Galactic Plane surveys with Hα:
spectroscopic follow-up opportunities

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Credits:

The consortium:

Core functions:
University of Hertfordshire (PI institution – IPHAS, VPHAS+);
Radboud University Nijmegen (PI institution – UVEX)
University of Cambridge (pipeline);
University of Graz (software oversight)

Other member institutions:
IAC, Warwick University, University College London, Tautenburg Observatory, Imperial College London, University of Manchester, Southampton University, Armagh Observatory, Macquarie University, Harvard-Smithsonian CfA, ESO, ESTEC, University of Valencia

Key individuals: Geert Barentsen, Romano Corradi, Jochen Eisloeffel, Hywel Farnhill, Boris Gaensicke, Robert Greimel, Eduardo Gonzalez-Solares, Paul Groot, Mike Irwin, Danny Steeghs, Jeremy Walsh

This talk is:-

1. Some scene-setting on the EGAPS surveys, IPHAS/UVEX and VPHAS+…

(i) Why did we bother starting
(ii) Present status

2. Spectroscopic follow-up: two contrasted demonstrators

(i) A sparse sample – classical Be stars as distant beacons
(ii) Dense sampling – Hα (in absorption) aiding intelligent target sampling for radial velocity work in the outer disk.

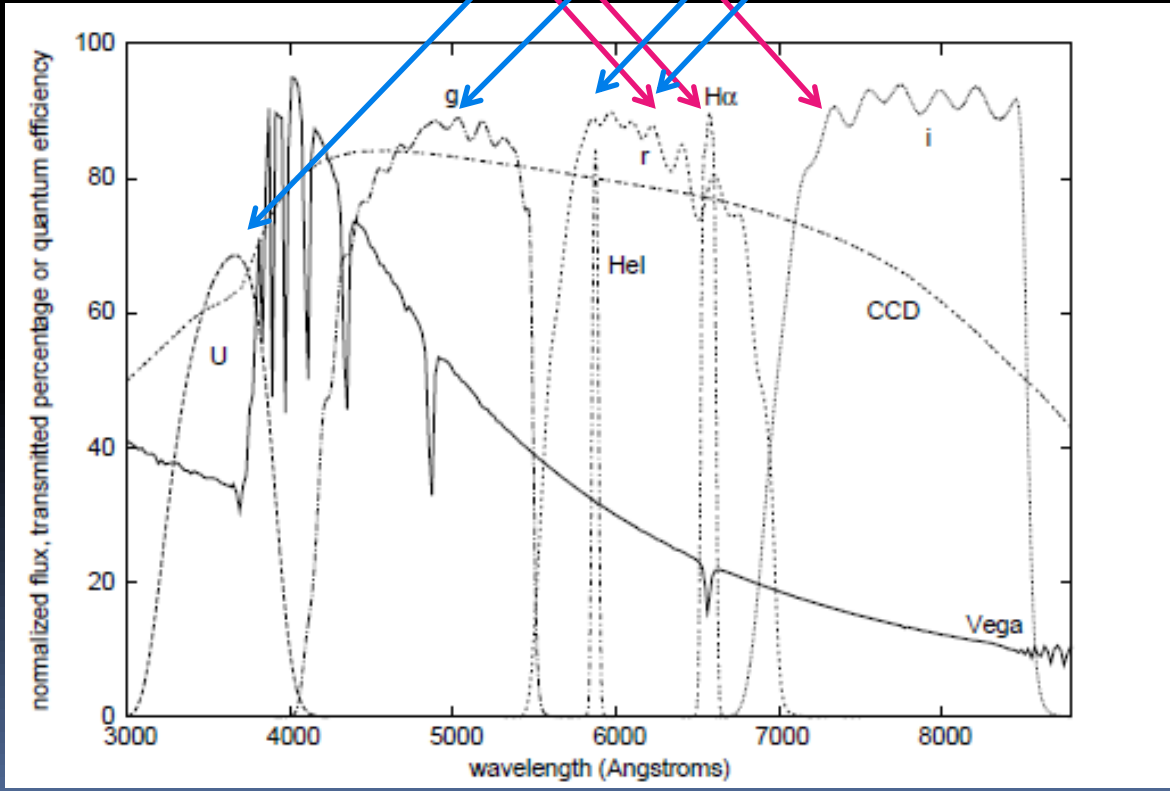
1. European Galactic Plane Surveys: 2 northern surveys (1 red with Hα, 1 blue); 1 merged red+blue survey in the south

EGAPS
EUROPEAN GALACTIC PLANE SURVEYS

=

IPHAS + UVEX + VPHAS+

5 filters (all except HeI)



(Spectrum of Vega, with filter transmission profiles on top -- from Groot et al 2009)

Where EGAPS began:- Back in 2003, with IPHAS on the Isaac Newton Telescope – Hα, backed up by r,i

Primary motivation:

Hα = the highest emissivity, non-ground-state transition of the most abundant element in the cosmos – usually excited by recombination

→*the* tracer of ionised gas….

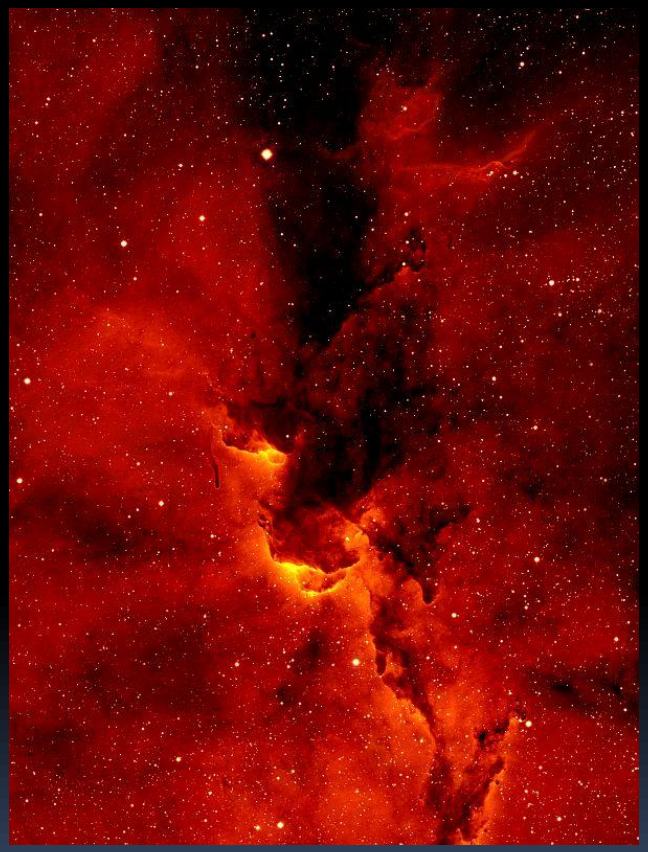
Spatially resolved imaging → detection of HII regions, bubbles/chimneys, planetary nebulae and supernova remnants

