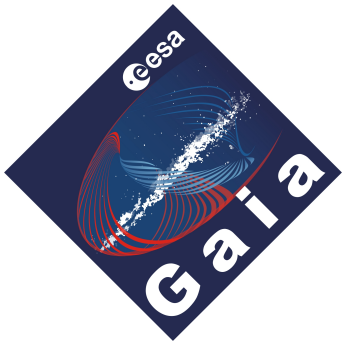




# Stellar rotation and the age of star determination

## Application to stellar clusters

Luca Santoro

Observatoire de la CÔTE d'AZUR

# Overview

1. Introduction
2. Projected rotational velocity distribution:
   application to 5 open clusters
3. Confrontation theory and observation
   in the special case of Hyades

   → AGE DETERMINATION
4. Conclusions and perspectives

# 1. Introduction

- Stellar physics in the Gaia context
- FLAME workpackage in CU8
  (Final Luminosity Age Mass Estimation)
- Test of rotation on stellar clusters
- Stellar structure and evolution with rotation

# 1. Introduction

## Why rotation is important?

- Rotation has an impact on the age determination (Maeder 1998, Chiosi 2009)

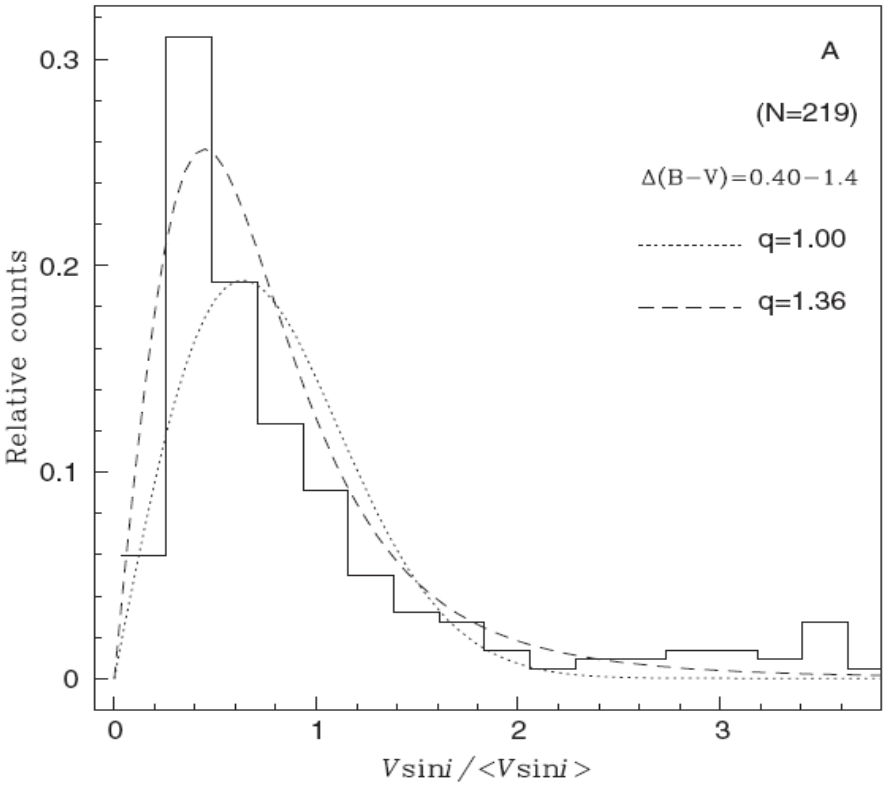
- To study angular momentum:
  - Loss of angular momentum from protostellar cloud to MS stars; (see Maeder 2009)

| The observed specific angular momentum in various objects ($cm^2\ s^{-1}$) | |
|---|---|
| Dense molecular cores | $10^{21\text{-}22}$ |
| Wide binaries | $10^{19\text{-}20}$ |
| Pre-MS stars (TTauri) | $10^{16\text{-}17}$ |
| Sun | $10^{15}$ |

- Scenario: magnetic field – angular momentum loss (Schatzman 1962)

