Towards 3D maps of the nearby ISM in its various phases

Rosine Lallement GEPI/Observatoire de Paris

Collaborators:

J-L Vergely (ACRI-ST)

L. Puspitarini, Hui-Chen Chen, P. Bonifacio, C. Babusiaux (GEPI),

L. Eyer (Geneva Observatory)

B. Welsh (SSL, Berkeley)

Outline

* 3D maps from inversion of absorption data

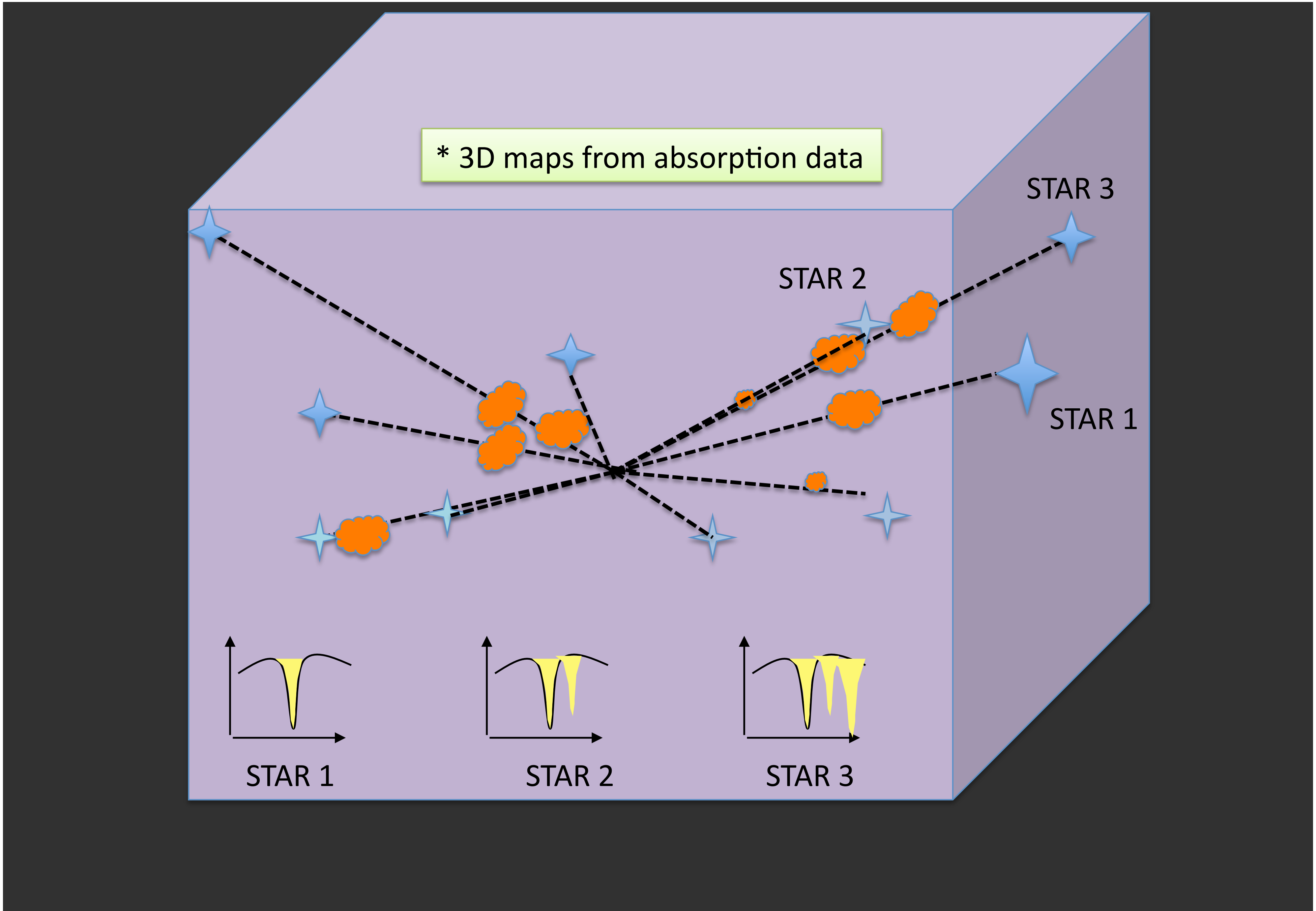
    *data, method, shortcomings, validation tests

    * recent dust extinction maps, comparison with gas absorption

•Mapping cavities => first comparison with X-ray background data
=> the hot, coronal phase

*Mapping large-scale abundance variations=> first, preliminary results

*PERSPECTIVES


* 3D maps from absorption data
STAR 3
STAR 2
STAR 1
STAR 1
STAR 2
STAR 3

Ideally:

-target stars evenly distributed everywhere in space
-on a very tight grid

-precise measurements of the absorbing columns

-precise measurements of the target distances

and , ideally for our purpose

-a choice of interstellar tracers adapted to the various phases

-target stars databases (strongly) biased

-today coarse grids for individual abs. data very limited datasets

-unequal accuracies on the absorbing columns

-inaccurate target distances, use of photometric distances

Every aspect in progress, but today real life is............

-Bayesian method for the general nonlinear inverse problem

(Tarantola Valette, 1980)

-Volume opacity (gas or dust) treated as **a continuous function of space**

-Data d and model m are random vectors that fluctuate around 'prior' values

-Line-of-sight integrals: d= g(m)

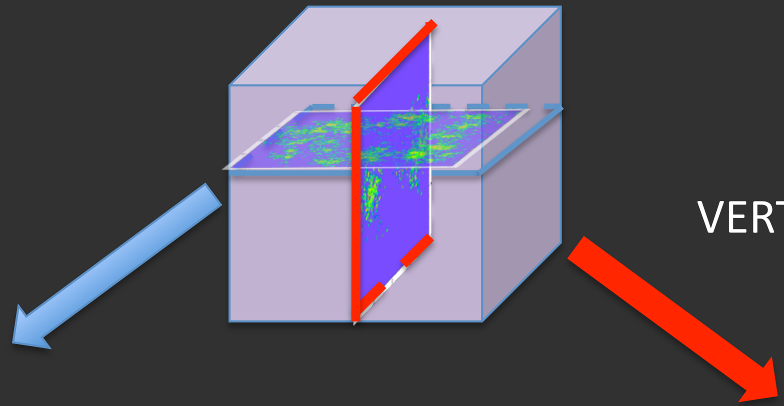
-Iterative method: minimization of d-g(m) compatible with allowed fluctuations

-Strong undetermination > **smoothing length introduced**

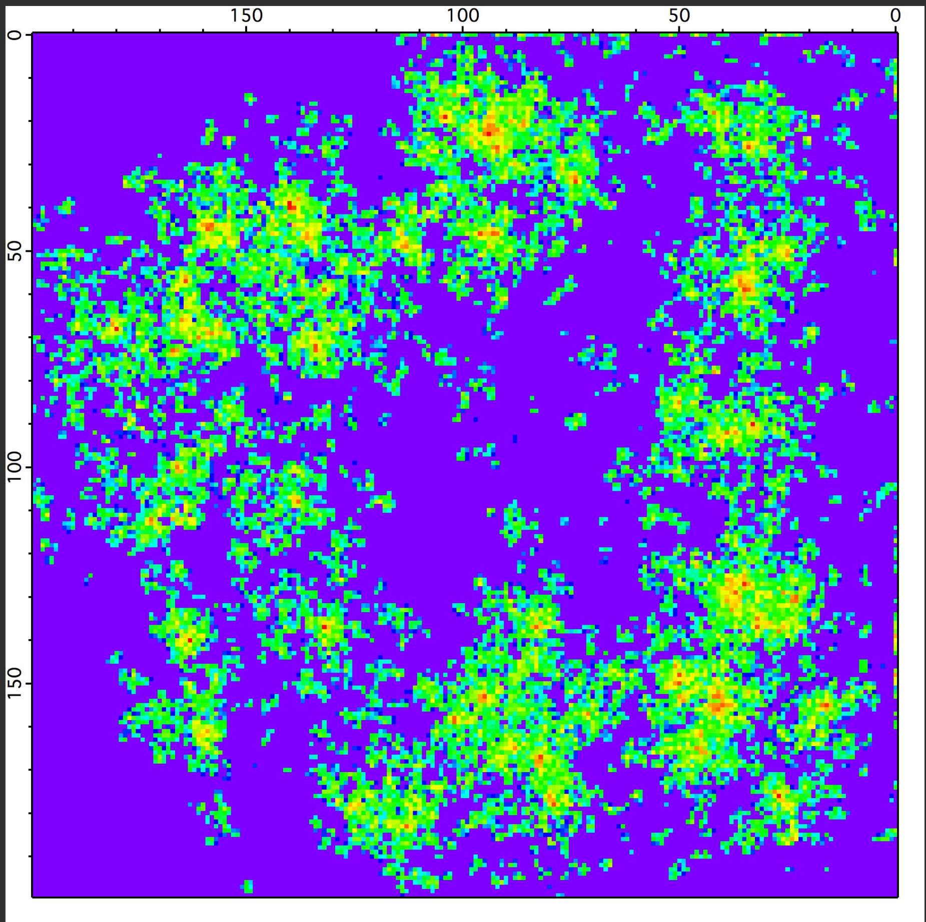
-The most recent inversions make use of two favoured sizes of clouds: to represent the dense(cold) and dilute(warm) phases

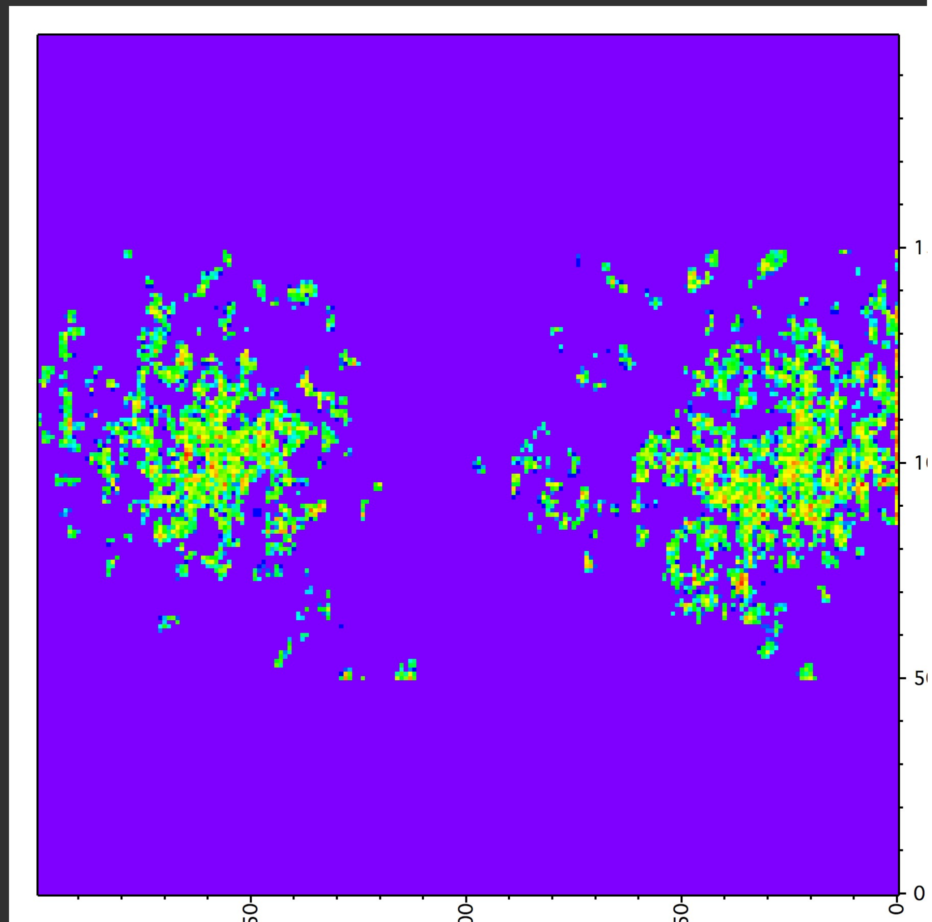
VALIDATION TESTS SIMULATED DUST DISTRIBUTION

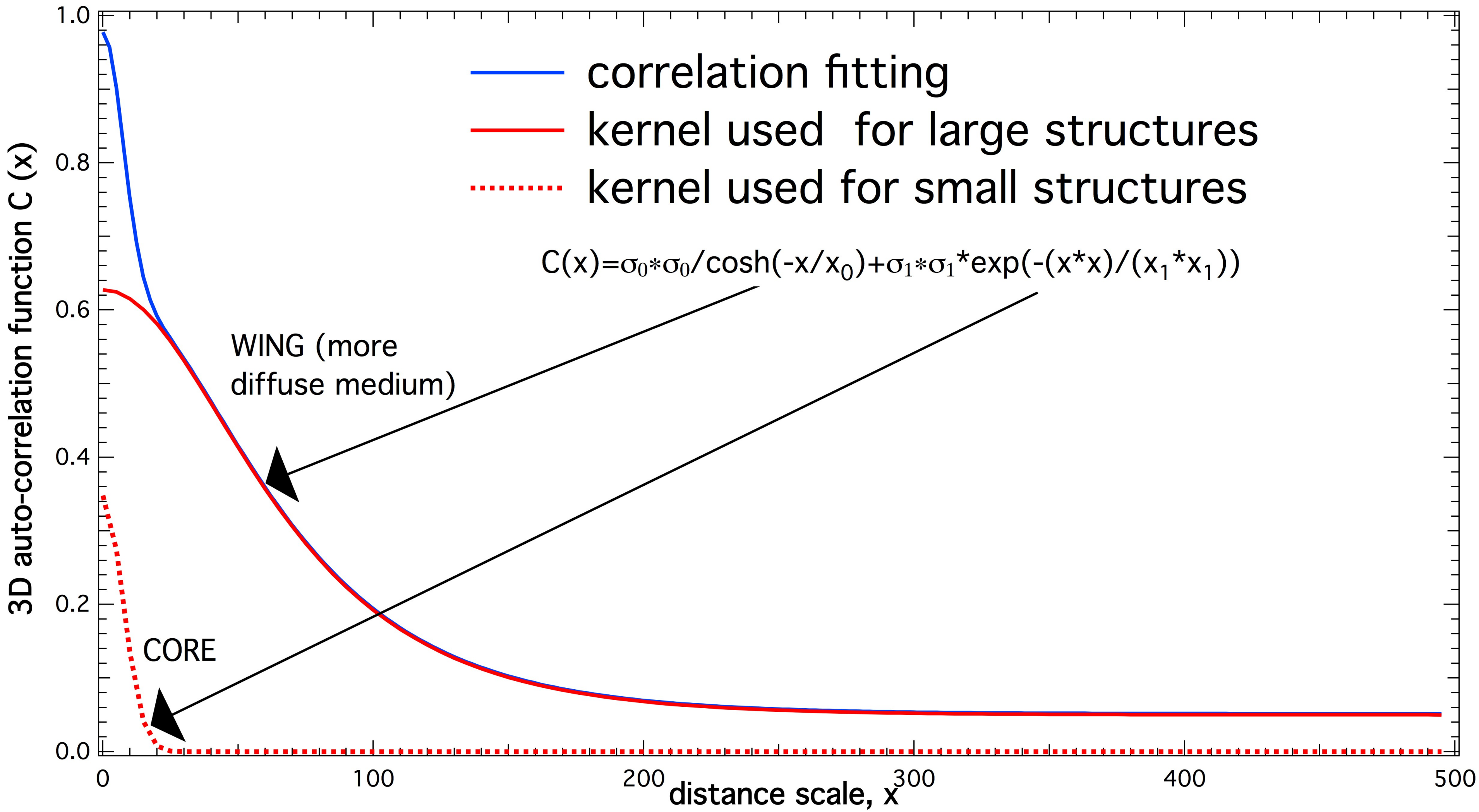
HORIZONTAL CUT



VERTICAL CUT

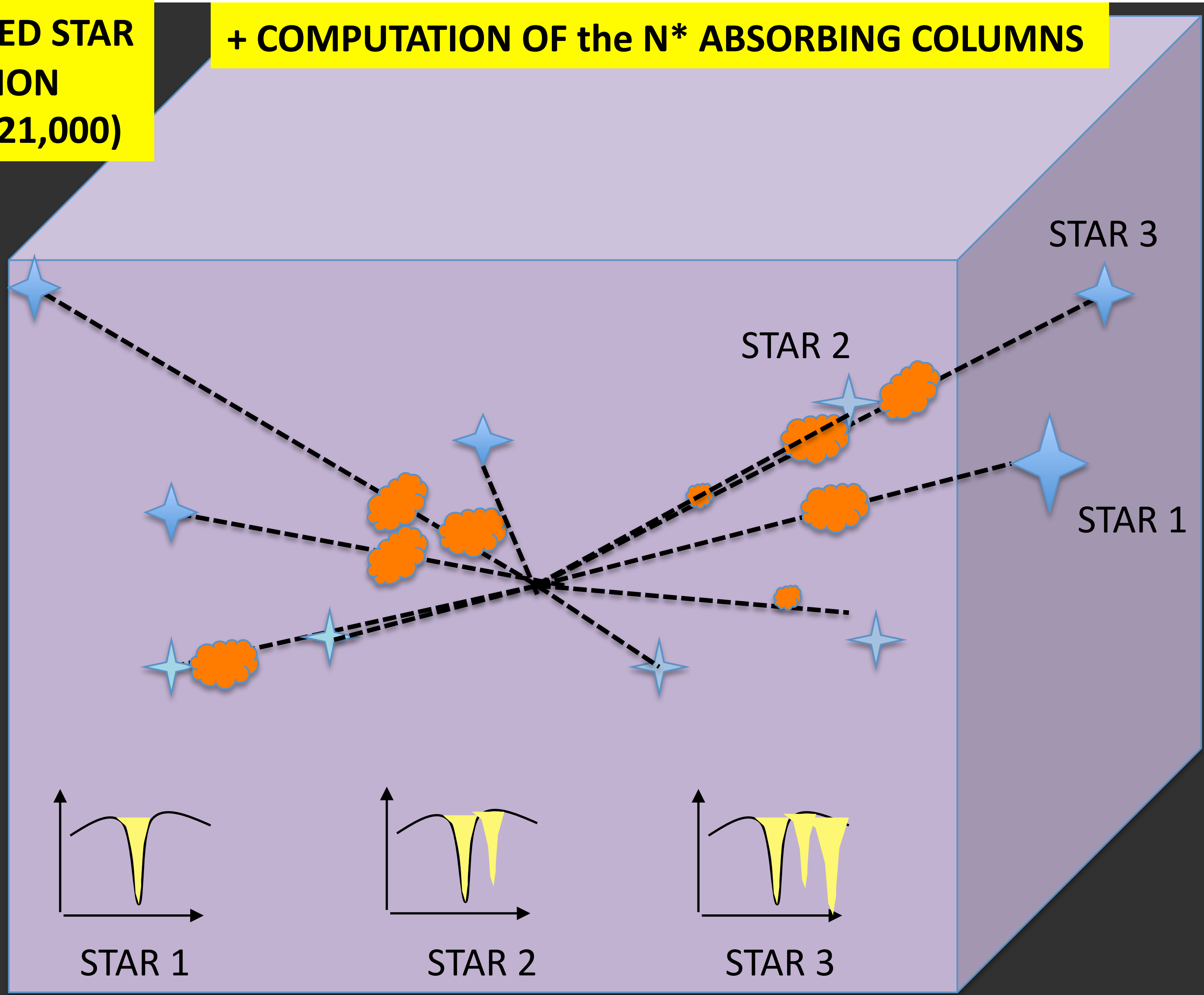





correlation fitting
kernel used for large structures
kernel used for small structures
C(x)=σ0*σ0/cosh(-x/x0)+σ1*σ1*exp(-(x*x)/(x1*x1))
WING (more diffuse medium)
CORE
3D auto-correlation function C (x)
distance scale, x
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500