Point sources → disks and winds of large numbers of Be and pre-main-sequence stars – and many different types, of evolved stars and compact binaries

…we do not understand *any* of these object classes adequately (samples usually too small or too incomplete)

IPHAS (www.iphas.org) – first ~arcsec resolution digital Hα survey, able to pick out emission line stars reliably/comprehensively

|b| < 5°, the complete northern Galactic Plane



(IC 1396b, r'i'Hα, N. Wright)

'simultaneous' r',i', Hα to ~20th magnitude, ~15000 fields observed, covering area twice

median seeing 1.1 arcsec

started 2003 – every pointing covered at least once by end 2008:

> 300 nights at the telescope

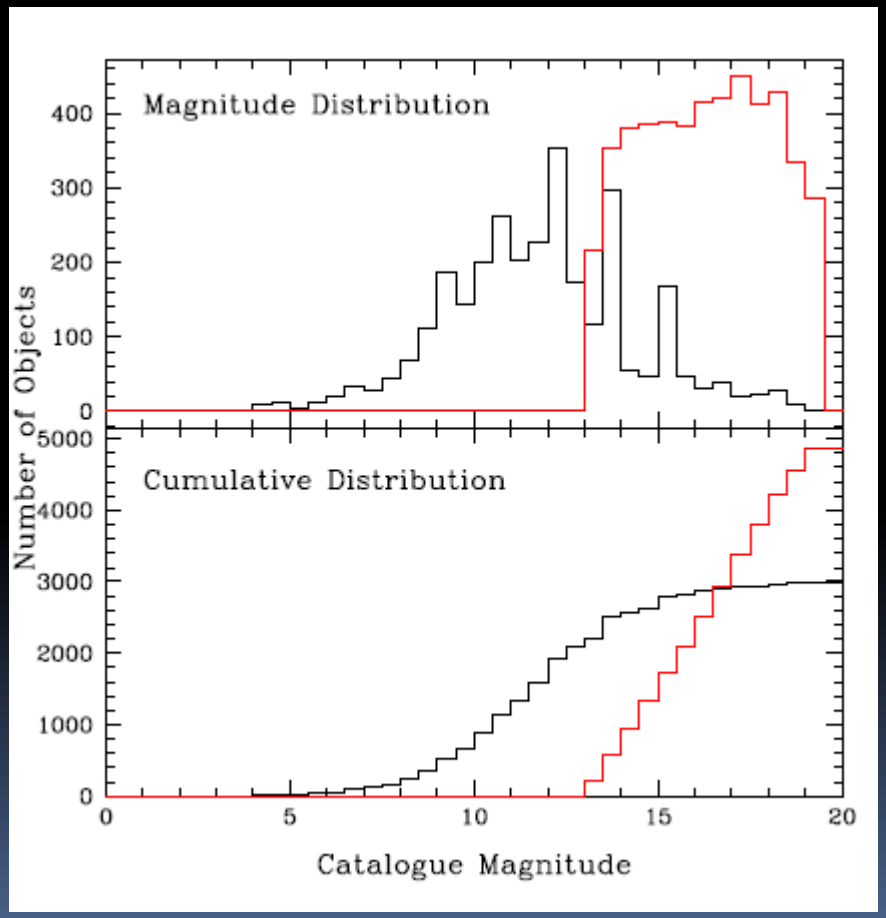
data pipelined at CASU

point source catalogues for ~half the area available via astrogrid (IDR) since end 2007

~complete release (to CDS) + paper nearly ready

Narrowband Hα picks out short-lived/important phases of stellar evolution

- In 2003: few emission line stars known below ~13th magnitude



On the way to being fixed in the north by IPHAS

Figure: comparison of Kohoutek & Wehmeyer catalogue, in black, with conservatively-selected Witham et al 2008 IPHAS catalogue, in red (80% of survey footprint) → ~5000 new emission line stars to r=19.5

2004-5 UVEX came into being as an INT survey:

- U, g, r and narrowband HeI
- Same footprint and 'double-pass' strategy as IPHAS

→To seek out UV-excess objects – compact binaries of all kinds, hot WDs, massive stars…

- About two-thirds done

In parallel, VPHAS+ for the VST had been proposed and approved as a merger of VPHAS (Hα, r, i) and UVEX-S (u, g, r)

- Contemporaneous u,g,r,i and Hα across the southern GP
- 'Double-pass' strategy again
- Order placed for narrowband Hα filter for VST

2009 Filter delivered and tested
2010 Bulge added to VPHAS+ footprint

VPHAS+ survey data collection underway by beginning 2012

VST Photometric Halpha Survey + (www.vphas.eu)

* 1800 sq.deg, |b| < 5°, plus small overlap at celestial equator, ~2000 fields.

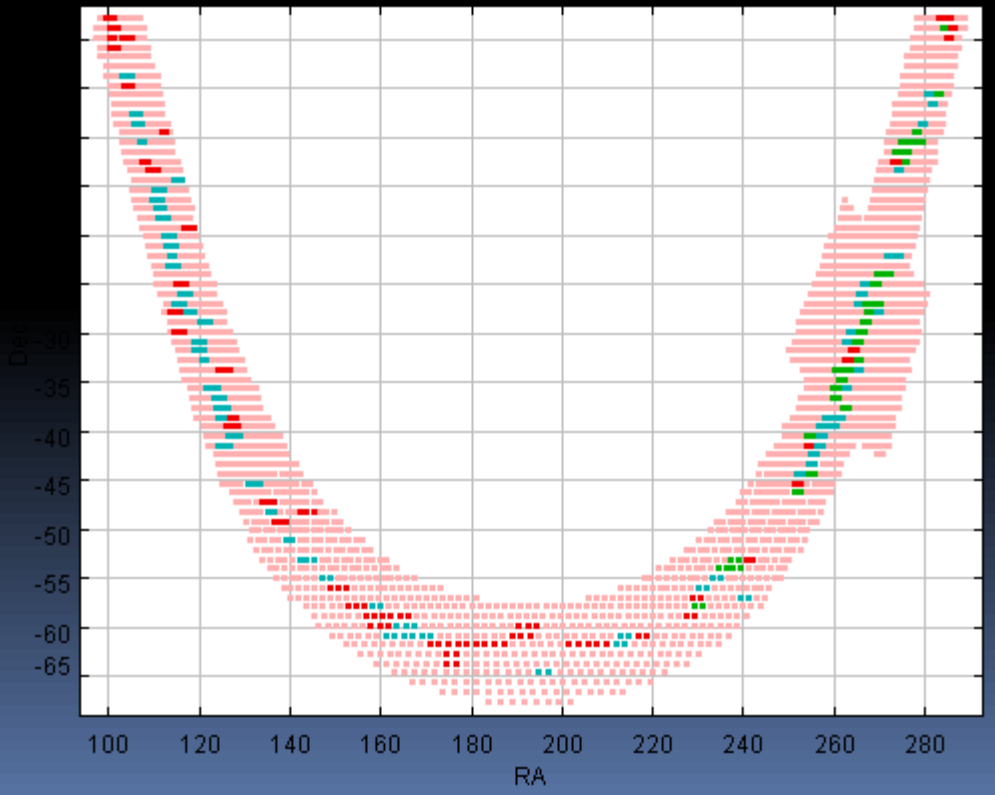
And also 200 sq.deg to cover Galactic Bulge, ~220 fields

