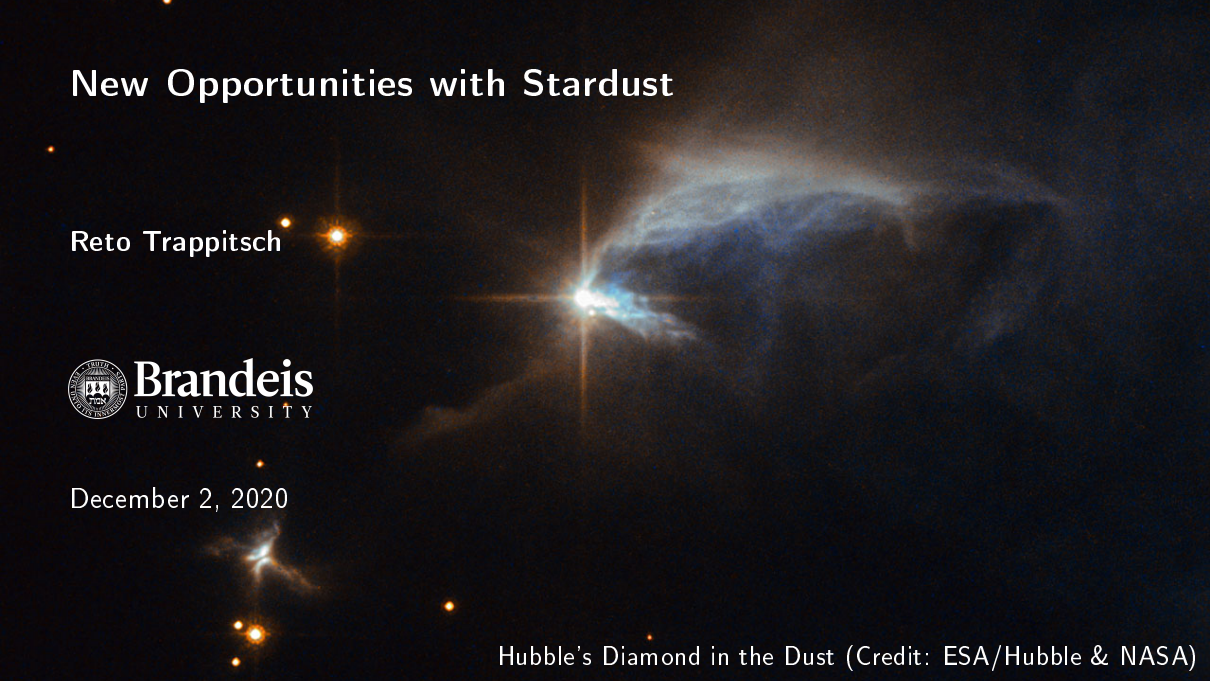
New Opportunities with Stardust

Reto Trappitsch

Brandeis UNIVERSITY

December 2, 2020

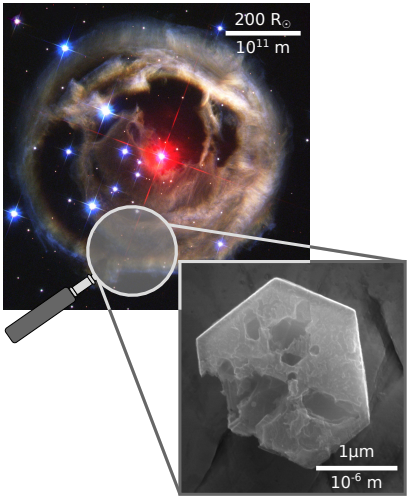


Hubble's Diamond in the Dust (Credit: ESA/Hubble & NASA)

