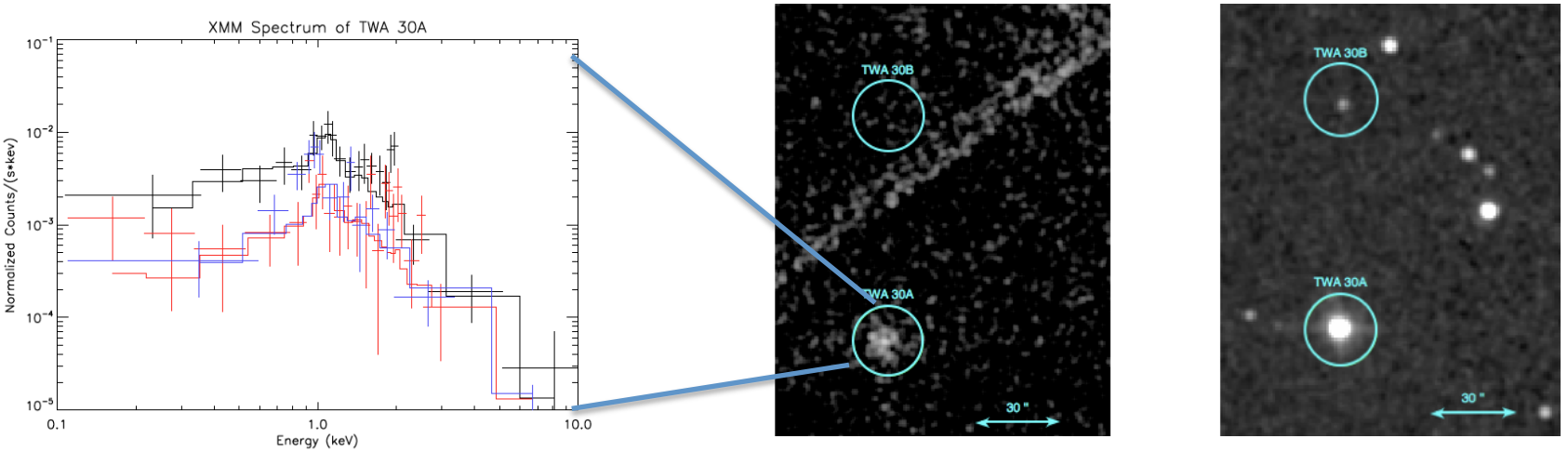
X-ray Investigations of Young Stars Near Earth



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The story of young stars near Earth begins with *TW Hya:*

classical T Tauri star without a birthplace

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

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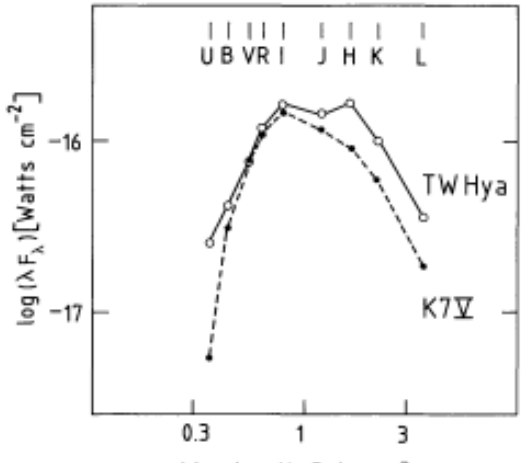
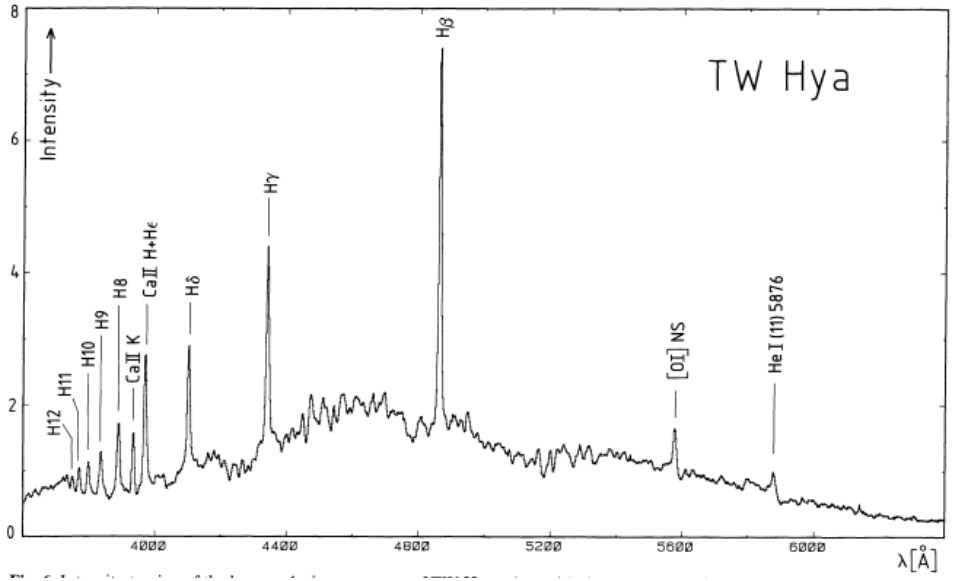


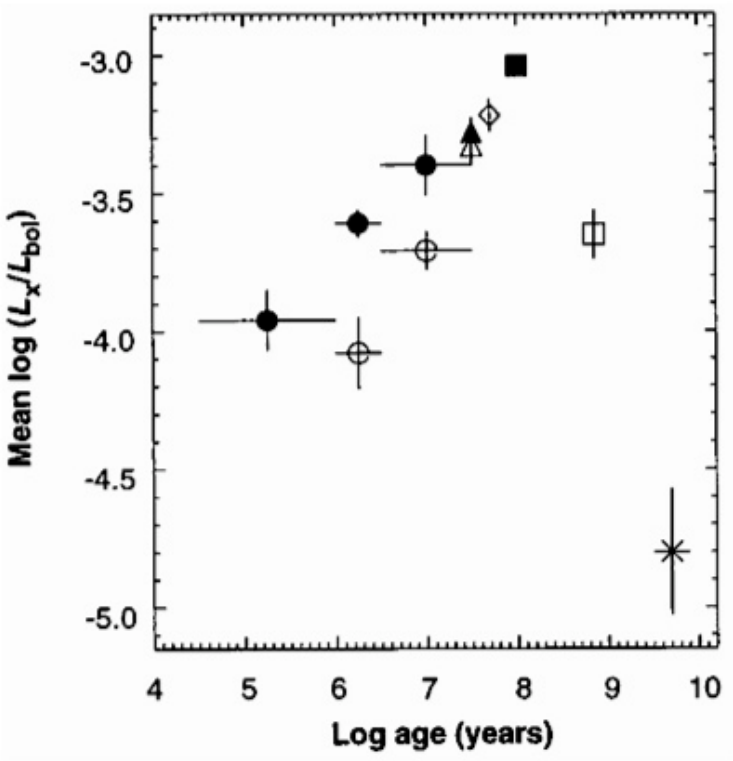
Henize (1976), Herbig (1978), and Rucinski & Krautter (1983) share credit for putting this seminal nearby, young star/ disk system "on the map"



