

The Magellanic Stream: the 'ram pressure plus collision' scenario

by François Hammer

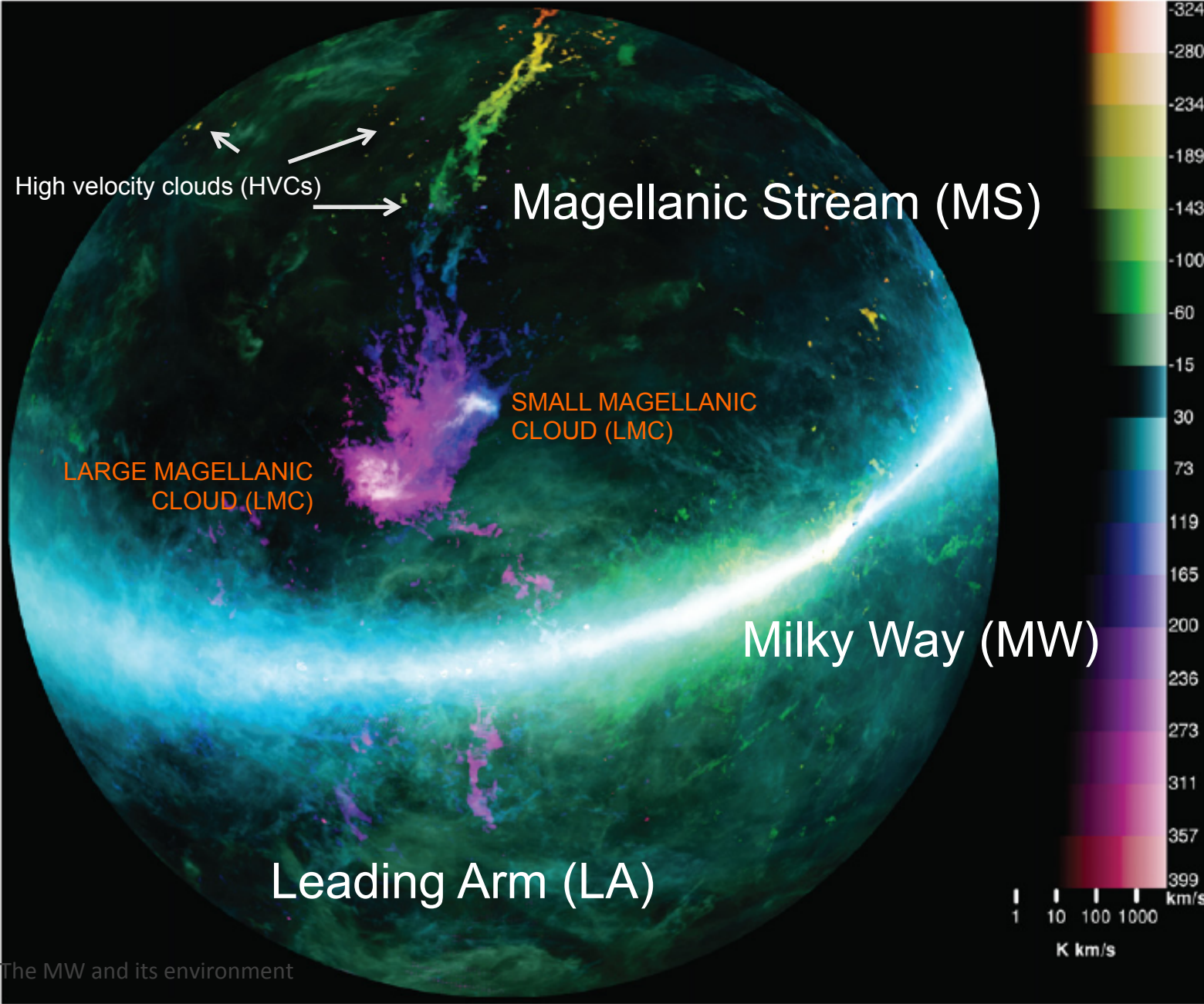


Based on Hammer, Yang, Flores, Puech & Fouquet, 2015, ApJ, 813, 110

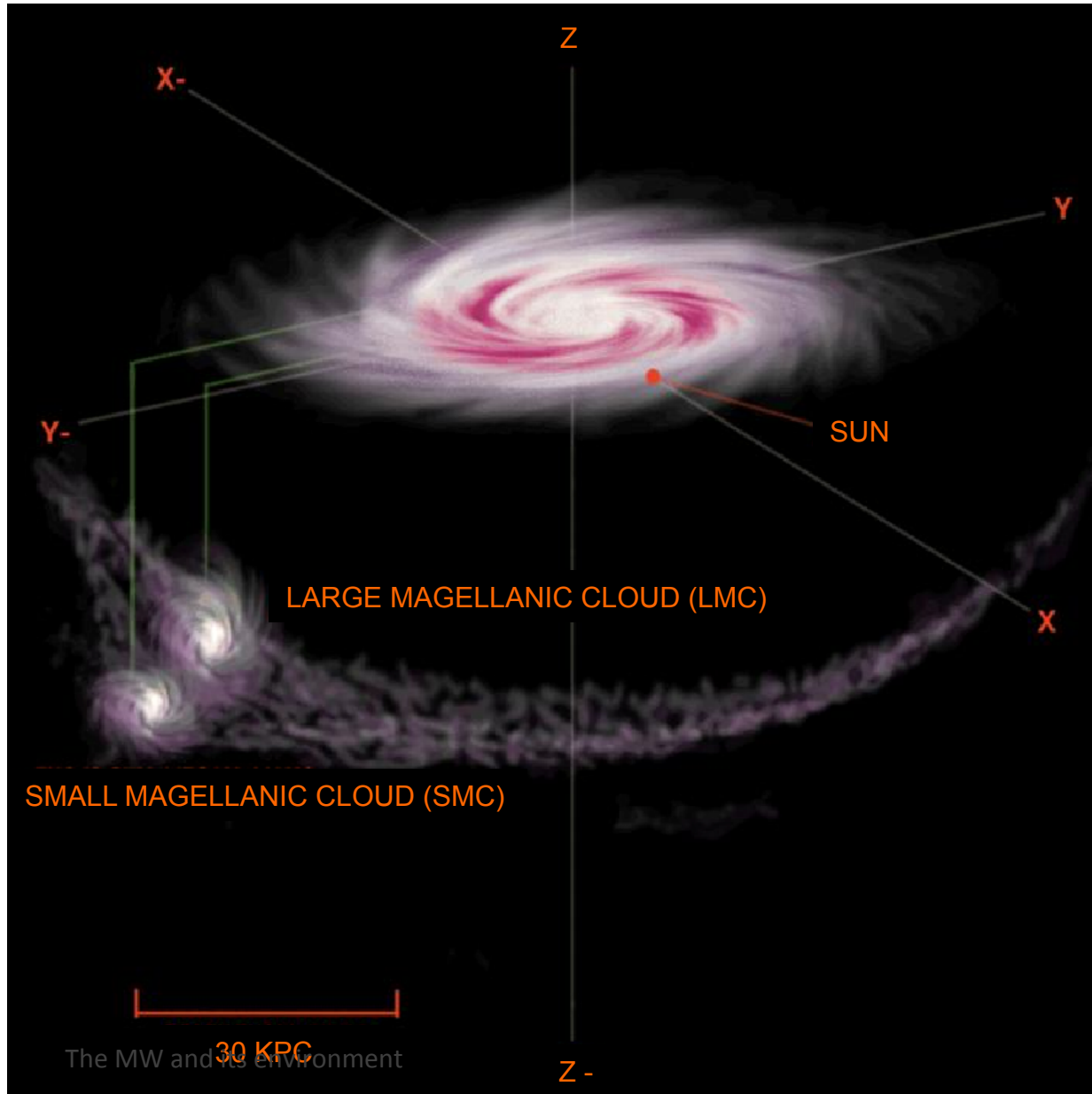
See paper and videos at <http://lia-origins.obspm.fr/images/videos/>

