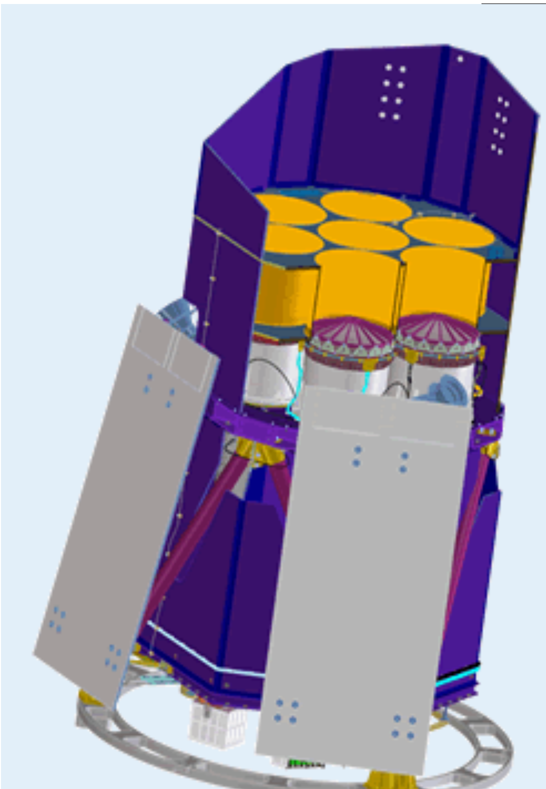
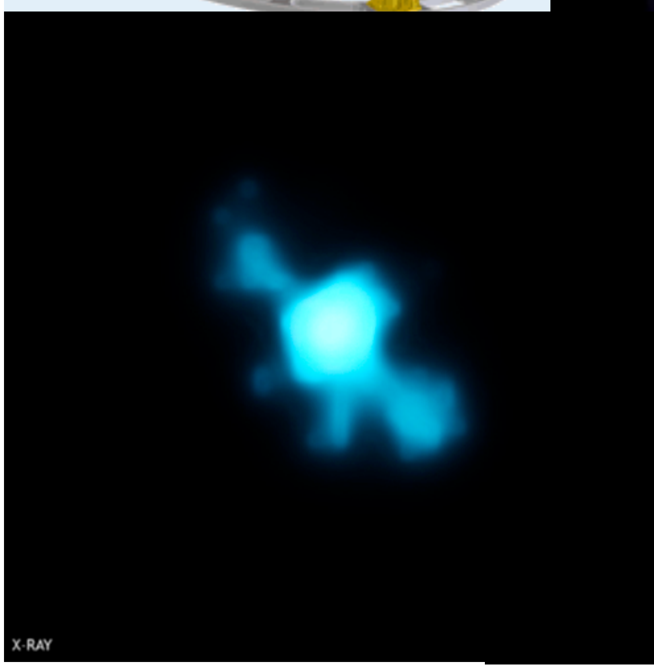
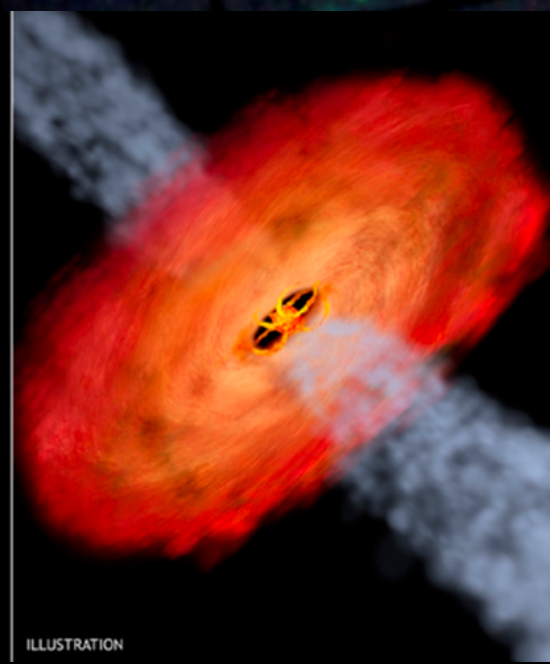
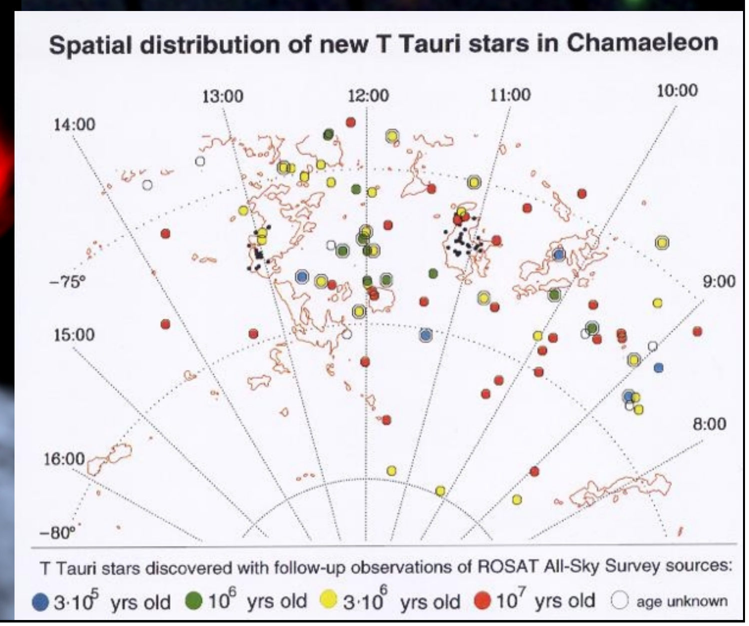


Prospects for eROSITA studies of nearby active stars and young stellar objects

Beate Stelzer
INAF / Osservatorio Astronomico di Palermo







eROSITA potential:

Complementary to Chandra/XMM studies
of physics of stellar atmospheres
and small-scale star formation

- probing galactic stellar population:
  A) Structure of the galactic disk
  B) Young associations in the solar neighborhood
  C) Diskless pre-main sequence stars

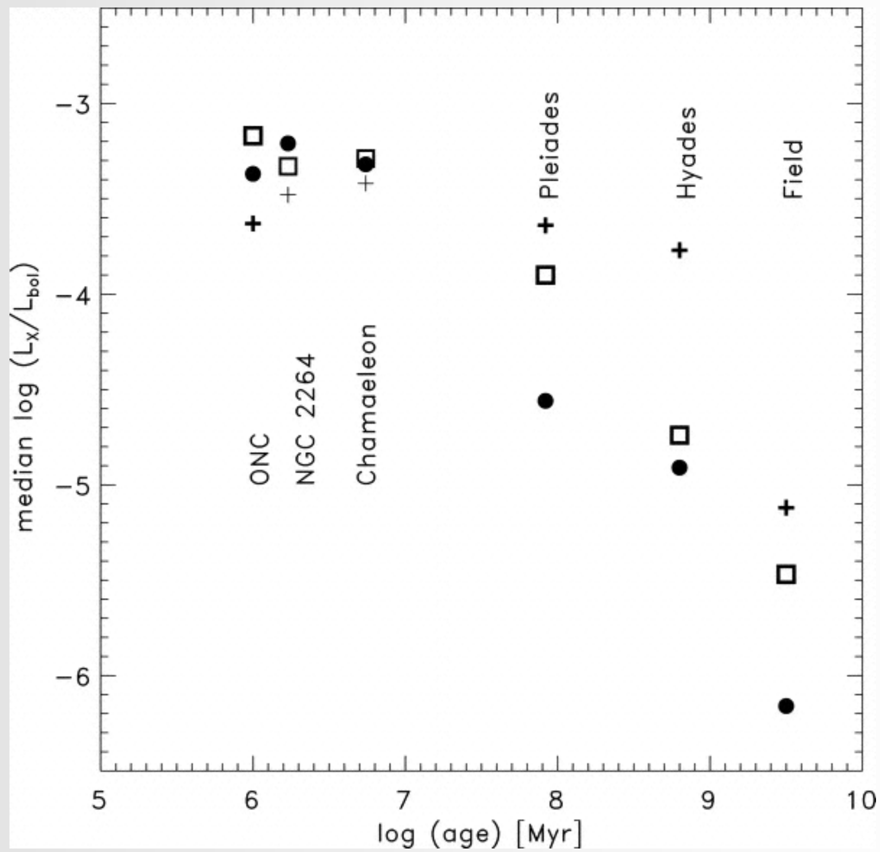
- Variability studies
  A) Flares
  B) Activity cycles

X-ray evolution with age

L_x drops by > 3 orders of mag
from the pre-main sequence (few Myrs)
to the main-sequence (Gyrs)

→X-ray surveys are "biased"
towards young stars

→L_x / age relation poorly constrained
for old stars



Preibisch & Feigelson (2005)

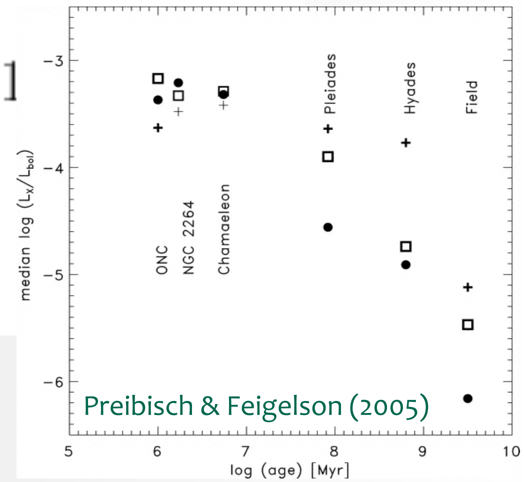
Rotation-activity-age connection on the main-sequence

Expected X-ray/age relation:

$$v_{\rm rot} \sim t^{\alpha} \qquad \alpha \sim -0.5 \text{ (Skumanich et al. 1972)}$$

$$L_{\rm X} \sim v_{\rm rot}^{\beta} \sim t^{\alpha\beta} \qquad \beta \sim 2 \text{ (Pallavicini et al. 1}$$

$$\longrightarrow \qquad L_{\rm X} \sim t^{-1}$$



Measuring X-ray/age relation:

A) comparison of observed and predicted galactic star counts

Problem:
Surveys either not deep enough (no old stars) or small area (few stars)

B) direct comparison of age/X-ray luminosity

Problem:
Age of individual stars not known

Rotation-activity-age connection on the main-sequence

Expected X-ray/age relation:

Potential for future wide-area X-ray surveys (eRosita):

high sensitivity + high number statistics

$f_{lim} \sim 10^{-14}$ erg/cm^2/s   All-Sky Survey

$f_{lim} \sim 10^{-16}$ erg/cm^2/s   All-Sky Survey at ecliptic poles

et al. 1991)

$$\longrightarrow \qquad L_x \sim t^{-1}$$

A) comparison of observed and predicted galactic star counts

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The relevance of X-ray source counts (vs. optical)

1.) L_x decreases of 3 orders of magnitude during the main sequence

→ young stars can be observed to much larger distance than old stars

2.) Galactic scale height depends on age

→ *Young stars dominate shallow stellar X-ray samples*
old stars dominate deep high latitude stellar X-ray samples

→ Galactic scale height depends on mass (stellar lifetime depends on mass)

→ X-ray source counts depend on age/mass distribution
(stellar birthrate can be inferred)

Predicting stellar source counts with a Galactic model

surveyed area

XLF = f (SpT)

number counts = $n = \frac{4\pi}{41,235} a \times$

$$\int_0^d \int_{L_{X\,min}}^{L_{X\,max}} \int_{M_{V\,min}}^{M_{V\,max}} \rho(M_V, l, b, r) f(L_X) dM_V dL_X r^2 dr$$

Favata et al. (1992)

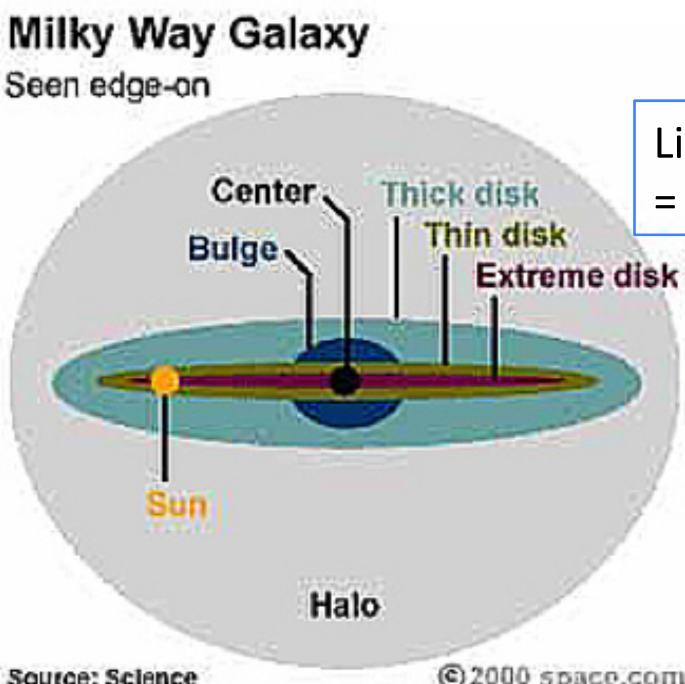
space density

Limiting distance = f (sensitivity, N_H)

from Gal. model:

$$\rho(z) = \rho_0 \exp\left(\frac{(R - R_{sun})}{H_0}\right) \exp\left(\frac{z}{h}\right)$$

$$H_0 = 3.5kpc, \quad h \equiv h(m_*, age)$$



http://rst.gsfc.nasa.gov/Sect20/A2a.html

Number counts and survey characteristics

Age parametrization:	$10^{7...8}$ yrs	$10^{8...9}$ yrs	$10^{9...10}$ yrs
with scale heights:	120 pc	200 pc	400 pc
with XLF:	Pleiades	Hyades	field stars

Number counts and survey characteristics

Age parametrization:	$10^{7\ldots8}$ yrs	$10^{8\ldots9}$ yrs	$10^{9\ldots10}$ yrs
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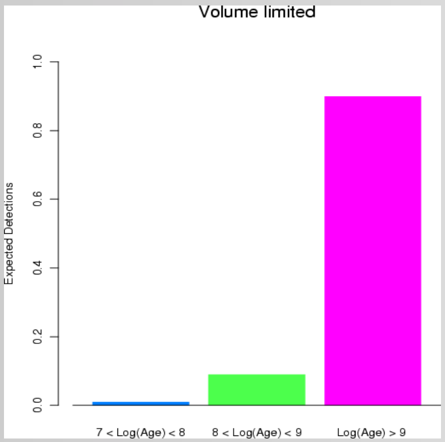
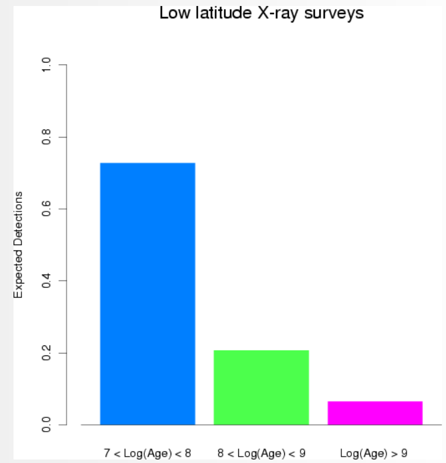
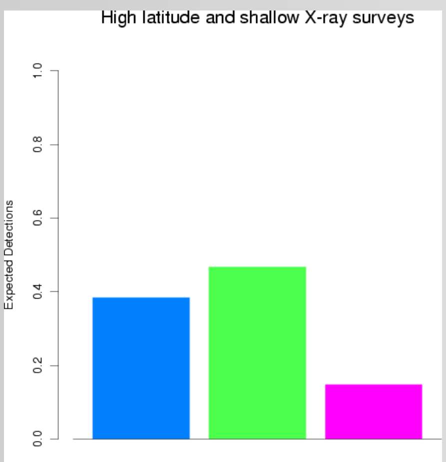


