Star formation with the E-ELT

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[Joana Ascenso (ESO)]

Wait, isn't Star Formation solved already?

(I'm pretty sure I saw it on the science cases of the VLT, Keck, SOFIA, Gemini, Spitzer, Herschel, ALMA...)

No.
Not even close.

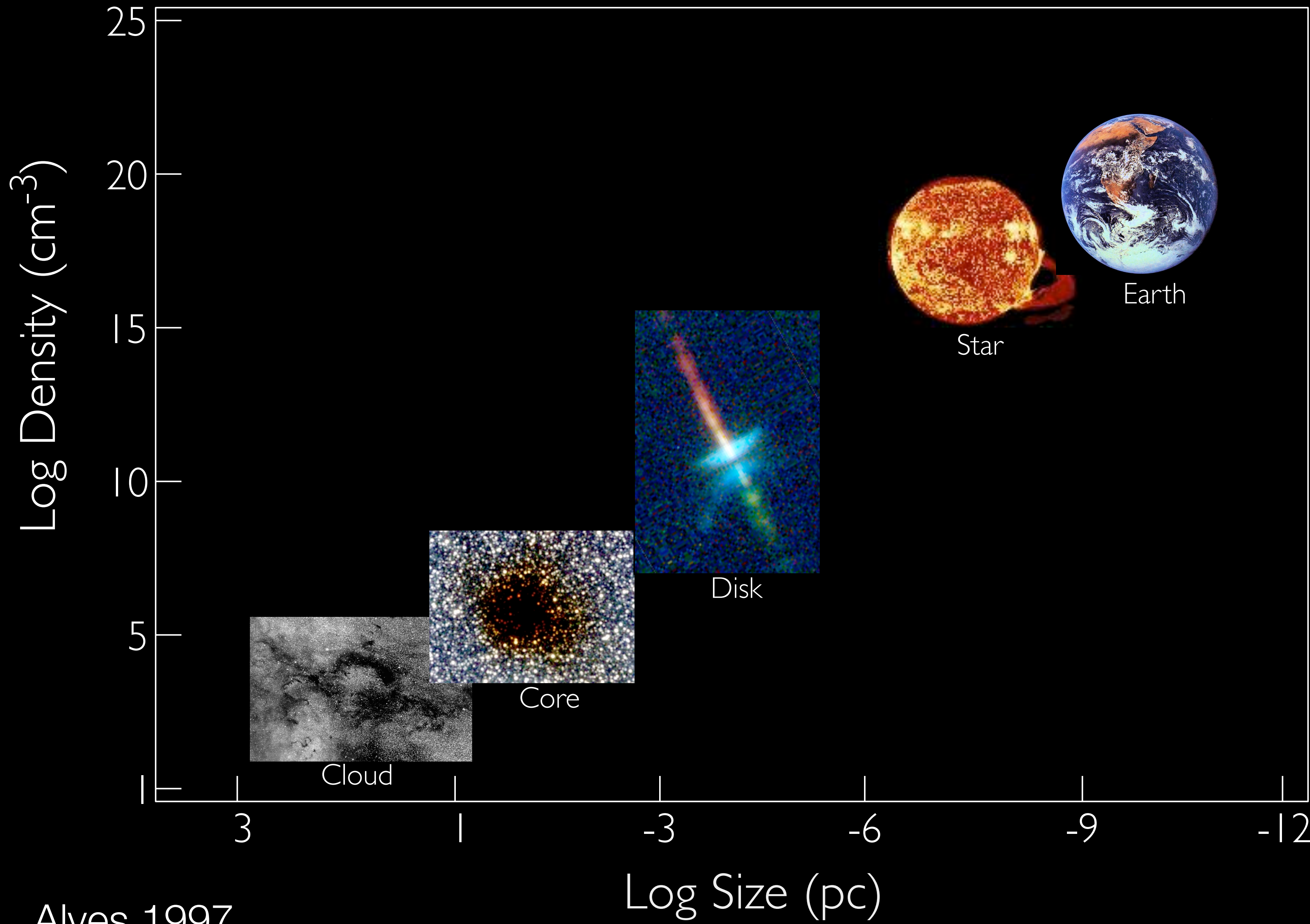
OK, but why should I care?

To understand star formation is to understand the favorite activity of the Universe: converting diffuse gas into Hydrogen burning stars and black holes.

Star formation lies deep in the core of two major ELT themes: planets and galaxy evolution.

And we don’t even have a rough predictive theory for it. Shame.

From Diffuse Gas to Stars and Planets



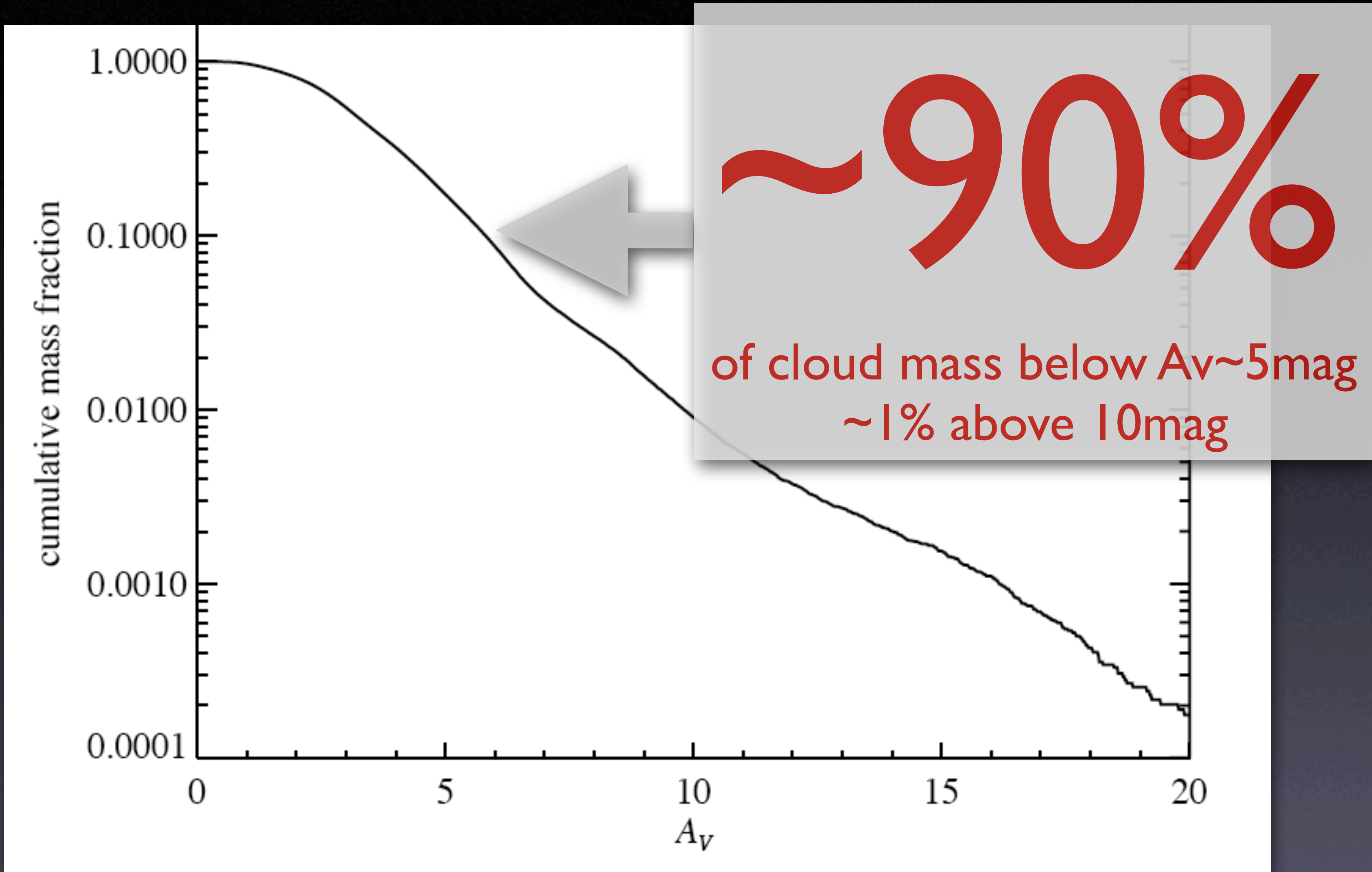
Alves 1997

7 things we're pretty sure about Star Formation (in the VLT era)

