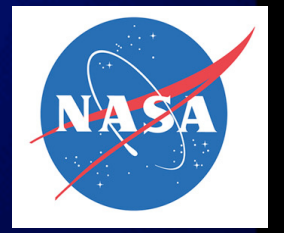
Where's the Matter?

Mapping the Dark Matter Halo of our Galaxy

Kathryn V Johnston

Astronomy Department

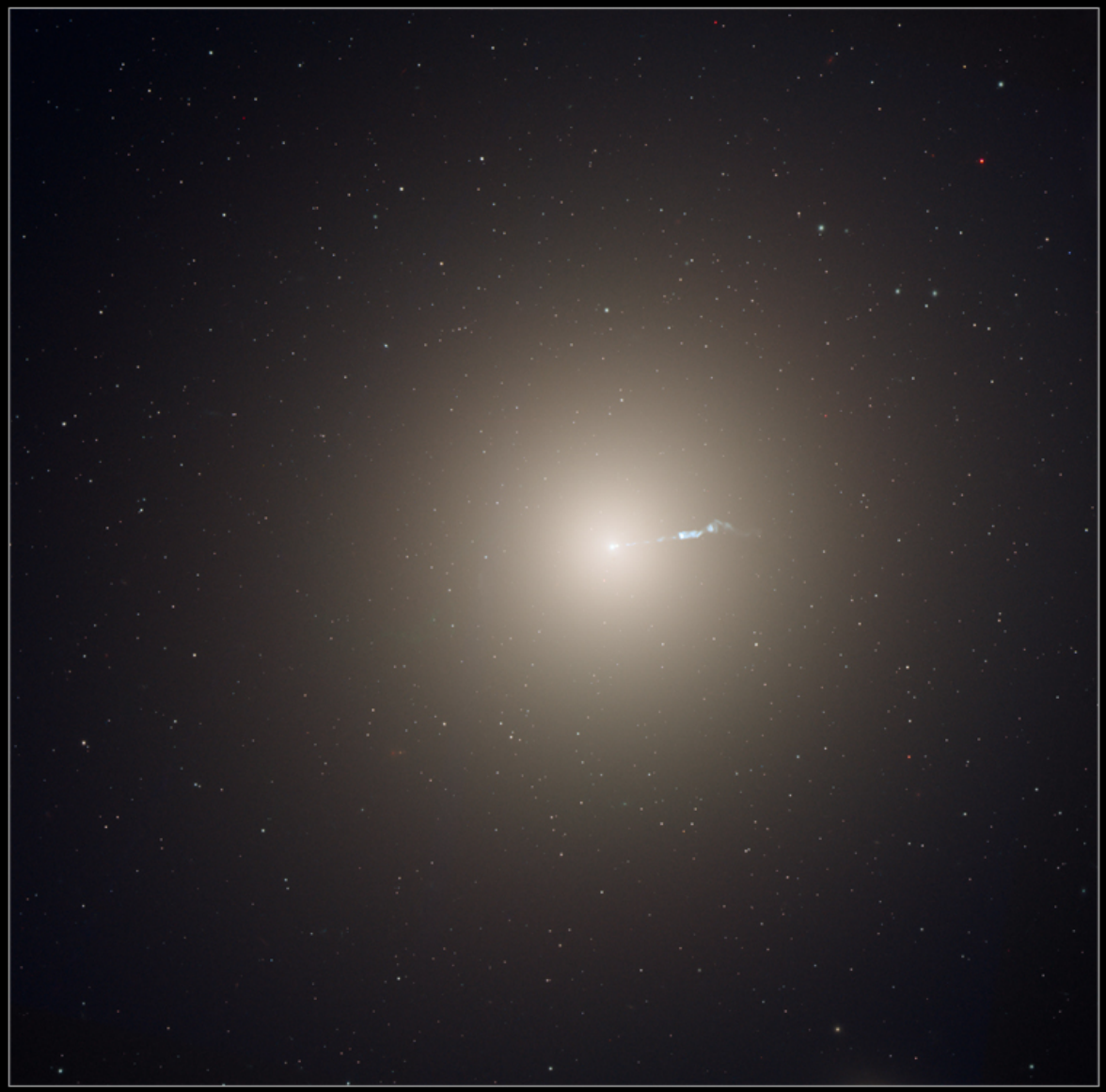
Columbia University



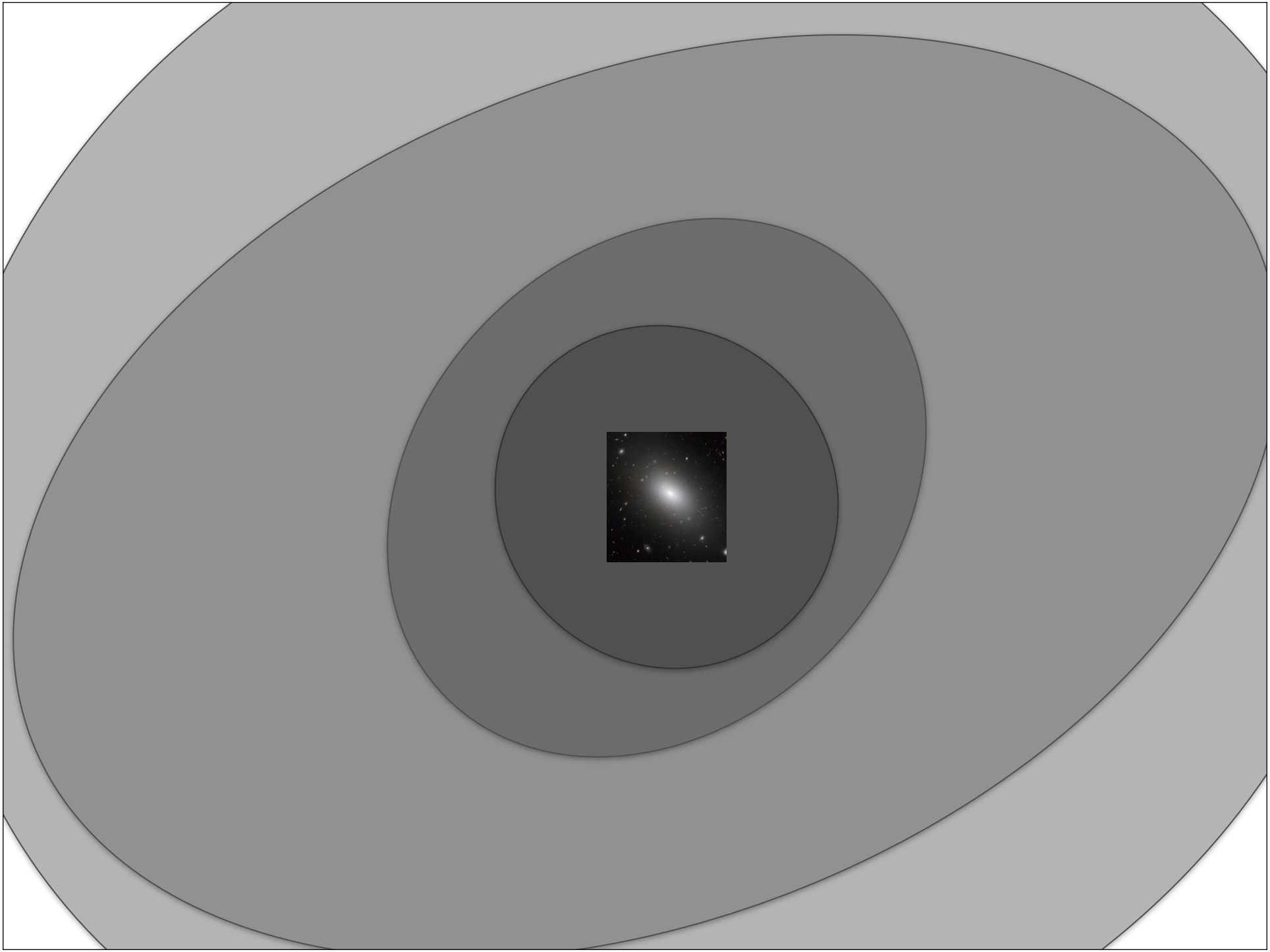
Career Path

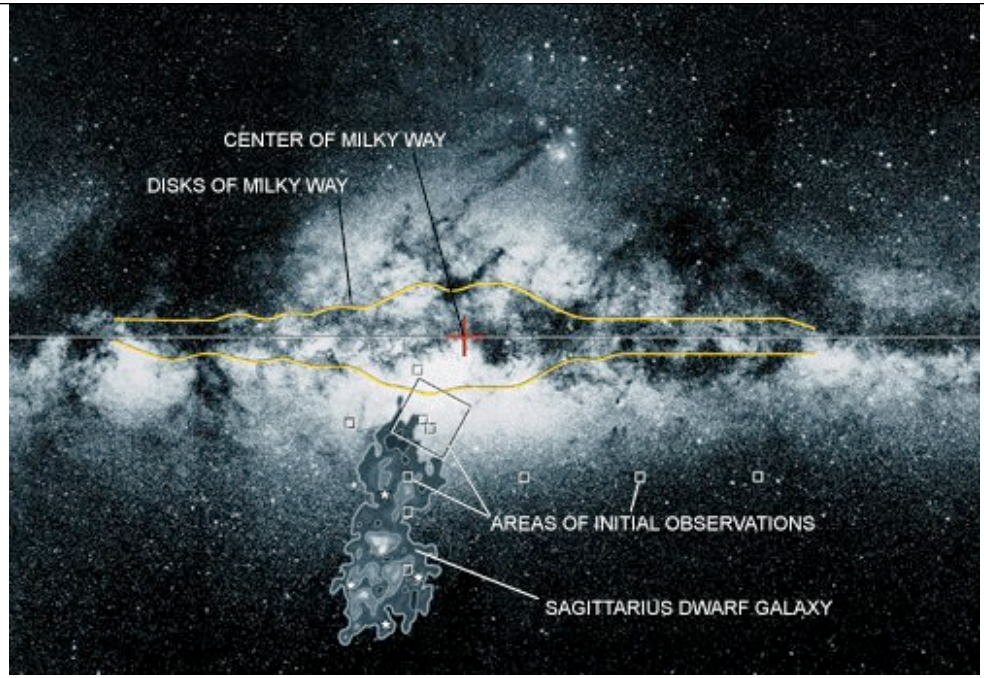
- BA in math, Cambridge University
  - ~30% women in math at my college
- PhD in Astronomy from UCSC
  - ~30% women in the program
- Postdoc at the Institute for Advanced Study
  - ~15% women members in astronomy
- Assistant professor at Wesleyan University
- Tenured professor (and now Chair) at Columbia University

