ULTRAVIOLET ASTRONOMY IN THE XXI CENTURY

e-Workshop 2020 – October 27-29

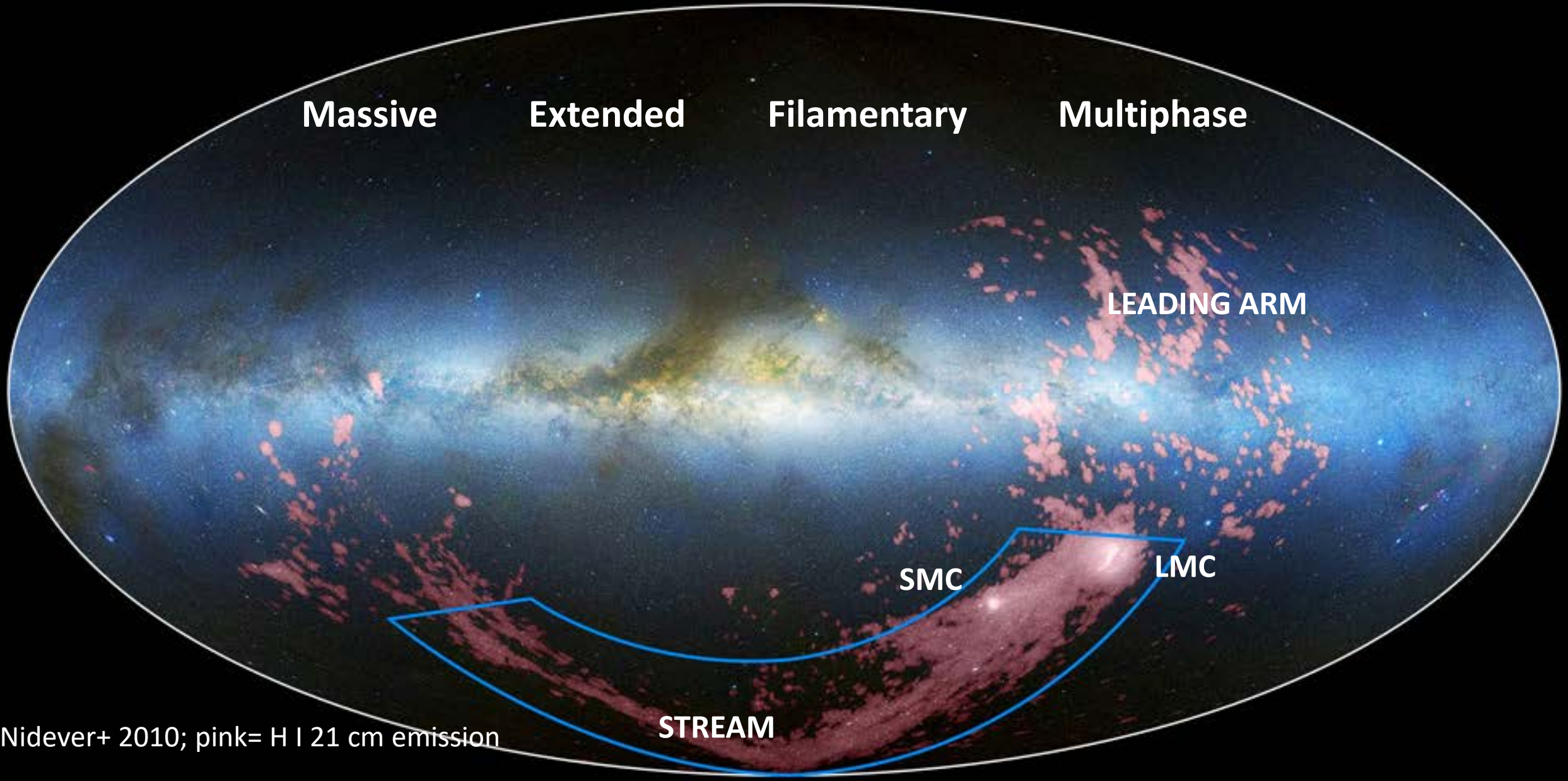
JcUVa

ULTRAVIOLET ABSORPTION SIGNATURES OF THE MAGELLANIC STREAM

Andrew Fox (STScI)