The HI Magellanic Stream: 230° length, with Leading Arm

Southern Hemisphere in HI from GASS

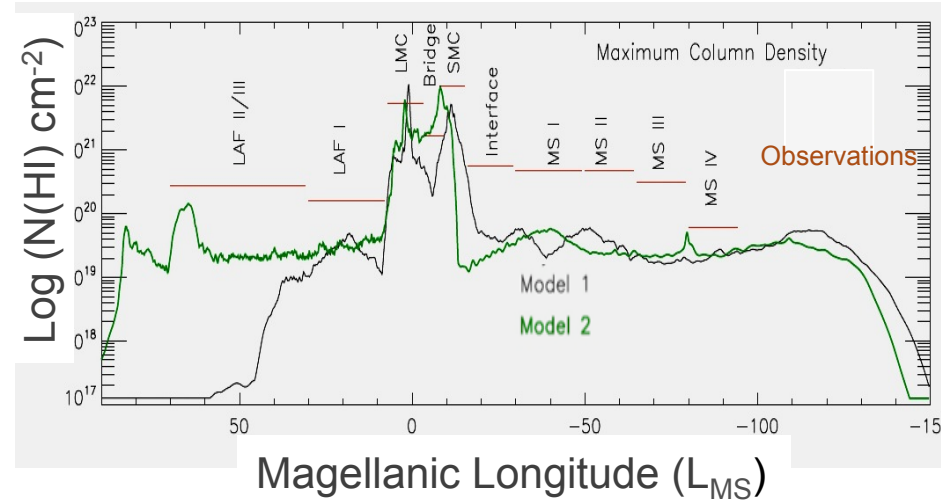
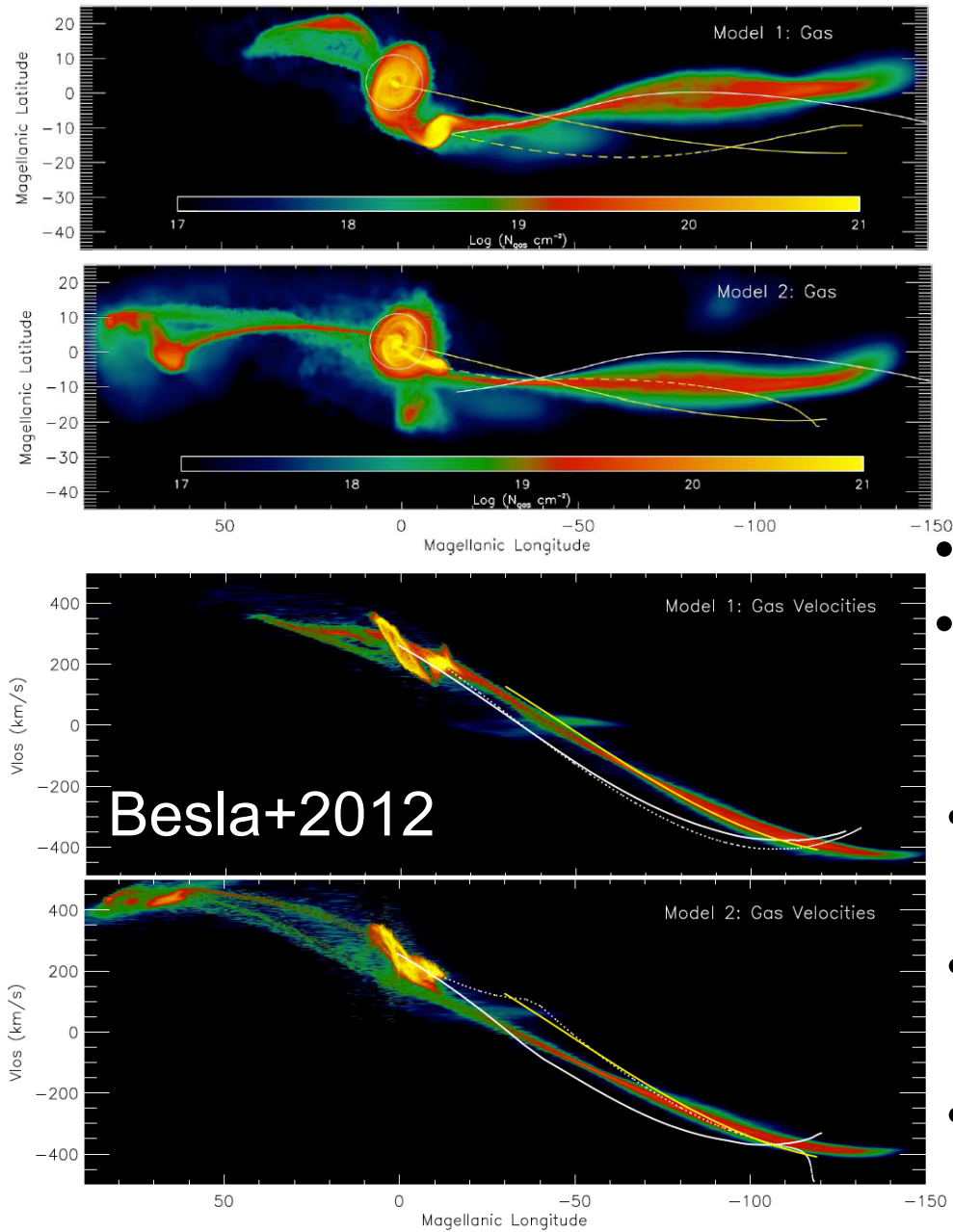


Explanation of the gigantic Magellanic Stream



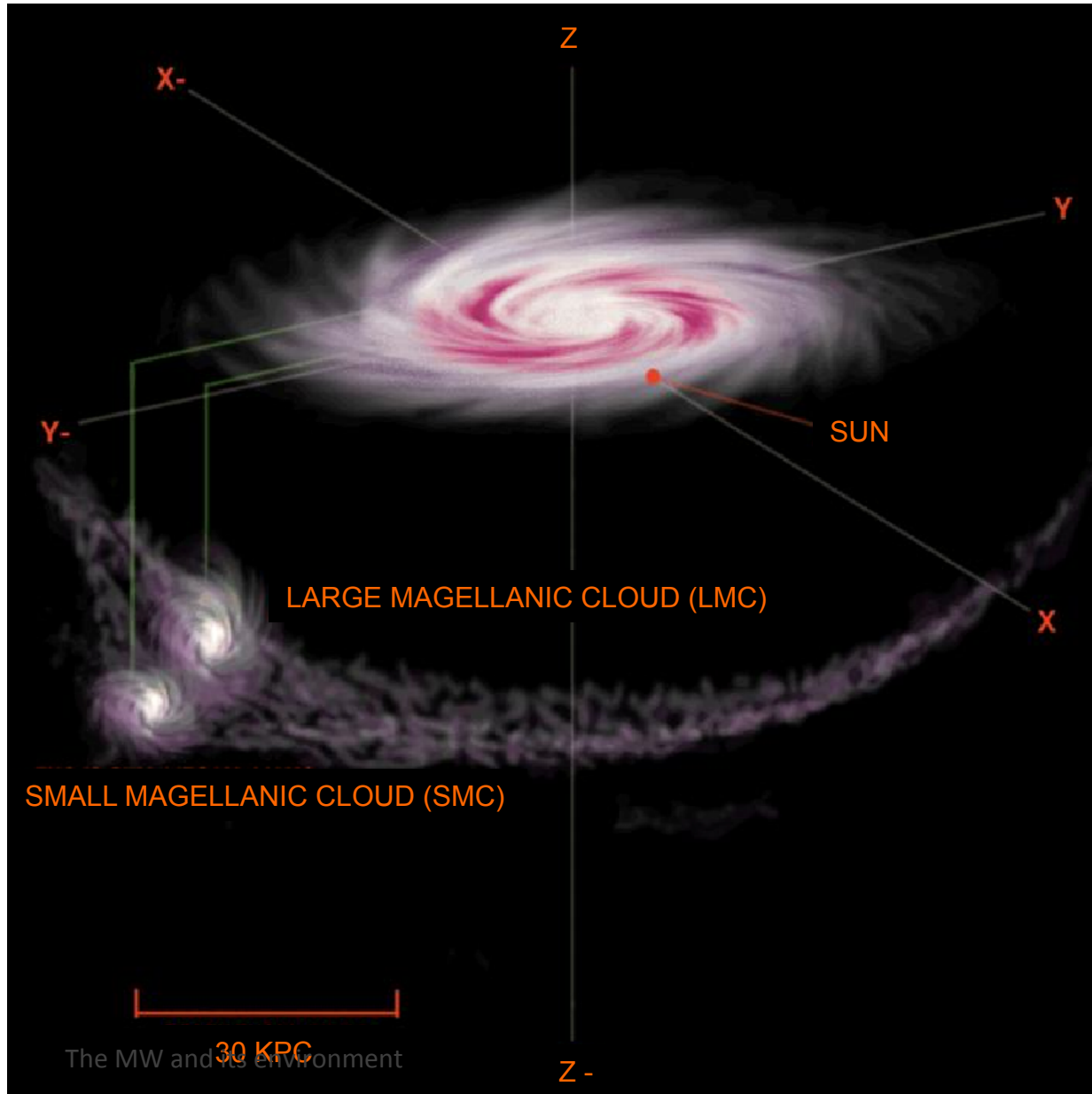
Firstly identified as the MS by Mathewson+74 after detections by van Kuilenburg and Wannier & Wrixon72