Elliptical Galaxy M87

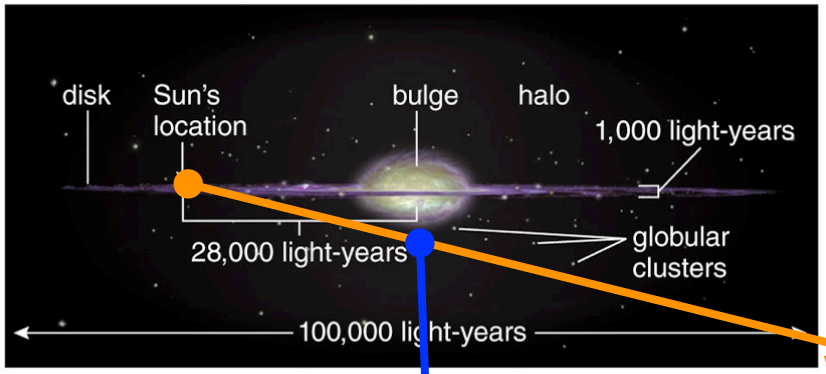


Hubble Heritage

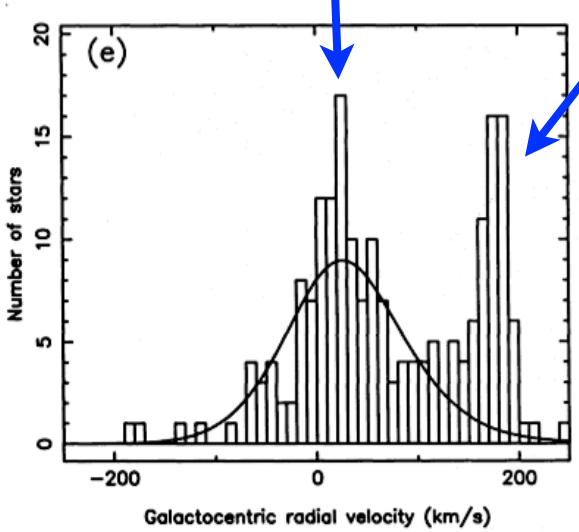


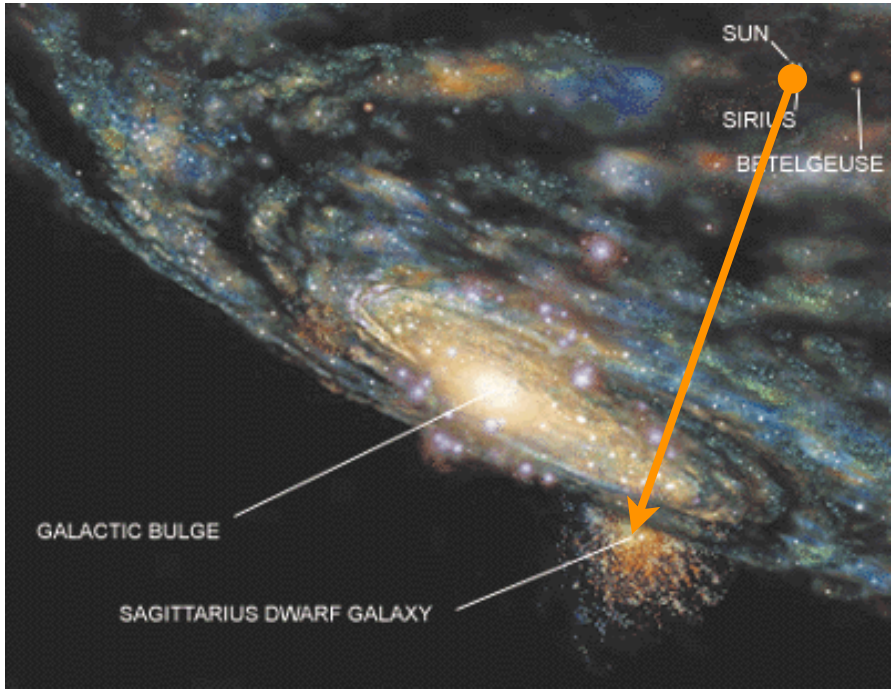

CENTER OF MILKY WAY
DISKS OF MILKY WAY
AREAS OF INITIAL OBSERVATIONS
SAGITTARIUS DWARF GALAXY

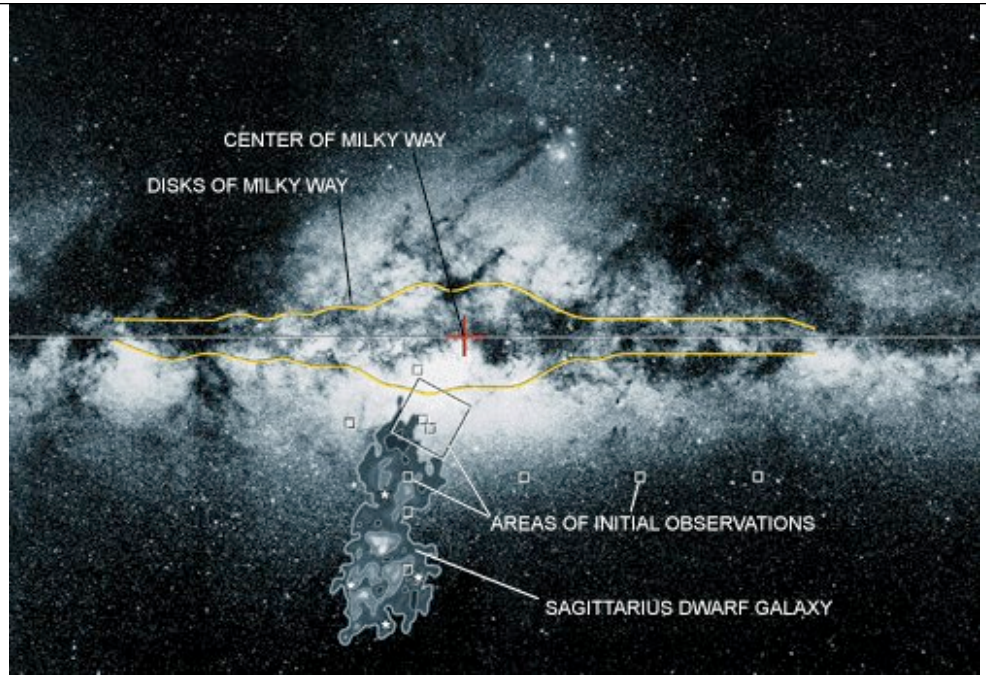
The Sagittarius Dwarf Galaxy



