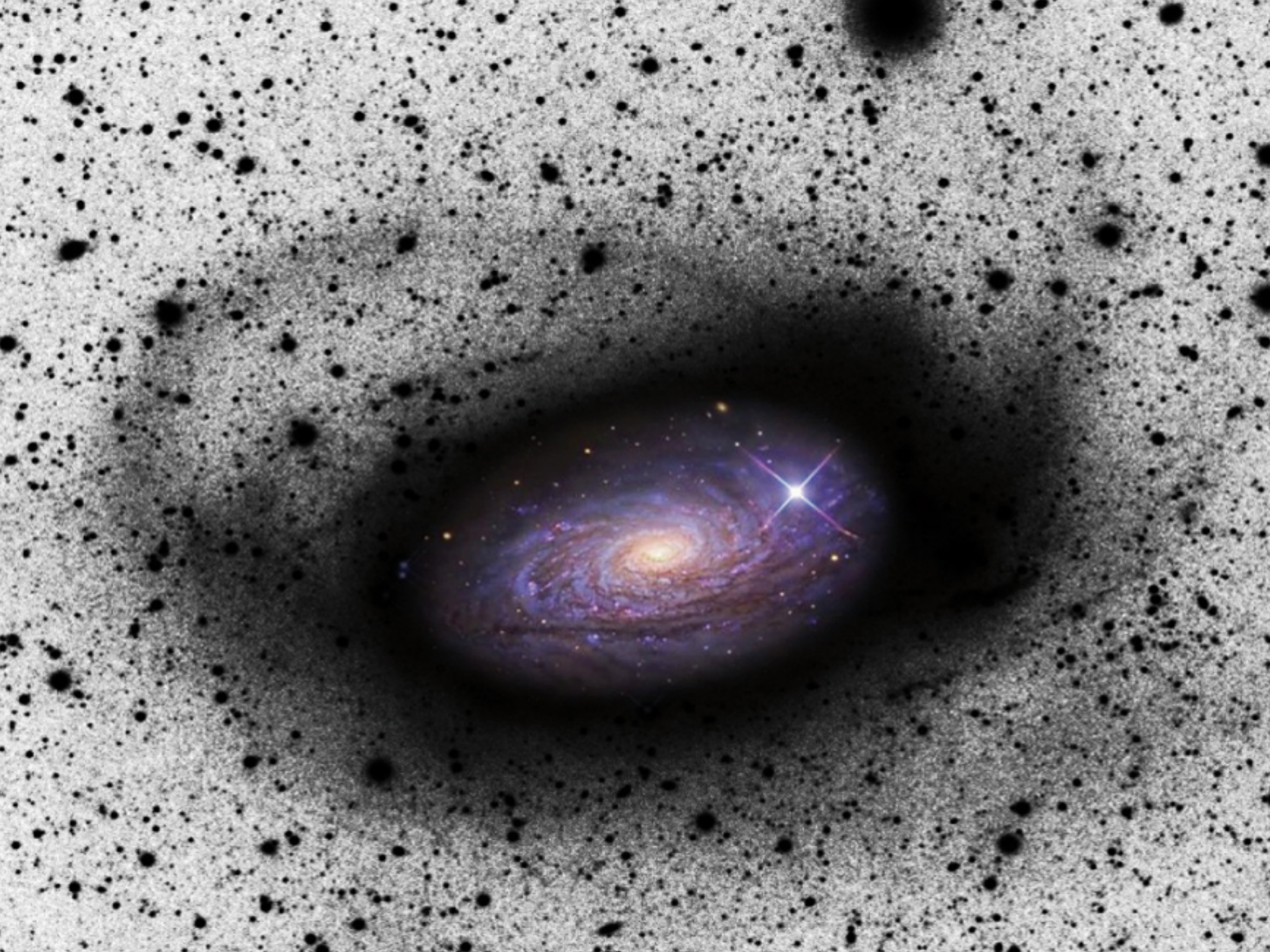
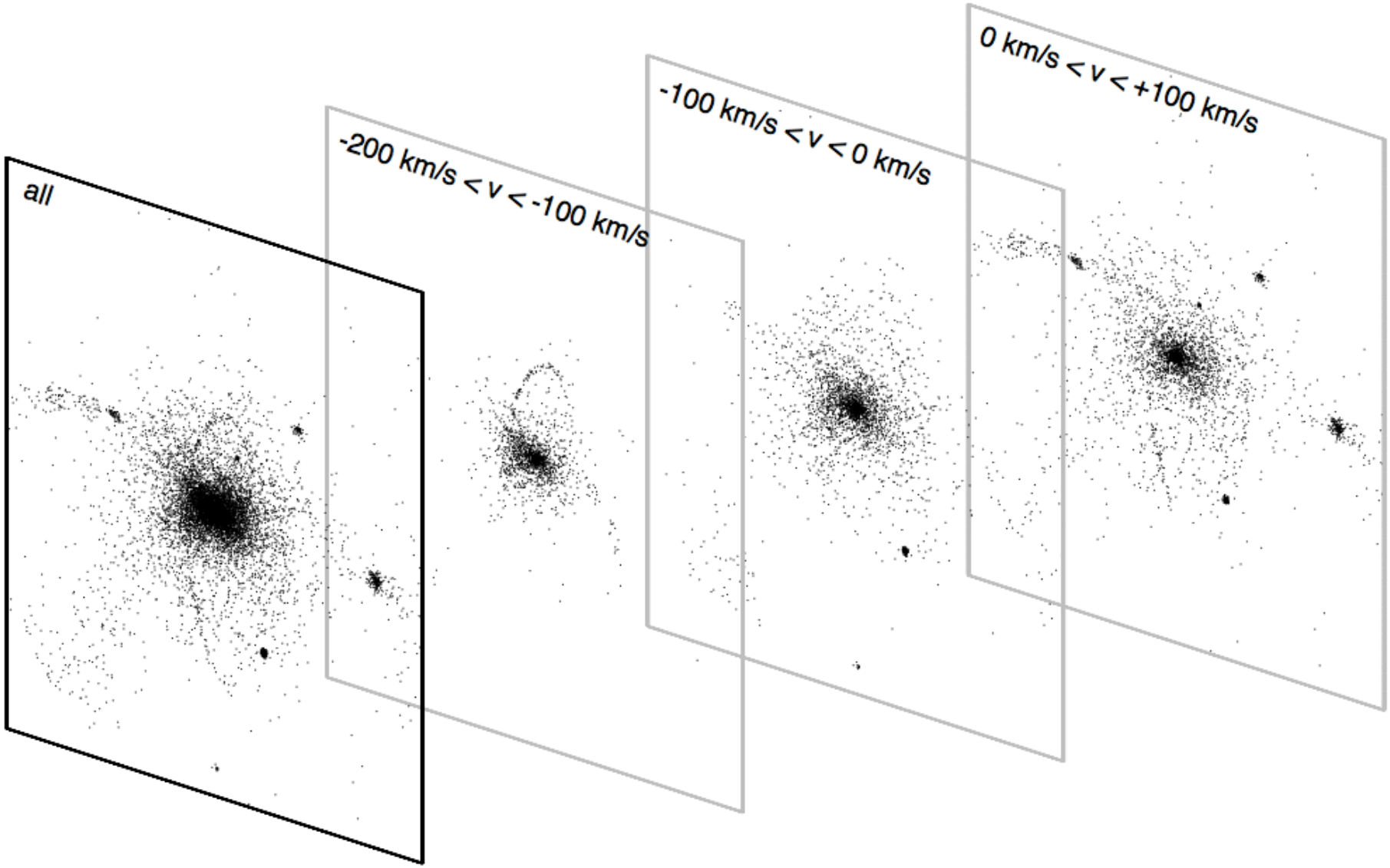
Remnant Globular Cluster Streams in Galaxy Halos

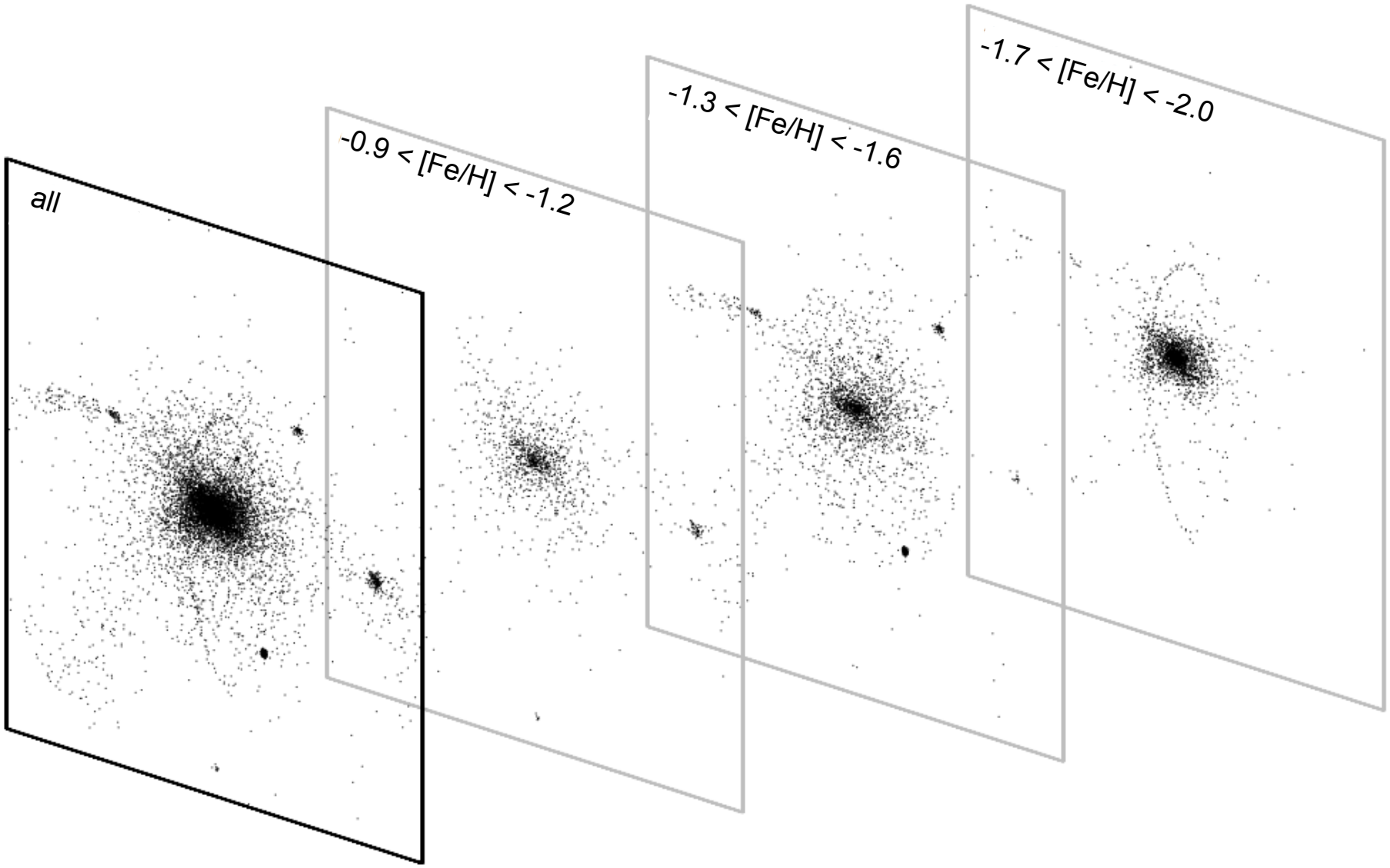
Michael West
Maria Mitchell Observatory
Lowell Observatory (after Aug 2015)

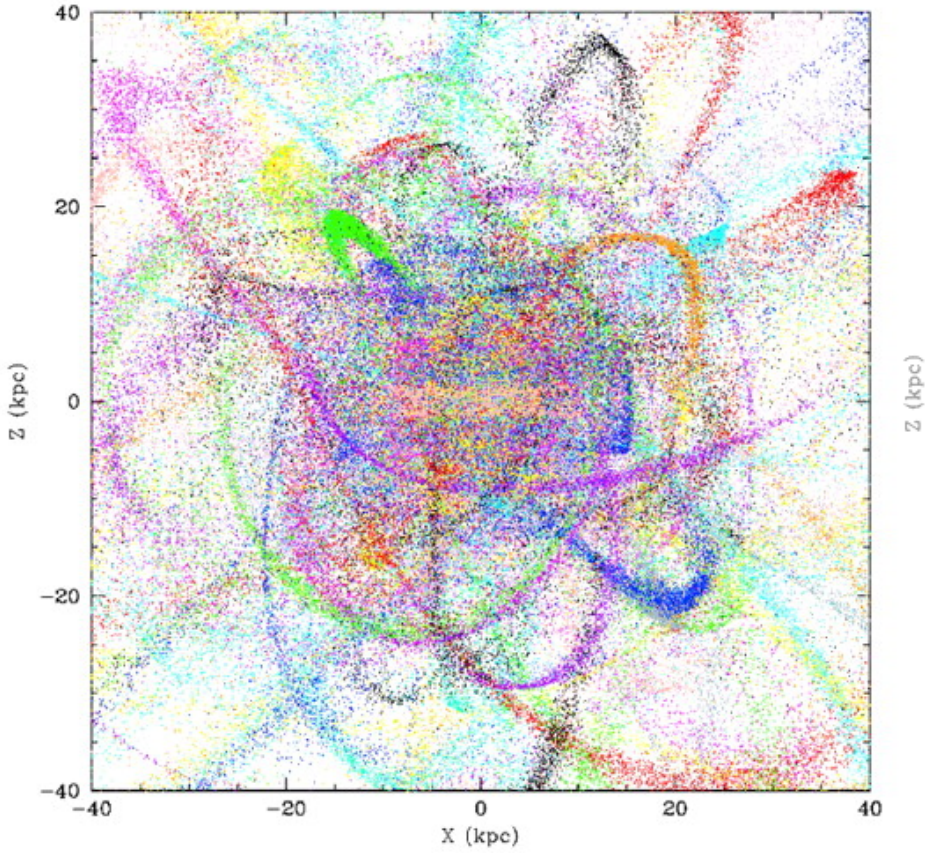
- Globular clusters as tracers of streams
- G1: globular cluster or galaxy?





