The composition of presolar spinel grain OC2: constraining AGB models

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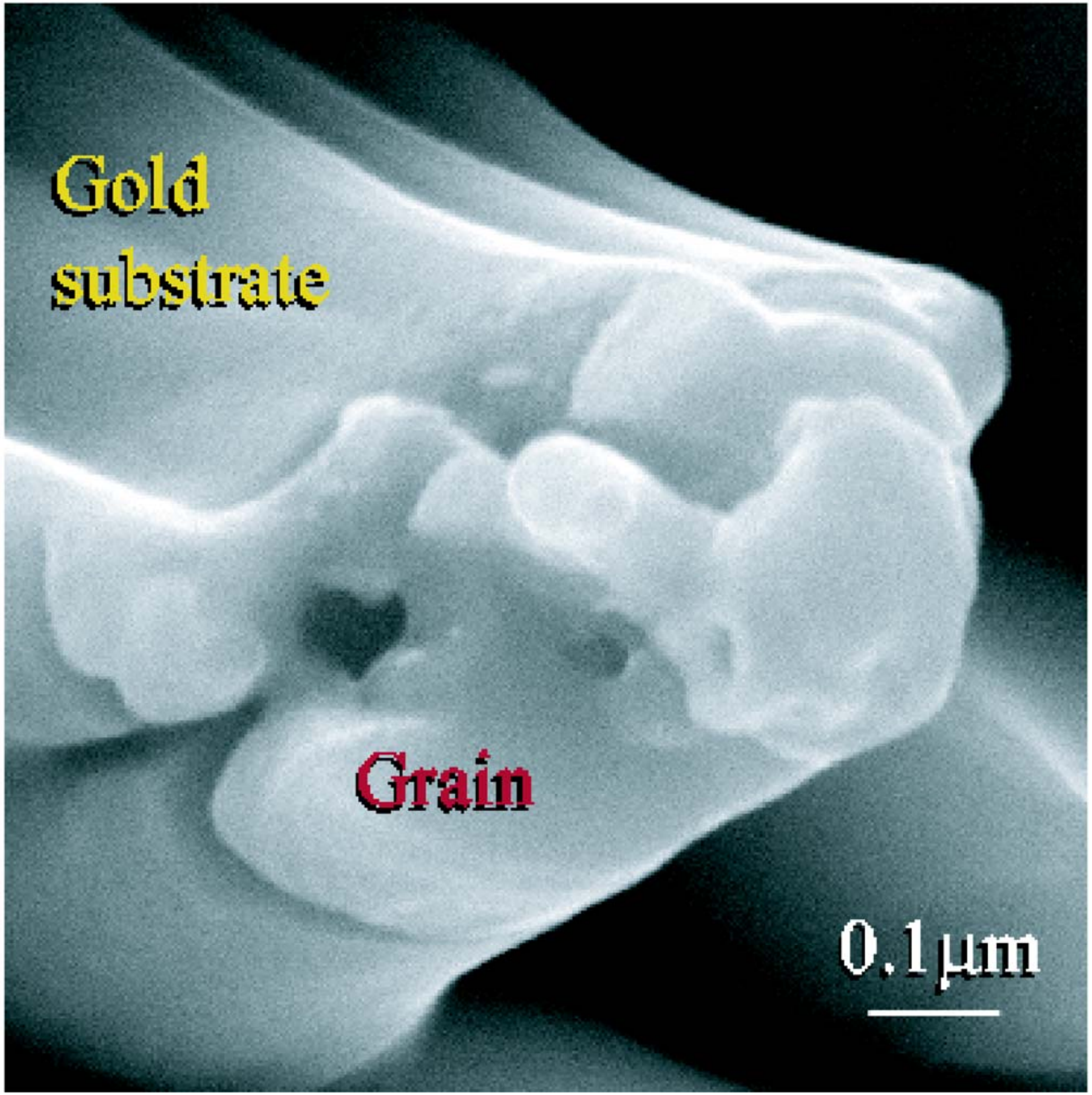
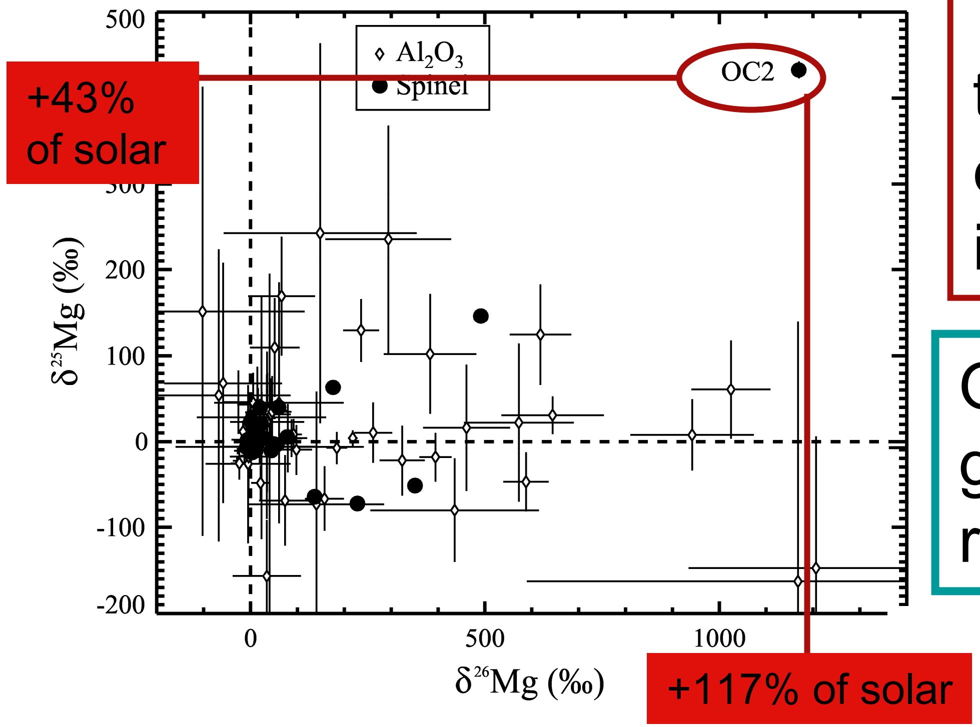
Scanning electron microscope image of presolar spinel grain OC2.

