The Outer Galactic Halo as Probed By RR Lyrae Stars From the Palomar Transient Facility + Keck

Judy Cohen (Caltech), Branimir Sesar (Caltech, MPIA), and Sophianna Banholzer (Caltech) + the PTF collaboration

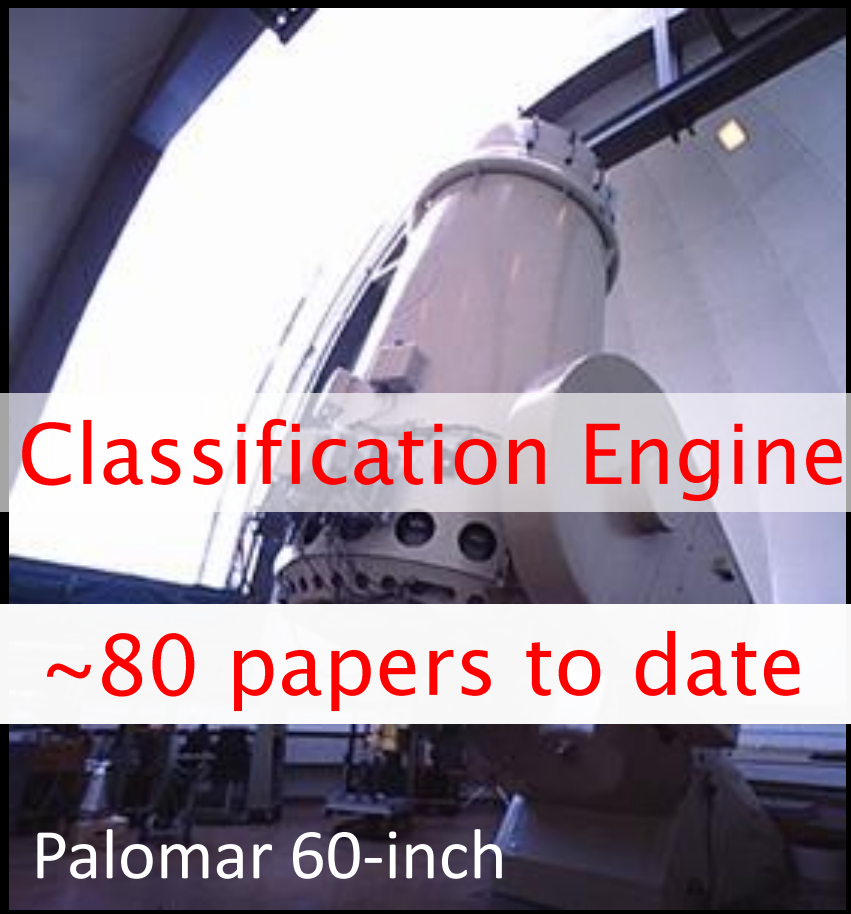
The Milky Way and its stars,

KITP conference, Santa Barbara, Feb. 2015

Palomar Transient Factory (PTF)

A wide-angle, high cadence survey designed to systematically explore the transient & variable sky

Palomar 48-inch



Palomar 60-inch

Discovery Machine + Classification Engine

~2000 Supernovae & ~80 papers to date

PI: Shri Kulkarni

Outer Halo RR Lyrae Stars

- Great “massless” probes of gravity field
- Can find out to ~110 kpc in the PTF database in fields with most epochs and best photometry
- Stand out as variable blue stars, amplitude 0.6 to 1.0 mag in R, easy to find if have accurate photometry & enough (>25) epochs of observation
- PTF many epochs, so measures period, phase
- Keck measures radial velocities , vr(Hα) amp 110 km/sec
- Must correct measured magnitude to mean mag, and measured vr to systemic vr – requires template light and velocity curves

Advantages of RR Lyr as Halo Probes

- Mean R mag for metal-poor RR Lyr is almost constant, get distance accurate to 5% in halo with a 0.3 dex range in [Fe/H] around -1.5 dex included
- Out to 100 kpc, bright enough to get vr with Keck in less than 30 min – longer - phase blurring
- Can use as massless probes, dynamical mass of the Milky Way, when combined with a density distribution of RR Lyr, which also can be derived from the survey.
- Use to find and study streams
- Low contamination of other blue, variable stellar objects, a very small fraction of QSOs.