© 2006 Pearson Education, Inc., publishing as Addison Wesley





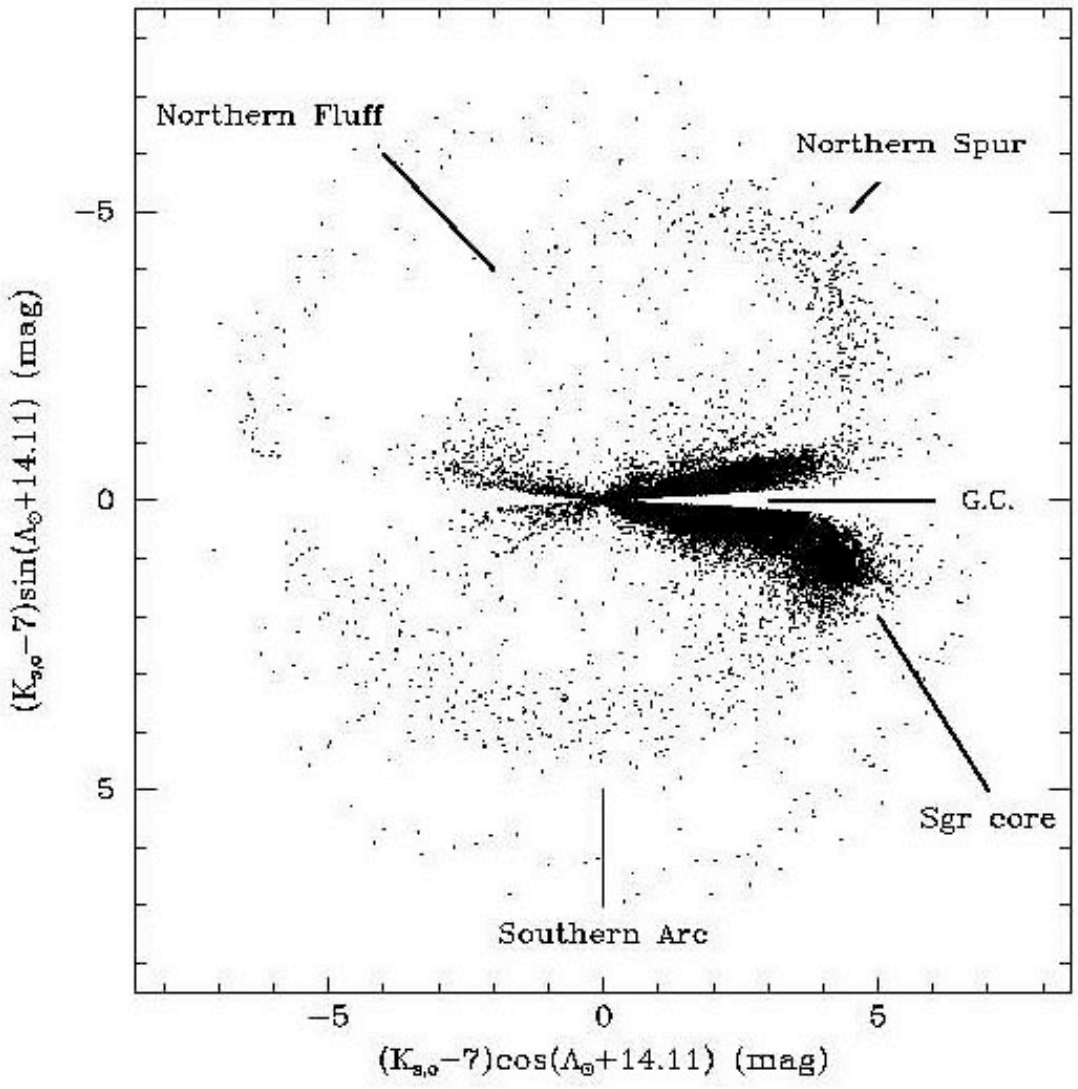

CENTER OF MILKY WAY
DISKS OF MILKY WAY
AREAS OF INITIAL OBSERVATIONS
SAGITTARIUS DWARF GALAXY

Sagittarius Dwarf Galaxy: debris

First maps of tails

- In carbon stars: Ibata et al (2001)

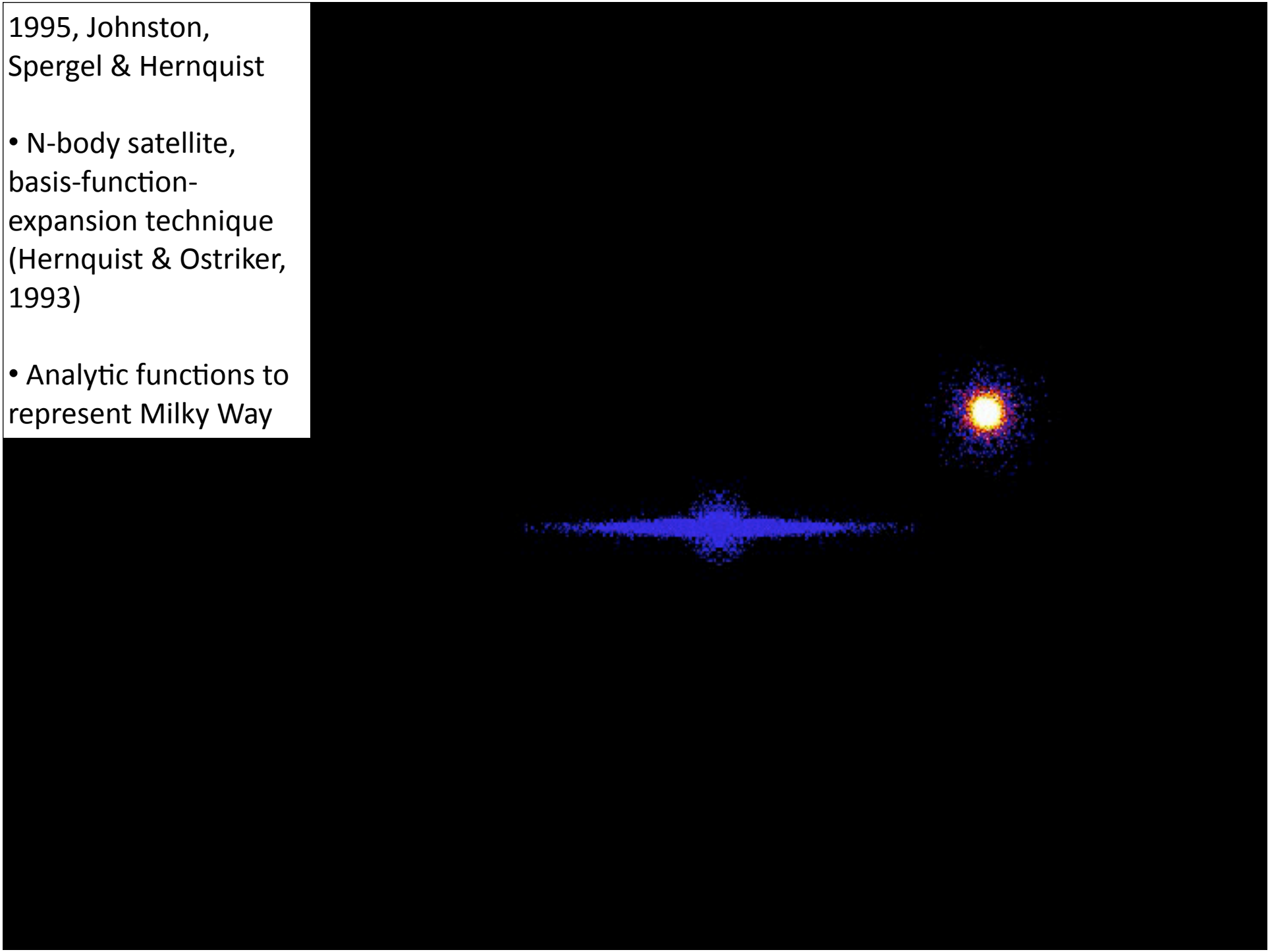
- In M-giants Majewski et al (2003)



