TRANSITION TEMPERATURE GAS IN THE GALACTIC HALO

BLAIR D. SAVAGE
UNIVERSITY OF WISCONSIN-MADISON

WARM GAS	T ~ 5000 K
TRANSITION TEMP. GAS	T ~ 10^5-10^6 K
HOT GAS	T > 10^6 K

THE FUSE O VI SURVEY

O VI IN THE GALACTIC THICK DISK

DISTRIBUTION AND KINEMATICS OF O VI
RELATIONSHIPS WITH OTHER ISM TRACERS

THE ORIGINS OF O VI

Primary Collaborators

FUSE O VI SURVEY

Wakker et al. 2003 ApJS, 146, 1

Savage et al. 2003, ApJS, 146, 125

Sembach et al. 2003, ApJS, 146, 165

Bart Wakker University of Wisconsin

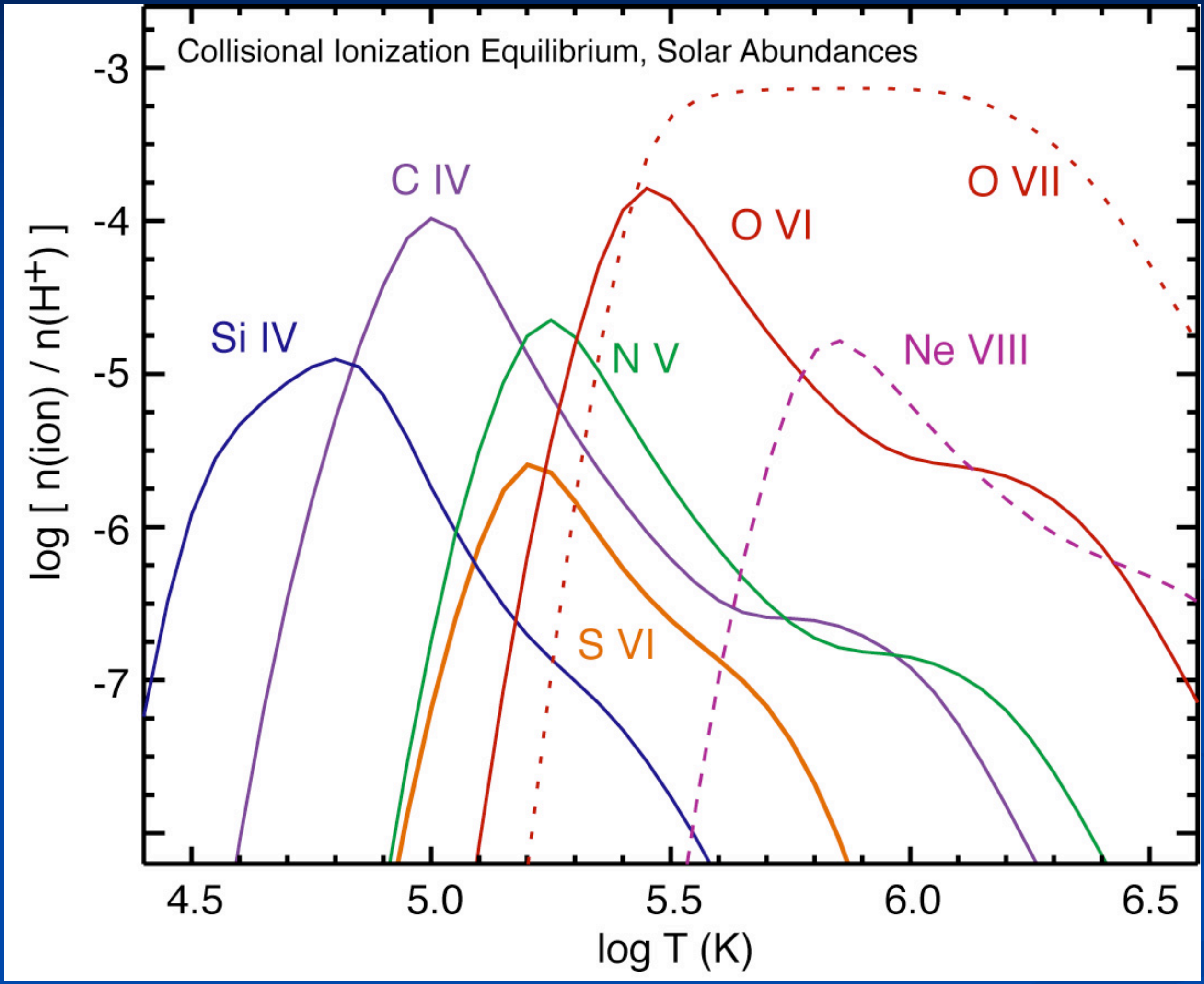
Kenneth Sembach STScI

Philipp Richter Potsdam University

Marilyn Meade University of Wisconsin

and members of the FUSE Instrument Team

High Ionization ISM / IGM Species



XMM/Chandra O VII,O VIII

FUSE O VI, S VI

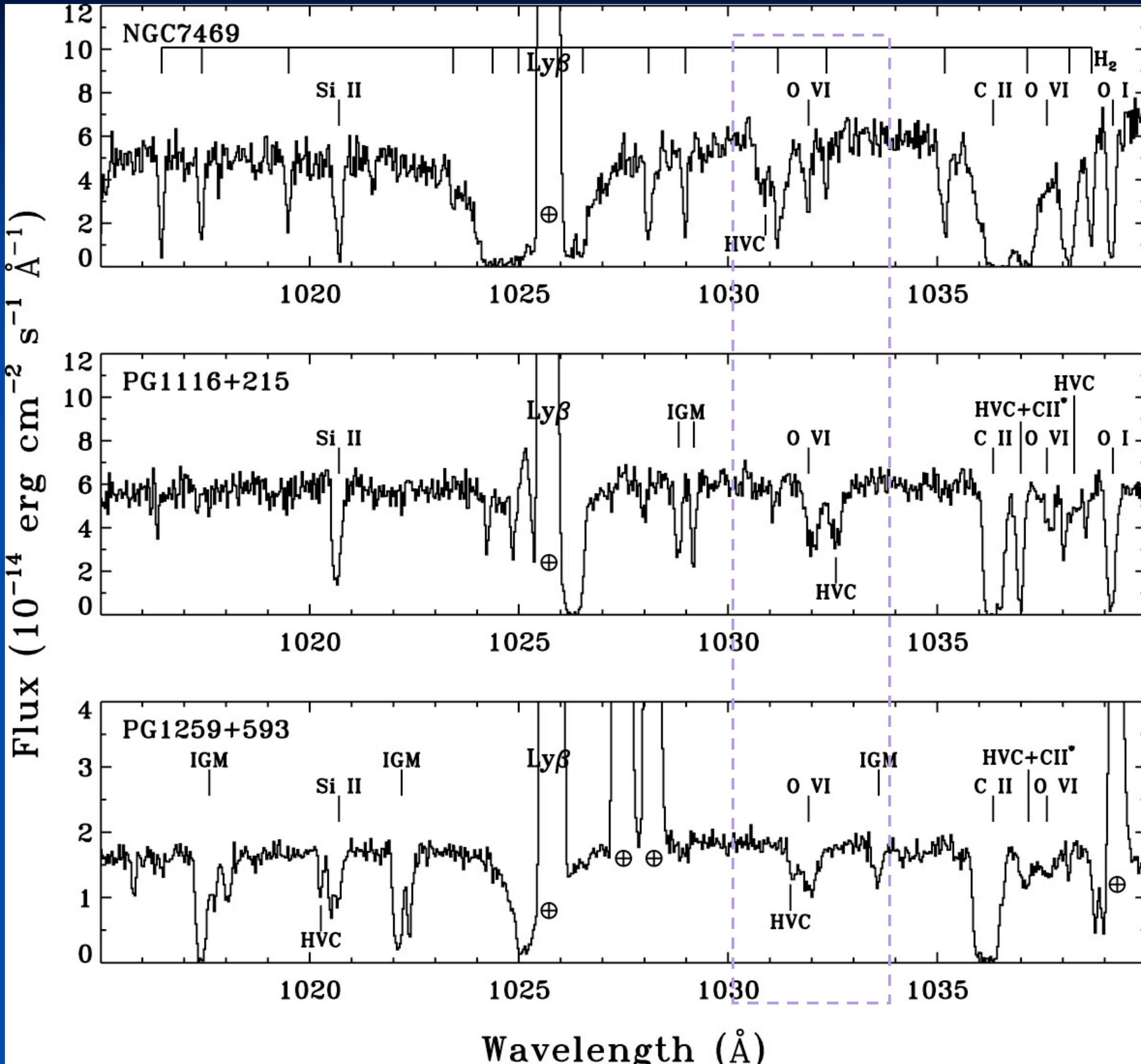
HST N V, C IV, Si IV

ISM COOLNG CURVE PEAKS NEAR $T \sim 10^5$ to 3×10^5 K

A MAJOR COOLANT IS EMISSION FROM O VI

CIE: Sutherland & Dopita (1993, ApJS, 88, 253)
Abundances: Anders & Grevesse (1989,Geochim. Cosmochim Acta, 53, 197)

