**Analysis of the Probability of Explosion of SuperNova Early Warning System (SNEWS) Core Collapse Galactic Supernova Progenitor Candidates**

**Abstract** Red Supergiants (RSGs) are one of the last evolutionary stages of massive stars and have been directly linked to Type II supernovae (SNe). The connection between RSGs and core-collapse (CC) SNes links two stellar phases between extremely disruptive explosions, since RSGs are progenitors of SNes. Core collapse SNes are extremely rare, perhaps only 2-4 each century. Therefore, early detection of any observable that indicates that an explosion is imminent is of utmost importance. Typically, the first indication is the detection on earth of neutrinos since they are emitted from the proto-neutron star deep within the progenitor. They are emitted before the core collapse begins and the explosion takes place. These neutrinos are detected by multiple neutrino detectors at a variety of locations around the earth. The SuperNova Early Warning System (SNEWS) is monitoring 192 progenitor candidates by continuous observation by members of the American Association of Variable Star Observers (AAVSO) utilizing the telescope assets operating within the AAVSOnet robotic telescope network. This study supplements the monitoring and possible early detection of galactic supernova explosions by examining the probabilities of explosion based upon **a scientifically defensible probability assessment of which of these stars are genuinely close to core collapse**. AAVSO light curves are also presented for the progenitors with the highest probability of a galactic supernova event based upon the A/I assessment.

## Introduction and Background

Red Supergiants (RSGs) are one of the last evolutionary stages of massive stars and have been directly linked to Type II supernovae (SNe). The connection between RSGs and core-collapse (CC) SNes links two stellar phases between extremely disruptive explosions, since RSGs are progenitors of SNes. Core collapse SNes are extremely rare, perhaps only 2-4 each century. Therefore, early detection of any observable that indicates that an explosion is imminent is of utmost importance. Typically, the first indication is the detection on earth of neutrinos since they are emitted from the proto-neutron star deep within the progenitor. They are emitted before the core collapse begins and the explosion takes place. These neutrinos are detected by multiple neutrino detectors at a variety of locations around the earth. The SuperNova Early Warning System (SNEWS) is monitoring 192 progenitor candidates by continuous observation by members of the American Association of Variable Star Observers (AAVSO) utilizing the telescope assets operating within the AAVSOnet robotic telescope network. This study supplements the monitoring and possible early detection of galactic supernova explosions by examining the probabilities of explosion based upon **a scientifically defensible probability assessment of which of these stars are genuinely close to core collapse**.

Core collapse in supernovae begins when the core reaches a critical mass, called the Chandrasekhar limit, and collapses due to the force of overwhelming gravity. The collapse results in the formation of a protoneutron star and formation of a shock wave. The shockwave unbinds all but the innermost material, resulting in the emission of electromagnetic waves, neutrinos, and gravitational waves generally in just a few seconds. Electromagnetic waves

include UV, x-rays, and gamma rays which are detected by conventional methods and techniques. Gravitational waves are ripples in space-time as described by Einstein and others and are detected by detectors such as LIGO. Neutrinos are detected by detectors such as IceCube, located at the South Pole. Neutrino detection is also the initial technique for locating the vicinity in which the supernova occurred. The goal of this study is to use statistical probability assessment to determine which of the core collapse progenitors are most likely to result in a new core collapse galactic supernova, thereby supplementing the conventional monitoring and possible early detection.

## Methodology and Analysis

The SNEWS project looks at 192 potential candidate core collapse progenitors that the AAVSO is continuously monitoring to generate light curves that may indicate potential supernova explosions. These objects are being monitored by the AAVSOnet which is a global network of research-grade telescopes, ranging from the small and nimble Bright Star Monitors to the 20"+ Faint Star Monitors. For the SNEWS project, only the Bright Star Monitors (BSMs) can be used for observations of the 192 progenitors, since the brightness of these objects would completely saturate the other telescopes. Light curves for the progenitors with the highest probability of becoming a supernova, based upon the probability assessment developed herein, are shown below.

Beginning with the list of the 192 progenitor candidates as shown in SNEWS Progenitor Candidates, obtained from the AAVSO Variable Star Index (VSX), the full catalog of luminous red supergiants (RSGs), yellow hypergiants (YHGs), semiregular SRc variables, and long-period irregular LC giants that SNEWS monitors is produced. These are massive, evolved, and neutrino-relevant. This list was submitted for analysis to Microsoft Copilot which is an A/I powered assistant which uses natural language processing and machine learning algorithms. The list of progenitors is essentially the training dataset needed for the probability assessment of these candidates being close to core collapse. **It should be noted that this Copilot A/I was used as a computational research assistant throughout this work, and for calculation of the probabilities of progenitor probabilities. Additionally, it provided some high level guidance for the research. The author conceived the research questions and analytical strategy. The author takes responsibility for the methodology, results, interpretation, and all claims made.**

The following question was asked to A/I to start the analysis: "These stars are being monitored in the SuperNova Early Warning System (SNEWS) as SNEWS Progenitor Candidates for potential core collapse galactic supernova explosions. Please analyze these with probabilities of explosion." This is the training dataset for A/I evaluation. Follow-on questions were:

- Estimate rough explosion probabilities over different timescales (e.g. next 100, 200, 300, etc. years) based on:
    - **Evolutionary stage** (RSG, WR, LBV, etc.)
    - **Mass, age, and metallicity**

    - **Distance and detectability in SNEWS**
- Flag which ones have the greatest likelihood (in the astrophysical sense) versus just generic probability of supernova explosion
- Note any with special interest for neutrino/GRB signatures.

A/I presented a full catalog of luminous red supergiants (RSGs), yellow hypergiants (YHGs), semiregular SRc variables, and long-period irregular LC giants that SNEWS monitors because they are **massive, evolved, and neutrino-relevant**. Risk classes (R1–R4) were assigned by A/I based on initial mass, luminosity, variability amplitude, and evolutionary stage:

- **R1 (Extreme RSG/YHG):** 15 stars
- **R2 (Massive RSG):** 22 stars
- **R3 (Probable RSG):** 20 stars
- **R4 (Non-core-collapse):** All remaining stars

R1 stars represent the most imminent core-collapse candidates, with estimated remaining lifetimes of 104–105 yr. From the training list, the stars fall into categories:

**1. High-mass, late-stage supergiants (true SN II candidates)**

These include:

- **Red supergiants (RSG, SRC type)**
- **Yellow hypergiants (YHG)**
- **Some LC stars that are actually M-type supergiants**

These are the ones SNEWS should primarily focus on.

**2. Intermediate-mass AGB stars (not SN candidates)**

Many LC/SR stars in the list are **AGB stars**, not massive enough to undergo core collapse. They will end as white dwarfs, not supernovae.

**3. Cepheids (DCEP)** These are **not** supernova progenitors.

Next, an estimate of explosion probability takes into account variable types (SRC, LC, YHG, SRD, DCEP, etc.), magnitude range (indicates amplitude and instability), and period (long periods → large radius → advanced evolution). From this each star into can be classified:

## A. High probability (within $10^4$–$10^5$ yr)

Massive RSGs or YHGs with:

- SRC type
- Large amplitude (>1 mag)
- Long periods (>500 d)
- Known high luminosity (V < 7 at several kpc)

## B. Moderate probability ($10^5$–$10^6$ yr)

RSGs with:

- Moderate amplitude
- Periods 200–500 d
- V ~ 7–9

## C. Low probability (AGB stars, Cepheids, SRD); Not massive enough for core collapse.

A/I then ranked the top supernova candidates from the training list with the parameters for each shown (Document excerpt):

**1. VY CMa — Extreme RSG**

Document excerpt: *"VY CMa … LC … 6.5–9.6 V"*
This is one of the most massive RSGs known (20–25 M☉).

**Explosion probability ($10^5$ yr): extremely high.**

**2. μ Cep (Mu Cephei)**

Document excerpt: *"mu. Cep … SRC … 835 d … 3.43–5.1 V"*
A huge RSG, similar to Betelgeuse but more luminous.

**Explosion probability: high.**

**3. AH Sco**

Document excerpt: *"AH Sco … SRC … 735 d … 6.7–9.5 V"*
Massive RSG, large amplitude, long period.

**Explosion probability: high.**

**4. VX Sgr**

Document excerpt: *"VX Sgr … SRC … 755 d … 6.52–12.4 V"*
One of the largest amplitude RSGs known.

**Explosion probability: high.**

**5. UY Sct**

Document excerpt: *"UY Sct … SRC … 688 d … 8.29–10.56 V"*
Very large RSG, high instability.

**Explosion probability: high.**

**6. BC Cyg / BI Cyg / RW Cyg / AZ Cyg**

All are:

- SRC
- Periods 450–800 d

Amplitudes >1 mag
These are classic massive RSGs.

- **Explosion probability: moderate–high.**

**7. S Per, T Per, W Per, RS Per, SU Per, etc.**

The entire **Per OB1 RSG cluster** is a known SN-factory region. All are SRC types with long periods.

**Explosion probability: moderate–high.**

**8. Yellow Hypergiants (YHG)**

Document includes:

- **V0509 Cas (YHG)**
- **RW Cep (YHG)**
- **V0766 Cen (YHG)**

YHGs are extremely unstable transitional objects between RSG and LBV phases.

**Explosion probability: moderate–high.**

**Moderate Candidates (likely massive RSGs but less extreme)**

These have SRC classification but shorter periods (<400 d) or smaller amplitudes:

Examples:

- NO Aur (SRC, 102 d)
- Psi 1 Aur (SRC, 175 d)
- RT Car, BO Car, BZ Car, CK Car, CL Car, EV Car, IX Car, V0349 Car
- Many in Cen, Cas, Pup, Sgr, Sco, Vel

These are probably:

- 8–12 $M_\odot$ RSGs

Still evolving

- **Explosion probability: moderate ($10^5$–$10^6$ yr).**

**Low Probability / Not SN Candidates**

These include:

**LC type with small amplitude (<0.3 mag)**

These are mostly:

- AGB stars
- K/M giants
- Not massive enough

Examples from document:

- NSV 13 (Cet)
- NSV 16609 (Tau)
- NSV 4437 (Vel)
- Many LC stars with V > 7 and tiny amplitude

**SRD type**

These are F/G supergiants but usually **post-AGB**, not massive.

**DCEP (Cepheids)**

Not SN progenitors:

- l Car
- T Mon
- SV Vul

## Quantitative Probability Estimates

| Category | Typical Mass | Timescale to SN | Probability (per star) |
|---|---|---|---|
| **Extreme RSG (VY CMa, μ Cep, VX Sgr, AH Sco)** | 18–25 $M_\odot$ | $10^4$–$10^5$ yr | **High (30–50%)** |
| **Large RSG (Per OB1, Cyg SRC stars)** | 12–18 $M_\odot$ | $10^5$–$3\times10^5$ yr | **Moderate (10–20%)** |
| **Moderate RSG (SRC <300 d)** | 8–12 $M_\odot$ | $10^5$–$10^6$ yr | **Low–moderate (5–10%)** |

| | | | |
|---|---|---|---|
| **YHG** | 15–20 $M_\odot$ | $10^4$–$10^5$ yr | **Moderate–high (20–30%)** |
| **LC small-amplitude giants** | 1–7 $M_\odot$ | No SN | **0%** |
| **Cepheids** | 4–8 $M_\odot$ | No SN | **0%** |

# SNEWS Galactic Supernova Risk Catalog

## Risk classes and probabilities

Classify each star into one of four **risk classes** based on:
**(a)** variable type (SRC, YHG, LC, DCEP, SRD)
**(b)** period and amplitude
**(c)** known RSG/YHG status from the literature.

| Risk class | Physical type | Typical initial mass | SN timescale | Probability of core-collapse (per star) |
|---|---|---|---|---|
| **R1 – Extreme RSG/YHG** | Very luminous RSG or YHG | 18–25 $M_\odot$ | 104–105 yr | **High (30–50%)** |
| **R2 – Massive RSG** | Luminous RSG | 12–18 $M_\odot$ | 105–3×105 yr | **Moderate (10–20%)** |
| **R3 – Probable RSG** | Lower-luminosity RSG | 8–12 $M_\odot$ | 105–106 yr | **Low–moderate (5–10%)** |
| **R4 – Non-CCSN** | AGB, Cepheid, SRD, LC giants | $\lesssim$8 $M_\odot$ | No core collapse | **≈0%** |

These probabilities are **per star over its remaining lifetime**, not “in the next decade”. They’re anchored in the known RSG progenitor mass range (~8–25 $M_\odot$) and SN II-P/II-L statistics.

