Small Galaxies, Big Science

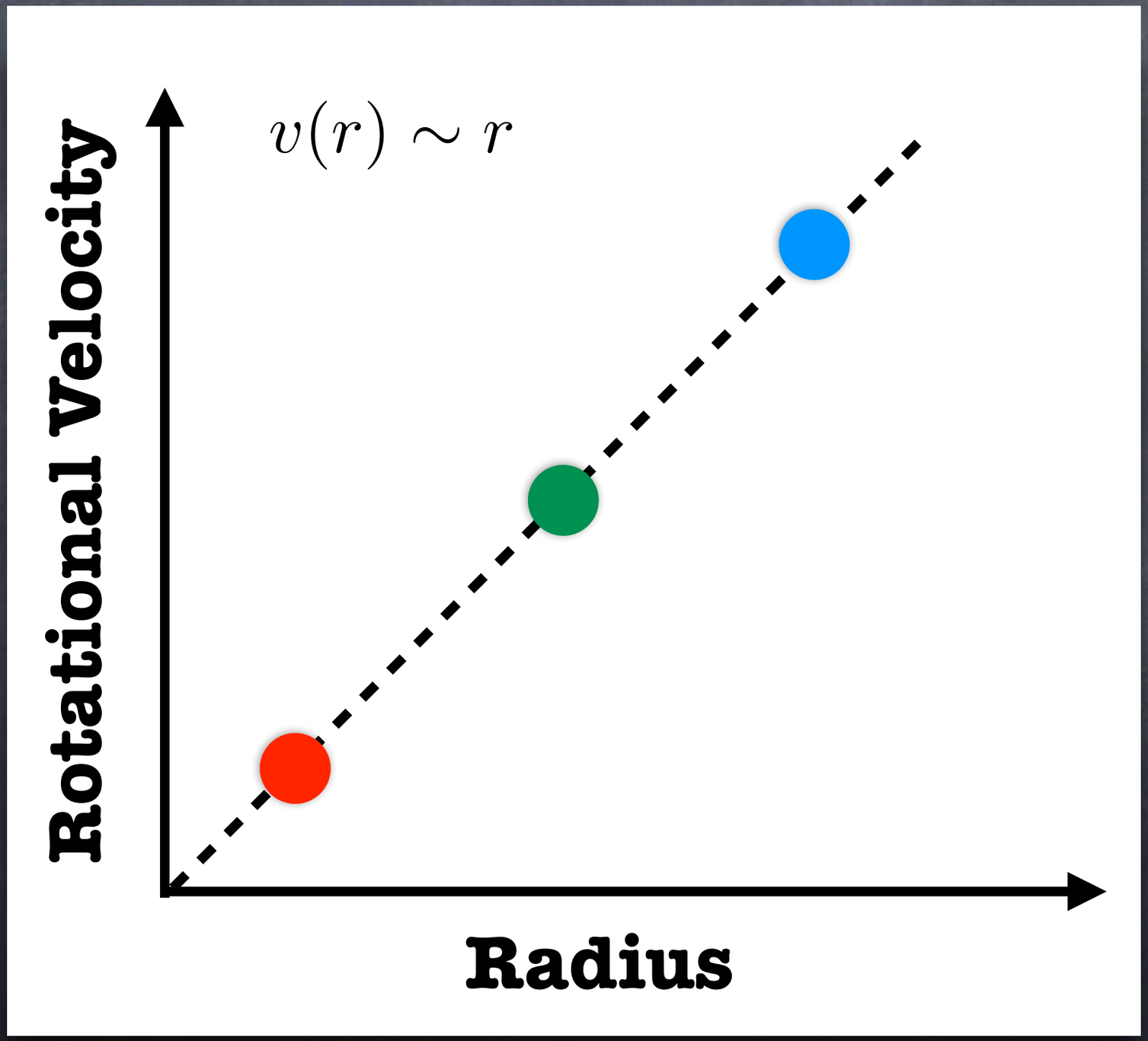
Alex Drlica-Wagner (Fermilab)

KITP Chalk Talk

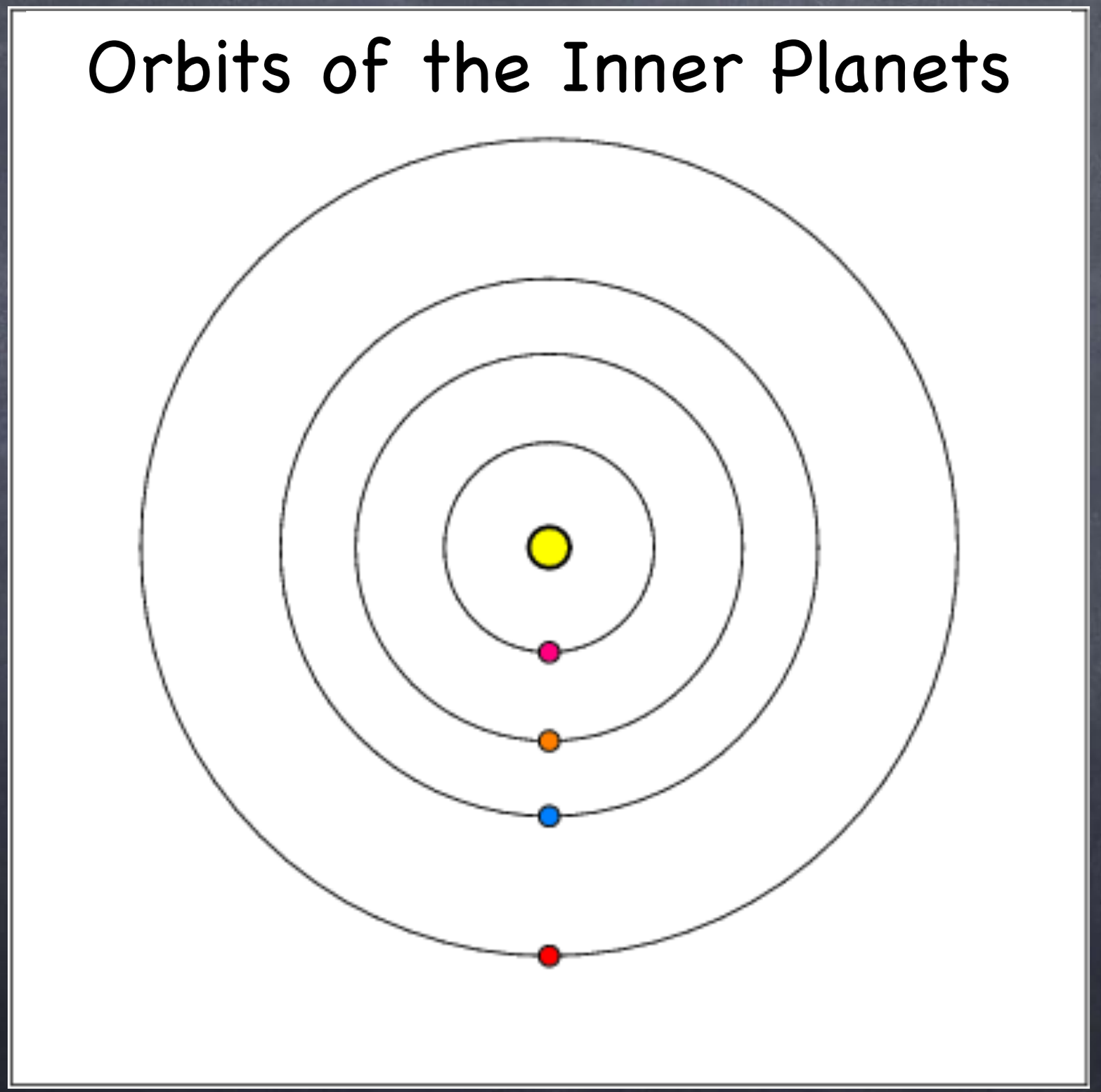
May 16, 2018

Measuring Mass

Measuring Mass



Measuring Mass



Measuring Mass

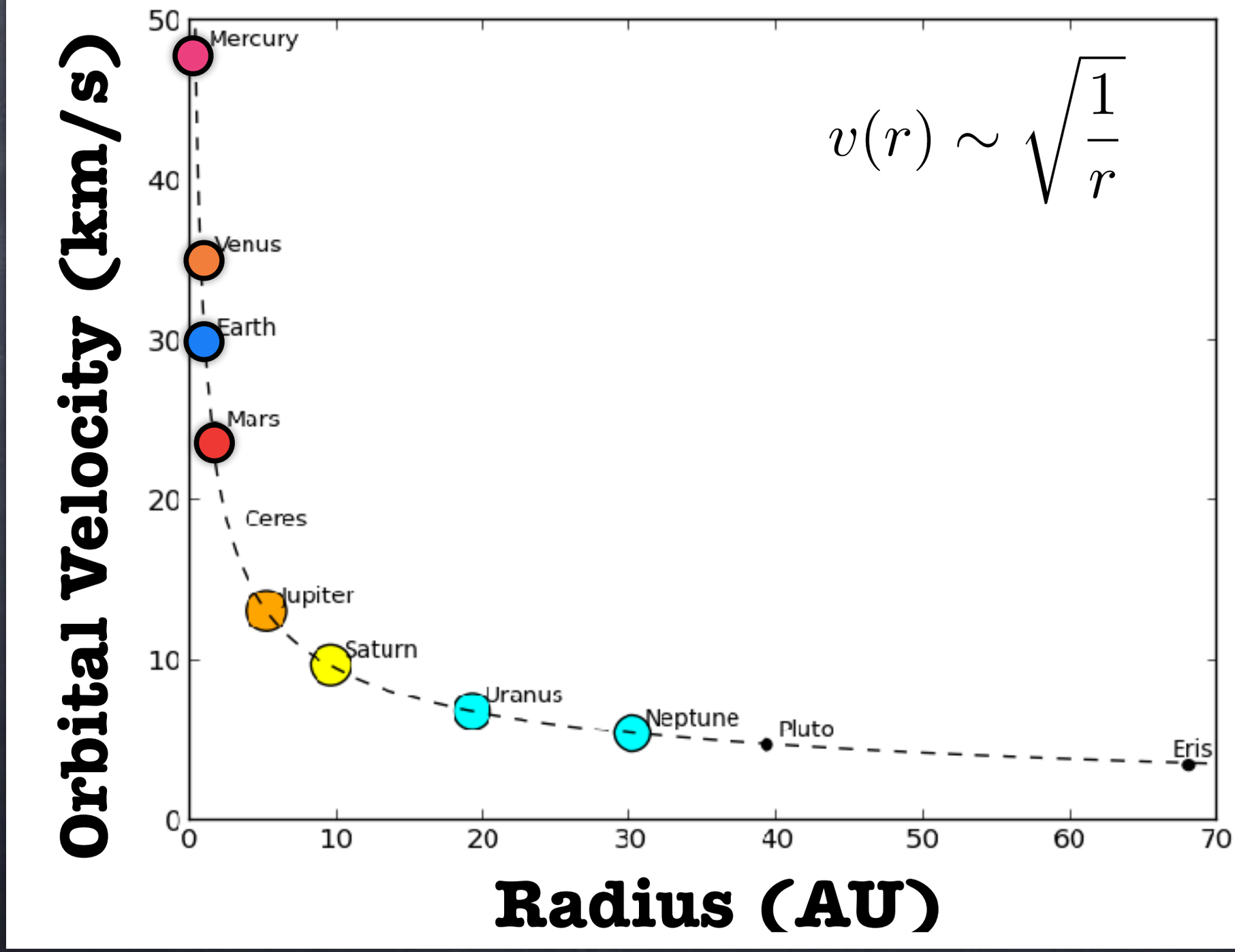
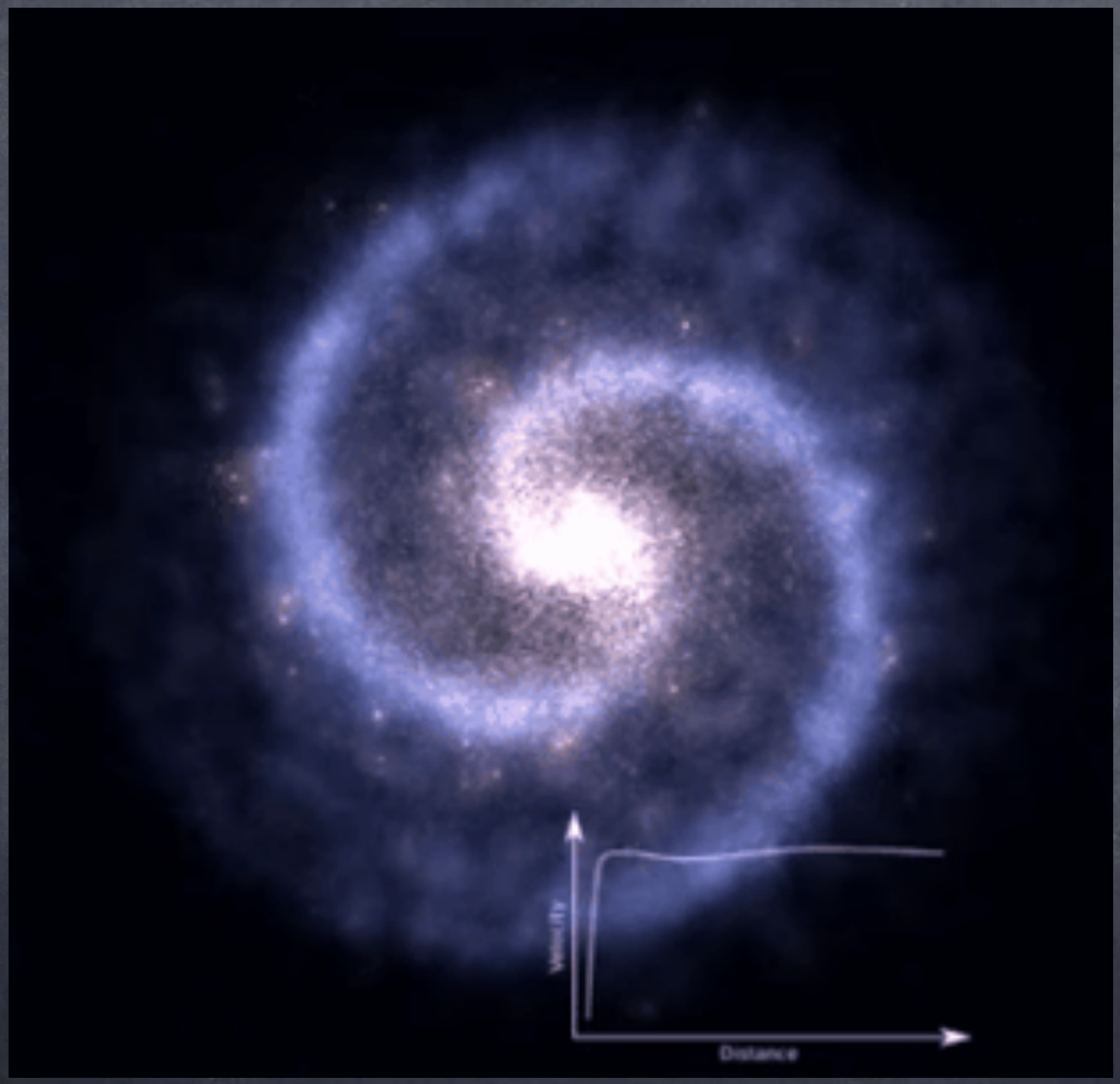