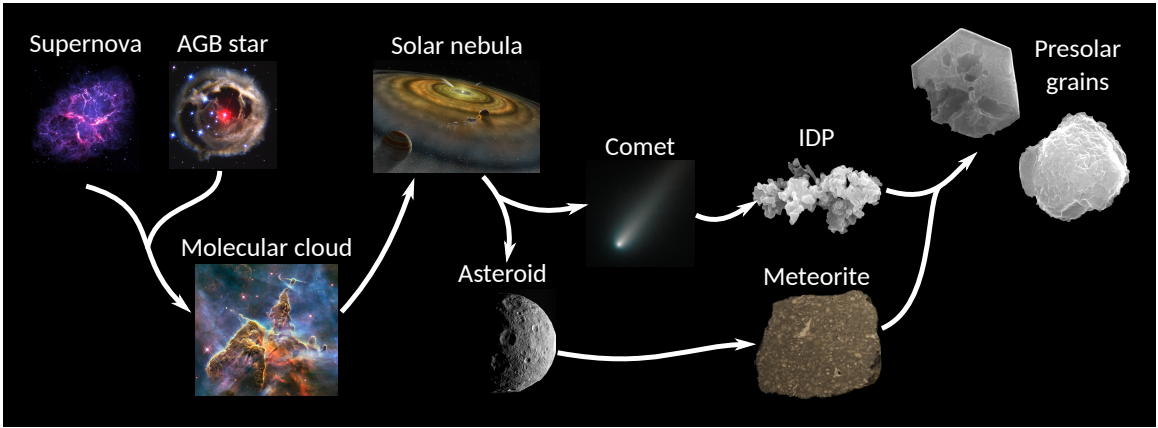
Starry messengers: Stardust in the laboratory

- Stardust grains condensed in the outflows of dying stars
- Grains can be extracted from meteorites
- Composition studied in laboratories to
  - Fingerprint the grain's parent star
  - Trace the formation of new elements
- Analyze isotopic composition with high precision
- Complementary to astronomical observations of elemental compositions
- Caveat: Not all stars produce dust!

Stardust grains enable hands-on astrophysics studies to decipher the inner workings of their parent stars

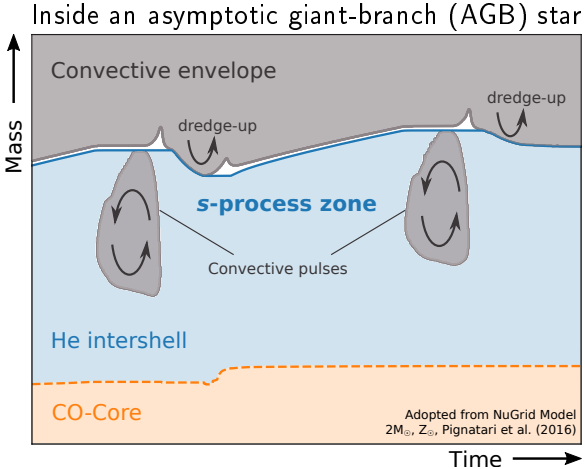


The interstellar history of stardust grains



Deciphering the slow neutron capture (*s*-) process in low-mass stars

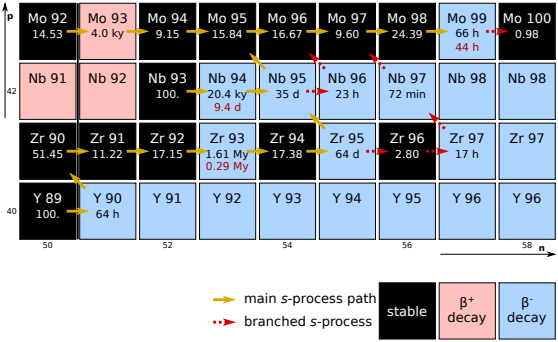
- *s*-process in AGB star takes place in He-intershell, products mixed into envelope
- *s*-process models have to explain:
  - Observed elemental abundances of AGB star envelopes
  - Isotopic composition of stardust grains
- Most analyzed stardust grains originate form AGB star and thus sample the *s*-process
- Multiple data sets available to compare to: Zr, Sr, Mo, Ba, ... (see, e.g., Liu et al.)
- Future: Measure multi-element composition of individual stardust grains



Isotopes destroyed during *s*-process also carry valuable information

- Recent molybdenum measurements (Stephan et al., 2019)
- Proton- (p) and neutron-rich (r) nuclides destroyed in *s*-process
- Not all material in the star goes through *s*-processing
- Mo_p/Mo_r composition of all grains solar
- Co-production of p and r nuclides?

Stardust grains allow tracing of minor nucleosynthesis sources that cannot be directly observed.