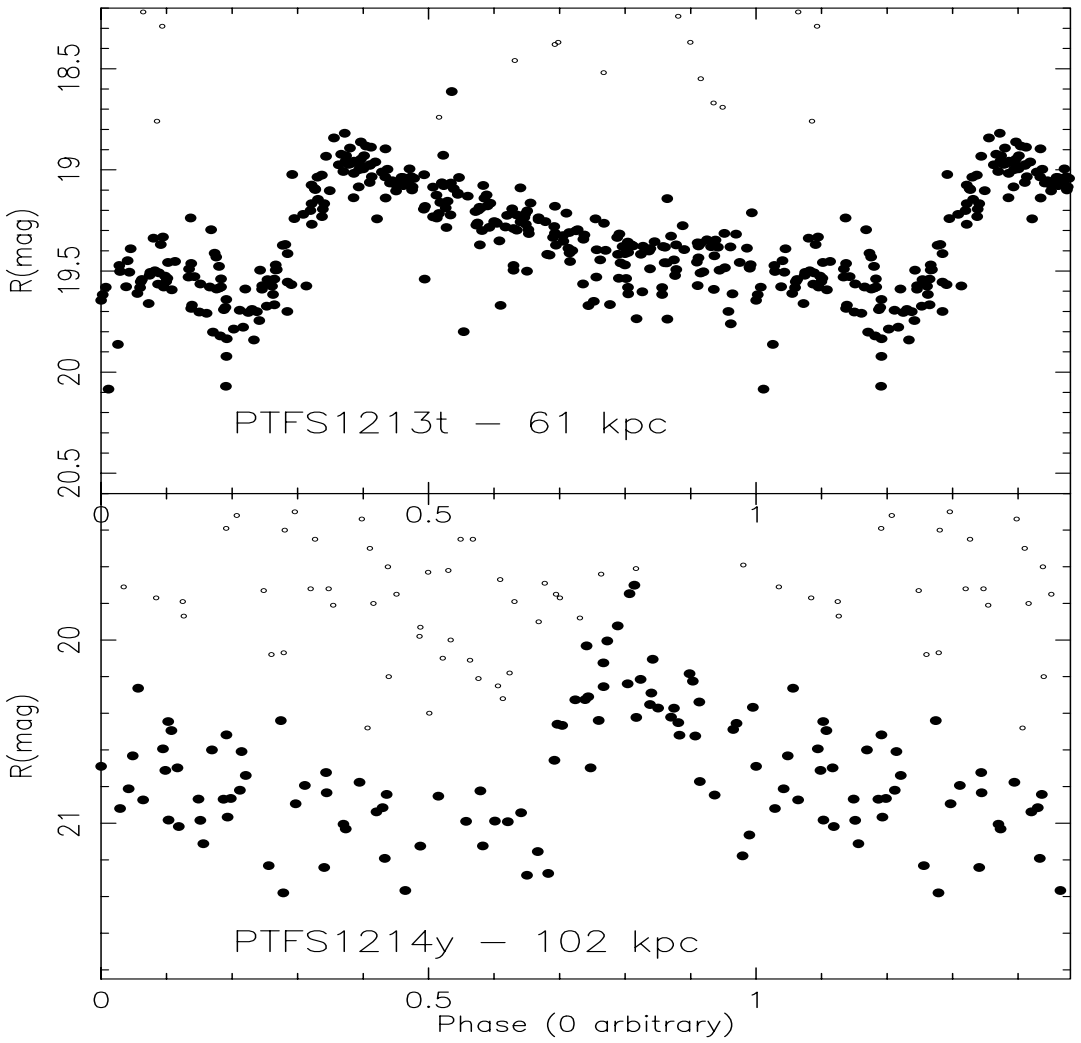
5 years of PTF + iPTF data

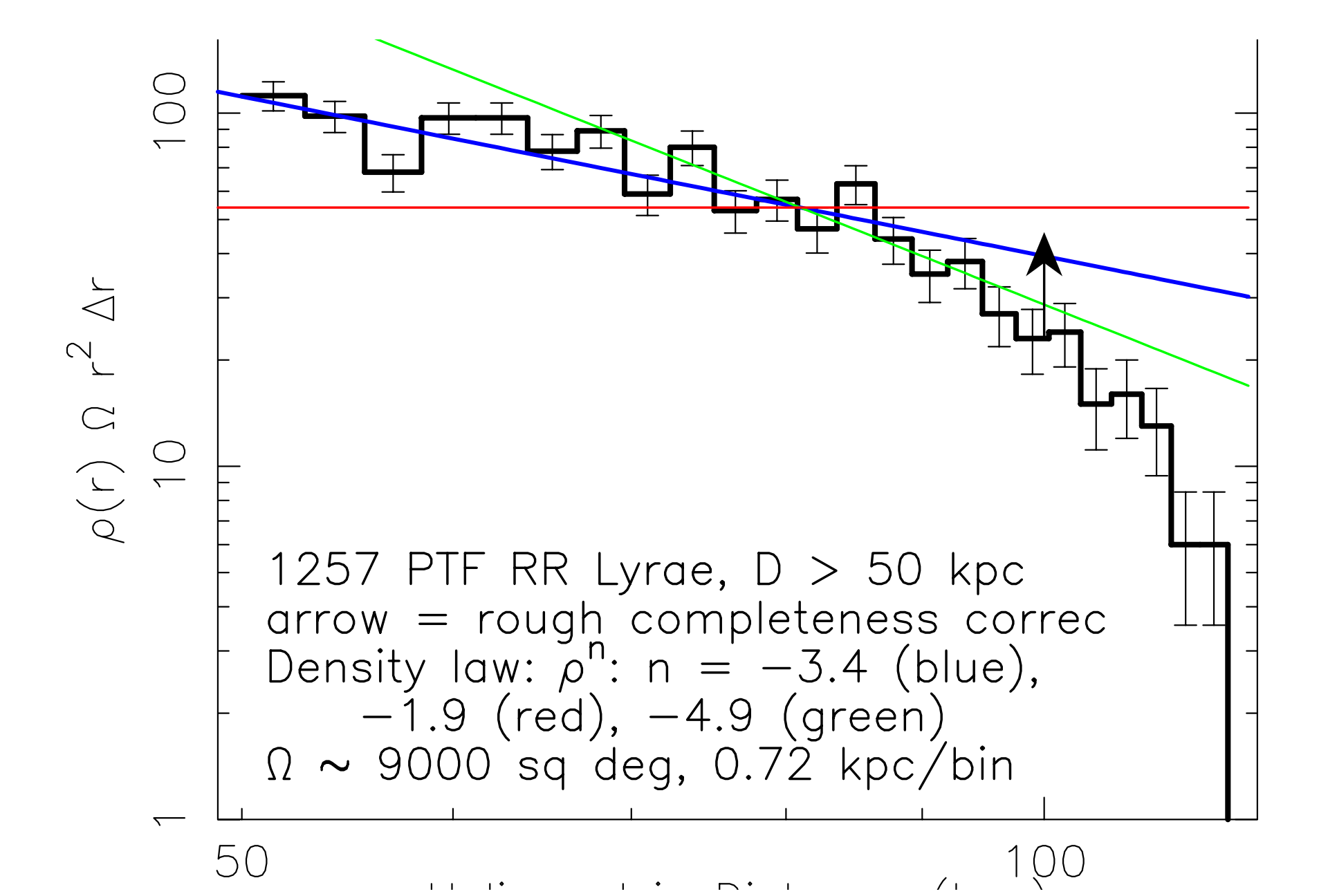
- We have found a sample of 1257 RR Lyr (ab) beyond 50 kpc in ~11,000 sq deg with more than 25 epochs of observation (~20% of the sky) – excludes RR Lyr in known dSph, Sgr stream, etc
- ~180 of these are beyond 90 kpc, max ~ 120 kpc

