Noble gases record Venus' formation and evolution

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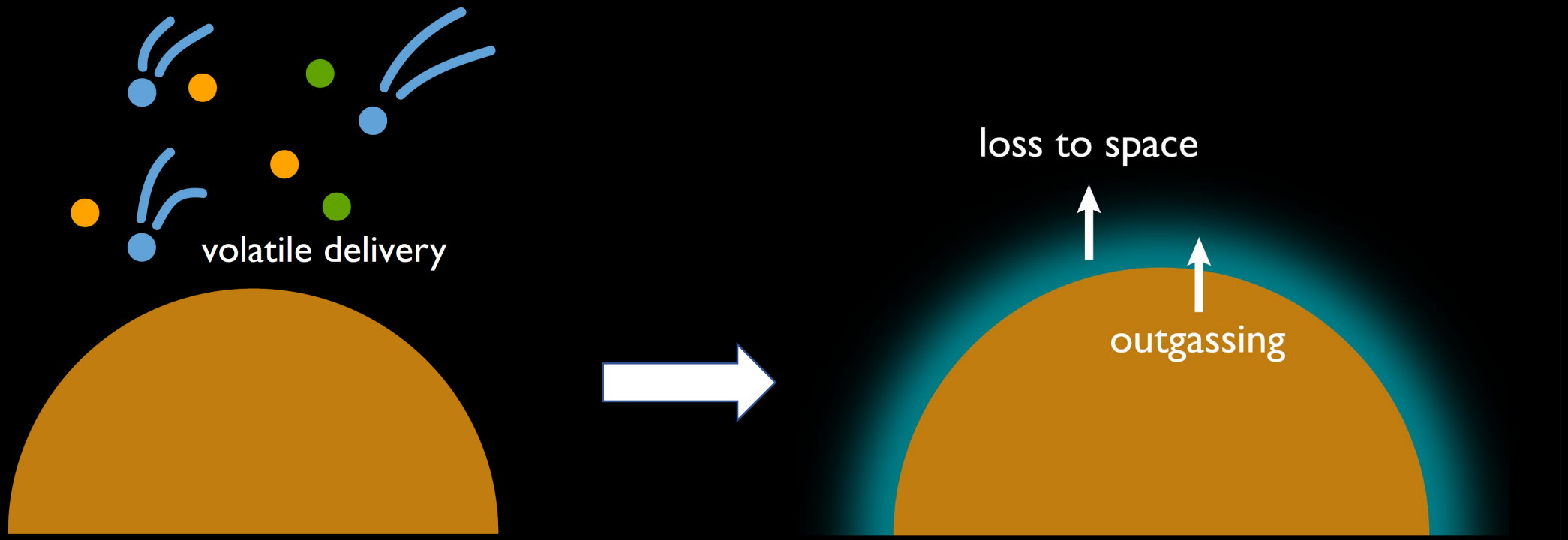
Noble gases record an integrated history of volatile delivery and transport



Array of isotopes that track accretion history, outgassing on different timescales, and atmospheric loss to space

