Small and time-variable structures in the interstellar medium of the Milky Way

Jonathan Smoker, Catherine McEvoy, Keith Smith, Philip Dufton, Francis Keenan, Andrew Fox, David Lambert, Michael Kennedy, Dan Welty, Jim Loureauch

ESO Chile, Queen's University Belfast, RAS, STSci, McDonald Observatory, University of Chicago, University of Louisiana

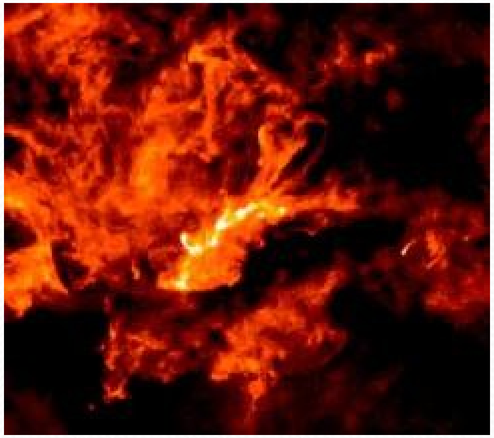
Talk outline

- Structure in the diffuse interstellar medium, why study it?
- FLAMES and FEROS observations of open clusters in the MW and Magellanic Clouds to investigate “small-scale” (pc) structure.
- The UVES-McDonald twin-epoch survey to investigate “tiny-scale” (AU) or time varying structure.

Why study the ISM?

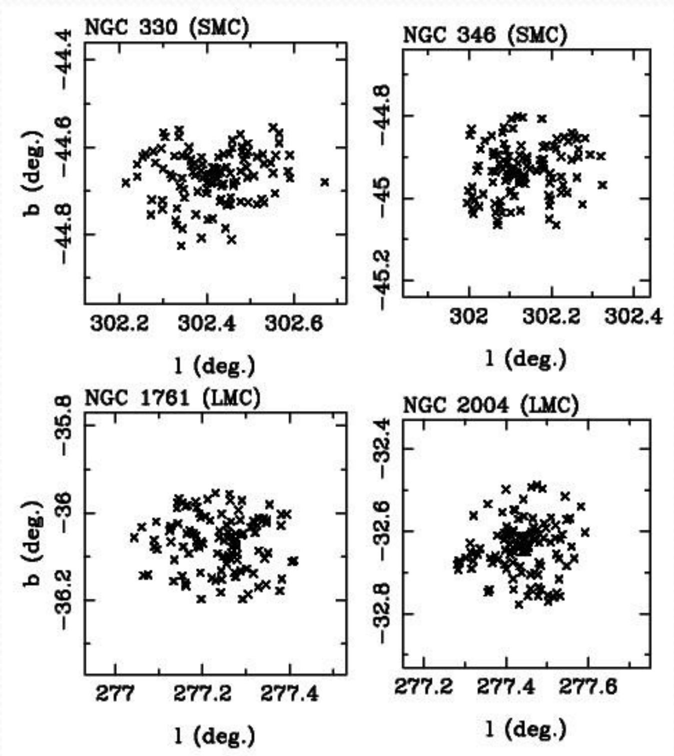
- Its composition has an imprint of the evolution of the Milky Way.
- Densities can be very low, so enable tests of physics and chemistry in environments hard to reproduce on the earth.
- It is the birthplace of stars

(Hershel image 5pc on a side, Gould belt survey).

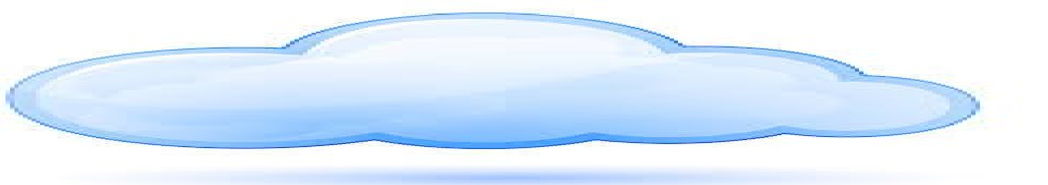


Two simple ways to measure structure in the diffuse ISM

1) Using background sources such as open and globular clusters:

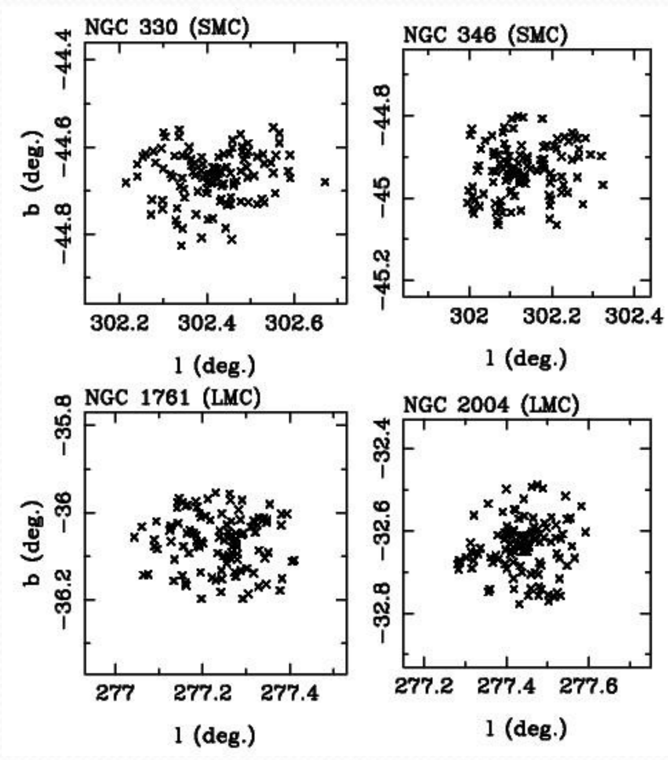


2) Taking twin epoch observations of a background source:

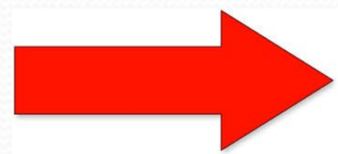


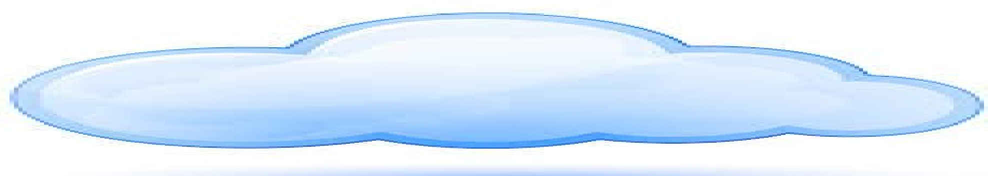
Two simple ways to measure structure in the diffuse ISM

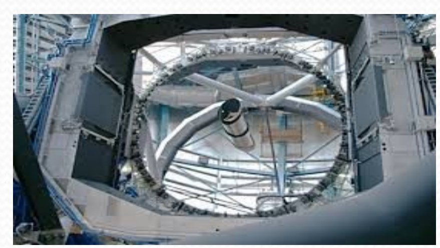
1) Using background sources such as open and globular clusters:



2) Taking twin epoch observations of a background source:

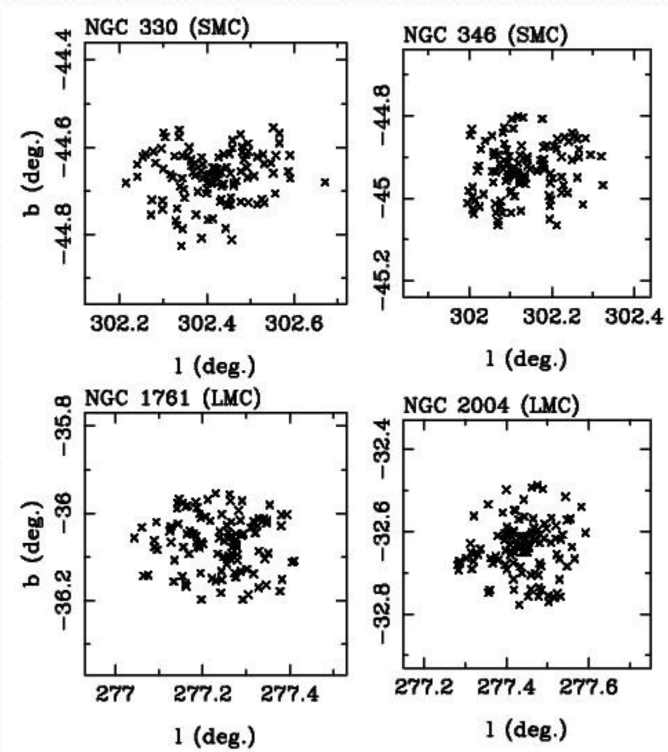




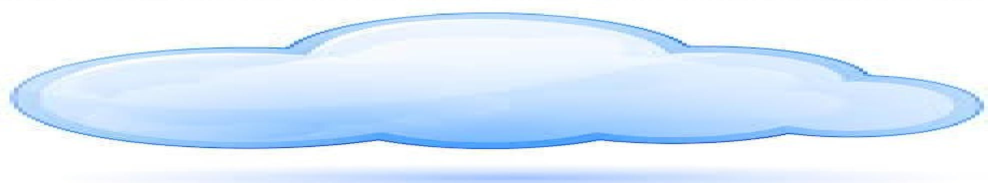


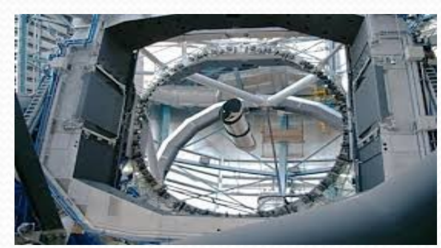
Two simple ways to measure structure in the diffuse ISM

1) Using background sources such as open and globular clusters:



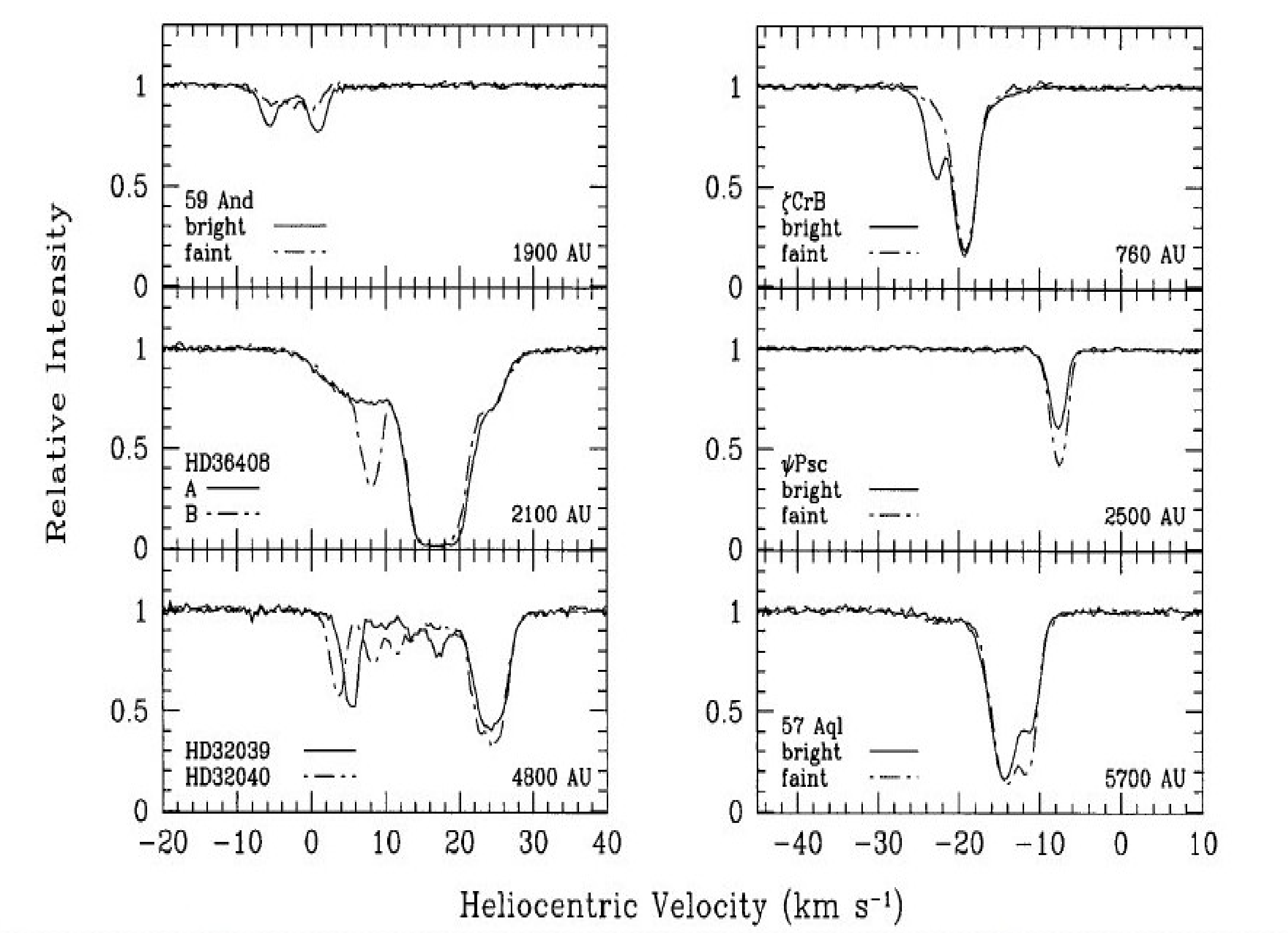
2) Taking twin epoch observations of a background source:





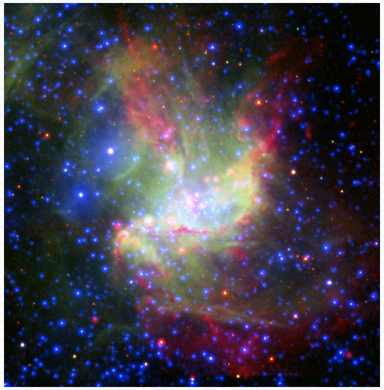
1) Structure in the ISM – small-scales (~arcsec / pc)

Watson & Meyer (1999) found structure in nearly all binary stars observed on scales of around 1000 AU using the NaI D lines. See also Smoker et al (2011 etc).