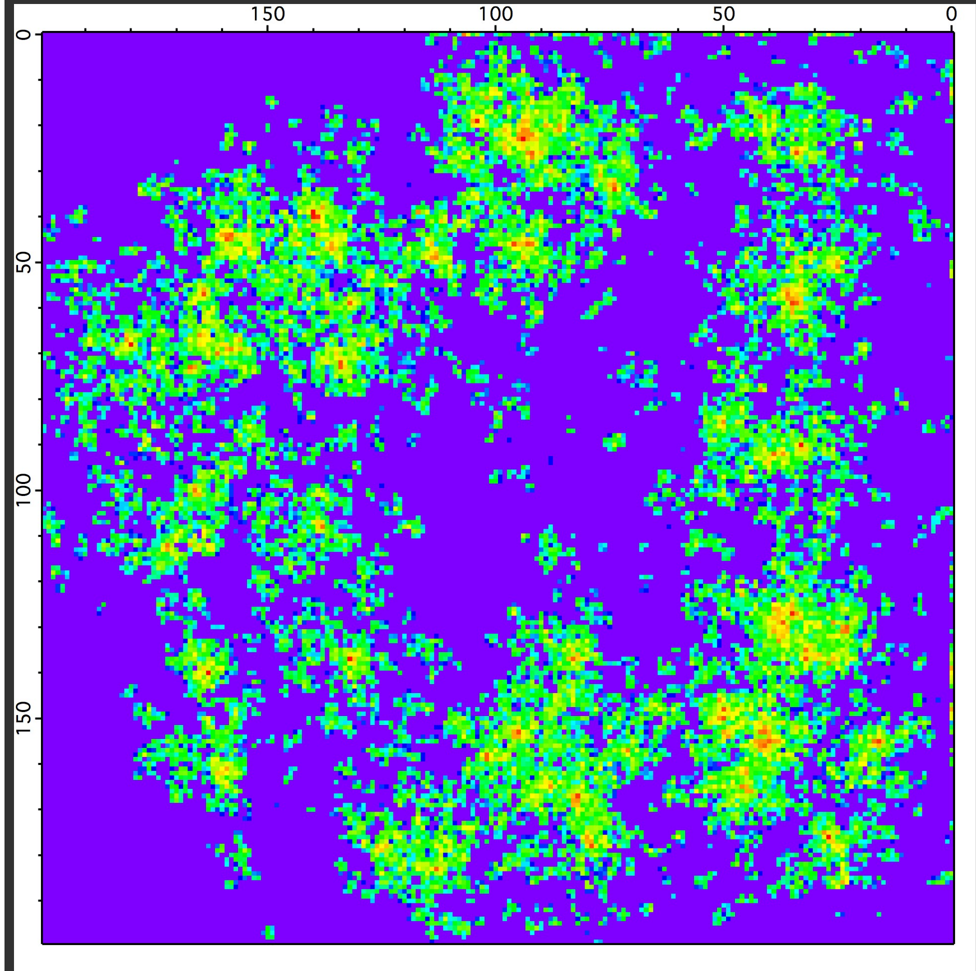
+ SIMULATED STAR DISTRIBUTION N* STARS (21,000)

