THE GAIA–ESO SURVEY: AGE AND GRAVITY SPREAD IN THE LAGOON NEBULA

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Astronomy & Astrophysics

The *Gaia*-ESO Survey: Age spread in the star forming region NGC 6530 from the HR diagram and gravity indicators⋆,⋆⋆

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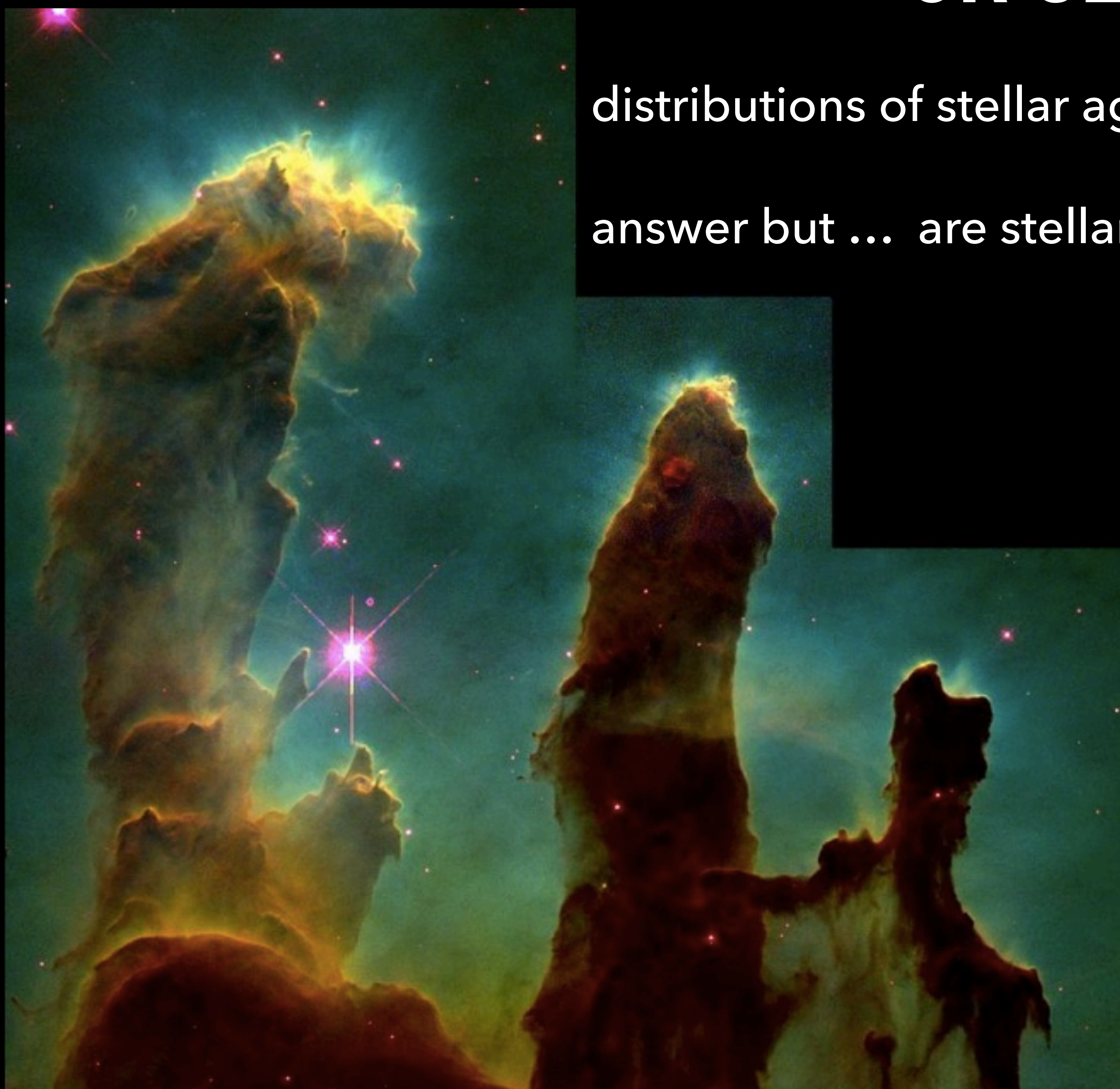
image:VPHAS+ Hα
(Drew+14)

