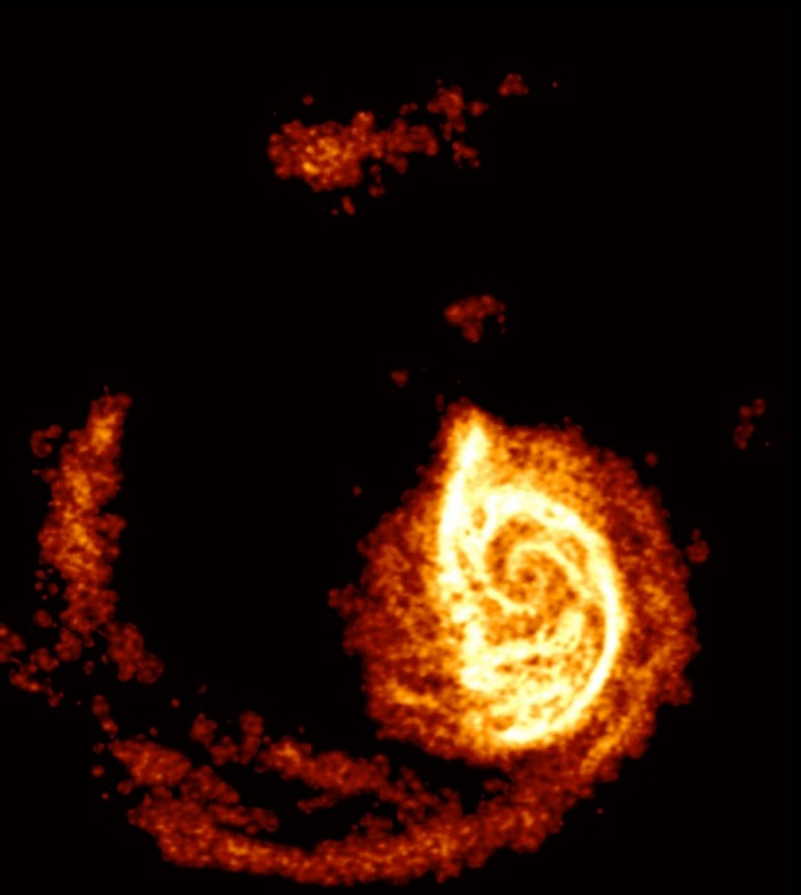
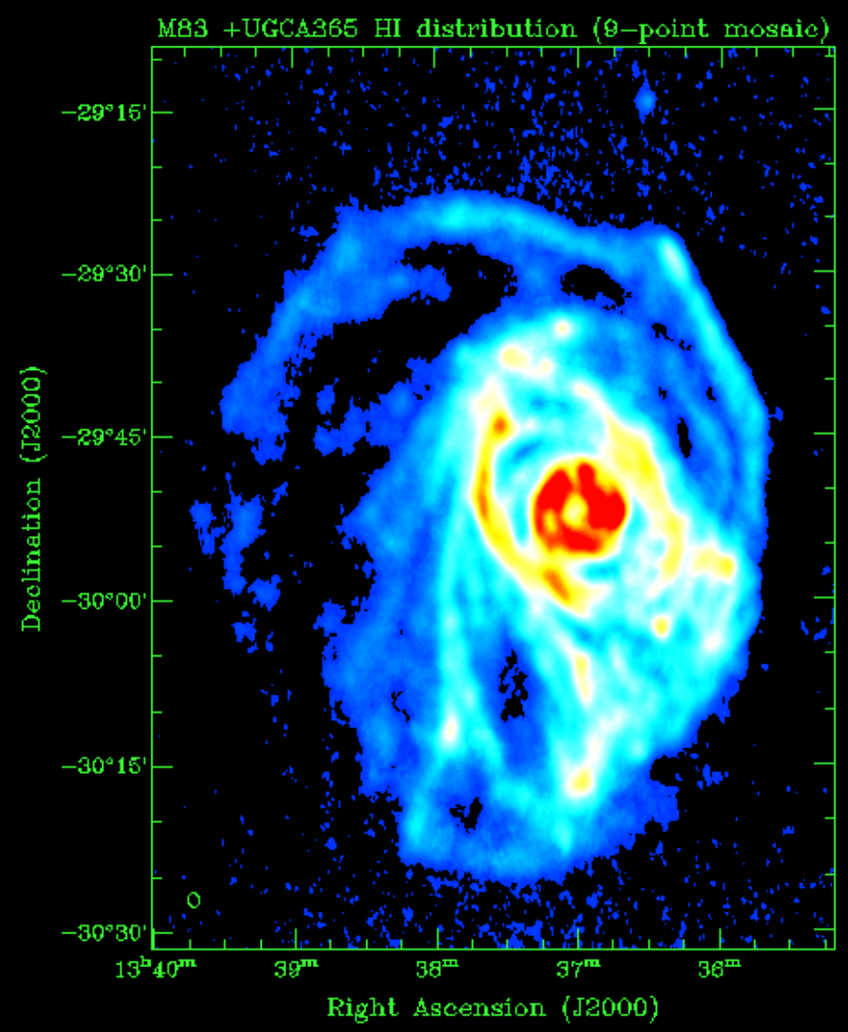
# A Group of Coherently Receding Halo Stars Towards Norma

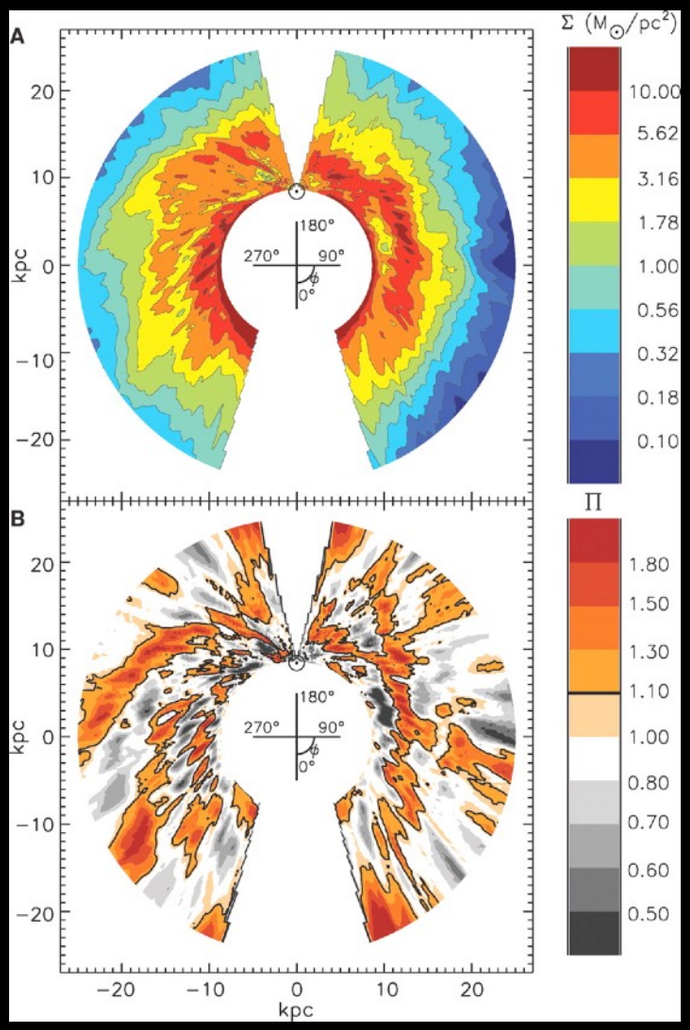
Sukanya Chakrabarti (RIT)

Collaborators: Rodolfo Angeloni (Universidad de La Serena), Ben Sargent (STSCI), Josh Simon (Carnegie), Ken Freeman (ANU), Wolfgang Gieren (Universidad de Concepcion), Piotr Konorski (Warsaw University), Gibor Basri (UCB), Leo Blitz (UCB), Bill Vacca (NASA Ames), Philip Chang (UWM), Andy Lipnicky (NRAO), Alice Quillen (U.Rochester), Roberto Saito (PUC, Chile), Massimo Marengo (Iowa State), Raja Guhathakurta (UCSC)

# Overview

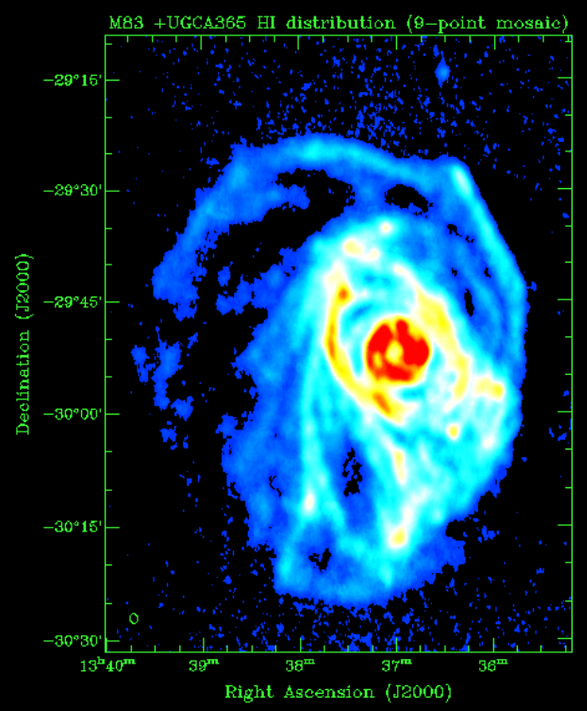



M83 +UGCA365 HI distribution (9-point mosaic)
−29°15'
−29°30'
−29°45'
−30°00'
−30°15'
−30°30'
Declination (J2000)
13h40m
39m
38m
37m
36m
Right Ascension (J2000)


A
B
Σ (M⊙/pc²)
10.00
5.62
3.16
1.78
1.00
0.56
0.32
0.18
0.10
Π
1.80
1.50
1.30
1.10
1.00
0.80
0.70
0.60
0.50
180°
270°
90°
0°
kpc
20
10
0
−10
−20

# Tidal imprints of dark-matter dominated dwarf galaxies

- Responsive cold outer disk
- Large cross-section for interaction
- Short term memory
- **The *best* of hydrodynamics!**




