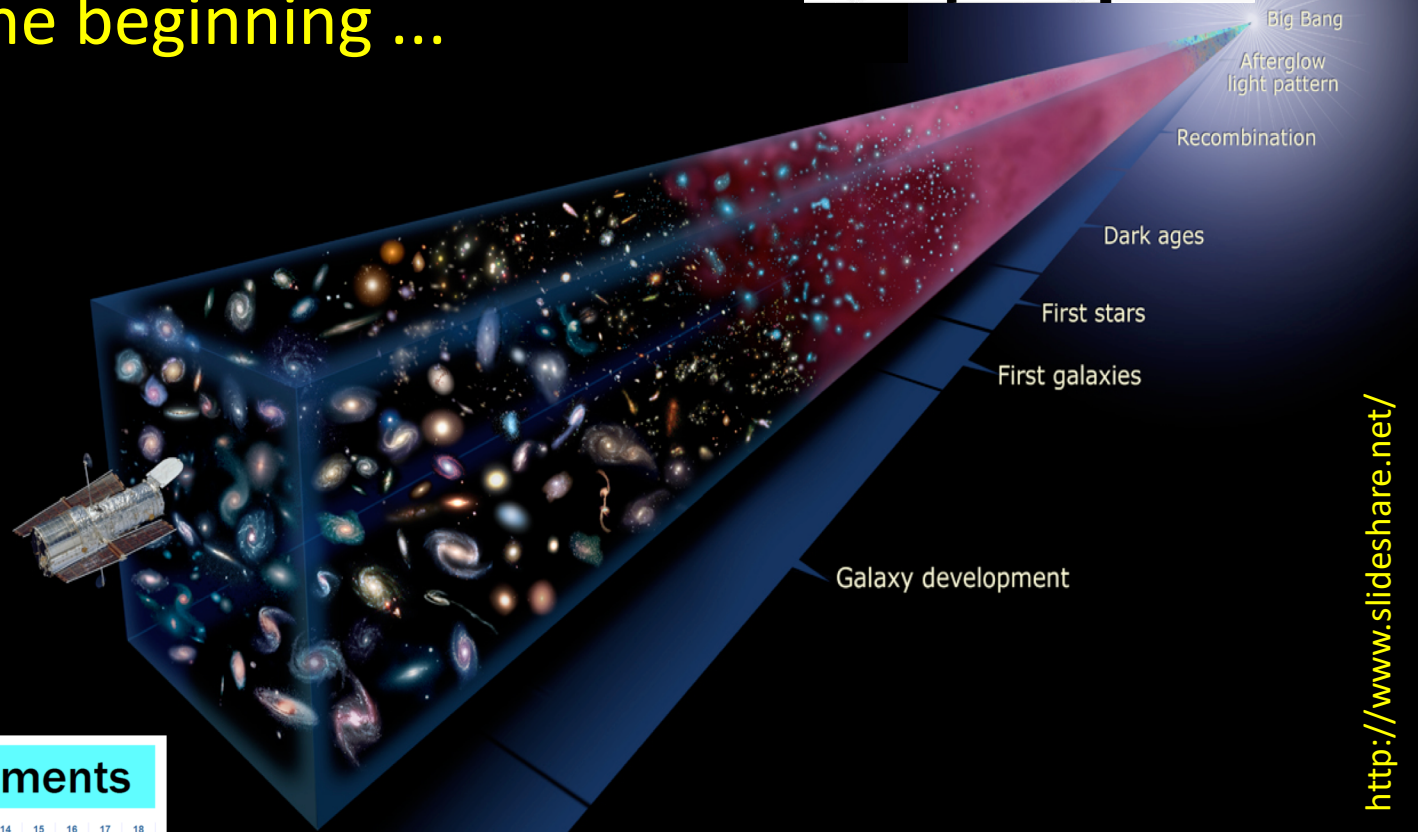


The Impact of improved Atomic Physics on the Chemical Compositions of Low Metallicity Stars

**Chris Sneden
Department of Astronomy
University of Texas at Austin**

How did the universe
produce only these
elements in the beginning ...

Hydrogen 1 H 1.00794	Helium 2 He 4.002602	Lithium 3 Li 6.941
--------------------------------------	--------------------------------------	------------------------------------



<http://www.slideshare.net/>

... and end up with this
wonderful elemental
complexity?



Periodic Table of Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18																		
1 H Hydrogen	Alloys & Symbol																19 K Potassium																		
2 He Helium																	20 Ca Calcium																		
3 Li Lithium	4 Be Beryllium	Solid														21 Sc Scandium																			
5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon	Liquid						11 Na Sodium	12 Mg Magnesium	13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon																
19 K Potassium	20 Ca Calcium	Gas																21 Sc Scandium																	
21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton	37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon		
55 Cs Cesium	56 Ba Barium	57-71 Lanthanoids	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon	87 Fr Francium	88 Ra Radium	89-103 Actinoids	104 Db Dubnium	105 Sg Seaborgium	106 Bh Bohrium	107 Hs Hassium	108 Mt Meitnerium	109 Ds Darmstadtium	110 Rg Roentgenium	111 Cn Copernicium	112 Nh Nihonium	113 Fl Flerovium	114 Mc Moscovium	115 Lv Livermorium	116 Ts Tennessine	117 Og Oganesson	118 Uuo Ununoctium

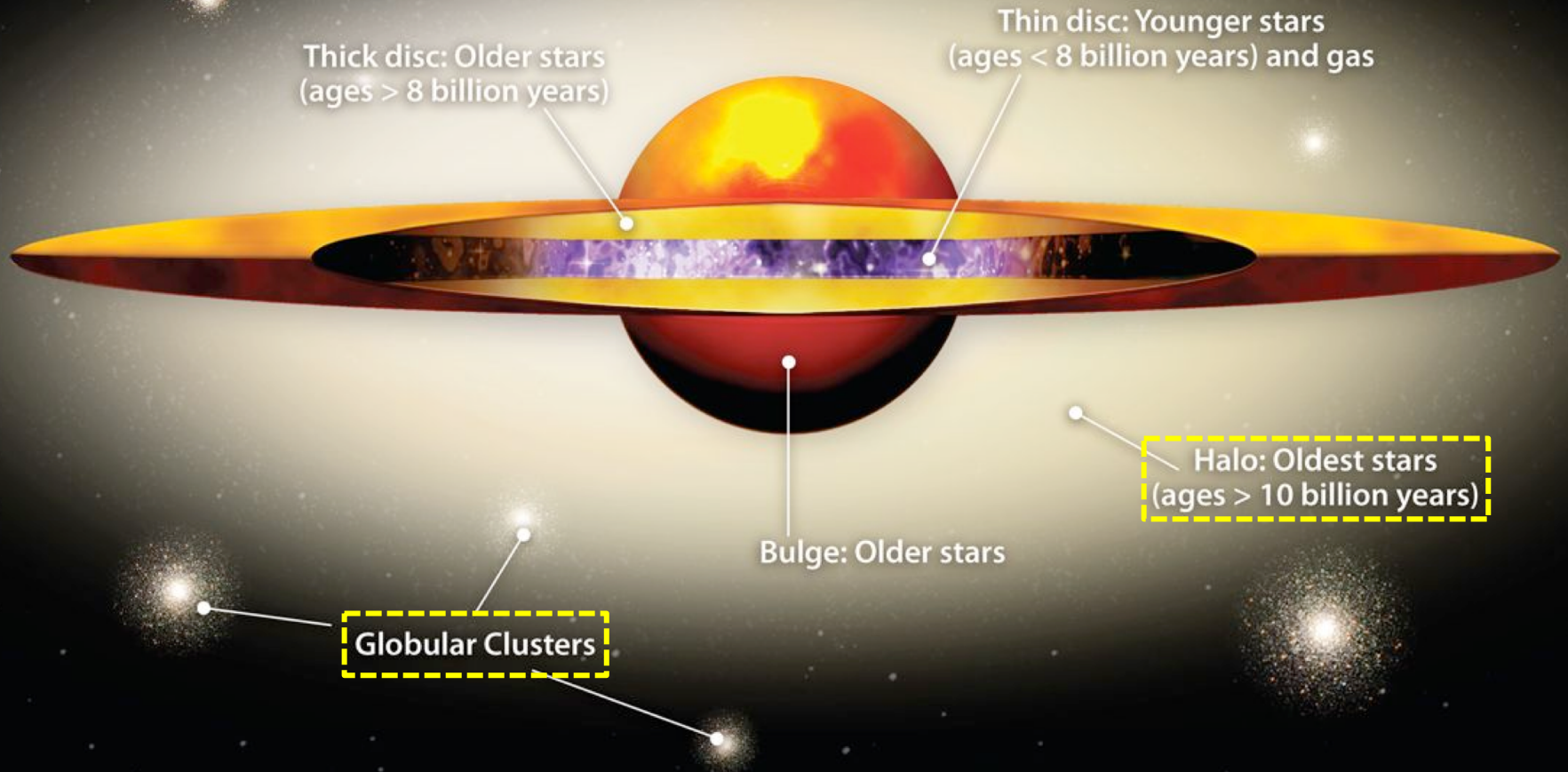
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

Design and Interface Copyright © 1997 Michael Dayan (michae@dayan.com) <http://www.ptable.com/>

89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium
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Ptable
com

detailed spectroscopy of halo stars reveals 1st Galactic element creation events



Outline of topics

- first, a general challenge on stellar chemical compositions
- neutron-capture elements: why do we care?
- r-process rich low metallicity stars: the leap forward in quality
- Fe-group elements: debunking (my!) past odd abundance claims
- don't stop now: attacking the lighter elements
- a wider look – what can we do with metal-rich neutron-capture elements?

Abundance Definitions

- $\log \varepsilon(X) = \log_{10}(N_X/N_H) + 12$ for element “X”
- $[X/Y] = \log_{10}(N_X/N_Y)_\star - \log_{10}(N_X/N_Y)_\odot$
- metallicity: the [Fe/H] value by common usage; almost all my stars are very metal-poor, or [Fe/H] < -2

**I'm speaking on behalf of MANY friends who
have contributed decades to this work**

a challenge from two decades ago ... just as relevant today

“So, even if the study of these surface layers appears rather boring to many of the astrophysicists, it cannot be neglected. As we have shown, even the most fundamental parameters of the most basic representation of stellar atmospheres suffer from significant uncertainties. The theoretical and observational tools needed to solve these problems are, to a large extent, available

It is therefore mostly a matter of will: there is still a lot to be done in the study of stellar atmospheres, what is needed is researchers who wish to tackle these problems.”

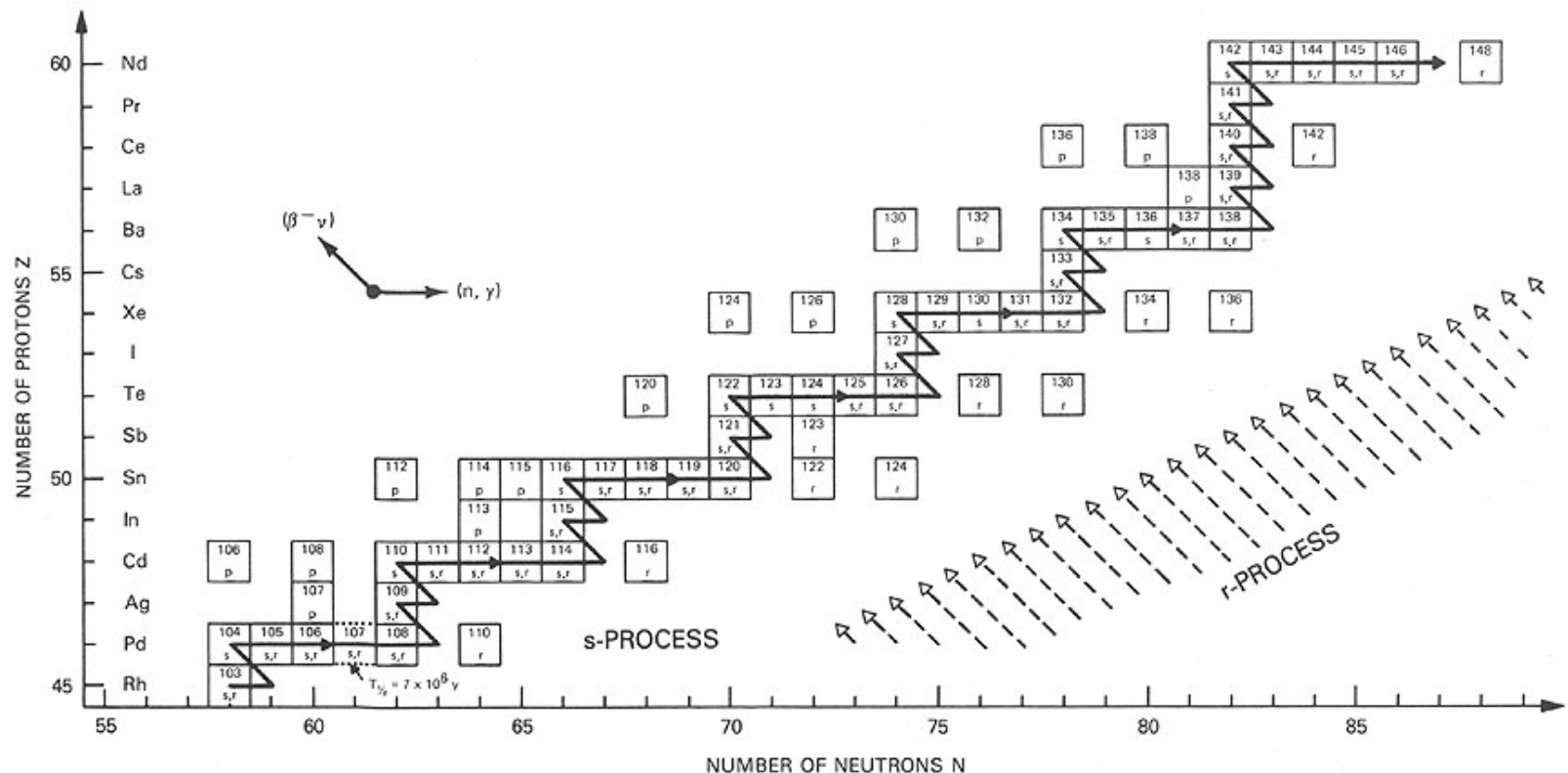
Pierre Magain, 1995, in “Stellar Evolution: What Should be Done”, Proc. 32nd Liège Int. Astrophysical Colloq, ed. A. Noels, D. Fraipont-Caro, M. Gabriel, N. Grevesse, and P. Demarque. Liege: Universite de Liege, Institut d'Astrophysique, 1995., p.139

usually includes all elements with $Z > 30$

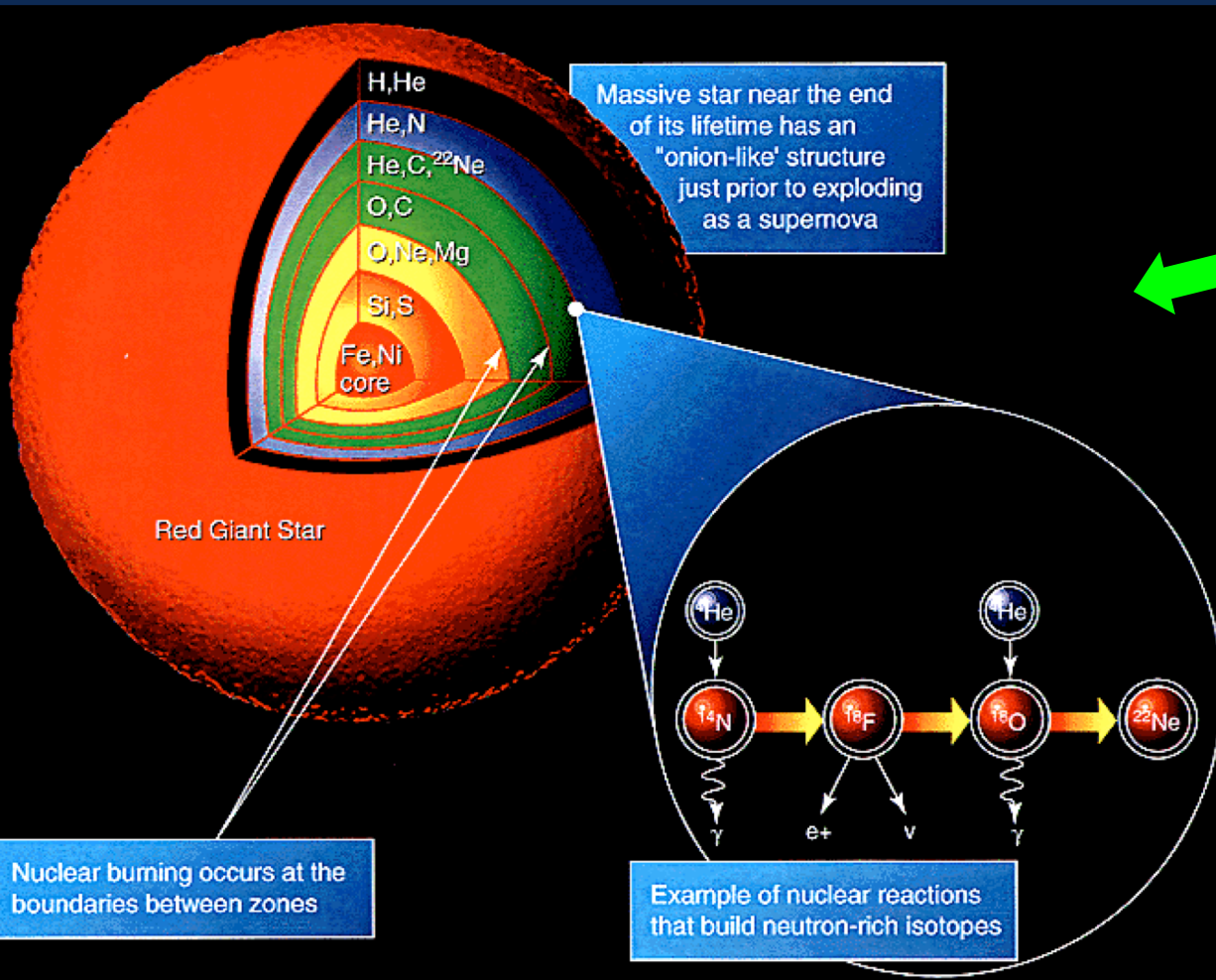
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
<div style="border: 1px solid black; padding: 5px; display: inline-block;">lanthanides</div>																	
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