Leeds, 18-21 June, 2019

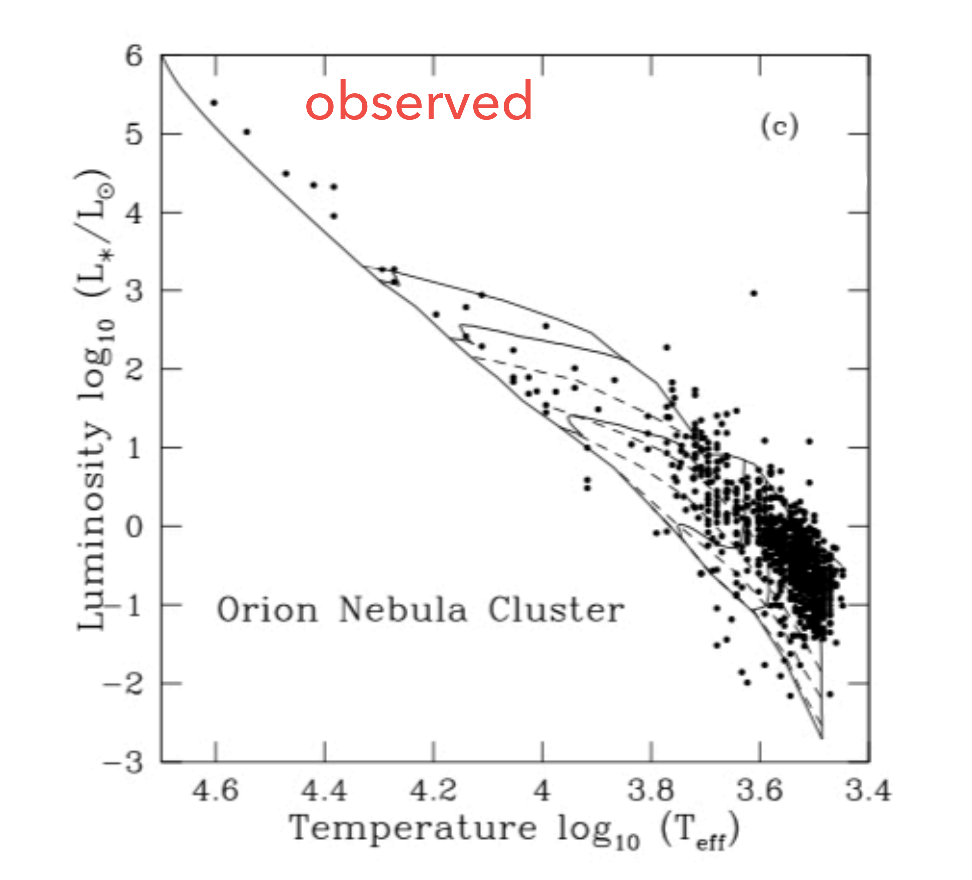
QUESTION

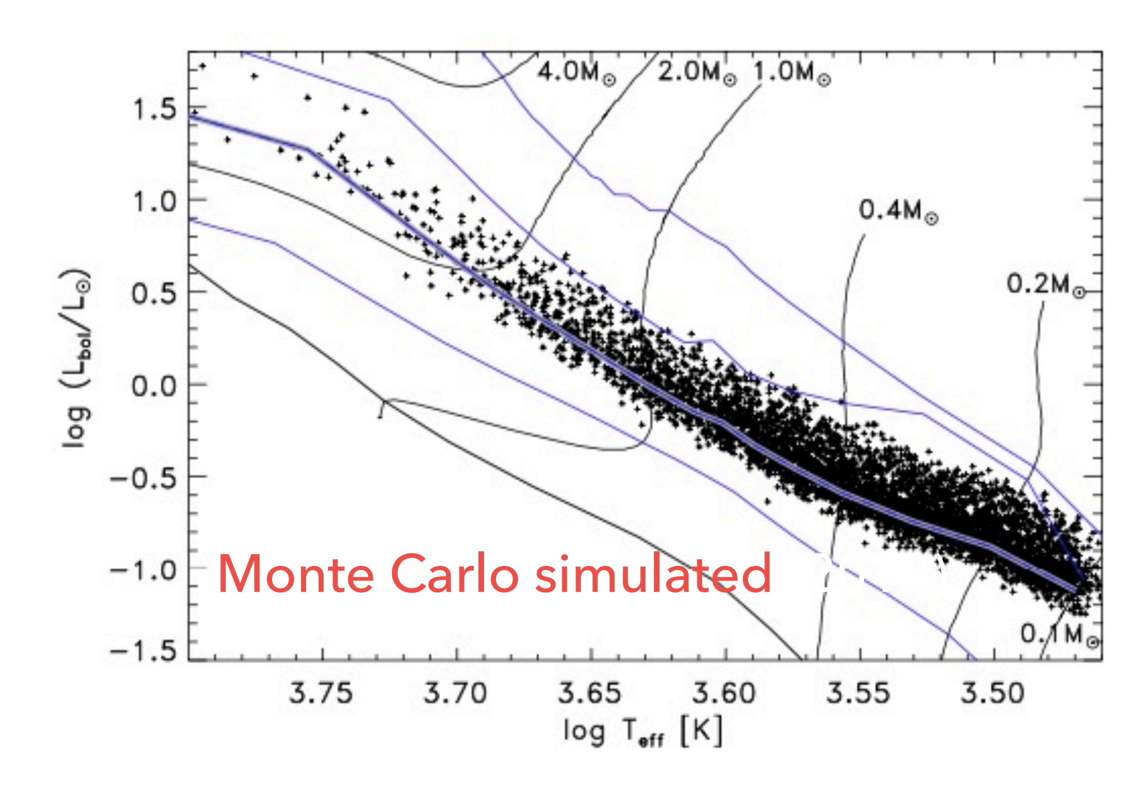
IS STAR FORMATION RAPID AND DYNAMIC OR SLOW AND QUASI STATIC?

distributions of stellar ages in young stellar clusters give us an answer but … are stellar ages accurate and precise enough?



WHAT THE LUMINOSITY SPREAD IN THE HR DIAGRAM TELLS US?





- Palla & Stahler (2000): accelerating SF
- Hartmann (2001, 2003): uncertainties & measurement errors
- Reggiani+11: little (1.5-3.5Myr) age spread in ONC
- Kudryavtseva+12: instantaneous SF in NGC3603
- Correnti12: slow SF in NGC 3603
- Preibisch (2012): uncertainties, misinterpretation of accelerating SF, projection effects
- Beccari+17: multiple sequence in the color-magnitudo diagram in ONC

BASIC INFORMATION

NGC 6530 IN THE LAGOON

distance: 1250 pc (Prisinzano+05)
confirmed by Gaia

population: >2000 members (Damiani+19)

literature age: 1-10 Myr

reddening: E(B-V)=0.27

- ✓ cluster associated to the Lagoon Nebula (M8)
- ✓ evidence of asymmetric expansion: ionized and neutral gas shells related to NGC6530 and OB stars (Damiani+18, Wright+19)
- ✓ hints of triggered star formation (SF) in molecular gas compressed by ionization front (Tothill+08)

DATA

Gaia-ESO Survey (GES)

(Gilmore et al. 2012, Randich et al. 2017)
VLT/FLAMES spectra for **2077 targets** in the NGC6530 field

iDR5 EW(Li) - FWZI (Hα)
radial and rotational velocities
T_{eff} - γ gravity index (Damiani+14)

Other data

- opt. photometry ESO-WFI (V, I) (Prisinzano+05) & VPHAS+ (Kalari+15)
- IR photometry from 2MASS and Spitzer
- Chandra ACIS-I X-ray detections
- Gaia DR2 kinematics and parallaxes