Atomic hydrogen (HI) Maps

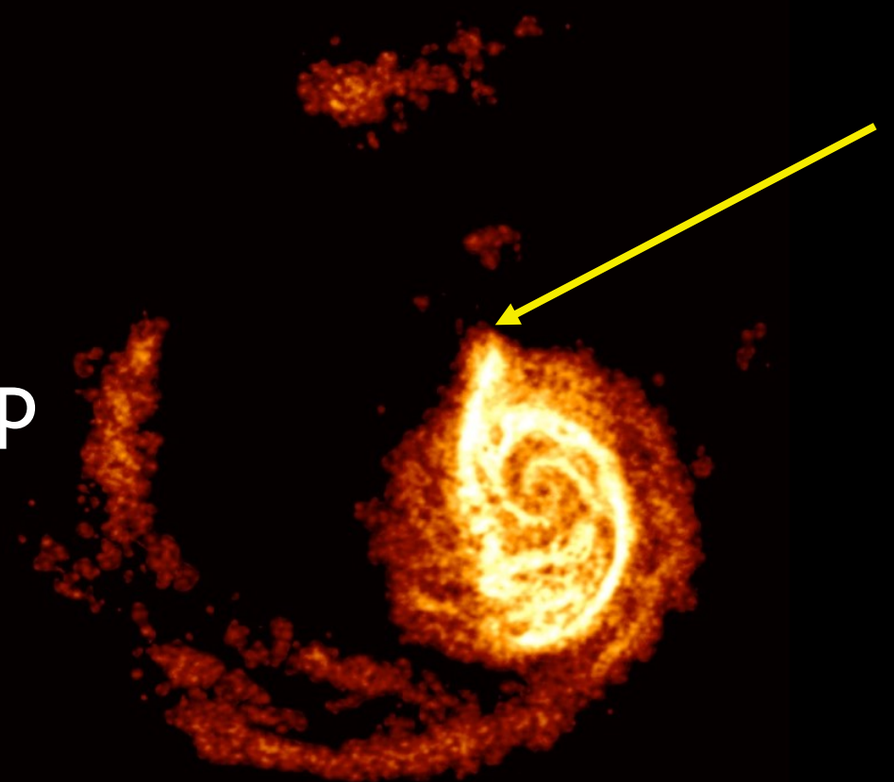
Footprints of Dark Sub-Halos

# Disturbances in HI disks in local spirals: Proof of Principle

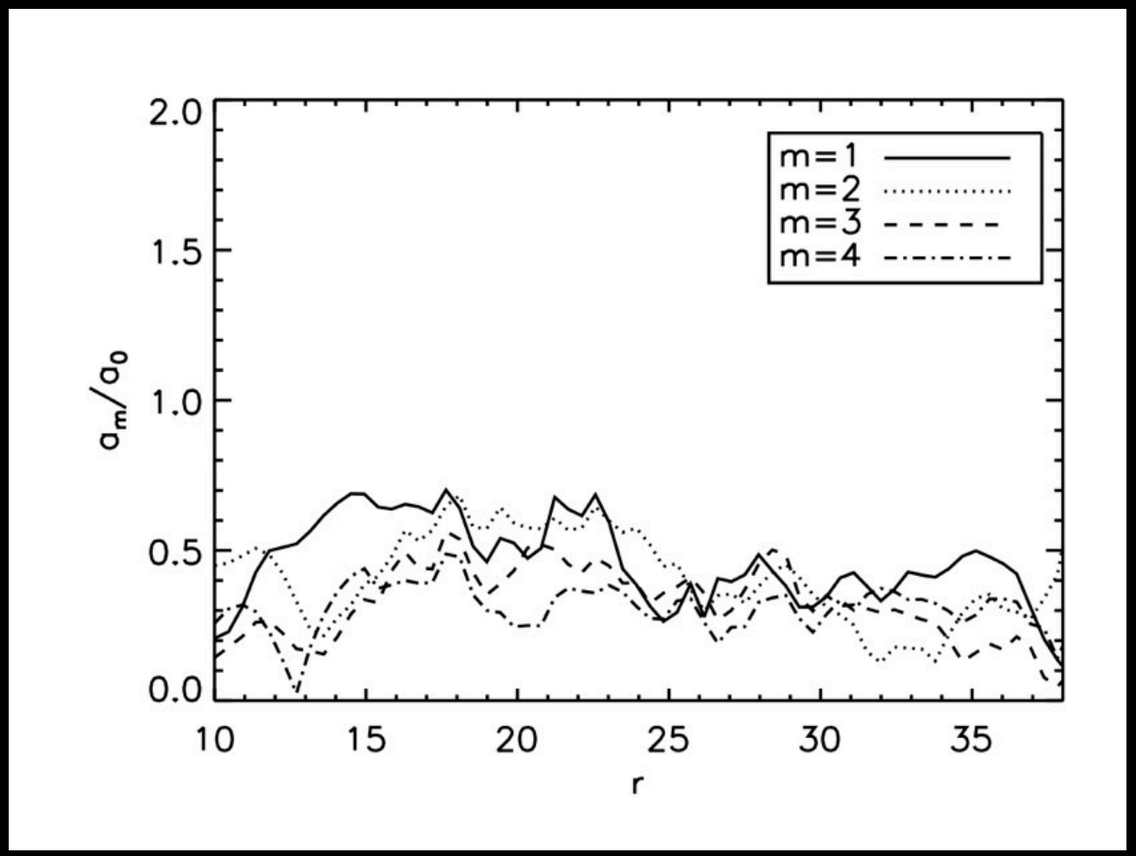

Grand et al. 2017 — similar structures in cosmological sims

# M51

HI Map



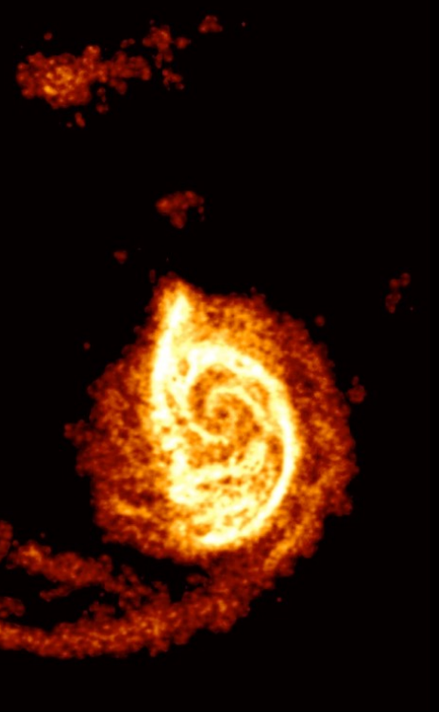
optical image

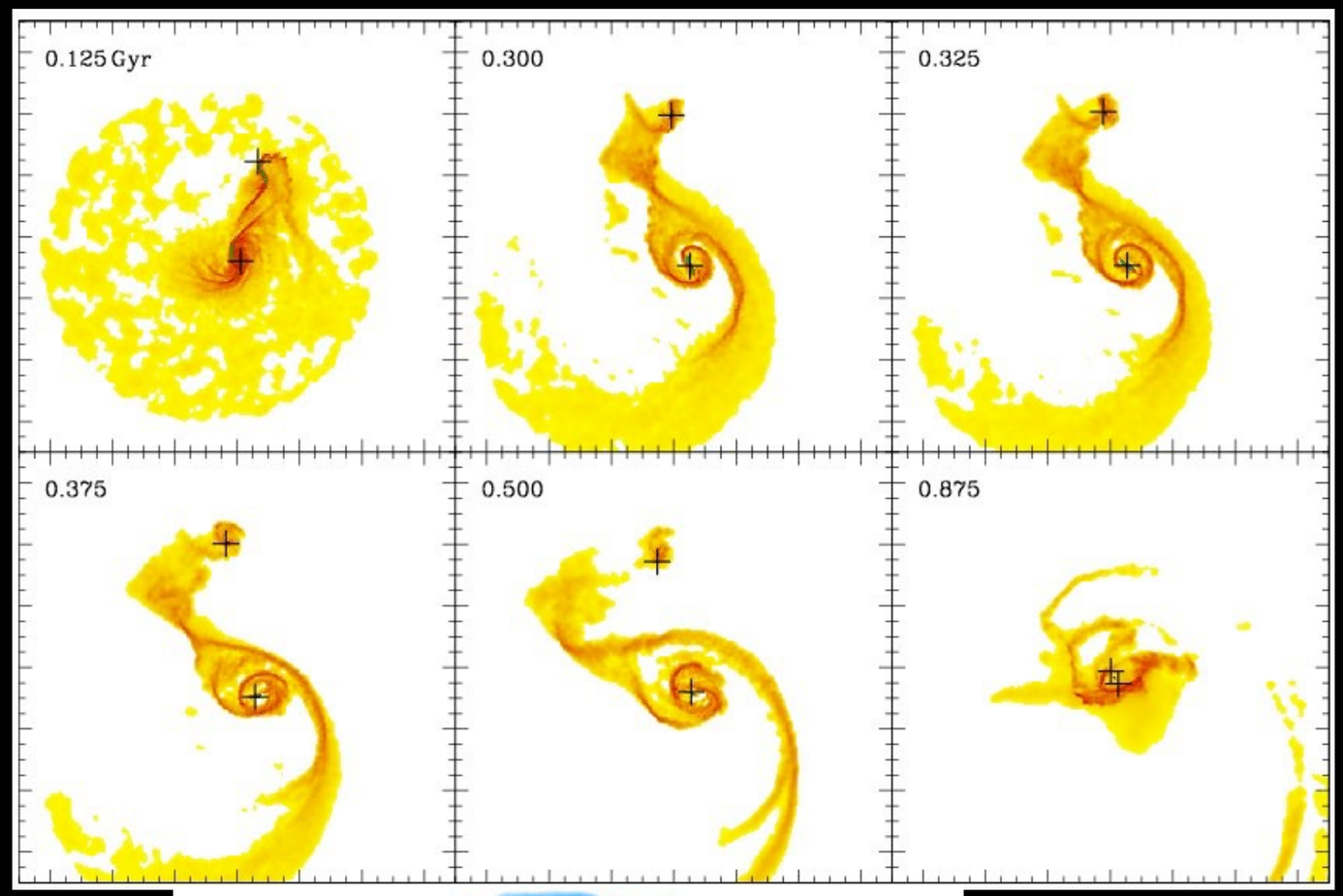


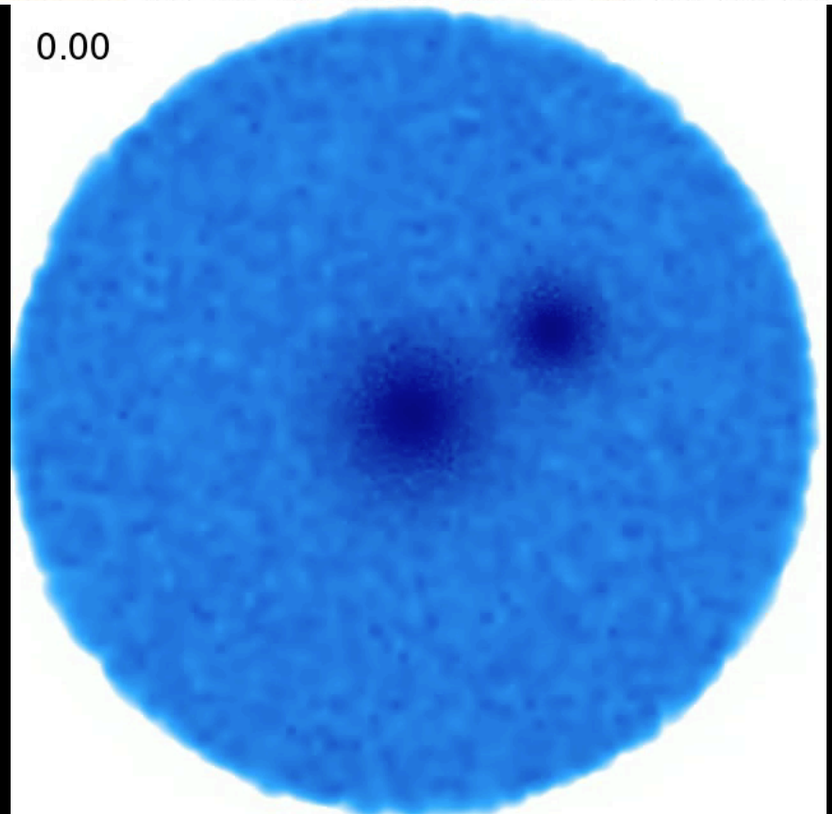

$$a_m(r) = \int \Sigma(r,\phi) e^{-im\Phi} d\phi$$

Local Fourier Amplitudes of HI data: Metric of Comparison to simulations

