



OB RUNAWAY STARS INSIDE SNRs S147 & IC443

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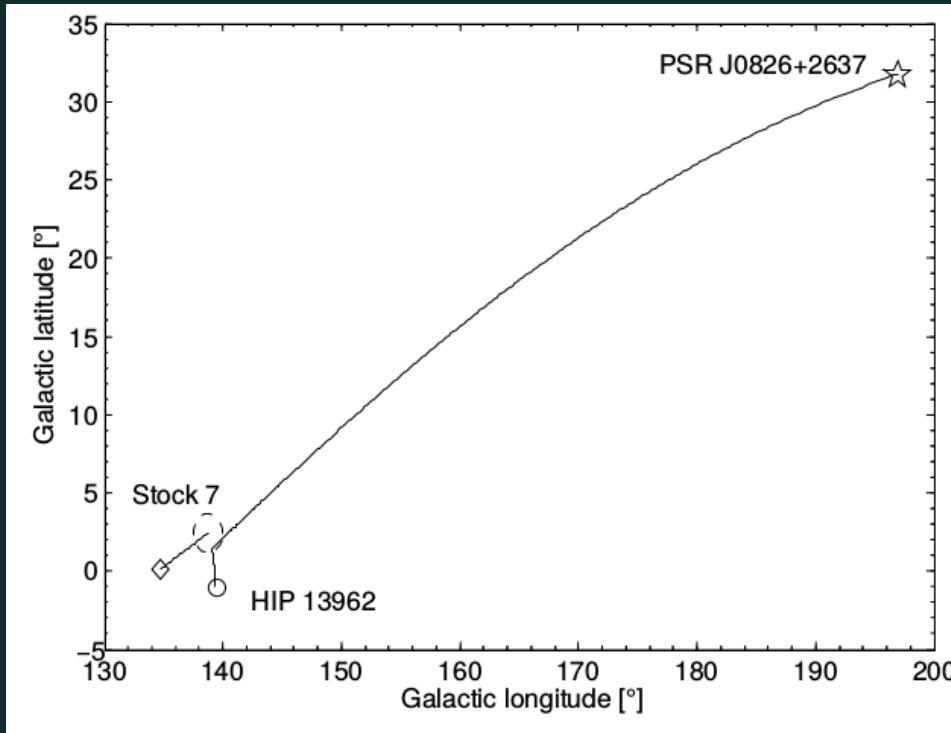




Introduction

- %20 of OB Stars are Runaways (Hoogerwerf+, 2001)
- High Space Velocity $> 25 \text{ km/s}$ (Tetzlaff, PhD-Thesis, 2014)
- Possible Scenarios:
 - Dynamical Ejection (Poveda, 1967)
 - Binary Supernova Ejection (Blaauw, 1961)
- PSR Space Velocity; 300-500 km/s (Lyne & Lorimer, 1995)
- Purposes:
 - NS—Progenitor Relation
 - Asymmetry in SNe
 - Precise SNR Parameters
 - SN Debris on Stellar Atmospheres

Introduction



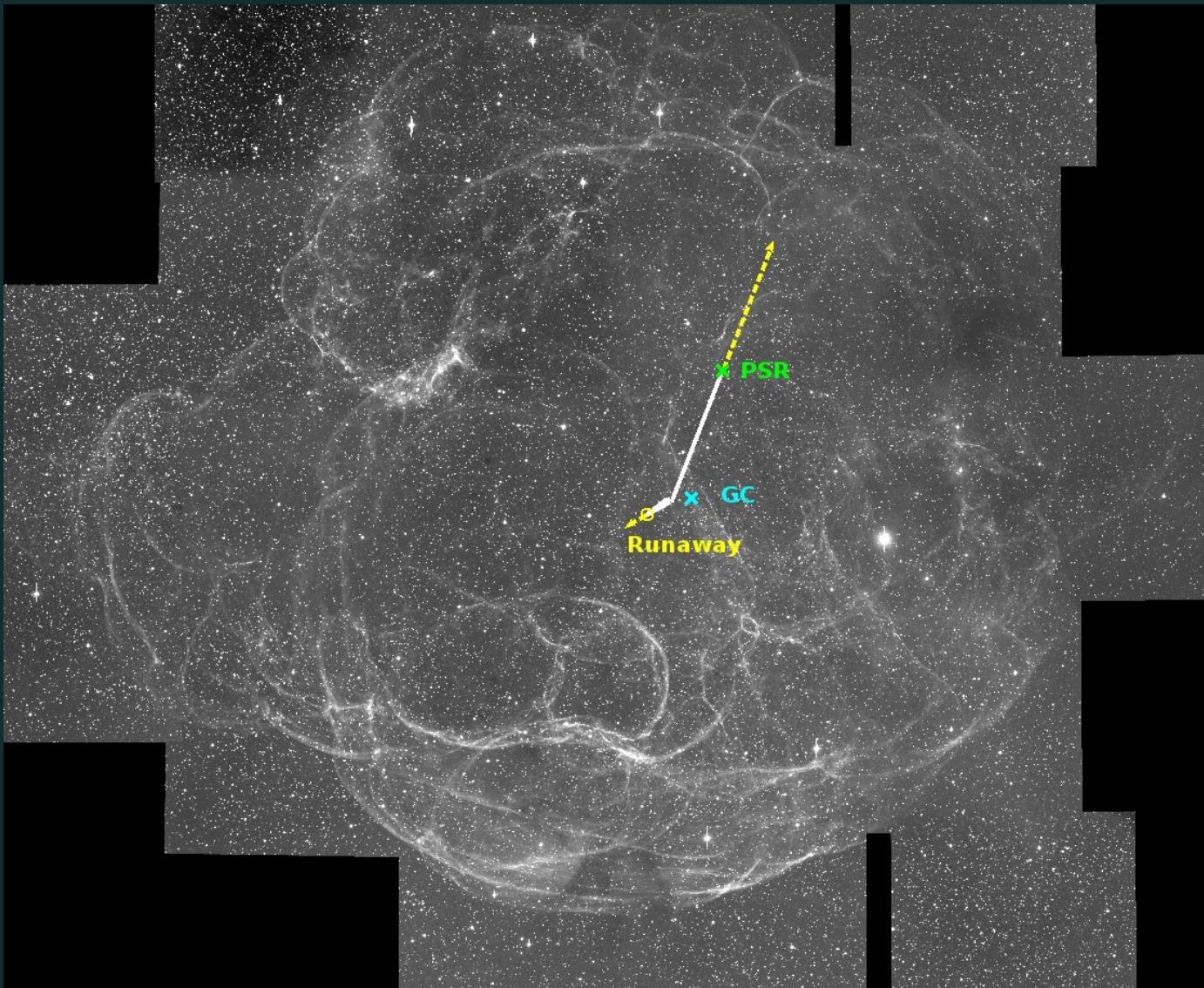
- NS-Runaway Couples (Hoogerwerf+, 2001; Tetzlaff, Dinçel+, 2014)
- Suffer from Large Space & Time Span
- Searching OB Runaways in their Hometown (SNR's)



Introduction (Method)

- Searching OB Runaway Stars Inside 24 SNRs
 - Targets within 1/6th of SNR Radius, <14 mag
 - Candidate Selection via BVJHK Colors
 - SpT Confirmation & RV Determination
- Calar Alto Observatory: CAFOS on 2.2 meter Telescope
- TUBITAK National Observatory: TFOSC on RTT-150
- University Observatory of Jena: FLECHAS on 90 cm Scmidt Telescope

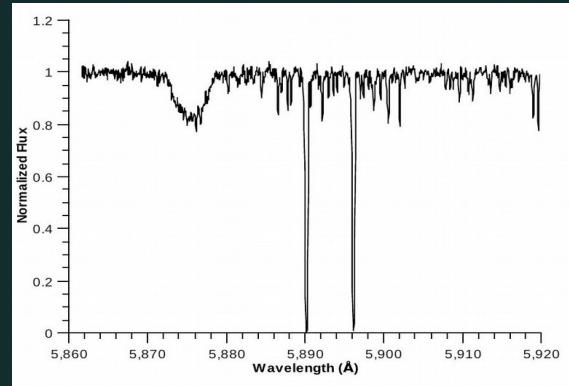
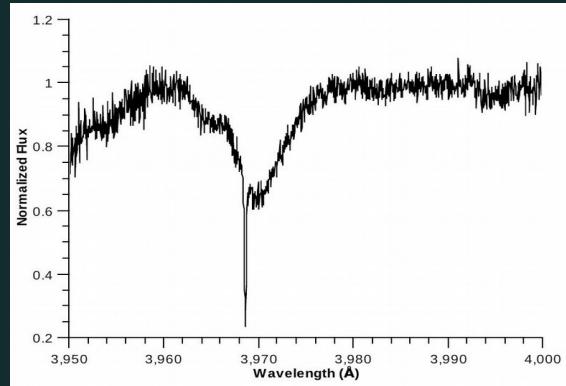
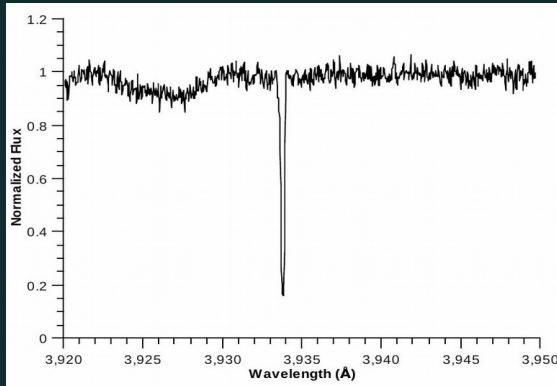
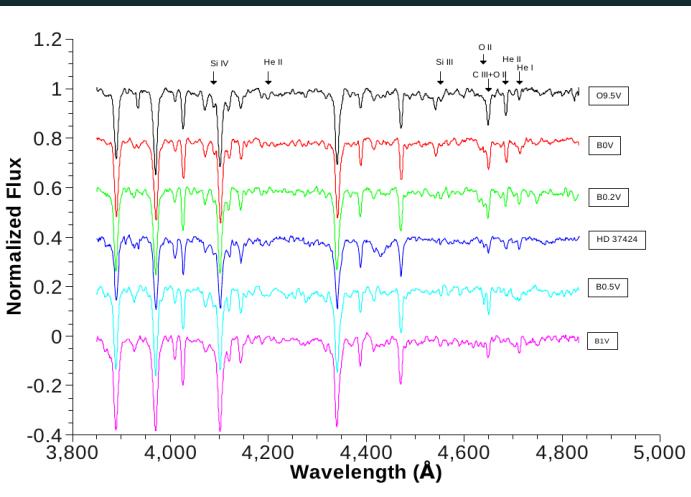
HD 37424 in SNR S147



HD 37424 (Observations)

Parameter	Value
<i>B</i>	9.062 ± 0.017
<i>V</i>	8.989 ± 0.019
<i>J</i>	8.666 ± 0.017
<i>H</i>	8.696 ± 0.026
<i>K</i>	8.699 ± 0.019
μ_{α}^*	10.8 ± 0.8
μ_{δ}	-10.2 ± 0.6

- TFOSC (TUG), R ~ 1300
- Spec Type Identification
- TRES (SAO), R ~ 40000
- RV & ISM lines;
 - CaII-H/K, NaI-D1/D2



HD 37424 (Measurements)

- SpT: B0.5V \pm 0.5
- Sp Plx: 1318 \pm 119 pc
- RV : -9.2 ± 6.5 km/s, -9.1 ± 5.5 km/s
- Call-K : 12.5 km/s
- Call-H : 11.7 km/s
- Nal-D1 : 11.9 km/s
- Nal-D2 : 11.7 km/s
- Distance (Ca-K/H): 1355^{+133}_{-121} pc
- 3D Peculiar Velocity: 74 ± 8 km/s