Small-scale structure - FLAMES data of 7 clusters

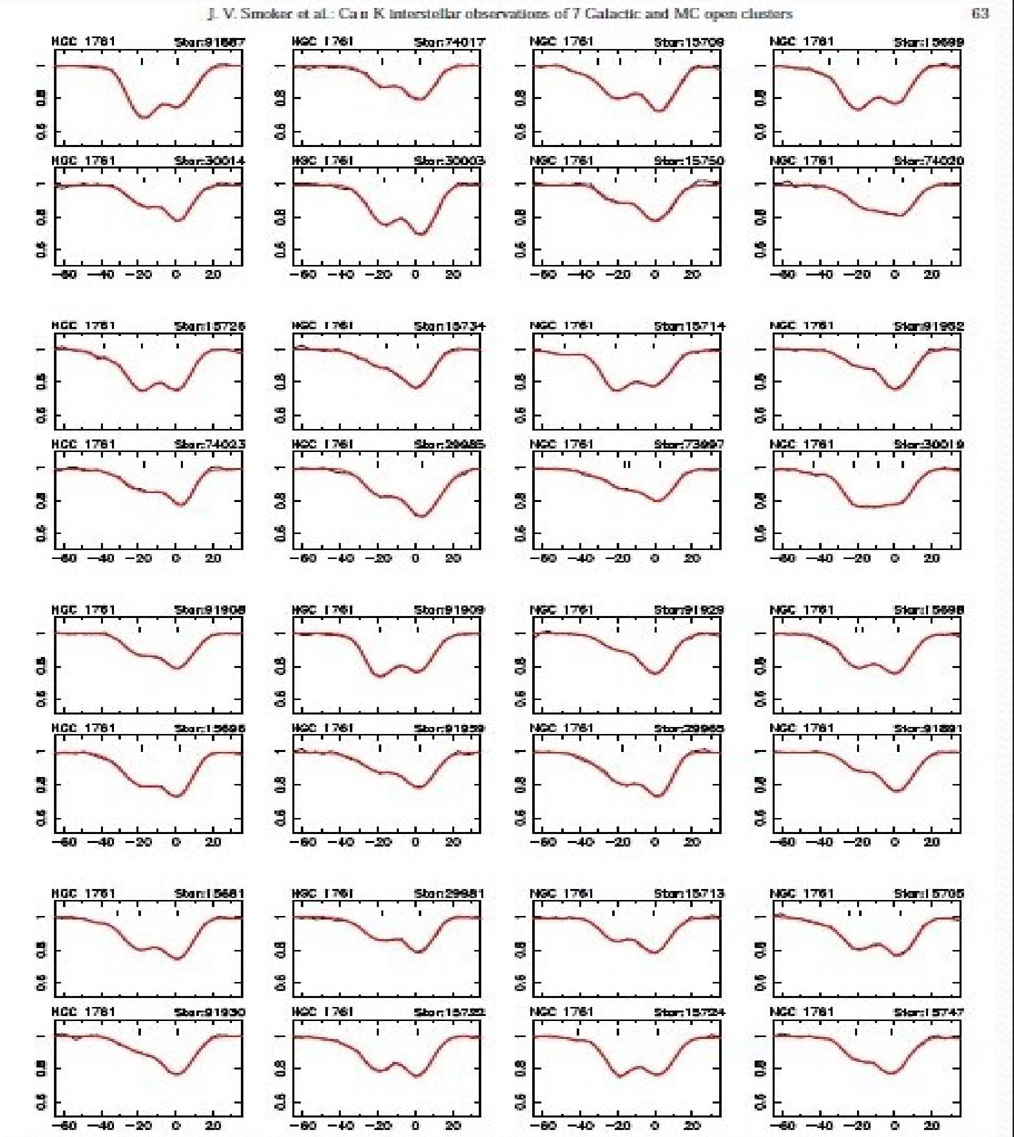
- Seven open clusters; three in the MW and two each in SMC and LMC.
- FLAMES CaII H&K lines spectral resolution 18,000 (Smartt FLAMES Large Programme).
- Minimum-maximum fibre-fibre distance from 12 arcseconds to 22 arcminutes (0.07 to 12 pc). **Typically 100 usable stars per field.**