FUSE Spectra with Low and High Velocity O VI Absorption

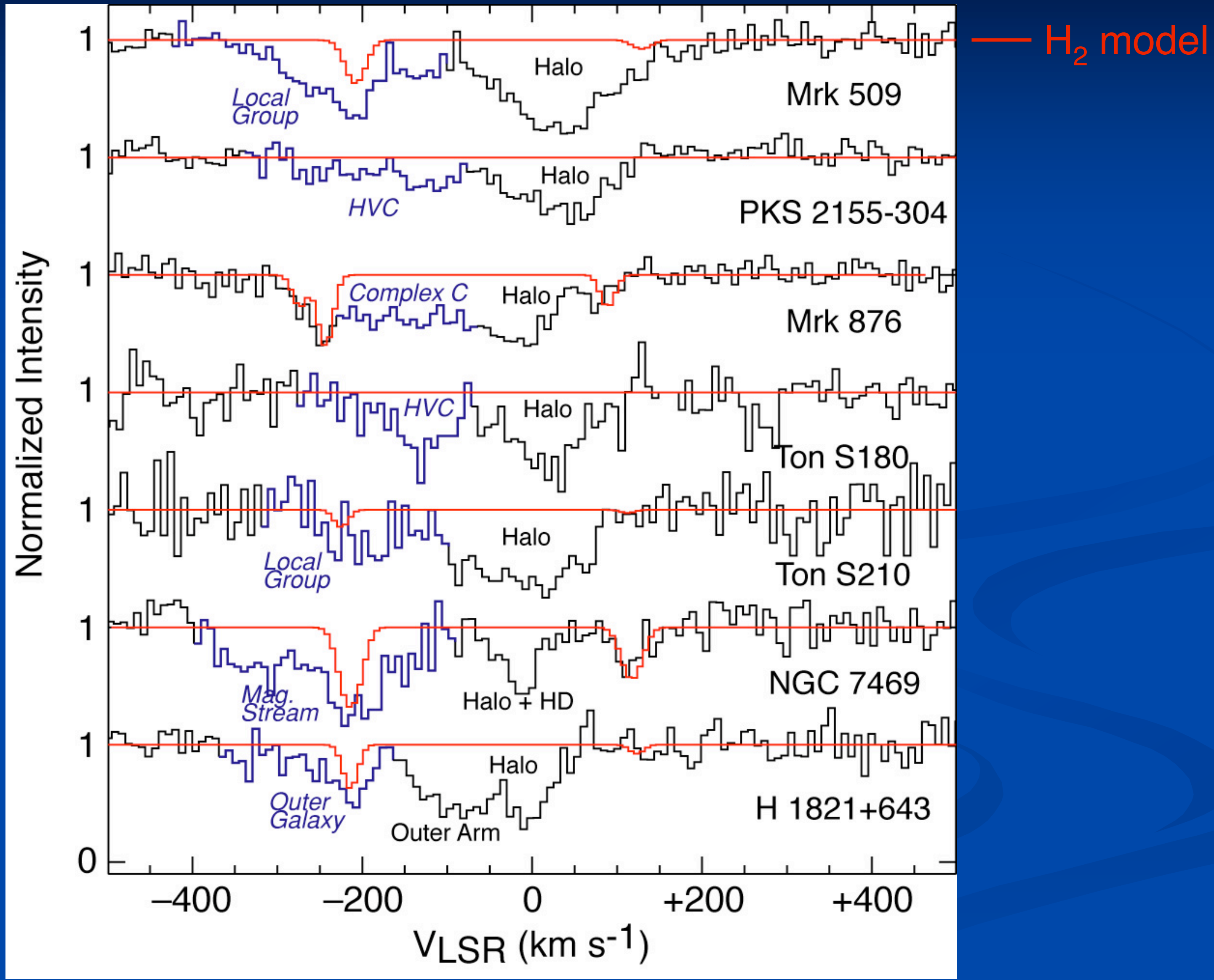


O VI
1031.926 Å
(usually clean)
1037.617 Å
(often blended)

Thick
Milky Way H_2 "Forest"
Thin

Sembach et al. (2003, ApJS, 146, 165)

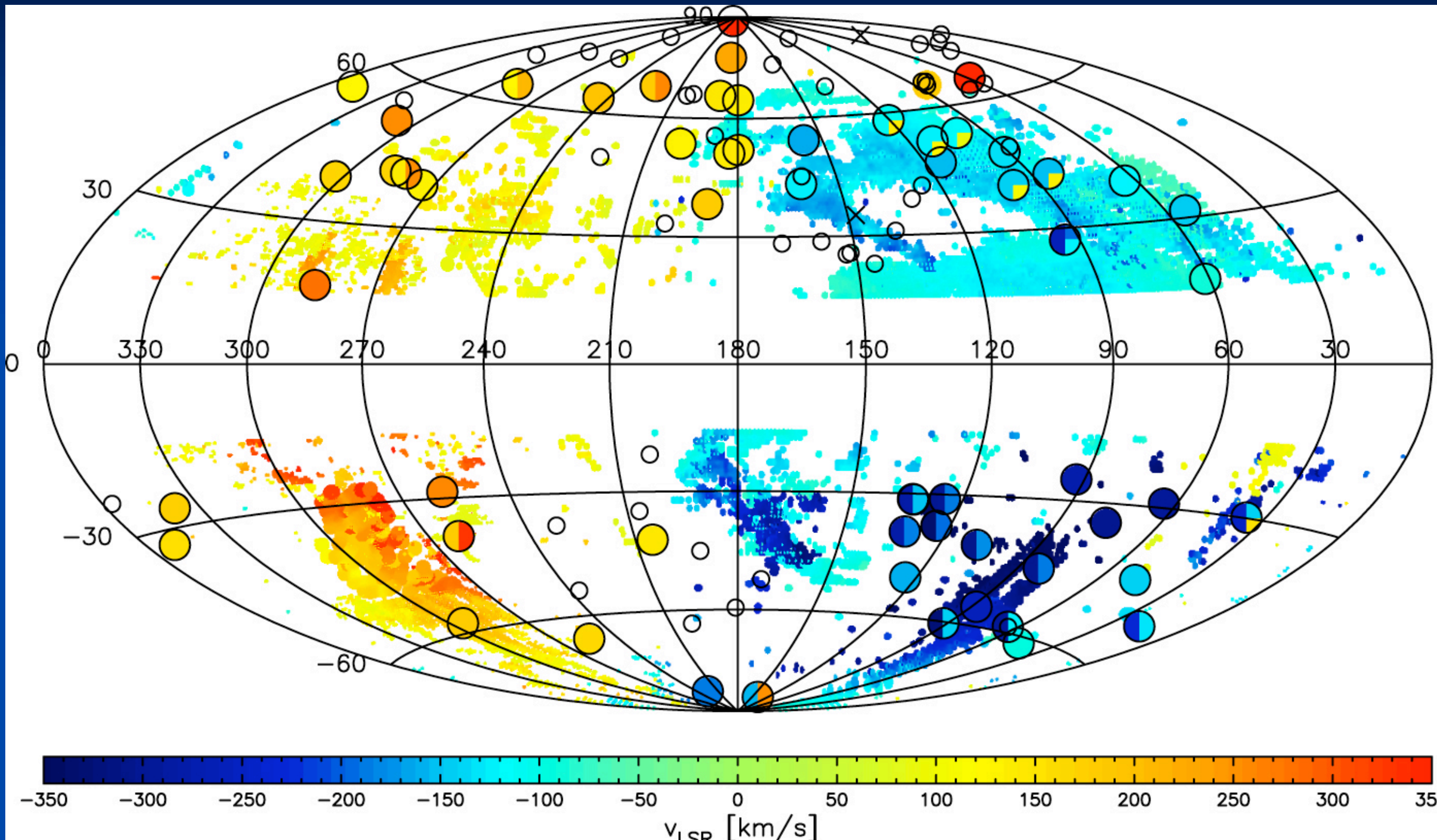
A SAMPLE OF O VI PROFILES



Sembach et al. (2000, ApJ, 538, L31)