Image Credit: Matthew Newby

Measuring Mass

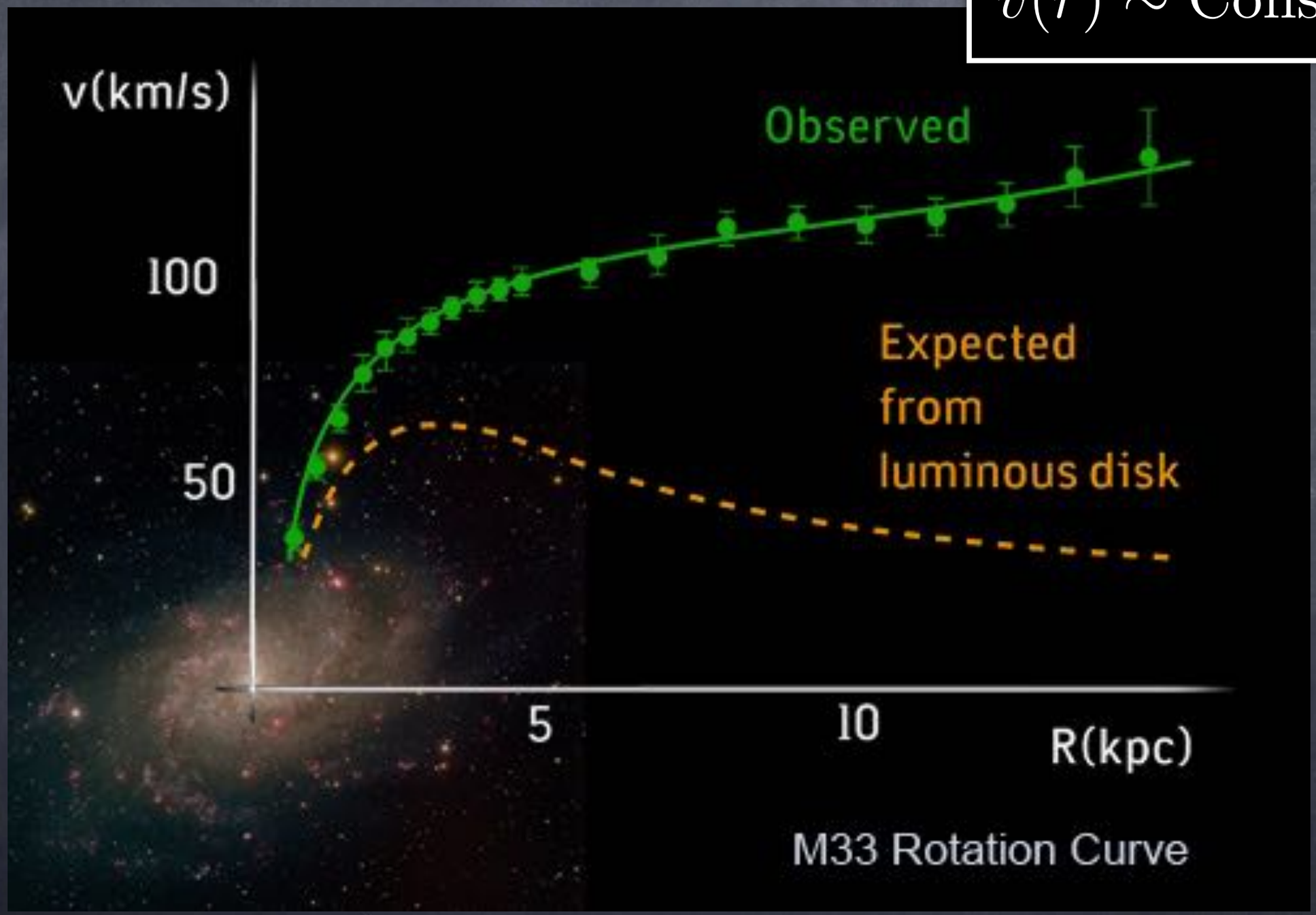


Simulation

Image Credit: Indo Berg

Measuring Mass

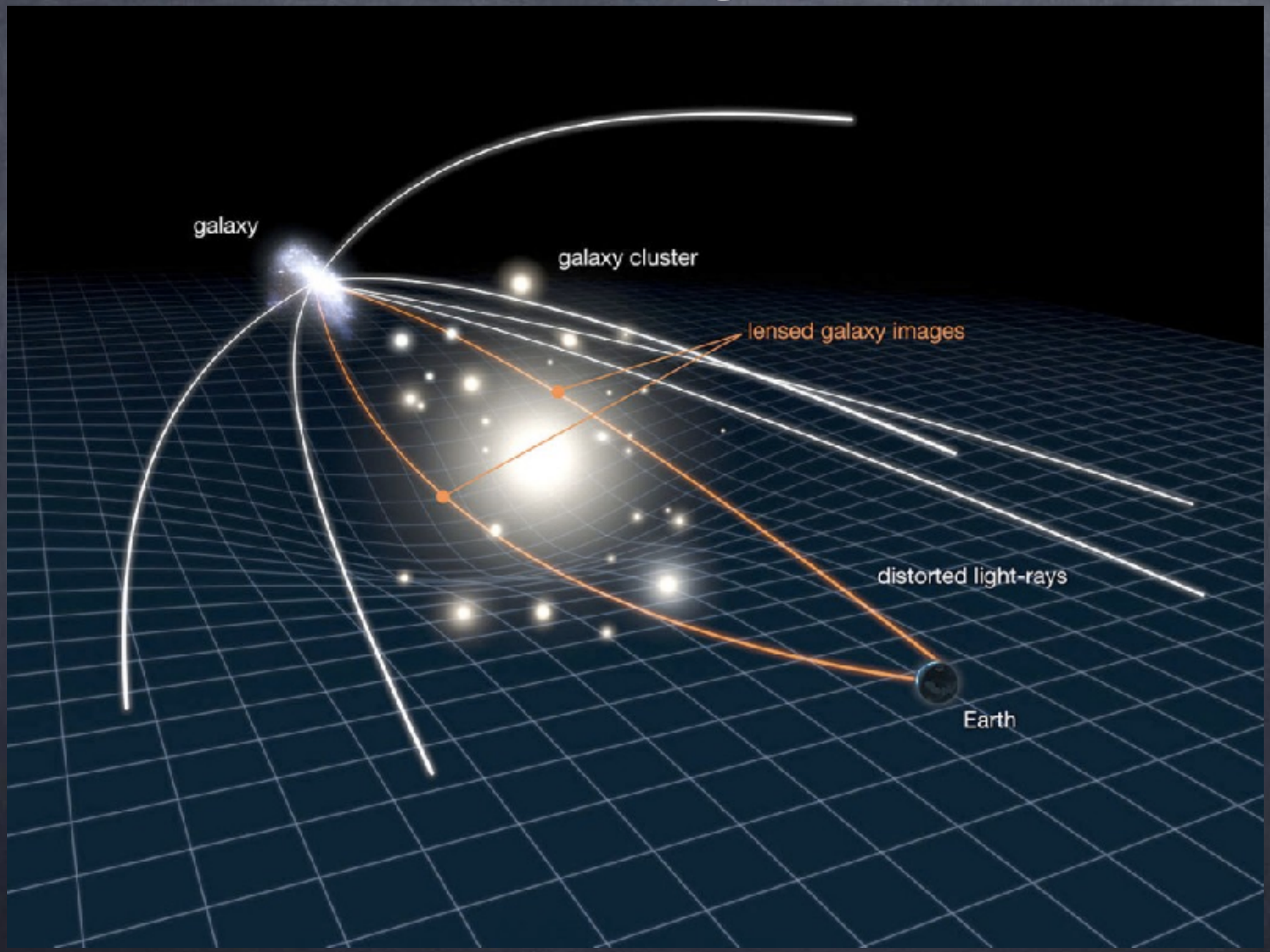
$$v(r) \sim \text{Constant}$$



Data

NOAO, AURA, NSF, T.A. Rector

Measuring Mass



(NASA/ESA)

Measuring Mass

Abell 2218; Johan Richard (HST; NASA/ESA)

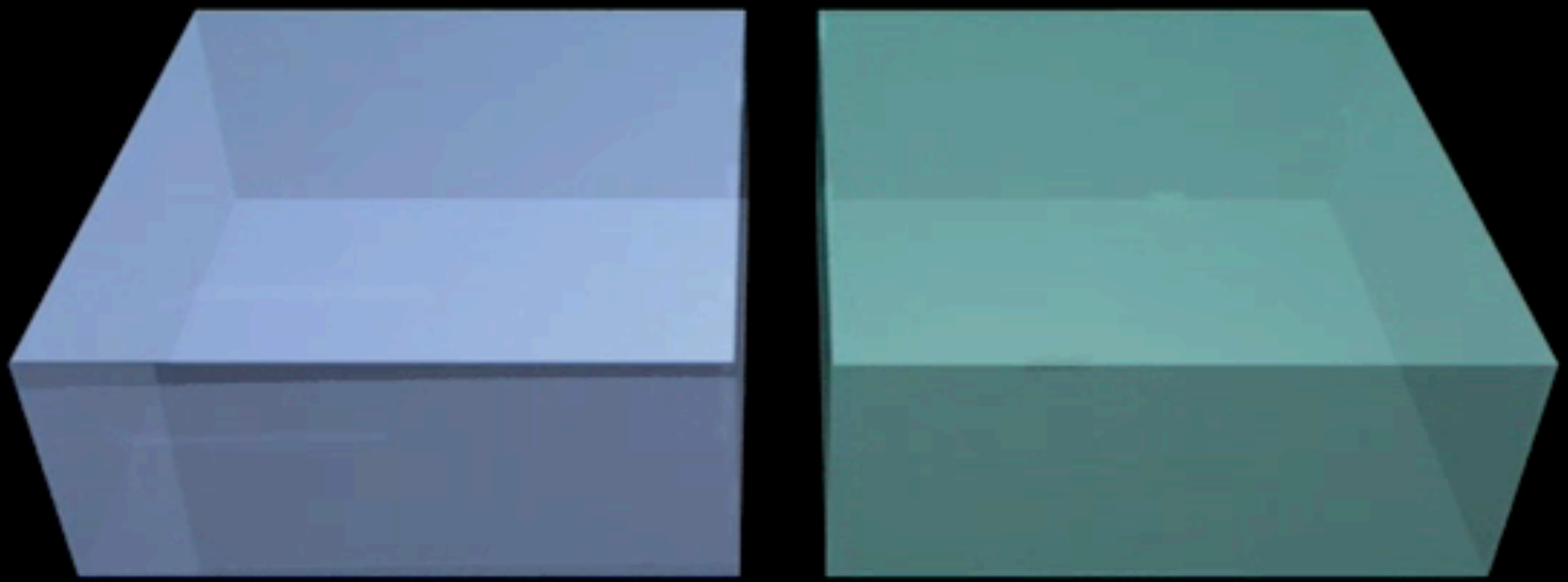
Measuring Mass

Total Matter
gravitational lensing

Visible Matter
x-ray emitting hot gas

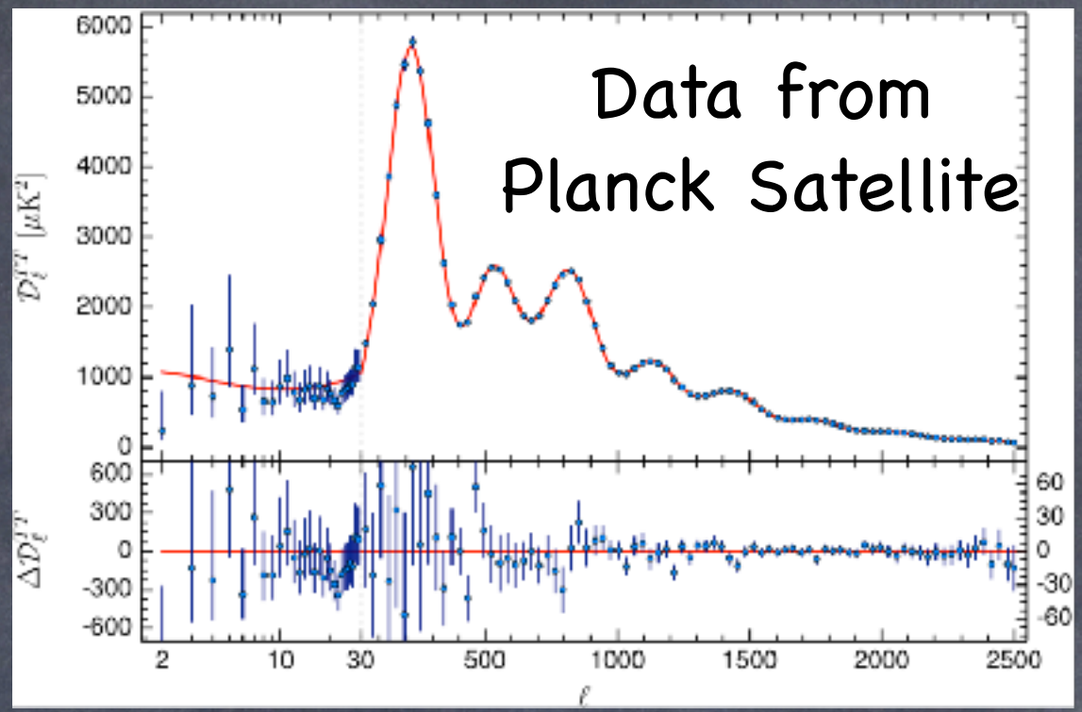
Most of the mass in clusters of galaxies is non-interacting

Bullet Cluster (Markevitch & Clowe, 2006)



https://map.gsfc.nasa.gov/media/030658/index.html

Measuring Mass

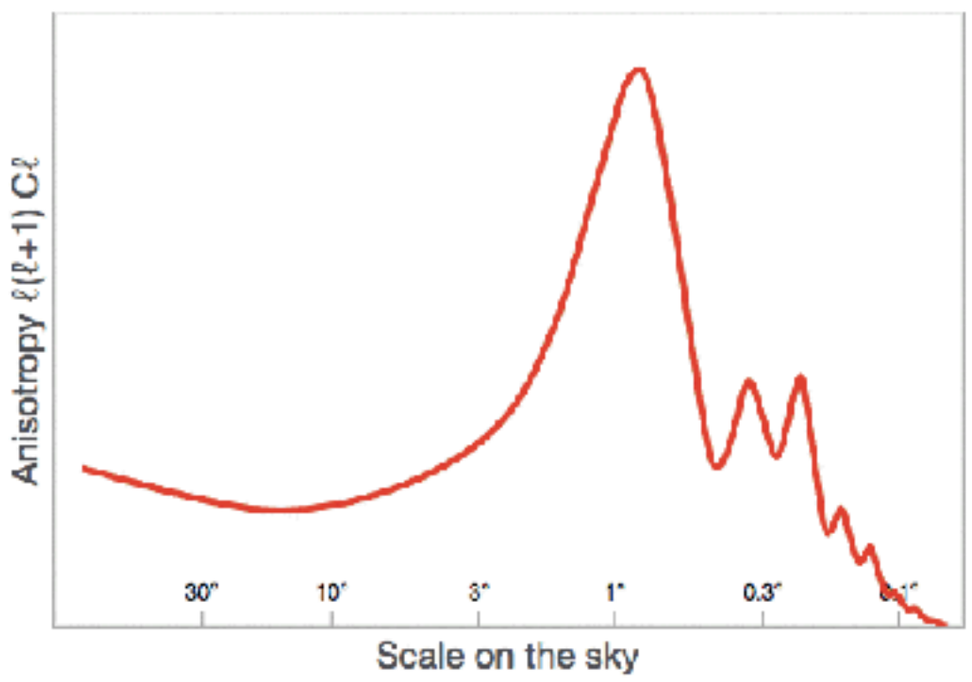


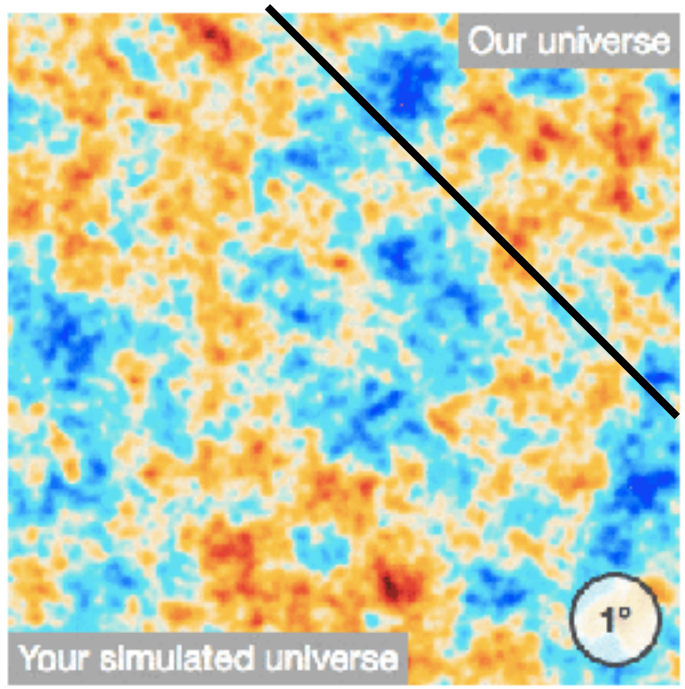
Simulation

Normal Matter (Ω_b = 0.05)

Dark Matter (Ω_c = 0.275)

Dark Energy (Ω_Λ = 0.675)

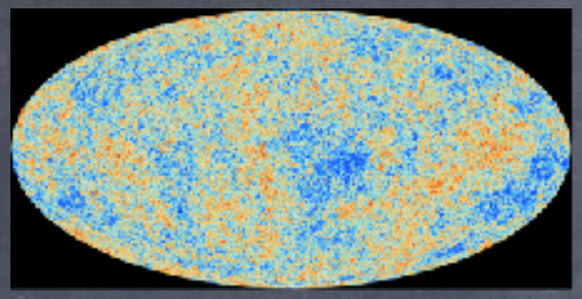




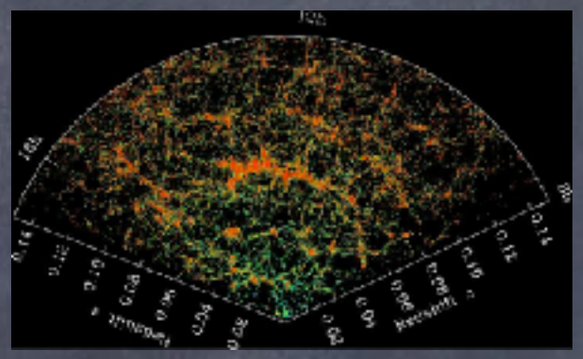
https://chrisnorth.github.io/planckapps/Simulator/

Composition of the Universe

Observable Universe



Clusters of Clusters



Clusters of Galaxies

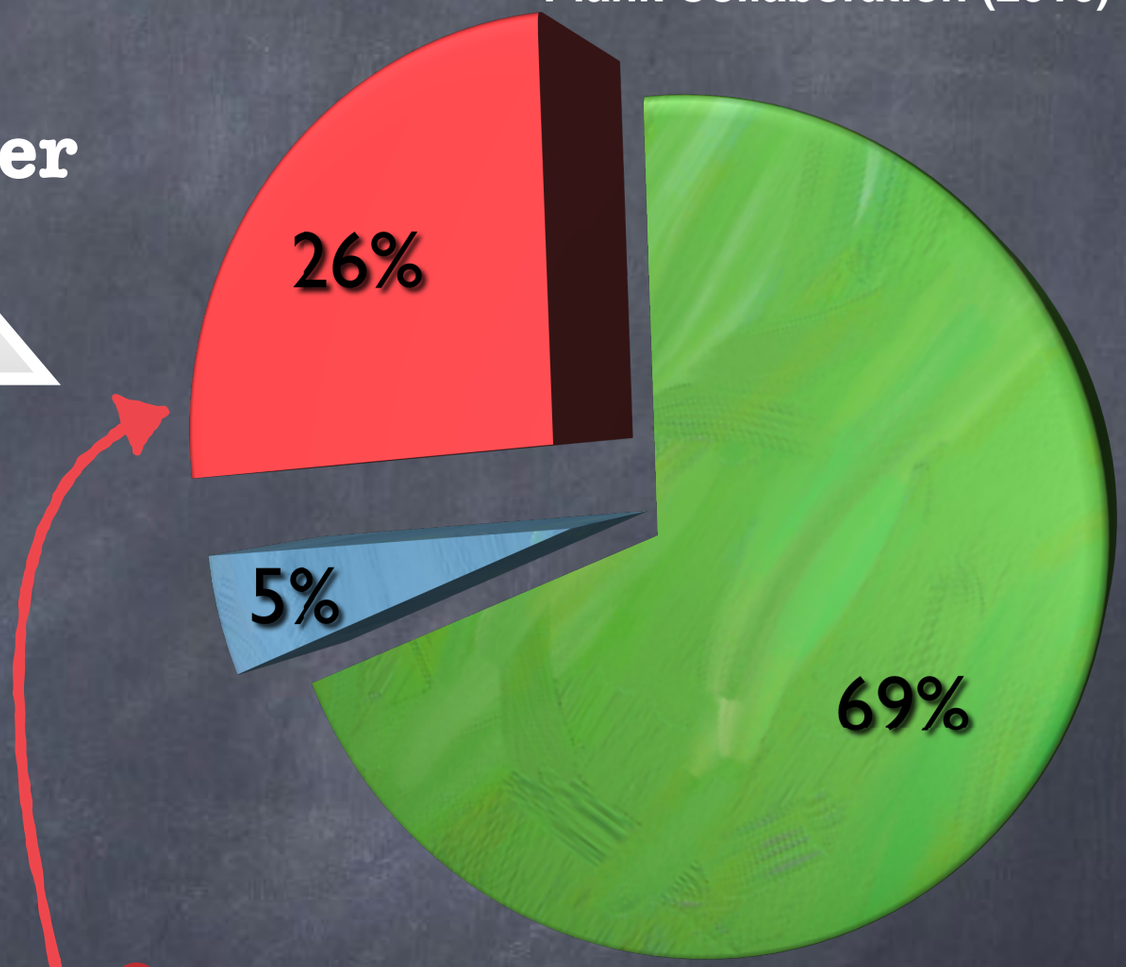
Individual Galaxies

Larger

Dark Matter

Smaller

Plank Collaboration (2016)



DARK MATTER
DARK ENERGY
ORDINARY MATTER

Topic of current KITP program

Questions?