* Data collection began 2011/12 New Year

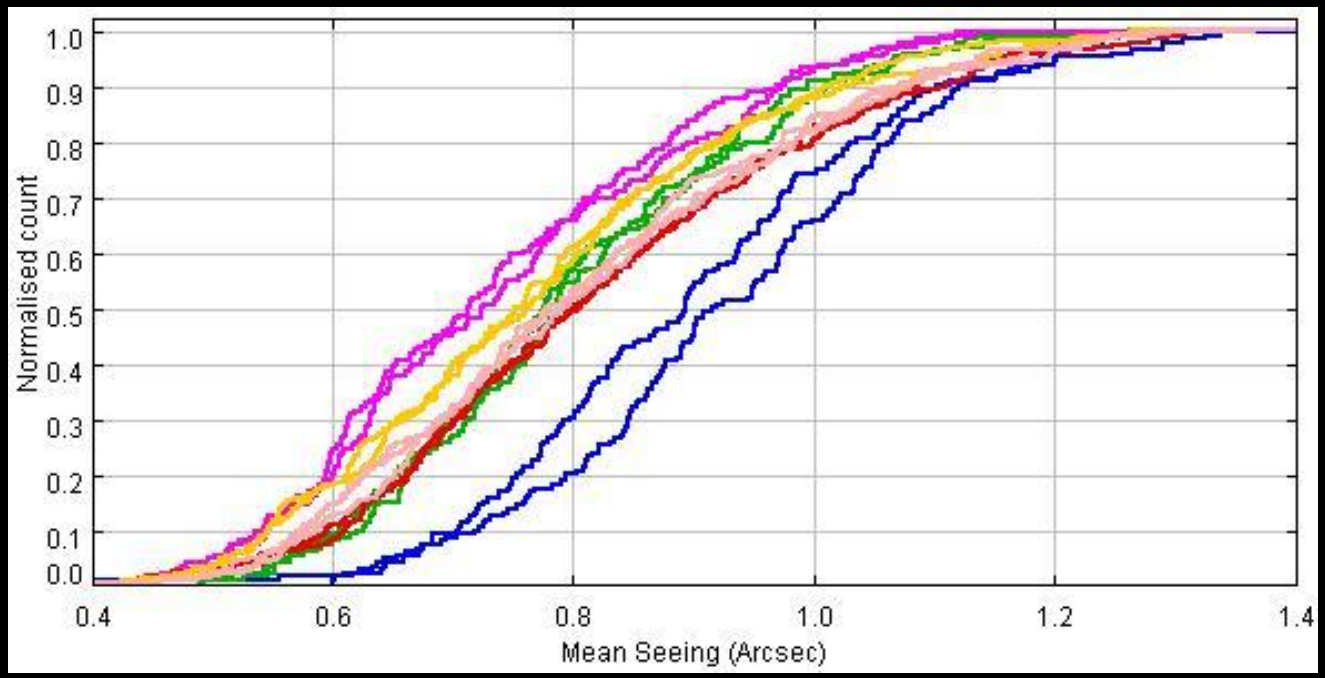
...split into u/g/r and Hα/r/i concatenations for operational reasons

....two offset pointings in all broadband filters, with a 3rd intermediate pointing also for Hα (segmented filter) → ~20th mag, 10-sigma in all

Right: Survey footprint (pink), and fields observed, by end of September, 2012:



VPHAS+ data quality looking good:-



Mean seeing data (A,B graded concatenations)

u: blue
g: green
r : mauve (blue concat)
r: red (red concat)
i: deep yellow
Ha: pink

90 percentile seeing so far ~1.0 arcsec g/r/i/Ha, 1.1 arcsec in u

2. Spectroscopic follow-up

(i) Sparse targets (emission line stars)

(ii) Dense target identification (A/F stars → radial velocities)

(i) Sparse sampling potential spectroscopic targets:

e.g. Massive emission line stars (classical Be stars), seen to great distance across MW disk

- Bright absolute magnitudes ($-4 < M_V < 0$)
- Still not understood… why/when the c'stellar disks
- Dominant emission line star type at $r < 17$
- 10-50 Myrs old …arm tracers?
- Photometric selection 'easy'
- Probes of long dust columns

…will be thousands of them…

A first faint (13<r<16.5) Galactic sample in/behind the Perseus Arm:

Raddi etal submitted

Top: ~200 of them in 100 sq.deg, picked out by r-Hα excess – checked against 2MASS data

Bottom: spatial distribution (unclustered)

