Metallicities of nearby thin disk stars

Klaus Fuhrmann, ..., 2003, pre/re. and properties of planet primaries at http://youngstars.mpe.mpg.de
Gamma Cep

Finding Chart
Gamma Cep Orbits

Hatzes 2003
FORMATION OF PEGASI-PLANETS
A VORTEX AT THE CRITICAL MASS?

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PLANET FORMATION BY NUCLEATED INSTABILITY

Growing a condensible element core to gravitationally catch nebula gas
The protoplanetary nebula

- theoretically and observationally uncertain,
- use solar system concept of minimum reconstitutive mass,
- vary nebula conditions to understand planet formation in general.
The core

- rigid body,
- particle-in-box planetesimal accretion-rate,
- feeding-zone with given initial mass.
The gaseous envelope

• from core surface to the unperturbed nebula (Hill-radius),
• dynamics of radiating fluids,
• time-dependent convection,
• spherical symmetry.
Equations: limiting cases

• static limit: stellar structure equations,
• convection@Sun: (1) fix mixing-length parameter; (2) test by zone-bottom passed (Wuchterl and Feuchtinger 1998),
• RR-Lyrae lightcurves are now correct (Feuchtinger 1999,...).
Equations for self-gravitating, convective, radiating fluids

\[ \frac{d}{dt} \left[ \int_{V(t)} \varrho \, d\tau \right] + \int_{\partial V} \varrho (u_{rel} \cdot dS) = 0, \quad \Delta M_r = \int_{V(t)} \varrho \, d\tau, \quad (A.2) \]

\[ \frac{d}{dt} \left[ \int_{V(t)} \varrho u_D \, d\tau \right] + \int_{\partial V} [\varrho u_{rel} + j_D] \cdot dS = \int_{V(t)} \dot{\varrho}_D \, d\tau, \quad \dot{\varrho}_D = \frac{A_D}{N_L Q_D} \varrho \varepsilon_{nuc}^D, \quad (A.3) \]

\[ \frac{d}{dt} \left[ \int_{V(t)} \varrho u \, d\tau \right] + \int_{\partial V} \varrho (u_{rel} \cdot dS) + \int_{V(t)} \left( \frac{\partial p}{\partial r} + \frac{\varrho GM_r}{r^2} \right) \, d\tau = C_M, \quad C_M = \int_V \kappa \varrho \frac{F}{c} \, d\tau, \quad (A.4) \]

\[ \frac{d}{dt} \left[ \int_{V(t)} \varrho (e + \omega) \, d\tau \right] + \int_{\partial V} [\varrho (e + \omega) u_{rel} + j_w] \cdot dS + \int_{V(t)} p \text{div} u \, d\tau = -C_E + \int_{V(t)} \varrho \varepsilon_{nuc}^D \, d\tau, \quad (A.5) \]

\[ \frac{d}{dt} \left[ \int_{V(t)} E \, d\tau \right] + \int_{\partial V} [E u_{rel} + F] \cdot dS + \int_{V(t)} P \text{div} u \, d\tau = C_E, \quad C_E = \int_V \kappa \rho (4\pi S - cE) \, d\tau, \quad (A.6) \]

\[ \frac{d}{dt} \left[ \int_{V(t)} \frac{F}{c^2} \, d\tau \right] + \int_{\partial V} \frac{F}{c^2} (u_{rel} \cdot dS) + \int_{V(t)} \left( \frac{\partial P}{\partial r} + \frac{F}{c^2} \frac{\partial u}{\partial r} \right) \, d\tau = -C_M, \quad P = \frac{1}{3} E, \quad (A.7) \]

\[ \frac{d}{dt} \left[ \int_{V(t)} \varrho \omega \, d\tau \right] + \int_{\partial V} \varrho \omega u_{rel} \cdot dS = \int_{V(t)} \left( S_\omega - S_\omega - D_{rad} \right) \, d\tau, \quad S_\omega = -\nabla_s \frac{T \partial P}{P} \Pi, \quad \tilde{S}_\omega = \frac{c_D}{\Lambda} \omega^{3/2}, \quad (A.8) \]

\[ j_w = gT \Pi, \quad \Pi = \frac{w}{T} u_c F_L \left[ -\sqrt{3/2} \alpha_8 \Lambda \frac{T \partial s}{w \partial r} \right], \quad \frac{1}{\Lambda} = \frac{1}{\alpha_{ML} H^\text{stat}} + \frac{1}{\beta_r r}, \quad H^\text{stat} = \frac{p}{\varrho} \frac{r^2}{GM_r}, \quad \tau_{rad} = \frac{c_p \kappa \rho^2 \Lambda^2}{4 \sigma T^3 \gamma^2}, \quad (A.9) \]