Simulating the Universe

Simulation: Wu, Hahn, Wechsler
Visualization: Kaehler

Dark matter shown as bright pixels!

The Milky Way

z=0.0

Simulation of the Dark Matter Halo

The Milky Way

80 kpc

Diemand et al. (2007)

Jargon: A dark matter "halo" is a gravitationally bound clump of dark matter

The standard model of cosmology predicts that there should be many* small galaxies around our Milky Way

* The quantitative value of "many" has been hotly debated over the last several decades (including the last several weeks...)

Milky Way

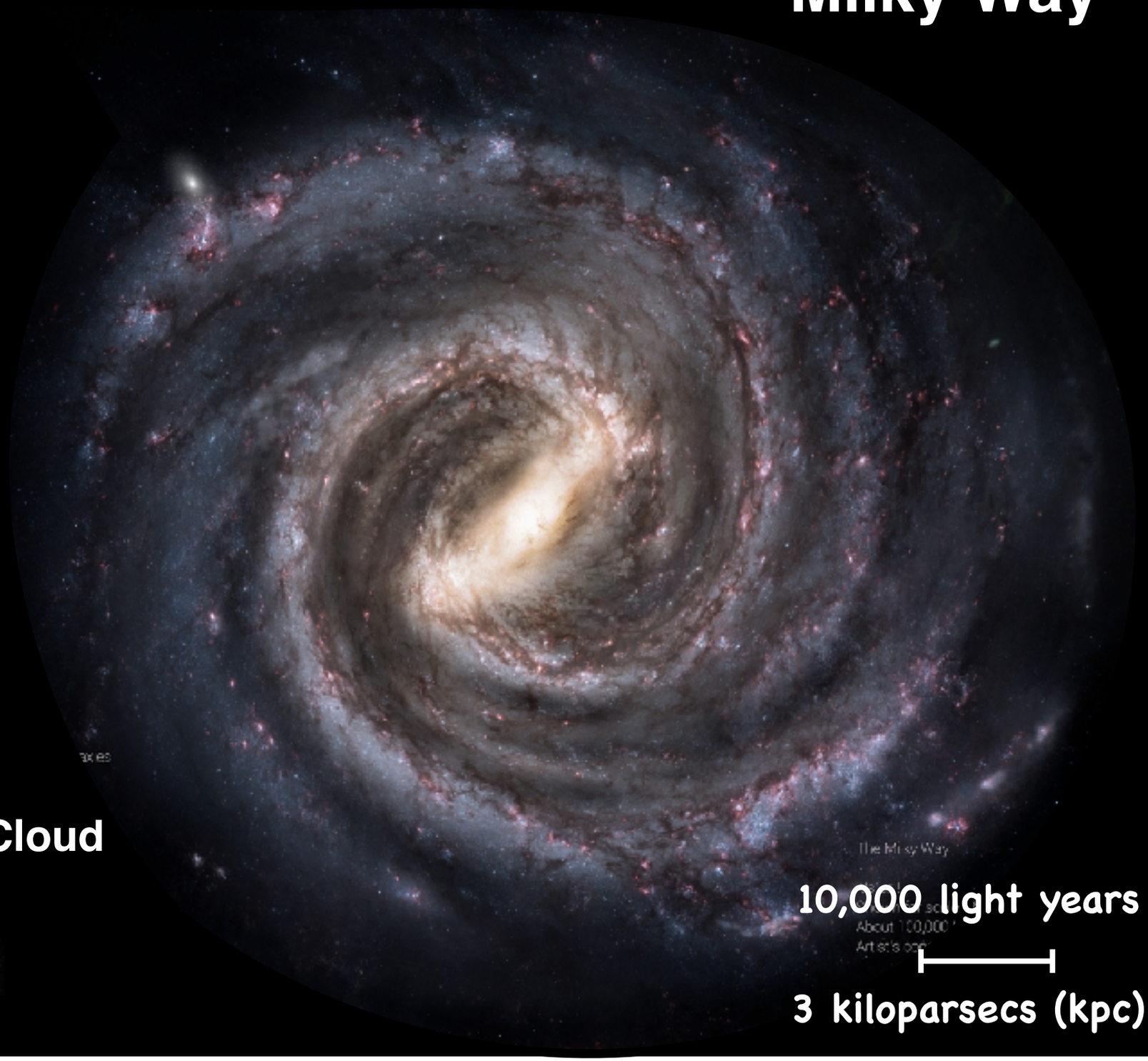
Large Magellanic Cloud
(LMC)

Small Magellanic Cloud
(SMC)

Naked Eye Visible

Large Magellanic Cloud
(LMC)

Milky Way



Small Magellanic Cloud
(SMC)

10,000 light years

3 kiloparsecs (kpc)

z=0.0

Simulation of the Dark Matter Halo

The Milky Way

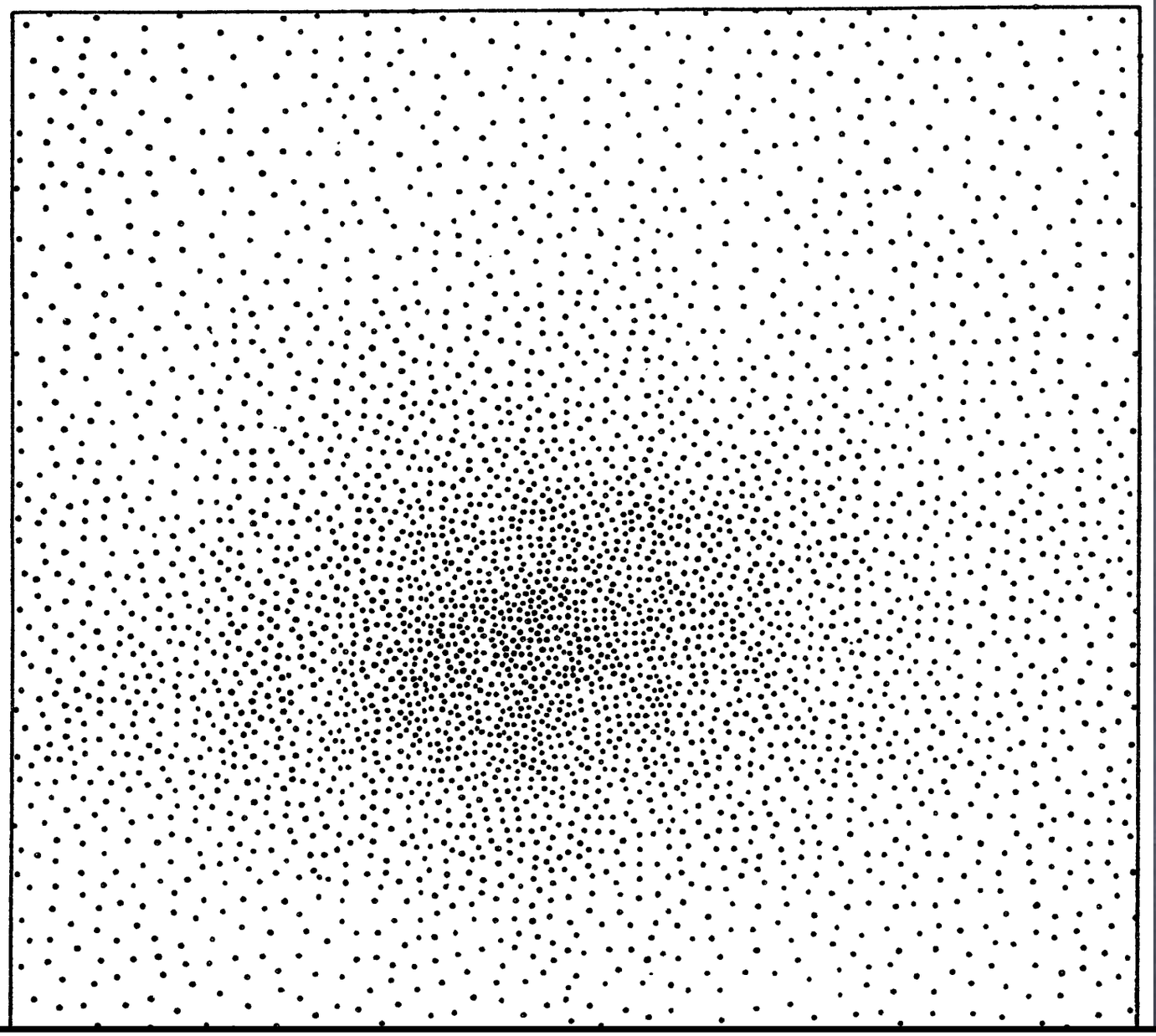
???

Large Magellanic Cloud (LMC)

80 kpc

Diemand et al. (2007)

Sculptor Dwarf Galaxy



Harlow Shapley

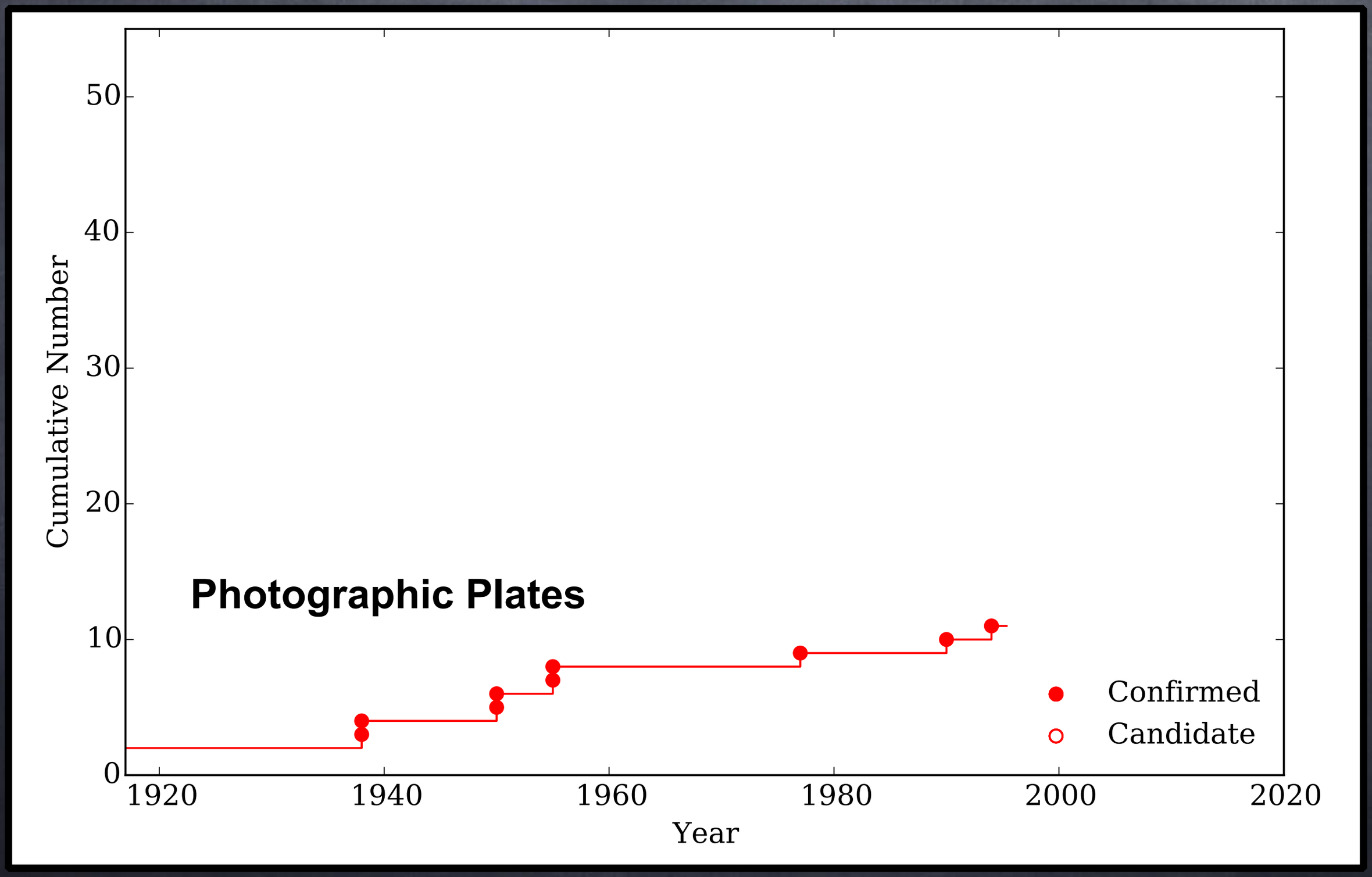
March 1, 1938

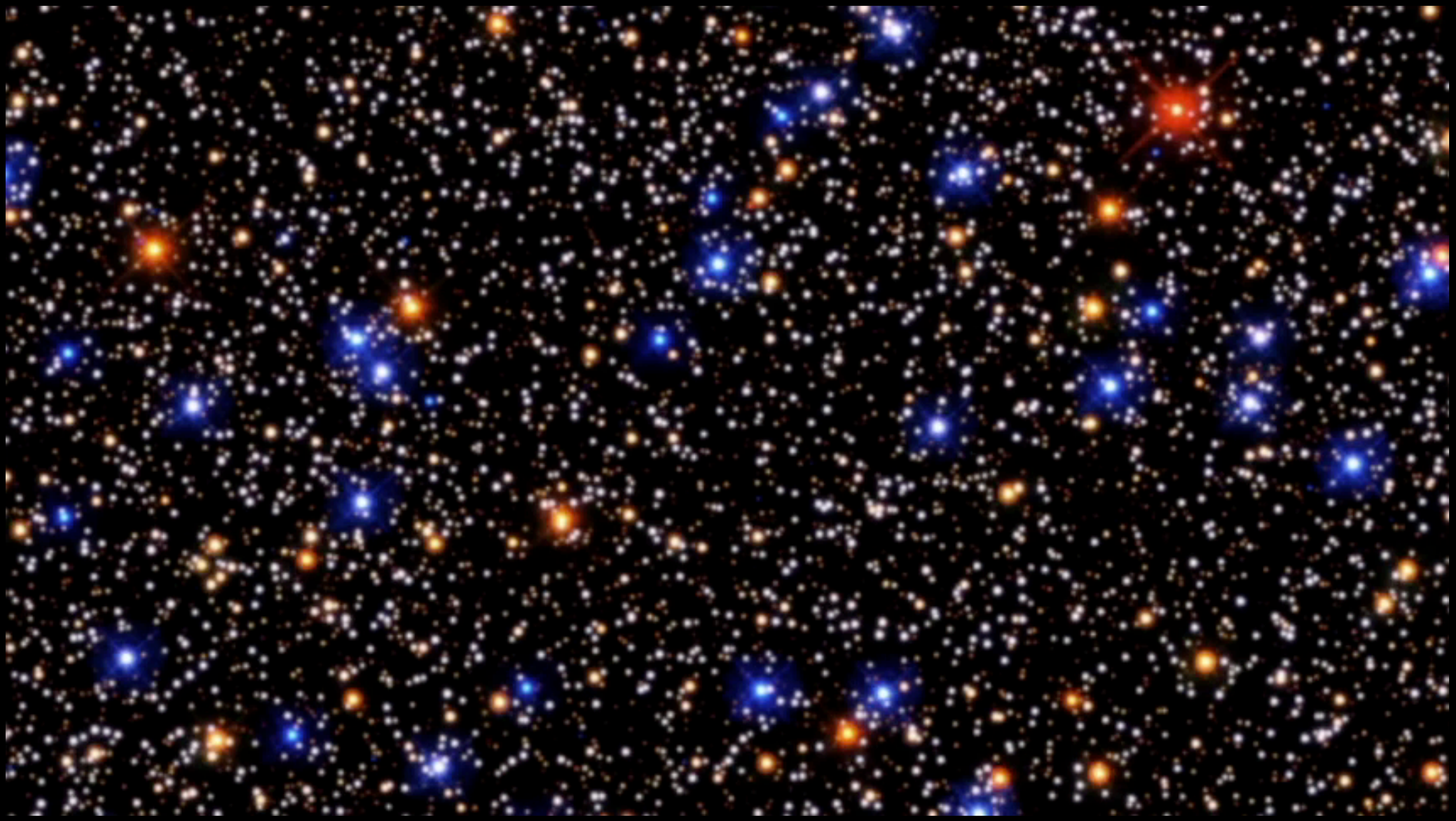
A Stellar System of a New Type. — A large rich cluster with remarkable characteristics appears on photographs received from the Boyden Station. Since nothing quite like it is now known, a detailed though preliminary description is given in the following pages.

