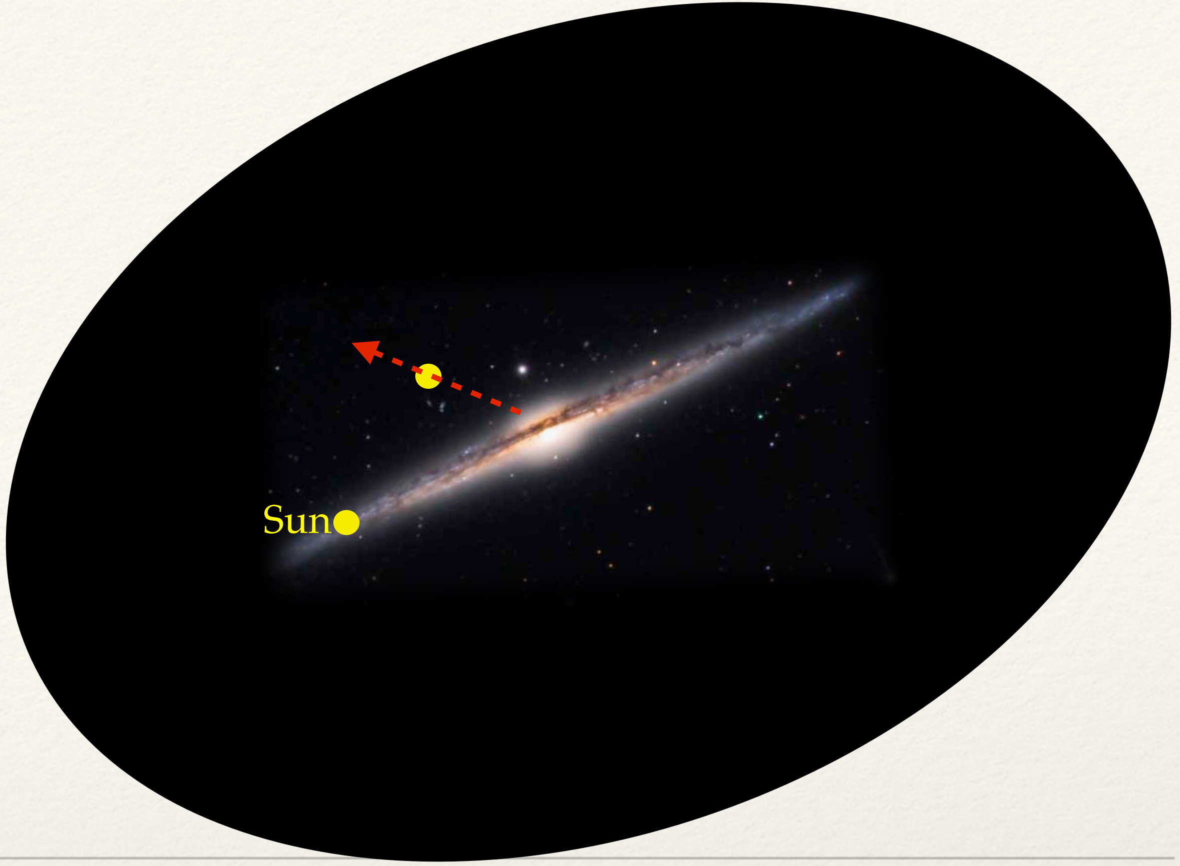


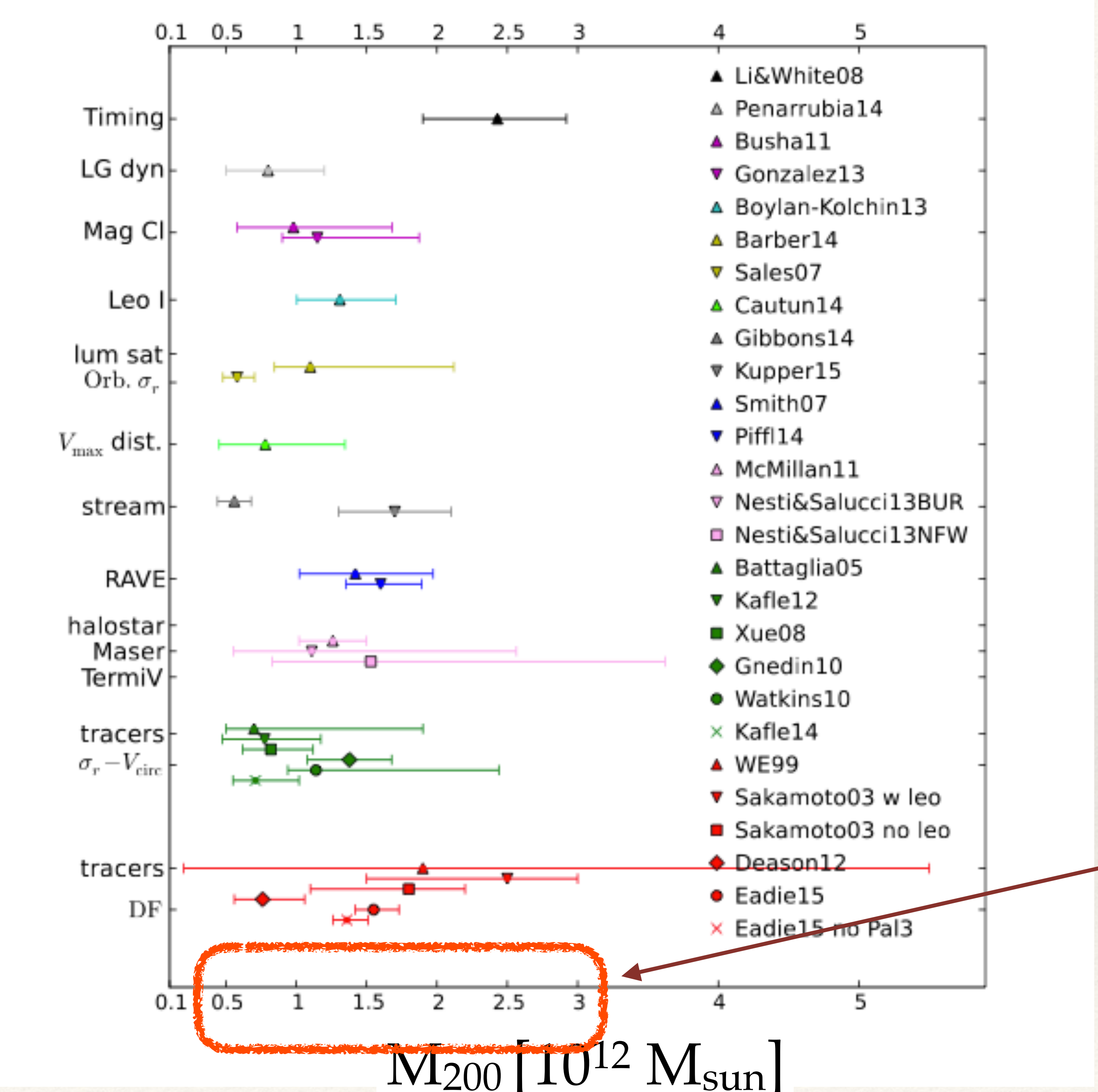
Aspen Winter conference, 8th February 2016

Constraining the Galactic dark matter Halo with *hypervelocity* stars

Elena Maria Rossi
Leiden Observatory,
The Netherlands

Collaborators
Re'em Sari (HUJI)
Shiho Kobayashi (Liverpool)
Tommaso Marchetti (PhD, Leiden)

Galactic Dark Matter Halo



Wang et al. 15

Large uncertainties in shape, orientation, coarseness, mass radial profile and <u>total mass</u>

e.g. Moore+99 ; Bullock +10; Law & Majewski 10; Vera-Ciro & Helmi 13; Pearson + 15; Gibbons, Belokurov & Evans 15; ,…..+ reference on figure on the left

A factor of ~6 in mass: is that important ?

Testing ΛCDM

In ΛCDM, for > 10^{12} M_{sun} Milky Way halos:

Mismatch between the number of low-mass sub-halos predicted and faint Milky Way's satellites:``the missing satellite problem"

(Klyplin +99; Moore + 99)