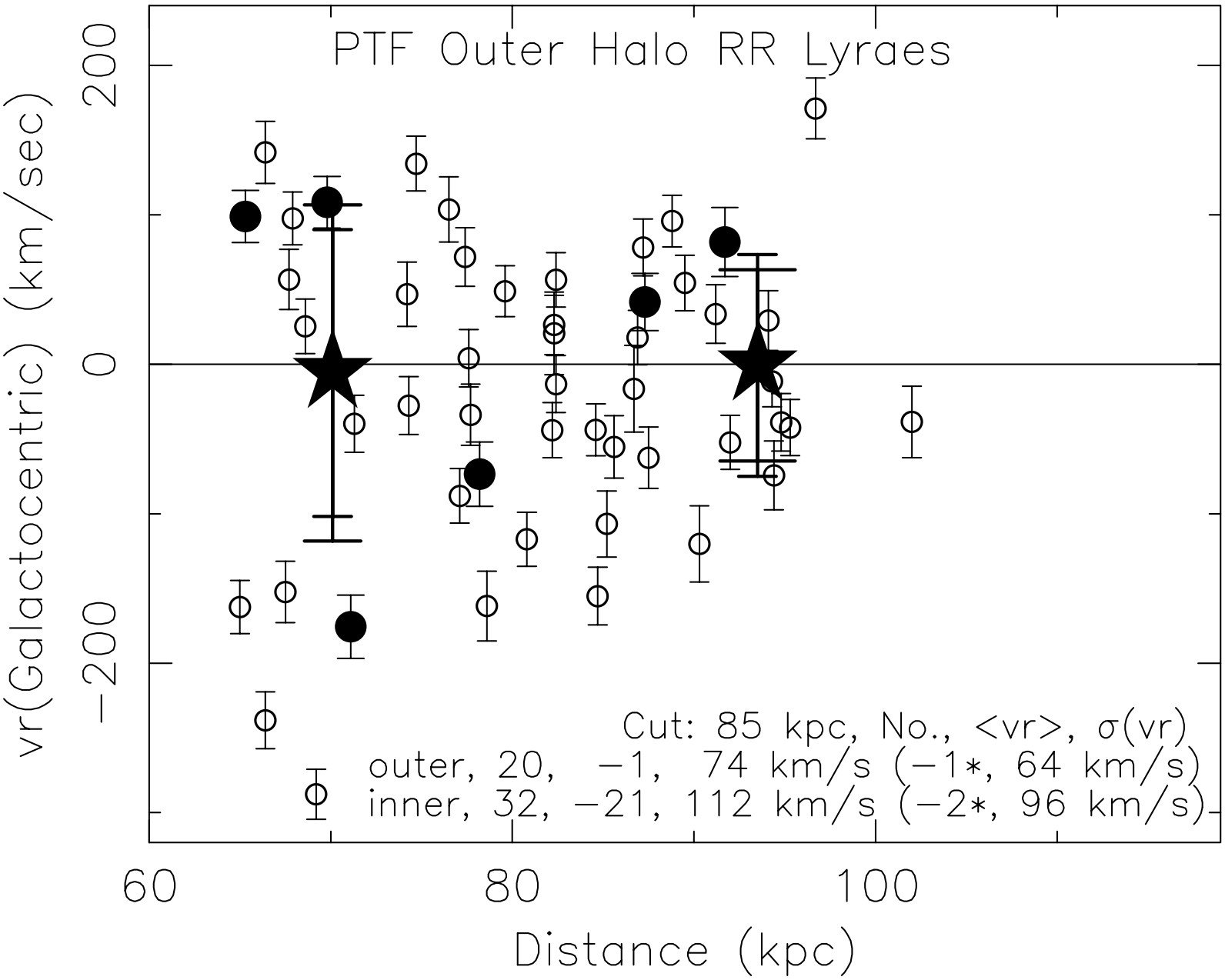
- We are working on the density distribution
- We are working on the completeness corrections
- We have started a spectroscopic program at Keck to determine vr for the RR Lyr beyond 70 kpc
- We are using RR Lyr to study structure in the outer halo
- GAIA will yield proper motions