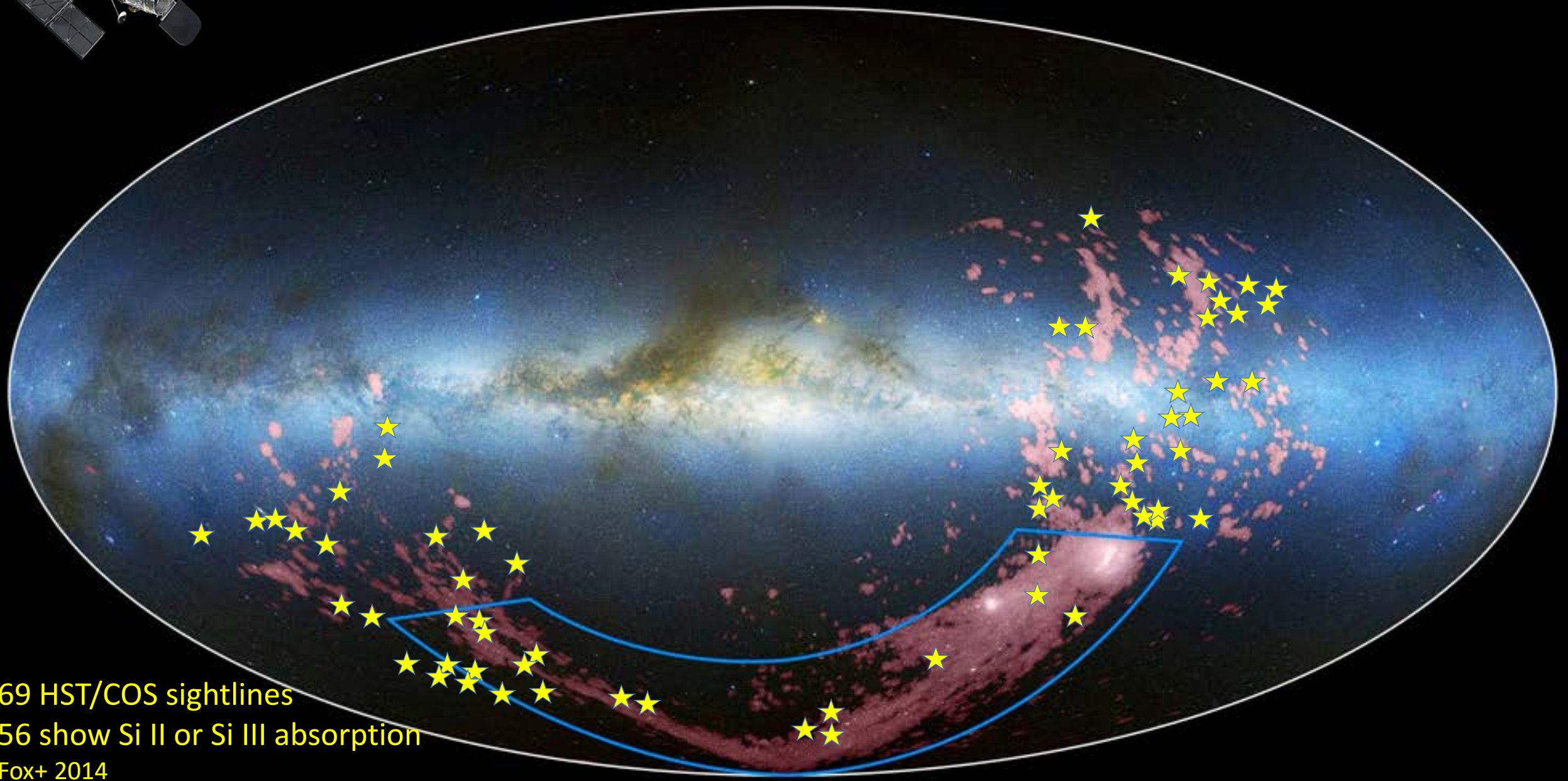
October 28 2020, NUVA Workshop

The Magellanic Stream



Nidever+ 2010; pink= H I 21 cm emission

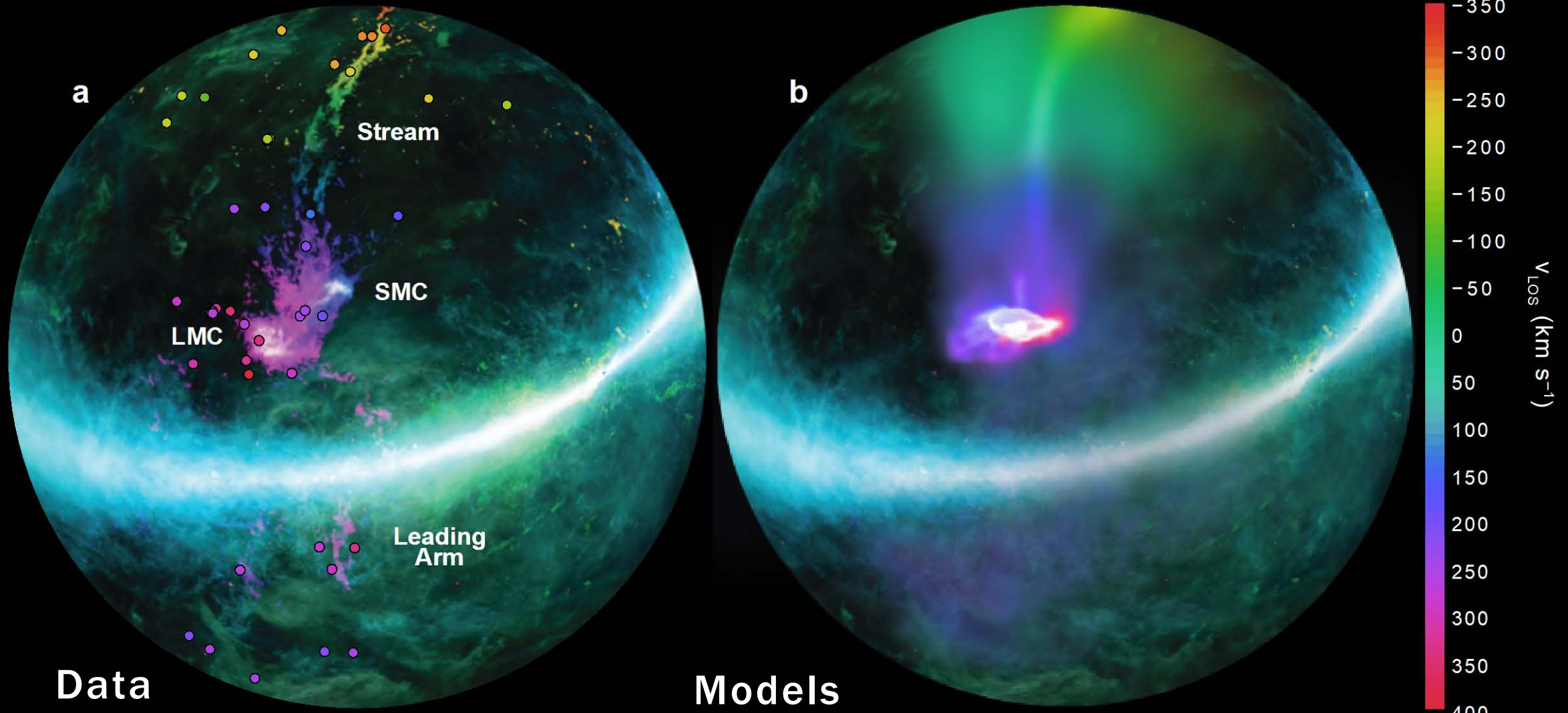
Magellanic Stream in UV Absorption



69 HST/COS sightlines
56 show Si II or Si III absorption
Fox+ 2014

Simulations of Magellanic Stream Formation

Lucchini+ 2020



Data

McClure-Griffiths+ 2009 (GASS survey)

Models

Using first-infall orbits (Besla+ 2007)

UV Studies of the Magellanic Stream

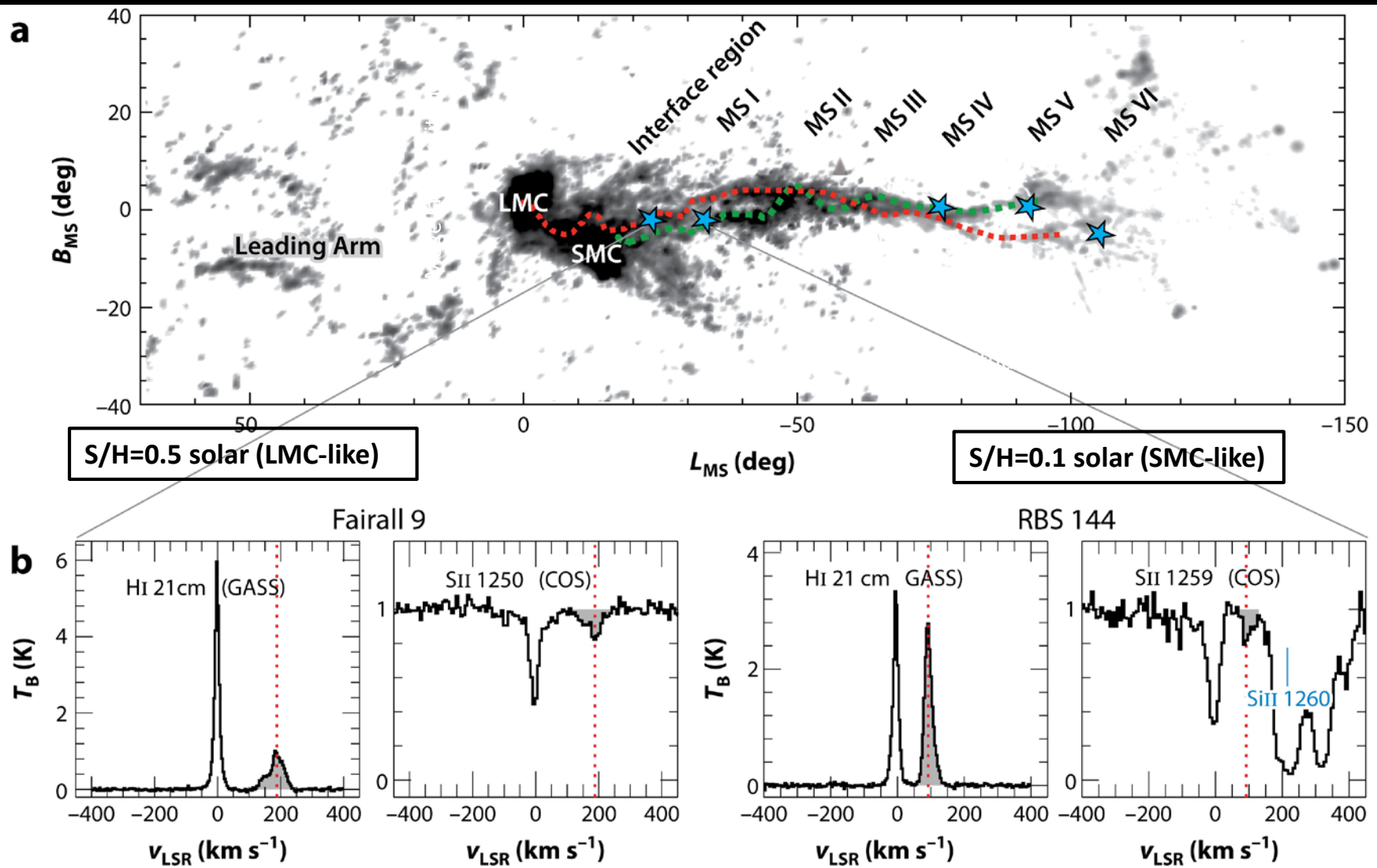
Metallicity

Magellanic Stream is Filamentary

A Tail of Two Galaxies

Magellanic Stream is Filamentary

A Tail of Two Galaxies



D'Onghia E, Fox AJ. 2016.
Annu. Rev. Astron. Astrophys. 54:363–400

UV spectroscopy shows that

- two filaments are chemically distinct
- LMC filament has 0.5 solar S abundance
- SMC filament has 0.1 solar S abundance

Fox+ 2010,2013, Richter+2013, Kumari+ 2015, Howk+ 2018

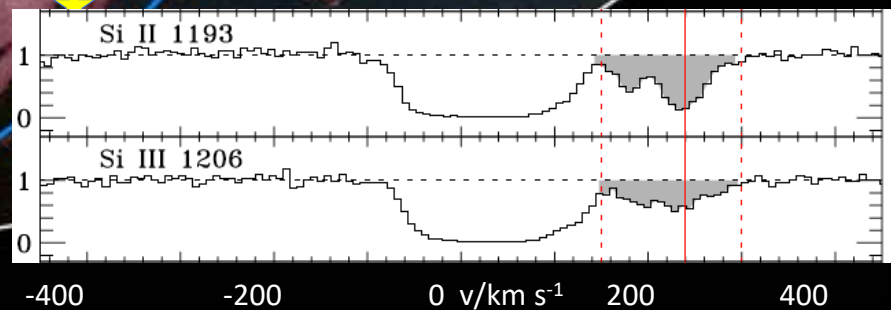
UV Studies of the Magellanic Stream

Ionization

Magellanic Stream is Mostly Ionized

$M(H\ I) \sim 4 \times 10^8\ M_\odot$ (Brüns+ 2005, 21 cm)

$M(H\ II) \sim 1\text{–}2 \times 10^9\ M_\odot$ (Fox+ 2014 UV; Barger+ 2017 Hα)



