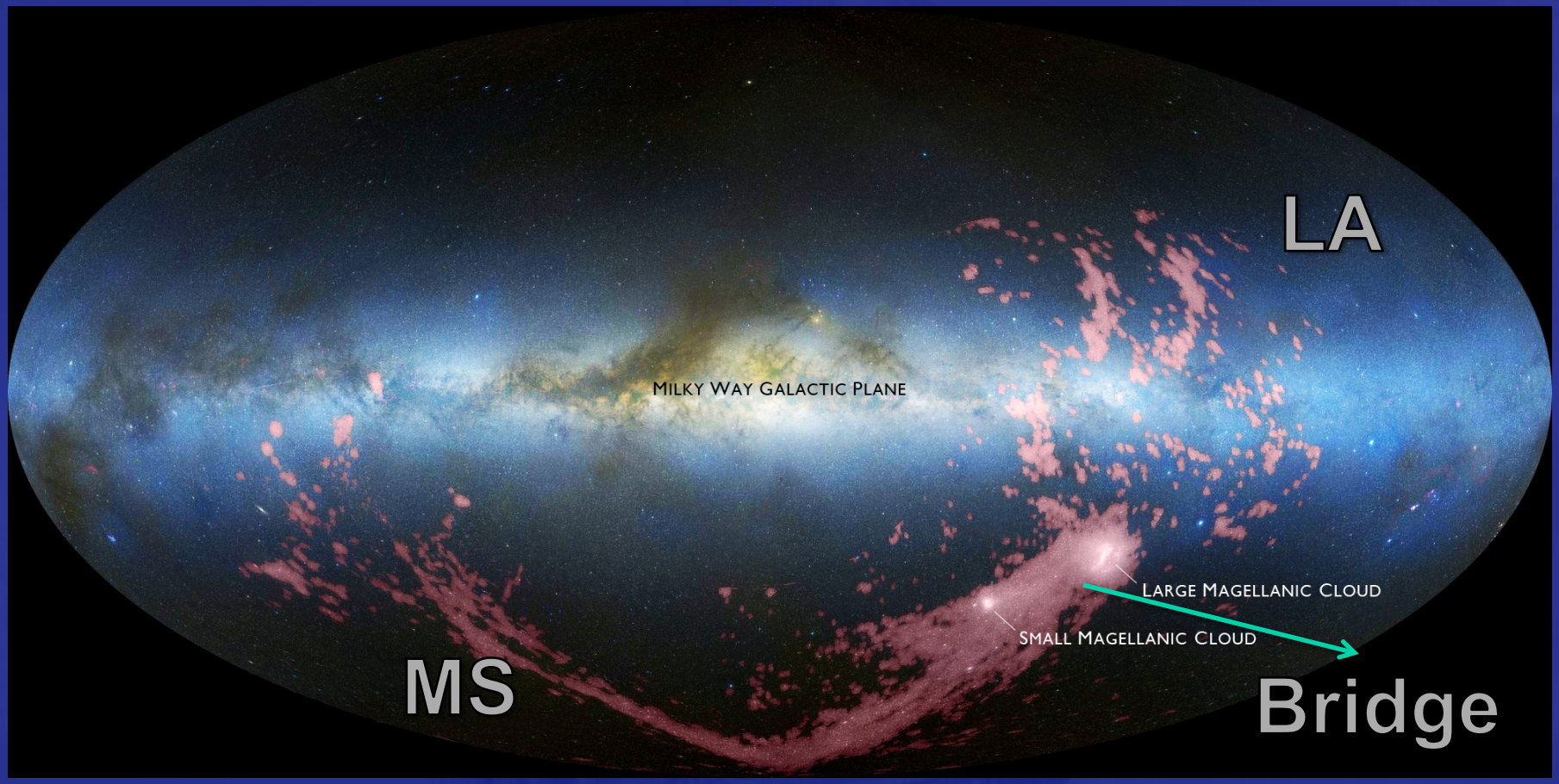
Recent Star Formation in the Leading Arm of the Magellanic Stream

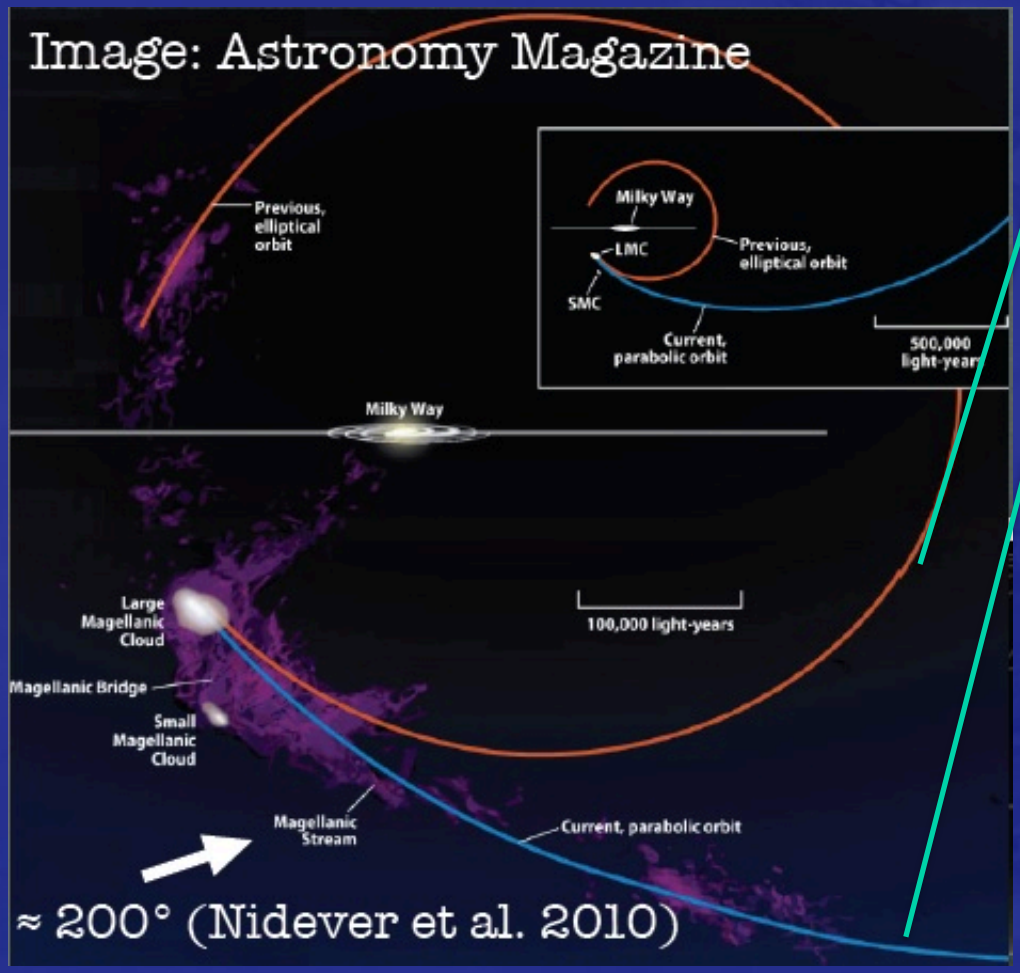
Dana I. Casetti-Dinescu
Southern Connecticut State University

Magellanic Clouds: The Nearest Gas-rich Galaxy Interaction



Nidever et al. 2010 - Magellanic Stream and Clouds in HI (red) with an optical all-sky image (blue, white, and brown; Mellinger 2009) in Aitoff projection with the direction to the Galactic Center at the center.

