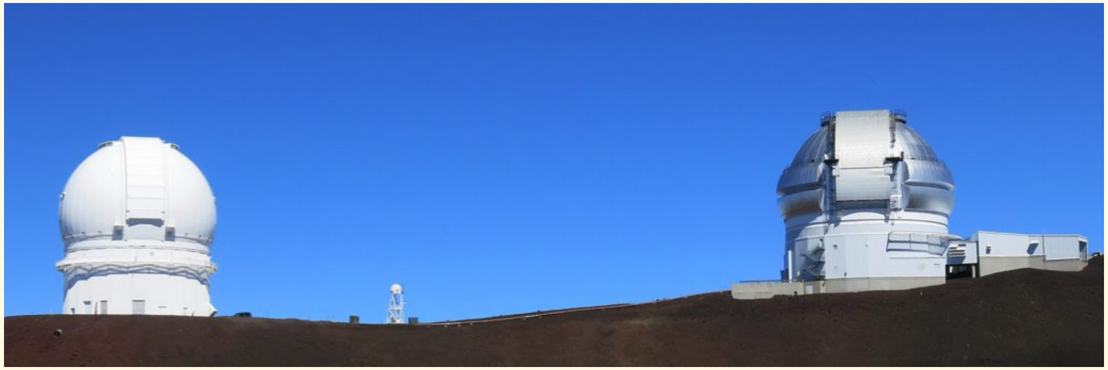
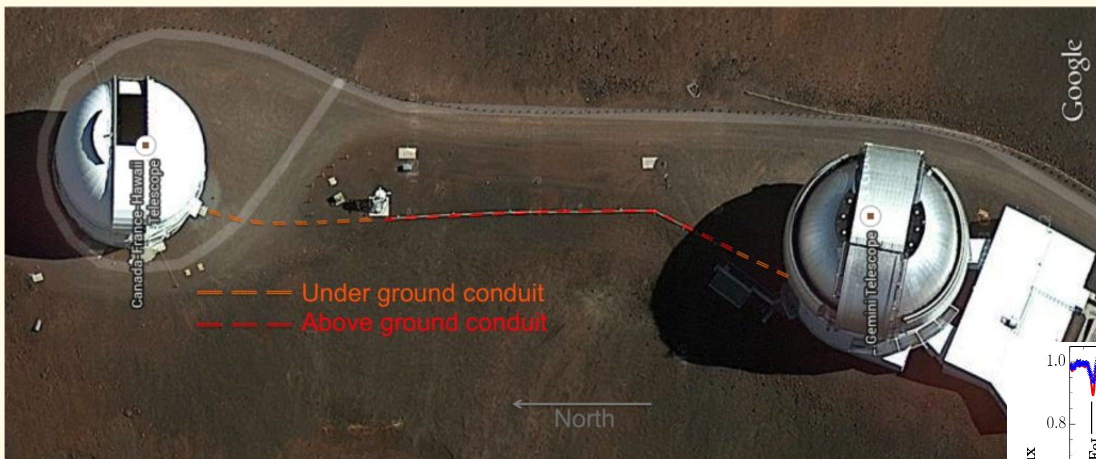
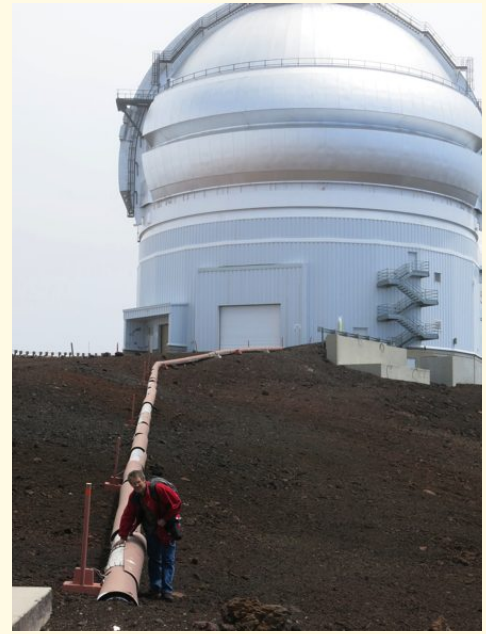
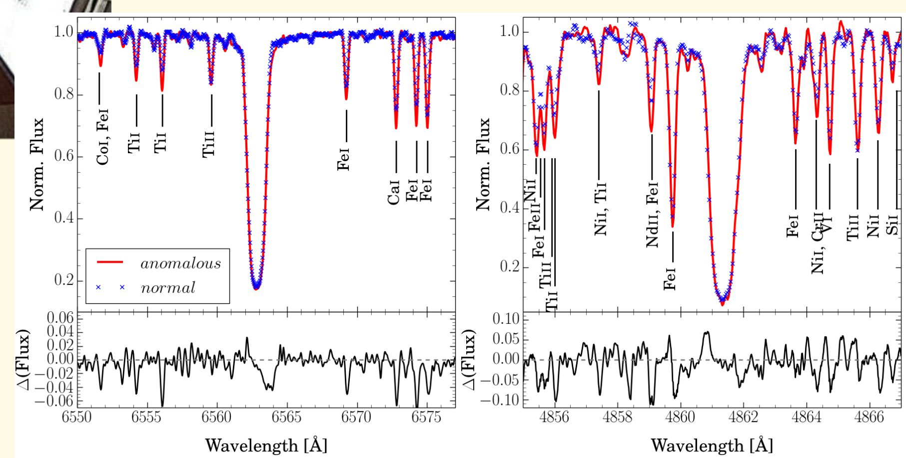
Science from the optical spectrograph GRACES
(Gemini Remote Access to CFHT ESPaDOnS Spectrograph)



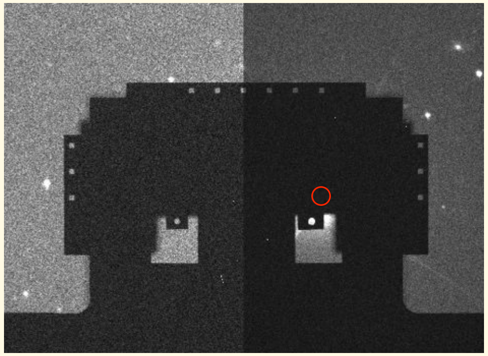


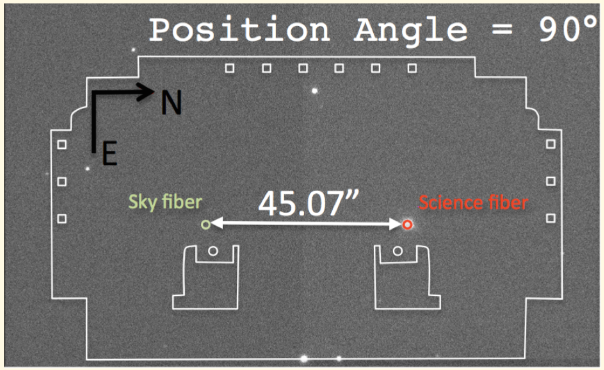


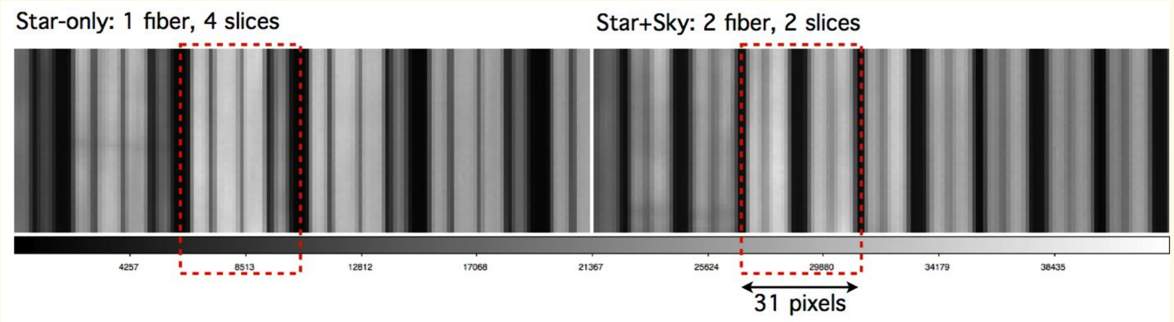


Jeff Carlin (LSST)

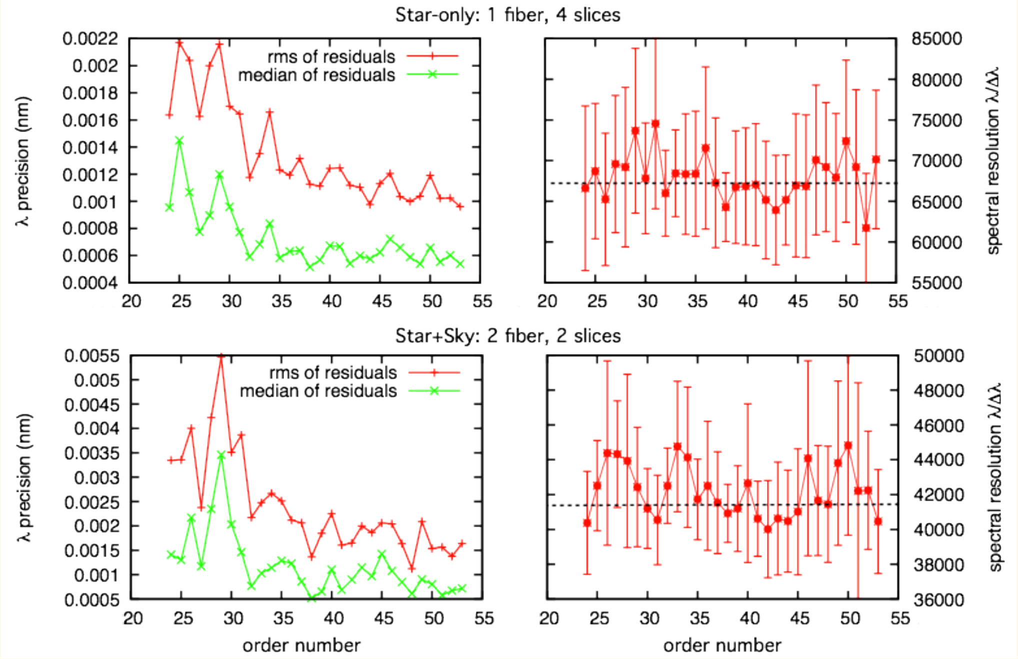
GRACES observing modes







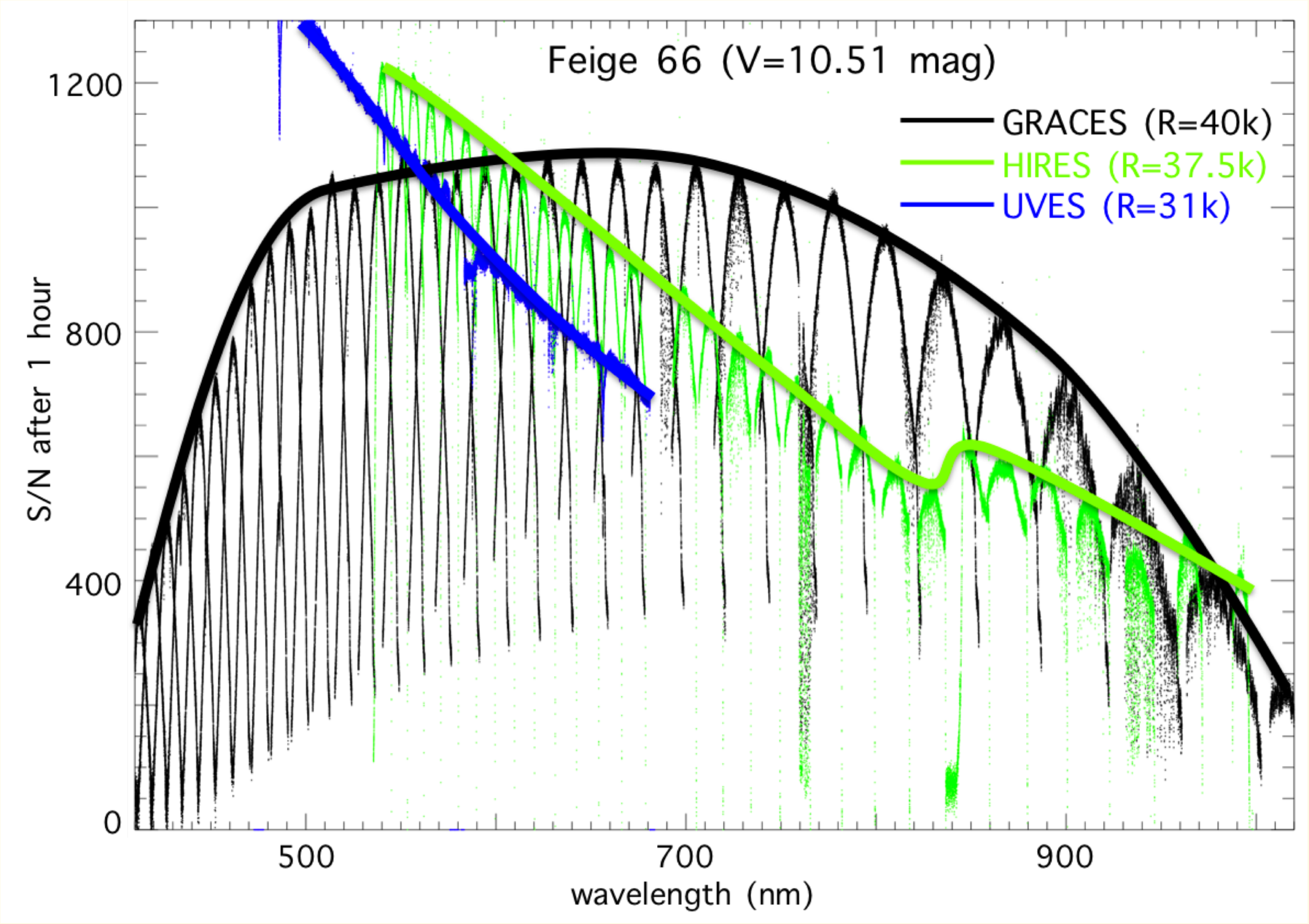
(Figures from Chené+2014)