1. Stars form in the cold interiors of dark molecular clouds, all the time

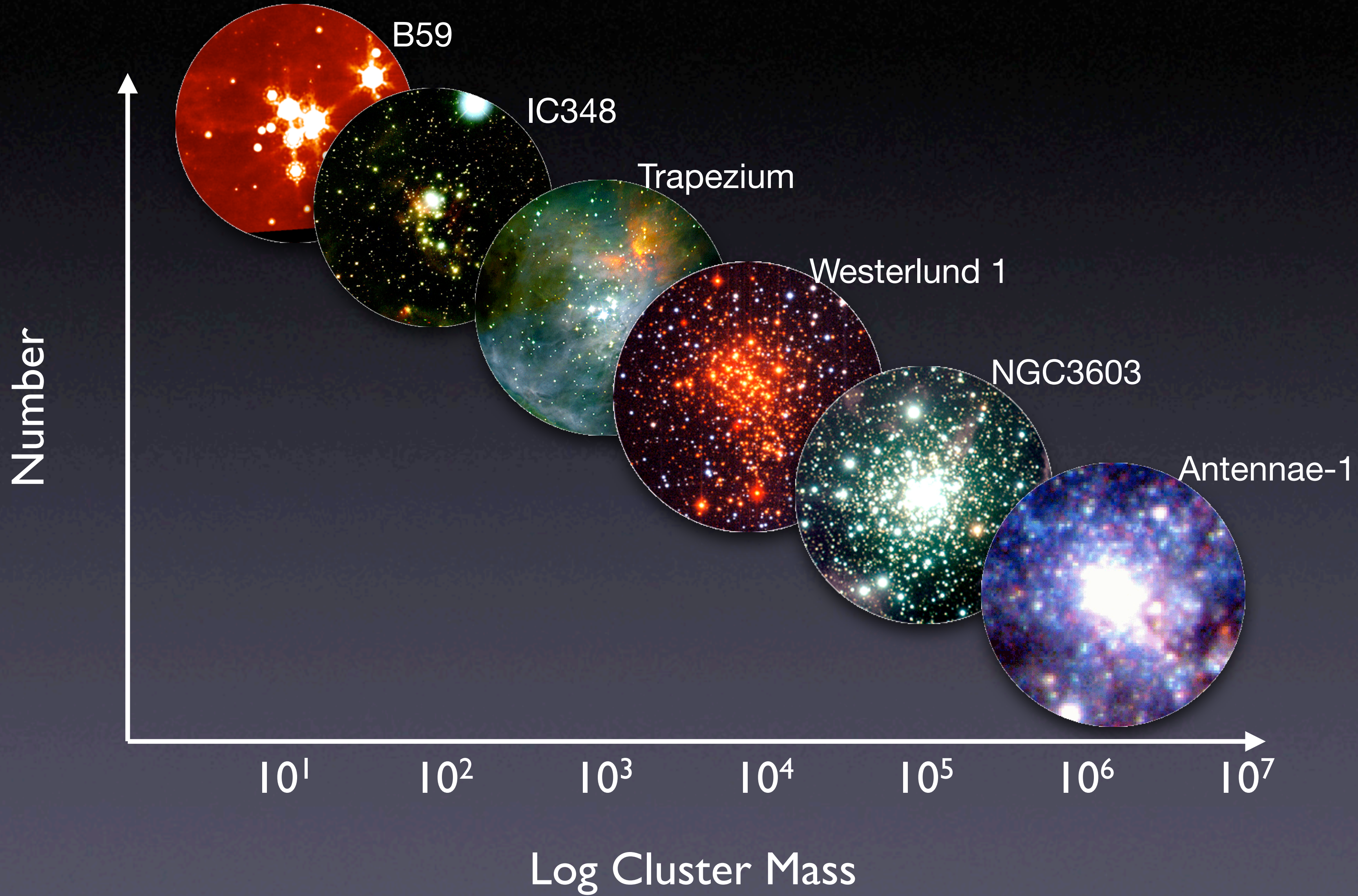
FORS2-VLT

2. Star formation is inefficient



Lombardi, Alves, Lada 2006

3. Most stars form in groups



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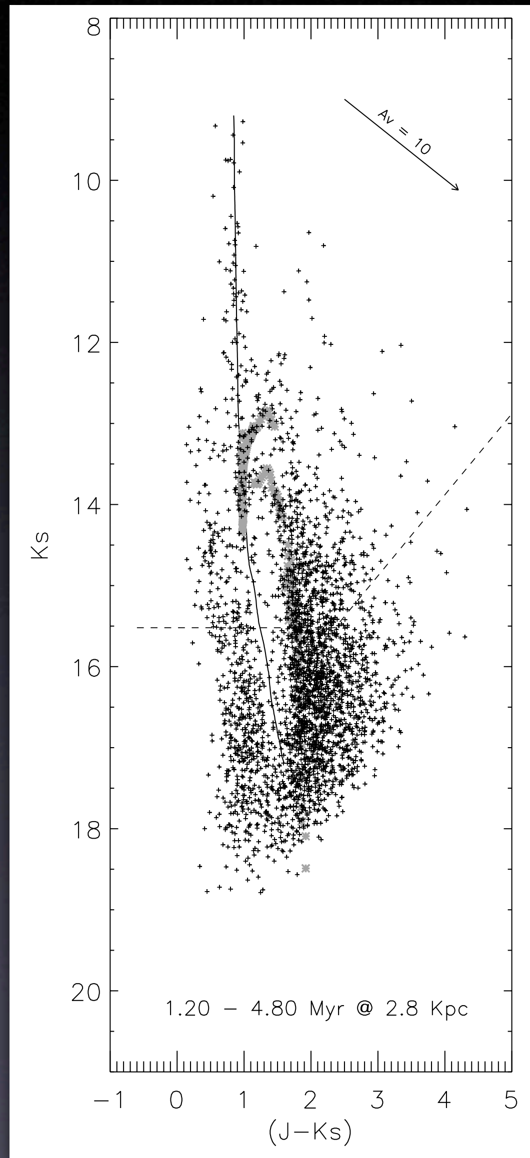
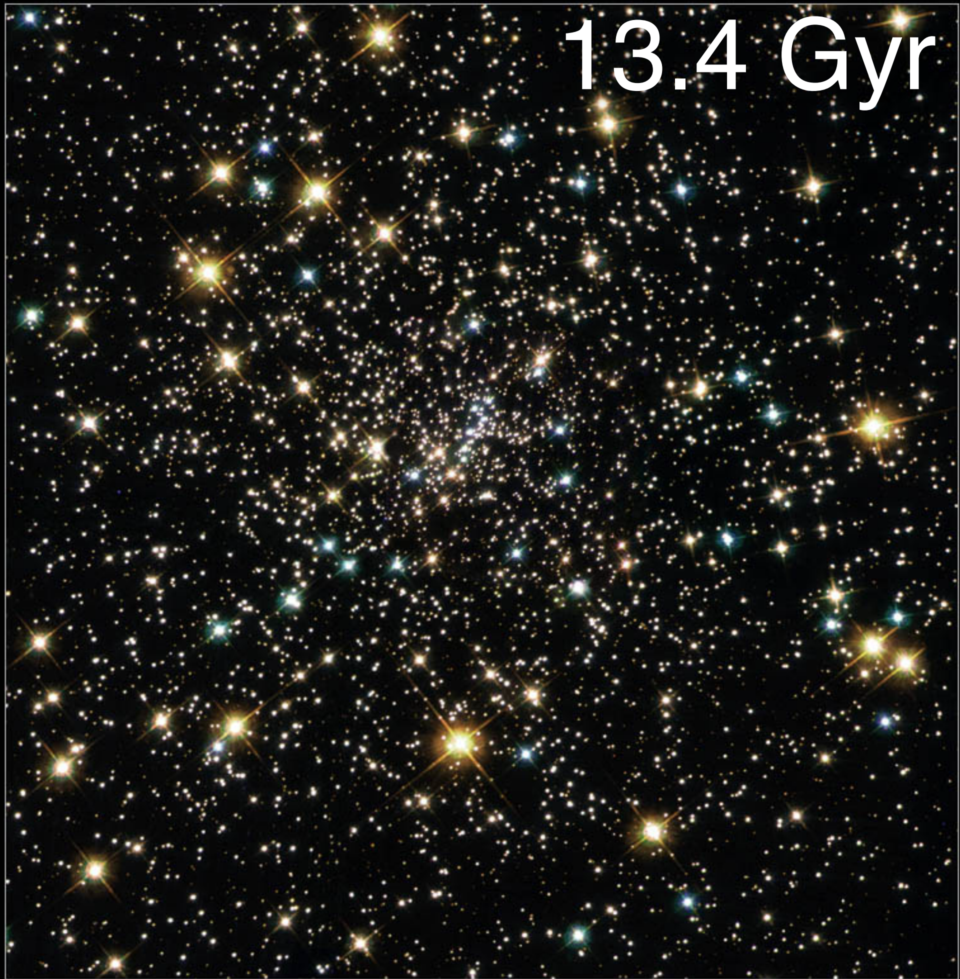


Ascenso et al. 2007

4. There is a characteristic product

Globular Cluster NGC 6397



Hubble Heritage

NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC03-21

The Orion Nebula and Trapezium Cluster
(VLT ANTU + ISAAC)

ESO PR Photo 03a/01 (15 January 2001)

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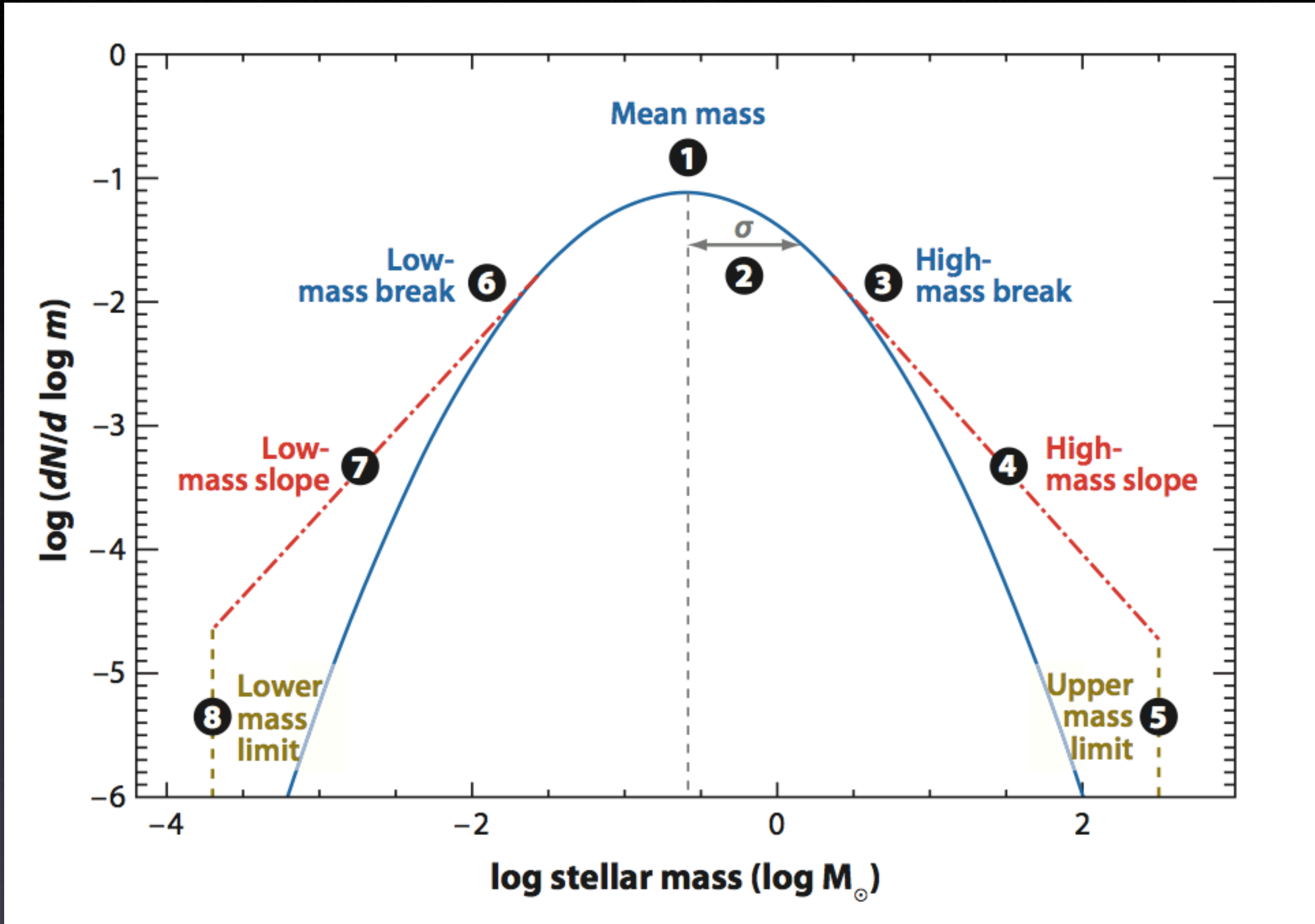
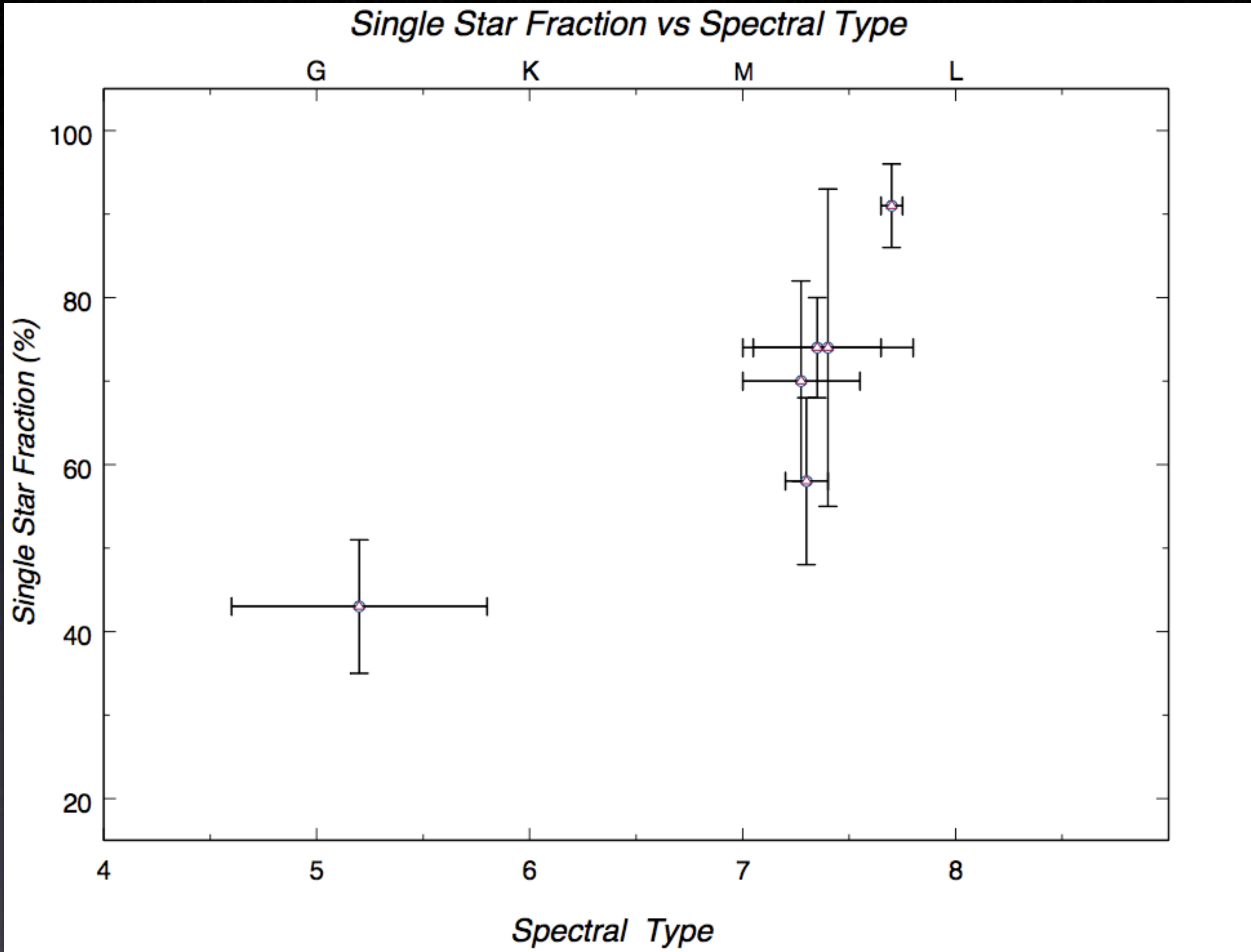
4. There is a characteristic product