The dearth of predictions from tidal models



- Already lack 9/10 of N(HI)
- Could not explain large ionized gas amount ($2 \cdot 10^9 M_{\odot}$, Fox+14)
- Can't explain absence of stars
- Can't explain the filaments
- Could not reproduce the 4 Leading Arm structures

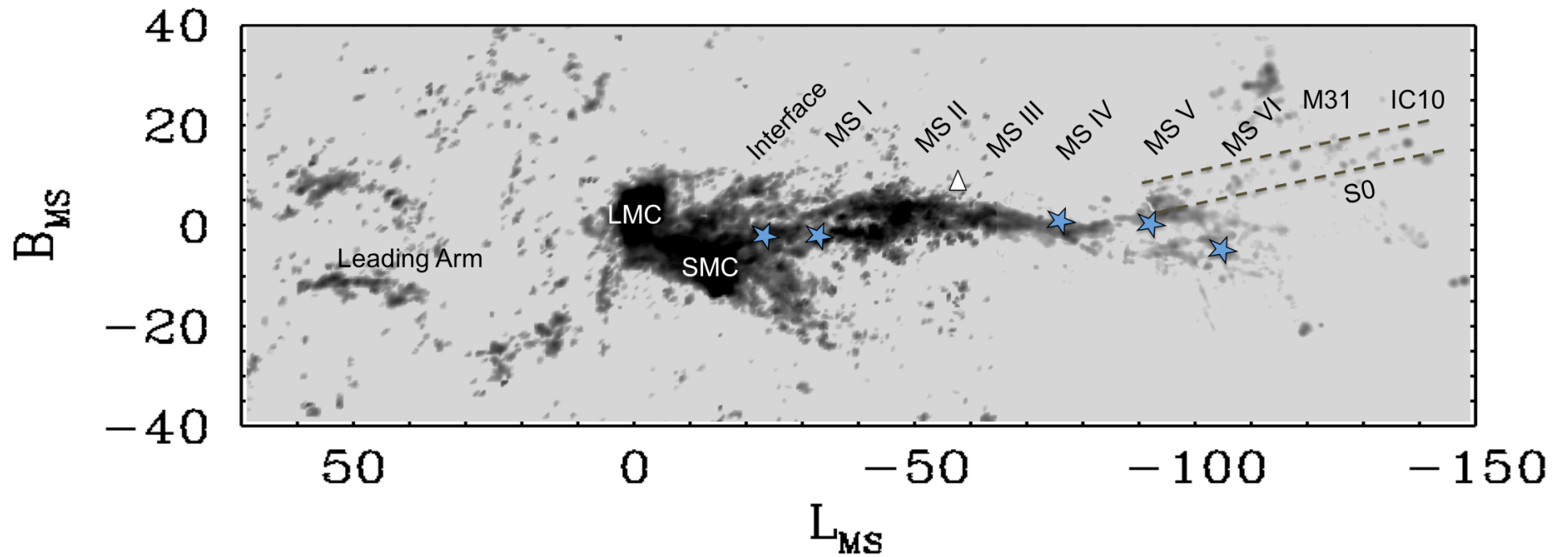
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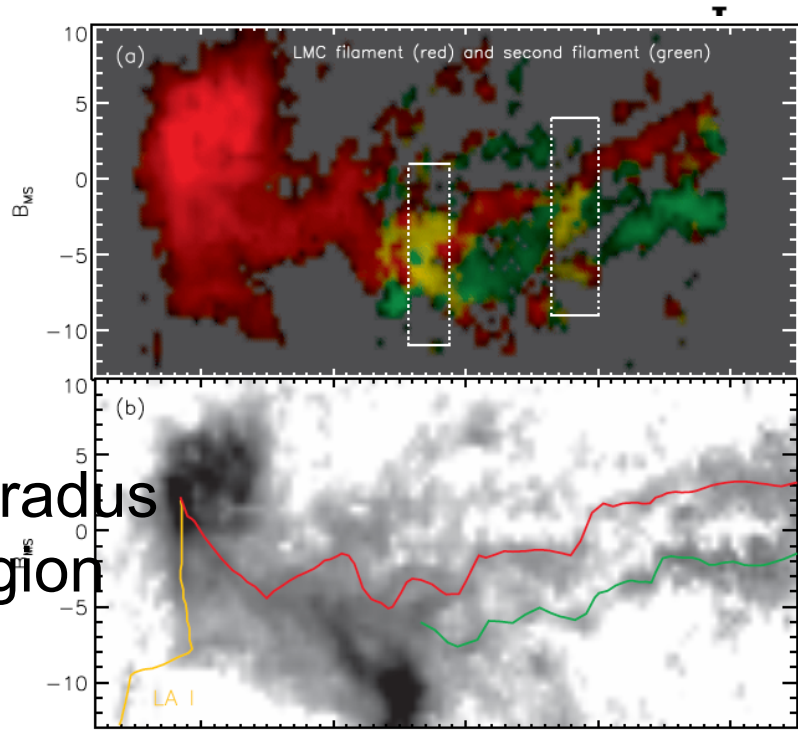
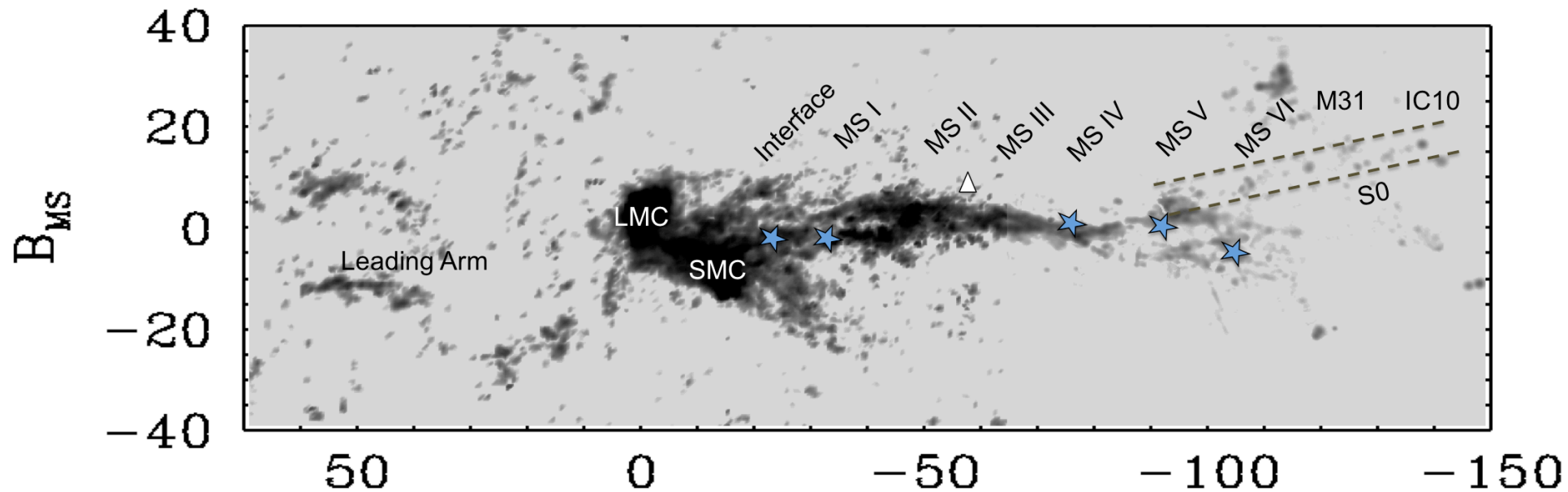
Mathewson (2012): still no satisfactory explanation since 1974