Sculptor Dwarf Galaxy

1.2m Telescope
Photographic Plates

Dwarf Galaxy Discovery Timeline





Credit: NASA, ESA, Anderson & van der Marel (STScI)

https://www.spacetelescope.org/videos/heic1017b/

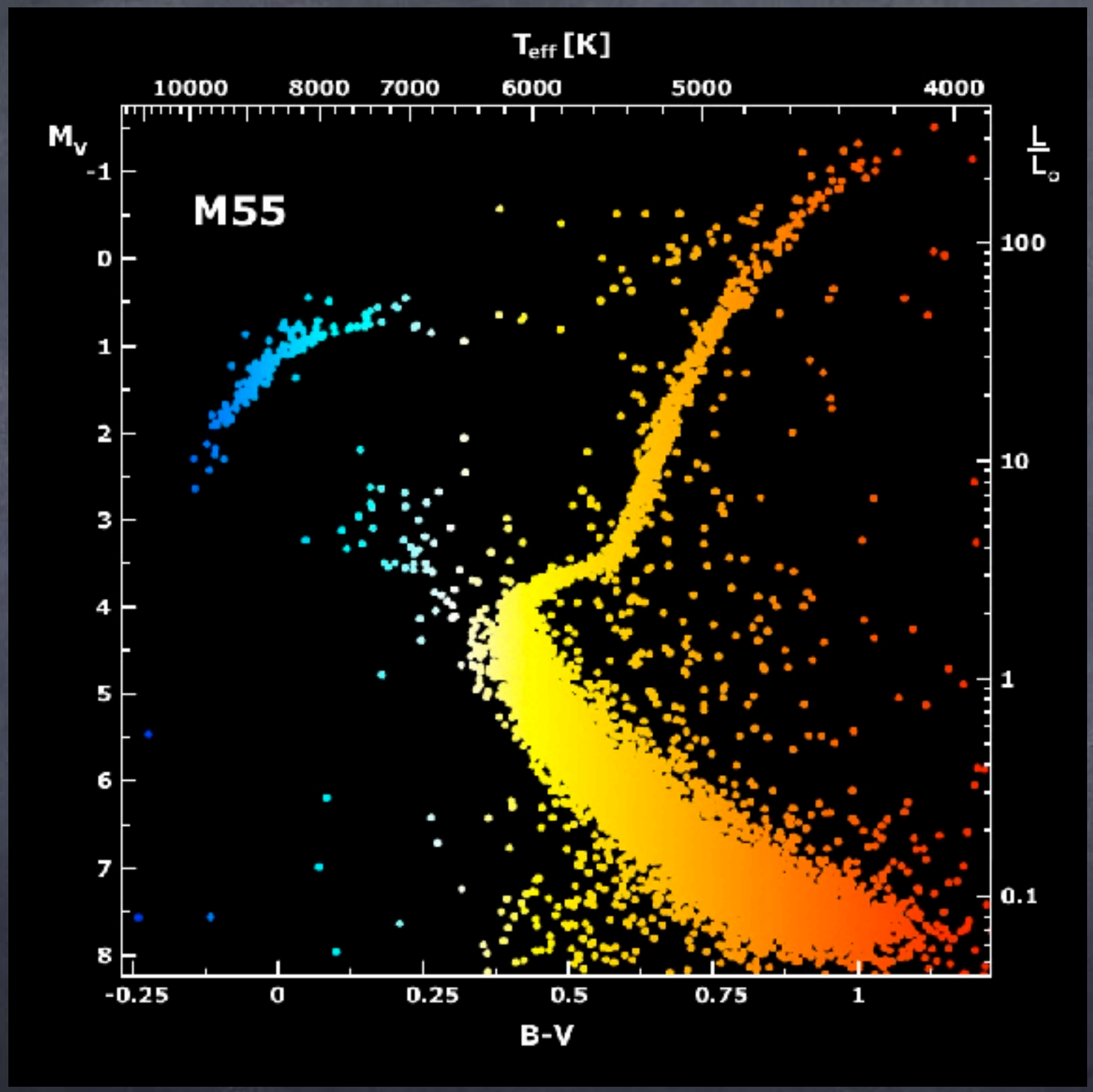
Temperature

Hotter ⟷ Cooler

Magnitude

Brighter ↑

Fainter ↓



Luminosity

Brighter ↑

Fainter ↓

Color

Bluer ⟷ Redder

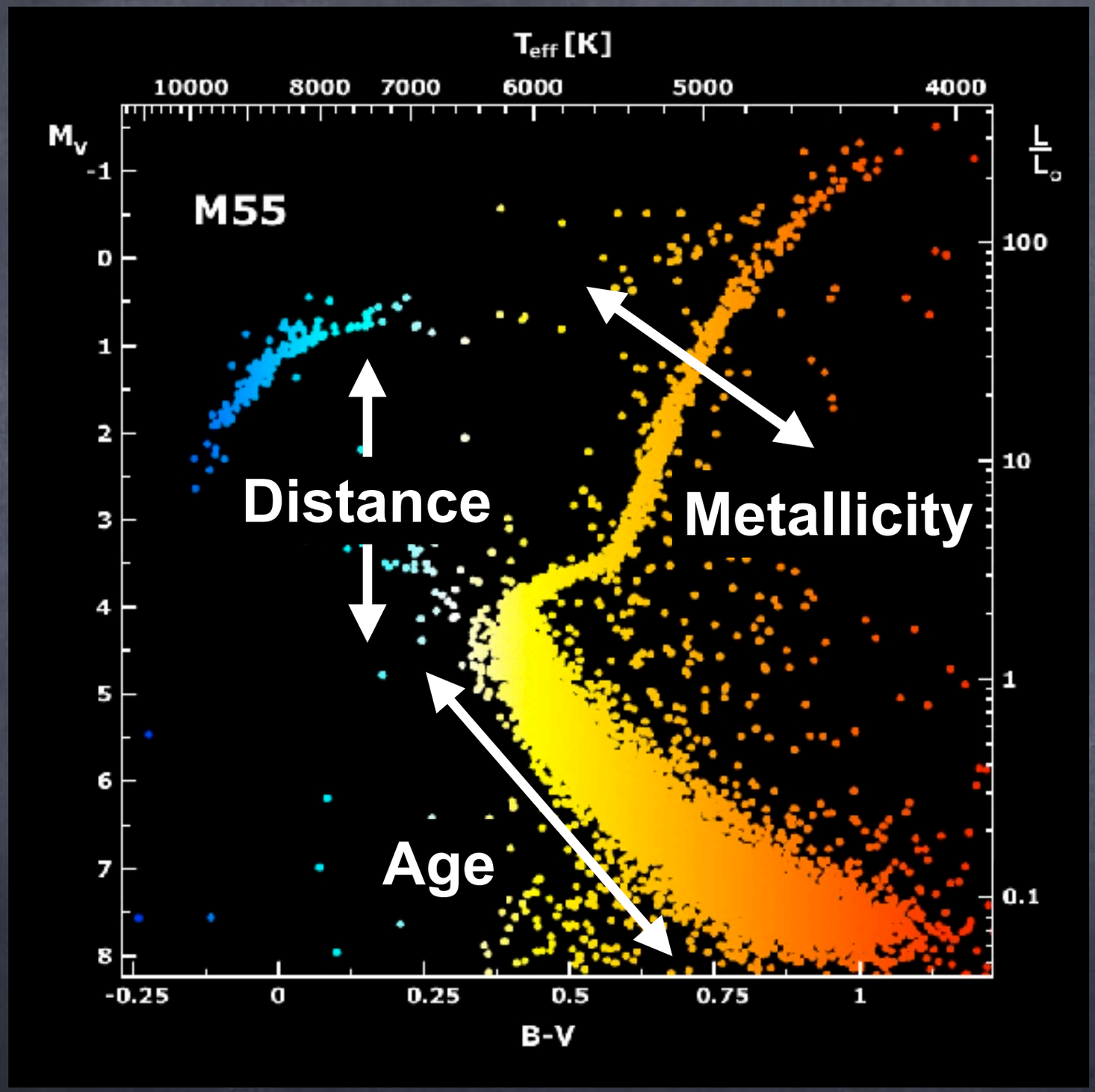
Temperature

Hotter ⟷ Cooler

Magnitude

Brighter ↑

Fainter ↓



Luminosity

Brighter ↑

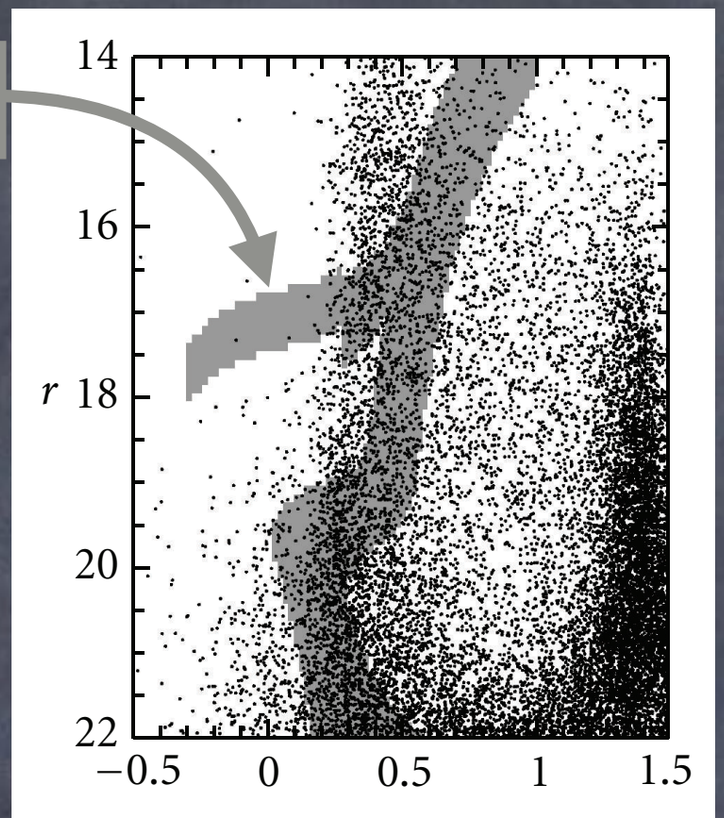
Fainter ↓

Color

Bluer ⟷ Redder

Matched Filter Searches

Stellar Isochrone

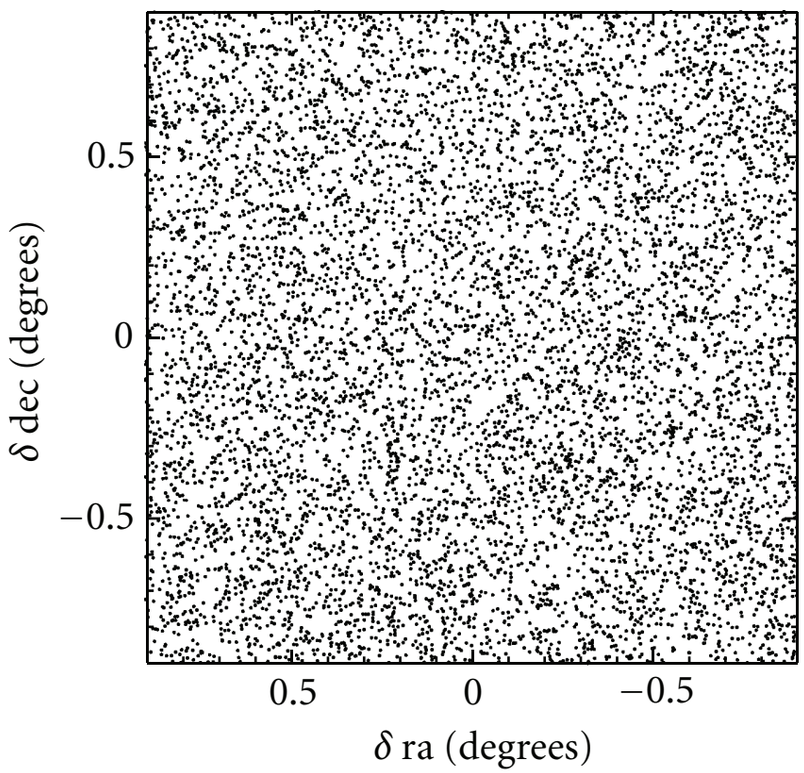


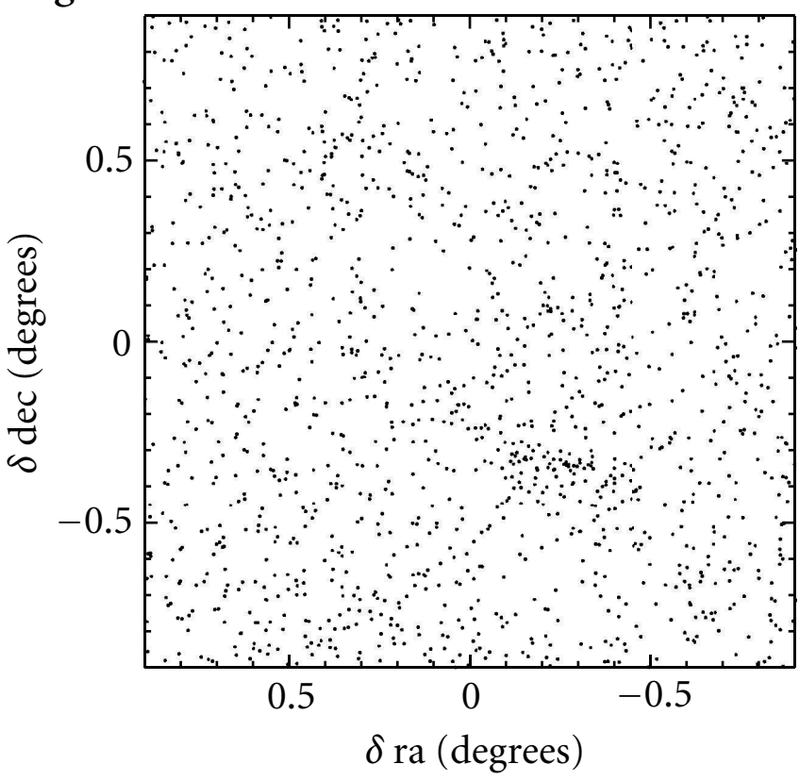
1) Start with a large catalog of stars

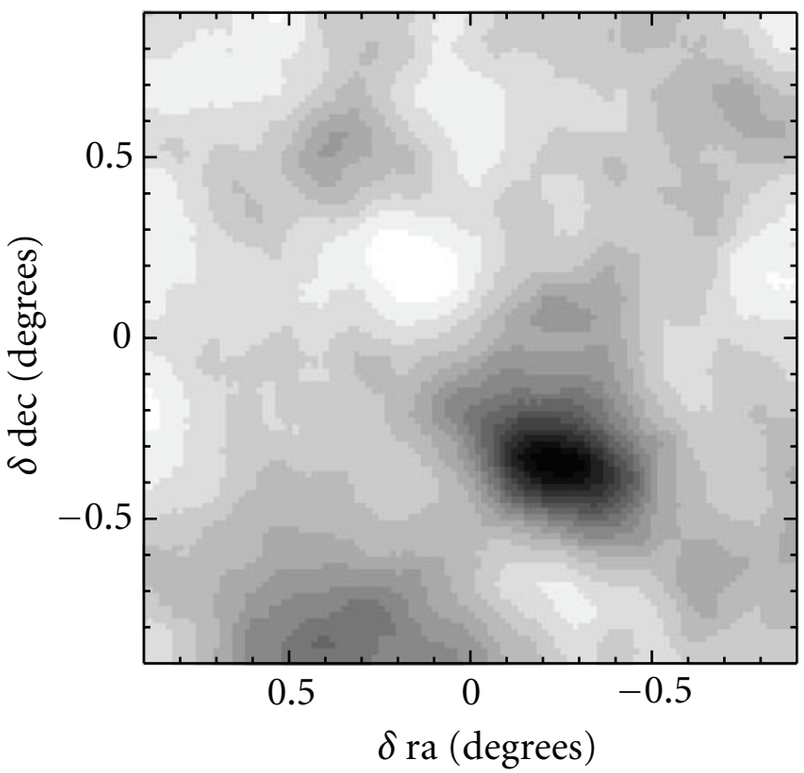
2) Apply a selection in color-magnitude space based on a stellar isochrone

3) Convolve with a spatial kernel

Koposov et al. (2008)
Walsh et al. (2009)
Willman et al. (2010)