# M51 Simulation Comparison

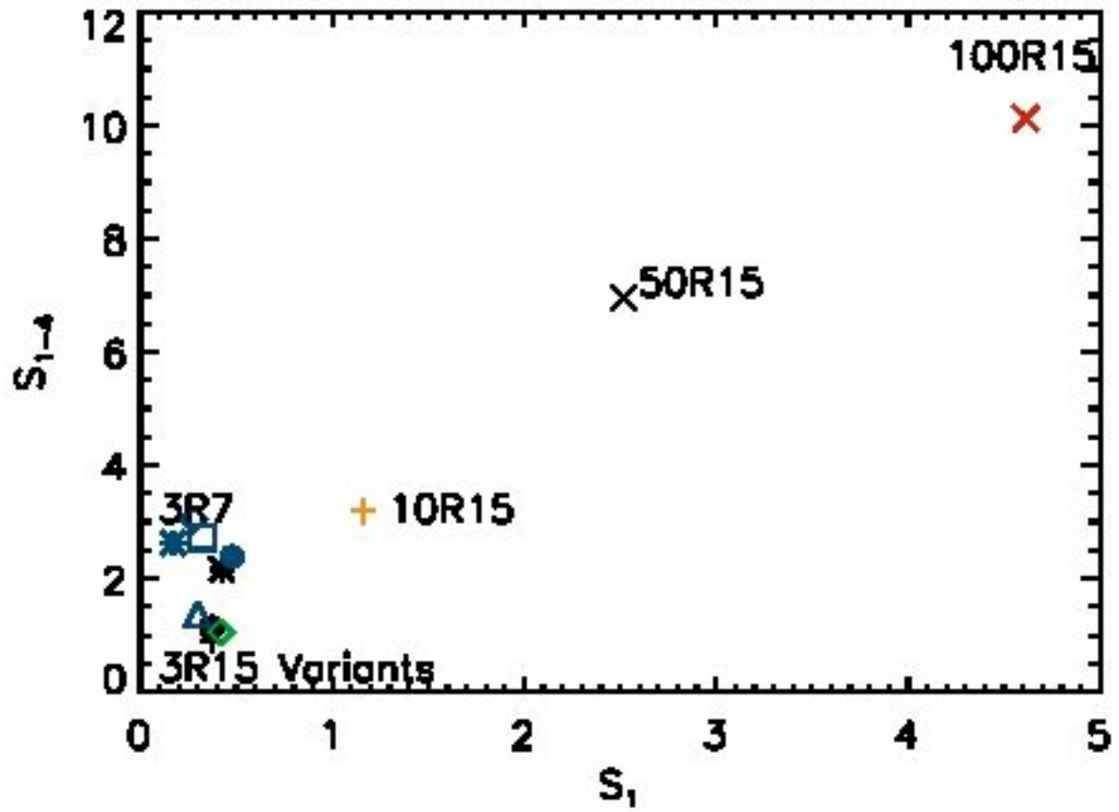


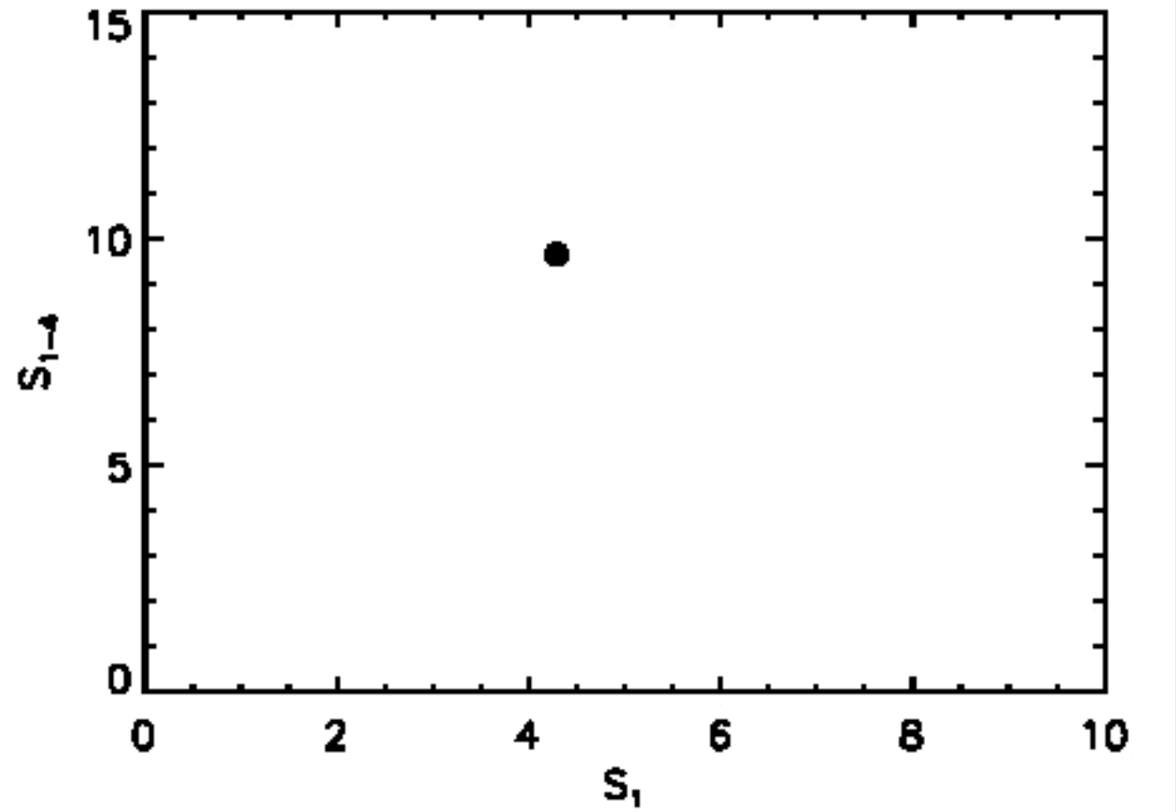


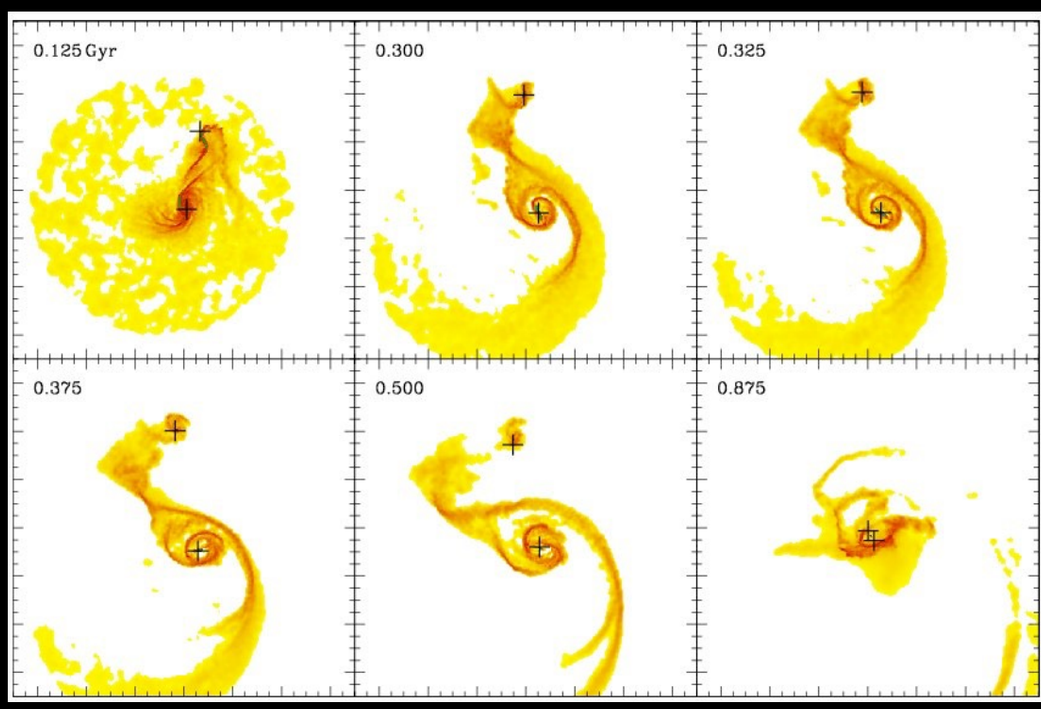

Chakrabarti, Bigiel, Chang & Blitz, 2011

# Variance Vs Variance

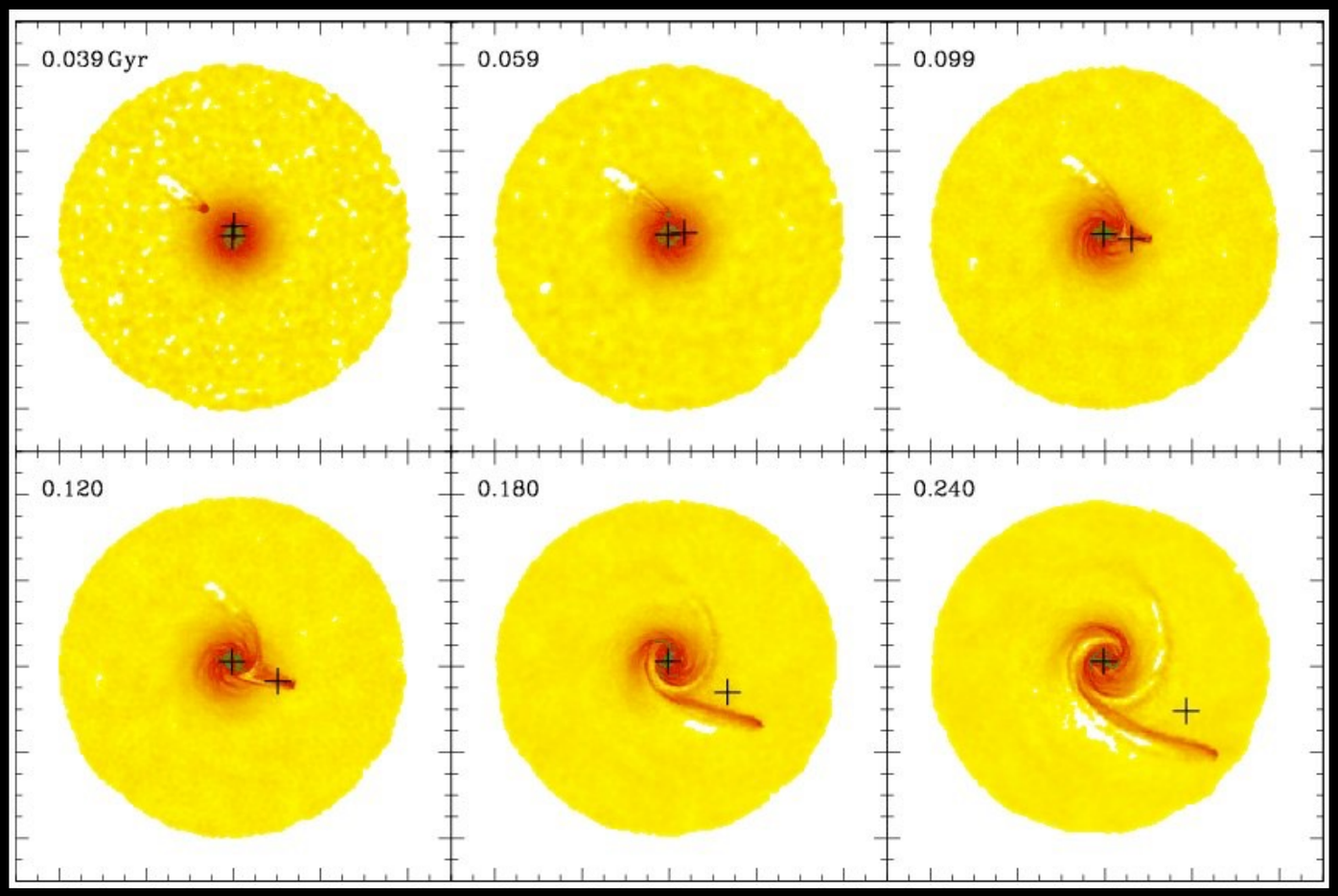


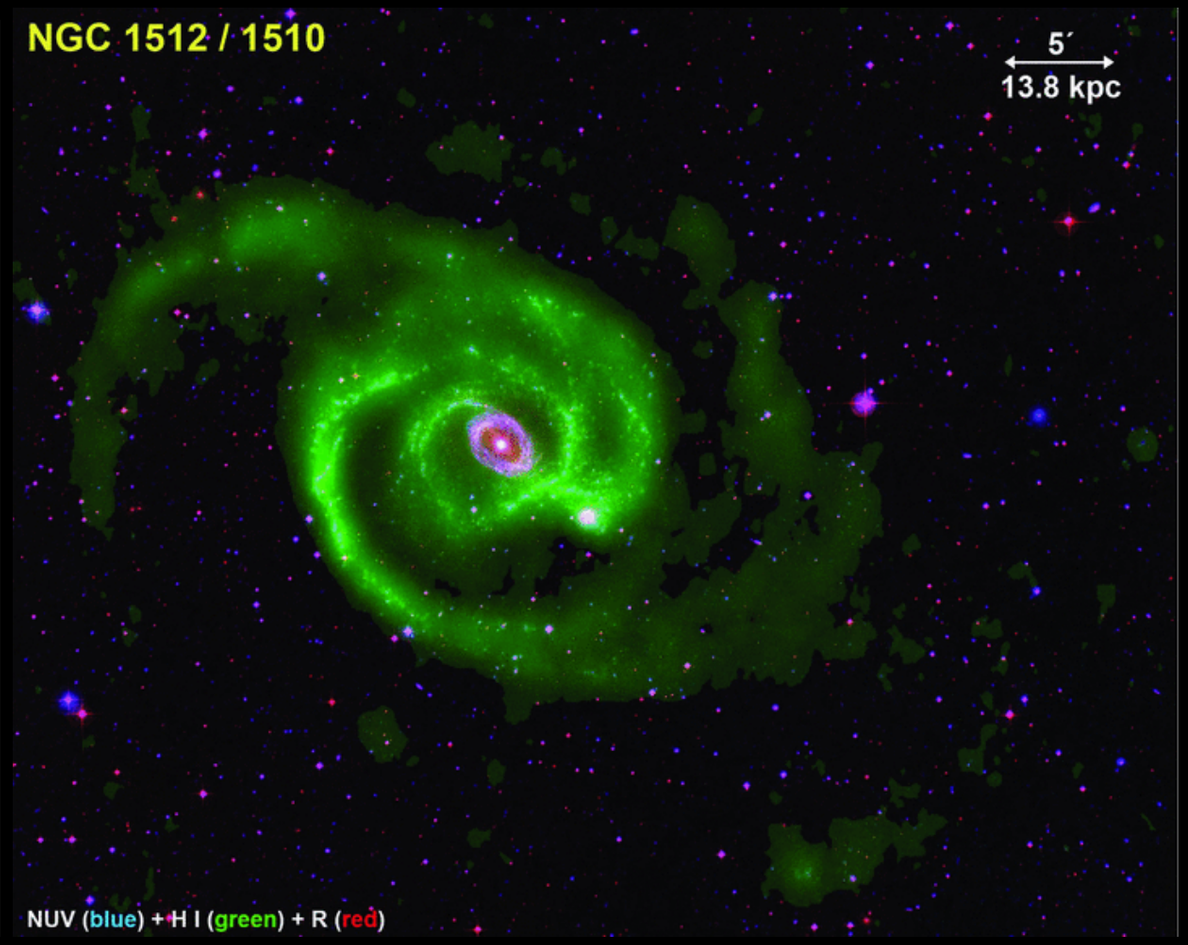




Best-fits -- close to origin on variance vs variance plot, shown at best-fit time. "Variants" include varying initial conditions (ICs), interstellar medium (ISM), SFR, orbital inclination, etc. Estimate of $M_s$ (1:3) close to observational numbers.