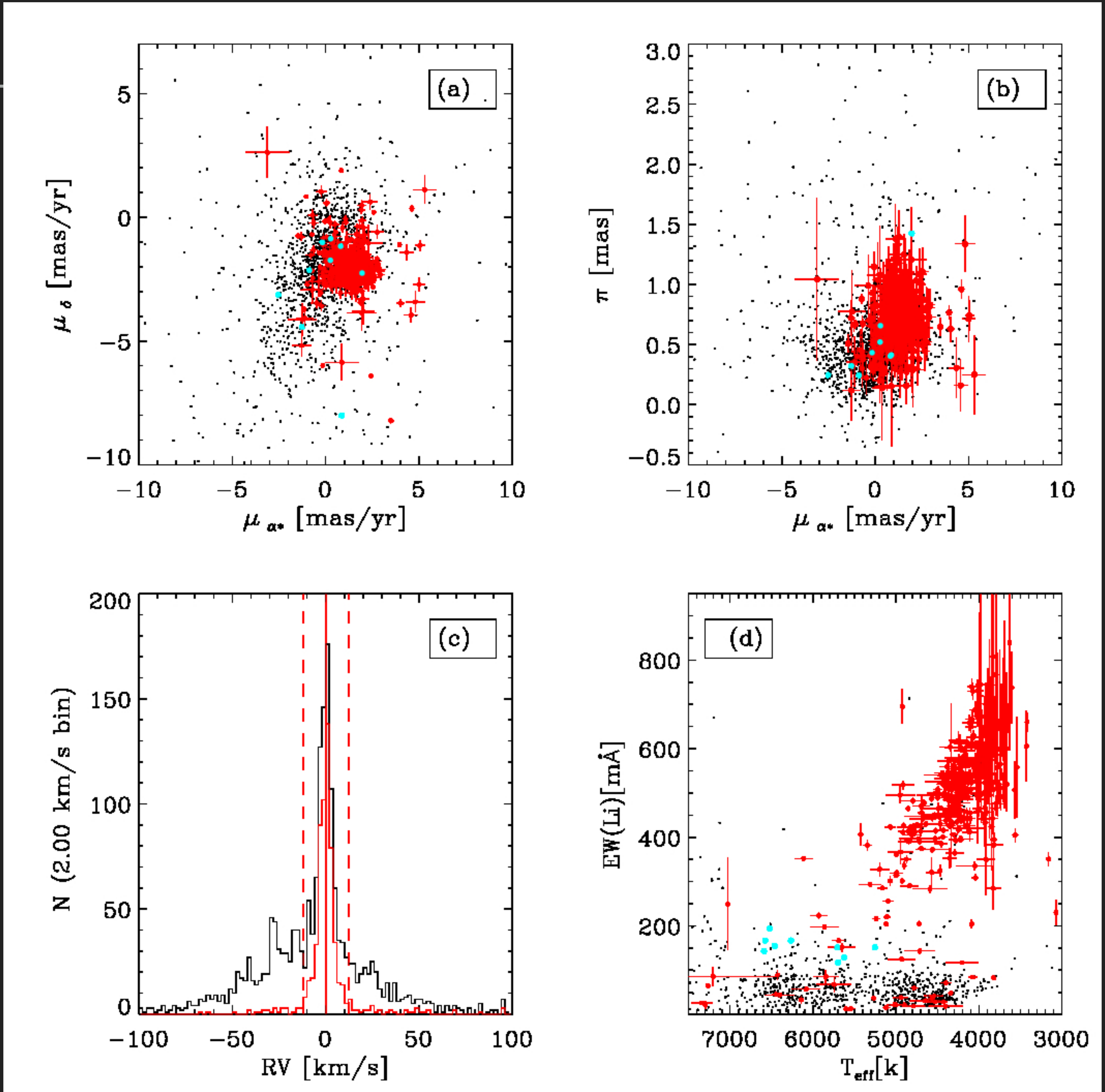
CLUSTER MEMBERSHIP

- Radial Velocities
- EW(Li)
- FWZI (Hα)
- r-Hα colors
- γ index
- Gaia proper motions
- Gaia parallaxes
- NIR excess

(Kumar &Anandarao (2010
Feigelson+2013
Broos+13)

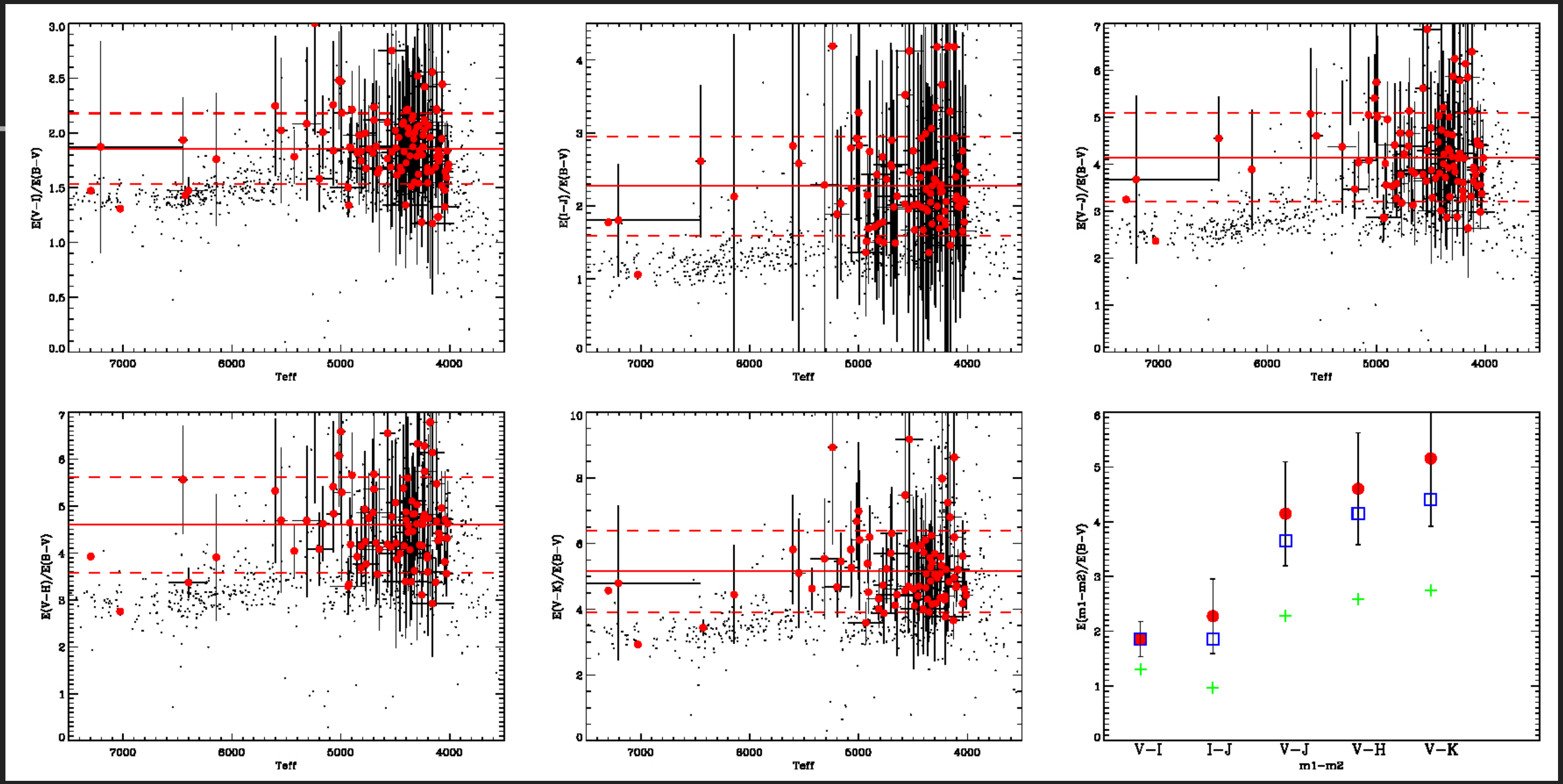
inclusive approach
652 members confirmed
9 probabile members

