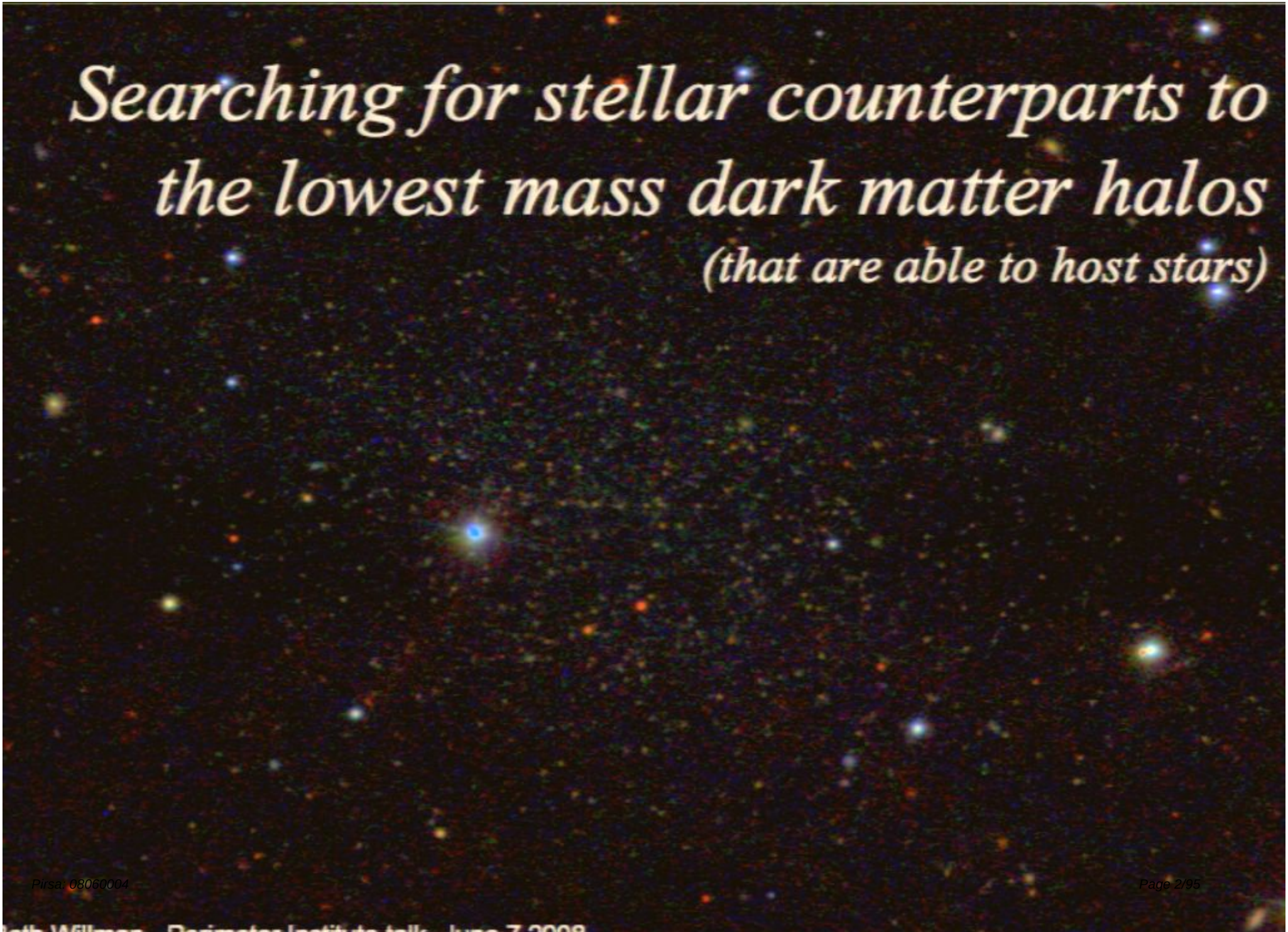
Title: Searching for stellar counterparts to dark matter halos on the smallest possible scales

Date: Jun 07, 2008 09:00 AM

URL: http://pirsa.org/08060004

Abstract:


Searching for stellar counterparts to
the lowest mass dark matter halos
(that are able to host stars)

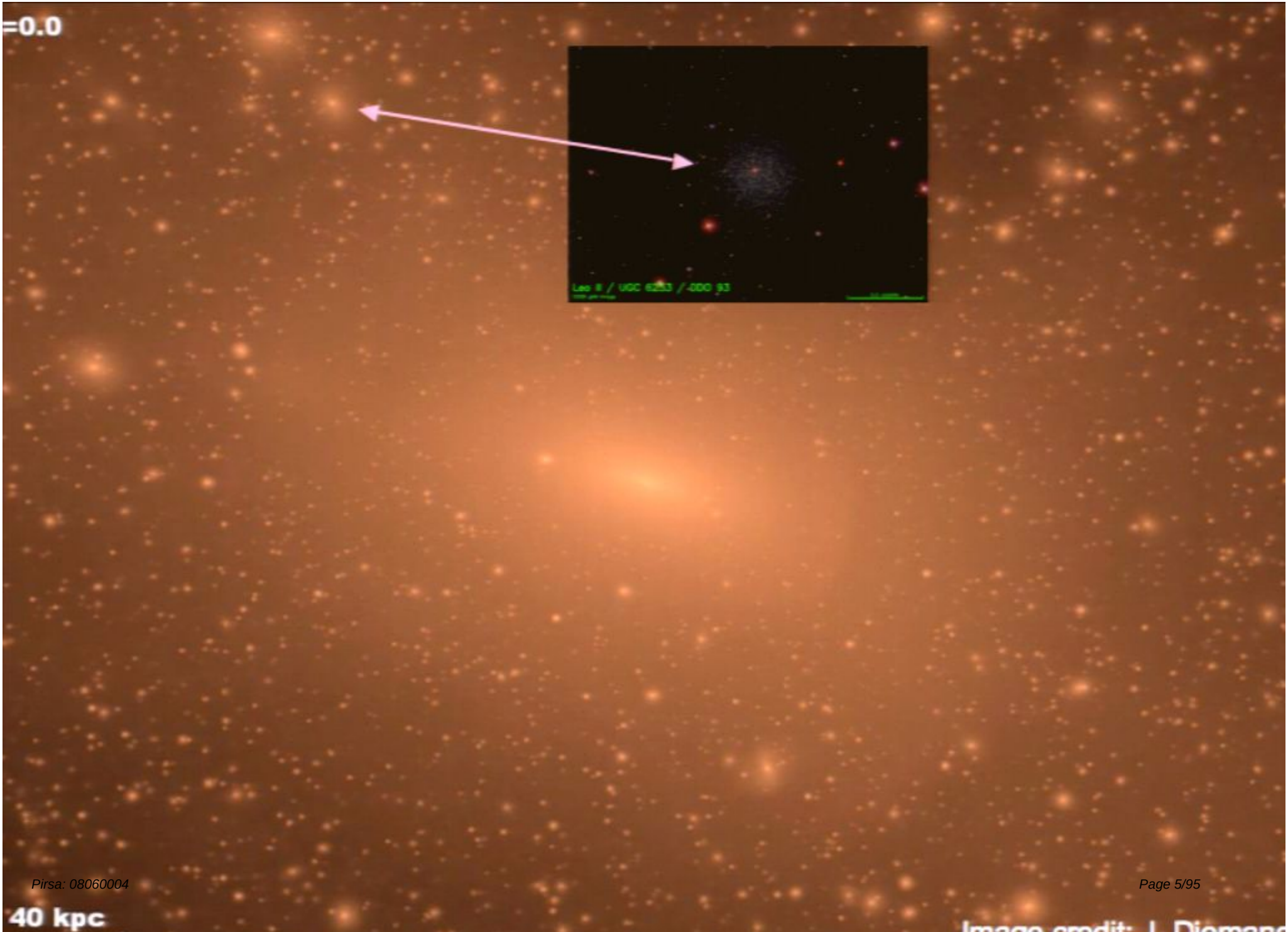
Searching for stellar counterparts to the lowest mass dark matter halos

(that are able to host stars)

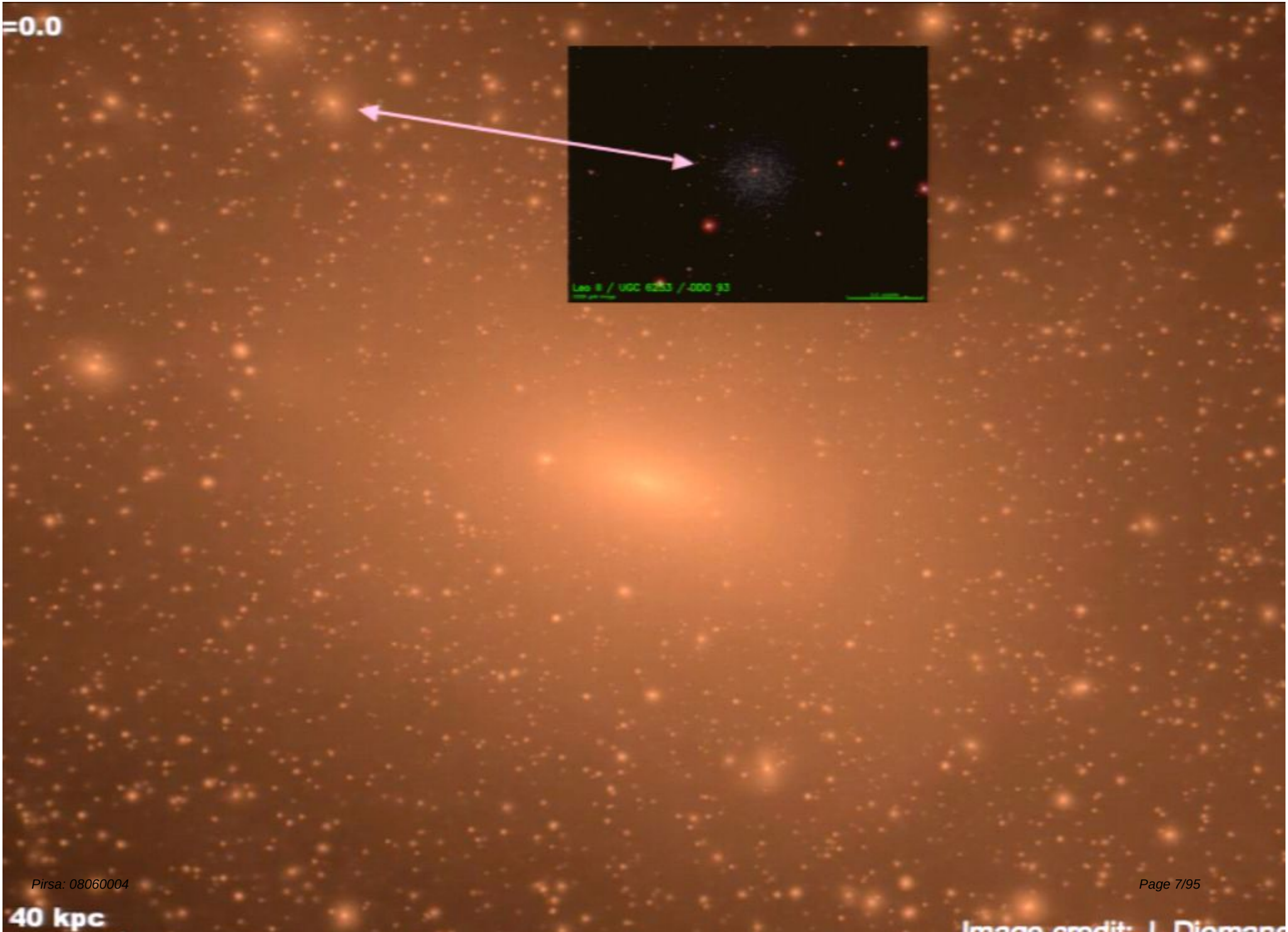
Erik Tollerud, Louie Strigari, James Bullock (UC Irvine)

Shane Walsh, Helmut Jerjen (Stromlo)

=0.0
40 kpc


=0.0
Leo II / UGC 6283 / DDO 93
40 kpc

- Methodology to find the least luminous galaxies
- The results and detection limits - Quantifying what we do and don't know; Predicting the luminosity function; Their spatial distribution
- Prospects for all sky and more sensitive searches


=0.0
Leo II / UGC 6253 / -000 93
40 kpc

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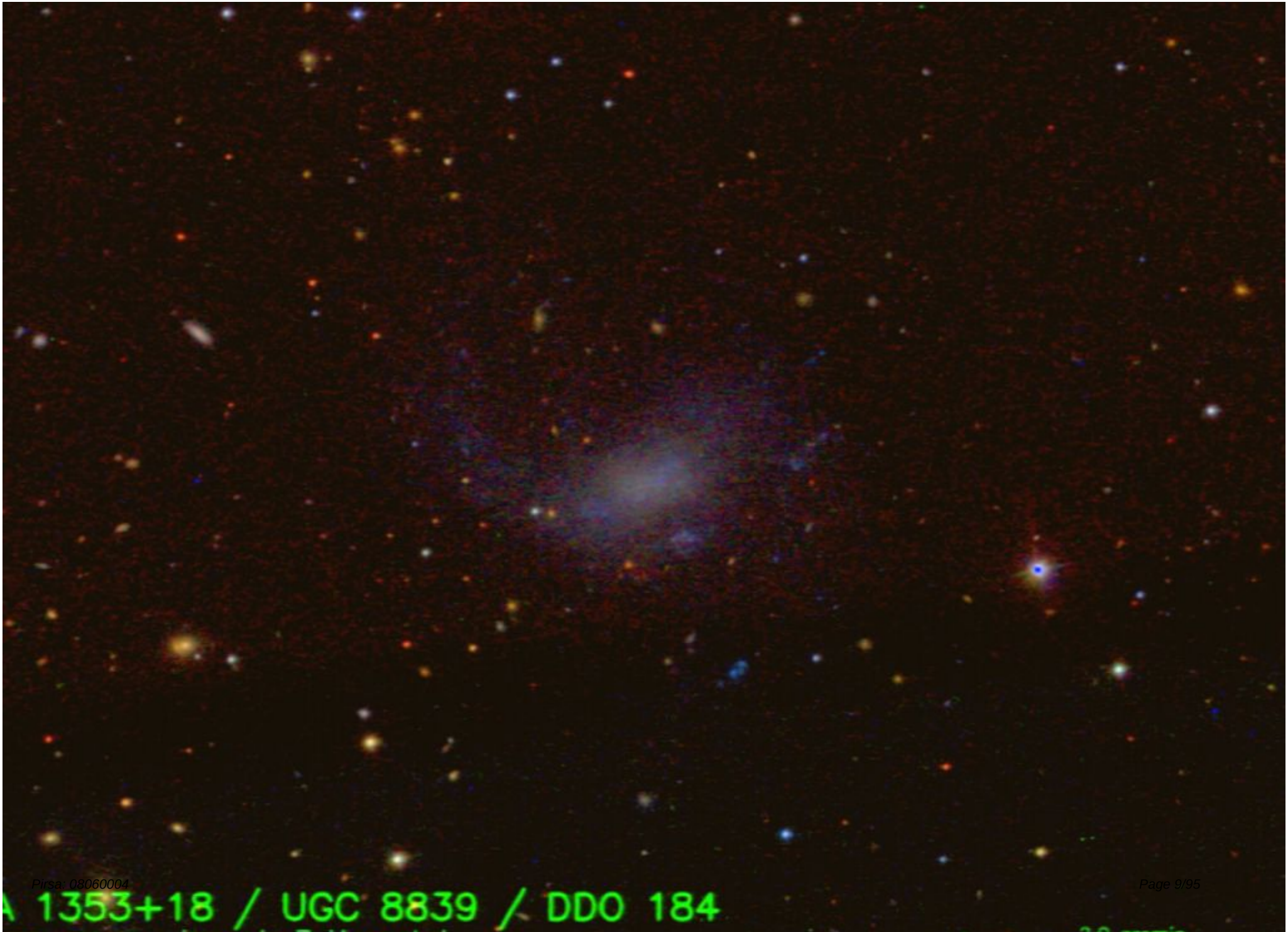
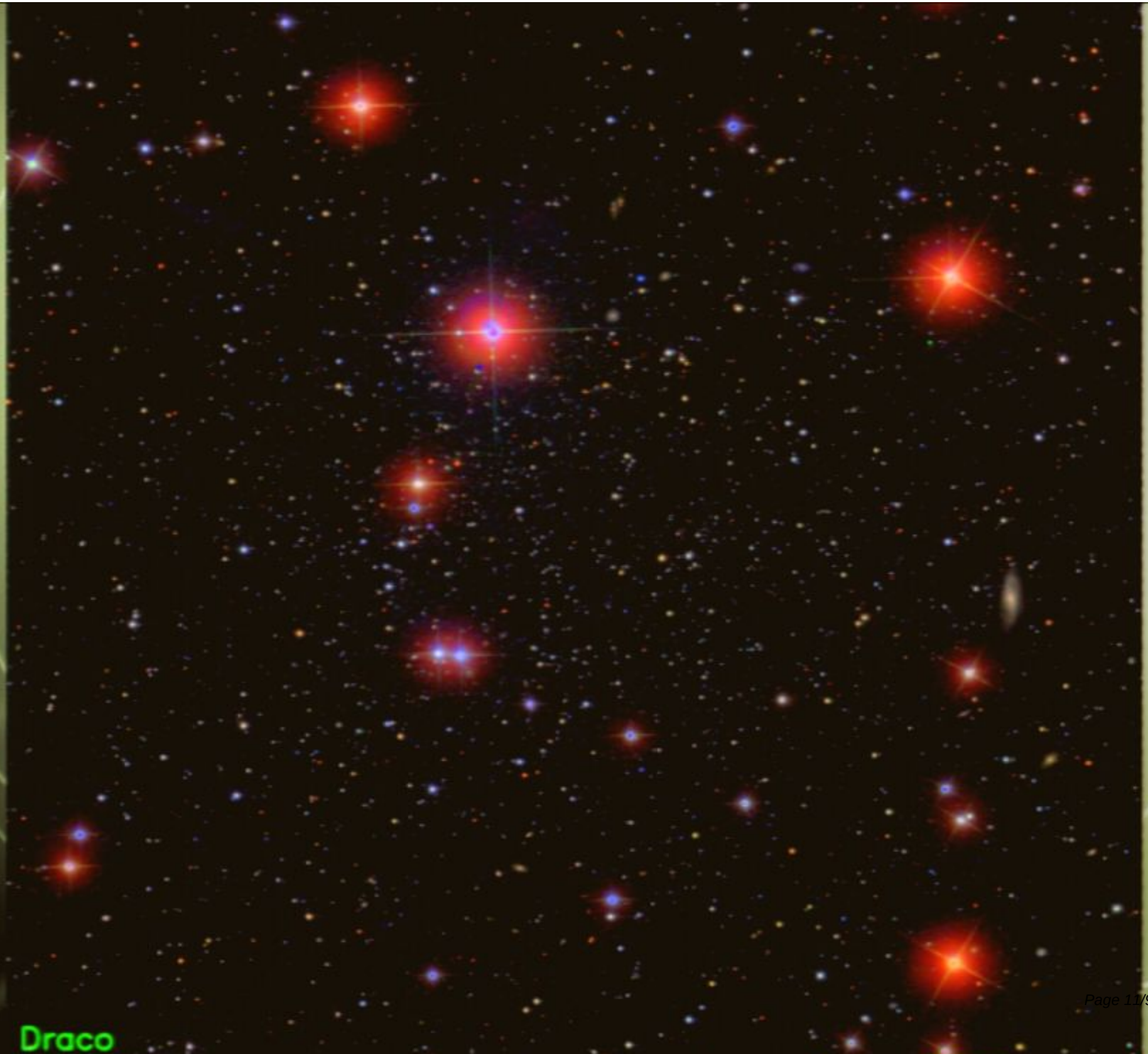
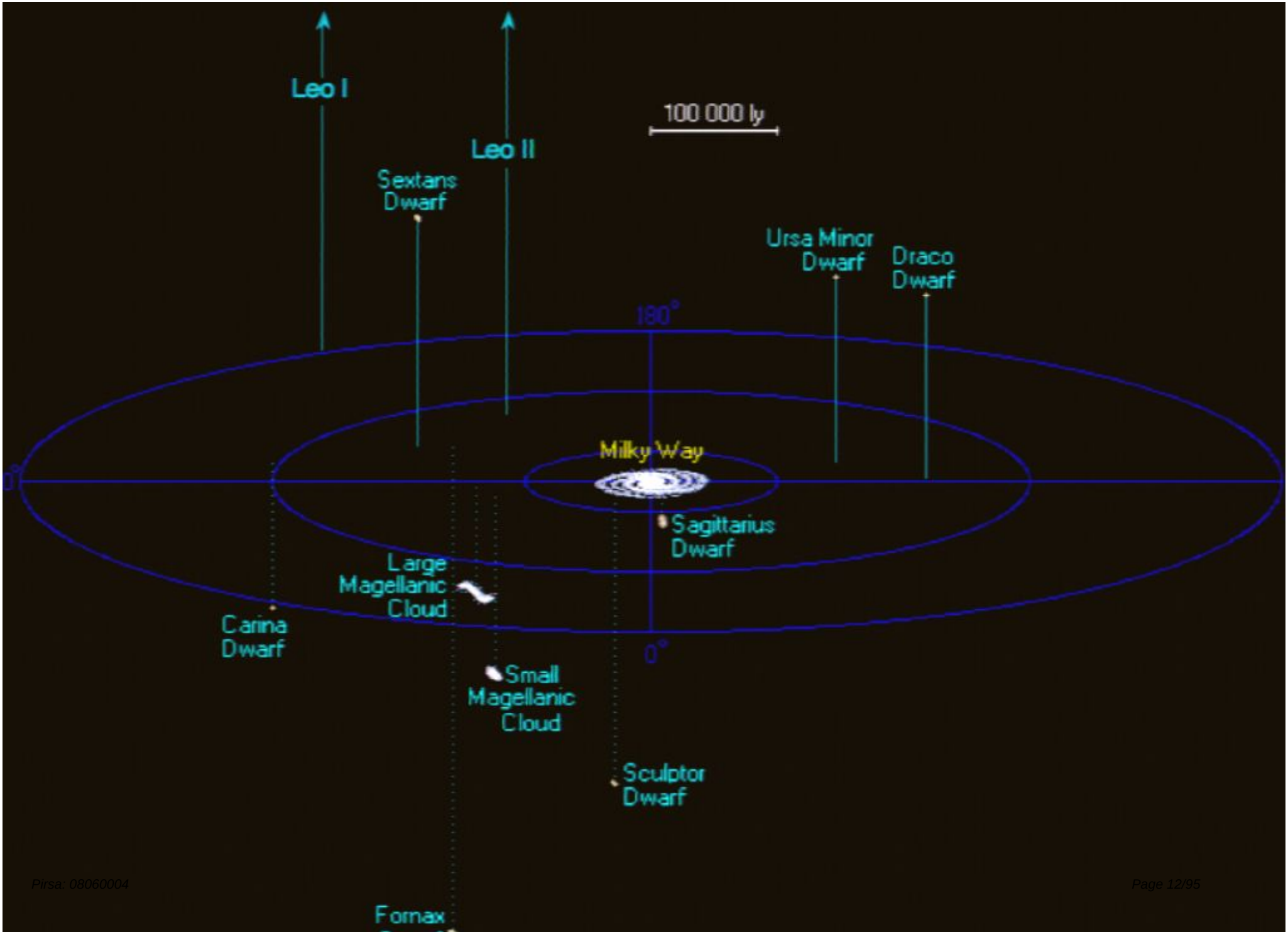

A 1353+18 / UGC 8839 / DDO 184

Leo II / UGC 6253 / DDO 93


Draco


Leo I
Leo II
100 000 ly
Sextans Dwarf
Ursa Minor Dwarf
Draco Dwarf
180°
Milky Way
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
Small Magellanic Cloud
Sculptor Dwarf
Fornax

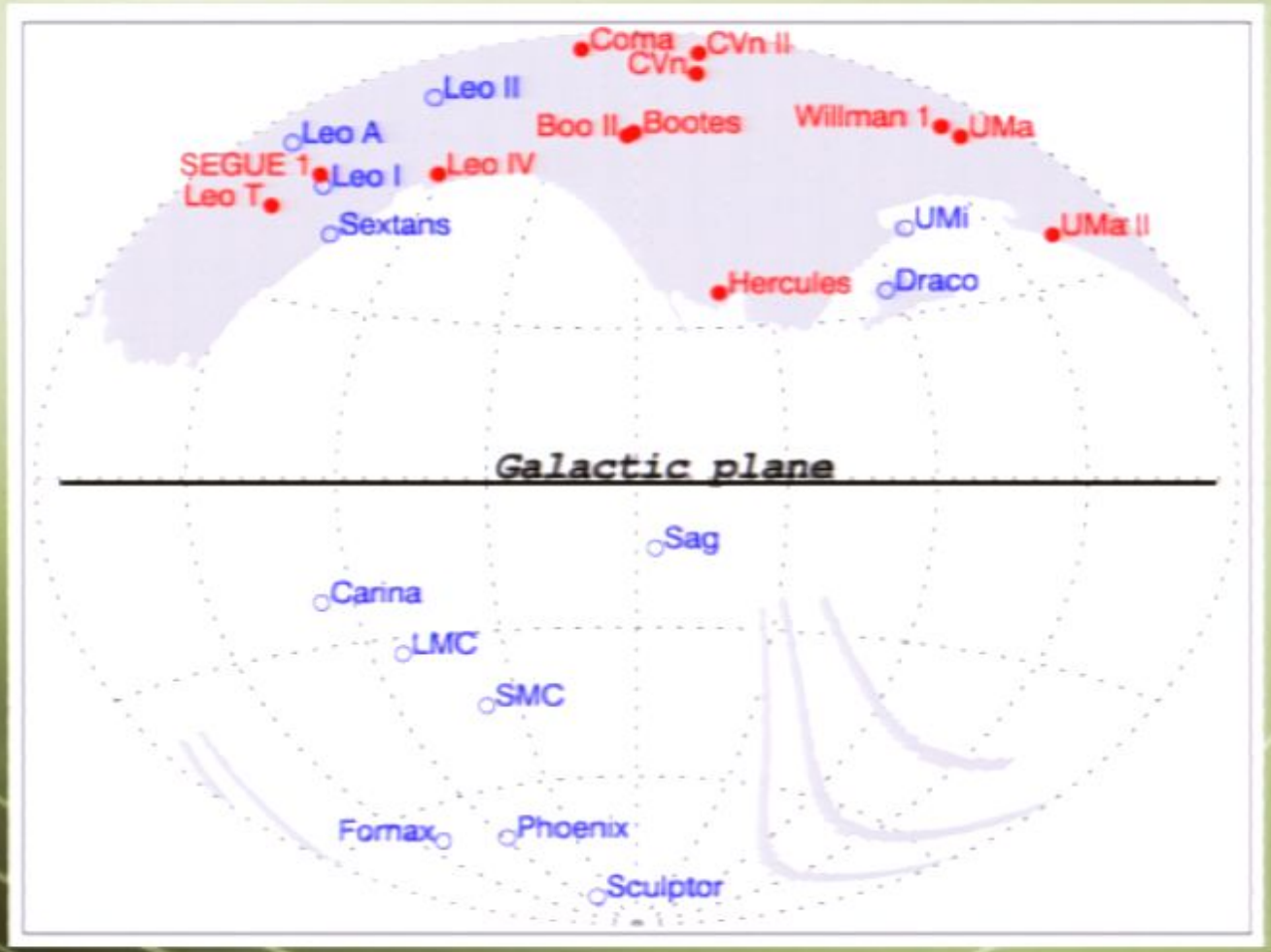
Sloan Digital Sky Survey

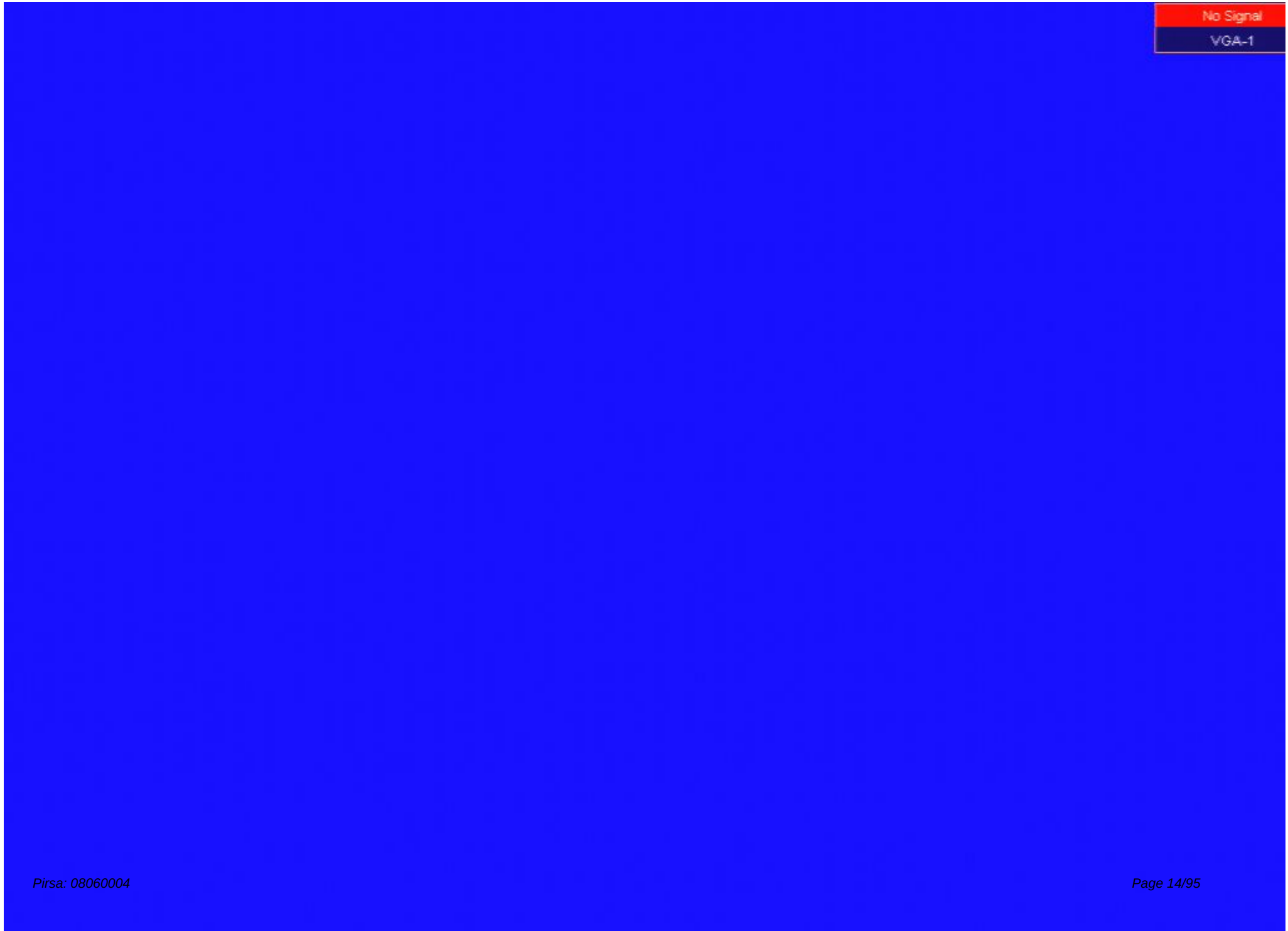
9,500 square degrees of imaging

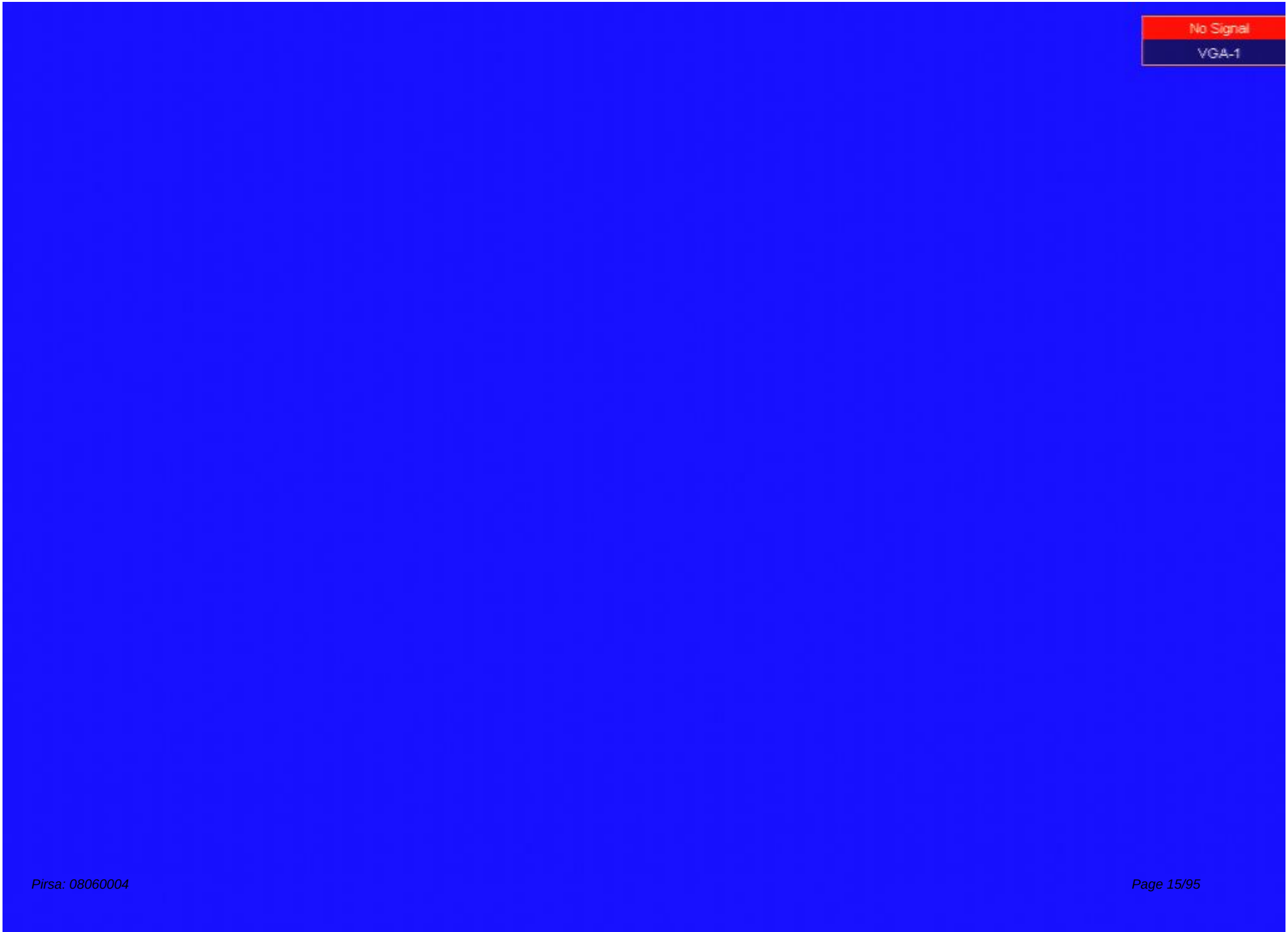
21,439,777 stars r < 22, g-r < 1

u, g, r, i, z

1 minute exposures on 2.5m telescope




No Signal
VGA-1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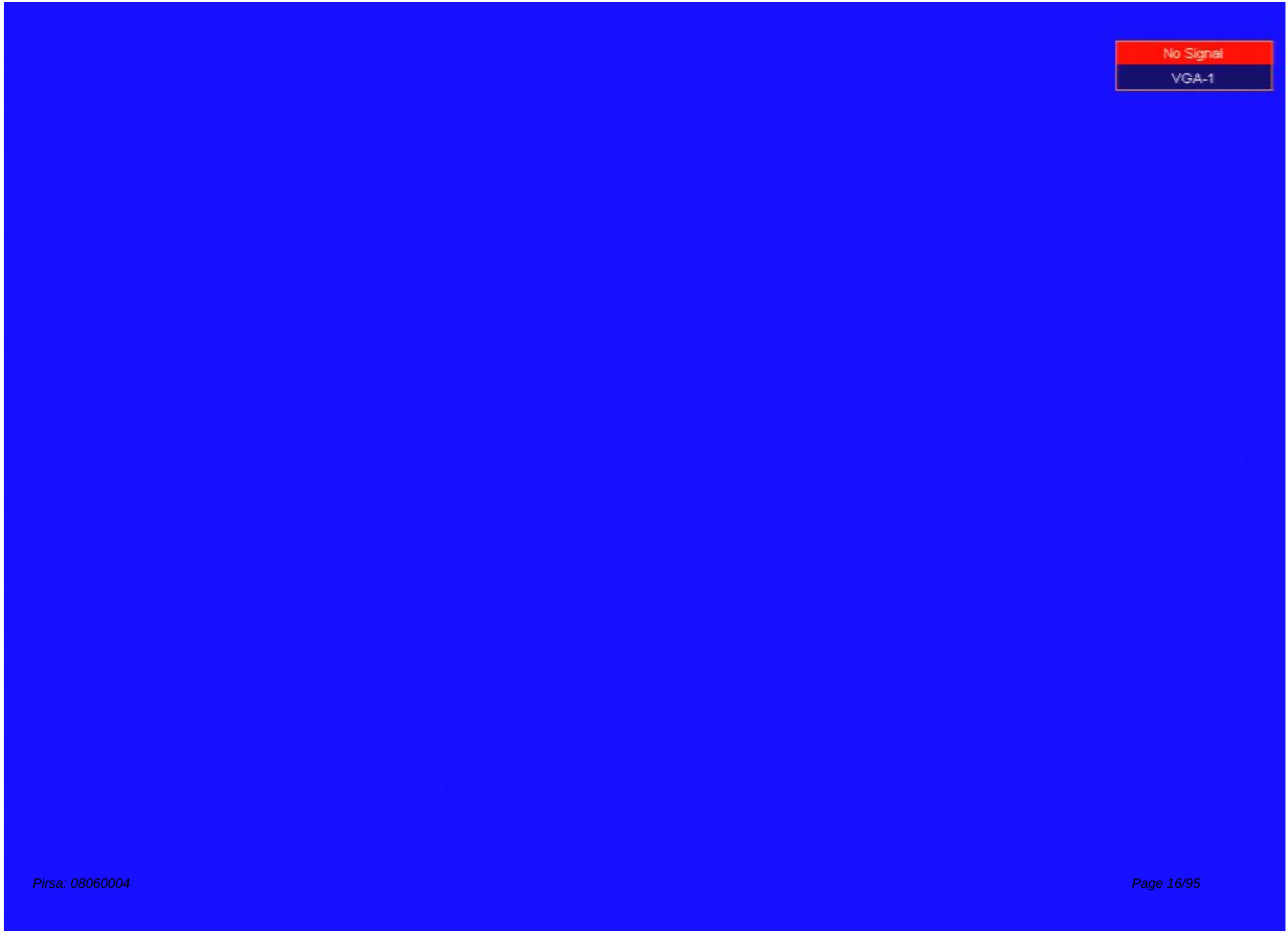
VGA-1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VGA-1