69 HST/COS sightlines

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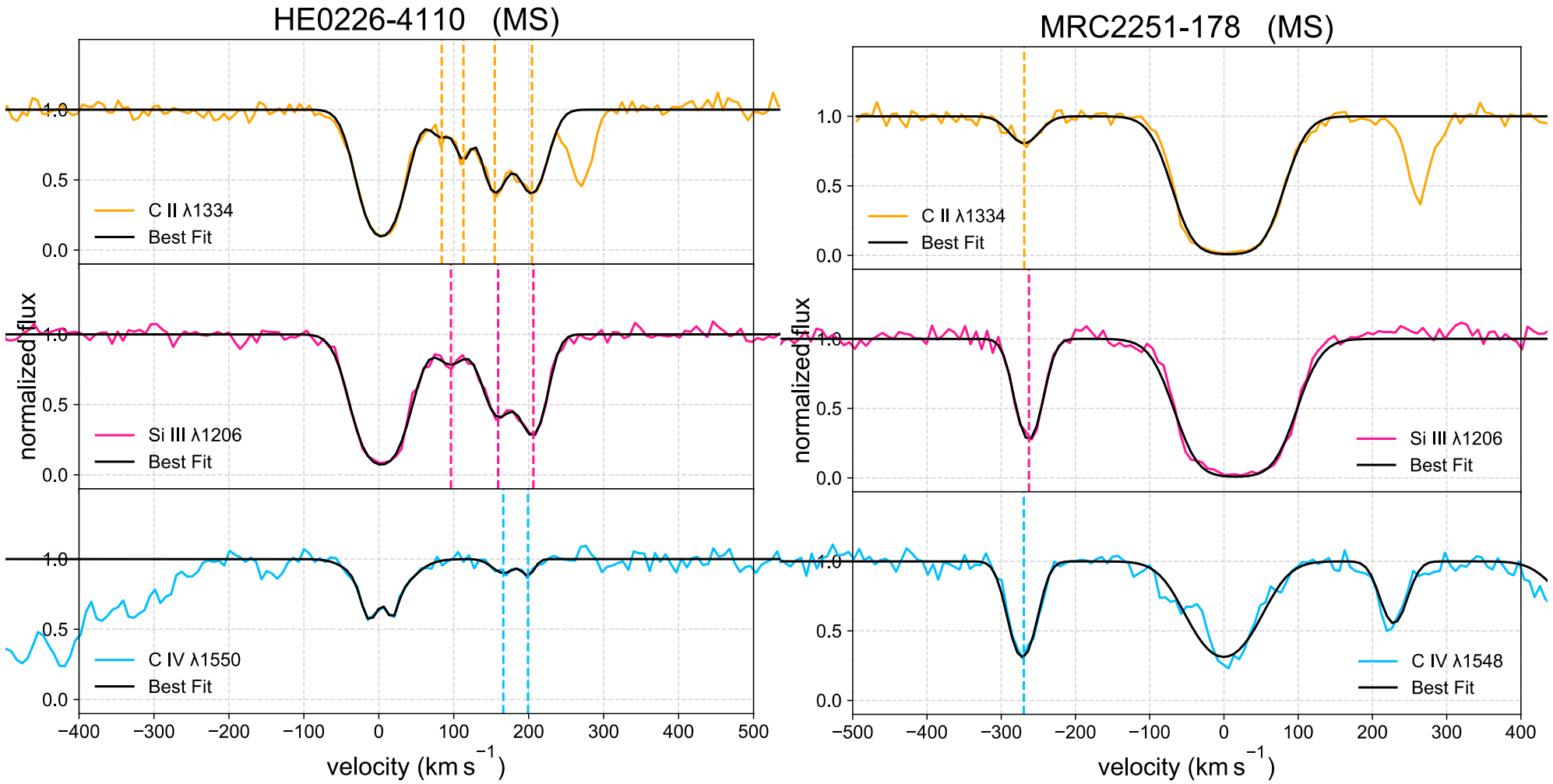
Fox+ 2014

UV Studies of the Magellanic Stream

Kinematics

UV Kinematics: Voigt Profile Analysis of HST/COS data

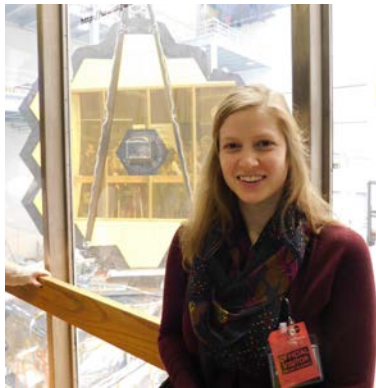


Low Ion
C II

Intermediate Ion
Si III

High Ion
C IV

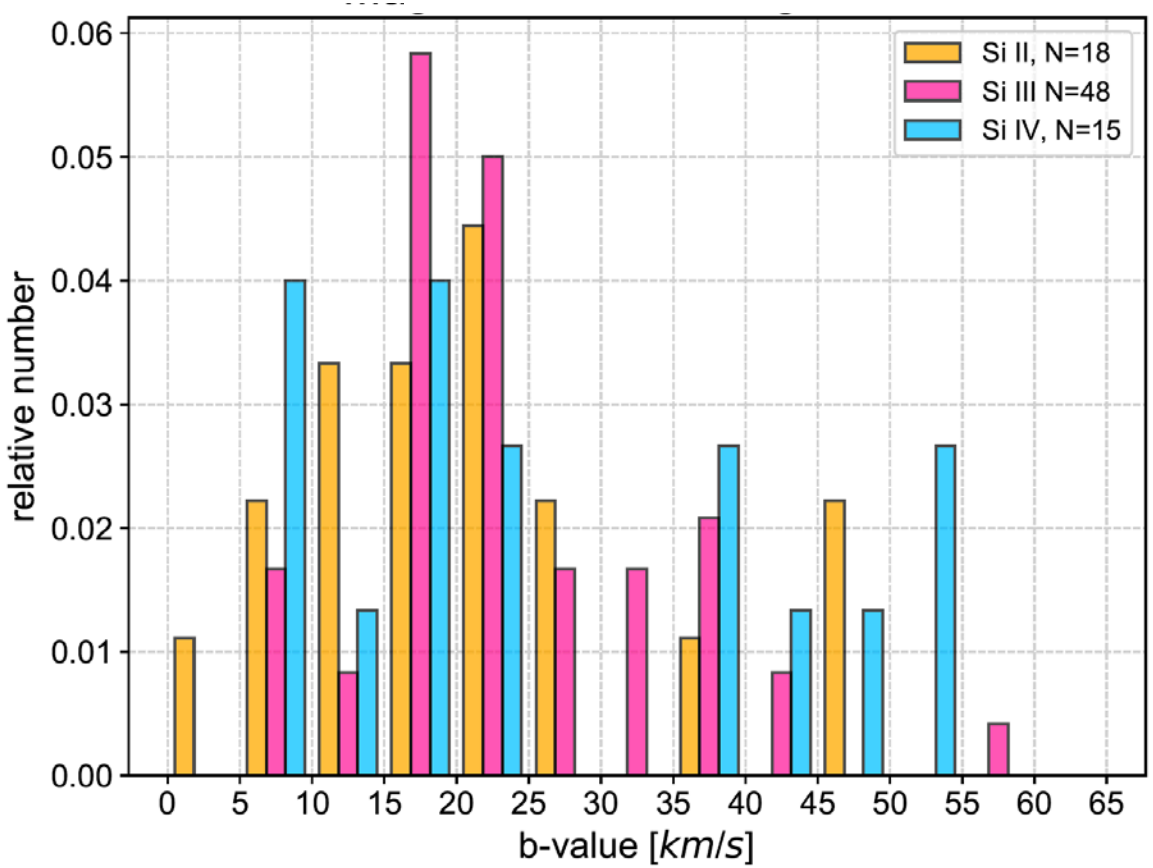
Elaine Frazer



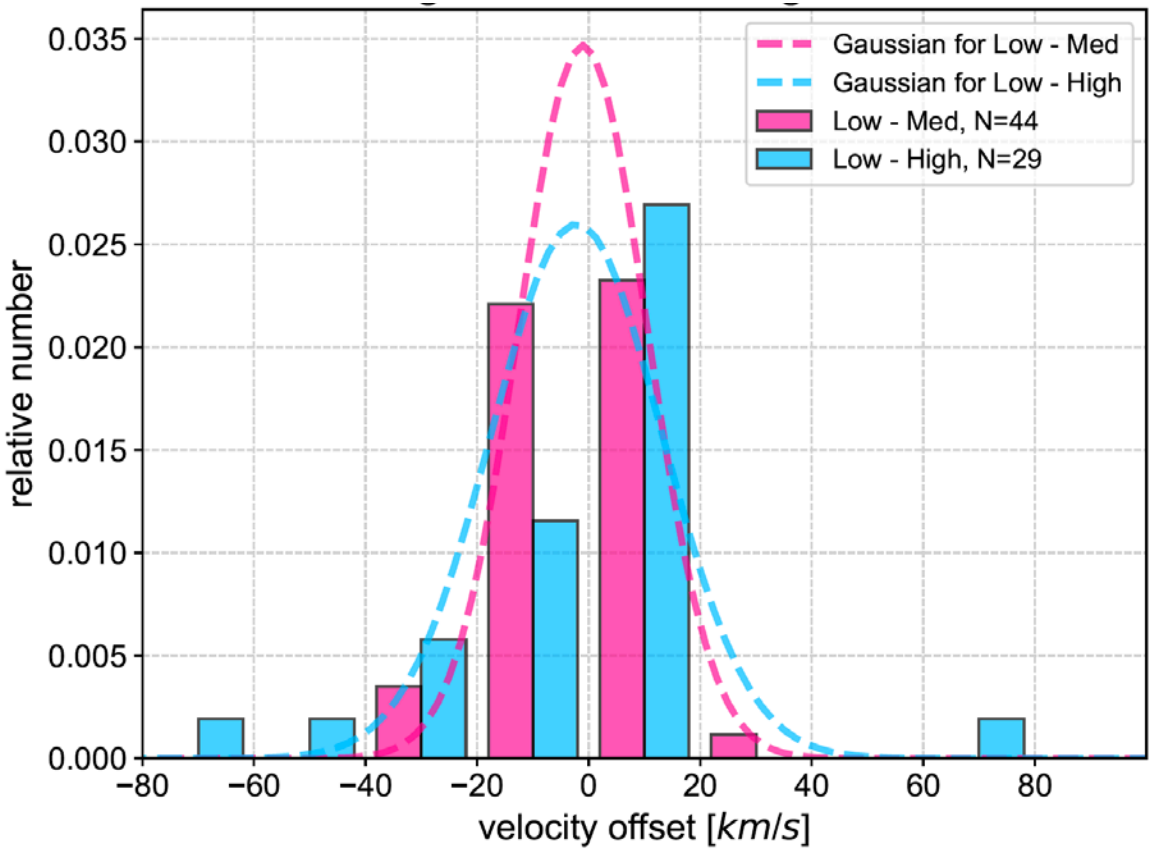
Fox, Frazer+ 2020, ApJ: 31 sightlines analyzed with Voigt profile models

