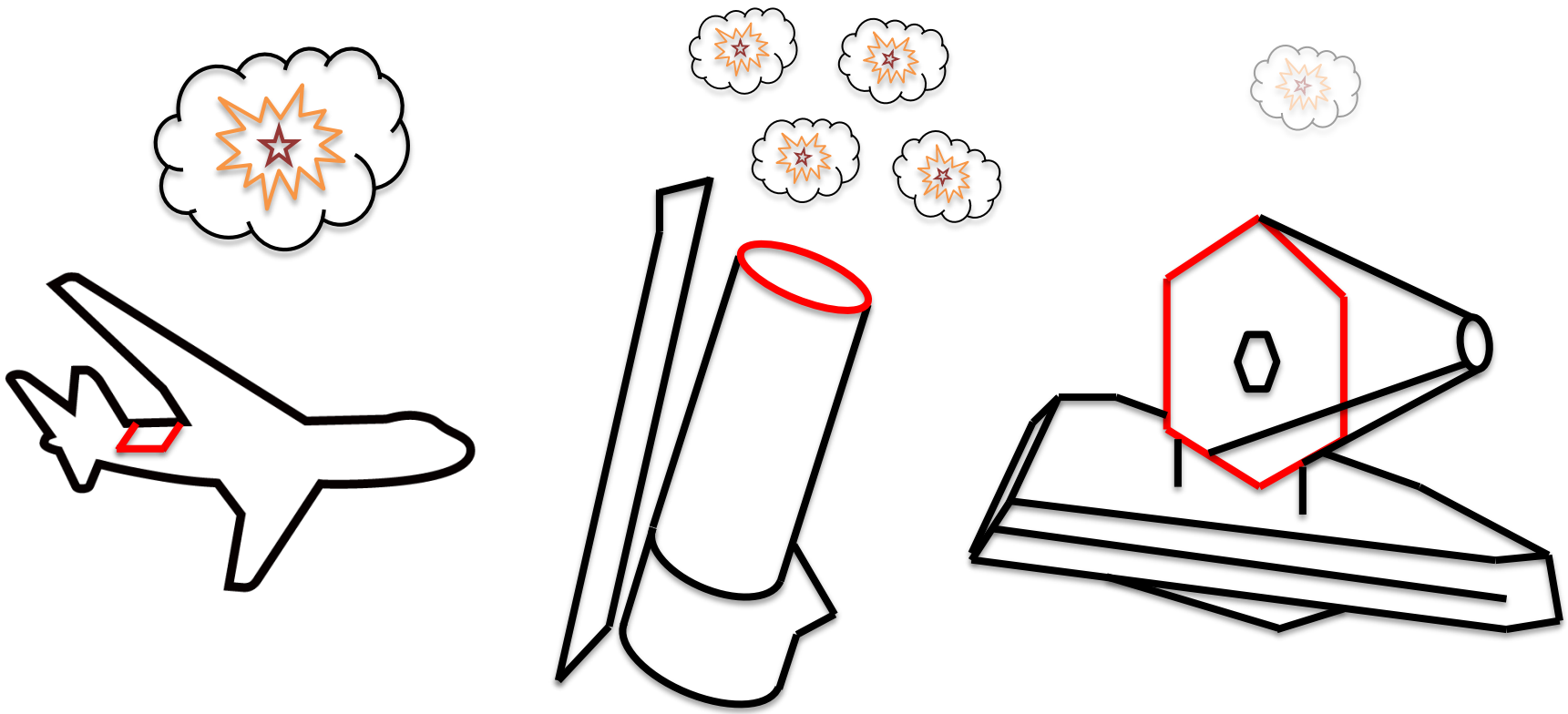
Investigating Dust Production and Survival with SOFIA and Beyond

Jet Propulsion Laboratory
California Institute of Technology

Caltech



Ryan M. Lau (JPL/Caltech)

Collaborators: Mansi Kasliwal (Caltech), Mike Ressler (JPL), Terry Herter (Cornell), Mark Morris (UCLA)

The Local Truth: Star-Formation and Feedback in the SOFIA Era
Asilomar, CA
October 19, 2016