The basic neutron-capture (n-capture) paths

- *these elements can't be made in standard charged-particle fusion:*
 - *Coulomb barriers; endothermic reactions*
- s-process: β -decays occur between successive n-captures
- r-process: rapid, short-lived neutron blast overwhelms β -decay rates
- *r- or s-process element: **solar-system** dominance by r- or s- production*



Why the interest in n-capture elements? In the early Galaxy they had to be made by massive stars during Type II supernova, **right?**



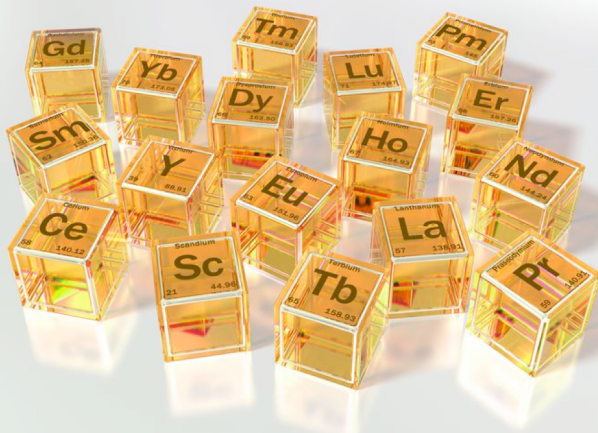
classic cut-away picture of a massive star about to detonate

we are sure that these objects made Fe-group elements and especially the light "alpha" elements like Mg, Si, Ca

Then came the binary neutron-star merger



<https://www.ligo.caltech.edu/news/ligo20180817>



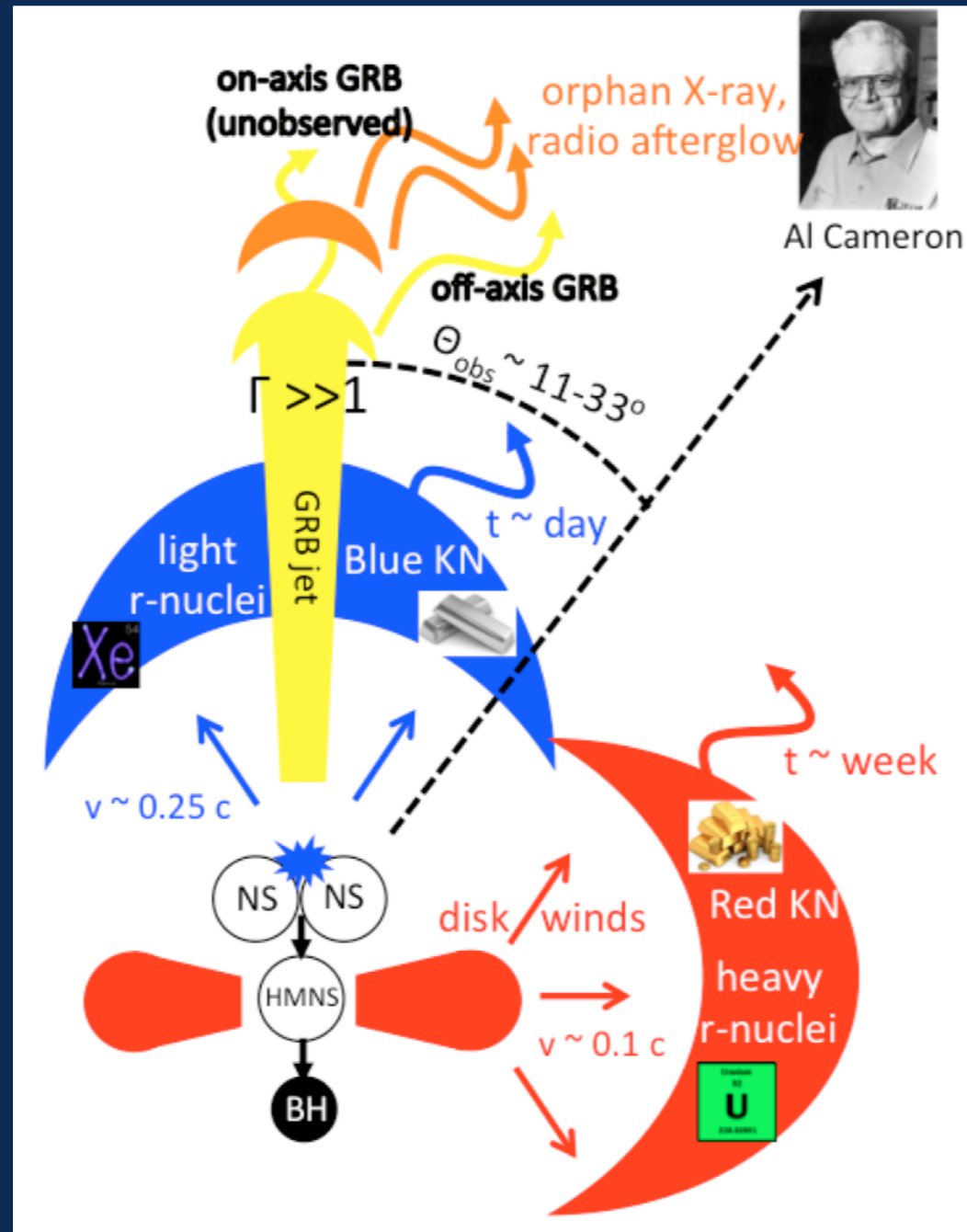
And headlines about
creating lanthanides
and GOLD



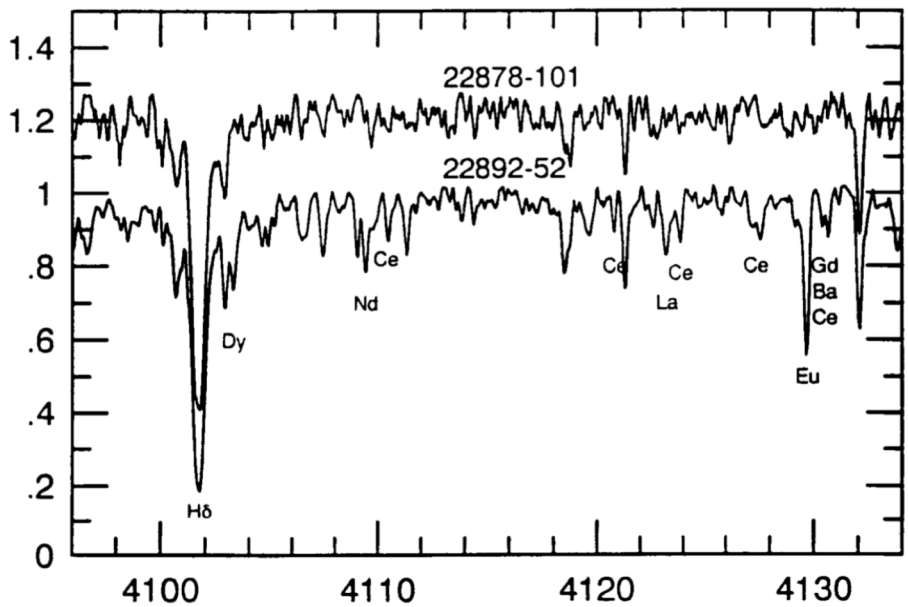
This was a true multi-messenger event from a “kilonova”

Within 11 hours, a bright but rapidly-fading thermal optical counterpart was discovered in NGC 4993. ... The rapid spectral evolution of the kilonova emission to near-infrared wavelengths demonstrates that a portion of the ejecta contains heavy lanthanide nuclei. Two weeks after the merger, rising non-thermal X-ray and radio emission were detected from the position of the optical transient.

Metzger+17a,b



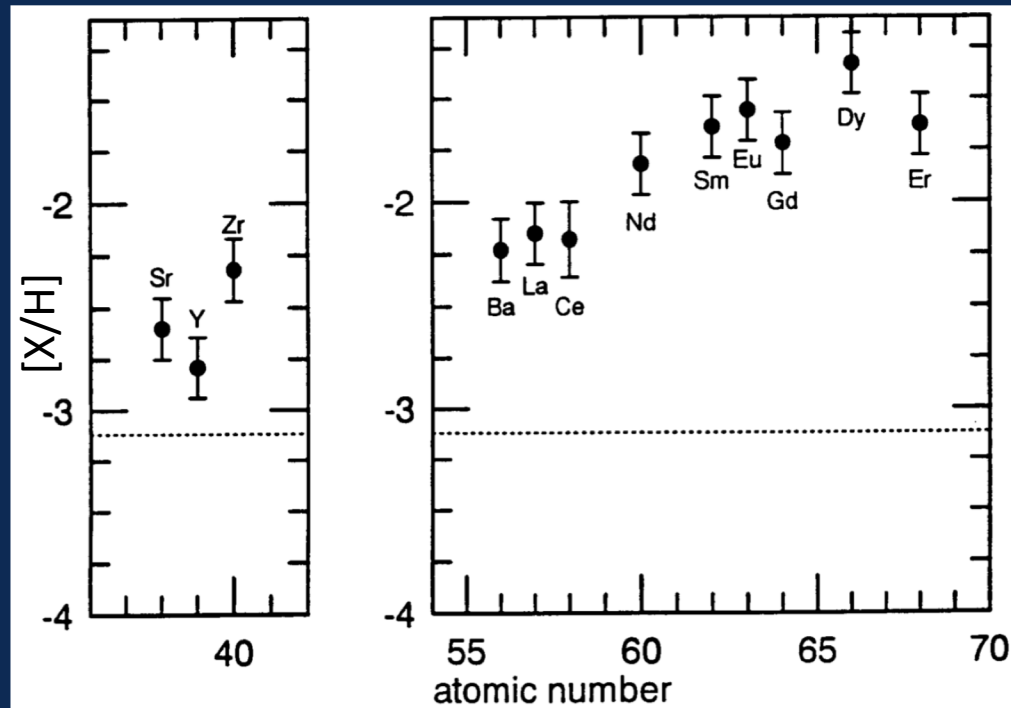
In 1994 a randomly observed halo star began a new major field of low metallicity, *r*-process-rich stars



high resolution, poor signal-to-noise; even so, the great strength of rare earth transitions are obvious

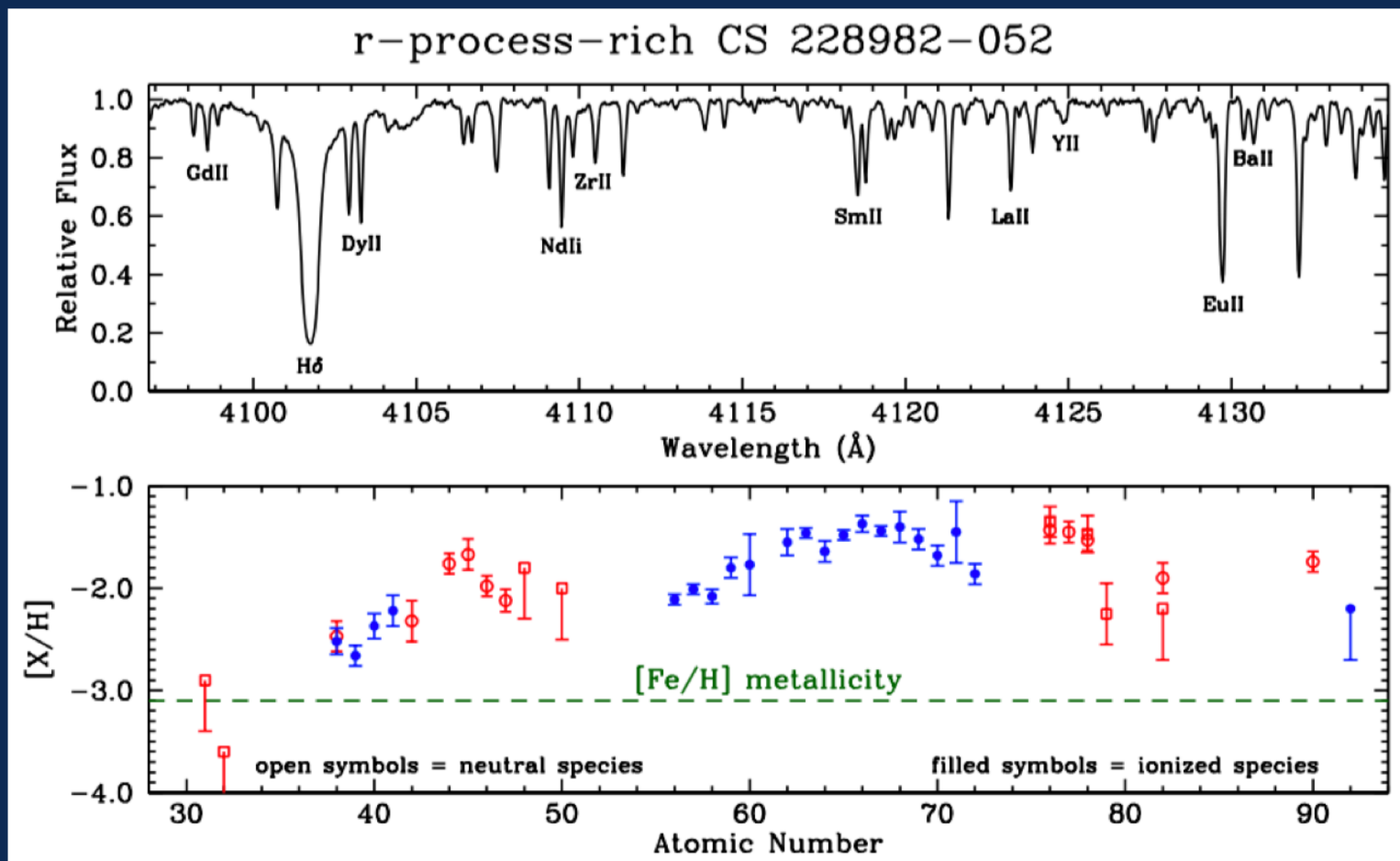
overabundances up to a factor of 30 (easy to spot)