The (X-ray-based) identification of the TW Hya Association:

The "nearest [known] region of recent star formation"

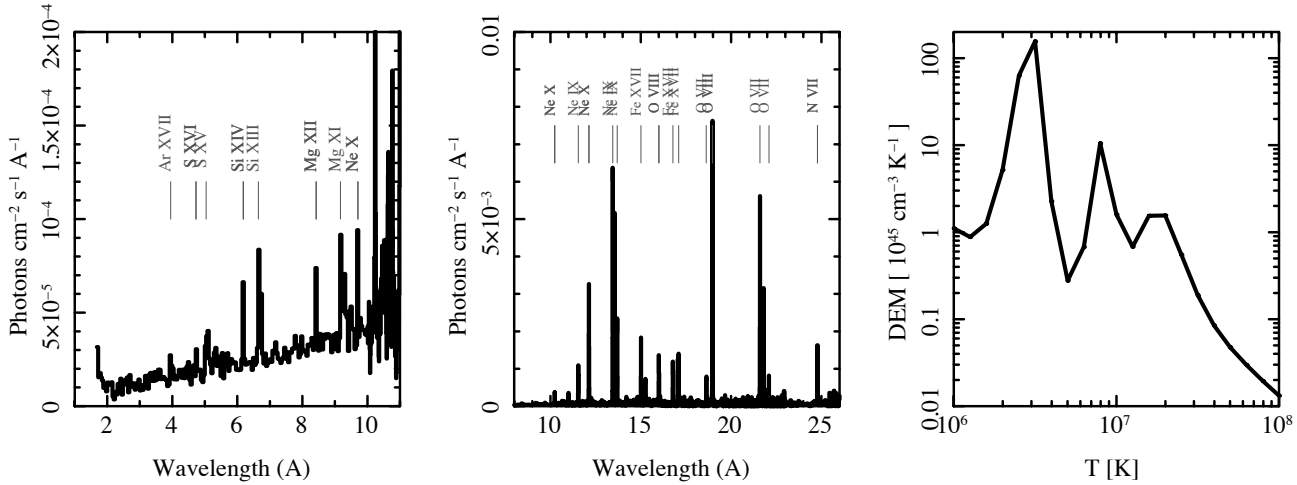
- RASS X-ray data demonstrated TW Hya and 4 other stars near it are similarly young & nearby (Kastner et al. 1997)
- age constrained at ~10-20 Myr
- all 5 are ~50 pc distant
- Over the next 15+ years, the candidate membership of the TWA would increase to >30 stars, and age estimates would converge on ~8 Myr…



Kastner et al. (1997)

…while TW Hya has become the "Crab Nebula"* of late-stage pre-MS accretion and protoplanetary disk evolution studies

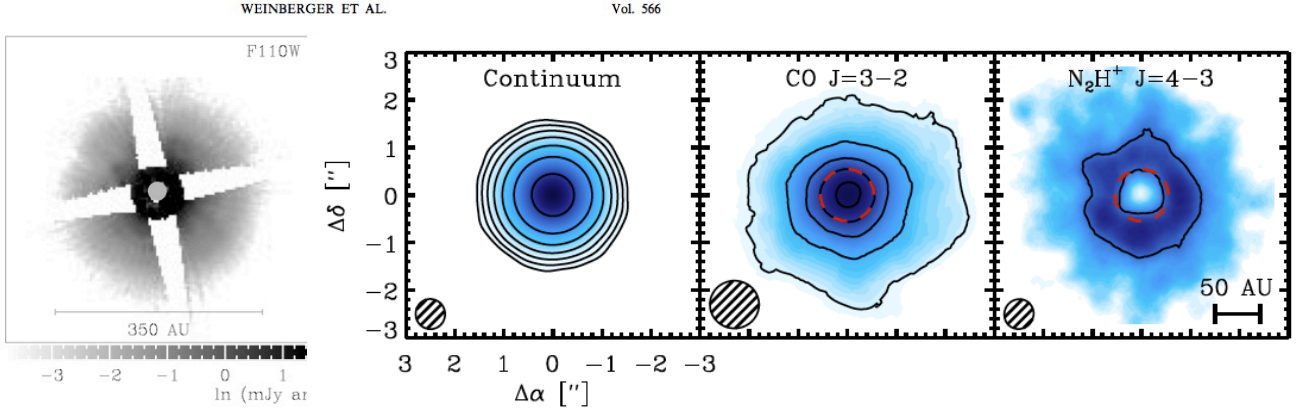
* *w/ apologies/thanks to David Wilner*



Left & center panels: 500 ks Chandra/HETG X-ray spectrum of TW Hya (see Brickhouse et al. 2010)

Right: differential emission measure

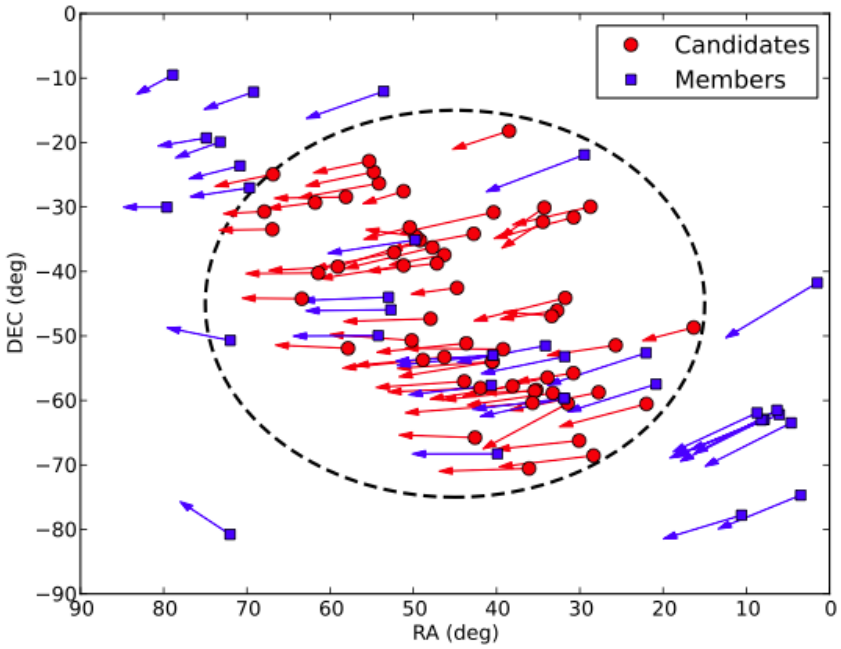
(presentation and analysis courtesy D. Huenemoerder)



