Probing Mass Loss Properties of Supernova Progenitors

Global Rapid Advanced Network Devoted to the Multi-messenger Addicts (GRANDMA),
Observatoire de la Cote d'Azure, Nice, France

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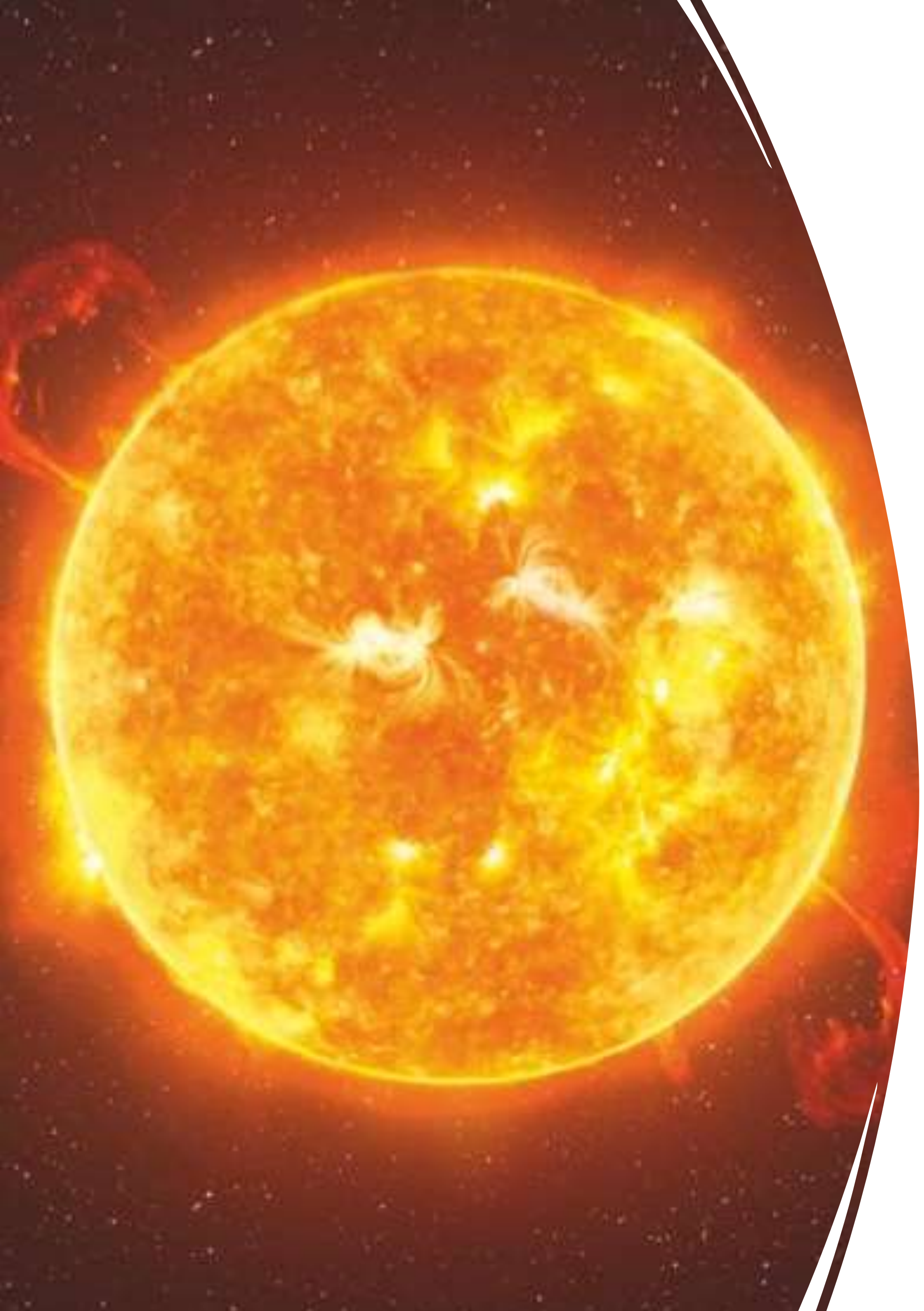
Overview

- Objective
- Explosive end products of massive stars
- Methodology
- Circumstellar material of massive stars
- Ultra Long Gamma Ray Burst (ulGRB) hosts galaxies
- Summary



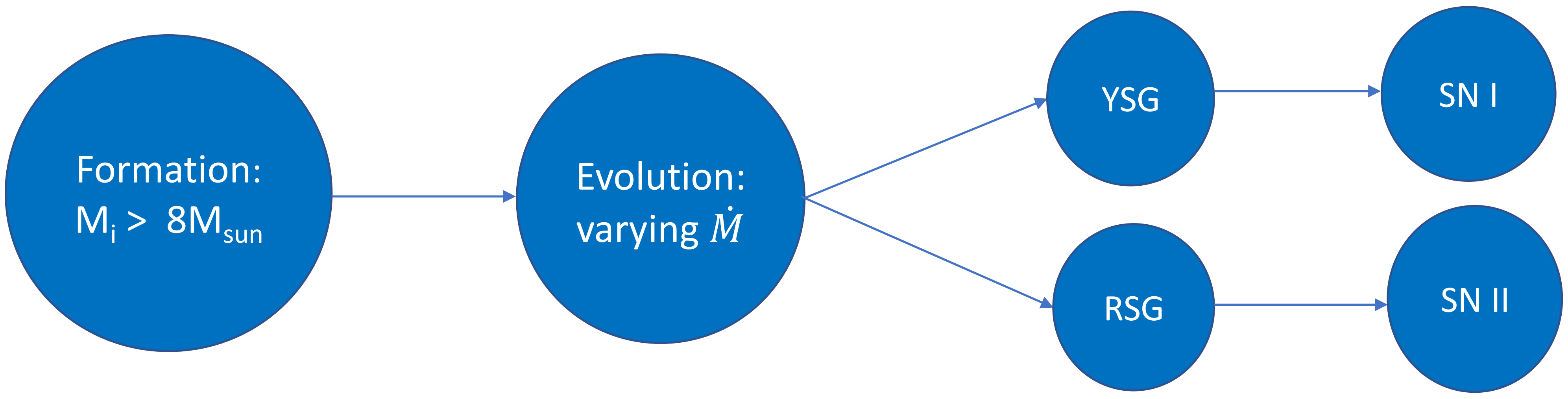
Source: https://nineplanets.org/kids/betelgeuse-star/

