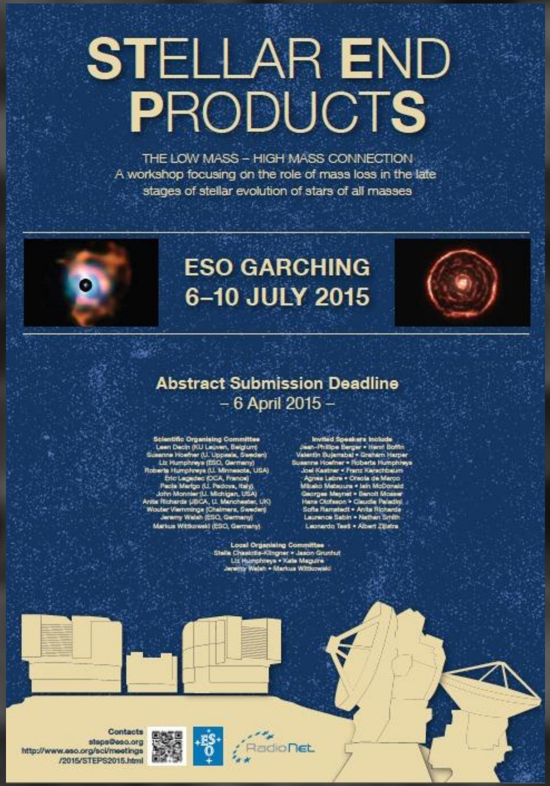

STELLAR END PRODUCTS

THE LOW MASS – HIGH MASS CONNECTION
A workshop focusing on the role of mass loss in the late stages of stellar evolution of stars of all masses

ESO GARCHING
6–10 JULY 2015

Abstract Submission Deadline
– 6 April 2015 –

Scientific Organising Committee
Leen Decin (KU Leuven, Belgium)
Susanne Hoefner (U. Uppsala, Sweden)
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Wouter Vlemmings (Chalmers, Sweden)
Jeremy Walsh (ESO, Germany)
Markus Wittkowski (ESO, Germany)

Invited Speakers Include
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Valentin Bujarrabal • Graham Harper
Susanne Hoefner • Roberta Humphreys
Joel Kastner • Franz Kerschbaum
Agnes Lebre • Orsola de Marco
Mikako Matsuura • Iain McDonald
Georges Meynet • Benoit Mosser
Hans Olofsson • Claudia Paladini
Sofia Ramstedt • Anita Richards
Laurence Sabin • Nathan Smith
Leonardo Testi • Albert Zijlstra

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Stella Chasiotis-Klingner • Jason Grunhut
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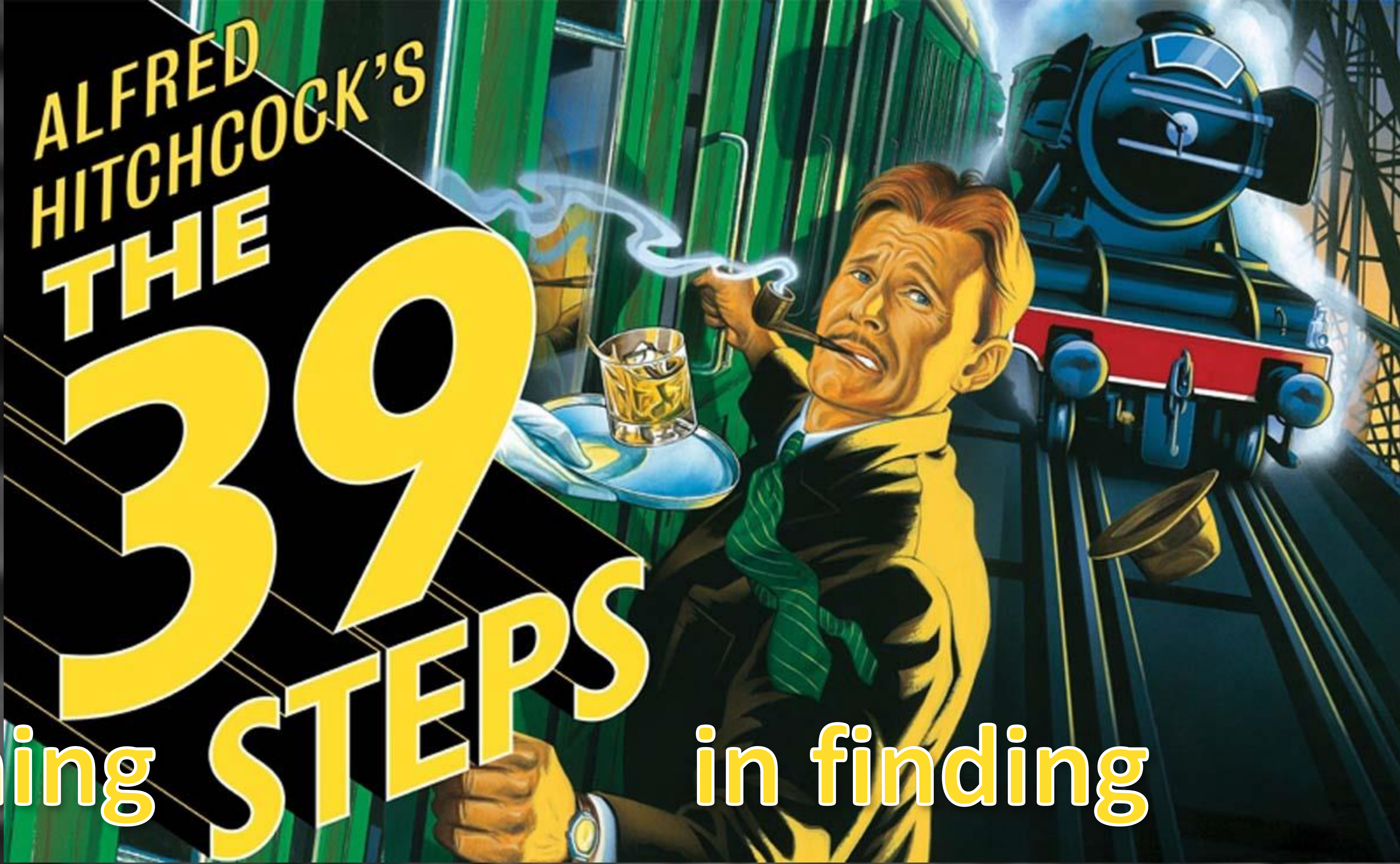

Enriching 39 STEPS in finding clues on complex giants

Franz Kerschbaum

Setting the stage

Tim De Zeeuw	**Welcome**
Albert Zijlstra (invited)	**Grand Overview**
Eric Lagadec	**Summary of the Recent Physics of Evolved Stars Meeting**
Hans Olofsson (invited)	**Radio/mm/Submm Observations of AGB and RSG stars**
Roberta Humphreys (invited)	**RSGs and AGBs in the Optical and Infrared - Evidence for Mass Loss, Circumstellar Ejecta and Episodic Events**
Leonardo Testi (invited)	**mm and Submm Interferometry, Current & Future Capabilities**
Jean-Philippe Berger (invited)	**Optical Interferometry: Current & Future Capabilities**

Setting the stage

Tim De Zeeuw	**Welcome**
Albert Zijlstra (invited)	**Grand Overview**
Eric Lagadec	**Stars Meeting**
Hans Olofsson (i	
Roberta	**Loss,**
Leona	
Jean-P	

… determine roles of magnetic fields, binarity, jets and collimated mass loss, metallicity, initial mass, <u>etc.</u> upon stellar evolution and end products – good luck Franz to summarize this!

The Messenger

No. 160 – June 2015

ALMA Long Baseline Campaign
VST nearby galaxy clusters survey
SINFONI elliptical lens survey

Setting the stage

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Leonardo Testi (invited)	**m**
Jean-Philippe Berger (invited)	

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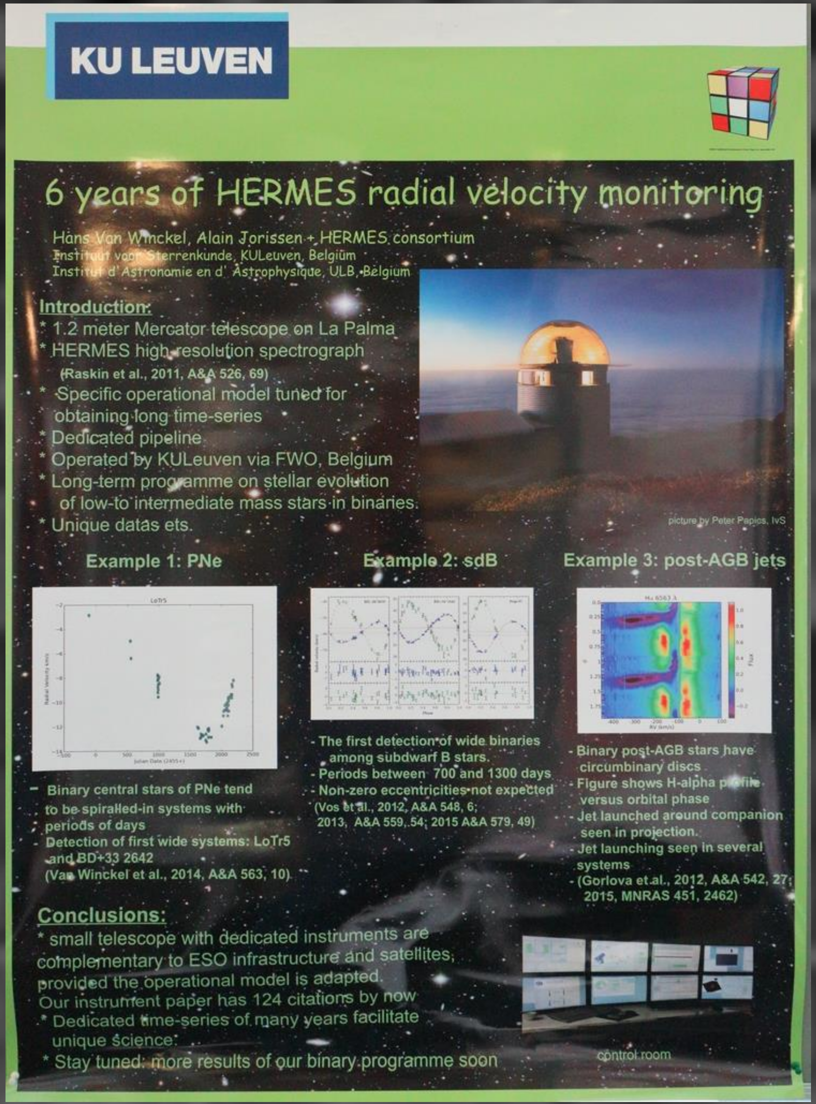
Jean-Philippe Berger (invited)	**Optical Interferometry: Current & Future Capabilities**

ACTION! (The 39 Steps, 1935)

- **Big samples, surveys, scans!**
- **Rethink, recalibrate formulas!**
- **Avoid high mass and other biases!**
- **Interferometry is not a niche!**
- **Photospheric imaging**



KU LEUVEN

6 years of HERMES radial velocity monitoring

Hans Van Winckel, Alain Jorissen + HERMES consortium
Instituut voor Sterrenkunde, KULeuven, Belgium
Institut d' Astronomie en d' Astrophysique, ULB, Belgium

Introduction:

- * 1.2 meter Mercator telescope on La Palma
- * HERMES high resolution spectrograph (Raskin et al., 2011, A&A 526, 69)
- * Specific operational model tuned for obtaining long time-series
- * Dedicated pipeline
- * Operated by KULeuven via FWO, Belgium
- * Long-term programme on stellar evolution of low-to intermediate mass stars in binaries.
- * Unique datas ets.

picture by Peter Papics, IvS

Example 1: PNe

- Binary central stars of PNe tend to be spiralled-in systems with periods of days
- Detection of first wide systems: LoTr5 and BD+33 2642 (Van Winckel et al., 2014, A&A 563, 10)

Example 2: sdB

- The first detection of wide binaries among subdwarf B stars.
- Periods between 700 and 1300 days
- Non-zero eccentricities not expected (Vos et al., 2012, A&A 548, 6; 2013, A&A 559, 54; 2015 A&A 579, 49)

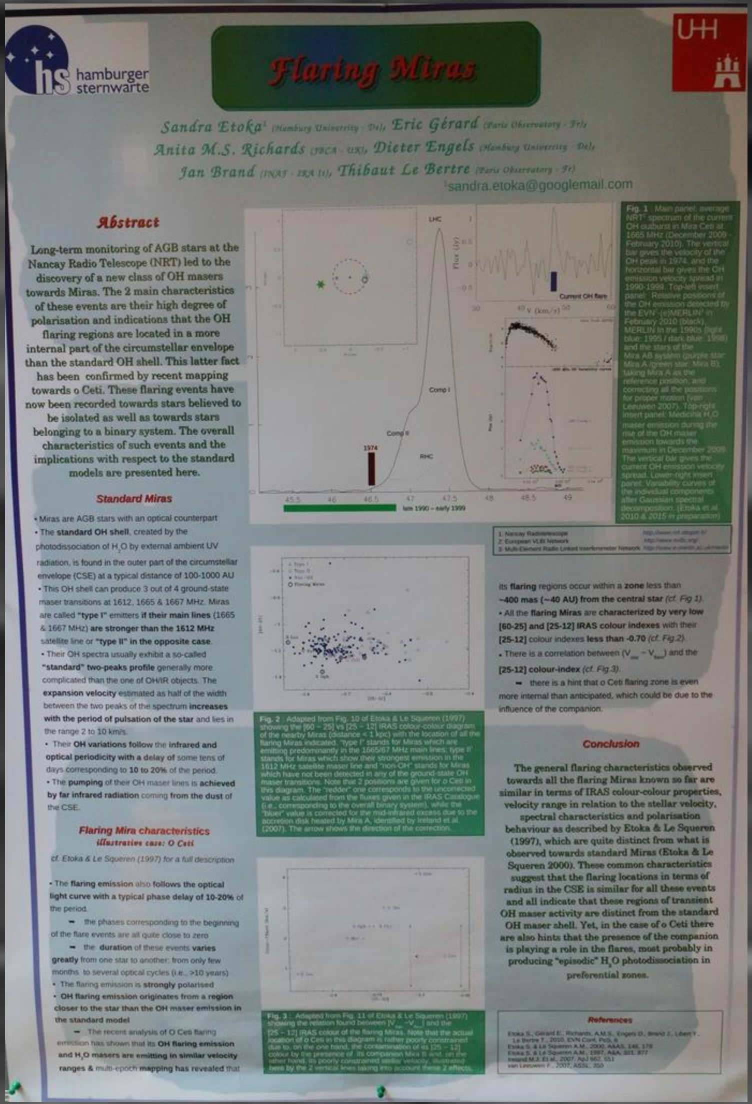
Example 3: post-AGB jets

- Binary post-AGB stars have circumbinary discs
- Figure shows H-alpha profile versus orbital phase
- Jet launched around companion seen in projection.
- Jet launching seen in several systems
- (Gorlova et.al., 2012, A&A 542, 27; 2015, MNRAS 451, 2462)

Conclusions:

- * small telescope with dedicated instruments are complementary to ESO infrastructure and satellites, provided the operational model is adapted. Our instrument paper has 124 citations by now
- * Dedicated time-series of many years facilitate unique science:
- * Stay tuned: more results of our binary programme soon

control room



hamburger sternwarte

Flaring Miras

Sandra Etoka[1] (Hamburg University - De), Eric Gérard (Paris Observatory - Fr), Anita M.S. Richards (JBCA - UK), Dieter Engels (Hamburg University - De), Jan Brand (INAF - IRA It), Thibaut Le Bertre (Paris Observatory - Fr)
[1]sandra.etoka@googlemail.com

Abstract

Long-term monitoring of AGB stars at the Nancay Radio Telescope (NRT) led to the discovery of a new class of OH masers towards Miras. The 2 main characteristics of these events are their high degree of polarisation and indications that the OH flaring regions are located in a more internal part of the circumstellar envelope than the standard OH shell. This latter fact has been confirmed by recent mapping towards o Ceti. These flaring events have now been recorded towards stars believed to be isolated as well as towards stars belonging to a binary system. The overall characteristics of such events and the implications with respect to the standard models are presented here.

Standard Miras

- Miras are AGB stars with an optical counterpart
- The **standard OH shell**, created by the photodissociation of H_2O by external ambient UV radiation, is found in the outer part of the circumstellar envelope (CSE) at a typical distance of 100-1000 AU
- This OH shell can produce 3 out of 4 ground-state maser transitions at 1612, 1665 & 1667 MHz. Miras are called **"type I"** emitters **if their main lines** (1665 & 1667 MHz) **are stronger than the 1612 MHz** satellite line or **"type II" in the opposite case**.
- Their OH spectra usually exhibit a so-called **"standard" two-peaks profile** generally more complicated than the one of OH/IR objects. The **expansion velocity** estimated as half of the width between the two peaks of the spectrum **increases with the period of pulsation of the star** and lies in the range 2 to 10 km/s.
- Their **OH variations follow** the **infrared and optical periodicity with a delay of** some tens of days corresponding to **10 to 20%** of the period.
- The **pumping** of their OH maser lines is **achieved by far infrared radiation** coming **from the dust** of the CSE.

Flaring Mira characteristics

illustrative case: O Ceti

cf. Etoka & Le Squeren (1997) for a full description

- The **flaring emission** also **follows the optical light curve with a typical phase delay of 10-20%** of the period.
  - the phases corresponding to the beginning of the flare events are all quite close to zero
  - the **duration** of these events **varies greatly** from one star to another: from only few months to several optical cycles (i.e., >10 years)
- The flaring emission is **strongly polarised**
- **OH flaring emission originates from a region closer to the star than the OH maser emission in the standard model**
  - The recent analysis of O Ceti flaring emission has shown that its **OH flaring emission and H_2O masers are emitting in similar velocity ranges** & multi-epoch **mapping has revealed** that its **flaring** regions occur within a **zone** less than **~400 mas (~40 AU) from the central star** *(cf. Fig 1)*.
- All the **flaring Miras** are **characterized by very low [60-25] and [25-12] IRAS colour indexes** with their **[25-12]** colour indexes **less than -0.70** *(cf. Fig 2)*.
- There is a correlation between ($V_{star} - V_{flare}$) and the **[25-12] colour-index** *(cf. Fig 3)*.
  - there is a hint that o Ceti flaring zone is even more internal than anticipated, which could be due to the influence of the companion.

Fig. 1 : Main panel: average NRT[1] spectrum of the current OH outburst in Mira Ceti at 1665 MHz (December 2009 - February 2010). The vertical bar gives the velocity of the OH peak in 1974, and the horizontal bar gives the OH emission velocity spread in 1990-1999. Top-left insert panel: Relative positions of the OH emission detected by the EVN[2]-(e)MERLIN[3] in February 2010 (black), MERLIN in the 1990s (light blue: 1995 / dark blue: 1998) and the stars of the Mira AB system (purple star: Mira A /green star: Mira B), taking Mira A as the reference position, and correcting all the positions for proper motion (van Leeuwen 2007). Top-right insert panel: Medicina H_2O maser emission during the rise of the OH maser emission towards the maximum in December 2009. The vertical bar gives the current OH emission velocity spread. Lower-right insert panel: Variability curves of the individual components after Gaussian spectral decomposition. (Etoka et al 2010 & 2015 *in preparation*)

1: Nancay Radiotelescope
2: European VLBI Network
3: Multi-Element Radio Linked Interferometer Network

Fig. 2 : Adapted from Fig. 10 of Etoka & Le Squeren (1997) showing the [60 – 25] vs [25 – 12] IRAS colour-colour diagram of the nearby Miras (distance < 1 kpc) with the location of all the flaring Miras indicated. "type I" stands for Miras which are emitting predominantly in the 1665/67 MHz main lines; type II" stands for Miras which show their strongest emission in the 1612 MHz satellite maser line and "non-OH" stands for Miras which have not been detected in any of the ground-state OH maser transitions. Note that 2 positions are given for o Ceti in this diagram. The "redder" one corresponds to the uncorrected value as calculated from the fluxes given in the IRAS Catalogue (i.e., corresponding to the overall binary system), while the "bluer" value is corrected for the mid-infrared excess due to the accretion disk heated by Mira A, identified by Ireland et al. (2007). The arrow shows the direction of the correction.

