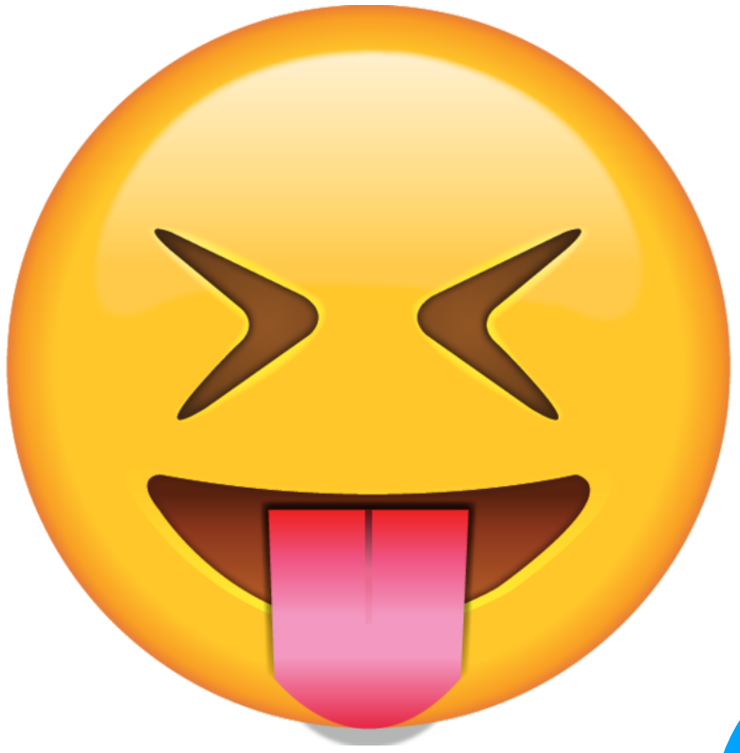
Where next?
Chemical phylogenies

Paula Jofré
Nucleo de Astronomia
Universidad Diego Portales
Chile

Chemical phylogenies……



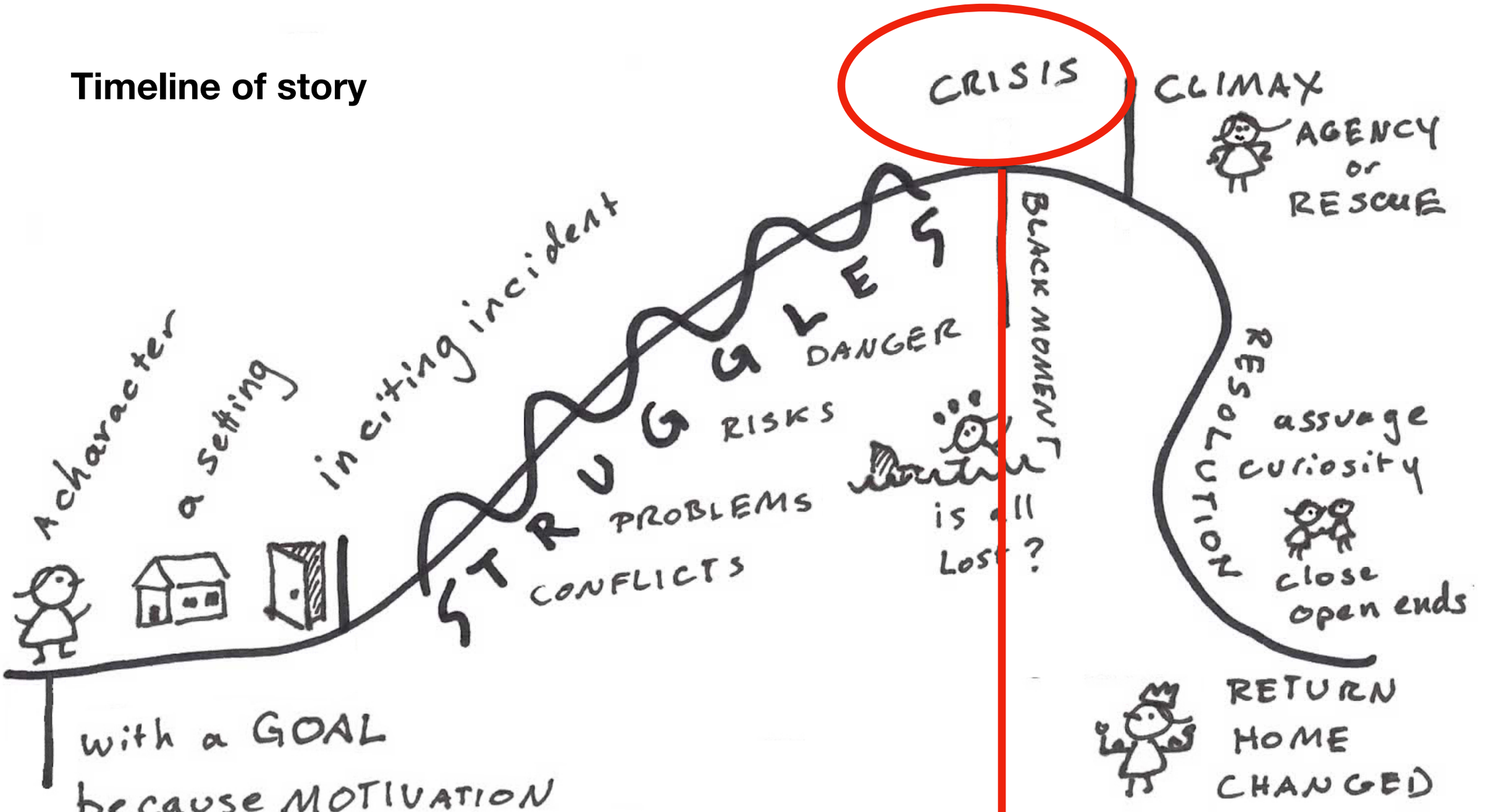
Yay! I finally get to talk about my dear project!

I will just tell a story

I haven’t really been able to do much since my 2017 analysis on 22 stars…

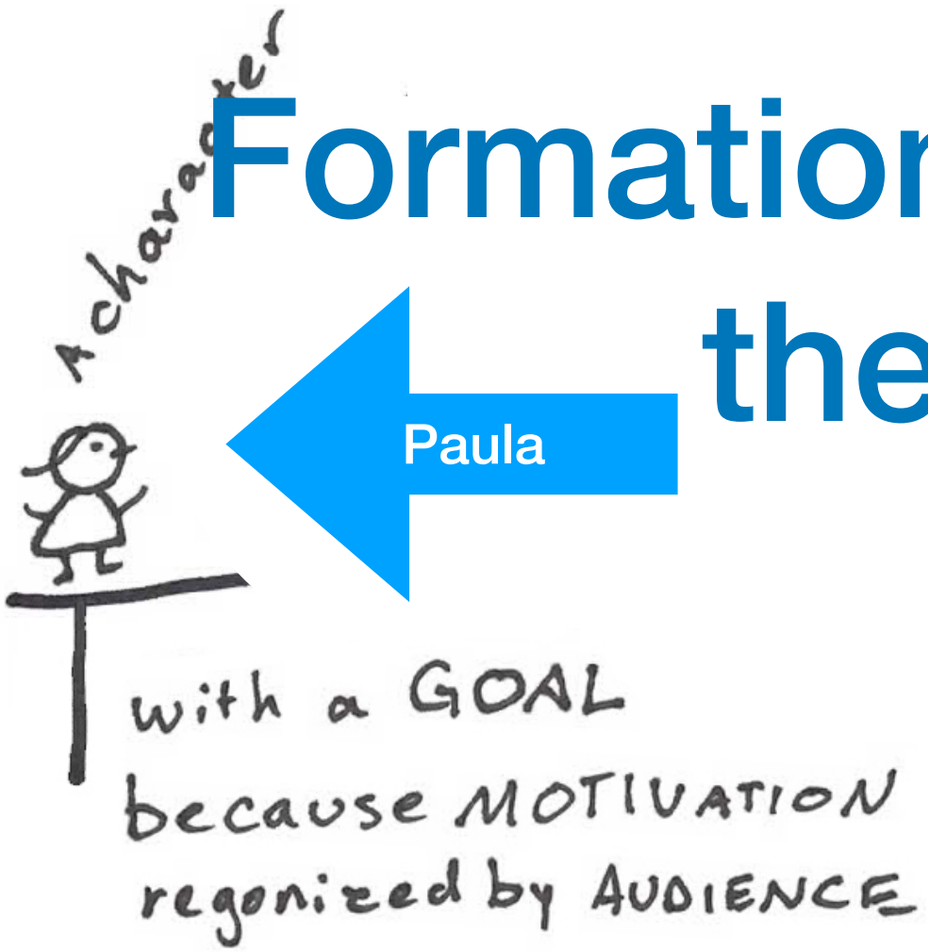
It’s too hard to do more and I don’t have the time I used to have when I was a postdoc!

