Ionization of the Local Interstellar Cavity by Hot White Dwarfs

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Thanks to: Martin Barstow, Nathan Dickinson (Univ of Leicester)
Jonathan Wheatley (UC Berkeley)

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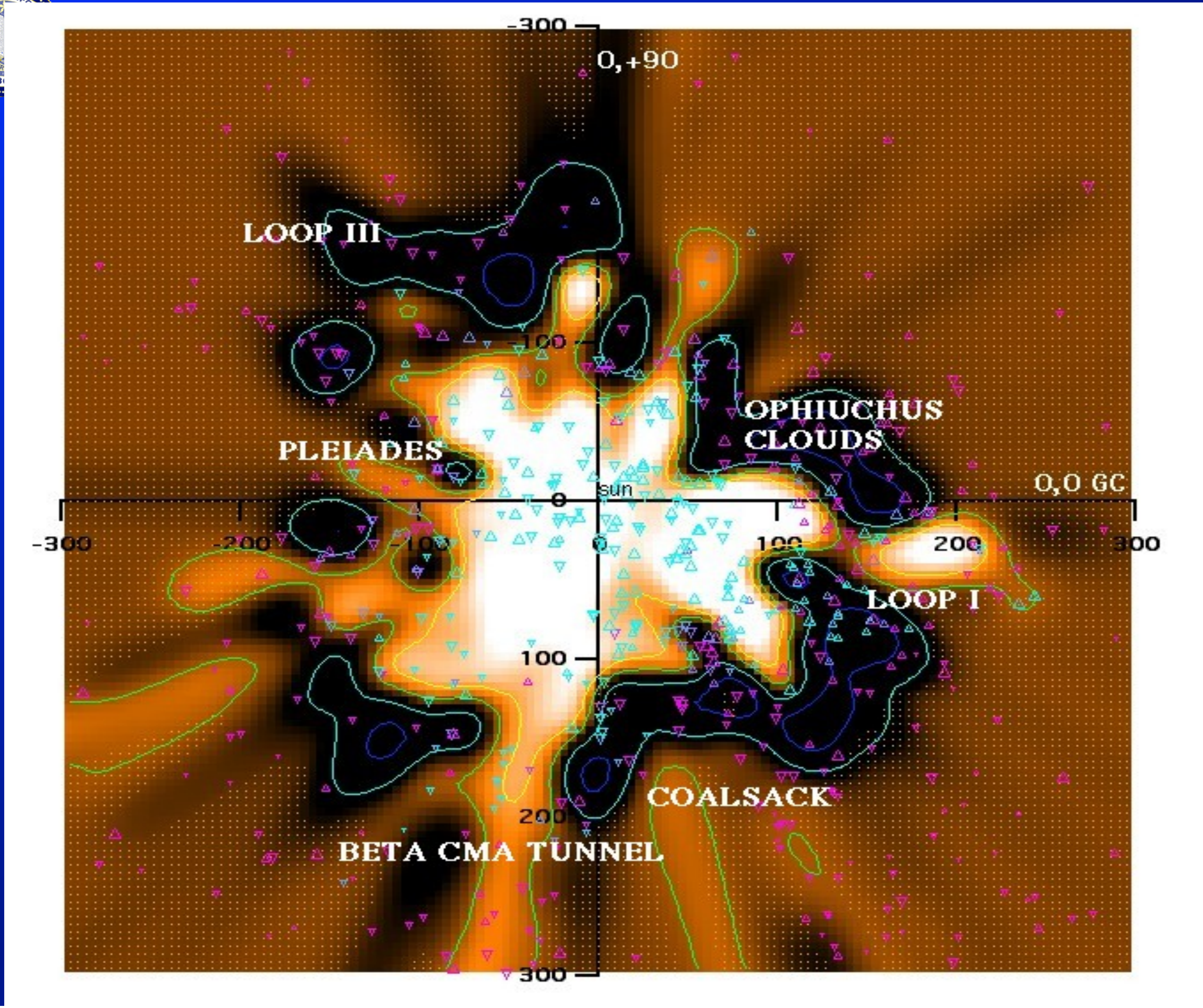
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LOOP III
-100
OPHIUCHUS
CLOUDS
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sun
0,0 GC
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-300
-200
-100
0
100
200
300
LOOP I
100
COALSACK
200
BETA CMA TUNNEL
300

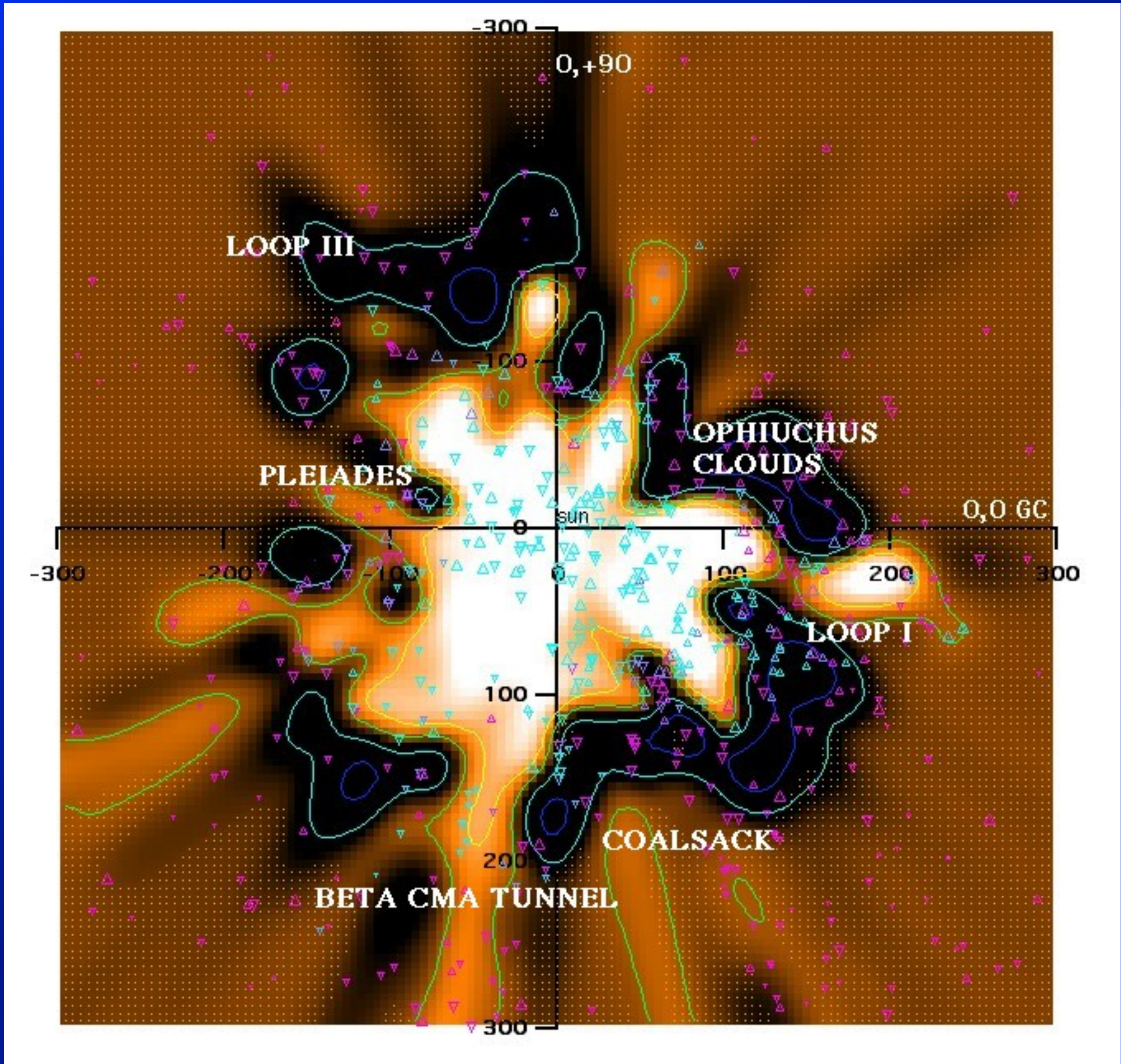
The Local Cavity: summary of size & shape

- The Local Cavity is **NOT bubble-shaped nor bubble-like**, but instead it has an asymmetric shape (50 -90pc radius) and it is surrounded by a highly fragmented boundary wall of neutral and partially ionized gas