# 2. Rotational velocity distribution

Pleiades (Soares et al. 2006)




Random distribution of i
Integral relation; Gaussian form;
Maxwell-Boltzmann form
Polynomial form
Non gaussian

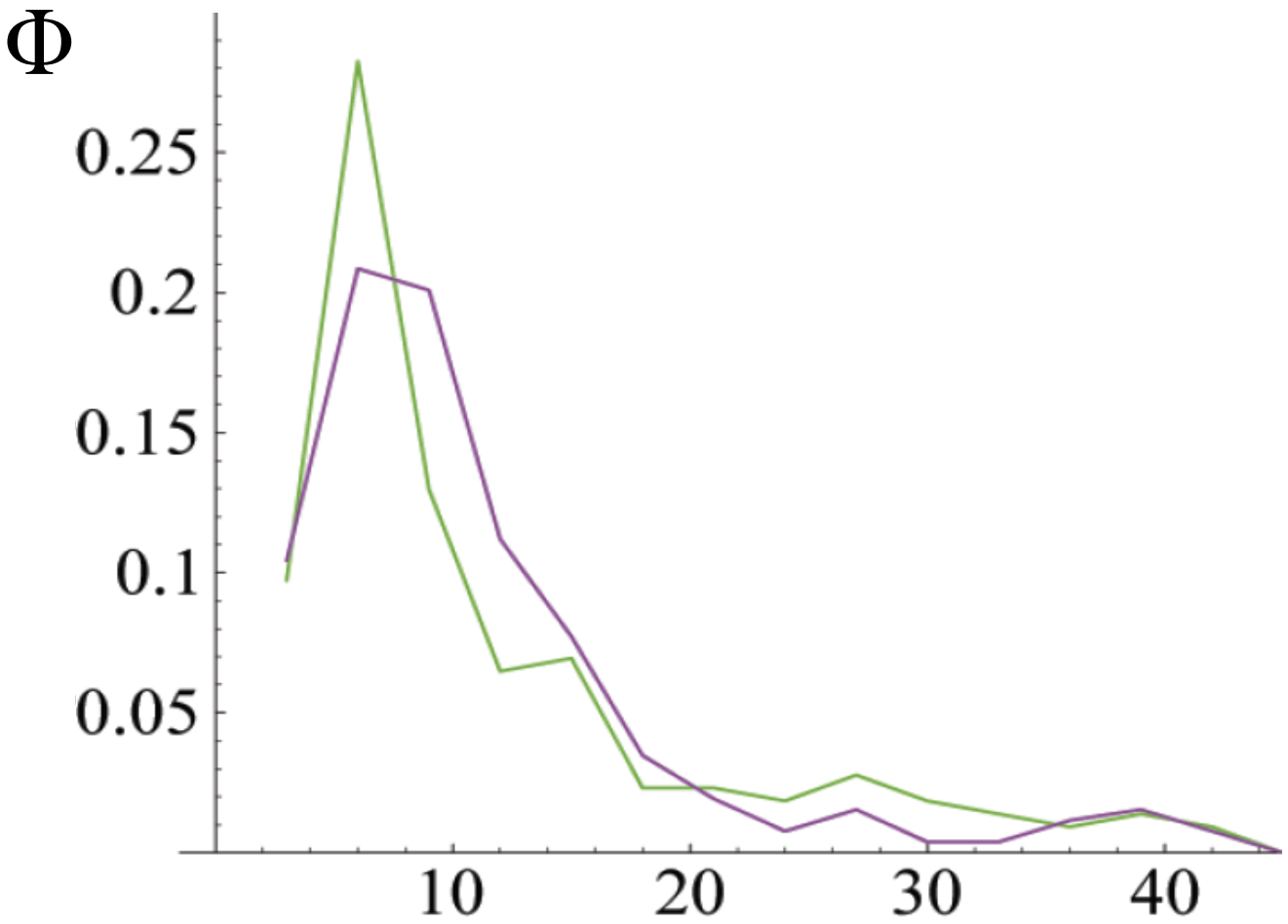
$$\phi_q(y) = B_q y \left[1 - (1-q)\frac{y^2}{\sigma^2}\right]^{1/(1-q)}$$

$$y_{peak} = \frac{\sigma}{\sqrt{3-q}}$$ Shape parameter

Confirmation of random distribution of spin axes via Monte-Carlo simulation:
Jackson & Jeffries 2009 arXiv 0911.1075J