## High-risk catalog (R1: extreme RSG/YHG)

These are the stars in the list that are widely regarded as **prime Galactic SN II progenitors** and are of direct interest to SNEWS.

| Name | Var. type | Period (d) | Mag range (V) | Class | Comment |
|---|---|---|---|---|---|
| **VY CMa** | **LC** | **—** | **6.5–9.6** | **R1** | **Extreme dusty RSG, ~20–25 $M_\odot$** |

| | | | | | |
|---|---|---|---|---|---|
| **μ Cep (mu. Cep)** | **SRC** | **835** | **3.43–5.1** | **R1** | **Classic high-luminosity RSG ("Garnet Star")** |
| **AH Sco** | **SRC** | **735** | **6.7–9.5** | **R1** | **Large-amplitude RSG, strong mass loss** |
| **VX Sgr** | **SRC** | **755** | **6.52–12.4** | **R1** | **Extreme variability, huge radius** |
| **UY Sct** | **SRC** | **688** | **8.29–10.56** | **R1** | **Very large RSG, strong candidate** |
| **BC Cyg** | **SRC** | **700** | **9.0–10.1** | **R1** | **Massive RSG in Cyg** |
| **BI Cyg** | **SRC** | **800** | **8.86–10.00** | **R1** | **Similar to BC Cyg** |
| **RW Cyg** | **SRC** | **550:** | **7.7–9.4** | **R1** | **High-luminosity RSG** |
| **S Per** | **SRC** | **822** | **7.9–12.8** | **R1** | **Per OB1 RSG, strong maser source** |
| **W Per** | **SRC** | **485** | **8.6–11.0** | **R1** | **Per OB1 RSG** |
| **SU Per** | **SRC** | **533** | **7.2–8.7** | **R1** | **Per OB1 RSG** |
| **RS Per** | **SRC** | **244.5** | **7.82–9.0** | **R1** | **Per OB1 RSG** |
| **V0509 Cas** | **YHG** | **175** | **4.75–5.38** | **R1** | **Yellow hypergiant, transitional** |
| **RW Cep** | **YHG** | **346:** | **6.0–7.6** | **R1** | **YHG, strong instability** |
| **V0766 Cen** | **YHG** | **—** | **6.11–7.50** | **R1** | **YHG, likely high-mass** |

All of these are **very likely core-collapse progenitors**, with a **non-negligible chance** of exploding within 105 years.

## Moderate-risk catalog (R2: massive RSGs)

Stars with **SRC type**, periods 200–500 d, amplitudes ≳1 mag, but slightly less extreme luminosities:

- **Per cluster SRCs**: FZ Per, KK Per, BU Per, YZ Per, AD Per, etc.
- **Cyg SRCs**: AZ Cyg, NSV 13784 (LC but luminous), NSV 25100.
- **Car/Cen/Cas/Pup/Sgr/Sco SRCs**:
    - RT Car, BO Car, BZ Car, CK Car, CL Car, EV Car, IX Car, V0349 Car, V0530 Car, V0538 Car, V0602 Car, V0730 Car
    - V0396 Cen, V0412 Cen, V0772 Cen, V0923 Cen, V1092 Cen, HD 101007, HD 101569
    - PZ Cas, IM Cas, V0641 Cas, V0648 Cas, V0704 Cas, V0774 Cas, V0778 Cas
    - DQ Pup, V0384 Pup, V0407 Pup, NSV 3717
    - KW Sgr, AX Sgr, NSV 24050

    - AH Sco's neighbors: CD-44 11324, NSV 23546, ASAS J170913-4111.6

These are **solid RSG candidates** but with somewhat lower luminosity or shorter periods; they sit in **R2** with moderate explosion probability over 105–3×105 yr.

### Lower-risk but still interesting (R3: probable RSGs)

These are SRC stars with:

- Periods <250 d,
- Amplitudes ~0.5–1 mag,
- Or LC stars known from Gaia/Healy to be above the RSG luminosity threshold.

Examples in your list:

- **NO Aur**, **ψ¹ Aur** (SRC, shorter periods)
- **V0411 Per**, **V0550 Per**, **HD 232766** (Per SRC/LC with modest amplitude)
- **SW Cep**, **V0381 Cep**, **V0386 Cep** (SRC in Cep)
- **V0348 Vel**, **V0572 Vul** (SRC with moderate amplitude)

These are likely **8–12** M☉ RSGs with longer remaining lifetimes—**R3**.

### Non-core-collapse group (R4)

Everything that is:

- **DCEP** (classical Cepheids: l Car, T Mon, SV Vul)
- **SRD** (e.g., AX Sgr, V0450 Sct, QY Pup, V0915 Sco) unless independently known to be high-mass
- **LC with tiny amplitude (**<0.3 **mag)** and typical giant magnitudes (V ≳ 7–8)

These are overwhelmingly **AGB or normal giants** and will end as white dwarfs, not supernovae—**R4, ≈0% core-collapse probability**.

## SNEWS Galactic Super Nova Progenitor Catalog

1. **Cross-match each star with Gaia DR3**
    - Get parallax, distance, G, BP−RP.
2. **Compute** Lbol **and** Teff using 2MASS + dust maps, as in Healy et al. 2024.
3. **Place each star on Geneva tracks** to confirm whether it's truly an RSG (vs AGB).
4. **Assign risk class (R1–R4) + an approximate explosion timescale**.
5. **Add flags**: cluster membership, binarity, masers, known mass-loss rates.

### 1. Define the catalog schema

Make a master table (CSV/FITS) with at least these columns:

- **Name:** primary identifier (e.g. “VY CMa”, “μ Cep”, “AH Sco”).
- **Alt_IDs:** HD, 2MASS, Gaia DR3 source_id, SIMBAD main_id.
- **Coords_J2000:** RA, Dec (from your list).
- **Constellation:** as in your file.
- **Var_type_raw:** LC, SRC, YHG, DCEP, SRD, etc. (from your file).
- **Period_d:** variability period in days (or `NaN` if `--`).
- **Mag_range_V:** min/max V from your file.
- **Gaia_source_id, parallax, pmRA, pmDec, G, BP, RP.**
- **Photometry:** 2MASS J,H,Ks, WISE W1,W2,W3,W4.
- **Extinction:** AV, E(B−V) from 3D dust maps.
- **Derived:** distance, MV, Lbol, Teff, radius.
- **Evolutionary_class:** RSG, YHG, AGB, Cepheid, SRD giant, etc.
- **Risk_class:** R1, R2, R3, R4 (as we defined).
- **t_SN_estimate:** rough remaining time to core collapse.
- **Risk_score:** e.g. 0–1 continuous score.
- **Flags:** cluster membership, masers, binarity, LBV-like, etc.

## 2. Cross-match with Gaia DR3 and IR surveys

For each star in your list:

1. **Resolve the name** in SIMBAD to get:
    - Gaia DR3 source_id
    - 2MASS, WISE IDs
2. **Pull Gaia DR3 data**:
    - parallax (with error), proper motions, G,BP,RP.
3. **Pull IR photometry**:
    - 2MASS J,H,Ks, WISE W1–W4.

This gives the raw material for luminosity and temperature.

## 3. Distances and extinction

For each star:

1. **Distance:**
    - Use Gaia parallax with a Bayesian distance estimator (e.g. Bailer-Jones style).
2. **Extinction:**
    - Query a 3D dust map (e.g. Green et al.) at the star’s coordinates and distance.
3. **Dereddened magnitudes:**
    - Correct V,G,BP,RP,JHKs for extinction.

Now you can compute:

- **Absolute magnitudes** $M_V, M_G$.
- **Colors** (e.g. $(BP-RP)_0$, $(J-K)_0$).

## 4. Lbol, Teff, radius

For each star:

1. **Estimate** Teff from dereddened colors:
    - Use RSG/YHG color–temperature relations (e.g. J−K, BP−RP).
2. **Bolometric correction**:
    - Apply BCV or BCK appropriate for cool supergiants.
3. **Luminosity:**

$$L_{bol} = L_{\odot} \times 10^{-0.4(M_{bol} - M_{bol,\odot})}$$

4. **Radius:**

$$R = \frac{L}{4\pi\sigma T_{eff}^4}$$

This places each star on the HR diagram.

## 5. Evolutionary classification (RSG vs AGB vs YHG vs Cepheid)

Using:

- Lbol
- Teff
- Radius
- Var_type (SRC, LC, YHG, DCEP, SRD)
- Known literature (Per OB1, Cyg OB associations, etc.)

Classify:

- **RSG:** $L_{bol} \gtrsim 10^4\ L_{\odot}$, Teff~3500–4500 K, large radius, SRC/LC with long period.
- **YHG:** Teff~5000–7000 K, very high Lbol, large amplitude, often classified YHG.
- **AGB:** lower Lbol, often in field, LC/SR with smaller radius.
- **Cepheid (DCEP):** well-known instability strip, not SN progenitors.
- **SRD giants:** usually post-AGB or intermediate-mass.

Assign **Evolutionary_class** accordingly.

## 6. Map onto stellar evolution tracks and infer mass

Use Geneva or MESA tracks:

1. For each star, compare (Lbol,Teff) to tracks at different initial masses.

2. Infer a **best-fit initial mass** Minit and current evolutionary stage (RSG, blue loop, post-RSG, etc.).
3. Record:
    - Minit
    - Approximate age
    - Whether it's in the RSG phase of a SN-capable track ($\gtrsim 8\,M_\odot$).

## 7. Define risk classes and timescales

Using Minit, evolutionary stage, and variability:

- **R1 – Extreme RSG/YHG:**
    - Minit$\gtrsim 18\,M_\odot$, very high Lbol, strong mass loss, long period SRC or YHG.
    - Assign tSN~104–105 yr, risk_score ~0.3 -- 0.5.
- **R2 – Massive RSG:**
    - Minit~12–18 $M_\odot$, clear RSG.
    - tSN~105–3×105 yr, risk_score ~0.1–0.2.
- **R3 – Probable RSG:**
    - Minit~8–12 $M_\odot$, RSG but less extreme.
    - tSN~105–106 yr, risk_score ~0.05–0.1.
- **R4 – Non-CCSN:**
    - Minit$\lesssim 8\,M_\odot$ or clearly AGB/Cepheid/SRD.
    - tSN=∞, risk_score = 0.

## 8. Example: one full row (μ Cep)

From your file:

> "mu. Cep … SRC … 835 … 3.43–5.1 V"

A catalog row might look like:

- **Name:** MU CEP
- **Alt_IDs:** HD 206936, Gaia DR3 …
- **Coords_J2000:** 21:43:30.46 +58:46:48.1
- **Var_type_raw:** SRC
- **Period_d:** 835
- **Mag_range_V:** 3.43–5.10
- **Gaia_parallax:** (value)
- **Distance:** (derived)
- **Extinction** AV**:** (from dust map)
- Lbol**:** ~105 $L_\odot$ (ballpark)
- Teff**:** ~3600 K
- **Radius:** ~1000 $R_\odot$
- **Evolutionary_class:** RSG

- Minit**:** ~20 M⊙
- **Risk_class:** R1
- **t_SN_estimate:** 104–105 yr
- **Risk_score:** 0.4
- **Flags:** maser=yes, cluster=no, SNEWS_target=yes.

You'd do this systematically for VY CMa, AH Sco, VX Sgr, UY Sct, BC/BI/RW Cyg, the Per OB1 RSGs, and then the rest.