The High Velocity H I + O VI Sky

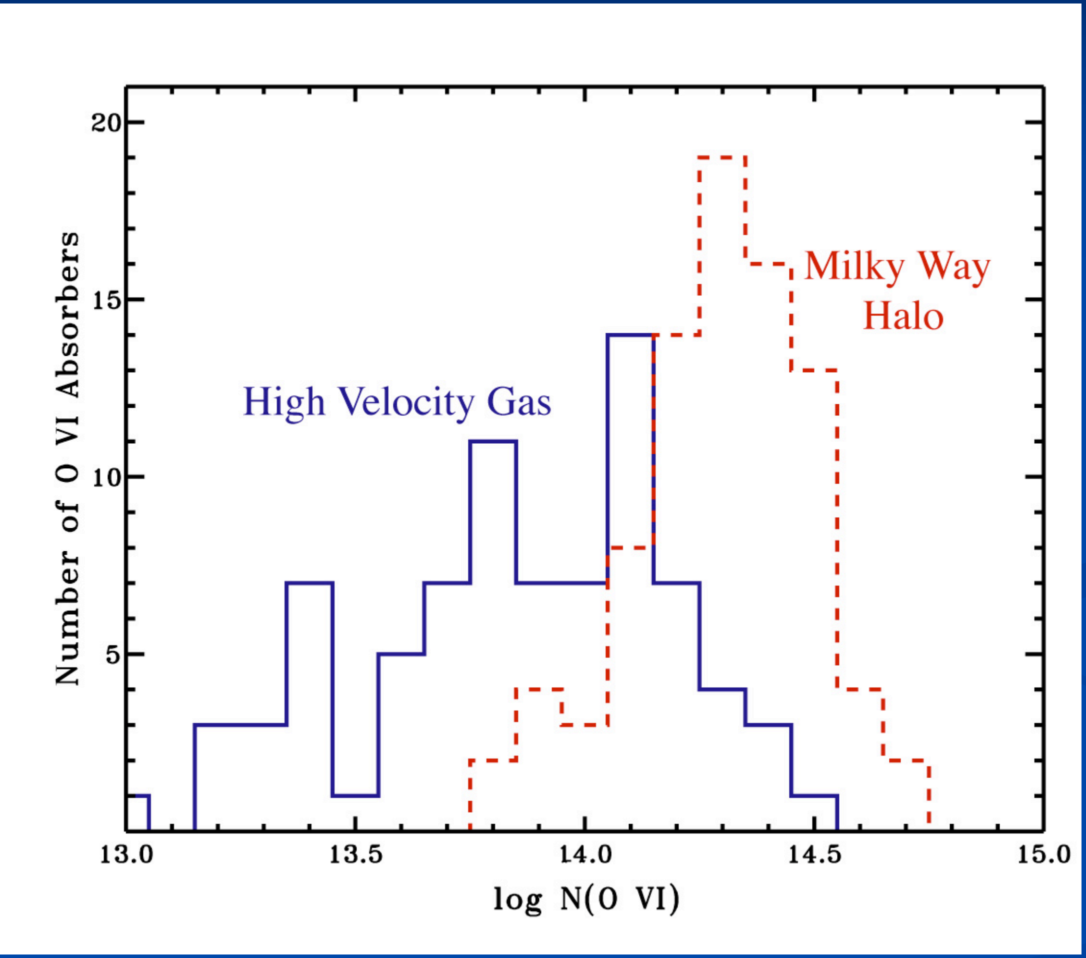
(Sembach et al. 2003, ApJ, 146. 165)



60% OF THE 100 EXTRAGALACTIC LINES OF SIGHT HAVE HIGH VELOCITY O VI WHICH OFTEN IS ASSOCIATED WITH H I HVCs

THE H I HVCs ARE INTERACTING WITH THE GAS IN AN EXTENDED (R >50 kpc) HOT GALACTIC CORONA

O VI Column Density Distributions



< log N > = 14.38±0.18

< log N > = 13.95±0.34

For SOLAR O/H
log N(O VI) = 14.0
Implies
logN(H^+)~18.0

Sembach et al. (2003, ApJS, 146, 165)