Fig. 3 : Adapted from Fig. 11 of Etoka & Le Squeren (1997) showing the relation found between $[V_{star} - V_{flare}]$ and the [25 – 12] IRAS colour of the flaring Miras. Note that the actual location of o Ceti in this diagram is rather poorly constrained due to, on the one hand, the contamination of its [25 – 12] colour by the presence of its companion Mira B and, on the other hand, its poorly constrained stellar velocity, illustrated here by the 2 vertical lines taking into account these 2 effects.

Conclusion

The general flaring characteristics observed towards all the flaring Miras known so far are similar in terms of IRAS colour-colour properties, velocity range in relation to the stellar velocity, spectral characteristics and polarisation behaviour as described by Etoka & Le Squeren (1997), which are quite distinct from what is observed towards standard Miras (Etoka & Le Squeren 2000). These common characteristics suggest that the flaring locations in terms of radius in the CSE is similar for all these events and all indicate that these regions of transient OH maser activity are distinct from the standard OH maser shell. Yet, in the case of o Ceti there are also hints that the presence of the companion is playing a role in the flares, most probably in producing "episodic" H_2O photodissociation in preferential zones.

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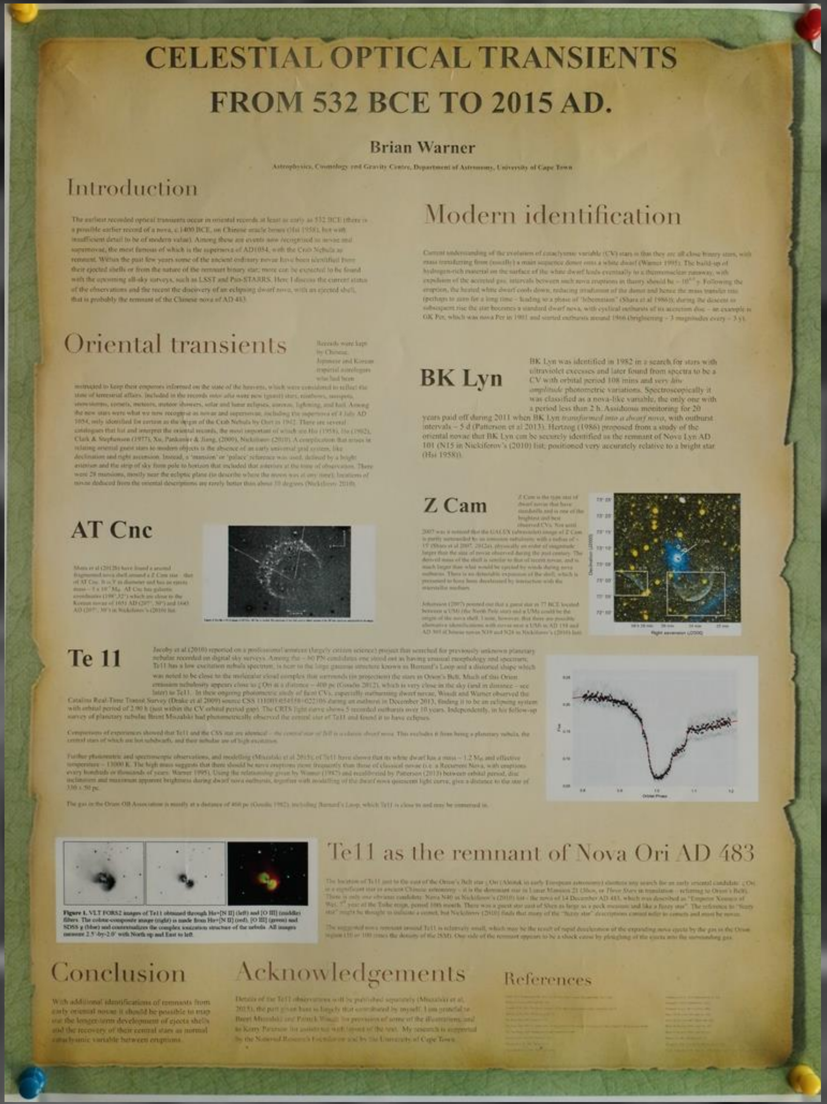


CELESTIAL OPTICAL TRANSIENTS FROM 532 BCE TO 2015 AD.

Brian Warner
Astrophysics, Cosmology and Gravity Centre, Department of Astronomy, University of Cape Town

Introduction

Oriental transients

Modern identification

BK Lyn

BK Lyn was identified in 1982 in a search for stars with ultraviolet excesses and later found from spectra to be a CV with orbital period 108 mins and very low amplitude photometric variations. Spectroscopically it was classified as a nova-like variable, the only one with a period less than 2 h. Assiduous monitoring for 20 years paid off during 2011 when BK Lyn *transformed into a dwarf nova*, with outburst intervals ~ 5 d (Patterson et al 2013). Hertzog (1986) proposed from a study of the oriental novae that BK Lyn can be securely identified as the remnant of Nova Lyn AD 101 (N15 in Nickiforov's (2010) list; positioned very accurately relative to a bright star (Hsi 1958)).

AT Cnc

Z Cam

Te 11

Te11 as the remnant of Nova Ori AD 483

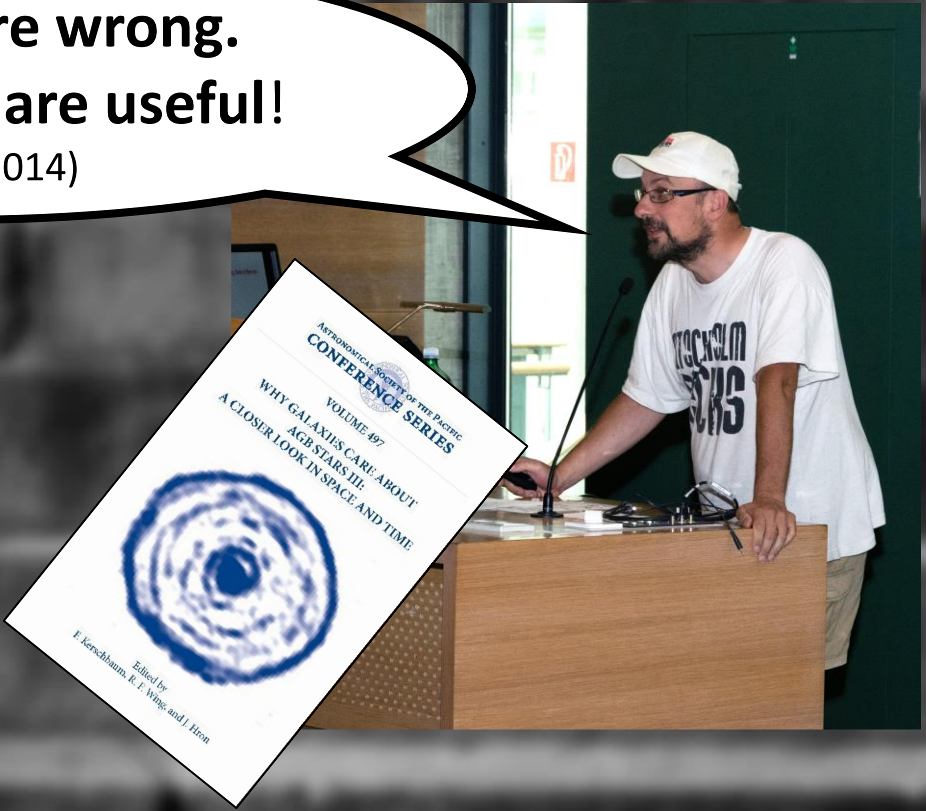
Conclusion

Acknowledgements

References

Stellar Evolution & Atmospheres

All models are wrong.
Some of them are useful!
(Aringer, 2014)



ASTRONOMICAL SOCIETY OF THE PACIFIC
CONFERENCE SERIES

VOLUME 497

WHY GALAXIES CARE ABOUT
AGB STARS III:
A CLOSER LOOK IN SPACE AND TIME

Edited by
F. Kerschbaum, R. F. Wing, and J. Hron

Stellar Evolution & Atmospheres

Georges Meynet (invited)	**Some Open Questions on the Physics of Stars**
Paola Marigo	**Linking Evolution of AGB Stars with Molecular Chemistry in their CSEs**
Alain Jorissen	**Atmospheric Tomography of Supergiant Stars**
Pierre Kervella (invited)	**The Atmosphere of Red Supergiants at High Angular Resolution**
Michael Gordon	**Yellow Supergiants: Unlocking the Mysteries of Post-RSG Evolution**
Ramiro De La Reza	**Complex Organic and Inorganic Compounds in Shells of Lithium-Rich K Giant Stars**
Benoit Mosser (invited)	**Mixed Modes in Red Giants: a Window on Stellar Evolution**

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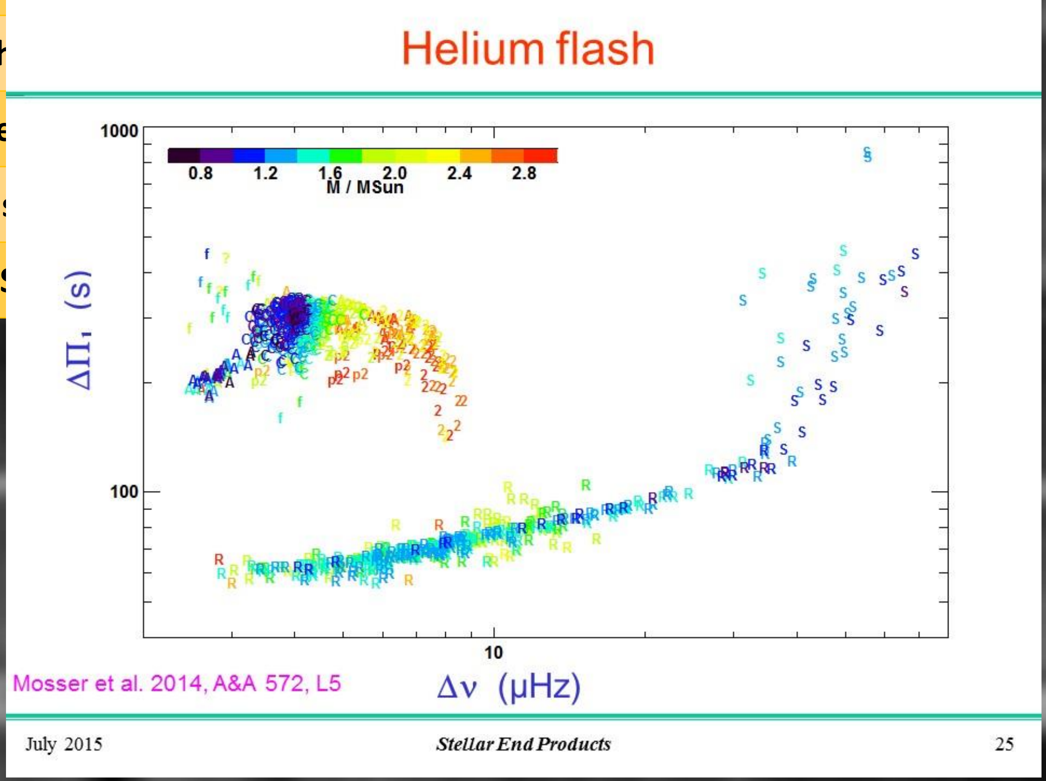

Helium flash

Mosser et al. 2014, A&A 572, L5

July 2015 *Stellar End Products* 25

Stellar Evolution & Atmospheres

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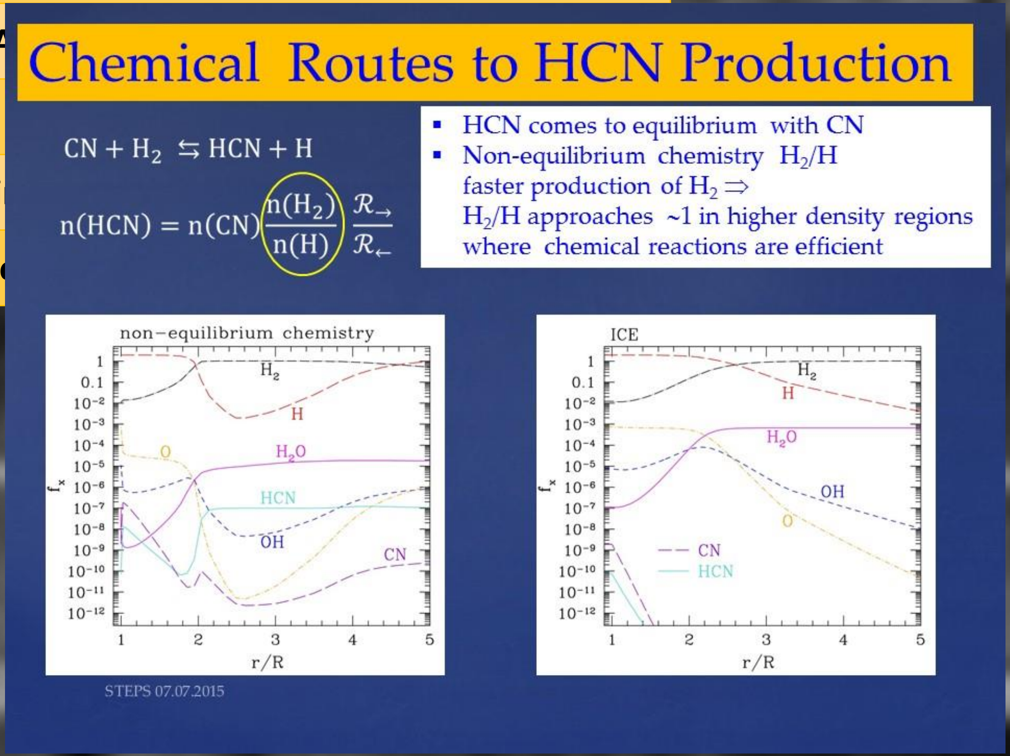

Chemical Routes to HCN Production

$$CN + H_2 \leftrightarrows HCN + H$$

$$n(HCN) = n(CN)\frac{n(H_2)}{n(H)}\frac{\mathcal{R}_{\rightarrow}}{\mathcal{R}_{\leftarrow}}$$

- HCN comes to equilibrium with CN
- Non-equilibrium chemistry H_2/H faster production of $H_2 \Rightarrow$ H_2/H approaches ~1 in higher density regions where chemical reactions are efficient

STEPS 07.07.2015

Stellar Evolution & Atmospheres

Georges Meynet (invited)	**Some Open Questions on the Physics of Stars**
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Alain Jorissen	**Atmospheric Tomography of Supergiant Stars**
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Michael Gordon	**Yellow Supergiants: Unl**
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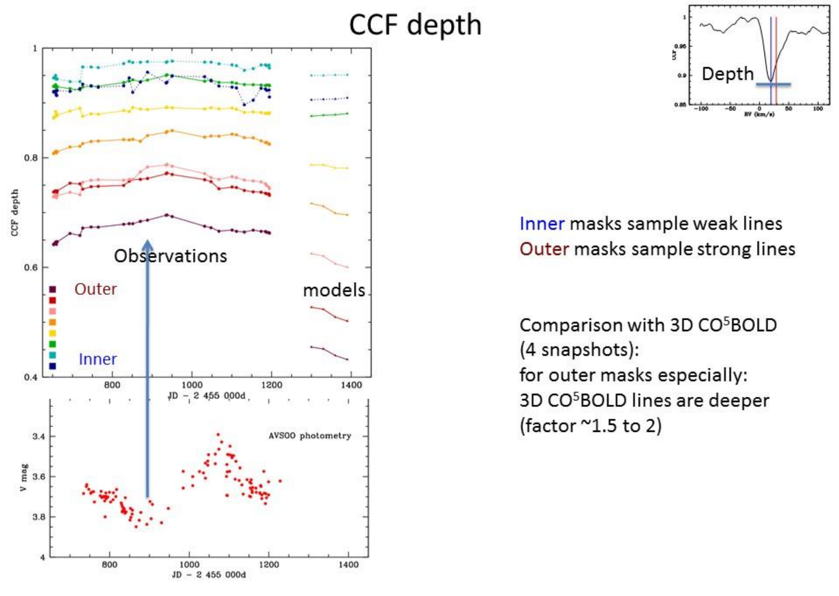
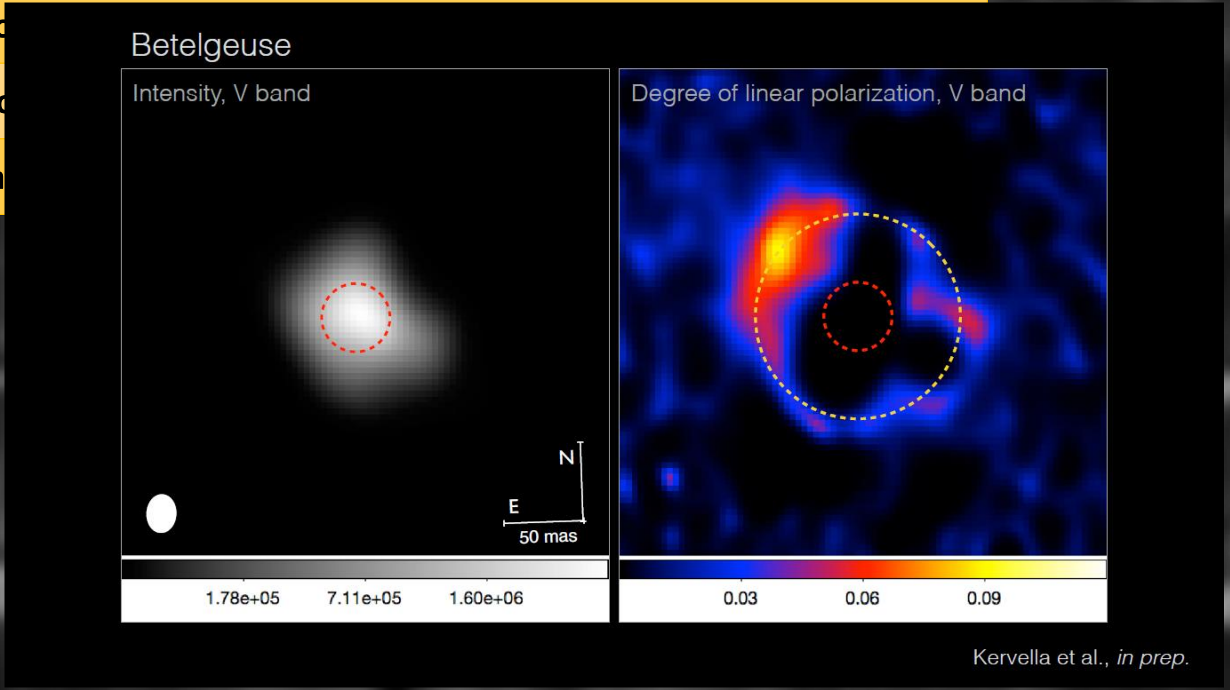


Inner masks sample weak lines
Outer masks sample strong lines

Comparison with 3D CO^{5}BOLD
(4 snapshots):
for outer masks especially:
3D CO^{5}BOLD lines are deeper
(factor ~1.5 to 2)



Kervella et al., *in prep.*

Abstract & Introduction

Super asymptotic giant branch (super-AGB) stars are in the mass range ~ 6.5-10 Mo and are characterised by off-centre carbon ignition prior to a thermally pulsing AGB phase which can consist from 10s to even 1000s of thermal pulses (TPs).

