Thick disks in galaxies

External galaxies:
NGC 4565, van der Kruit and Searle 1981

Milky Way:
Gilmore and Reid 1983
Milky Way’s thick disk stars

- Kinematically hotter than thin disk stars
- Old stars
  Edvarsson et al. 1993:

- High [alpha/Fe] ratios
  Type II SNe make more alpha elements than Fe. (Fuhrmann 1998, Bensby+ 2003)
Formation theories abound

(1) Special events:

(a) accretion of small satellite which heats existing thin disk (Quinn and Goodman 1986, Walker, Mihos and Hernquist 1996, Velazquez and White 1999, Villalobos and Helmi 2008, Kazantzidis + 2008) and leaves its stars in disk as it disrupts
(1) Large infalling satellite heats up the disk:

Kazantzidis et al 2008
More formation theories

(1) Special events with gas + cosmology:
   (b) gas-rich mergers common in early universe;
       can form thick disks then
       (Brook+ 2004,2005,2007, Springel and Hernquist 2005,
       Robertson+ 2006)
   (c) stars accreted from very early mergers may
       also form a thick disk (Abadi et al 2003)
Brook+ 2004: early formation includes gas-rich mergers; disk can form but is hotter than later-forming thin disk
More formation theories

(2) Nothing special: secular (slow) evolution can cause older stars in disk to become hotter, thickens disk
(a) disk heating by “lumps” such as spiral arms and giant molecular clouds .... likely to saturate at lower scale heights than our thick disk
(b) Radial migration: “surfing the spiral waves”
(2b) Radial mixing in disks:

- Resonant scattering of disk stars by spiral structure: from circular orbits to circular orbits at a different radius
- Dynamics: Sellwood and Binney 2002
- High resolution n-body+SPH: Roskar et al 2008a,b
- Analytical chemical evolution including kinematics: Schoenrich and Binney 2009a,b
Redistribution by (Transient) Spiral Arms: (slide from Rok Roskar)

~ 20 kpc
Age-metallicity relations near Sun

Nordstrom et al 2004

Schoenrich and Binney 2009
Mimicking a thick disk

• Radial migration can reproduce solar neighborhood thick disk observations without an extra component (Schoenrich and Binney 2009)
  ■ Inner disk has higher surface density, so more restoring force.
  ■ To make a constant scale height disk this requires higher vertical velocity dispersion there
Mimicking the thick disk

Inner disk stars which migrate further out will keep their higher velocity dispersion => thick disk!

Shorter enrichment timescales in inner disk => higher [alpha/Fe] stars there