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ABSTRACT

For almost one hundred T Tauri stars, infrared emission of circumstellar dust has been observed. This dust is interpreted to be part of a protoplanetary disk orbiting the central star. T Tauri stars are young stellar objects and evolve into solar type stars. Planets are believed to form in these disks. The spectral energy distribution of a disk depends on its temperature profile. Different disk regions emit at different wavelengths. The disk-star boundary layer is hot and emits $H\alpha$. Inner disk regions at around 1 AU with a temperature of a few hundred Kelvin can be probed in near infrared wavelength regimes. Outer disk regions at around 100 AU distance from the star are colder and emit far infrared and sub-millimeter radiation. Also, X-ray emission from the stellar surface can reveal information on disk properties. Emission from stellar surface and boundary layer may be shielded by circumstellar gas and dust. T Tauri stars with low $H\alpha$ emission, i.e. no boundary layer, show stronger X-ray emission than classical T Tauri stars, because the inner disk regions of weak emission-line T Tauri stars may be clear of material. In this paper, first ROSAT all sky survey results on the X-ray emission of T Tauri stars and correlations between X-ray luminosity and properties of T Tauri disks are presented. Due to atmospheric absorption, X-ray and most infrared observations cannot be carried out on Earth, but from Earth orbiting satellites (e.g. IRAS, ROSAT, ISO) or from lunar based observatories, which would have special advantages such as a stable environment.

1. INTRODUCTION

One of the questions most interesting to all humankind has always been, whether there is life other than on Earth. Life is possible on planets only. There seems to be no life on other planets in our planetary system. Planets outside our own planetary system could not be observed so far, because they are too distant, too small, too dark, and too close to the (possibly bright) star they circle, i.e. planets are too faint for direct observation.

Stars form in collapsing interstellar clouds[1]. Planetary systems form in circumstellar dust and gas disks. Dust settles in the equatorial plane and grows due to sticking, colliding, and merging. Dust coagulation leads to the formation of solid bodies kilometers in size. Due to radial migration, gas drag, and gravitational interaction[2], these so-called planetesimals either coalesce or cease to grow. They get fewer in number and larger in size. Eventually, only a few planetesimals are left over, the planets. This process (from the initial collaps of an interstellar cloud to the formation of planets) lasts approximatelly up to a few 10^7 years.

Since the mid 1980ies, protoplanetary disks are observed around young, low-mass, pre-main sequence stars, so-called T Tauri stars. For a sample of some 100 T Tauri stars in the Taurus-Auriga star forming region, the spectral energy distribution has been observed. Particulary, far infrared, millimeter, and sub-millimeter emission observed indicates the existence of cold circumstellar dust[3]. Planetary systems like the one we live in are believed to form in such disks. In Taurus-Auriga, star and planet formation seems to be an ongoing process. Due to its low distance of 140 pc, Taurus-Auriga is one of the best studied regions of star formation.

T Tauri stars are named after their prototype T Tauri and defined mainly by their spectrum[4,5]: $H\alpha$ emission and Lithium (and Ca) absorption lines. They show variable luminosity and are very young (up to a few million years). T Tauri masses range from a few tenth to three solar masses. In the Hertzsprung-Russell diagram, T Tauri stars lie above the main sequence, because they are still contracting down the Hayashi tracks, T Tauri stars are low-mass, pre-main sequence stars. There are two sub-groups, classical and weak-emission line T Tauri stars. Classical T Tauri stars (CTTS) show strong $H\alpha$ emission, while weak-emission line T Tauri stars (WTTS) have $H\alpha$ equivalent width smaller than 10 Angstrom. Many classical T Tauri stars seem to be surrounded by disks, while most weak-line T Tauri stars don't (naked). T Tauri stars eventually evolve into solar-type stars possibly with planets.

We discuss recent observations and interpretations of the spectral energy distribution of T Tauri stars (chapter 2), summarize results on actual disk observations including new statistical analyses (chapter 3), and report on new X-ray observations of T Tauri stars with the Röntgen Satellite ROSAT (chapter 4). X-rays of late-type stars like T Tauri stars (spectral type G, K, or M) are of corconal origin and due to magnetic activity on the surface of the stars. CTTS and WTTS show both different X-ray fluxes and different X-ray spectra. this may be due to different X-ray absorption by circumstellar material. Since this paper was given at ' International Space University's (ISU) second Alumni Conference during ISU's summer session in Huntsville, USA, where a International Lunar Far-Side Observatory design project was carried out. possible observation from a lunar based observatory will be discussed in the last chapter.