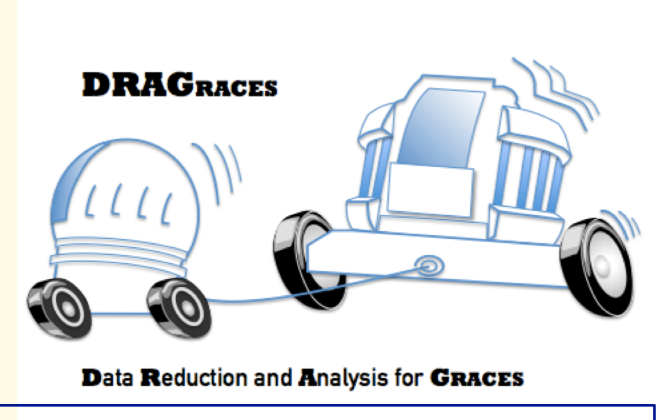
One fiber (object-only): R~67500

Two fiber (object+sky): R~40000

GRACES useful wavelength range: ~420-1010 nm; high sensitivity in the red



Data reduction:



OPERA - Open source Pipeline for ESPaDOnS Reduction and Analysis

OPERA:
CFHT-supported software (in C) for ESPaDOnS reduction.

Extracted 1D spectra output as multi-extension FITS files.

* OPERA-reduced spectra made available to users through the Gemini archive

http://www.cfht.hawaii.edu/en/projects/opera/

DRAGRACES:
IDL pipeline based on the Gemini quick-look tool.

Extracted 1D spectra output as multi-extension FITS files, with each echelle order in its own extension.

Support at Gemini Data Reduction User Forum: http://drforum.gemini.edu/

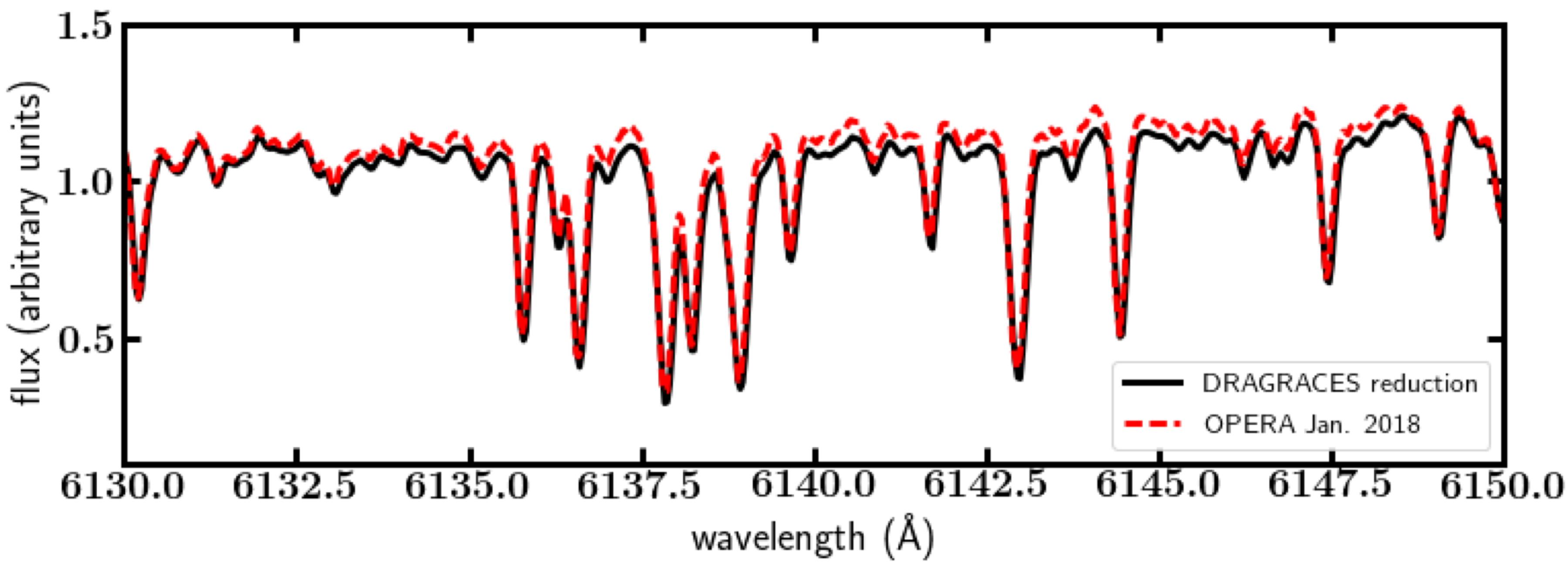
https://github.com/AndreNicolasChene/DRAGRACES

https://www.gemini.edu/sciops/instruments/graces/data-format-and-reduction/data-reduction

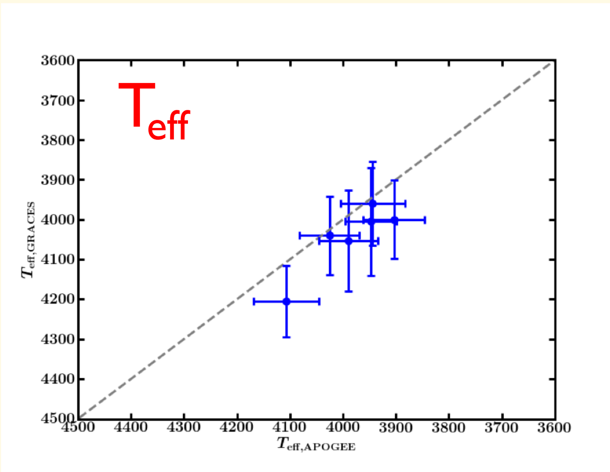
Data reduction comparison:

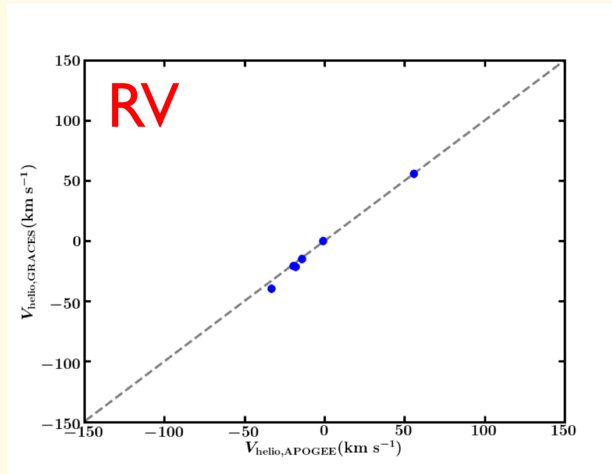
*** A comparison from early 2018 shows that once the kinks were worked out, the two pipelines produce nearly identical spectra. Thus **either pipeline should be sufficient for your science program**.

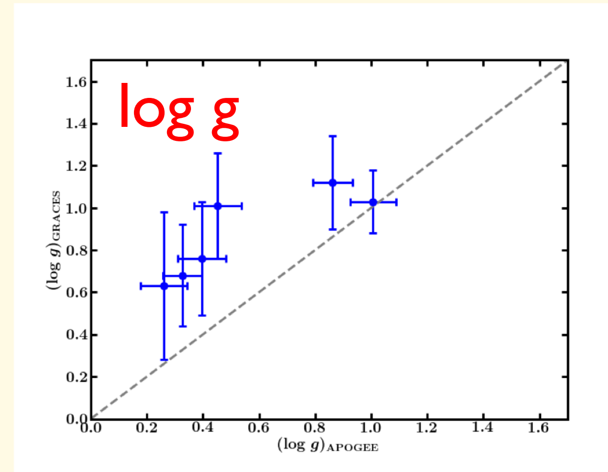
Spectrum of ν Vir from our 2016A program, extracted using both pipelines:

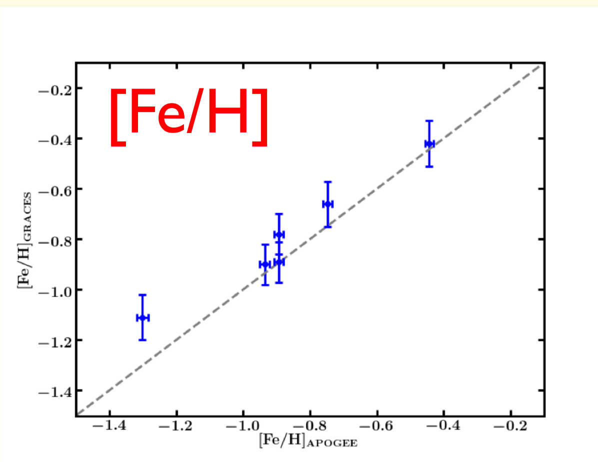


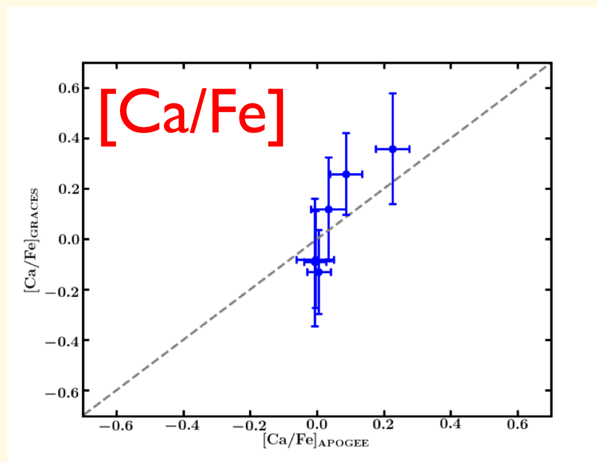
Validation via comparison to APOGEE:

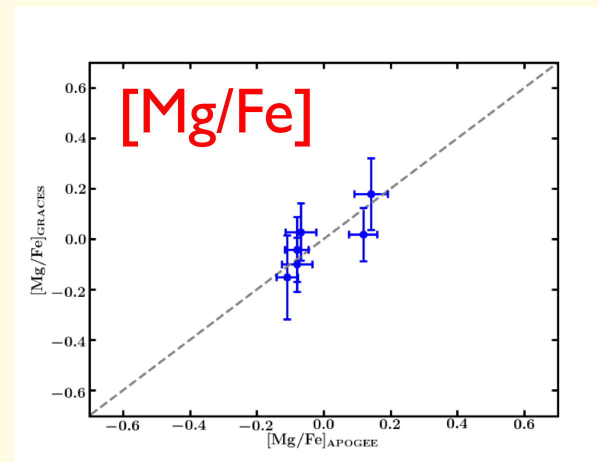












6 stars from our program (PI: Carlin, GN-2016A-Q-67) in APOGEE DR14. Our GRACES stellar parameters, abundances agree with APOGEE.