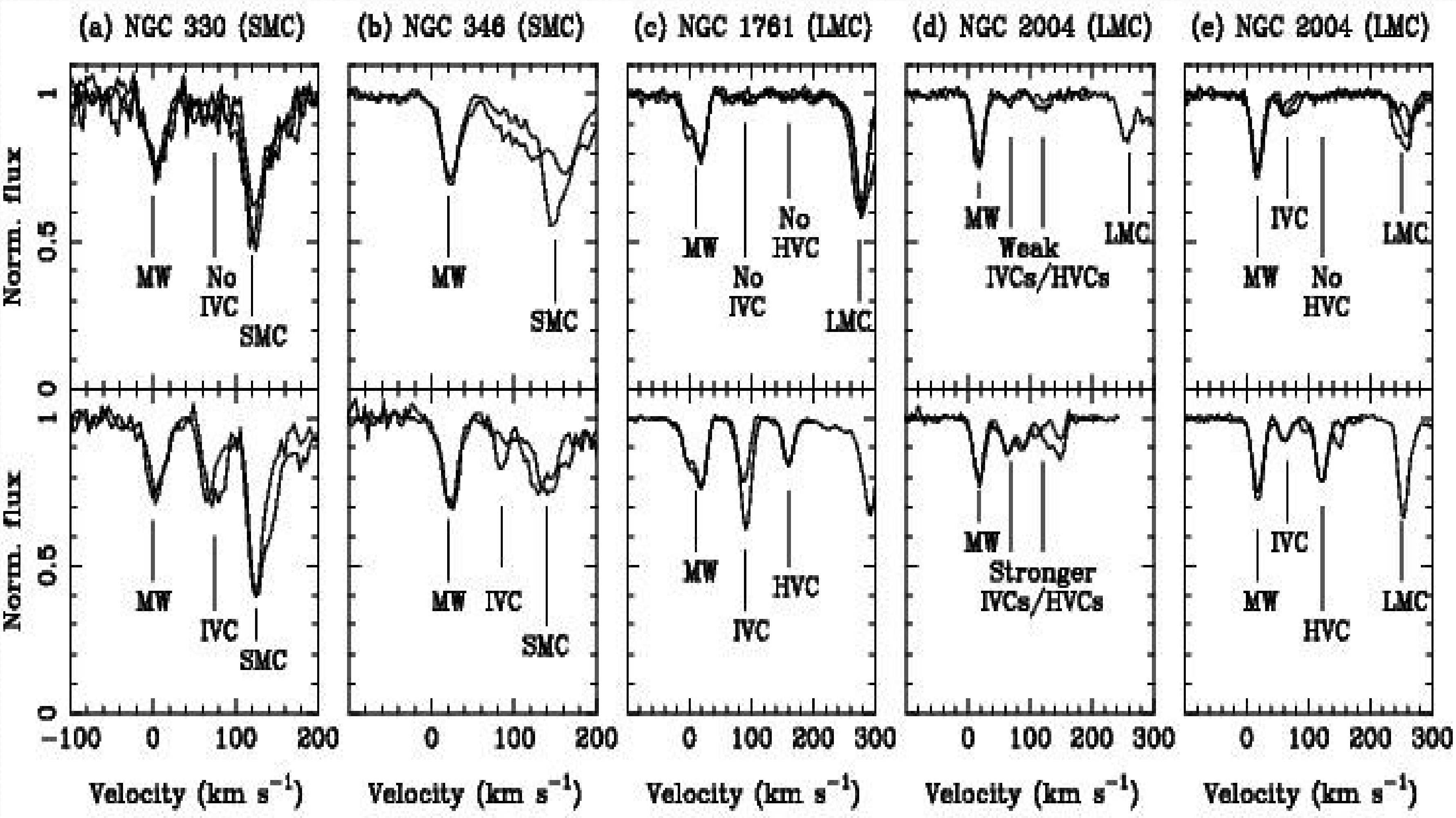
Small-scale structure results - FLAMES

When we go down to ~arcmin scale then structure in the ISM is very apparent…

(Meyer & Louroush 1999; Smoker et al. 2015 CaII FLAMES-GIRAFFE NGC 1761 data; star separation from 12” to 600”).



FLAMES CaII data of MW and MC OCs

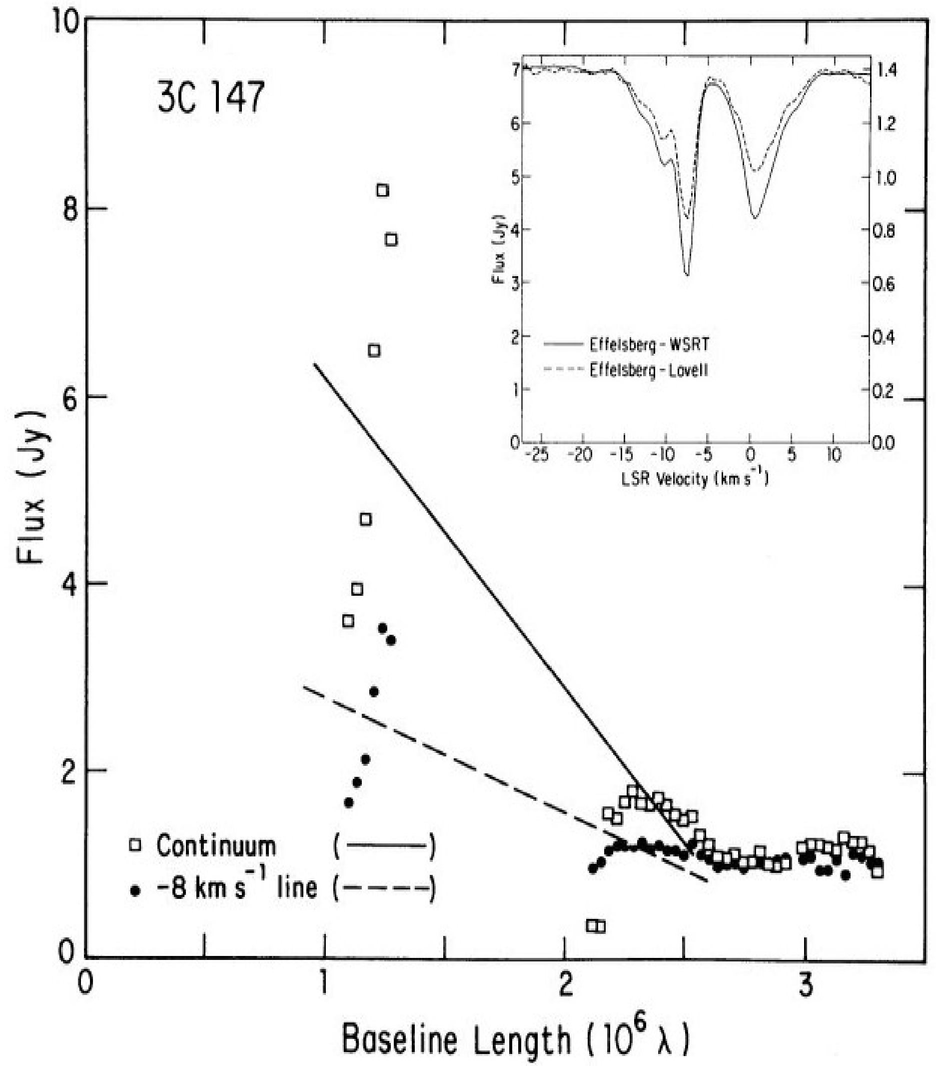


FLAMES – results

- Galactic CaII equivalent width varies by around 10% over scales of 10-20 arcseconds.
- I/HVC gas varies by factors exceeding 10 over similar scales.
- Can be explained by a simple ISM model (van Loon et al. 2009) of spheres with filling factor 0.3 and sizes from 1 AU to 10pc.
- HOWEVER, likely other models would also fit.
- The velocities of the LMC HVC components are consistent with a wind from the LMC (c.f. Lehner et al 2009 and see Richter et al 2014).
- CaII/OI ratios are subsolar by -0.2 to -1.5 dex implying dust depletion or ionisation in I/HVCs.

2) Structure in the ISM – tiny scale (AU)