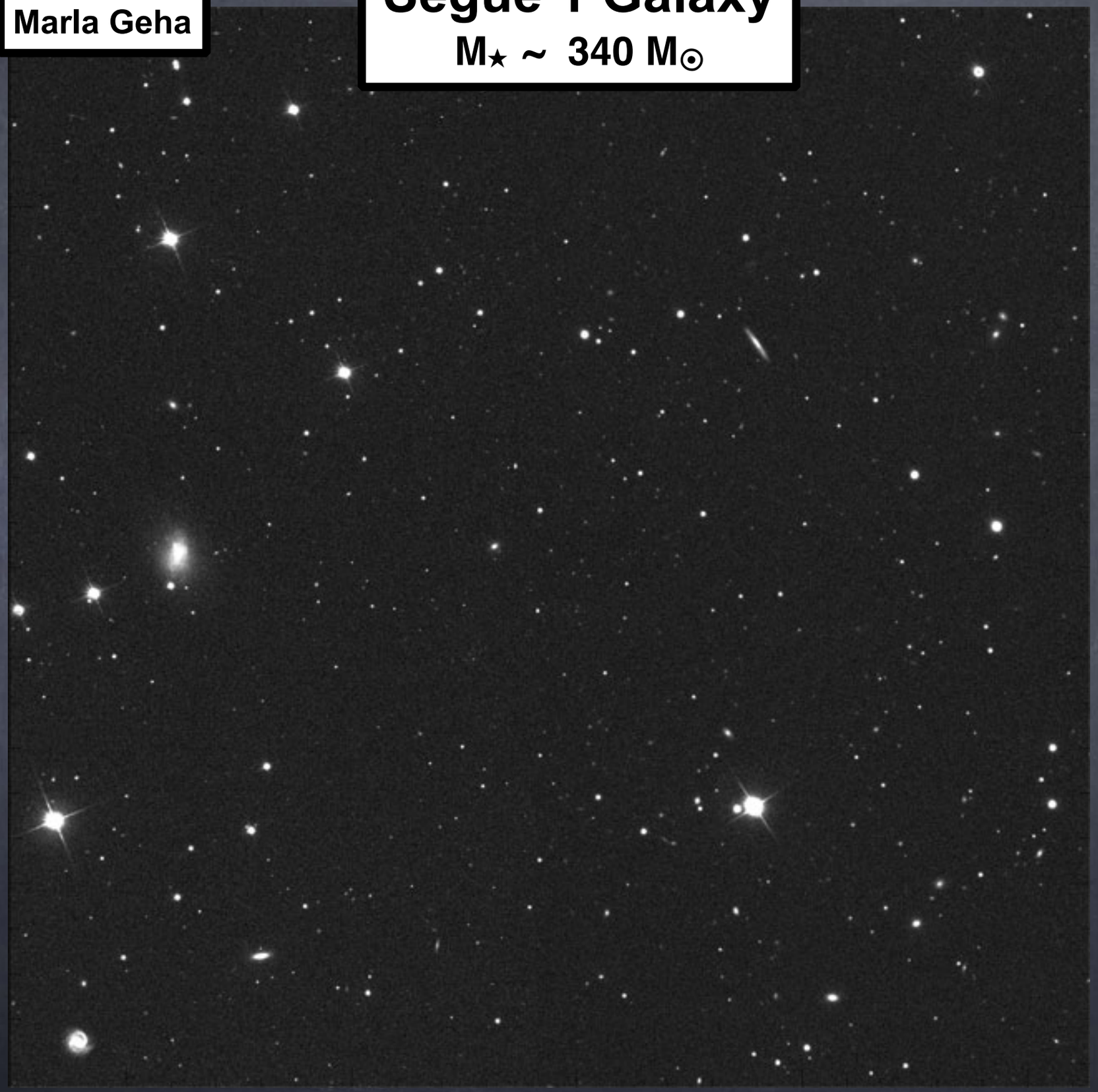




Marla Geha

Segue 1 Galaxy

$M_\star \sim 340\ M_\odot$



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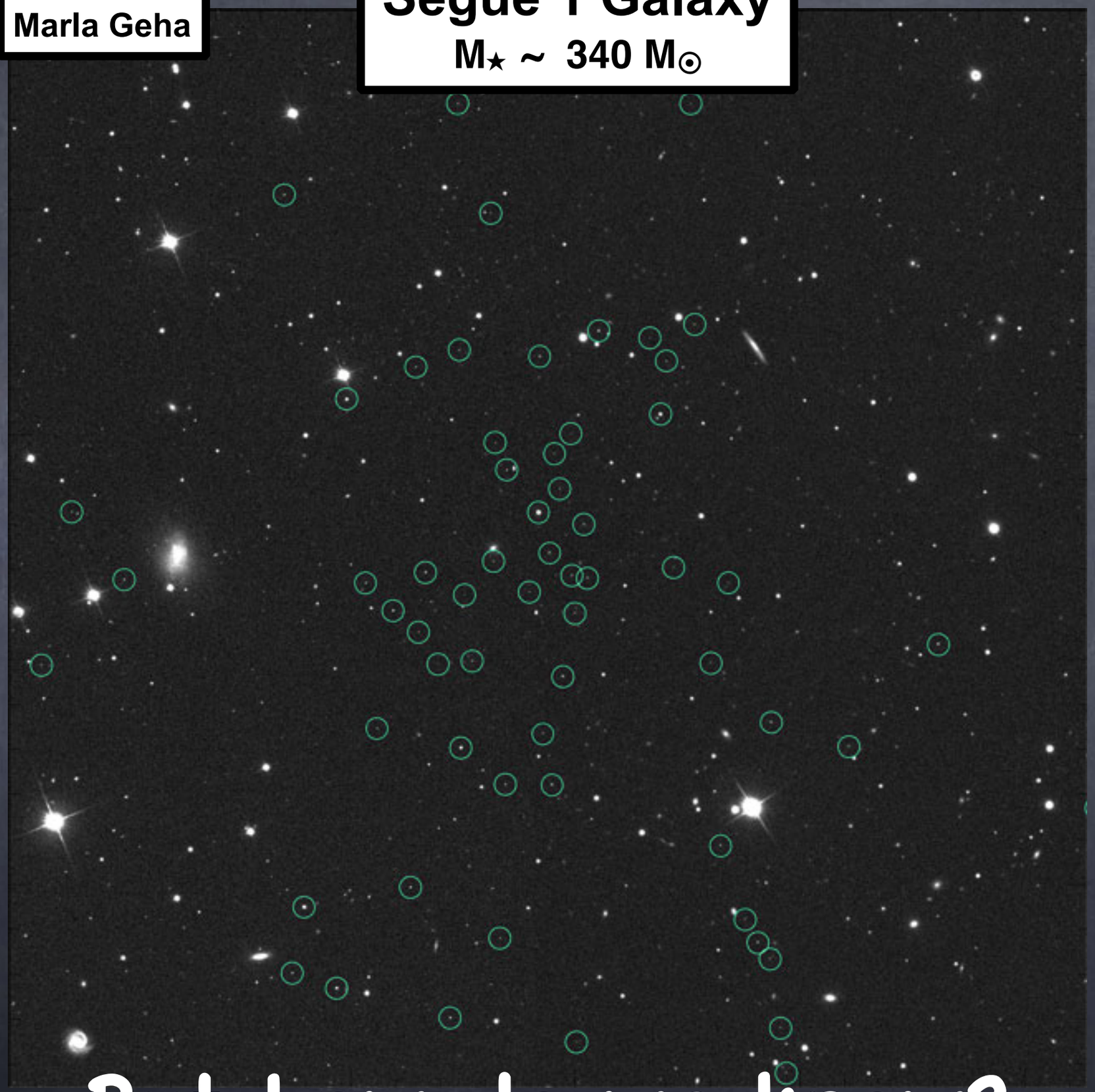
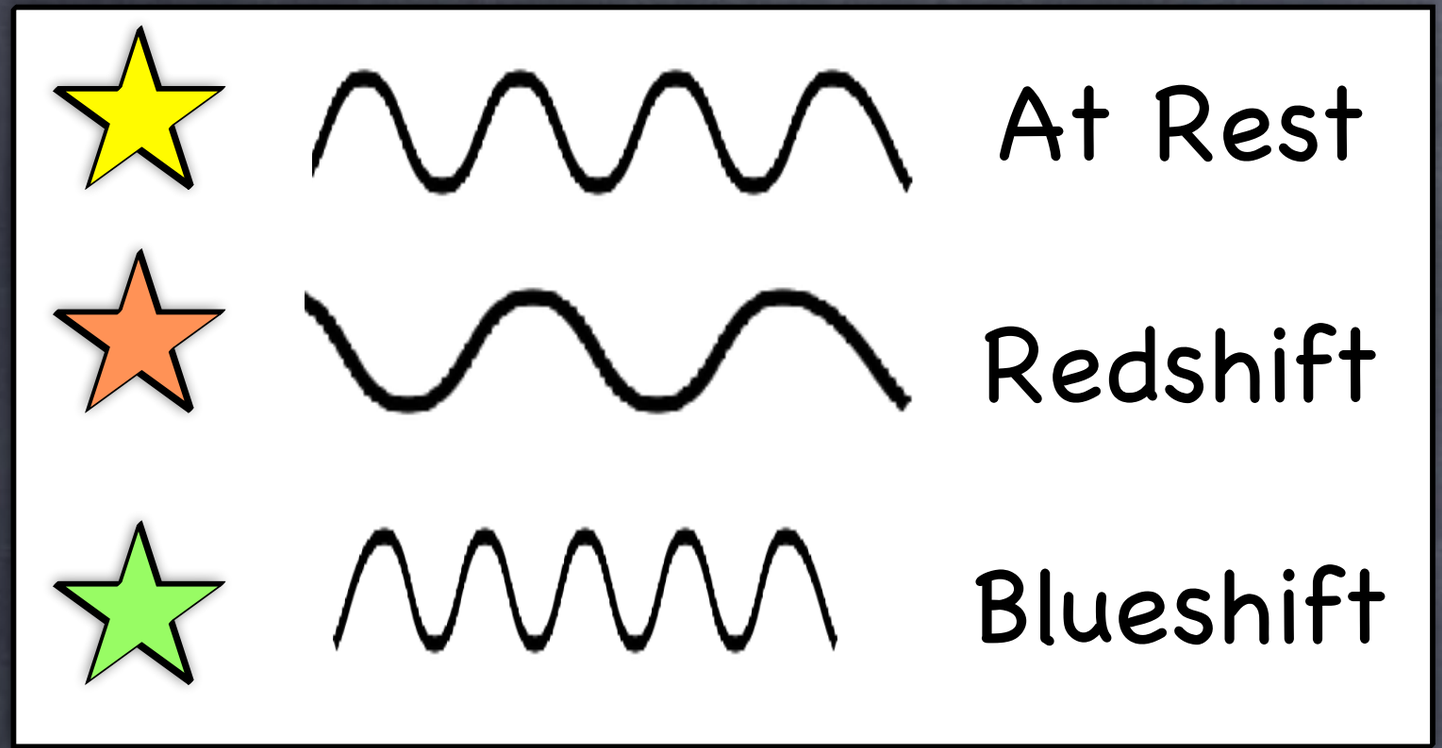
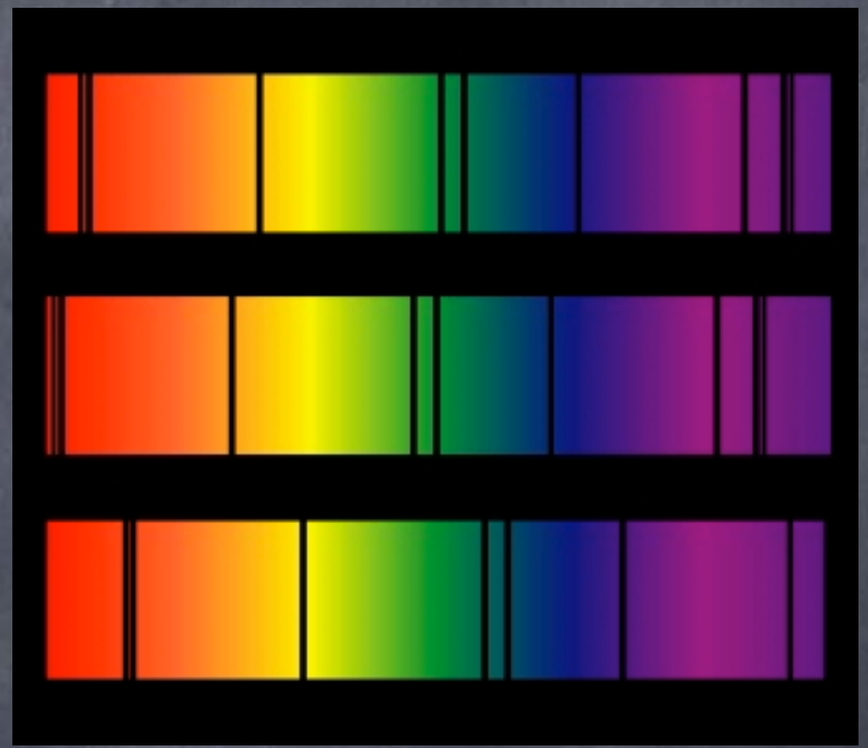
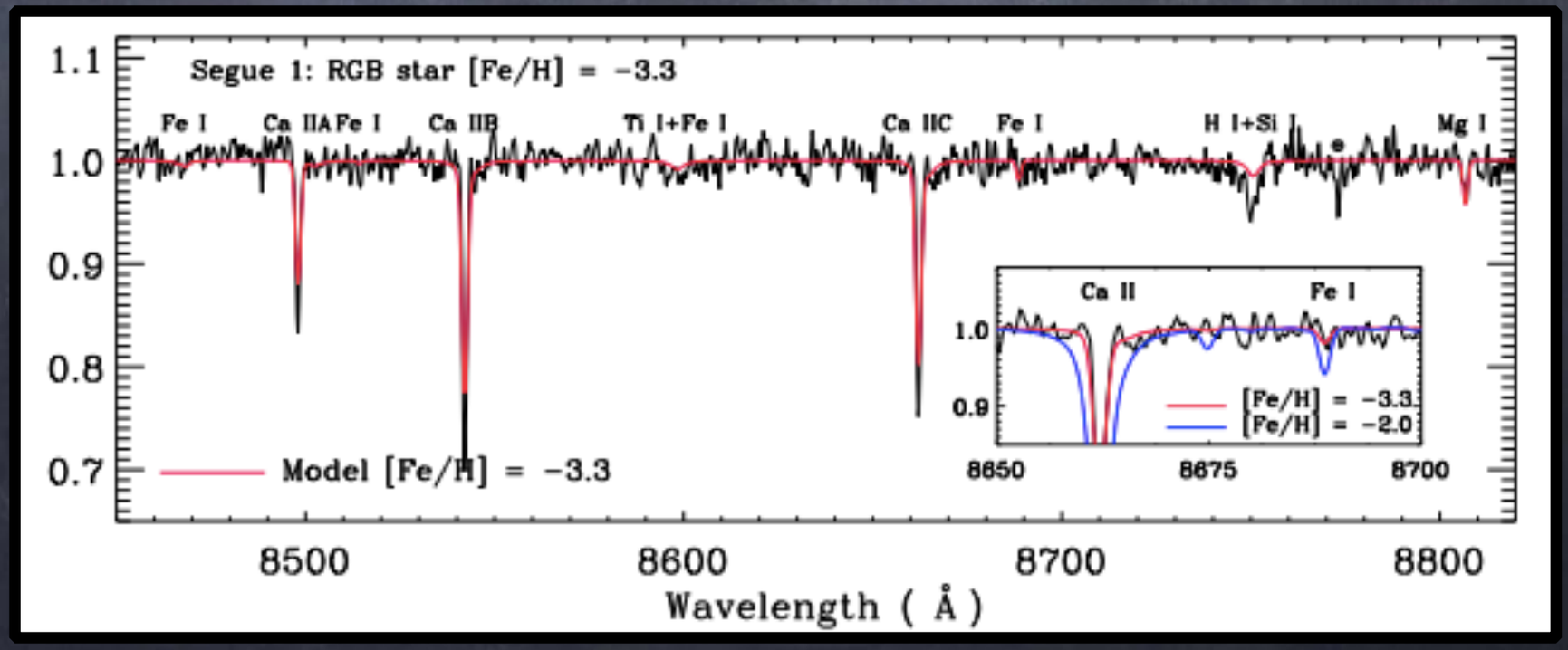


But how do we know?