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)

Identifying young stars near Earth: The present state of the art

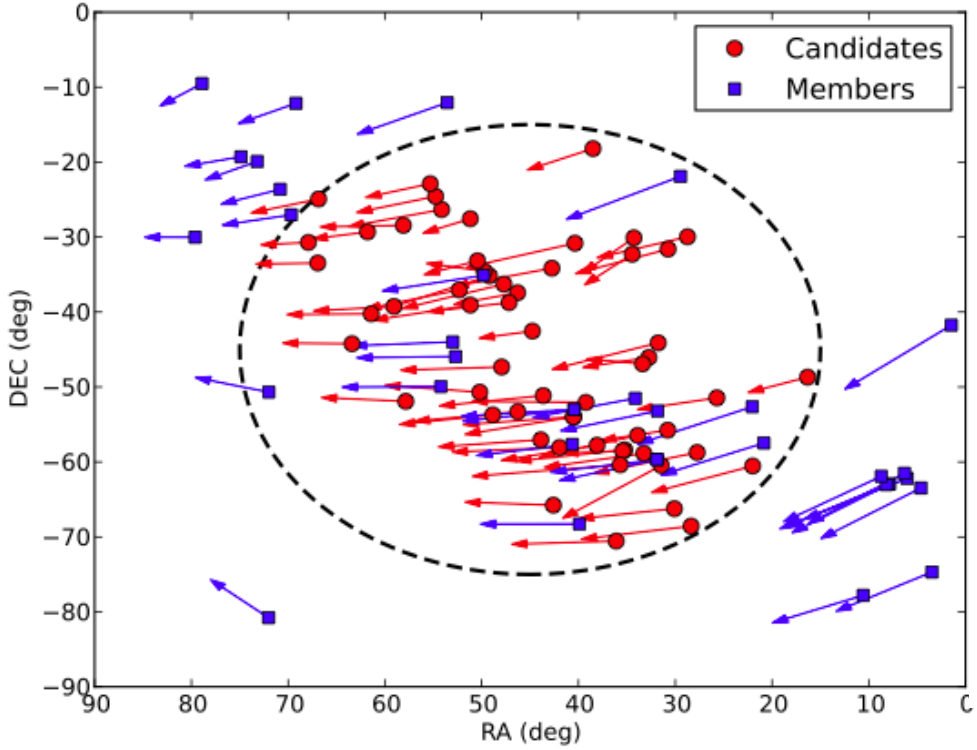
- Galactic kinematics techniques (space velocity analyses) have become increasingly sophisticated
  - E.g., Song et al. (2002); Torres et al. (2006, 2008); Malo et al. (2013, 2014a,b)
- X-rays (RASS) have been superceded by UV (Galex) as a means to isolate large samples of candidate nearby, young stars
  - Rodriguez et al. (2011); Shkolnik et al. (2012)
- Combination of techniques (UV + kinematics) is particularly powerful
  - Rodriguez et al. (2011, 2013): Galex Near/Young Star Search ("GALNYSS")

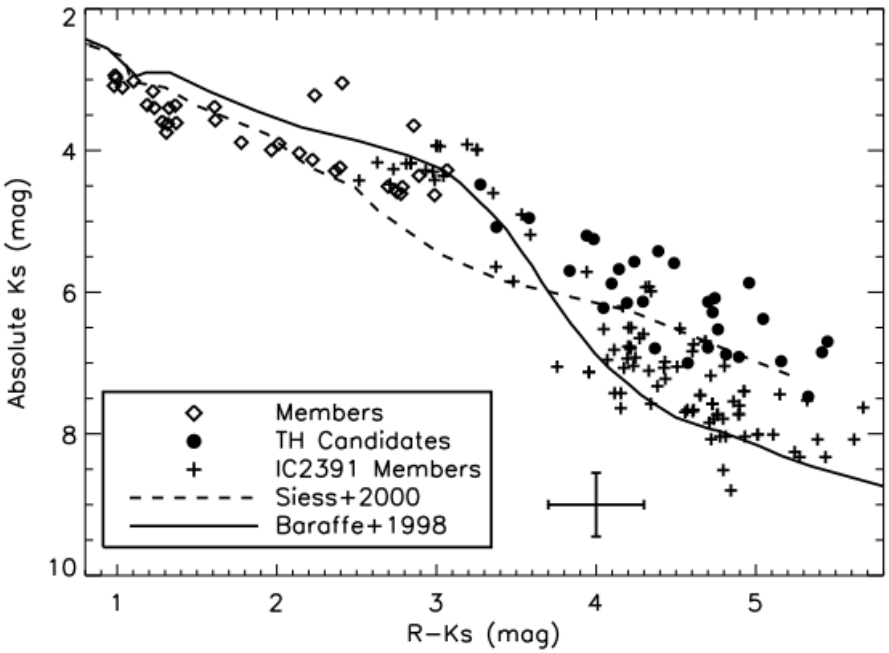


From Rodriguez et al. (2013)

Galex & WISE help reveal the lowest-mass members of the nearby young star population

New M-type members of the Tuc-Hor Association (age ~30 Myr)