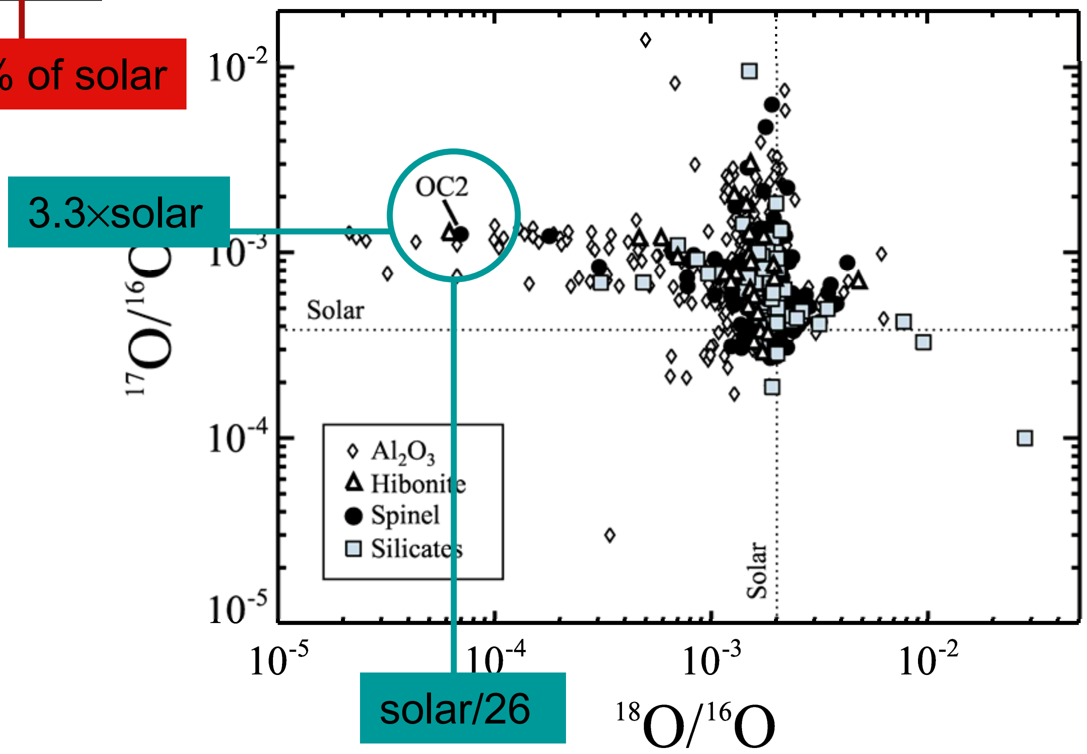
This 800nm ruby-like gem is sitting on a gold pedestal, following the ion probe isotopic analysis, because the gold substrate sputters faster than the grain does.