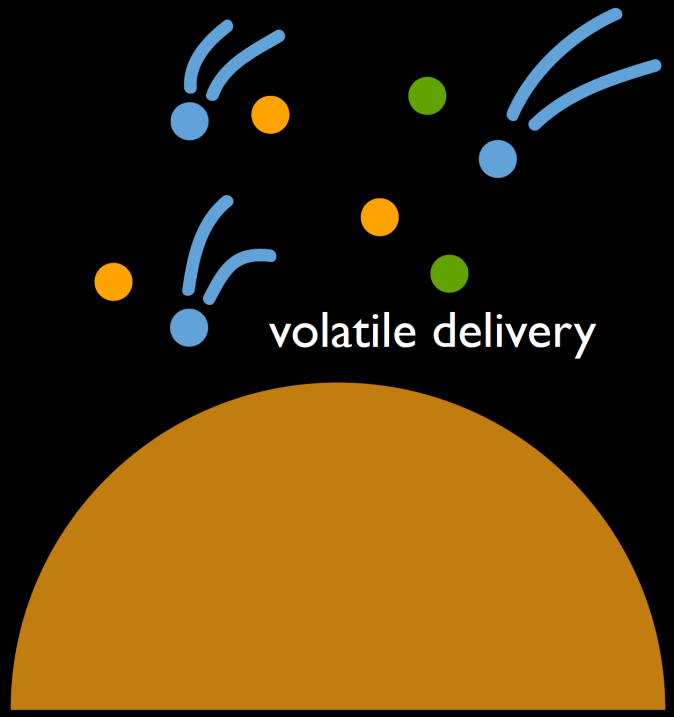
Noble gas primer

- ^{3}He, ^{4}He
- ^{20}Ne, ^{21}Ne, ^{22}Ne
- ^{36}Ar, ^{38}Ar, ^{40}Ar
- ^{78}Kr, ^{80}Kr, ^{82}Kr, ^{83}Kr, ^{84}Kr, ^{86}Kr
- ^{124}Xe, ^{126}Xe, ^{128}Xe, ^{129}Xe, ^{130}Xe, ^{131}Xe, ^{132}Xe, ^{134}Xe, ^{136}Xe