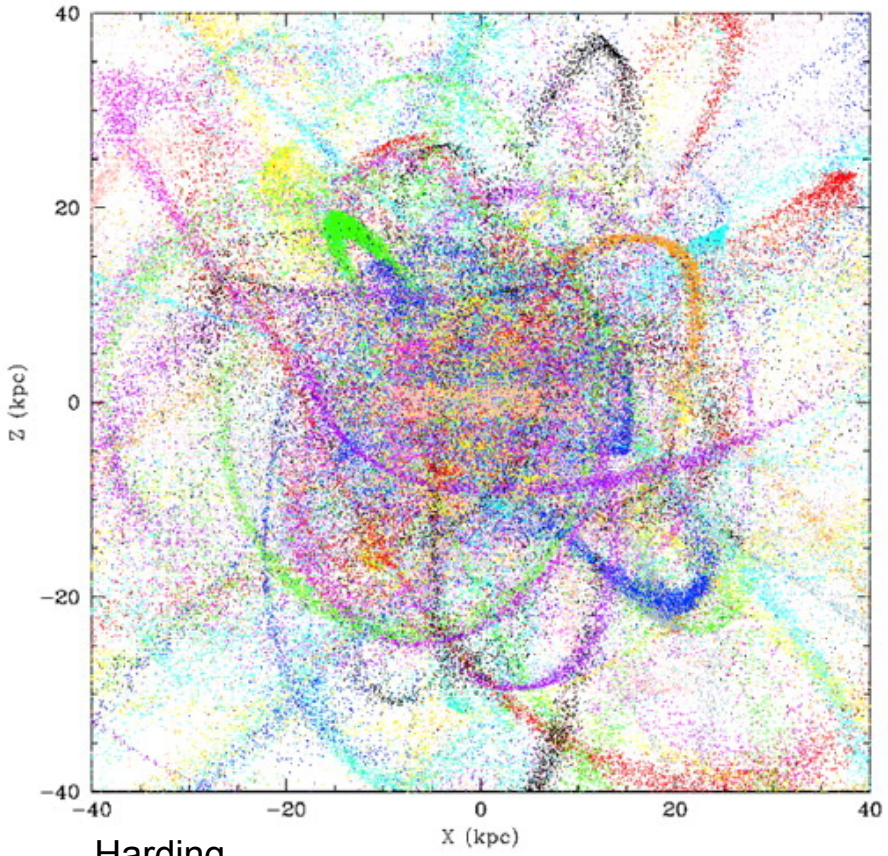
Bullock & Johnston


all
-0.9 < [Fe/H] < -1.2
-1.3 < [Fe/H] < -1.6
-1.7 < [Fe/H] < -2.0

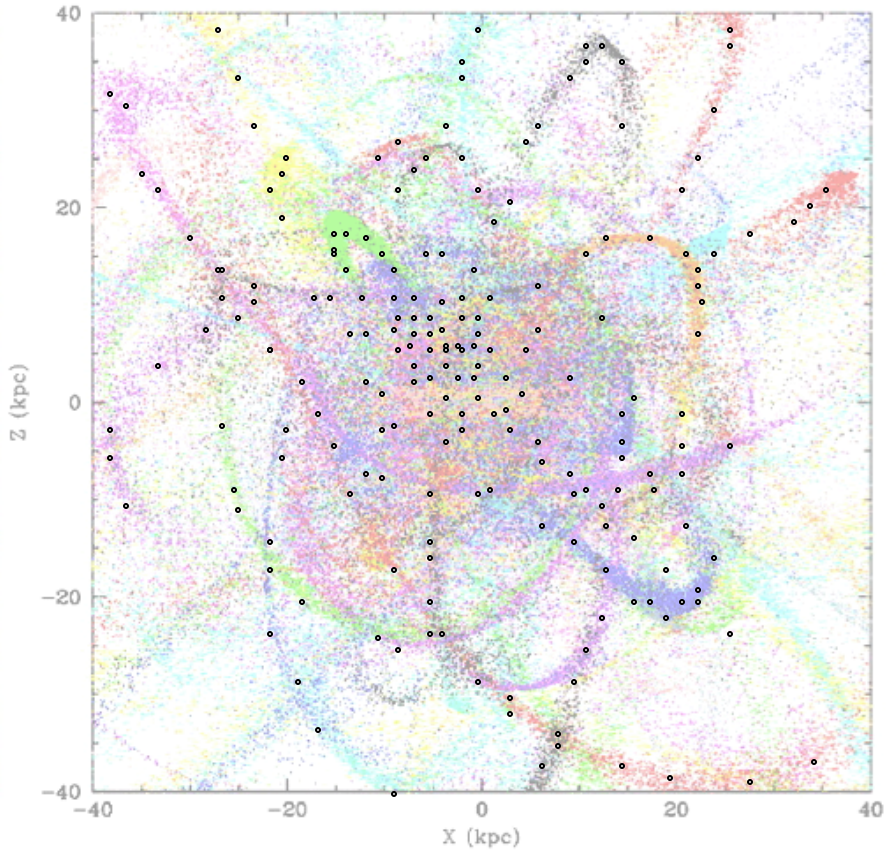


Harding

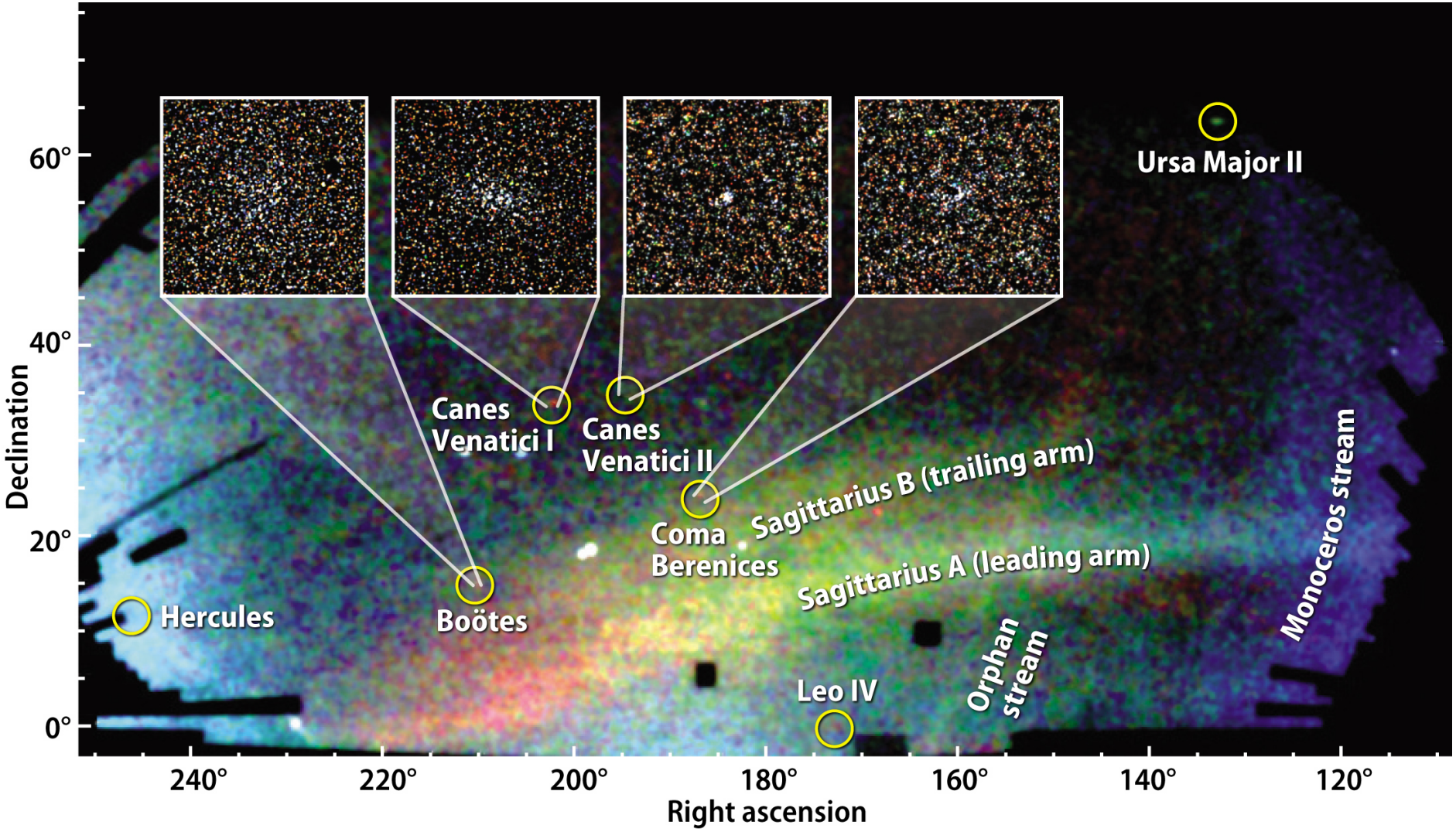
○ = globular clusters



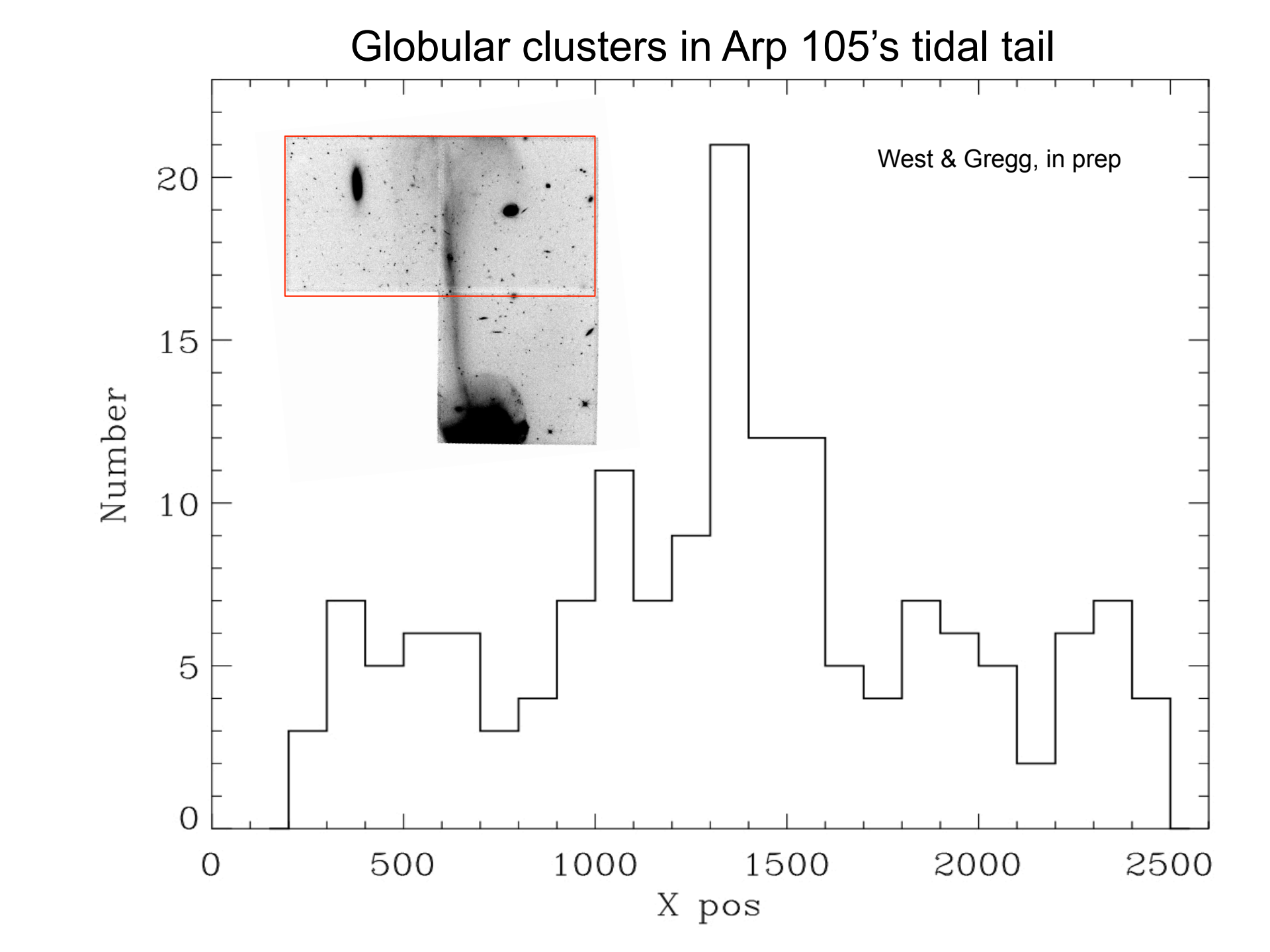
Harding



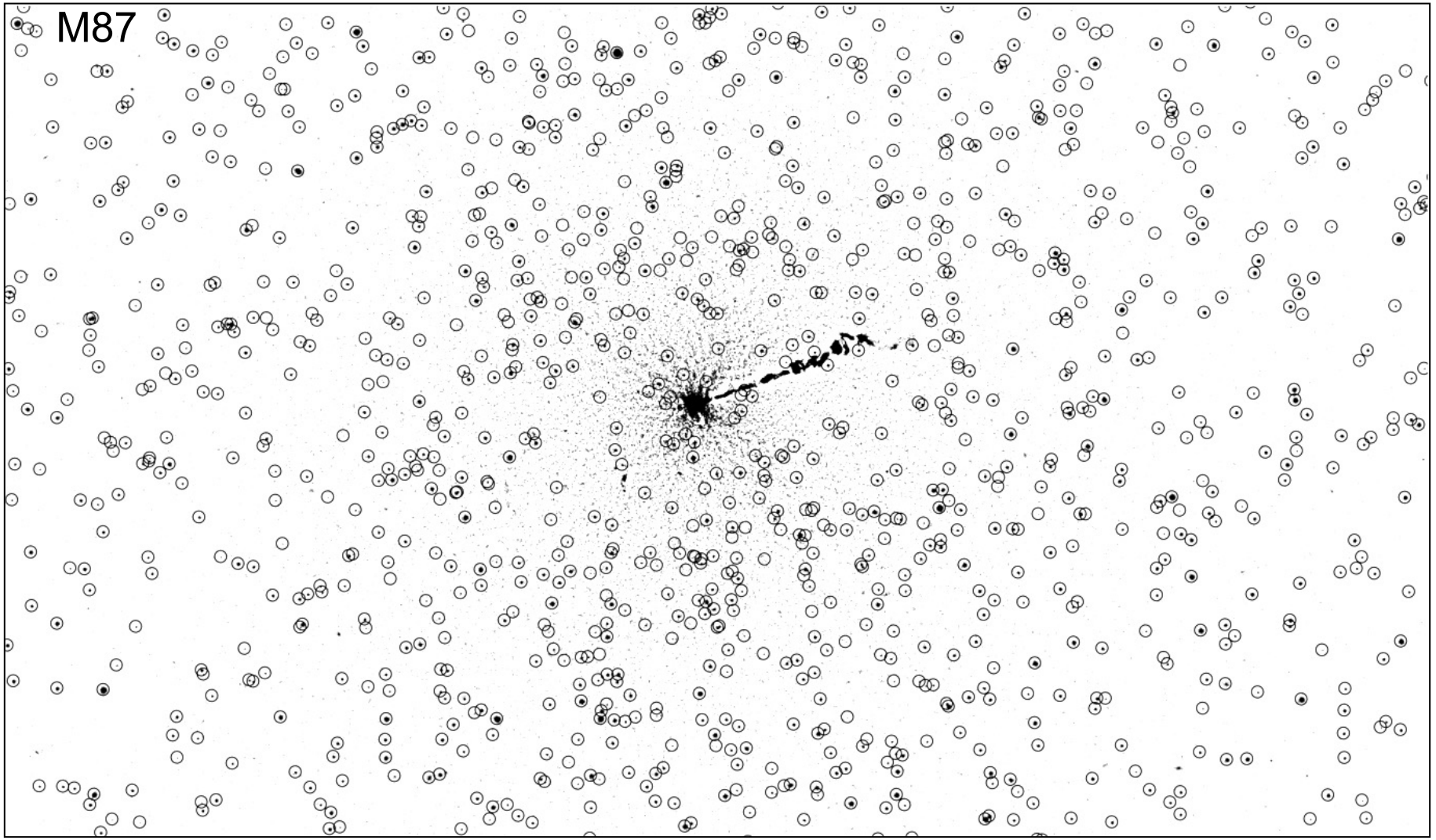
Globular clusters are sparse but luminous tracers of streams

