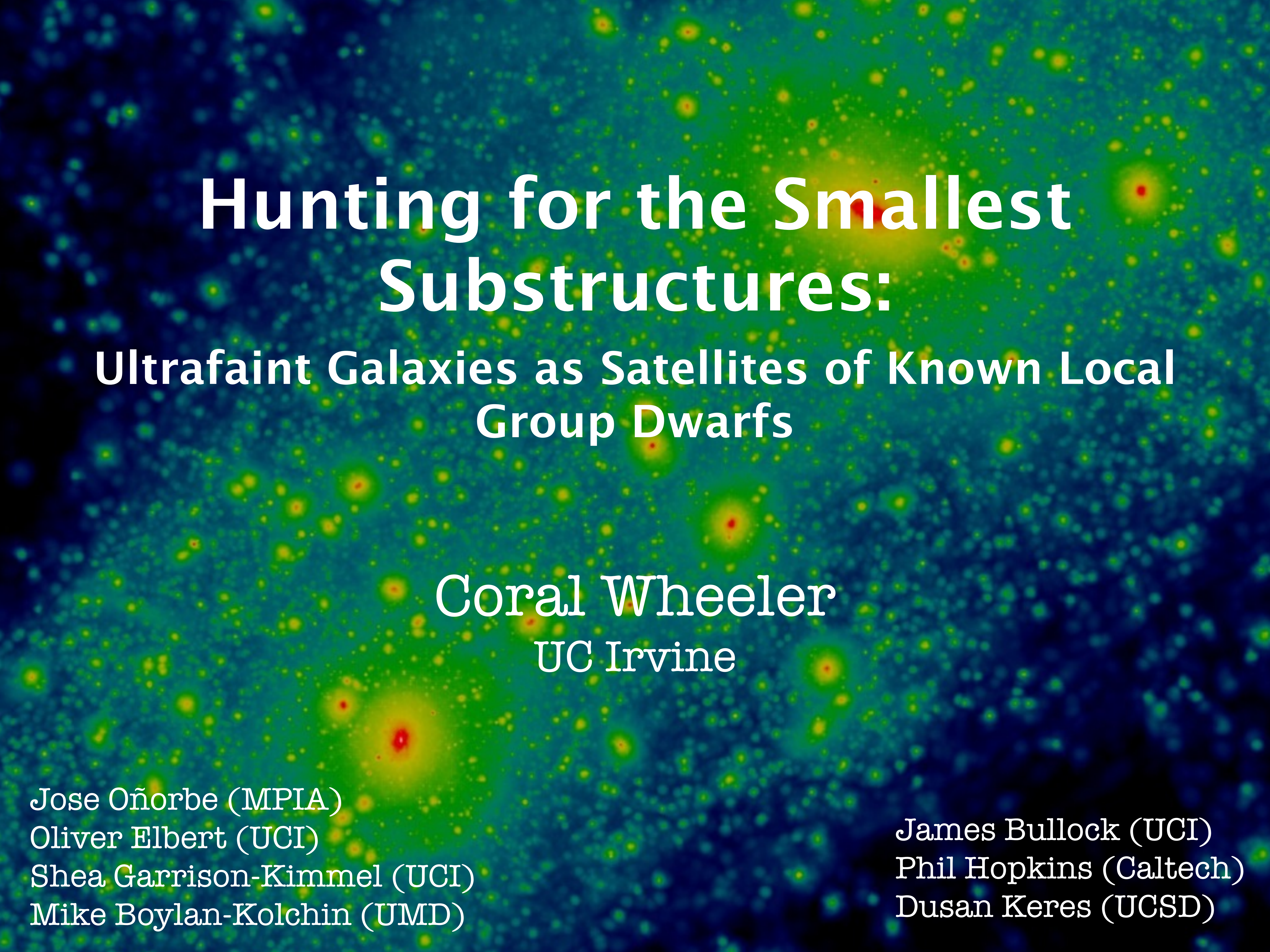

Hunting for the Smallest Substructures:

Ultrafaint Galaxies as Satellites of Known Local Group Dwarfs

Coral Wheeler
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Jose Oñorbe (MPIA)
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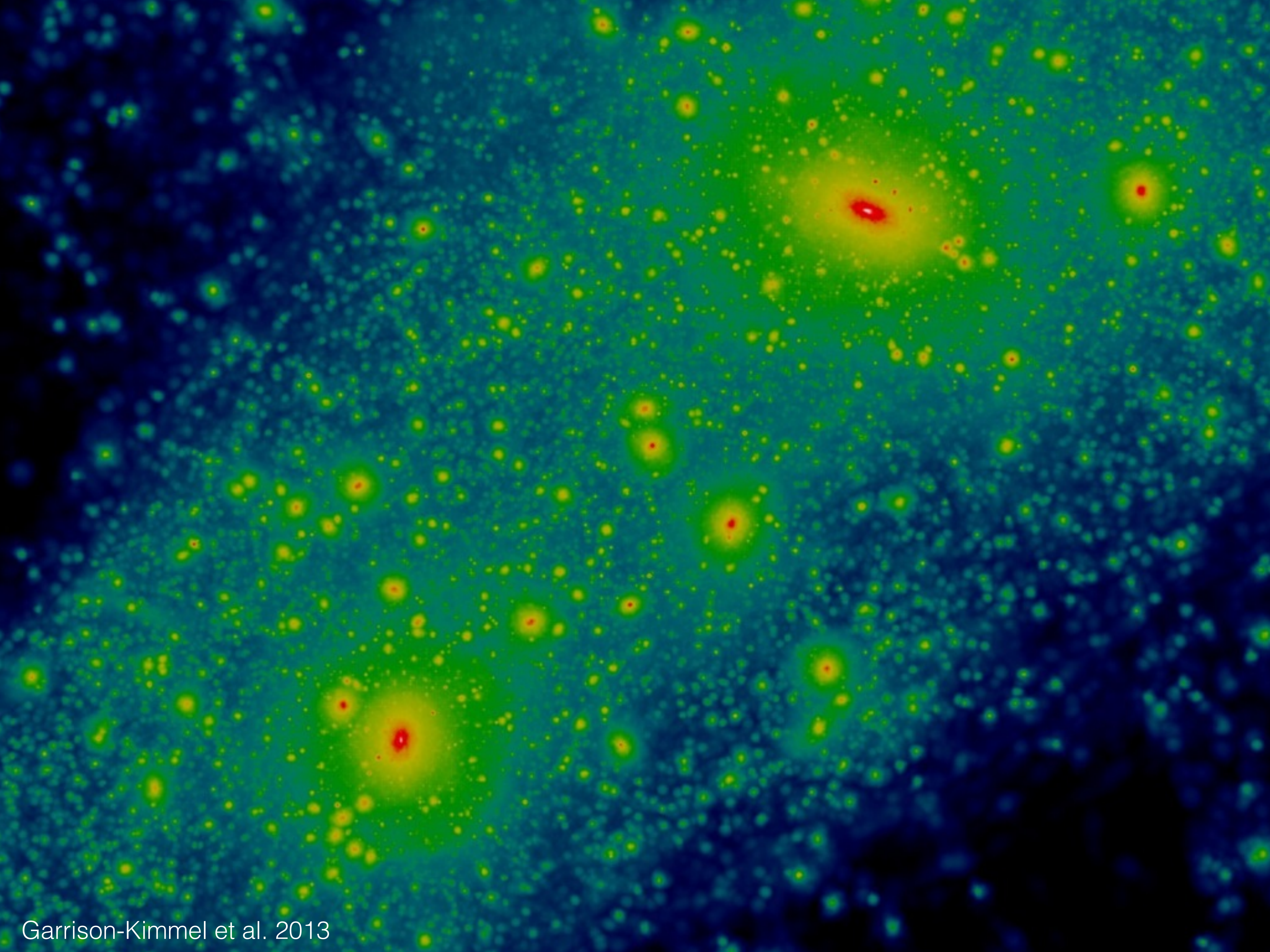
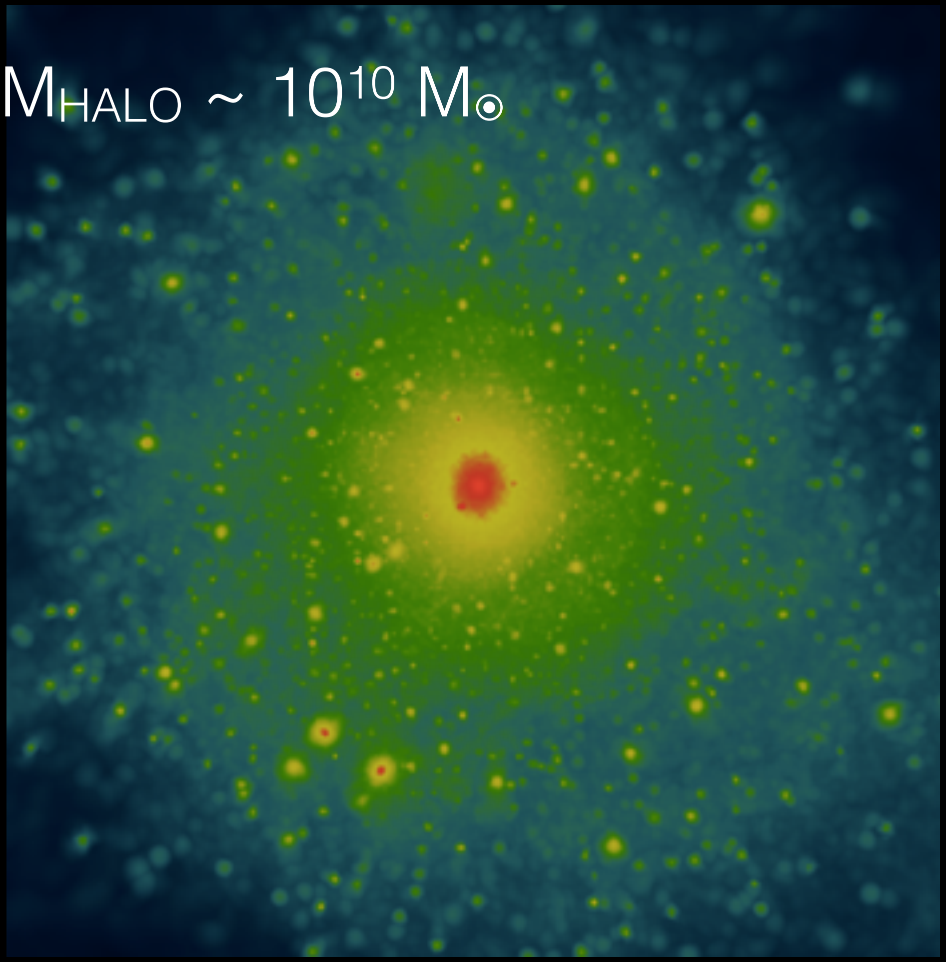
Shea Garrison-Kimmel (UCI)
Mike Boylan-Kolchin (UMD)

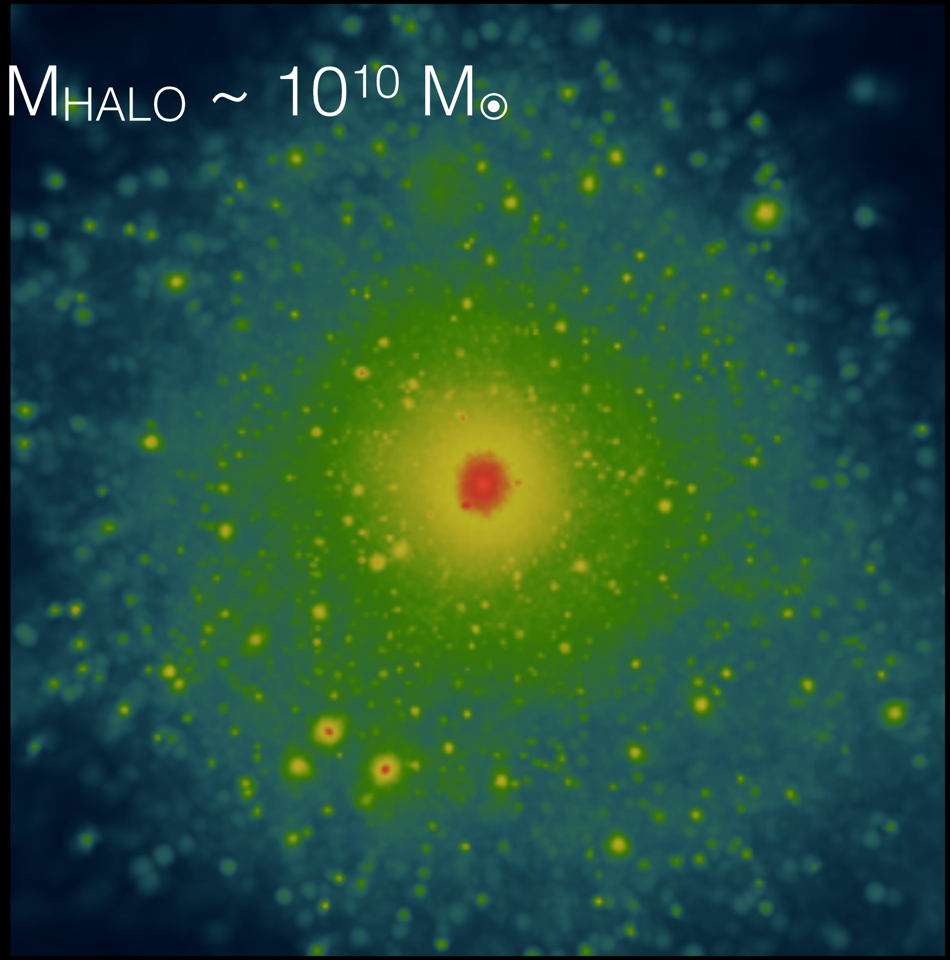
James Bullock (UCI)
Phil Hopkins (Caltech)
Dusan Keres (UCSD)



Garrison-Kimmel et al. 2013



$M_{HALO} \sim 10^{10}\ M_{\odot}$



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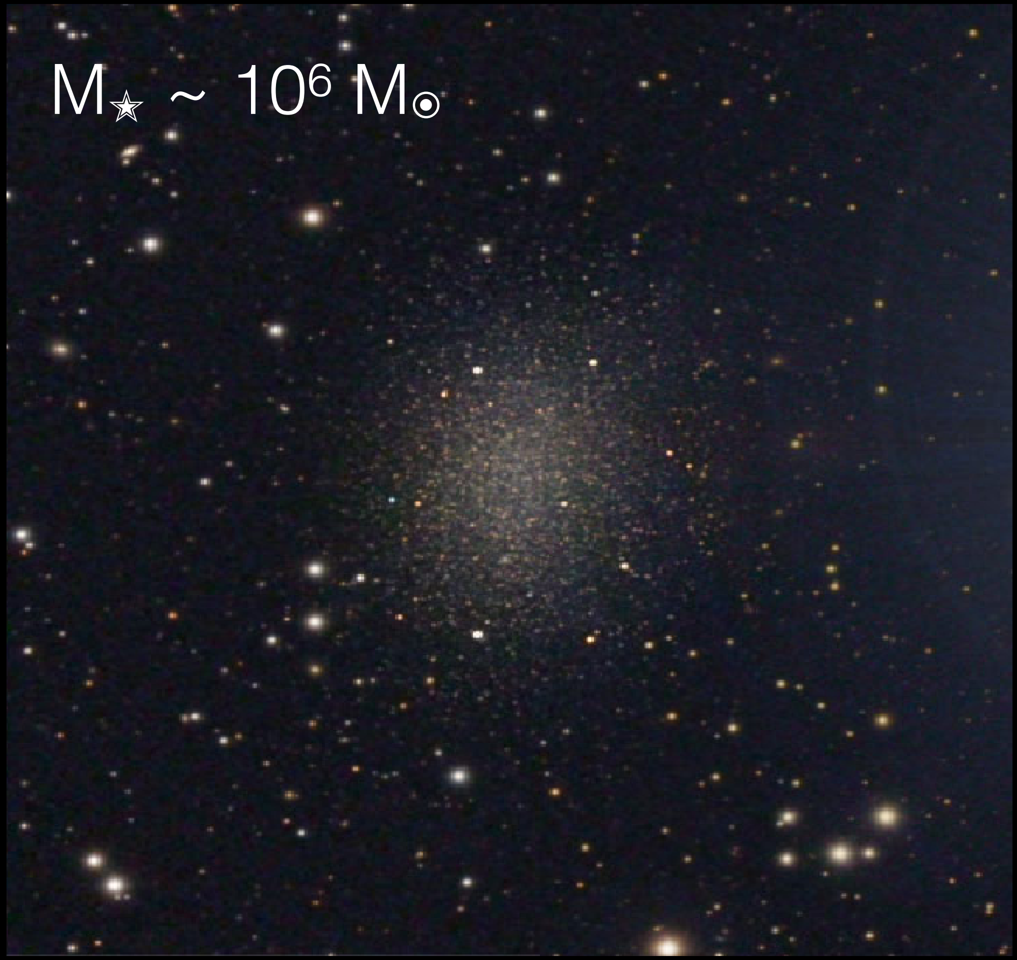
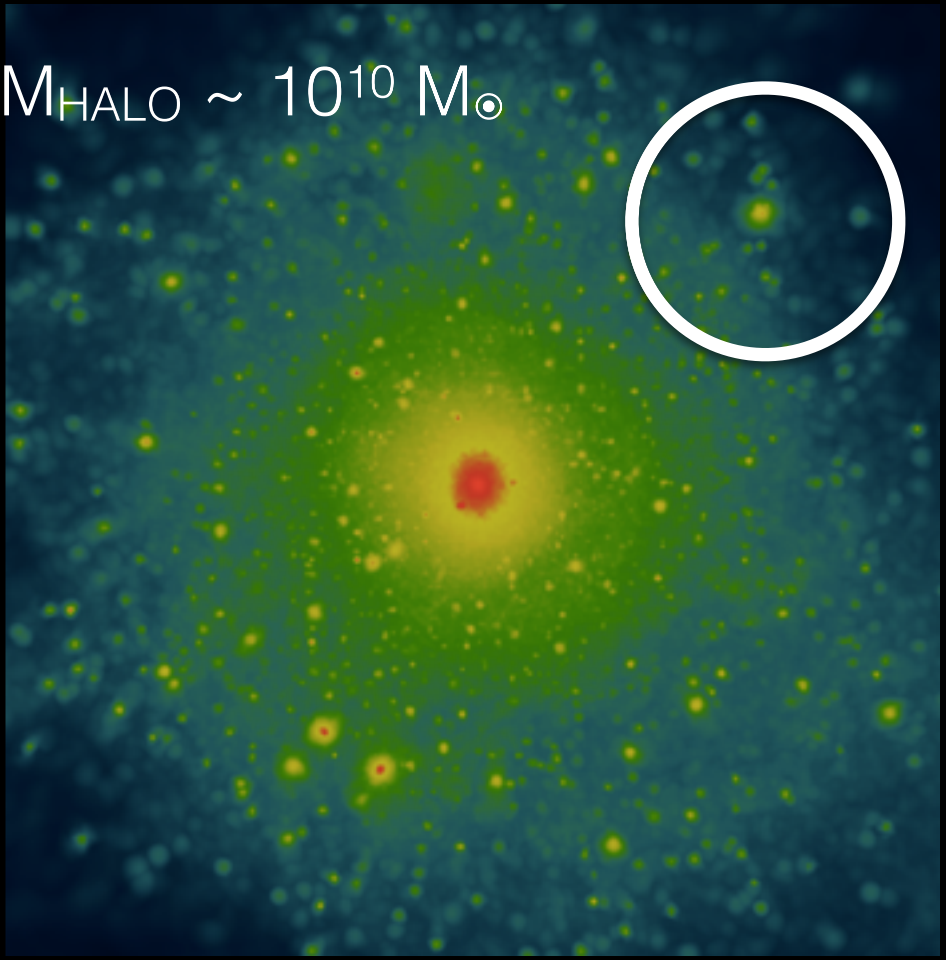
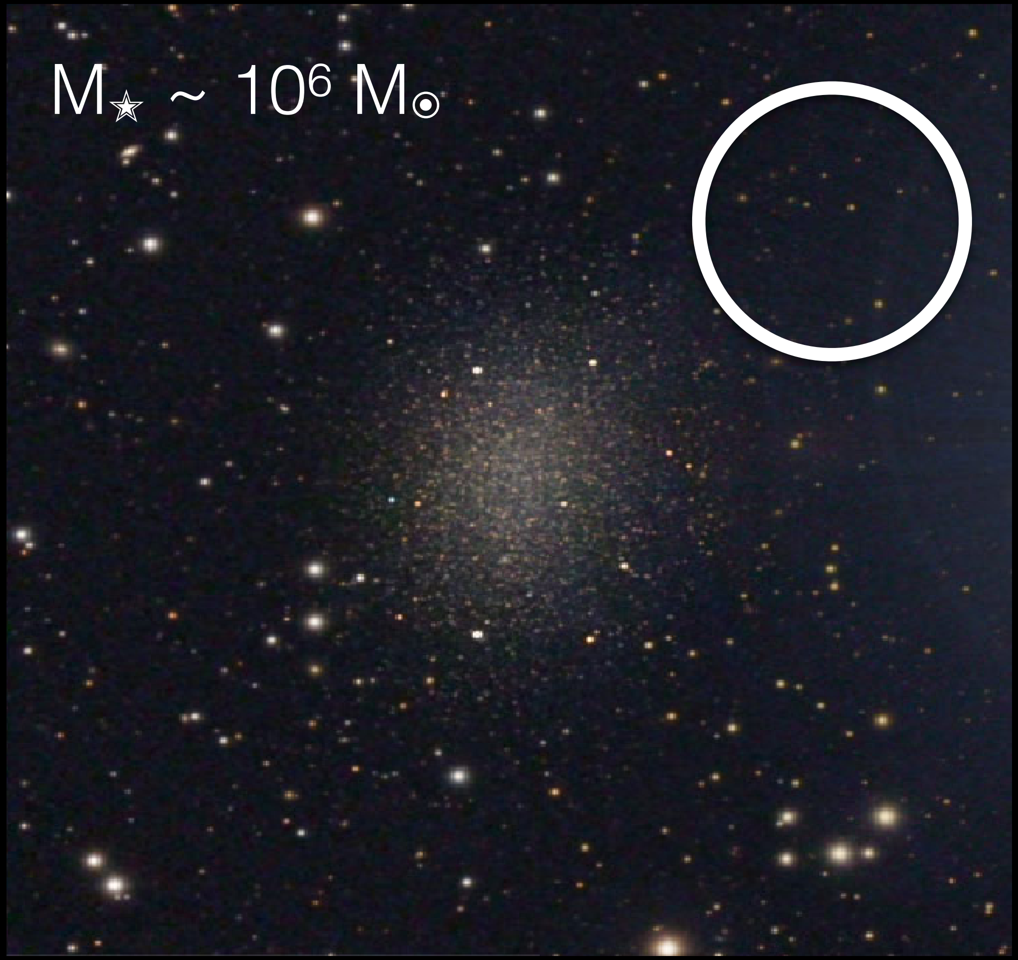


$M_{\star} \sim 10^{6}\ M_{\odot}$

Do massive, isolated dwarf (M_{HALO}~10^{10} $M_{\odot}$) galaxies have star-forming satellites?





