SN Ia Progenitors

Brian P. Schmidt

Wolfgang Kerzendorf, Anna Frebel, Martin Asplund,
Ken Nomoto, Philipp Podsiadlowski

The Research School of Astronomy & Astrophysics
Mount Stromlo and Siding Spring Observatories

THE AUSTRALIAN NATIONAL UNIVERSITY

- 1.35m telescope with 5.2 sq degree im
- 12s reado exchange
- All Southe steradians epochs
- First light this year.

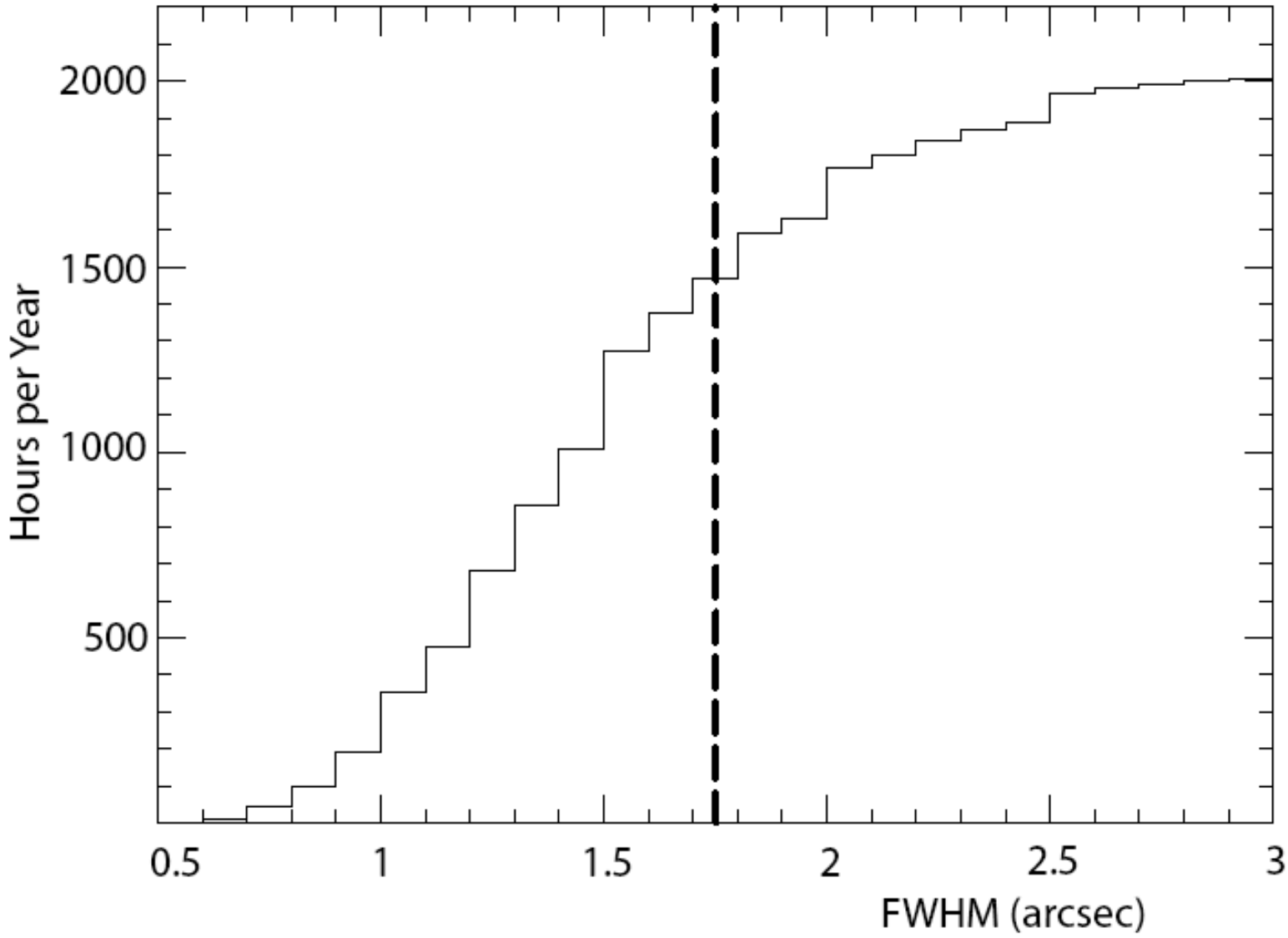
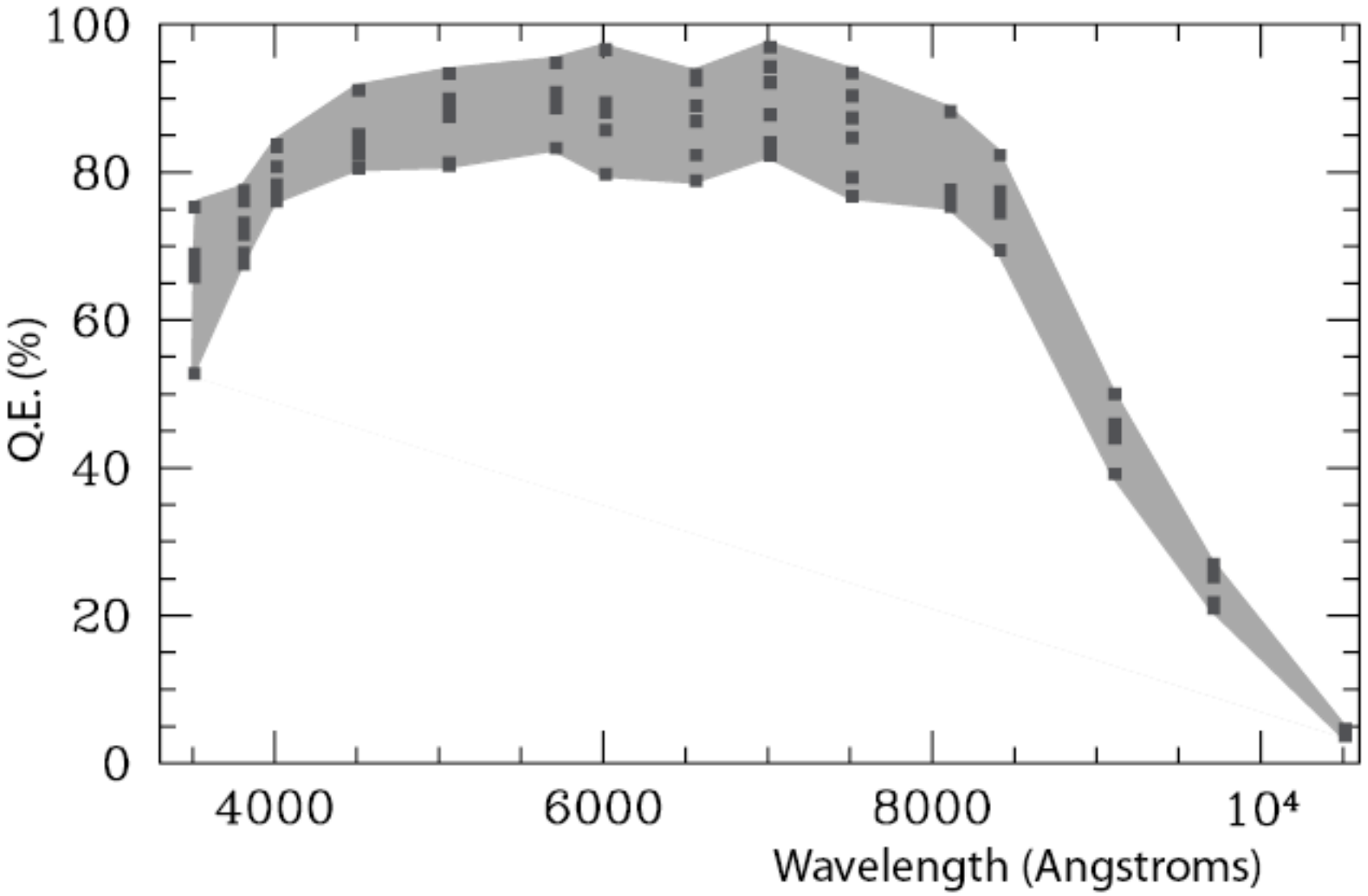
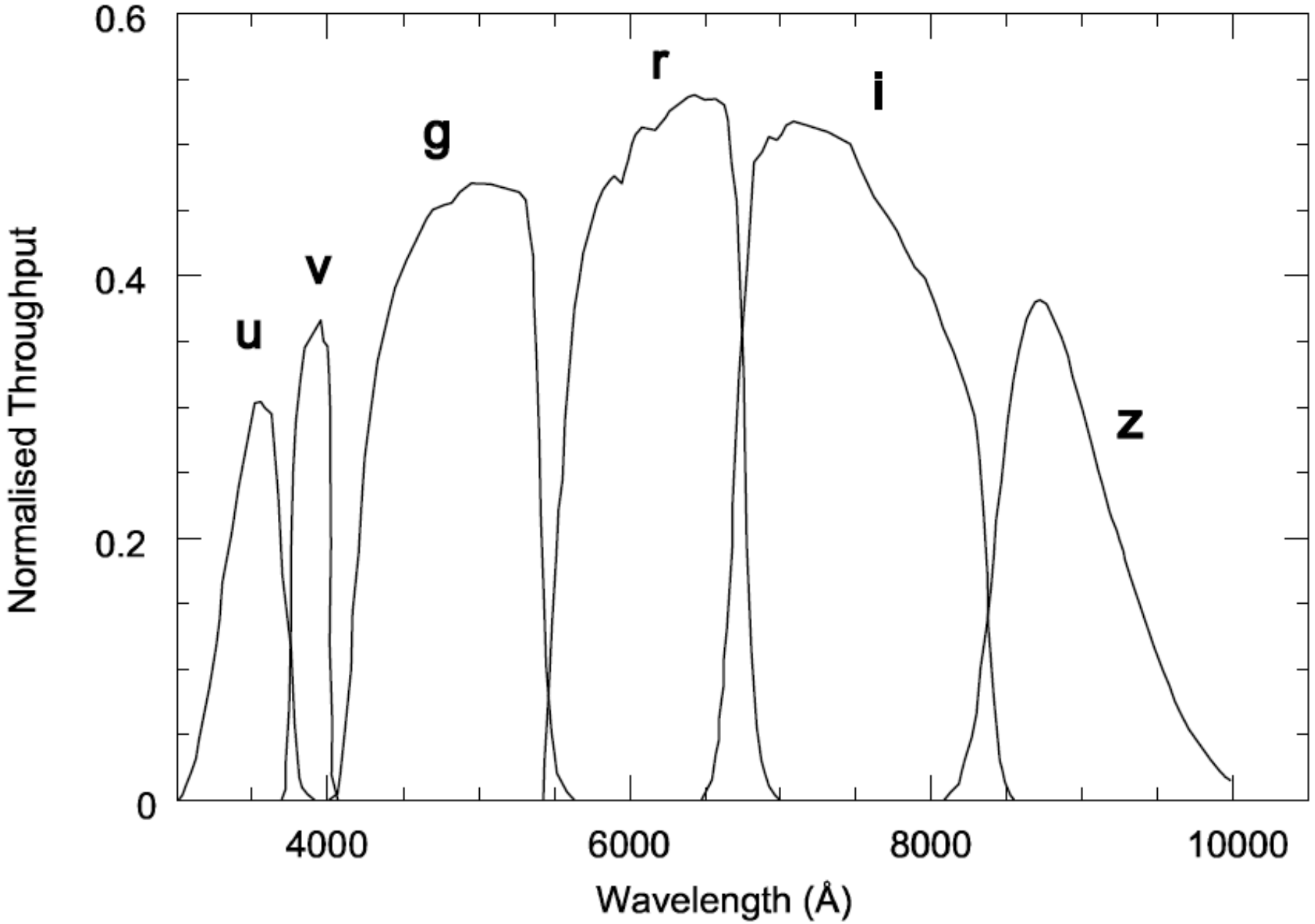


Figure 3: Seeing at Siding Spring derived from logs of the Anglo-Australian Telescope.


100
80
60
40
20
0
Q.E. (%)
4000
6000
8000
10⁴
Wavelength (Angstroms)

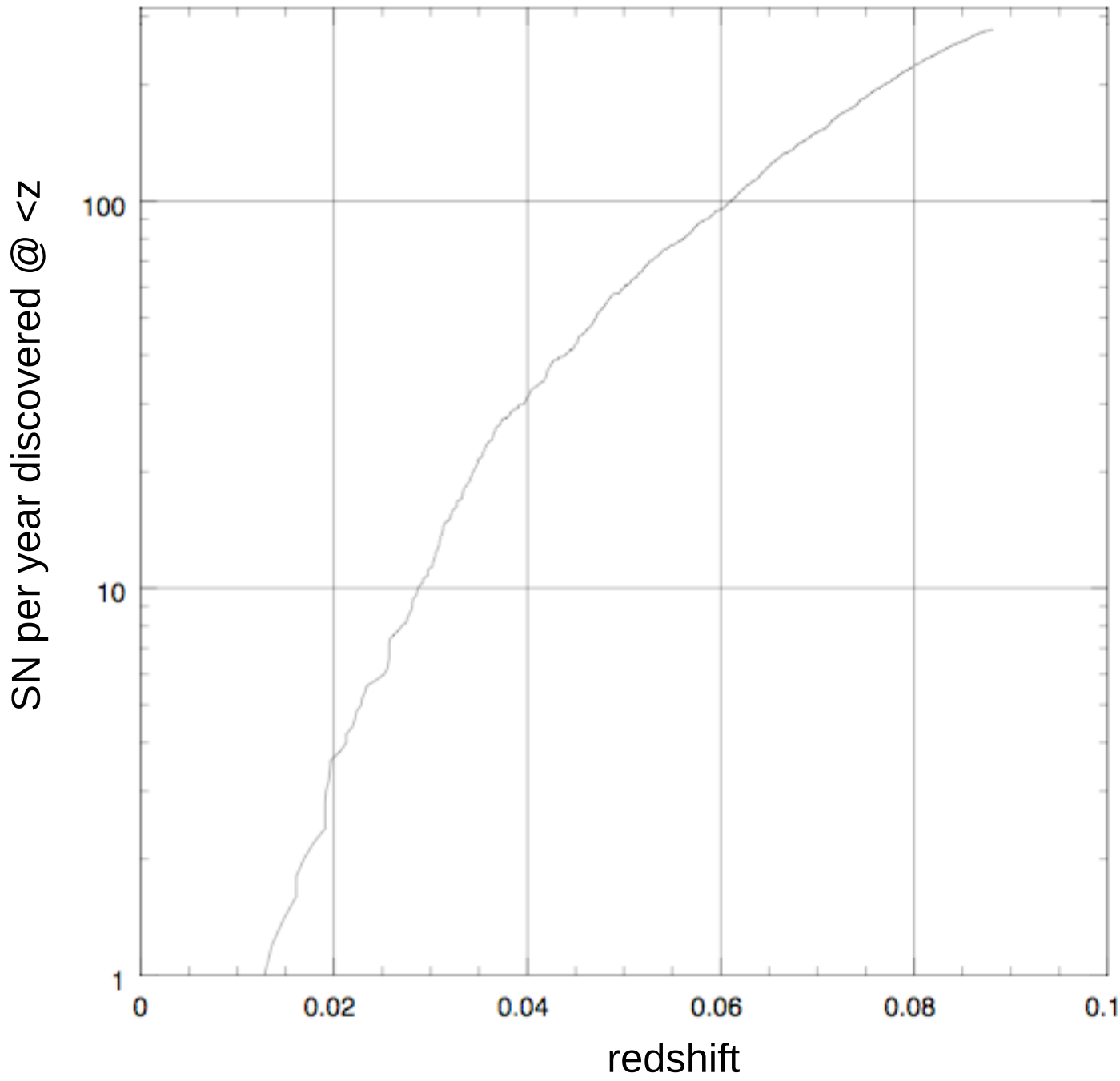

0.6
0.4
0.2
0
Normalised Throughput
u
v
g
r
i
z
4000
6000
8000
10000
Wavelength (Å)