+ COMPUTATION OF the N* ABSORBING COLUMNS

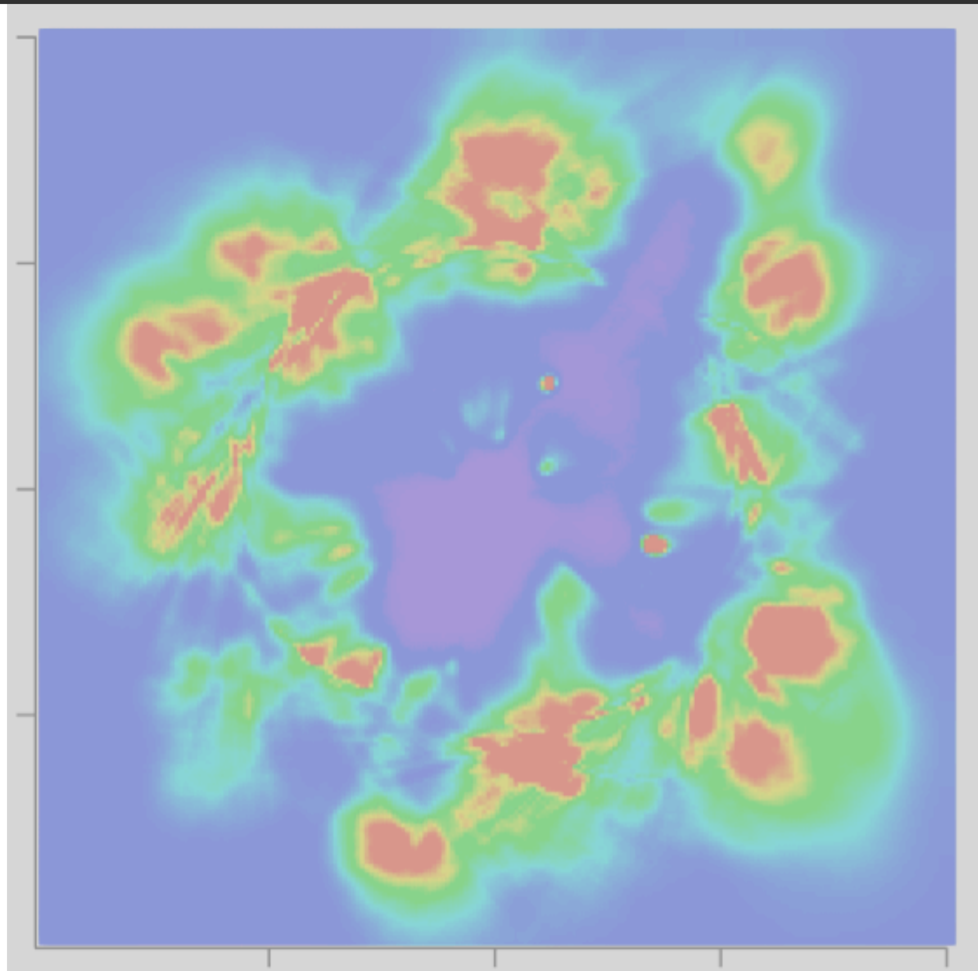


INVERSION OF THE 21,000 SIMULATED COLUMNS + TARGET DIRECTIONS AND DISTANCES

INITIAL DISTRIBUTION



INVERTED DISTRIBUTION



23,000 color excess measurements

Distances

Hiparcos parallaxes + photometric parallaxes for 15,000 *

Photometric data

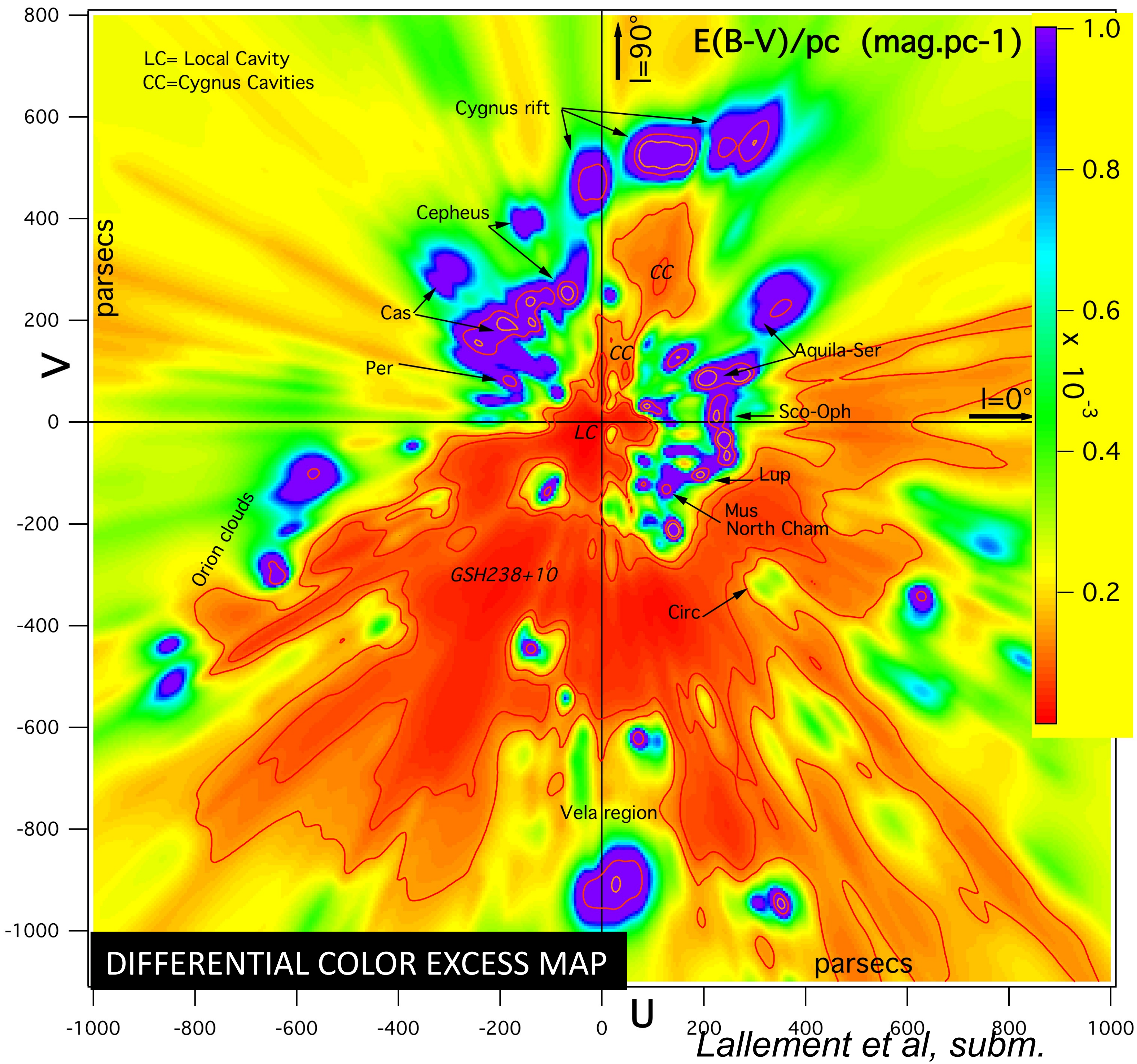
Strömgren catalogs

Geneva photometric database (E(B-V)+d

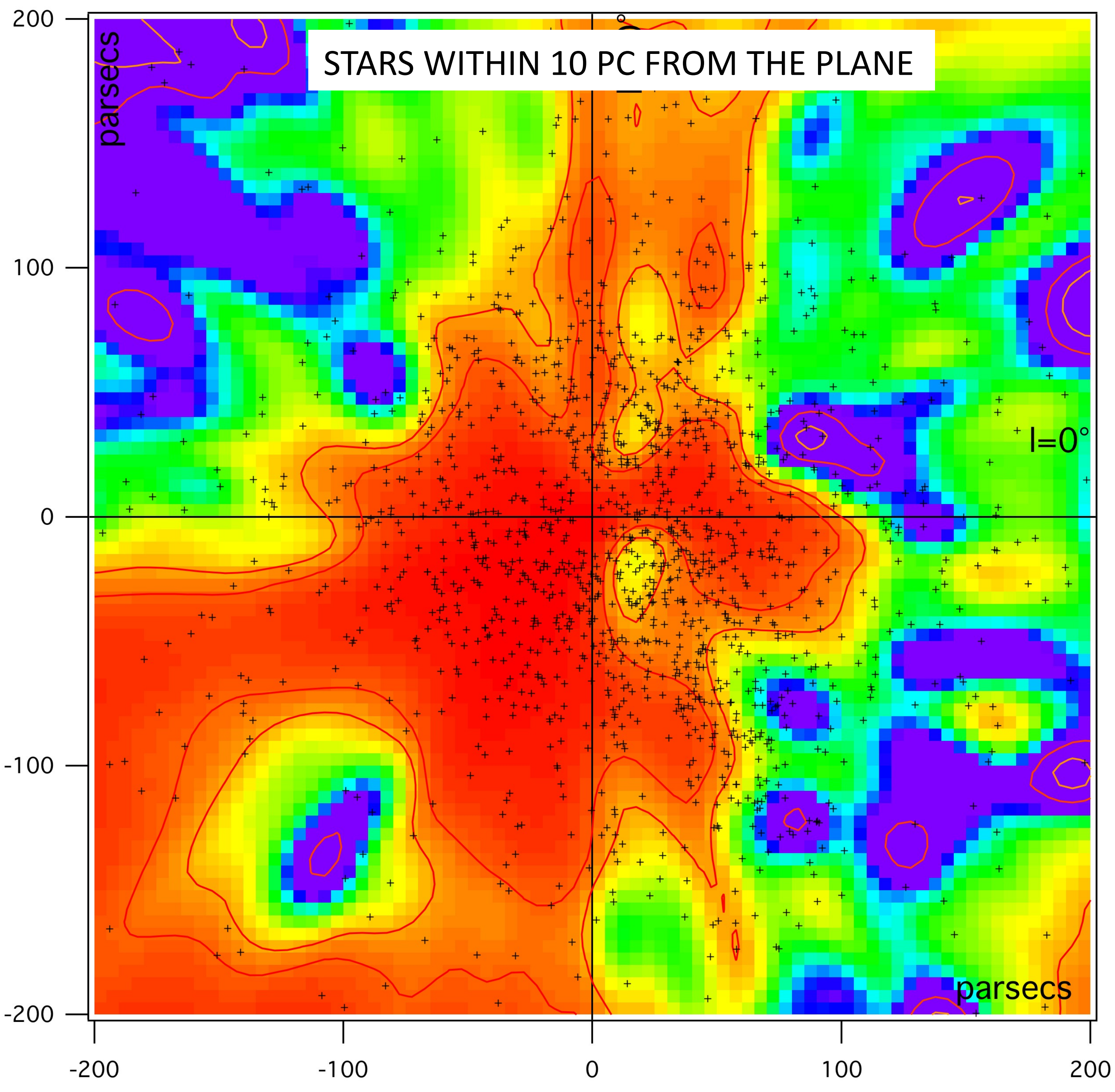
Geneva-Copenhagen Survey

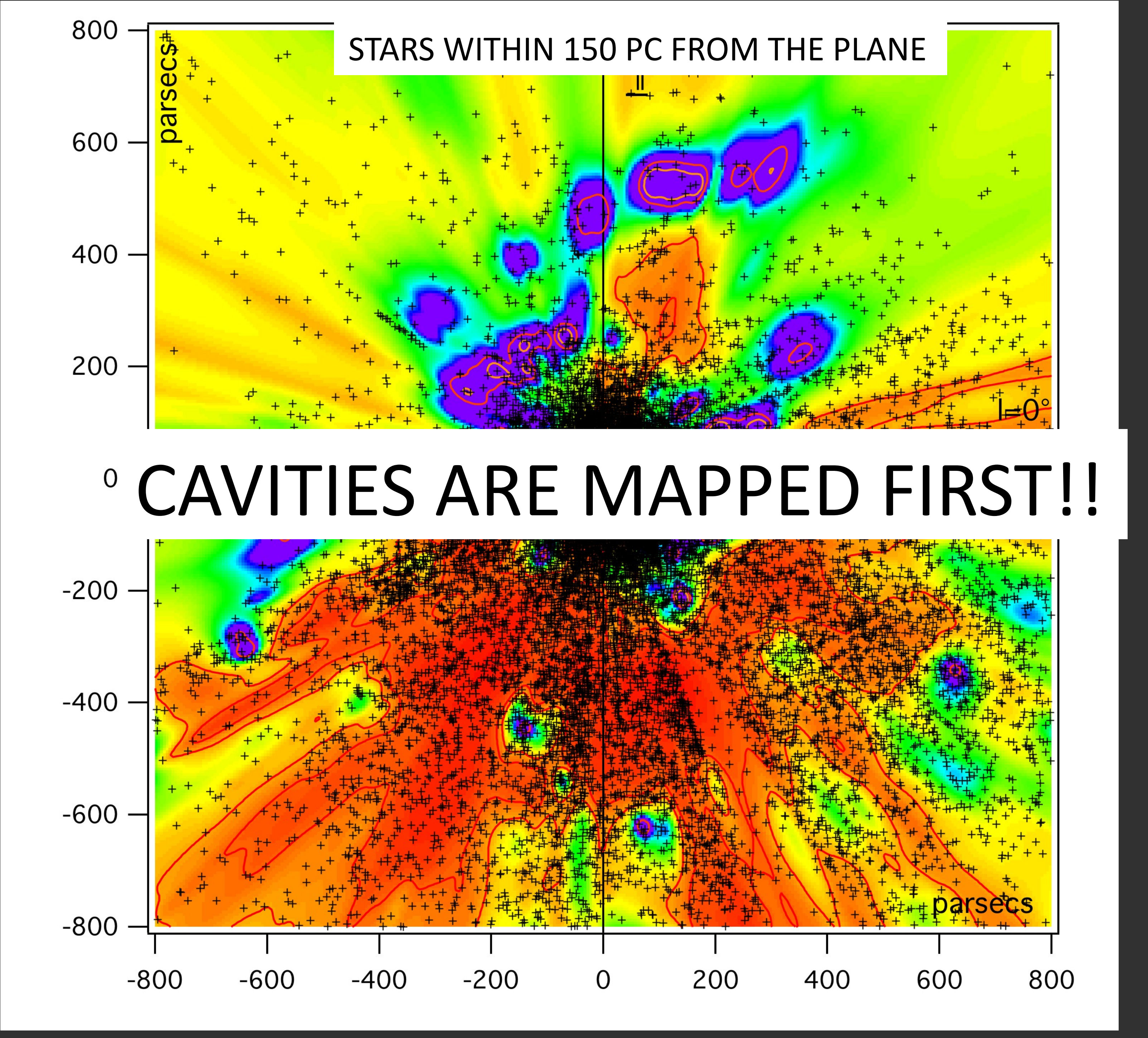
Open clusters

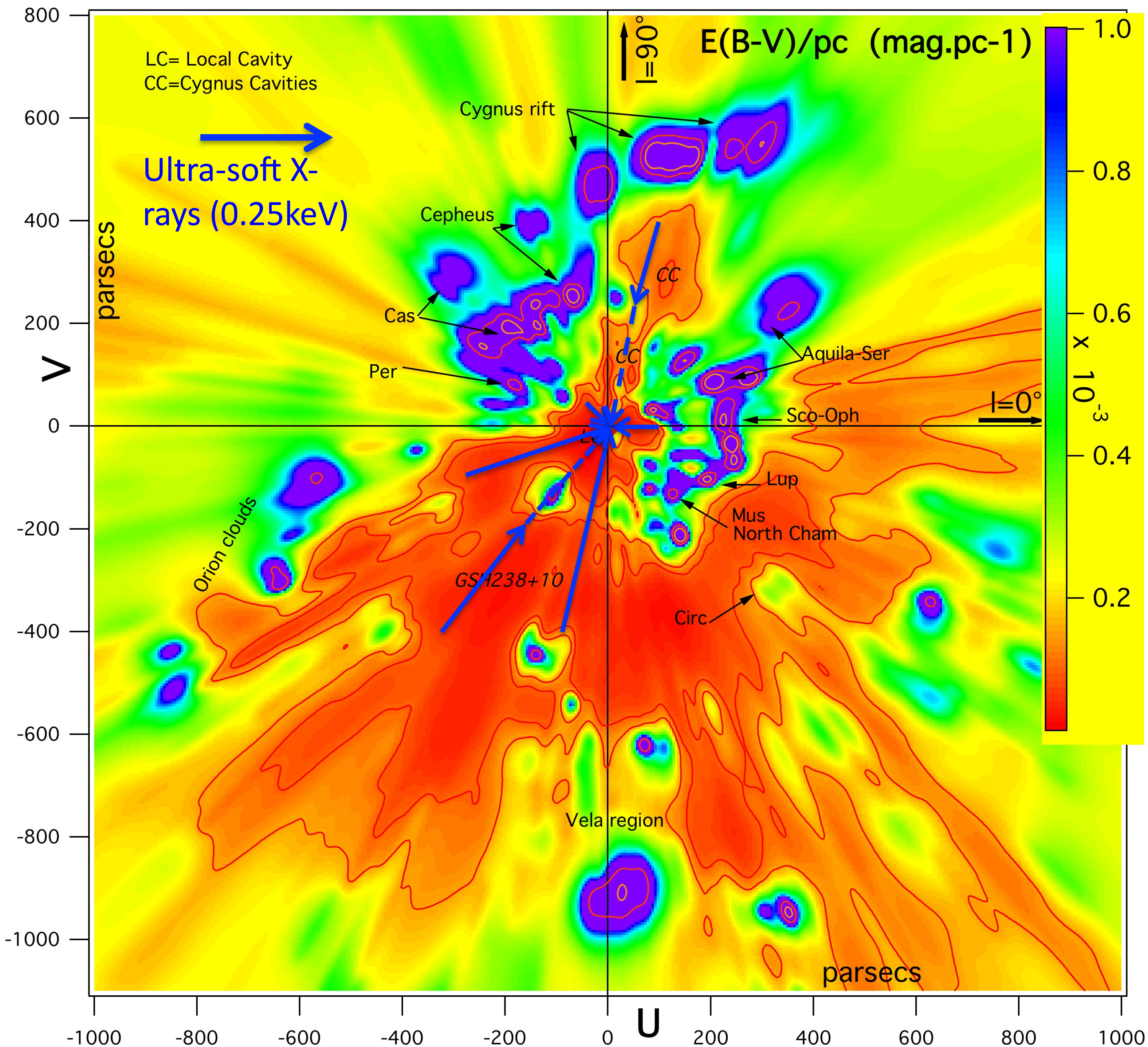
3D DUST DISTRIBUTION 0 –> ≈1000 pc



LC= Local Cavity
CC=Cygnus Cavities
E(B-V)/pc (mag.pc-1)
l=90°
l=0°
Cygnus rift
Cepheus
Cas
Per
CC
CC
LC
Aquila-Ser
Sco-Oph
Lup
Mus
North Cham
Orion clouds
GSH238+10
Circ
Vela region
parsecs
V
U
parsecs
x 10^-3
1.0
0.8
0.6
0.4
0.2
800
600
400
200
0
-200
-400
-600
-800
-1000
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
DIFFERENTIAL COLOR EXCESS MAP
Lallement et al, subm.


STARS WITHIN 10 PC FROM THE PLANE
parsecs
l=0°
parsecs
200
100
0
-100
-200
-200
-100
0
100
200