DWARF GALAXIES ON FIRE

$m_{dm} \sim 1000\ M_\odot$

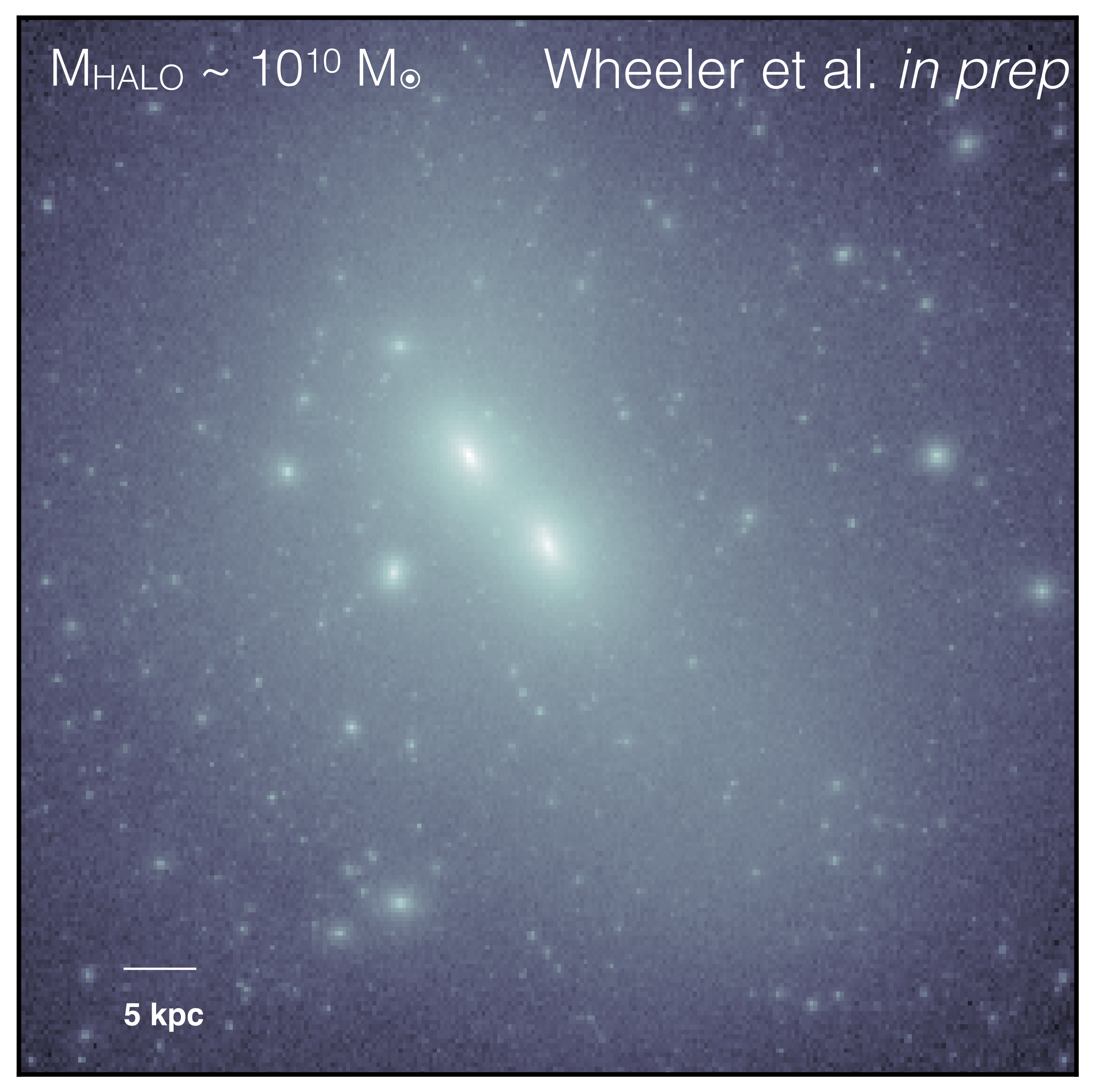
$f_{soft,DM} \sim 25pc$

$m_{gas} \sim 250\ M_\odot$

$f_{soft,gas} \sim 2pc$

Run with FIRE/Gizmo

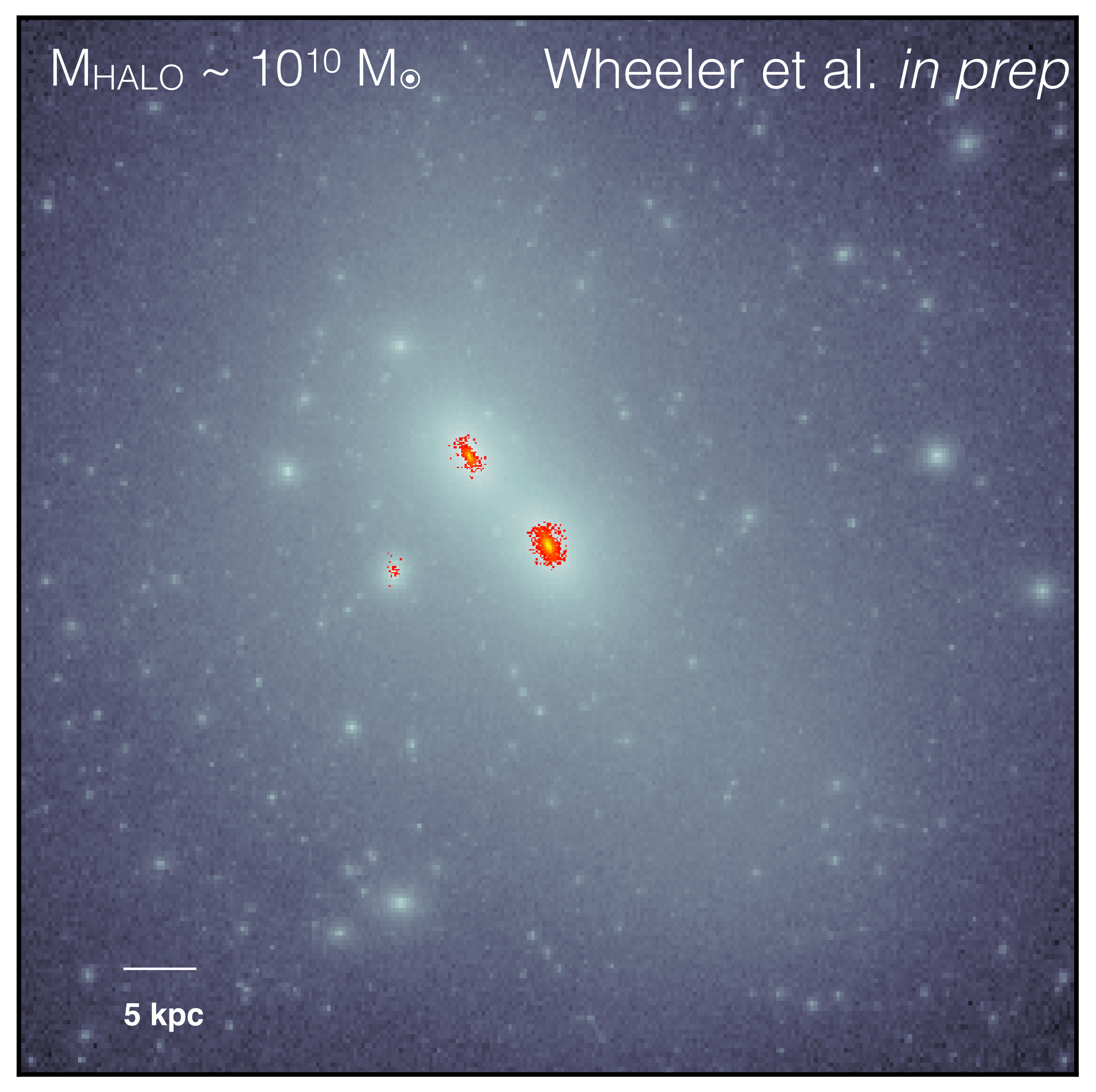
Hopkins et al. 2014
Onorbe et al. 2014


$M_{HALO} \sim 10^{10}\ M_\odot$

Wheeler et al. *in prep*

DWARF GALAXIES ON FIRE

Hopkins 2013,2014



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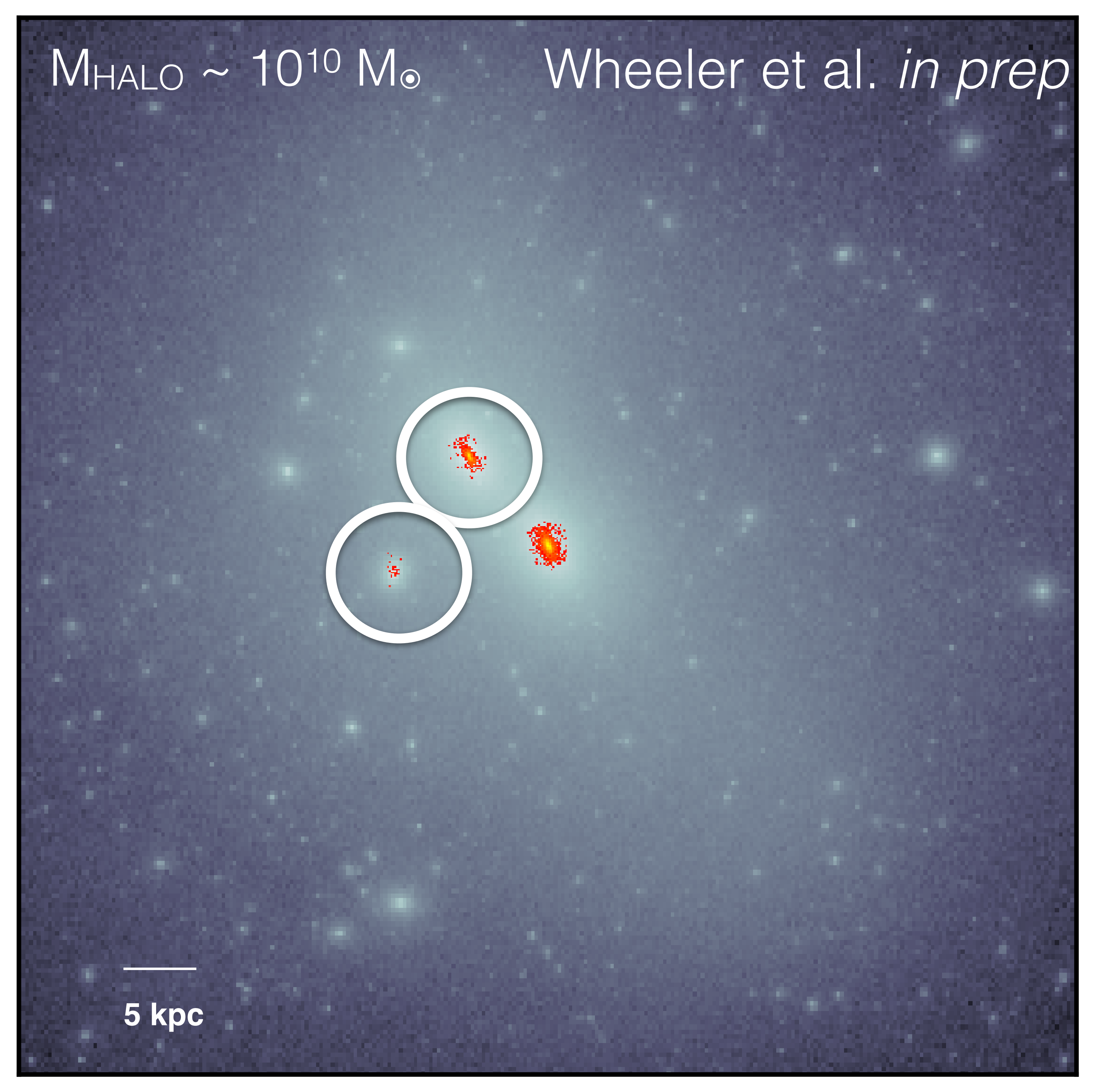

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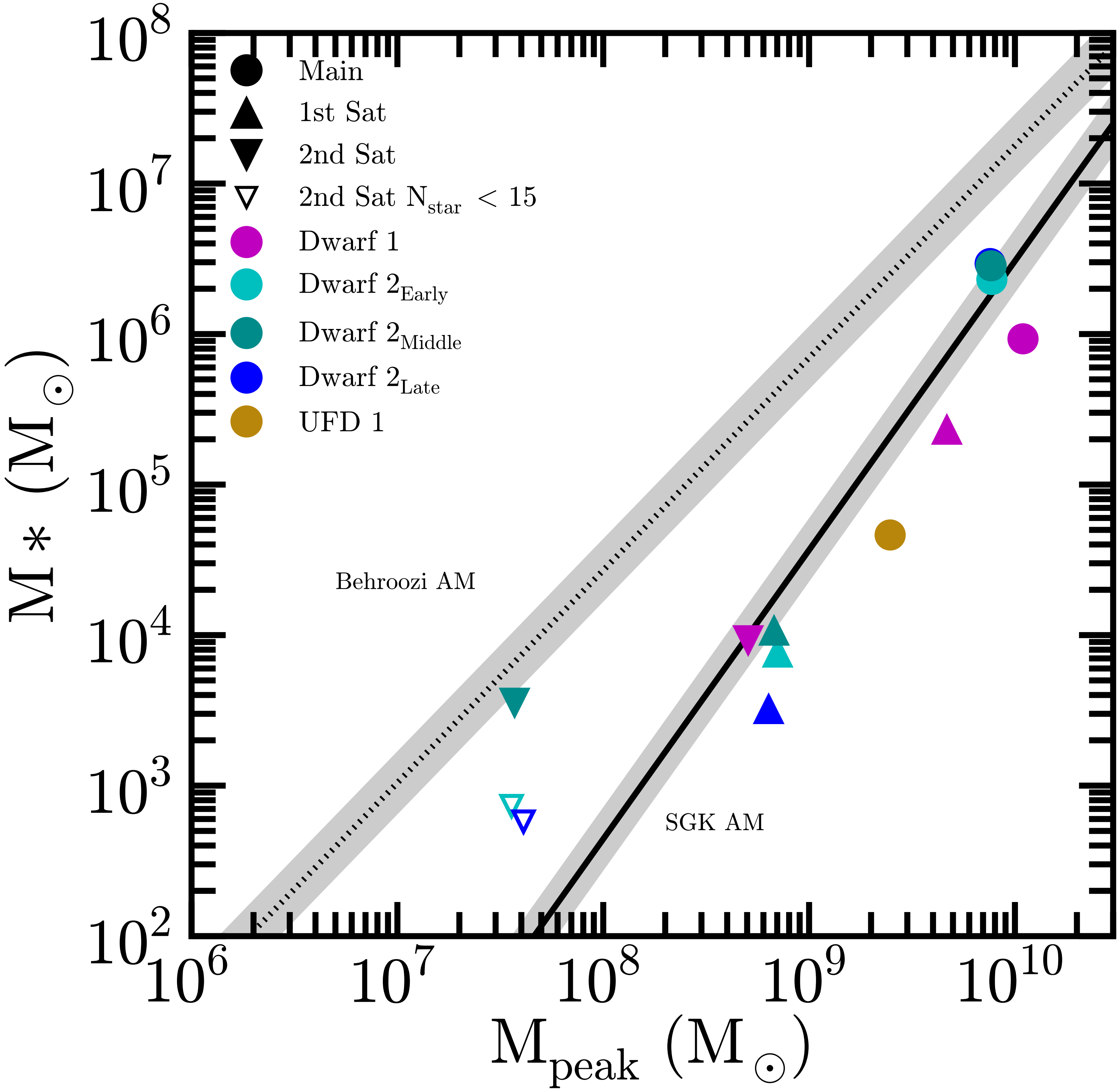
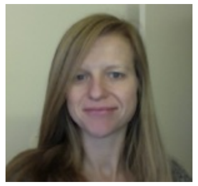


10^8
10^7
10^6
10^5
10^4
10^3
10^2
M_* ($M_\odot$)
10^6
10^7
10^8
10^9
10^{10}
M_{peak} ($M_\odot$)
● Main
▲ 1st Sat
▼ 2nd Sat
▽ 2nd Sat $N_{\mathrm{star}} < 15$
● Dwarf 1
● Dwarf 2_{Early}
● Dwarf 2_{Middle}
● Dwarf 2_{Late}
● UFD 1
Behroozi AM
SGK AM



Hunting for the Smallest Substructures: Ultrafaint Galaxies as Satellites of Known Local Group Dwarfs

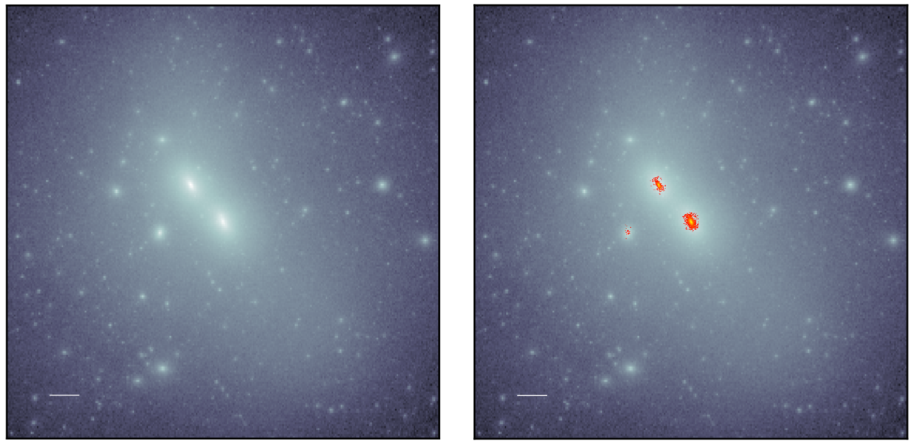
Coral Wheeler[1], Jose Onorbe[2], James S. Bullock[1], Michael Boylan-Kolchin[3], Oliver Elbert[1], Shea Garrison-Kimmel[1], Phil Hopkins[4], Dusan Keres[5]

1-University of California, Irvine, 2-MPIA, 3-University of Maryland 4-Caltech, 5-UCSD

Introduction

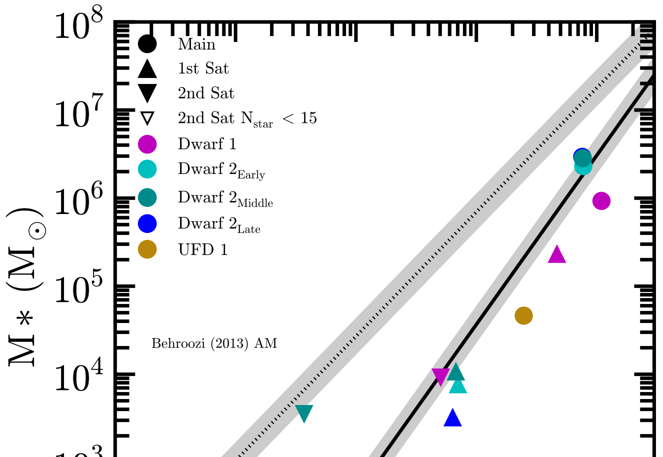
If Lambda-CDM is correct, then all dark matter halos hosting galaxies, from those hosting dwarfs to those hosting giants, are filled with abundant substructure down to very low mass scales ($<< 10^9$ $M_\odot$). Specifically, even the dark matter halos of Local Group field dwarfs should be filled with subhalos, many of which should be fairly massive ($\sim 10^8$ $M_\odot$), and thus are potential targets for hosting small (ultra-faint) galaxies. If these tiny satellites are detected, it would provide evidence that low-mass dark matter halos contain substructure, as predicted in the standard paradigm.

Massive subhalos form stars



Left: Dark matter only visualization of one of the simulated Dwarfs (Dwarf 1, $M_{vir} \sim 10^{10}$ $M_\odot$) and its subhalos. The largest subhalo (up and to the left of its host) has a dark matter mass that peaked at almost half of the host's virial mass ($M_{peak} \sim 5 \times 10^9$ $M_\odot$). Right: Stellar mass density for all massive star-forming satellites overlaid on top of the dark matter. The two most massive satellites form approximately 2×10^5 $M_\odot$ and 5×10^3 $M_\odot$ in stars respectively. A distance of 5 kpc is marked in the lower left corner.