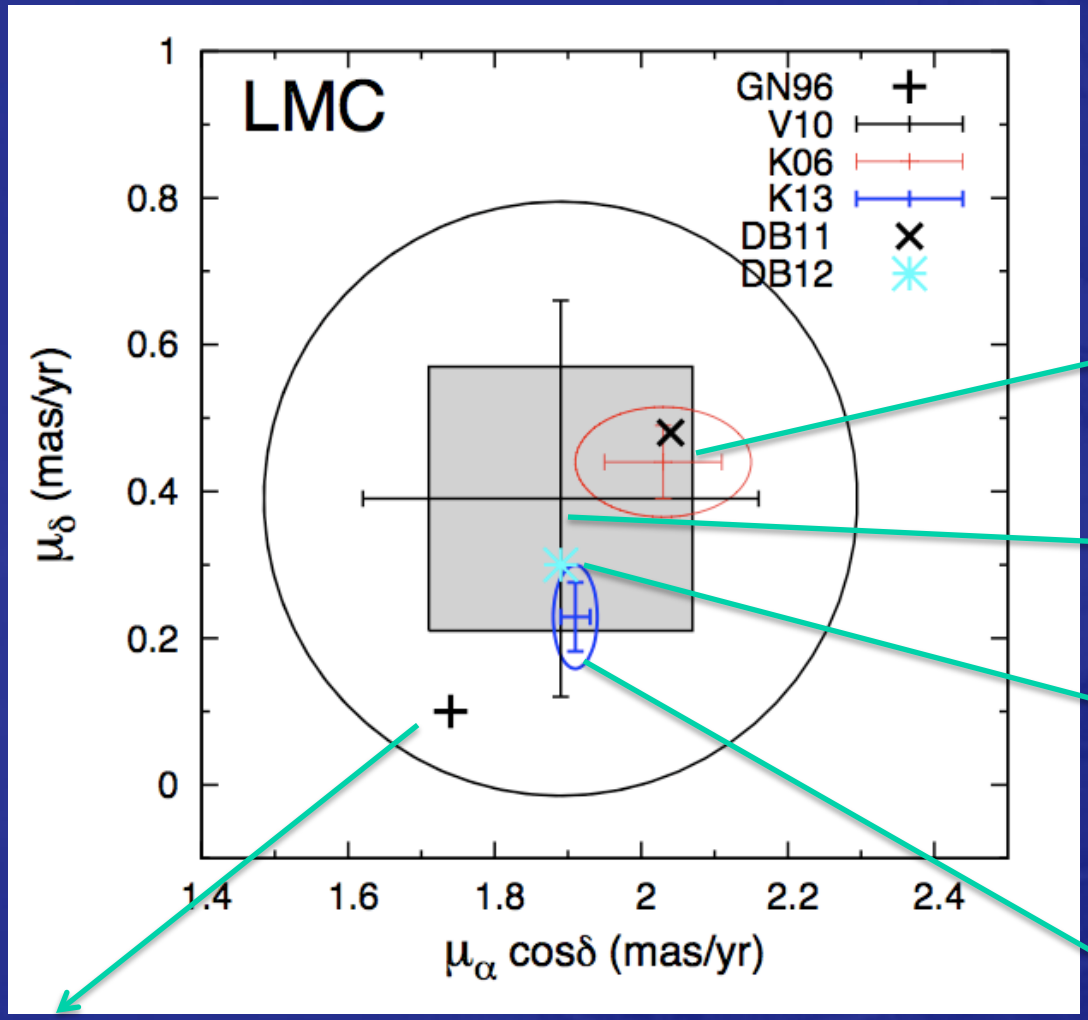
Orbital History: To Circumnavigate or Not



"Very" old orbit – cca 1990

"New" orbit: HST-based, Kallivayalil et al 2006

Orbital History: Proper Motions ~ 2013



HST 2006 – first infall

Vieira 2010- ground-based

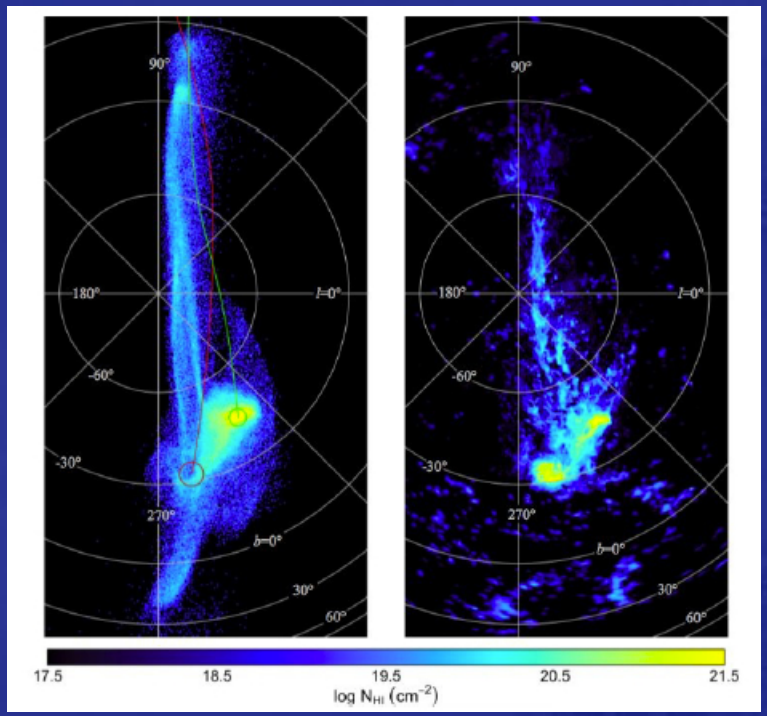
Diaz & Bekki 2012 – best model

HST 2013 –one or two previous peri passage(s)

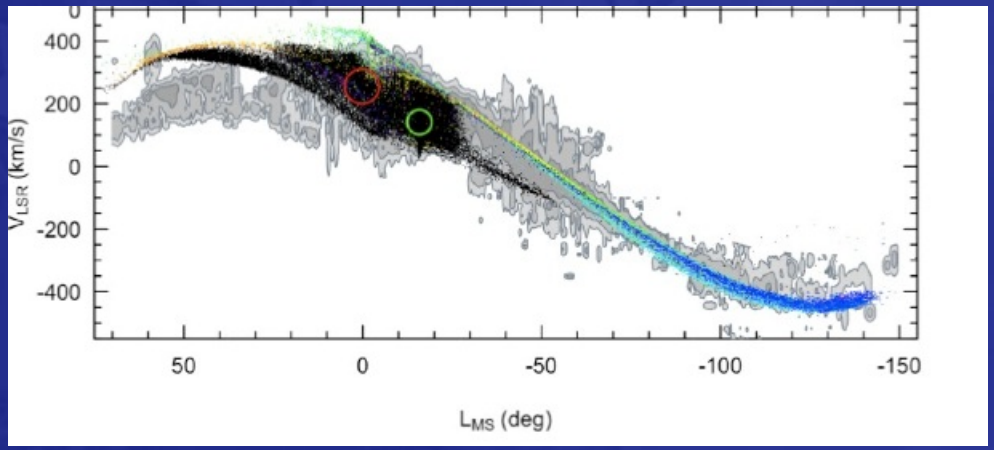
"Very" old work: bound orbits

Orbital History: Modelling in a Nutshell

Morphology of the Magellanic Stream: LA most difficult



Kinematics of the Magellanic Stream: LA most discrepant



Diaz & Bekki 2012,
Nidever et al. 2010

Orbital History: Final Remarks

- MW mass is critical: a change from 1 to 2 10^{12} $M_{\odot}$ changes the outcome from 1 to 2 pericenter passages.

- LMC and SMC masses !

- Accurate modeling – live MW and Clouds potentials to account for dynamical evolution; must include hydrodynamics.

See review by D'Onghia & Fox – ARAA 2015

Orbital History: Final Remarks

One critical piece of information is missing!

Orbital History: Final Remarks

One critical piece of information is missing!

Direct distances

Distances to the Magellanic Stream

Gas: kinematical distance; an estimate of 20 kpc for a cloud HVC 306-2+230 in the LA which appears to interact with the Galactic disk (McClure-Griffiths et al. 2008).

Stars: direct distance; but no stars known, except stars in the Bridge (young: Irwin et al. 1990, intermediate+old: e.g., Noel et al. 2015) which reflect the recent (100-200Myr) collision between the Clouds.

Distances to the Magellanic Stream

Gas: kinematical distance; an estimate of 20 kpc for a cloud HVC 306-2+230 in the LA which appears to interact with the Galactic disk (McClure-Griffiths et al. 2008).

Stars: direct distance; but no stars known, except stars in the Bridge (young: Irwin et al. 1990, intermediate+old: e.g., Noel et al. 2015) which reflect the recent (100-200Myr) collision between the Clouds. Are there any more like these? And where?