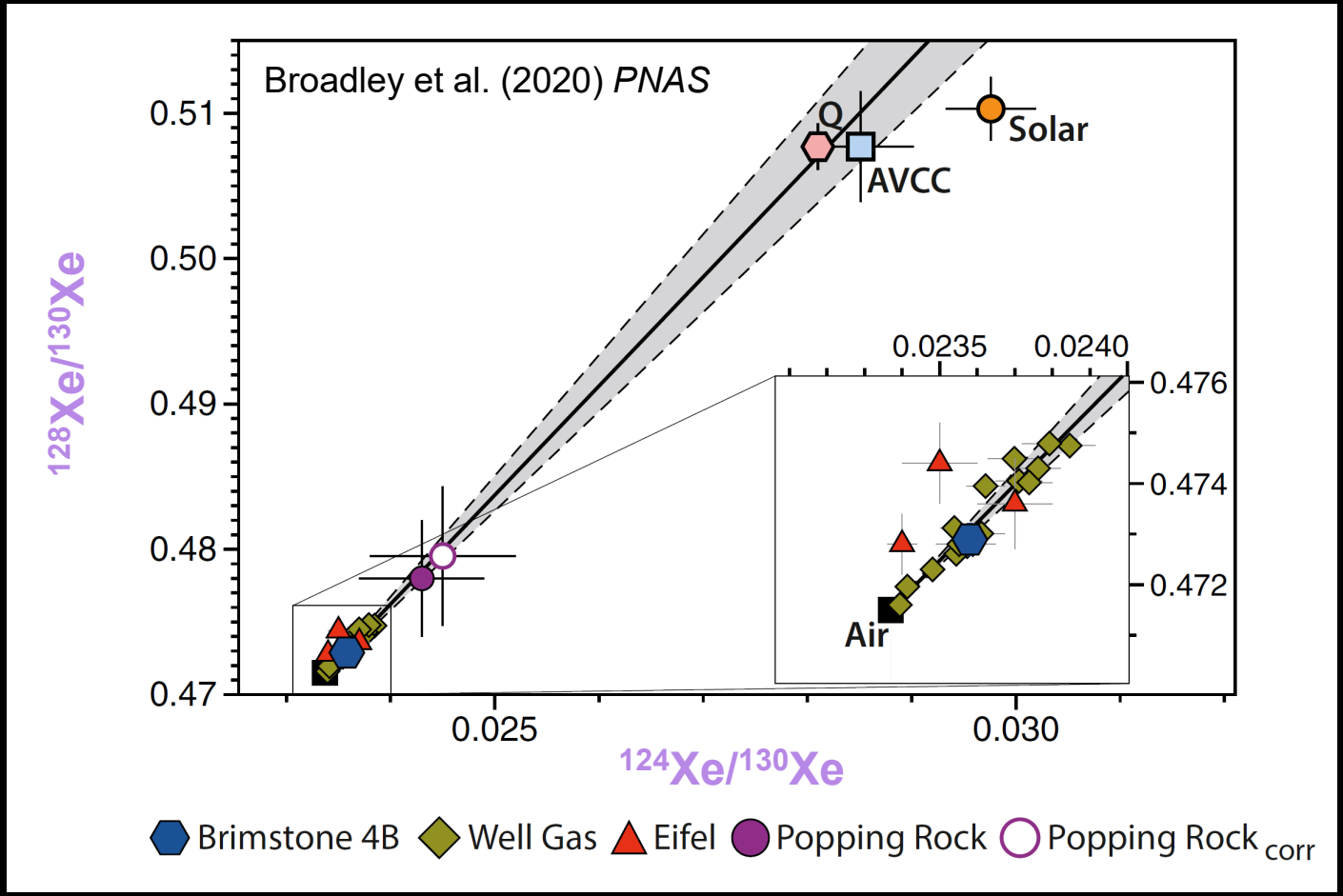
Noble gas primer

- ^{3}He, ^{4}He — radiogenic, primordial
- ^{20}Ne, ^{21}Ne, ^{22}Ne
- ^{36}Ar, ^{38}Ar, ^{40}Ar
- ^{78}Kr, ^{80}Kr, ^{82}Kr, ^{83}Kr, ^{84}Kr, ^{86}Kr — Pu, U fission products
- ^{124}Xe, ^{126}Xe, ^{128}Xe, ^{129}Xe, ^{130}Xe, ^{131}Xe, ^{132}Xe, ^{134}Xe, ^{136}Xe

Pairs of primordial isotopes can serve as fingerprints of accreted volatiles

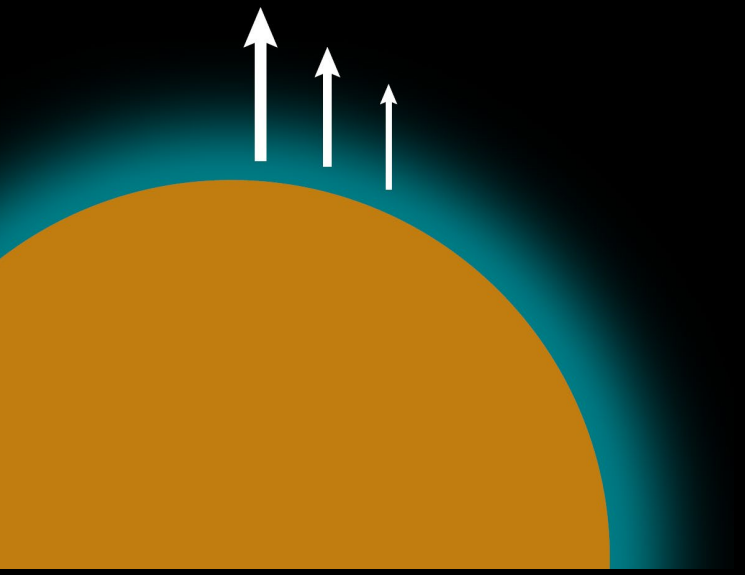


Example from Earth's mantle-derived samples:

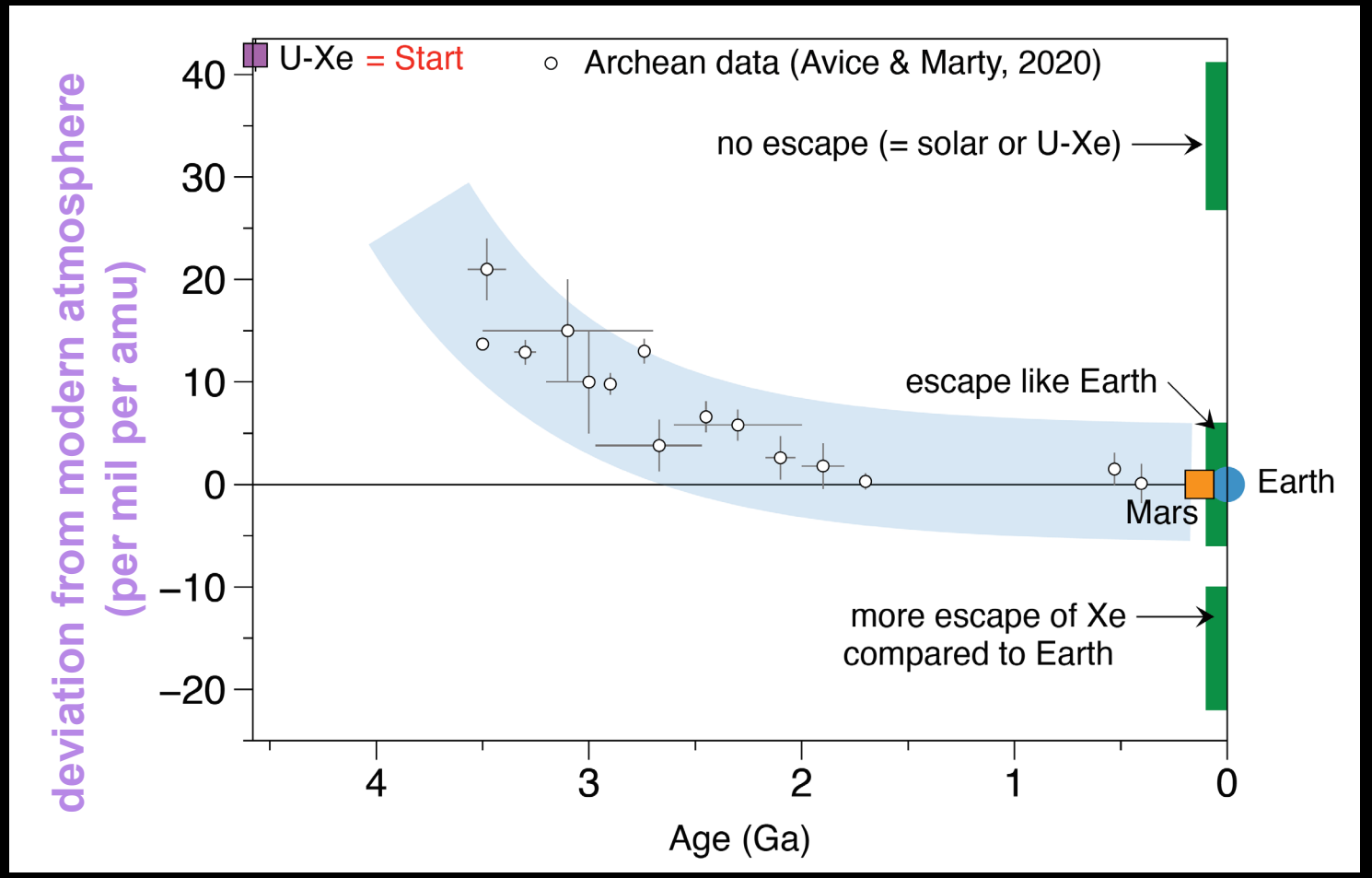


Pairs of primordial isotopes can also trace atmospheric loss to space

mass-fractionating loss to space

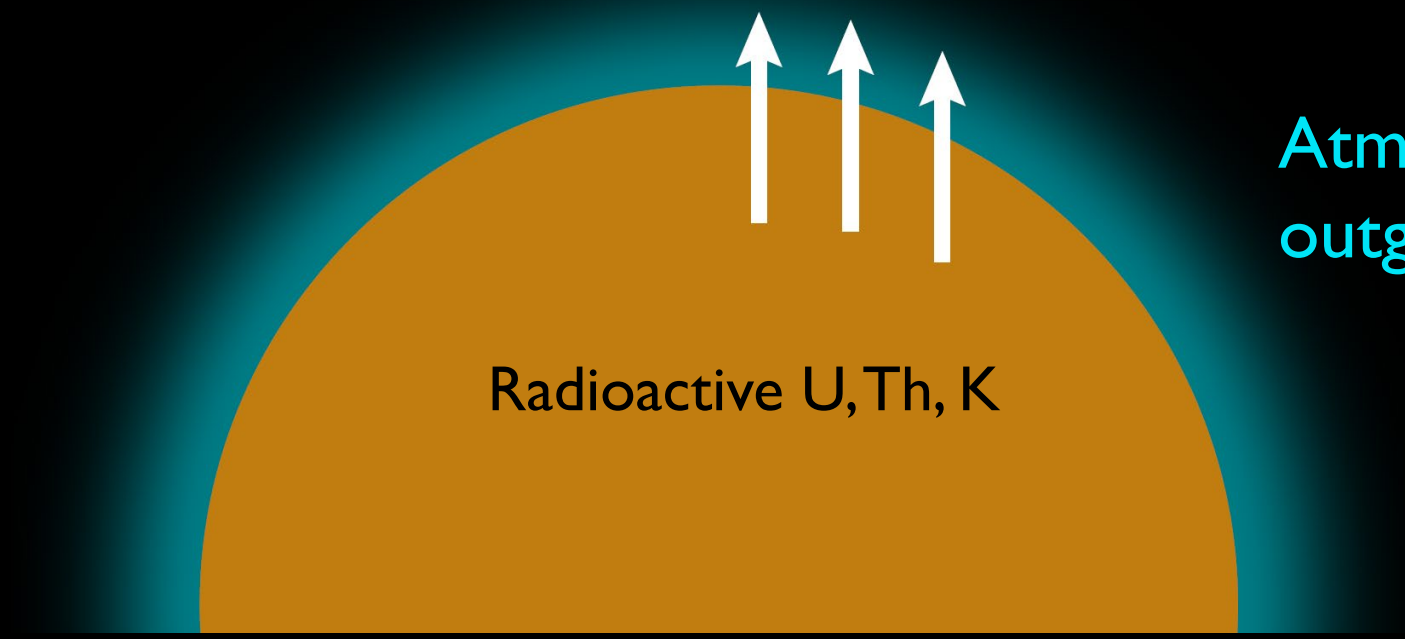


Example from samples of Earth's atmosphere over time:



Ratios of radiogenic to primordial isotopes track outgassing on different timescales

Outgassing raises interior radiogenic to primordial ratios



e.g., high mantle $^{4}He/^{3}He$ and $^{40}Ar/^{36}Ar$

Atmosphere accumulates outgassed volatiles

More outgassing → high atmospheric $^{4}He/^{3}He$ and $^{40}Ar/^{36}Ar$

Noble gases are a multi-track recording: if we listen carefully, we can hear the whole song of a planet

giant impacts, early outgassing

$^{129}I \rightarrow {}^{129}Xe$ Pu-fission derived Xe

$t_{1/2}$ = 15.7 Myr $t_{1/2}$ = 80 Myr

Atmospheric loss?

Accretion of volatiles

present day

0 1 2 3 4 Gyr

? Long-term outgassing: Episodic? Continuous?

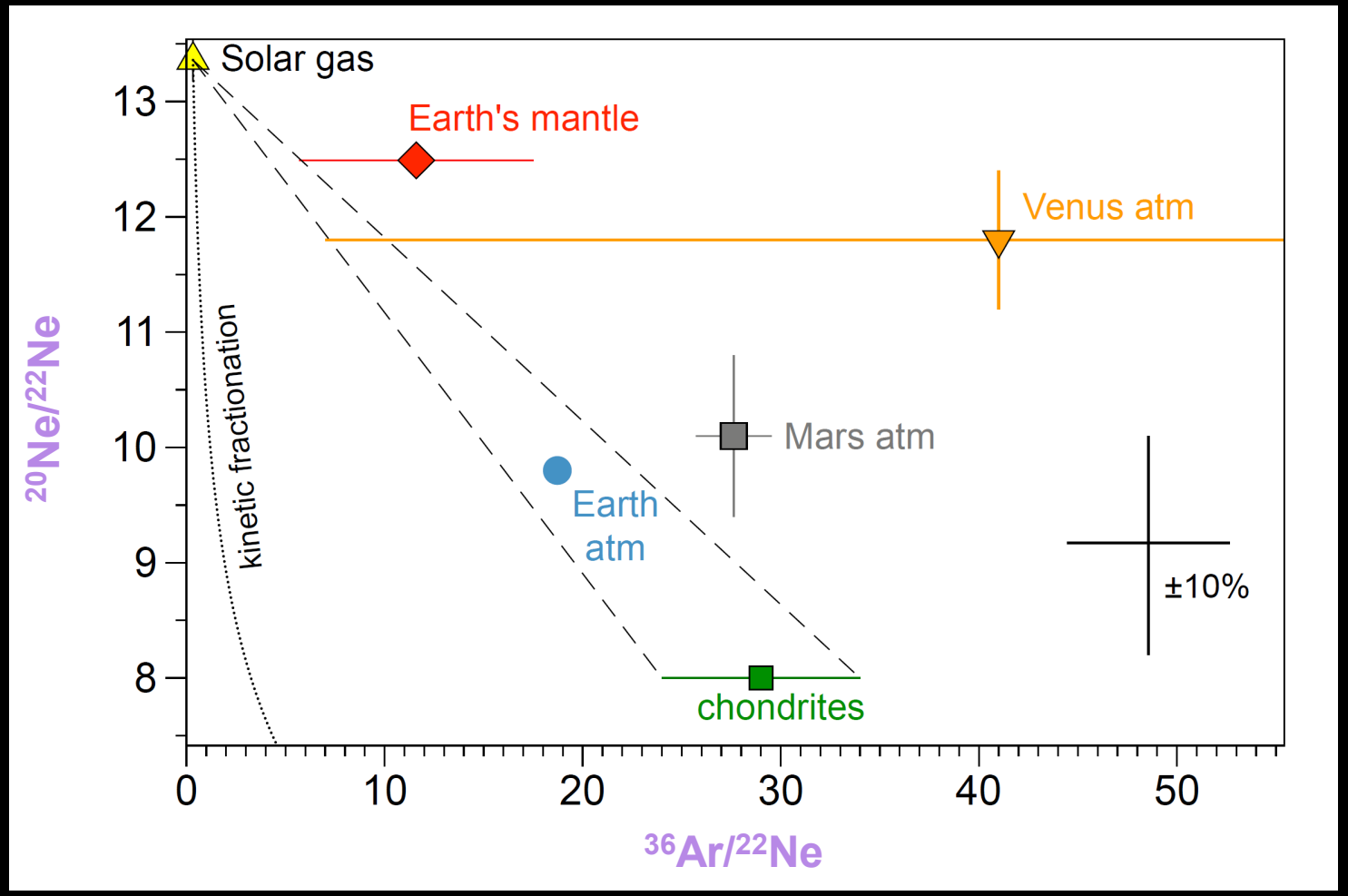
^{4}He, ^{21}Ne, ^{40}Ar, U-fission derived Xe

