NUCLEOSYNTHESIS
CONSTRAINTS FROM PLANETARY NEBULA ABUNDANCES

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1. INTRODUCTION

2. O, S, Ne, Ar, N, He IN PN AS NUCLEOSYNTHESIS CONSTRAINTS

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1. INTRODUCTION

Why study planetary nebulae?
Planetary nebulae have strong emission lines of H, He, O, N, Ne, S, Ar, etc, including forbidden lines and recombination lines. The analysis of these lines gives abundances accurate to about 0.2 dex or better.
Planetary nebulae (PN) allow the determination of accurate abundances of elements that are not produced by the progenitor stars (O, S, Ne, Ar).

→ Chemical evolution of the host galaxies

Accurate abundances of elements that are produced by the progenitor stars are also measured in PN (He, N, C).

→ Intermediate mass star nucleosynthesis

Some of these elements are difficult to study in stars.

→ Comparison with stellar data
## 2. O, S, Ne, Ar, N, He IN PN AS NUCLEOSYNTHESIS CONSTRAINTS

<table>
<thead>
<tr>
<th>System</th>
<th>Number of objects</th>
<th>Reference</th>
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<tbody>
<tr>
<td>MW disk - Sample A</td>
<td>234</td>
<td>IAG</td>
</tr>
<tr>
<td>MW disk - Sample B</td>
<td>372</td>
<td>IAG + Literature</td>
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<td>MW bulge</td>
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<td>IAG</td>
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<tr>
<td>LMC</td>
<td>282</td>
<td>IAG, SRM, LD</td>
</tr>
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<td>SMC</td>
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<td>MW</td>
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<td>CGSB</td>
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<td>BCG</td>
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<td>Izotov</td>
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Metallicity differences: SMC, LMC and the Milky Way
In the Galaxy, it is important to distinguish distance-independent correlations from the correlations that depend on the distances, such as the abundance gradients observed in the galactic disk.

We will consider the abundances of Neon, Argon, and Sulphur compared to the better determined Oxygen abundances. The data refer to the MW disk, bulge, interface and the Magellanic Clouds.
Distance-independent correlations

Neon, Argon, Sulphur: PN

MW disk, bulge, interface, SMC, LMC
Neon, Argon, Sulphur: PN

MW disk, bulge, interface, SMC, LMC
HII regions,
Blue Compact Galaxies
Ne, Ar: good
S: not so good

MW disk, bulge, interface, SMC, LMC
MW: Sample A

log(Ne/H)+12

log(O/H)+12
(1) sulphur anomaly
(2) higher dispersion
Cavichia et al. (2010)
He, N: Abundances are changed by the evolution of the progenitor star
Nitrogen Abundances as functions of He/H
Nitrogen Abundances as functions of He/H

Comparison with theoretical models

Marigo (2003)
Nitrogen Abundances as functions of He/H
Nitrogen Abundances as functions of He/H

Comparison with theoretical models

Marigo (2003)
These are synthetic evolutionary models for the thermally-pulsing AGB with masses of 1.1 to 5 solar masses, in which up to three dredge-up episodes occur, apart from hot-bottom processes (HBB) for the most massive objects.

According to these models, progenitors having 0.9 to 4 solar masses and solar composition can explain the “normal” abundances, He/H < 0.15, while for objects with higher enhancements (He/H > 0.15) masses of 4 to 5 solar masses are needed, plus an efficient HBB.
Comparison with theoretical models

Karakas (2003)

Initial masses of 1.0 to 6.0 $M_\odot$, metallicities $Z = 0.004$, 0.008 and 0.02
CONCLUSIONS

- PN abundances of O, Ne, Ar show good correlations, indicating that Ne and Ar vary in lockstep with O. Abundances relative to oxygen are essentially constant.

- Sulphur is still a problem:
  1. PN abundances in the MW are lower than expected.
  2. Average dispersion is higher than for Ne and Ar.

- Taking into account the abundances of elements that are produced by the progenitor stars (N, He), agreement with theoretical models is fair, but abundance determinations should be improved and expanded.
3. OXYGEN AS A METALLICITY PROXY: THE O X Fe RELATION IN THE GALAXY

\[ [\text{Fe/H}] = \gamma + \delta [\log (\text{O/H}) + 12] \]

The parameter \( \delta \) relates the Fe and O abundances.

Measurements of the oxygen abundances and [Fe/H] metallicities in stars can be used to estimate the O x Fe relation in the Galaxy. This is important in the comparison of [Fe/H] and O/H radial abundance gradients.
ALL DATA
\[ \delta = 1.310 \pm 0.014 \]
\[ r = 0.94 \]
THE NEW SAMPLE

Disk + Halo

$\delta = 1.11 \pm 0.02$

Ramirez et al. (2012)
Thin Disk  
\[ \delta = 1.11 \pm 0.03 \]

Thick Disk  
\[ \delta = 1.31 \pm 0.05 \]
CONCLUSIONS

There is a well defined correlation between the iron and oxygen abundances in the Galaxy, which is valid for the galactic disk and approximately for the halo.

The average slope of the Fe – O relation is
\[ \delta = 1.11 \pm 0.014 \] for the thin disk
\[ \delta = 1.31 \] for the thick disk.

Assuming linear radial gradients in the galactic disk, parameter \( \delta \) gives the ratio between the \([\text{Fe/H}]\) gradient as measured in cepheids and open clusters and the \(\text{O/H}\) gradient from planetary nebulae and HII regions.
Thank You

Vielen Dank