# THE AGB NEWSLETTER

*An electronic publication dedicated to Asymptotic Giant Branch stars and related phenomena*

Official publication of the IAU Working Group on Abundances in Red Giants

No. 157 — 2 August 2010

http://www.astro.keele.ac.uk/AGBnews

Editors: Jacco van Loon and Albert Zijlstra

## *Editorial*

Dear Colleagues,

It is our pleasure to present you the 157$^{\text{th}}$ issue of the AGB Newsletter. There has been a lot of activity, as usual. Besides plenty of interesting articles, two very nice reviews have appeared.

We hope to see many of you in Vienna in two weeks time!

The next issue is planned to be distributed on the 2$^{\text{nd}}$ of September 2010.

Editorially Yours,
Jacco van Loon and Albert Zijlstra

## *Food for Thought*

This month's thought-provoking statement is:

*The key to understanding the interiors of AGB stars is held by astro-seismology.*

Reactions to this statement or suggestions for next month's statement can be e-mailed to agbnews@astro.keele.ac.uk (please state whether you wish to remain anonymous)

# *Refereed Journal Papers*

## Astronomical identification of $CN^-$, the smallest observed molecular anion

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We present the first astronomical detection of a diatomic negative ion, the cyanide anion $CN^-$, as well as quantum mechanical calculations of the excitation of this anion through collisions with para-$H_2$. $CN^-$ is identified through the observation of the $J = 2$–1 and $J = 3$–2 rotational transitions in the C-star envelope IRC +10 216 with the IRAM 30-m telescope. The U-shaped line profiles indicate that $CN^-$, like the large anion $C_6H^-$, is formed in the outer regions of the envelope. Chemical and excitation model calculations suggest that this species forms from the reaction of large carbon anions with N atoms, rather than from the radiative attachment of an electron to CN, as is the case for large molecular anions. The unexpectedly large abundance derived for $CN^-$, 0.25% relative to CN, makes likely its detection in other astronomical sources. A parallel search for the small anion $C_2H^-$ remains so far unconclusive, despite the previous tentative identification of the $J = 1$–0 rotational transition. The abundance of $C_2H^-$ in IRC +10 216 is found to be vanishingly small, $< 0.0014\%$ relative to $C_2H$.

**Accepted for publication in A&A Letters**
*Available from* arXiv:1007.0662

## Transformations between 2MASS, SDSS and *BVI* photometric systems for late-type giants

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We present colour transformations from Two Micron All Sky Survey (2MASS) photometric system to Johnson–Cousins system and to Sloan Digital Sky Survey (SDSS) system for late-type giants and *vice versa*. The giant star sample was formed using surface gravity constraints ($2 < \log g \leq 3$) to Cayrel de Strobel et al.'s (2001) spectroscopic catalogue. 2MASS, SDSS and Johnson–Cousins photometric data was taken from Cutri et al. (2003), Ofek (2008) and van Leeuwen (2007), respectively. The final sample was refined applying the following steps: (1) the data were dereddened, (2) the sample stars selected are of the highest photometric quality. We give two-colour dependent transformations as a function of metallicity as well as independent of metallicity. The transformations provide absolute magnitudes and distance determinations which can be used in space density evaluations at relatively short distances where some or all of the SDSS magnitudes of late-type giants are saturated.

**Accepted for publication in Astronomische Nachrichten**
*Available from* arXiv:1006.4475

## Thermal fluctuations and nanoscale effects in the nucleation of carbonaceous dust grains

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We investigate the role of thermal fluctuations and of the finite number of monomers in small clusters of carbon atoms on the nucleation rate of carbonaceous grains. Thermal fluctuations are due to the quantized nature of the energy exchanges between the clusters, the gas, and the radiation field. Nanoscale effects modify the spontaneous detachment of monomers due to the finite amount of internal energy contained in small clusters. We find that both corrections have a big impact on the stability of the clusters and on the rate of nucleation. We implement our model within a Monte Carlo code to derive the new stability conditions for clusters as well as nucleation rates. Due to computing limitations, we can explore the consequences of this approach only at high temperatures, at which particle interactions are not much less frequent than photon interactions. We found that the combined effect of the detachment correction and the temperature fluctuations produces faster nucleation. We also found that the nucleation rate depends on the composition of the gas and not only on the partial pressure of the compound that condensates into grains. This is a unique result of this model that can be used to prove or disprove it.