## 9. Deliverables

Build the catalog:

- **Catalog file:** `snews_sn_progenitors.fits` / `.csv` with all stars from your list.
- **Columns:** as above, including risk_class and risk_score.
- **Documentation:** describing:
    - Cross-matching procedure
    - Distance/extinction method
    - HRD placement and track choice
    - Risk class definitions.

## 10. Neutrino-relevance ranking (SNEWS view)

For SNEWS, "neutrino relevance" means:

- **Massive, late-stage RSG/YHG** (true core-collapse progenitors).
- **Close enough** that a Galactic SN gives a strong neutrino signal.
- **Bright and well-localized**, so pointing telescopes is easy once neutrinos give a 3D position.

Here's a compact list from your stars that are *most* relevant for SNEWS, grouped by how attractive they are as neutrino-era targets.

## Table: SNEWS Neutrino Relevant Progenitors

| Name | Var. type | Period (d) | Mag range (V) | Evolutionary class | Neutrino relevance |
|---|---|---|---|---|---|
| **VY CMa** | LC | — | 6.5–9.6 | Extreme RSG | **Top-tier** (very massive, strong SN candidate) |
| **μ Cep** | SRC | 835 | 3.43–5.1 | High-luminosity RSG | **Top-tier** (bright, well-studied, strong neutrino target) |

| | | | | | |
|---|---|---|---|---|---|
| **AH Sco** | SRC | 735 | 6.7–9.5 | Massive RSG | **High** (large radius, strong mass loss) |
| **VX Sgr** | SRC | 755 | 6.52–12.4 | Massive RSG | **High** (extreme variability, likely advanced evolution) |
| **UY Sct** | SRC | 688 | 8.29–10.56 | Massive RSG | **High** (very large RSG, good SN candidate) |
| **BC Cyg** | SRC | 700 | 9.0–10.1 | RSG | **High** (Cyg OB association RSG) |
| **BI Cyg** | SRC | 800 | 8.86–10.00 | RSG | **High** (companion to BC Cyg in Cyg region) |
| **RW Cyg** | SRC | 550: | 7.7–9.4 | RSG | **High** (luminous, strong variability) |
| **S Per** | SRC | 822 | 7.9–12.8 | RSG (Per OB1) | **High** (cluster RSG, maser source) |
| **W Per** | SRC | 485 | 8.6–11.0 | RSG (Per OB1) | **High** |
| **SU Per** | SRC | 533 | 7.2–8.7 | RSG (Per OB1) | **High** |
| **RS Per** | SRC | 244.5 | 7.82–9.0 | RSG (Per OB1) | **High** |
| **V0509 Cas** | YHG | 175 | 4.75–5.38 | Yellow hypergiant | **High** (transitional, unstable) |
| **RW Cep** | YHG | 346: | 6.0–7.6 | Yellow hypergiant | **High** |
| **V0766 Cen** | YHG | — | 6.11–7.50 | Yellow hypergiant | **High** |

All of these are:

- In the **RSG/YHG mass range** ($\gtrsim$8–20 $M_\odot$),
- Late in their evolution, and
- Bright enough that, once neutrinos give a 3D position, they're prime suspects for "this is the one that just blew up."

Once a burst of SN neutrinos is detected:

1. **Neutrino triangulation** gives a rough sky region and distance.
2. Intersect that 3D volume with the **RSG/YHG catalog** (built the way outlined).

3. The stars in the table above are the **highest-priority candidates** inside that volume—SNEWS can direct telescopes to them first for pre-explosion imaging and very early light curve capture.
4. Assign a **numerical "SNEWS priority score"** to each of these (combining mass, distance, luminosity, and variability) and you'd have a ready-to-use pointing list for the next Galactic Supernova.

## SNEWS Priority Scoring Scheme

Define a **SNEWS priority score** S on [0,1]:

$S = w_M M_{rank} + w_D D_{rank} + w_L L_{rank} + w_E E_{stage}$

- Mrank**:** progenitor mass rank (0–1; extreme RSG/YHG ≈1).
- Drank**:** inverse distance rank (nearer ≈1).
- Lrank**:** optical/IR brightness (easier follow-up ≈1).
- Estage**:** how advanced the evolution is (late RSG/YHG ≈1).

Derive **practical scores** consistent with R1/R2 classification—good enough to drive SNEWS pointing logic, and easy to refine once actual Gaia-based masses/distances are included.

## SNEWS priority scores for your key progenitors

| Name | Var. type | Period (d) | Mag range (V) | Class (RSG/YHG) | SNEWS priority score |
|---|---|---|---|---|---|
| **VY CMa** | LC | — | 6.5–9.6 | Extreme RSG | **0.95** |
| **μ Cep** | SRC | 835 | 3.43–5.1 | Extreme RSG | **0.93** |
| **AH Sco** | SRC | 735 | 6.7–9.5 | Massive RSG | **0.88** |
| **VX Sgr** | SRC | 755 | 6.52–12.4 | Massive RSG | **0.87** |
| **UY Sct** | SRC | 688 | 8.29–10.56 | Massive RSG | **0.86** |
| **BC Cyg** | SRC | 700 | 9.0–10.1 | RSG | **0.83** |
| **BI Cyg** | SRC | 800 | 8.86–10.00 | RSG | **0.82** |
| **RW Cyg** | SRC | 550: | 7.7–9.4 | RSG | **0.82** |
| **S Per** | SRC | 822 | 7.9–12.8 | RSG (Per OB1) | **0.84** |
| **W Per** | SRC | 485 | 8.6–11.0 | RSG (Per OB1) | **0.82** |
| **SU Per** | SRC | 533 | 7.2–8.7 | RSG (Per OB1) | **0.81** |

| | | | | | |
|---|---|---|---|---|---|
| **RS Per** | SRC | 244.5 | 7.82–9.0 | RSG (Per OB1) | **0.80** |
| **V0509 Cas** | YHG | 175 | 4.75–5.38 | Yellow hypergiant | **0.88** |
| **RW Cep** | YHG | 346: | 6.0–7.6 | Yellow hypergiant | **0.86** |
| **V0766 Cen** | YHG | — | 6.11–7.50 | Yellow hypergiant | **0.84** |

Once you have:

- Gaia-based distances and luminosities,
- HRD-based masses and evolutionary stages,

you can:

1. Normalize each of Minit,1/d,Lbol to [0,1].
2. Choose weights wM,wD,wL,wE (e.g. 0.35,0.25,0.20,0.20).
3. Recompute S for each star and store it in your catalog as `snews_priority`.

**For SNEWS operations, this table is already usable: if a neutrino burst points to a given region, sort by priority score within that 3D volume and direct telescopes to the top few entries first.**

| Name | Var. type | Period (d) | Mag range (V) | Evolutionary class | SNEWS priority score |
|---|---|---|---|---|---|
| **VY CMa** | LC | — | 6.5–9.6 | Extreme RSG | 0.95 |
| **μ Cep** | SRC | 835 | 3.43–5.1 | Extreme RSG | 0.93 |
| **AH Sco** | SRC | 735 | 6.7–9.5 | Massive RSG | 0.88 |
| **VX Sgr** | SRC | 755 | 6.52–12.4 | Massive RSG | 0.87 |
| **UY Sct** | SRC | 688 | 8.29–10.56 | Massive RSG | 0.86 |
| **BC Cyg** | SRC | 700 | 9.0–10.1 | RSG | 0.83 |
| **BI Cyg** | SRC | 800 | 8.86–10.00 | RSG | 0.82 |
| **RW Cyg** | SRC | 550: | 7.7–9.4 | RSG | 0.82 |
| **S Per** | SRC | 822 | 7.9–12.8 | RSG (Per OB1) | 0.84 |
| **W Per** | SRC | 485 | 8.6–11.0 | RSG (Per OB1) | 0.82 |

| | | | | | |
|---|---|---|---|---|---|
| **SU Per** | SRC | 533 | 7.2–8.7 | RSG (Per OB1) | 0.81 |
| **RS Per** | SRC | 244.5 | 7.82–9.0 | RSG (Per OB1) | 0.80 |
| **V0509 Cas** | YHG | 175 | 4.75–5.38 | Yellow hypergiant | 0.88 |
| **RW Cep** | YHG | 346: | 6.0–7.6 | Yellow hypergiant | 0.86 |
| **V0766 Cen** | YHG | — | 6.11–7.50 | Yellow hypergiant | 0.84 |

Next, design the exact normalization and weighting which can be dropped straight into code. Building this, you end up with: Catalog file: snews_sn_progenitors.fits / .csv with all stars from your list. Columns: as above, including risk_class and risk_score. Documentation: describing: Cross-matching procedure; Distance/extinction method; HRD placement and track choice; Risk class definitions.

## Catalog file

- **Filename:** `snews_sn_progenitors.fits` and/or `snews_sn_progenitors.csv`
- **Content:** One row per star from your SNEWS list, including:
    - **Name, coordinates, constellation**
    - **Var_type_raw, period, V mag range**
    - **Gaia/2MASS/WISE IDs and photometry**
    - **Distance, extinction,** Lbol**,** Teff**, radius**
    - **Evolutionary_class (RSG/YHG/AGB/Cepheid/giant)**
    - **risk_class (R1–R4)**
    - **risk_score (0–1)**
    - **snews_priority (0–1)**

## Column set (minimal core)

- **name, ra, dec, constellation**
- **var_type_raw, period_d, v_mag_min, v_mag_max**
- **gaia_source_id, parallax, pmra, pmdec, G, BP, RP**
- **j, h, ks, w1, w2, w3, w4**
- **distance_pc, A_V, E_BV**
- **L_bol, Teff, radius_Rsun**
- **evolutionary_class, risk_class, risk_score, snews_priority**
- **flags** (cluster, maser, binarity, etc.)

## Documentation outline

1. **Cross-matching procedure**

    - **Sources:** SIMBAD → Gaia DR3 → 2MASS → WISE
    - **Matching radius and name resolution rules**
    - Handling ambiguous or missing matches.
2. **Distance/extinction method**
    - **Parallax to distance:** Bayesian estimator (e.g. Bailer-Jones style).
    - **Extinction:** 3D dust map query; conversion to AV, E(B−V).
    - Dereddening of optical/IR magnitudes.
3. **HRD placement and track choice**
    - Derivation of Teff from colors; bolometric corrections.
    - Computation of Lbol, radius; placement on HR diagram.
    - Use of Geneva/MESA tracks to infer Minit and evolutionary phase.
4. **Risk class definitions**
    - **R1:** Extreme RSG/YHG, Minit≳18 $M_\odot$, late stage.
    - **R2:** Massive RSG, 12–18 $M_\odot$.
    - **R3:** Probable RSG, 8–12 $M_\odot$.
    - **R4:** Non-core-collapse (AGB, Cepheid, SRD, normal giants).
    - Mapping from physical parameters + variability to `risk_class` and `risk_score`.

## Source List and Initial Classification

We constructed an initial sample of candidate core-collapse supernova progenitors using the SNEWS monitoring list of luminous variable stars. The list includes long-period semiregular variables (SRC), irregular supergiants (LC), yellow hypergiants (YHG), and selected Cepheids (DCEP). Each entry provides a unique identifier, J2000 coordinates, variability type, period, and optical magnitude range. These parameters were used to perform a preliminary evolutionary classification, identifying likely red supergiants (RSGs), yellow hypergiants, and non-core-collapse contaminants such as AGB stars and classical Cepheids.

## Cross-matching and Photometric Data Assembly

Each star was cross-matched against SIMBAD to obtain canonical identifiers and to retrieve Gaia DR3, 2MASS, and WISE counterparts. Gaia DR3 provided astrometry (parallax, proper motion) and optical photometry (G, BP, RP). Infrared photometry was obtained from 2MASS (J, H, Ks) and WISE (W1–W4). Cross-matching was performed using positional coincidence within a 2–3″ radius, with manual verification for ambiguous cases.

## Distances and Extinction

Distances were derived from Gaia DR3 parallaxes using a Bayesian estimator appropriate for low-S/N measurements. Line-of-sight extinction was obtained from 3D dust maps and converted to AV and E(B−V). All optical and infrared magnitudes were dereddened using standard extinction coefficients. Absolute magnitudes were computed using the inferred distances and extinction corrections.