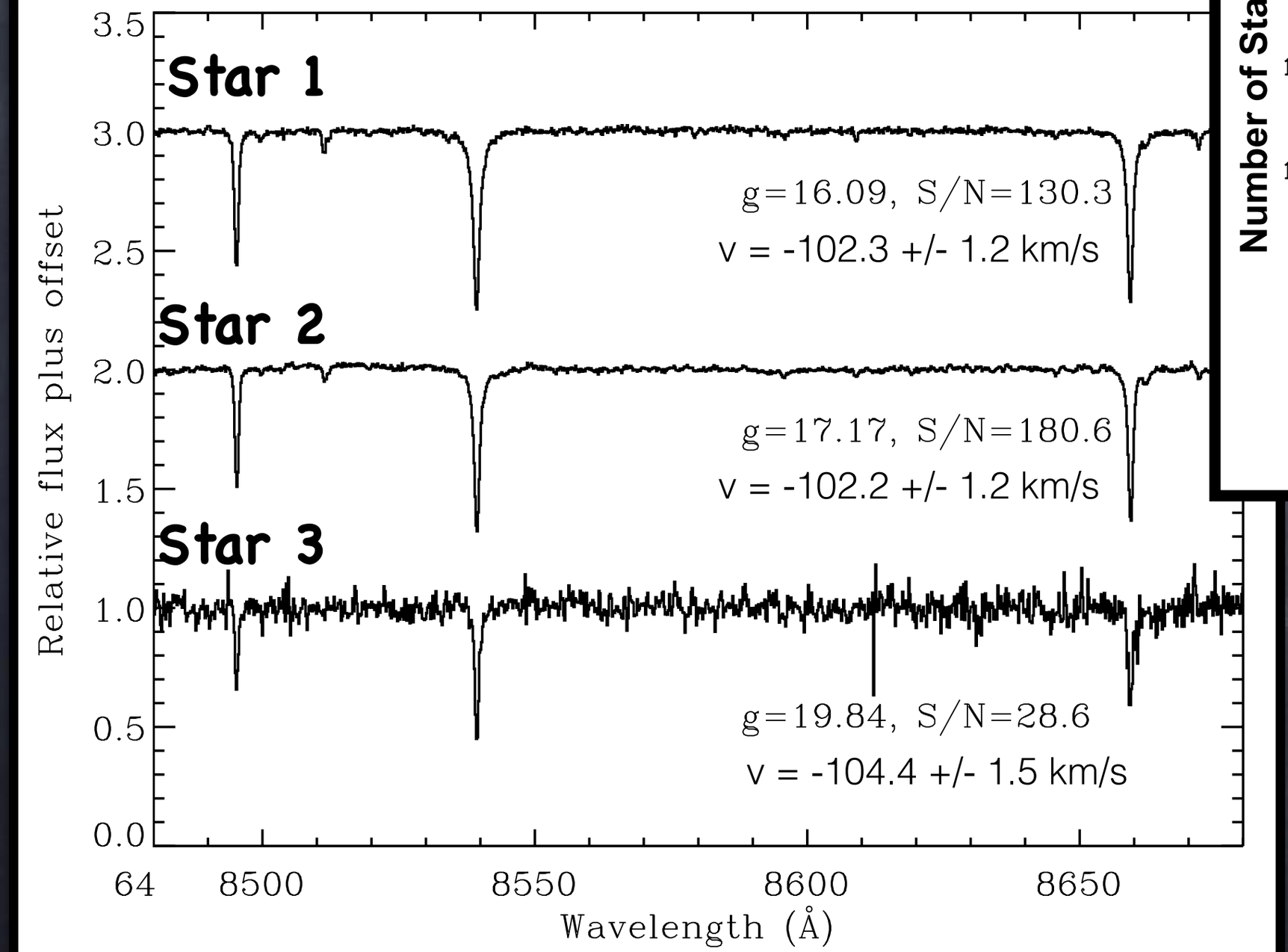
Measuring Velocities

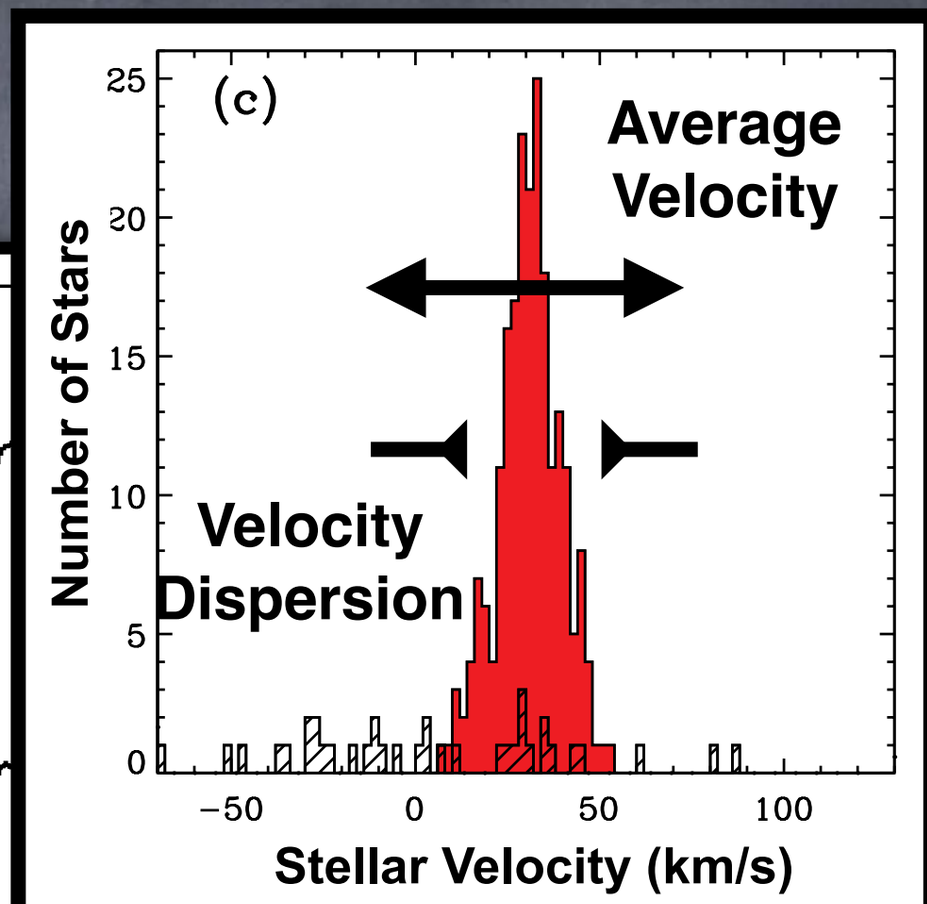




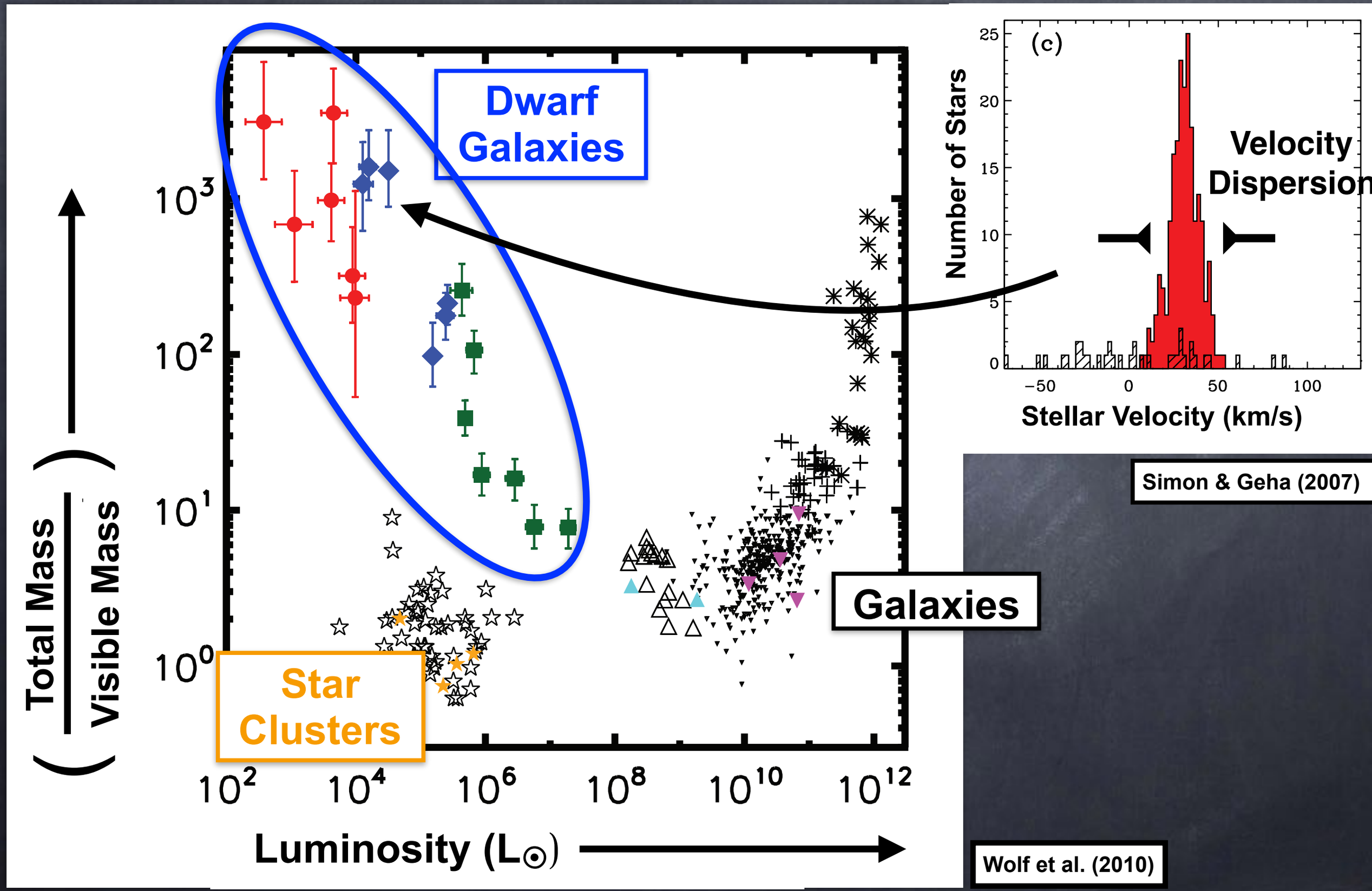


Measuring Velocities





"Galaxy" Defined

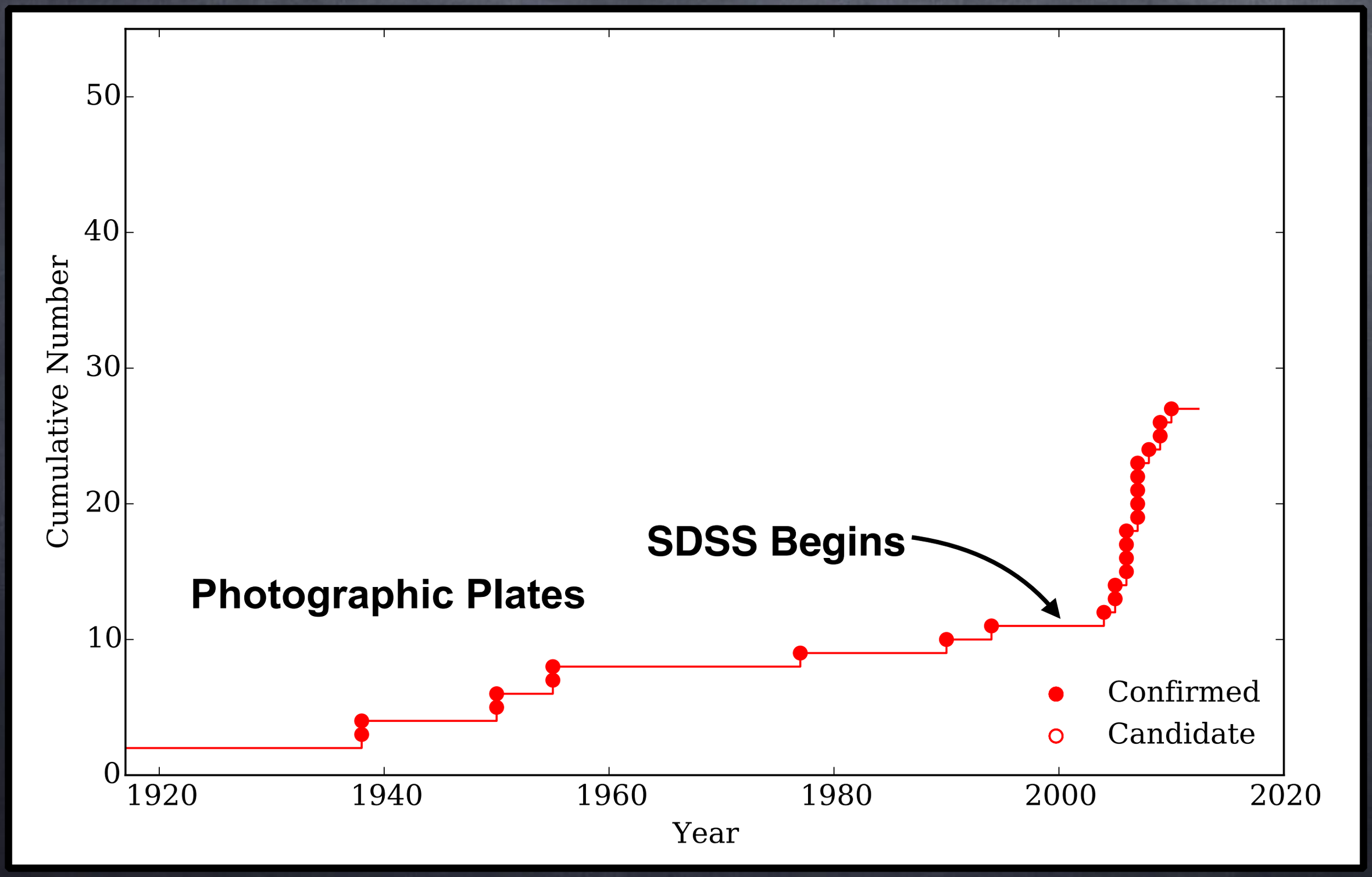


"Galaxy" Defined

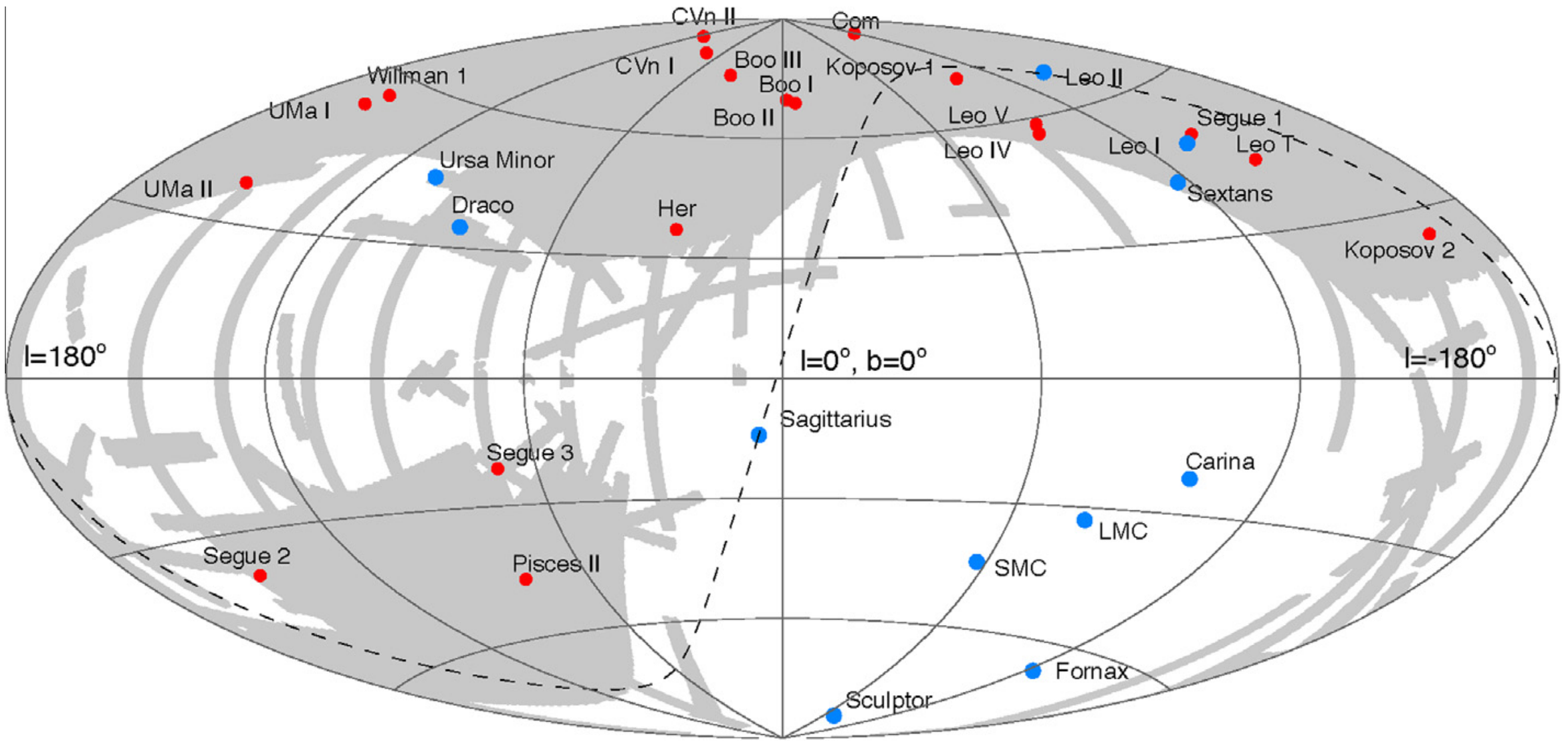
"A galaxy is a gravitationally bound collection of stars whose properties cannot be explained by a combination of baryons and Newton's laws of gravity"

Willman & Strader (2012)

Dwarf Galaxy Discovery Timeline



Dwarf Galaxy Discovery Map



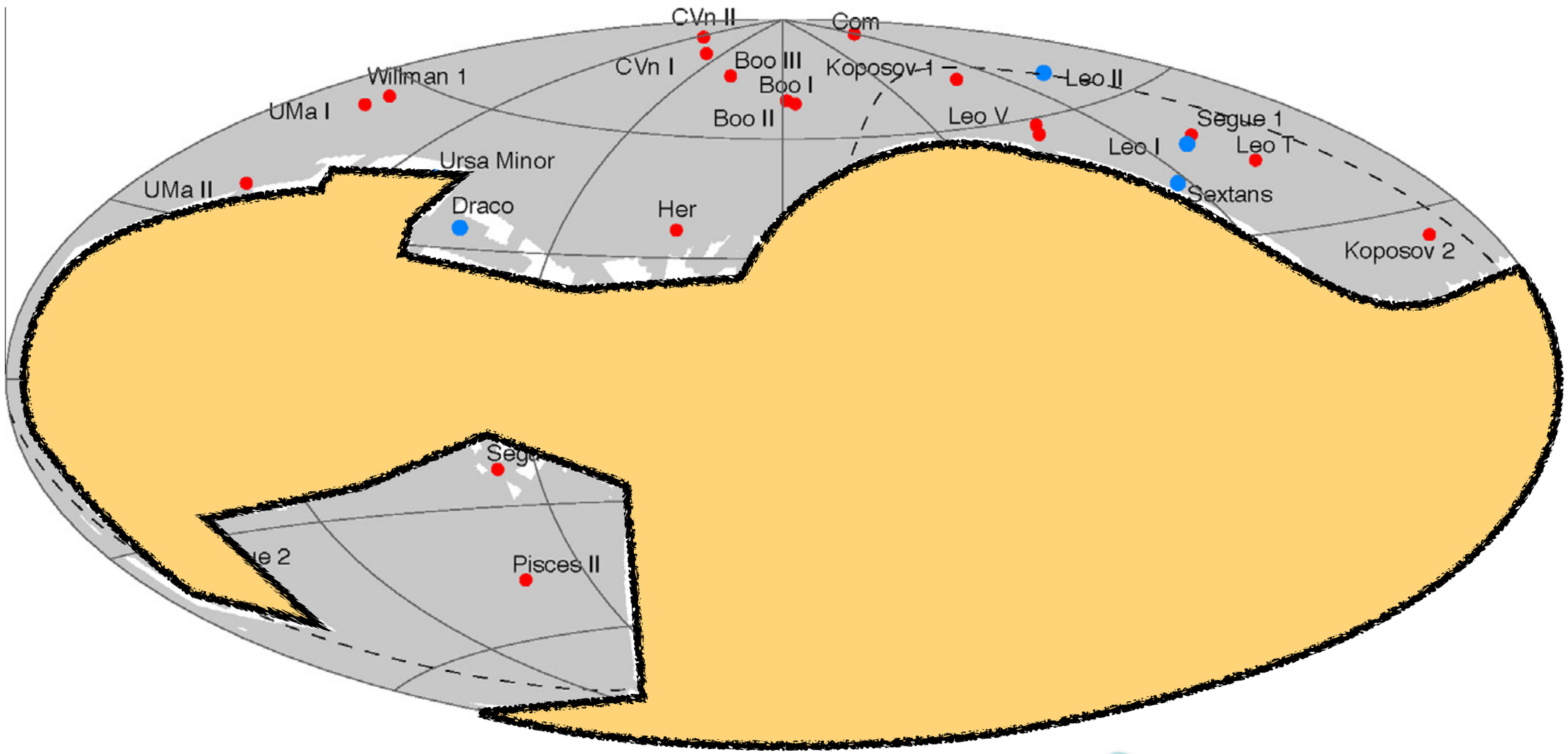
Sky Covered by SDSS

Discovered before SDSS (classical dwarfs)

Discovered with SDSS (ultra-faint dwarfs)

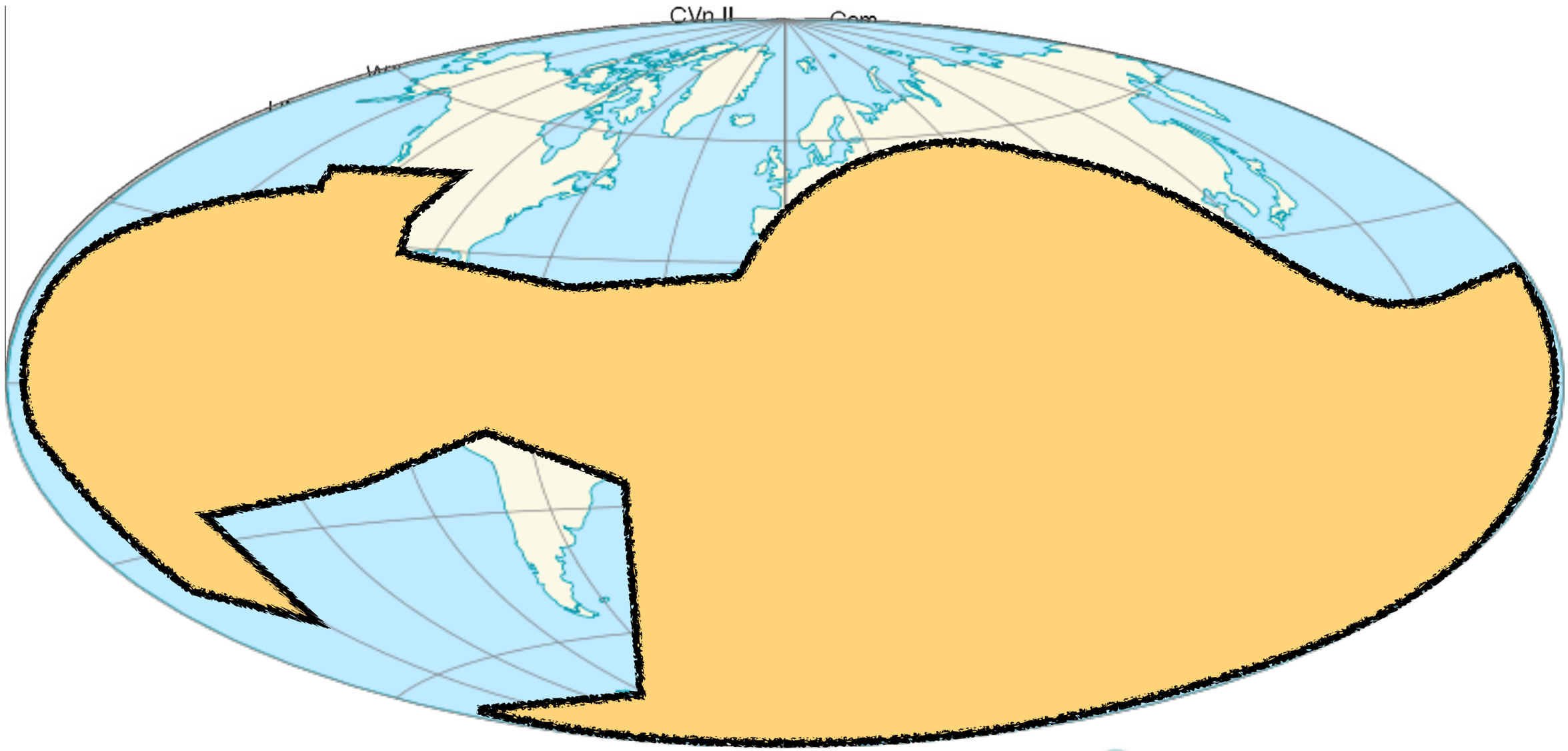
(Belokurov 2013)