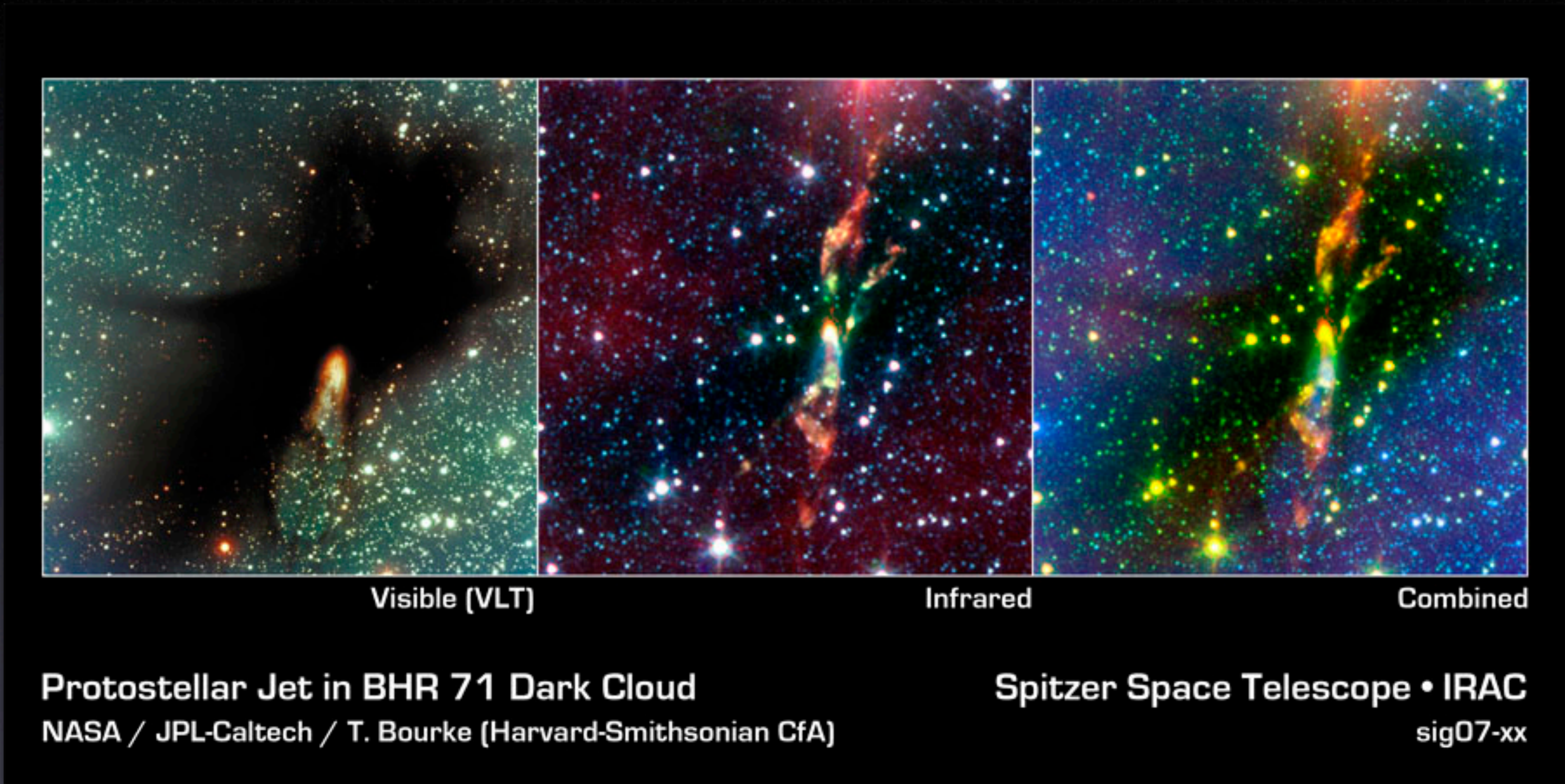
Bastian et al. 2012

4. There is a characteristic product



Lada 2006

5. Feedback is ubiquitous



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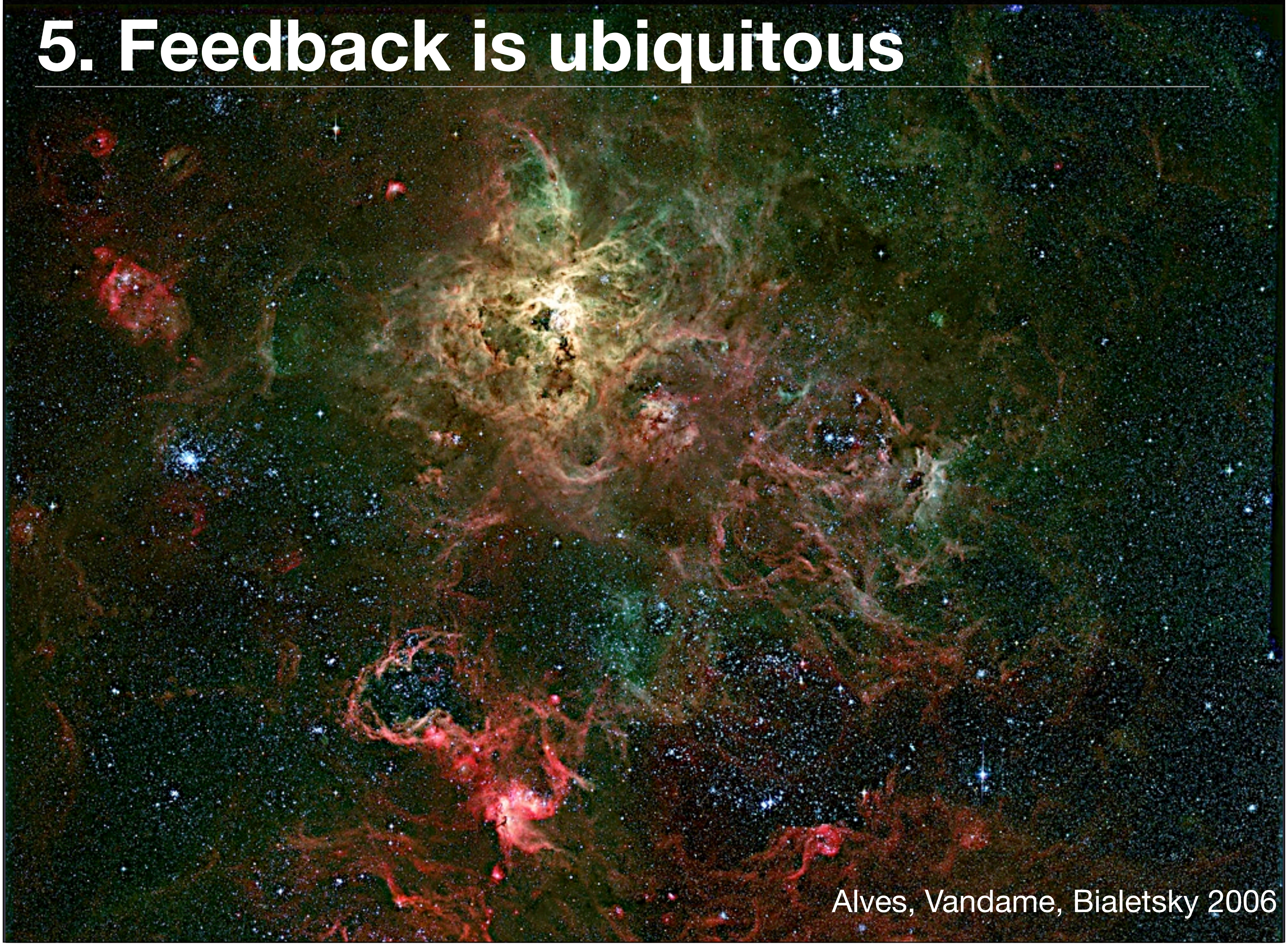
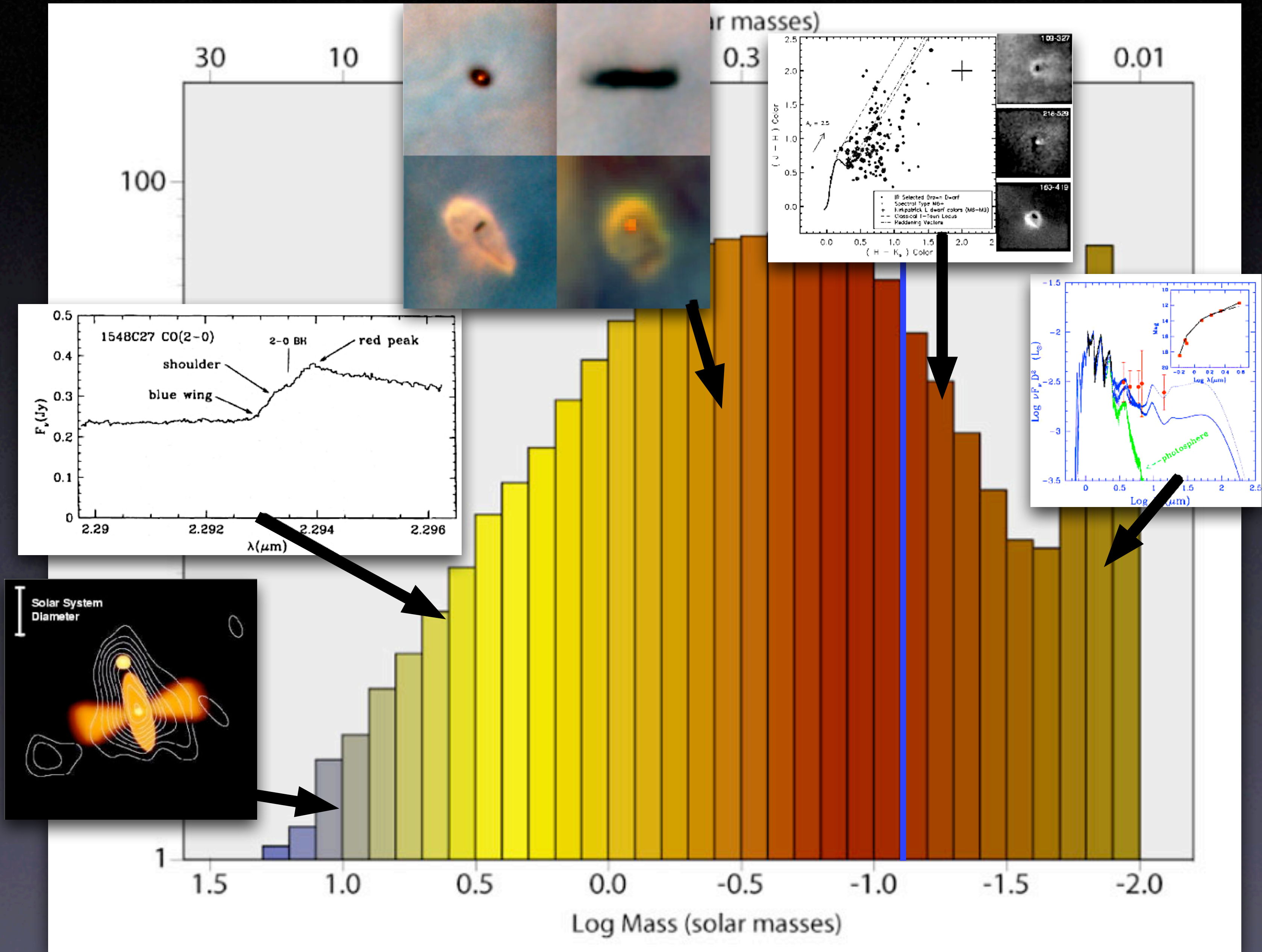