**Submitted to MNRAS**
*Available from* arXiv:1006.5726

## Systematic detection of magnetic fields in massive, late-type supergiants

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We report the systematic detection of magnetic fields in massive ($M > 5$ M$_\odot$) late-type supergiants, using spectropolarimetric observations obtained with ESPaDOnS at the Canada–France–Hawai'i Telescope. Our observations reveal detectable Stokes $V$ Zeeman signatures in Least-Squares Deconvolved mean line profiles in one-third of the observed sample of more than 30 stars. The signatures are sometimes complex, revealing multiple reversals across the line. The corresponding longitudinal magnetic field is seldom detected, although our longitudinal field error bars are typically 0.3 G (1 $\sigma$). These characteristics suggest topologically complex magnetic fields, presumably generated by dynamo action. The Stokes $V$ signatures of some targets show clear time variability, indicating either rotational modulation or intrinsic evolution of the magnetic field. We also observe a weak correlation between the unsigned longitudinal magnetic field and the Ca II K core emission equivalent width of the active G2Iab supergiant $\beta$ Dra and the G8Ib supergiant $\epsilon$ Gem.

**Accepted for publication in MNRAS**
*Available from* arXiv:1006.5891

## Numerical simulations of thermohaline convection: Implications for extra-mixing in low-mass RGB stars

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Low-mass stars are known to experience extra-mixing in their radiative zones on the red-giant branch (RGB) above the bump luminosity. To determine if the salt-fingering transport of chemical composition driven by $^3$He burning is efficient enough to produce RGB extra-mixing, 2D numerical simulations of thermohaline convection for physical conditions corresponding to the RGB case have been carried out. We have found that the effective ratio of a salt-finger's length to its diameter $a_{\rm eff} < 0.5$ is more than ten times smaller than the value needed to reproduce observations ($a_{\rm obs} > 7$).

On the other hand, using the thermohaline diffusion coefficient from linear stability analysis together with $a = a_{\rm obs}$ is able to describe the RGB extra-mixing at all metallicities so well that it is tempting to believe that it may represent the true mechanism. In view of these results, follow-up 3D numerical simulations of thermohaline convection for the RGB case are clearly needed.

**Submitted to Astrophysical Journal**
*Available from* arXiv:1006.5481

## Integrated stellar populations: Confronting photometry with spectroscopy

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We investigate the ability of spectroscopic techniques to yield realistic star formation histories (SFHs) for the bulges of spiral galaxies based on a comparison with their observed broadband colors. Full spectrum fitting to optical spectra indicates that recent (within $\sim 1$ Gyr) star formation activity can contribute significantly to the $V$-band flux, whilst accounting for only a minor fraction of the stellar mass budget which is made up primarily of old stars. Furthermore, recent implementations of stellar population (SP) models reveal that the inclusion of a more complete treatment of the thermally pulsating asymptotic giant branch (TP-AGB) phase to SP models greatly increases the NIR flux for SPs of ages 0.2–2 Gyr. Comparing the optical–NIR colors predicted from population synthesis fitting, using models which do not include all stages of the TP-AGB phase, to the observed colors reveals that observed optical–NIR colors are too red compared to the model predictions. However, when a 1 Gyr SP from models including a full treatment the TP-AGB phase is used, the observed and predicted colors are in good agreement. This has strong implications for the interpretation of stellar populations, dust content, and SFHs derived from colors alone.

**Published in The Astrophysical Journal, 718, 768 (2010)**
*Available from* arXiv:1006.3831

## A high resolution VLT/FLAMES study of individual stars in the centre of the Fornax dwarf spheroidal galaxy

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For the first time we show the detailed late-stage chemical evolution history of small nearby dwarf spheroidal galaxy

