Milky Way Companions

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UT Astronomy Bag Lunch

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Outline

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What Can We Learn From Companions?

- Close $\Rightarrow$ easy to observe their brightest stars
  - We can get lots of data on their stellar population
- Let us test cold dark matter (CDM) theories
  - Theory says we're missing 90% of the expected dark matter halos
- Let us observe galaxy mergers from the inside

Known Companions

- LMC + SMC
- 7 from photographic plates
- 1 from automated search of photographic plates
- 1 from a kinematic survey of the bulge
- 5 from SDSS from 2005-2006
- 5 from Belokurov et al. 2007 (using SDSS)
- Some more since...

Where Are These Companions?

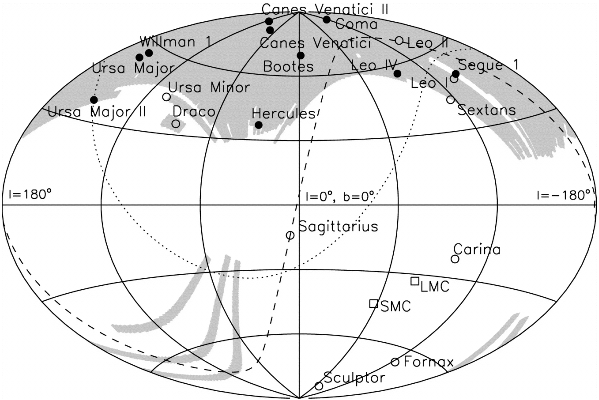
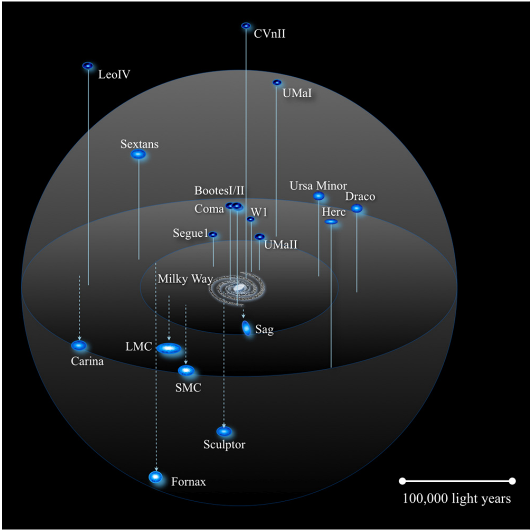


Fig. 7 from Belokoruv et al. 2007

Locations of Milky Way satellites in Galactic coordinates. Filled circles are satellites discovered by SDSS, and open circles are previously known Milky Way dSphs. The light gray shows the area of sky covered by the SDSS and its extensions to date. The dashed and dotted lines show the orbital planes of the Sagittarius and Orphan Streams, taken from Fellhauer et al. (2006) and Fellhauer et al. (2007), respectively.

Prettier Version



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Outline

Cats and Dogs, Hair and a Hero

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CATS AND DOGS, HAIR AND A HERO: A QUINTET OF NEW MILKY WAY COMPANIONS[1]

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ABSTRACT

We present five new satellites of the Milky Way discovered in Sloan Digital Sky Survey (SDSS) imaging data, four of which were followed up with either the Subaru or the Isaac Newton Telescopes. They include four probable new dwarf galaxies—one each in the constellations of Coma Berenices, Canes Venatici, Leo, and Hercules—together with one unusually extended globular cluster, Segue 1. We provide distances, absolute magnitudes, half-light radii, and color-magnitude diagrams for all five satellites. The morphological features of the color-magnitude diagrams are generally well described by the ridge line of the old, metal-poor globular cluster M92. In the past two years, a total of 10 new Milky Way satellites with effective surface brightness $\mu_v \gtrsim 28$ mag arcsec^{-2} have been discovered in SDSS data. They are less luminous, more irregular, and apparently more metal-poor than the previously known nine Milky Way dwarf spheroidals. The relationship between these objects and other populations is discussed. We note that there is a paucity of objects with half-light radii between ~40 and ~100 pc. We conjecture that this may represent the division between star clusters and dwarf galaxies.

Subject headings: galaxies: dwarf — Local Group

Cats and Dogs and What?