Timeline of story



Time

Now



Formation and evolution of the Milky Way

Payel Das (Rudolf Peierls Centre for Theoretical Physics, Oxford, UK)
Patricia Tissera (Departamento de Astronomia, Andres Bello, Chile)
Chiaki Kobayashi (Centre for Astrophysics Research, Hertfordshire, UK)
Keith Hawkins (Austin Texas, USA)

Robert Foley (Leverhulme Centre for Human Evolutionary Studies, Cambridge, UK)
Keaghan Yaxley (Leverhulme Centre for Human Evolutionary Studies, Cambridge, UK)

Holly Jackson, MIT, USA
Danielle de Brito, UDP, Chile

a setting

Chemical tagging and Galactic archaeology

Reconstructing Ancient Star Groups

We now conjecture that the heavy element metallicity dispersion may provide a way forward for tagging groups of stars to common sites of formation. With sufficiently

THE NEW GALAXY: Signatures of Its Formation

Ken Freeman
Mount Stromlo Observatory, Australia National University, Weston Creek, ACT 2611, Australia; email: kcf@mso.anu.edu.au

Joss Bland-Hawthorn
Anglo-Australian Observatory, 167 Vimiera Road, Eastwood, NSW 2122, Australia; email: jbh@aao.gov.au

Chemical tagging and Galactic archaeology

Reconstructing Ancient Star Groups

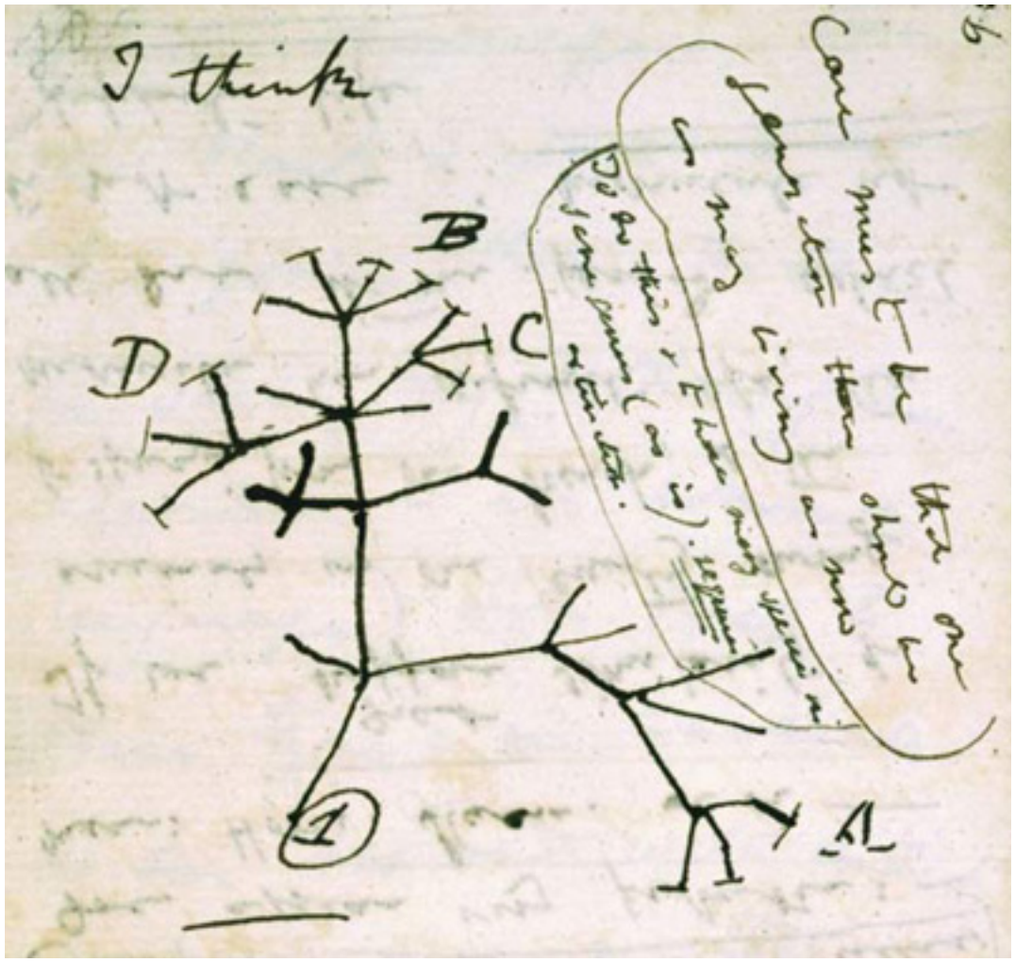
We now conjecture that the heavy element metallicity dispersion may provide a way forward for tagging groups of stars to common sites of formation. With sufficiently

in exciting incident

inciting incident

King's Research Exchange Evening:
Role of Visual in Science

Evolution

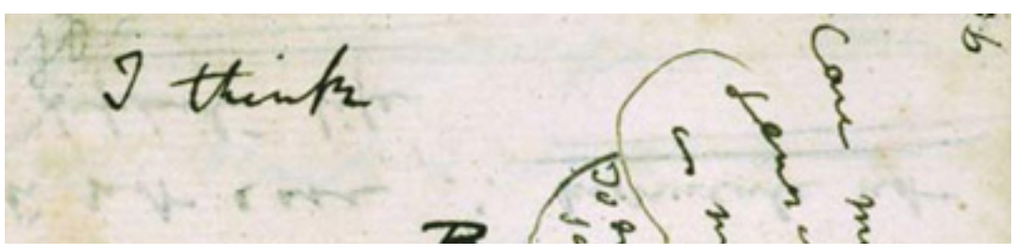


Darwin's theory and Tree of Life

inciting incident

King's Research Exchange Evening:
Role of Visual in Science

Evolution



Every species evolved from one common primordial form

By comparing the similarities and differences in the DNA sequences of different species it is possible to reconstruct their shared history as an evolutionary tree, also known as phylogeny

The features that define a population - its traits - have evolved somewhere along these branches, outcomes of some universal set of evolutionary forces

Chemical evolution of the Galaxy

Traits that evolve with time: need to be inherited from one generation to the next

Stellar abundances - stellar DNA

Stellar phylogenies

The ISM is the shared environment of stars
With stellar DNAs we study the chemical evolution of the ISM

Chemical Abundance Space

An intriguing prospect is that reconstructed star clusters can be placed into an evolutionary sequence, i.e., a family tree, based on their chemical signatures. Let

Building a tree

SOLAR NEIGHBOURHOOD

(NISSEN 15/16)