The filamentary structure of the MS



- Filamentary structure of the MS
- DNA-like appearance

Putman+03 and references therein



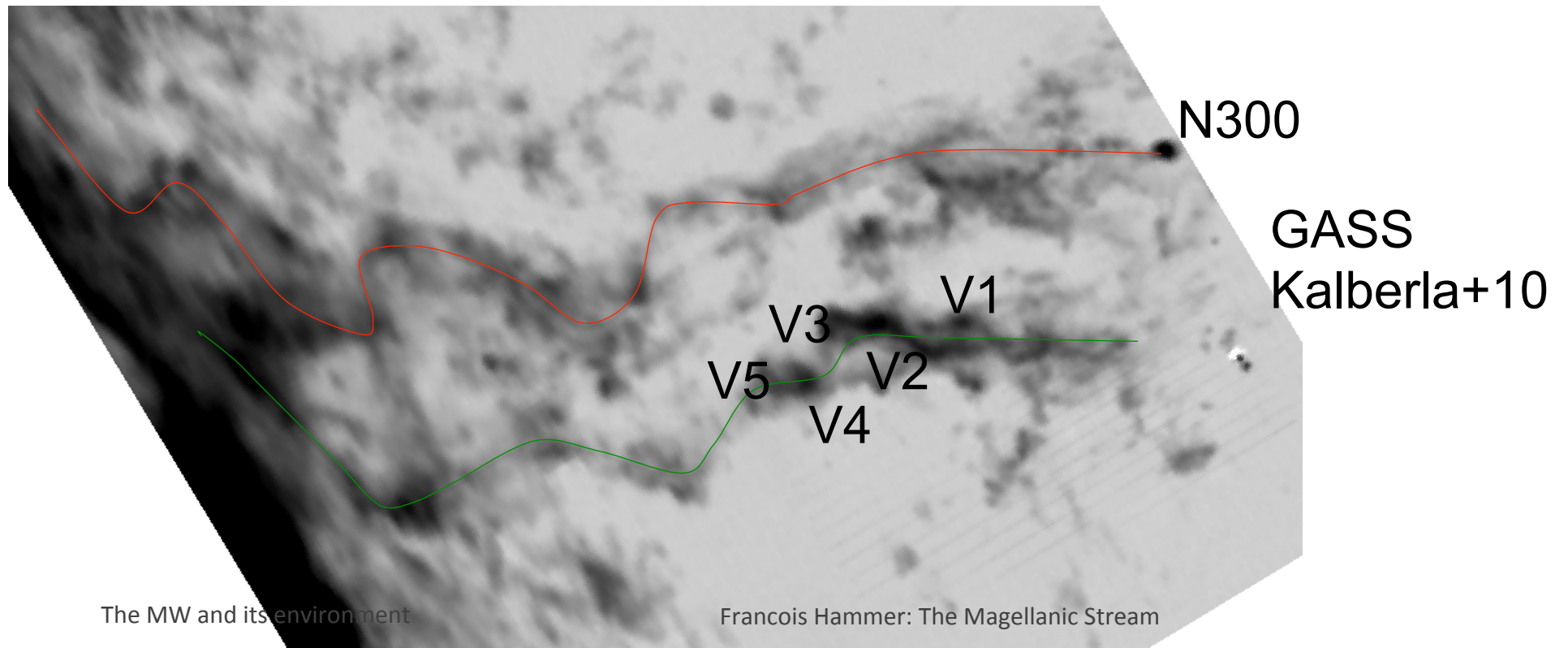
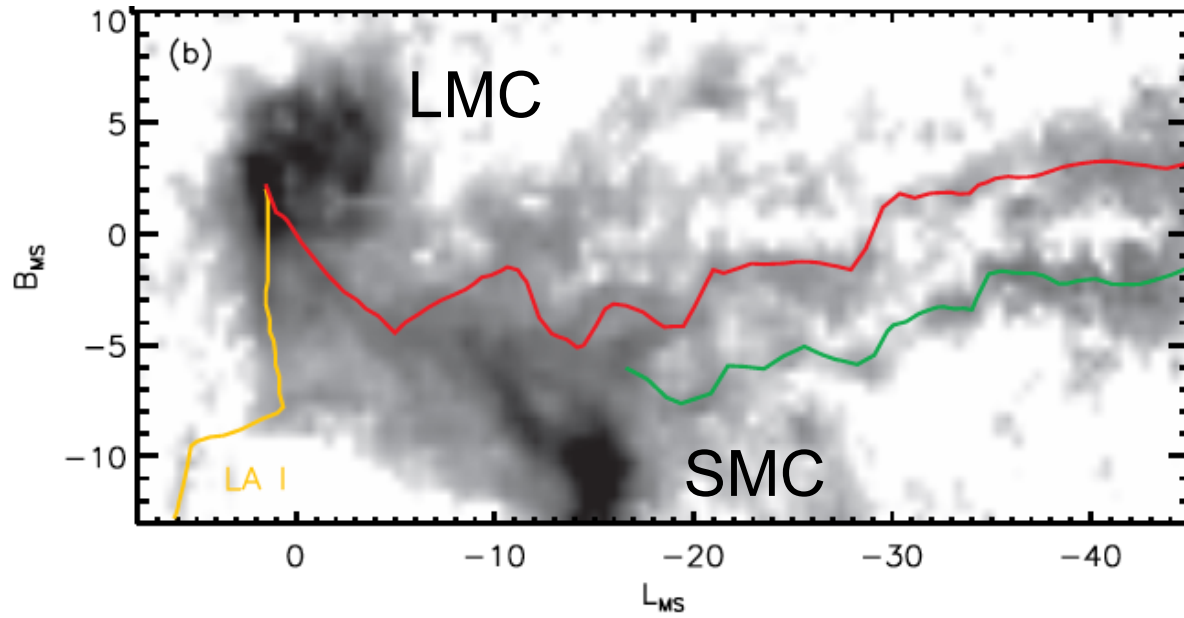
30 Doradus
SF region

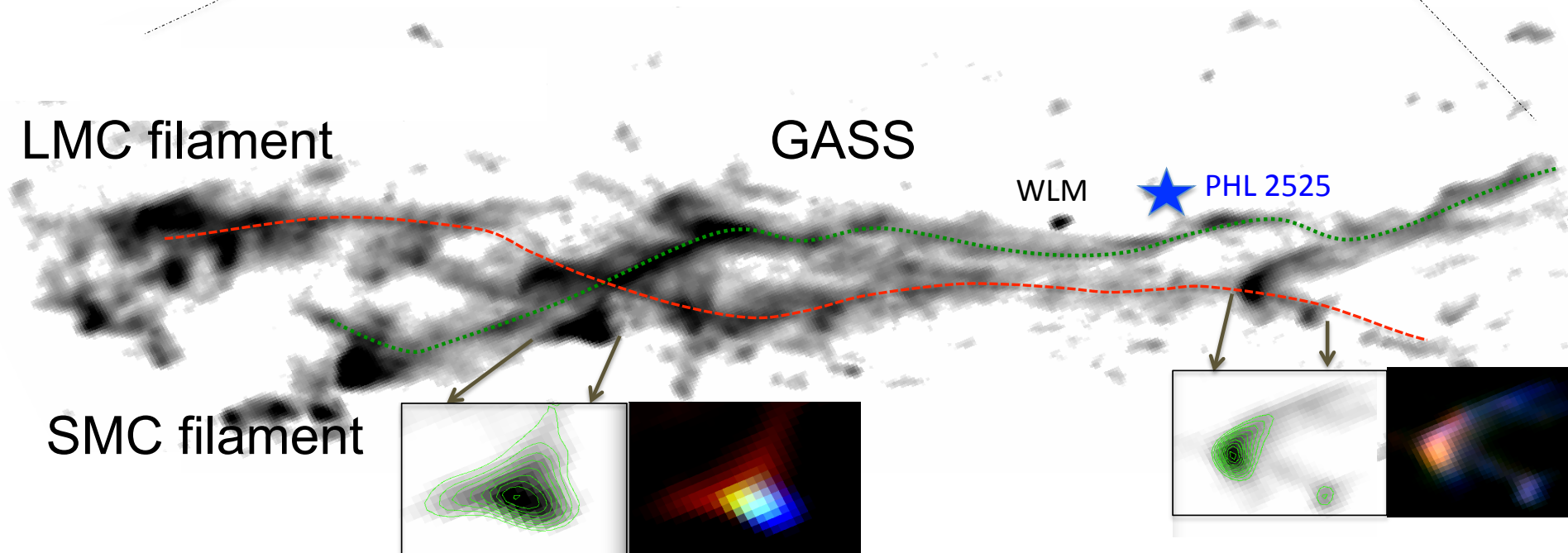
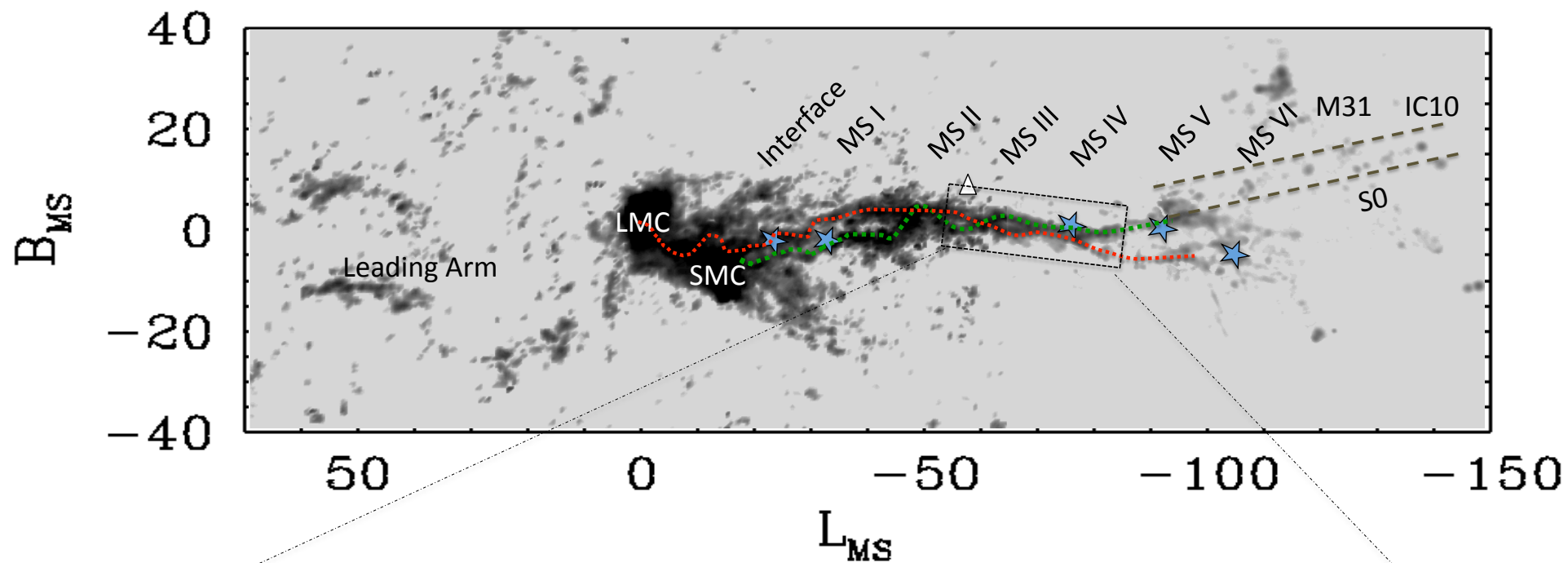
MS with 2 filaments
Nidever+08

