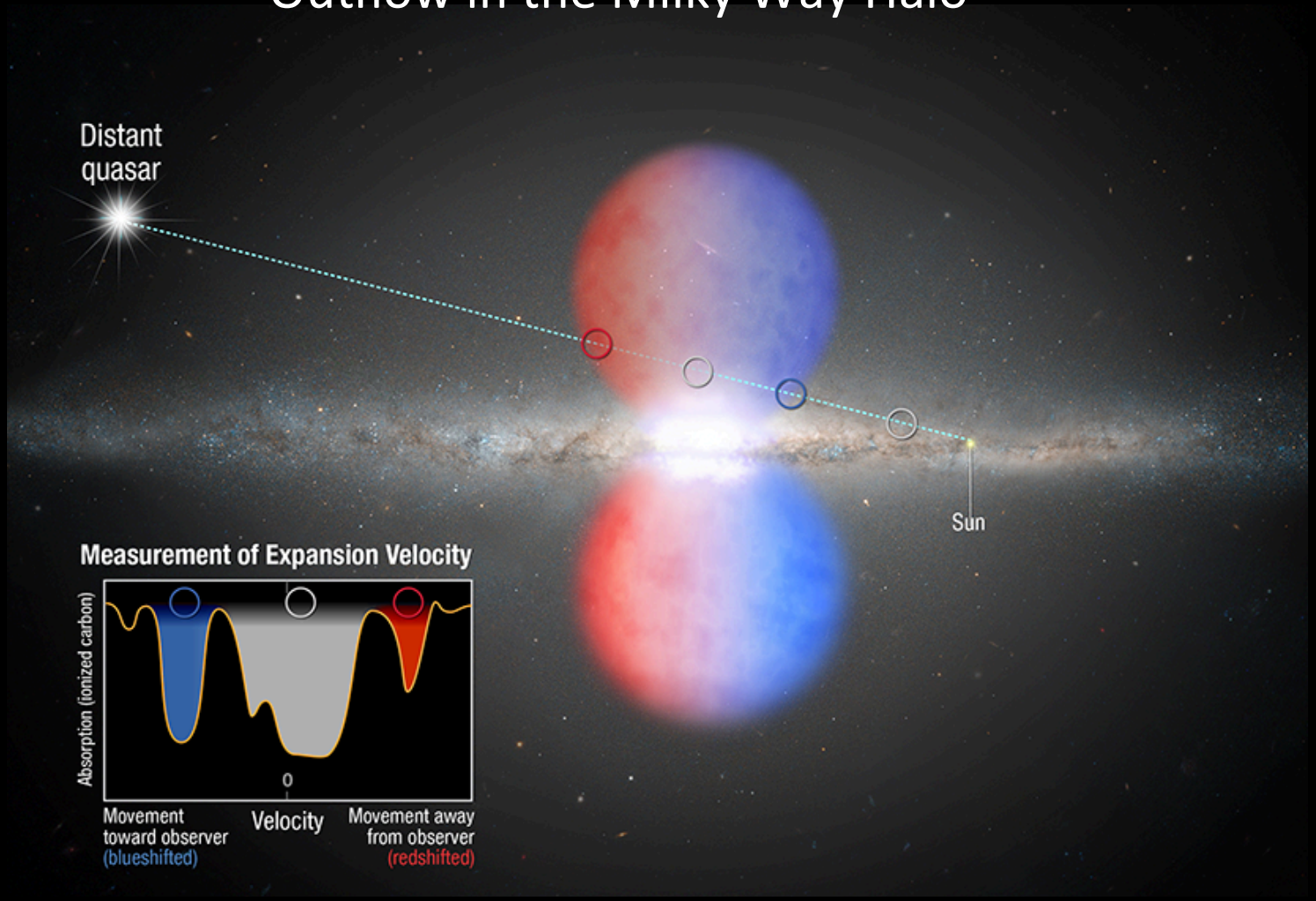
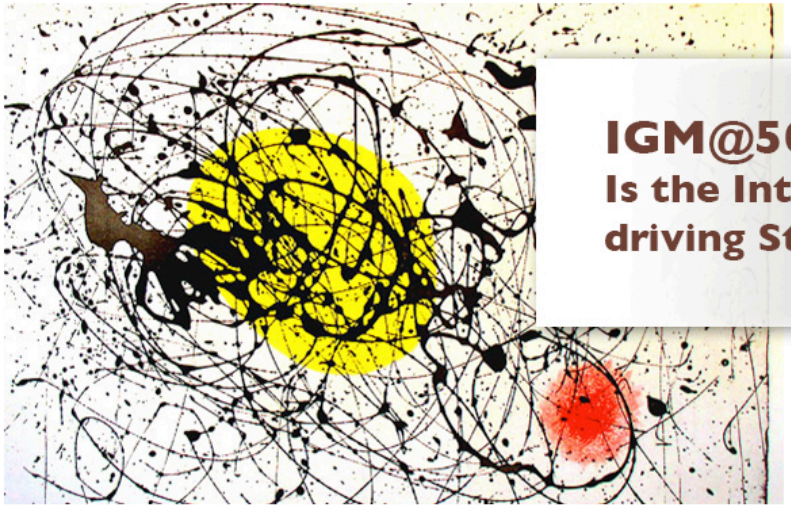
Hubble Observations of Inflow and Outflow in the Milky Way Halo



Andrew Fox, STScI

IGM@50, Spineto, June 2015



IGM@50
Is the Intergalactic Medium driving Star Formation?

International Conference
June 8-12 2015
Abbazia di Spineto
ITALY

Intro: UV high-velocity clouds (HVCs) as tracers of in/outflow

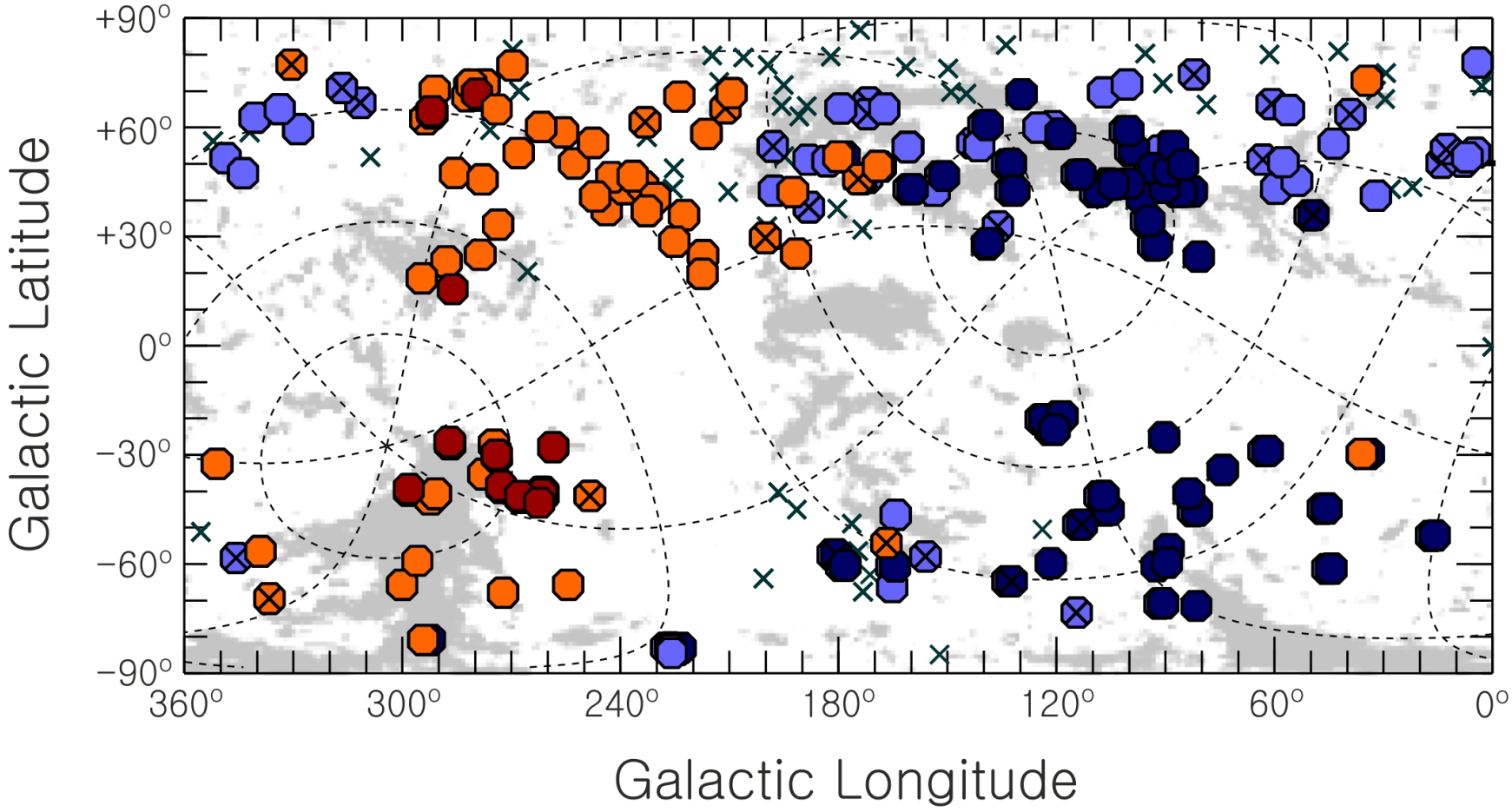
Part I: Galactic Center Outflow

Part II: Magellanic Stream (Inflow)

All sky map of *HST*/COS AGN sightlines

241 sightlines with **any S/N [**as of Jan 2015]
coded by velocity of Si III absorption
orange = v_{LSR} >+100 km s^{-1} ; blue = v_{LSR}<-100 km s^{-1} ; x=no detection

from Philipp Richter



see Shull+ 2009, Collins+ 2009, Lehner+2012, Herenz+2013, Richter+2015, also Sembach+ 2003, Fox+ 2006 for O VI

