X-raying the interstellar medium at high latitudes

Ciro Pinto

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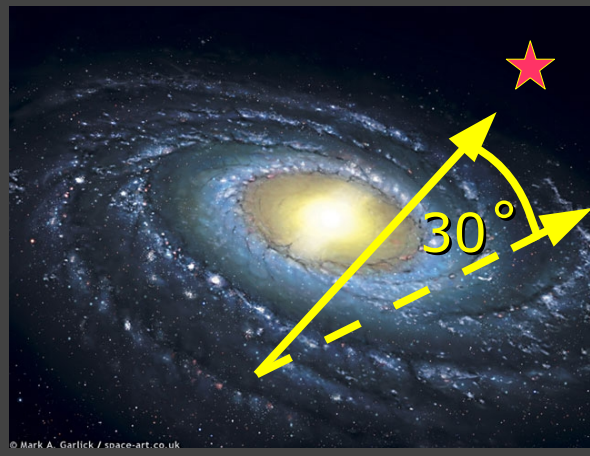
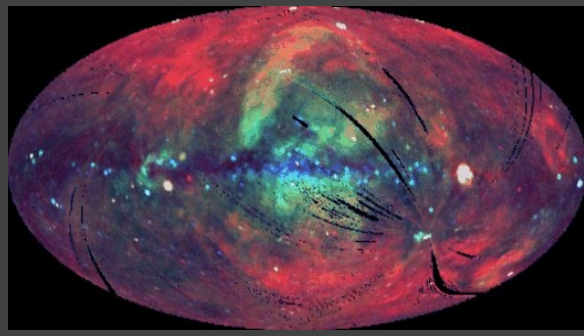
Netherlands Institute for Space Research

Interstellar forest at high latitudes: UV / X-ray Spectroscopy of Mrk 509

- Motivation: the role of the ISM
- Methods:
  - UV → Disk and Halo clouds
  - X-ray → Abundances and dust fractions
- Questions:

  → Which is their dynamical structure ?
  → What is heating the clouds ?
  → Where are they located ?
  → Where are they from ?





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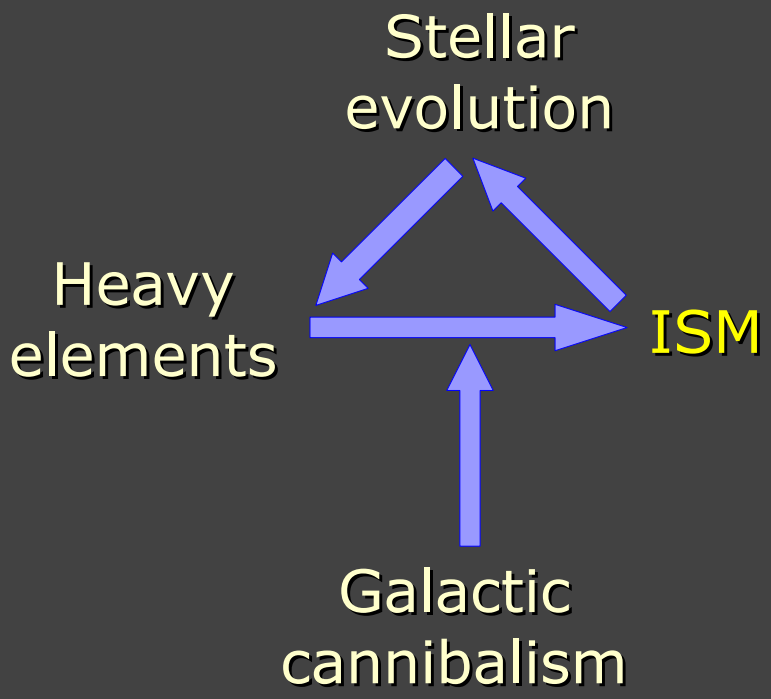
Interstellar medium (ISM) and Galactic life cycle



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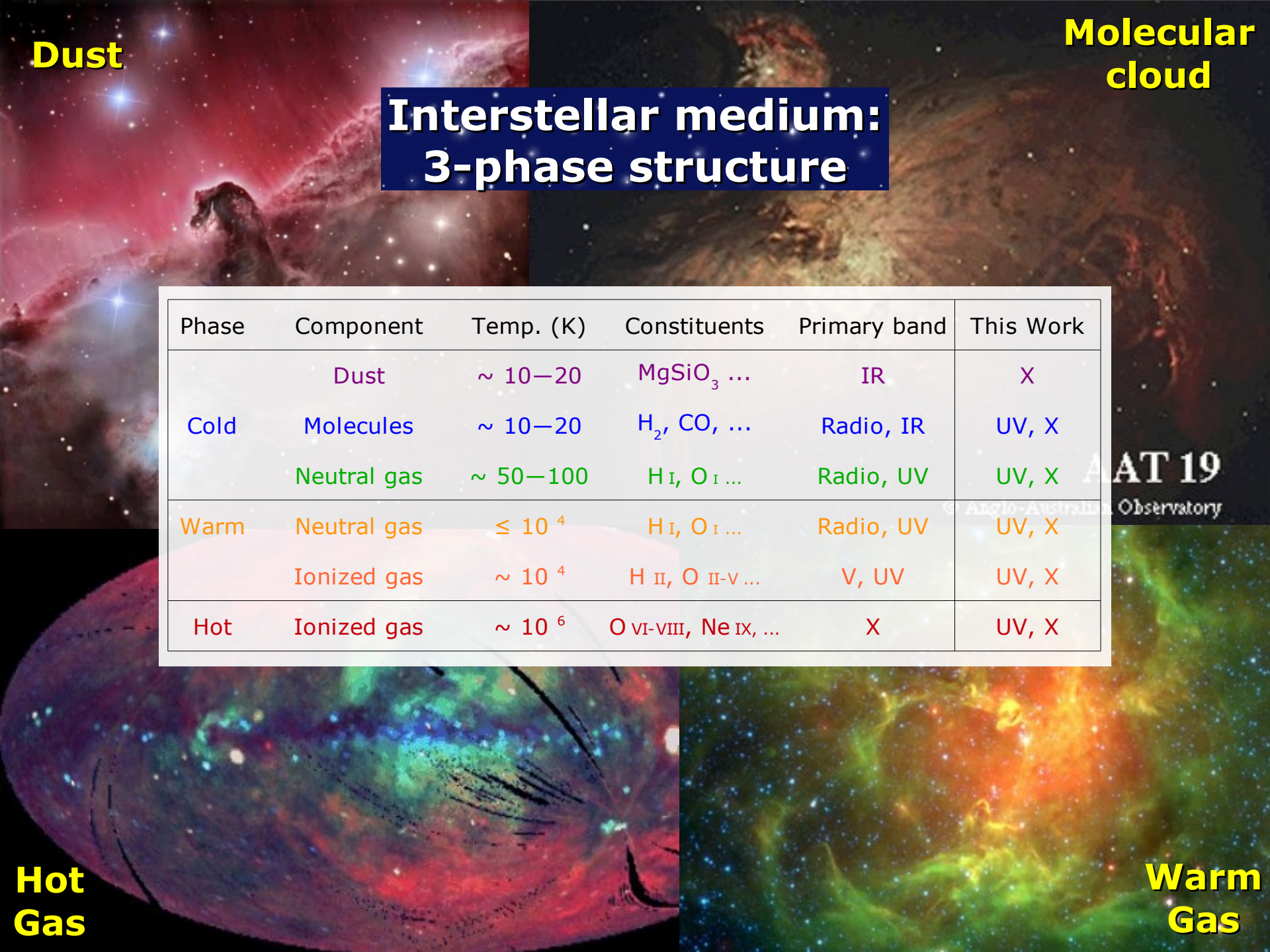