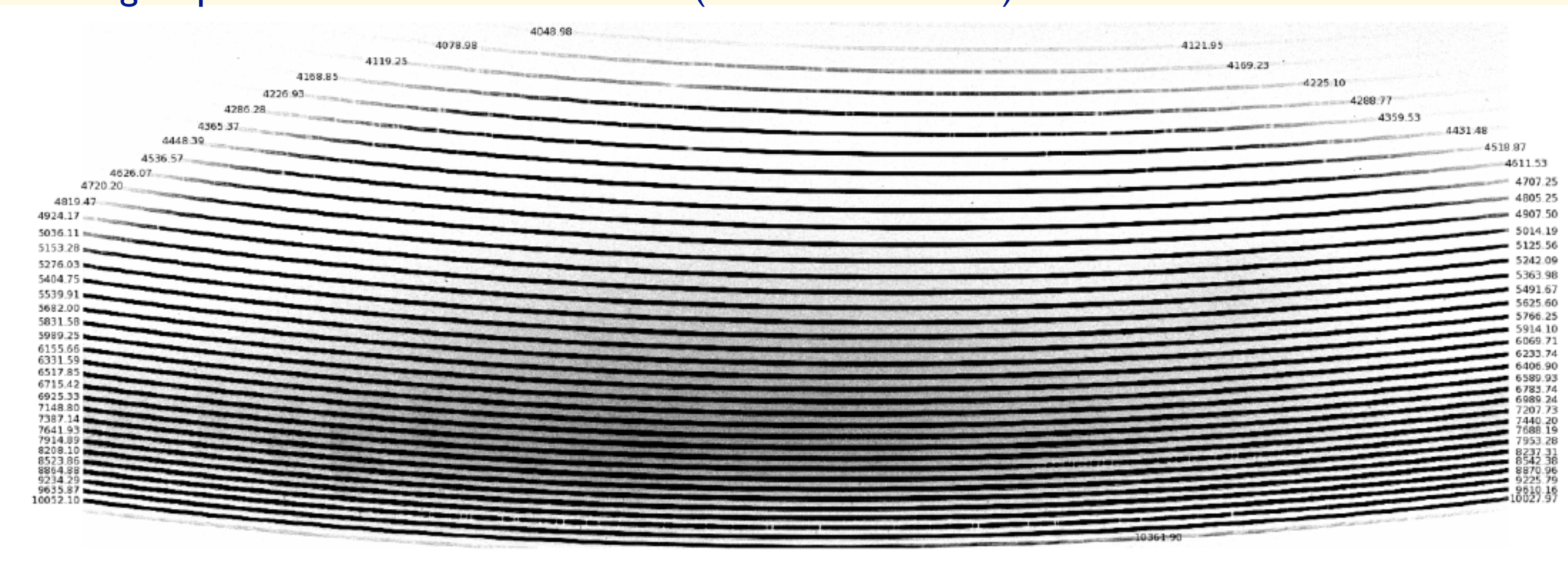
Science results from GRACES*

Elements with spectral lines in GRACES spectra:

alpha: O, Mg, Si, Ca, Ti (I & II)
Fe-peak: V, Cr, Mn, Co, Ni, Zn
Li, Cu

light/odd-Z: Na, Al, K
neutron-capture: Rb, Y, Zr, Ba, La, Eu, Nd
(both s- and r-process)

First light spectrum of A3 star HIP 57258 (from Chene+2014):

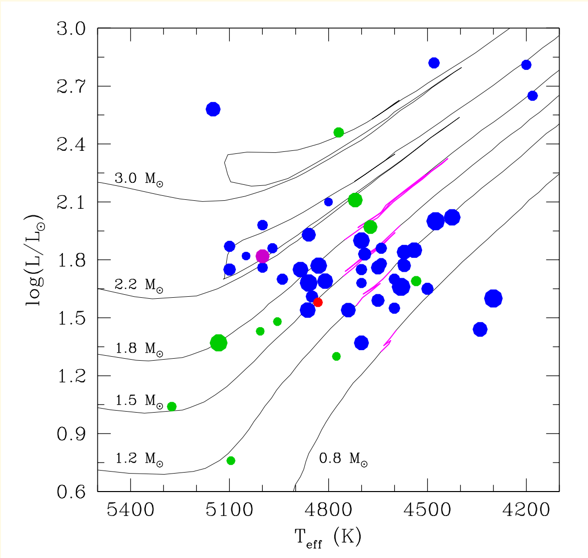


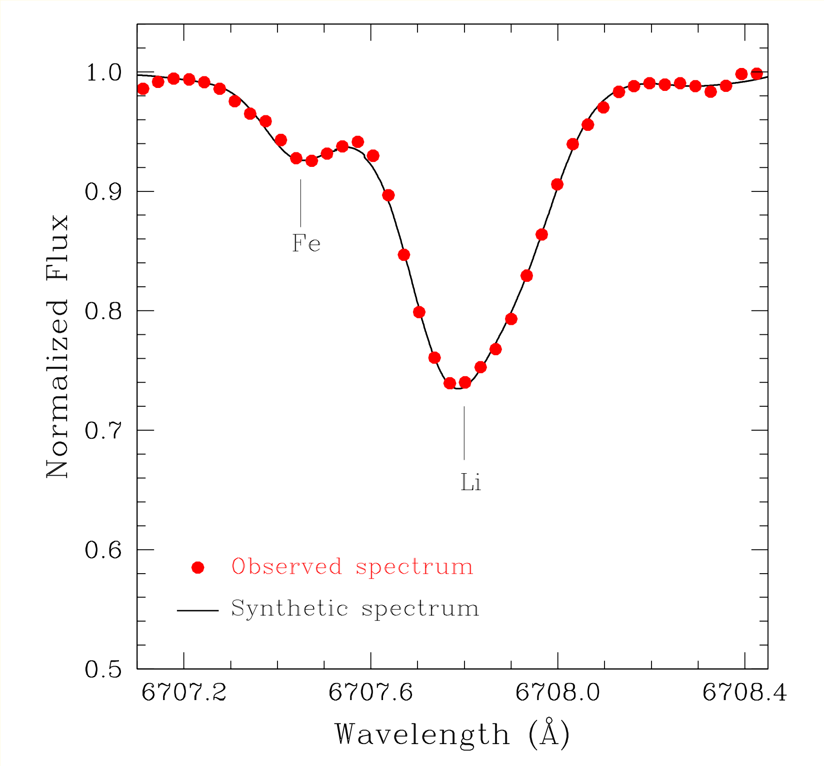
* Not a comprehensive list – apologies if I left out your favorite!

KIC 9821622: An interesting lithium-rich giant in the Kepler field (Jofre+2015, A&A 584, L3)

Early science target during on-sky testing

A(Li) = 1.80, high alpha ([α/Fe] = 0.31), enhanced Fe-peak, *r*-process → contamination by supernova ejecta?

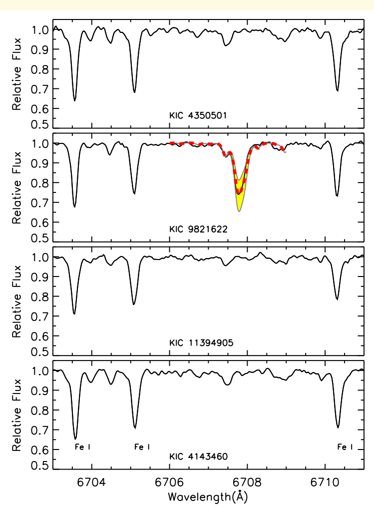


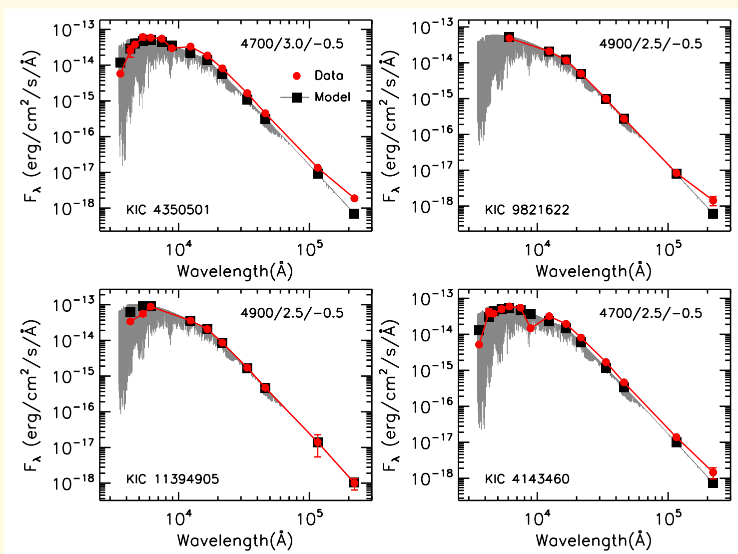


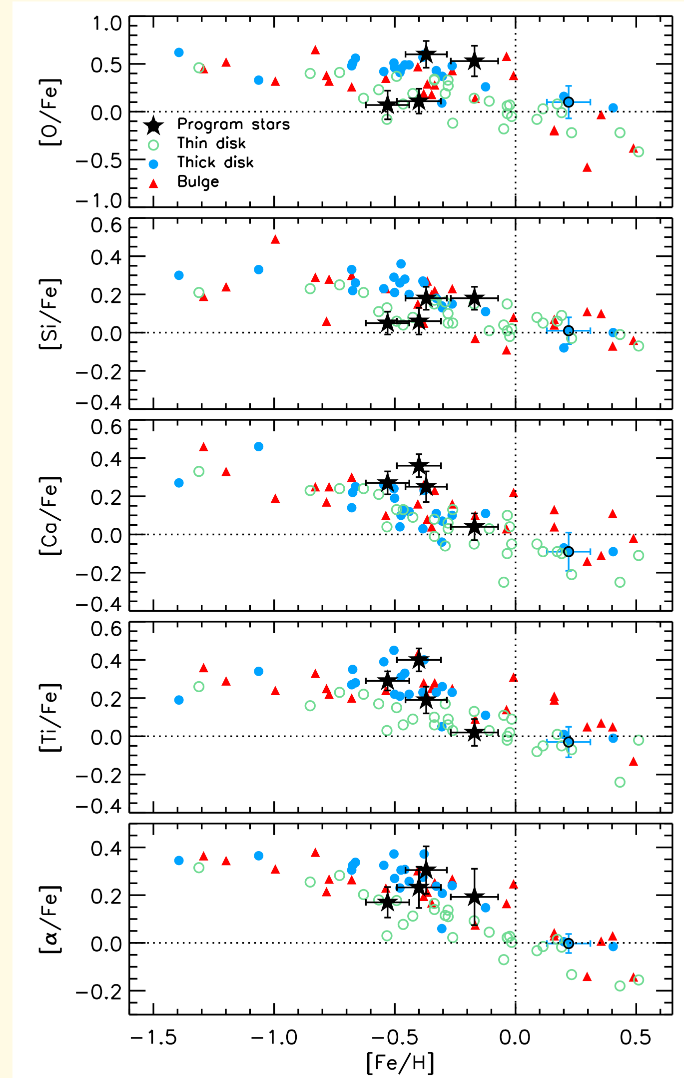
GRACES observations of young [α/Fe]-rich stars (Yong+2016, MNRAS, 459, 487)

4 massive, young (< 4 Gyr) stars with [α/Fe] > 0.2, suggested to be blue stragglers