1995, Johnston, Spergel & Hernquist

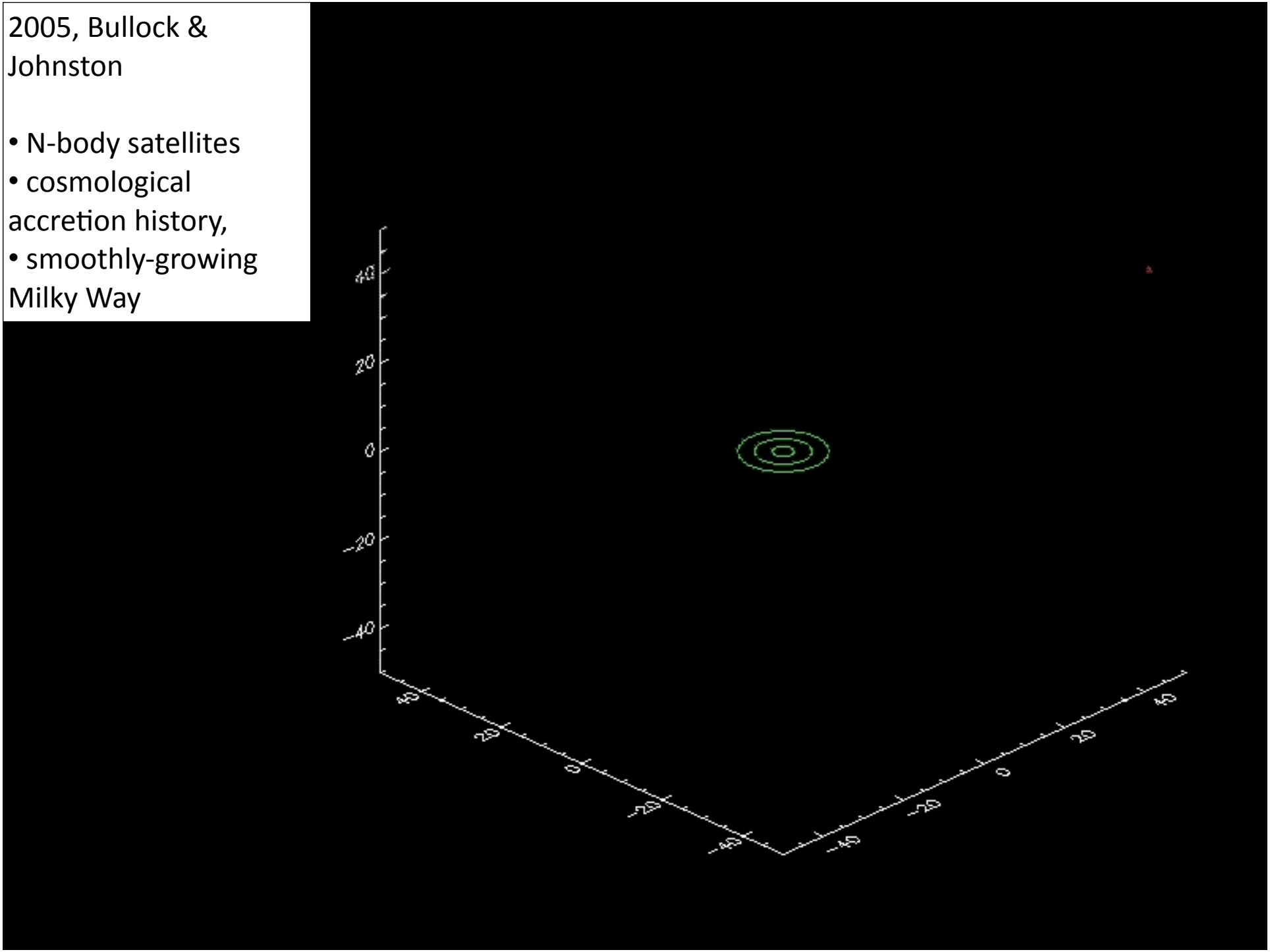
• N-body satellite, basis-function-expansion technique (Hernquist & Ostriker, 1993)

• Analytic functions to represent Milky Way



2005, Bullock & Johnston

- N-body satellites
- cosmological accretion history,
- smoothly-growing Milky Way