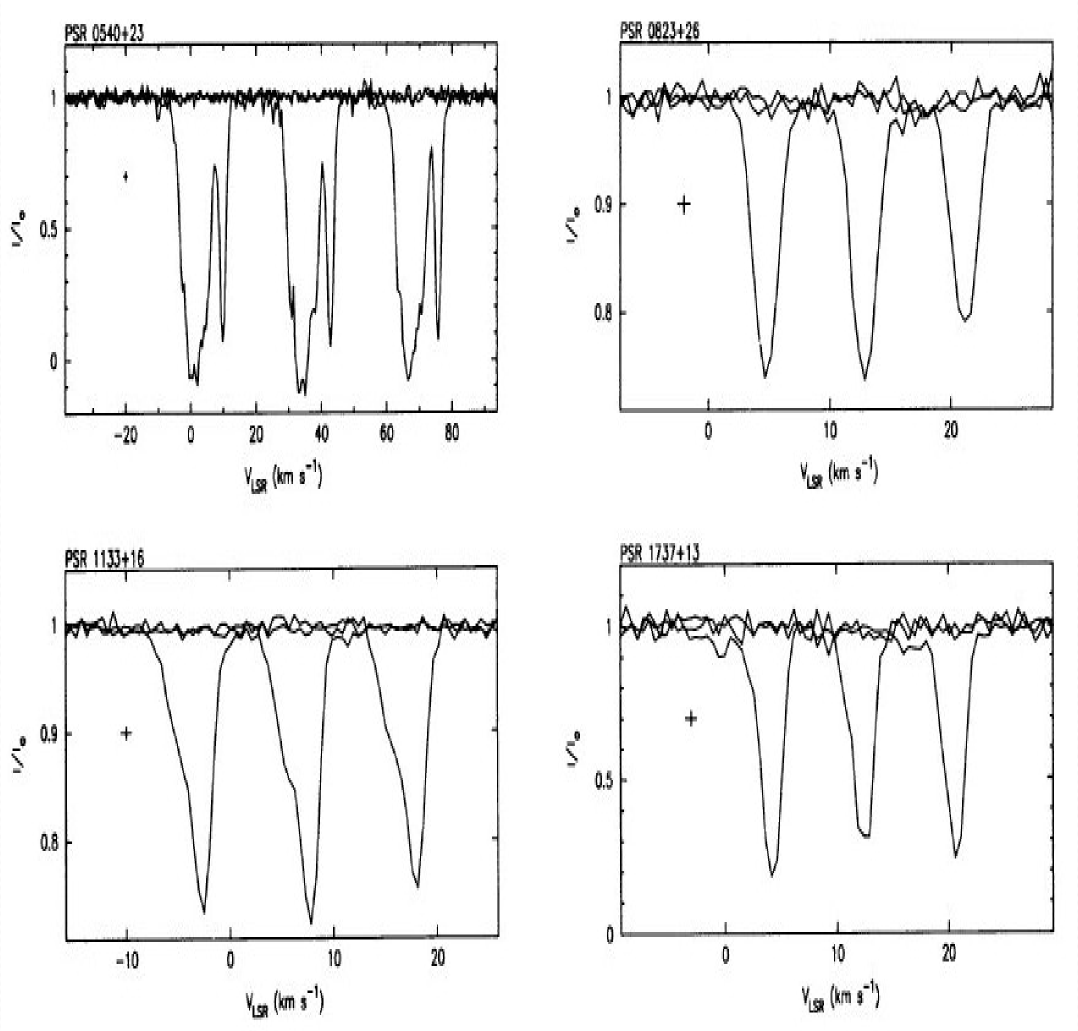
Diamond al. (1989) found varying HI absorption on different scales implying clouds of size 25 AU or smaller (also Brogan et al 2005, Roy et al 2012 etc etc).



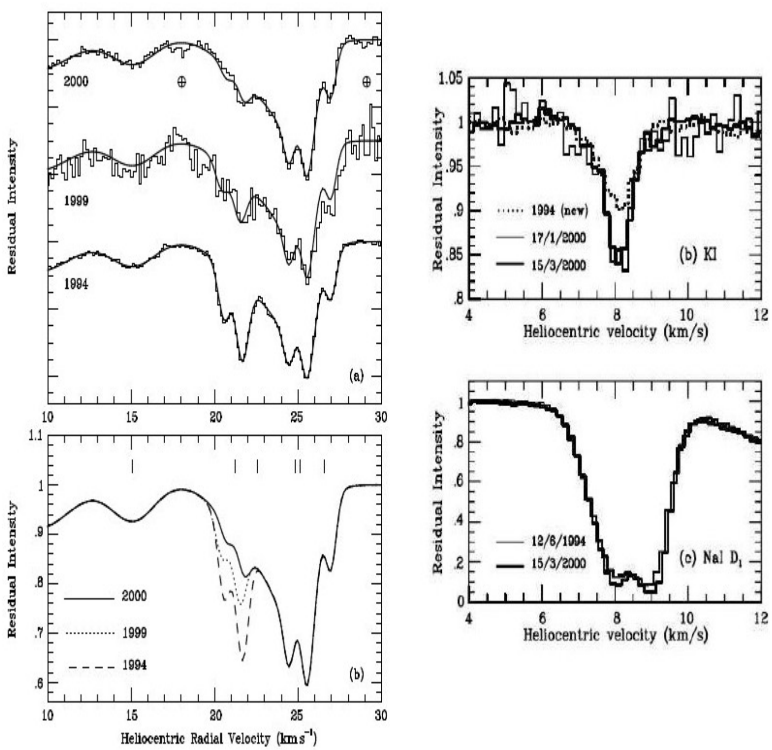
Structure in the ISM –tiny scale (AU)

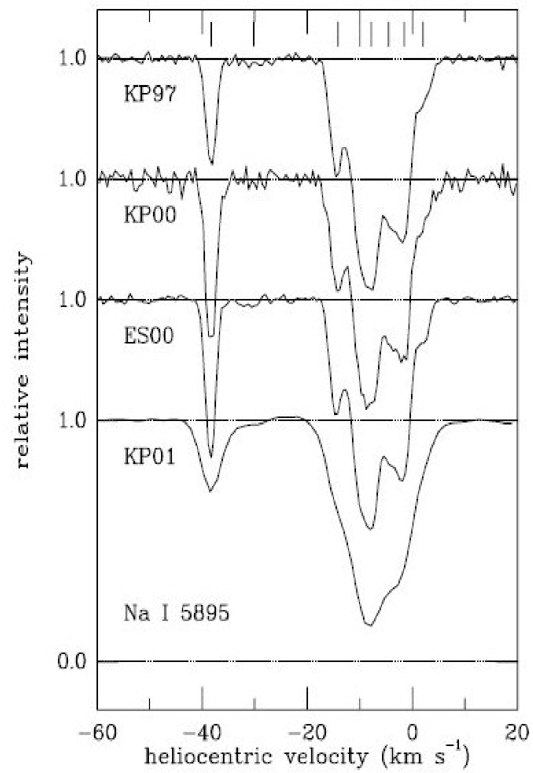
Frail et al. (1989) found varying HI absorption on scales of 1-100 AU using pulsar absorption. Not always observed (Johnston 2003).

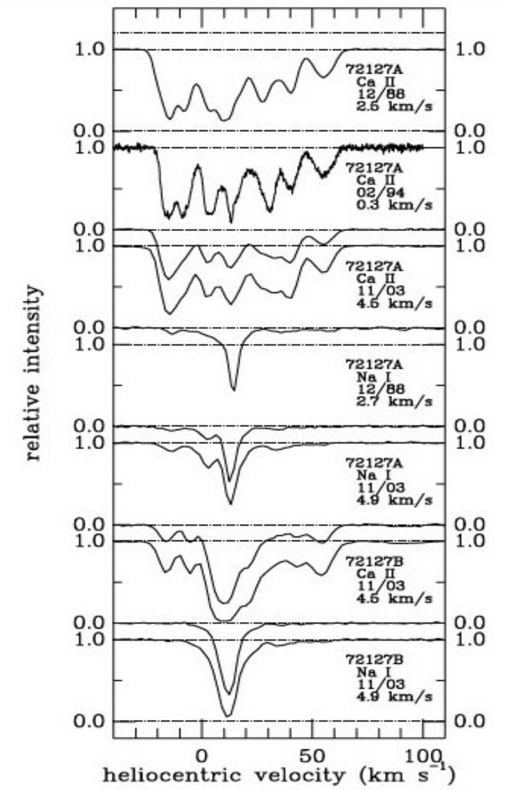
This is sometimes seen in the optical (next slide)



Structure in the ISM – AU scale NaI (time- variable)







Price et al. (2000), Crawford (2002), Welty (2007, 2008).