Magellanic Stream Kinematics

Linewidth Distribution



Velocity Offset Distribution



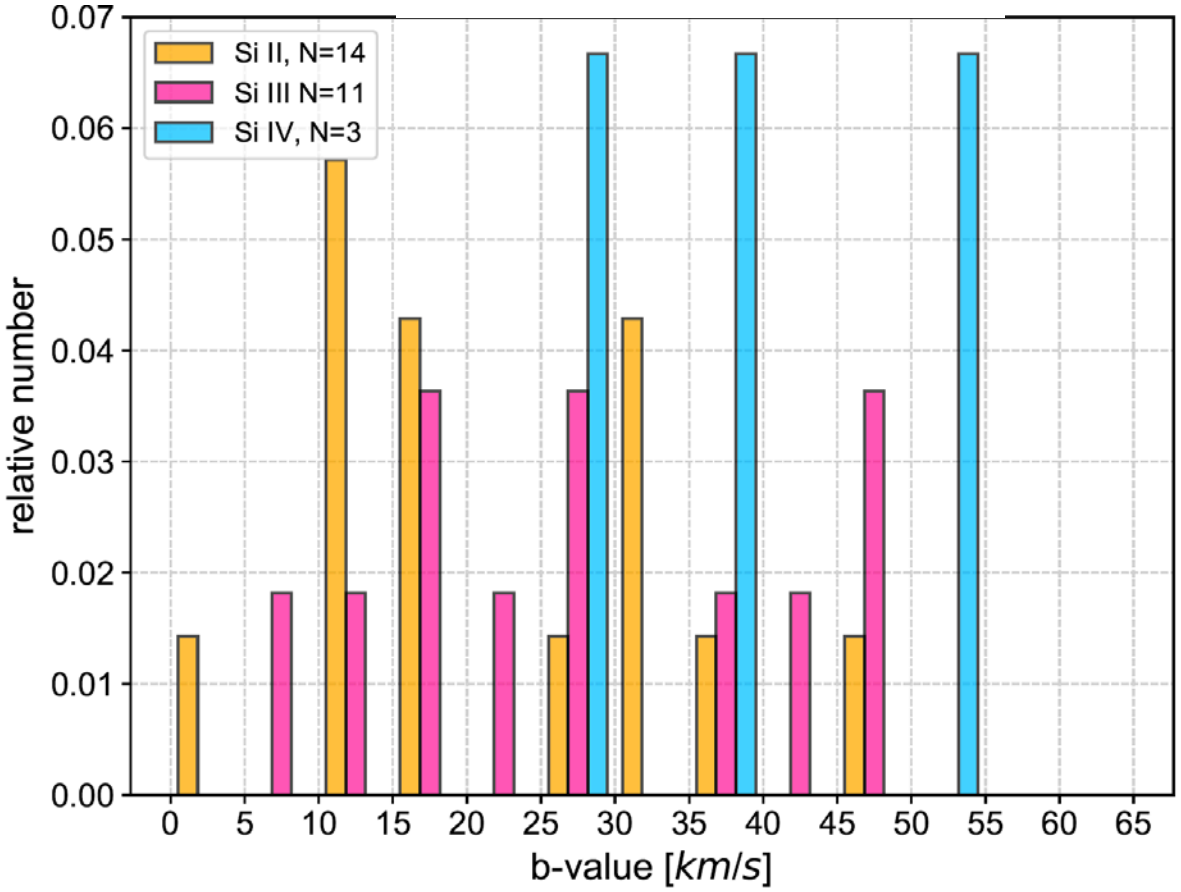
- In the Stream, linewidths of Si II, Si III, Si IV all distribute *similarly*
- Velocity centroids of high and low ions show reasonable alignment

