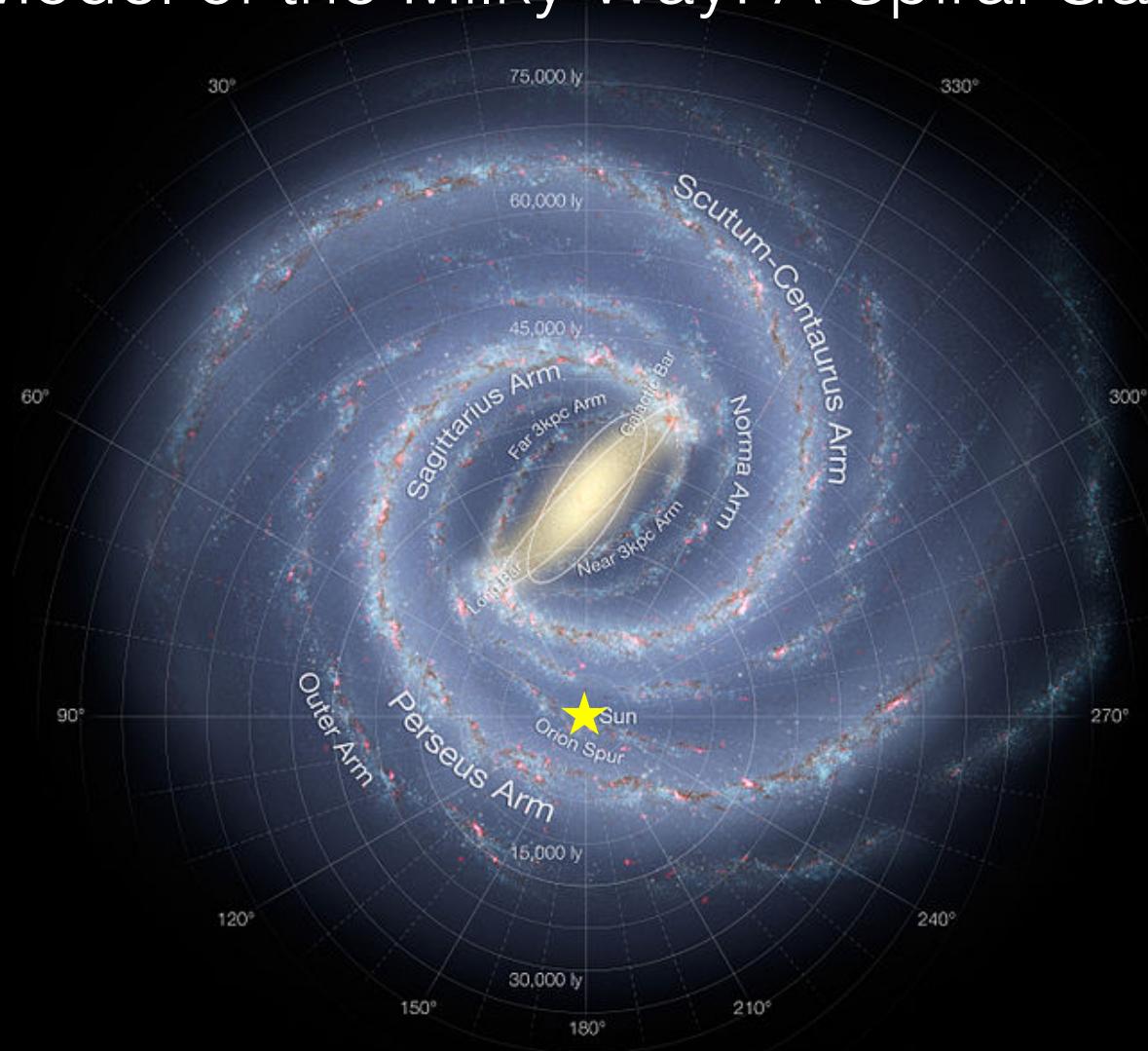


# A Model of the Milky Way: A Spiral Galaxy





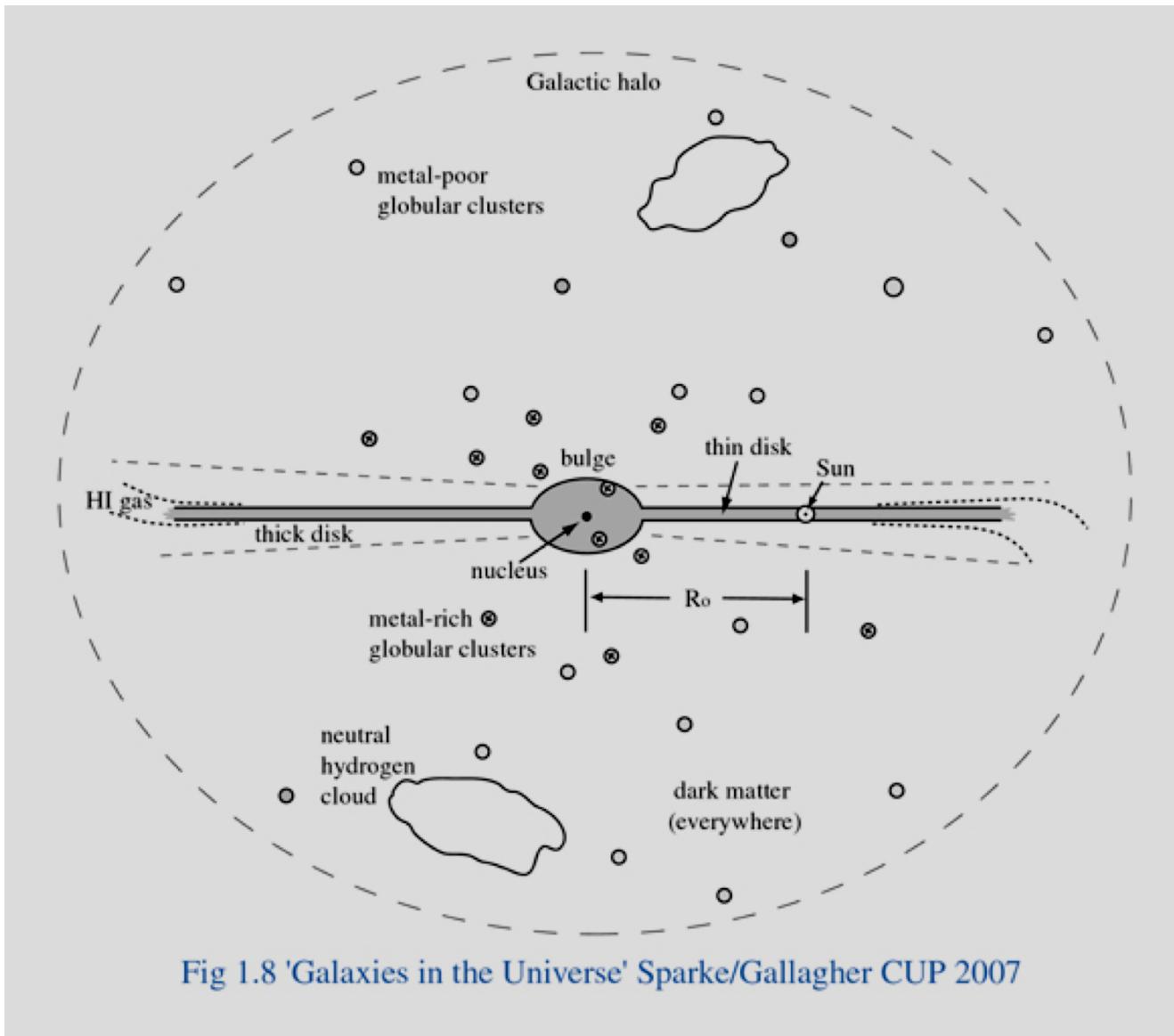
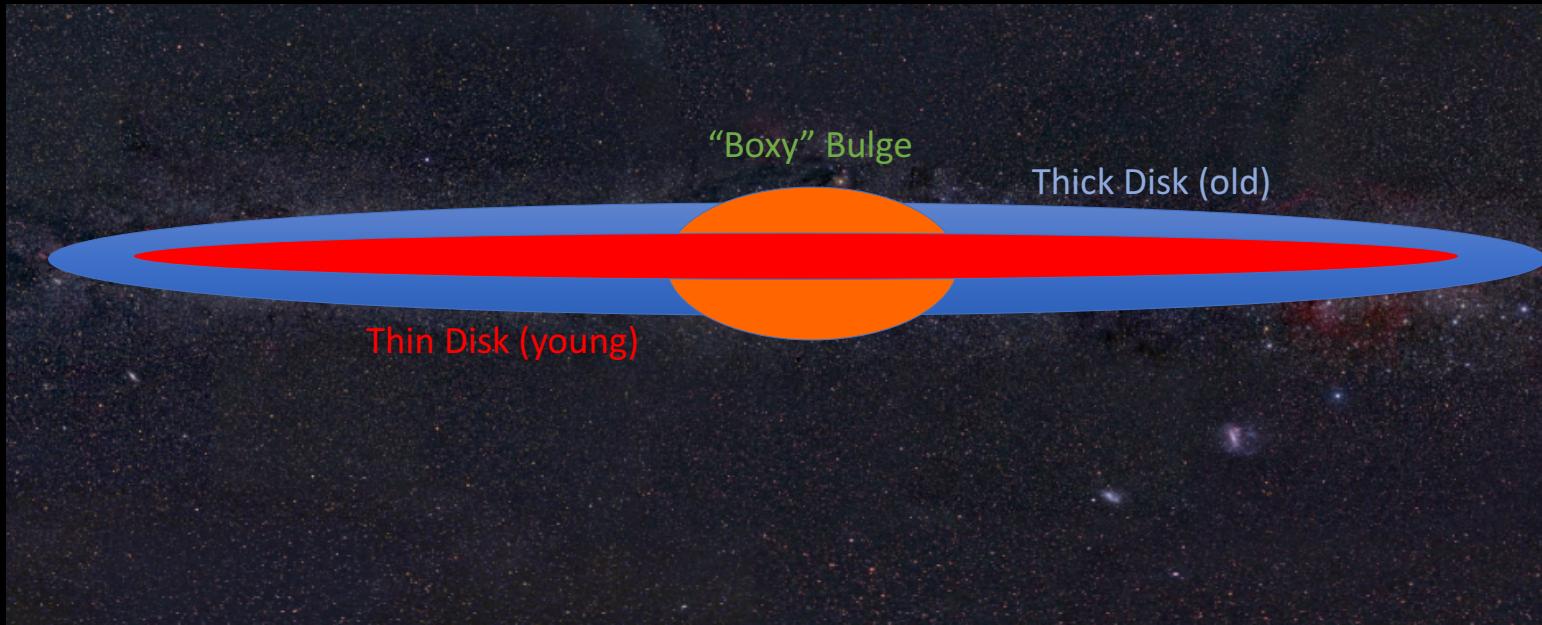