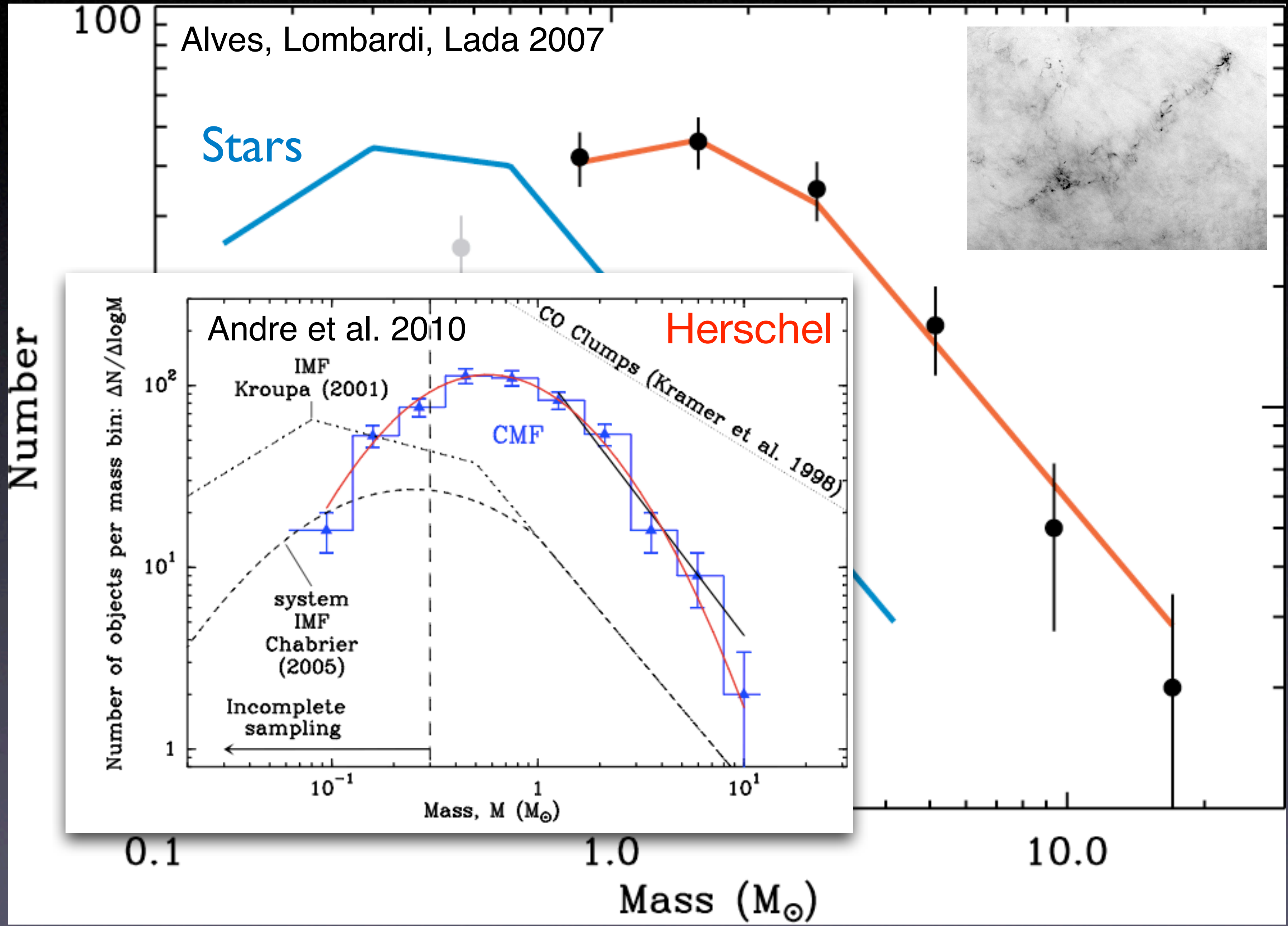
Alves, Vandame, Bialetsky 2006

6. Stars form via accretion disks



Shepard et al. Najita et al. Muench et al. Testi et al.

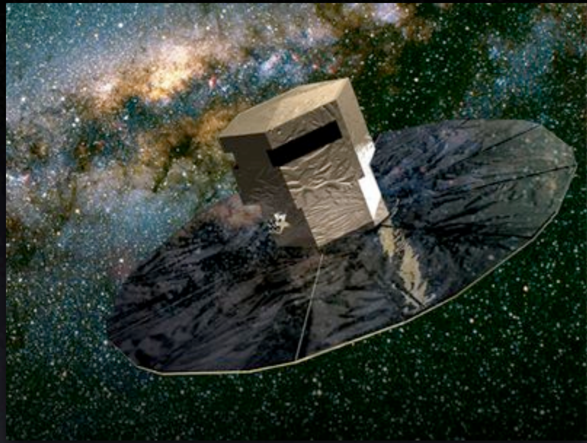
7. Core Mass Function —> IMF?



Fast Forward to 2022

Fast Forward to 2022

Gaia data base available



• Distances to stars in nearby SF regions will have precisions of 1% or less (PMS models the “only” uncertainty)
• A whole “new” Milkyway, cluster dispersion into the Galactic field population

VLT, Spitzer, WISE, Herschel, ALMA for more than a decade

• Local YSO census essentially “complete”. SEDs from optical to mid IR.
• First studies of resolved disks and planet formation
• Molecular cloud structure and the CMF —> IMF (?)
• Census of the rare massive Galactic proto-clusters (Herschel-Spitzer-VISTA-ALMA), sites of ongoing massive star formation

Fast Forward to 2022

JWST will be almost fully funded by 2022, Brazil joins in 2021
- Synergy:
• JWST will be more sensitive, will have ~4x the FoV but the ELT will have better spatial (~7x higher) and spectral resolution (~100x higher) which is critical for Star Formation studies.

Distance	50 pc	Taurus	Orion
JWST@K-band	3.6 AU	10 AU	28 AU
ELT@K-band	0.5 AU	1.4 AU	4 AU

Fast Forward to 2022

ELT Sweet Spot

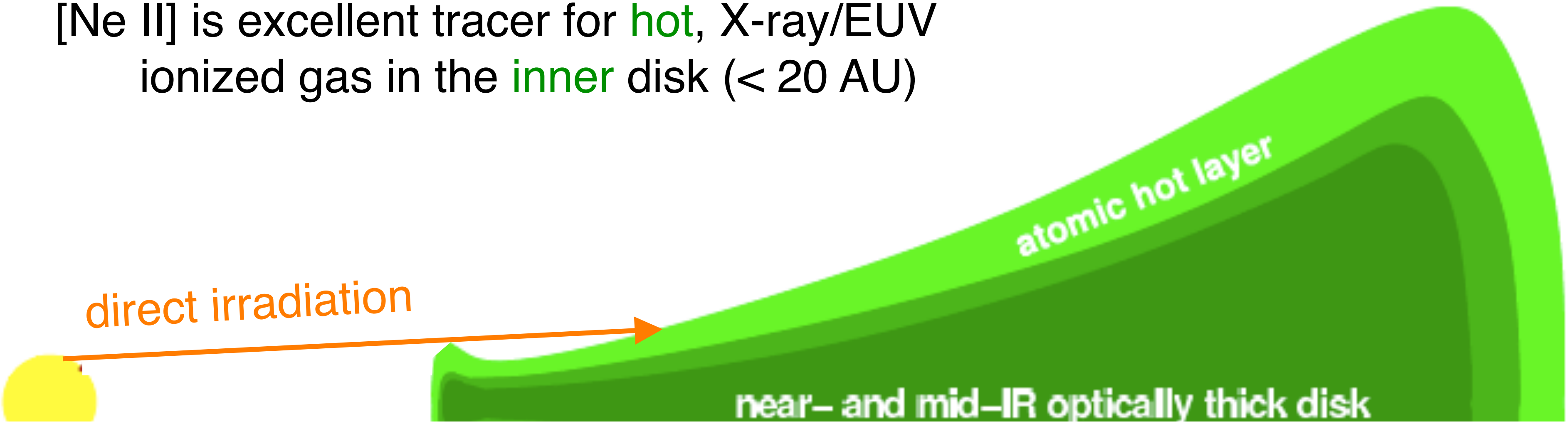
Up to Orion (400pc)

• Resolved protoplanetary disks, outflow mechanism, planet formation, direct proto-planet imaging

See posters:
P36: Y. Tsamis, Studies of photoevaporating protoplanetary discs
P35: R. Siebenmorgen, E-ELT observations of shadows, gaps, and ring-like structures in proto-planetary disks
P23: M. Meyer, Star and Planet Formation with the E-ELT
P25: F. Millour, From MATISSE to METIS: possible synergies

[Ne II] 12.81μm: Probing Hot Inner-Disk Gas Atmospheres?

[Ne II] is excellent tracer for hot, X-ray/EUV ionized gas in the inner disk (< 20 AU)



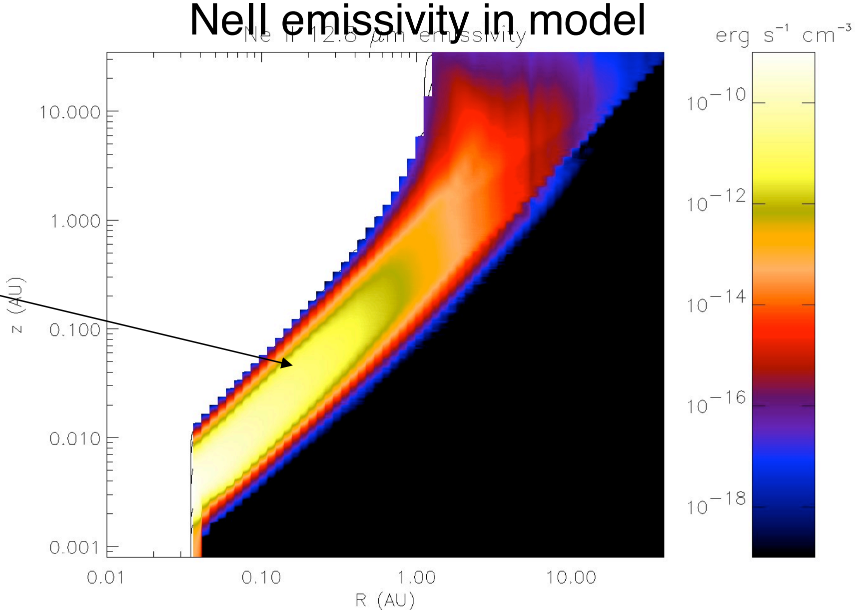
Where does it form? Why does it form? Ionisation source? Heating source?

Model: r < 10-20 AU: hot inner disk

Alternatives: [Ne II] from shocks, jets, photoevaporative winds

Need high spectral resolving power!