increasing abundance with atomic number $Z \rightarrow$ the *r*-process



Sneden, Preston, McWilliam, & Searle 1994

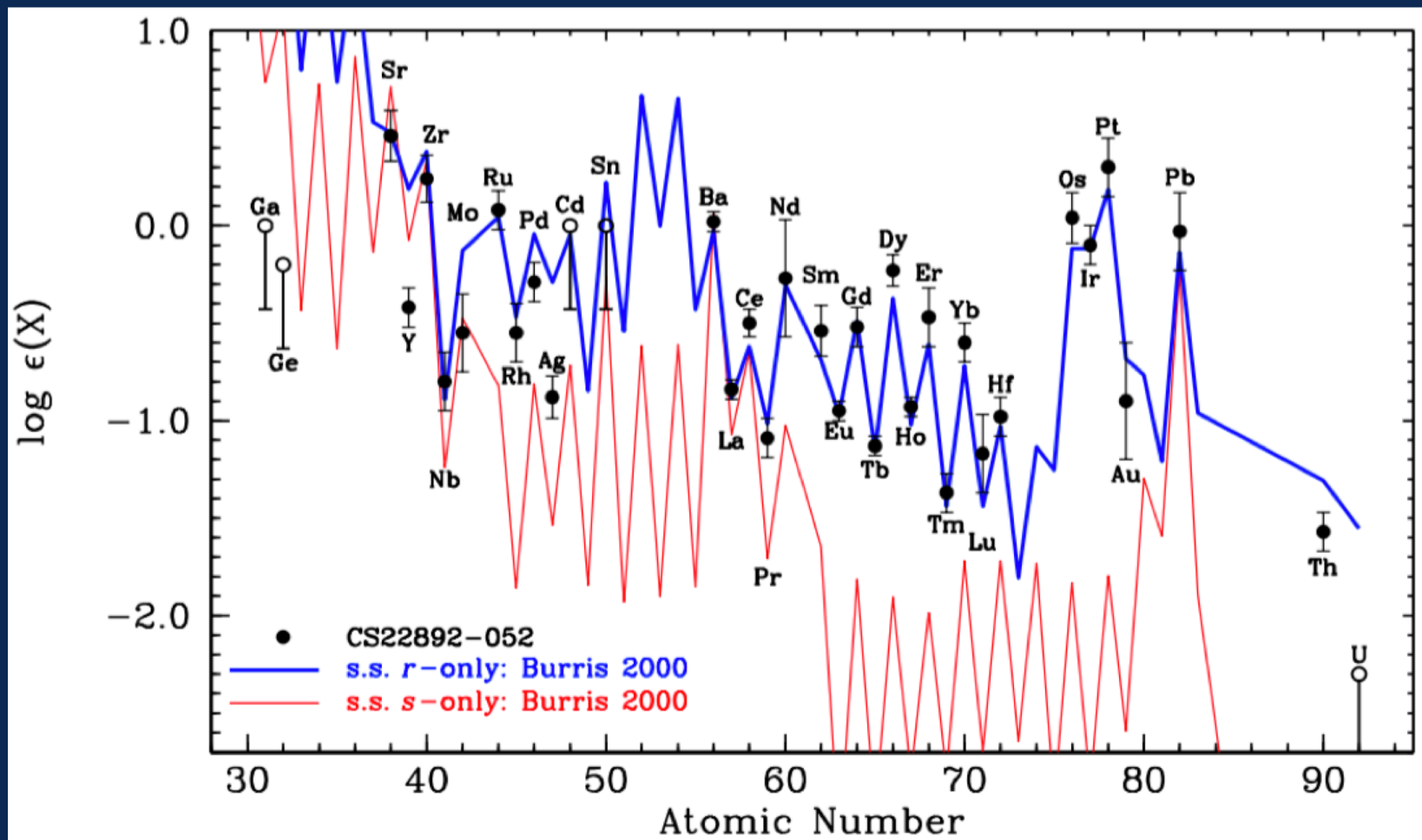
now look only a decade later



Snedden + 2003

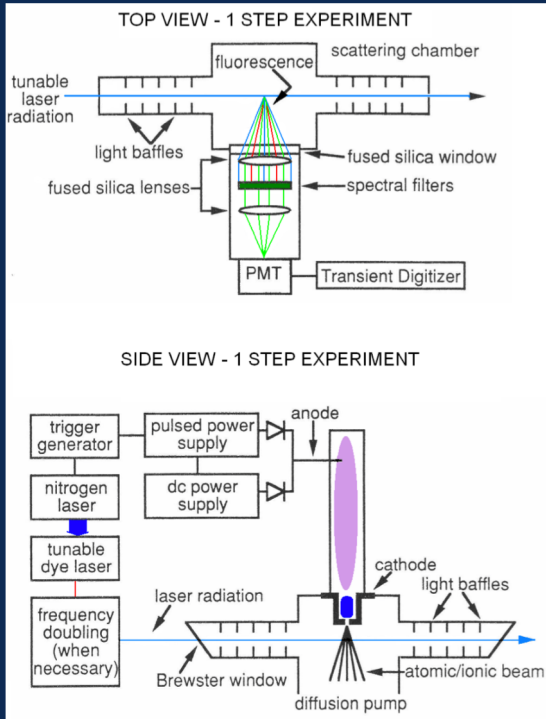
WHAT CHANGED? Much better instruments getting much better spectra
Improved model stellar atmospheres
a quiet revolution in laboratory and theoretical atomic physics
for transitions accessible to cool-star spectroscopy

the abundance pattern is a near-perfect
solar system *r*-process match

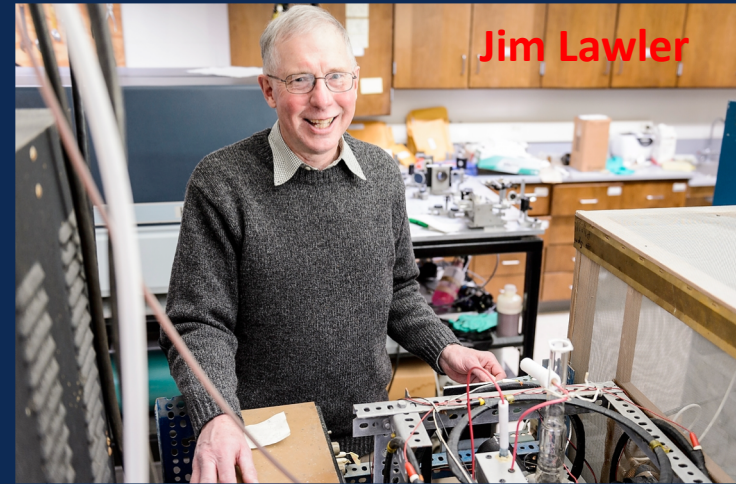


Snedden et al. 2003

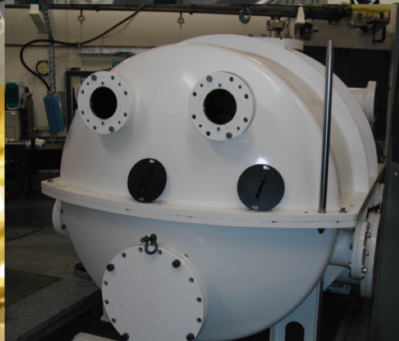
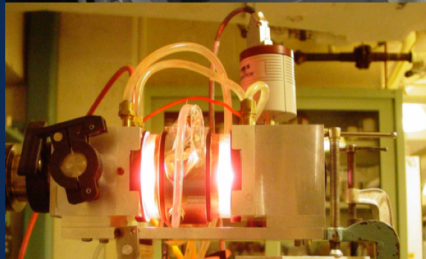
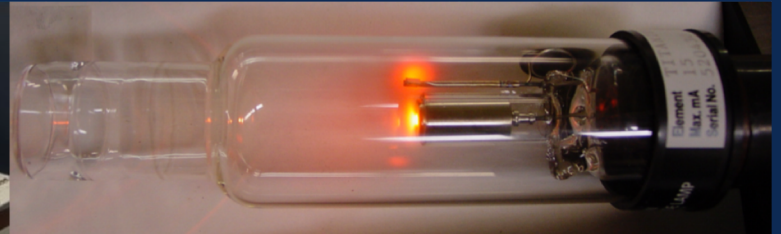
My focus has been to help on the transition data issue:
transition probabilities, hyperfine substructure; isotopic wavelength shifts



Wisconsin lab atomic
physics studies have
made major
contributions to
stellar spectroscopy



Jim Lawler



University of Wisconsin-Madison lab atomic contributions

																as of September 2019									
H																									
Li	Be															B	C	N	O	F	Ne				
Na	Mg															Al	Si	P	S	Cl	Ar				
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr								
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe								
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn								
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub														
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu									
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr									

Wisconsin lab astro: major additions to reliable transitions of n -capture and Fe-group species

the iron group		lanthanides	
Sc I	Lawler et al. (2019)	Ba II	Gallagher (1967)
Ti I	Lawler et al. (2013)	La II	Lawler et al. (2001a)
V I	Lawler et al. (2014) Holmes et al. (2016) Wood et al. (2017)	Ce II	Lawler et al. (2009)
Cr I	Sobeck et al. (2007)	Pr II	Li et al. (2007) Snedden et al. (2009)
Mn I	Den Hartog et al. (2011)	Nd II	Den Hartog et al. (2003)
Fe I	O'Brian et al. (1991) Ruffoni et al. (2014) Den Hartog et al. (2014) Belmonte et al. (2017)	Pm II	unstable element
Co I	Lawler et al. (2015)	Sm II	Lawler et al. (2006)
Ni I	Wood et al. (2014)	Eu II	Lawler et al. (2001c)
Cu I	OK?	Gd II	Den Hartog et al. (2006)
Zn I	OK?	Tb II	Lawler et al. (2001b)
Sc II	Lawler et al. (2019)	Dy II	Wickliffe et al. (2000) Snedden et al. (2009)
Ti II	Wood et al. (2013)	Ho II	Lawler et al. (2004)
V II	Wood et al. (2014)	Er II	Lawler et al. (2008)
Cr II	Lawler et al. (2017)	Tm II	Wickliffe & Lawler 1997 Snedden et al. (2009)
Mn II	Den Hartog et al. (2011)	Yb II	Snedden et al. (2009)
Fe II	Melendez & Barbuy (2009) Den Hartog 2019 Den Hartog 2020	Lu II	Quinet et al. (1999) Fedchak et al. (2000) Snedden et al. (2009)
Co II	Salih et al. (1985) Mullin et al. (1998) Lawler et al. (2018)	Hf II	Lawler et al. (2007)
Ni II	Fedchak & Lawler (1999) Wood et al. (2014)		
Cu II	useful lines < 2200 Å		
Zn II	useful lines < 2200 Å		

important lab work
also from groups at
U. Mons, U. Coll.
London, U. Lund, U.
Liège, NIST, and
others

“No field of science places higher demand on the quantity and accuracy of atomic data than astrophysics” (Nave+2019)
what have we learned by applying these lab data to r -process-rich stars?

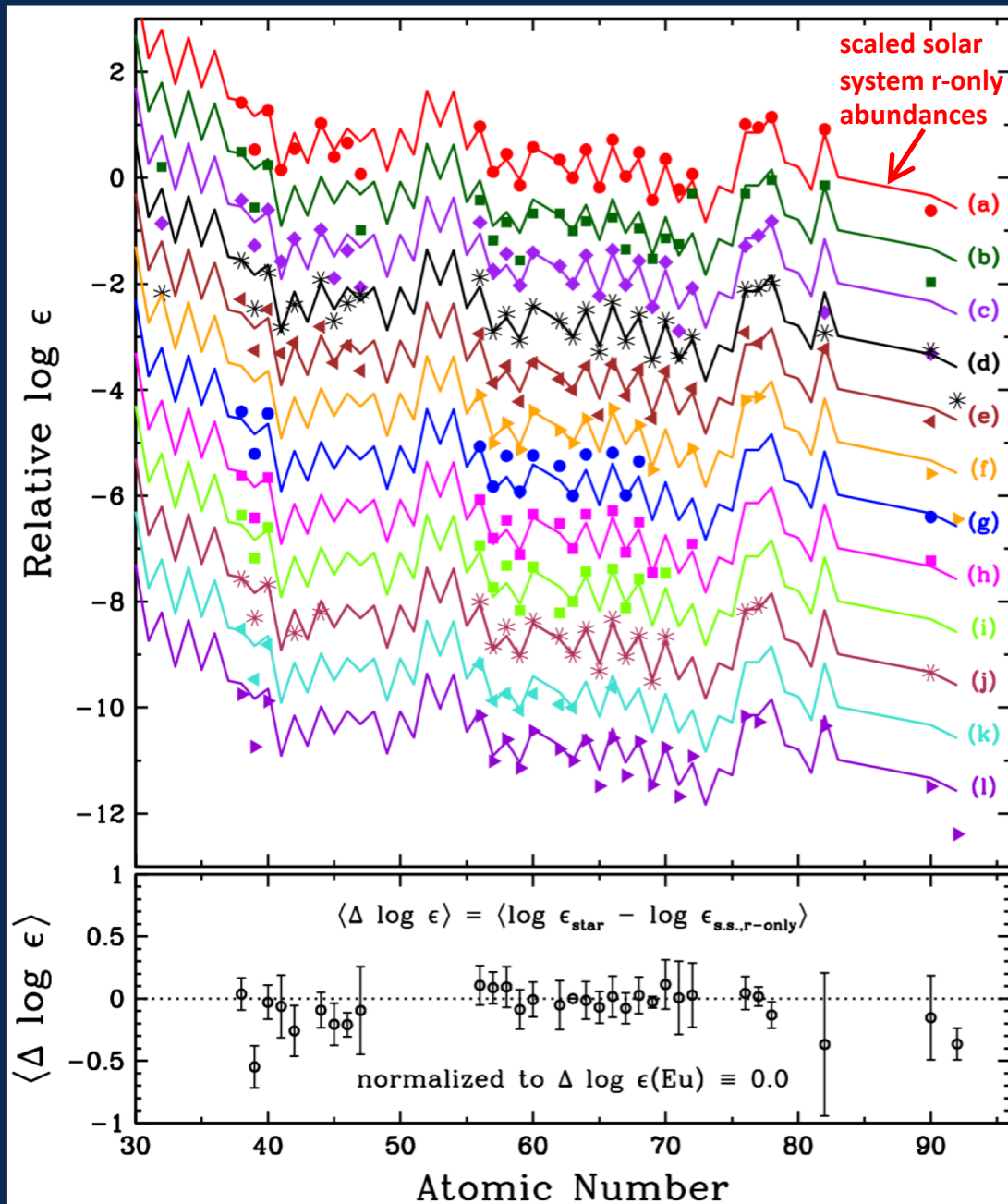
Così fan tutte?

Application of the vastly improved lab data:

very *r*-rich stars have
“the same” 2nd and 3rd
peak scaled abundances

upper panel: 13 *r*-II abundance
distributions and the scaled solar
r-process distribution

Lower panel: mean differences
with respect to the solar *r*-process



Cowan+ 2020+

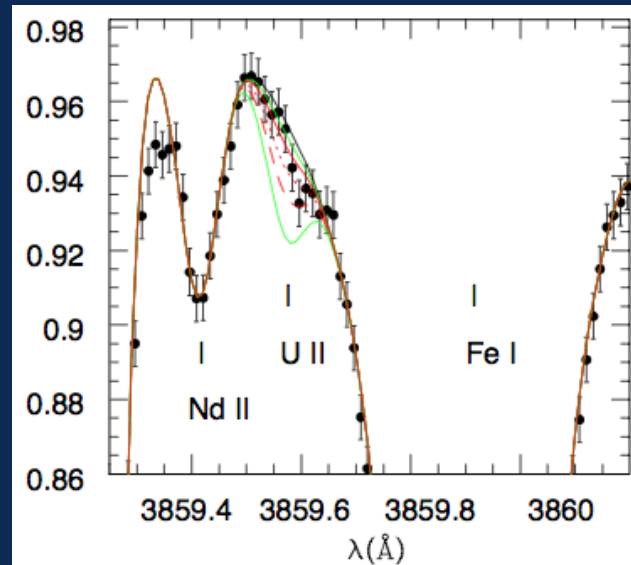
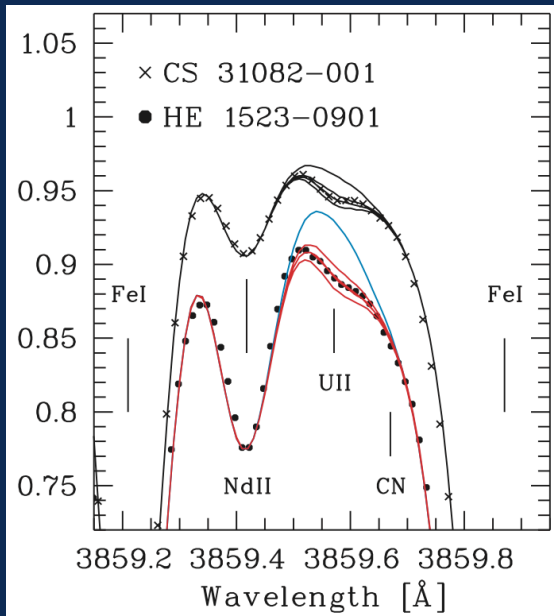
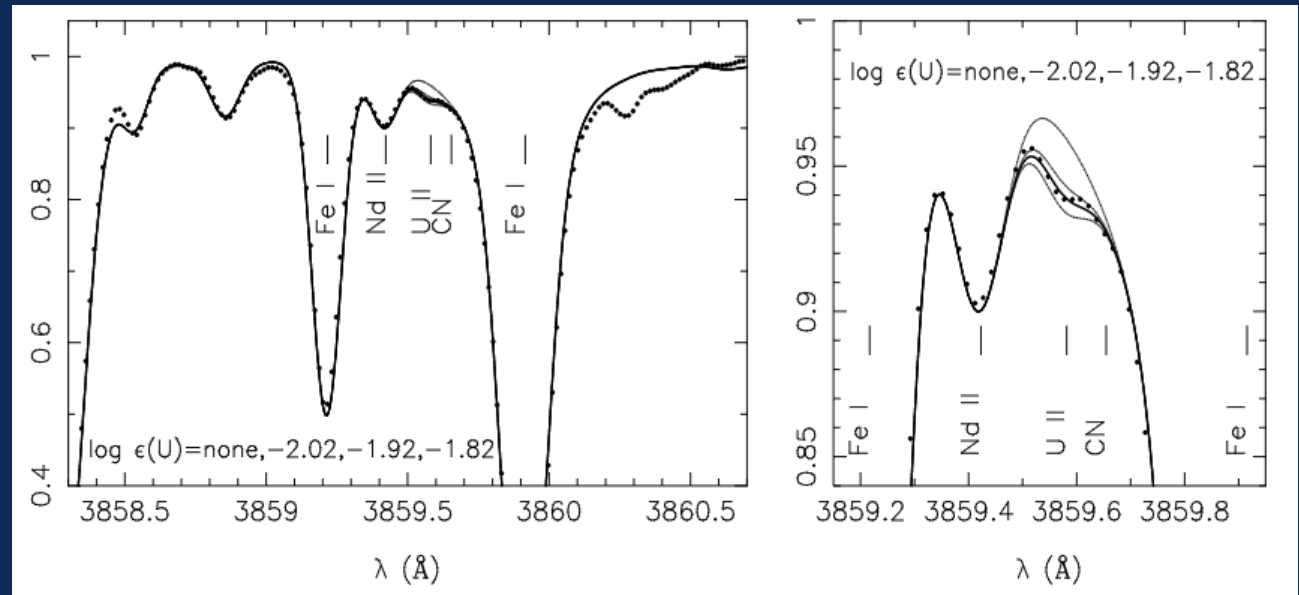
We have uranium detections in *r*-process-rich stars

First detection:

CS 31082-001
(Hill et al. 2002)

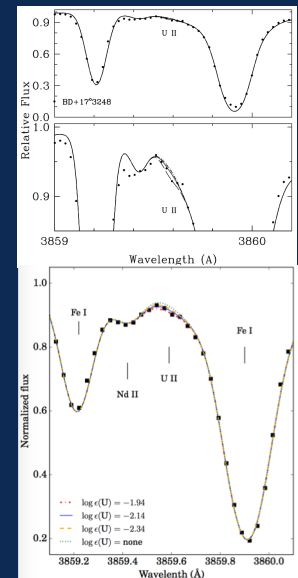
The single U II line:
it is weak!
it is blended!
only with weak CN!