Fig 1.8 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

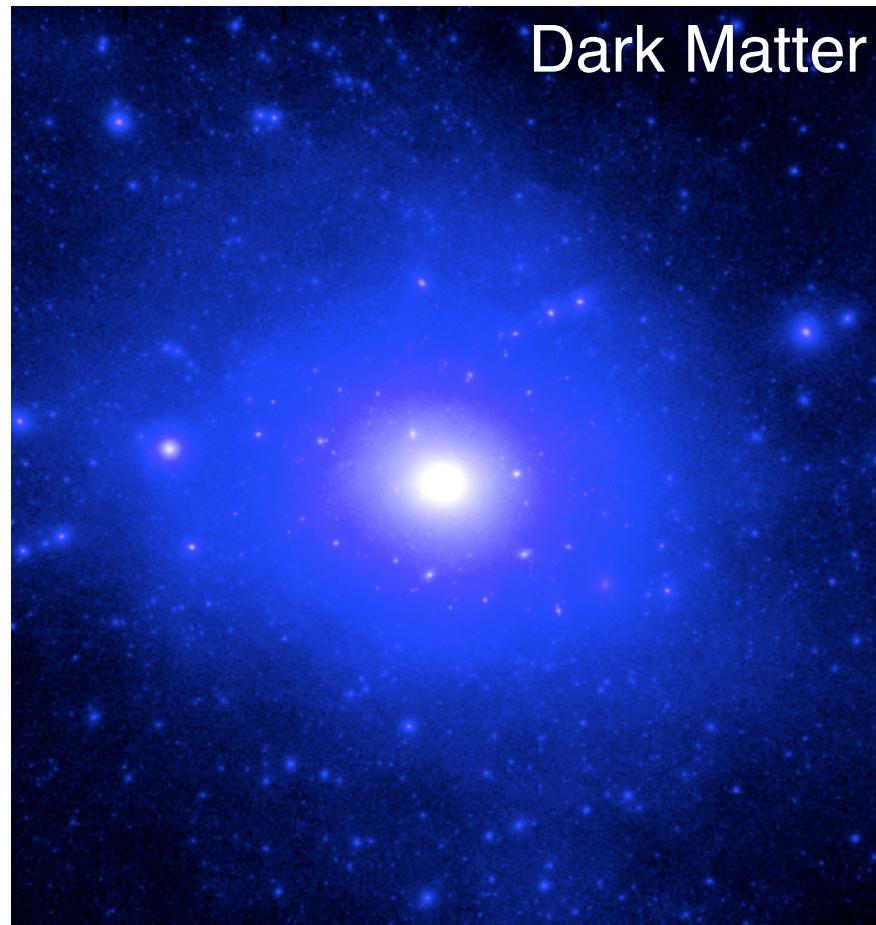
# The Structure of our Milky Way Disk:



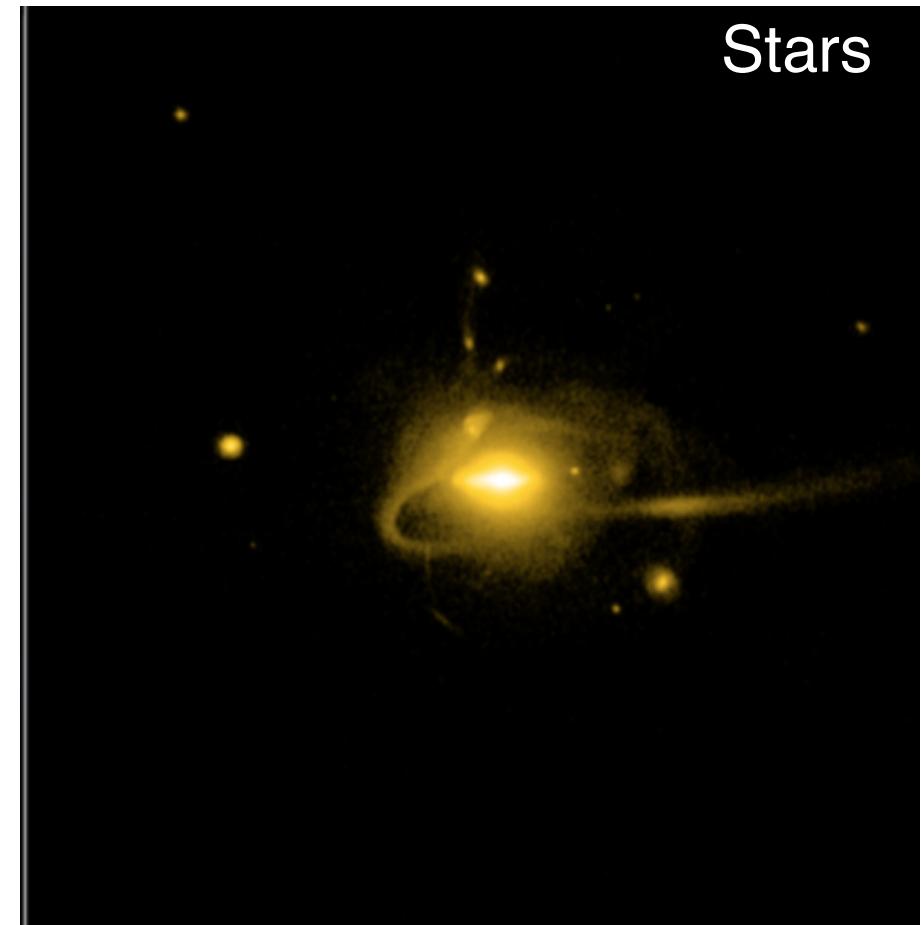
Diameter  $\sim$  100,000 light years

Mass  $\sim$  60 billion times the mass of the Sun

# Dark Matter vs. Stars



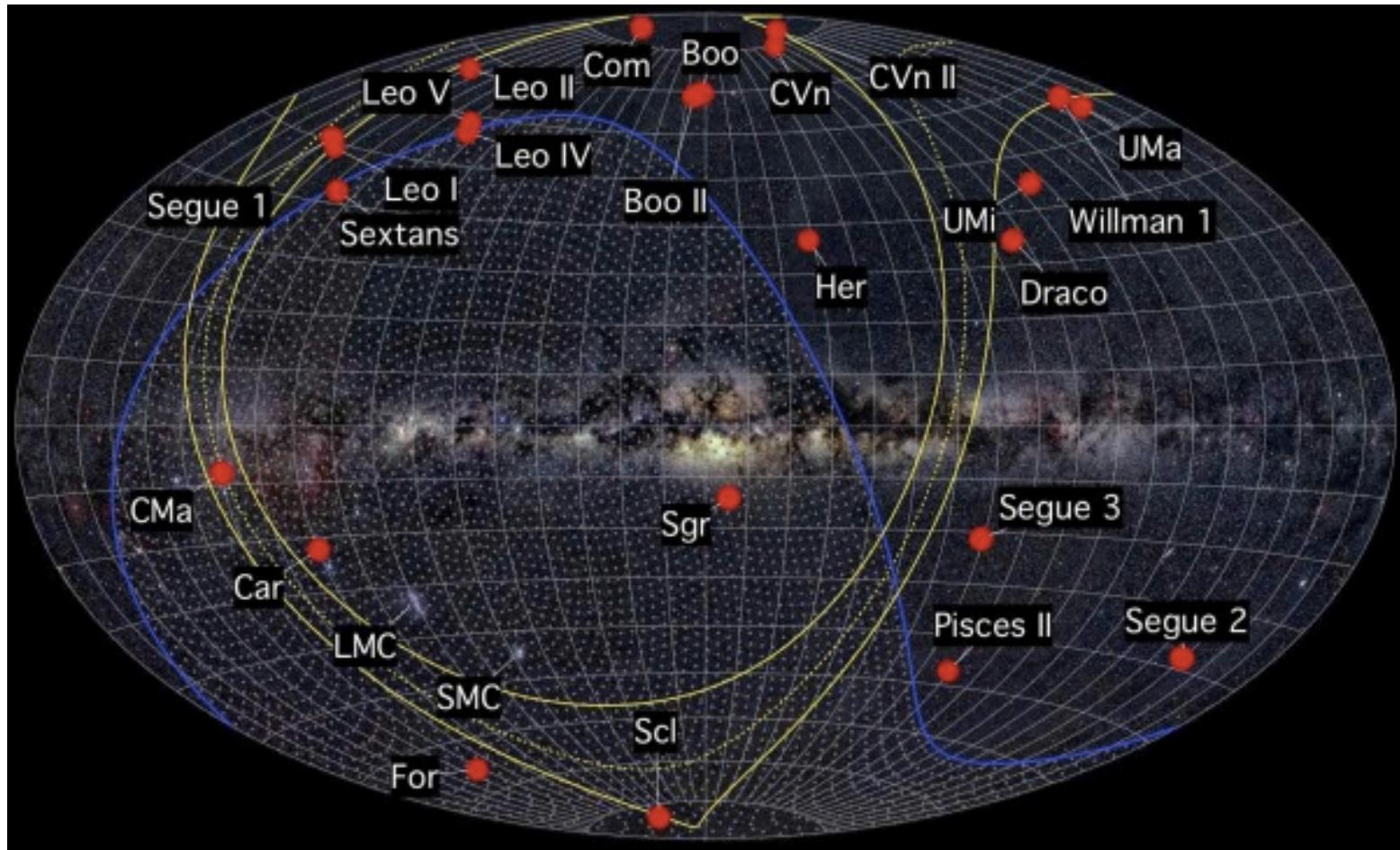
Dark Matter



Stars

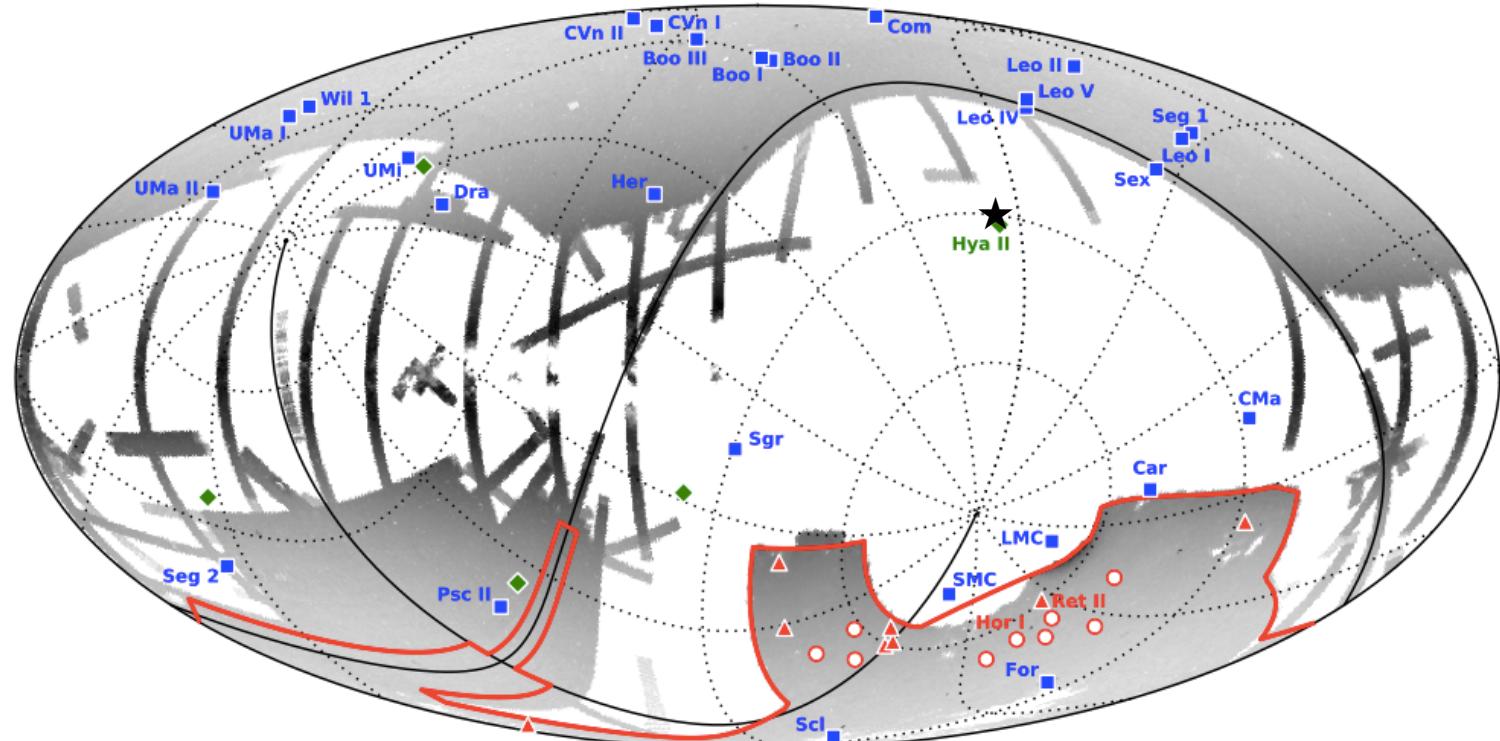
Wetzel+2016

# Our Milky Way has many Neighbors



26 Satellites as of Feb 2015

# Possible New Dwarfs found by DES Survey +PANSTARRS +SMASH survey = **~ 50 ?**



Bechtol + 2015 (DES); Koposov+2015; Laevens +2015;  
Martin, Nidever, Besla+ 2015 (SMASH), Drlica-Wagner+2015  
(DES), Homma+2016 ... more to come with LSST!