in the Local Group. We present the results of a high resolution ($R \sim 20\,000$) FLAMES/GIRAFFE abundance study at ESO/VLT of 81 photometrically selected red giant branch stars in the central $25'$ of the Fornax dwarf spheroidal galaxy. We also carried out a detailed comparison of the effects of recent developments in abundance analysis (e.g., spherical models *vs.* plane-parallel) and the automation that is required to efficiently deal with such large data sets. We present abundances of $\alpha$-elements (Mg, Si, Ca and Ti), iron-peak elements (Fe, Ni and Cr) and heavy elements (Y, Ba, La, Nd and Eu). Our sample was randomly selected, and is clearly dominated by the younger and more metal rich component of Fornax which represents the major fraction of stars in the central region. This means that the majority of our stars are 1–4 Gyr old, and thus represent the end phase of chemical evolution in this system. Our sample of stars has unusually low [$\alpha$/Fe], [Ni/Fe] and [Na/Fe] compared to the Milky Way stellar populations at the same [Fe/H]. The particularly important role of stellar winds from low metallicity AGB stars in the creation of $s$-process elements is clearly seen from the high [Ba/Y]. Furthermore, we present evidence for an $s$-process origin of Eu.

**Accepted for publication in A&A**
*Available from* arXiv:1007.1007

## Water content and wind acceleration in the envelope around the oxygen-rich AGB star IK Tau as seen by Herschel/HIFI

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During their asymptotic giant branch, evolution low-mass stars lose a significant fraction of their mass through an intense wind, enriching the interstellar medium with products of nucleosynthesis. We observed the nearby oxygen-rich asymptotic giant branch star IK Tau using the high-resolution HIFI spectrometer onboard *Herschel*. We report on the first detection of $H_2{}^{16}O$ and the rarer isotopologues $H_2{}^{17}O$ and $H_2{}^{18}O$ in both the ortho and para states. We deduce a total water content (relative to molecular hydrogen) of $6.6 \times 10^{-5}$, and an ortho-to-para ratio of 3:1. These results are consistent with the formation of $H_2O$ in thermodynamical chemical equilibrium at photospheric temperatures, and does not require pulsationally induced non-equilibrium chemistry, vaporization of icy bodies or grain surface reactions. High-excitation lines of $^{12}CO$, $^{13}CO$, $^{28}SiO$, $^{29}SiO$, $^{30}SiO$, HCN, and SO have also been detected. From the observed line widths, the acceleration region in the inner wind zone can be characterized, and we show that the wind acceleration is slower than hitherto anticipated.

**Accepted for publication in Astronomy & Astrophysics**
*Available from* arXiv:1007.1102

## Quantifying the uncertainties of chemical evolution studies. II. Stellar yields

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Context. Galactic chemical evolution models are useful tools for interpreting the large body of high-quality observational data on the chemical composition of stars and gas in galaxies that have become available in recent years.

Aims. This is the second paper of a series that aims at quantifying the uncertainties in chemical evolution model predictions related to the underlying model assumptions. Specifically, it deals with the uncertainties due to the choice of the stellar yields.
Methods. We adopted a widely used model for the chemical evolution of the Galaxy to test the effects of changing the stellar nucleosynthesis prescriptions on the predicted evolution of several chemical species. Up-to-date results from stellar evolutionary models were carefully taken into account.
Results. We find that, except for a handful of elements whose nucleosynthesis in stars is well understood by now, large uncertainties still affect model predictions. This is especially true for the majority of the iron-peak elements, but also for much more abundant species such as carbon and nitrogen. The main causes of the mismatch we find among the outputs of different models assuming different stellar yields and among model predictions and observations are (i) the adopted location of the mass cut in models of type II supernova explosions, (ii) the adopted strength and extent of hot bottom burning in models of asymptotic giant branch stars, (iii) the neglection of the effects of rotation on the chemical composition of the stellar surfaces, (iv) the adopted rates of mass loss and of (v) nuclear reactions, and (vi) the different treatments of convection.
Conclusions. Our results suggest that it is mandatory to include processes such as hot bottom burning in intermediate-mass stars and rotation in stars of all masses in accurate studies of stellar evolution and nucleosynthesis. In spite of their importance, both these processes still have to be better understood and characterized. As for massive stars, presupernova models computed with mass loss and rotation are available in the literature, but they still wait for a self-consistent coupling with the results of explosive nucleosynthesis computations.