- The Local Cavity **is linked** to other adjacent interstellar cavities through narrow "tunnels", the most important being the link with the Loop I superbubble

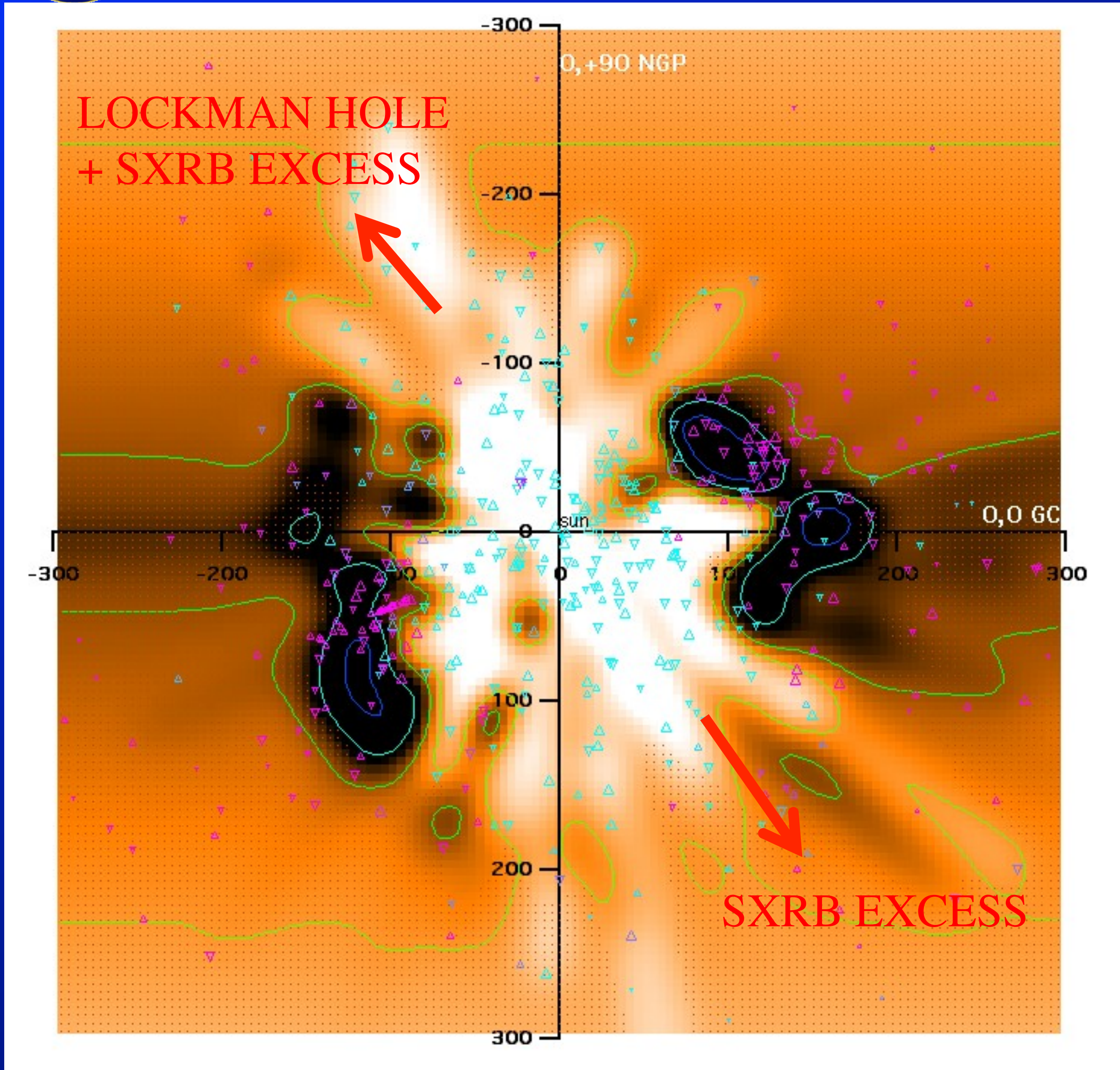
- There is a ~ 300pc long x 50pc wide very low neutral density ($n_H \sim 0.005$ cm^{-3}) tunnel in the direction of the two early type stars of β and ε CMa.

