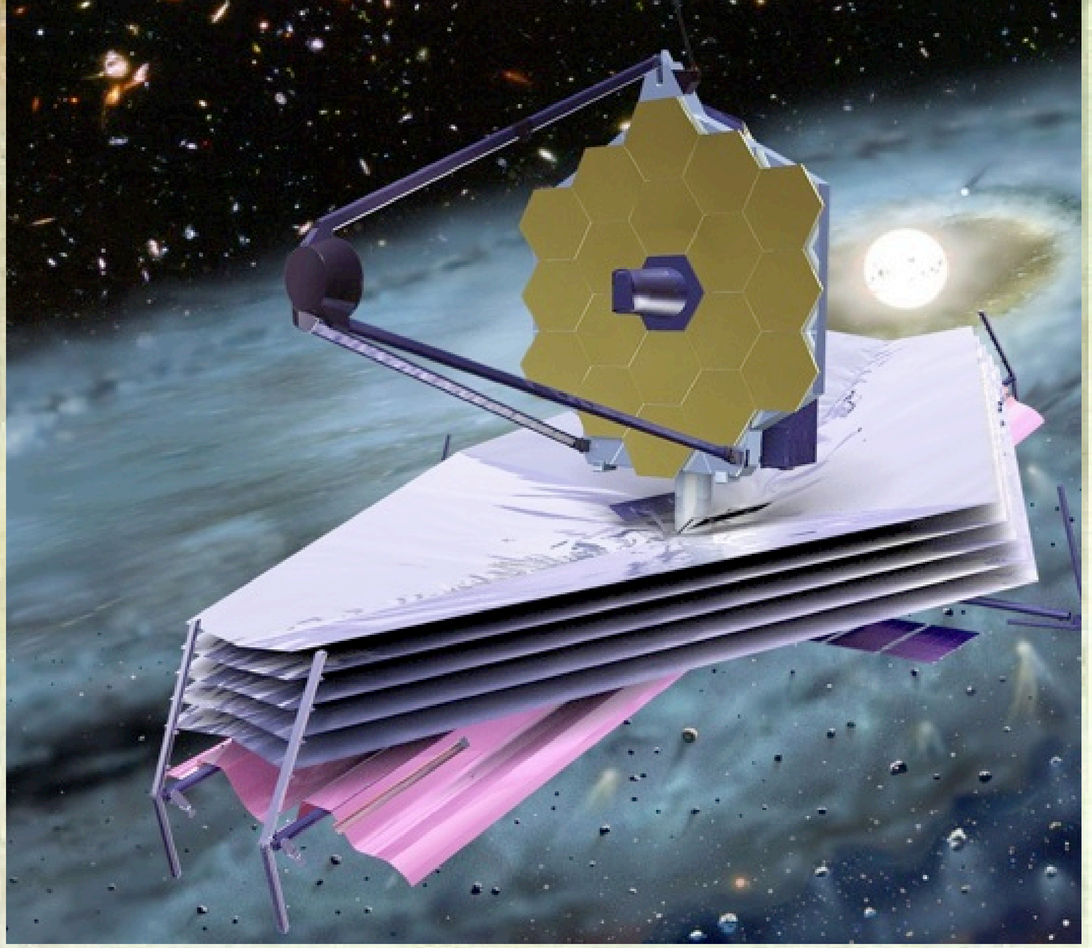
- first light in 2014?
- 20000 sq deg every 3 nights!
- u,g,r,i,z,Y
- g~24 in 15 sec; g~28 co-added
- 3D structure of Local Group from RRLyrae variables
- Microlensing searches throughout LG - mass distribution of compact objects
- Great for proper motions of faint, nearby objects
- Eventually deep stellar populations studies out to ~15Mpc

c.f. PanSTARRS

- launch 2011
- ~1 billion stars surveyed to V~20
- astrometric accuracy: 15μas at V=15
- velocities for 10^8 stars (2-10km/s) to V=17
- ~10% accuracy parallaxes to 10kpc

- launch in 2015+
- astrometric accuracy: 1μas (=0.7mm on Moon!!!)
- global accuracy limit: 4μas
- Sgr stream prime target