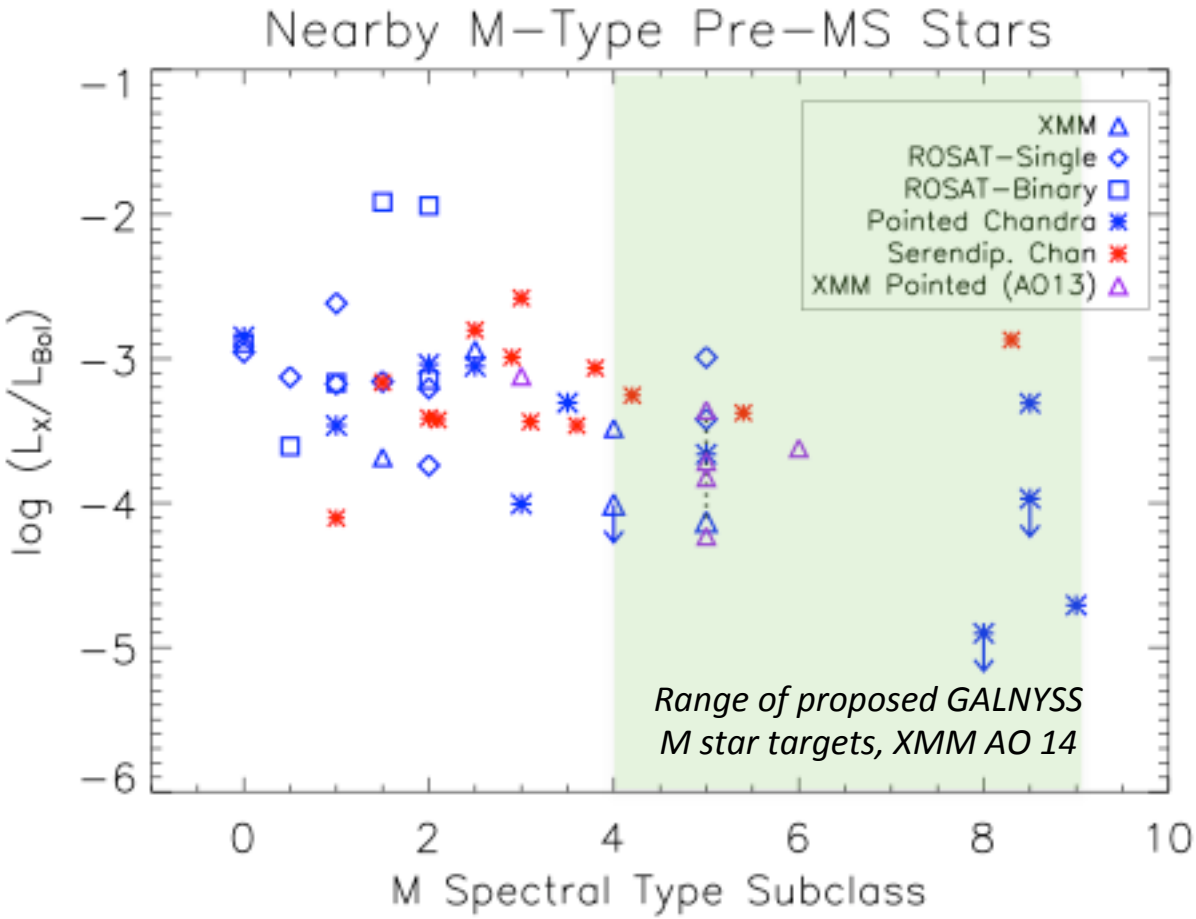




Rodriguez et al. (2013)

X-rays from young M stars near Earth

Probing magnetic activity near the H-burning limit



Principe et al. (2014, in prep.)

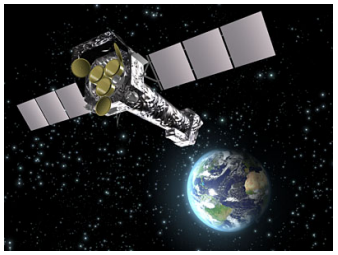
X-rays from actively accreting young stars near Earth

Probing irradiation of gaseous protoplanetary disks

ACTIVELY ACCRETING T TAURI STAR SYSTEMS* WITHIN ~100 PC

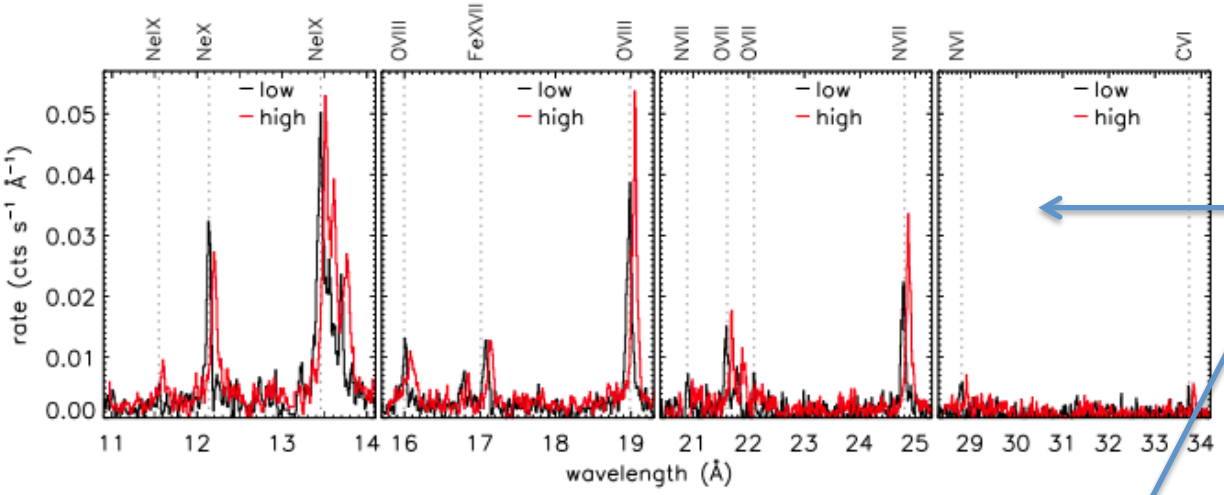
system	spectral type	Assoc.	D (pc)	age (Myr)	$M_\star$ ($M_\odot$)	Disk M_{CO} (M_{Earth})	Disk incl. (°)
T Cha A	K0	ϵ Cha	110	6	1.5	0.08	60
MP Mus	K1	ϵ Cha	103	6	1.2	0.06	30
V4046 Sgr AB	K5+K7	β Pic	73	23	0.90+0.85	0.1	35
TW Hya	K7	TWA	54	8	0.7	0.02	7
Hen 3–600 AB	M3+M3.5	TWA	45	8	0.2+0.2	...	< 45
TWA 30 AB	M4+M5	TWA	42	8	0.1+0.1	...	>60
LDS 5605 AB	M5+M5	β Pic	65	23	0.1+0.1	...	< 45