- Four new galaxies:
    - Cat = Leo (Leo IV)
    - Dog = Canes Venatici (CVn II)
    - Hair = Coma Berenices (Com)
    - Hero = Hercules (Her)
- One new globular cluster
    - Segue 1
- Used data from SDSS DR5 + SEGUE

What is SEGUE?

- Sloan Extension for Galactic Understanding and Exploration
- Aims to map the 3D structure of the Galaxy using 240,000 stellar spectra
- Useful for finding companions

http://www.segway.com

Where's Waldo – I Mean the Coma Berenices dSph Galaxy?

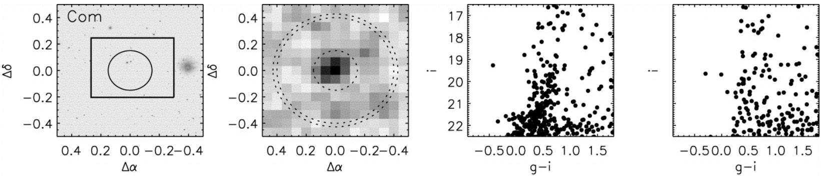
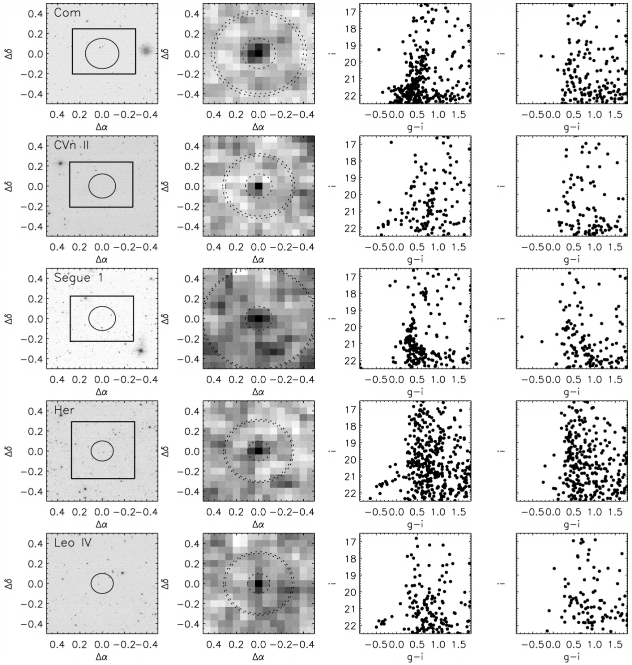


Fig. 1 (cropped) from Belokoruv et al. 2007

Discovery panels for the five new satellites. The first column is a cutout of the SDSS, with a box showing the location of the Subaru field (34′ × 27′) or INT field (34′ × 34′) and a circle marking the central part of the object. The second column shows the pixelated stellar density. The pixels are 4′ on each side. For each object, three circles are shown of radii r_1, r_2, and r_3. The CMD of stars lying within the circle of radius r_1 is given in the third column. The CMD of stars lying in the annulus defined by the outer radii (r_2 and r_3) is given in the fourth column. [For Coma, r_1, r_2, r_3 are (0.15°, 0.4°, 0.43°), for CVn II (0.12°, 0.3°, 0.32°), for Segue 1 (0.12°, 0.5°, 0.51°), for Her (0.1°, 0.3°, 0.32°), and for Leo IV (0.1°, 0.3°, 0.32°).]



Com
CVn II
Segue 1
Her
Leo IV
Δδ
Δα
i
g−i

CMDs From Follow-Up Data

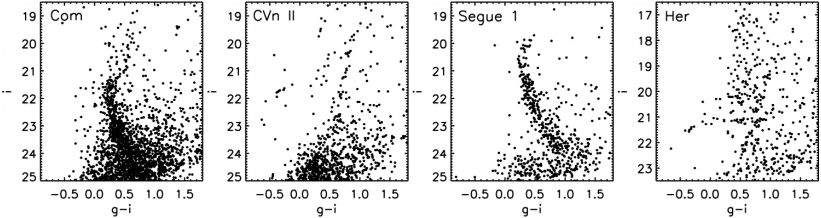


Fig. 2 from Belokoruv et al. 2007

CMDs of the central parts of Com, CVn II, Segue 1, and Her (*from left to right*) from the Subaru/INT follow-up data.