Current state of knowledge:

Atmospheric noble gas measurements are from Venera missions and Pioneer Venus

Even with large uncertainties, can make first-order comparisons with Earth, Mars

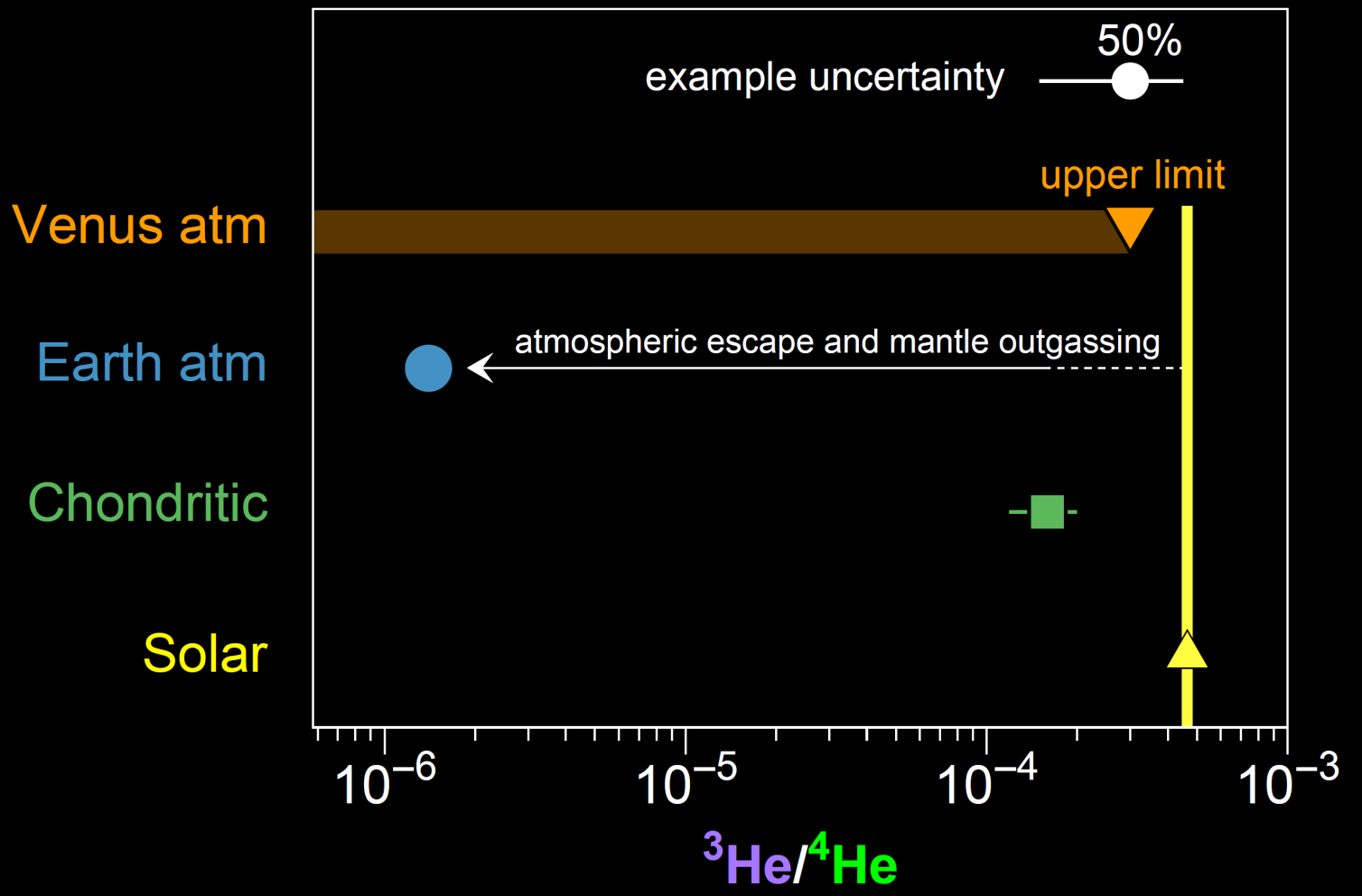
→ greater solar contribution to Venus atm; did comets add Ar?