NeII emissivity in model

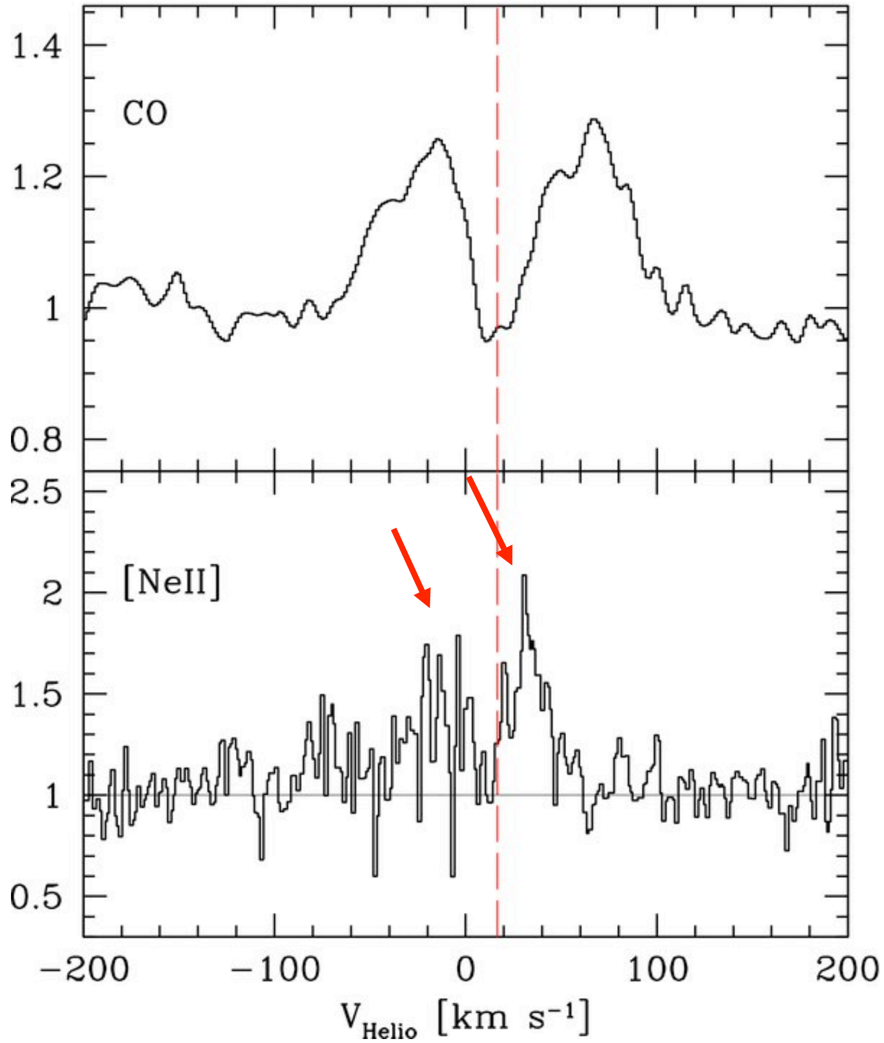


(Schisano, Ercolano, Güdel 2009)

[NeII] from a Keplerian inner disk...
(double-peaked; near-edge-on)

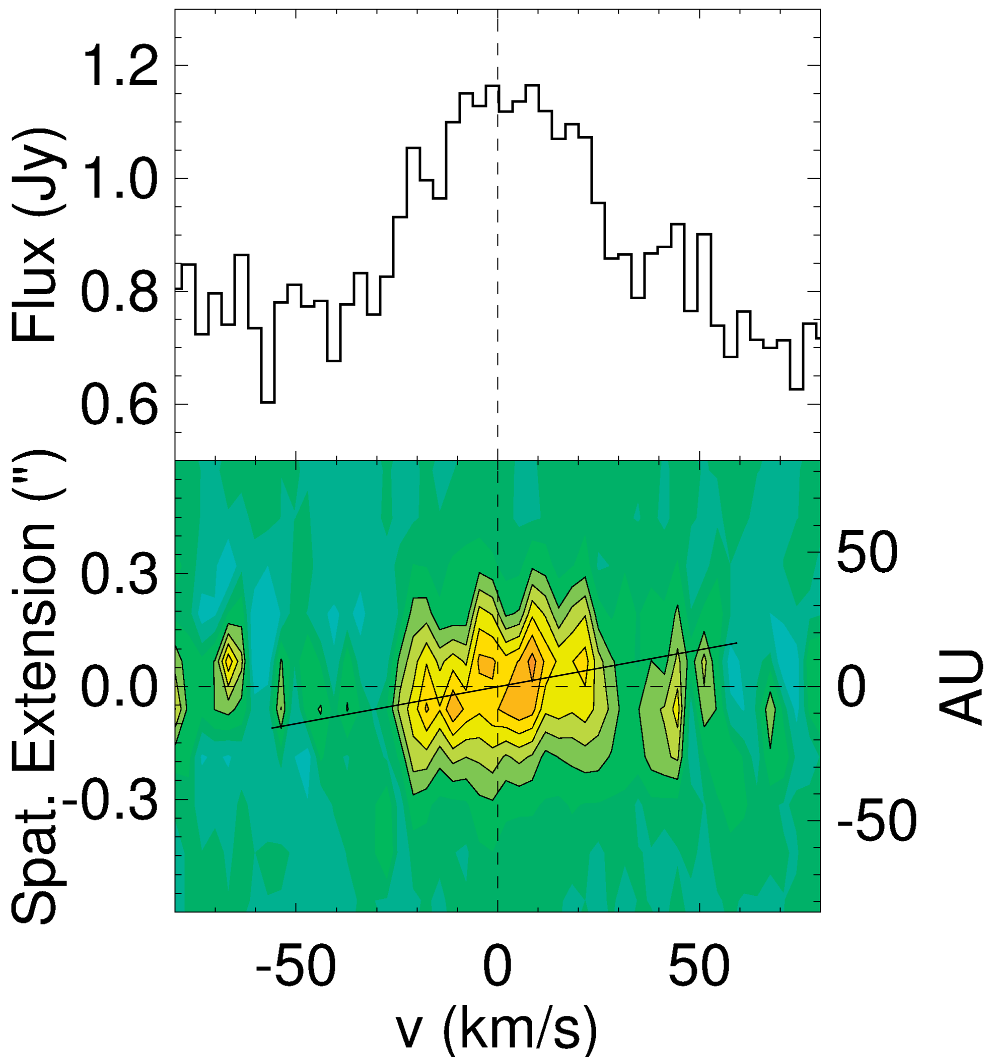
or a bi-polar jet?
(slope in *extended* PV; near-edge-on)

AA Tau



(Najita et al.2009)

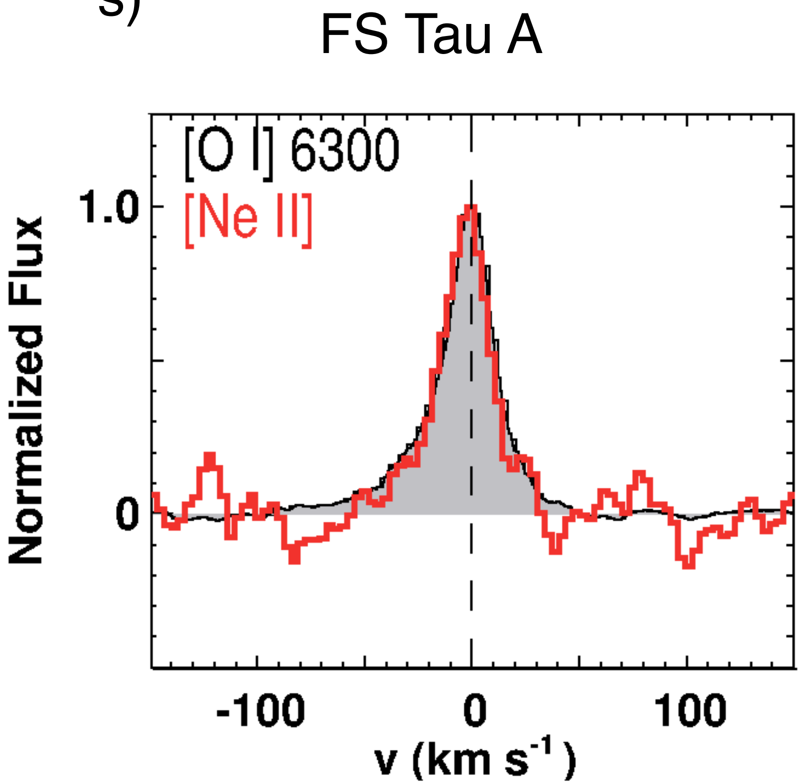
CoKu Tau 1

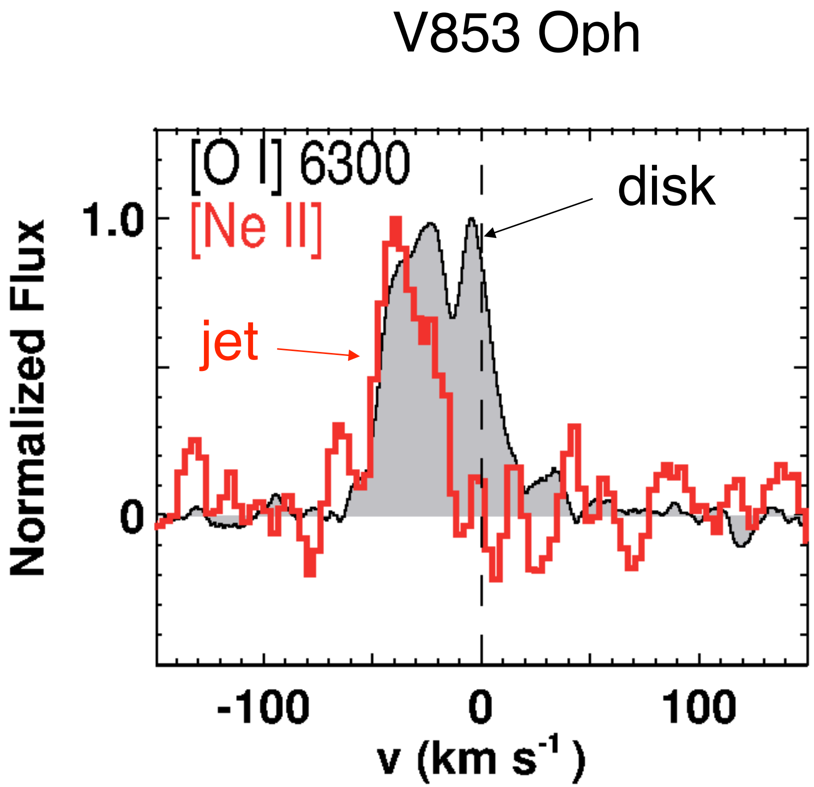


(Baldovin Saavedra et al. 2012)

[NeII] from a photoevaporating disk wind? (blue asymmetry)

or shocks in a bipolar jet? (>> 10 km/s)





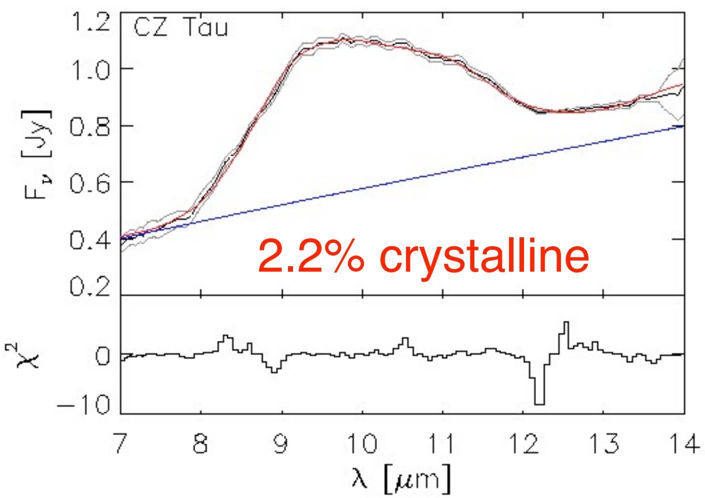
(VISIR, R ~ 30,000) (Baldovin Saavedra et al. 2012)

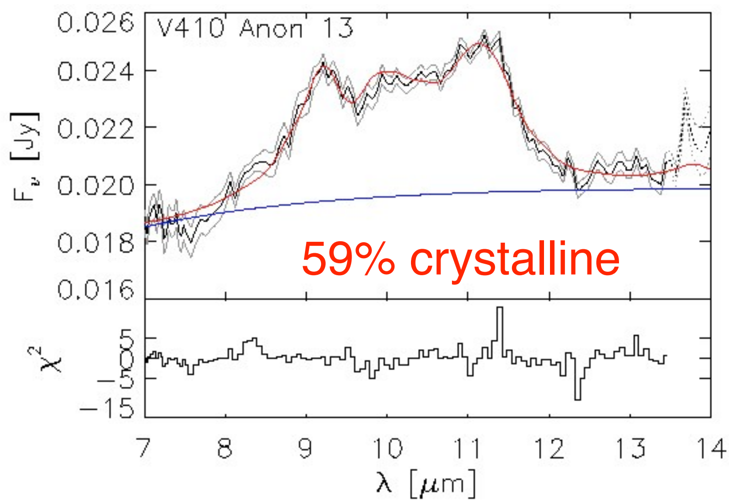
No definitive systematics yet.