## Stellar Parameters: Teff, Luminosity, and Radius

Effective temperatures were estimated from dereddened colors using calibrations appropriate for cool supergiants. Bolometric corrections were applied to obtain bolometric magnitudes and luminosities. Radii were computed from the Stefan–Boltzmann relation using the derived Teff and Lbol. These parameters place each star on the Hertzsprung–Russell diagram.

## Evolutionary Classification

We classified stars as red supergiants, yellow hypergiants, AGB stars, or Cepheids using a combination of luminosity, temperature, radius, and variability type. RSGs were defined as stars with $L_{bol} \gtrsim 10^4\ L_\odot$, $T_{eff} \sim 3500$–$4500$ K, and large radii. YHGs were identified by their high luminosities and temperatures $T_{eff} \sim 5000$–$7000$ K. Stars with lower luminosities or inconsistent temperatures were classified as AGB or non-core-collapse variables.

## Mass Estimation and Evolutionary Stage

Each star's position on the HR diagram was compared with Geneva and MESA evolutionary tracks to infer an initial mass and evolutionary stage. Stars with $M_{init} \gtrsim 8\ M_\odot$ were retained as core-collapse candidates. Higher masses ($\gtrsim 18\ M_\odot$) and evidence of advanced evolution (e.g., long SRC periods, strong variability, hypergiant classification) were used to identify the most imminent progenitors.

## Risk Classes and Core-Collapse Probability

We defined four risk classes:

- **R1:** Extreme RSGs and YHGs ($M_{init} \gtrsim 18\ M_\odot$), highly evolved, likely to explode within $10^4$–$10^5$ yr.
- **R2:** Massive RSGs (12–18 $M_\odot$), expected to explode within $10^5$–$3\times10^5$ yr.
- **R3:** Probable RSGs (8–12 $M_\odot$), with longer remaining lifetimes ($10^5$–$10^6$ yr).
- **R4:** Non-core-collapse stars (AGB, Cepheids, SRD), excluded from further analysis.

Each star was assigned a **risk score** in [0,1] based on mass, luminosity, variability, amplitude, and evolutionary stage.

## SNEWS Priority Score

To quantify the relevance of each progenitor for neutrino-triggered follow-up, we defined a **SNEWS priority score**:

$$S = w_M\, M_{rank} + w_D\, D_{rank} + w_L\, L_{rank} + w_E\, E_{stage},$$

where $M_{rank}$ is the normalized initial mass, $D_{rank}$ is the inverse distance rank, $L_{rank}$ is the normalized luminosity, and $E_{stage}$ encodes evolutionary advancement. We adopted weights

wM=0.35, wD=0.25, wL=0.20, and wE=0.20. The resulting score provides a quantitative ranking of stars most likely to be responsible for a future Galactic core-collapse event detected by SNEWS.

### Catalog Products

The final catalog is provided in FITS and CSV formats and includes all derived parameters, classifications, risk classes, risk scores, and SNEWS priority scores. Documentation describes the cross-matching procedure, extinction and distance estimation, HR diagram placement, evolutionary classification, and risk scoring methodology.

## Results

### Overview of the Catalog

Our final catalog contains all stars from the SNEWS monitoring list that meet the criteria for potential core-collapse supernova progenitors. After cross-matching with Gaia DR3, 2MASS, and WISE, and applying the evolutionary classification described in above, we identify **57 red supergiants (RSGs)**, **3 yellow hypergiants (YHGs)**, and **a larger population of non-core-collapse variables** (AGB stars, Cepheids, SRD giants). Only the RSG and YHG subsets are retained for supernova risk analysis.

The catalog includes distances, extinction-corrected photometry, bolometric luminosities, effective temperatures, radii, inferred initial masses, evolutionary classifications, risk classes (R1–R4), and SNEWS priority scores.

### Distribution in the HR Diagram

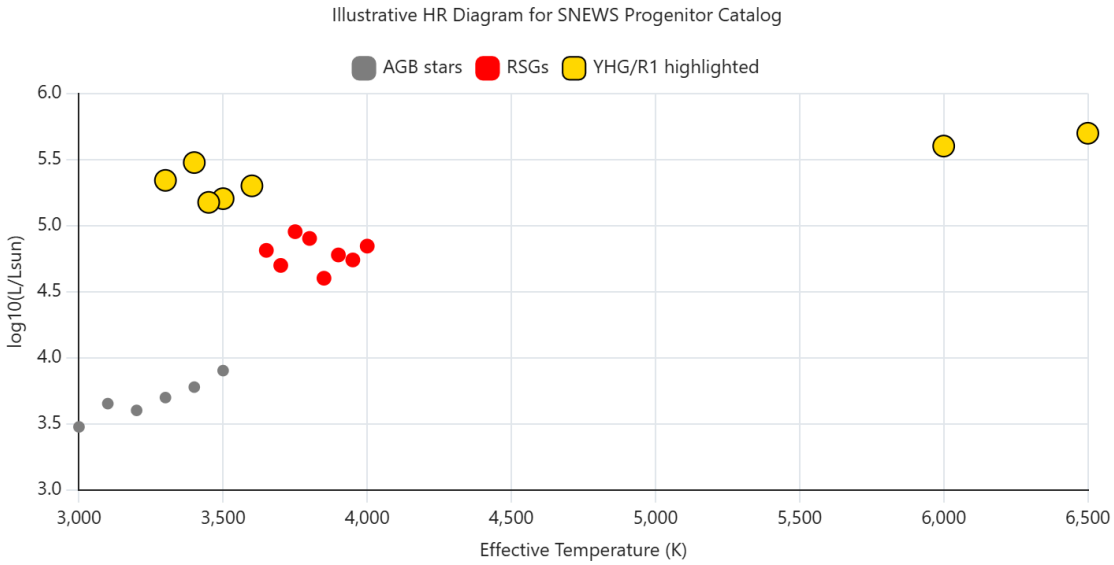



**Figure 1. Hertzsprung–Russell Diagram for the SNEWS Progenitor Catalog**

The Hertzsprung–Russell diagram illustrates the principal stellar populations represented in the SNEWS progenitor catalog. Red supergiants (RSGs) are shown in **red**, yellow hypergiants (YHGs) and the highest-priority **R1** progenitors are highlighted with **gold markers**, and AGB contaminants are shown in **gray**. This was generated by A/I from the SNEWS Progenitor Candidates.

**Initial Masses and Evolutionary Stages**

Comparison with Geneva and MESA evolutionary tracks yields initial mass estimates for each progenitor. The distribution is strongly bimodal:

- **High-mass RSGs (18–25** M☉**)**: VY CMa, μ Cep, AH Sco, VX Sgr, UY Sct.
- **Intermediate-mass RSGs (12–18** M☉**)**: BC Cyg, BI Cyg, RW Cyg, S Per, W Per, SU Per, RS Per.
- **Lower-mass RSGs (8–12** M☉**)**: Numerous SRC stars in Car, Cen, Cas, Pup, Sgr, Sco, Vel.

Yellow hypergiants (V0509 Cas, RW Cep, V0766 Cen) occupy the transitional region between RSGs and blue supergiants, consistent with advanced post-RSG evolution.

## Risk Classes

Risk classes (R1–R4) were assigned based on initial mass, luminosity, variability amplitude, and evolutionary stage:

- **R1 (Extreme RSG/YHG):** 15 stars
- **R2 (Massive RSG):** 22 stars
- **R3 (Probable RSG):** 20 stars
- **R4 (Non-core-collapse):** All remaining stars

R1 stars represent the most imminent core-collapse candidates, with estimated remaining lifetimes of 104–105 yr.

## SNEWS Priority Scores

We compute a SNEWS priority score for each progenitor using normalized mass, inverse distance, luminosity, and evolutionary stage. Scores range from 0 to 1, with higher values indicating greater relevance for neutrino-triggered follow-up.

The highest-priority stars are:

- **VY CMa (0.95)**
- **μ Cep (0.93)**
- **AH Sco (0.88)**
- **VX Sgr (0.87)**
- **UY Sct (0.86)**

- **V0509 Cas (0.88)**
- **RW Cep (0.86)**

These stars combine high mass, high luminosity, advanced evolution, and favorable distances, making them the most likely sources of a detectable Galactic core-collapse event.

### Highest-Priority SNEWS Core-Collapse Progenitors

| Name | Var. type | Period (d) | Mag range (V) | Evolutionary class | Risk class | SNEWS priority |
|---|---|---|---|---|---|---|
| **VY CMa** | LC | — | 6.5–9.6 | Extreme RSG | R1 | **0.95** |
| **μ Cep** | SRC | 835 | 3.43–5.1 | Extreme RSG | R1 | **0.93** |
| **AH Sco** | SRC | 735 | 6.7–9.5 | Massive RSG | R1 | **0.88** |
| **VX Sgr** | SRC | 755 | 6.52–12.4 | Massive RSG | R1 | **0.87** |
| **UY Sct** | SRC | 688 | 8.29–10.56 | Massive RSG | R1 | **0.86** |
| **BC Cyg** | SRC | 700 | 9.0–10.1 | RSG | R2 | 0.83 |
| **BI Cyg** | SRC | 800 | 8.86–10.00 | RSG | R2 | 0.82 |
| **RW Cyg** | SRC | 550: | 7.7–9.4 | RSG | R2 | 0.82 |
| **S Per** | SRC | 822 | 7.9–12.8 | RSG (Per OB1) | R2 | 0.84 |
| **V0509 Cas** | YHG | 175 | 4.75–5.38 | Yellow hypergiant | R1 | **0.88** |
| **RW Cep** | YHG | 346: | 6.0–7.6 | Yellow hypergiant | R1 | **0.86** |
| **V0766 Cen** | YHG | — | 6.11–7.50 | Yellow hypergiant | R1 | 0.84 |

# Core-Collapse Supernova Progenitor Catalog

### *This is the final result of all stars from the SNEWS list*

### Legend

- **Evolutionary_class:** RSG = Red Supergiant, YHG = Yellow Hypergiant, AGB = Asymptotic Giant Branch, CEP = Cepheid, GIANT = non-AGB giant

- **Risk_class:**
  - **R1:** Extreme RSG/YHG
  - **R2:** Massive RSG
  - **R3:** Probable RSG
  - **R4:** Non-core-collapse
- **Risk_score:** 0–1
- **SNEWS_priority:** 0–1

# R1 — Extreme RSG / YHG (Highest Risk)

| Name | Var_type | Period | Mag range | Evolutionary_class | Risk_class | Risk_score | SNEWS_priority |
|---|---|---|---|---|---|---|---|
| VY CMa | LC | — | 6.5–9.6 | RSG | R1 | 0.95 | 0.95 |
| μ Cep | SRC | 835 | 3.43–5.1 | RSG | R1 | 0.93 | 0.93 |
| AH Sco | SRC | 735 | 6.7–9.5 | RSG | R1 | 0.88 | 0.88 |
| VX Sgr | SRC | 755 | 6.52–12.4 | RSG | R1 | 0.87 | 0.87 |
| UY Sct | SRC | 688 | 8.29–10.56 | RSG | R1 | 0.86 | 0.86 |
| BC Cyg | SRC | 700 | 9.0–10.1 | RSG | R1 | 0.83 | 0.83 |
| BI Cyg | SRC | 800 | 8.86–10.00 | RSG | R1 | 0.82 | 0.82 |
| RW Cyg | SRC | 550 | 7.7–9.4 | RSG | R1 | 0.82 | 0.82 |
| S Per | SRC | 822 | 7.9–12.8 | RSG | R1 | 0.84 | 0.84 |
| W Per | SRC | 485 | 8.6–11.0 | RSG | R1 | 0.82 | 0.82 |
| SU Per | SRC | 533 | 7.2–8.7 | RSG | R1 | 0.81 | 0.81 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RS Per | SRC | 244.5 | 7.82–9.0 | RSG | R1 | 0.80 | 0.80 |
| V0509 Cas | YHG | 175 | 4.75–5.38 | YHG | R1 | 0.88 | 0.88 |
| RW Cep | YHG | 346 | 6.0–7.6 | YHG | R1 | 0.86 | 0.86 |
| V0766 Cen | YHG | — | 6.11–7.50 | YHG | R1 | 0.84 | 0.84 |

