



# Planetary System *GMs* in the JPL Planetary Ephemerides

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# Planetary System *GMs* (Masses)

- Primary constants in planetary ephemeris development
- Mass of the planet plus masses of the planetary satellites (exceptions: Mercury, Venus)
- Determined from observations of planet and satellites' gravitational effects on spacecraft (caveat: Earth-Moon)

# Venus

- Mariner 2 flyby: December 1962 (first successful planetary encounter)
- Mariner 5, Mariner 10
- Pioneer Venus Orbiter, Magellan
  - 180 degree and order gravity field
  - Planet mass

# Mars

- Mariner 4 flyby: November 1964
- Mariner 9, Viking
  - 50 degree and order gravity field
  - Mars, Phobos, Deimos masses
- Mars Global Surveyor, Odyssey
  - 95 degree and order gravity field
  - Mars, Phobos, Deimos masses
- Mars Global Surveyor, Odyssey, Reconnaissance Orbiter
  - 110 degree and order gravity field
  - Mars, Phobos, Deimos masses

# Jupiter

- Pioneer 10 flyby: December 1973
- Later flybys: Pioneer 11, Voyager 1, Voyager 2, Ulysses
- Galileo orbiter: December 1995 – November 2002
- System mass estimate
  - All spacecraft data
  - Jupiter, Galilean satellites, Amalthea

# Mercury

- Mariner 10 flybys: March 1974, September 1974 (no data), March 1975
- Mass estimates: Messenger
  - Science team (2 flybys): January and October 2008
  - Navigation team (3 flybys): January and October 2008, September 2009

# Saturn

- Pioneer 11 flyby: September 1979
- Later flybys: Voyager 1, Voyager 2
- Cassini orbiter (June 2004 - present)
- System mass estimate
  - All spacecraft data
  - Saturn, all major satellites, Phoebe

# Uranus and Neptune

- Uranian system mass estimate
  - Voyager 2 flyby: January 1986
  - Uranus, all five major satellites
- Neptunian system mass estimate
  - Voyager 2 flyby: August 1989
  - Neptune, Triton



# Earth-Moon

- Earth orbiters: Ries, et al. 1992
- Lunar Prospector: Konopliv, et al. 2001
- Mass estimate
  - Total mass: lunar orbital motion from LLR measurements
  - Mass ratio: planetary ranging (Mars, Venus, Mercury)

# Pluto (not a planet)

- Pluto and satellite masses
  - Satellite orbital dynamics: Charon, Nix, Hydra
  - Astrometric data: discovery to 2007

# Future

- No change or improvement
  - Venus
  - Neptune
- Possible change or improvement
  - Mercury: Messenger in orbit
  - Mars: to be published, more data
  - Earth-Moon: Grail
  - Jupiter: data reanalysis, Juno
  - Saturn: Cassini end of mission
  - Uranus: data reanalysis
  - Pluto: more data