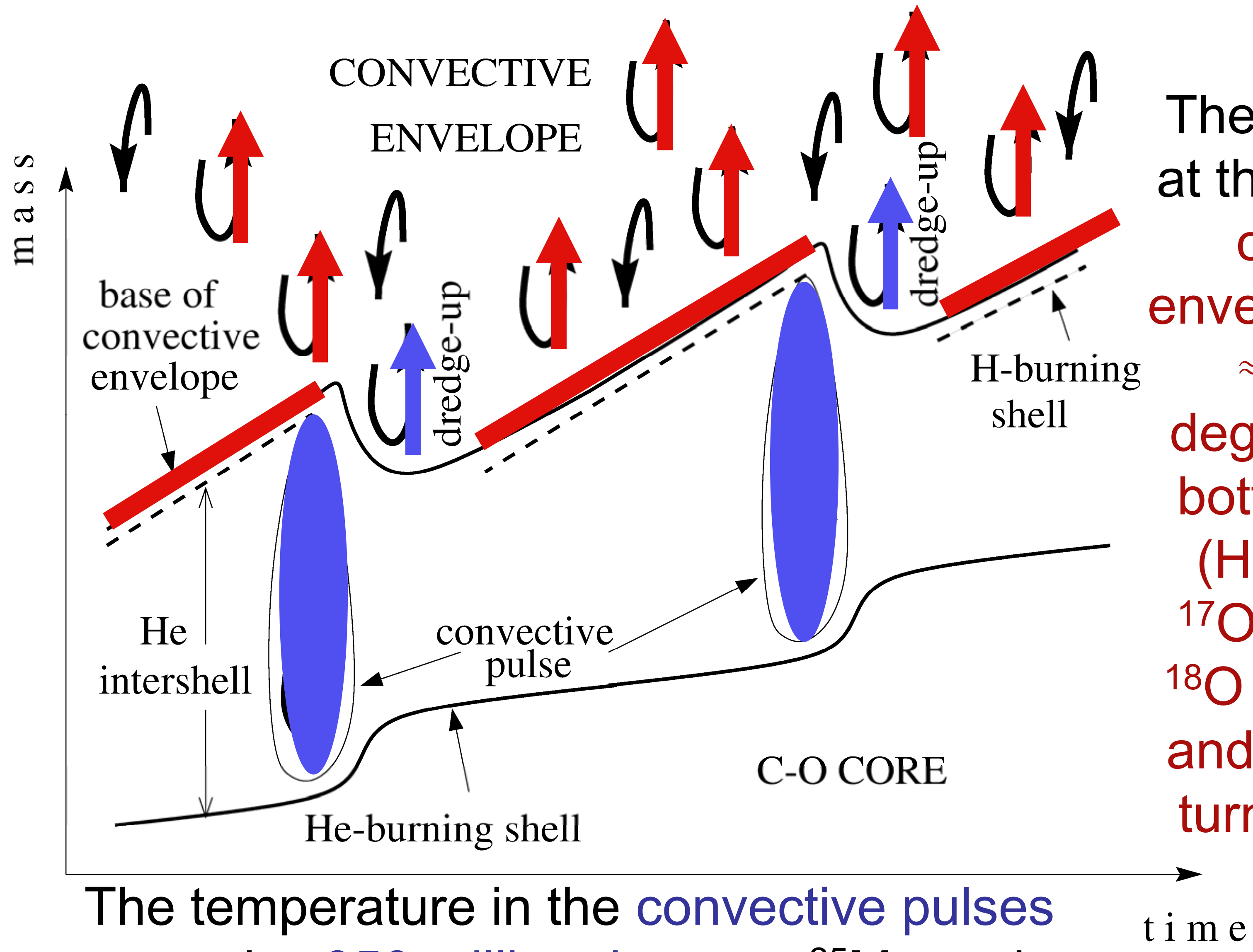
The most remarkable feature of the composition of OC2 is large excesses of the heavy Mg isotopes.