2. SPECTRAL ENERGY DISTRIBUTION OF T TAURI STARS

T Tauri stars can be observed in many different wavelengths: Optical (star itself), X-rays (stellar corona and surface), ultraviolett (hot boundary layer between disk and stellar surface), near and mid infrared (cold circumstellar gas, few 1000 Kelvin), far infrared (hot circumstellar dust close to the star, few 100 K), and sub-millimeter (sub-mm) and millimeter (mm) emission (cold dust in a few to some 100 AU distance from the star, down to a few 10 K). Different wavelengths originate from material at different temperatures, i.e. at different d. rances from the star that heats the material. Different wavelengths probe different regions of a disk.

Observations in many wavelengths give the spectral energy distribution (SED) of star and disk. The SED depends on the temperature profile of a disk, i.e. on the radial dependence of the disk temperature. From any given point (i.e. any given temperature) on the surface of the disk, a spectrum is emitted. The spectral energy distribution of the disk as a whole consists of these spectra. Assuming blackbody radiation of a disk element (at distance r and polar angle ϕ) at temperature T with frequency ν, Planck constant h, and Boltzmann constant k, the Planck function runs as

$$B_\nu(T(r,\phi)) = \frac{2h\nu^3}{c^2} \left(\exp\frac{h\nu}{kT} - 1 \right)^{-1} \tag{1}$$

With angle δ between line of sight and disk plane, the luminosity of the disk between inner and outer disk radii r_* and r_u is

$$L_\nu = 4\pi\cos\delta \int_0^{2\pi} \int_{r_*}^{r_u} \nu B_\nu(T) \cdot (1 - exp(-\tau)) \, r \, dr \, d\phi \tag{2}$$

with τ as optical depth (depending on frequency): $\tau = \kappa \cdot \sigma / \cos\delta$ with surface density σ and opacity κ.

Isolated dust grains at distance r from star have a temperature $T(r) \sim r^{-1/2}$. For a dust grain on the surface of a self-luminous, axi-symmetric disk, the temperature runs as

$$T = \left(\frac{3 \, G \, M_c \, \dot{M}}{8 \, \pi \, \sigma \, r^3} \right)^{1/4} \sim r^{-3/4} \tag{3}$$

with gravitational constant G, mass of central object M_c, mass accretion rate $\dot{M}$.

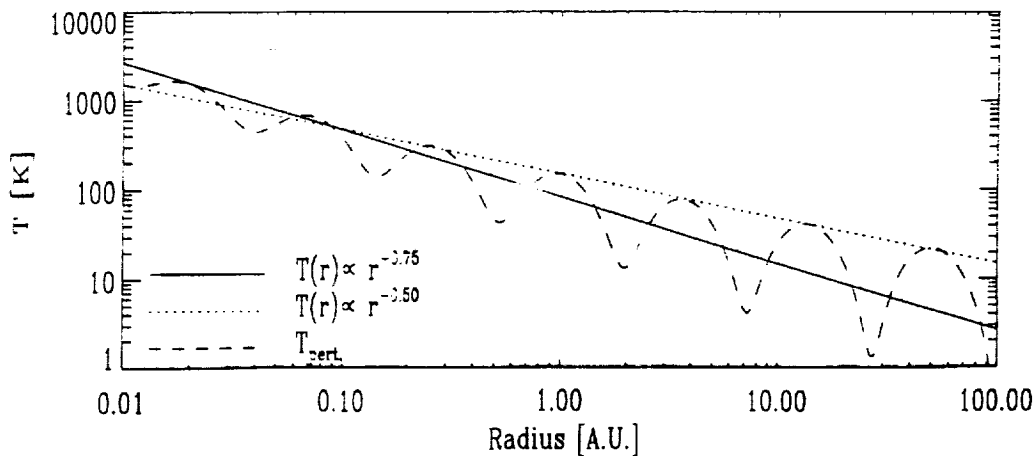Fig.1: Theoretical temperature profiles of a disk (Sterzik[6])

The temperature index q is defined as

$$T \sim r^{-q}$$
(4)