SNR S147

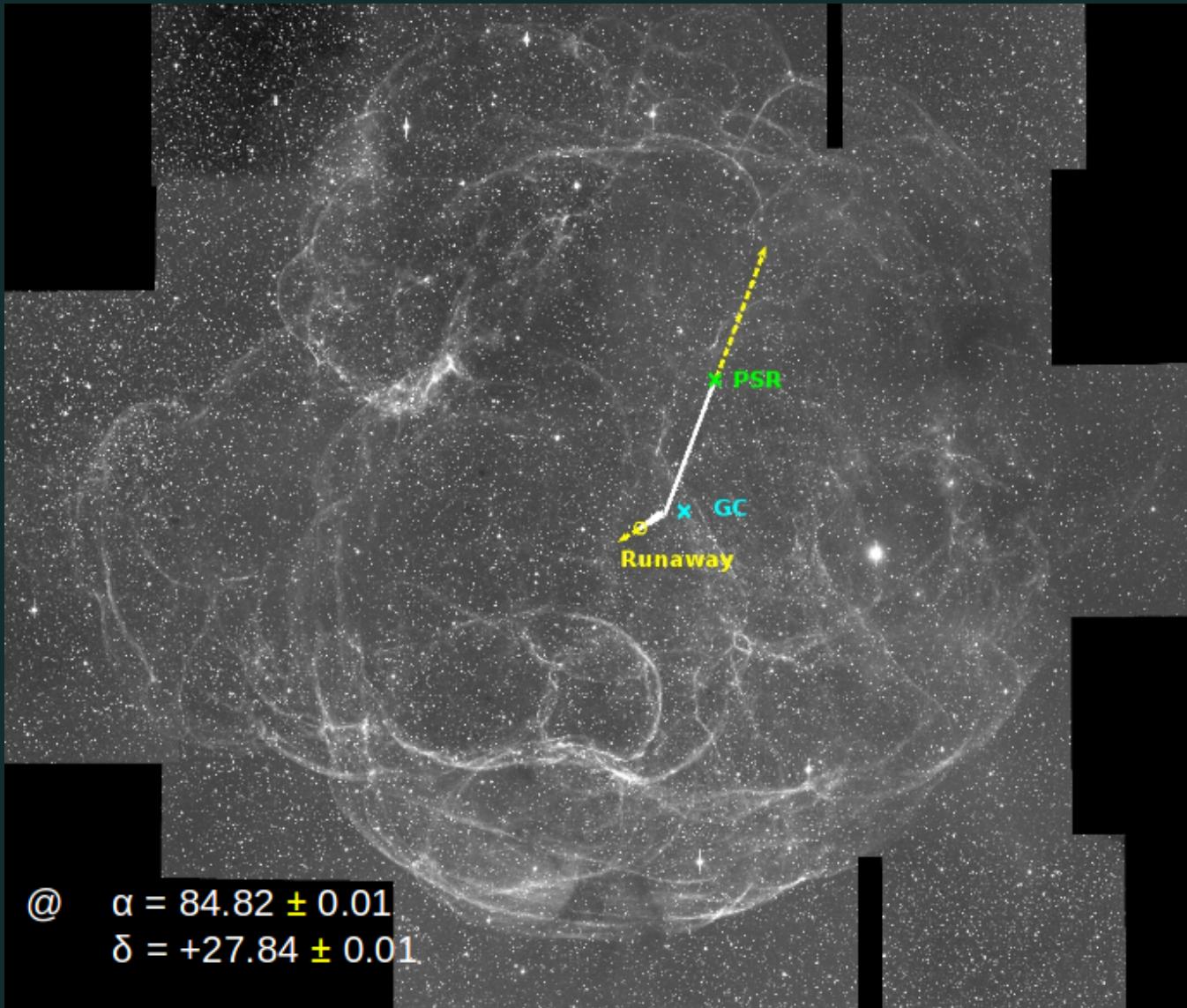


SNR & PSR

- Shell Type SNR
- Optical Filaments
- Sedov Age: 100–200 kyr
- Gal: 180.0-1.7
- Diam: 180 arcmin
- Dist: 0.8–1.8 kpc
- NS: PSR J0538+2718
- Radio, Optical, Gamma
- Faint X-ray
- P : 143 ms
- P_{dev} : $3.6694515 \cdot 10^{-15}$
- $\tau = 618$ kyr
- Kin Age: 30 ± 4 kyr
- PWN in X-ray
- Dist: $1.3^{+0.22}_{-0.16}$ kpc
- μ_a^* : -23.57 ± 0.1
- μ_δ : 52.87 ± 0.1 mas/yr
- V_{trans} : 357 km/s (flat rotation)

References in Dinçel+ 2015

Kinematics

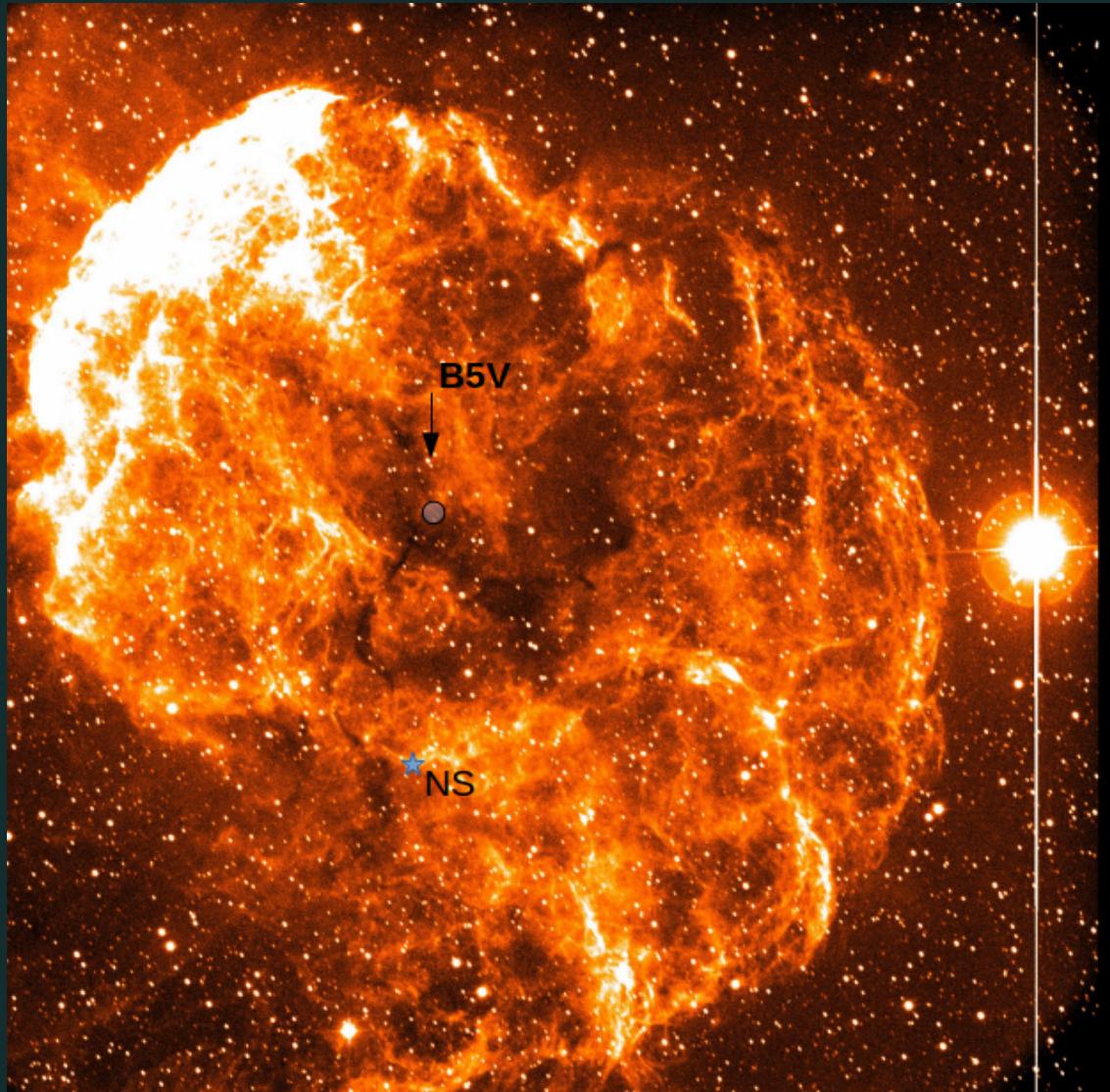


Kinematics (pre-SN Binary)

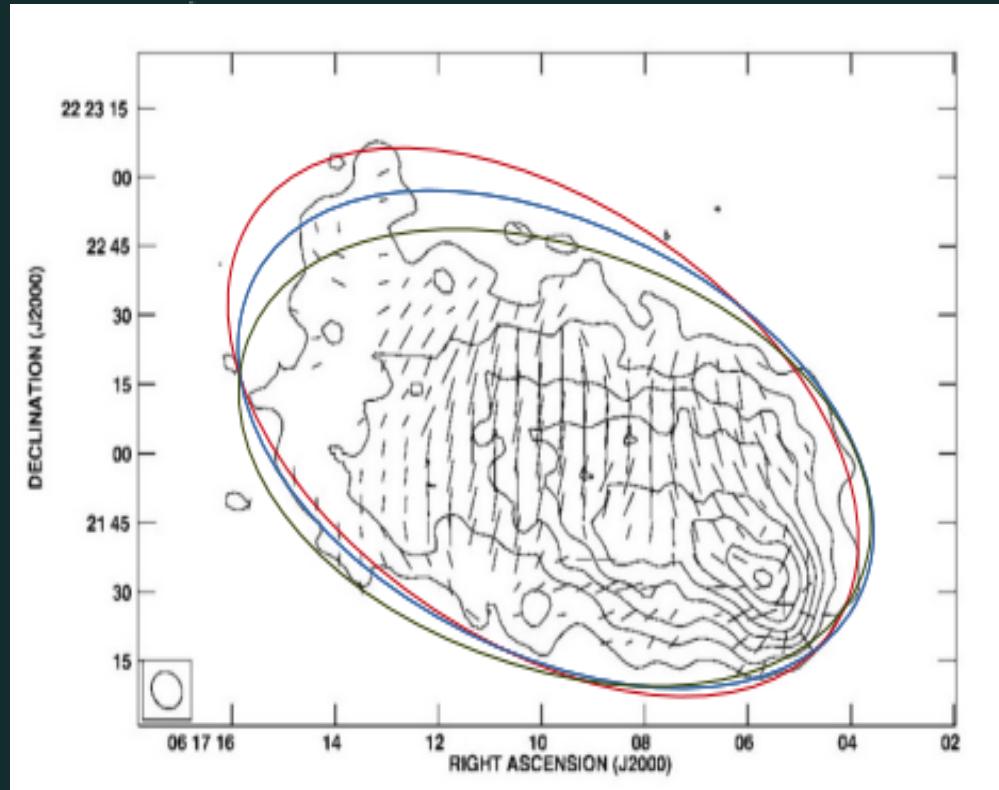
- For $13 M_{\text{sun}}$; at 1.3 kpc
- Close Binary
- Low Progenitor Final Mass (van den Heuvel, 1993, Woosley+ 1995)