  → **UV ions in Stream are predominantly single-phase and photoionized**

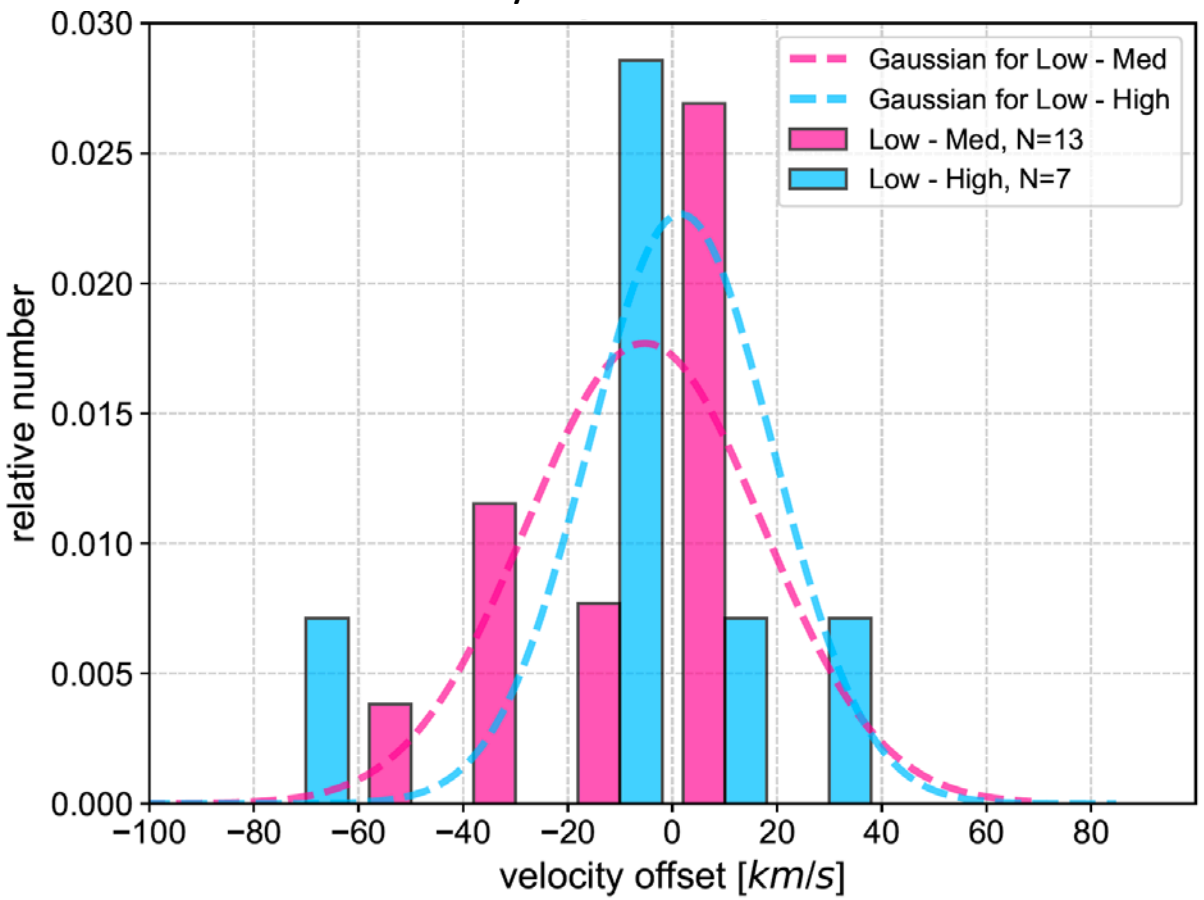
Fox, Frazer et al. 2020, ApJ

Leading Arm Kinematics

Linewidth Distribution



Velocity Offset Distribution

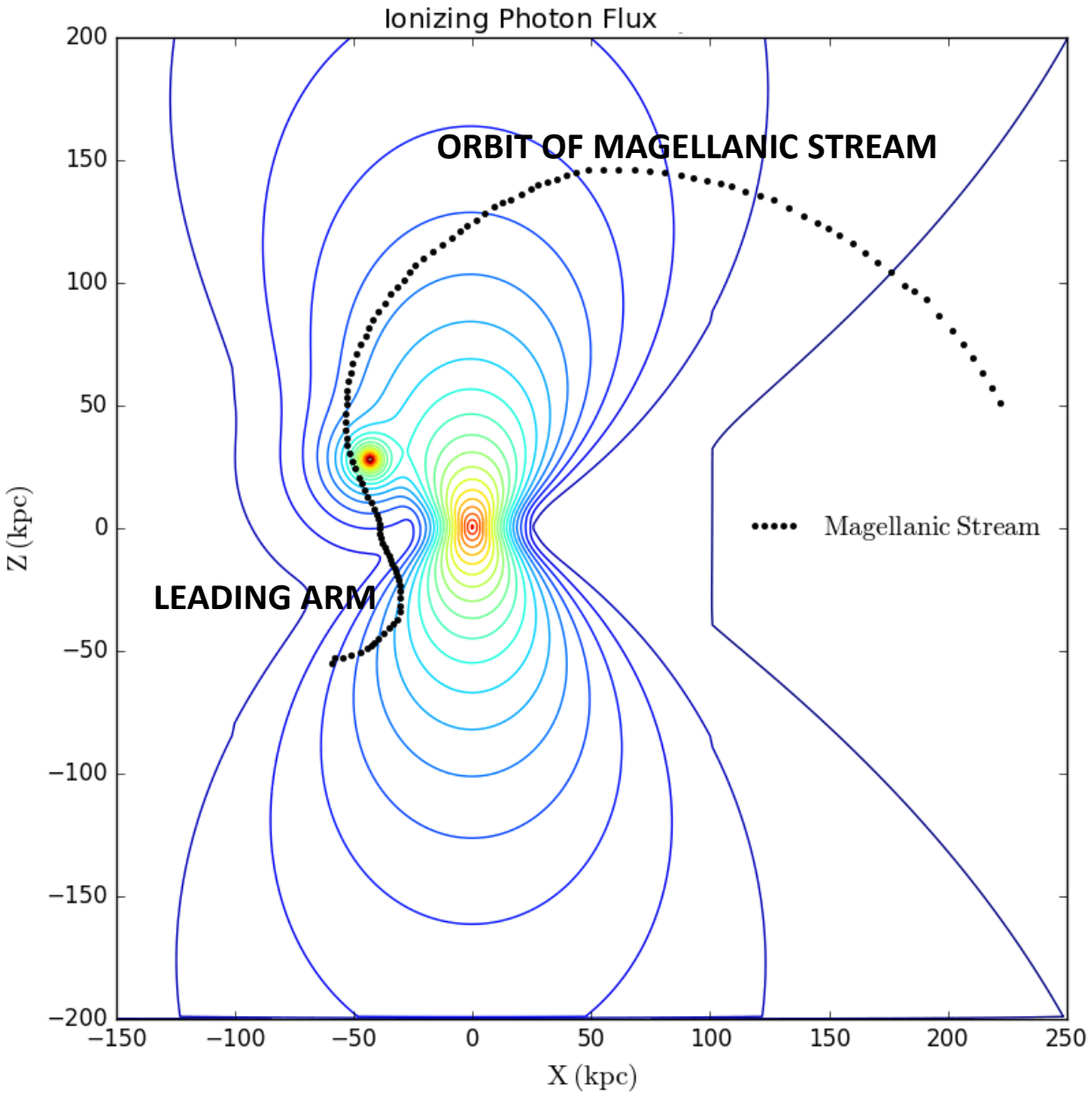


- In the Leading Arm, Linewidths of Si II, Si III, Si IV distribute *differently*.
- Velocity offset distribution is slightly broader than Stream

→ **UV ions in Leading Arm are multi-phase**

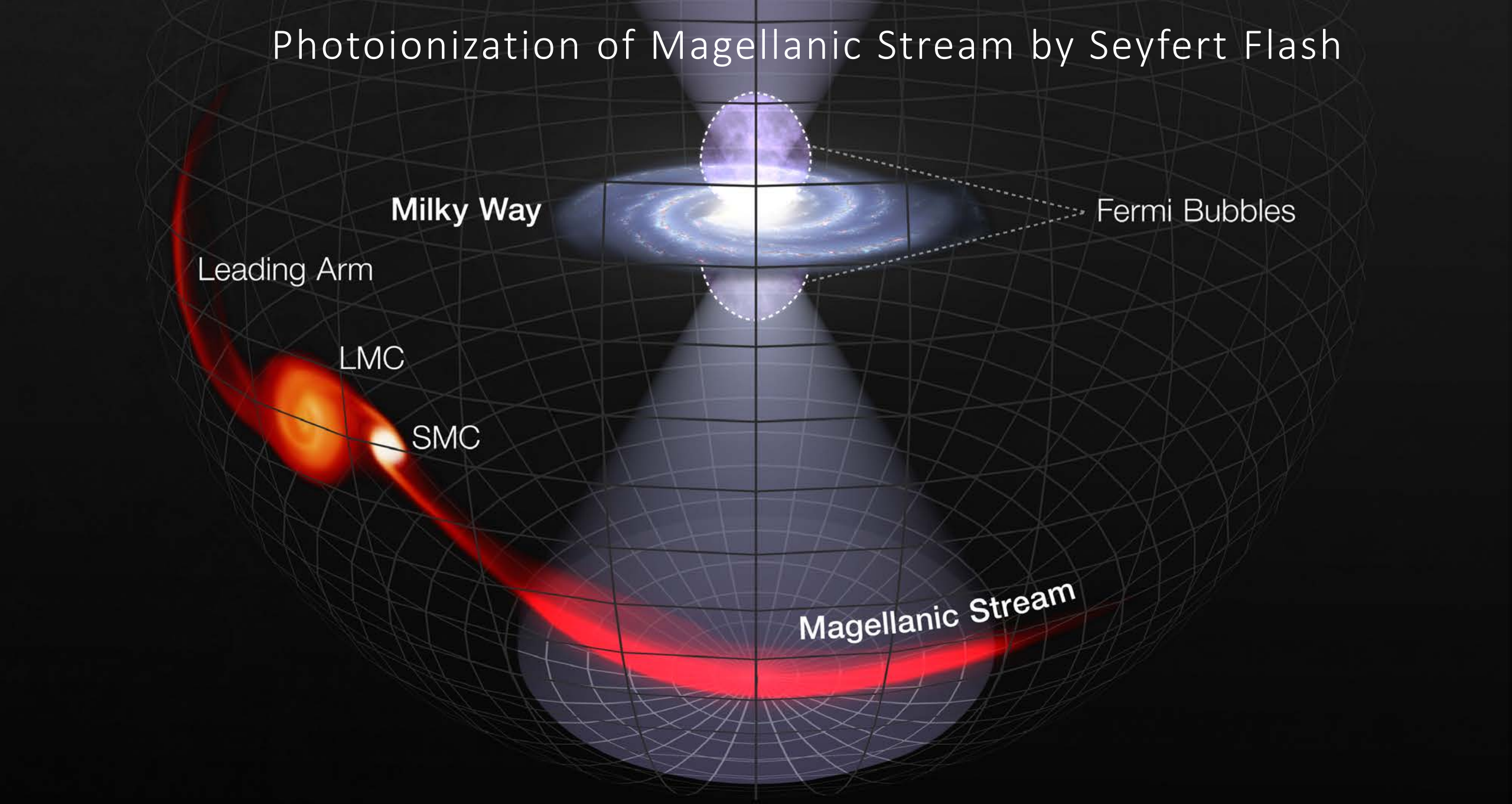
Fox, Frazer et al. 2020, ApJ

The Seyfert Flare model (Bland-Hawthorn+ 2013, 2019)



- Stream photoionized by flash of ionizing radiation
- Likely candidate is **Seyfert Flare** at GC 3.5±1 Myr ago
- Explains enhanced Hα emission below Galactic pole
- Flare could trace event that created **Fermi Bubbles**, because timescales match (2.5-4.0 Myr ago).
- Leading Arm lies outside the ionization cone, so does not experience the Seyfert flash