2005, Bullock & Johnston

Image credit: Sanjib Sharma from Johnston/Bullock/ Font/Robertson collaboration

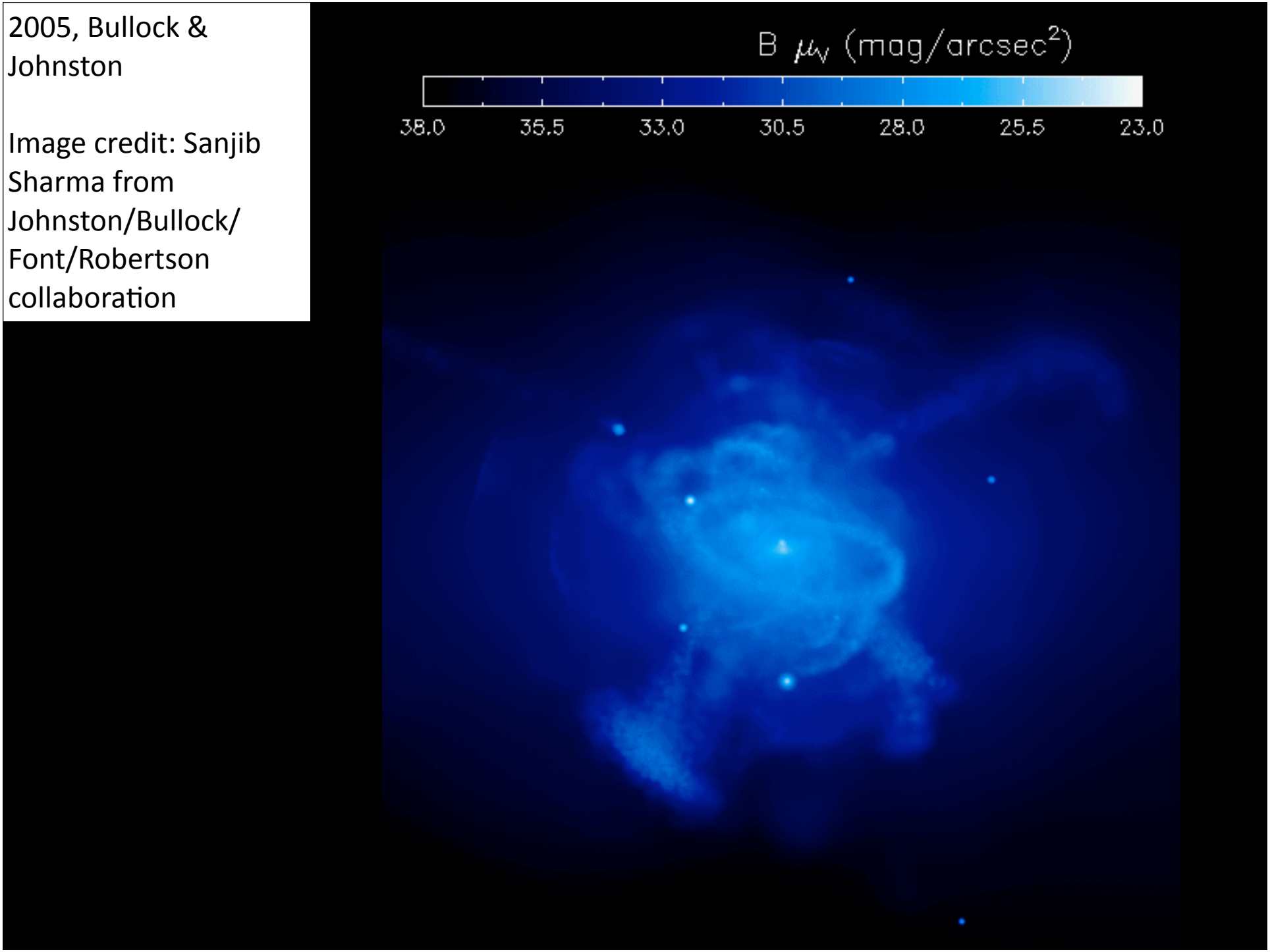
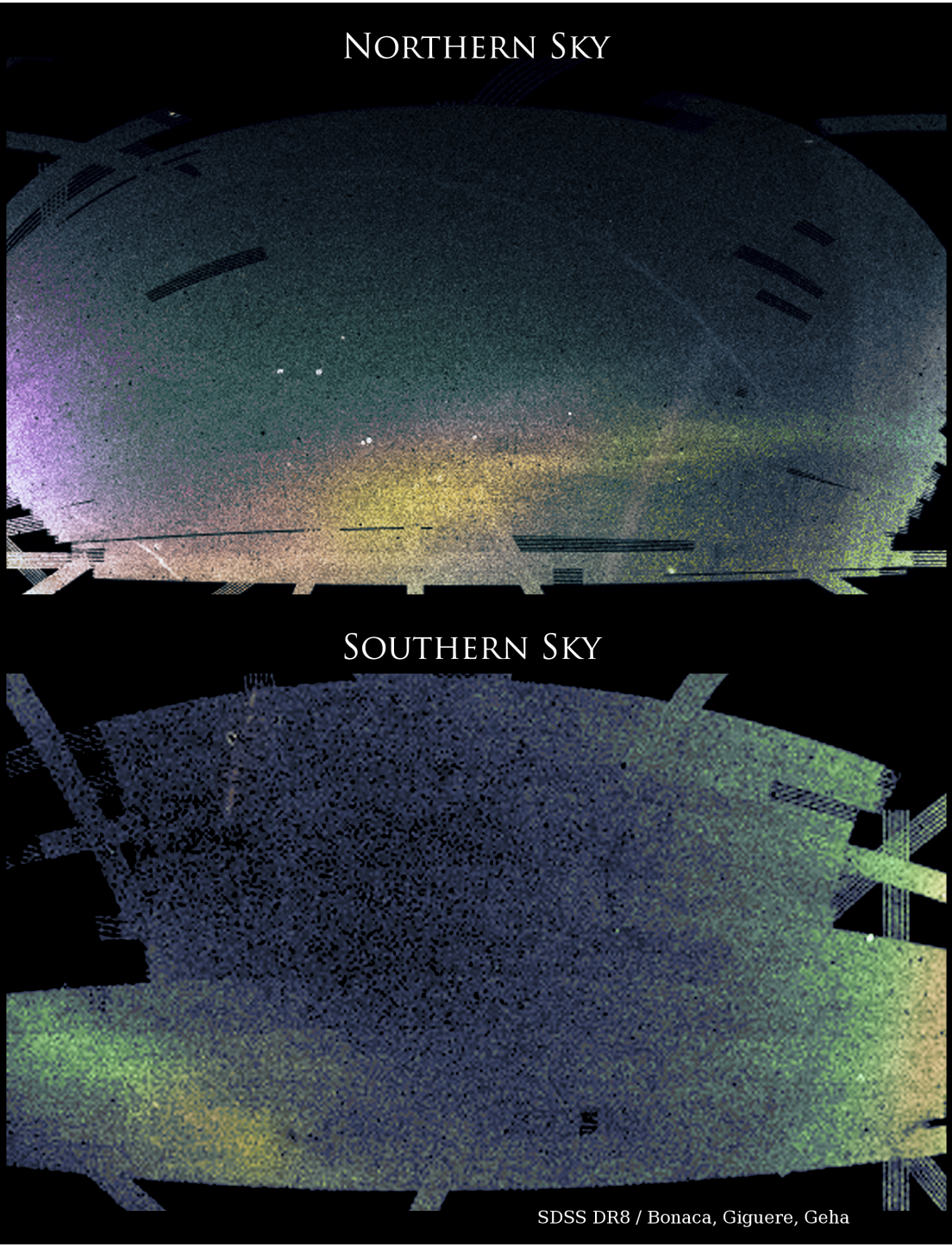
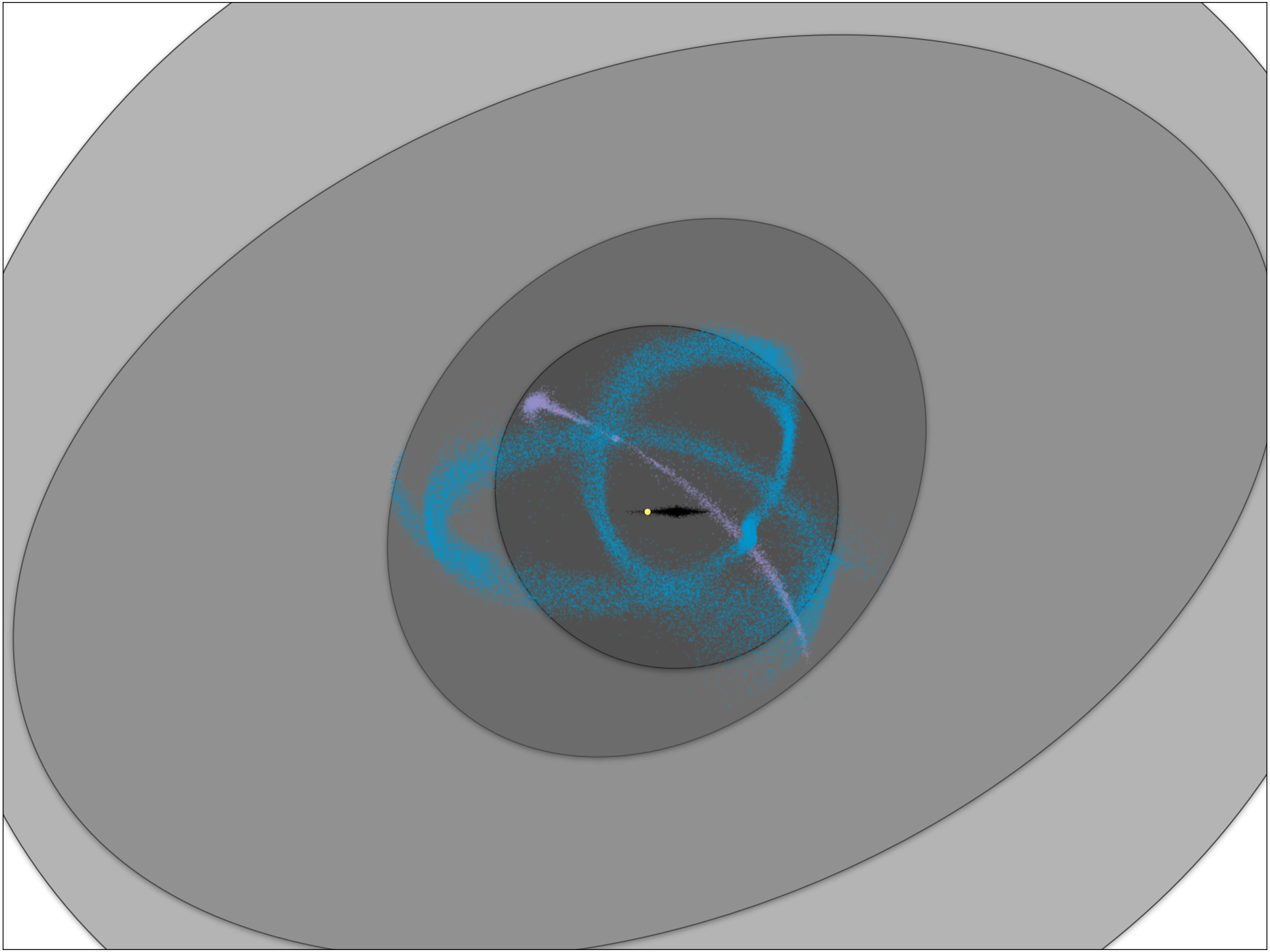


Image by from Ana Bonaca (Yale).

Data from SDSS.

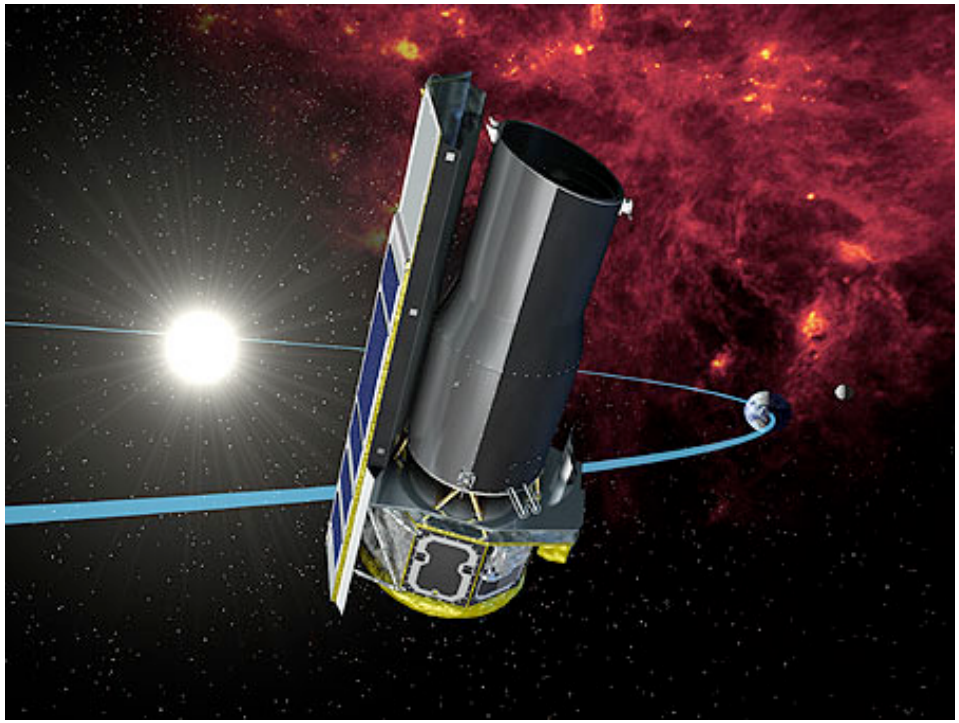
See classic “Field of Streams” paper, Belokurov et al (2005).