OB-type Star Search: A Cross-Catalog Approach

Photometry

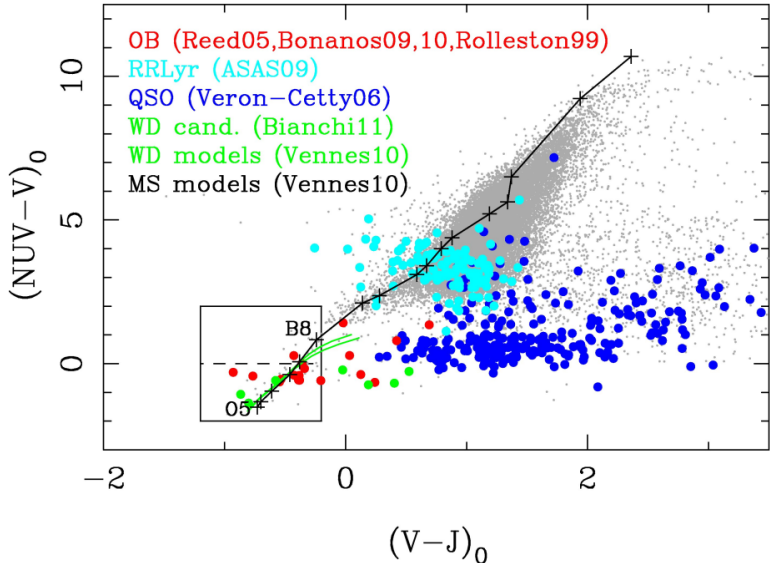
GALEX DR5 (Bianchi et al. 2011)	**NUV**	all-sky 1771-2831Å, λ_{eff} = 2315.7Å, NUV_{lim} = 20.8
2MASS (Skrutskie et al. 2006)	**J**	all-sky (also made use of 6x2MASS)
APASS (Henden et al. 2011)	**V**	AAVSO all-sky survey (B,V, g, r, i) $10 < V < 17.0$, $\varepsilon_V \sim 0.06$ mag

Astrometry/Photometry

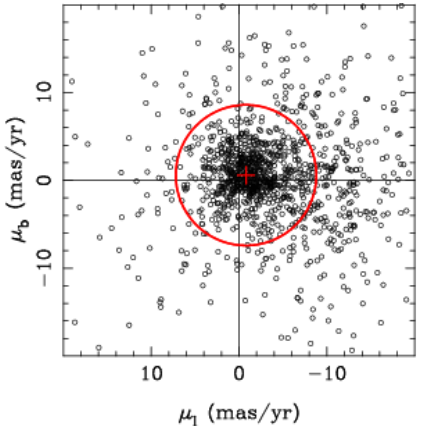
SPM4 (Girard et al. 2011)	**μ, V**	$\delta < -20^o$, $V_{lim} \sim 17.5$ $\varepsilon_V \sim 0.05$ mag

OB-type Star Search: A Cross-Catalog Approach

Color selection



Proper-motion selection



Final Selection Criteria

$\Delta\mu \leq 8.0$ mas/yr

$-2.0 \leq (NUV\text{-}V)_0 \leq 0.0$

$-1.2 \leq (V\text{-}J)_0 \leq -0.2$

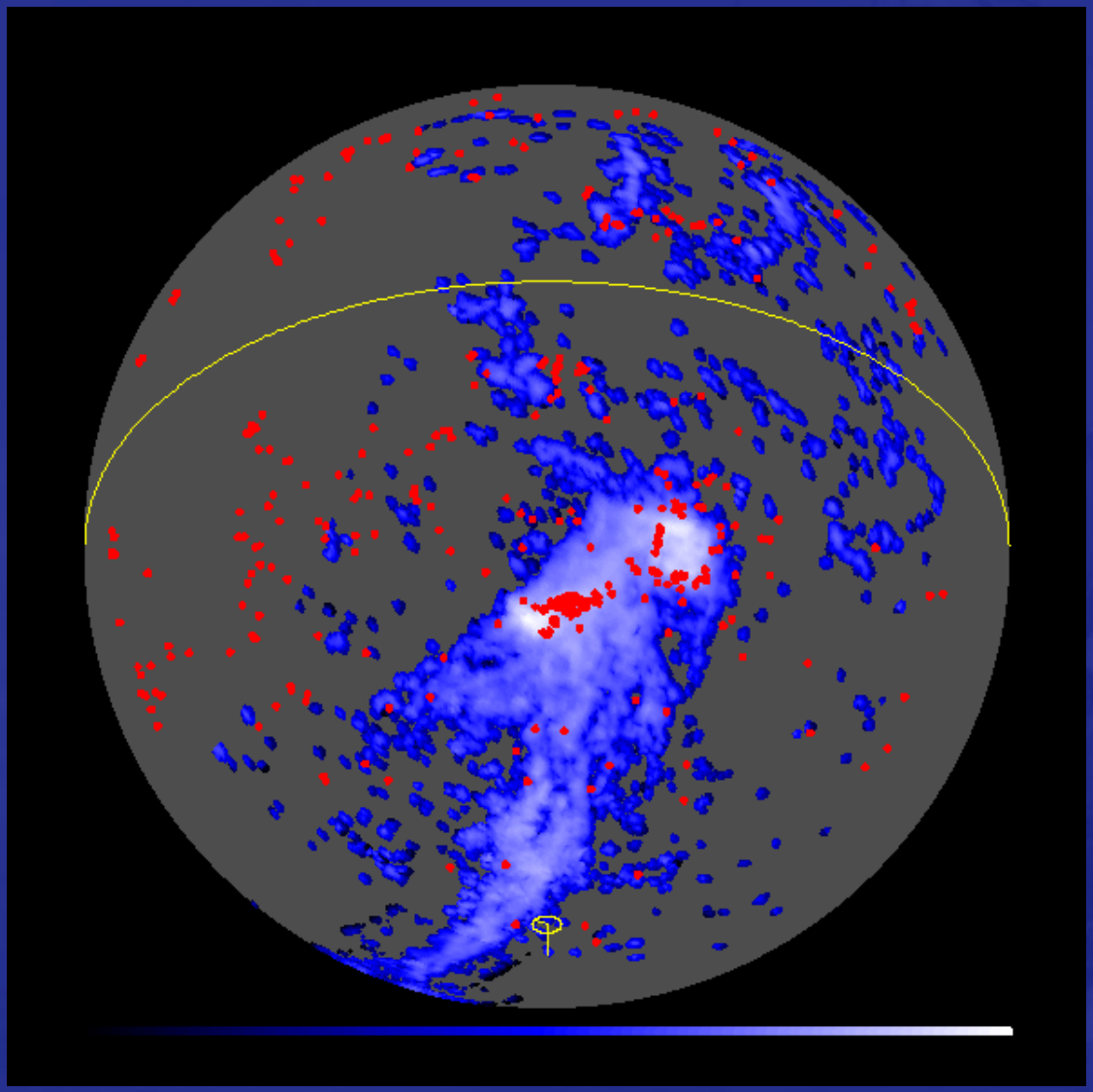
$13.0 \leq V_0 \leq 17.0$

($\varepsilon_\mu \leq 4.0$ mas/yr)

($\varepsilon_{NUV} \leq 0.10$, $\varepsilon_J \leq 0.15$)

$E(B\text{-}V) \leq 0.5$

OB-type Star Search: A Cross-Catalog Approach



Results:

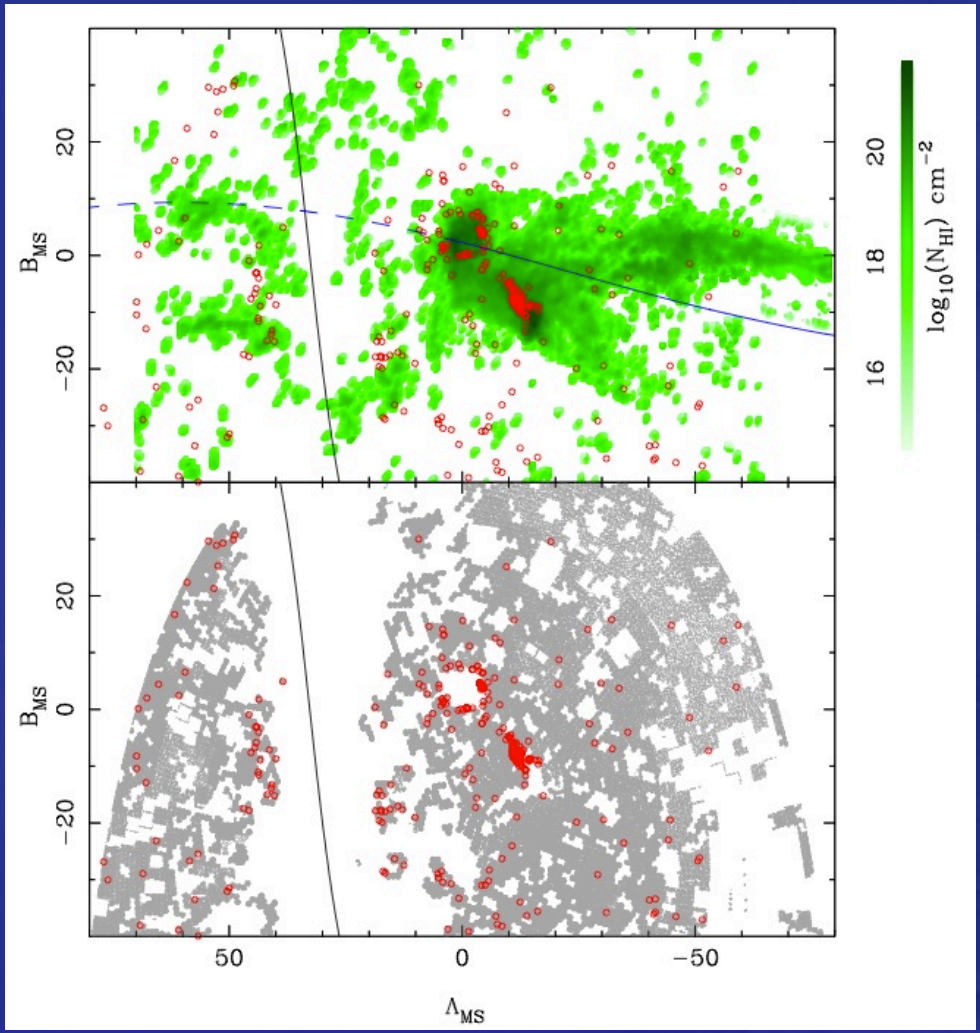
567 OB-type star candidates (from an initial ~4 million)

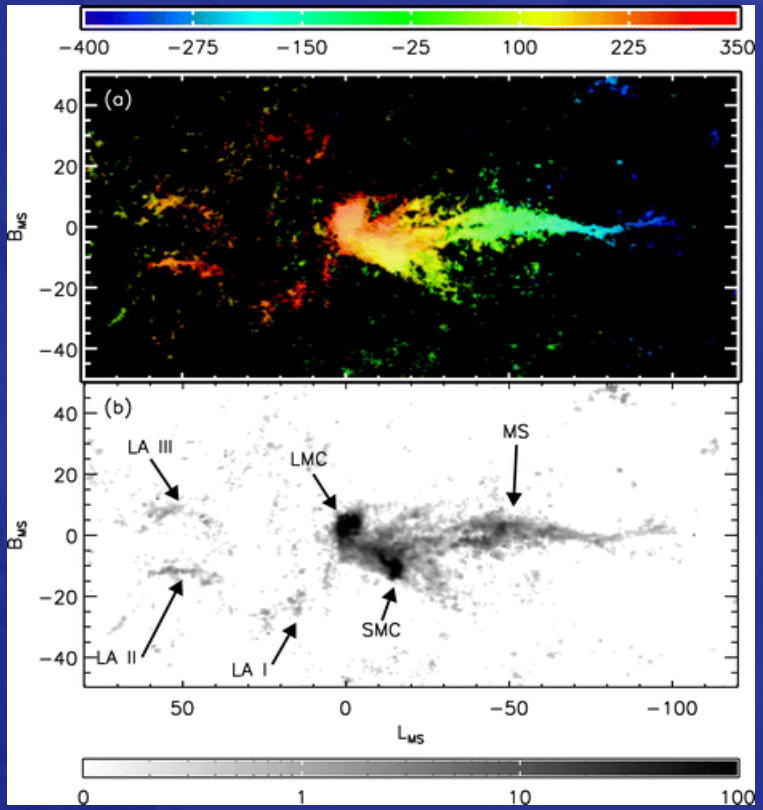
Casetti-Dinescu et al. 2012

HI density

(Nidever et al. 2010)