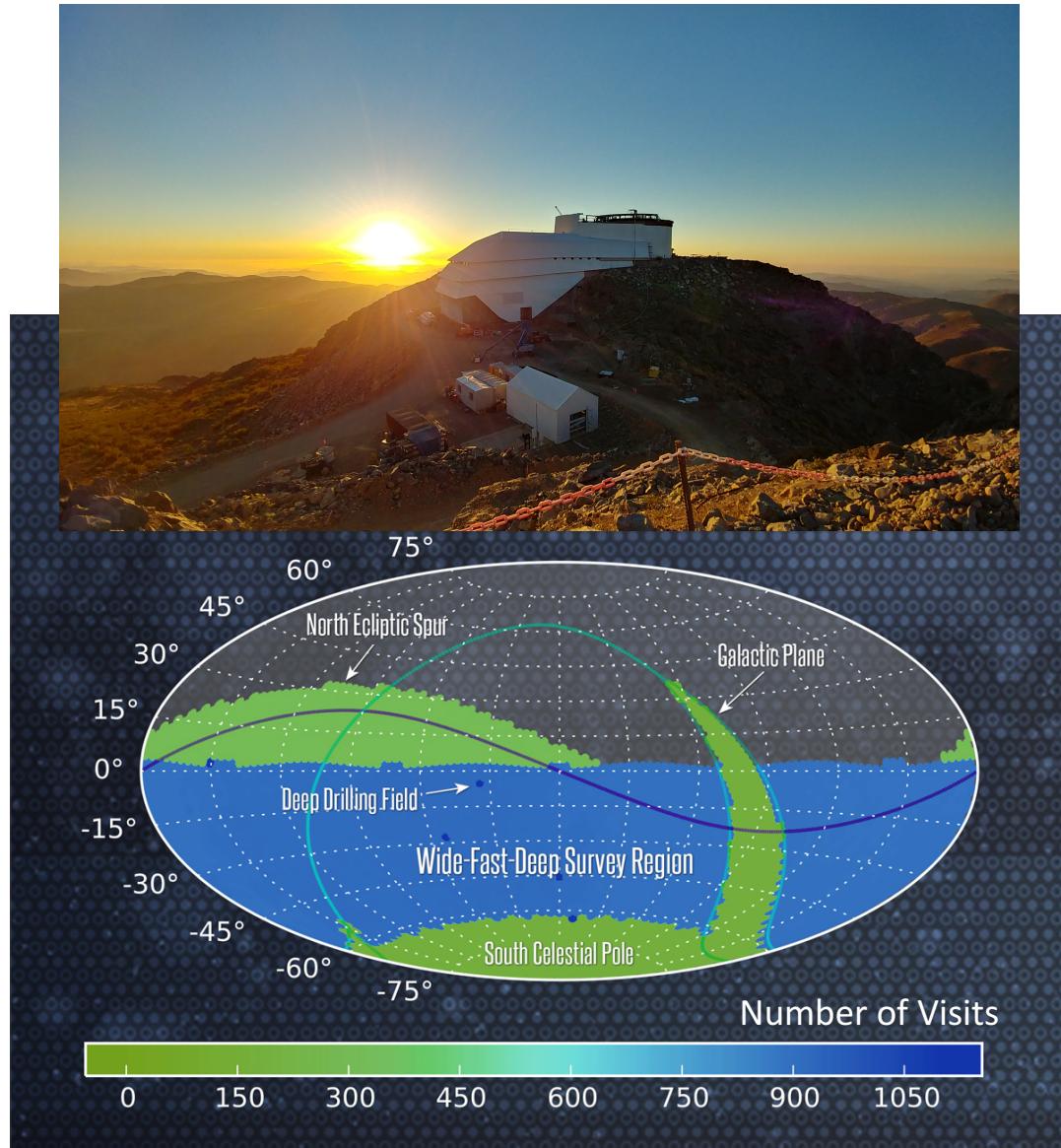
# LSST:

## The structure and evolutionary history of the Milky Way

### Constrain Dark Energy & Dark Matter

This telescope will produce the deepest, widest, image of the Universe:

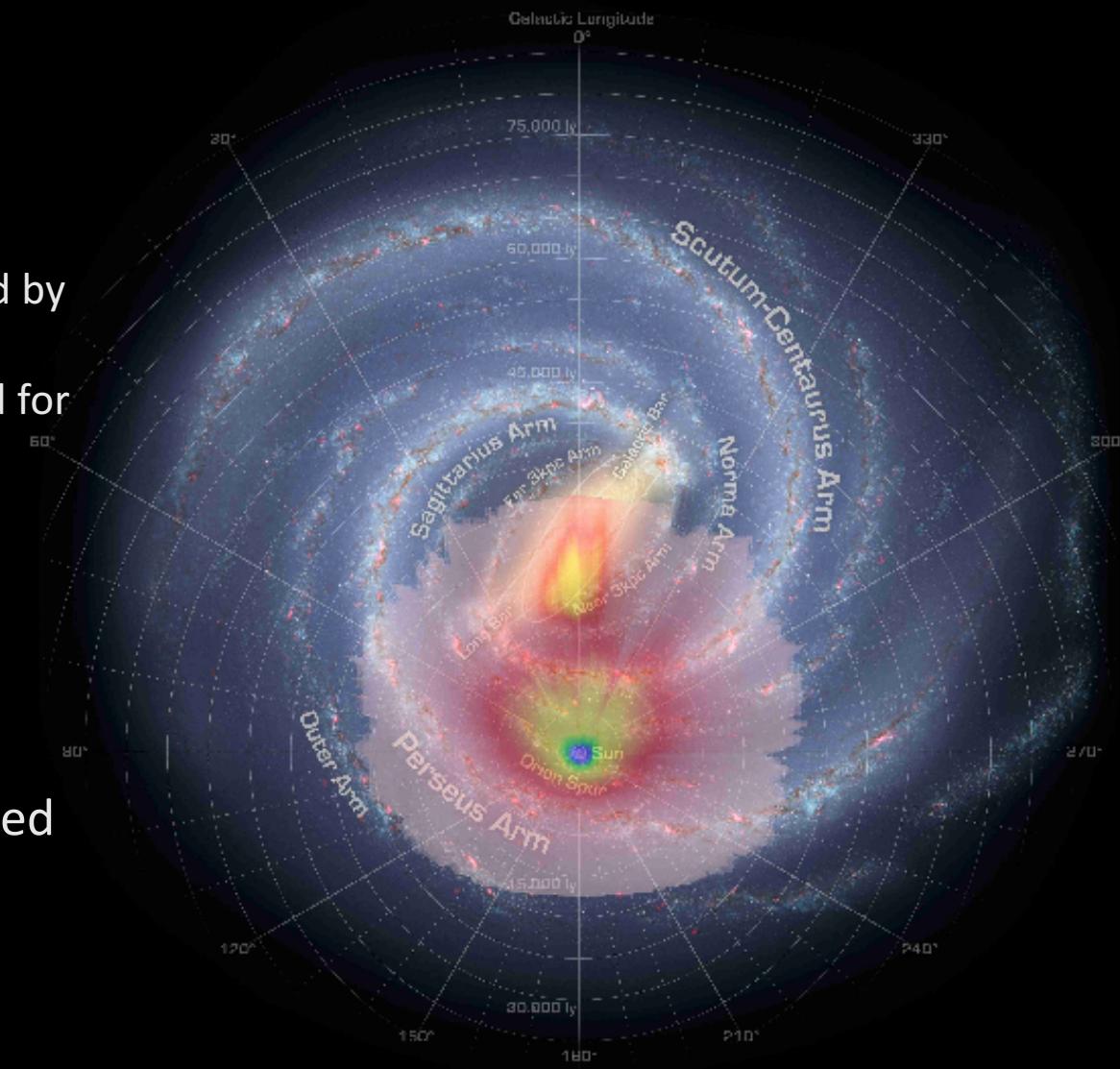
- 27-ft (8.4-m) mirror, the width of a singles tennis court
- 3200 megapixel camera
- Each image the size of 40 full moons (Wide field!)
- 37 billion stars and galaxies
- 10 year survey of the sky: starting 2022
- 10 million alerts, 1000 pairs of exposures, 15 Terabytes of data .. every night!