Interstellar medium: 3-phase structure

Phase	Component	Temp. (K)	Constituents	Primary band	This Work
	Dust	~ 10—20	$MgSiO_3$ ...	IR	X
Cold	Molecules	~ 10—20	H_2, CO, ...	Radio, IR	UV, X
	Neutral gas	~ 50—100	H I, O I ...	Radio, UV	UV, X
Warm	Neutral gas	≤ 10^4	H I, O I ...	Radio, UV	UV, X
	Ionized gas	~ 10^4	H II, O II-V ...	V, UV	UV, X
Hot	Ionized gas	~ 10^6	O VI-VIII, Ne IX, ...	X	UV, X

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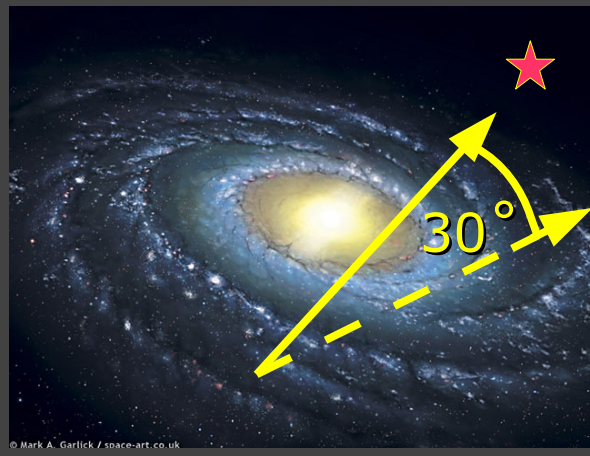

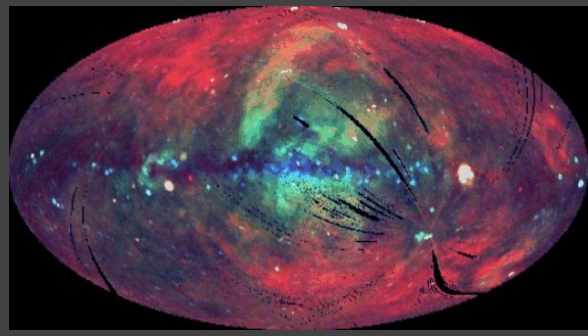

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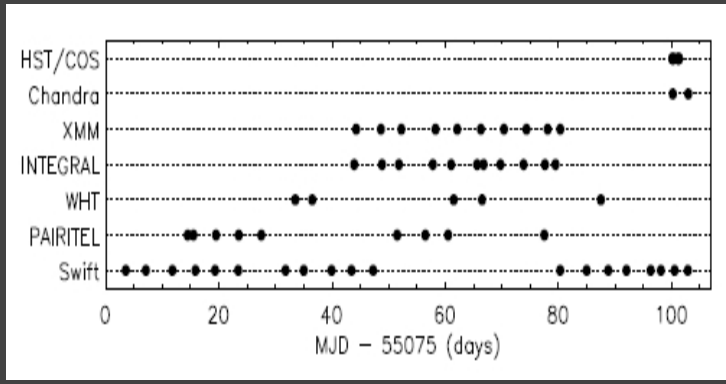
The Mrk 509 Multi-wavelength Campaign

- Observations:

  600 ks XMM-Newton, 1.14 Gs INTEGRAL
  180 ks Chandra, 26 ks COS/HST
  7.2 ks PAIRITEL, 14.5 ks WHT, 20 ks SWIFT
  + archival data, e.g. FUSE



Kaastra et al 2011a

- Aims & Contributions:

Campaign overview	→ talk of J. Kaastra (Plenary session 1)
AGN UV outflow	→ talk of J. Kriss (Session G.5)
Nature of Soft X-ray excess	→ talk of M. Mehdipour (Session G.5)
Realistic comptonization models	→ talk of P. Petrucci (Session G.5)
AGN UV versus X-ray outflow	→ poster of J. Ebrero (G14)
Fe K reverberation	→ poster of G. Ponti (G36)
Abundances of absorbers	→ poster of K. Steenbrugge (G45)
Galactic interstellar medium	→ this talk

