

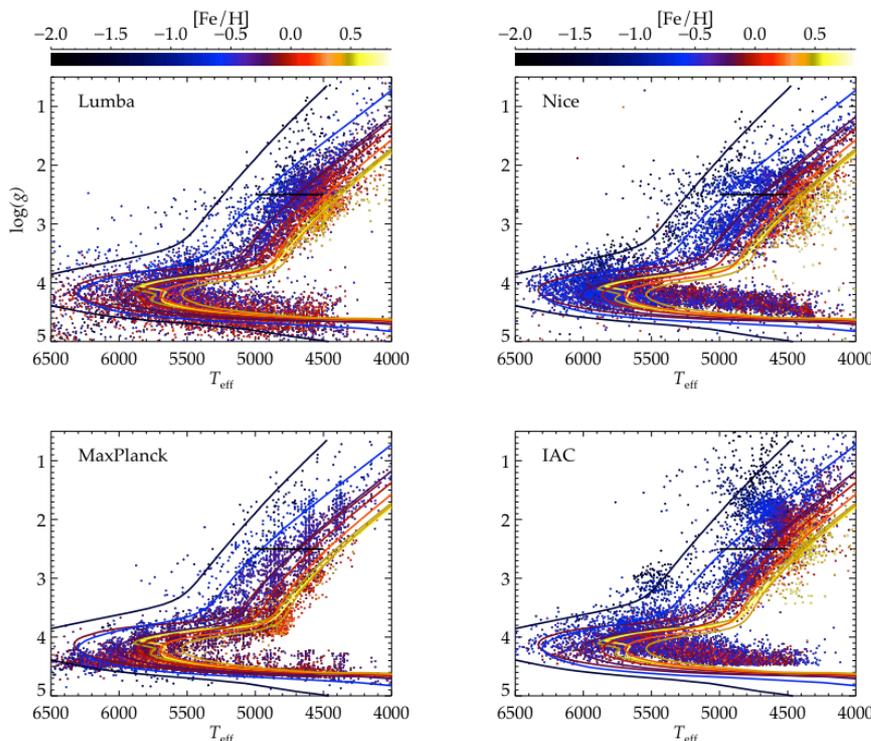
## Final review

This document summarizes the progress made and actions taken by the grant holder (Lind) from the beginning of the project duration (13/03/2014) until the present day. It is divided into sub-categories for convenience. Concluding remarks and a publication list are given at the end.

### Galactic archaeology with stellar surveys

With >400 co-investigators, the Gaia-ESO Public Spectroscopic Survey has grown to dominate the research field of Galactic archaeology in Europe, now more than half-way through its planned 5-year duration. Lind is heavily involved in the data analysis of this unprecedented survey and was awarded so called “builder” status for her efforts in 2013. Since March 2014, she has co-authored 13 Gaia-ESO publications and first-authored one. In addition to data-release and calibration, they describe how survey data have been used to conduct chemo-dynamical studies of clusters and field stars in the Galactic disk (e.g. Bergemann et al. 2014, Recio-Blanco et al. 2014, Magrini et al. 2014, Ruchti et al. 2015, Kordopatis et al 2015).

The publication lead by Lind describes the discovery of the first halo star with strong anomaly in its Mg and Al abundances, a tell-tale signature of a globular cluster origin (Lind et al. 2015). Combining the chemical patterns with backwards orbit-integration, the star was tentatively suggested as an escapee from the massive cluster Omega Centauri – a prediction that, if confirmed by more detailed measurements, would be the first practical realisation of the concept of “chemical tagging” (linking long-lost stellar debris to a progenitor cluster).



*Figure 1: Stellar parameters for ~10,000 stars included in Gaia-ESO’s fourth internal data release. The lines are predictions by stellar models. In competition with leading analysis teams in Europe, Lind’s work (“Lumba”) give the best representation of predicted evolutionary phases and was selected as reference scale for the survey.*

The spectrum analysis method developed by Lind for the Gaia-ESO Survey has proven highly successful in the competition with other leading analysis teams in Europe. Recently, Lind single-

handedly analysed spectra for ~40 000 stars included in the fourth internal data release, more than any other of the thirteen analysis nodes currently involved. Further, the stellar parameters resulting from Lind's pipeline have been assessed to have the smallest systematic errors and therefore selected as reference scale for the survey homogenization work (Figure 1).