# Galaxies with known optical companions contd.



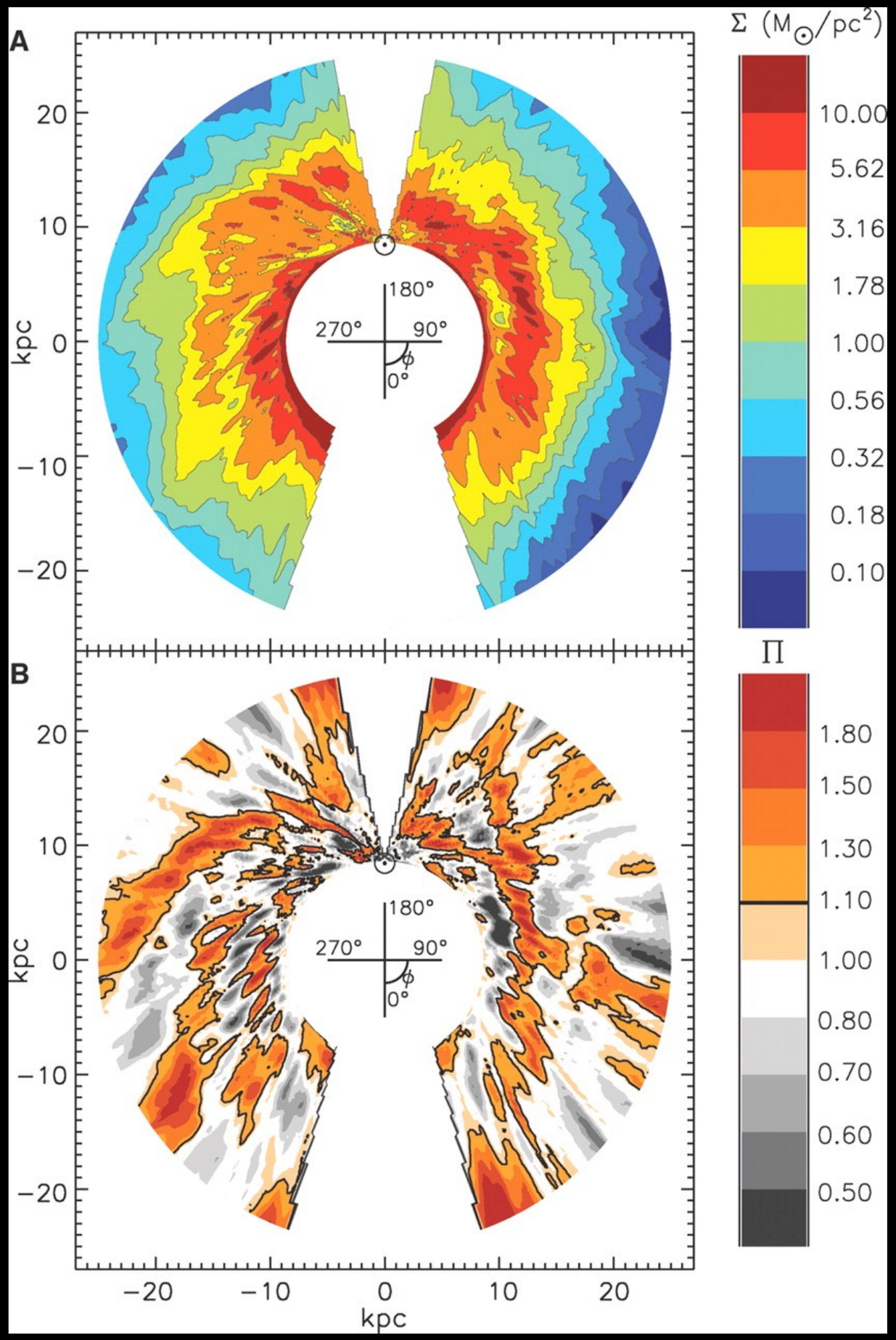



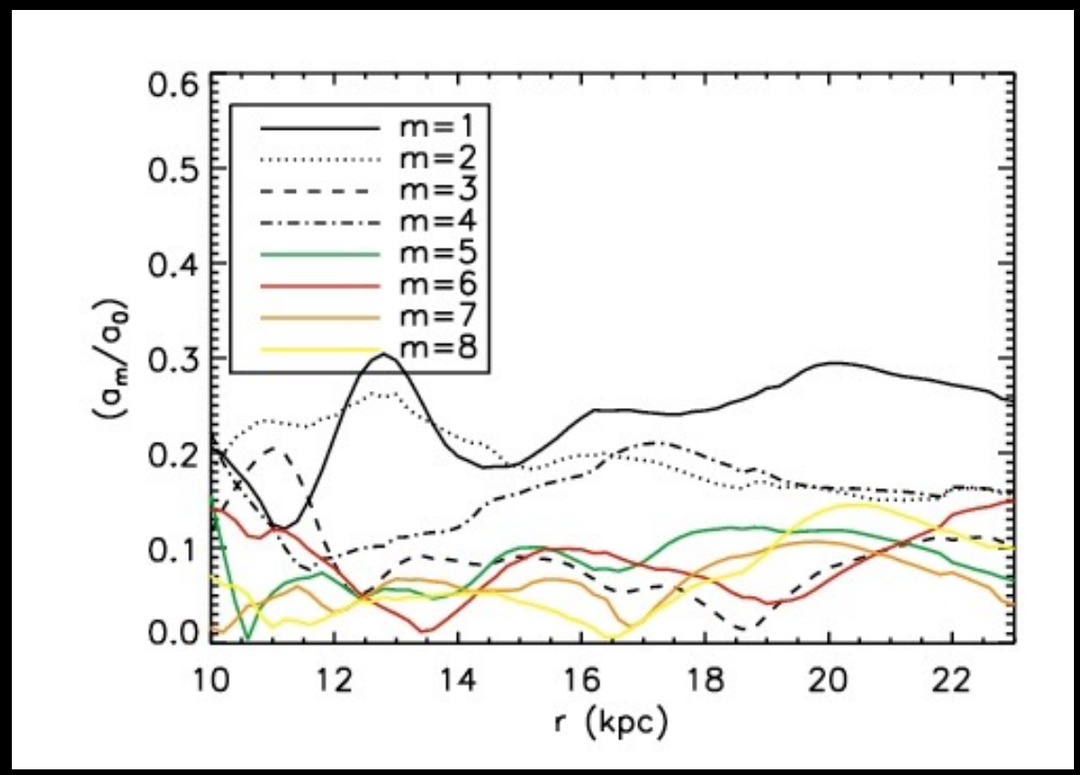

- ~1:100 satellite, $R_{peri}$ = 7kpc (close agreement with Koribalski & Sanchez 09) (global fourier amplitudes)
- Method works for 1:3 - 1:100 mass ratio satellites

# HI Map of Milky Way

HI maps: Levine, Blitz & Heiles 2006. What caused these structures well outside the solar circle?

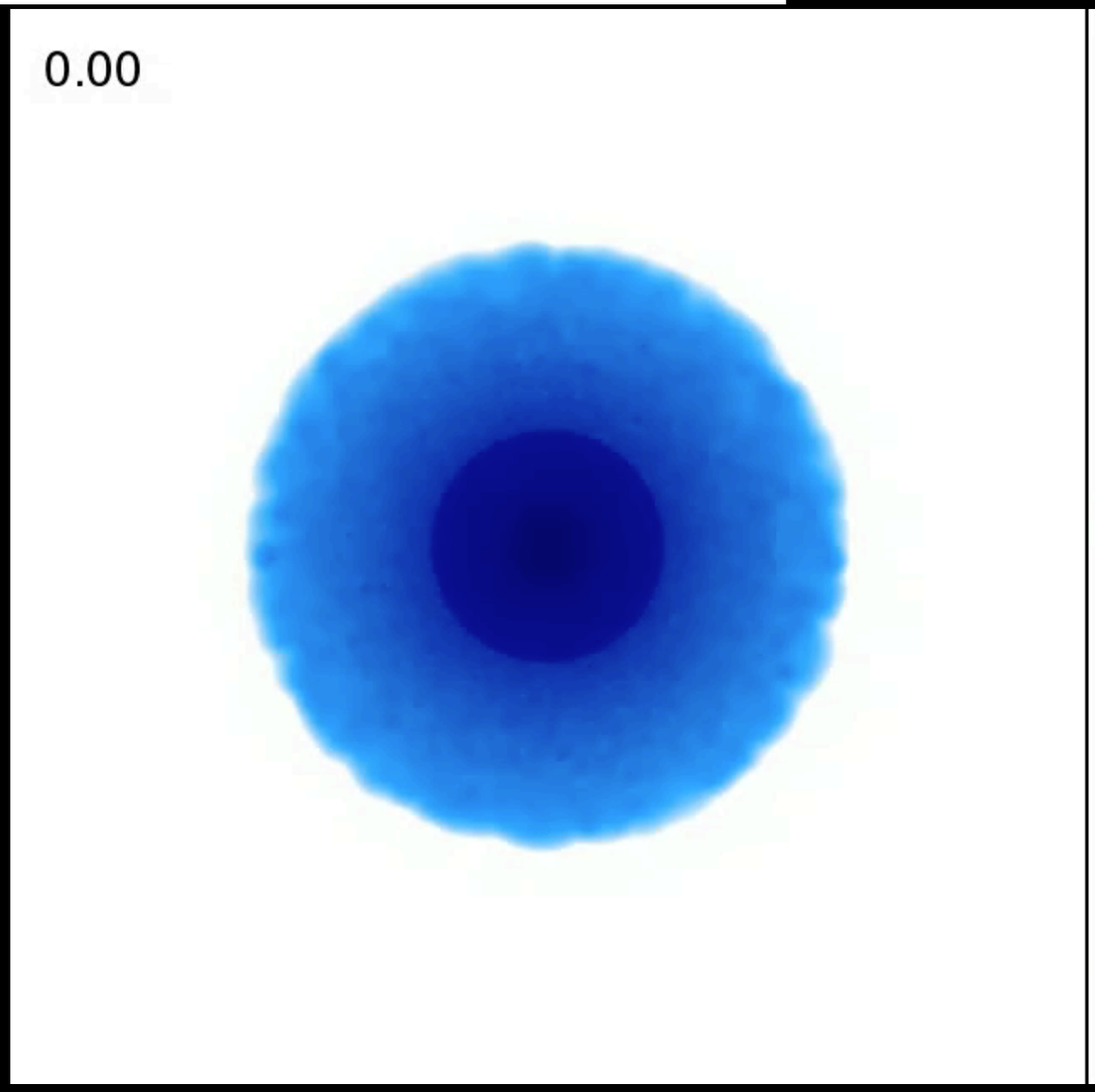
$a_m(r) = \int \Sigma(r,\phi) e^{-im\Phi} d\phi$