Progenitor mass (M_{\odot})	2	5	10	15	20	25
Binary separation (R_{\odot})	9^{-1}_{+3}	49^{-9}_{+11}	152^{-26}_{+37}	281^{-49}_{+68}	425^{-75}_{+101}	576^{-101}_{+137}
Orbital velocity (km s^{-1})	481 ± 49	192 ± 20	96 ± 10	64 ± 7	48 ± 5	38 ± 4
Orbital period (d)	$0.85^{-0.22}_{+0.32}$	9^{-2}_{+4}	45^{-11}_{+17}	103^{-26}_{+39}	176^{-44}_{+66}	259^{-65}_{+98}
Roche lobe radius (R_{\odot})				110^{-19}_{+27}	177^{-31}_{+42}	251^{-44}_{+60}

IC 443 & CXOU J061705.3+222127



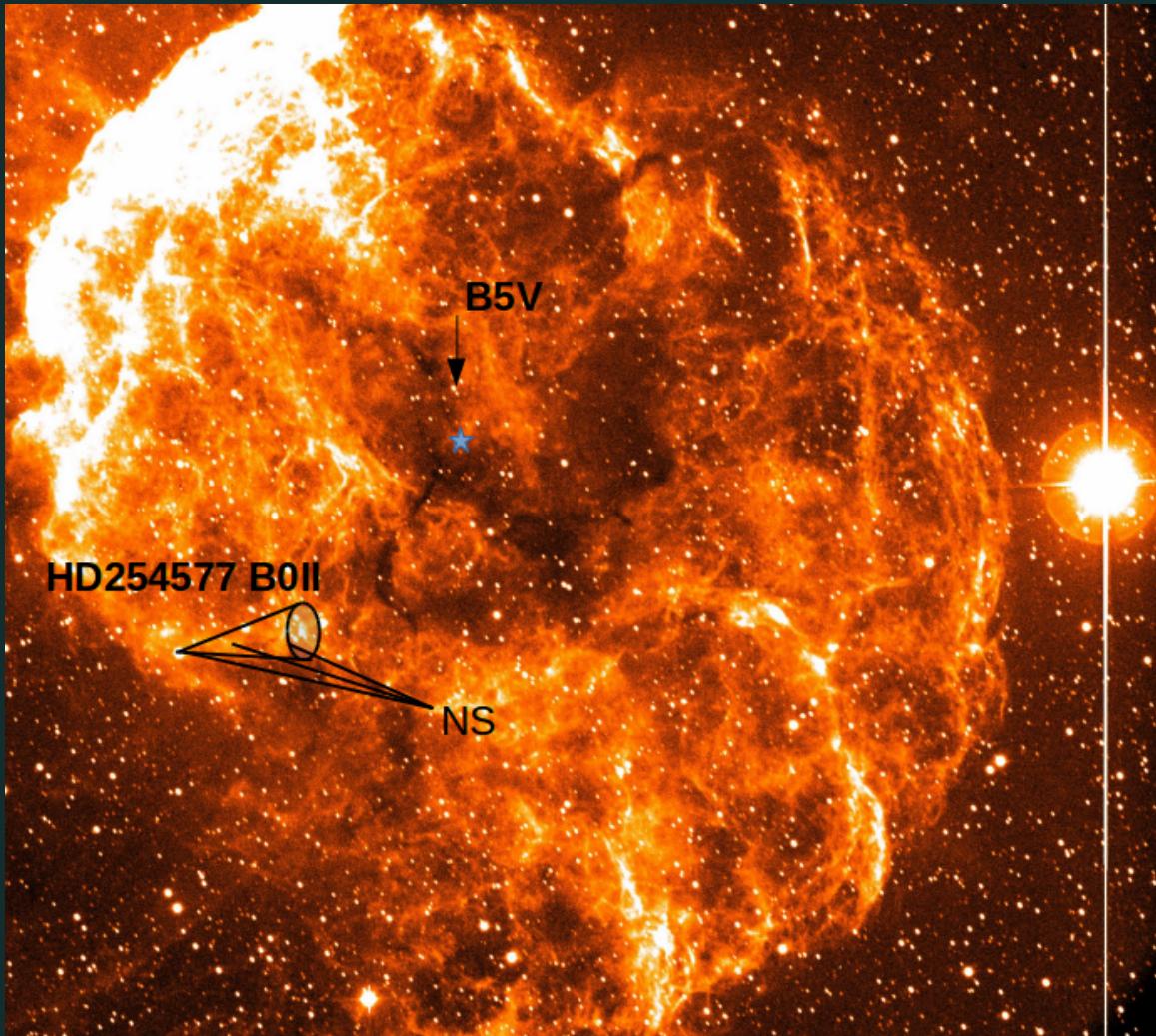
IC443



- Bow Shock PWN Does NOT Point GC of SNR
- Possible PA; 71 ± 5 deg
- $\mu_\alpha^* : -18.1 \pm 33.4$ mas/yr
- $\mu_\delta : -1.2 \pm 33.4$ mas/yr (Swartz+, 2015)

Image: Olbert+, 2001

IC 443

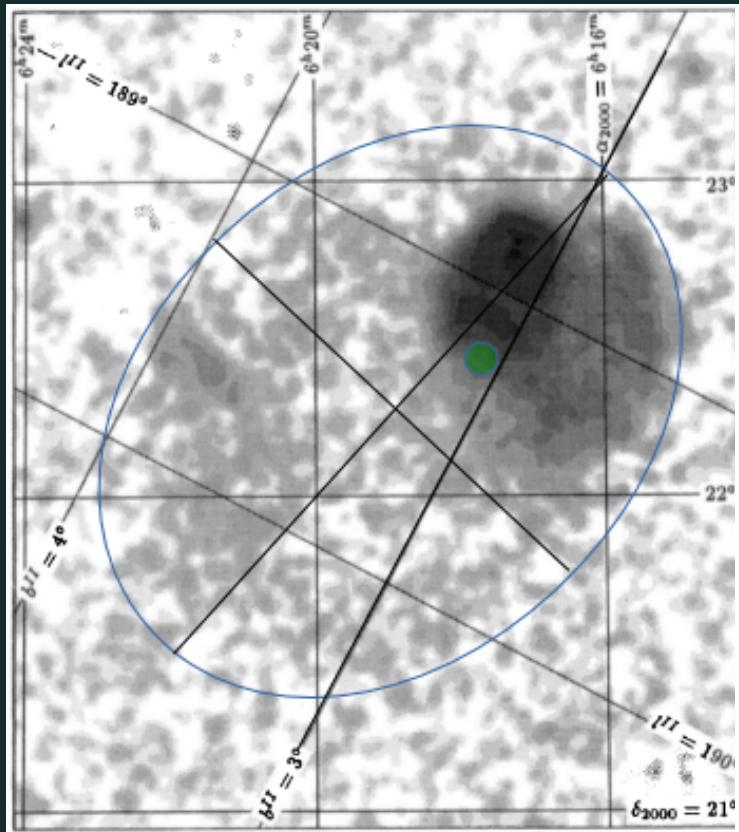




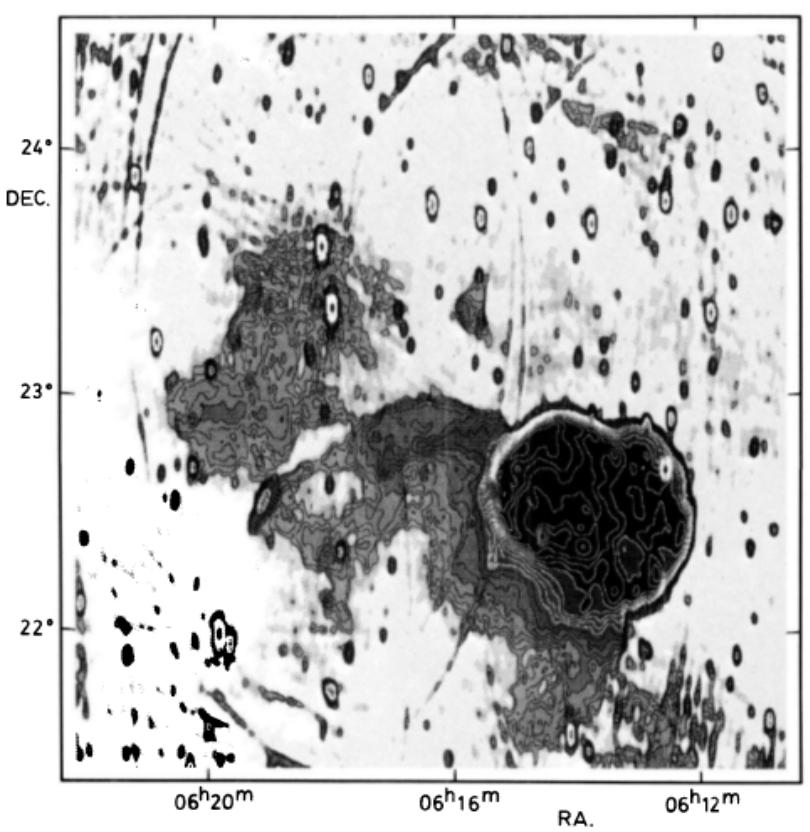
HD 254577

- Gem OB1 Association: $\mu_\alpha^* = -0.5$ $\mu_\delta = -2.2 \pm 0.8$, 1.1 mas/yr
- HD 254577: $\mu_\alpha^* = 4.0$ $\mu_\delta = -2.5 \pm 0.8$, 1.0 mas/yr
- SpT=B0II-III, (FLECHAS, Dincel+, 2015 in prep.)
- Member of Gem OB1 (Garmany, 1992)
- Only Runaway out of 12 others.
- RV: 18 ± 7 km/s (Cross Correlation with HD43818, B0II-III)
- RVrel: 12 ± 4 km/s
- 3D Pec_Vel = 35.6 ± 12 km/s