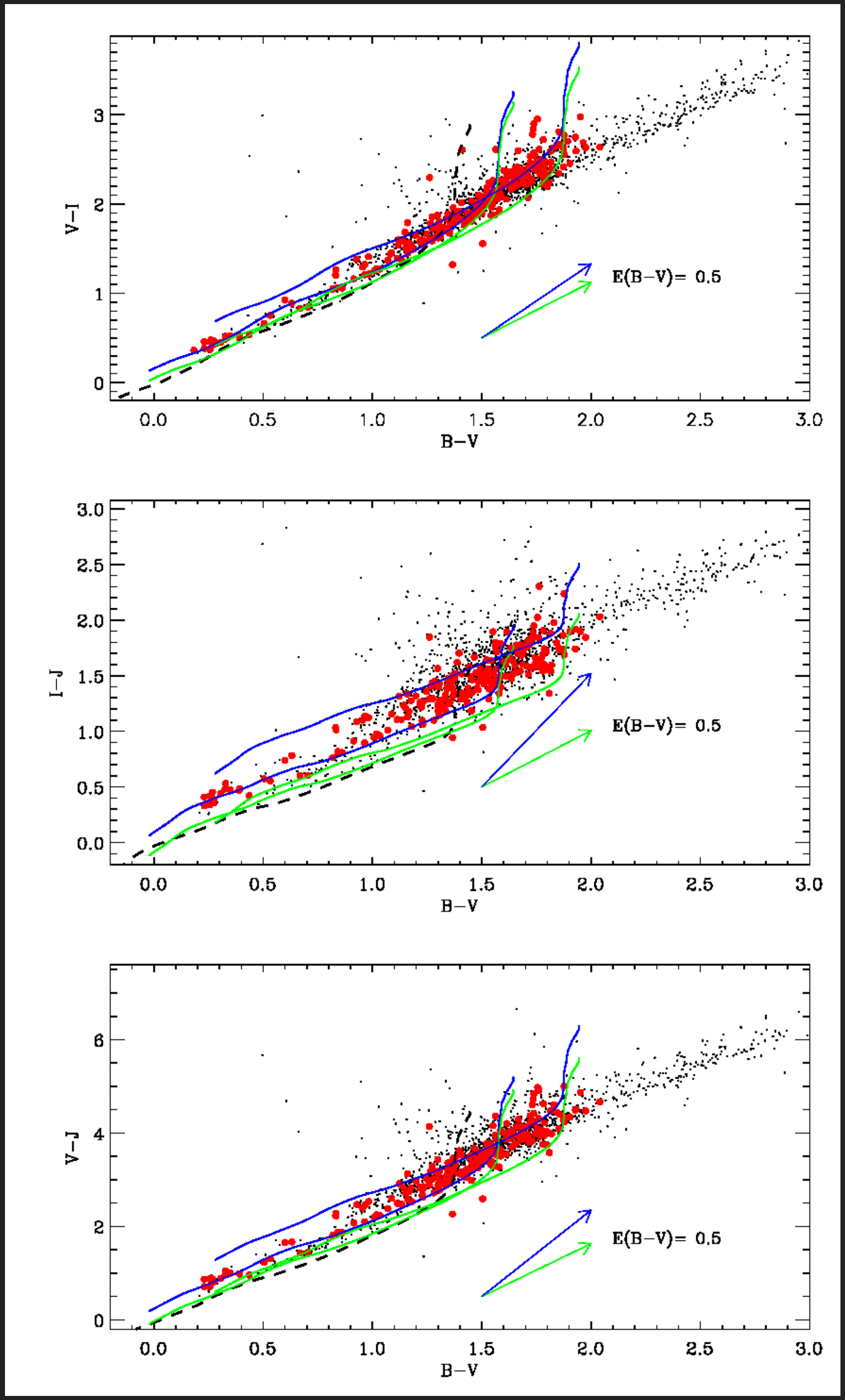
new definition:
333 CTTSe:
accretors OR disk
328 WTTSp:
no accretion nor disk