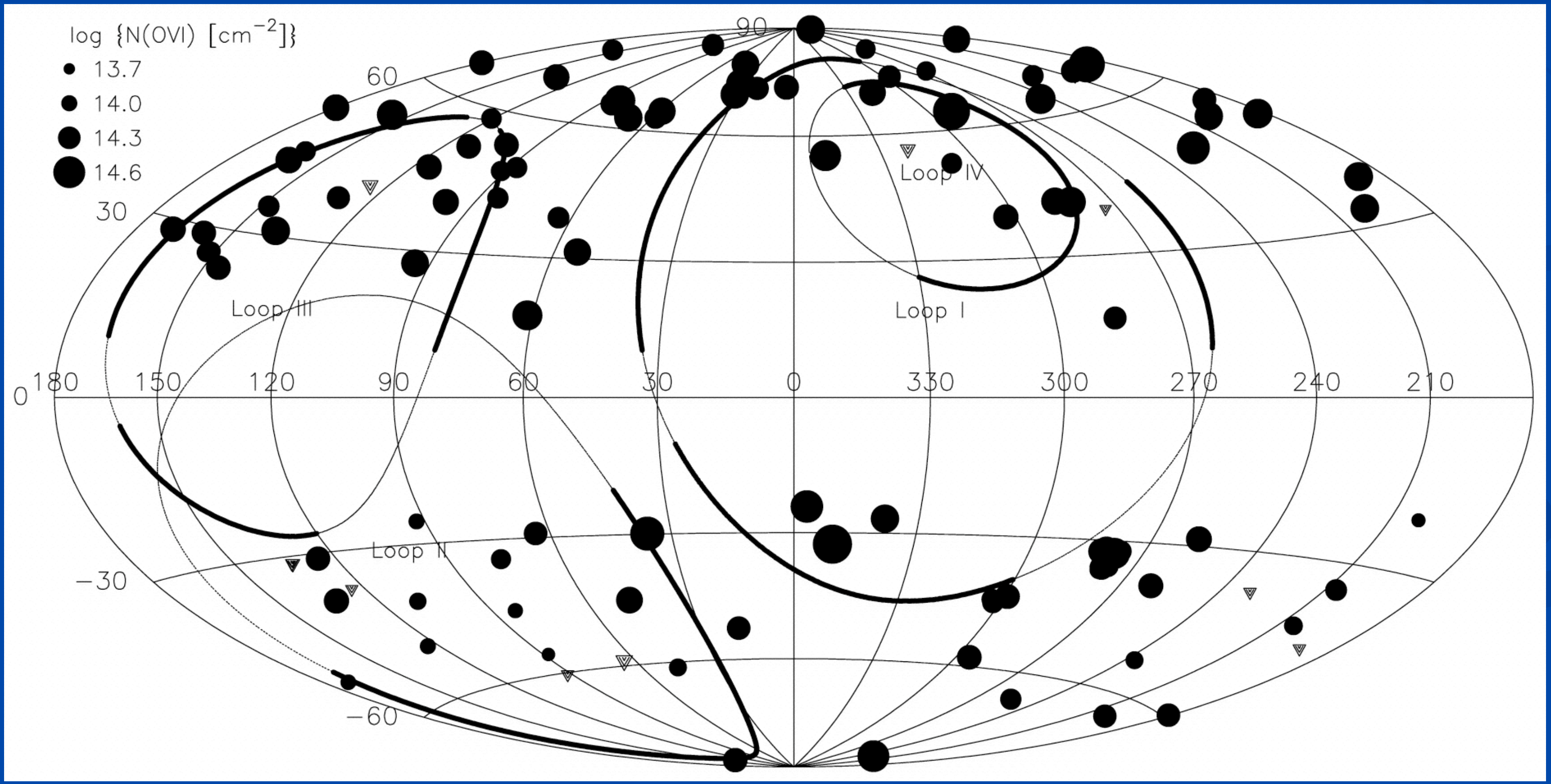
SKY DISTRIBUTON OF THICK DISK N(O VI)

Savage et al. (2003, ApJS, 146, 125)