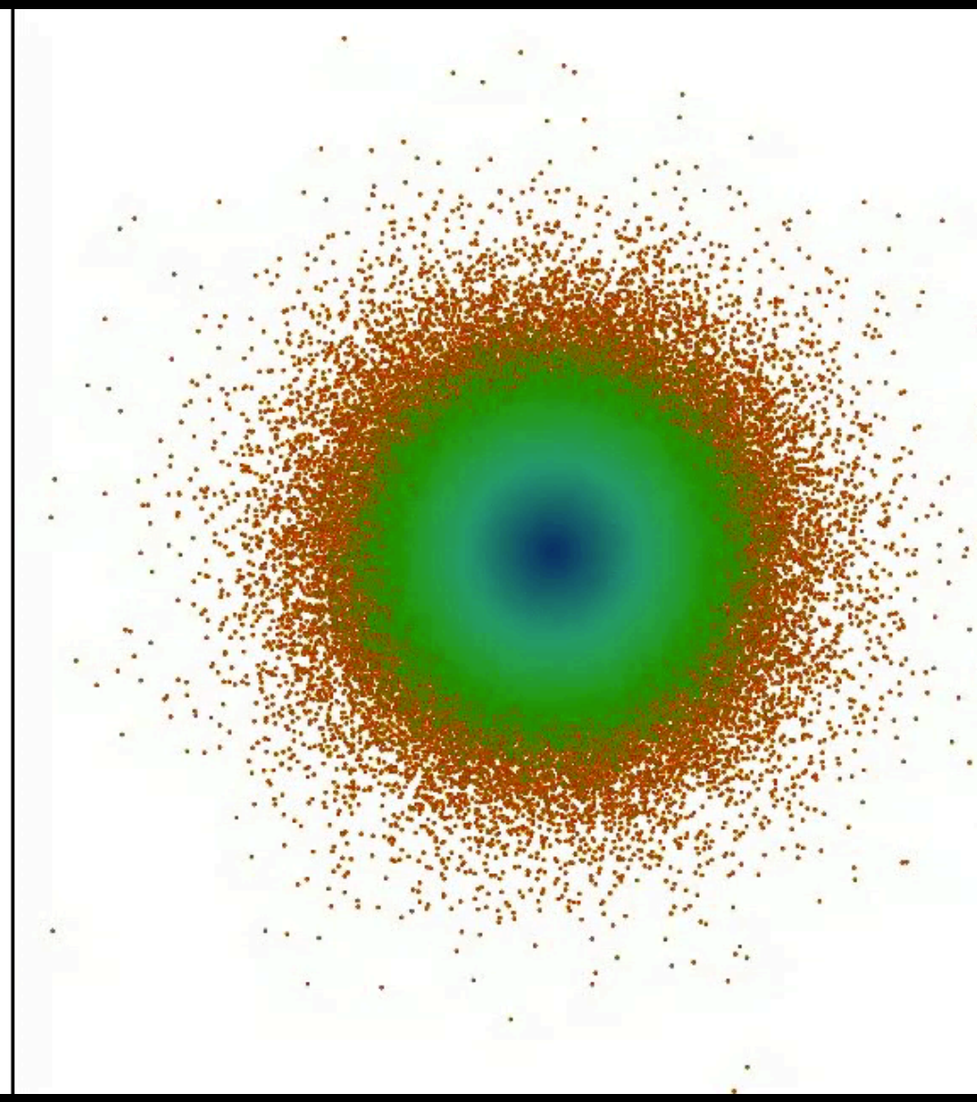


# Simulations

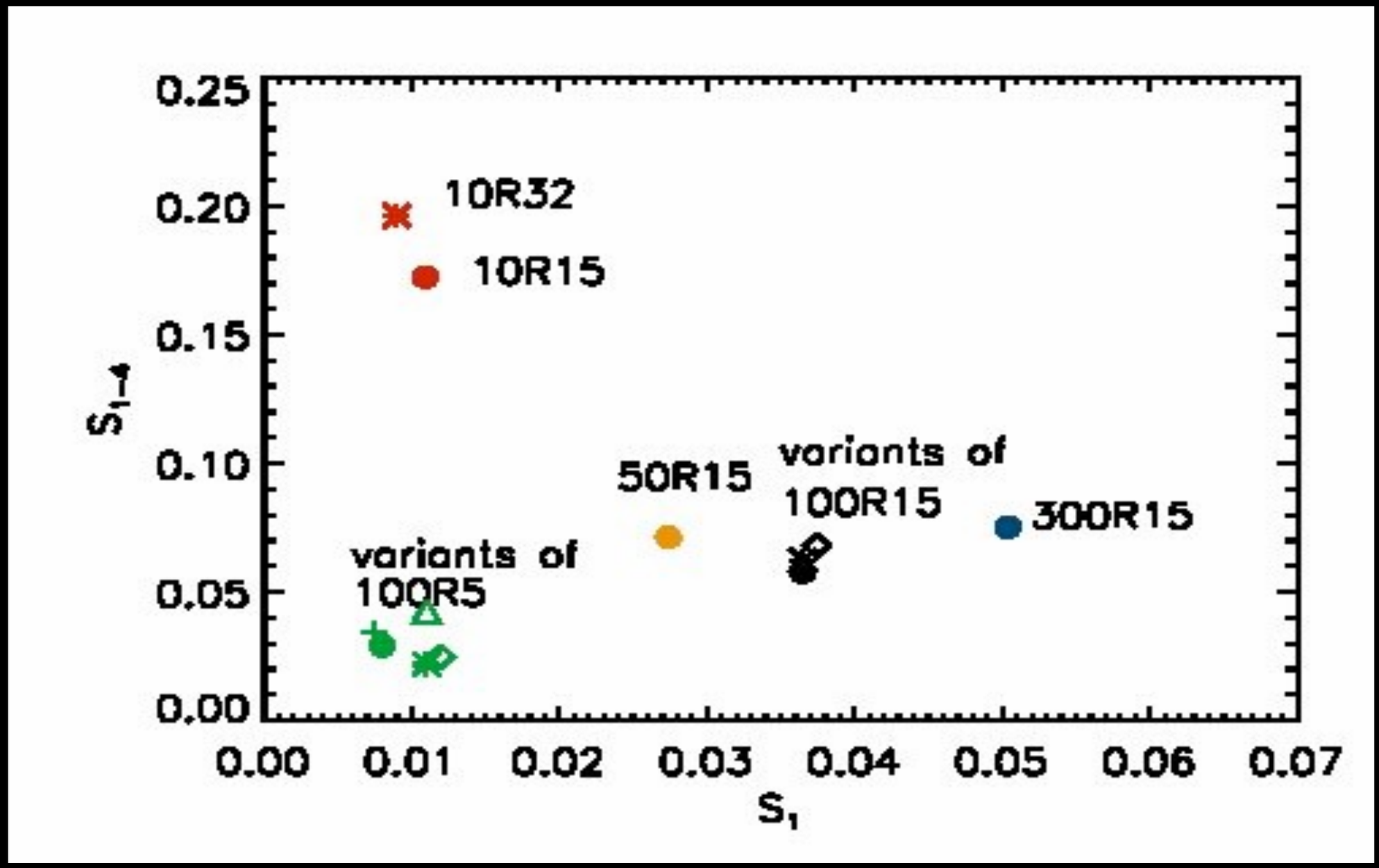
| $M_s$ | $R_{peri}$ | inclination |
|---|---|---|
| 1:10-1:1000 | 0.1-50kpc | $f_{gas}$ (0.1-0.3), EQS |



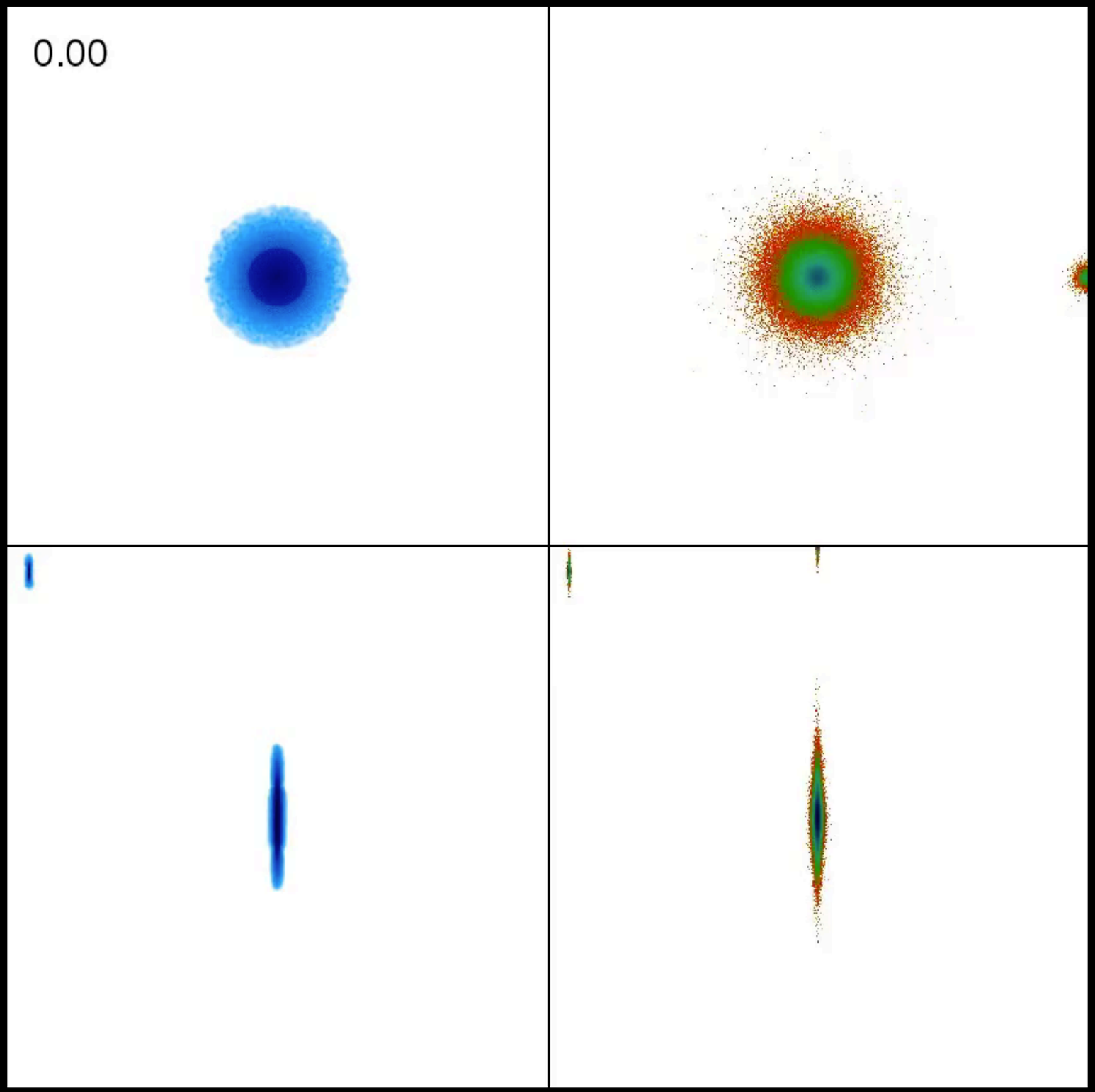
Parameter space survey of simulations to explain observed disturbances in HI map of Milky Way. Chakrabarti & Blitz 2009.

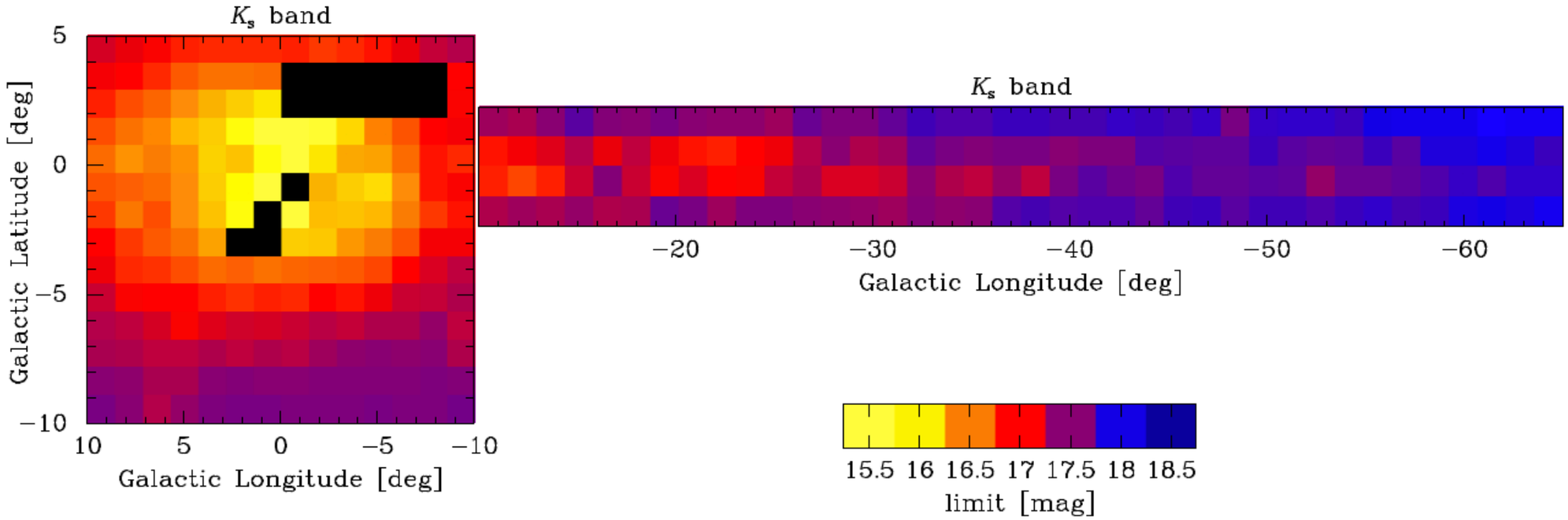
# Initial Conditions, Orbits -- what really matters?