Lind has recently adapted her method to enable analysis of spectra of the GALAH survey of half a million bright stars in the solar neighborhood (De Silva et al. 2015). Her pipeline will be exclusively used for abundance analysis of all targets. Finally, she has taken lead of the work package (~35 people) for parameter and abundance analysis of all Galactic sources observed by 4MOST, a next generation multi-object spectrograph that will see first light in ~2020 (de Jong et al. 2014). During her time as a Marie-Curie Fellow Lind has participated in several conferences and workshops for the Gaia-ESO Survey, the GALAH Survey and the 4MOST project.

### NLTE radiative transfer

One of the main goals of the projects is to construct a model atom library for spectral-line formation calculations in non-local thermodynamic equilibrium (NLTE). Lind is co-supervising two PhD students at Uppsala University whose thesis projects involve such calculations. Yeisson Osorio successfully defended his thesis in June 2015. He has constructed a new model atom for magnesium and demonstrates the impact on abundance determination of cool stars in two publications published in A&A (Osorio et al. 2015). Osorio will continue with calcium. Thomas Nordlander is conducting a similar study for aluminum and a first publication is expected soon. Both Mg and Al are astrophysically crucial elements and the new atomic models are free from the large uncertainties in collisional data that plague earlier work.

Lind is further collaborating with PhD student Anish Amarsi at the Australian National University. Amarsi has calculated oxygen NLTE line formation in 3D radiation-hydrodynamical model atmospheres. During Amarsi's research visit to Uppsala in April 2015, significant improvements were made to the MPI-parallelised 3D, NLTE code such that calculations even for extremely complex species (e.g. neutral iron) are now numerically feasible. Lind has also developed a method to simplify complex atoms, while preserving NLTE behavior, to increase numerical efficiency. These results are being written up for publication in MNRAS.

The situation is now such that Lind and her colleagues have well-constrained model atoms for almost all of the astrophysically important lighter elements (Li, Na, O, Mg, Al, Si, Ca). Lind is preparing a publication presenting a new model atom library for all iron peak elements,  $Z=21-30$ , i.e. Sc-Zn, aiming for a publication 2016. The library makes use of last few years' progress in the calculations of energy levels and transition probabilities (Kurucz 2007-2014) as well as collisional cross sections (Barklem et al. in prep). Once finalized, the model atoms will be used for NLTE analysis of large survey data sets, which is currently done only for a few elements.

Largely because of her expertise in NLTE line formation calculations, Lind has previously established close collaborations with colleagues at Australian National University. Since the start of the project in March 2014, this has resulted in two co-authored publications on various aspects of multiple populations in metal-poor globular clusters (Marino et al., 2014, 2015) and four publications on the abundances patterns of the most metal-poor stars in the halo (Jacobsson et al. 2014, Bessel et al. 2015) and the bulge (Howes et al. 2014, 2015). Lind was also asked to perform NLTE calculations for the Sun for Na, Mg, and Ca, for the latest revision of the solar chemical composition (Scott et al. 2014).