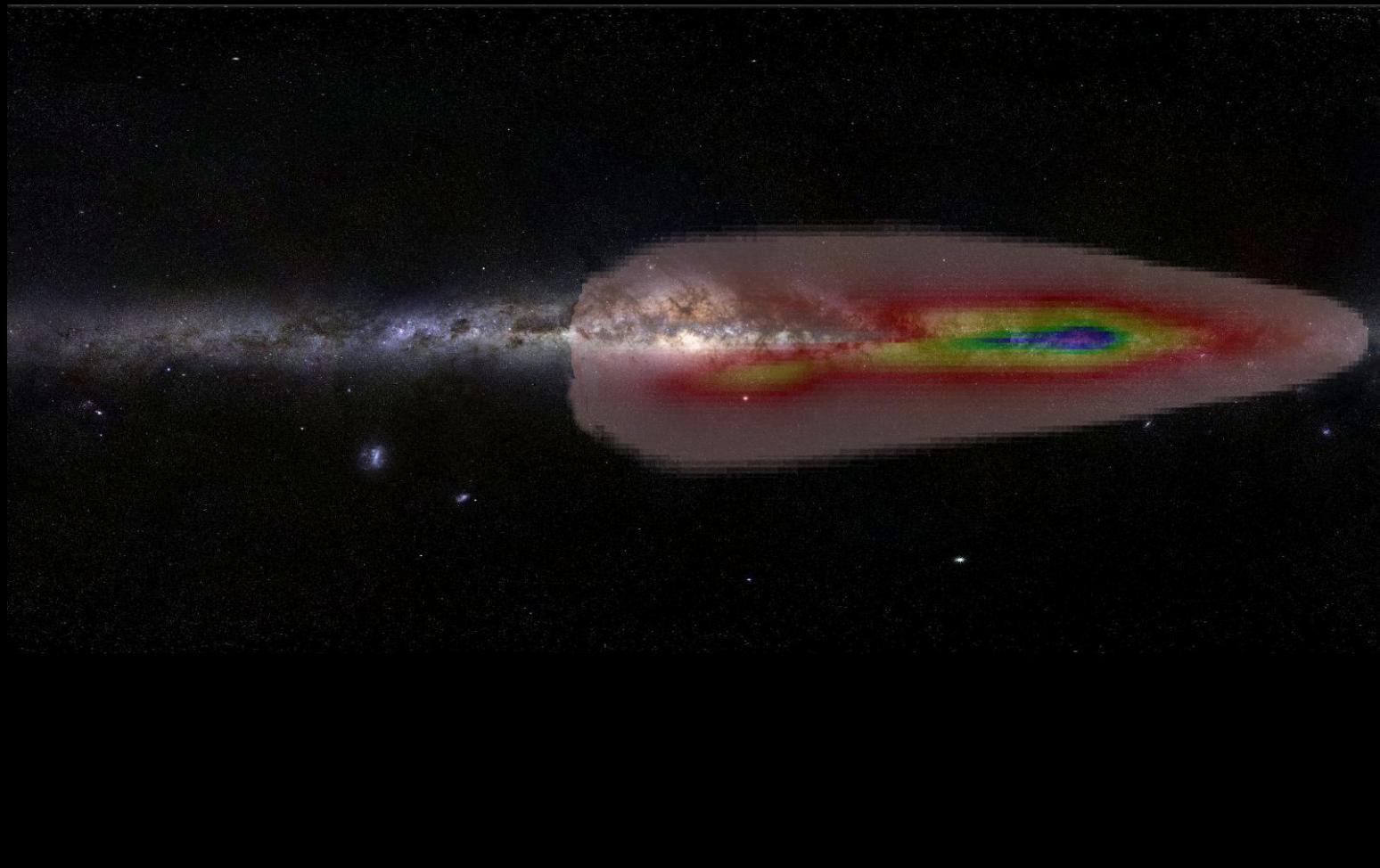
# GAIA

Gaia is a space observatory operated by the European Space Agency. It is designed for astrometry.

ASTROMETRY:  
measuring the  
positions and  
distances of stars  
with unprecedented  
precision.



# GAIA



Proper Motions

Barnard's Star



# GAIA

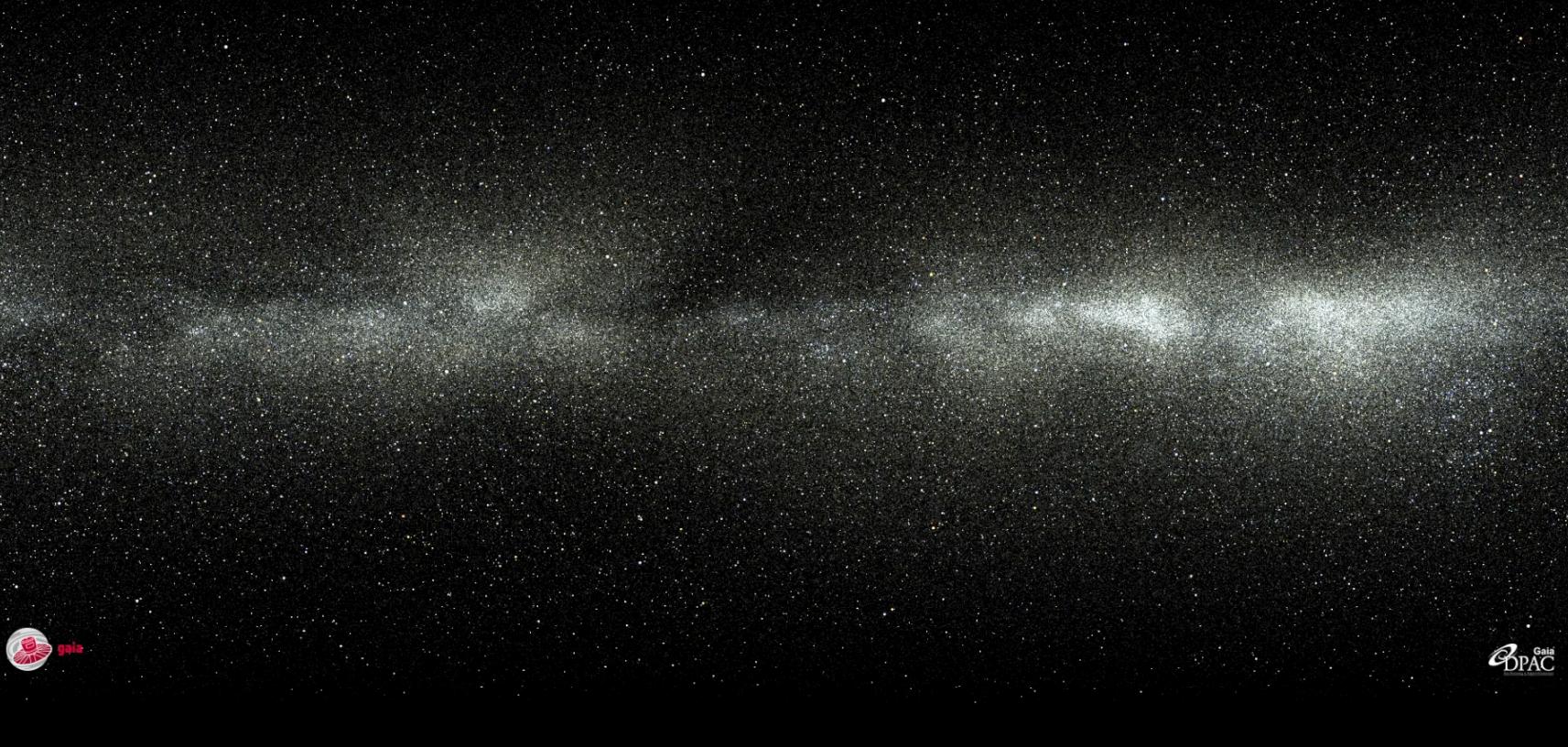
Data Release 1: Sep. 2016

Data Release 2 : April 2018 – during this semester!!