22 SOLAR TWINS
HARPS SPECTRA

ASTROMETRIC DATA

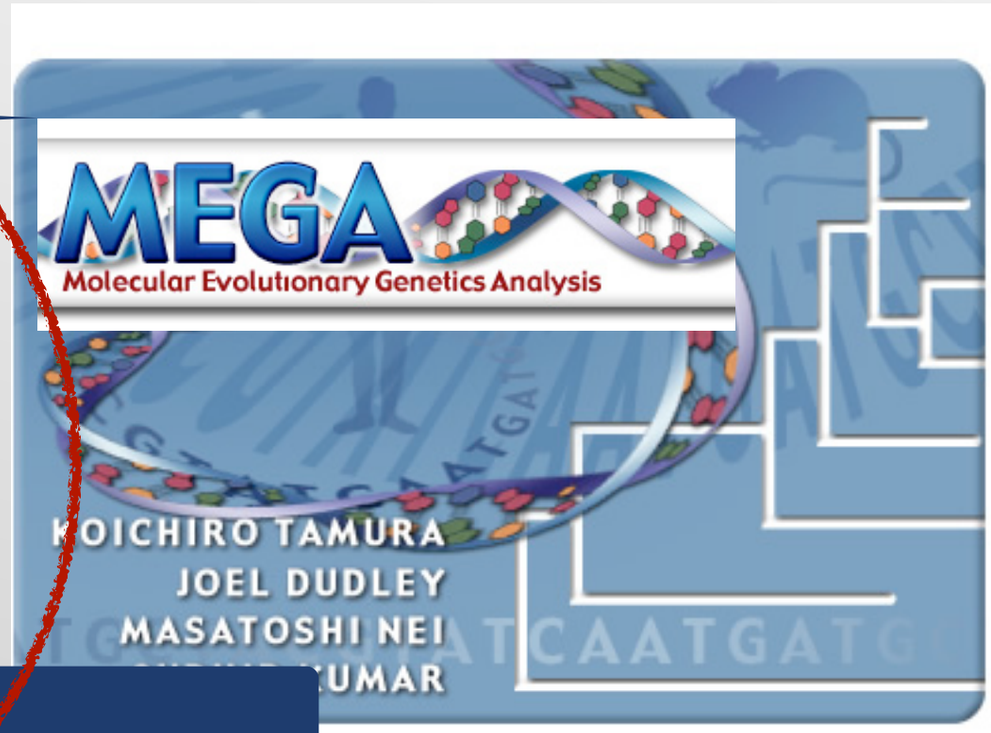
ACCURATE
STELLAR PARAMS
17 [X/FE]
AGES

ACCURATE
KINEMATICS

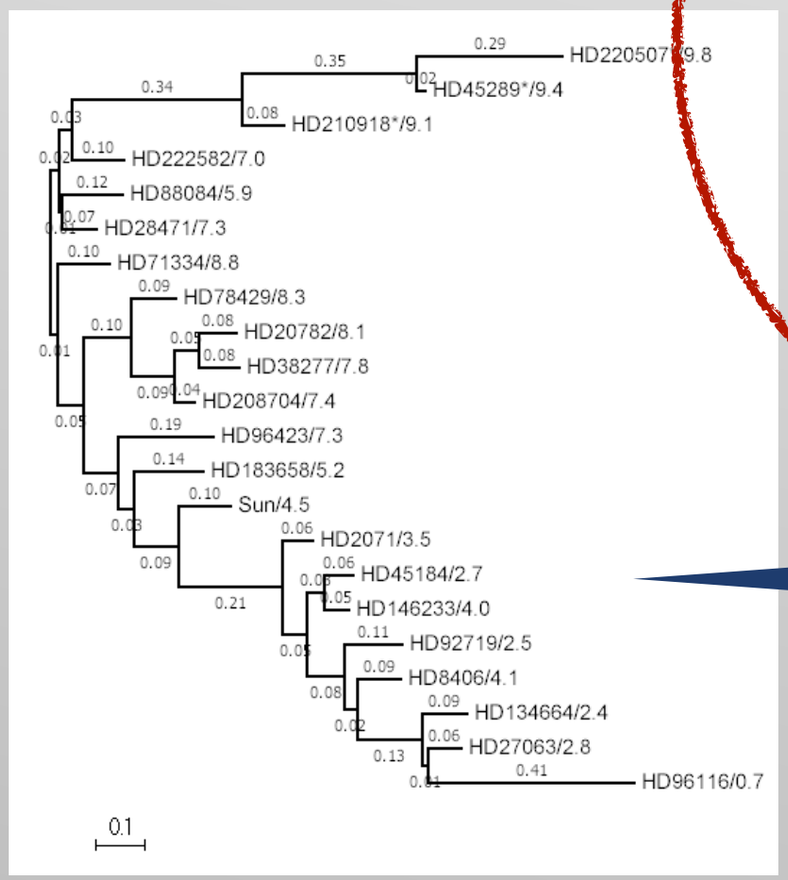
Building a tree

SOLAR NEIGHBOURHOOD

1. INPUT CHEMICAL DISTANCE MATRIX
2. NEIGHBOUR-JOINING CLUSTERING ALGORITHM
3. QUICK AND EASY TO CALL FROM CONSOLE



Bootstrap + Monte Carlo give us 1 consensus tree out of 1000 trees



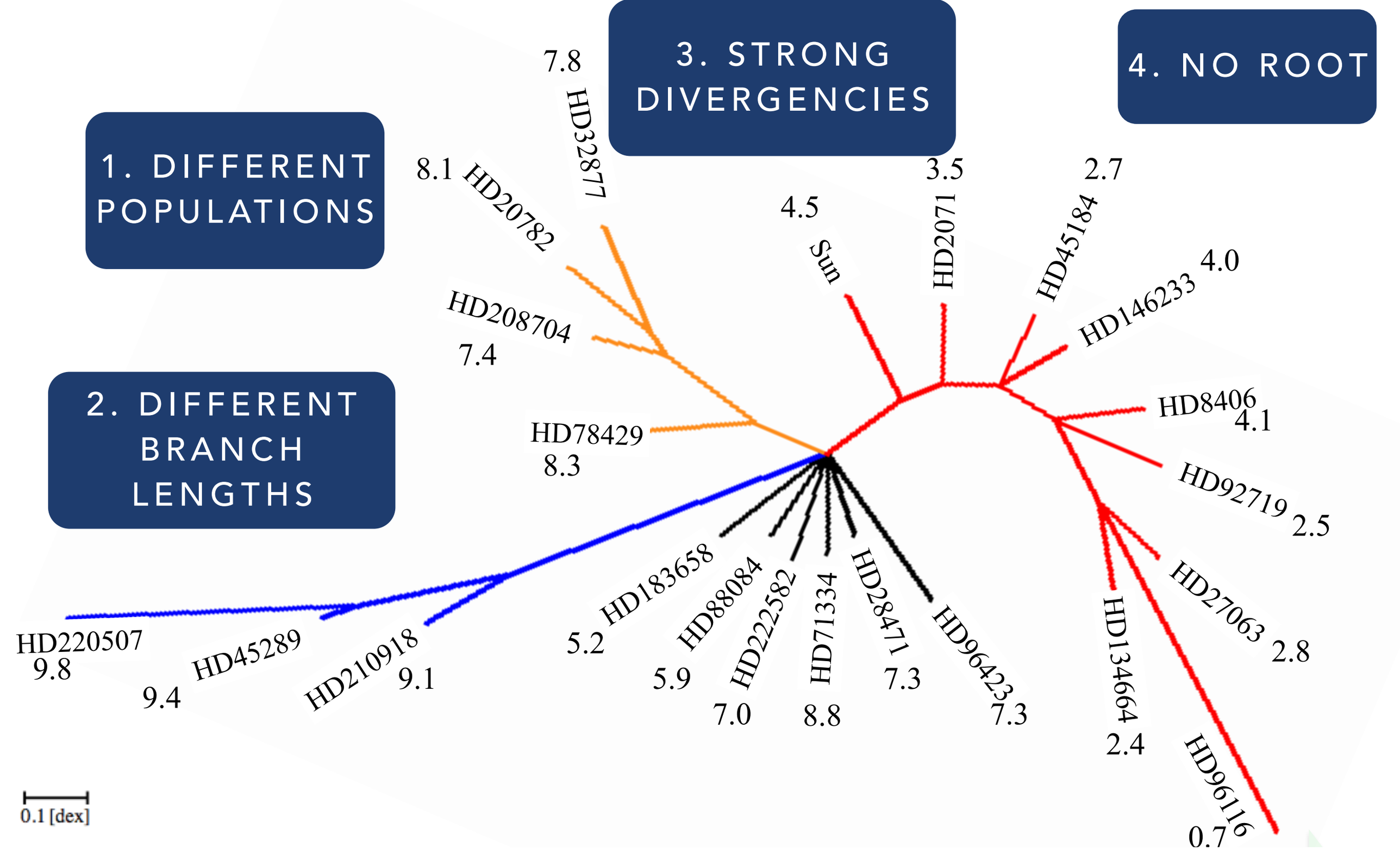