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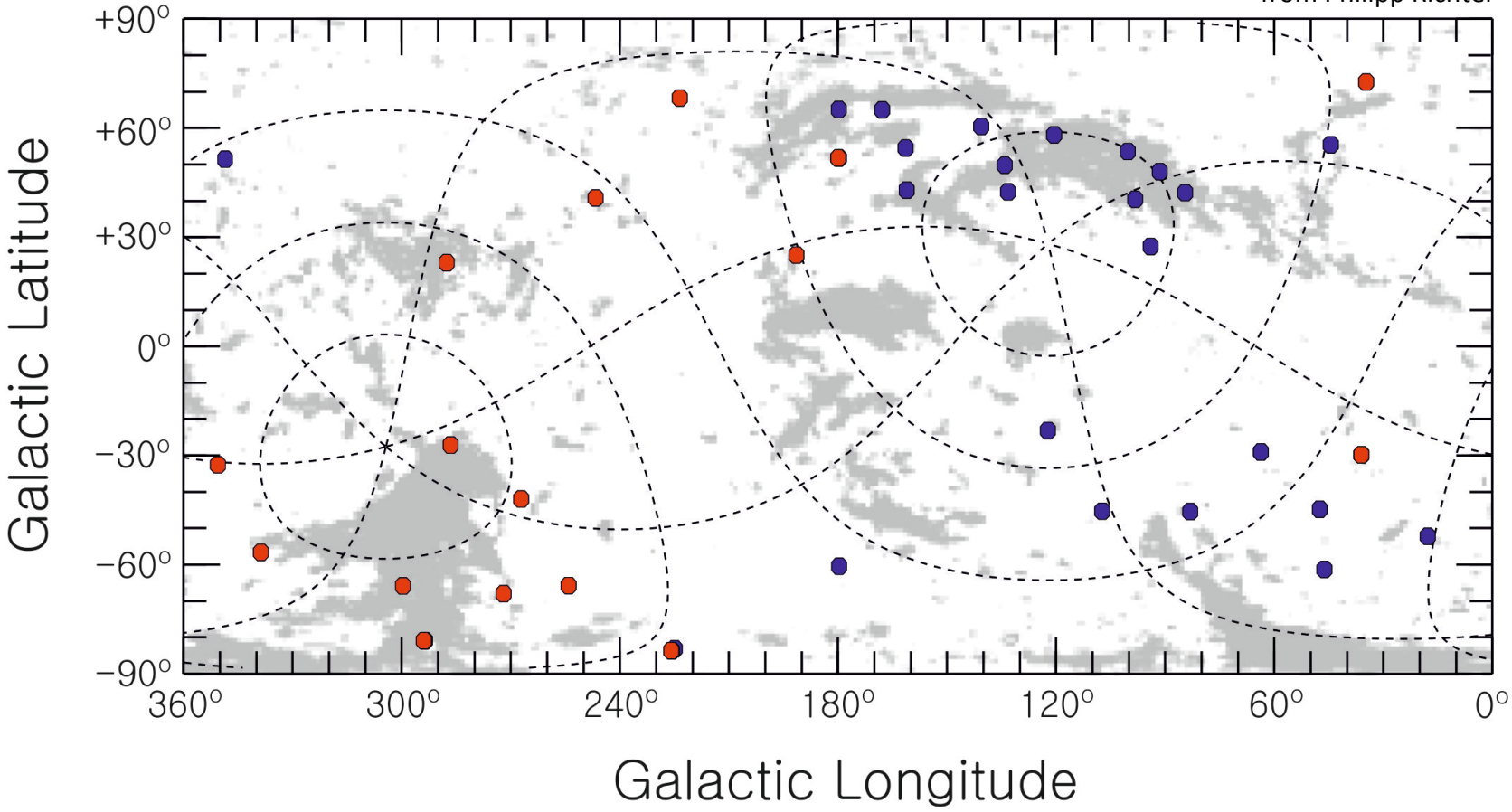
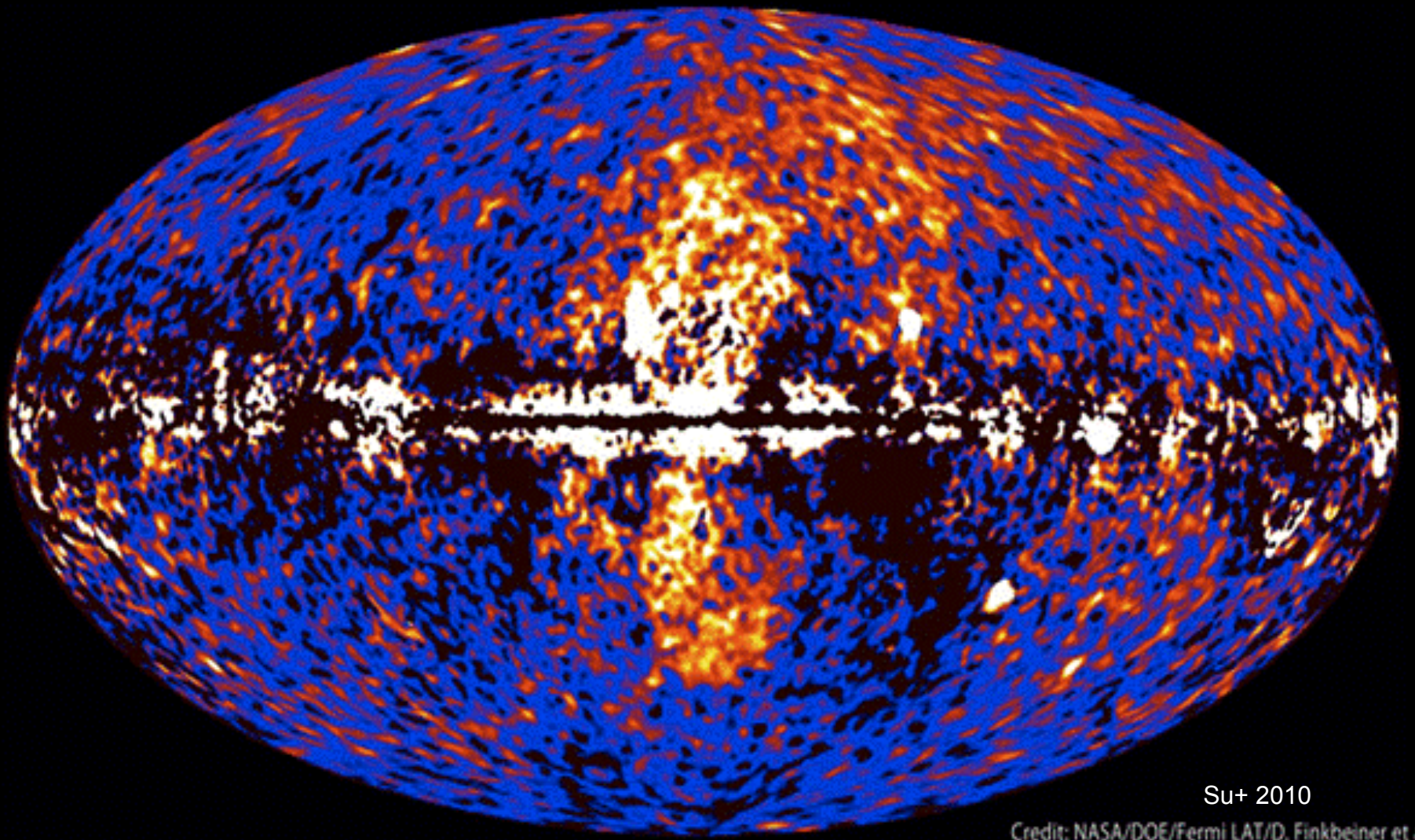


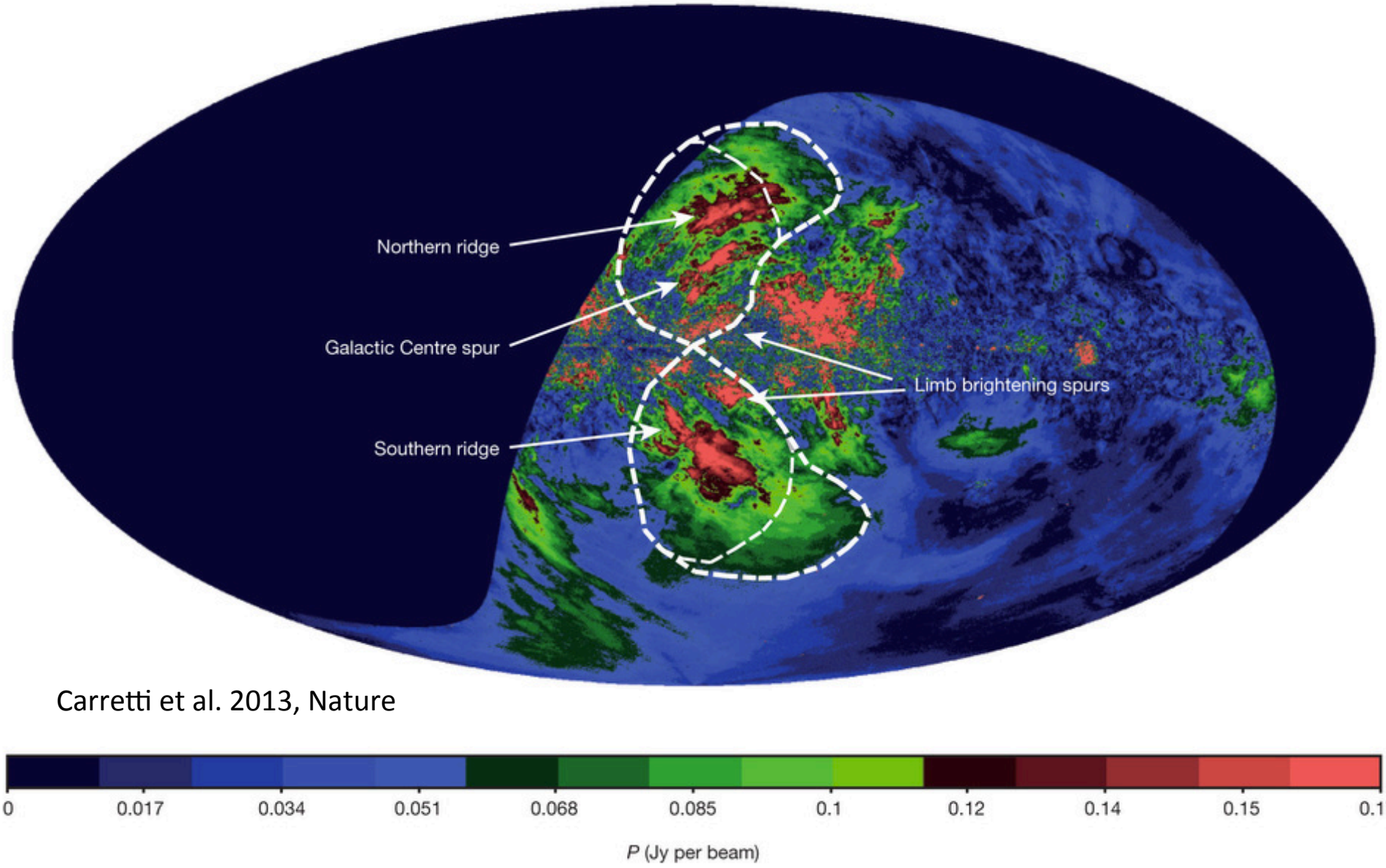
f_{cov}~68% for UV HVCs at |*b*|>20° and |v_{LSR}|>90 km s^{-1} (Lehner+2012)