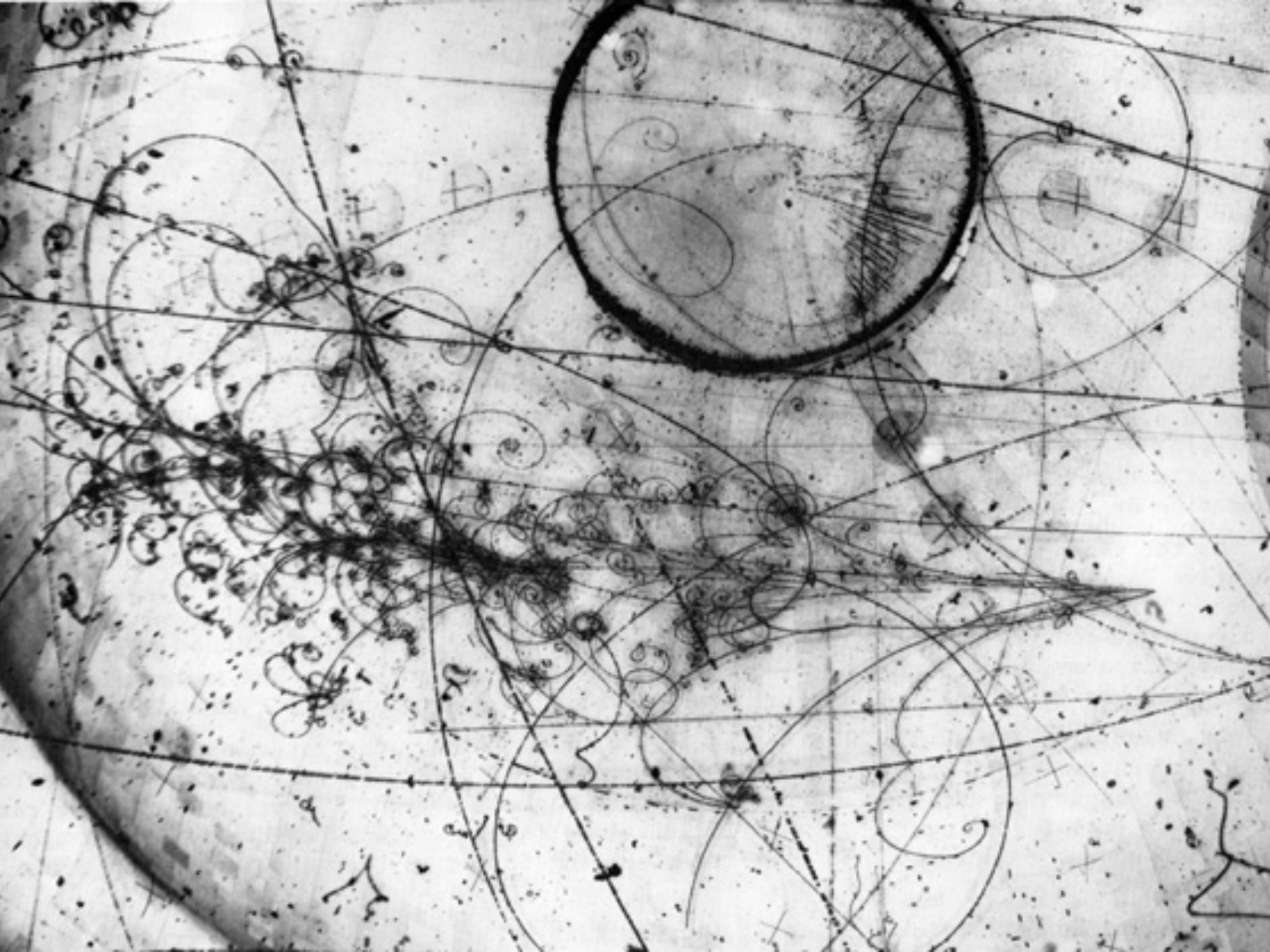

Ursa Major II
Canes Venatici I
Canes Venatici II
Coma Berenices
Sagittarius B (trailing arm)
Sagittarius A (leading arm)
Monoceros stream
Hercules
Boötes
Leo IV
Orphan stream
60°
40°
20°
0°
Declination
240°
220°
200°
180°
160°
140°
120°
Right ascension

Globular clusters in Arp 105's tidal tail



Can we detect remnant streams of globular clusters in galaxy halos?

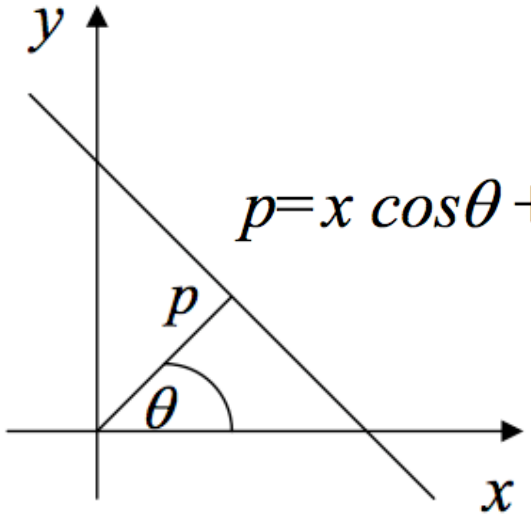


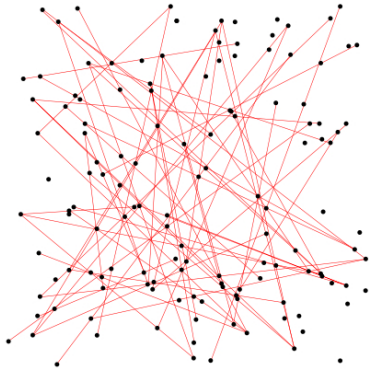


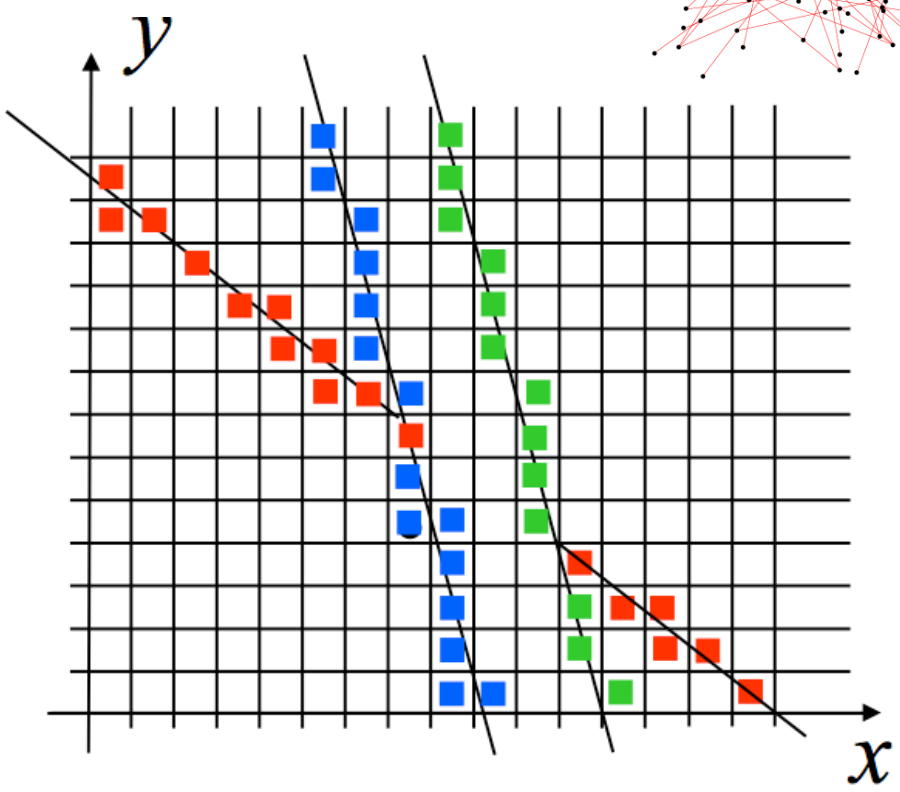
Hough Transform

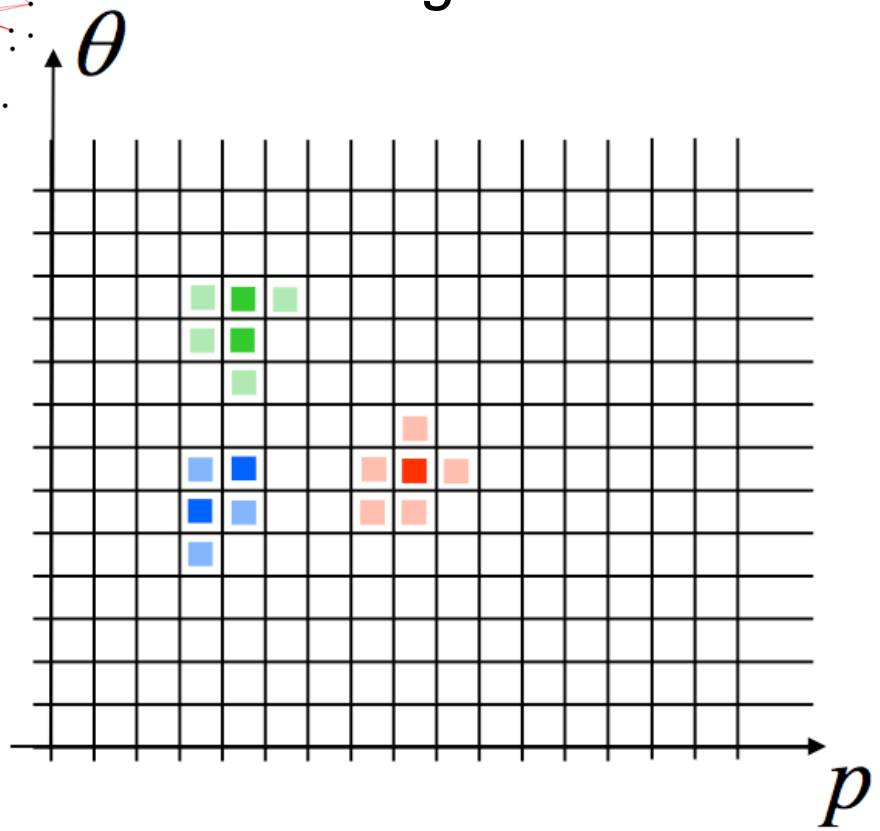
detects lines in noisy data as maxima in parameter space