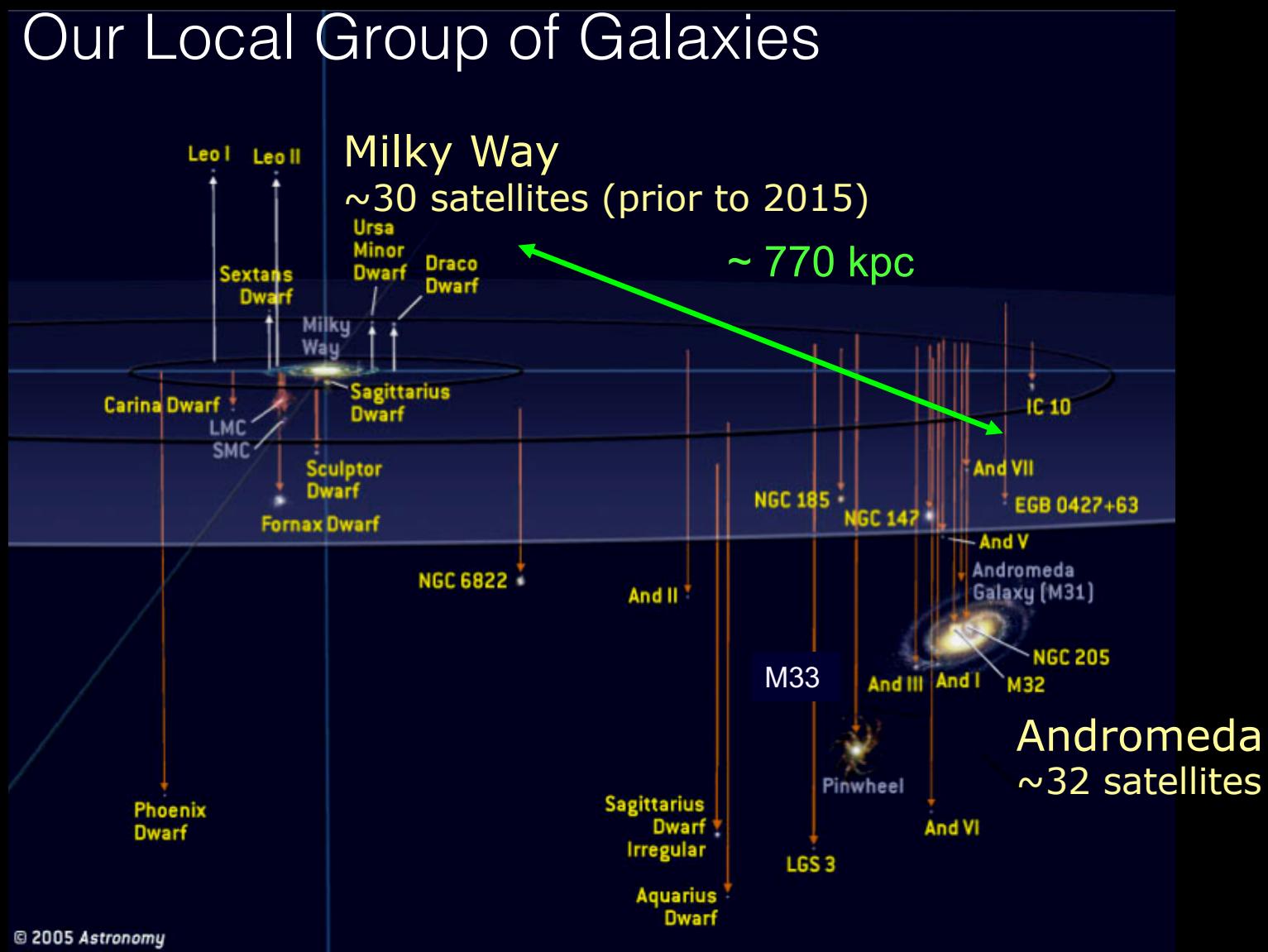
Data Release 3: Mid to late 2020 -- during your grad careers!

Mission Duration: Until 2022

Years from now: 3,363,750



# Our Local Group of Galaxies



# HSTPROMO

## The HST Proper Motion Collaboration

(<http://www.stsci.edu/~marel/hstpromo.html>)

- Characteristic velocity accuracy necessary  
~ 10 km/s at 70 kpc (Milky Way halo/satellite dynamics)

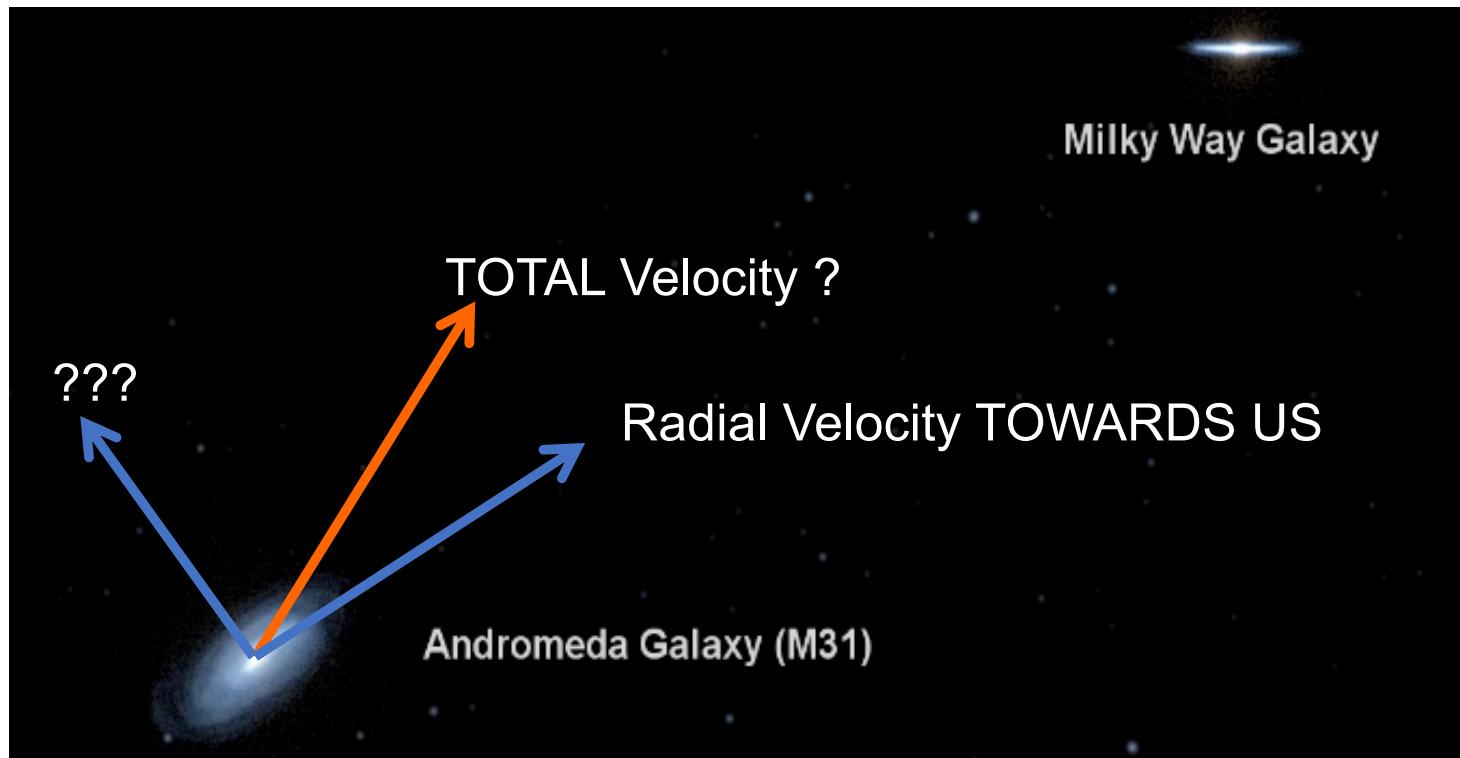
- Corresponding PM accuracy  
**~ 30  $\mu$ as / yr**

