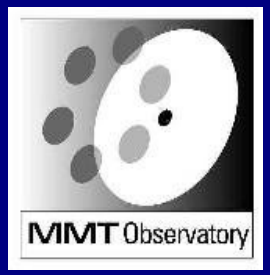
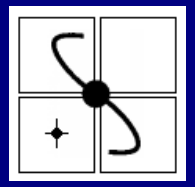
Mapping the Asymmetric Thick Disk – The Hercules Thick Disk Cloud

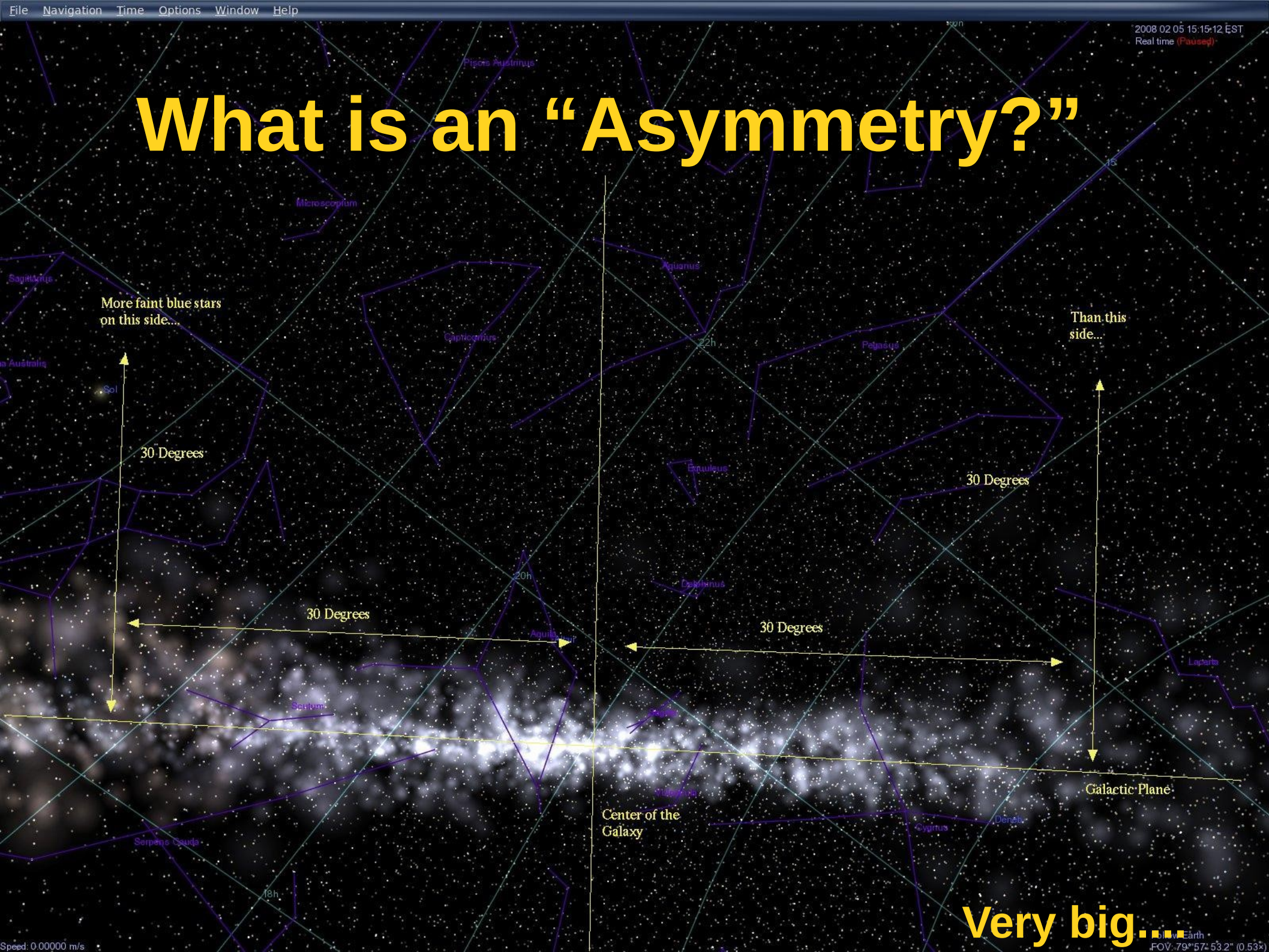




Jeffrey A. Larsen, United States Naval Academy

Roberta M. Humphreys, University of Minnesota

Juan E. Cabanela, Minnesota State University Moorhead


File Navigation Time Options Window Help
2008 02 05 15:15:12 EST
Real time (Paused)
What is an "Asymmetry?"
More faint blue stars on this side....
30 Degrees
30 Degrees
Than this side...
30 Degrees
30 Degrees
Galactic Plane
Center of the Galaxy
Very big....
Sol
Microscopium
Aquarius
Capricornus
Pegasus
Equuleus
Delphinus
Aquila
Scutum
Serpens Cauda
Cygnus
Deneb
Lacerta
22h
20h
18h
Speed: 0.00000 m/s
FOV: 79°57'53.2" (0.53x)

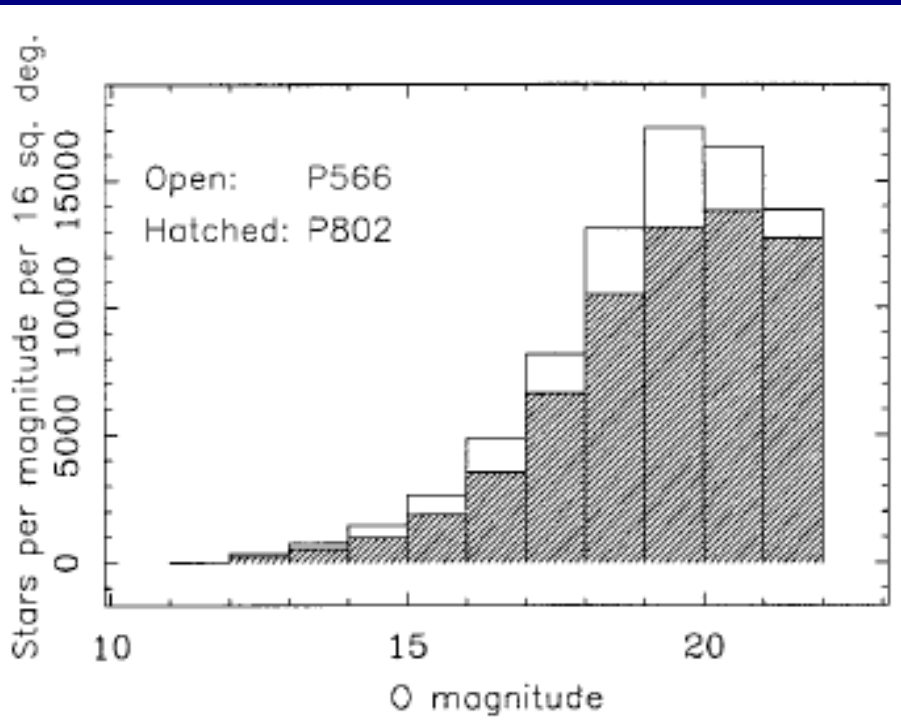
Larsen and Humphreys (1996)

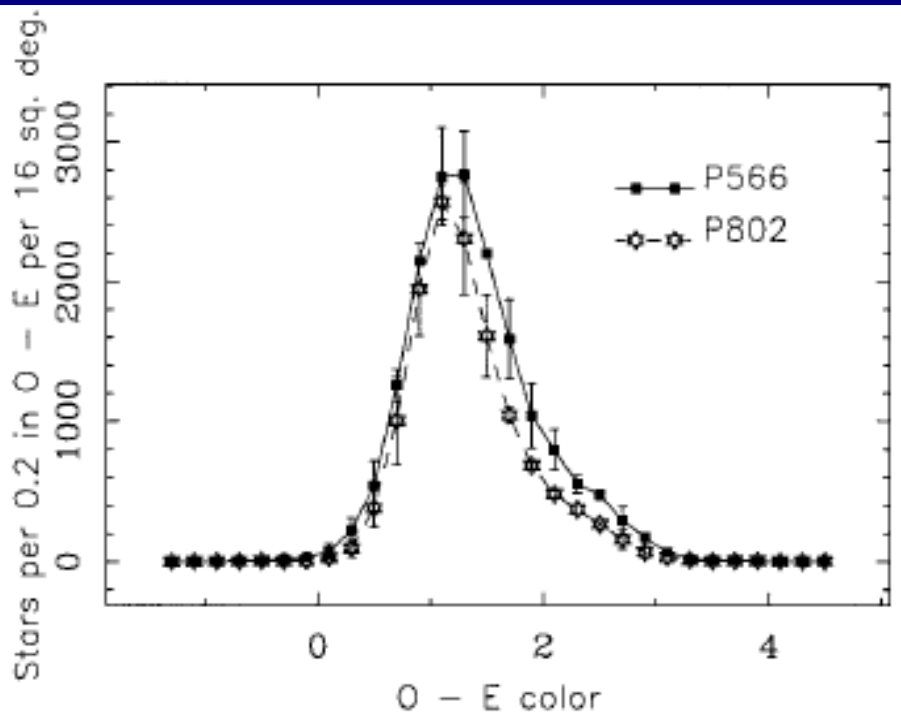
Minnesota Automated Plate Scanner (MAPS)

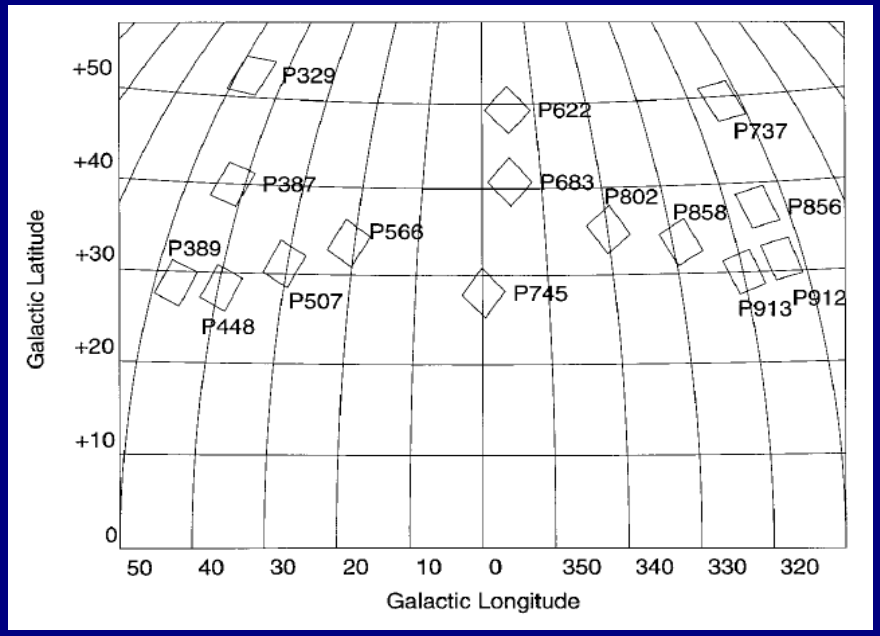
Digitized Palomar Observatory Sky Survey (POSS I) between 1990 and 1996 with |b| > 20

16 square degree fields, with color and class.