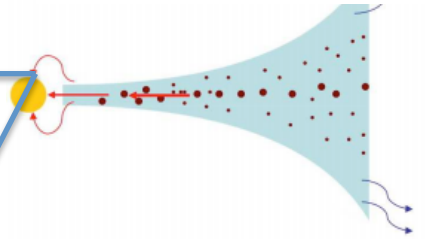
** Compiled from Sacco et al. (2014), Huenemoerder et al. (2007), Looper et al. (2010), Zuckerman et al. (2014), and refs. therein*

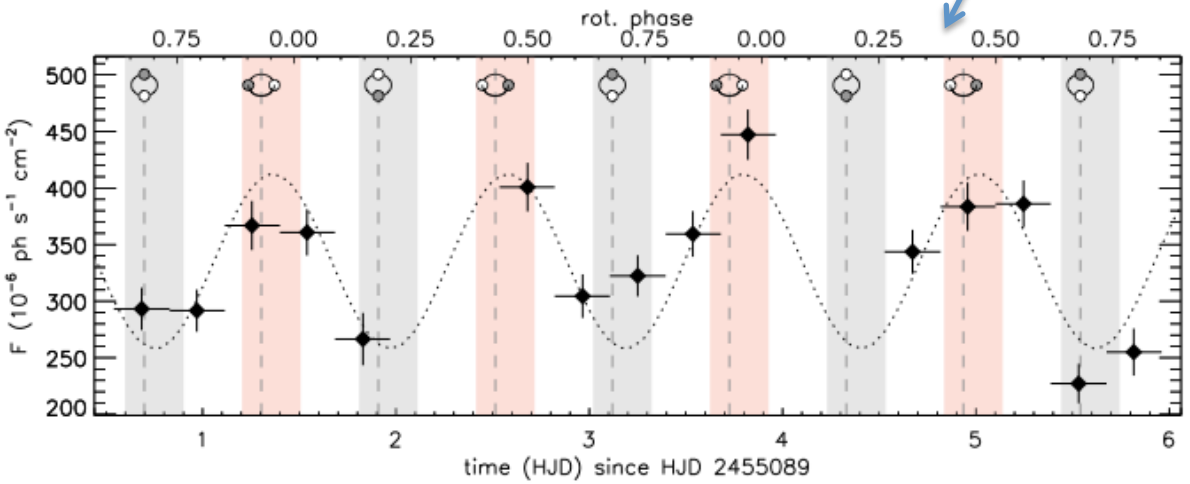


X-rays and pre-MS accretion disks: XMM time-resolved X-ray gratings spectroscopy of V4046 Sgr

X-rays from stellar accretion and coronal activity



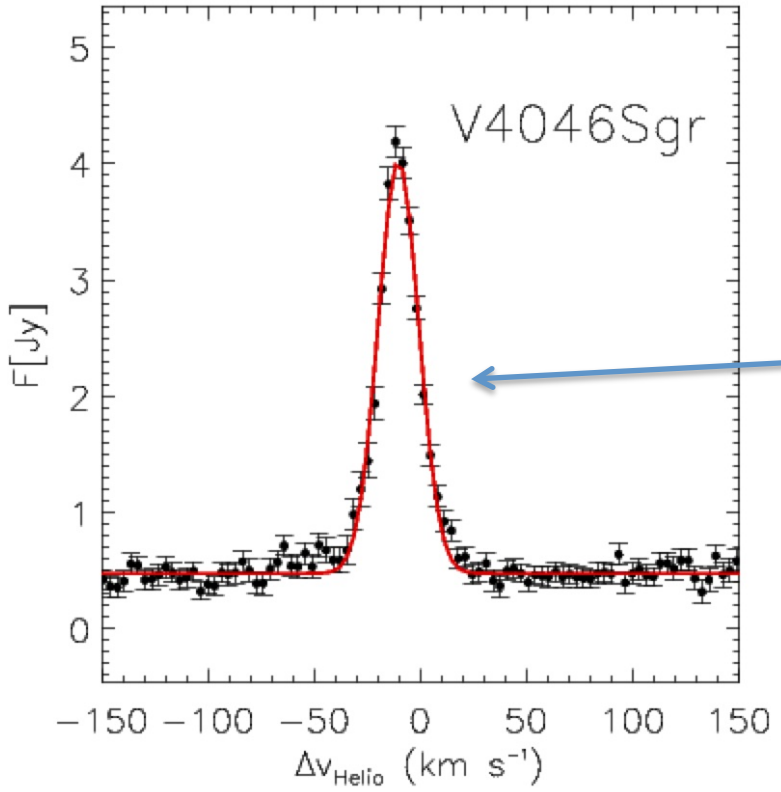




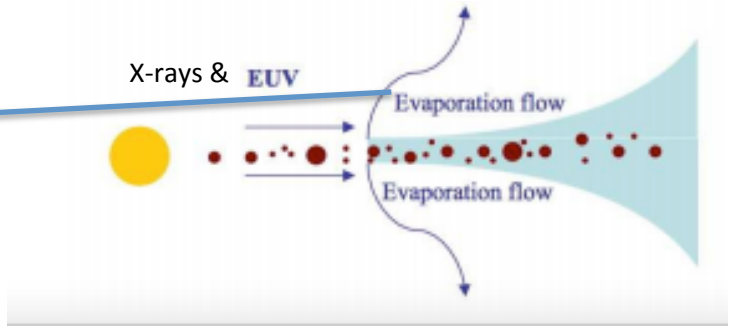
***Top**: XMM/RGS spectra extracted during low (black) and high (red) states; spectra shifted in wavelength, for clarity*

***Bottom**: apparent rotational modulation of low-T lines attributable to accretion shocks (Argiroffi et al., 2012, ApJ)*

VLT/VISIR spectroscopy of mid-IR [Ne II] emission from V4046 Sgr: evidence for *X-ray-induced disk photoevaporation*