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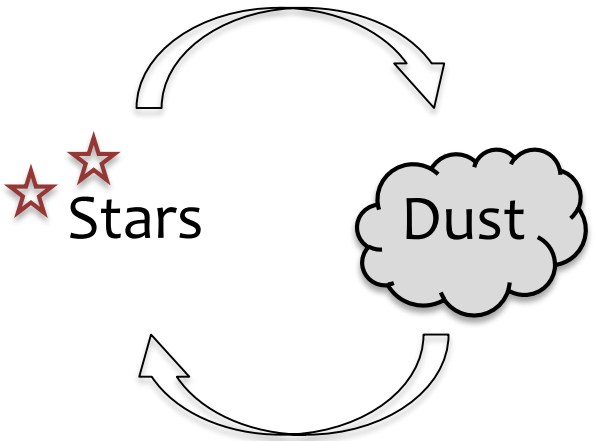
Outline

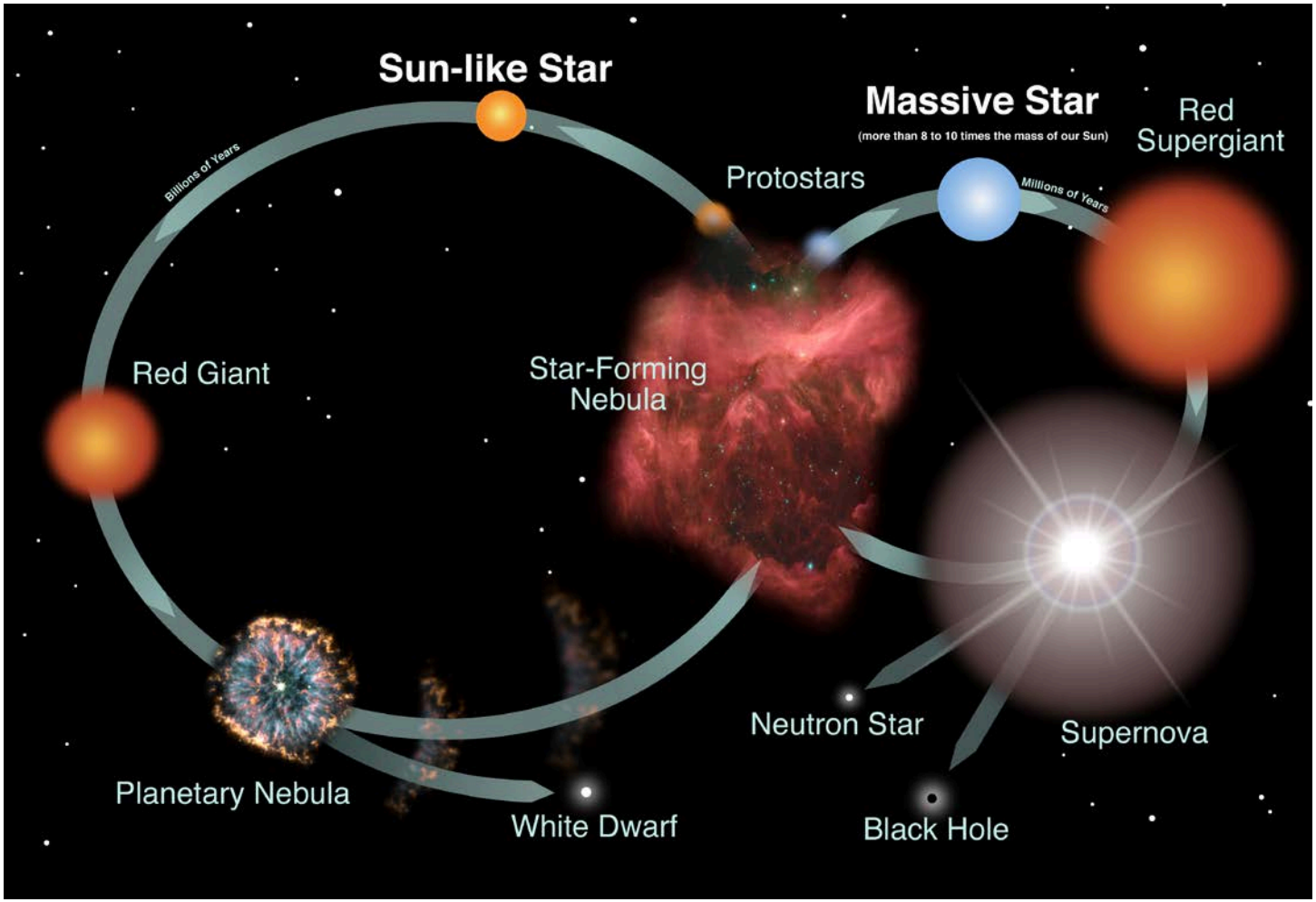
- Background and motivation: Plot holes in the story of stars and dust