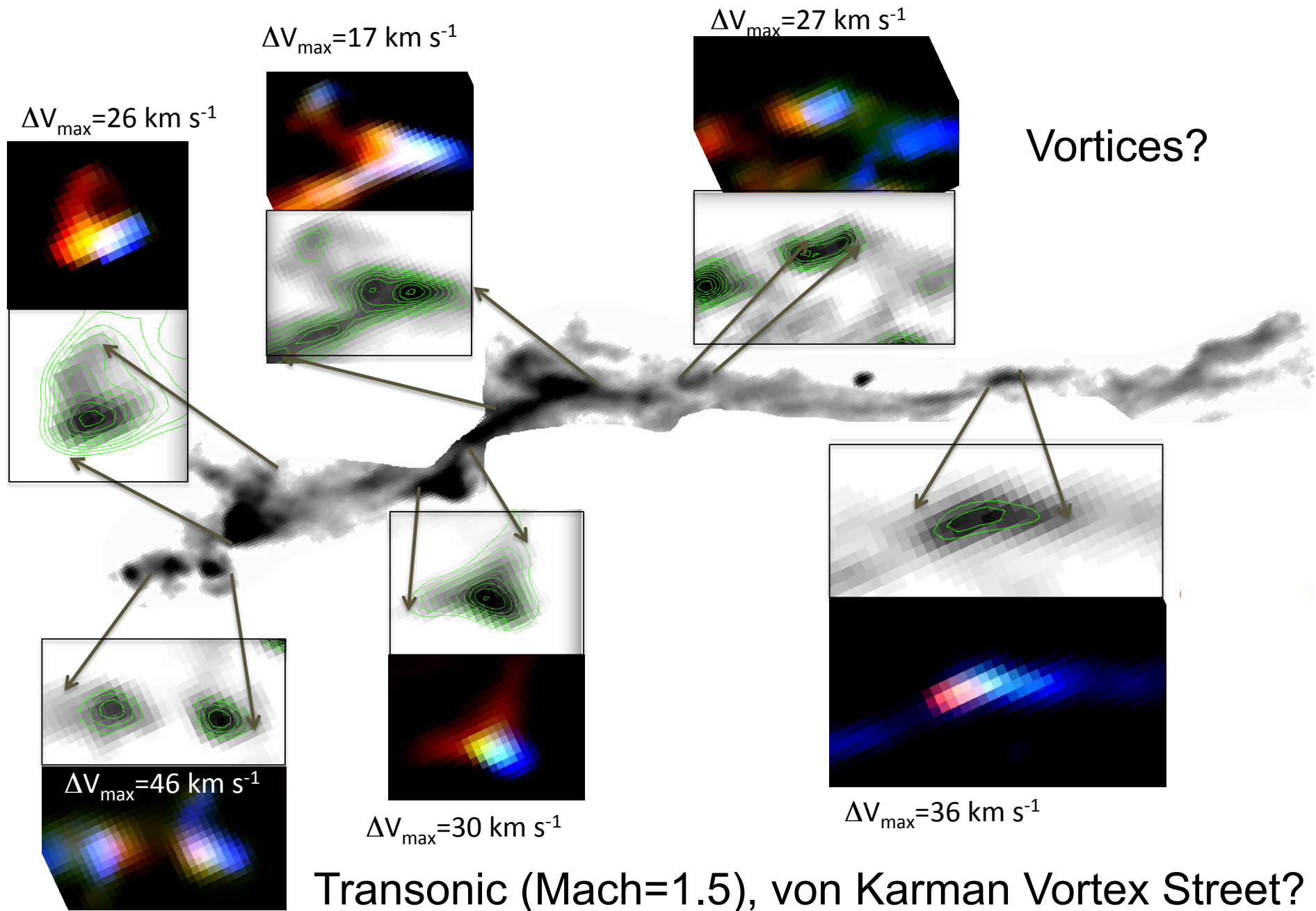
The MW and its environment

-10 -20 -30 -40
 L_{MS}

:: The Magellanic Stream



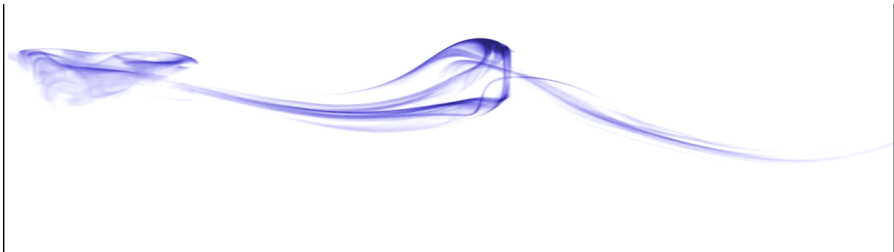




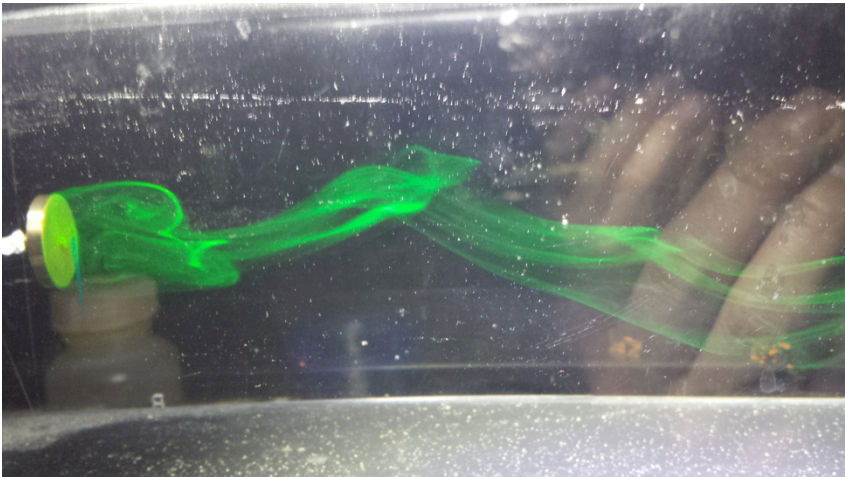
The MW and its environment

Francois Hammer: The Magellanic Stream

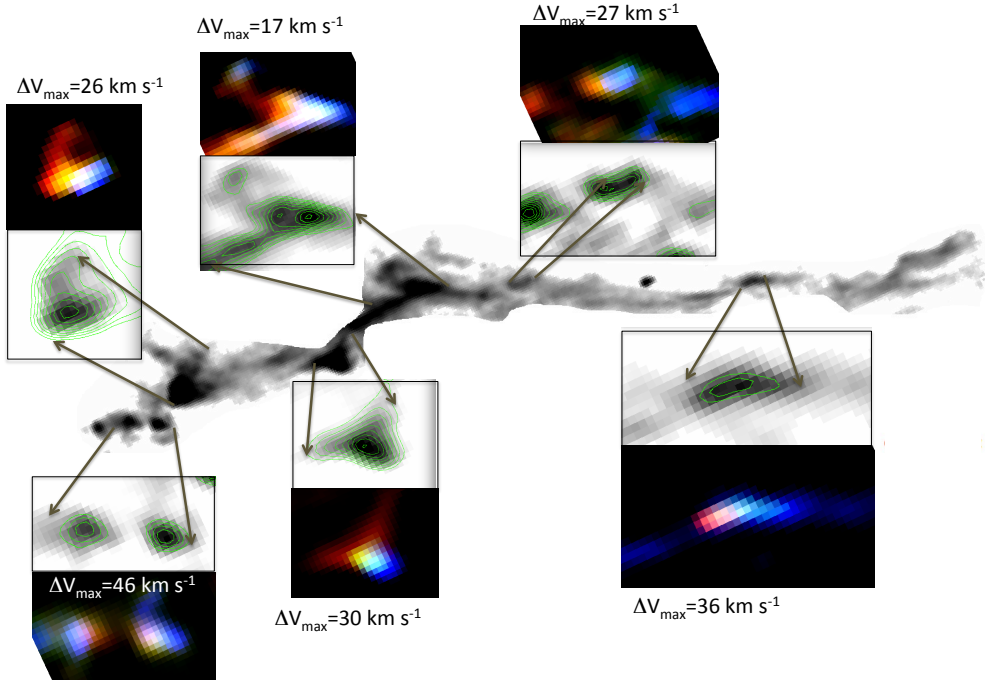
Similar behaviour than hydrodynamical flows with similar (Re, Strouhal) numbers, including vortices (or hairpin shedding)



First wake instabilities on a flow, Re=400, Wesfreid et al. 2014



The MW and its environment



Francois Hammer: The Magellanic Stream

Ram pressure exerted by the hot gas (10^6K) of the Milky Way halo

Evidences for a prominent halo hot gas affecting the Magellanic Stream & Clouds:

- Associated high velocity clouds are disrupted (multi-phases, Karlberla & Haud, 2006) $\rightarrow \rho_{\text{hot}} \sim 10^{-4} \text{ cm}^{-3}$ at 50 kpc
- X-ray observations (Gupta et al., 2012, Hodges-Kluck, Miller & Bregman, 2016)
- LMC gas disk has shrunk (Nidever, 2013)

The unusual properties of the LMC disks

RGB+AGB (van der Marel, 2006)

HI (Kim 98)
Images scaled

0^m 6^h0^m 30^m 5^h0^m 30^m 4^h0^m

RA (J2000)

5 kpc

Ram-pressure plus collision scenario

Hammer et al. 2015