Sensitivity - SNR=10 Vega Mags

	u	v	g	r	i	z
30s 2” D	18.6	19.1	20.4	19.7	18.8	18.1
30s 2” G	18.3	18.9	20.1	19.5	18.7	18.0
30s 2” B	17.1	18.1	19.0	18.9	18.3	17.7

Survey

- Survey Speed: 2 minutes per field (v,g,i)
  - 1250 sq/degrees per 8hr night.
  - Use bad seeing time (worst 1/3rd + augment with 60hrs/year to fill in gaps) to do 1250 sq/degree continual SN search
  - Spectroscopic follow-up of anything brighter than 18.5
  - In collaboration with IN2P3 (Pain, Austier, Guy, Regnault)


SN per year discovered @ <z
100
10
1
0
0.02
0.04
0.06
0.08
0.1
redshift

SN Progenitor Possibilities

- WD Accretes material from friend and exceeds 1.38 $M_{¤}$
- WD-WD merger exceeds 1.38 $M_{¤}$
- WD accretes Helium, sub 1.38$M_{¤}$ edge-lit detonations

SN Progenitor Possibilities

- WD Accretes material from friend and exceeds 1.38 $M_{¤}$ (Odds on favourite 1:10 short)
- WD-WD merger exceeds 1.38 $M_{¤}$ (Long shot - 30:1)
- WD accretes Helium, sub 1.38$M_{¤}$ edge-lit detonations (Rank Outsider: Odds currently undefined!)

- Makes Sense to look for the friend
  - Ruiz-Lapuente and colleagues have emphasized this, calculated missing pieces, sifted through historical data, and analysed a lot of data from a variety of sources.

Single Degenerate Chandrasekhar mass SN Ia

Donation via Roche Lobe overflow from Main Sequence or Red Giant Star…

Supersoft sources

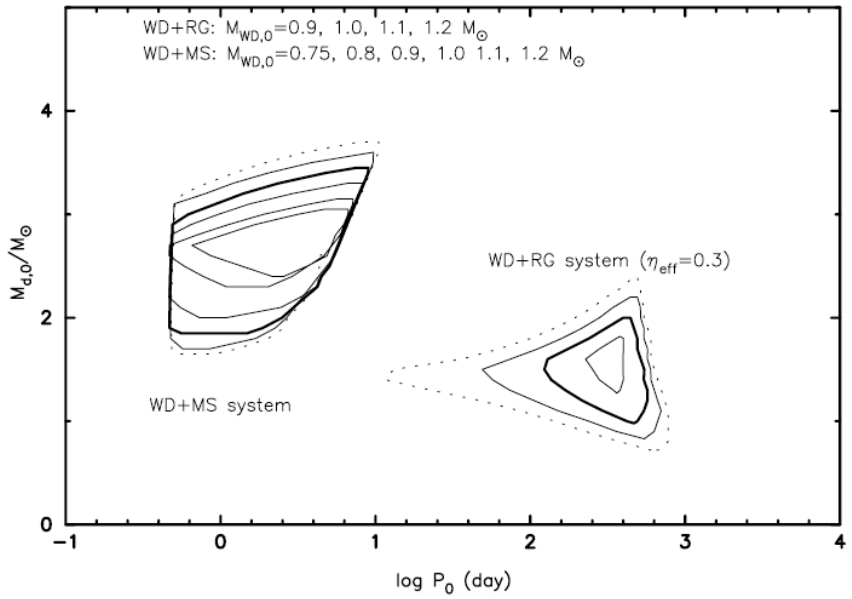


FIG. 13.—Same as Fig. 12 but for the much lower mass-stripping efficiency of $\eta_{\rm eff} = 0.3$. We add the region for $M_{\rm WD,0} = 1.2\ M_\odot$ both for the WD + MS and WD + RG systems (*dotted lines*). The region for $M_{\rm WD,0} = 0.8\ M_\odot$ vanishes for the WD + RG system.

THE ASTROPHYSICAL JOURNAL, 522:487–503, 1999 September 1

HACHISU, KATO, & NOMOTO

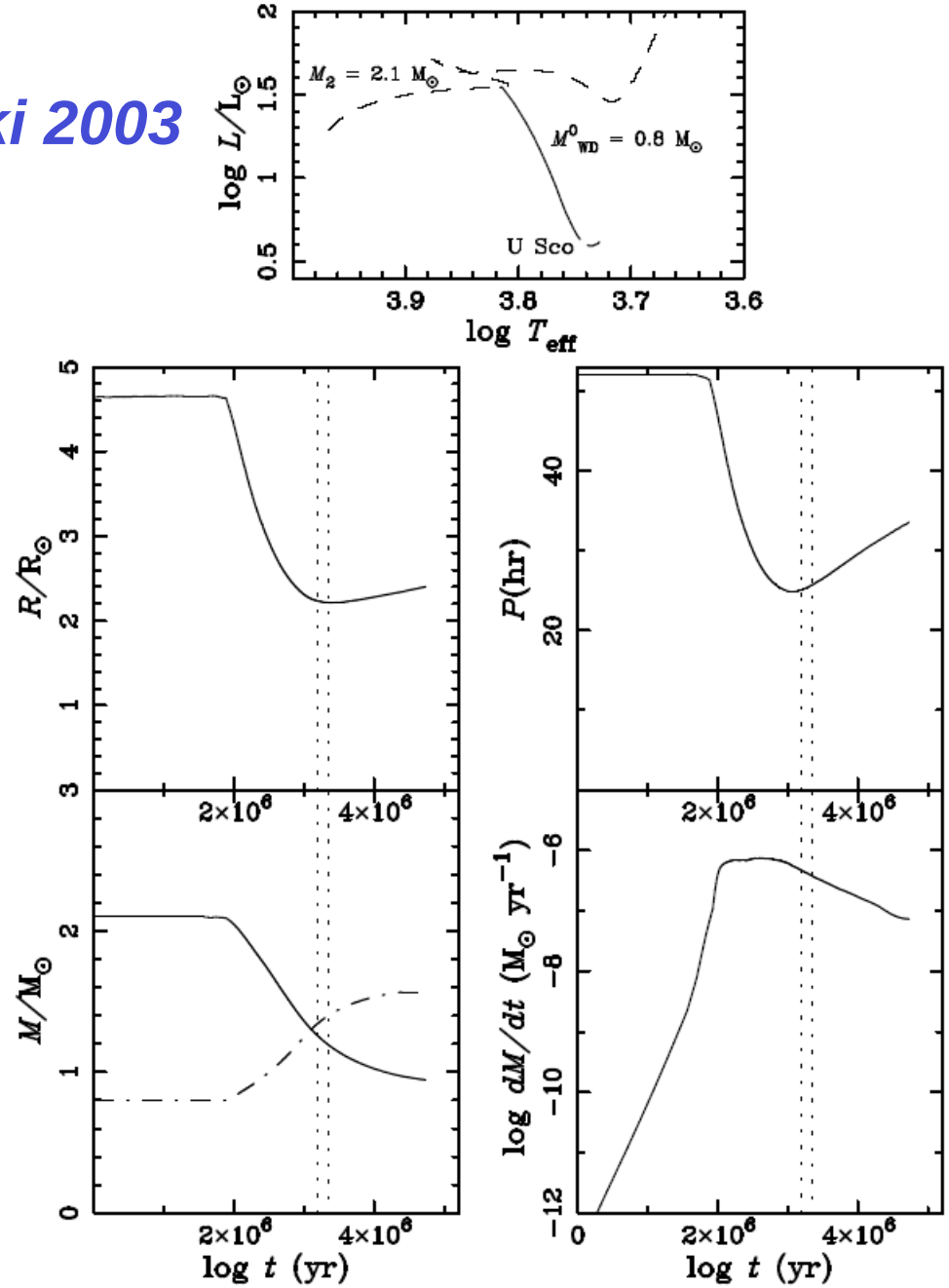
Podsiadlowski 2003
Han & Podsiadlowski 2003

Supersoft X-ray sources

Evolved ~2 $M_{¤}$
Main Sequence or
Red Giant Star…

UScorpii has
>1.**35$M_{¤}$WD** and
Is still growing (but is it made of CO?).

Hachisu et al. 2000;
Thoroughgood et al. 2001



THE ASTROPHYSICAL JOURNAL, 550:L53–L56, 2001 March 20

IDENTIFICATION OF THE COMPANION STARS OF TYPE IA SUPERNOVAE

R. CANAL,[1,2] J. MÉNDEZ,[1,3] AND P. RUIZ-LAPUENTE[1,4]

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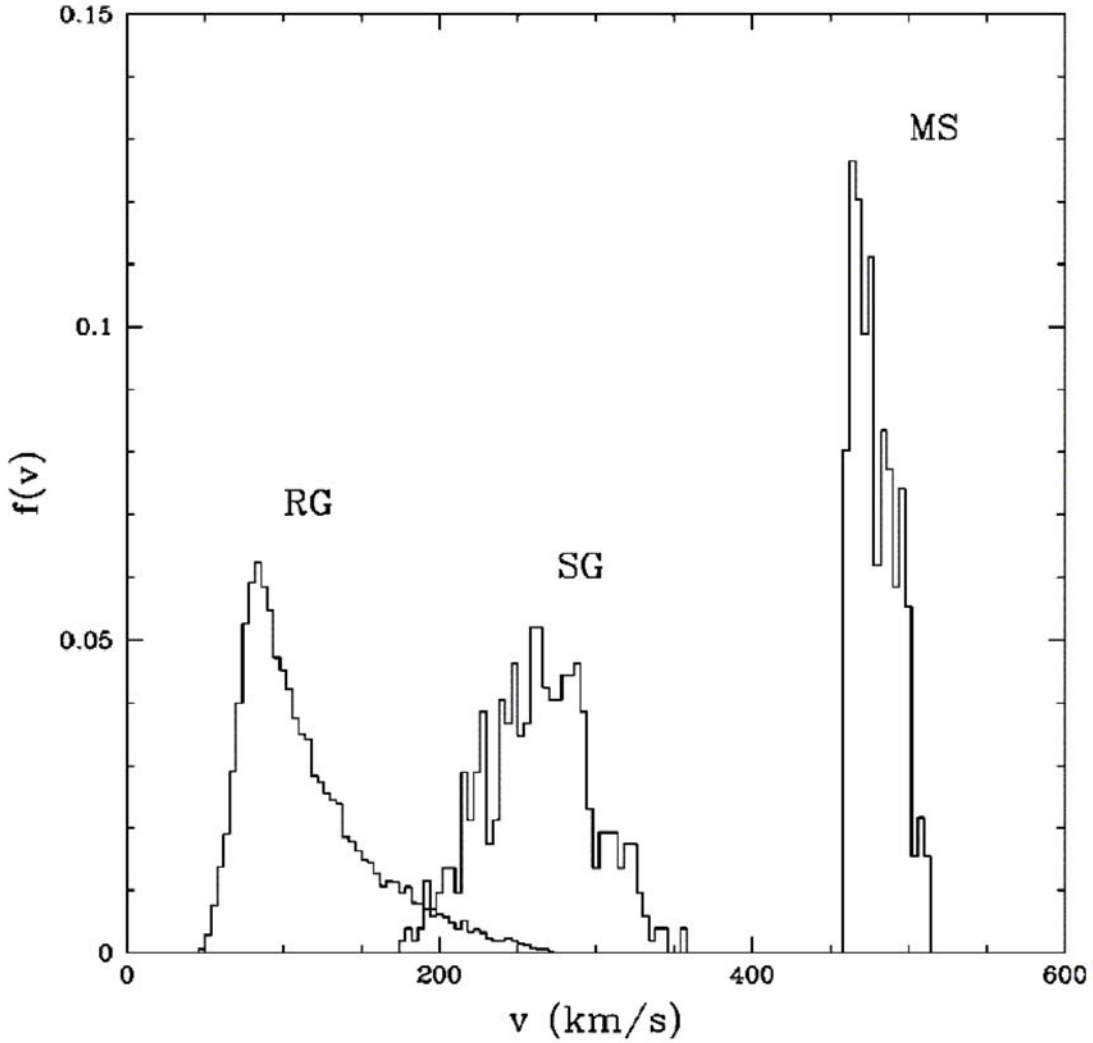
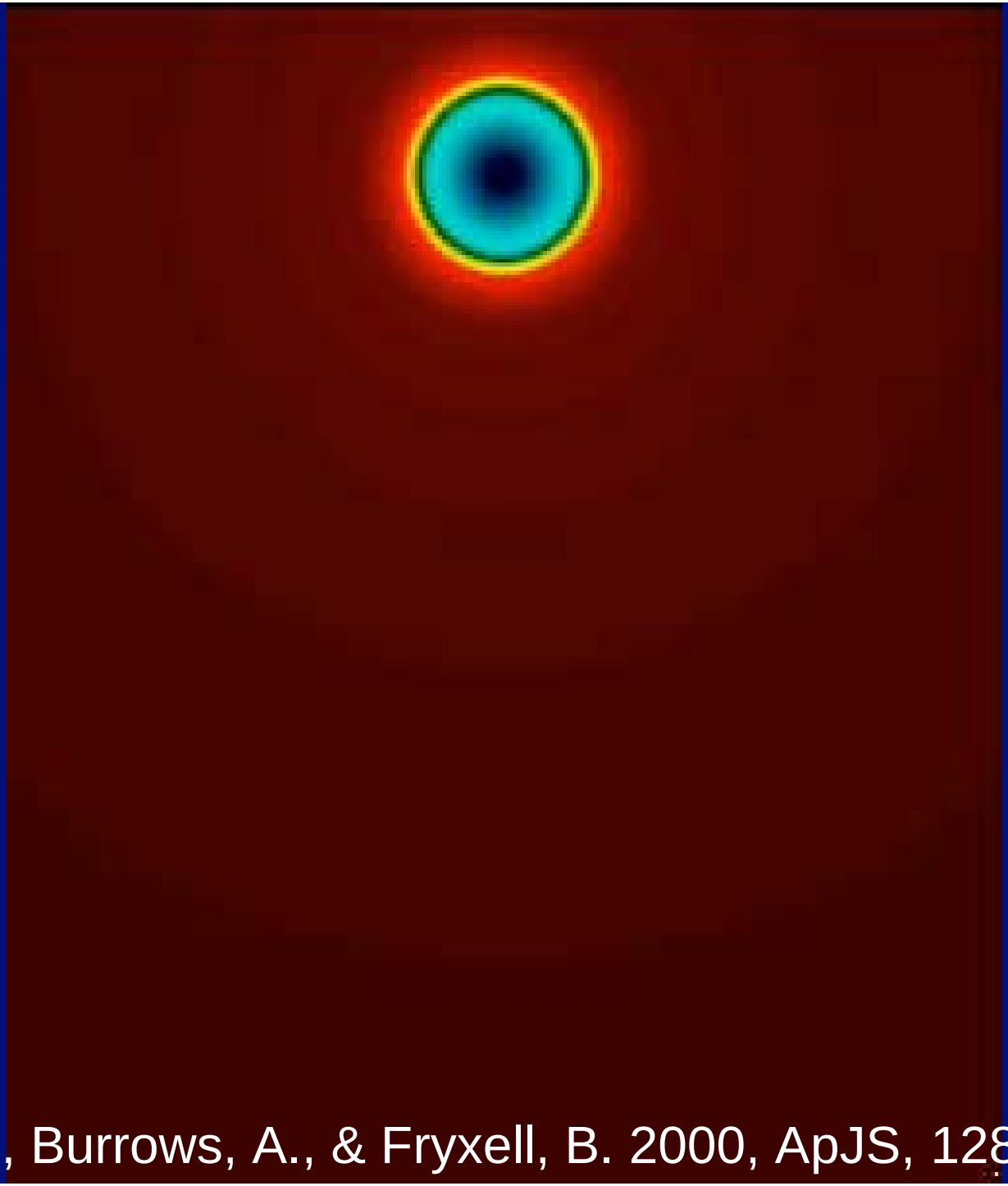