coordinate transformation with voting



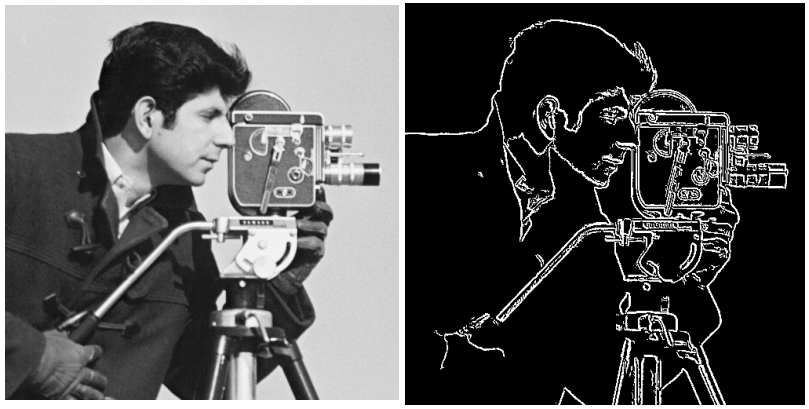






Many uses of the Hough transform…

feature extraction in digital images



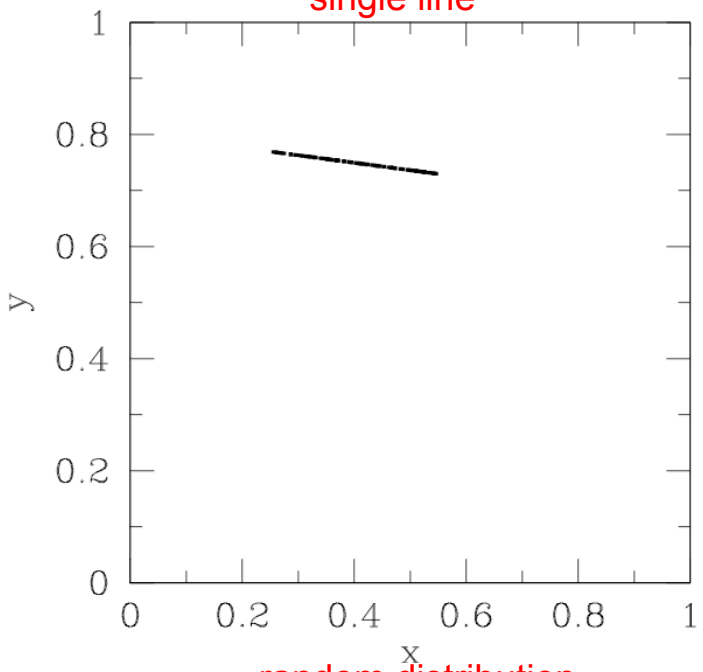
character recognition

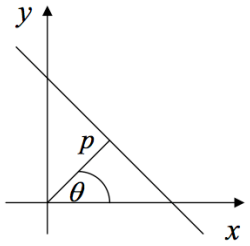
airport security

face recognition

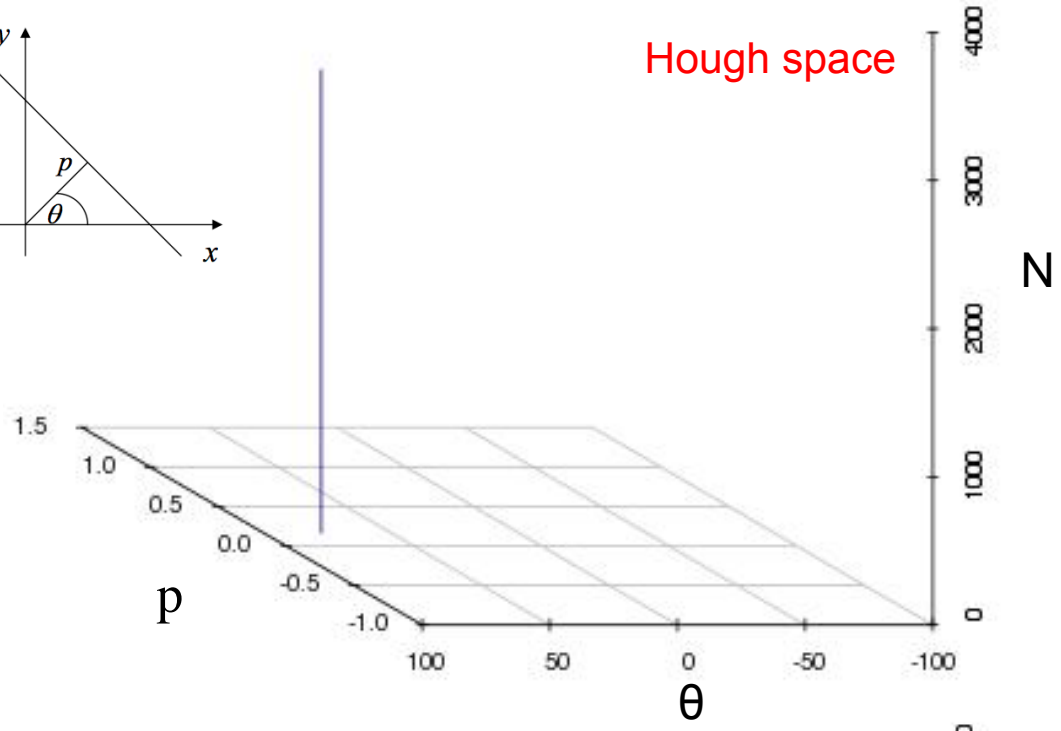
fingerprint identification

single line

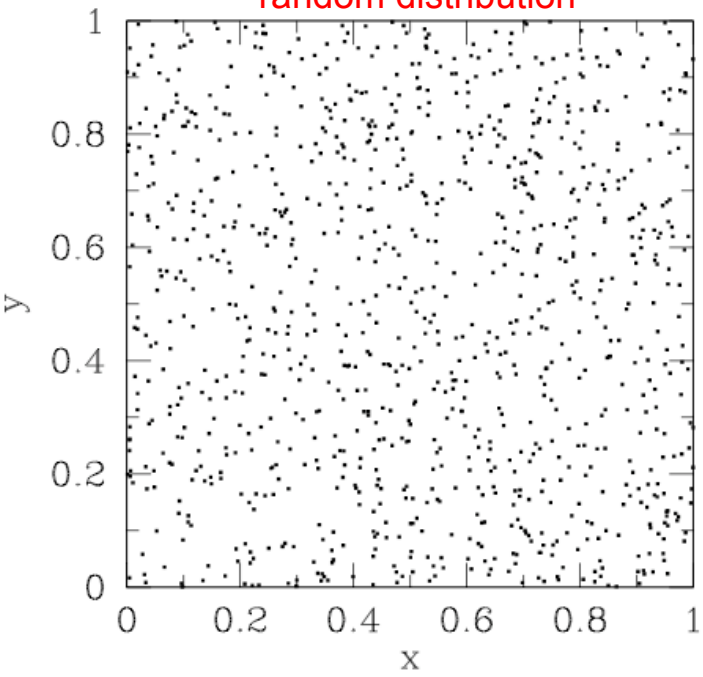


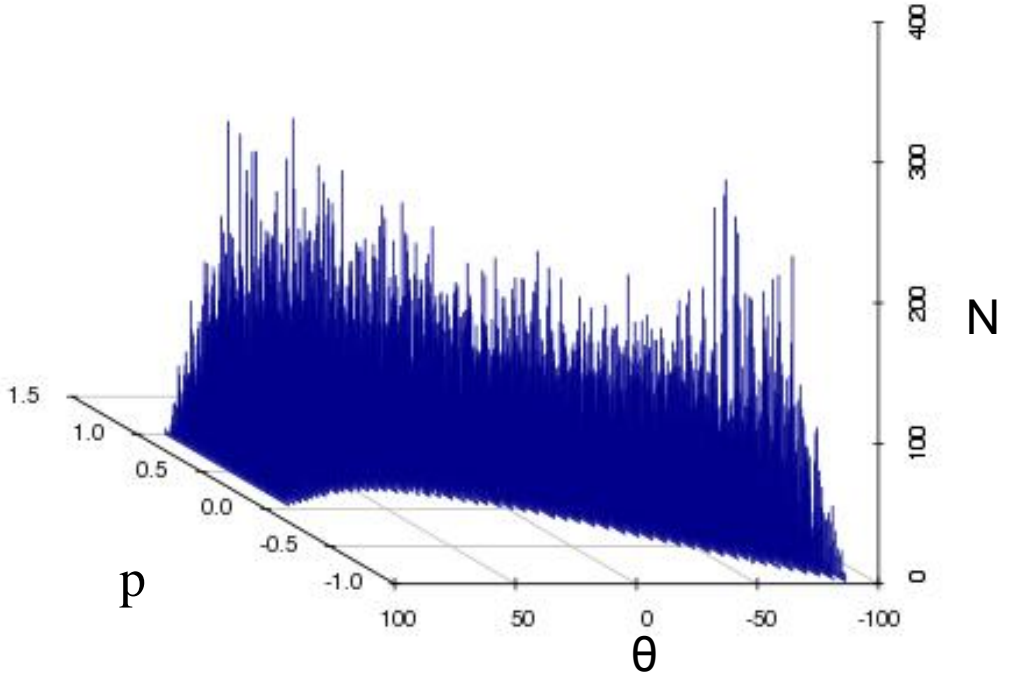


Hough space

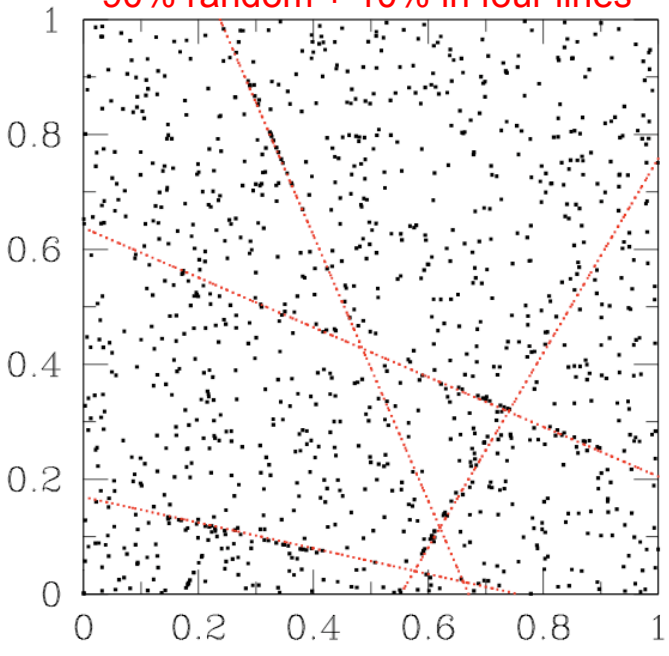


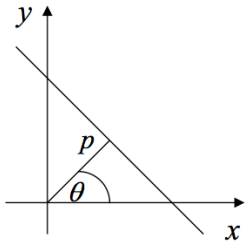
random distribution

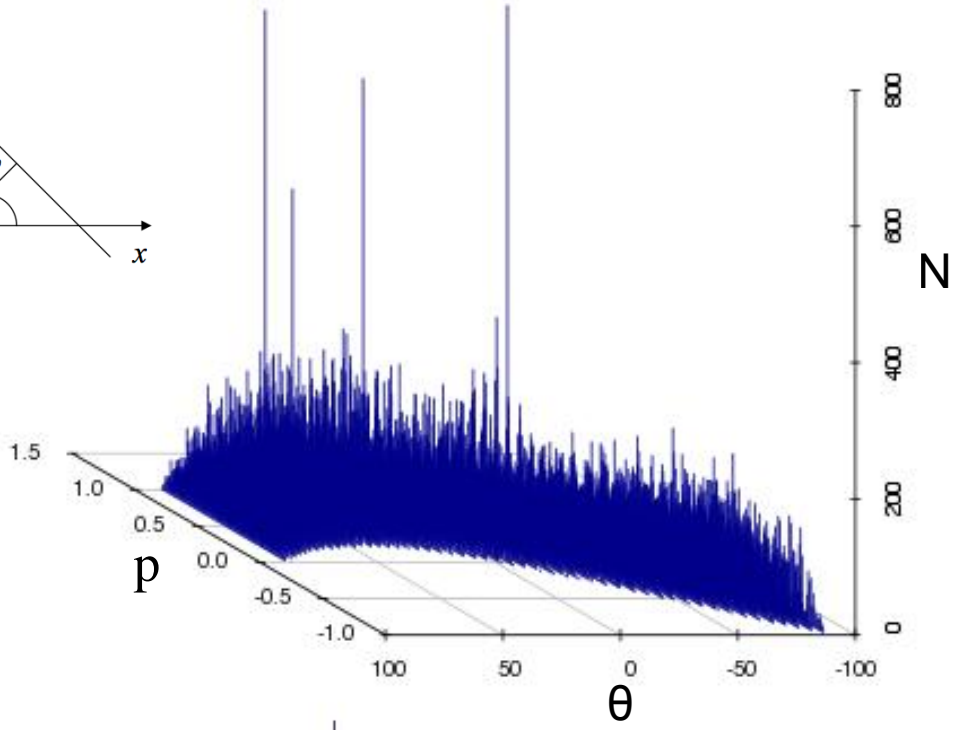