Abundances look "normal", but IR excess in SEDs suggests possible binaries



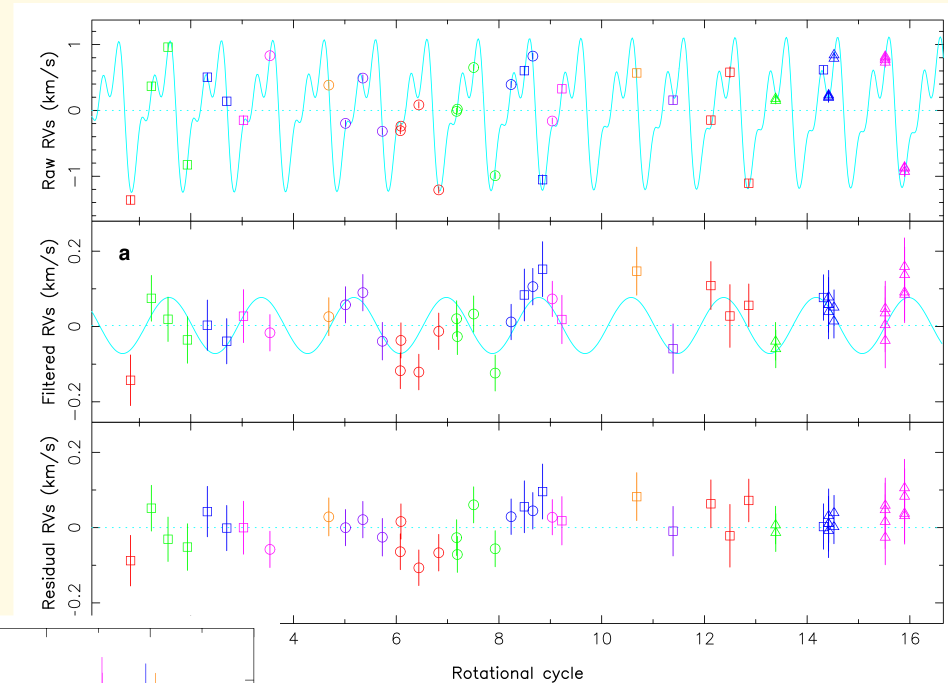


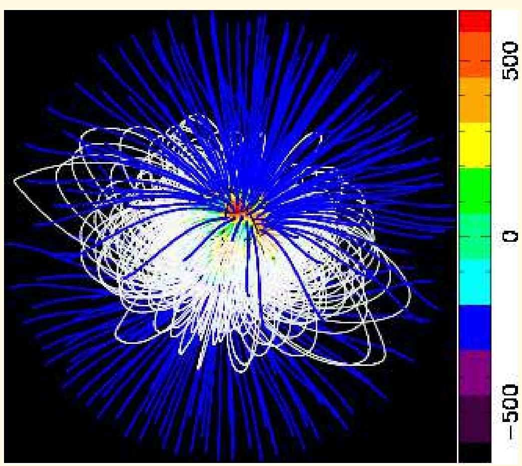


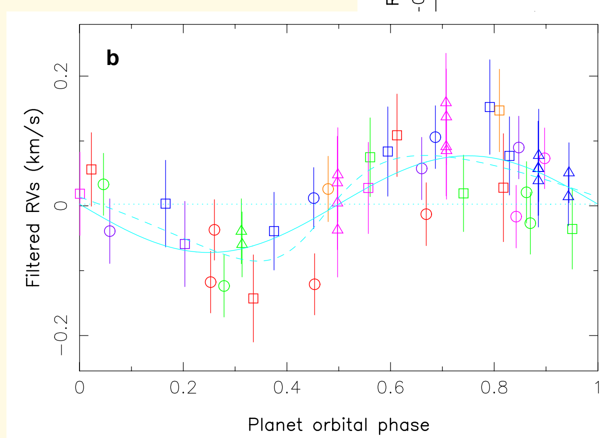
A hot Jupiter orbiting a 2-Myr-old solar-mass T Tauri star (Donati+2016, Nature, 534, 662; Donati+2017, MNRAS, 465, 3343)

21/75 RV epochs with GRACES, plus spectropolarimetry (ESPaDOnS, NARVAL) to measure magnetic activity

→ Hot Jupiters can migrate inwards over short timescales

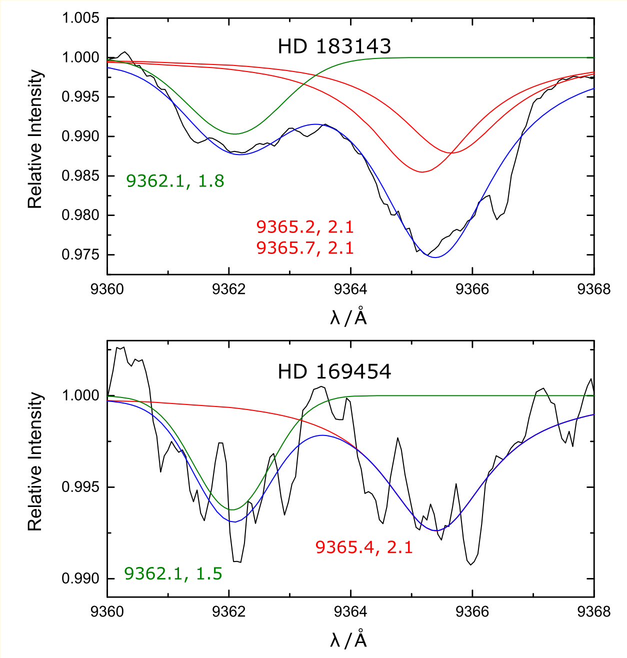


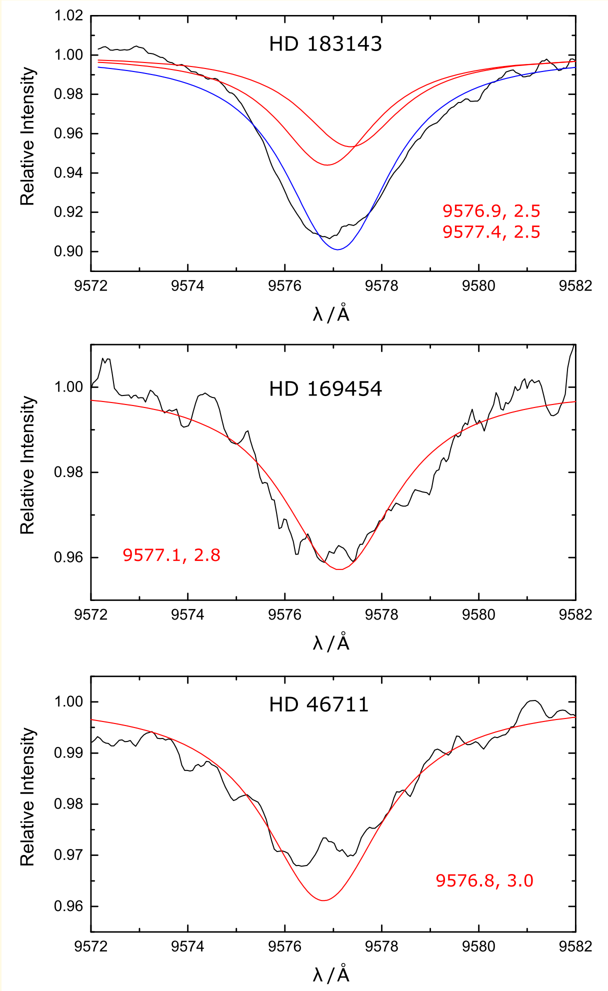




Gas-phase Absorptions of C60+: A New Comparison with Astronomical Measurements (Walker+2016, ApJ, 831, 130)

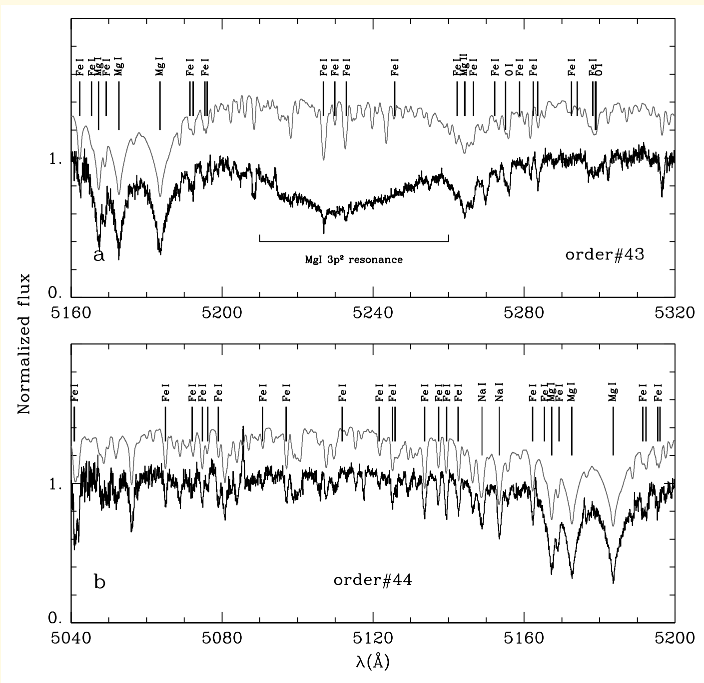
Lab measurements of DIB wavelengths confirmed in clouds along lines of sight toward bright stars

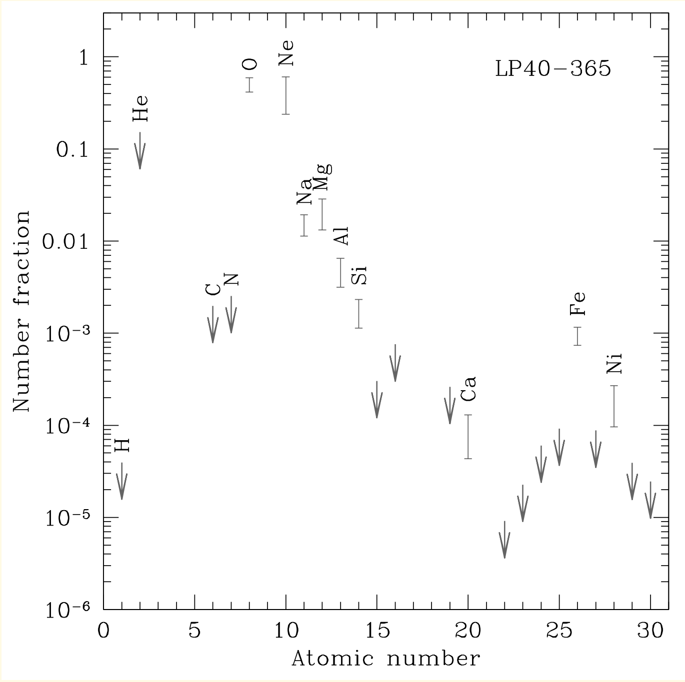


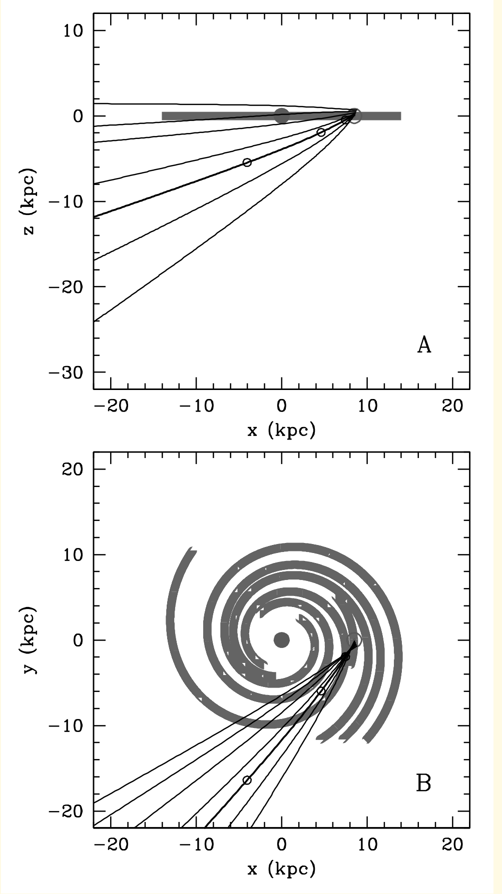


An unusual white dwarf star may be a surviving remnant of a subluminous Type Ia supernova (Vennes+2017, Science, 357, 680)

Hypervelocity WD with unusual abundances
→ a "partially burnt remnant" ejected in a type Iax SN event?