Complete to ~20 magnitude in blue (103a-O) and red (103a-E) emulsions.



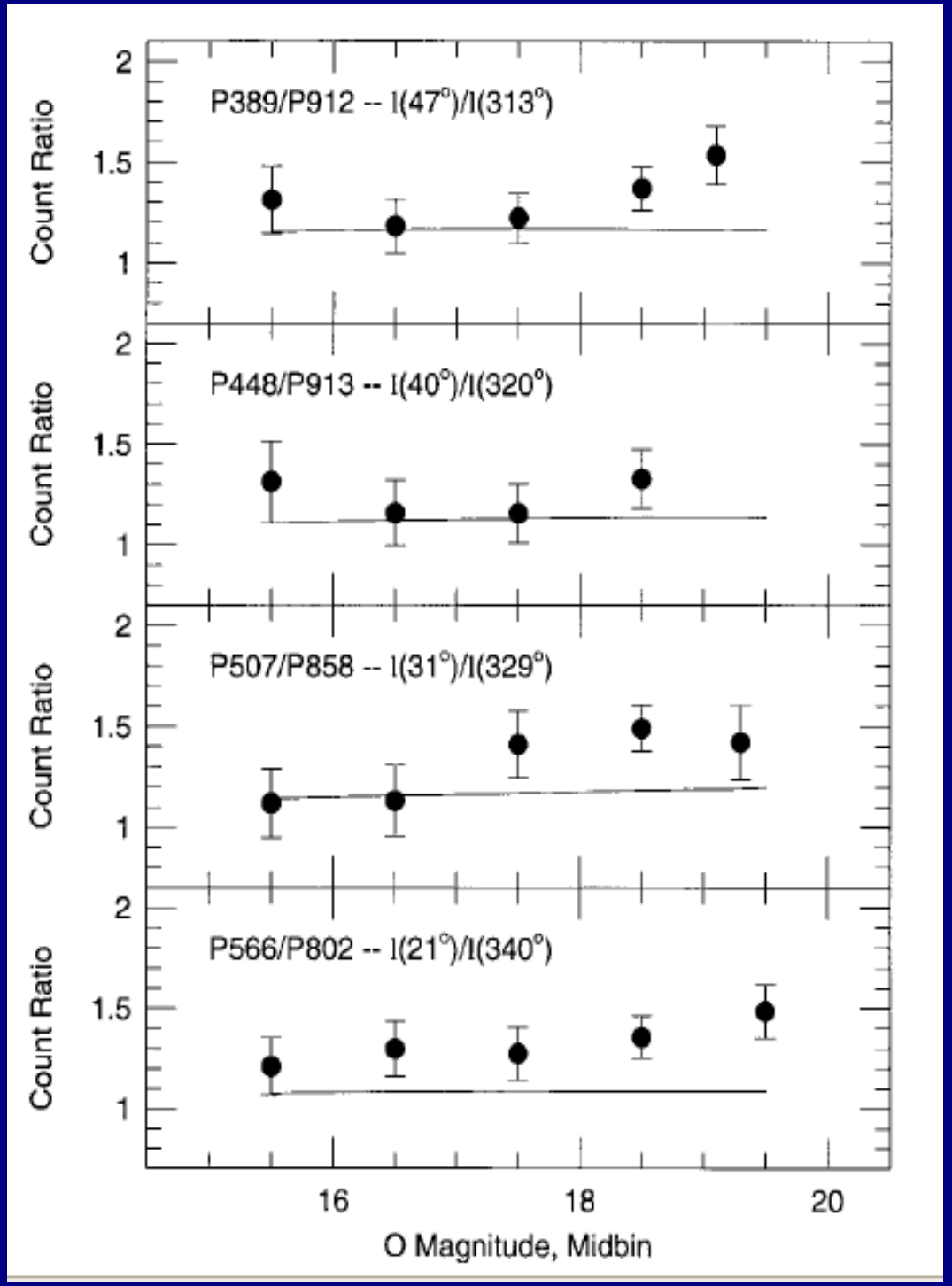




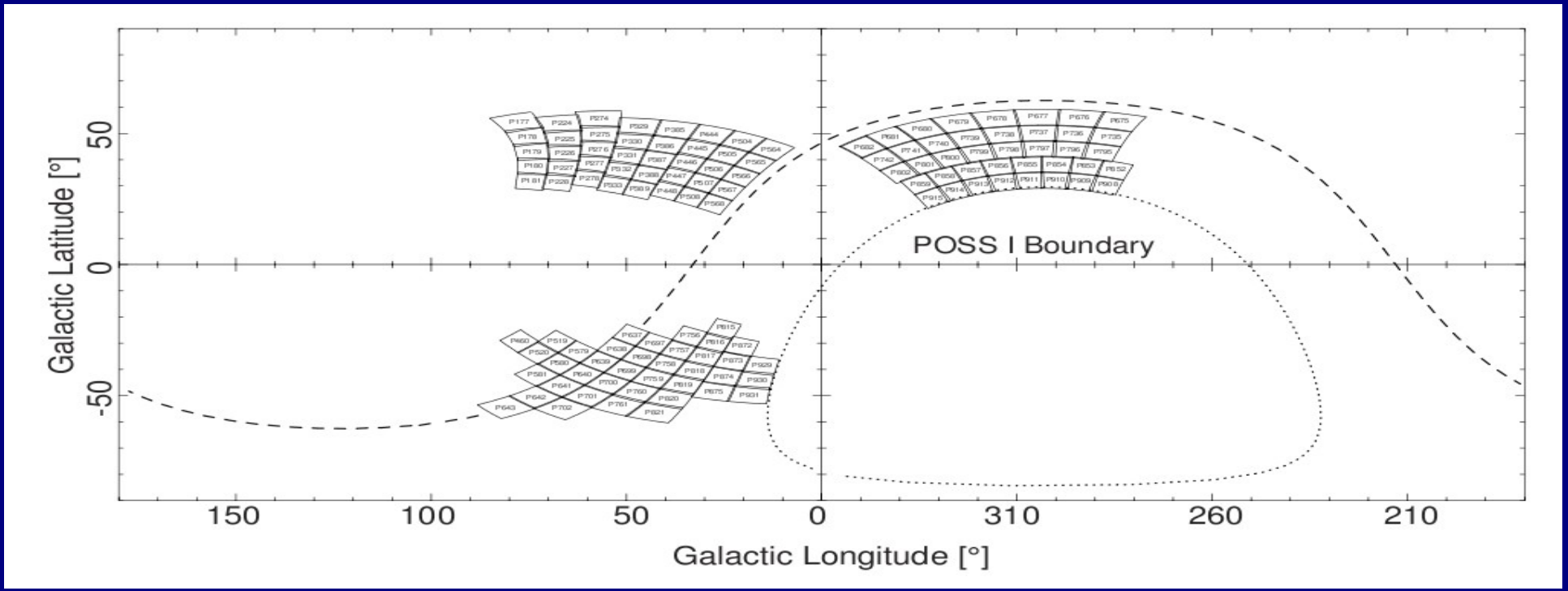
Found while trying to probe overall shape of various components.

Excess was faint bluer (late G, early F) stars in the field. Close (~3 kpc).

The feature was large! ~30 degrees on the sky!



Parker, Humphreys and Larsen (2003)
Parker, Humphreys and Beers (2004)