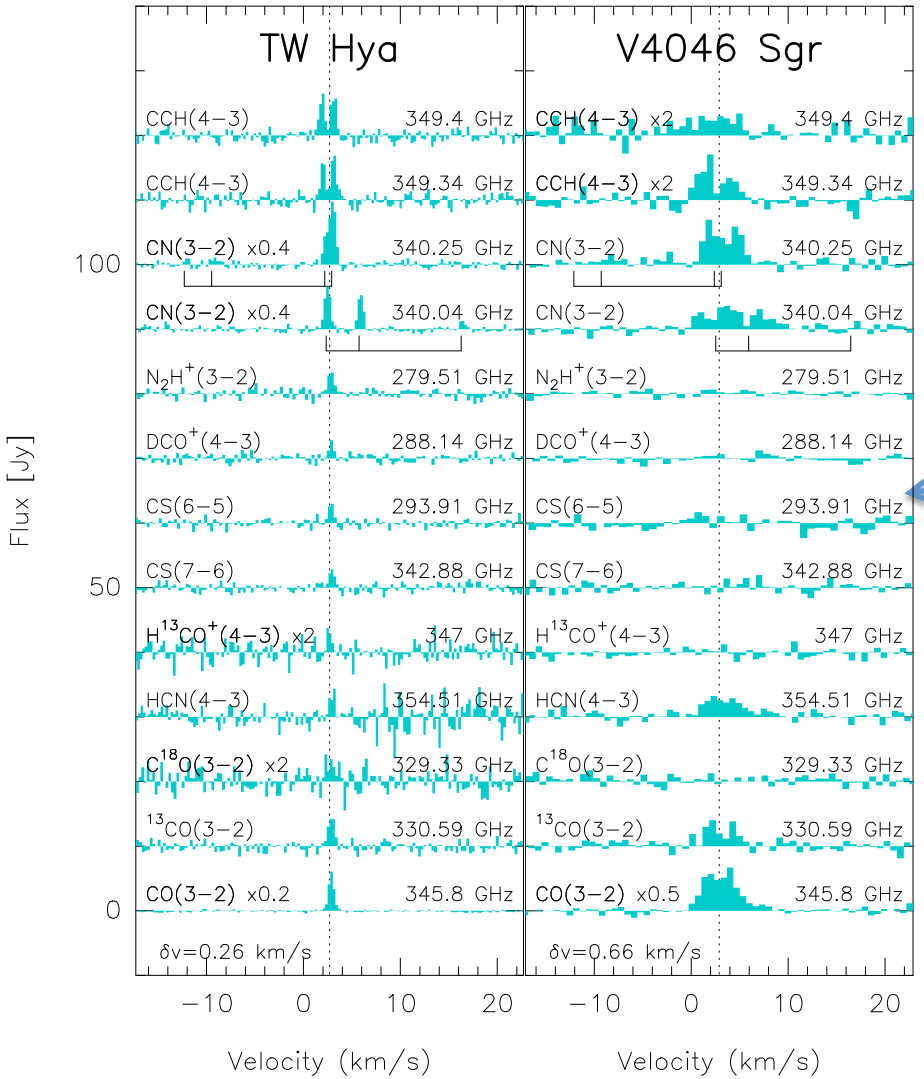


Mid-IR line emission from photoevaporative disk wind

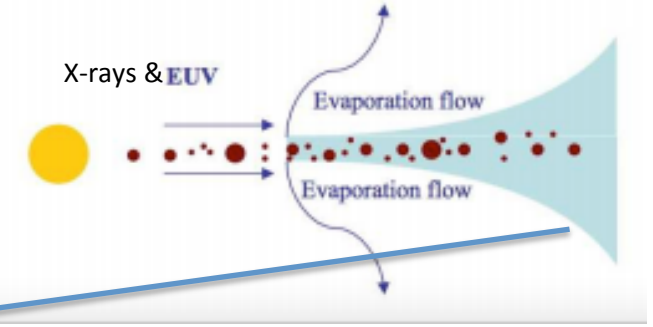


VLT/VISIR spectroscopy of 12.8 micron [Ne II] emission from V4046 Sgr; high ionization potential of Ne I requires high-E photon irradiation… …narrow linewidths and small line blueshifts are indicative of photoevaporative flows (Sacco et al. 2012, ApJ)

Molecular spectroscopy with the APEX 12 m: Fingerprint of an *irradiated molecular disk* orbiting V4046 Sgr (& TW Hya)



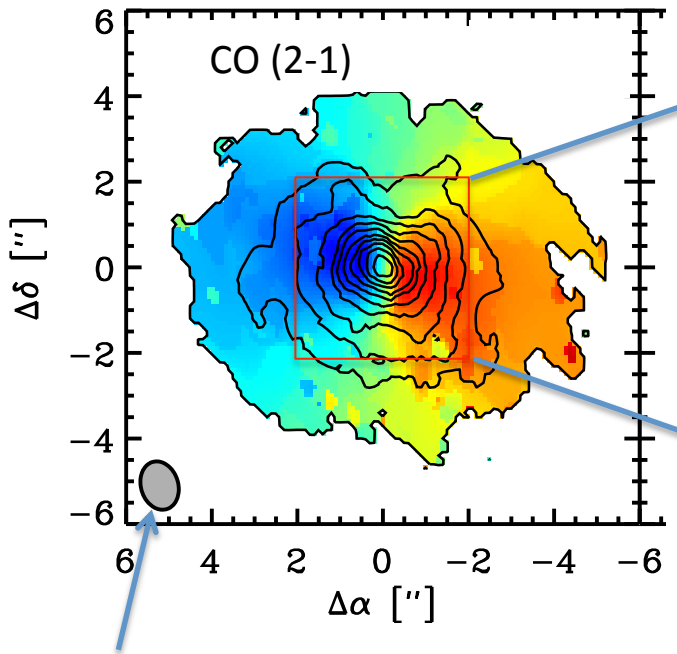
Radio line emission from cold, irradiated gas in the outer disk



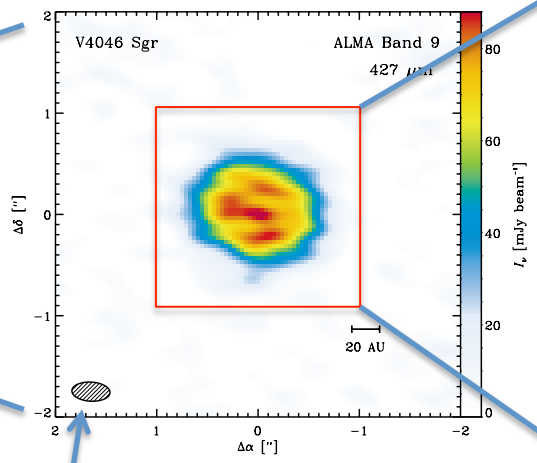
(Kastner et al. 2014, ApJ)