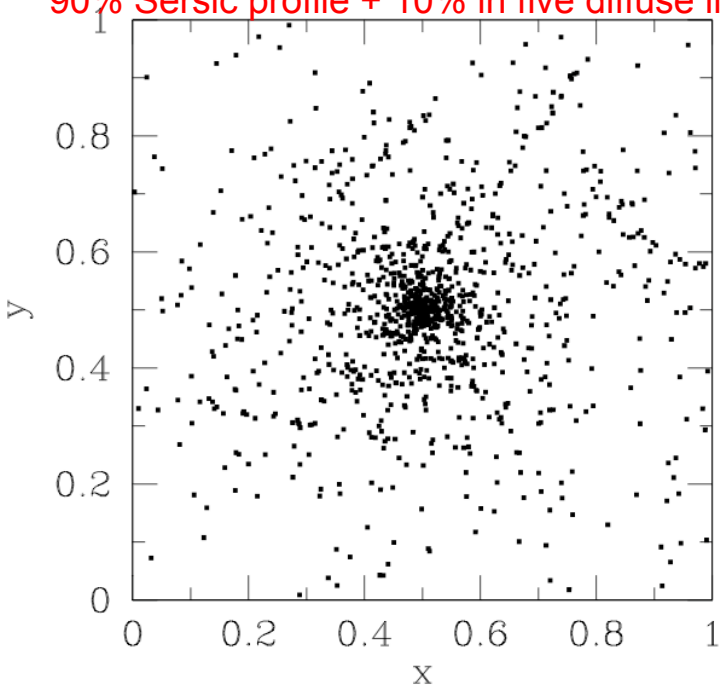
90% random + 10% in four lines

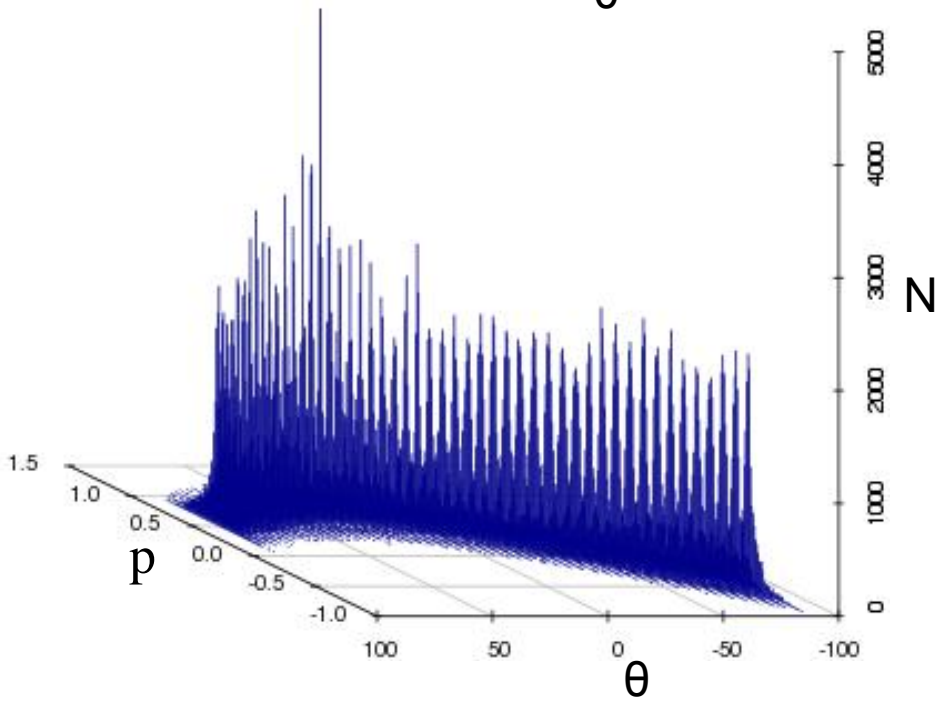


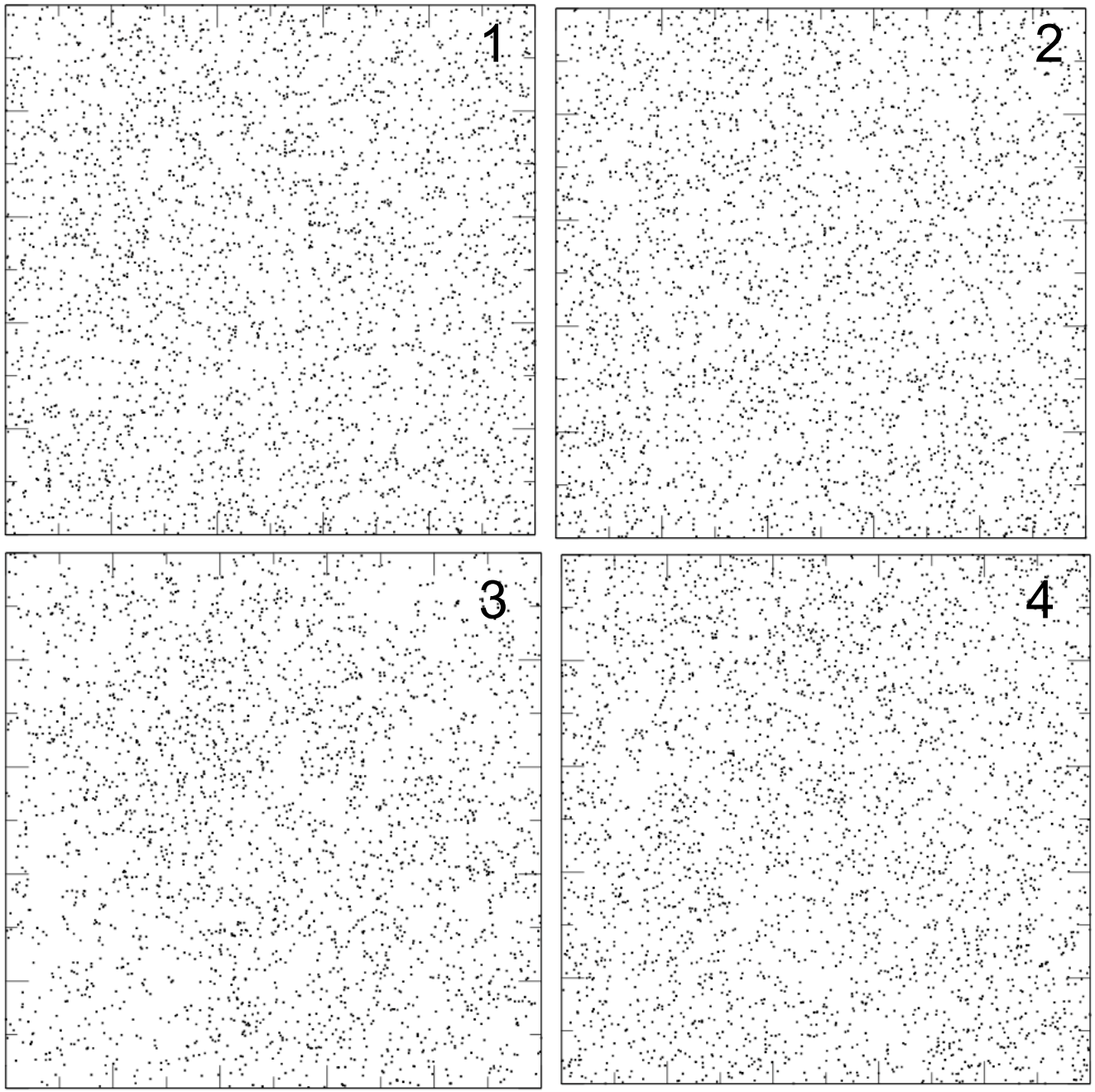


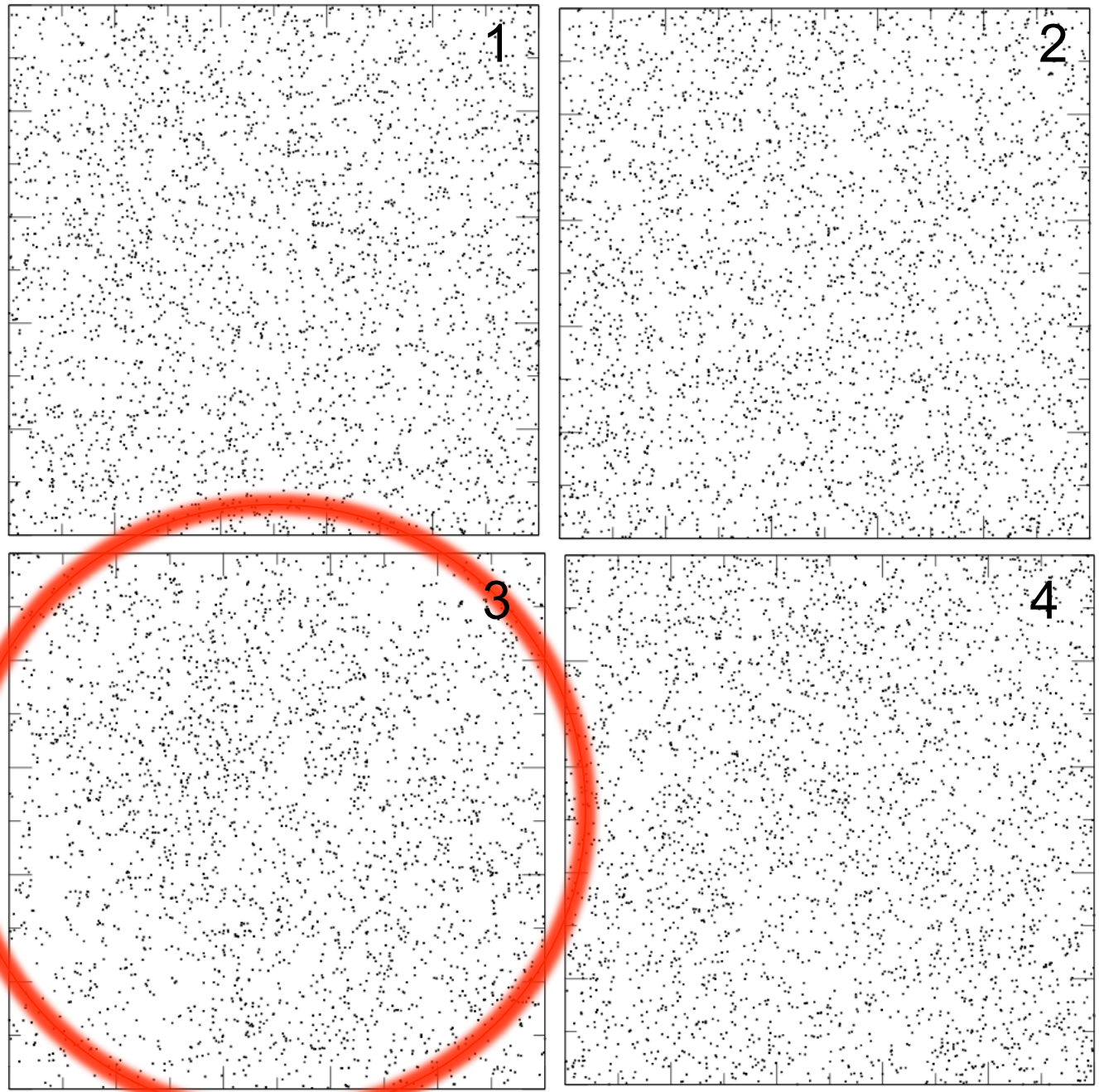


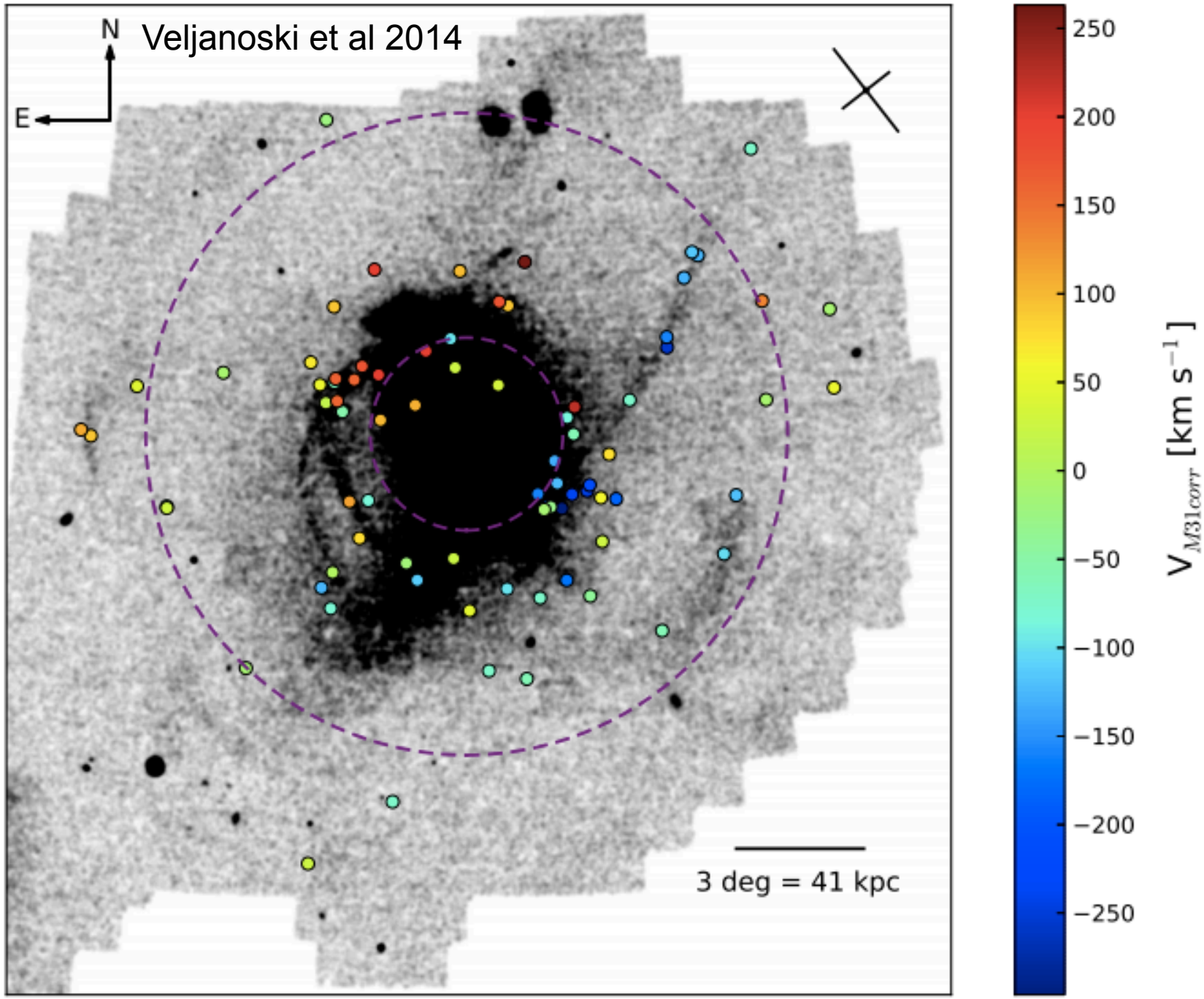
90% Sersic profile + 10% in five diffuse lines

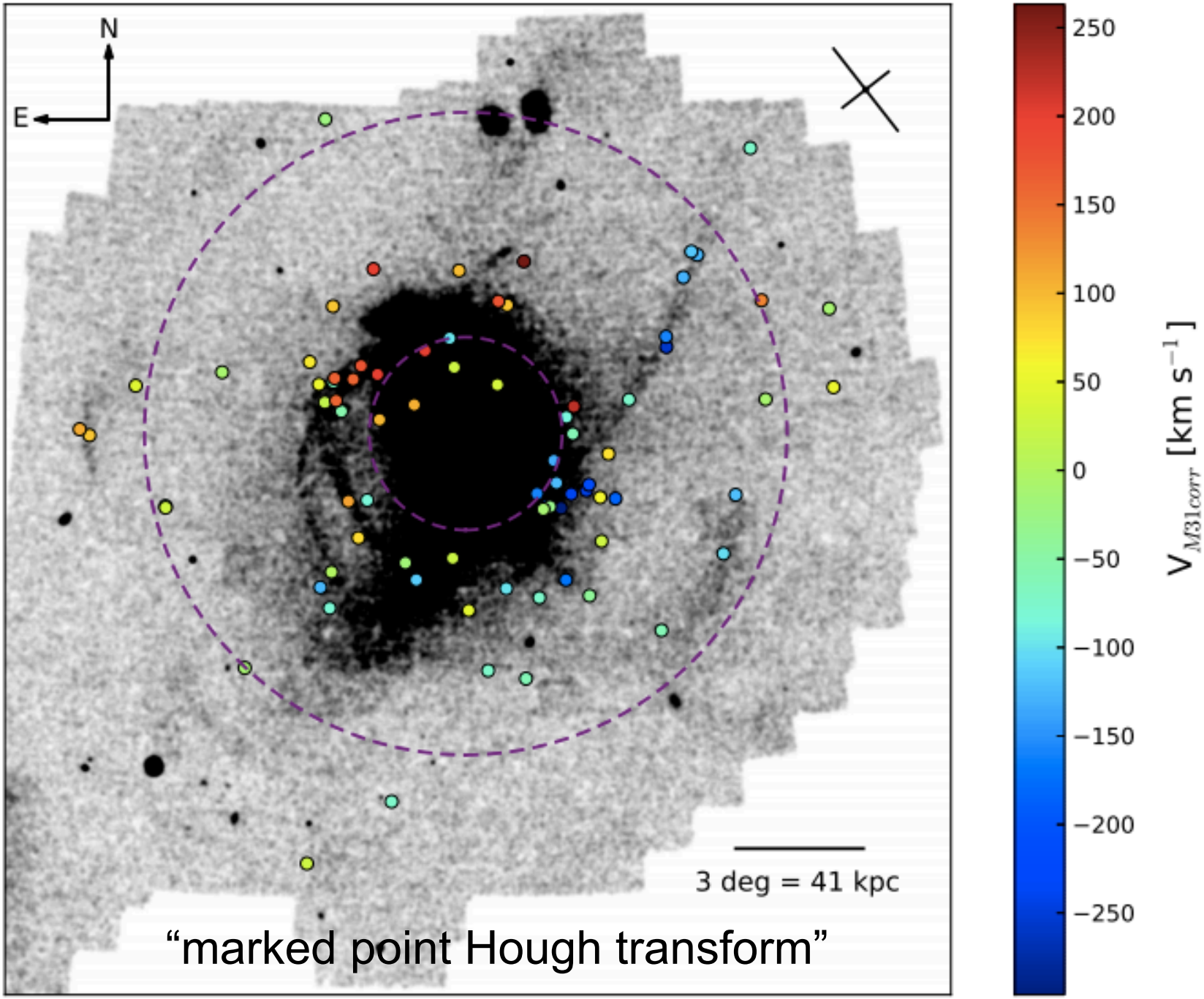




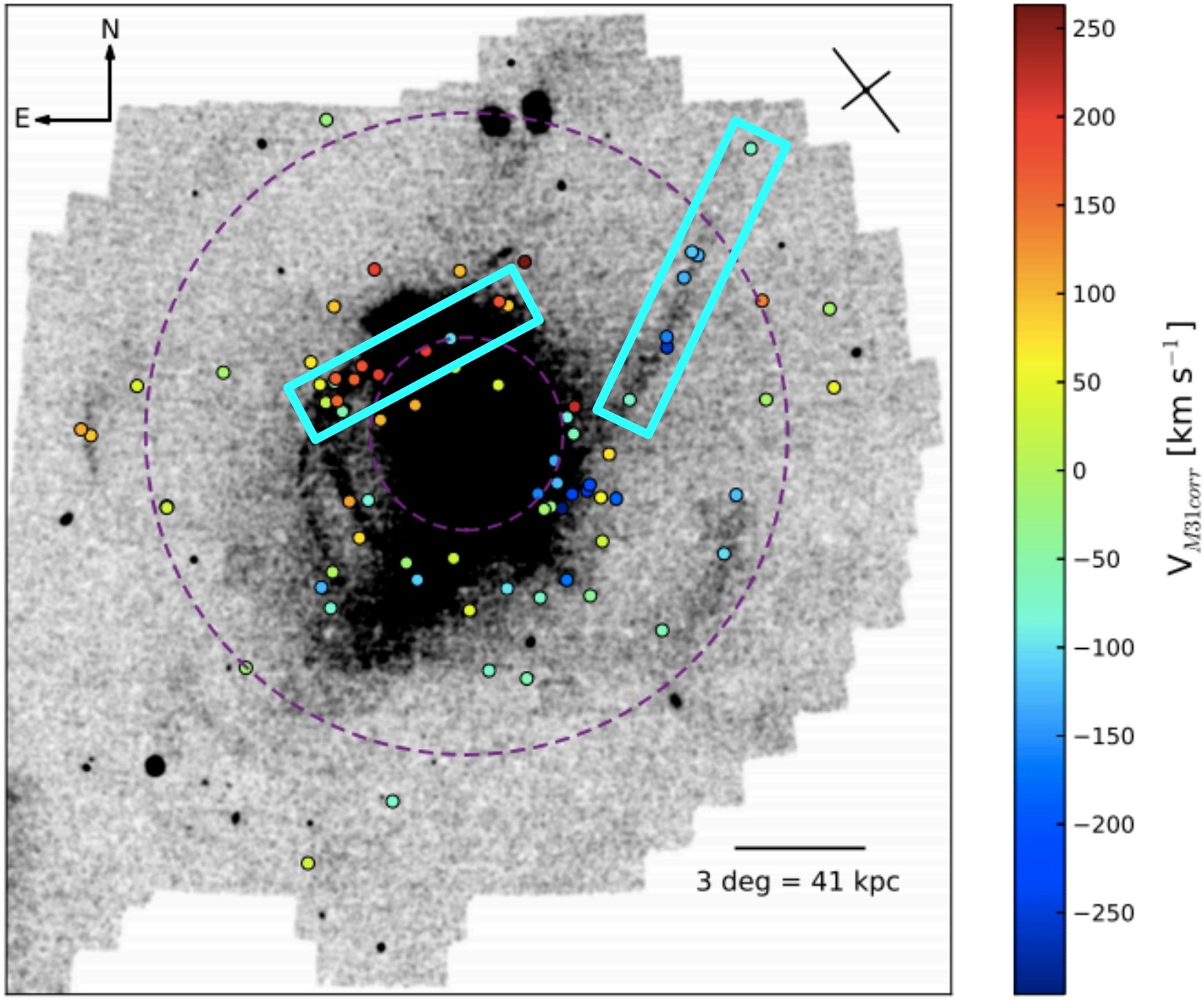

1
2
3
4


1
2
3
4

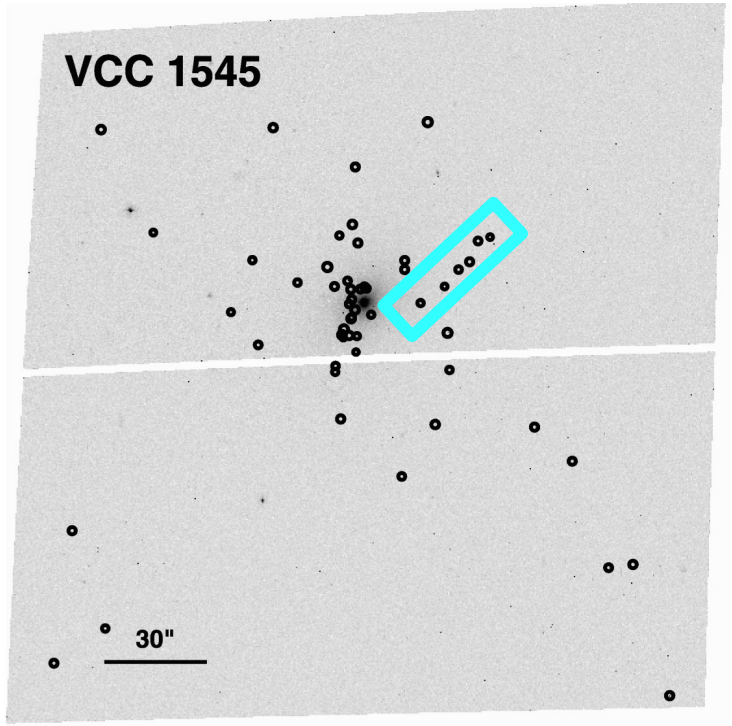

N
E
Veljanoski et al 2014
3 deg = 41 kpc
250
200
150
100
50
0
−50
−100
−150
−200
−250
$V_{M31corr}$ [km s^{-1}]

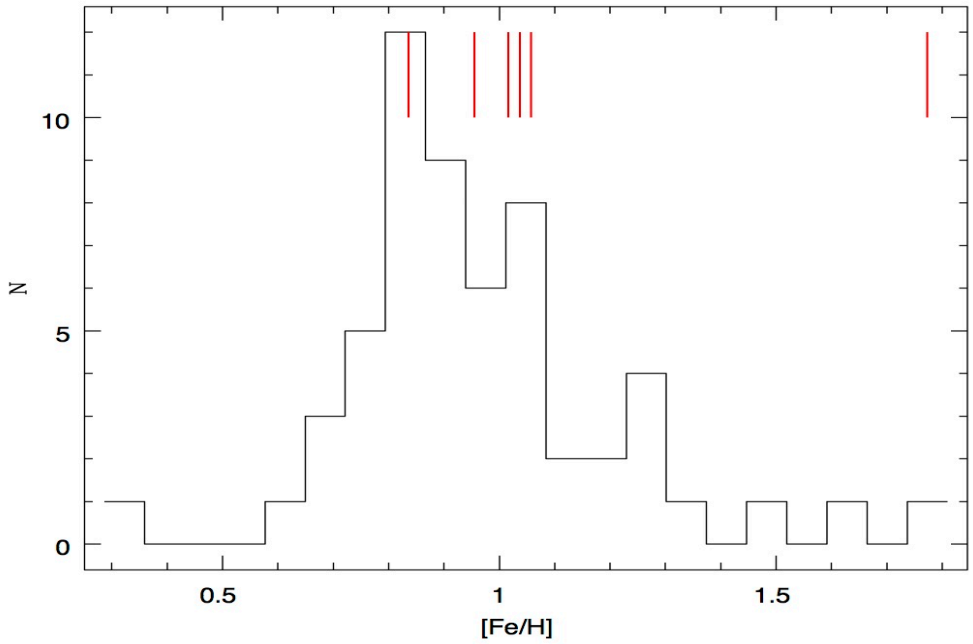


“marked point Hough transform”