1. OUTPUT THE RELATIVE CHEMICAL SIMILARITIES BETWEEN STARS IN FORM OF A TREE

1. DIFFERENT POPULATIONS

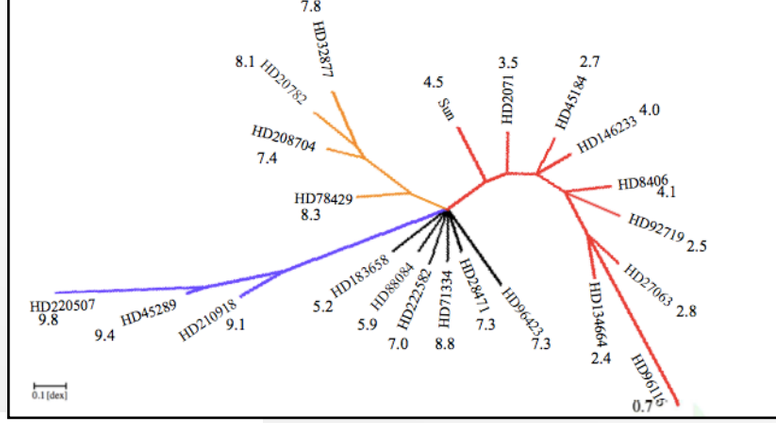
2. DIFFERENT BRANCH LENGTHS

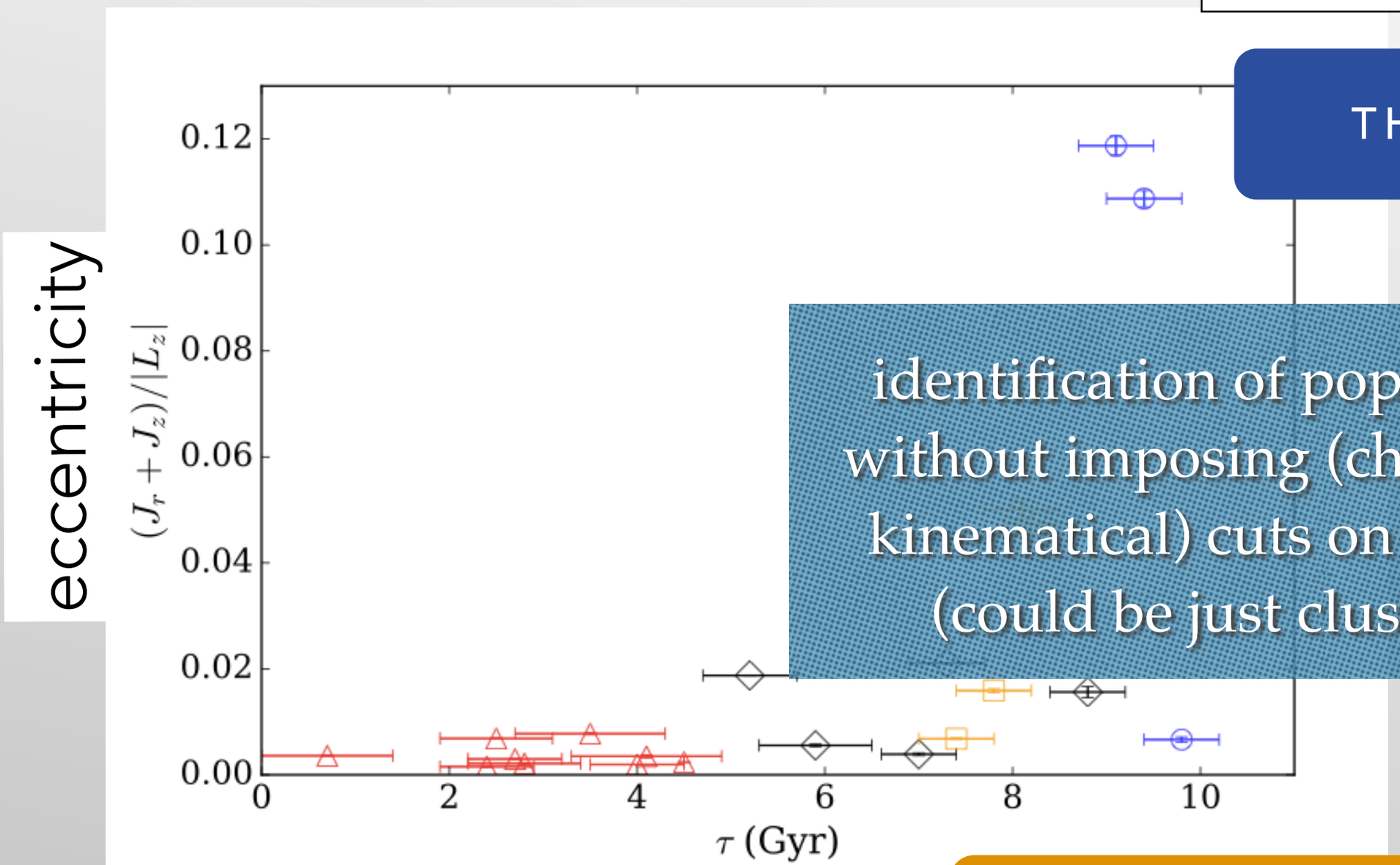
3. STRONG DIVERGENCIES

4. NO ROOT



1. DIFFERENT (GALACTIC) POPULATIONS





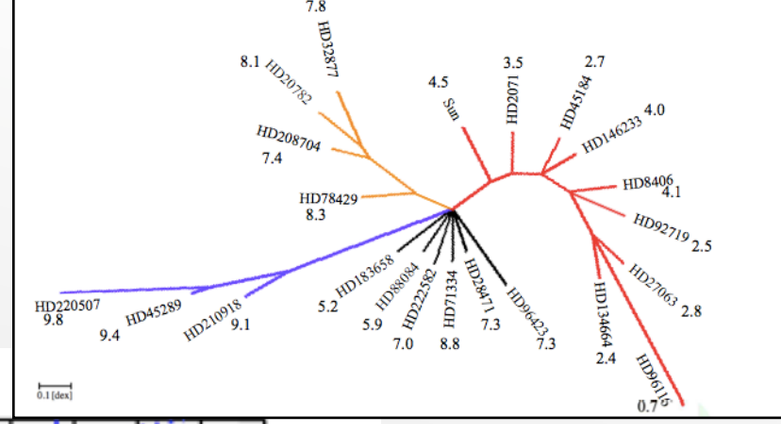
THICK DISK

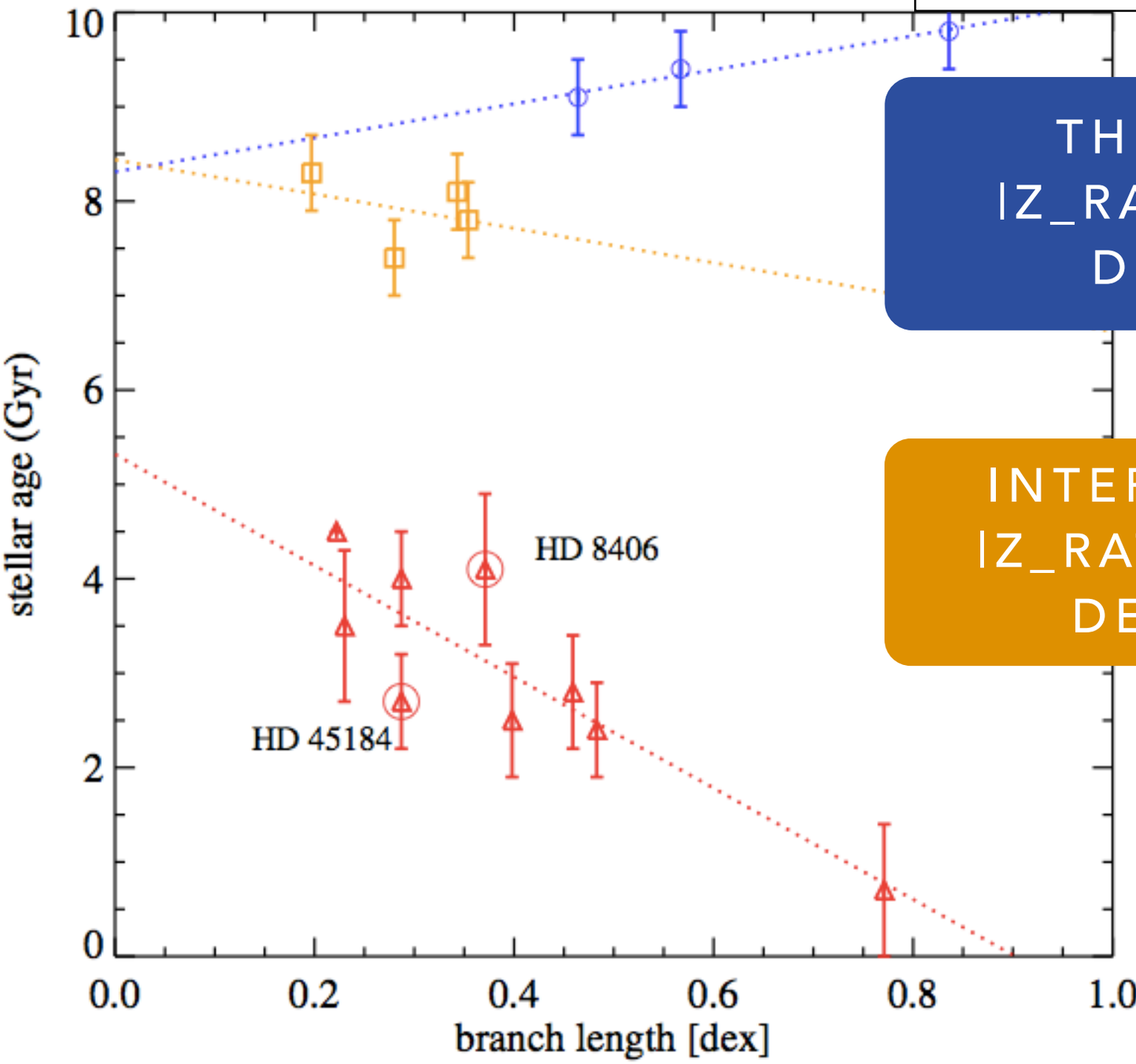
identification of populations without imposing (chemical or kinematical) cuts on the data (could be just clustering