Photoionization of Magellanic Stream by Seyfert Flash



Credit NASA/ESA/L. Hustak

Summary

UV absorption studies have been critical for our understanding of Stream

UV studies probe the basic physical and chemical conditions of CGM gas

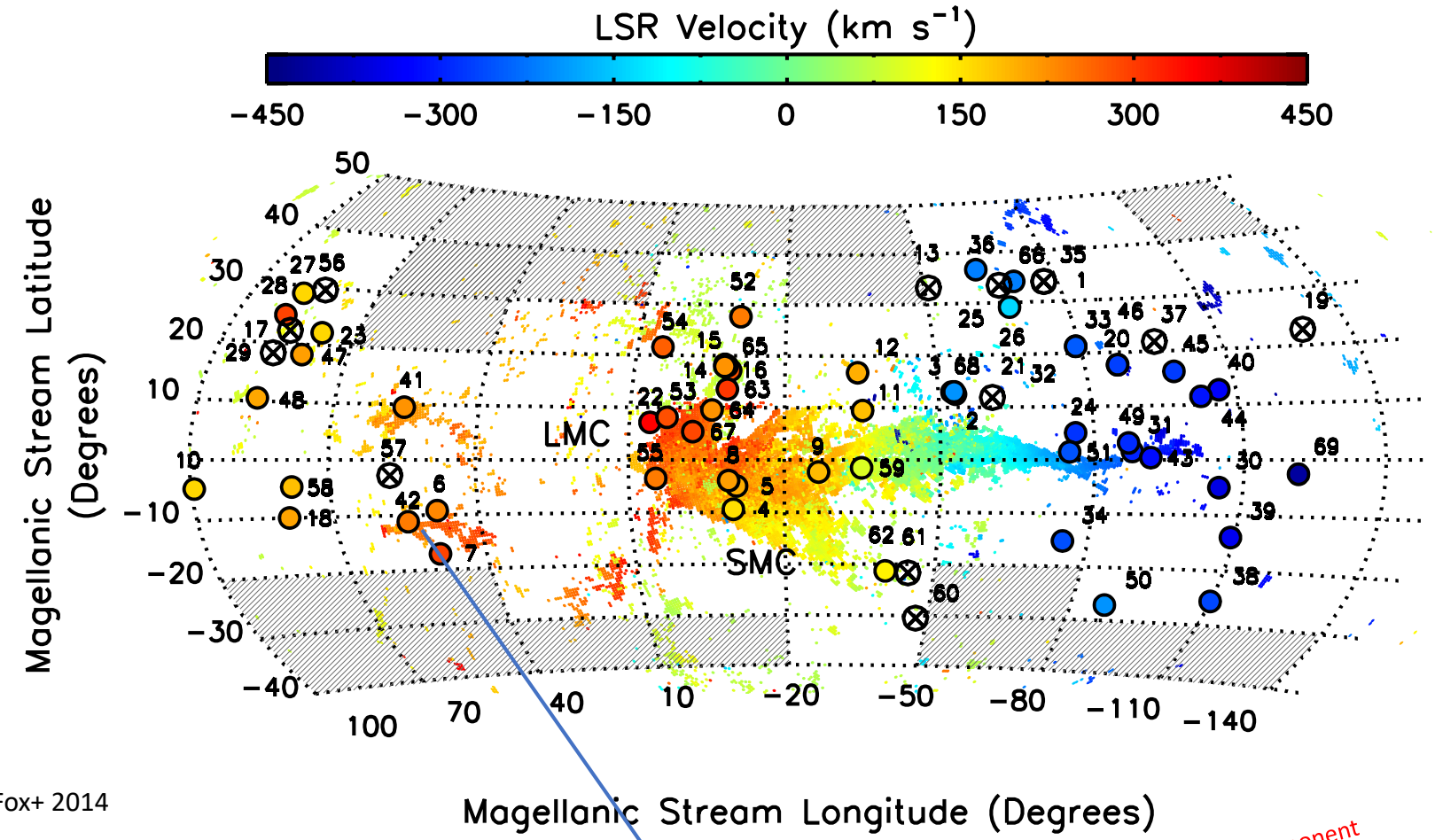
- Metallicity
- Kinematics
- Ionization

Technical keys to this work have been UV spectra of background AGN with

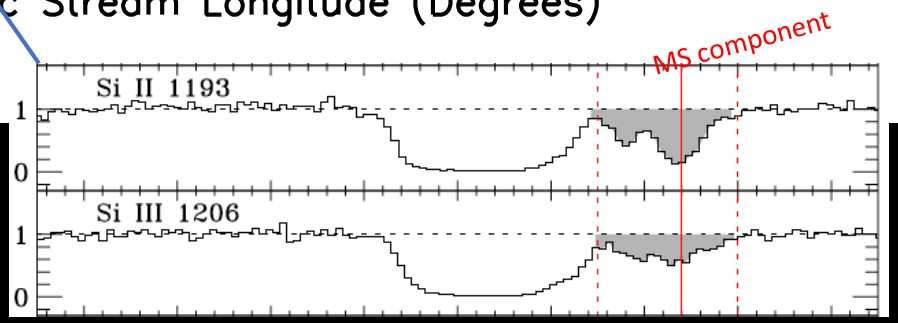
- High **spectral resolution** ($R \gtrsim 20{,}000$) coverage of the FUV (1150-1700 A)
- High **sensitivity** (COS G130M/G160M data reached GALEX NUV≈18)
- Low, stable **background levels**
- **Archives** that are well calibrated, well curated, and accessible

Extra Slides

Magellanic Stream has high ionization level



Fox+ 2014



- measure Si II, Si III, H I line strengths
- model with photoionization code
- derive H^+ column N(H II)
- multiply by cross-section -> H^+ mass

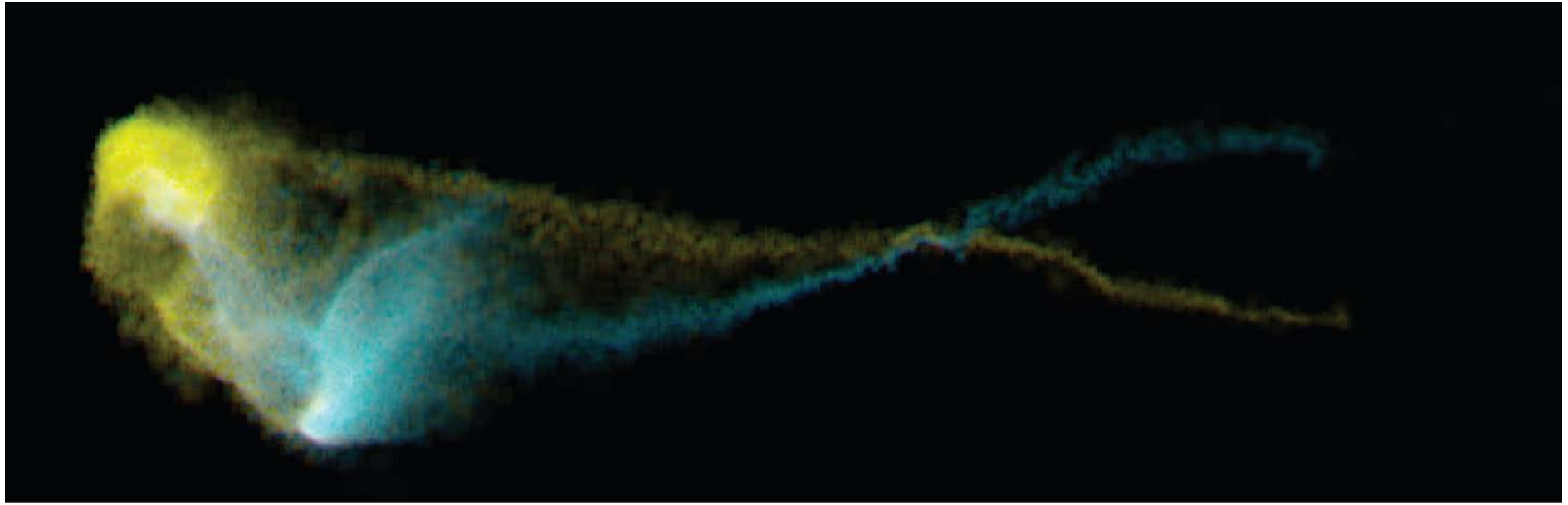
Stream contains more gas mass than is left in LMC+SMC

Gas mass = H I mass + H II mass

= 4.9×10^{8} $M_{\odot}$ + ~1.5×10^{9} $M_{\odot}$ (d=55 kpc)

~2×10^{9} $M_{\odot}$

~2 x ISM mass of MCs [M(H I)=0.4×10^{9} $M_{\odot}$ in LMC and in SMC]



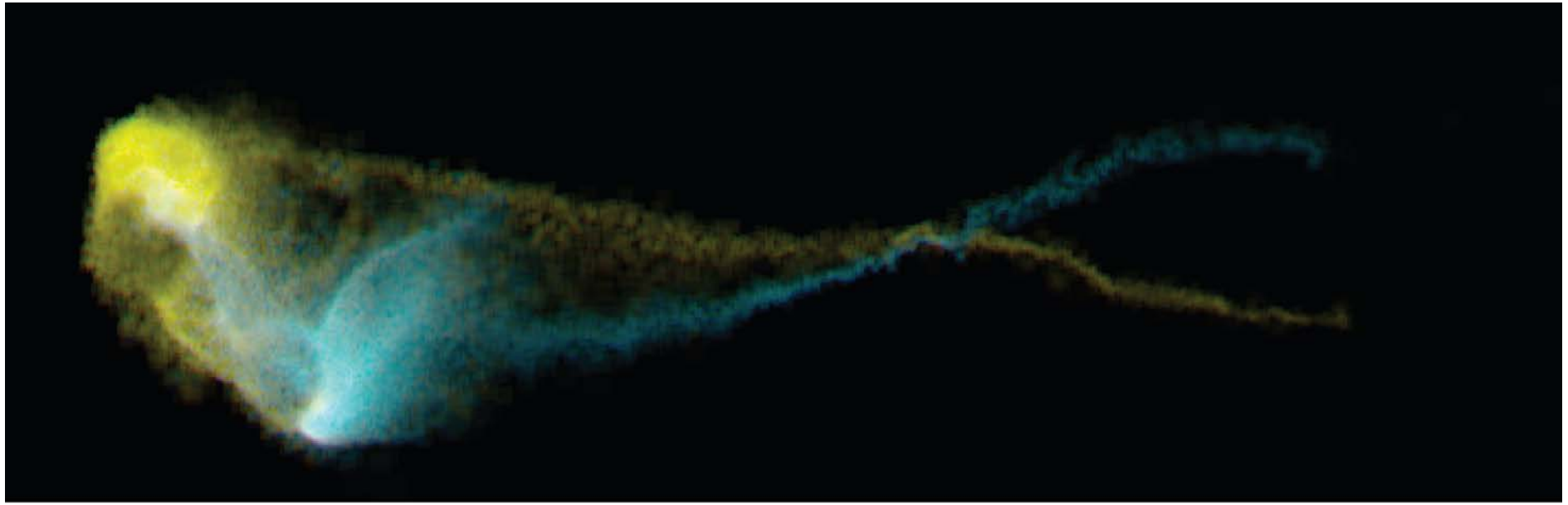
Stream has potential to elevate Galactic SFR

Total inflow rate in Magellanic Gas: ~4–7 $M_\odot yr^{-1}$ (~$M_{gas}v/d$; d=55–100 kpc and v=–100 km s^{-1})

Total inflow rate in all other HVCs: ~0.4–1.4 $M_\odot yr^{-1}$ (Lehner & Howk 2011)

Milky Way SFR = 1.9 ± 0.4 $M_\odot yr^{-1}$ (Chomiuk & Povich 2011)

but gas has to survive trip to disk to fuel future star formation



Motivation for the Magellanic Corona

1) High mass of the LMC: $M_h(LMC) \approx 10^{11}\ M_\odot$ inferred from
   - Deflections to stellar streams (Erkal+2018, 2019)
   - Detection of galaxies in Magellanic group (Bechtol+ 2015, Kallivayalil+ 2018)

   A high-mass LMC should have a warm CGM at $T_{vir} > 10^5$ K (virial theorem)