Of ≈600 known presolar oxide grains, only 10 have $^{18}O/^{16}O$ ratios as low as that of OC2.



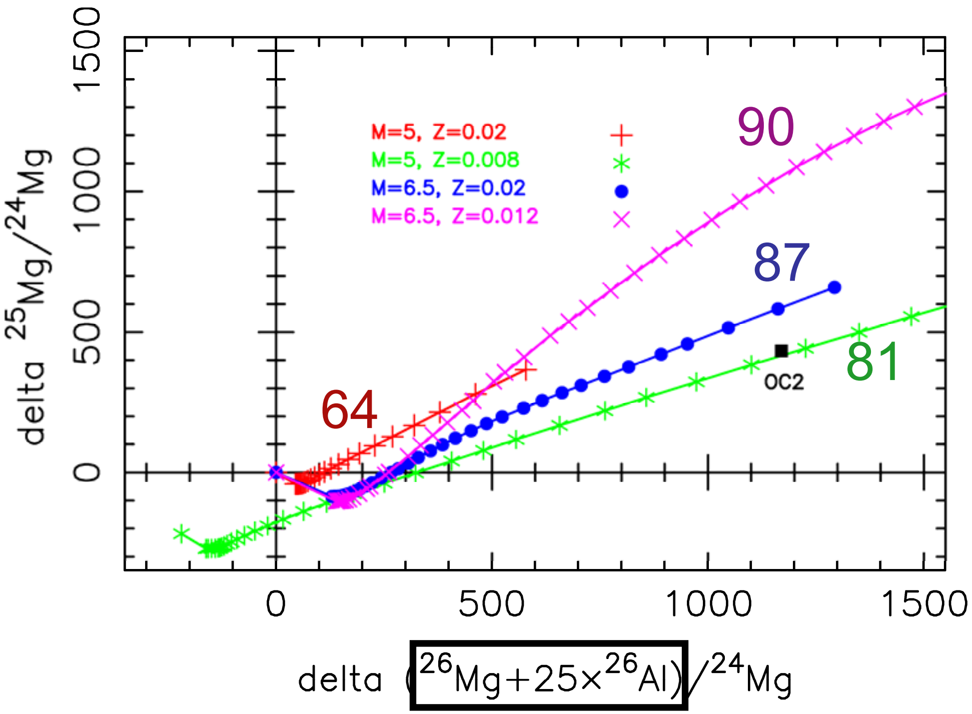
The origin of grain OC2 has been tentatively attributed to an intermediate-mass AGB star ≈ 4 - 7 $M_\odot$



The temperature at the base of the convective envelope exceeds ≈50 million degrees and hot bottom burning, (HBB) occurs: ^{17}O is produced, ^{18}O is destroyed, and ^{25}Mg can be turned into ^{26}Al.

The temperature in the convective pulses exceeds ≈350 million degrees. ^{25}Mg and ^{26}Mg are produced in similar amount by $^{22}Ne+\alpha$ and then mixed into the envelope by the third dredge-up.