- Evidence for $\rho_{\text{hot}} \sim 10^{-4} \text{ cm}^{-3}$ at the MS distance (Kalberla & Haud, 2006)
- consistent with the fact that the LMC HI disk has been shrunk
- Gas of the Magellanic Clouds stripped by ram-pressure exerted by the hot gas in the Milky Way halo
- Feedback is expelling gas at the LMC outskirts, consistent with observations of 30 Doradus (Nidever+08)
- The Magellanic Stream: Two gigantic transonic filaments
- $Re = 445 \times f_{\mu}^{-1}$ with $f_{\mu} \leq 1$ (viscosity suppression factor, Roediger et al. 2013), implying a moderately turbulent MS
- $Mach \sim 1.5$ ($V_{\text{sound}} \sim 200 \text{ km/s}$, $V \sim 300 \text{ km/s}$)

Ram-pressure plus collision scenario

Hammer et al. 2015

~ 200 Myr old collision between the
Magellanic Clouds

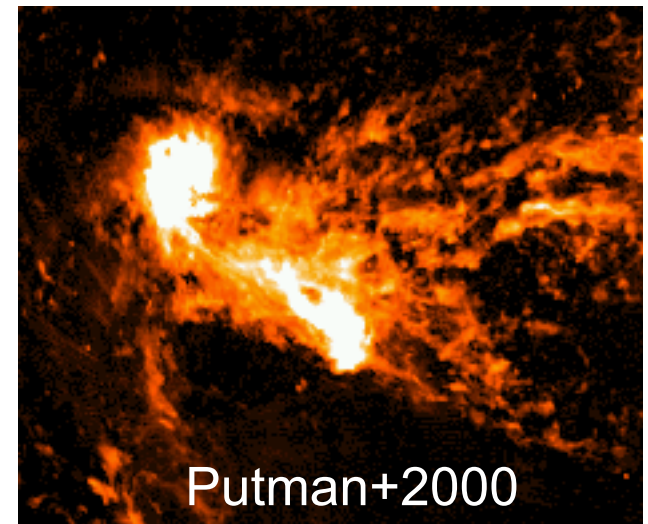
Evidenced by:

the Bridge

same SFH peak of the Clouds

proper motions

Relics in GASS data (anomalous HVCs)



Modelling

GADGET2 (2 M particles)

- Milky Way: total mass, 5 to 8 $10^{11}M_{\odot}$
hot gas mass, 3 to 9 $10^{10}M_{\odot}$

2 Gyr in isolation to equilibrate hot gas halo and cold gas in disk
within the dark matter halo

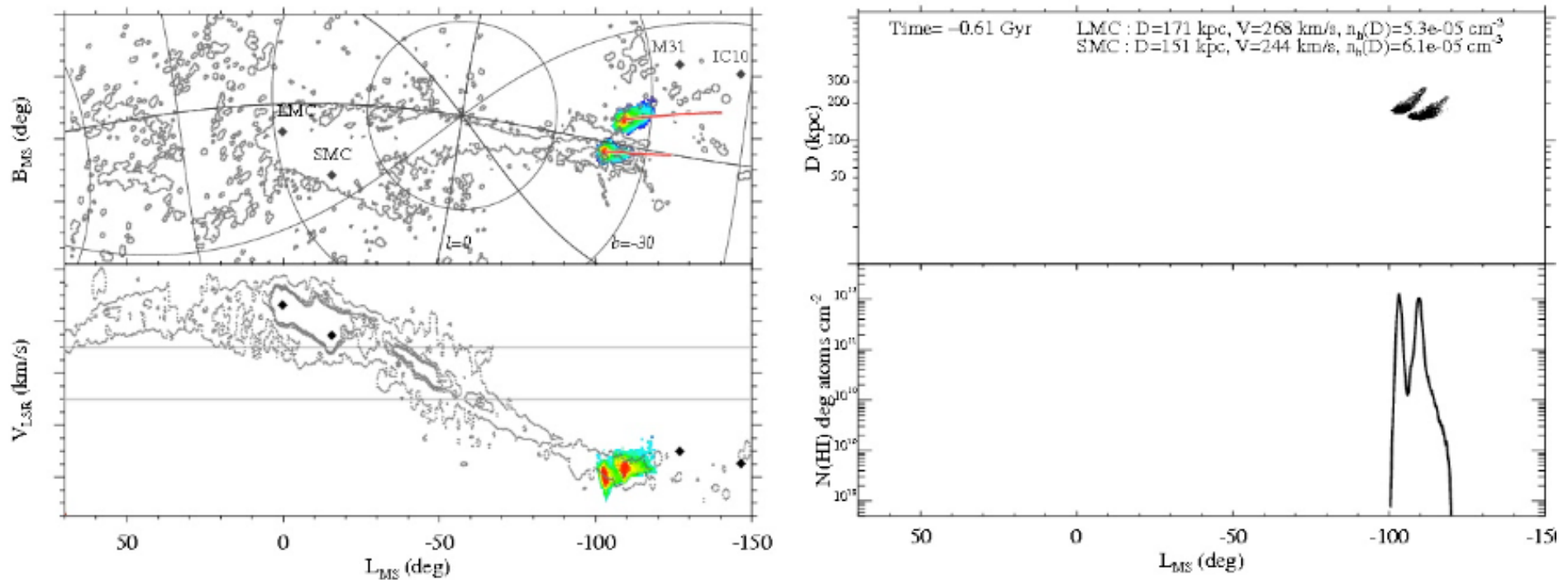
- Initial LMC: mass, 1.8-5 10^9M_{\odot} ; f_{gas} , 40-60%
- Initial SMC: mass ~ 0.7 LMC mass, f_{gas} , 40-70%