They sit on the M*-M$_{halo}$ relation



METHODS

We run ultra-high resolution simulations ($m_{gas} \sim 250$ $M_\odot$, force res ~ 1pc) of isolated dwarf galaxies (10^9 $M_\odot < M_{vir} < 10^{10}$ $M_\odot$) with GIZMO[a], a state-of-the-art code that utilizes the highly sophisticated FIRE (Feedback in Realistic Environments) recipes[b] for converting gas into stars and capturing the energy fed back from those stars into the surrounding medium. Included are stellar winds from O-type and AGB stars, supernovae explosions, radiation pressure in optically thick gas, long-range radiation flux escaping star-forming regions, and photoionization heating from young stars. We run five simulations of three dwarf halos. Two halos have $M_{vir} \sim 10^{10}$ $M_\odot$ (Dwarf 1 and Dwarf 2). For Dwarf 2 we present three runs (Early, Middle and Late) with slight variations in the sub-grid physics. We also run one isolated ultra-faint (UFD, $M_{vir} \sim 10^9$ $M_\odot$). Dwarf 1, Dwarf 2_{Early}, and the UFD were all run with the same sub-grid recipes. Using these simulations, we predict that isolated dwarf galaxies ($M^* \sim 10^6$ $M_\odot$) in the Local Group should host ultra-faint galaxies ($M^* \sim 3000$ $M_\odot$) as satellites.

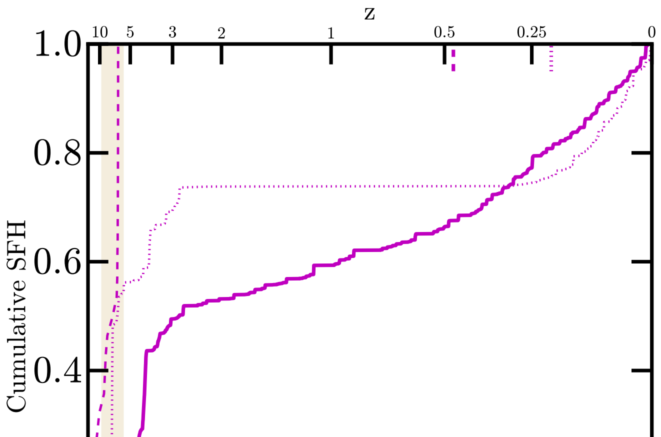
References

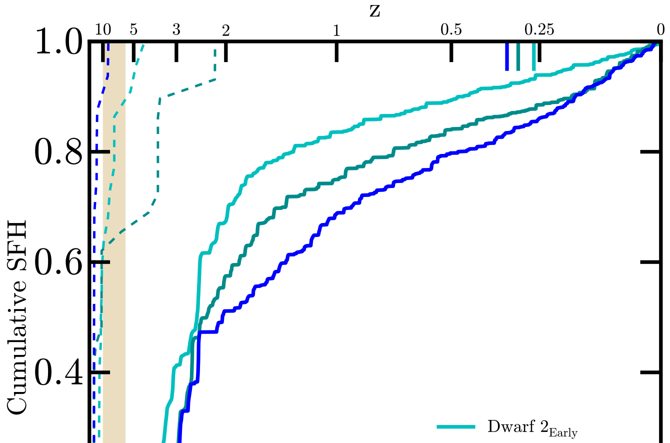
a Hopkins P. F., 2014, ArXiv e-prints, arXiv:1409.7395

b Hopkins P. F., Keres D., Onorbe J., Faucher-Giguere C.-A., Quataert E., Murray N., Bullock, J. S., 2014, MNRAS, 445, 581

c Garrison-Kimmel S., Boylan-Kolchin M., Bullock J. S., Lee K., 2014, MNRAS, 438, 2578

Ultra-faint satellites form all or most of their stars before reionization





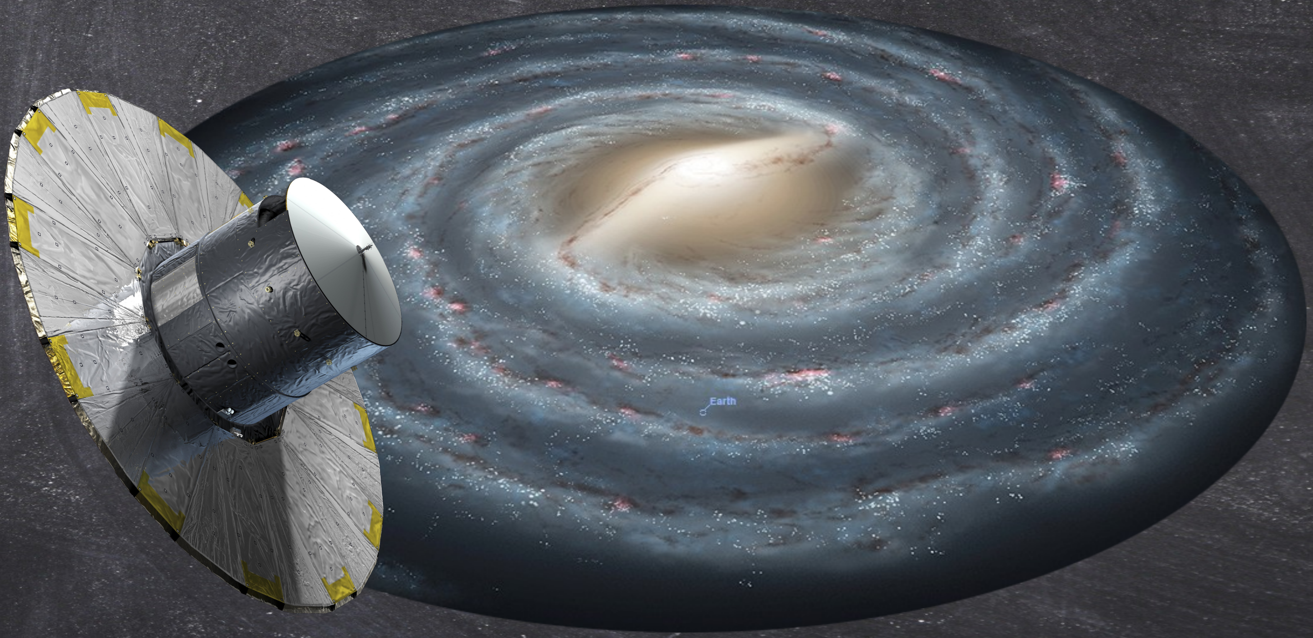
Action-based Dynamical Models for the Milky Way

Wilma Trick
(MPIA, Heidelberg)

Hans-Walter Rix , Jo Bovy, Glenn van de Ven

Long term goal:

→ Get MW potential from Gaia data!

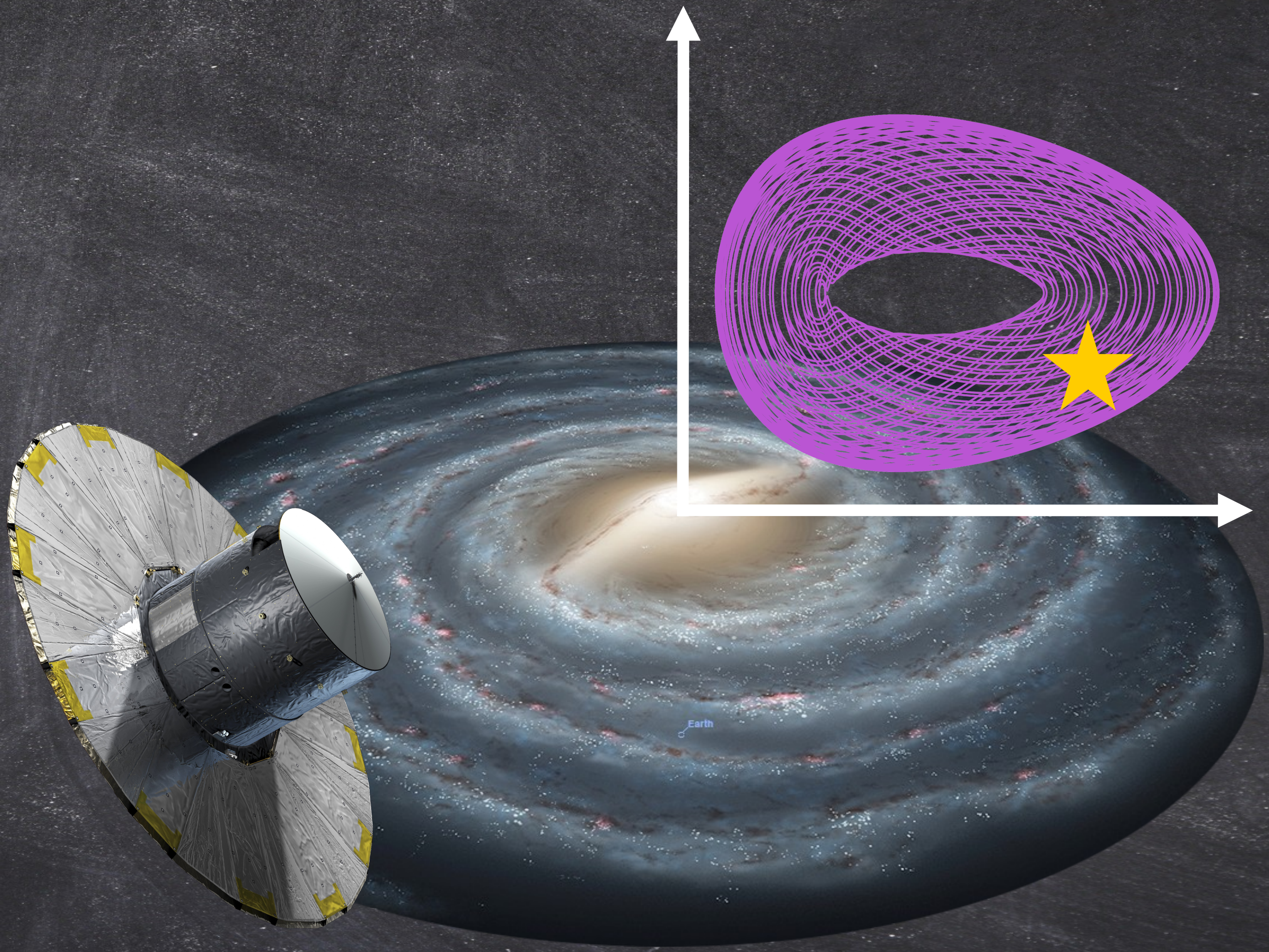


Long term goal:

→ Get MW potential from Gaia data!

What are actions?

- natural labels for stellar orbits
- depend on potential



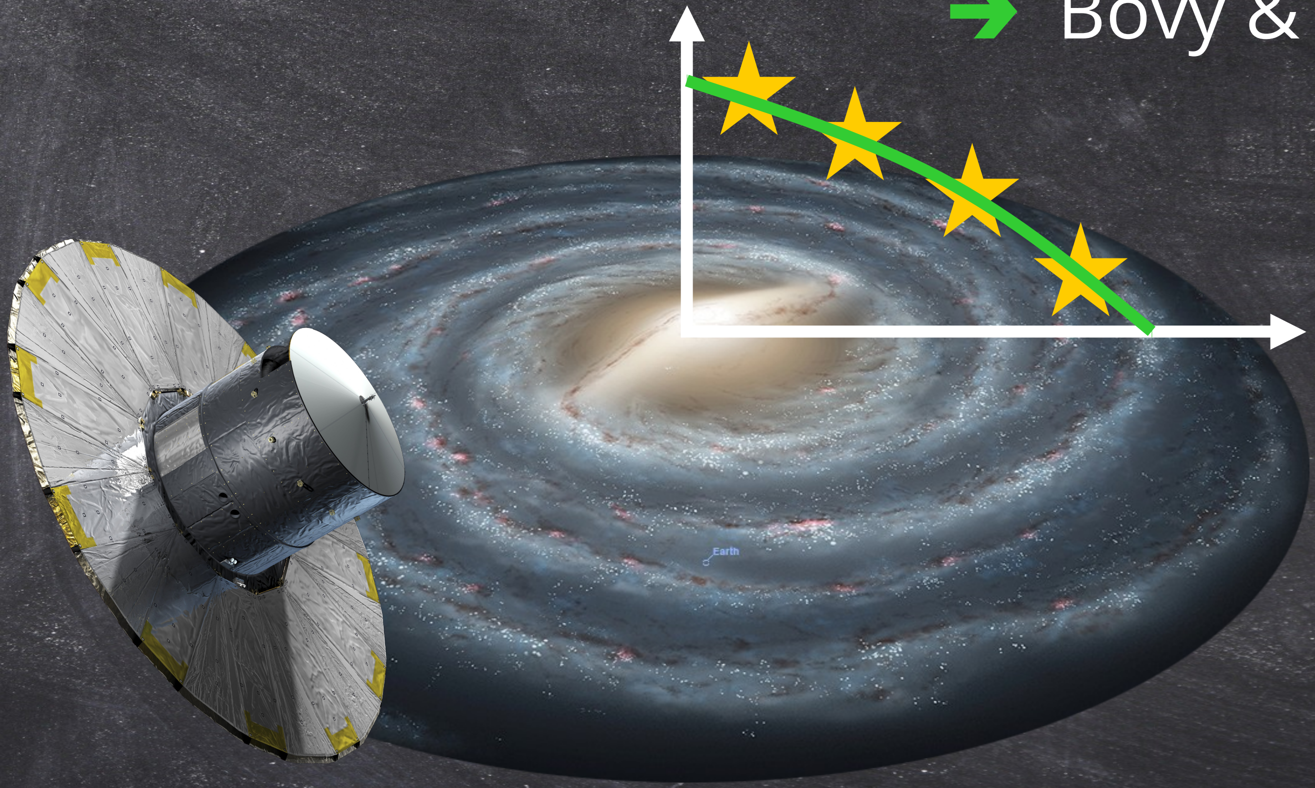
Long term goal:

→ Get MW potential from Gaia data!

Modeling:

- use action distribution function by Binney & McMillan (2011)
- recover potential & DF simultaneously !

→ Bovy & Rix (2013)



Long term goal:

➔ Get MW potential from Gaia data!

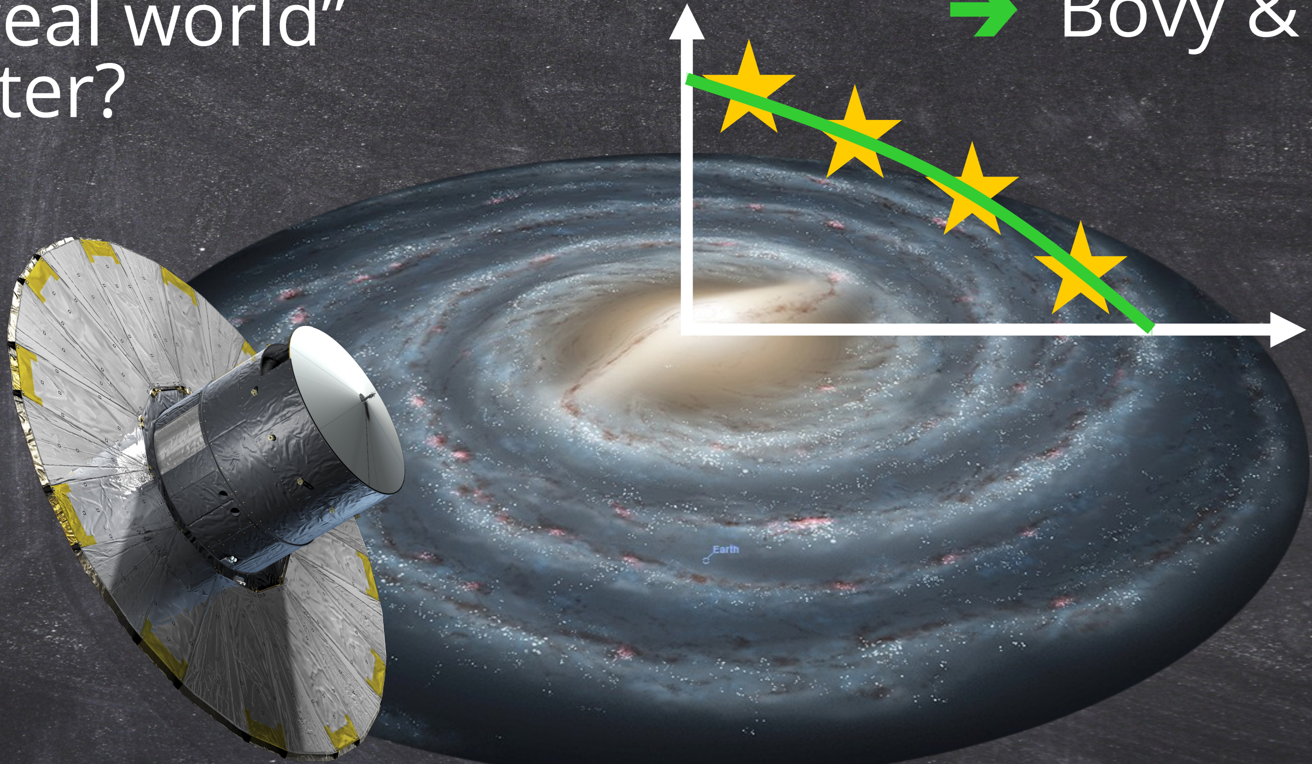
This work's goal:

➔ How much do deviations "model vs. real world" matter?

Modeling:

- use action distribution function by Binney & McMillan (2011)
- recover potential & DF simultaneously !

➔ Bovy & Rix (2013)

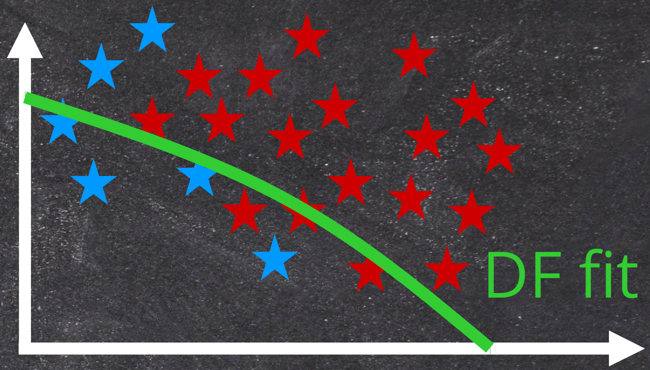


How to deal with „Real World“ issues

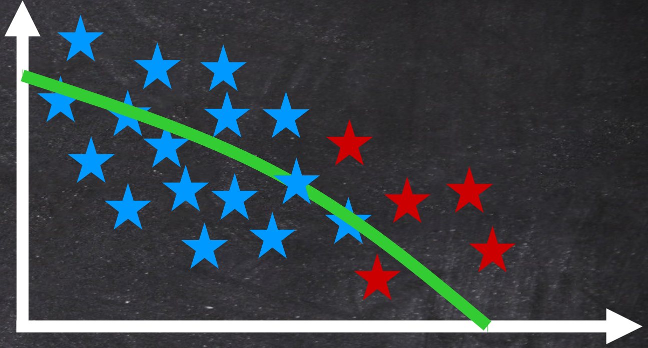
- Where do the most informative stars live?
- What if we get the completeness within the observation volume wrong?
- What if stars do not follow our assumed simple distribution function?
- How to deal with measurement errors?

My favourite result!