Evidence for *circumbinary* planet formation in the X-irradiated disk orbiting V4046 Sgr

Early Science imaging w/ ALMA and Gemini Planet Imager

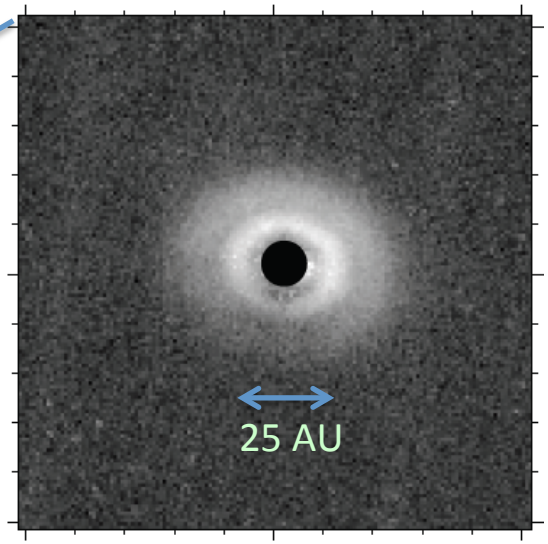


SMA beam: similar to orbit of Neptune, at distance of V4046 Sgr
(Rosenfeld et al. 2013)



*ALMA beam…similar to orbit of **Saturn**…Reveals dust ring w/ radius similar to orbit of Neptune.*

(Andrews, Rosenfeld, Kastner et al. in prep.)



*GPI near-infrared polarimetric imaging… reveals **inner dust ring** with radius similar to the orbit of **Saturn***

(Rapson, Kastner, Andrews, et al., in prep.)

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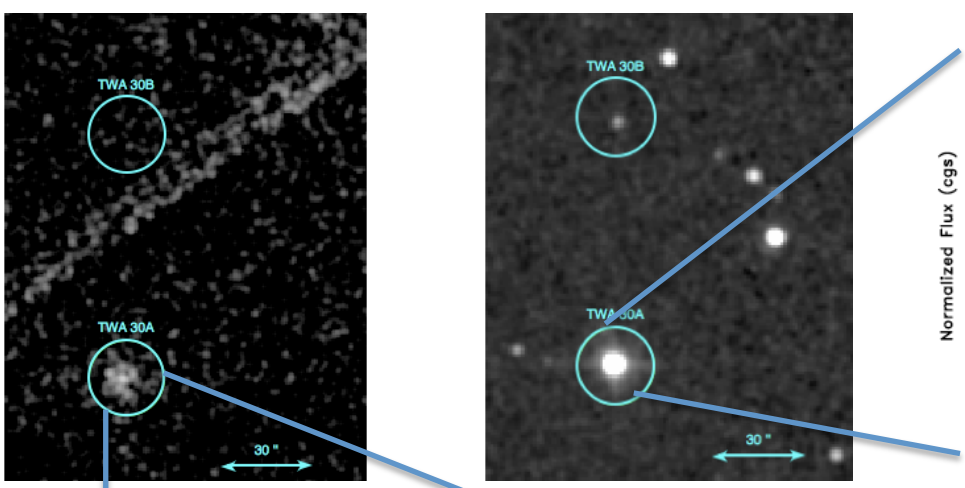
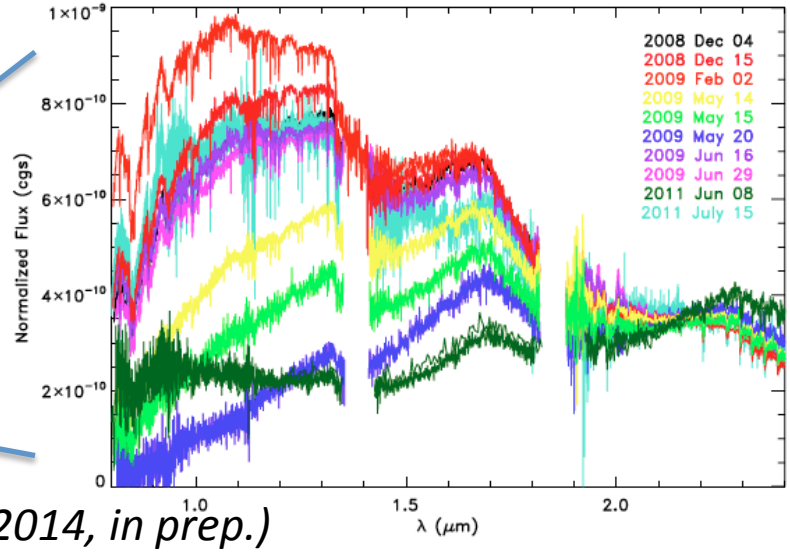
** Compiled from Sacco et al. (2014), Huenemoerder et al. (2007), Looper et al. (2010), Zuckerman et al. (2014), and refs. therein*

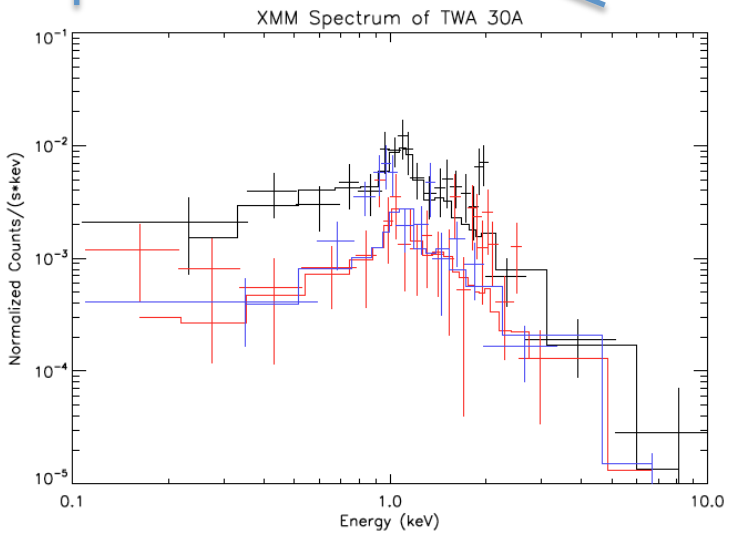
Simultaneous X-ray & near-IR spectroscopy of the nearly edge-on, 8 Myr-old star/disk system TWA 30A