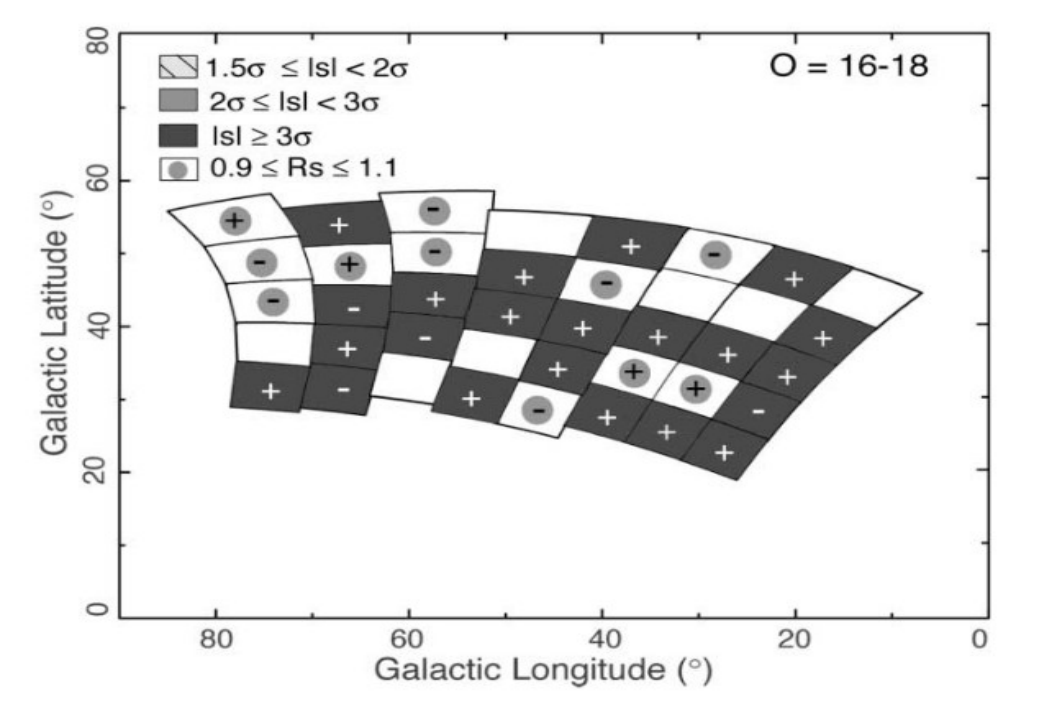


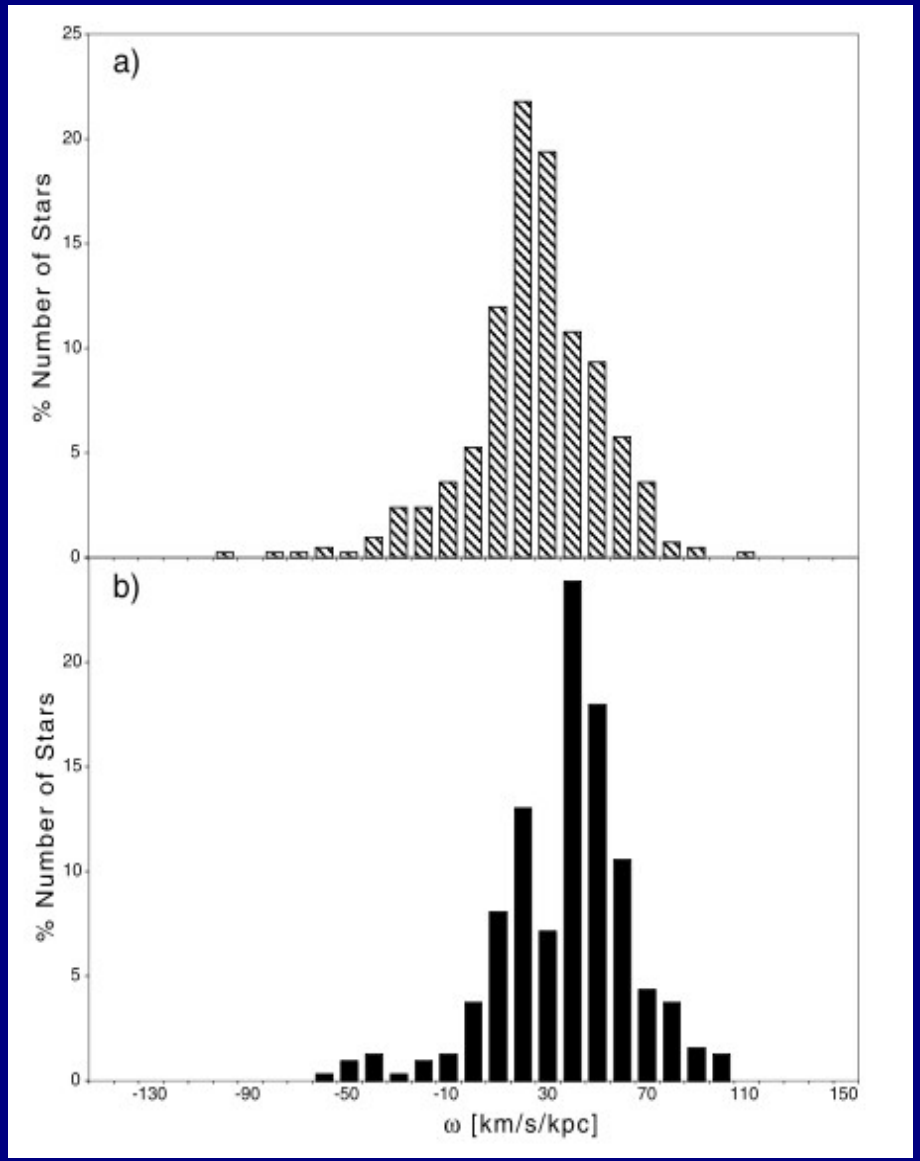
Extended spectroscopic and star count study of the excess which targeted the region around the initial discovery.

Main results:

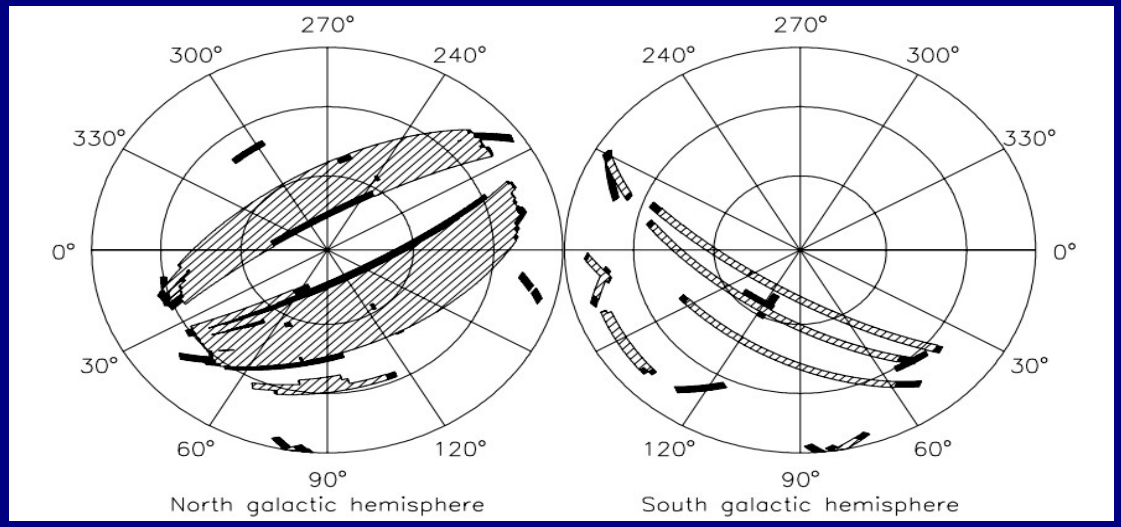
Feature was indeed large and continuous.

There was a measurable difference in rotation velocities between Q1 and Q4.



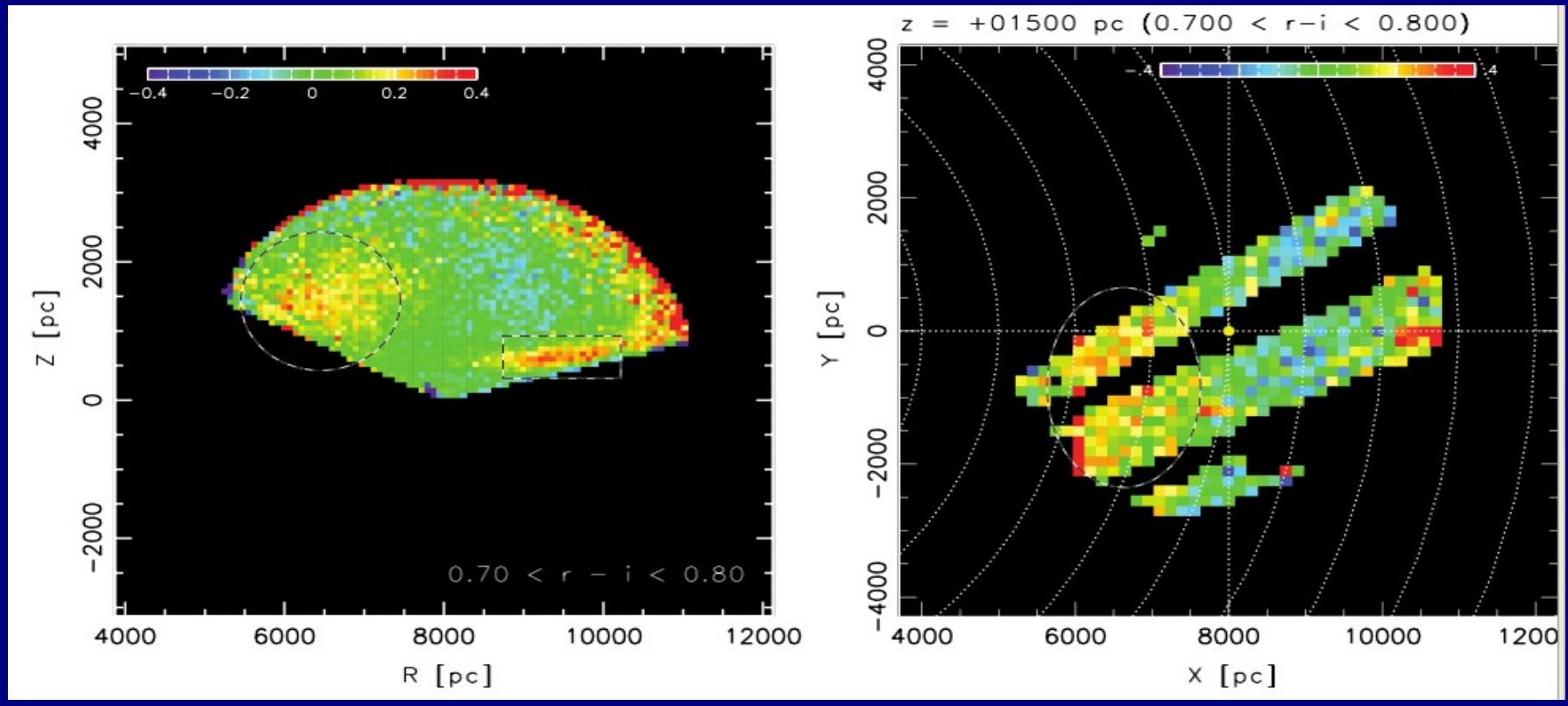


Juric et al. (2008)

