Satellite Quenching and the Lifecycle of Dwarfs

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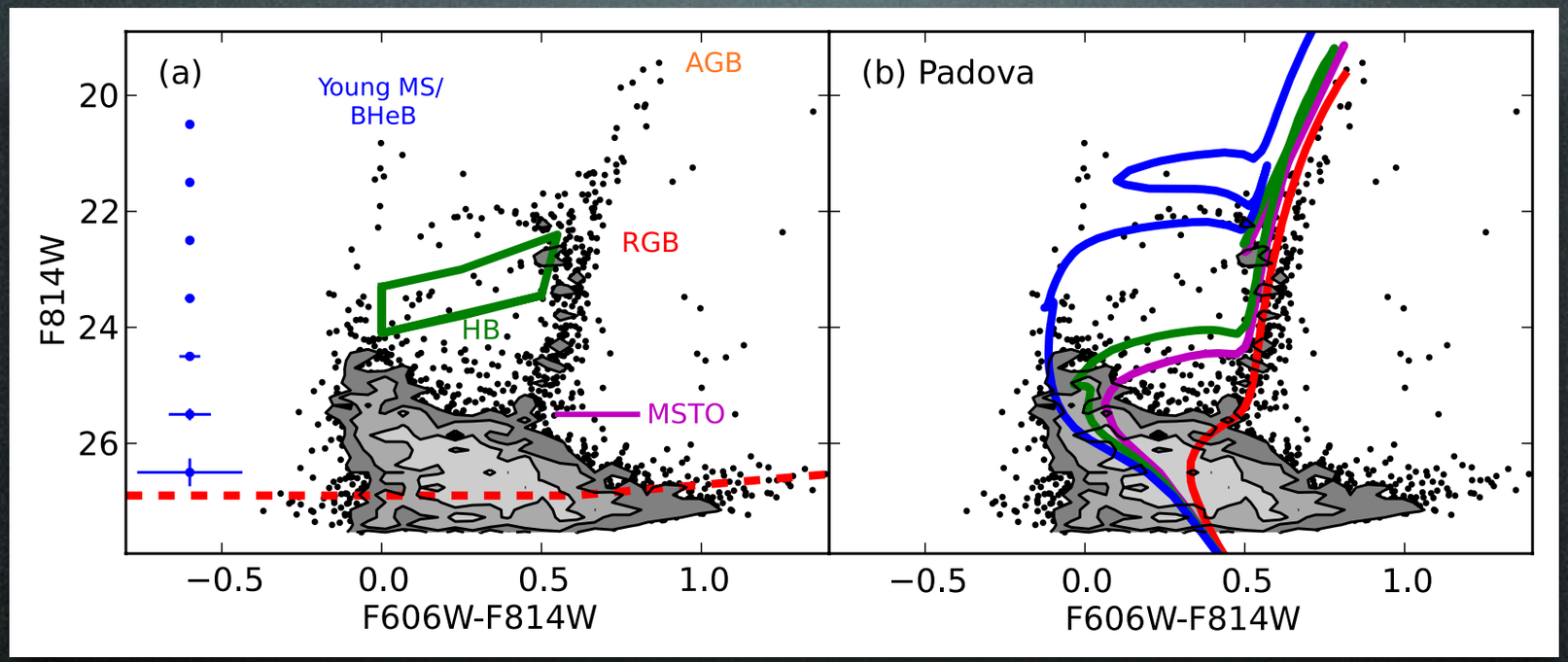
+ Eddie Schlafly, Nicolas Martin, Eric Morganson, HW Rix, + PS1 Collaboration

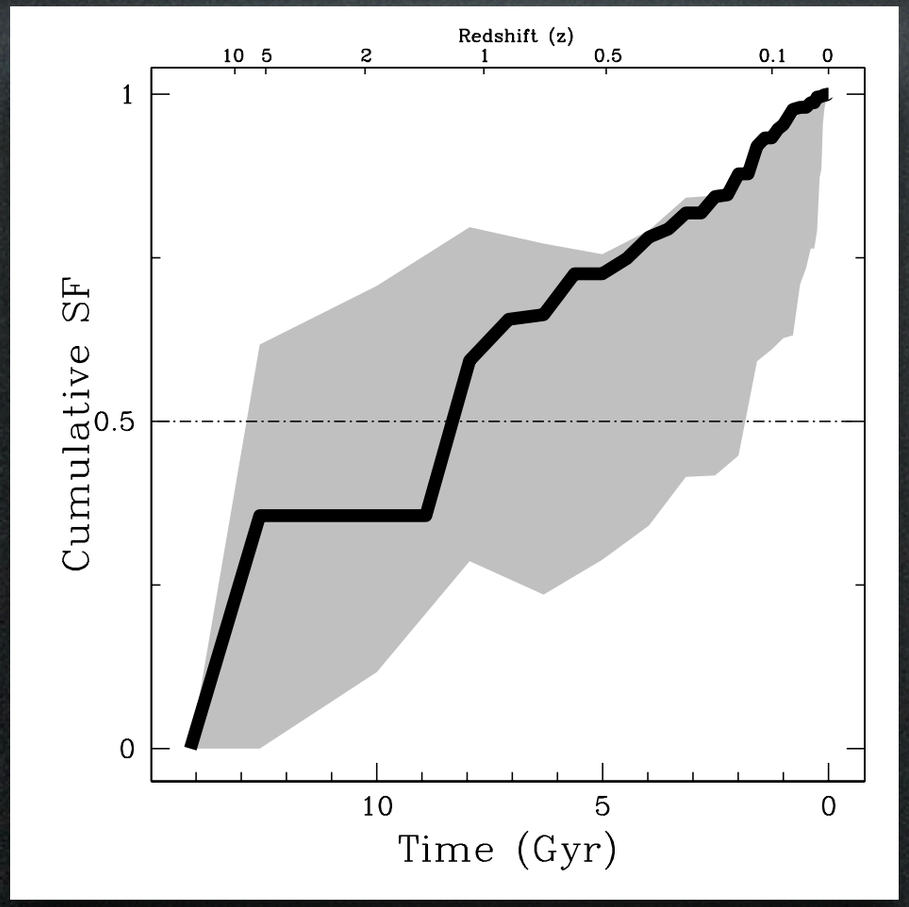
“Lifecycle” of Dwarfs

- We want to be able to tell the story of each individual dwarf
- What affects dwarfs? What major events?
- What sets the difference between dSphs and dIrrs?
- How do these effects differ across mass, from L★ to ultrafaints?

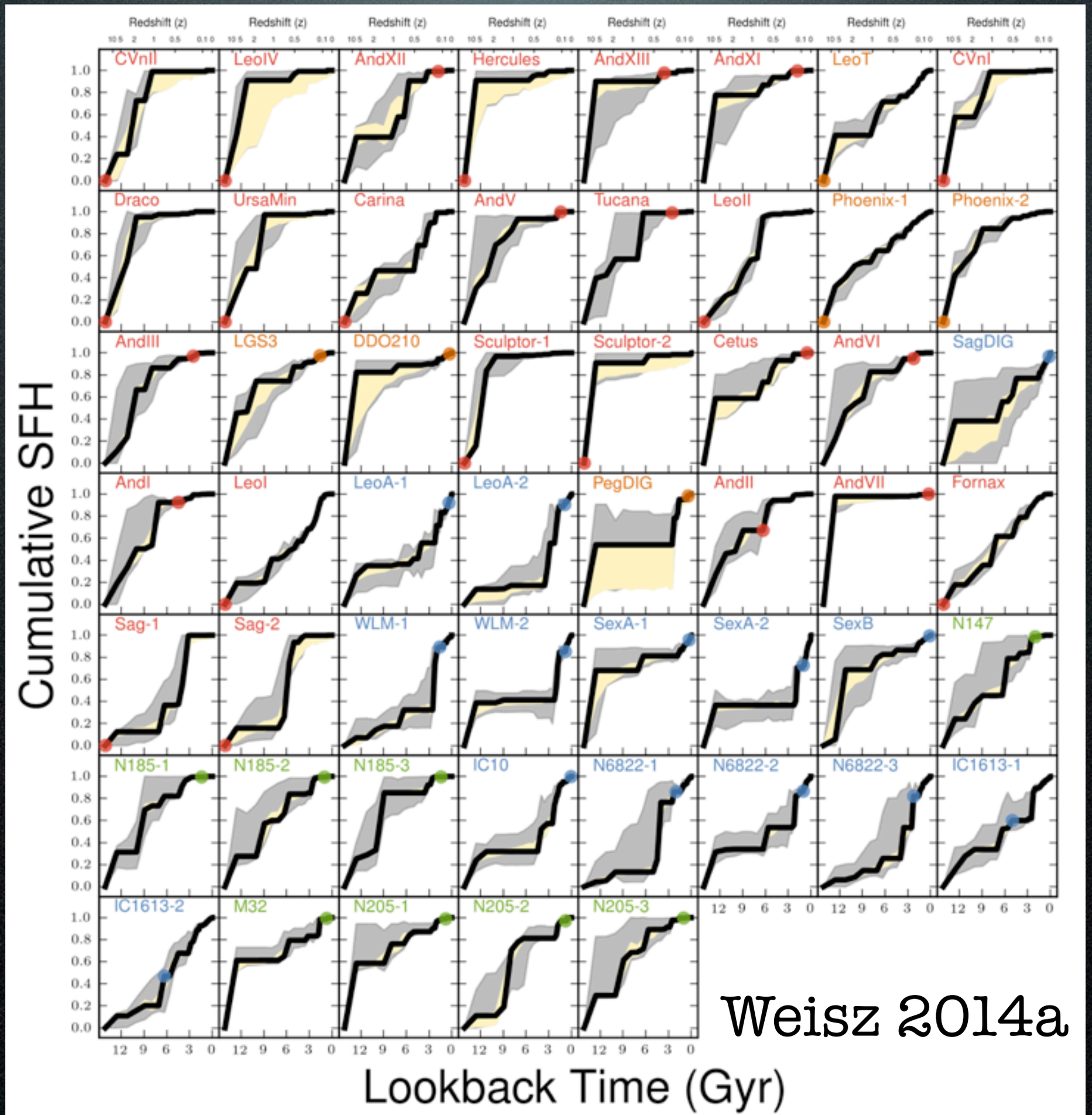
- Reionization?
- Gas accretion?
- Starbursts?
- Tides?
- Ram pressure?

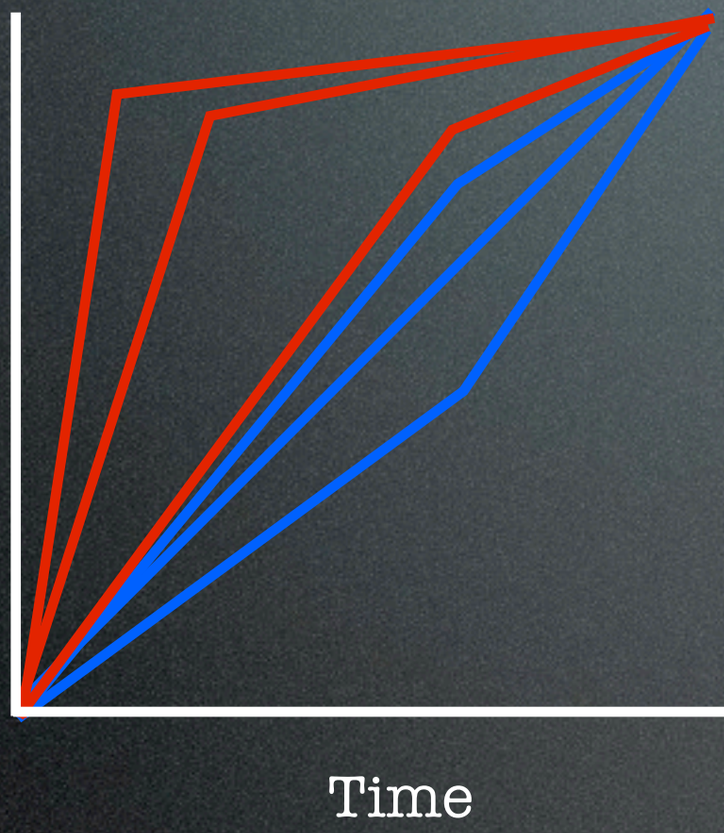
Leo T

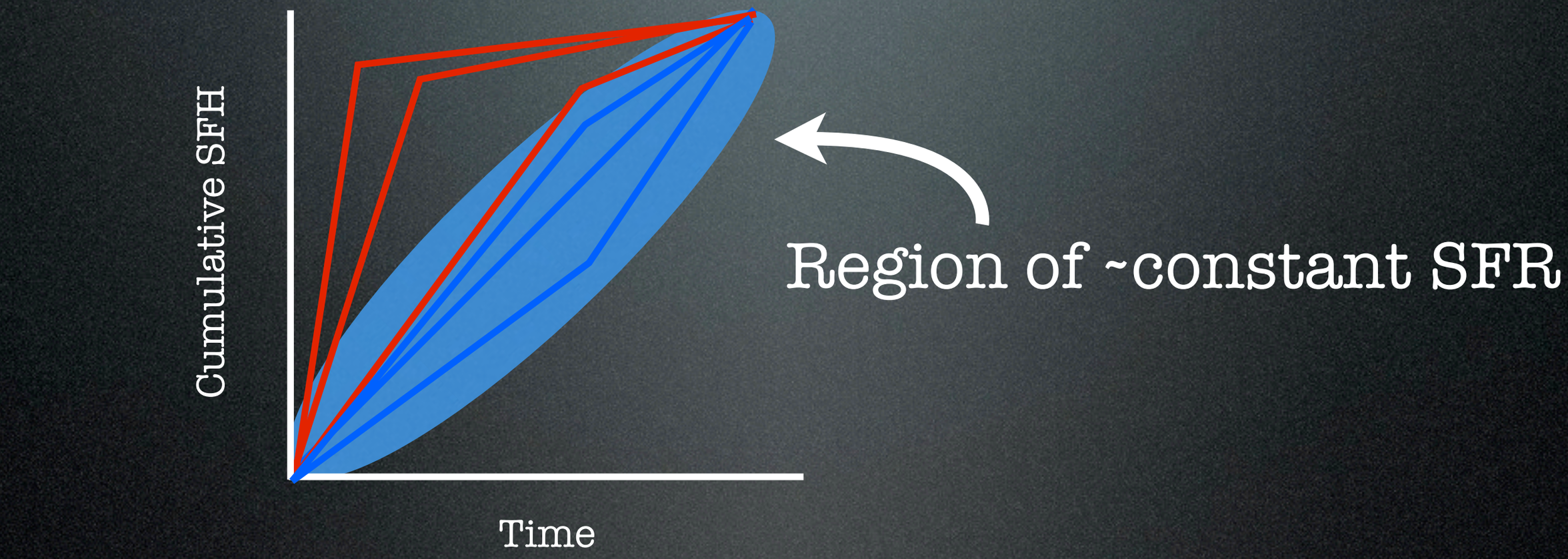




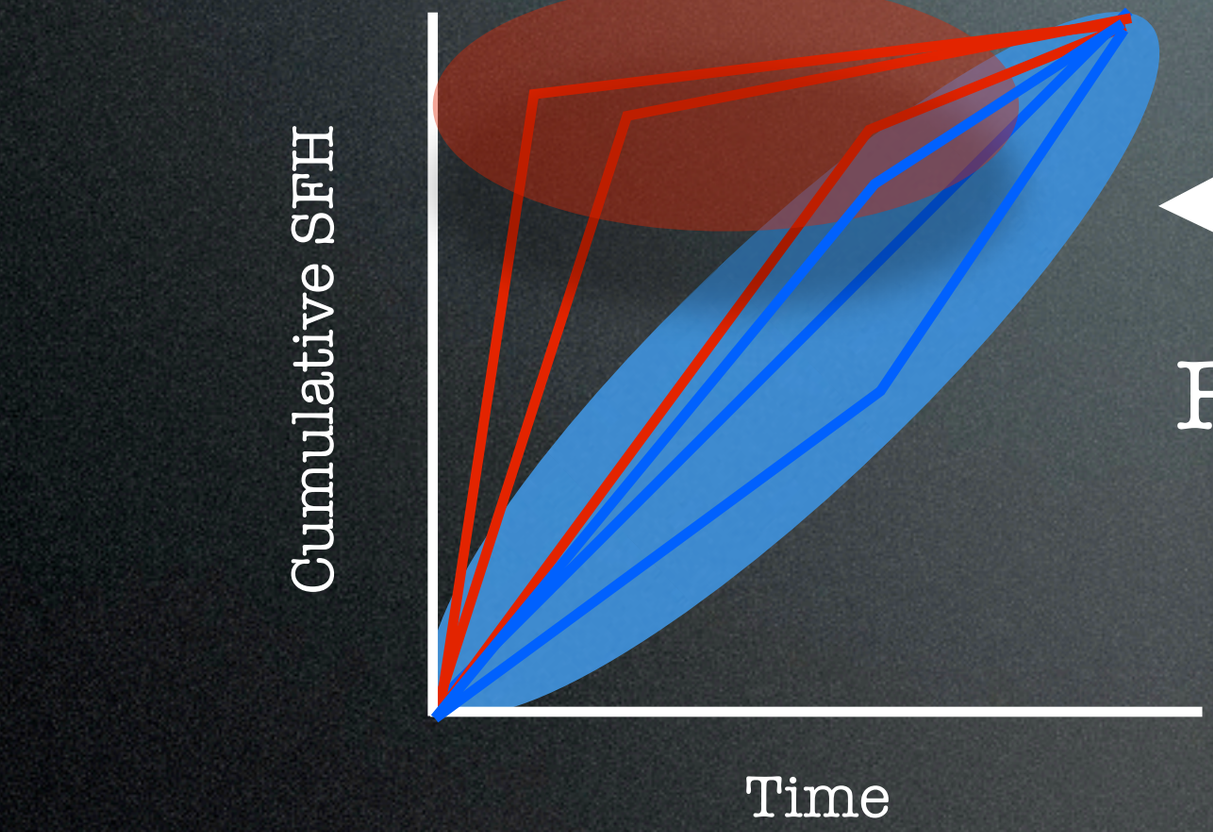
Weisz et al. 2012


Redshift (z)
10.5 2 1 0.5 0.1 0
CVnII
LeoIV
AndXII
Hercules
AndXIII
AndXI
LeoT
CVnI
Draco
UrsaMin
Carina
AndV
Tucana
LeoII
Phoenix-1
Phoenix-2
AndIII
LGS3
DDO210
Sculptor-1
Sculptor-2
Cetus
AndVI
SagDIG
AndI
LeoI
LeoA-1
LeoA-2
PegDIG
AndII
AndVII
Fornax
Sag-1
Sag-2
WLM-1
WLM-2
SexA-1
SexA-2
SexB
N147
N185-1
N185-2
N185-3
IC10
N6822-1
N6822-2
N6822-3
IC1613-1
IC1613-2
M32
N205-1
N205-2
N205-3
0.0 0.2 0.4 0.6 0.8 1.0
12 9 6 3 0
Cumulative SFH
Lookback Time (Gyr)
Weisz 2014a