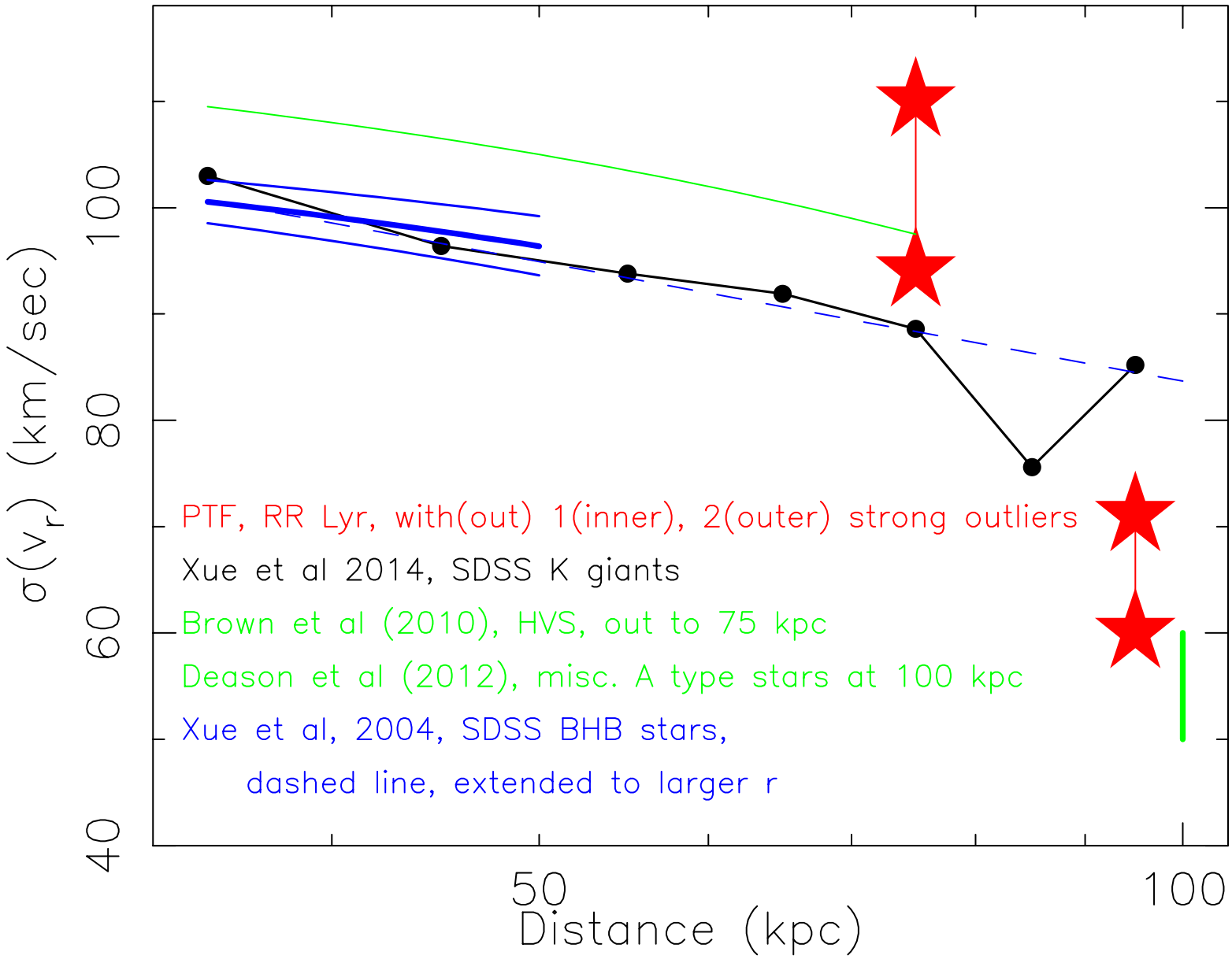
RR Lyr d 61 kpc, 340 epochs, 28 upper limits

RR Lyr d 102 kpc, 149 epochs of which 61 are upper limits




100
10
1
ρ(r) Ω r² Δr
1257 PTF RR Lyrae, D > 50 kpc
arrow = rough completeness correc
Density law: ρⁿ: n = −3.4 (blue),
−1.9 (red), −4.9 (green)
Ω ~ 9000 sq deg, 0.72 kpc/bin
50
100


PTF Outer Halo RR Lyraes
vr(Galactocentric) (km/sec)
200
0
−200
60
80
100
Distance (kpc)
Cut: 85 kpc, No., <vr>, σ(vr)
outer, 20, −1, 74 km/s (−1*, 64 km/s)
inner, 32, −21, 112 km/s (−2*, 96 km/s)


σ(v_r) (km/sec)
40
60
80
100
50
100
Distance (kpc)
PTF, RR Lyr, with(out) 1(inner), 2(outer) strong outliers
Xue et al 2014, SDSS K giants
Brown et al (2010), HVS, out to 75 kpc
Deason et al (2012), misc. A type stars at 100 kpc
Xue et al, 2004, SDSS BHB stars,
dashed line, extended to larger r

Analysis Ongoing: results thus far

- From 1257 candidate RR Lyr, spectra of 61 yields 52 RR Lyr, 3 QSOs, rest SNR too low
- From the counts binned in radius we derive a power law density distribution for n(r) with γ = -3.5 (+- 0.3).
- From σ(vr) plus the density distribution we derive a preliminary total mass inside 105 kpc of 6.6 x 10**11 solar masses, lower than most previous studies.

Why is 10% accuracy for total mass of MW so difficult ?

M propto (f(oblateness) + $|\gamma|$ -2β) Sum[(sqrt(r_i) $v^2_{r,i}$]

γ Power law slope of ρ(r). Can determine from RR Lyr out to at least distance 100 kpc

β Velocity anisotropy of orbits. hard to determine

Oblateness profile – inner halo – SDSS, outer halo, may need to wait for LSST.