Part I: Outflowing Gas

The Galactic Center



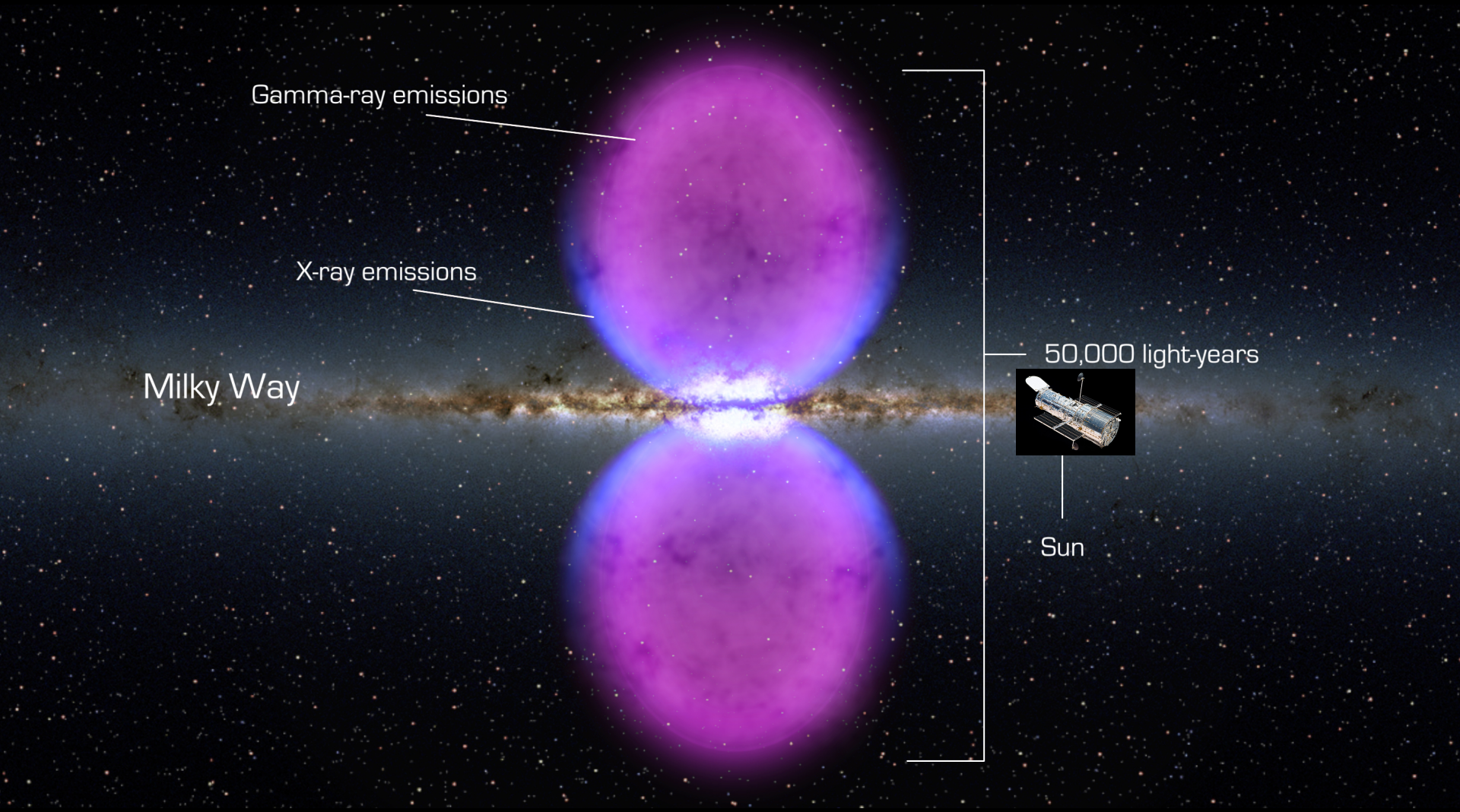
Fermi Bubbles (FBs; γ-rays)