Marietta, E., Burrows, A., & Fryxell, B. 2000, ApJS, 128, 615

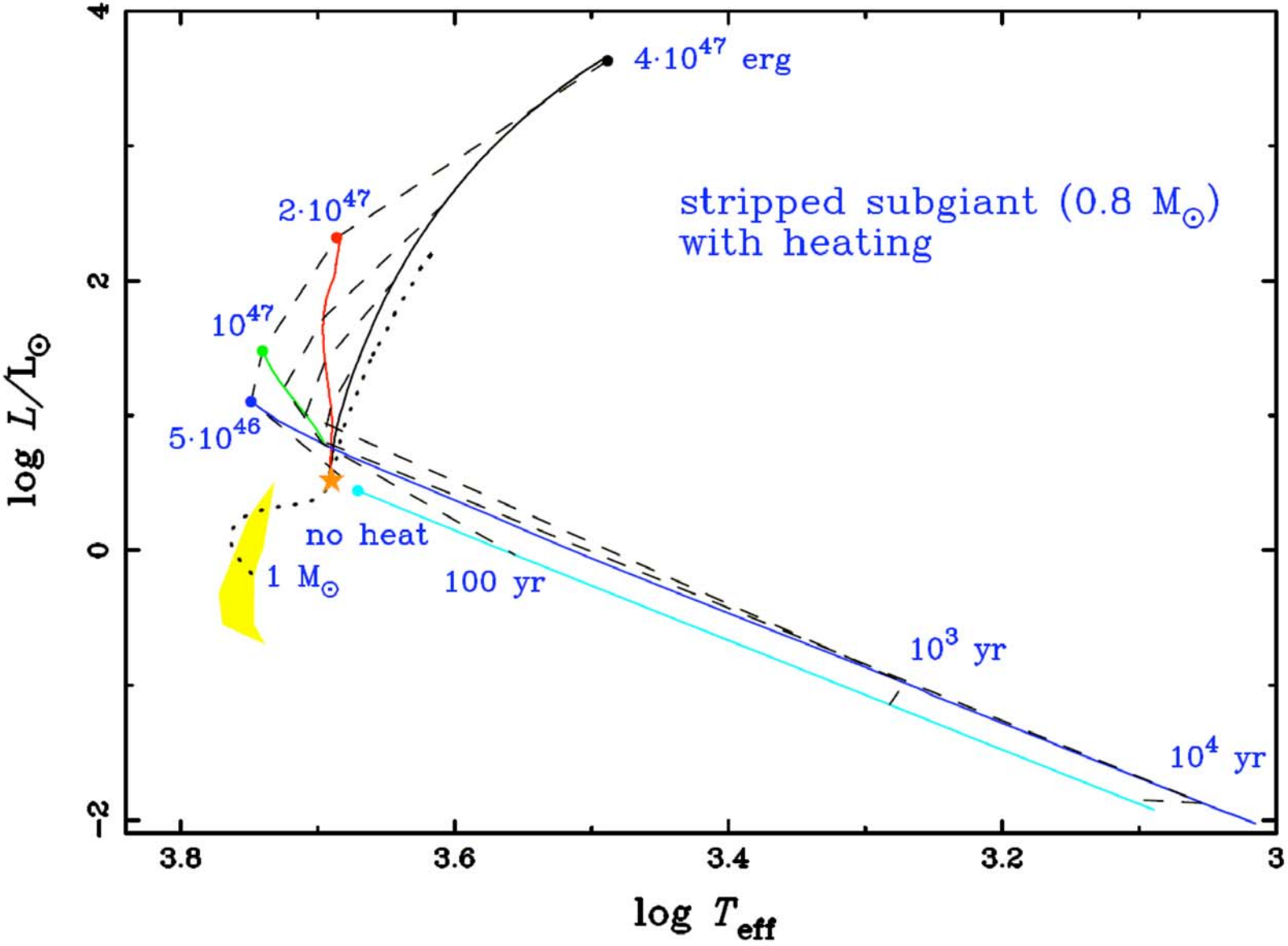
Summary of Simulations

Simulations	M ($M_\odot$)	a (km)	a/R	SN Model	ΔM ($M_\odot$)[a]
HCV	1.017 (MS)	2.04×10^6	3.00	W7	0.15
HCVa	1.017 (MS)	1.75×10^6	2.57	W7	0.23
HCVb	1.017 (MS)	2.72×10^6	4.00	W7	0.074
HCVc	1.017 (MS)	4.08×10^6	6.00	W7	0.022
HCVd	1.017 (MS)	8.16×10^6	12.00	W7	0.0018
HCVL	1.132 (SG)	3.39×10^6	2.78	W7	0.17
HCVLa	2.118 (SG)	4.50×10^6	2.78	W7	0.25
HALGOLa.....	0.977 (red giant)	3.00×10^8	2.52	W7	0.54 (98%)
SYMB	0.977 (red giant)	3.76×10^8	3.16	Hedt	0.53 (96%)

Summary of Simulations

- Dwarfs and subgiants do not lose too much mass, and are largely unchanged by explosion.
- Giants can lose a lot of mass, and should end up remaining as giants, or as an exposed hot cores.
- All objects remain, and should have $L>L_{¤}$

Podsiadlowski 2003

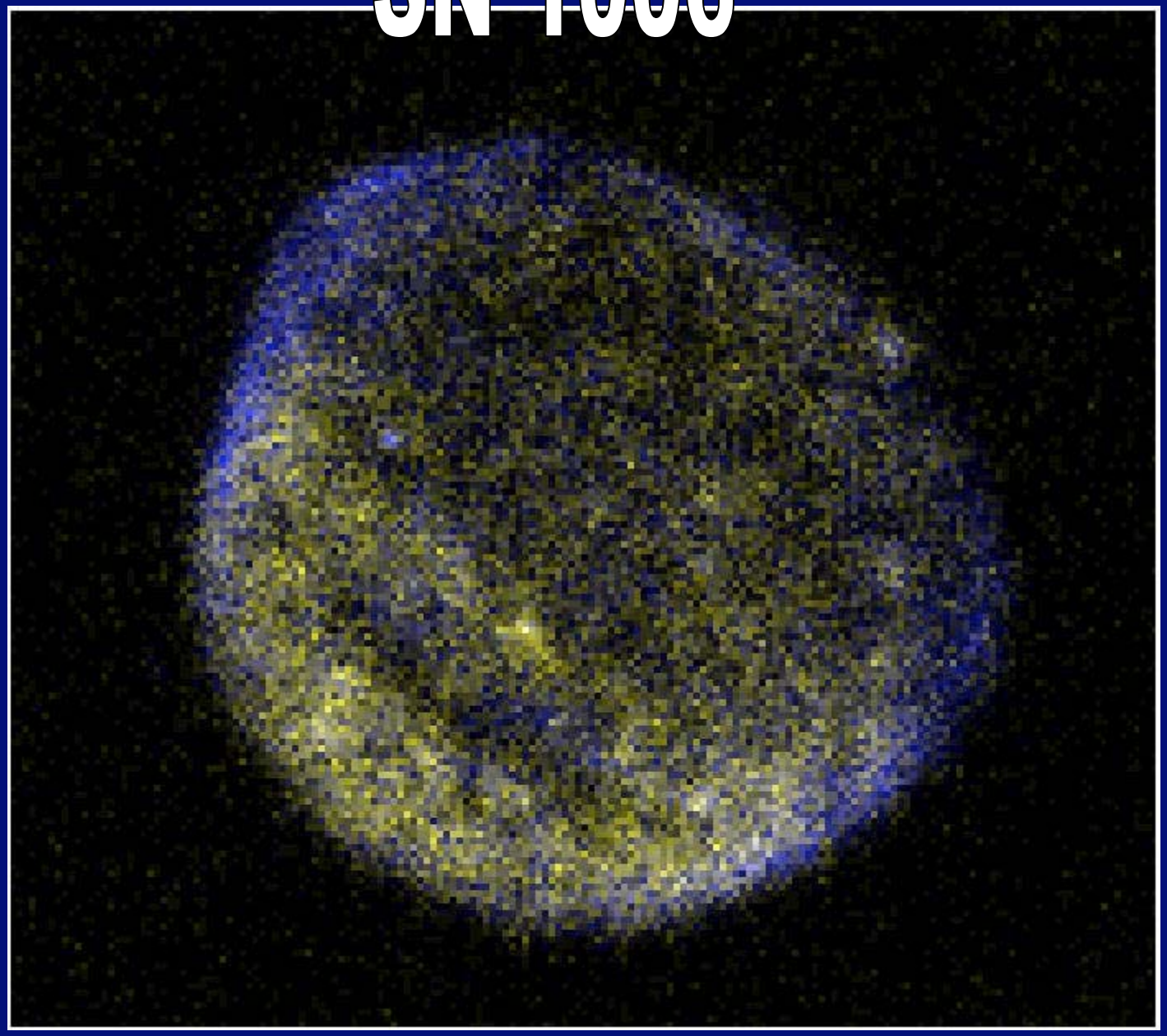


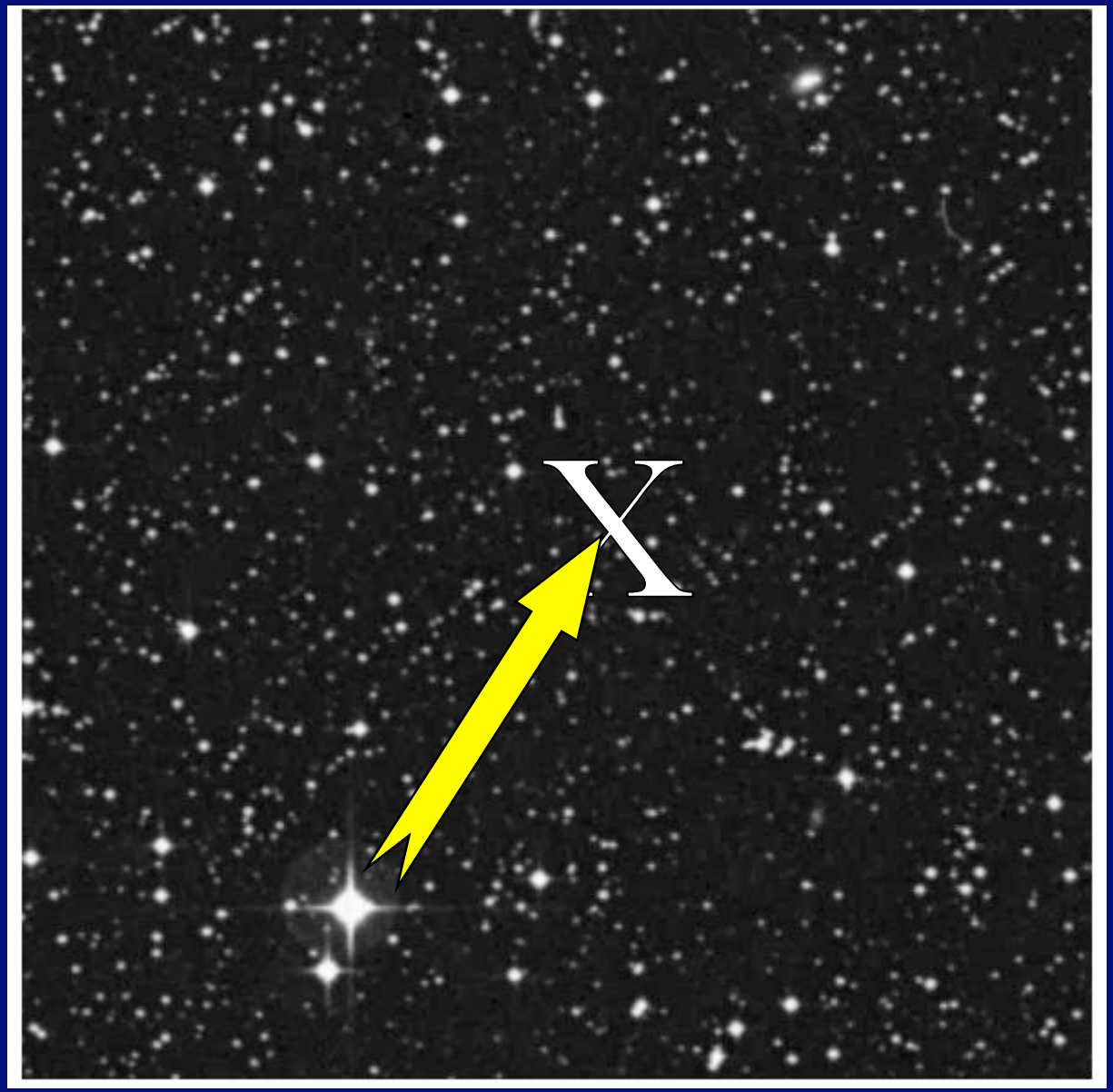
Historical SN Ia

- Definite SN Ia (light curve – remnant composition
- Young (the younger the better)
- Near (nearer the better)