THIN DISK

INTERMEDIATE

2. DIFFERENT BRANCH LENGTHS



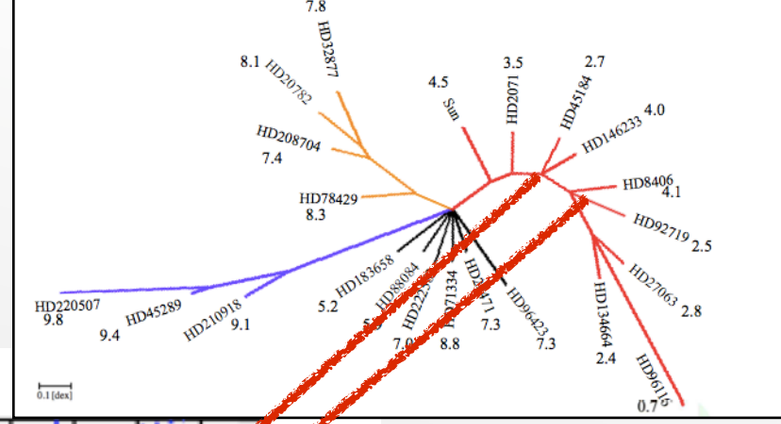


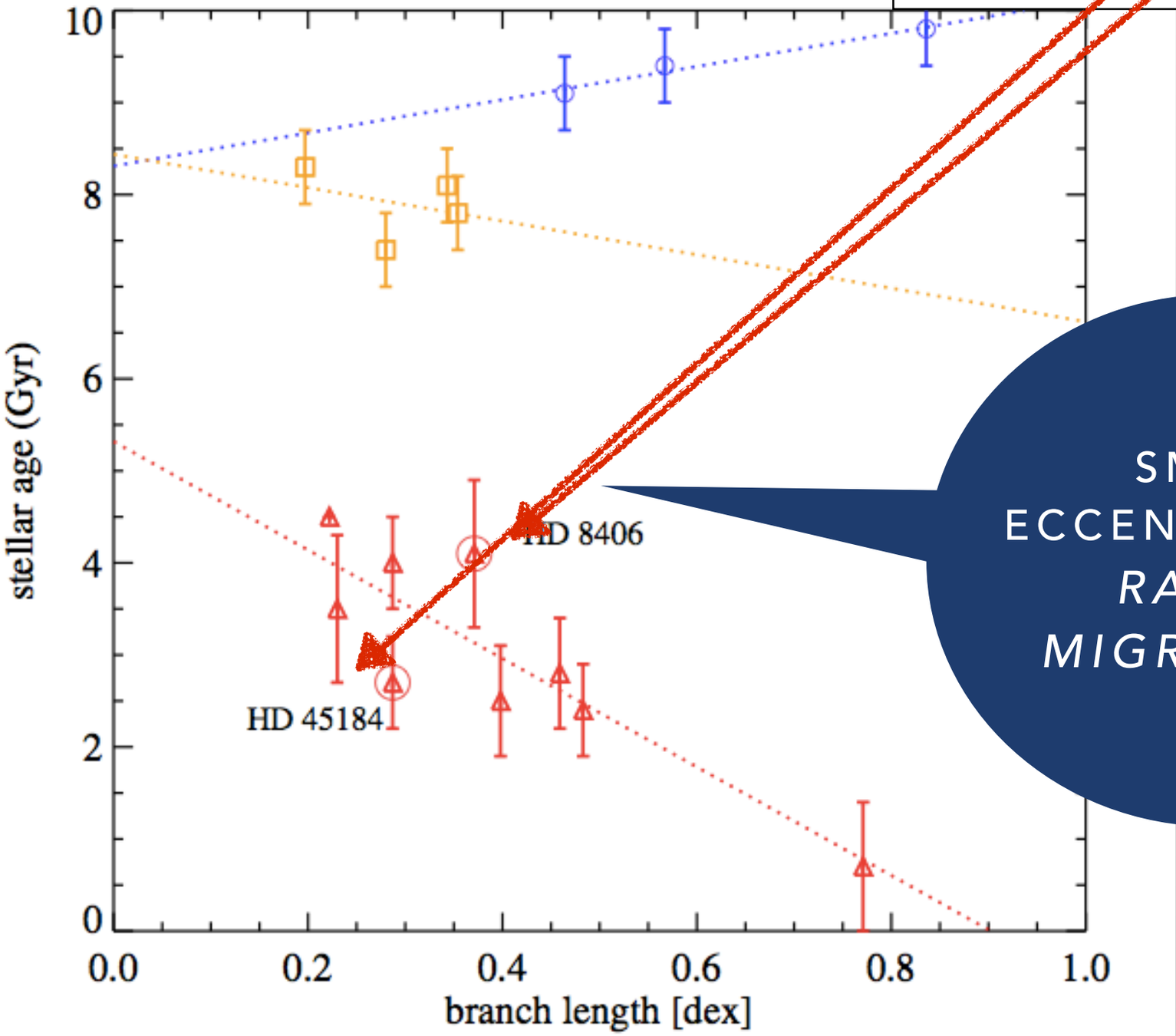
THICK DISK
|Z_RATE| = 0.66 DEX/GYR

INTERMEDIATE
|Z_RATE| = 0.27 DEX/GYR

THIN DISK
|Z_RATE| = 0.17 DEX/GYR

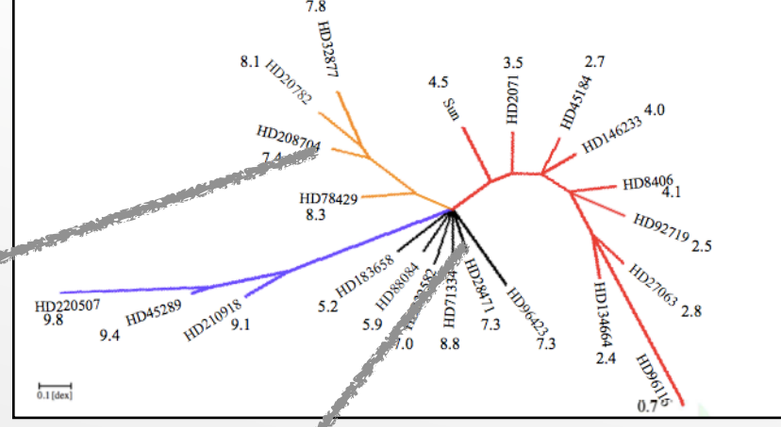
3. STRONG DIVERGENCIES

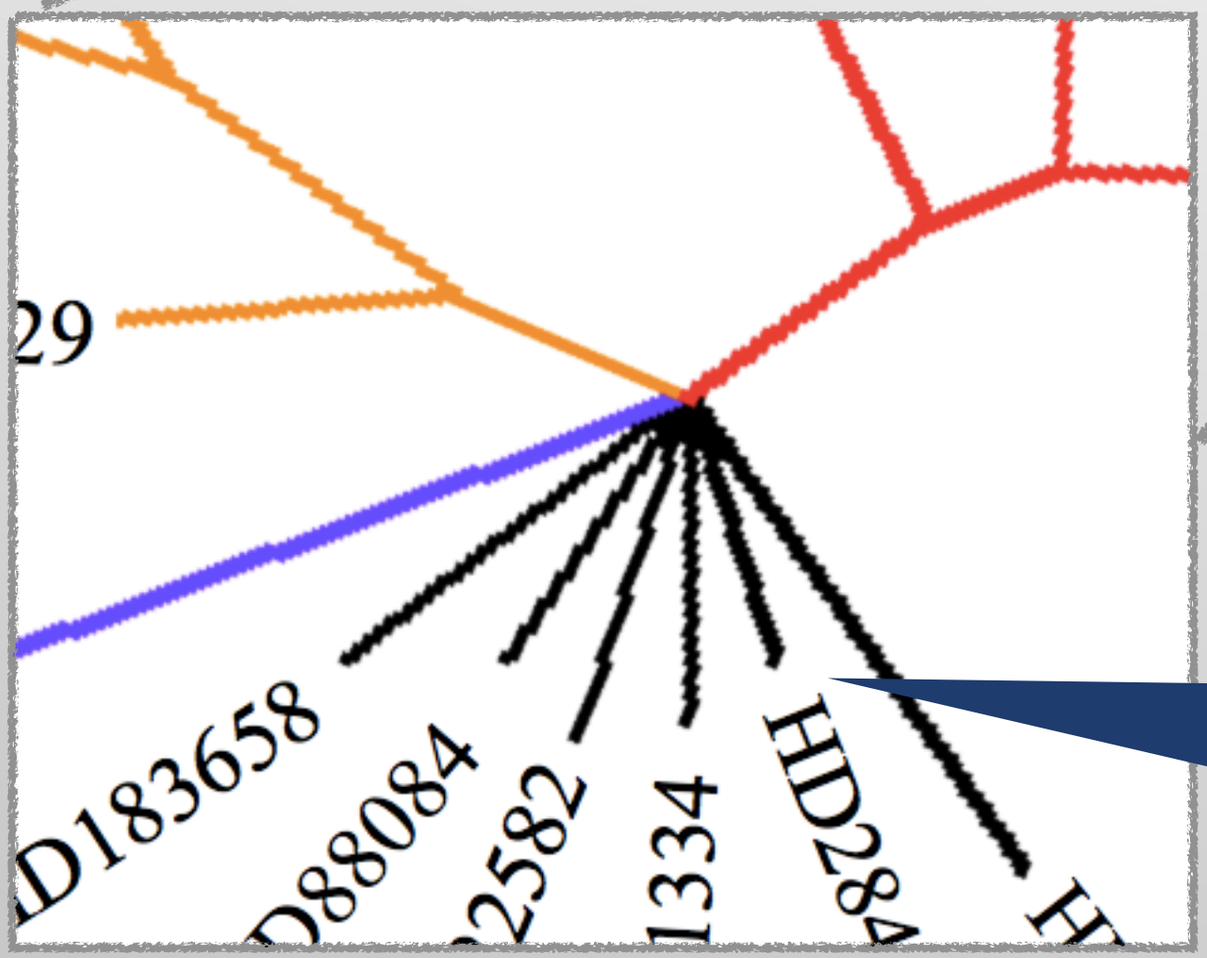




SMALL ECCENTRICITIES
RADIAL MIGRATION?