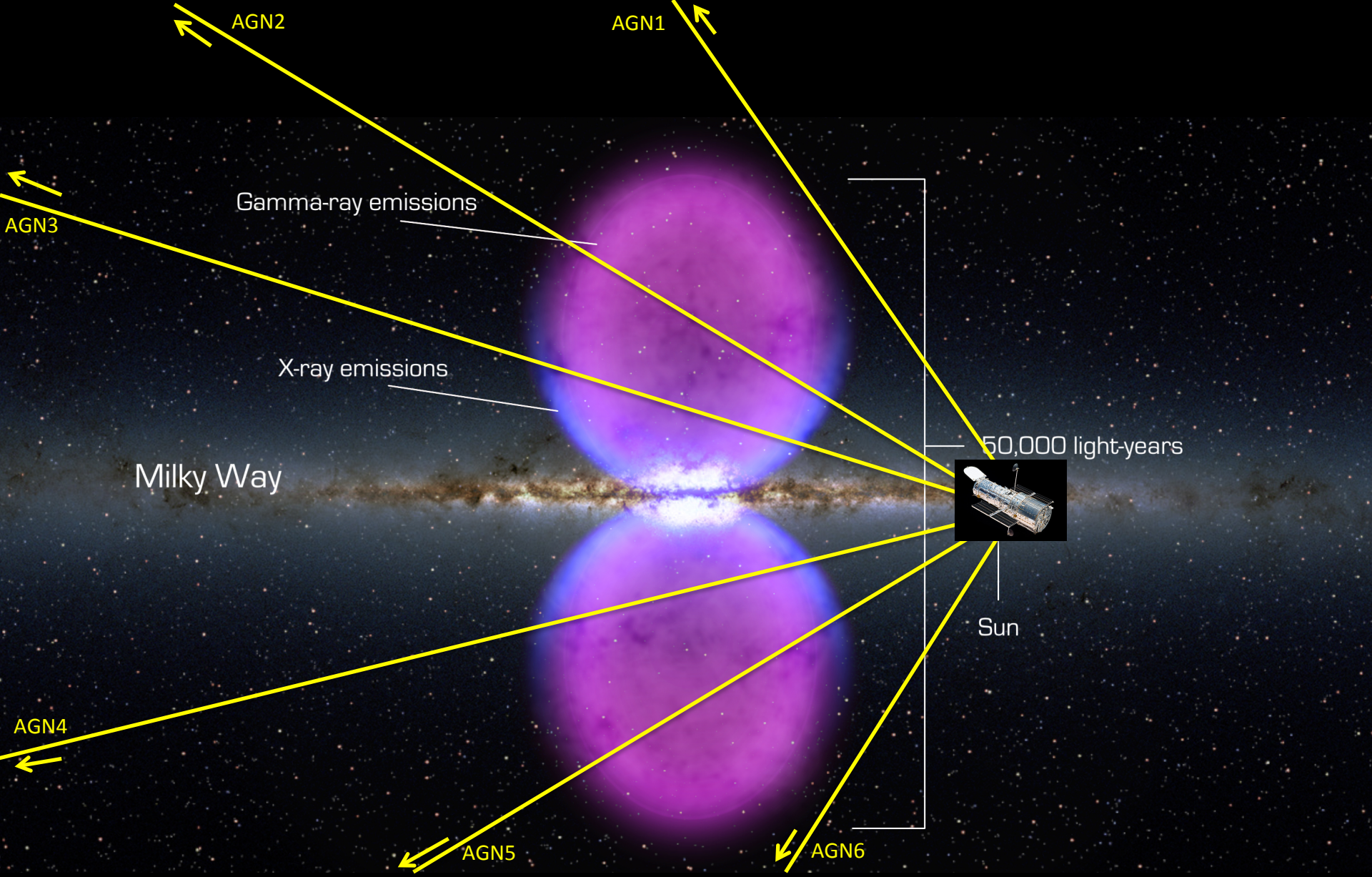
Carretti et al. 2013, Nature

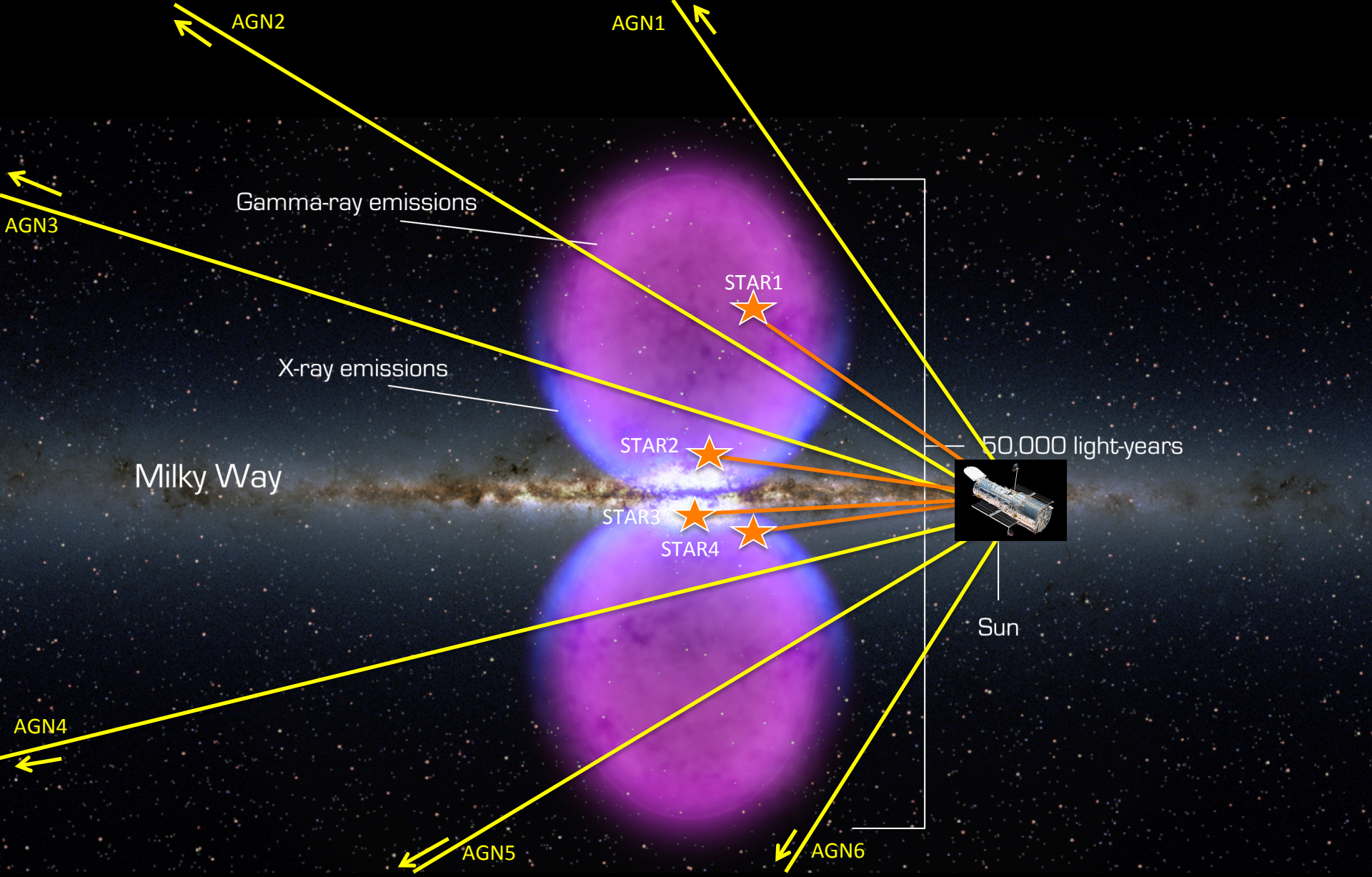
Polarized Radio Emission 2.3 GHz (Synchrotron); E_{mag}~10^{55} erg

A Hubble Experiment



NASA/GSFC


AGN2
AGN1
AGN3
Gamma-ray emissions
X-ray emissions
Milky Way
50,000 light-years
Sun
AGN4
AGN5
AGN6
NASA/GSFC


AGN2
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Gamma-ray emissions
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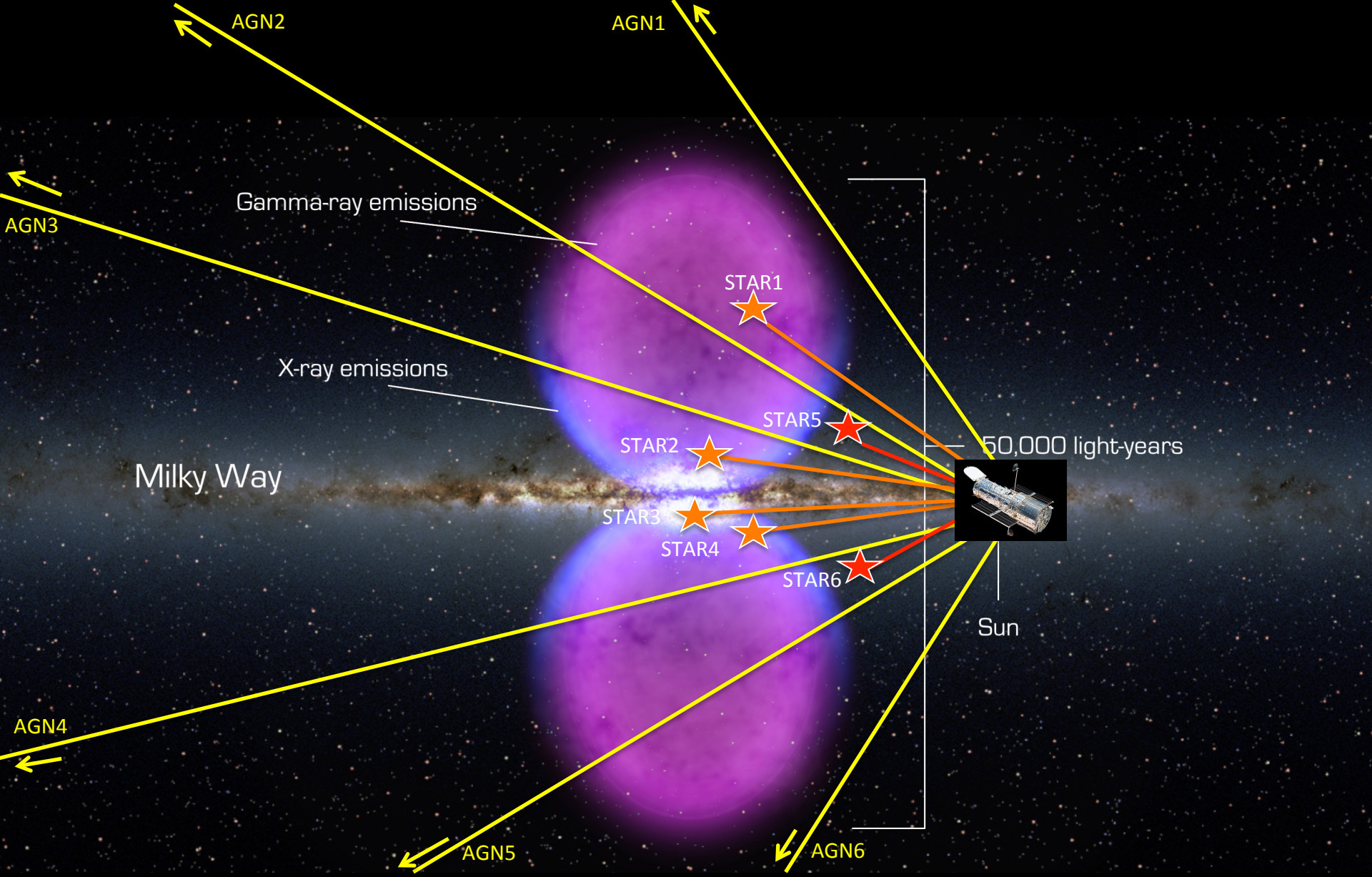
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STAR6
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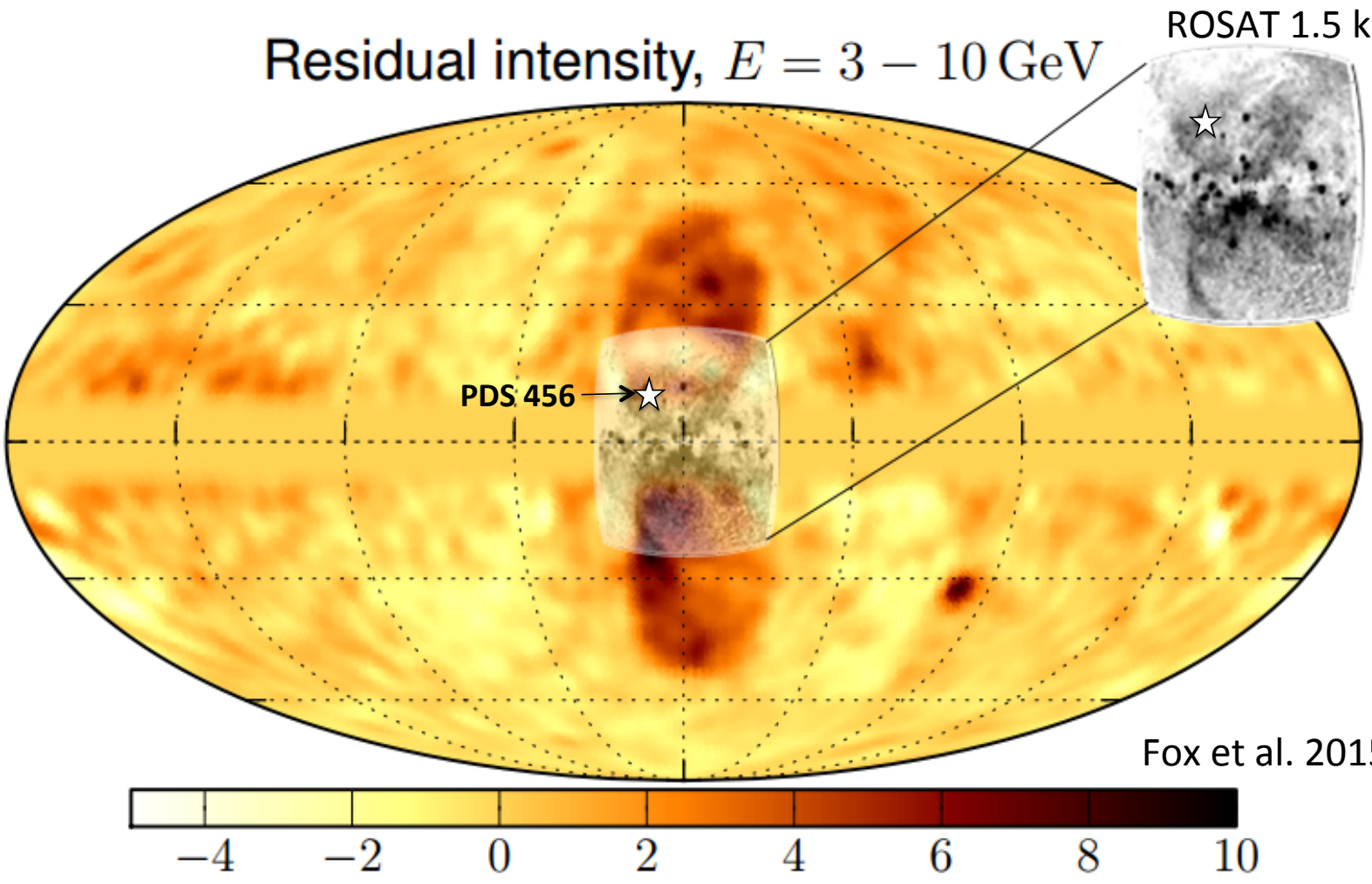
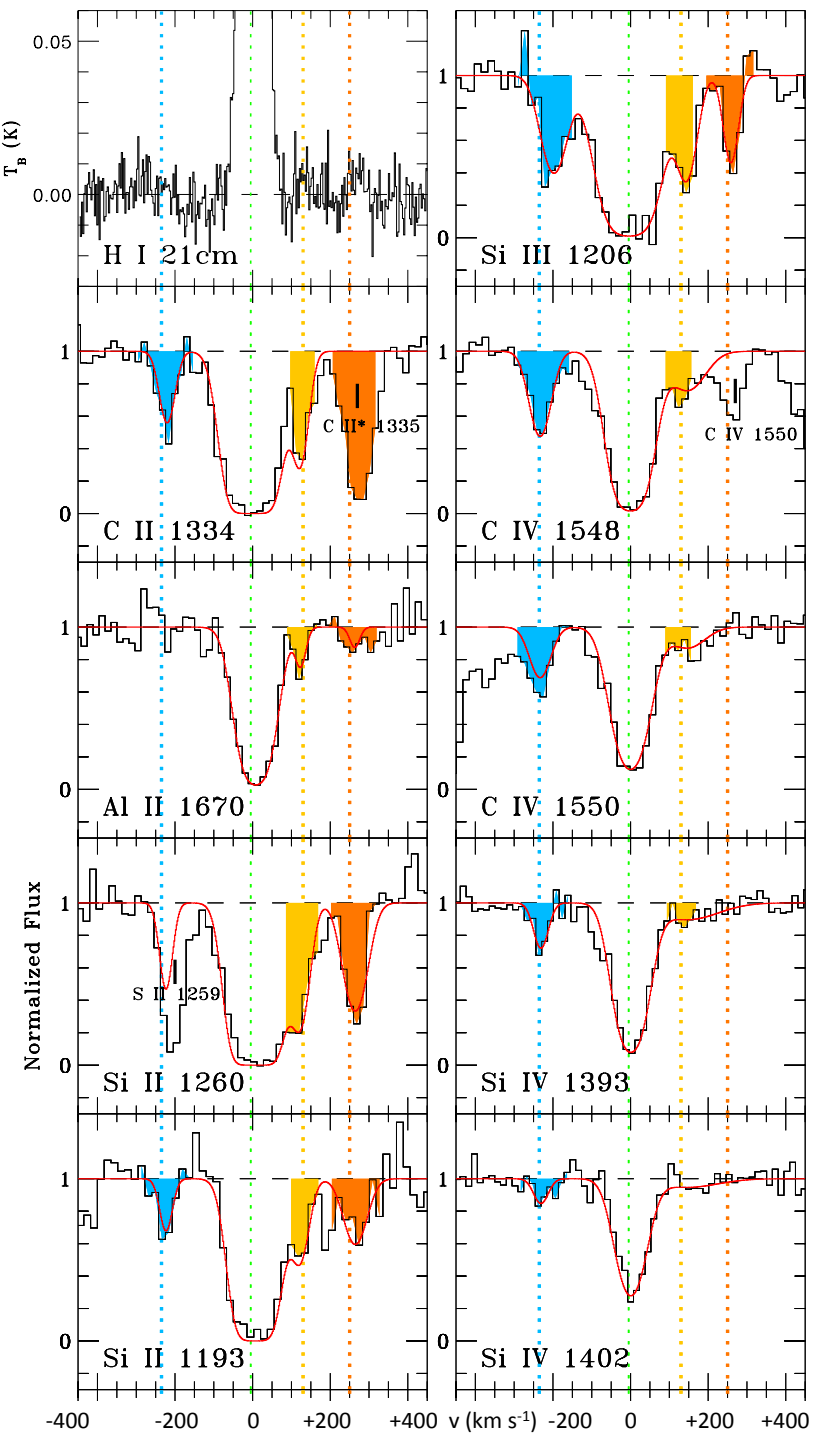
AGN4
AGN5
AGN6
NASA/GSFC