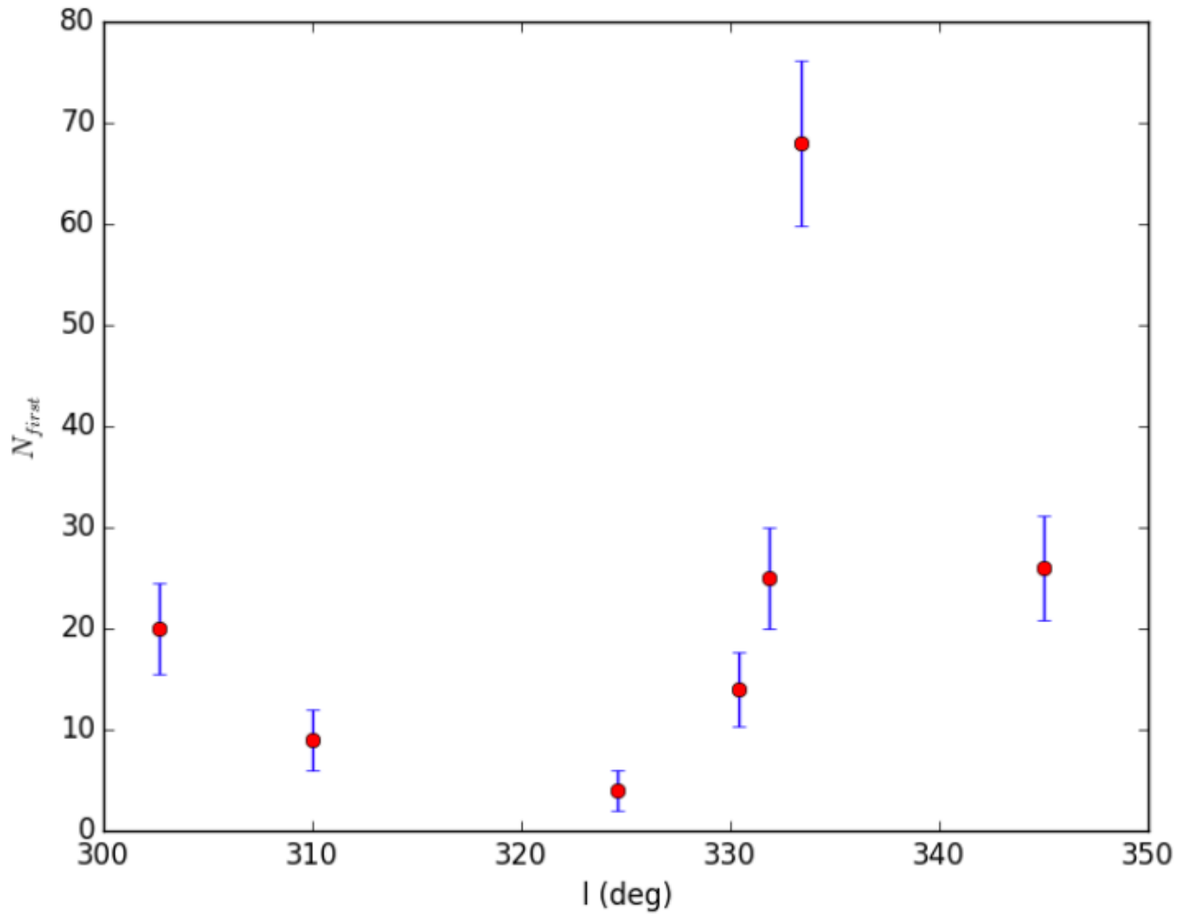



- Not very sensitive to initial conditions (for parameters comparable to spirals).