(~ speed of human hair growth  
at distance of the Moon)

With HST we can measure a  
change of 0.006 ACS/WFC pixels  
over a 10 yr baseline



# What is the 3D velocity of M31?

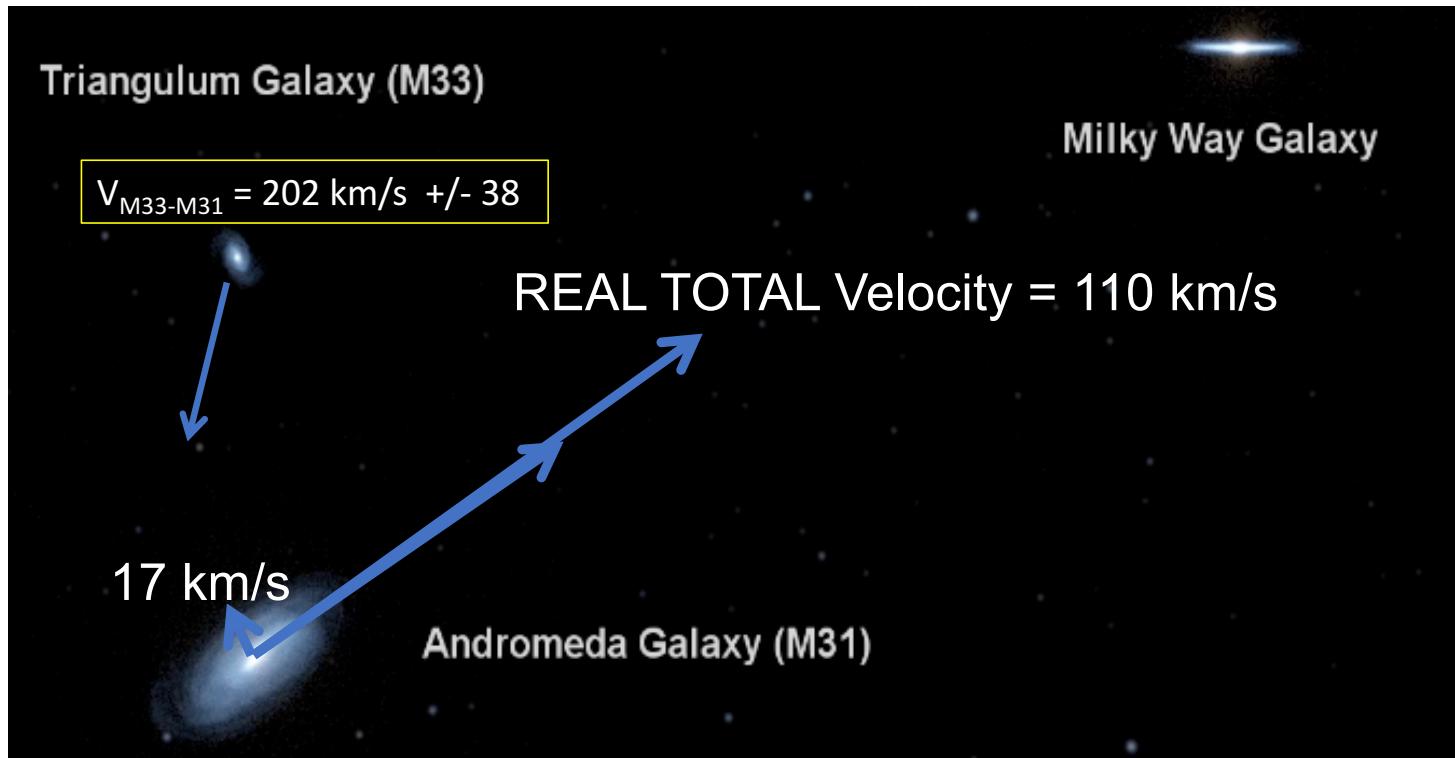


# HSTPROMO: The First Direct Proper Motion Measurement of M31



Sohn + 2012 (12  $\mu$ as accuracy) - M31 is coming straight at us!

# Andromeda is heading DIRECTLY towards us!



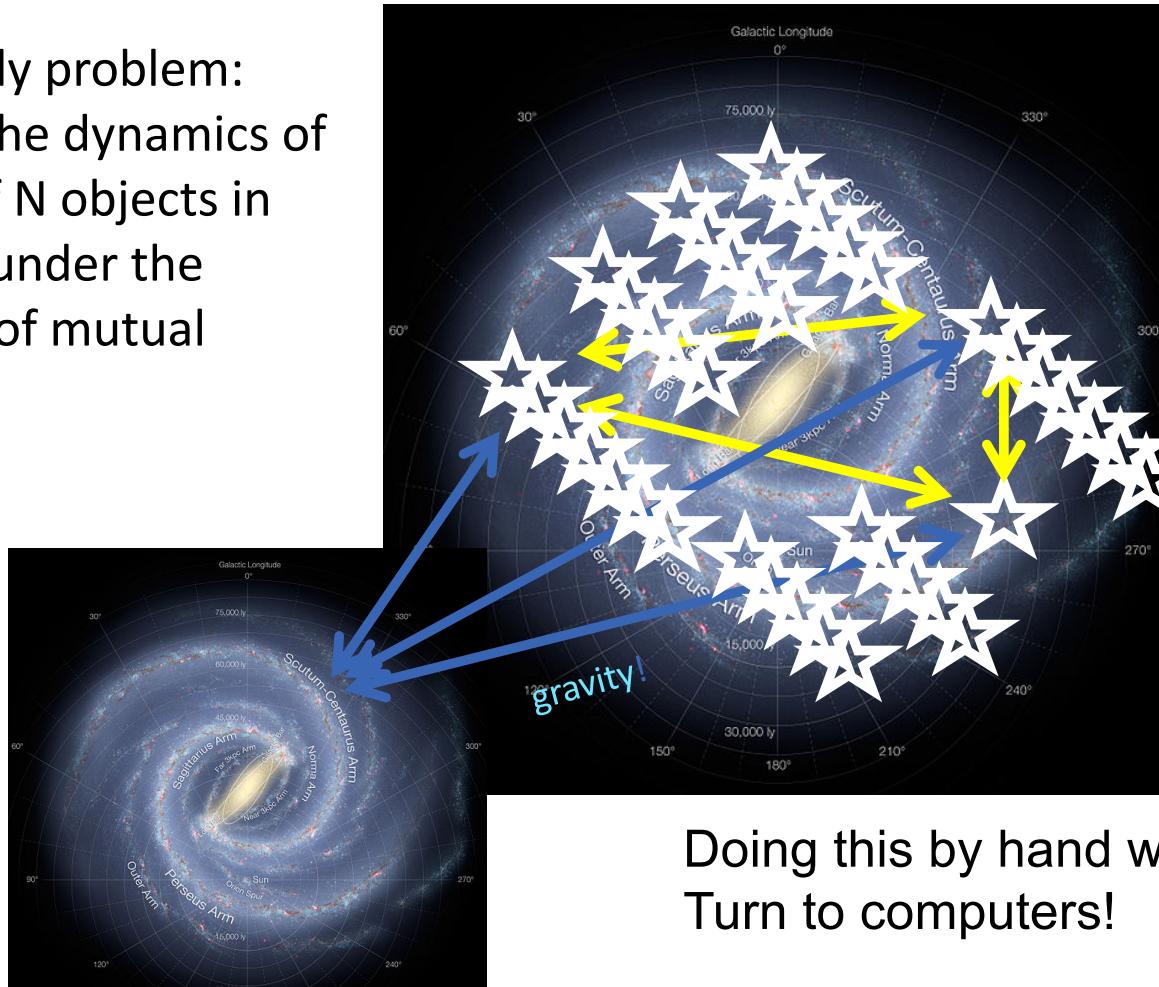
With the new M31 proper motion measurement we can predict the timing of the collision between the MW & M31:  **$3.87^{+0.42}_{-0.32}$  Gyr** van der Marel,Besla+2012