First Results: toward QSO PDS 456 (*l*, *b*=10.4°, +11.2°)



Fox et al. 2015



Hubble/COS spectra

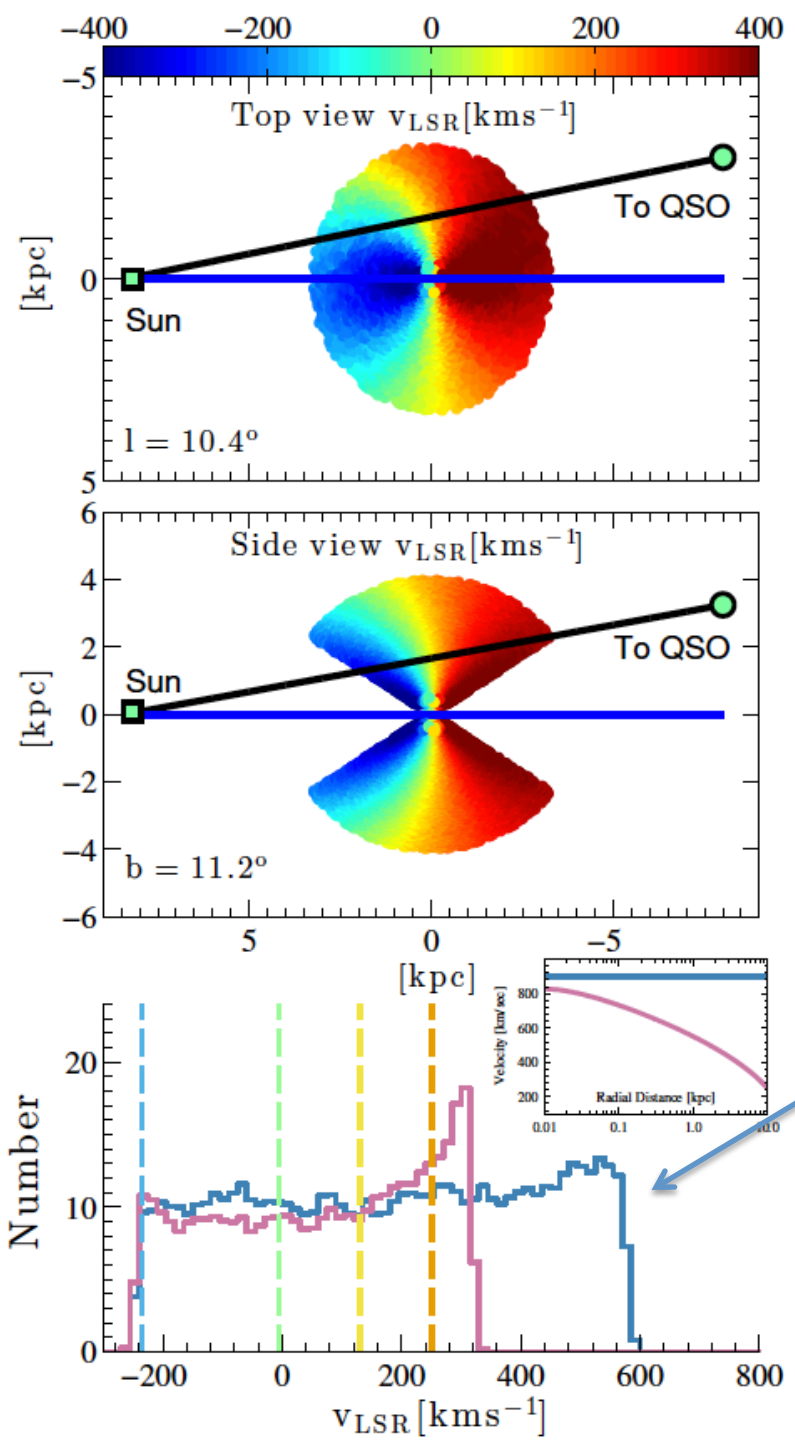
Three high-velocity components seen at LSR velocities of −235, +130, +250 km s^{-1}

Seen in low ions (C II, Si II, Al II, Si III; T~10^4 K) and high ions (C IV, Si IV; T~10^5 K) -> multiphase gas

No Green Bank Telescope H I 21 cm emission down to N(H I)=3×10^{17} cm^{-2} (3σ) -> highly ionized

Unlikely to be foreground HVCs given number of components and ~symmetric velocities ±250 km s^{-1}

Interpretation: seeing near (blueshifted) and far (redshifted) side of expanding biconical Galactic wind