Given a temperature profile (Fig.1) with q between $1/2$ and $3/4$, one can model the spectral energy distribution[6,7] (Fig.2). Also, the other way round, after having measured a disk's SED, one can calculate the temperature index q, i.e. the temperature profile of the disk. The flatness of the SED is given by q and is connected with the infrared spectral index (and yields the temperature profile using equations 3 and 4):

$$\text{IR-Spectral index} \;=\; \alpha_{IR} \;=\; \frac{d\log L_\nu}{d\log \nu} \;=\; 4 \;-\; \frac{2}{q}$$
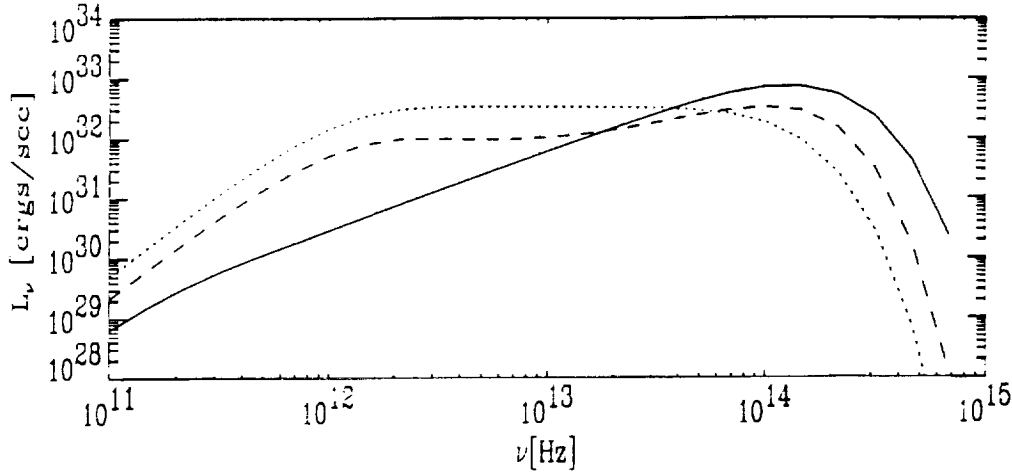(5)

Fig.2: Theoretical SEDs for different temperature profiles (Sterzik[6])

The SED flatness q should by theory be $3/4$. But, for most disks observed so far, the temperature index q lies between $1/2$ and $3/4$, i.e. spectra are often too flat[3]. A possible solution according to which disks are flared, i.e. disks that are much thicker at outer disk radii than at inner disk portions[8], is not favored any more, because disks would have to be much more flared than theoretical contraints allow to fit with observed disk flatness. A new solution recently published[9], suggests disks surrounded by remnant dusty nebulae and re-radiation of star light down to the disk resulting in flat spectra. This solution seems to be able to solve the flat spectra problem.

Having observed the SED of a disk, i.e. the luminosity of a disk, one can calculate mass and outer radius of a disk. For typical T Tauri disks, one gets masses between 0.001 and 0.1 solar masses and radii of around $100 AU$. This is in good agreement with theoretical assumptions for the protosolar nebula.

If one would distribute material of this mass spherically around the star (assuming a plausible r^{-2} distribution), the absorption would be very high, one could not see the star anymore. Assuming the collapse model of star formation and given the angular momentum problem, the material must be distributed in a flat disk.

Forbidden line emission (e.g. O I) is seen only in one direction. though stellar wind is ejected in both direction up and down. One side is absorbed by disk, unless the line of sight lies in the plane of the disk.

Wings in $H\alpha$ emission line profiles show evidence of accretion with decreasing rate for older stars. Accretion of material onto the star leads to hot spots on the stellar surface that rotate around the star. This results in luminosity variations being observed as light curves[10]. Enhanced accretion can lead to outflow enhancement (shocks), e.g. so-called FU Orionis phenomena.

The resolution of disk observations is not sufficient to resolve the disk. There is no direct evidence for disks. Only for one T Tauri star (HL Tau), interferomeric observation of a disk-shaped feature around the star was attemped with some success[11], but for other stars, interferometric observations were unsuccessfully.

The evolutionary picture of classical T Tauri stars evolving into weak-line T Tauri stars is consistent with the existence of disks. Indeed, weak-line T Tauri stars seem on average to be older than classical T Tauri stars, though absolute age determination is difficult. A classical T Tauri star with disk forms from a collapsing cloud, disk and star surface interact resulting in a very hot boundary layer, which emitts UV radiation (strong $H\alpha$ emission). Later, the disk accretes partly onto the star and/or planetesimals form. The disk dissipates after some time (millions of years) resulting in a star without hot boundary layer, i.e. with weak UV emission: weak-line T Tauri star. Weak-line T Tauri stars are sometimes called naked T Tauri stars (NTTS[12]), because most of them are not surrounded by disks.