IC 443

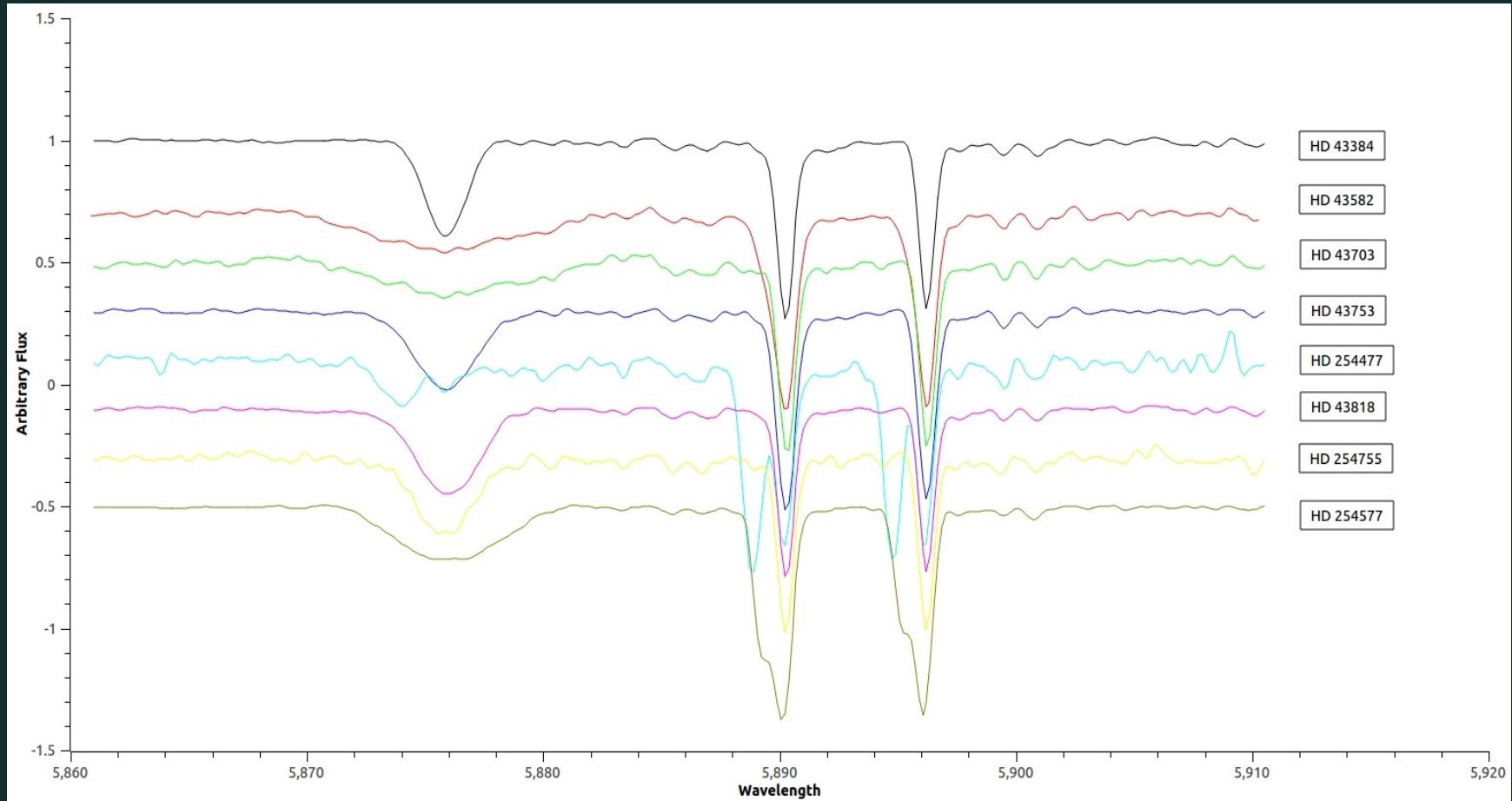


Soft X-ray Image (Asaoka+, 1994)



Radio Image (Braun+, 1986)

HD254577 (ISM)



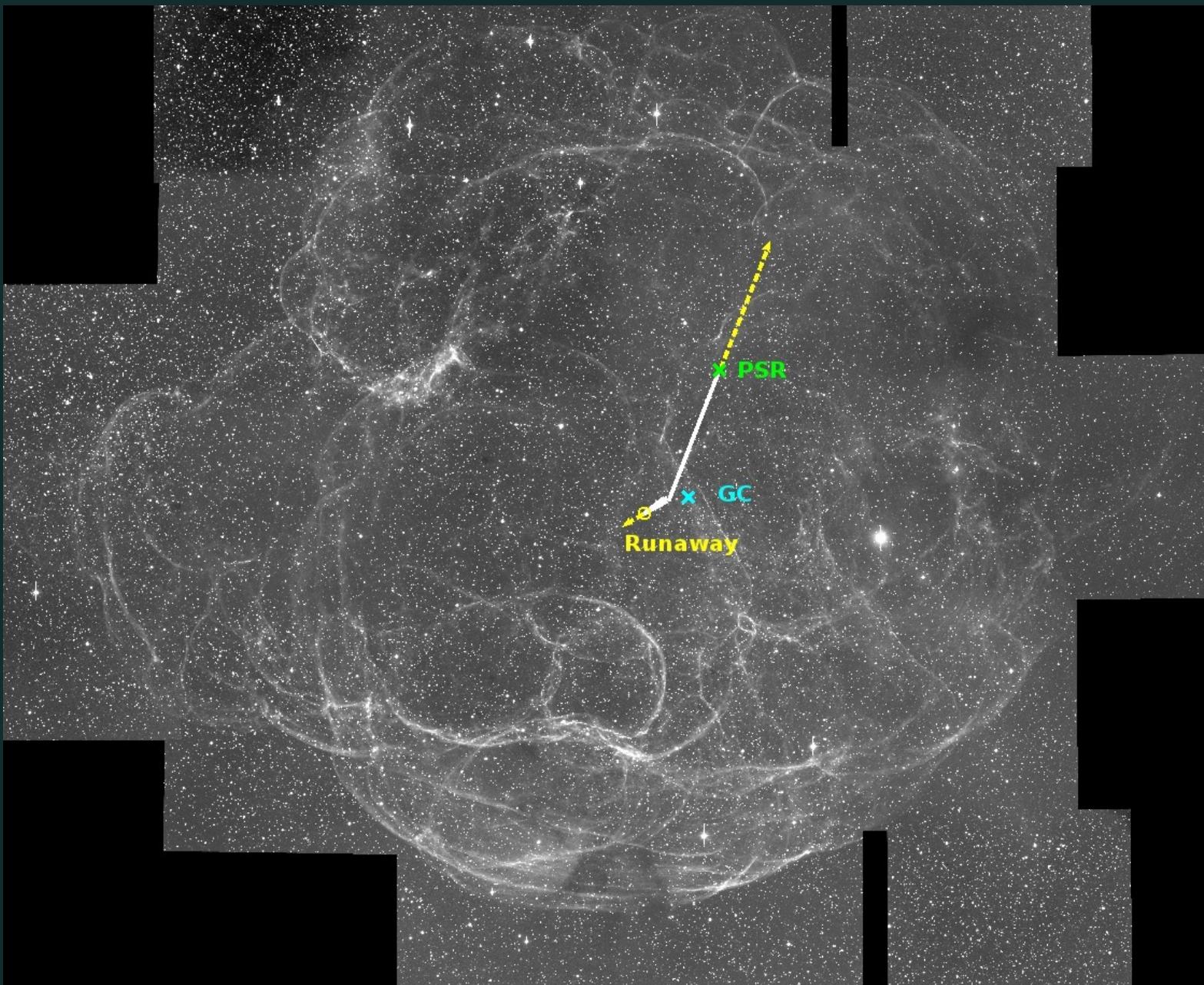


Results & Conclusion

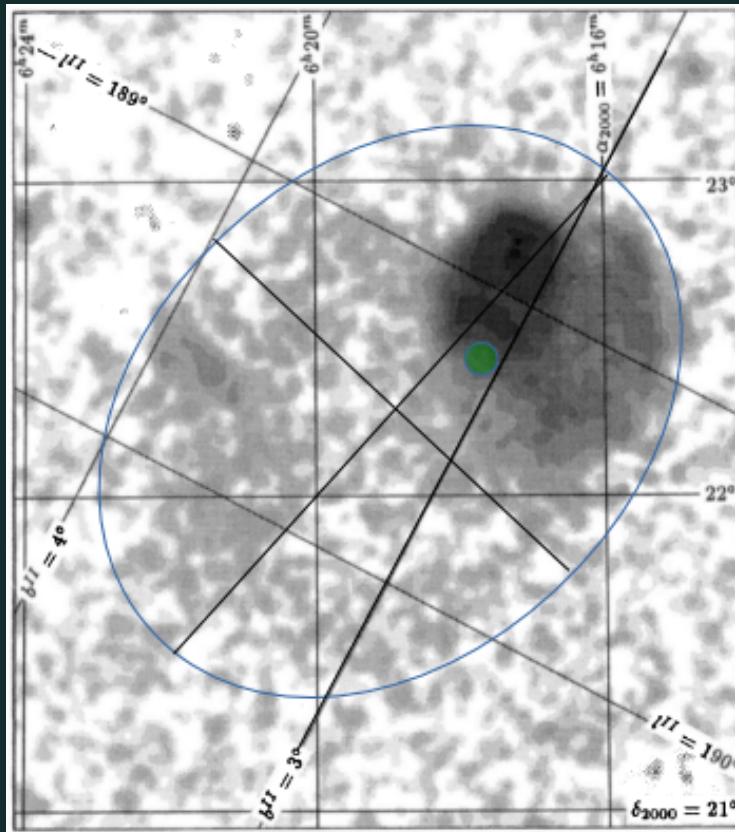
- HD 37424 in S147
- Discovery of Runaway – PSR Pair with High Accuracy
- High Mass Progenitor ($>13 M_{\text{sun}}$) for PSR J0538+2718
- Precise SNR Distance: 1333 ± 112 pc
- SNR Age: 30 ± 4 kyr, $A_V: 1.28 \pm 0.06$ mag
- A Step for PSR – Progenitor Binary Evolution Relation
- HD 254577; Precise Proper Motion of NS Needed
 - IC443 & G189.6+3.3: One SNR
- High Resolution / S/N Observations Done; SN Debris



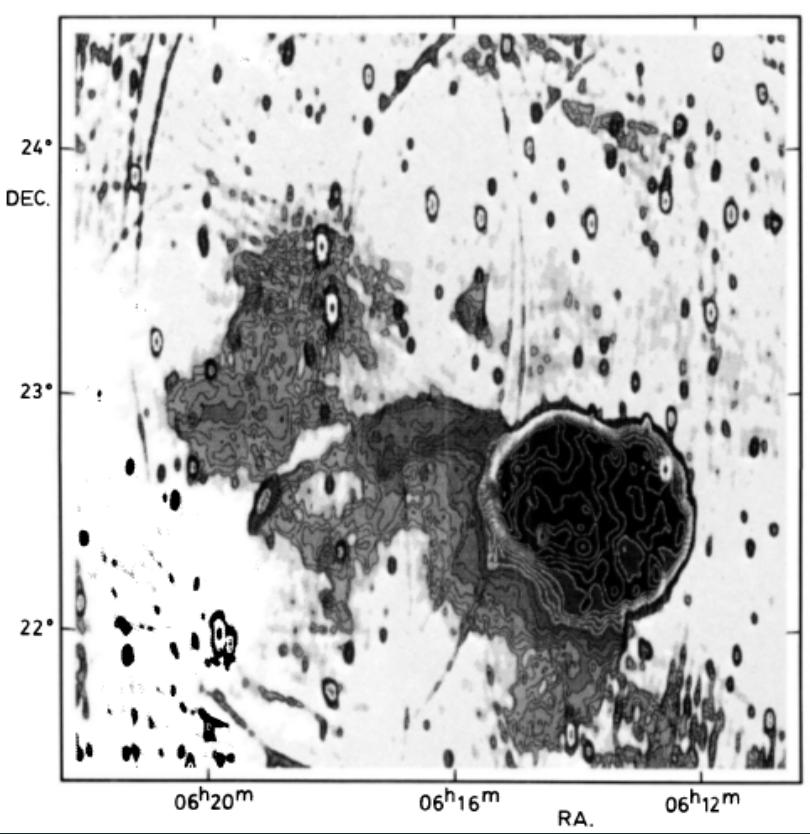
Thank You



IC 443



Soft X-ray Image (Asaoka+, 1994)



Radio Image (Braun+, 1986)

IC 443

- HD 254577 $\mu_{\alpha}^*=4.0$ $\mu_{\delta}=-2.5$ mas/yr $\pm 0.8, 1.0$
- SpT=B0II-III, (FLECHAS, Dincel+, 2015 in prep.)
- Member of Gem OB1 (Garmany, 1992)
- Only Runaway out of 12 others.
- Bow Shock PWN tail Points this Star