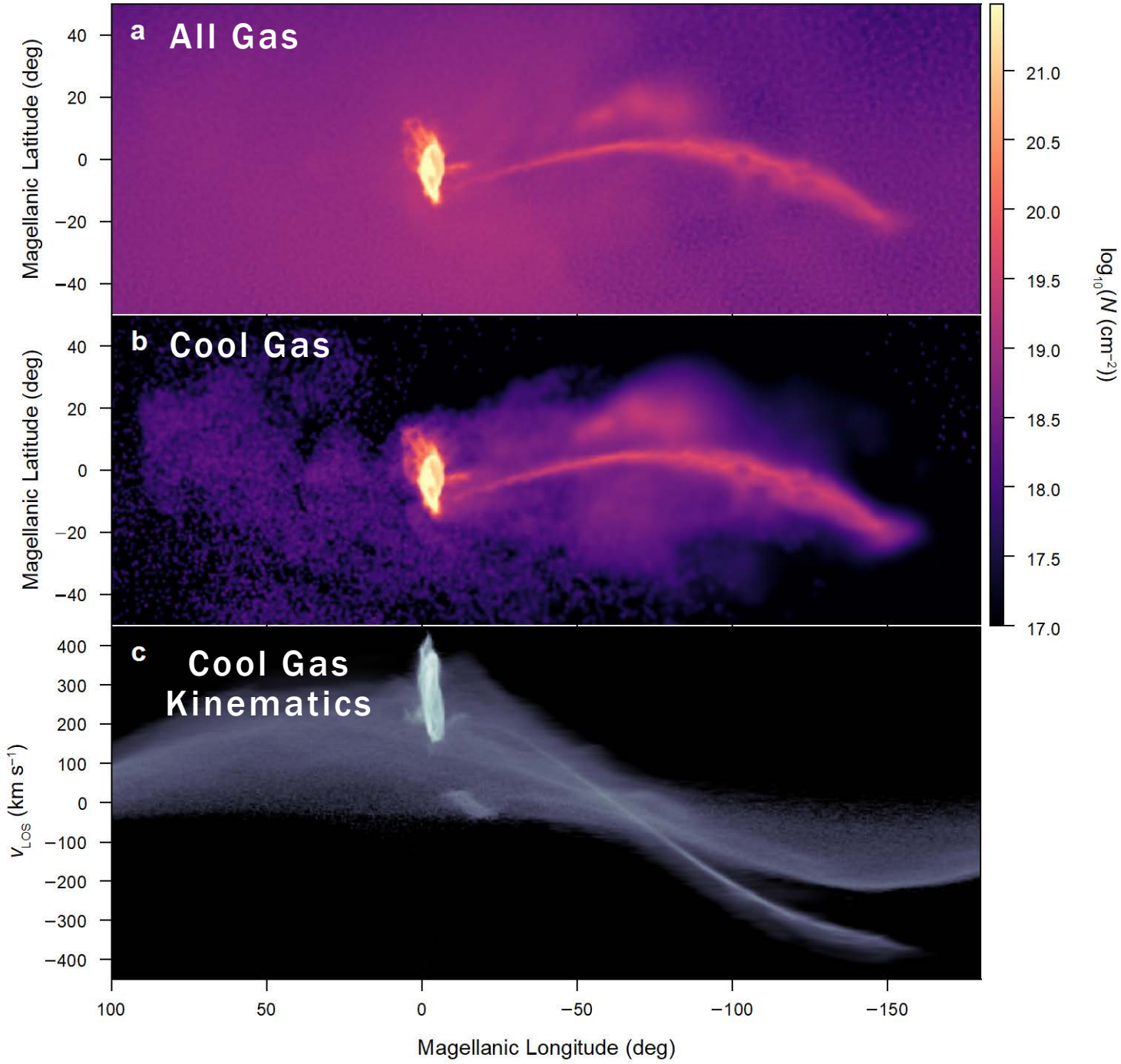
2) Detection of C IV & Si IV absorption in spectra of hot LMC stars (Wakker+ 1998, Lehner & Howk 2007)
   - Tentative detection of the corona?

What does a Magellanic Corona do to the Magellanic Stream?

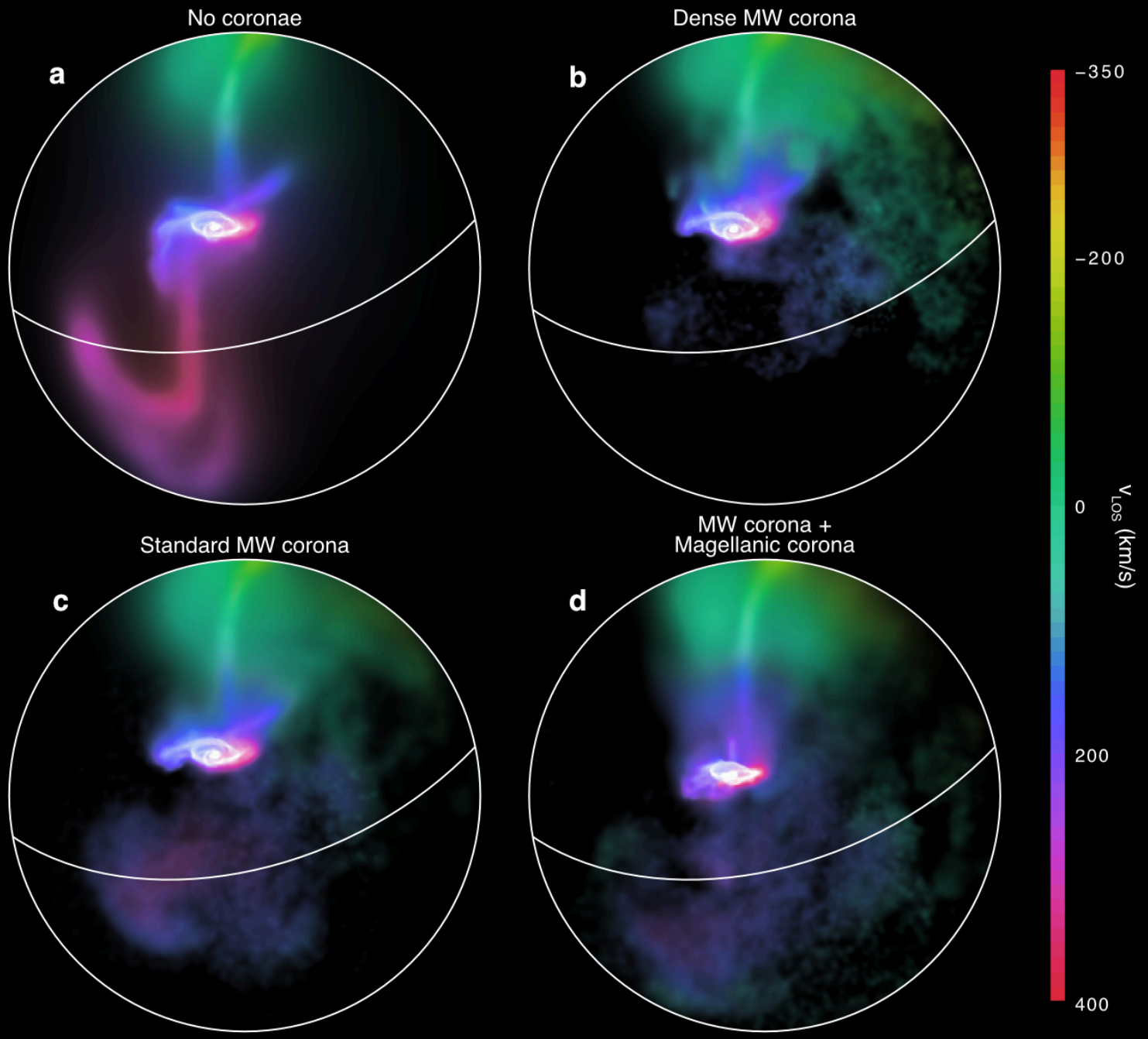
Scott Lucchini

Lucchini, D'Onghia, Fox et al. 2020, Nature

Gas Distribution Observed vs Simulated

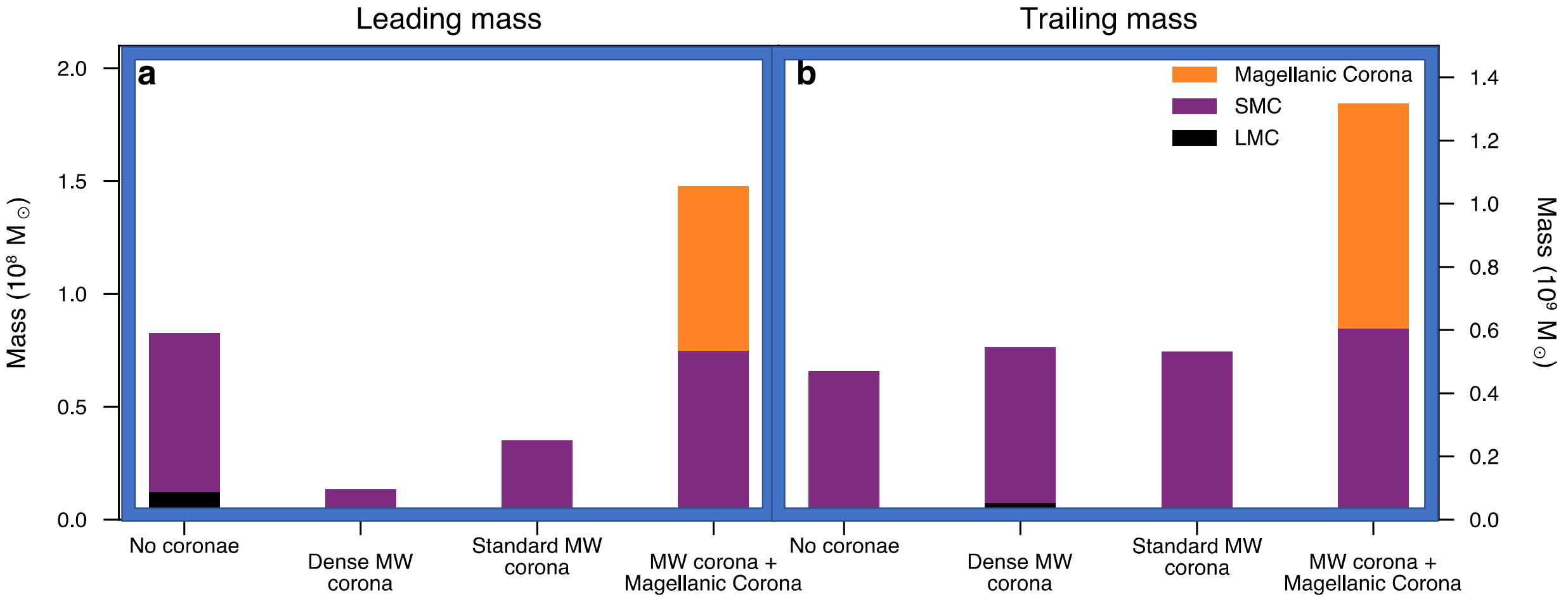


Lucchini et al.