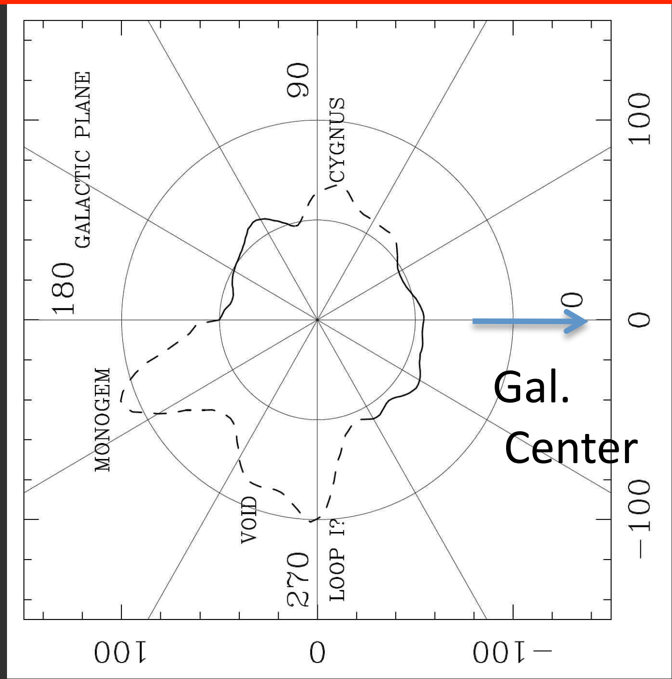

STARS WITHIN 150 PC FROM THE PLANE
CAVITIES ARE MAPPED FIRST!!
parsecs
parsecs
l=0°
800
600
400
200
0
-200
-400
-600
-800
-800
-600
-400
-200
0
200
400
600
800



LC= Local Cavity
CC=Cygnus Cavities
Ultra-soft X-rays (0.25keV)
E(B-V)/pc (mag.pc-1)
x 10^-3
1.0
0.8
0.6
0.4
0.2
l=90°
l=0°
Cygnus rift
Cepheus
Cas
Per
CC
CC
Aquila-Ser
Sco-Oph
Lup
Mus
North Cham
Circ
Orion clouds
GSH238+10
Vela region
parsecs
V
parsecs
U
800
600
400
200
0
-200
-400
-600
-800
-1000
-1000
-800
-600
-400
-200
0
200
400
600
800
1000

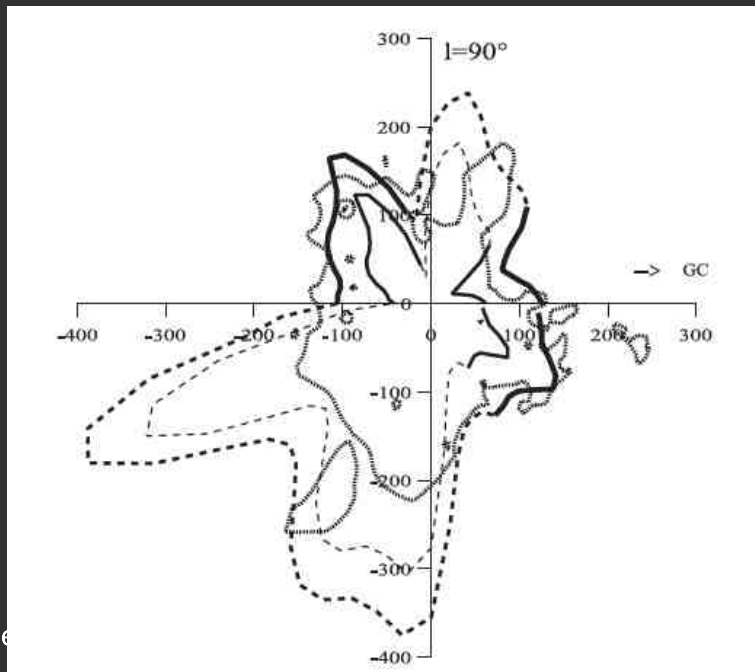
USING THE MAPS TO INFER HOT ISM PROPERTIES

We start with the ROSAT maps of unabsorbed 0.25 keV diffuse soft X-ray background
Snowden et al, 1998

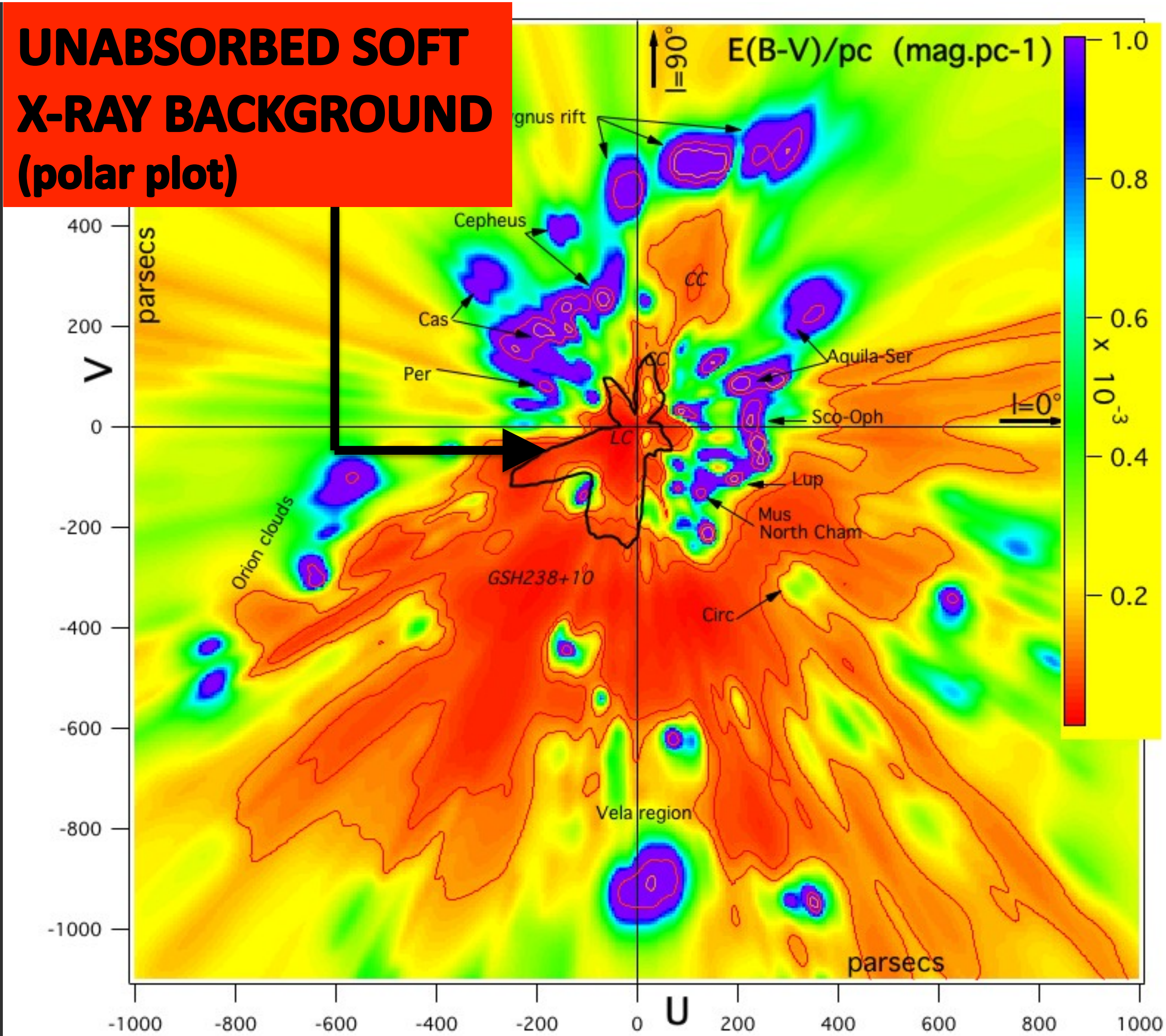


Galactic Plane

We remove the contribution of the solar wind charge transfer X-ray emission (two cases)
Lallement et al, 2004



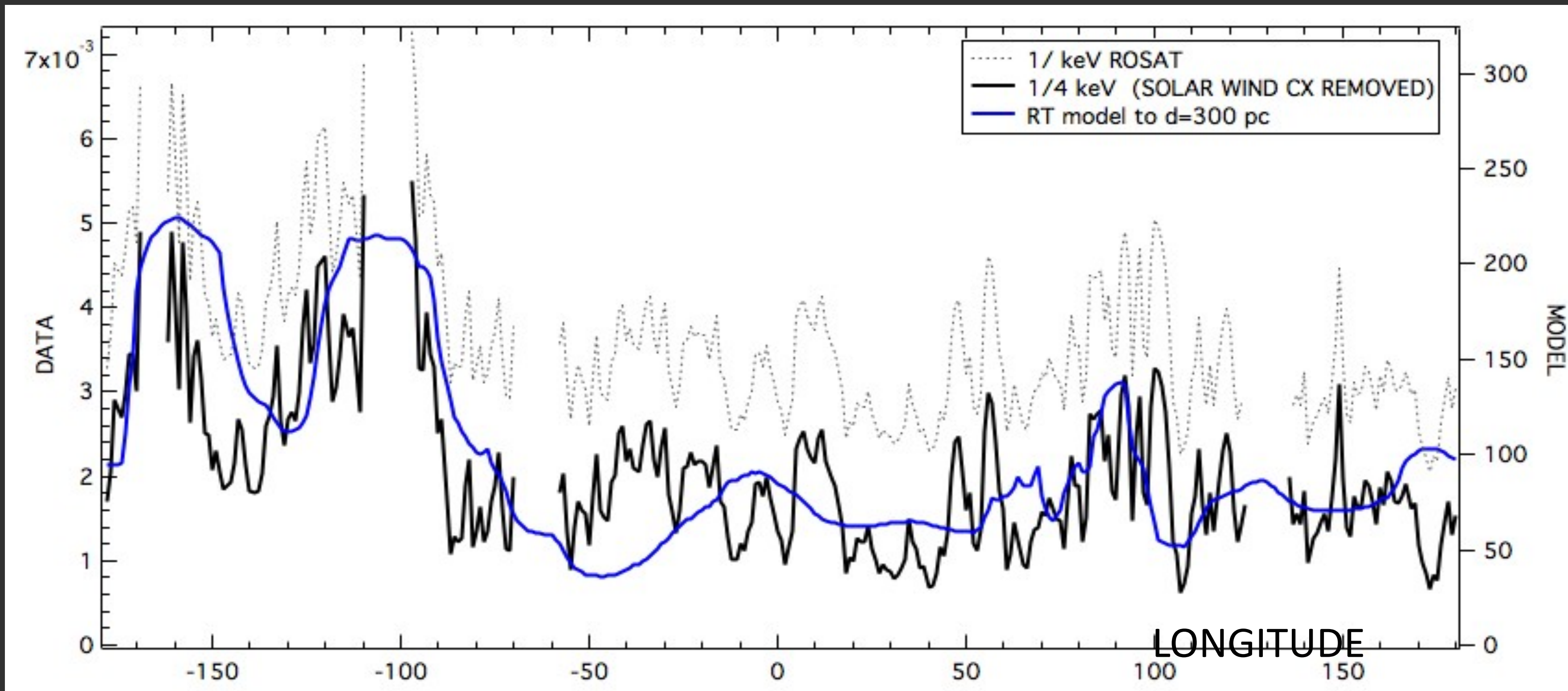
UNABSORBED SOFT X-RAY BACKGROUND (polar plot)



More quantitatively

Radiative transfer models within the maps:
We assume that all cavities emit in X-rays, and all clouds absorb