Kinematic Biconical Outflow Models

Cone opening angle =100−110° to match X-rays

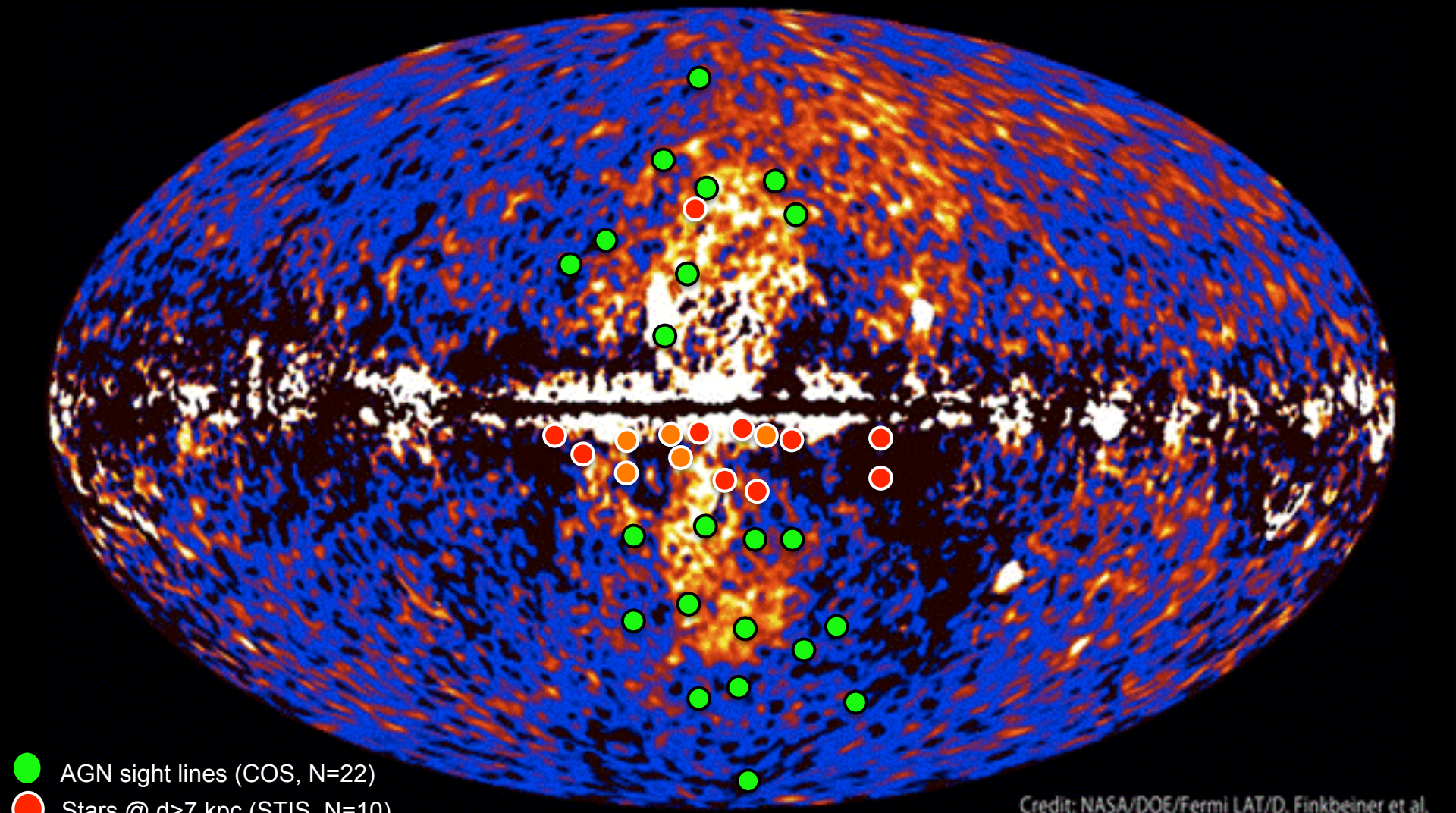
Infer outflow velocity ≈900−1000 km s^{-1} (to match HV components)

velocity distribution after 100 model realizations

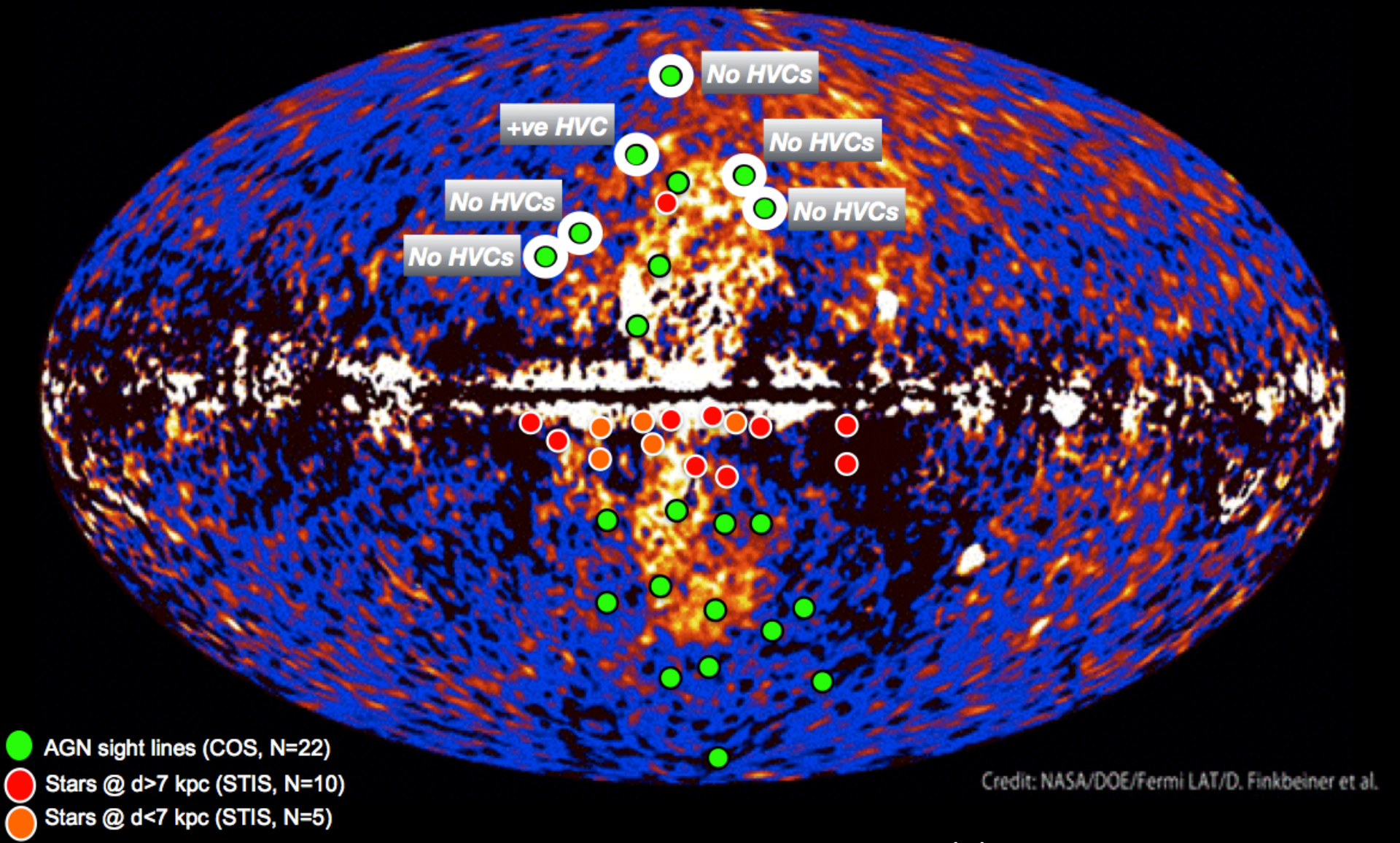
Momentum-driven (ballistic) wind (purple) favored over constant-velocity wind (blue)

Implied wind age ≈2.5−4.0 Myr matching Fermi Bubble age estimates

Our Cycle 21 *HST* program: UV-bright targets in GC region

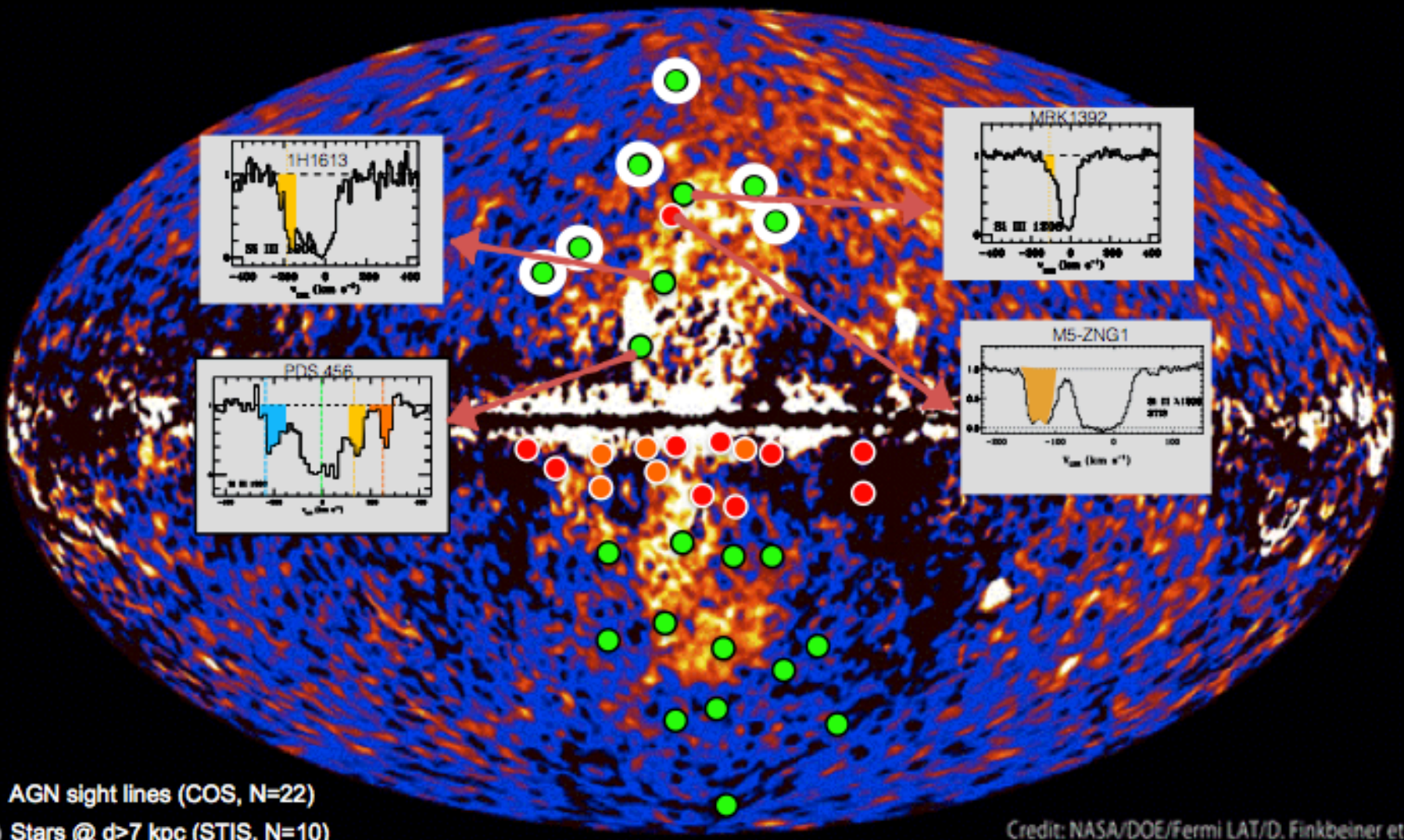


Preliminary results



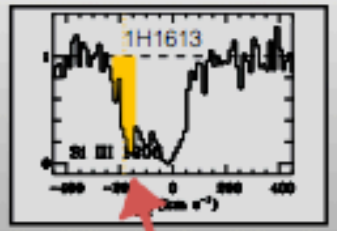
Bordoloi+ 2015, in prep.