Their fates are quite uncertain and depend primarily on the competition between the core growth and mass-loss rates.

If the stellar envelope is removed prior to the core reaching the mass for electron captures in the core ~1.375 Mo (Nomoto 1984), an ONe white dwarf will remain, otherwise the star will undergo an electron-capture supernova leaving behind a neutron star.

We briefly describe the factors which influence these different fates, determine their relative fractions and provide mass boundaries.

Super-AGB stars bridging the divide between low-mass and high-mass stars

Carolyn Doherty[1], Pilar Gil-Pons[2]
John Lattanzio[1], Lionel Siess[3]

Monash Centre for Astrophysics, Monash University, Melbourne, Australia[1]
Polytechnical University of Catalonia, Barcelona, Spain[2]
Institute dAstronomie et dAstrophysique,
Universit Libre de Bruxelles, Brussels, Belgium[3]

MoCA

Method / Model Descriptions

The evolution of massive AGB and super-AGB stars was calculated using the Monash stellar evolution program (MONSTAR).

This program is a 1D hydrostatic evolution program which includes 7 main species: H, ^{3}He, ^{4}He, ^{12}C, ^{14}N, ^{16}O and Z.

For a current review of MONSTAR see Campbell and Lattanzio (2008) & Doherty et al 2010 & 2015.

A large grid of models were computed with initial masses ~5-10 $M_\odot$ over 5 metallicities in the range Z=0.02-0.0001.

Our models were run from the zero age main sequence to near the end of the TP-AGB phase.

We examine the important boundaries such as M_{up} (the minimum mass for carbon ignition), M_{mass} (lower limit for massive star) and M_n (the lower limit for neutron star formation).

Pre/Post second dredge-up core mass

After core H, He and C burning, the core mass of the star is reduced due to second dredge-up (2DU) – see Fig 1.

This post 2DU core mass is the core mass at the start of the AGB phase, with the final fate of the star determined by the subsequent competition between the growth of the core and mass loss from the stellar envelope.

Figure 1: Pre and post 2DU core masses. The dotted black horizontal line represents the M_{ec} (mass limit for electron captures in the core ~1.375Mo)

Final Fate?

Core Growth ~10 Mo

Mass-loss rates

The mass-loss rate for super- & massive AGB stars is very uncertain, e.g in Fig.2 we see large variation using different commonly used mass loss prescriptions.

The uncertainty in mass-loss rate increases at lower metallicity!

For our calculations we use the (relatively rapid mass-loss rate) from Vassiliadis & Wood (1993) & do not apply an explicit metallicity scaling.

Figure 2: Mass loss rates for commonly used prescriptions during the super-AGB phase for a 8.5 Mo Z=0.02 model. Time axis offset with t=0 corresponding to the 1st TP.

Core growth - Third Dredge-up?

Rubidium observations in luminous O-rich AGB stars (e.g. Garcia-Hernandez et al. 2006) are strong evidence for the occurrence of third dredge up (3DU) in the massive AGB and super-AGB stars.

In Fig 3. we show the 3DU efficiency λ* as a function of core mass from our calculations. Two main points of interest are; the clear lack of a metallicity dependence (at large core masses) and a decrease of λ with increasing core mass. This efficient 3DU reduces the likelihood that super-AGB stars grow enough to explode as EC-SN.

Figure 3: Maximum λ as a function of core mass. * Where λ is the ratio of mass dredged up by the envelope compare to the mass growth of the core. A λ value of one equates to no core growth.

Convergence Issues Fe-Peak Instability

All computations of super-/massive AGB stars cease converging prior to the removal of the entire [illegible] envelope. In some cases > 2 M [illegible] envelope remains. The cause of this "instability" is due to Fe-peak bump [illegible] at the base of the envelope local luminosity [illegible] to exceed the Eddington luminosity. The star is therefore no longer in hydrostatic equilibrium and the code crashes (e.g. Lau et. al. 2012). What would happen in a real star? most likely: i) total envelope [illegible] of the remaining envelope, or ii) envelope [illegible] with an enhanced mass-loss rate. This instability is an interesting problem which should be explored with hydrodynamic simulations.

Initial to final mass relation (IFMR)

In Fig. 4 we show our calculated IFMRs, which includes 3 types of white dwarfs (WDs): ONe,CO(Ne)*&CO WDs.

Lower metallicity models (stars) leave more massive WDs for the same initial mass.

Due to the fast mass-loss and slow core growth rates our models grew by at most 0.03 Mo during the entire (S)AGB phase.

*Note: CO(Ne) white dwarfs are those that have undergone off-centre carbon ignition but the flame did not reach the centre (Doherty et al. 2010).

Supernovae from Super-AGB stars?

We find the mass range for EC-SN is very fine (see Fig 5) ~ 0.1- 0.2 Mo. Using a Kroupa initial mass function (IMF) we find ≈ 2-5 % of all CC-SN will be EC-SN.

At high Z our models compare favorably with parametric studies by Poelarends et.al 2008 & Siess 2007, but at lower Z, because we do not apply at Z mass loss scaling, we find far

Figure 5: Final Fates Diagram. M_{up}, M_n and M_{mass}. CC=Core Collapse, EC=Electron capture

Comparisons

Observations and other model results

We compare our predictions to observationally derived IFMRs.

Large spread in results with maximum WD mass ~7.6 - 10+ Mo

Large variation in model predictions cf. Siess 2010 & Ventura et al. 2013. This is primarily due to differences in treatment of convective boundaries during core burning.

Figure 4: Initial to final mass relation. Grey shading represents the range of our model results (see Doherty et al.)

Conclusion

We have computed the full thermally pulsing evolution of a large grid of massive AGB and super-AGB stars over a range of metallicities Z=0.02-0.0001.

Our models with moderate mass loss and efficient 3DU increase their core mass by only ≈ 0.03 Mo during the TP- (S)AGB phase. Due to this, the majority of our super-AGB models end their lives as ONe white dwarfs. We also note a fine ~0.1 Mo region of formation of hybrid CO(Ne) white dwarfs. We predict (for single stars and assuming a Kroupa IMF), that at maximum between 2 to 5% of all supernova will be electron capture supernova.

References

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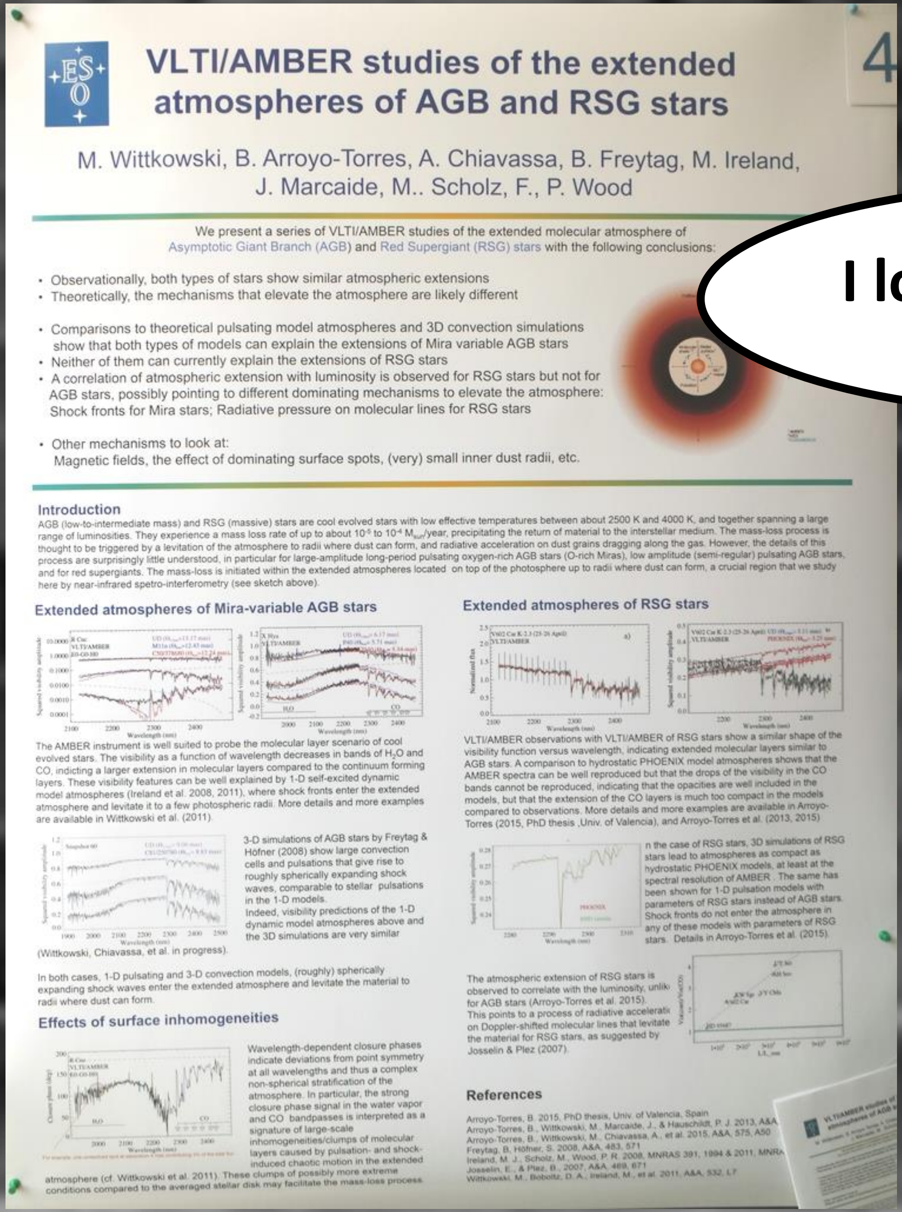
Poelarends et. al. 2008 ApJ, 675
Campbell & Lattanzio, 2008, A&A
Vassiliadis & Wood, 1993, ApJ

1.



4

VLTI/AMBER studies of the extended atmospheres of AGB and RSG stars

M. Wittkowski, B. Arroyo-Torres, A. Chiavassa, B. Freytag, M. Ireland,
J. Marcaide, M.. Scholz, F., P. Wood

We present a series of VLTI/AMBER studies of the extended molecular atmosphere of Asymptotic Giant Branch (AGB) and Red Supergiant (RSG) stars with the following conclusions:

- Observationally, both types of stars show similar atmospheric extensions
- Theoretically, the mechanisms that elevate the atmosphere are likely different

- Comparisons to theoretical pulsating model atmospheres and 3D convection simulations show that both types of models can explain the extensions of Mira variable AGB stars
- Neither of them can currently explain the extensions of RSG stars
- A correlation of atmospheric extension with luminosity is observed for RSG stars but not for AGB stars, possibly pointing to different dominating mechanisms to elevate the atmosphere: Shock fronts for Mira stars; Radiative pressure on molecular lines for RSG stars

- Other mechanisms to look at:
  Magnetic fields, the effect of dominating surface spots, (very) small inner dust radii, etc.

Introduction

AGB (low-to-intermediate mass) and RSG (massive) stars are cool evolved stars with low effective temperatures between about 2500 K and 4000 K, and together spanning a large range of luminosities. They experience a mass loss rate of up to about 10^{-5} to 10^{-4} M_{sun}/year, precipitating the return of material to the interstellar medium. The mass-loss process is thought to be triggered by a levitation of the atmosphere to radii where dust can form, and radiative acceleration on dust grains dragging along the gas. However, the details of this process are surprisingly little understood, in particular for large-amplitude long-period pulsating oxygen-rich AGB stars (O-rich Miras), low amplitude (semi-regular) pulsating AGB stars, and for red supergiants. The mass-loss is initiated within the extended atmospheres located on top of the photosphere up to radii where dust can form, a crucial region that we study here by near-infrared spetro-interferometry (see sketch above).

Extended atmospheres of Mira-variable AGB stars

The AMBER instrument is well suited to probe the molecular layer scenario of cool evolved stars. The visibility as a function of wavelength decreases in bands of H_2O and CO, indicting a larger extension in molecular layers compared to the continuum forming layers. These visibility features can be well explained by 1-D self-excited dynamic model atmospheres (Ireland et al. 2008, 2011), where shock fronts enter the extended atmosphere and levitate it to a few photospheric radii. More details and more examples are available in Wittkowski et al. (2011).

3-D simulations of AGB stars by Freytag & Höfner (2008) show large convection cells and pulsations that give rise to roughly spherically expanding shock waves, comparable to stellar pulsations in the 1-D models. Indeed, visibility predictions of the 1-D dynamic model atmospheres above and the 3D simulations are very similar

(Wittkowski, Chiavassa, et al. in progress).

In both cases, 1-D pulsating and 3-D convection models, (roughly) spherically expanding shock waves enter the extended atmosphere and levitate the material to radii where dust can form.

Extended atmospheres of RSG stars

VLTI/AMBER observations with VLTI/AMBER of RSG stars show a similar shape of the visibility function versus wavelength, indicating extended molecular layers similar to AGB stars. A comparison to hydrostatic PHOENIX model atmospheres shows that the AMBER spectra can be well reproduced but that the drops of the visibility in the CO bands cannot be reproduced, indicating that the opacities are well included in the models, but that the extension of the CO layers is much too compact in the models compared to observations. More details and more examples are available in Arroyo-Torres (2015, PhD thesis ,Univ. of Valencia), and Arroyo-Torres et al. (2013, 2015)

n the case of RSG stars, 3D simulations of RSG stars lead to atmospheres as compact as hydrostatic PHOENIX models, at least at the spectral resolution of AMBER . The same has been shown for 1-D pulsation models with parameters of RSG stars instead of AGB stars. Shock fronts do not enter the atmosphere in any of these models with parameters of RSG stars. Details in Arroyo-Torres et al. (2015)

The atmospheric extension of RSG stars is observed to correlate with the luminosity, unlike for AGB stars (Arroyo-Torres et al. 2015). This points to a process of radiative acceleration on Doppler-shifted molecular lines that levitate the material for RSG stars, as suggested by Josselin & Plez (2007).

Effects of surface inhomogeneities

Wavelength-dependent closure phases indicate deviations from point symmetry at all wavelengths and thus a complex non-spherical stratification of the atmosphere. In particular, the strong closure phase signal in the water vapor and CO bandpasses is interpreted as a signature of large-scale inhomogeneities/clumps of molecular layers caused by pulsation- and shock-induced chaotic motion in the extended atmosphere (cf. Wittkowski et al. 2011). These clumps of possibly more extreme conditions compared to the averaged stellar disk may facilitate the mass-loss process

References

Arroyo-Torres, B. 2015, PhD thesis, Univ. of Valencia, Spain
Arroyo-Torres, B., Wittkowski, M., Marcaide, J., & Hauschildt, P. J. 2013, A&A
Arroyo-Torres, B., Wittkowski, M., Chiavassa, A., et al. 2015, A&A, 575, A50
Freytag, B., Höfner, S. 2008, A&A, 483, 571
Ireland, M. J., Scholz, M., Wood, P. R. 2008, MNRAS 391, 1994 & 2011, MNRA
Josselin, E., & Plez, B., 2007, A&A, 469, 671
Wittkowski, M., Boboltz, D. A., Ireland, M., et al. 2011, A&A, 532, L7

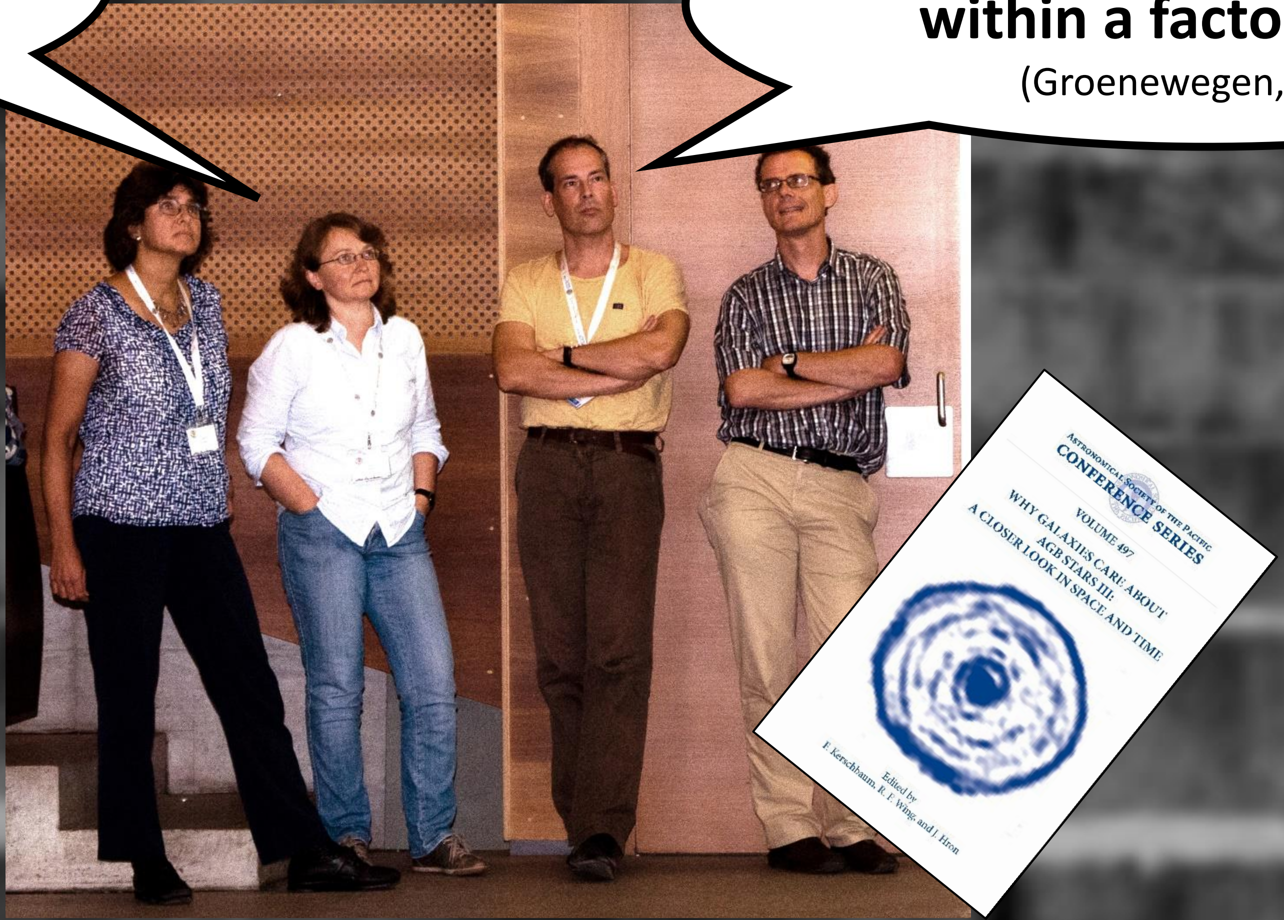
I love these fringes!