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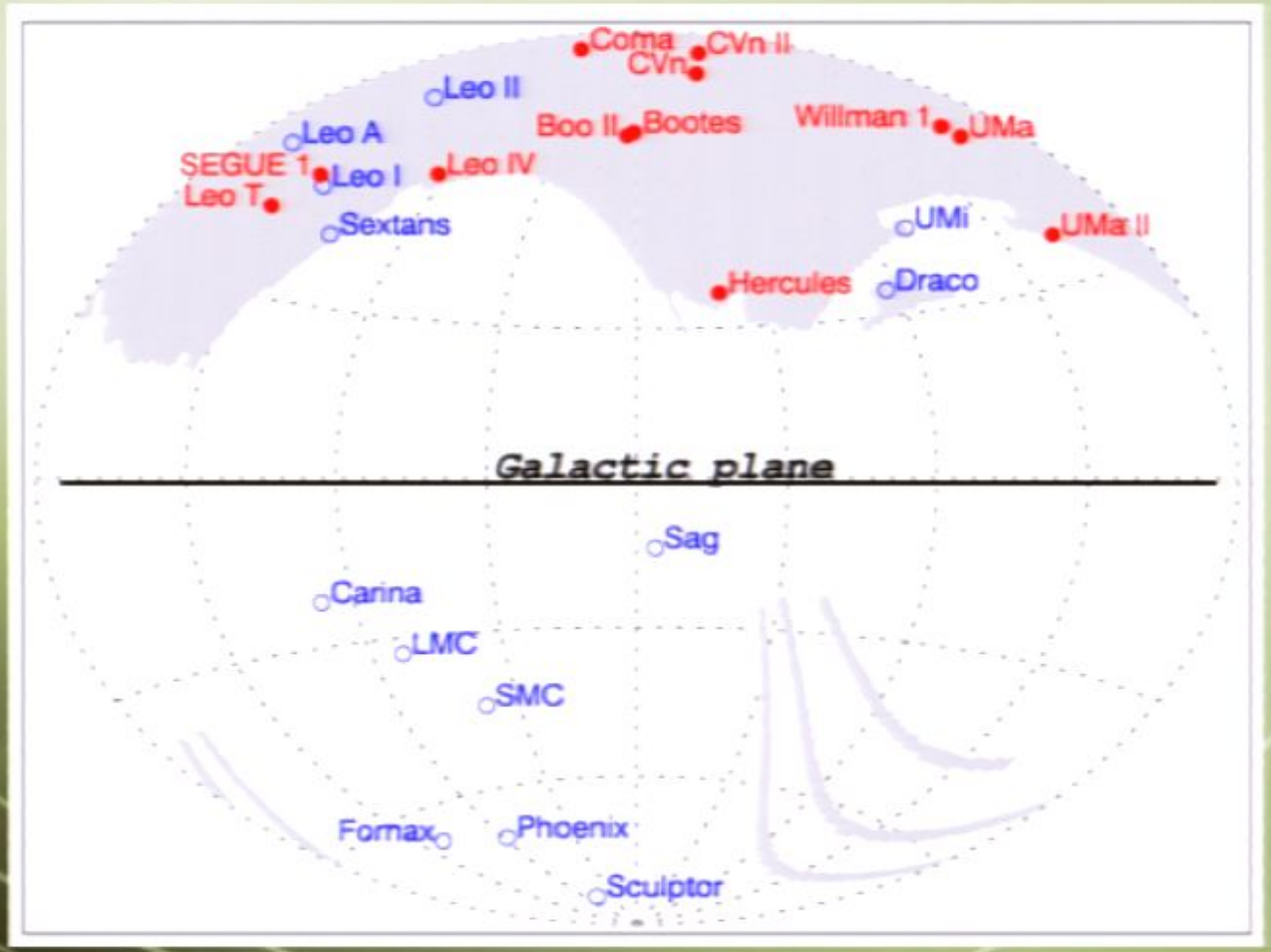
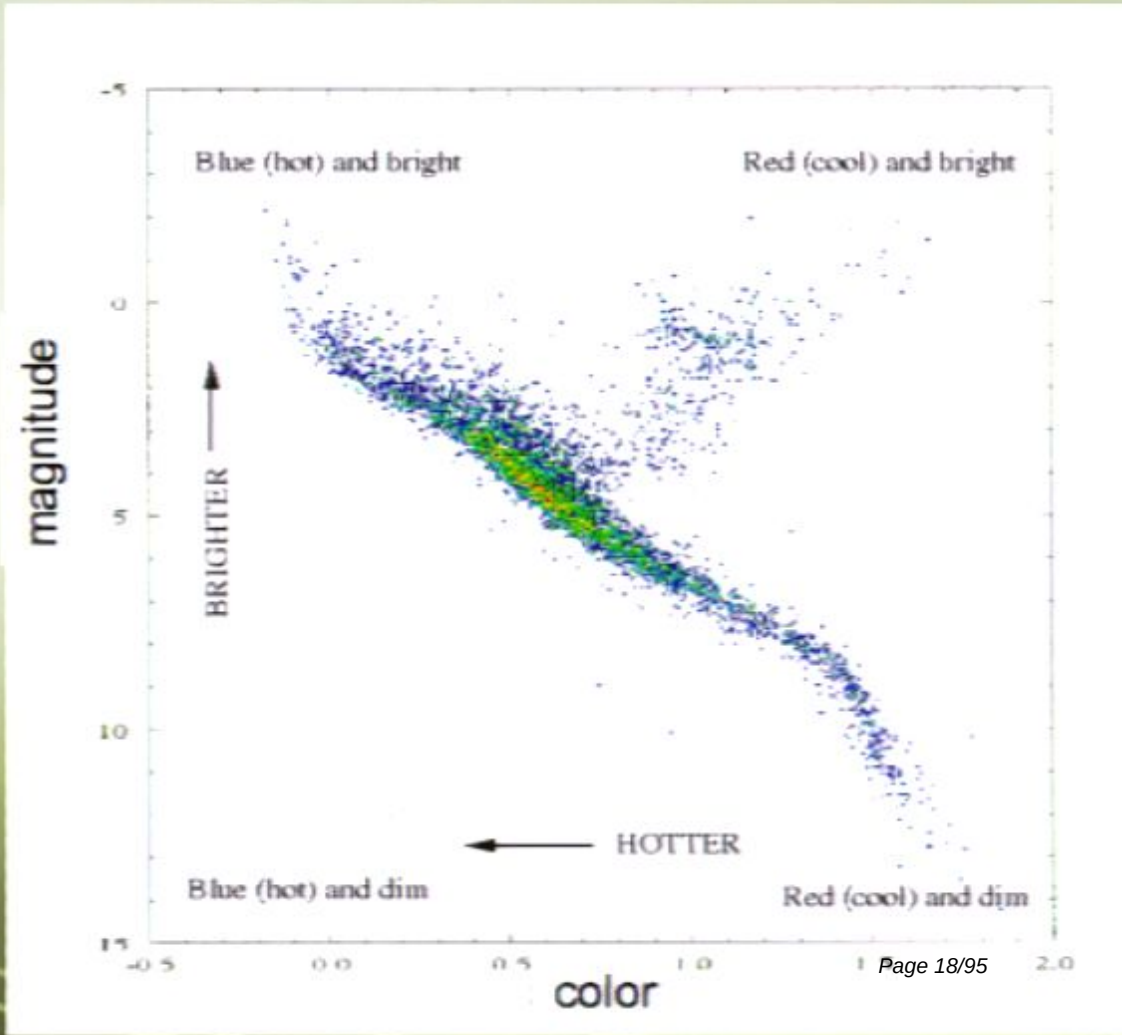
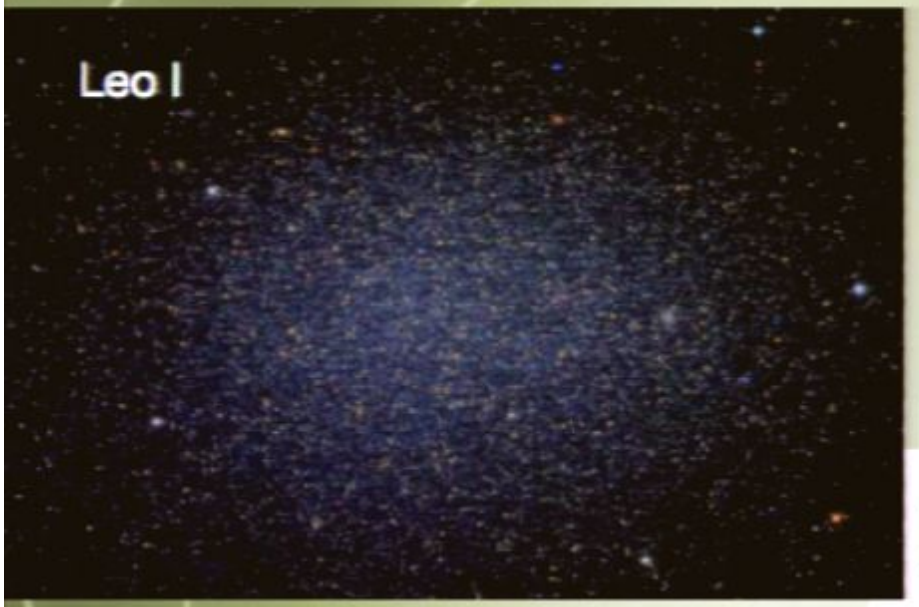
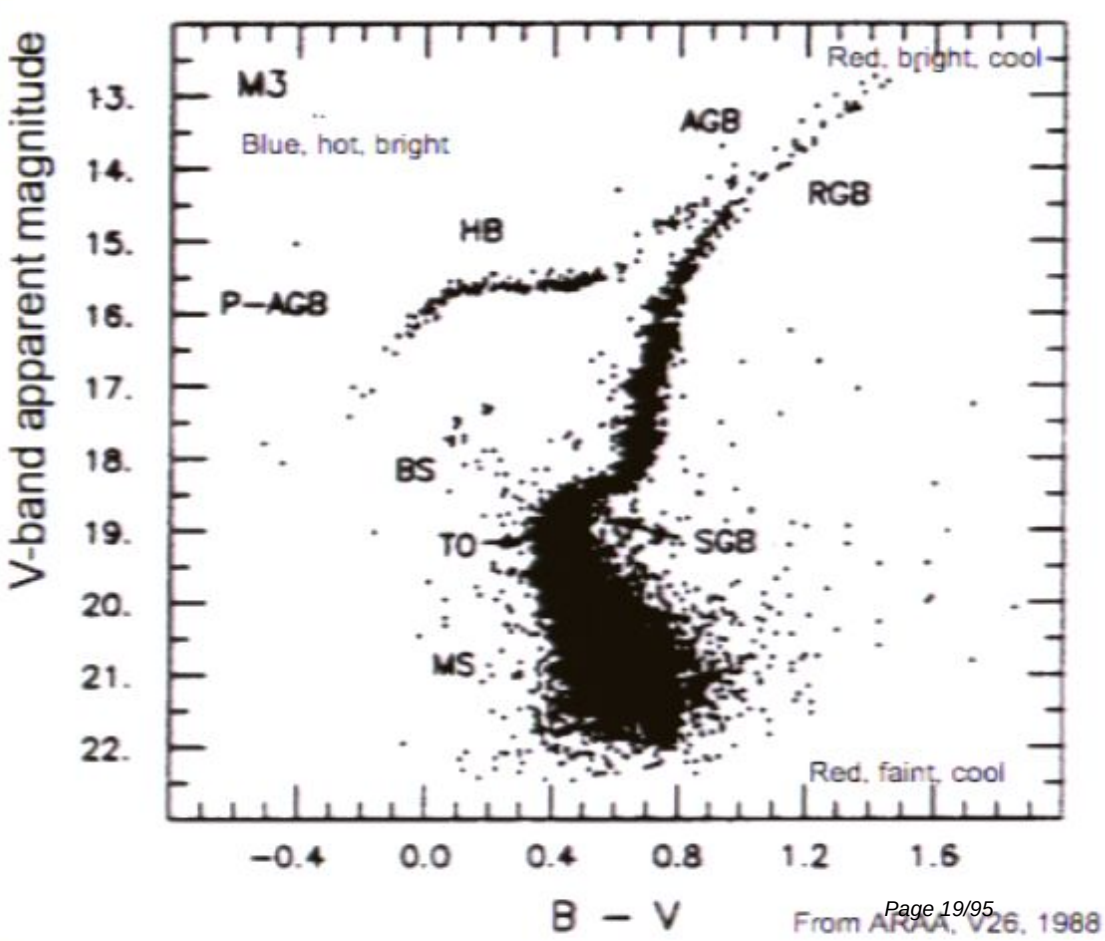


Resolved stars reveal the least luminous systems

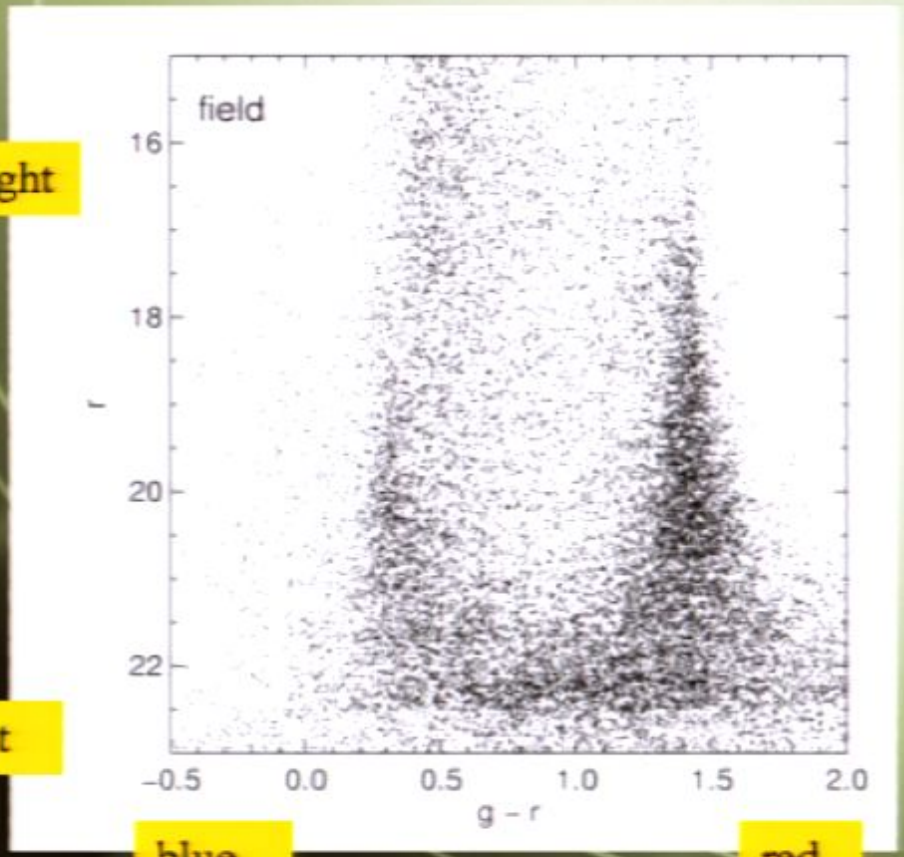


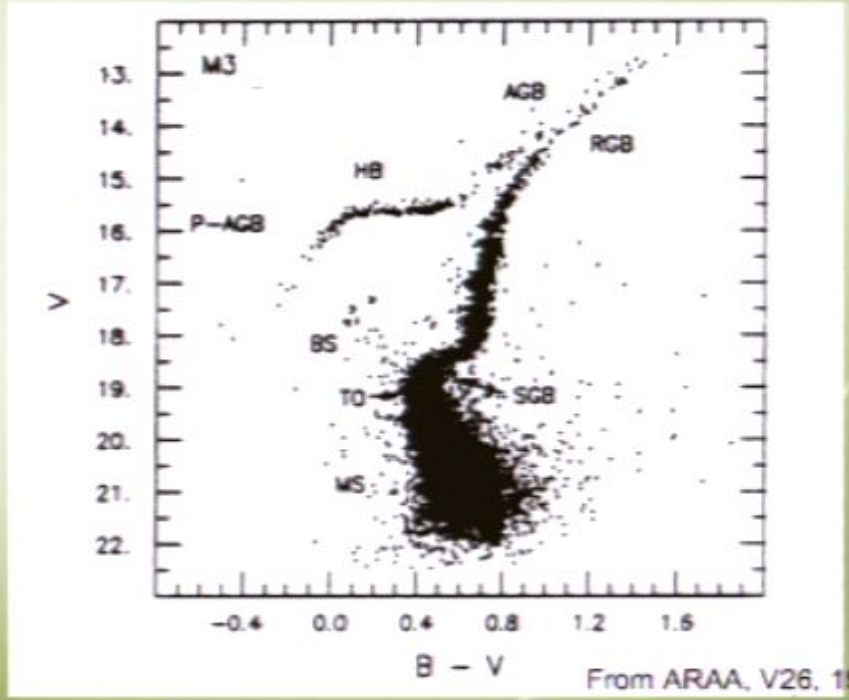


Resolved stars reveal the least luminous systems



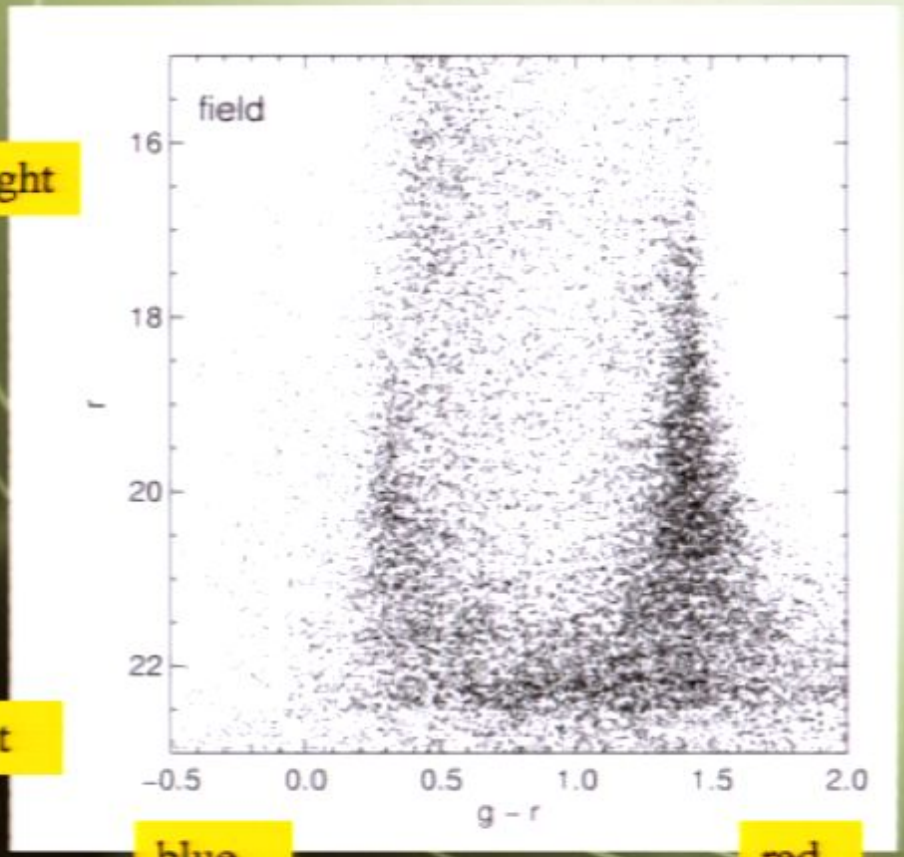
How To Find Resolved Dwarf Galaxies

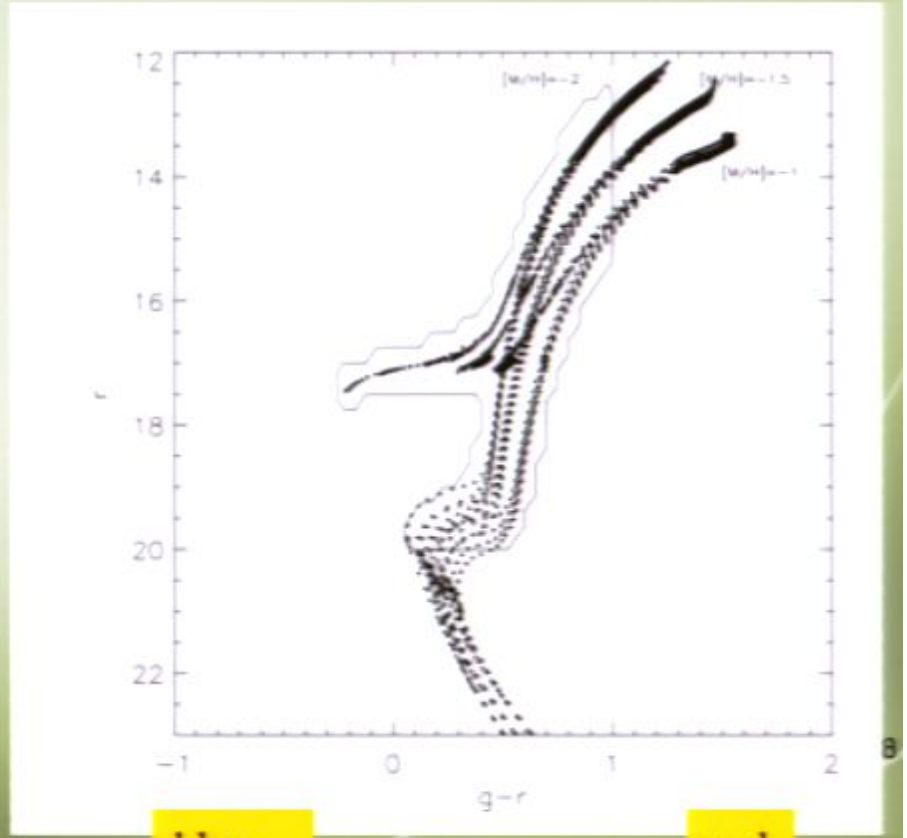




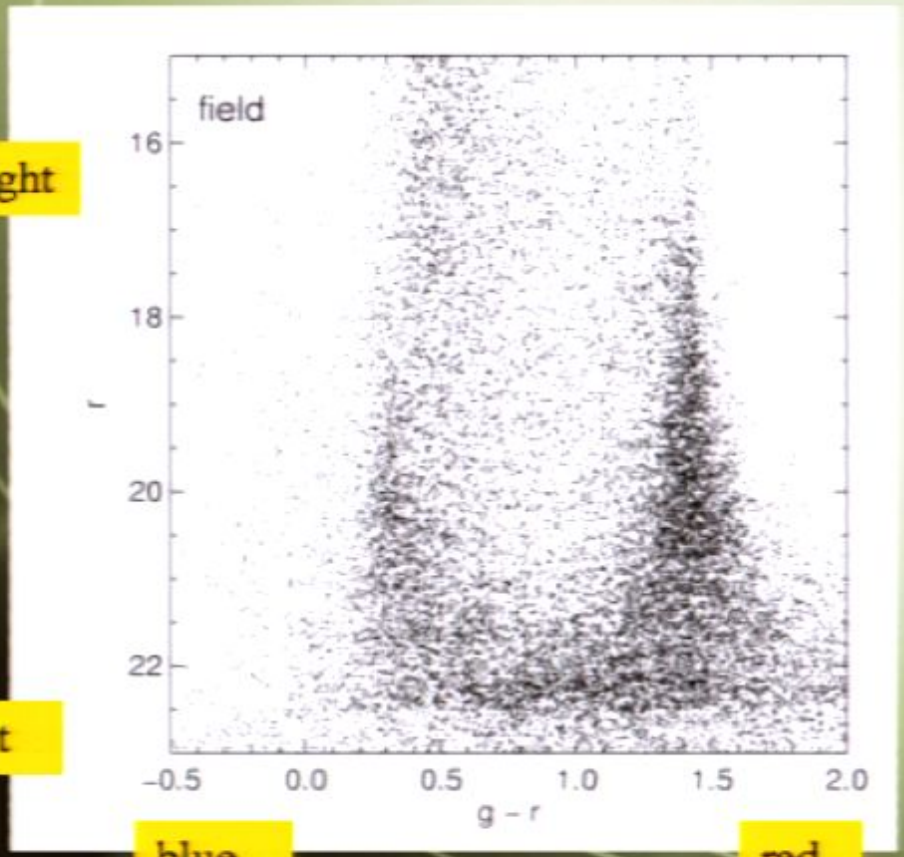
From ARAA, V26, 1988

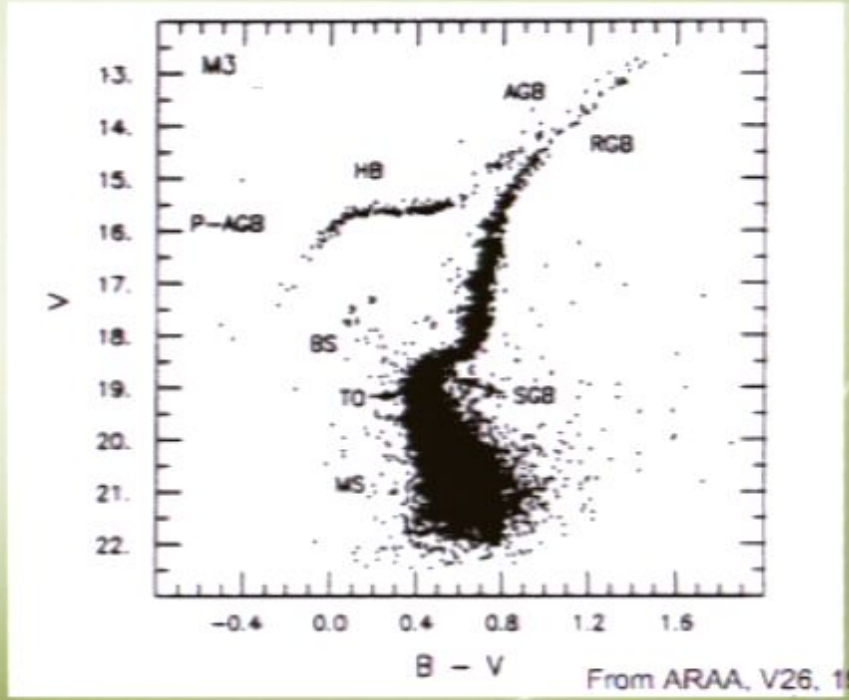
How To Find Resolved Dwarf Galaxies





How To Find Resolved Dwarf Galaxies





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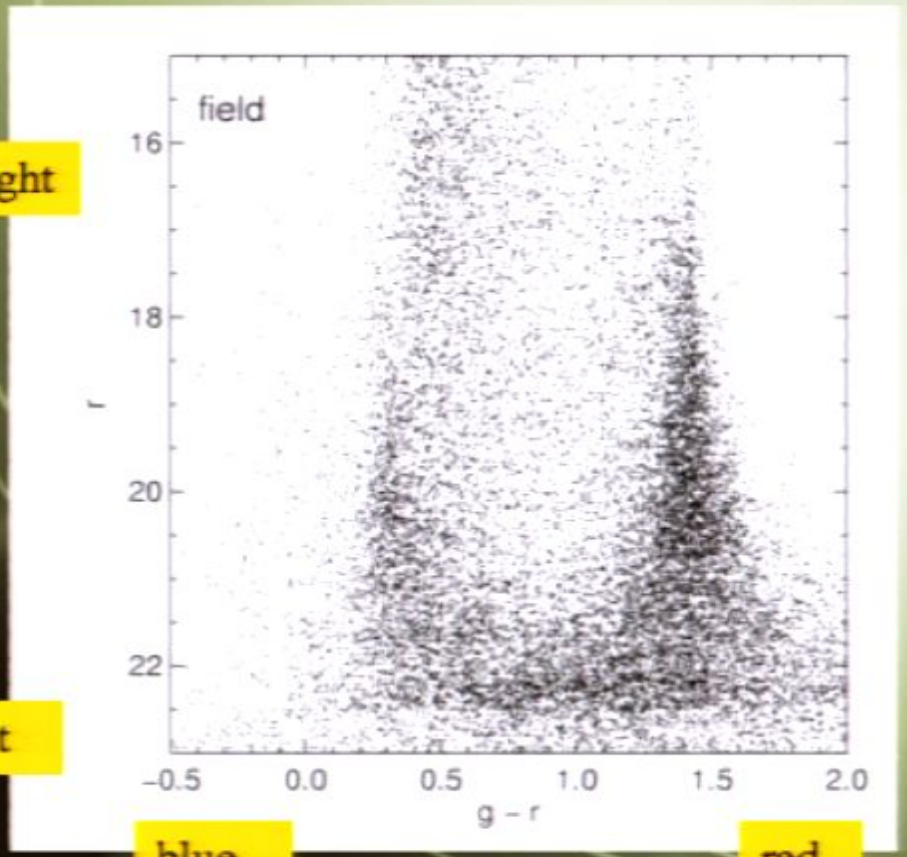
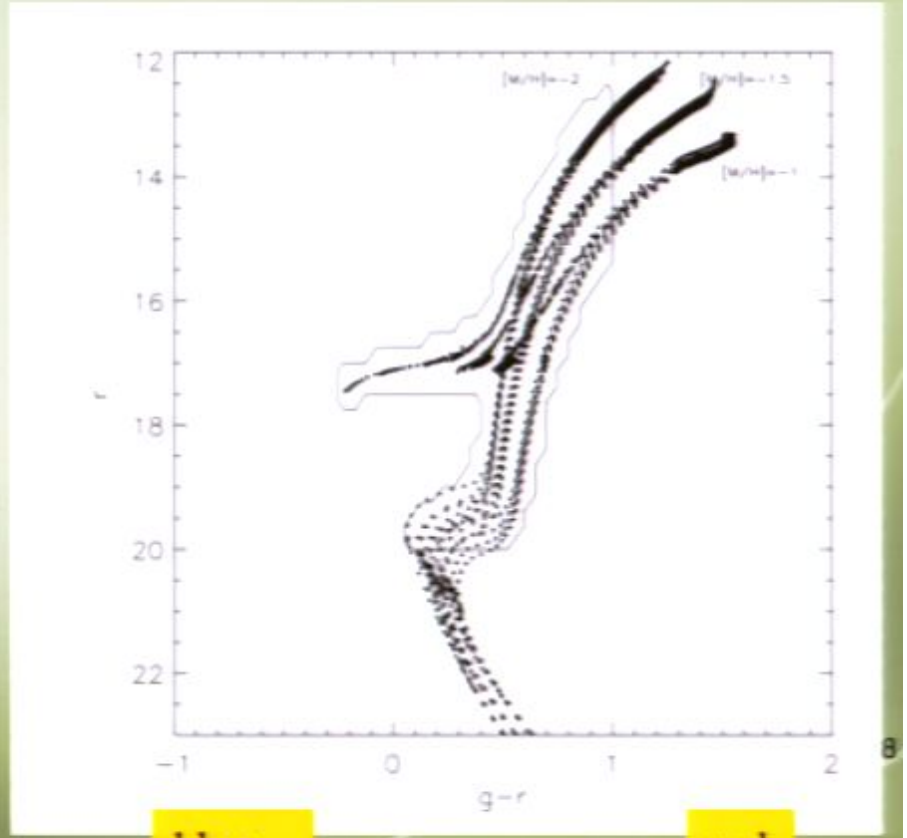
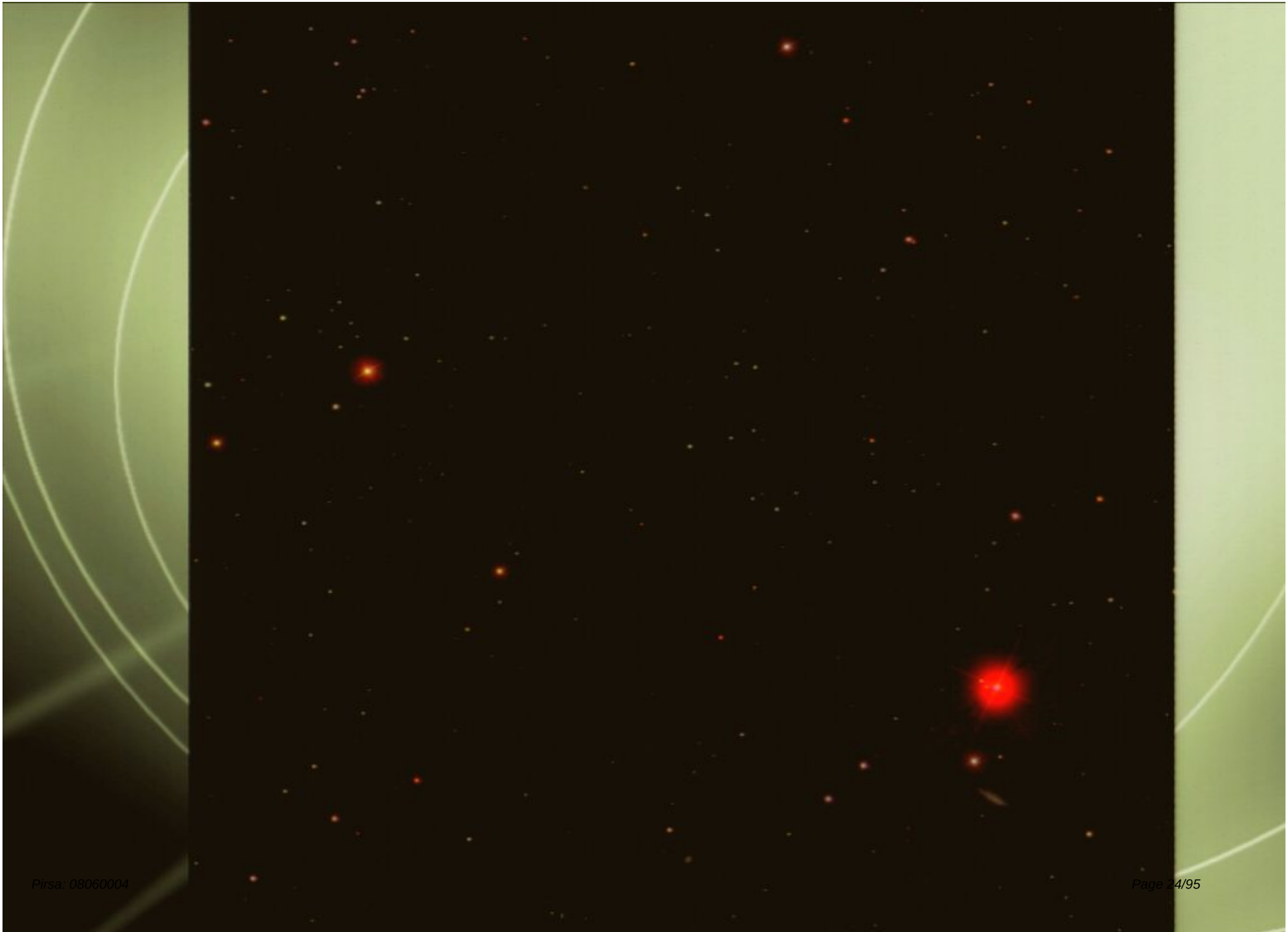
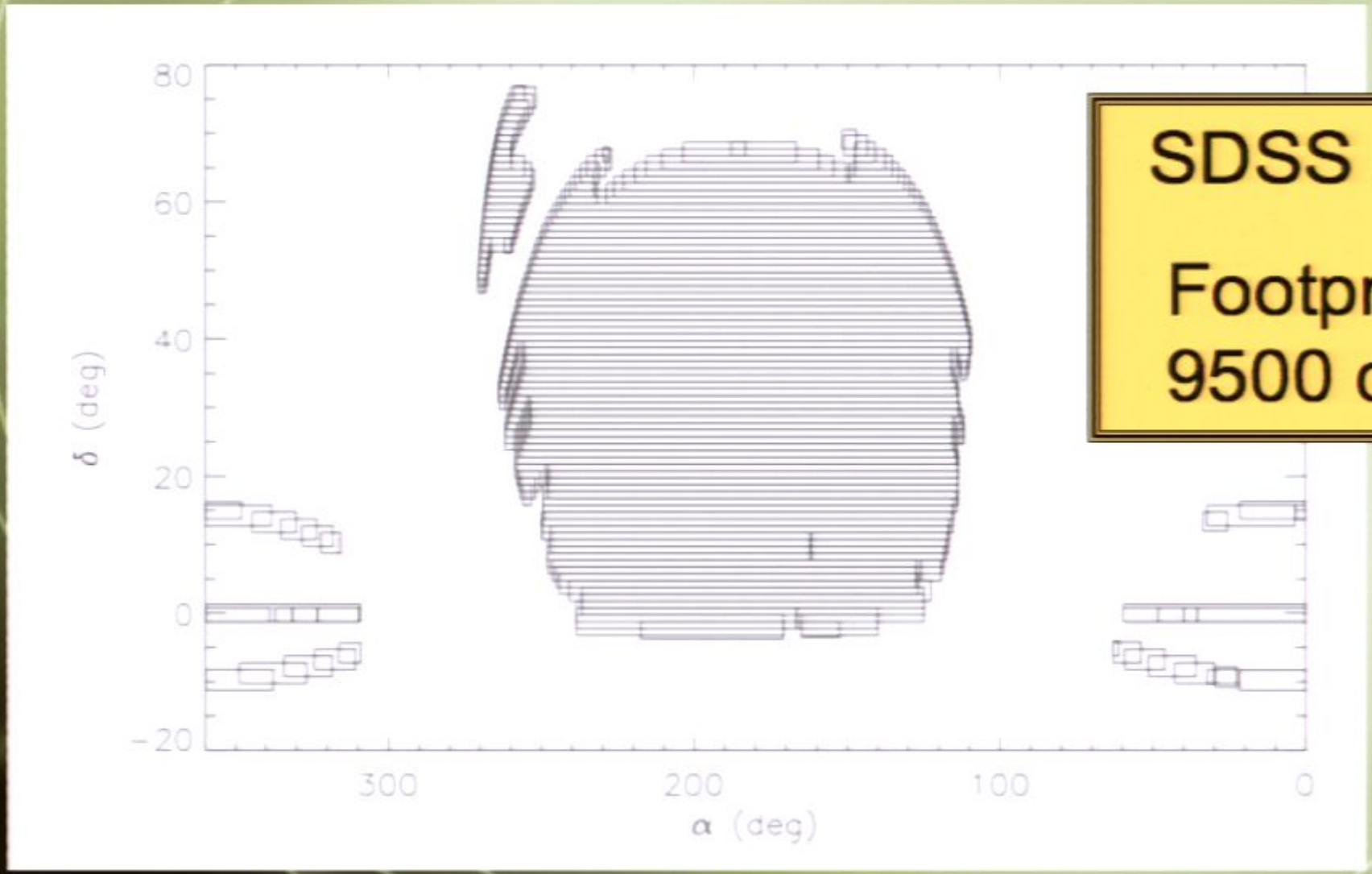
How To Find Resolved Dwarf Galaxies