- Ruiz Lapuente (2004, ApJ and 2004 Nature)
  - SN 1006
  - Tycho's SN

SN 1006





1994

$$\theta = 0.264'' \left(\frac{2\text{kpc}}{\text{D}} \right) \left(\frac{v}{100\ \text{km/s}} \right) \left(\frac{t}{25\text{yrs}} \right)$$

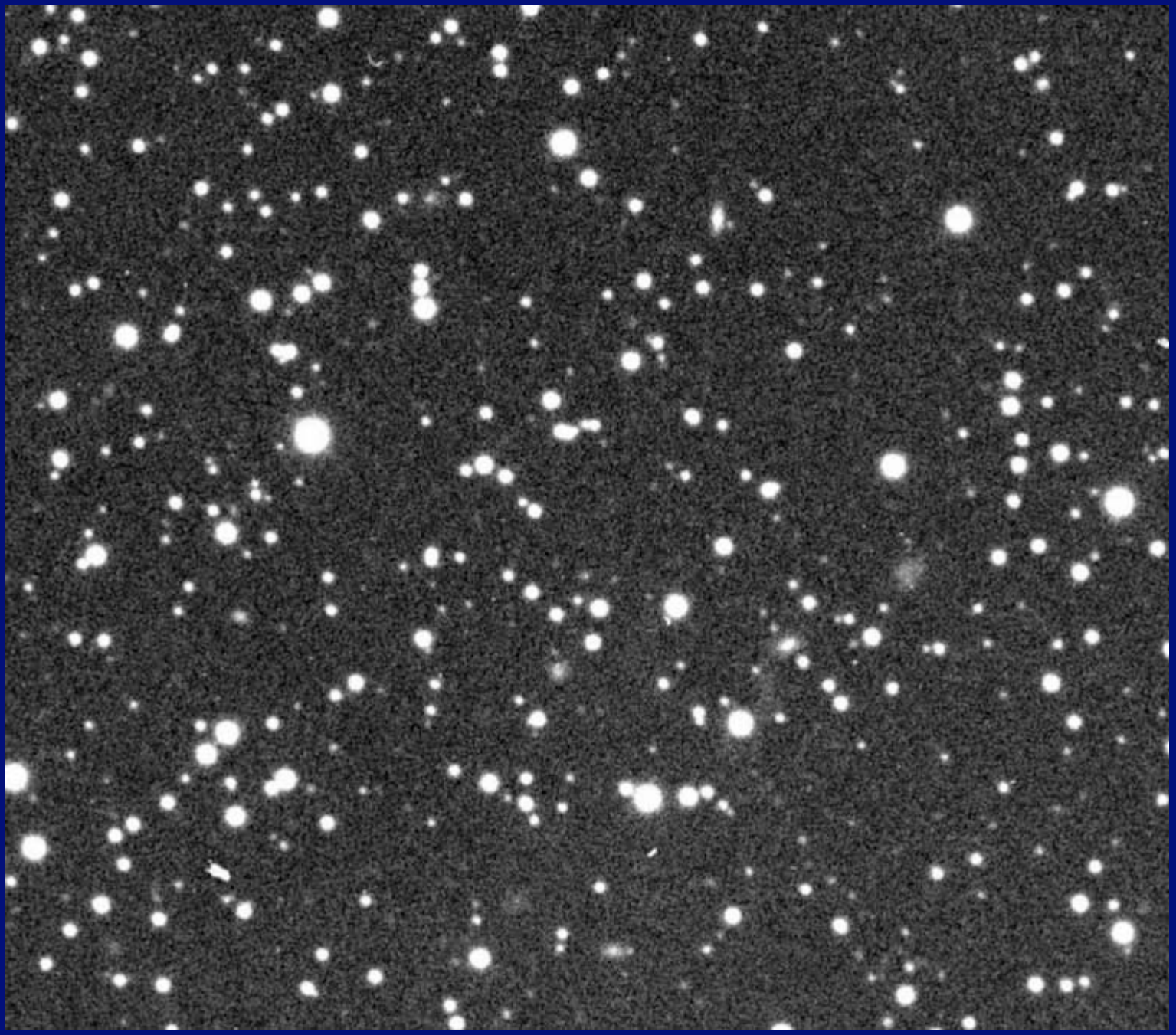
What's it proper motion?

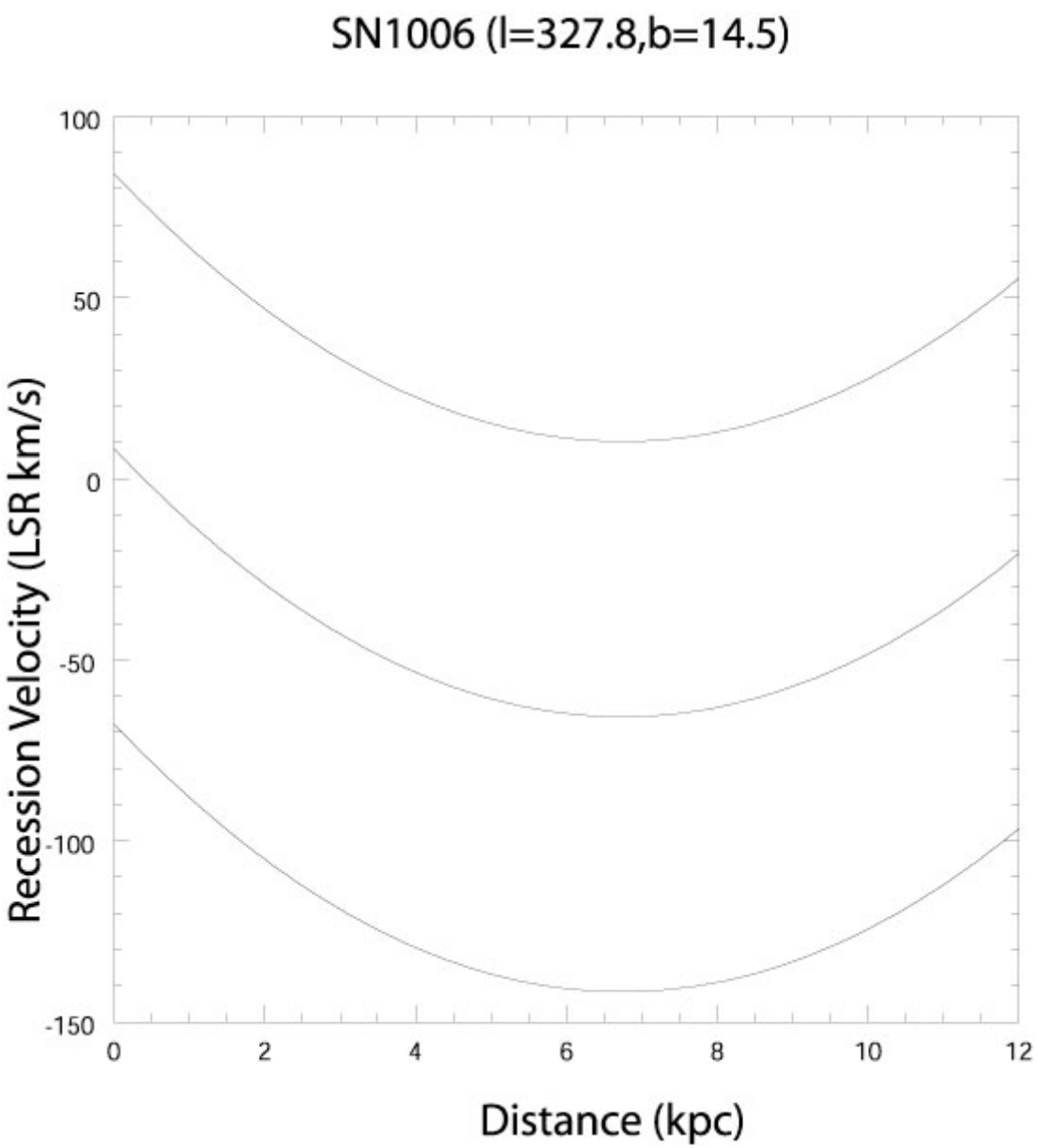
$$\theta = 10.6'' \left(\frac{2\text{kpc}}{\text{D}} \right) \left(\frac{v}{100\ \text{km/s}} \right) \left(\frac{t}{1000\text{yrs}} \right)$$

How Far has it moved?

$$m = 16 - 2.5 \log \left(\frac{L}{L_{sun}} \right) + 5 \log \left(\frac{D}{2\text{kpc}} \right)$$

How Bright is it?




SN1006 (l=327.8,b=14.5)
Recession Velocity (LSR km/s)
100
50
0
-50
-100
-150
0
2
4
6
8
10
12
Distance (kpc)