Distribution of neutral (NaI) gas < 300pc



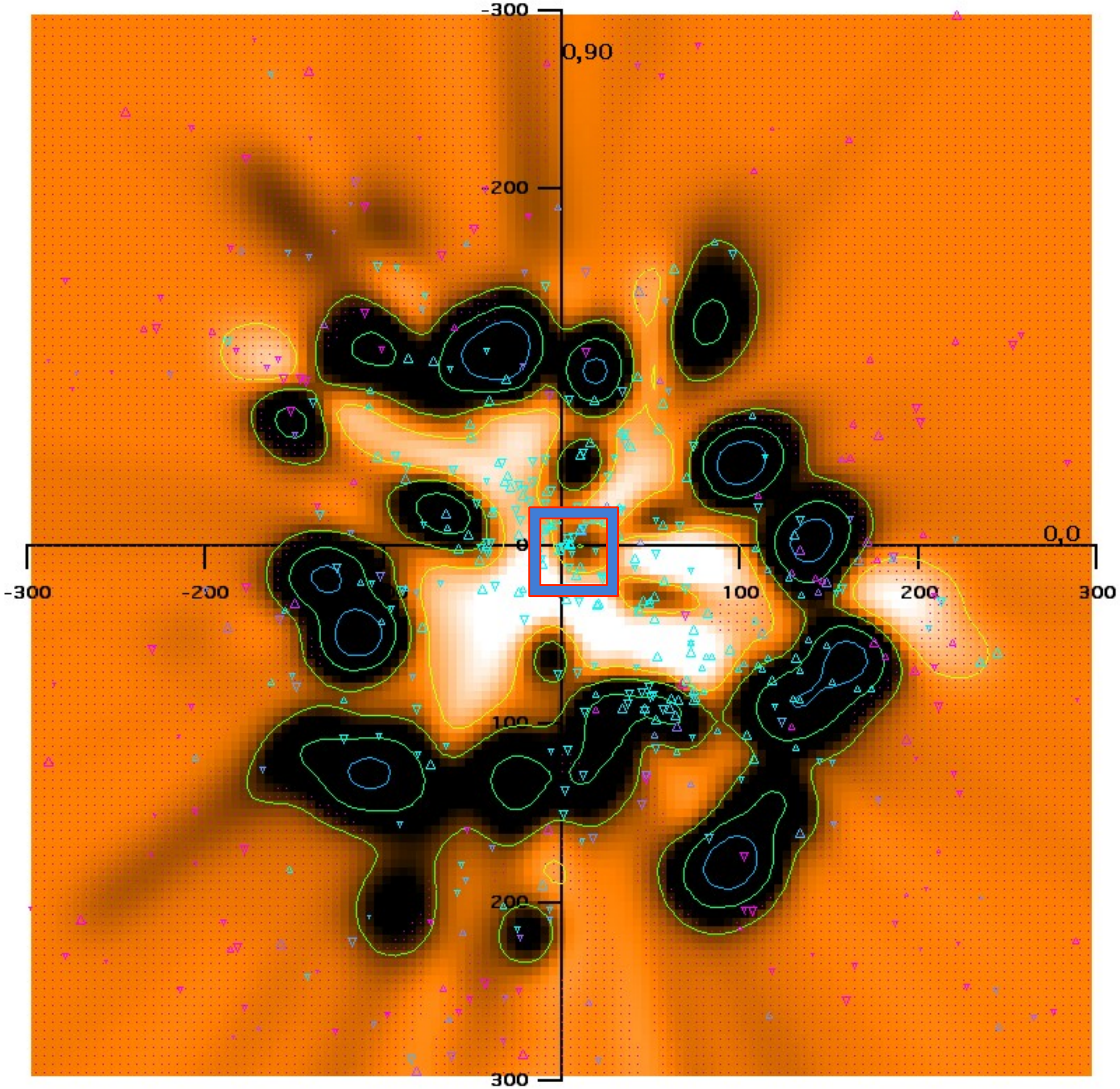
Welsh et al 2010

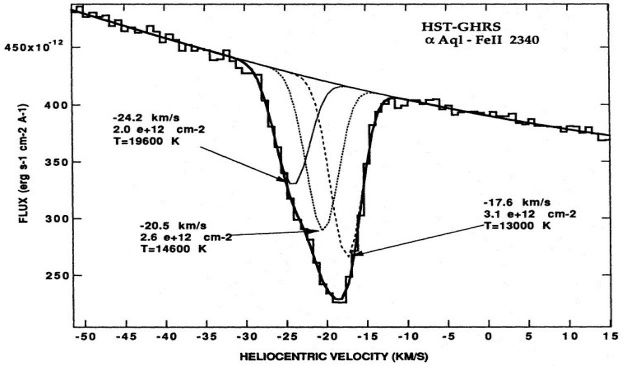
The Local Chimney

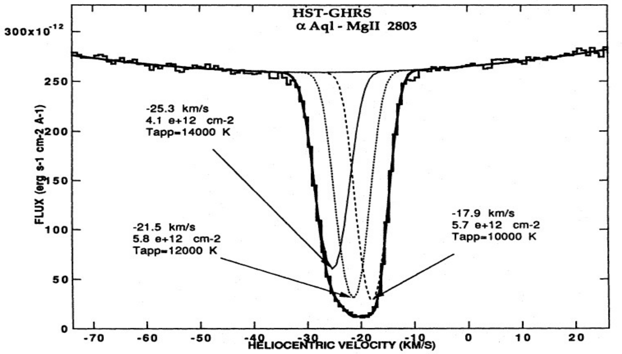


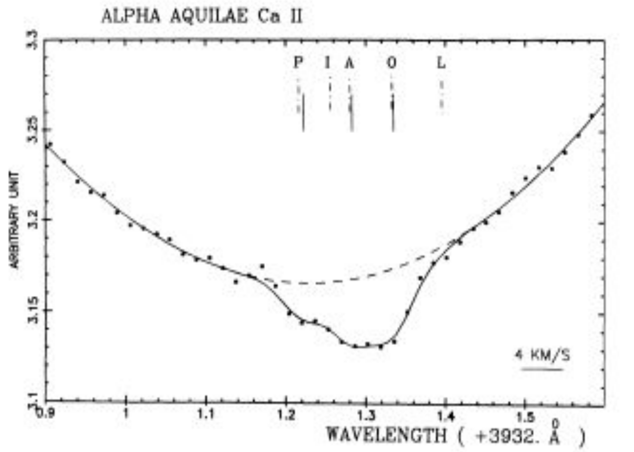
The Cavity also **has no definite "boundary"** at high + and -ve galactic latitudes, such that it essentially "opens" into the overlying inner (hot) & ionized galactic halo.

Local distribution of partially ionized (CaII) gas

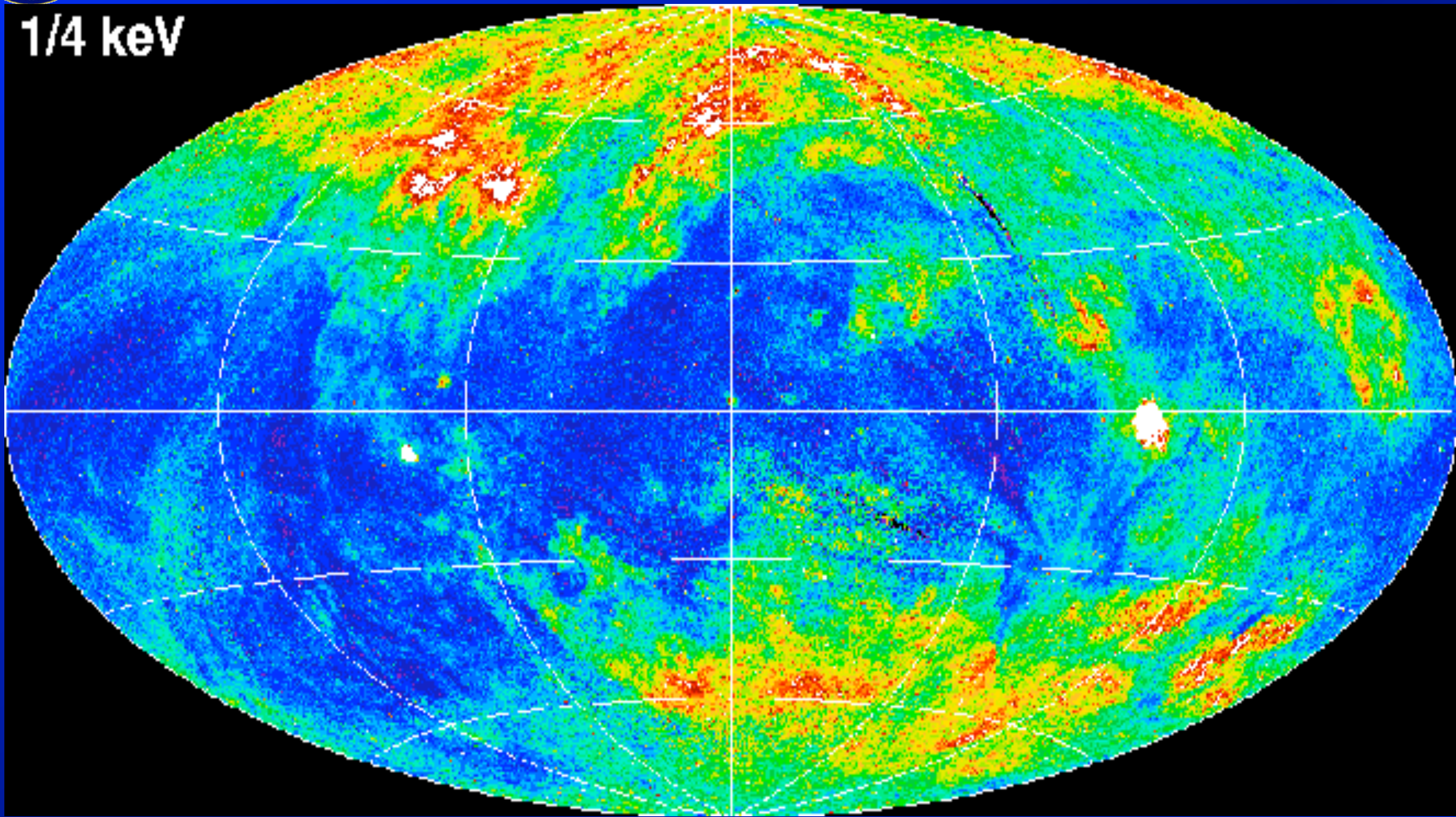








What is inside the Local Cavity?