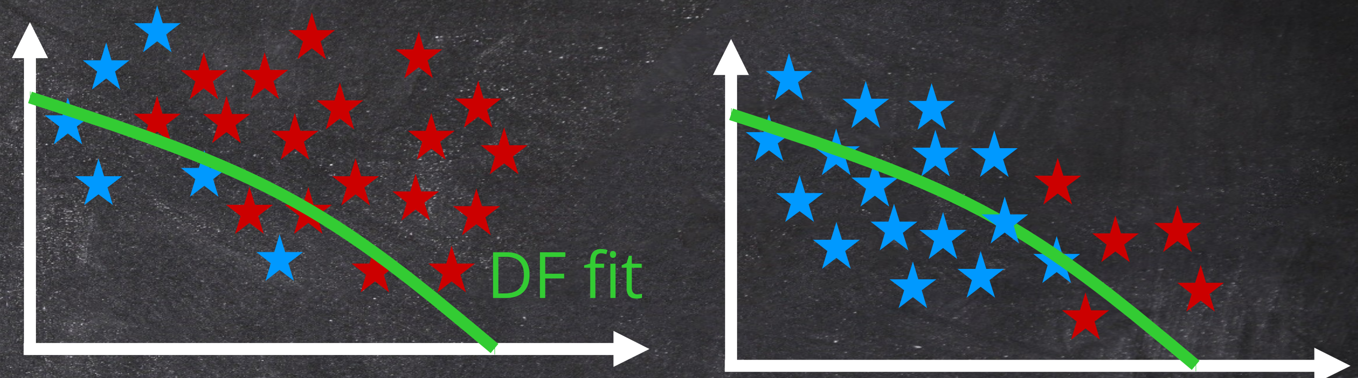
dynamically hot
stellar population



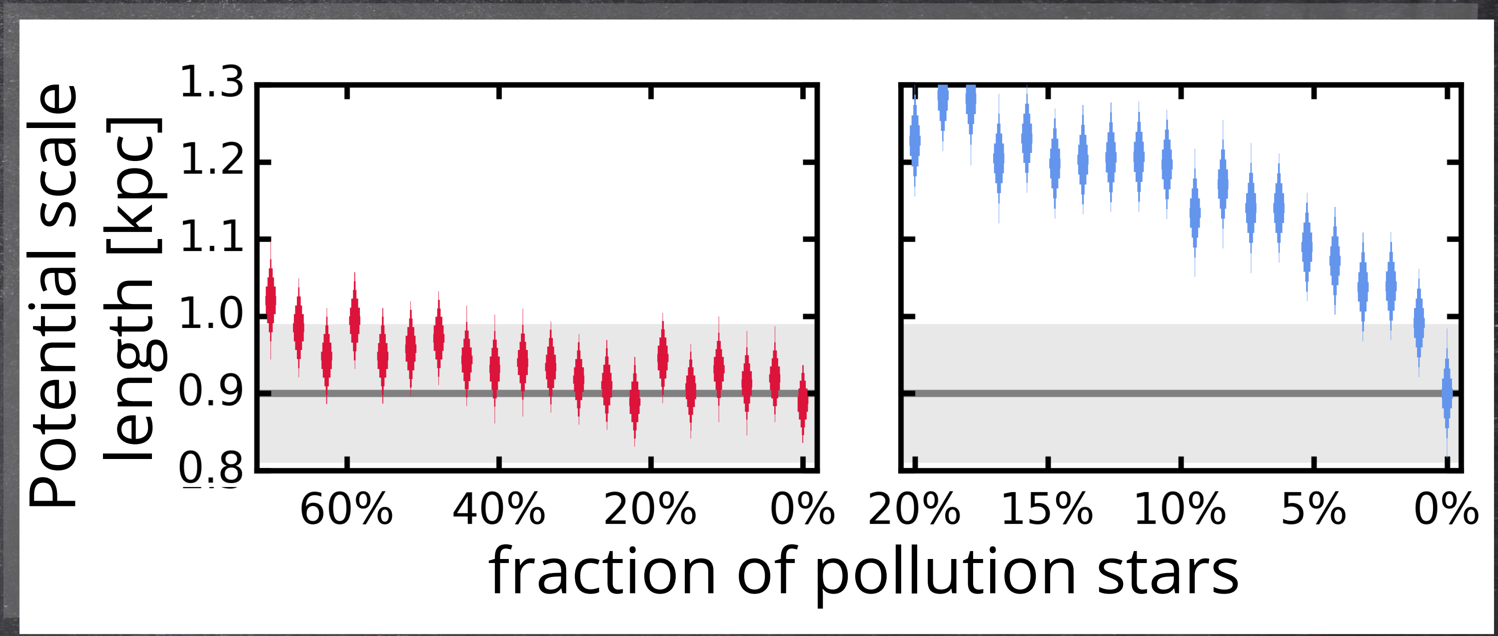
dynamically cold
stellar population



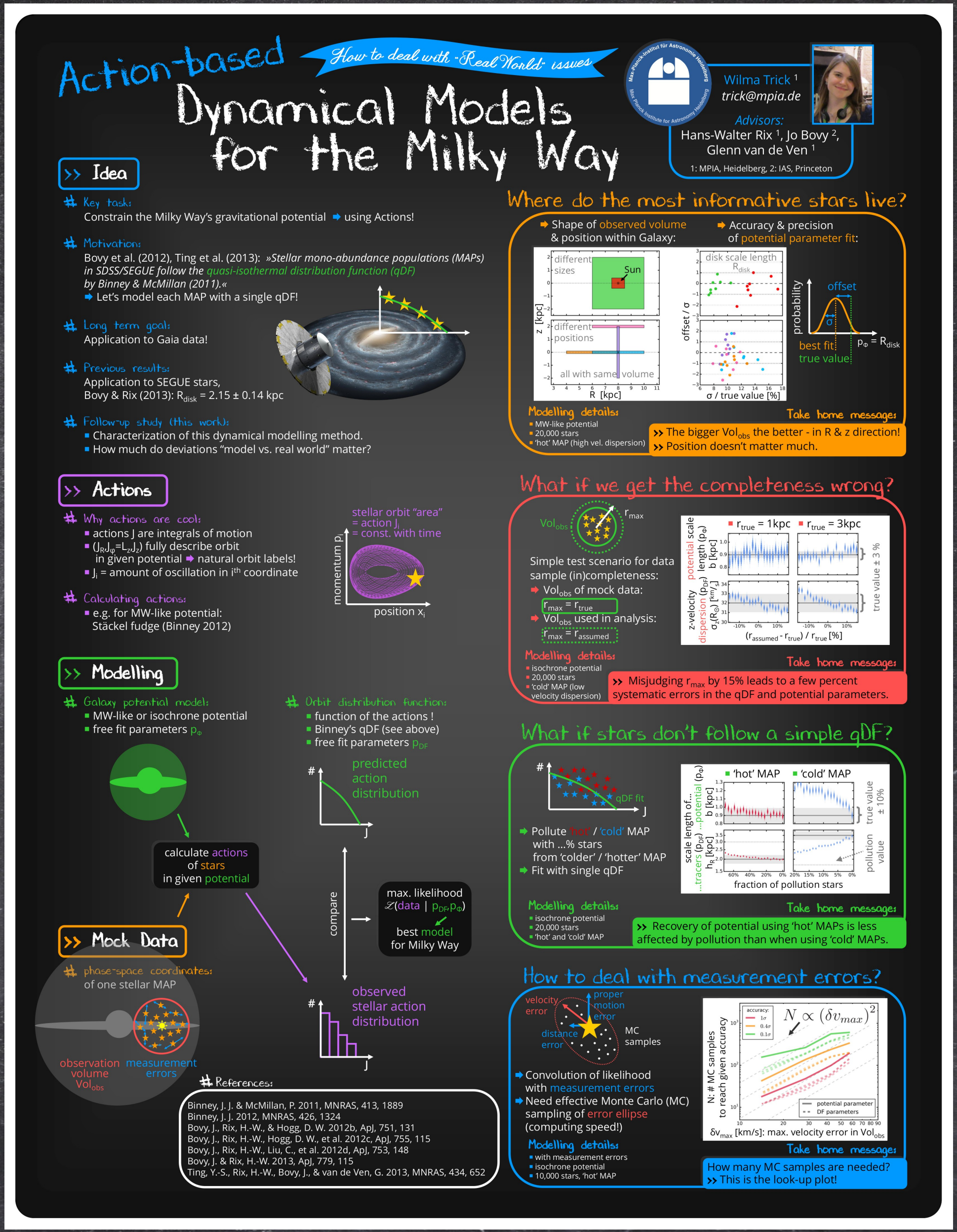
My favourite result!


dynamically hot stellar population

dynamically cold stellar population



›› Recovery of potential using 'hot' stars is less affected by pollution than when using 'cold' stars.



Action-based Dynamical Models for the Milky Way

How to deal with "Real World" issues

Wilma Trick [1]
trick@mpia.de
Advisors:
Hans-Walter Rix [1], Jo Bovy [2],
Glenn van de Ven [1]
1: MPIA, Heidelberg, 2: IAS, Princeton

>> Idea

Key task:
Constrain the Milky Way's gravitational potential ➡ using Actions!

Motivation:
Bovy et al. (2012), Ting et al. (2013): *»Stellar mono-abundance populations (MAPs) in SDSS/SEGUE follow the quasi-isothermal distribution function (qDF) by Binney & McMillan (2011).«*
➡ Let's model each MAP with a single qDF!

Long term goal:
Application to Gaia data!

Previous results:
Application to SEGUE stars,
Bovy & Rix (2013): $R_{disk} = 2.15 \pm 0.14$ kpc

Follow-up study (this work):
- Characterization of this dynamical modelling method.
- How much do deviations "model vs. real world" matter?

>> Actions

Why actions are cool:
- actions J are integrals of motion
- $(J_R, J_\varphi = L_z, J_z)$ fully describe orbit in given potential ➡ natural orbit labels!
- J_i = amount of oscillation in i^{th} coordinate

Calculating actions:
- e.g. for MW-like potential: Stäckel fudge (Binney 2012)

stellar orbit "area"
= action J_i
= const. with time

>> Modelling

Galaxy potential model:
- MW-like or isochrone potential
- free fit parameters p_Φ

Orbit distribution function:
- function of the actions !
- Binney's qDF (see above)
- free fit parameters p_{DF}

predicted action distribution

calculate actions of stars in given potential

max. likelihood $\mathscr{L}$(data | p_{DF}, p_Φ)
best model for Milky Way

observed stellar action distribution

>> Mock Data

phase-space coordinates:
of one stellar MAP

observation volume Vol_{obs}

measurement errors

Where do the most informative stars live?

➡ Shape of observed volume & position within Galaxy:

➡ Accuracy & precision of potential parameter fit:

Modelling details:
- MW-like potential
- 20,000 stars
- 'hot' MAP (high vel. dispersion)

Take home message:
>> The bigger Vol_{obs} the better - in R & z direction!
>> Position doesn't matter much.

What if we get the completeness wrong?

Simple test scenario for data sample (in)completeness:
➡ Vol_{obs} of mock data: $r_{max} = r_{true}$
➡ Vol_{obs} used in analysis: $r_{max} = r_{assumed}$

Modelling details:
- isochrone potential
- 20,000 stars
- 'cold' MAP (low velocity dispersion)

Take home message:
>> Misjudging r_{max} by 15% leads to a few percent systematic errors in the qDF and potential parameters.

What if stars don't follow a simple qDF?

➡ Pollute 'hot' / 'cold' MAP with ...% stars from 'colder' / 'hotter' MAP
➡ Fit with single qDF

Modelling details:
- isochrone potential
- 20,000 stars
- 'hot' and 'cold' MAP

Take home message:
>> Recovery of potential using 'hot' MAPs is less affected by pollution than when using 'cold' MAPs.

How to deal with measurement errors?

➡ Convolution of likelihood with measurement errors
➡ Need effective Monte Carlo (MC) sampling of error ellipse (computing speed!)

Modelling details:
- with measurement errors
- isochrone potential
- 10,000 stars, 'hot' MAP

Take home message:
How many MC samples are needed?
>> This is the look-up plot!

References:

Binney, J. J. & McMillan, P. 2011, MNRAS, 413, 1889
Binney, J. J. 2012, MNRAS, 426, 1324
Bovy, J., Rix, H.-W., & Hogg, D. W. 2012b, ApJ, 751, 131
Bovy, J., Rix, H.-W., Hogg, D. W., et al. 2012c, ApJ, 755, 115
Bovy, J., Rix, H.-W., Liu, C., et al. 2012d, ApJ, 753, 148
Bovy, J. & Rix, H.-W. 2013, ApJ, 779, 115
Ting, Y.-S., Rix, H.-W., Bovy, J., & van de Ven, G. 2013, MNRAS, 434, 652

For more
check out
my poster! ;-)

Reconstructing the Stellar Accretion History of the Galactic Halo:

A future constraint on the nature of dark matter via statistical chemical tagging

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1 PIFI Post-doctoral Fellow, Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences
2 Department of Astronomy (Columbia U.) 3 Department of Statistics (Columbia U.)

Motivation:

- **Observations of the Galactic halo support the theory that accreted dwarf galaxies built it up over time via hierarchical merging** (Newberg et al. 2002; Majewski et al. 2003; Belokurov et al. 2006)
- Observations of stellar populations in nearby dwarf galaxies has led to the "cusped vs. cored" central density debate over the state of dark matter (DM) in these systems (e.g., de Blok 2010, Peñarrubia et al. 2012)
- **If hierarchical merging of satellites constitutes the prevailing mode of building the stellar halo** as suggested by both observations (see above) and simulations (N-body, SPH, AMR, etc. — both with & without gas), **then devising a way to recover its accretion history profile (AHP) would place further constraints on the nature of DM in dwarf galaxies** (see, e.g., Diemand & Moore 2009)

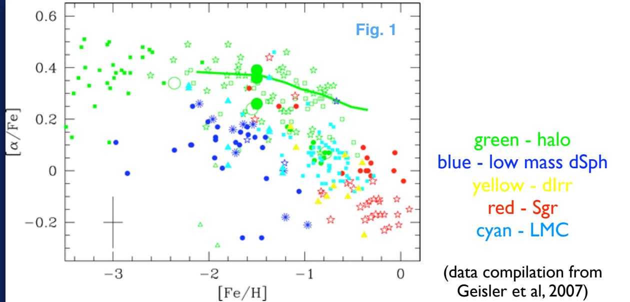

Fig. 1

(data compilation from Geisler et al, 2007)

Observations vs. Simulations + SAMs:

- A compilation of observations (Fig. 1) given in Geisler et al. (2007) unveil the **potential for "statistical chemical tagging" of past dwarf galaxy accretion** into the Galactic halo (see, e.g., Schlaufman et al. 2012)
- **Mock observations of stellar chemical abundances (Fig. 2) generated from the semi-analytic chemical evolution models (SAMs)** of Robertson et al. (2005) and implemented in the Bullock & Johnston (2006) accreted halo simulations by Font et al. (2006) **show remarkable similarities to the observational data in Figure 1**

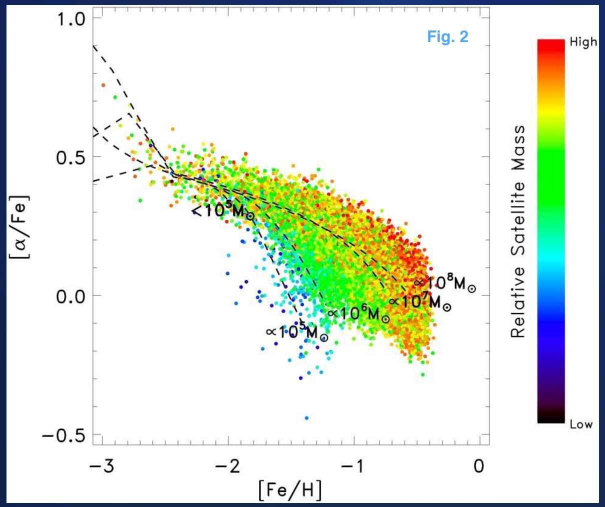

Fig. 2

Mixture Modeling of the Halo:

- Chemical abundance ratio distributions (CARDs) are generated from the mock stellar abundances in the ~1500 model dwarf galaxy simulations across 11 halo realizations
- **Satellite template sets (STS) are created from binning models by time of accretion and satellite mass/luminosity** (e.g., Fig. 3) — STS are labeled by # of time bin × # of mass bins (see abstract for details)
- **Each STS is then used** in conjunction with the expectation-maximization (EM) algorithm **to analyze ~10,000 mock observations of each halo realization generating an AHP for each of them**

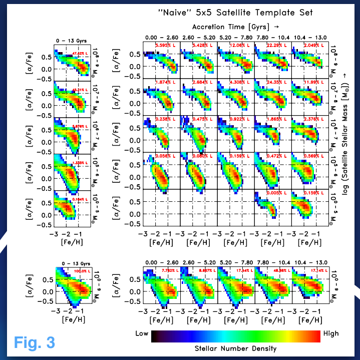

Fig. 3

Results I - Individual AHPs:

- Figs. 4 - 7 show **EM estimates (open black symbols)** and their respective **true values (colored donuts)** where the **colors = their FoE (see legends)**
- 1x5 STS (Fig. 4) represents the LF for all acc. satellites for 5 mass scales (i.e., one acc. time bin)
- 5x1 STS (Fig. 5) represents the acc. time function for all acc. satellites for 5 time epochs (i.e., one mass bin)
- **1x5 STS EM est. show remarkable agreement** for all mass bins while the 5x1 STS do considerably worse
- **Differences in 1x5 vs. 5x1 STS EM est. performance are due to their relative degeneracies in CARD-space** (see left and bottom of Fig. 3)

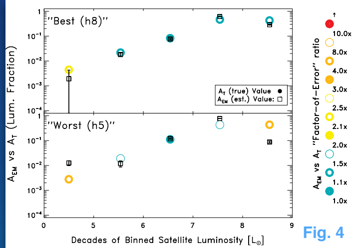

Fig. 4

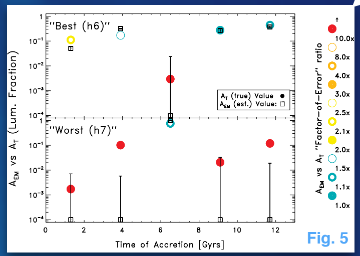

Fig. 5

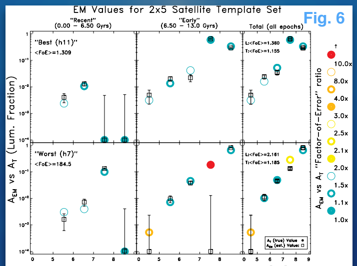

Fig. 6

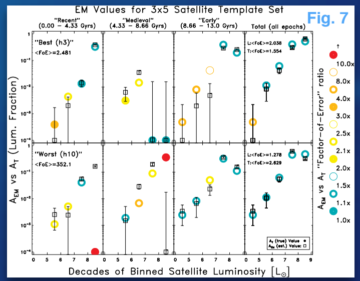

Fig. 7

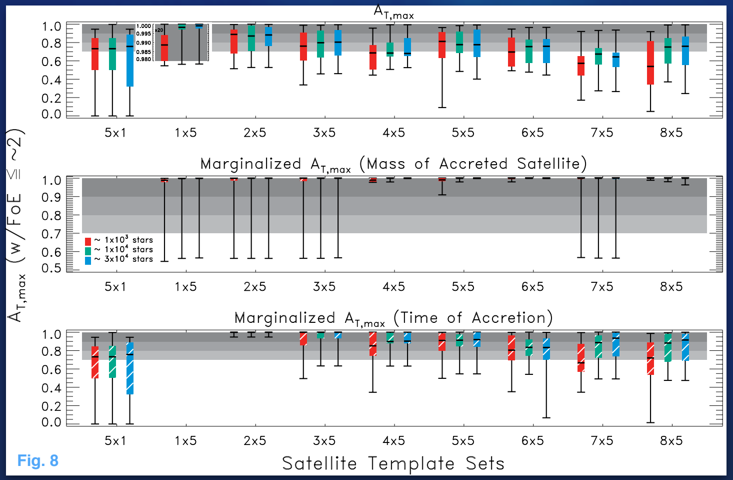

Fig. 8

Concluding Remarks:

Current/near-off surveys e.g. **APOGEE, GAIA, & GALAH + current data should provide a suitably well-mixed ~1,000 - 10,000 CARD sample to apply this technique in the next 2-3 years** (>10,000 samples may have to wait for TMT, GMT, and/or the ELT).

Results II - $A_{T,max}$ Vs. FoE:

- **Fig. 8 summarizes the performance of our analysis** (min, max & quartiles for 11 halo results from each STS)
- Three panels show the max total of rel. contributions to the halo luminosity ($A_{T,max}$) that have FoE ≲ 2
- Top — $A_{T,max}$ w/o any marginalization of estimates in time or mass
  Middle — $A_{T,max}$ after marginalization over est. in time (i.e. one time bin)
  Bottom — $A_{T,max}$ after marginalization over est. in mass (i.e. one mass bin)
- **Fair est. from 2x5 & 3x5 STS** ("early vs. late" accretion) **for AHPs are achievable**
- **Marginalization in time and mass reveals that additional information (i.e. larger STS) can be exploited** to improve LF or acc. time estimates

Short Abstract (see arXiv:1410.6166 for paper):

While some observational studies have placed limits on the quantity and nature of accreted dwarf galaxies' contributions to the Milky Way (MW) stellar halo (e.g., Unavane et al. 1996; Schlaufman et al. 2012), none has given a detailed account of their total relative contributions. In this study we test the prospects of using chemical abundances found in stars of the stellar halo to determine its formation history. To do this we utilize a statistical procedure called the expectation-maximization (EM) algorithm on ≥ 1000 mock observations of the stellar chemical abundance ratios ([α/Fe], [Fe/H]) (from Robertson et al. 2005; Font et al. 2006) found in the eleven simulated "MW-like" halos of Bullock & Johnston (2005) to recover the relative stellar mass contributions from representative accreted dwarf galaxies (templates). Here, we "naively" partitioned ~1500 accreted dwarf satellite models by their accretion times (i.e. equally separating them in time), and by assigning mass separations mainly by decades ranging from about one thousand to a billion solar masses. Using these templates we find that in most cases investigated we can recover luminosity fractions (LF) that cover ≳ 90% of the total relative stellar mass contributions (from each progenitor template) to within a factor of 2.