Frebel et al. 2007



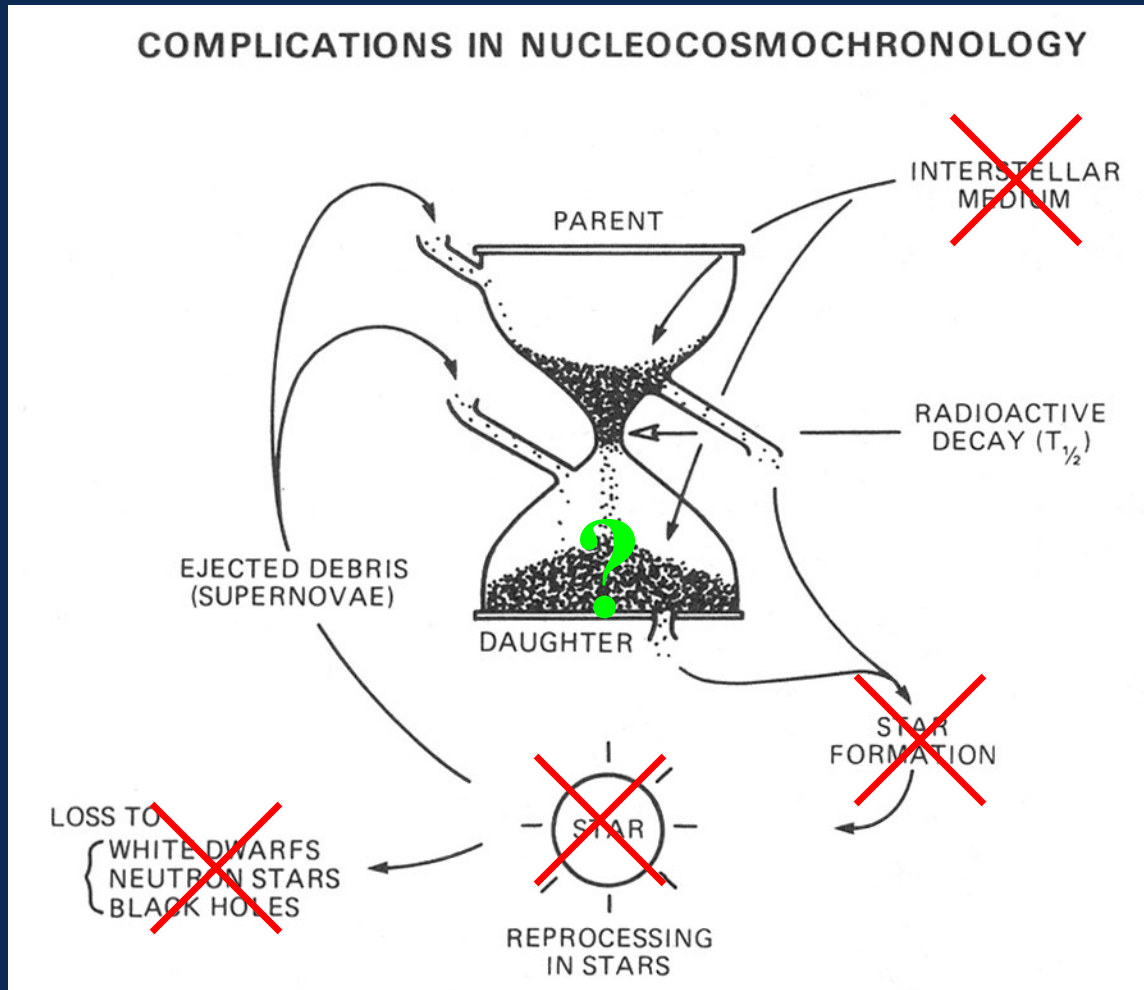
Hill et al. 2017

Cowan et al 2002



Placco et al. 2017

Radioactive cosmochronometry is *NOT* complex for metal-poor *r*-rich stars



Galactic chemical evolution effects do not matter for radioactive elements Th and U “frozen” into *metal-poor stars born near the start of the Galaxy*.

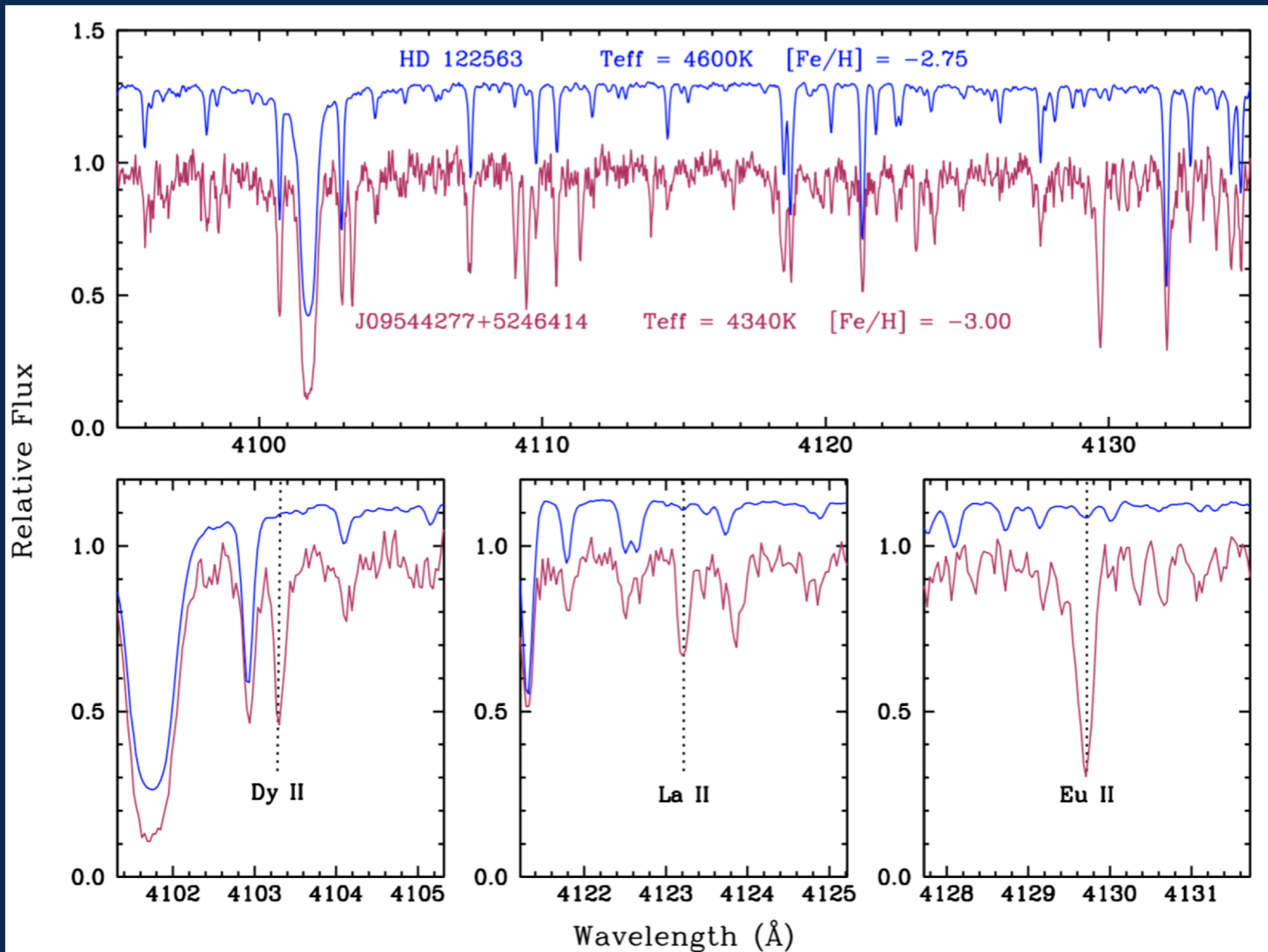
Daughter product Pb is also a direct *n*-capture synthesis product; it is a complex mess!

The hunt to better understand the r-process: the *R*-Process Alliance (RPA)

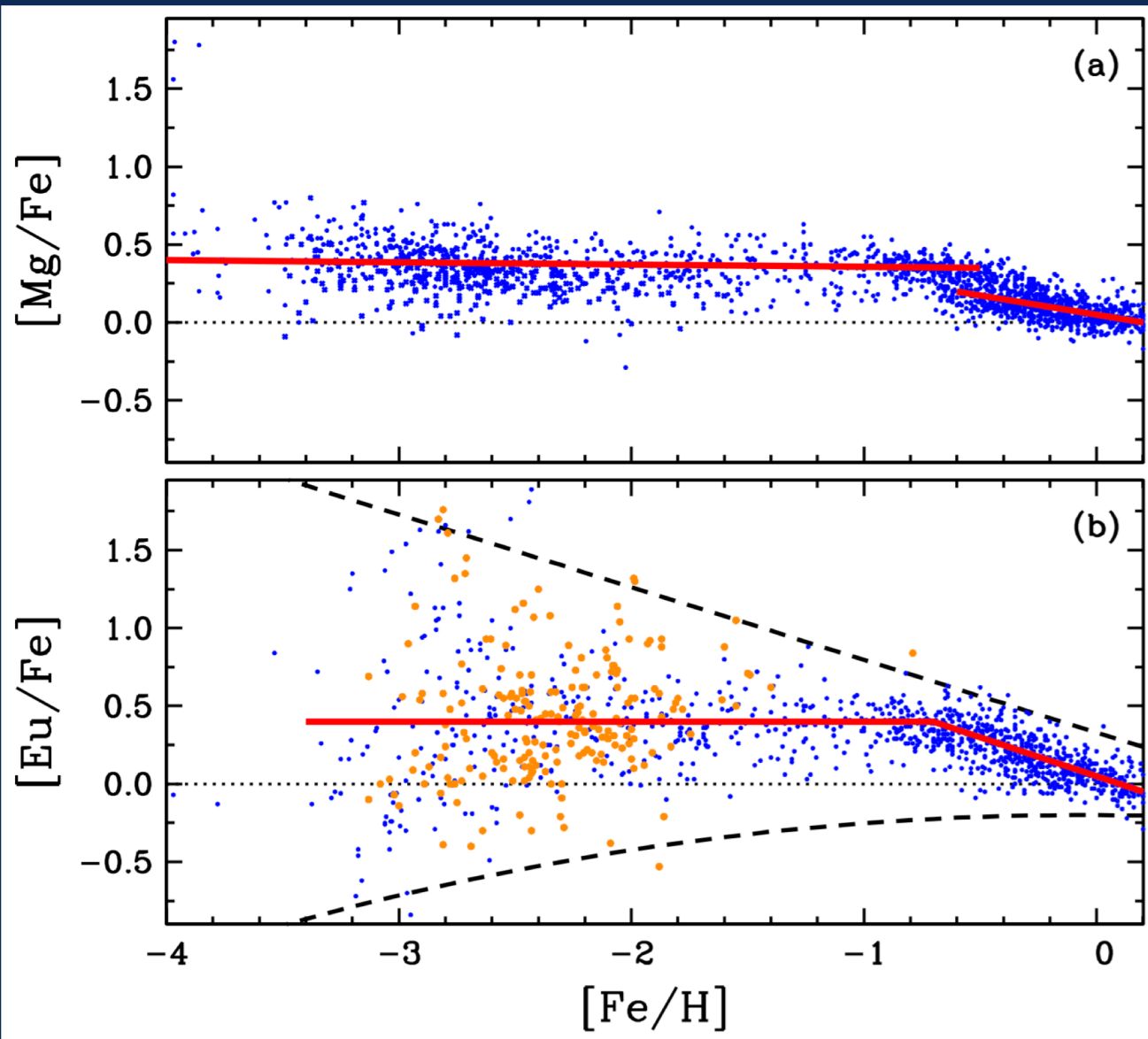
- combines observations, theory and modeling, and experiments
- investigates different aspects of the r-process
- first goal: find the true halo distribution of r-process abundances
- want *approximate* totals to be:
 - 100 *r*-II
 - 500 *r*-I
 - 100 *r*-limited
- these totals can facilitate real statistics for the first time
- can potentially lead to more U detections
- can try to understand the 1st peak abundance distributions
- can look for “imperfections” in the *r*-II abundance sets

led by Tim Beers (U Notre Dame), with major effort by John Cowan, Rana Ezzeddine, Anna Frebel, Terese Hansen, Andrea Kunder, Vini Placco, Ian Roederer, Charli Sakari Kim Venn, Rosie Wyse, et al.!

Here is a typical low S/N snapshot spectrum of a new RPA *r*-II star



2019 version of a 2008 ARA&A figure on Eu/Fe



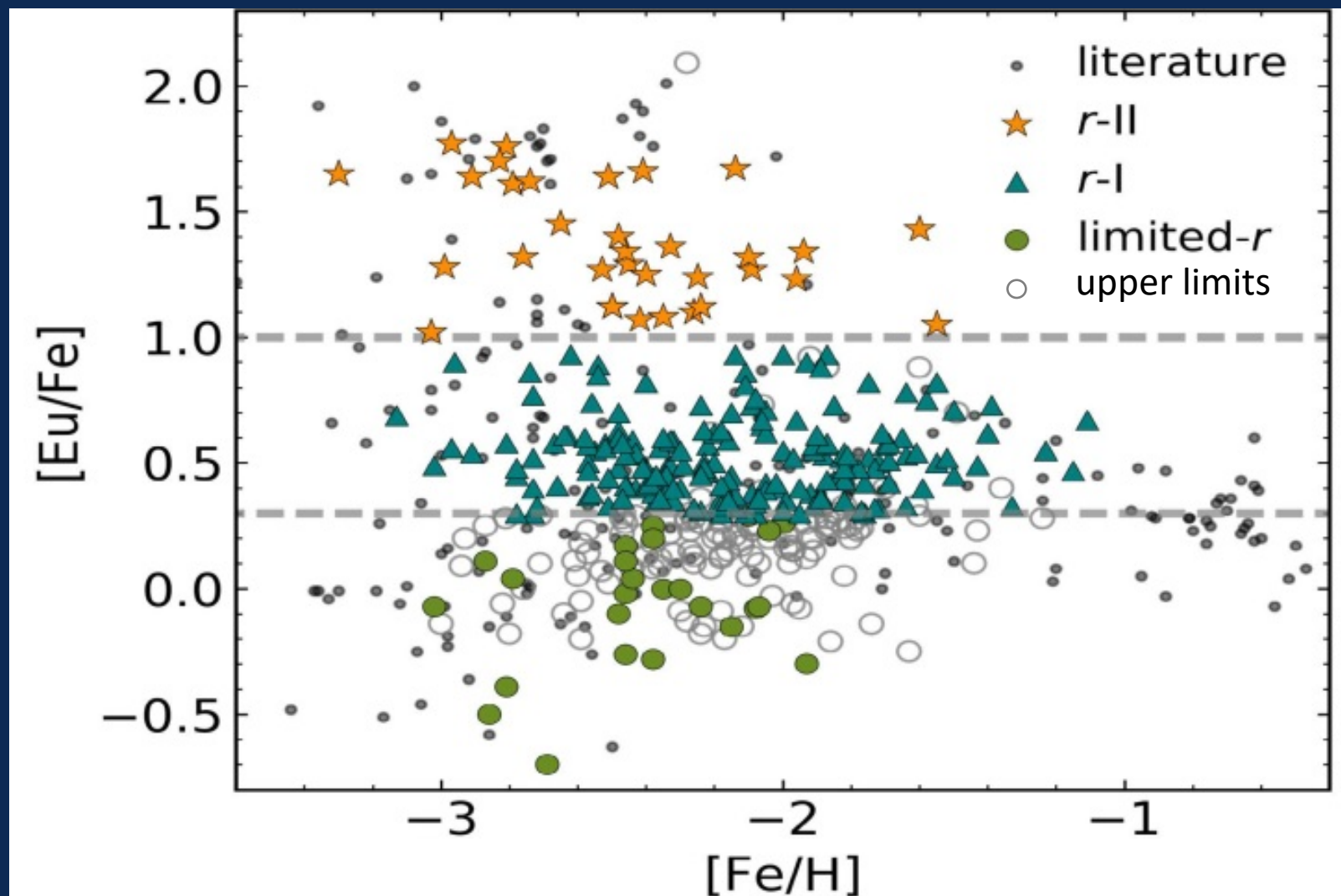
the 2-dex $[Eu/Fe]$ spread is now confirmed with large samples

the lack of points for $[Fe/H] < -3.4$ is probably just a detection issue

note: relatively few stars with $[Eu/Fe] < -0.3$

Hansen et al. 2018, Sakari et al. 2018 are the orange points

Overall Progress of RPA Snapshot High-Res Spectroscopy



30 NEW r -II STARS ... and counting (~15 more in hand)

SUMMARY of N-Capture Results


neutron-capture elements were once neglected
Periodic Table exotica

They have emerged as important signposts to
explosive death stages of early Galactic element
donors, particularly those parts created in the r -
process

the developing statistical knowledge of the r -process
occurrence will provide constraints on early Galactic
chemical evolution