3. STRONG DIVERGENCIES

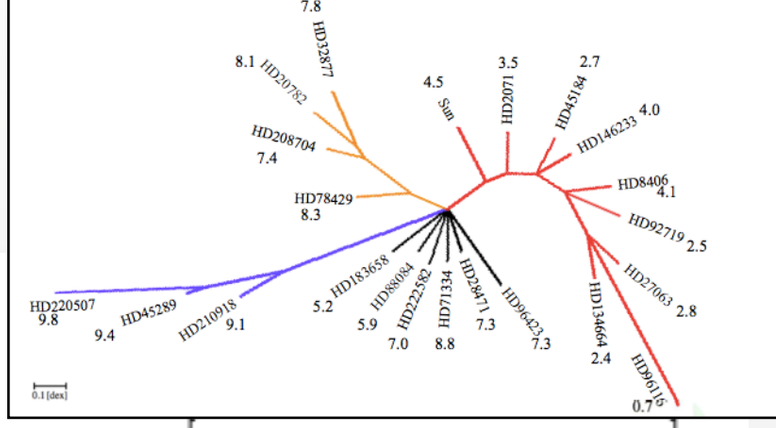


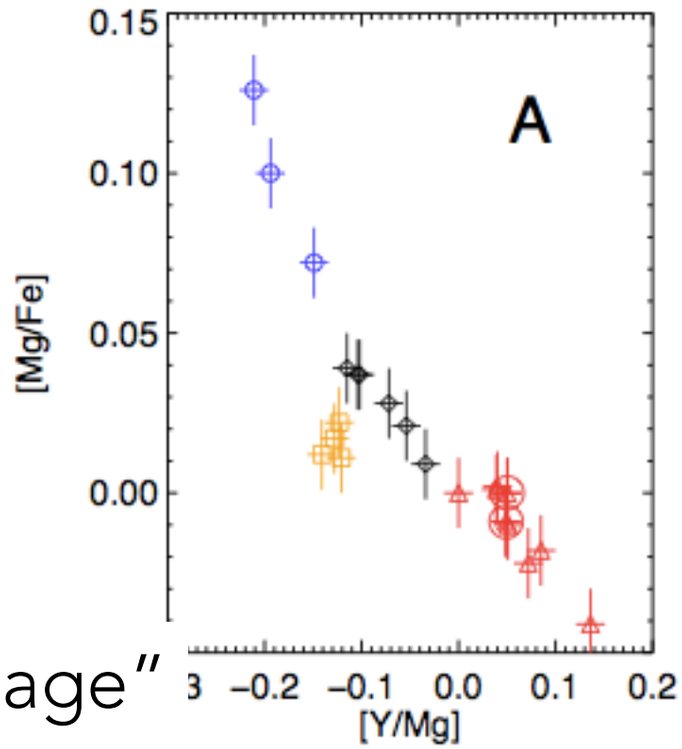


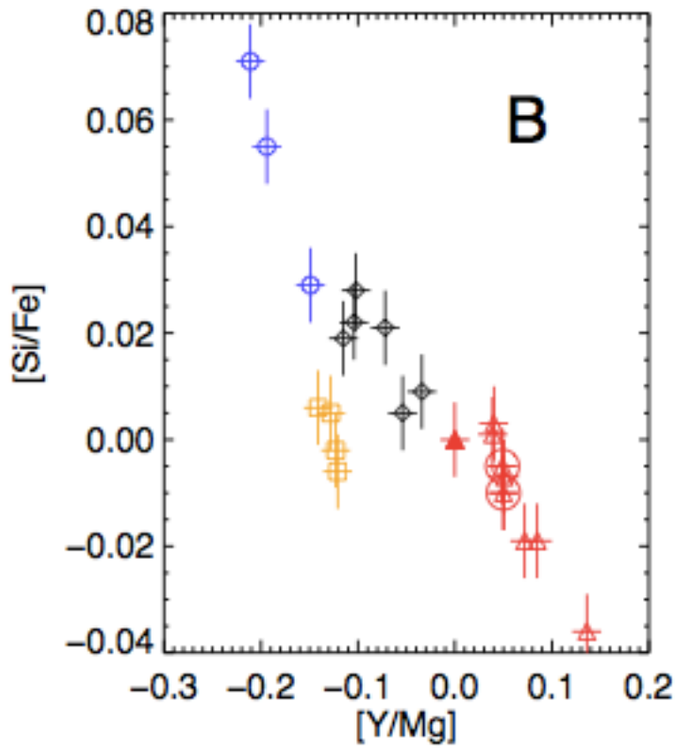
STAR-LIKE PHYLOGENY

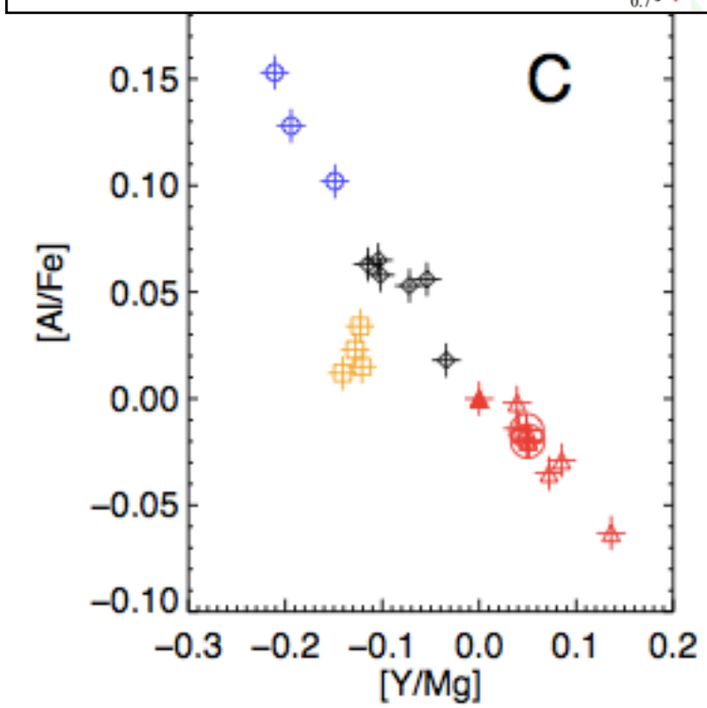
SOMETHING EXTREME ~8 GYR AGO, OR INCOMPLETE DATA?

INTERMEDIATE POPULATION









"chemical age" (Nissen15,16)

EXTRAGALACTIC?
AT SOLAR [FE/H]?
(SATELLITES ARE METAL- POOR)
INNER DISK?

PHYLOGENETIC THINKING IS VERY POWERFUL: ADDS THE RECONSTRUCTION OF **HISTORY** TO CLASSICAL CHEMICAL TAGGING CLASSIFICATION METHODS