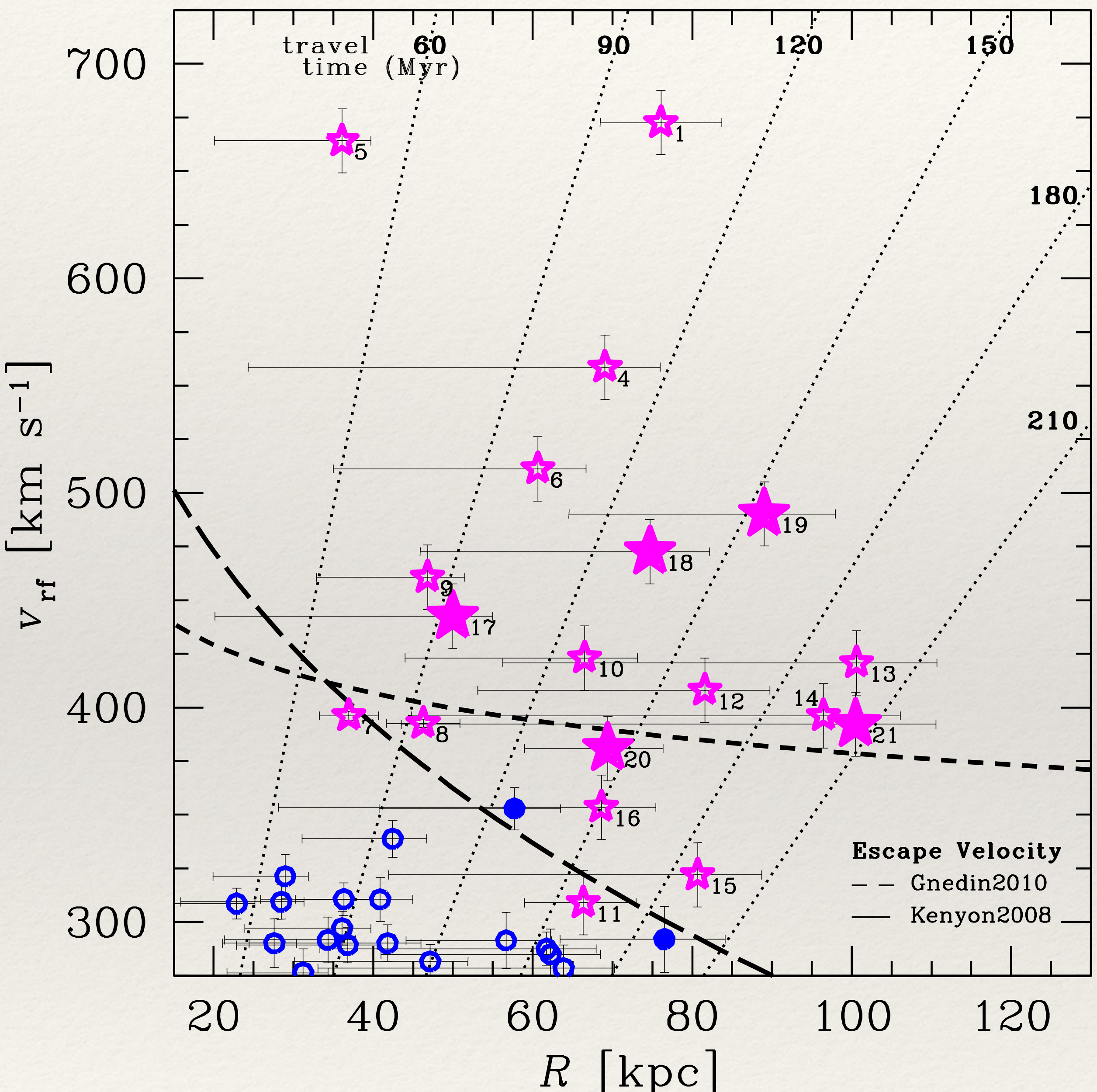
the most massive sub-haloes predicted do not correspond to any of the known satellites of the Milky Way: ``the too big to fail problem"

(Boylan-Kolchin, Bullock, & Kaplinghat 11)

A lighter Halo (< 10^{12} M_{sun}) can solve the problem

==> halo mass determination *within that range* can thus be used to test cosmological models

Hyper-velocity stars



Brown 2015

So far, a small fraction detected:

- First detection in 2005 (Brown et al.),
- ~20 so far discovered
- Estimated ~10^4 of all masses out to about 100 kpc (Brown et al. 07)

Current discovery strategy yields biased sample:

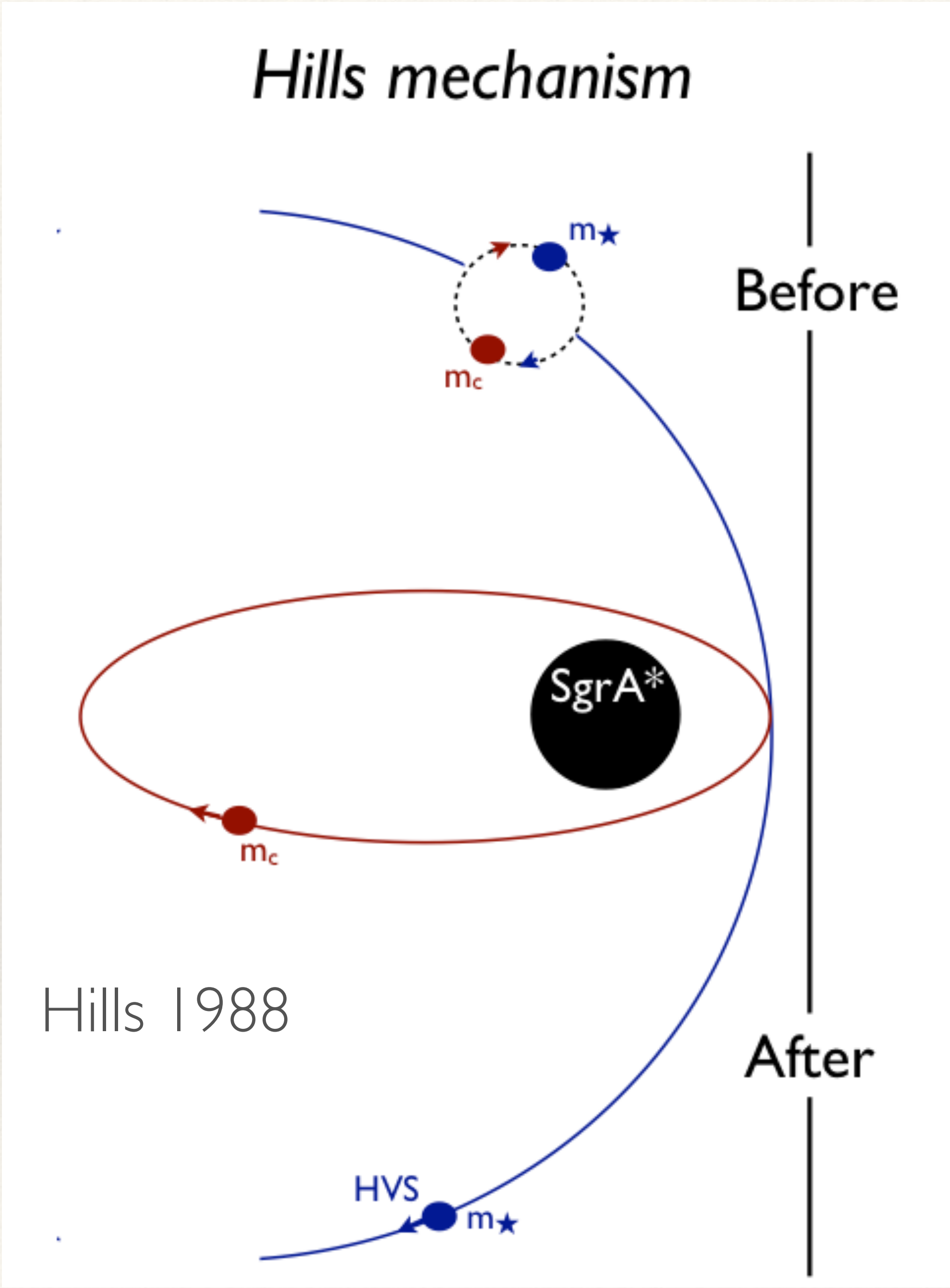
- Found spectroscopically (SDSS)
- Targeting the outer halo
- All late B-Type stars (~3-4 M_{sun})
- Only line-of-sight velocities

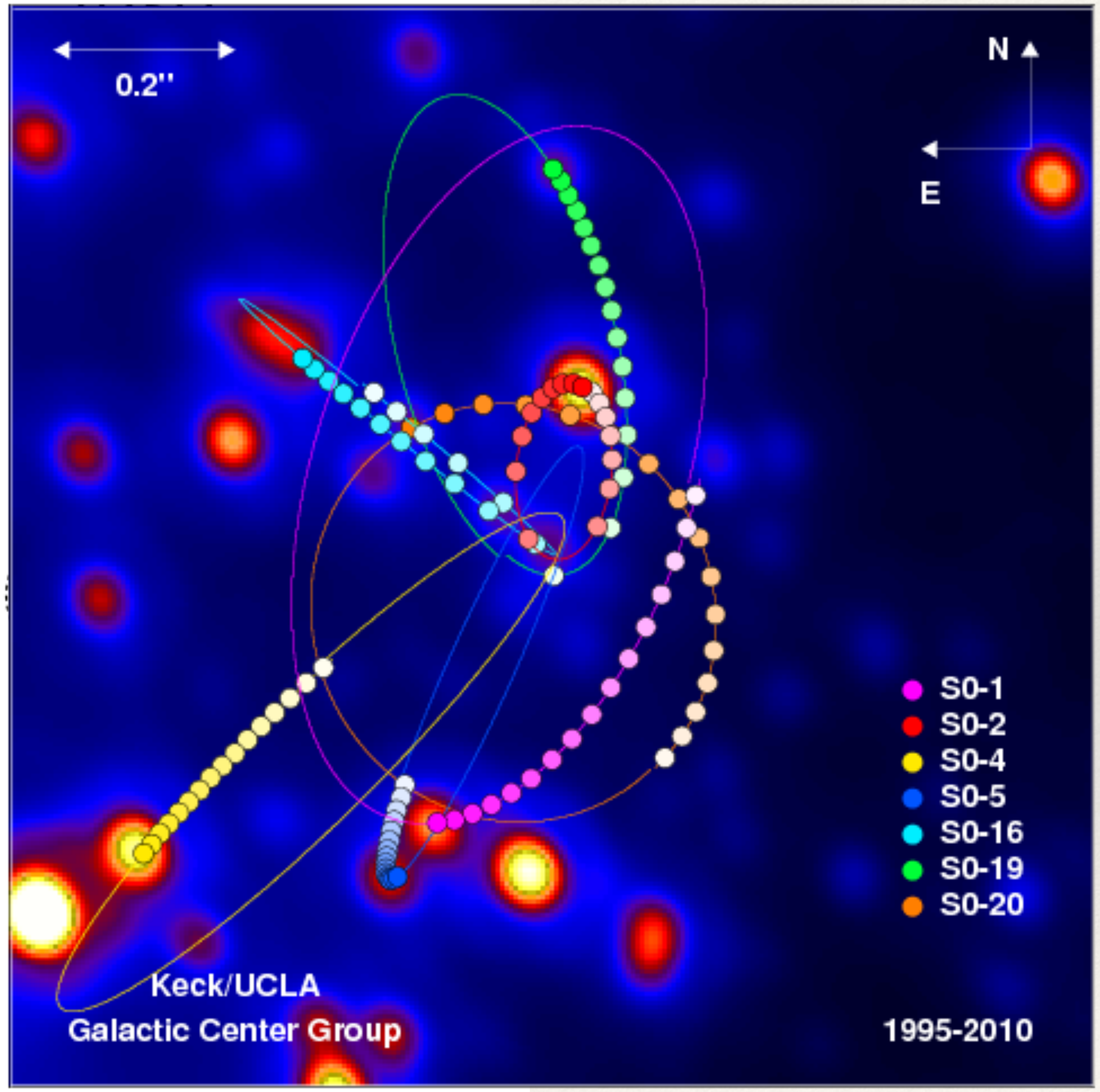
HVSs are exceptional tools

- Allow study of Galactic Centre stars, in more accessible part of the sky
- Are alternative dynamical tracers of the Galactic Potential