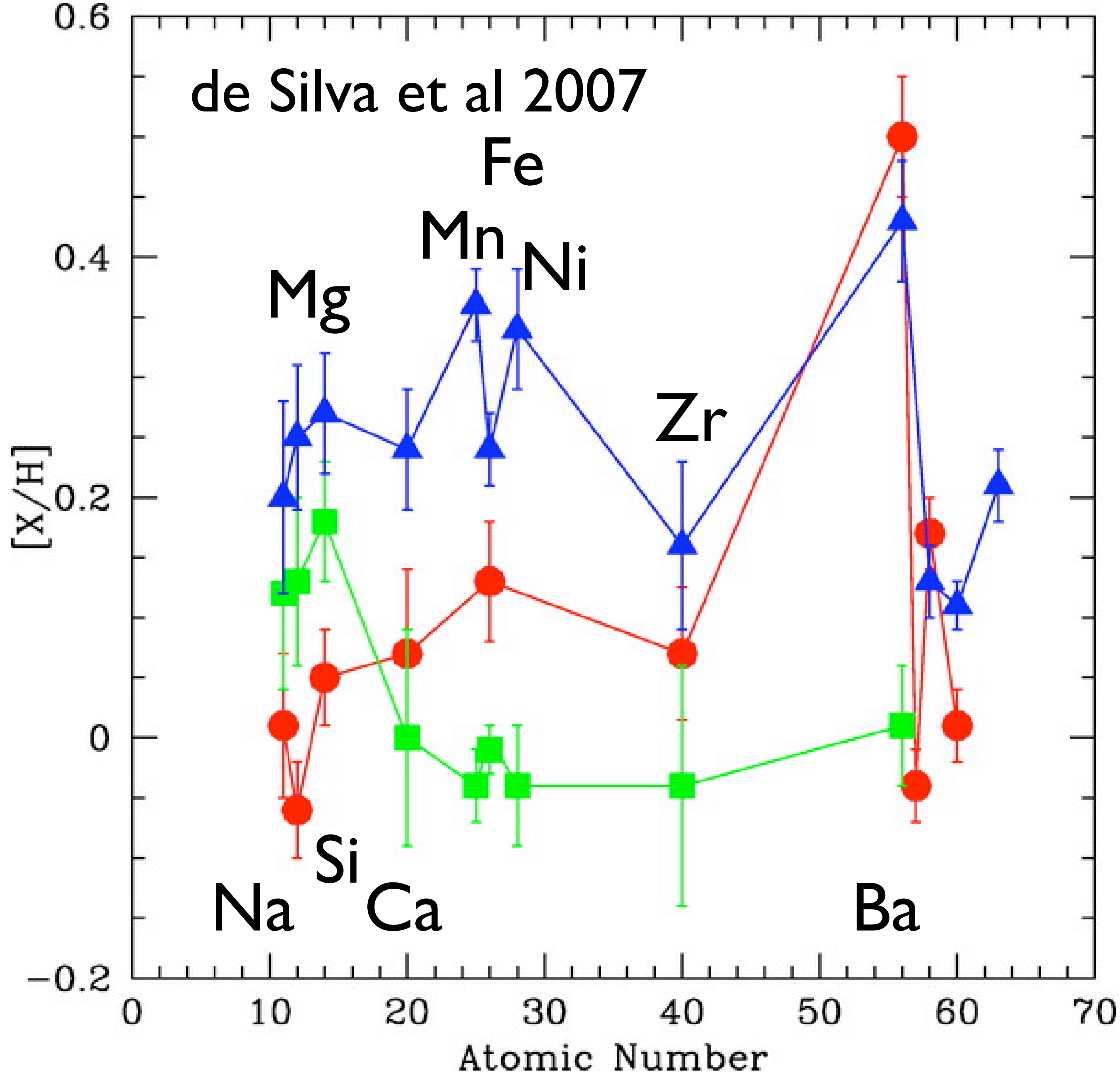
JWST

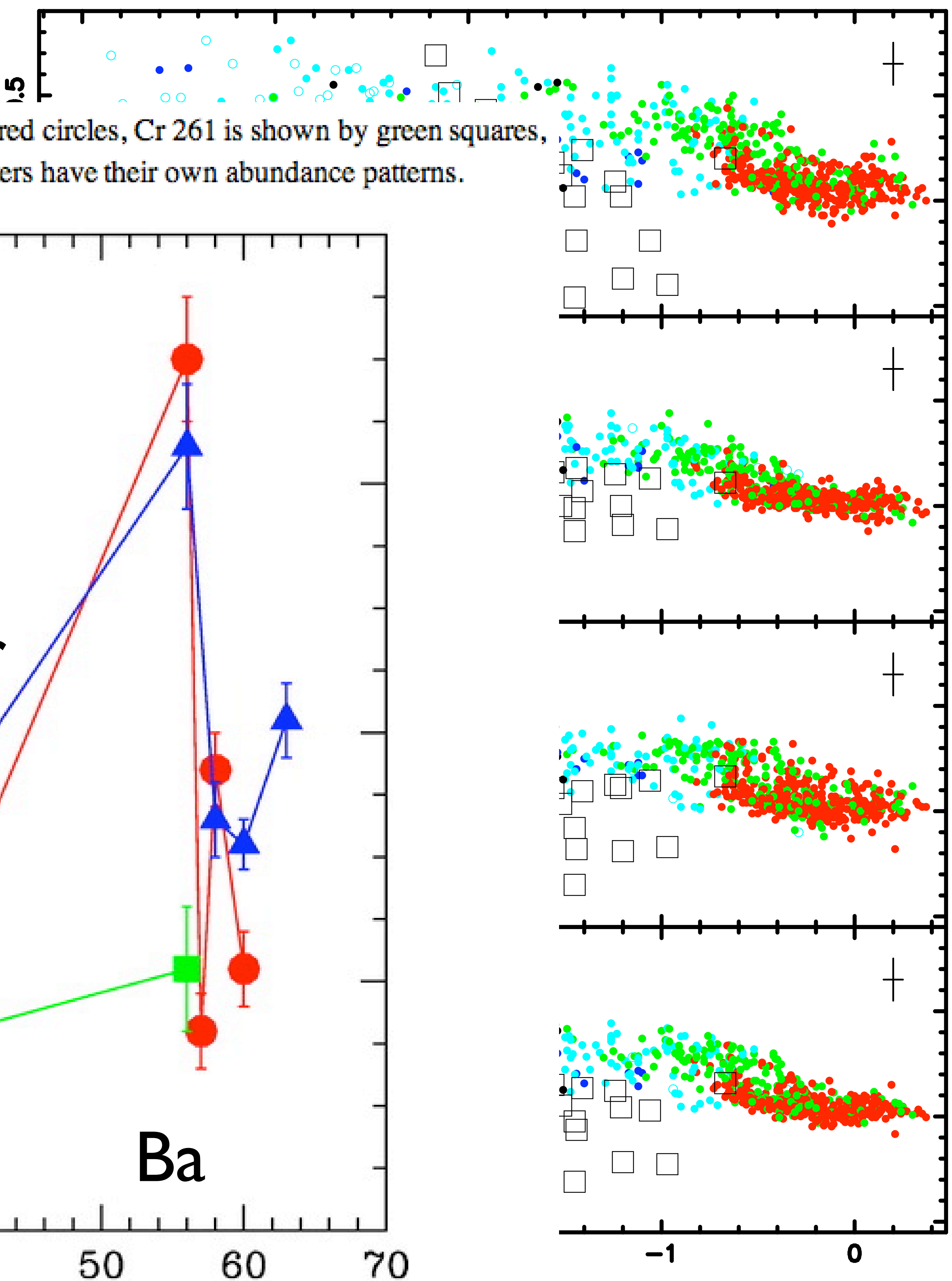


- 6.5m aperture
- 2x 2.2’ x 2.2’ field
- With WFPC2, Anderson & King 2002 have shown 0.002pix limiting systematic error in centroiding.
- JWST: pixel scale 32mas... so may be able to go arbitrarily deep with ~10μas/yr in 10yrs baseline
- Wonderful synergy with GAIA/SIM
  - Using GAIA/SIM reference frame can probe very much deeper, allowing proper motion survey of distant Local Group members