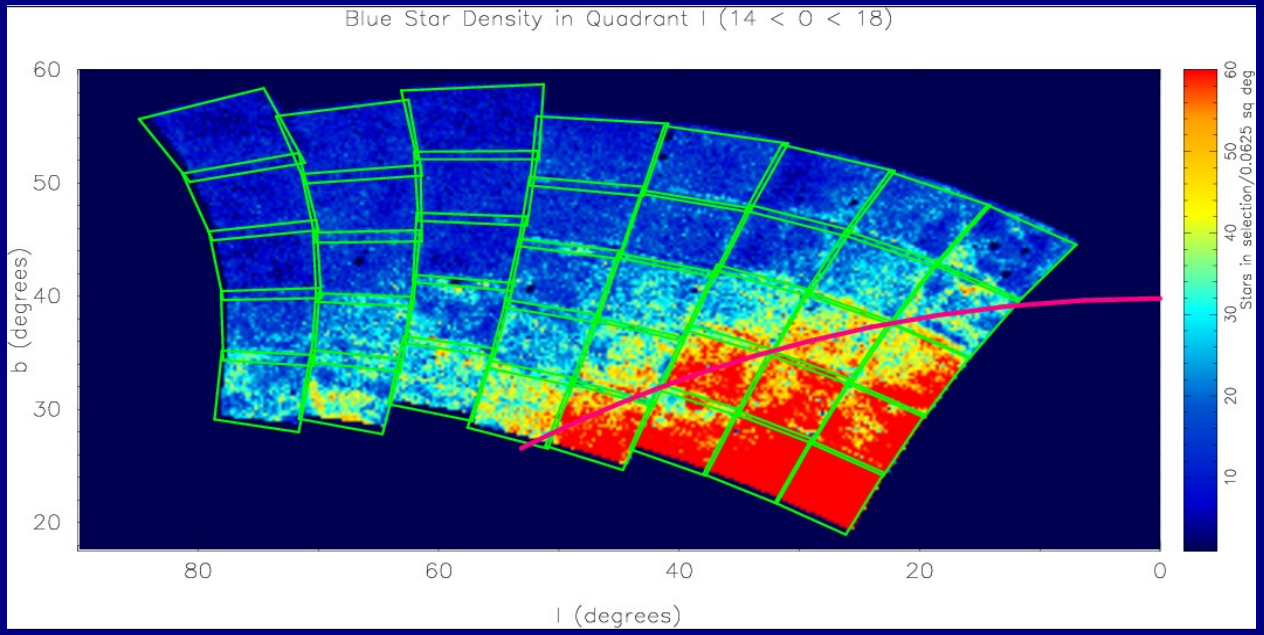


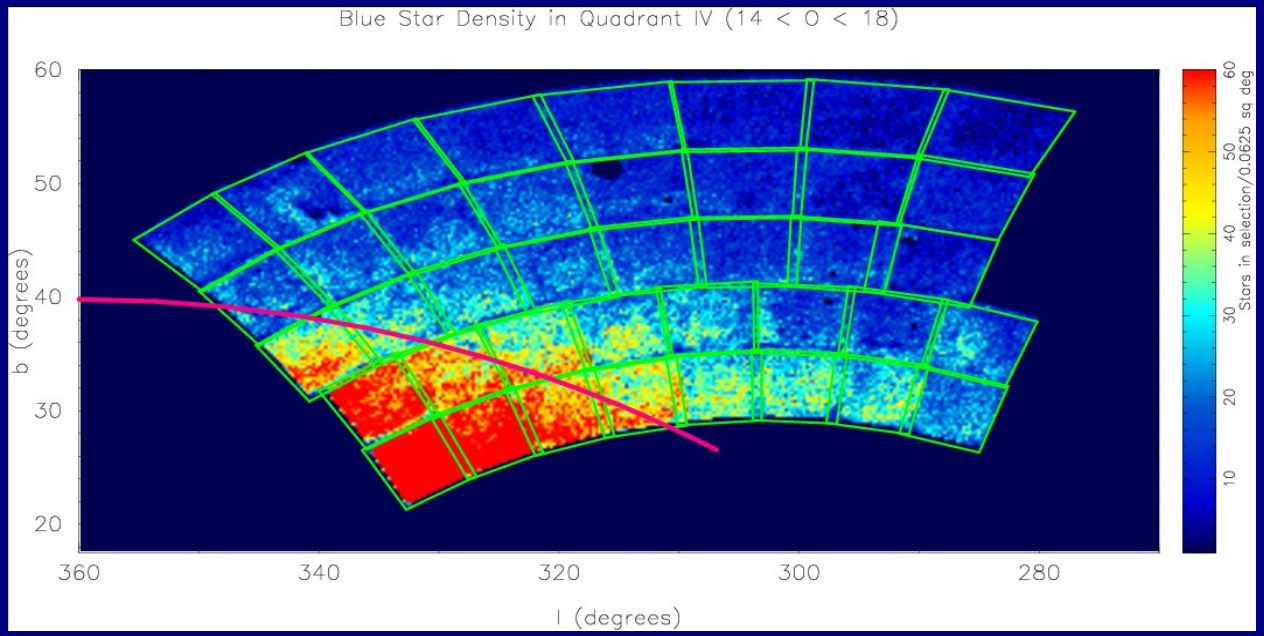
Photometric parallax.

Found this excess at the lowest galactic latitudes surveyed by SDSS.



Is it a ring? Larsen (2008)





APS plate data using entire plates (messy to work with!)

Shows stars with O < 20 and colors blueward of B-V = 0.6 (O-E = 1)

Feature higher in Q1 (top) than Q4 (bottom).

The purpose of this project:

This asymmetry (named the Hercules Thick Disk Cloud) is an interesting feature needing further study!

Distinguish between three competing origin scenarios:

1) A triaxial thick disk.

2) Interaction of thick disk stars with the bar.

3) It is a merger remnant.

Imaging Program

67 fields, ~1 square degree each.

UBVR photometry for 1.2 million stars.

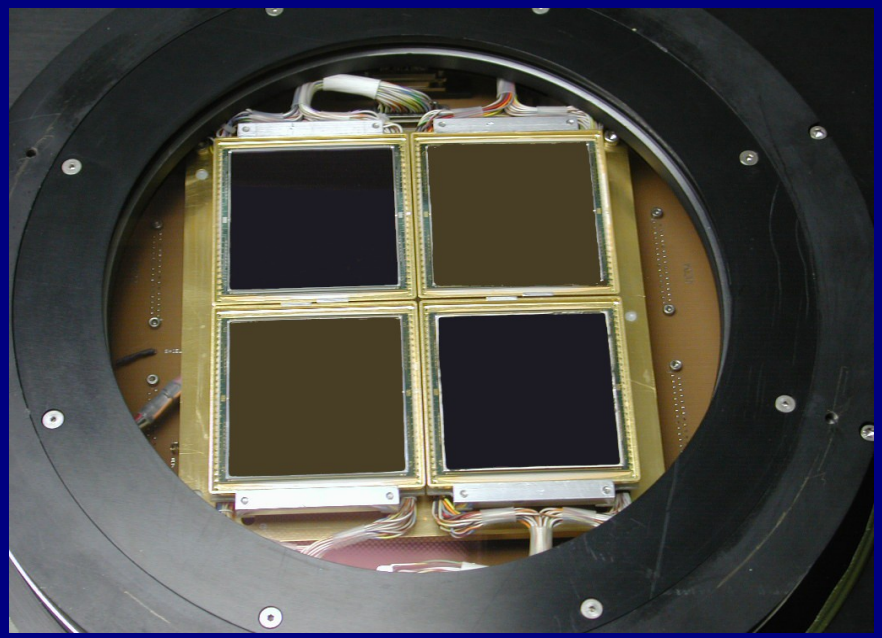
Southern Hemisphere: 18 fields from SMARTS 1.0 meter telescope with Y4KCam imager. Typically complete to V=19.0.

Single image f.o.v. ~ 0.25 square degrees, 9 images per field.

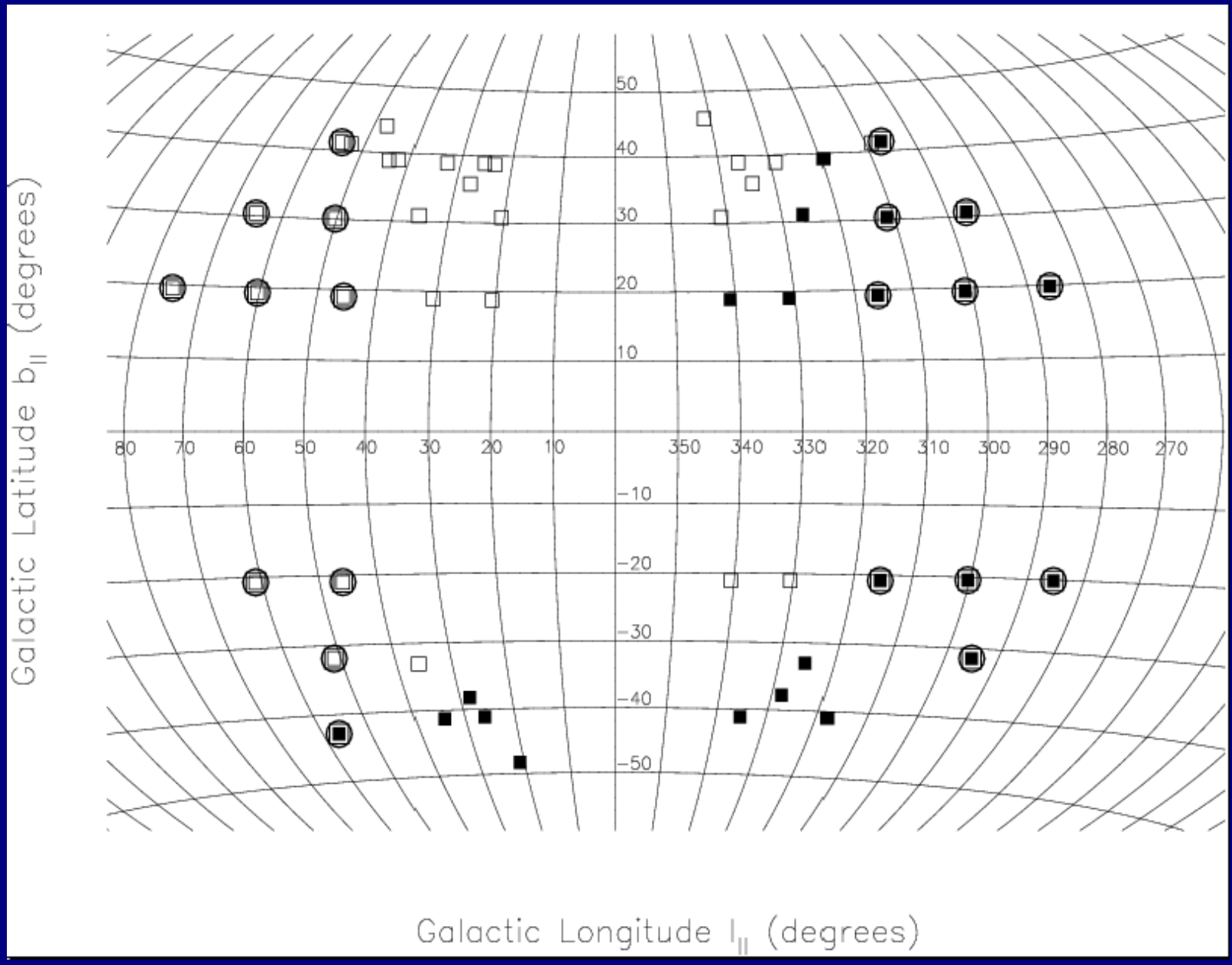
Northern Hemisphere: 49 fields from Bok 2.3 meter telescope with 90Prime imager. Typically complete to V=21.