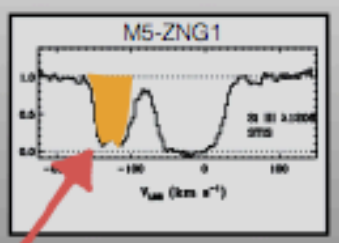
Preliminary results

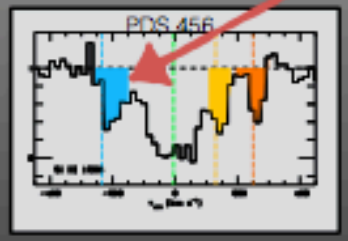


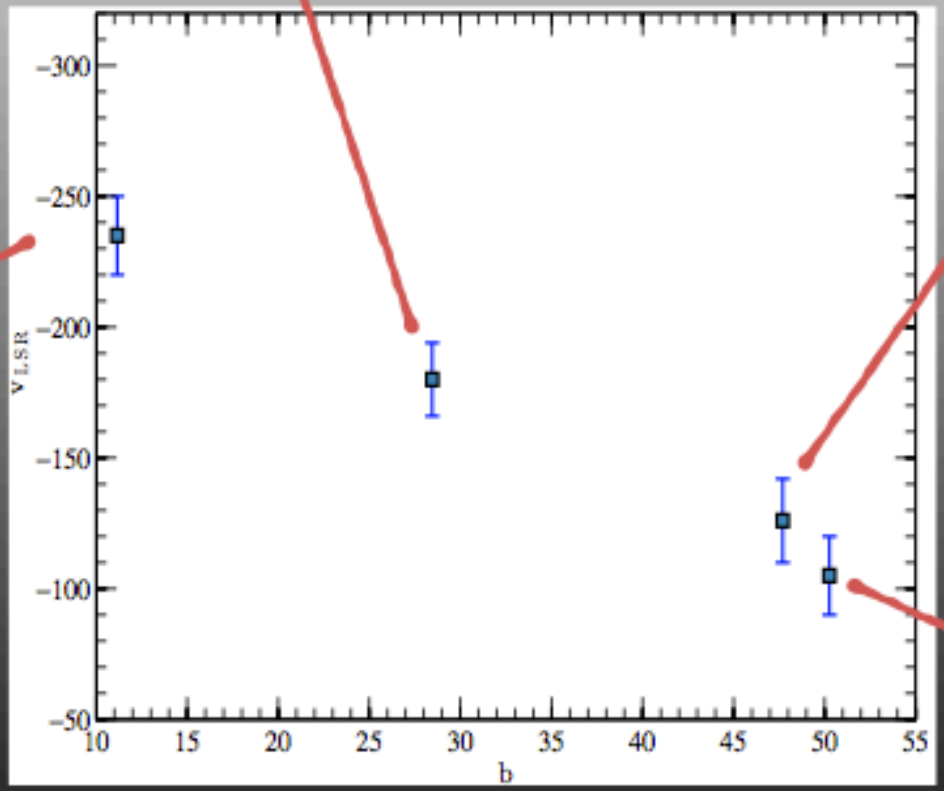
Bordoloi+ 2015, in prep.

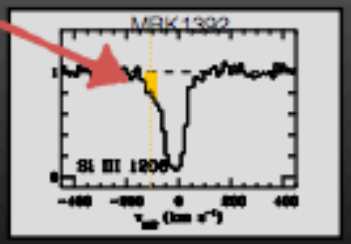
Projected Outflow velocity Radial Profile











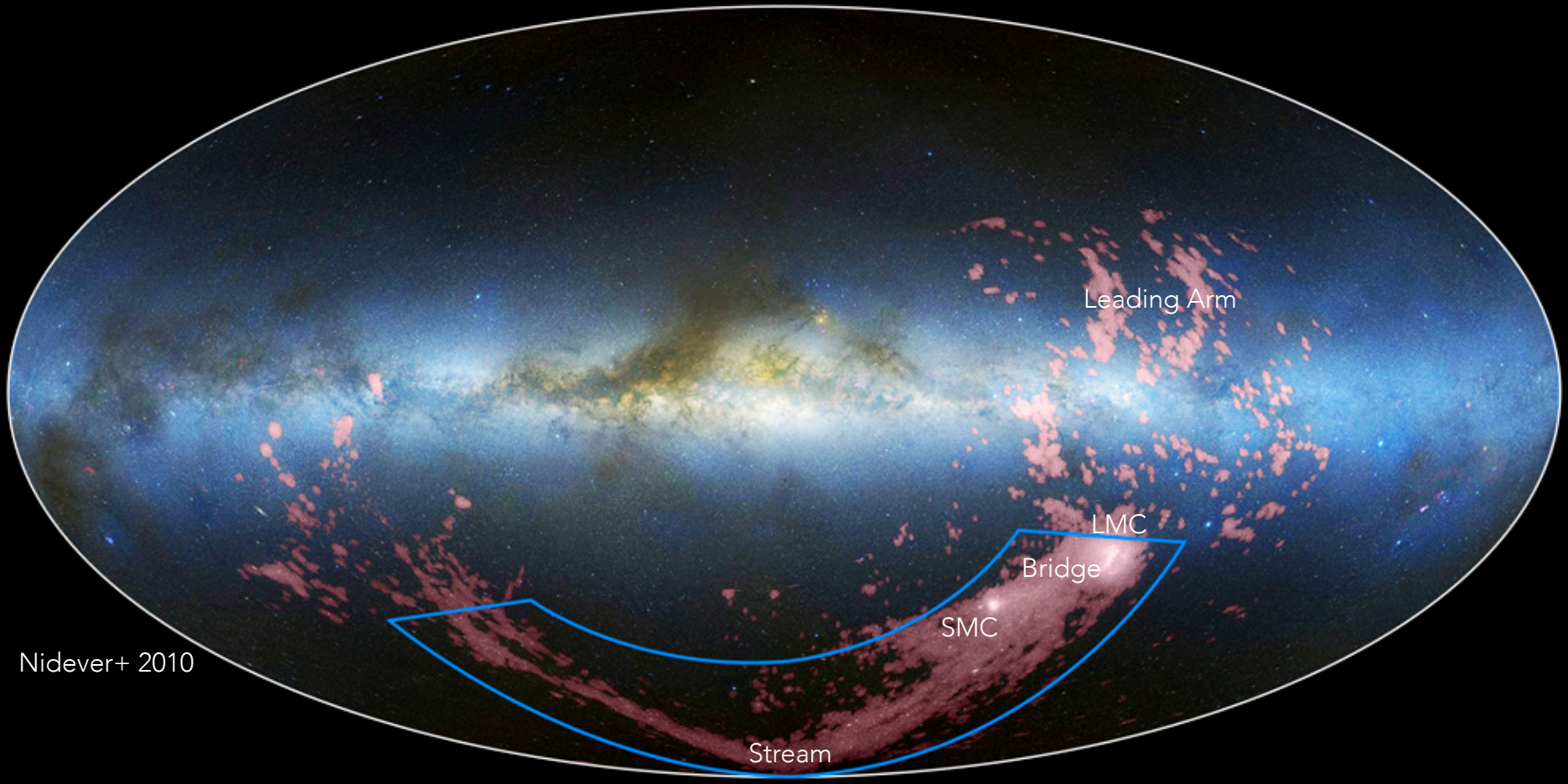
Bordoloi+ 2015, in prep.