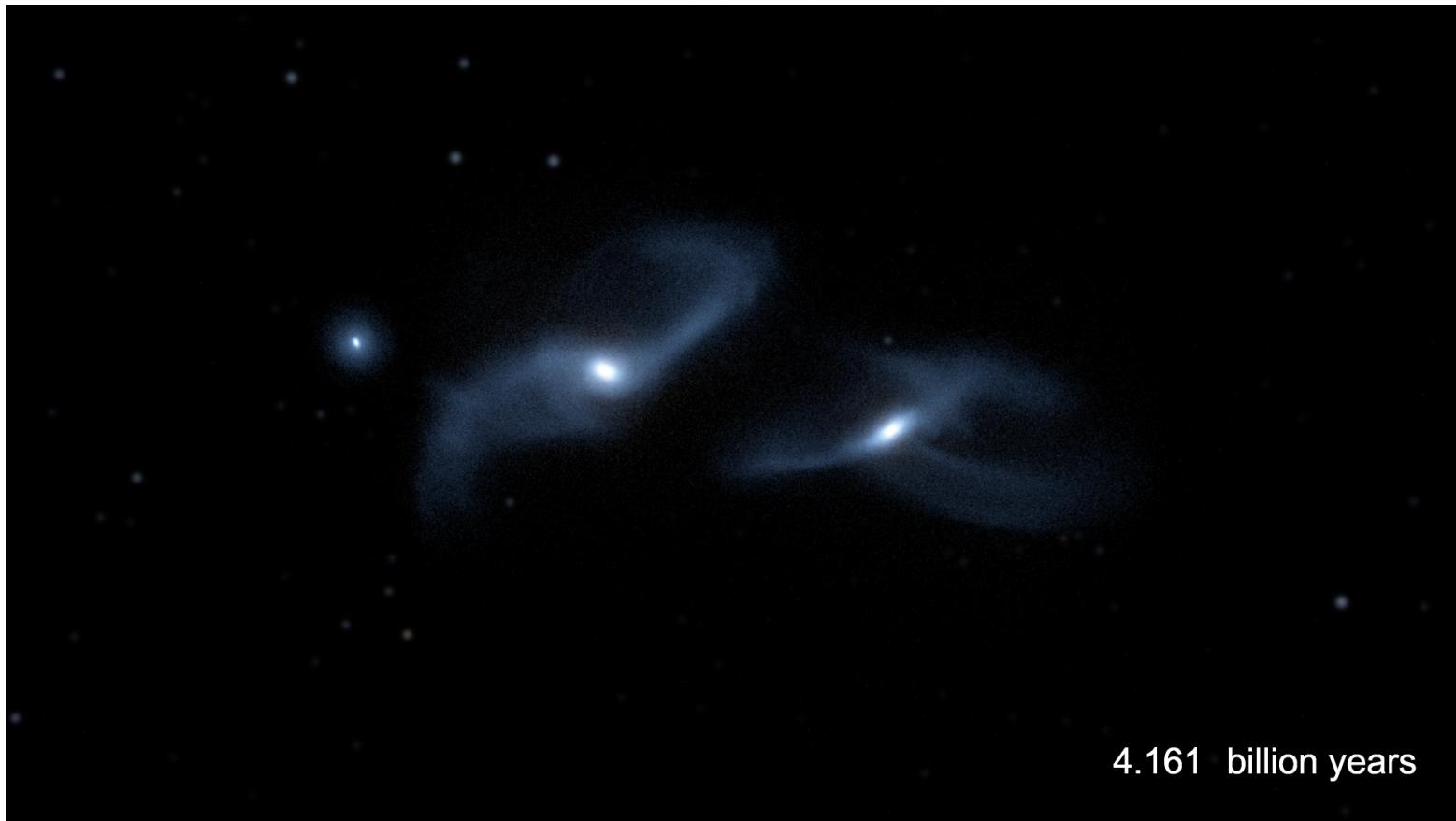
Artistic License: Z. Levay and R. van der Marel (STScI), T.Hallas, and A. Mellinger

# Simulating a Galaxy Collision

The N-body problem:  
solve for the dynamics of  
a group of N objects in  
3D space under the  
influence of mutual  
gravity.

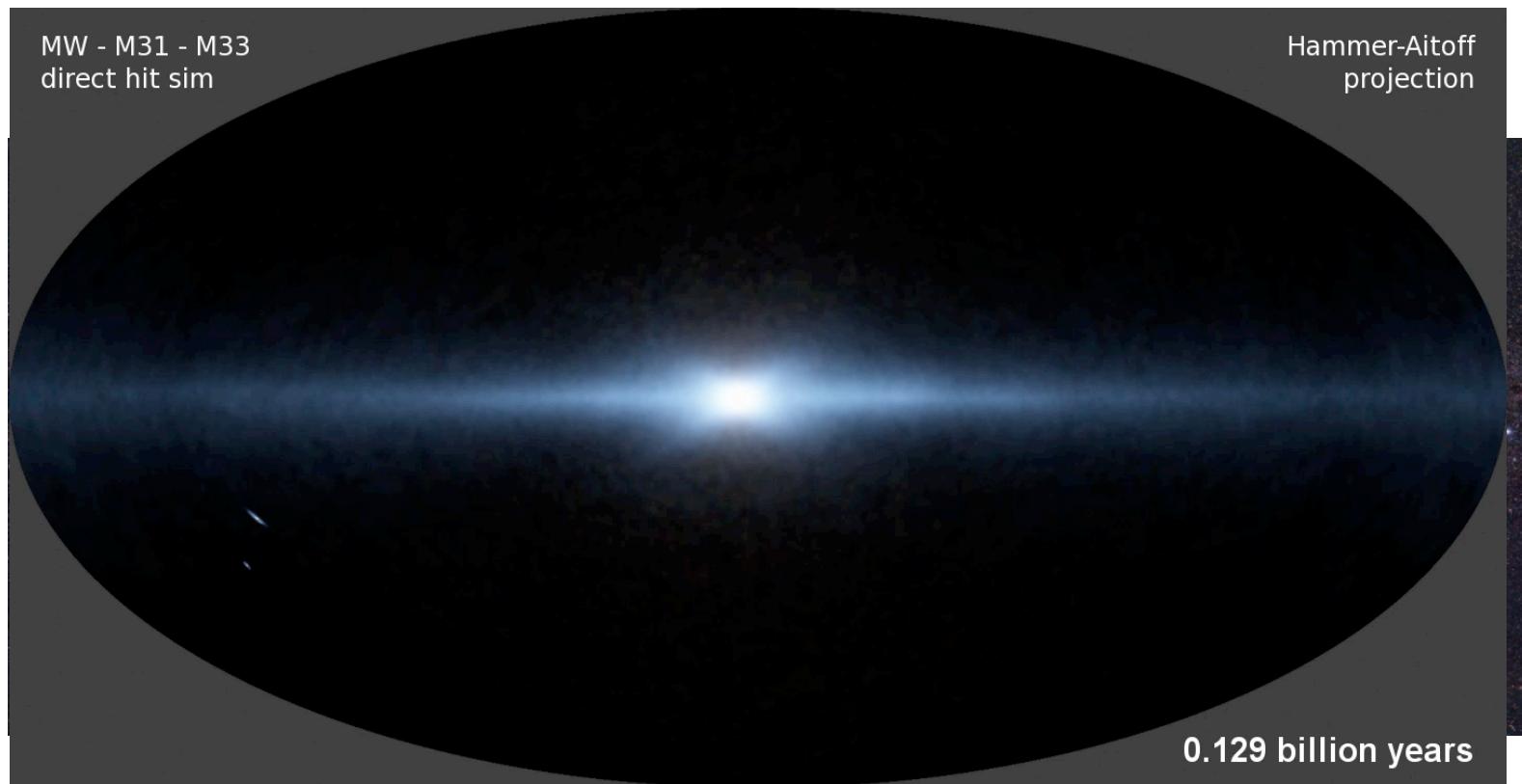


Doing this by hand would suck!  
Turn to computers!



Credit: Besla, Frank Summers

# How might the night sky change?



Credit: Besla, Frank Summers