SMHASH

Spitzer **M**erger **H**istory **A**nd **S**hape of the **H**alo



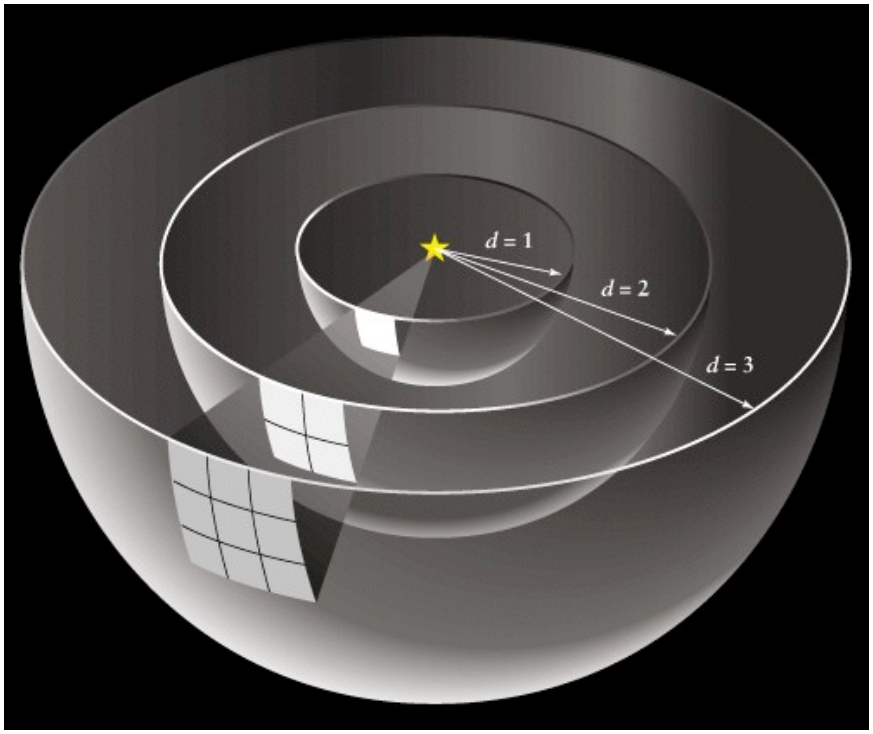
- RR Lyraes: intrinsic 2% scatter in P-L relation in IR
  (Madore & Freedman 2012 and Spitzer Cycle 9 work)

Johnston, Madore, Majewski, , Besla, Bono, Clementini, Cioni, Coehn, Freedman, Grillmair, Kallivayalil, Kollmeier, Law, Marengo, Mondon, Nidever, Pietrzynski, Persson, Price-Whelan, Rich, Scowcroft, Seibert, Smith, Sesar, Soszynski, Thompson, Udalski, van der Marel

Light from stars

- For a star:
  - distance *d*
  - apparent brightness *B*
  - luminosity *L*

$$B = \frac{L}{4\pi d^2}$$

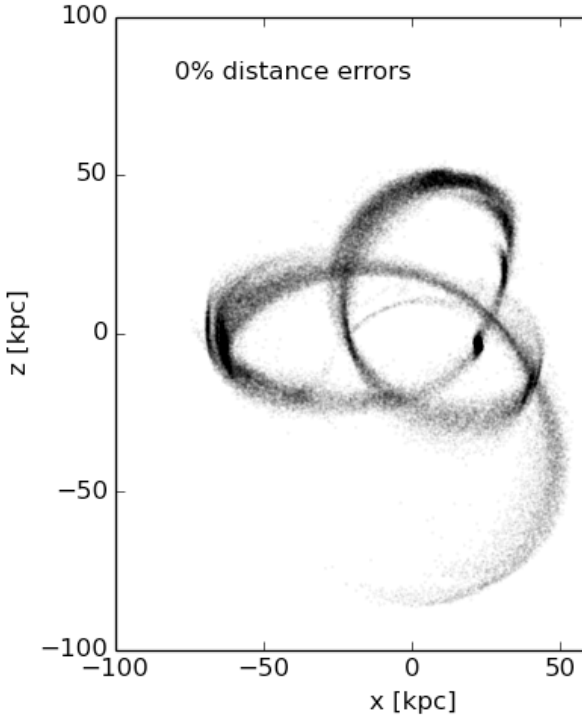


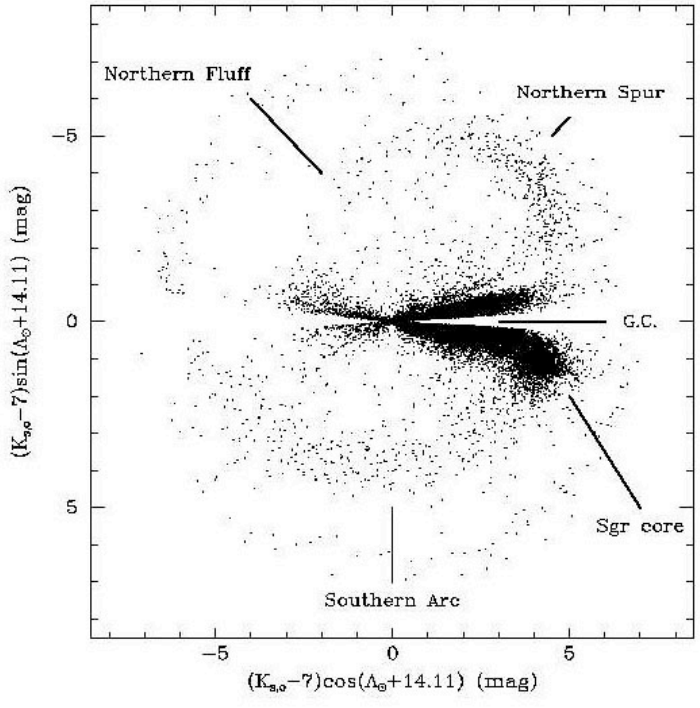
SMASH:

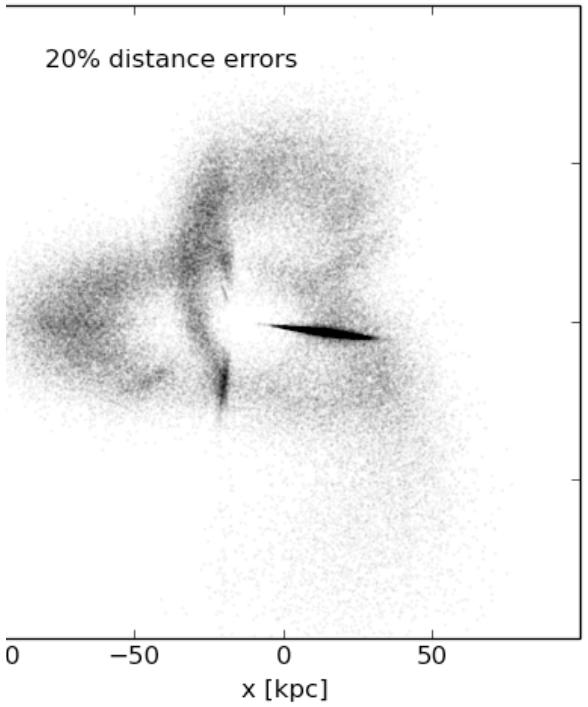
2% distances

⇔

position *within* stream







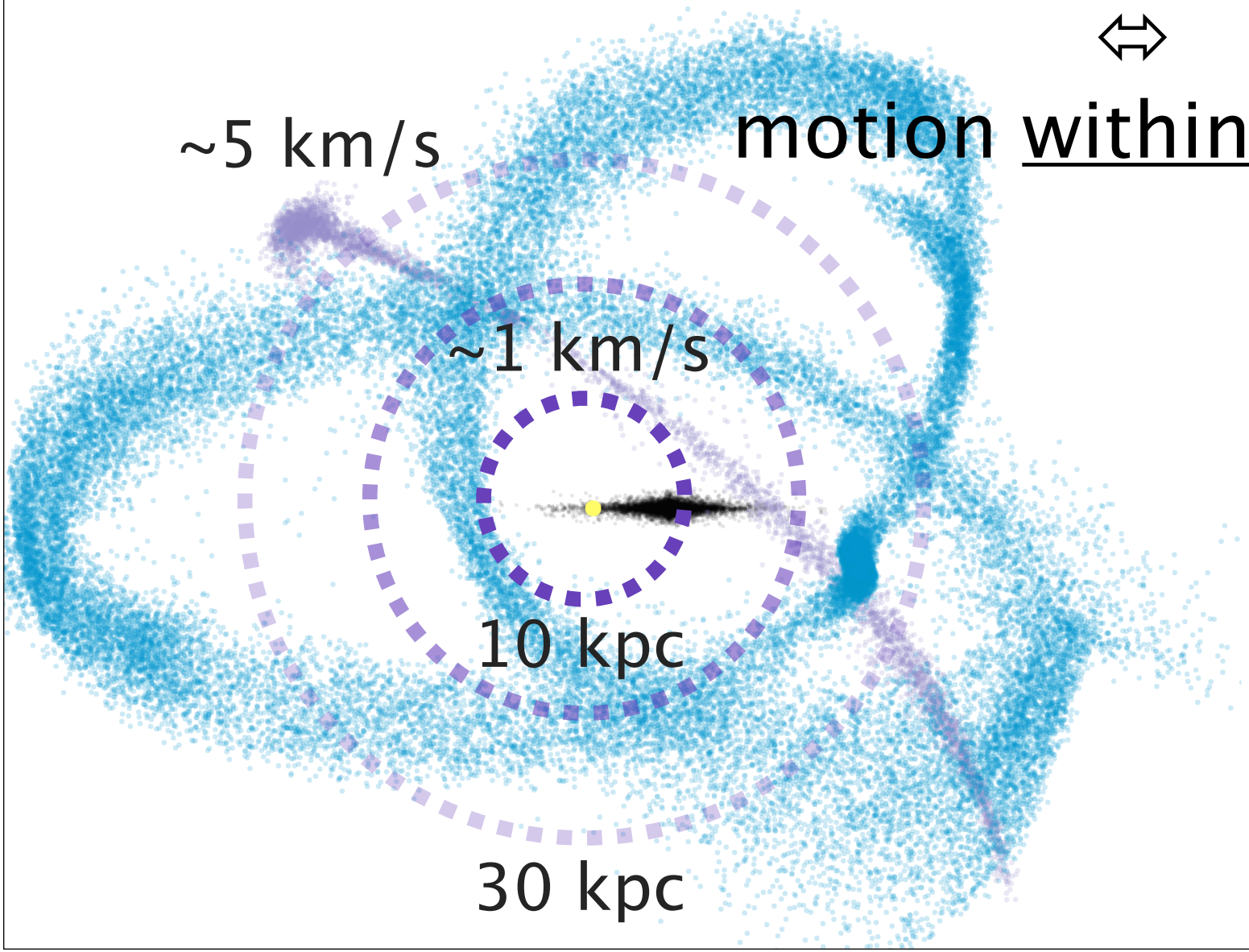
Gaia!

Gaia:

proper motion error

⇔

motion within stream



Adrian
Price-Whelan

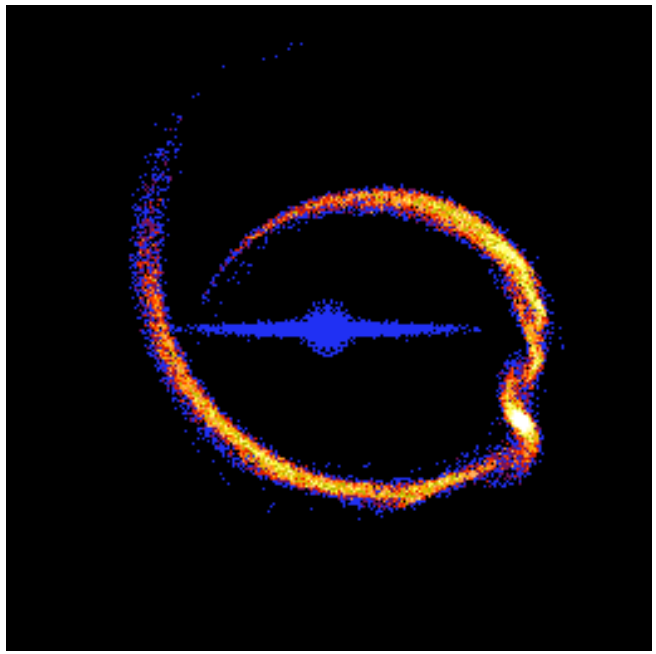
e.g. REWINDER

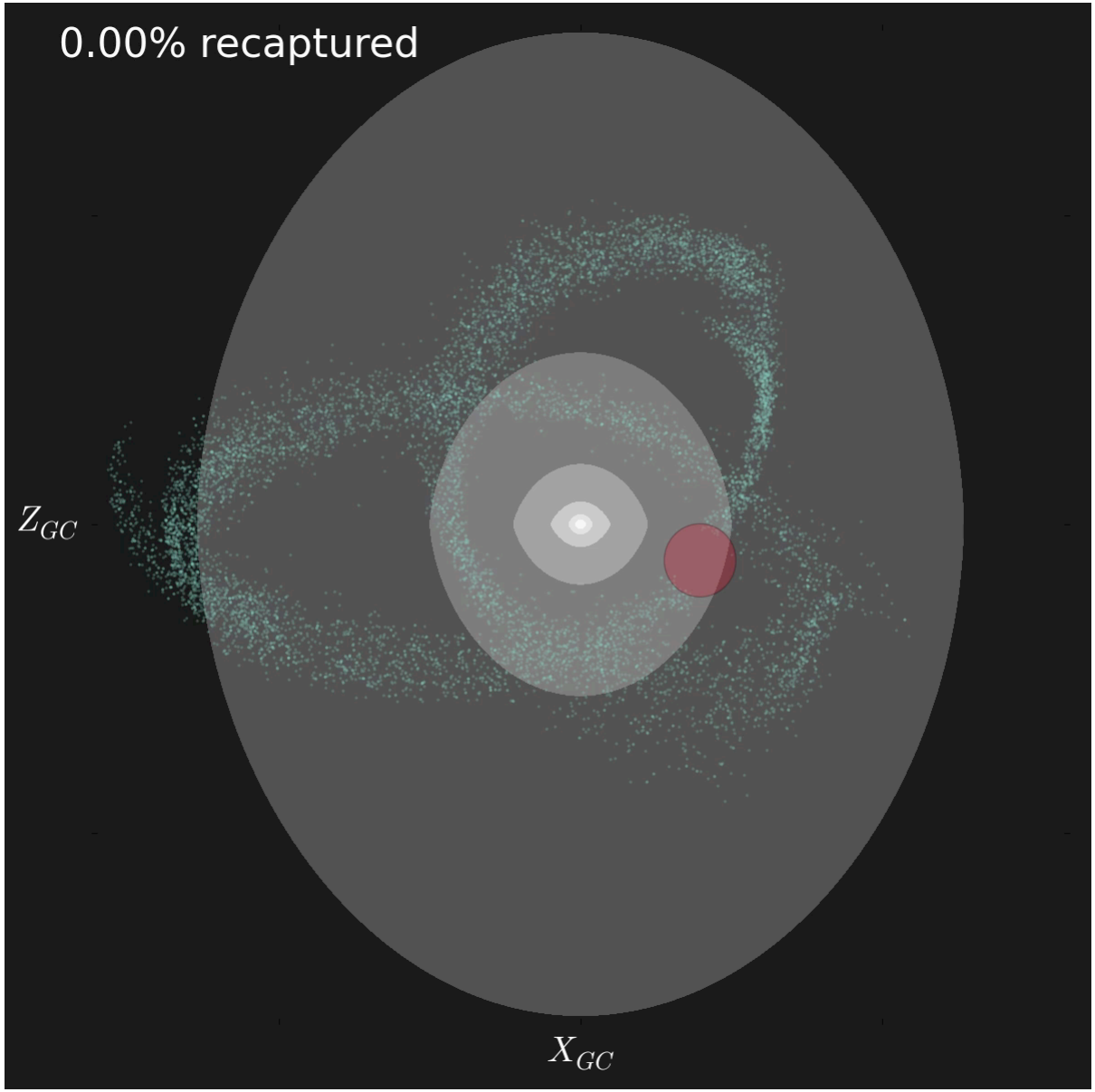
(Johnston, Zhao, Spergel & Hernquist, 1999)
(Price-Whelan & Johnston, 2013)
(Price-Whelan, Hogg, Johnston & Hendel, 2014)