Differential Hess Diagrams

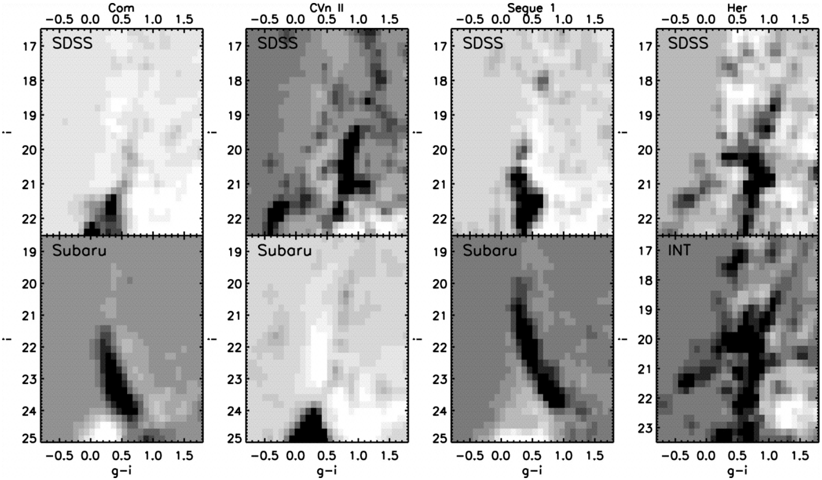


Fig. 3 from Belokoruv et al. 2007

Differential Hess diagrams using SDSS (*top*) and Subaru or INT (*bottom*) data for Com, CVn II, Segue 1, and Her. In each case, the normalized Hess diagram constructed with stars selected within r_1 is subtracted from the normalized Hess diagram constructed with stars selected between r_2 and r_3.

Differential Hess Diagrams: Contours

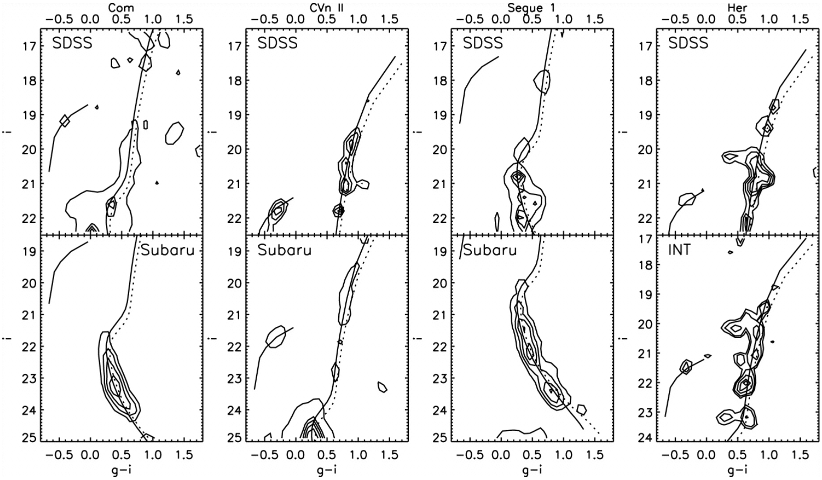


Fig. 4 from Belokoruv et al. 2007

Contour levels on the differential Hess diagrams using SDSS (*top*) and Subaru or INT (*bottom*) data for Com, CVn II, Segue 1, and Her. The ridgeline of M92 is overlaid as a solid line and that of M13 as a dotted line, using the data of Clem (2005).