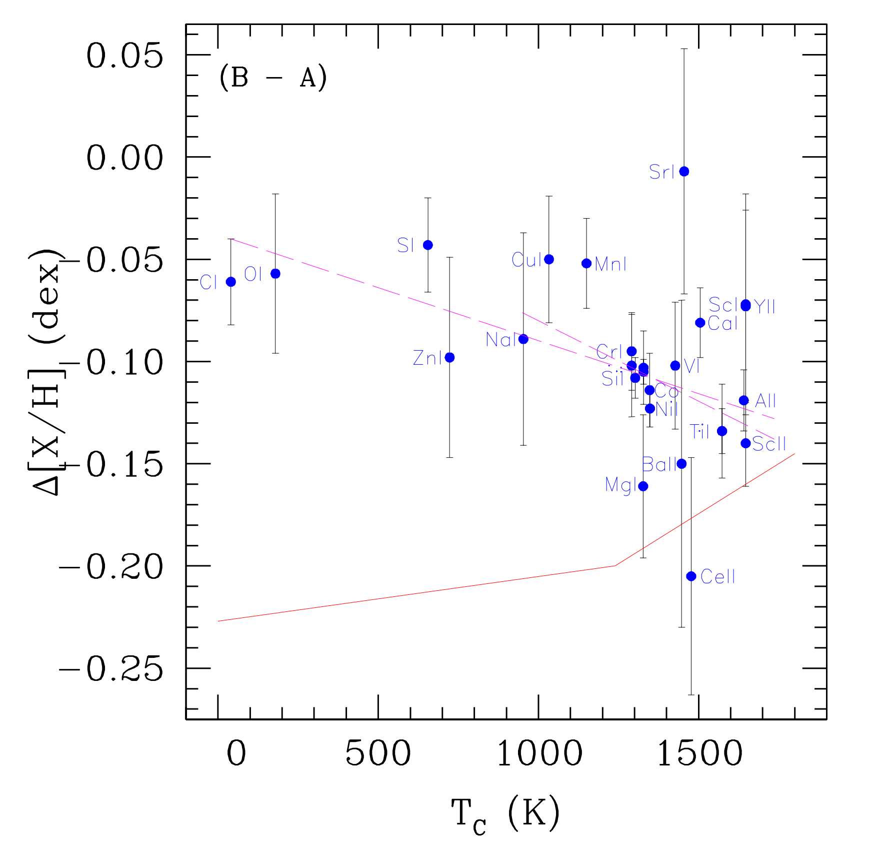


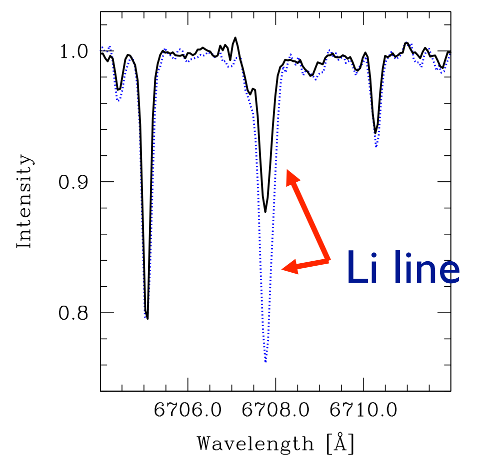


Signatures of rocky planet engulfment in HAT-P-4. Implications for chemical tagging studies (Saffe+2017, A&A, 604, 4)

HAT-P-4 is ~0.1 dex more metal-rich than its binary companion, with ~0.3 dex higher Li abundance

→ This, plus abundance trends with condensation temperature, suggests accretion of a giant planet



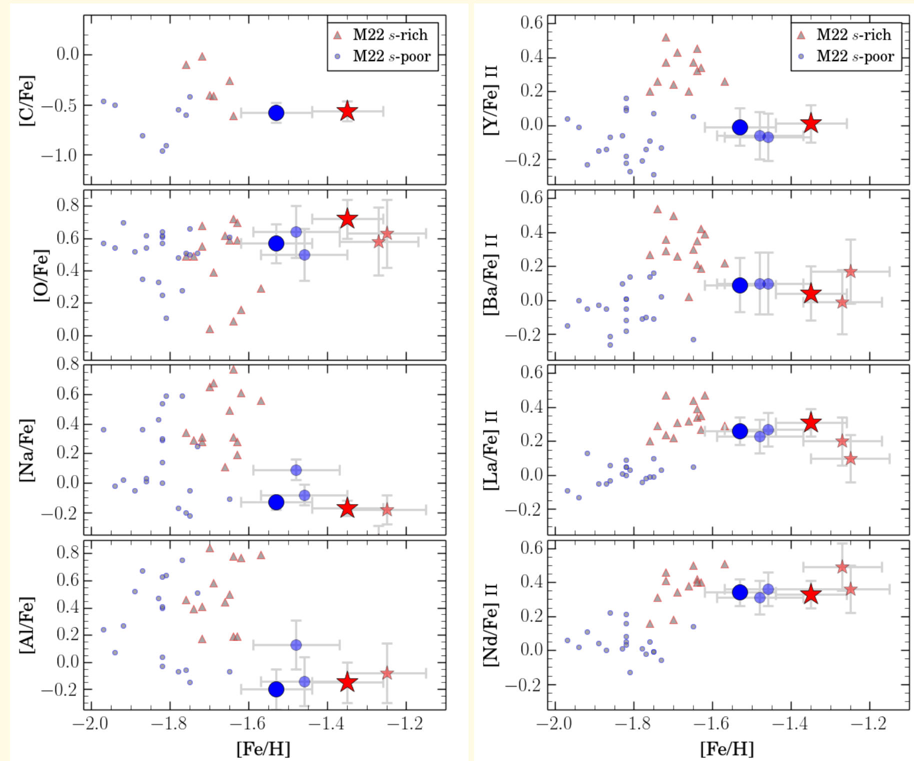


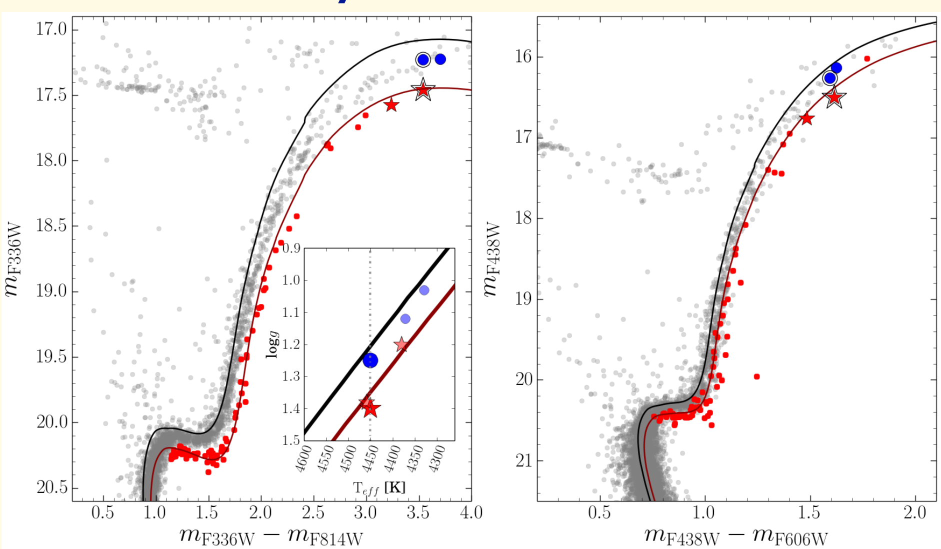
Metallicity Variations in the Type II Globular Cluster NGC 6934

(Marino+2018, ApJ, 859, 81)

Stars along anomalous RGB sequence are ~0.2 dex higher in [Fe/H] than the typical sequence, but no light-element (C, O, Na) variation

→ Metallicity variation in NGC 6934

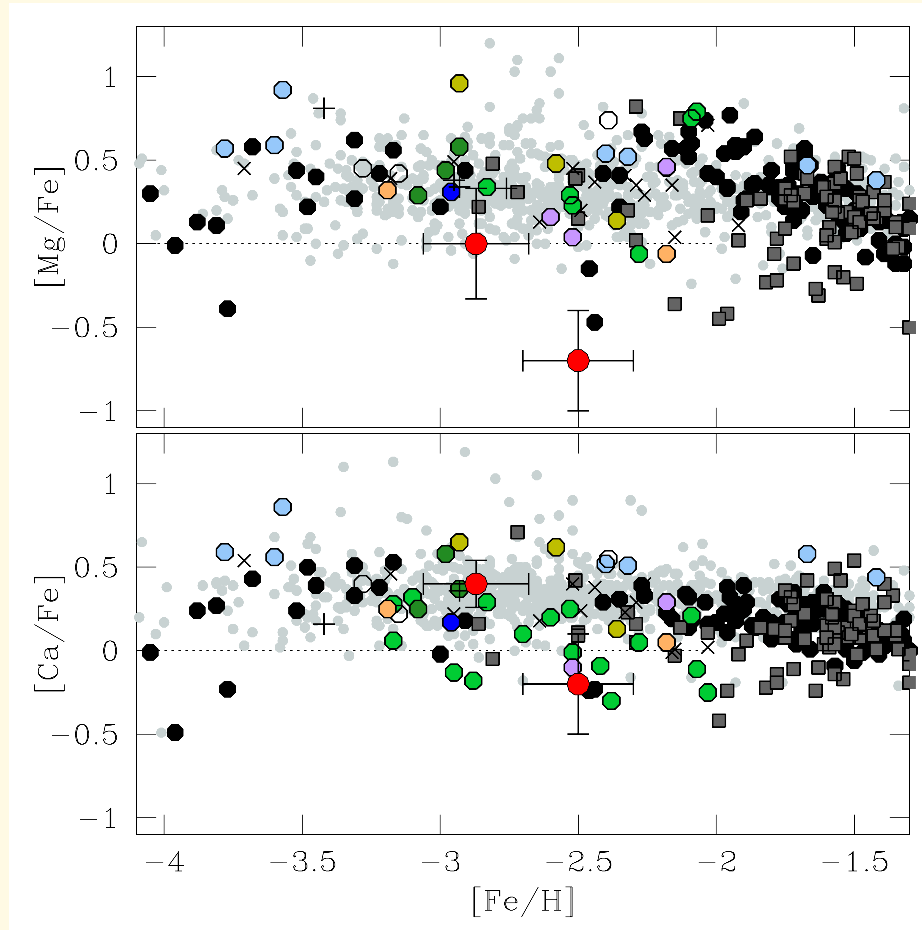


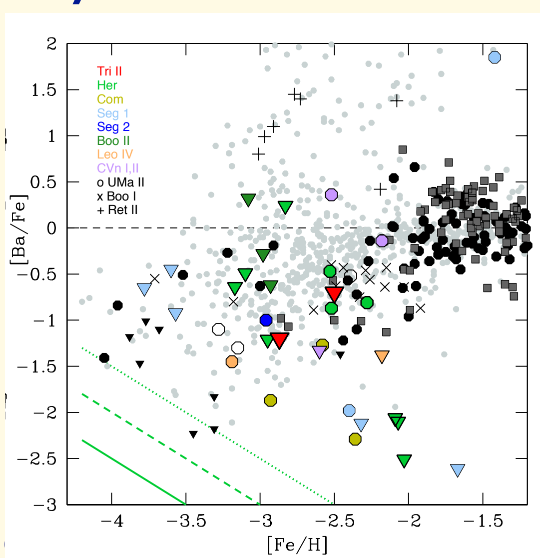


Gemini/GRACES spectroscopy of stars in Tri II (Venn+2017, MNRAS, 466, 3741)

Observed 2 stars (V=17.3, V=18.8), found Tri II has metallicity spread characteristic of dwarf galaxies

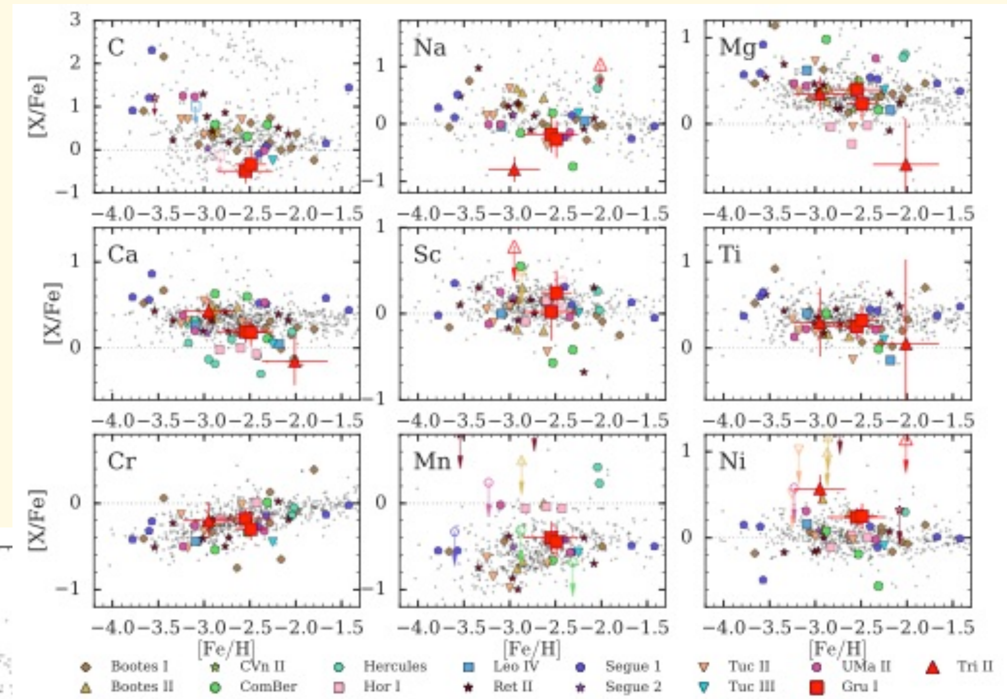
Ca abundances typical for dSphs, but Mg is low → inhomogeneous mixing or yields from few SNe?