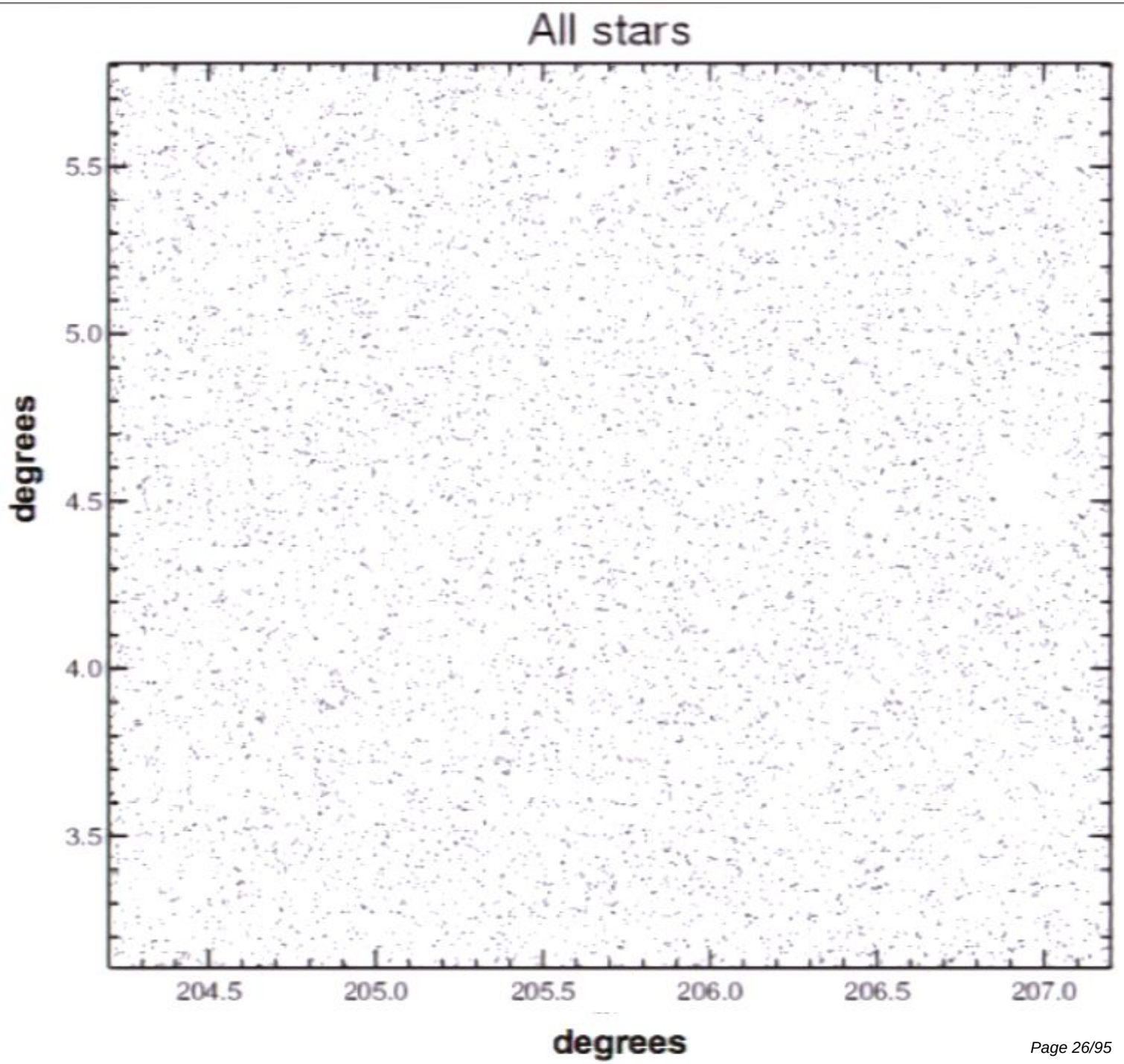


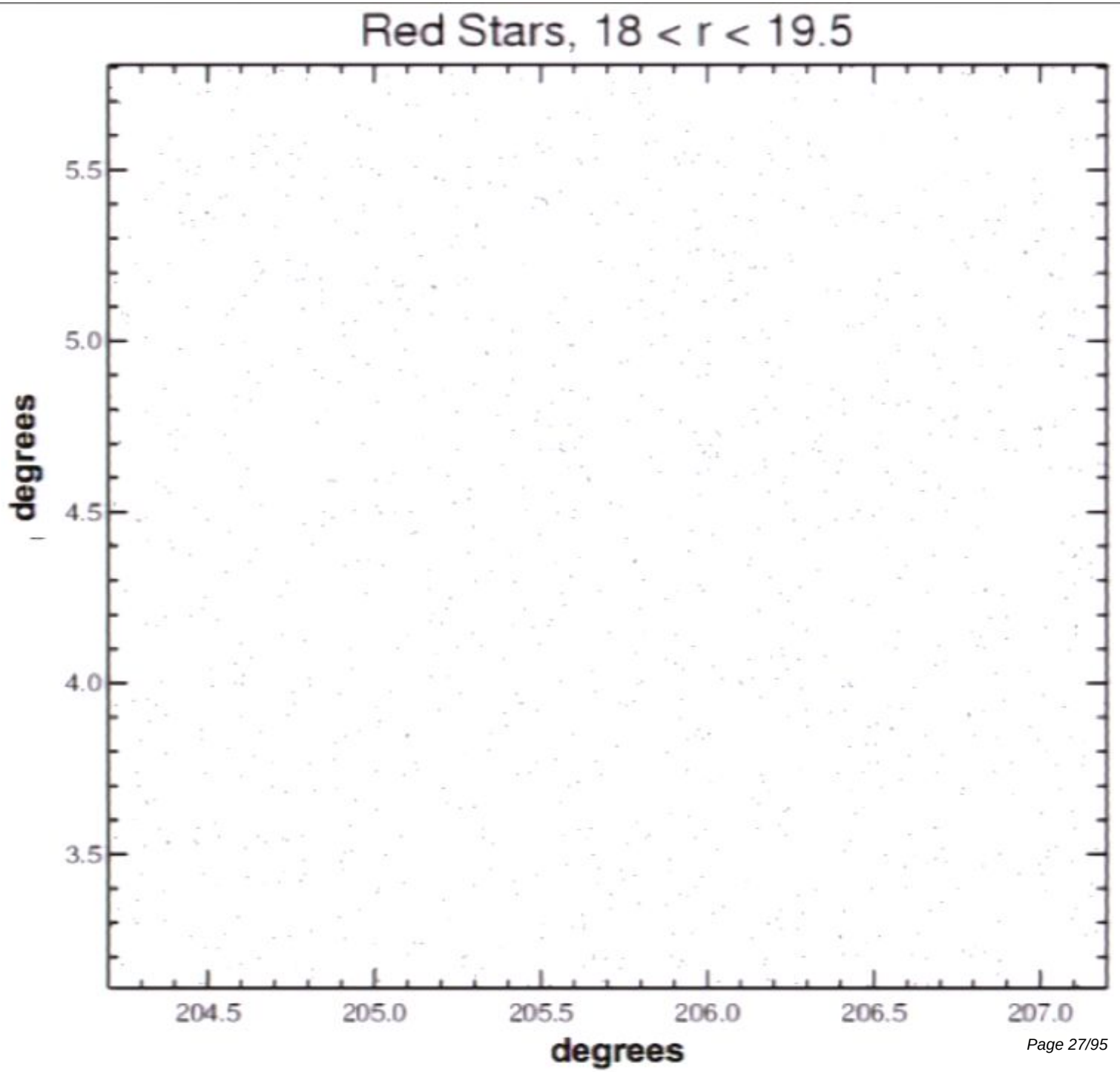


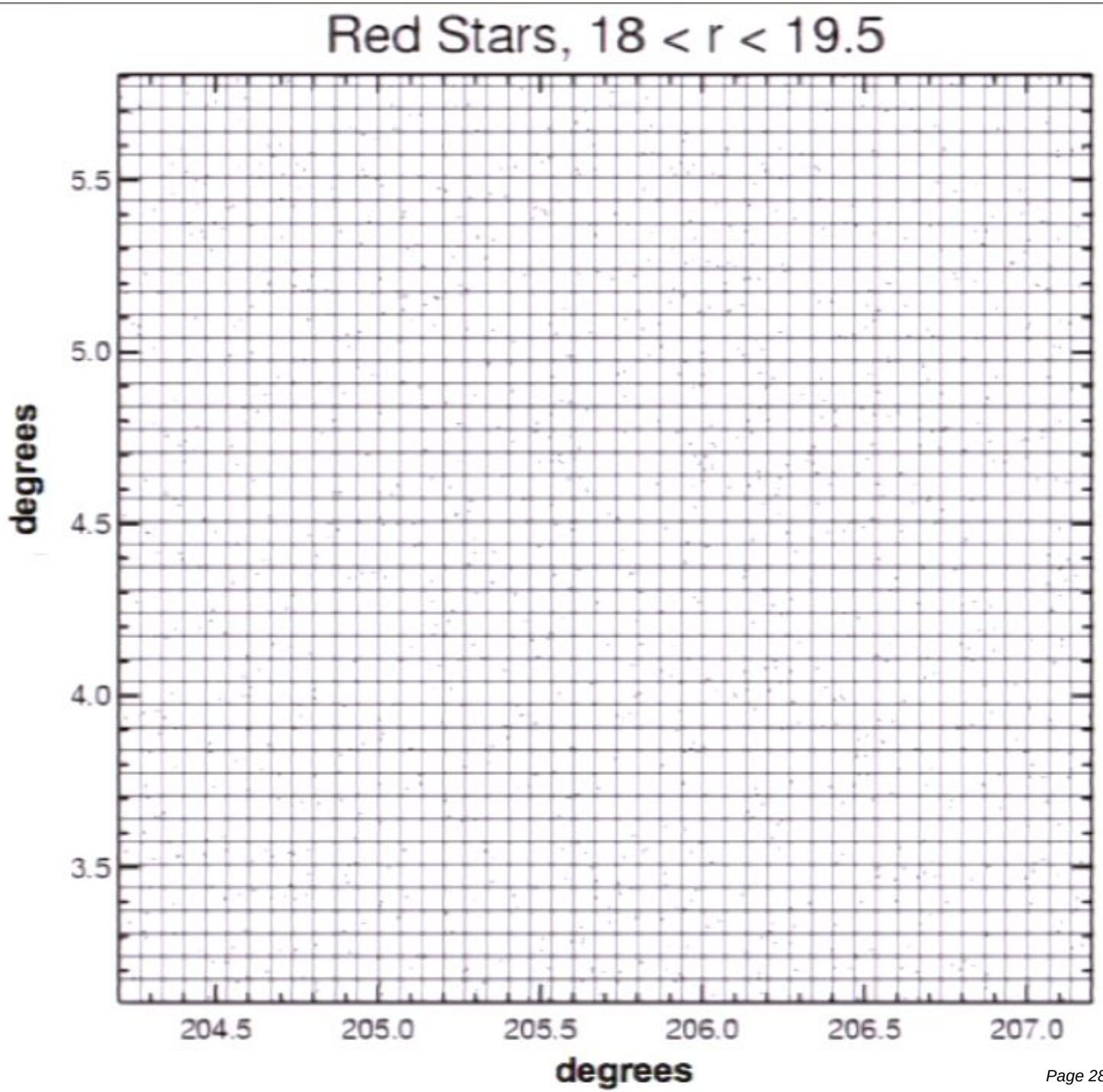


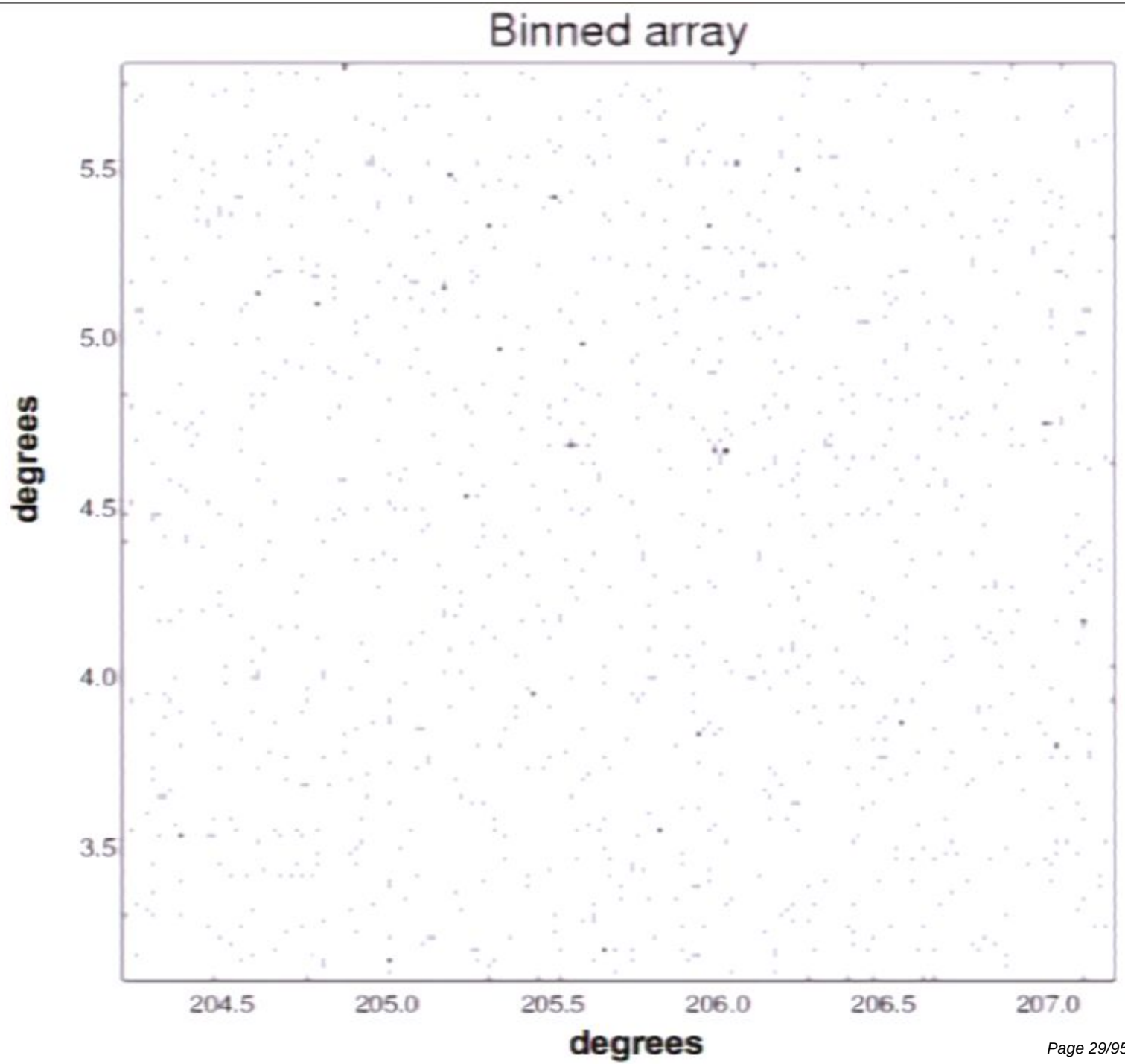
SDSS DR6

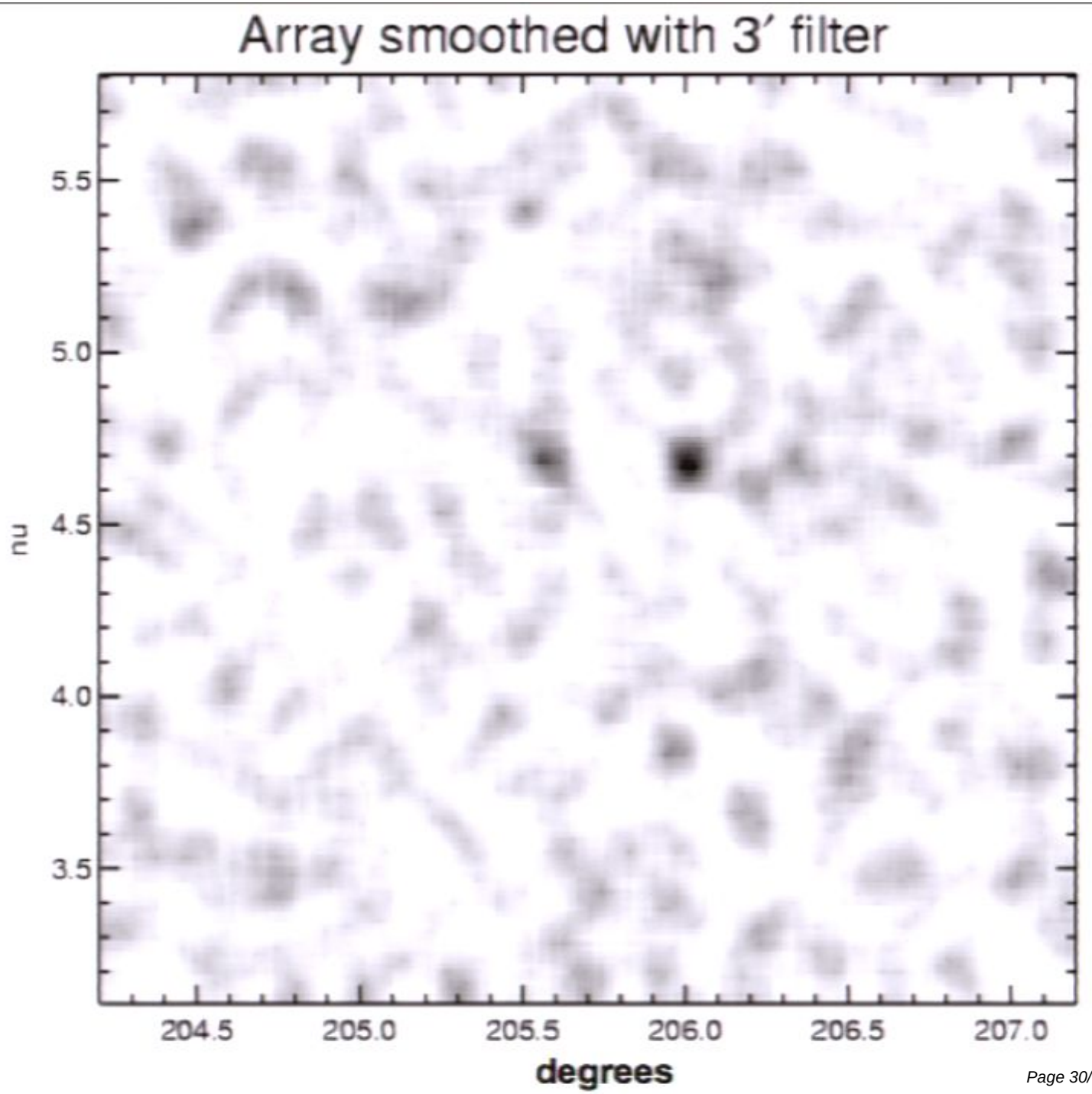
Footprint - 9500 deg^2


All stars
degrees
5.5
5.0
4.5
4.0
3.5
204.5
205.0
205.5
206.0
206.5
207.0
degrees

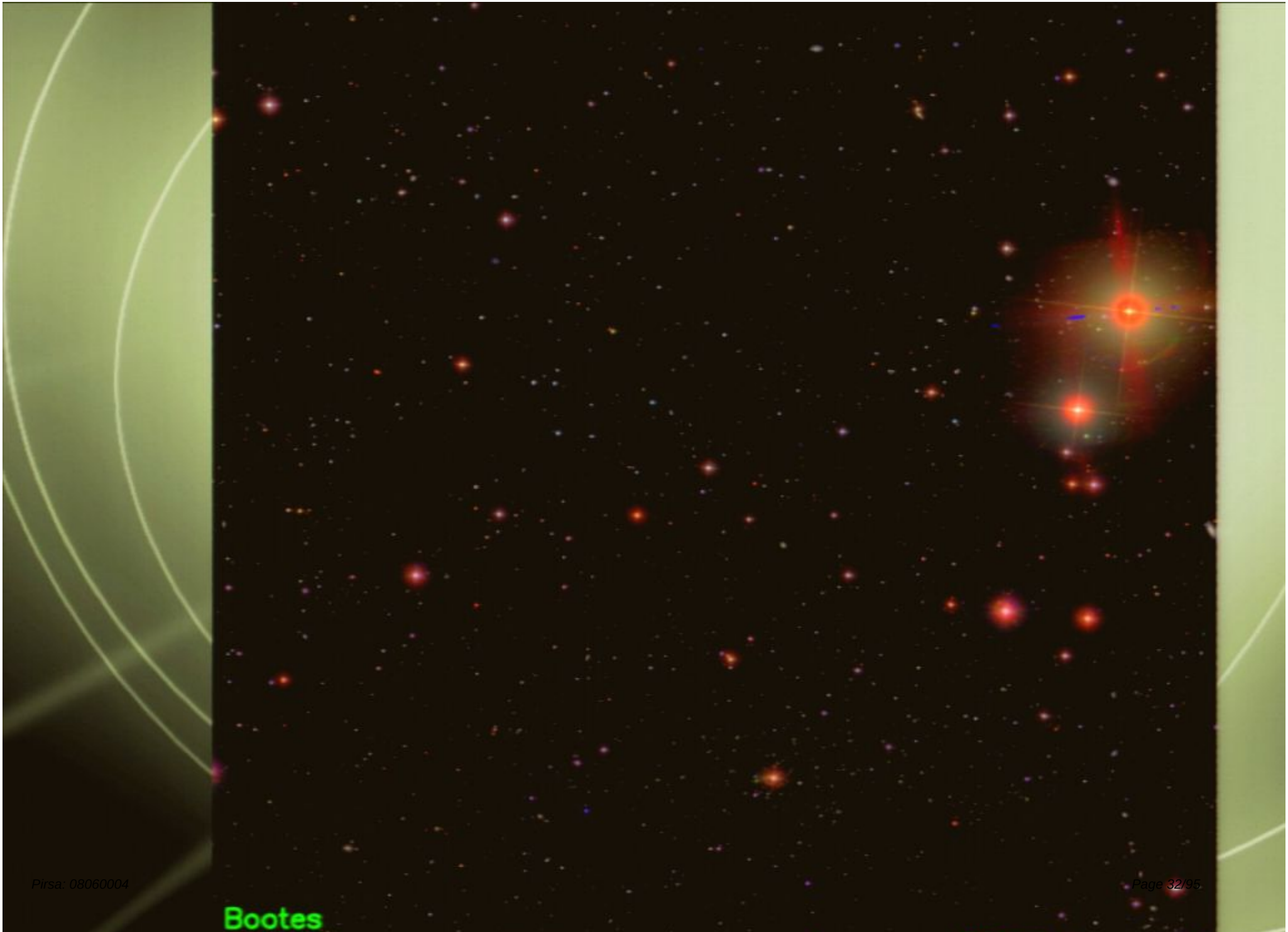

Red Stars, 18 < r < 19.5
5.5
5.0
4.5
4.0
3.5
degrees
204.5
205.0
205.5
206.0
206.5
207.0
degrees

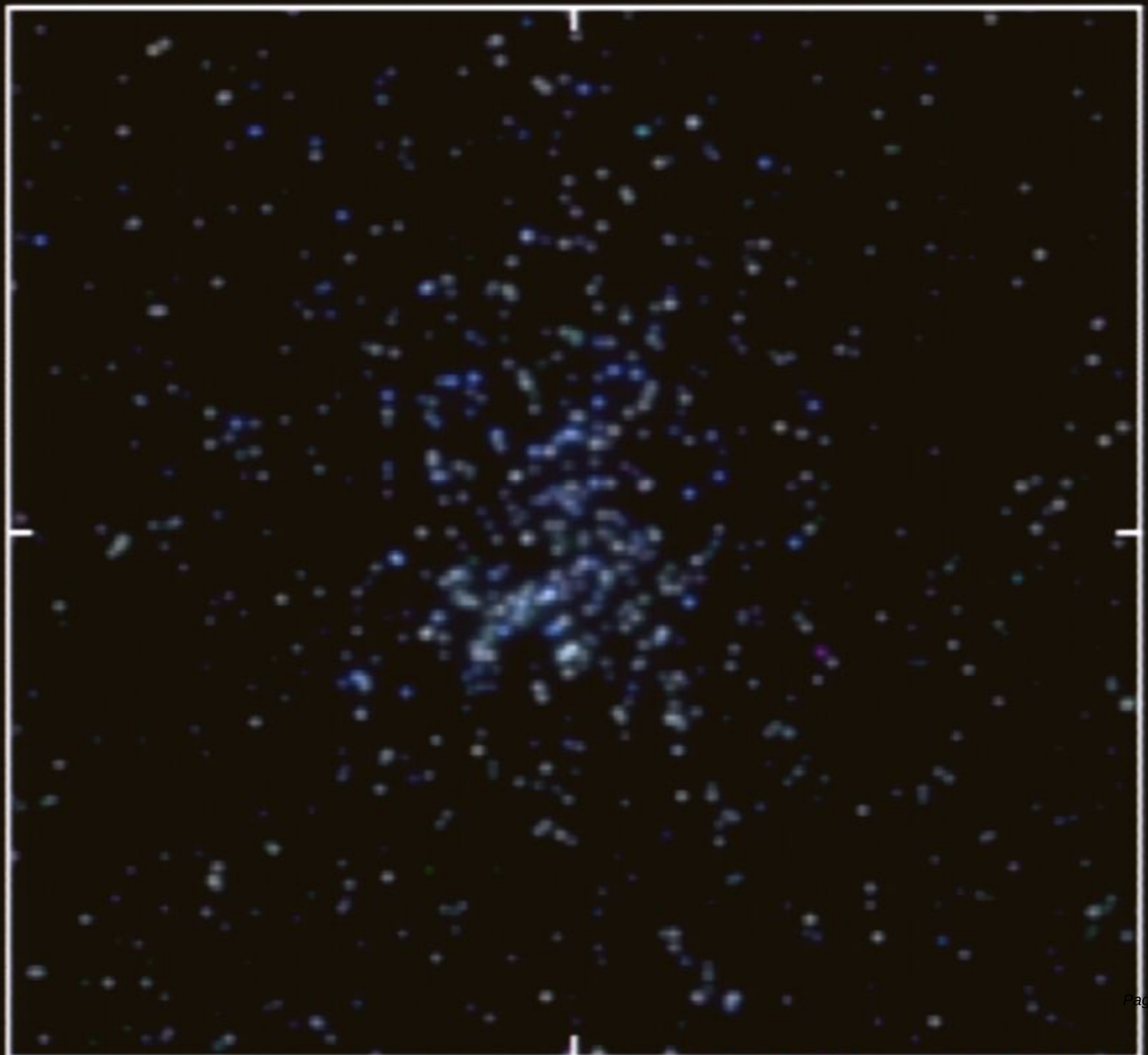

Red Stars, 18 < r < 19.5
5.5
5.0
4.5
4.0
3.5
degrees
204.5
205.0
205.5
206.0
206.5
207.0
degrees

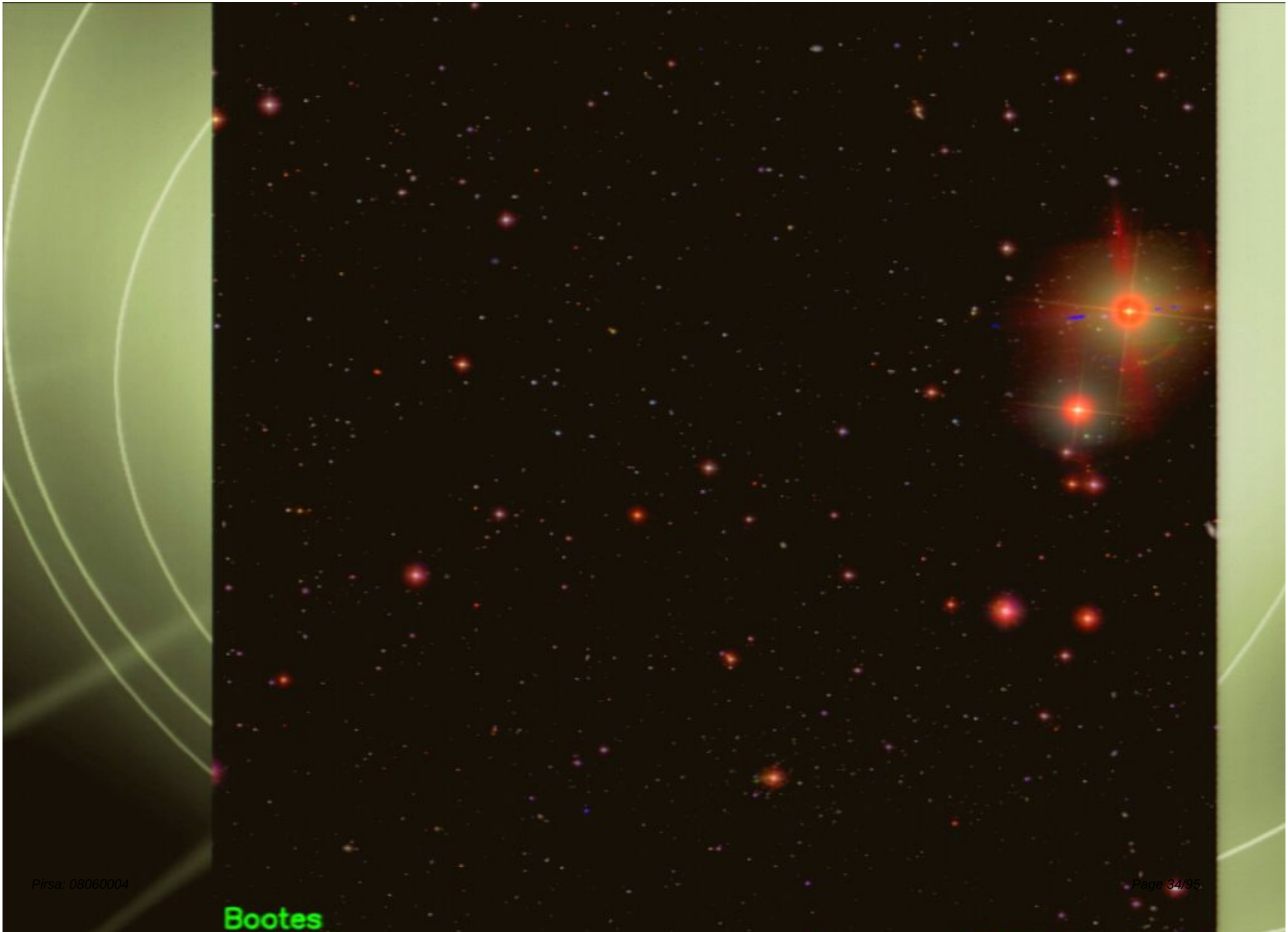

Binned array
5.5
5.0
4.5
4.0
3.5
degrees
204.5
205.0
205.5
206.0
206.5
207.0
degrees

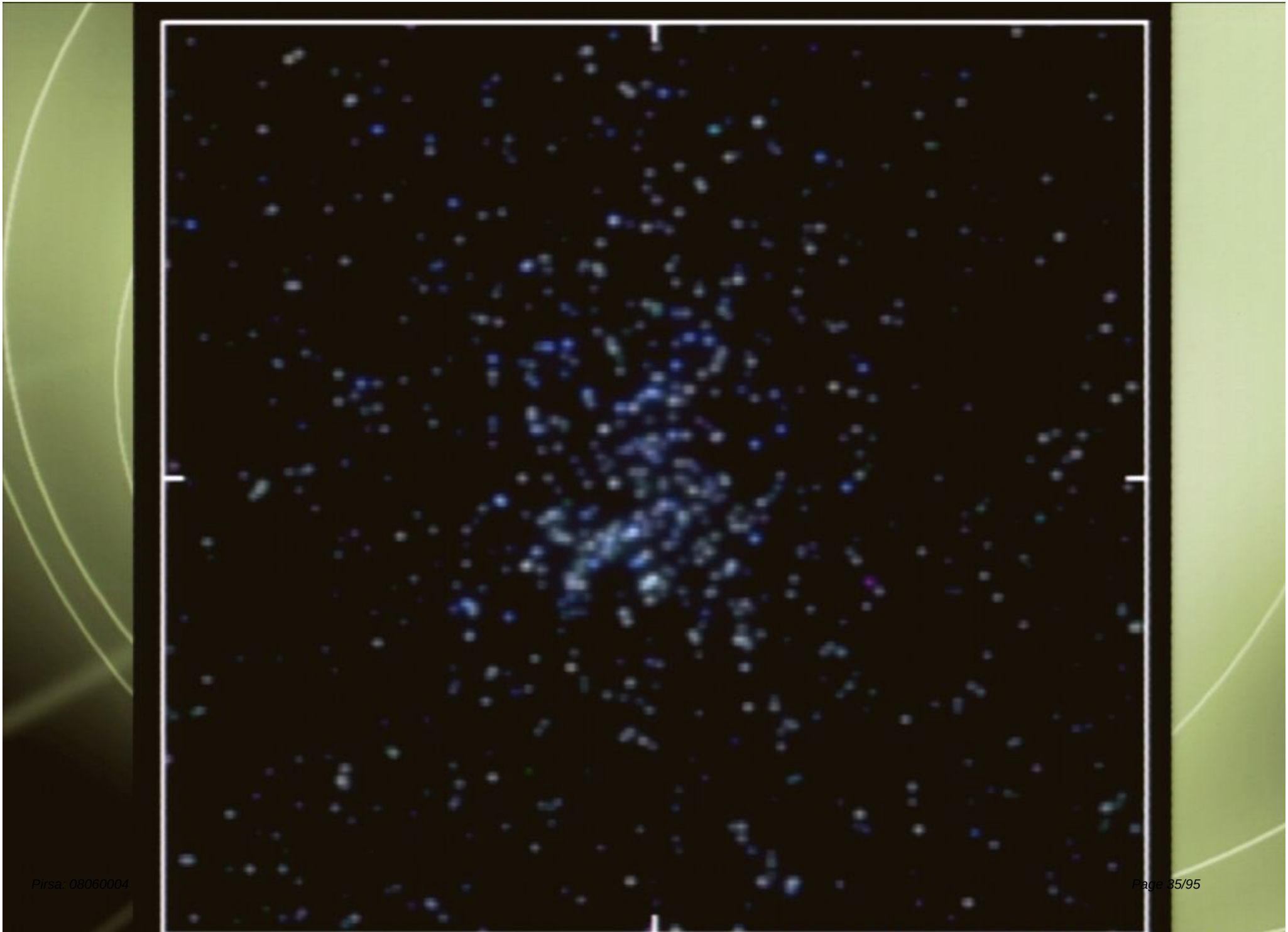

Array smoothed with 3′ filter
5.5
5.0
4.5
4.0
3.5
nu
204.5
205.0
205.5
206.0
206.5
207.0
degrees

Willman 1

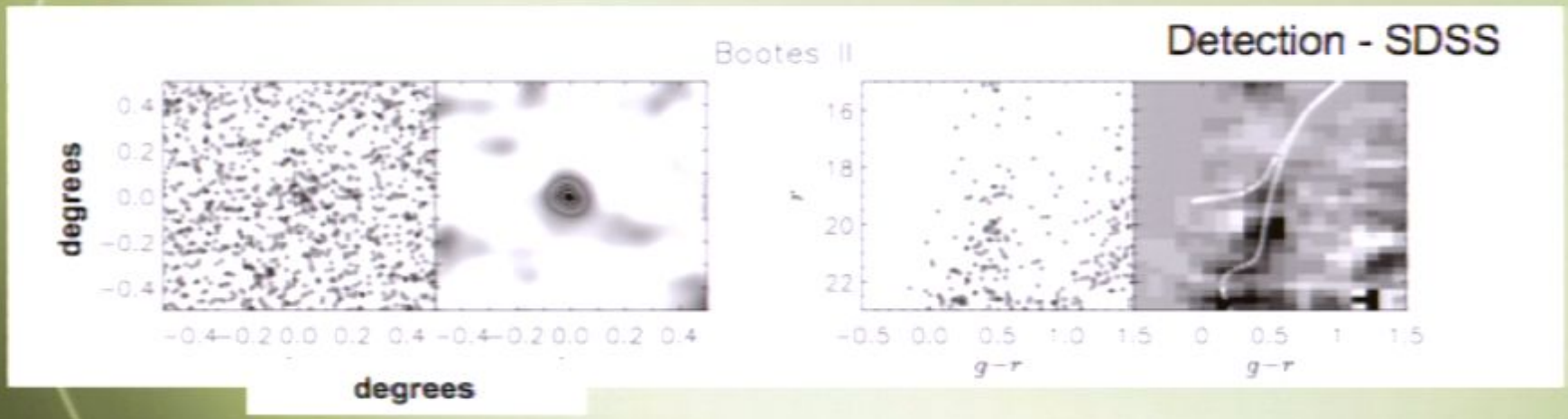

Bootes



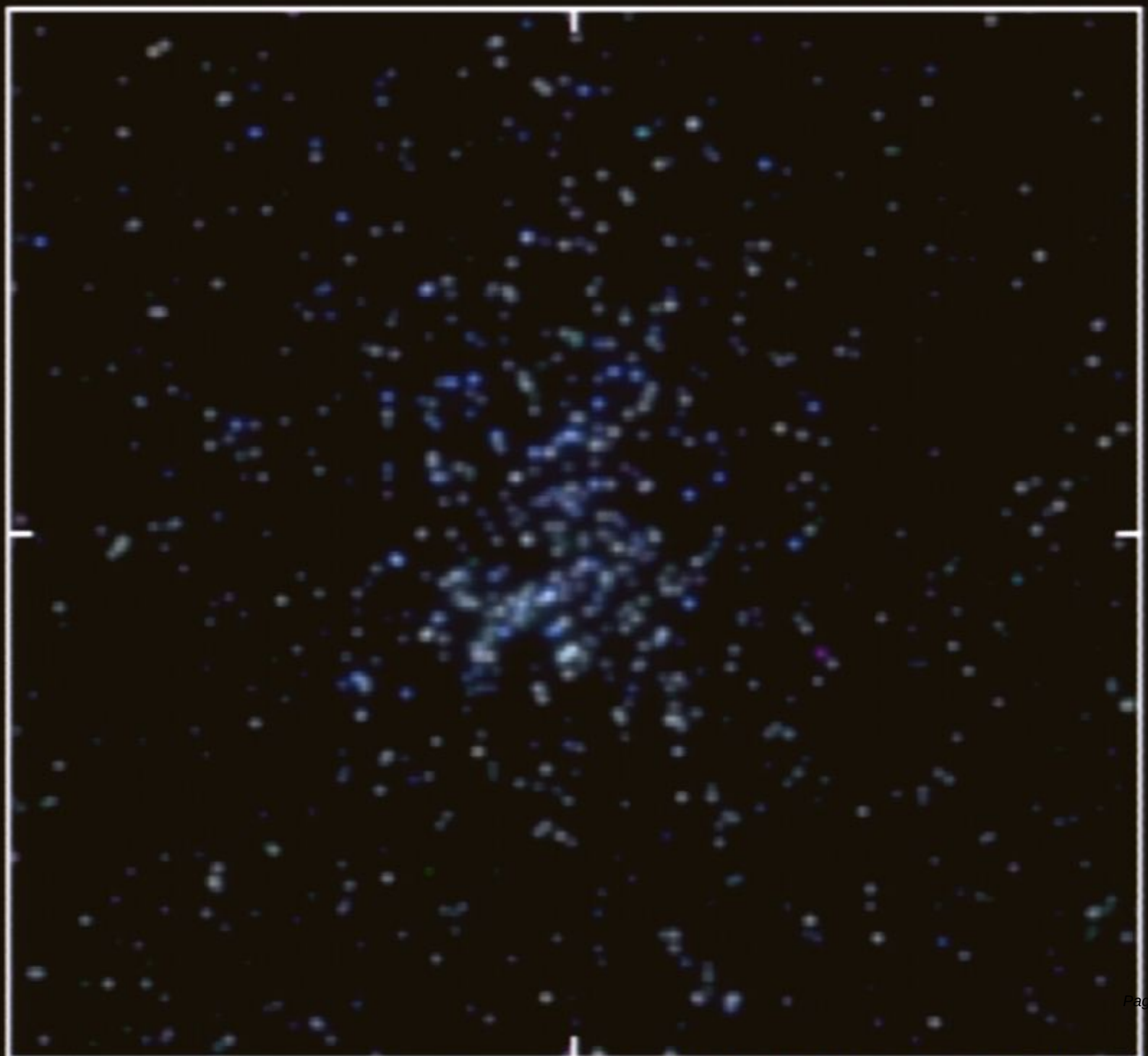

Bootes



Detection and Confirmation of new Milky Way Dwarfs: example, Bootes II



Walsh, Jerjen & Willman 2007; Walsh et al 2008



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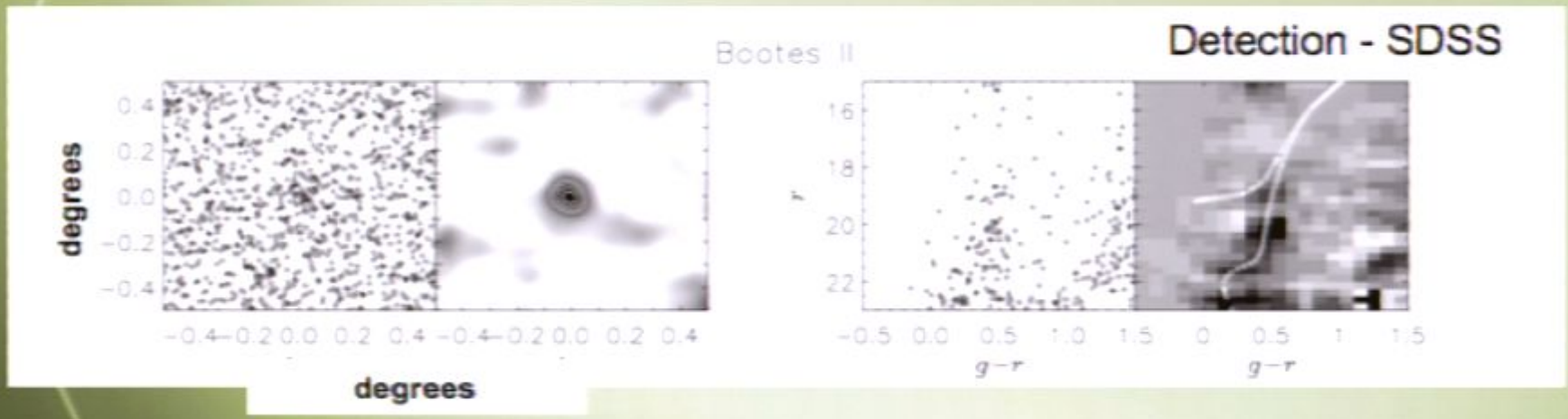