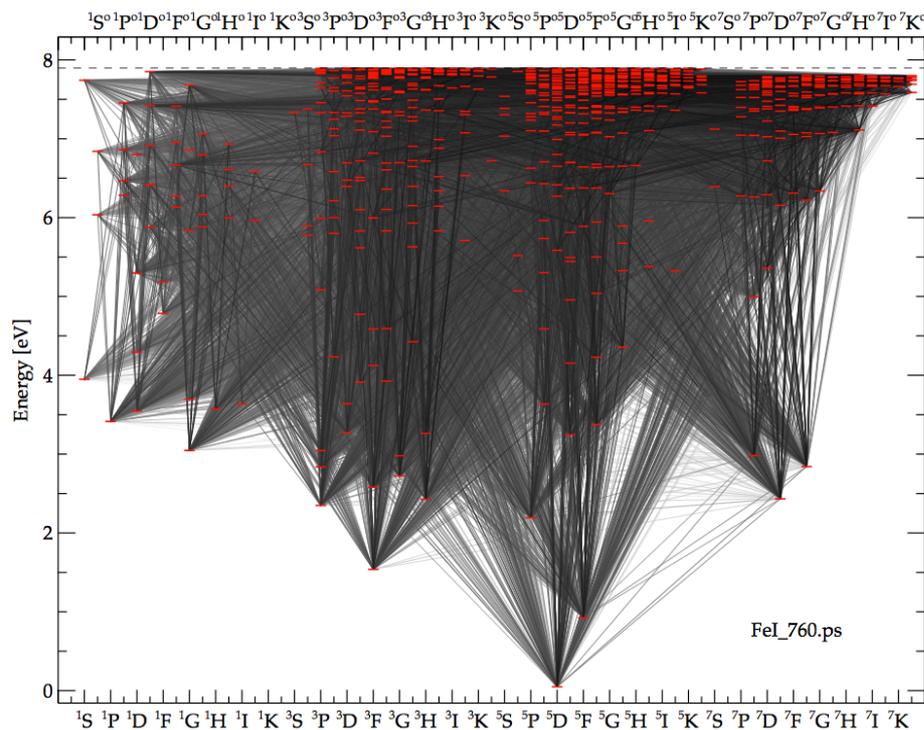


Figure 2: New atomic model for neural iron.

### Teaching and supervision

As detailed above, Lind has taken on the role of co-supervisor for PhD students Nordlander, and Osorio. She has the main supervising responsibility for the second half of Nordlander's thesis.

In 2014, Lind was awarded €40k from the Department of Physics and Astronomy via funds reserved to strengthen gender equality. She used the money to hire postdoc Pieter Gruyters for 4 months, starting in March 2015. Gruyters was hired to analyse Lind's pre-existing VLT observations of the metal-poor globular cluster M30 and use the results to test stellar physics. The results have been written up and a paper submitted to *Astronomy & Astrophysics*. The referee report is positive.

Prior to the start of the project, Lind had limited previous experience with teaching at the undergraduate level (~10 contact hours), which is an important merit to qualify for lectureship positions. She therefore volunteered to undertake the teaching responsibility for a mechanics class for second year engineering students at Uppsala University. This very rewarding experience encompassed ~30 contact teaching hours with students during January-March 2015.

### Conferences and outreach activities

Lind has attended ten international conferences/workshops (see list at the end of the document) since the beginning of the project, including giving seven invited talks. Her work has created publicity worldwide, in particular in connection to the receipt of the Sofja Kovalevskaja Award:

- Participation in a German multi-media outreach project consisting of a short film episode, explaining the origin of the elements in a simplified manner aimed at the general public. The film is available in social media:

<https://www.youtube.com/watch?v=iWCS2qcRkjs>

- Public talk at the Day of Astronomy in Uppsala:

<http://www.astronominsdag.se/upsala>

- Participation in a short radio interview for Swedish Radio in connection to the 200<sup>th</sup> anniversary of the famous astronomer Anders Ångström.

<http://sverigesradio.se/sida/avsnitt/456504?programid=412>

- Newsletter of the Ångström Laboratory, Uppsala (English)

<https://www.uu.se/en/media/news/article/?id=5080&area=5,12,16&typ=artikel&lang=en>

- Local newspaper in Uppsala (in Swedish)

<http://www.physics.uu.se/nyheter/enskild-nyhet/?tarContentId=455588>

- Forschung und Lehre (TBP in German)

[www.forschung-und-lehre.de](http://www.forschung-und-lehre.de)

- Faculty for Science and Technology, Uppsala University, TBP in the annual brochure with information for prospective students (Swedish).