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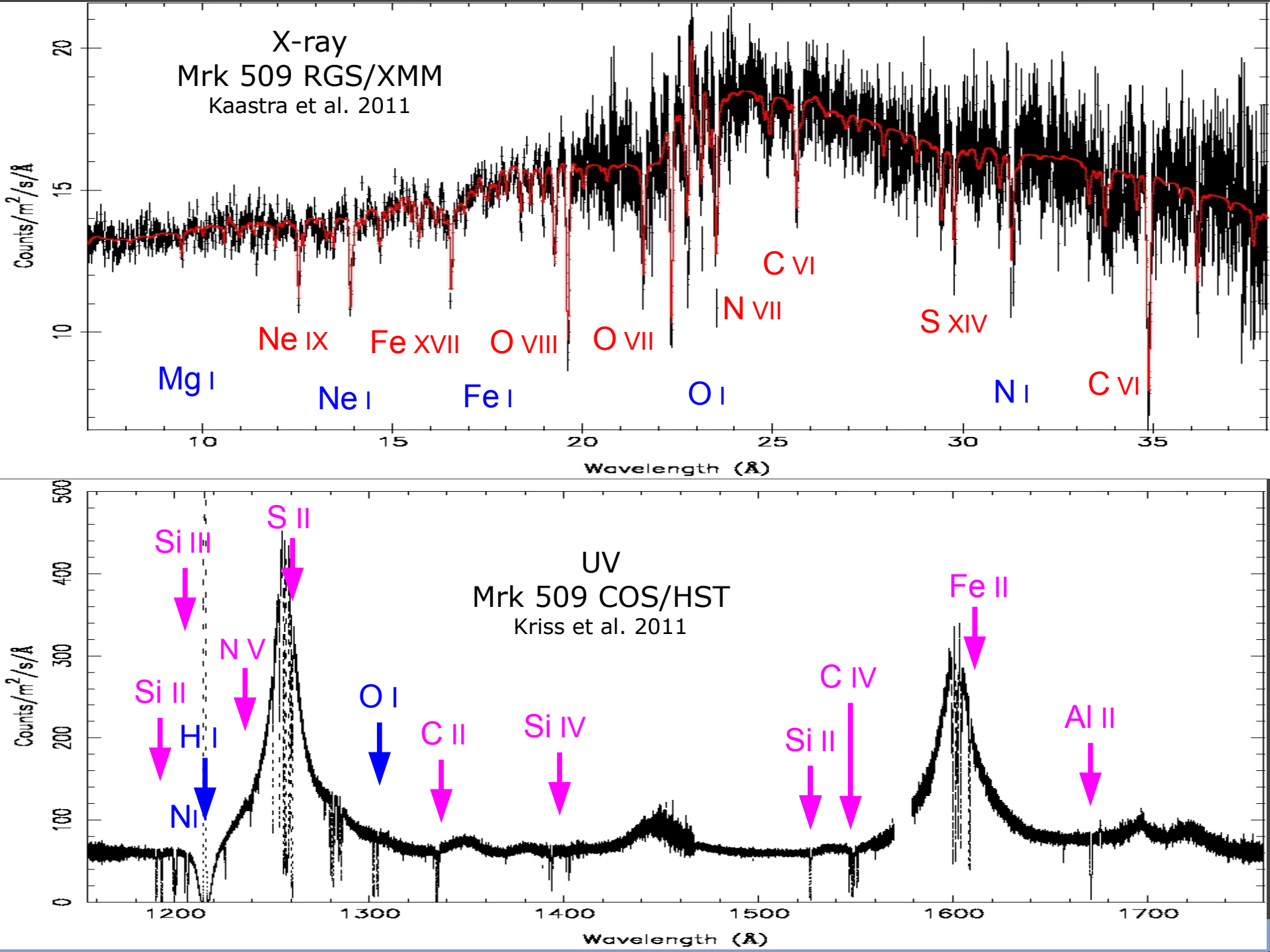
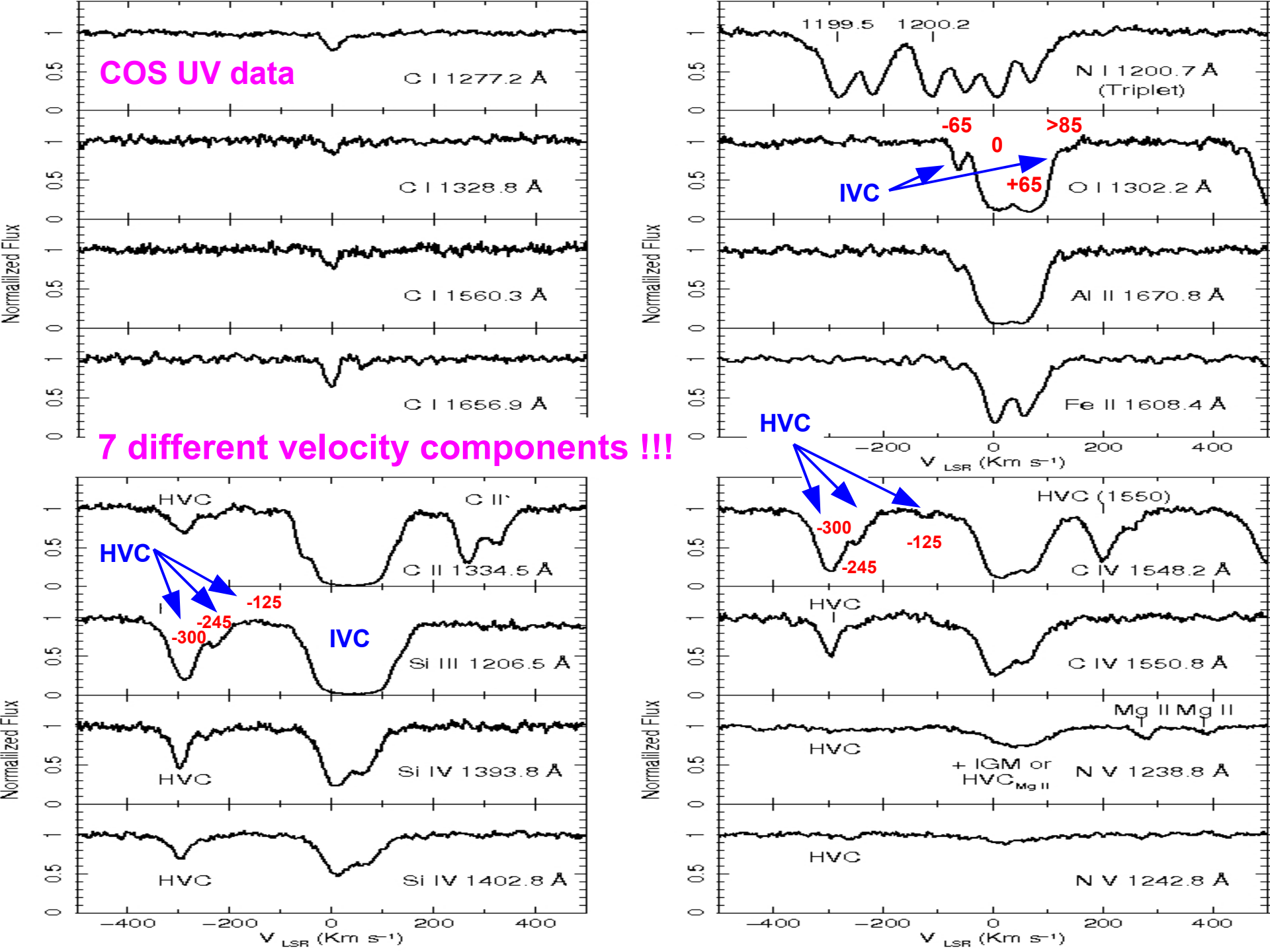

X-ray
Mrk 509 RGS/XMM
Kaastra et al. 2011
Counts/m²/s/Å
Wavelength (Å)
Mg I
Ne IX
Ne I
Fe XVII
Fe I
O VIII
O VII
O I
N VII
C VI
S XIV
N I
C VI
UV
Mrk 509 COS/HST
Kriss et al. 2011
Si III
S II
Si II
N V
H I
N I
O I
C II
Si IV
Si II
C IV
Fe II
Al II