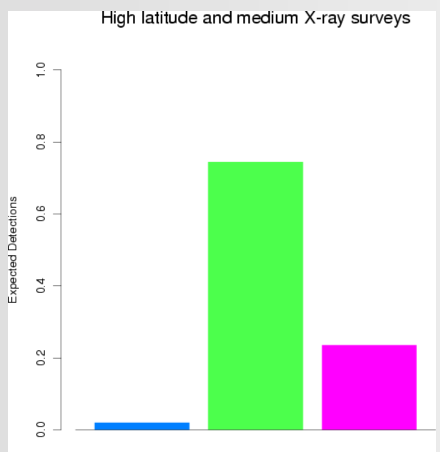
Volume limited surveys

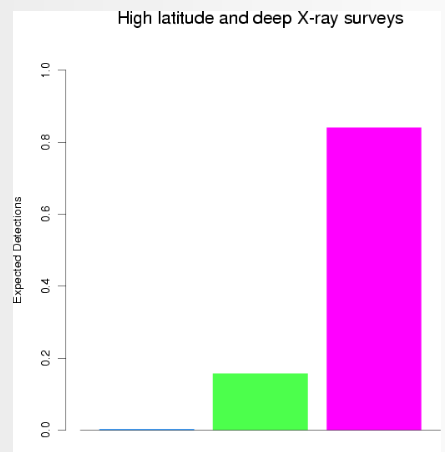
Low latitude X-ray surveys



High latitude X-ray surveys

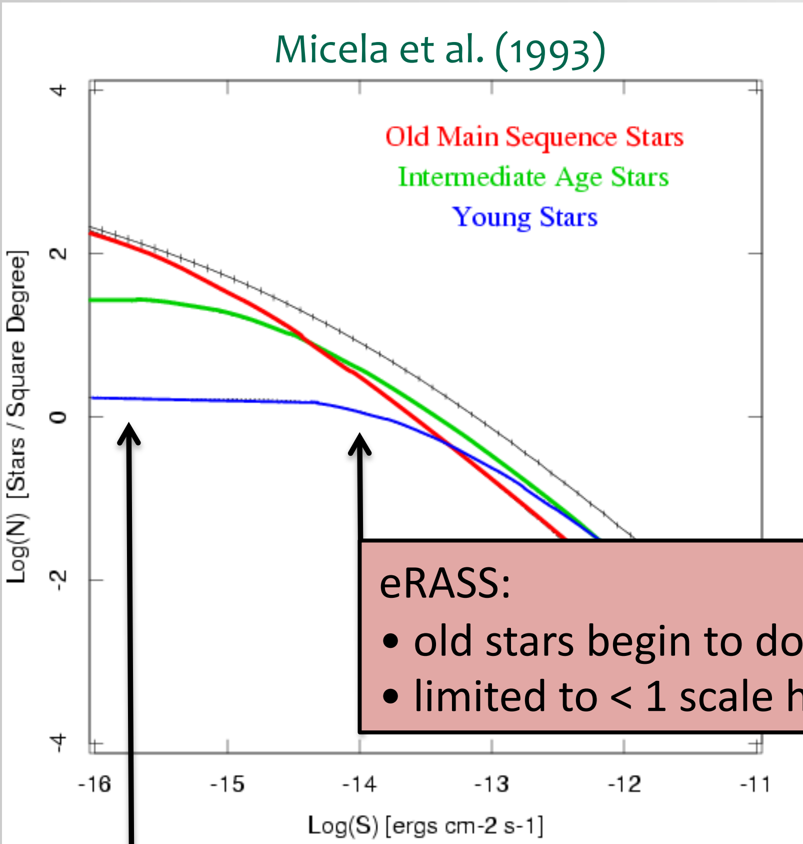






eROSITA stellar counts

Prediction for constant birthrate



eRASS:
- old stars begin to dominate
- limited to < 1 scale height

eRASS ecliptic poles:
- beyond scale height for young and i.med.age
- overwhelmingly dominated by old stars

Previous stellar counts from X-ray surveys

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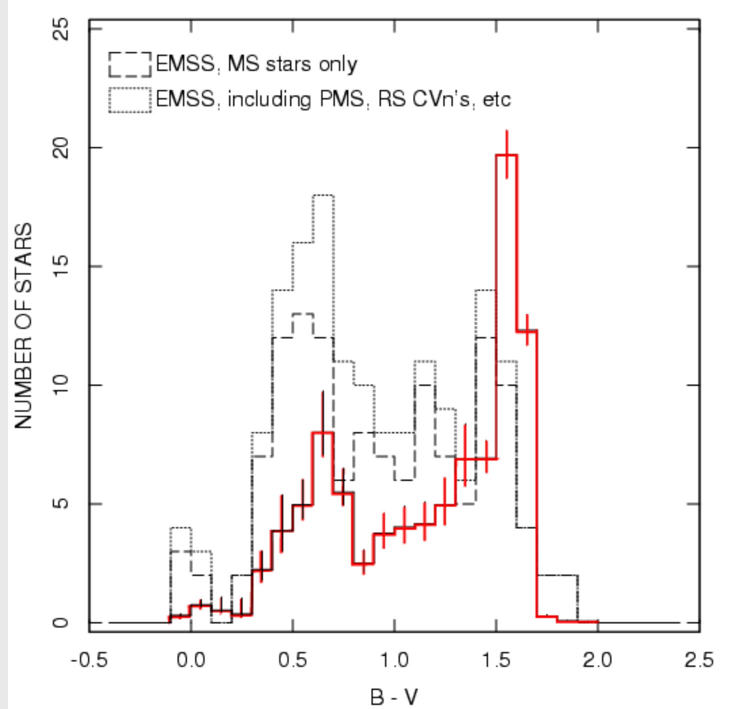
EMSS: 70 FG stars observed,
24 predicted

→ "excess of yellow stars"

Candidates:

A) Pop.II stars or giants
B) RS CVn binaries

C) Young active main-sequence stars



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EMSS: 70 FG stars observed,
24 predicted

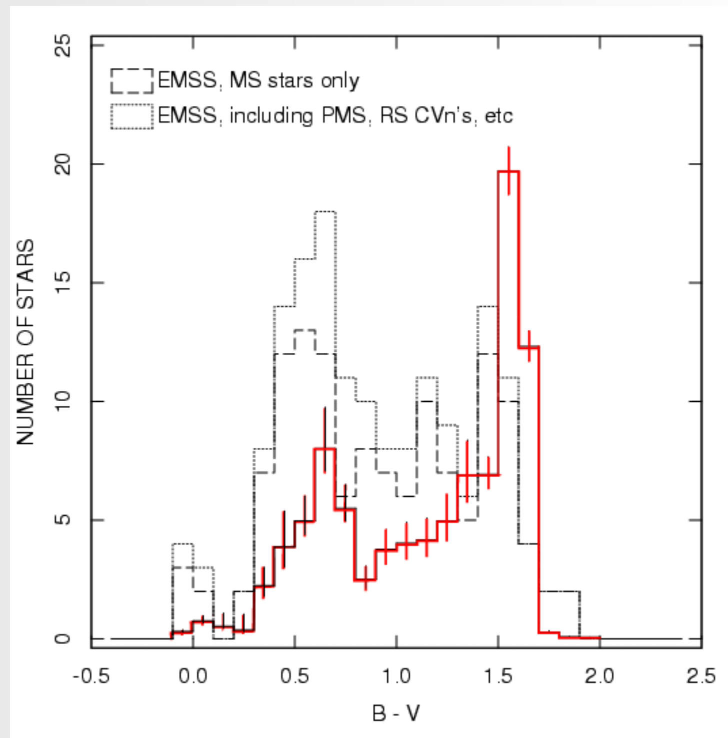
→ "excess of yellow stars"

Candidates:

A) Pop.II stars or giants ✗ low space density

B) RS CVn binaries ✗ at most 25 add. predicted but space density + scale height uncertain

C) Young active main-sequence stars ✓ high Li abundance



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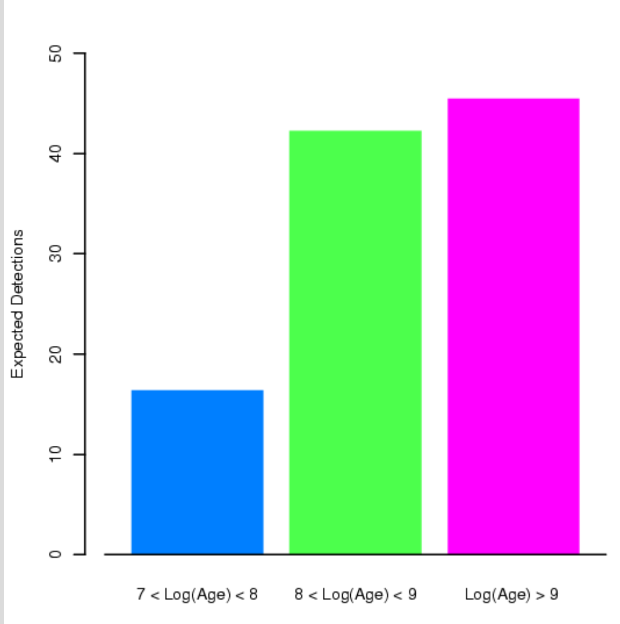
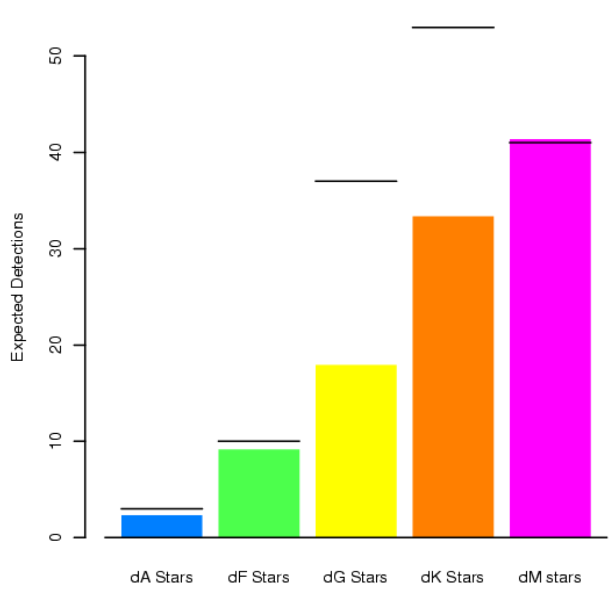
ROSAT North Ecliptic Pole:
(b ~ 30 deg; t <= 40ksec)

- mostly intermediate/old age dK/dM stars expected
- "yellow excess" persists, concentrated at young age





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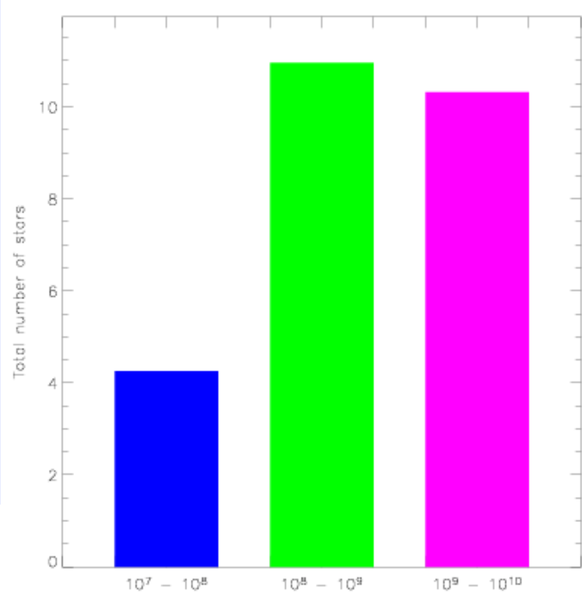
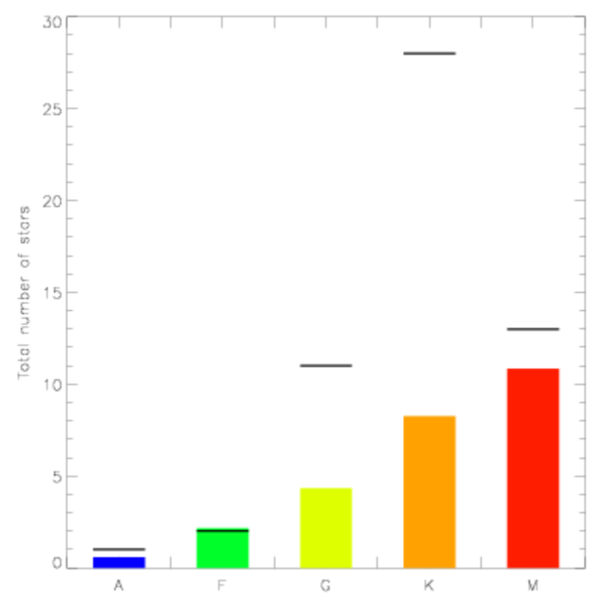
XMM Bright Serendip.Survey:
(b > 20 deg)

….again "yellow excess"

Problem with
Young active star interpretation:
Why no 'M-star excess' ?