- Interview in local newspaper in Heidelberg

[http://www.rnz.de/wissen/wissenschaft-regional\\_artikel,-Kovalevskaja-Preistraegerin-Karin-Lind-kommt-ans-Heidelberger-Max-Planck-Institut-fuer-Astronomie-\\_arid,143638.html](http://www.rnz.de/wissen/wissenschaft-regional_artikel,-Kovalevskaja-Preistraegerin-Karin-Lind-kommt-ans-Heidelberger-Max-Planck-Institut-fuer-Astronomie-_arid,143638.html)

### Concluding remarks

Since March 2014, Lind has authored 30 refereed journal publications, generating a total of 418 citations and counting. Significant progress has been made for all scientific goals set up for the project and she has taken on leading role in international survey consortia. She has taken steps to further her career development by teaching and supervising at the graduate and undergraduate levels and via participation in a mentorship program for women on non-permanent contracts at the Faculty of Science and Technology.

During 2015, Lind was awarded a €1.6M Sofja Kovalevskaja award from the German Alexander von Humboldt foundation as well as a 0.6M€ Marie Skłodowska Curie International Career Grant by the Swedish Research Council. By acceptance of these substantial grants, the project ended prematurely and her time in Uppsala was cut short by a couple of months. She brought the funds to Germany and is currently in the process of opening her own research group at the Max Planck Institute for Astronomy in Heidelberg. The group will conduct science by means of stellar spectroscopy in the field of Galactic Archaeology, with particular focus on the Milky-Way halo and the first stars.

## List of publications since March 2014

The publications marked with \* have been written by students or postdocs under Lind's supervision at the time of writing.

Howes, L. M., Asplund, M., Casey, A. R., Keller, S. C., Yong, D., Gilmore, G., **Lind, K.**, et al., 2014, *Monthly Notices of the Royal Astronomical Society*, 445, 4241, *The Gaia-ESO Survey: the most metal-poor stars in the Galactic bulge* [**15 citations**]

Den Hartog, E. A., Ruffoni, M. P., Lawler, J. E., Pickering, J. C., **Lind, K.**, & Brewer, N. R., 2014, *The Astrophysical Journal Supplement Series*, 215, 23, *Fe I Oscillator Strengths for Transitions from High-lying Even-parity Levels* [**9 citation**]

Smiljanic, R., Korn, A. J., Bergemann, M., et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 570, A122, *The Gaia-ESO Survey: The analysis of high-resolution UVES spectra of FGK-type stars* [**38 citations**]

Marino, A. F., Milone, A. P., Yong, D., et al. [including **Lind, K.**], 2014, *Monthly Notices of the Royal Astronomical Society*, 442, 3044, *The halo+cluster system of the Galactic globular cluster NGC 1851* [**14 citations**]

Ruffoni, M. P., Den Hartog, E. A., Lawler, J. E., Brewer, N. R., **Lind, K.**, Nave, G., & Pickering, J. C., 2014, *Monthly Notices of the Royal Astronomical Society*, 441, 3127, *Fe I oscillator strengths for the Gaia-ESO survey* [**17 citations**]

Recio-Blanco, A., de Laverny, P., Kordopatis, G., et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 567, A5, *The Gaia-ESO Survey: the Galactic thick to thin disc transition* [**29 citations**]

Damiani, F., Prisinzano, L., Micela, G., et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 566, A50, *Gaia-ESO Survey: Empirical classification of VLT/Giraffe stellar spectra in the wavelength range 6440-6810Å in the  $\gamma$  Velorum cluster, and calibration of spectral indices* [**2 citations**]

Sacco, G. G., Morbidelli, L., Franciosini, E., et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 565, A113, *The Gaia-ESO Survey: processing FLAMES-UVES spectra* [**15 citations**]

Bergemann, M., Ruchti, G. R., Serenelli, A., et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 565, A89, *The Gaia-ESO Survey: radial metallicity gradients and age-metallicity relation of stars in the Milky Way disk* [**39 citations**]

Jofre, P., Heiter, U., Soubiran, C., et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 564, A133, *Gaia FGK benchmark stars: Metallicity* [**56 citations**]