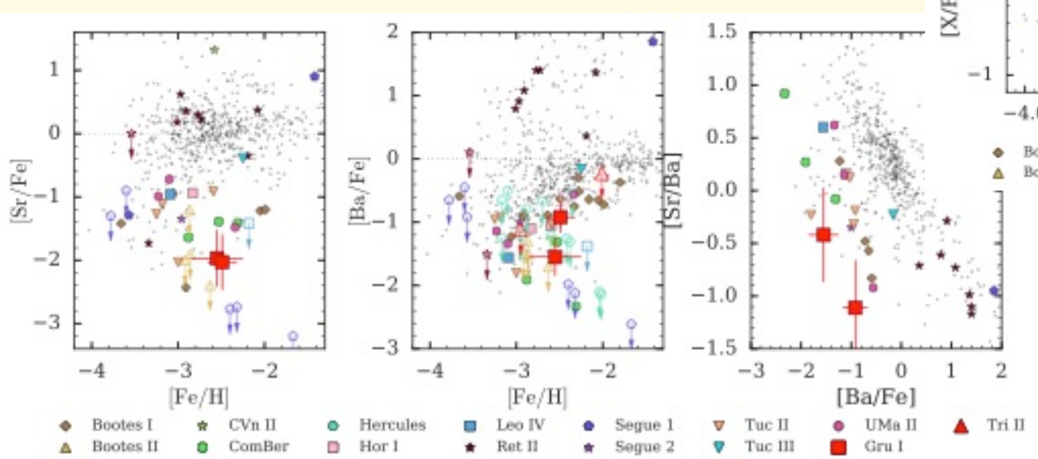




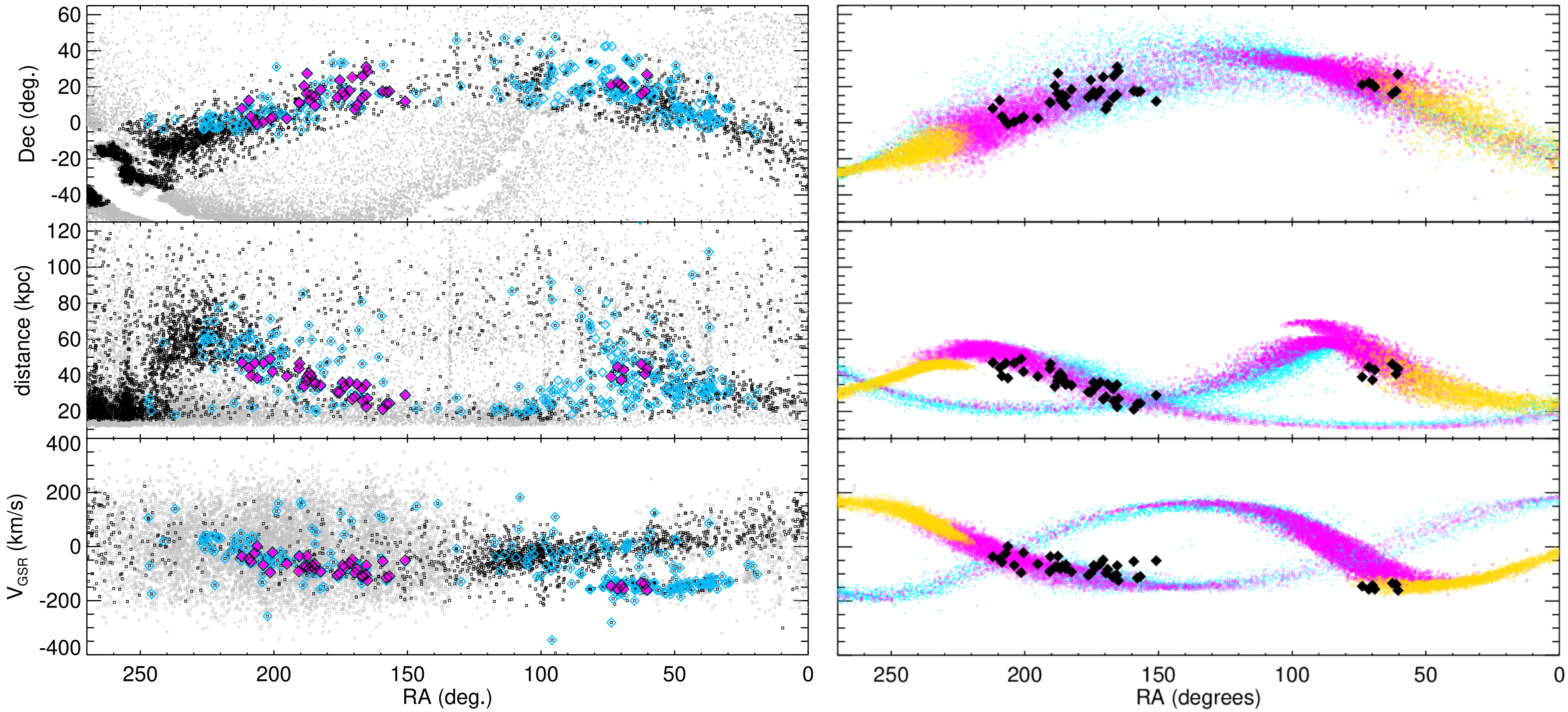
Chemical Abundances in the Ultra-Faint Dwarf Galaxies Grus I and Triangulum II: Neutron-Capture Elements as a Defining Feature of the Faintest Dwarfs (Ji+2018, ApJ, *accepted*, arXiv:1809.02182)

Both have low neutron-capture abundances. GCs are typically halo-like in neutron-capture elements → is the low abundance in dwarf galaxies a distinguishing feature?



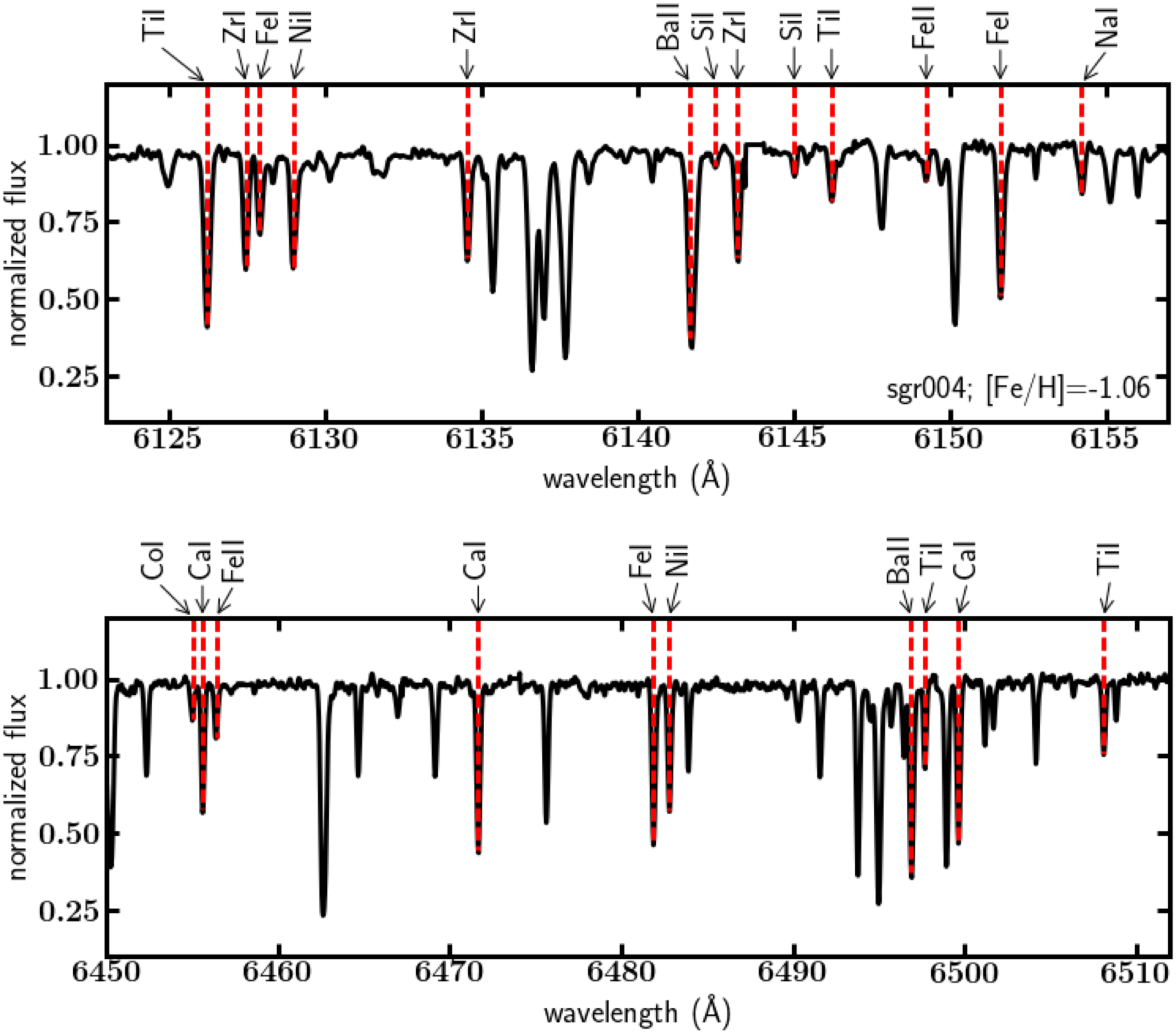


Sagittarius stream high-resolution spectra



Model: Law & Majewski (2010)

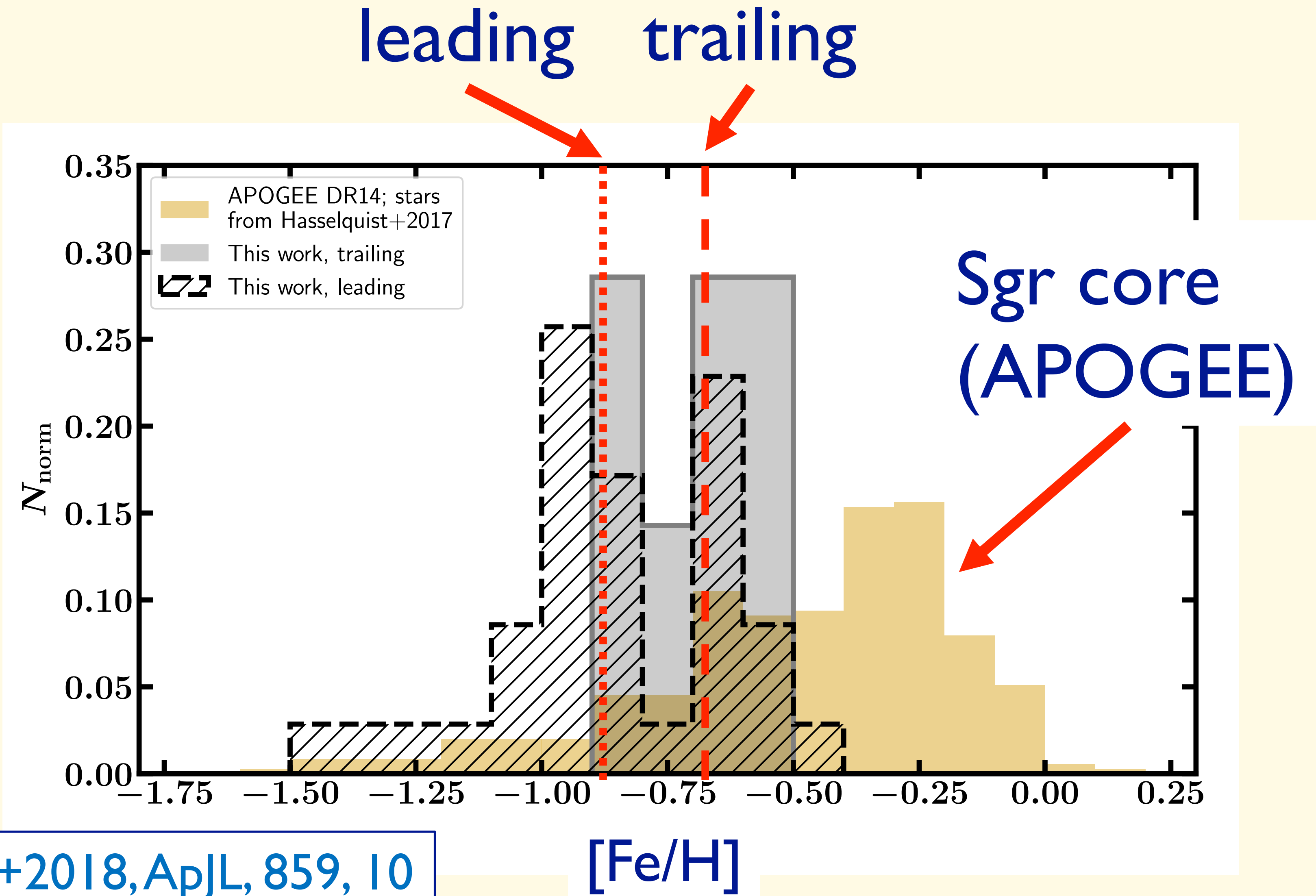
Gemini+GRACES (R~67,500) spectra of 42 LAMOST-selected Sagittarius M-giants (15.5<g<18.1; 11.2<K_S<12.6)