OB-type Star Search: A Cross-Catalog Approach





HI data - Nidever et al. 2008

The Team

Lan Zhang
Univversidad de Chile, Santiago, Chile, and NAOC, Beijing, China

Christian Moni Bidin
Univ. Catolica del Norte, Antofagasta, Chile

Rene Mendez
Universidad de Chile Santiago, Chile

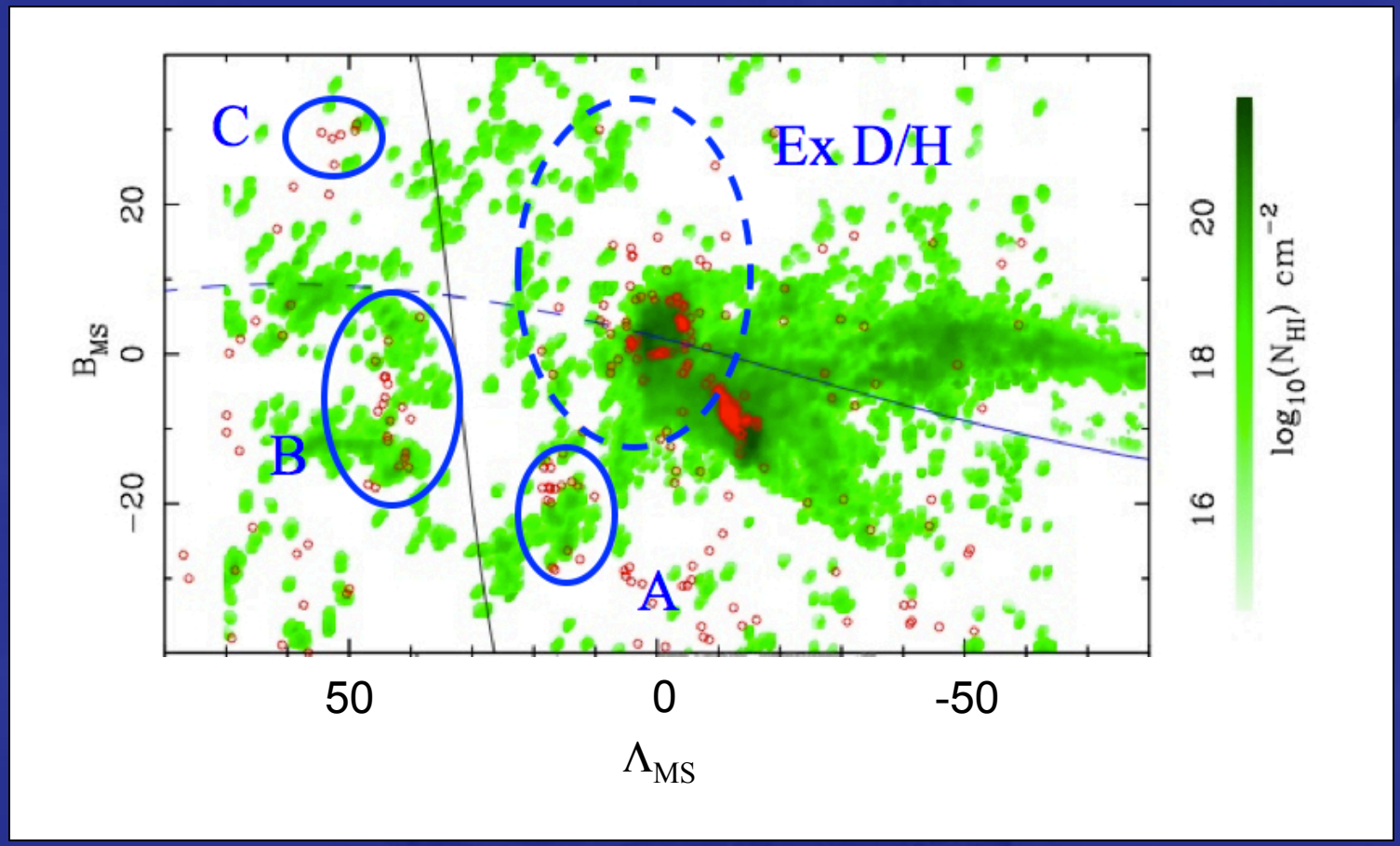
Terry Girard
Yale University

Kathy Vieira
CIDA Merida, Venezuela

Vladimir Korchagin
Southern Federal University Rostov-on-Don, Russia

Bill van Altena
Yale University

OB-type Star Search: Spectroscopic Target Selection



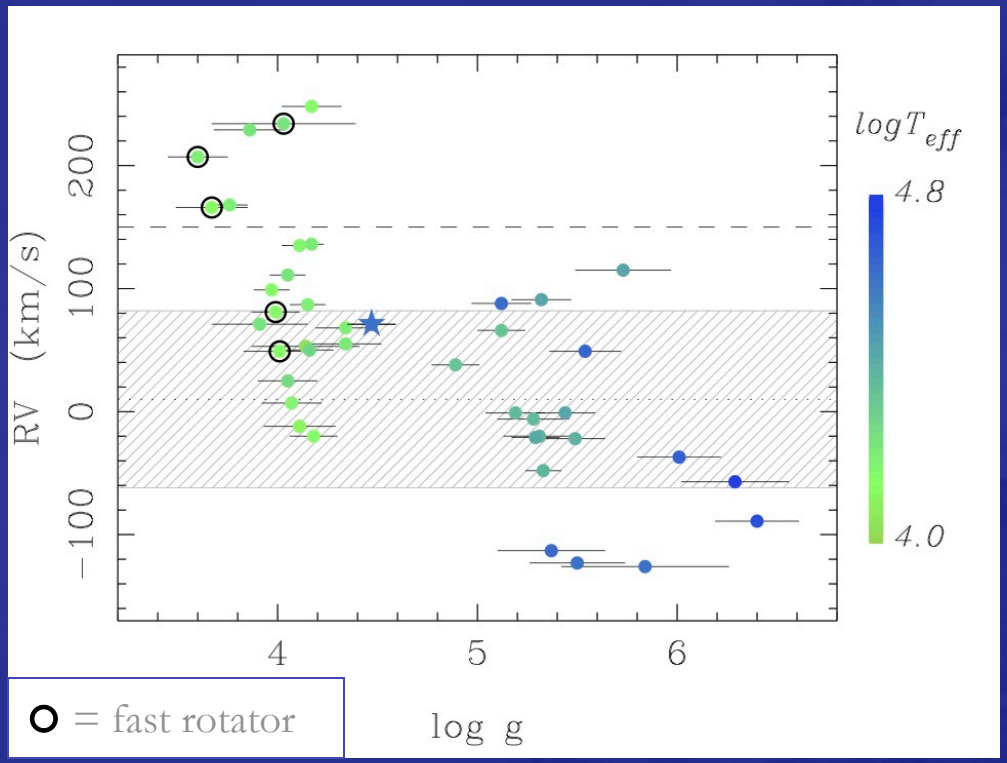
HI data - Nidever et al. 2008

OB-type Stars: Spectroscopic Follow-up

Twin 6.5m Magellan telescopes: Baade and Clay Las Campanas, Chile

Date	Instrument	Specs	# of stars	Notes
Apr 2013	Baade IMACS	1A; 3700-5200A	42	LA; clumps A, B, C Published - 2014
Apr 2014	Clay MIKE	0.1A; 3200-5000A 0.2A; 4900-10000A	8	LA: Subsample from A,B
Jan/Feb 2015	Baade IMACS	1A; 3700-5200A	31	LMC extended disk/halo
Apr 2016	Clay MIKE	0.1A; 3200-5000A 0.2A; 4900-10000A	9	LA: Subsample from A,B

OB-type Stars in the Leading Arm: Spectroscopic Findings of the Intermediate Resolution Run

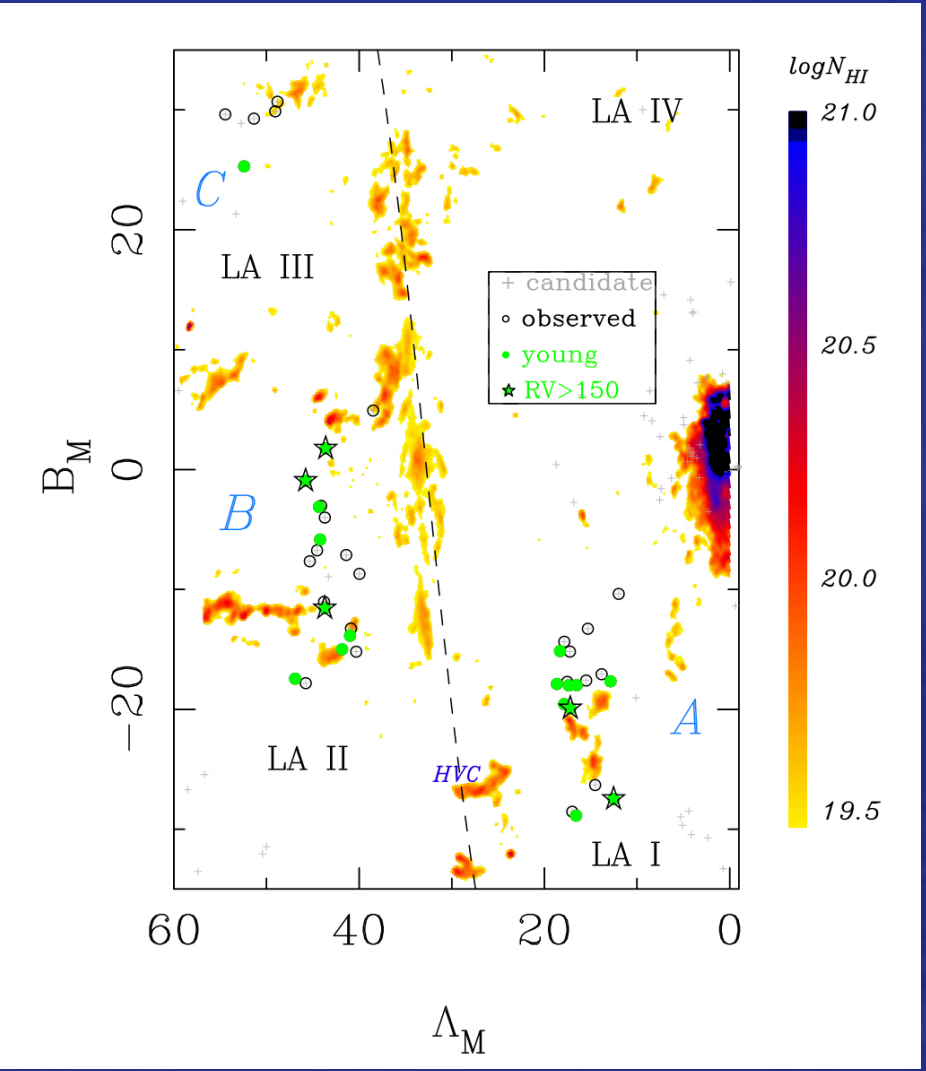


Found 19 young, massive stars, including...