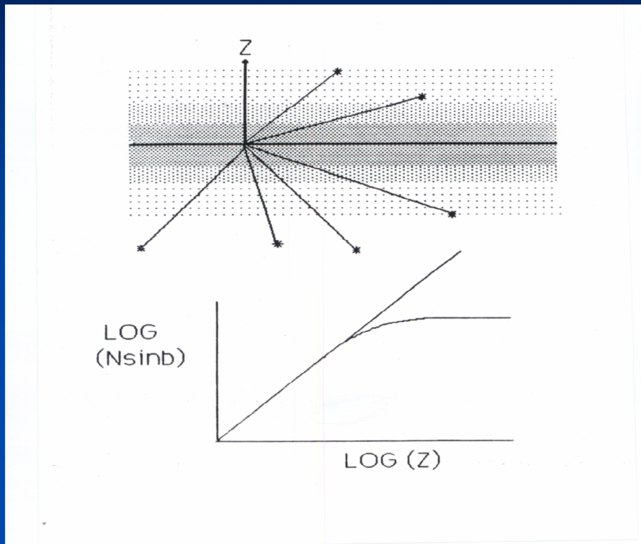
100 EXTRAGALACTIC DIRECTIONS

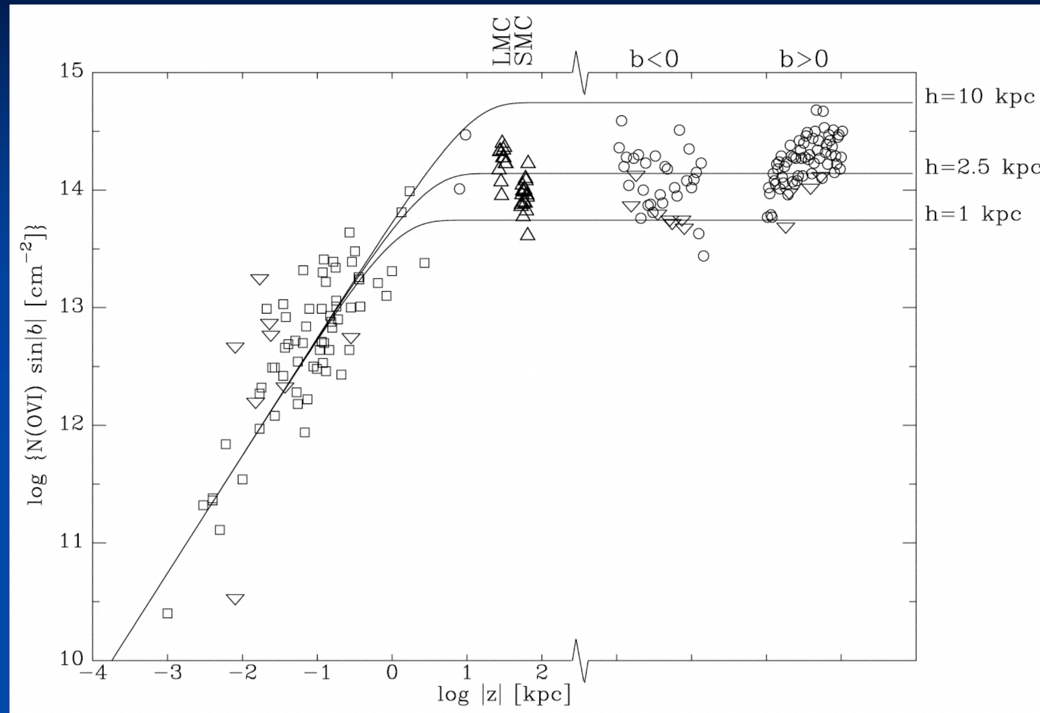
DISTRIBUTION IRREGULAR ~10x spread in N(O VI)

~1.8X EXCESS OF O VI IN THE NORTH



EXTENSION OF THE HIGHLY IONIZED IONS INTO THE HALO





EXPONENTIAL SCALE HEIGHTS OF THE HIGHLY IONIZED ATOMS

Si IV 5.1±0.7 kpc HST

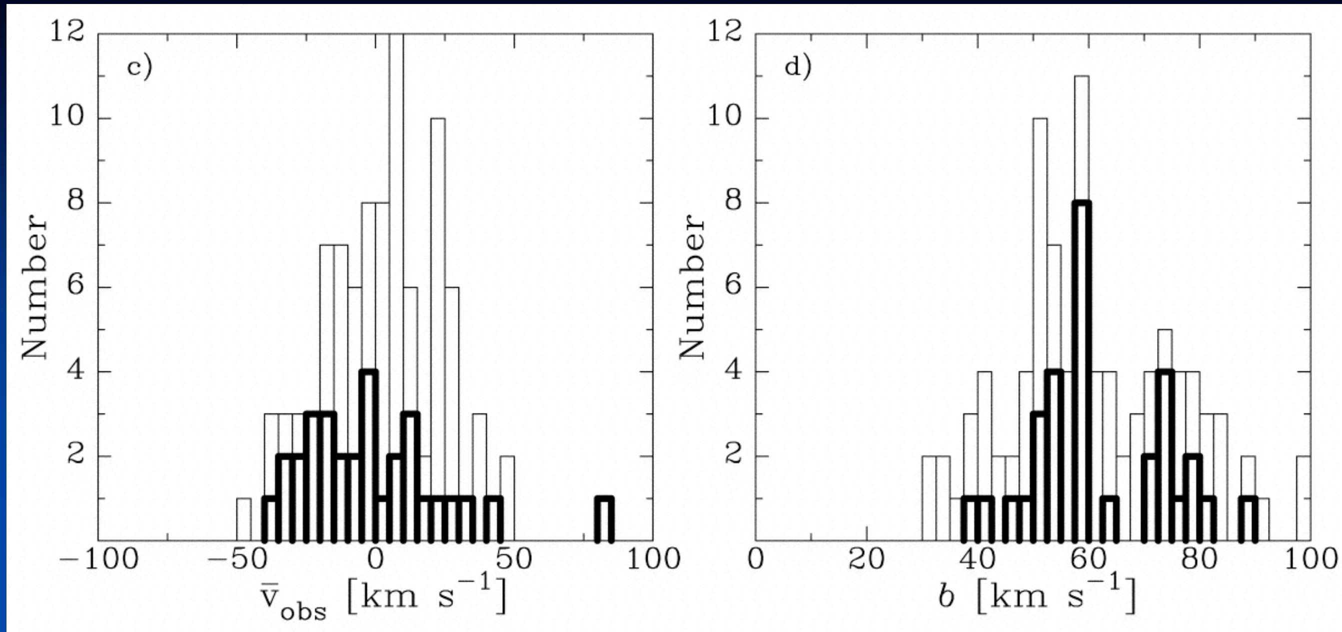
C IV 4.4±0.6 kpc HST

N V 3.3±0.5 kpc HST

Savage, Sembach & Lu 1997, AJ, 113, 2158

O VI 2.3(south) to 4 (north) kpc FUSE

assumes $n(O\ VI)_o = 1.7 \times 10^{-8}\ cm^{-3}$ from O VI disk survey (Jenkins et al. 2001)



O VI LINE VELOCITIES

for |b| > 45°

$<v_{obs}> = 0 \pm 21$ km s^{-1}(STD)