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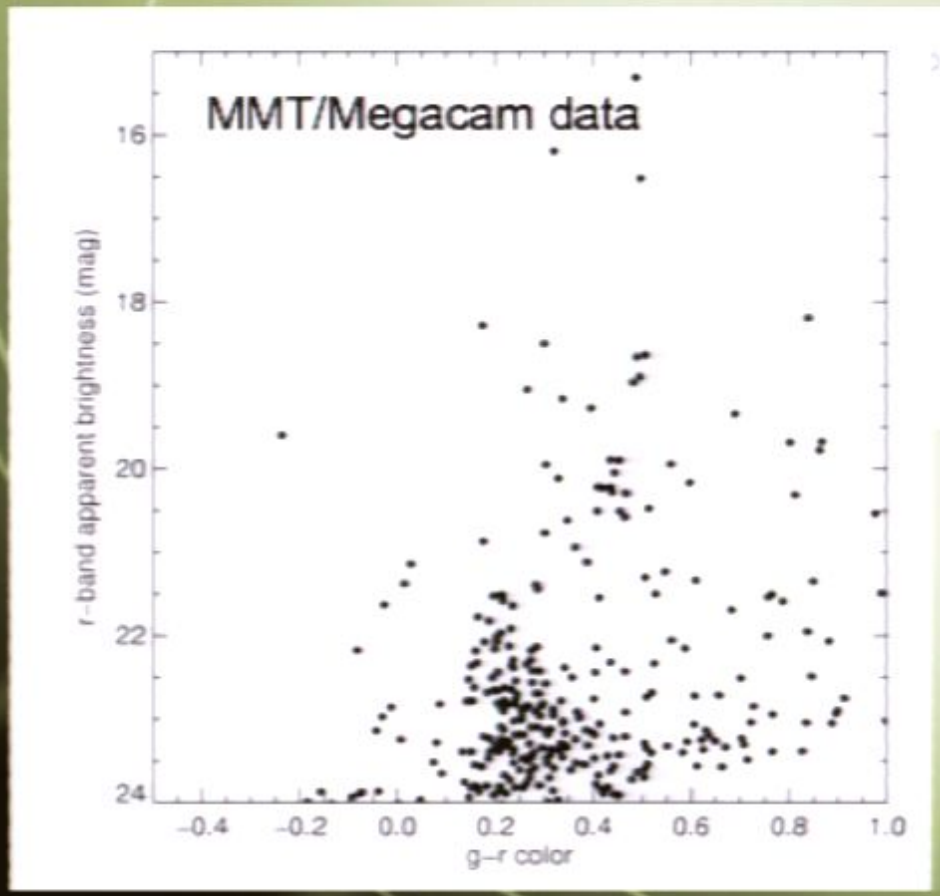

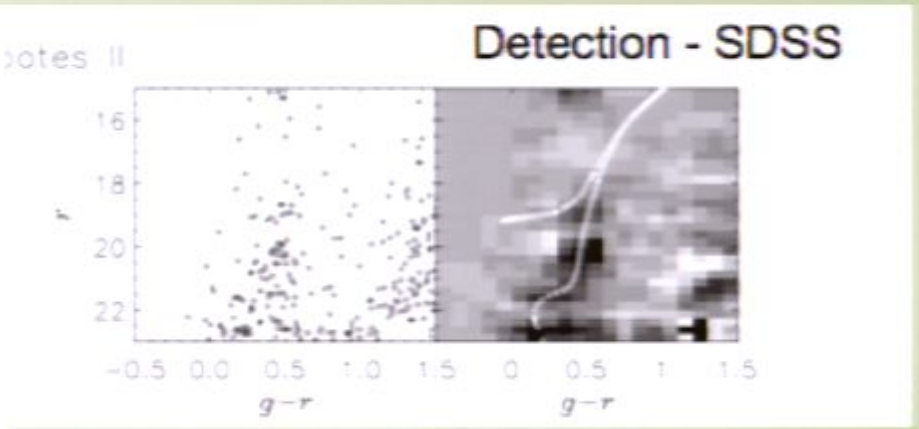

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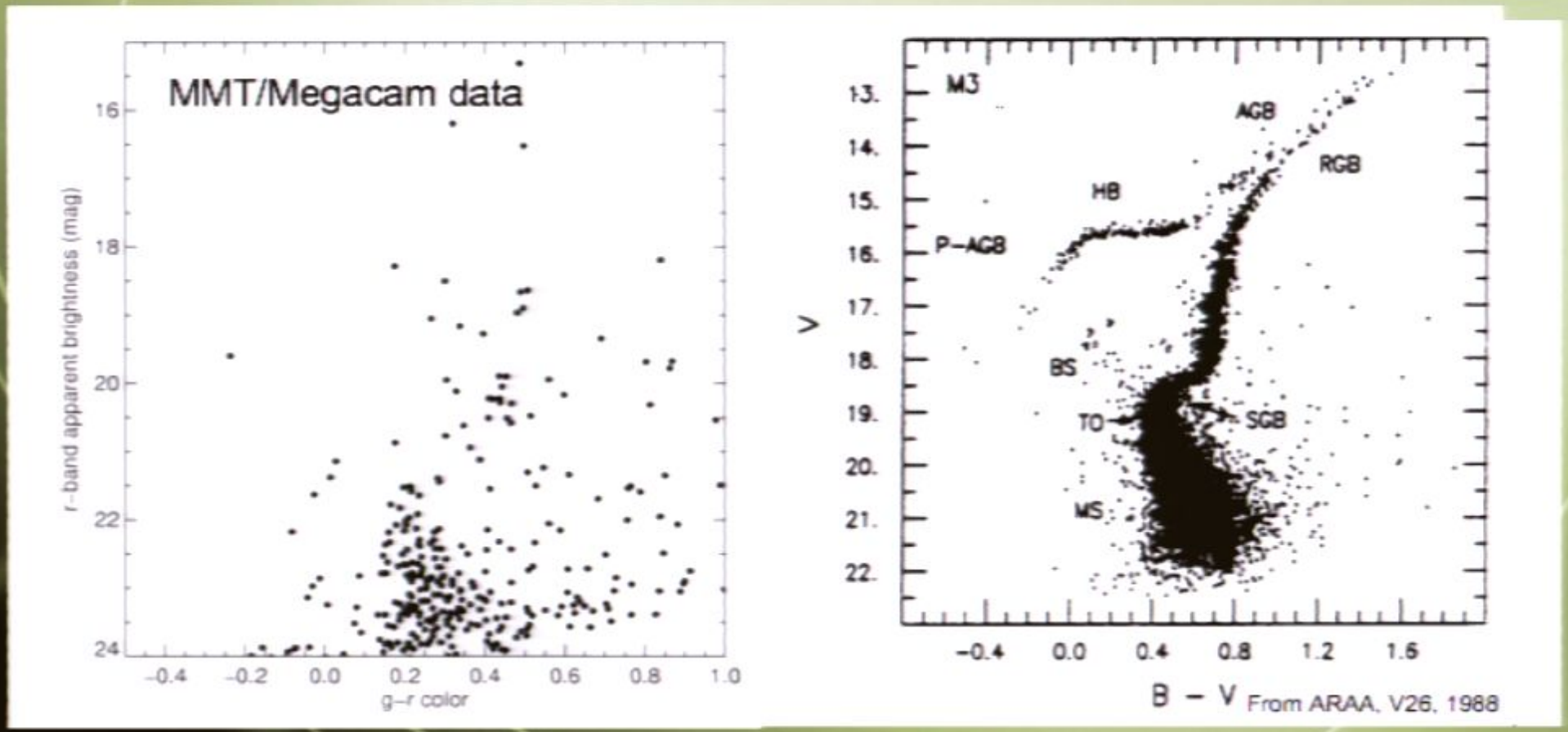

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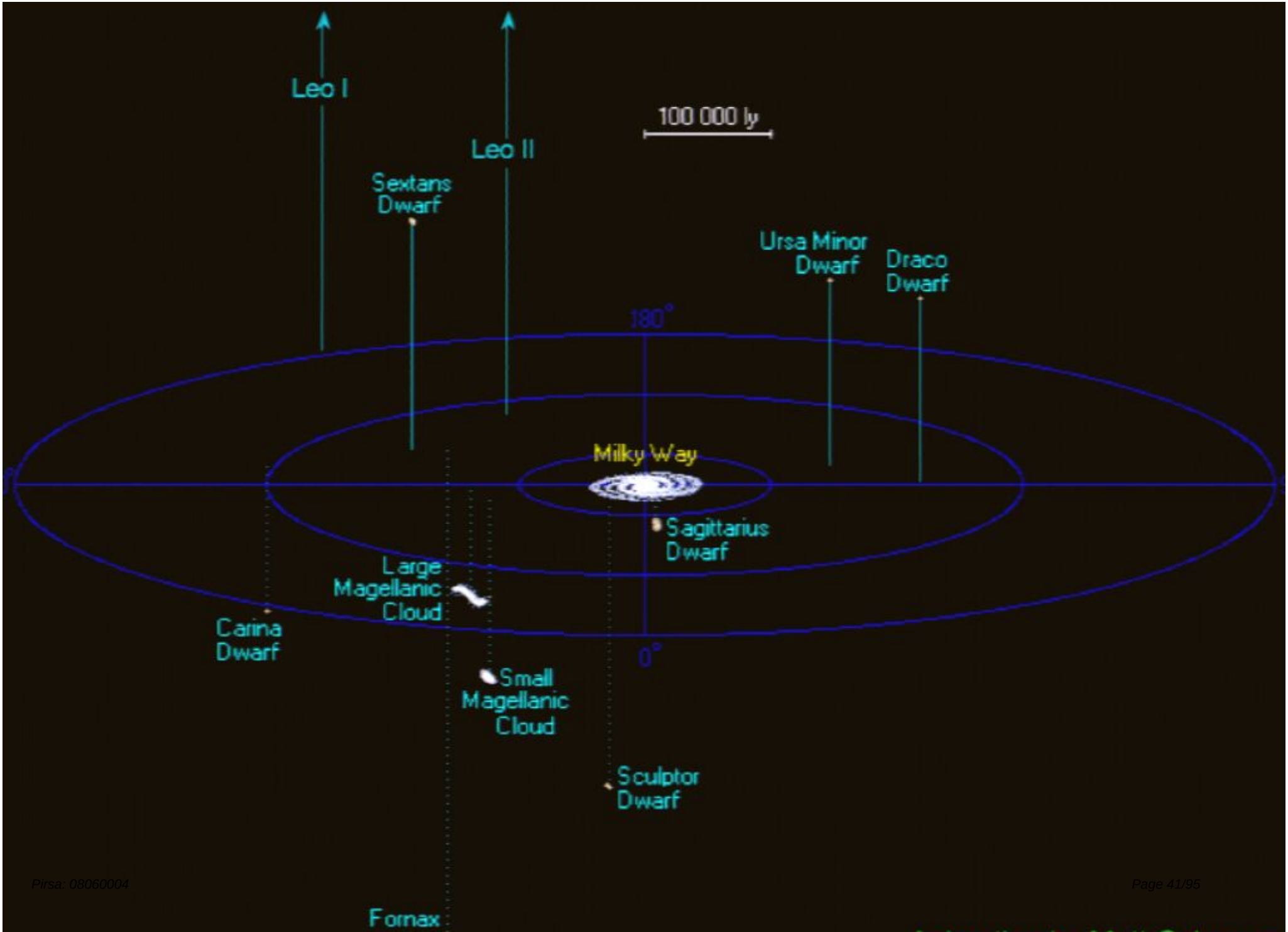
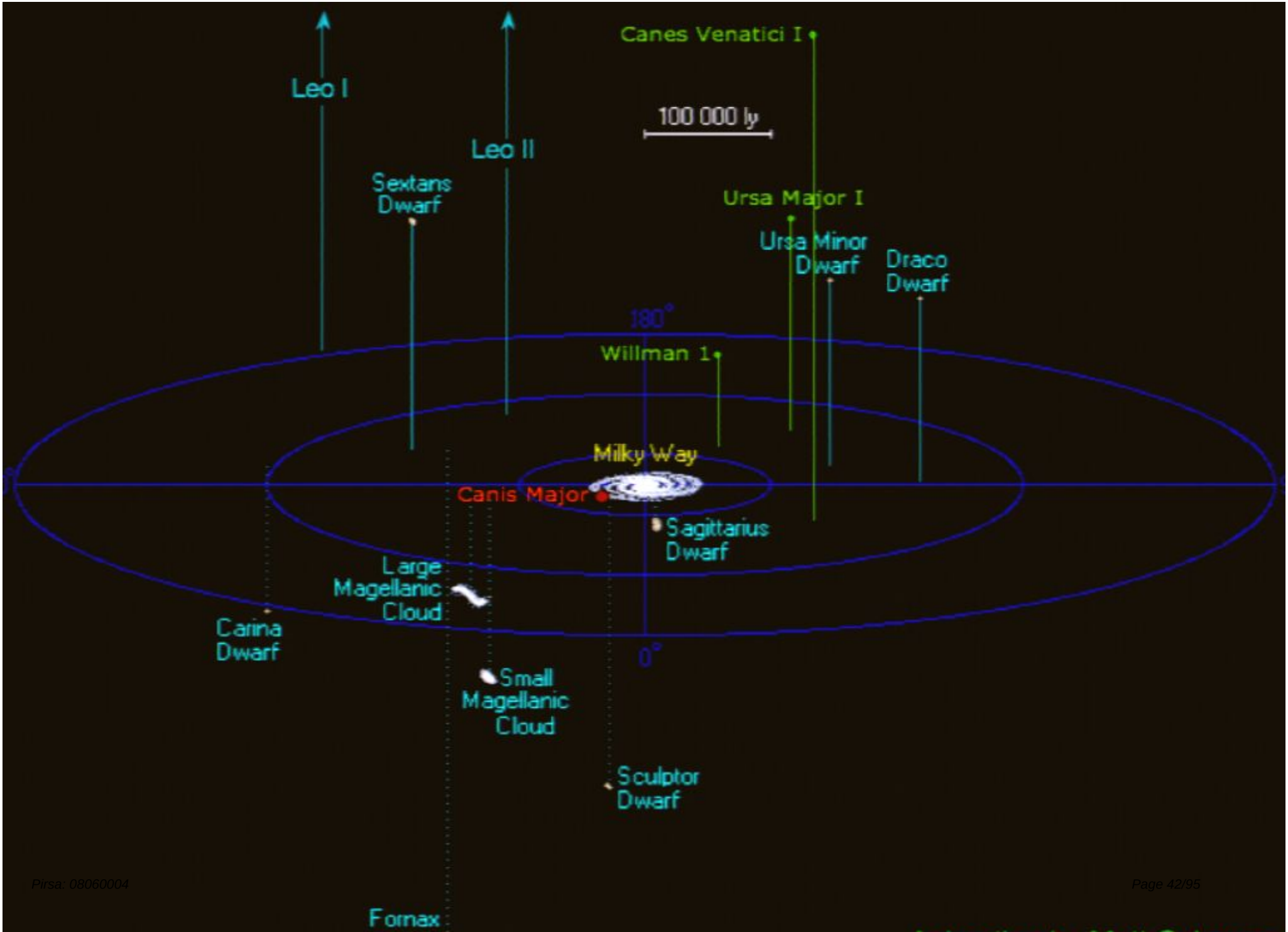
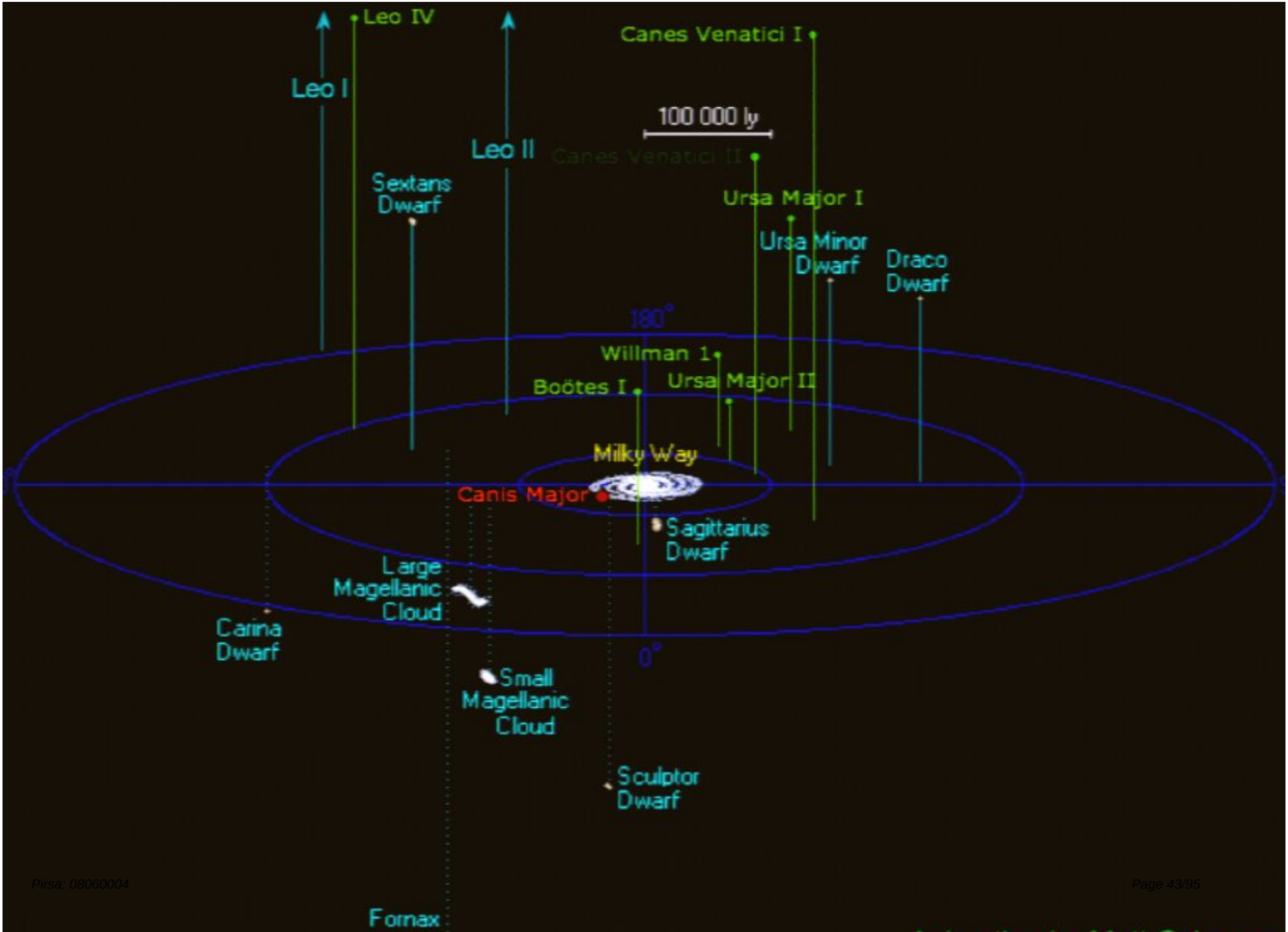
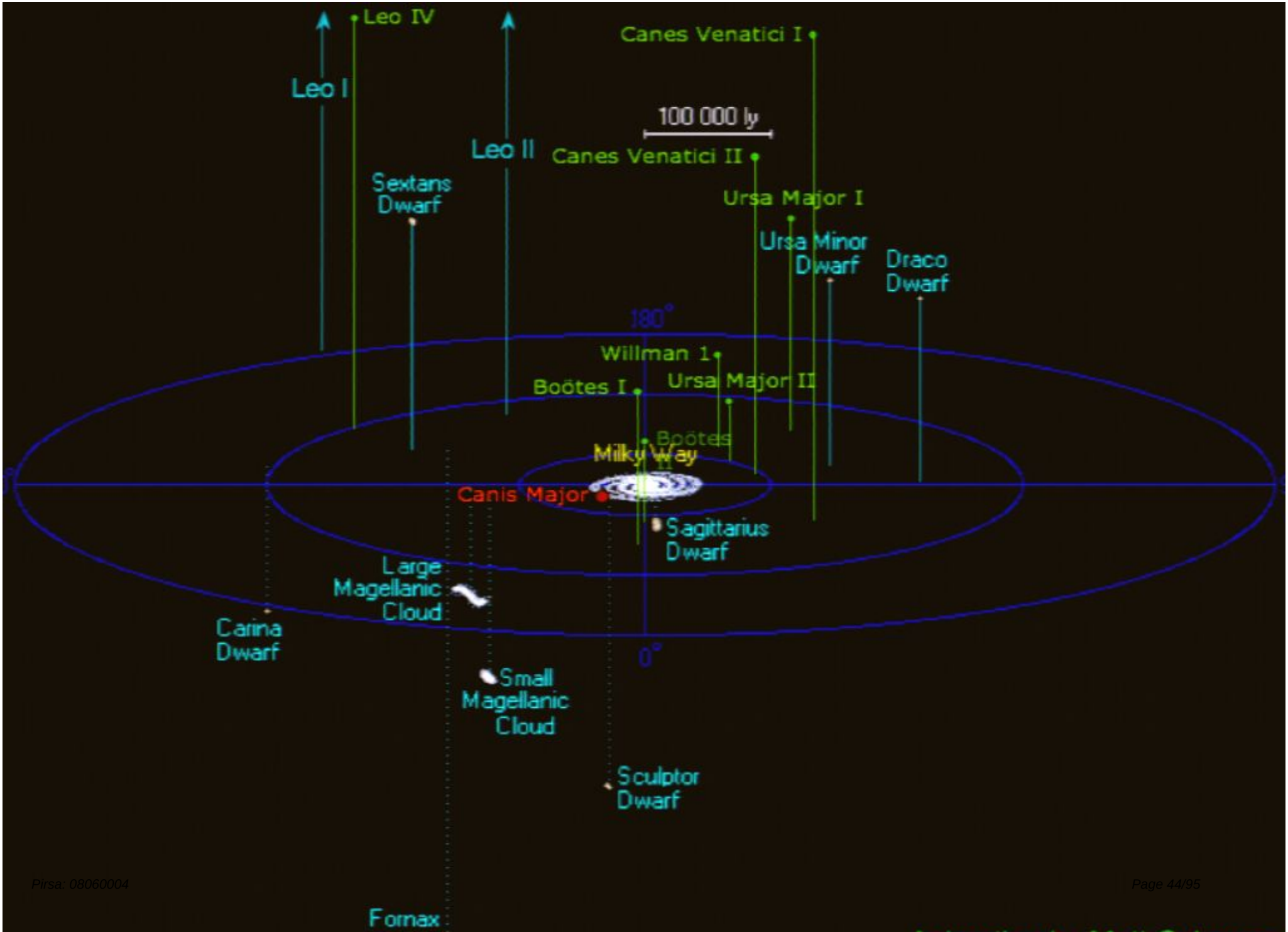
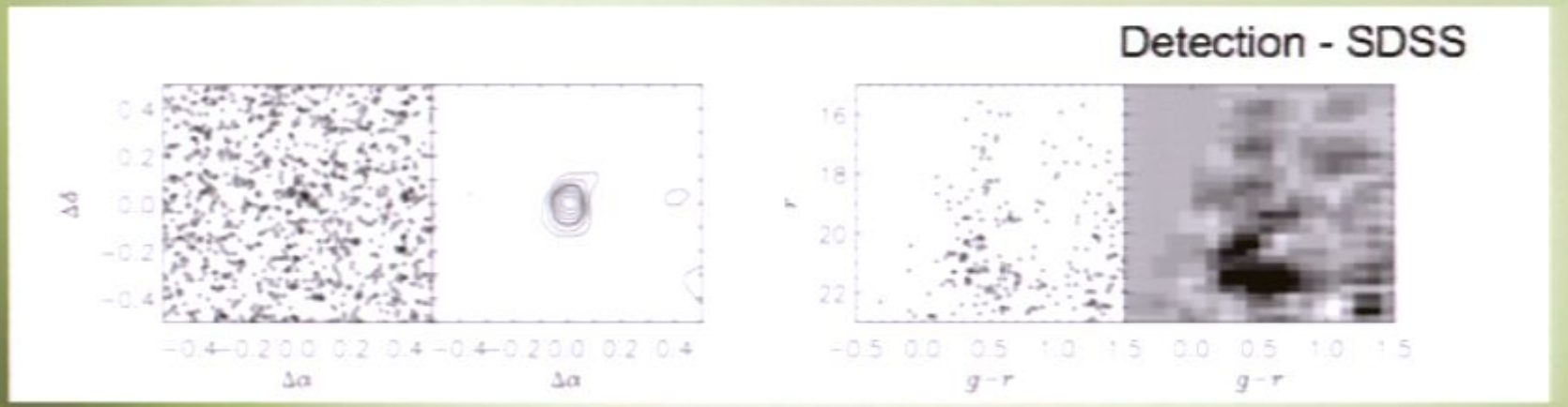

Leo I
Leo II
100 000 ly
Sextans Dwarf
Ursa Minor Dwarf
Draco Dwarf
180°
Milky Way
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
Small Magellanic Cloud
Sculptor Dwarf
Fornax


Canes Venatici I
Leo I
100 000 ly
Leo II
Sextans Dwarf
Ursa Major I
Ursa Minor Dwarf
Draco Dwarf
180°
Willman 1
Milky Way
Canis Major
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
Small Magellanic Cloud
Sculptor Dwarf
Fornax

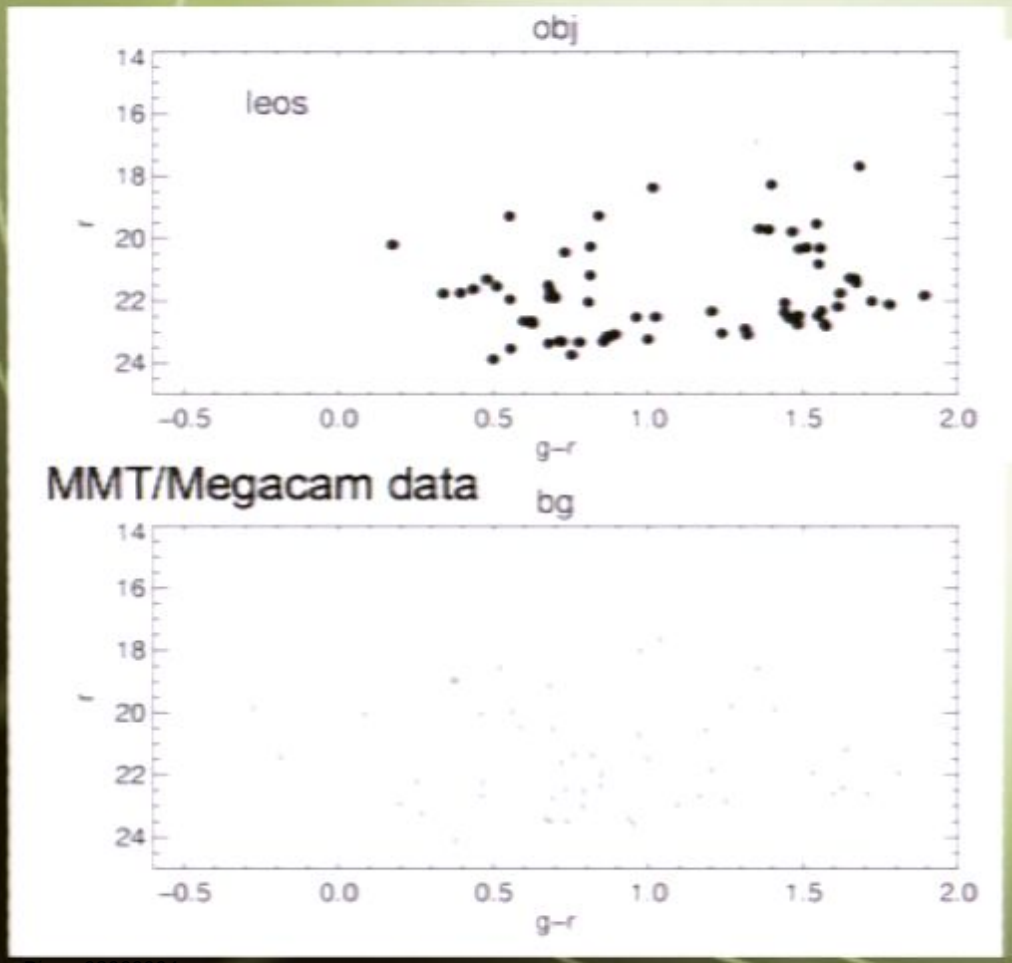

Leo IV
Canes Venatici I
Leo I
100 000 ly
Leo II
Canes Venatici II
Sextans Dwarf
Ursa Major I
Ursa Minor Dwarf
Draco Dwarf
180°
Willman 1
Boötes I
Ursa Major II
Milky Way
Canis Major
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
Small Magellanic Cloud
Sculptor Dwarf
Fornax

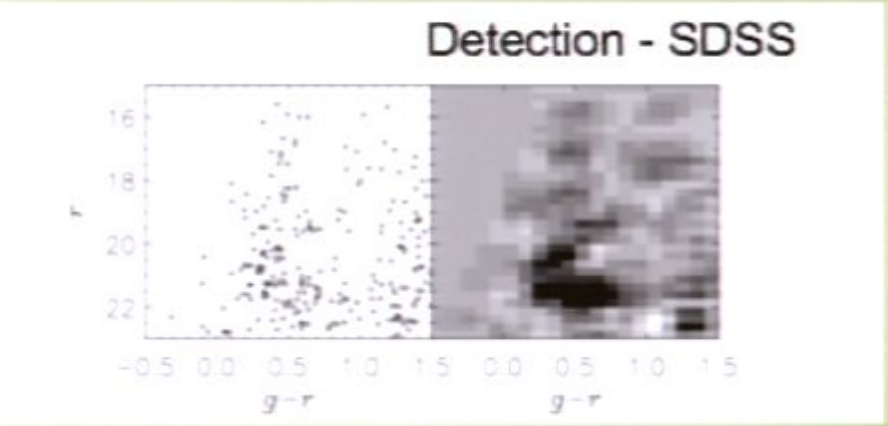

Leo IV
Canes Venatici I
Leo I
100 000 ly
Leo II
Canes Venatici II
Sextans Dwarf
Ursa Major I
Ursa Minor Dwarf
Draco Dwarf
180°
Willman 1
Boötes I
Ursa Major II
Boötes
Milky Way
Canis Major
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
Small Magellanic Cloud
Sculptor Dwarf
Fornax

Detection and Confirmation of new Milky Way Dwarfs: ???



Detection and Confirmation of new Milky Way Dwarfs: ???





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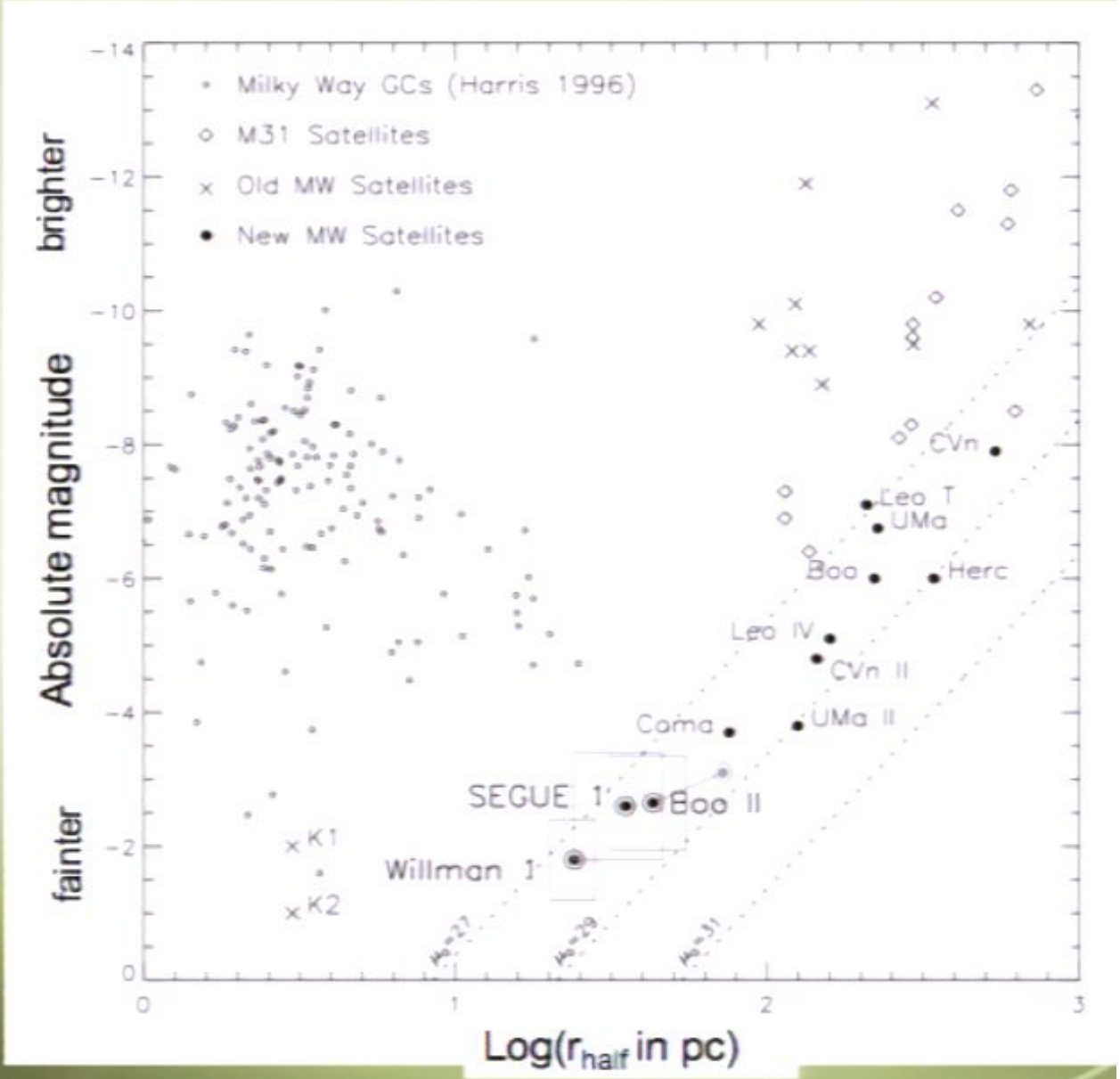

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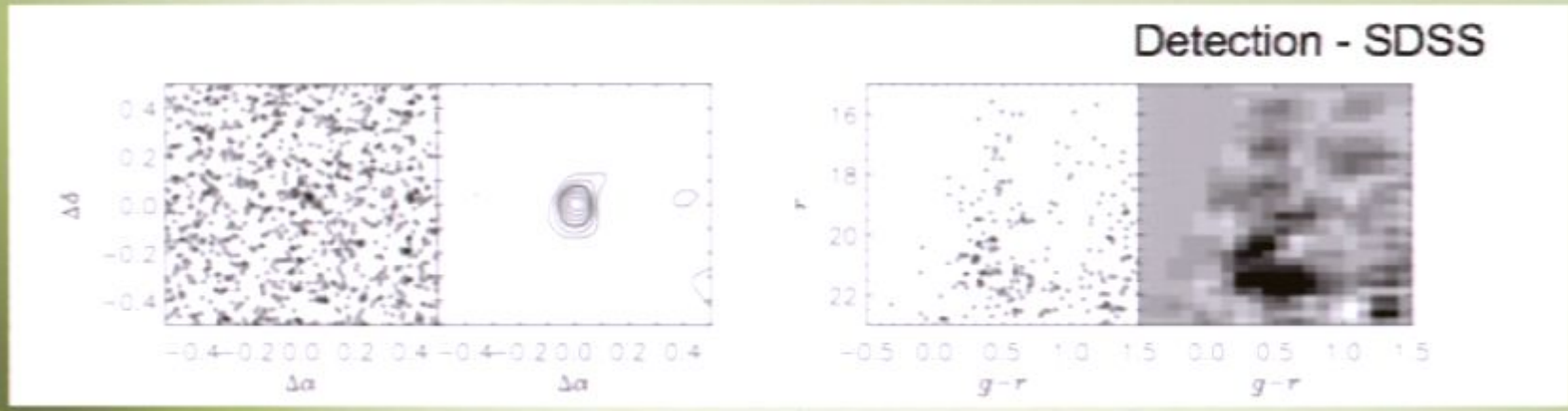