(Gnedin et al. 2005 Yu, Q. & Madau, P. 2007)

Origin of Hypervelocity stars



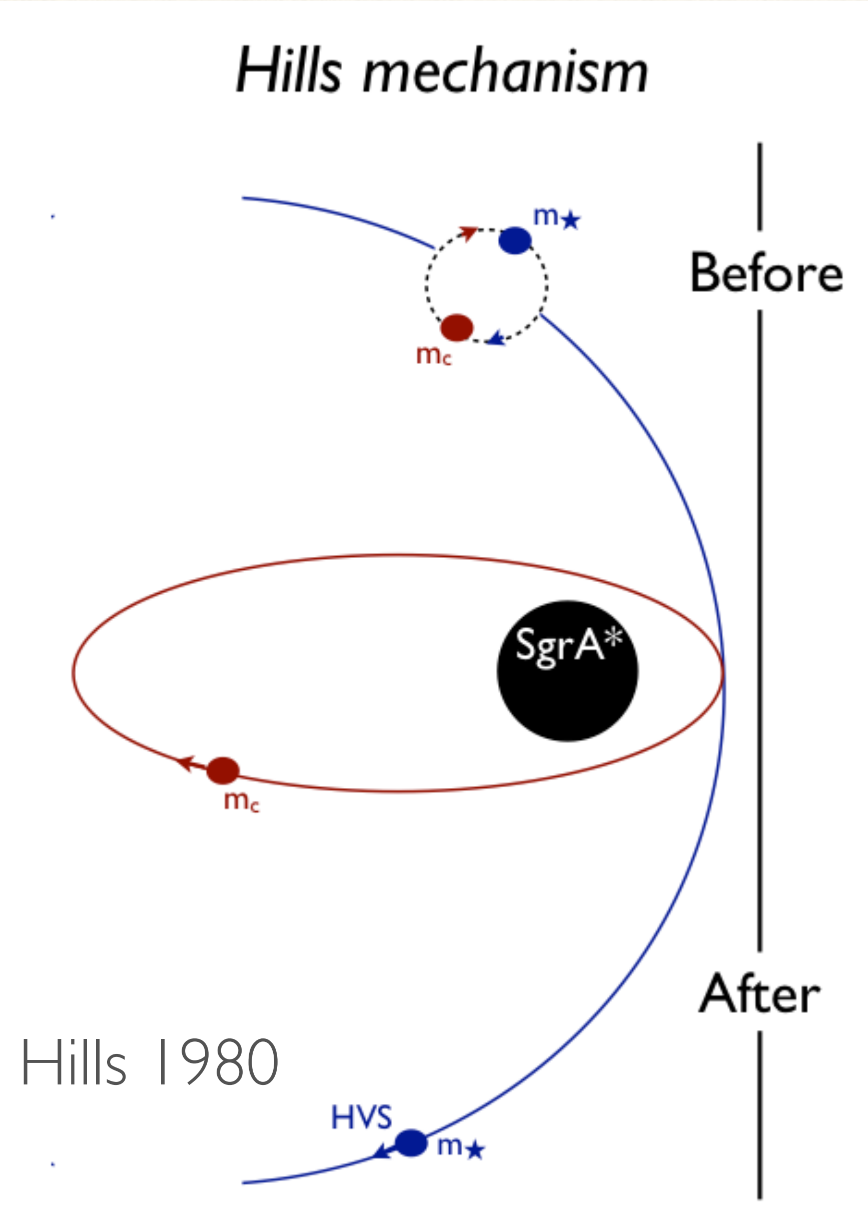


S-star cluster at < 0.04 pc from SgrA*

Perets + 07; Antonini & Merritt 13; Madigan + 14

Sari, Kobayashi & EMR 2010; Kobayashi+ 2012;
EMR, Kobayashi & Sari 14

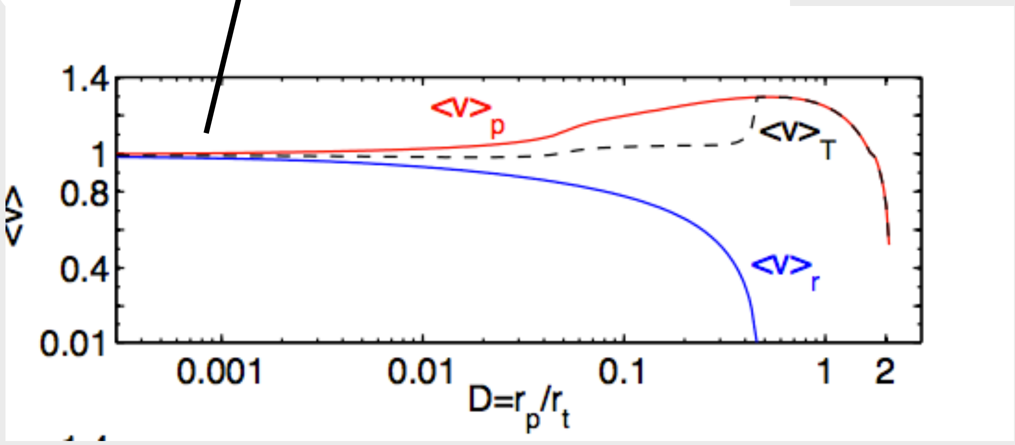
Ejection velocity



We use a restricted 3-body formalism, exploiting m/M <<1

The HVS ejection velocity *analytically* depends on binary mass and separation

$$v_{HVS} \cong \sqrt{\frac{2Gm_c}{a}} \left(\frac{M}{m}\right)^{1/6}$$



numerical factor here of the order of unity

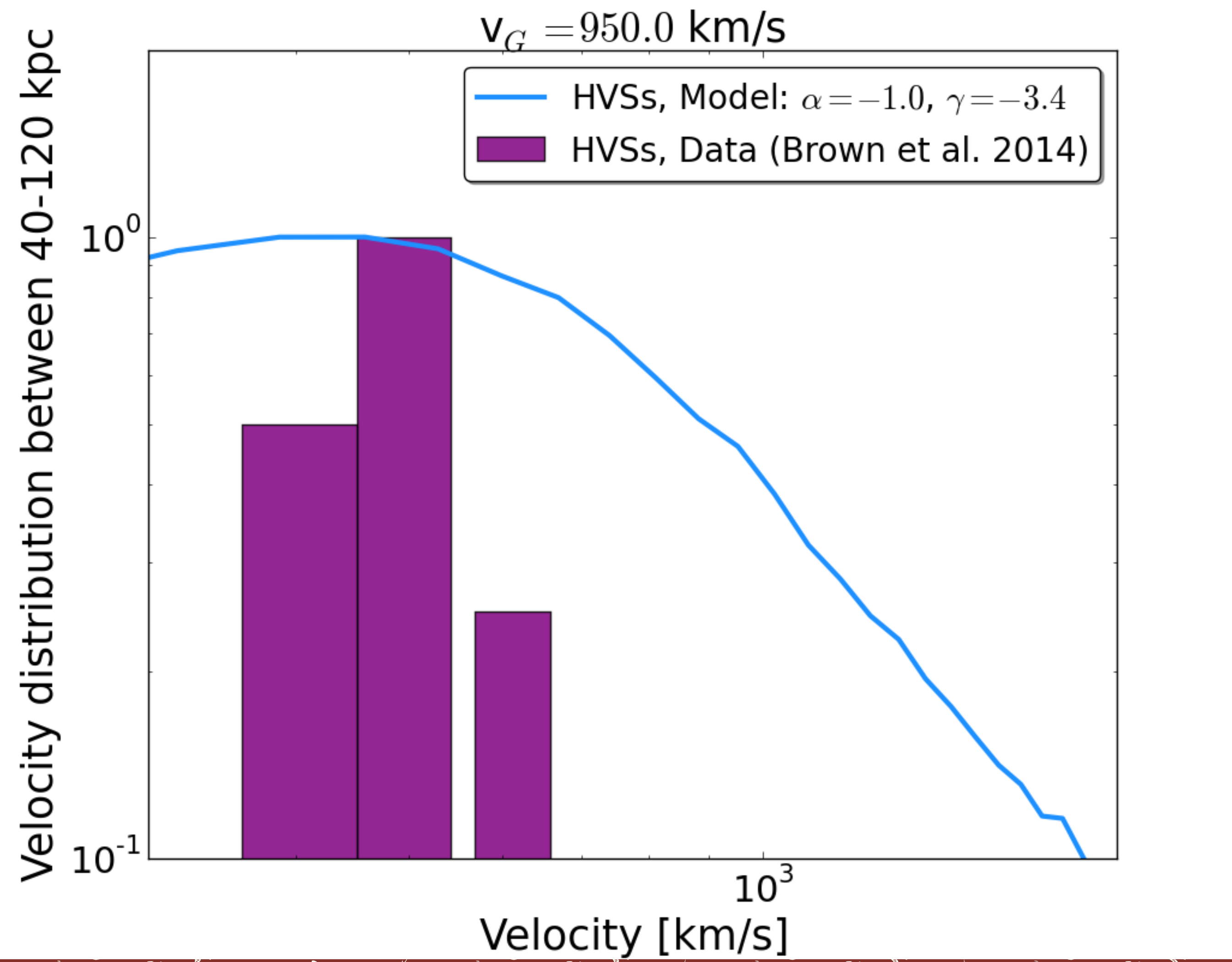
Given separation and mass distributions => HVS velocity distribution