**Accepted for publication in Astronomy and Astrophysics**
*Available from* arXiv:1006.5863

# Oscillation mode lifetimes of red giants observed during the initial and first anticentre long run of CoRoT

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Long timeseries of data increase the frequency resolution in the power spectrum. This allows for resolving stochastically excited modes with long mode lifetimes, as well as features that are close together in frequency. The CoRoT fields observed during the initial run and second long run partly overlap, and stars in this overlapping field observed in both runs are used to create timeseries with a longer timespan than available from the individual runs. We aim to measure the mode lifetimes of red giants and compare them with theoretical predictions. We also investigate the dependence of the mode lifetimes on frequency and the degree of the oscillation modes. We perform simulations to investigate the influence of the gap in the data between the initial and second long run, the total length of the run and the signal-to-noise ratio on the measured mode lifetime. This provides us with a correction factor to apply to the mode lifetimes measured from a maximum likelihood fit to the oscillation frequencies. We find that the length of the timeseries, the signal-to-noise ratio and possible gaps do have a non-negligible effect on the measurements of the mode lifetime of stochastically excited oscillation modes, but that we can correct for it. For the four stars for which we can perform a fit of the oscillation frequencies, we find that the mode lifetimes depend on frequency and on degree of the mode, which is in quantitative agreement with theoretical predictions.

**Accepted for publication in A&A**
*Available from* arXiv:1006.4284

# IPHAS extinction distances to Planetary Nebulae

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The determination of reliable distances to Planetary Nebulae (PNe) is one of the major limitations in the study of this class of objects in the Galaxy. The availability of new photometric surveys such as IPHAS covering large portions of the sky gives us the opportunity to apply the "extinction method" to determine distances of a large number of objects. The technique is applied to a sample of 137 PNe located between $-5^\circ$ and $+5^\circ$ in Galactic latitude, and between $29.52^\circ$ and $215.49^\circ$ in longitude. The characteristics of the distance–extinction method and the main sources of errors are carefully discussed. The data on the extinction of the PNe available in the literature, complemented by new observations, allow us to determine extinction distances for 70 PNe. A comparison with statistical distance scales from different authors is presented.

**Accepted for publication in A&A**
*Available from* arXiv:1007.0939
*and from* http://www.iac.es/folleto/research/preprints/?c=view&pre_id=10052

# Ba stars and other binaries in first- and second-generation stars in globular clusters

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The determination of the Ba abundance in globular cluster (GC) stars is a very powerful test to address several issues in the framework of multiple population scenarios. We measured the Ba content for a sample of more than 1200 stars in 15 Galactic GCs, using high-resolution FLAMES/Giraffe spectra. We found no variation in [Ba/Fe] ratios for different stellar populations within each cluster; this means that low-mass asymptotic giant branch stars do not significantly contribute to the intracluster pollution. Very interestingly, we obtained that the fraction of Ba stars in first generation (FG) stars is close to the values derived for field stars ($\sim 2\%$); on the other hand, second-generation (SG) stars present a significant lower fraction. An independent and successful test, based on radial velocity variations among giant stars in NGC 6121, confirms our finding: the binary fraction among FG stars is about $\sim 12\%$ to be compared with $\sim 1\%$ of SG stars. This is an evidence that SG stars formed in a denser environment, where infant mortality of binary systems was particularly efficient.

**Accepted for publication in The Astrophysical Journal Letters**
*Available from* arXiv:1007.2164

# Lithium abundances in red giants of M 4: evidence for AGB stars pollution in globular clusters?

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The determination of Li and proton-capture element abundances in globular cluster (GC) giants allows us to constrain several key questions on the multiple population scenarios in GCs, from formation and early evolution, to pollution and dilution mechanisms. In this Letter, we present our results on Li abundances for a large sample of giants in the intermediate-metallicity GC NGC 6121 (M 4), for which Na and O have been already determined by Marino et al. The stars analyzed are both below and above the red giant branch bump luminosity. We found that the first and second generation stars share the same Li content, suggesting that a Li production must have occurred. This is a strong observational evidence providing support for the scenario in which asymptotic giant branch stars are GC polluters.