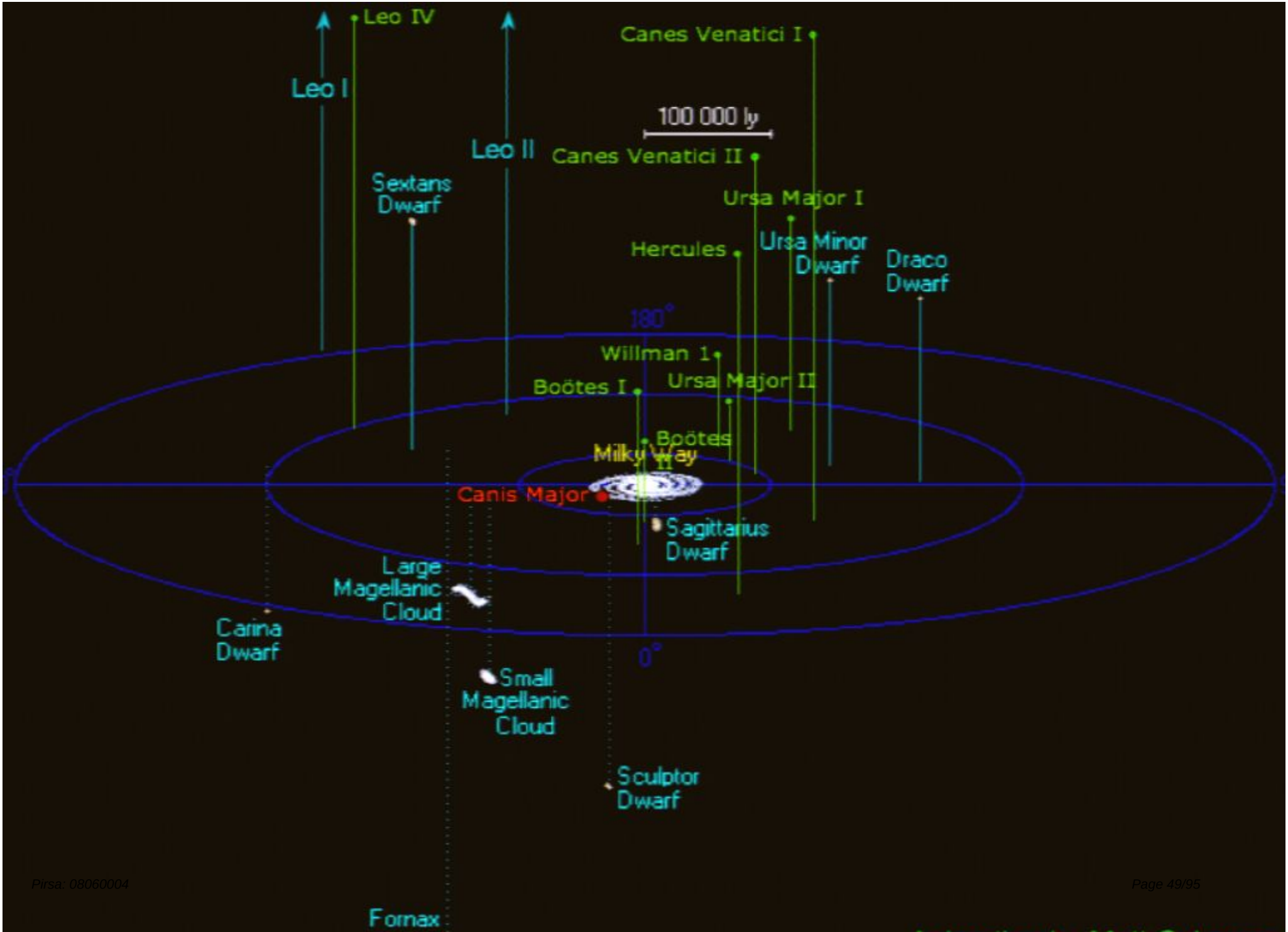
Leo IV
Canes Venatici I
Leo I
100 000 ly
Leo II
Canes Venatici II
Sextans Dwarf
Ursa Major I
Ursa Minor Dwarf
Hercules
Draco Dwarf
180°
Willman 1
Ursa Major II
Boötes I
Boötes
Milky Way
Canis Major
Sagittarius Dwarf
Large Magellanic Cloud
Carina Dwarf
0°
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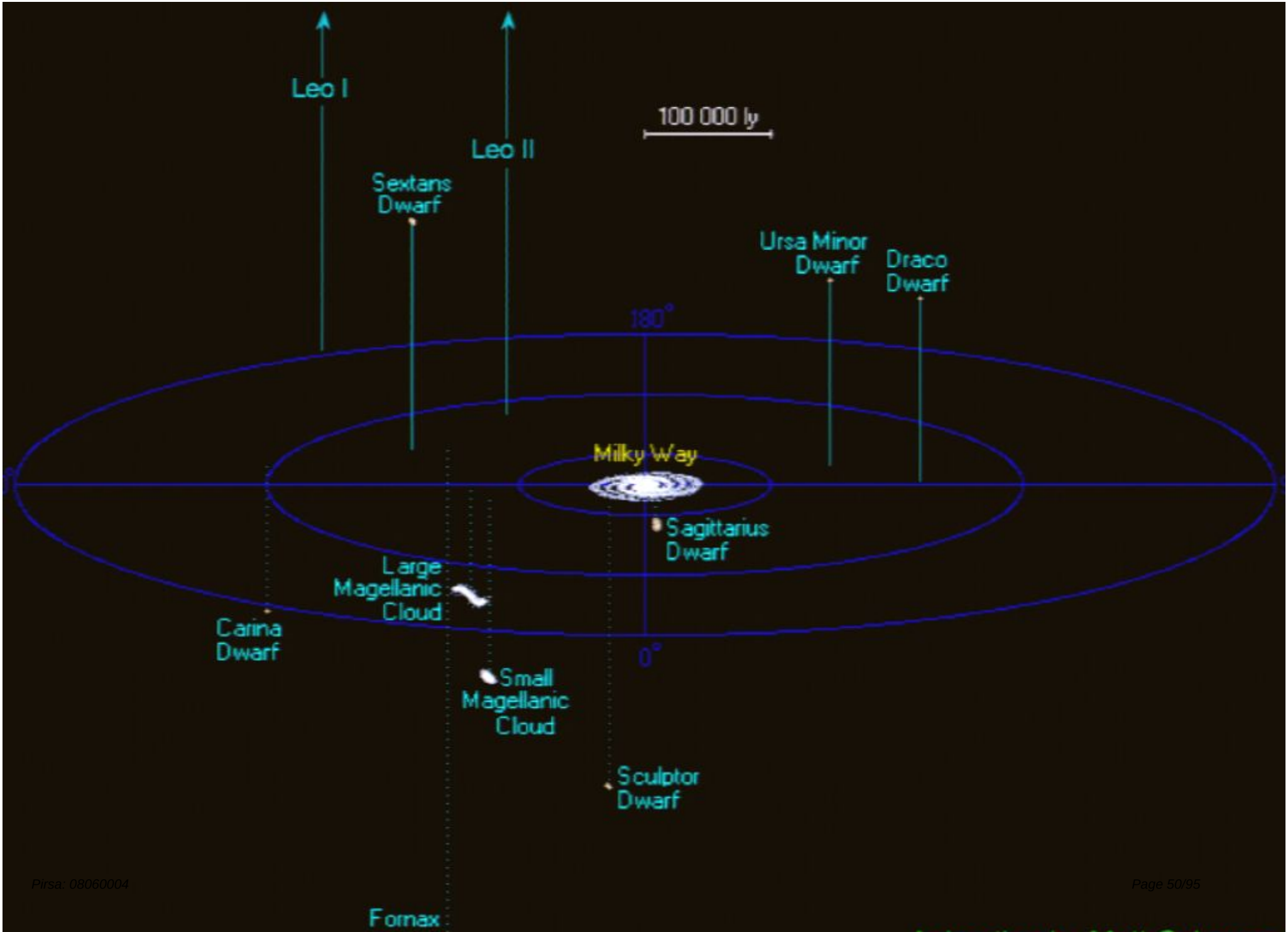
Fornax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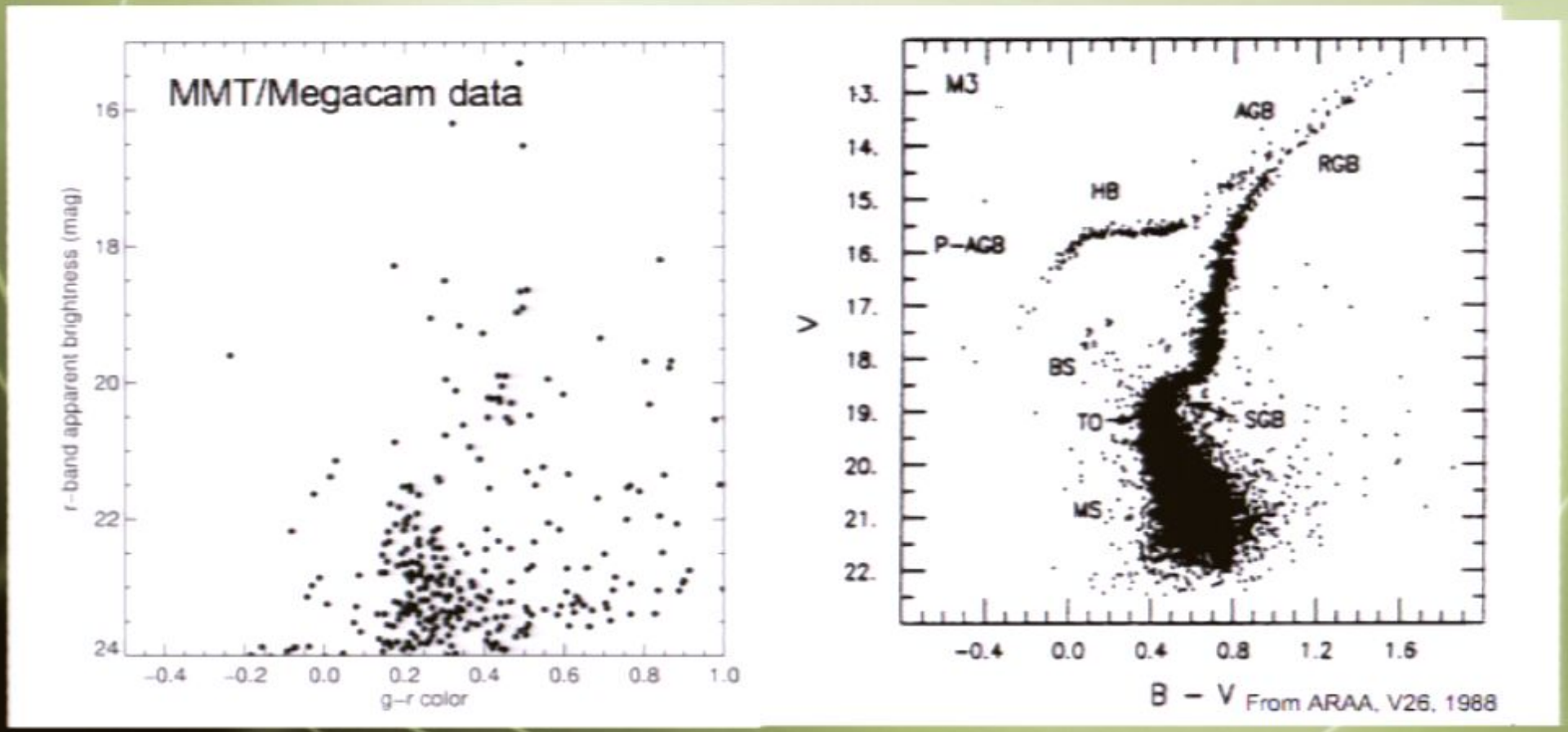
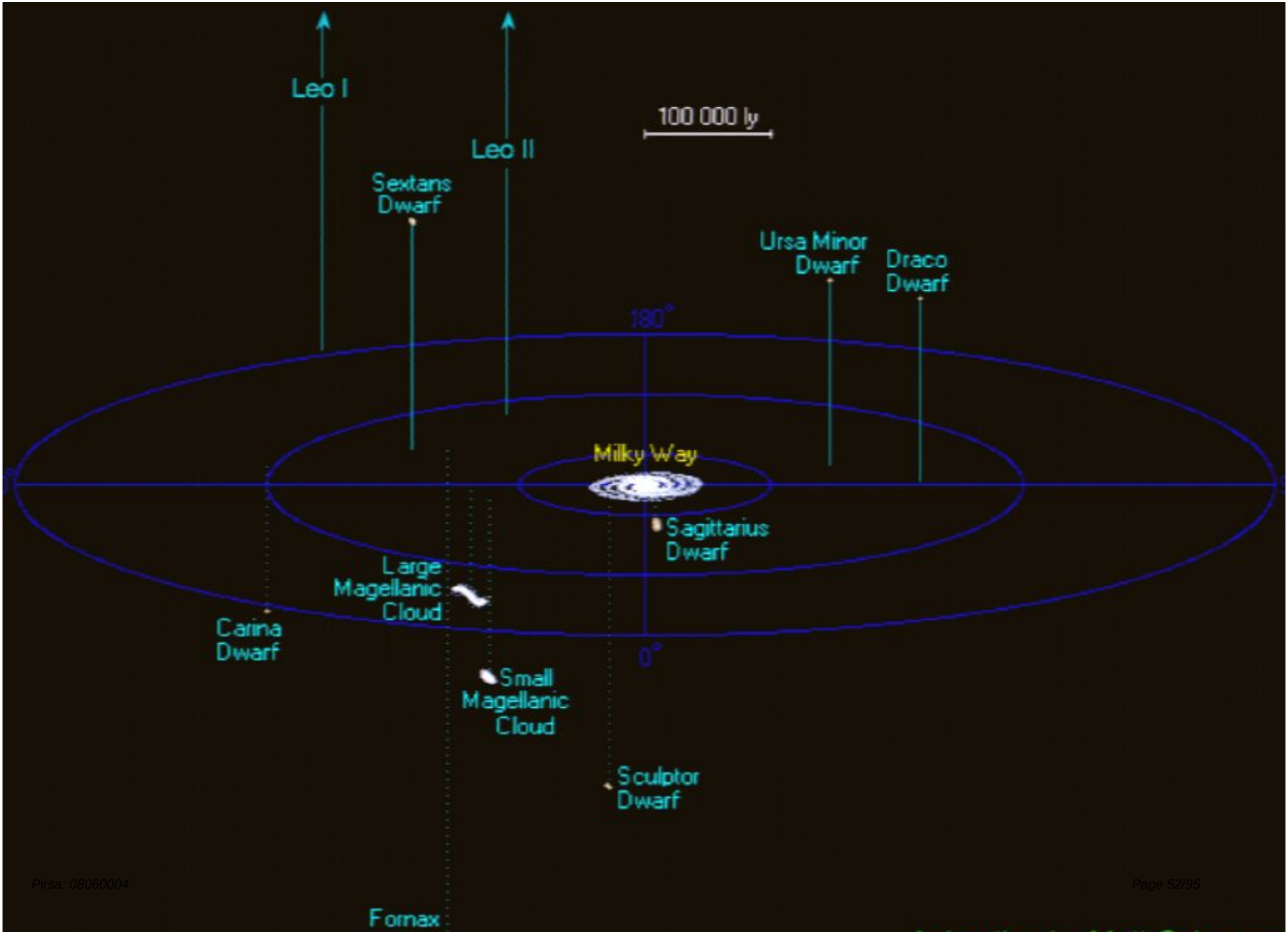
Detection and Confirmation of new Milky Way Dwarfs: example, Bootes II



Walsh, Jerjen & Willman 2007; Walsh et al 2008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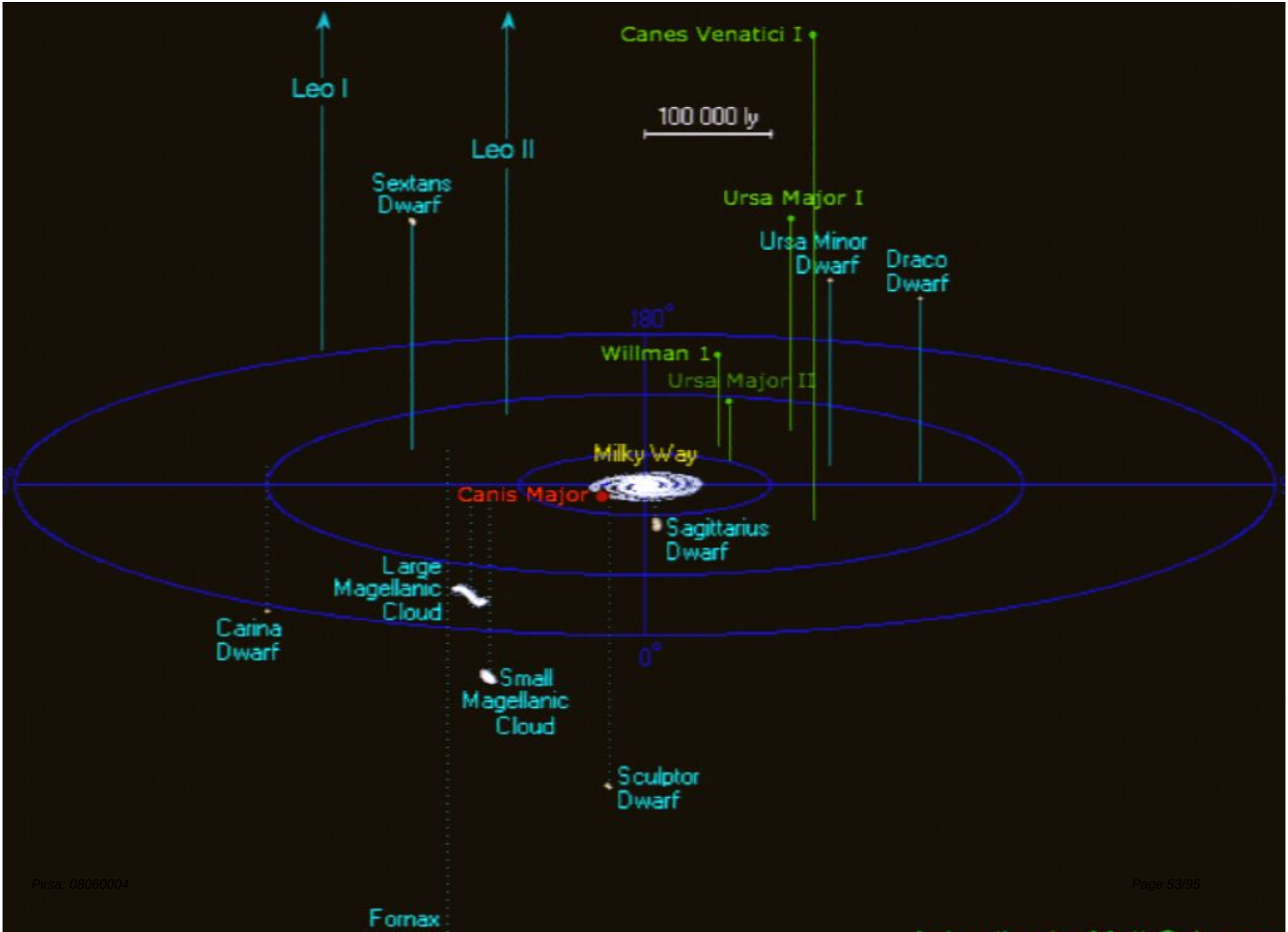
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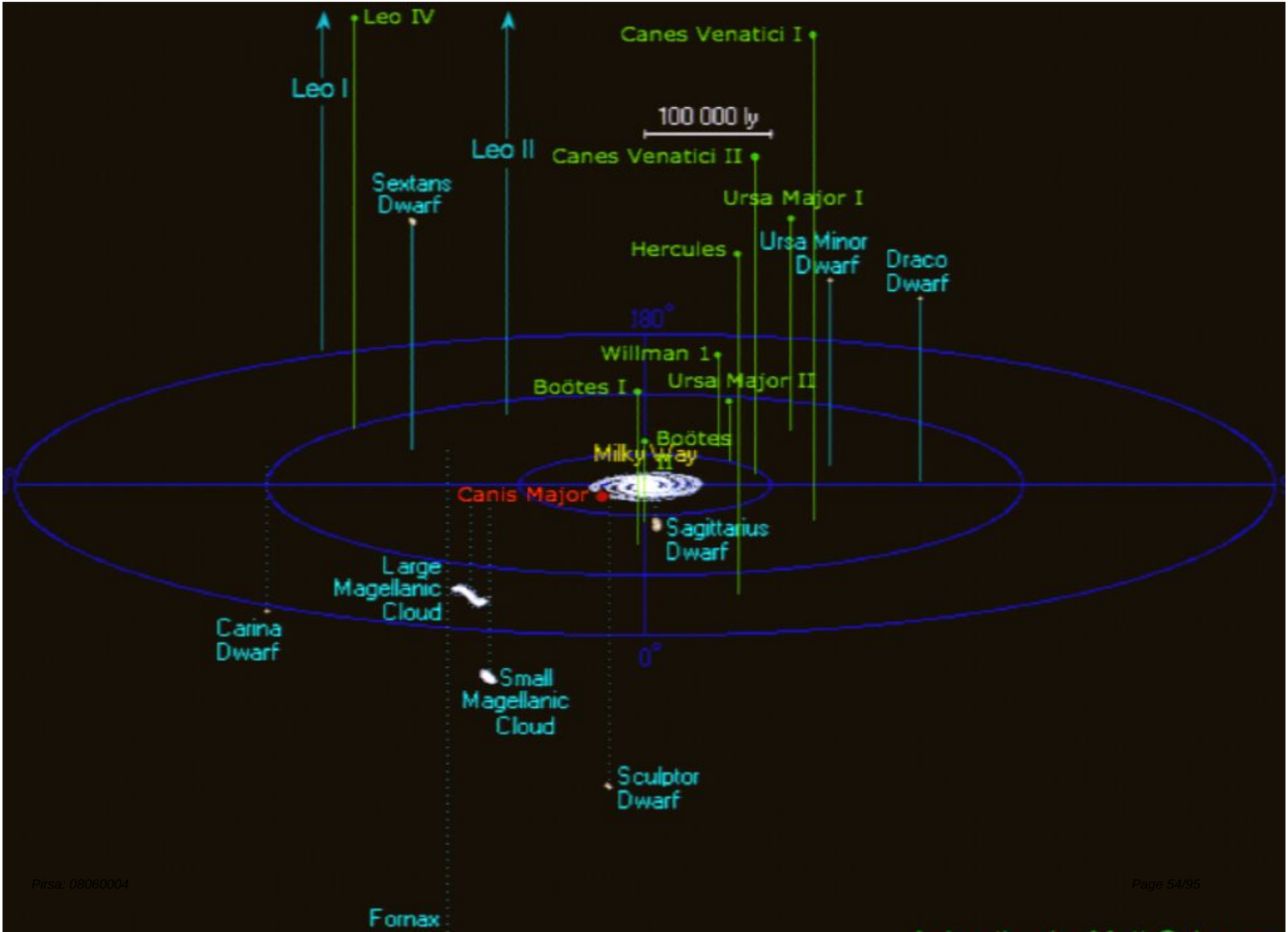
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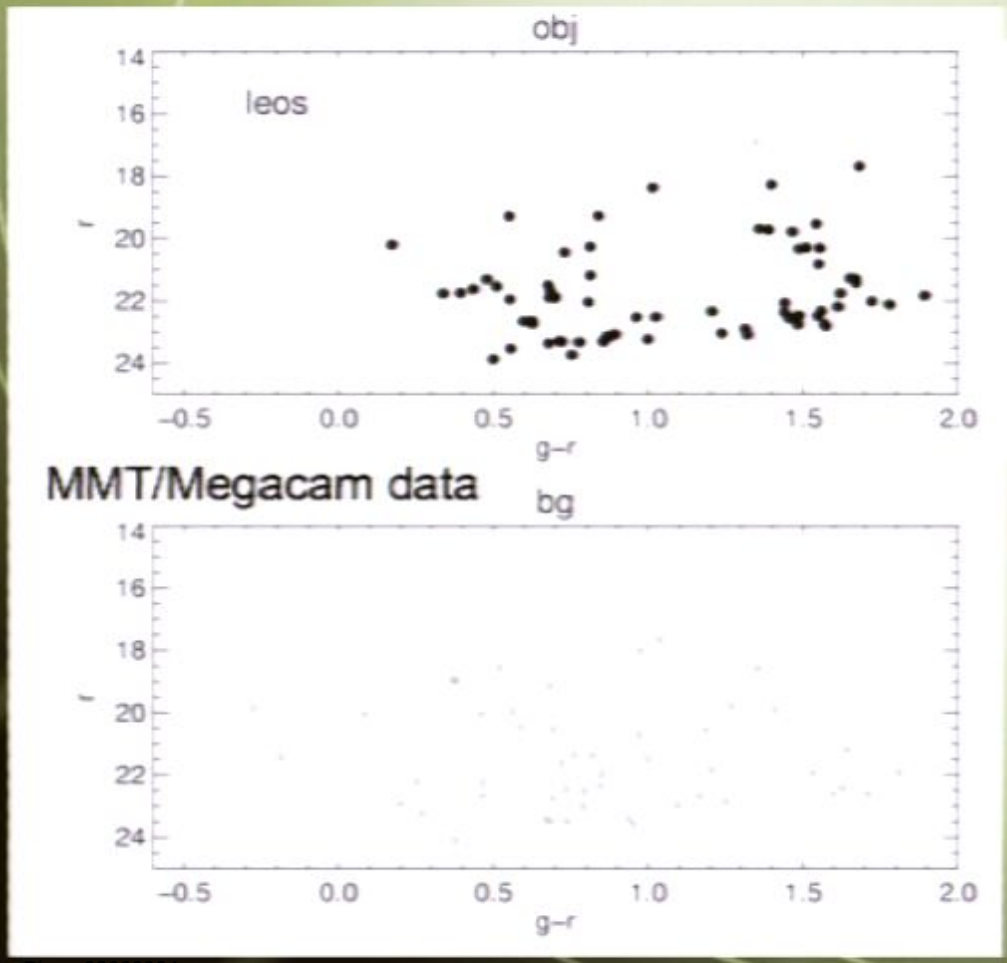

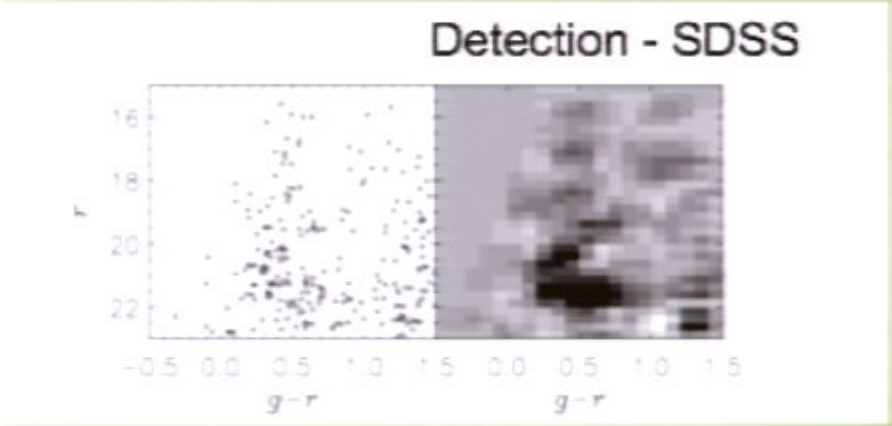

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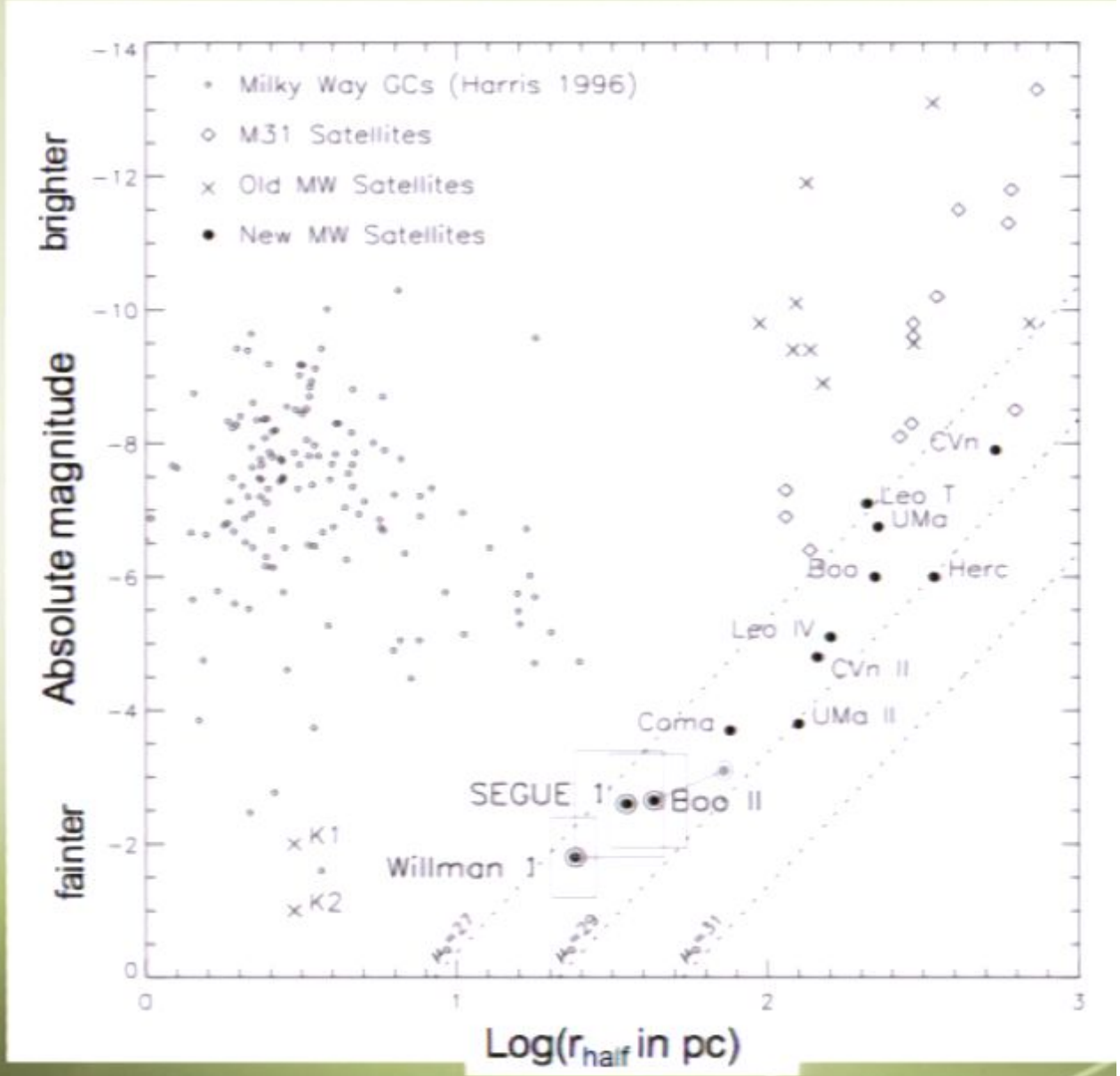
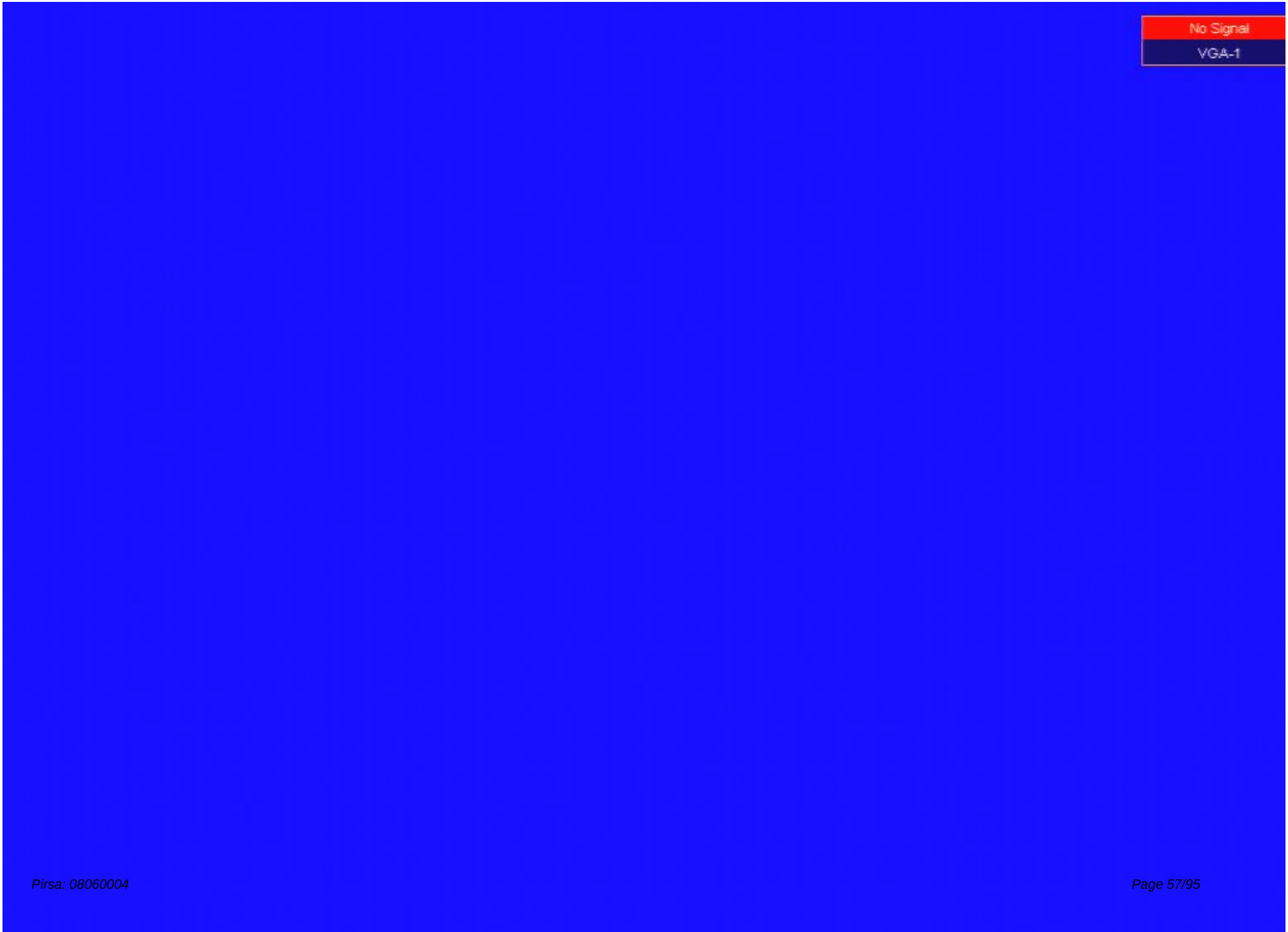
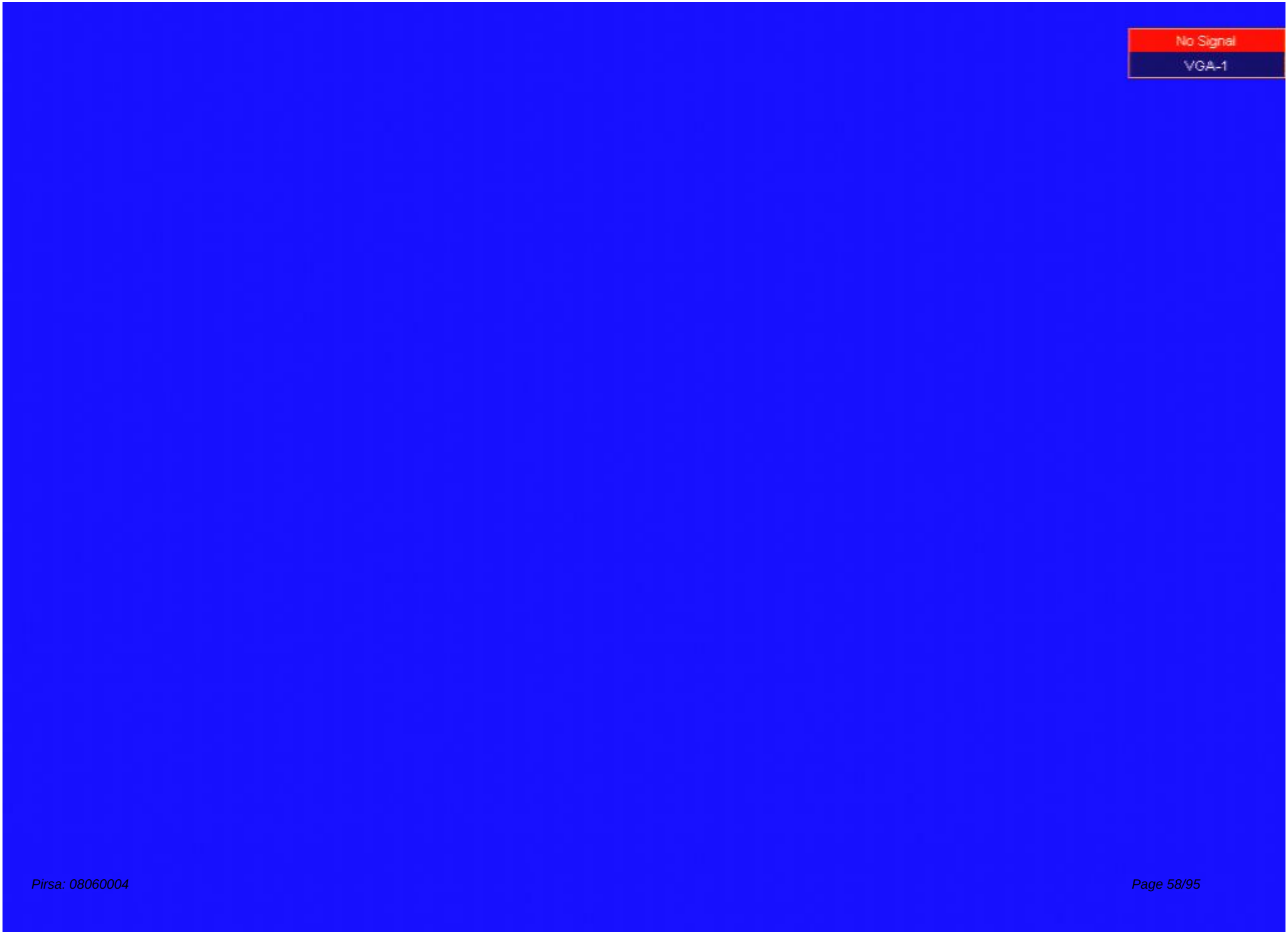



No Signal
VGA-1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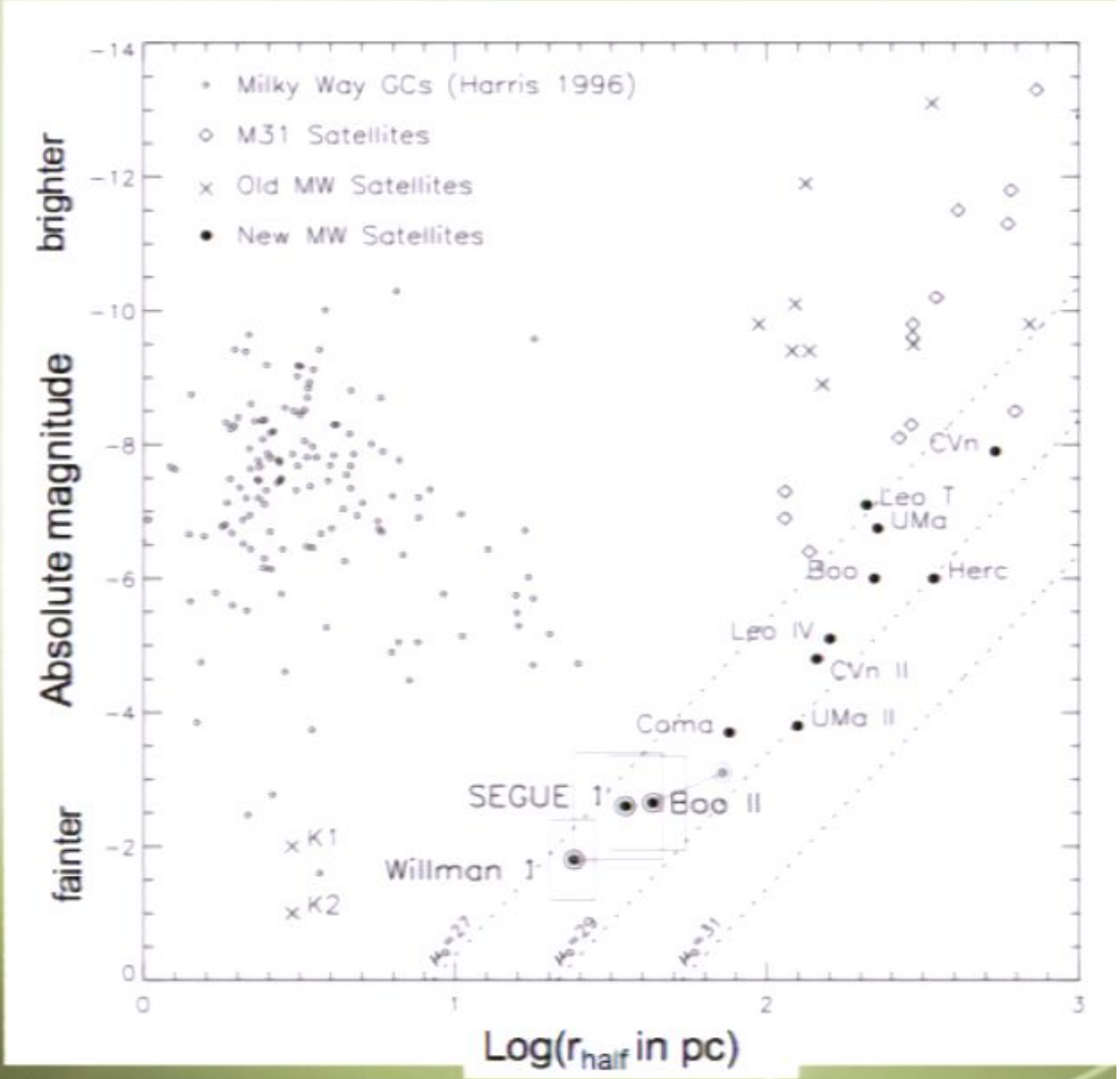