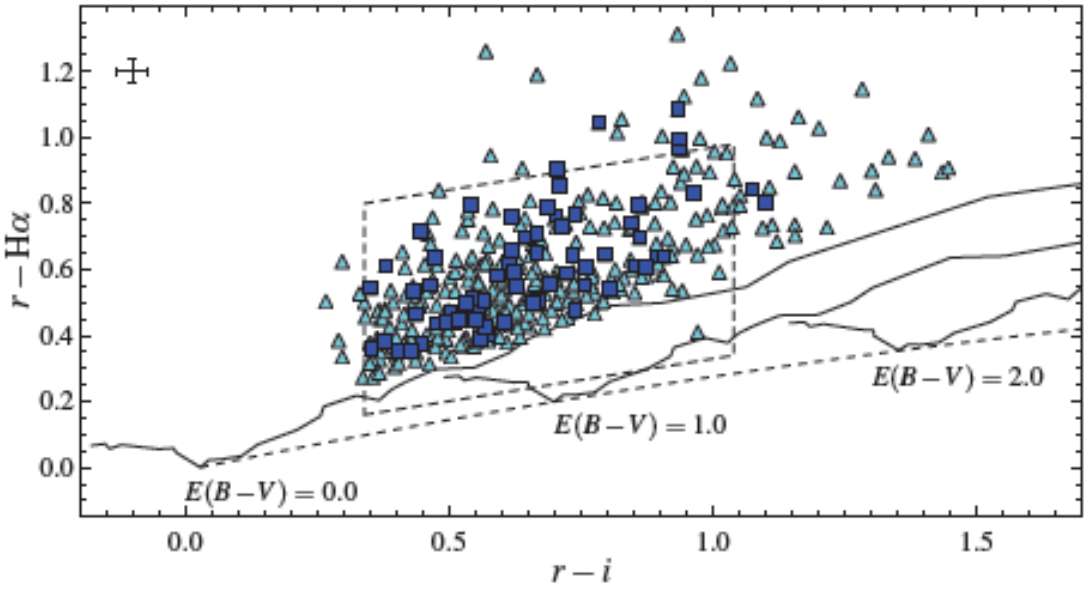
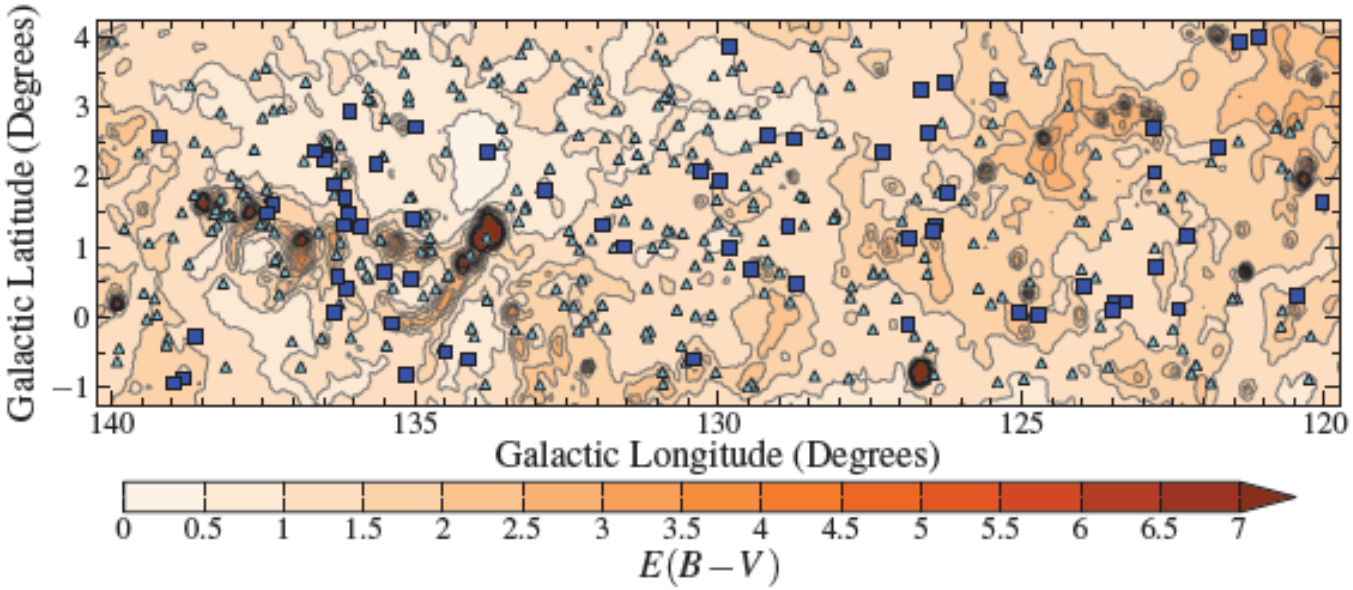


Figure 1. IPHAS colour-colour diagram of the observed targets (cyan triangles). Black solid lines are synthetic main sequence loci, at $E(B-V) = 0.0$, 1.0, 2.0 (see e.g. Table 2 in Drew et al. 2005). These move parallel to the reddening vector that is plotted as the early-A reddening curve (dashed lower curve). The box drawn above the unreddened main sequence defines the region in which CBe stars with $A_r \sim 4$ are likely to be located (cf Fig. 3 and the discussion to be found in Corradi et al. (2008).The CBe stars, for which we have obtained intermediate-resolution spectra, are picked out as blue squares. Typical error bars are plotted in the upper left corner.



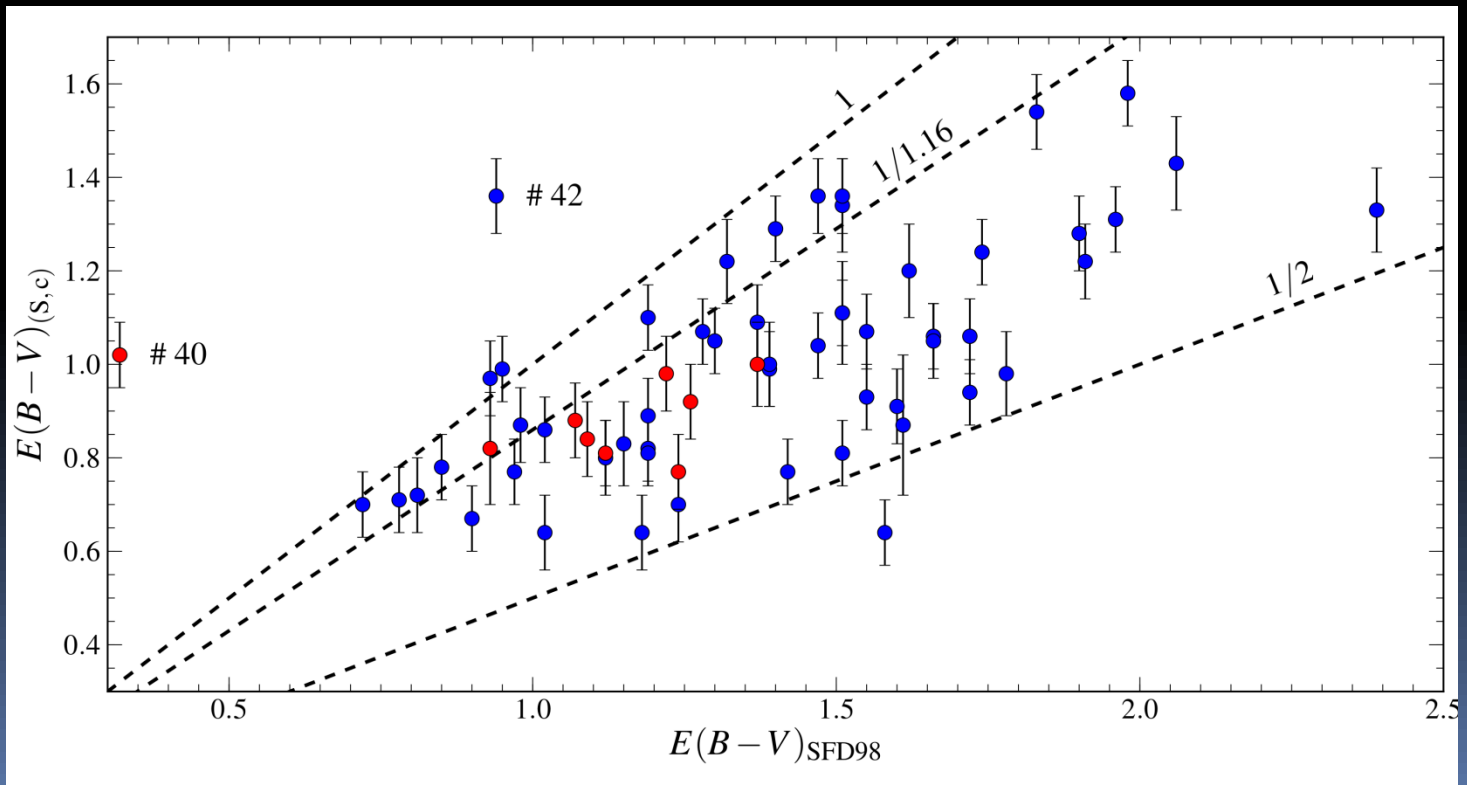
But GOOD (S/N ~100) spectroscopy at 1-2 A resolution needed to nail down Teff, log g