E-ELT METIS: High R spectroscopy for disk/wind/jet identification
Direct imaging within 20 AU: location on disk or in jet

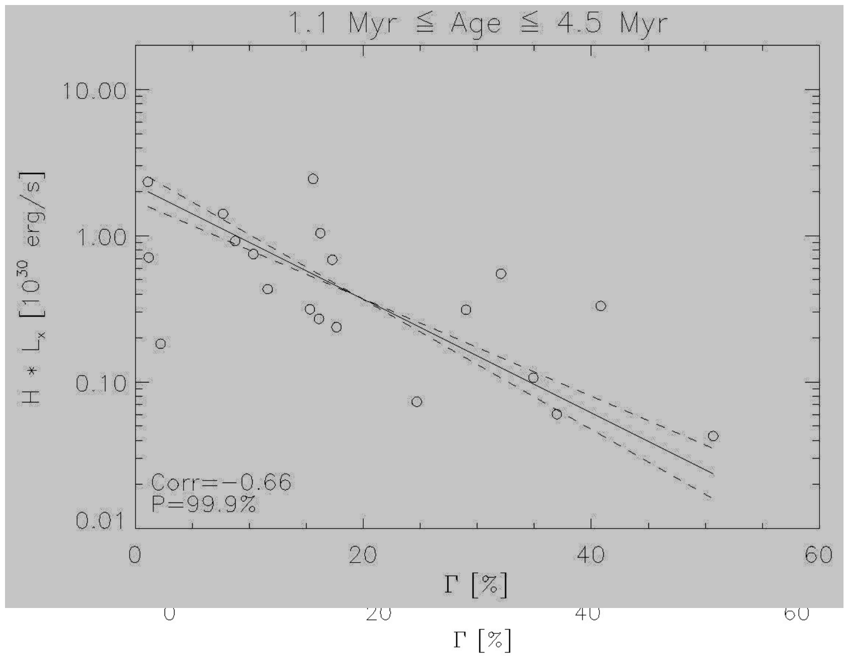
Crystalline and Amorphous Dust Grains

Amorphous/crystalline structure of circumstellar dust in T Tauri disks:





Anti-correlation between crystallinity
and stellar magnetic activity (X-rays).



Model: Stellar wind destroys lattice.
Annealing re-crystallizes -> equilibrium
(Glauser, Güdel et al. 2009)

ELT: crystallization fraction and gradients
as a function of disk radius:
physical causes of A ⟷ C?

Organics in Disks of T Tauri Stars

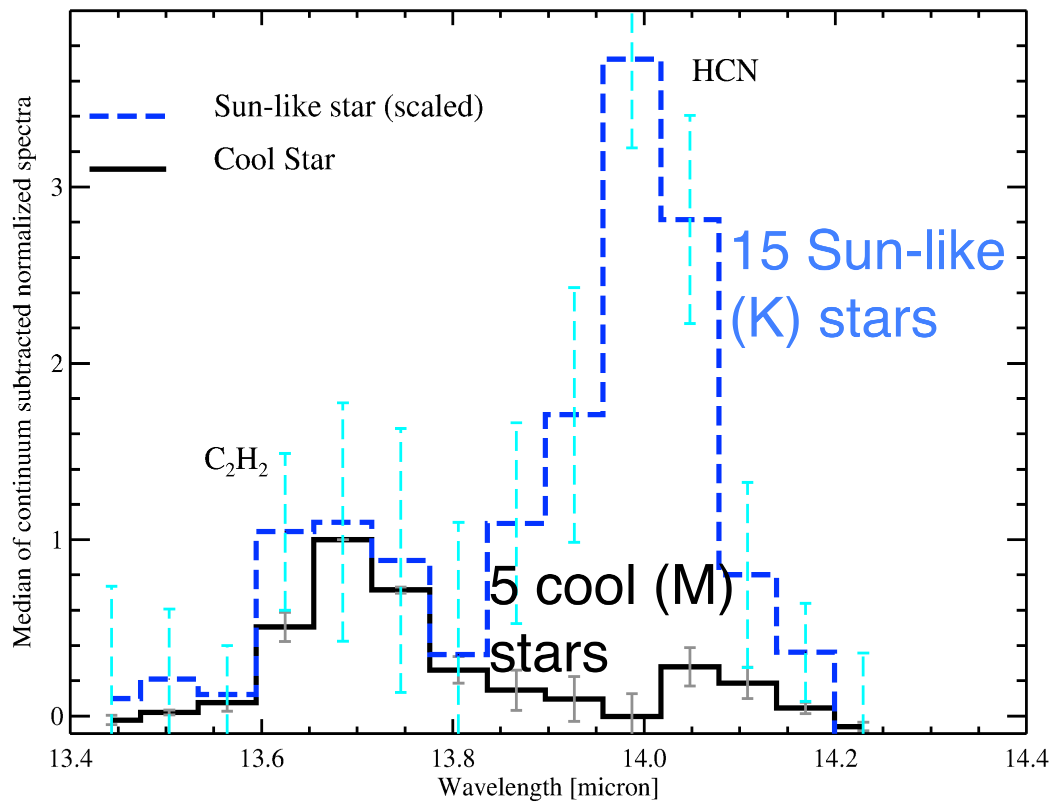
Synthesis of organic molecules in disks depends on central star

M dwarfs:
HCN underabundance

HCN synthesis from N after photodissociation of N_2
by stellar UV < 110 nm
(due to accretion)

accretion-related UV is much stronger in K stars than M.

median spectrum of two samples



(Pascucci et al. 2009)

ELT: * spatial dependence in disk, larger samples
* extension to other organic molecules
* implications for pre-biotic chemistry?

Fast Forward to 2022

ELT Sweet Spot

Massive star formation, Massive Clusters

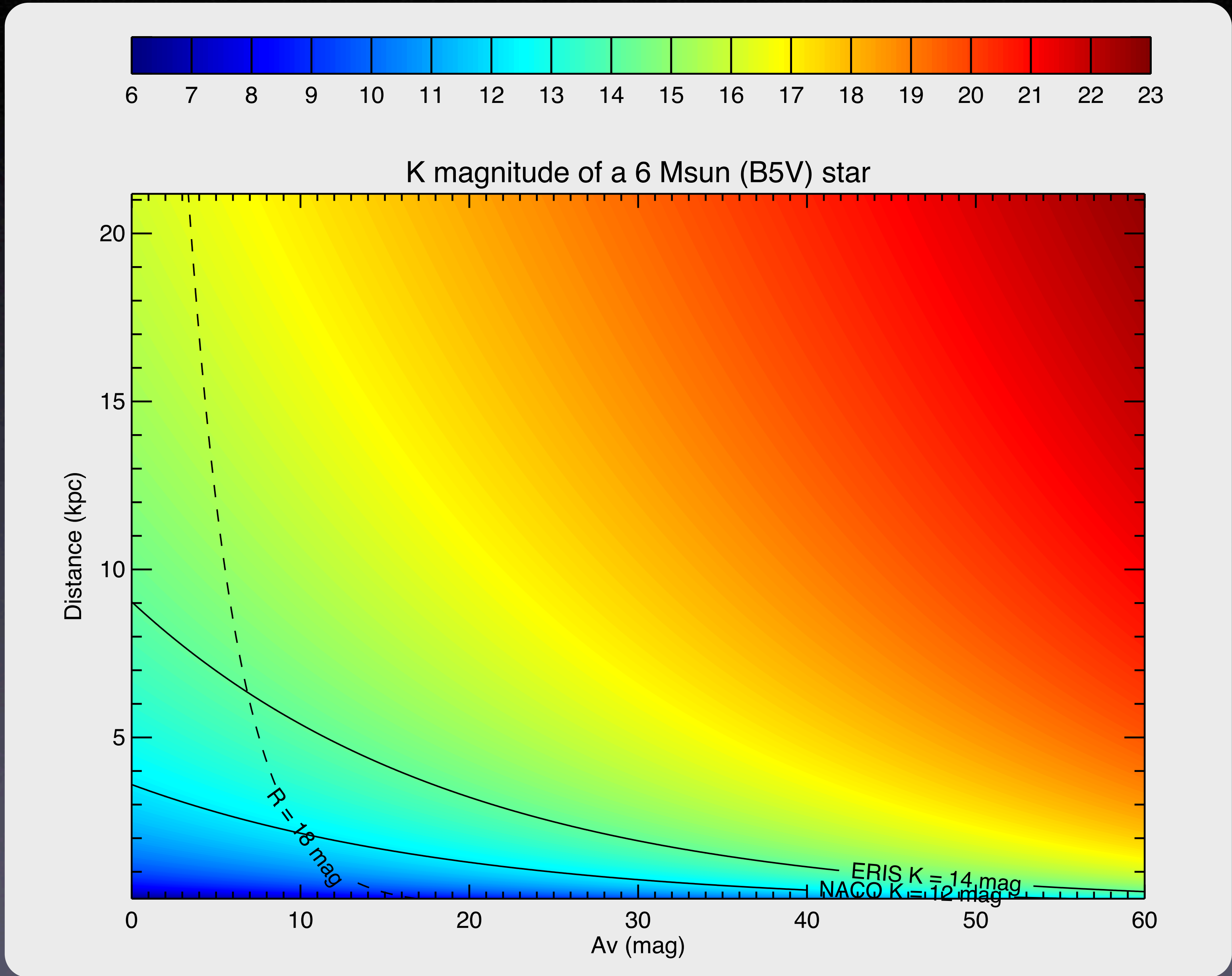
- IMF of massive clusters, to below Deuterium Burning Limit (up to the LMC). Proper motions/parallaxes. Young clusters in nearby galaxies.