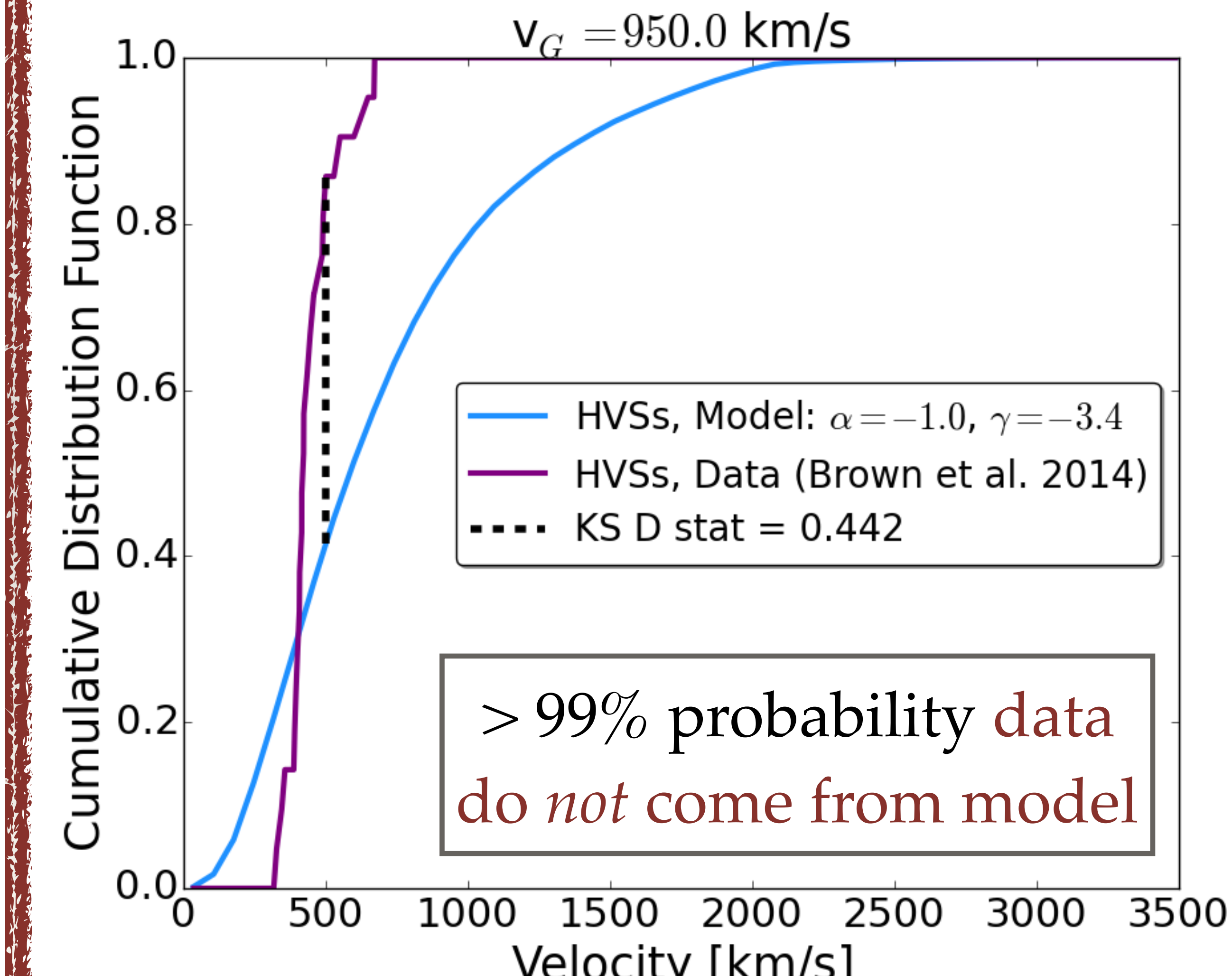
velocity distribution *in the halo*

Agnostic approach: to define the Galactic Potential
only by its *escape velocity* ``V$_G$" from the inner Halo (at ~25 kpc)

shaped by

$$v^2 = v_{ej}^2 - V_G^2$$





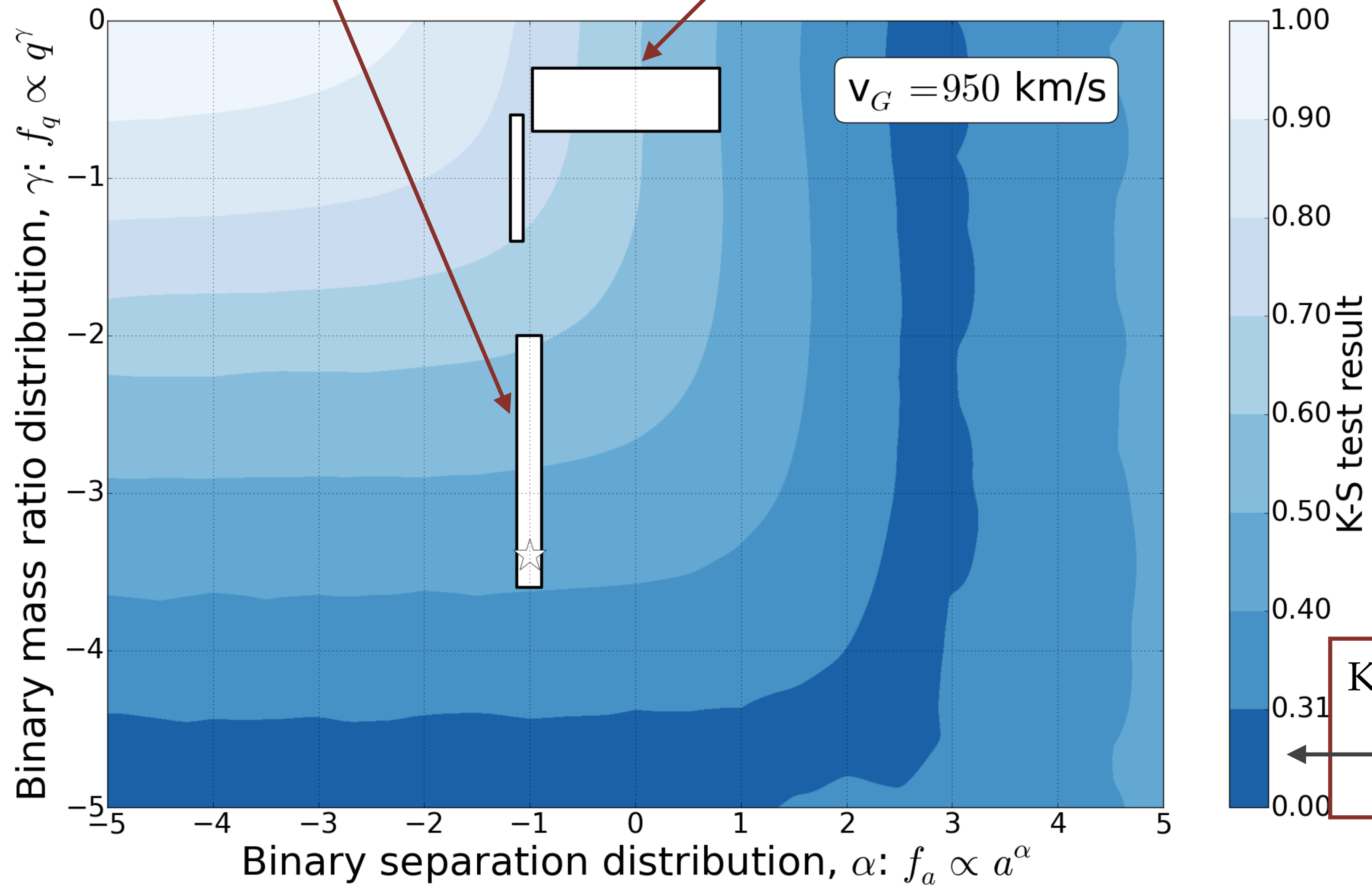
$>99\%$ probability data do *not* come from model

EMR, Kobayashi & Sari 14; EMR, Marchetti in prep.