Part II: Inflowing Gas

The Magellanic Stream

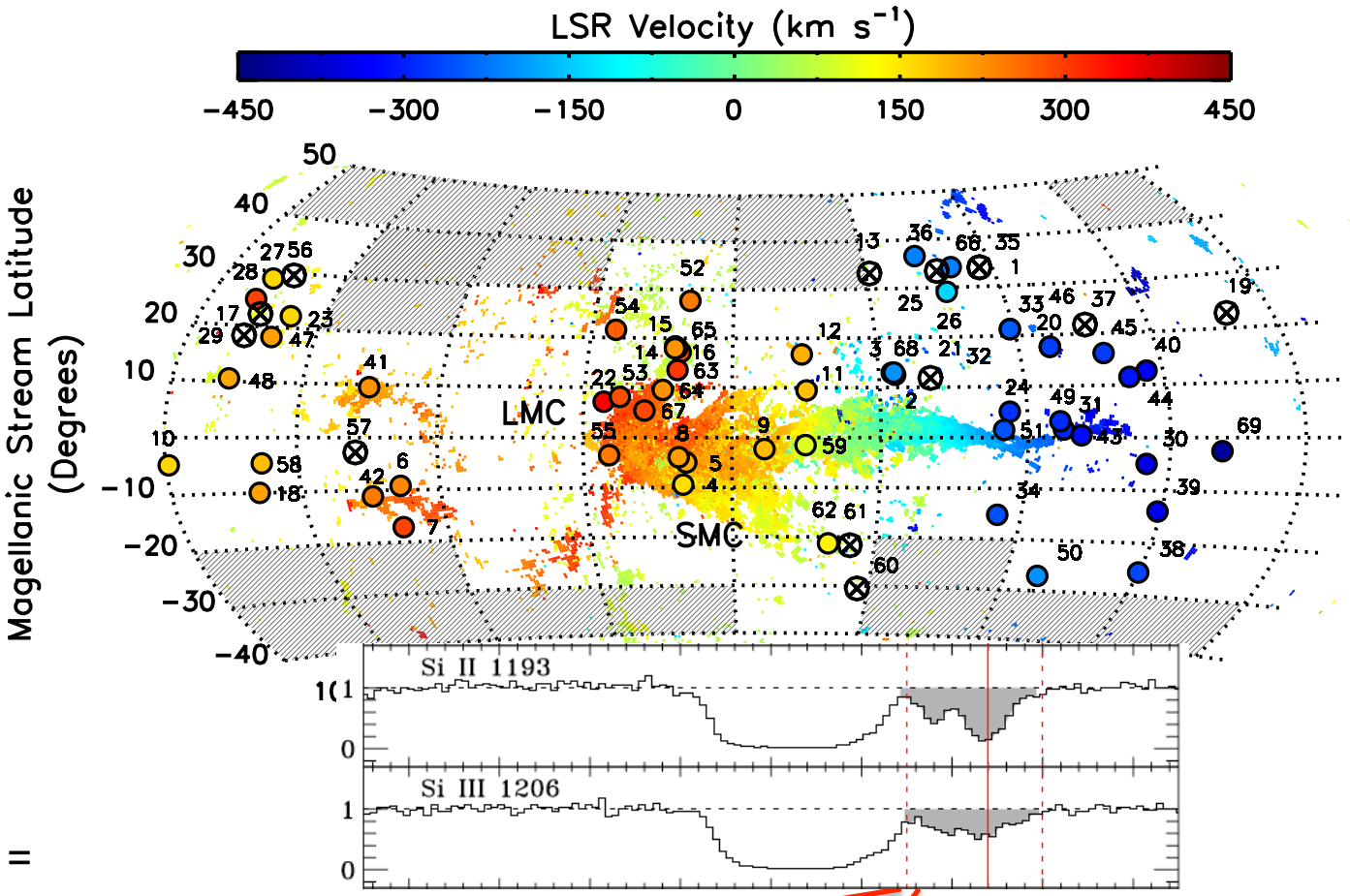
The Magellanic Stream

LAB Radio Survey



- Extended filament trailing Magellanic Clouds
- ~2×10^8 $M_\odot$ in H I gas (Brüns+ 2005)
- Great tracer of gaseous accretion

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



Gas Mass =

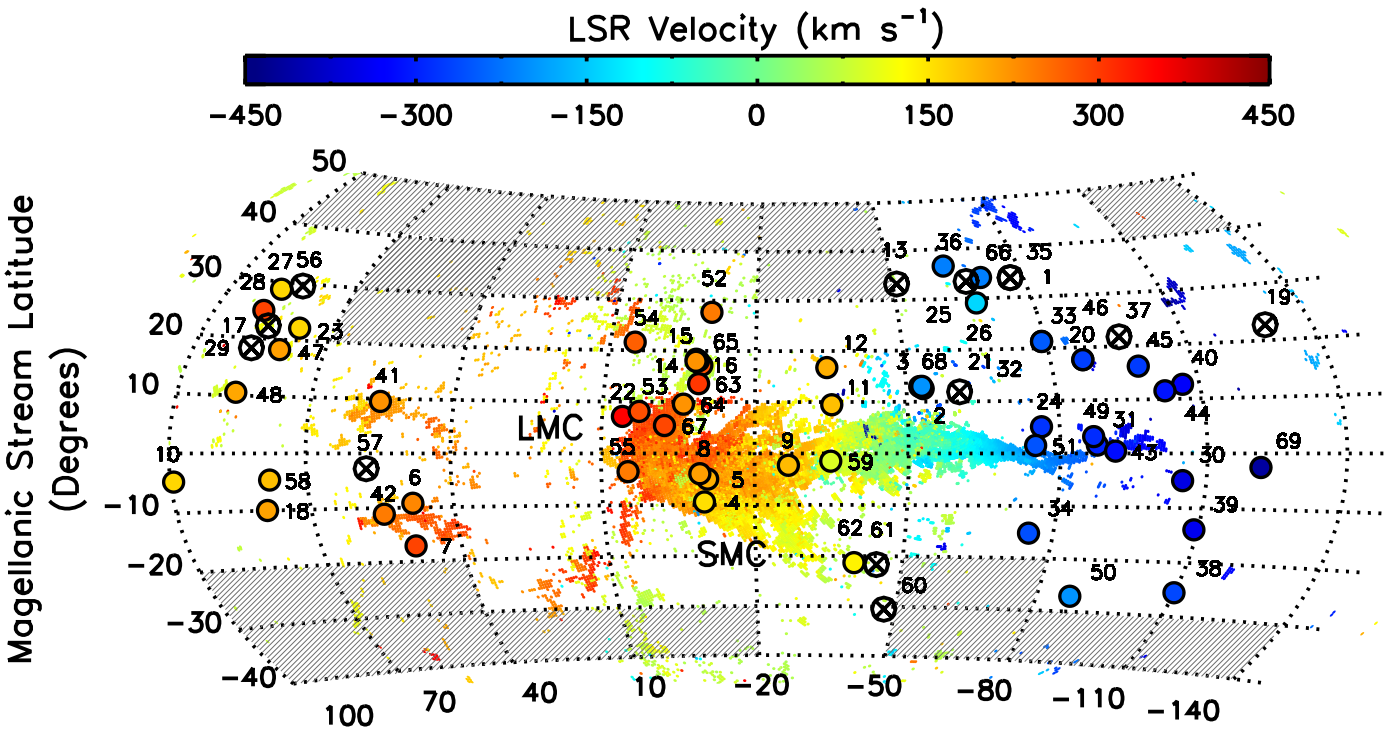
= 4.9×10^8 M$_\odot$ + ~10×10^8 M$_\odot$ + ~5×10^8 M$_\odot$

from photoionization modeling to Si III/Si II ratios

~2×10^9 M$_\odot$ if d=55 kpc

~twice the current-day ISM mass of the Magellanic Clouds (0.8×10^9 M$_\odot$)

Magellanic gas can elevate Galactic SFR if it reaches disk



Total MS inflow rate: ~4–7 $M_\odot yr^{-1}$ for *d*=55–100 kpc and *v*=–100 km s^{-1}

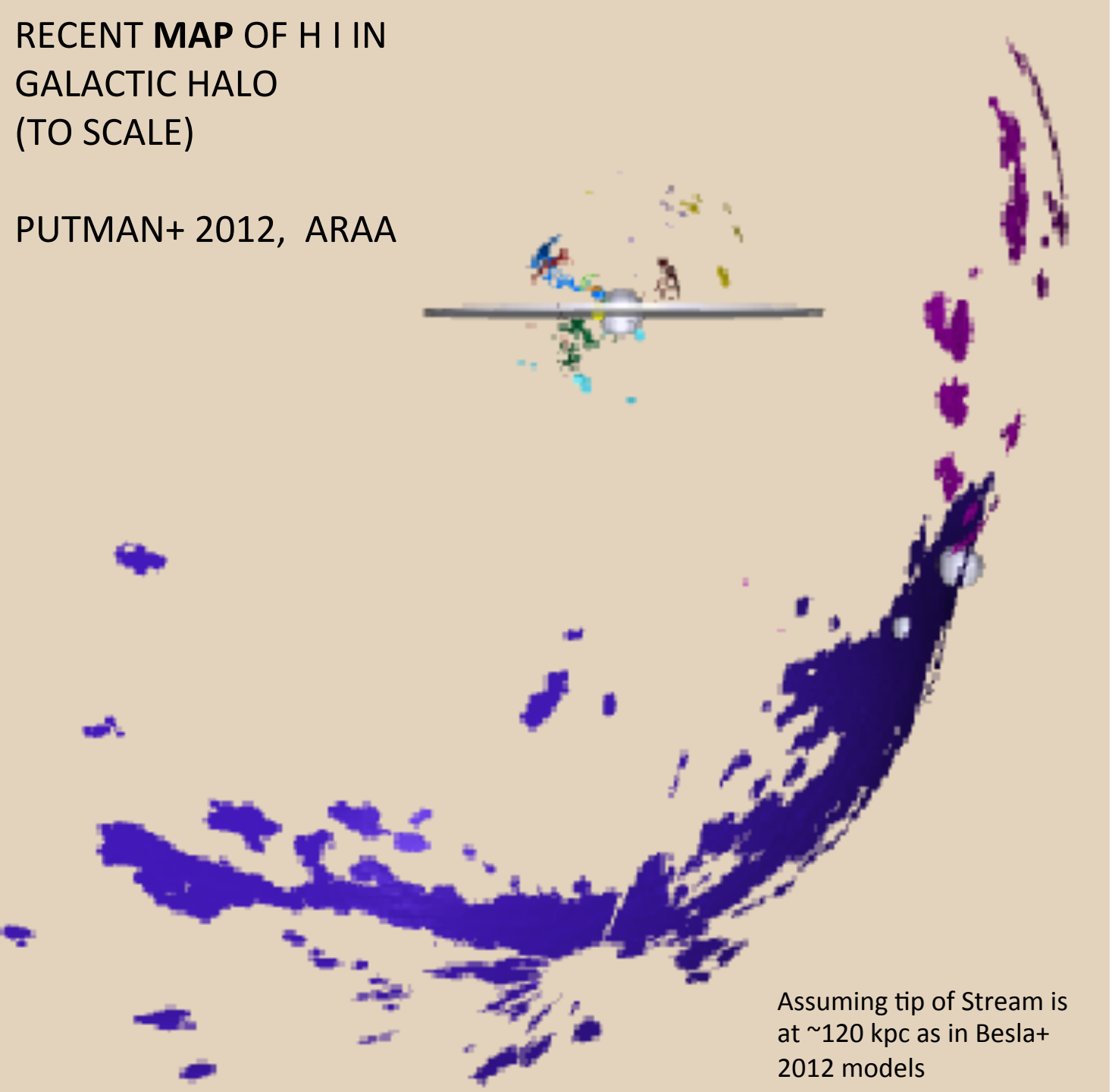
Total HVC inflow rate: 0.1–1.4 $M_\odot yr^{-1}$ (Putman+ 2012; Lehner & Howk 2011)

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

Big question: does the inflow survive its passage through the hot corona?

RECENT **MAP** OF H I IN GALACTIC HALO
(TO SCALE)

PUTMAN+ 2012, ARAA



Assuming tip of Stream is at ~120 kpc as in Besla+ 2012 models

Is the IGM driving star formation?

For the (future) Milky Way, no. Tidal stripping is.