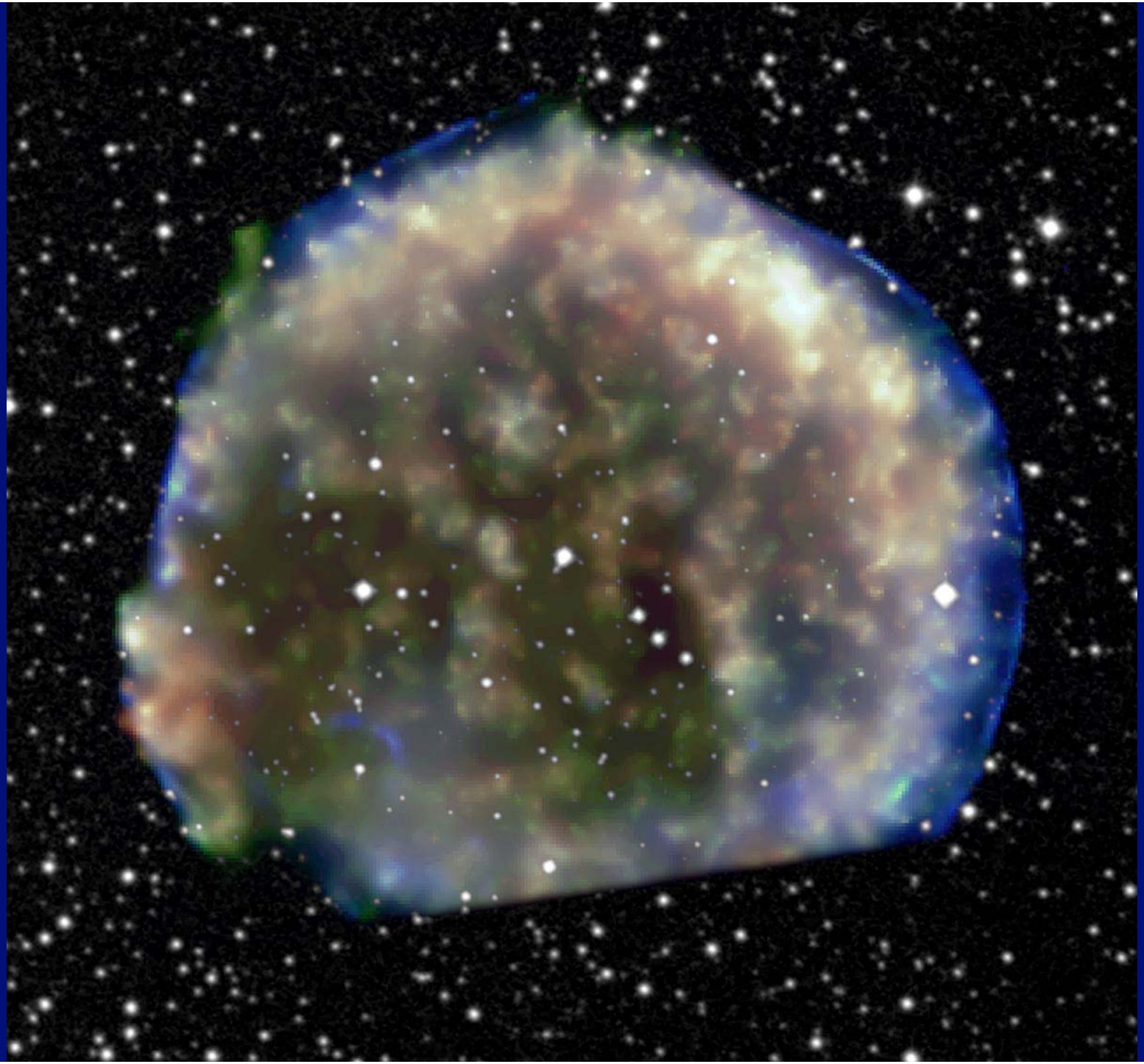
Data Available

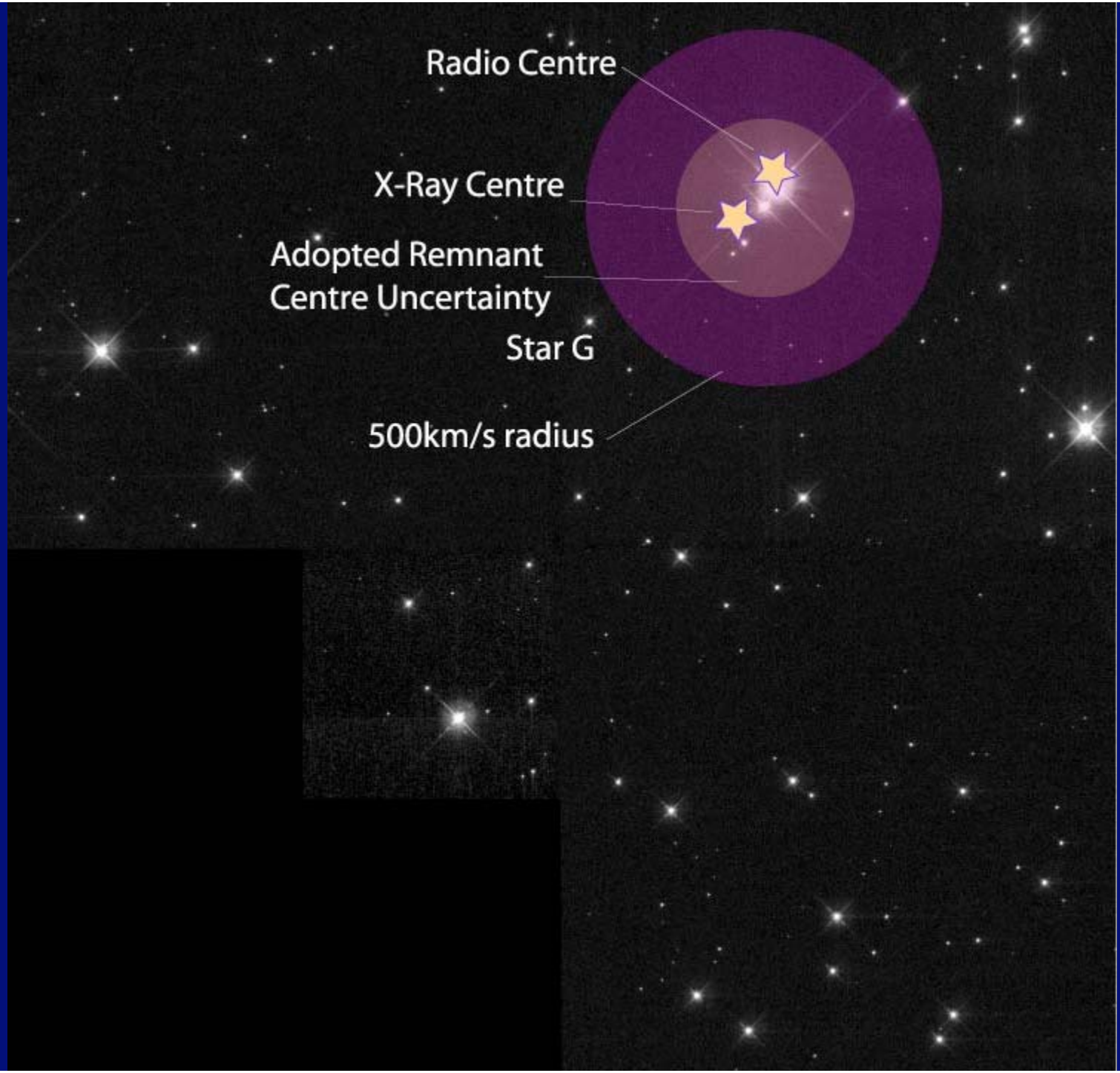
- UK Schmidt plates in 1974 & 1991 to V=20
  - Astro precision: 0.5 (99% confidence)
- CTIO 4m plates to V=22 in 1976 and 1979
  - Astro precision: 0.2 (99% confidence)
- HST (WFPC2) of inner region to V=25 in 1996/97 (Fesen et al) plus ACS data to be taken in 2003 (Ruiz-Lapuente et al.)
  - Astro precision: 0.05? (99% confidence)
- R=40000 VLT spectra of all objects brighter than 15mag (Ruiz-Lapuente, Langer et al)
- R=3000 Gemini, Magellan and 2.3m spectra of all objects brighter than 18

This is all still being analysed. Nothing obvious, but there is a lot to sift through.

Tycho SN 1572

- Distance ~2.8kpc
- 1.85 mags of extinction
- 435 years old




Radio Centre
X-Ray Centre
Adopted Remnant
Centre Uncertainty
Star G
500km/s radius

$$\theta = 0.021''\left(\frac{3\text{kpc}}{\text{D}}\right)\left(\frac{v}{100\ \text{km/s}}\right)\left(\frac{t}{3\text{yrs}}\right)$$

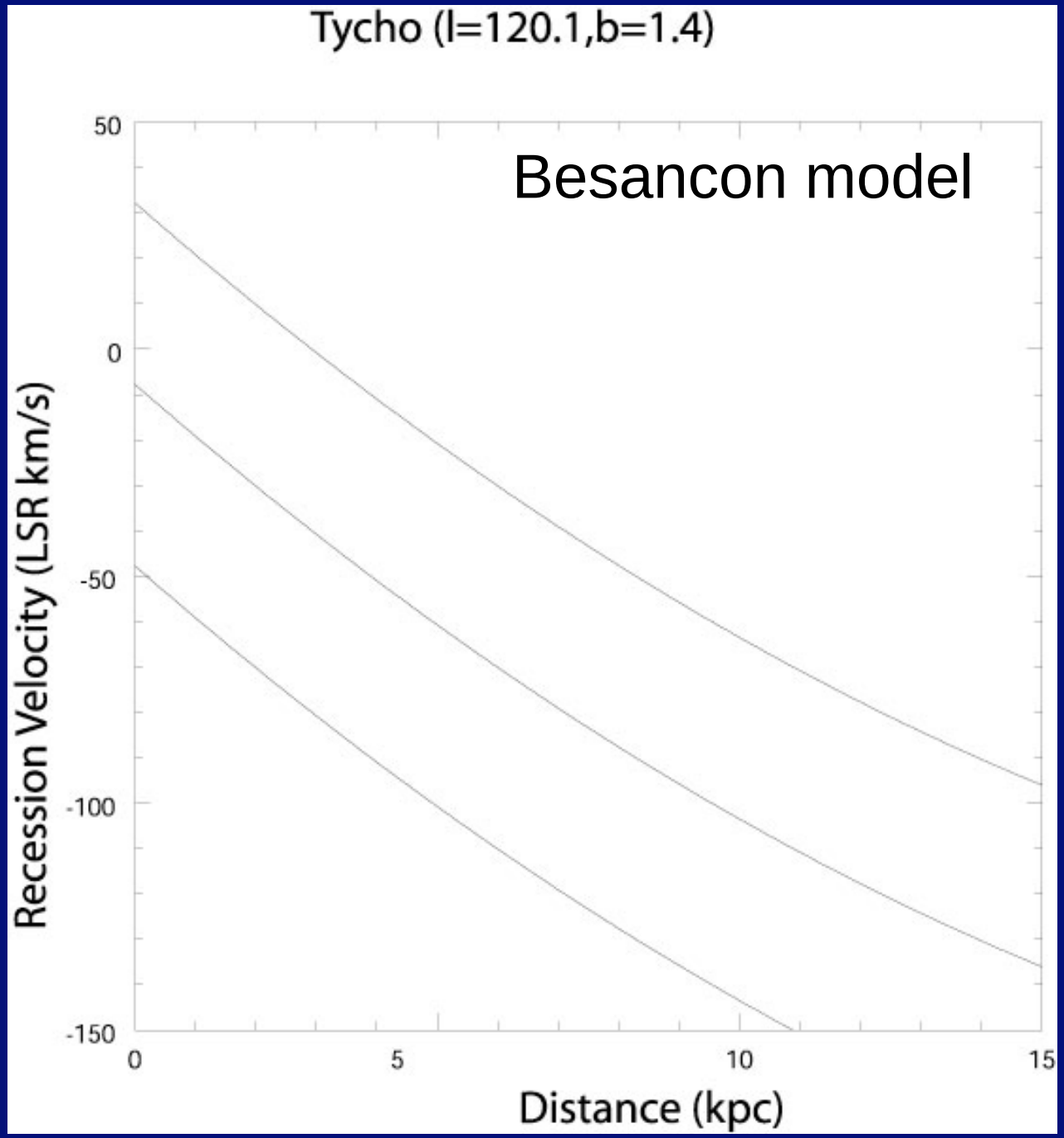
What's it proper motion?

$$\theta = 3.0''\left(\frac{3\text{kpc}}{\text{D}}\right)\left(\frac{v}{100\ \text{km/s}}\right)\left(\frac{t}{434\ \text{yrs}}\right)$$

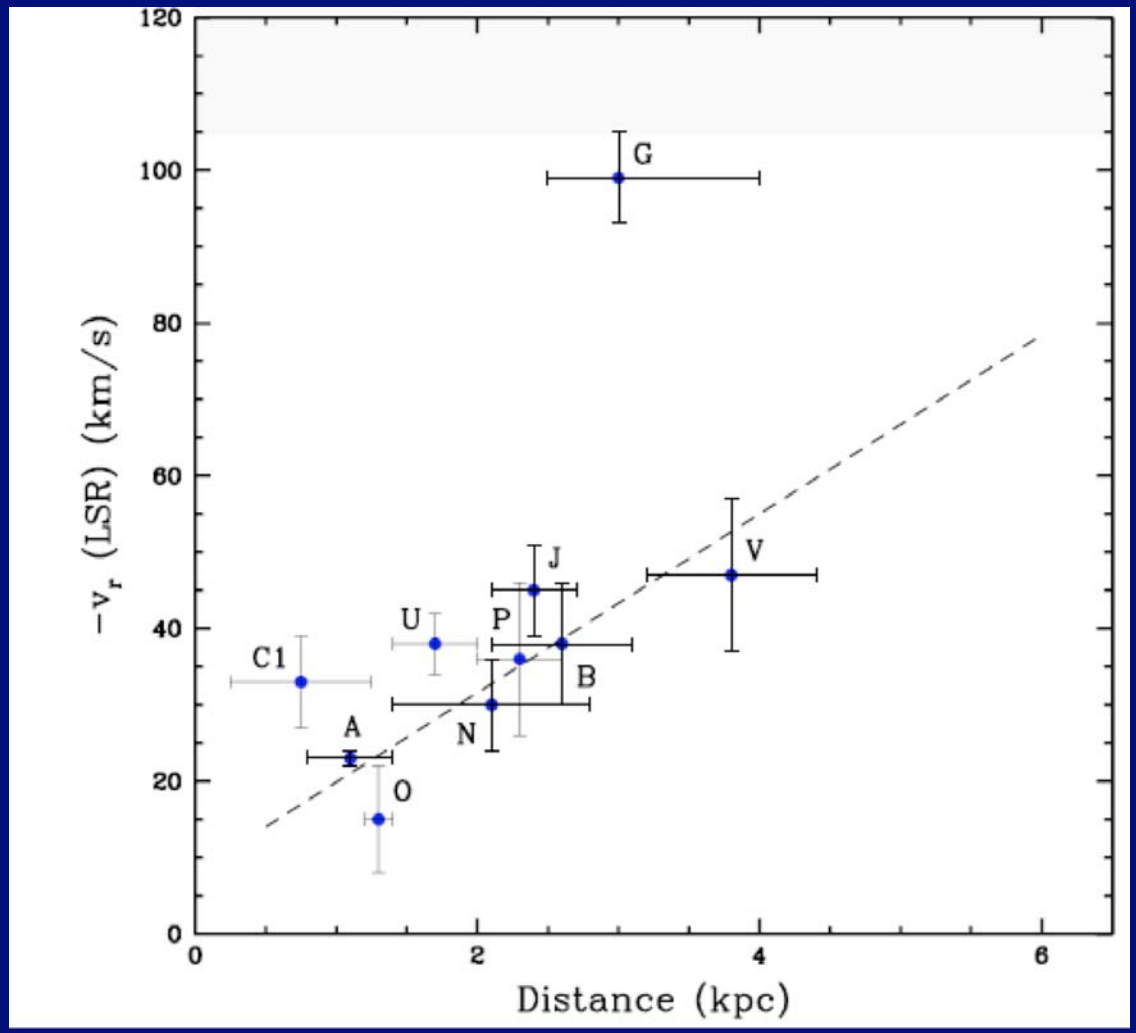
How Far has it moved?

$$m = 18.9 - 2.5\log\left(\frac{L}{L_{sun}}\right) + 5\log\left(\frac{D}{3\text{kpc}}\right) + (A_V - 1.85)$$

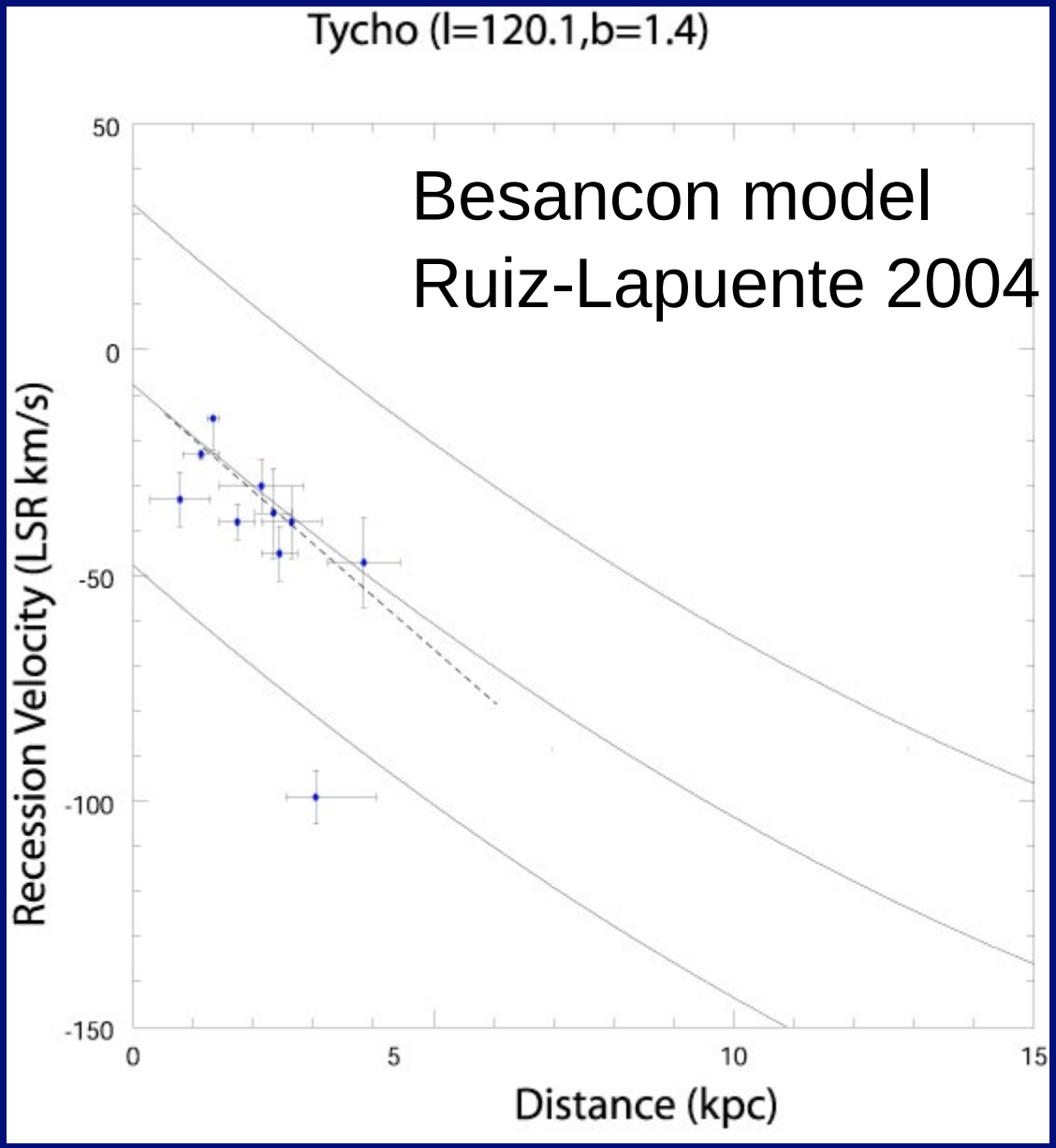
How Bright is it?