What do these results imply?

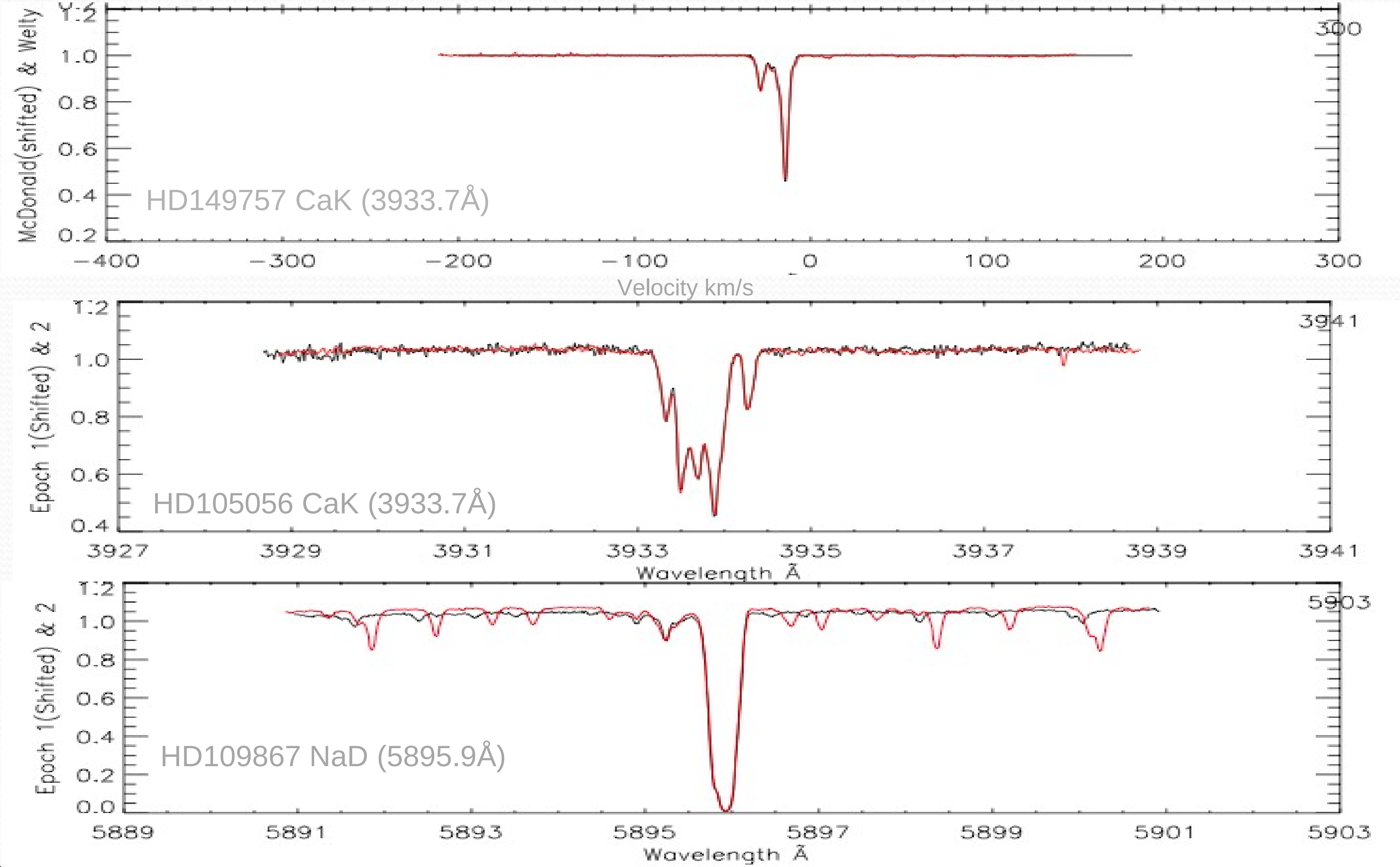
- About 25 examples of variation in the optical. There may be clouds of AU-size in the ISM.
- If this is the case, then this implies that they are over-dense with regards to the normal ISM.
- Such clouds should not be stable & dissipate over short timescales or be constrained by some over-pressure. Continuous formation?
- Possible alternatives are that the (trace species) NaI clouds are not spherical (sheets, filaments), we just see statistical fluctuations, or that the physical conditions differ in different sightlines (ionisation, density etc), although this does not explain N(HI) variations.

UVES-McDonald survey time variable structure

- We observed **105** **early-type** **stars at two epochs** with either UVES (R=80,000) or McDonald 2.7-m (R=160,000) with S/N>300. The first UVES epoch was the Paranal Observatory Project and for McD we used Welty et al. data from the 1990s.
- Between the two epochs ~5 and 20 years had passed. During this time the stars move due to their PMs from 0 to 1000 AU.
- Although numbers are small still this is the largest such survey we know of to date looking for optical variability.