Are binary stars in GC different?

late B-type binaries Star forming regions;
Sana + 13

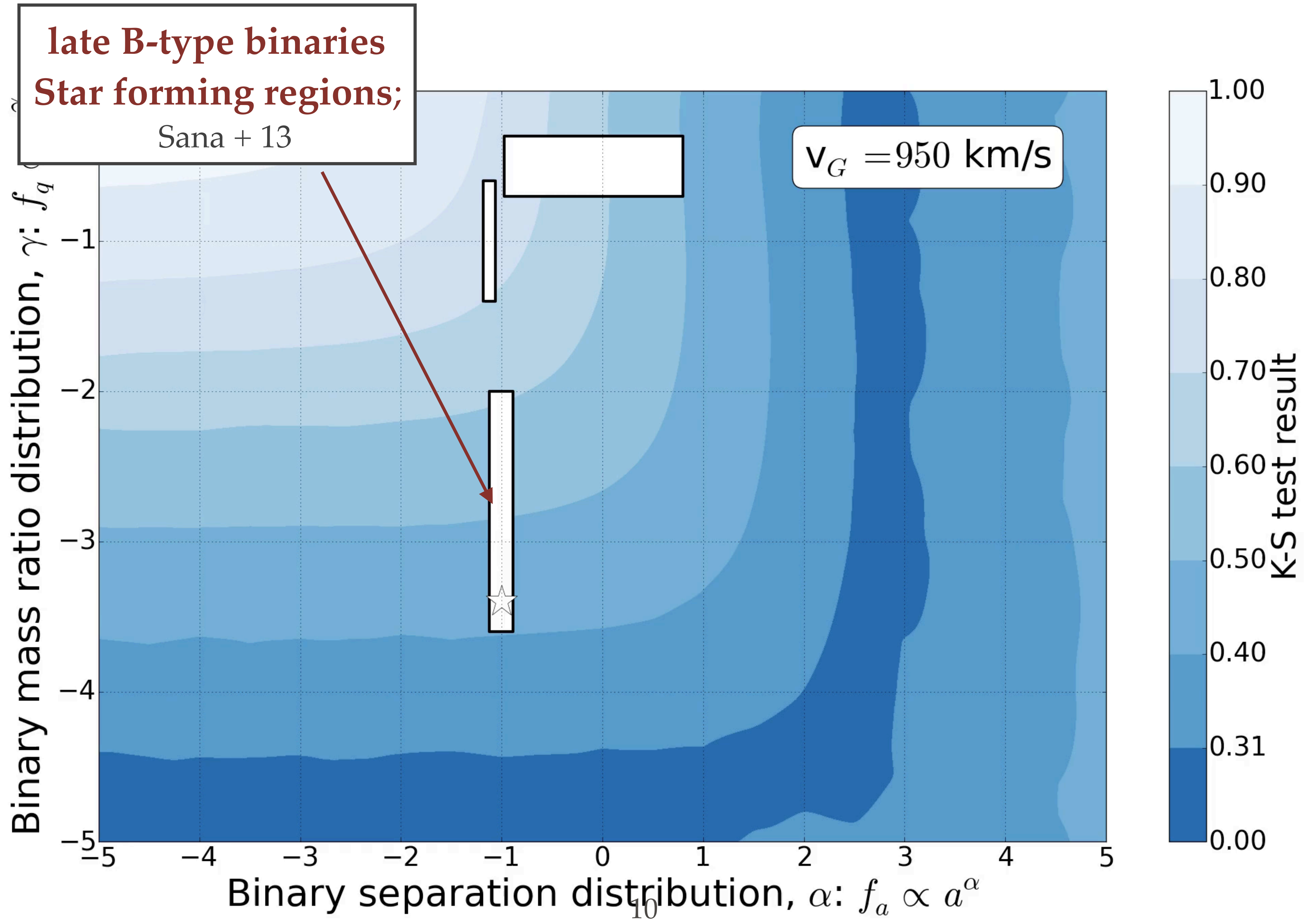
late B-type binaries in Solar Neighbourhood;
Kouwenhoven+07; Duchene & Kraus 13



K-S test fails to reject that data come from model

EMR+ in prep.

Constraining “V_G” range



720 km/s <V_G< 780 km/s

note: ~720 km s^{-1} is the escape velocity from the bulge

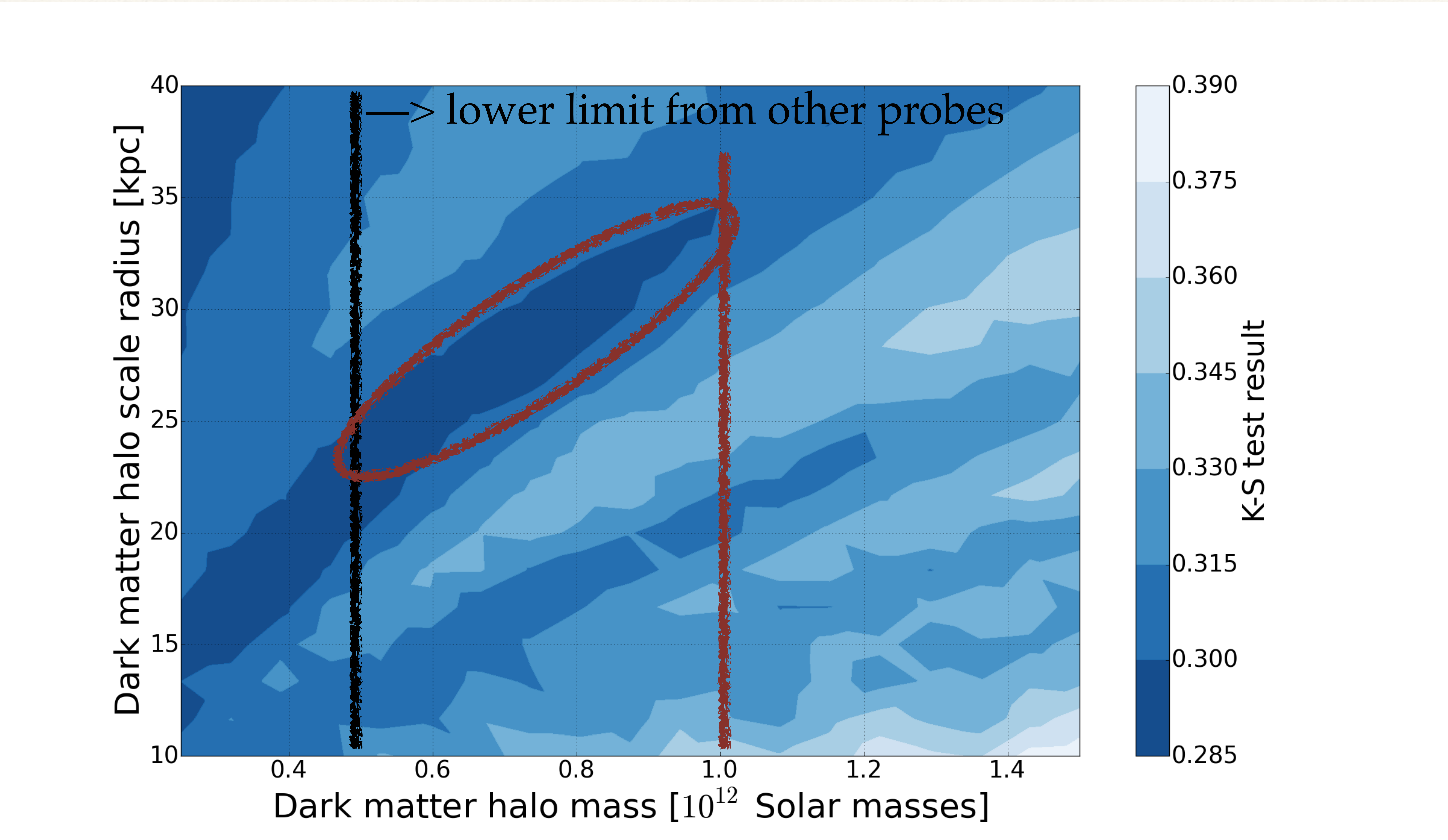
===> For 720 km/s < V_G < 780 km/s
stripe of minima overlaps with observed binary population in star forming regions BUT never overlaps with Solar Neighbourhood data

Lets' take NWF and de-project the V_G range onto Mass-scale radius plane for values make with a star

…plus the potential for the disc and bulge (Hernquist 1990)

Constraining the Halo mass

$\alpha = -1$ and $\gamma = -3.5$



HVS data suggest a light halo with mass < 10^{12} M_{sun}

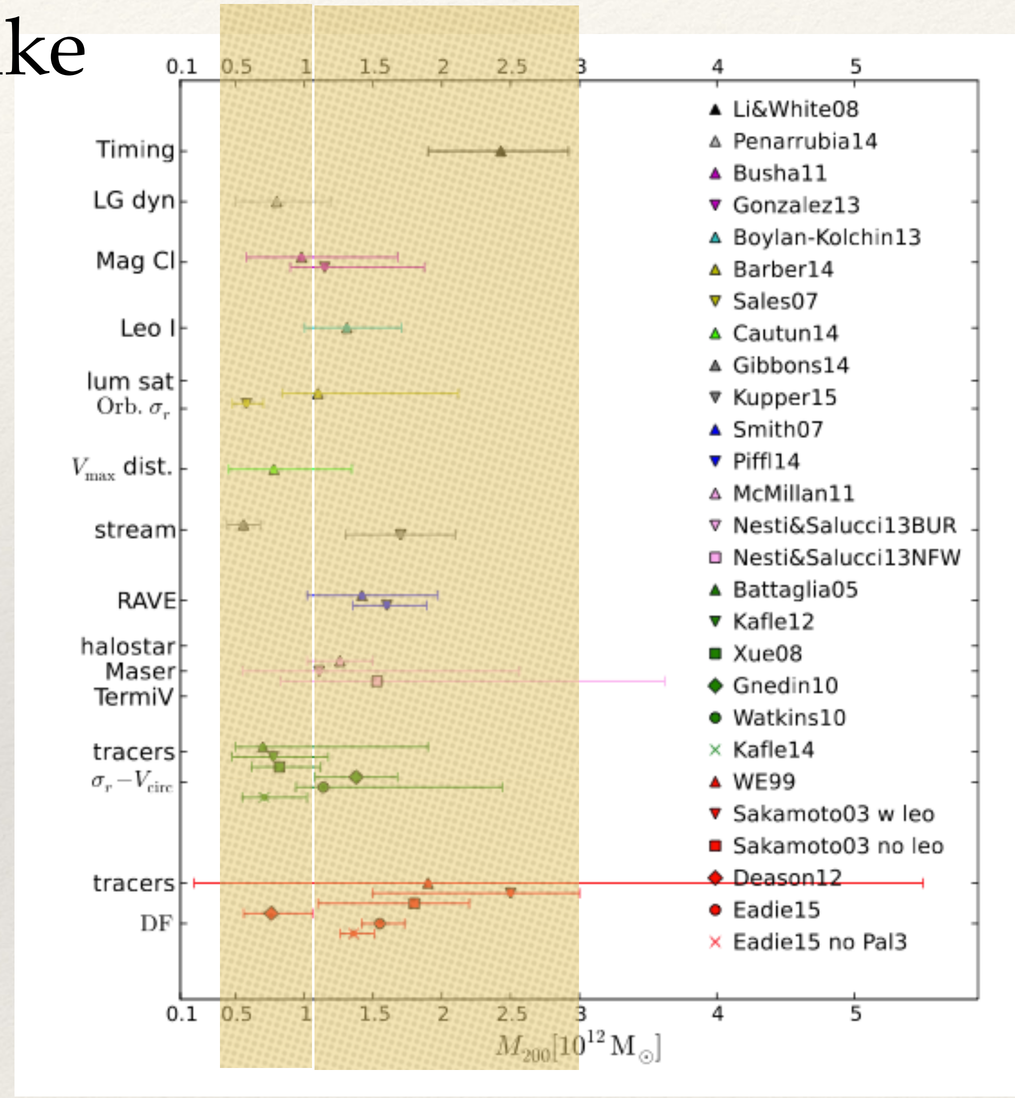
Conclusions and Caveats

— Massive > 10^{12} M_{sun} Halo & GC binaries <u>*not*</u> like those observed in either star and non-star forming regions