REDDENING LAW

TOWARDS NGC6530





proven to be non-standard using independently spectroscopy and photometry

compatible with R=5.0

INTRINSIC COLOR-MAGNITUDE AND HR DIAGRAMS FOR WTTSp & CTTSe

-**Ages:** Pisa isochrone

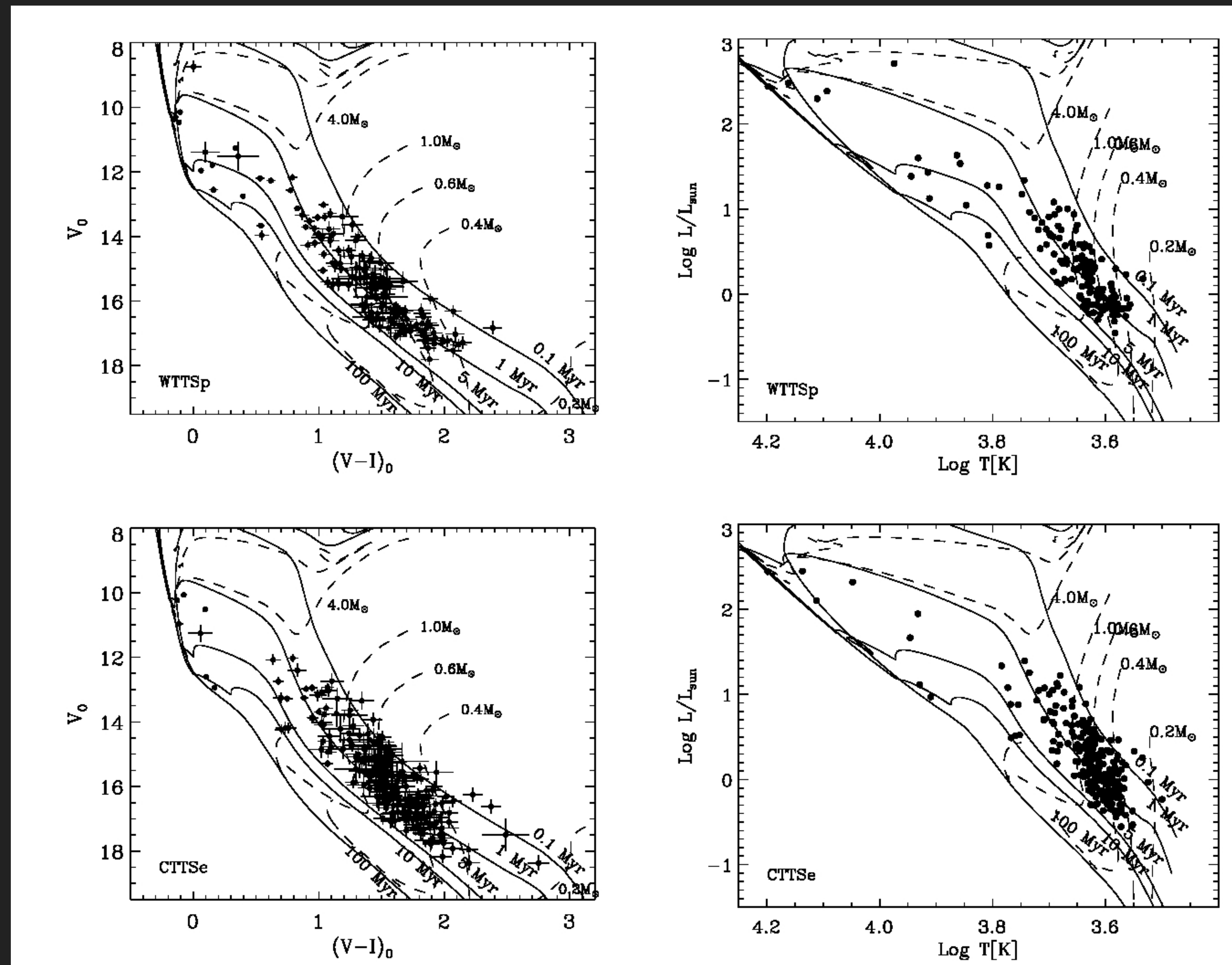
bilinear interpolation

(Tognelli+11, Randich+17)

ages for

147 WTTSp & 240 CTTSe

HR diagram of WTTSp is not affected by variability accretion



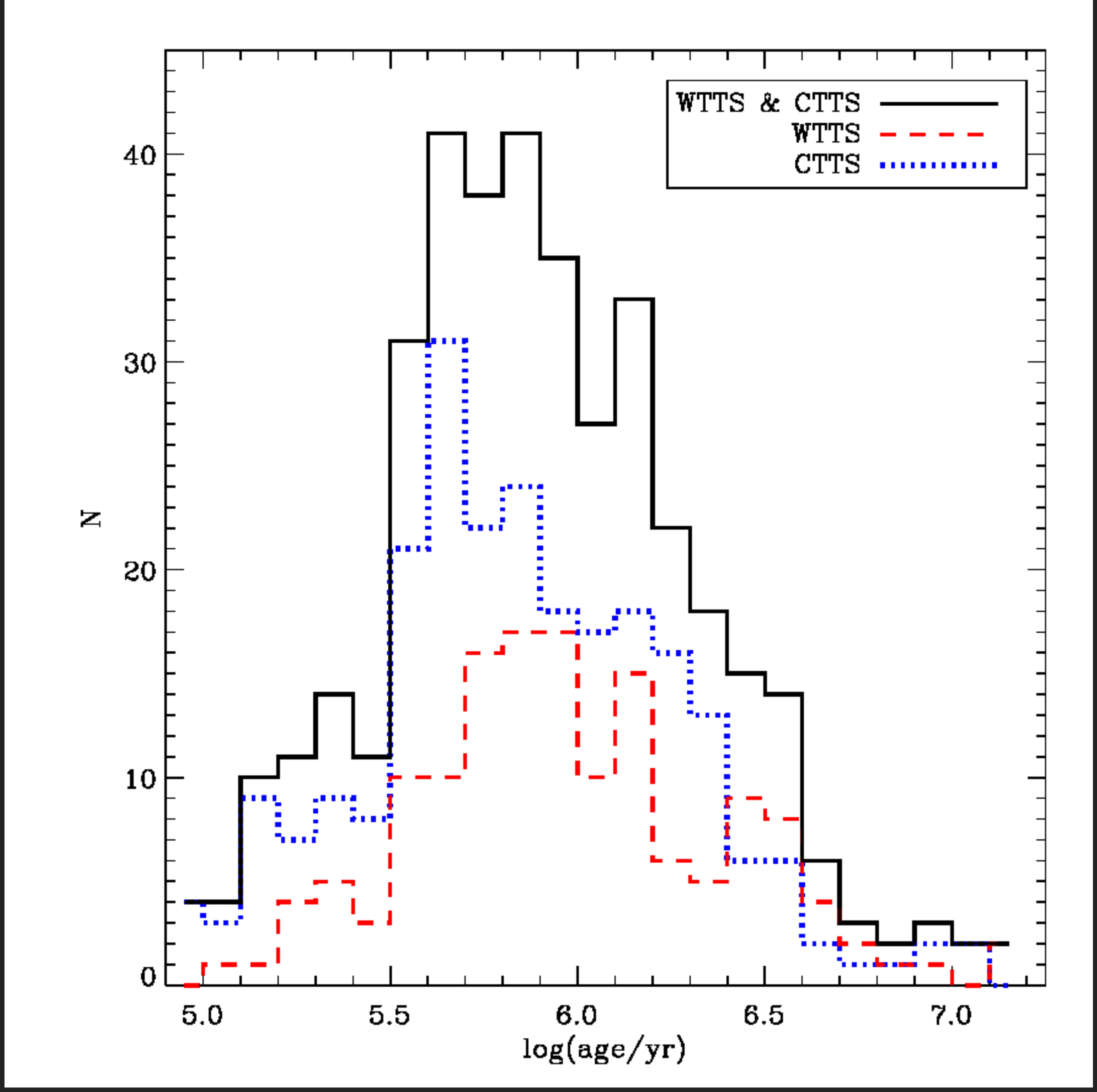
- Overall **similar luminosity spread** in both CTTSe and WTTSp

LOG-NORMAL AGE DISTRIBUTION

mean log age [dex]	dispersion [dex]	sample
5.84	0.36	all members
5.92	0.35	WTTSp
5.81	0.37	CTTSe

in the low mass range

(T_{eff}<5500 K $0.24 < M/M_{\odot} < 2.80$)



- no substantial difference in age spread between WTTSp and CTTSe
- but … is this age spread due to errors?