A.A. Michelson, undated

Mass Loss Mechanisms & Dust

Is there a problem? Yes!
(Höfner, 2014)

“There is good agreement within a factor of 10.”
(Groenewegen, 2014)



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Sara Bladh	**How M-type AGB Stars Bite the Dust**
Theo Khouri	**Investigating the Wind-Driving Mechanism in R Doradus**
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Peter Scicluna	**Large Dust Grains in RSG Winds: High-Contrast Polarimetric Observations of VY CMa**
Anita Richards (invited)	**Radio/Sub-mm Clues to the Origins of Asymmetries and Clumps**
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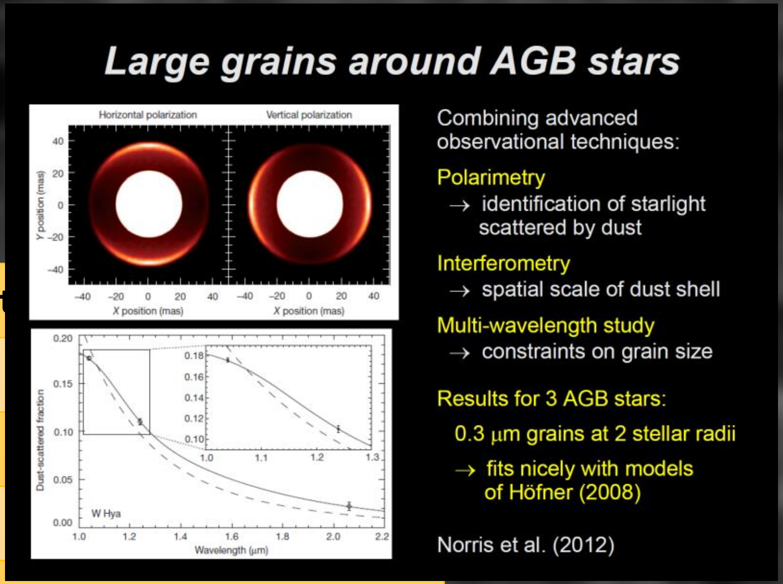


Large grains around AGB stars

Combining advanced observational techniques:

Polarimetry
→ identification of starlight scattered by dust

Interferometry
→ spatial scale of dust shell

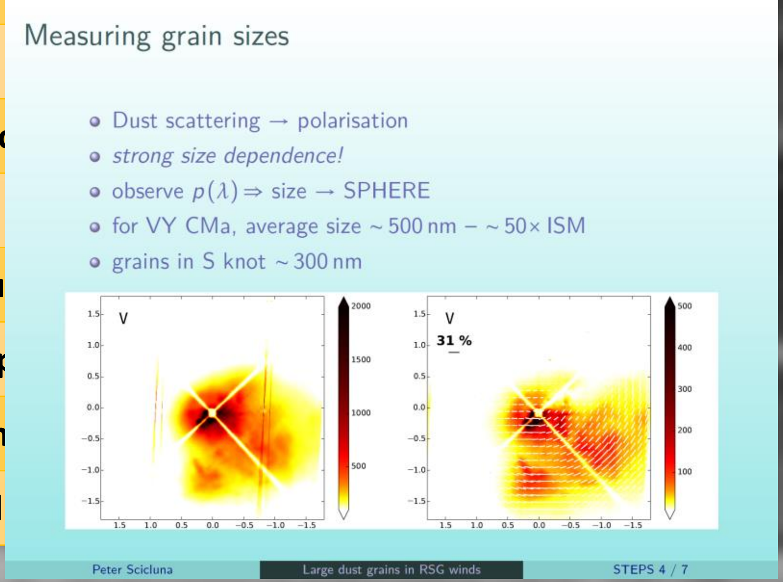
Multi-wavelength study
→ constraints on grain size

Results for 3 AGB stars:

0.3 μm grains at 2 stellar radii

→ fits nicely with models of Höfner (2008)

Norris et al. (2012)



Measuring grain sizes

- Dust scattering → polarisation
- *strong size dependence!*
- observe $p(\lambda) \Rightarrow$ size → SPHERE
- for VY CMa, average size ~ 500 nm – ~ 50× ISM
- grains in S knot ~ 300 nm

Peter Scicluna | Large dust grains in RSG winds | STEPS 4 / 7

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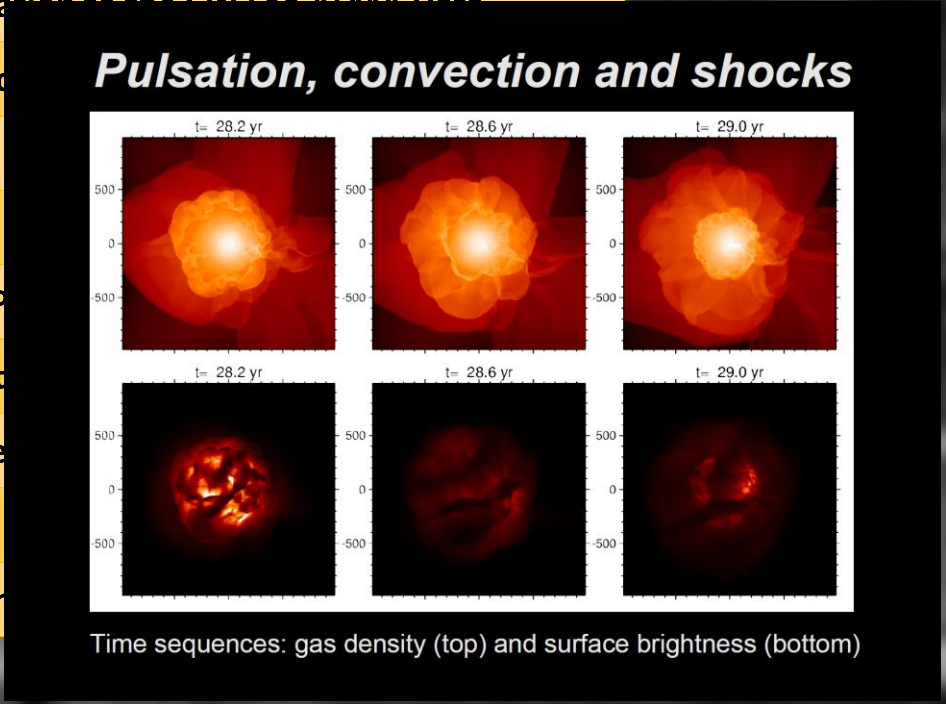
Pulsation, convection and shocks

Time sequences: gas density (top) and surface brightness (bottom)

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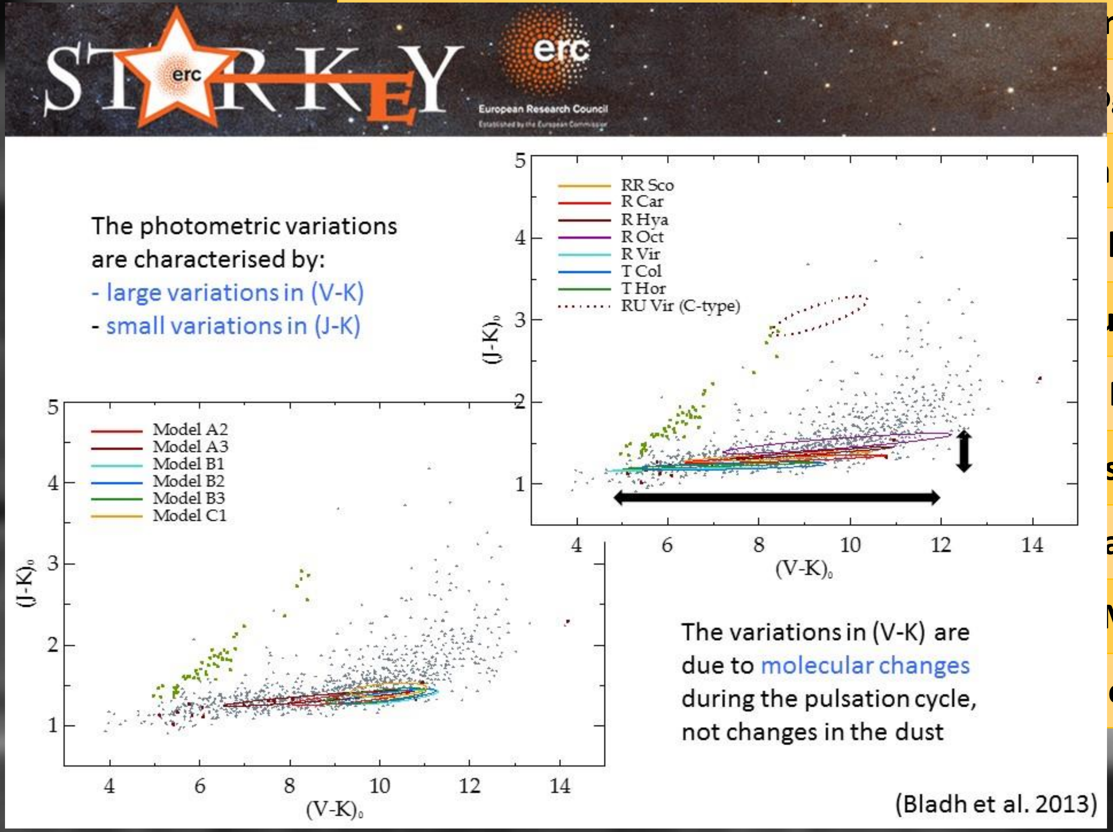
	ce of Mass Loss on the Cepheid Instability Strip



The photometric variations are characterised by:
- large variations in (V-K)
- small variations in (J-K)

The variations in (V-K) are due to molecular changes during the pulsation cycle, not changes in the dust

(Bladh et al. 2013)

Mass Loss Mechanisms & Dust

Cool stars too
hot to stand!

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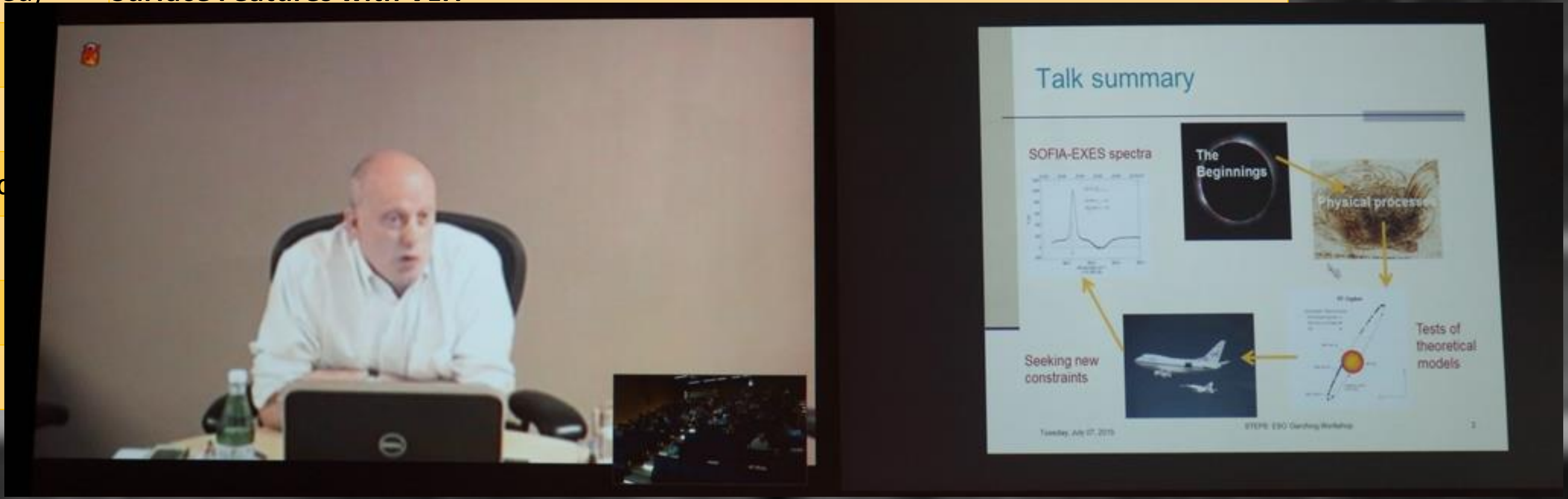

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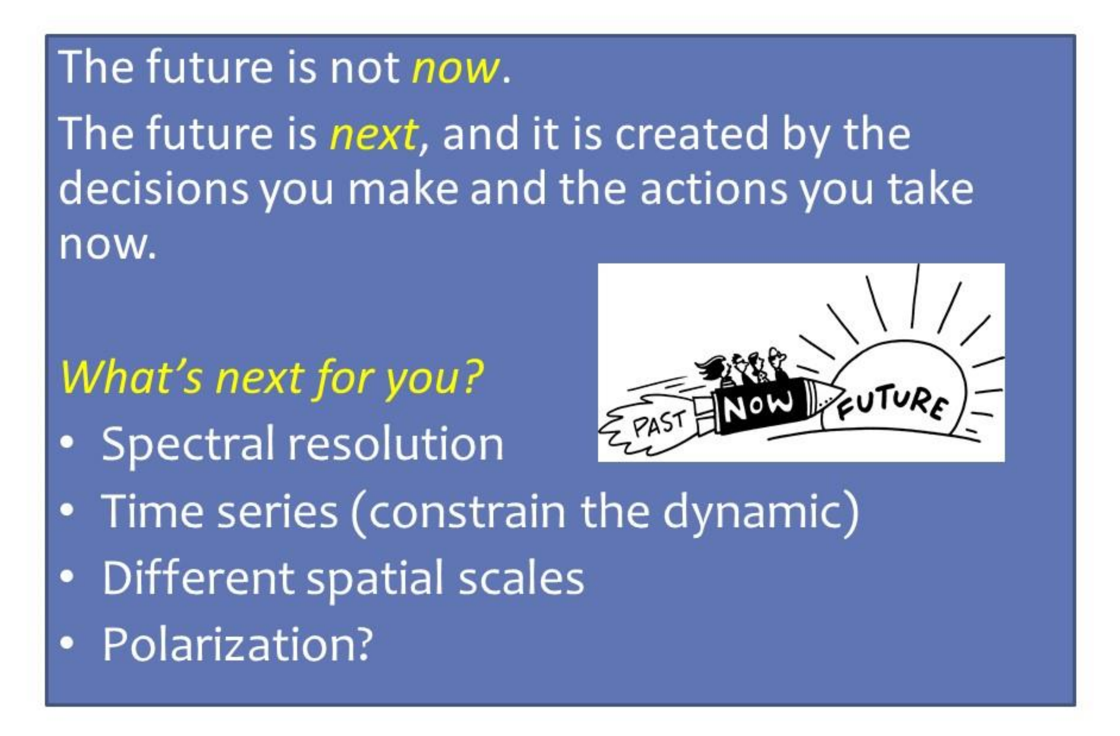

The future is not *now*.

The future is *next*, and it is created by the decisions you make and the actions you take now.

What's next for you?

- Spectral resolution
- Time series (constrain the dynamic)
- Different spatial scales
- Polarization?

Mass Loss Mechanis

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Sara Bladh	**How M-type AGB Stars**
Theo Khouri	**Investigating the Wind-**
Ward Homan	**Analytical Morphologic**
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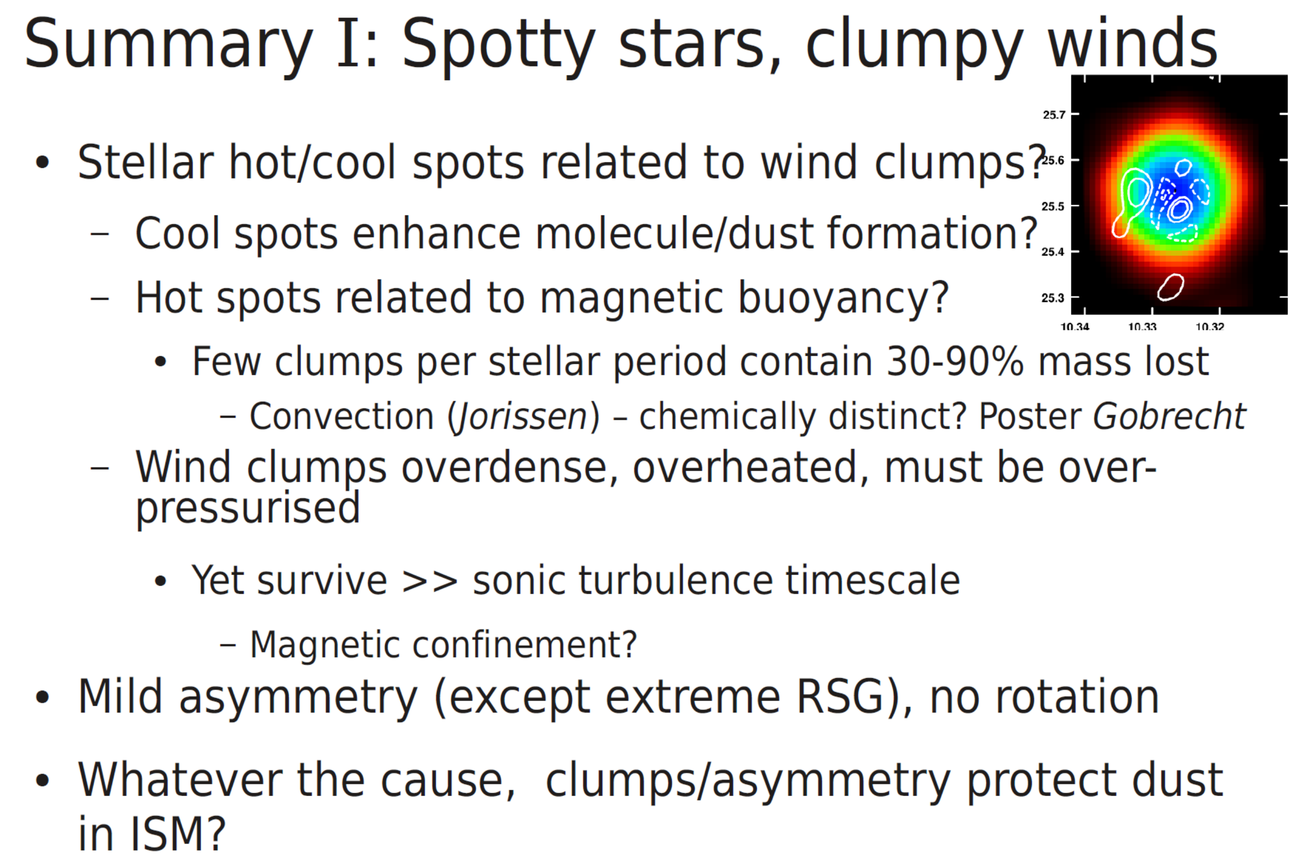

Summary I: Spotty stars, clumpy winds

- Stellar hot/cool spots related to wind clumps?
  - – Cool spots enhance molecule/dust formation?
  - – Hot spots related to magnetic buoyancy?
    - Few clumps per stellar period contain 30-90% mass lost
      - – Convection (*Jorissen*) – chemically distinct? Poster *Gobrecht*
  - – Wind clumps overdense, overheated, must be over-pressurised
    - Yet survive >> sonic turbulence timescale
      - – Magnetic confinement?
- Mild asymmetry (except extreme RSG), no rotation
- Whatever the cause, clumps/asymmetry protect dust in ISM?

Binaries, Shells & Shaping

…enough riddles to keep us happy for a while...