Single image f.o.v. ~1.04 square degrees.

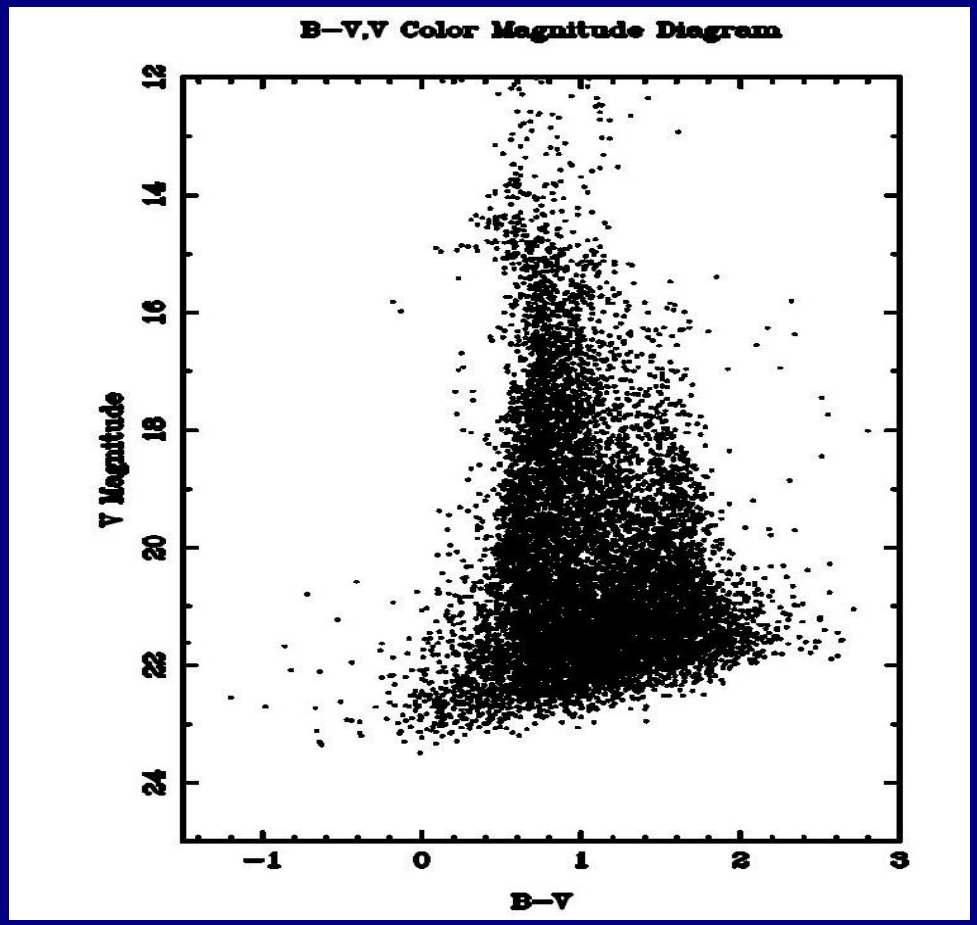
p

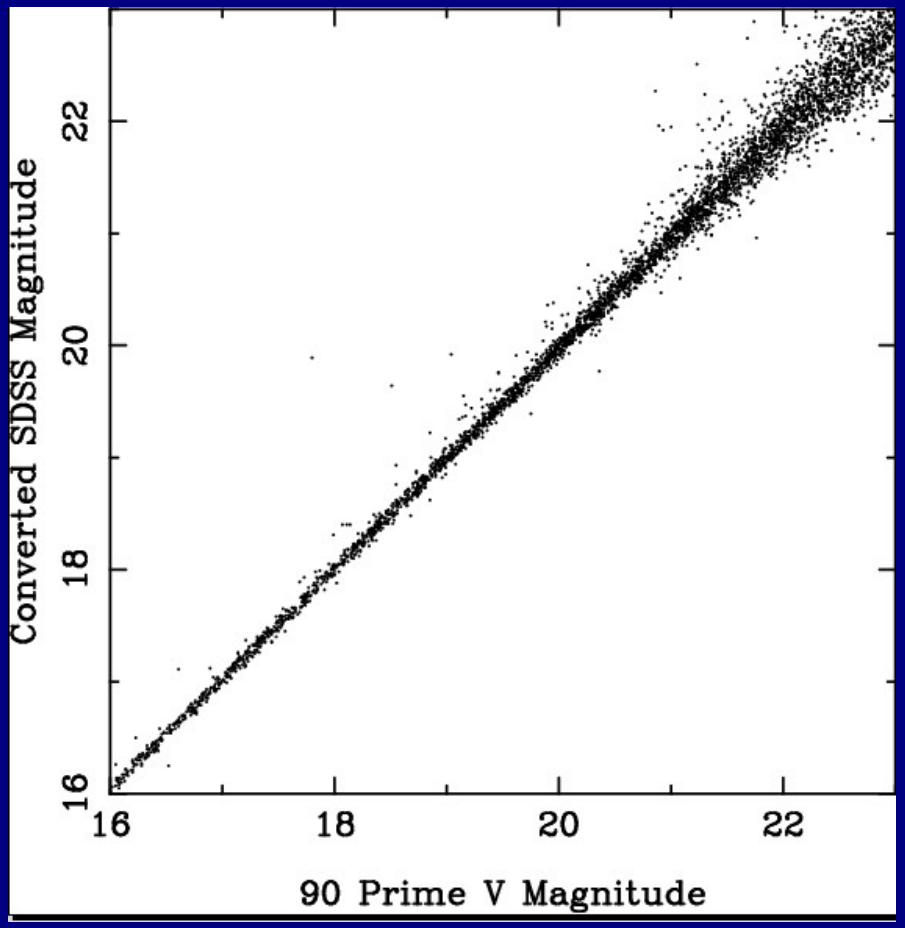


Distribution of program fields on the sky designed to allow for comparisons based on symmetry of lines of sight.

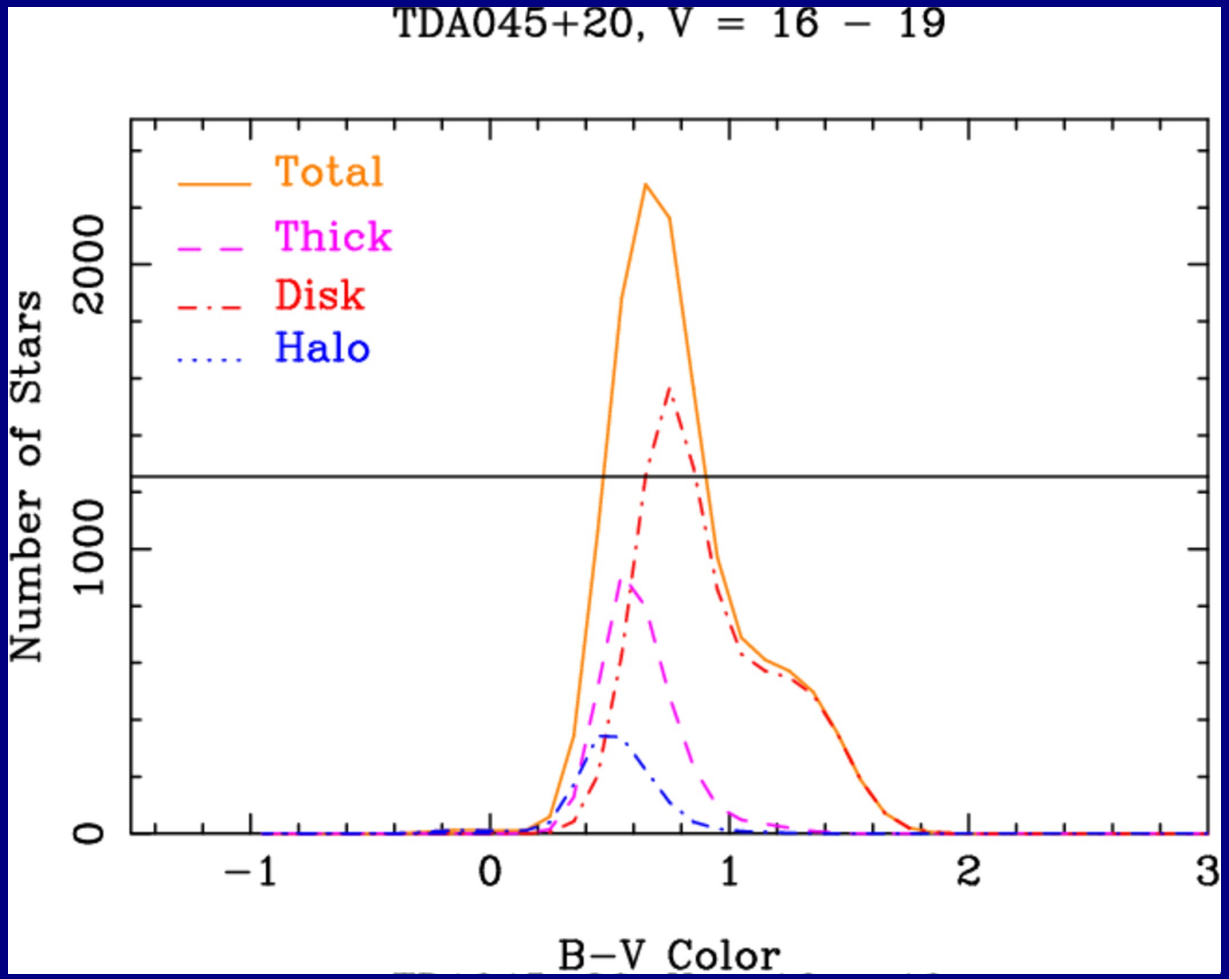


Sample C-M diagram and photometric comparison.





Analysis Philosophy



Model independence as much as possible – use symmetry!

Galactic star count model: GALMOD (Larsen 2004), based on Bahcall/Soneira and Gilmore/Reid models.

Used to determine effective color cuts and identify dominant populations in various color-mag domains.