See talks:
A. Stolte (massive clusters) and R. Oudmaijer (massive stars)

Posters on extra-galactic populations:
P022: S. Larsen, Detailed chemical abundance analysis of semi-resolved stellar populations
P030: G. Pugliese, High Dispersion Spectroscopy of GCs with a metallicity spread in M31
P012: L. Greggio, Studying the Stellar Metallicity Gradient in Virgo Ellipticals with E-ELT Photometry

The youngest massive stars

Ascenso 2013



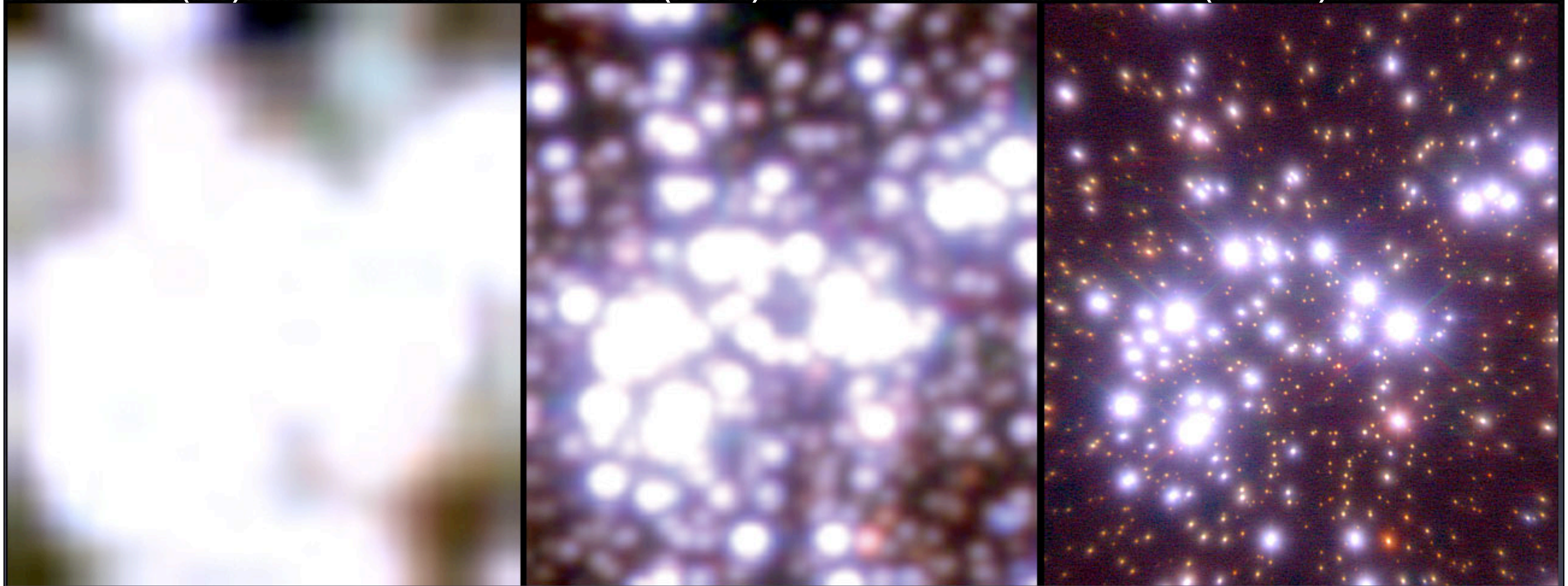
The youngest massive stars

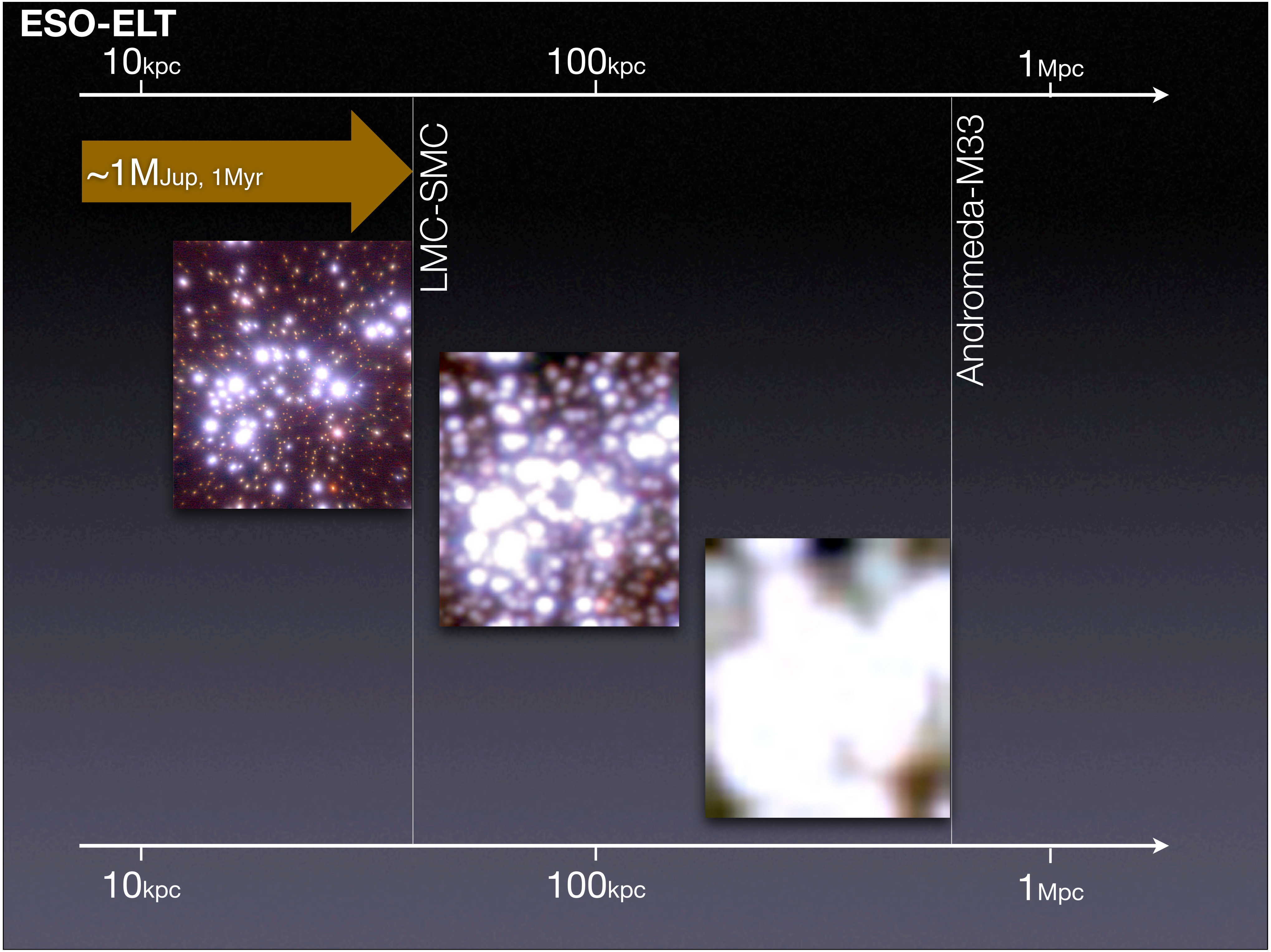
Alves, Ascenso, Meingast in prep

Core of Westerlund 2

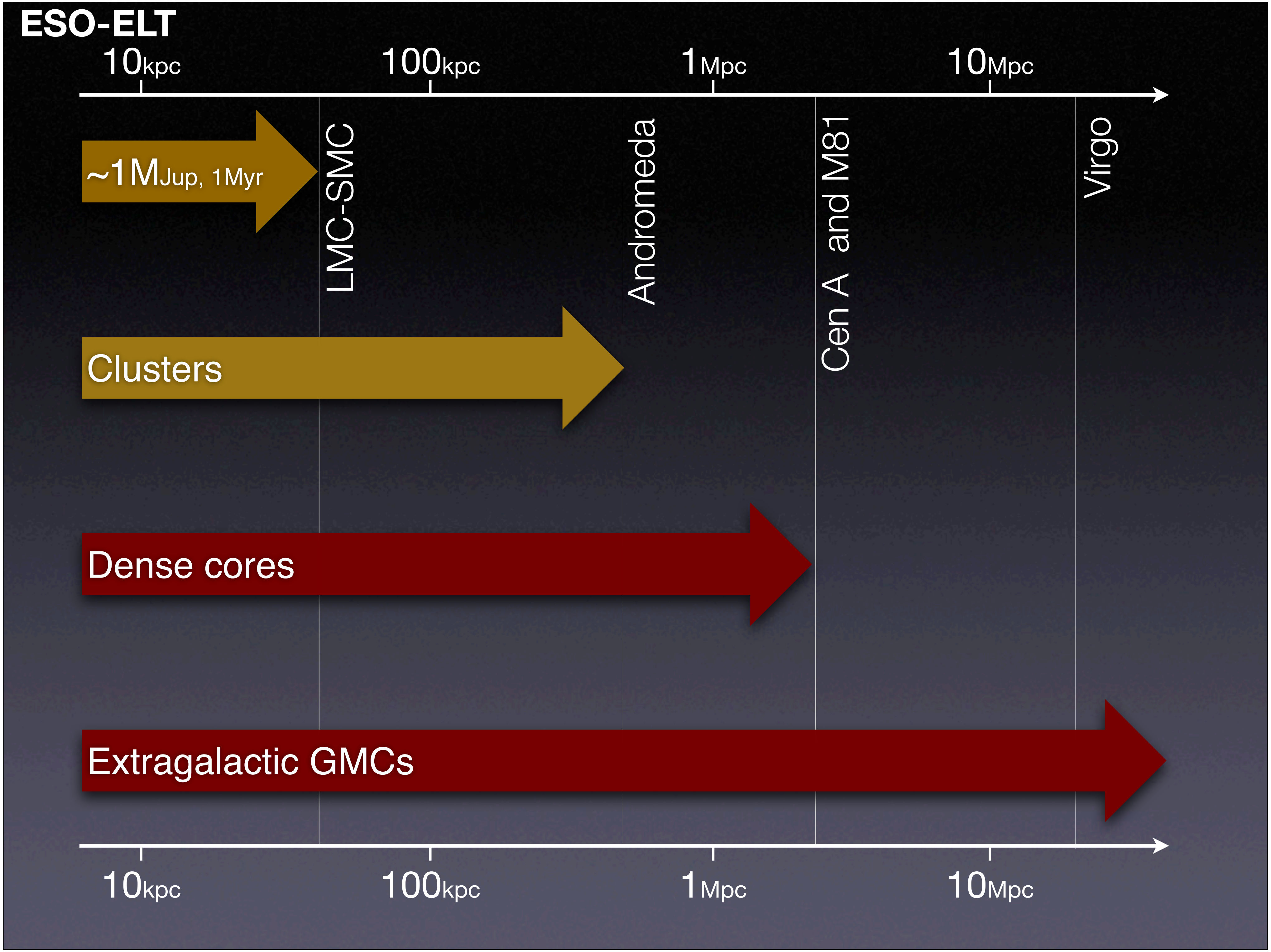
Ascenso et al. 2007

2MASS (2”) SOFI (0.6”) NACO (0.05”)

