Making Mars:
The story Mars tells about planet formation and migration in the early Solar System

Katherine Kretke
Southwest Research Institute
Forming the Terrestrial Planets

Raymond et al 2006
Anatomy of an orbit

Semi-major axis

Eccentricity ~ 0.7
Eccentricity = 0
Forming the Terrestrial Planets

Raymond et al 2006
Problem with Mars

Raymond et al 2009
Maybe we’re just “lucky” that Mars is small

Fischer & Ciesla (2014)
Maybe planetary building blocks weren’t uniformly distributed

Hansen 2009
Maybe there was never much mass there initially because of photoevaporation

Izidoro et al 2014
Or because planets grew by accreting pebbles

Levison et al 2015b
Planet Migration

 Courtesy of Phil Armitage
“Grand Tack”
The Grand Tack terrestrial planets

Digression on Composition

\[ \delta^{18}O = \left[ \frac{(\frac{^{18}O}{^{16}O})_{\text{sample}}}{(\frac{^{18}O}{^{16}O})_{\text{standard}}} - 1 \right] \times 1,000 \]

\[ \epsilon^{143}Nd = \left[ \frac{(\frac{^{143}Nd}{^{144}Nd})_{\text{sample}}}{(\frac{^{143}Nd}{^{144}Nd})_{\text{standard}}} - 1 \right] \times 10,000 \]

\[ \Delta^{17}O = \delta^{17}O - \delta^{17}O_{\text{standard}} \]

Enstatite Chondrites

Ordinary Chondrites

Carbonaceous Chondrites

More Volatile Rich
Mars is different than the Earth

Brasser et al 2017 and references within
And more similar to the ordinary Chondrites

Brasser et al 2017 and references within
In the Grand Tack planets get their building blocks from different initial locations

Brasser et al 2017
Brasser et al 2017
Mars might have initially formed in the Asteroid Belt

Encounters with Jupiter

Brasser et al 2017
Not Everyone Agrees

Bulk Earth composition
- BE Javoy et al. 2010
- BE (OCCAM, this study)

Bulk Mars composition
- Sanloup et al. 1999
- Lodders and Fegley 1997
- Burbine and O'Brien 2004
- Taylor 2013
- bulk Mars (OCCAM)

Fitoussi et al 2016
One thing we do know is that Mars formed quickly.

Radioactive Decay ($^{182}\text{Hf} \rightarrow ^{182}\text{W}$)
Radioactive Isotopes

- Hf = Lithophile (prefers the Silicate Mantle)
- W = Siderophile (prefers the Iron Core)
Radioactive Isotopes

Planet Formed & Differentiated Late

Planet Formed & Differentiated Early
Mars formed quickly, within 2-5 Myr

Conclusions

- Mars is both a puzzle and a very important clue in our understanding of how the Solar System formed.
- Planets and all Solar System bodies have the tendency to move... we cannot assume that everything formed where we see them now.
- Mars witnessed our very early Solar System.
- We need more data, both about Mars to better understand its composition and from Venus (at least the atmosphere) and Mercury to really understand the composition of the early Solar System.