-five fast rotators
-five stars with RVs > 150 km/s consistent with Leading Arm membership;

Casetti-Dinescu et al. 2014

OB-type Stars in the Leading Arm: Spectroscopic Findings of the Intermediate Resolution Run



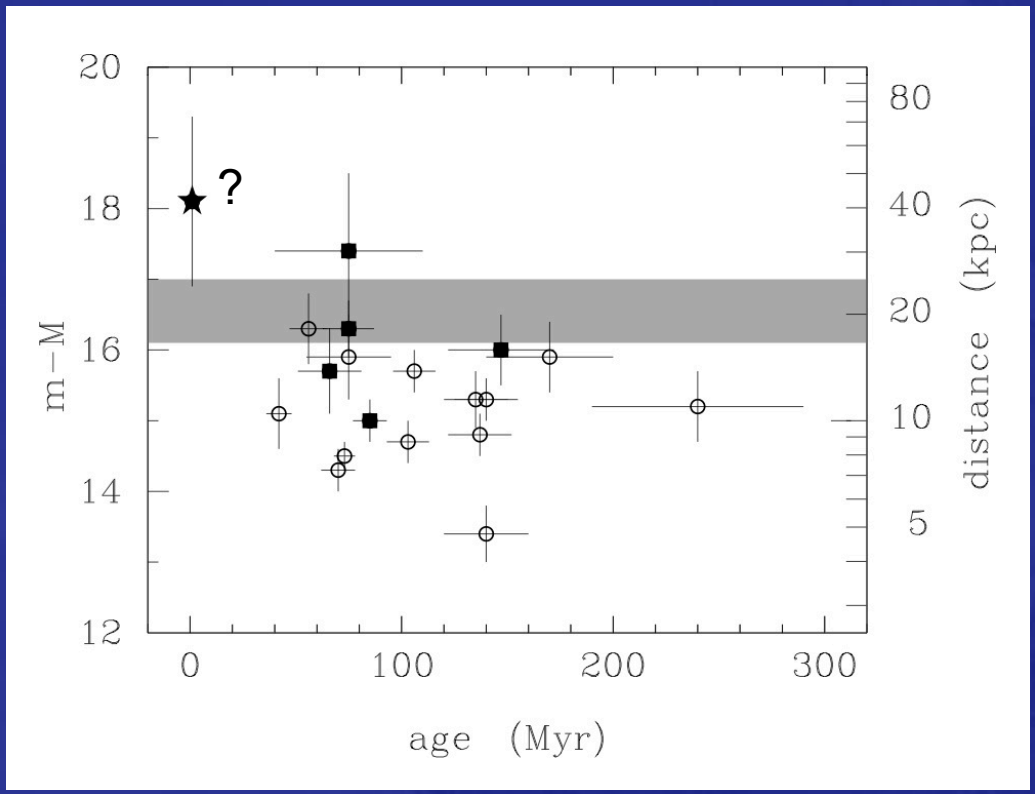
Found 19 young, massive stars above and below the Galactic plane in regions LA I and LA II-III.

five with RVs > 150 km/s consistent with Leading Arm membership;

Casetti-Dinescu et al. 2014

HI data – GASS (150-450 km/s)

OB-type Stars in the Leading Arm: Spectroscopic Findings of the Intermediate Resolution Run



Gray band is kinematical distance to a particular high-velocity cloud in the LA. (McClure-Griffiths et al. 2008)

■ = RV>150km/s, ★ = O6 star

For the five young, LA members (RV>150 km/s)...

Distances are ~10-30 kpc from the Sun

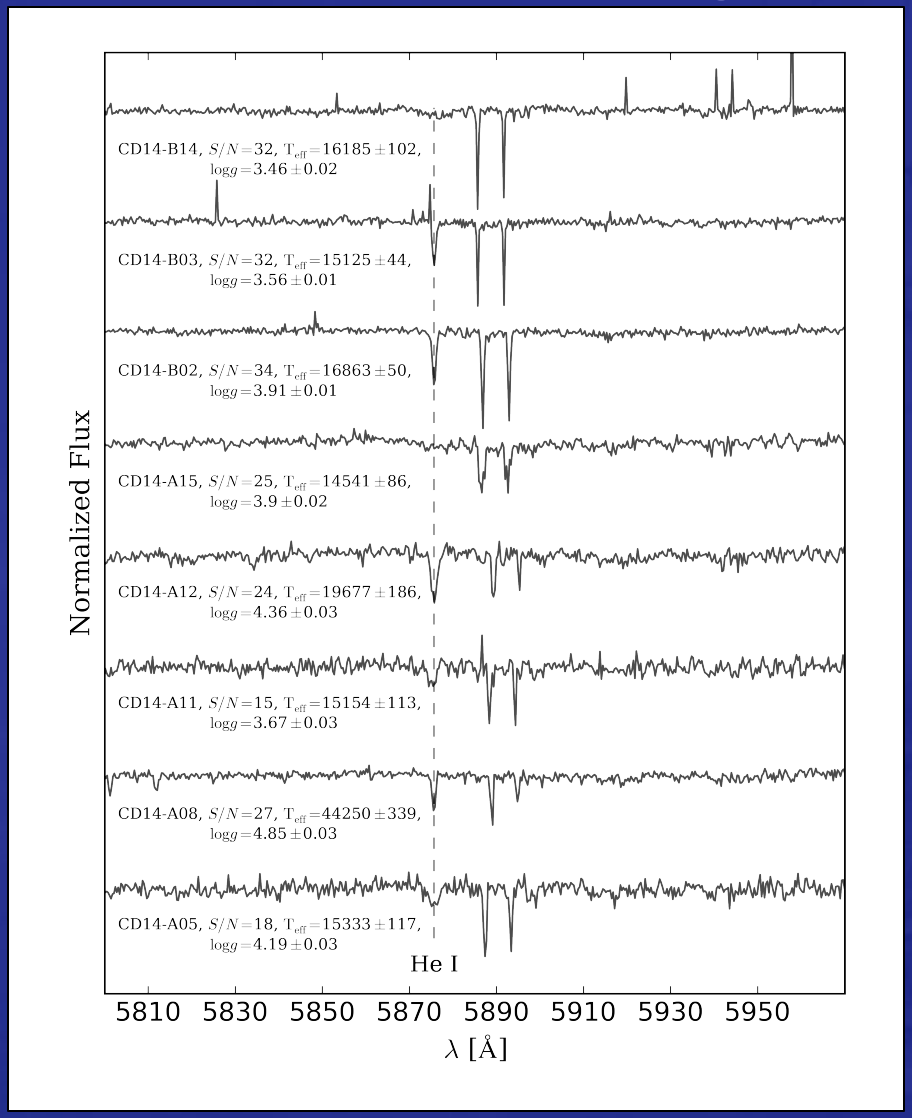
Ages are ~60 - 140 Myr, i.e. recently formed.

Casetti-Dinescu et al. 2014

OB-type Stars: Spectroscopic Follow-up

Date	Instrument	Specs	# of stars	Notes
Apr 2013	Baade IMACS	1A; 3700-5200A	42	LA; clumps A, B, C Published - 2014
Apr 2014	Clay MIKE	0.1A; 3200-5000A 0.2A; 4900-10000A	8	LA: Subsample from A,B
Jan/Feb 2015	Baade IMACS	1A; 3700-5200A	31	LMC extended disk/halo
Apr 2016	Clay MIKE	0.1A; 3200-5000A 0.2A; 4900-10000A	9	LA: Subsample from A,B

OB-type Stars in the Leading Arm: Spectroscopic Findings of the High Resolution Run