Goals:

- **Reconstruct the AHP of the Galactic halo from modeling its stellar CARDs**
- **Test whether ΛCDM simulations are consistent with the AHP** constructed from the chemical abundance observations **of the stellar Galactic halo**

Current & Future Plans:

- **Optimize the selection of STS** for use in analyzing the stellar halo via the EM algorithm
- **Create new models that incorporate MDYs to distribute chemical abundances in satellite dwarfs (see, e.g., Lee et al. 2013)**
- **Use model templates with real data to constrain the AHP of the Galactic halo and the nature of DM**

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Robertson, B., Bullock, J. S., Font, A. S., Johnston, K. V., & Hernquist, L. 2005, ApJ, 632, 872
Schlaufman, K. C., Rockosi, C. M., & Lee, Y. S. et al. 2012, ApJ, 749, 77
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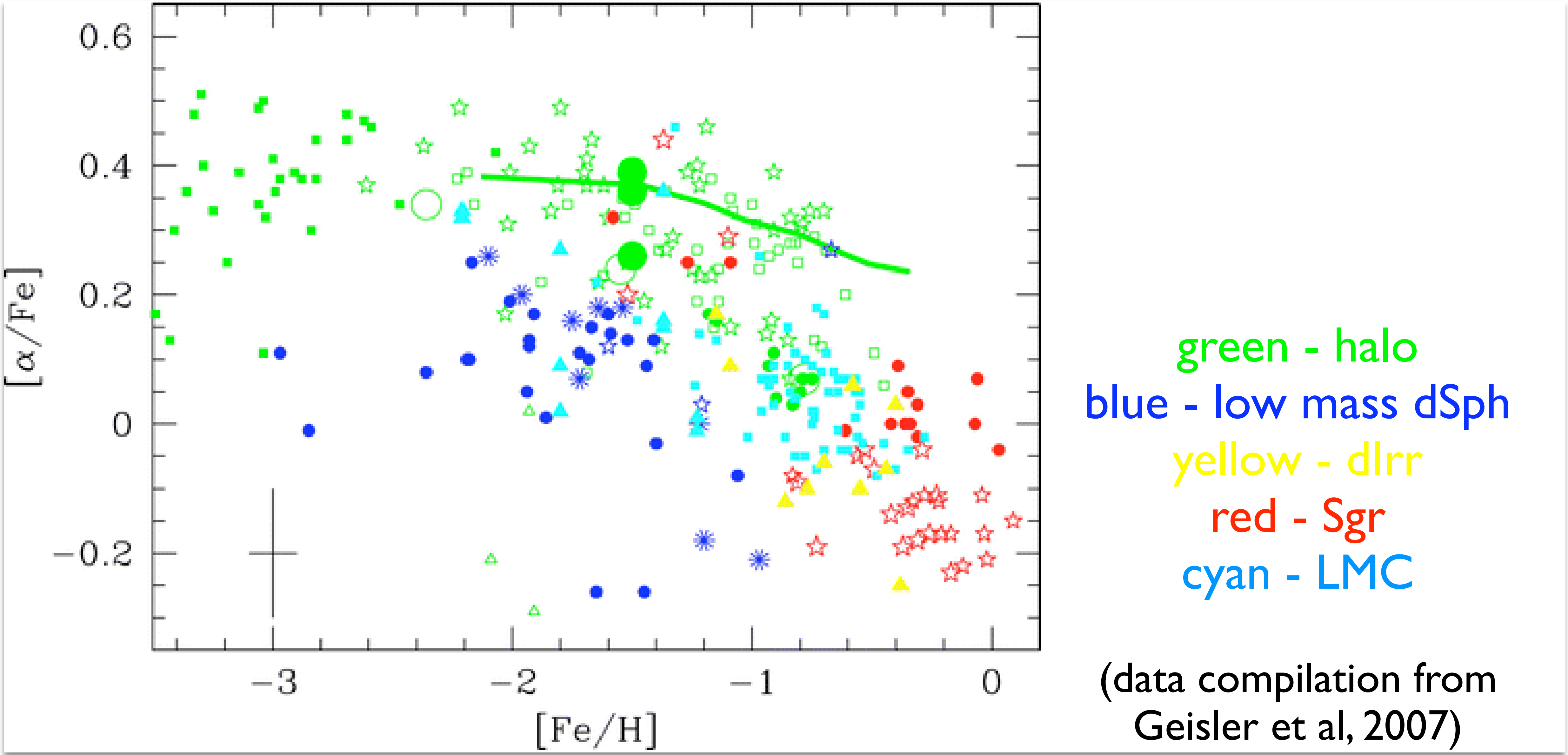
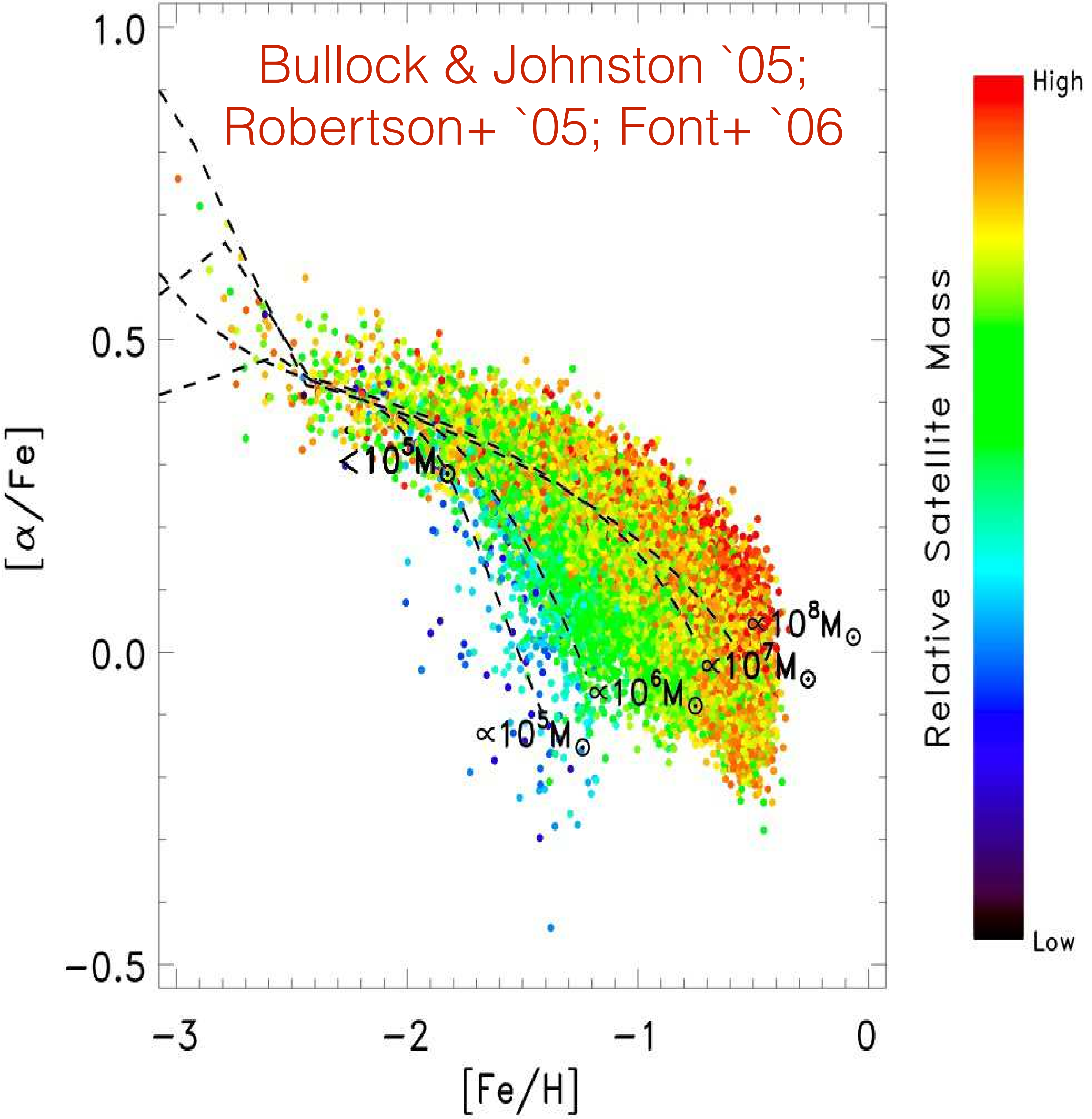
Motivation



green - halo
blue - low mass dSph
yellow - dIrr
red - Sgr
cyan - LMC

(data compilation from Geisler et al, 2007)

- Observations indicate that dwarf galaxies lie “unique” locations in chemical abundance ratio distribution (CARD) space



Bullock & Johnston `05; Robertson+ `05; Font+ `06

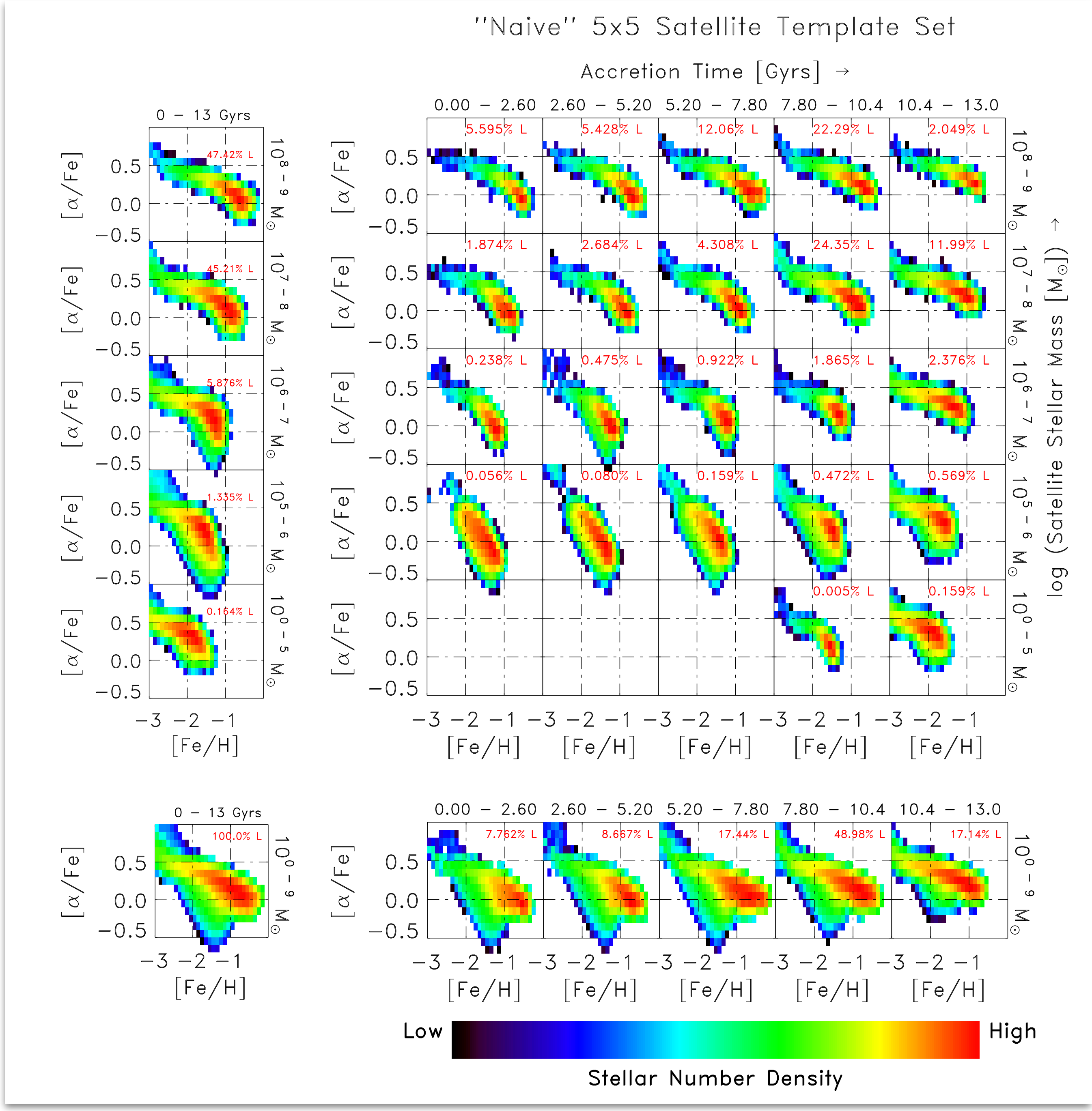
- ✦ Models indicate the same “uniqueness” CARD space

Summary of Method

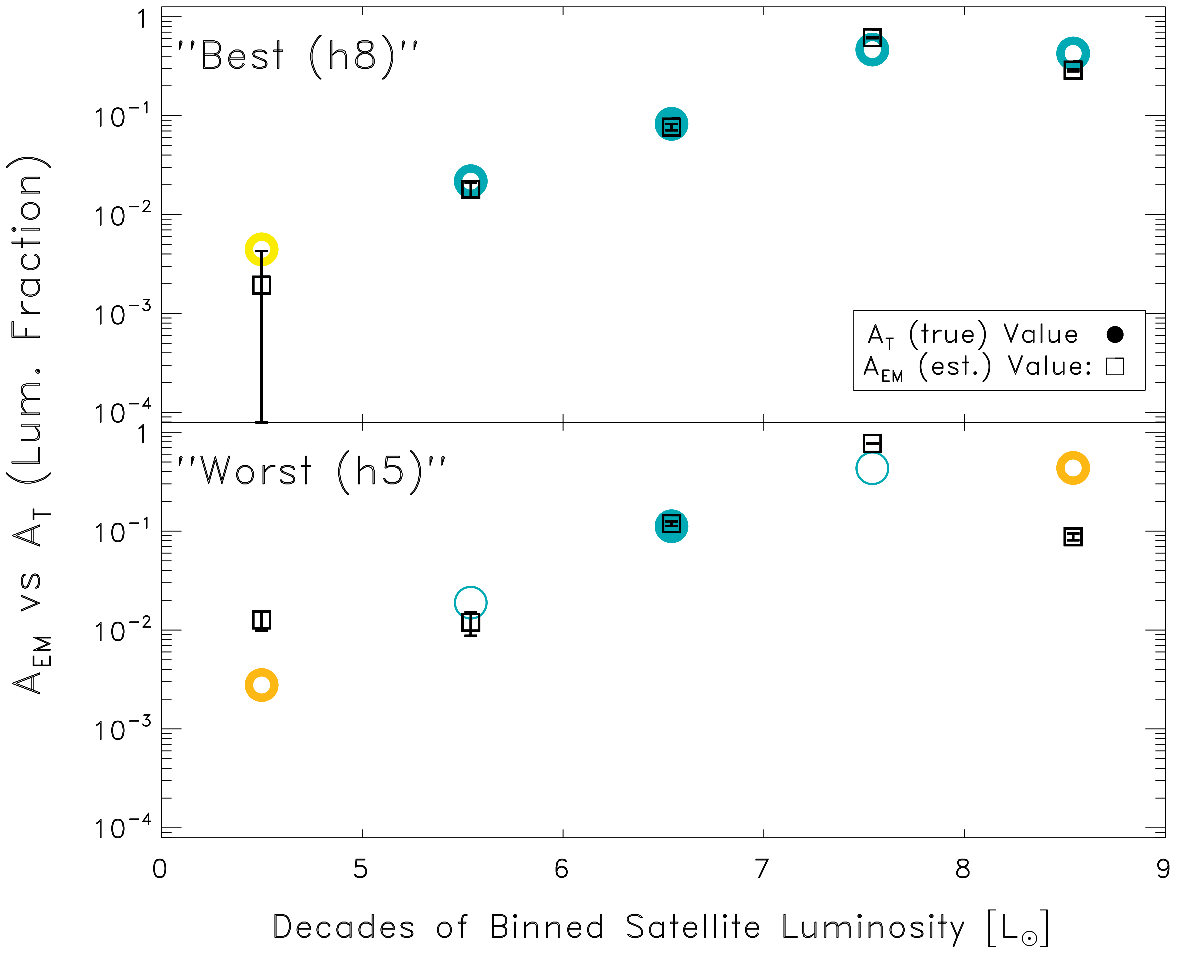
- Construct satellite template sets (STS) to use in generative mixture models of “MW-like” halos

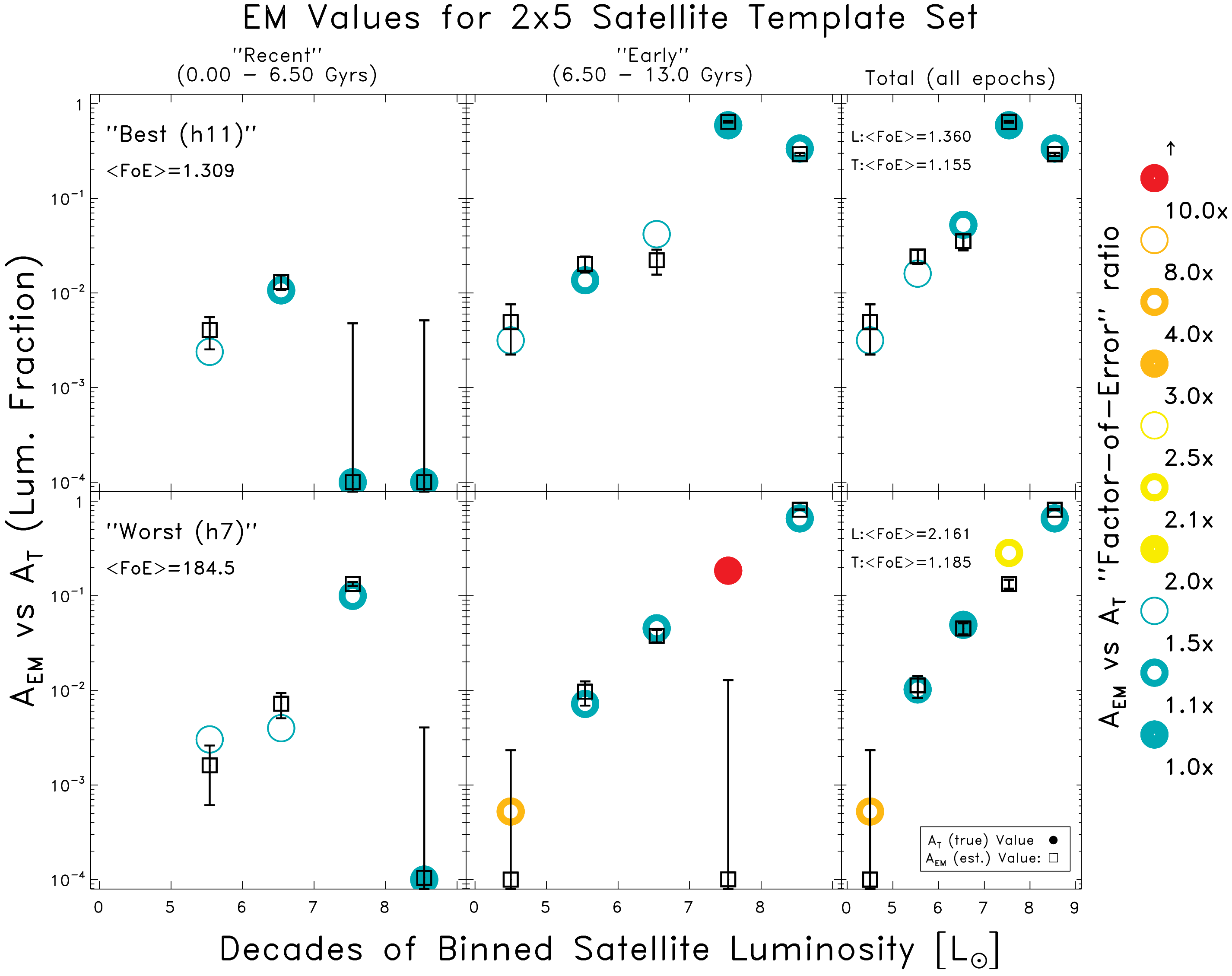
- We apply the EM algorithm to simulated halo accretion data using STS

- Obtain estimates for the rel. contributions to the total luminosity of each simulated halo



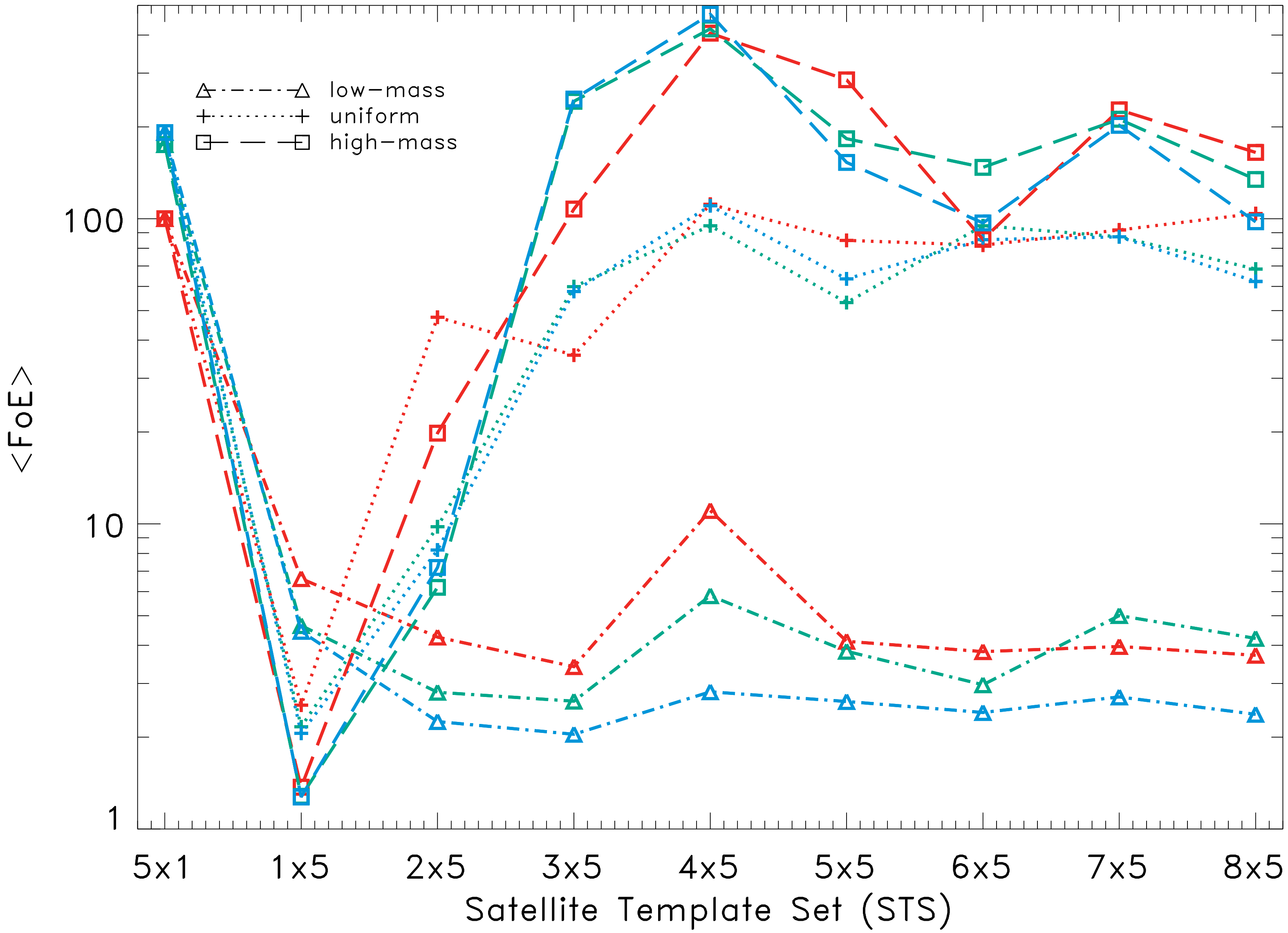
Some Notable Results





- Results indicate that we can recover the accretion history of the halo in most cases examined with “high precision” — i.e., within a FoE = 2

Some Notable Results



- Method is particularly sensitive to older accretion events involving low-luminous dwarfs e.g. ultra-faint dwarfs — precisely those events that are too ancient to be seen by phase-space studies of stars and too faint to be seen by high-z studies of the early Universe.