Reproduce present-day stellar and gas mass within 20% accuracy

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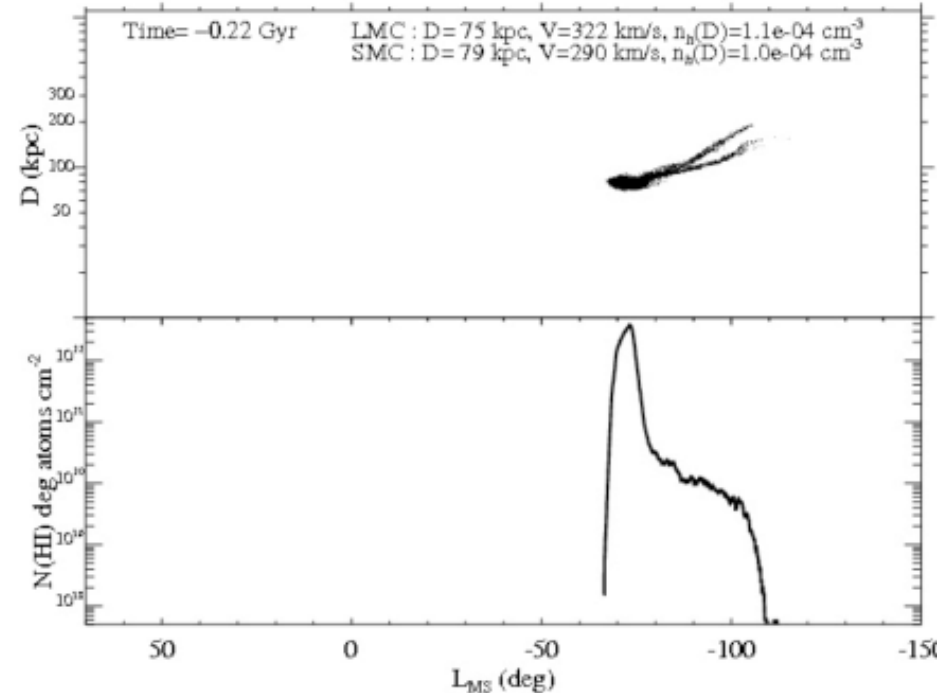
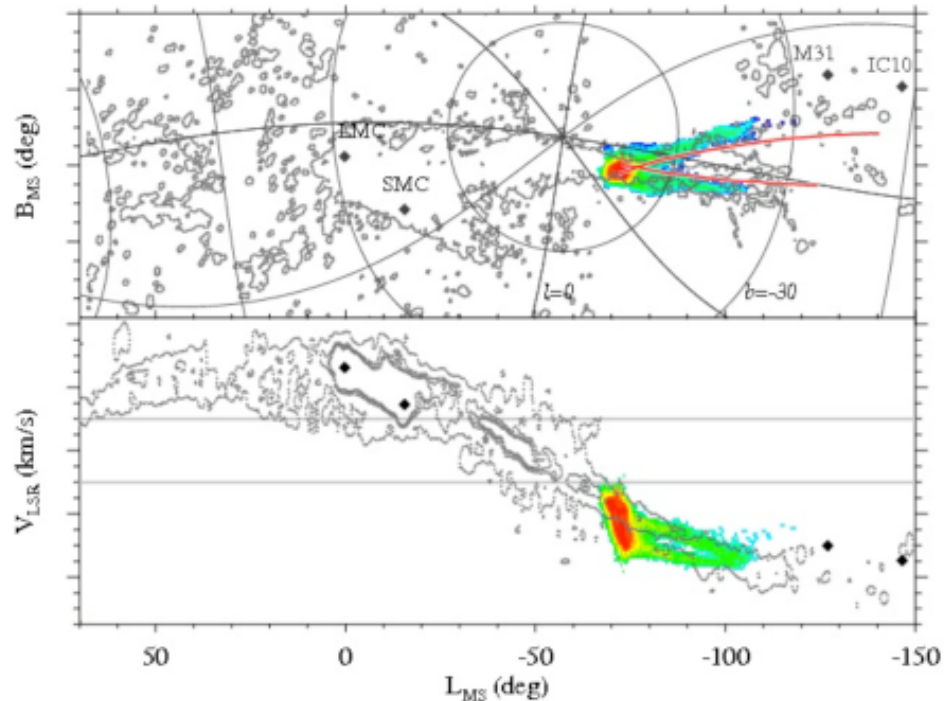
Hammer et al. 2015

Gas of the Clouds stripped by ram-pressure exerted by the hot gas in the Milky Way halo



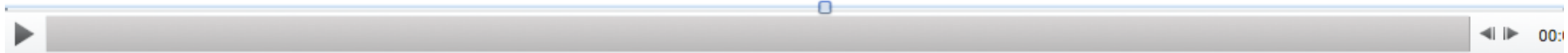
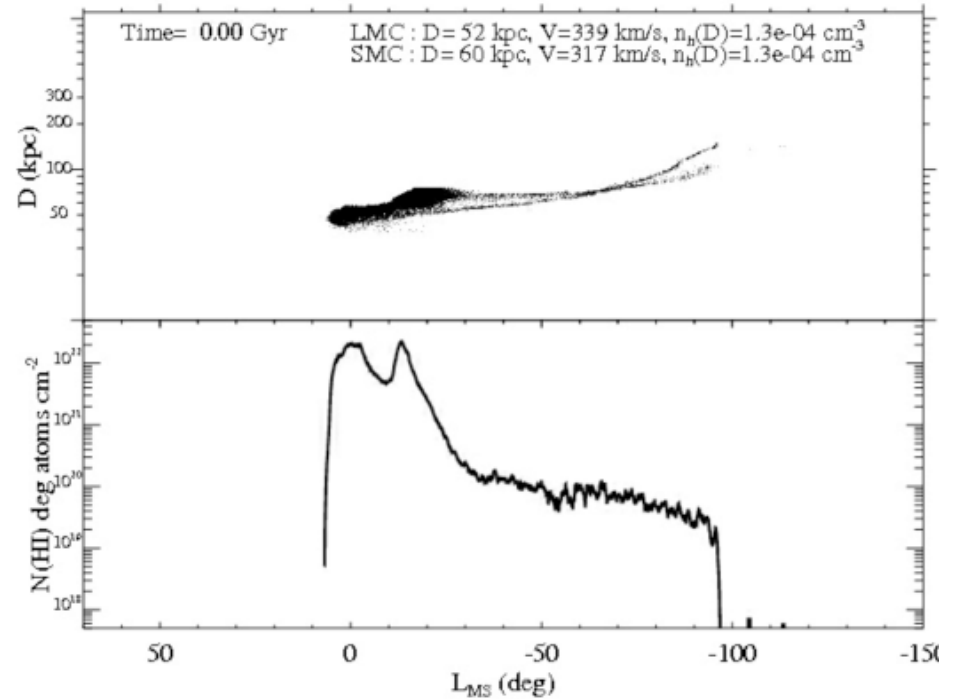
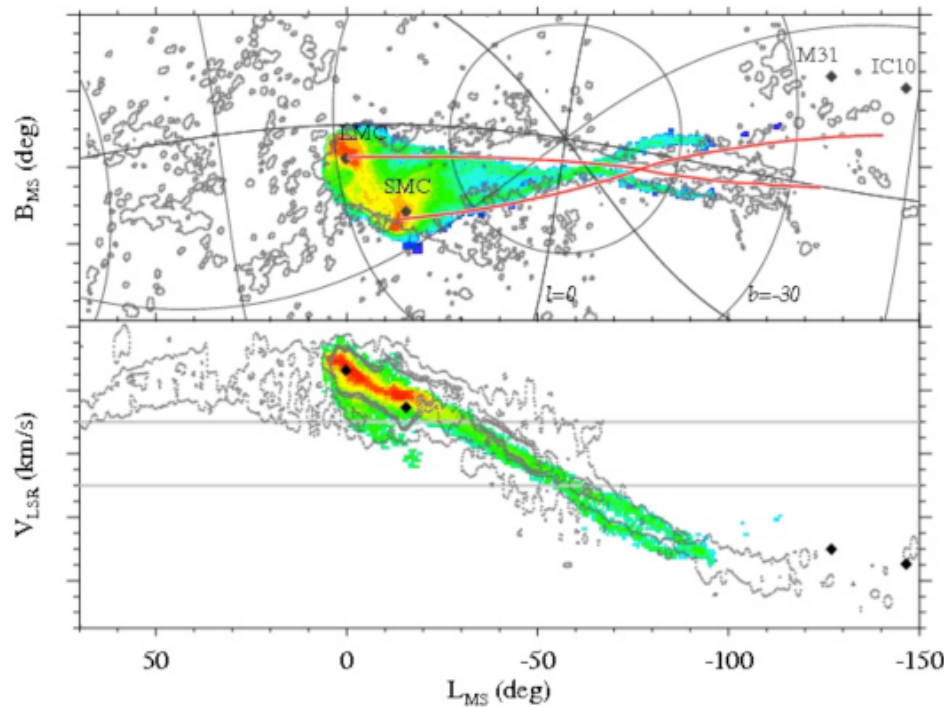
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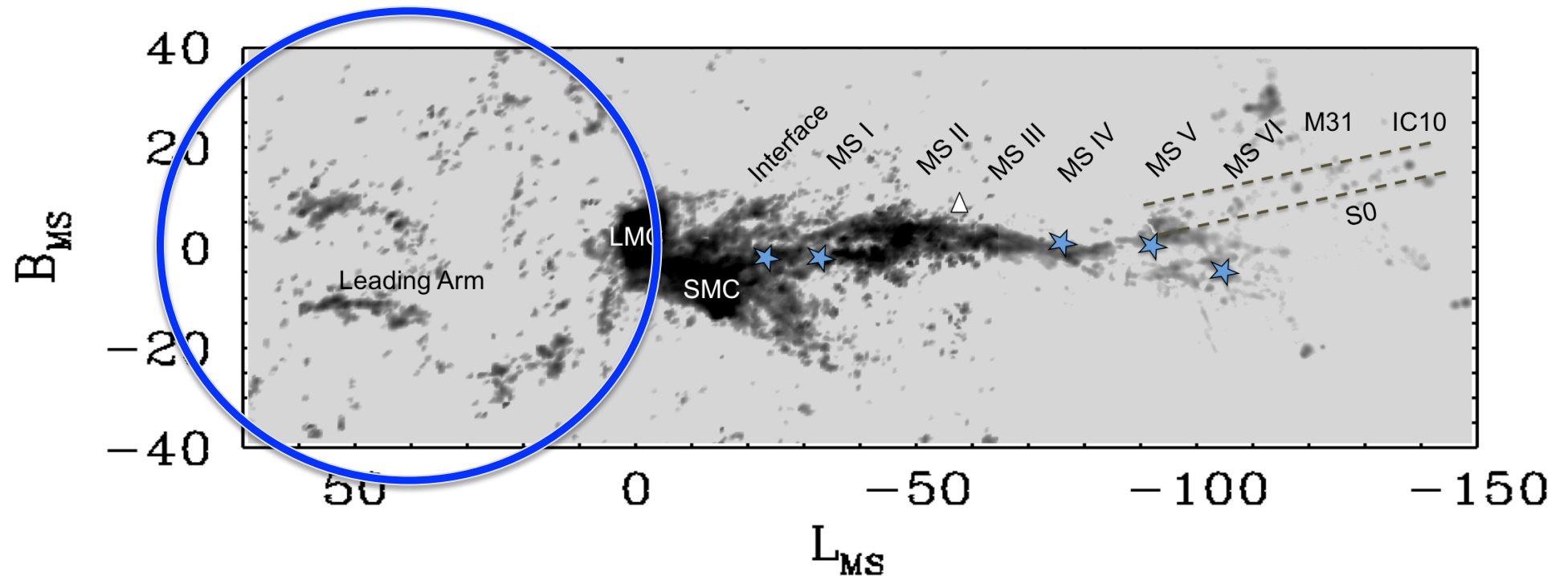