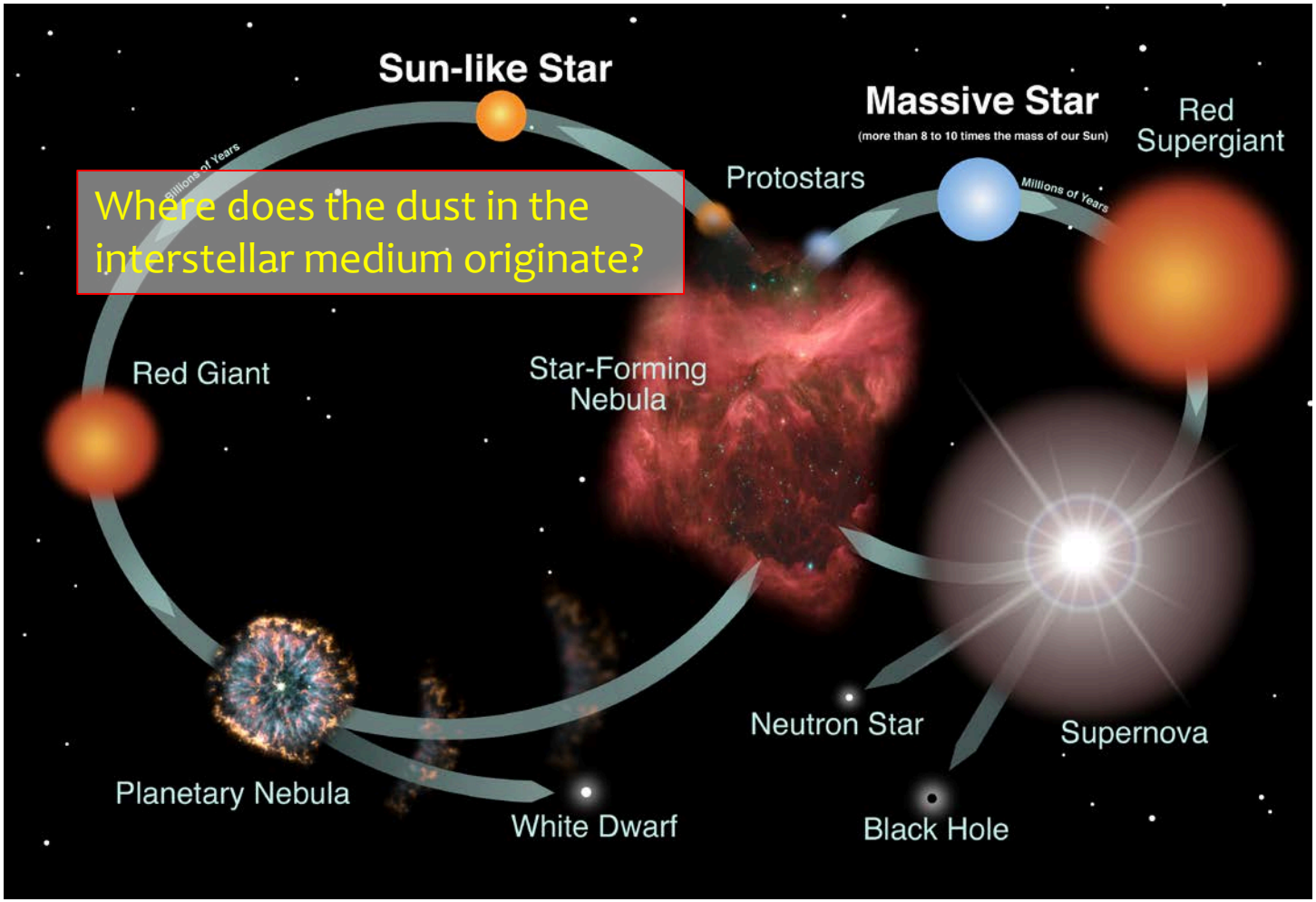
- The resurgence of IR and time-domain astronomy