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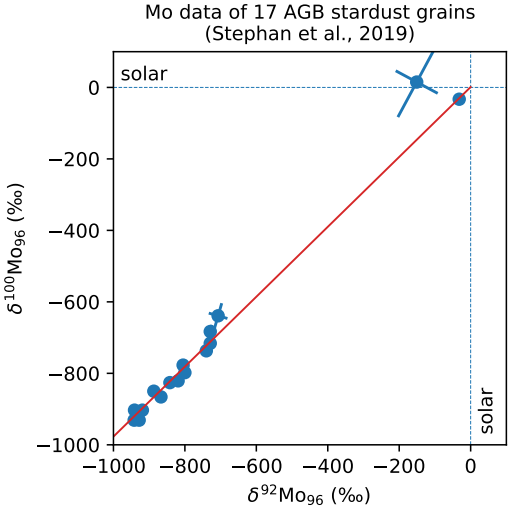

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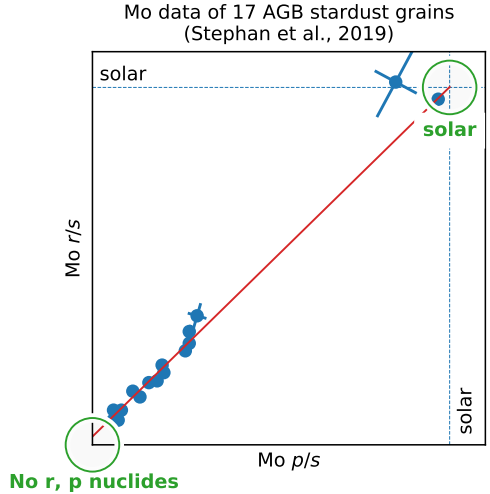

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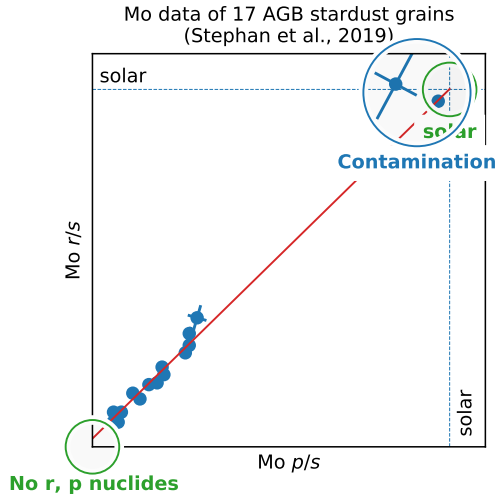

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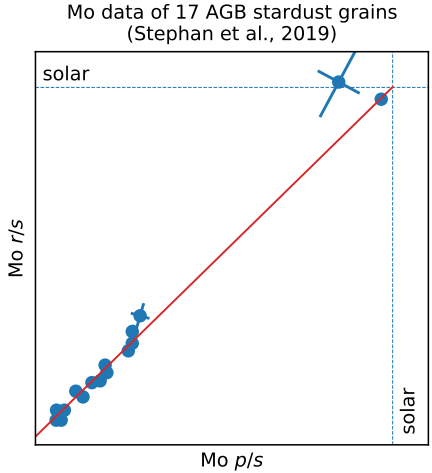
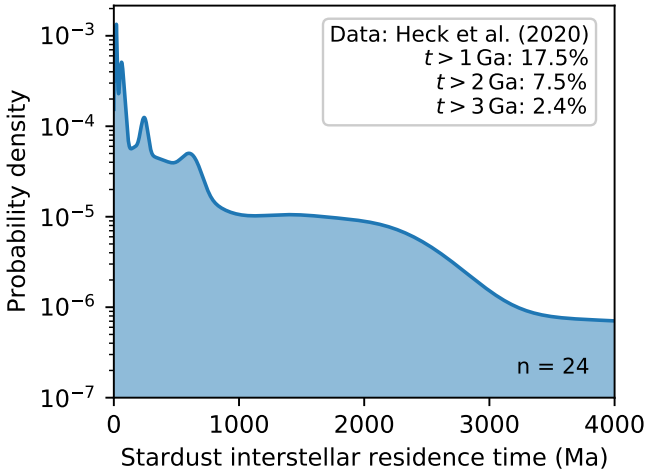
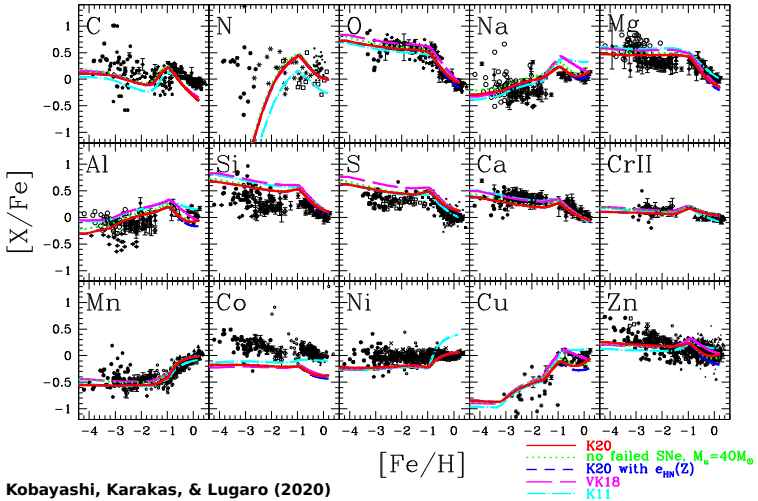