The Fe-group elements

most abundant elements after H, He, C, N, O;
easily accessible spectroscopically (but ...);
many UV-optical lines in *various* metallicity stars

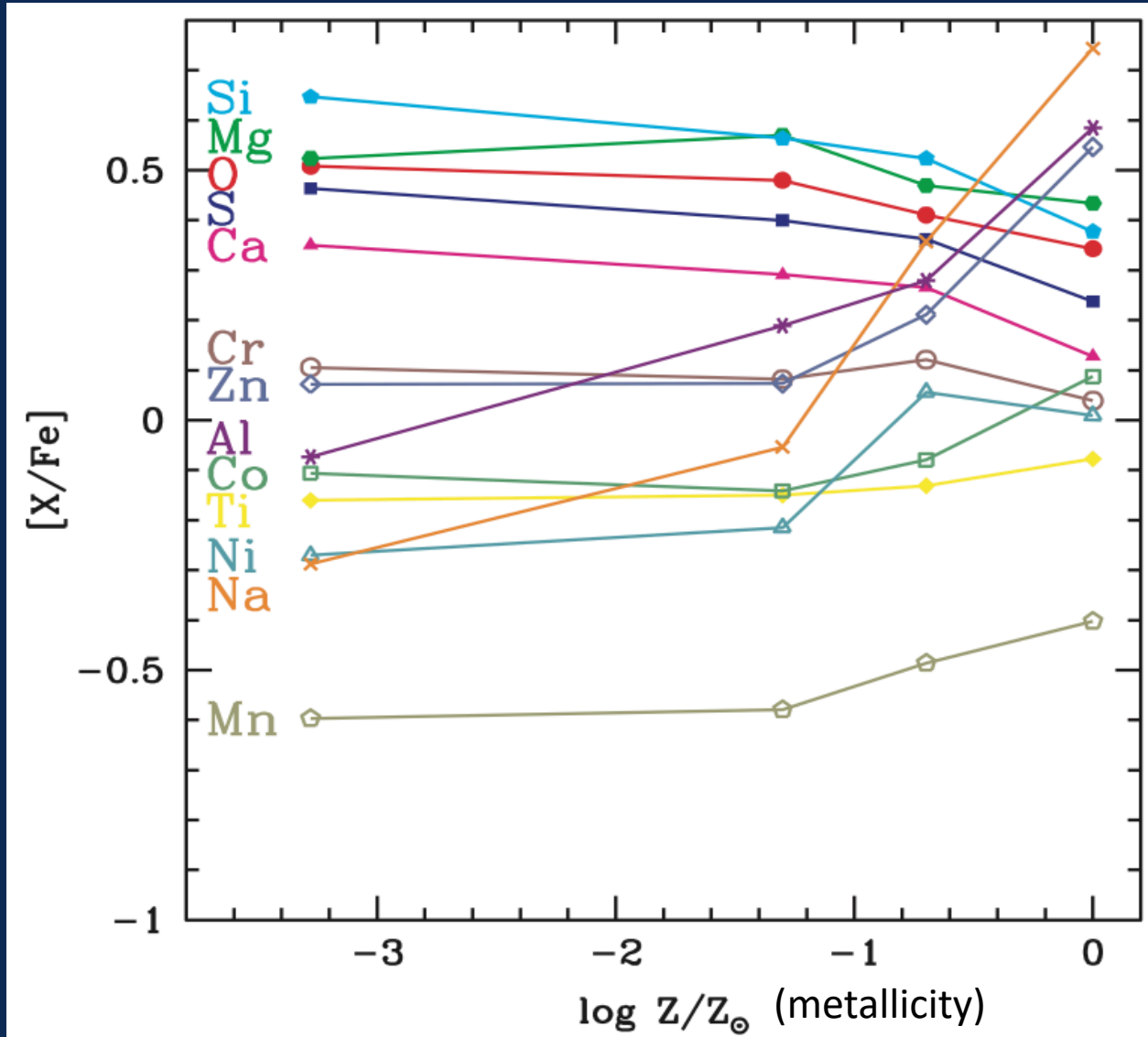
H																	He	
Li	Be											B	C	N	O	F	Ne	
Na	Mg											Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub							
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Wisconsin lab astro: major contributions to observable transitions of n-capture and Fe-group species

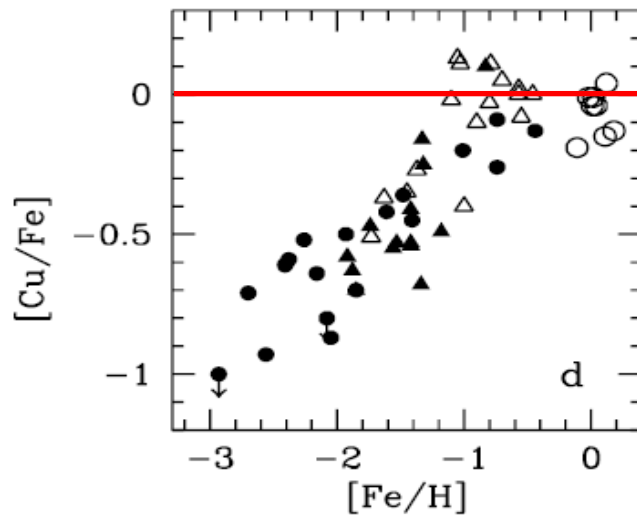
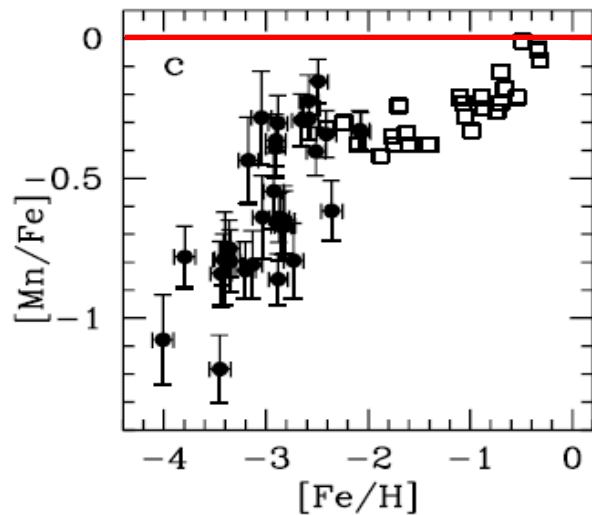
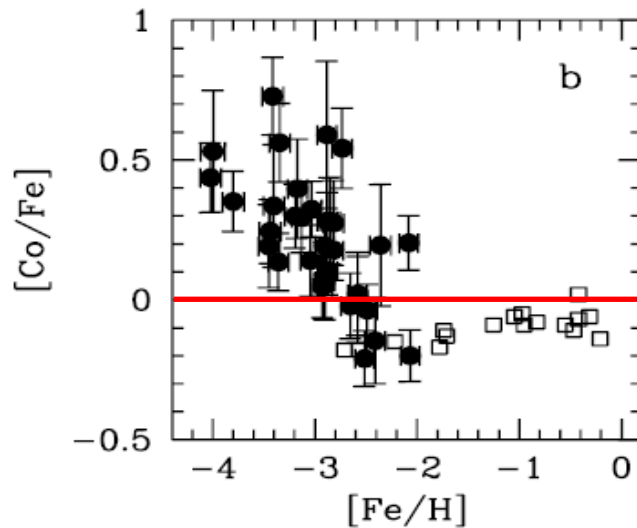
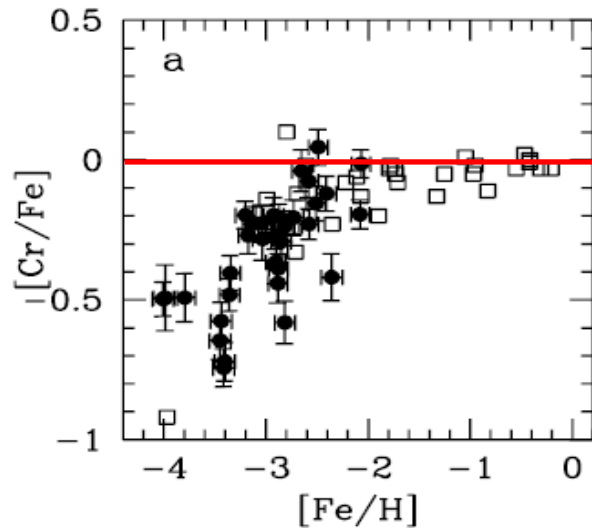
the iron group		lanthanides															
Lawler et al. (2019)	Sc II	Lawler et al. (2019)	Sc I														Gallagher (1967)
Wood et al. (2013)	Ti II	Lawler et al. (2013)	Ti I														Lawler et al. (2001a)
Wood et al. (2014)	V II	Lawler et al. (2014)	V I														Lawler et al. (2009)
Lawler et al. (2017)	Cr II	Sobeck et al. (2007)	Cr I														Li et al. (2007) Snedden et al. (2009)
Den Hartog et al. (2011)	Mn II	Den Hartog et al. (2011)	Mn I														Den Hartog et al. (2003)
Melendez & Barbuy (2009) Den Hartog 2019 Den Hartog 2020	Fe II	O'Brian et al. (1991) Ruffoni et al. (2014) Den Hartog et al. (2014) Belmonte et al. (2017)	Fe I														unstable element
Salih et al. (1985) Mullman et al. (1998) Lawler et al. (2018)	Co II	Lawler et al. (2015)	Co I														Lawler et al. (2006)
Fedchak & Lawler (1999) Wood et al. (2014)	Ni II	Wood et al. (2014)	Ni I														Lawler et al. (2001c)
useful lines < 2200 Å	Cu II	OK?	Cu I														Wickliffe et al. (2000) Snedden et al. (2009)
useful lines < 2200 Å	Zn II	OK?	Zn I														Lawler et al. (2004)
																	Lawler et al. (2008)
																	Wickliffe & Lawler 1997 Snedden et al. (2009)
																	Snedden et al. (2009)
																	Quinet et al. (1999) Fedchak et al. (2000) Snedden et al. (2009)
																	Lawler et al. (2007)

important lab work
also from groups at
U. Mons, U. Coll.
London, U. Lund, U.
Liège, NIST, and
others

theoretical high-mass star models generate abundances that can be compared to observed trends



those predictions clash with past claims of non-solar abundance ratios at low metallicity



Cr, Mn, Cu are very underabundant w.r.t. Fe

Co is very overabundant

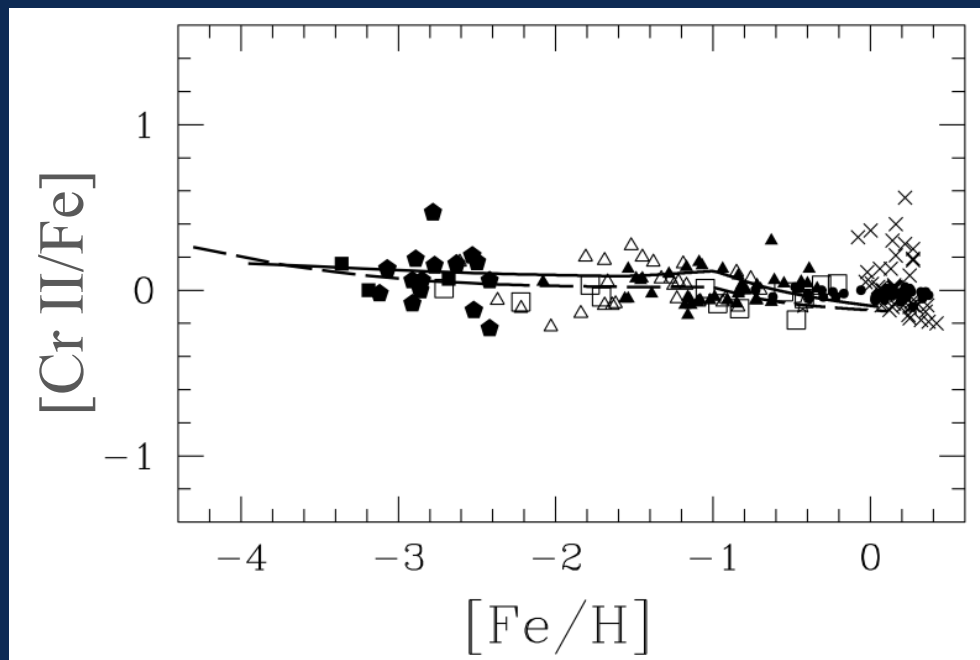
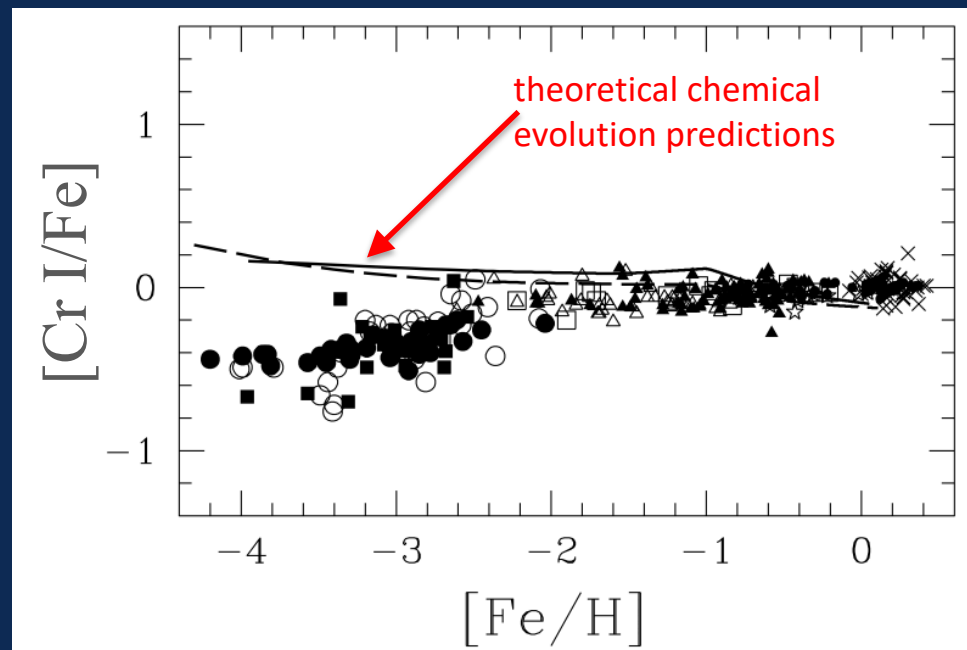
McWilliam 1997, but mostly based on McWilliam, Preston, Sneden, & Searle 1995

But massive star element synthesis models cannot reproduce most of these observed abundances!