# The Tidal Players of the Milky Way

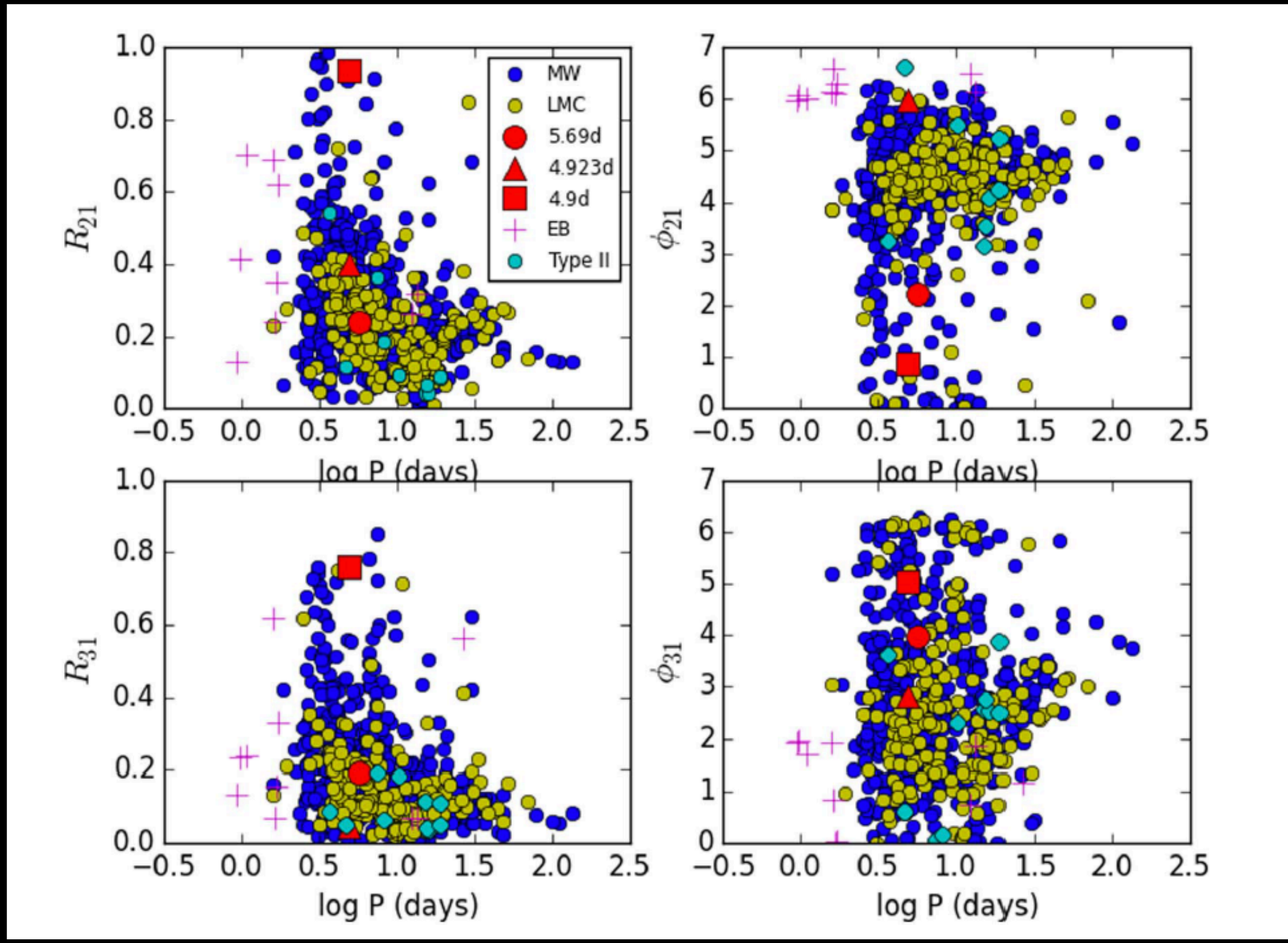




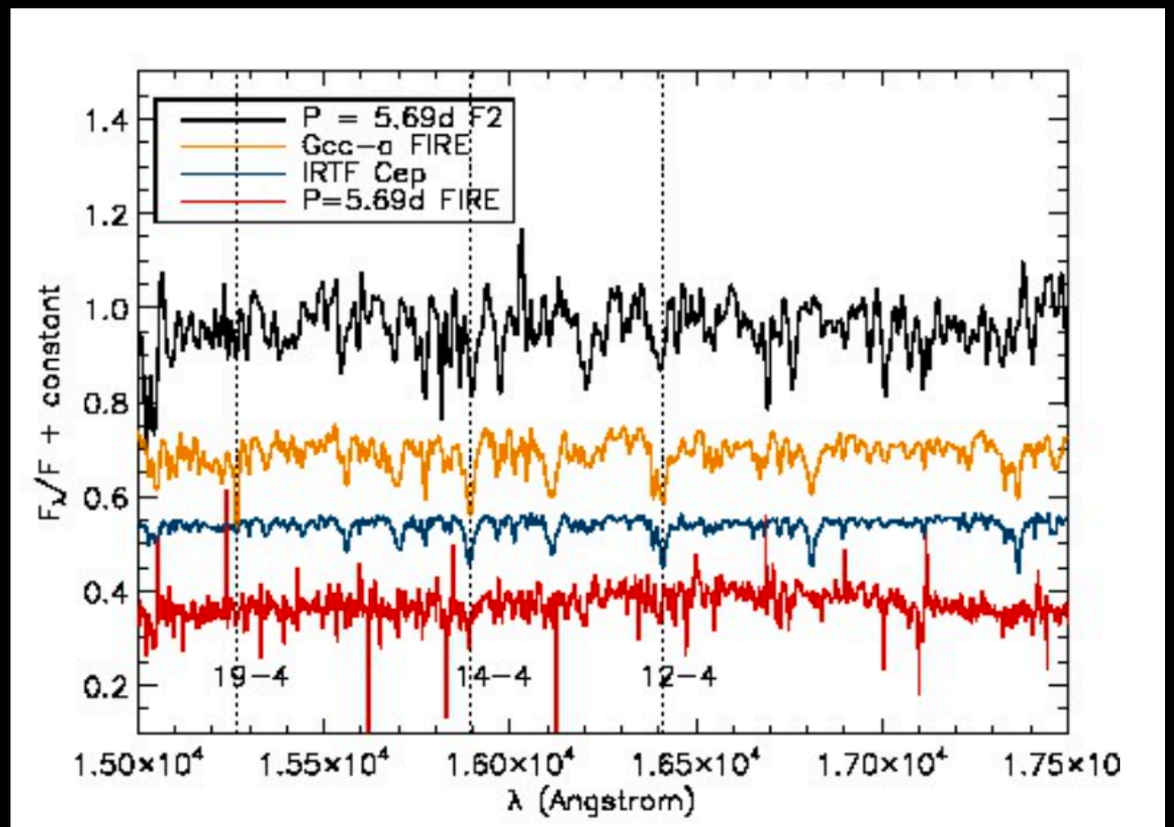



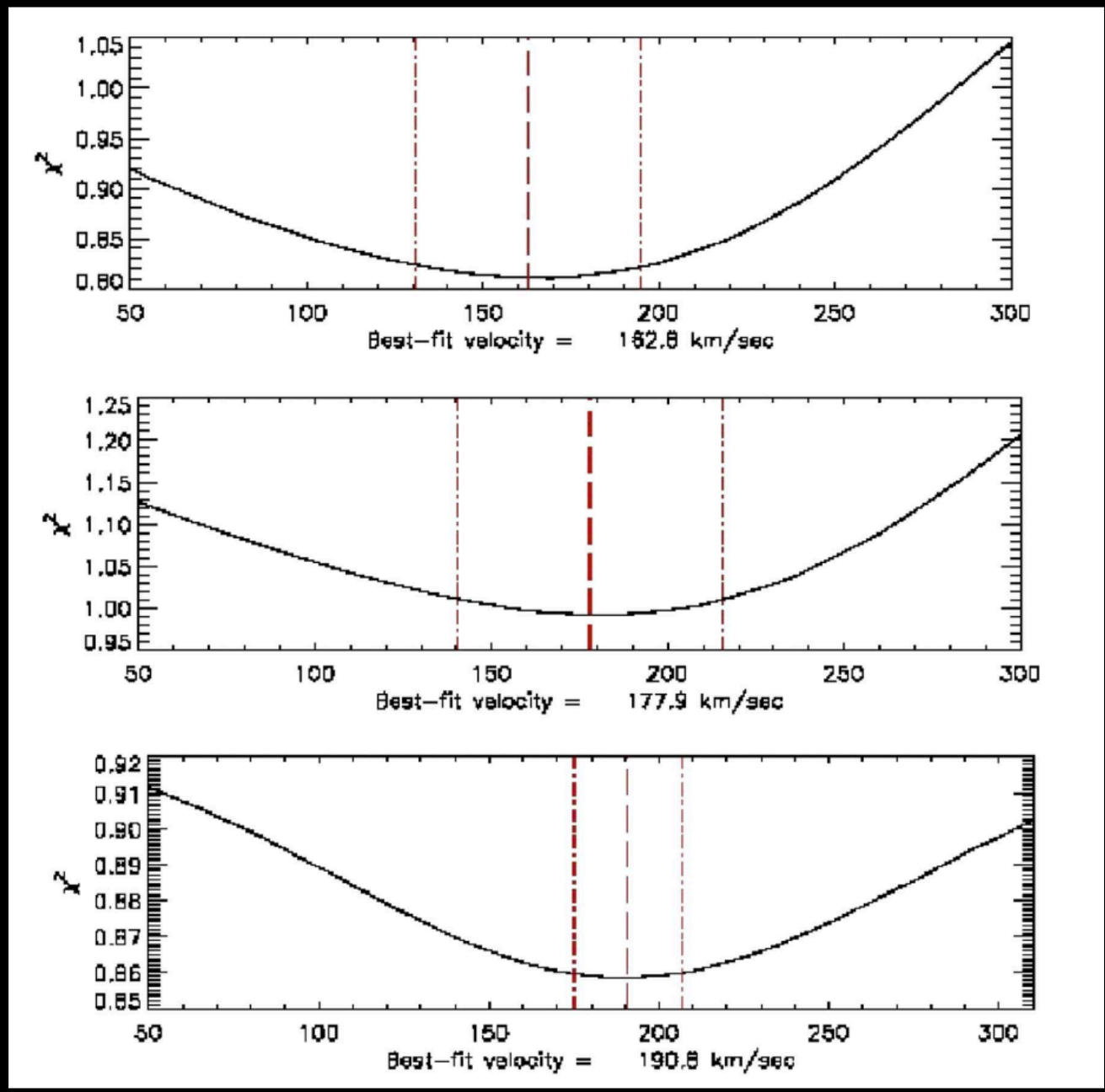

5-sigma excess of variables (P > 3 days, $K_s$ > 15 mag) in VVV (Saito et al. 2012)
disk area towards l ~ 333 (Chakrabarti et al. 2015; 2017)

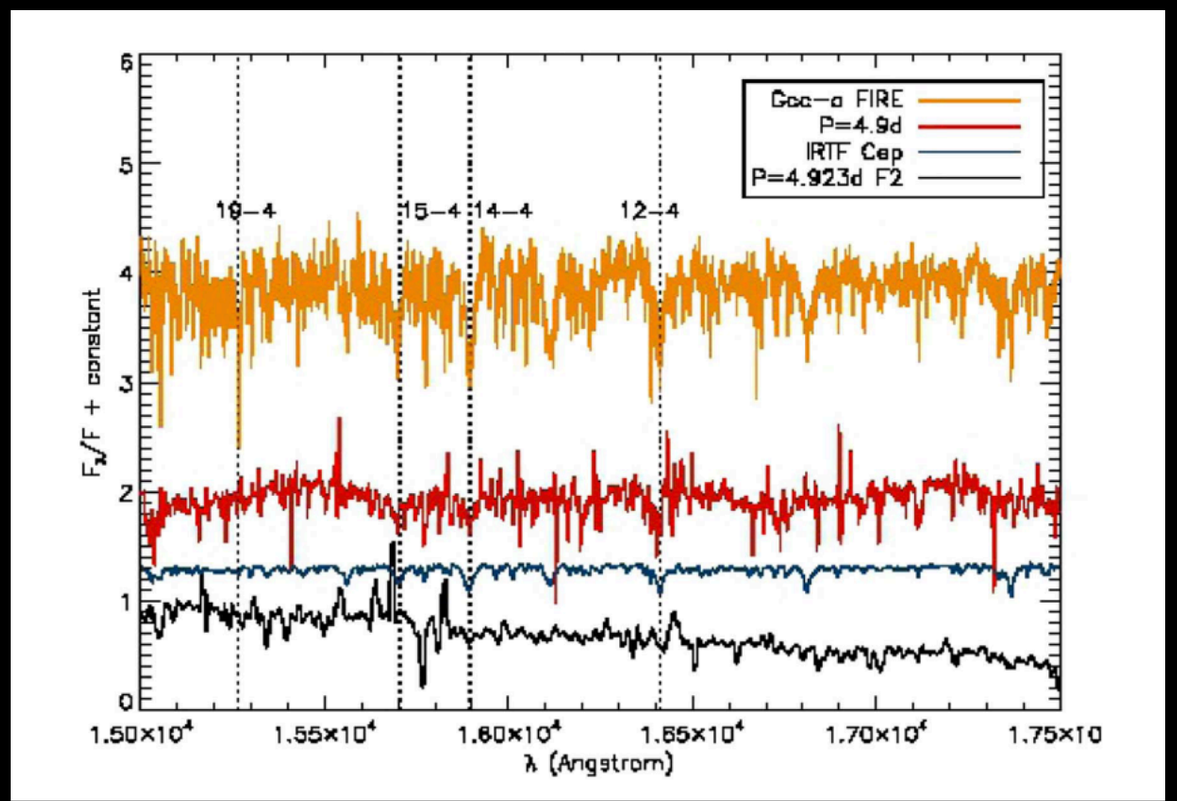
# A Group of Variable Stars



# Flamingos-2 Spectra



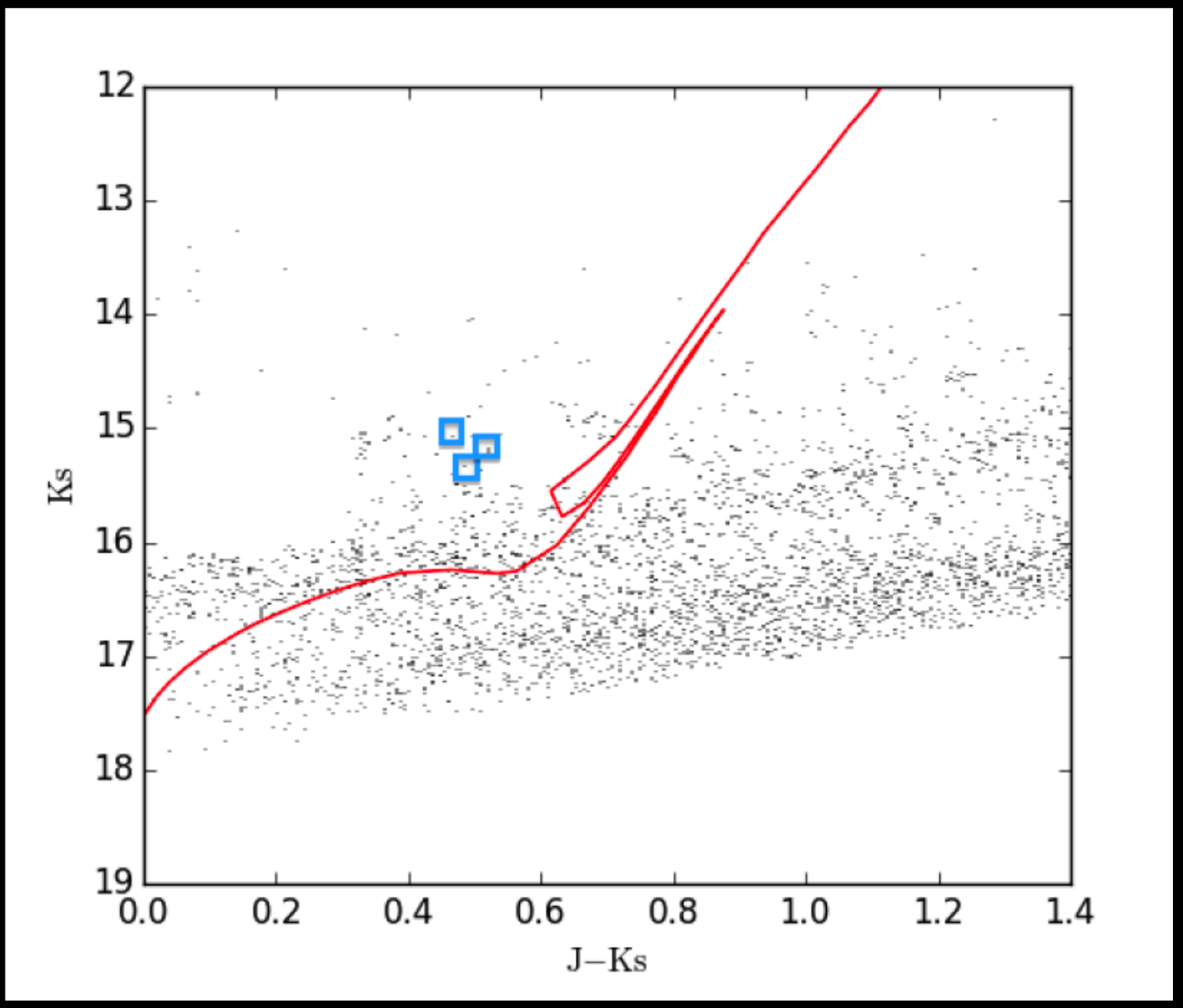




Average $v_r$ ~ 169 km/s

# F2 Spectra — Implications

- Radial velocities are distinct from the galactic disk.
- Probability that these stars are foreground Milky Way stars is $7 \times 10^{-4}$ %
- Probability that they are large amplitude spotted stars in a binary is $10^{-5}$ %
- Spectra or light curves do not clearly establish what these variable stars are.
- If Type I Cepheids, they would be at 78 kpc.

# Future Work




Result from extinction correcting target tiles close to l ~ 333 and subtracting Galactic background tile. Excess comparable to location of red clump stars at ~ 80 kpc.

Ongoing: <u>Deeper Spitzer 4.5 um photometry of target fields (Ben Sargent PI): H-4.5um for better extinction correction.</u>

- More spectra of other Cepheid candidates and higher S/N spectra

# Acknowledgments