OR

— Light < 10^{12} M_{sun} Halo & GC binaries <u>*like*</u> those observed in star forming regions with $\alpha \sim -1$ and $\gamma \sim -3.5$

==> this would support ΛCDM



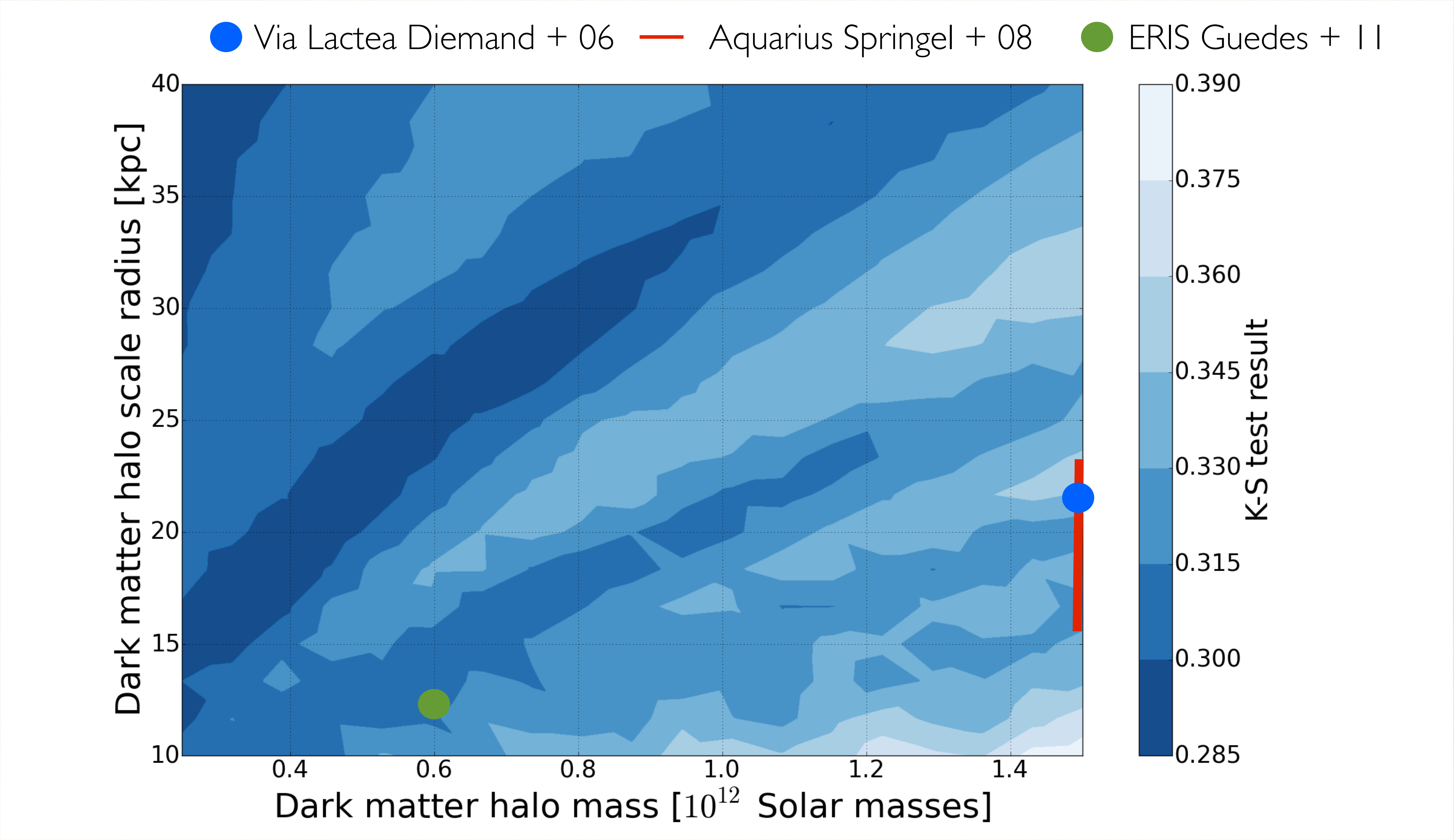
Caveat: the semi-major axis distribution may reflect a selection in binaries that fall into the tidal radius:

if e.g.full loss cone, than a *light* halo + binaries like in Solar N. is also OK