Example Gemini-GRACES spectrum

[Fe/H]=-1.06
T_{eff}=4225 K
log g = 1.03

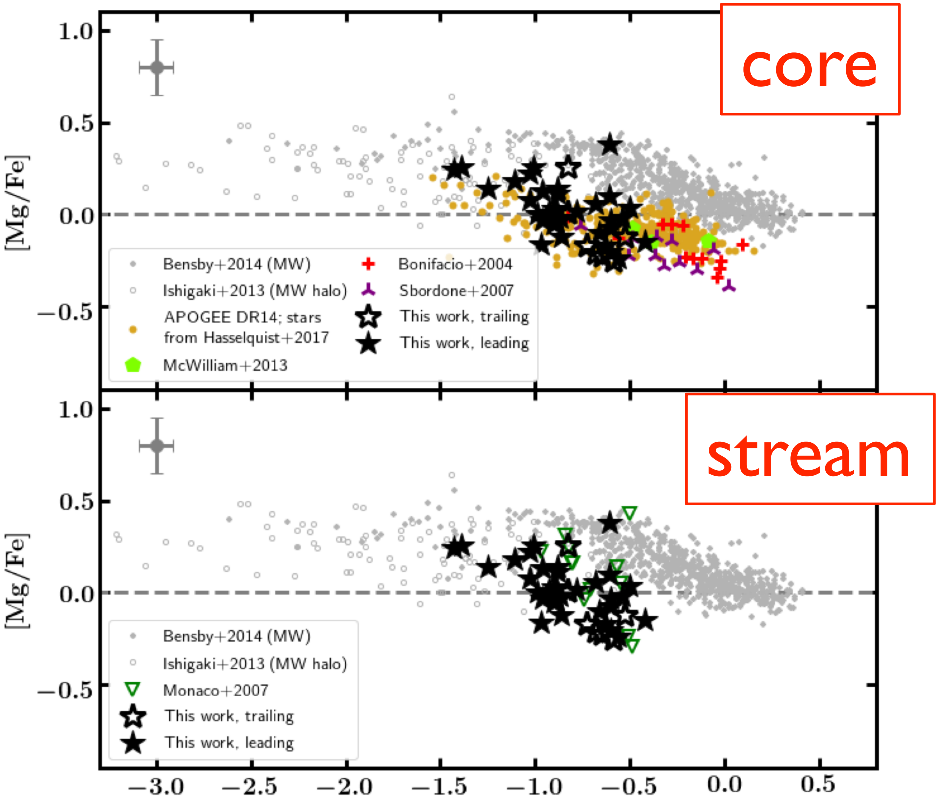
Metallicities from GRACES spectra – median [Fe/H] is lower in leading arm stars than in the trailing tail



Carlin+2018, ApJL, 859, 10

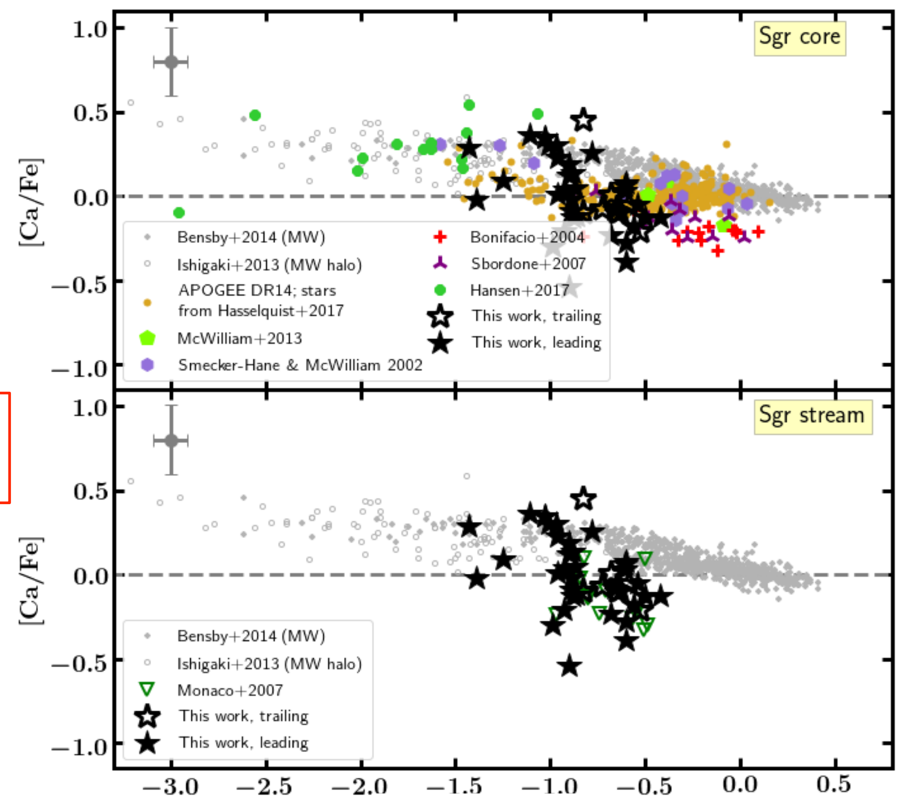
Alpha elements in the Sgr core vs. the stream

[Mg/Fe] vs. [Fe/H]



[Fe/H]

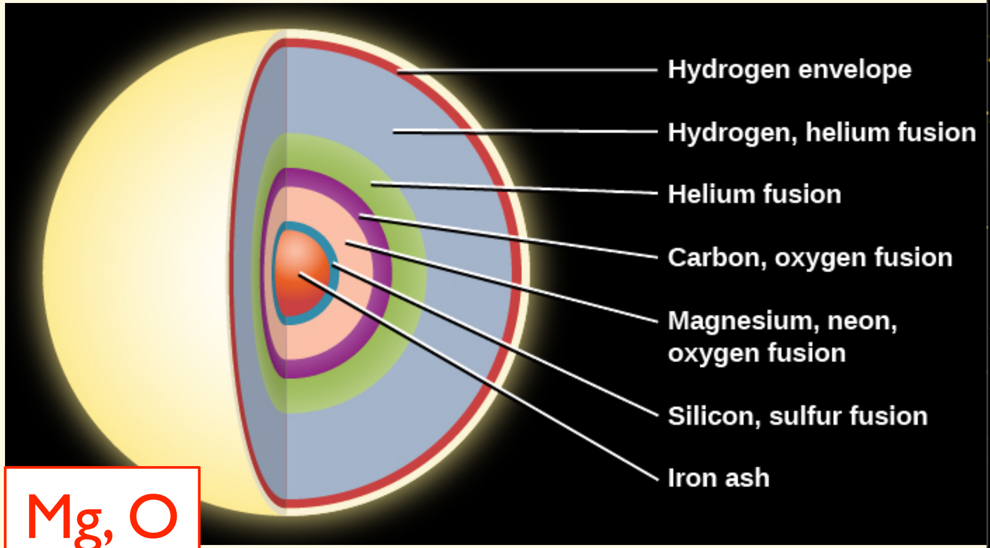
[Ca/Fe] vs. [Fe/H]



[Fe/H]

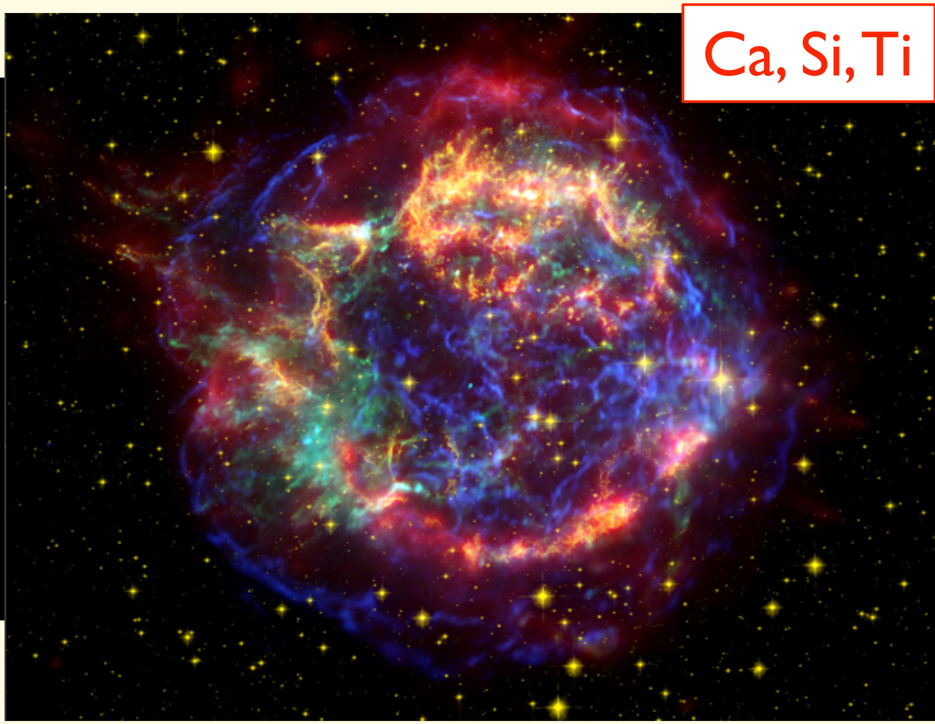
Not all alpha elements are the same: hydrostatic α-elements vs. explosive α-elements