Adapted from Marty (2012)

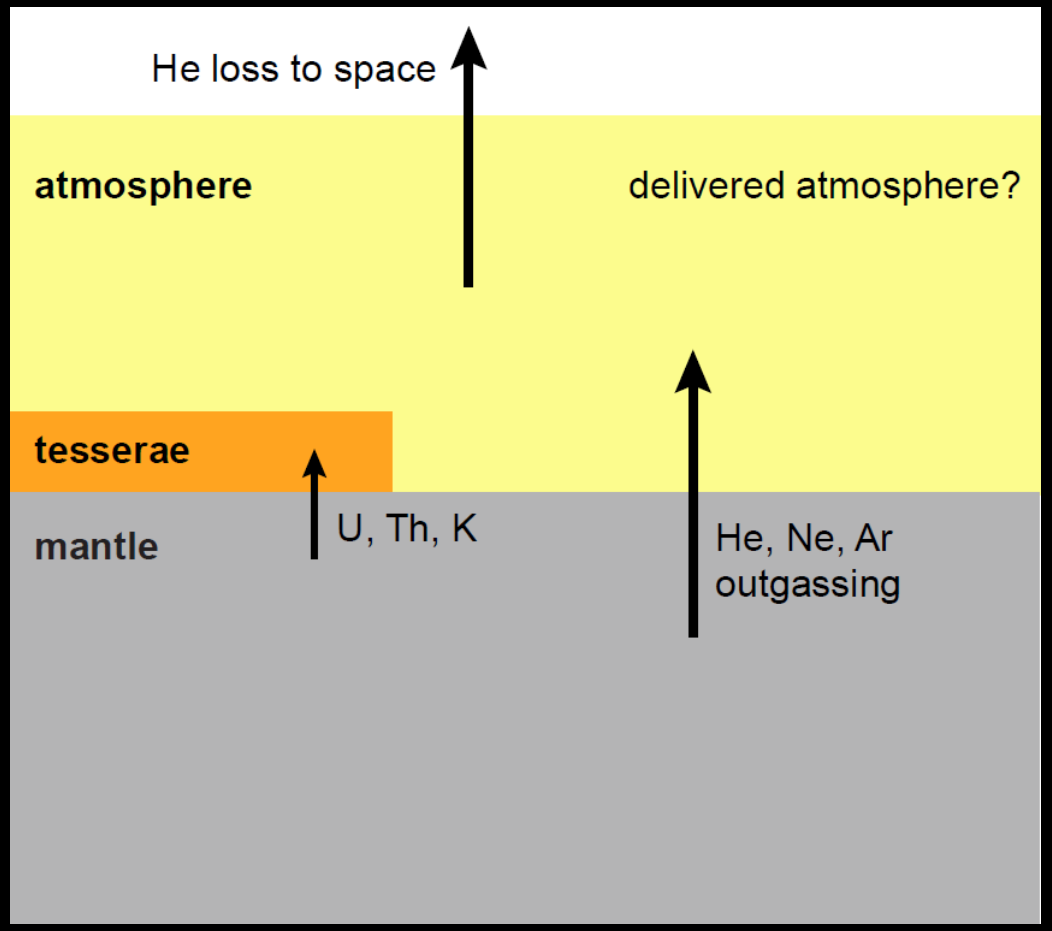
Donahue and Pollack (1983); Istomin et al. (1983); Moroz (1983); Donahue and Russell (1997); Wieler (2002)

Improved measurements would have a big payoff, even if the best achievable errors seem large



Compiled data from Wieler (2002)

Forward modeling to identify planetary formation and evolution scenarios that satisfy uncertain constraints