Lucchini et al.

Why the Corona Matters – the Mass Budget



Lucchini et al.

STREAM TEAM


Fox


Richter


Wakker


Lehner


Bland-
Hawthorn


D'Onghia


Lucchini


Howk


Bustard


Barger


Haffner


Casetti-Dinescu


Westmeier


Kumari


Rodriguez-Hidalgo


Thom

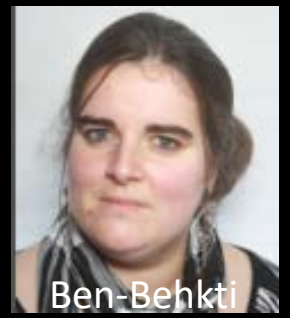

Tumlinson


Charlton


Ely


Hernandez


Fechner

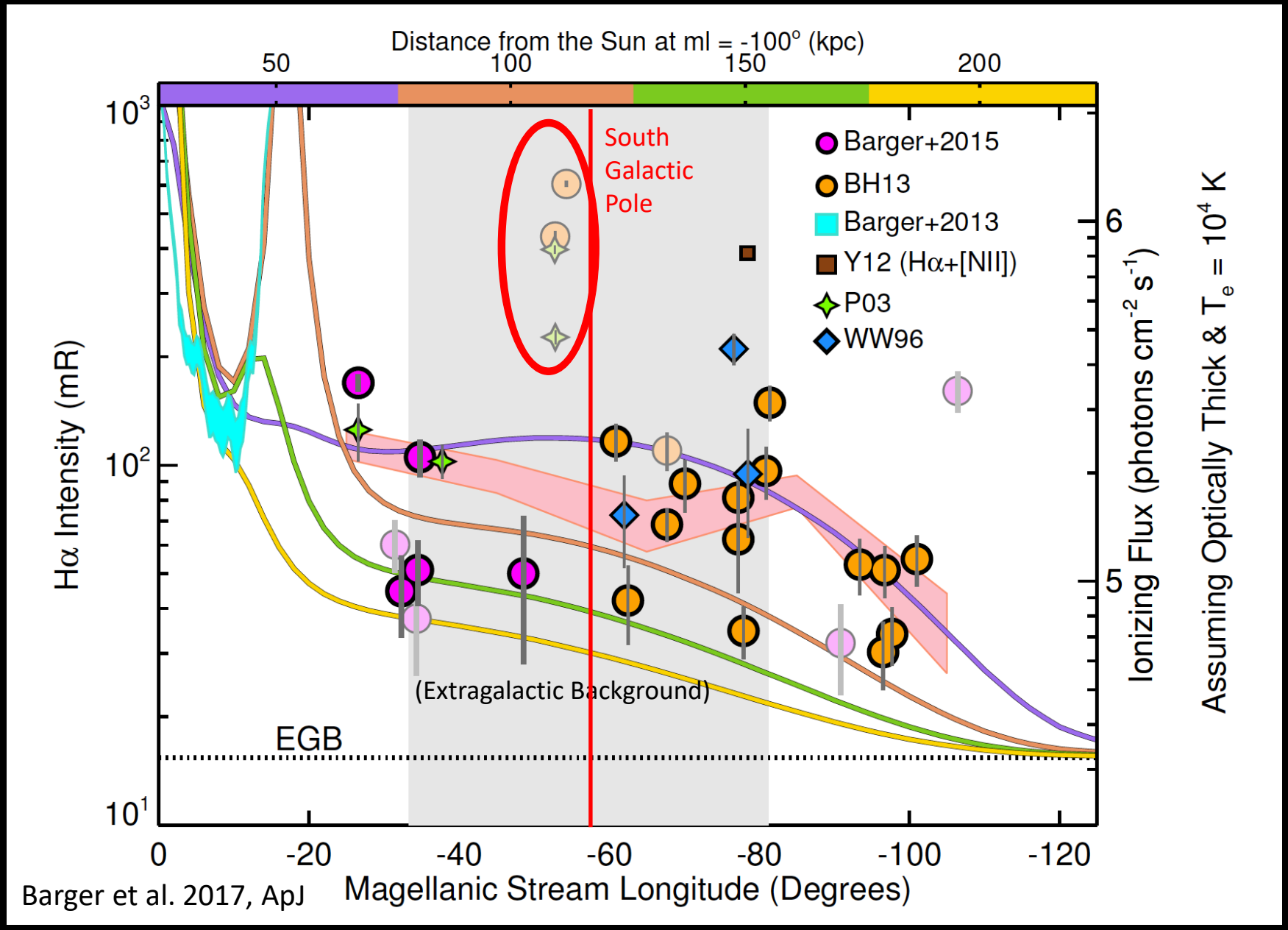

Ben-Behkti


Misawa


Zweibel

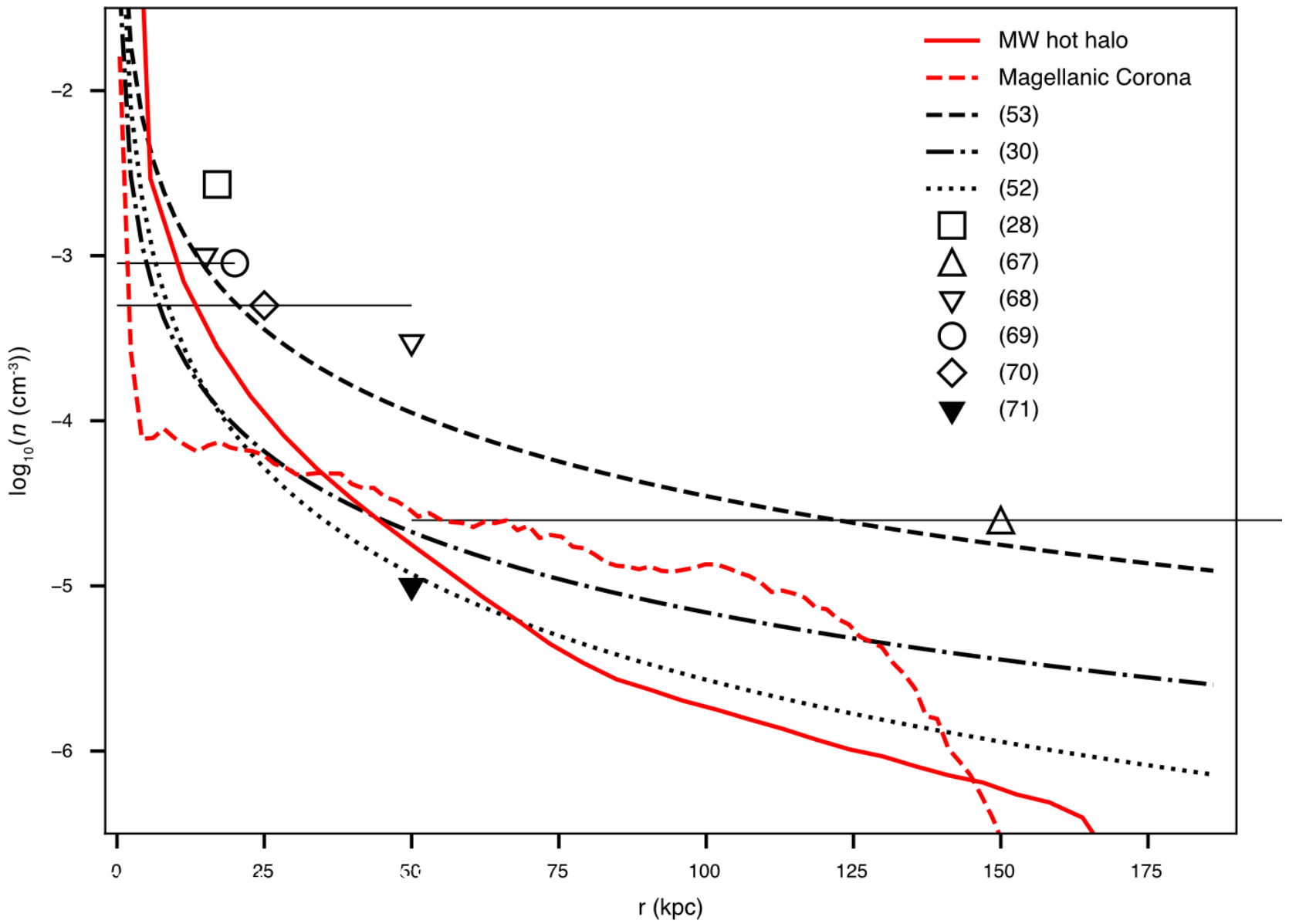
Ionized Gas **Emission** from Stream (Hα)

Wisconsin Hα Mapper (WHAM) Telescope



Barger et al. 2017, ApJ

Radial Density Profiles of Coronae



LMC-SMC Separation vs. Time