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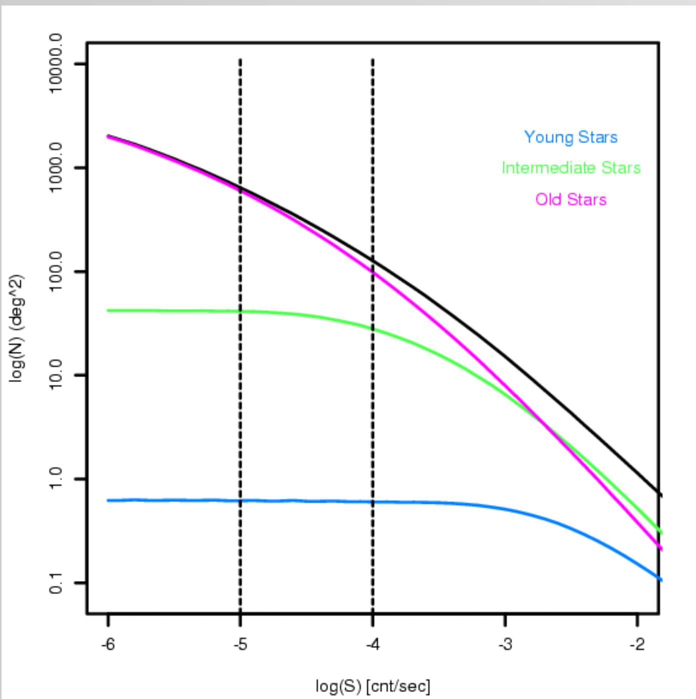
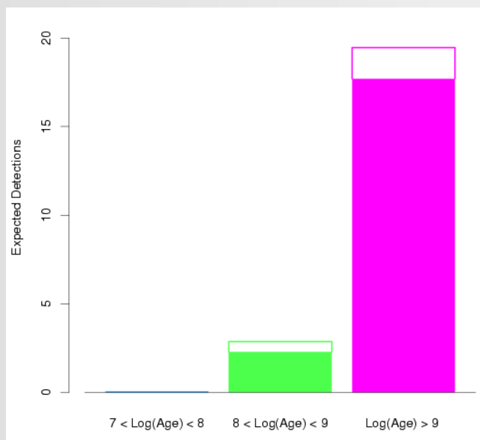


Chandra Deep Field North:

- all young and intermed. mass stars detected
- sample dominated by old dM stars



age parametrization:
Pleiades, Hyades, $L_x \sim t^{-1...-2}$

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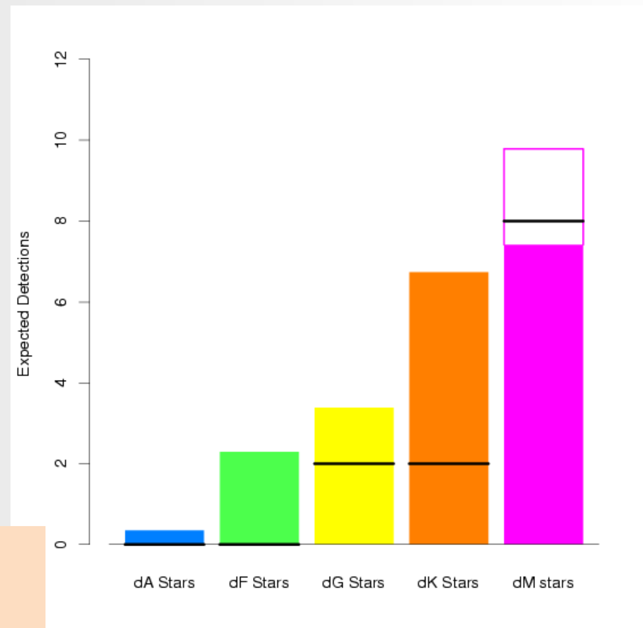
Chandra Deep Field North:

- age parametrization:
  Pleiades, Hyades, $L_x \sim t^{-1...-2}$

→ 39 stars predicted (11 observed)



CDFN:
Expected decay law ($L_x \sim t^{-1}$) produces too many stars
→ Decline of X-ray luminosity with age must be faster

Rotation-activity-age connection on the main-sequence

Expected X-ray/age relation:

$$v_{\rm rot} \sim t^{\alpha} \qquad \alpha \sim -0.5 \text{ (Skumanich et al. 1972)}$$

$$L_{\rm X} \sim v_{\rm rot}^{\beta} \sim t^{\alpha\beta} \qquad \beta \sim 2 \text{ (Pallavicini et al. 1991)}$$

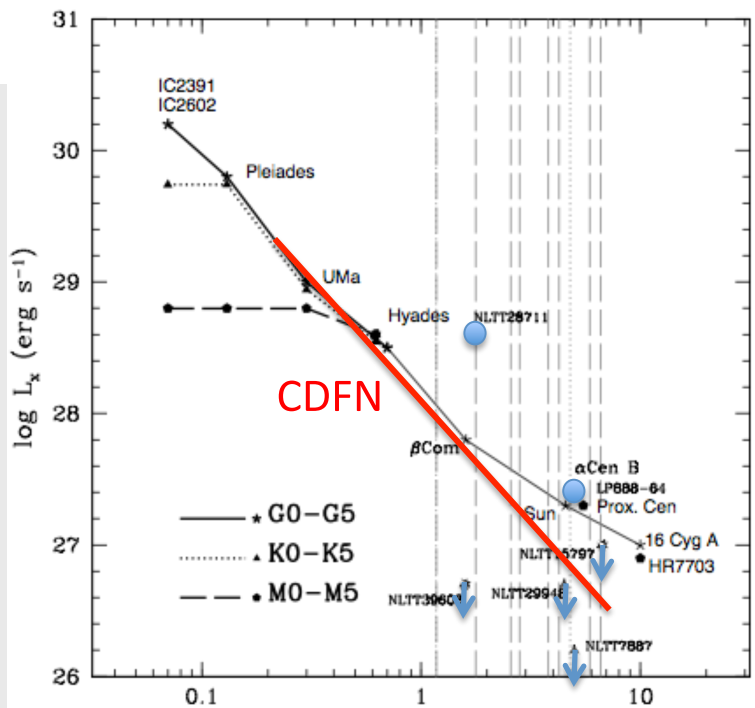
$$\longrightarrow \qquad L_{\rm X} \sim t^{-1}$$

B) Direct comparison of age/X-ray luminosity

Ongoing Chandra + XMM-Newton program (PI Ribas):

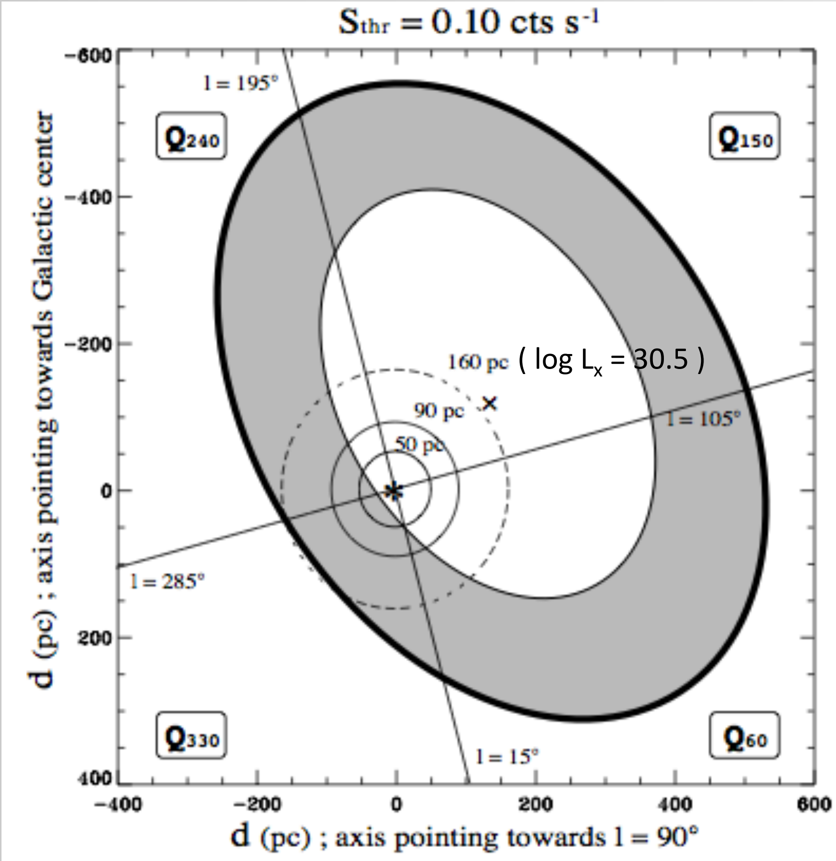
“Calibrating the time-evolution of the high-energy emission of GKM stars”

…for GKM star companions to WDs
…concentrating on M-stars



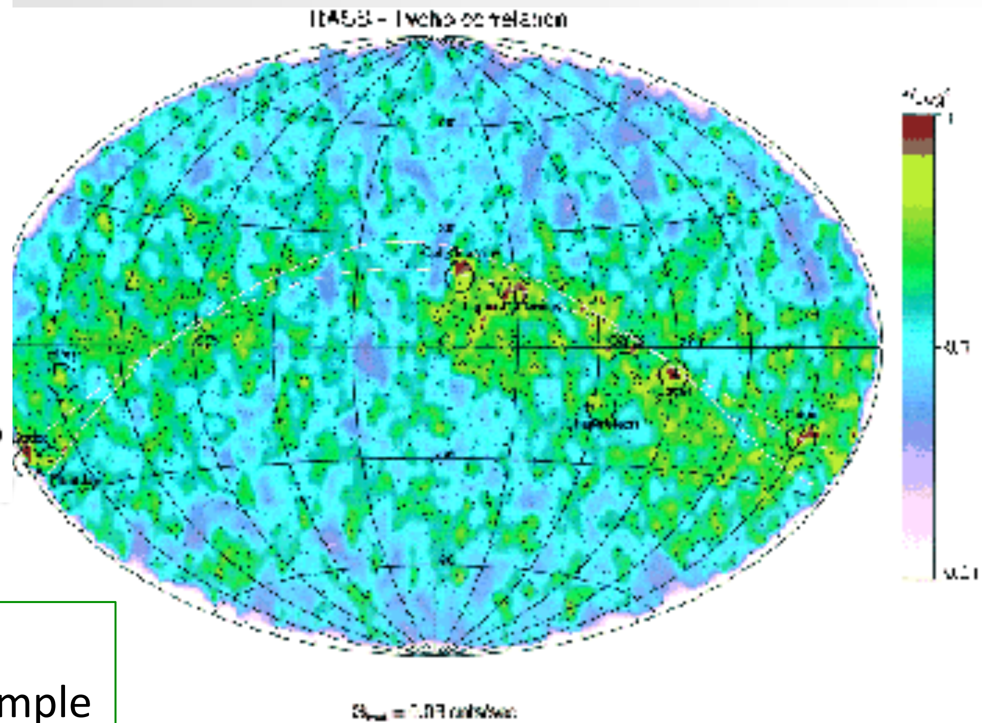
Garces et al, in prep.

The X-ray view of the Gould Belt



Guillout et al. (1998b)

The Gould Belt (Gould 1879)
(a ring of bright stars
tilted towards the Galactic plane)
was detected in the RASS.



8600 stars
of the RasTyc sample

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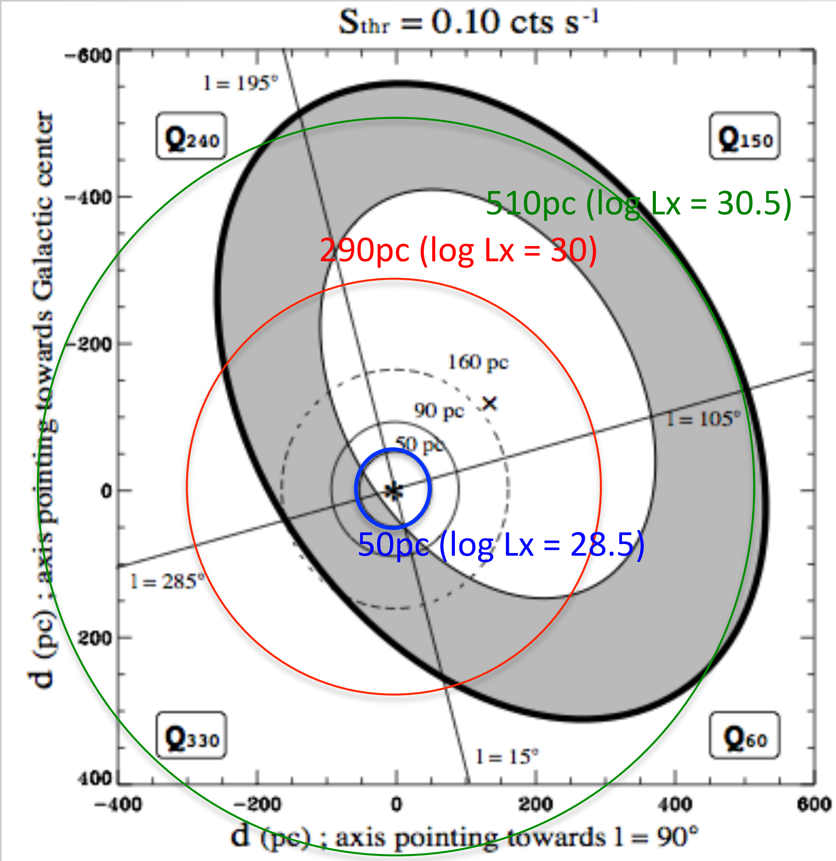

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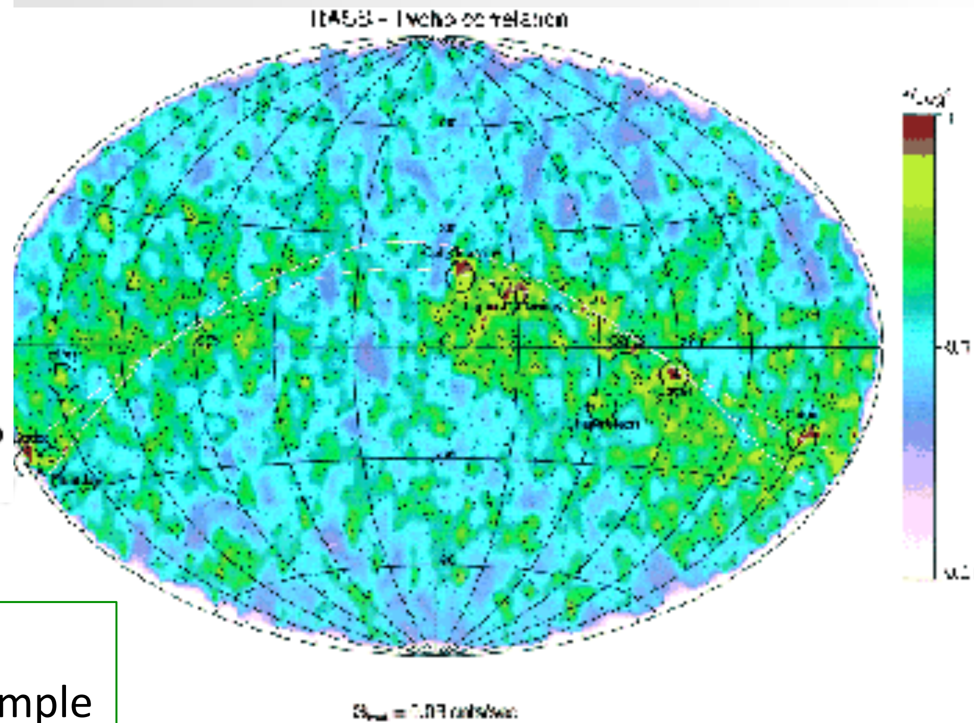

8600 stars
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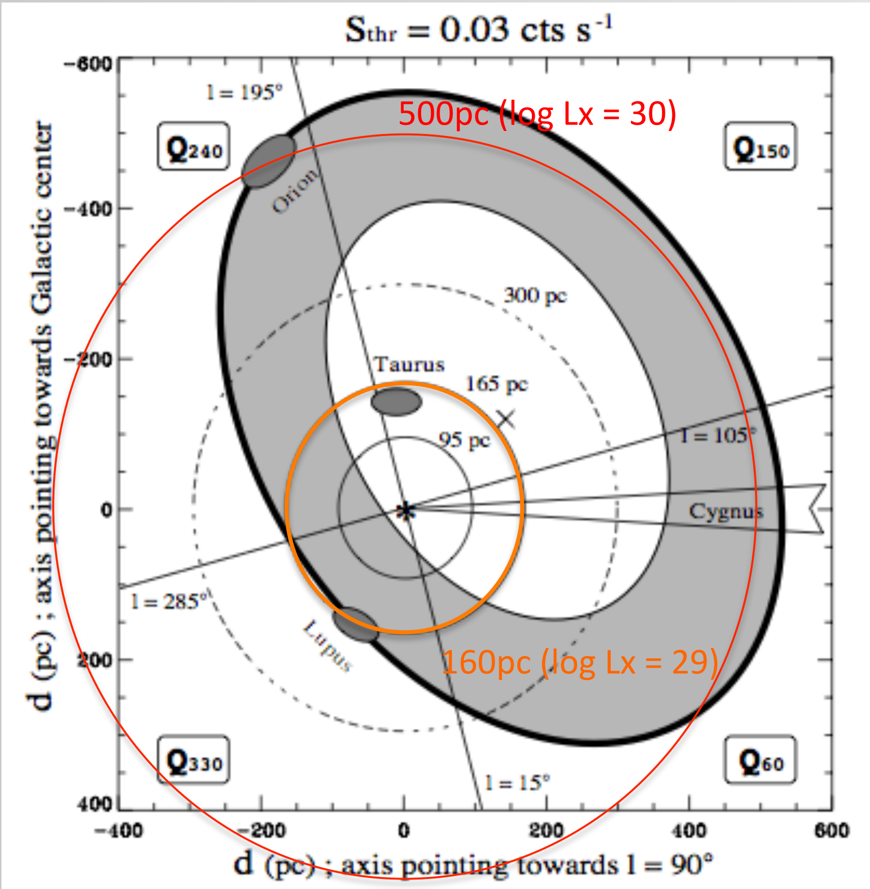
Guillout et al. (1998a)

eROSITA with $f_x = 10^{-13}$ erg/cm²/s:

- will reach into far side of Gould Belt for the X-ray brightest stars

The X-ray view of the Gould Belt



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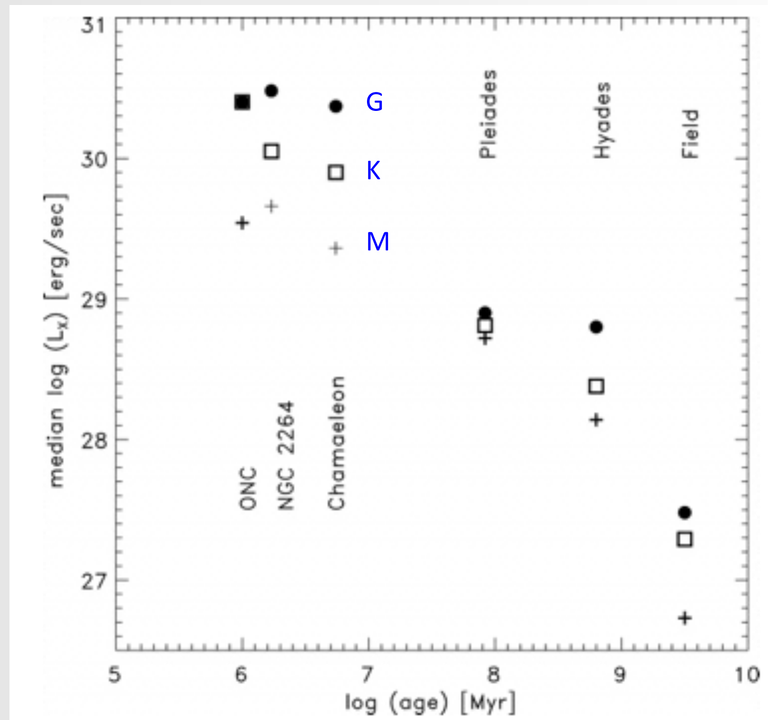
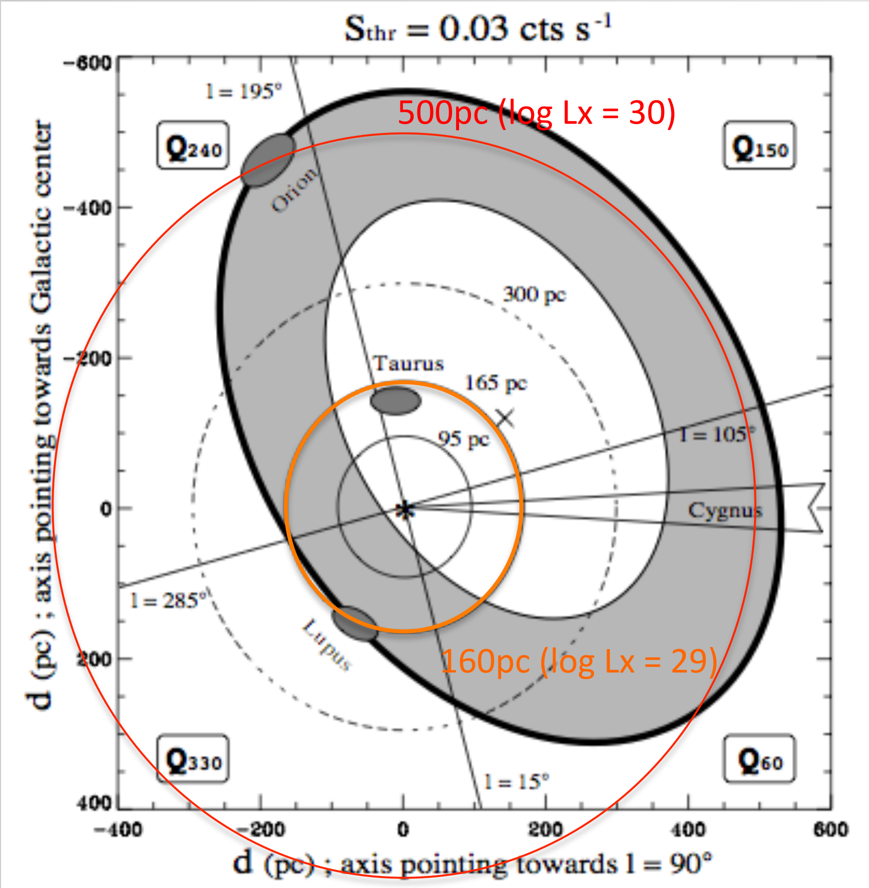


Preibisch & Feigelson (2005)

<u>eROSITA with $f_x = 3\ 10^{-14}$ erg/cm^2/s:</u>

- will cover the whole Gould Belt for the X-ray brightest stars
- will detect all K-type stars in nearby SFR (Taurus, Lupus, …)

The X-ray view of the Gould Belt



Guillout et al. (1998b)

The Gould Belt
(a ring of bright stars
tilted towards the Galactic plane)
was detected in the RASS.

Magnitude limit Tycho: V = 10.5
→ SpT A5 @ 500pc
→ no P.M. available for eROSITA stars

need GAIA
with magnitude limit: V = 20 (SpT M)

eROSITA with $f_x = 3\ 10^{-14}$ erg/cm^2/s:

- will cover the whole Gould Belt for the X-ray brightest stars
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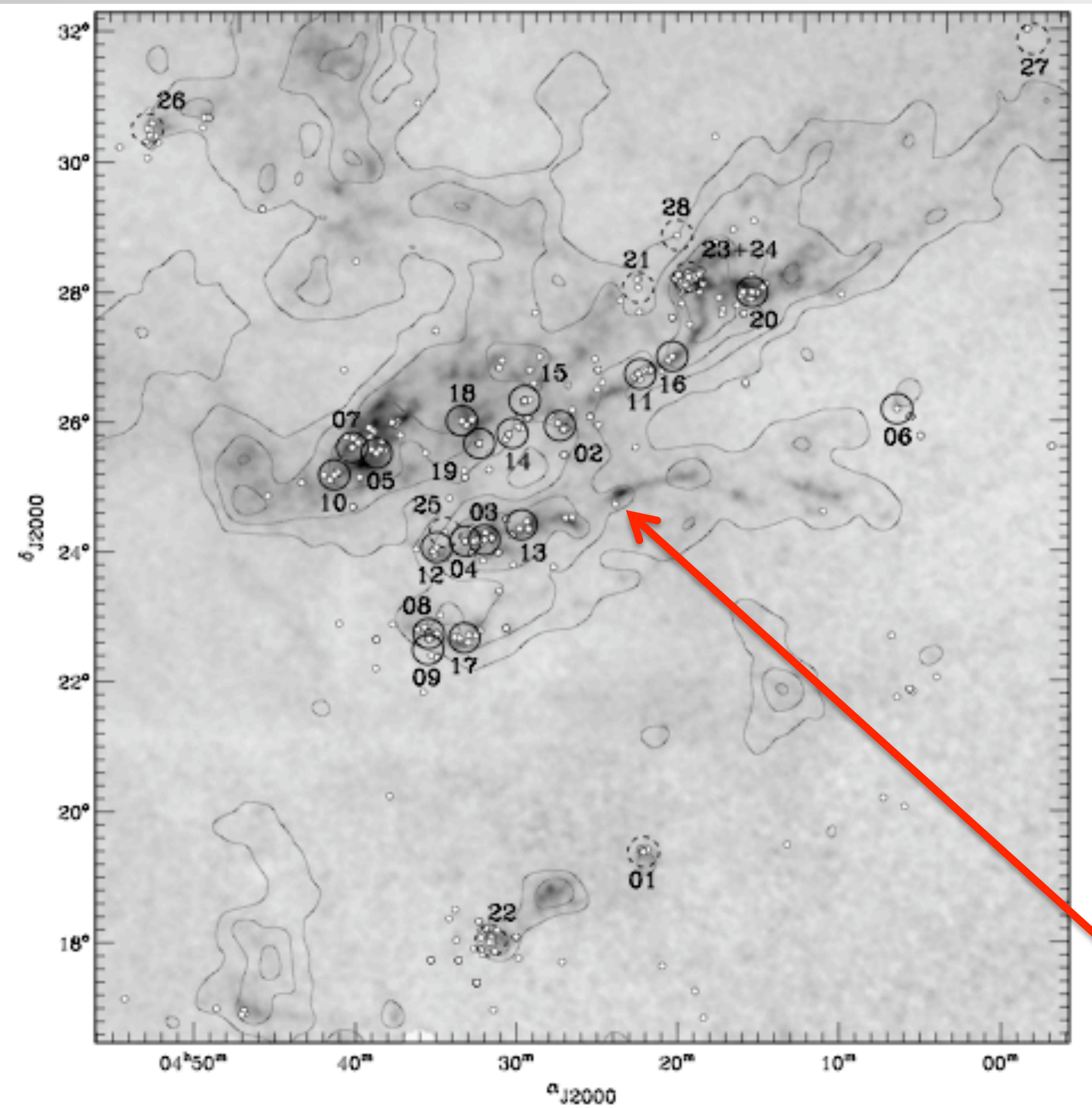
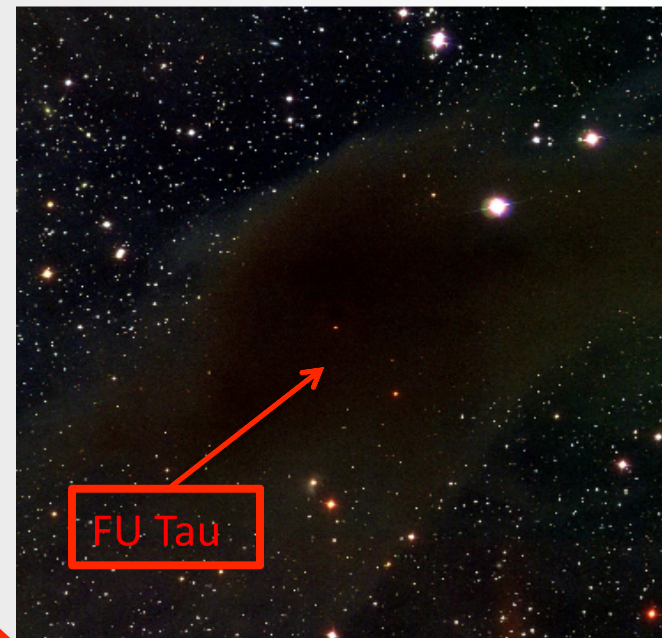
XMM-Newton Extended Survey in Taurus (XEST)



19 x 30 ks XMM-Newton
in Taurus Molecular cloud
(+ 9 XMM-Newton fields
in Taurus from archive)

PI Guedel

15 papers in A&A Special Issue 468



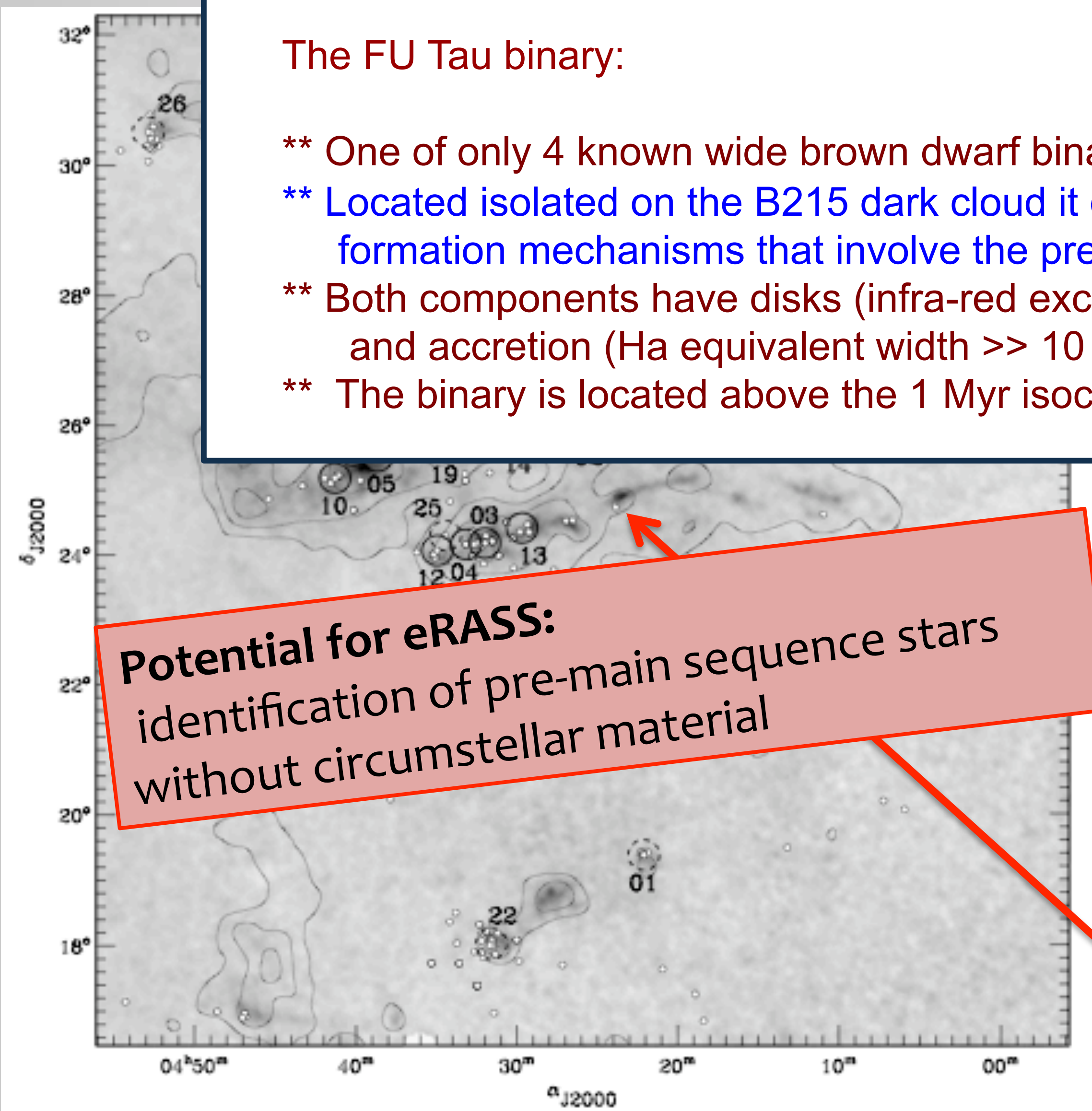
B215

Luhman et al. (2009)