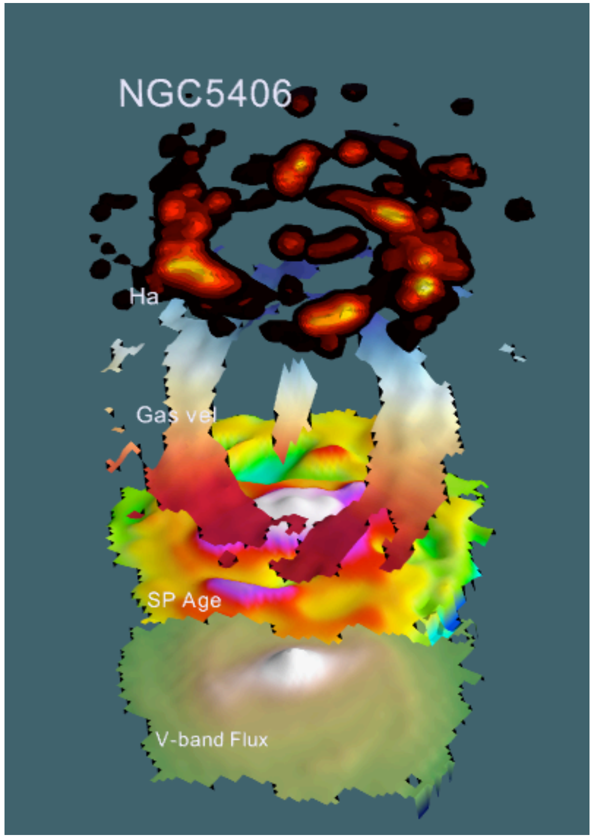




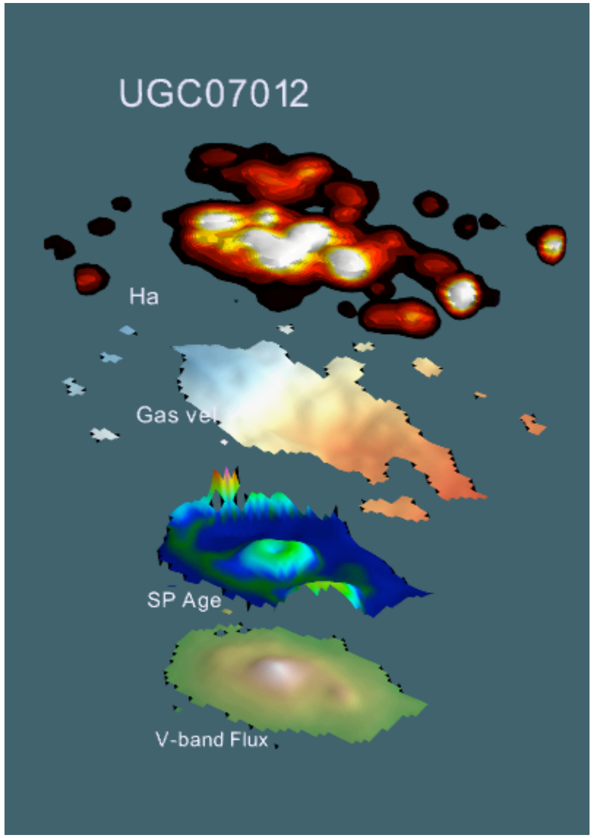
ESO-ELT
10kpc
100kpc
1Mpc
~1MJup, 1Myr
LMC-SMC
Andromeda-M33
10kpc
100kpc
1Mpc


ESO-ELT
10kpc
100kpc
1Mpc
10Mpc
~1MJup, 1Myr
LMC-SMC
Andromeda
Cen A and M81
Virgo
Clusters
Dense cores
Extragalactic GMCs
10kpc
100kpc
1Mpc
10Mpc

Interplay Kinematics & Star Formation at z~3



CALIFA
IFU survey
local galaxies
e.g. Sanchez+12



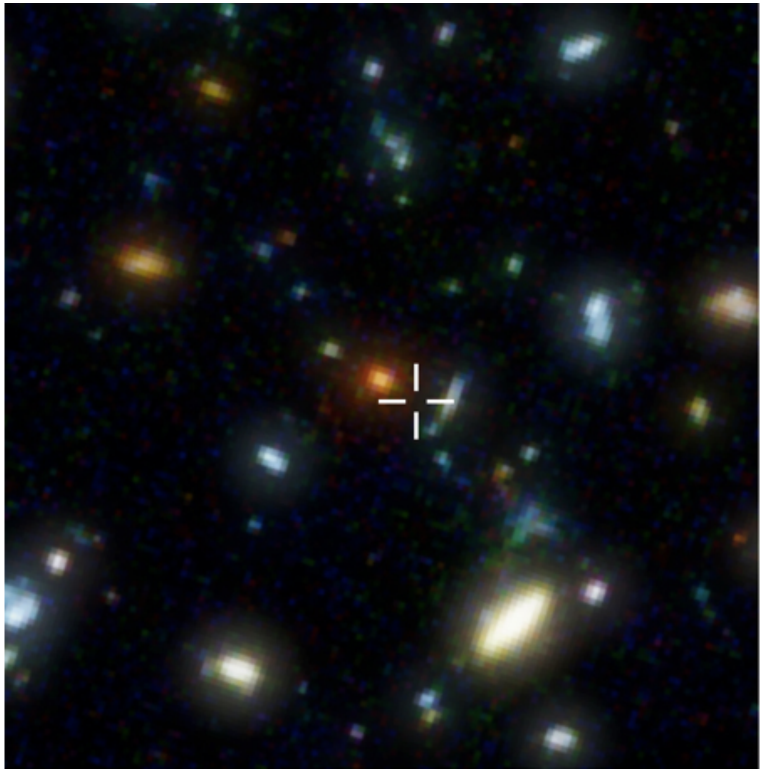
ELT IFU spectroscopy (e.g. MOSAIC) with MOAO (0.07”) resolves like CALIFA ~600pc at *z~3* (Hα in K-band)

What are the local and global conditions for SF at *z~3*?

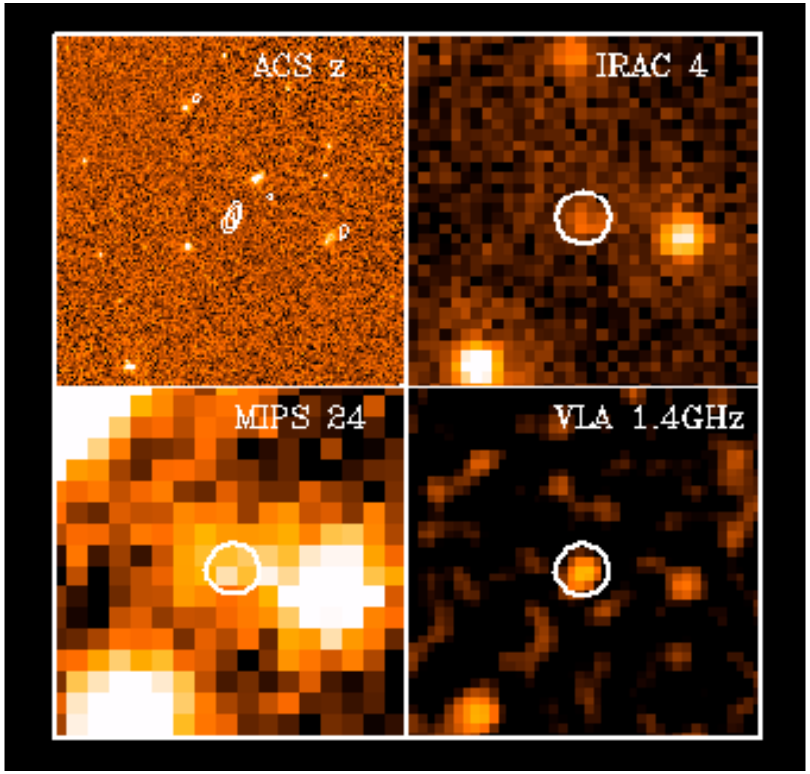
Is internal turbulence or inflow of gas main triggering agent?

Extragalactic ELT projects by Ziegler, Maier, Dannerbauer et al. (Vienna)

Extremely Dust Obscured High-z Starbursts



Walter+12, Nature



Dannerbauer+, 2008

MIR imaging & spectroscopy (METIS) of Hα, Paα, SiVI of optically faint galaxies to reveal SF, Stellar Populations, AGN

What is the composition, distribution, morphology of the stellar population?

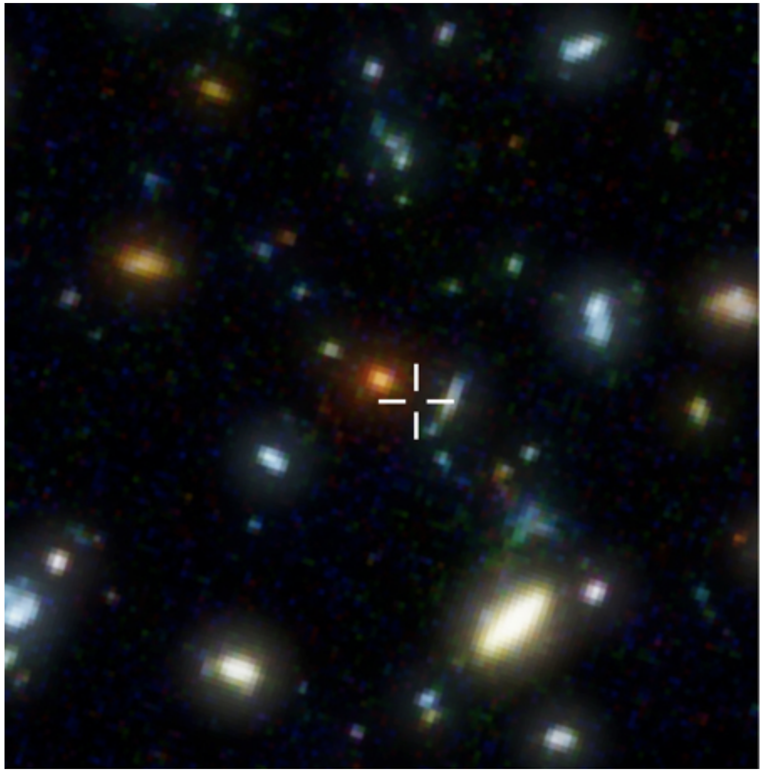
How are star-formation sites located compared to its fuel: molecular clouds?

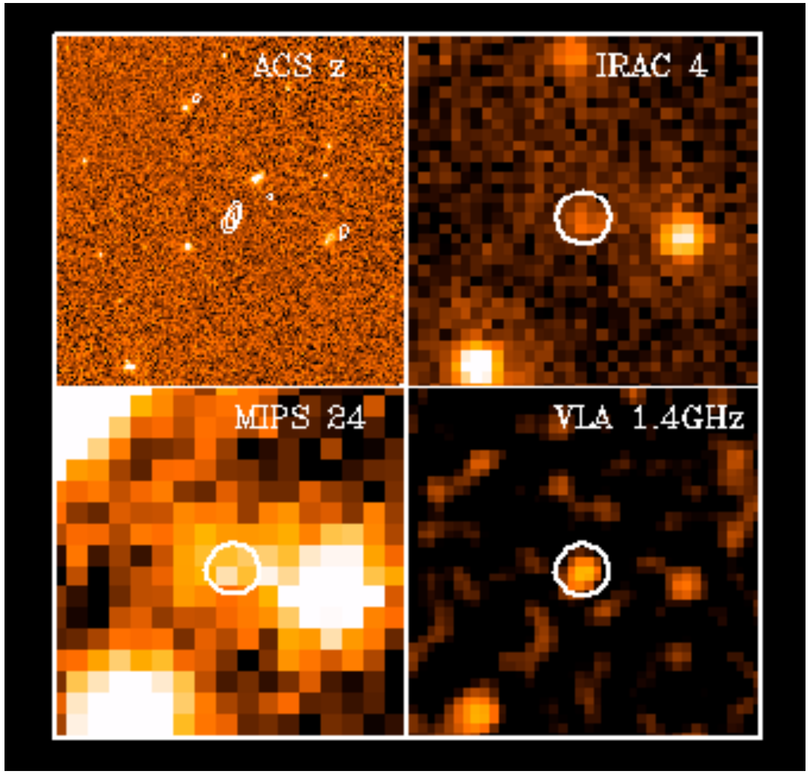
What is the fraction of their stellar mass to the total mass?

Extragalactic ELT projects by Ziegler, Maier, Dannerbauer et al. (Vienna)

Extremely Dust Obscured High-z Starbursts

Walter+12, Nature





Dannerbauer+, 2008

MIR imaging & spectroscopy (METIS) of Hα, Paα, SiVI of optically faint galaxies to reveal SF, Stellar Populations, AGN

Are their rest-frame optical+NIR SEDs different to extreme local ULIRGs? Which is the degree of obscuration?
What is powering source of IR luminosity: Starburst vs AGN?

Extragalactic ELT projects by Ziegler, Maier, Dannerbauer et al. (Vienna)

Conclusions

ELT resolution is absolutely critical to advance star formation cases in the next decade

Regarding local SF regions, the ELT will bring AU resolution to the study of individual objects, disks, proto-planets (even without EPICS).

Regarding the formation of clusters and massive stars, given that a statistical sample is needed, we will have to dig deep into the highly extincted plane of the Milky Way and the LMC/SMC with ELT.

Conclusions

one more thing:

expect the unexpected

(extra-solar planets was not on the VLT science case)