We compare the composition of OC2 to our detailed models of AGB stars.



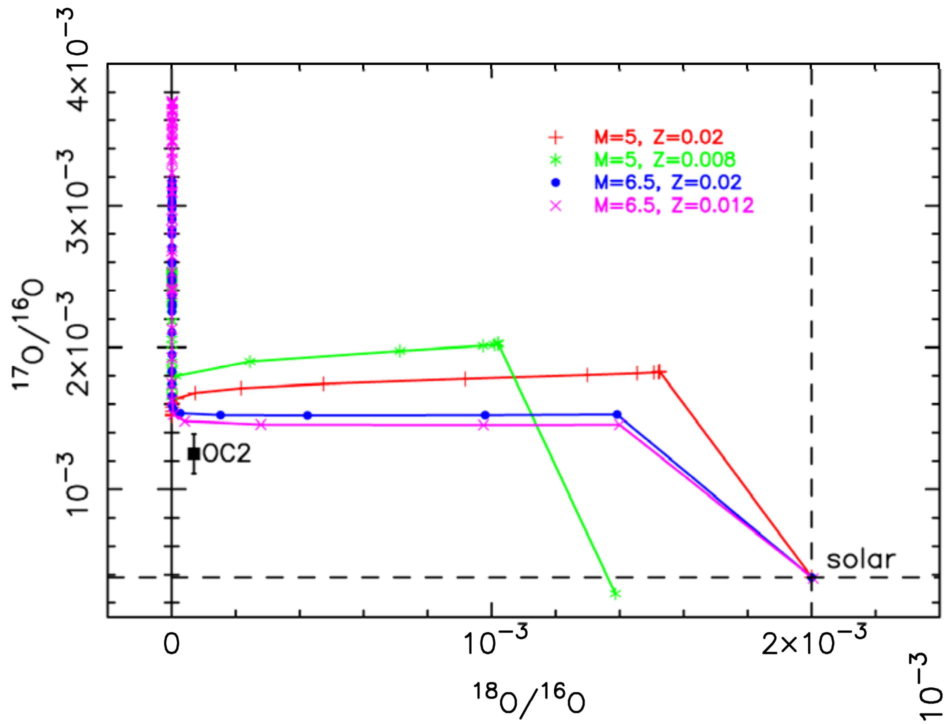
We find the following conditions to match the Mg composition of OC2:

1. T in the convective pulses > 352 million degrees and/or total mass TDU > 0.05 $M_\odot$
2. T at the base of the convective envelope ≈ 80 - 85 million degrees.

Maximum temperatures at the base of the convective envelope in million degrees.

These are verified in our 5,0.008 and 6.5,0.02 models.