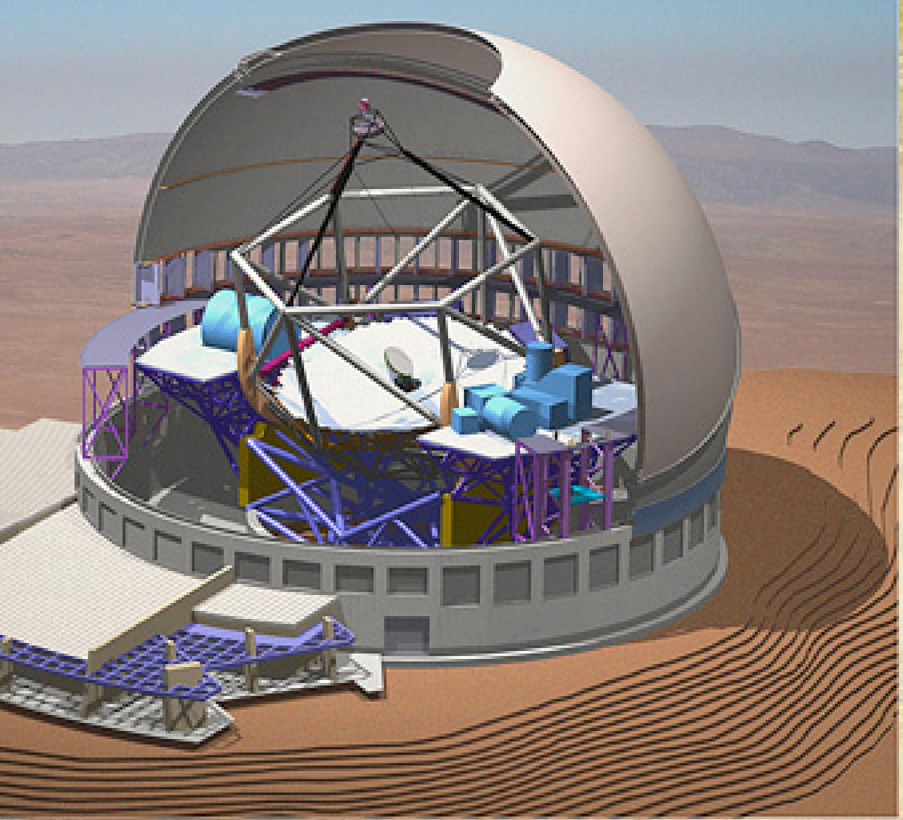
WFMOS

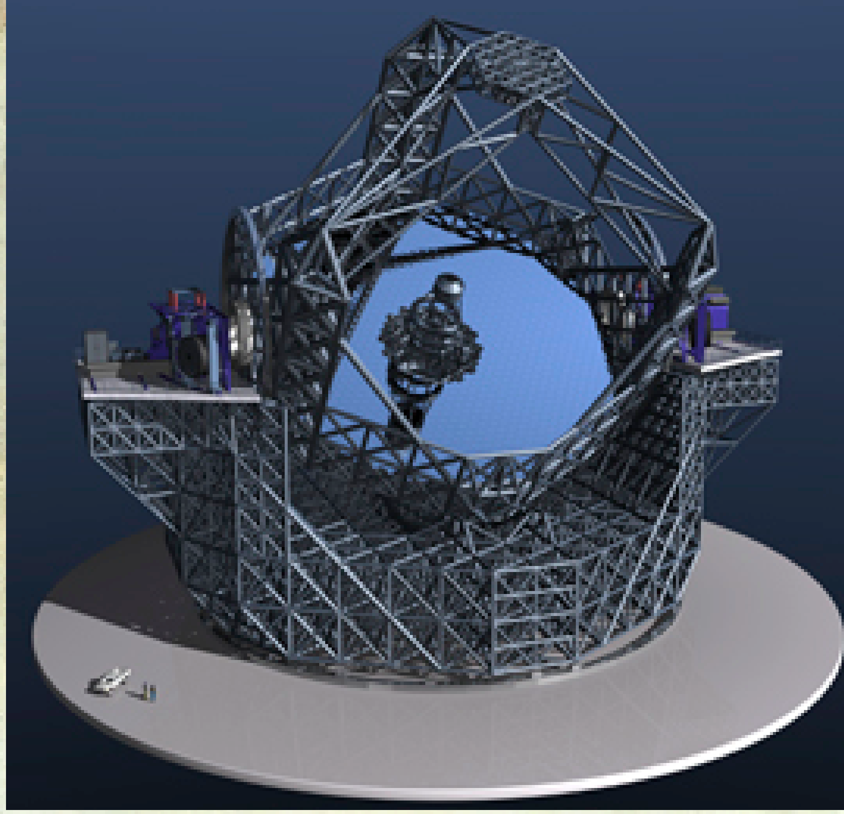
Abundance patterns of the three studied clusters. The Hyades is shown by red circles, Cr 261 is shown by green squares, and the HR 1614 moving group is shown by blue triangles. The three clusters have their own abundance patterns.





TMT / E-ELT





- AO astrometry (tied to GAIA/SIM)
- RGB kinematics to 5Mpc
- Detailed chemical abundances throughout Local Group
- Direct detection of DM clumps (~ 1 m/s/yr)
- Direct measurement of acceleration in Bulge (~ 1 m/s/yr)

What we are ultimately aiming for

- A representative inventory of the:
  - ages
  - orbits
  - chemical composition
  - spatial distribution
- of stars in a statistically useful sample of nearby galaxies (spanning a range of galaxy type, mass, and environment)
- Complete 3D kinematics in a number of systems to nail the dark matter distribution

What can we expect? Very exciting times!

- Can stars reveal both the dark matter properties and the galaxy formation process?
- Quite likely. In the near field, we are obtaining billions of spatial, dynamical, and chemical measurements!
- Will also need to undertake dynamical and chemodynamical simulations to sufficient resolution to interpret these observations... not easy!