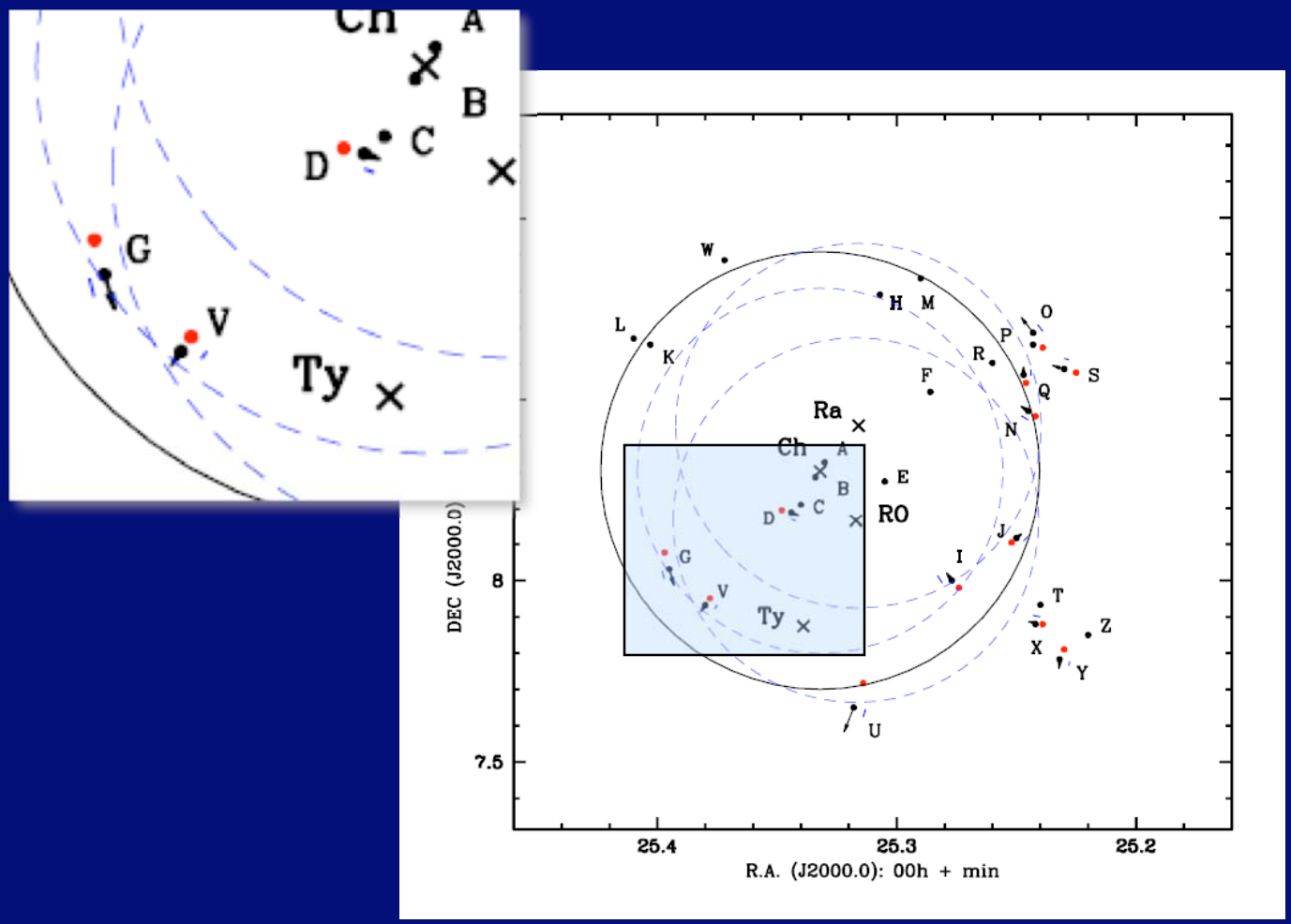

Tycho (l=120.1,b=1.4)
Besancon model
Recession Velocity (LSR km/s)
50
0
-50
-100
-150
0
5
10
15
Distance (kpc)

Ruiz-Lapuente 2004 Nature

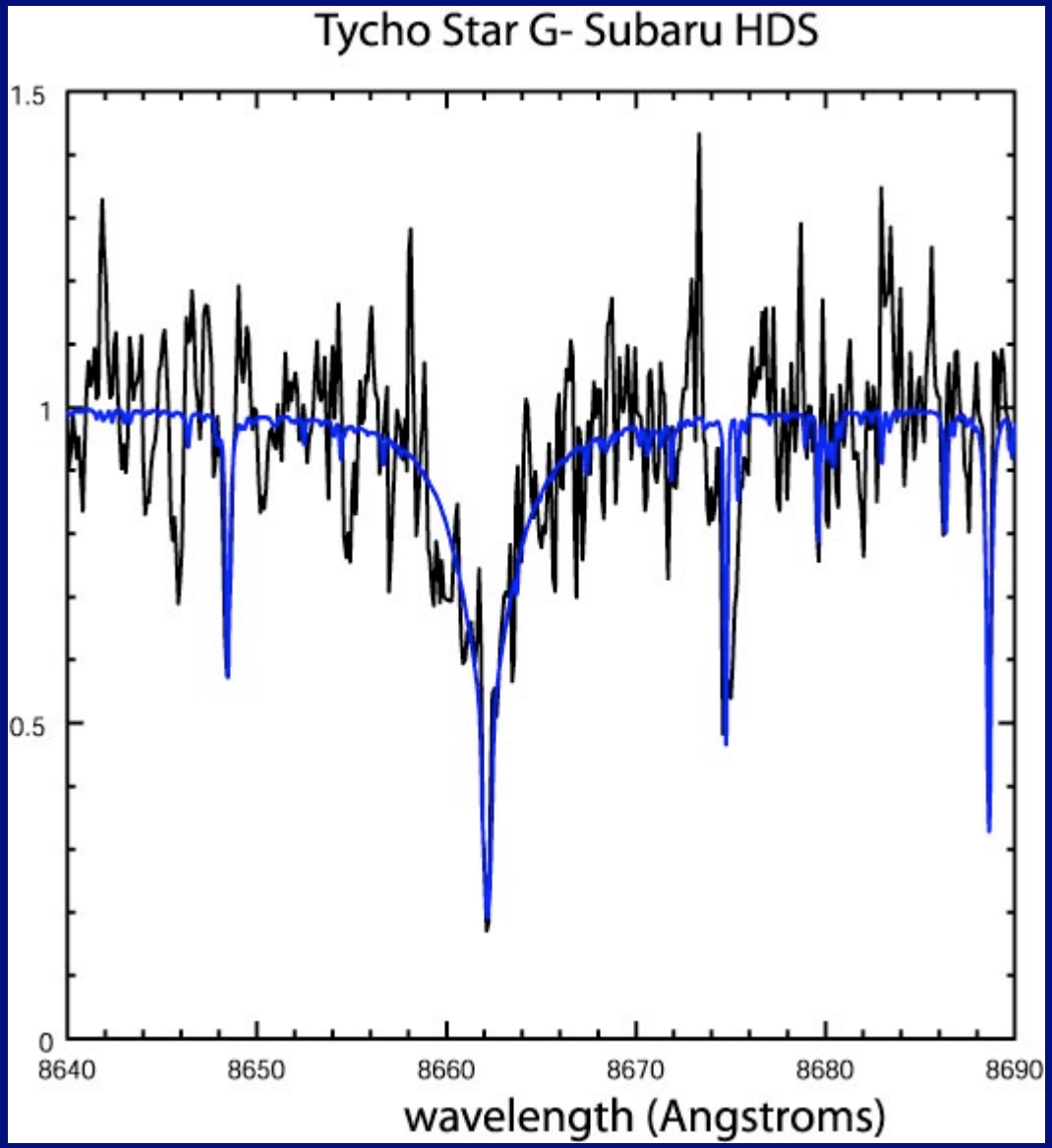


Log(g)=3.5+/- 0.5
V(VSR)=-95 km/s
Solar metallicity

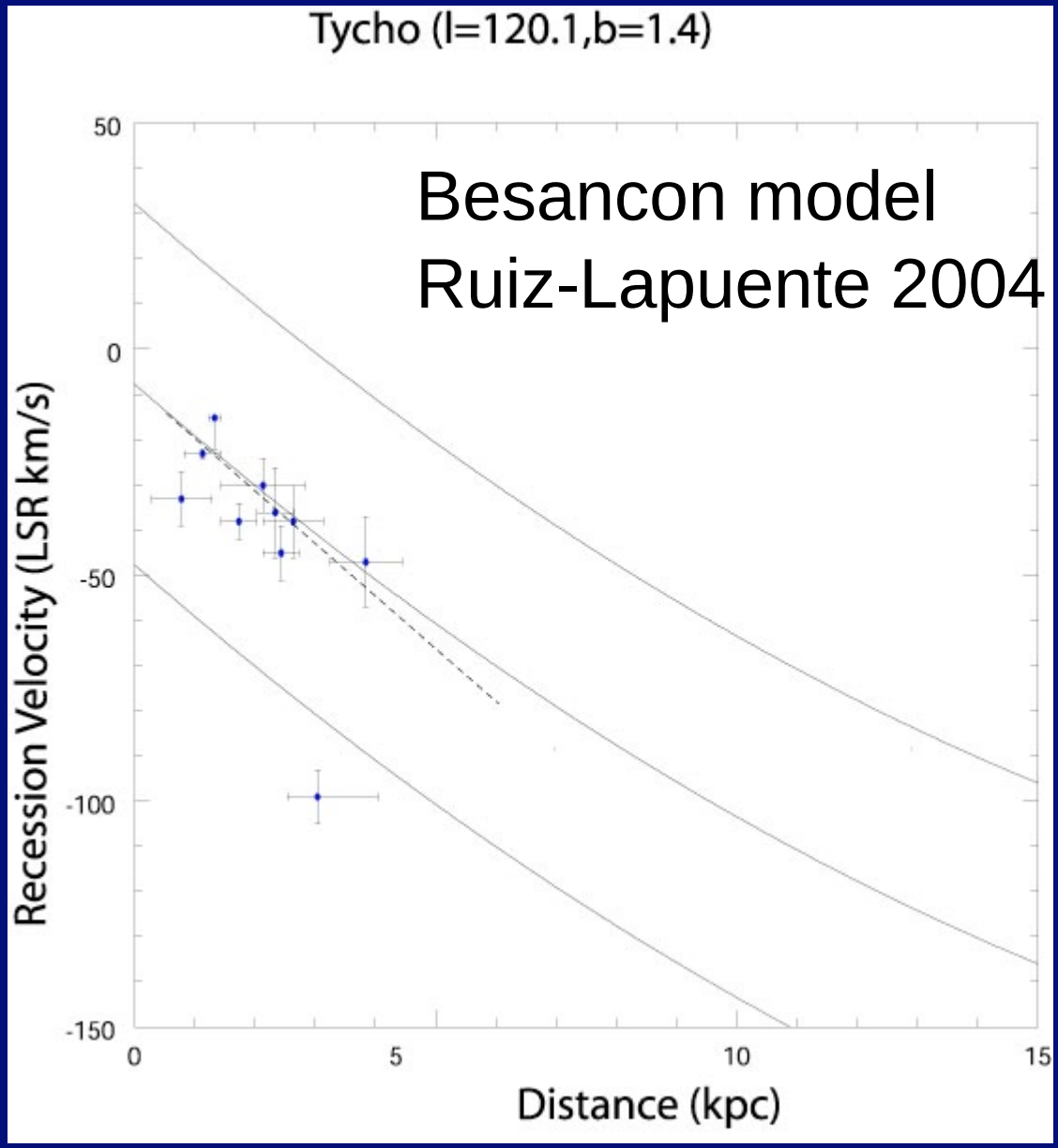

Tycho (l=120.1,b=1.4)
Besancon model
Ruiz-Lapuente 2004
Recession Velocity (LSR km/s)
Distance (kpc)
50
0
-50
-100
-150
0
5
10
15