Star Count Technique

For our analysis:

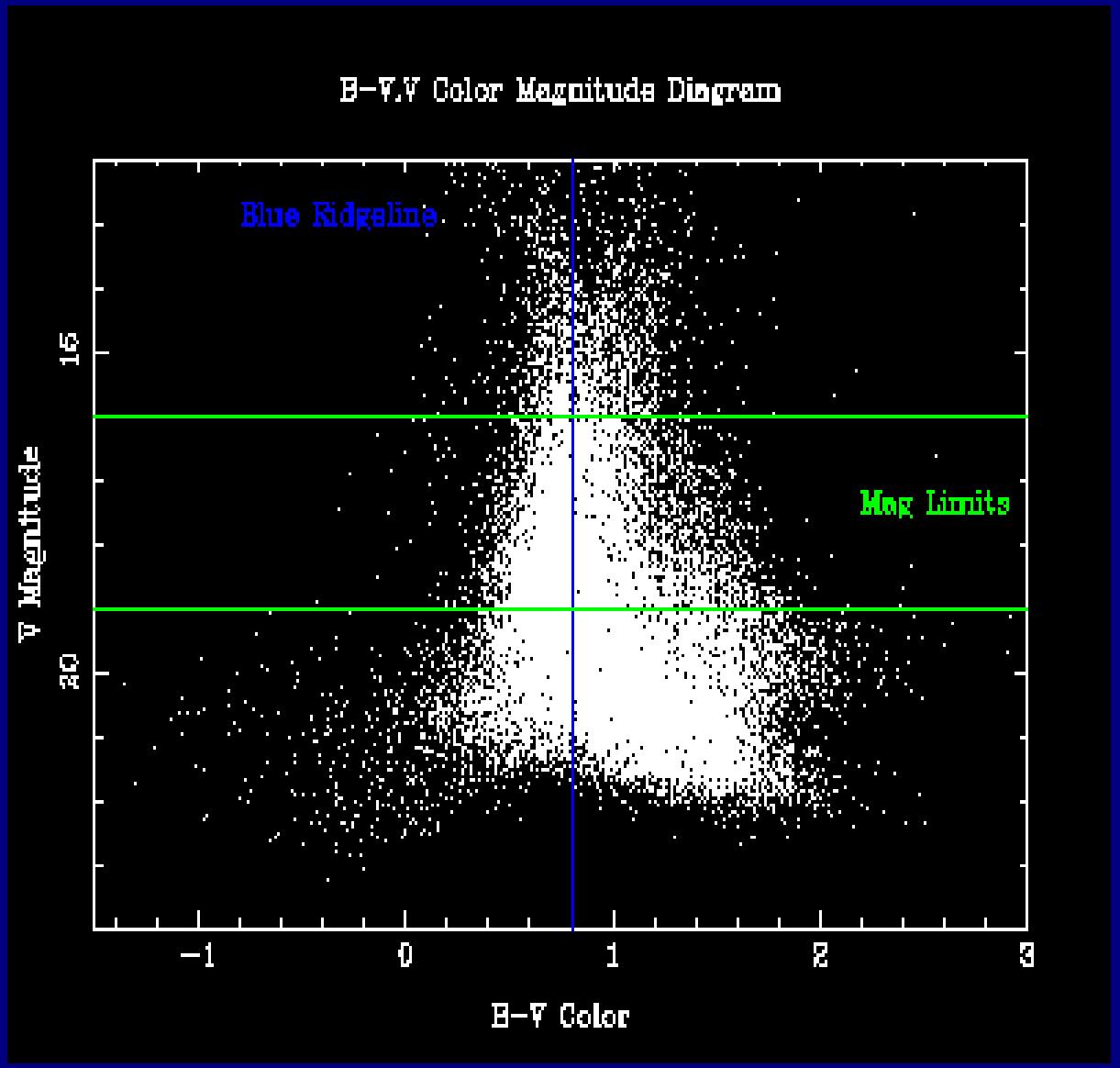
1) Completeness

2) Correct for extinction (Schegel, 1998)

3) Isolation of magnitude range.

4) Identification of fiducial features (e.g. The “Blue Ridge.”)

5) Performance of star counts using a range of colors determined by GALMOD. 16-19 typically.



Example CTIO field from October 2008
Complete to 20.0 in V.

Results - High Galactic Longitude Fields

Field Ratio	GALMOD Ratio Predictions			Observed Count Ratios		
	16 < V < 19	17 < V < 18	18 < V < 19	16 < V < 19	17 < V < 18	18 < V < 19
Quadrant 1 / Quadrant 4 ratios above the Galactic Plane						
E45N20 / W45N20	**1.00**	**1.00**	**1.00**	**1.14 ± 0.04**	**1.21 ± 0.02**	**1.00 ± 0.05**
E50N31 / W50N31	**1.00**	**1.00**	**1.00**	**1.22 ± 0.08**	**1.28 ± 0.09**	**1.08 ± 0.09**
E55N42 / W55N42	1.00	1.00	1.00	1.02 ± 0.08	0.98 ± 0.11	0.99 ± 0.10
E60N20 / W60N20	1.00	1.00	1.00	1.03 ± 0.04	1.01 ± 0.07	0.93 ± 0.06
E65N31 / W65N31	1.00	1.00	1.00	1.01 ± 0.07	1.07 ± 0.11	0.82 ± 0.09
E57N20 / W75N20	1.00	1.00	1.00	1.01 ± 0.04	0.97 ± 0.07	0.96 ± 0.07
Quadrant 1 / Quadrant 4 ratios below the Galactic Plane						
E45S20 / W45S20	1.00	1.00	1.00	0.94 ± 0.03	1.01 ± 0.06	0.87 ± 0.04
E60S20 / W60S20	1.00	1.00	1.00	1.00 ± 0.04	0.89 ± 0.05	1.17 ± 0.07
Quadrant 1 ratios above/below the Galactic Plane						
E45N20 / E45S20	**0.94**	**0.94**	**0.97**	**1.13 ± 0.04**	**1.18 ± 0.06**	**1.10 ± 0.05**
E50N31 / E50S31	**0.97**	**0.97**	**0.98**	**1.13 ± 0.04**	**1.17 ± 0.11**	**1.04 ± 0.09**
E60N20 / E60S20	0.94	0.93	0.96	0.90 ± 0.05	0.86 ± 0.06	0.84 ± 0.05
Quadrant 4 ratios above/below the Galactic Plane						
W45N20 / W45S20	0.94	0.94	0.97	0.94 ± 0.04	0.94 ± 0.06	0.92 ± 0.05
W60N20 / W60S20	0.94	0.93	0.96	0.82 ± 0.05	0.73 ± 0.04	1.00 ± 0.07

The excess does NOT exist at high longitudes.
Displayed only by the two closest fields.

Preliminary Results from full imaging dataset.

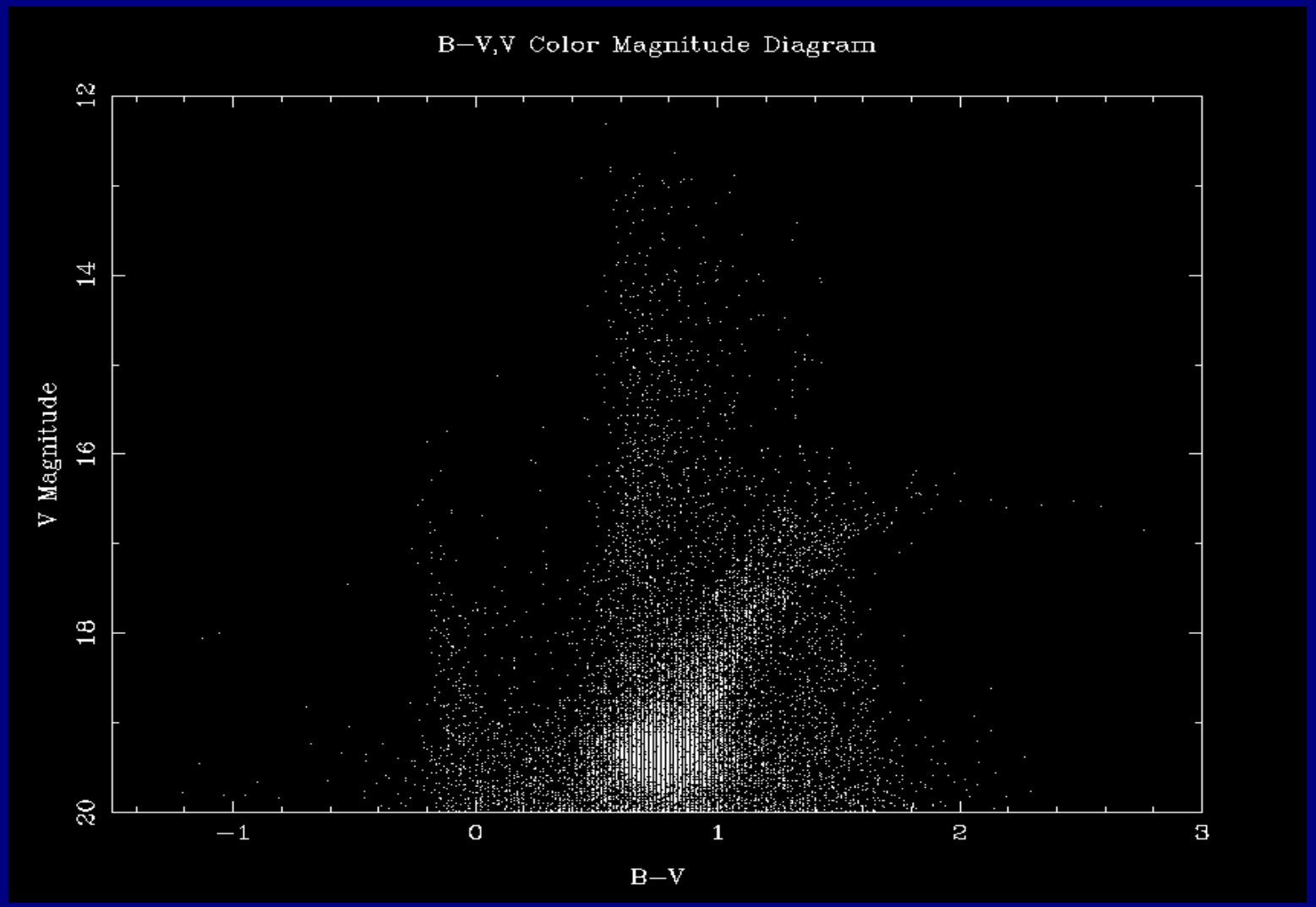
1) Analyze entire imaging data set.

2) Preliminary in that only symmetries across l=0 are considered (above/below plane involves model).