Objective

- To understand the role $\dot{M}$ plays in the evolution of massive stars
- To understand the mass-loss processes that produce different types of supernova (SNe) progenitors and types

Explosive end product of massive stars

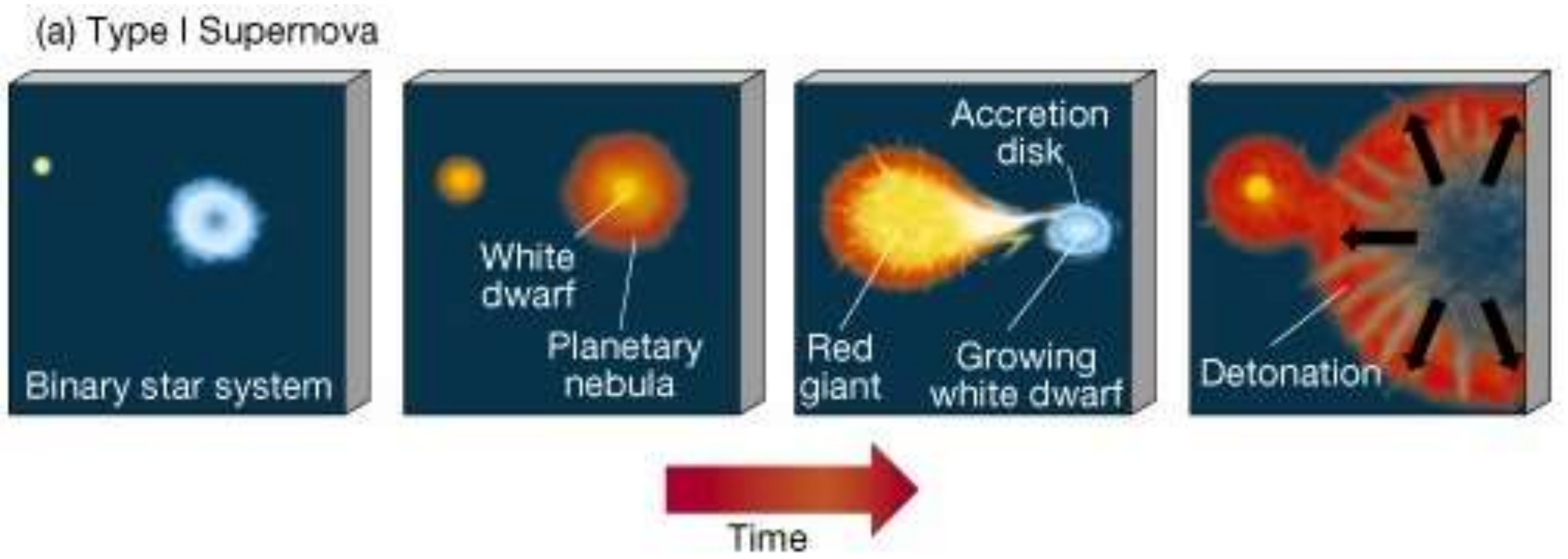
- Massive stars expand and cool down into red supergiant (RSG) or yellow supergiant (YSG).



- Probing the circumstellar environment can help us recreate the mass-loss histories of evolved stars