Ionization of the Local Cavity Gas

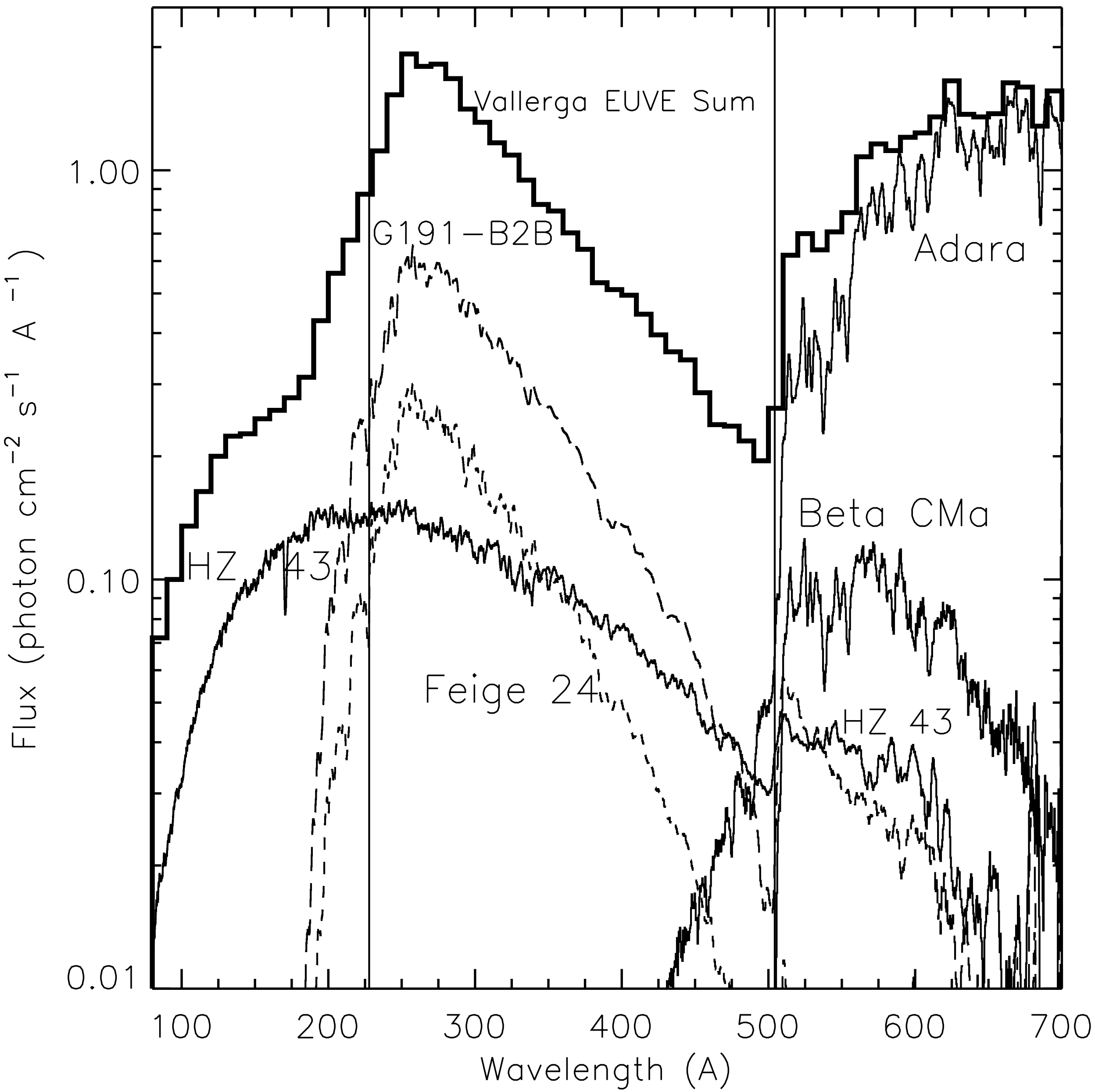
- Observations at EUV wavelengths show that the B1-type stars ε CMa and β CMa (d ~ 150pc) are mainly responsible for the photo-ionization *of the Local Cloud complex surrounding the Sun* (Vallerga 1998)

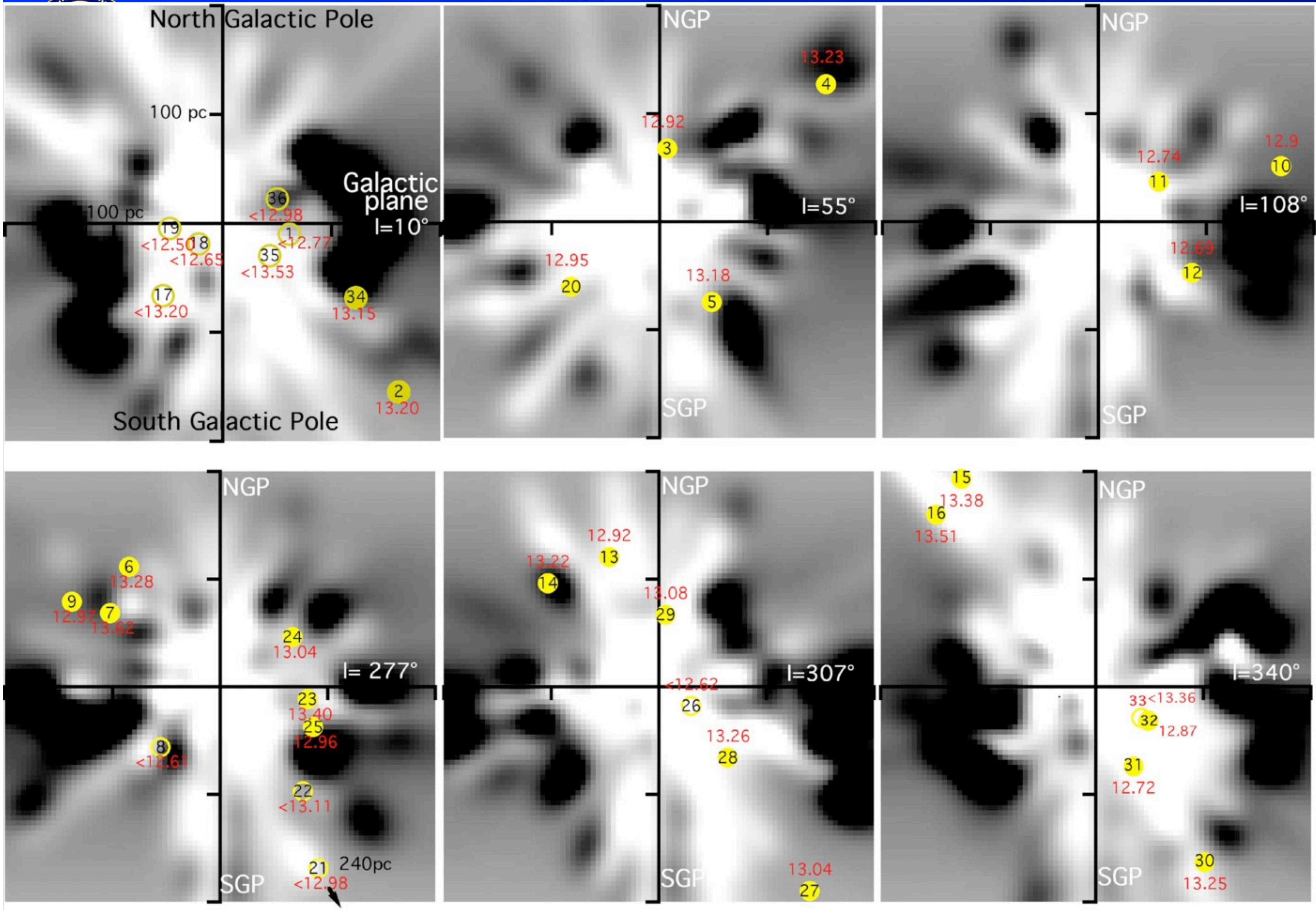
- This is largely due to the very low level of (absorbing) neutral gas ($n_H \sim 0.01$ cm^{-2}) found along their 150pc long sight-line

- There is a yet unexplained over-ionization of Helium with respect to Hydrogen in the Local Cloud gas as derived from the EUV spectra of local hot white dwarf stars. Is this linked to eruptive local CV systems?

- We know very little about the ionization at other locations within the Local Cavity…..could other stellar sources such as hot white dwarfs produce ionized Stromgren spheres that might dominate their very local environment?

The EUV radiation field *at the Earth*





(Barstow et al 2010)