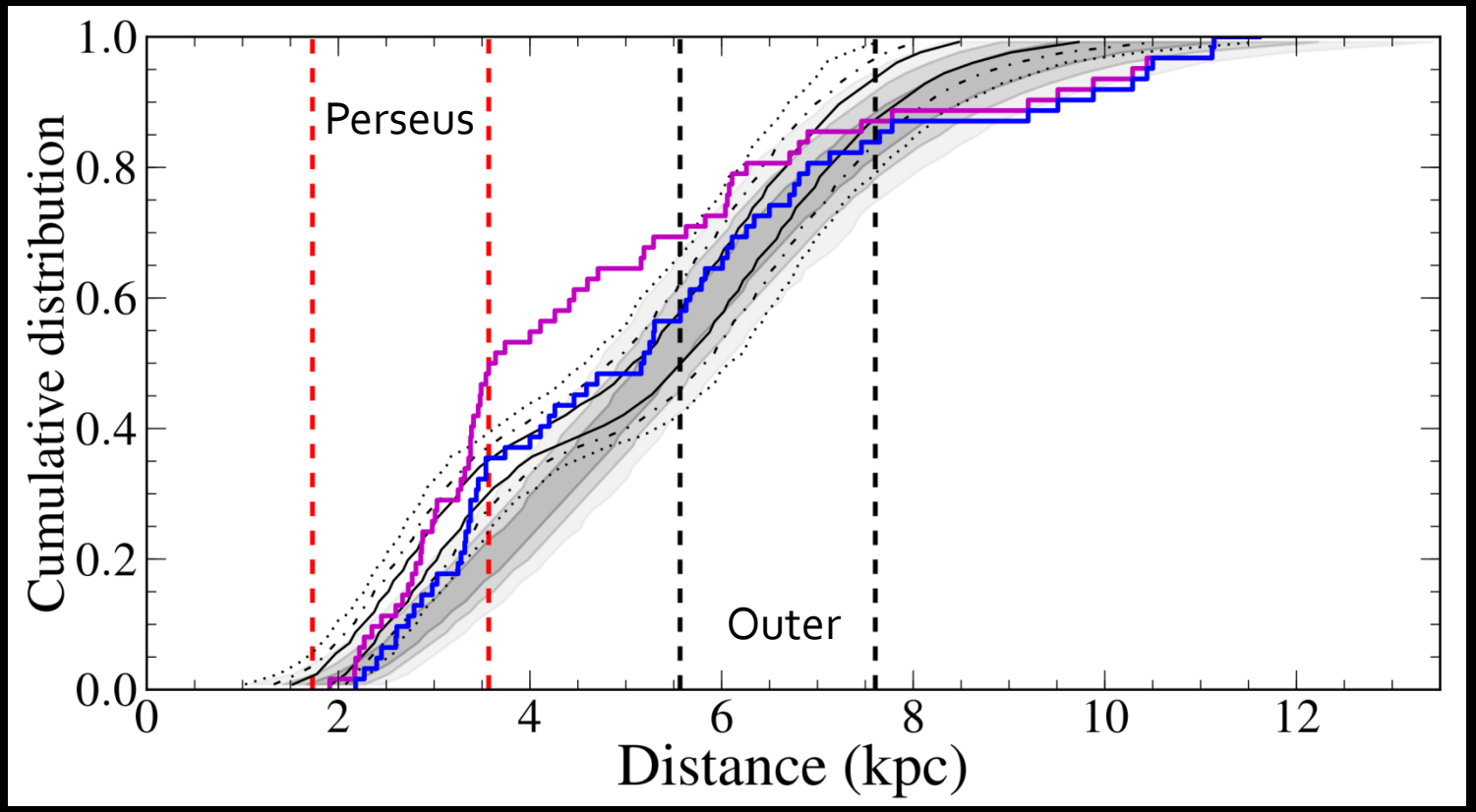
→To model and correct for optically-thin c'stellar disk emission

→ To obtain interstellar reddening (only)

→ To identify likely absolute magnitude/distance …until we have Gaia astrometry

Figure: SFD98 colour excesses, E(B-V), compared with 63 classical Be star reddenings in/behind Perseus Arm …consistent with their status





Do the 63 classical Be stars tell us anything distinctive yet?