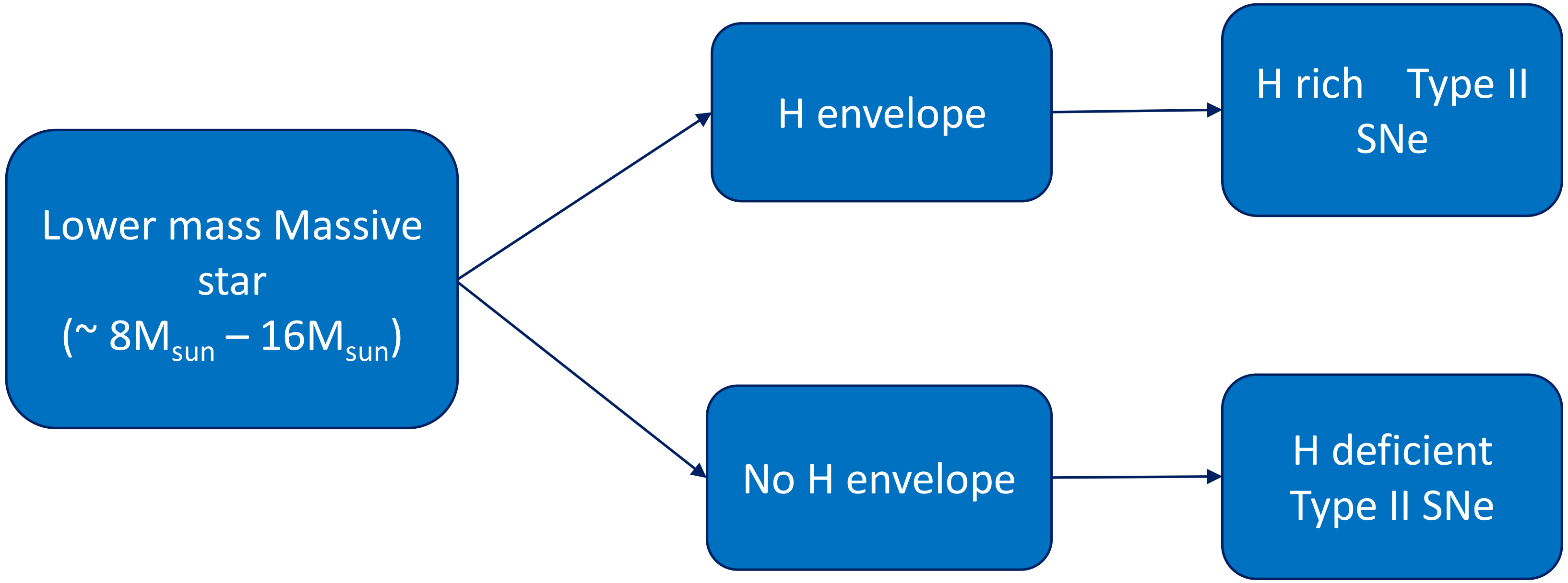
Core Collapse Supernova

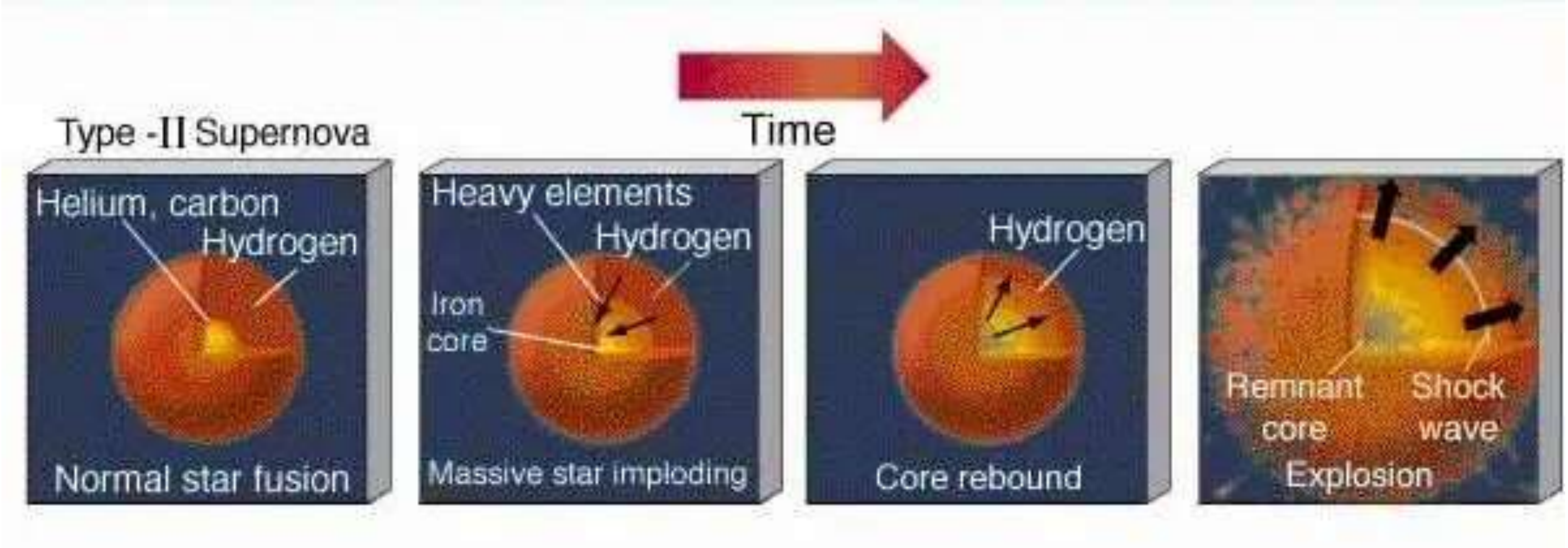
More Massive star with strong stellar winds → H deficient → Type Ibc SNe