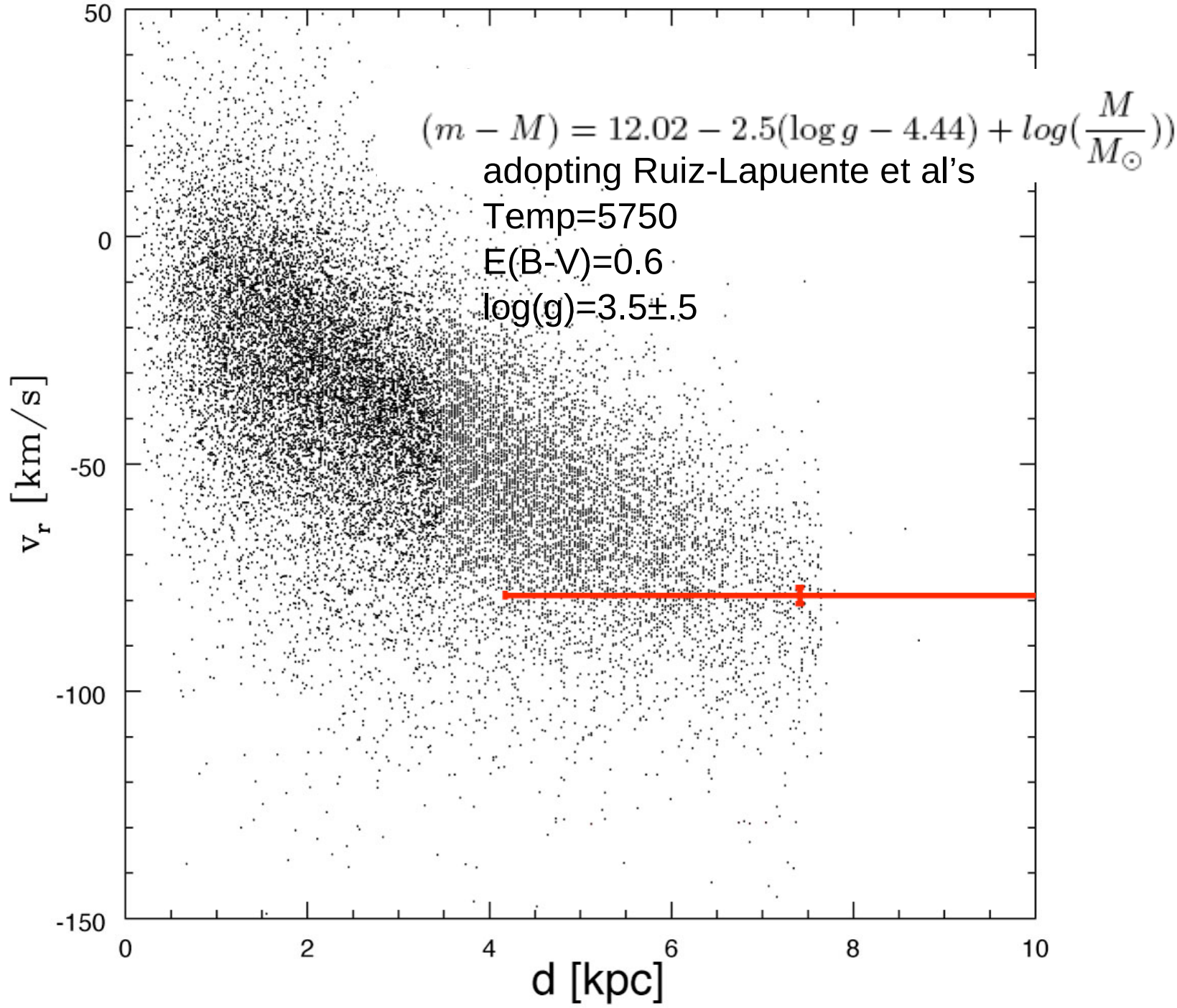


2-sigma proper motion… But not really where you Want it to be in 1572…



Vel (LSR)=-79±2 km/s (-93km/s topocentric)
Fe/H=Solar

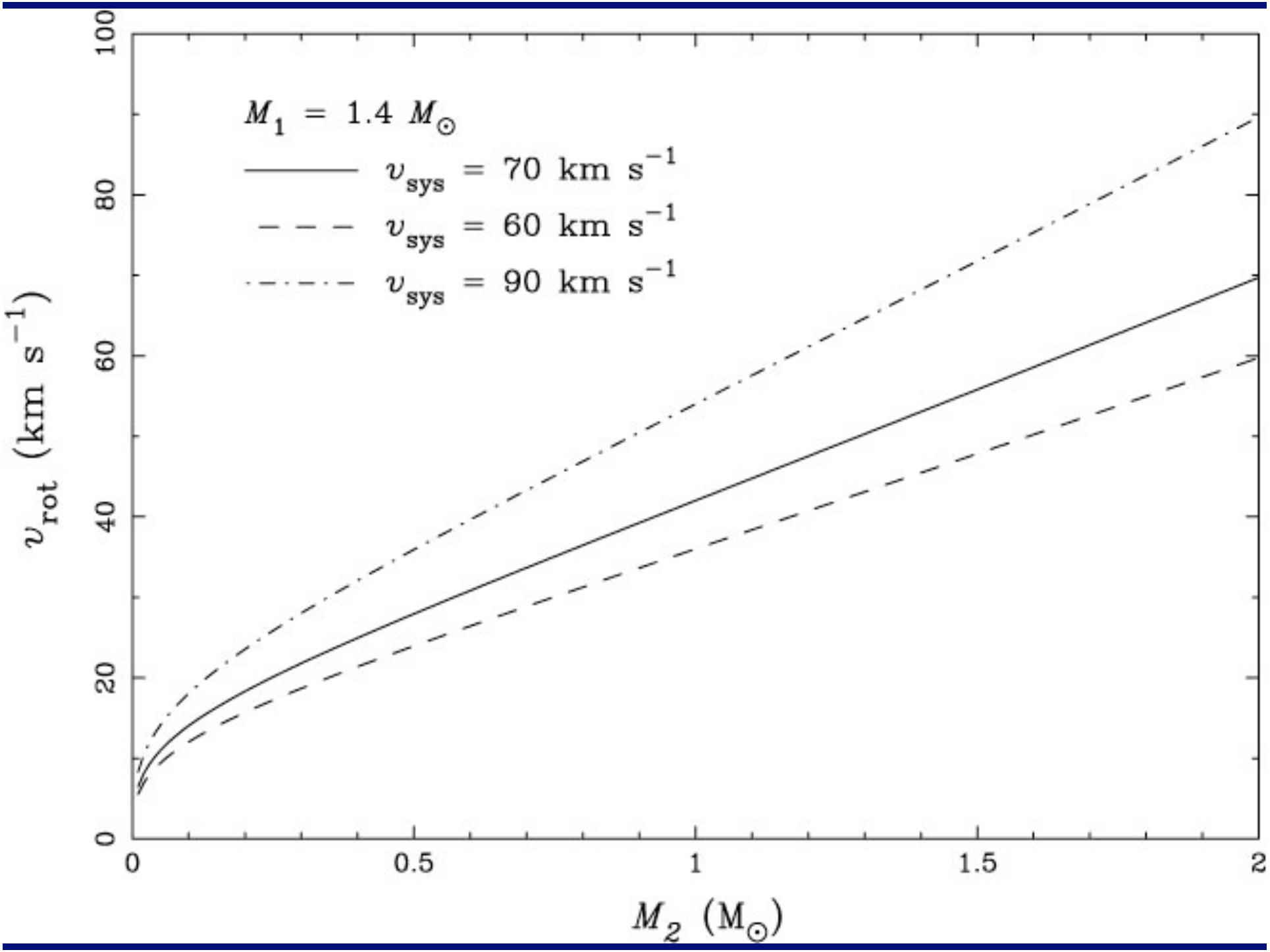

Tycho (l=120.1,b=1.4)
Besancon model
Ruiz-Lapuente 2004
Recession Velocity (LSR km/s)
Distance (kpc)
50
0
-50
-100
-150
0
5
10
15

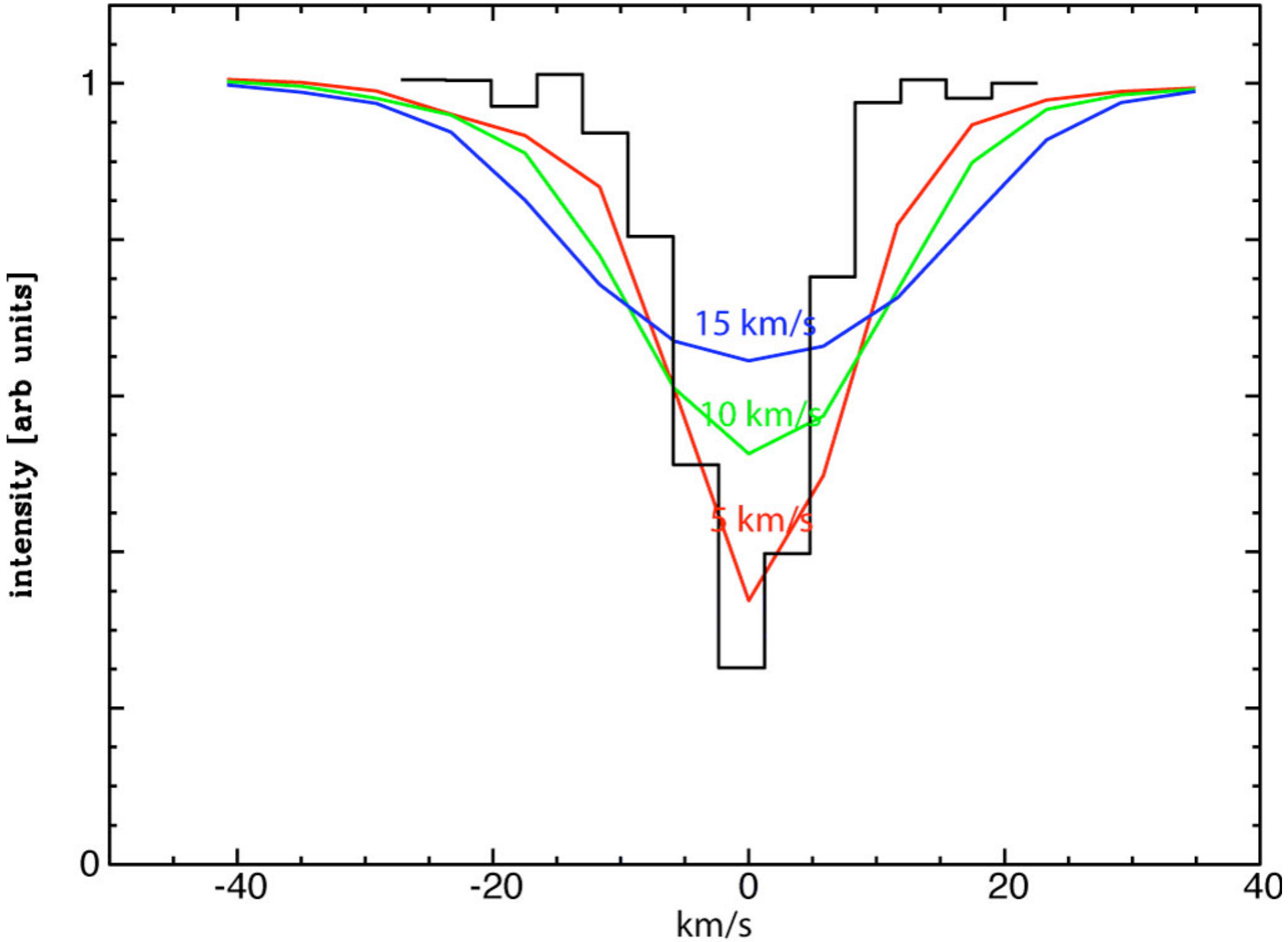

$(m - M) = 12.02 - 2.5(\log g - 4.44) + log(\frac{M}{M_\odot})$
adopting Ruiz-Lapuente et al's
Temp=5750
E(B-V)=0.6
log(g)=3.5±.5
50
0
-50
-100
-150
v_r [km/s]
0
2
4
6
8
10
d [kpc]

Rotation!

The heart of this model is accretion from a companion onto a White Dwarf.

Assuming this is roche lobe overflow (could possibly be a wind-if red giant), the donor star will be tidally locked to the rotation period of the system.


$M_1 = 1.4\ M_\odot$
$v_{sys} = 70$ km s^{-1}
$v_{sys} = 60$ km s^{-1}
$v_{sys} = 90$ km s^{-1}
v_{rot} (km s^{-1})
M_2 (M$_\odot$)
0
20
40
60
80
100
0
0.5
1
1.5
2


1
0
intensity [arb units]
15 km/s
10 km/s
5 km/s
-40
-20
0
20
40
km/s

Rotation is a good way to single out stars!