COS UV data
C I 1277.2 Å
C I 1328.8 Å
C I 1560.3 Å
C I 1656.9 Å
Normalized Flux
1199.5
1200.2
N I 1200.7 Å
(Triplet)
-65
0
+65
>85
IVC
O I 1302.2 Å
Al II 1670.8 Å
Fe II 1608.4 Å
HVC
7 different velocity components !!!
HVC
C II
C II 1334.5 Å
HVC
-300
-245
-125
IVC
Si III 1206.5 Å
HVC
Si IV 1393.8 Å
HVC
Si IV 1402.8 Å
V LSR (Km s⁻¹)
HVC (1550)
-300
-245
-125
C IV 1548.2 Å
HVC
C IV 1550.8 Å
Mg II Mg II
HVC
+ IGM or
HVC Mg II
N V 1238.8 Å
HVC
N V 1242.8 Å
V LSR (Km s⁻¹)

The ISM model

- Features intrinsic to the AGN subtracted

→ Detmers et al. 2011
→ Kriss et al. 2011

- 3 ISM phases:

cold collisionally-ionized gas + dust + molecules

warm photo-ionized gas

hot collisionally-ionized gas

- Same structure taken for each velocity component

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Cold gas: intermediate velocity clouds (IVC)

→ Collisionally-ionized cold gas

Velocities:

$|v| \leq 100$ km s^{-1}

$\sigma_v \sim$ 6-10 km s^{-1}

Column ratios:

$N_{+0} \sim 90\%$

$N_{+65} \sim 7\%$

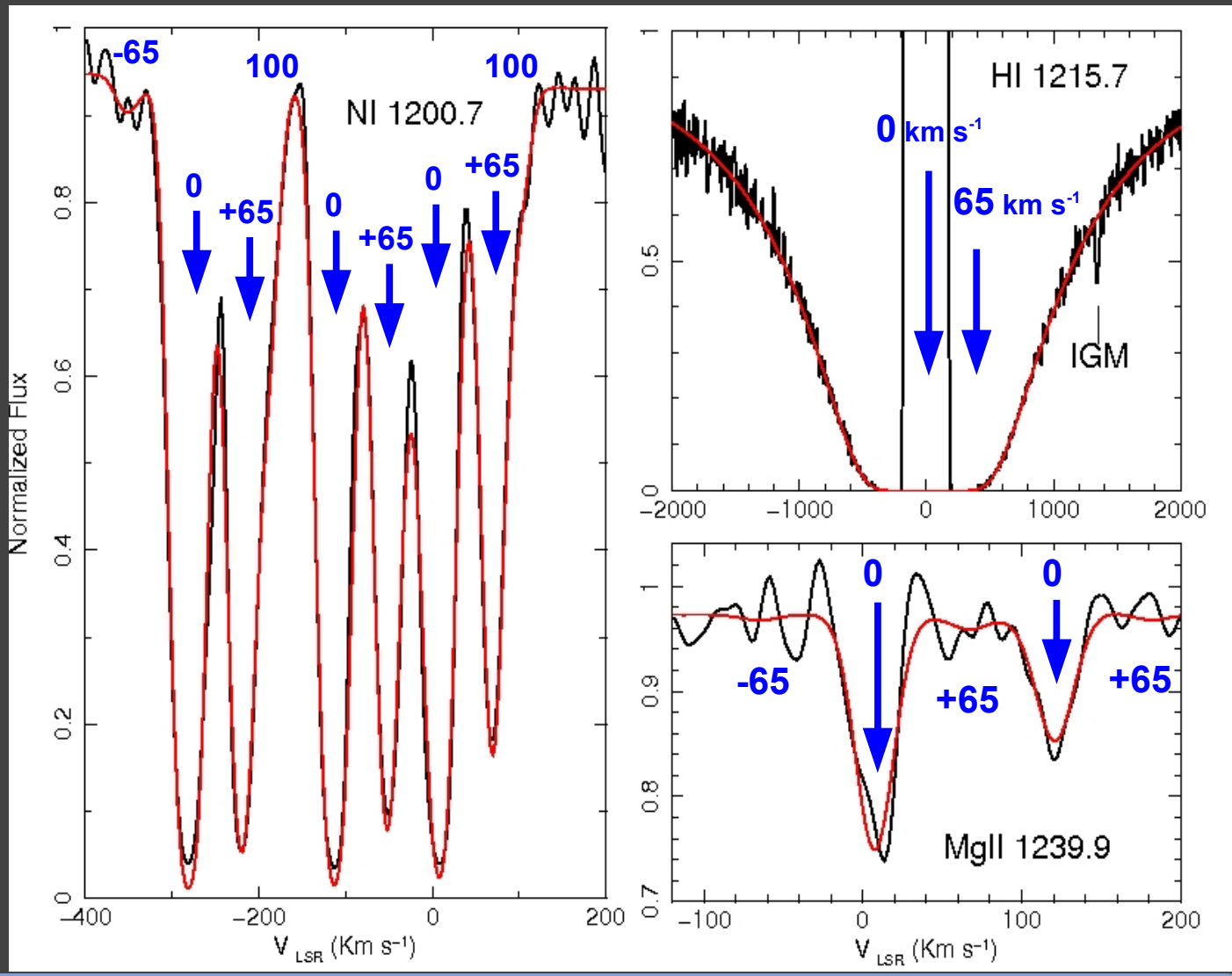
$N_{others} \sim 3\%$

$A(X) / A(X)_{SUN}$

N > 0.1

Mg ~ 0.5

Fe, S, O ~ 1

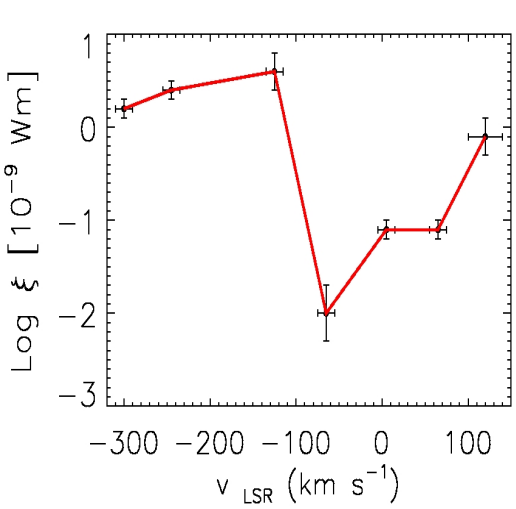


Warm-hot gas: IVC and HVC complexity

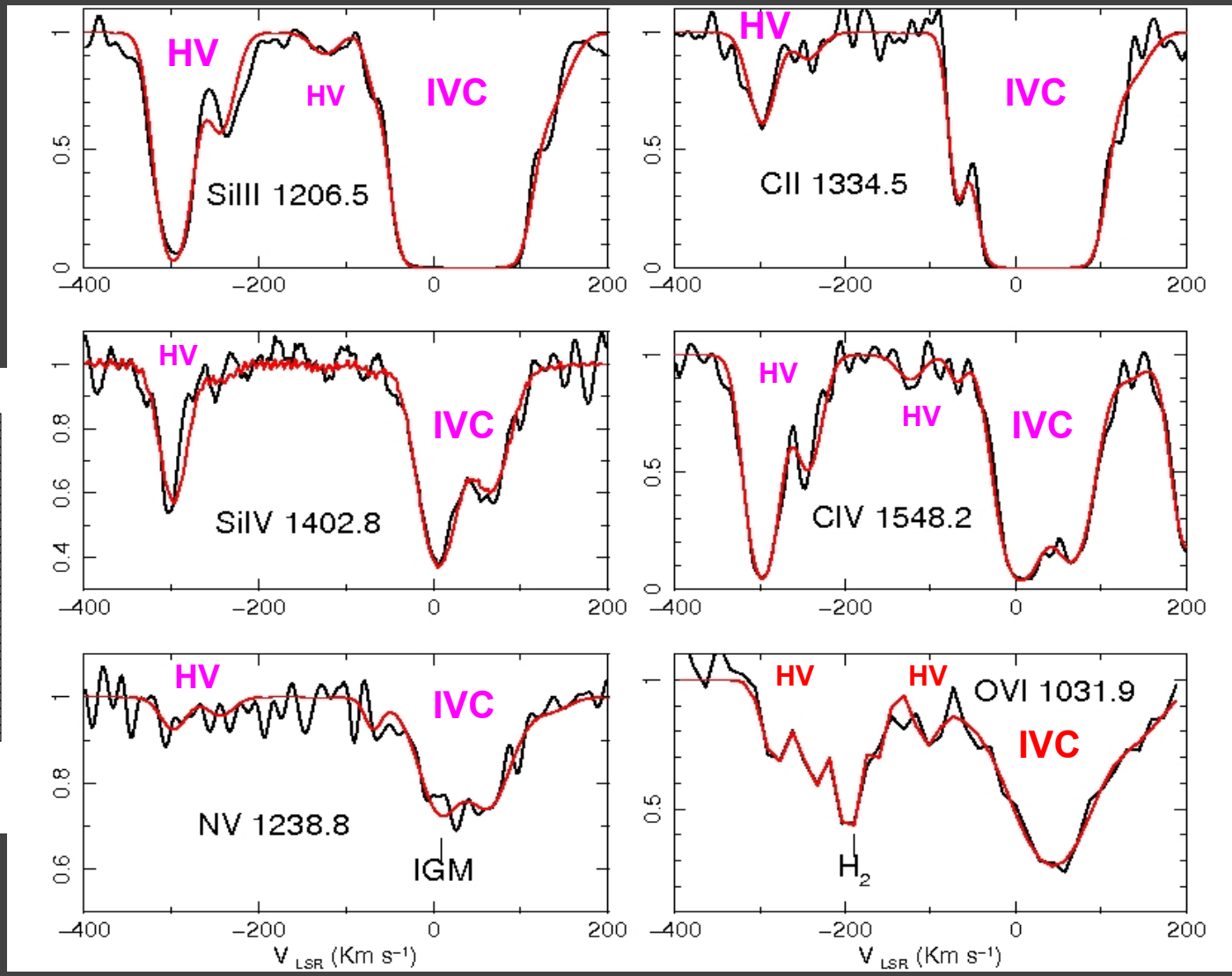
PHOTO-IONIZED
WARM GAS

$\xi = L / n r^2$

7 components



SED = QSO & galaxies



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Collisionally-ionized
HOT GAS → O VI, VII, VIII

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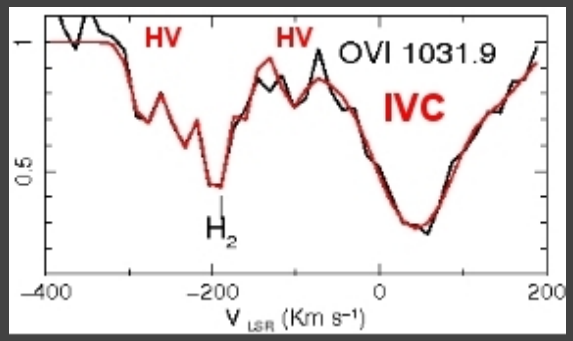
ISM = Cold + Warm + Hot phases