3. OBSERVED T TAURI DISK PROPERTIES

The 1.3 mm continuum emission of 86 T Tauri stars in the well known Taurus-Auriga star forming region have been observed[3]. Since continuum emission and line width are not correlated, free-free emission by ionized gas can be excluded as reason for this 1.3 mm emission. Instead, the observed far infrared flux is caused by stellar photons that were absorbed by dust grains and re-radiated in the far infrared. Therefore, their is dust and gas in the circumstellar vicinity around the T Tauri stars observed. As explained above, this dust is believed to be distributed in a flat disk in the equatorial plane of the star. The 1.3 mm flux contributes one point to the SED of the star-disk system, important mainly to determine the flatness of the SED, i.e. temperature profile and other properties of the disk.

From equations given in chapter 2 and a few more assumptions, one can get the following properties of the disks observed[3]:

- Spectral energy distribution flatness q

- Distance r_1 from the star (in units of distance between Sun and Earth, AU), the border between optical thick and optical thin regions of the disk

- Temperature T_1 (in Kelvin) at distance 1 AU from the star

- Mass M_d of the disk (in units of solar mass $M_\odot$)

Table 1 gives all these properties of those 34 T Tauri stars, for which a disk has been observed[3]. Also given in table 1, are stellar masses M_* in solar masses and the type of the star, i.e. WTTS or CTTS (one star in neither a WTTS nor a CTTS, but an Ae star, i.e. a star of spectral type A with emission line).

These data have been evaluated both by Beckwith et al.[3] and by Morfill and Sterzik[7], some of the most important results are:

- Approximatelly one half of the CTTS observed do have disks. Almost no WTTS are surrounded by 1.3 mm emitting material, i.e. most WTTS are naked. Their disks are already dissipated (if they have had disks at all during earlier stages). If they have had disks, planetesimals may have already formed around these WTTS. As yet, bodies as large as planetesimals can not be detected or observed directly.

- Disk masses do not depend on disk sizes if outer disk radii lie between 20 AU and 300 AU.

- Disk temperature at 1 AU depends on 60 μm flux, but does not depend on q.

- For almost all disks, q does not lie in the range predicted by theory (around 3/4), but between 1/2 and 3/4. Many disks are too flat (q around 1/2), especially those with high temperatures.

- Disk mass and stellar age are not correlated, thus, a disk does not dissipate before the star has reach an age of around 10^7 years.

- The radial distribution of dust surface density is consistent with a $\sigma \sim r^{-1.5}$ law, disk masses are small.

- Disks are quite cold with temperatures between 63 K and 388 K (at 1 AU). Temperature and age are not correlated.

Table 1: T Tauri disk properties							
Star	other designation	type	$M_*/M_\odot$	q	T_1/K	$M_d/M_\odot$	r_1/AU
FN Tau	Haro 6-2	CTTS	0.27	0.54	156	0.004	3
DE Tau	MHa 259-8	CTTS	0.44	0.57	133	0.007	4
RY Tau		CTTS	1.69	0.51	360	0.039	20
T Tau		CTTS	1.91	0.51	390	0.016	7
DG Tau	MHa 259-10	CTTS	0.56	0.51	308	0.041	15
IQ Tau	Lk Hα 265	WTTS	0.54	0.64	128	0.040	15
UX Tau A		WTTS	1.49	0.52	169	0.009	5
DK Tau	MHa 259-12	CTTS	0.65	0.62	188	0.005	3
HK Tau	Haro 6-12	CTTS	0.55	0.46	150	0.005	3
HL Tau	Haro 6-14	CTTS	0.55	0.49	307	0.10	25
V710 Tau	Lk Hα 266	CTTS	0.42	0.64	112	0.038	12
UZ Tau	UZ Tau f/p	CTTS	0.44	0.62	173	0.054	14
GG Tau	MHa 257-2	CTTS	0.65	0.55	180	0.29	
DL Tau	MHa 259-13	CTTS	0.56	0.59	158	0.087	24
CI Tau	MHa 259-20	CTTS	0.70	0.58	156	0.063	20
DM Tau	MHa 257-6	CTTS	0.62	0.51	108	0.034	13
AA Tau	MHa 259-17	CTTS	0.67	0.55	135	0.021	9
DN Tau	MHa 259-18	CTTS	0.62	0.58	123	0.027	11
HP Tau	Lk Hα 258	CTTS	1.43	0.50	203	0.005	4
DO Tau	MHa 259-15	CTTS	0.72	0.54	203	0.018	9
DP Tau	MHa 259-19	CTTS	0.60	0.61	144	0.003	2
GO Tau	MHa 259-24	CTTS	0.67	0.60	93	0.057	17
DQ Tau	MHa 257-7	CTTS	0.67	0.59	141	0.025	9
DR Tau	MHa 257-8	CTTS	0.55	0.62	227	0.028	11
DS Tau	MHa 259-2	CTTS	1.29	0.66	100	0.010	6
UY Aur		CTTS	0.65	0.55	243	0.004	2
GM Aur	MHa 259-1	CTTS	0.72	0.51	152	0.060	19
V773 Tau	HD 283447	CTTS	1.74	0.75	207	0.010	6
V892 Tau	Elias 1	Ae	1.03	0.49	388	0.013	7
V819 Tau	WK X-Ray 1	WTTS	0.72	0.65	68	0.032	13
FT Tau	Haro 6-6	CTTS		0.55	139	0.034	13
Haro 6-13		CTTS	0.55	0.54	200	0.014	5
FY Tau	Haro 6-17	CTTS		0.70	156	0.003	2
FZ Tau	Haro 6-18	CTTS		0.66	152	0.004	3