N
E
3 deg = 41 kpc
250
200
150
100
50
0
−50
−100
−150
−200
−250
$V_{M31corr}$ [km s^{-1}]

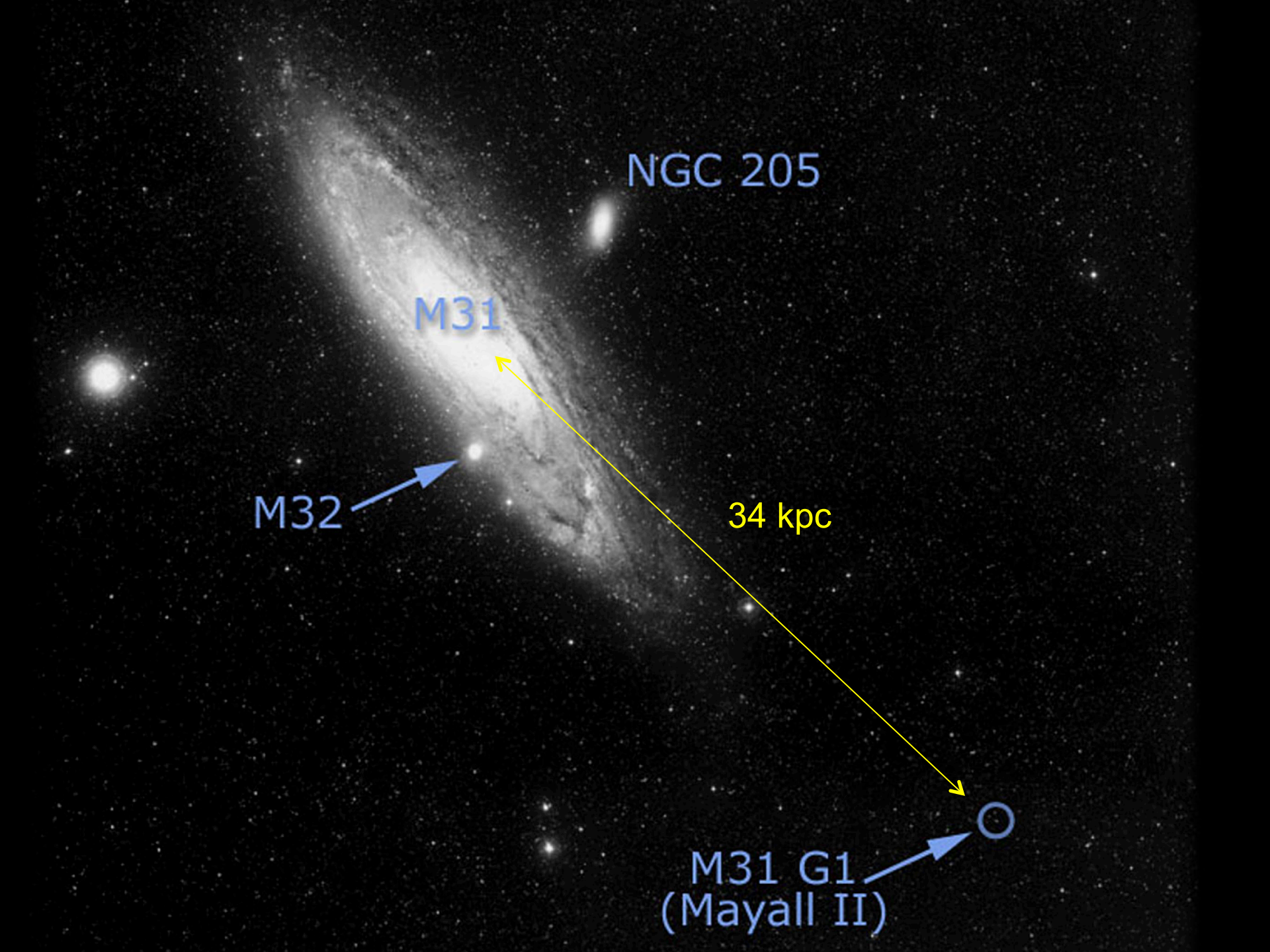
VCC1545

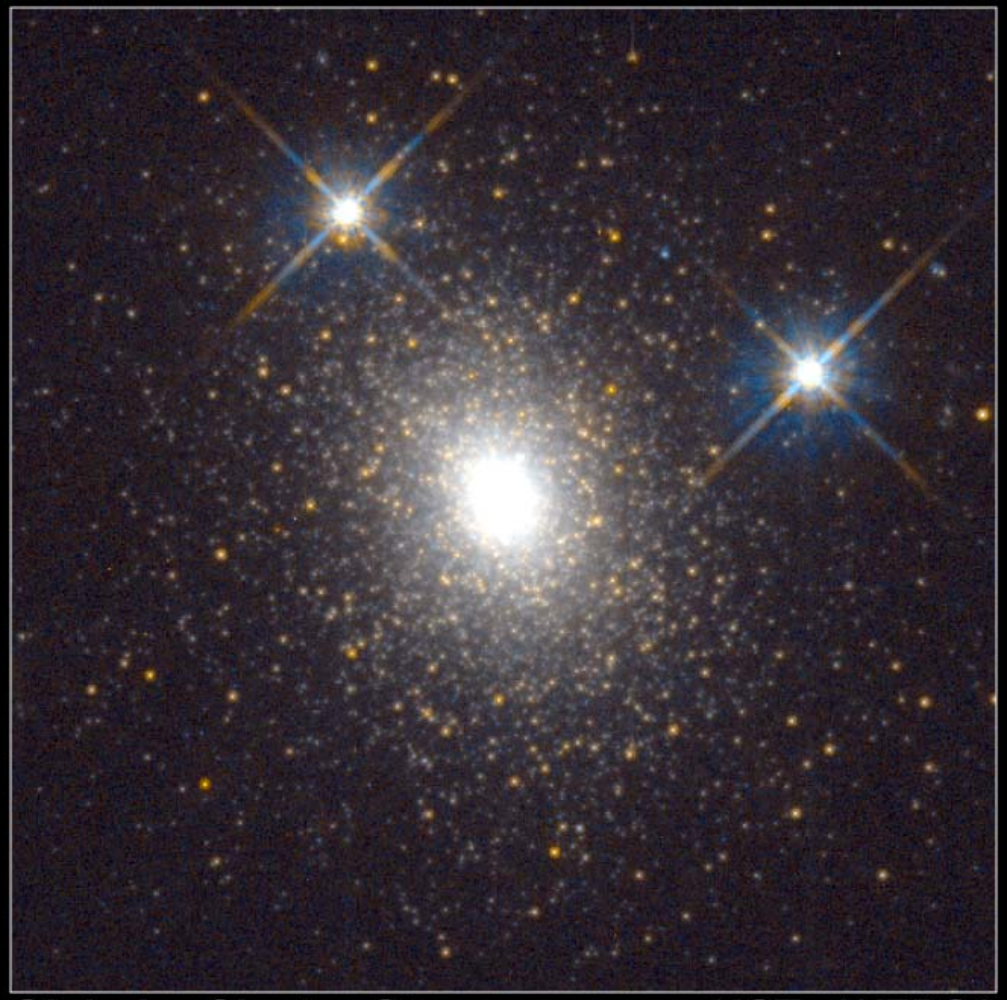




G1: globular cluster or galaxy?

Gregg, West & Lemaux (2015, in prep)


NGC 205
M31
M32
34 kpc
M31 G1
(Mayall II)



Globular Cluster G1 in Galaxy M31

HST • WFPC2

Oddities about G1:

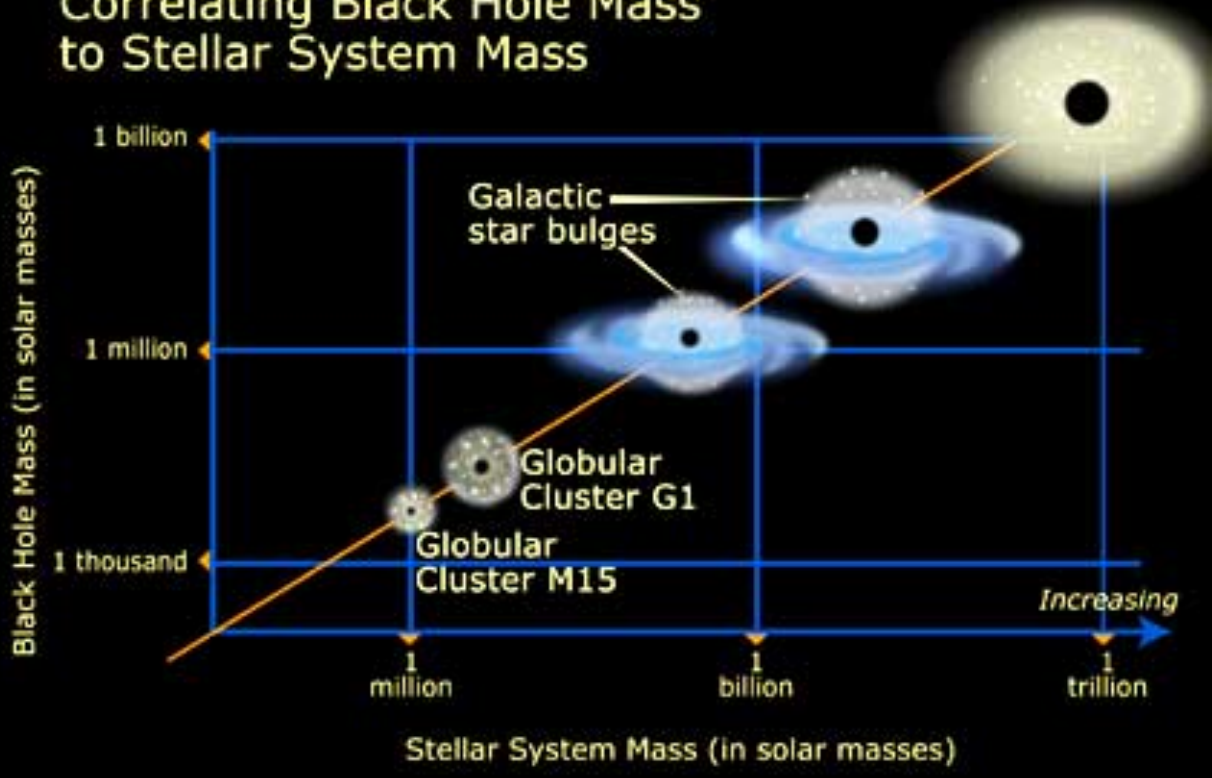
- Most massive known globular cluster

  ~ 10^7 solar masses

- Stars have a range of chemical composition
- Elongated shape
- Home to an 20,000 solar mass black hole

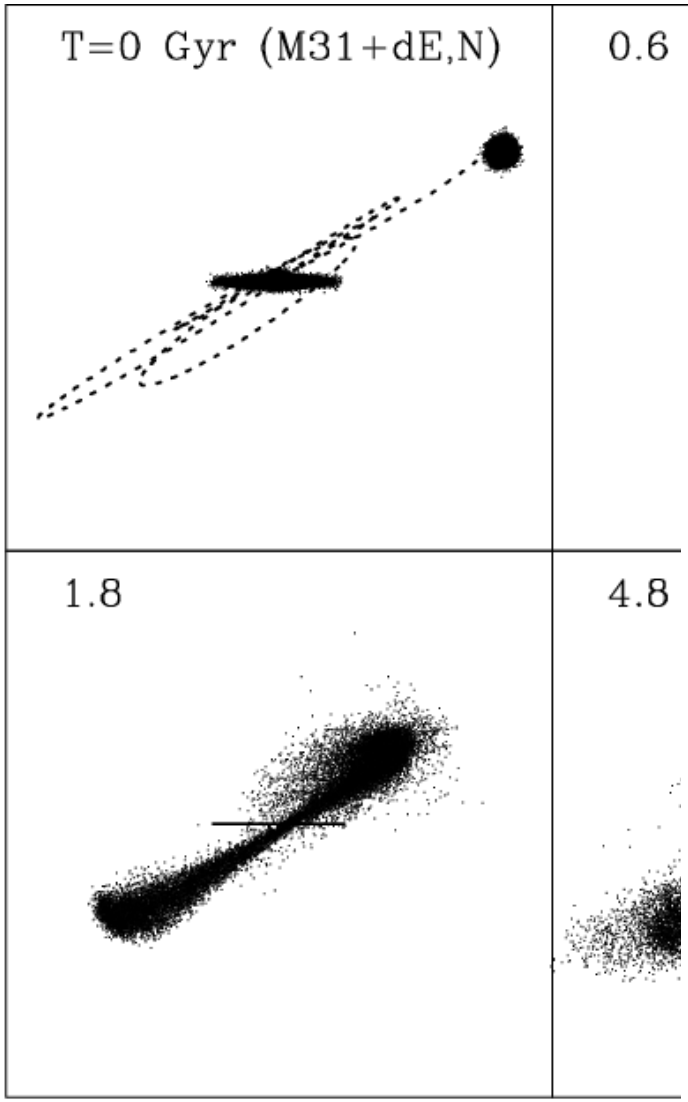
Globular clusters known to have black holes

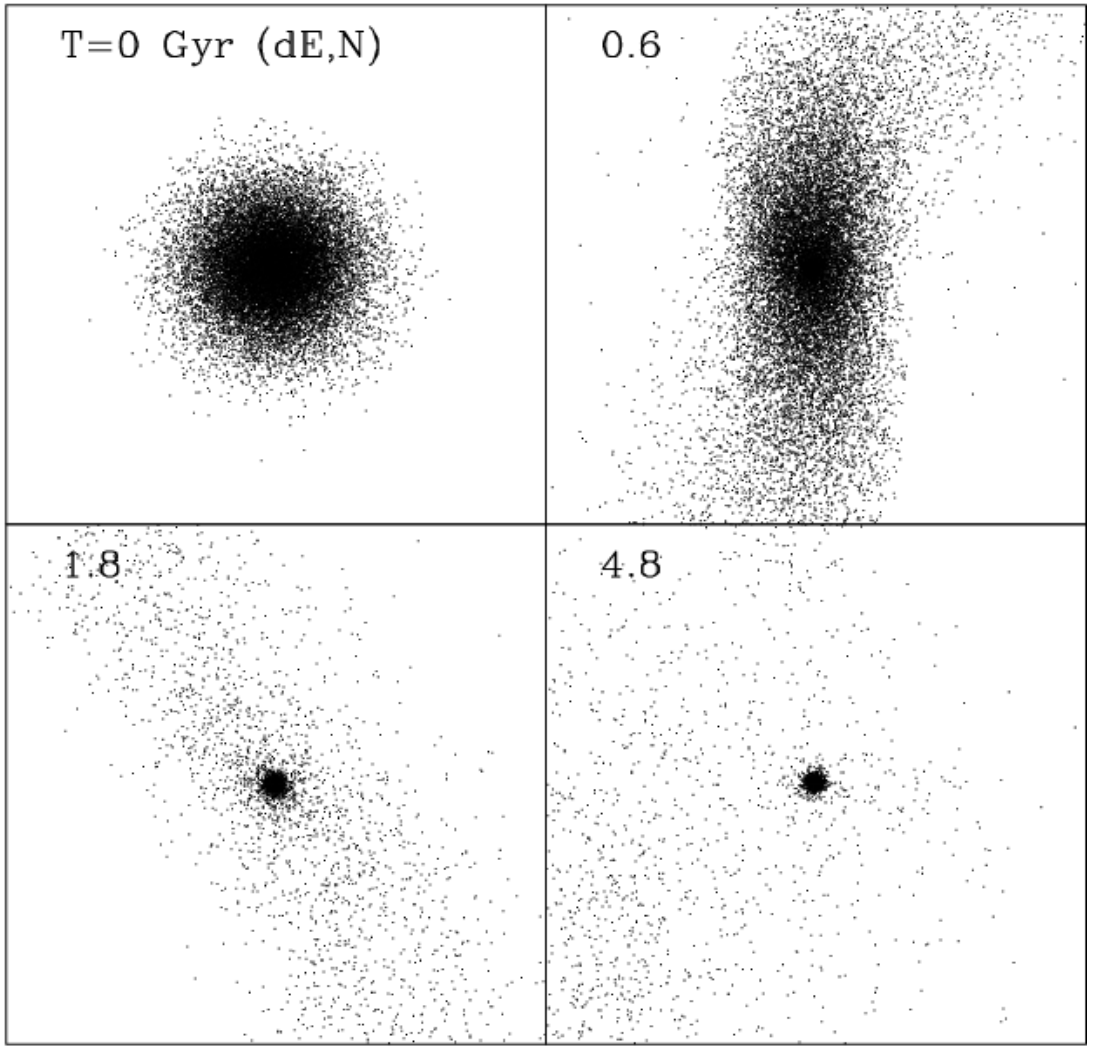
Correlating Black Hole Mass to Stellar System Mass