**Published in The Astrophysical Journal, 716, L166 (2010)**
*Available from* arXiv:1005.3376

# Echoes of a decaying planetary system: the gaseous and dusty disks surrounding three white dwarfs

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We have performed a comprehensive ground-based observational program aimed at characterizing the circumstellar material orbiting three single white dwarf stars previously known to possess gaseous disks. Near-infrared imaging unambiguously detects excess infrared emission towards Ton 345 and allows us to refine models for the circumstellar dust around all three white dwarf stars. We find that each white dwarf hosts gaseous and dusty disks that are roughly spatially coincident, a result that is consistent with a scenario in which dusty and gaseous material has its origin in remnant parent bodies of the white dwarfs' planetary systems. We briefly describe a new model for the gas disk heating mechanism in which the gaseous material behaves like a "Z II" region. In this Z II region, gas primarily composed of metals is photoionized by ultraviolet light and cools through optically thick allowed Ca II-line emission.

**Accepted for publication in ApJ**
*Available from* arXiv:1007.2023

# Period–luminosity relations of pulsating M giants in the solar neighbourhood and the Magellanic Clouds

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We analyse the results of a 5.5-yr photometric campaign that monitored 247 southern, semiregular variables with relatively precise Hipparcos parallaxes to demonstrate an unambiguous detection of Red Giant Branch (RGB) pulsations in the solar neighbourhood. We show that Sequence A′ contains a mixture of AGB and RGB stars, as indicated by a temperature related shift at the TRGB. Large Magellanic Cloud (LMC) and Galactic sequences are compared in several ways to show that the P–L sequence zero-points have a negligible metallicity dependence. We describe a new method to determine absolute magnitudes from pulsation periods and calibrate the LMC distance modulus using Hipparcos parallaxes to find $\mu_{\rm LMC} = 18.54 \pm 0.03$ mag. Several sources of systematic error are discussed to explain discrepancies between the MACHO and OGLE sequences in the LMC. We derive a relative distance modulus of the Small Magellanic Cloud (SMC) relative to the LMC of $\Delta\mu = 0.41 \pm 0.02$ mag. A comparison of other pulsation properties, including period–amplitude and luminosity–amplitude relations, confirms that RGB pulsation properties are consistent and universal, indicating that the RGB sequences are suitable as high-precision distance indicators. The M giants with the shortest periods bridge the gap between G and K giant solar-like oscillations and M-giant pulsation, revealing a smooth continuity as we ascend the giant branch.

**Accepted for publication in MNRAS**

*Available from* arXiv:1007.2974

# *Herschel*/HIFI observations of high-$J$ CO transitions in the protoplanetary nebula CRL 618

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We performed *Herschel*/HIFI observations of several CO lines in the far-infrared/sub-mm in the protoplanetary nebula CRL 618. The high spectral resolution provided by HIFI allows measurement of the line profiles. Since the dynamics and structure of the nebula is well known from mm-wave interferometric maps, it is possible to identify the contributions of the different nebular components (fast bipolar outflows, double shells, compact slow shell) to the line profiles. The observation of these relatively high-energy transitions allows an accurate study of the excitation conditions in these components, particularly in the warm ones, which cannot be properly studied from the low-energy lines.
The $^{12}$CO $J = 16$–15, 10–9, and 6–5 lines are easily detected in this source. $^{13}$CO $J = 10$–9 and 6–5 are also detected. Wide profiles showing spectacular line wings have been found, particularly in $^{12}$CO 16–15. Other lines observed simultaneously with CO are also shown. Our analysis of the CO high-$J$ transitions, when compared with the existing models, confirms the very low expansion velocity of the central, dense component, which probably indicates that the shells ejected during the last AGB phases were driven by radiation pressure under a regime of maximum transfer of momentum. No contribution of the diffuse halo found from mm-wave data is identified in our spectra, because of its low temperature. We find that the fast bipolar outflow is quite hot, much hotter than previously estimated; for instance, gas flowing at 100 km s$^{-1}$ must have a temperature higher than $\sim 200$ K. Probably, this very fast outflow, with a kinematic age $< 100$ yr, has been accelerated by a shock and has not yet cooled down. The double empty shell found from mm-wave mapping must also be relatively hot, in agreement with the previous estimate.