…not at current error levels (more work to do):
Distances derived from them in blue; in grey/black simple simulations of e-folding distribution, and restricting them to Perseus and Outer Arms only

(ii) Densely sampled follow-up spectroscopy

→Selection of large numbers of ordinary stars according to type, e.g. A and F stars in the thin disk as potential kinematic tracers.

e.g. To test the Galactic rotation law outside the Solar Circle

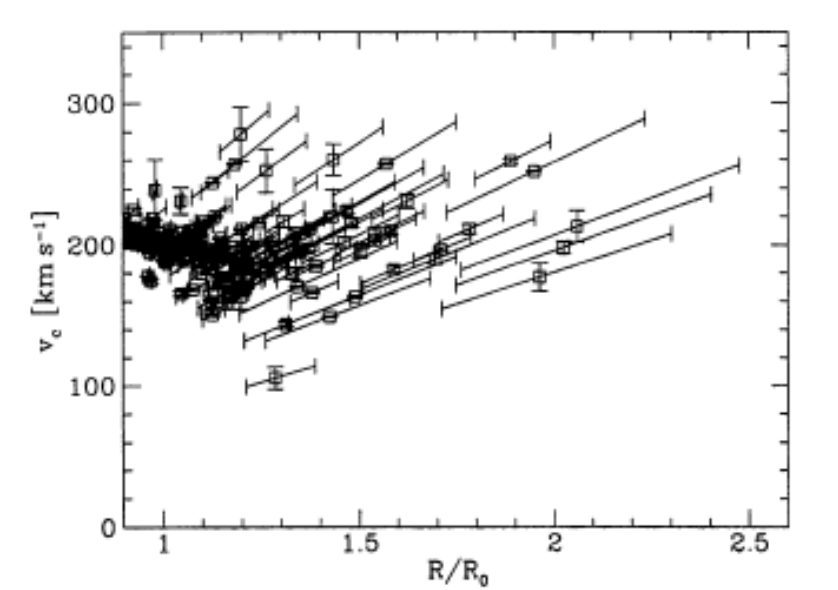


Figure 2. The same data as shown in Fig. 1 but with the effects of errors in W and d shown independently.

Left: Binney & Dehnen 1997 illustrated just how bad our grip on it is…

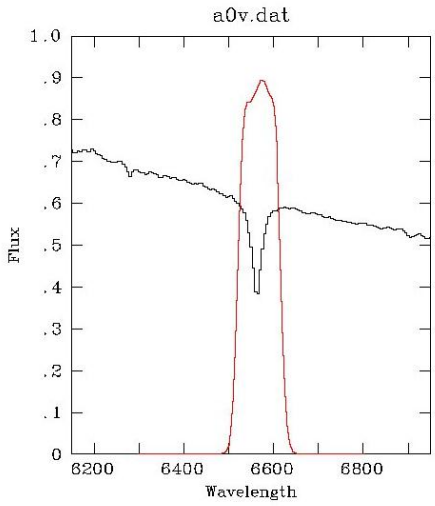
Challenge: to build suitable large samples of targets 5-10 kpc away, and measure their radial velocities.
How does distribution compare with forward modelling (simulation) of them?

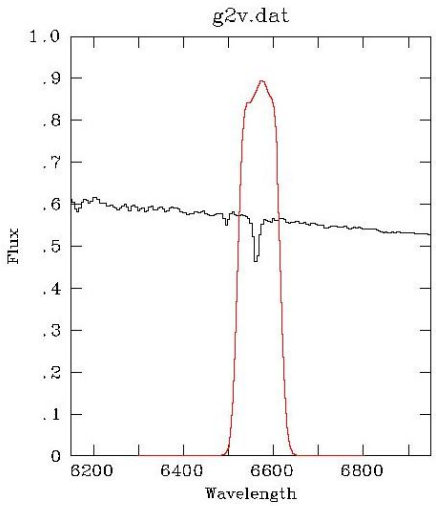
(Farnhill – part of PhD programme, using MMT/HectoSpec data)

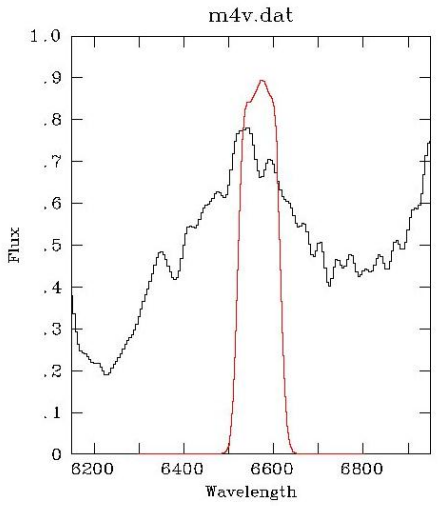
Hα – as a marker for stellar intrinsic colour:

r'-Hα as a colour 'excess' measured to - now routine - photometric accuracy (~0.03 mags)

→ *quantitative indicator of stellar intrinsic colour (~spectral type)*







A0V: r'-Hα = 0.00 G2V: r'-Hα = 0.23 M4V: r'-Hα = 0.89

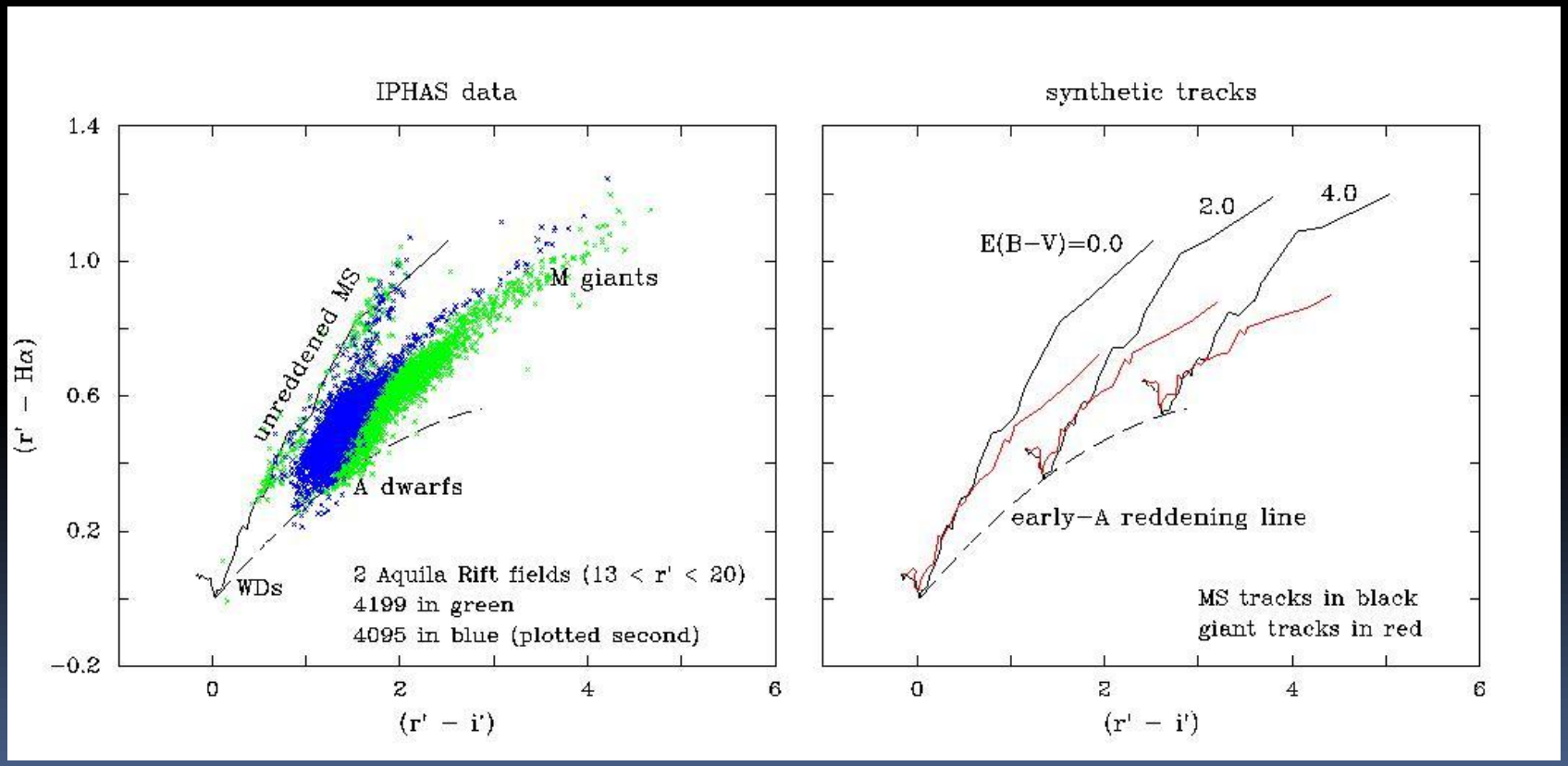
….and for nebulae (no continuum), r'-Hα ~ 3