Stardust grains sample up to 3 billion years prior to Solar System formation

- Measure time stardust grain spent in interstellar medium (Heck et al., 2020)
- Currently small database of "only" 24 grains
- Stardust grains span a range of more than 3 billion years
- **Future**: Many more measurements for better distribution



"Traditional" galactic chemical evolution (GCE) comparisons

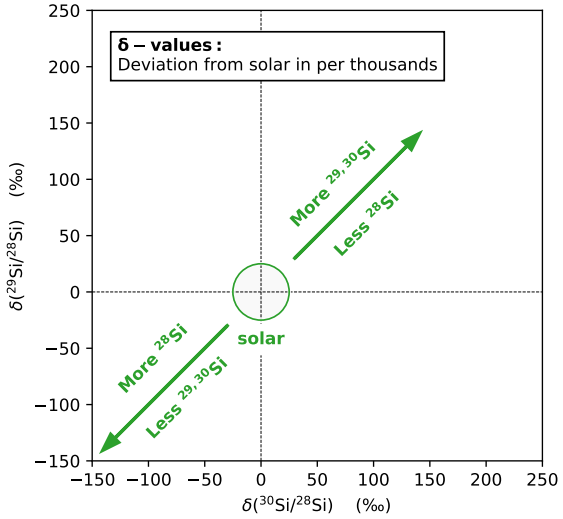


Kobayashi, Karakas, & Lugaro (2020)

Utilizing stardust measurements to study galactic chemical evolution (GCE)

- AGB stardust grains contain complementary information
- Sample ~ 3 Ga of GCE
- Need high-precision measurements!
- Stardust grains enriched in secondary isotopes compared to Solar System
  $\rightarrow$ Requires heterogeneous GCE
- Future: More targeted multi-element measurements in individual grains

Stardust grains measurement are complementary and valuable to study GCE



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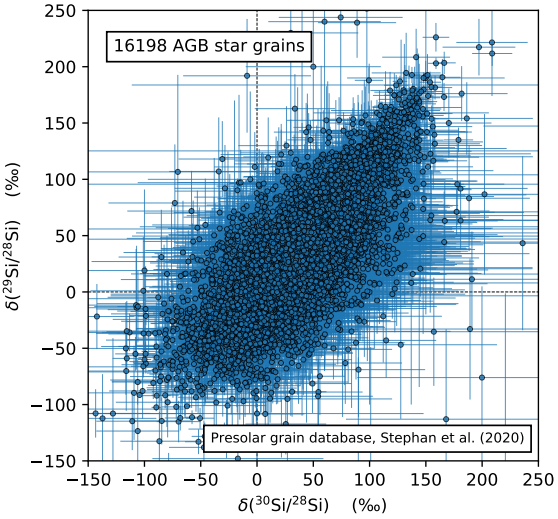

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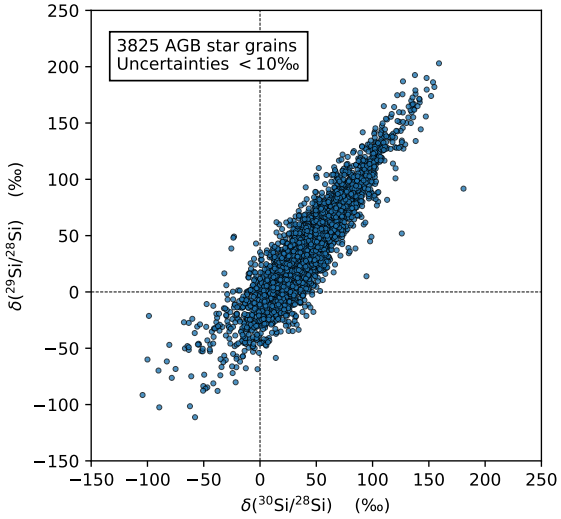