IC443

- Gem OB1 Association, $\mu_a^* = -0.5$ $\mu_\delta = -2.2 \pm 0.8, 1.1$ mas/yr
- Shell Type SNR, 45' Diameter
- ~ 1.5 kpc
- Age Estimates; 3 — 60 kyr (X-ray vs. Optical Studies)
- PWN G189.22+2.90, X-ray NS
- UCAC4-563-26625, $\mu_a^* = 5.4$ $\mu_\delta = -0.8 \pm 3.7, 2.4$ mas/yr
- SpT= B5V, $V=13.4$ mag, $Av=3.4$ mag, $d=1.5$ kpc
- UCAC4-563-26616, $\mu_a^* = -2.1$ $\mu_\delta = -6.9 \pm 2.3, 1.1$ mas/yr
- SpT=A1V, $V=12.5$ mag, $Av=1.2$ mag, $d=1.2 \pm 0.4, 0.3$ kpc



HD254577 (RV)

- Observed with FLECHAS
- RV Measured with 4 other Members
- Cross Correlation & Individual lines
- $\text{RV}_{\text{Assoc}} = 11.2 \pm 6 \text{ km/s}$
- $\text{RV}_{\text{HD254577}} = 18.0 \pm 7 \text{ km/s}$
- $\text{RV}_{\text{HD43818}} = 17.0 \pm 6 \text{ km/s}$
- $3D \text{ Pec}_\text{Vel} = 35.6 \pm 12 \text{ km/s}$
- ISM lines Ca II & Na I upto -107 km/s



HD 254577 (ISM)

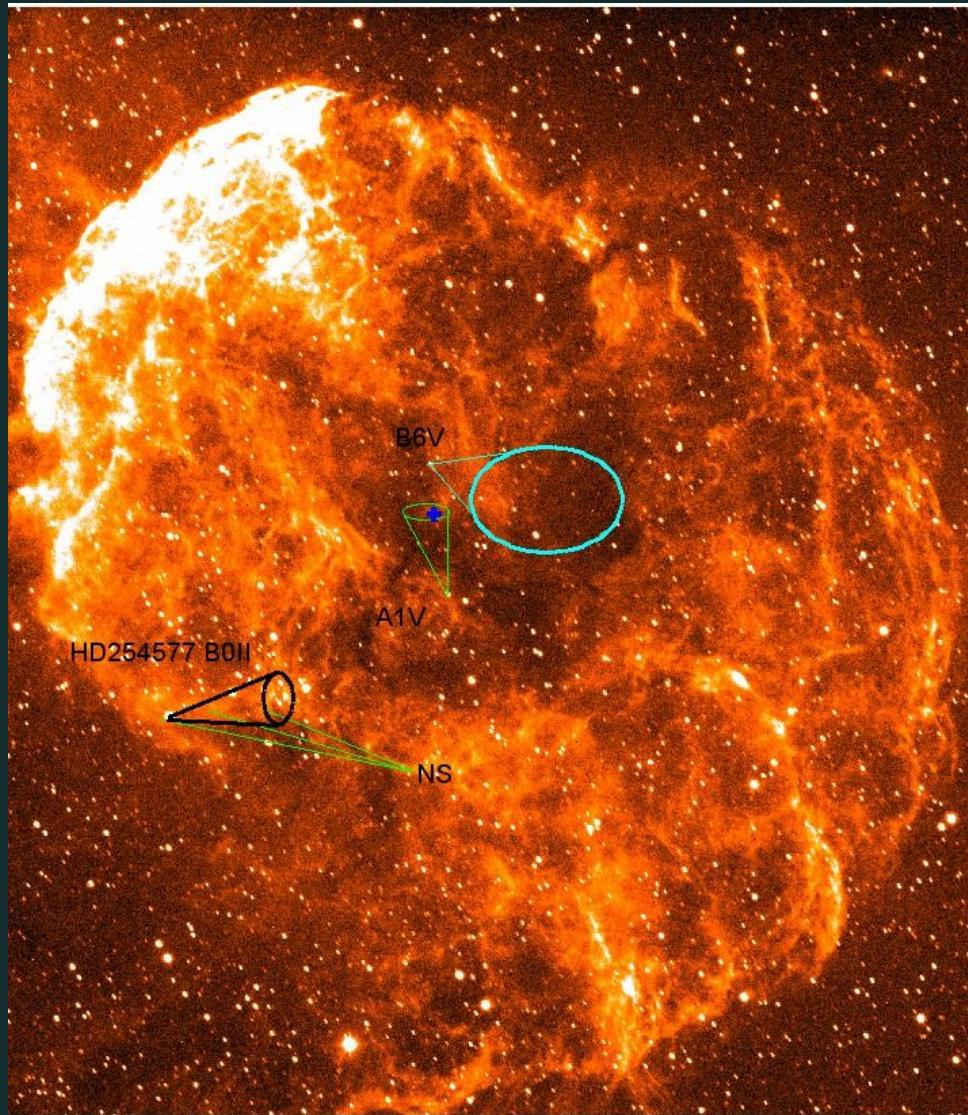
- +20 & +50 km/s ISM Lines (Sallmen+, 2003)
- +20 km/s, It can be Foreground HII Region
- No +50 km/s Feature Detected (Hirschauer+, 2009)
- Weak +74 km/s Feature from HD 43572
- Strong Blue Shifted Lines from All Background Stars
- Velocities upto -97 km/s



IC 443

- Unisotropic Dense Ambient Medium
- Two SNR's Still Possible
- Explosion Center; One SNR
- NS Velocity must be Measured
- NS $\mu_a^* = -18.1$ $\mu_\delta = -1.2 \pm 33.4$ mas/yr
- High Uncertainty, Accuracy? (Private Comm,
Weispricht+, 2015, in prep.)

IC 443



Results & Conclusion

- HD 37424 in S147; only Confirmed
- HD 254577; pm of NS Necessary
- SNR Gamma Cygni & CTB 109; two OBs to be Investigated; Poor Proper Motion Measurements
- Other SNRs have No OB Runaways within the Search Region up to 14 mag.
- Reasons;
 - Geo. Center Problem
 - Less Massive Progenitors
 - Runaway Progenitors



Results & Conclusion

- Following SNR's Have No OB Runaways
 - G65.3 +5.7
 - Cygnus Loop
 - HB 21
 - DA 530
 - Tycho SNR
 - HB 9
 - G166.0+4.3
 - Crab Nebula

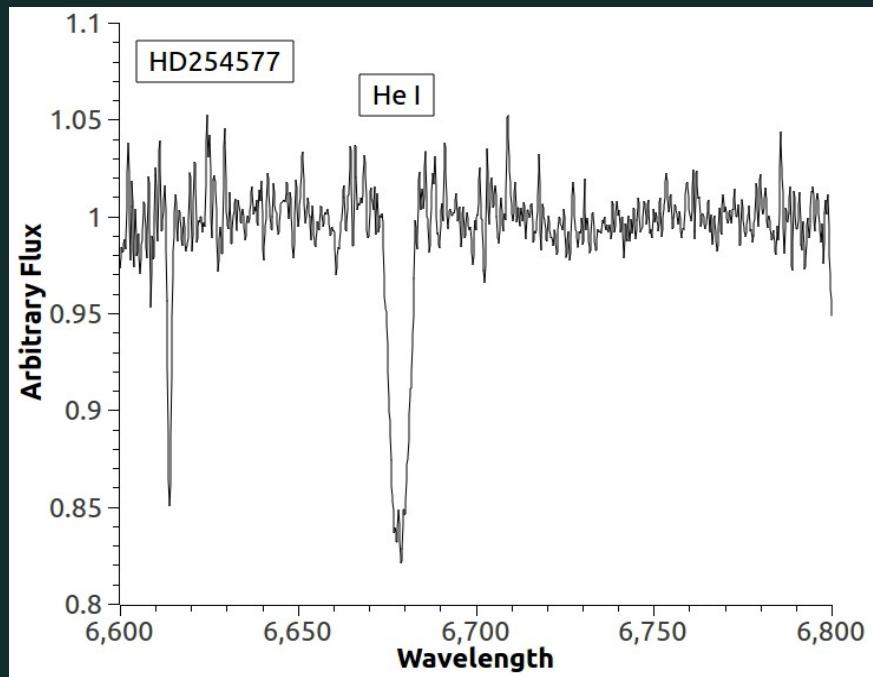
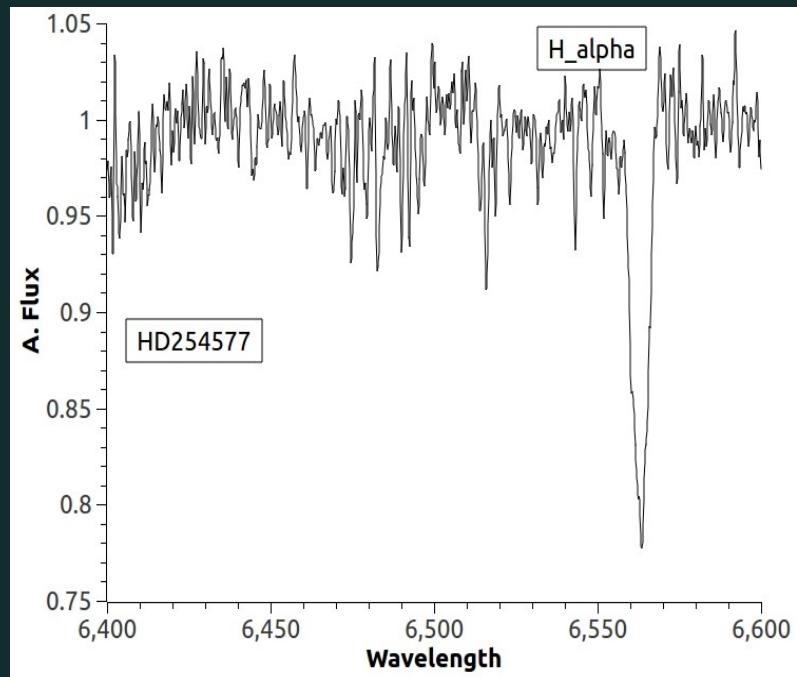
Future Work

- Subaru Observations of HD 37424 and HD254577
- Larger Search Region for Bright Stars and nearby SNR's
- Southern Hemisphere SNR's (Proposals are Given)
- Searching for Late-Type Stars inside SNRs
- 42 High Resolution (40-90k) Star Spectra for SN Debris
(Tetzlaff+, 2014)