hydrostatic



Mg, O

explosive

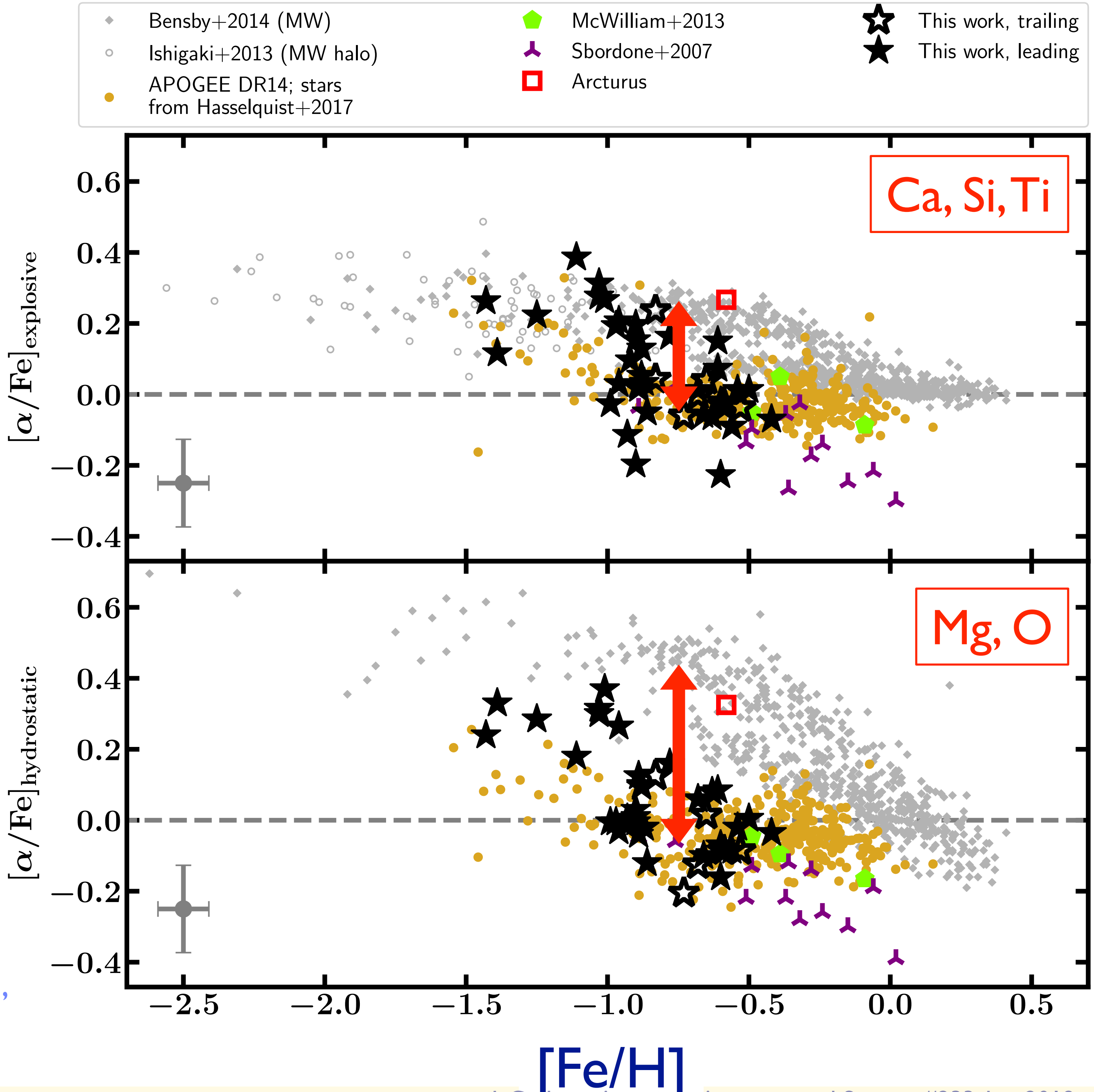


Ca, Si, Ti

explosive

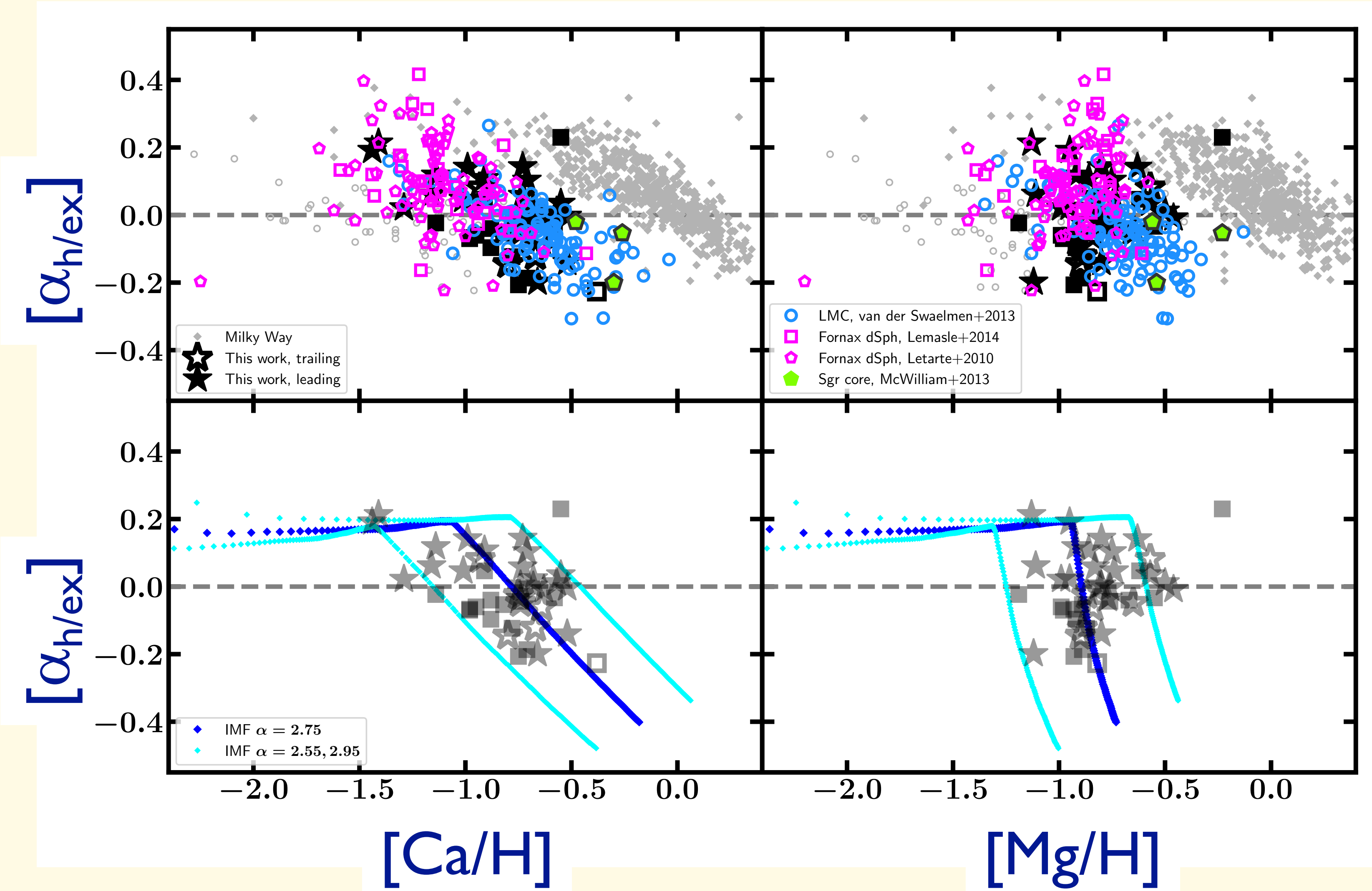
vs.

hydrostatic
α-elements



Following McWilliam+2013, ApJ, 778, 149

HEx ratio ([$\alpha_{hydrostatic}/\alpha_{explosive}$], or [$\alpha_{h/ex}$])



Blue: LMC

Magenta: Fornax

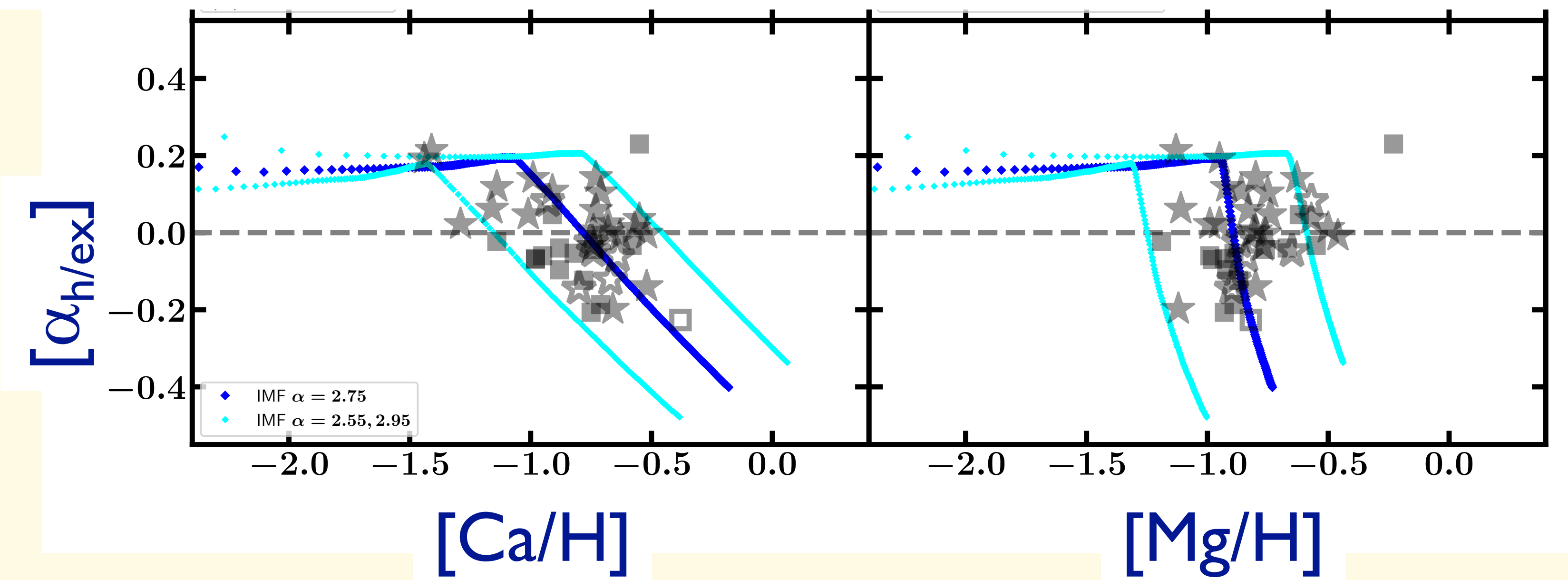
Green: Sgr core

Carlin+2018, ApJL, 859, 10

HEx ratio ([$\alpha_{hydrostatic}/\alpha_{explosive}$], or [$\alpha_{h/ex}$])

A *flexCE** chemical evolution model with IMF slope -2.75 (i.e., steeper than Salpeter), SNIa delay time 1.2 Gyr, and strong outflow matches the properties of Sgr stream stars

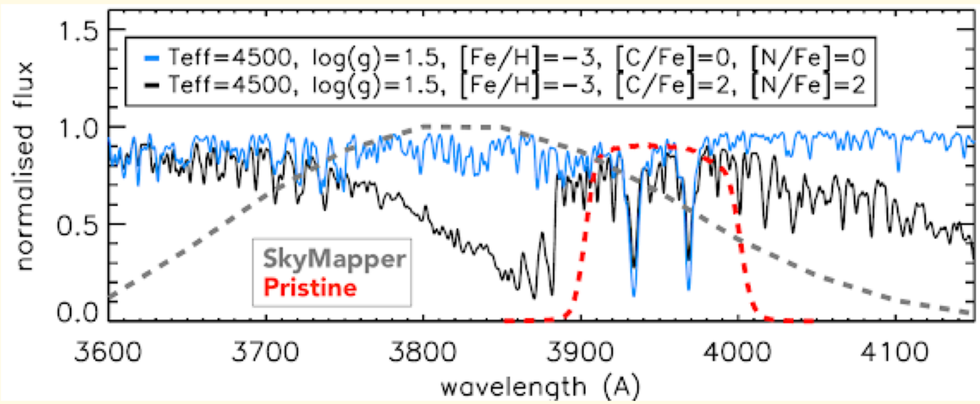
* Andrews+2017 (ApJ 835, 224)

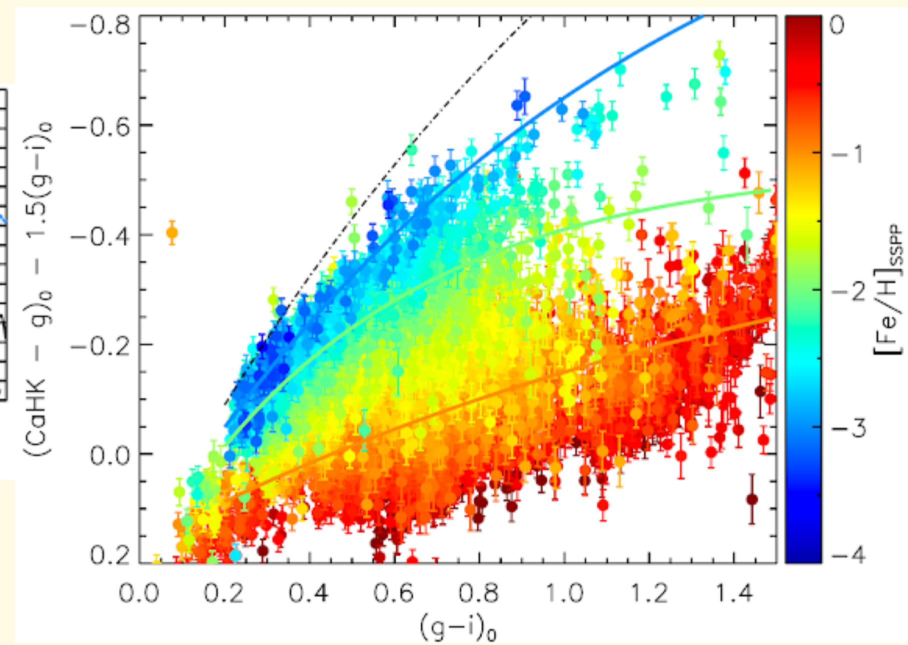


Carlin+2018, ApJL, 859, 10

Approved GRACES large & long program now underway (?) - “Chemistry of new metal-poor stars found in the Pristine Survey”; PI Venn; GN-2019A-LP-102

- Detailed chemical abundances of already-confirmed metal-poor stars





GRACES provides high-resolution (R=40,000 or 67,500) echelle spectroscopy at Gemini North, enabling a variety of science projects that benefit from its sensitivity/throughput and broad useable wavelength range.