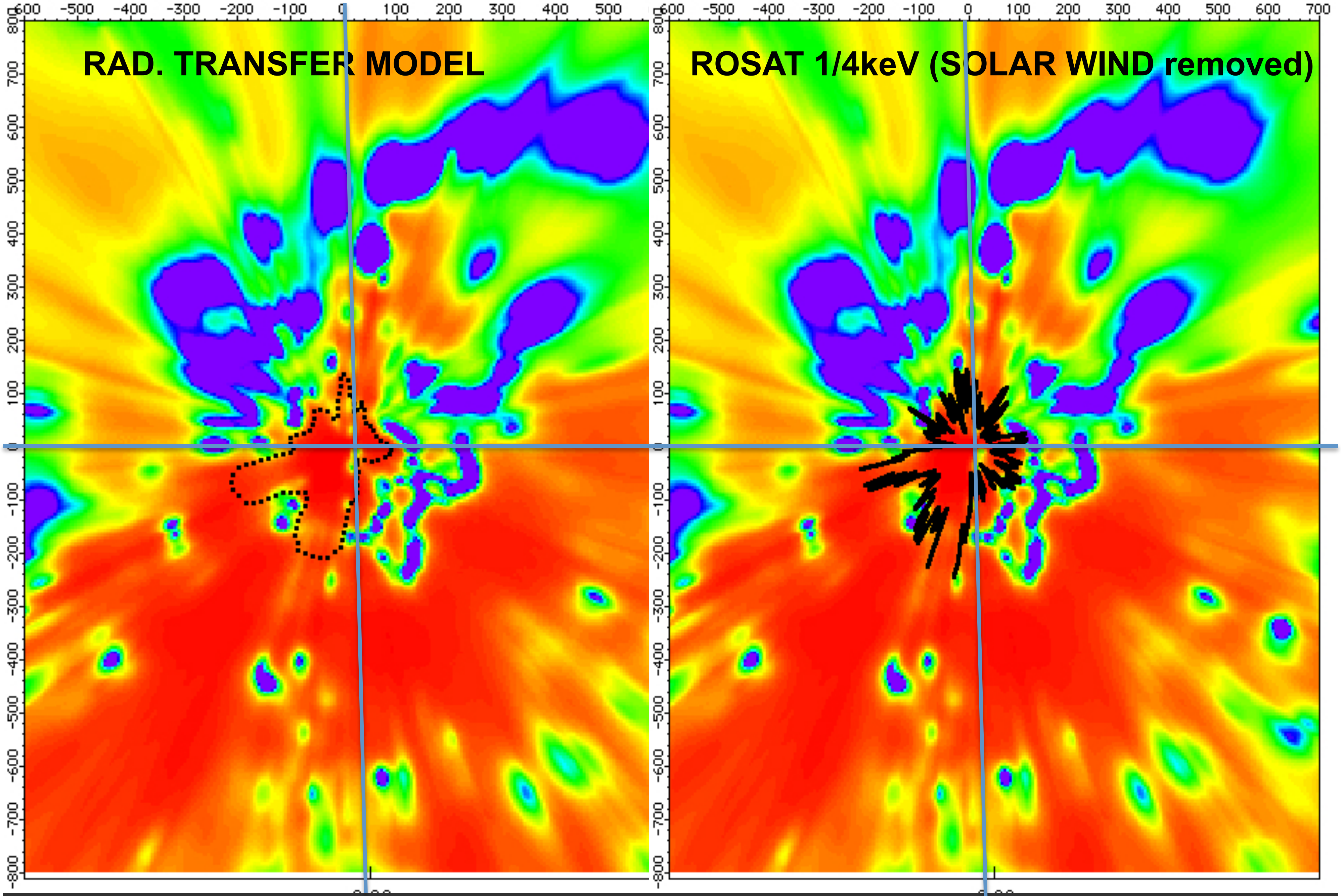
Diffuse 0.25keV X-ray background (absorbed +unabsorbed)



Volume emissivity of the hot gas in the cavities

Preliminary computations: Puspitarini et al (in progress)

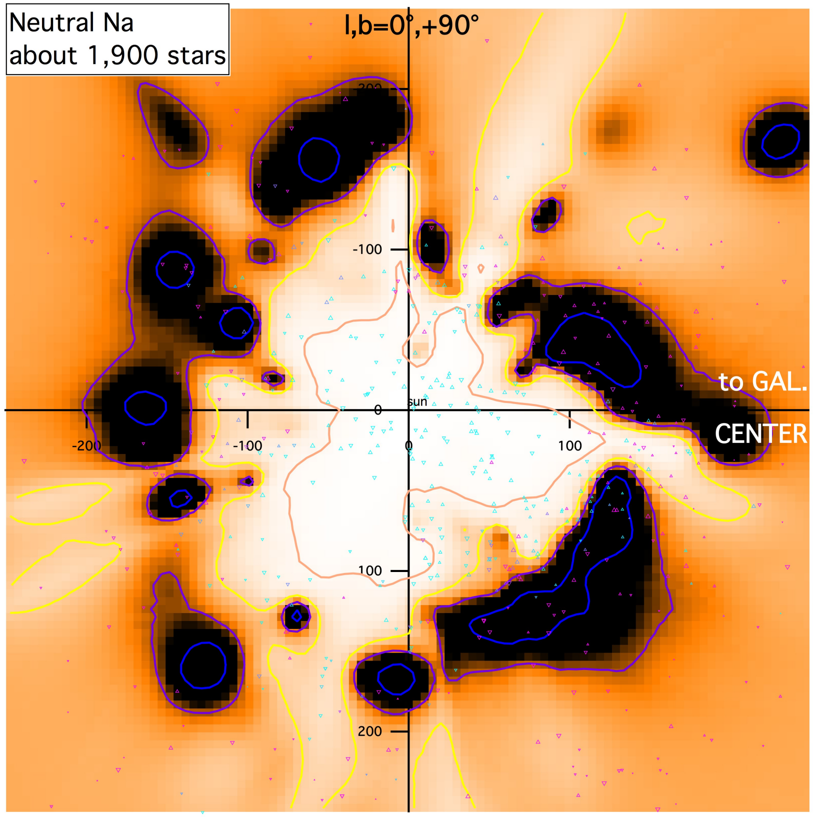
If T=1MK => n(e-)= 6 10 $^{-3}$ cm^{-3} => P(mean)= 2nT= 12,000 cm^{3} K

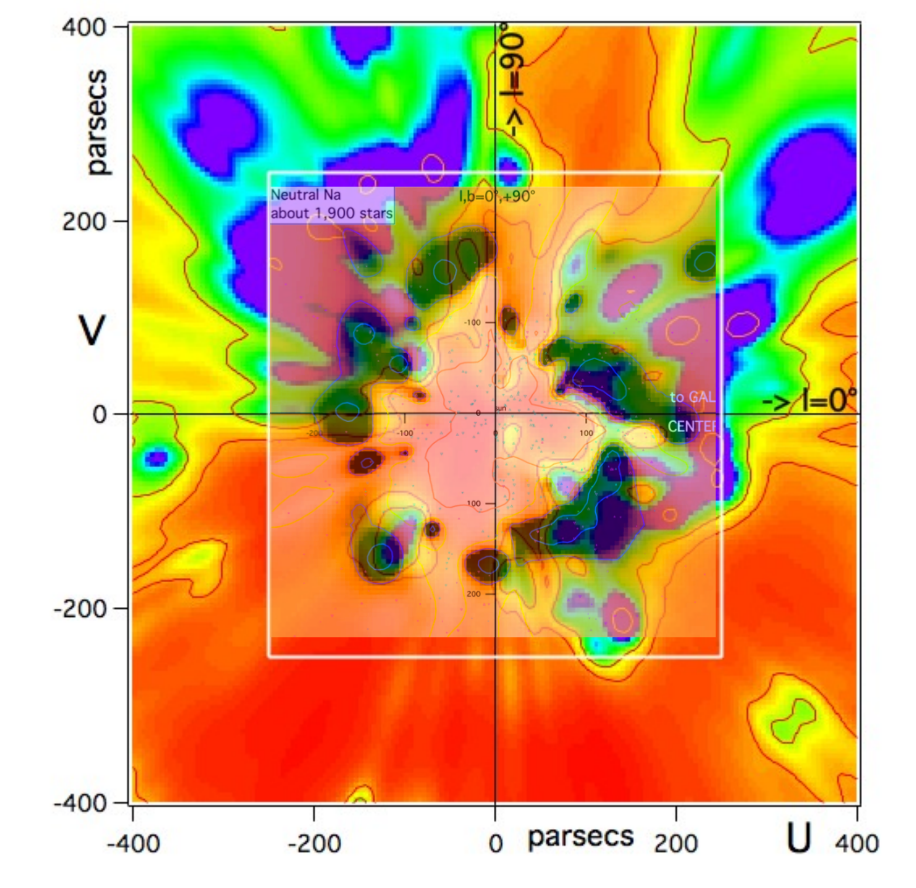


Preliminary computations: Puspitarini et al (in progress)

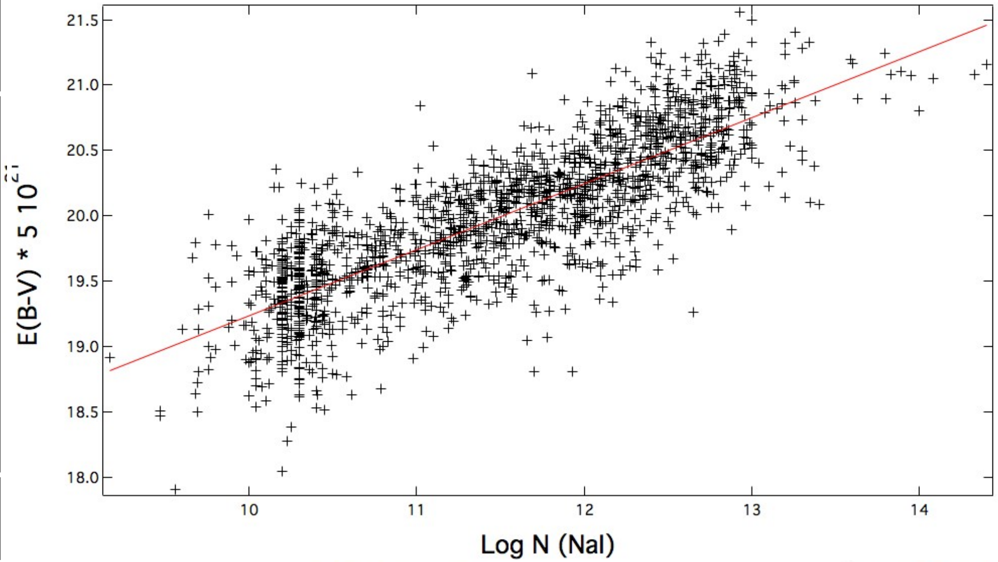
If T=1MK => n(e-)= 6 10^{-3} cm^{-3} => P(mean)= 2nT= 12,000 cm^3 K

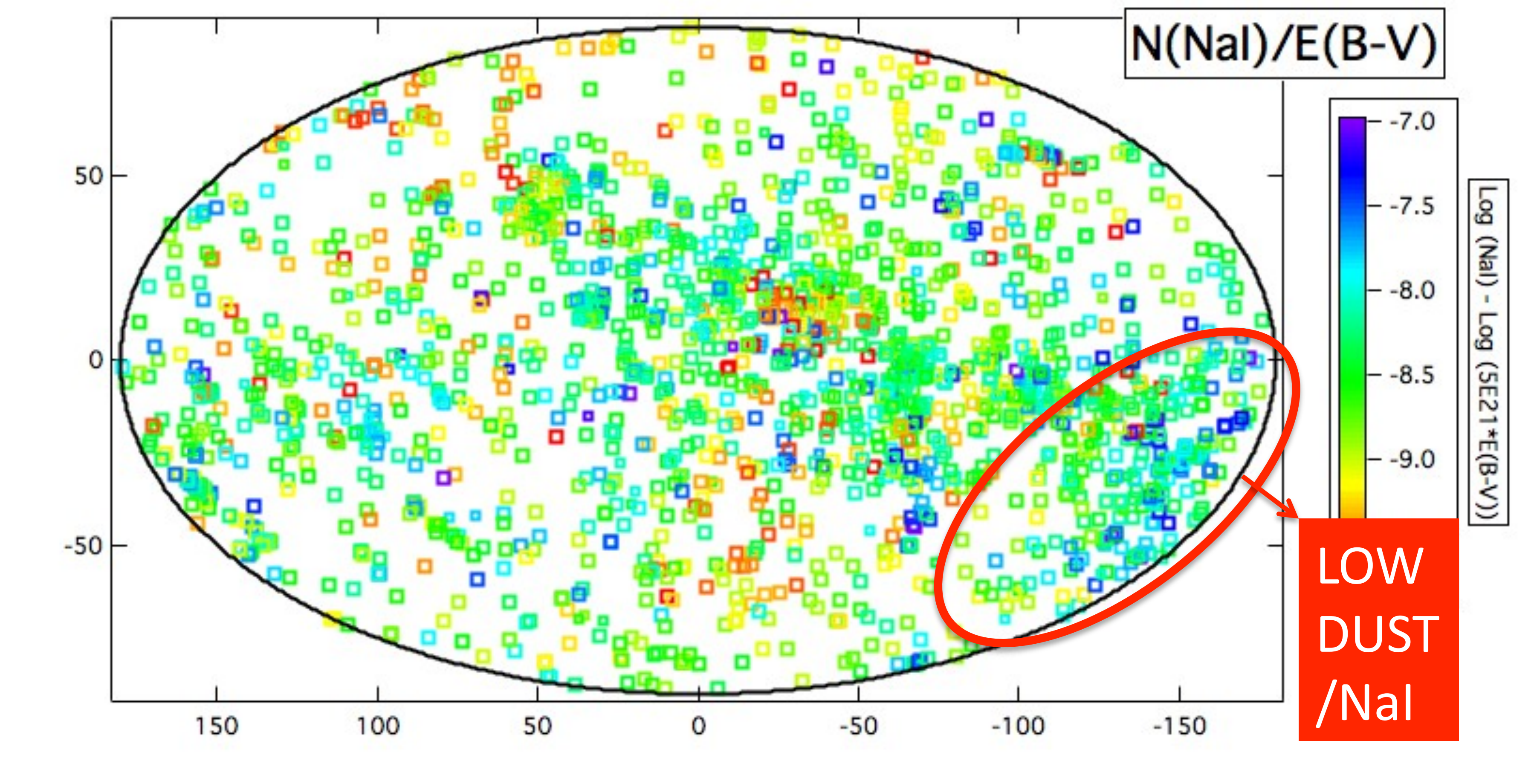
USING THE MAPS TO INFER relations between THE DUST and GASEOUS SPECIES



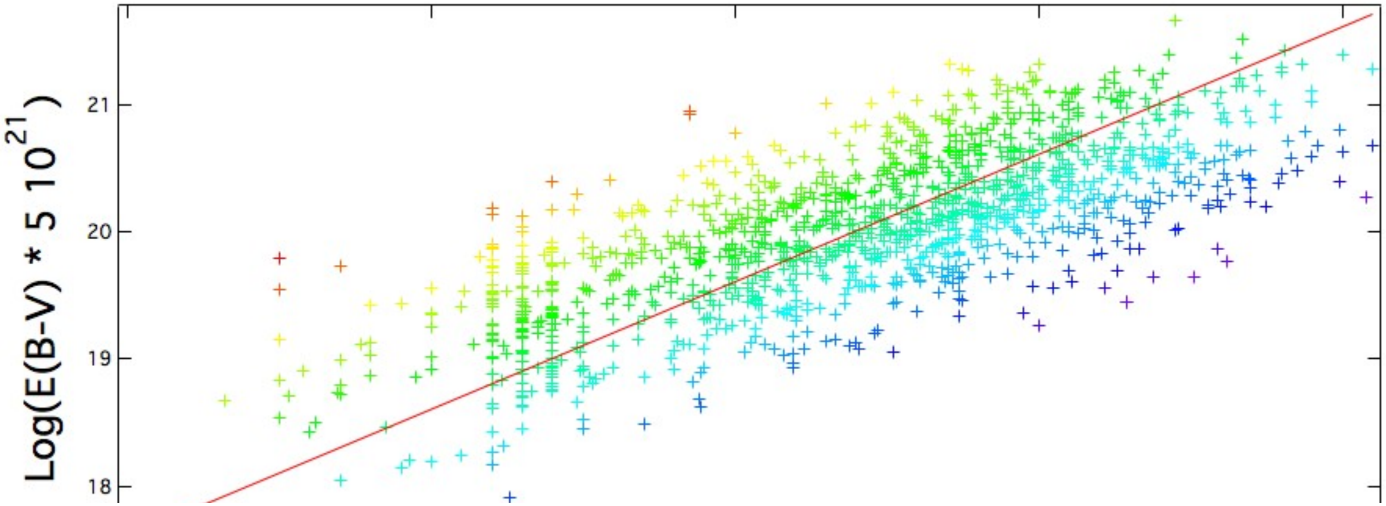


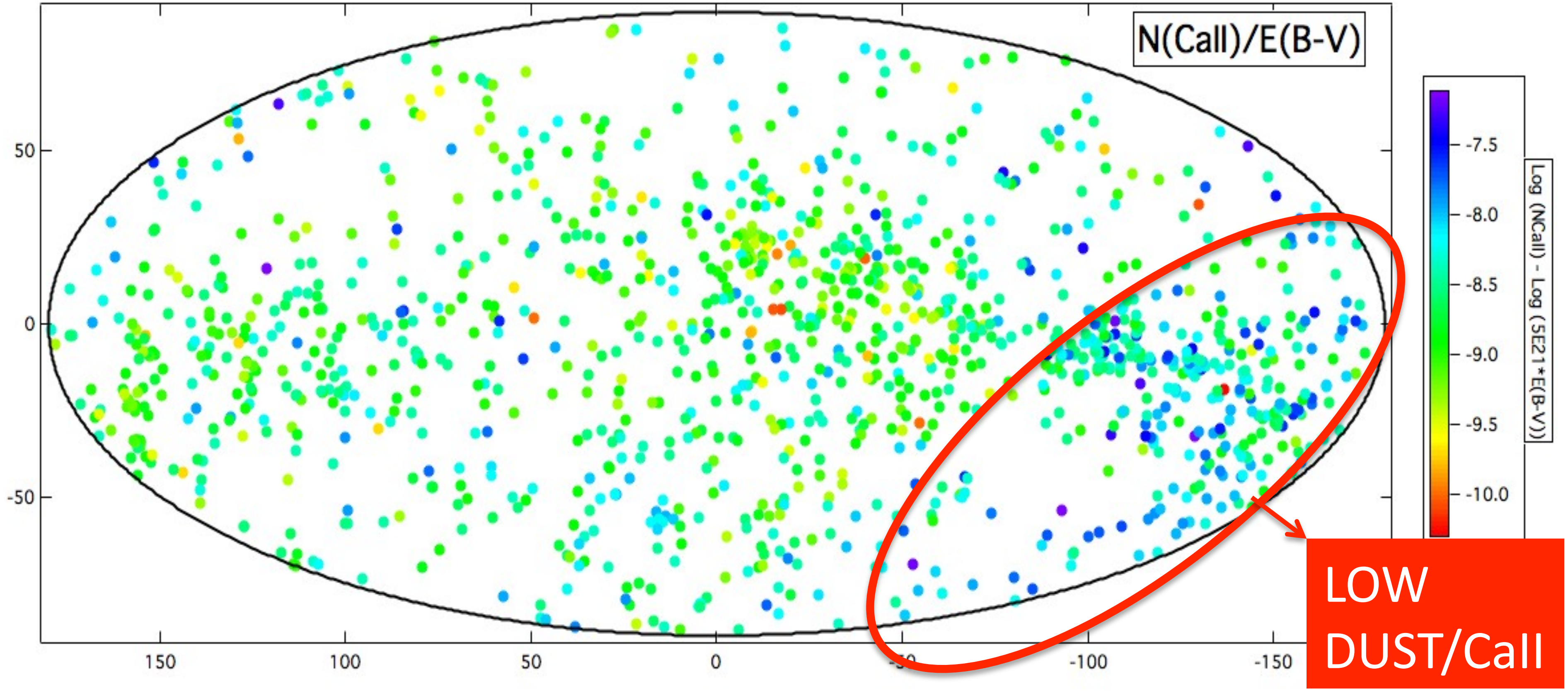
COLOR EXCESS
(computed from
the 3D dust cube)
VS
NEUTRAL SODIUM
(direct measurements)