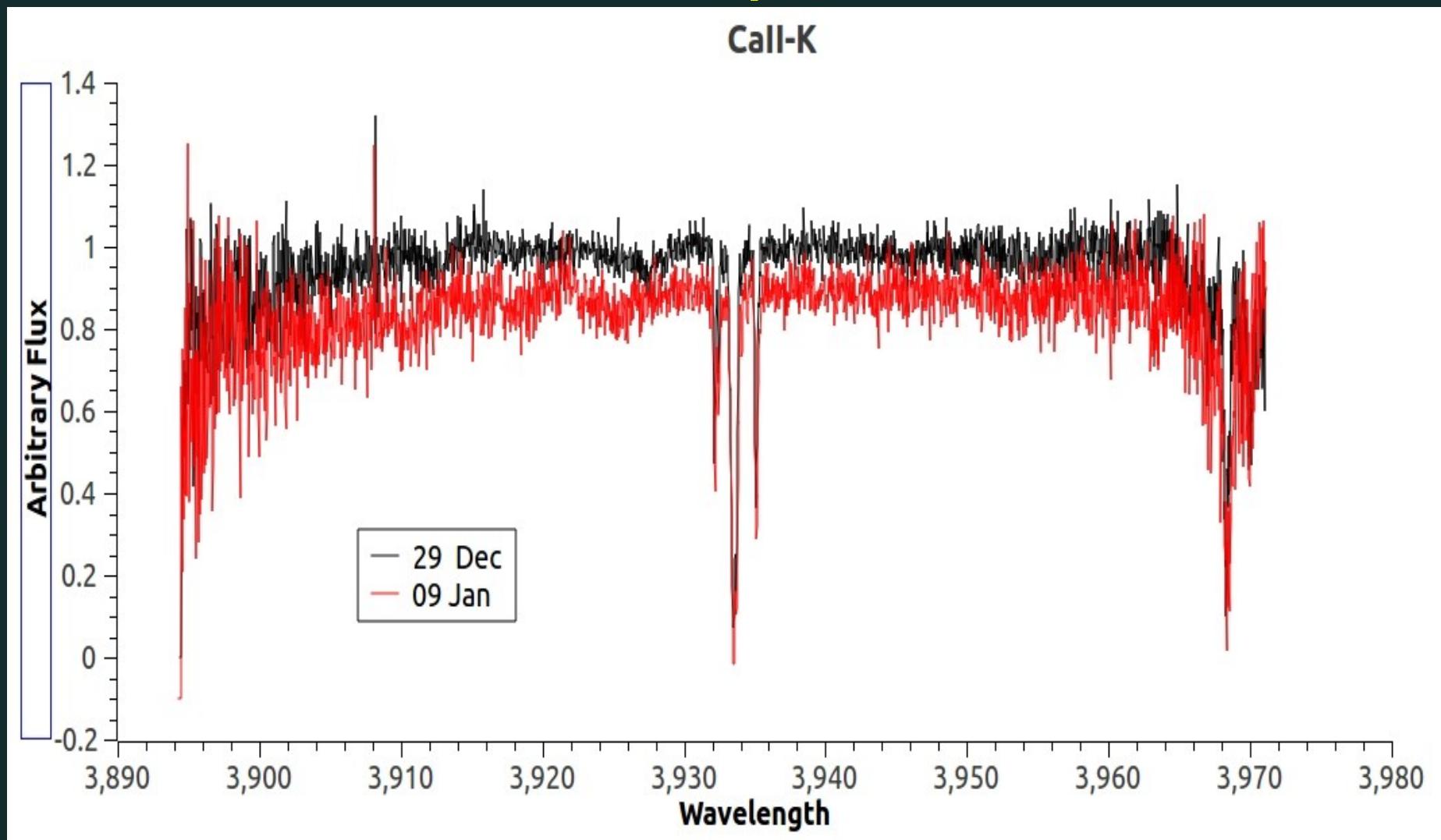
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HD254577