# 2. Rotational velocity distribution

## Application to 5 open clusters




- Hyades
- Alpha persei
- Pleiades
- Blanco 1
- Praesepe

Mermilliod et al. 2009
WEBDA database

$y=V_{rot}$ sini (km/s)

# 2. Rotational velocity distribution

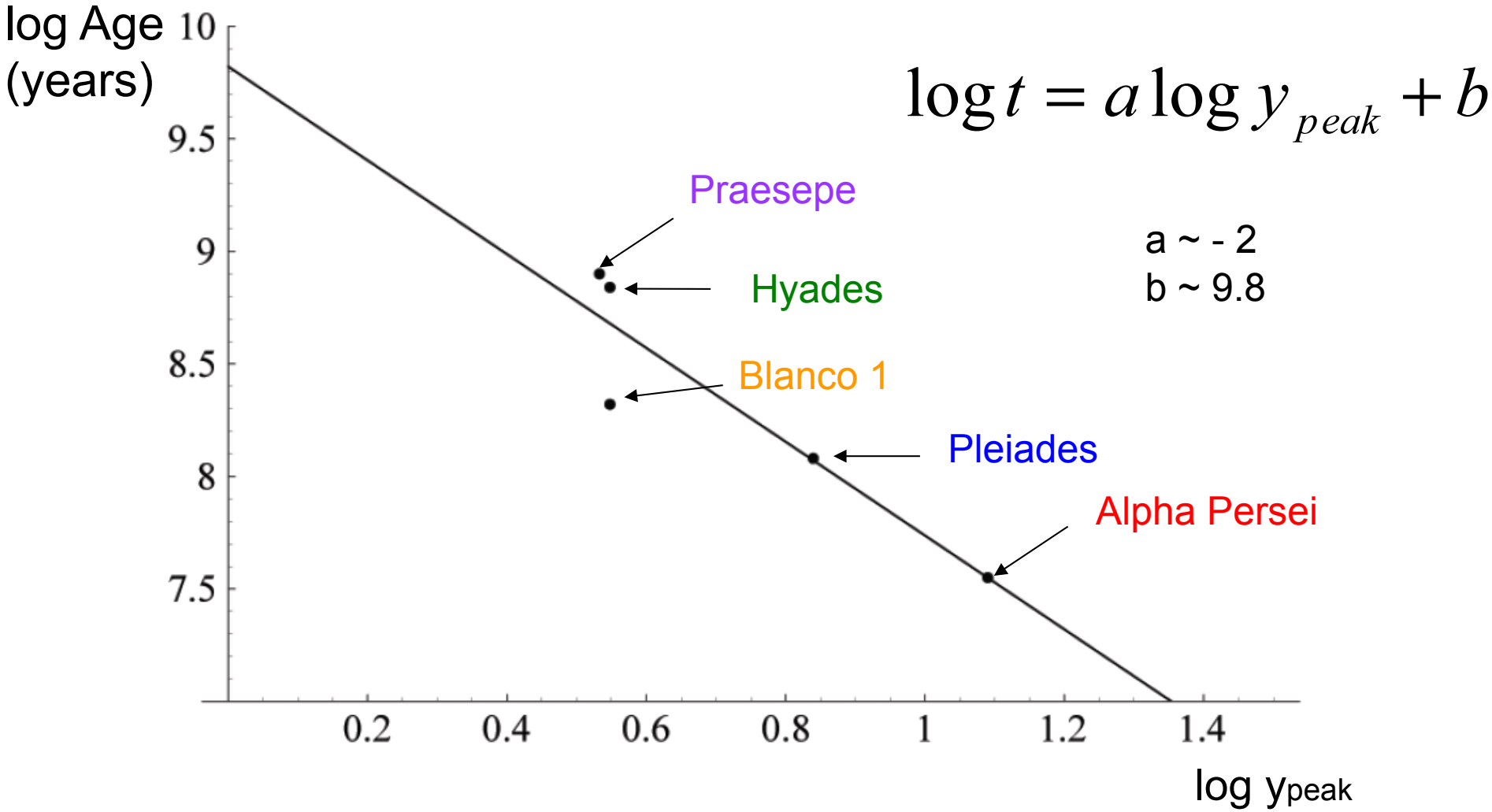
## Results of our statistical analysis

| | Alpha Persei | Pleiades | Blanco 1 | Hyades | Praesepe |
|---|---|---|---|---|---|
| q | 1,14 | 1,38 | 1,51 | 1,51 | 1,54 |
| σ | 16,83 | 8,75 | 4,27 | 4,27 | 4,02 |
| ypeak | 12,34 | 6,91 | 3,5 | 3,5 | 3,34 |
| age (Myr) * | 35 | 120 | 208 | 650 | 800 |

* age from Van Leeuwen 2009,
Lebreton et al. 2001

# 2. Rotational velocity distribution

## Determination of a deceleration law




$$\log t = a \log y_{peak} + b$$

a ~ - 2
b ~ 9.8

# 3. Confrontation theory and observation in the special case of Hyades

- **Advantages**

  -Distance, metallicity & helium abundance known with good accuracies

  -Known Vrot.sin i

  -Few known binary systems (masses, sin i)

Perryman M. A. C. et al. 1998, Lebreton Y. et al. 2001, Cayrel de Strobel G. et al. 1997, Mermilliod J.-C. et al. 2009, WEBDA database, Patience J. et al. 1988

# 3. Confrontation theory and observation in the special case of Hyades

- **Stellar evolution code: Cesam2k (Morel 1997 & Pichon)**

  - Convection theory Canuto & Mazzitelli (1991)
  - MARCS atmospheres (Gustafsson et al. 2008)
  - Burgers diffusion
  - EOS OPAL Rogers & Iglesias (1992)
  - no overshoot
  - Rotation theory: Maeder & Zahn (1998) and following papers

→ We need Vrot for each star

# 3. Confrontation theory and observation in the special case of Hyades

## Distribution of Vrot (= x) from Vrot sini (= y)

- Using Soares et al 2006 function, we reproduce the observational distribution function
- We reconstruct the distribution f(x) of Vrot using Chandrasekhar & Munch (1950) inversion formula

$$f(x) = -\frac{2}{\pi} x^2 \frac{\partial}{\partial x} x \int_x^\infty \frac{\phi(y)}{y^2 (y^2 - x^2)^{1/2}} dy$$