There are five disks with low far infrared excess, i.e. no emission of dust at high temperature, i.e. no material at a few AU distance from the star, i.e. a gap in the inner disk. Such a gap clearing can be interpreted as planetesimal formation. But, a perturbed temperature profile can also account for the missing FIR excess[13].

An additional statistical analysis of the Beckwith sample has been performed recently[14]. We summarize a few results. A correlation analysis was done with the Statistical Analysis System (SAS) program. The Pearson correlation coefficient ρ tests linear correlation of two parameters. If ρ is positive, the parameters studied are positive linear correlated, if ρ is negative, the parameters are negative linear correlated. But the significance of the correlation can not be concluded from ρ. Let p be the propability for mistakenly denying the hypothesis the parameters studied were not correlated, then, if p is very close to 0. the correlation is very siginificant.

Disk mass M_d and distance r_1, the border between optical thick and thin region in the disk, are positive linear correlated with $\rho = 0.96$ and $p < 10^{-4}$, i.e. the correlation is very sigificant. See figure 3 for a display of the correlation. A linear regression gives

$$\frac{r_1}{AU} = (2.95 \pm 0.49) + (256 \pm 13) \frac{M_d}{M_\odot} \tag{6}$$

We conclude that, the more massive a disk is, the larger is the optical thick part of the disk.

Also, square root of disk mass and r_1 are significantly positive linear correlated with $\rho = 0.98$. A linear regression gives
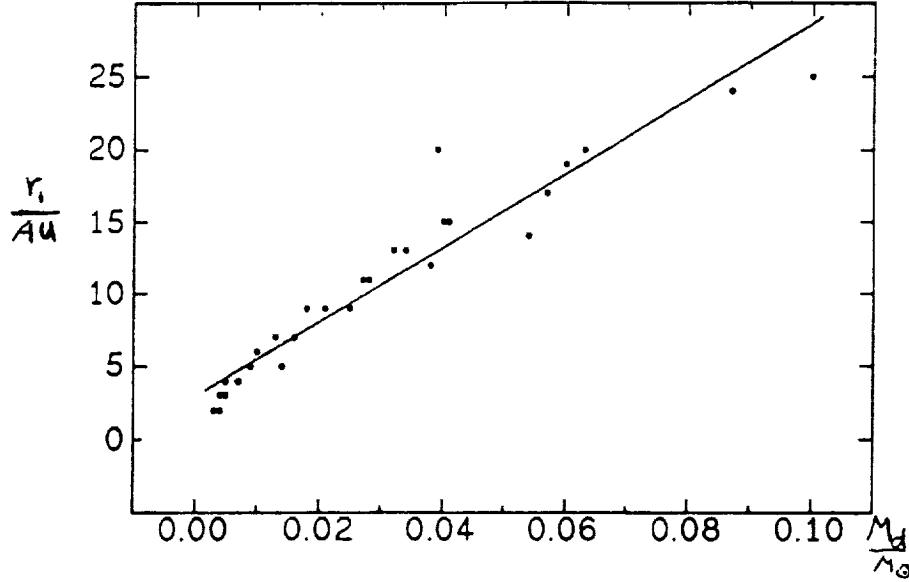
$$\frac{r_1}{AU} = 70 \sqrt{\frac{M_d}{M_\odot}} \, AU \tag{7}$$