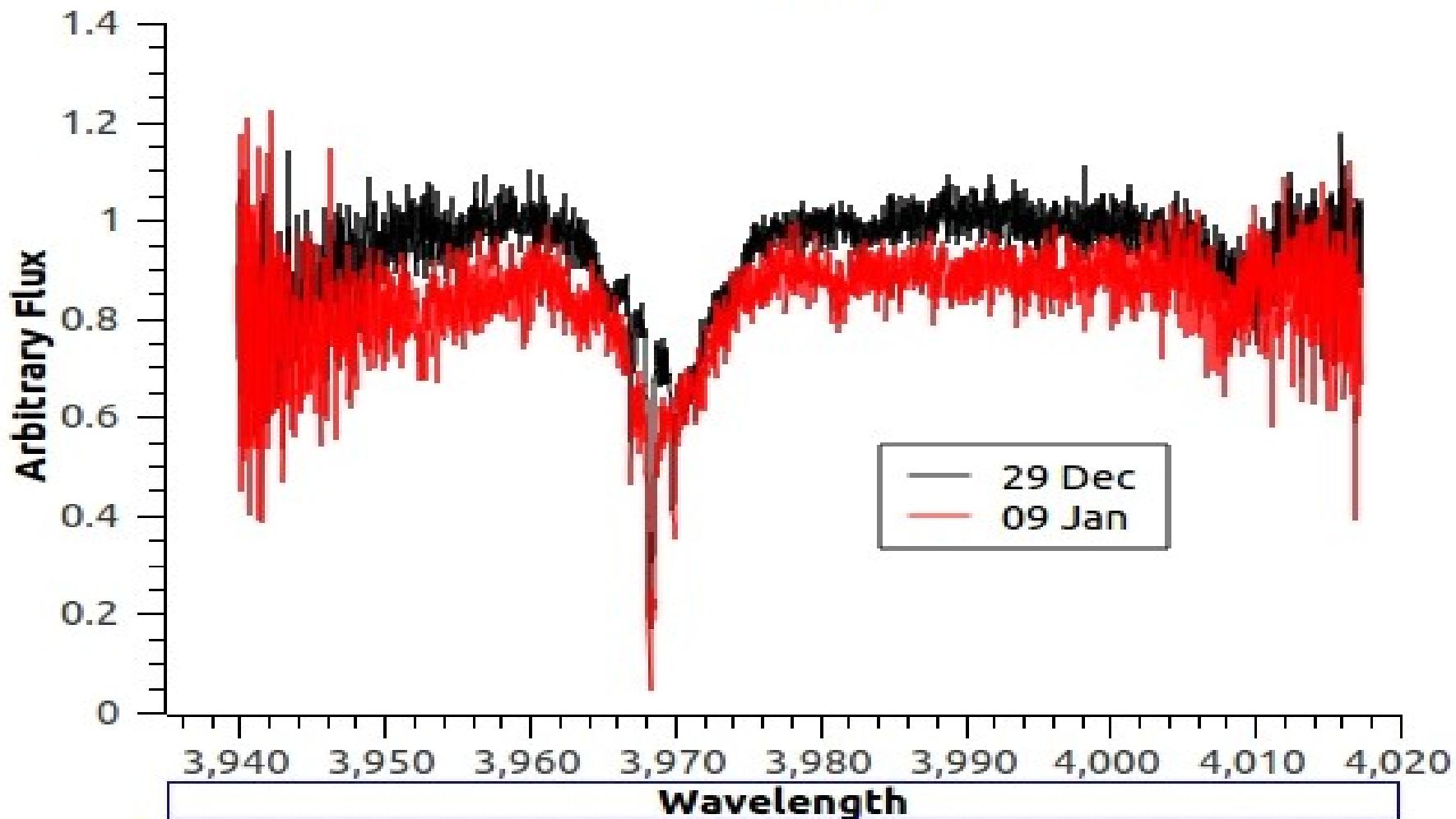
TRES Spectra

CaII-K

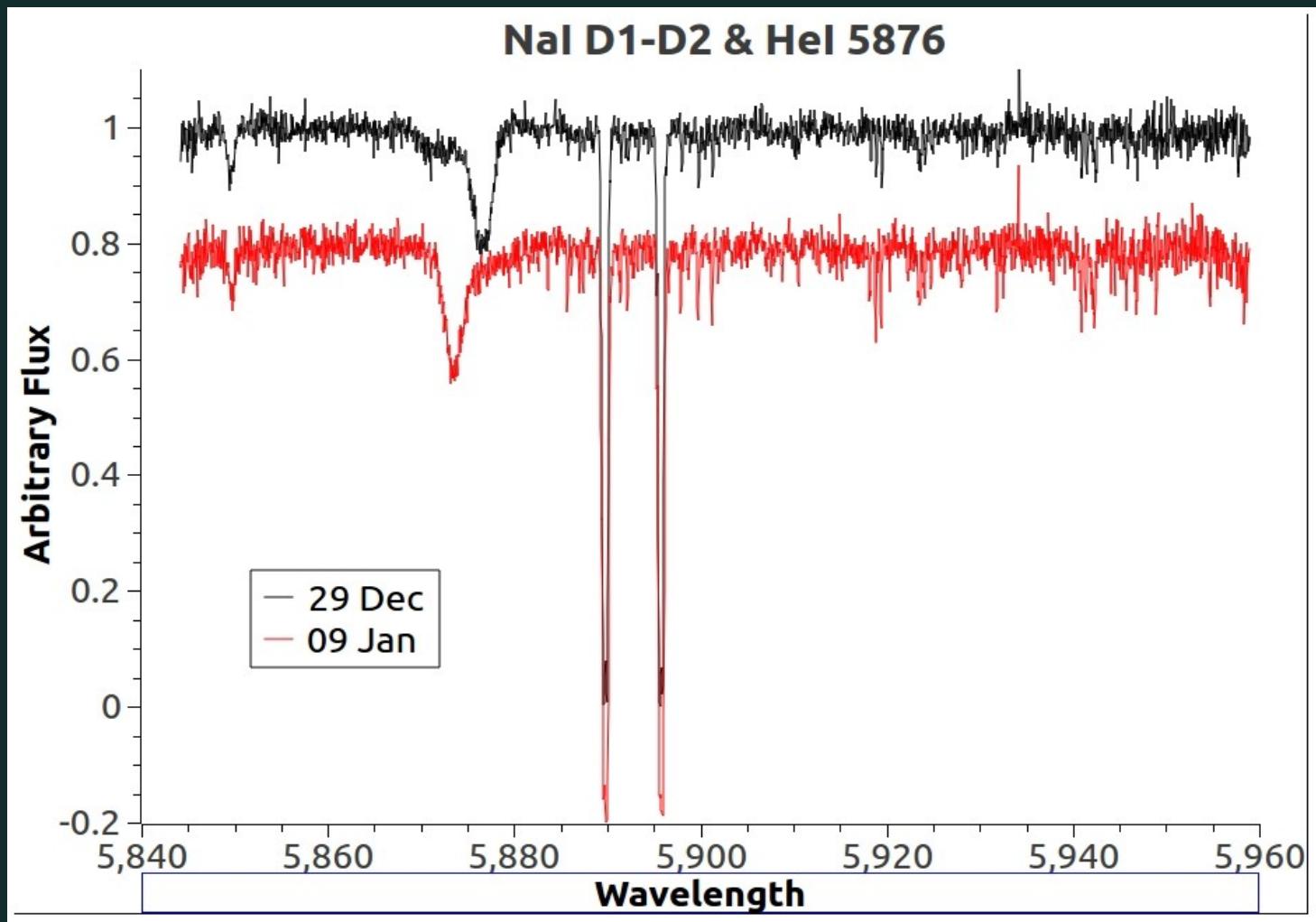


TRES Spectra

CaII-H



TRES Spectra

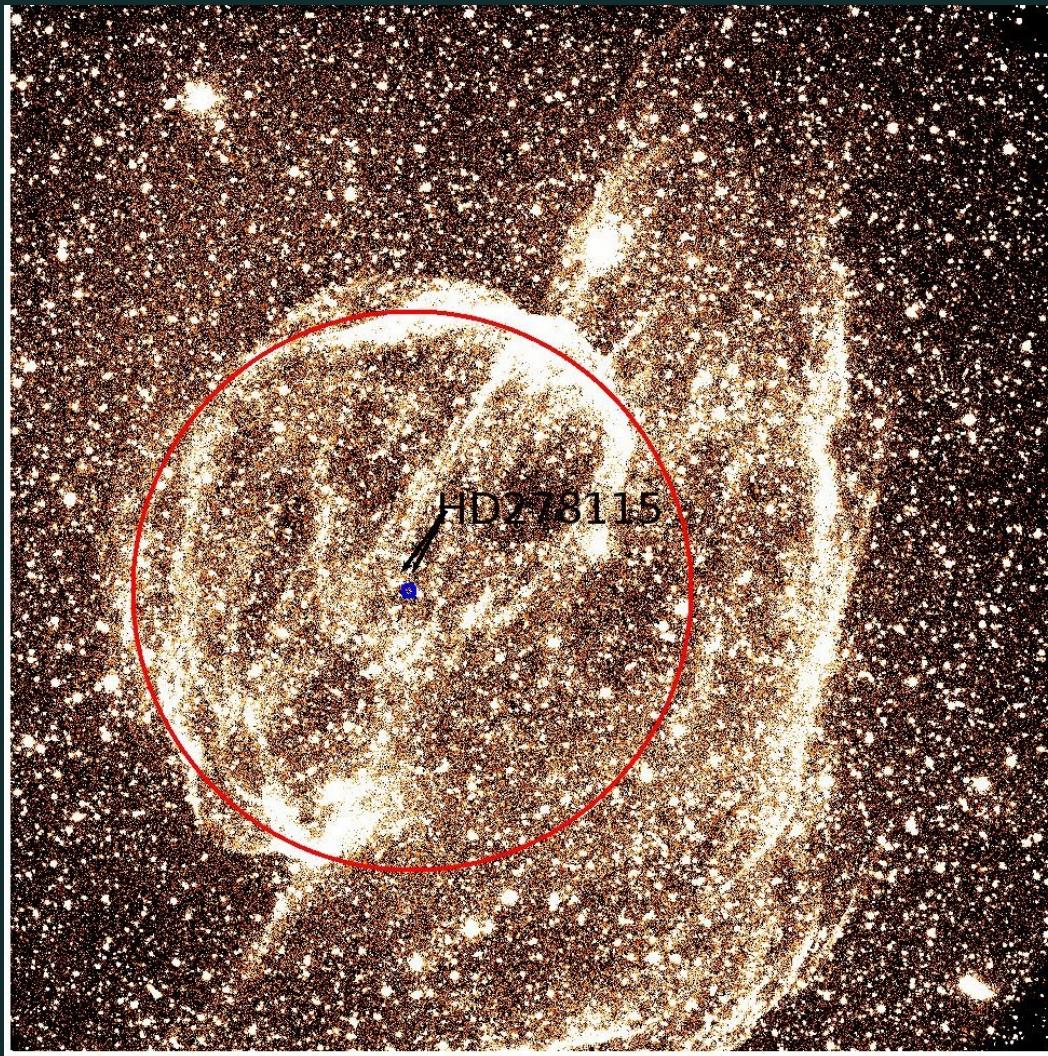




Results

- Through Absolute Photometry: 10.3 ± 0.2 mag
- Period ~ 20 days
- SNR distance is < 3 kpc
- TYC 2917-1415-1 Another Possible Runaway
- $V=12.0$ mag. $\text{pm}(\text{Ra})=-5.2$ $\text{pm}(\text{Dec})=-2.1$ mas/yr
- HD278115 $\text{pm}(\text{Ra})=-2.5$ $\text{pm}(\text{Dec})=-0.3$ mas/yr
- ~ 2 kpc
- The only candidate left

Results

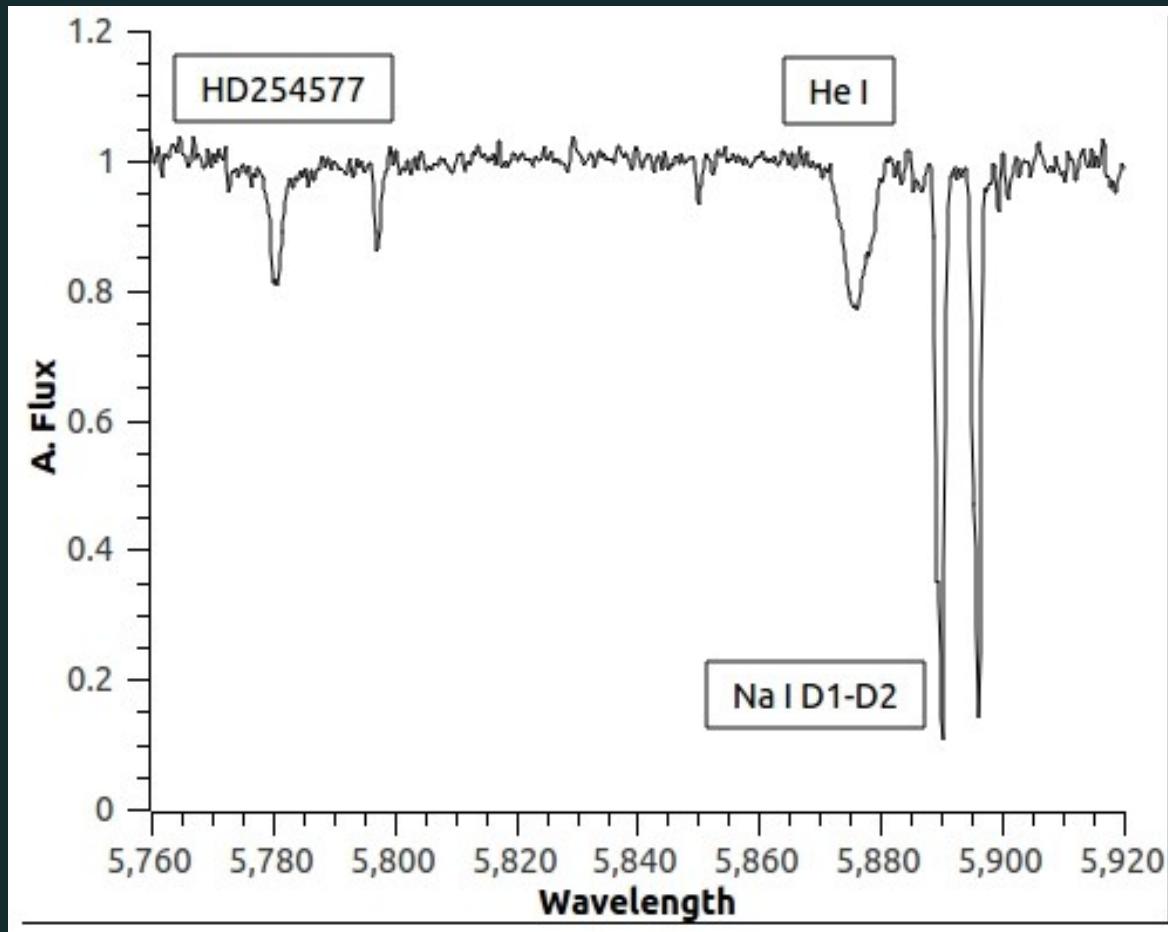




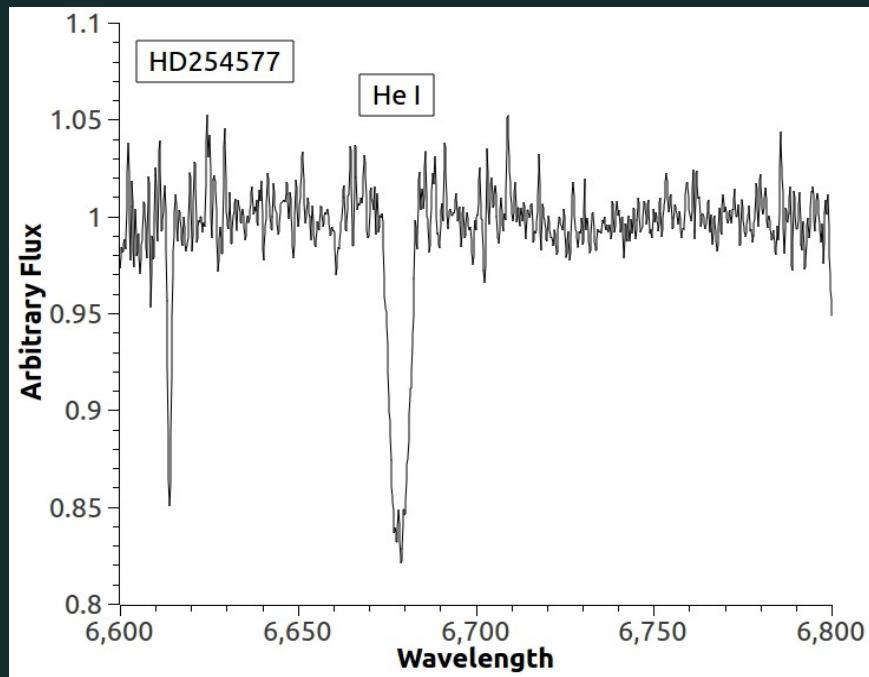
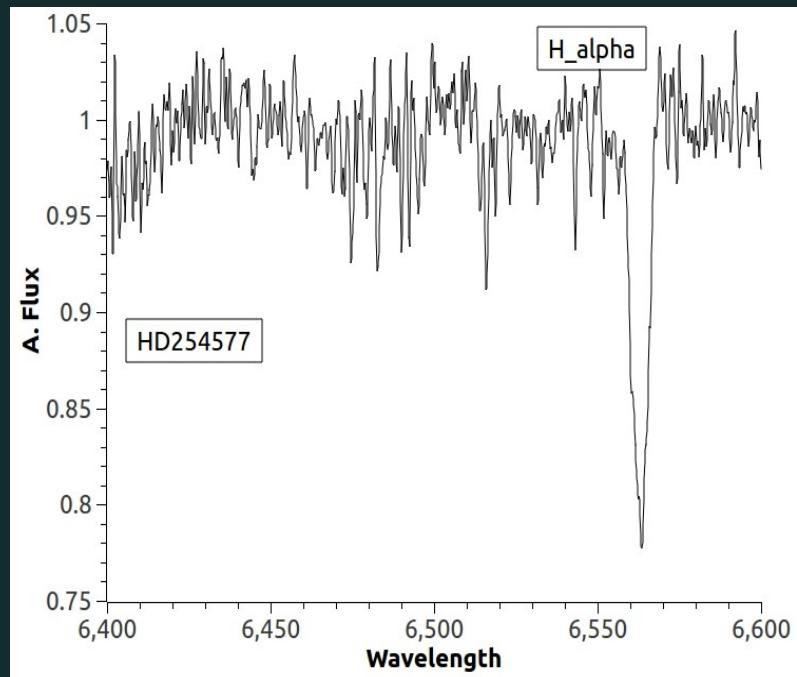
IC443

- NS pm(Ra)=-18.1 pm(Dec)=-1.2 +/-33.4 masec/yr
- High Uncertainty, Accuracy?
- SNR age 30 kyr, 1—60 kyr NS-Runaway Coincidence