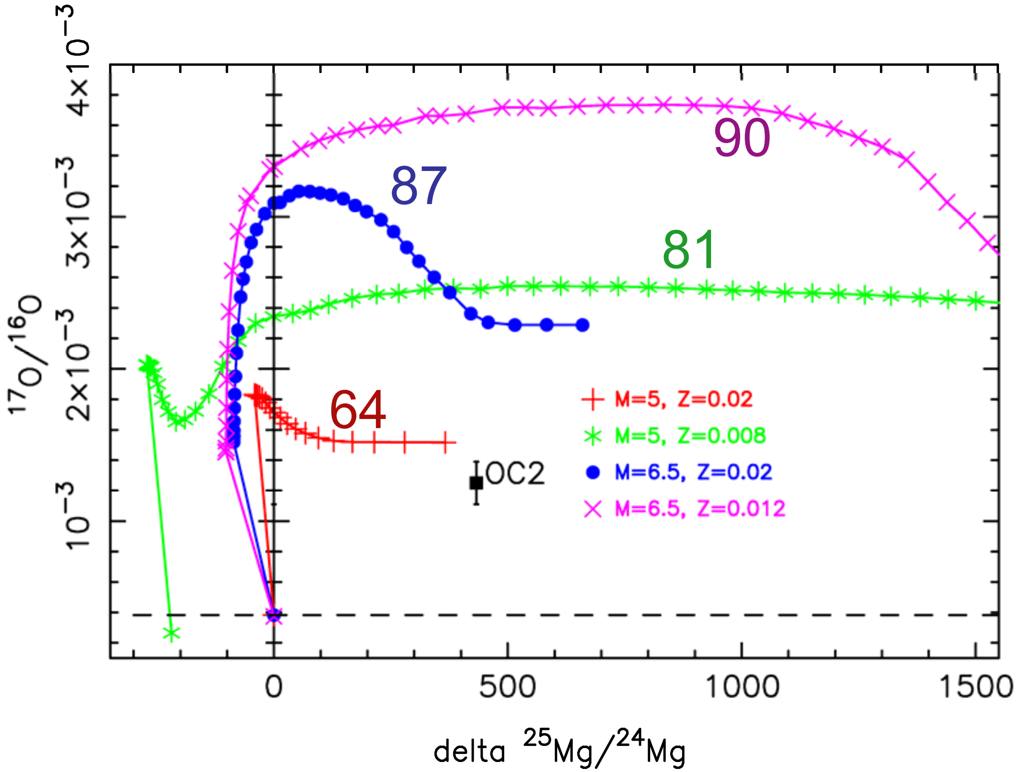
^{26}Al is incorporated in spinel and decays into ^{26}Mg in 0.7 million years. Aluminium was incorporated in spinel grains ≈25 times more preferentially than Mg, given that spinel is $MgAl_2O_4$, i.e. Al/Mg=2 while it is 0.08 in the Solar System.



All models deplete ^{18}O very quickly and cannot match OC2. However, the measured $^{18}O/^{16}O$ ratio can be explained by a 2% level of terrestrial contamination, which is reasonable.

$^{17}O/^{16}O \approx$
$^{16}O(p,\gamma)^{17}F/^{17}O(p,\alpha)^{14}N.$

This increases with T and is too high in our models to match OC2.