Computer simulation of ‘galaxy threshing’

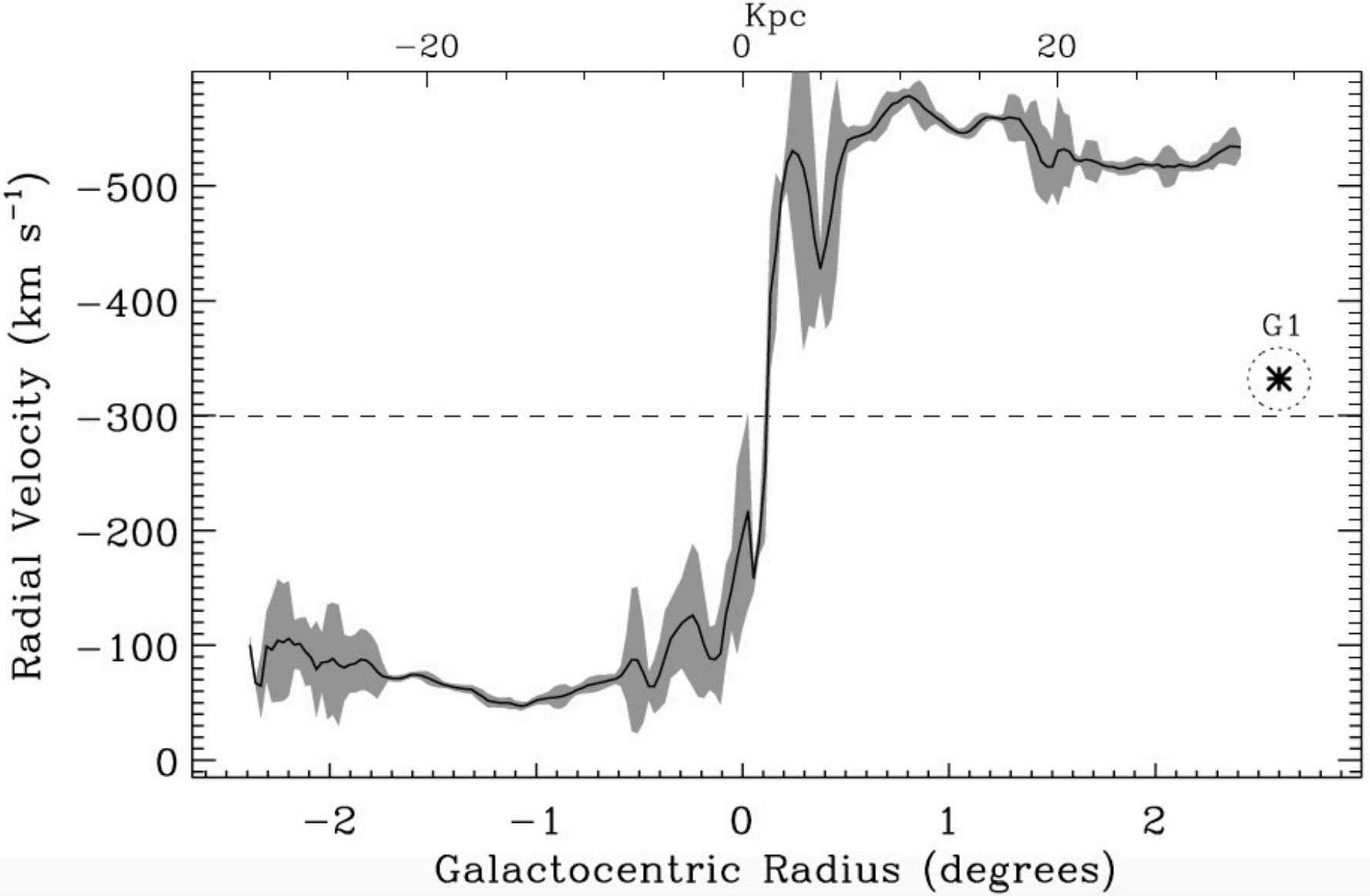
Andromeda and dwarf galaxy encounter

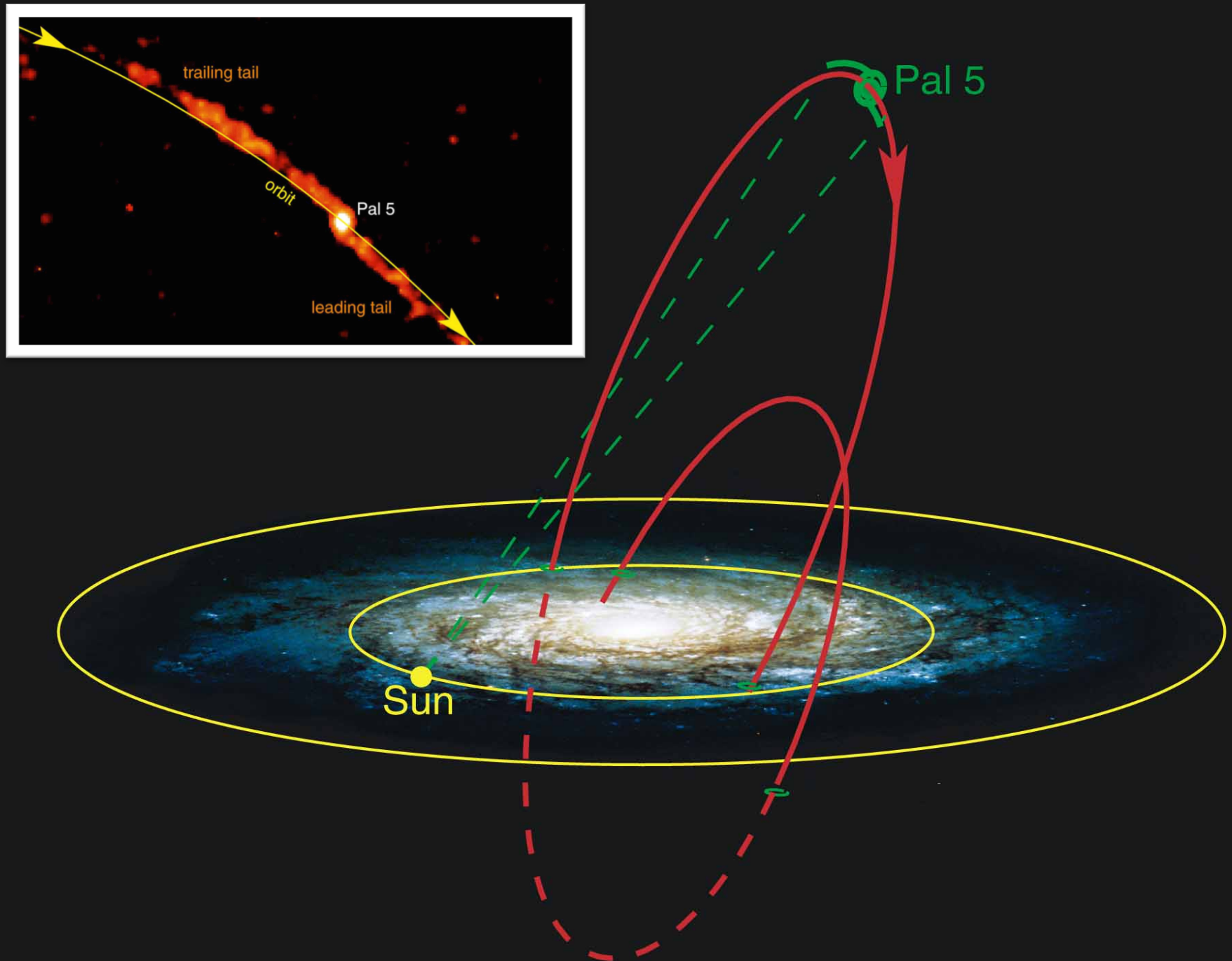




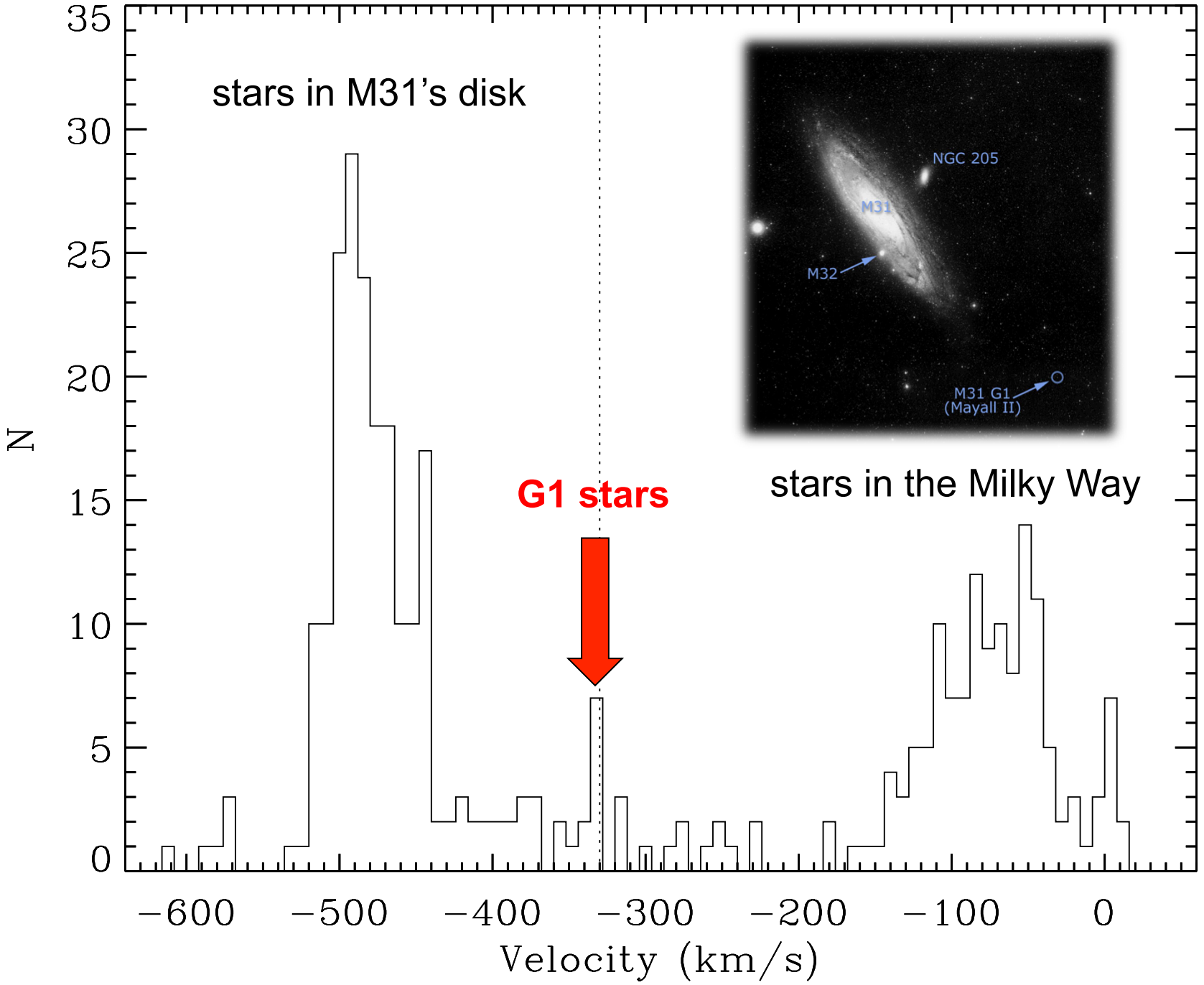
Bekki & Chiba (2004)