Dispersion of tidal debris in the Via Lactea II halo

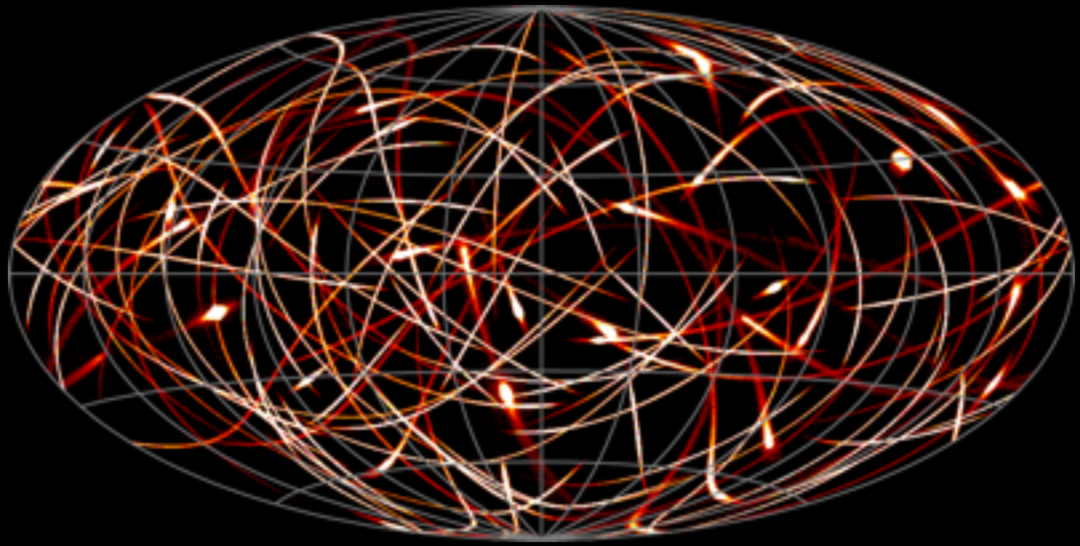
Wayne Ngan, Raymond Carlberg, Brandon Bozek, Rosemary Wyse, Alex Szalay, Piero Madau

Via Lactea II dark matter density at z=0 (Diemand et al, 2008)

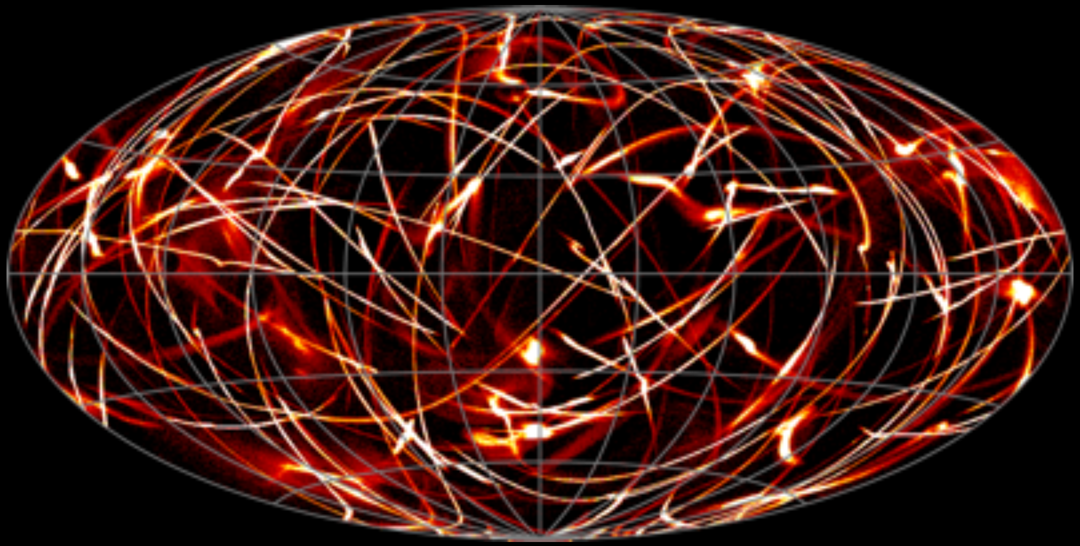
- High resolution dark matter simulation of Milky Way-sized halo
- Model this potential **without** assuming NFW, logarithmic, etc profiles
- Use halo finder to isolate and remove subhalos -- "smooth" vs "lumpy" versions
- Simulate globular cluster disruptions in these potentials

Dispersion of tidal debris in the Via Lactea II halo

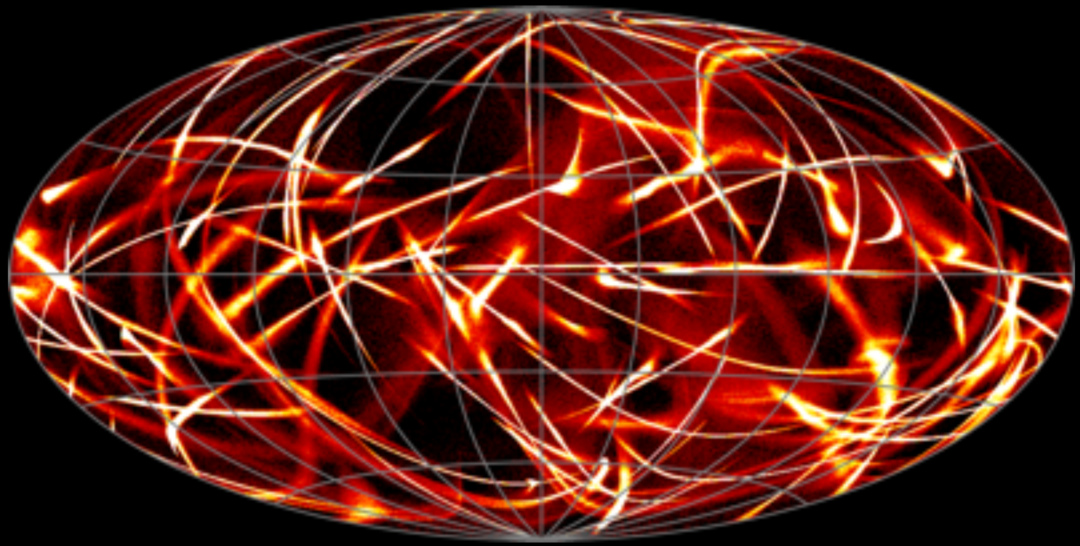
100 globular cluster streams inside these dark matter halos



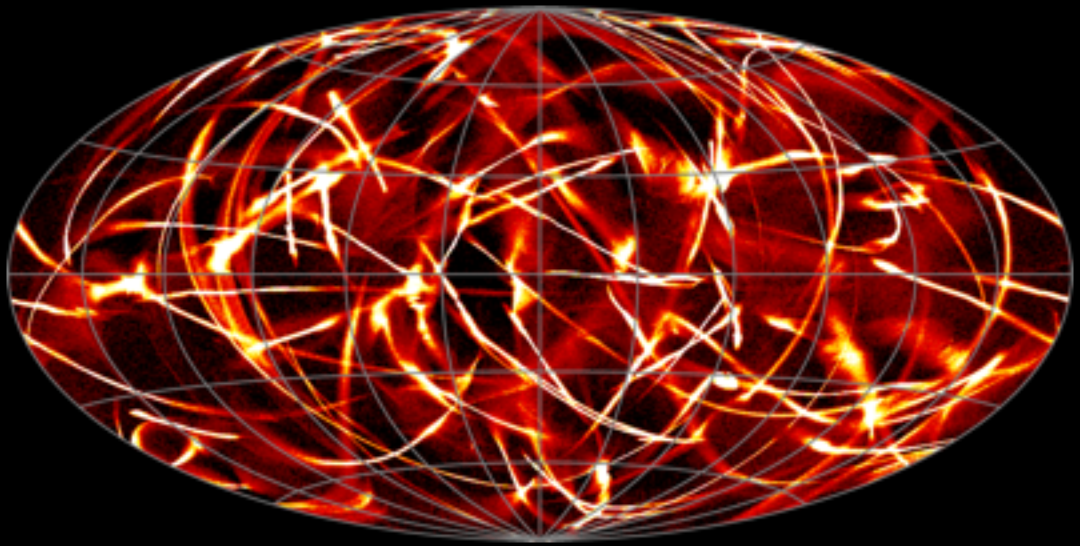
Spherical (NFW) halo, smooth



Spherical (NFW) halo, lumpy



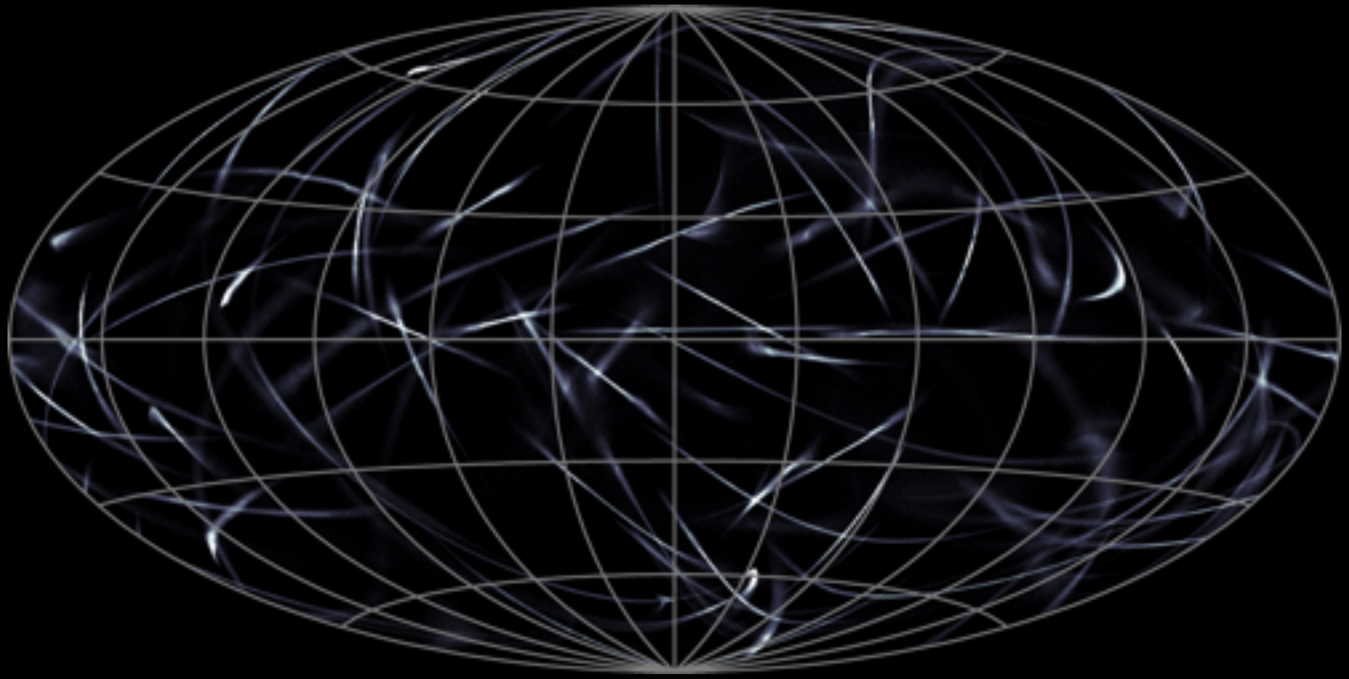
VL-2 halo, smooth



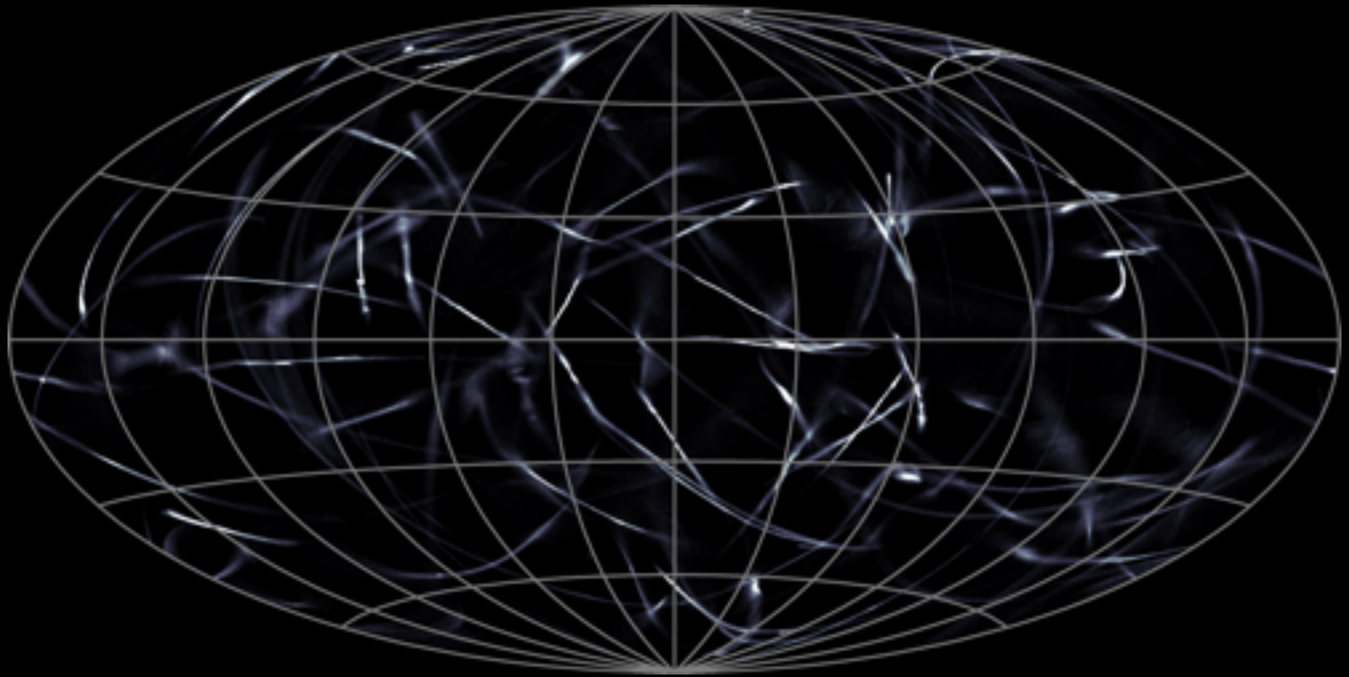
VL-2 halo, lumpy

Dispersion of tidal debris in the Via Lactea II halo

The **densest** streams in VL-2



VL-2 halo, smooth



VL-2 halo, lumpy

- Halo shape makes debris more dispersed
- Subhalos make thin streams clumpier
- Observational expectation: Still plenty of thin streams inside r < 30 kpc

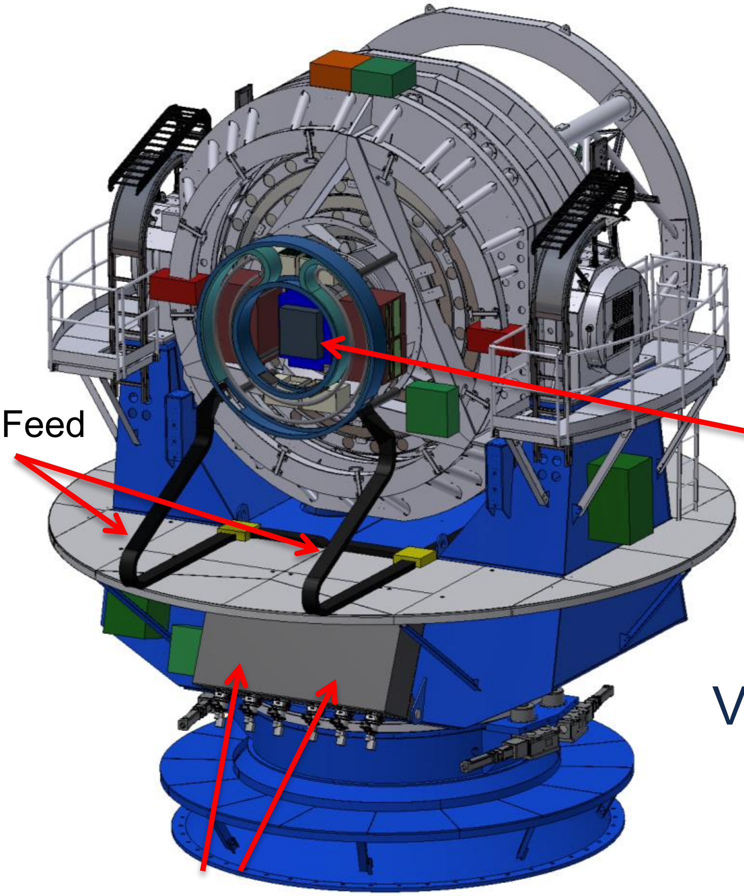
4MOST – 4m Multi-Object Spectroscopic Telescope

Andreas Quirrenbach (LSW Heidelberg)

4MOST Consortium (PI Roelof de Jong, AIP)

Facility Instrument Overview

- New Wide-field Corrector, fiber positioner and three spectrographs
- Spectrographs mounted on telescope fork (gravitation invariant)
- Short fiber run (~15 m)

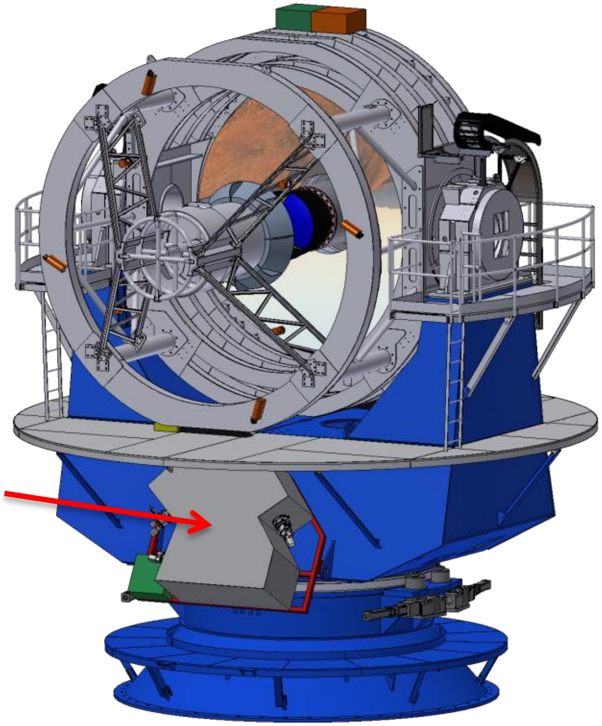


Fiber Feed

Fiber positioner

Low-Res Spectrographs

VISTA telescope



High-Res Spectrograph

R. Haynes et al., SPIE 9147-243
D. Haynes et al., SPIE 9147-235

Main Science Drivers

A 5 Year 4MOST Survey Provides

- **Euclid/LSST/SKA** (and other surveys) complement:
  - Dark Energy & Dark Matter (BAO, RSD, lensing)
  - Galaxy evolution (groups & clusters)
  - Transients (SNe Ia, GRB)
  - >13 $\times 10^6$ spectra of m_V~20-22.5 mag LRGs & ELGs
- **eROSITA** complement:
  - Cosmology with x-ray clusters to z~0.8
  - X-ray AGN/galaxy evolution and cosmology to z~5
  - Galactic X-ray sources, resolving the Galactic edge
  - 2 $\times 10^6$ spectra of AGN and galaxies in 50,000 clusters
- **Gaia** complement:
  - Chemo-dynamics of the Milky Way
  - Stellar radial velocities, parameters and abundances
  - 13 $\times 10^6$ spectra @ R~5000 of m_V~15-20 mag stars
  - 2 $\times 10^6$ spectra @ R~20,000 of m_V~14-16 mag stars

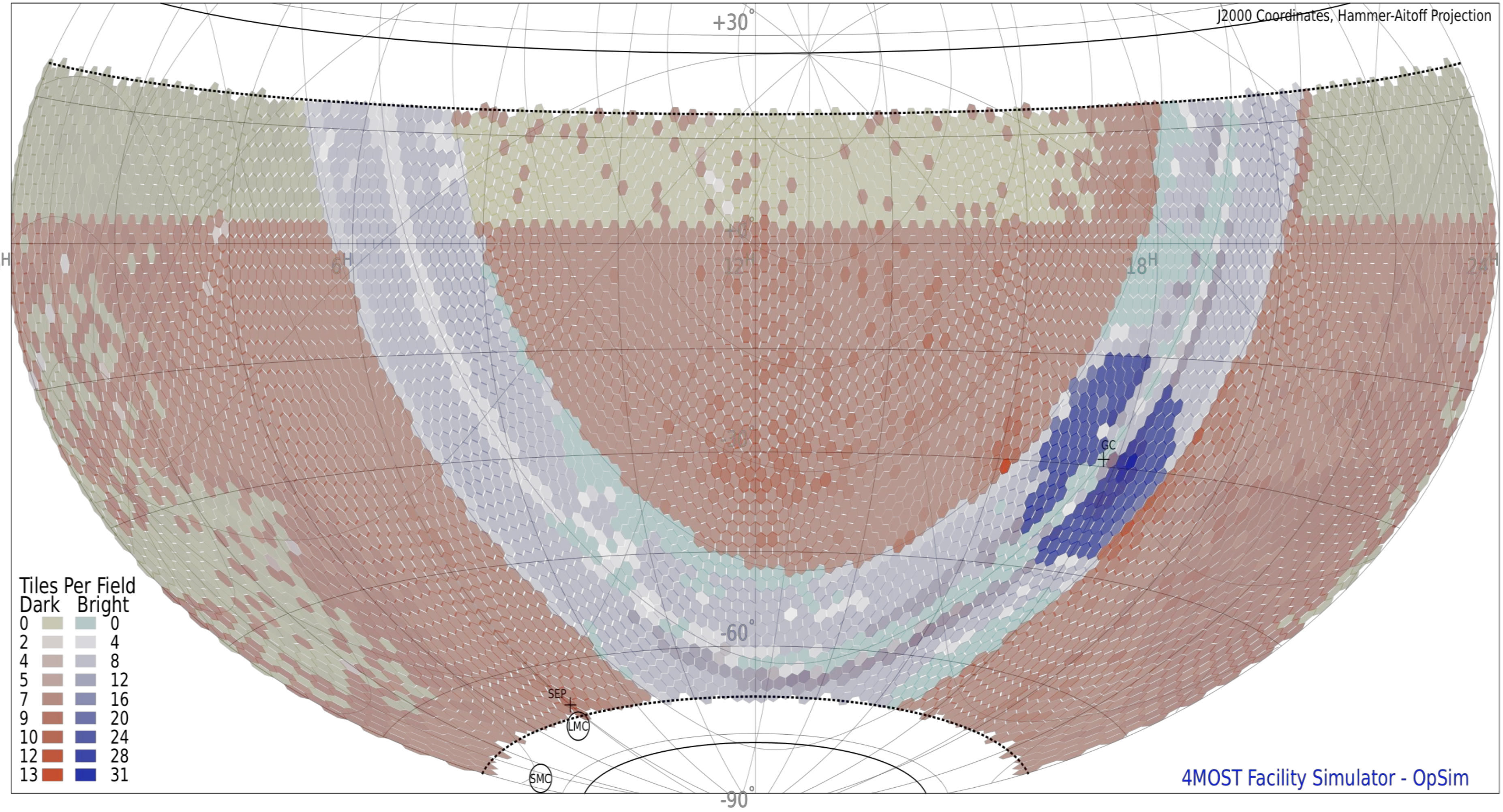
+ ~15 million spectra for community proposals