HD254577

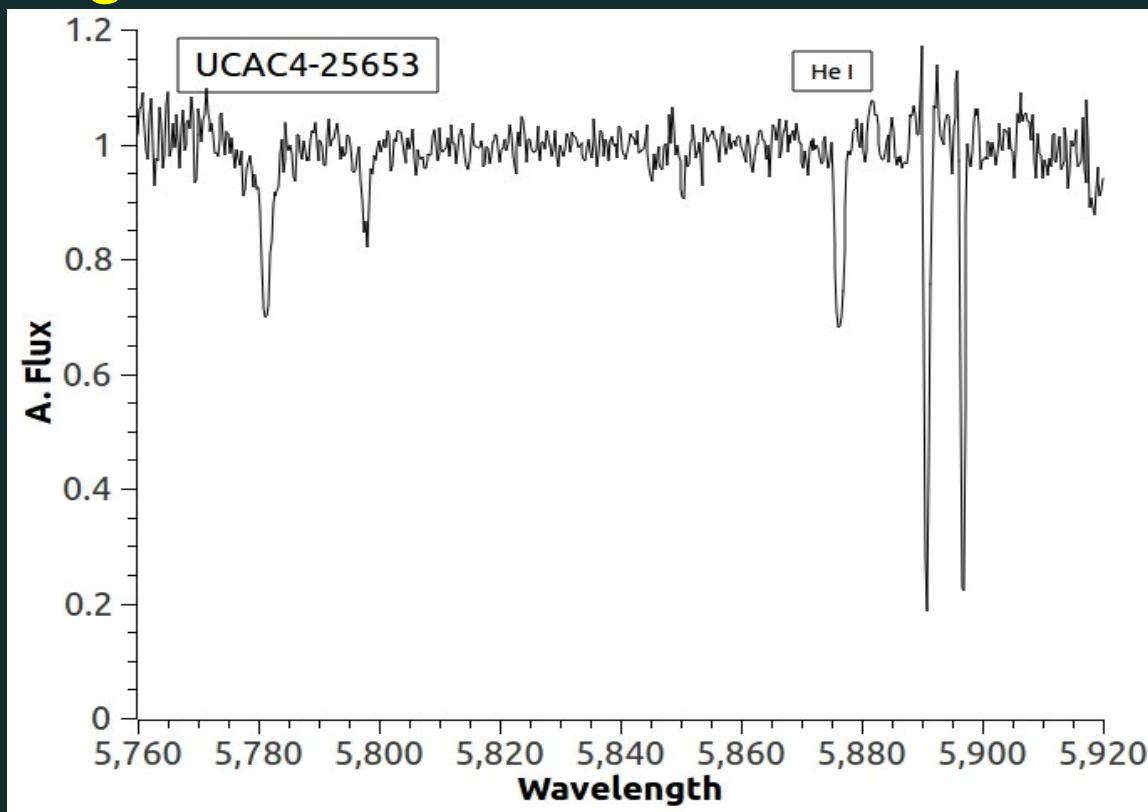


HD254577



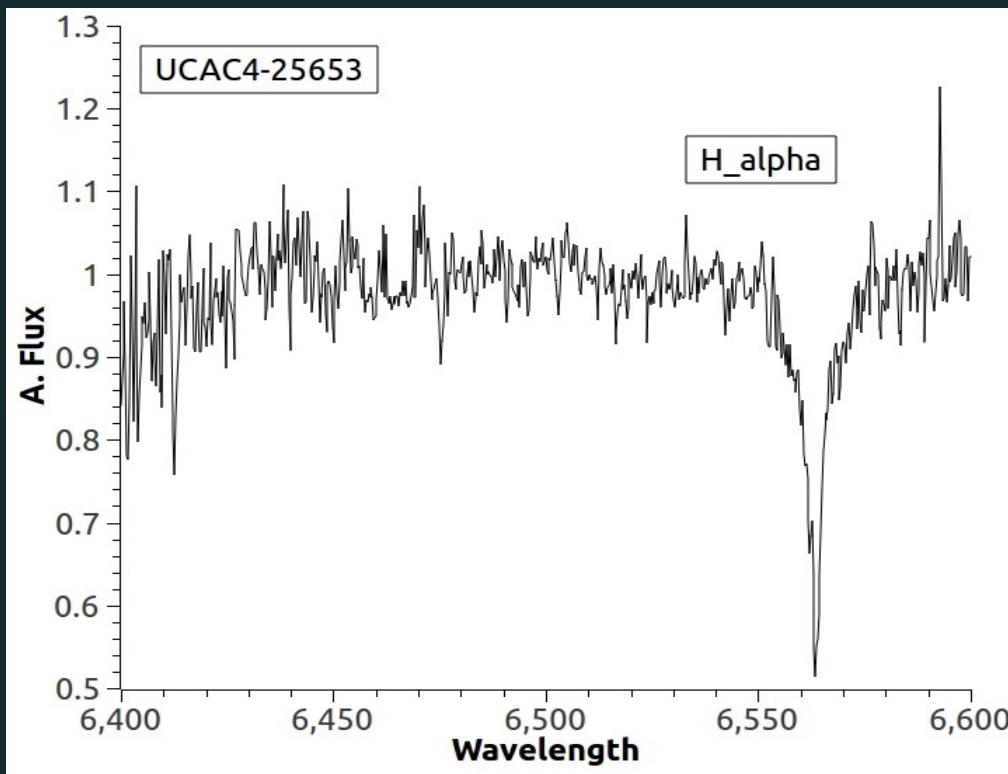
UCAC4-25653

11.7 mag Observed with 1x4



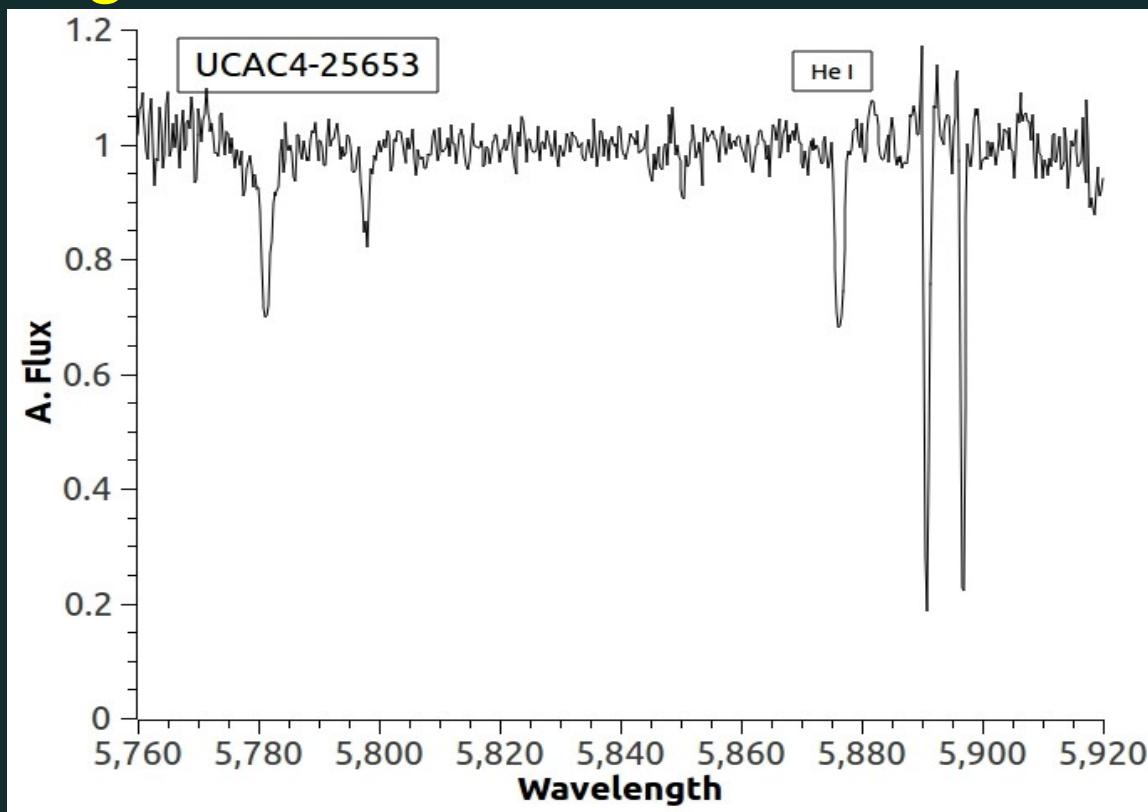
UCAC4-25653

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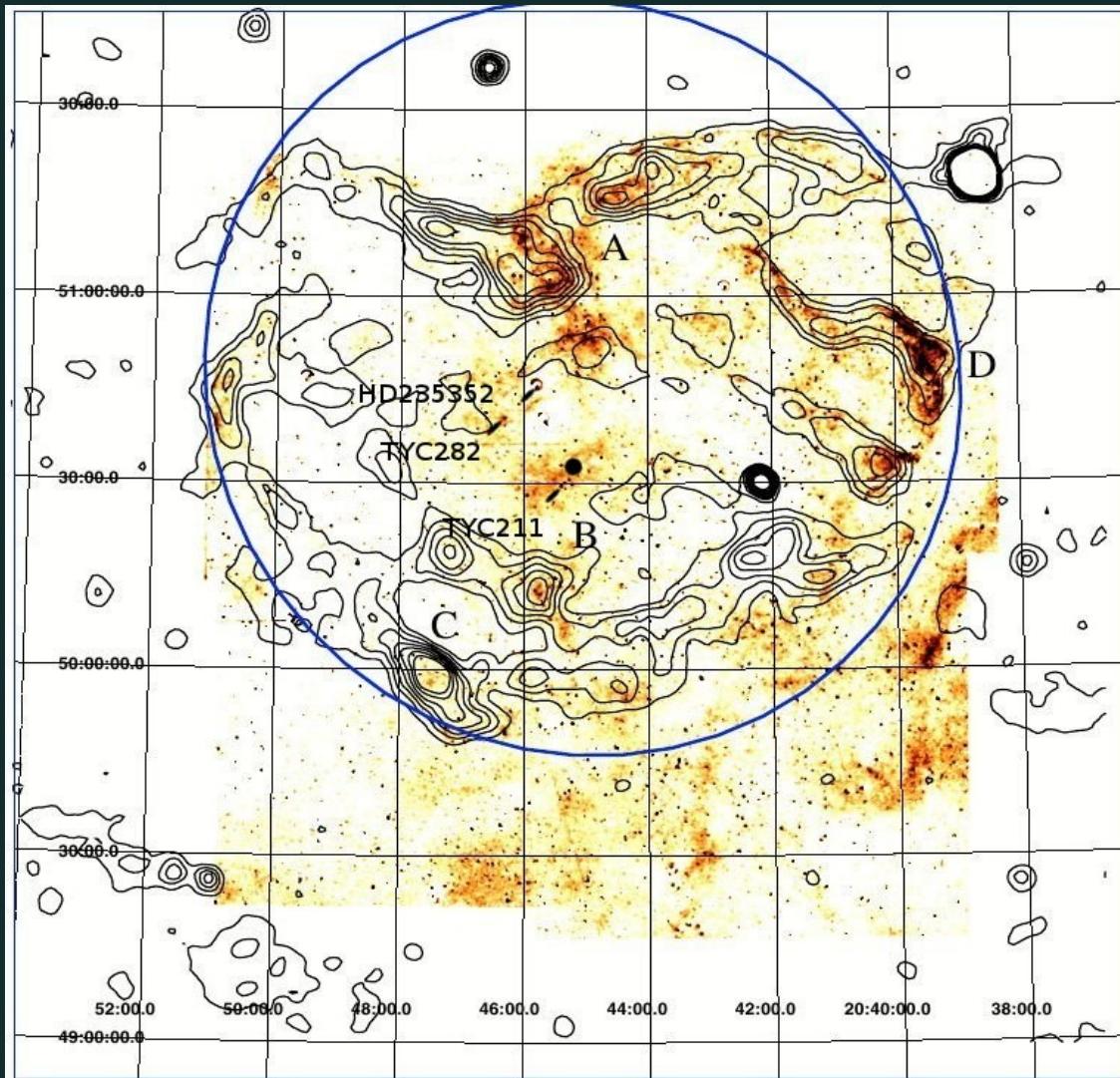


UCAC4-25653

11.7 mag Observed with 1x4



SNR HB 21





SNR HB 21

- TYC 3586-282-1, V=10 mag
- Pec pm, $\text{pm}(\text{Ra})=+5.2$ $\text{pm}(\text{Dec})=-3.6 \pm 0.8$ masec/yr
- Cyg OB7, $\text{pm}(\text{Ra})=-1.2$ $\text{pm}(\text{Dec})=-1.8 \pm 0.8$ masec/yr
- OR $\text{pm}(\text{Ra})=-3.2$ $\text{pm}(\text{Dec})=-5.6 \pm 1.2$ masec/yr
- Observations ongoing for RV measurements.