Observations of Local 300,000K gas

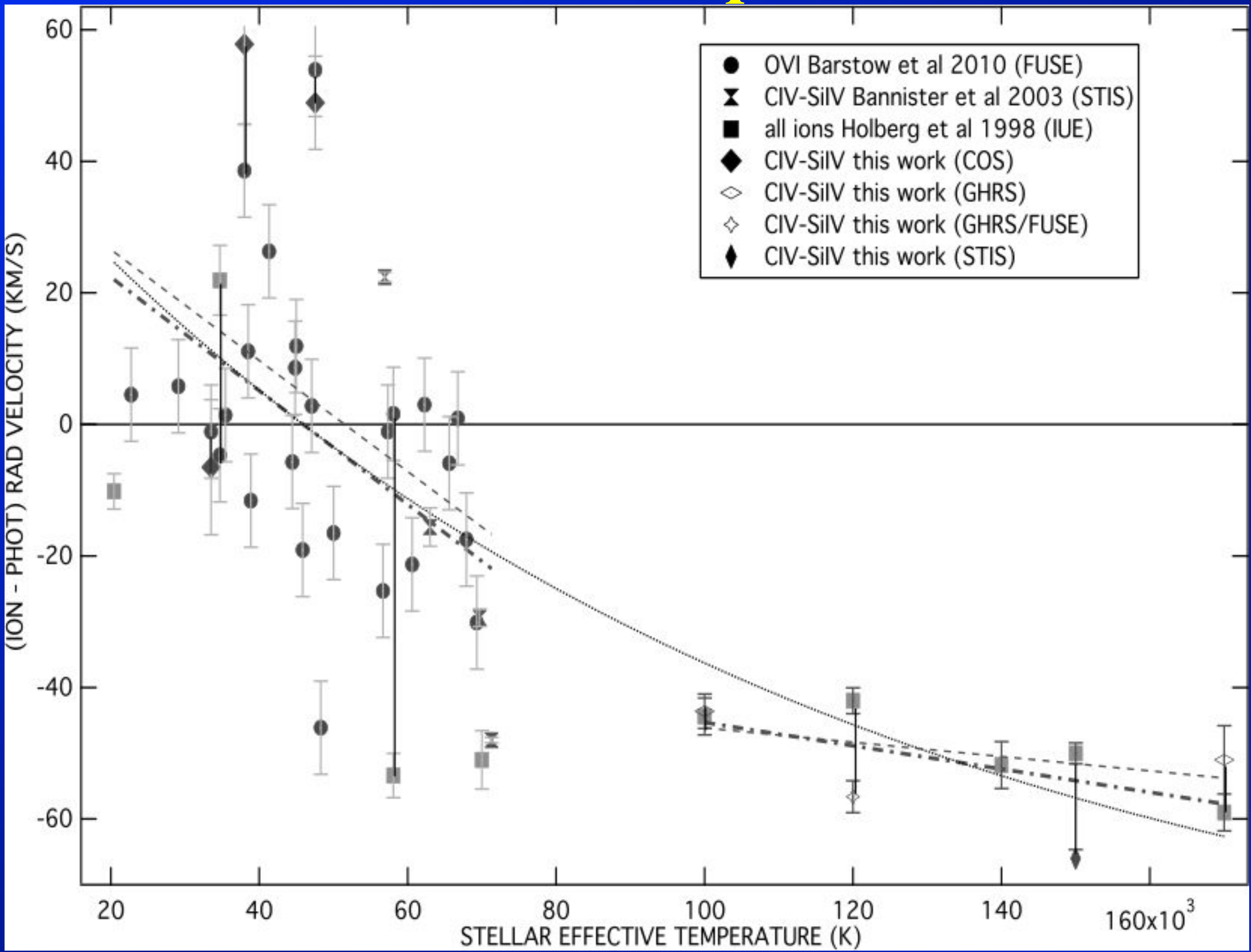
- There is still a "vigorous" debate as to whether any million degree gas, which may be required for the formation of OVI in transition zones, is present within the Local Cavity

- Recent HST-COS observations of high ions (CIV, SiIV and NV), that have counterparts in OVI absorption at a similar velocity, suggest that such ions may well be formed in a circumstellar (and NOT interstellar) environment

  (Lallement et al 2011, Dickinson et al 2012, 2013)

- These high ions can be formed through the evaporation-accretion of infalling dusty asteroid-like material in the white dwarf atmosphere

The apparent dependence of high ion velocity on stellar temperature



Lallement et al 2011

High stellar temperature, high radiation pressure expels falling debris, thus –ve velocity shift
Low stellar temperature, low radiation pressure unable to prevent accretion, thus +ve velocity shift

So….what is the ionizing contribution from hot WD's?

Dupree and Raymond (1983) first suggested that "ionization spheres" around hot white dwarfs smight be widely dispersed throughout the Local Cavity

Tat & Terzian (1999) calculated the ionization impact from all white dwarfs within 20pc and reported only very occasional mergers between their (small) Stromgren Spheres

We now have improved estimates of the distances, temperatures and stellar atmosphere parameters for most white dwarfs < 200pc

So………..

Stromgren spheres of local hot WDs within an existing interstellar cavity

The radius of a Stromgren sphere is given by:

$$R = (3/4\pi \ \text{x} \ S_* / \eta^2 \beta^2)^{1/3}$$

Where S^* = stellar (EUV) flux, $\eta = n_e$, β = recomb coefficient

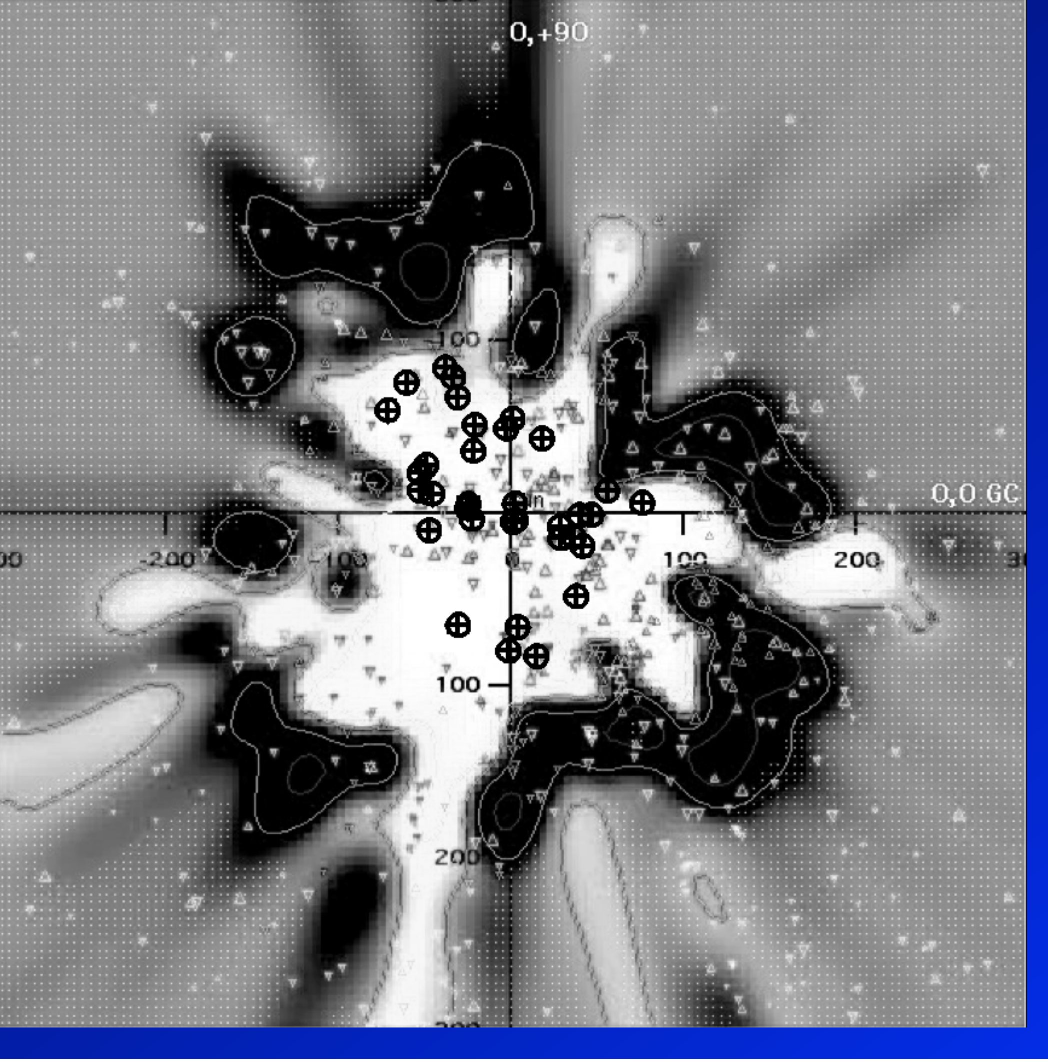
We need to know the ionizing EUV photon flux, S*…….from white dwarf stellar atmosphere models