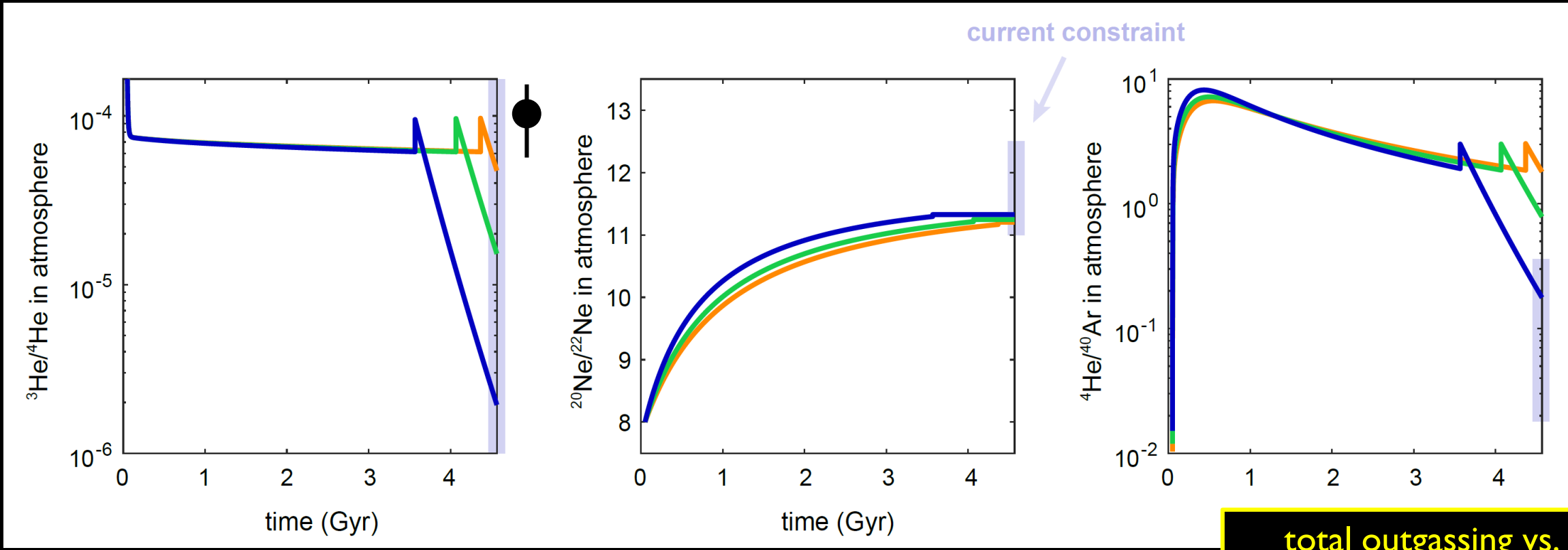


What works?
Continuous outgassing?
Stagnant lid?
Big resurfacing event(s)?

Run it forward to get constraints on timing, extent, rate

Part of work with Cupid's Arrow hypervelocity probe proposal science team

Forward modeling of continuous outgassing transitioning to stagnant lid after a resurfacing event at 1 Ga, 0.5 Ga and 0.2Ga



total outgassing vs. delivery, outgassing rate, resurfacing history

Map out successful parameter spaces → improved and m
noble gas data will allow us to narrow down successful parameters

Conclusions

Next-generation noble gas analyses of the atmosphere of Venus are critical to understanding accretion, atmospheric loss, and geodynamics on Gyr-timescales

The current state of knowledge is incomplete and uncertain

Important science impact can be gained even with 10-50% uncertainties on critical abundances and isotope ratios (smaller would be better! 1-5% please)

Wish list: improved precision measurements of atmospheric He, Ne, Ar, Kr and Xe abundances and isotope ratios with modern analytical capabilities

Current state of knowledge:

Abundance and isotope ratio data are uncertain and incomplete

	Venus	Earth
^{4}He abundance	0.6-12 ppmv (model-dependent)	5.24±0.05 ppmv
^{3}He/^{4}He	Upper limit 3×10^{-4}	$(1.39 \pm 0.01)\times10^{-6}$
^{20}Ne abundance	4.3-13 ppmv excluding uncertainties!	18.18 ± 0.04 ppmv
^{20}Ne/^{22}Ne	11.8 ± 0.6	9.8 ± 0.08
^{40}Ar abundance	31^{+20}_{-10} ppmv	0.934 ± 0.001 %
^{40}Ar/^{36}Ar	1.11 ± 0.02	298.56 ± 0.31
^{84}Kr abundance	25^{+13}_{-18} ppbv	0.65 ± 0.01 ppmv
^{129}Xe abundance	<9.5 ppbv	23 ± 1 ppbv

Wieler (2002) and refs therein; Porcelli et al. (2002) and refs therein; Lee et al. (2006)