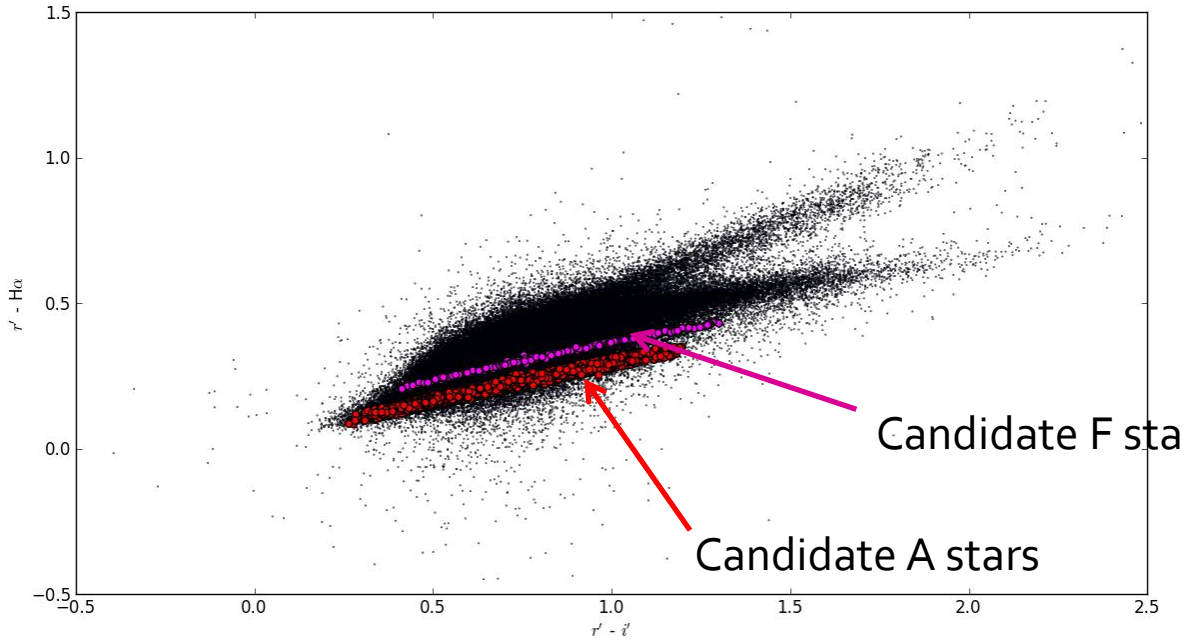
IPHAS/VPHAS+ (r-Hα, r-i) colour-colour diagram

r'-Hα is overwhelming sensitive to spectral type

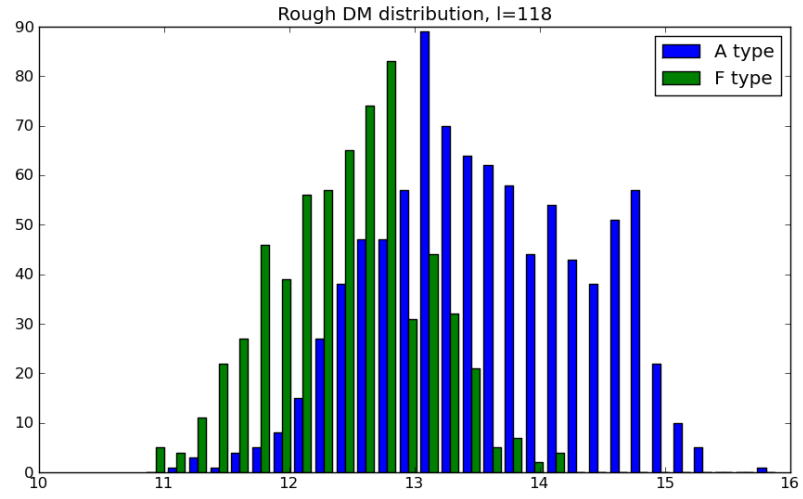
r'-i' carries a strong reddening dependence

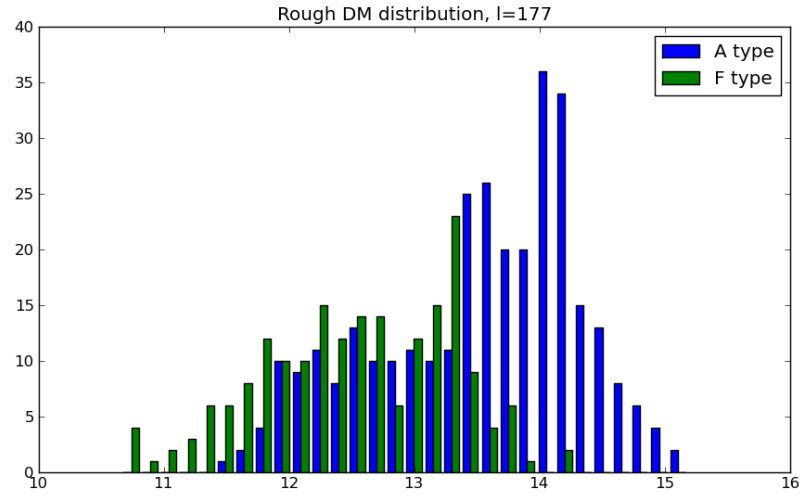
When combined: temperature sequences sweep out area as they are reddened
→ can assign (type, reddening) to each location in the colour-colour plane