Fig.3: Correlation between r_1 and M_d (Neuhäuser[14])

We have also found a positive linear correlation between stellar mass $M_\star$ and disk temperature T_1 at distance 1 AU with $\rho = 0.46$ and $p = 0.01$. As displayed in figure 4, this correlation does not seem to be significant, though the small p-value formally indicates significance. A linear regression gives

$$\frac{T_1}{K} = (115 \pm 29) + (91 \pm 33) \frac{M_\star}{M_\odot} \tag{8}$$
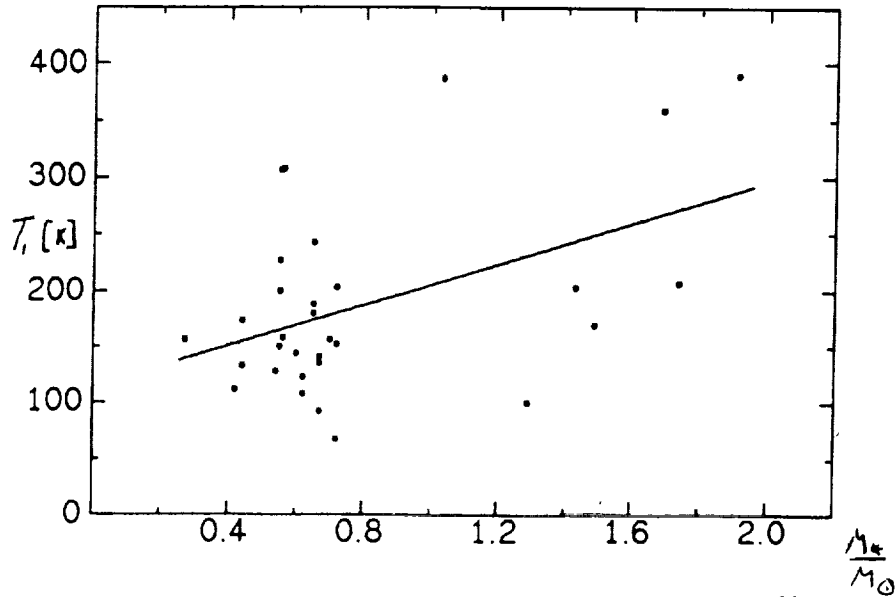
Fig.4: Correlation between T_1 and $M_\star$ (Neuhäuser[14])

In case of the protosolar disk, the stellar mass in known to be 1 $M_\odot$, i.e. we get $T_1 = (206 \pm 43)K$ for disk temperature at 1 AU. This is in good agreement with theoretical models using, e.g., 280 K as temperature at 1 AU (Kyoto model of protosolar disk[15,16]).

4. X-RAY EMISSION OF T TAURI STARS

T Tauri stars are still quite young and very active. Strong magnetic activity results in coronal loops and X-ray emission. Flares were observed, too. X-ray flux during the T Tauri phase is by a few orders of magnitude larger than X-ray flux of the present Sun.

X-ray emission of T Tauri stars was for the first time measured with the *Einstein* observatory. Many weak-line T Tauri stars show X-ray emission, but only a very few classical T Tauri stars according to the limited sample that was observed by the *Einstein* observatory[17]. Ground-based optical follow-up observation of unidentified *Einstein* X-ray sources resulted in the discovery of some 30 new weak-line T Tauri stars that were not found with previous $H\alpha$ surveys because their UV emission is too small.

During the ROSAT all sky survey, virtually all T Tauri stars were observed in the 0.1 to 2.4 keV range. Detection rates are in agreement with previous *Einstein* observatory observations: 54% of all weak-line T Tauri stars and only 12% of the classical T Tauri stars are strong enough to be detected with X-rays. Classical T Tauri stars and weak-line T Tauri stars also show different X-ray fluxes. This can be due to the fact that WTTS are a older then CTTS and rotate faster (therefore more magnetic activity on the stellar surface). Another reason can be different absorption.