Simultaneous
UV / X-ray spectral fits



Temperatures

$T_{cold} \geq 10\,000$ K

$T_{hot} \sim$ 1-2 mln K

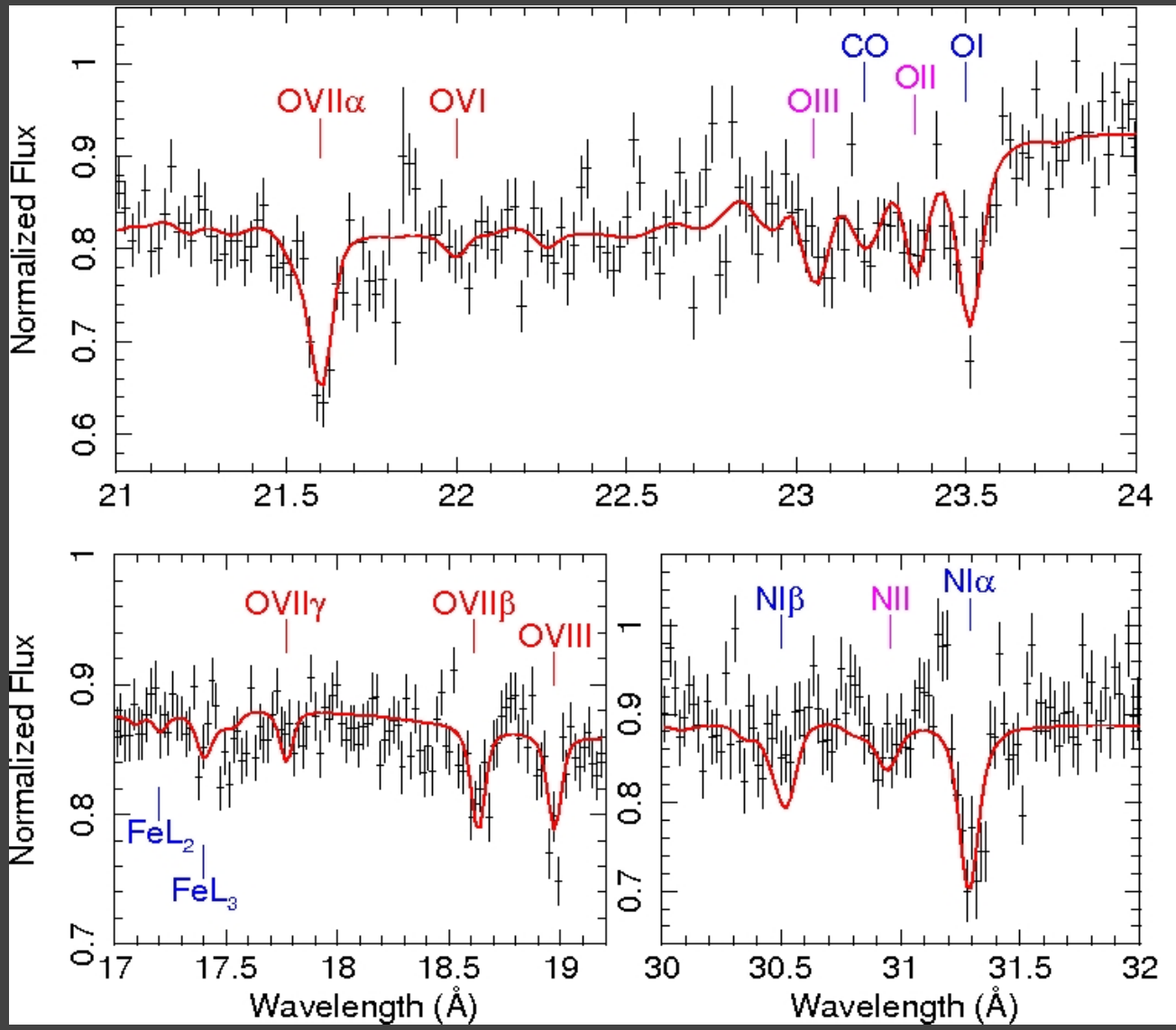
Dust Fractions

O I ~ 20 %

Fe I ≥ 90 %

C I > 50%

Al I, Ni I > 90%



A(X) / $A(X)_{SUN}$ →

O = 1.0 ± 0.1 Fe = 1.0 ± 0.1

N = 0.8 ± 0.1 Ne = 1.3 ± 0.2

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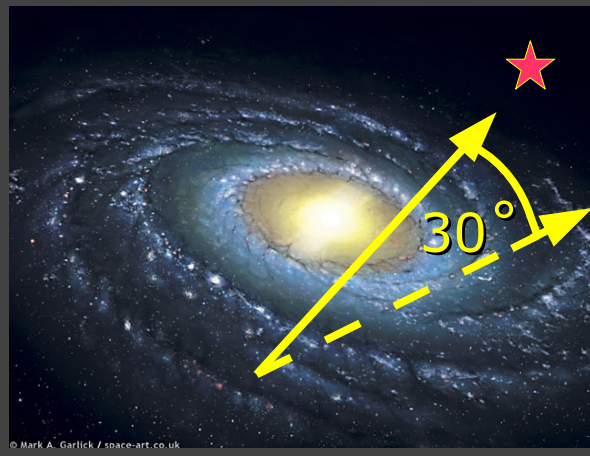

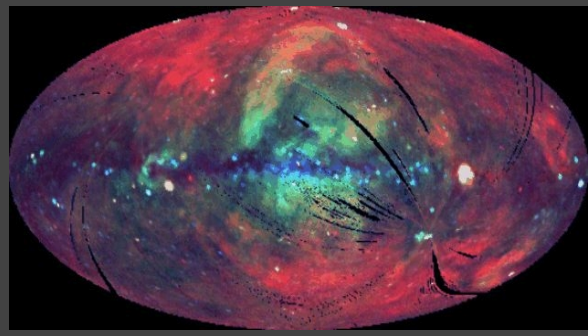

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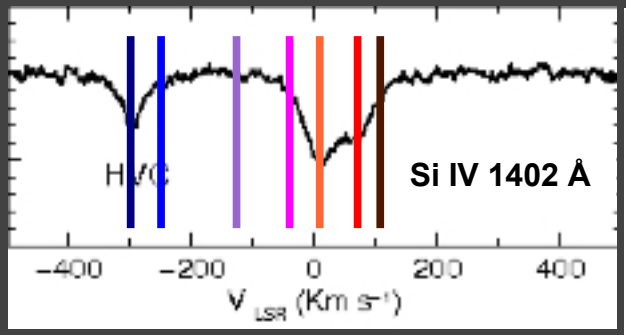
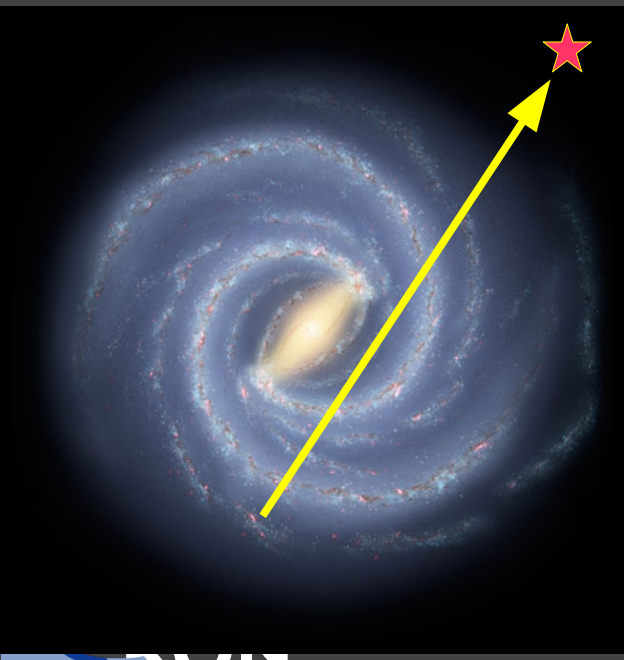
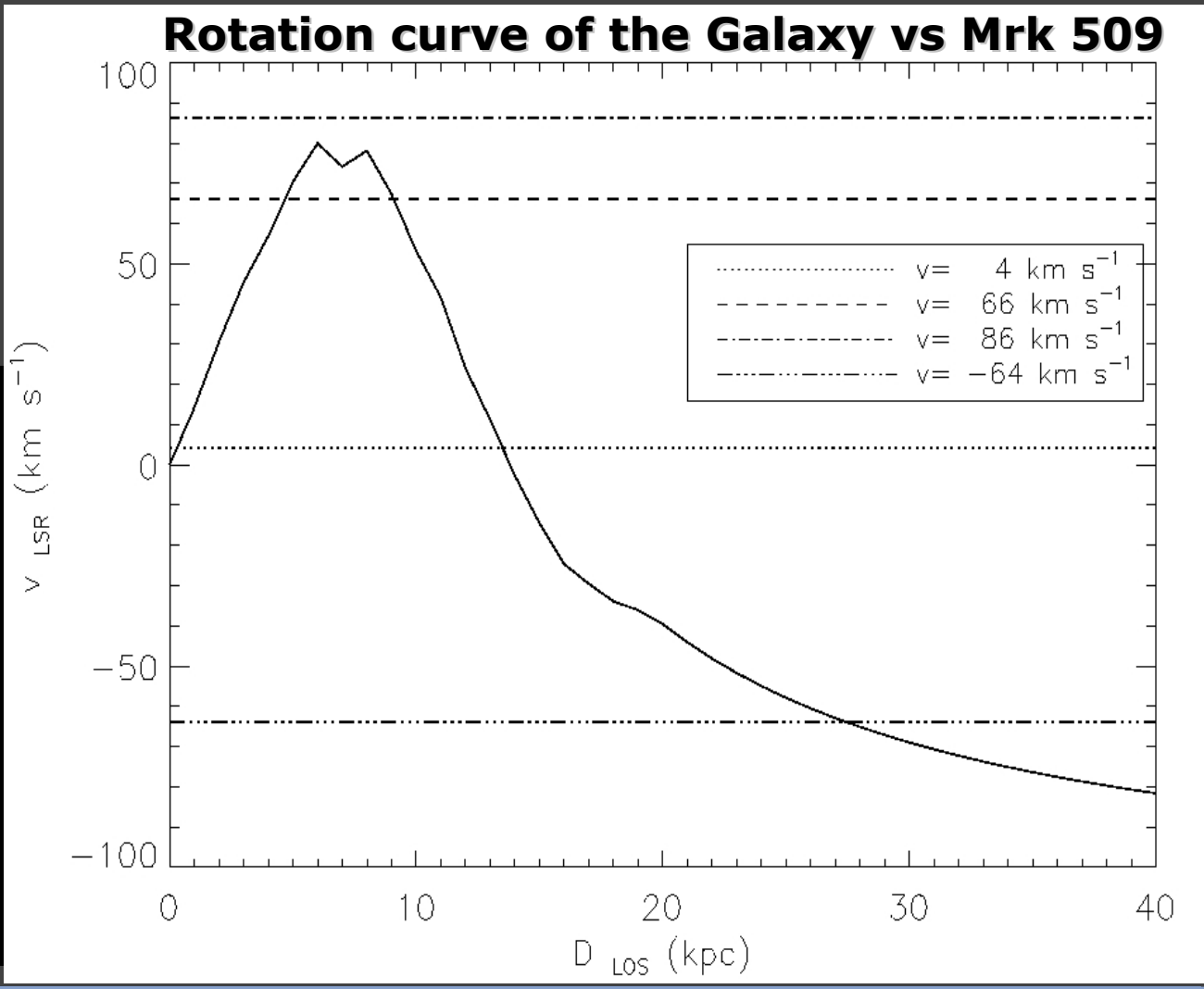
Dynamical structure: IVC location