- Accomplishments, milestones and goals with **SOFIA, Spitzer** and **JWST**

Loose Threads and Plot Holes in the Story of Stars and Dust

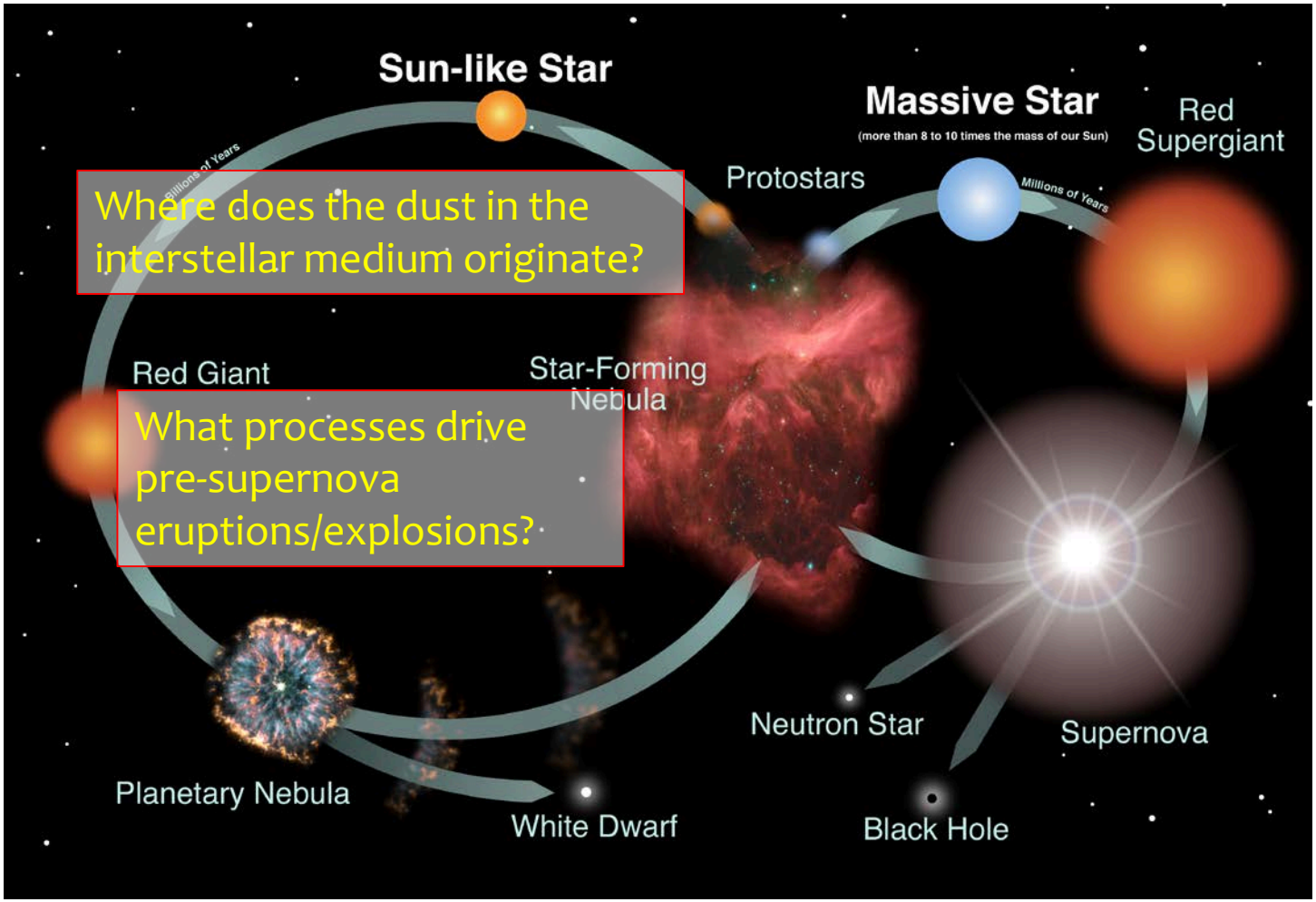


Loose Threads and Plot Holes in the Story of Stars and Dust



Where does the dust in the interstellar medium originate?