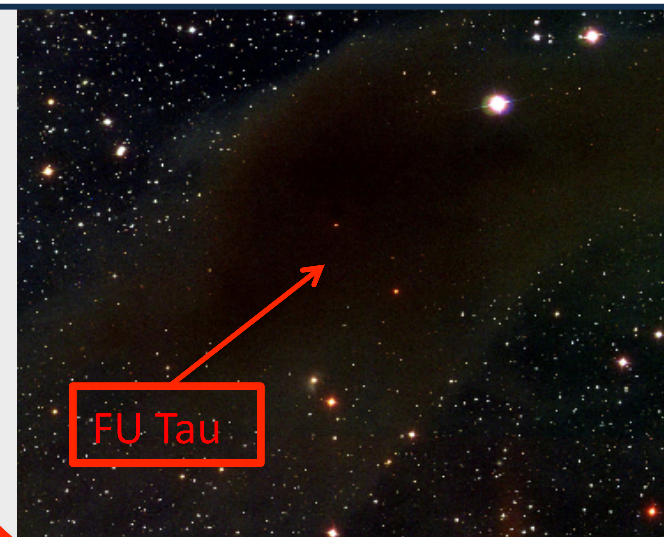
XMM-Newton Extended Survey in Taurus (XEST)

The FU Tau binary:

** One of only 4 known wide brown dwarf binaries (200 AU; M7.25+M9.25).
** Located isolated on the B215 dark cloud it questions brown dwarf formation mechanisms that involve the presence of higher-mass stars.
** Both components have disks (infra-red excess) and accretion (Ha equivalent width >> 10 Å)
** The binary is located above the 1 Myr isochrone in the HRD, esp. FU Tau A



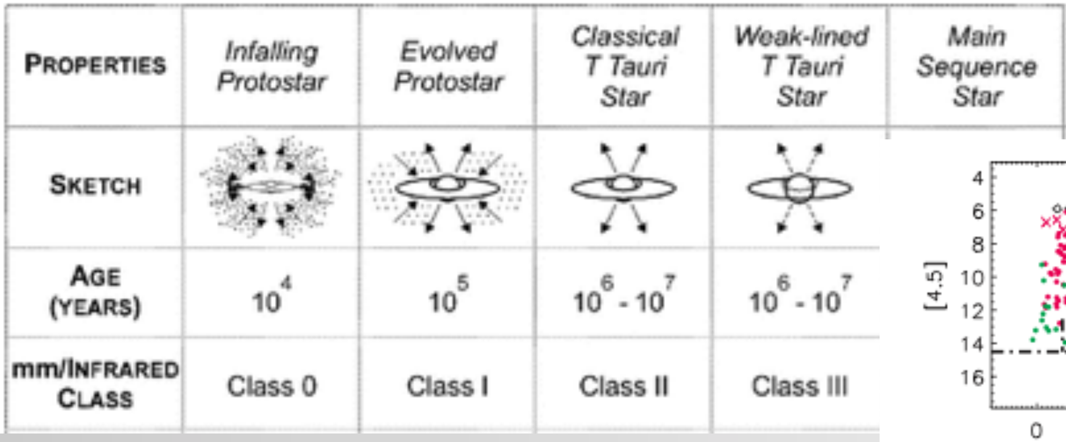
Potential for eRASS:
identification of pre-main sequence stars without circumstellar material



B215

Luhman et al. (2009)

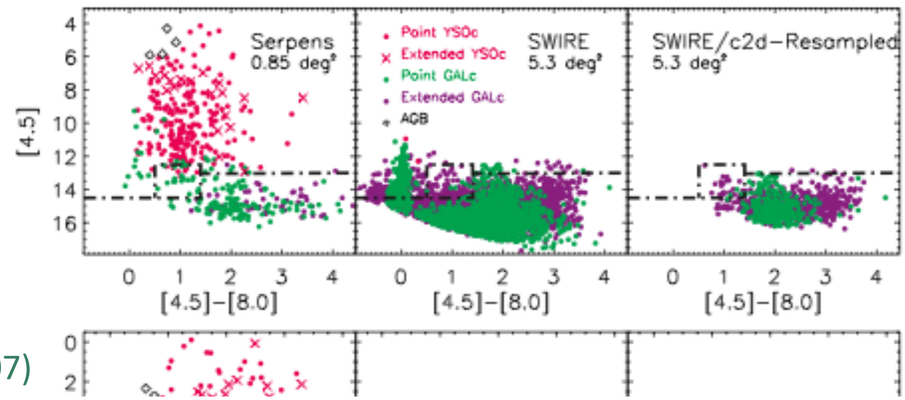
Relevance of X-rays for identification of YSOs



PROPERTIES	Infalling Protostar	Evolved Protostar	Classical T Tauri Star	Weak-lined T Tauri Star	Main Sequence Star
SKETCH					
AGE (YEARS)	10^4	10^5	$10^6 - 10^7$	$10^6 - 10^7$	
mm/INFRARED CLASS	Class 0	Class I	Class II	Class III	

Feigelson & Montmerle (1999)

Spitzer c2d survey (of 5 nearby SFR) efficiently selects Class 0 – II sources…



Harvey et al. (2007)

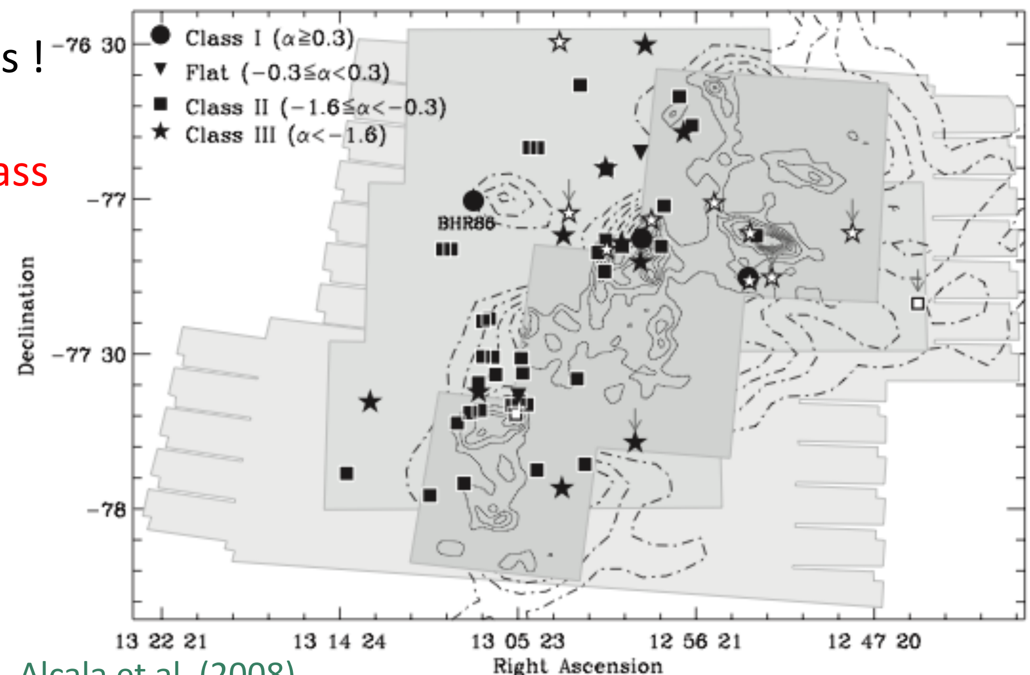
….but miss large fraction of Class III sources !

X-ray emission does not depend on YSO class
→ Efficient to identify Class III

High extinction in SFRs
--> Need hard X-ray survey

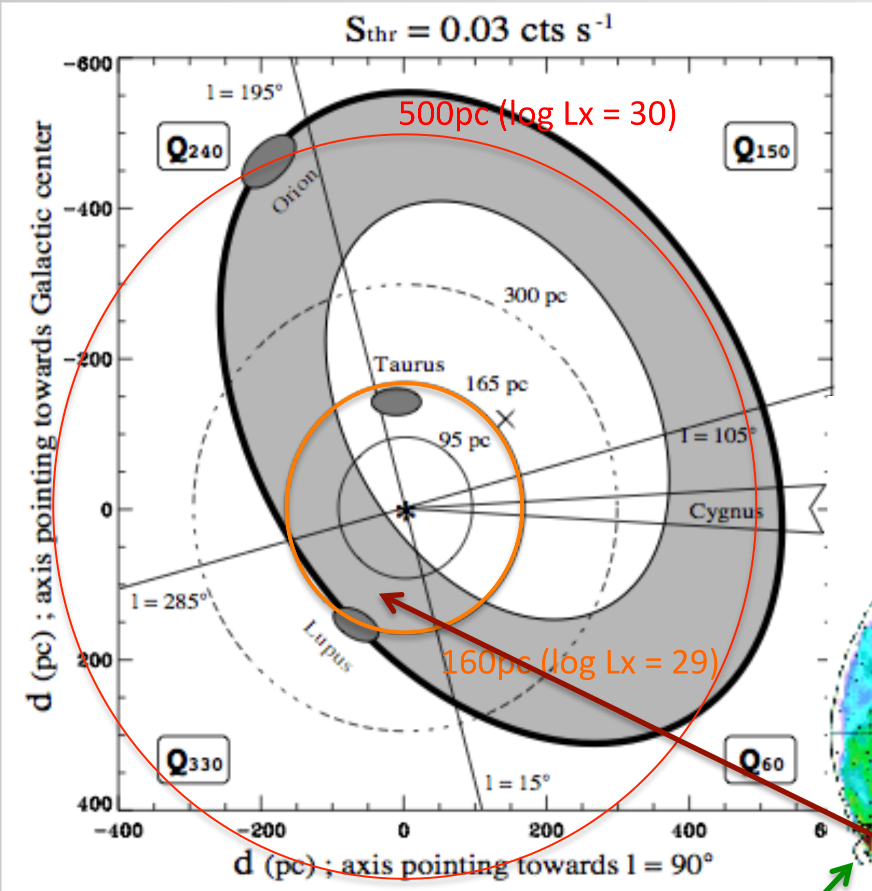
$$\frac{f_x(A_V\!=\!20)}{f_x(A_V\!=\!0)} = 1/2 \text{ @ 2.5-10.0 keV}$$

$$\frac{f_x(A_V\!=\!20)}{f_x(A_V\!=\!0)} = 1/50 \text{ @ 0.2-2.5 keV}$$



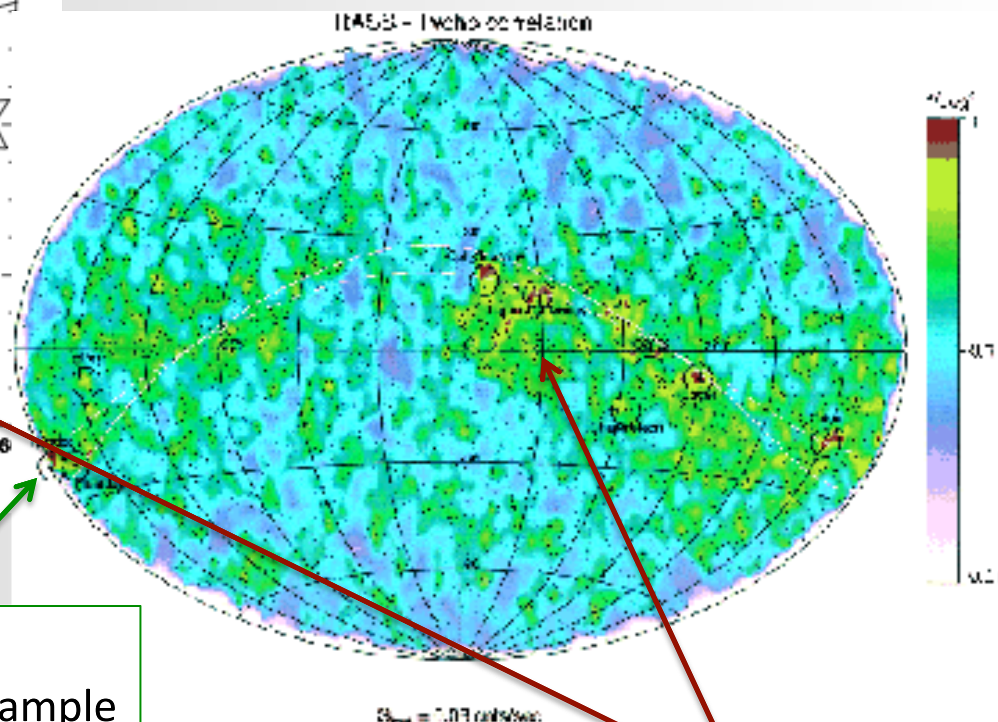
Alcala et al. (2008)

The X-ray view of the Gould Belt



Guillout et al. (1998b)

The Gould Belt
(a ring of bright stars
tilted towards the Galactic plane)
was detected in the RASS.



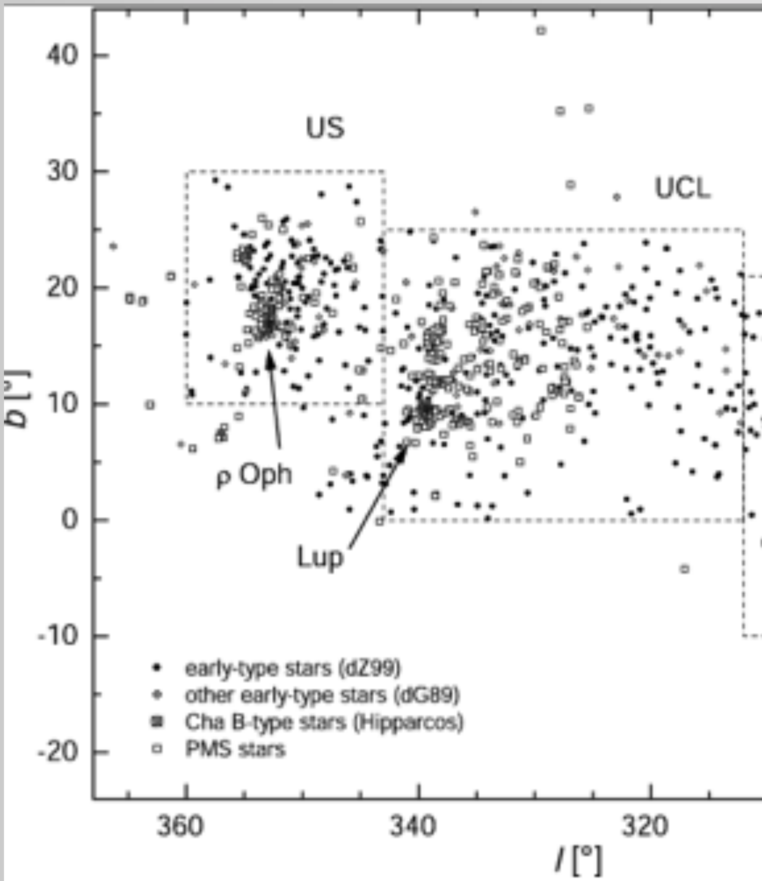
Guillout et al. (1998a)

8600 stars
of the RasTyc sample

Sco-Cen-Lup

eROSITA with $f_x = 3\ 10^{-14}$ erg/cm^2/s:
- will cover the whole Gould Belt for the X-ray brightest stars
- will detect all K-type stars in nearby SFR (Taurus, Lupus, …)