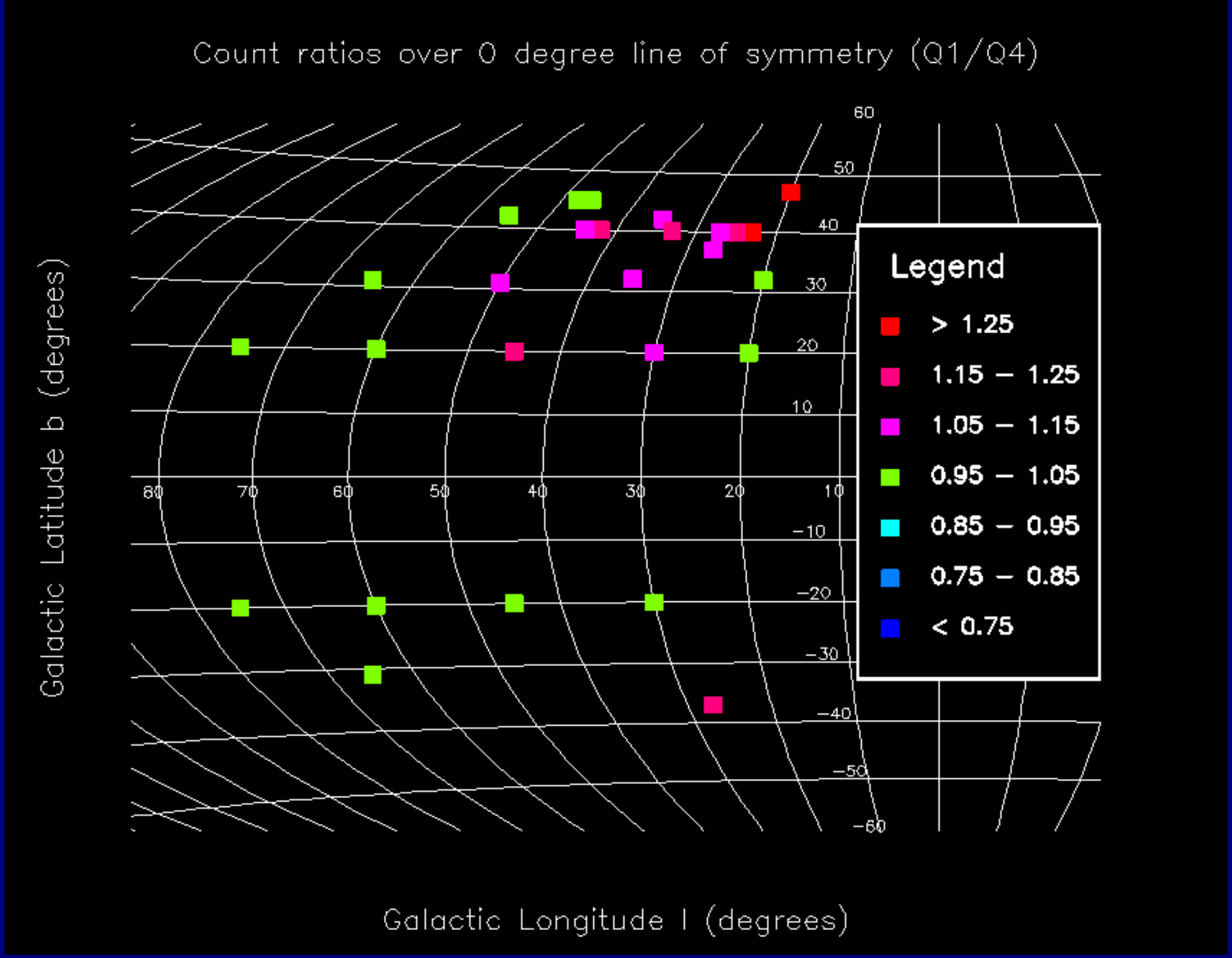
3) Also preliminary in that it only uses one color.

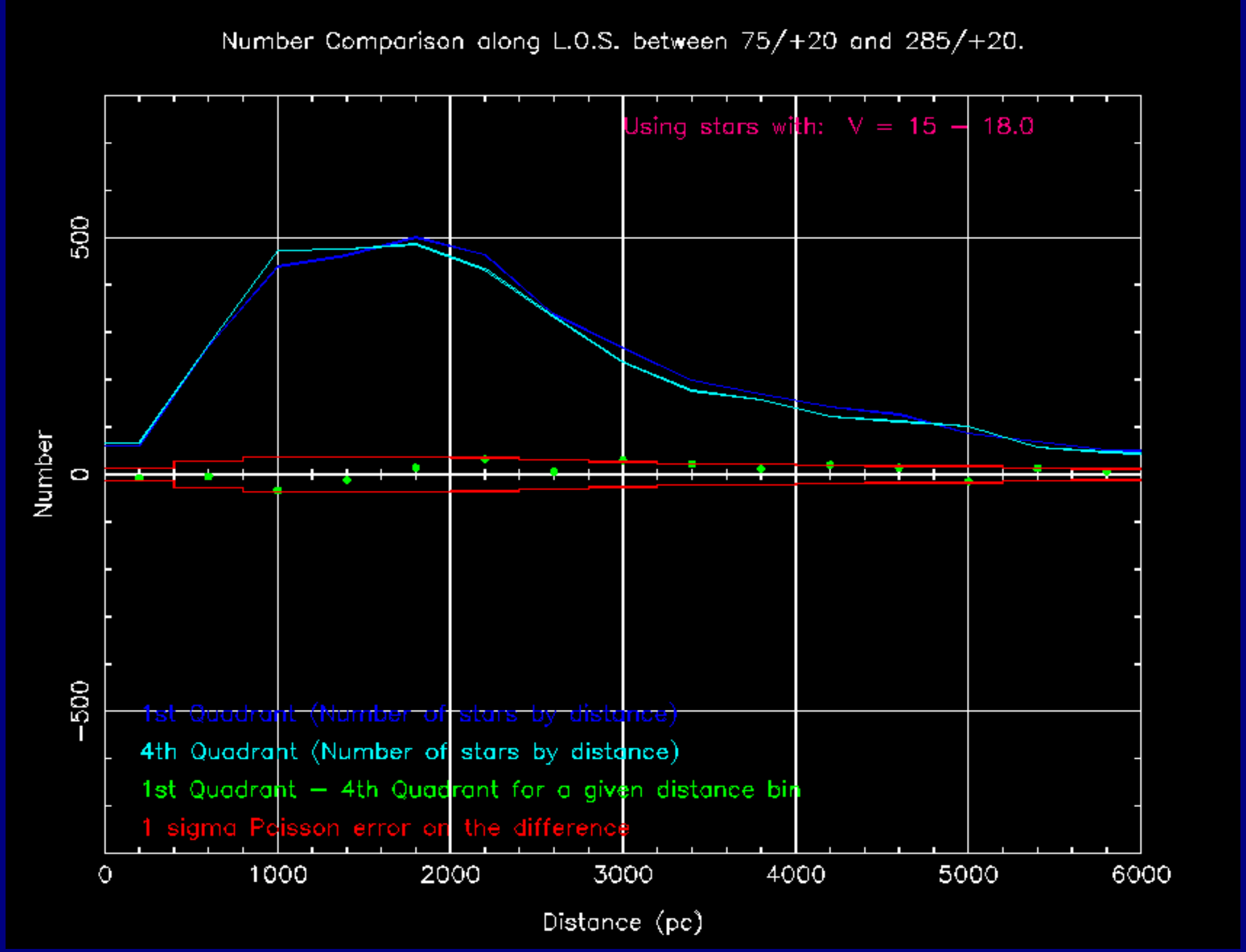
and...

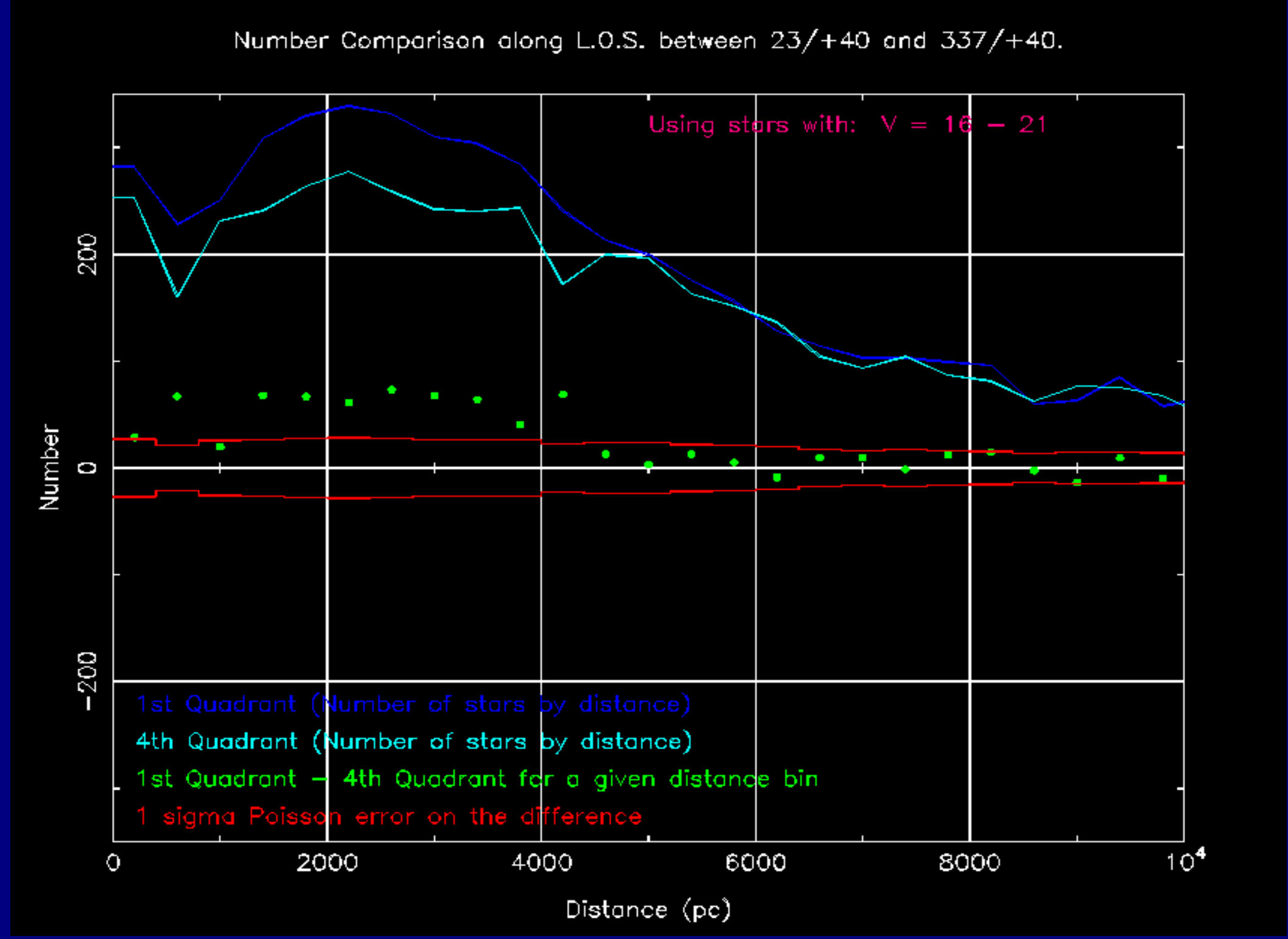
At least one field pair “contaminated”