Dynamical structure: IVC location

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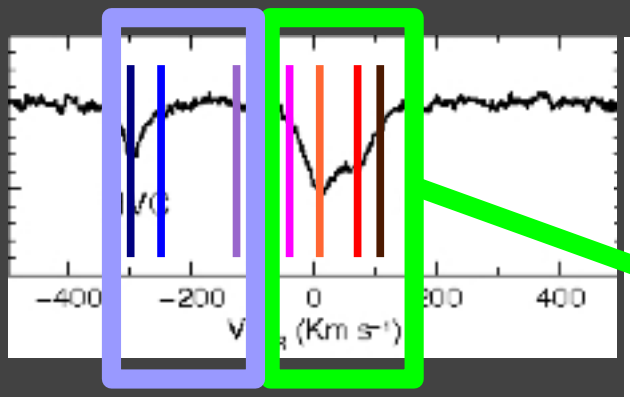
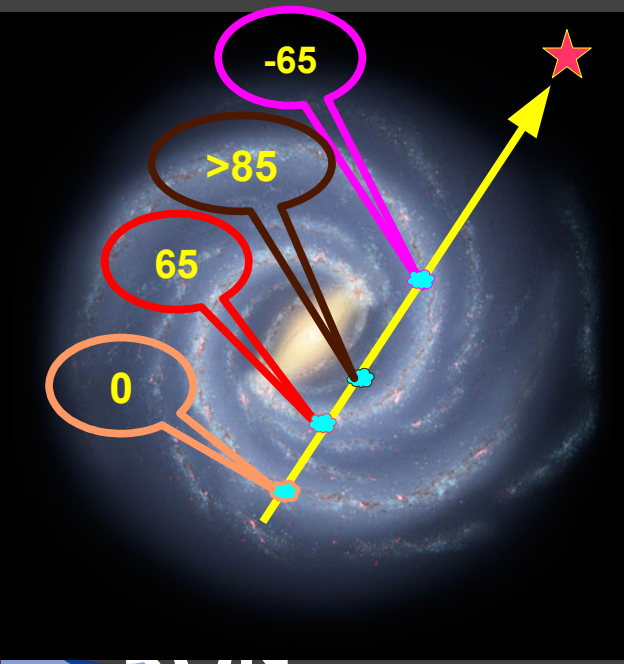
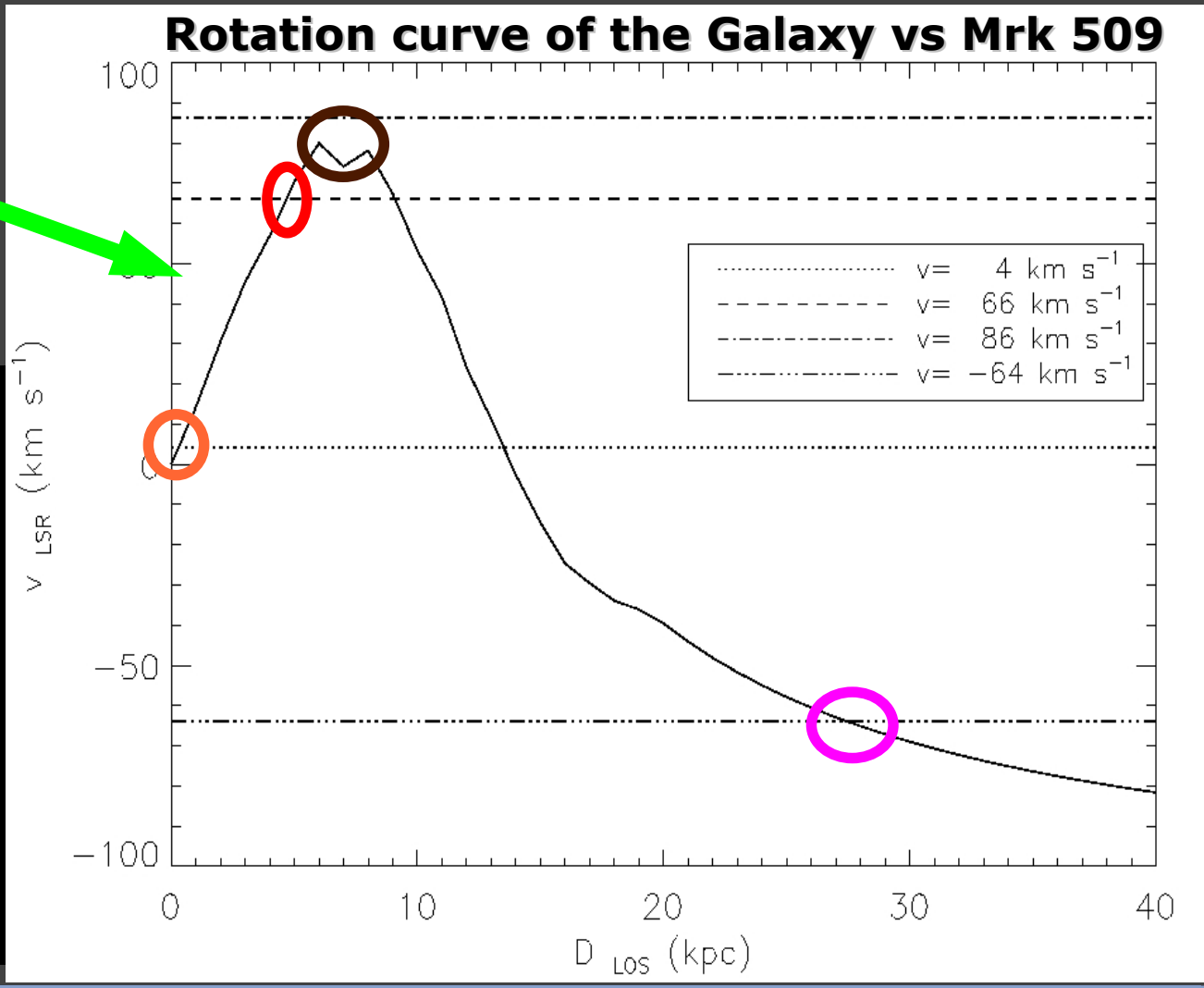