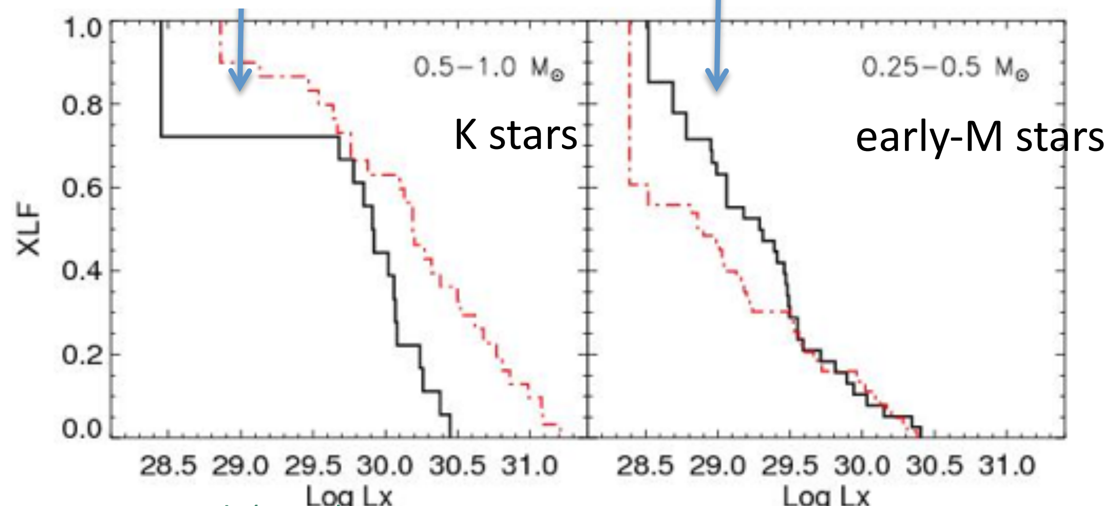
Large-scale star formation in Sco-Cen-Lup



Sartori et al. (2003)

eROSITA @ 150pc:
log L_x [erg/s] ~ 29.0

X-ray luminosities @ 5 Myrs
(λOri and σOri clusters)



Franciosini et al. (2011)

LCC. Only over the past decade has the availability of high quality astrometry (*Hipparcos*, Tycho, etc.) and the *ROSAT* All-Sky Survey, enabled the efficient identification of low-mass UCL and LCC members. Given the numbers of B-type stars in UCL and LCC, there are probably *thousands* of low-mass members awaiting discovery.

Preibisch & Mamajek (2010)

Sco-Cen OB associations:
~150 B stars
3 subgroups: 5-15 Myrs (Usco,LCC,UCL)
100s low-mass members from RASS

Preibisch & Mamajek (2010)

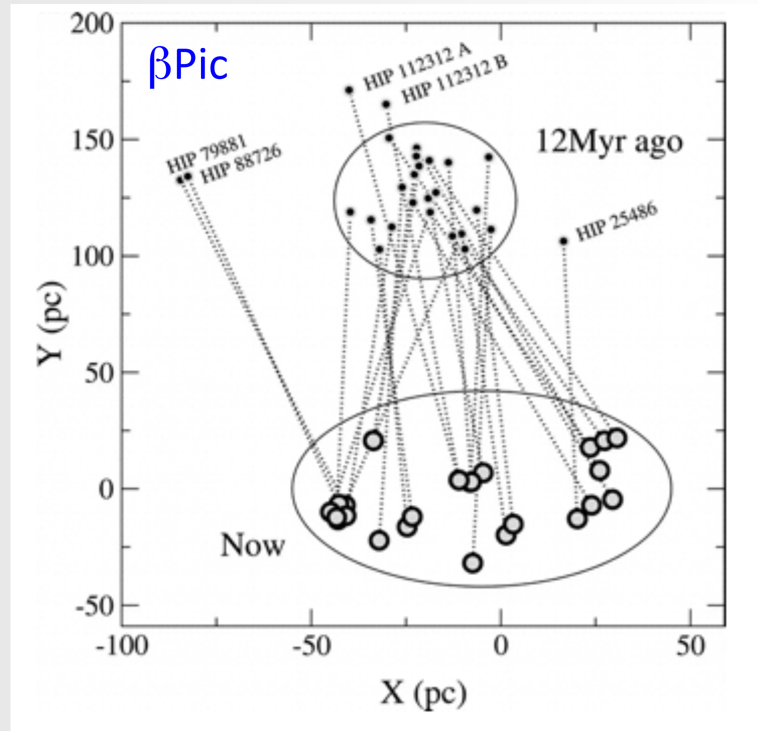
→ Majority of K-stars and > 50% of early M-stars
In Usco detectable with eROSITA

Local star formation history
(young, nearby stellar associations)

Table 2. Space distribution, mean distances and ages of the nearby associations

Assoc.	X [pc]	X Range [pc]	Y [pc]	Y Range [pc]	Z [pc]	Z Range [pc]	D [pc]	Age [Myr]
β Pic	20	-32/76	-5	-33/21	-15	-29/-1	31±21	10
Tuc-Hor	3	-61/43	-24	-47/-4	-35	-44/-30	48±7	30
Col	-42	-106/9	-56	-168/1	-47	-99/6	82±30	30
Car	14	-2/33	-94	-154/-39	-17	-33/5	85±35	30
TW Hya	15	2/34	-44	-61/-26	21	10/27	48±13	8
ϵ Cha	50	34/60	-92	-105/-78	-28	-44/-12	108±9	6
Oct	22	-79/142	-106	-138/-60	-68	-85/-38	141±34	20?
Argus	5	-55/64	-115	-154/-6	-18	-67/8	106±51	40
AB Dor	-6	-94/73	-14	-131/58	-20	-66/23	34±26	70

Torres et al. (2008)

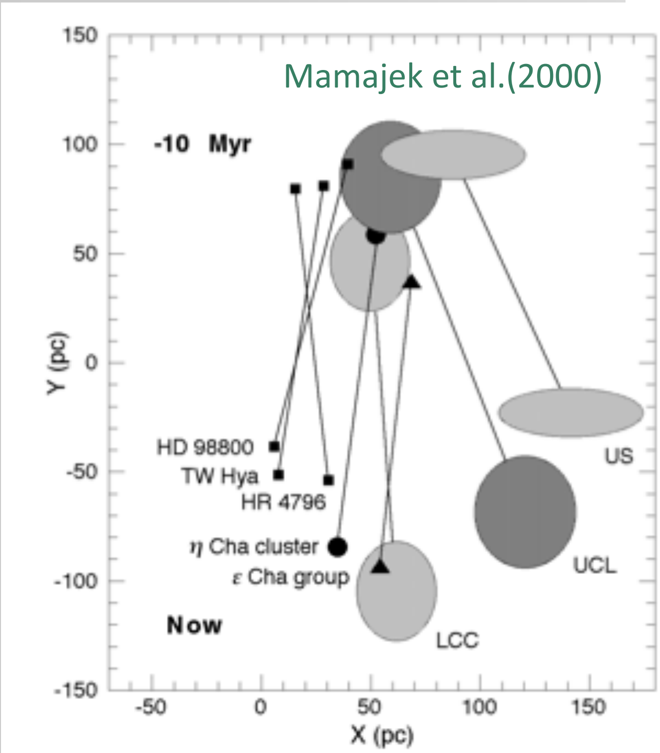


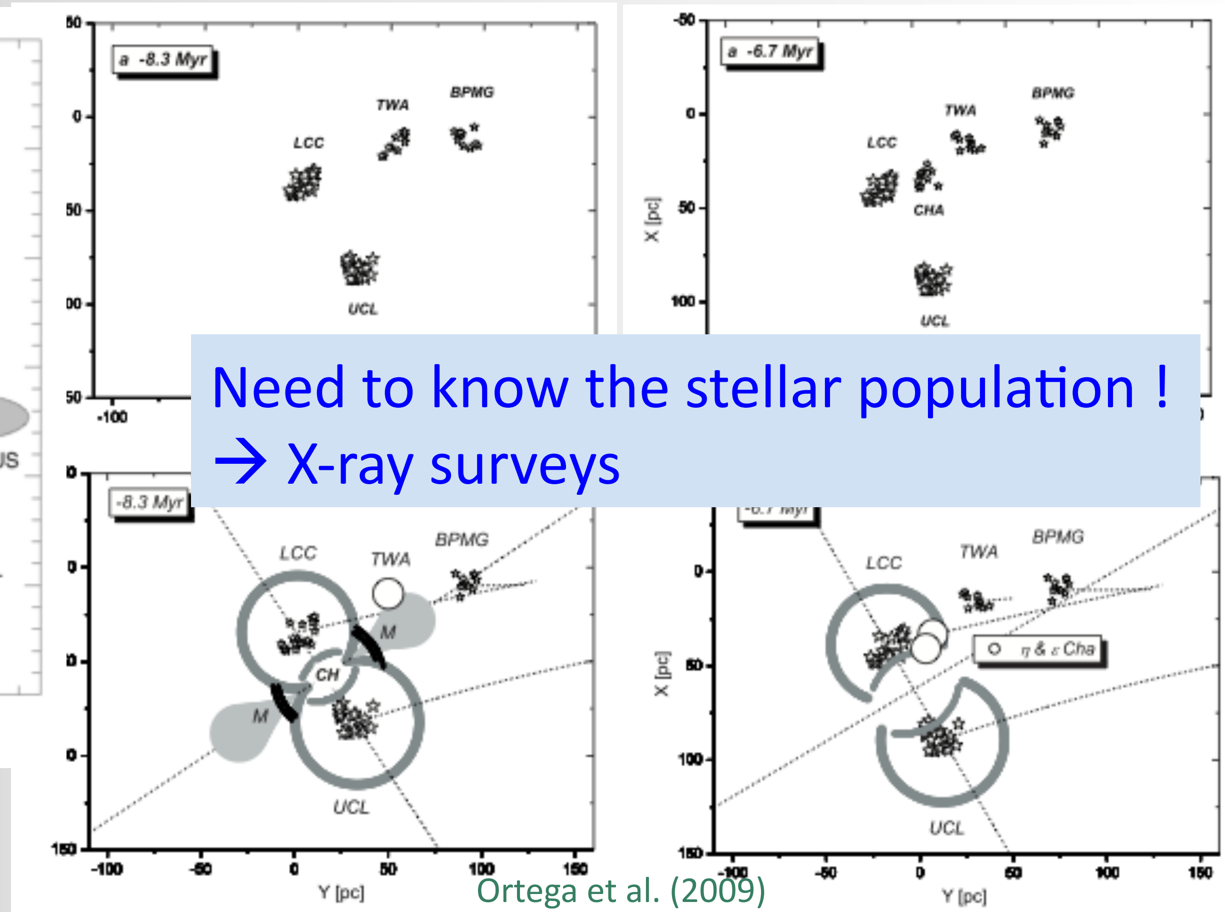
Song et al. (2003)

9 young comoving groups
In the solar neighborhood

Backward integration of orbital motion
For individual stars
→ Common origin

Controversial views of local star formation history





Need to know the stellar population !
→ X-ray surveys

Backtracing stellar associations into the past:

A) All paths converge (Mamajek et al. 2000; Ortega et al 2009)

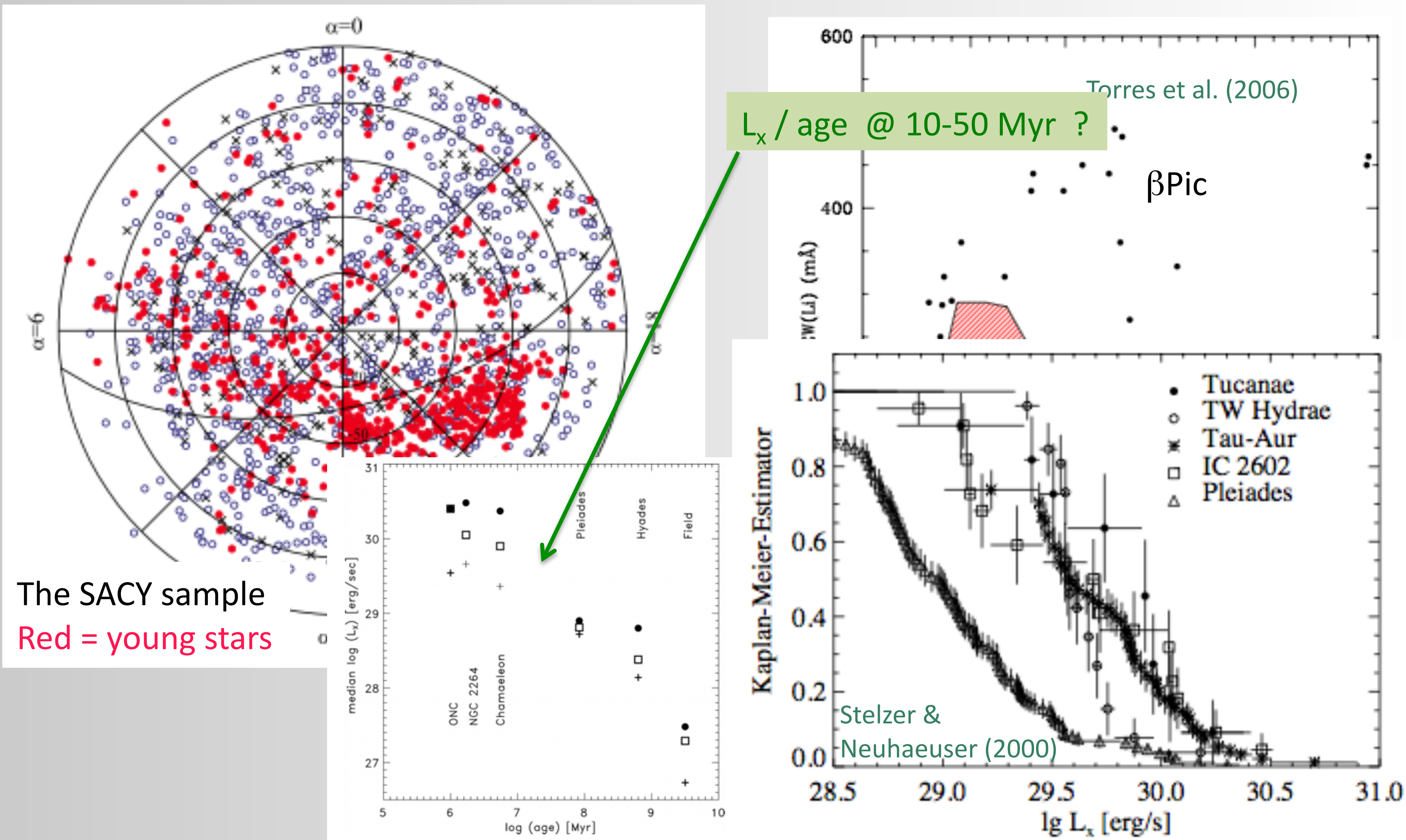
←→

B) Young associations distant from Sco-Cen by 20-100pc at al time
SF in UCL/LCC triggered by spiral arm shock;
SF in YLAs triggered by LCC/UCL SN (Fernandez et al. 2008)

Search for associations containing young stars (SACY)

Cross-correlation for southern Tycho/Hipparcos catalog with ROSAT/BSC

→Spectroscopic follow-up for ~ 2000 stars



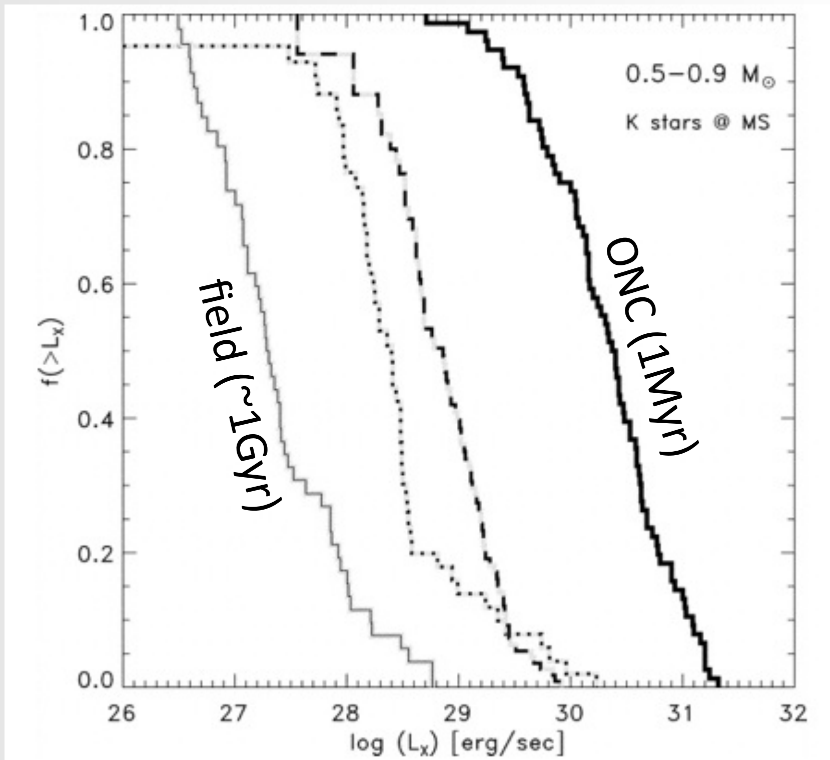
X-ray variability
as a tool to discover young stars ?