Citation for flowchart: Nomoto et al., 1996, IAUS, 165, 119

Source: http://astronomy.nju.edu.cn/~lixd/GA/AT4/AT421/HTML/AT42103.htm





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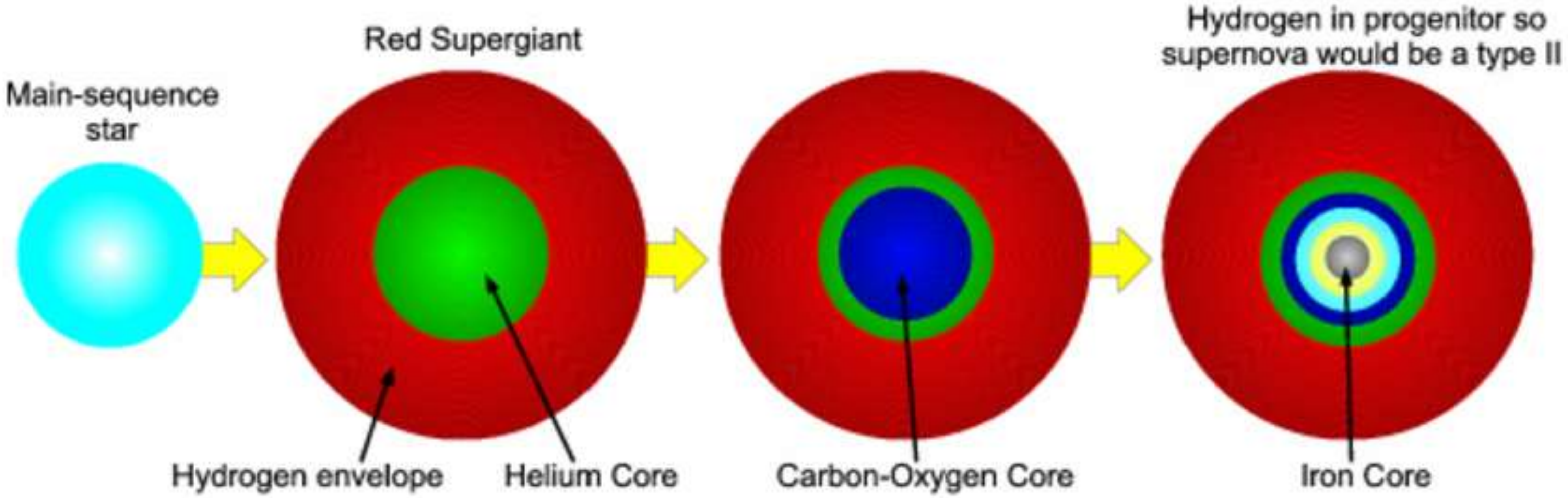
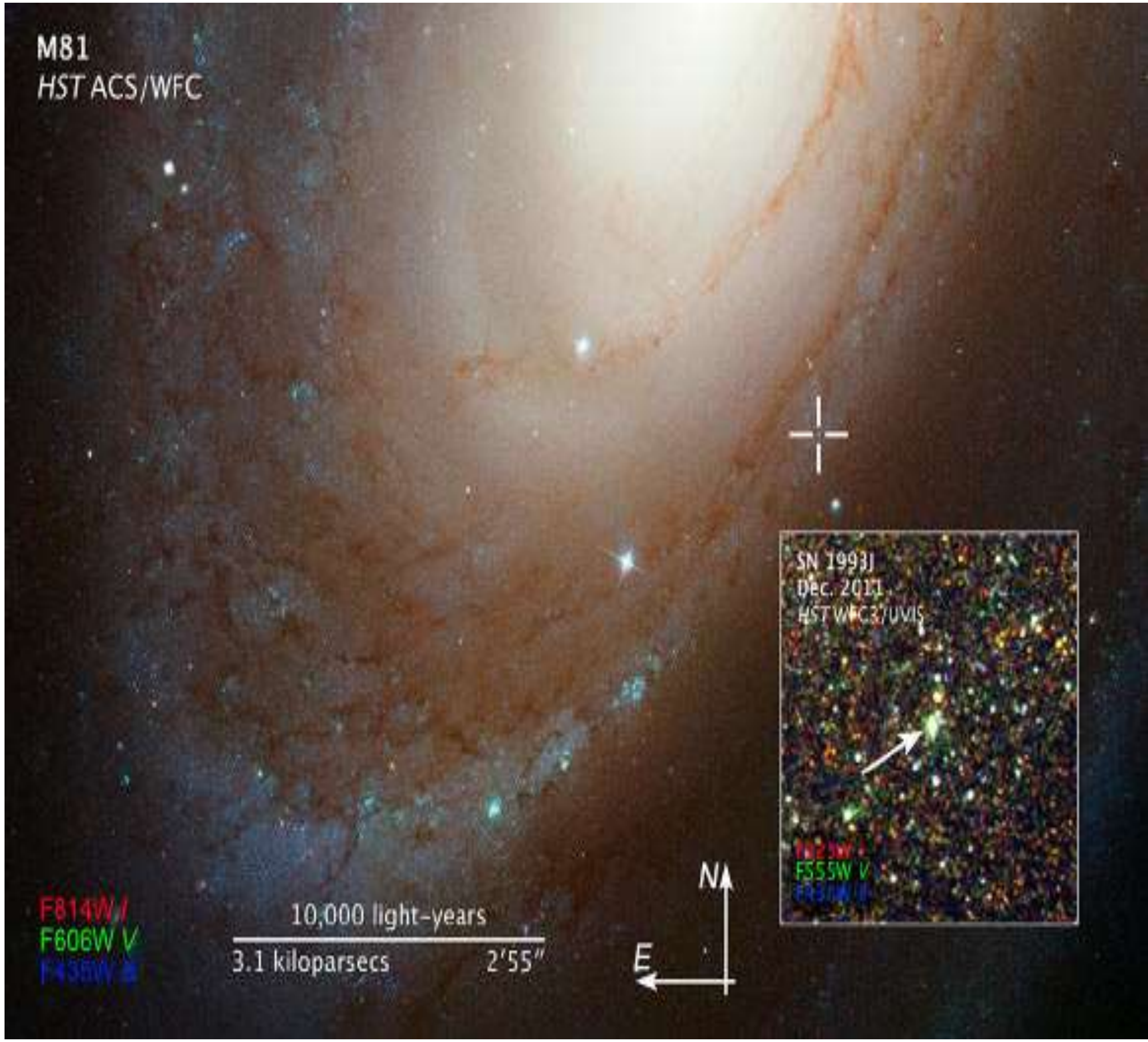
Red Supergiant



Source: Massive stars in their death throes, J.J. Elridge, https://royalsocietypublishing.org/doi/full/10.1098/rsta.2008.0160

Red Supergiant

- Spectral type: K or M
- Temperature: below 4,100K (cool and large star)
- M_i: 8-30 M_{sun}
- H-rich Type II b or Type II p supernova