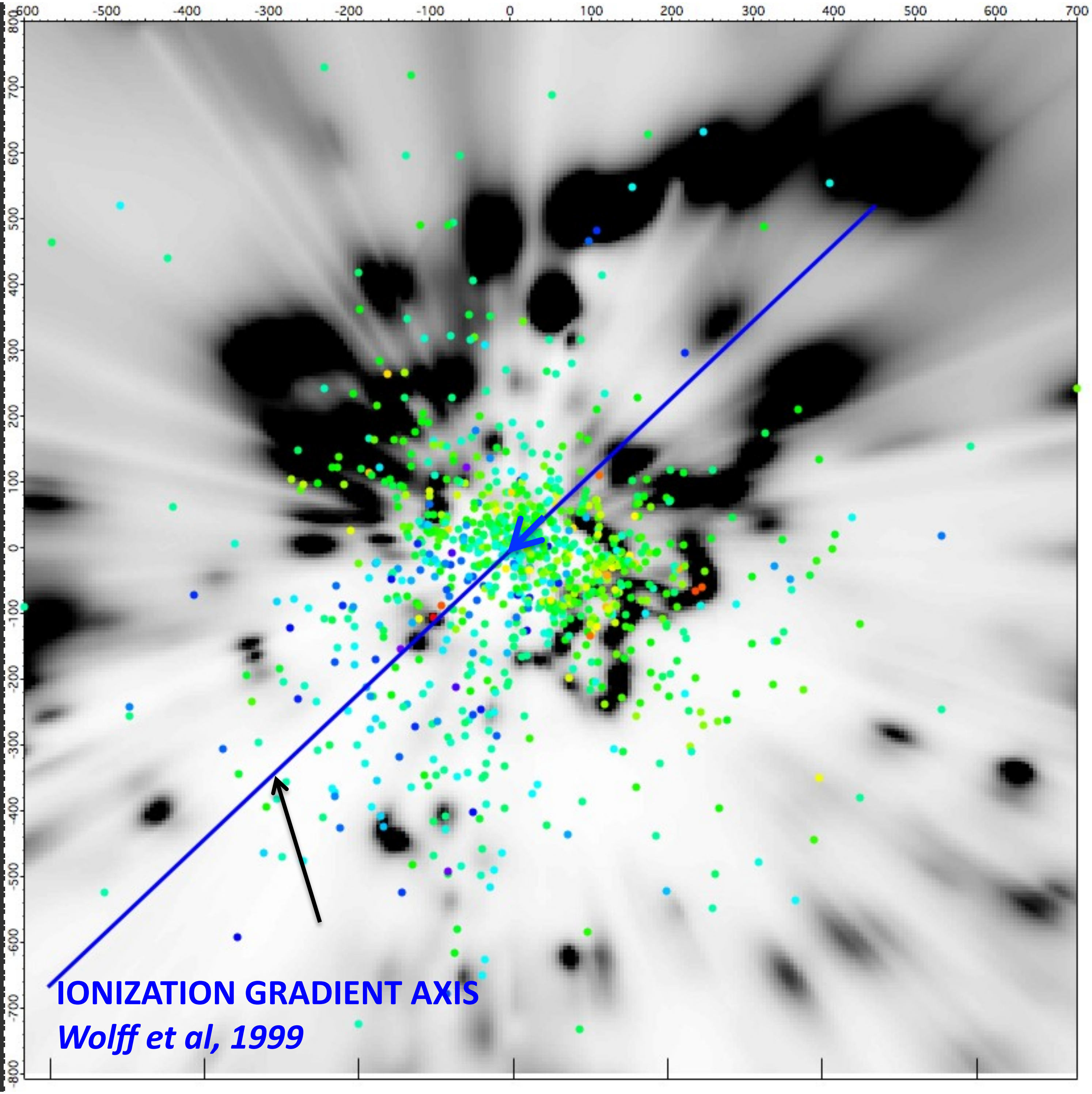




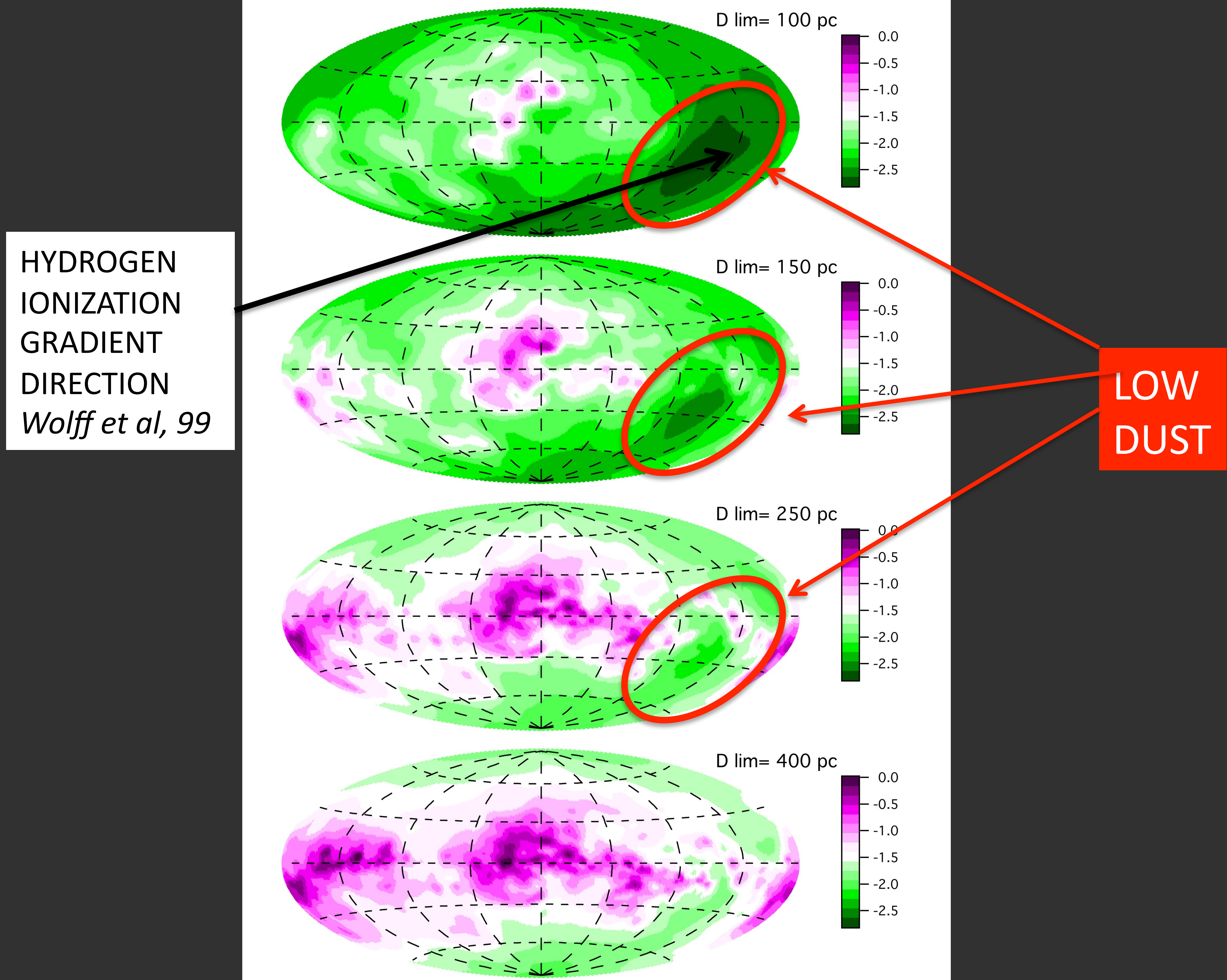
COLOR EXCESS VS IONIZED CALCIUM

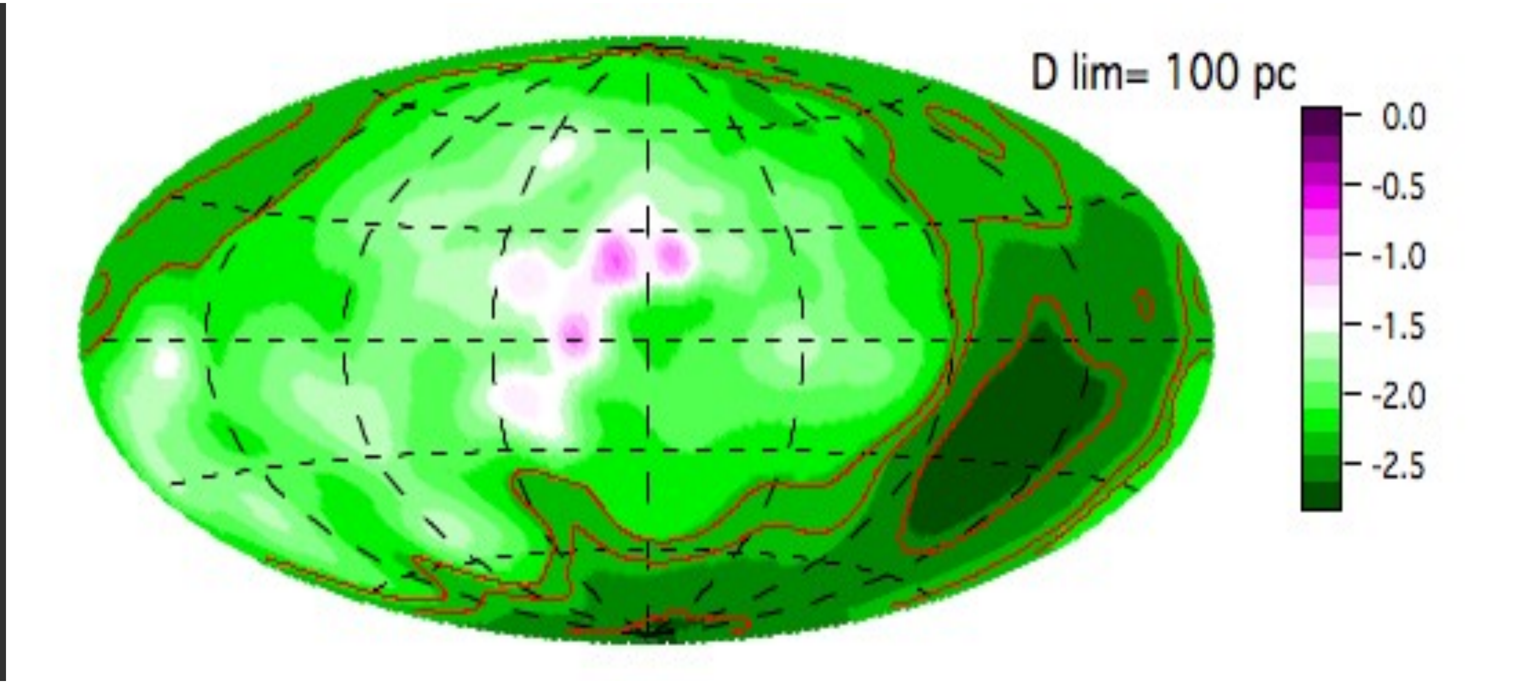


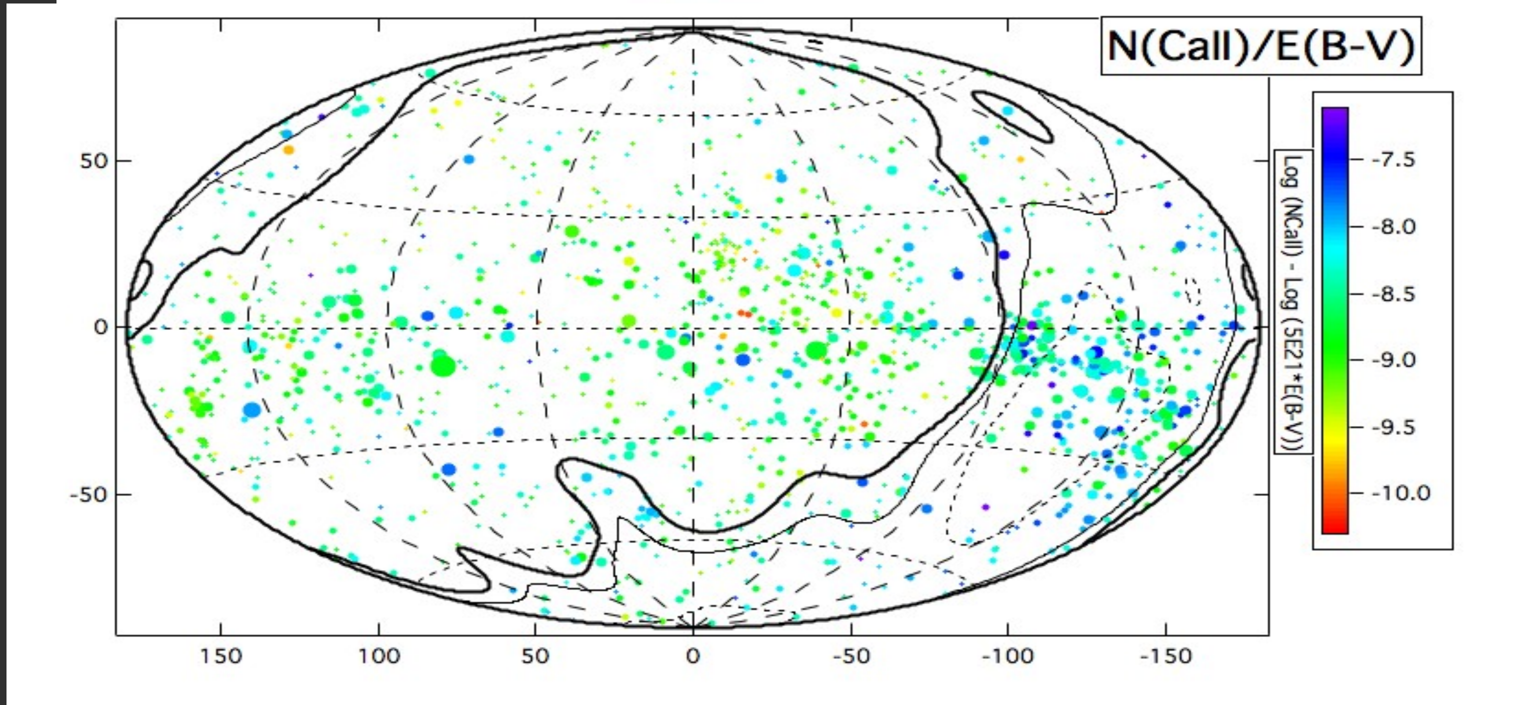


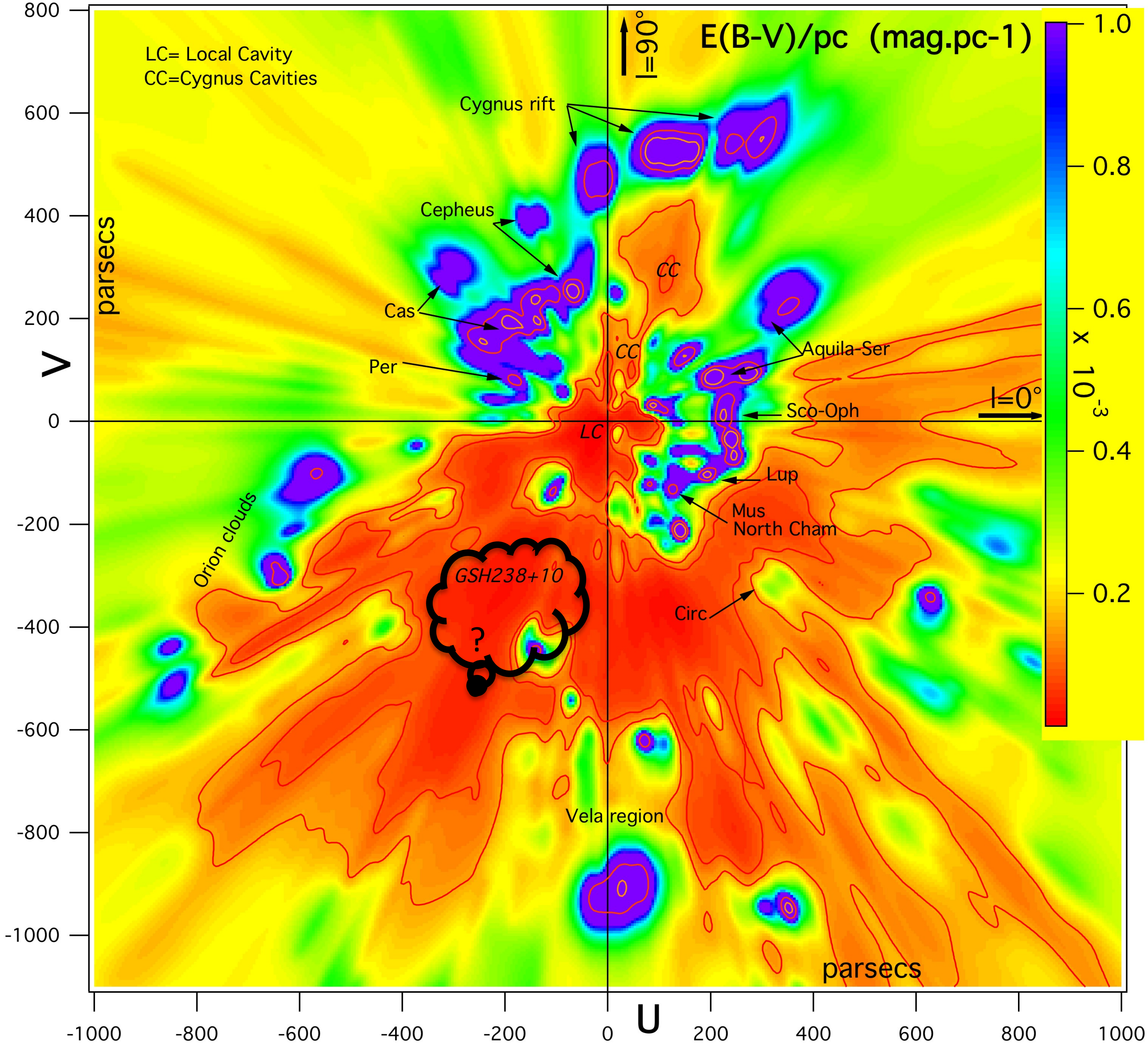


-600 -500 -400 -300 -200 -100 0 100 200 300 400 500 600 700
800 700 600 500 400 300 200 100 0 -100 -200 -300 -400 -500 -600 -700 -800
IONIZATION GRADIENT AXIS
Wolff et al, 1999


HYDROGEN
IONIZATION
GRADIENT
DIRECTION
Wolff et al, 99
LOW
DUST
D lim= 100 pc
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
D lim= 150 pc
D lim= 250 pc
D lim= 400 pc


D lim= 100 pc
0.0
-0.5
-1.0
-1.5
-2.0
-2.5


N(CaII)/E(B-V)
Log (NCaII) - Log (5E21*E(B-V))
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
50
0
-50
150
100
50
0
-50
-100
-150



LC= Local Cavity
CC=Cygnus Cavities
E(B-V)/pc (mag.pc-1)
l=90°
l=0°
x 10-3
1.0
0.8
0.6
0.4
0.2
Cygnus rift
Cepheus
Cas
Per
CC
CC
LC
Aquila-Ser
Sco-Oph
Lup
Mus
North Cham
Orion clouds
GSH238+10
?
Circ
Vela region
parsecs
V
parsecs
U
800
600
400
200
0
-200
-400
-600
-800
-1000
-1000
-800
-600
-400
-200
0
200
400
600
800
1000

Perspectives: we need more data and more interstellar tracers

-extinction (or color excess) ➔ traces the dust
➔associated with all phases (except in the coronal phase where grains are evaporated)

-difficult measurement: spectrophotometry helps reducing degeneracies
Future: stellar spectroscopic surveys with MOS (associated with Vis, IR photometric surveys and Gaia!

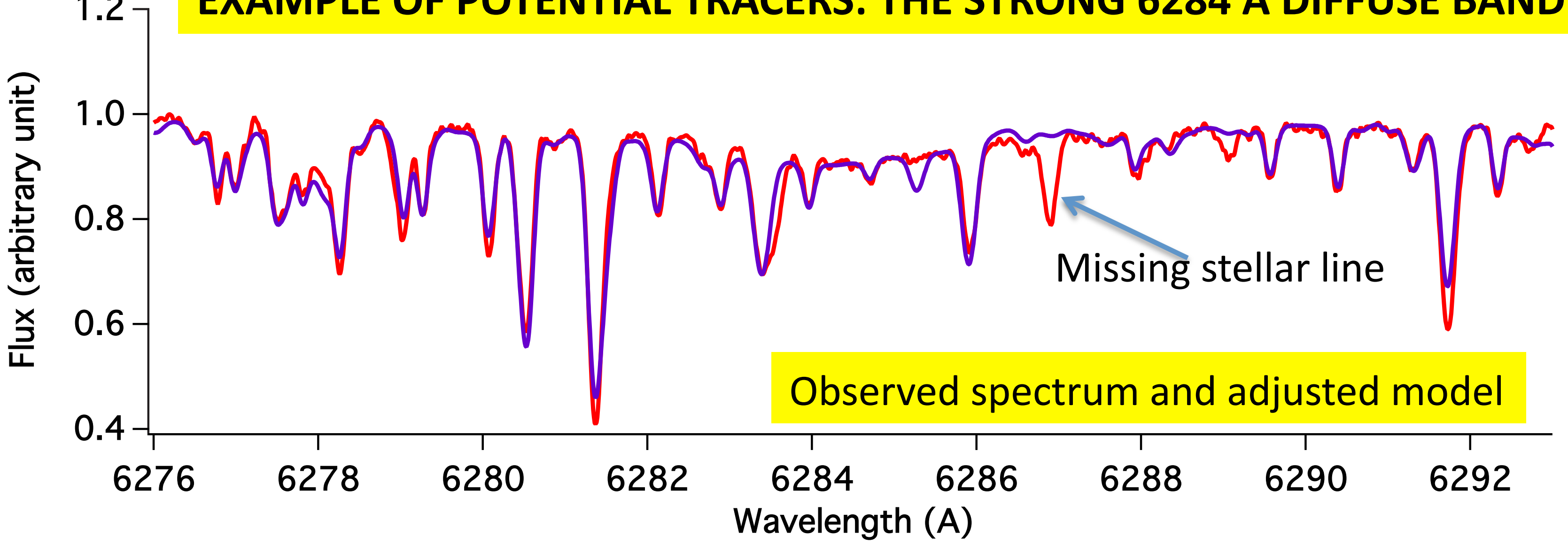
-gaseous absorption lines: today only NaI, CaII
NaI traces essentially the diffuse ISM (also dense cores and filaments but very few target stars available exactly beyond those objects)
-CaII traces the diffuse ISM and the warm neutral and ionized gas

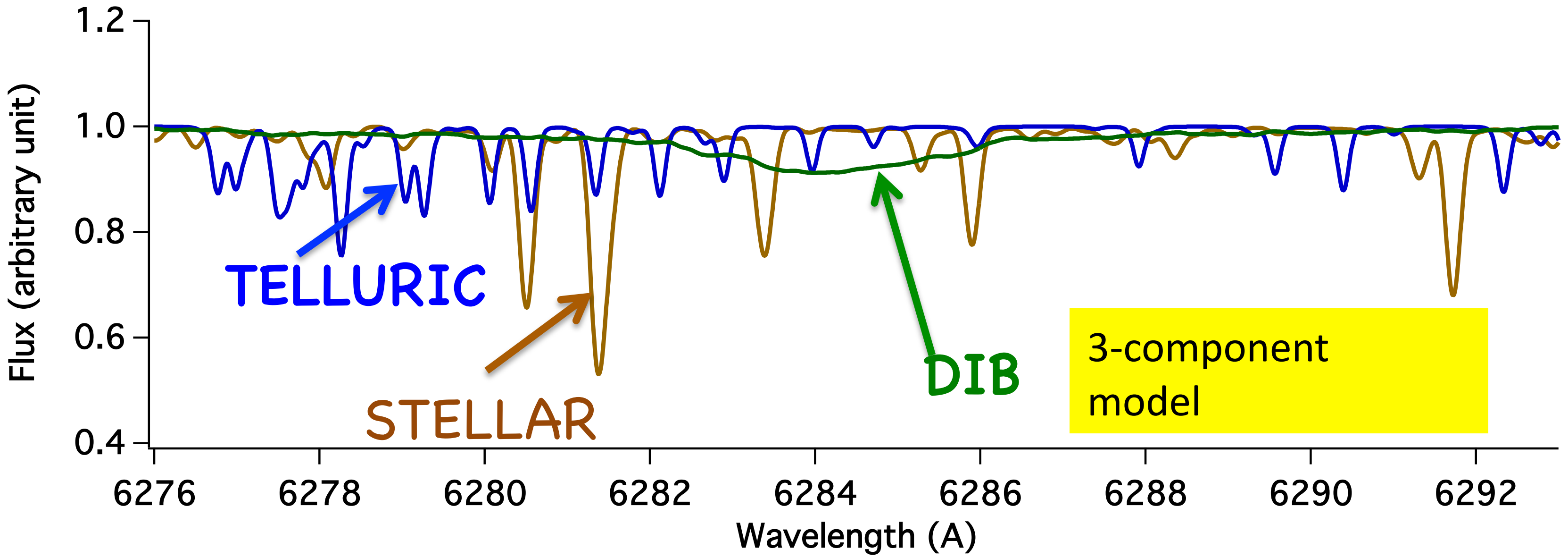
-easy measurement for early-type stars => limited number and achievable spatial resolution
Future: extraction of lines from all stellar types by modeling the stellar spectra

-**future**: diffuse absorptions bands

-numerous, mostly unsaturated
Future: -can be extracted for all types by means of stellar synthetic spectra
-better determinations of the media they trace