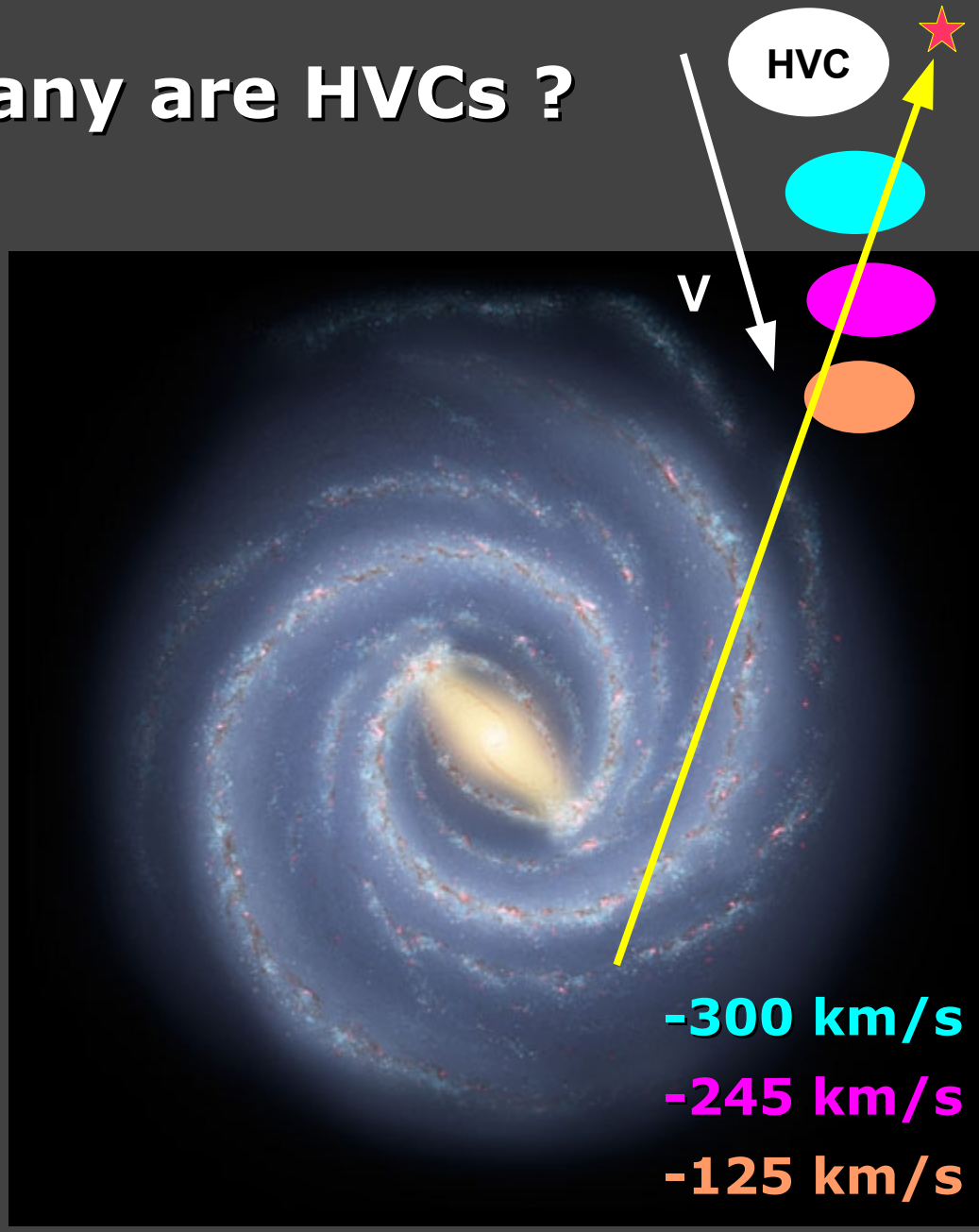


Where and How many are HVCs ?

- HV HI absent (but at 2°)
- Same abundances Si/C ~ 1
- Same SED
- Collisional ionization
- Slower layers more ionized

→ outskirt of 1 captured cloud

→ Non-primordial cloud impacting with the halo



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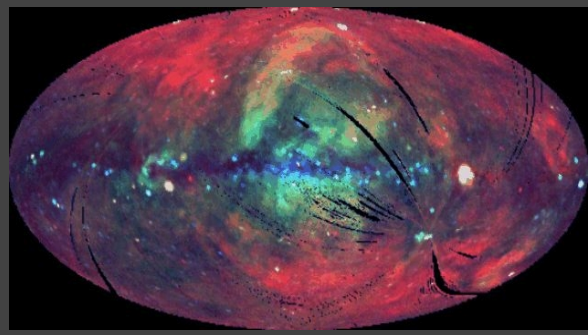
Interstellar forest at high latitudes: UV / X-ray Spectroscopy of Mrk 509

- High-energy spectroscopy golden age
  - Dynamics, chemistry, physics of ISM
  - Different environments
  - History of ISM and Galaxy

- Present & future: COS, XMM, Candra, Astro-H, Athena
  - High resolution in both UV & X-rays
  - Enlarge atomic & molecular database
  - Multi-wavelength workspace



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