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Gas of the Clouds stripped by ram-pressure exerted by the hot gas in the Milky Way halo



Formation of the Leading Arm

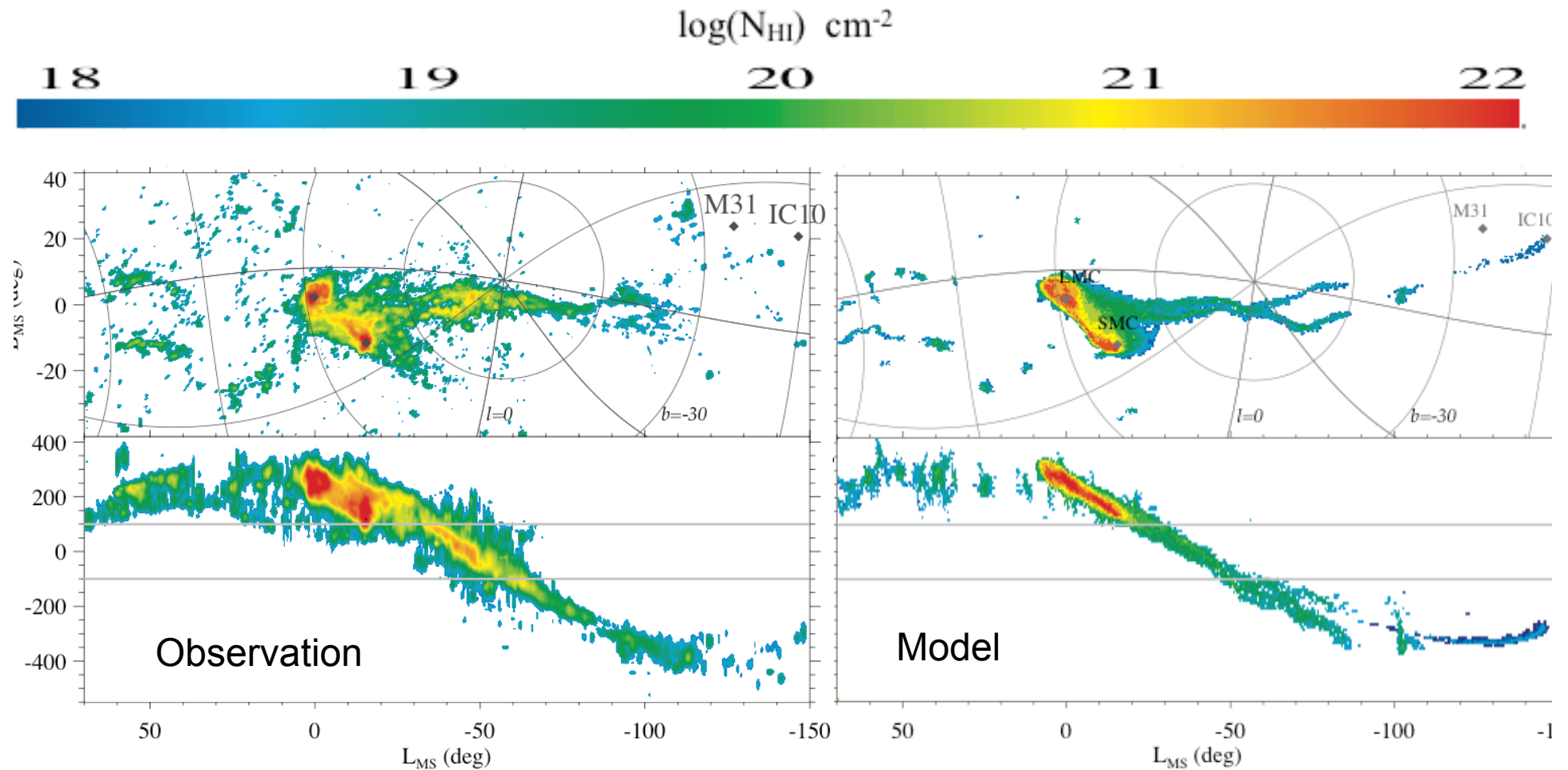


Former passages of leading and ram-pressure stripped dlrrs
(*a la Lucio Mayer, 2009; LA firstly reproduced by Yang et al; 2014*)

Similar orbits than LMC's, ALL material being part of the VPOS
(*Pawlowski14*)

Explanation of the gigantic Magellanic System

Gas of the Clouds and dSph progenitors stripped by ram-pressure exerted by the hot gas in the Milky Way halo, dSph progenitors follow similar orbits than the LMC (VPOS)



The Magellanic System: a corner stone to understand

- how galaxies are fed by gas (to form stars)
- to understand the Local Group content and origin
- Ram pressure + collision between Magellanic Clouds: by far the only model reproducing Magellanic Stream properties
- Implementing hydrodynamical solver (GIZMO, Hopkins, 2014) to reproduce KH instabilities (vortices) incl. SF in the Leading Arm (Casetti+14)
- Stream tip end is pointing to the M31 system (IC10, Nidever+13): what is the role of the ancient gas-rich merger that formed M31 (Hammer+10)?
- Test the dark matter content of dSphs (Yang+14) and Clouds progenitors: experiment tidal dwarfs as well as massive dwarfs arriving in a group, as proposed by d'Onghia & Lake, 2008