Friel, E. D., Donati, P., Bragaglia, A., et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 563, A117, *Gaia-ESO Survey: Properties of the intermediate age open cluster NGC 4815* [**13 citations**]

Jeffries, R. D., Jackson, R. J., Cottaar, M., et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 563, A94, *The Gaia-ESO Survey: Kinematic structure in the Gamma Velorum*

*cluster* [27 citations]

Magrini, L., Randich, S., Romano, et al. [including **Lind, K.**], 2014, *Astronomy and Astrophysics*, 563, A44, *The Gaia-ESO Survey: Abundance ratios in the inner-disk open clusters Trumpler 20, NGC 4815, NGC 6705* [21 citations]

Scott, P., Grevesse, N., Asplund, M., Sauval, A. J., **Lind, K.**, Takeda, Y., Collet, R., Trampedach, R., & Hayek, W., 2015, *Astronomy and Astrophysics*, 573, AA25, *The elemental composition of the Sun. I. The intermediate mass elements Na to Ca* [25 citations]

**Lind, K.**, Koposov, S. E., Battistini, C., et al., 2015, *Astronomy and Astrophysics*, 575, L12, *The Gaia-ESO Survey: A globular cluster escapee in the Galactic halo* [5 citations]

Lanzafame, A. C., Frasca, A., Damiani, A., et al. [including **Lind, K.**], *Astronomy & Astrophysics*, 576, 80, *The Gaia-ESO Survey: Analysis of pre-main sequence stellar spectra* [9 citations]

Marino A., Milone, A. P., Karakas, A. I., Casagrande, L., Yong, D., Shingles, L., Da Costa, G., Norris, J. E., Stetson, P. B., **Lind, K.** et al., *Monthly Notices of the Royal Astronomical Society*, 450, 815, *Iron and s-elements abundance variations in NGC5286: comparison with anomalous globular clusters and Milky Way satellites* [10 citations]

De Silva, G. M., Freeman, K. C., Bland-Hawthorn J., et al. [including **Lind, K.**], *Monthly Notices of the Royal Astronomical Society*, 449, 2604, *The GALAH Survey: Scientific Motivation* [31 citations]

\* Osorio, Y., Barklem, P. S., **Lind, K.**, Belyaev, A. K., Spielfiedel, A., Guito, M., & Feautrier, N., 2015, *Astronomy & Astrophysics*, 579, 53, *Mg line formation in late-type stellar atmospheres: I. The model atom* [5 citations]

Bessel M. S., Collet R., Keller S., Frebel A., Heger A., Casey A., Masseron T., Asplund M., Jacobson H. R., **Lind, K.**, et al. 2015, *The Astrophysical Journal*, 806, 16, *Nucleosynthesis in a Primordial Supernova: Carbon and Oxygen Abundances in SMSS J031300.36-670839.3* [6 citations]

Jacobson H. R., Keller S., Frebel A., Casey A., Asplund M., Bessel M., Da Costa G. S., **Lind, K.**, et al. 2015, *The Astrophysical Journal*, 807, 171, *High-Resolution Spectroscopic Study of Extremely Metal-Poor Star Candidates from the SkyMapper Survey* [4 citations]

Ruchti, G. R., Read, J. I., Feltzing, S., Serenelli, A. M., McMillan, P., **Lind, K.**, Bensby, T., Bergemann, M. et al., 2015, *Monthly Notices of the Royal Astronomical Society*, 450, 2874, *The Gaia-ESO Survey: a quiescent Milky Way with no significant dark/stellar accreted disc* [11 citations]

Jackson, R. J., Jeffries, R. D., Lewis, J. et al. [including **K. Lind.**], 2015, *Astronomy & Astrophysics*, 580, 75, *The Gaia-ESO Survey: Empirical determination of the precision of stellar radial velocities and projected rotation velocities* [1 citation]

Heiter U., **Lind K.**, Asplund M., Barklem P. S., Bergemann M., Magrini L., Masseron T., Mikolaitis Š., Pickering J. C., Ruffoni, M. P., 2015, *Physica Scripta*, 90, 1040, *Atomic and molecular data for optical stellar spectroscopy* [3 citations]