SNe 1993J (progenitor: K0 RSG) ; Galaxy: M81; Source: NASA Hubblesite: https://hubblesite.org/contents/media/images/2014/38/3413-Image.html?news=true

Yellow Supergiant

- Spectral type: G or F
- Temperature: 4,000K – 7000 K (cool and large star)
- M_i: 8-20 M_sun
- H-poor Type I b supernova

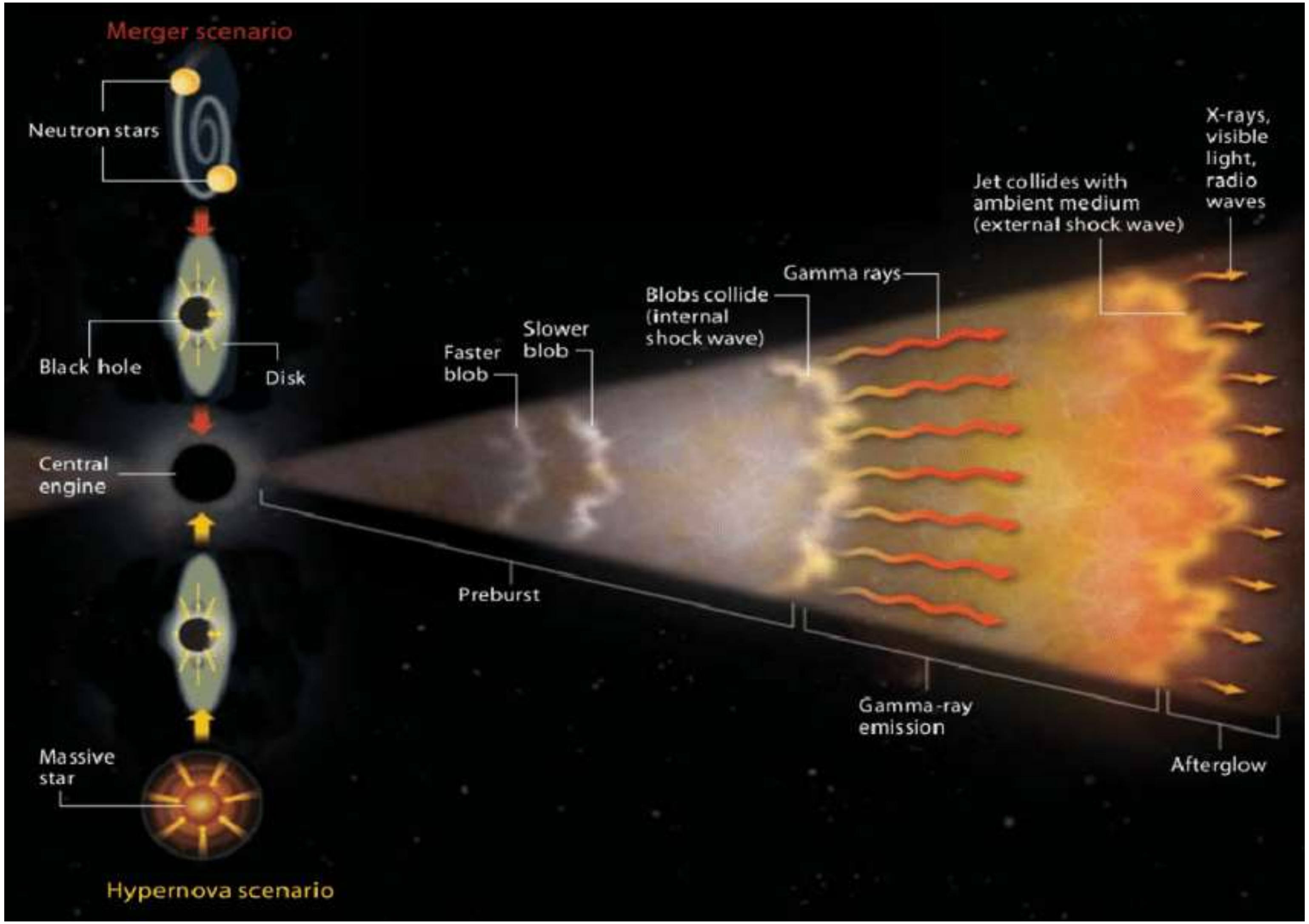
SNe 2011dh (progenitor: YSG) ; Galaxy: M51; Source: Phys Org; https://phys.org/news/2015-12-imaging-supernova-shell.html

Gamma Ray Burst (GRB)

- An intensely bright and powerful explosion due to the collapse of massive stars or the merger of two compact objects.

- Have been detected up to redshift z = 9

- Our only chance to understand early Universe massive stellar evolution and chemical enrichment at the stellar scale.