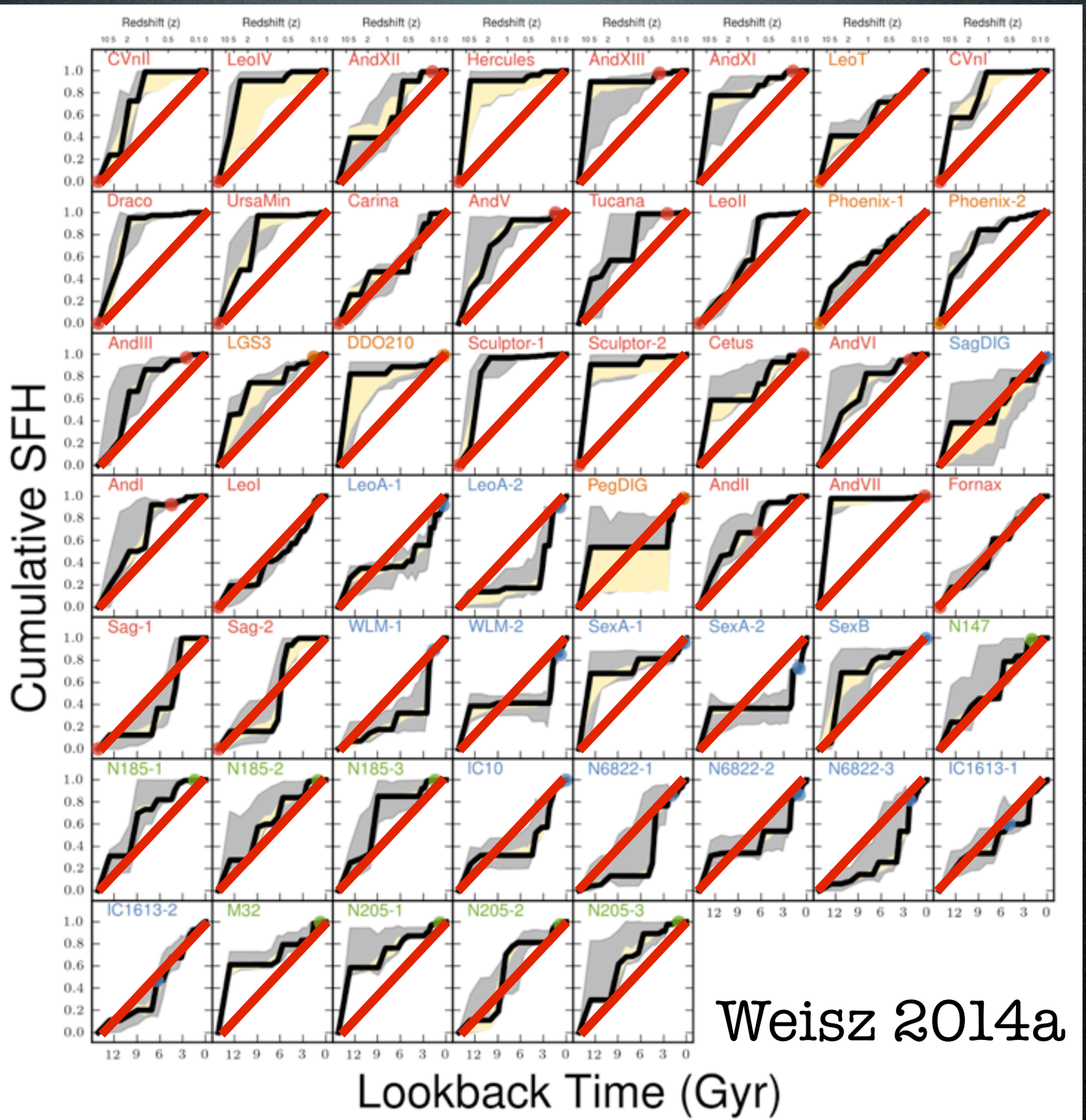

Cumulative SFH
Time


Cumulative SFH
Time
Region of ~constant SFR

Many show some quenching “Event”



Region of ~constant SFR


Redshift (z)
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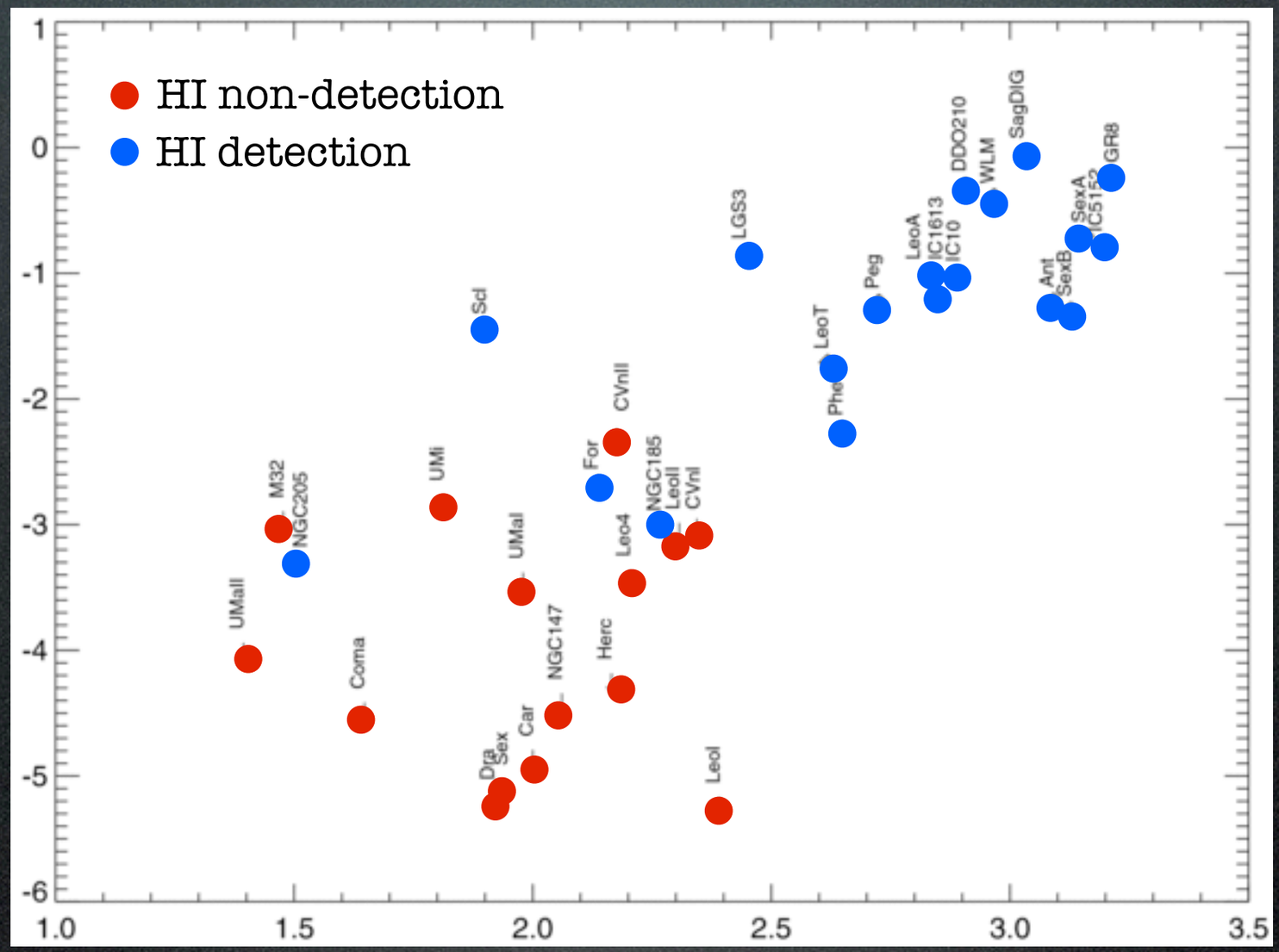
M32
N205-1
N205-2
N205-3
0.0 0.2 0.4 0.6 0.8 1.0
12 9 6 3 0
Cumulative SFH
Lookback Time (Gyr)
Weisz 2014a

- SFHs are consistent with "percolating" SF + eventual shutoff
- Very few dwarfs in the "bottom right" --- all dwarfs have old populations
- Plenty of present-day dSphs with extended SF --- dSph vs dIrr was not set in the early universe

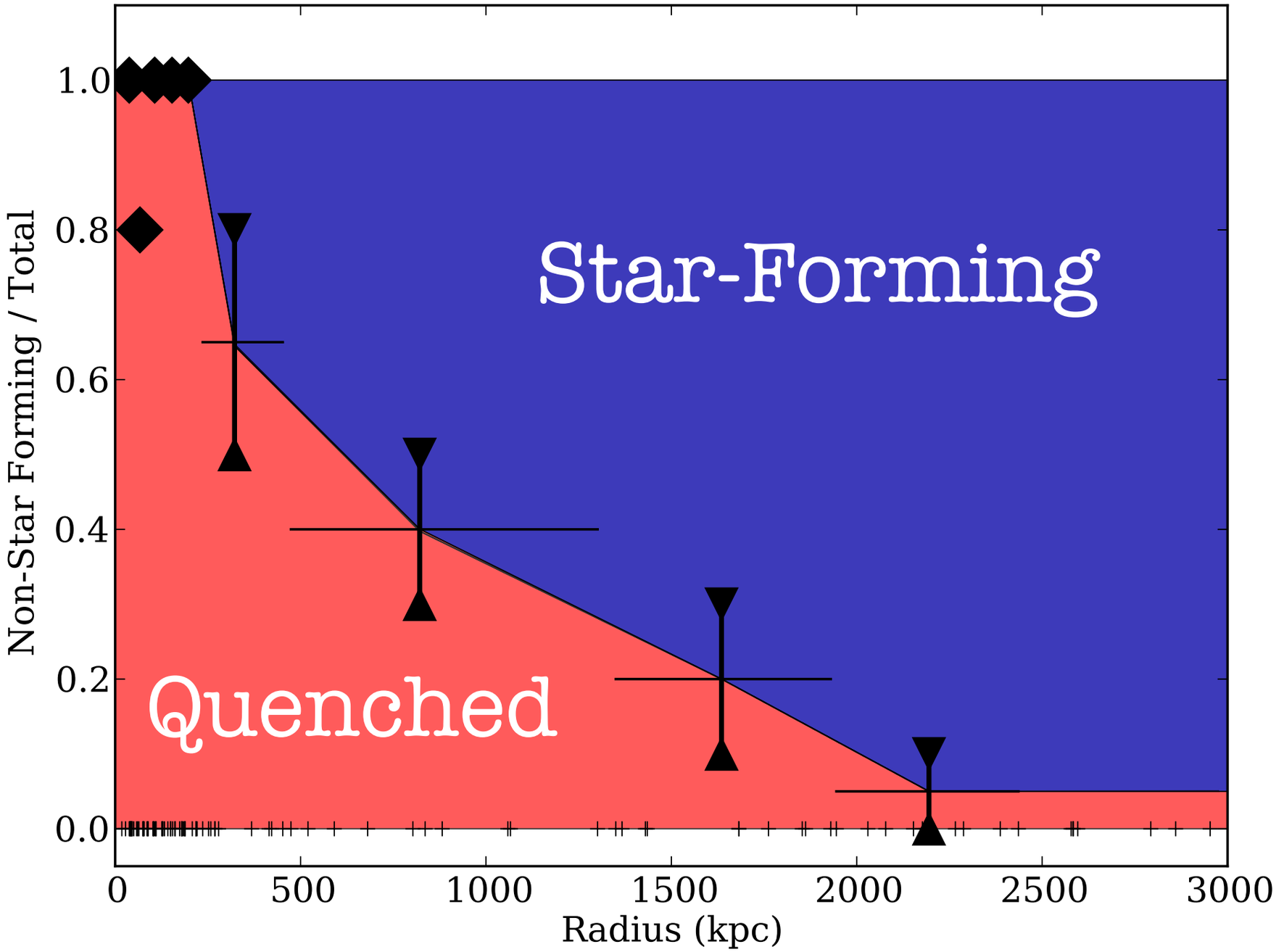
- Quenching is The Main Event
- Semi-simultaneous SF shutoff, gas removal, morphological transformation
- What initiates this event?

100 kpc

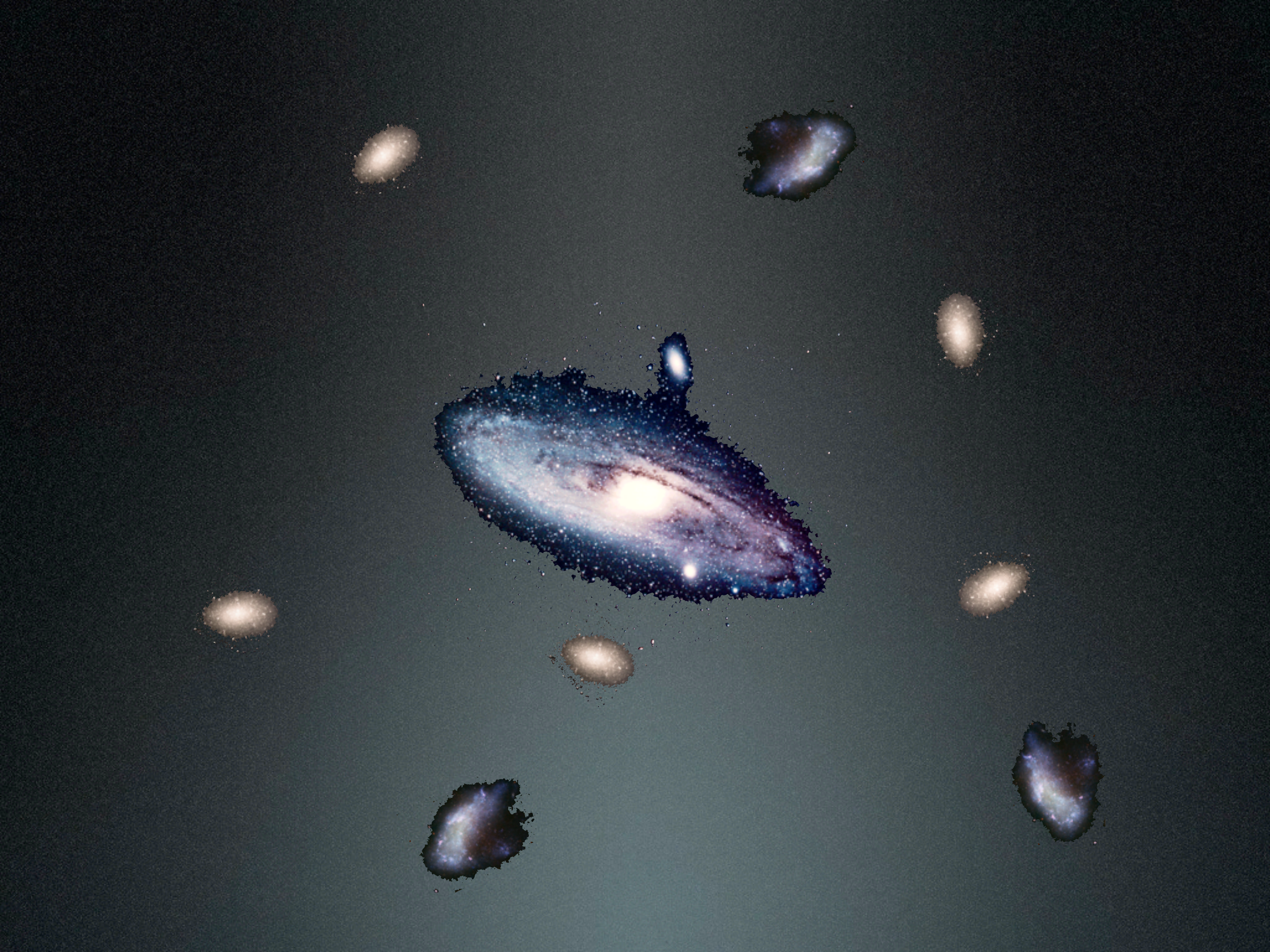
1 Mpc



Grcevich & Putman (2009)