Isodensity Contours

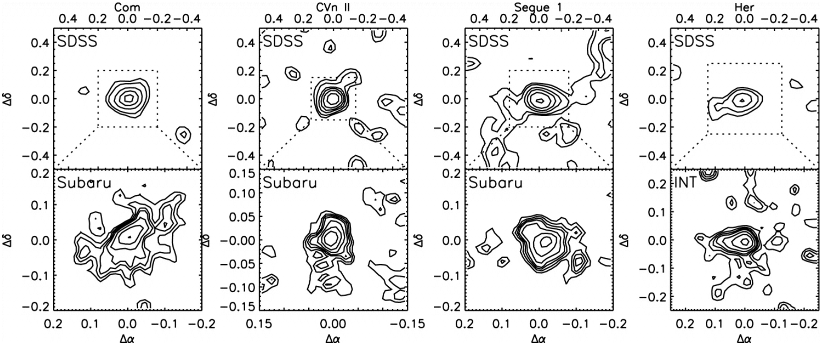


Fig. 5 from Belokoruv et al. 2007

Isodensity contours for Com, CVn II, Segue 1, and Her I. Membership is determined using a mask constructed from the M92 ridgeline. The top panels show CMD-selected stars with $18 < i < 22.5$. There are 30×30 pixels, smoothed with a Gaussian with FWHM of 3 pixels. Contour levels are 2, 3, 5, 7, 10, and 15 σ above the background. The bottom panels show the central parts of the objects in Subaru/INT data. There are 30×30 pixels, smoothed with a Gaussian with FWHM of 2.2 pixels. Contour levels are 2, 3, 4, 5, 7, 10, and 15 σ above the background.

Some Misc. Results

- $\gtrsim 50$ dwarf companions expected in total
- Rough correlation with irregularity and distance
- All dwarf companions seem very metal-poor

Dwarf Galaxies or Globular Clusters?

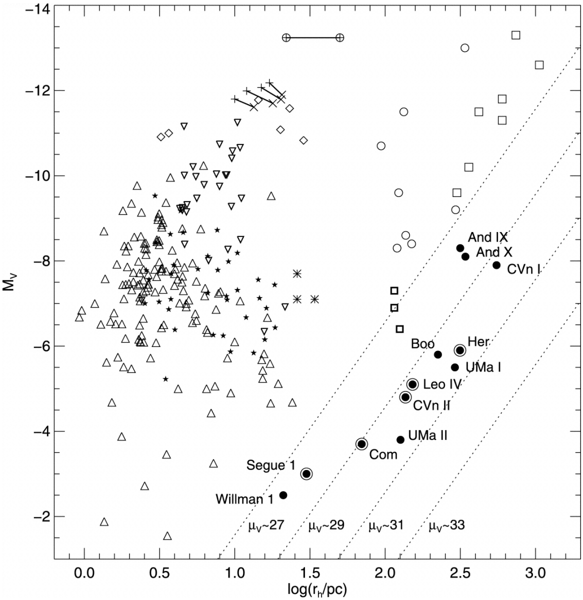
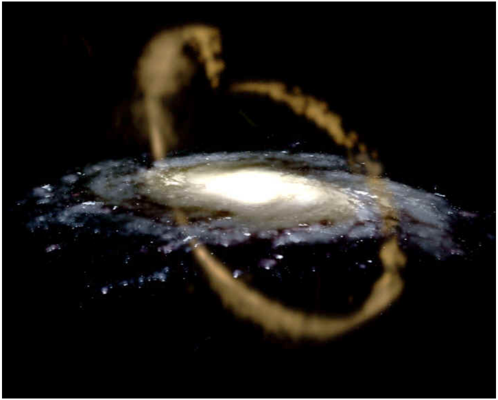


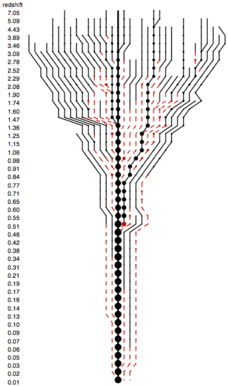
Fig. 8 from Belokoruv et al. 2007

Outline

Sometimes it's Okay to Eat Your Neighbors



http://apod.nasa.gov



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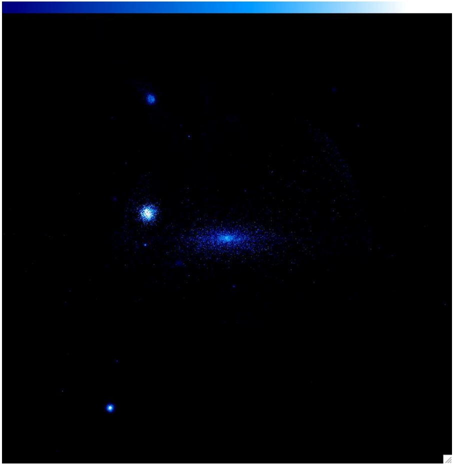
Simulated Surface Brightness Images