THE ASTROPHYSICAL JOURNAL, 550:L53–L56, 2001 March 20

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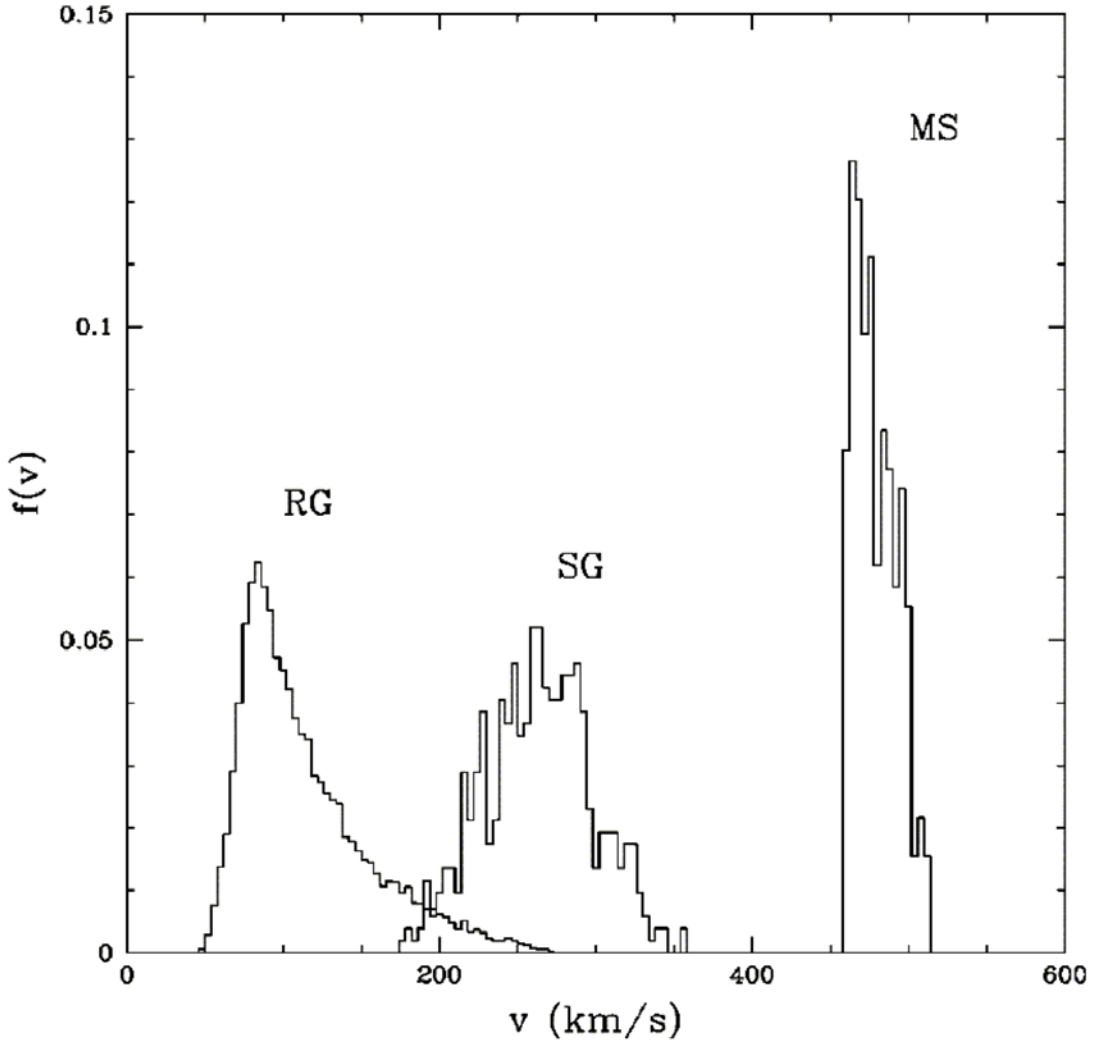
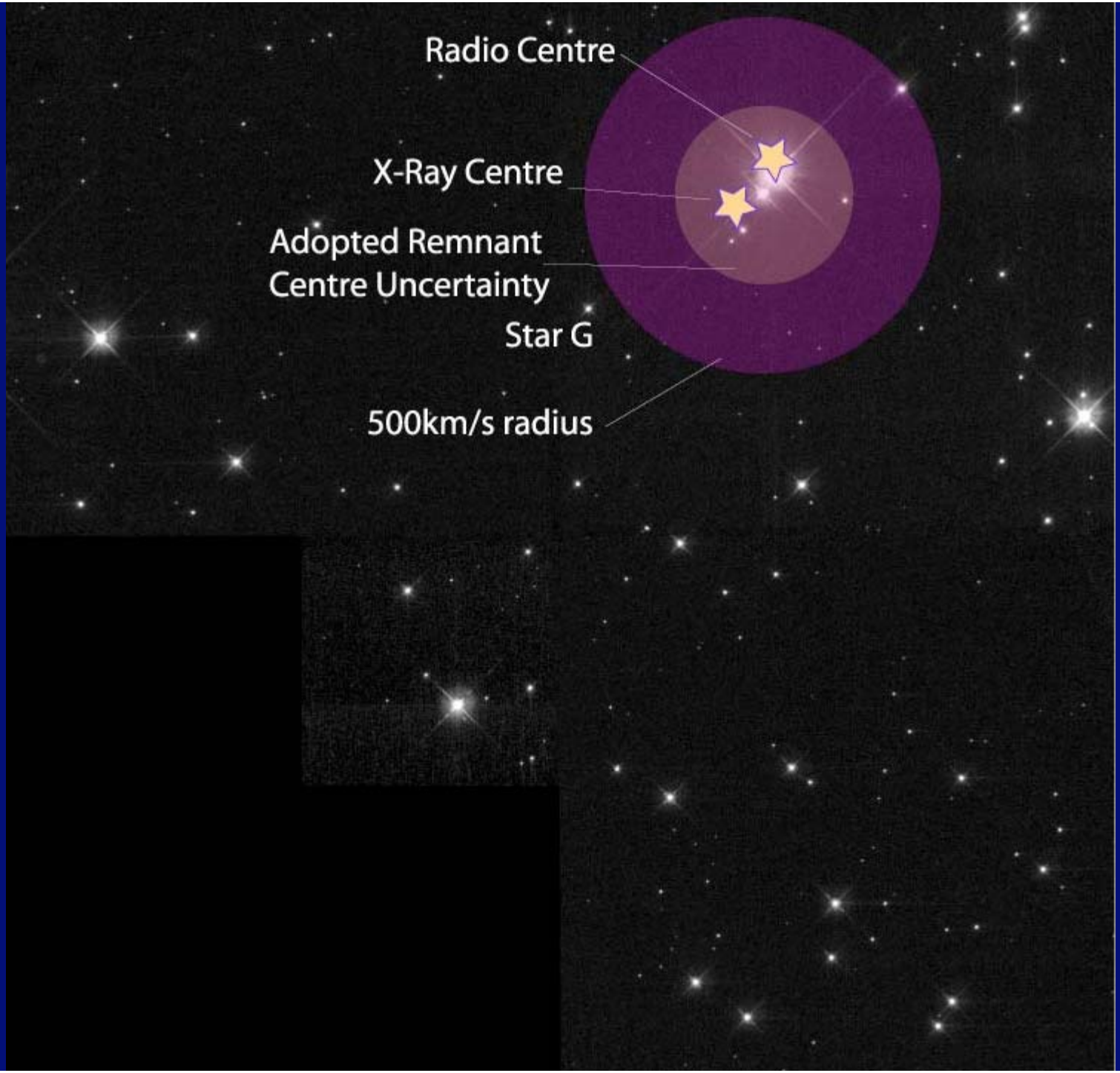


The Plan

- Tycho is the easiest SNR to tackle..Its compact size makes it relatively easy…
- High-res spectra of everything we can get. Data taken by Gal-Yam et al. in late 2006. Data to be analysed.

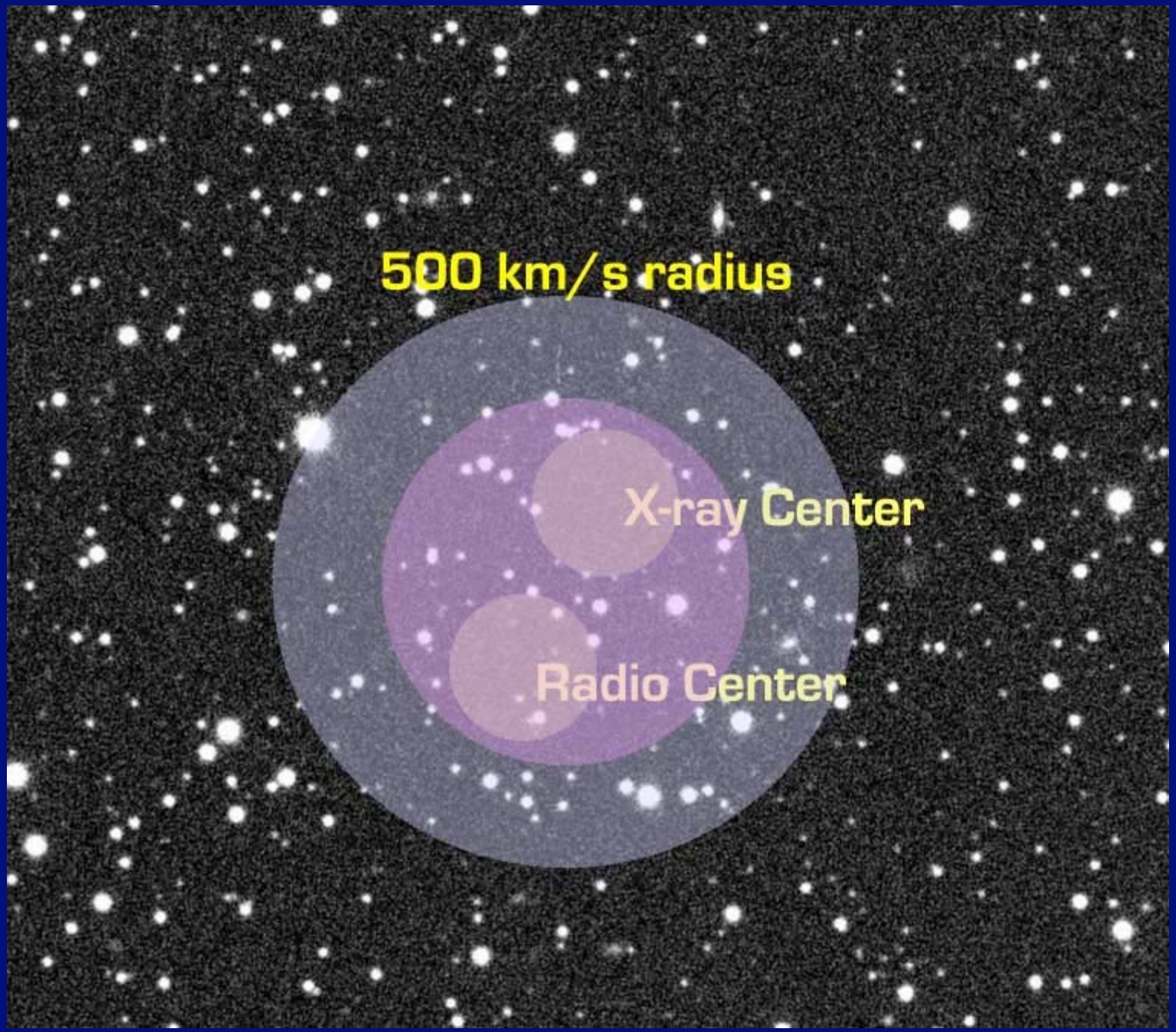

Radio Centre
X-Ray Centre
Adopted Remnant
Centre Uncertainty
Star G
500km/s radius

A few things to note

Things that move slowly and are hard to detect are the giants…

- Which we expect to have had a lot of the envelope removed
- But they should be very bright

- Things that are faint (He stars), should be moving very fast and stand out in deep multi-epoch imaging)
- Very cool (faint stars) should stand out in deep imaging (via colours)

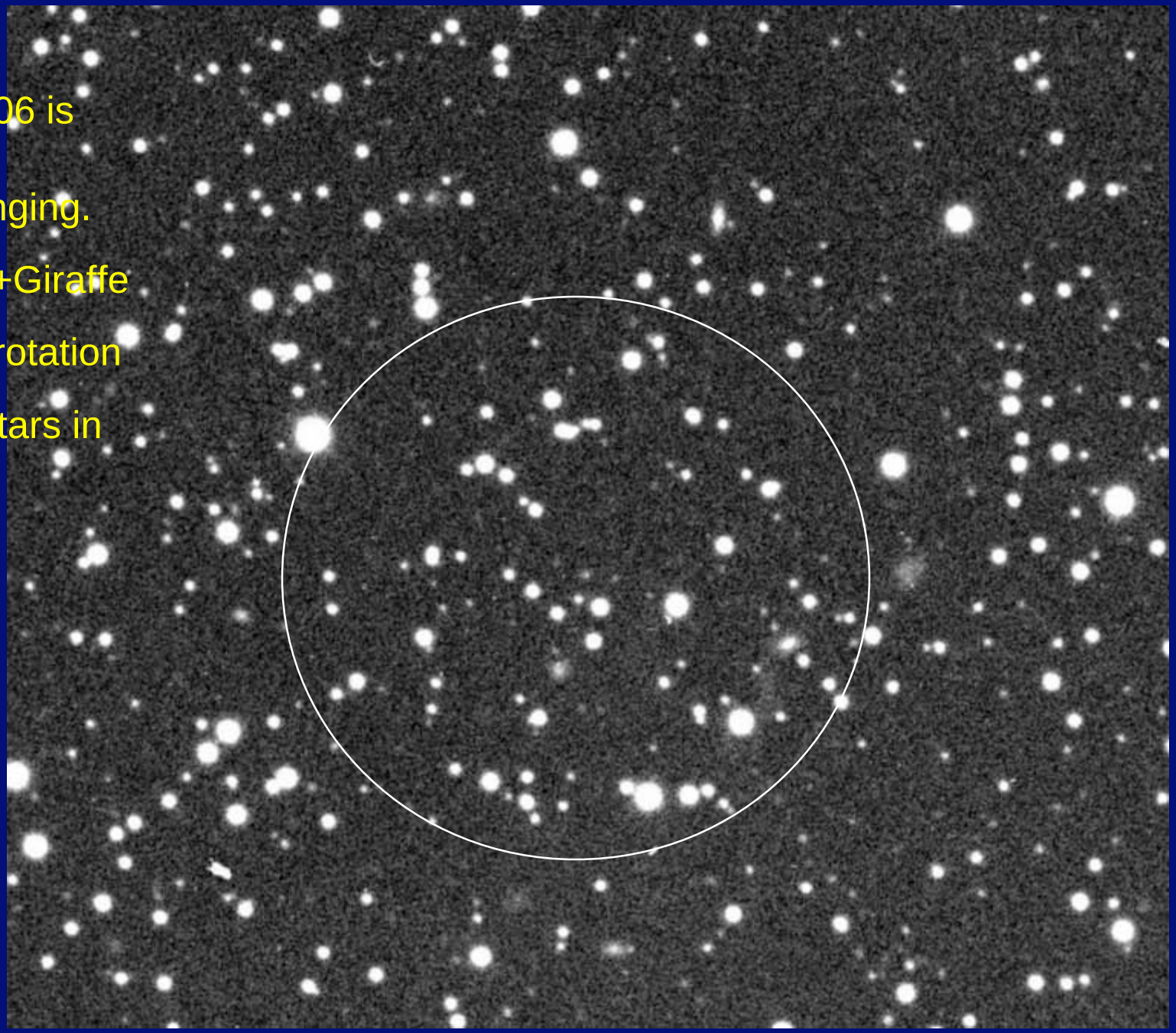

500 km/s radius
X-ray Center
Radio Center

SN 1006 is more challenging.

UVES+Giraffe

to get rotation

of all stars in core.



Other Possibilities for systems if nothing found…

- Edge-lit has Helium WD secondary (but not seen in HST data)
- Double Degenerate has no secondary
- Long delay time between accretion and explosion

Conclusions

Lundqvist, KITP

- No circumstellar emission from a "normal" Type Ia SN has never been seen in any wavelength region. Best limits are obtained in the radio and indicate $<10^{-7}$ $M_{\odot}$ yr^{-1}.
- Optical evidence for episodic mass loss exist for at least two suspected Type Ia SNe (SN 2002ic and SN 2005gj). Radio and X-ray emission was not detected (due to absorption by the circumstellar shell). The shells could be asymmetric.
- Late emission from three normal Type Ia SNe indicate that at most 0.03 $M_{\odot}$ of solar abundance material exists in the center of any of these supernovae. This is much less than in any of the models calculated by Marietta et al. (2000) and put constraints on single degenerate models.

Summary:

Friday's discussion.

Binary Population Synthesis results indicate that:

1. In a population with ages between ~ 200 million and 2 billion years, "Supersoft source" binaries (including the shrouded ones) can produce between 50 (Yungelson 2004) and 90 (Förster et al. 2006) per cent of WD growing to $M_{chandra}$.
2. At other epochs the Double Degenerate mergers appear to dominate the formation rate of degenerate objects with a mass $\geq M_{chandra}$.

3. Forster et al.(2006) conclude: it is too early to rule out any of the proposed Type Ia scenarios.

My Score Card

4=OK 8=BAD

8s=PROB BADS8 = MAYBE BAD

model	Physics explodes	Rate vs. Observed	Tycho 1006	Mass loss Hydrogen
SuperSoft MS or SG				
Supersoft Red Giant				
He dwarf				
Double WD				

What will it take to say Single Degenerate channel is wrong?

- eliminate Red Giants (done)
- eliminate stripped red giants (probably done)
- eliminate Helium stars (probably done)
- eliminate MS or SG stars by rotation and lack of motion (will be done).

Things to do!

1. Avishay to reduce data on Tycho
2. Someone with ESO connections to obtain rotation data on SN1006
3. Hydro Calculation with realistic supersoft system
4. Double Degenerate Merger Calculations made more sophisticated
5. Wait for Galactic SN Ia