Deep searches for early-type stars in the Galactic Plane

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The previous talks this session → why massive stars are scientifically important

Here:

- how optically-based spectroscopy following up optical photometry across the wide field finds and characterises them
  - $H\alpha$ excess → the emission line population
  - blue excess → the non-emission stars

- some words on using these intrinsically-luminous stars to open up the 3D Galactic ISM on a grand scale
Source materials: the EGAPS surveys to ~20th magnitude, ~1” resolution

The Northern Galactic Plane, \(-5^\circ < b < +5^\circ\)

**IPHAS**: \(r,i,H \alpha\), INT since 2003

- survey description – Drew et al 2005
- DR2 on Vizier and iphas.org – Barentsen et al 2014
- 3D extinction map – Sale et al 2014
- deep \(r,i\) star counts – Farnhill et al, in prep

**UVEX**: \(u,g,r\), INT since 2006

- survey description – Groot et al 2009

The Southern Galactic Plane, and Bulge

**VPHAS+**: \(u,g,r,i,H \alpha\), VST since 2012

- survey description – Drew et al 2014

![Source materials: the EGAPS surveys to ~20th magnitude, ~1” resolution](image)
1. Emission Line Stars

Emission line stars towards Perseus Arm ($120^\circ < l < 140^\circ$) – Raddi et al 2015
Emission line stars in the northern Plane:

Automatic selection based on \( r' - \text{H\alpha} \) ‘excess’, with \( 13 < r' < 19.5 \)

4853 objects \( \text{(from Witham et al 2008)} \)

→ FAST spectrum of every listed object to \( r \sim 16.5 \)

→ Around 70% are classical Be stars
BCD classification system

- Developed by Barbier, Chalonge & Divan from early 1940s
- Uses measures of the Balmer discontinuity (BD) near 3700 Å
- Shape/contrast of BD depends on spectral type and luminosity class

...now automated.
**BCD classification system**

The basic parameters that describe the energy around BD are:

- **D**, the Balmer jump depth (dex), an effective temperature indicator.
- **λ1**, the average position of the BD, given as the difference λ1-3700Å, very sensitive to log g.
- **φb**, the color gradient, which is the continuum near the BD.
- **φuv**, the slope of the Balmer continuum.

![Graph showing relation between D and Duv](image)

![Graph showing spectral lines comparison](image)
BCD classification system

Each star is defined by a unique point $(D, \lambda_1, \phi_0)$.

- The normal stars are near the $\Sigma$ surface.
- Metal-poor stars are behind the $\Sigma$ surface.
- Metal-rich stars are in front of the $\Sigma$ surface.

(Chalonge & Divan 1973)
Northern Plane distance mapping of brighter CBe (using automated BCD spectroscopic parallax)

IPHAS-selected CBe stars to r ~16.5:
- from Gkouvelis et al in prep.
- from Raddi et al 2013, 2015

(Triangles are masers)
2. Non-emission line OB stars

(W26 in Westerlund 1, Wright et al 2014)
A trial of VPHAS+ photometry in the Carina Arm:

First step: select candidate O/early-B stars from the u-g, g-r diagram, above B3 reddening line:

(AAOmega targets, on VPHAS+ Hα image)
Optical diagrams

NIR diagrams

Optical colours pin down O/early B types well – even in the field
Second: fit $u,g,r,i,J,H,K \rightarrow$ OB status gains support
\[ \rightarrow \text{measure extinction parameters, } A_0 \text{ and } R_V, \text{ well} \]

\[ \chi^2 = 5.60 \]

\[ \log(T_{\text{eff}}) = 4.49^{+0.11}_{-0.07} \]

\[ A_0 = 6.82^{+0.08}_{-0.10} \]

\[ R_V = 3.72^{+0.06}_{-0.06} \]

\[ \mu = 12.02^{+1.24}_{-0.75} \]
As near-Rayleigh-Jeans objects in the optical:

O and early-OB OIR SEDs – very weakly dependent on effective temperature

→ O/early-B SEDs are favoured for probing extinction laws.

→ grip on extinction gets **even tighter** if stellar parameters are measured separately via spectroscopy (see e.g. Maiz-Apellaniz et al 2014)

*Right: VPHAS+/Carina Arm OB-star parameter errors: ΔA₀ and ΔRᵥ < 0.1*
Third step – take spectra, and determine success rate

Results of AAOmega trial: very high conversion rate – poorer fit sources (right panel) still scientifically interesting!
Top: blue spectrum (AAOmega 580V, R = 1300) $\rightarrow$ O7V-III
Bottom: CaT region (AAOmega 1700D, R = 10000) ...less informative

8620Å DIB, 5% depth, EW 0.25Å, approx $\rightarrow A_0 < 3$, well below 6.8
The Milky Way’s r >14 OB stars from EGAPS surveys:

A. Wide-field spectroscopic follow-up can confirm and characterise early type stars to $A_0 \sim 9$

→ numbers of optically-accessible undiscovered O and (all) B stars, from 14th to 19th mag exceed 0.5 million

- R=5000 optical spectroscopy → well-suited to measuring key stellar parameters, kinematics
- no bias to detection in clusters → settle the in-situ/runaway debates ...true relation to spiral arm shocks (and other MW structures)
- well-positioned, and needs to exploit Gaia astrometry from 2017

B. ...fabulous resource to inform 3D ISM models to 5-10kpc distances across the Galactic Plane

- stellar parameters → to better exploit photometric fitting
- wealth of detected interstellar absorption features
- with relative flux calibration ...even more power to delineate extinction law variety
Thank You