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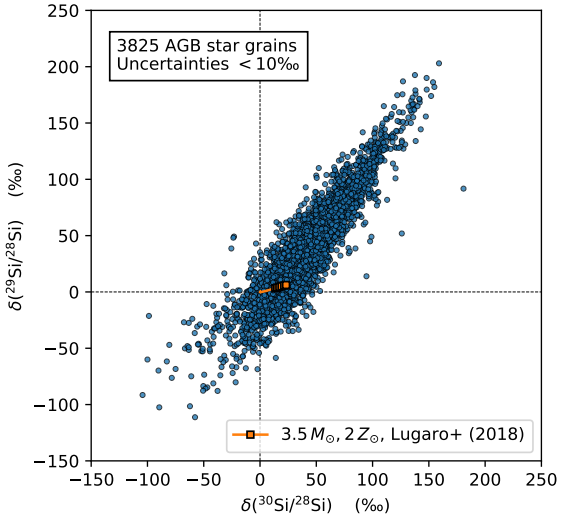
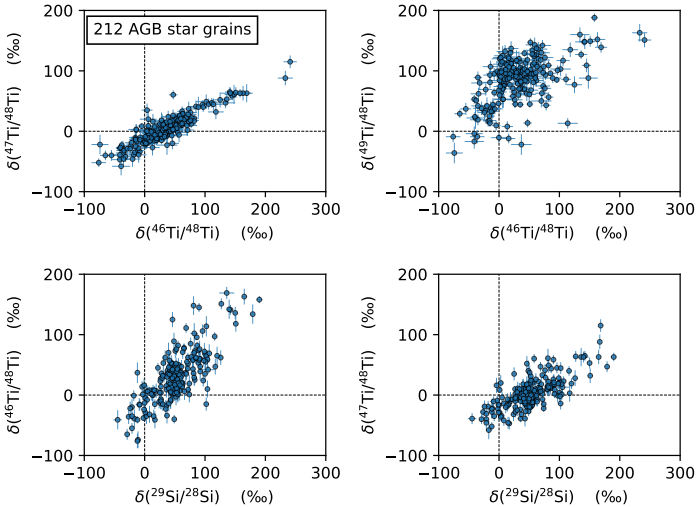
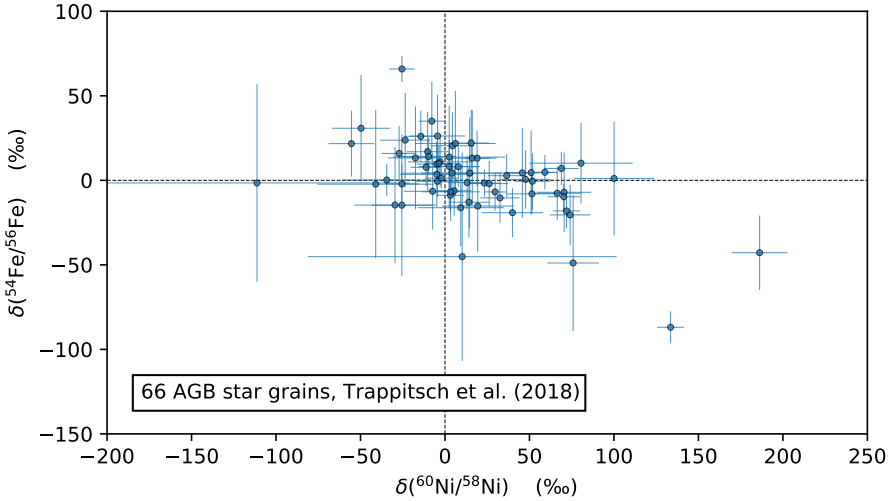


Abundant GCE dominated elements in AGB stardust grains



Less abundant iron and nickel require improved techniques



Stardust: Additional messengers for astrophysics!

- Stardust grain enable studying:
  - Individual nucleosynthesis sources
  - GCE over ~ 3 Ga prior to Solar System
- Benefits of stardust analyses
  - Study otherwise inaccessible areas of interest
  - High-precision stellar measurements
- Current bottlenecks & the future:
  - High-precision trace-element measurements limited to few laboratories
  - More integration with astronomy and astrophysics
  - Targeted, multi-element studies of many individual stardust grains