Source: Researchgate

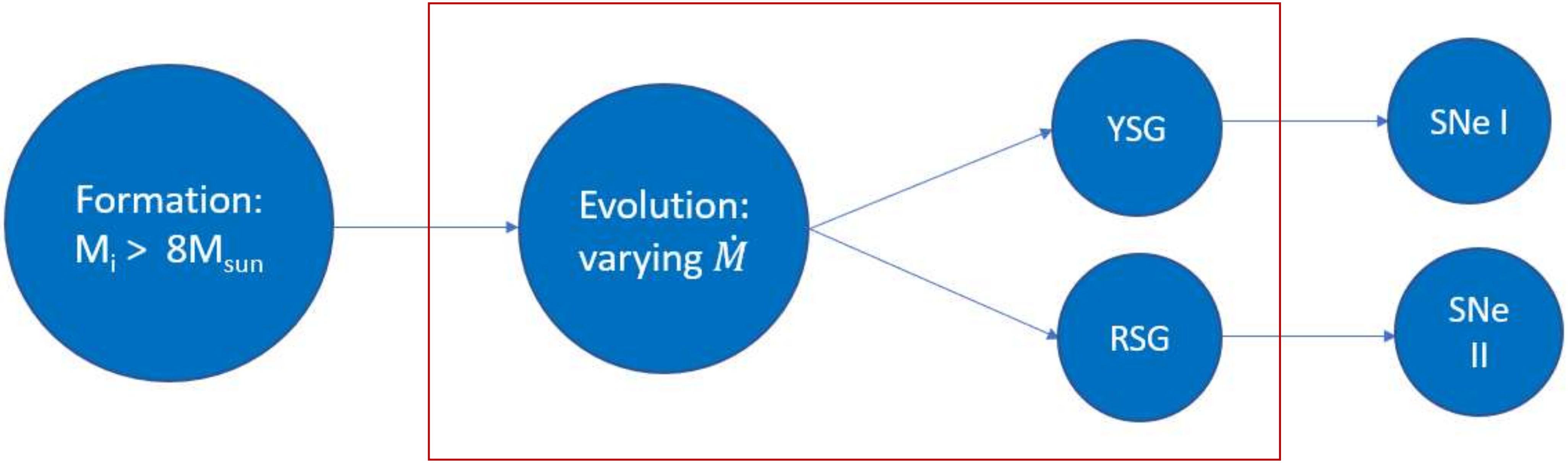
Long Gamma Ray Burst (LGRB):

- t > 2 seconds.
- Due to the gravitational collapse of an extremely massive star (>20M_sun).
- Shock wave and circumburst medium interaction produce a longer-lived synchrotron emission called "afterglow", which is detectable at X-ray through radio wavelength.
- Afterglow allows localization at sub arc second precision.

Ultra Long Gamma Ray Burst:

- t > 10,000 seconds.
- Likely a separate class, with three main progenitors:
    1) an ultra-massive stellar progenitor, very similar to Pop III stars
    2) the tidal disruption of a dwarf star
    3) and a newborn magnetar

Methodology



1- Use high spatial imaging to study circumstellar environment of evolved massive stars

2 - Photometric and Spectroscopic survey of ulGRB and LGRB host galaxies

Instruments used for data collection

- Method 1: Very Large Telescope : Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE).

- Method 2: Virgin Island Robotic Telescope (VIRT), U.S. Virgin Island and Zadko Telescope, University of Western Australia.

Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE)

SPHERE: Extreme adaptive optics and Coronagraph.

Instruments:

- *IRDIS*
- IFDS
- ZIMPOL

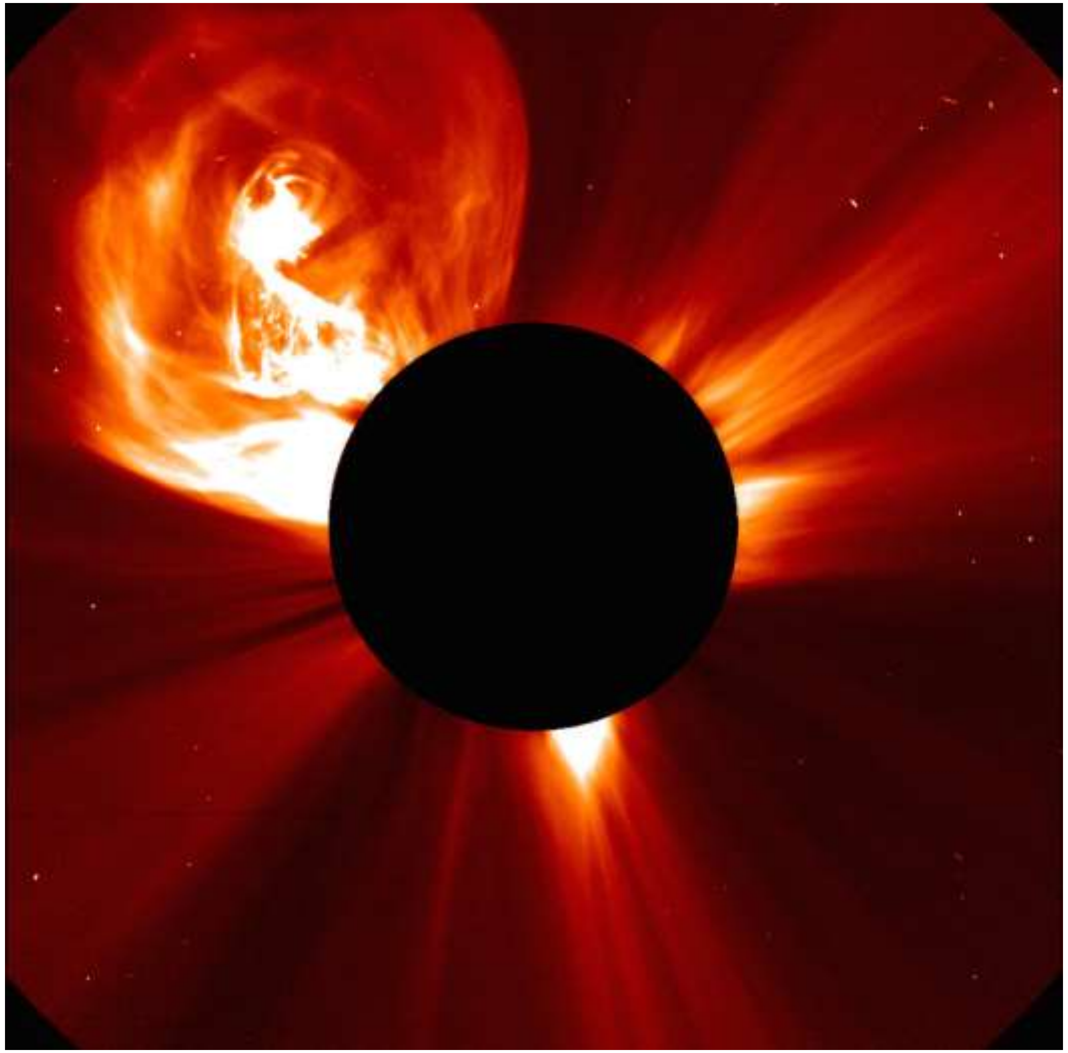
IRDIS - Infra-Red Dual-beam Imager and Spectrograph