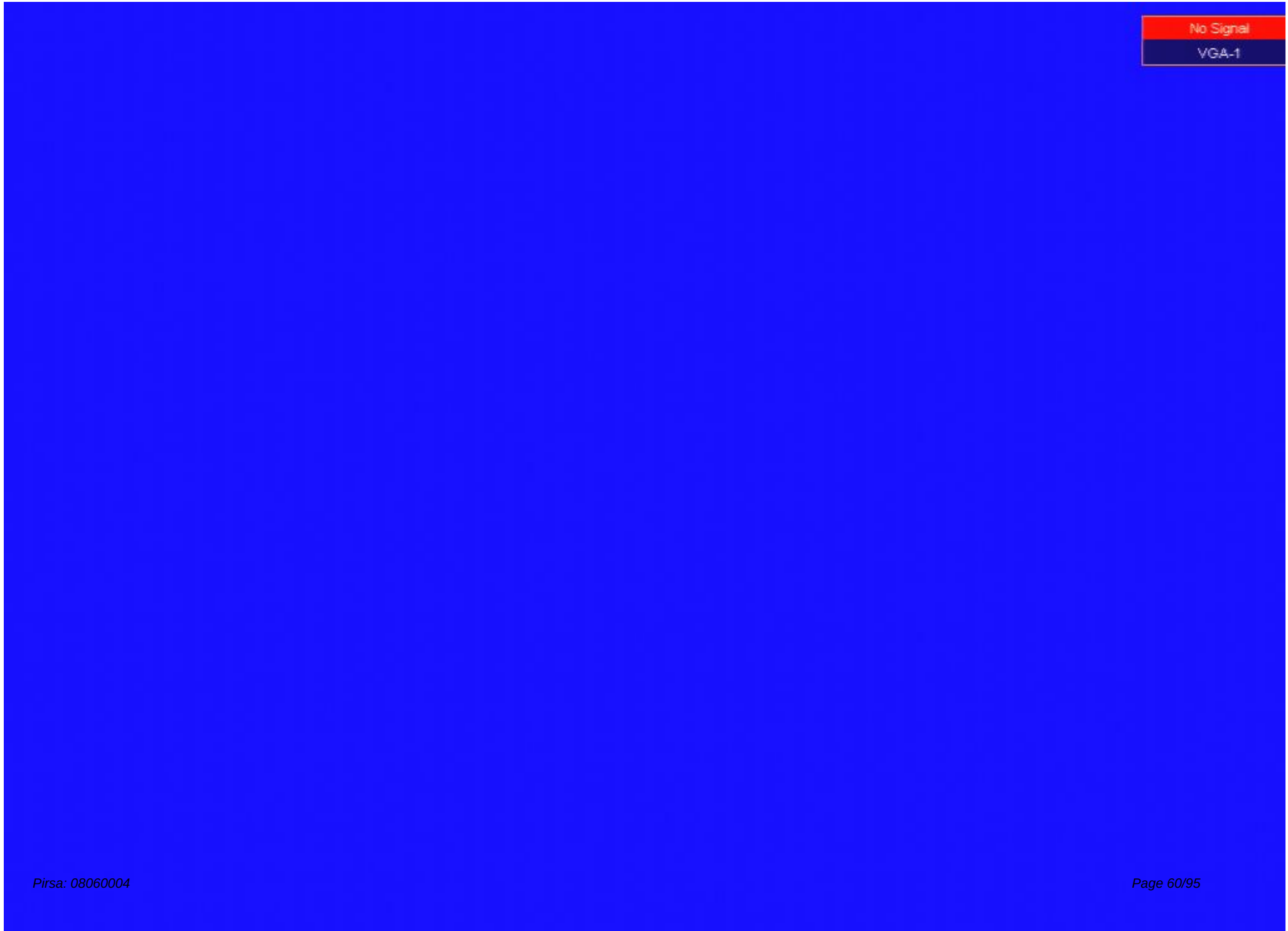
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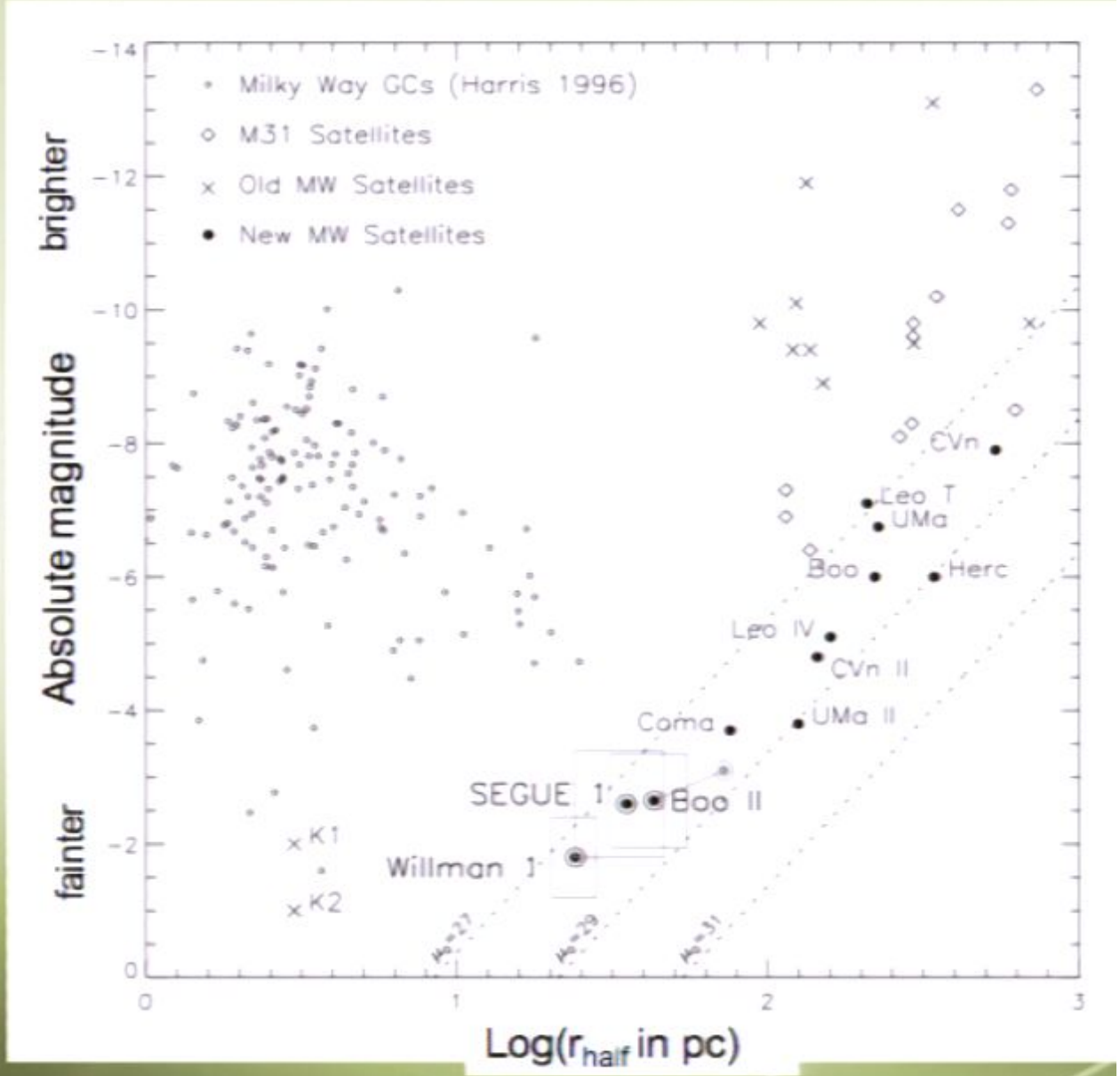
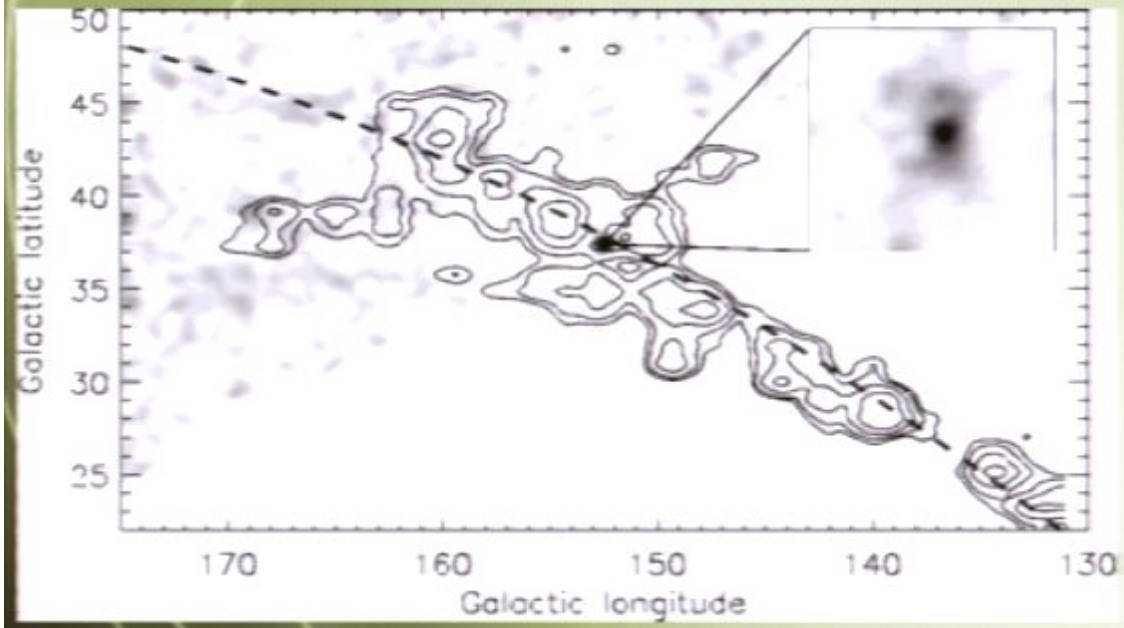
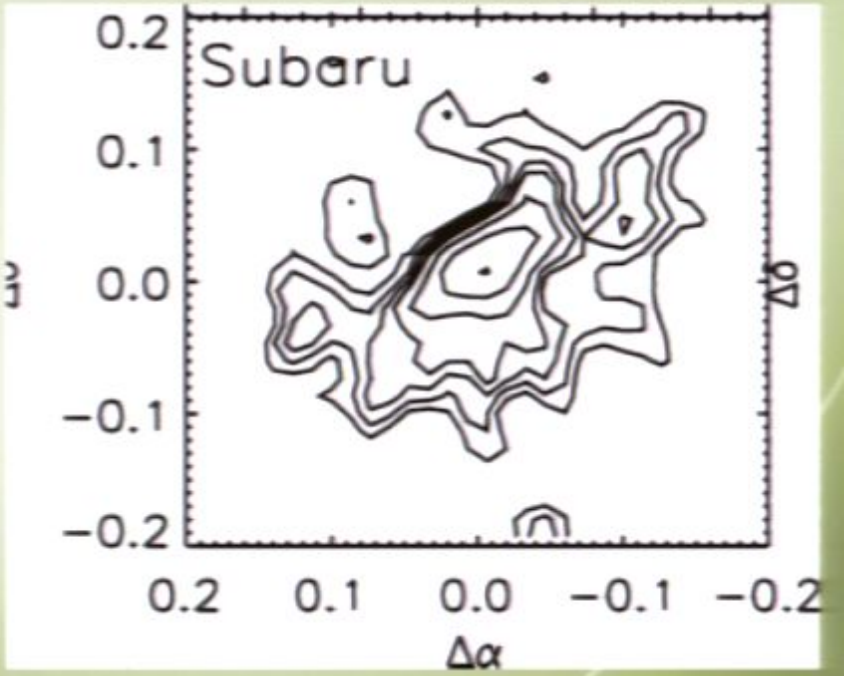


Figures from Zucker et al 2006; Belokurov et al 2007

Ursa Major II



May still have very high M/L if tidally disturbed, but would affect dynamical modeling



Coma Berenices

Many of the least luminous objects appear distorted

Tides?

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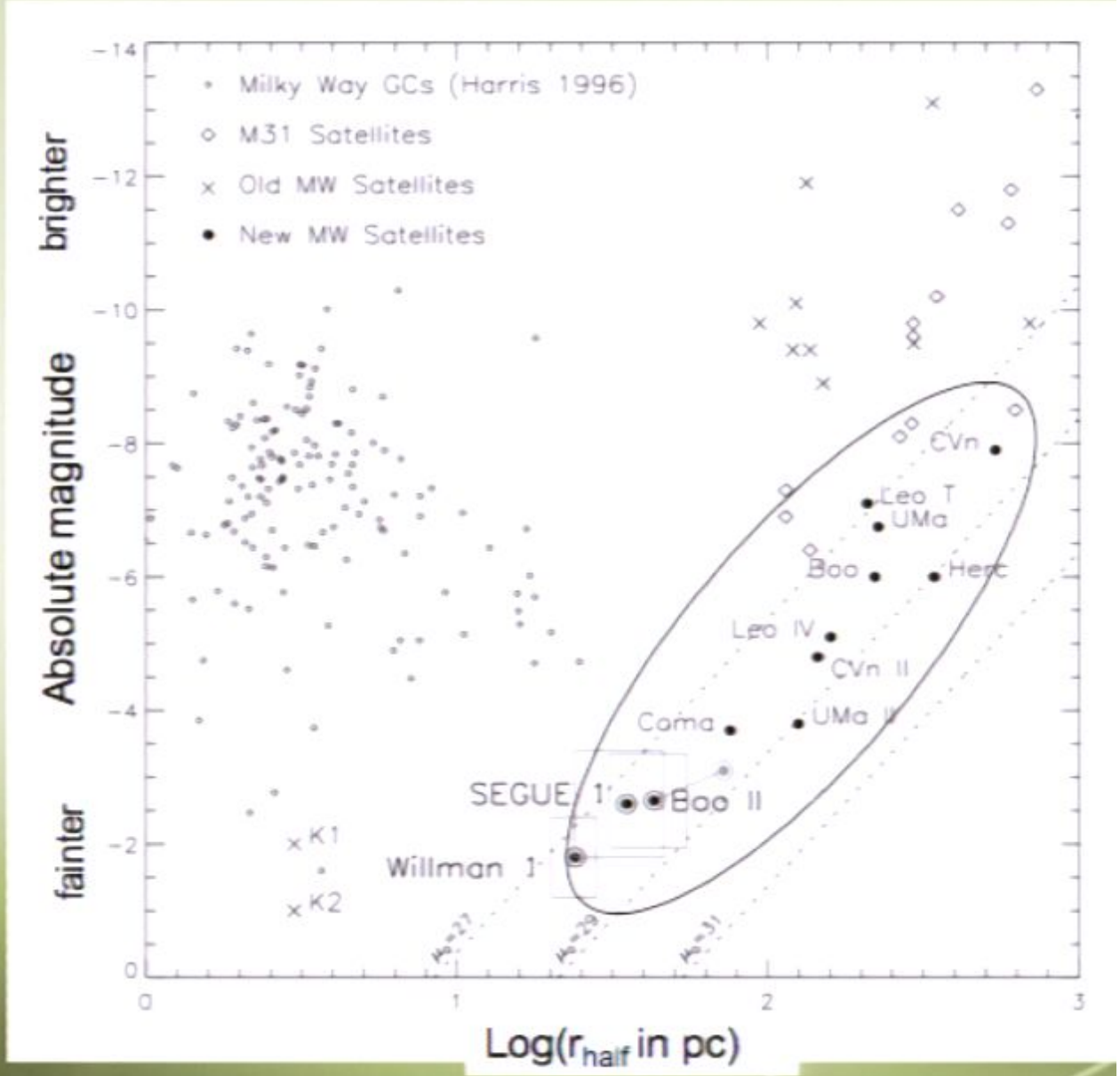

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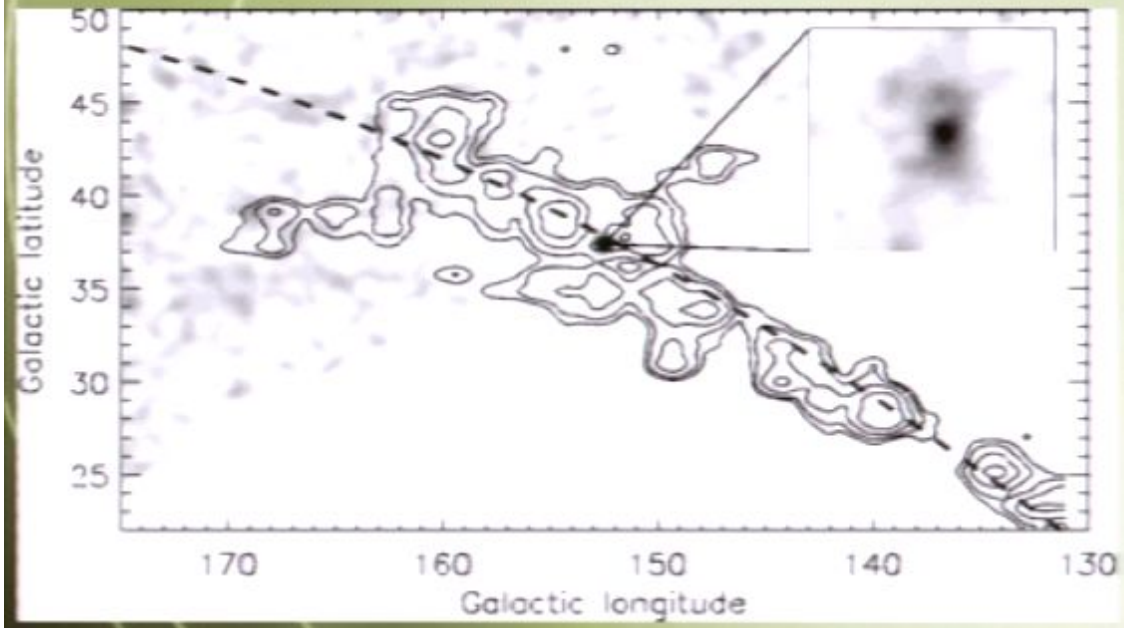

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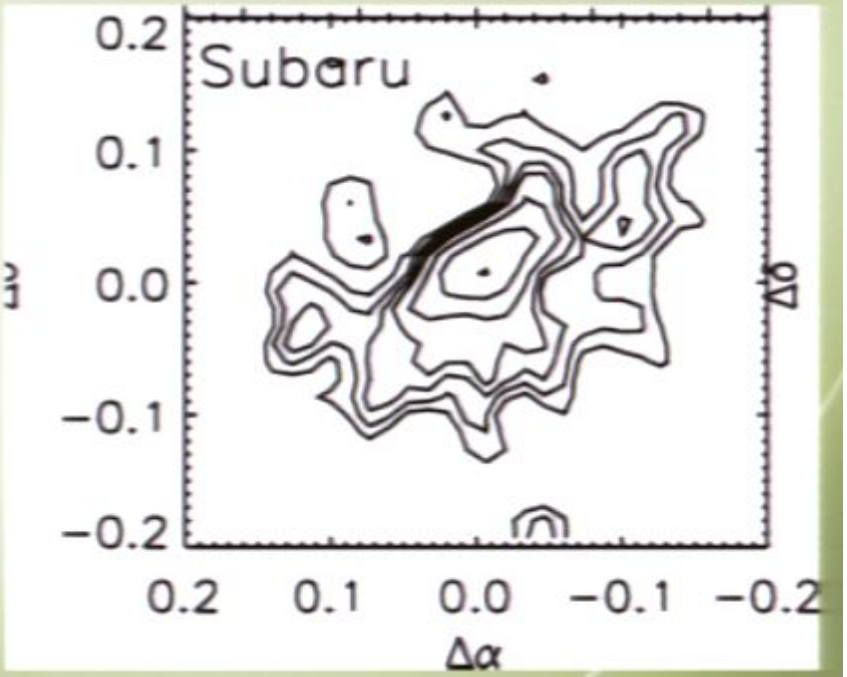

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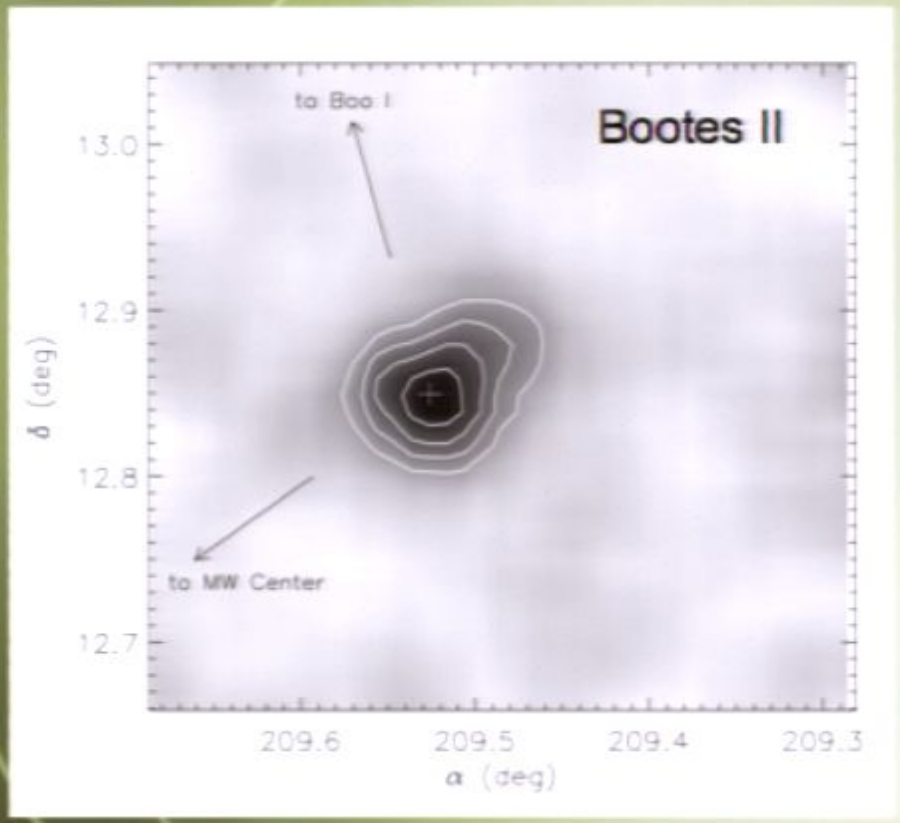
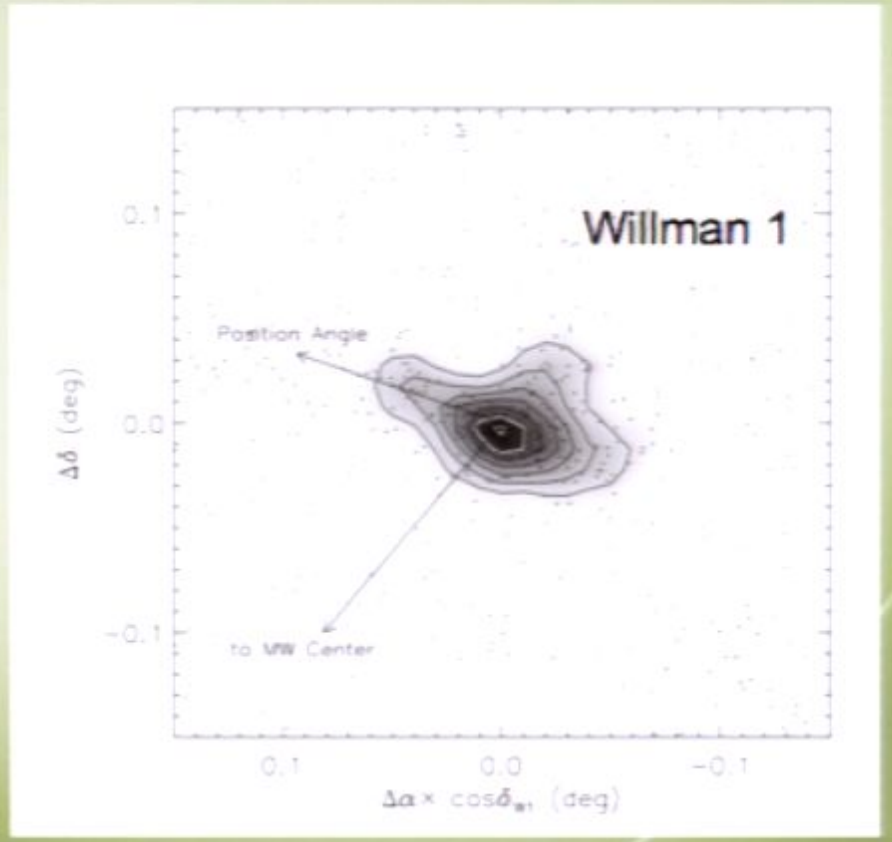


There may be lots more of these least luminous objects



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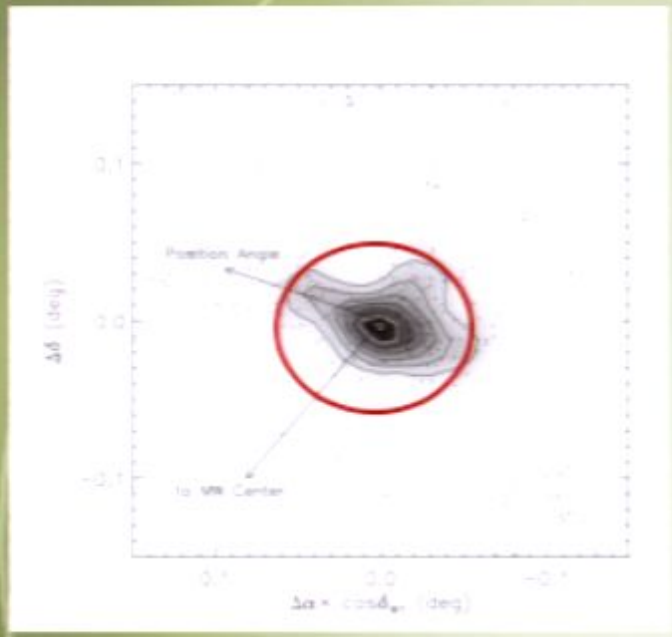
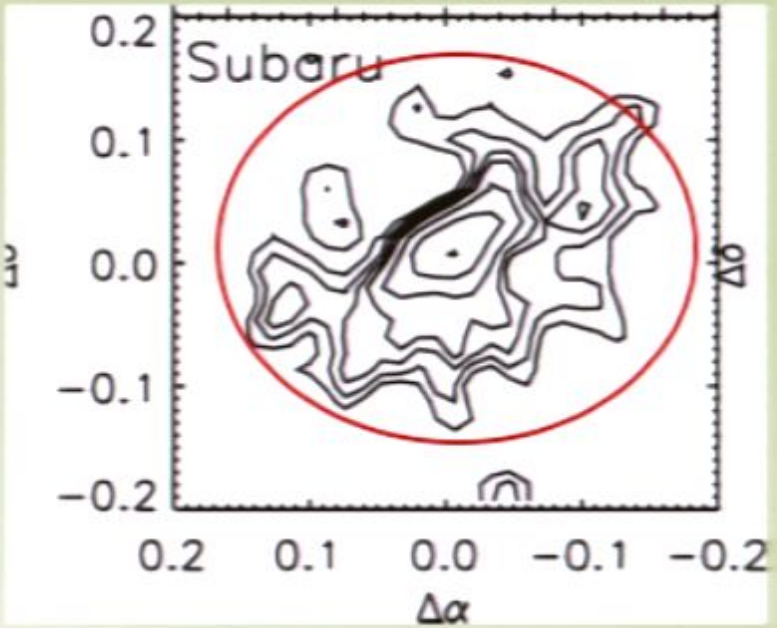
Tides?

Walsh et al., submitted;

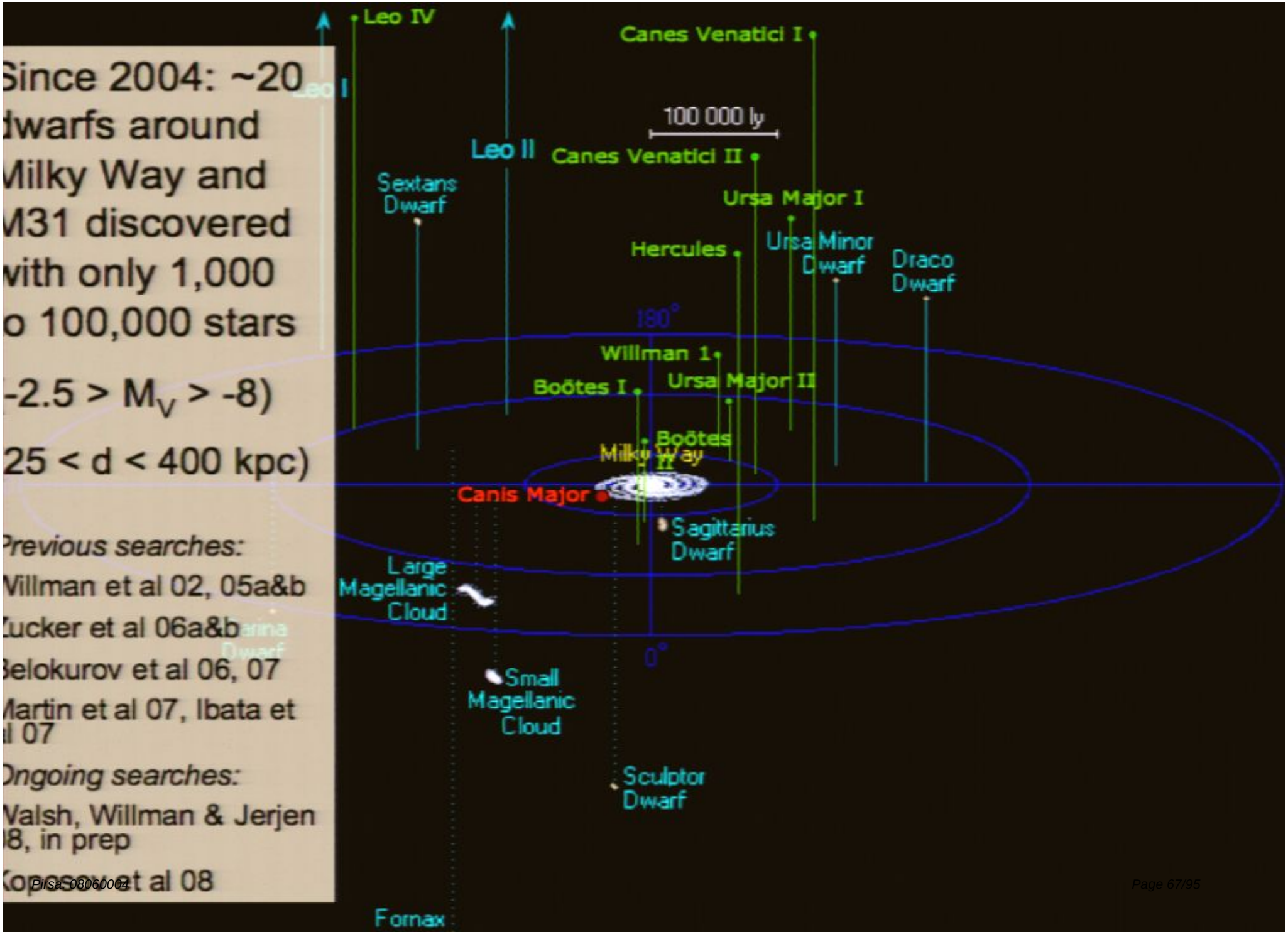




	R_{tidal} if mass = $10^7 M_{Sun}$	Extent (lower limit)	Mass if r_{tid} = extent
Segue 1	570 pc	30 pc	$1 \times 10^3 M_{sun}$
Bootes II	845 pc	82 pc	$9 \times 10^3 M_{sun}$
Vil 1	740 pc	43 pc	$2 \times 10^3 M_{sun}$
Com Ber	830 pc	80 pc	$8 \times 10^3 M_{sun}$
Ursa Major II	670 pc	170 pc	$2 \times 10^5 M_{sun}$

Distances of the 5 least luminous dwarfs are 25 - 45 kpc

Luminosities are ~ few thousand L_{Sun}


Since 2004: ~20
dwarfs around
Milky Way and
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(-2.5 > M_V > -8)
(25 < d < 400 kpc)
Previous searches:
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Belokurov et al 06, 07
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Ongoing searches:
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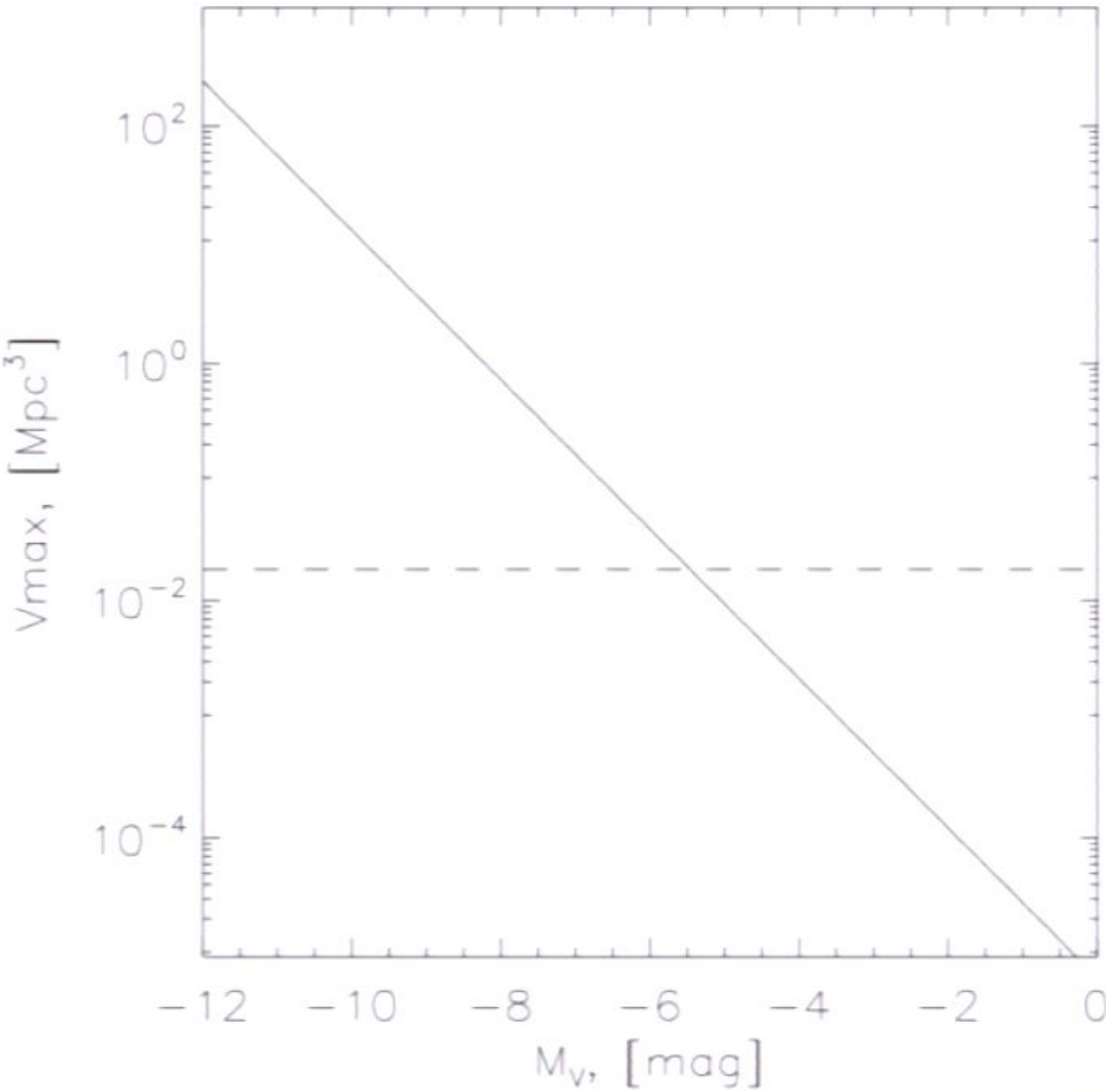
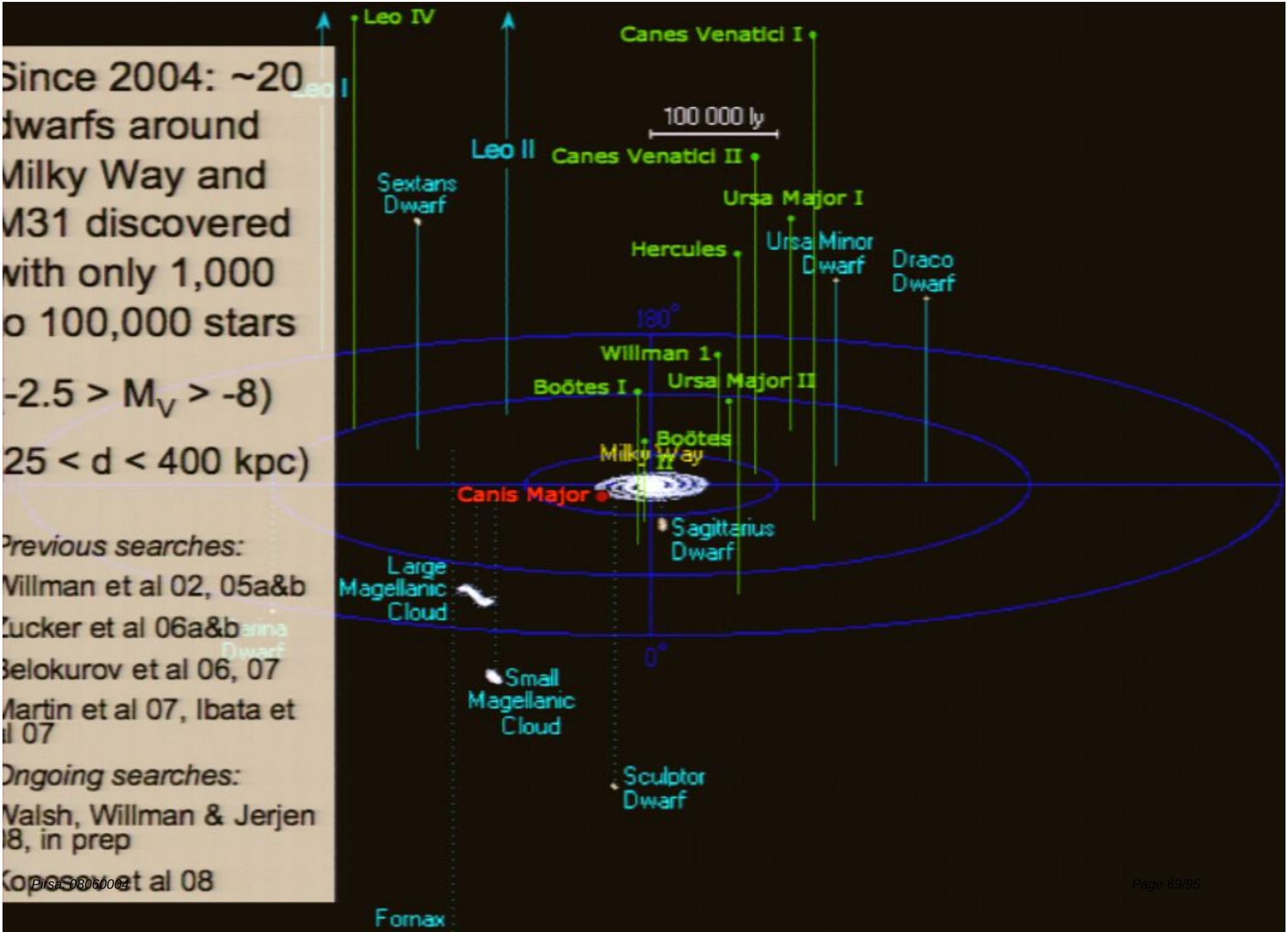