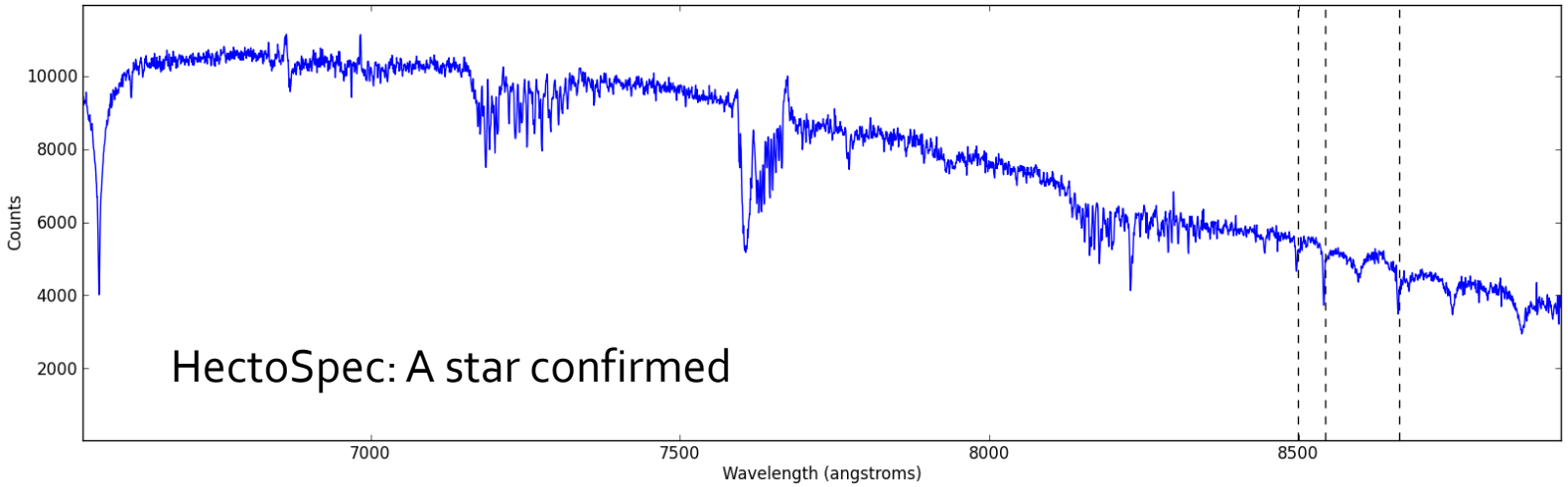


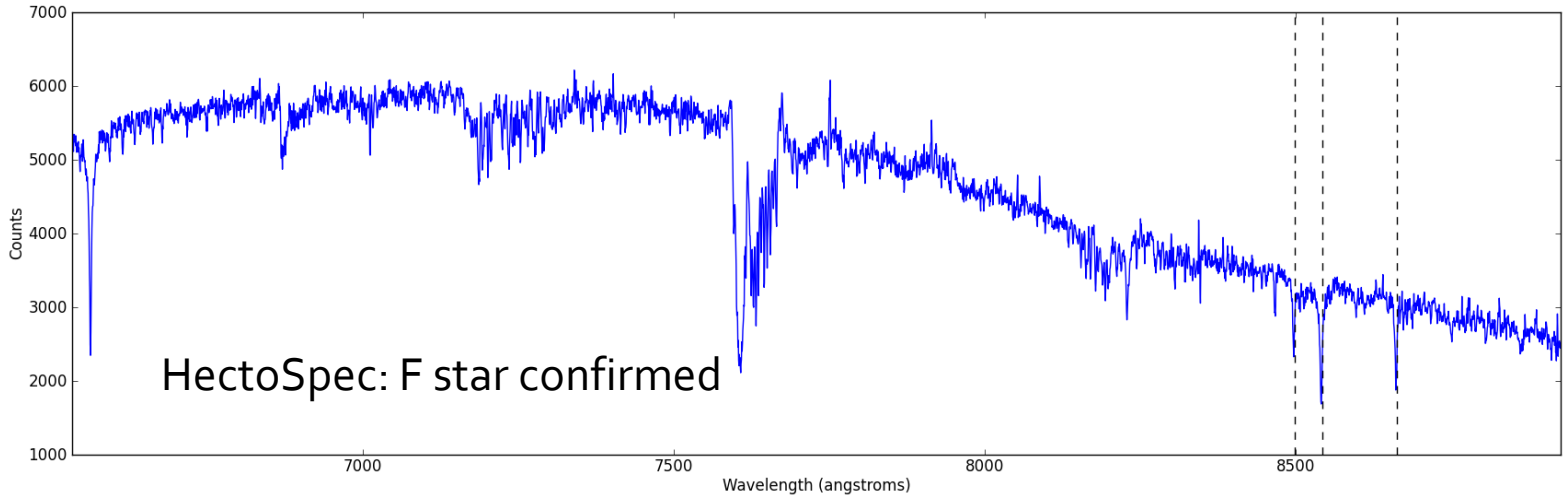
Putting this to use:
Selection from (r-i , r-Ha) CCD
→1500 A/F candidates at long. 118,
→500 A/F at long. 177 (control)
16.5 < i < 19.5
12 < DM < 15





So far – photometric selection shown to work…
Next: to type them all, correct for reddening, measure radial velocities… Do the science





In conclusion – the EGAPS surveys, IPHAS, UVEX and VPHAS+:

- The first optical digital ~1 arcsec resolution surveys of the entire Galactic Plane within |b| < 5 …and inner Bulge
  - compiling u,g,r,i broadband information, enhanced by narrowband Hα, for point sources to 20th magnitude.
  - → updating inventory of Hα emission line stars – young, evolved and massive – in the Milky Way disk (10-20000 objects)
  - → opportunities to select more incisively for stellar intrinsic colour
  - → can bring the wide field to bear on star-cluster studies
  - → a significant complementary resource for the Gaia revolution coming

Thank You

RCW38 (u,g,Ha) by VPHAS+/H Farnhill