Surveys with better spectra have always confirmed these trends

But something was
clearly amiss:
neutral and ionized
Cr transitions gave
different answers

Kobayashi et al. 2006



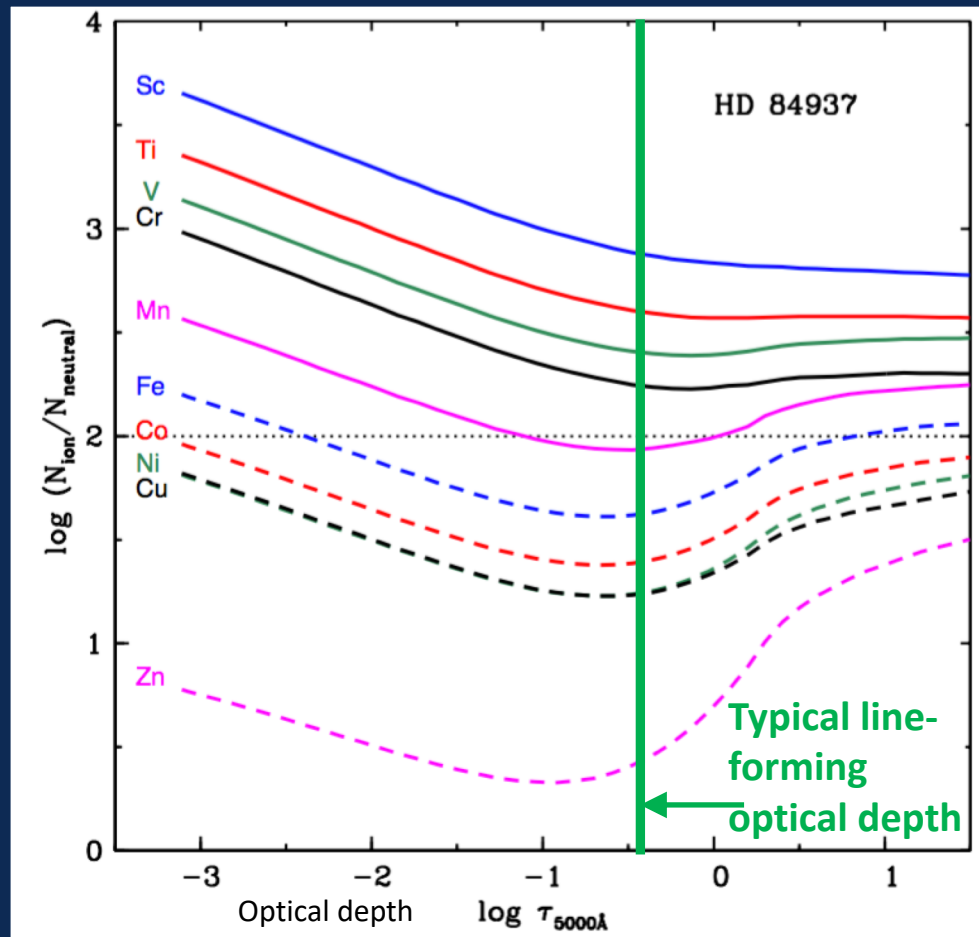
same theory, different observed
species of an element

example: at $[\text{Fe/H}] = -3$
 $[\text{Cr/Fe}] \approx -0.4$ from neutral lines
 $[\text{Cr/Fe}] \approx 0.0$ from ionized lines

*which abundance is right?
or maybe neither of them?!*

First issue: one must use ionized species for fundamental abundances in low metallicity stars

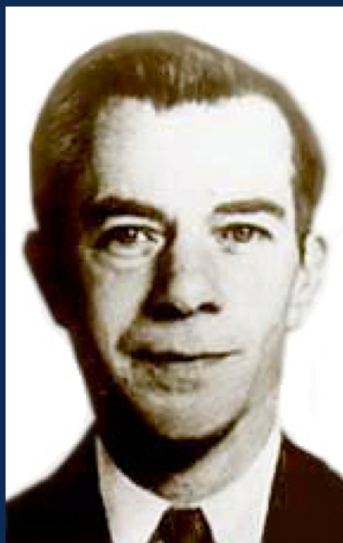
The “Saha” ionization balance



Snedden+2016

ions dominate Saha balances for Fe-group elements in warm metal-poor stars
The neutral species are mostly trace fractions →
big corrections from neutral number densities to elemental abundances

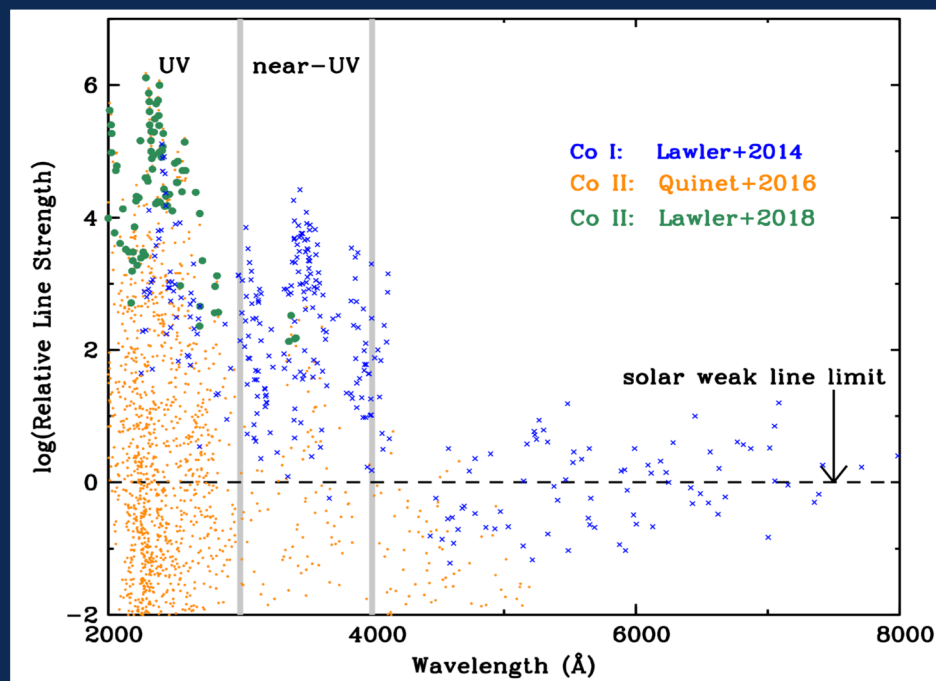
remember the American philosopher-criminal Willie Sutton



Sutton's Law: A famous apocryphal story is that Sutton was asked why he robbed banks. Allegedly he replied:

**"Because that's where
the money is"**

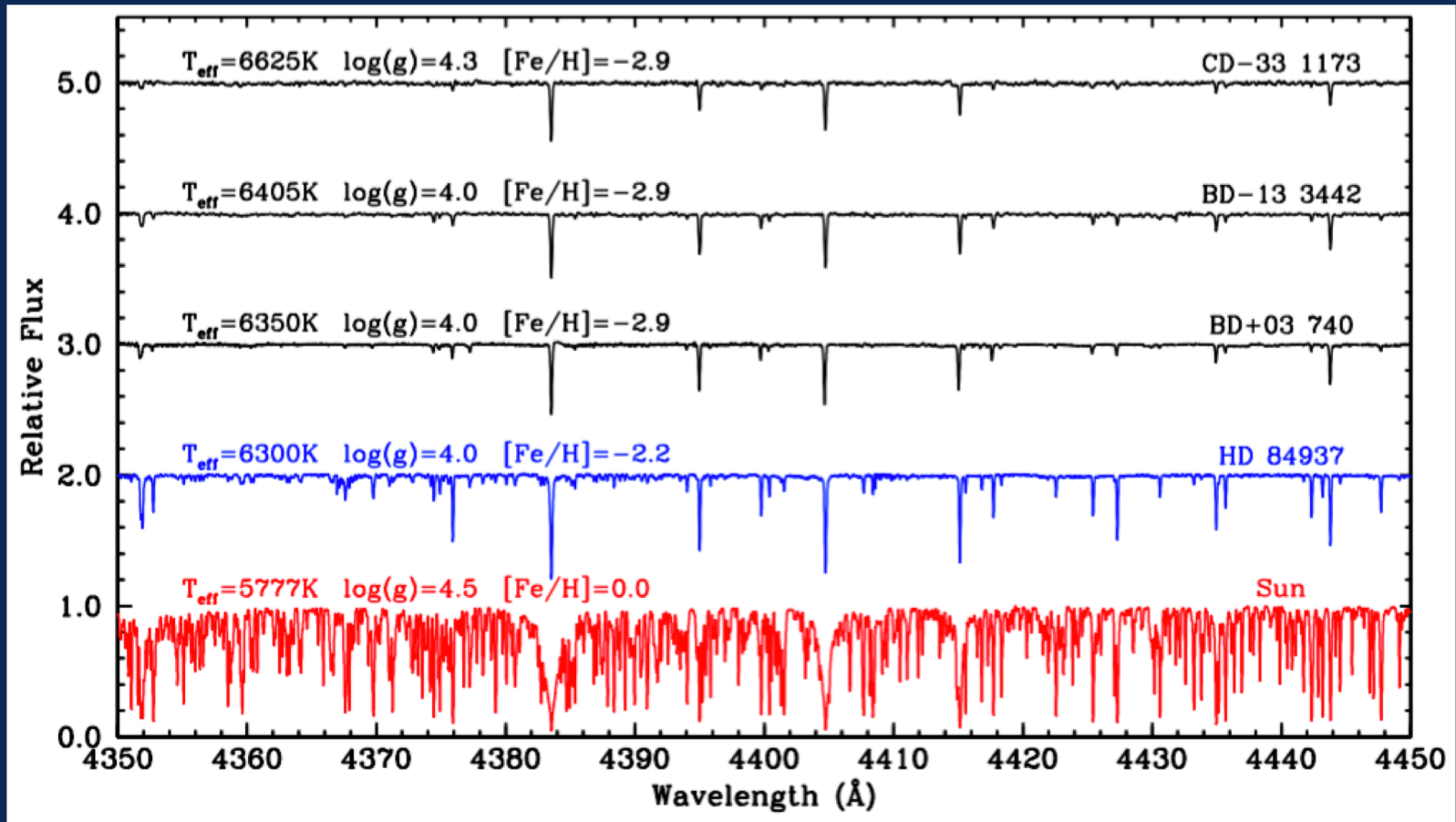
ionized-species lines are mostly in the UV



***Sounds easy: explore near-UV and
especially UV spectral regions***

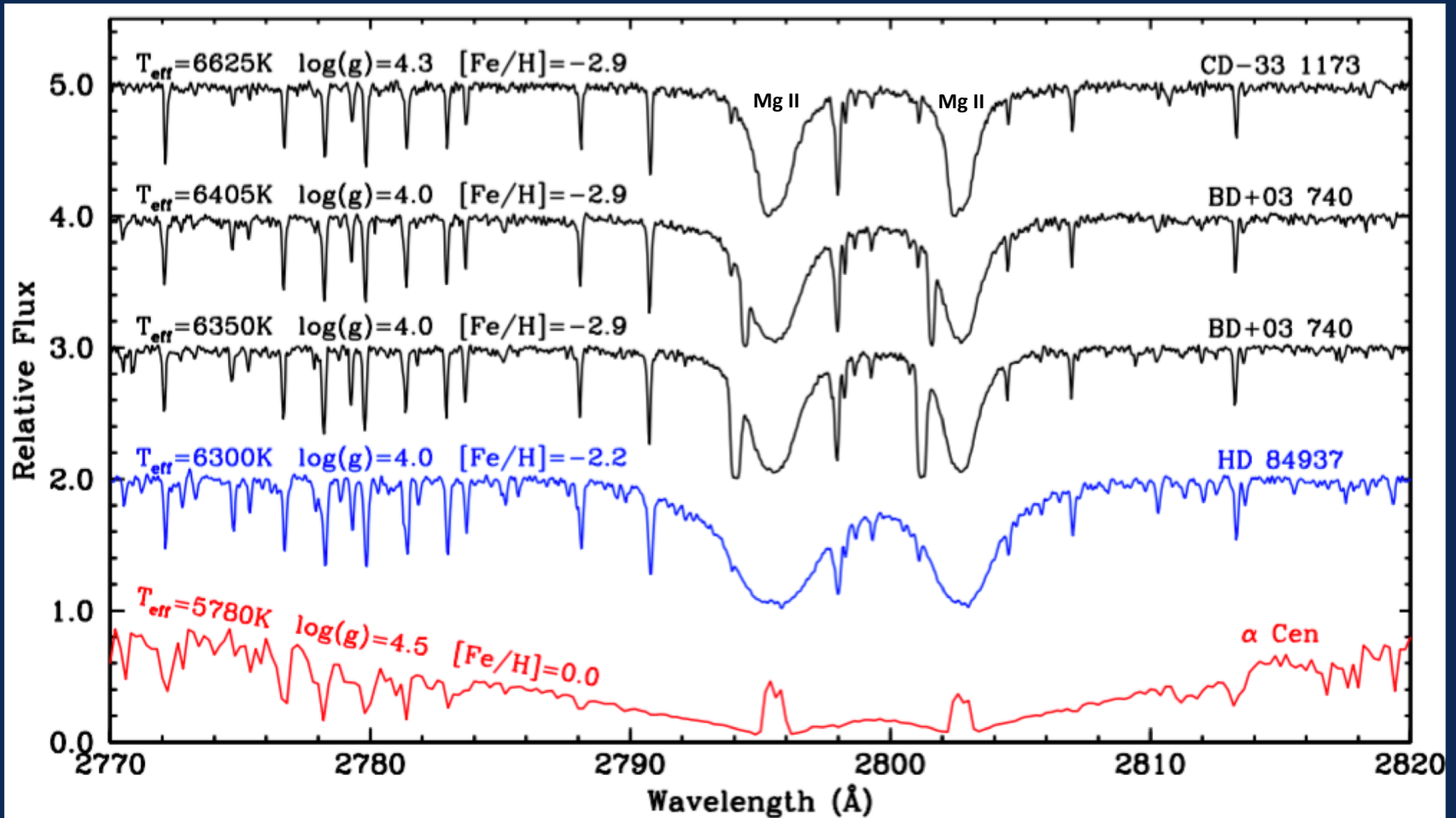
***This means targeting warm main
sequence stars, not red giants***

The blue-yellow region is barren in low metallicity main sequence stars



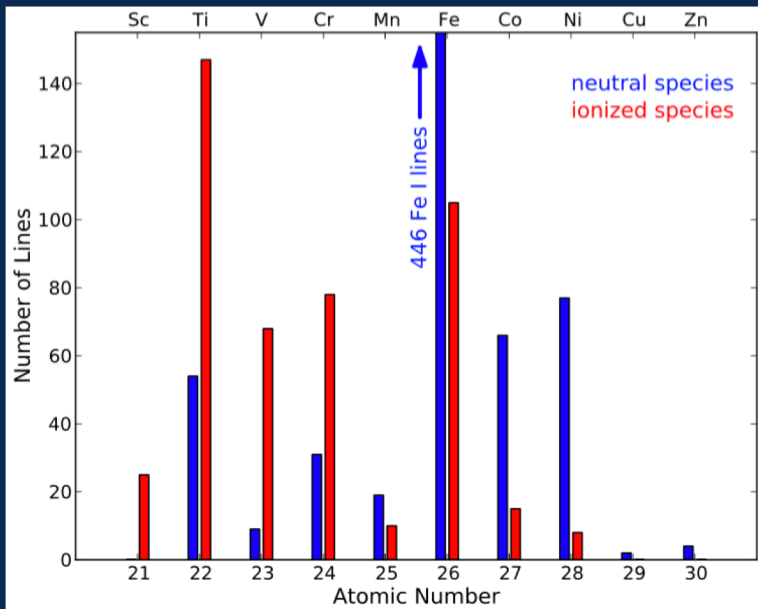
only Fe I, Fe II, and Ti II survive to be detected in these regions at $[\text{Fe}/\text{H}] \sim -3$

In the UV, metal-poor main sequence stars are very accessible for quantitative spectroscopy



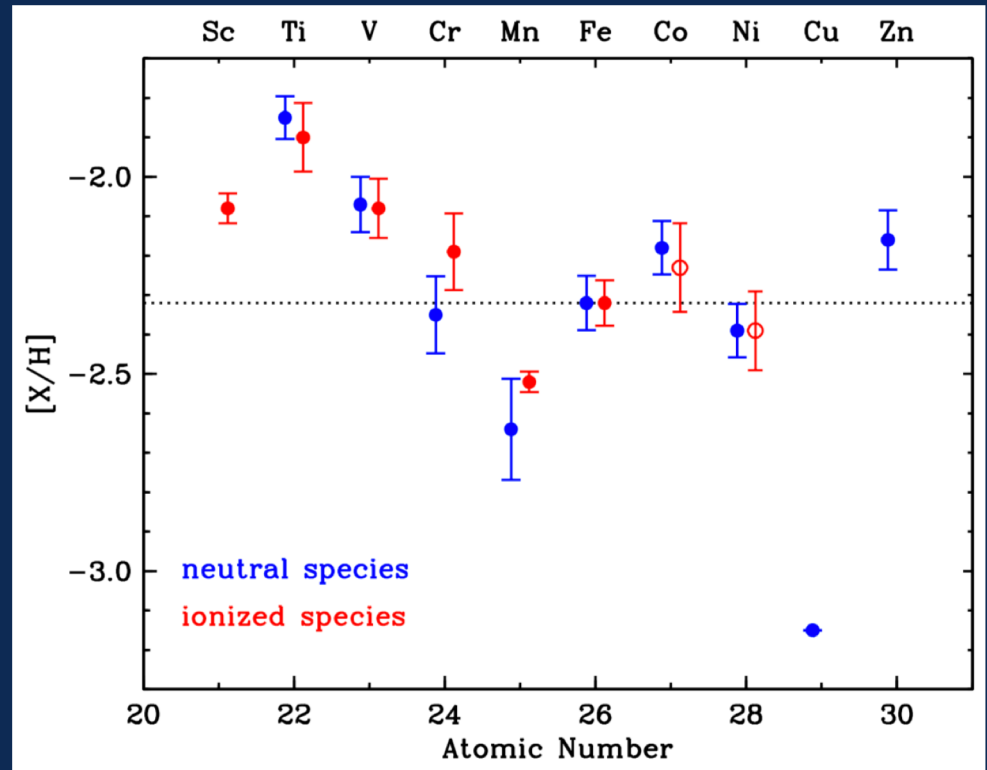
these are HST/STIS spectra: $\lambda = 2300\text{--}3050 \text{ \AA}$ $R = \lambda/\Delta\lambda = 25,000$ $S/N \approx 70$