ERRORS ON STELLAR AGES

$\sigma(V\text{-}I)_0$ depends on T_{eff} errors

$\sigma(V)_0$ depends on - photometric errors on V and I

- error on spectroscopic T_{eff}

- ph. variability: extinction ★ - included in A(V)

accretion bursts ▲ (Gullbring+98, Baraffe+09)

hot spots ▲ (Cody+14, Stauffer+16)

cool spots ● (Cody+14, Stauffer+16)

- distance error: systematic - does not affect the spread
random component is negligible

- binarity: systematic bias mimicking younger ages

★ all targets

▲ only CTTSe

● only WTTSp

MONTECARLO SIMULATIONS FOR EACH STAR

- three sets of 1000 values of T_{eff}, V and I, normally distributed, with dispersions equal to σT_{eff}, σV and σI of the star
- one set of 1000 ΔI values with mean $\langle \Delta I \rangle = 0.11$ and $\sigma(\Delta I) = 0.03$ (Henderson & Stassun, 2012)
- one set of 1000 dI/dV values with mean $\langle dI/dV \rangle = 0.67$ and $\sigma(dI/dV) = 0.13$ (Herbst+94)

added the simulated errors to V_0 and $(V-I)_0$ and derived

1000 values of stellar ages for each star –> 0.09 dex (random error)

binarity: 1000 $\Delta \log L$ values between 0.05 and 0.3 (Hartmann, 2001) –>

dV added to a coeval 1Myr population –> 0.10 dex (systematic error)

TOTAL ISOCHRONAL AGE UNCERTAINTY vs. OBSERVED SPREAD

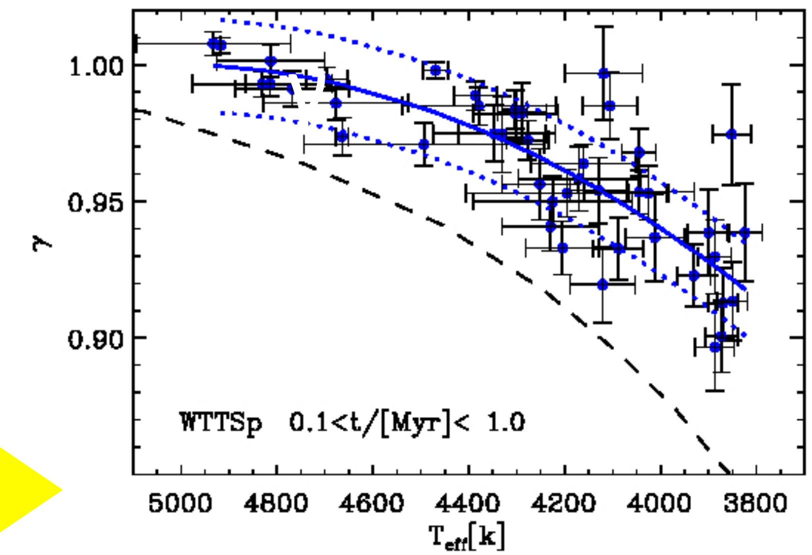
0.13 dex < 0.36 dex

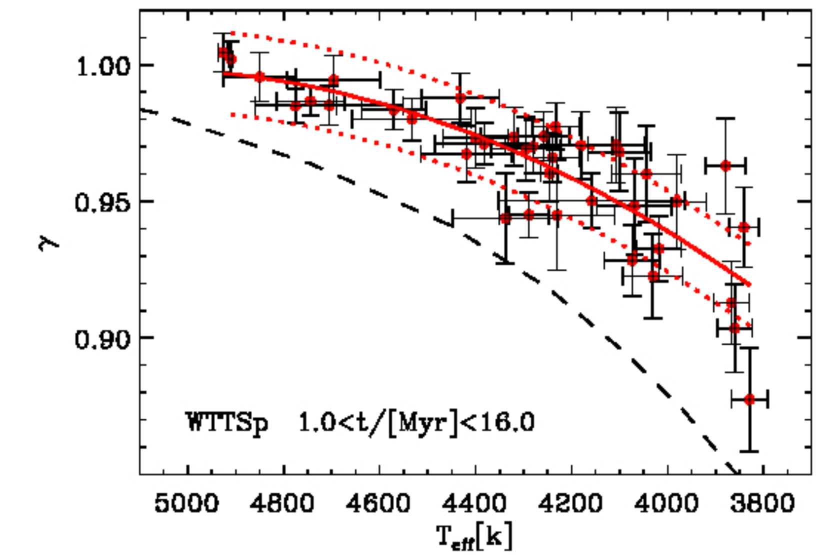
EVIDENCE OF A SMALL BUT REAL AGE SPREAD!

