The First Young Moving Groups*

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TW Hya: a T Tauri star far from any dark cloud

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Henize (1976), Herbig (1978), and Rucinski & Krautter (1983) share credit for putting this seminal nearby, young star/disk system “on the map”
“Isolated T Tauri stars”

• de la Reza et al. (1989, ApJL) and Gregorio-Hetem et al. (1992 AJ), combining IRAS excesses w/ Li measurements, identify a handful of young stars in the general vicinity of TW Hya
  – Are these 5 stars runaways from some cloud, or were they formed in situ from a low-mass cloud?
  – How old are they?
  – Are they nearby, as suggested by their high galactic latitudes?
The identification of the TW Hya Association: The “nearest [known] region of recent star formation”

• RASS X-ray data demonstrates these 5 stars are indeed young & nearby (Kastner et al. 1997, Science)
  – Evidence that all 5 are near peak $L_{X}/L_{bol}$ for K&M stars
    • => not as young as cloud-embedded TTS
    • yet have strong Li
  – => age constrained at ~10-20 Myr

• D estimates then follow
  – all 5 are all ~50 pc distant
  – Hipparcos confirms D’s of ~50 pc to TW Hya & HD 98800

• Over the next 10+ years, the candidate membership of the TWA would increase to >30 stars, and age estimates would converge on ~8 Myr...

From Kastner et al. (1997)
...while TW Hya has become the “Crab Nebula”* of late-stage pre-MS accretion and protoplanetary disk evolution studies

*w/ apologies/thanks to David Wilner

Left: molecular line spectrum of TW Hya, from Kastner et al. (1997)
Above: Chandra X-ray spectrum, from Kastner et al. (2002)

Left panel: HST imaging of TW Hya disk in scattered light (Weinberger et al. 2001); remaining 3 panels: ALMA & SMA mm-wave imaging (Qi et al. 2013)
The “young association” link between HR 4796A and β Pic

- Jura et al. (1998 ApJ): large IR-excess A stars HR 4796A, β Pic, and 49 Cet are all underluminous for their colors ($T_{\text{eff}}$’s)
  - Stauffer et al (1995) had previously determined an age of 8 +/- 2 Myr for HR 4796A from isochronal age of its M-type comoving companion
  - Jura et al.: HR 4796AB might be part of the TWA
    - later confirmed by Webb et al. (1999)

- Implies that β Pic & 49 Cet are also ‘young’ (Jura et al. 1998)...do they also have comoving, low-mass “friends”? 
The ID of the βPMG

  - Labeled the “βPMG” even though only 4 stars survive after ByN et al’s scrutiny of space motions & age diagnostics
  - Isochronal age: 20 +/- 10 Myr
- Wider availability and application of space velocities leads to ID of 17 more βPMG members (Zuckerman et al 2001)
  - “comoving, youthful group [that is] closest to Earth”
- These early βPMG studies engendered much larger efforts to ID nearby young MGs and their members
The Present State of the Art

• Galactic kinematics techniques (space velocity analyses) have become increasingly sophisticated
  – Song et al. (2002 & numerous other papers)
  – Torres et al. (2006, 2008)
    • Search for Associations Containing Young Stars (SACY)
  – Malo et al. (2013, 2014a,b)
    • Bayesian Analysis for Nearby Young AssociationNs (BANYAN)

• X-rays (RASS) have been superceded by UV (Galex) as a means to isolate large samples of candidate nearby, young stars
  – Rodriguez et al. (2011); Shkolnik et al. (2012)

• Combination of techniques (UV + kinematics) is particularly powerful
  – e.g., Rodriguez et al. (2011, 2013): Galex Near/Young Star Search (“GALNYSS”)
Identifying and age-dating NYMGs and their members: the βPMG as “litmus test”

From Mamajek & Bell (2014)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Age (Myr)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrado y Navascués et al. (1999)</td>
<td>$20 \pm 10$ Myr</td>
<td>CMD isochronal age (KM stars)</td>
</tr>
<tr>
<td>Zuckerman et al. (2001)</td>
<td>$12^{+8}_{-4}$ Myr</td>
<td>H-R diagram isochronal age (GKM stars) + Li depletion</td>
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<tr>
<td>Ortega et al. (2002)</td>
<td>11.5 Myr</td>
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<td>$10.8 \pm 0.3$ Myr</td>
<td>Traceback age</td>
</tr>
<tr>
<td>Torres et al. (2006)</td>
<td>$\sim 18$ Myr</td>
<td>Linear expansion age</td>
</tr>
<tr>
<td>Makarov (2007)</td>
<td>$22 \pm 12$ Myr</td>
<td>Traceback age</td>
</tr>
<tr>
<td>Mentuch et al. (2008)</td>
<td>$21 \pm 9$ Myr</td>
<td>Li depletion</td>
</tr>
<tr>
<td>Macdonald &amp; Mullan (2010)</td>
<td>$\sim 40$ Myr</td>
<td>Li depletion (magneto-convection models)</td>
</tr>
<tr>
<td>Binks &amp; Jeffries (2014)</td>
<td>$21 \pm 4$ Myr</td>
<td>Li depletion boundary</td>
</tr>
<tr>
<td>Malo et al. (2014)</td>
<td>$26 \pm 3$ Myr</td>
<td>Li depletion boundary</td>
</tr>
<tr>
<td>Malo et al. (2014)</td>
<td>$21.5 \pm 6.5$ Myr (15 – 28 Myr)</td>
<td>H-R diagram isochronal age (KM stars)</td>
</tr>
<tr>
<td>This work</td>
<td>$22 \pm 3$ Myr</td>
<td>CMD isochronal age (FG stars)</td>
</tr>
<tr>
<td>Final</td>
<td>$23 \pm 3$ Myr (1σ)</td>
<td>Li depletion boundary</td>
</tr>
<tr>
<td></td>
<td>$[\pm 2$ Myr (stat.), $\pm 2$ Myr (sys.)]</td>
<td>&amp; CMD isochronal age (FGKM stars)</td>
</tr>
</tbody>
</table>
Move over, TW Hya...make room for βPMG member V4046 Sgr

SMA CO image of the disk orbiting V4046 Sgr
(from Rosenfeld et al. 2013)
IAU Symposium #314
Young Stars & Planets Near the Sun
Zeroth Announcement

• May 11-15, 2015; Atlanta, GA (GSU campus)
  – GSU-sponsored Symposium website coming soon

• Topics:
  1. Nearby young moving groups (NYMGs): identification, ages, origins
  2. What NYMGs teach us about early stellar evolution
  3. Dispersal of protoplanetary disks; nature & origins of debris disks
  4. How NYMGs inform us about early evolution of planetary systems
  5. Nearby young stars and planets: the likely impacts of new and future facilities


• LOC: S. Lepine, I. Song, R. White