(Van Winckel, 2014)

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Two ways to identify a binary:

You see it

You have no other idea

(Noam Soker, 2015)

Binaries, Shells & Shaping

Orsola De Marco (invited)	**Binary Stars Across the Mass Spectrum; From Observations to Theory and Back**
Shazrene Mohamed	**Shaping the Outflows of Evolved Stars**
Michel Hillen	**The First mas Image of a Post-AGB Binary: the Inner 10 AU of IRAS08544-4431**
Sofia Ramstedt (invited)	**Winds and Circumstellar Morphology of Binary AGB Stars with ALMA**
Miguel Montarges	**The Dusty Disk and Companion of L2 Pup, the nearest AGB Star, Observed with SPHERE**
Foteini Lykou	**Shaping Nebulae via Disks in AGB Stars**
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Sebastian Ohlmann	**Hydrodynamic Simulations of Common Envelope Phases**

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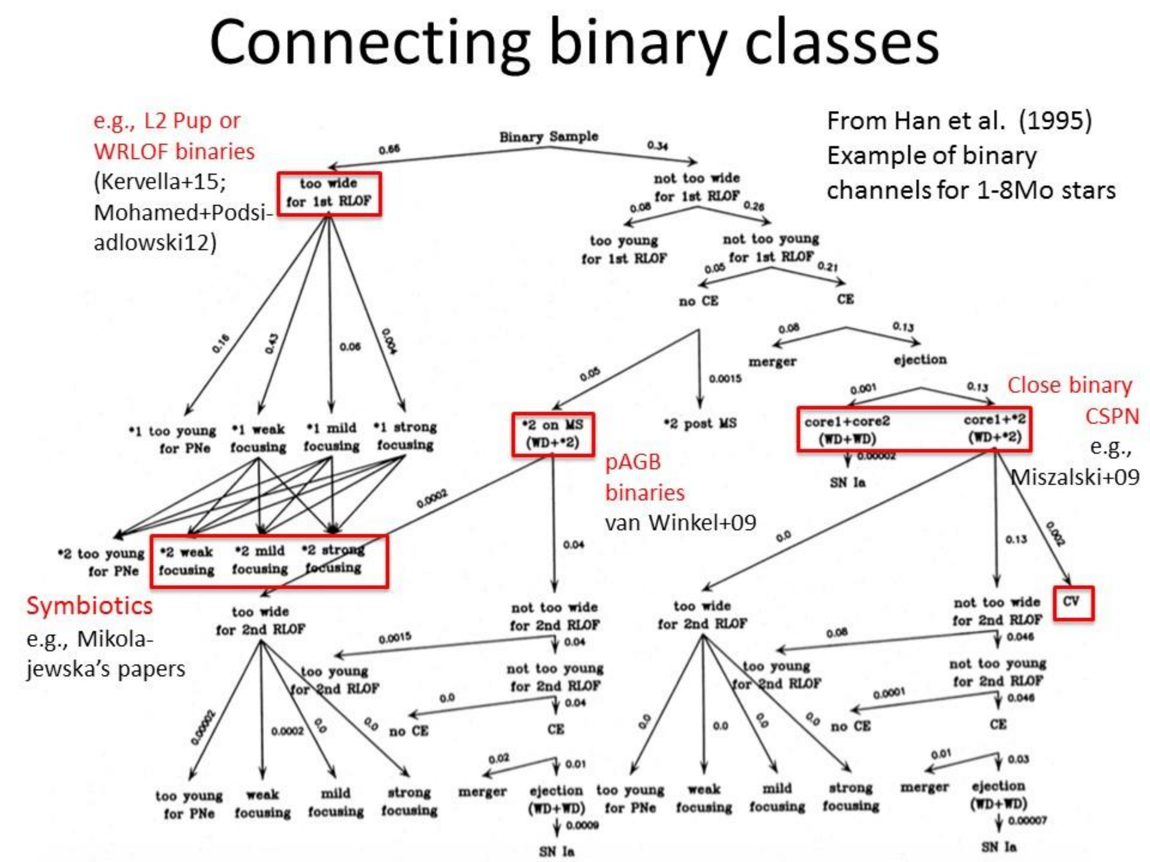

Connecting binary classes

From Han et al. (1995)
Example of binary
channels for 1-8Mo stars

e.g., L2 Pup or
WRLOF binaries
(Kervella+15;
Mohamed+Podsi-
adlowski12)

pAGB
binaries
van Winkel+09

Close binary
CSPN
e.g.,
Miszalski+09

Symbiotics
e.g., Mikola-
jewska's papers

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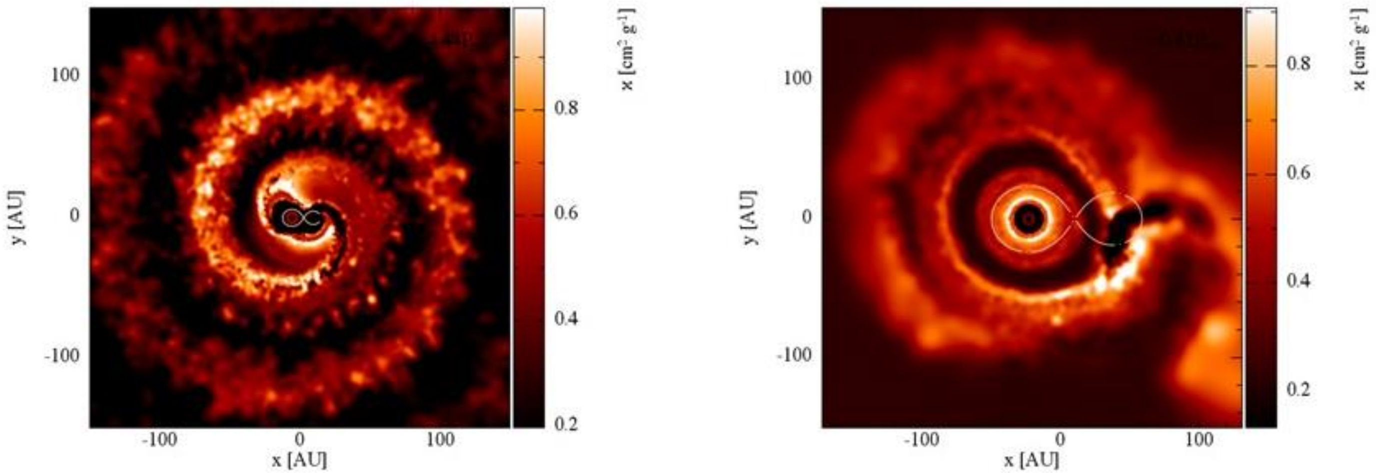

15 AU separation

60 AU separation

Mohamed & Podsiadlowski 2007, 2012

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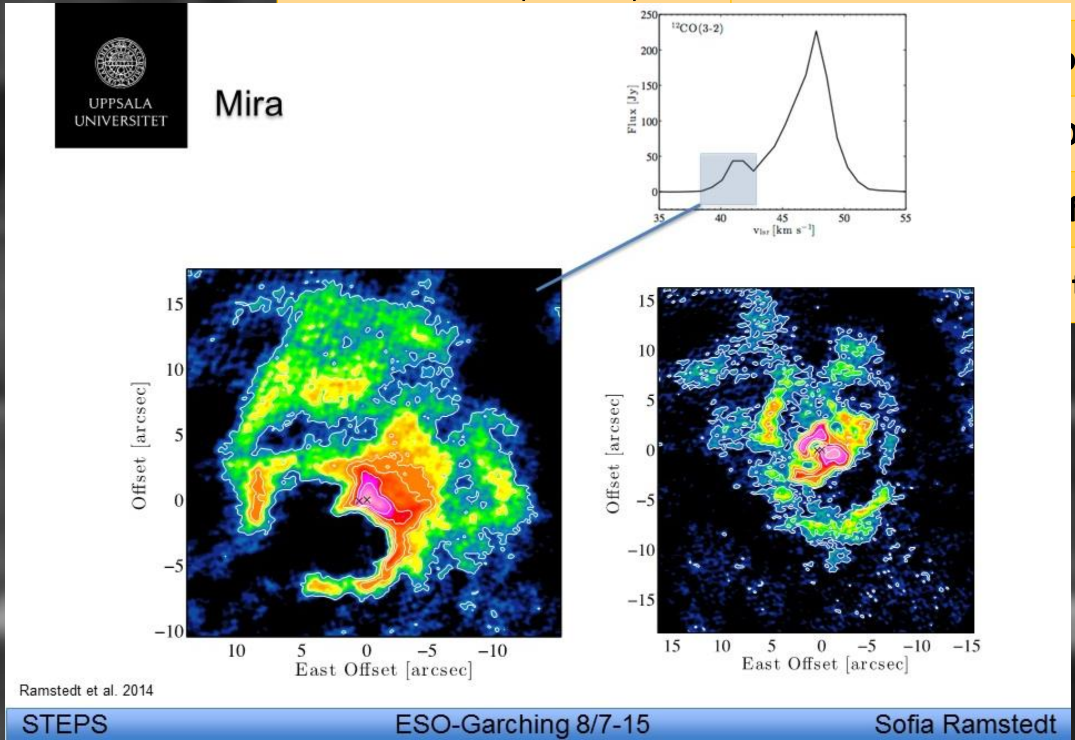
UPPSALA UNIVERSITET

Mira

Ramstedt et al. 2014

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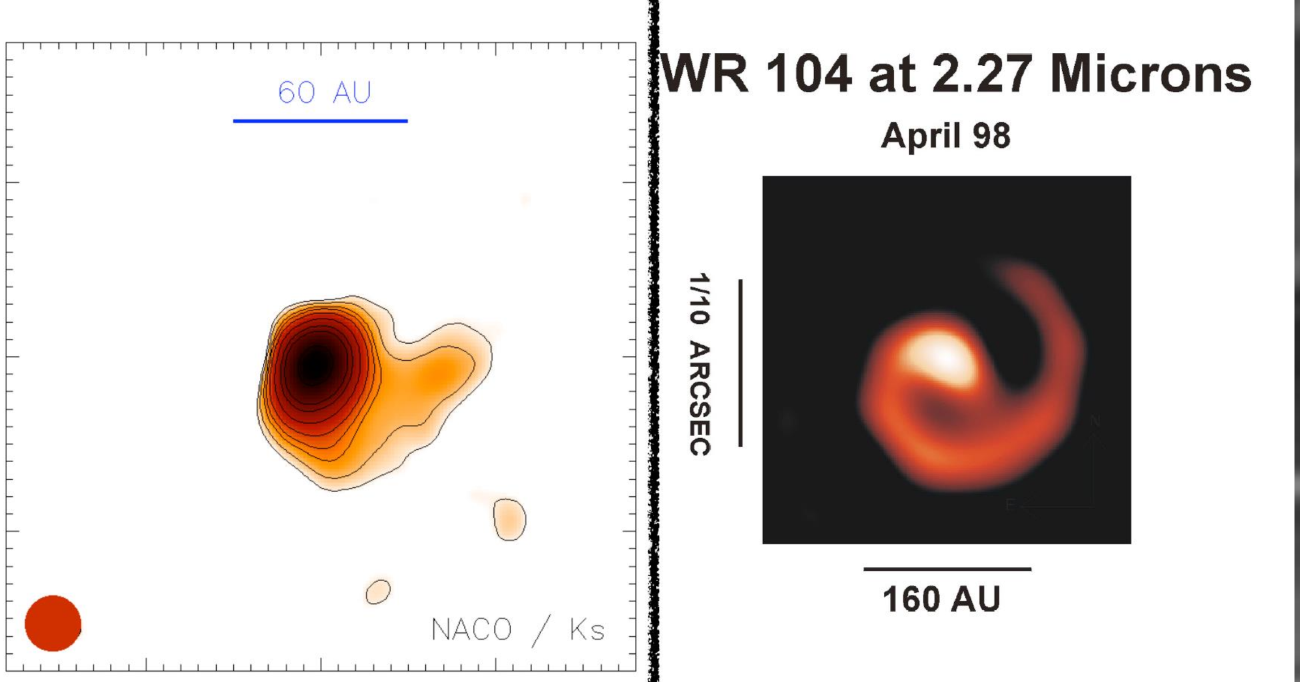
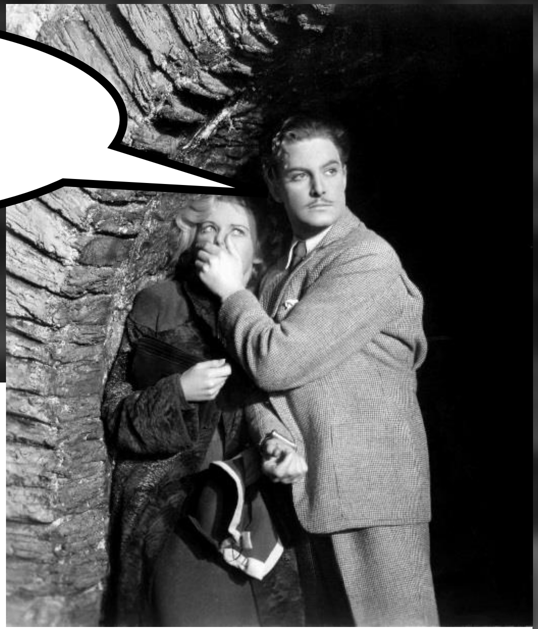
Foteini Lykou

8 July 2015

Star ‘X’



Lykou et al. in prep



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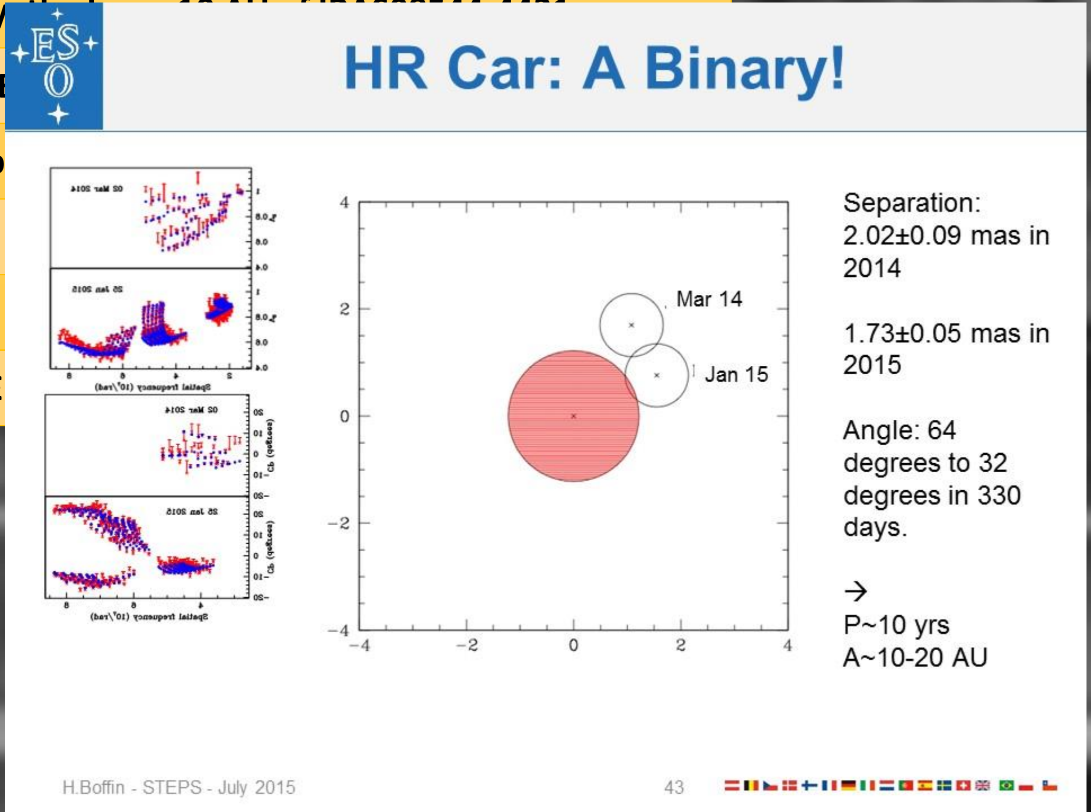


HR Car: A Binary!

Separation:
2.02±0.09 mas in 2014

1.73±0.05 mas in 2015

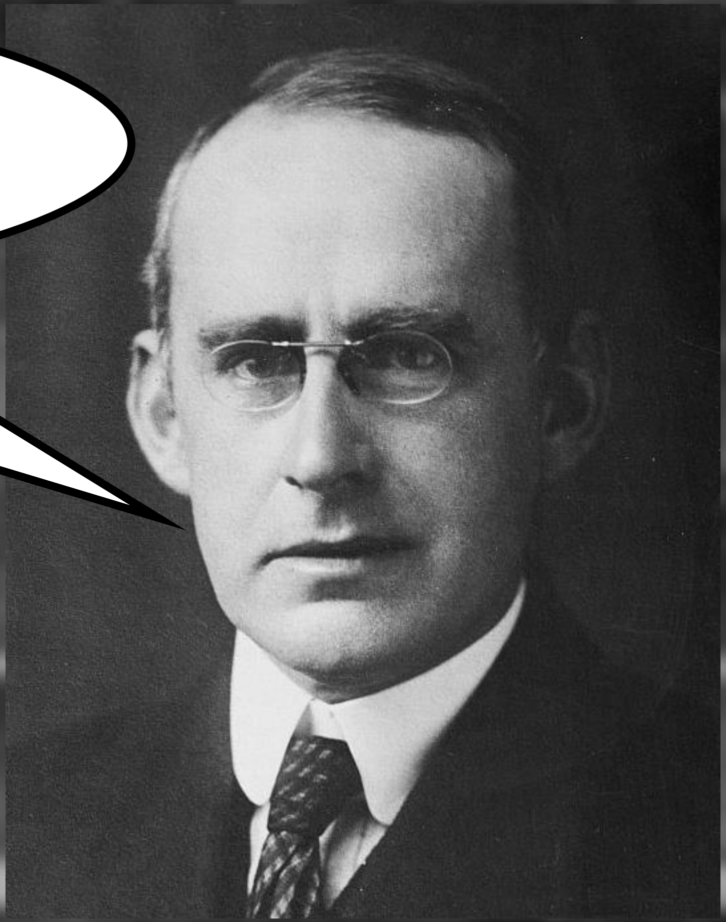
Angle: 64 degrees to 32 degrees in 330 days.

→
P~10 yrs
A~10-20 AU

H.Boffin - STEPS - July 2015 43

Magnetic Fields

> …it is reasonable to hope that in the not too distant future we shall be competent to understand so simple a thing as a star.
>
> (Eddington, 1936)



Magnetic Fields

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Wouter Vlemmings (invited)	**Magnetic Fields in Evolved Stars: Theory & Radio/Submm Line Observations**
Laurence Sabin (invited)	**Detection of Magnetic Fields in Evolved Stars: From the Envelope to the Photosphere**
Alizee Duthu	**Magnetic Fields in C-Rich Evolved Objects**

Magnetic Fields

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	n Evolved Stars: From the Envelope to the Photosphere
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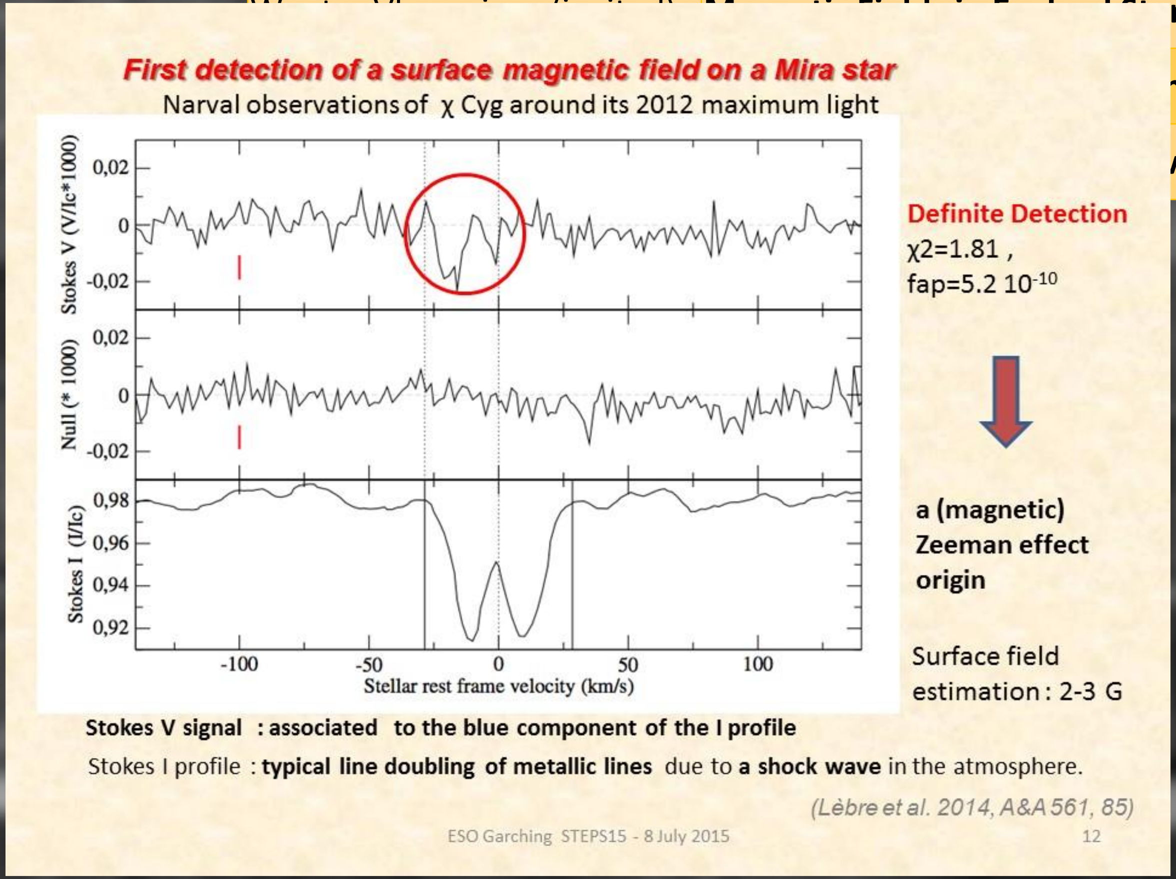

First detection of a surface magnetic field on a Mira star

Narval observations of χ Cyg around its 2012 maximum light

Definite Detection

$\chi 2=1.81$,

fap=5.2 10^{-10}

a (magnetic) Zeeman effect origin

Surface field estimation : 2-3 G

Stokes V signal : associated to the blue component of the I profile

Stokes I profile : **typical line doubling of metallic lines** due to **a shock wave** in the atmosphere.