- back-up slides

the Halo mass in simulations

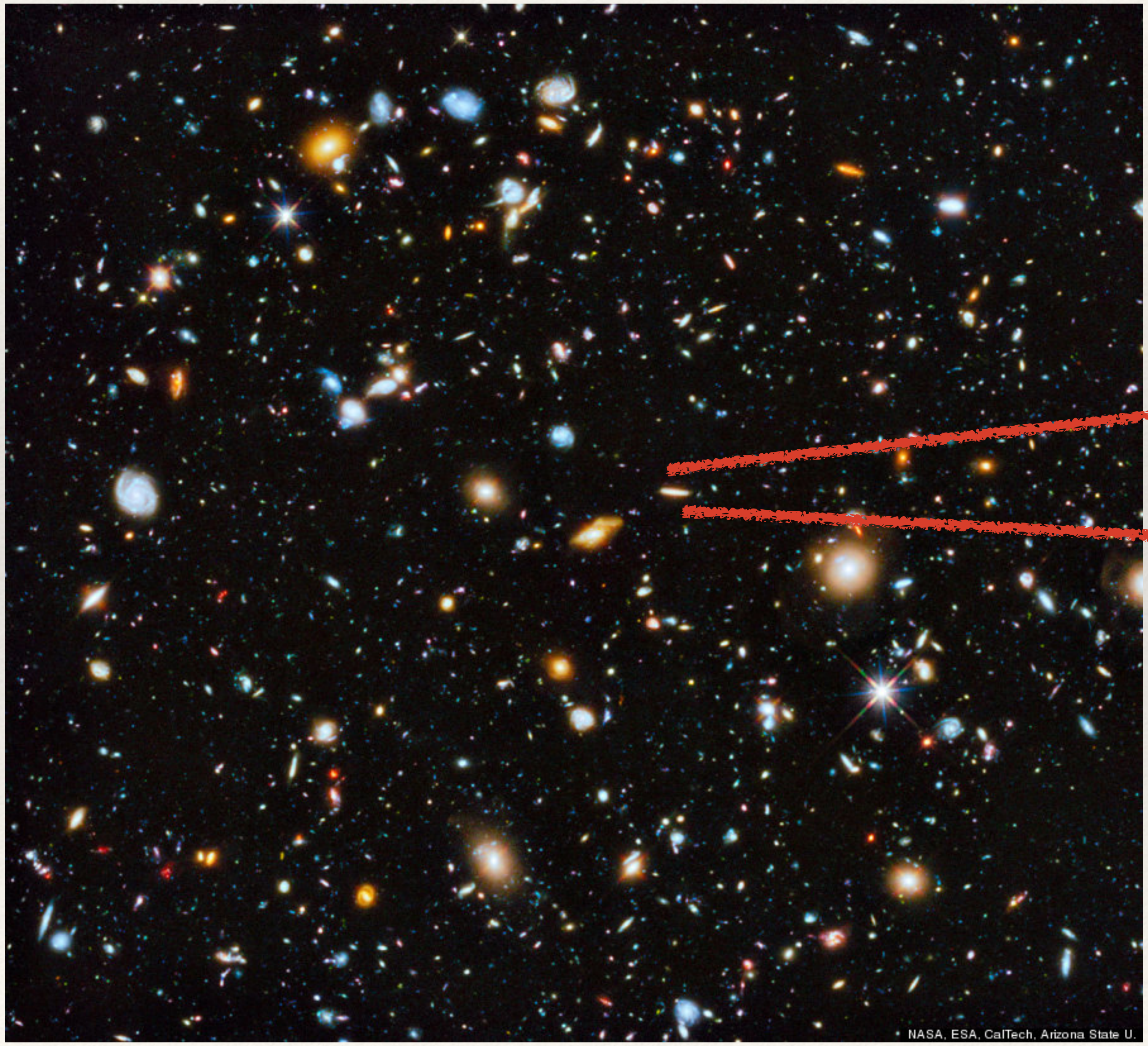
$\alpha = -1$ and $\gamma = -3.5$



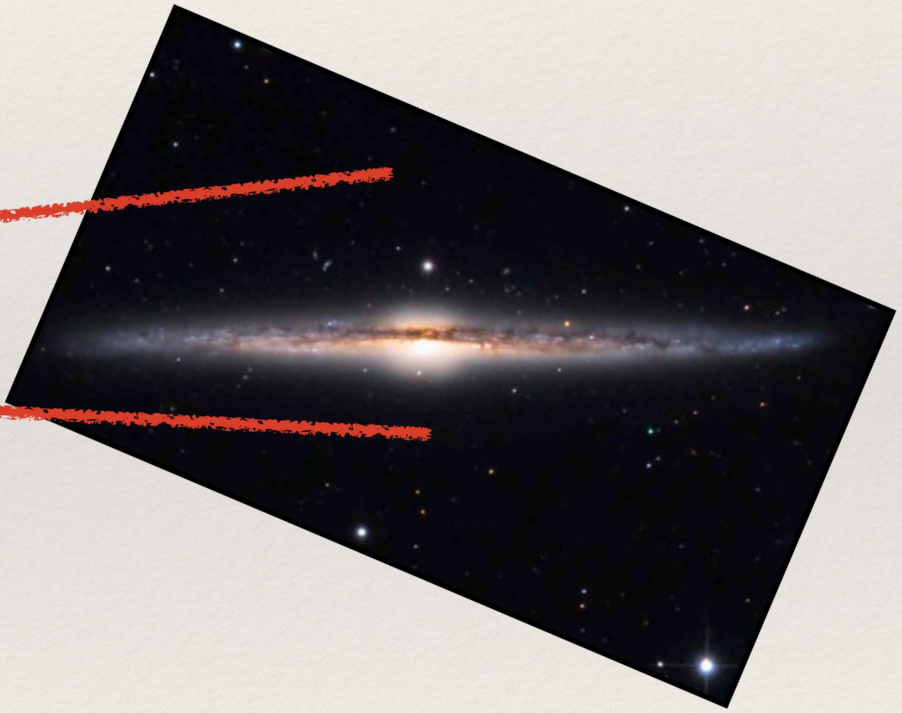
The Universe's evolution

Understanding the Universe's evolution is understanding galaxies

Hubble Space Telescope, Arizona U.



galaxies are the Universe's ``bricks"

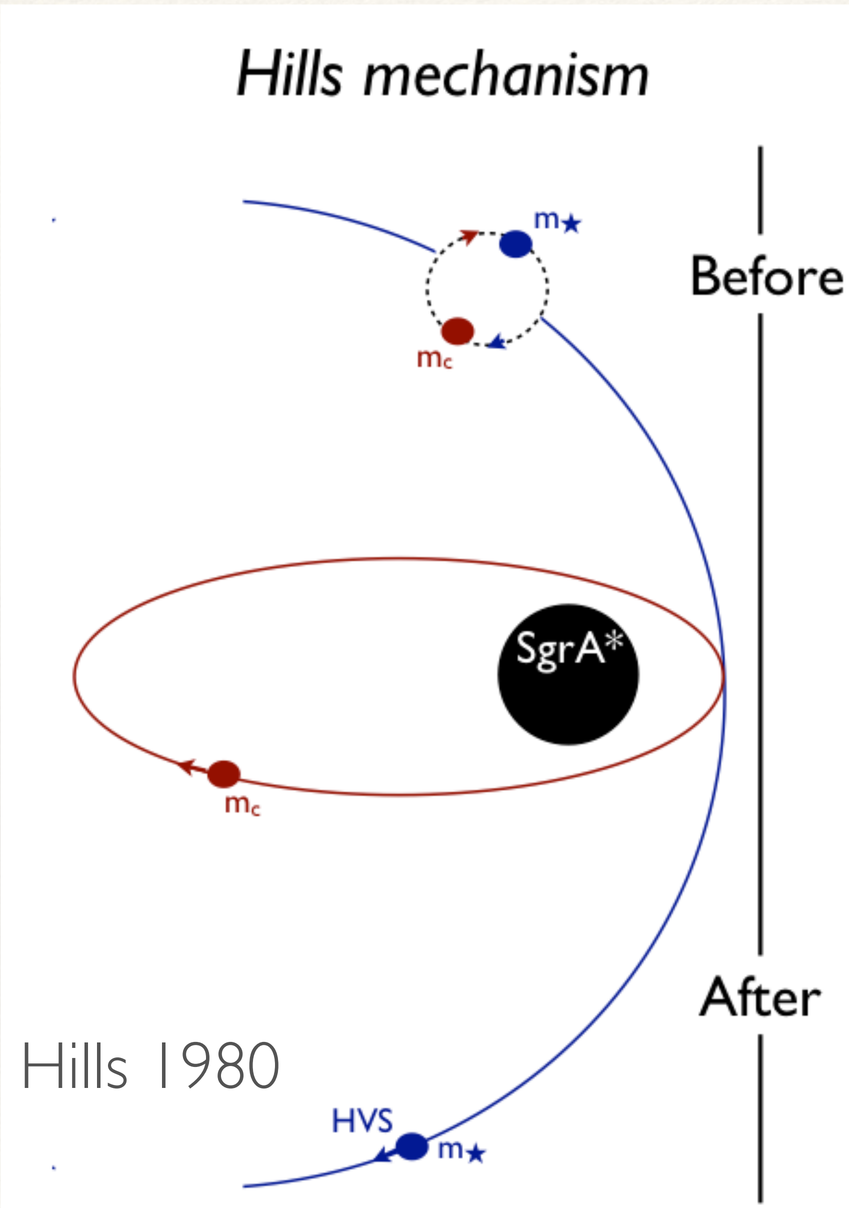


An outstanding laboratory: the Milky Way

The galaxy formation

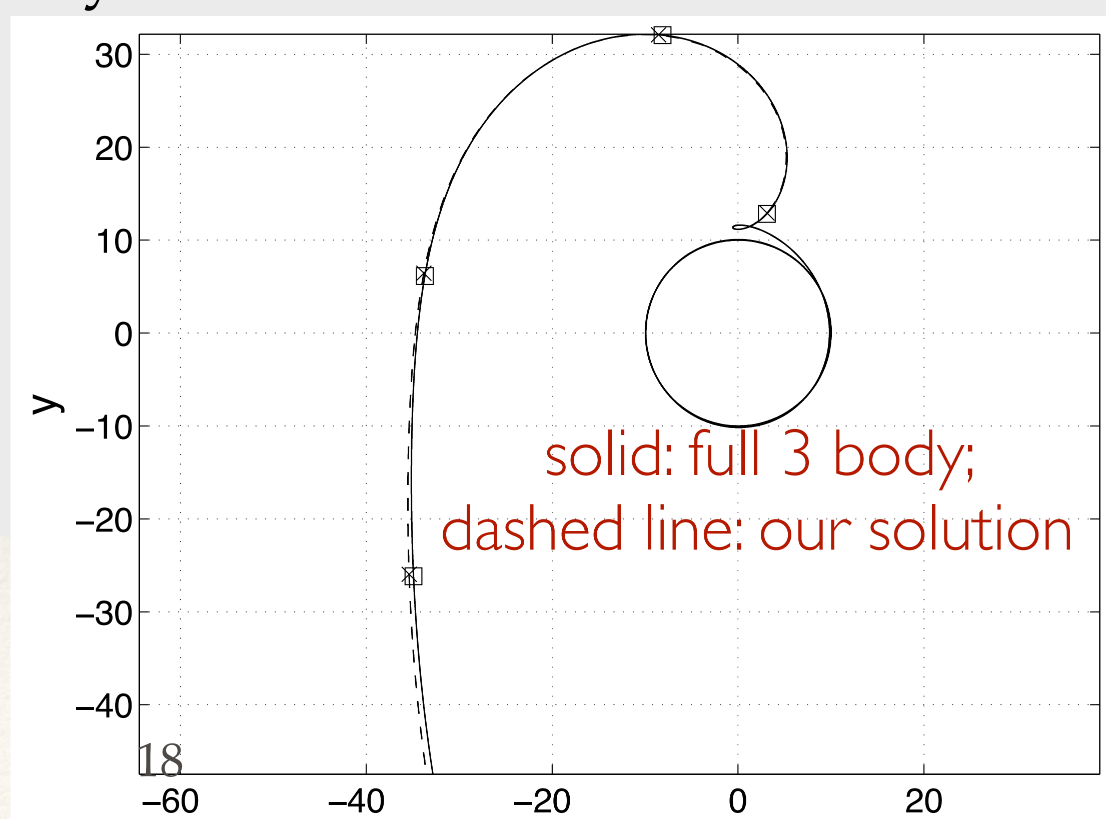
- It is traditionally addressed with Simulations + Observations
- Successful field but still many open questions. Let's consider our own Galaxy:
    - The visible part is hard to reproduce
    - The Dark Halo is poorly constrained and different realisations of the MW give different mass, shape and lumpiness

Our computational method



- Others: Velocities and trajectories are calculated via 3-body or N-body interactions for a given parameter space (e.g. Brown's group; Gualandris +)

- We: restricted 3-body formalism, exploiting m/M <<1 ==> more efficient method
Sari, Kobayashi & EMR 2010; Kobayashi+ 2012; EMR, Kobayashi & Sari 14

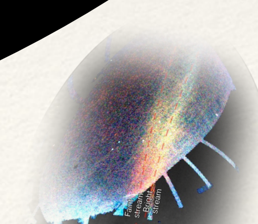


dynamical tracers

e.g. Johnson, Hogg
Gibbons, Law &
Majewski, Helmi,
Wang, Bullock,
Ibata, Price-Whelan,
Belokurov…