XMM-Newton slew: log L_x [erg/s] = 30.1 17 counts in ~10sec
RASS: log L_x [erg/s] < 29 assuming $f_{lim} = 10^{-13}$ erg/cm²/s

Spectral Type K
Photometric distance ~ 100 pc

XMM/TOO (13 Oct 2011)
will reach log L_x [erg/s] = 27.5

Spectroscopic follow-up planned:
Lithium, RV → age, space motion



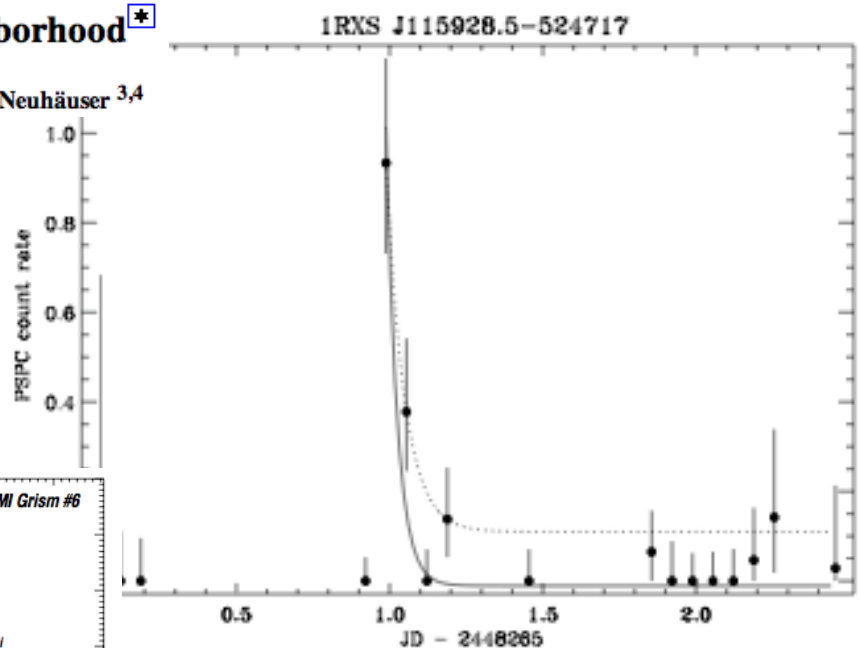
Preibisch & Feigelson (2005)

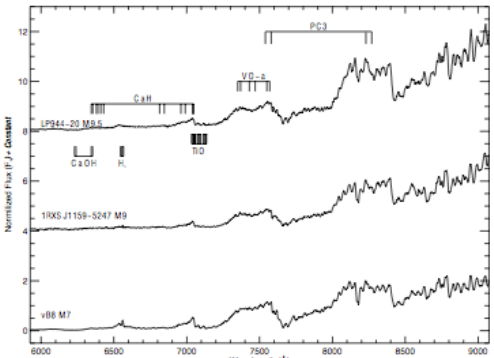
Identifying stars by their X-ray variability

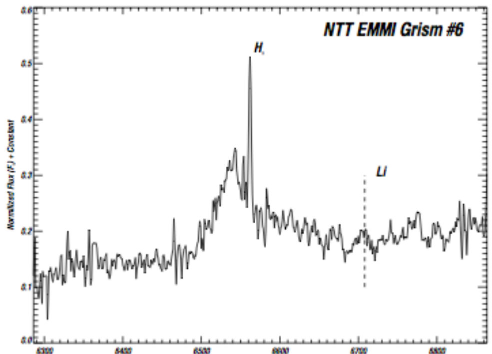
A new strongly X-ray flaring M 9 dwarf in the solar neighborhood

V. Hambaryan[1] - A. Staude[1] - A. D. Schwope[1] - R.-D. Scholz[1] - S. Kimeswenger[2] - R. Neuhäuser [3,4]

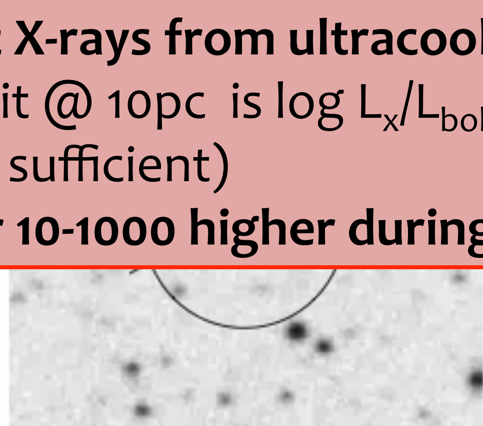
Optical follow-up of a RASS flaring source:
- spectral type M9 (very low-mass star)
- strong Hα emission
- d ~ 11 pc (very nearby)
- high proper motion

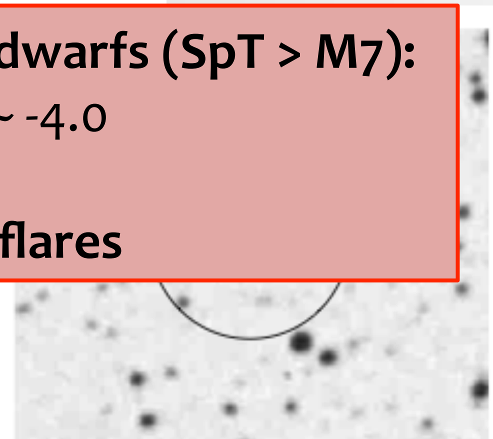


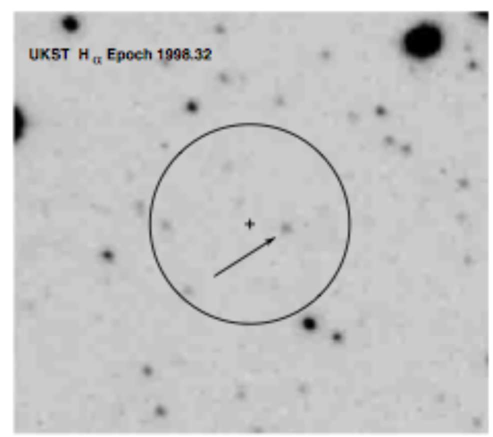




Quiescent X-rays from ultracool dwarfs (SpT > M7):
eRASS limit @ 10pc is log L_x/L_{bol} ~ -4.0
(likely not sufficient)
But factor 10-1000 higher during flares

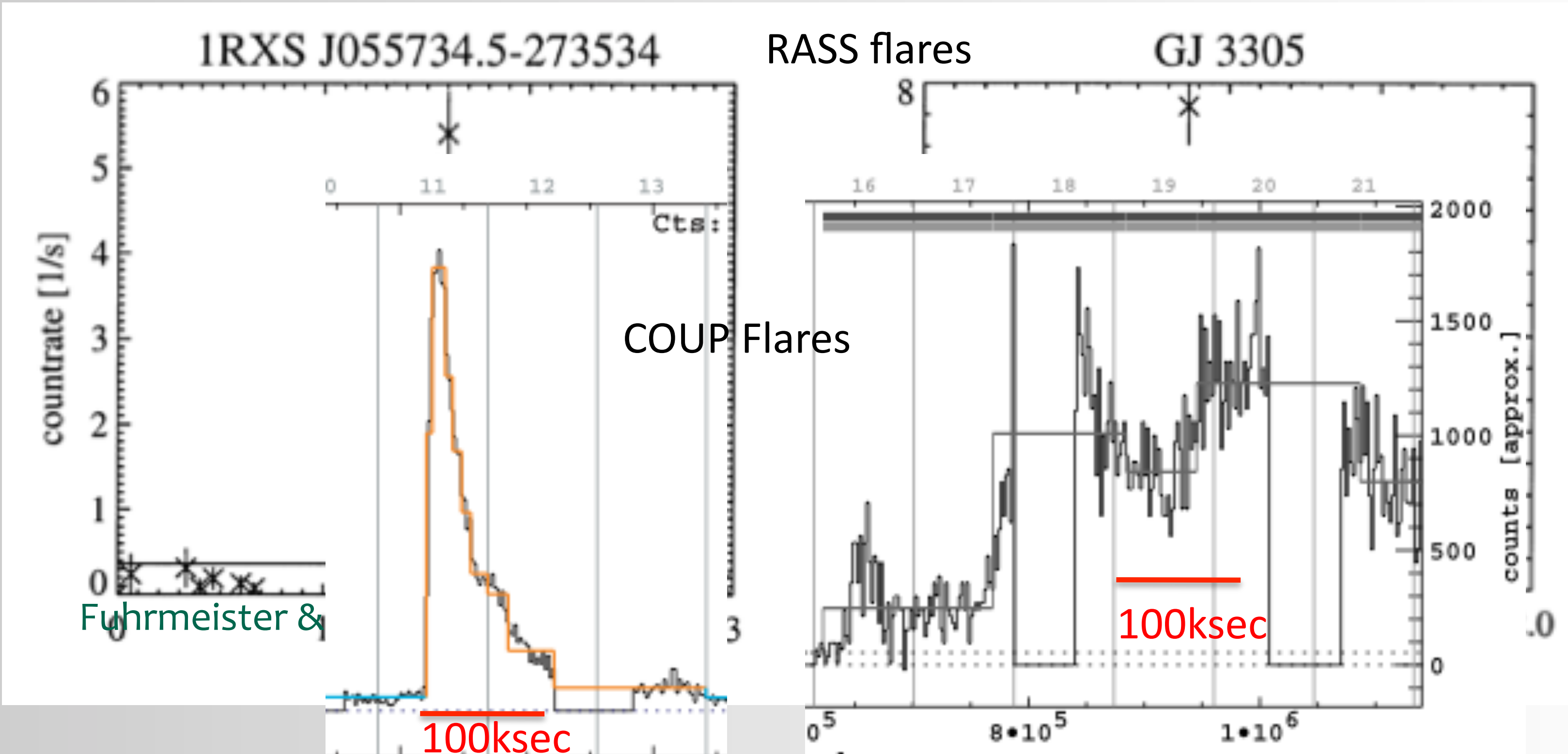






Identifying stars by their X-ray variability

Systematic study of X-ray variability in the RASS:
among 30000 sources
~ 1200 variable of which ~ 750 stars

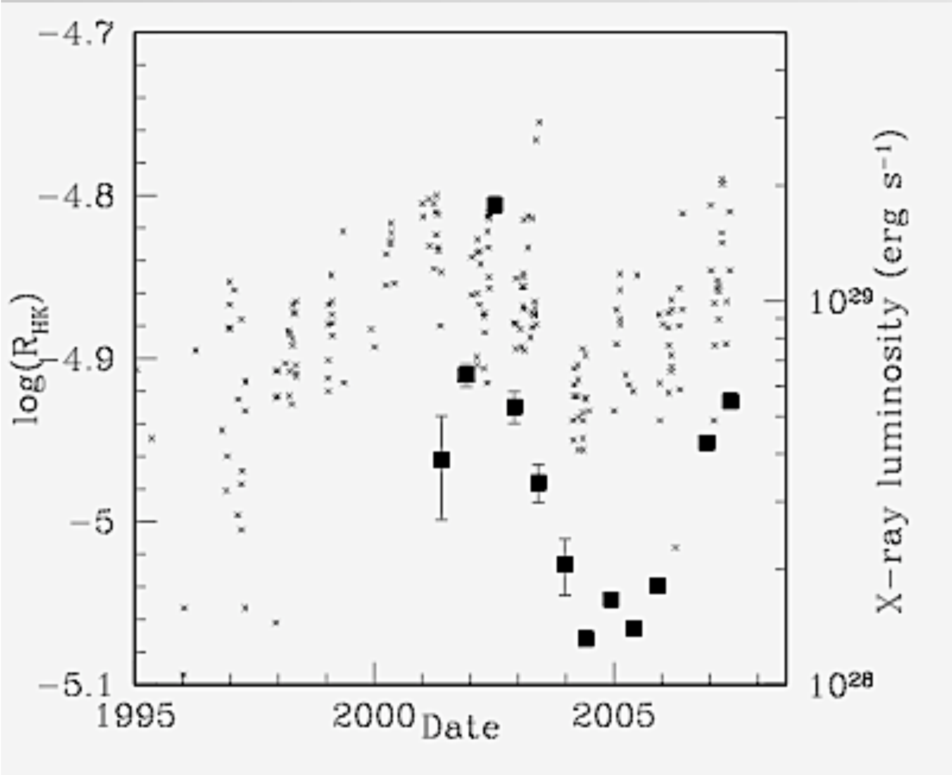


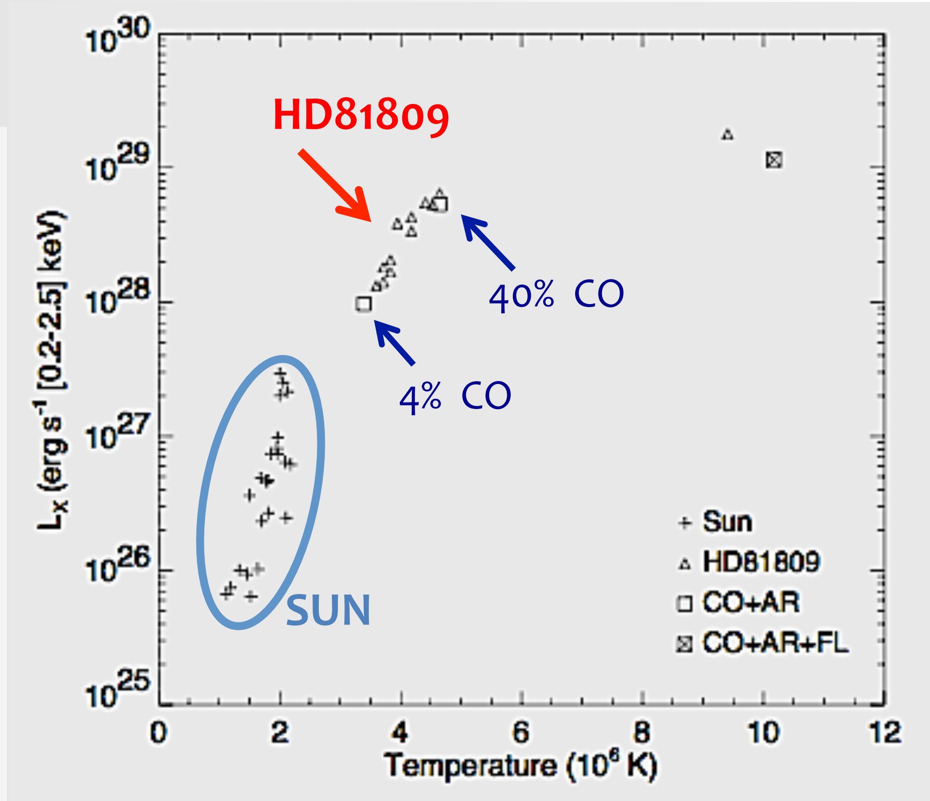
Flare science with eRASS:

- identifying stars
- statistics (counting events)
- flare physics (decay, temperature evolution) only for long flares

X-ray activity cycles on low-activity stars

HD81809   G2IV + G9IV (unresolved in X-rays)
8.2 yr periodic Ca II H+K cycle
(Favata et al. 2004, 2008):



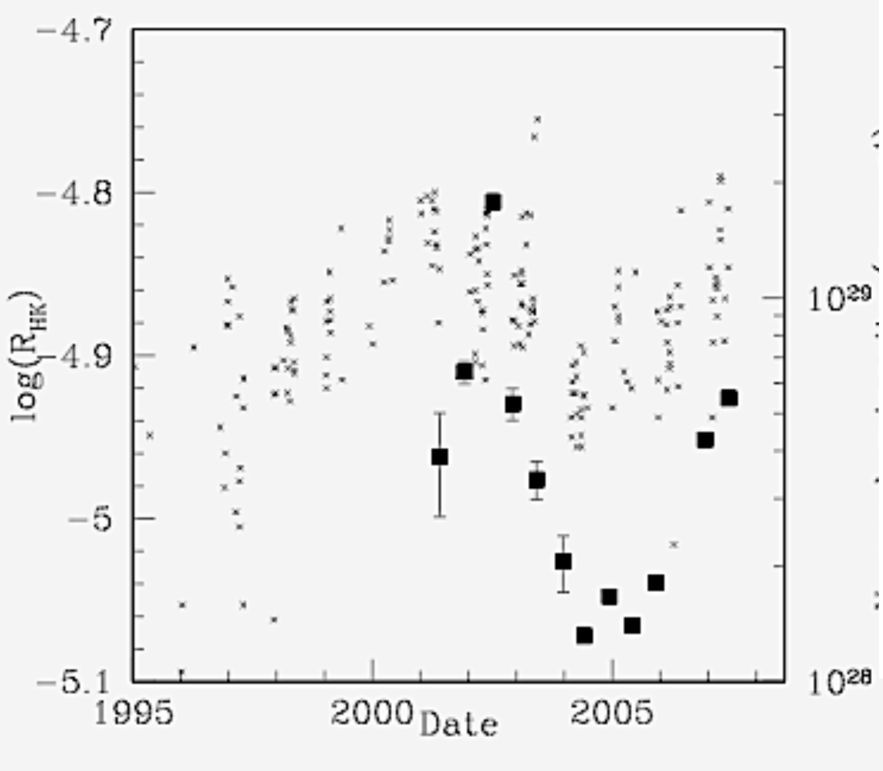


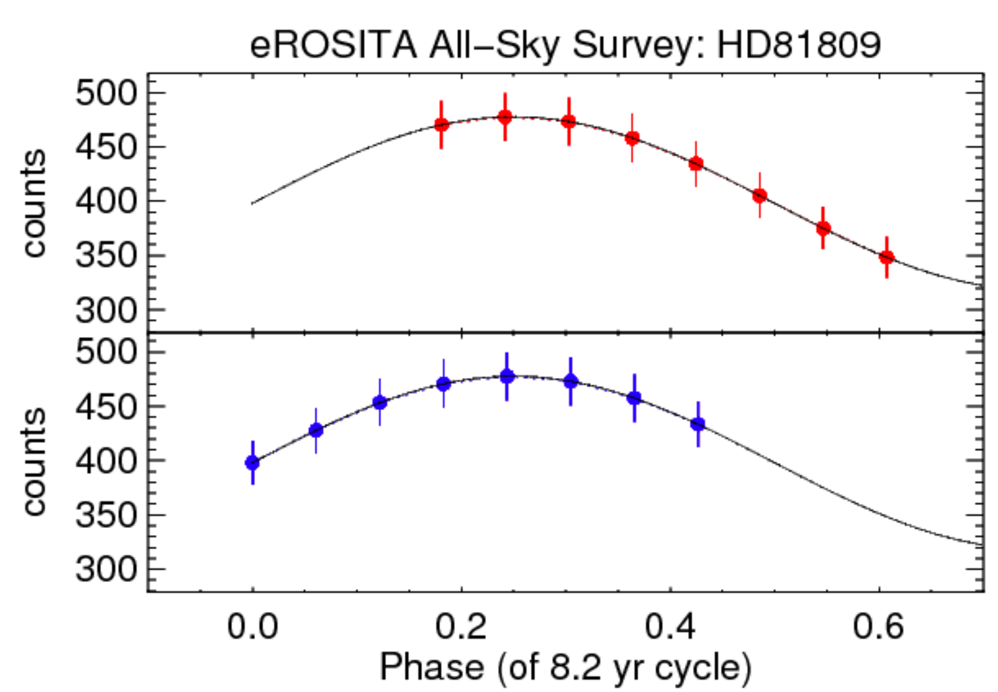
<u>After 7 yrs of XMM monitoring:</u>
X-ray cycle coincident with Ca II cycle;
Amplitude of L_x ~ 1 dex

HD81809 along high-activity extension of Sun;
X-ray variability across the cycle due to variable coverage with
cores of active regions (CO)

X-ray activity cycles on low-activity stars

HD81809 G2IV + G9IV (unresolved in X-rays)
8.2 yr periodic Ca II H+K cycle
(Favata et al. 2004, 2008):





...with help by Christian Schmid (SIMPUT)

After 7 yrs of XMM monitoring:
X-ray cycle coincident with Ca II cycle;
Amplitude of L_x ~ 1 dex

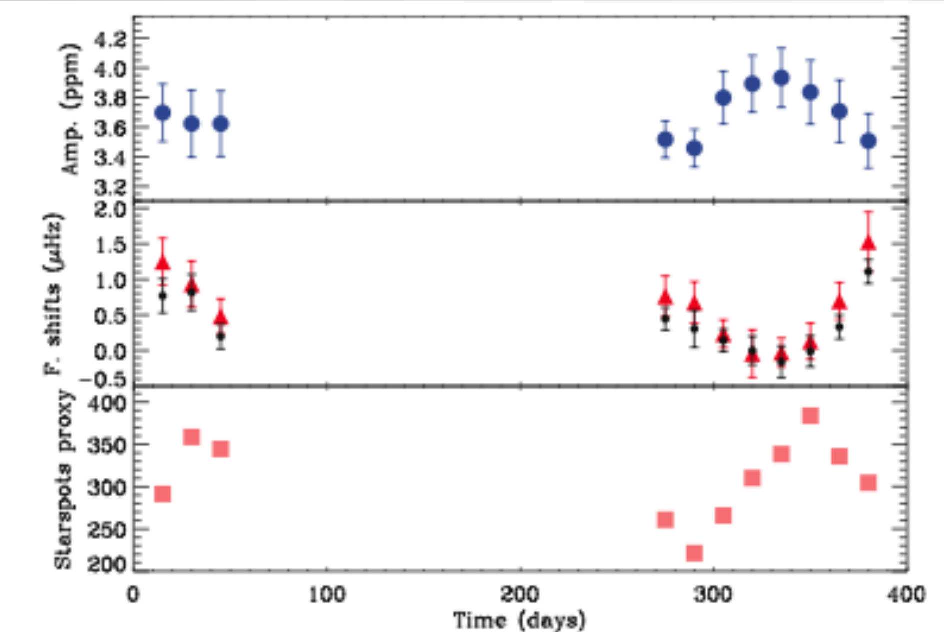
eROSITA All-Sky Survey:
8 * 3 scans in 4 yrs
with ~ 400 cts in each visit

Detecting X-ray activity cycles with eROSITA

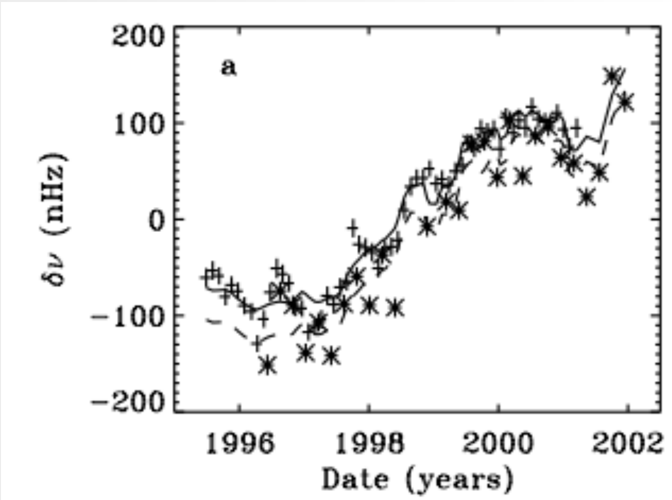
Typical Ca II cycles: P_{cyc} ~ 2.5 – 25 yrs (Baliunas et al. 1995)

Few shorter cycles:

- Metcalfe et al. (2010) -- Ca II cycle ~ 1.6yr
- Garcia et al. (2010): -- oscillations measured with CoRoT → 120d cycle (?)



Garcia et al. (2010), Sci 329



Howe et al. (2002)
Frequency changes over solar cycle

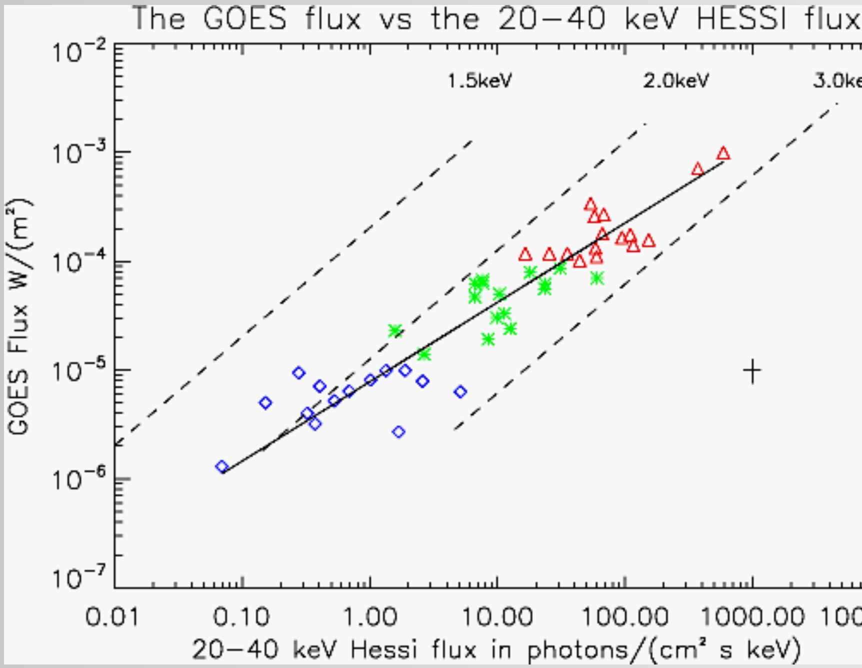
Potential for eRosita:

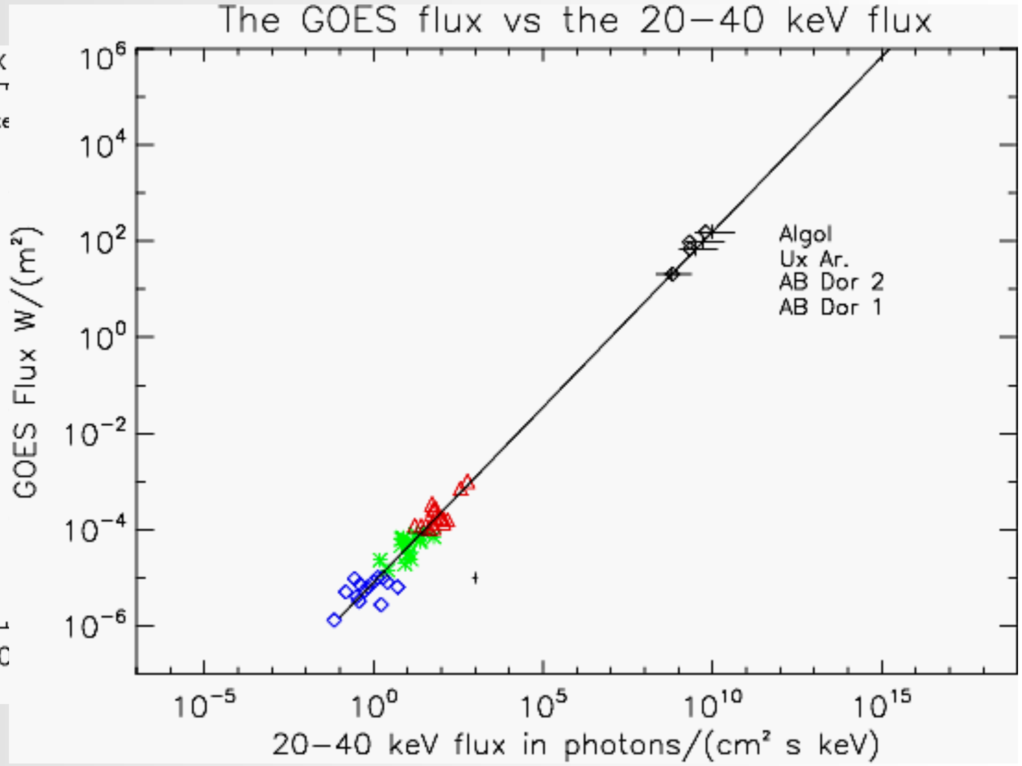
monitor stars with short (1-5 yrs) activity cycles
(many more may be revealed with CoRoT and Kepler)

long-term monitoring with 1 instrument avoids cross-calibration problems

Solar-stellar flare scaling laws

Examine peak flux in soft X-rays (GOES) and hard X-rays (RHESSI) for wide range of solar flares (C-, M-, X-Class events) (Isola et al. 2007):





RESULTS:
- power-law relation between soft + hard X-ray peak flux
- 60-80keV emission is non-thermal
- stellar soft/hard X-ray peak flux is extrapolation of Sun to higher fluxes

eROSITA potential:

Complementary to Chandra/XMM studies
of physics of stellar atmospheres
and small-scale star formation

- probing galactic stellar population:
  A) Structure of the galactic disk
  B) Young associations in the solar neighborhood
  C) Diskless pre-main sequence stars
  → Star formation history, disk evolution, IMF
- Variability studies
  A) Flares
  B) Activity cycles
  → Mechanims of magnetic activity