(Lèbre et al. 2014, A&A 561, 85)

ESO Garching STEPS15 - 8 July 2015 12

Magnetic Fields

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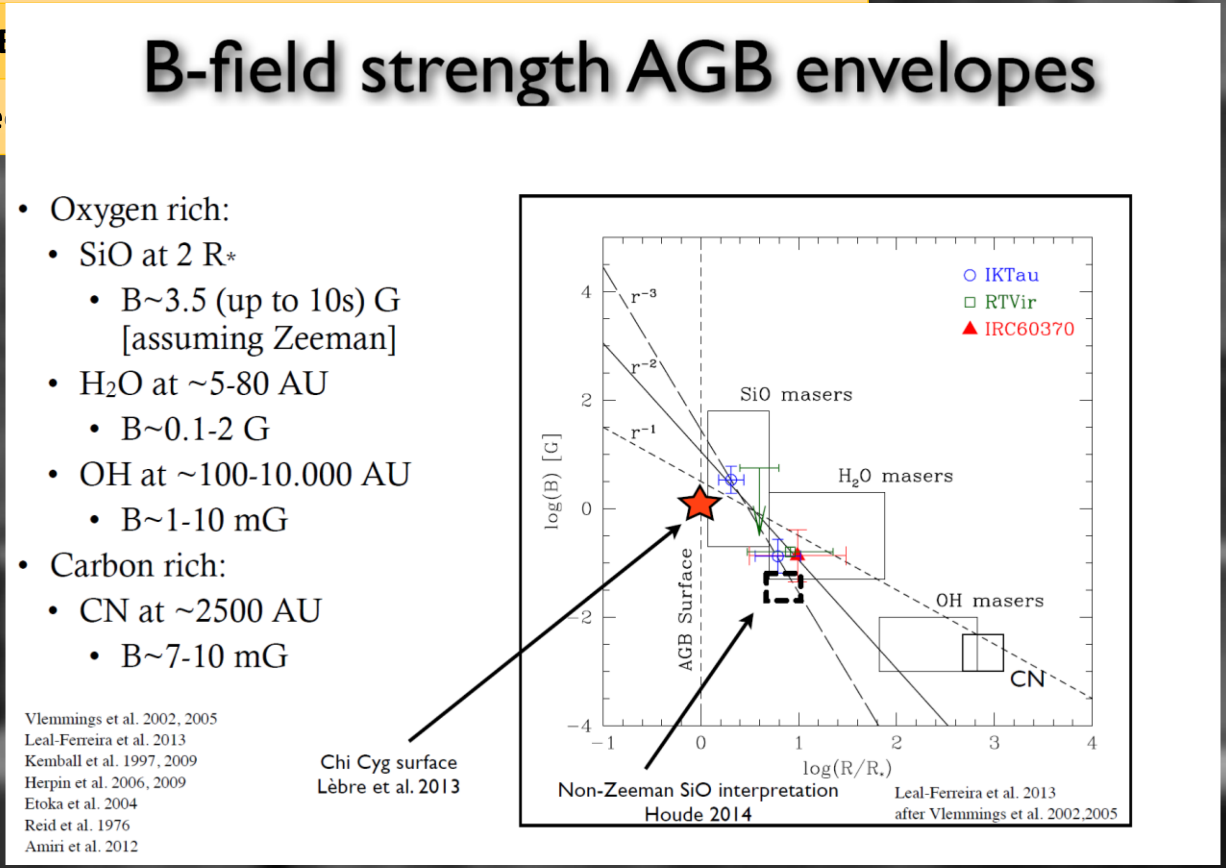


B-field strength AGB envelopes

- Oxygen rich:
  - SiO at 2 R*
    - B~3.5 (up to 10s) G [assuming Zeeman]
  - H_2O at ~5-80 AU
    - B~0.1-2 G
  - OH at ~100-10.000 AU
    - B~1-10 mG
- Carbon rich:
  - CN at ~2500 AU
    - B~7-10 mG

Vlemmings et al. 2002, 2005
Leal-Ferreira et al. 2013
Kemball et al. 1997, 2009
Herpin et al. 2006, 2009
Etoka et al. 2004
Reid et al. 1976
Amiri et al. 2012

Chi Cyg surface
Lèbre et al. 2013

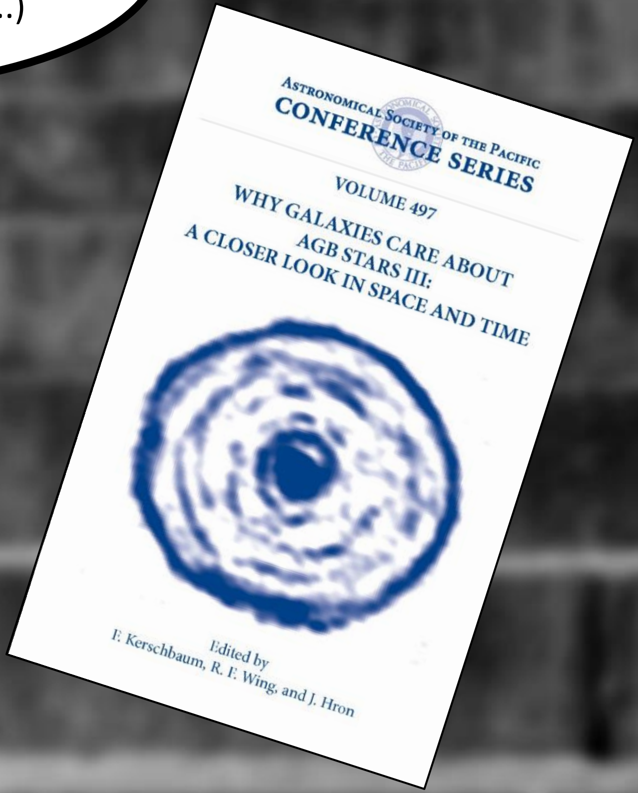
Non-Zeeman SiO interpretation
Houde 2014

Leal-Ferreira et al. 2013
after Vlemmings et al. 2002,2005

Evolved Stars and the Cycle of Matter

WE CARE!

(2006, 2010, 2014, 201x ...)



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Evolved Stars and the Cycle of Matter

WE TOO!

Evolved Stars and the Cycle of Matter

Iain McDonald (invited)	**How to Make and Break Dust Around Metal-Poor Stars**
Jonathan Mackey	**Cold Gas in Hot Star Clusters: the Fate of Winds from Red Supergiants**

Evolved Stars and the Cycle of Matter

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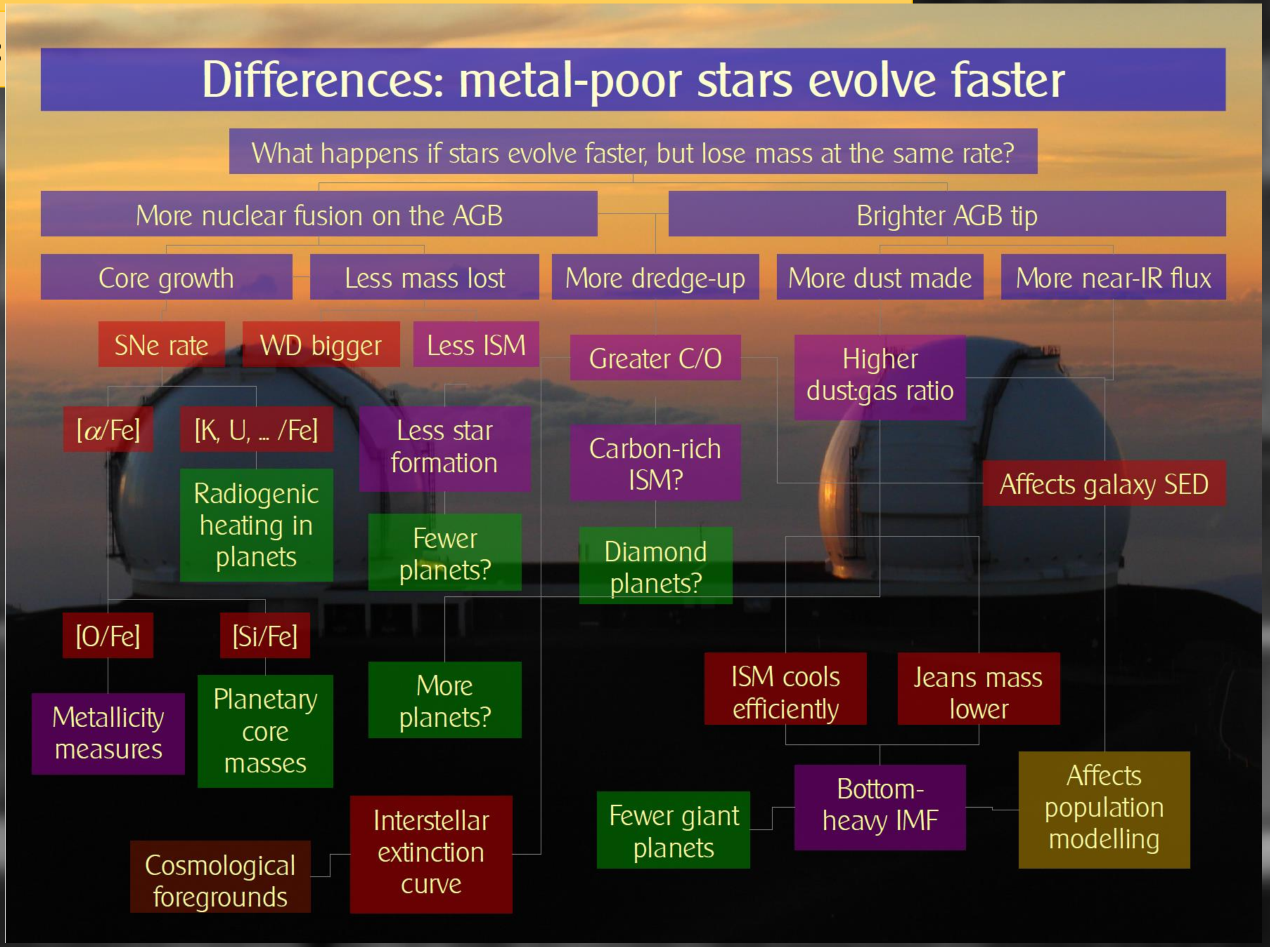

Differences: metal-poor stars evolve faster

What happens if stars evolve faster, but lose mass at the same rate?

More nuclear fusion on the AGB

Brighter AGB tip

Core growth

Less mass lost

More dredge-up

More dust made

More near-IR flux

SNe rate

WD bigger

Less ISM

Greater C/O

Higher dust:gas ratio

[α/Fe]

[K, U, ... /Fe]

Less star formation

Carbon-rich ISM?

Affects galaxy SED

Radiogenic heating in planets

Fewer planets?

Diamond planets?

[O/Fe]

[Si/Fe]

Metallicity measures

Planetary core masses

More planets?

ISM cools efficiently

Jeans mass lower

Bottom-heavy IMF

Affects population modelling

Fewer giant planets

Cosmological foregrounds

Interstellar extinction curve

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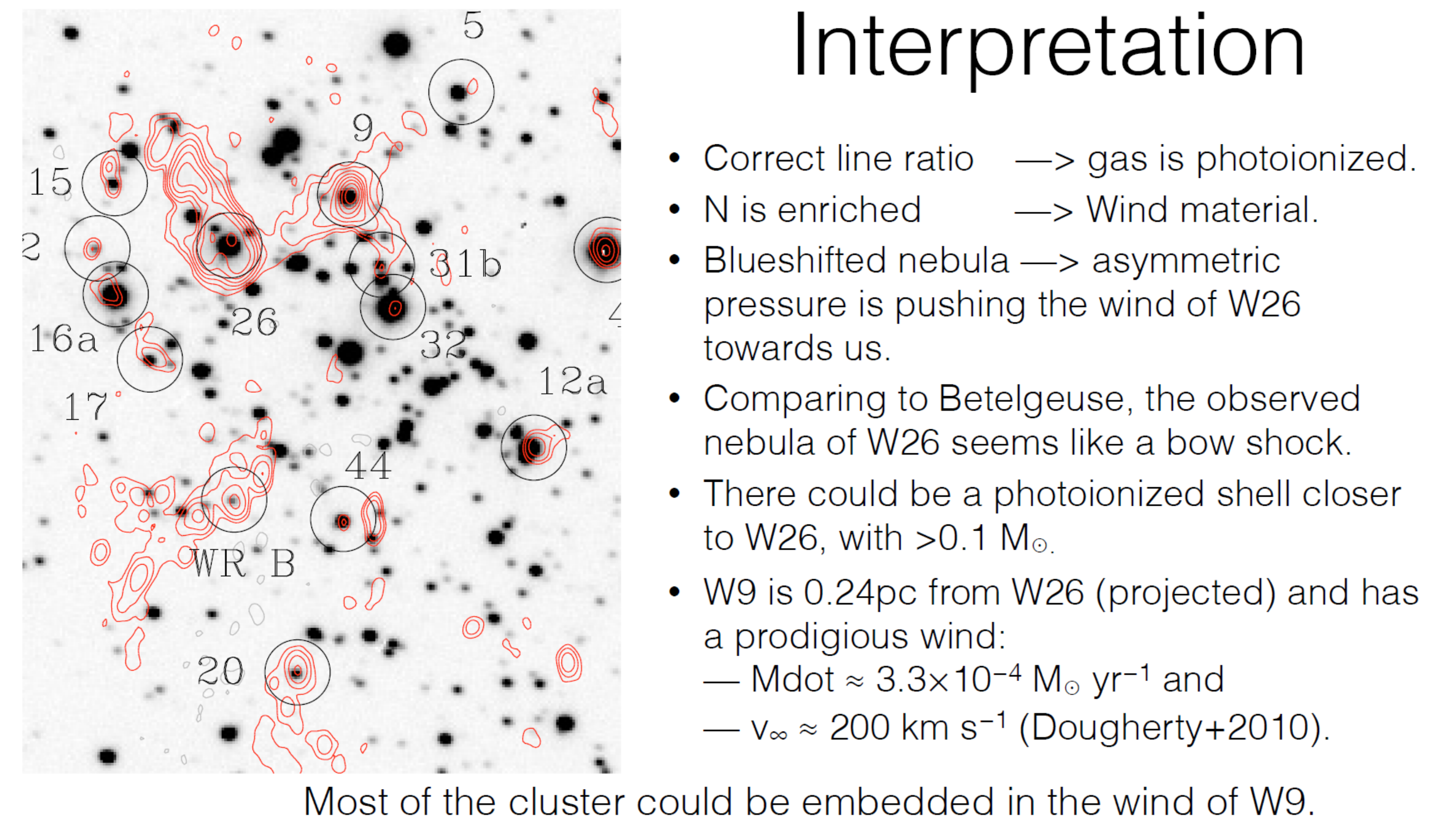
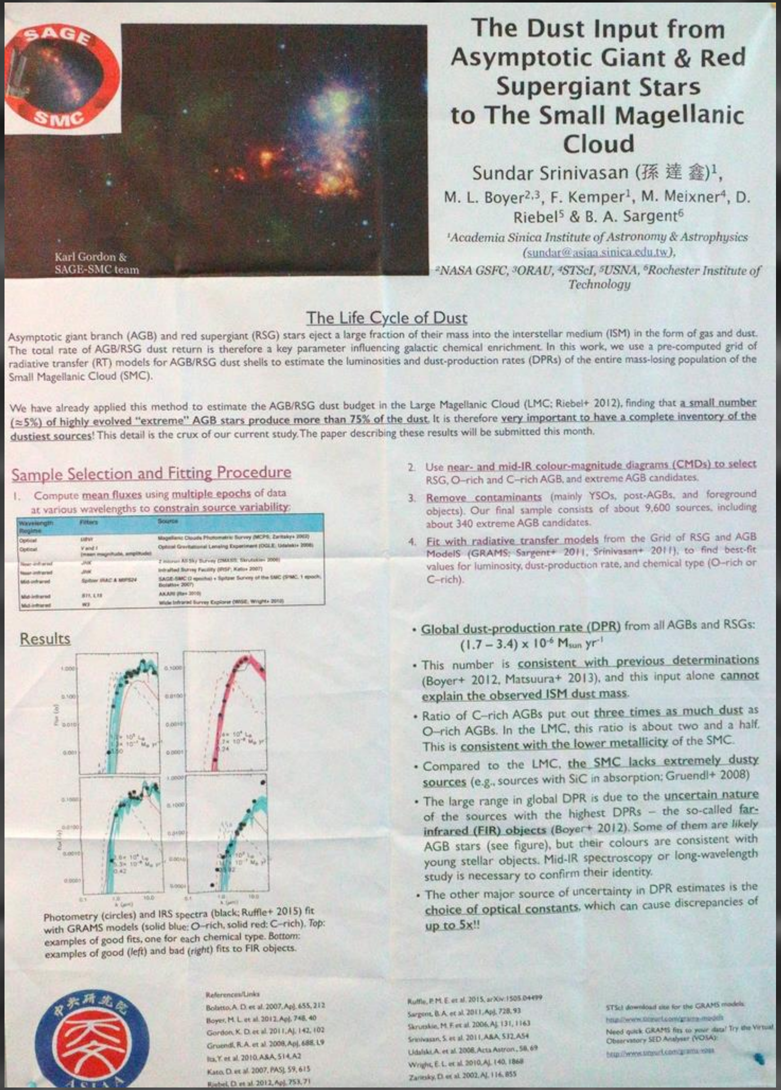


Interpretation

- Correct line ratio —> gas is photoionized.
- N is enriched —> Wind material.
- Blueshifted nebula —> asymmetric pressure is pushing the wind of W26 towards us.
- Comparing to Betelgeuse, the observed nebula of W26 seems like a bow shock.
- There could be a photoionized shell closer to W26, with >0.1 $M_\odot$.
- W9 is 0.24pc from W26 (projected) and has a prodigious wind:
  — Mdot ≈ 3.3×10^{-4} $M_\odot$ yr^{-1} and
  — $v_\infty \approx 200$ km s^{-1} (Dougherty+2010).

Most of the cluster could be embedded in the wind of W9.