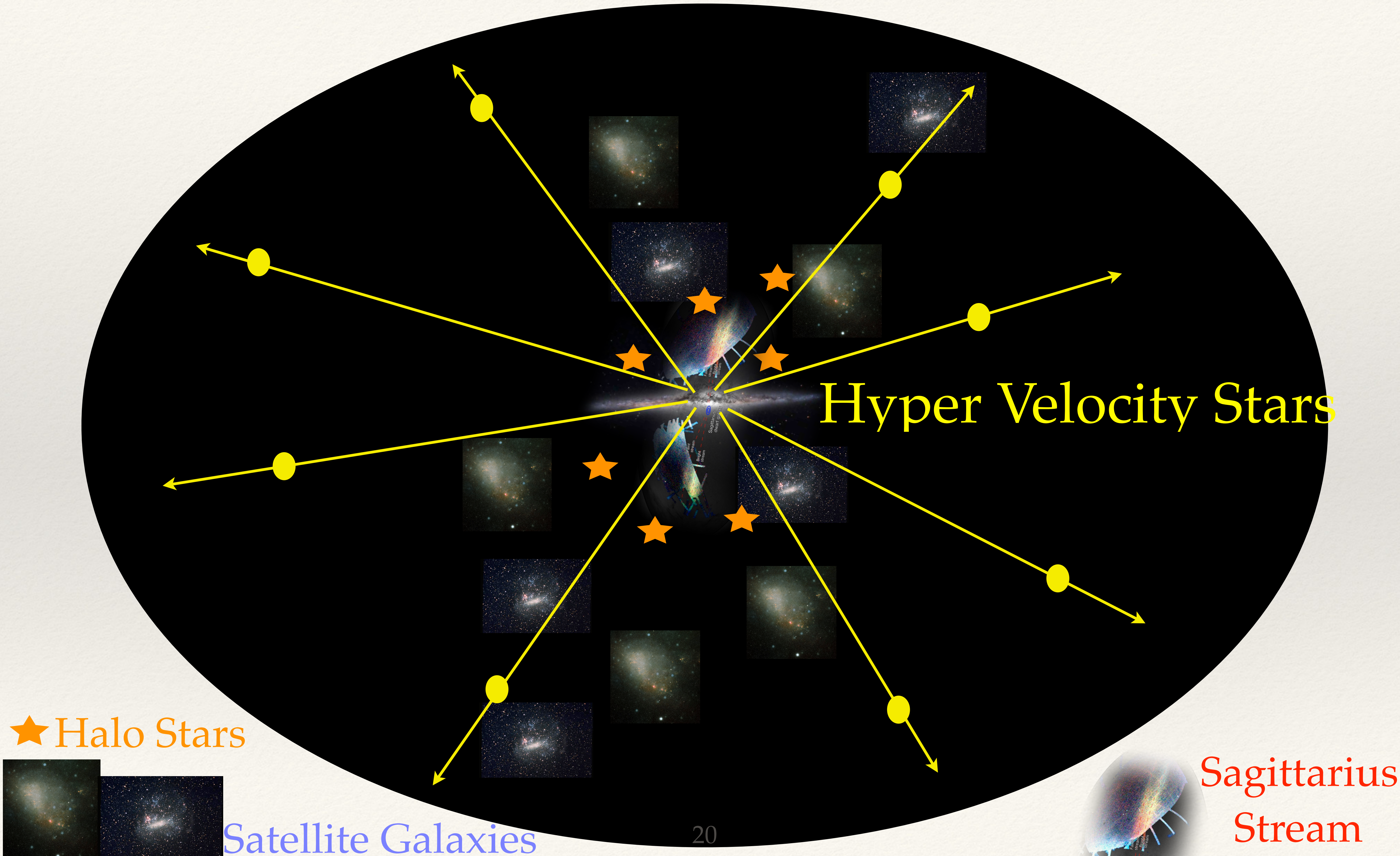
Halo Stars

Satellite Galaxies

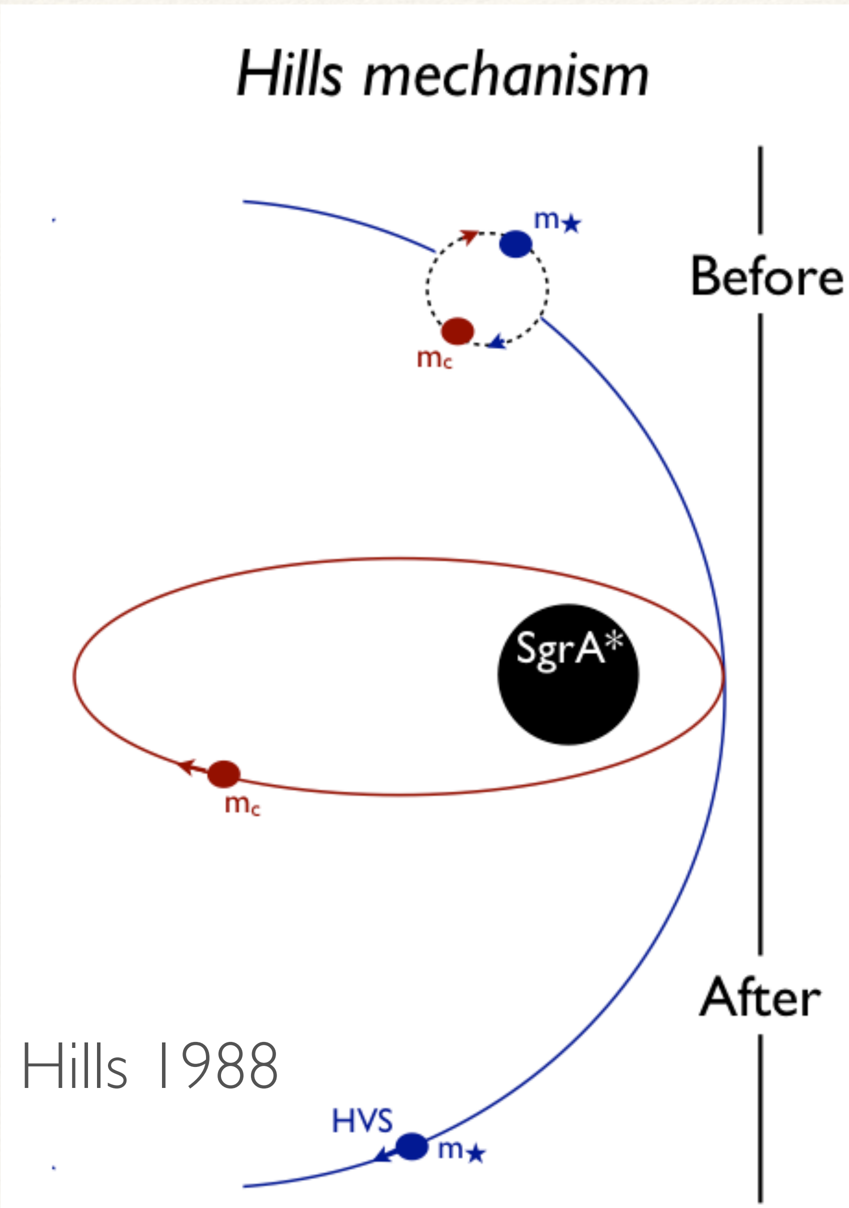


Sagittarius
Stream

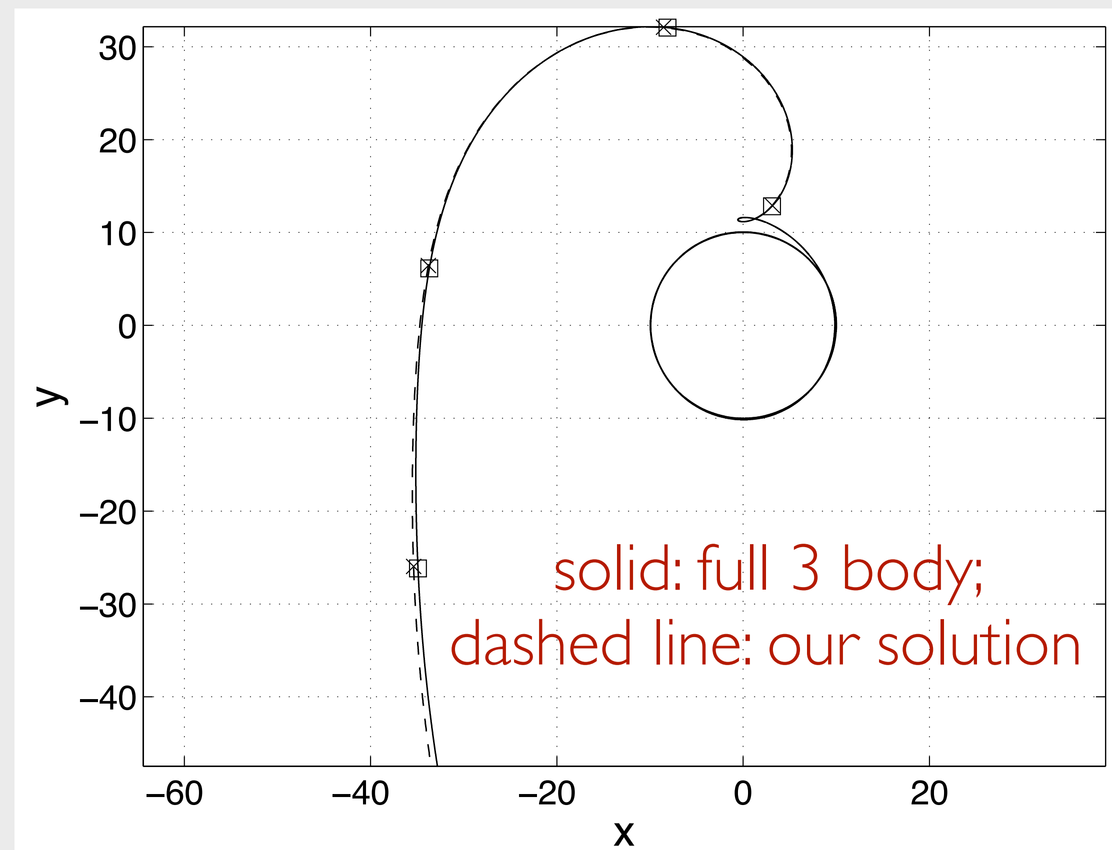
dynamical tracers



Our computational method



We use a restricted 3-body formalism, exploiting m/M <<1 ==> more efficient method than N-body.



Sari, Kobayashi & EMR 2010; Kobayashi+ 2012; EMR, Kobayashi & Sari 14