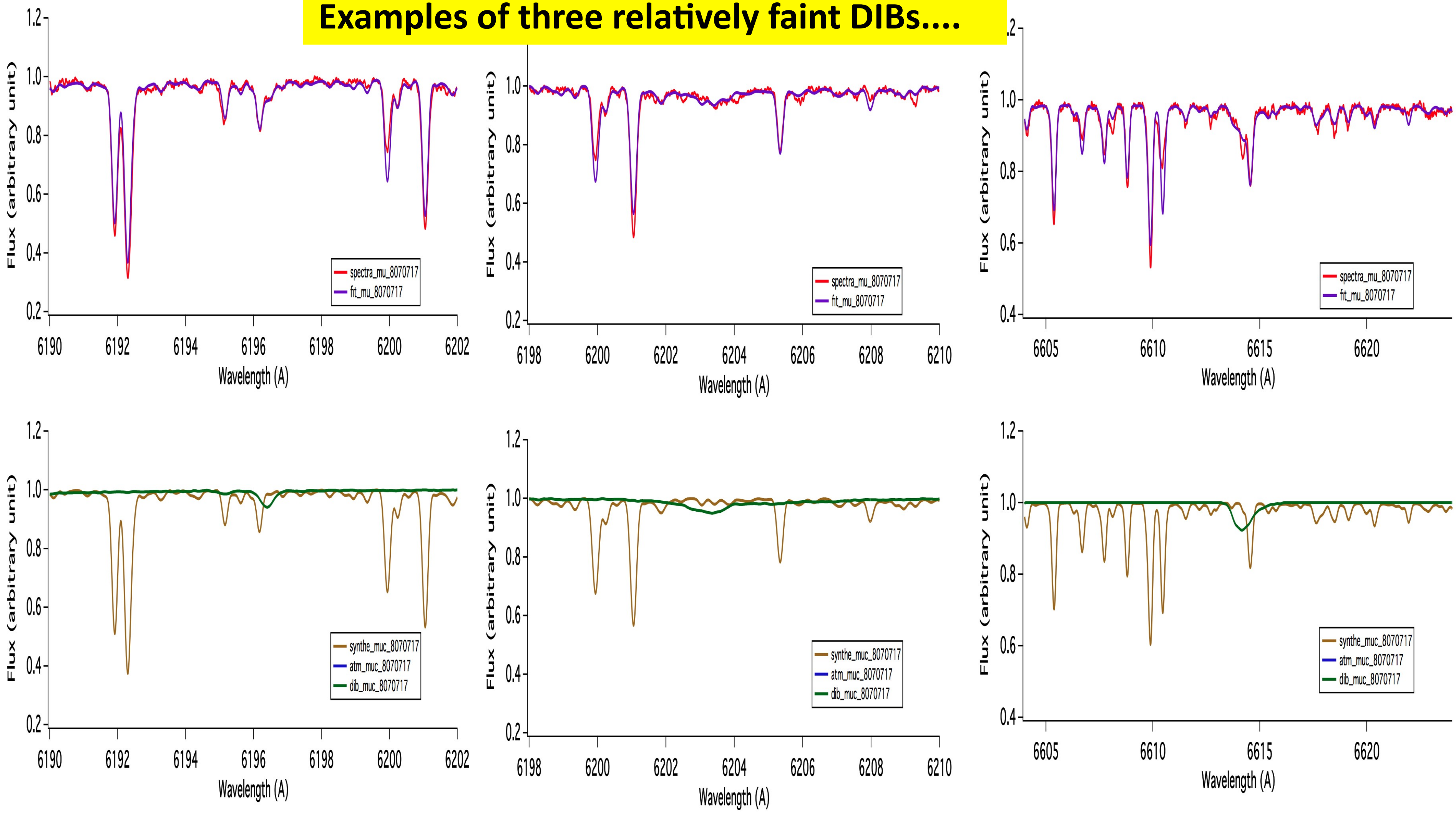
EXAMPLE OF POTENTIAL TRACERS: THE STRONG 6284 Å DIFFUSE BAND



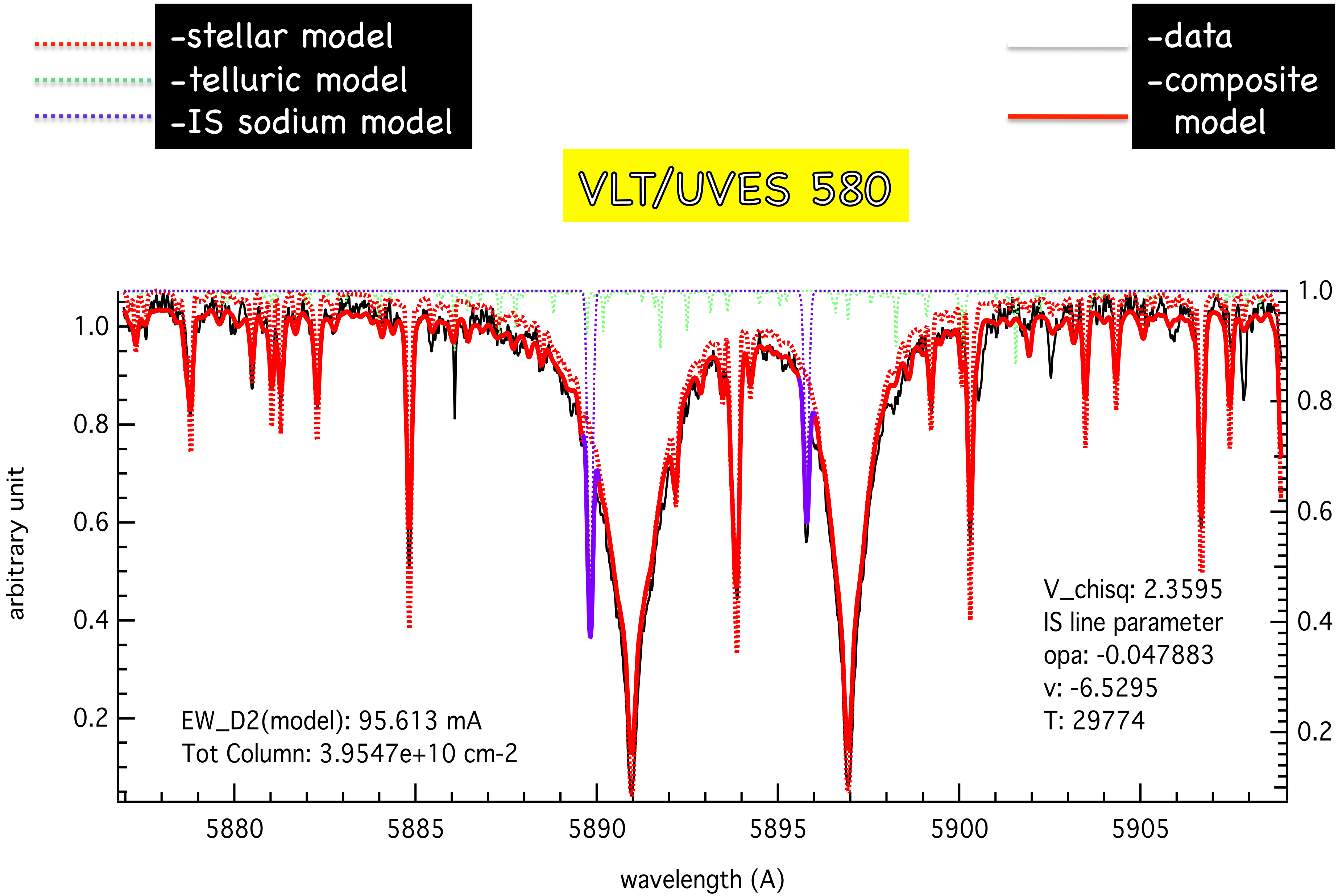


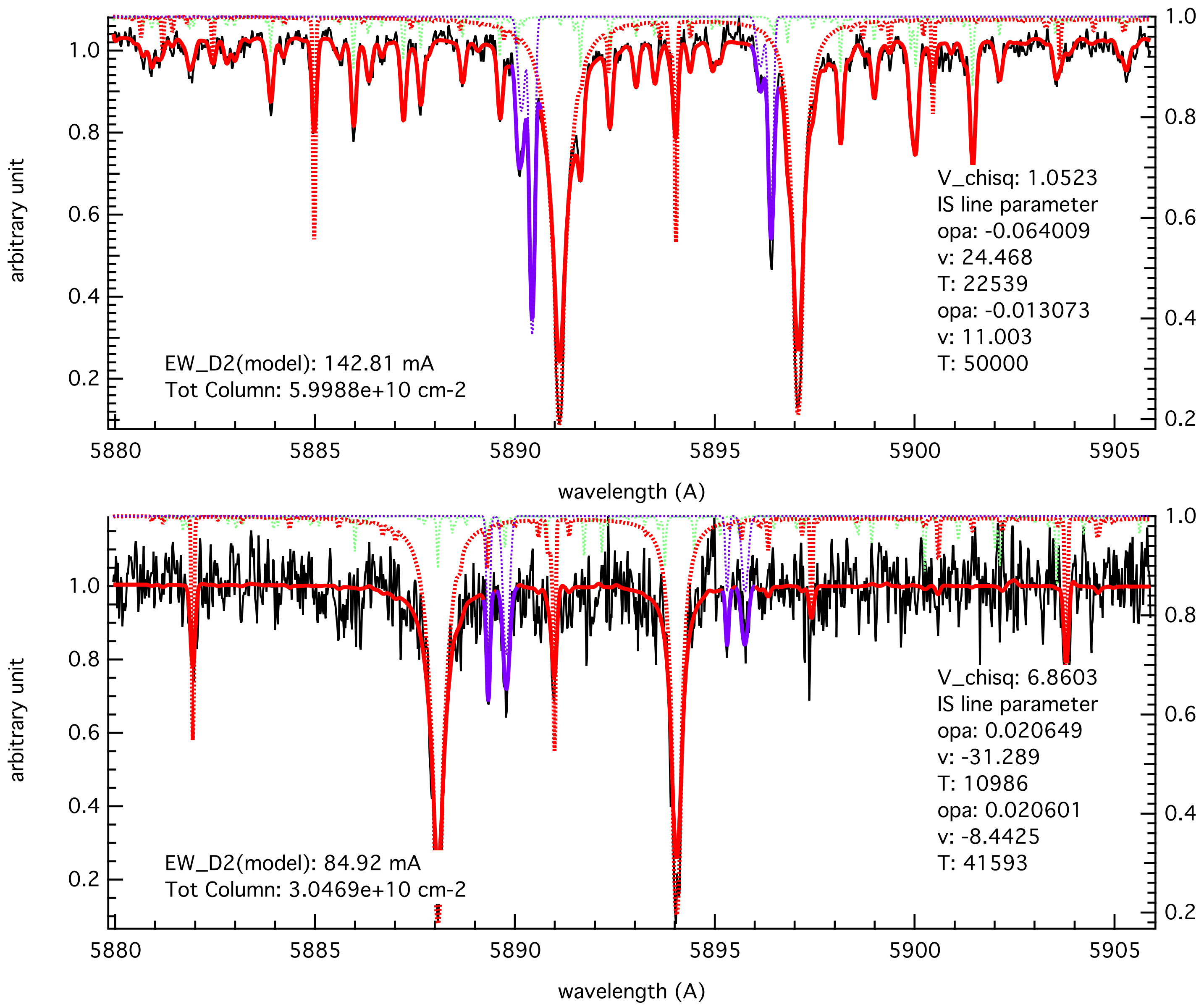
There are more than 400 diffuse bands (DIBs)....

Examples of three relatively faint DIBs....



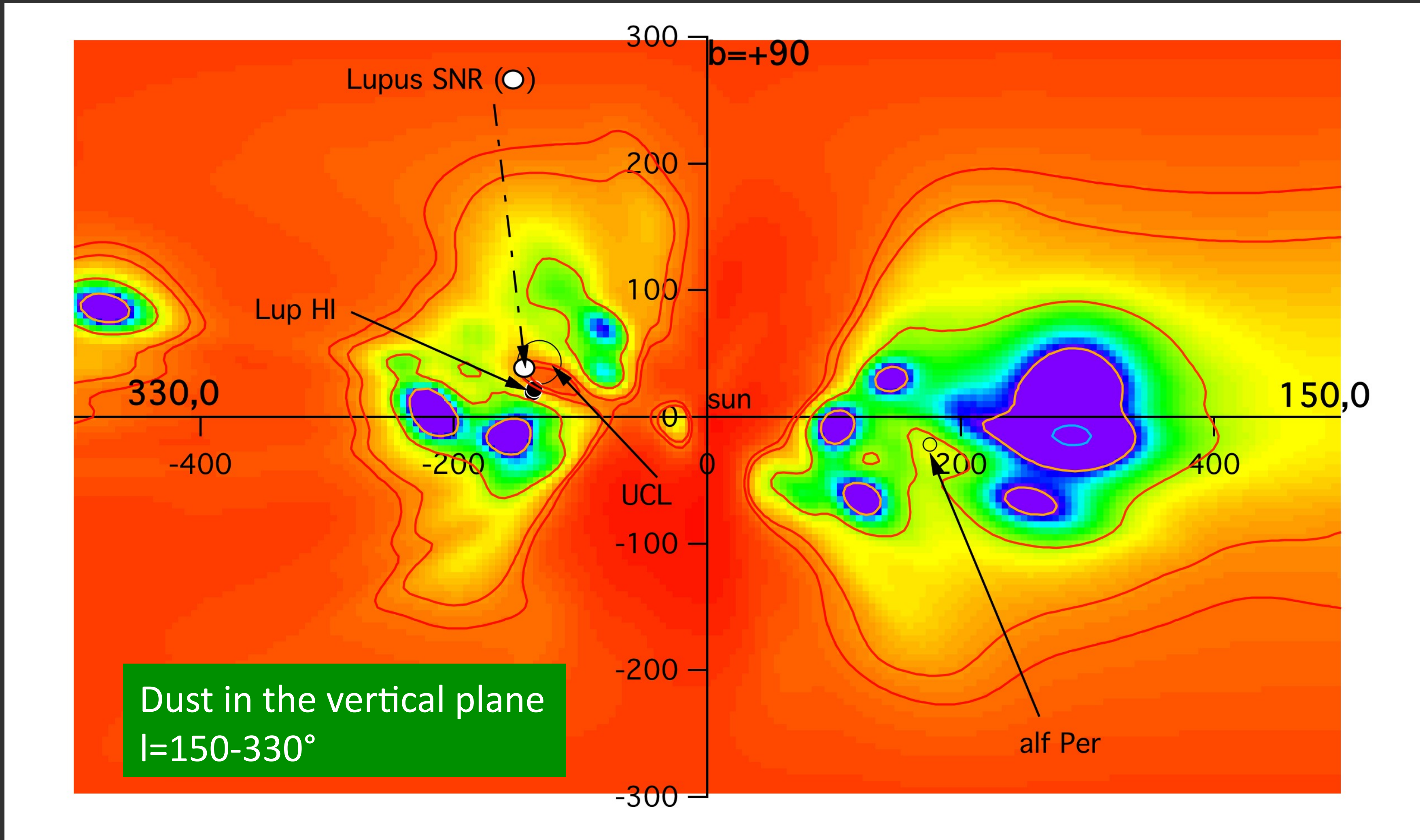
INTERSTELLAR NEUTRAL SODIUM



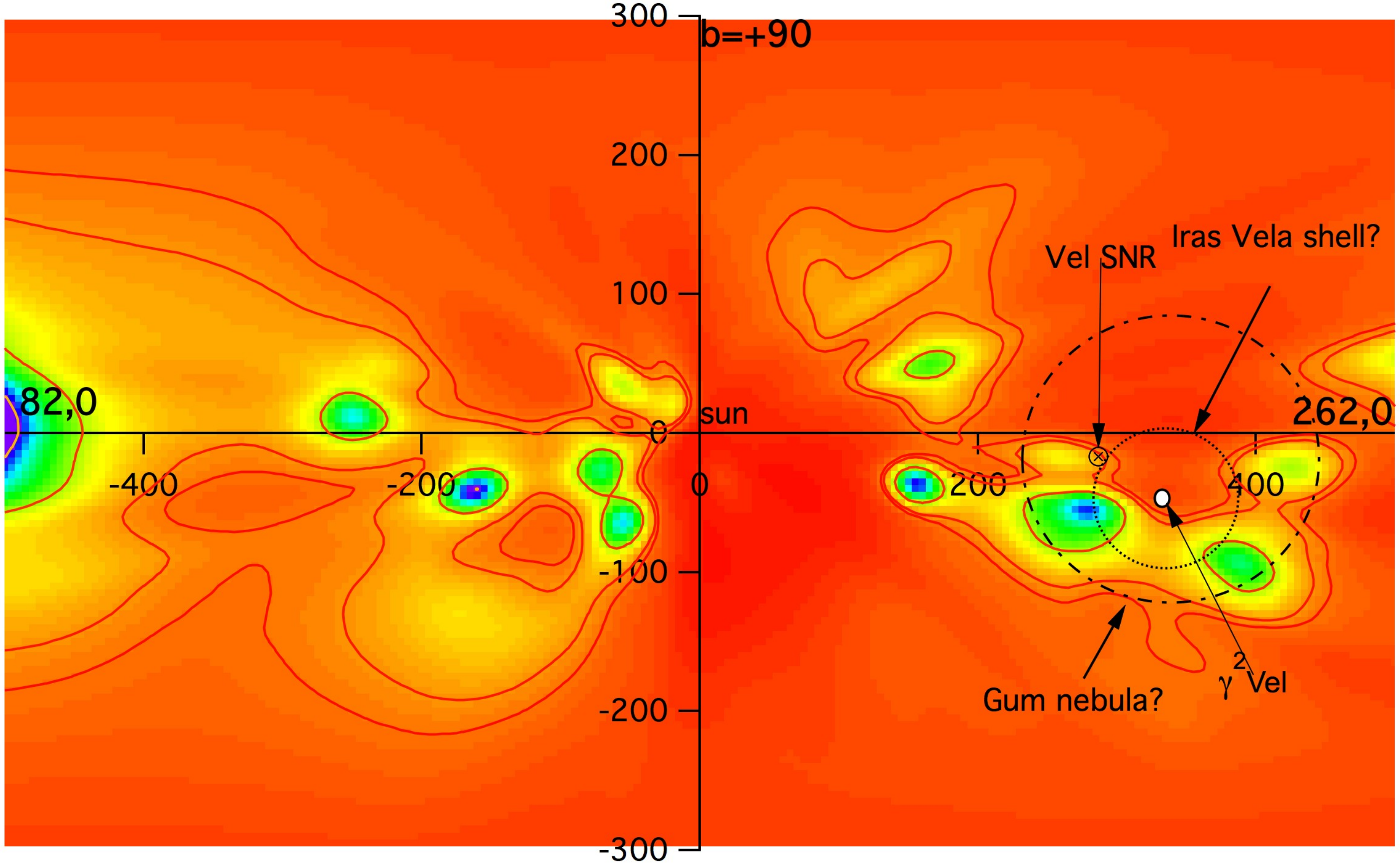


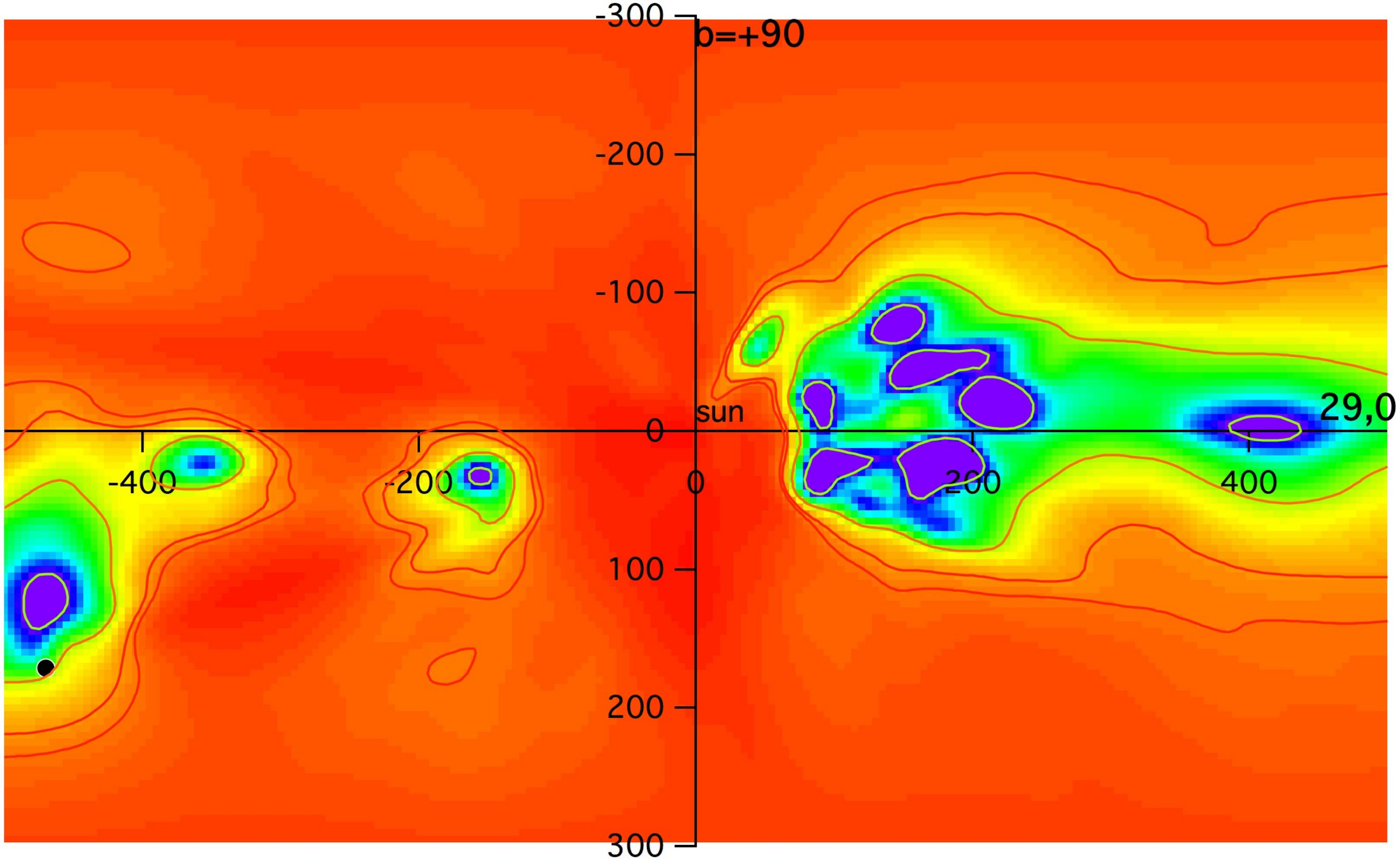
1.0
0.8
0.6
0.4
0.2
arbitrary unit
EW_D2(model): 142.81 mA
Tot Column: 5.9988e+10 cm-2
V_chisq: 1.0523
IS line parameter
opa: -0.064009
v: 24.468
T: 22539
opa: -0.013073
v: 11.003
T: 50000
5880
5885
5890
5895
5900
5905
wavelength (A)
EW_D2(model): 84.92 mA
Tot Column: 3.0469e+10 cm-2
V_chisq: 6.8603
IS line parameter
opa: 0.020649
v: -31.289
T: 10986
opa: 0.020601
v: -8.4425
T: 41593

Thank you!