Dwarf Galaxy Discovery Map



(Belokurov 2013)

Dwarf Galaxy Discovery Map



Sky Covered by SDSS
Uncovered Sky

Discovered before SDSS (classical dwarfs)
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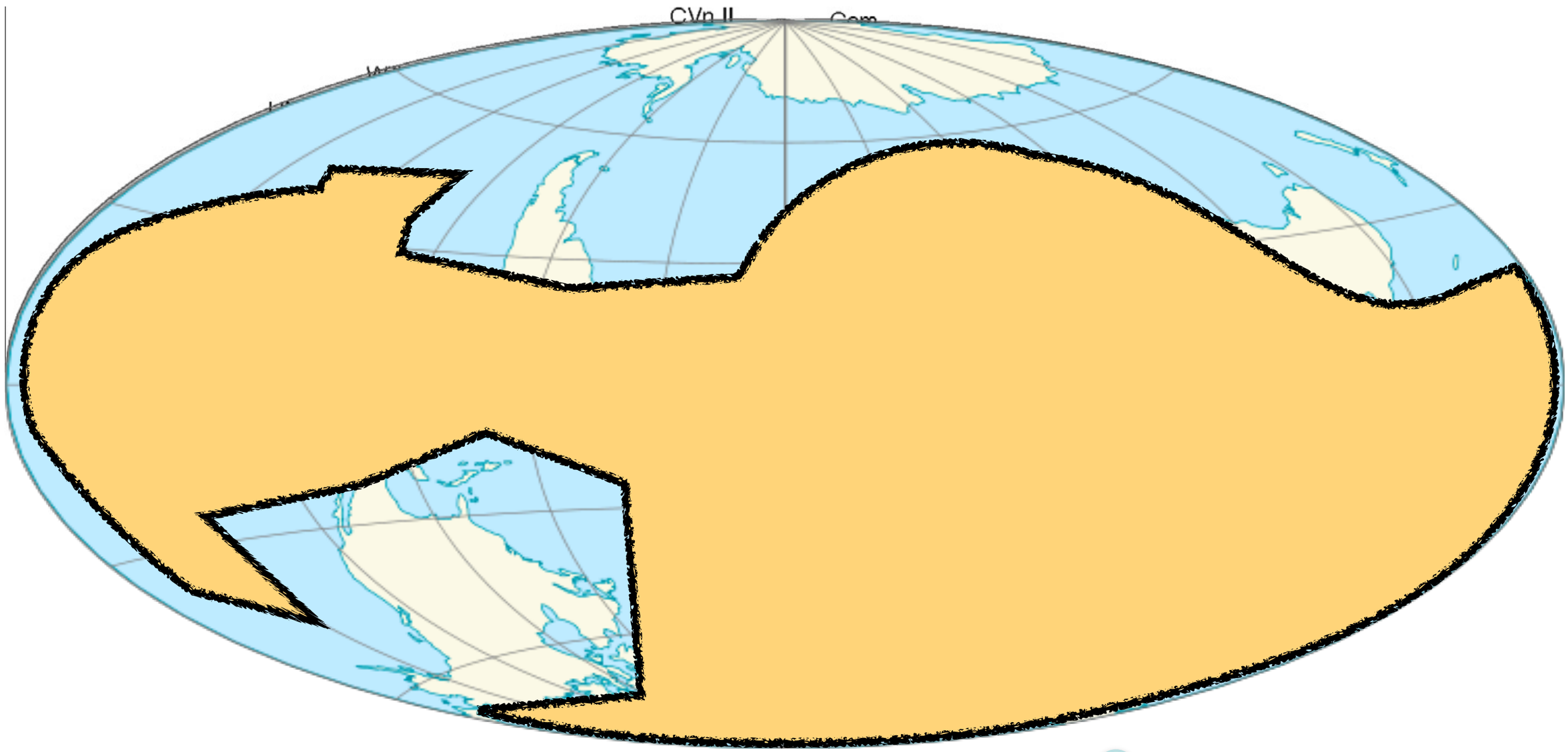
Dwarf Galaxy Discovery Map



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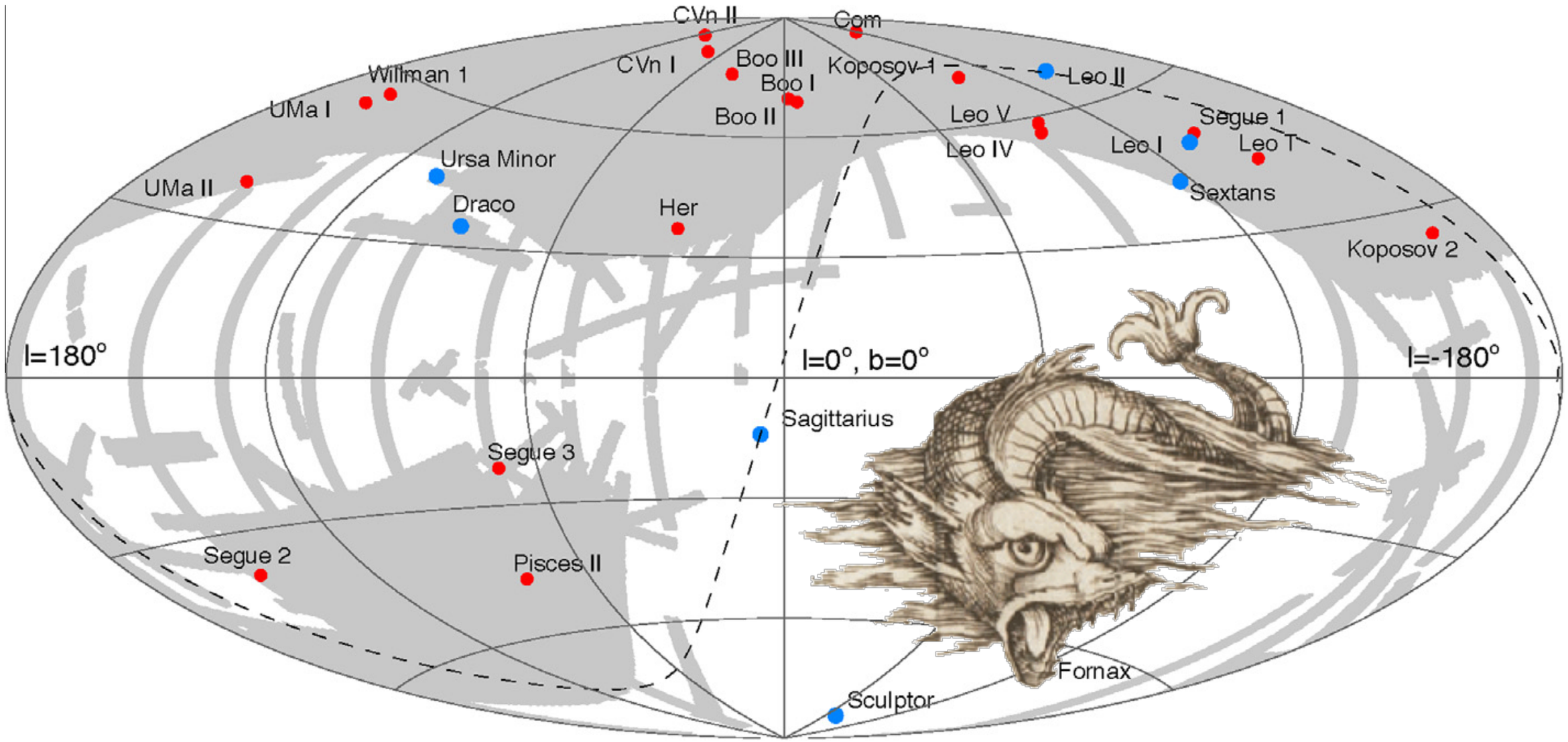

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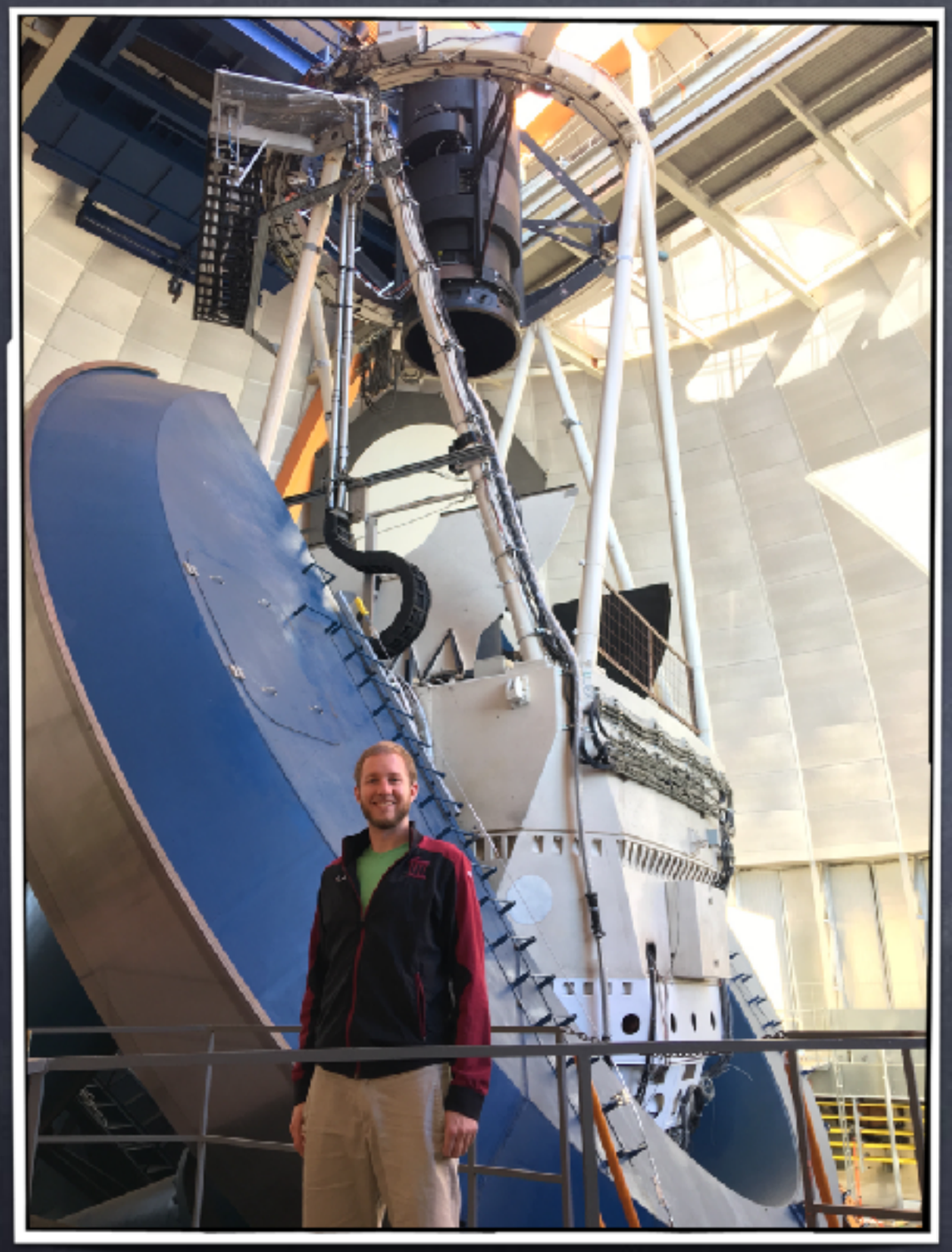
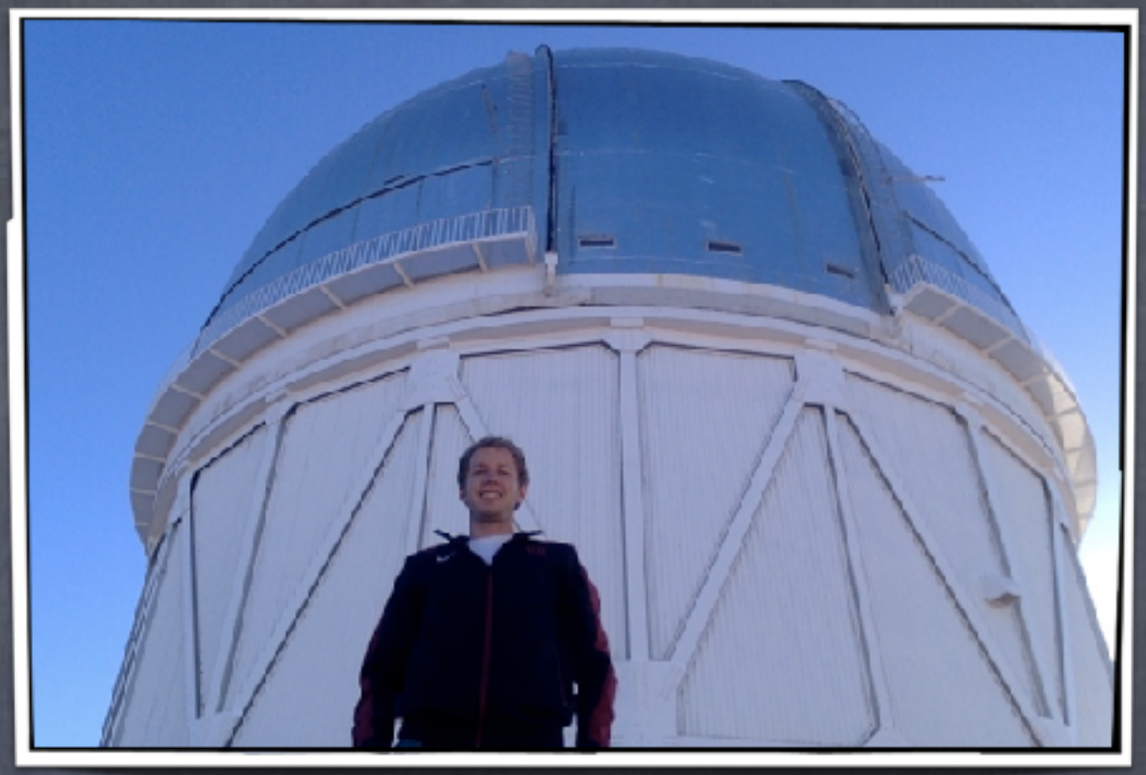
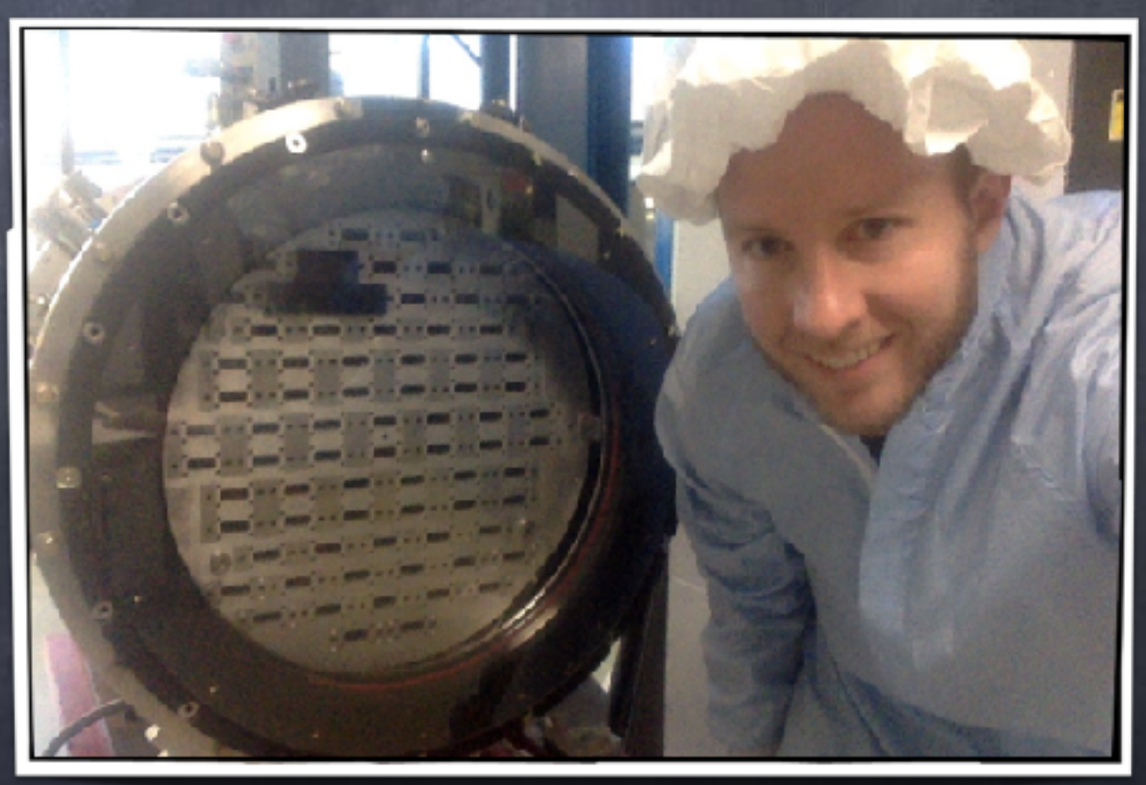
(Belokurov 2013)