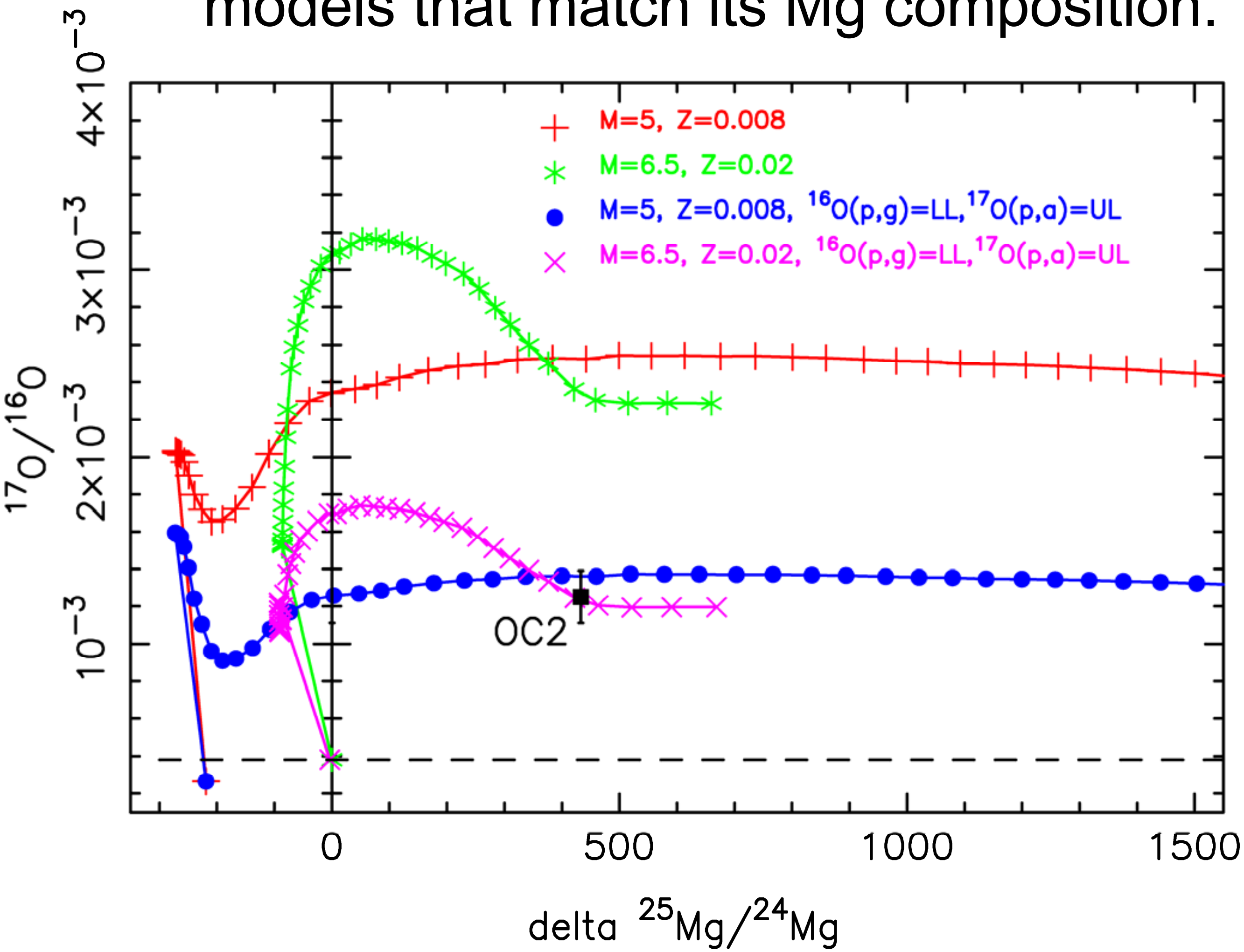


If we take

the ***upper limit*** for the $^{17}O(p,\alpha)^{14}N$ rate (+25%) and

the ***lower limit*** for the $^{16}O(p,\gamma)^{17}F$ rate (-43%)

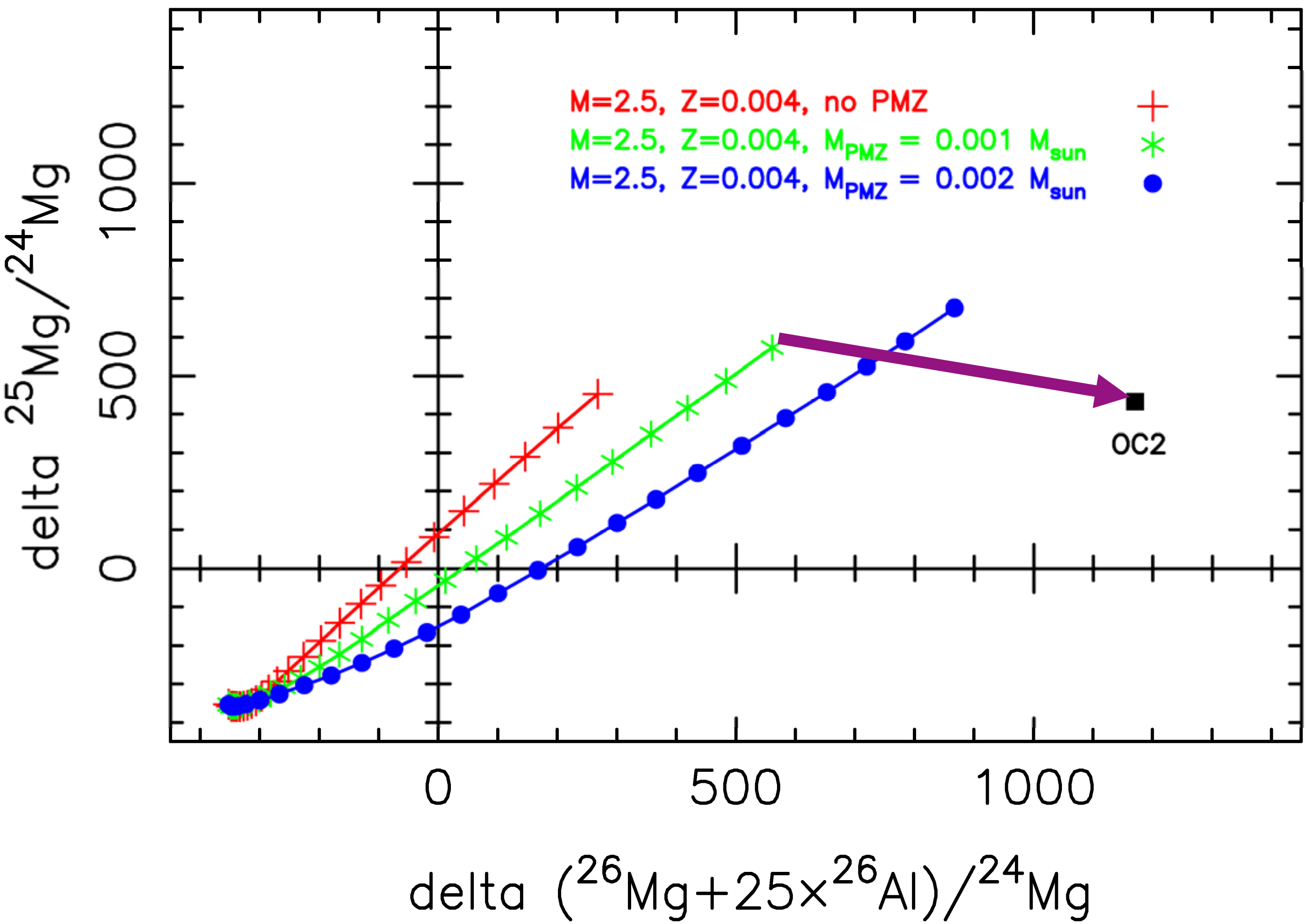
we obtain a solution for the $^{17}O/^{16}O$ ratio of OC2 using the same models that match its Mg composition.