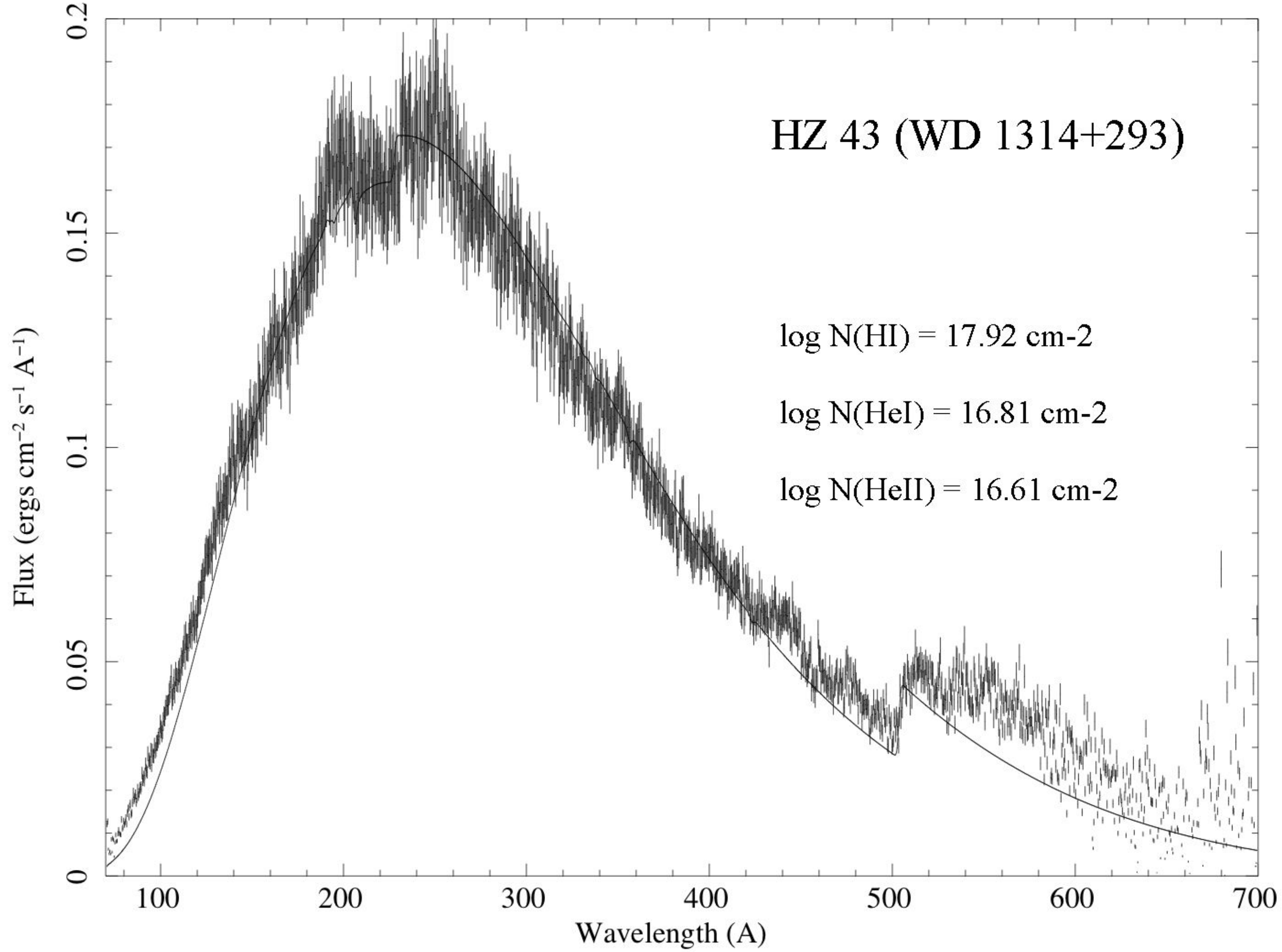
We need to assume a value of ambient gas electron density, n_e

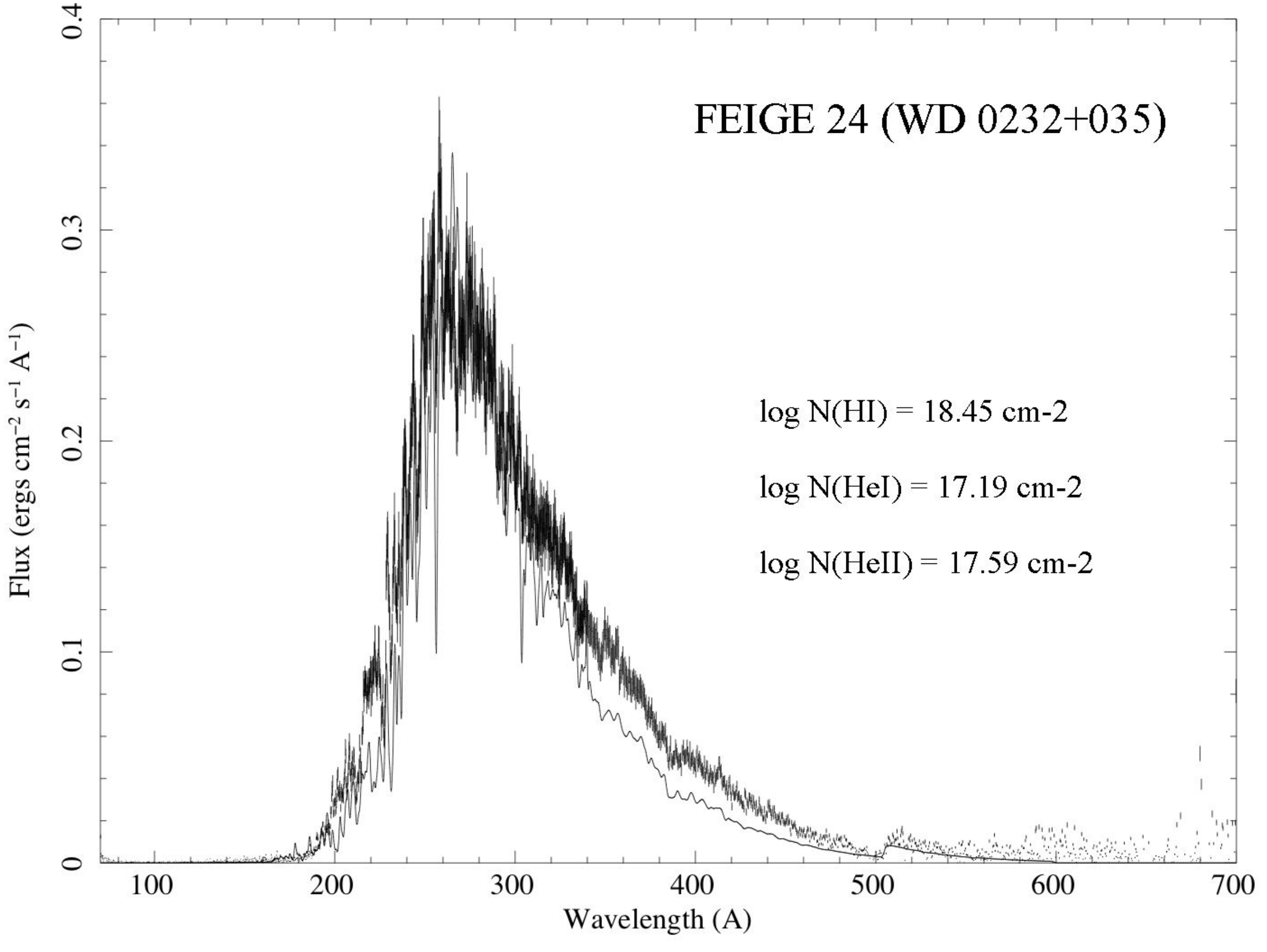
We need to know which WD's are located within the Local Cavity

Local Hot White Dwarfs

- We select 33 white dwarfs with T > 20,000K located within 100pc of the Sun (i.e. within the Local Cavity) (Barstow et al 2010)




HZ 43 (WD 1314+293)
log N(HI) = 17.92 cm-2
log N(HeI) = 16.81 cm-2
log N(HeII) = 16.61 cm-2
Flux (ergs cm−2 s−1 A−1)
Wavelength (A)
0
0.05
0.1
0.15
0.2
100
200
300
400
500
600
700



FEIGE 24 (WD 0232+035)
log N(HI) = 18.45 cm-2
log N(HeI) = 17.19 cm-2
log N(HeII) = 17.59 cm-2
Flux (ergs cm^{-2} s^{-1} A^{-1})
0
0.1
0.2
0.3
0.4
100
200
300
400
500
600
700
Wavelength (A)

Stromgren Sphere Radii

- Using our derived values of S* flux, we calculate the number of ionizing photons 80 – 912 Å

- We assume values of ambient electron density in the range, $n_e = 0.04$ to $0.1\ cm^{-3}$

- These values of n_e based on measurements of the *integrated values* towards local gas clouds