X-ray flux of T Tauri stars seems to be correlated with $H\alpha$ equivalent width: decreasing flux with increasing UV emission. This can be explained if the $H\alpha$ emitting region absorbs X-rays, i.e. classical and weak-line T Tauri stars may emit similar X-ray spectra and fluxes, but different X-ray emission is observed because of different absorption. Absorption should have different effects on X-rays of different energies. Indeed, a new result of ROSAT observation is that CTTS and WTTS have different X-ray hardness ratios. This can in principle be due to either intrinsically different spectra or to different absorption. For T Tauri stars most authors assume a one temperature spectrum (1 keV). If WTTS and CTTS are coeval, their X-ray spectra should not be different. Absorption can be caused by the interstellar medium, the intercloud gas, and circumstellar material. ROSAT observes in three energy channels: soft (0.1-0.4 keV), hard 1 (0.5-0.9 keV), and hard 2 (0.9-2.1 keV) (also, hard: $0.5 - 2.1$ keV). Let Z_s, Z_h, Z_{h1}, Z_{h2} be the count rates observed in the different energy bands soft, hard , hard 1, and hard 2, respectively, then for hardness ratios 1 and 2:

$$HR\,1 = \frac{Z_h - Z_s}{Z_h + Z_s} \quad \text{and} \quad HR\,2 = \frac{Z_{h2} - Z_{h1}}{Z_{h2} + Z_{h1}} \tag{9}$$

For further discussion and interpretation of different hardness ratios, it is important to know what fraction of the absorption of stellar X-rays is caused by interstellar medium, intercloud gas, and circumstellar material. By comparing results for Taurus-Auriga with other star forming regions like ScoCen (without intercloud gas), Lupus, and Perseus (more distant than Tau-Aur), we find evidence that intercloud absorption is not the main reason for different hardness ratios, because WTTS and CTTS show different hardness ratios even in ScoCen, where all intercloud gas was blown away by a recent supernova shock front. Also, by statistical reasons, we can exclude interstellar medium as the main absorbing material. CTTS seem to cluster along dark filaments, while WTTS are distributed all over the Taurus-Auriga star forming cloud complex. In all star forming regions studied, we find average hardness ratios of CTTS and WTTS to be very different. Therefore, given the different spatial distributions of CTTS and WTTS, it is for statistical reasons very unlikely that absorption of interstellar medium resulted in these differences.

Another argument for excluding different X-ray spectra as reason for different X-ray hardness ratios is the following. Assuming similar X-ray spectra, the only reason for different hardness ratios is different absorption. The harder the observed X-ray emission is, the more absorbed the X-rays are. Theoretically modeling the energy dependent effect of more material in the line of sight on absorption of X-rays gives the shift in hardness ratios 1 and 2 that results due to more absorption. We can therefore weight $HR\,1$ and $HR\,2$ according to their significance as tracer for more or less absorption in order to get the effective hardness. The weighted hardness should be correlated with visual extinction observed in the line of sight. We do have found this correlation. Detailed studies of X-ray emission of known T Tauri stars in the Taurus-Auriga star forming region will be published soon[18].

Being the only possible cause for absorption remaining, we find absorption by circumstellar material to be the main reason for different hardness ratios of CTTS and WTTS. This material consists of the boundary layer (hot gas) between star and dust and gas disk and/or the remnant star formation nebula. Therefore, X-ray hardness ratios can be interpreted as indirect evidence for the existence of circumstellar material.

Since absorption of X-rays of classical T Tauri stars happens mainly within the boundary layer (UV) and only stars with disks have a hot boundary layer, weak X-ray flux may be taken as indication for a disk. Weak-line T Tauri stars have no disk, i.e. no boundary layer. i.e. strong X-ray flux is observed. Whether the X-ray emission of a CTTS can be detected, may depend more or less only on the angle between the line of sight and the plane of the disks. If this angle lies in the range of around 30 to 60 degree, we do not have to look through steller wind or disk, therefore, X-ray are less absorbed. But not all CTTS with an angle δ in the above range should be expected to be detecable in X-rays, because accretion of material onto the star may be along tubes that are alined along the magnetic field lines. Hot gas in these tubes can absorb X-rays.