4MOST is a general purpose spectroscopic survey facility serving many astrophysical communities

Instrument Specification

Specification	Design value
Field-of-View (hexagon)	>4.0 degree^2 (⌀>2.5°)
Multiplex fiber positioner	~2400
Medium Resolution Spectrographs (2x) # Fibers Pass band Velocity accuracy	R~5000–7000 1600 fibers 390-930 nm < 2 km/s
High Resolution Spectrograph (1x) # Fibers Pass bands Velocity accuracy	R~20,000 800 fibers 393-436 & 516-572 & 610-675 nm < 1 km/s
# of fibers in Ø=2’ circle	>3
Fiber diameter	Ø=1.4 arcsec
Area (first 5 year survey)	>2h x 16,000 deg^2
Number of science spectra (5 year)	~75 million of 20 min

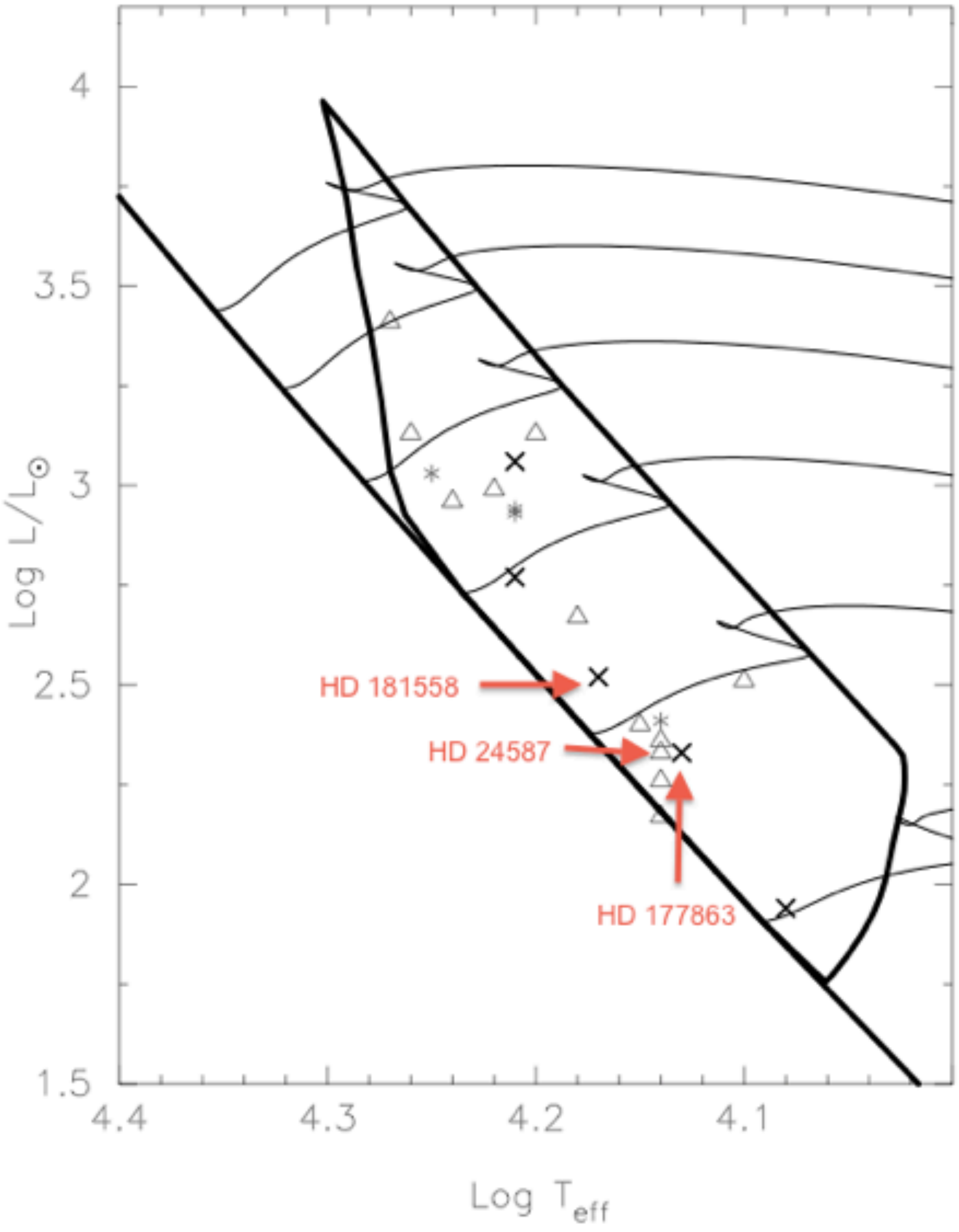
Sky Coverage Simulation



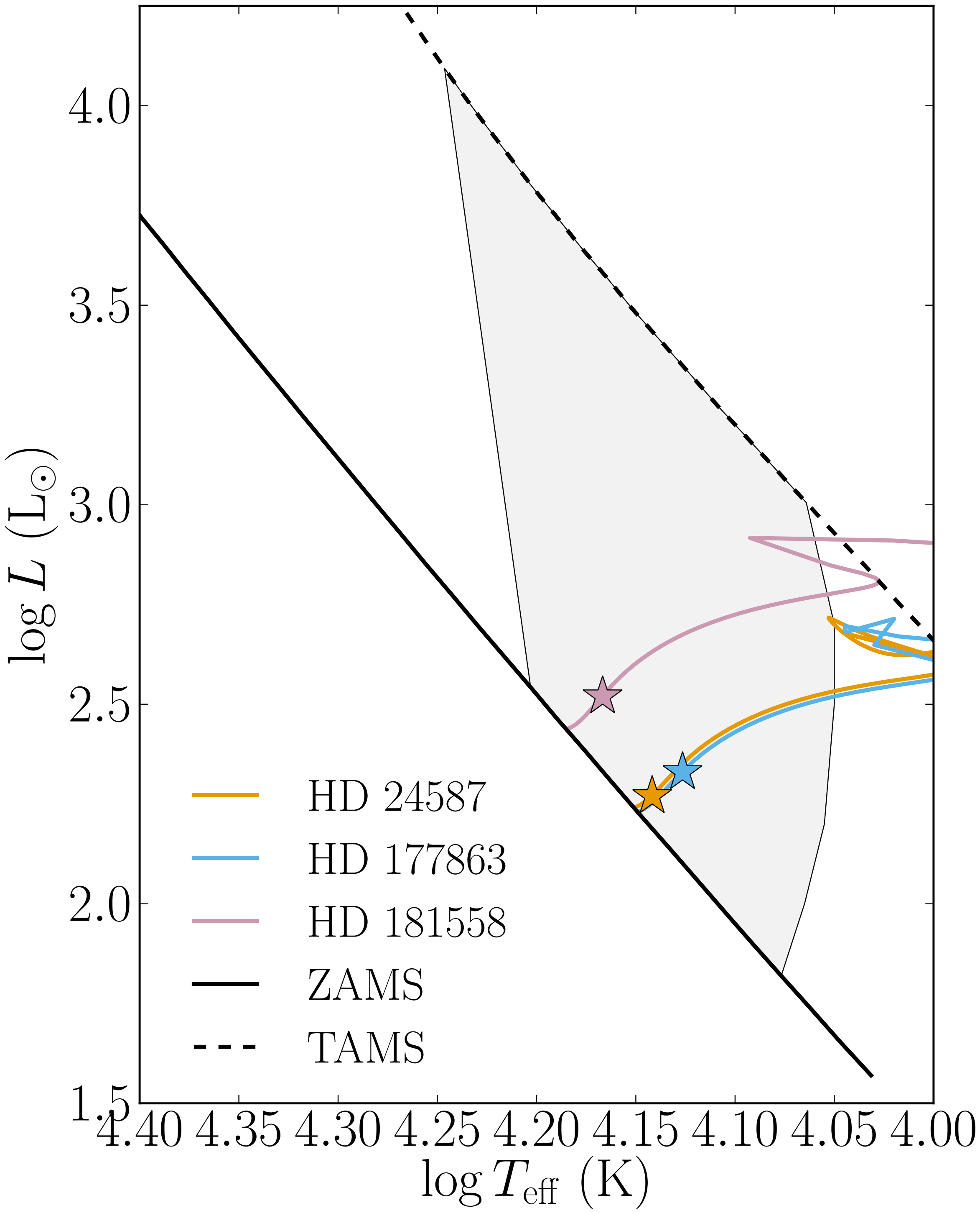
Extreme Angular Momentum Transport by Gravity Waves in Slowly Pulsating B Stars

Jacqueline Goldstein (UW-Madison)
Rich Townsend (UW-Madison)
Ellen Zweibel (UW-Madison)

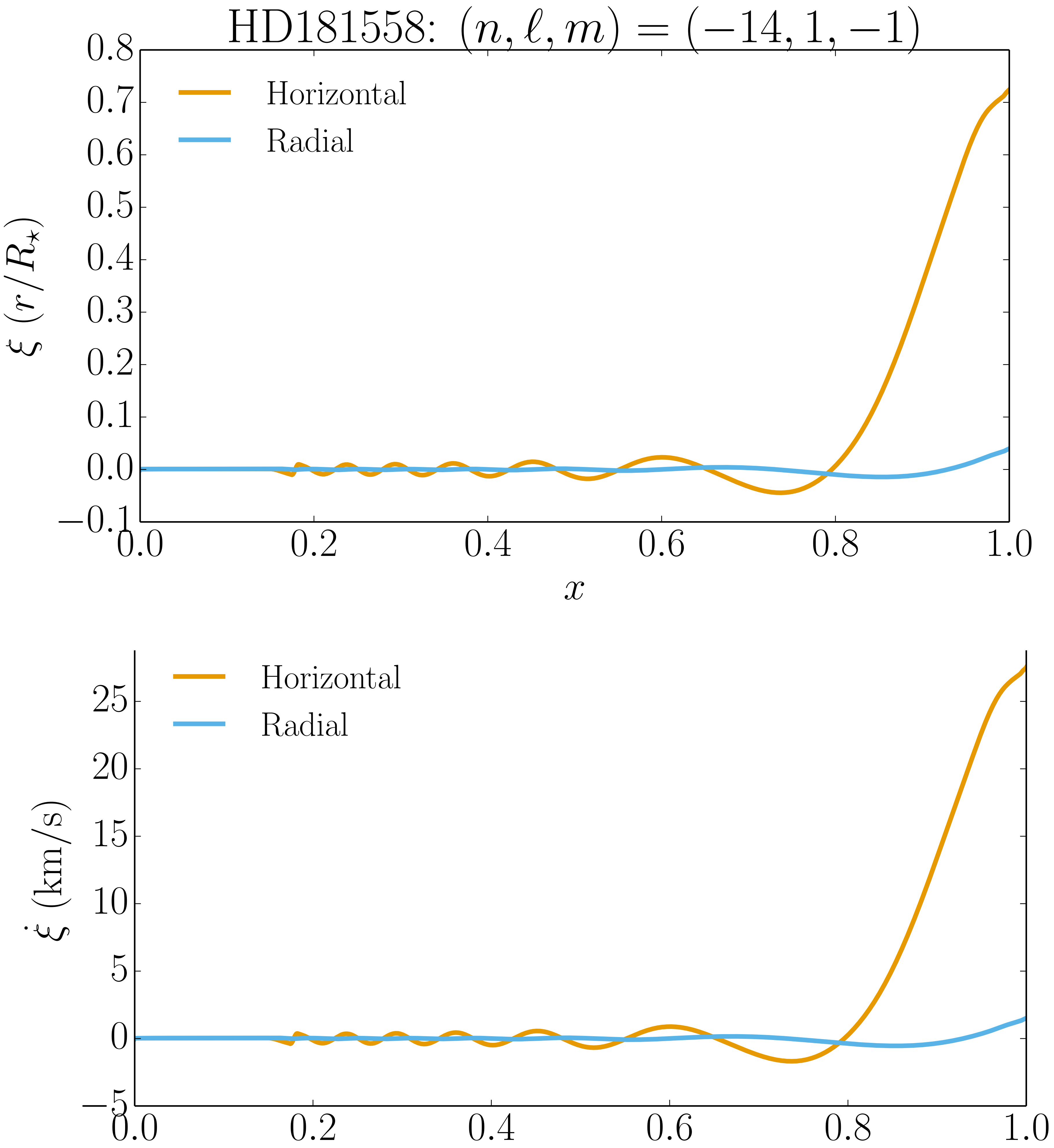
The Milky Way and its Stars (KITP)
Feb 2 2014



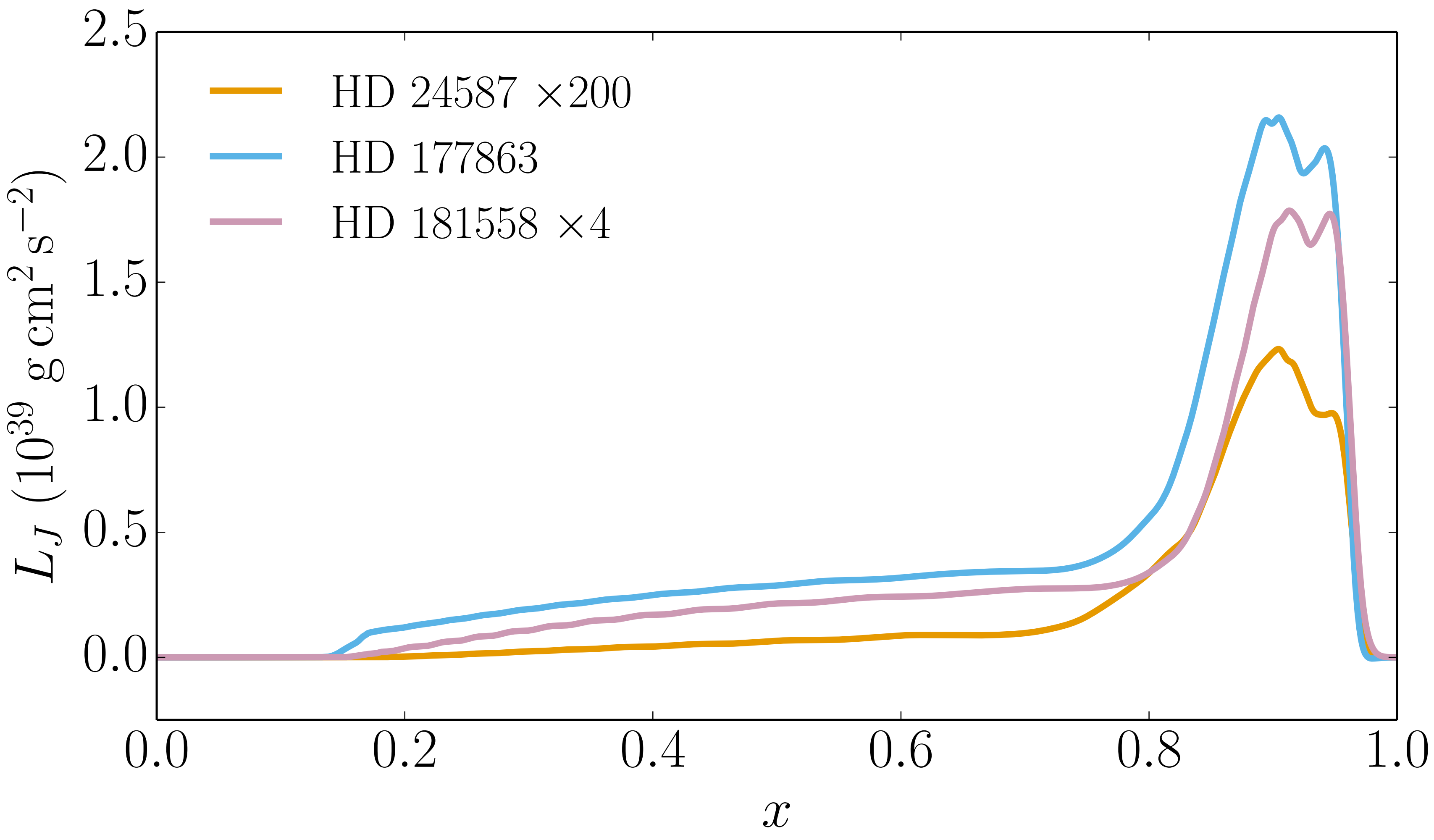
(Aerts 1999)

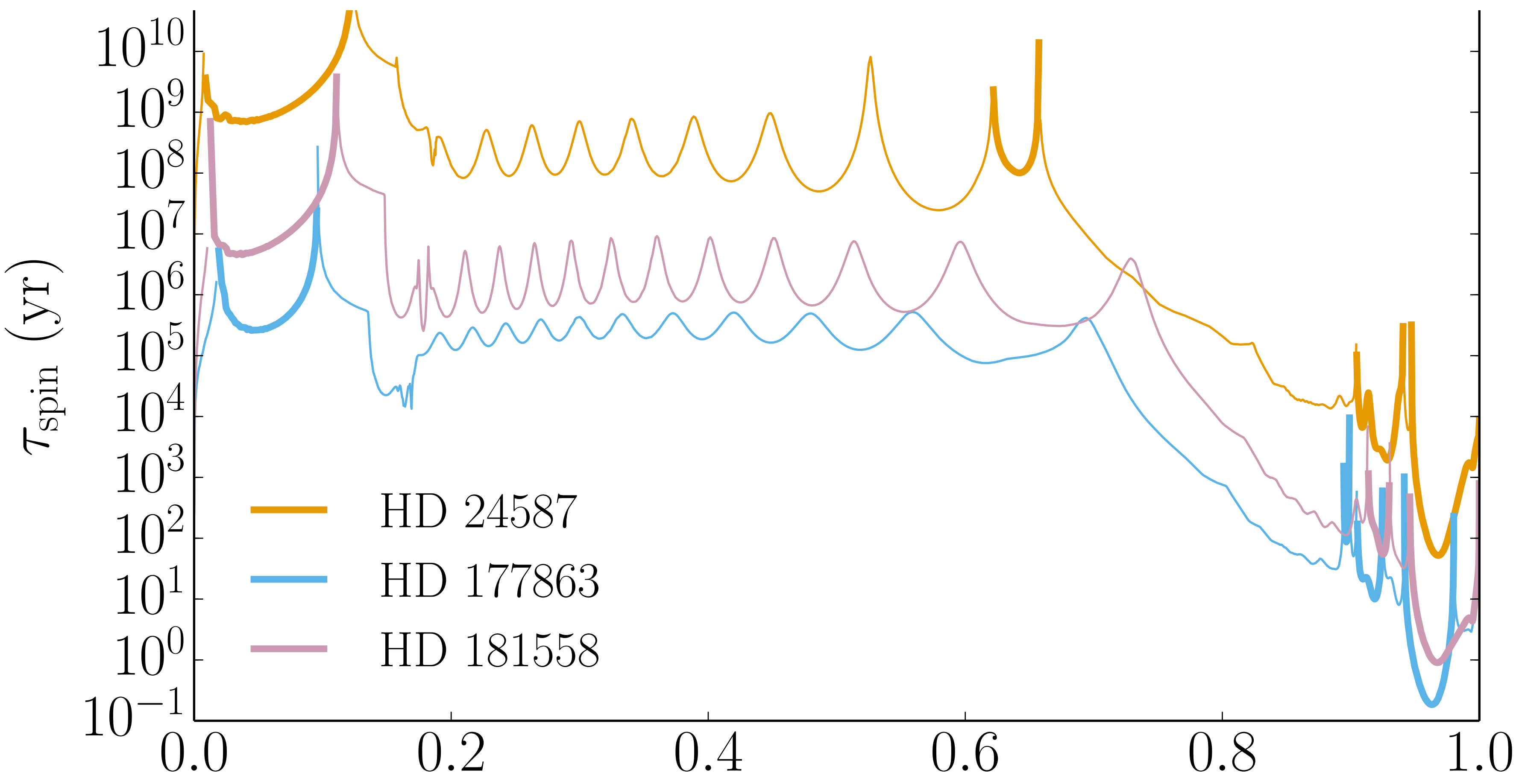


MESA



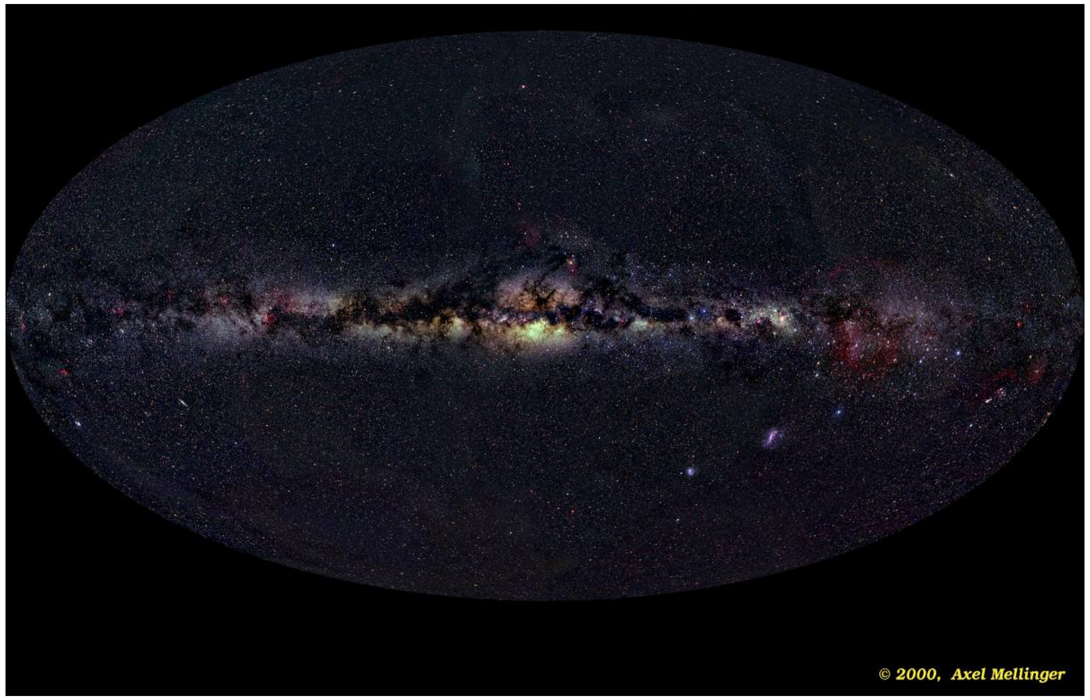
HD181558: $(n, \ell, m) = (-14, 1, -1)$


HD 24587 ×200
HD 177863
HD 181558 ×4
L_J (10^{39} g cm^2 s^{-2})
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
x