Brian Koberlein

The Dark Energy Survey







iPhone Camera

+

=

+

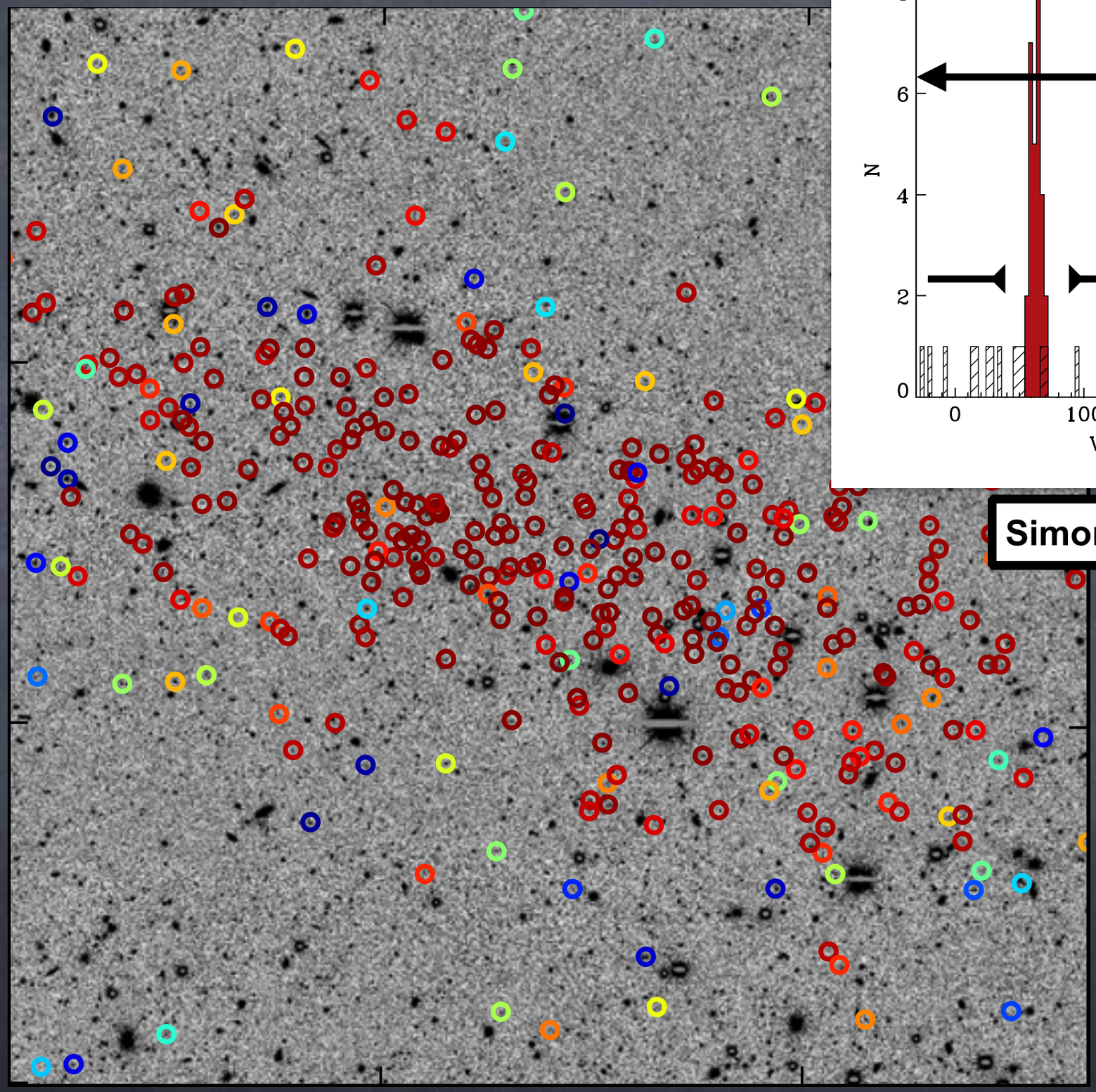
+ 2 more filters

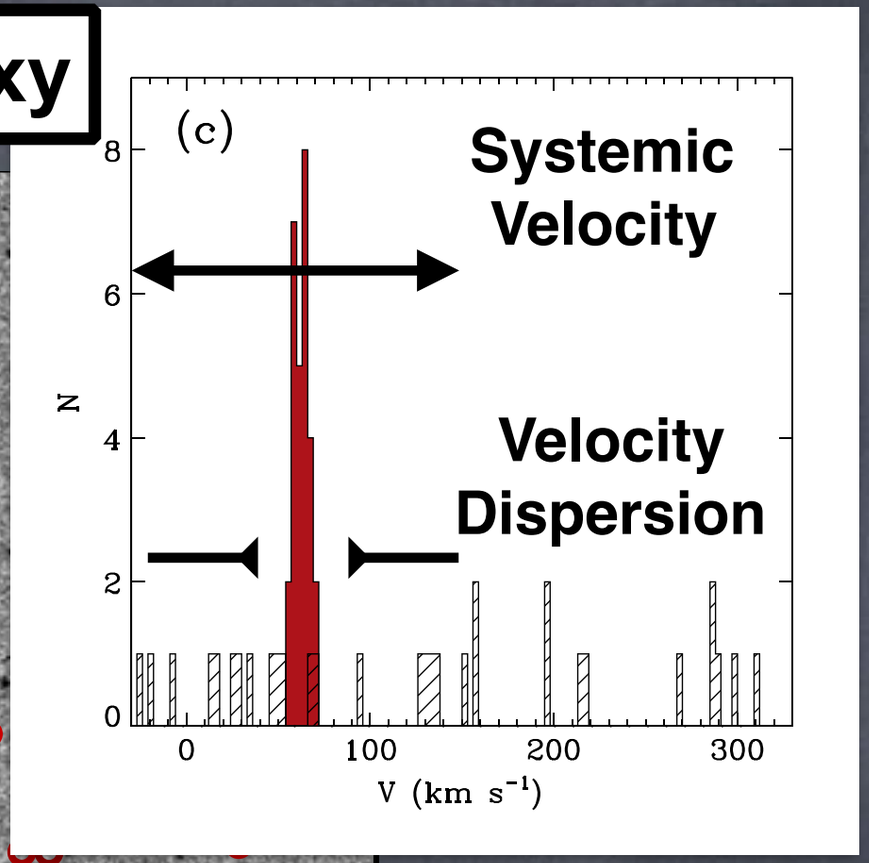
For Scale

Reticulum II Dwarf Galaxy

Bechtol, ADW et al. (2015)

Reticulum II Dwarf Galaxy

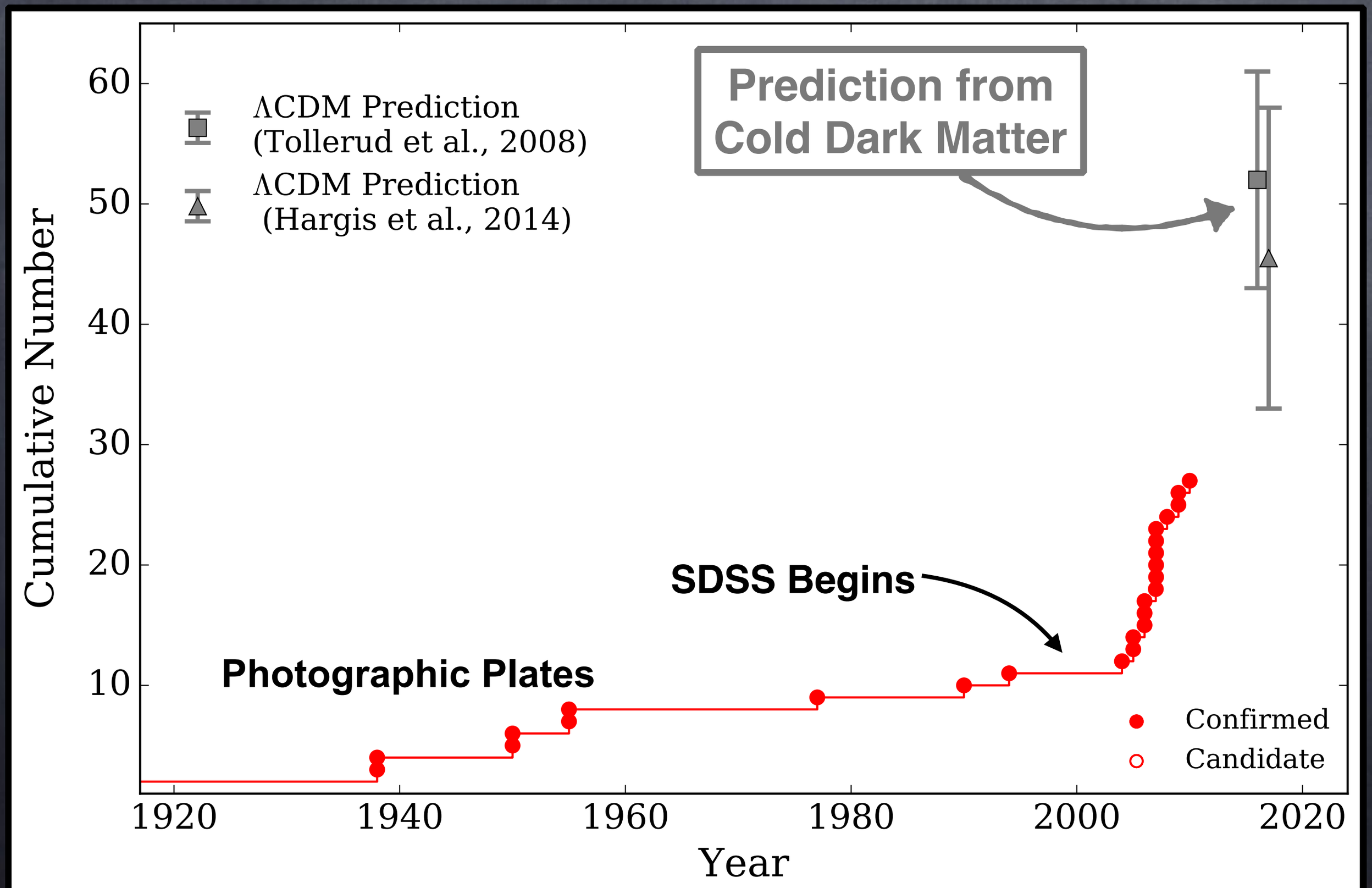




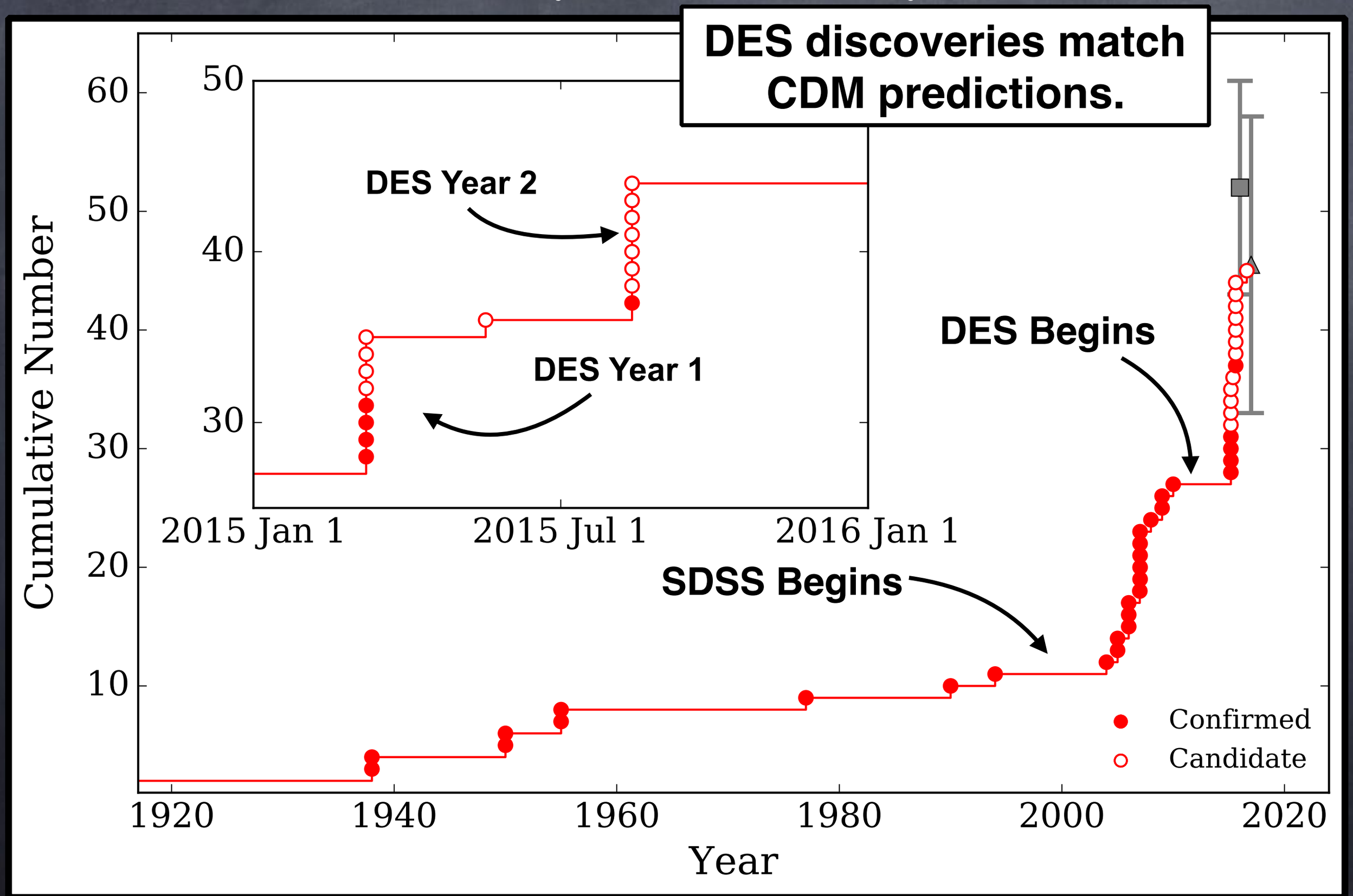
Simon, ADW et al. (2015)

Bechtol, ADW et al. (2015)

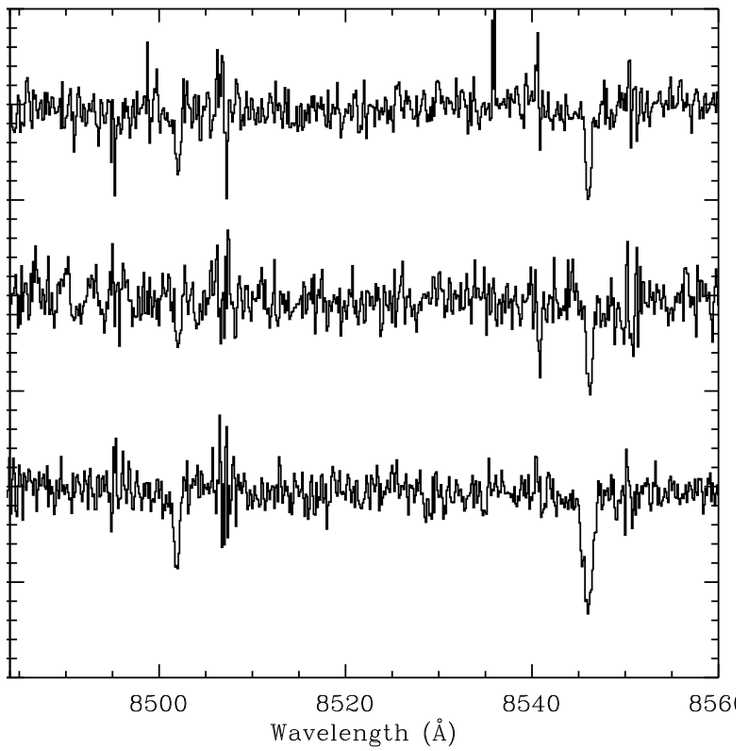
Dwarf Galaxy Discovery Timeline



Dwarf Galaxy Discovery Timeline



Dwarf Galaxy Discovery Timeline



~2 nights on 6.5+ meter telescope (with good weather)

Cumulative Number

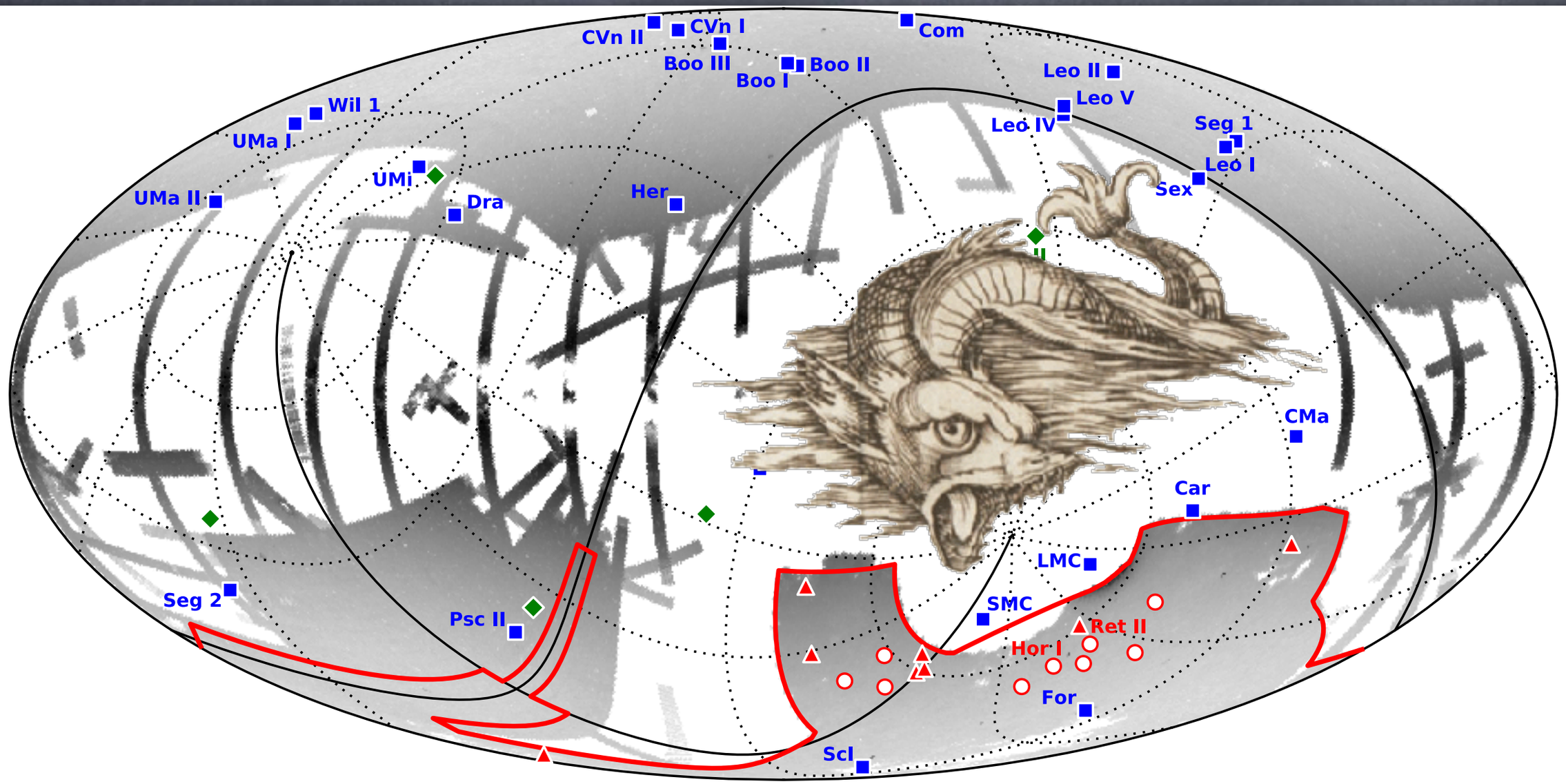
60
50
40
30
20
10

1920
1940
1960
1980
2000
2020

Year

Confirmed
Candidate

Dwarf Galaxy Discovery Map



Blue - Previously discovered satellites
Green - Discovered since 2015 with PanSTARRS, SDSS, etc.

Red outline - DES footprint
Red circles - DES Y1 satellites
Red triangles - DES Y2 satellites

Dwarf Galaxy Discovery Timeline

LSST is Coming!

Questions?