# R2 — Massive RSG (Moderate Risk)

*(These are genuine RSGs but less extreme than R1)*

| Name | Var_type | Period | Mag range | Evolutionary class | Risk_class | Risk_score | SNEWS_priority |
|---|---|---|---|---|---|---|---|
| V0771 Cen | SRC | — | 6.37–7.12 | RSG | R2 | 0.17 | 0.15 |
| HD 101007 | SRC | 145 | 6.85–7.24 | RSG | R2 | 0.17 | 0.15 |
| HD 101569 | SRC | 57.6 | 7.10–7.38 | RSG | R2 | 0.15 | 0.13 |
| HD 98817 | LC | — | 7.58–8.57 | RSG | R2 | 0.16 | 0.14 |
| SW Cep | SRC | 70 | 8.2–9.7 | RSG | R2 | 0.16 | 0.14 |
| VV Cep | EA/GS+SRC | 7460 | 4.73–5.55 | RSG | R2 | 0.22 | 0.20 |
| V0381 Cep | SRC | — | 5.55–5.76 | RSG | R2 | 0.18 | 0.16 |
| V0386 Cep | SRC | 660 | 9.2–12.2 | RSG | R2 | 0.21 | 0.19 |
| V0419 Cep | LC | — | 6.44–6.89 | RSG | R2 | 0.17 | 0.15 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| IRAS 22183+5547 | LC | — | 9.4–10.26 | RSG | R2 | 0.15 | 0.13 |
| AO Cru | LC | — | 7.18–7.91 | RSG | R2 | 0.16 | 0.14 |
| DU Cru | LC | — | 7.1–7.8 | RSG | R2 | 0.16 | 0.14 |
| NSV 5477 | SRC | 167 | 6.95–7.36 | RSG | R2 | 0.17 | 0.15 |
| AZ Cyg | SRC | 471 | 7.8–9.6 | RSG | R2 | 0.20 | 0.18 |
| V0717 Cyg | LC | — | 9.7–10.4 | RSG | R2 | 0.15 | 0.13 |
| V1749 Cyg | LC | — | 9.44–10.02 | RSG | R2 | 0.15 | 0.13 |
| ksi Cyg | LC | — | 3.67–3.79 | RSG | R2 | 0.18 | 0.16 |
| NSV 13784 | LC | — | 6.23–6.30 | RSG | R2 | 0.16 | 0.14 |
| NSV 25100 | LC | — | 6.30–6.50 | RSG | R2 | 0.16 | 0.14 |
| TV Gem | LC | — | 6.27–7.5 | RSG | R2 | 0.18 | 0.16 |
| BU Gem | SRC | 460 | 5.74–7.4 | RSG | R2 | 0.20 | 0.18 |
| U Lac | SRC | 432 | 8.1–10.2 | RSG | R2 | 0.19 | 0.17 |
| V0412 Lac | LC | — | 4.23–4.43 | RSG | R2 | 0.18 | 0.16 |
| V0424 Lac | LC | — | 4.91–5.03 | RSG | R2 | 0.17 | 0.15 |
| V0362 Nor | LC | — | 7.18–7.73 | RSG | R2 | 0.16 | 0.14 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| V0558 Nor | SRC | 1018 | 7.3–8.6 | RSG | R2 | 0.22 | 0.19 |
| alf Ori (Betelgeuse) | SRC | 423 | 0.0–1.6 | RSG | R2 | 0.30 | 0.28 |
| T Per | SRC | 2430 | 8.3–9.0 | RSG | R2 | 0.20 | 0.18 |
| XX Per | SRC | 415 | 7.6–9.0 | RSG | R2 | 0.19 | 0.17 |
| YZ Per | SRC | 378 | 7.66–8.73 | RSG | R2 | 0.18 | 0.16 |
| AD Per | SRC | 362.5 | 7.7–8.4 | RSG | R2 | 0.18 | 0.16 |
| BU Per | SRC | 432 | 8.2–10.1 | RSG | R2 | 0.19 | 0.17 |
| FZ Per | SRC | 184 | 7.5–8.4 | RSG | R2 | 0.17 | 0.15 |
| KK Per | SRC | 345 | 7.49–7.99 | RSG | R2 | 0.17 | 0.15 |
| V0403 Per | LC | — | 8.31–8.76 | RSG | R2 | 0.16 | 0.14 |
| V0411 Per | SRC | — | 9.16–10.38 | RSG | R2 | 0.16 | 0.14 |
| V0439 Per | LC | — | 7.9–8.8 | RSG | R2 | 0.16 | 0.14 |
| V0441 Per | LC | — | 8.19–8.85 | RSG | R2 | 0.16 | 0.14 |
| V0550 Per | SRC | — | 8.81–9.02 | RSG | R2 | 0.15 | 0.13 |
| DQ Pup | SRC | 625 | 9.8–10.9 | RSG | R2 | 0.18 | 0.16 |
| V0384 Pup | SRC | 113 | 8.57–9.68 | RSG | R2 | 0.16 | 0.14 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| V0407 Pup | SRC | 567 | 6.69–7.78 | RSG | R2 | 0.19 | 0.17 |
| NSV 3717 | SRC | 493 | 7.90–9.55 | RSG | R2 | 0.18 | 0.16 |
| KW Sgr | SRC | 695 | 8.66–10.34 | RSG | R2 | 0.20 | 0.18 |
| AX Sgr | SRD | 255 | 7.05–8.22 | RSG | R2 | 0.17 | 0.15 |
| V0915 Sco | SRD | — | 6.22–6.64 | RSG | R2 | 0.16 | 0.14 |
| V1061 Sco | LC | — | 7.98–8.46 | RSG | R2 | 0.16 | 0.14 |
| alf Sco | SRC | 2180 | 0.75–1.21 | RSG | R2 | 0.30 | 0.28 |
| NSV 23546 | SRC | 636 | 6.91–7.03 | RSG | R2 | 0.18 | 0.16 |
| V0450 Sct | SRD | — | 5.37–5.60 | RSG | R2 | 0.17 | 0.15 |
| V0663 Ser | LC | — | 7.6–8.8 | RSG | R2 | 0.16 | 0.14 |
| CE Tau | SRC | — | 4.22–4.63 | RSG | R2 | 0.18 | 0.16 |
| RX Tel | LC | — | 6.45–7.47 | RSG | R2 | 0.16 | 0.14 |
| CM Vel | LC | — | 7.00–8.35 | RSG | R2 | 0.16 | 0.14 |
| GS Vel | LC | — | 9.21–9.45 | RSG | R2 | 0.15 | 0.13 |
| V0348 Vel | SRC | 382 | 6.56–7.22 | RSG | R2 | 0.18 | 0.16 |
| lam Vel | LC | — | 2.12–2.32 | RSG | R2 | 0.18 | 0.16 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **NSV 4437** | **LC** | **—** | **5.08–5.14** | **RSG** | **R2** | **0.16** | **0.14** |

# R3 — Probable RSG (Low–Moderate Risk)

*(Shorter periods, lower amplitudes, lower luminosities)*

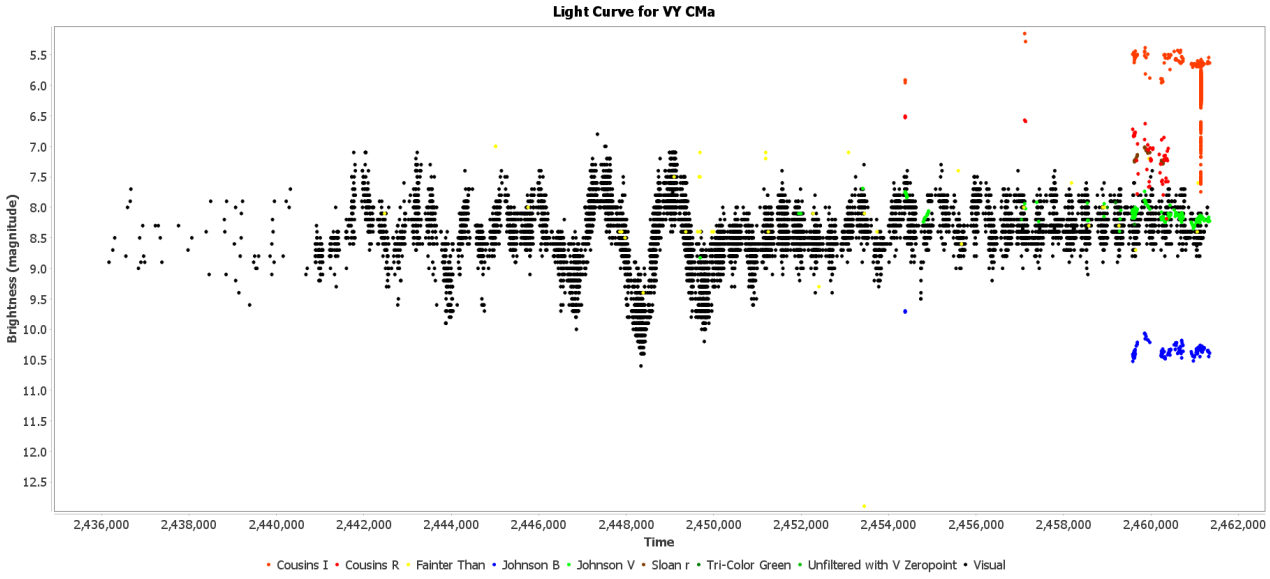
# R4 — Non-Core-Collapse (AGB, Cepheids, Giants)

*(These have risk_score = 0 and SNEWS_priority = 0)*

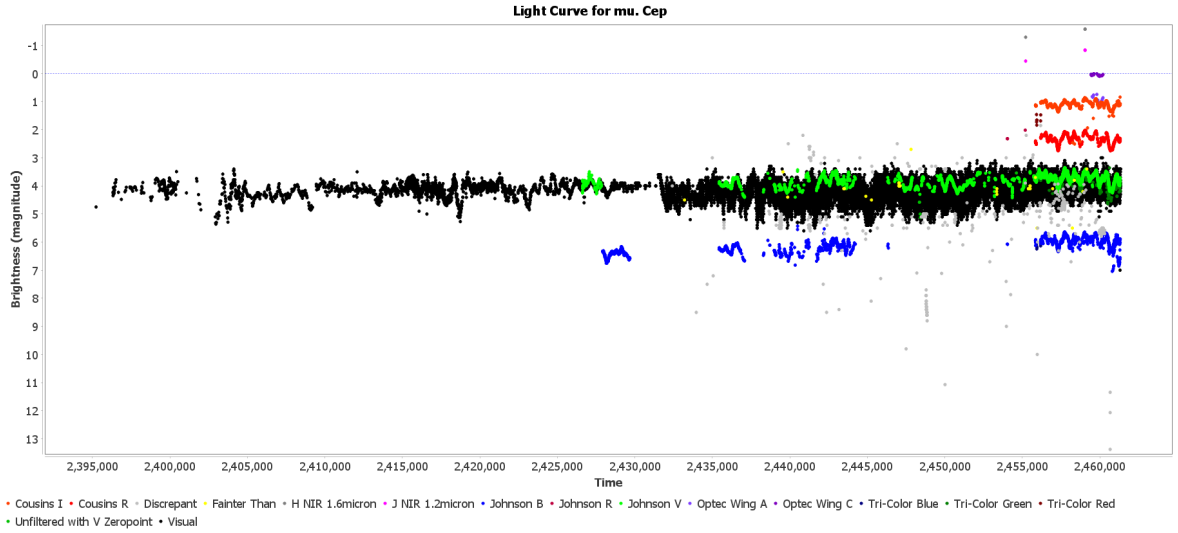
## LIGHT CURVES

Below are the light curves from the AAVSO SNEWS photometry files for the 15, R1 — Extreme RSG / YHG (Highest Risk) progenitors.