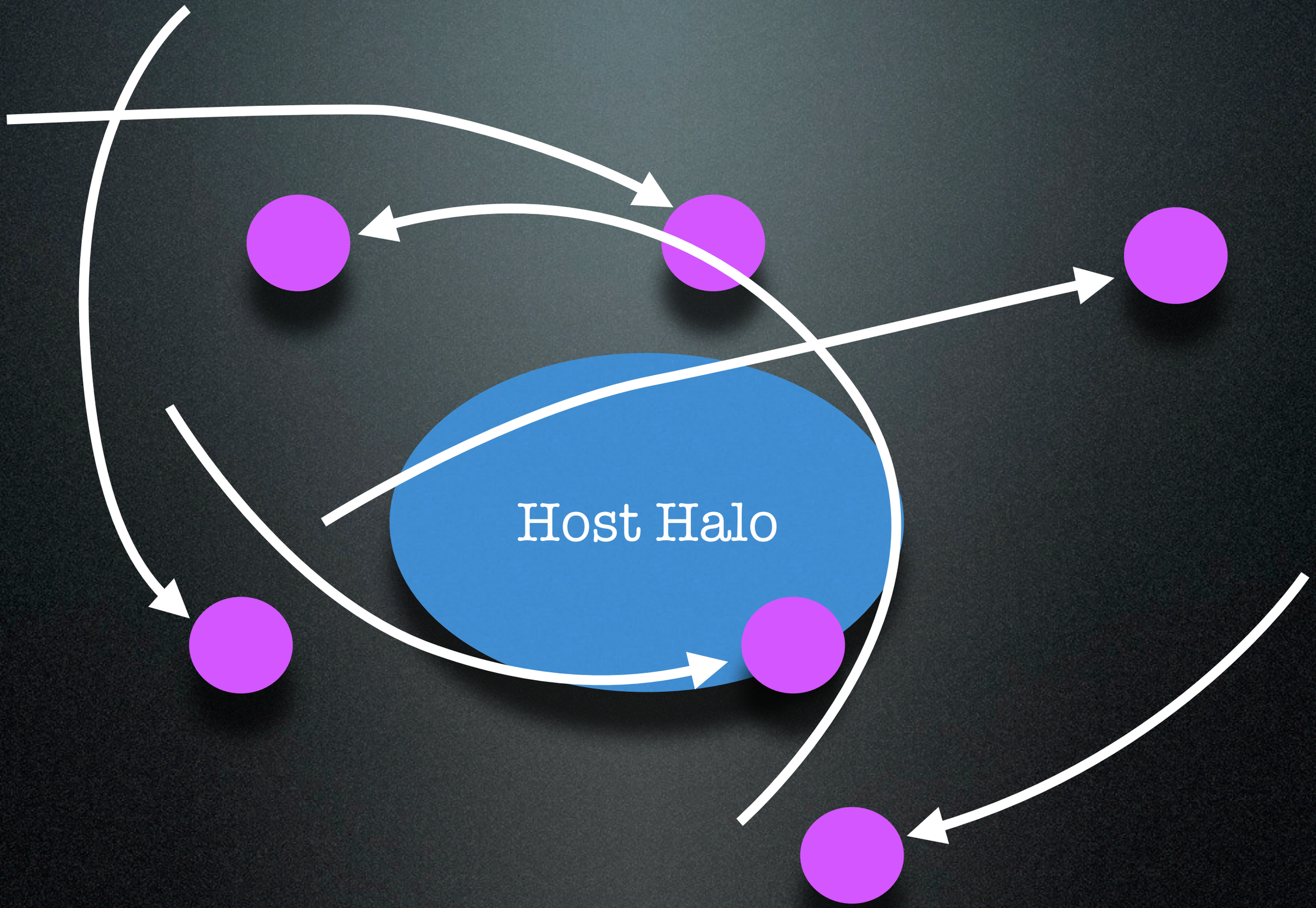


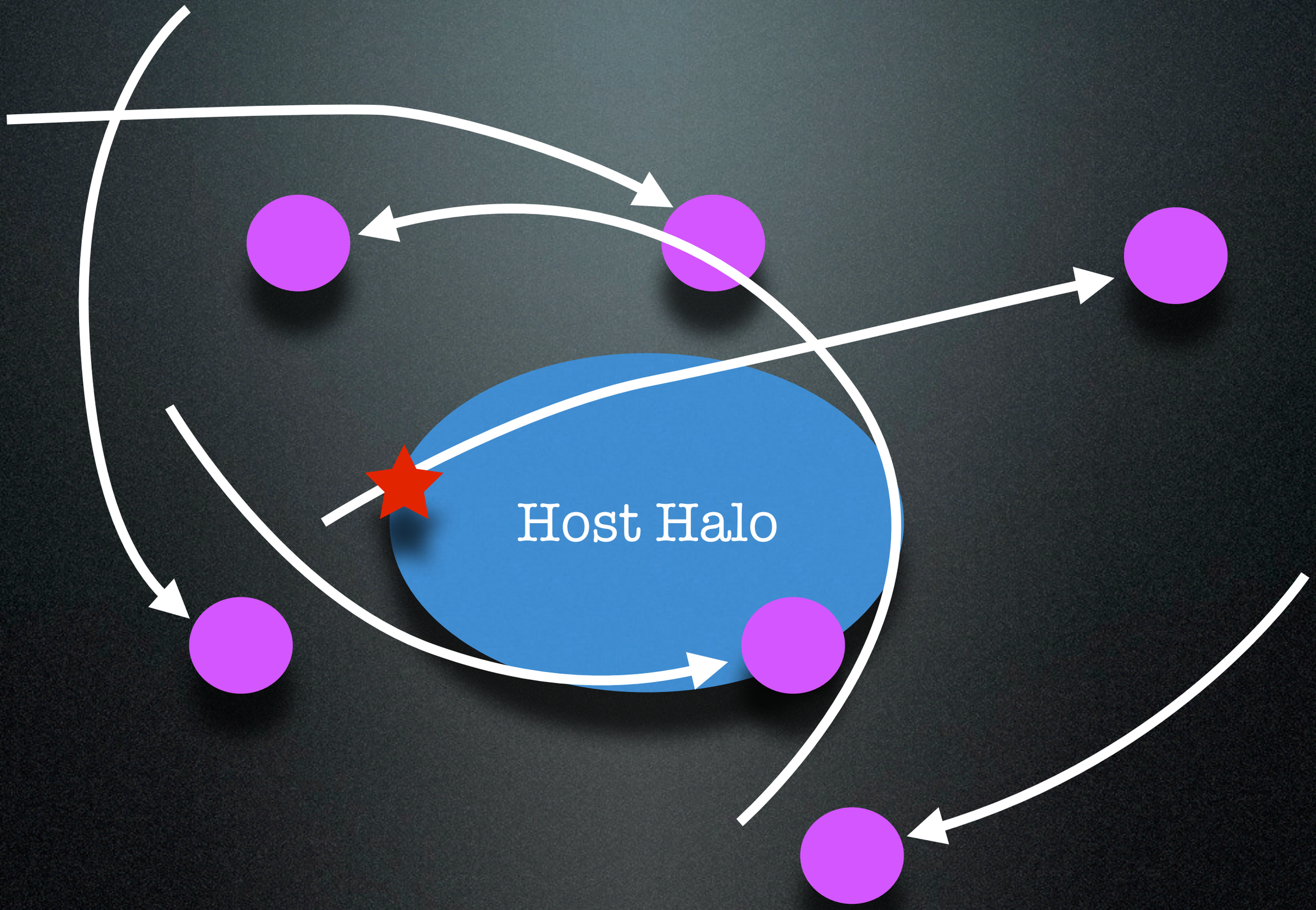
Slater & Bell 2013

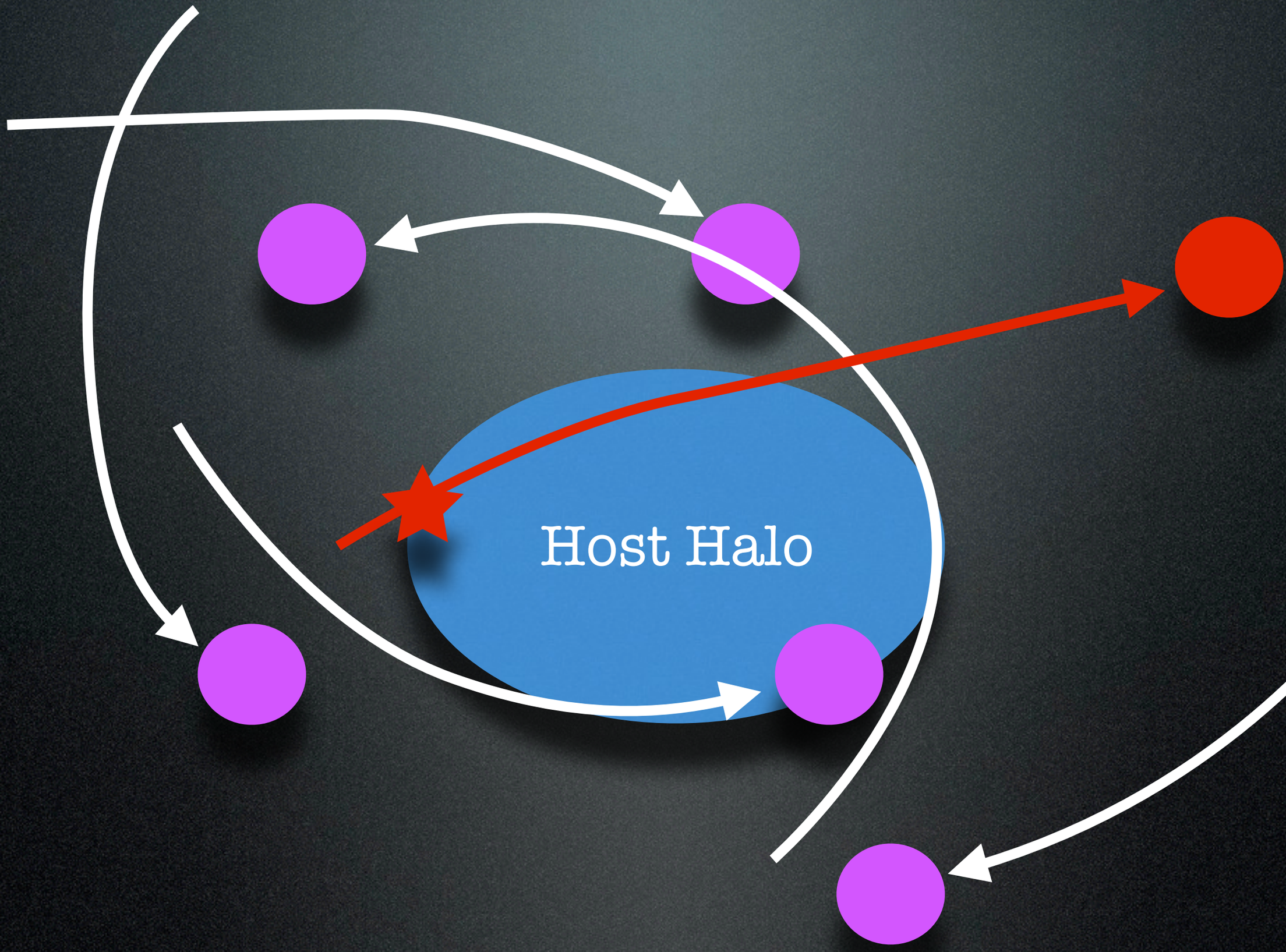


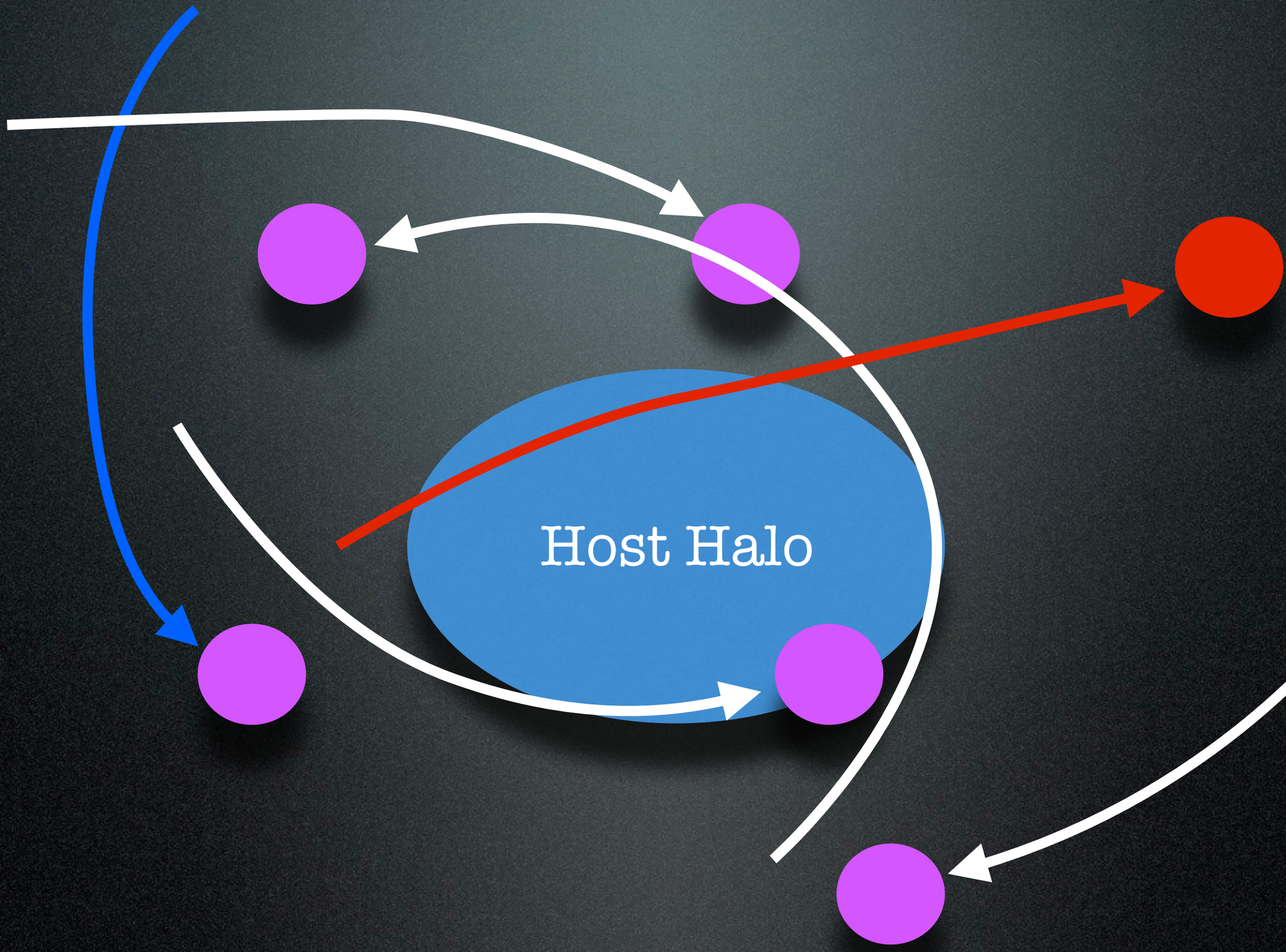
Satellite Halos

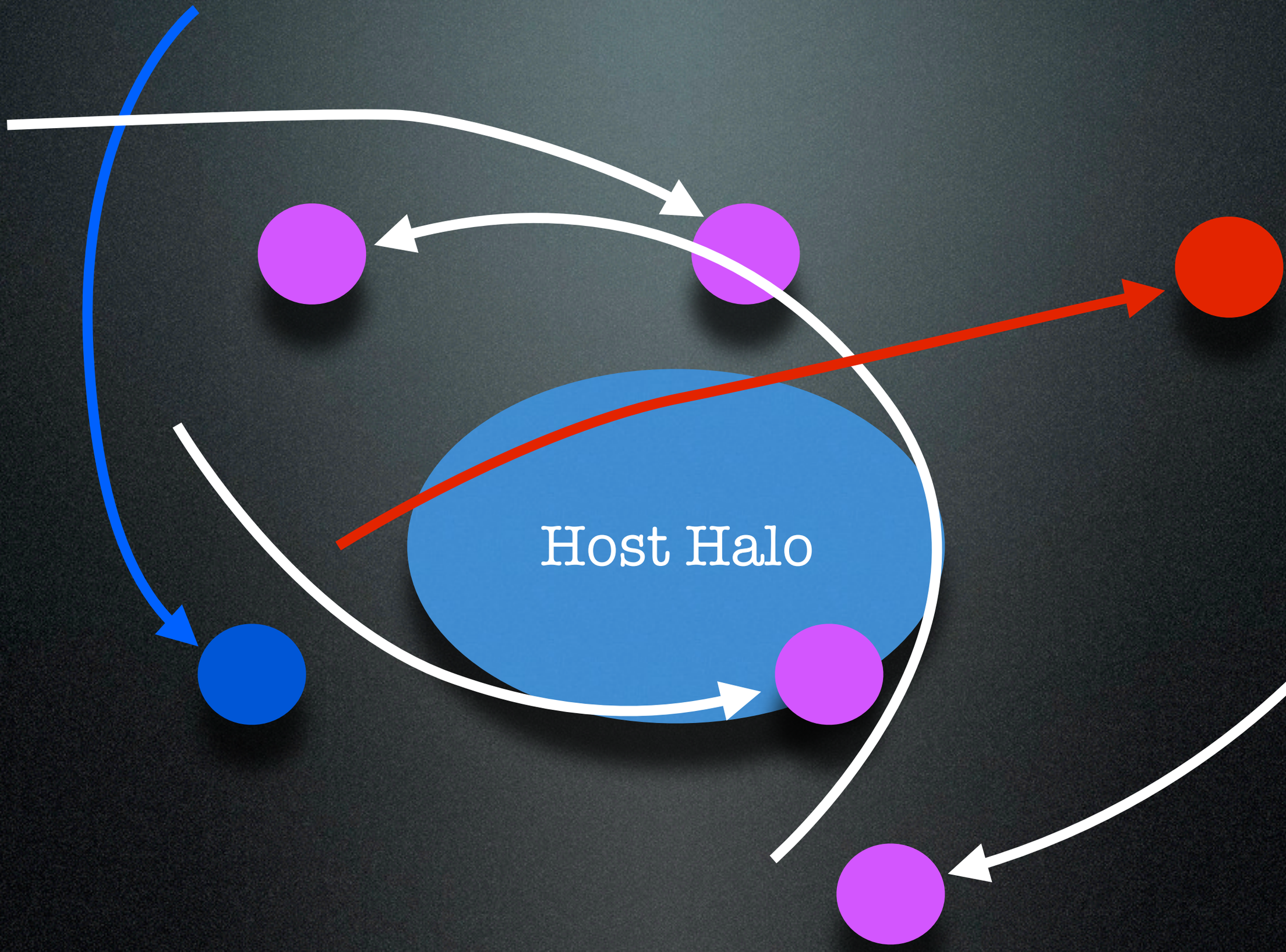
Host Halo

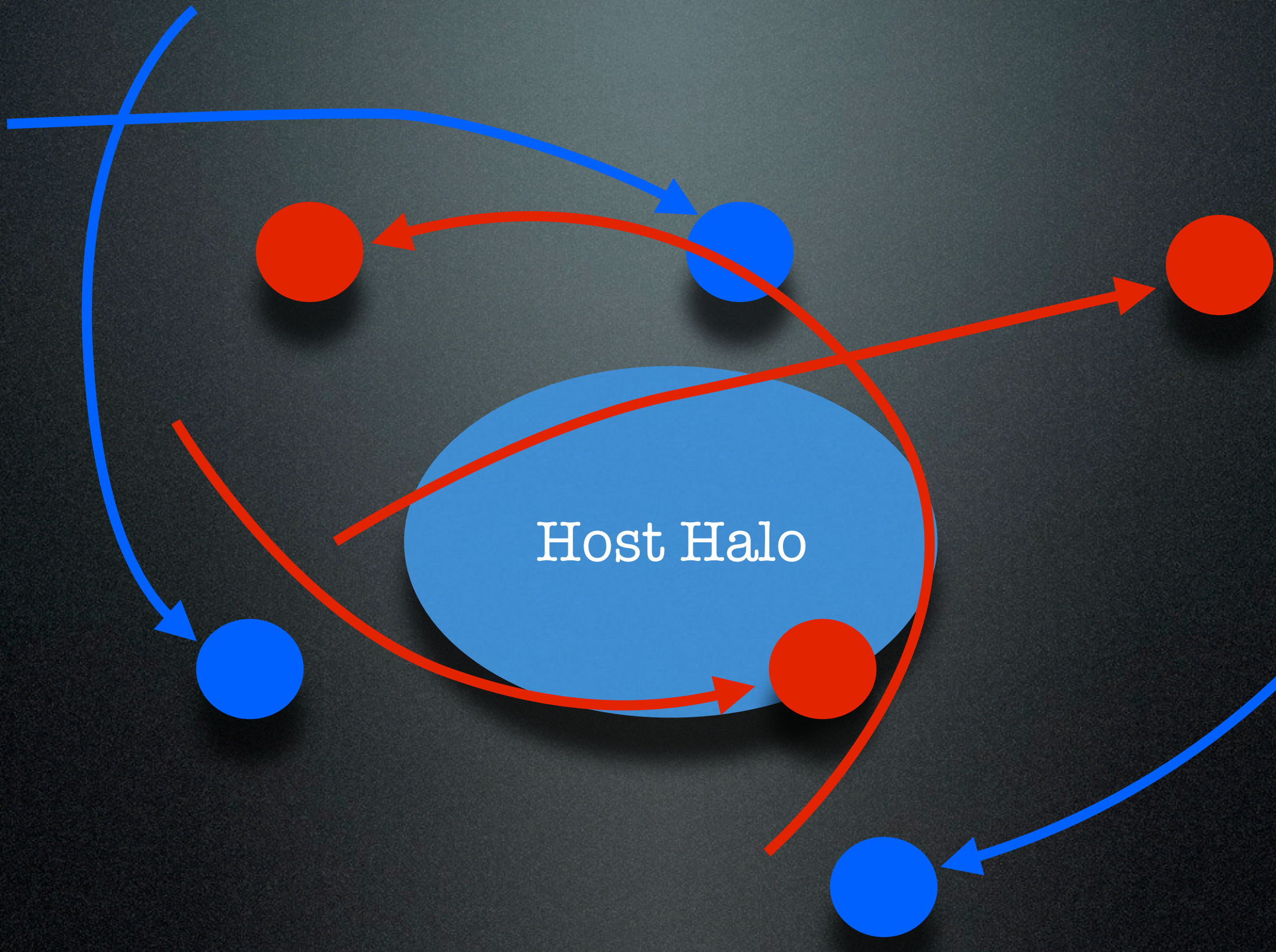

Host Halo


Host Halo

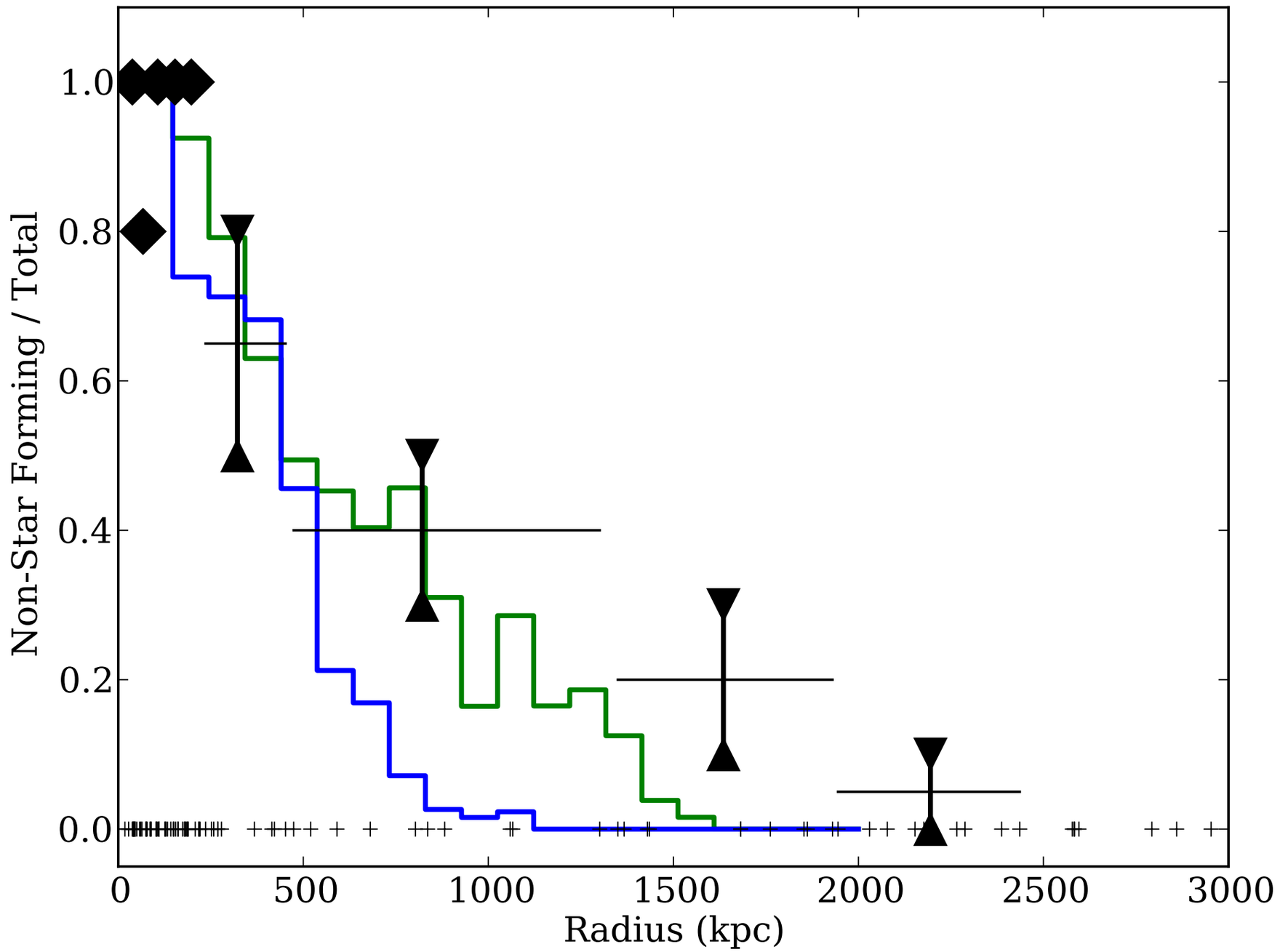

Host Halo


Host Halo

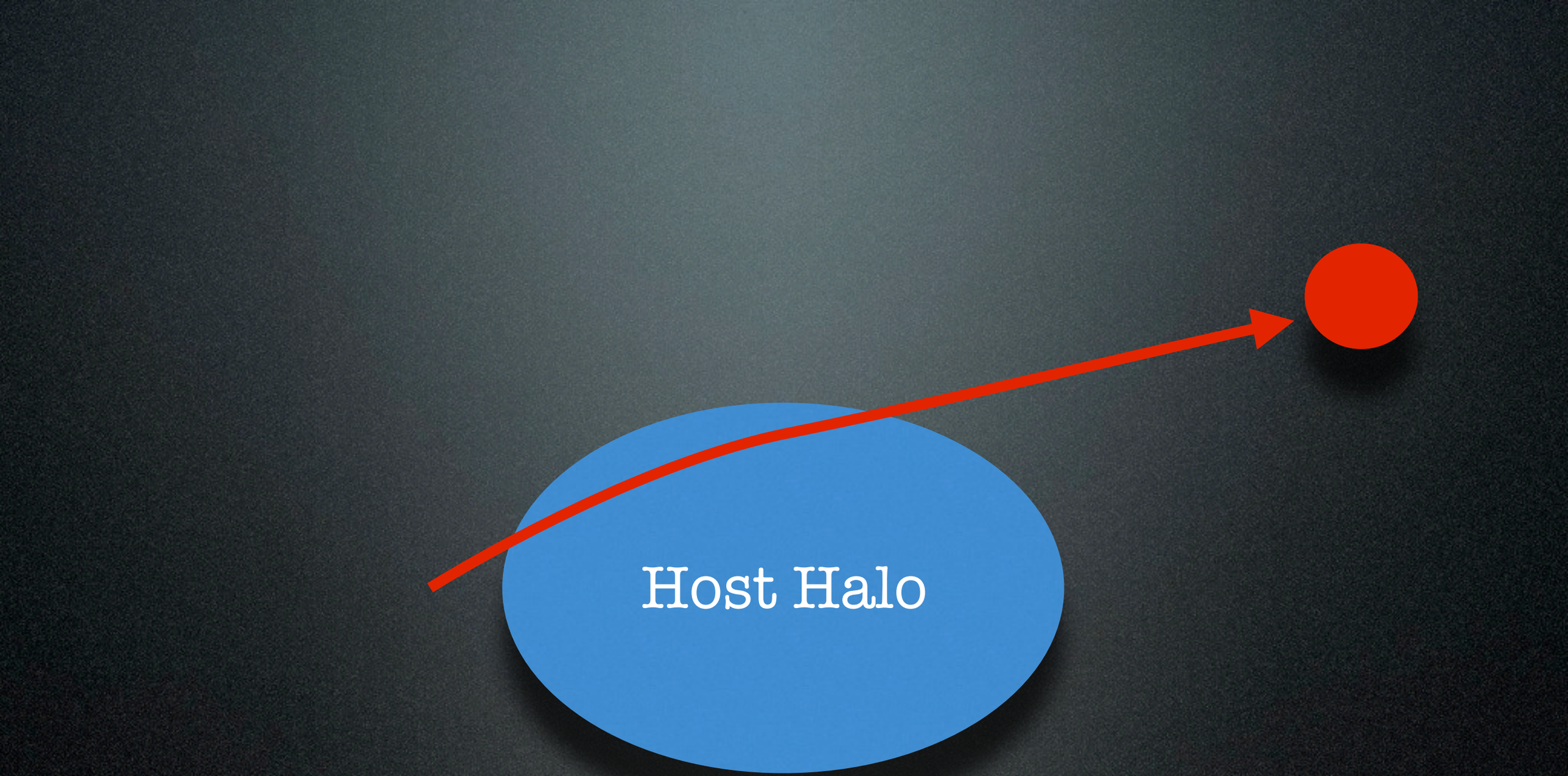

Host Halo

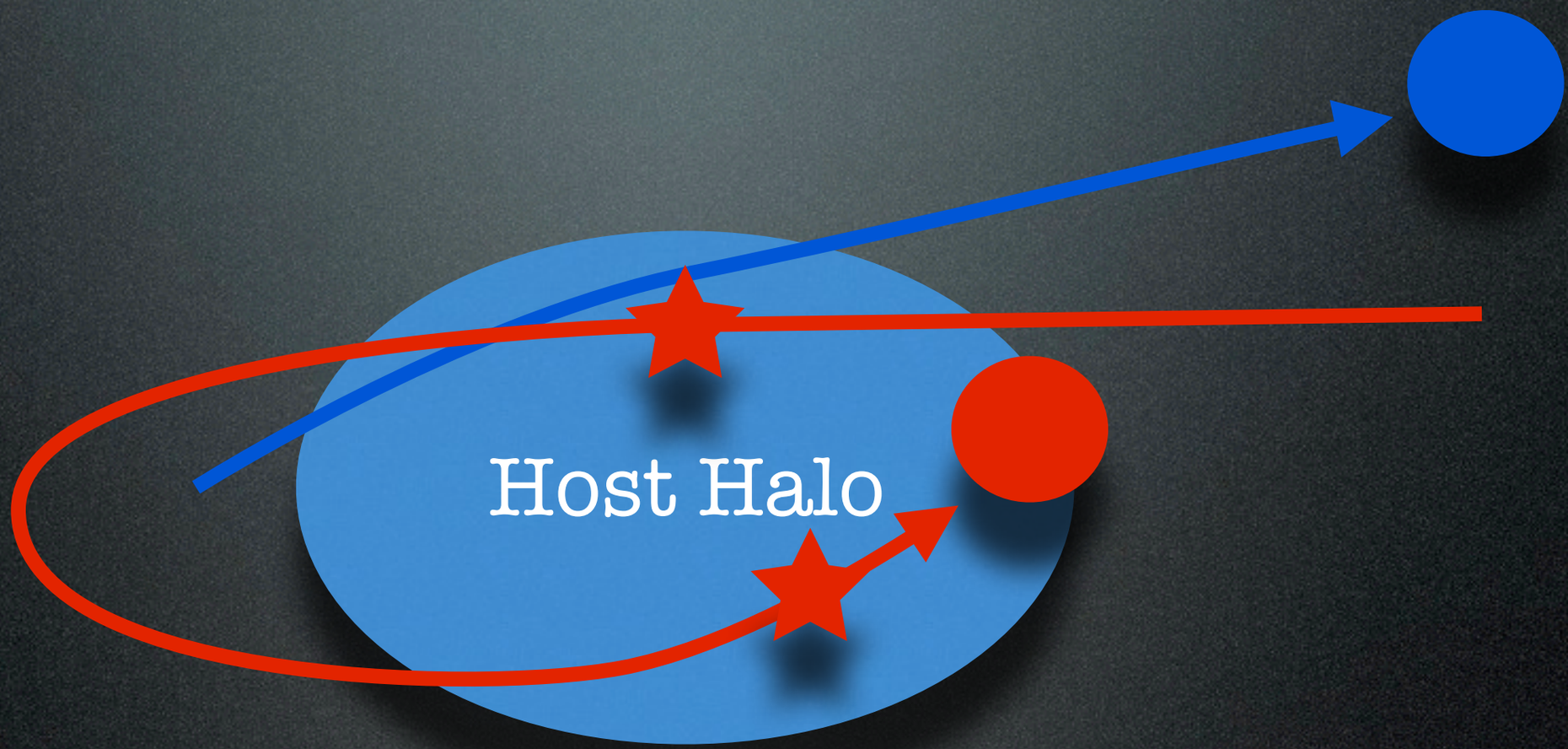

Host Halo

≥1 Pericenter for quenching

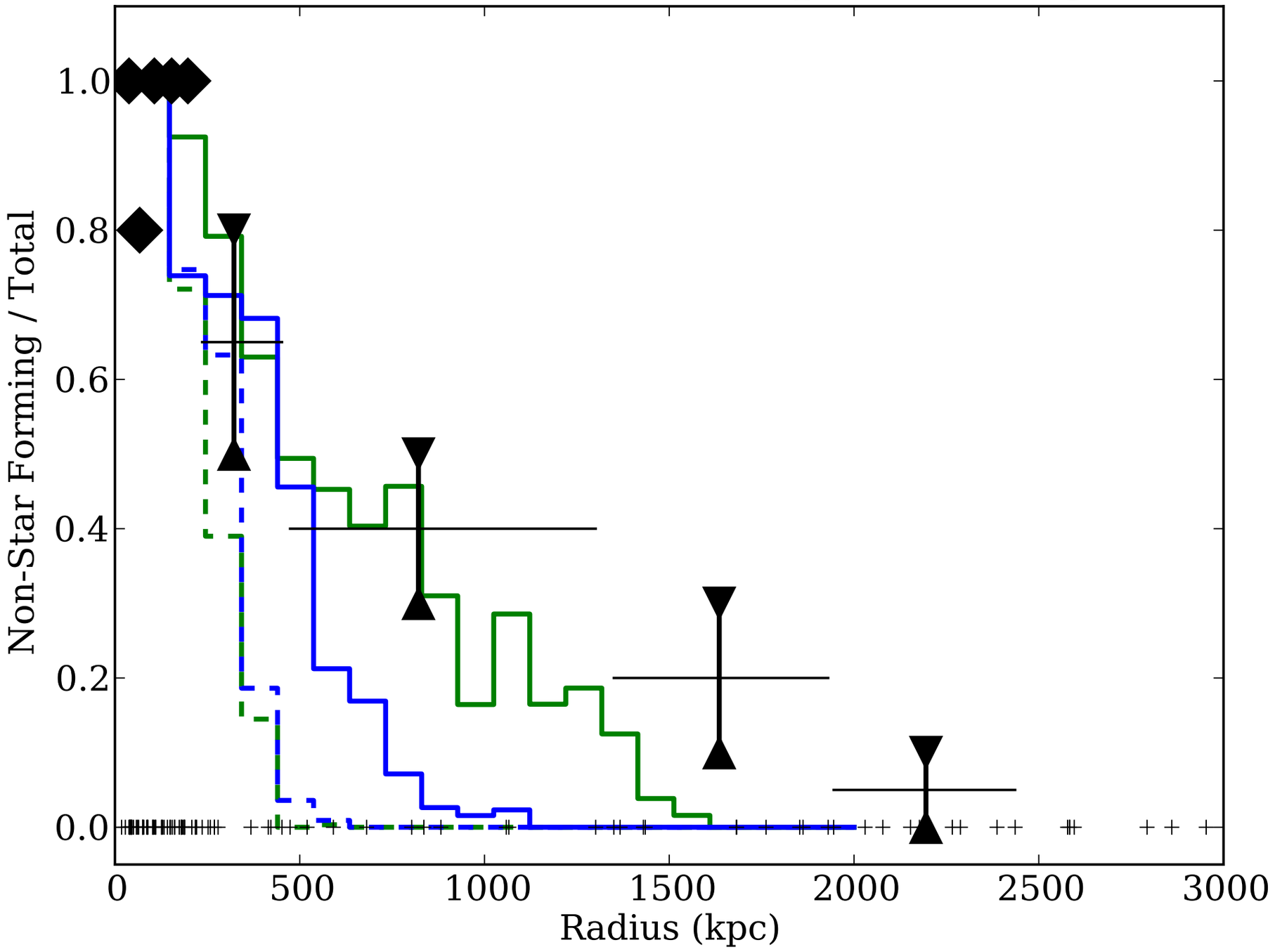


Slater & Bell 2013

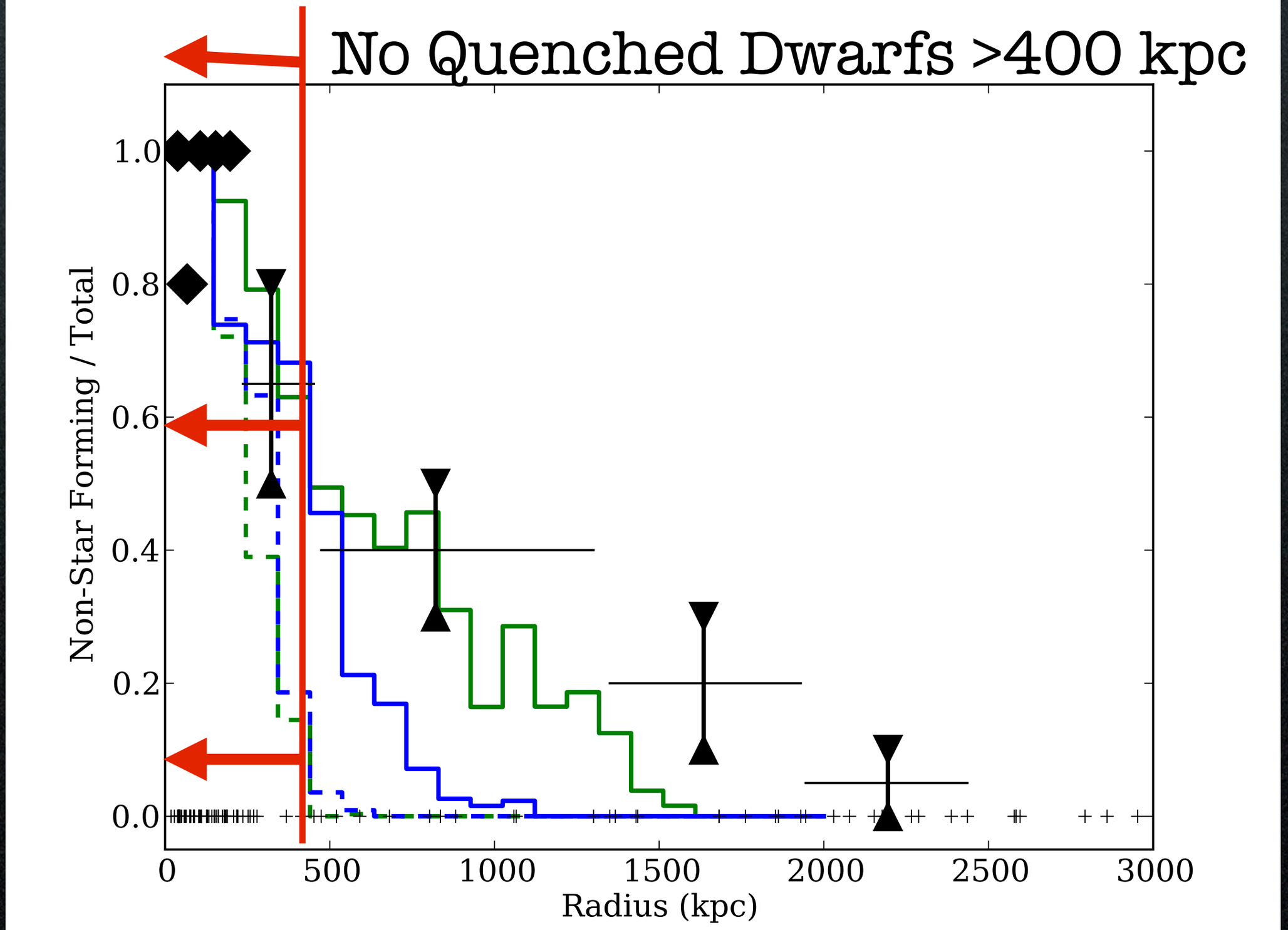

Host Halo


Host Halo

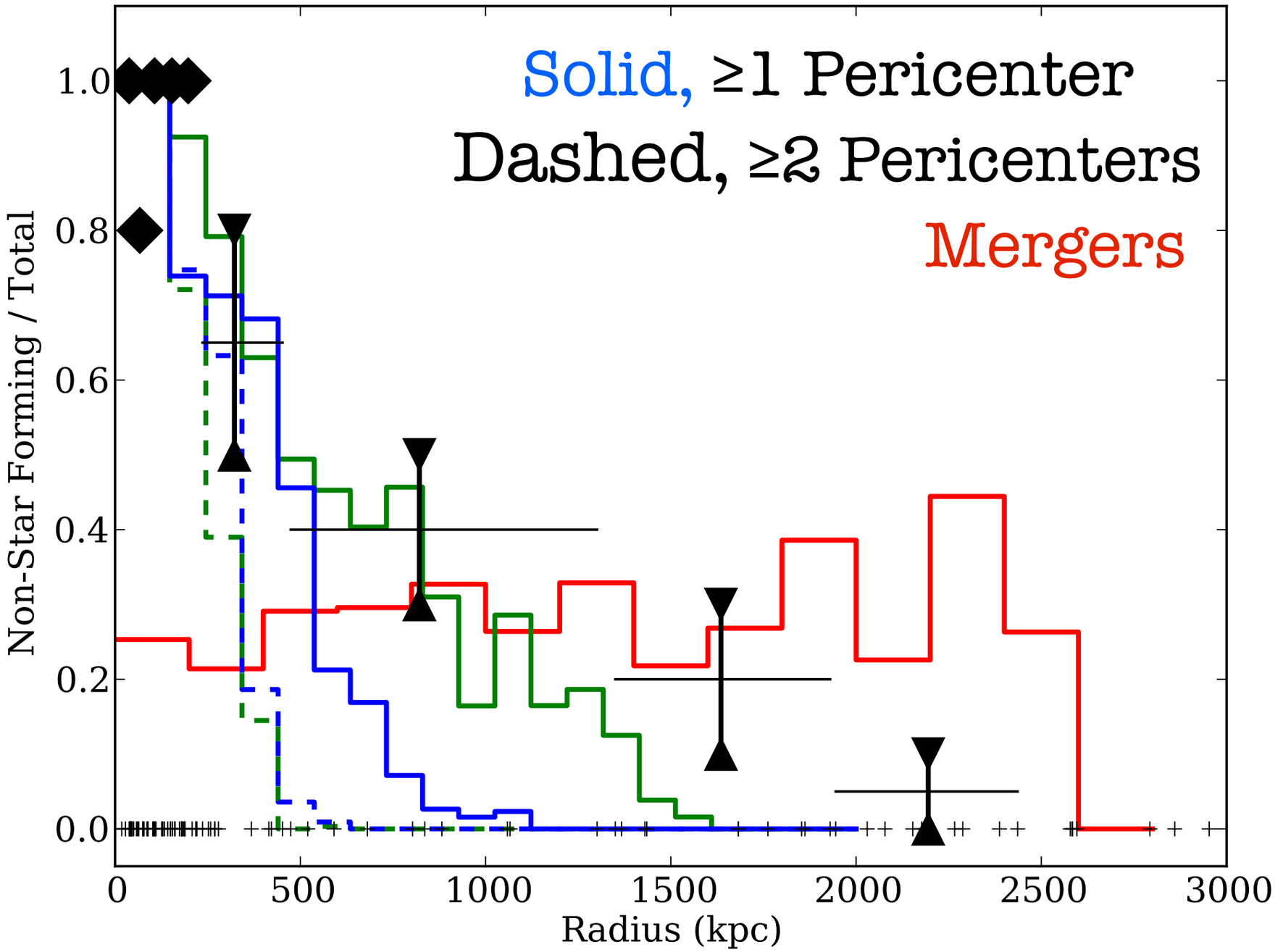
≥2 Pericenters for quenching



Slater & Bell 2013



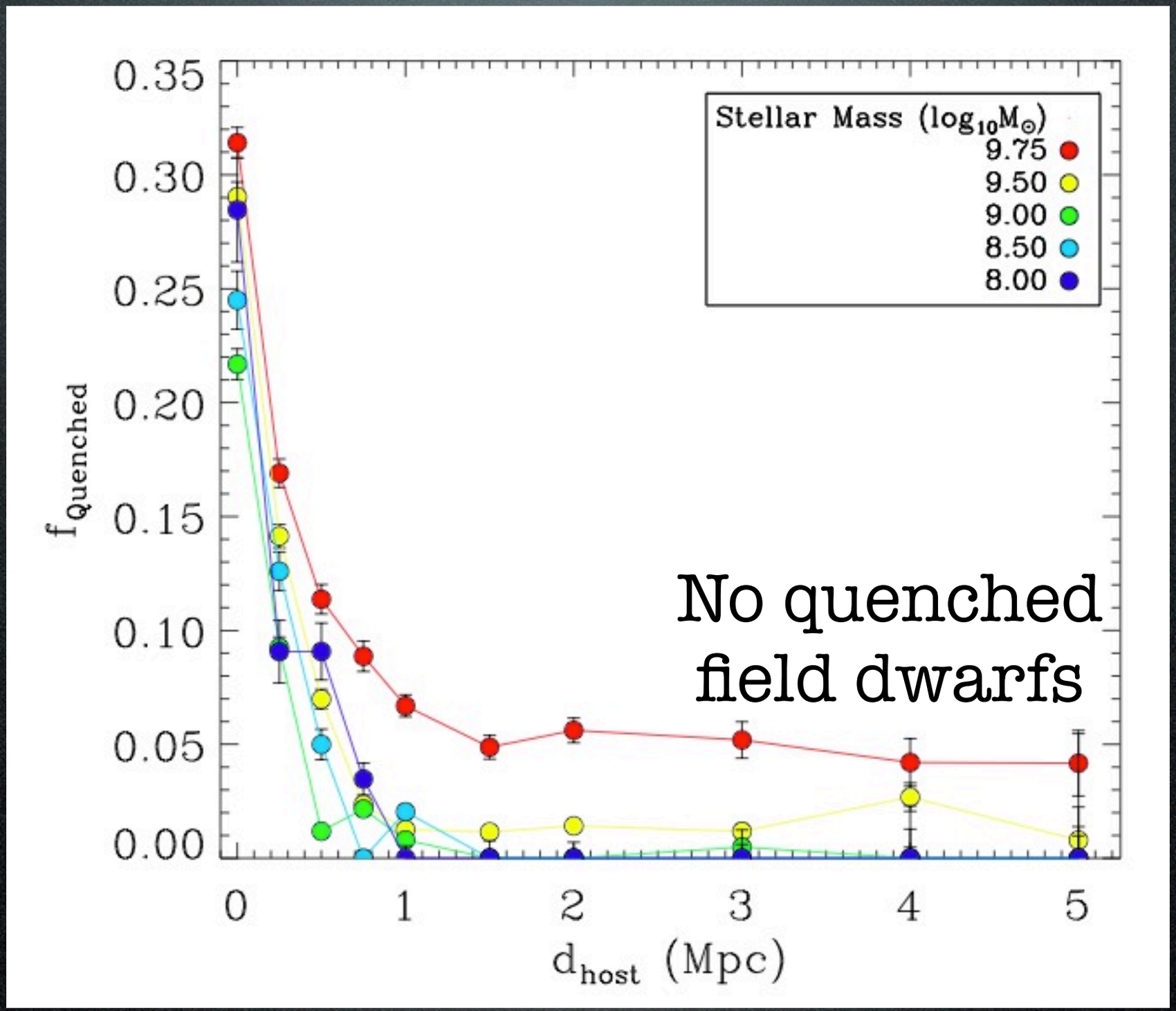