Alternative solution:

a low-mass (2.5 - 3.5 $M_\odot$) low-Z (0.004 - 0.008) AGB star.

In this case ^{25}Mg and ^{26}Mg are also produced by *n*-captures in the ^{13}C pocket.



To get the extra needed ^{26}Al and the right O ratios, one must invoke some **extra mixing - cool bottom processing**.

The Fe and Cr composition:

	IM AGB $Z \approx Z_\odot$	LM AGB $Z \approx 0.3\,Z_\odot$	OC2
$\delta(^{57}Fe/^{56}Fe)$	≈ 80	≈ 370	170±191
$\delta(^{54}Cr/^{52}Cr)$	≈ 180	Negative? +≈600	102±117
$\delta(^{50}Cr/^{52}Cr)$	≈ 0	Negative?	26±71
$\delta(^{53}Cr/^{52}Cr)$	≈ 0	Negative?	-56±45

Effect of Galactic chemical evolution?

Summary and conclusions 1

1. The O, Mg and Al composition of OC2 could be produced by an IM-AGB of $Z \approx Z_{\odot}$, or by a LM-AGB of $Z \approx 0.3\ Z_{\odot}$ with efficient extra mixing. The large uncertainty in the Fe composition of OC2 does not allow us to determine which model is better, but the Cr composition favors the origin in an IM-AGB star.
2. Using our IM-AGB models it is possible to find a solution. Conditions are: **TDU mass > 0.05 $M_{\odot}$ and/or $T_{intershell}$ > 360 million degrees, $T_{HBB} \approx$ 80 - 85 million degrees**, *upper limit* for the $^{17}O(p,\alpha)^{14}N$ rate, *lower limit* for the $^{16}O(p,\gamma)^{17}F$ rate.

Summary and conclusions 2: *this is just the beginning!*

- Further laboratory analysis may identify additional grains with isotopic compositions similar to OC2 and thus provide more opportunities to test the findings of the present work.
- We need to compare OC2 to models computed with different physics assumptions to analyze stellar model uncertainties and derive constraints on the choice of the physics in AGB models.