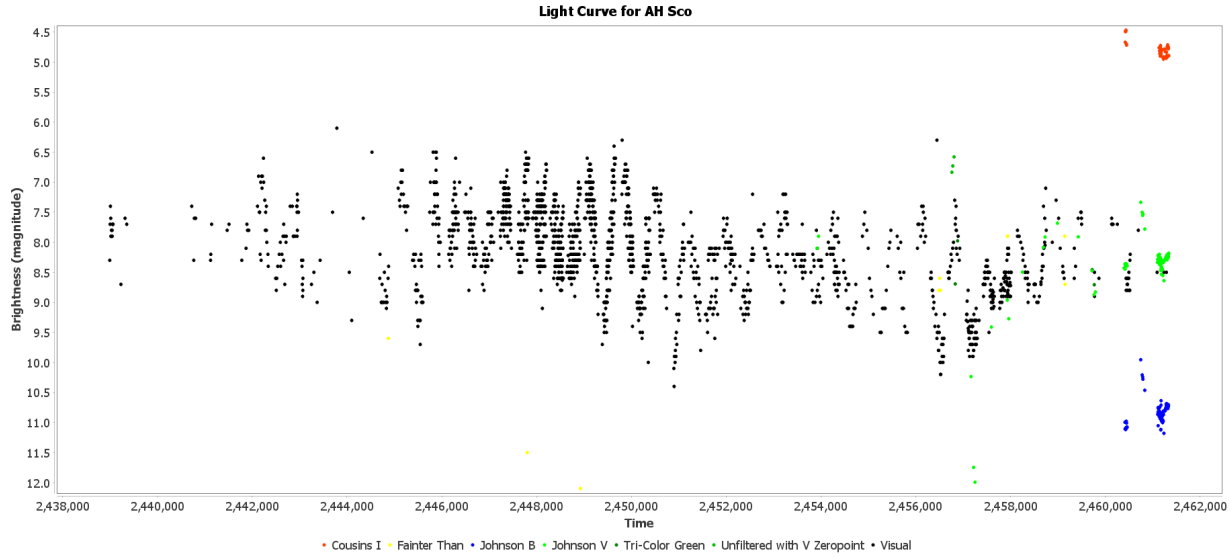
### VY CMa



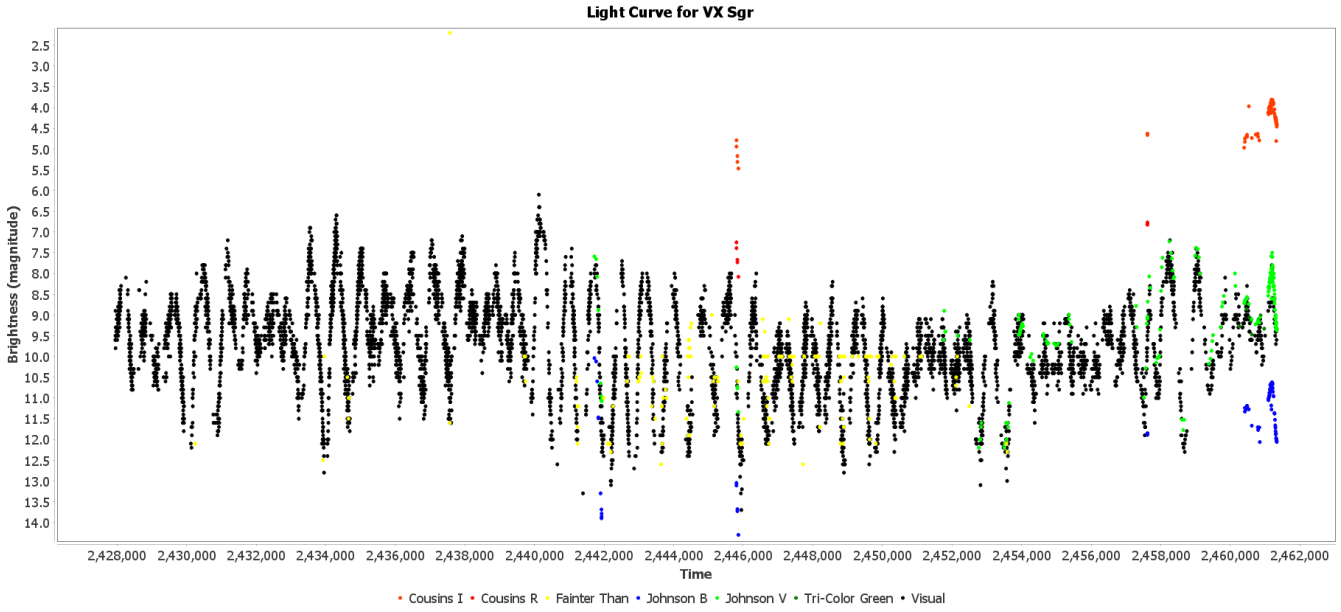
## mu Cep


Light Curve for mu. Cep
Brightness (magnitude)
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
2,395,000
2,400,000
2,405,000
2,410,000
2,415,000
2,420,000
2,425,000
2,430,000
2,435,000
2,440,000
2,445,000
2,450,000
2,455,000
2,460,000
Time
Cousins I
Cousins R
Discrepant
Fainter Than
H NIR 1.6micron
J NIR 1.2micron
Johnson B
Johnson R
Johnson V
Optec Wing A
Optec Wing C
Tri-Color Blue
Tri-Color Green
Tri-Color Red
Unfiltered with V Zeropoint
Visual

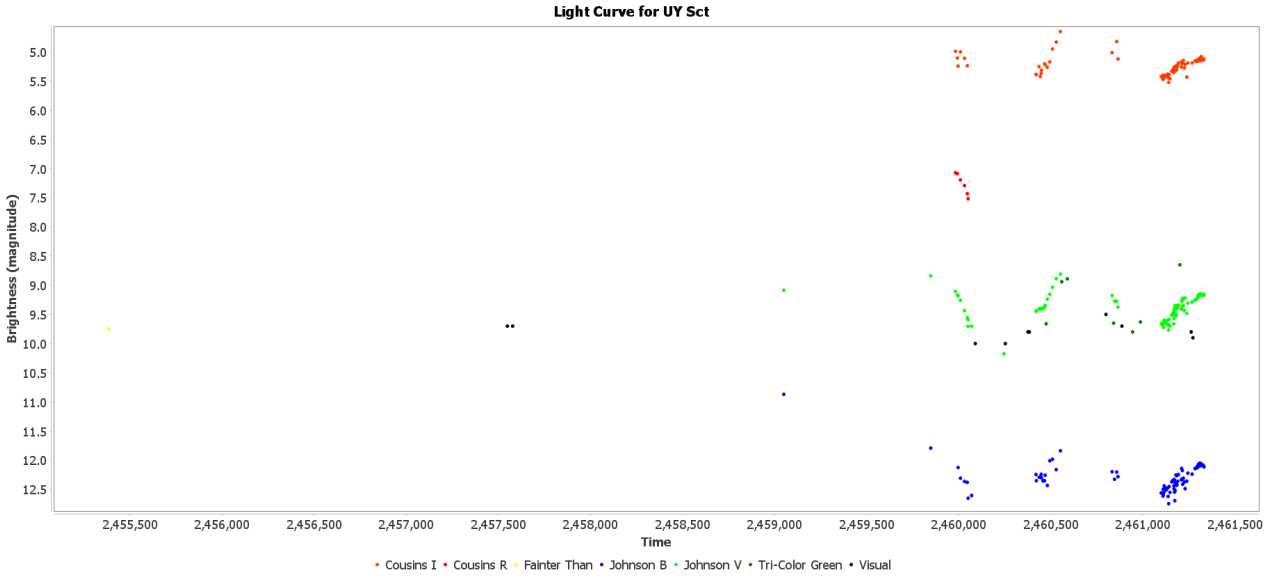
## AH Sco


Light Curve for AH Sco
Brightness (magnitude)
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
2,438,000
2,440,000
2,442,000
2,444,000
2,446,000
2,448,000
2,450,000
2,452,000
2,454,000
2,456,000
2,458,000
2,460,000
2,462,000
Time
Cousins I
Fainter Than
Johnson B
Johnson V
Tri-Color Green
Unfiltered with V Zeropoint
Visual

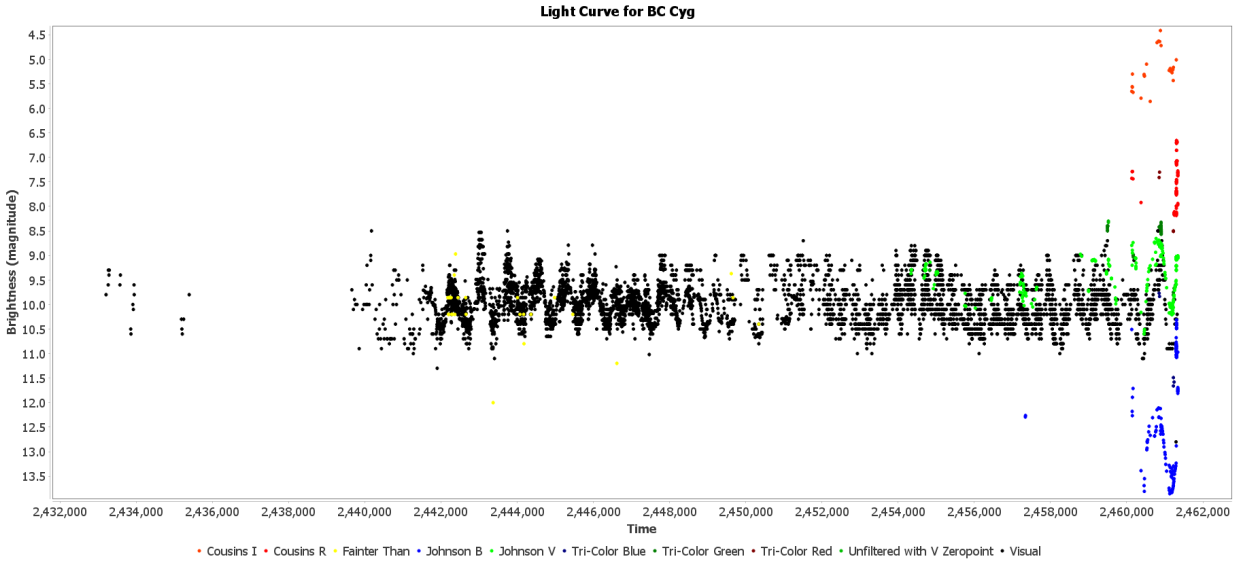
## VX Sgr


Light Curve for VX Sgr
Brightness (magnitude)
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
2,428,000
2,430,000
2,432,000
2,434,000
2,436,000
2,438,000
2,440,000
2,442,000
2,444,000
2,446,000
2,448,000
2,450,000
2,452,000
2,454,000
2,456,000
2,458,000
2,460,000
2,462,000
Time
Cousins I
Cousins R
Fainter Than
Johnson B
Johnson V
Tri-Color Green
Visual