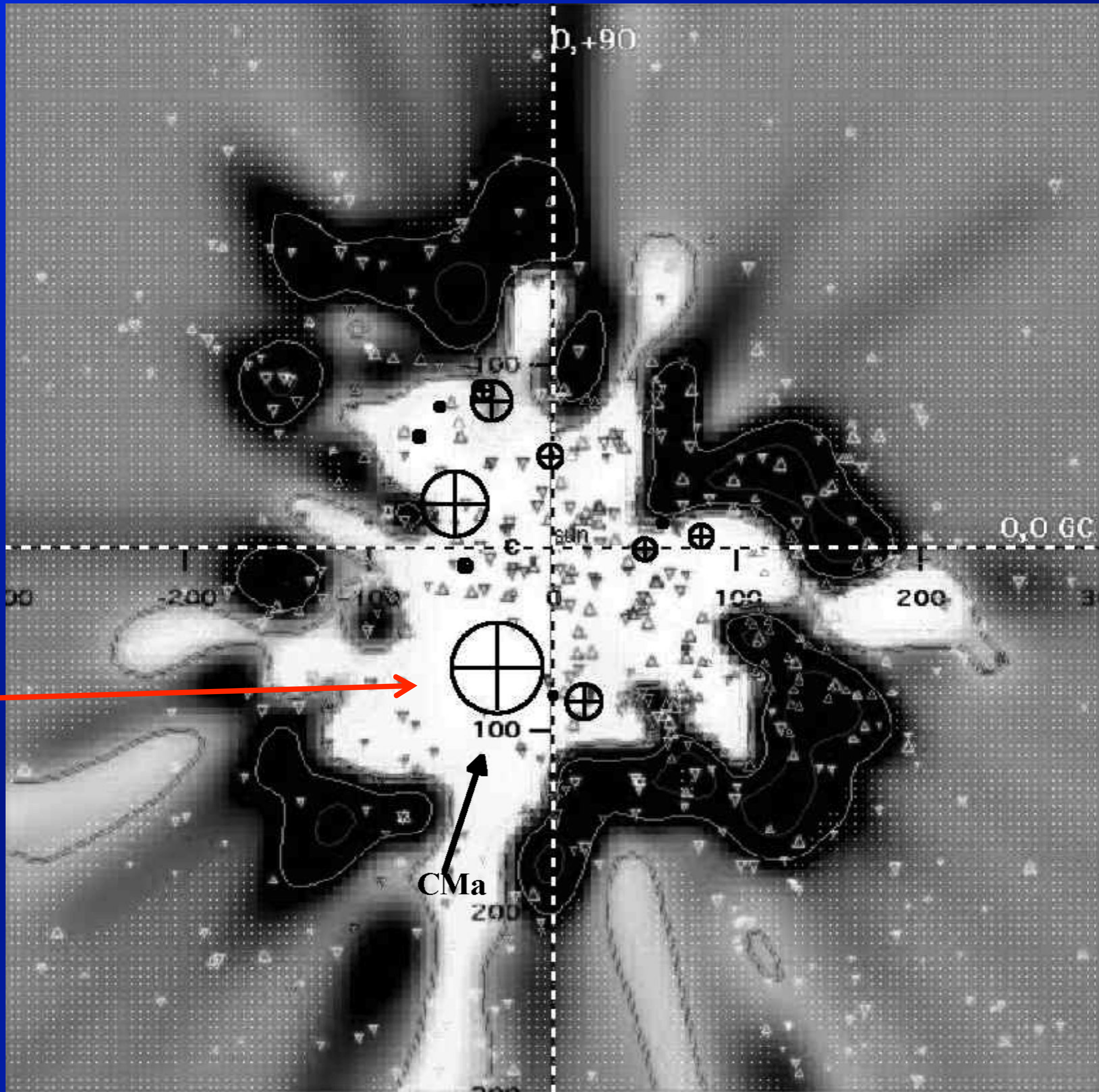
- We then calculate the radii of each WD Stromgren Sphere and plot these on maps of the Local Cavity

- Ionized bubble radii > 5pc are not uncommon

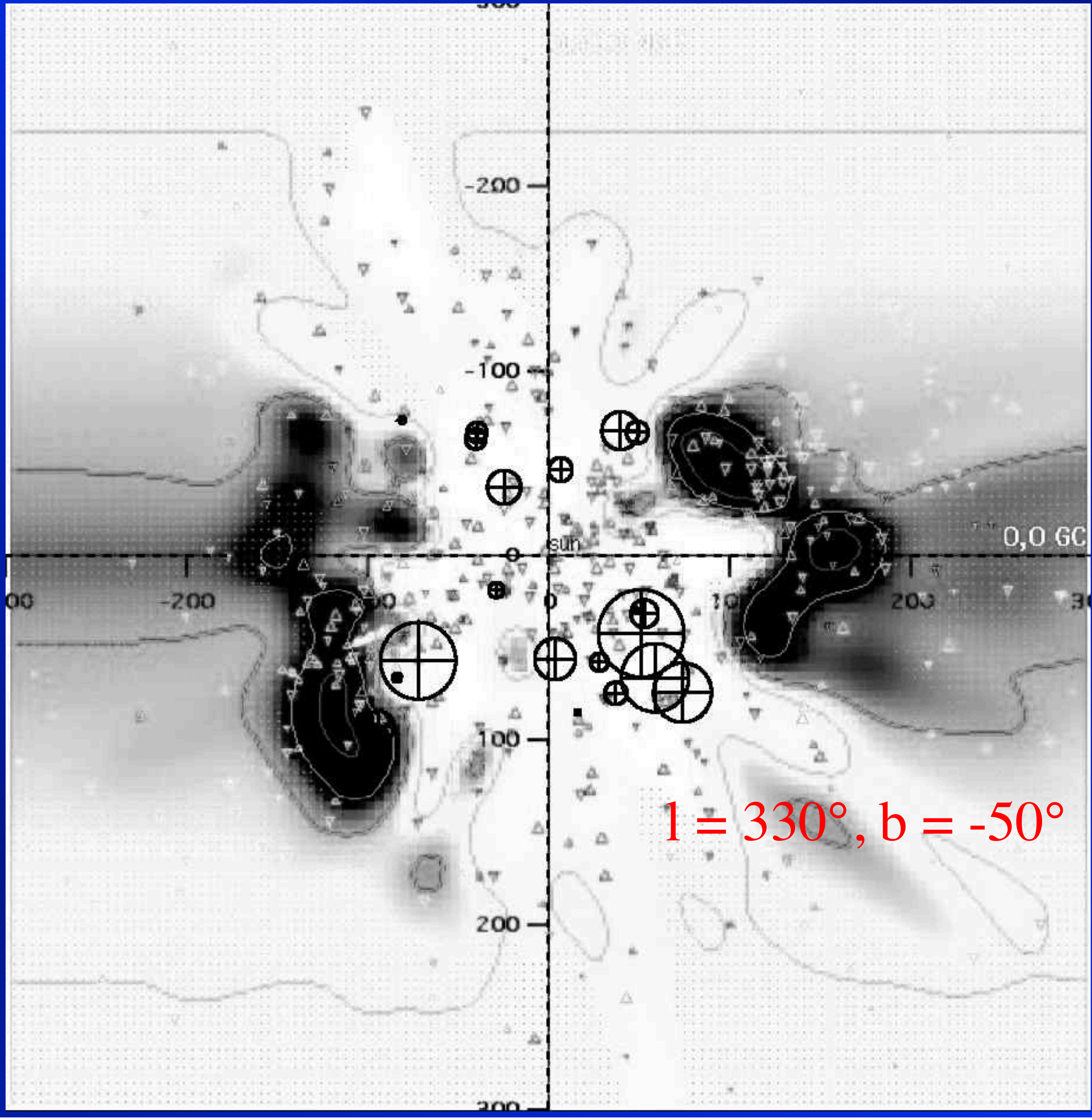
Ionization by WD's in the plane

$n_e = 0.04\ cm^{-3}$

WD 0621-376
diameter = 48pc



Ionization by WD's out of the galactic plane



Summary

Even at the lowest value of ambient electron density the HII Stromgren Spheres only amount to ~ 6% of the Local Cavity volume

HeII spheres ~ HII sphere sizes for T > 45,000K

None of the WD ionization spheres seem to have any influence on the Local Cloud complex

The region in the direction of l = 330°, b = -50° at distances 60 -90pc may be dominated by ionization due to white dwarfs

The two CMa early B stars still appear to dominate ionization conditions throughout most of the Local Cavity