5. LUNAR OBSERVATORY OBSERVATIONS

Disks mainly emitt in infrared and UV wavelengths that are not accessible for ground-based observatories (due to atmospheric absorption). Infrared observation was done by the Infrared Astronomical Satellite (IRAS) and will be done by the Infrared Space Observatory (ISO). UV observation is done by the Extreme Ultraviolett Explorer (EUVE). X-ray observation was done by the *Einstein* observatory and is still be done by ROSAT. Direct imaging of protoplanetary disks is attempted with Hubble Space Telescope (HST), though HST can resolve only disk larger than typical T Tauri disks.

Lunar based observatories would have similar advantages as orbiting satellites have, and additionally several more (relevant for optical, IR, UV, and X):

- Near perfect vacuum

- High seismic stability

- Slow rotation (i.e. very long exposures possible)

- No fluid sheath or liquid core (rotation modeling with high accuracy)

- Stable thermal environment (sun-shielding easy)

- Earth-Moon-Interferometry (e.g. optical)

- Low gravity (large structures with no debris floating)

- Remote operation possible and cheap

Another very interesting observation would be low-frequency Earth-Moon interferometry in the millimeter wavelength regime in order to resolve the structure of disks.

6. ACKNOWLEDGEMENTS

7.REFERENCES

1. F.H. Shu, F.C. Adams, S. Lizano, "Star formation in molecular clouds: Observation and theory", Ann. Rev. Astron. Astrophy., **25**, pp 23, 1987

2. Neuhäuser, R. and Feitzinger, J.V., "Radial Migration of Planetesimals", Astrophy. and Space Science special issue, proceedings of the conference on "Planetary systems: Formation, evolution, and detection" held Dec. 1992 in Pasadena, USA, ed. by Burke, Rahe, and Roettger, in press, 1993

3. S.V.W. Beckwith, A.I. Sargent, R.S Chini, R. Güsten, "A survey for circumstellar disks around young stellar objects", A.J., **99**, pp 924, March 1990

4. I. Appenzeller and R. Mundt, "T Tauri stars", Astron. Astrophys. Ann. Rev., **27**, pp 293, 1989

5. C. Bertout, "T Tauri stars: Wild as dust", Astron. Astrophy. Ann. Rev., **27**, pp 351, 1989

6. M.F. Sterzik, "Strukturierungsprozesse in protoplanetaren Akkretionsscheiben", PhD thesis, Garching, Feb. 1993

7. G.E. Morfill and M.F. Sterzik, "Protoplanetary disks: Observations and physical processes", ESA Proc. 24th ESLAB Symp., pp 219, Nov. 1990

8. S.J. Kenyon and L. Hartmann, "Spectral energy distribution of T Tauri stars: Disk flaring and limits on accretion", ApJ, **323**, pp 714, Dec. 1987

9. A. Natta, "The temperature profile of T Tauri disks", ApJ, in press, Aug. 1993

10. J. Bouvier, submitted, 1993

11. S.V.W. Beckwith, A.I. Sargent, N.Z. Scoville, C.R. Masson, B. Zuckerman, T.G. Phillips, "Small-scale structure of the circumstellar gas of HL Tau and R Monocerotis", ApJ, **309**, pp 755, Oct. 1986

12. F.M. Walter, A. Brown, R.D. Mathieu, P.C. Myers, F.J. Vrba, "X-ray sources in regions of star formations. III. Naked T Tauri stars associated with the Taurus-Auriga complex", A.J., **96**, pp 297, July 1988

13. A.P. Boss and H.W. Yorke, "An alternative to unseen companions to T Tauri stars", ApJ, **411**, L99, July 1993

14. R. Neuhäuser, "Radialwanderung von Planetesimalen in der protoplanetaren Planetenentstehungsscheibe", Diplom theses, Bochum, July 1992

15. C. Hayashi, "Structure of the solar nebular, growth and decay of magnetic fields and effect of magnetic and turbulent viscosity on the nebula", Progr. Theor. Phy. Suppl., **70**, pp 35, 1981

16. T. Nakano, "Formation of planets around stars of various masses - I. Formulation and a star of one solar mass", Mon. Noc. R. astr. Soc., **224**, pp 107, 1987

17. E.D. Feigelson, J.M. Jackson, R.D. Mathieu, P.C. Myers, F.M. Walter, "An X-ray survey for pre-main-sequence stars in the Taurus-Auriga and Perseus molecular clouds", A.J., **94**, pp 1251, Nov. 1987

18. R. Neuhäuser, M.F. Sterzik, J.H.M.M. Schmitt, "ROSAT survey observation of T Tauri stars in Taurus-Auriga-Perseus", in preparation, 1993