Very Large Telescope (ESO); Photo credits: Jean-Baptiste Feldmann.

Cite: https://www.eso.org/sci/facilities/paranal/instruments/sphere/inst.html

Coronagraph

- An opaque disc used to block central starlight.
- About 50 planets have been discovered through direct imaging using coronagraphs.
- For example: HR 8799 system- 4 Jupiter sized exoplanets.



Coronagraphy of Sun; Source: The Origin, Early Evolution and Predictability of Solar Eruptions

Virgin Island Robotic Telescope (VIRT)

- A 0.5m robotic Cassegrain telescope nick named the Virgin Island Robotic Telescope (VIRT).

- It is the only research grade telescope in the Caribbean dedicated to rapid optical follow up of astrophysical transients.

- Some capabilities of VIRT are:
  - Queue-scheduled observing
  - Rapid response to Swift-GRB and other transient alerts

Zadko Telescope (University of Western Australia)

- 1-m hybrid Ritchey-Chretien design.

- Primary science goals: Rapid optical follow-up observations for

  GRBs,

  Gravitational Waves,

  Fast Radio Bursts, and

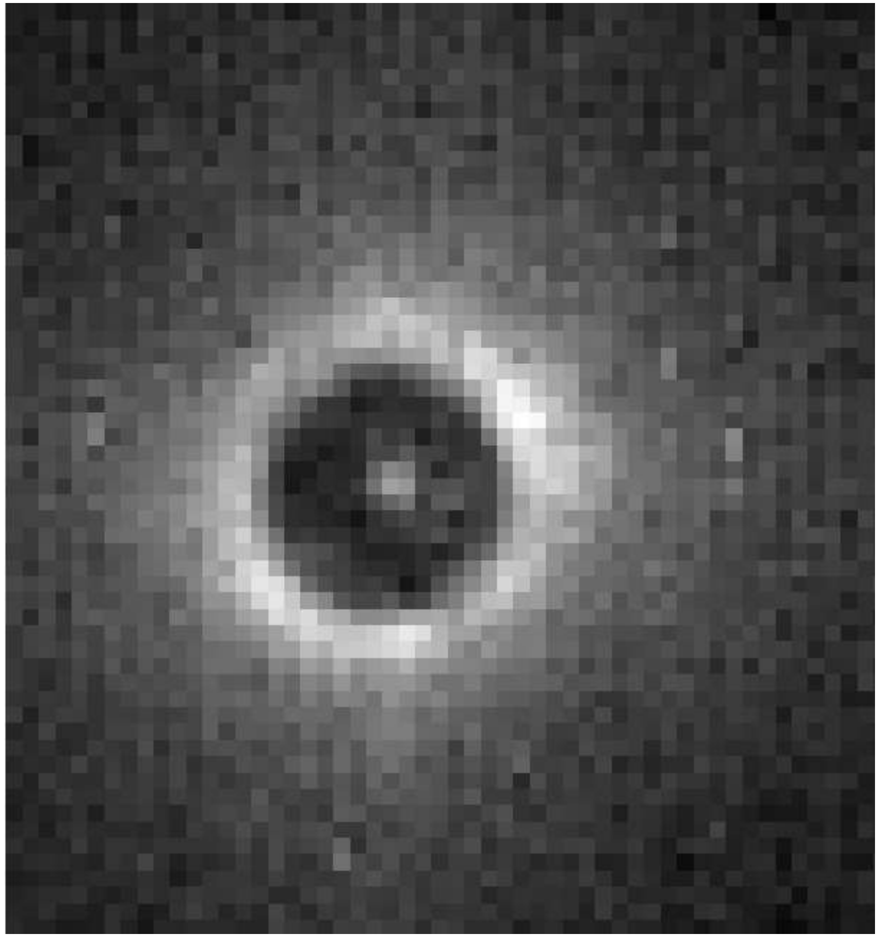
  ANTARES neutrino detections.

Zadko ; Source: The University of the Western Australia; https://www.zt.ems.uwa.edu.au/specifications

Circumstellar Material of Massive Stars

- 7 supernova progenitors was observed with coronagraph and J and K filter.

- Vortex Image Processing pipeline is used to get the flux and other characteristics of the annuli of the stars.