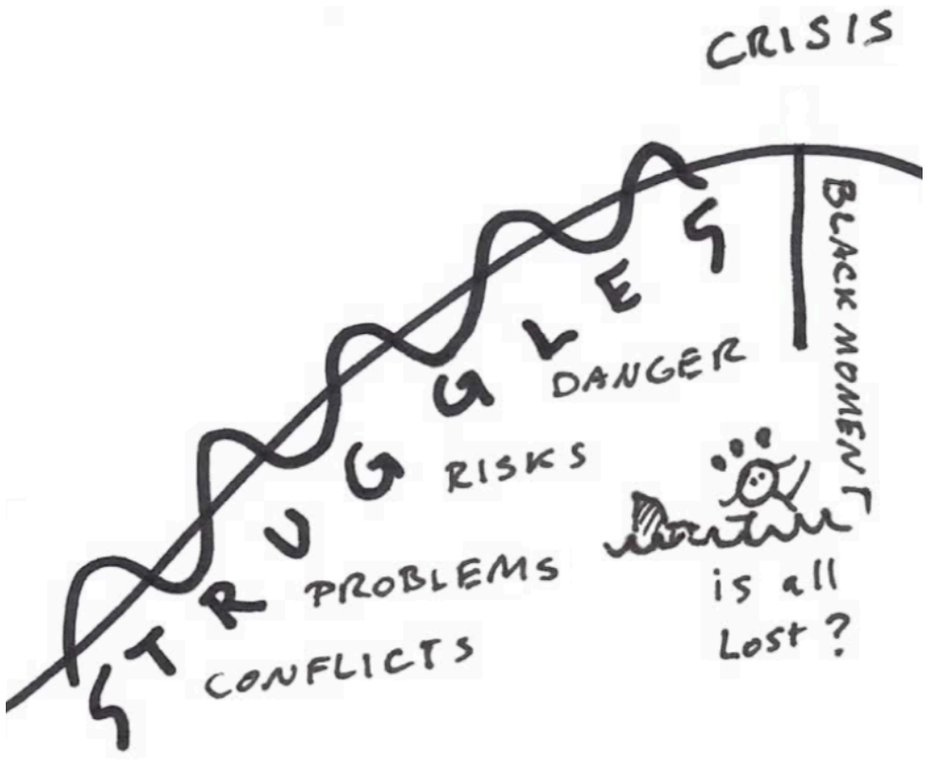
inciting incident

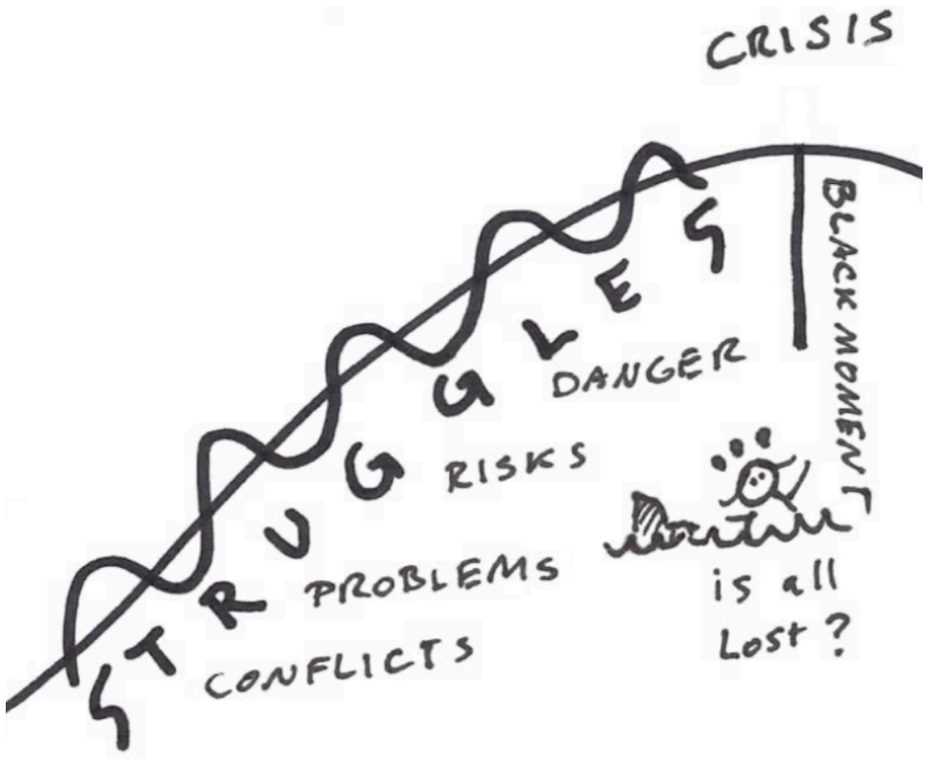
CONICYT
Ministerio de Educación
Gobierno de Chile

Fondecyt
Fondo Nacional de Desarrollo Científico y Tecnológico

Science News 2018
Scientist-to-Watch

PHYLOGENETIC THINKING IS VERY POWERFUL: ADDS THE RECONSTRUCTION OF **HISTORY** TO CLASSICAL CHEMICAL TAGGING CLASSIFICATION METHODS


CRISIS
BLACK MOMENT
STRUGGLES
DANGER
RISKS
PROBLEMS
CONFLICTS
is all
Lost ?