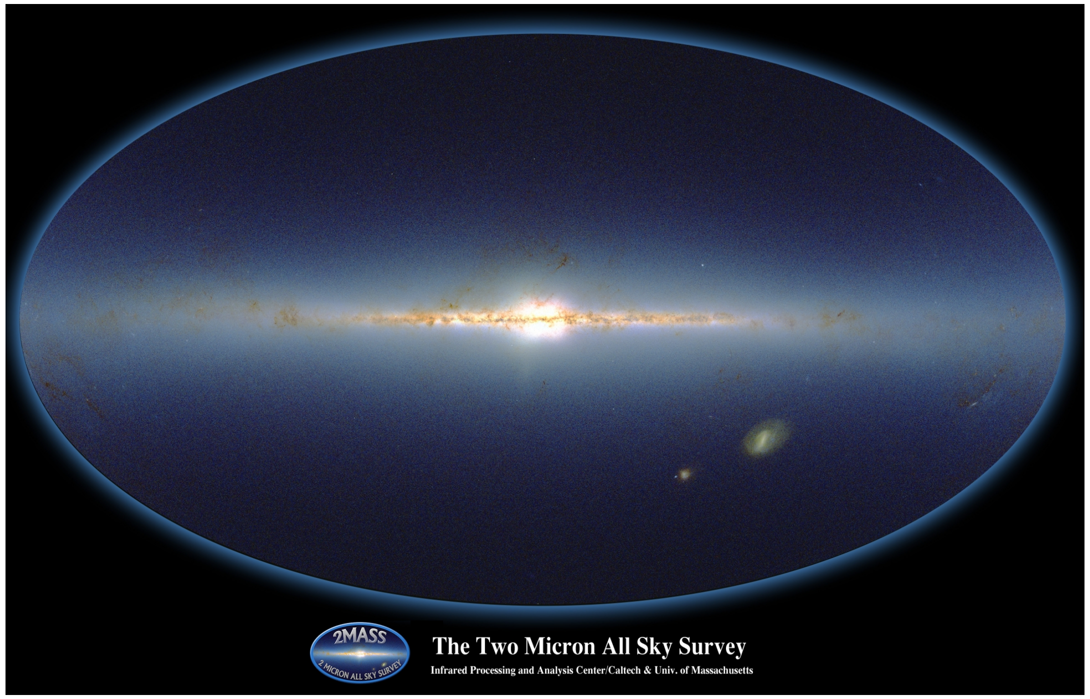

$\tau_{\rm spin}$ (yr)
10^{10}
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
HD 24587
HD 177863
HD 181558
0.0
0.2
0.4
0.6
0.8
1.0

SDSS-IV/APOGEE-2 OVERVIEW:

CURRENT OPTICAL SPECTROSCOPIC SURVEYS

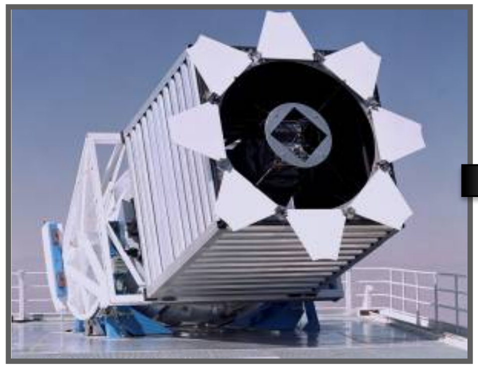


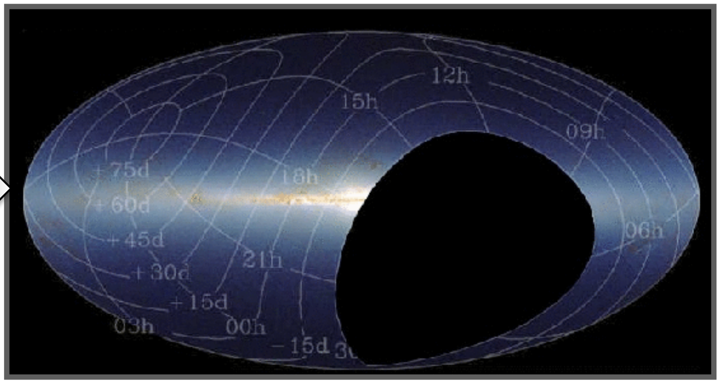
CURRENT NEAR INFRARED SPECTROSCOPIC SURVEYS



- SDSS-IV Project 2014-2020 (bright time allocation; co-targeting with MaNGA [halo])
- Large-Scale ($N_{stars} \sim 3*10^5$)
- High-Resolution Spectral Data ($R \sim 22{,}500$)
- High Signal-to-Noise ($S/N \geq 100$)
- Near-infrared wavelength coverage (H-band; 1.51-1.69 μm)
- Primary Data Products of radial velocities, atmospheric parameters (T_{eff}, *log g*, [Fe/H]), individual element relative abundance ratios (C, N, O, Na, Mg, Al, Si, S, K, Ca, Ti, V, Mn, Ni)
- Primary targets (M,K,G) giants (in all Galactic components)
- Core, Goal, and Ancillary Science Programs
- Two observational facilities (APOGEE-2N-APO; APOGEE-2S-LCO)

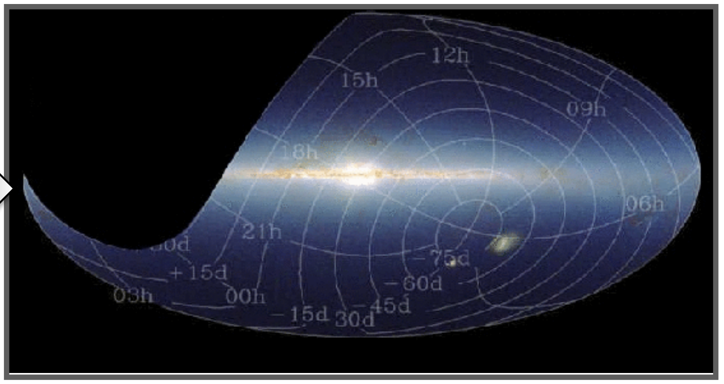
DUAL HEMISPHERE VIEW:





APACHE POINT OBSERVATORY [APO]:

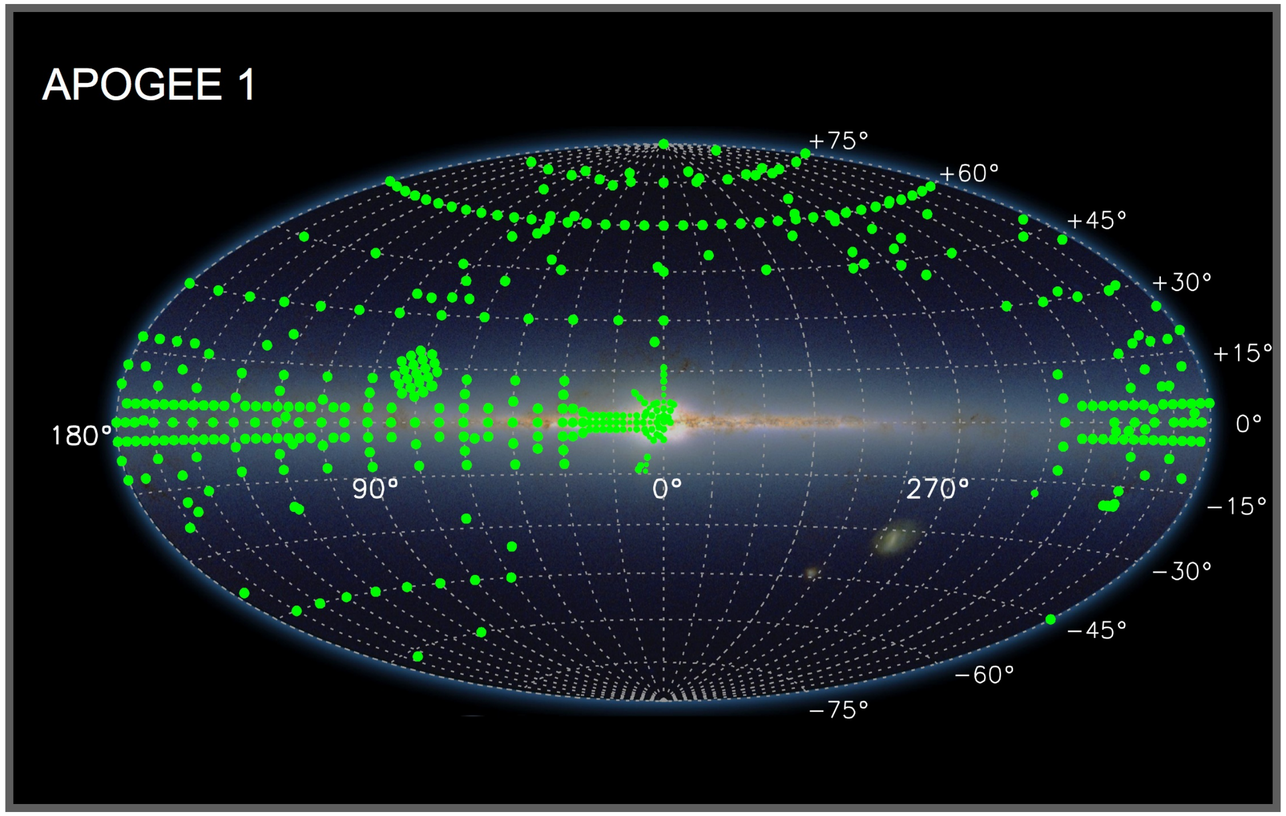
- Northern Hemisphere Site (New Mexico, USA)
- 2.5m Sloan Foundation Telescope (f#/7.5)
- 2014-2020 Survey Operational Period
- Approx.196,000 Stars, 2444 Visits
- Time Allocation of 90% Core, 5% Goal, 5% Ancillary
- Co-targeting program with the MaNGA Survey

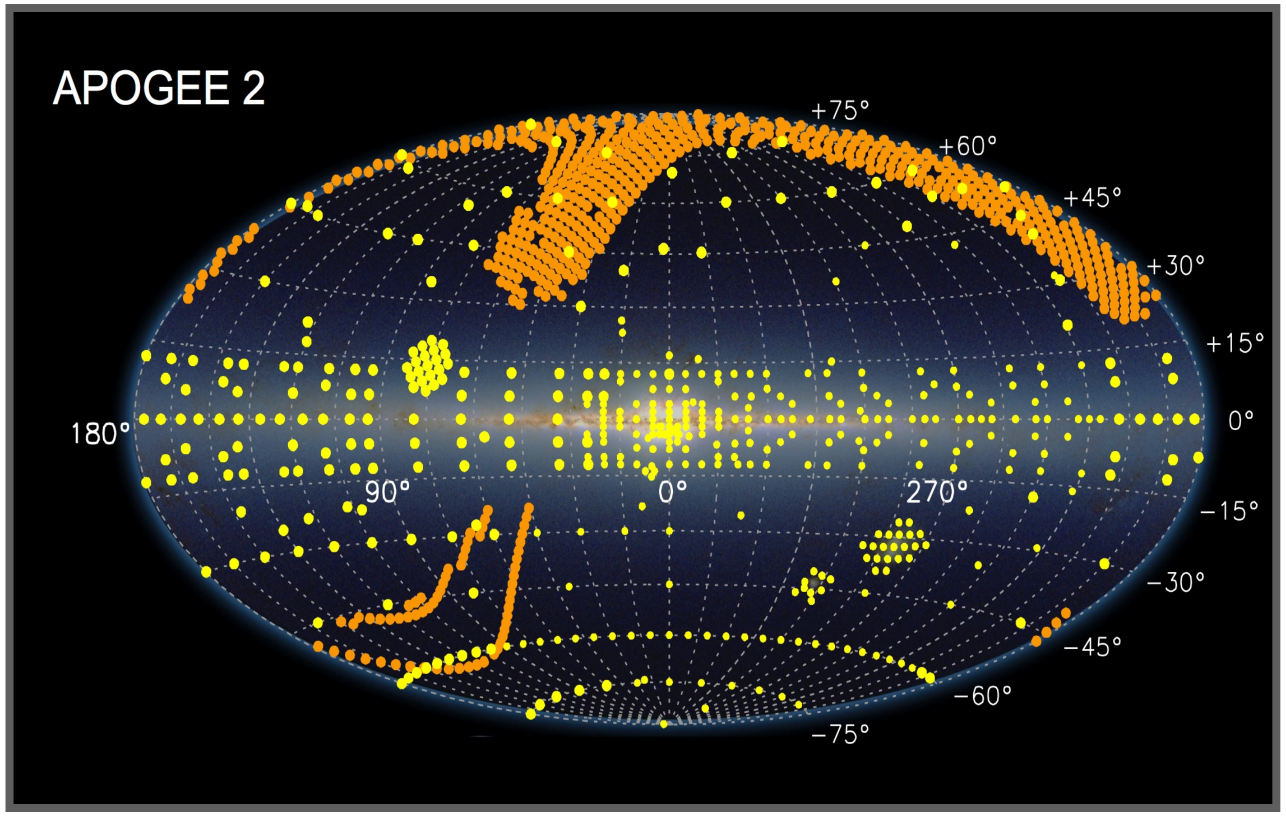


LAS CAMPANAS OBSERVATORY [LCO]:

- Southern Hemisphere Site (Chile)
- 2.5m Irene du Pont Telescope (f#/5)
- 2016-2020 Survey Operational Period
- Approx. 96,000 Stars, 1512 Visits
- Time Allocation of 95% Core, 2.5% Goal, 2.5% Ancillary

APOGEE CURRENT UPDATE AND EXPECTATIONS:





APOGEE-2N:

- Survey Start: July 1st, 2014
- Summer Shutdown Period: ~6 weeks (beginning 7-15-2014)
- Modifications Made: Replacement of Blue Chip Detector
- No. Acquired Stellar Spectra: ~50,000
- APOGEE-2 Led Weather/Engineering Loss: 370/643 (est.)
- MaNGA Led Weather/Engineering Loss: 35/93 (est.)

APOGEE-2S:

- Anticipated Survey Start: Q3 2016
- Instrument Funding Status: Fully-funded (build is underway)

- Total Survey Period:10 Years [2011-2020]
- Anticipated Number of Observed Stars: ~ 420,000
- Galactic Components: Bulge (full extent), Disk (all quadrants), Halo
- Sweeping Goal Science Program
- Dedicated Ancillary Science Program


WAIT. HOLD ON. STOP TALKING.
SHOW ME THE DATA
meme.am

METALLICITY DISTRIBUTION OF M DWARFS AND LOCAL GALACTIC EVOLUTION

N. Hejazi, M. M. De Roberis (Physics and Astronomy Department, York University, Toronto, ON M3J 1P3, Canada) And P. C. Dawson (Physics Department, Trent University, Peterborough, Canada, K9J 7B8)

Photometric Metallicity Calibration

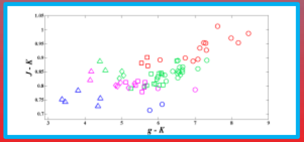
Based on a sample of 71 dwarfs, we developed an optical-NIR photometric calibration to estimate the metallicity of late-K and early-to-mid M dwarfs. The best fit is a 2nd order polynomial in SDSS *g* and 2MASS *JK* photometry, applicable for $-0.73 \leq [Fe/H] \leq +0.30$.

[Fe/H]	
[+0.15,+0.30]	🟥
[-0.10,+0.15]	🟩
[-0.40,-0.10]	🟪
[-0.73,-0.40]	🟦

Color-coded Metallicities

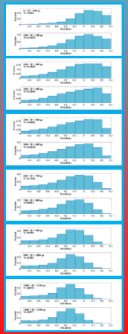
Spectral Type	
[M0,K6]	△
[M2,M1]	◇
[M4,M3]	□
[M6,M5]	○

Symbol-coded Spectral Types



The (g-K)-(J-K) diagram for the 71 dwarfs in our calibration sample

Age-Metallicity Relation



Dividing the stars into 100 pc thick bins to 1.2 kpc clearly shows that mean metallicity decreases with Galactic height. This can be attributed to the age-metallicity relation, i.e., stars which formed at earlier times in the Galaxy's history, on average, have lower metallicities. In addition, due to disk dynamical heating, stars dissipate from the Galactic plane, increasing their vertical distance from the plane in the course of time. As a result, the older stars are more likely to be found at larger Galactic heights.

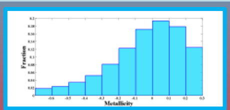
Acknowledgements

We would first like to thank Patrick Hall for his thoughtful discussions involving the calibration sample and for his guidance in the statistical analysis of the large sample. We kindly thank Andrew Mann, John Bochanski, Andrew West, Sébastian Lépine, Ryan Terrien, Vincent Woolf, Rohit Deshpande and Chad Bender for their helpful suggestions. This work was supported by the Natural Sciences and Engineering Research Council of Canada.

Why M Dwarfs?

- Most numerous stars in the Milky Way
  - About 70% of all stars in the Galaxy by number
  - Nearly half the stellar mass of the Galaxy
- Main sequence lifetimes longer than the current age of the Universe: excellent tracers of Galactic evolution
- Providing stars with a wider range of ages than G and K dwarfs for representing the local metallicity distribution

M-dwarf Metallicity Distribution



We applied the calibration to determine the metallicity of the M dwarfs in the large sample. Around 94% of these stars have H ≤ 1000 pc. The volume-corrected metallicity distribution has a peak around +0.05 dex, giving a mean metallicity of about -0.04 dex.

Conclusion

Using a sample of dwarf stars, a photometric calibration to determine the metallicity of M dwarfs was presented. The calibration was applied to a large sample of over 1.3 million M dwarfs. Our results shows a decrease in mean metallicity as a function of Galactic height, indicating the age-metallicity relation. Several Galactic chemical models proposed to solve the G and K dwarf problems were examined through the observed metallicity distribution of M dwarfs. It was shown that these models could, to some extent, mitigate the M dwarf problem as well.

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Observation

We selected a sample of 1,312,000 M dwarfs from SDSS DR and 2MASS catalogs with clean photometry and Galactic heights ≤ 2 kpc., meeting the following conditions:

- Stars had $b \geq 50°$ to minimize Galactic extinction
- Typical color ranges for late-K and M dwarfs: $i\text{-}z \geq 0.25$ and $r\text{-}i \geq 0.47$
- Metallicity color cuts: $3.37 \leq g\text{-}K \leq 8.46$ and $0.71 \leq J\text{-}K \leq 1.01$
- Removal of M giants with color cuts: $J\text{-}H > 0.8$, $0.15 < H\text{-}K < 0.3$
- Color range for the photometric parallax used to estimate distances: $0.50 < r\text{-}z < 4.53$

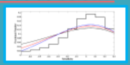
Galactic Chemical Evolution Models

The closed box model with initial metallicities and yields as below:

$Z_0 = 0$ (The Simple Closed Box Model, SCBM) and $y = 0.022$

$Z_0 = 0.002$ and $y = 0.020$

$Z_0 = 0.003$ and $y = 0.019$



The SCBM shows "the M dwarf problem (MDP)". The models with pre-enrichment mitigate MDP. All the yields above are larger than the value estimated for the solar neighborhood $y_{Sol} \approx 0.012\text{-}0.014$.

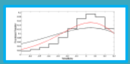
The exponential inflow model (EIM) with the assumptions as below:

1- Star formation rate = $dS/dt \propto G$: $S \equiv$ star mass and $G \equiv$ gas mass

2- Accretion rate $\propto \exp(-\alpha t)$: $t \equiv$ time and $\alpha \equiv$ constant

The SCBM as above

The EIM with $y = 0.022$



The EIM mitigates the MDP but its yield is larger than y_{Sol}.

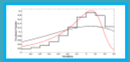
Clayton's models (CM) with the assumptions as below:

1- Star formation rate as above

2- Accretion rate = $\frac{k}{t+t_0}G$: k is an integer and t_0 is arbitrary.

The SCBM as above

The CM with $y = 0.016$ and $k = 7$



The CM mitigates the PDM but a modification of this model for high- metallicity tail is needed. The yield value is rather consistent with y_{Sol}.

There have been many other models proposed to solve the G and K dwarf problems which need to be tested through M-dwarfs metallicity distributions as well.