-8 stars: 3 above the Galactic plane and 5 below the plane

-stellar parameters: Teff, logg, He abund, vsini

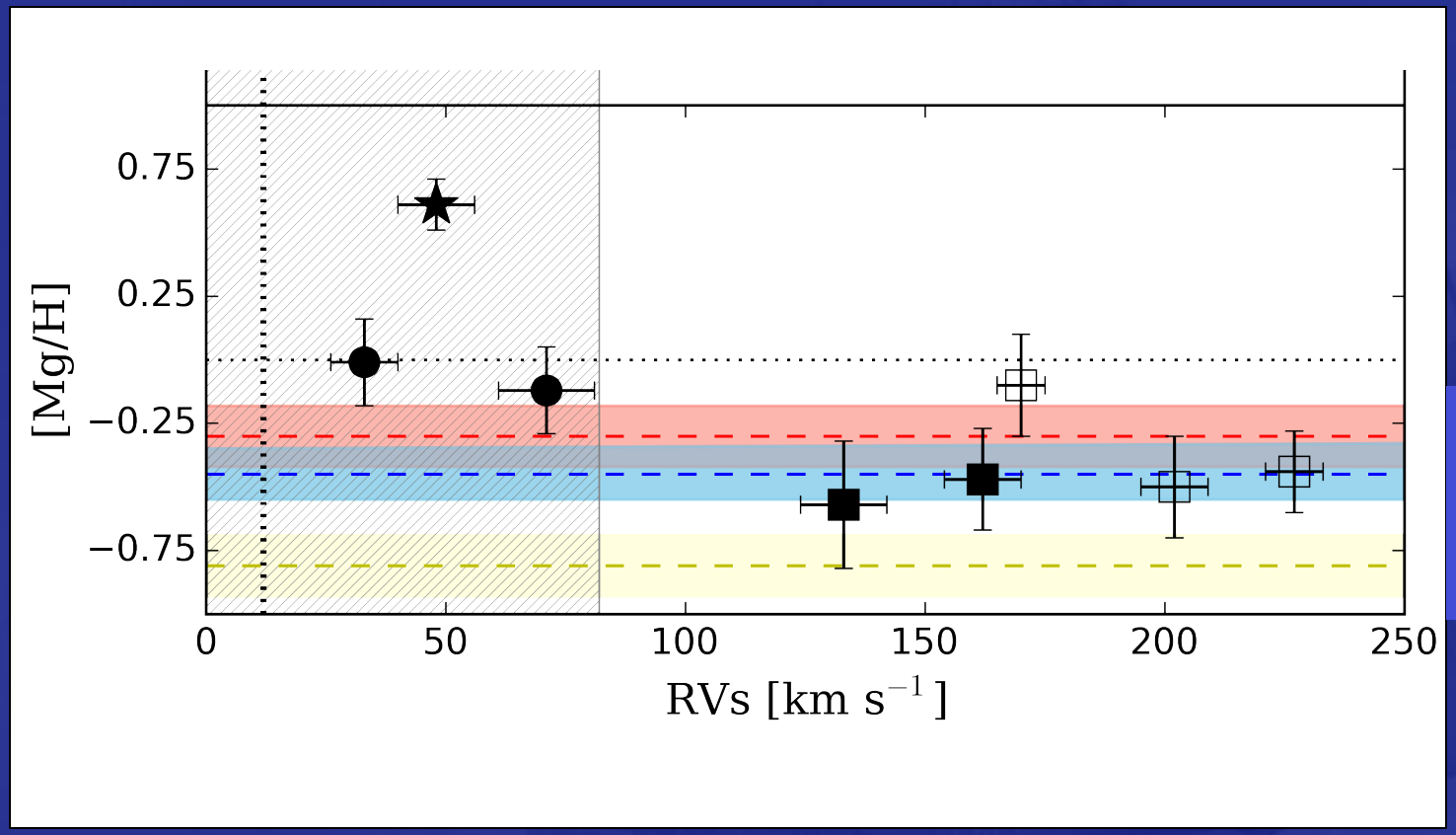
-abundances of He, C, N, O, Mg, Si, S.

-determine RVs, distances and ages

- Method: fit observed spectra with synthetic spectra from libraries for O and B-type stars (Lanz & Hubeny 2003, 2007).

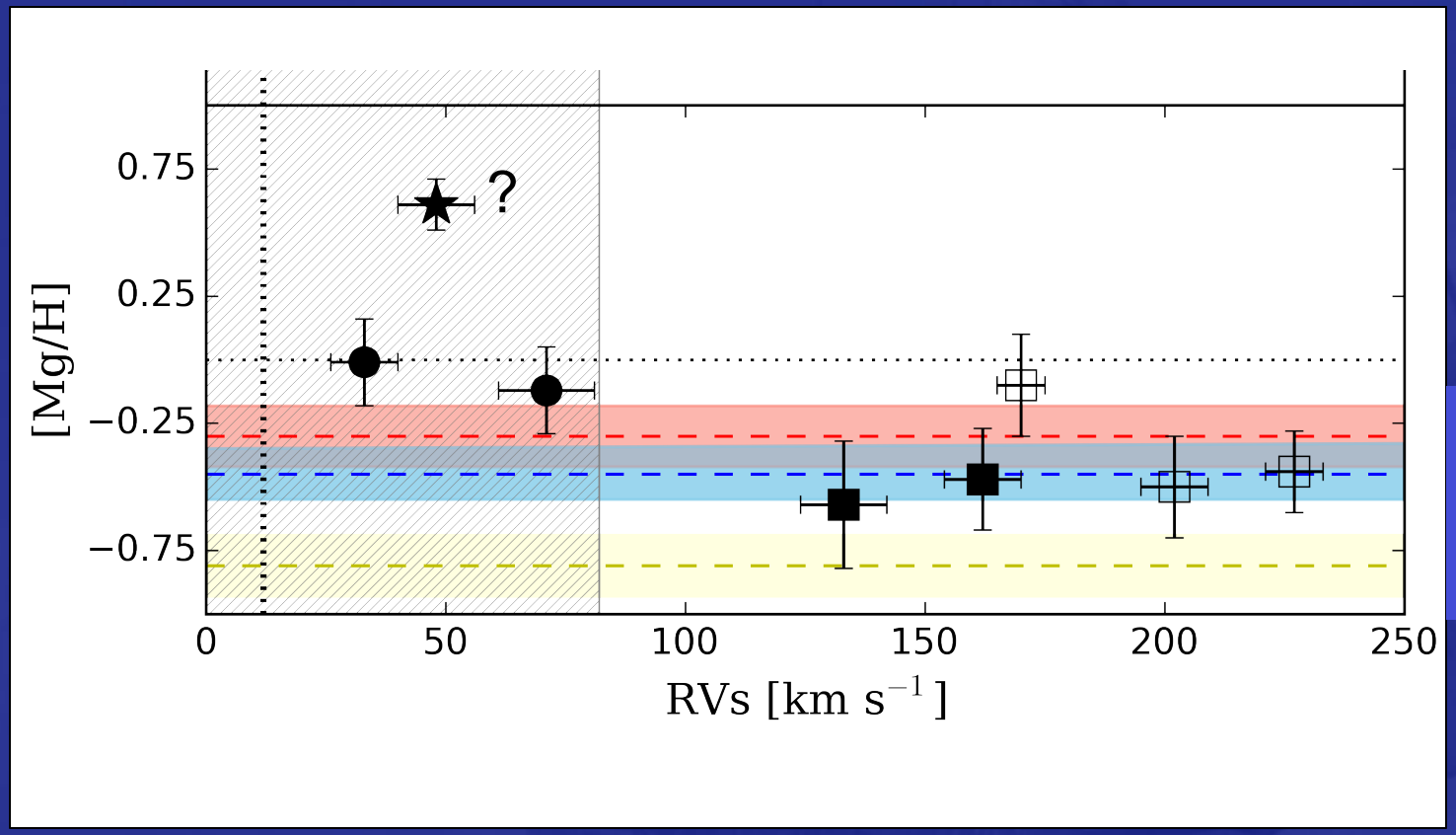
Zhang, L. et al. 2016, submitted

OB-type Stars in the Leading Arm: Spectroscopic Findings of the High Resolution Run