Results

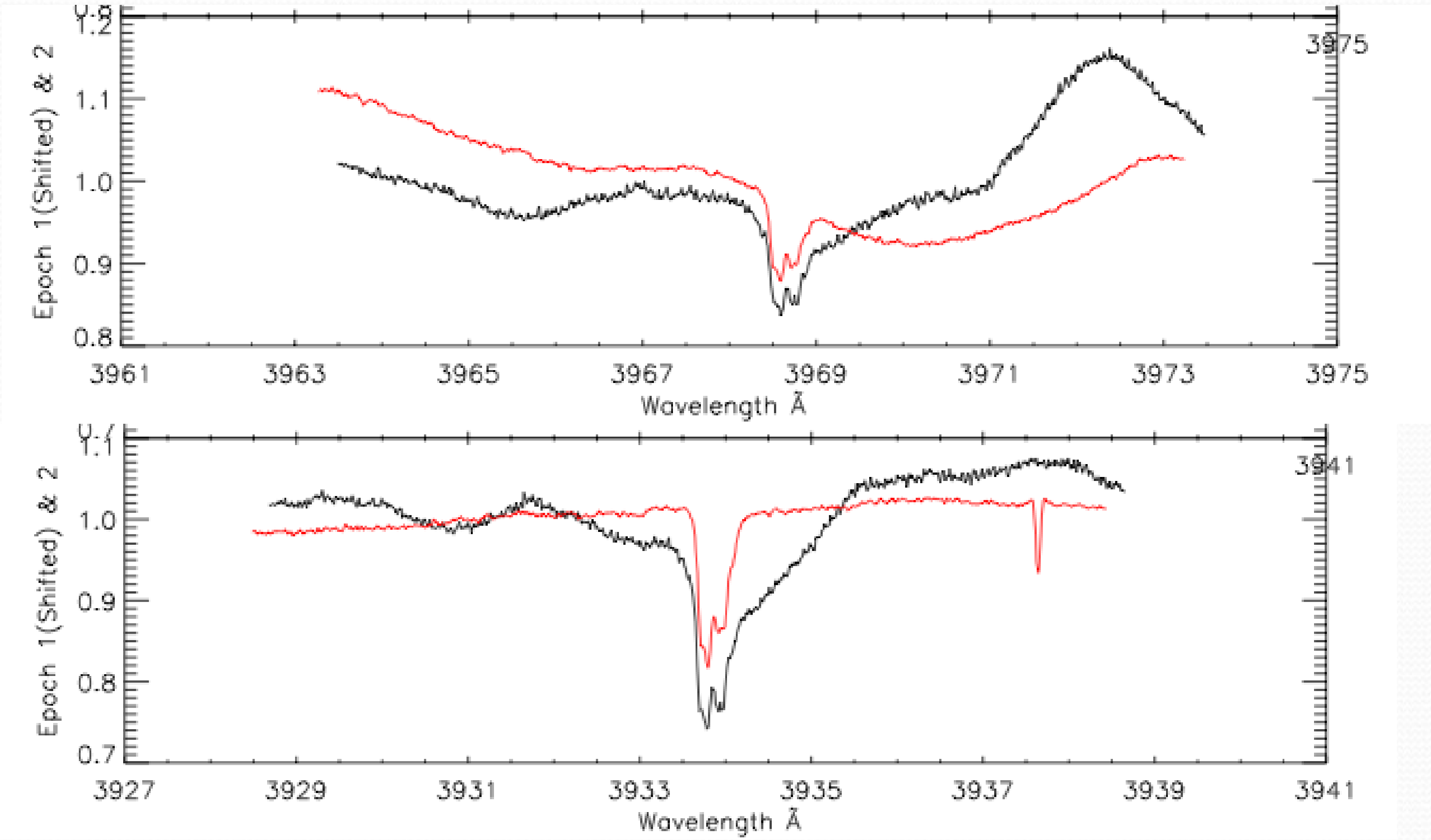
Vast majority of the spectra analysed show no variation in the interstellar lines:



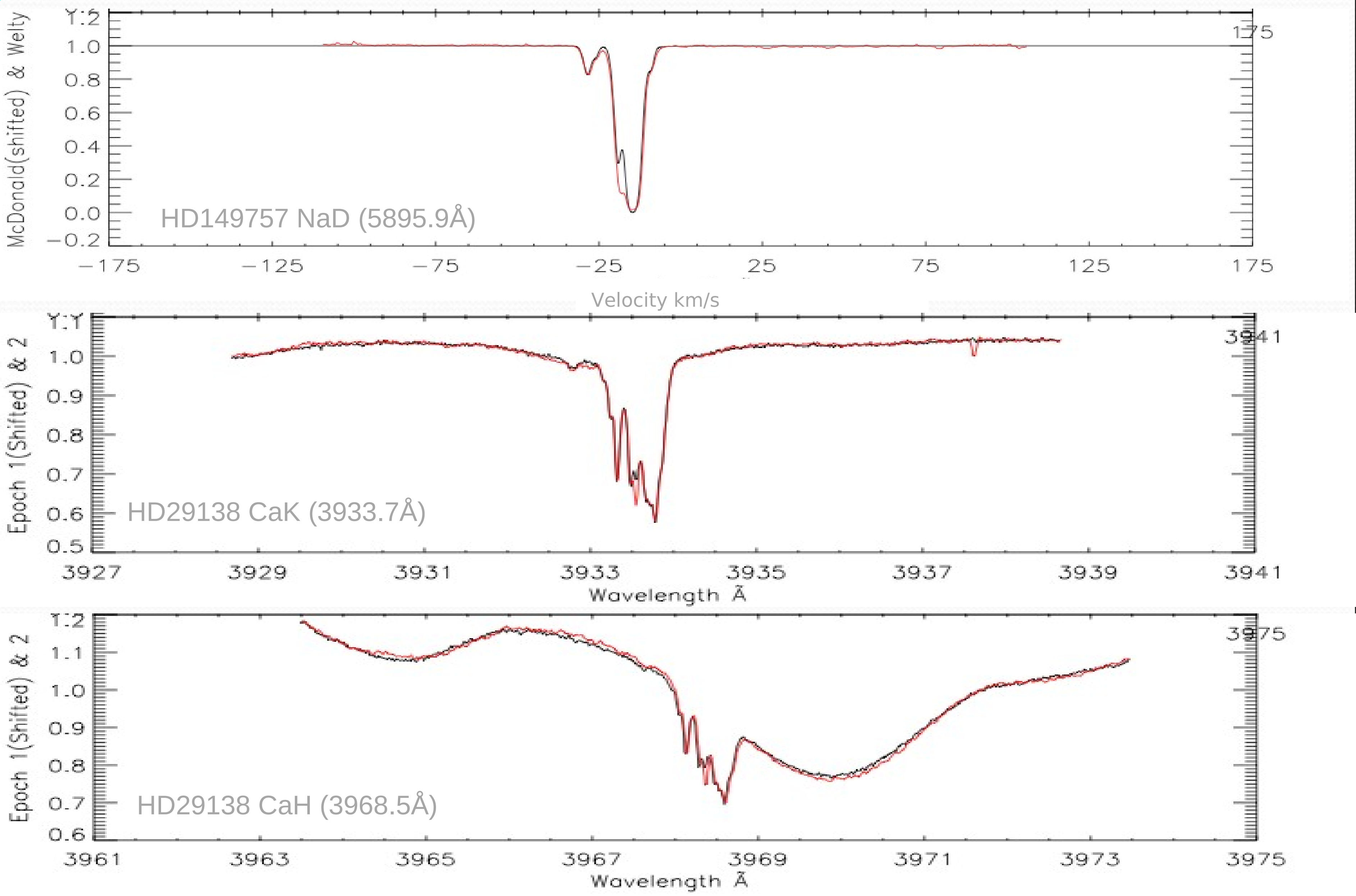
Some show variation likely caused by circumstellar lines (e.g. the following two Be stars)

HD 58978: Be Star

Proper motions *mas/yr* [error ellipse]:**-7.76 4.82 [0.25 0.34 0]**



However, some show more obvious variations in the interstellar lines…



UVES/McD – analysis

- CaI/CaII ratio used to estimate n(e) of around 0.5 cm^{-3} (assuming they co-habitate....).

- Assume the electrons come from ionised C, assuming carbon depletion of 60% and assuming a normal abundance of C gives an estimate of the total Hydrogen column density.