M31 rotation curve

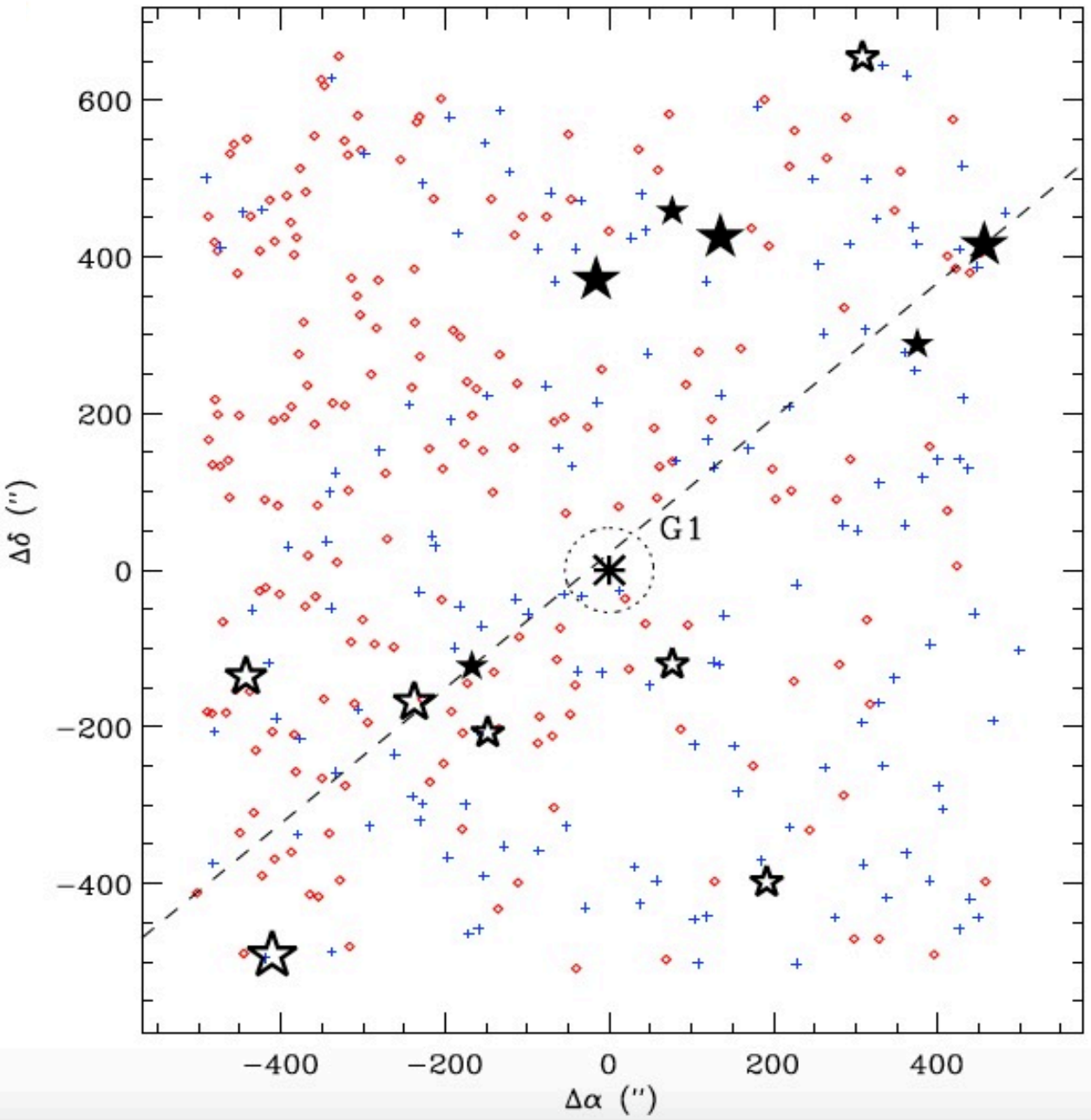



trailing tail
orbit
Pal 5
leading tail
Pal 5
Sun

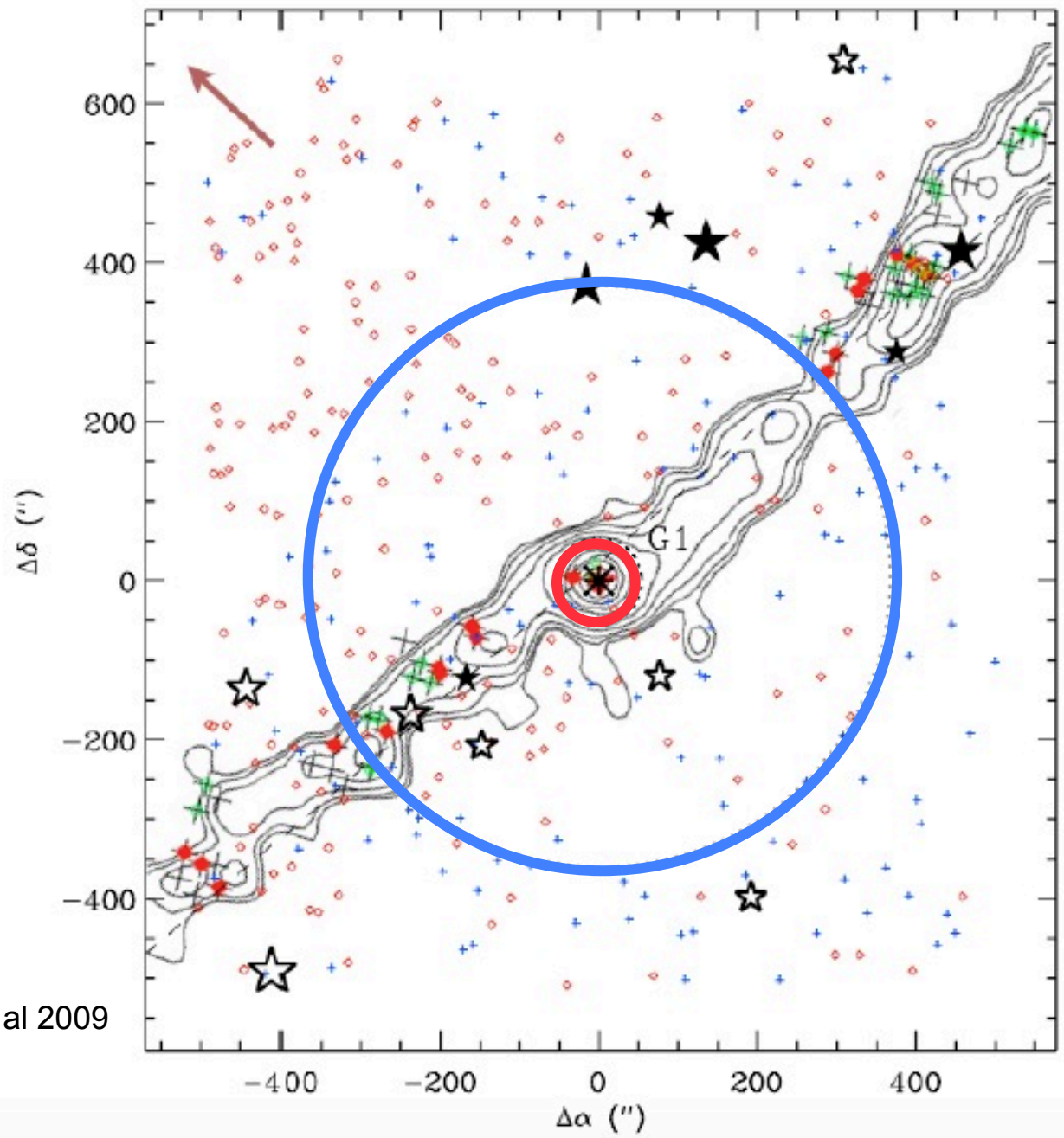
We used DEIMOS to measure velocities of 351 RGB stars around G1 to look for evidence of stripping


stars in M31's disk
G1 stars
stars in the Milky Way
NGC 205
M31
M32
M31 G1
(Mayall II)
N
Velocity (km/s)
0
5
10
15
20
25
30
35
−600
−500
−400
−300
−200
−100
0

Spatial distribution of stars within +/- 25 km/s of G1

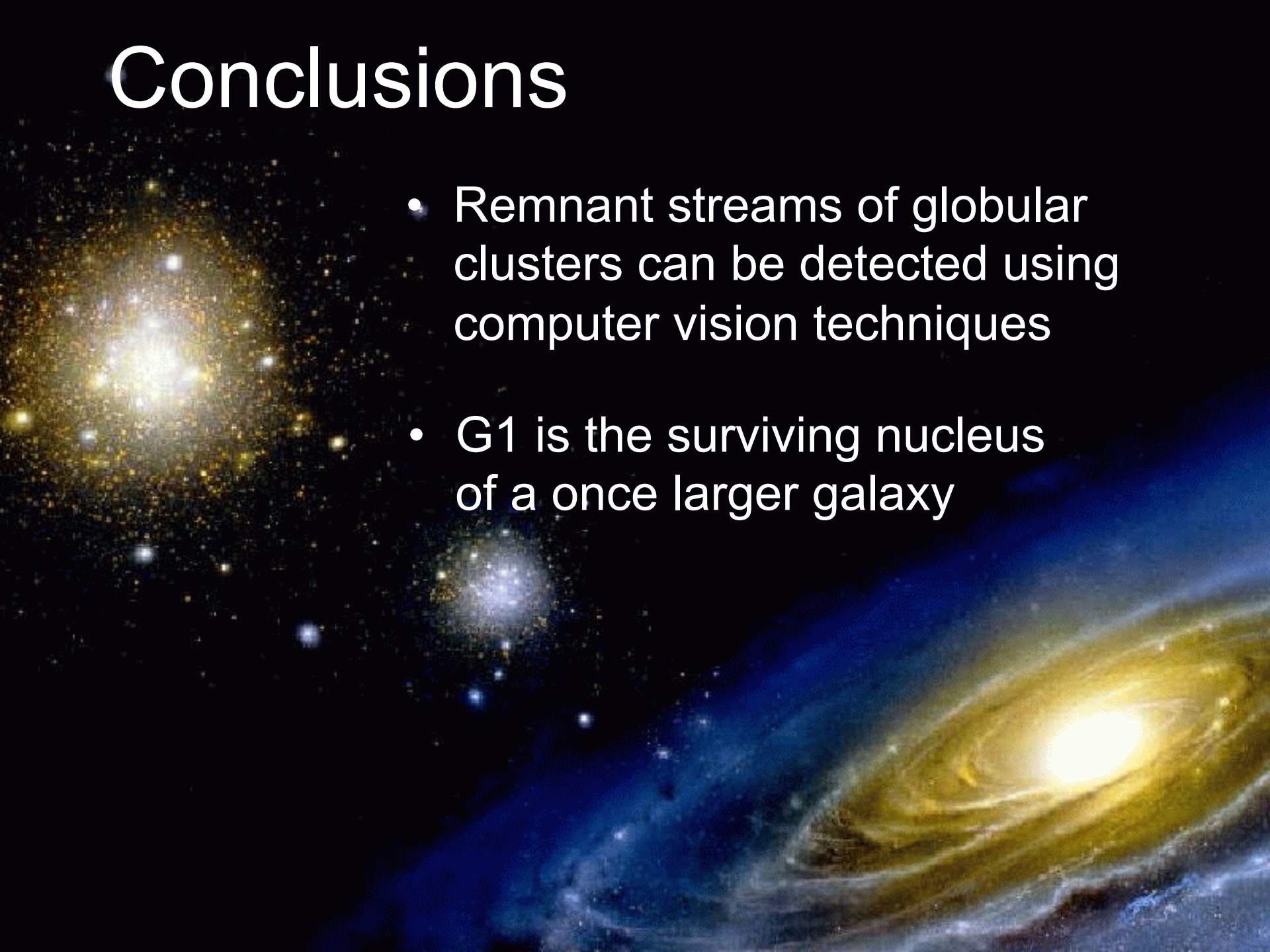


G1 stream compared to Pal 5 stream

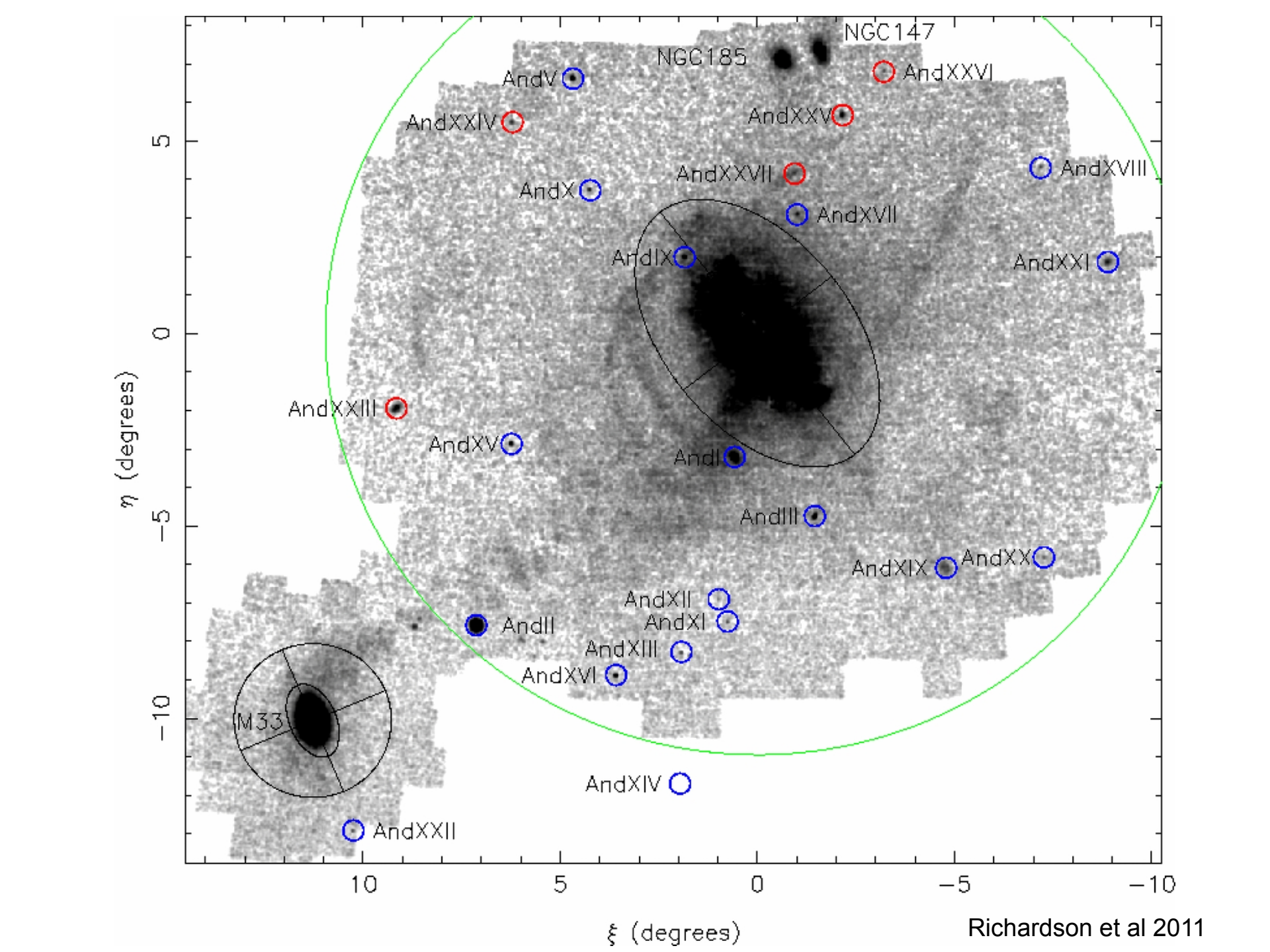


Odenkirchen et al 2009

Conclusions



- Remnant streams of globular clusters can be detected using computer vision techniques
- G1 is the surviving nucleus of a once larger galaxy



Richardson et al 2011

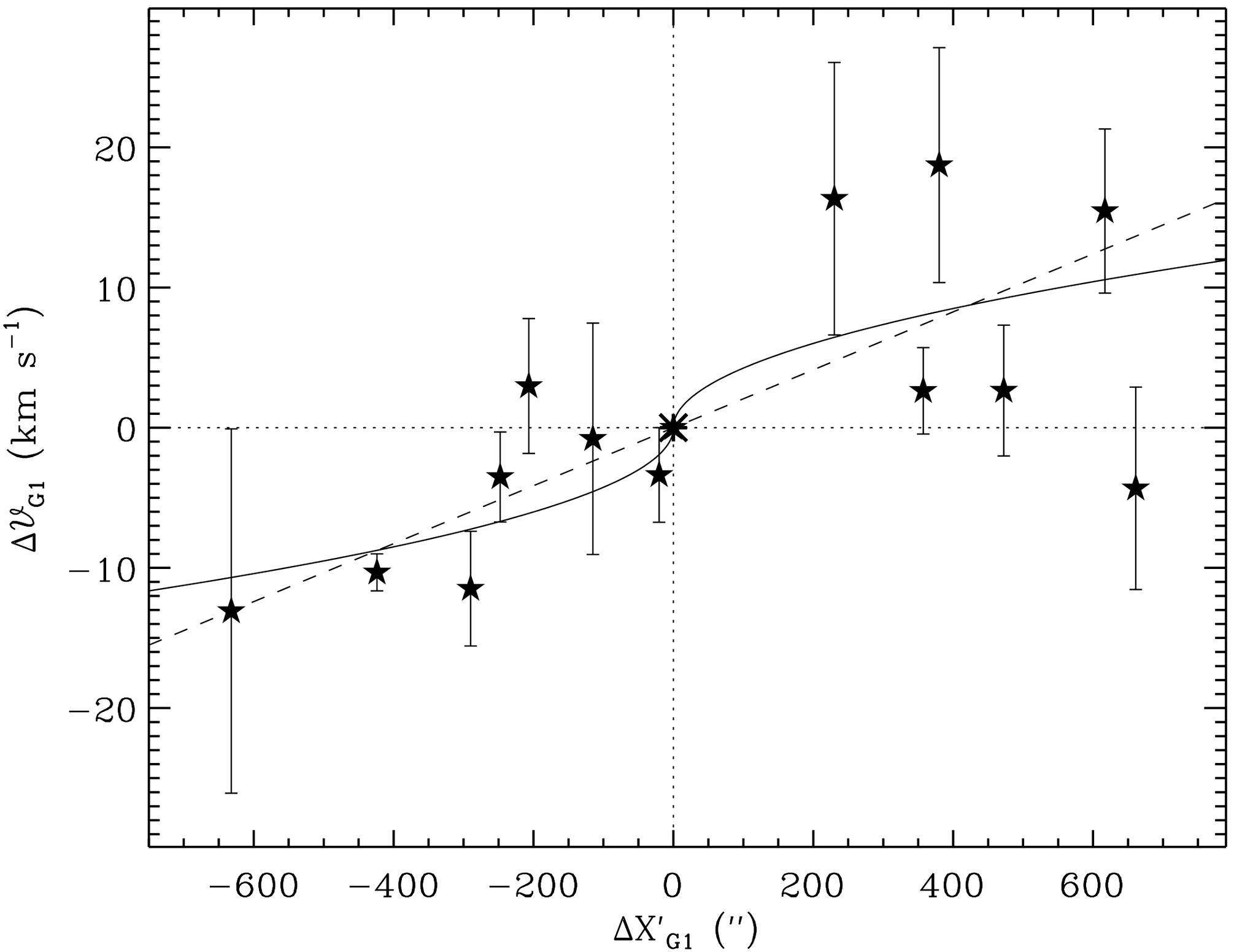



Figure 6