First results: HD 84937

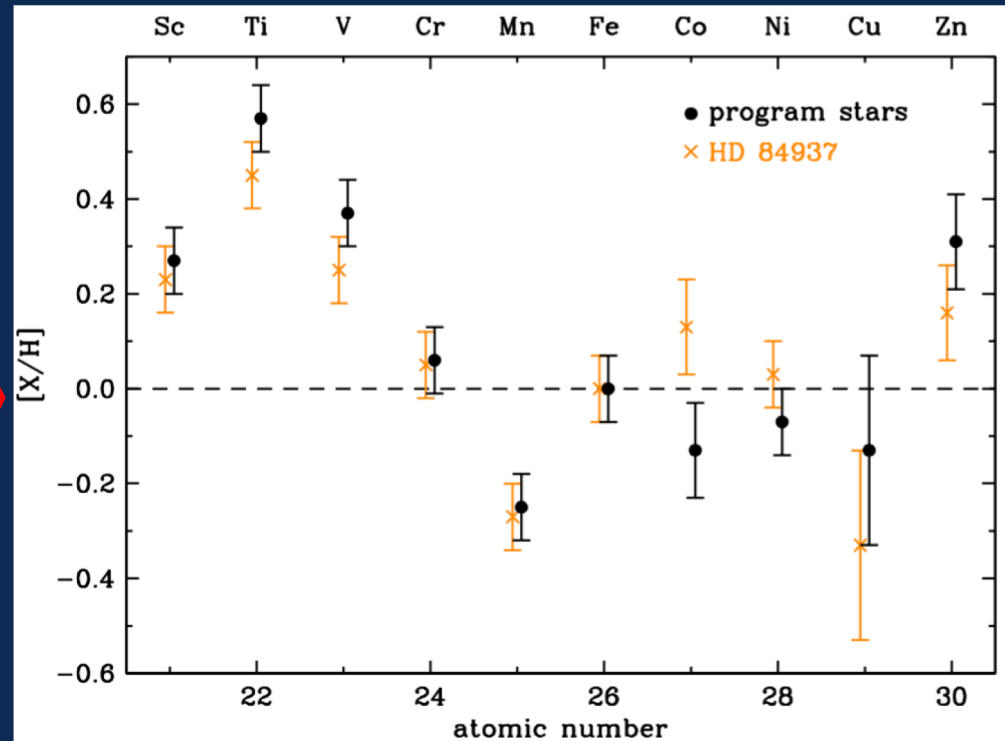
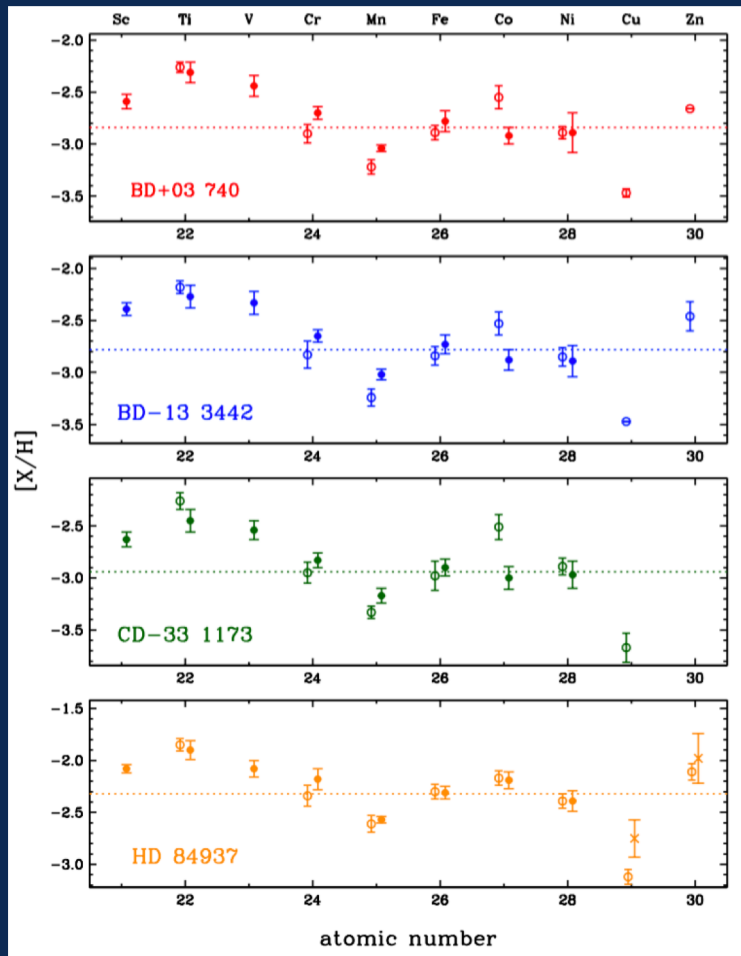


- *neutrals, ions give same abundances for 7 elements: good Saha balance*
- *standard LTE analysis shows no obvious breakdown*

- *at $[Fe/H] = -2.3$ there is no sign of a Cr/Co abundance anomaly*
- *some details reveal possible NLTE effects in neutral species*
- *what about Sc, Ti, and V?*

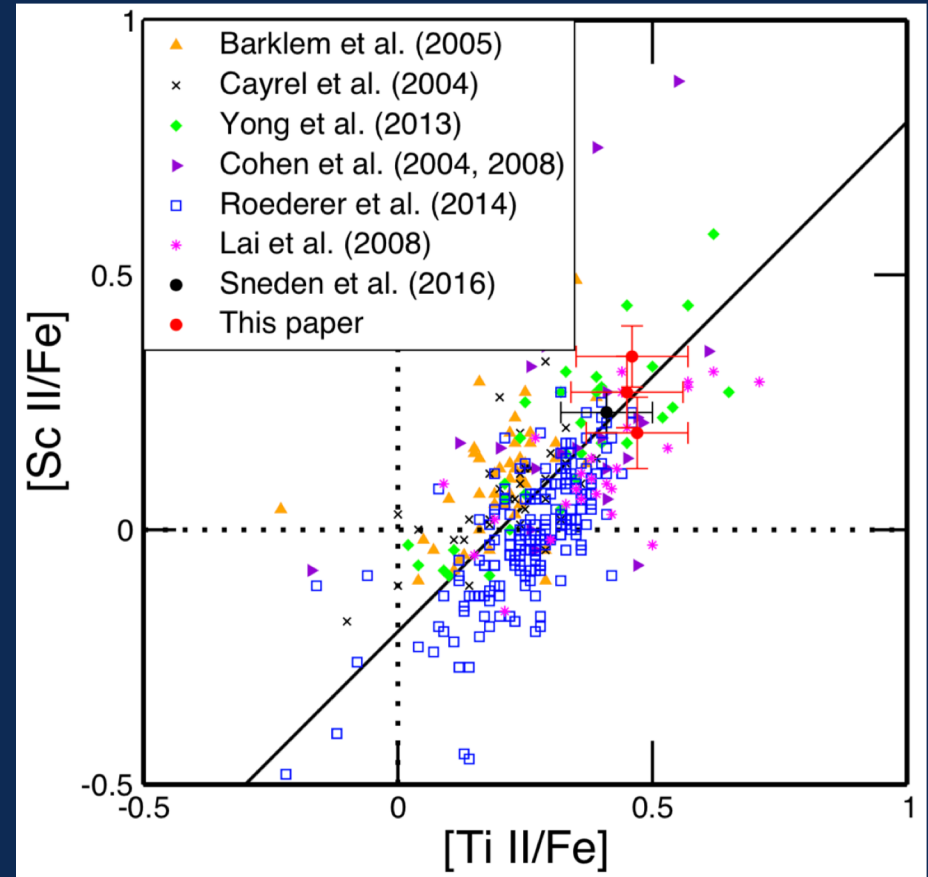
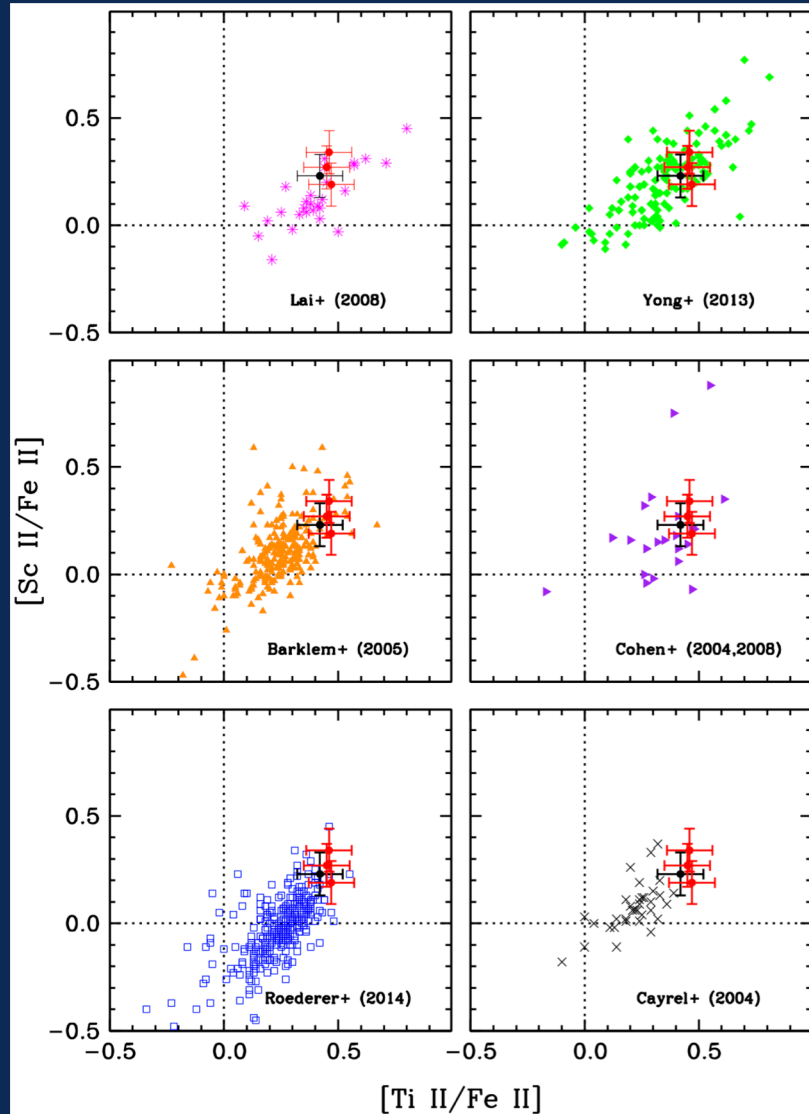


the full “survey” of HST/STIS data on low metallicity main sequence stars



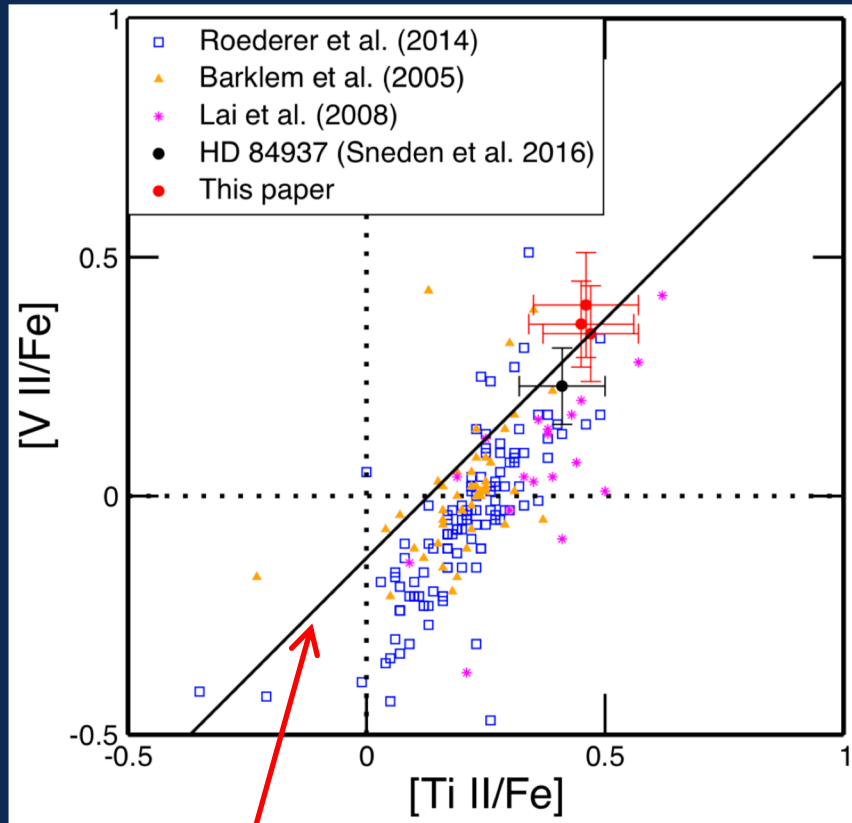
- 1) large overabundances of Sc, Ti, V
- 2) no Cr deficiency
- 3) Co overabundance **only** from Co I

Correlated Sc-Ti-V exist in large surveys, but have not been much noticed

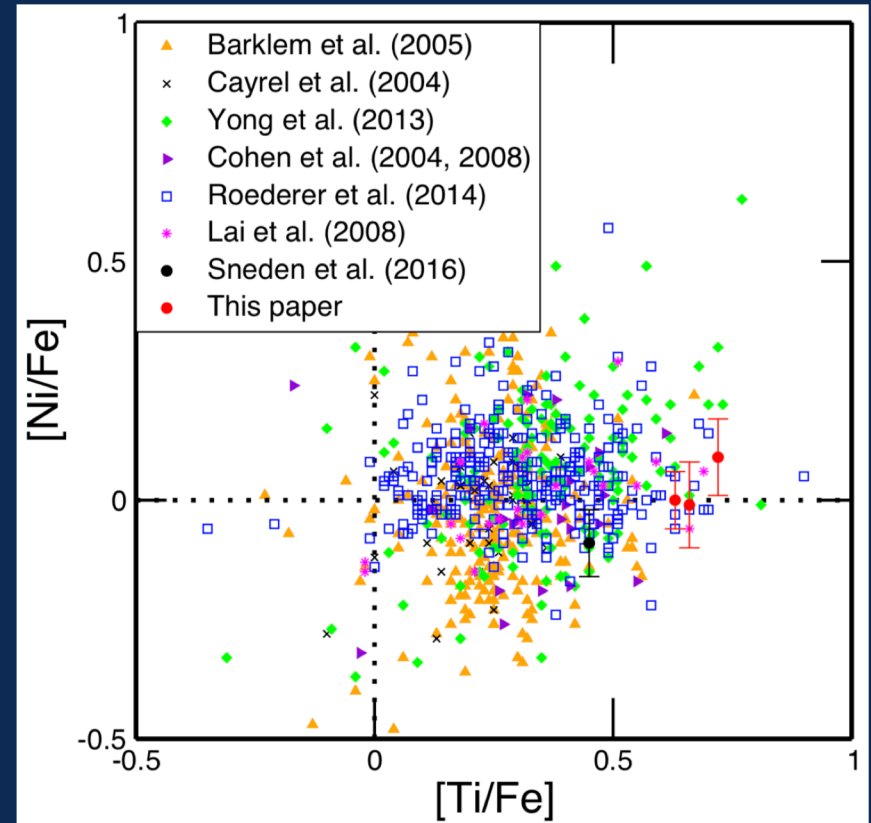


Is this the final “proof” that Ti is NOT an “alpha” element?