# 3. Confrontation theory and observation in the special case of Hyades

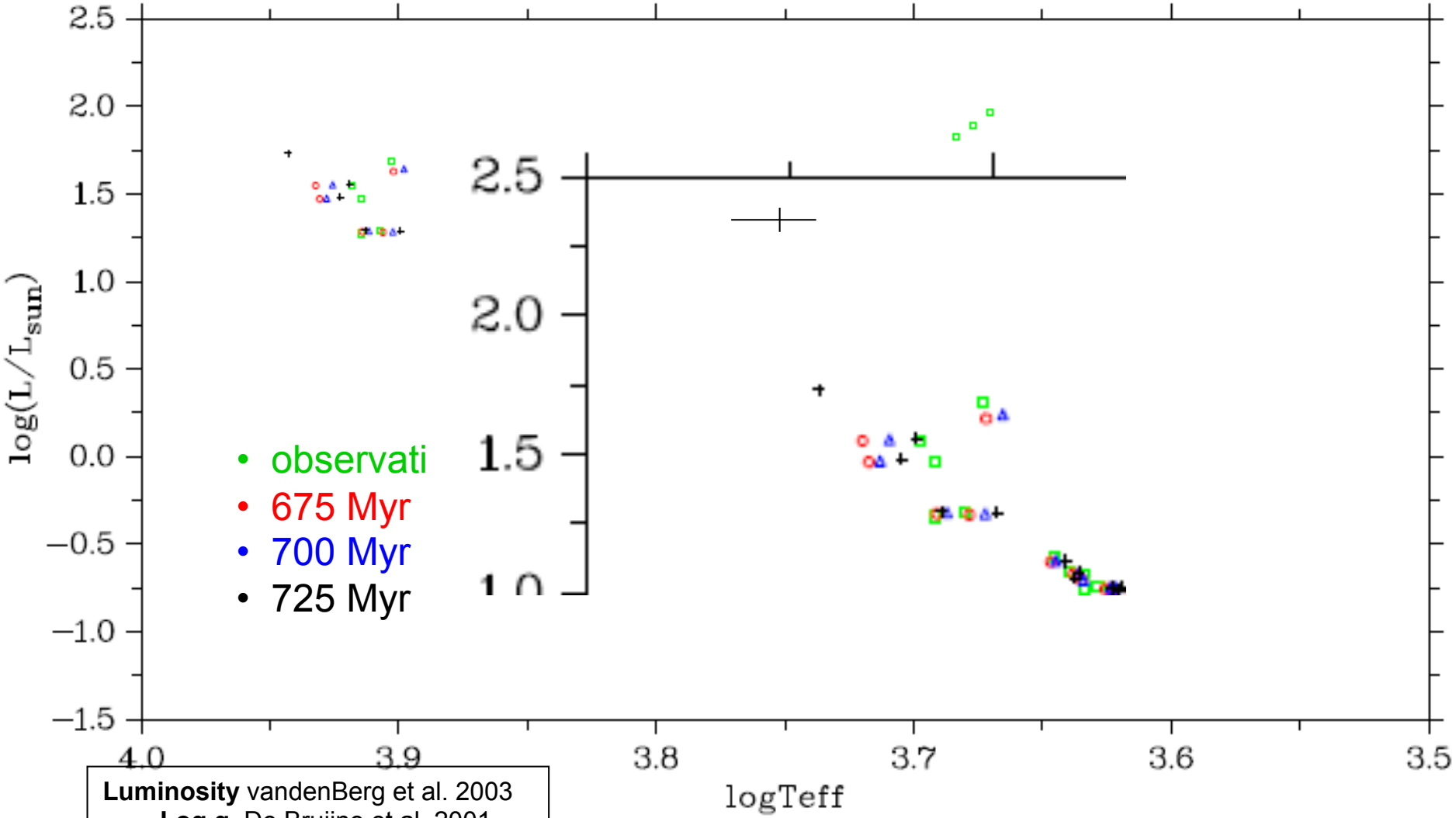
**We tested our procedure on Hyades binary stars:**

| Name | **Vrot sin i (km/s)** | **Vrot (km/s)** | **Statistical Vrot (km/s)** |
|---|---|---|---|
| HIP 20019 | 10.7 ± 2.7 | 10.7 ± 2.7 | 15 ± 2 |
| HIP 20087 | 100.8 ± 5.0 | 123.2 ± 6.2 | 129 ± 2 |
| HIP 20894 | 16.3 ± 1.0 | 19.9 ± 1.2 | 21 ± 2 |

Torres et al 1997 I, II, III
Peterson & Solensky 1988

Our results ☺

# 3. Confrontation theory and observation in the special case of Hyades




**Luminosity** vandenBerg et al. 2003
**Log g** De Bruijne et al. 2001
**Log g** Beck 2008
**Log Teff** Alonso et al. 1996