**Accepted for publication in Astronomy & Astrophysics**

*Available from* arXiv:1007.1570

# *Herschel*/HIFI deepens the circumstellar $NH_3$ enigma

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Circumstellar envelopes (CSEs) of a variety of evolved stars have been found to contain ammonia ($NH_3$) in amounts that exceed predictions from conventional chemical models by many orders of magnitude. The observations reported here were performed in order to better constrain the $NH_3$ abundance in the CSEs of four, quite diverse, oxygen-rich stars using the $NH_3$ ortho $J_K = 1_0$–$0_0$ ground-state line. We used the Heterodyne Instrument for the Far Infrared aboard *Herschel* to observe the $NH_3$ $J_K = 1_0$–$0_0$ transition near 572.5 GHz, simultaneously with the ortho-$H_2O$ $J_{Ka,Kc} = 1_{1,0}$–$1_{0,1}$ transition, toward VY CMa, OH 26.5+0.6, IRC +10 420, and IK Tau. We conducted non-LTE radiative transfer modeling with the goal to derive the $NH_3$ abundance in these objects' CSEs. For the latter two stars, Very Large Array imaging of $NH_3$ radio-wavelength inversion lines were used to provide further constraints, particularly on the spatial extent of the $NH_3$-emitting regions. Results. We find remarkably strong $NH_3$ emission in all of our objects with the $NH_3$ line intensities rivaling those obtained for the ground state $H_2O$ line. The $NH_3$ abundances relative to $H_2$ are very high and range from $2 \times 10^{-7}$ to $3 \times 10^{-6}$ for the objects we have studied. Our observations confirm and even deepen the circumstellar $NH_3$ enigma. While our radiative transfer modeling does not yield satisfactory fits to the observed line profiles, it leads to abundance estimates that confirm the very high values found in earlier studies. New ways to tackle this mystery will include further *Herschel* observations of more $NH_3$ lines and imaging with the Expanded Very Large Array.

**Accepted for publication in Astronomy & Astrophysics**
*Available from* arXiv:1007.1413

# The effects of stellar population synthesis on the distributions of the asteroseismic observables $\nu_{\rm max}$ and $\Delta\nu$ of red-clump stars

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The distributions of the frequencies of the maximum oscillation power ($\nu_{\rm max}$) and the large frequency separation ($\Delta\nu$) of red giant stars observed by CoRoT have a dominant peak. Miglio et al. (2009) identified that the stars are red-clump stars. Using stellar population synthesis method, we studied the effects of Reimers mass loss, binary interactions, star formation rate and the mixing-length parameter on the distributions of the $\nu_{\rm max}$ and $\Delta\nu$ of red-clump stars. The Reimers mass loss can result in an increase in the $\nu_{\rm max}$ and $\Delta\nu$ of old population which lost a considerable amount of mass. However, it leads to a small decrease in those of middle-age population which lost a little bit of mass. Furthermore, a high mass-loss rate impedes the low-mass and low-metal stars evolving into core-helium burning (CHeB) stage. Both Reimers mass loss and star formation rate mainly affect the number of CHeB stars with $\nu_{\rm max}$ and $\Delta\nu$, but hardly affect the peak locations of $\nu_{\rm max}$ and $\Delta\nu$. Binary interactions also can lead to an increase or decrease in the $\nu_{\rm max}$ and $\Delta\nu$ of some stars. However, the fraction of CHeB stars undergoing binary interactions is very small in our simulations. Therefore, the peak locations are also not affected by binary interactions. The non-uniform distributions of $\nu_{\rm max}$ and $\Delta\nu$ and are mainly caused by the most of red-clump stars having an approximate radius rather than mass. The radius of red-clump stars decreases with increasing the mixing-length parameter. The peak locations of $\nu_{\rm max}$ and $\Delta\nu$ can, thus, be affected by the mixing-length parameter.

**Accepted for publication in MNRAS**
*Available from* arXiv:1007.1752

# ATCA observations of SiO masers in the Galactic Center

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We present the Australia Telescope Compact Array (ATCA) observations of the SiO masers in the Galactic Center in transitions of $v = 1$, $J = 2$–1 at 86 GHz and $v = 1$, $J = 1$–0 at 43 GHz. Two 86-GHz SiO masers were detected within the central parsec, and they are associated with IRS 10EE and IRS 15NE, respectively. We detected eighteen 43-GHz SiO masers within a projected separation of $< 2$ pc from Sagittarius A$^\star$ (Sgr A$^\star$), among which seven masers are newly discovered from our observations. This raises the total number of 43-GHz SiO masers within the central 4 parsecs of the GC region to 22. Simultaneous observations at 86 and 43 GHz showed that the intensity of 43-GHz SiO maser is $\sim 3$ times higher than that of 86-GHz maser in IRS 10EE (an OH/IR star), while the integrated flux of the SiO maser emission at 43 GHz is comparable with that at 86 GHz in IRS 15NE (an ordinary Mira variable). These results are consistent with previous observations of massive late-type stars in the Galaxy in which the 86-GHz SiO maser is in general weaker than the 43-GHz SiO maser in OH/IR stars, while the two transitions are comparably strong in Mira stars.