O VI MOVES TOWARD AND AWAY FROM THE PLANE WITH EQUAL FREQUENCY

Savage et al. 2003, ApJS, 146, 125

O VI LINE WIDTHS

b ranges from 30 to 99 km s^{-1}

$<b> = 60 \pm 15$(STD) km s^{-1}

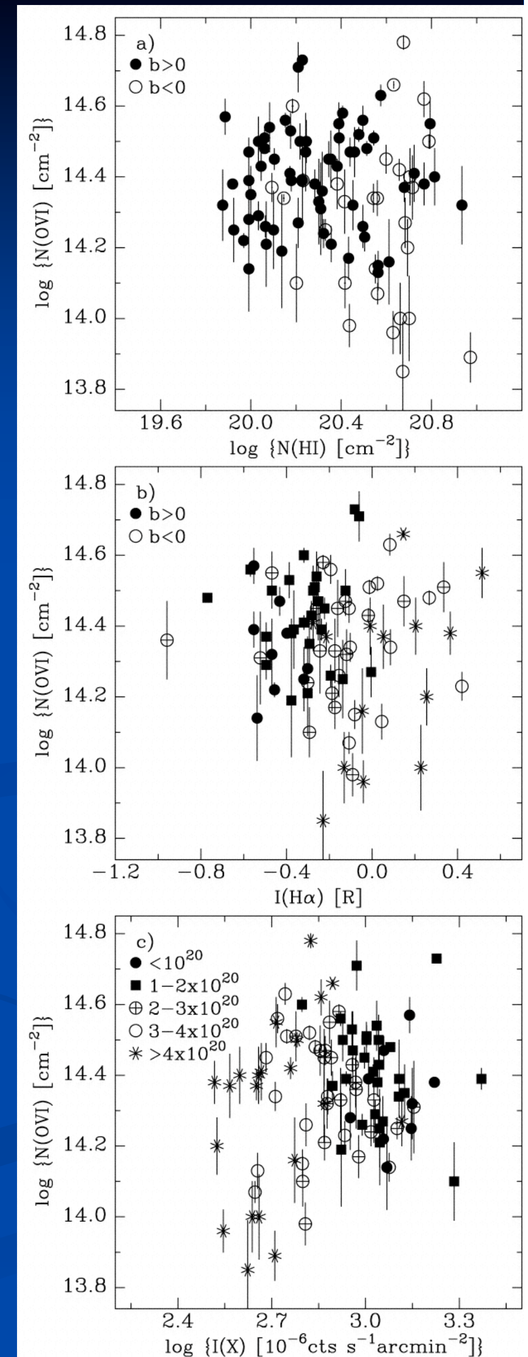
b = 18 km s^{-1} at 3×10^5 K

THERMAL
INFLOW
OUTFLOW
TURBULENCE
GALACTIC ROTATION

logN(O VI)

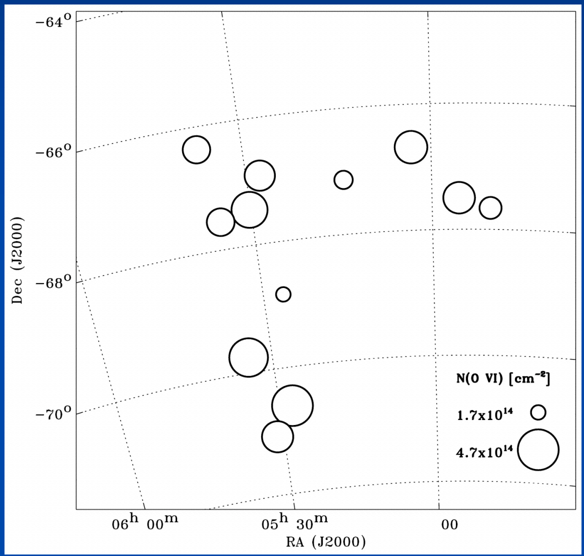
IS POORLY
CORELATED WITH
OTHER ISM TRACERS
INCLUDING
N(H I)
I(H□)
I(0.25 kev X-rays)

Savage et al. 2003, ApJS, 146, 125



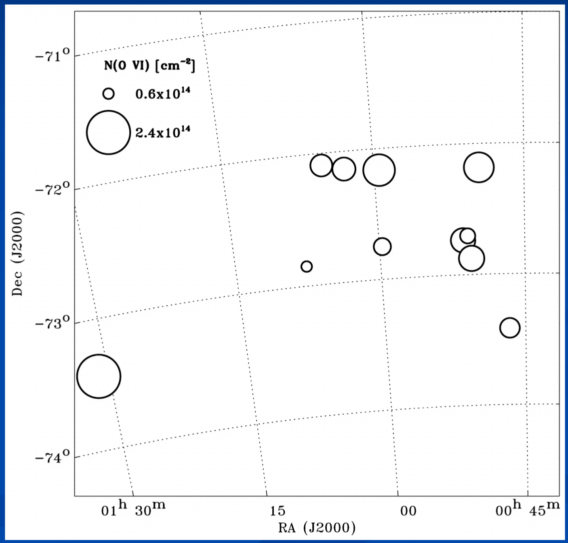
THE O VI DISTRIBUTION CONTAINS STRUCTURES
ON SCALES >0.3°

Howk et al. (2002, ApJ, 572, 264) FOUND 3x VARIATIONS IN N(O VI) OVER
0.3° to 5° ANGULAR SCALES TOWARD THE LMC AND SMC



LMC

SMC



TOWARD THE GLOBULAR CLUSTER NGC 6752
(Lehner & Howk 2004, PASP, 116, 895)
(l = 336.5 , b = -25.6, d = 3.9 kpc, z = -1.7 kpc)
NO VARIATIONS ARE SEEN OVER 0.04° to 0.2° SCALES

MILKY WAY HALO OVI IS SMOOTH ON SCALES <0.2°
CORRESPONDING TO A SPATIAL SCALE OF <10 pc.
O VI IS VERY PATCHY ON LARGER SCALES