STREAM
TEAM

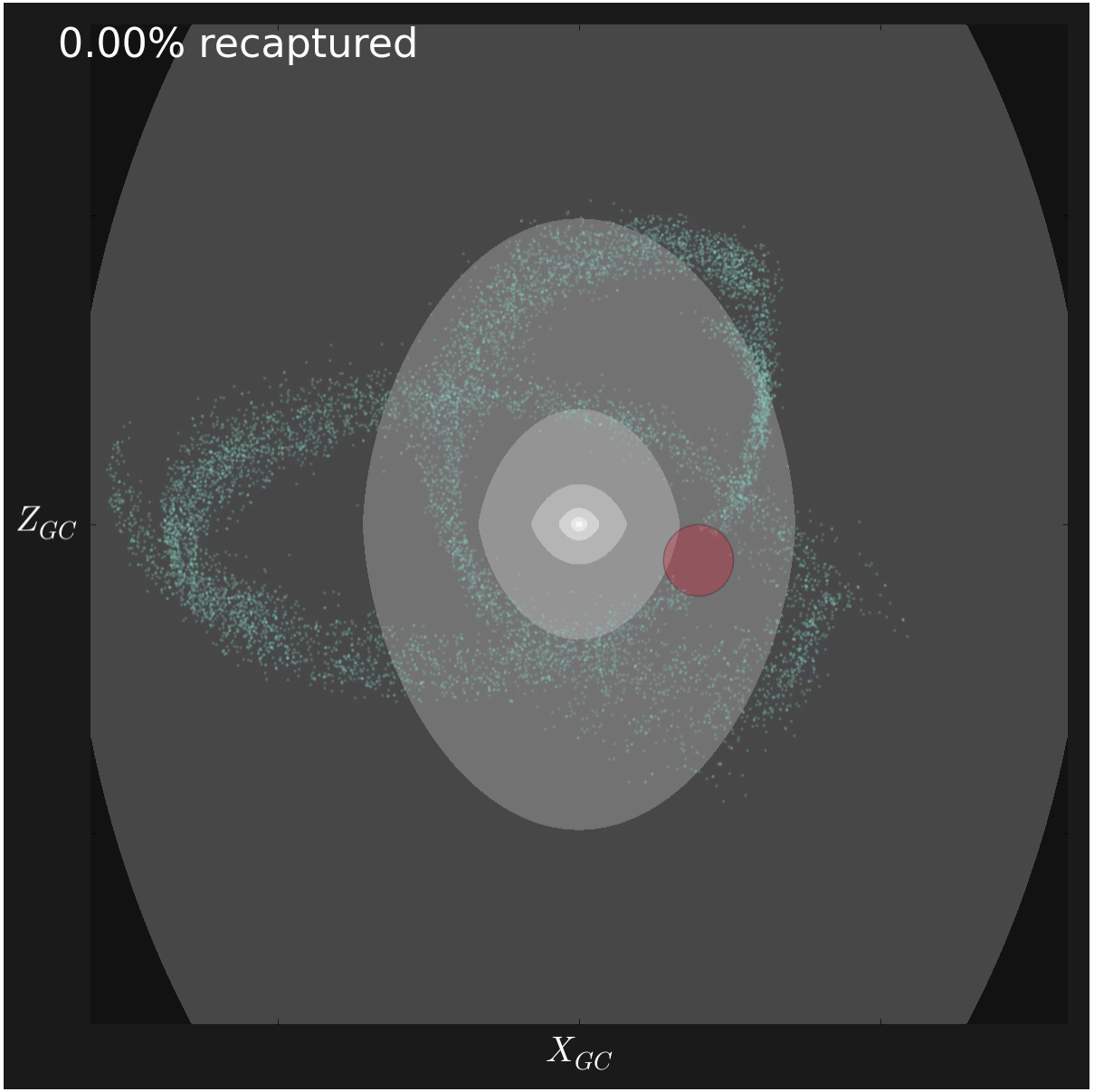
"debris once all part of same object"

- Assume full phase-space info $\Leftrightarrow (x,y,z,v_x,v_y,v_z)$
- Integrate these "final conditions" *backwards*
- In correct potential, stars recombine with satellite





recombines when $\left(\frac{\Delta \mathbf{x}}{R_{\text{tide}}}\right)^2 + \left(\frac{\Delta \mathbf{v}}{v_{\text{esc}}}\right)^2 < \text{limit}$



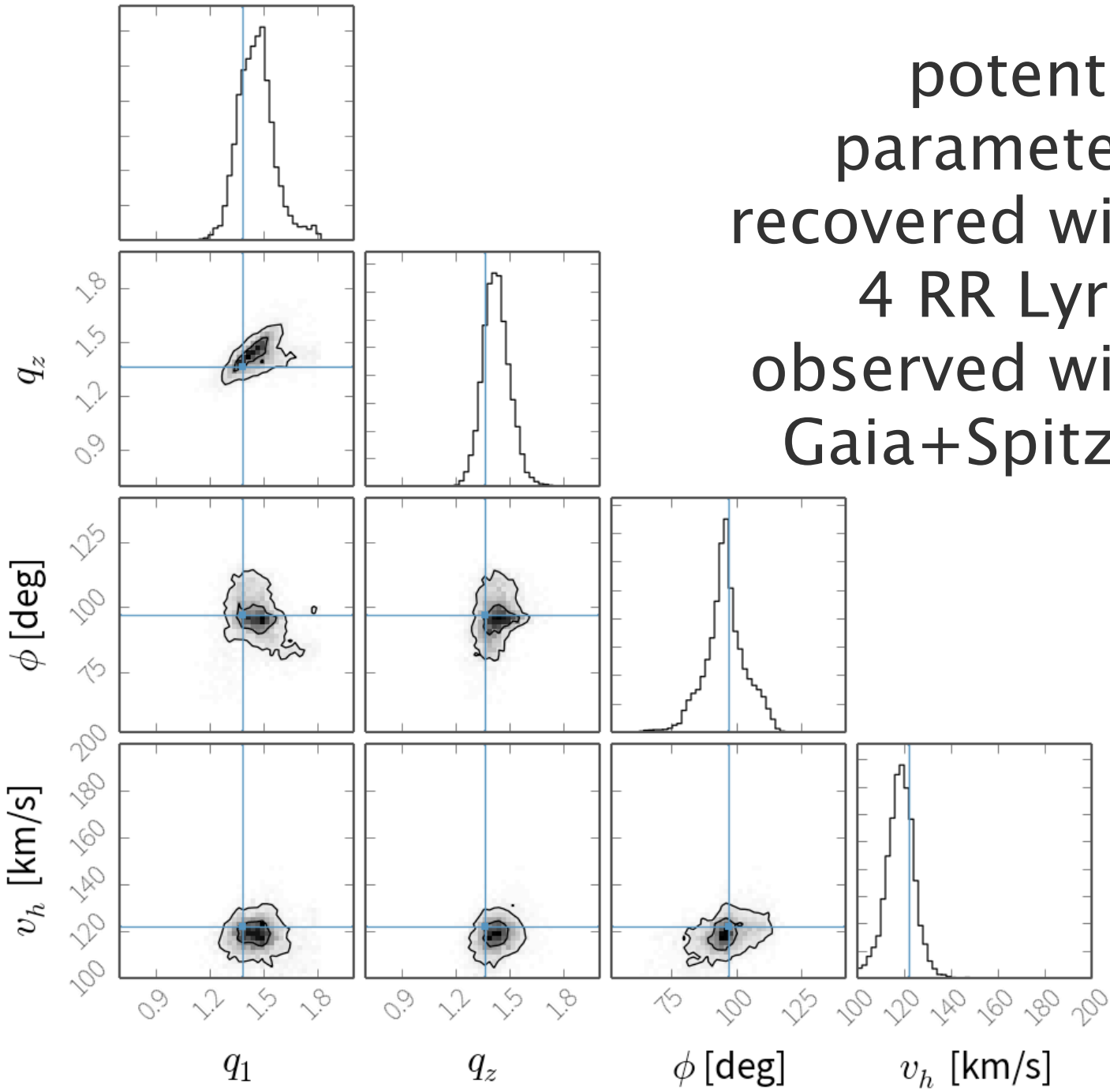
recombines when $\left(\frac{\Delta \mathbf{x}}{R_{\text{tide}}}\right)^2 + \left(\frac{\Delta \mathbf{v}}{v_{\text{esc}}}\right)^2 < \text{limit}$

potential parameters recovered with 4 RR Lyrae observed with Gaia+Spitzer

Flattening Perpendicular To disk

Orientation in Disk plane

Velocity scale Of halo



Conclusion

dead/dying satellites + *Gaia* + *Spitzer*

=

3-D map

of a

dark matter halo

..... with some caveats still to be addressed .....