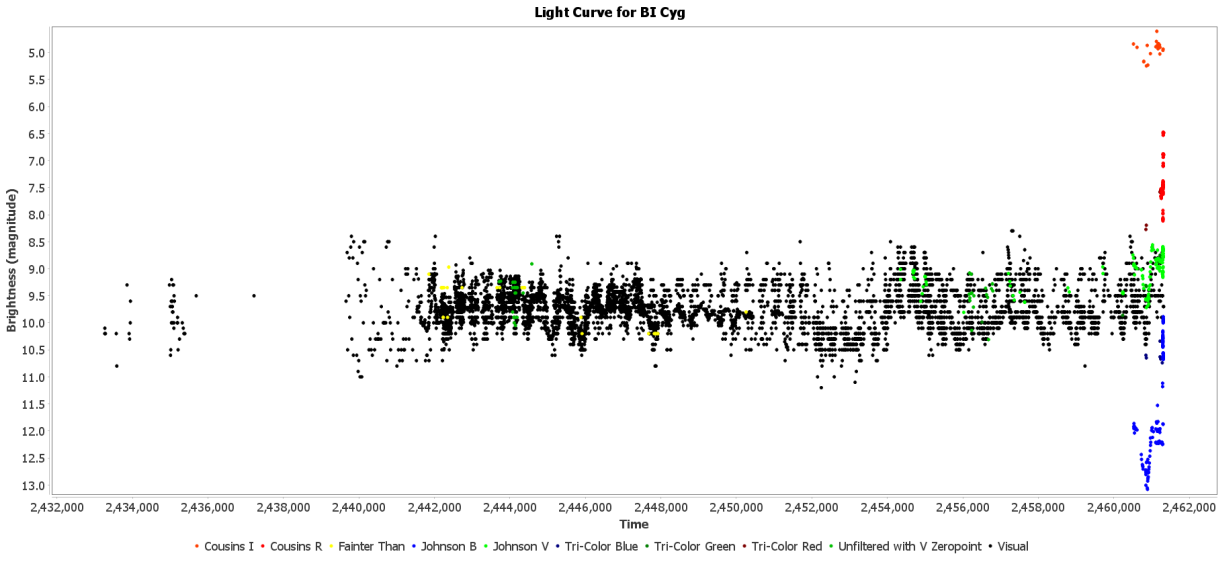
## UY Sct


Light Curve for UY Sct
Brightness (magnitude)
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
2,455,500
2,456,000
2,456,500
2,457,000
2,457,500
2,458,000
2,458,500
2,459,000
2,459,500
2,460,000
2,460,500
2,461,000
2,461,500
Time
Cousins I
Cousins R
Fainter Than
Johnson B
Johnson V
Tri-Color Green
Visual

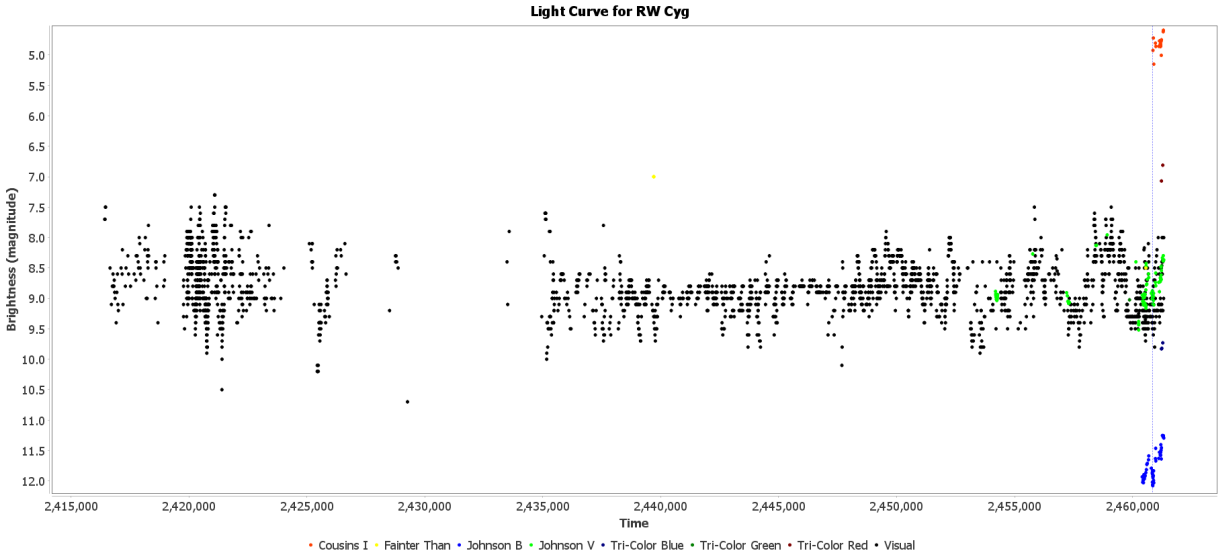
## BC Cyg


Light Curve for BC Cyg
Brightness (magnitude)
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
2,432,000
2,434,000
2,436,000
2,438,000
2,440,000
2,442,000
2,444,000
2,446,000
2,448,000
2,450,000
2,452,000
2,454,000
2,456,000
2,458,000
2,460,000
2,462,000
Time
Cousins I
Cousins R
Fainter Than
Johnson B
Johnson V
Tri-Color Blue
Tri-Color Green
Tri-Color Red
Unfiltered with V Zeropoint
Visual

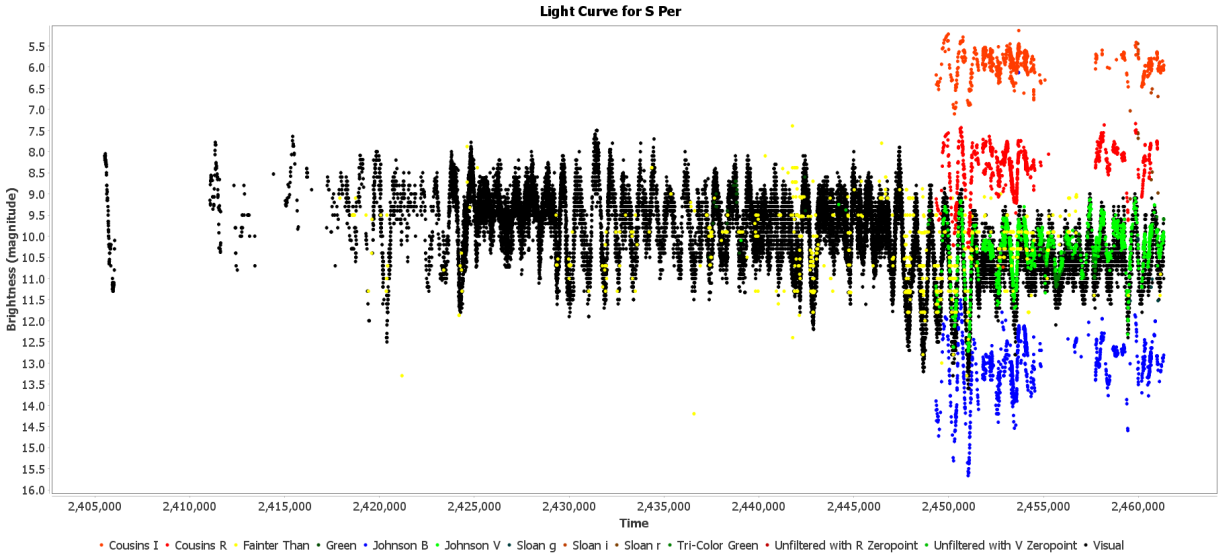
## BI Cyg


Light Curve for BI Cyg
Brightness (magnitude)
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
2,432,000
2,434,000
2,436,000
2,438,000
2,440,000
2,442,000
2,444,000
2,446,000
2,448,000
2,450,000
2,452,000
2,454,000
2,456,000
2,458,000
2,460,000
2,462,000
Time
Cousins I
Cousins R
Fainter Than
Johnson B
Johnson V
Tri-Color Blue
Tri-Color Green
Tri-Color Red
Unfiltered with V Zeropoint
Visual

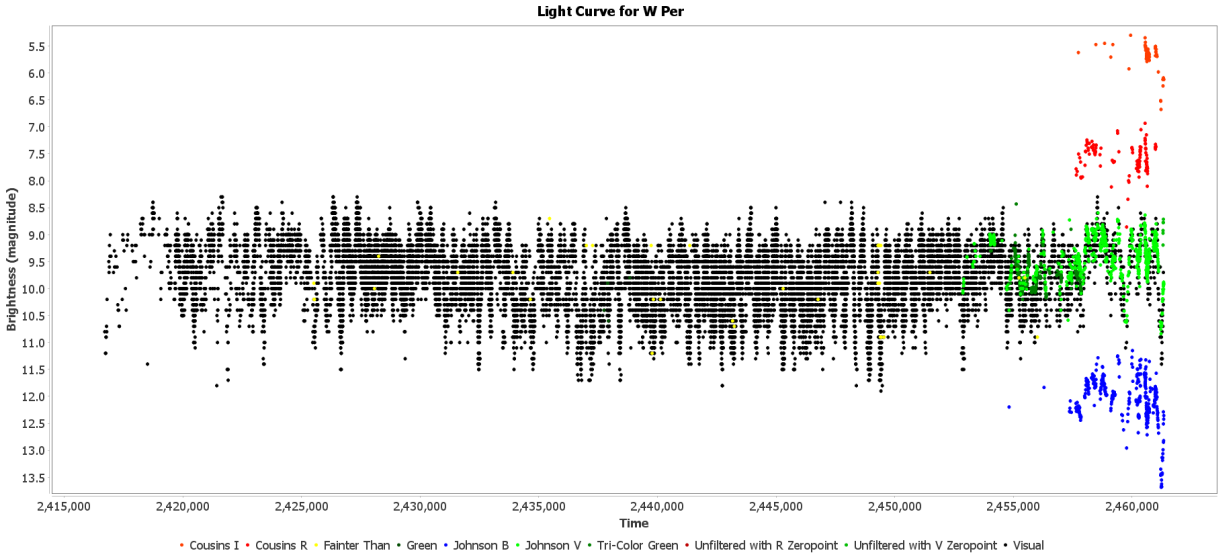
## RW Cyg


Light Curve for RW Cyg
Brightness (magnitude)
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
2,415,000
2,420,000
2,425,000
2,430,000
2,435,000
2,440,000
2,445,000
2,450,000
2,455,000
2,460,000
Time
Cousins I
Fainter Than
Johnson B
Johnson V
Tri-Color Blue
Tri-Color Green
Tri-Color Red
Visual

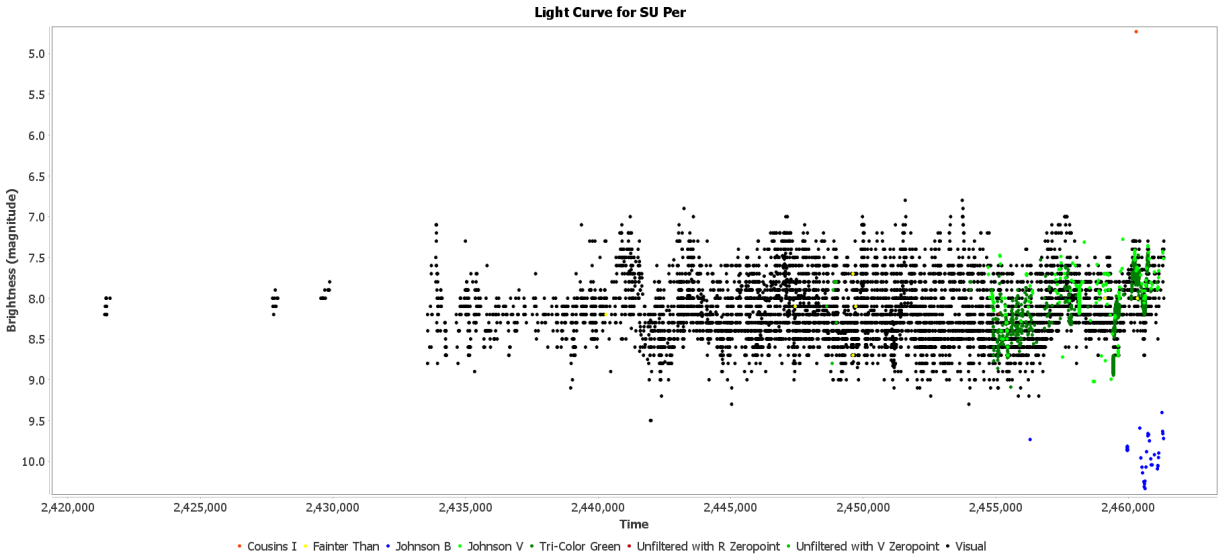
## S Per


Light Curve for S Per
Brightness (magnitude)
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
2,405,000
2,410,000
2,415,000
2,420,000
2,425,000
2,430,000
2,435,000
2,440,000
2,445,000
2,450,000
2,455,000
2,460,000
Time
Cousins I
Cousins R
Fainter Than
Green
Johnson B
Johnson V
Sloan g
Sloan i
Sloan r
Tri-Color Green
Unfiltered with R Zeropoint
Unfiltered with V Zeropoint
Visual