Slater & Bell 2013



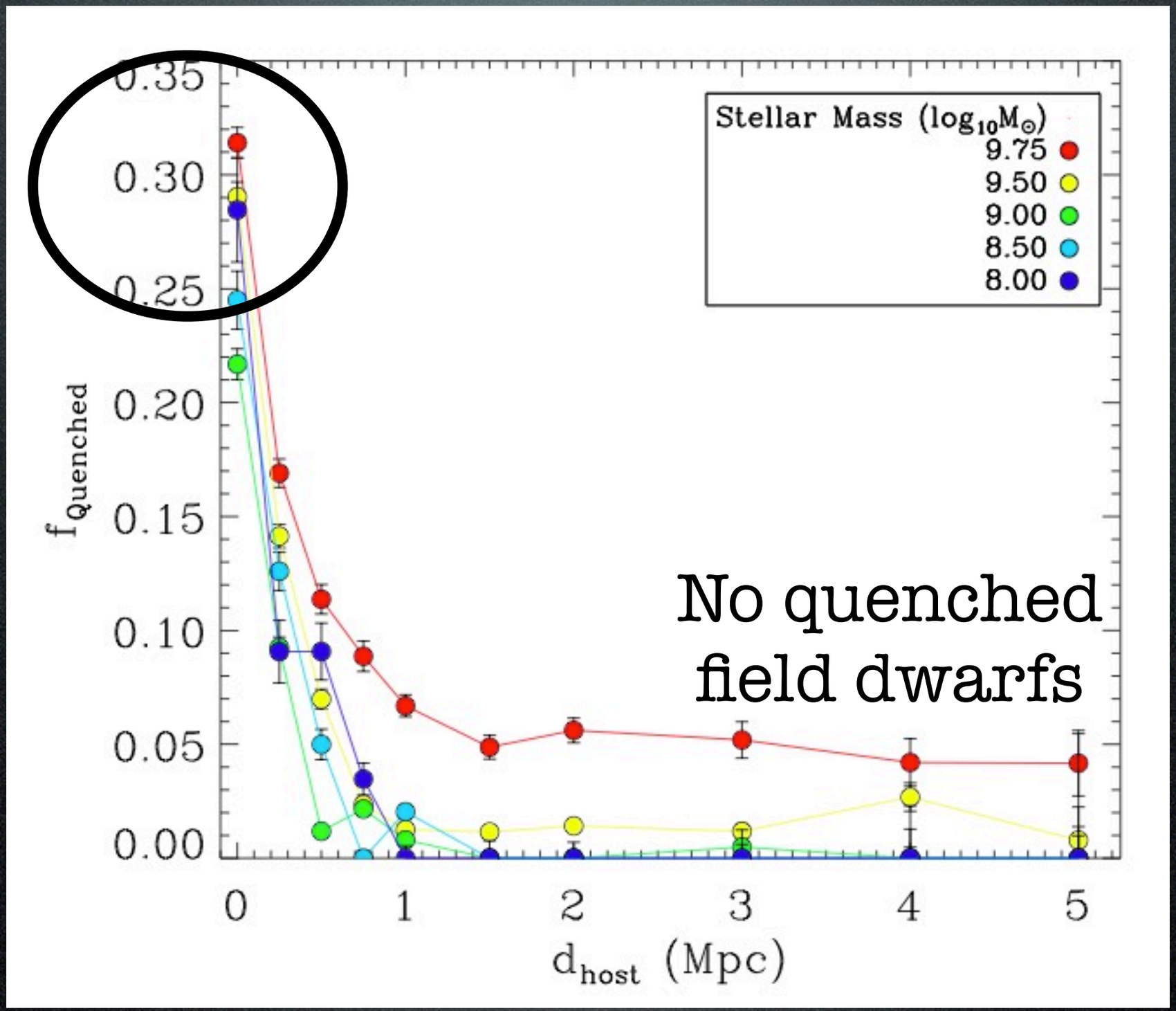
Slater & Bell 2013

- Tidal/ram pressure transformation works if and only if a single pass is sufficient.
- Requiring 2 passes cannot explain the MW, something else must be active
- Mergers are not required, but not ruled out.

- Using all LG dwarfs, low-mass dwarfs are over-represented.
- Is there a mass dependence in quenching?



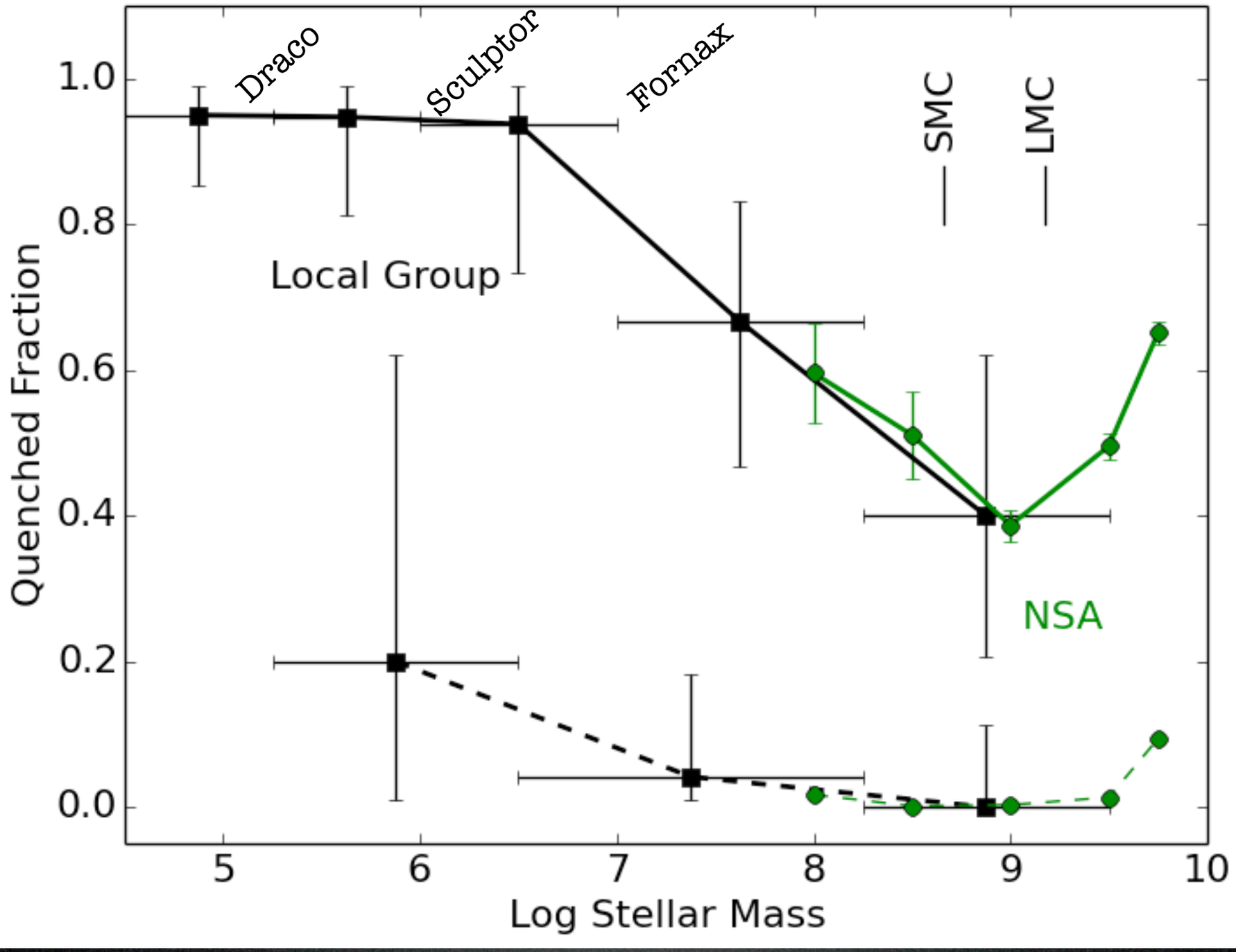
Geha et al. (2012)



Geha et al. (2012)

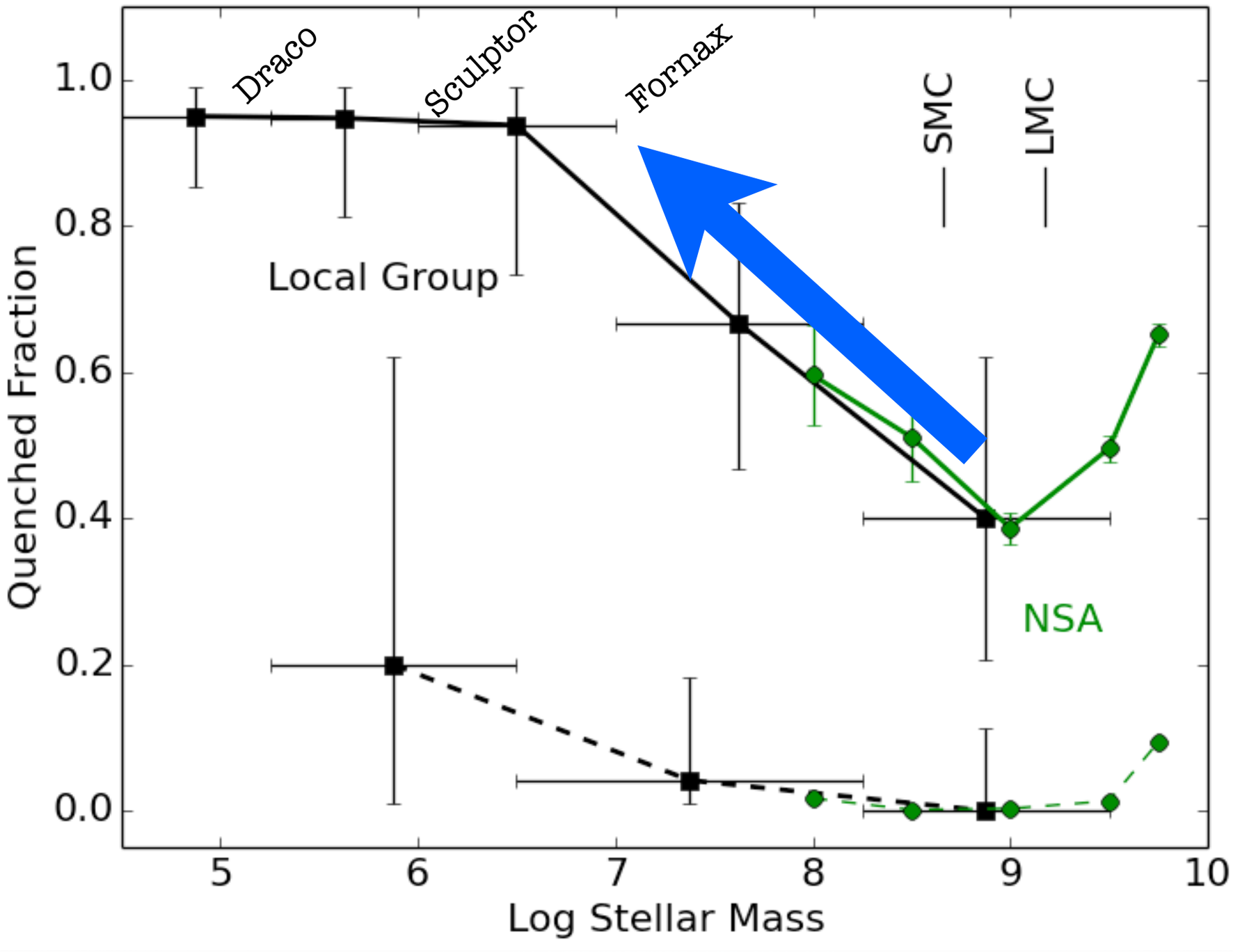
- Use SDSS at high masses (LMC/SMC)
- Corrected for interloper contamination
- Combine with robust LG data

Only Satellites, <500 kpc



Slater & Bell 2014

Only Satellites, <500 kpc



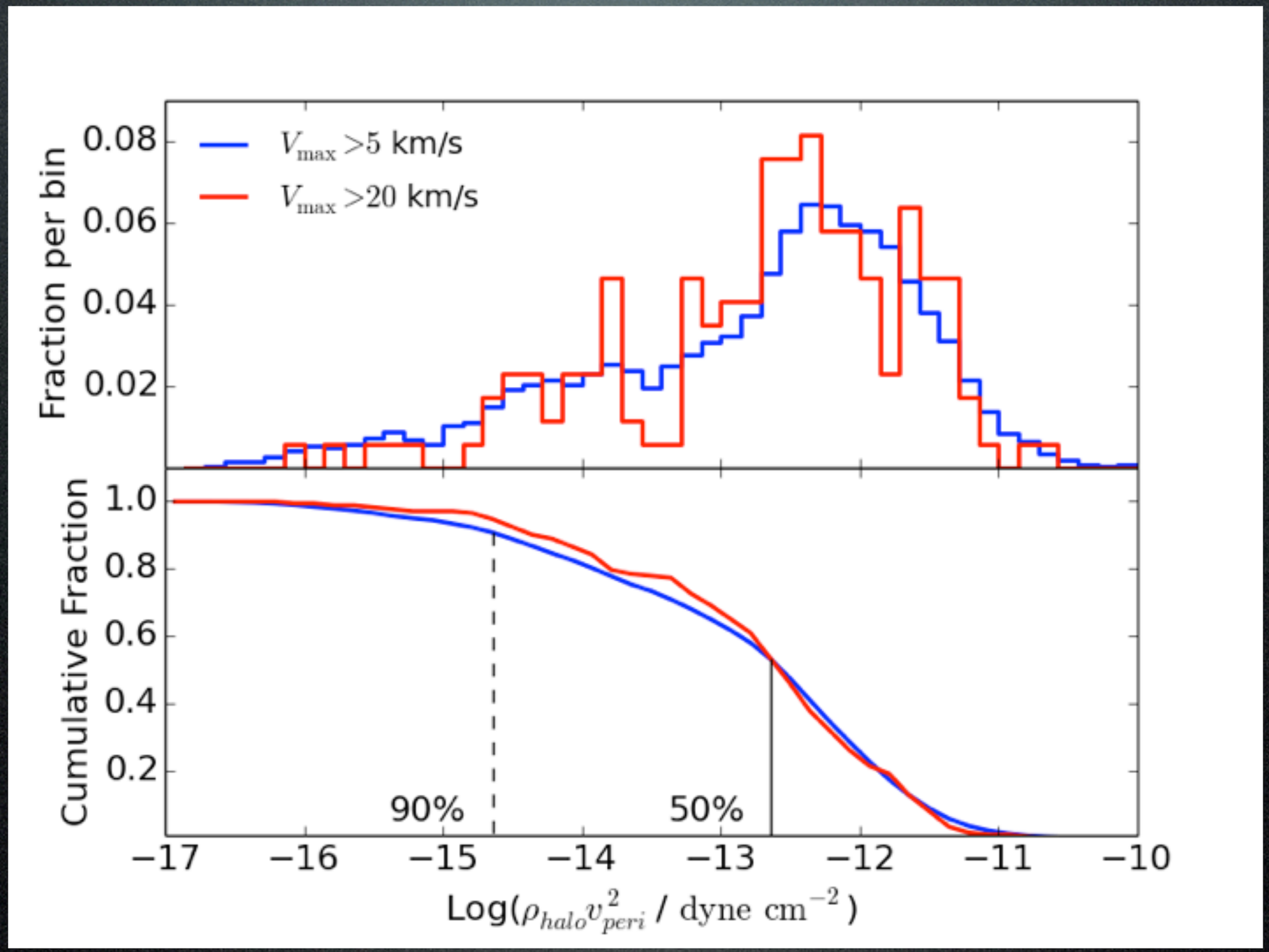
Slater & Bell 2014

- At 10^8 $M_\odot$, 50% of halos are quenched

- Assume ram pressure causes quenching, parameterized by ρv^2

- What must the ram pressure criterion be such that 50% of satellites are quenched? 90%?

Maximum ρv^2 seen by each satellite



Via Lactea II simulation +
Miller & Bregman (2013) gas halo

- If I want to quench 50% of satellites, $\rho v^2 \geq 10^{-12.5}$ dyne/cm^2 is the criterion.

- To quench 90%, $\rho v^2 \geq 10^{-14.5}$ dyne/cm^2

- The “susceptibility” to ram pressure changes by a factor of 100, while mass changes by factor of 30.

- If I want to quench 50% of satellites, $\rho v^2 \geq 10^{-12.5}$ dyne/cm^2 is the criterion.

=0.3 eV/cm^3

- To quench 90%, $\rho v^2 \geq 10^{-14.5}$ dyne/cm^2

- The "susceptibility" to ram pressure changes by a factor of 100, while mass changes by factor of 30.