The correlation of Ti with V is also clear, but it is absent with heavier Fe-group elements



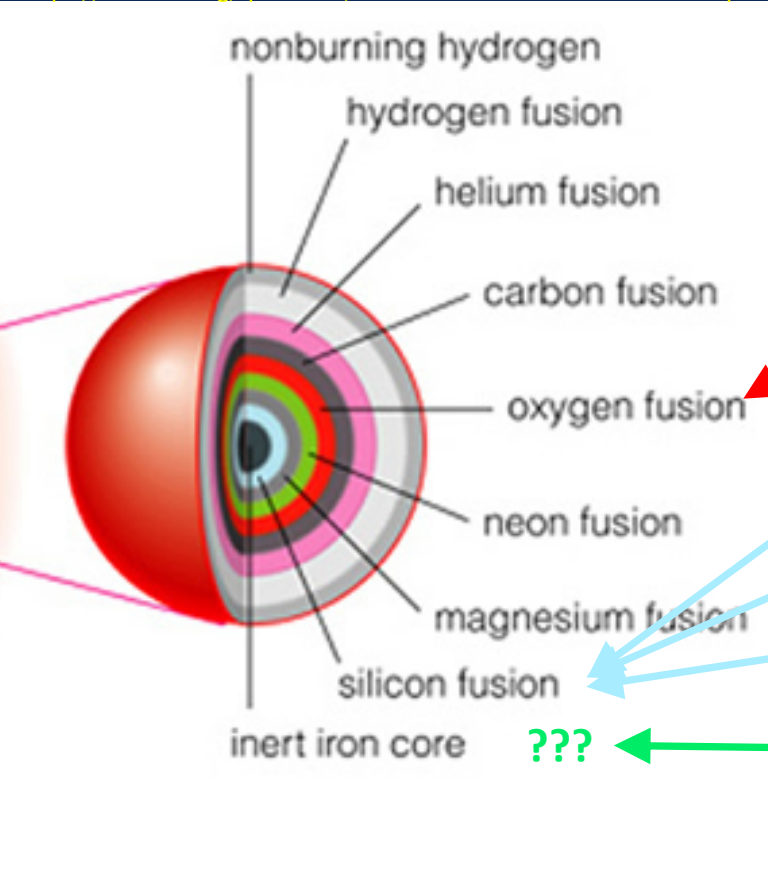
The 45° line is arbitrarily shifted to go through the mean of our 4 stars



and no obvious correlation of [Sc,Ti,V/Fe] with [Cr/Fe], [Mn/Fe], [Co/Fe], ...

Where are the Fe-group elements synthesized in massive stars?

<https://socratic.org/questions/how-is-most-of-a-star-s-total-life-spent>



Probable synthesis site for:

Si, S, Ar – oxygen fusion

Ca, Mn – “incomplete Si fusion”

Ti, Fe, Co, Ni, (Cu) – Si fusion

V, Cr, Zn – Si fusion with $Y_e > 0.5$

Sc – “inner layers with $Y_e > 0.5$ ”

see Curtis et al. 2019

Y_e = proton/nucleon ratio ... strongly affected during the explosion by neutrino and anti-neutrino captures on protons and neutrons

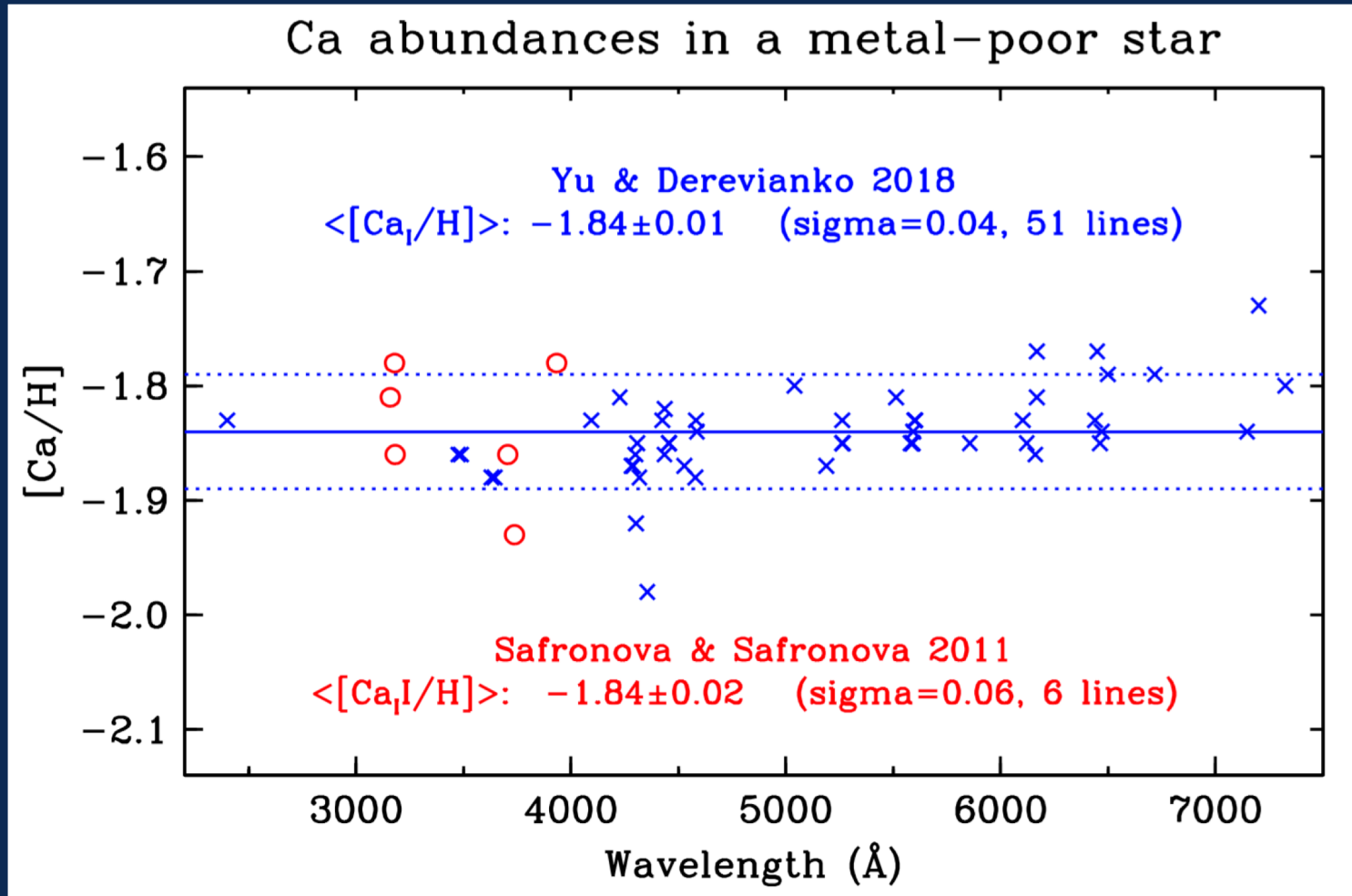
SUMMARY of Fe-group Results

for the first time Fe abundances in metal-poor stars are being derived from (a) enough lines, and (b) with the right (ionized) species

We do not believe past claims of large [Co/Fe] abundances at low metallicity

Sc, Ti, and V ARE correlated — hey nucleosynthesis people: it is time to get back to work

don't stop now! Many very common elements need modern transition data



the Wisconsin group is measuring new lifetimes for Ca

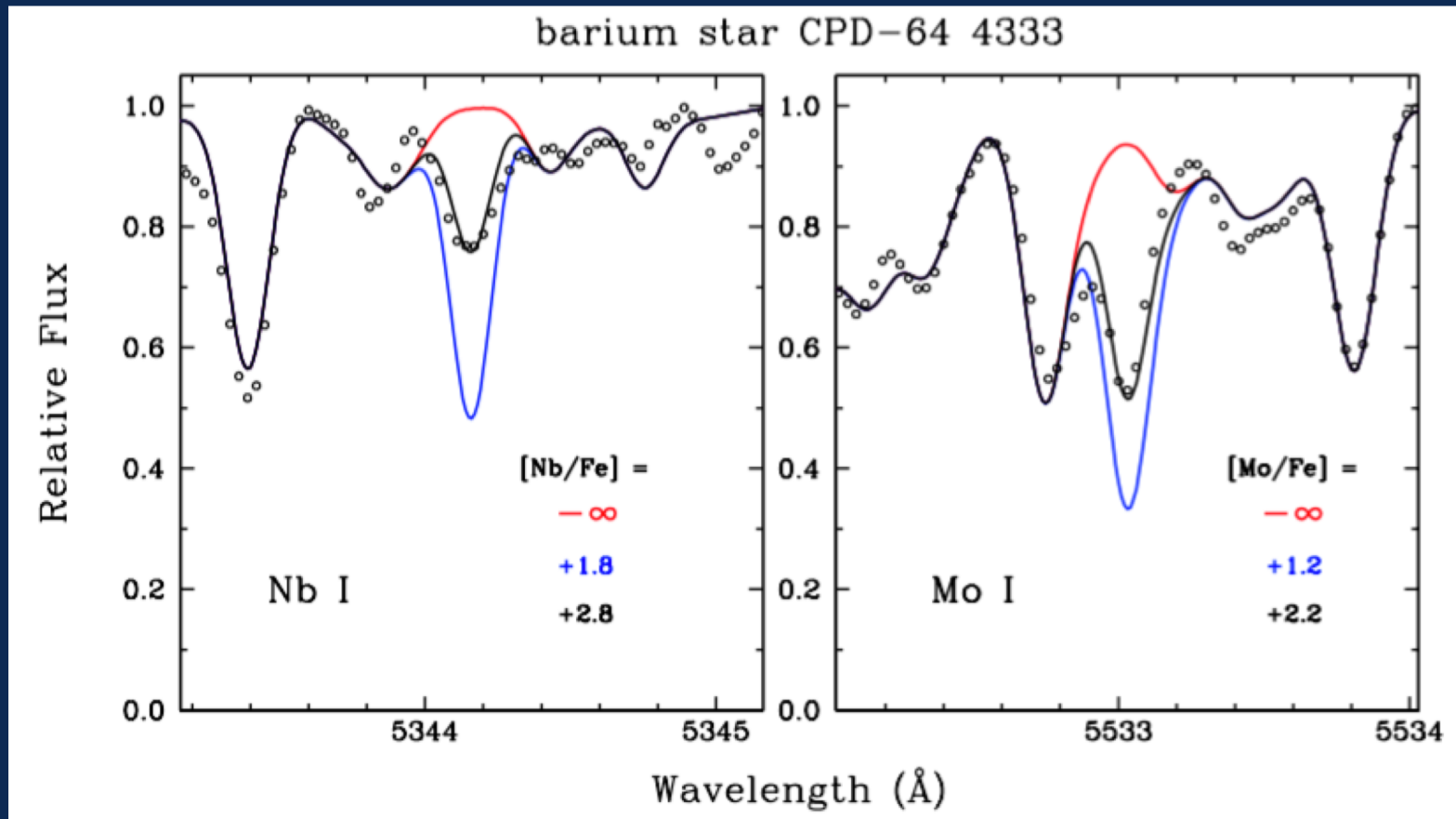
Université de Mons Atomic Physics has contributed greatly to the lab/theory improvements

H	observable n-capture elements																He						
Li	Be 1	observable elements with Mons group papers 1=neutral 2 = first ion																B	C	N	O	F	Ne
Na	Mg																	Al	Si	P	S	Cl	Ar
K	Ca	Sc 2	Ti 2	V	Cr 2	Mn	Fe	Co	Ni 2	Cu	Zn	Ga	Ge 1,2	As 2	Se 2	Br	Kr						
Rb	Sr	Y 1,2	Zr 1,2	Nb 1,2	Mo 1,2	Tc 2	Ru 1,2	Rh 1,2	Pd 1,2	Ag 2	Cd 1,2	In 2	Sn 1	Sb 1	Te 2	I	Xe						
Cs	Ba 1,2		Hf 1	Ta 1,2	W 1,2	Re	Os 1,2	Ir 1,2	Pt 2	Au 1,2	Hg 1	Tl 1	Pb 2	Bi 2	Po	At	Rn						
Fr	Ra 1,2		Rf	Db	Sa	Bh	Hs	Mt	Uun	Uuu	Uub												
		La 1	Ce 2	Pr 2	Nd 1,2	Pm 2	Sm 2	Eu 2	Gd 2	Tb 2	Dy 2	Ho	Er 2	Tm	Yb 2	Lu 1							
		Ac 1,2	Th	Pa	U 2	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr							

Émile Biémont, Pascal Quinet, Patrick Palmeri, Michel Godefroid, and friends

this chart does not show their contributions to more ionized atomic species!

notice that many of their unique contributions have been for “neglected” species

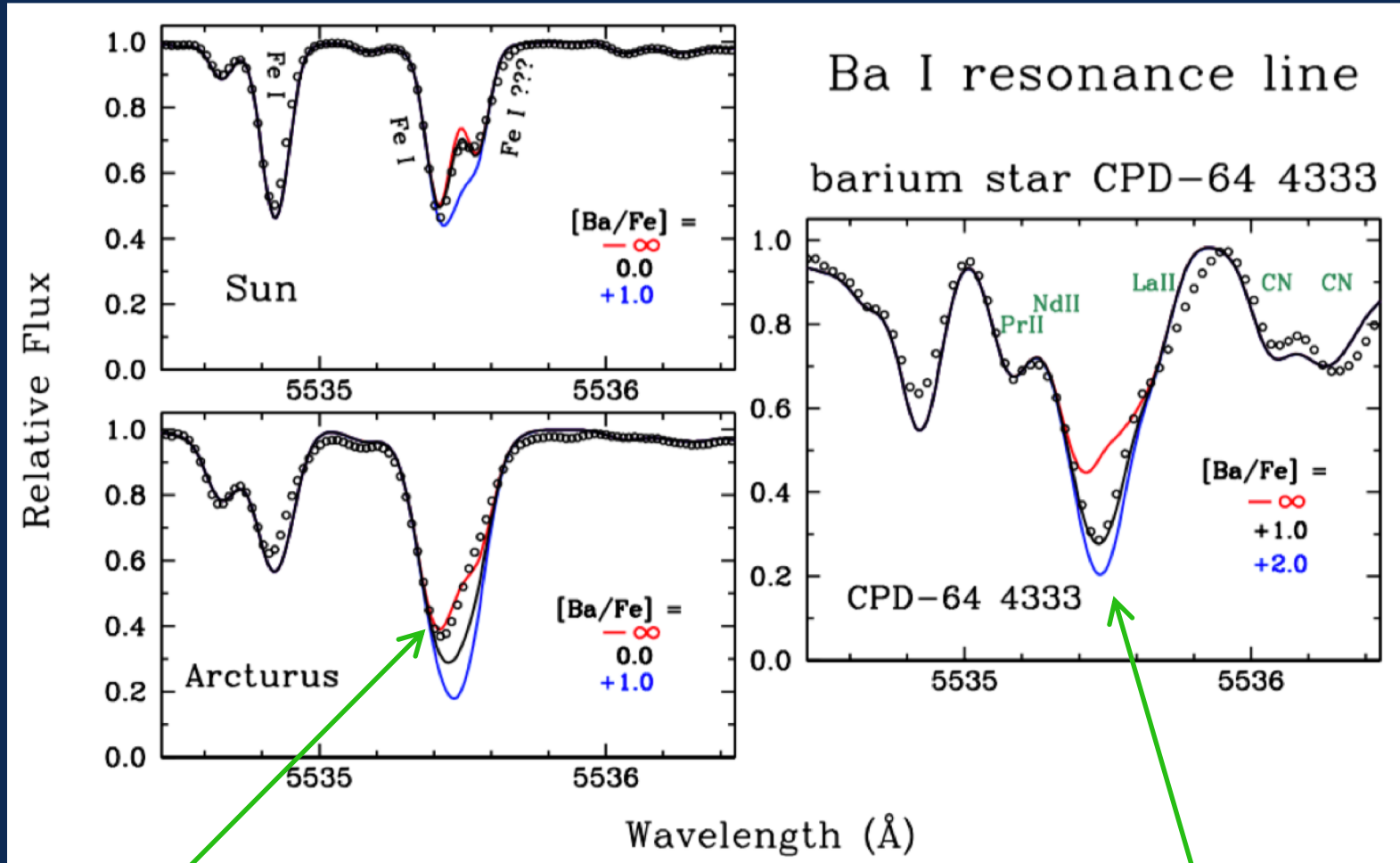


M. Roriz, C. Pereira et al., in prep

barium stars: high metallicity s-process-enhanced red giant stars

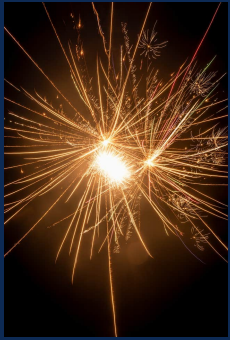
this is just “conscientiousness raising” with easy to detect transitions

Even the very elusive neutral barium is detectable in the right kind of stellar atmosphere



Ba I is undetectable in ordinary stars

Simple detection with a rational abundance is a victory here



we really should be celebrating!

- all aspects of abundance studies in stars of all metallicities have greatly improved over the past several decades
- we are rapidly approaching true “precision” abundance results
- stellar abundances now can quantitatively confront nucleosynthesis theory

but we should not ignore a sobering reality

G. Nave et al. 2019, Bull. Am. Ast. Soc., 51, 1

- atomic spectroscopy has been shrinking ... there could be no groups left at the end of the next decade unless significant effort is made to recruit and train new people
- by the time new UV telescopes are launched (e.g. LUVVOIR) there will be no people left who know how to calibrate them or measure required data for the interpretation of their spectra
- ***What is the purpose of gathering higher spectral resolution observations if the origin of the spectrum is misunderstood and the wavelengths of the lines are not adequately known?***



MANY THANKS FOR INVITING ME TO SPEAK AT THIS MEETING