Karl Gordon &
SAGE-SMC team

The Dust Input from Asymptotic Giant & Red Supergiant Stars to The Small Magellanic Cloud

Sundar Srinivasan (孫 達 鑫)[1],
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The Life Cycle of Dust

Asymptotic giant branch (AGB) and red supergiant (RSG) stars eject a large fraction of their mass into the interstellar medium (ISM) in the form of gas and dust. The total rate of AGB/RSG dust return is therefore a key parameter influencing galactic chemical enrichment. In this work, we use a pre-computed grid of radiative transfer (RT) models for AGB/RSG dust shells to estimate the luminosities and dust-production rates (DPRs) of the entire mass-losing population of the Small Magellanic Cloud (SMC).

We have already applied this method to estimate the AGB/RSG dust budget in the Large Magellanic Cloud (LMC; Riebel+ 2012), finding that a small number (≈5%) of highly evolved "extreme" AGB stars produce more than 75% of the dust. It is therefore very important to have a complete inventory of the dustiest sources! This detail is the crux of our current study. The paper describing these results will be submitted this month.

Sample Selection and Fitting Procedure

1. Compute mean fluxes using multiple epochs of data at various wavelengths to constrain source variability:

Wavelength Regime	Filters	Source
Optical	UBVI	Magellanic Clouds Photometric Survey (MCPS; Zaritsky+ 2002)
Optical	V and I (mean magnitude, amplitude)	Optical Gravitational Lensing Experiment (OGLE; Udalski+ 2008)
Near-infrared	JHK	2 micron All Sky Survey (2MASS; Skrutskie+ 2006)
Near-infrared	JHK	Infrared Survey Facility (IRSF; Kato+ 2007)
Mid-infrared	Spitzer IRAC & MIPS24	SAGE-SMC (2 epochs) + Spitzer Survey of the SMC (S3MC; 1 epoch; Bolatto+ 2007)
Mid-infrared	S11, L15	AKARI (Ita+ 2010)
Mid-infrared	W3	Wide Infrared Survey Explorer (WISE; Wright+ 2010)

2. Use near- and mid-IR colour-magnitude diagrams (CMDs) to select RSG, O-rich and C-rich AGB, and extreme AGB candidates.
3. Remove contaminants (mainly YSOs, post-AGBs, and foreground objects). Our final sample consists of about 9,600 sources, including about 340 extreme AGB candidates.
4. Fit with radiative transfer models from the Grid of RSG and AGB ModelS (GRAMS; Sargent+ 2011, Srinivasan+ 2011), to find best-fit values for luminosity, dust-production rate, and chemical type (O-rich or C-rich).

Results

Photometry (circles) and IRS spectra (black; Ruffle+ 2015) fit with GRAMS models (solid blue: O-rich, solid red: C-rich). *Top:* examples of good fits, one for each chemical type. *Bottom:* examples of good (*left*) and bad (*right*) fits to FIR objects.

- Global dust-production rate (DPR) from all AGBs and RSGs: $(1.7-3.4)\times10^{-6}\ M_{sun}\ yr^{-1}$
- This number is consistent with previous determinations (Boyer+ 2012, Matsuura+ 2013), and this input alone cannot explain the observed ISM dust mass.
- Ratio of C-rich AGBs put out three times as much dust as O-rich AGBs. In the LMC, this ratio is about two and a half. This is consistent with the lower metallicity of the SMC.
- Compared to the LMC, the SMC lacks extremely dusty sources (e.g., sources with SiC in absorption; Gruendl+ 2008)
- The large range in global DPR is due to the uncertain nature of the sources with the highest DPRs – the so-called far-infrared (FIR) objects (Boyer+ 2012). Some of them are *likely* AGB stars (see figure), but their colours are consistent with young stellar objects. Mid-IR spectroscopy or long-wavelength study is necessary to confirm their identity.
- The other major source of uncertainty in DPR estimates is the choice of optical constants, which can cause discrepancies of up to 5x!!

References/Links
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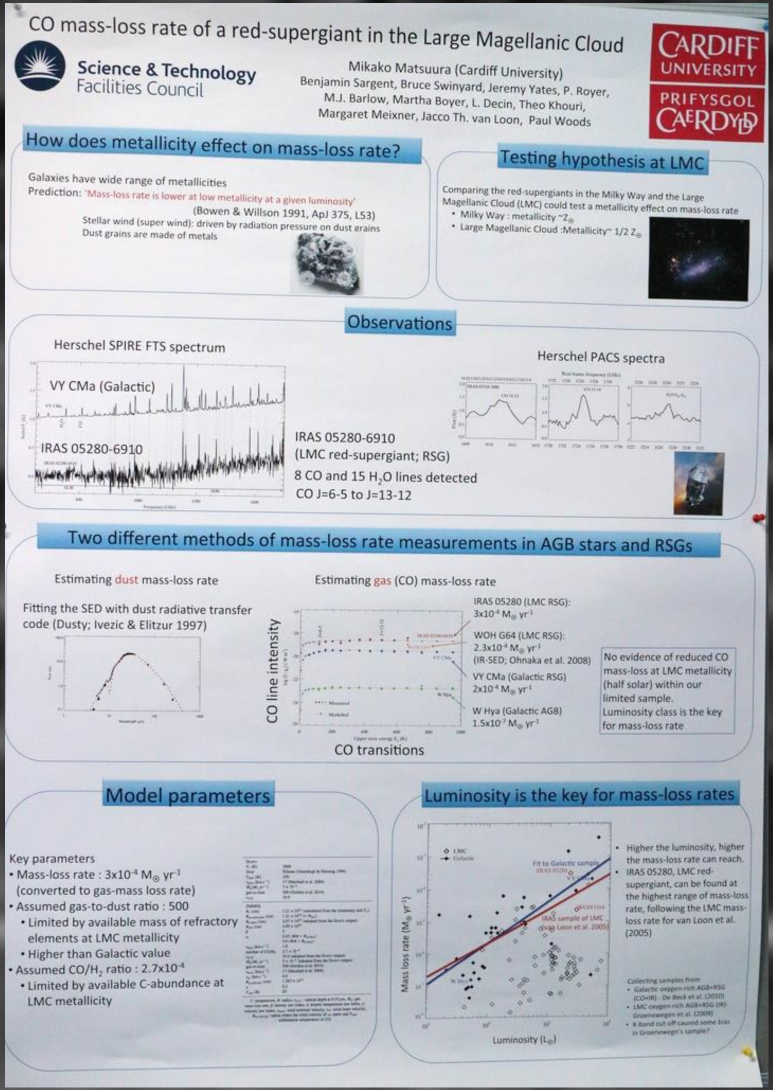
Zaritsky, D. et al. 2002, AJ, 116, 855

STScI download site for the GRAMS models:
http://www.tinyurl.com/grams-models
Need quick GRAMS fits to your data? Try the Virtual Observatory SED Analyser (VOSA):
http://www.tinyurl.com/grams-vosa



CO mass-loss rate of a red-supergiant in the Large Magellanic Cloud

Science & Technology Facilities Council

Mikako Matsuura (Cardiff University)
Benjamin Sargent, Bruce Swinyard, Jeremy Yates, P. Royer,
M.J. Barlow, Martha Boyer, L. Decin, Theo Khouri,
Margaret Meixner, Jacco Th. van Loon, Paul Woods

Cardiff University
Prifysgol Caerdydd

How does metallicity effect on mass-loss rate?

Galaxies have wide range of metallicities
Prediction: 'Mass-loss rate is lower at low metallicity at a given luminosity'
(Bowen & Willson 1991, ApJ 375, L53)
Stellar wind (super wind): driven by radiation pressure on dust grains
Dust grains are made of metals

Testing hypothesis at LMC

Comparing the red-supergiants in the Milky Way and the Large Magellanic Cloud (LMC) could test a metallicity effect on mass-loss rate

- Milky Way : metallicity ~$Z_\odot$
- Large Magellanic Cloud :Metallicity~ 1/2 $Z_\odot$

Observations

Herschel SPIRE FTS spectrum

IRAS 05280-6910
(LMC red-supergiant; RSG)
8 CO and 15 H_2O lines detected
CO J=6-5 to J=13-12

Herschel PACS spectra

Two different methods of mass-loss rate measurements in AGB stars and RSGs

Estimating dust mass-loss rate

Fitting the SED with dust radiative transfer code (Dusty; Ivezic & Elitzur 1997)

Estimating gas (CO) mass-loss rate

IRAS 05280 (LMC RSG):
$3\times10^{-4}\ M_\odot\ yr^{-1}$
WOH G64 (LMC RSG):
$2.3\times10^{-4}\ M_\odot\ yr^{-1}$
(IR-SED; Ohnaka et al. 2008)
VY CMa (Galactic RSG)
$2\times10^{-4}\ M_\odot\ yr^{-1}$
W Hya (Galactic AGB)
$1.5\times10^{-7}\ M_\odot\ yr^{-1}$

No evidence of reduced CO mass-loss at LMC metallicity (half solar) within our limited sample.
Luminosity class is the key for mass-loss rate

Model parameters

Key parameters

- Mass-loss rate : $3\times10^{-4}\ M_\odot\ yr^{-1}$ (converted to gas-mass loss rate)
- Assumed gas-to-dust ratio : 500
  - Limited by available mass of refractory elements at LMC metallicity
  - Higher than Galactic value
- Assumed CO/H_2 ratio : 2.7×10^{-4}
  - Limited by available C-abundance at LMC metallicity

Luminosity is the key for mass-loss rates

- Higher the luminosity, higher the mass-loss rate can reach.
- IRAS 05280, LMC red-supergiant, can be found at the highest range of mass-loss rate, following the LMC mass-loss rate for van Loon et al. (2005)

Collecting samples from

- Galactic oxygen-rich AGB+RSG (CO+IR) - De Beck et al. (2010)
- LMC oxygen-rich AGB+RSG (IR)- Groenewegen et al. (2009)
- K-band cut-off caused some bias in Groenewegen's sample?

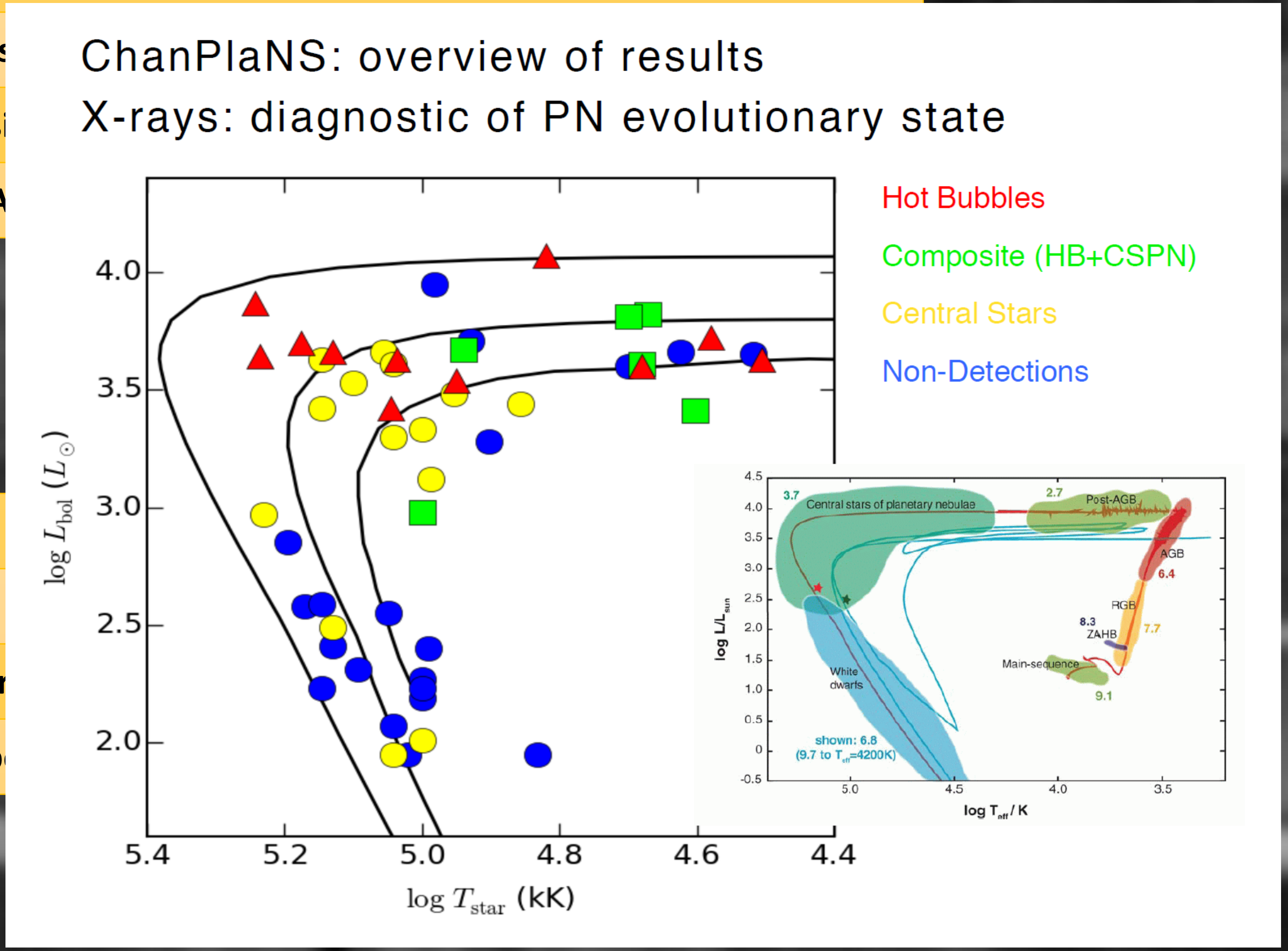
End Products

(The 39 Steps, 1935)

End Products

Joel Kastner (invited)	**Planetary Nebulae: a Contemporary (Multiwavelength) Perspective**
Valentin Bujarrabal (invited)	**Molecular Line Observations**
Daniel Tafoya	**Sub-millimeter Maser Emissi**
Mark Hollands	**Ancient Planetary Systems A**

Rubina Kotak (invited)	**Supernovae**
Mikako Matsuura (invited)	**Supernova 1987A**
Noam Soker	**Nebulae Powered by a Centr**
Santiago Gonzalez	**The Rise-Time of Type II Sup**



ChanPlaNS: overview of results

X-rays: diagnostic of PN evolutionary state

Hot Bubbles

Composite (HB+CSPN)

Central Stars

Non-Detections

End Products

Joel Kastner (invited)	**Planetary Nebulae: a Contemporary (Multiwavelength) Perspective**
Valentin Bujarrabal (invited)	**Molecular Line Observations of Planetary and Protoplanetary Nebulae: Keplerian Disks**
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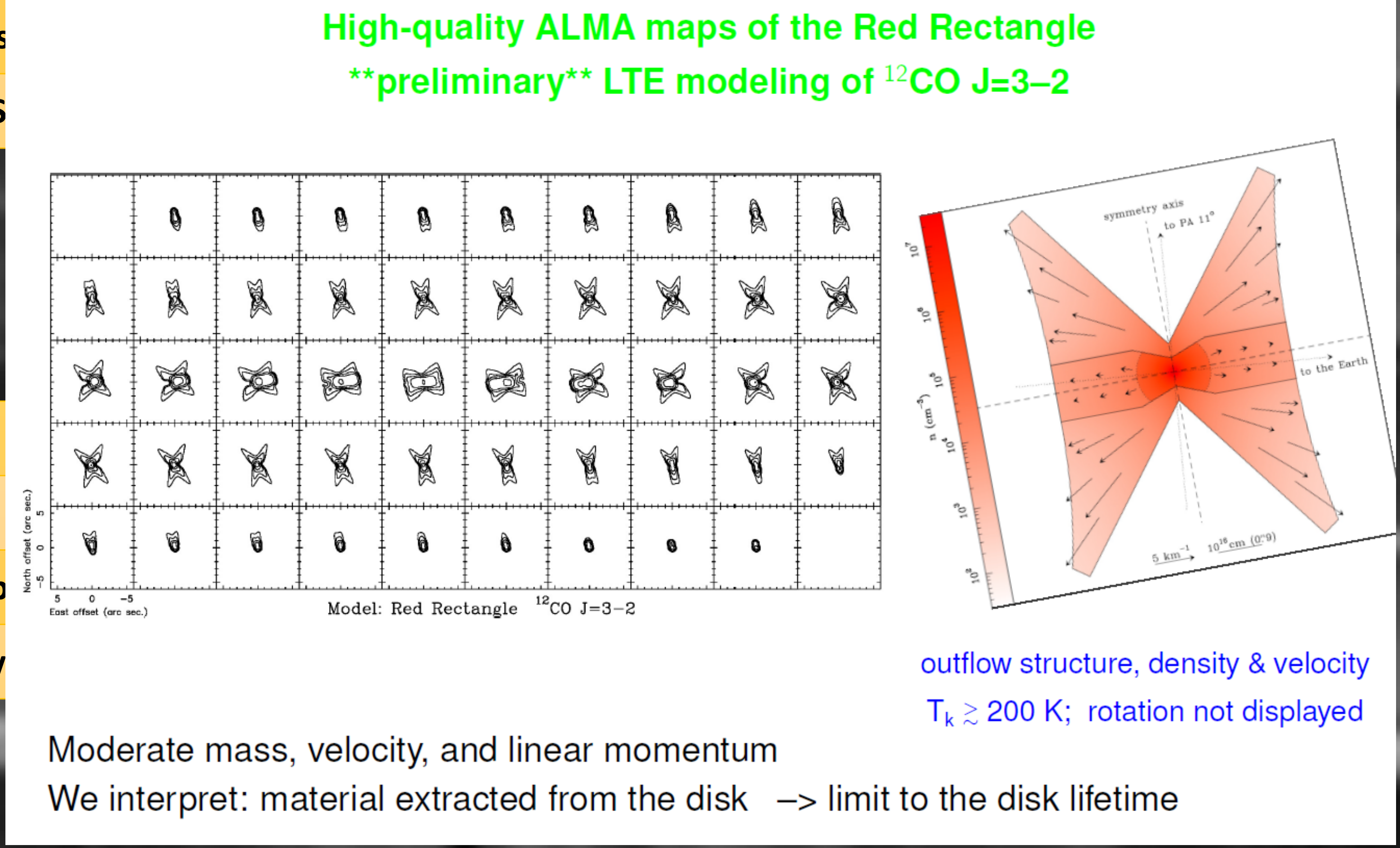