10^2
10^0
10^{-2}
10^{-4}
Vmax, [Mpc^3]
−12
−10
−8
−6
−4
−2
0
M_V, [mag]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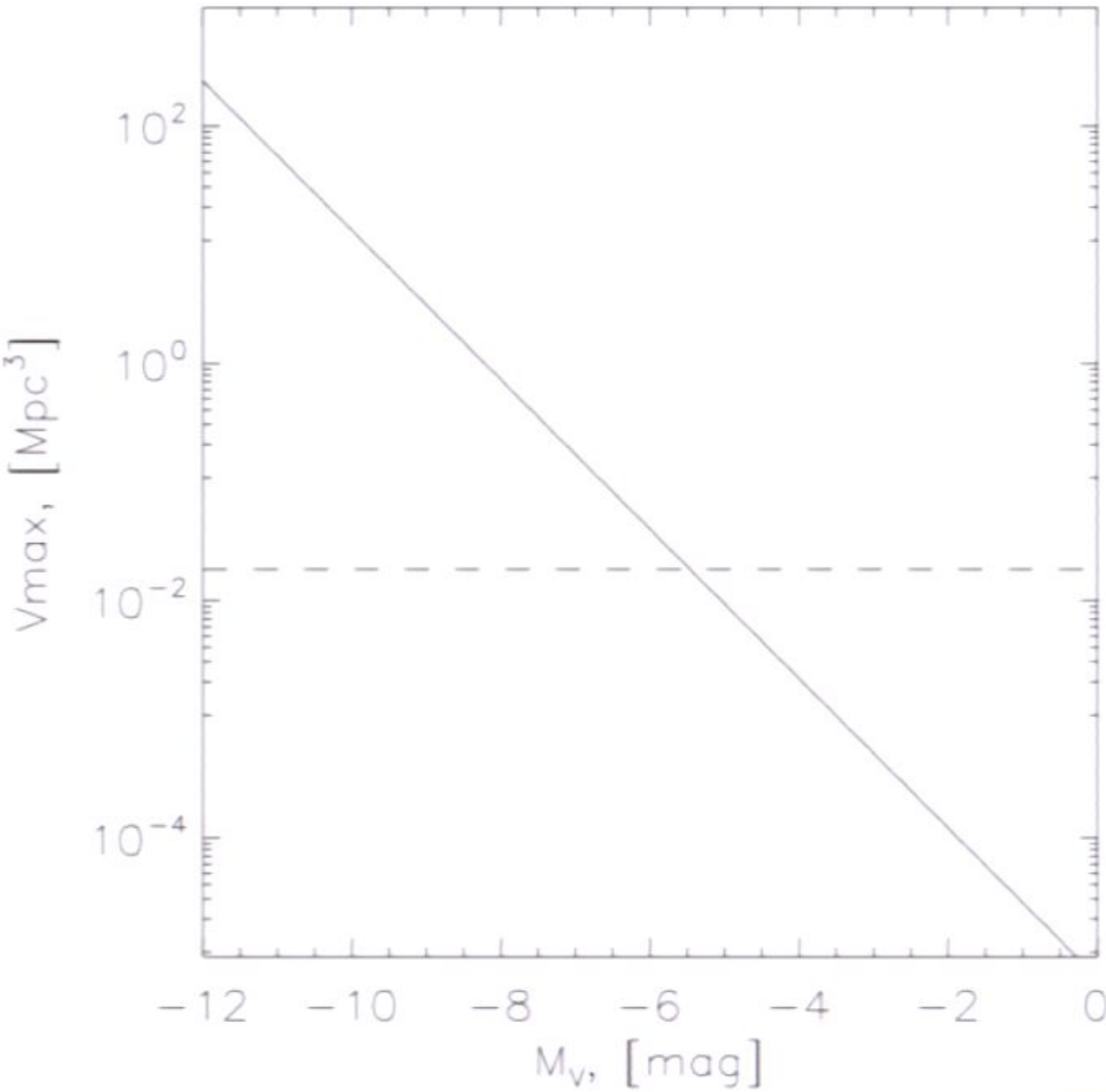
10^2
10^0
10^{-2}
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Vmax, [Mpc^3]
−12
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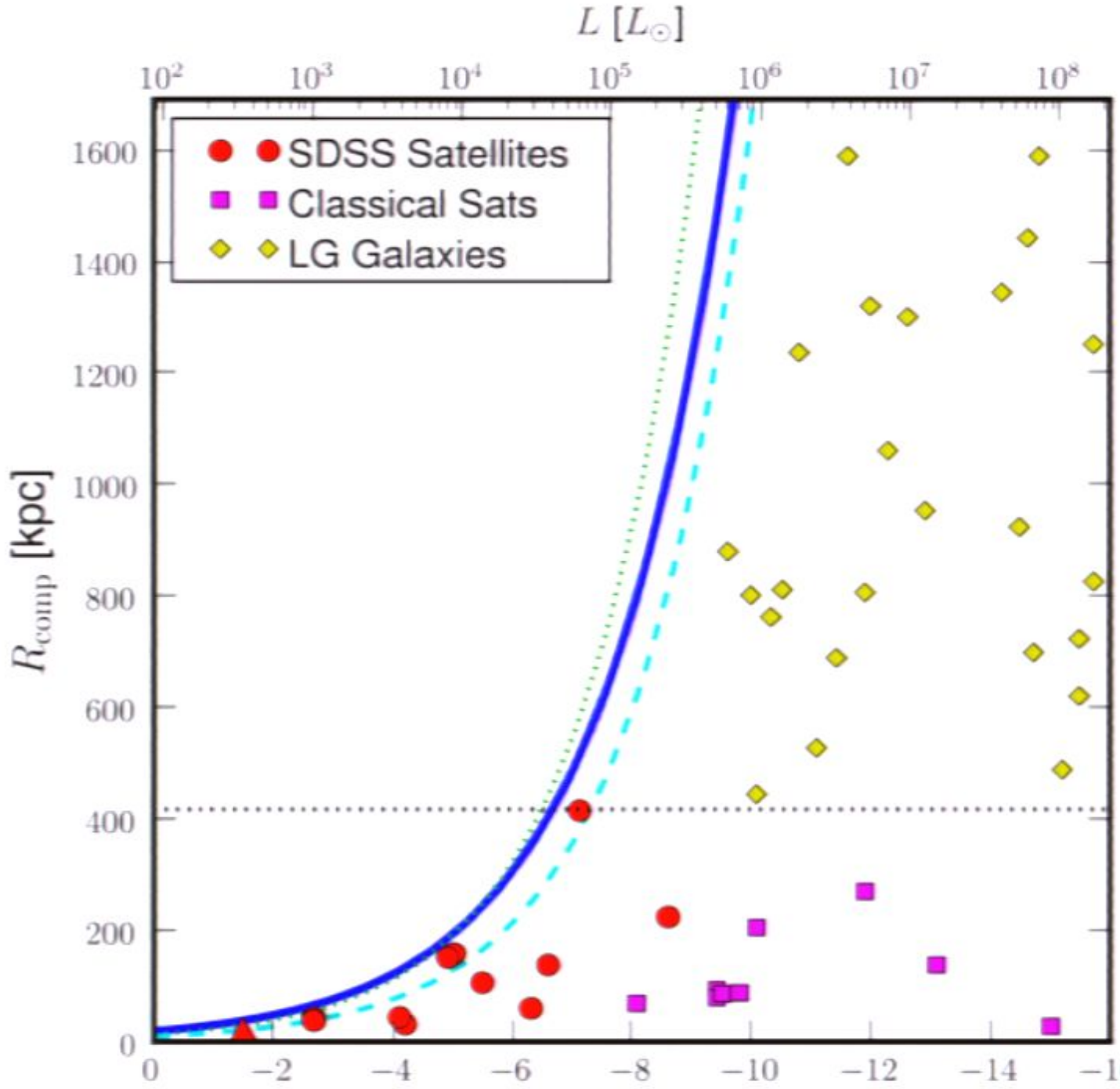
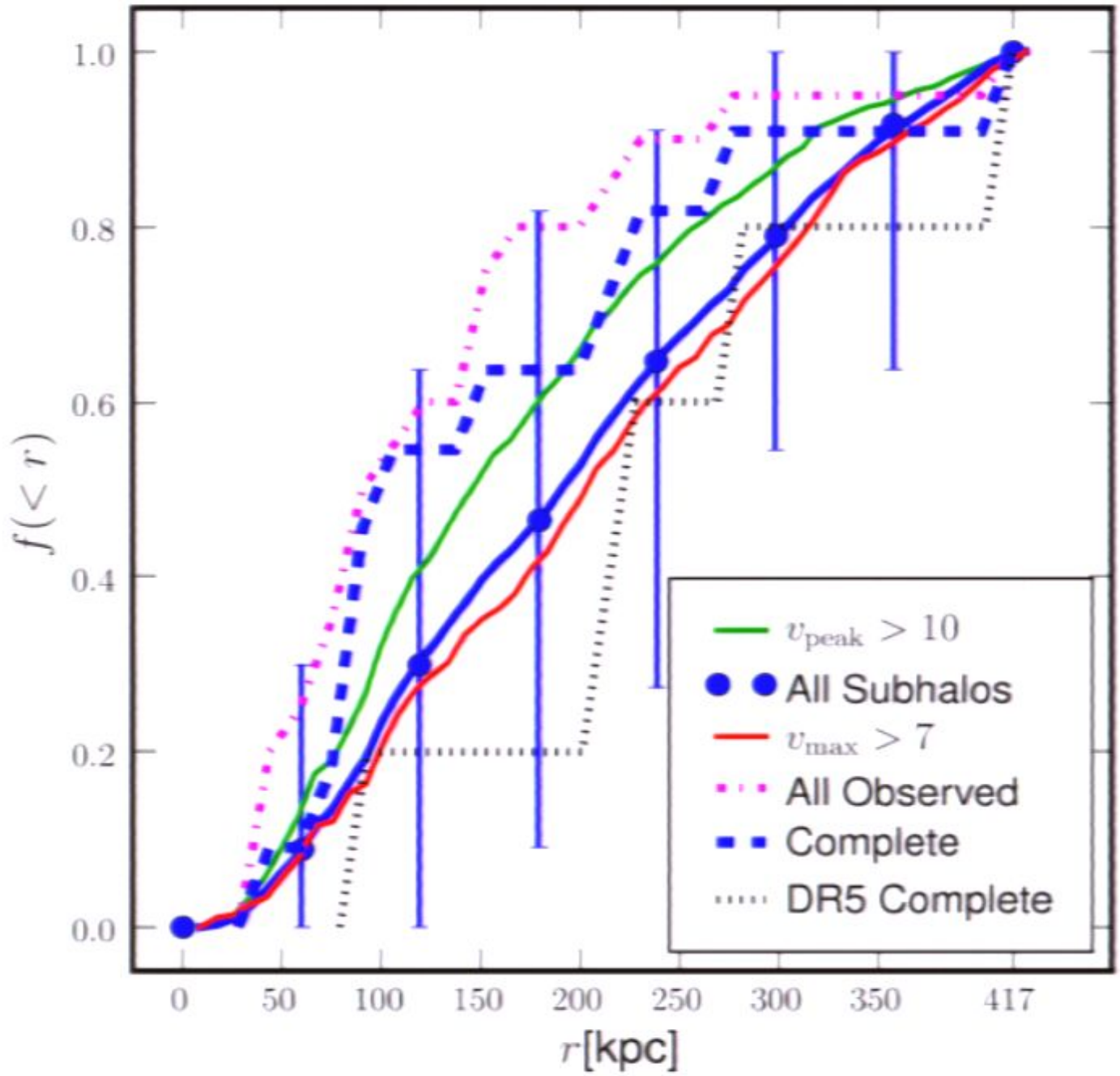
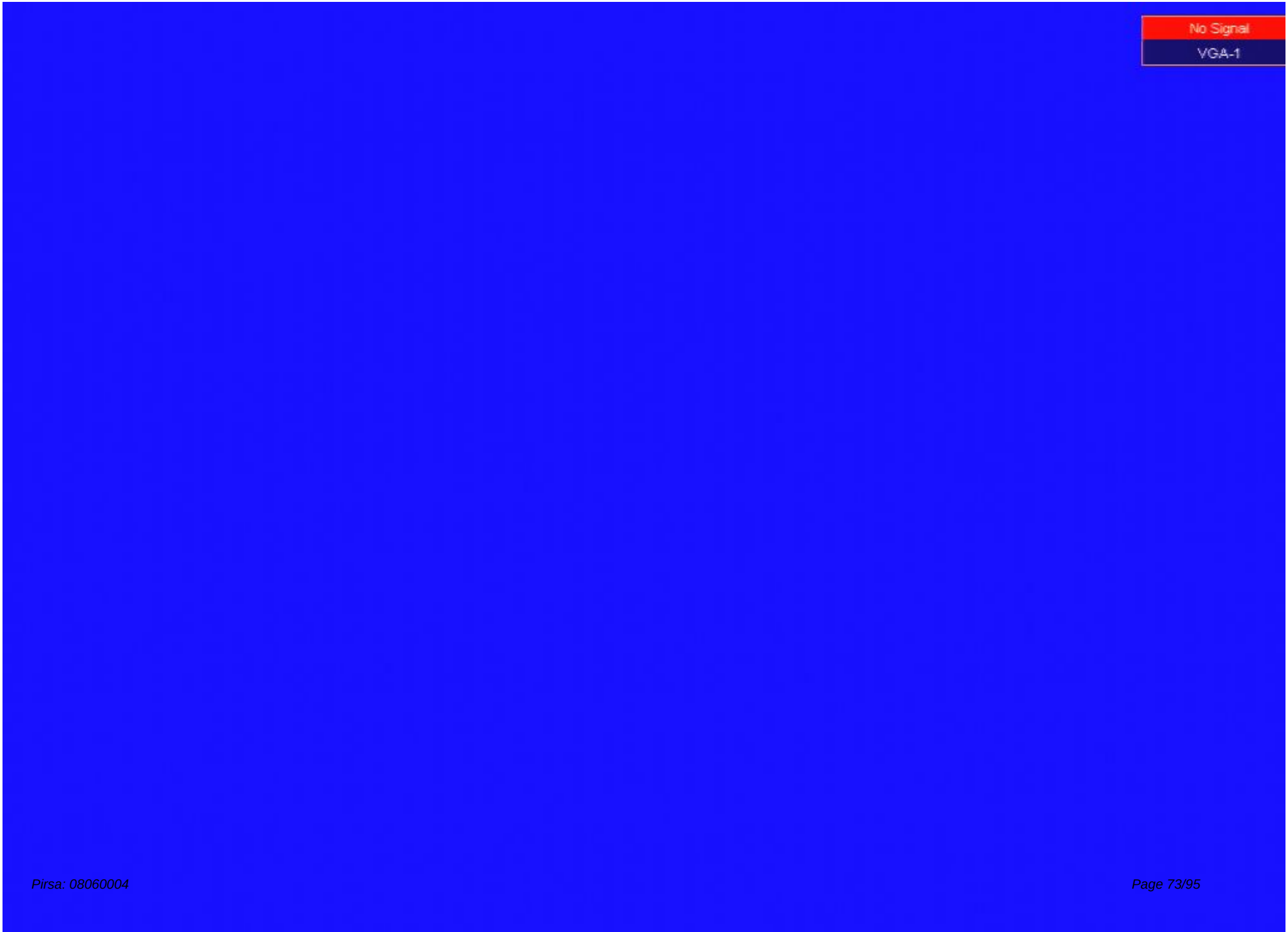
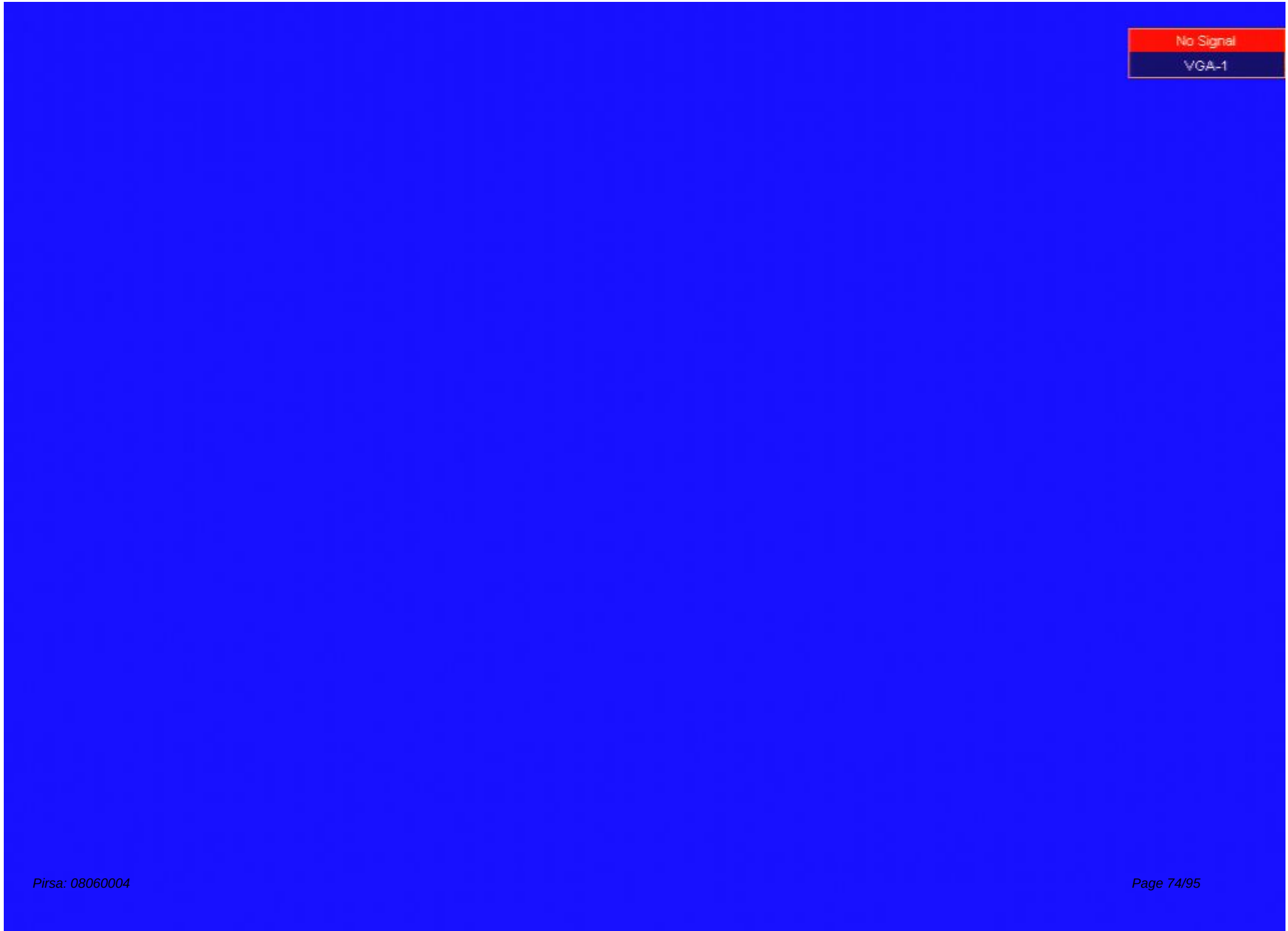

$L\ [L_\odot]$
10^2
10^3
10^4
10^5
10^6
10^7
10^8
SDSS Satellites
Classical Sats
LG Galaxies
$R_{\rm comp}$ [kpc]
1600
1400
1200
1000
800
600
400
200
0
0
−2
−4
−6
−8
−10
−12
−14
−16
M_V


1.0
0.8
0.6
0.4
0.2
0.0
$f(< r)$
0
50
100
150
200
250
300
350
417
r[kpc]
$v_{\rm peak} > 10$
All Subhalos
$v_{\rm max} > 7$
All Observed
Complete
DR5 Complete


No Signal
VGA-1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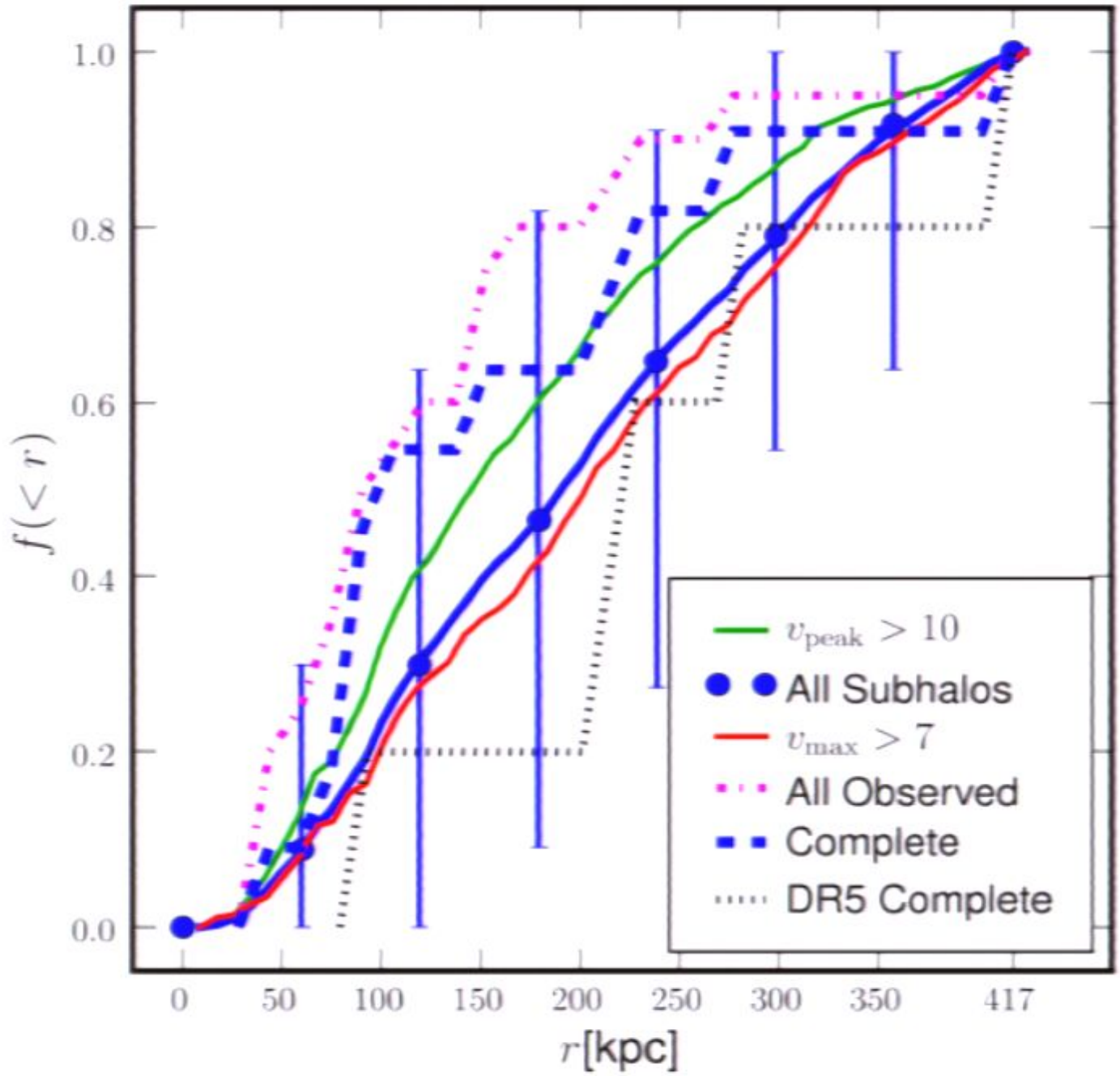
1.0
0.8
0.6
0.4
0.2
0.0
$f(< r)$
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50
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300
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417
r[kpc]
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All Subhalos
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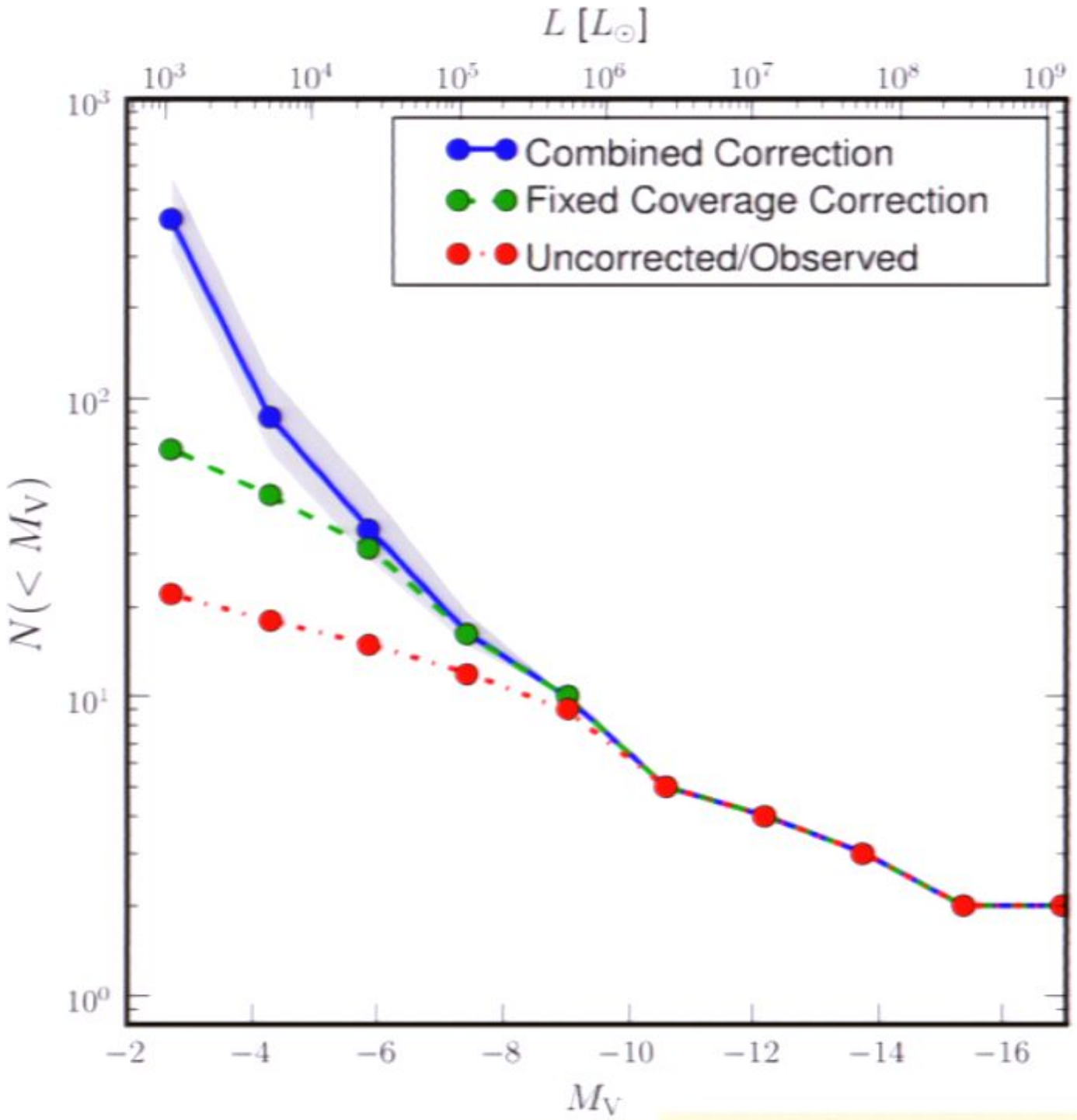
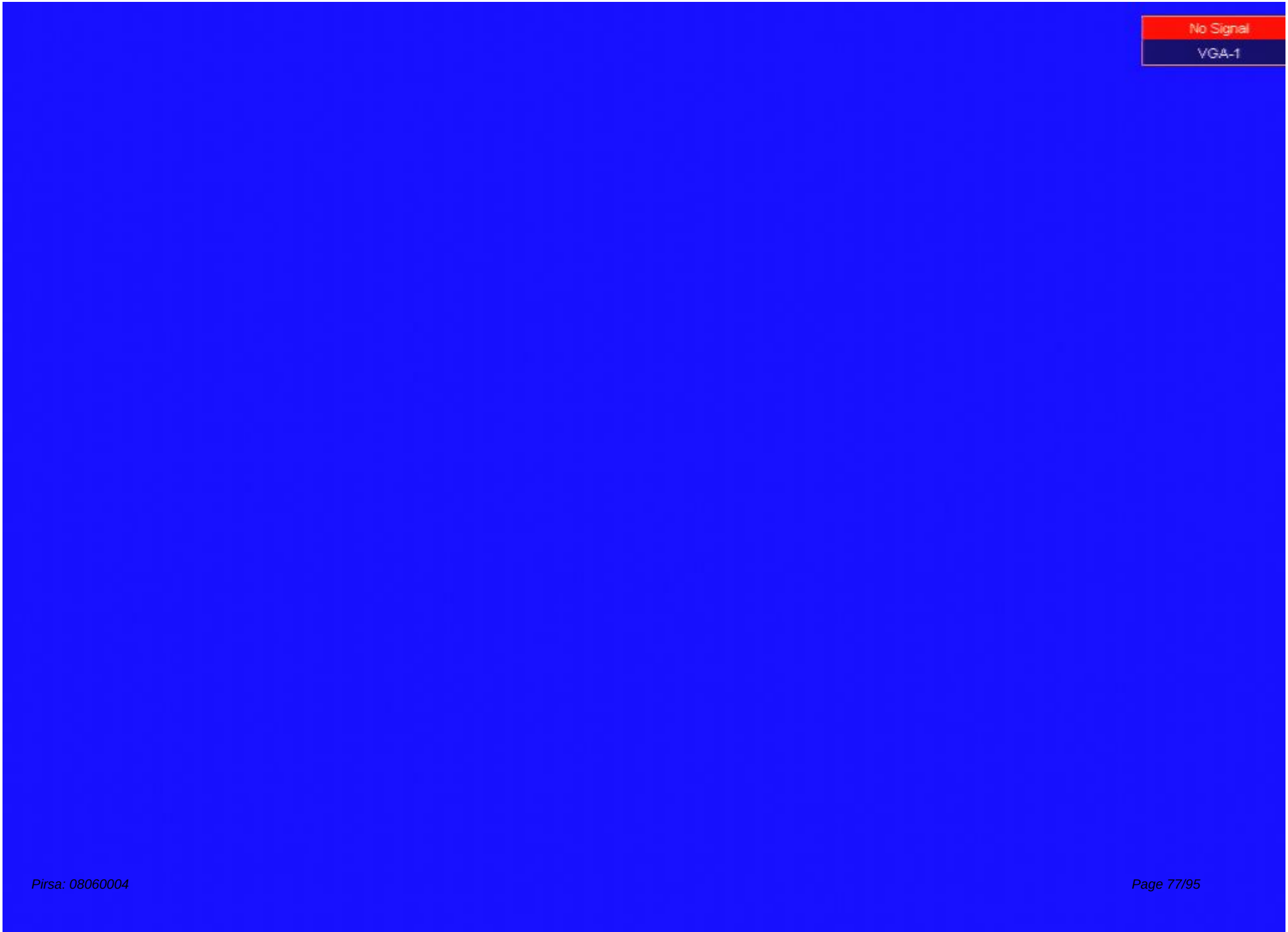
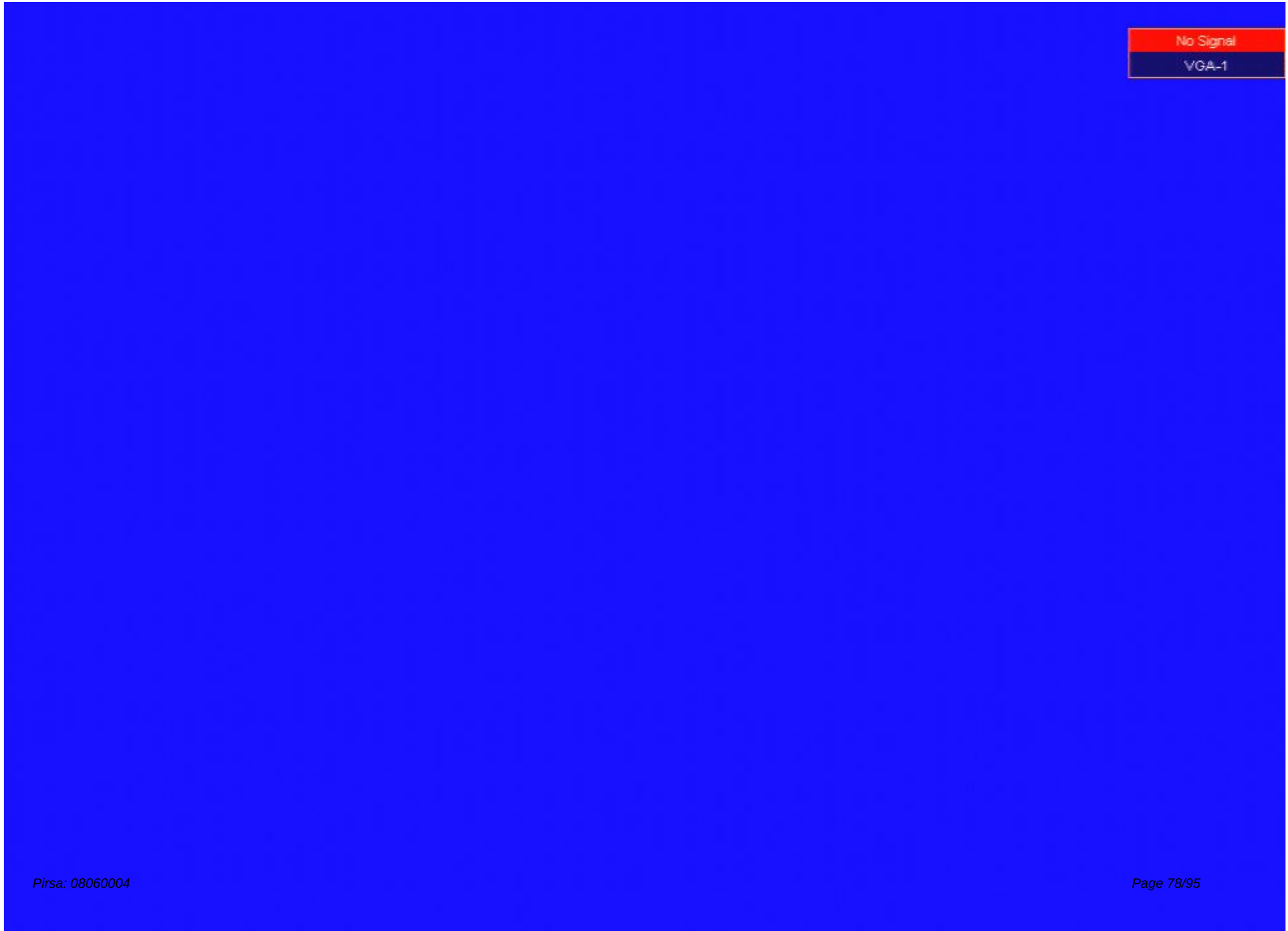
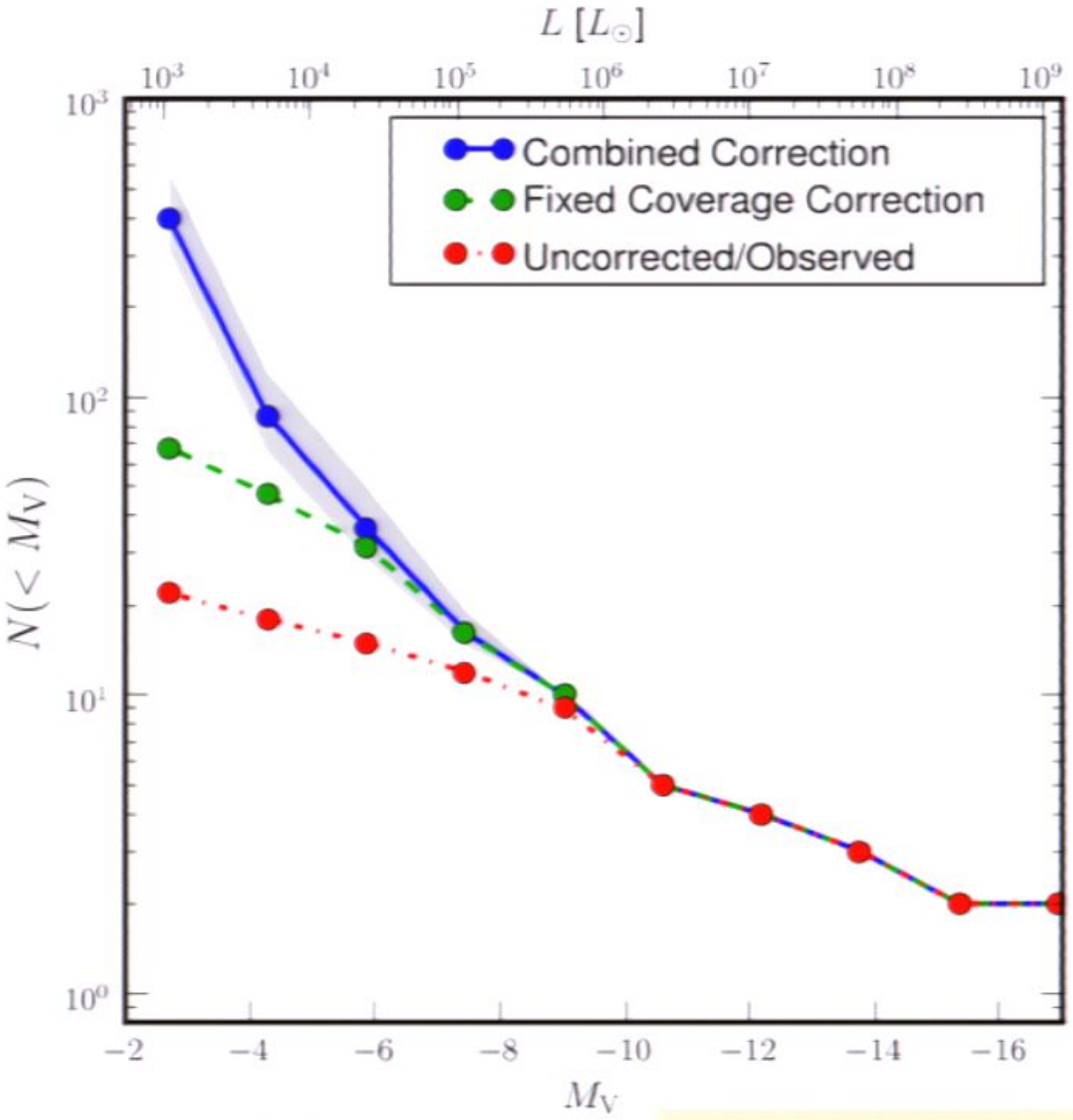
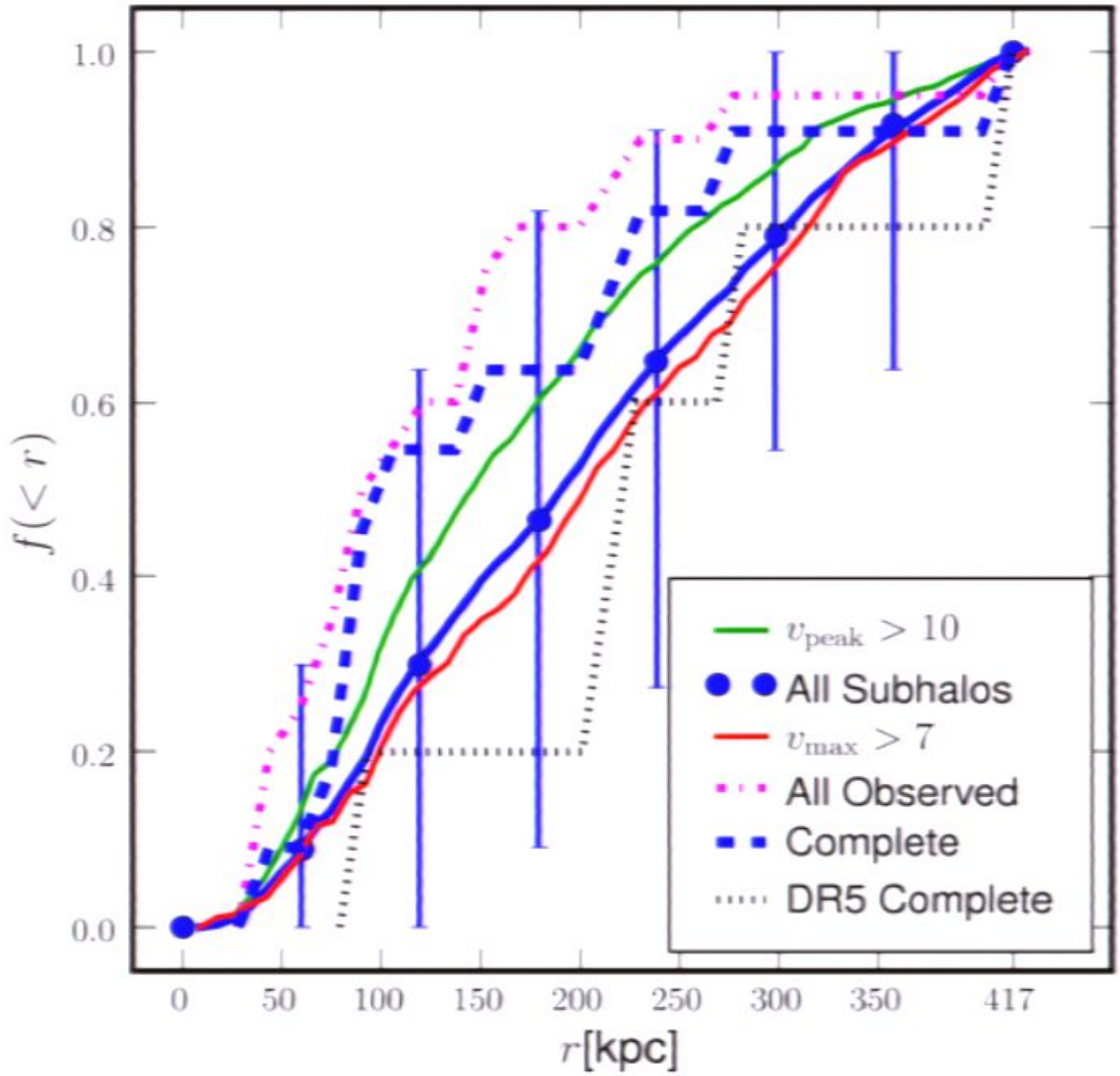
All Observed
Complete
DR5 Complete