Black = 28 Magnitudes per square arcsecond



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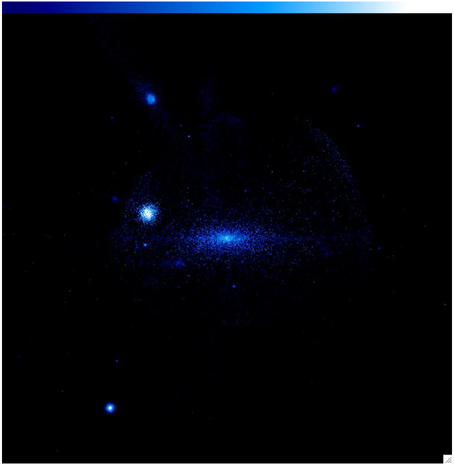
Simulated Surface Brightness Images

Black = 30 Magnitudes per square arcsecond



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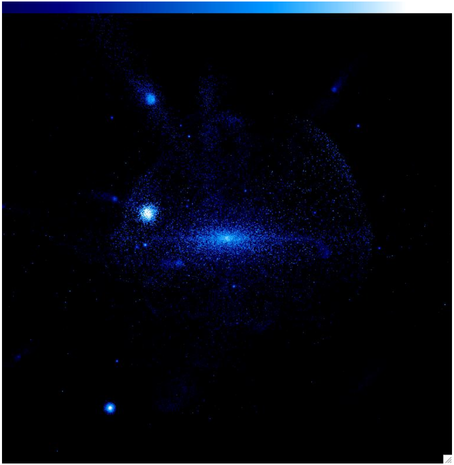
Simulated Surface Brightness Images

Black = 32 Magnitudes per square arcsecond



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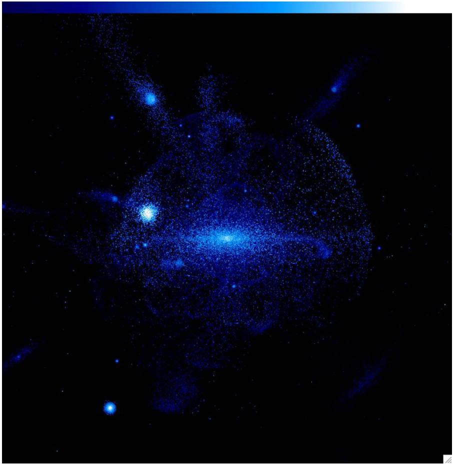
Simulated Surface Brightness Images

Black = 35 Magnitudes per square arcsecond



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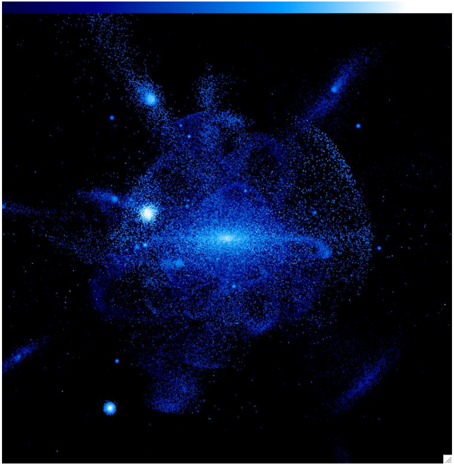
Simulated Surface Brightness Images

Black = 40 Magnitudes per square arcsecond



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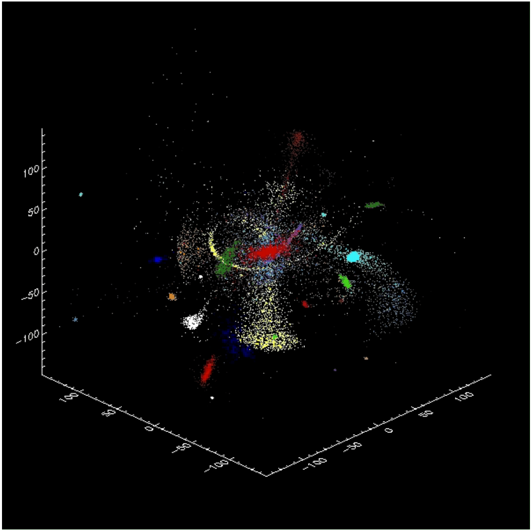
And Finally a Movie



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References

- Belokurov, V., et al. 2007, ApJ, 654, 897
- Johnston, K. V., Bullock, J. S., Sharma, S., Font, A., Robertson, B. E., & Leitner, S. N. 2008, ApJ, 689, 936