Hansen C. J., Ludwig H.-G., Seifert W., Koch A., Xu W., Caffau E., Christlieb N., Korn A. J., **Lind K.**, Sbordone L. et al., 2015, *Astronmische Nachrichten*, 336, 665, *Stellar science from a blue wavelength range. A possible design for the blue arm of 4MOST* [**1 citation**]

Jofré, P., Heiter, U., Soubiran, C., A, et al. [including **Lind K.**], 2015, *Astronomy & Astrophysics*, 582, 81, *Gaia FGK benchmark stars: abundances of  $\alpha$  and iron-peak elements* [**5 citations**]

Kordopatis, G., Wyse, R. F. G., Gilmore, G., et al. [including **Lind K.**], 2015, *Astronomy & Astrophysics*, 582, 122, *The Gaia-ESO Survey: characterisation of the  $[\alpha/Fe]$  sequences in the Milky Way discs* [**3 citations**]

Guiglion, G., Recio-Blanco, A., de Laverny, P., et al. [including **Lind K.**], 2015, *Astronomy & Astrophysics*, 583, 91, *The Gaia-ESO Survey: New constraints on the Galactic disc velocity dispersion and its chemical dependencies* [**2 citations**]

Howes L. M., Casey A. R., Asplund M., Keller S. C., Yong D., Nataf D. M., Poleski R., **Lind K.**, et al., 2015, *Nature*, 527, 484, *Extremely metal-poor stars from the cosmic dawn in the bulge of the Milky Way* [**2 citations**]

\* Gruyters P., **Lind K.**, Richard O., Grundahl F., Asplund M., Casagrande L., Milone A., Charbonnel C., Primas F., Korn A. J., accepted after revision in *Astronomy & Astrophysics*, 2016. *Atomic diffusion and mixing in old stars: The lithium content of M30 and the discovery of a Li-rich SGB star*

Conference talks since March 2014

Swedish Days of Astronomy (“Astronomdagarna”)

Uppsala, Sweden, Oct. 2015

Title: *The Accuracy of Stellar Metallicities*

**[Invited Talk]**

4MOST All Hands Meeting

Cambridge, United Kingdom, Sep. 2015

Title: *Galactic Analysis Pipelines*

**[Invited Discussion]**

GALAH All Hands Meeting

Sydney, Australia, Sep. 2015

Title: *SME analysis for the GALAH Survey*

**[Contributed Talk]**

IAU General Assembly: “Stellar Behemoths: Red Supergiants across the Local Universe”

Honolulu, Hawaii, Aug. 2015

Title: *Towards realistic modelling of spectral line formation - lessons learnt from red giants*

**[Invited Talk]**

IAU General Assembly: “Bridging Laboratory Astrophysics and Astronomy”

Honolulu, Hawaii, Aug. 2015

Title: *Modelling cool star spectra with inadequate input physics*

**[Invited Talk]**

MPIA Conference: “Frontiers of Stellar Spectroscopy in the Local Group and Beyond”

Heidelberg, Germany, Apr. 2015

Title: *Modeling the Spectra of Cool Star Atmospheres*

**[Invited Review]**

12<sup>th</sup> Russbach Nuclear Astrophysics School

Rußbach am Paß Gschütt, Austria, Mar. 2015

Title: *New Spectroscopic Analysis Techniques for Galactic Archaeology*

**[Invited Talk]**

Gaia-ESO Survey Second Science Meeting

Porto, Portugal, Nov. 2014

Title: *Systematic Uncertainties in Stellar Spectroscopy*

**[Contributed Talk]**

EWASS 2014: European Week of Astronomy and Space Science

Geneva, Switzerland, Jul. 2014

Title: *NLTE effects on He lines in the Sun and Metal-poor Stars*

**[Contributed Talk]**

AAO Conference: “Great Barriers in Galactic Archaeology”

Palm Cove, Australia, May 2014

Title: *3D and NLTE analysis for large stellar surveys* **[Invited Talk]**