\[ \varepsilon^D_{nuc} = \frac{Q_D}{\varrho} \tilde{r}_2 H(p, \gamma)^3 \text{He}, \quad \tilde{r}_2 H(p, \gamma)^3 \text{He} = \varrho \frac{N_L}{A_p} \frac{N_L}{A_D} (\sigma V) \tilde{r}_2 H(p, \gamma)^3 \text{He}, \quad D_{rad} = \frac{\omega}{\tau_{rad}}, \quad j_D = -\alpha_M \Lambda \omega^{1/2} \frac{\partial \varepsilon_{CD}}{\partial r}. \quad (A.10) \]
A Pegasi-Planet

- 0.05 AU from a solar-mass star,
- in minimum reconstitutive mass nebula,
- 15 earth-masses solids,
- feeding-zone 150 earth-masses gas.
Pegasi-planet: mass-accretion

0.05 AU, HNN85 nebula, M_feed = 15/150 M

Mass / Earth-Mass

Age / [Million Years]
PEGASI-PLANET LUMINOSITY

0.05 AU, HNN85 nebula, M_feed = 15/150 M
PEGASI-PLANET LUMINOSITY II

0.05 AU, HNN85 nebula, M_feed = 15/150 M

- Rapid contraction
- Depletion of planetesimals
- Hydrostatic
- Critical mass
- Core accretion
- Fully convective
Evolution around Maximum Luminosity

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**Graph Description**

- **Luminosity / Solar Luminosity**
  - Y-axis: 0.0000 to 0.0020
- **Age - 440290 / [Years]**
  - X-axis: 0 to 250

- **Key Events**
  - **Collapse**
  - **Rebounce Peak**
  - **Rapid Gas Accretion**
  - **Nebula Depletion**

**Parameters**

- **0.05 AU, HNN85 nebula, M_feed = 15/150 M**

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**Graph Annotation**

- The graph illustrates the evolution of luminosity around the maximum luminosity point for a HNN85 nebula with a mass feed of 15/150 solar masses.
- Key events such as collapse, rebounce peak, rapid gas accretion, and nebula depletion are marked on the graph.

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**Additional Notes**

- The graph provides insights into the dynamic processes occurring during the early stages of stellar evolution.
- Understanding these transitions is crucial for modeling stellar formation and evolution.
Are assumptions about feeding masses OK?

Is there a plausible nebula with sufficient mass close-in?
Nebula-mass interior of orbit radius
Density-factor for nebula instability

![Graph showing the density-factor for nebula instability](image)
Nebula-mass interior of orbit at marginal stability
Nebula-mass: Min vs. Max

Mass Nebulae: Minimum and Maximum Mass

Nebula Mass / Jupiter Mass vs. Orbital Radius / [AU]

- Solid line represents minimum mass.
- Dashed line represents maximum mass.
Nebula-mass in Jupiter mass feeding-zone
Properties of young planets
PEGASI-PLANET

0.05 AU, HNN85 nebula, M_feed = 15/150 M

Luminosity / Solar Luminosity

Age / [Million Years]
Brown dwarf collapse

Hydrostatic, initially fully convective
Dynamic and formation vs. hydrostatic and hot
PEGASI-PLANETS

• Pegasi-planets form in-situ if mass is available,

• Nebulae providing sufficient mass in feeding zones are plausible,

• Use formation-models to determine planetary properties for pre-main sequence stellar ages.
Subcritical Proto-Planets

- Hydrostatic to few percent, globally
- Weakly dependent on nebula assumptions for "radiative" envelopes
- More massive envelope at given core for "convective" protoplanets
The global picture

Isothermal protoplanets
by Bojan Pecnik
All protoplanets at given orbit

Pecnik 2003. subm.
Local and Global Critical Mass

Fermi gas
Multiple Envelope Equilibria

\[ \log\left(\frac{M_{\text{core}}}{M_{\text{Earth}}}\right) = -2, \ a = 5.2 \text{ au} \]

Diagram showing the relationship between envelope density \( \rho_{\text{env}} \) and height \( h \) with various markers indicating different density values and mass ratios.
All (isothermal) subcritical protoplanets

- Hydrostatically fill Hill-Sphere
- Few percent corrections for slowly rotating protoplanets (Götz 2003)
- Rotation determined by flow around planet
- Vortex formed by growing protoplanet interacting with ambient quasi-keplerian nebula → Rotation of giant planets
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