Fits images of the HD50877 supernova progenitor target observed using SPHERE instrument with coronagraph in the center

HDUST

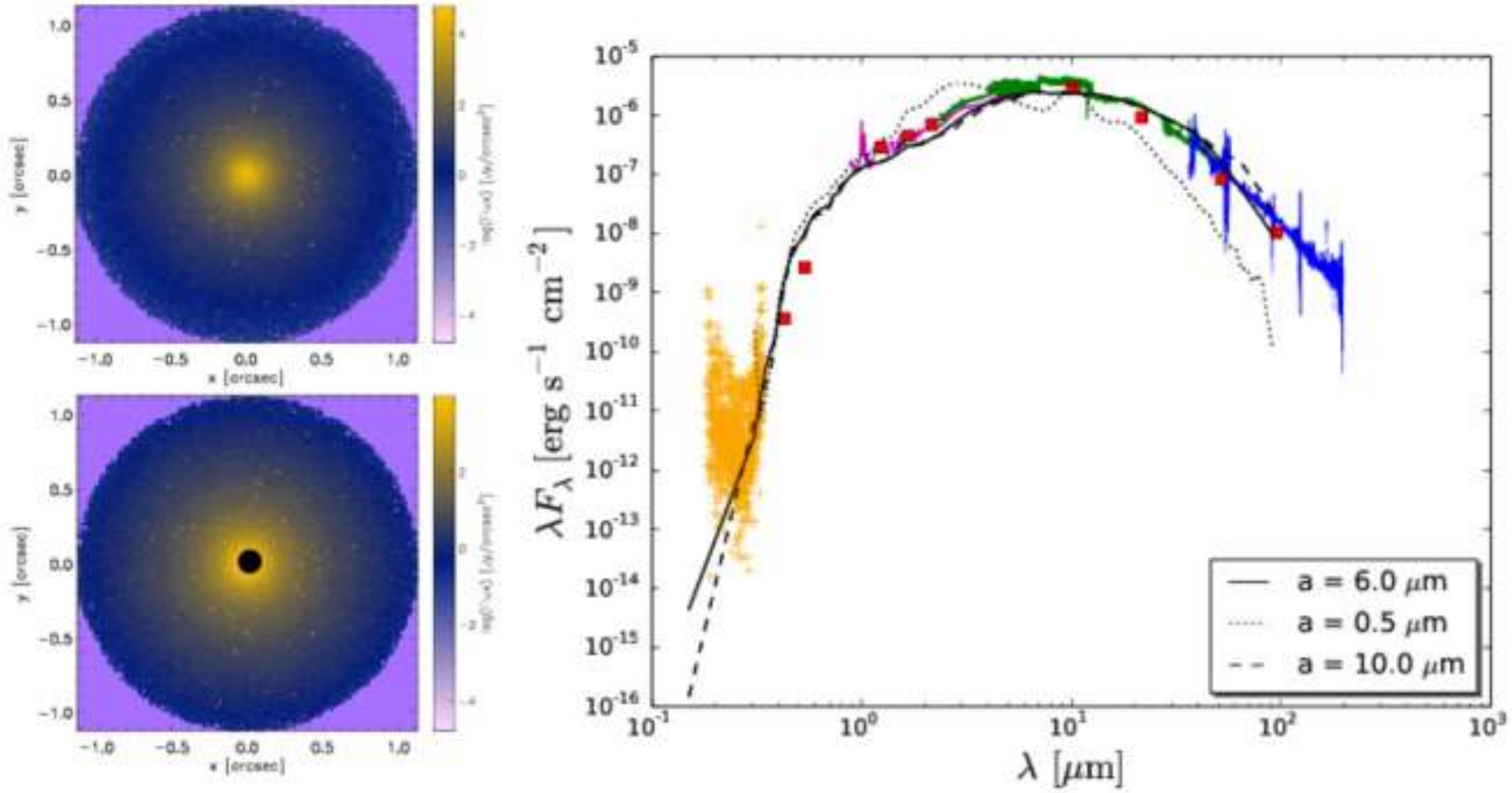
- 3-D non-LTE Monte Carlo radiative transfer code.
- To model the reprocessed radiation from a central source (i.e., star) by a surrounding dusty region.
- It fits 3-D geometries of the envelope, including clumps, shells, etc.
- We will use HDUST to fit combined SPHERE and archival data to determine dust:

    1) spatial distribution and structure

    2) size and composition

- Derive $\dot{M}$ history of RSGs and YSGs.

Credit: Carciofi & Bjorkman, 2006, ApJ, 639, 1081.



Simulation of HDUST fit on coronographic data of VY Cma

Ultra Long Gamma Ray Burst (ulGRB) Hosts Galaxies

- To observe the host galaxies of the known ulGRB and LGRB candidates.

- The observed ulGRBs using VIRT are:

ul-GRB	RA	Dec	Filter
GRB101225	00:00:47.49	+44:36:1.4	I, R, C
GRB111209	00:57:22.60	-46:48:3.9	I, R, C
GRB121027	04:14:23.34	-58:49:47	I, R, C
GRB130925	02:44:42.93	-26:09:10.2	I, R, C
GRB170714	02:17:23.98	+01:59:28	I, R, C

Ultra Long Gamma Ray Burst (ulGRB) Hosts Galaxies

- Data analysis: standard reduction processing, source extraction and photometric calibration.
- Obtain time on bigger instrument to get spectroscopic data of these candidates.
- Compare the two results and examine the difference to put mass constraint on the progenitors.
- Whether population III stars are dominating the formation rates in the galaxies.

Summary

- Massive stars with similar initial mass (e.g., RSG and YSG, 8-30M_{sun}) evolve to have different end point.
- What causes these different end point?
- Coronographic images of 8 supernova targets observed to study the circumstellar material and wind profile of supernova progenitors.
- Known ulGRBs and LGRBs have been observed to compare the two results and examine the difference in their characteristics.
- To put mass constraint on the progenitors.
- The role of $\dot{M}$ in the evolution of massive stars and the different types of supernova (SNe) progenitors and the SNe types.

Acknowledgement

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Questions, comments, and thoughts are all welcome!