Zhang, L. et al. 2016, submitted

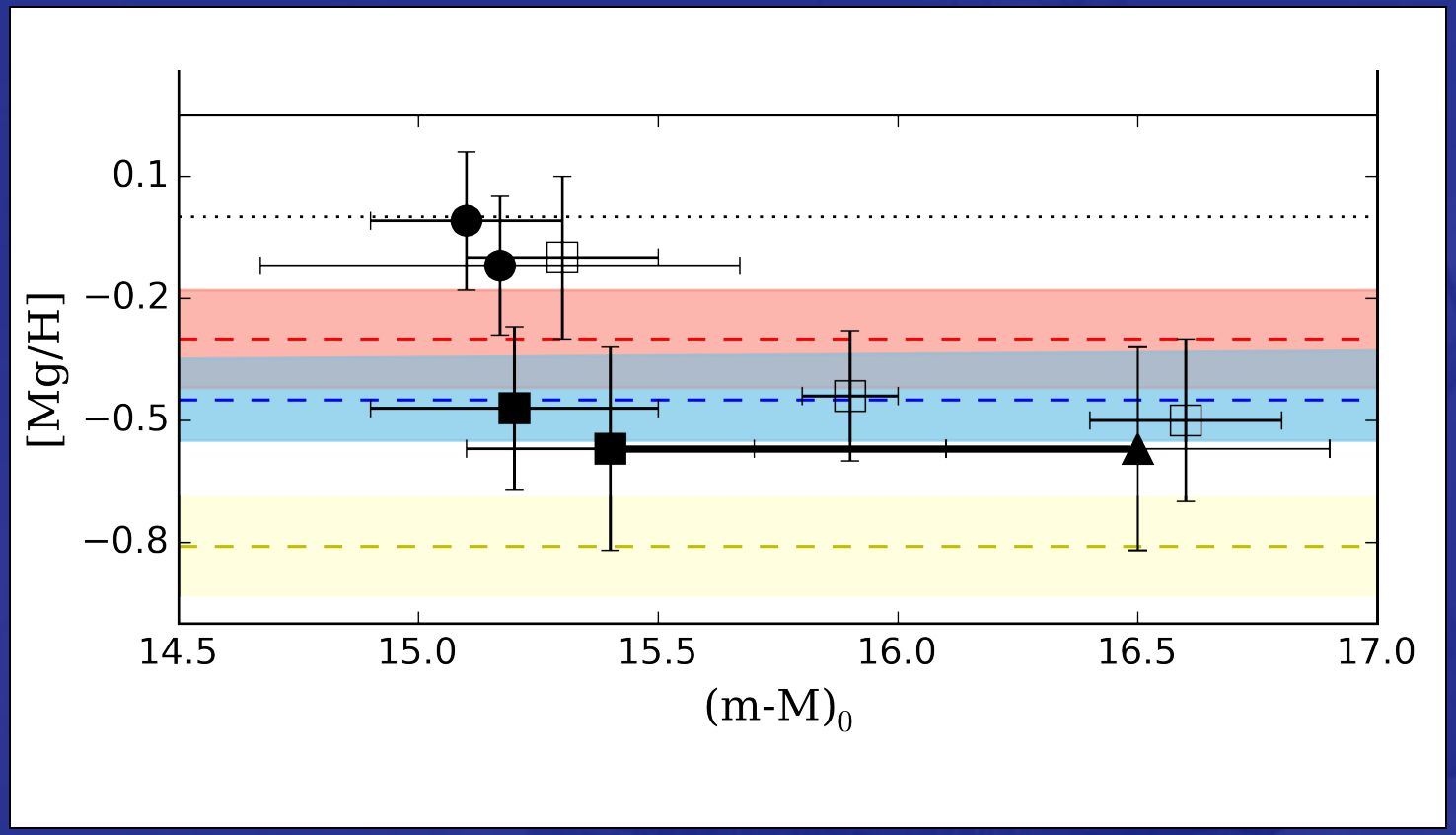
OB-type Stars in the Leading Arm: Spectroscopic Findings of the High Resolution Run



<[Mg/H]> = -0.07±0.06 -0.42±0.16

Zhang, L. et al. 2016, submitted

OB-type Stars in the Leading Arm: Spectroscopic Findings of the High Resolution Run



Zhang, L. et al. 2016, submitted

Summary:

- 18 young (60-140 Myr), massive stars have been found in the Leading Arm of the gaseous Magellanic Stream, above and below the Galactic plane. *Keep in mind areal incompleteness of the survey (GALEX area coverage)!*

- 7 stars RV > 130 km/s, 5 stars RV > 150 km/s.

- heliocentric distances of kinematical LA members range between 10 and 30 kpc.

- average Mg abundance of LA kinematical members is [Mg/H]= -0.42 ± 0.16 , and of non members is -0.07 ± 0.06.

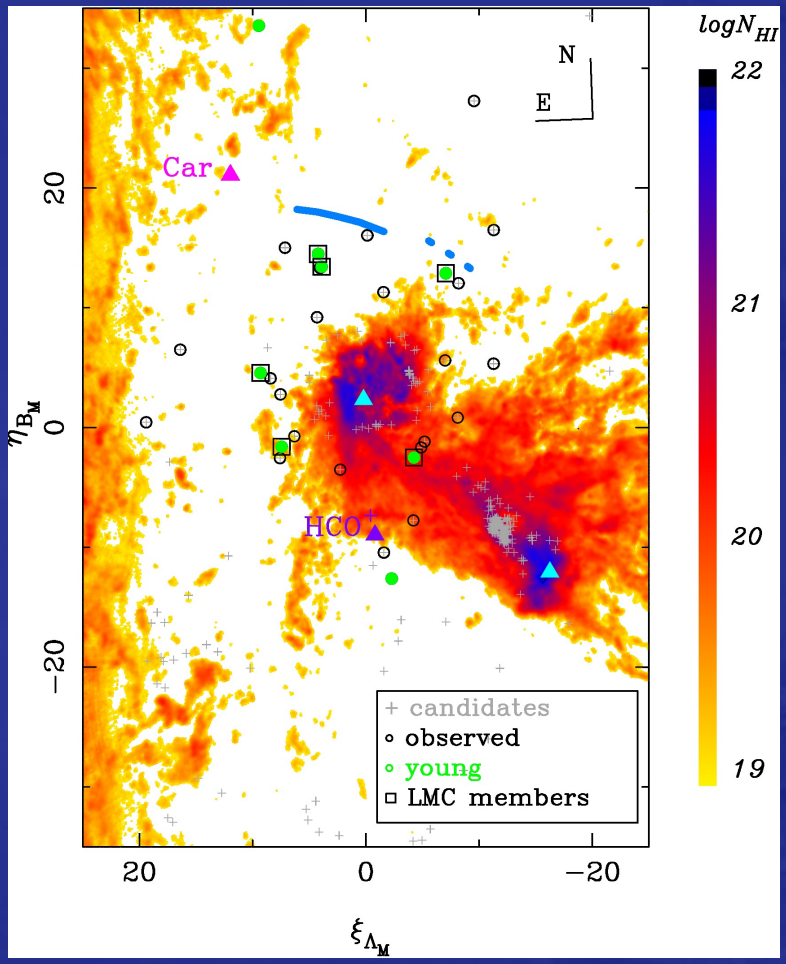
- on average, [Mg/H] of kinematical LA members appears similar to LMC values (as given by NGC 2004).

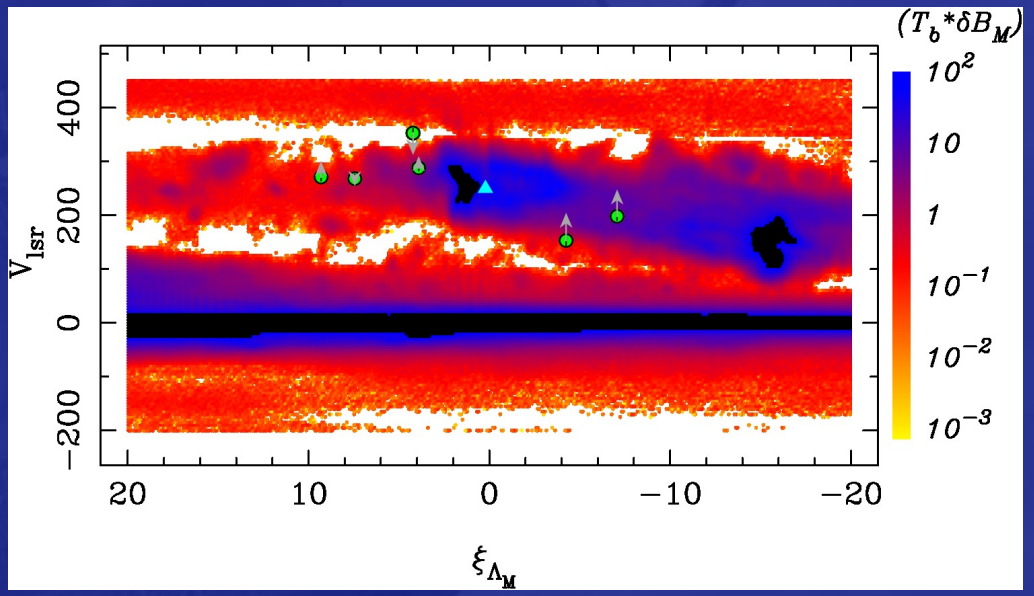
OB-type Stars: Spectroscopic Follow-up

Date	Instrument	Specs	# of stars	Notes
Apr 2013	Baade IMACS	1A; 3700-5200A	42	LA; clumps A, B, C Published - 2014
Apr 2014	Clay MIKE	0.1A; 3200-5000A 0.2A; 4900-10000A	8	LA: Subsample from A,B
Jan/Feb 2015	Baade IMACS	1A; 3700-5200A	31	LMC extended disk/halo
Apr 2016	Clay MIKE	0.1A; 3200-5000A 0.2A; 4900-10000A	9	LA: Subsample from A,B

Preview:

Young stars in the periphery of the LMC !





Stay tuned for more !

Moni-Bidin et al. 2016, (subm.)