**Accepted for publication in ApJ Letters**
*Available from* arXiv:1007.4788

## Infrared period–luminosity relations of evolved variable stars in the Large Magellanic Cloud

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We combine variability information from the *MAssive Compact Halo Objects* (MACHO) survey of the Large Magellanic Cloud (LMC) with infrared photometry from the Spitzer Space Telescope *Surveying the Agents of a Galaxy's Evolution* (SAGE) survey to create a dataset of $\sim 30\,000$ variable red sources. We photometrically classify these sources as being on the first ascent of the Red Giant Branch (RGB), or as being in one of three stages along the Asymptotic Giant Branch (AGB): oxygen-rich, carbon-rich, or highly reddened with indeterminate chemistry ("extreme" AGB candidates). We present linear period–luminosity relationships for these sources using 8 separate infrared bands (J, H, K, 3.6, 4.5, 5.8, 8.0, and 24 $\mu$m) as proxies for the luminosity. We find that the wavelength dependence of the slope of the period–luminosity relationship is different for different photometrically determined classes of AGB stars. Stars photometrically classified as O-rich show the least variation of slope with wavelength, while dust-enshrouded extreme AGB stars show a pronounced trend toward steeper slopes with increasing wavelength. We find that O-rich AGB stars pulsating in the fundamental mode obey a period–magnitude relation with a slope of $-3.41 \pm 0.04$ when magnitude is measured in the 3.6-$\mu$m band, in contrast to C-rich AGB stars, which obey a relation of slope $-3.77 \pm 0.05$.

**Accepted for publication in The Astrophysical Journal**

*Available from* arXiv:1007.5029

## Distance and proper motion measurement of the red supergiant, S Persei, with VLBI $H_2O$ maser astrometry

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We have conducted VLBA phase-referencing monitoring of $H_2O$ masers around the red supergiant, S Persei, for six years. We have fitted maser motions to a simple expanding-shell model with a common annual parallax and stellar proper motion, and obtained the annual parallax as $0.413 \pm 0.017$ mas, and the stellar proper motion as ($-0.49 \pm 0.23$ mas yr$^{-1}$, $-1.19 \pm 0.20$ mas yr$^{-1}$) in right ascension and declination, respectively. The obtained annual parallax corresponds to the trigonometric distance of $2.42^{+0.11}_{-0.09}$ kpc. Assuming the Galactocentric distance of the Sun of 8.5 kpc, the circular rotational velocity of the LSR at the distance of the Sun of 220 km s$^{-1}$, and a flat Galactic rotation curve, S Persei is suggested to have a non-circular motion deviating from the Galactic circular rotation for 15 km s$^{-1}$, which is mainly dominated by the anti-rotation direction component of $12.9 \pm 2.9$ km s$^{-1}$. This red supergiant is thought to belong to the OB association, Per OB1, so that this non-circular motion is representative of a motion of the OB association in the Milky Way. This non-circular motion is somewhat larger than that explained by the standard density-wave theory for a spiral galaxy, and is attributed to either a cluster shuffling of the OB association, or to non-linear interactions between non-stationary spiral arms and multi-phase interstellar media. The latter comes from a new view of a spiral arm formation in the Milky Way suggested by recent large $N$-body/smoothed particle hydrodynamics numerical simulations.