Challenges for chemical tagging

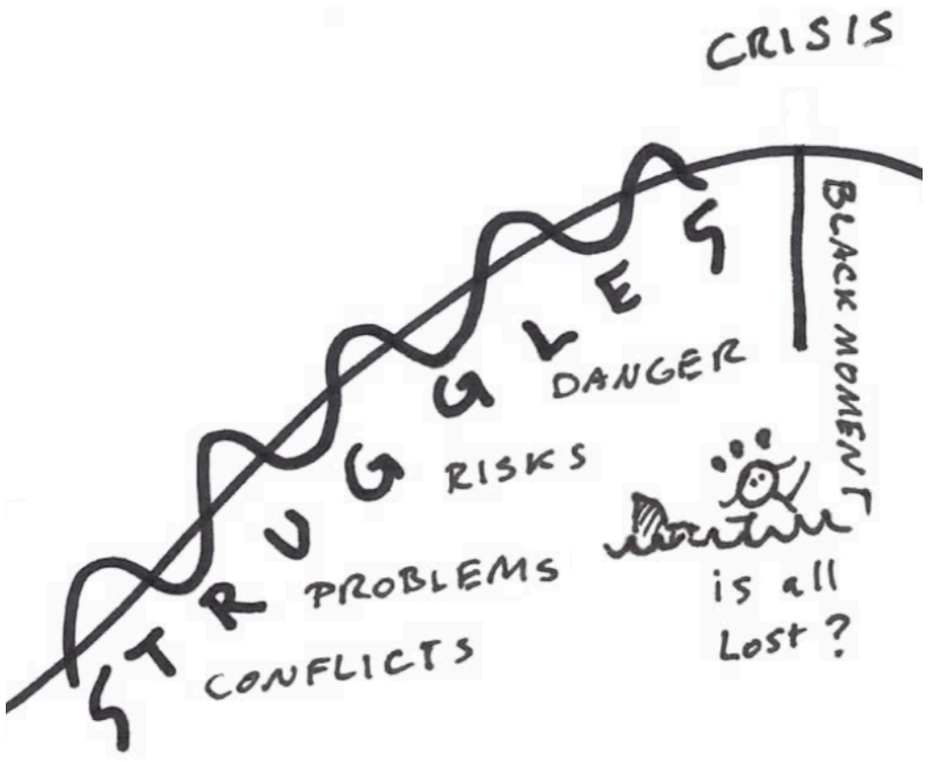
Uncertainties in abundances small enough? (Jofré+2019, ARA&A, vol 57, Accuracy and Precision of Industrial stellar abundances)
See also Nissen&Gustafsson 2018

Uncertainties in ages small enough? (many talks)

Are clouds (clusters, binaries) chemically homogeneous?
(Liu+2016, Tucci Maia+2019, + Koz's talk)

Are chemical pattern retain through a stellar lifetime (diffusion etc)?(Dotter+2017, Lin's talk)

Has the chemical space have enough dimensions to resolve differences?
(Ting+2015)



Challenges for building trees given complexity of nature

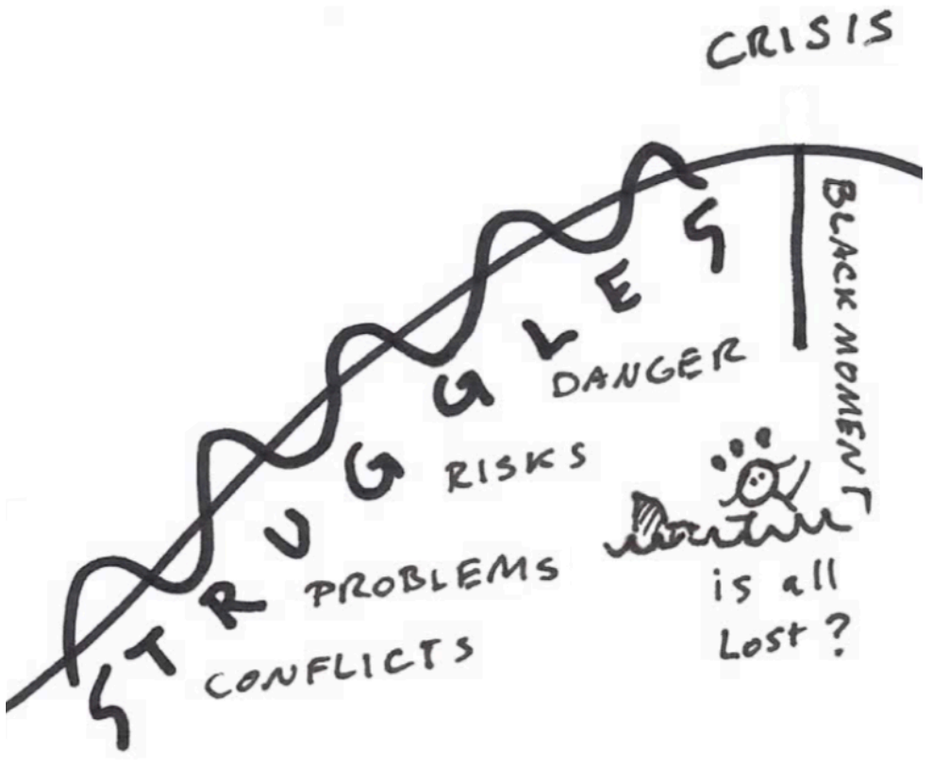
What is the best tree (Bootstap, Max Likelihood, Bayes)?

How to implement the fact that not every trait evolves at same rate everywhere and always?

How to implement the fact the evolving system is not isolated?

How to deal with millions of objects?

Data vs model?



Challenges for tree thinking

Baum Sci, 310, 979 (2005)

Tree diagrams are used in many non-evolutionary contexts: illustration of clustering

Phylogenetic trees show historical relationships, not similarities

Although closely related species tend to be similar to another, this is not necessarily the case if the rate of evolution is not uniform

Beginners (like me) should learn how to read trees and to understand what trees communicate.

We should learn how to read trees and to understand what trees communicate….

The tree that connects all stars in the Milky Way whose phylogeny tell us the history of our own Galaxy

Nucleo de Astronomia, UDP

- Chile's astronomy is perhaps the community that is growing the fastest - no wonder, so are the facilities that are being installed in our dessert. Chile is investing in the development of astronomy like few countries.

- Astronomy Nucleus, UDP, Santiago de Chile - started 2013 - I joined as 5th Faculty in 2017 (the stellar/galactic person), now we are 7 faculty + 7 post-docs, 4 PhD students, 1 outreach coordinator.

    - 1 more faculty to join **(We're hiring!)**

    - Telescopes, many funding programmes (ESO-Chile, ALMA/CASSACA/ECOS/Belgium/STINT/Gemini/MaxPlanck/FAPESP/Newton/…-Conicyt, Fondecyt, etc), international networks, etc

    - SDSS-V, LSST, GMT, 4MOST, E-ELT, MOONS, ALMA….

Revolution in Astronomy Data—> Revolution in Chilean Astronomy