THE FILLING FACTOR OF O VI IN THE HALO IS SMALL

~ few x10^{-2}

P/k ~ 7000-10,000 K cm^{-3}

FROM O VI EMISSION vs O VI ABSORPTION

FOR 6 LINES OF SIGHT

Dixon et al. (2002), Shelton et al. (2001), Welsh et al. (2002), Shelton (2002, 2003)

REMOVING LOCAL BUBBLE CONTAMINATION

Shelton, Sallmen & Jenkins (2007, ApJ, 659, 365)

Robin Shelton’s talk (today)

THE ORIGINS OF THICK DISK O VI

CONDUCTIVE INTERFACES
(Borkowsky, Balbus & Fristrom 1990, ApJ, 355, 501)

TURBULENT MIXING LAYERS
(Slavin, Shull & Begelman 1993, ApJ, 407, 83)

COOLING SN BUBBLES
(Shelton 1998, ApJ, 504, 785)

COOLING GALACTIC FOUNTAIN GAS
(Shapiro and Field 1976, ApJ, 205, 762)
(Edgar and Chevalier 1986, ApJ, 310, L27)
(Shapiro and Benjamin 1991, PASP, 103, 923)

For logN(O VI) = 14.1 need a flow rate of
$\sim 1.4 M(Sun)[n_H(0)/10^{-3}\ cm^{-3}]\ yr^{-1}$

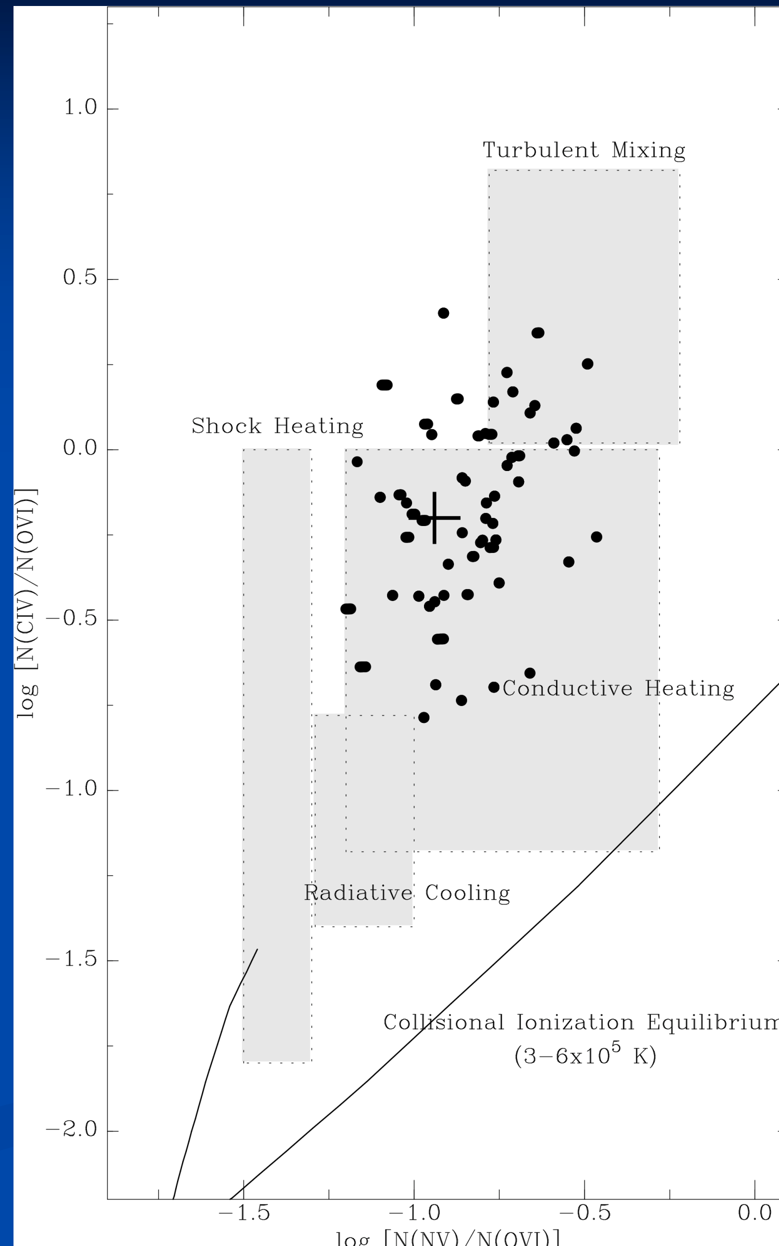
ION TO ION RATIOS CAN BE USED TO DISCRIMINATE AMONG DIFFERENT IONIZATION MECHANISMS

IONIC RATIOS

over 20 Km s^{-1} VELOCITY INTERVALS

for 8 EXTRAGALACTIC LINES OF SIGHT

CONDUCTIVE HEATING
&
TURBULENT MIXING
ARE CONSISTENT WITH
MANY DATA POINTS



MOST BASIC CONCLUSIONS

THE MILKY WAY HAS AN INHOMOGENEOUS THICK DISK
OF TRANSITION TEMPERATURE GAS
EXTENDING ~2 TO 5 Kpc TO EACH SIDE OF THE GALACTIC PLANE

THE NORTHERN GALACTIC POLAR REGION
HAS A 0.25 DEX
ENHANCEMENT OF O VI

THE H I HIGH VELOCITY CLOUDS CONTAIN
MULTIPLE GAS PHASES INCLUDING O VI, N V and C IV

THE H I/O VI HVCs IMPLY THE GALAXY HAS
AN EXTENDED (R > 50 kpc) HOT GASEOUS CORONA