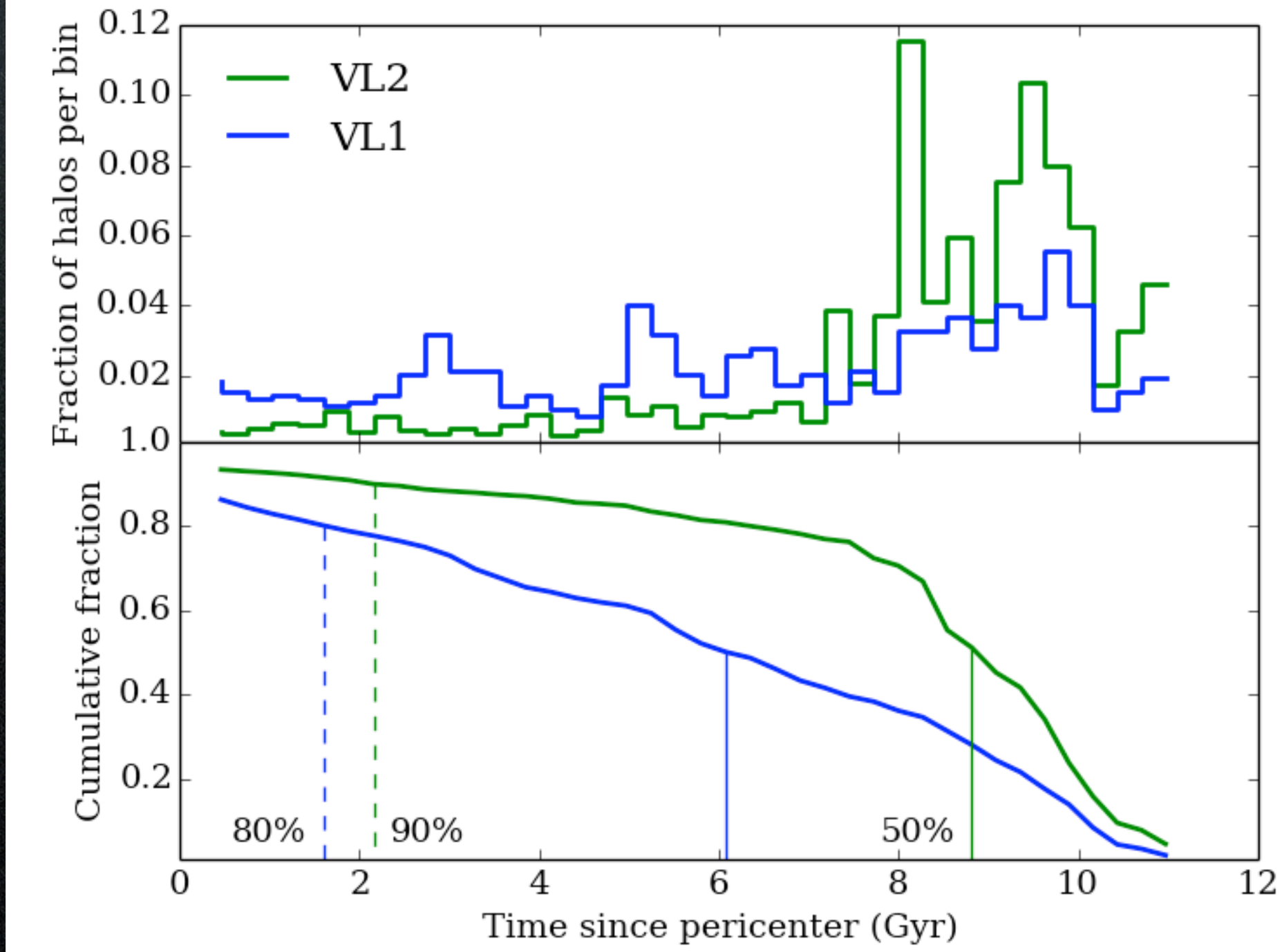
- Assume quenching occurs when ram pressure~restoring force (Gunn & Gott)

- $\rho v^2 = 2\pi G\, \Sigma_\star \Sigma_{gas}$

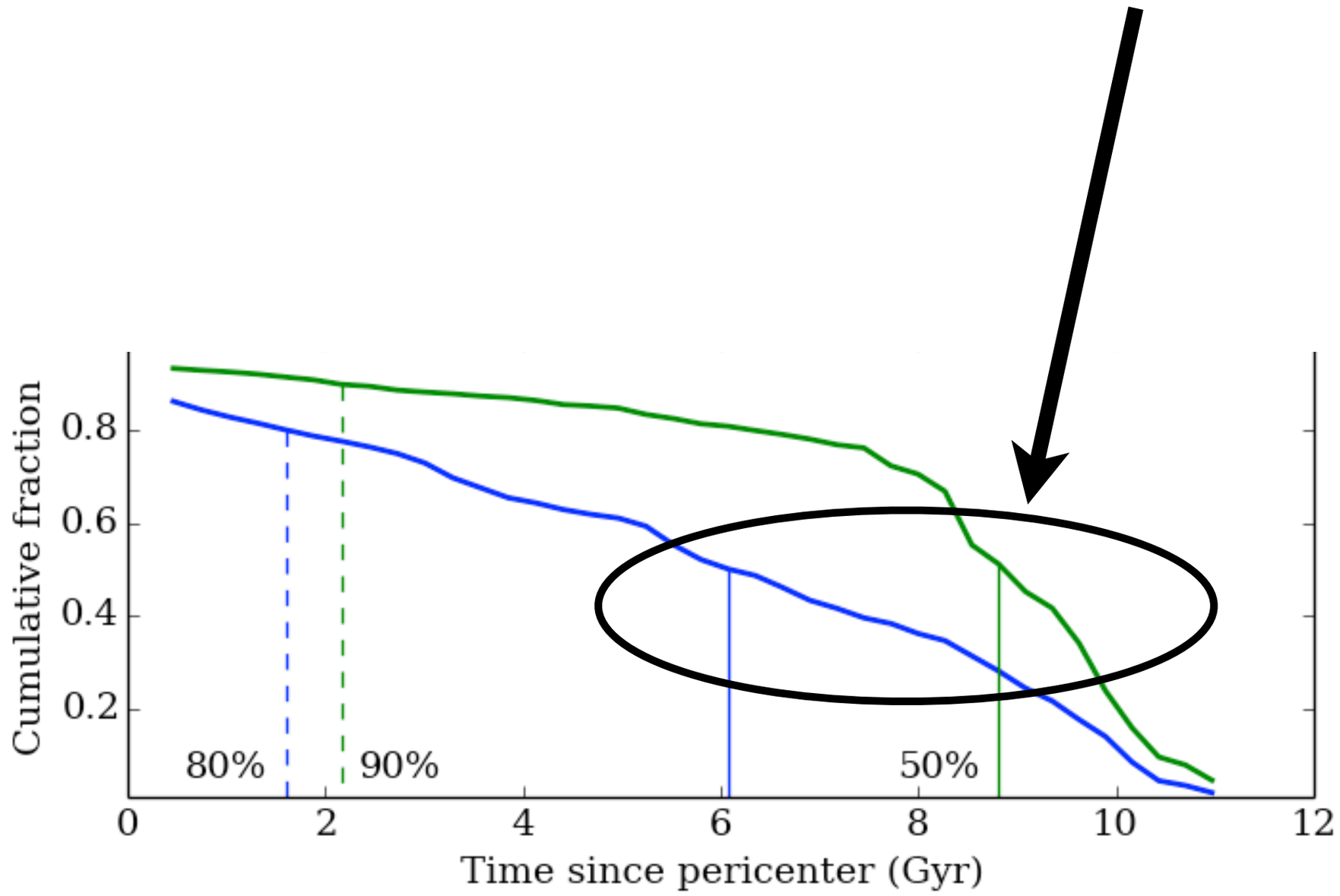
- Plausible M^2 scaling, but mass distribution in dIrrs is messy

- Thermal processes may also play a role, detailed physics is uncertain.

- Alternative model: What if quenching is just halo infall + delay time?
- How quickly must satellites be quenched?

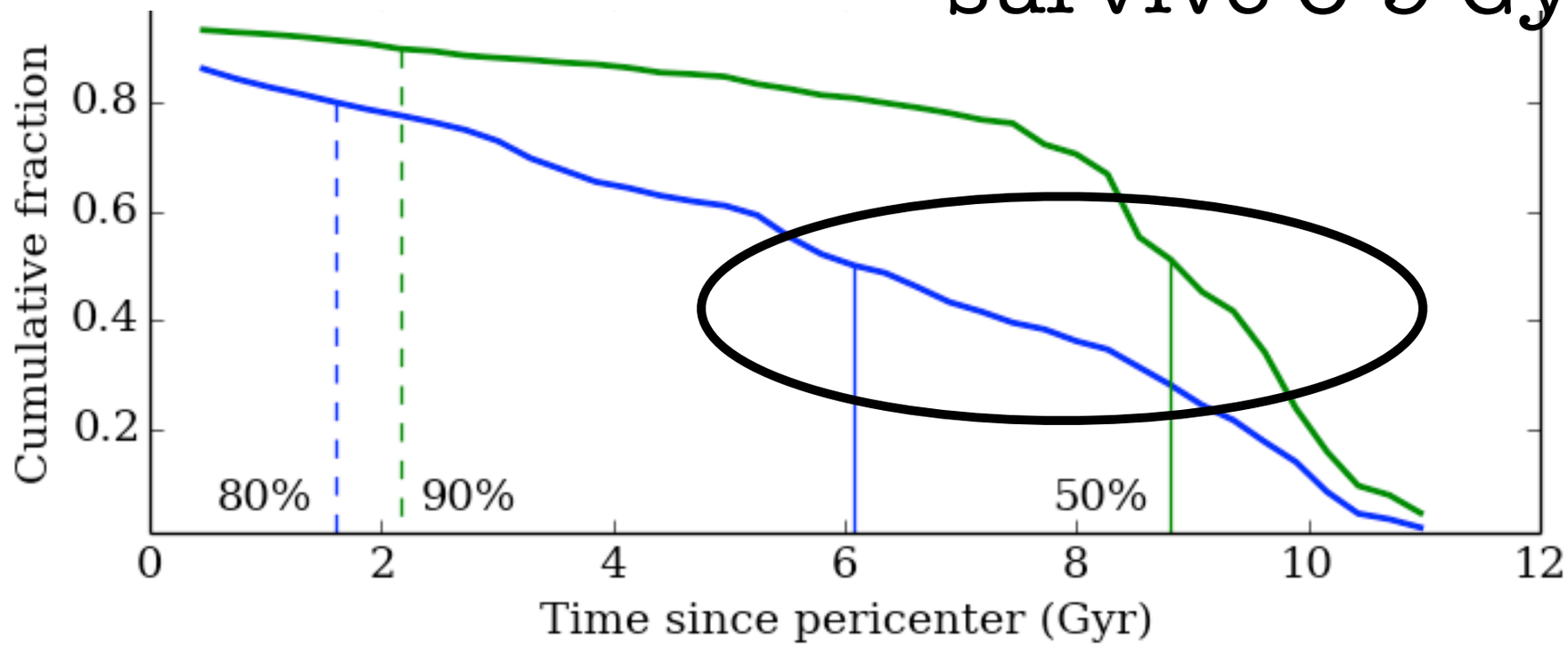

VL2
VL1
Fraction of halos per bin
0.12
0.10
0.08
0.06
0.04
0.02
1.0
Cumulative fraction
0.8
0.6
0.4
0.2
80%
90%
50%
0
2
4
6
8
10
12
Time since pericenter (Gyr)

50% of halos fell in
>6-9 Gyr ago



50% of halos fell in >6-9 Gyr ago

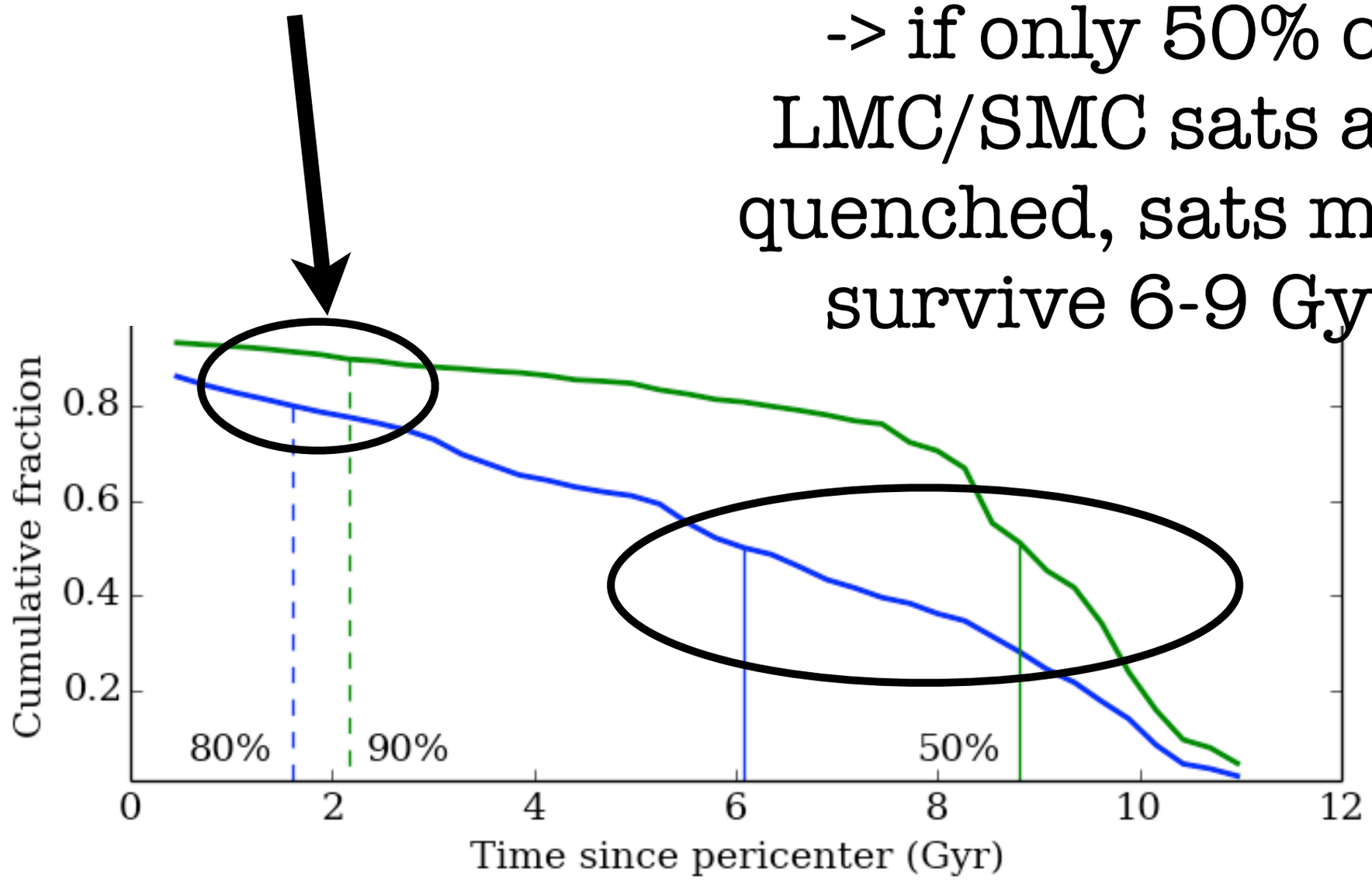
-> if only 50% of LMC/SMC sats are quenched, sats must survive 6-9 Gyr



80% of halos fell in >2 Gyr ago

50% of halos fell in >6-9 Gyr ago

-> if only 50% of LMC/SMC sats are quenched, sats must survive 6-9 Gyr

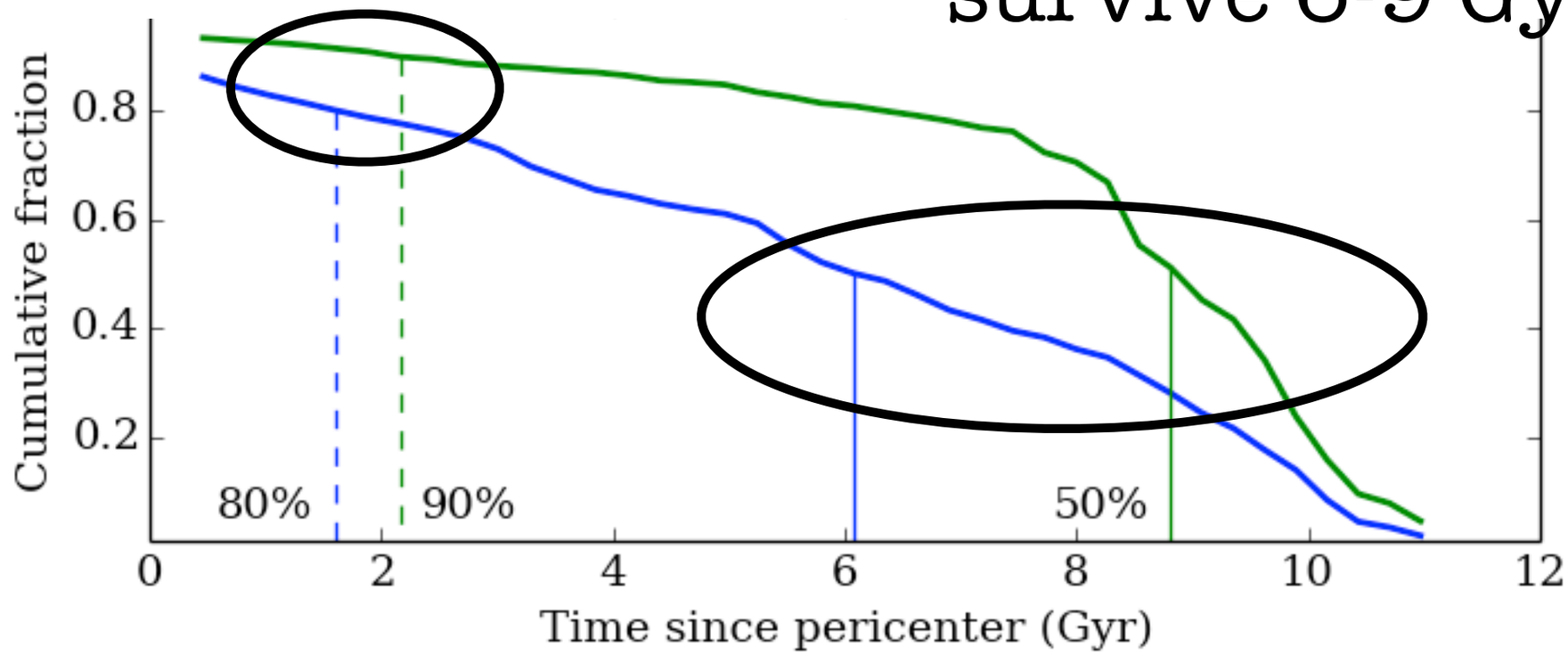


80% of halos fell in >2 Gyr ago

-> if 90% of low mass sats are quenched, Q'ing must be fast

50% of halos fell in >6-9 Gyr ago

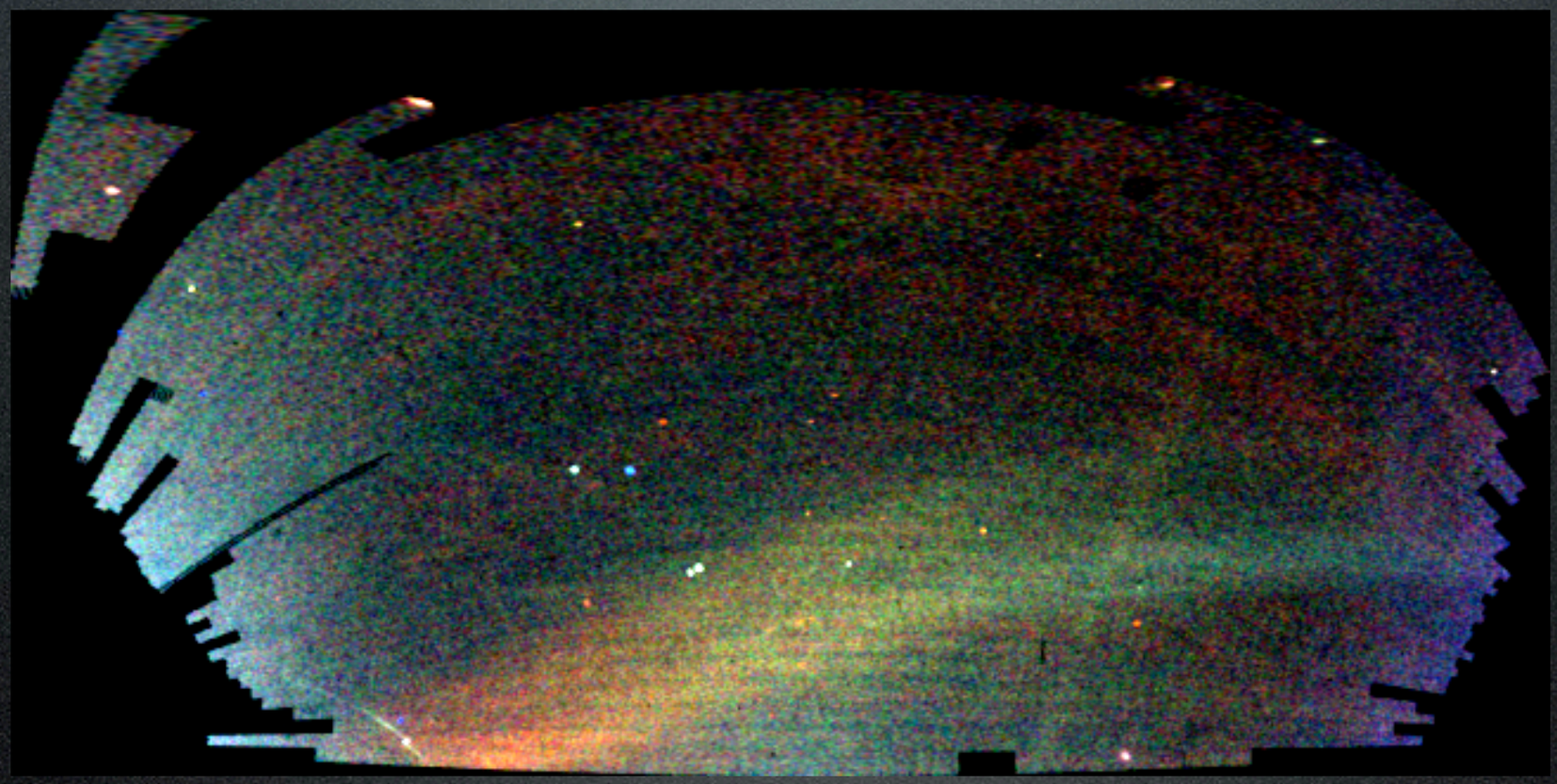
-> if only 50% of LMC/SMC sats are quenched, sats must survive 6-9 Gyr



- Effects of hosts on their satellites: rapid quenching of dwarfs (<SMC)

- Switch gears: what effects do satellites have on their hosts?