Lessons learned for studies of other regions of the ISM

- Hot white dwarfs may not be the best probes of interstellar absorption in the UV -------- we really don't understand their atmospheres

- White dwarfs with T > 60,000K can produce large (d ~ 50pc) ionized spheres within existing low density interstellar cavities

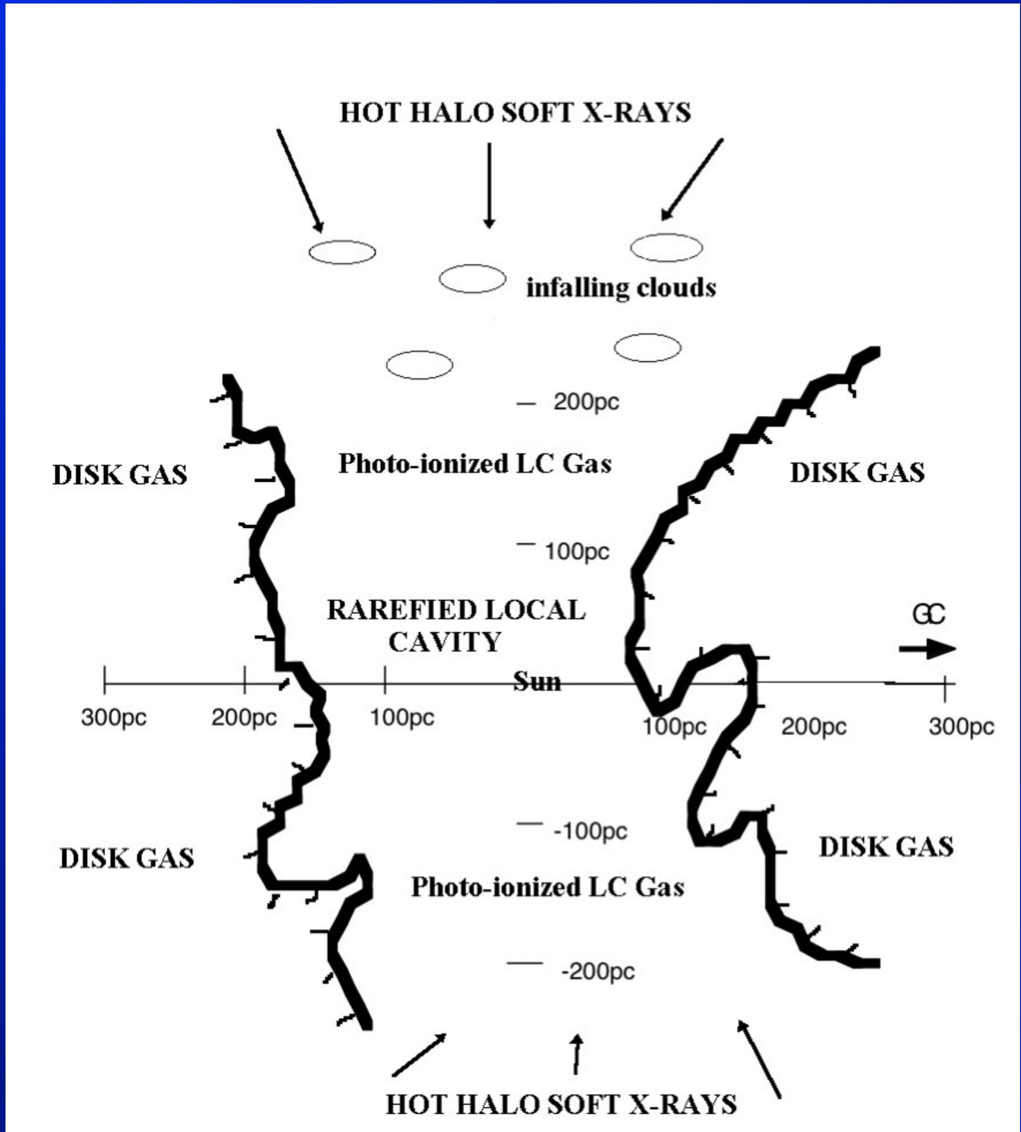
- Hot white dwarf (H) ionization within large interstellar cavities is mostly a secondary effect at ~ 10% level, but it can completely dominate in certain small-scale regions, especially for HeII

- We just learned that Linsky & Redfield are about to submit a similar paper based on WD ionization of the local ISM <30pc in which they conclude they may dominate in some of the nearby clouds

END

Does theory match observations of the LC?

The Hot Top model (Welsh & Shelton 2009)



Infalling hot halo gas provides a source of soft X-rays & OVI at high latitudes

Mid-plane gas clouds photo-ionized by ε & β CMa plus nearby hot white dwarfs

Very little 10^6K gas at mid-plane so gas pressure imbalance problem goes away

A case against the local presence of hot gas

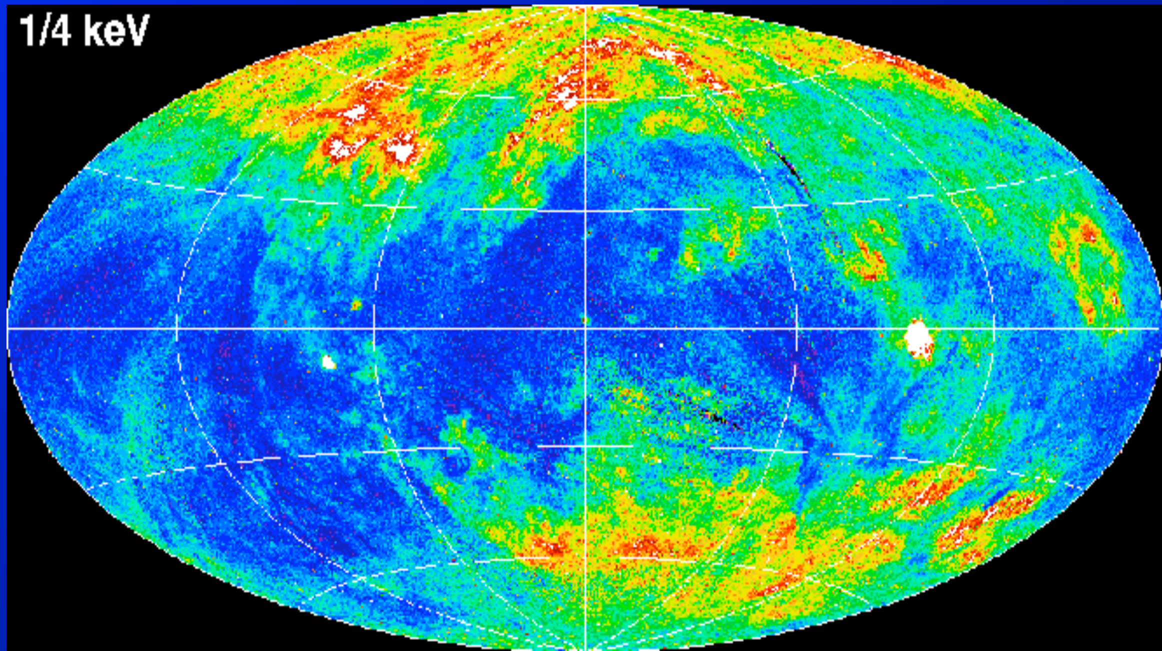
- **NO EUV emission lines** from a hot local gas were detected by both the NASA EUVE and CHIPS missions

- The pressure derived for the hot 10^6 K gas >> pressure derived for the local diffuse clouds ---- how can this be sustained?

- Analysis of the ROSAT SXRB spectra by Koutroumpa et al (2010) and others, suggest that any contribution from a hot Local Cavity gas must be small (< 10%) at low latitudes. At high latitudes the signal probably arises in a hot halo gas.

- X-ray shadow data for the Local Leo Cold Cloud (d ~ 20pc, T ~ 20K) place a very low limit of < 1.1 Snowdens pc^{-1} for the 1/4keV emissivity from a hot Local Cavity gas (Peek et al 2011)

The case for hot gas within the Local Cavity



Snowden et al 1997

- *observations of the ubiquitous million degree soft X-ray background (which due to absorption, must be located locally)*

- *the presence of OVI (λ1032Å) interstellar absorption in the FUV spectra of nearby hot white dwarfs (T ~ 300,000K)*

- *Local Cavity gas should have properties similar to other stellar wind-driven bubbles or cooling SNR's which emit in X-rays (e.g. Eridanus bubble etc)*