High-quality ALMA maps of the Red Rectangle

preliminary LTE modeling of ^{12}CO J=3–2

outflow structure, density & velocity

$T_k \gtrsim 200$ K; rotation not displayed

Moderate mass, velocity, and linear momentum

We interpret: material extracted from the disk –> limit to the disk lifetime

End Products

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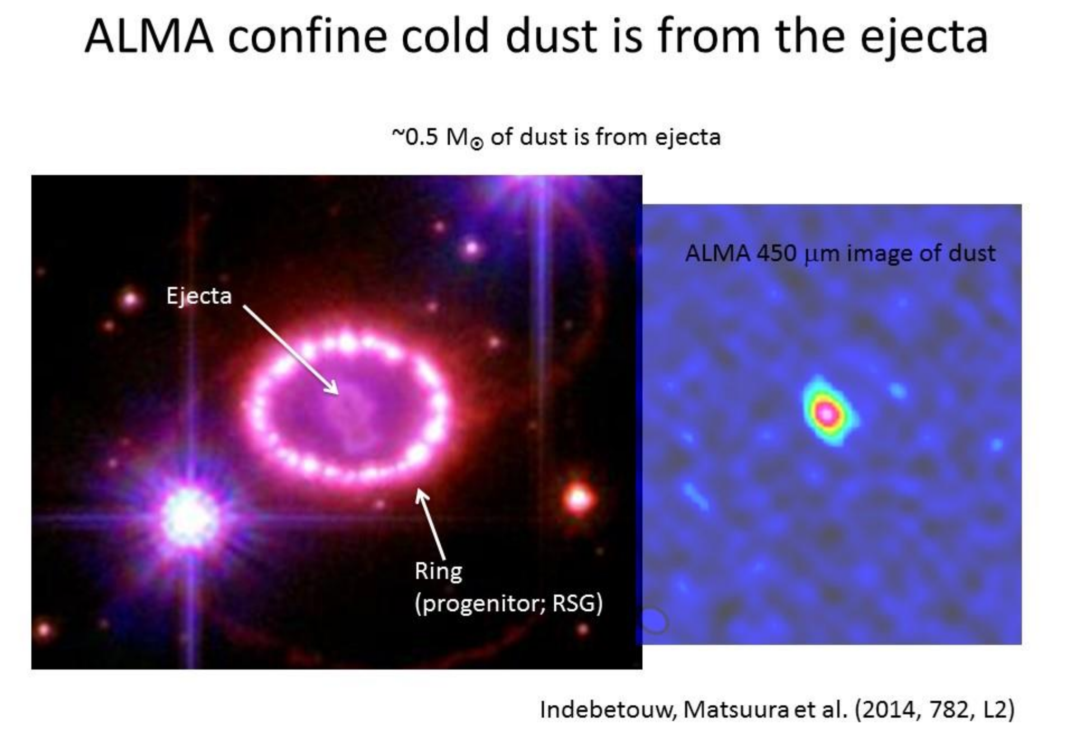
Valentin Bujarrabal (invited)	**Molecular Line Observations of Planetary and Protoplanetary Nebulae: Keplerian Disks**
Daniel Tafoya	**Sub-millimeter Maser Emission from Water Fountain Nebulae**
Mark Hollands	**Ancient Planetary Systems Around White Dwarfs**

Rubina Kotak (invited)	**Supernovae**
Mikako Matsuura (invited)	**Supernova 1987A**
Noam Soker	**Nebulae Powered by a Central Explosion**
Santiago Gonzalez	**The Rise-Time of Type II Supernovae**

End Products

Joel Kastner (invited)	**Planetary Nebulae: a Contemp**
Valentin Bujarrabal (invited)	**Molecular Line Observations o**
Daniel Tafoya	**Sub-millimeter Maser Emissio**
Mark Hollands	**Ancient Planetary Systems Arc**



ALMA confine cold dust is from the ejecta

~$0.5\ M_\odot$ of dust is from ejecta

Indebetouw, Matsuura et al. (2014, 782, L2)

Rubina Kotak (invited)	**Supernovae**
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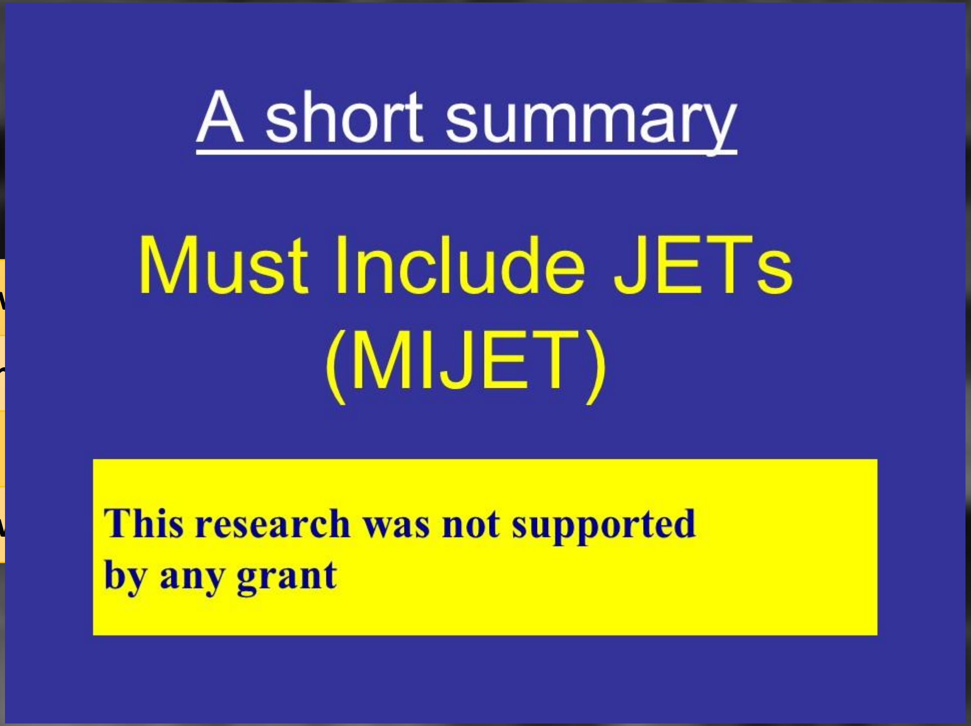

A short summary

Must Include JETs (MIJET)

This research was not supported by any grant

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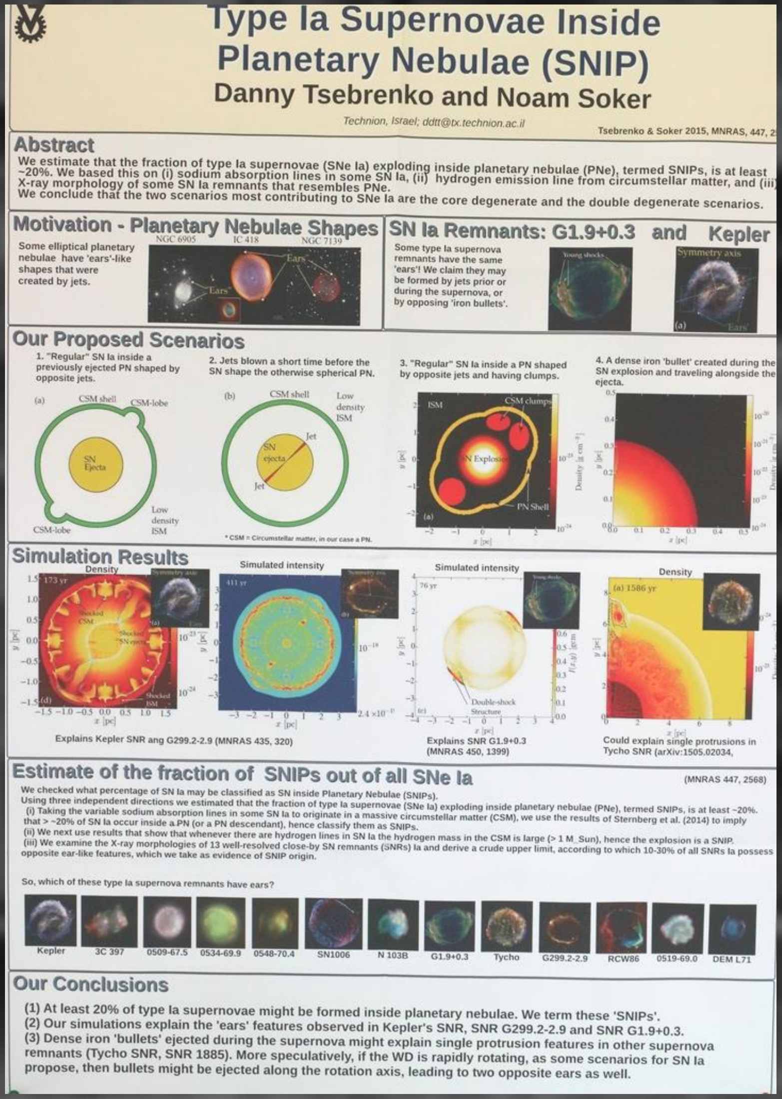

Type Ia Supernovae Inside Planetary Nebulae (SNIP)

Danny Tsebrenko and Noam Soker

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Tsebrenko & Soker 2015, MNRAS, 447, 2

Abstract

We estimate that the fraction of type Ia supernovae (SNe Ia) exploding inside planetary nebulae (PNe), termed SNIPs, is at least ~20%. We based this on (i) sodium absorption lines in some SN Ia, (ii) hydrogen emission line from circumstellar matter, and (iii X-ray morphology of some SN Ia remnants that resembles PNe.
We conclude that the two scenarios most contributing to SNe Ia are the core degenerate and the double degenerate scenarios.

Motivation - Planetary Nebulae Shapes

Some elliptical planetary nebulae have 'ears'-like shapes that were created by jets.

SN Ia Remnants: G1.9+0.3 and Kepler

Some type Ia supernova remnants have the same 'ears'! We claim they may be formed by jets prior or during the supernova, or by opposing 'iron bullets'.

Our Proposed Scenarios

1. "Regular" SN Ia inside a previously ejected PN shaped by opposite jets.
2. Jets blown a short time before the SN shape the otherwise spherical PN.
3. "Regular" SN Ia inside a PN shaped by opposite jets and having clumps.
4. A dense iron 'bullet' created during the SN explosion and traveling alongside the ejecta.

* CSM = Circumstellar matter, in our case a PN.

Simulation Results

Explains Kepler SNR ang G299.2-2.9 (MNRAS 435, 320)

Explains SNR G1.9+0.3 (MNRAS 450, 1399)

Could explain single protrusions in Tycho SNR (arXiv:1505.02034,

Estimate of the fraction of SNIPs out of all SNe Ia

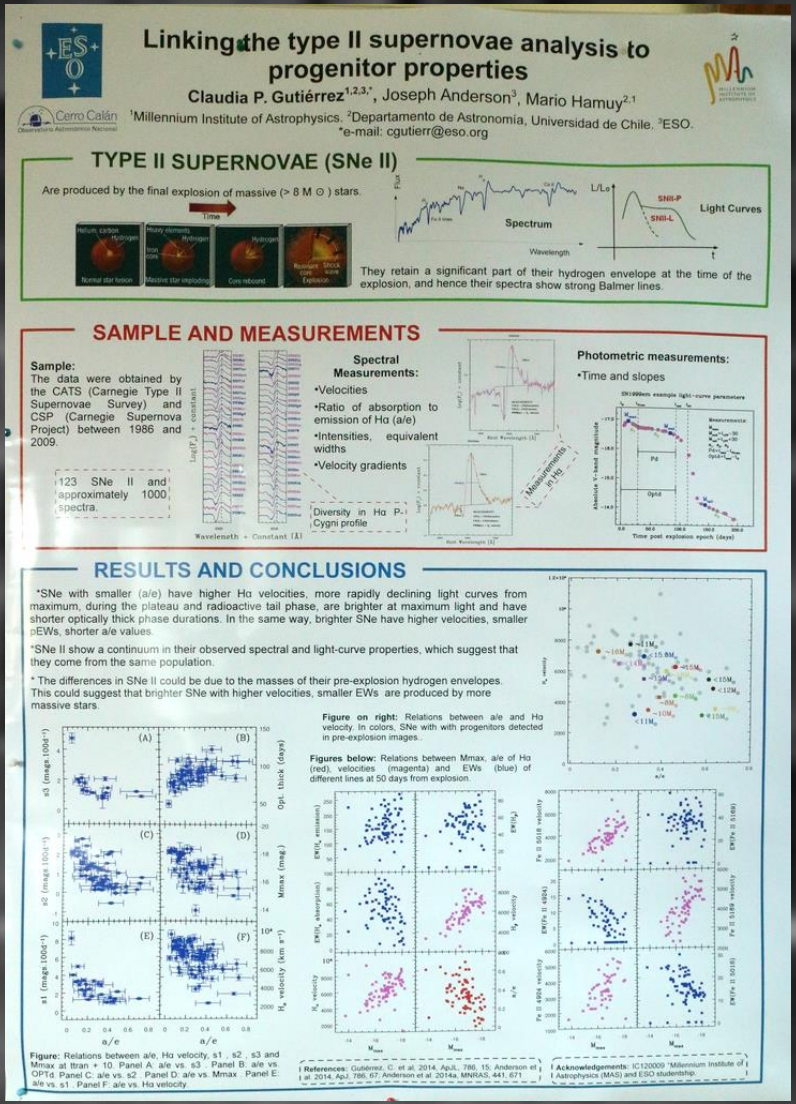
(MNRAS 447, 2568)

We checked what percentage of SN Ia may be classified as SN inside Planetary Nebulae (SNIPs).
Using three independent directions we estimated that the fraction of type Ia supernovae (SNe Ia) exploding inside planetary nebulae (PNe), termed SNIPs, is at least ~20%.
(i) Taking the variable sodium absorption lines in some SN Ia to originate in a massive circumstellar matter (CSM), we use the results of Sternberg et al. (2014) to imply that > ~20% of SN Ia occur inside a PN (or a PN descendant), hence classify them as SNIPs.
(ii) We next use results that show that whenever there are hydrogen lines in SN Ia the hydrogen mass in the CSM is large (> 1 M_Sun), hence the explosion is a SNIP.
(iii) We examine the X-ray morphologies of 13 well-resolved close-by SN remnants (SNRs) Ia and derive a crude upper limit, according to which 10-30% of all SNRs Ia possess opposite ear-like features, which we take as evidence of SNIP origin.

So, which of these type Ia supernova remnants have ears?

Our Conclusions

(1) At least 20% of type Ia supernovae might be formed inside planetary nebulae. We term these 'SNIPs'.
(2) Our simulations explain the 'ears' features observed in Kepler's SNR, SNR G299.2-2.9 and SNR G1.9+0.3.
(3) Dense iron 'bullets' ejected during the supernova might explain single protrusion features in other supernova remnants (Tycho SNR, SNR 1885). More speculatively, if the WD is rapidly rotating, as some scenarios for SN Ia propose, then bullets might be ejected along the rotation axis, leading to two opposite ears as well.



Linking the type II supernovae analysis to progenitor properties

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TYPE II SUPERNOVAE (SNe II)

Are produced by the final explosion of massive (> 8 M ⊙) stars.

They retain a significant part of their hydrogen envelope at the time of the explosion, and hence their spectra show strong Balmer lines.

SAMPLE AND MEASUREMENTS

Sample:
The data were obtained by the CATS (Carnegie Type II Supernovae Survey) and CSP (Carnegie Supernova Project) between 1986 and 2009.

123 SNe II and approximately 1000 spectra.

Spectral Measurements:
- Velocities
- Ratio of absorption to emission of Hα (a/e)
- Intensities, equivalent widths
- Velocity gradients

Diversity in Hα P-Cygni profile

Measurements in Hα

Photometric measurements:
- Time and slopes

RESULTS AND CONCLUSIONS

*SNe with smaller (a/e) have higher Hα velocities, more rapidly declining light curves from maximum, during the plateau and radioactive tail phase, are brighter at maximum light and have shorter optically thick phase durations. In the same way, brighter SNe have higher velocities, smaller pEWs, shorter a/e values.

*SNe II show a continuum in their observed spectral and light-curve properties, which suggest that they come from the same population.

* The differences in SNe II could be due to the masses of their pre-explosion hydrogen envelopes. This could suggest that brighter SNe with higher velocities, smaller EWs are produced by more massive stars.

Figure on right: Relations between a/e and Hα velocity. In colors, SNe with with progenitors detected in pre-explosion images.

Figures below: Relations between Mmax, a/e of Hα (red), velocities (magenta) and EWs (blue) of different lines at 50 days from explosion.

Figure: Relations between a/e, Hα velocity, s1 , s2 , s3 and Mmax at ttran + 10. Panel A: a/e vs. s3 . Panel B: a/e vs. OPTd. Panel C: a/e vs. s2 . Panel D: a/e vs. Mmax . Panel E: a/e vs. s1 . Panel F: a/e vs. Hα velocity.

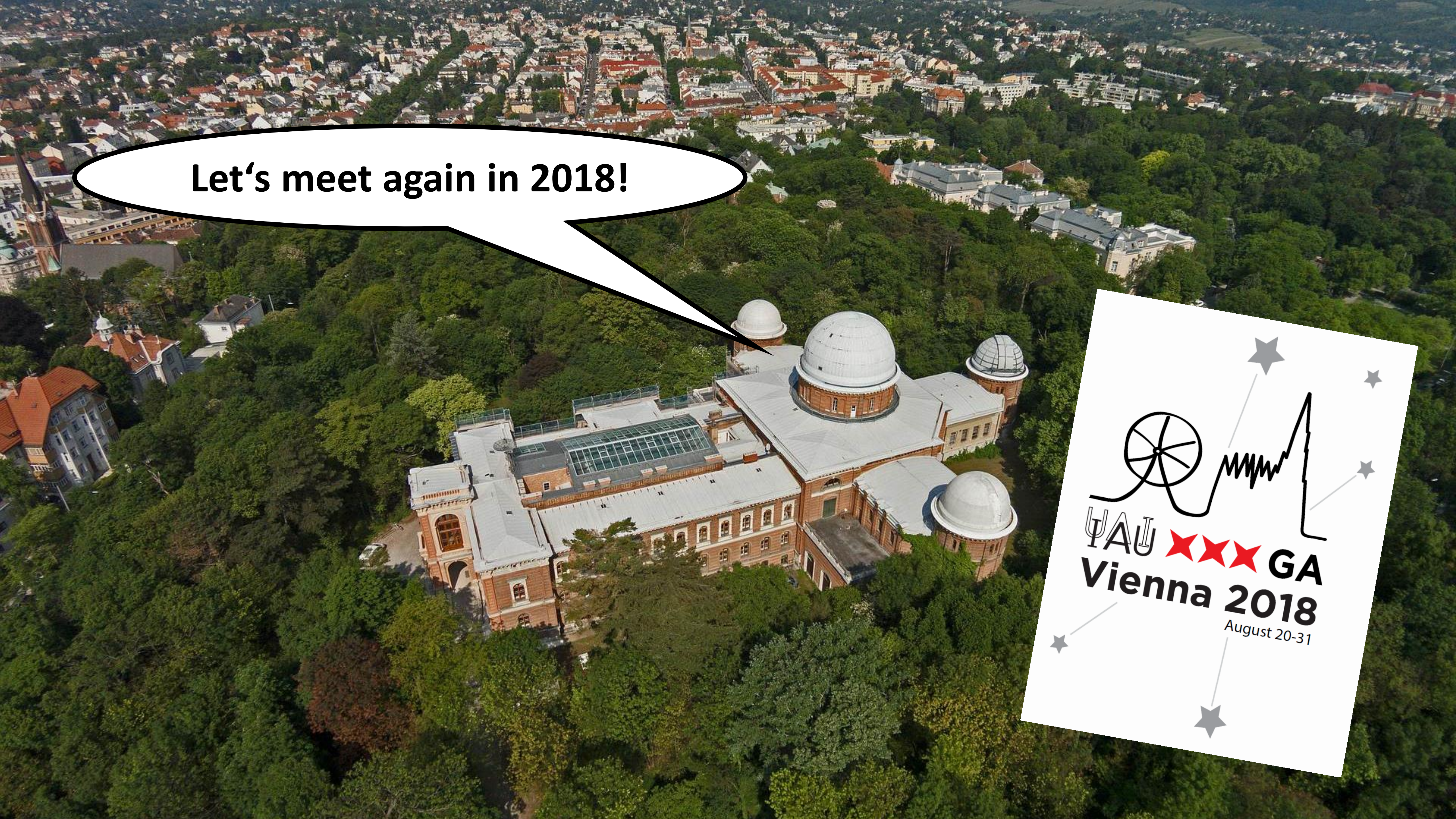
References: Gutiérrez, C. et al 2014, ApJL, 786, 15; Anderson et al. 2014, ApJ, 786, 67; Anderson et al. 2014a, MNRAS, 441, 671

Acknowledgements: IC120009 "Millennium Institute of Astrophysics (MAS) and ESO studentship.

So?

All this was very loose guessing, and I don't pretend it was ingenious or scientific.

(The 39 Steps, 1935)



Let‘s meet again in 2018!