γ INDEX

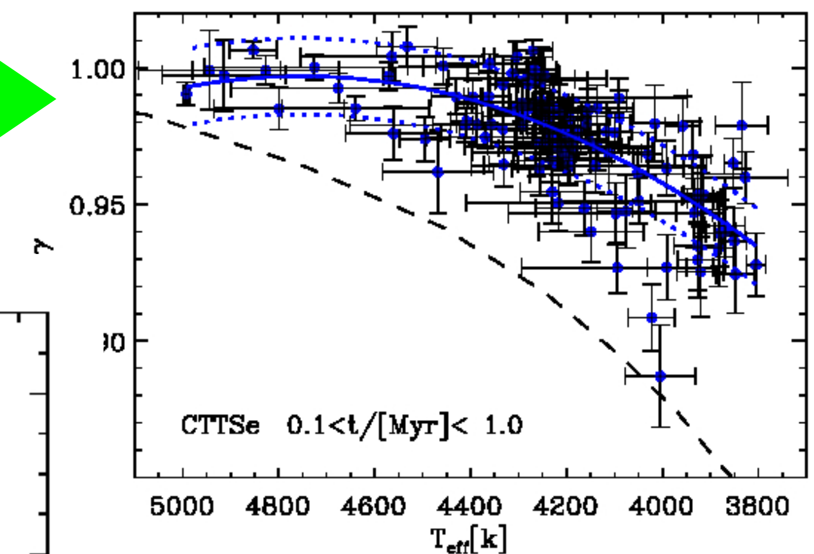
SPECTROSCOPIC GRAVITY INDICATOR

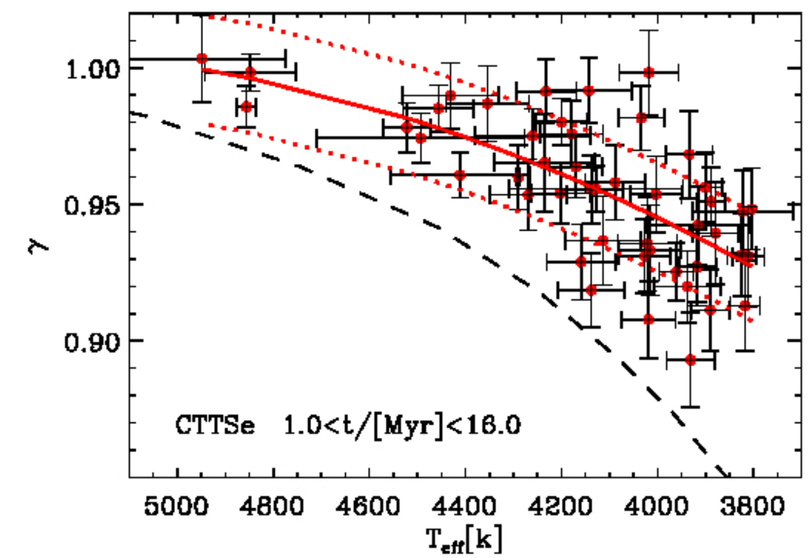
WTTSp

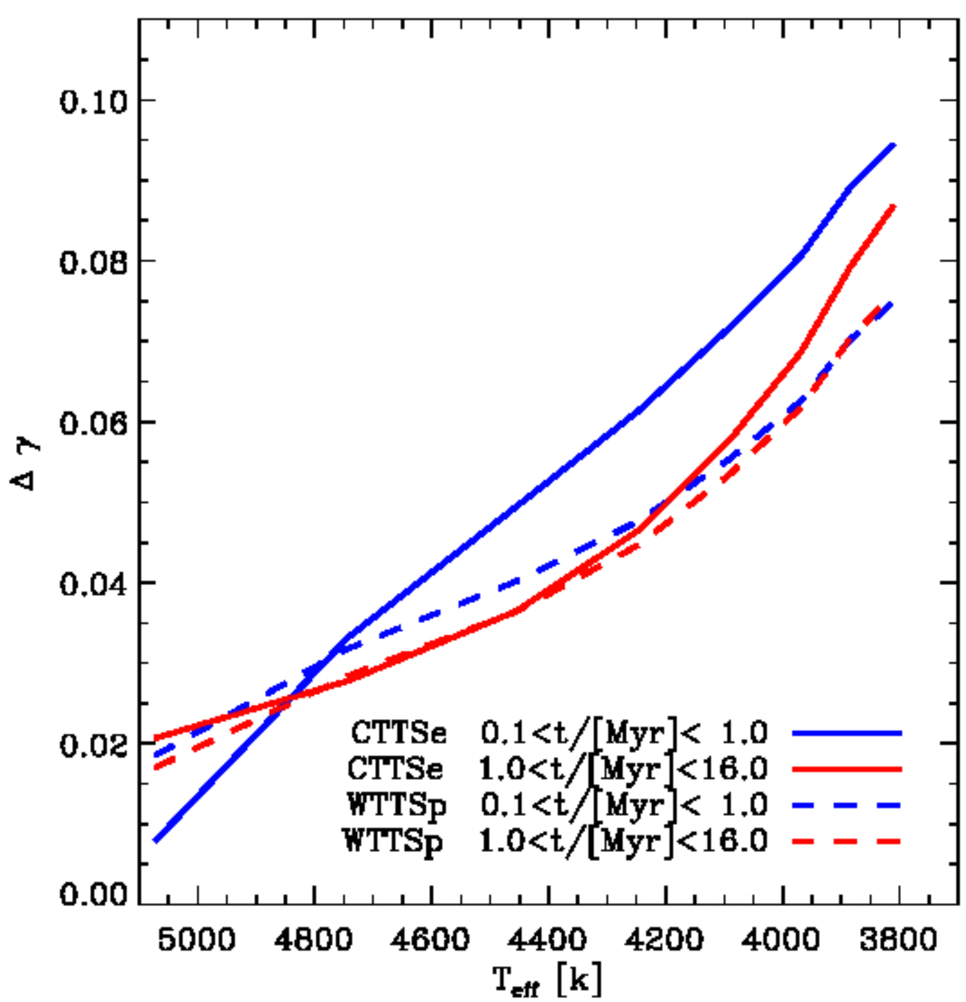




CTTSe







youngest

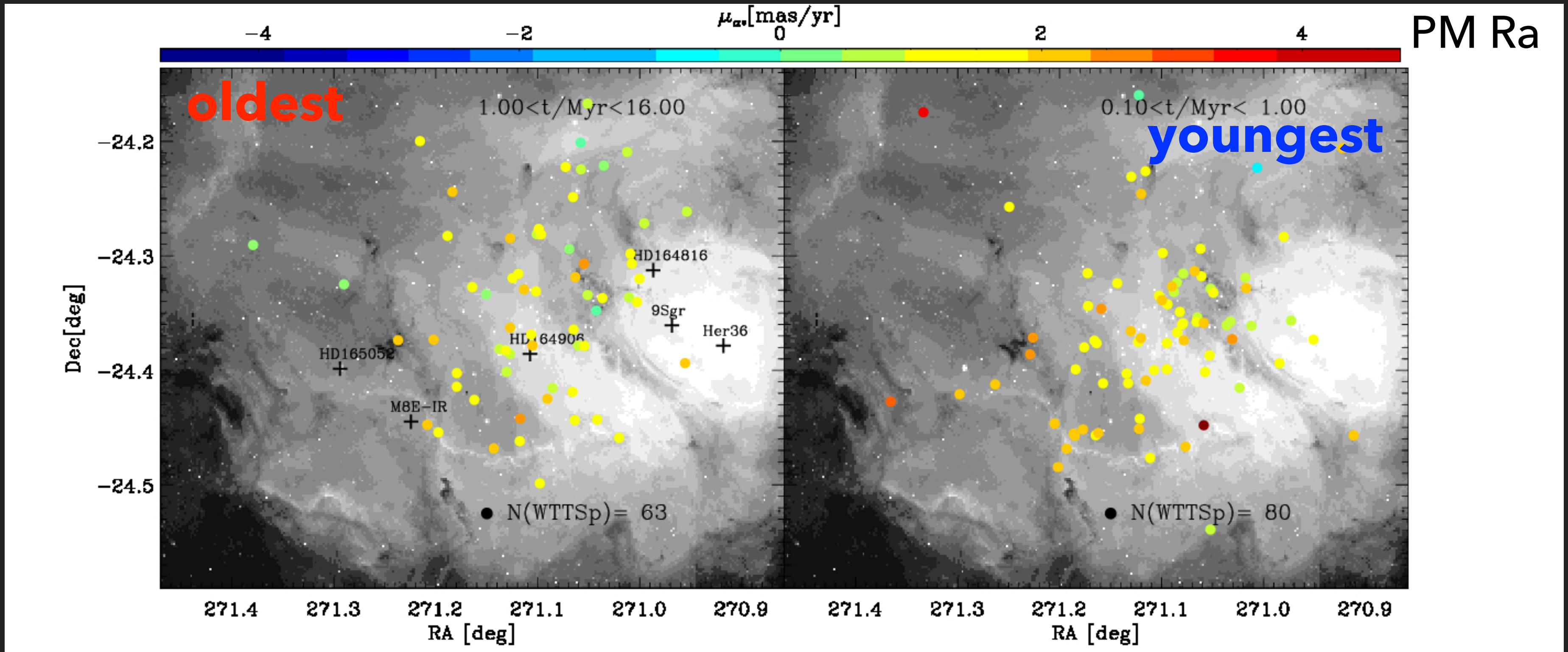
oldest

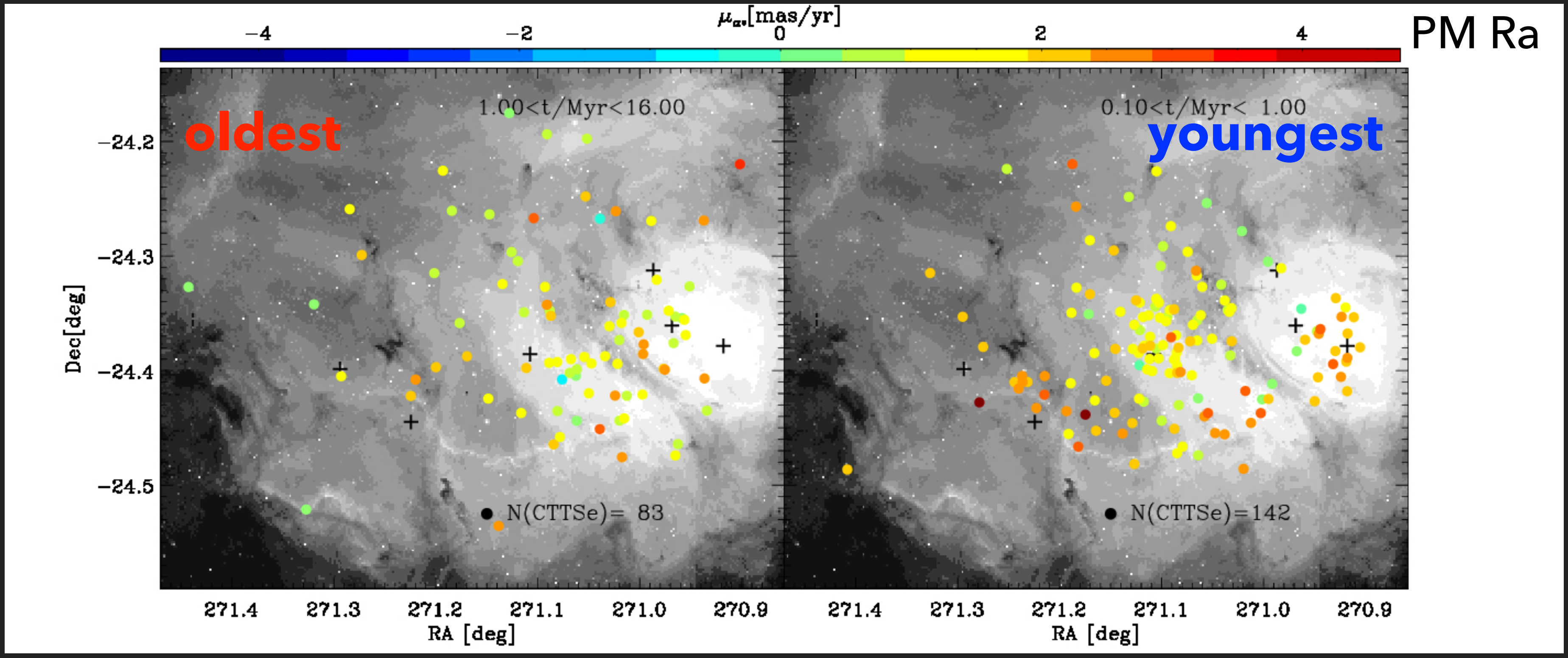
EVIDENCE OF GRAVITY SPREAD!

SPATIAL DISTRIBUTIONS

YOUNGEST CTTSe vs. OLDEST CTTSe and WTTSp

- youngest CTTSe: two radial concentrations (NGC6530 & 9Sgr/Her36)
- youngest CTTSe: bow-shape from Her36 to M8E-IR
- other members: sparse distribution
- youngest CTTSe: proper motion pattern





CONCLUSIONS

- observed age spread is larger than age error spread, evidence of a real age spread
- spectroscopic gravity spread supporting age spread
- peculiar spatial distribution supporting age spread
- kinematics difference evidence of two different SF events triggered and pushed by two different ionizing fronts. Consistent with previous scenarios suggested in the literature