“Field of Streams”



GC

Anticenter

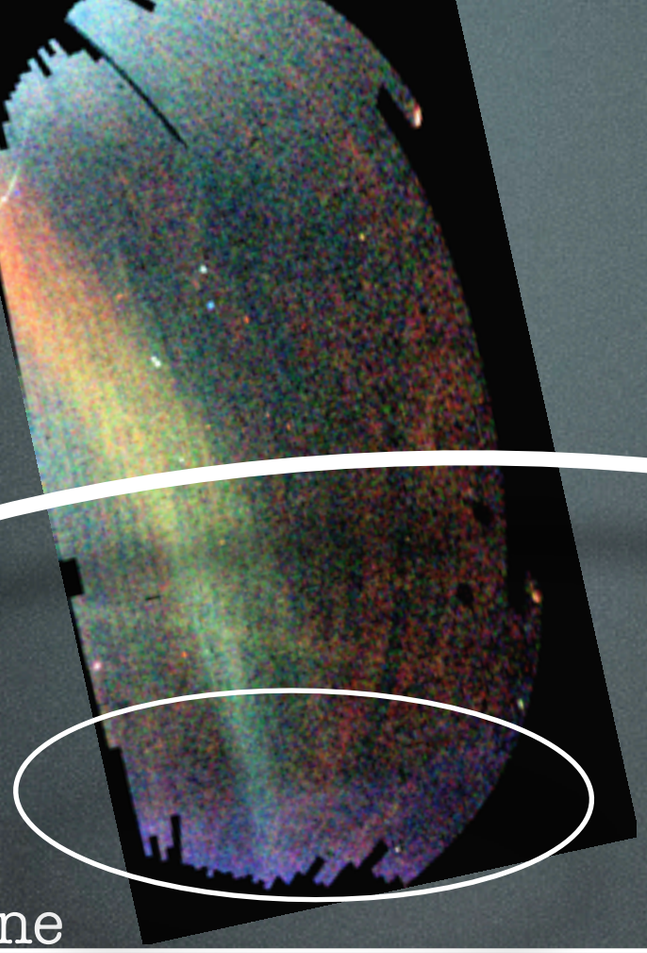
Belokurov et al. (2007)

Monoceros Ring

Galactic Center

Anticenter

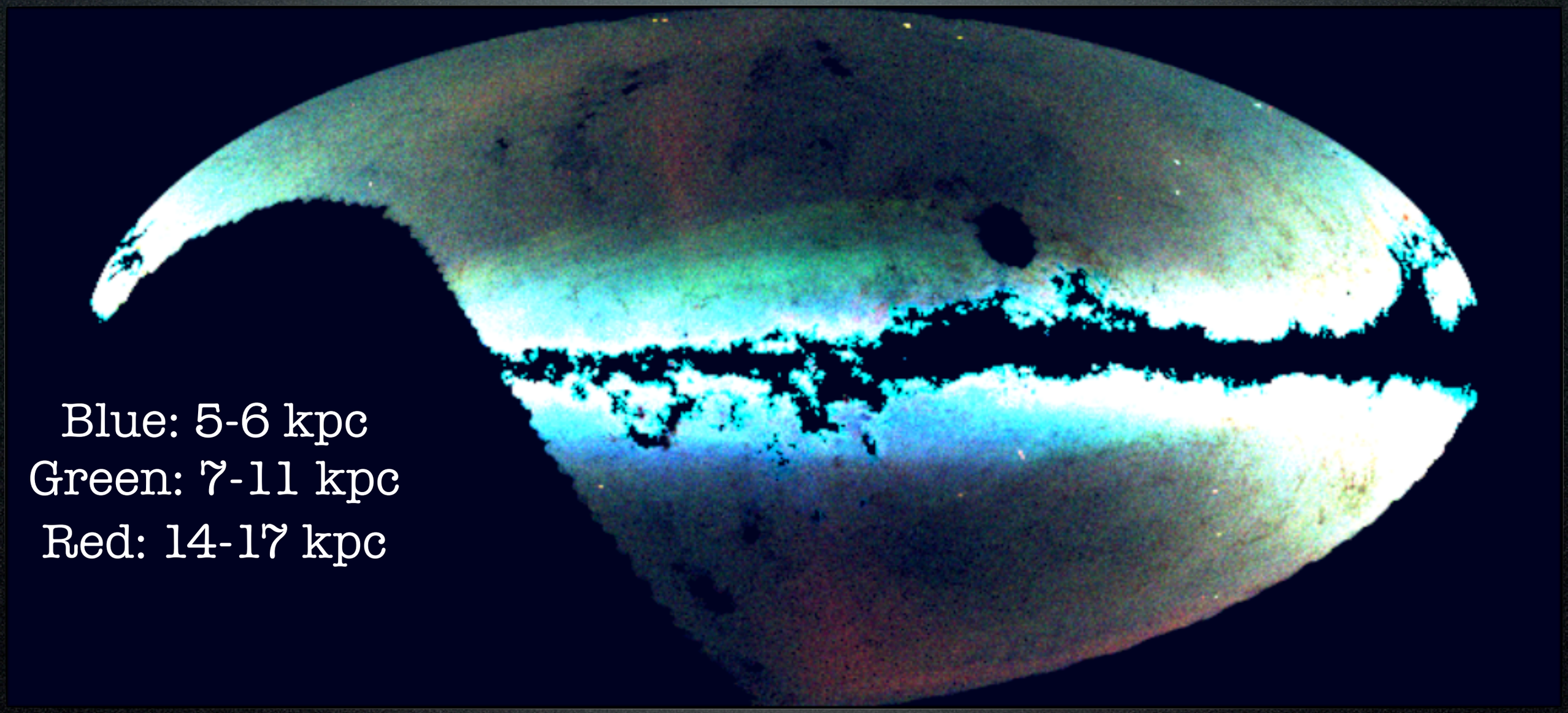
- Pan-STARRS 3pi survey
- Continuous disk coverage
- SDSS-like depth single-epoch, stacking is in progress

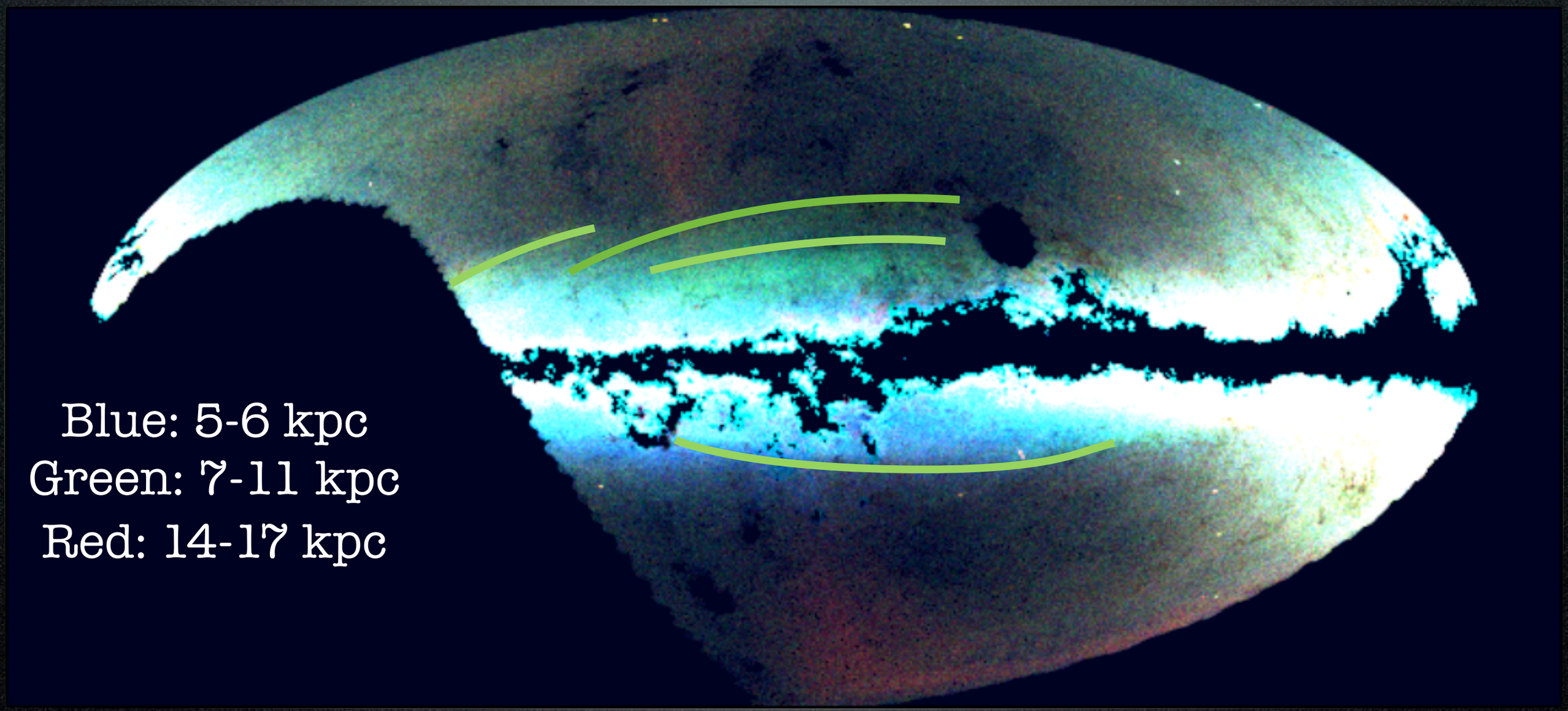


Galactic Plane

GC

Anticenter


Blue: 5-6 kpc
Green: 7-11 kpc
Red: 14-17 kpc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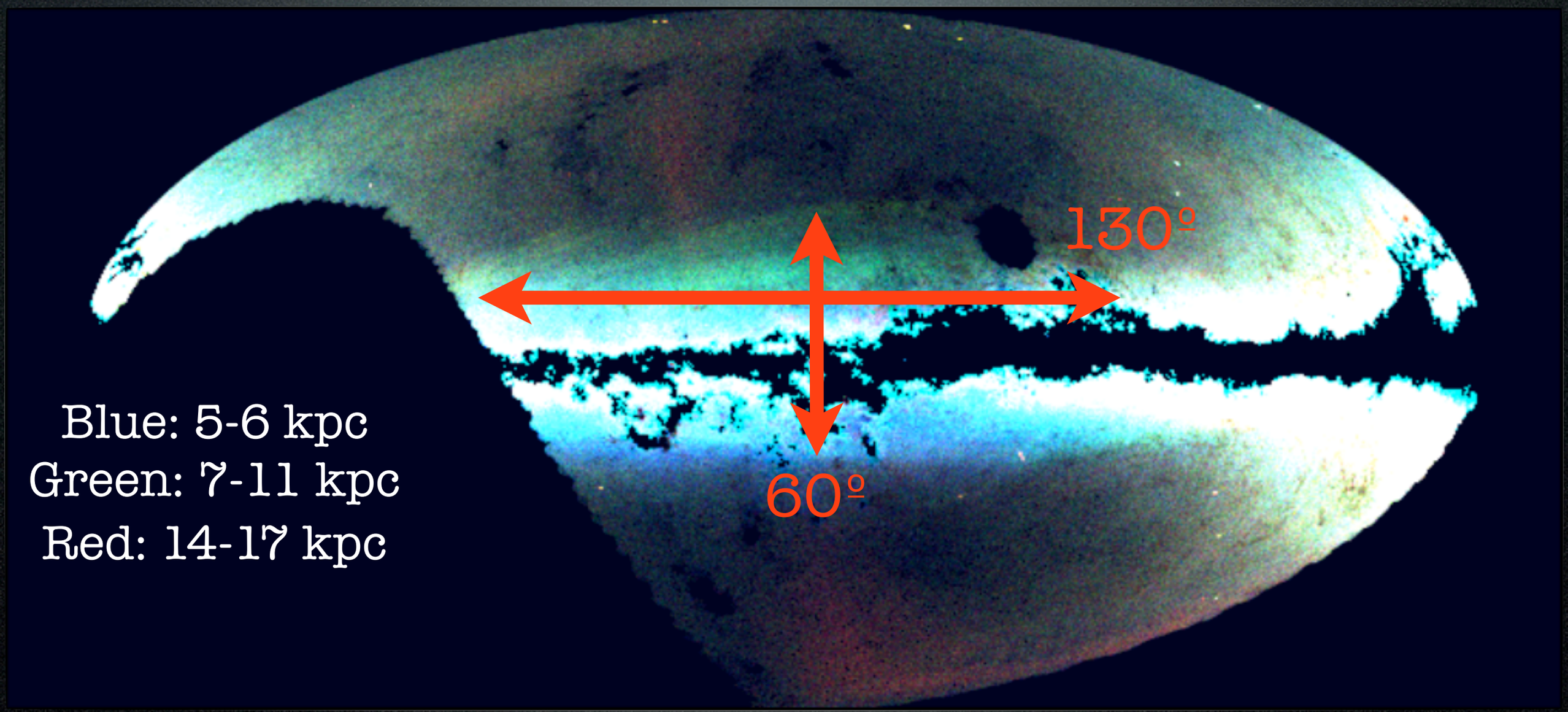
130º
60º
Blue: 5-6 kpc
Green: 7-11 kpc
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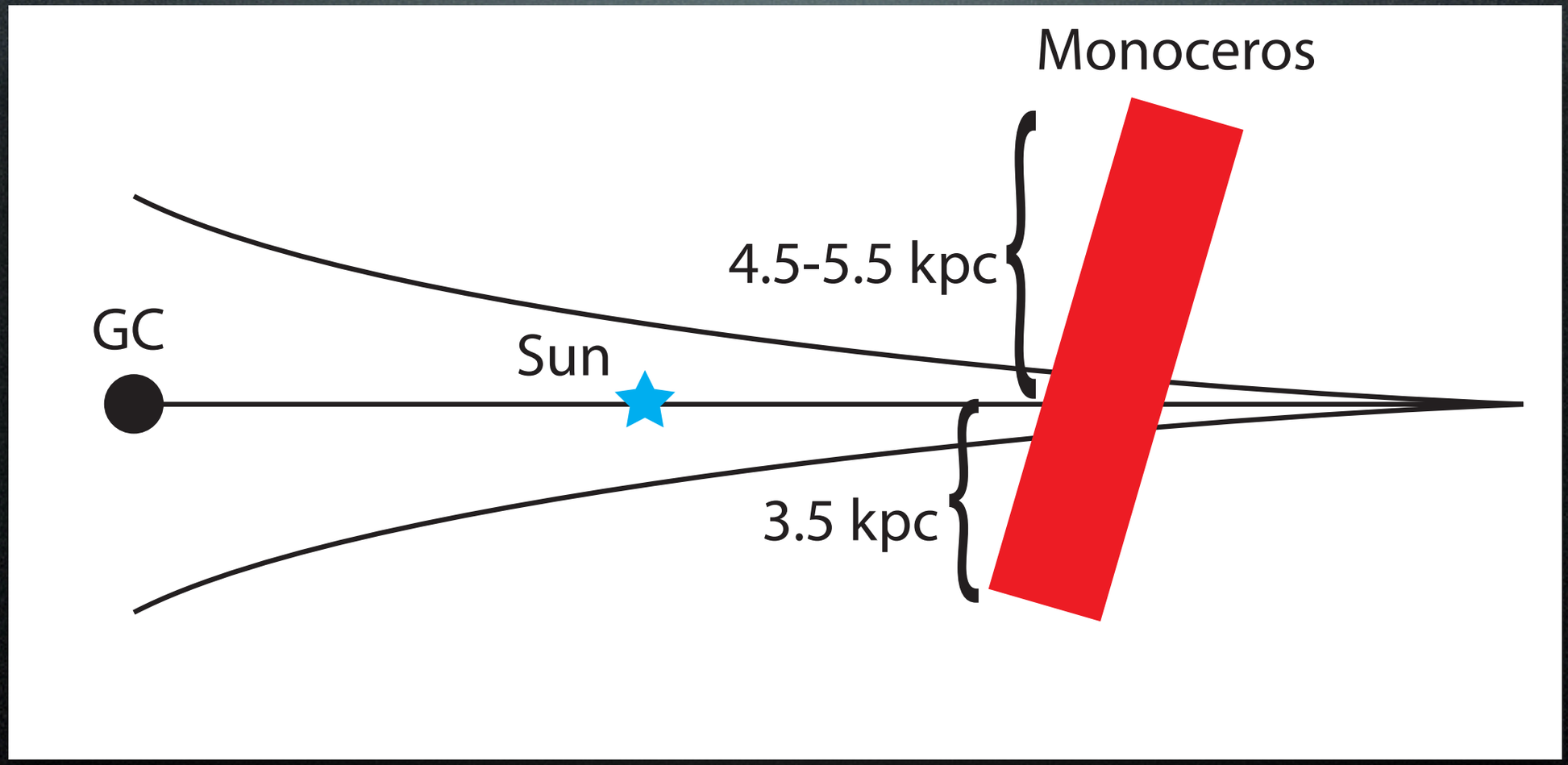

Monoceros
4.5-5.5 kpc
GC
Sun
3.5 kpc

The map shows that Monoceros is ...