**Accepted for publication in Astrophysical Journal**

*Available from* arXiv:1007.4874

## Population synthesis of common envelope mergers: I. Giant stars with stellar or substellar companions

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Using a population synthesis technique, we have calculated detailed models of the present-day field population of objects that have resulted from the merger of a giant primary and a main-sequence or brown dwarf secondary during common envelope evolution. We used a grid of 116 stellar and 32 low-mass/brown dwarf models, a crude model of the merger process, and followed the angular momentum evolution of the binary orbit and the primary's rotation prior to merger, as well as the merged object's rotation after the merger. We find that present-day merged objects that are observable as giant stars or core-helium burning stars in our model population constitute between 0.24% and 0.33% of the initial population of ZAMS binaries, depending upon the input parameters chosen. The median projected rotational velocity of these merged objects is $\sim 16$ km s$^{-1}$, an order of magnitude higher than the median projected rotational velocity in a model population of normal single stars calculated using the same stellar models and initial mass function. The masses of the merged objects are typically less than $\sim 2$ M$_\odot$, with a median mass of 1.28 M$_\odot$, which is slightly more than, but not significantly different from, their normal single star counterparts. The luminosities in our merged object population range from $\sim$ 10–100 L$_\odot$, with a strong peak in the luminosity distribution at $\sim 60$ L$_\odot$, since the majority of the merged objects (57%) lie on the horizontal branch at the present epoch. The results of our population synthesis study are discussed in terms of possible observational counterparts either directly involving the high rotational velocity of the merger product or indirectly, via the effect of rotation on envelope abundances and on the amount and distribution of circumstellar matter.

**Accepted for publication in The Astrophysical Journal**
*Available from* arXiv:1007.4545

# *Review Papers*

## Observations and interpretation of solar-like oscillations in red-giant stars

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Over the past decade the study of solar-like oscillations in red-giant stars has developed significantly. Not only the number of red-giant stars for which solar-like oscillations have been observed has increased, but the quality of these observations has improved as well. These steps forward were possible thanks to the development of instrumentation to measure radial velocity variations with a precision of the order of m/s, as well as the launch of dedicated space missions, which provide timeseries of data with unprecedented photometric precision. Many more exciting discoveries are to be expected in the (near) future. This article provides an overview of the development of the field over the last decade, discusses difficulties encountered and overcome in interpreting the observational data, and addresses some challenges and opportunities for further research.

**Published in Astronomische Nachrichten**
*Available from* arXiv:1006.4390

# Evolutionary and pulsational properties of white dwarf stars

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White dwarf stars are the final evolutionary stage of the vast majority of stars, including our Sun. Since the coolest white dwarfs are very old objects, the present population of white dwarfs contains a wealth of information on the evolution of stars from birth to death, and on the star formation rate throughout the history of our Galaxy. Thus, the study of white dwarfs has potential applications to different fields of astrophysics. In particular, white dwarfs can be used as independent reliable cosmic clocks, and can also provide valuable information about the fundamental parameters of a wide variety of stellar populations, like our Galaxy and open and globular clusters. In addition, the high densities and temperatures characterizing white dwarfs allow to use these stars as cosmic laboratories for studying physical processes under extreme conditions that cannot be achieved in terrestrial laboratories. Last but not least, since many white dwarf stars undergo pulsational instabilities, the study of their properties constitutes a powerful tool for applications beyond stellar astrophysics. In particular, white dwarfs can be used to constrain fundamental properties of elementary particles such as axions and neutrinos, and to study problems related to the variation of fundamental constants.
These potential applications of white dwarfs have led to a renewed interest in the calculation of very detailed evolutionary and pulsational models for these stars. In this work, we review the essentials of the physics of white dwarf stars. We enumerate the reasons that make these stars excellent chronometers and we describe why white dwarfs provide tools for a wide variety of applications. Special emphasis is placed on the physical processes that lead to the formation of white dwarfs as well as on the different energy sources and processes responsible for chemical abundance changes that occur along their evolution. Moreover, in the course of their lives, white dwarfs cross different pulsational instability strips. The existence of these instability strips provides astronomers with an unique opportunity to peer into their internal structure that would otherwise remain hidden from observers. We will show that this allows to measure with unprecedented precision the stellar masses and to infer their envelope thicknesses, to probe the core chemical stratification, and to detect rotation rates and magnetic fields. Consequently, in this work, we also review the pulsational properties of white dwarfs and the most recent applications of white dwarf asteroseismology.

**Published in The Astronomy and Astrophysics Review**
*Available from* arXiv:1007.2659
*and from* www.springerlink.com