# 6. Application to Hyades

## Comparisons with different CESAM evolution models

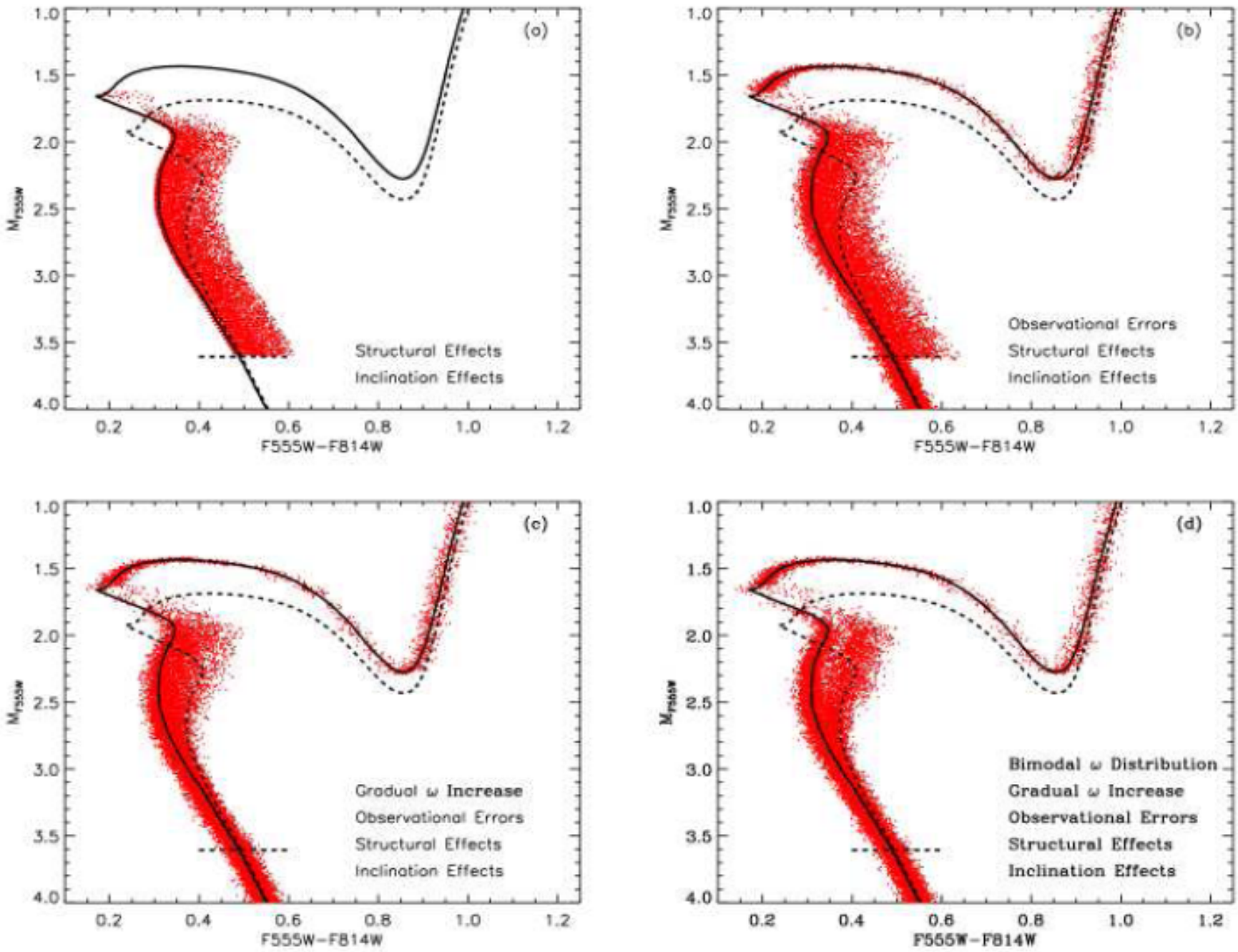
- Perryman et al. 1998: 625±50 Myr
- Lebreton et al. 2001: 650 Myr
- De Bruijne et al. 2001: 625 Myr

- Morel & Thévenin 2002: 570±15Myr
  without rotation
- Our age determination: 700±25 Myr
  with rotation

# Conclusions / Perspectives

- Context Gaia data processing
- Statistical inversion
  → Vrot distribution law
- Stellar evolution with rotation
  → Age determination of Hyades cluster (15 % older)

- We need isochrones with rotation
  for ages<1.5 Gyr for Gaia auxiliary data of DPAC
- Applications to multiple systems
  with masses>1.5 Msun




Bastian, de Mink 2009

- Hyades
- Alpha persei
- Pleiades
- Blanco 1
- Praesepe