- Values derived for nH exceed 2000 cm^{-3} which are in the upper range of normal diffuse interstellar gas, but big errors.

Summary

All sightlines show small-scale (pc) CaII variations. Nothing new there! Likely several models can describe variation seen.

About 1-2% of sightlines show time variation, with transverse scales of >50 AU (nothing smaller).

The "variable" sightlines do not seem to be associated with known SN remnants (within the errors; GAIA will help here).

Electron densities and NH are at the upper end of "normal" diffuse sightlines (nH exceeds 2000 cm^{-3}), but large errors.

Not yet clear if we measure ionisation or column density variations in the varying sightlines....

Summary

All sightlines show small-scale (pc) CaII variations. Nothing new there! Likely several models can describe variation seen.

About 1-2% of sightlines show time variation, with transverse scales of >50 AU (nothing smaller).

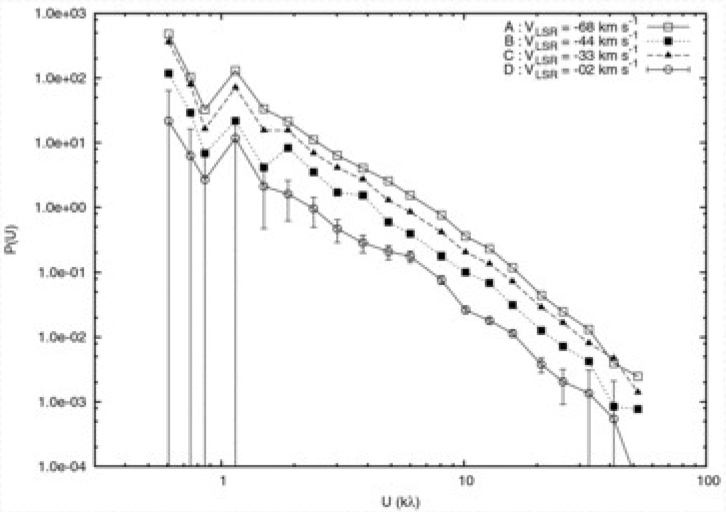
The "variable" sightlines do not seem to be associated with known SN remnants (within the errors; GAIA will help here).

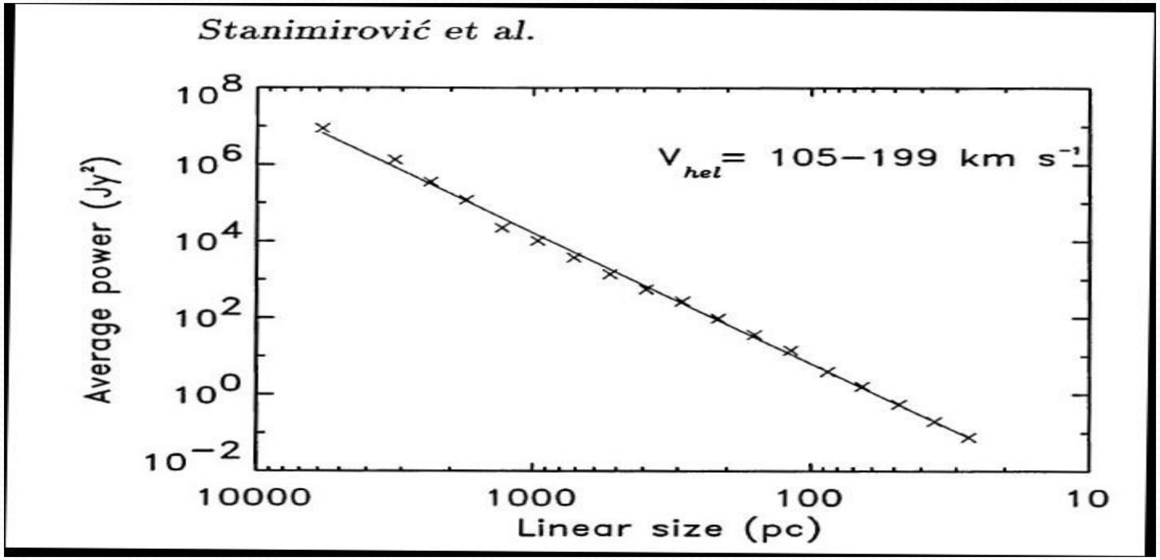
Electron densities and NH are at the upper end of "normal" diffuse sightlines (nH exceeds 2000 cm^{-3}), but large errors.

The END

Power spectra

A power law slope in SMC, LMC and Milky Way all about -3 (Roy et al top, Stanmimirovic et al)





Equilibrium Temp vs nH (Bate & Keto 2015)

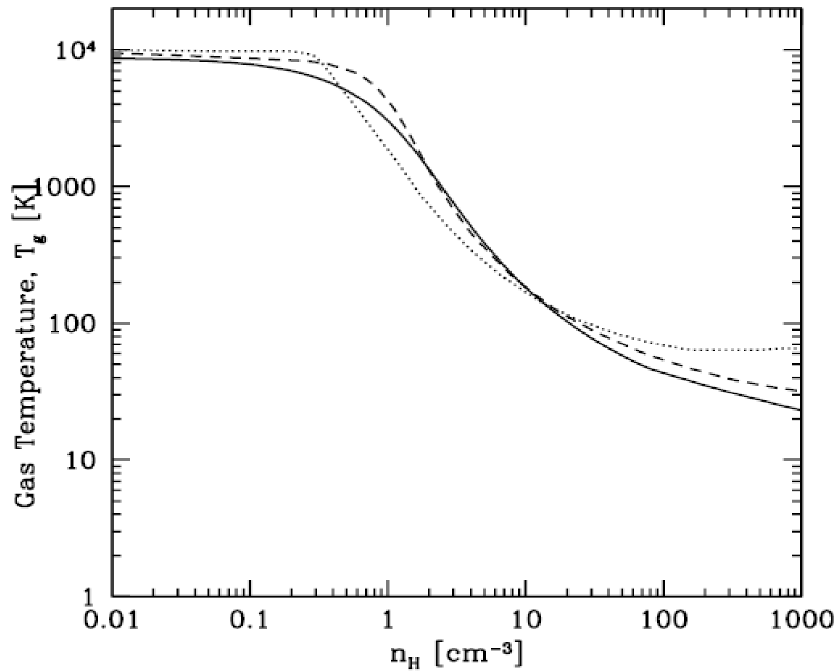


Figure 1. The equilibrium temperature as a function of the number density of hydrogen nuclei, n_{H}, in the warm and cold neutral mediums achieved by considering cosmic ray and photoelectric heating (without extinction) balanced by cooling due to electron recombination, and fine structure emission from carbon and oxygen (solid line; equations 24, 26, 30, 32, and 33). The dashed line gives the result obtained by Wolfire et al. (2003) for solar metallicity gas at a Galactic radius of 8.5 kpc. The dotted line gives the result from the model of Glover & MacLow (2007a).

LMCVLSR vs RA (Smoker et al., Lehner et al.)