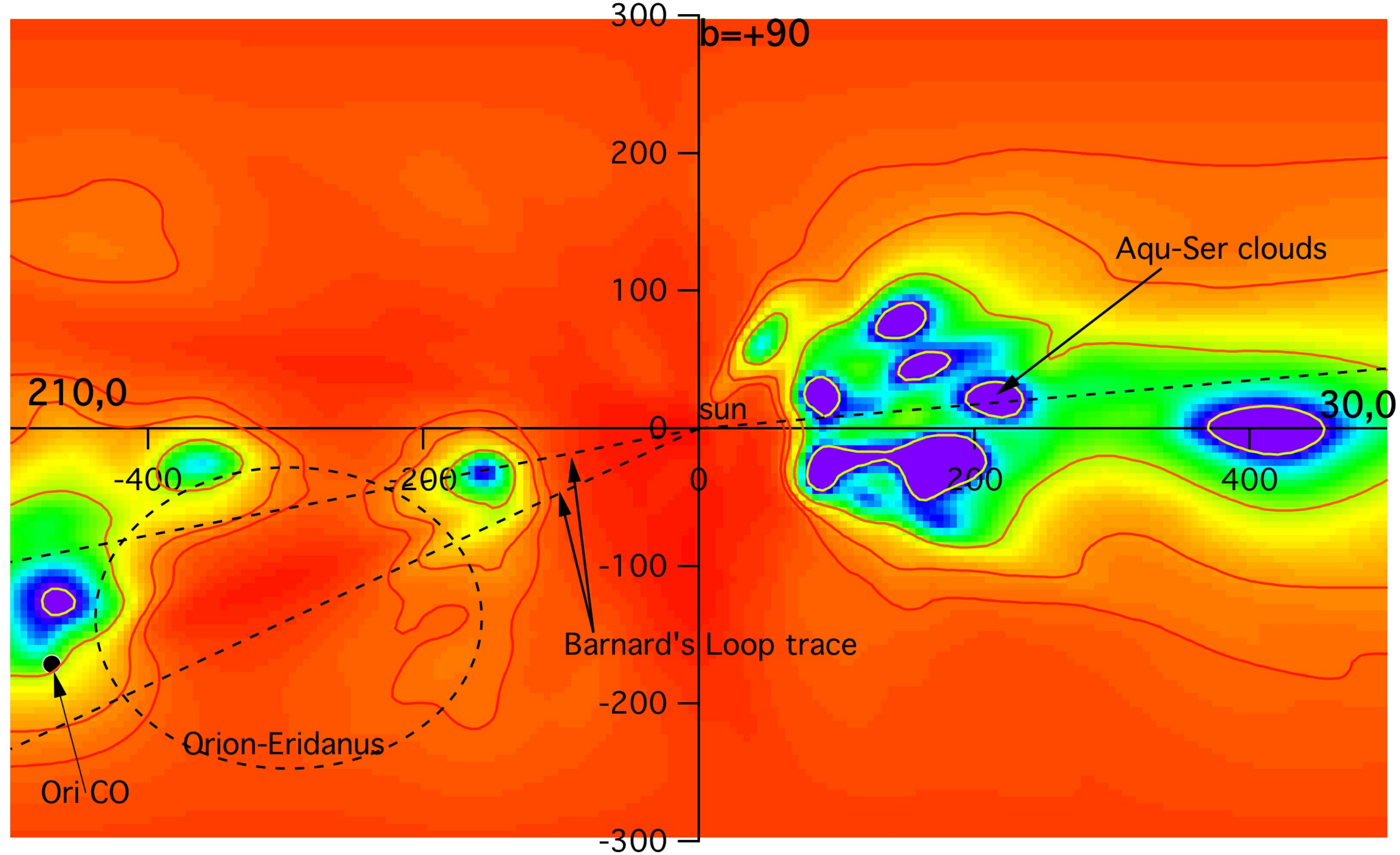


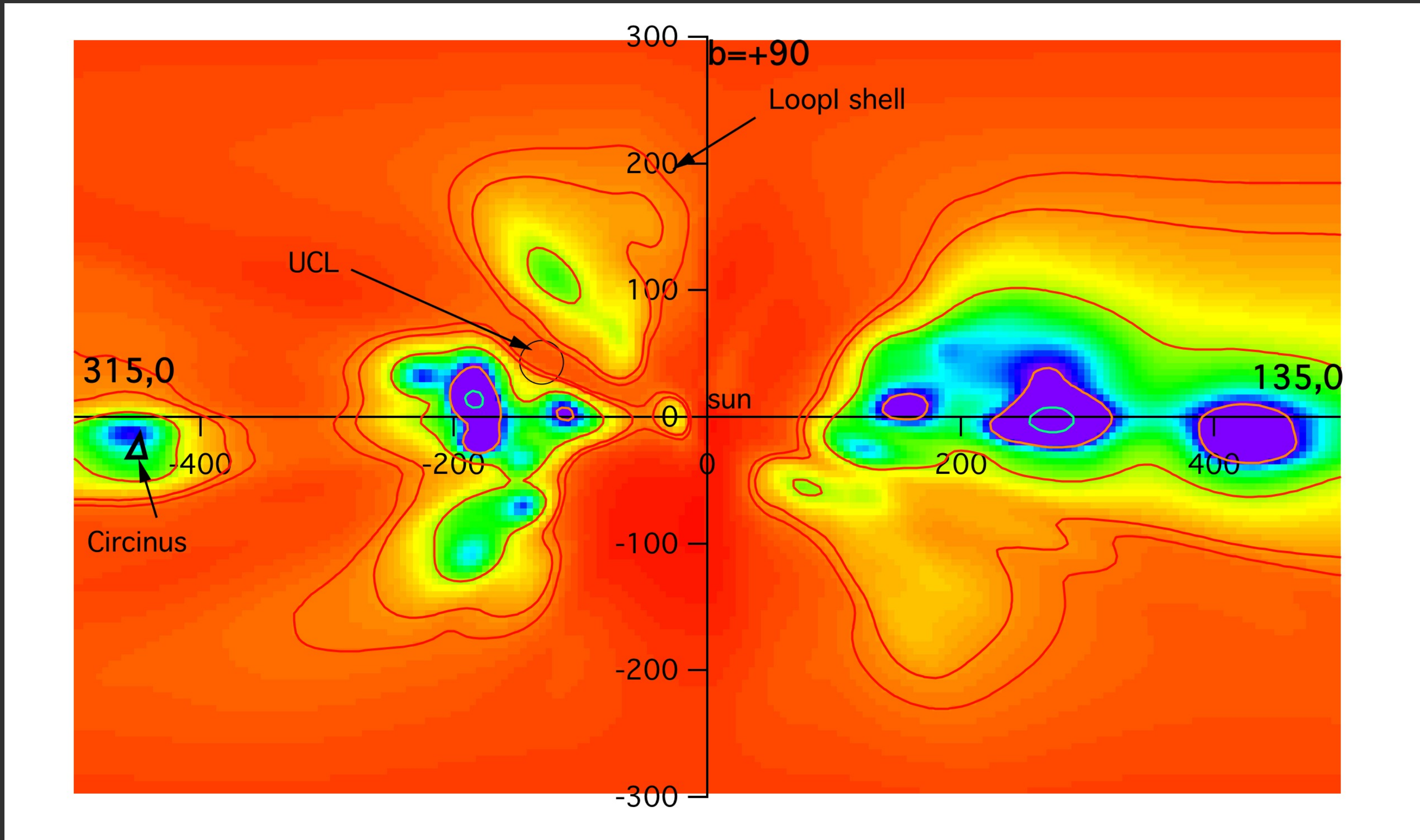
b=+90
Lupus SNR
Lup HI
UCL
sun
330,0
150,0
alf Per
300
200
100
0
-100
-200
-300
-400
-200
0
200
400
Dust in the vertical plane
l=150-330°

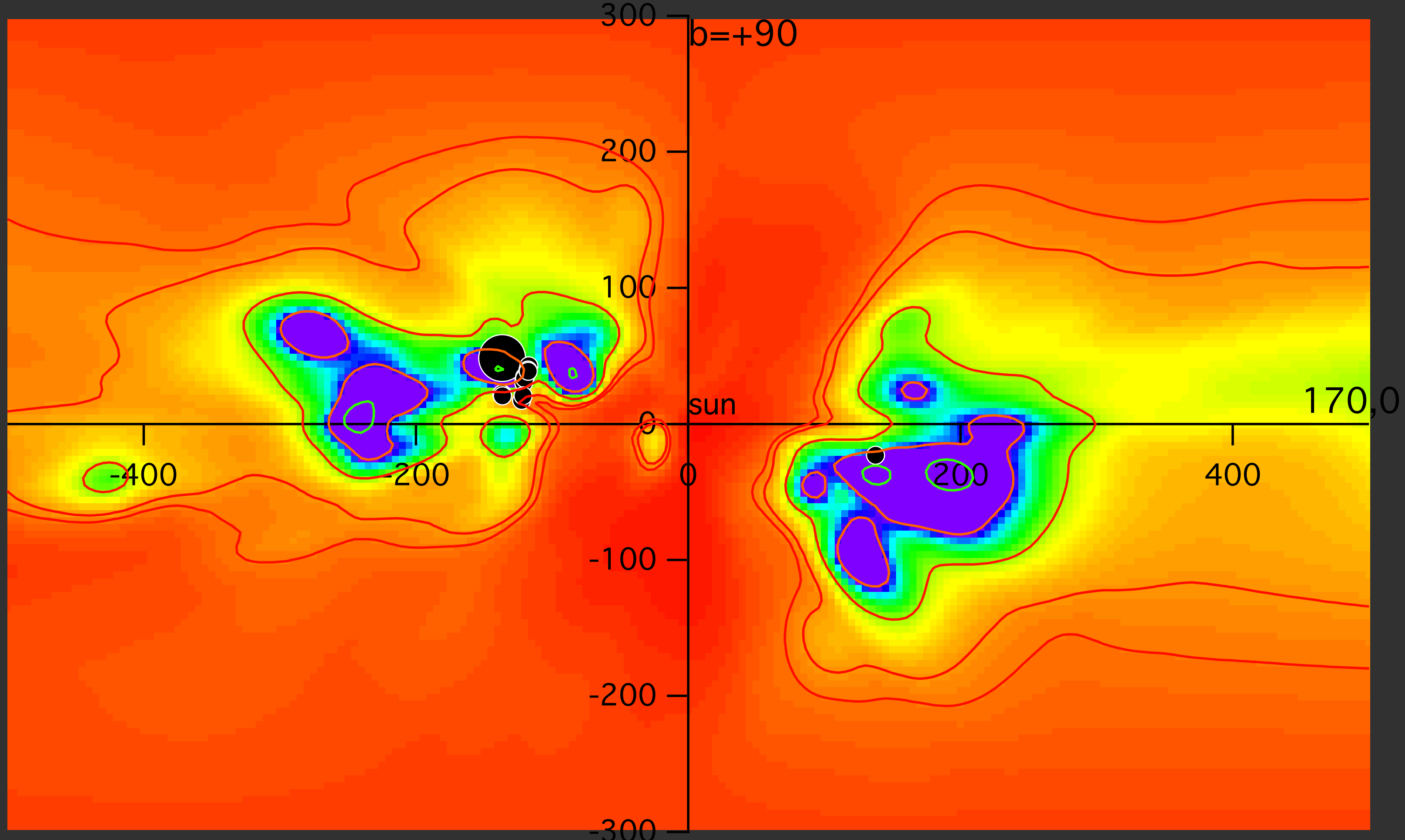

300
b=+90
200
100
Vel SNR
Iras Vela shell?
82,0
sun
262,0
0
-400
-200
0
200
400
-100
-200
-300
Gum nebula?
γ² Vel



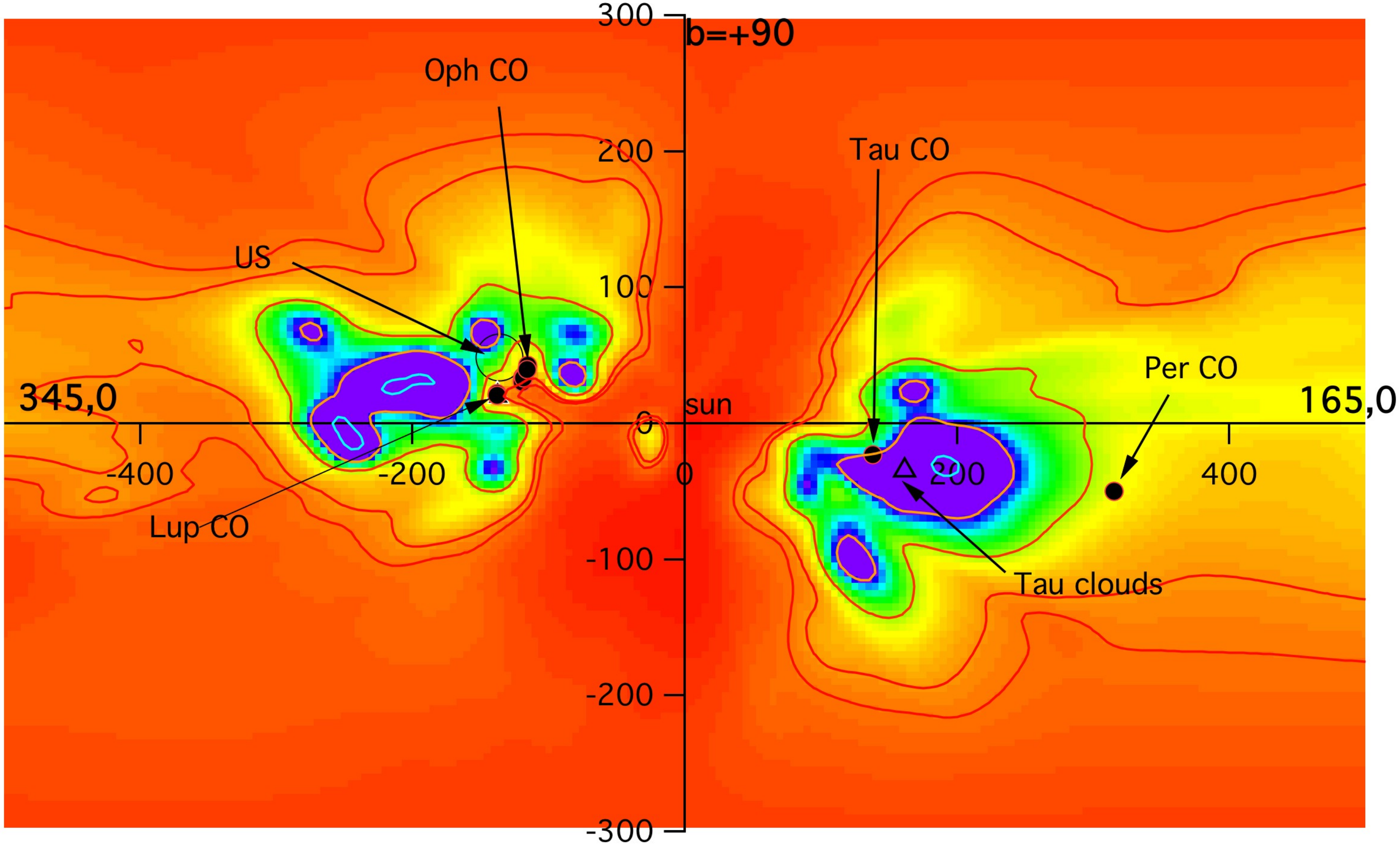
b=+90
-300
-200
-100
0
100
200
300
-400
-200
0
200
400
sun
29,0

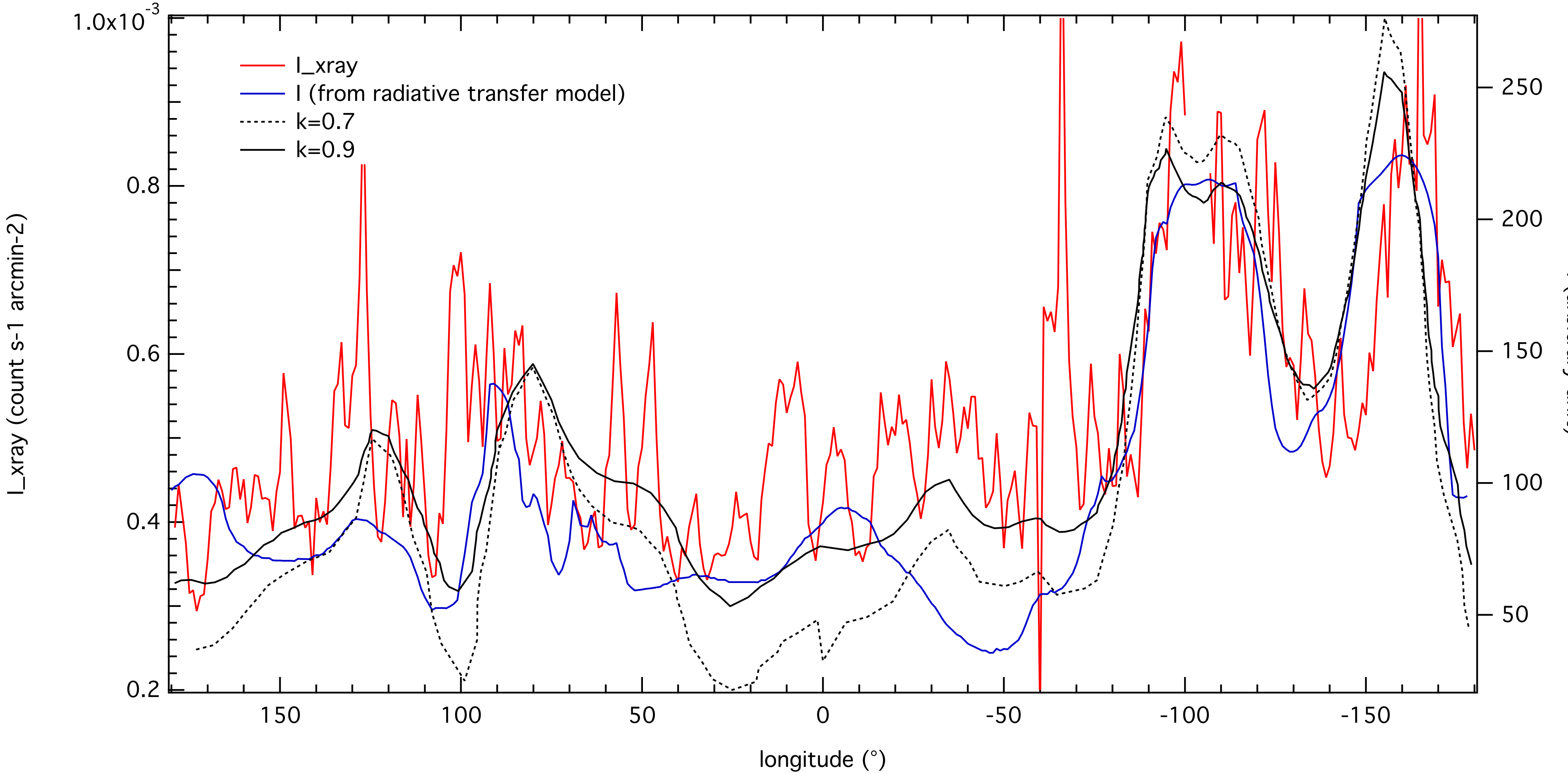

300
b=+90
200
100
Aqu-Ser clouds
210,0
sun
30,0
0
-400
-200
0
200
400
-100
Barnard's Loop trace
-200
Orion-Eridanus
Ori CO
-300


300
b=+90
LoopI shell
200
UCL
100
315,0
sun
135,0
0
-400
-200
0
200
400
Circinus
-100
-200
-300



300
200
100
0
-100
-200
-300
b=+90
sun
170,0
-400
-200
0
200
400


300
200
100
0
-100
-200
-300
b=+90
Oph CO
US
Tau CO
Per CO
345,0
165,0
sun
-400
-200
0
200
400
Lup CO
Tau clouds



1.0x10^-3
0.8
0.6
0.4
0.2
I_xray (count s-1 arcmin-2)
I_xray
I (from radiative transfer model)
k=0.7
k=0.9
250
200
150
100
50
I (arbitrary unit)
150
100
50
0
-50
-100
-150
longitude (°)