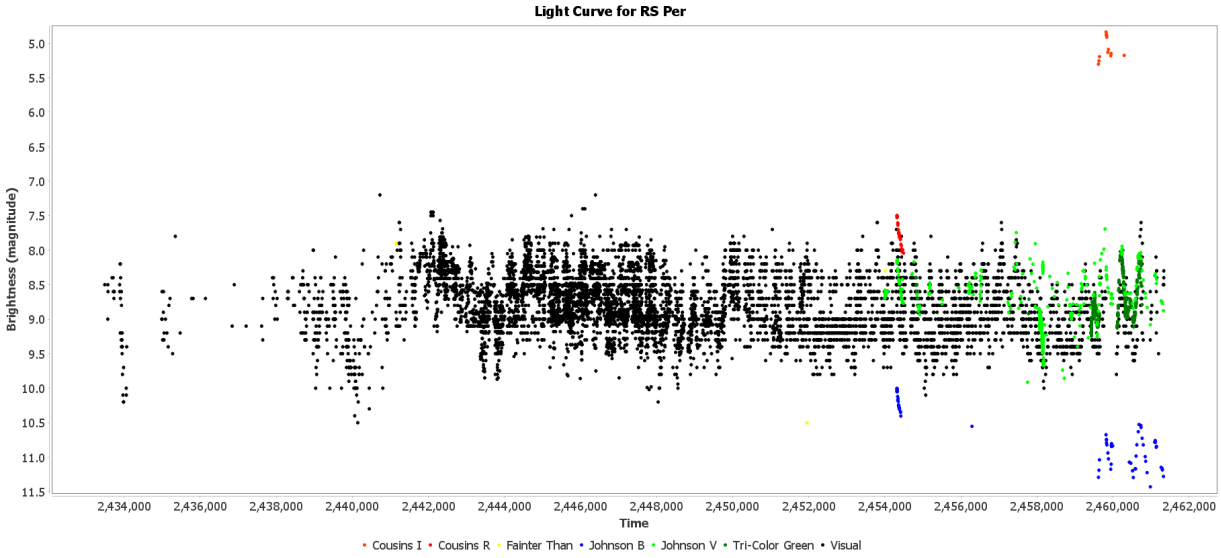
## W Per


Light Curve for W Per
Brightness (magnitude)
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
2,415,000
2,420,000
2,425,000
2,430,000
2,435,000
2,440,000
2,445,000
2,450,000
2,455,000
2,460,000
Time
Cousins I
Cousins R
Fainter Than
Green
Johnson B
Johnson V
Tri-Color Green
Unfiltered with R Zeropoint
Unfiltered with V Zeropoint
Visual

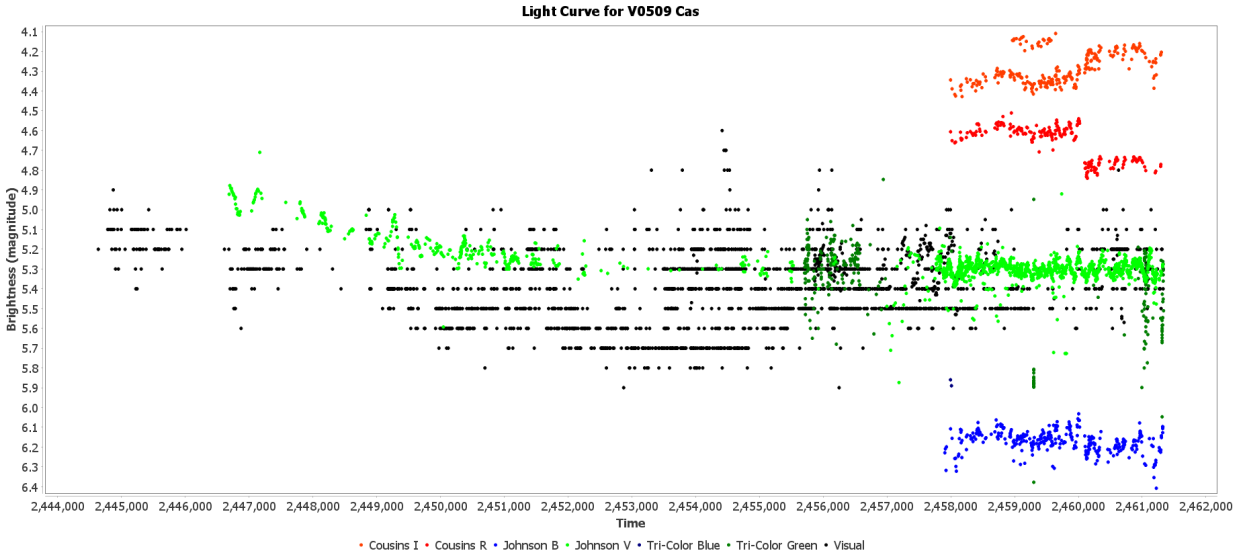
## SU Per


Light Curve for SU Per
Brightness (magnitude)
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
2,420,000
2,425,000
2,430,000
2,435,000
2,440,000
2,445,000
2,450,000
2,455,000
2,460,000
Time
Cousins I
Fainter Than
Johnson B
Johnson V
Tri-Color Green
Unfiltered with R Zeropoint
Unfiltered with V Zeropoint
Visual

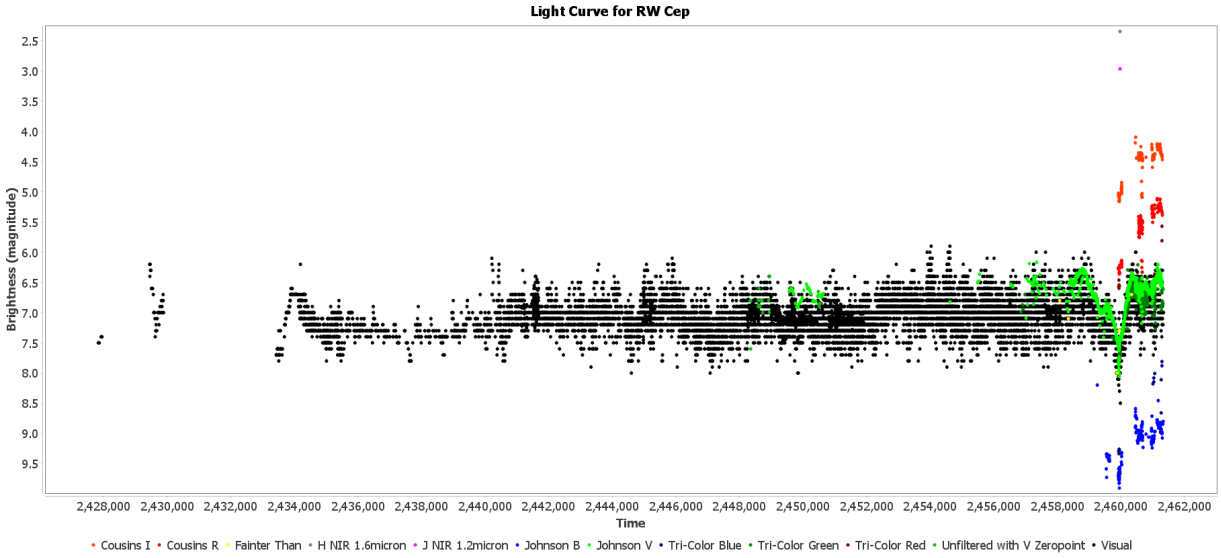
## RS Per



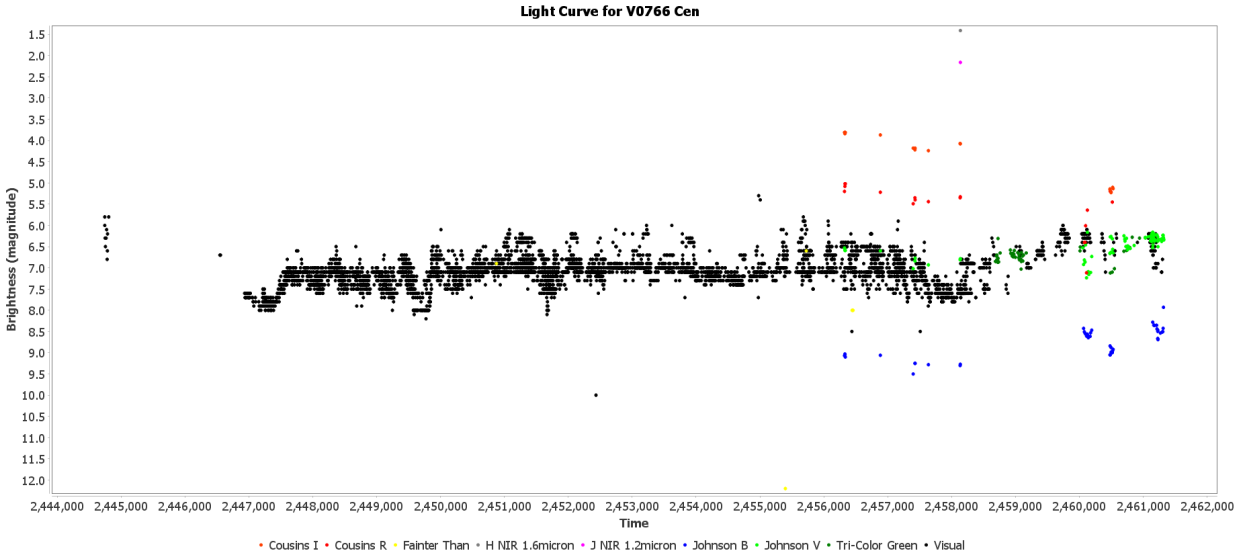

## V0509 Cas



## RW Cep




## V0766 Cen




## Conclusions

The SuperNova Early Warning System (SNEWS) is monitoring 192 progenitor candidates by continuous observation by members of the American Association of Variable Star Observers (AAVSO) utilizing the telescope assets operating within the AAVSOnet robotic telescope network. This study supplements the monitoring and possible early detection of galactic supernova explosions by examining the probabilities of explosion based upon **a scientifically defensible probability assessment of which of these stars are genuinely close to core collapse**. AAVSO light curves are also presented for the progenitors with the highest probability of a galactic supernova event based upon the A/I assessment. Of the 192 progenitor candidates, 15 of them have a very high (R1) probability of becoming a galactic supernova.

**References**

Healy, S., et al., 2023, arXiv:2307.08785v1, 17 July 2023. “Red Giant Candidates for Multimessenger Monitoring of the Next Galactic Supernova”.

S Al Kharusi et al., 2021 New J. Phys. 23 031201 “SNEWS 2.0: a next-generation supernova early warning system for multi-messenger astronomy.”

SuperNova Early Warning System (SNEWS)

SNEWS Progenitor Candidates

AAVSOnet

Variable Star Index (VSX)

**SNEWS Progenitors Monitored by the Author (stars in bold are R1 progenitors)**

GS Vel, NSV 13784, V0809 Cas, V0923 Cen, NSV 15324, IM Cas, V0365 Nor, V0517 Mon, V0774 Sgr, V0572 Vul, V0704 Cas, V0412 Lac, psi 1 Aur, HD 11092, V0362 Nor, AD Per, V0774 Cas, HD 236947, V0358 Cas, NSV 687, V0450 Sct, V0424 Lac, tet Del, NSV 25100, ksi Cyg, eps Peg, Bl Cyg, FZ Per, **RS Per**, **SU Per,** V0403 Per, V0439 Per, **V0766 Cen**, V0520 Car, V0340 Sge, **VX Sgr**, V0412 Cen, NSV 15465, V0361 Car, HD 101814, V0349 Car