Nowhere near Segue/SDSS fields....
MAY be associated with Cetus Polar Stream


Count ratios over 0 degree line of symmetry (Q1/Q4)
Galactic Latitude b (degrees)
Galactic Longitude l (degrees)
Legend
> 1.25
1.15 – 1.25
1.05 – 1.15
0.95 – 1.05
0.85 – 0.95
0.75 – 0.85
< 0.75
60
50
40
30
20
10
−10
−20
−30
−40
−50
−60
80
70
60
50
40
30
20
10


Number Comparison along L.O.S. between 75/+20 and 285/+20.
Using stars with: V = 15 – 18.0
500
0
−500
Number
1st Quadrant (Number of stars by distance)
4th Quadrant (Number of stars by distance)
1st Quadrant – 4th Quadrant for a given distance bin
1 sigma Poisson error on the difference
0
1000
2000
3000
4000
5000
6000
Distance (pc)


Number Comparison along L.O.S. between 23/+40 and 337/+40.
Using stars with: V = 16 – 21
200
0
−200
Number
1st Quadrant (Number of stars by distance)
4th Quadrant (Number of stars by distance)
1st Quadrant – 4th Quadrant for a given distance bin
1 sigma Poisson error on the difference
0
2000
4000
6000
8000
10^4
Distance (pc)

Estimate of size/mass.

Typical 1 square degree field has ~500 stars blueward of the blue ridge belonging to the excess. (Late F/early G).

Over entire 500 square degree field of view, that's 250000 F/G type stars.

Estimated total mass of feature assuming the turnoff color is close to this and the feature has a solar neighborhood luminosity function: a couple million solar masses!

Spectroscopy --- Kinematics and Metallicities

Parker, Humphreys and Beers (2004) found a kinematic signature associated with the Thick Disk stars that showed the star count excess:

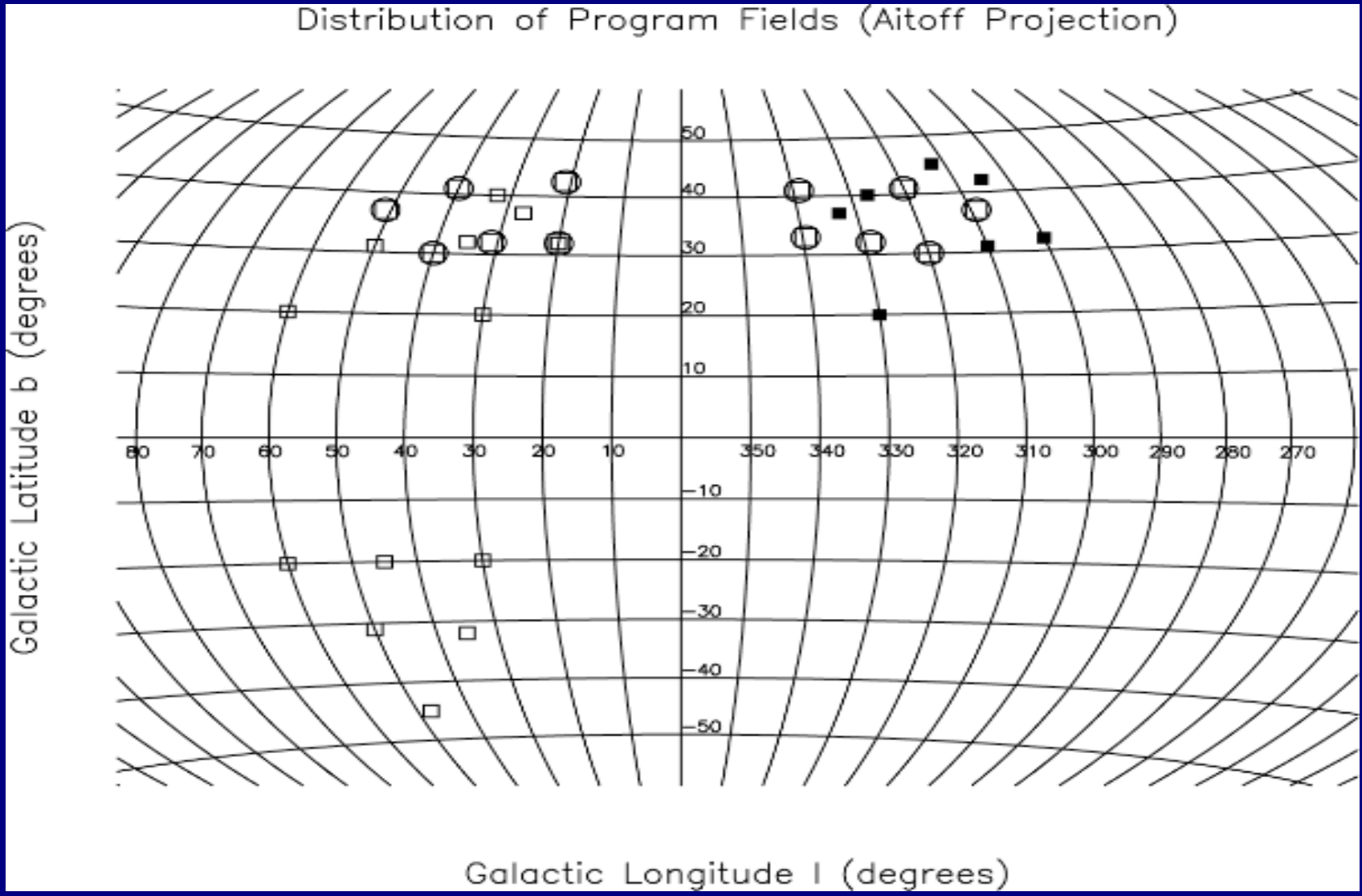
--- a slower effective rotation rate (VLSR and ω) in Q1 that is longitude dependent, a solution for the radial, tangential and vertical components yielded a significant lag of 80 –90 km/s in the direction of galactic rotation.

--- in Q4 the same population had only a 20 km/s lag

We have greatly extended this work to more fields and fainter magnitudes

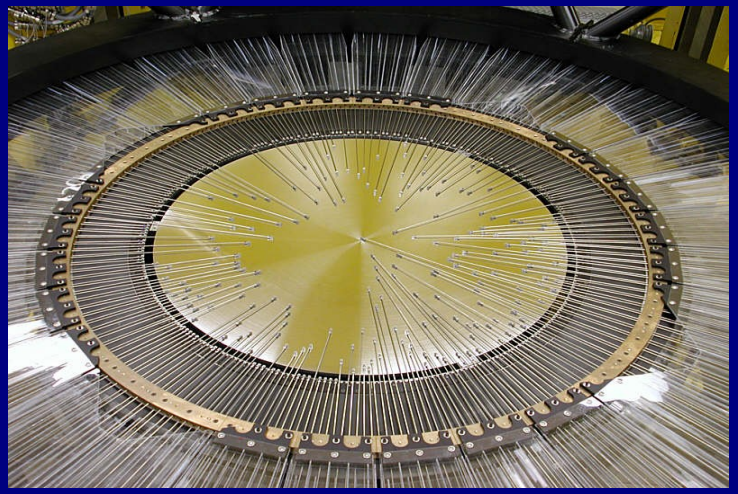
Parker et al --- 12 fields (6 each Q1 and Q4 above plane)
this program -- added 20 new fields, above and below plane

Distribution of Project Fields



Open squares are MMT/Hectospec, filled squares CTIO/Hydra, circles Parker 2004

Observations at MMT (6.5m)

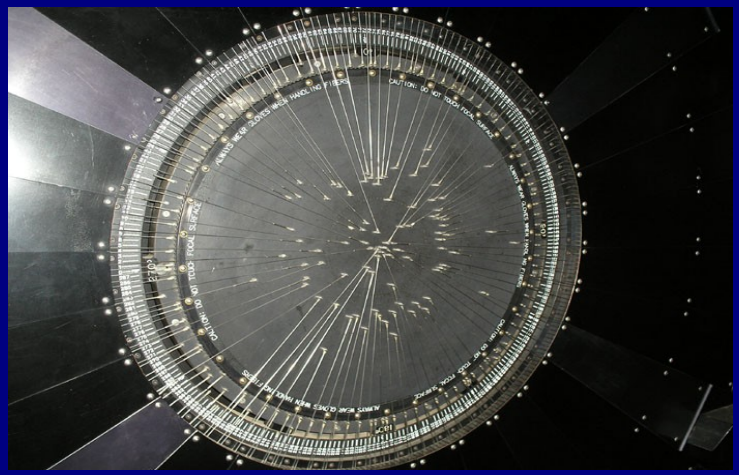


- Hectospec 300 fibers
- 600 l grating (blue – 480 nm)
- 13 fields, spectra V ~ 17 – 19 mag
- 2700 new spectra
- R ~ 9600

Development of **especroad** – exportable Hectospec reduction package

http://iparrizar.mnstate.edu/~juan/research/ESPECROAD/

Observations at CTIO (4m)



- Hydra 138 fibers
- 632 l grating (KPGL-1) (blue – 420 nm)
- 7 fields, spectra V ~ 16 – 18 mag
- 1030 new spectra
- R ~ 4800

Total spectra :

~ 4400 for velocities, spectral types,
and metallicities (in collaboration with Tim Beers)

Preliminary results:

A first –look at the velocities confirms the velocity asymmetry and rotation lag found by Parker et al 2004 in Q1.

Further analysis with respect to distance and population will depend on the metallicities.

Where we're going...

Population separation using multiple colors.

Kinematics as a function of population and metallicity.

Determine size and mass.


Questions?
10/19/2008 19:00