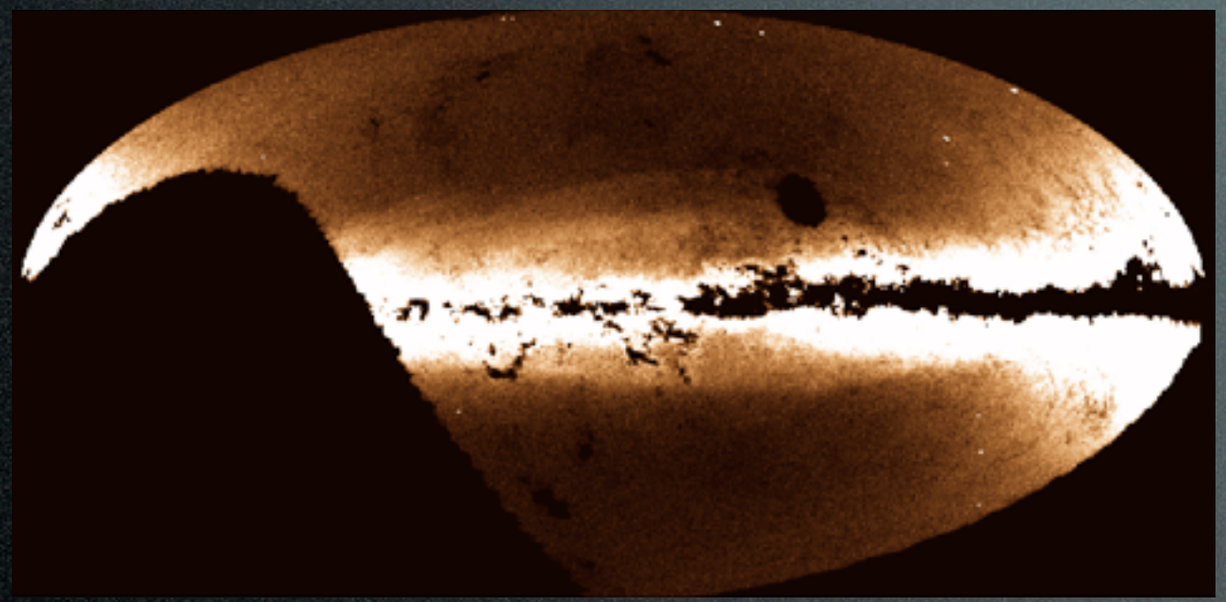
- Extended in longitude, with sharp edge
- Both sides of the disk (southern coverage is new!)
- Several “whispy” structures at similar distances, possibly related

But what is Monoceros?

Tidal Stream?
Kicked-up disk?
Flare?
Warp?

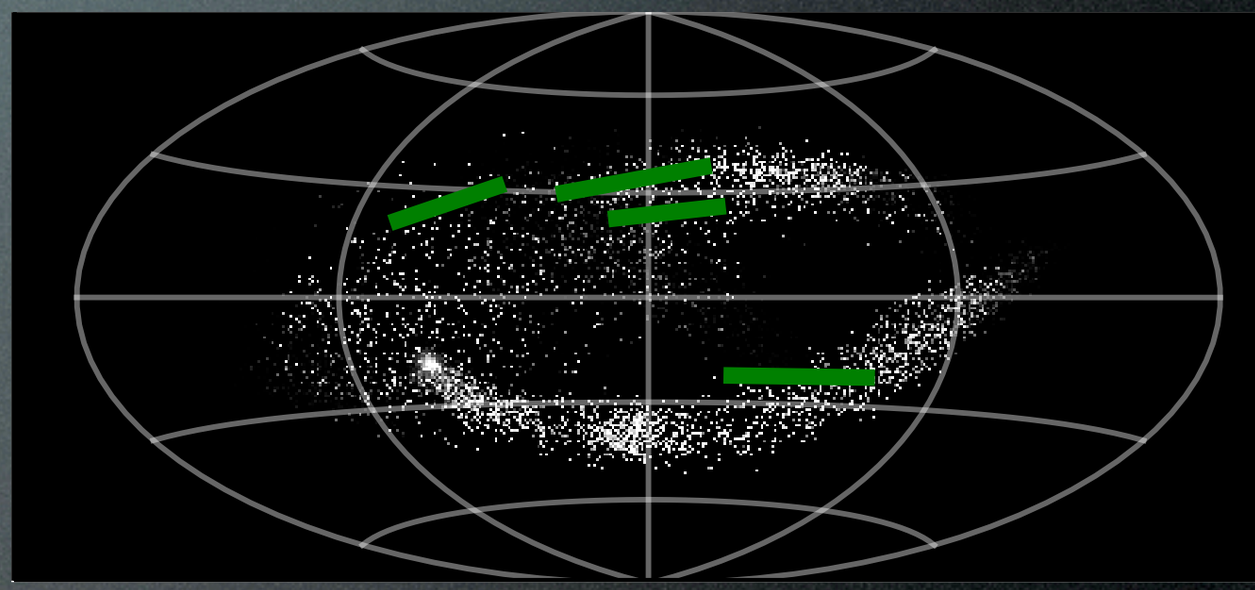
Accreted Satellite Model

Mid-Distance Slice



Observed

7-10 kpc slice



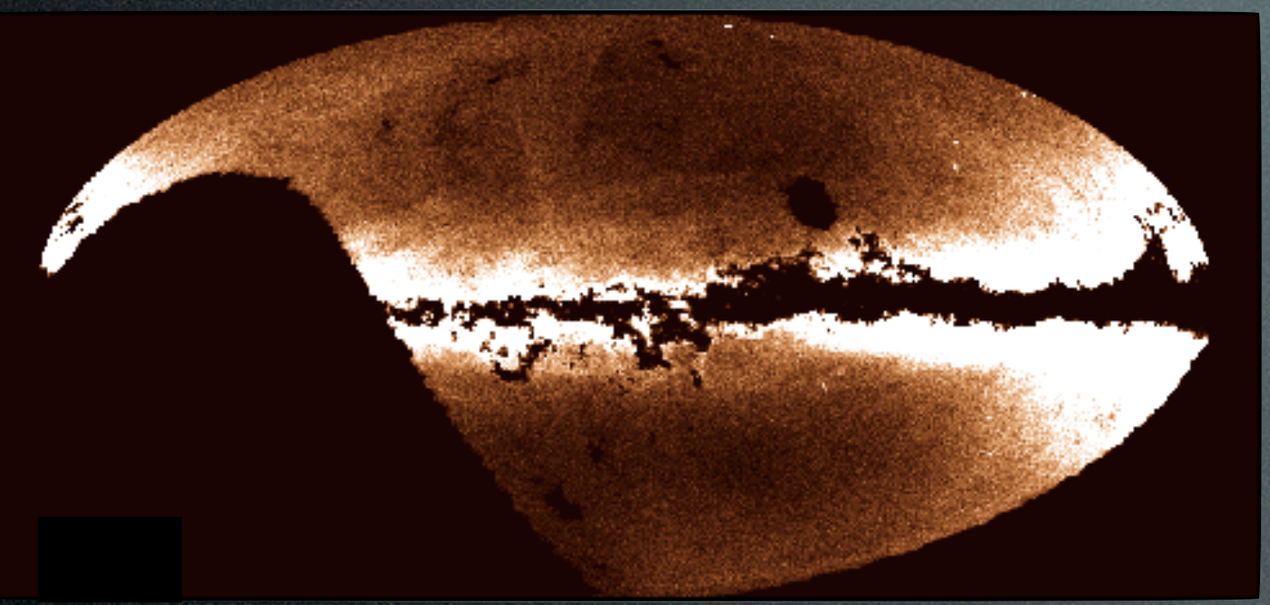
Model

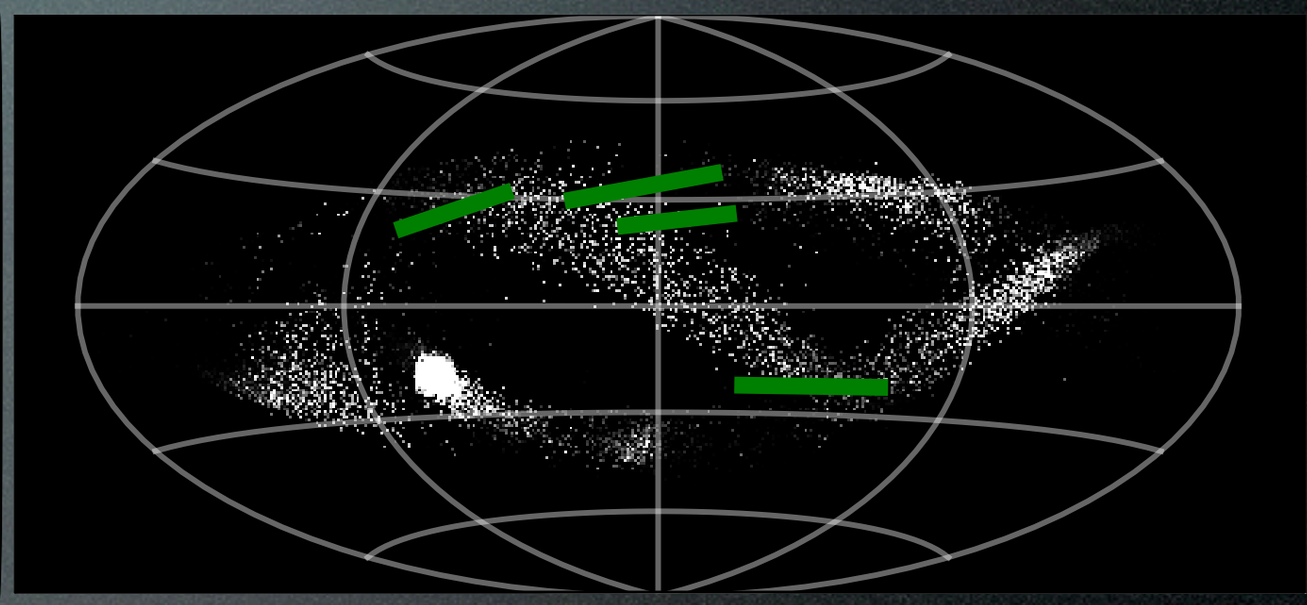
Sharp edge, North and South - ✔

Peñarrubia et al. (2005)

Accreted Satellite Model

Far Slice





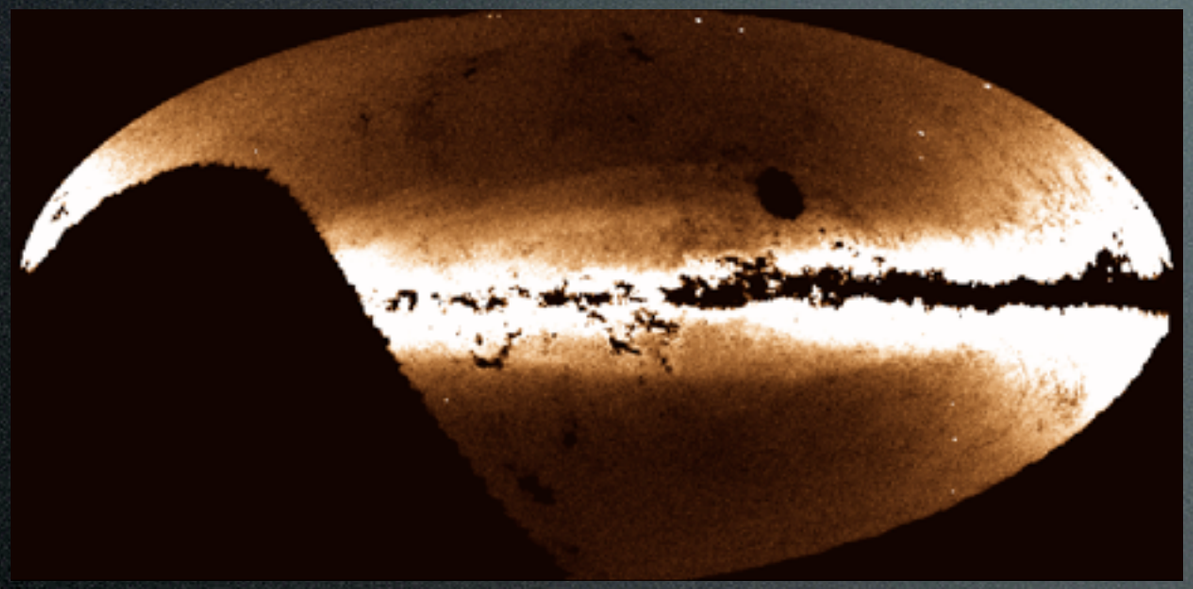
Observed
13-15 kpc slice

Model

Sharp edge, North and South - ✔

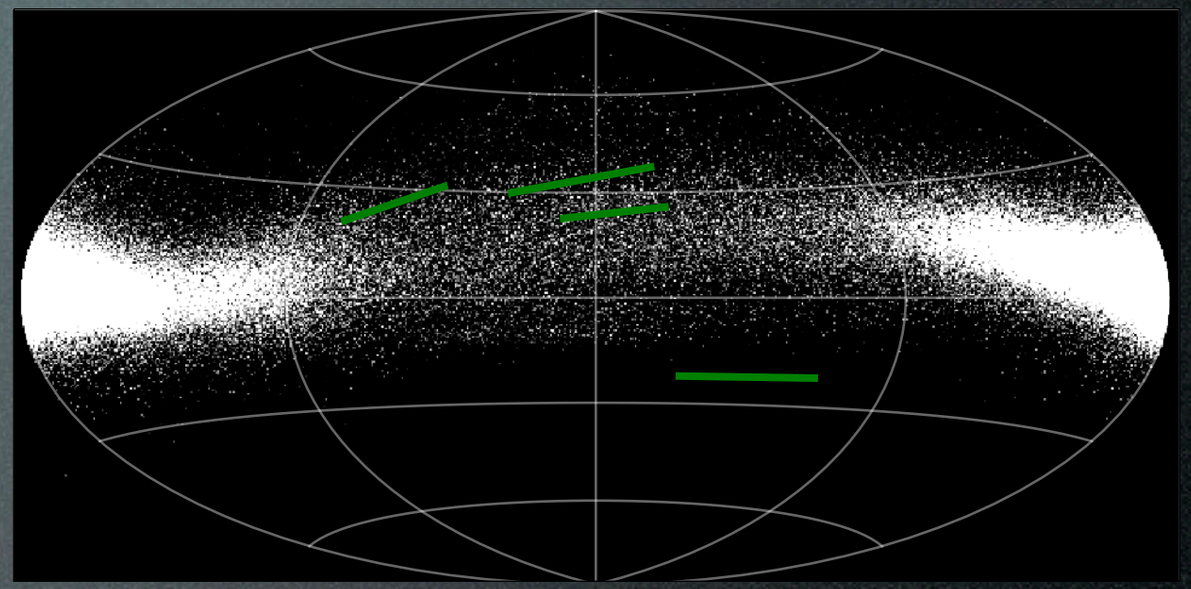
No distant material observed - ✖

Disrupted Disk Model



Observed

7-10 kpc slice



Model

Right height above the plane - ✔

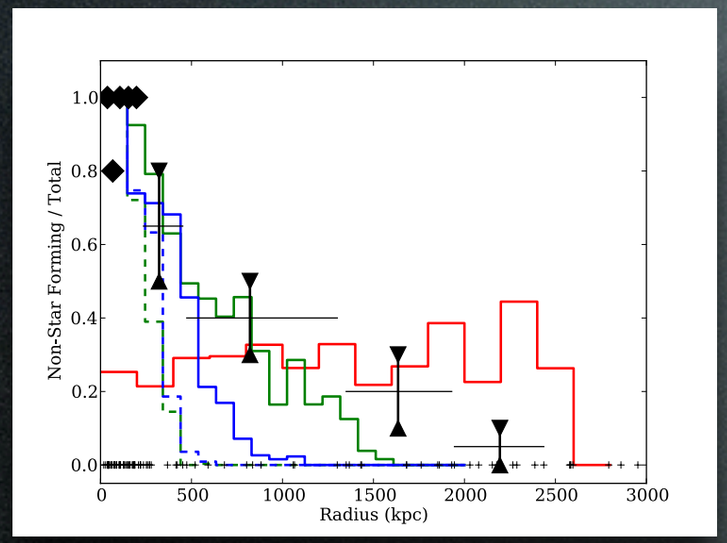
Entire disk is severely warped - ✖

Kazantzidis et al. (2008)

- Pan-STARRS shows the enormous extent of the Monoceros Ring

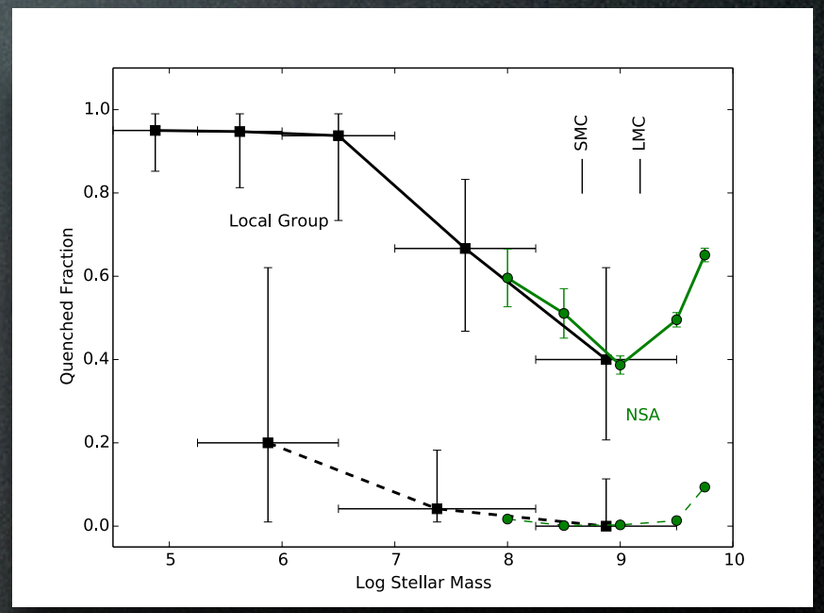
- PS1 maps can test different formation scenarios

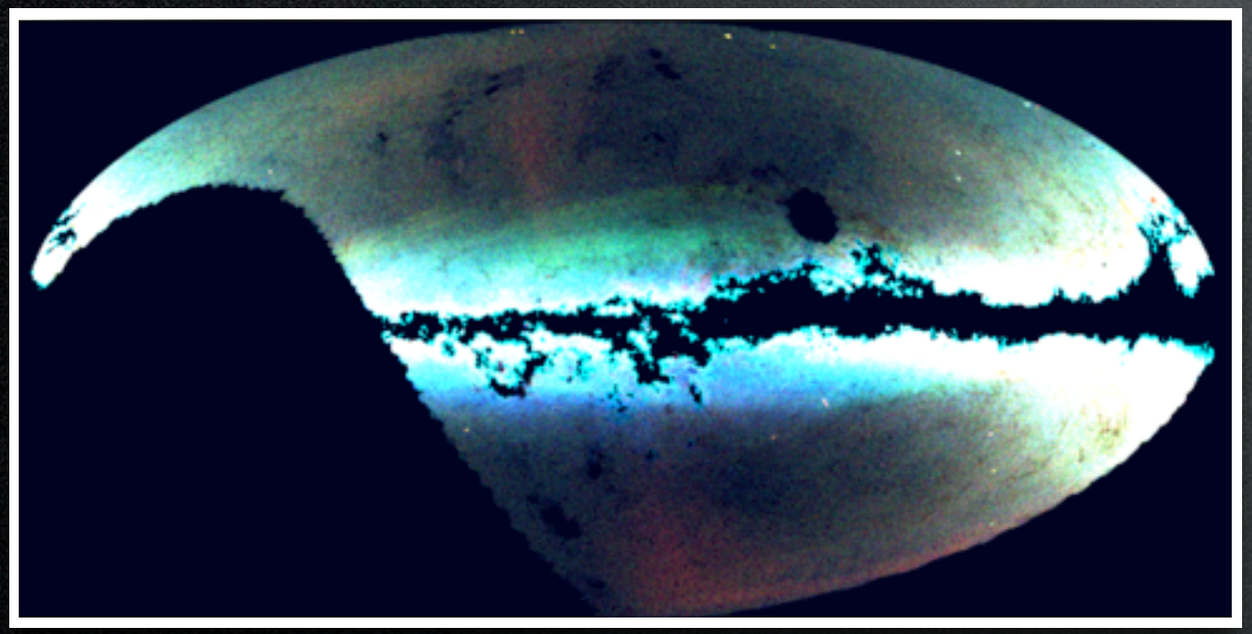
- Disk/satellite interaction seems unavoidable, but details are not yet understood



Tides/ram pressure can explain quenching if one pass is sufficient

Drastic change in quenching effectiveness from dSph to LMC/SMC-mass dwarfs





The Outer Disk is a complex place!