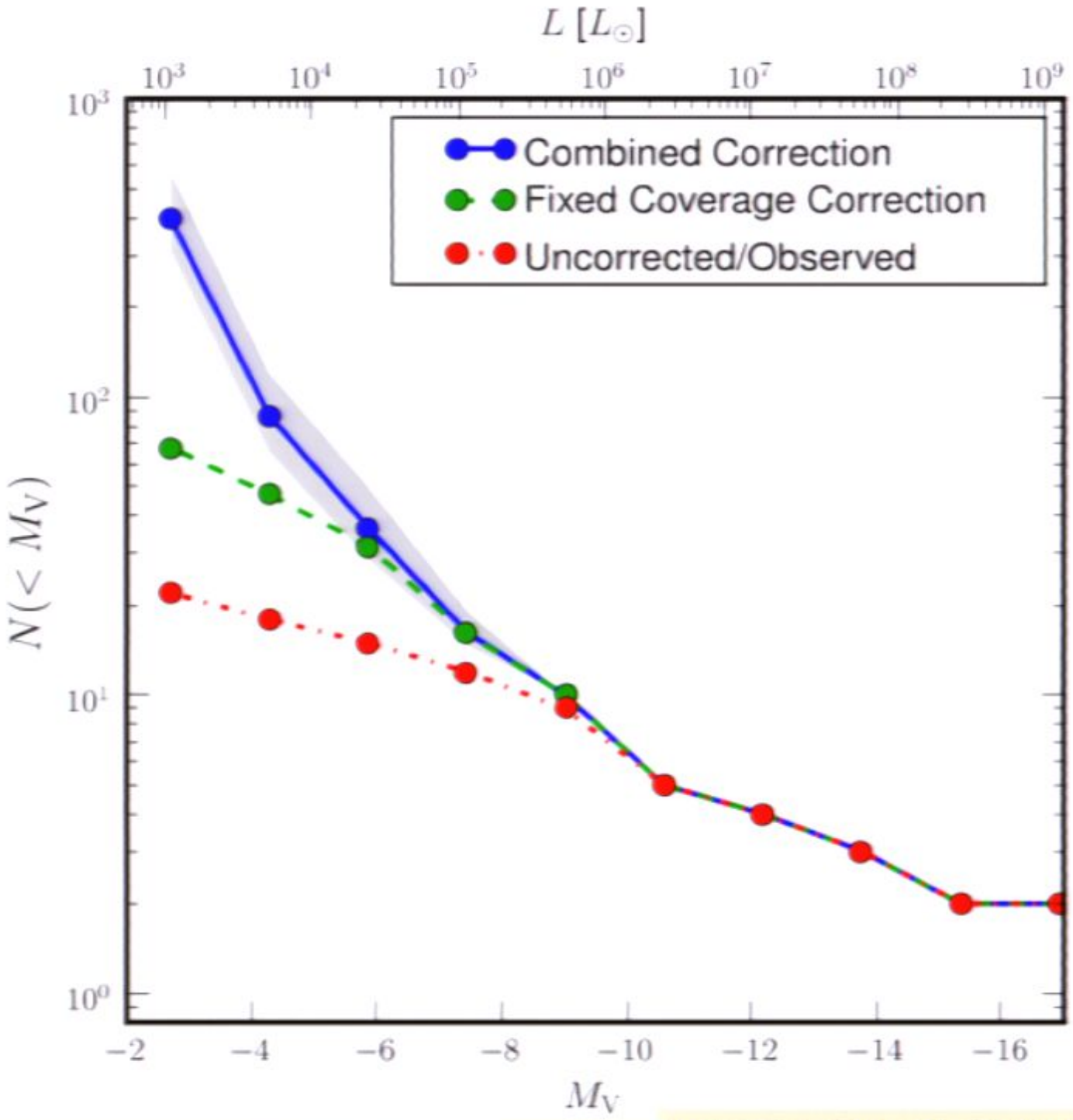

$L\ [L_\odot]$
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Combined Correction
Fixed Coverage Correction
Uncorrected/Observed
$N(< M_V)$
10^3
10^2
10^1
10^0
-2
-4
-6
-8
-10
-12
-14
-16
M_V


No Signal
VGA-1


No Signal
VGA-1


$L\ [L_\odot]$
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Combined Correction
Fixed Coverage Correction
Uncorrected/Observed
$N(< M_V)$
10^3
10^2
10^1
10^0
-2
-4
-6
-8
-10
-12
-14
-16
M_V


1.0
0.8
0.6
0.4
0.2
0.0
$f(< r)$
0
50
100
150
200
250
300
350
417
r[kpc]
$v_{\rm peak} > 10$
All Subhalos
$v_{\rm max} > 7$
All Observed
Complete
DR5 Complete


$L\ [L_\odot]$
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Combined Correction
Fixed Coverage Correction
Uncorrected/Observed
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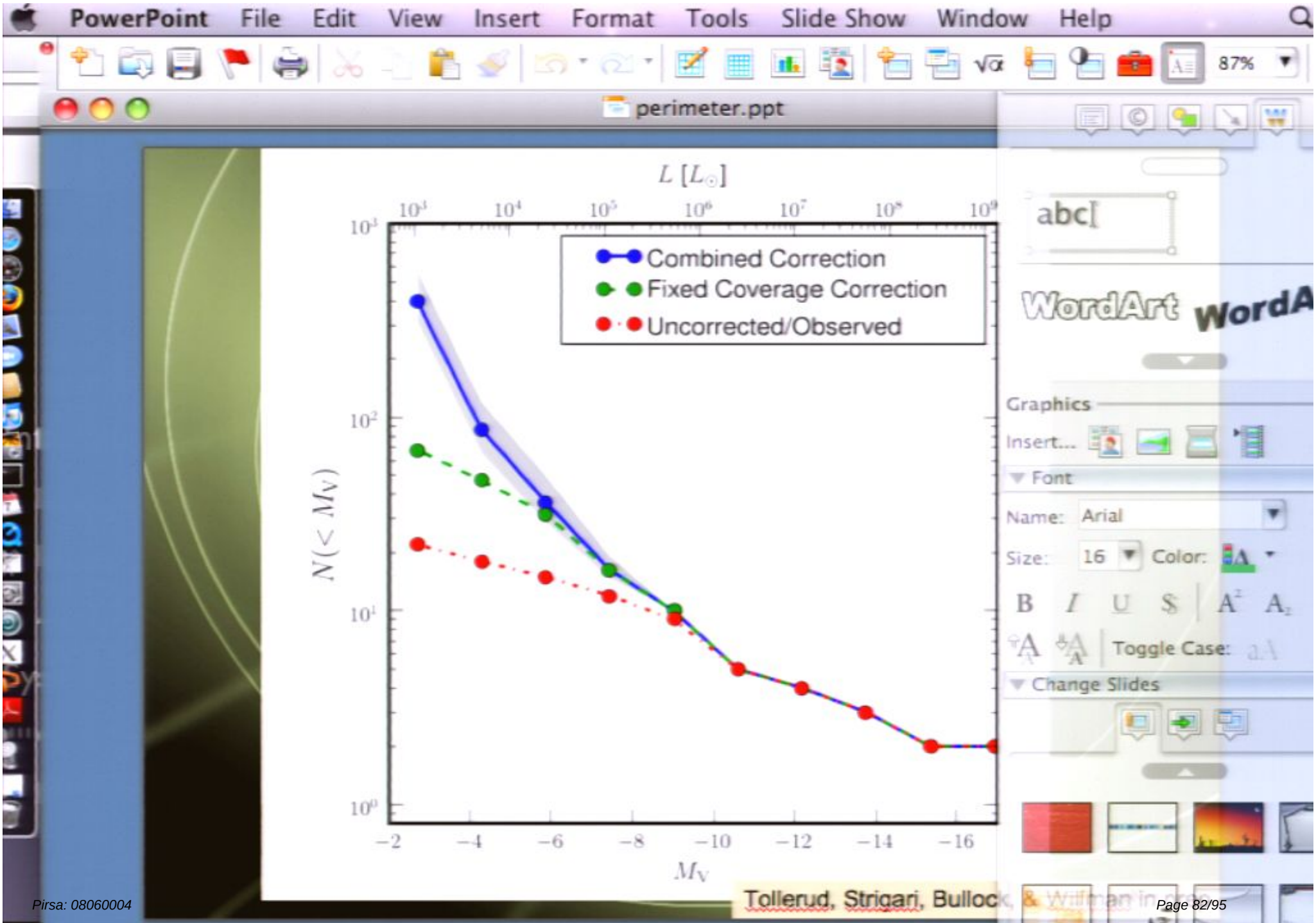
10^3
10^2
10^1
10^0
-2
-4
-6
-8
-10
-12
-14
-16
M_V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$L\ [L_\odot]$
10^3 10^4 10^5 10^6 10^7 10^8 10^9
10^3
10^2
10^1
10^0
$N(< M_V)$
Combined Correction
Fixed Coverage Correction
Uncorrected/Observed
-2 -4 -6 -8 -10 -12 -14 -16
M_V
Tollerud, Strigari, Bullock
abc
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Graphics
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Font
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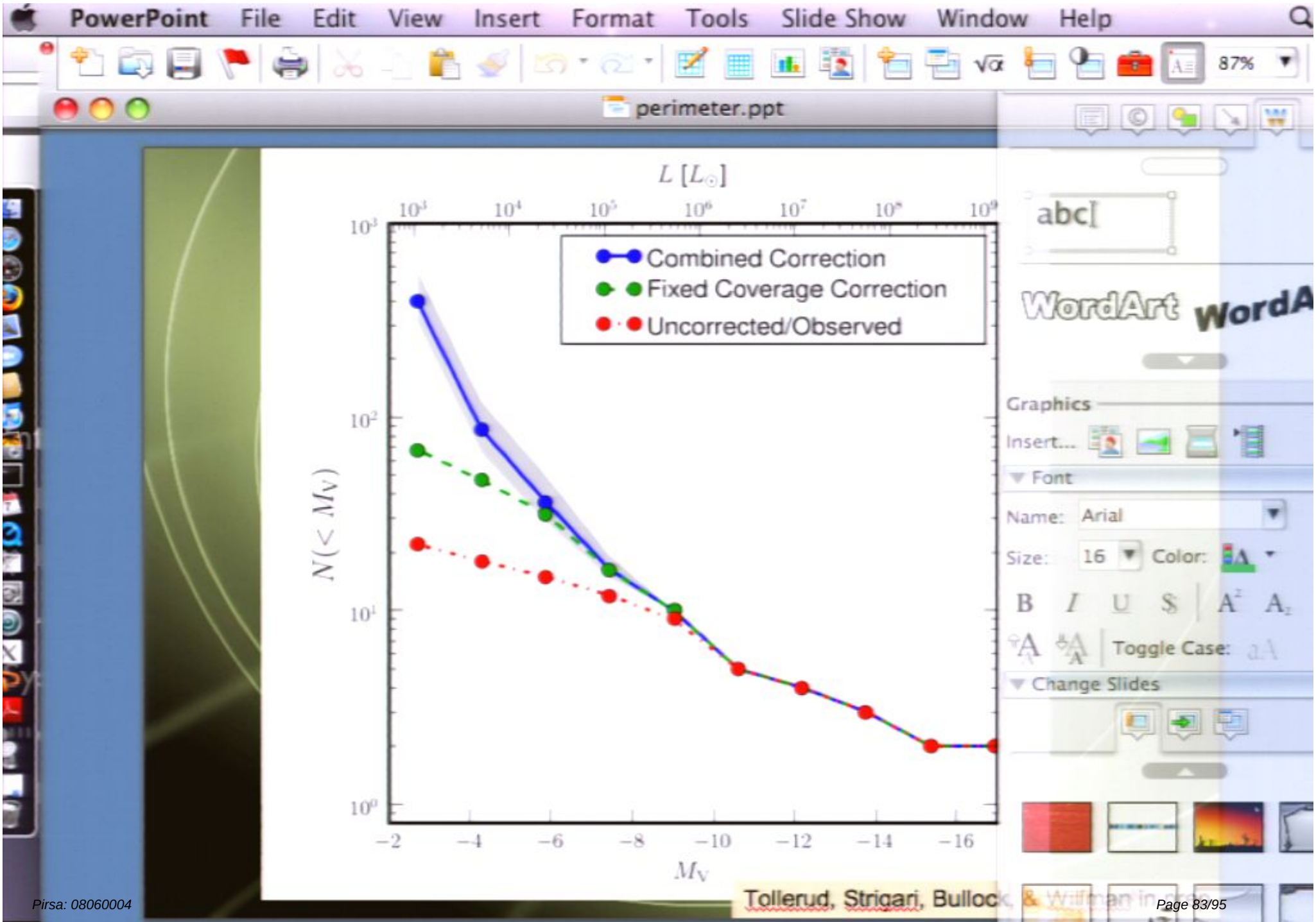
Size: 16
Color:
Toggle Case:
Change Slides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$L\ [L_\odot]$
10^3 10^4 10^5 10^6 10^7 10^8 10^9
10^3
10^2
10^1
10^0
$N(< M_V)$
Combined Correction
Fixed Coverage Correction
Uncorrected/Observed
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M_V
Tollerud, Strigari, Bullock & Wilman in prep
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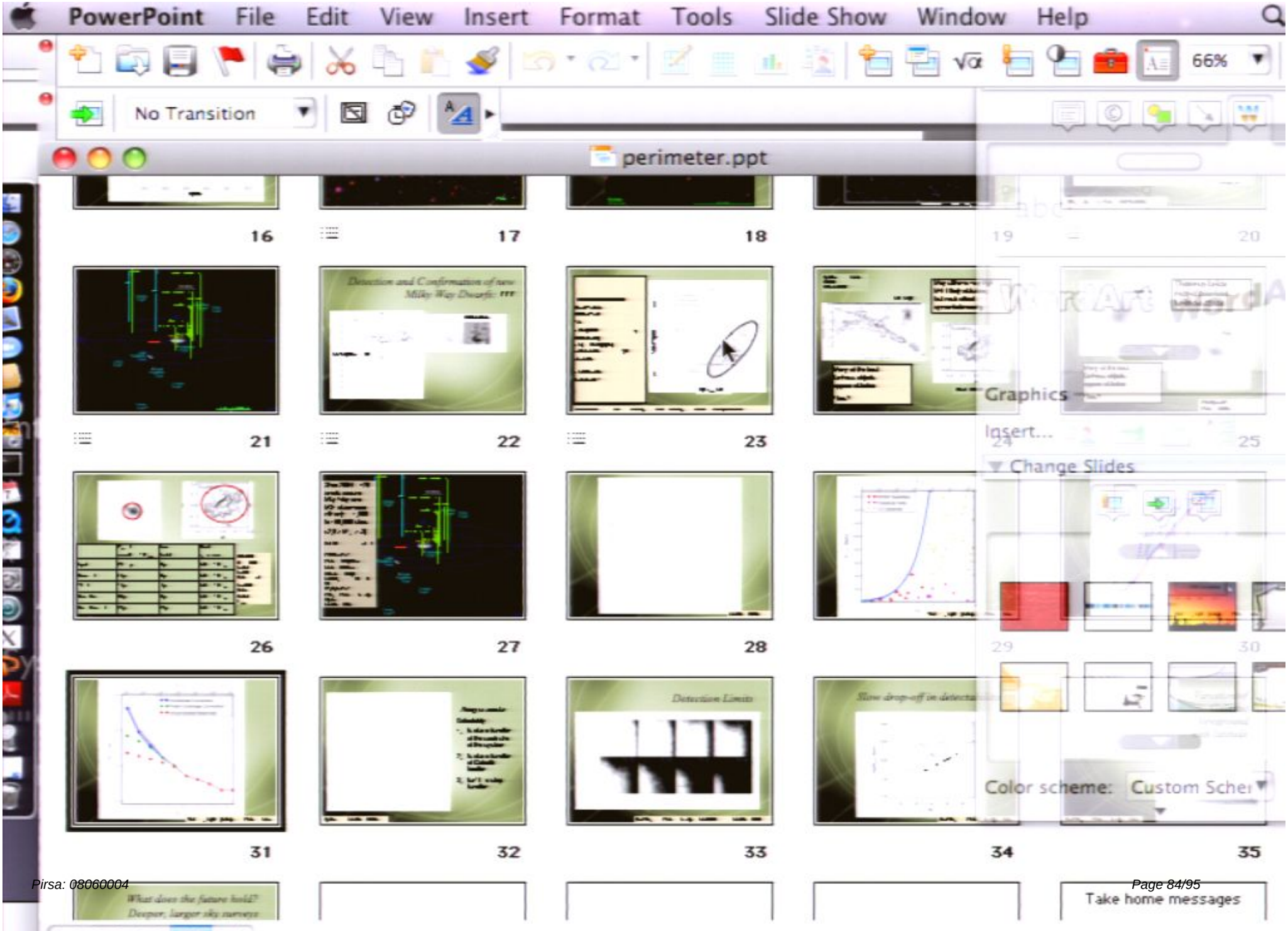
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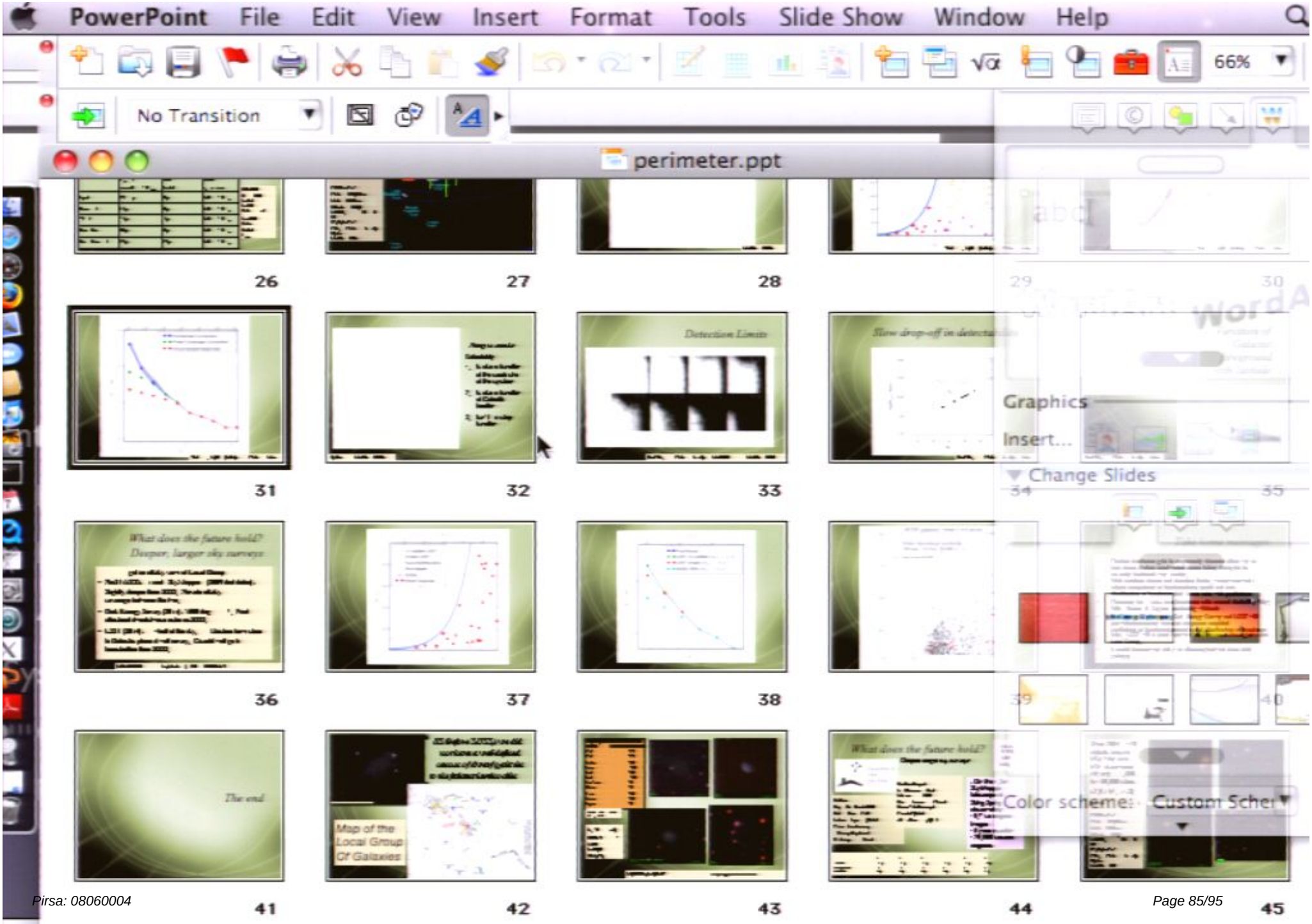
What does the future hold?
Take home messages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Detection Limits
What does the future hold?
Deeper, larger sky surveys
The end
Map of the Local Group Of Galaxies
Graphics
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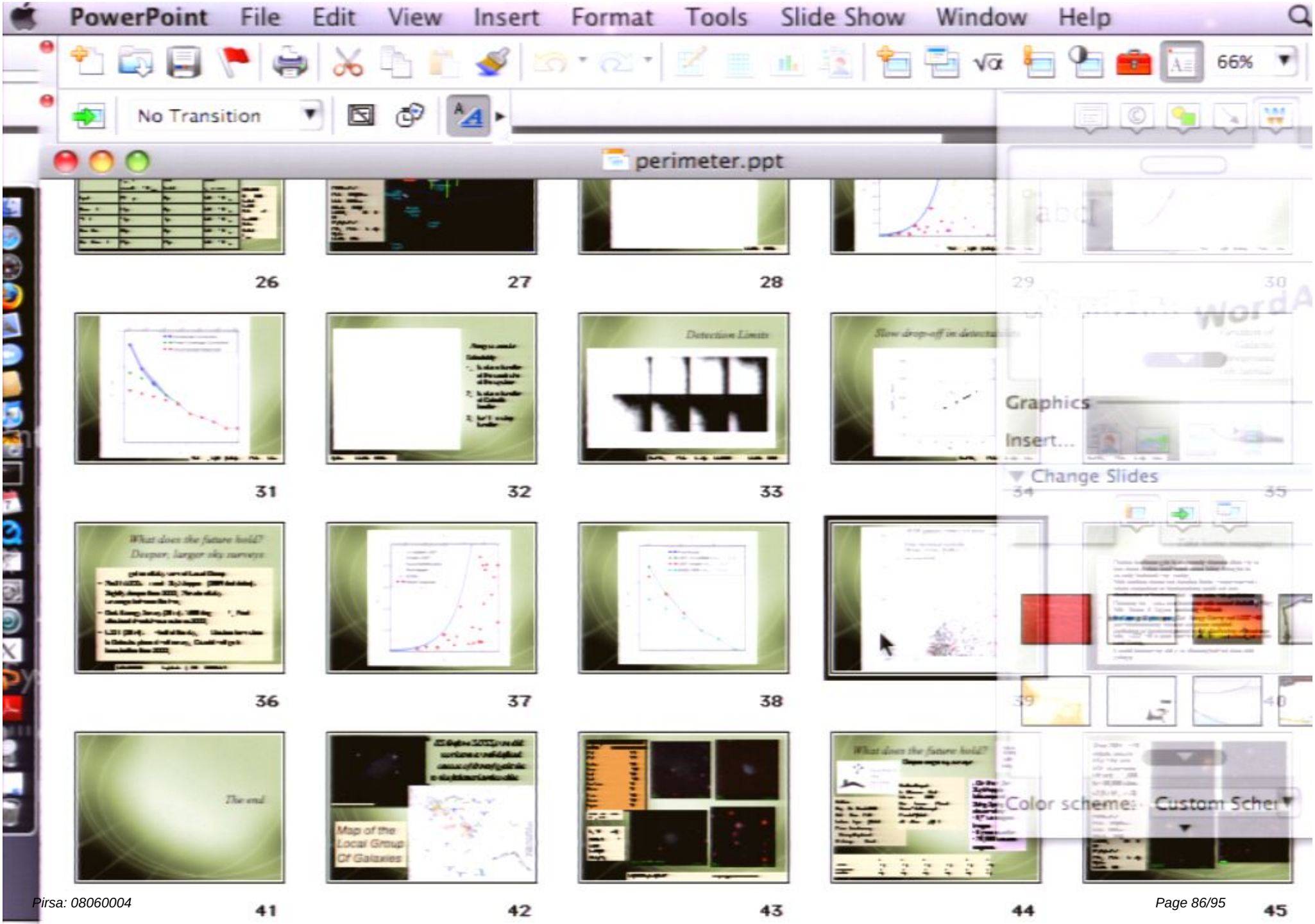
Color scheme: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Detection Limits
Graphics
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Change Slides
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What does the future hold?
Deeper, larger sky surveys
39
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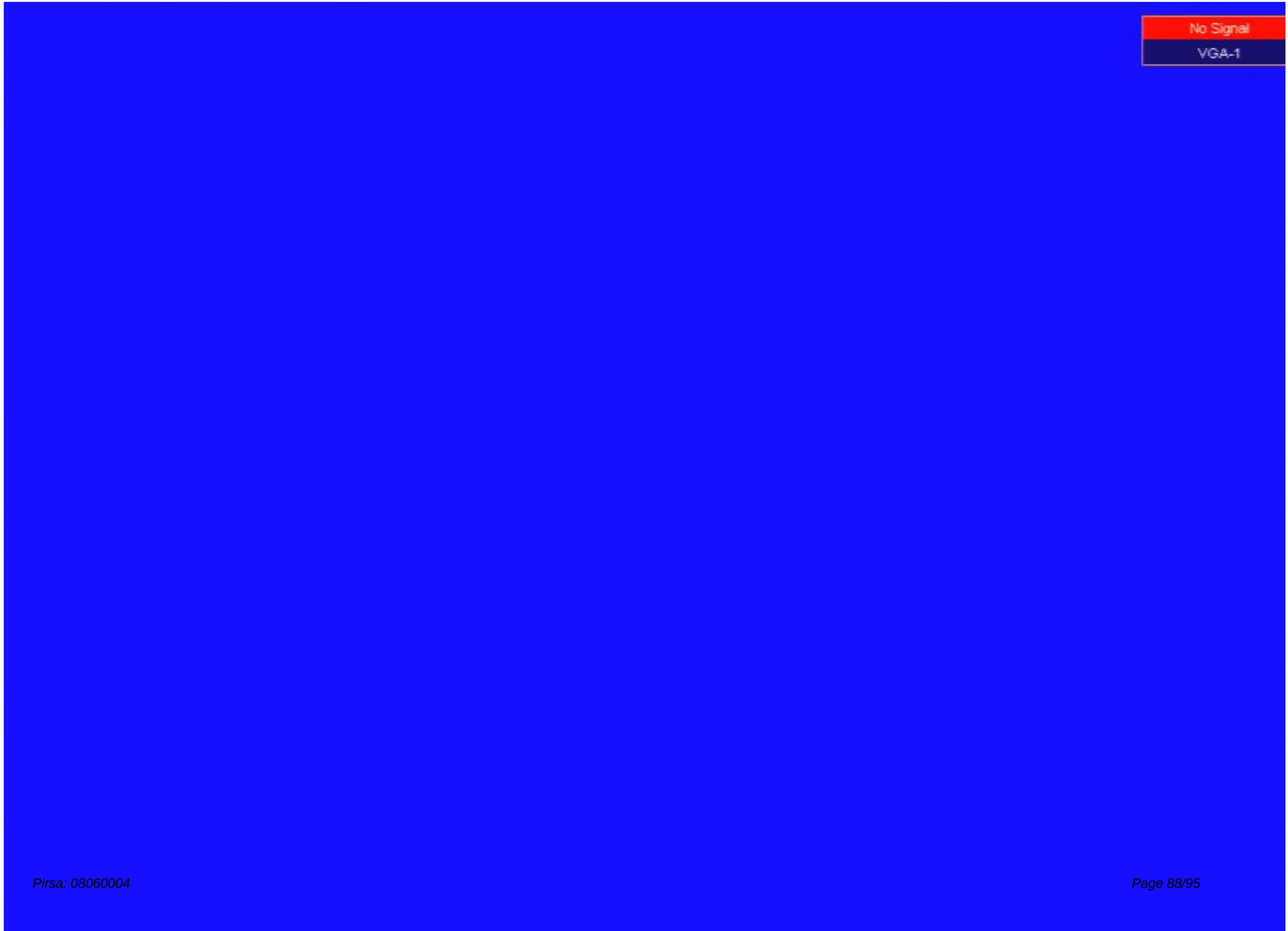
41
The end
42
Map of the Local Group Of Galaxies
43
44
What does the future hold?
Color scheme:
Custom Scheme
45

Take home messages

- The least luminous galaxies are presently the most direct way to learn about the least massive dark matter halos; these galaxies can only be found very nearby.
- With uniform datasets and detection limits, we move toward a robust comparison of the abundance, spatial and mass distribution of luminous dark matter subs with predictions
- There may be 300-1000 luminous subs around the Milky Way; Wil1, Bootes II, Segue 1 are the big wildcards
- PanStarrs, SkyMapper, Dark Energy Survey and LSST will provide the necessary dataset to test present empirical predictions of the abundance and spatial distribution of luminous subs. LSST will expand known ultra-faint census throughout the Local Group.
- It could become very tricky to disentangle dwarfs from tidal garbage.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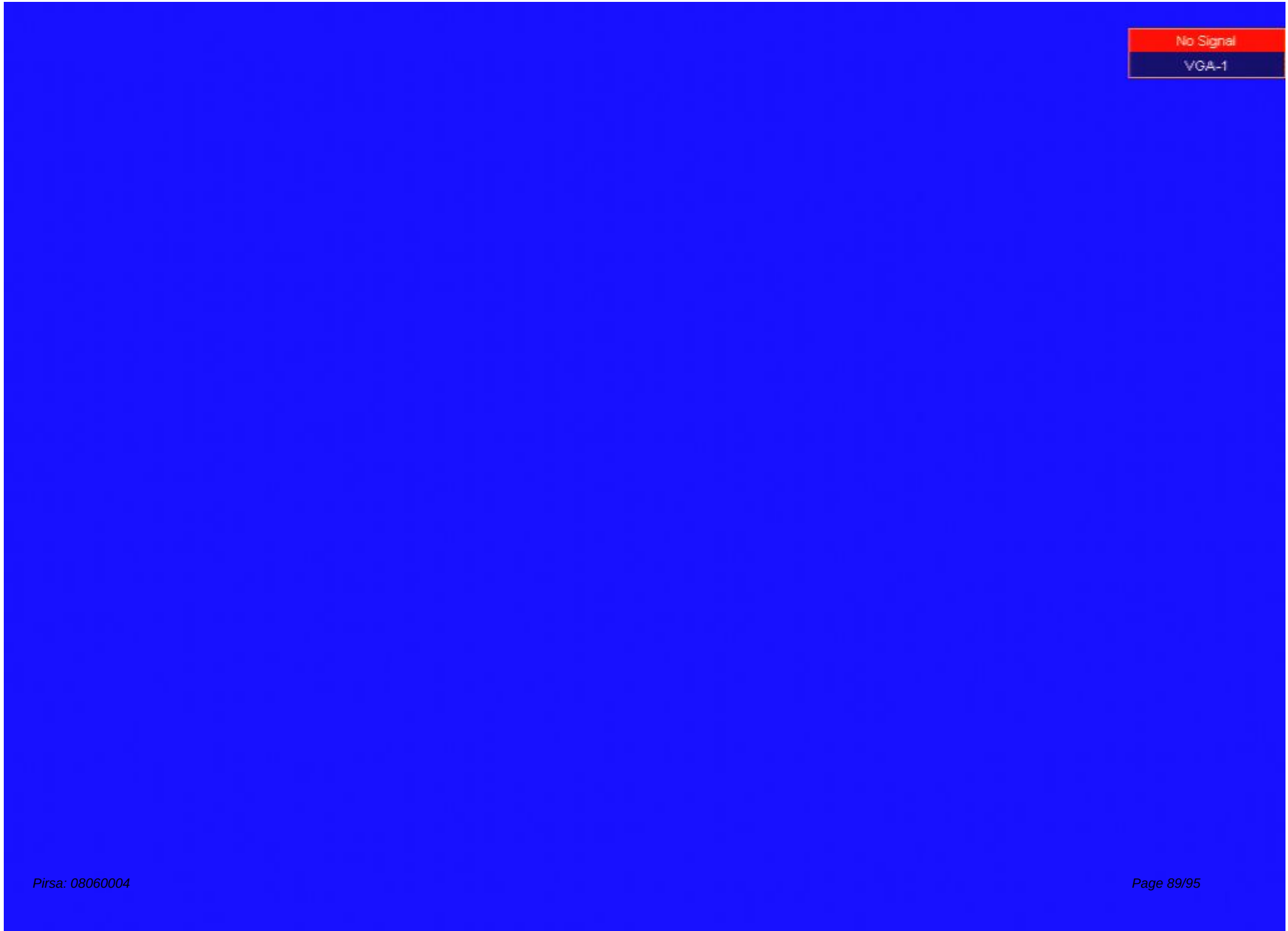
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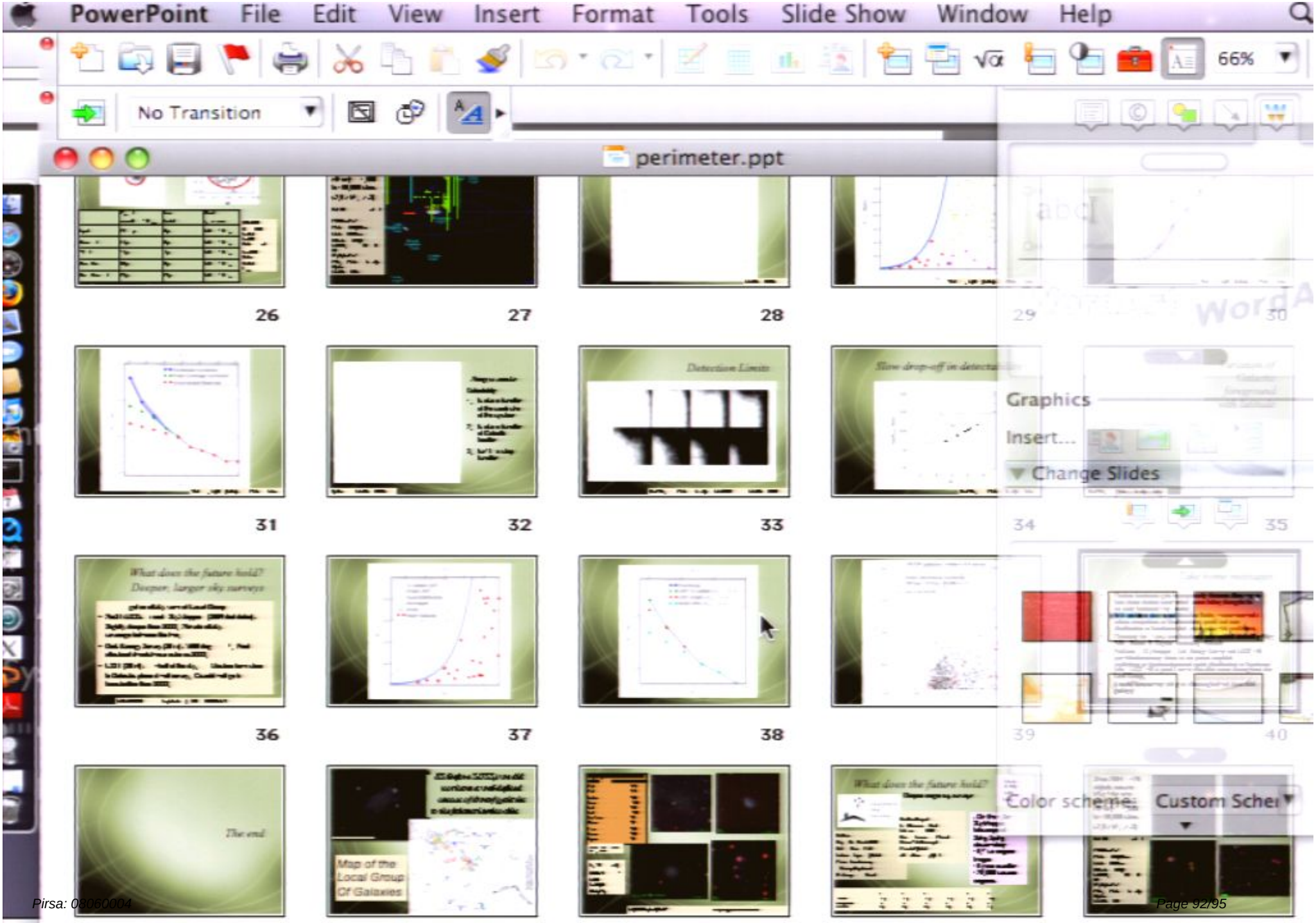
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What does the future hold?
Deeper, larger sky surveys
Detection Limits
Slow drop-off in detection
The end
Map of the Local Group Of Galaxies

Local Group with micro-to-milli arcsecond astrometry

Internal stellar proper motions

- Dark matter density of dwarfs
- Halo mass, lumpiness from streams and hyper velocity stars
- Angular momentum distribution of outer halo stars

Systematic proper motions

- Orbits of Galactic satellites and star clusters
- Local Group galaxies [M31, LMC, SMC]

Local Group with micro-to-milli arcsecond astrometry

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Dynamics of Milky Way Dwarf Satellites

Louie Strigari
University of California, Irvine

Small-Scale Structure of Dark Matter
Perimeter Institute
June 7, 2008

Collaborators: James Bullock, Manoj Kaplinghat, Marla Geha, Josh Simon, Beth Willman