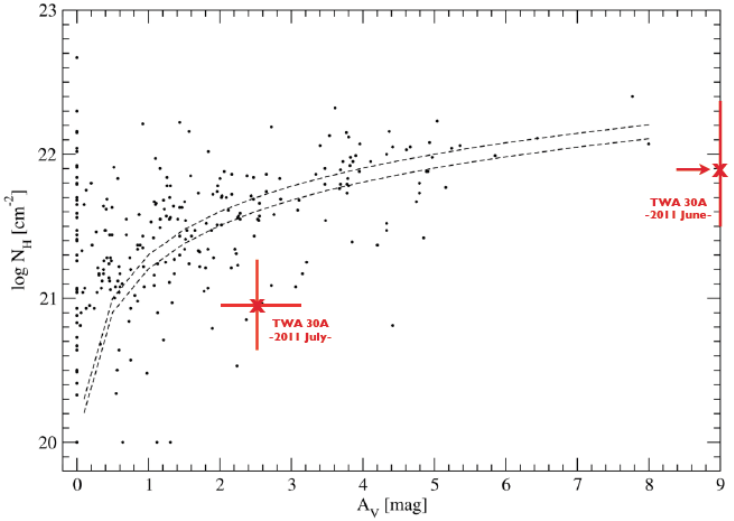
Monitoring the X-irradiation of the protoplanetary disk orbiting ***a young mid-M star***





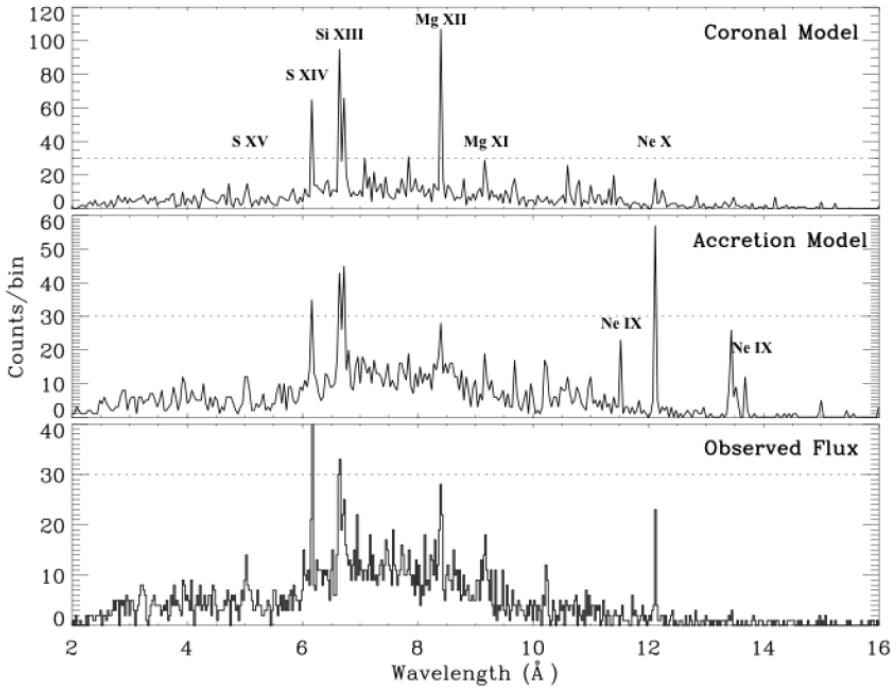
Principe et al. (2014, in prep.)

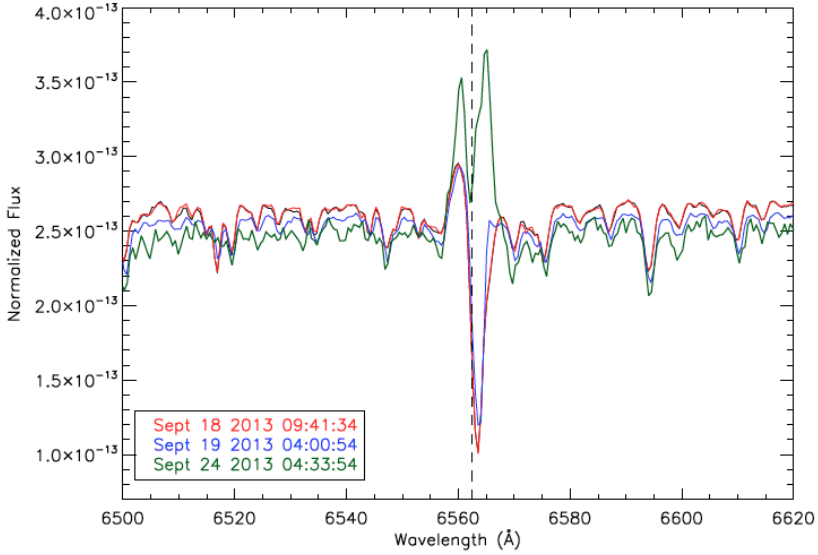


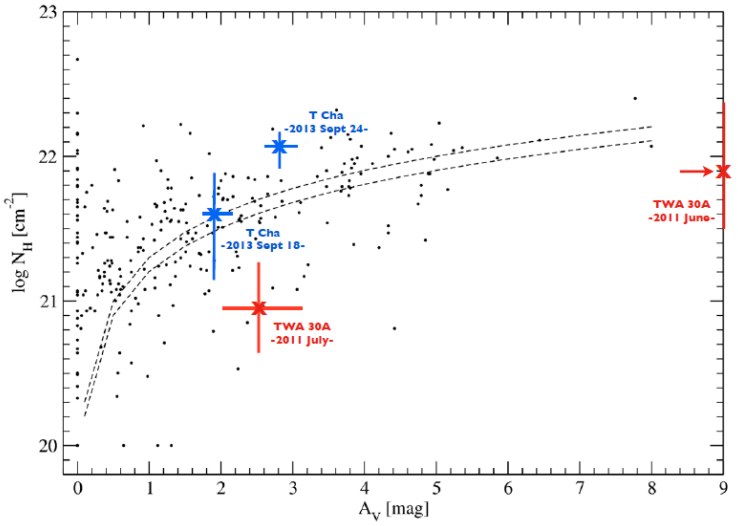


Simultaneous X-ray & optical spectroscopy of the highly inclined, 6 Myr-old star/disk system T Cha

*Monitoring the X-irradiation of the protoplanetary disk orbiting a **young solar analog***







Principe et al. (2014, in prep.)

IAU Symposium 314

Young Stars & Planets Near the Sun

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May 11-15, 2015

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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 lik*ely impacts of new and future facilities*

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