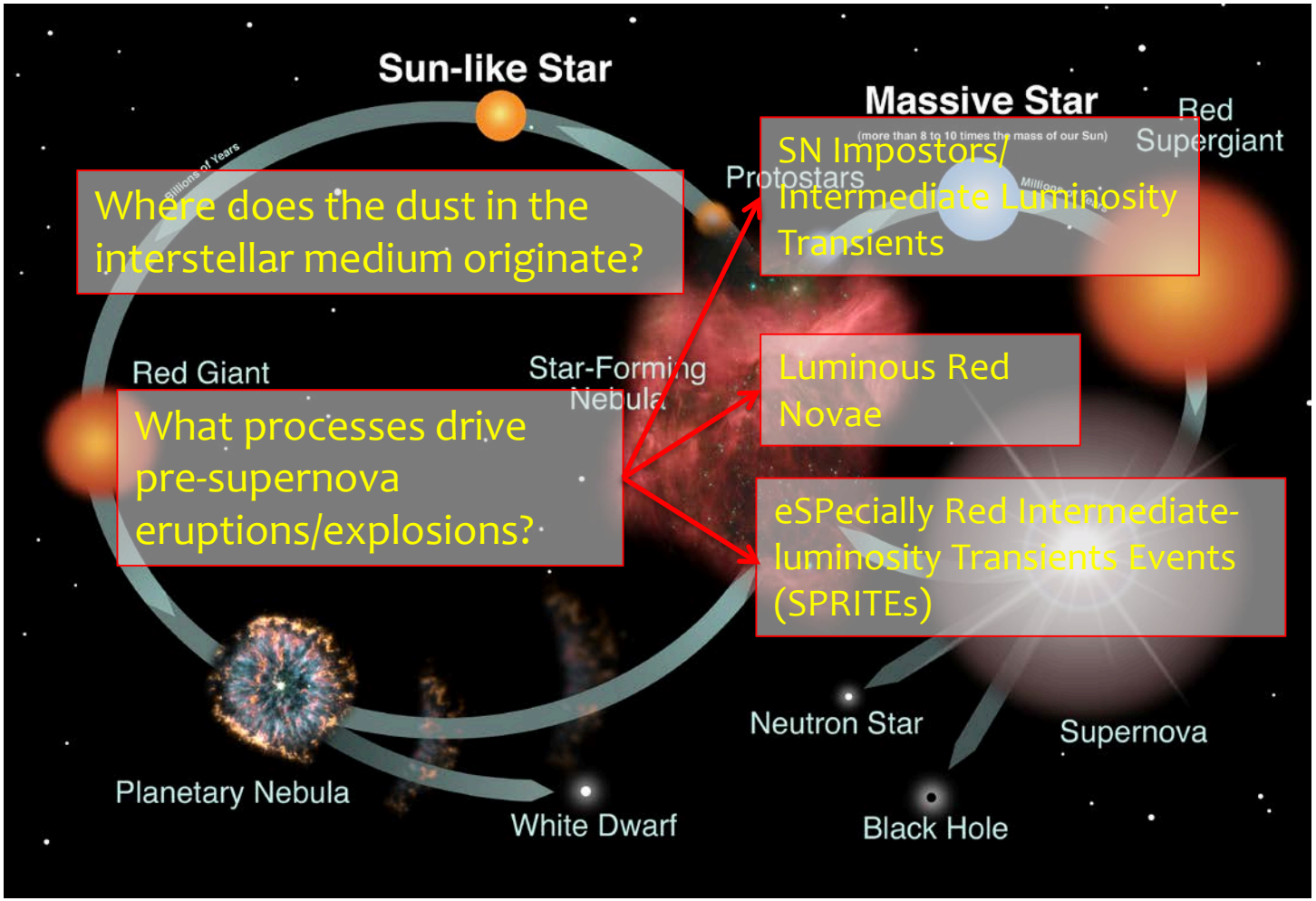
Loose Threads and Plot Holes in the Story of Stars and Dust



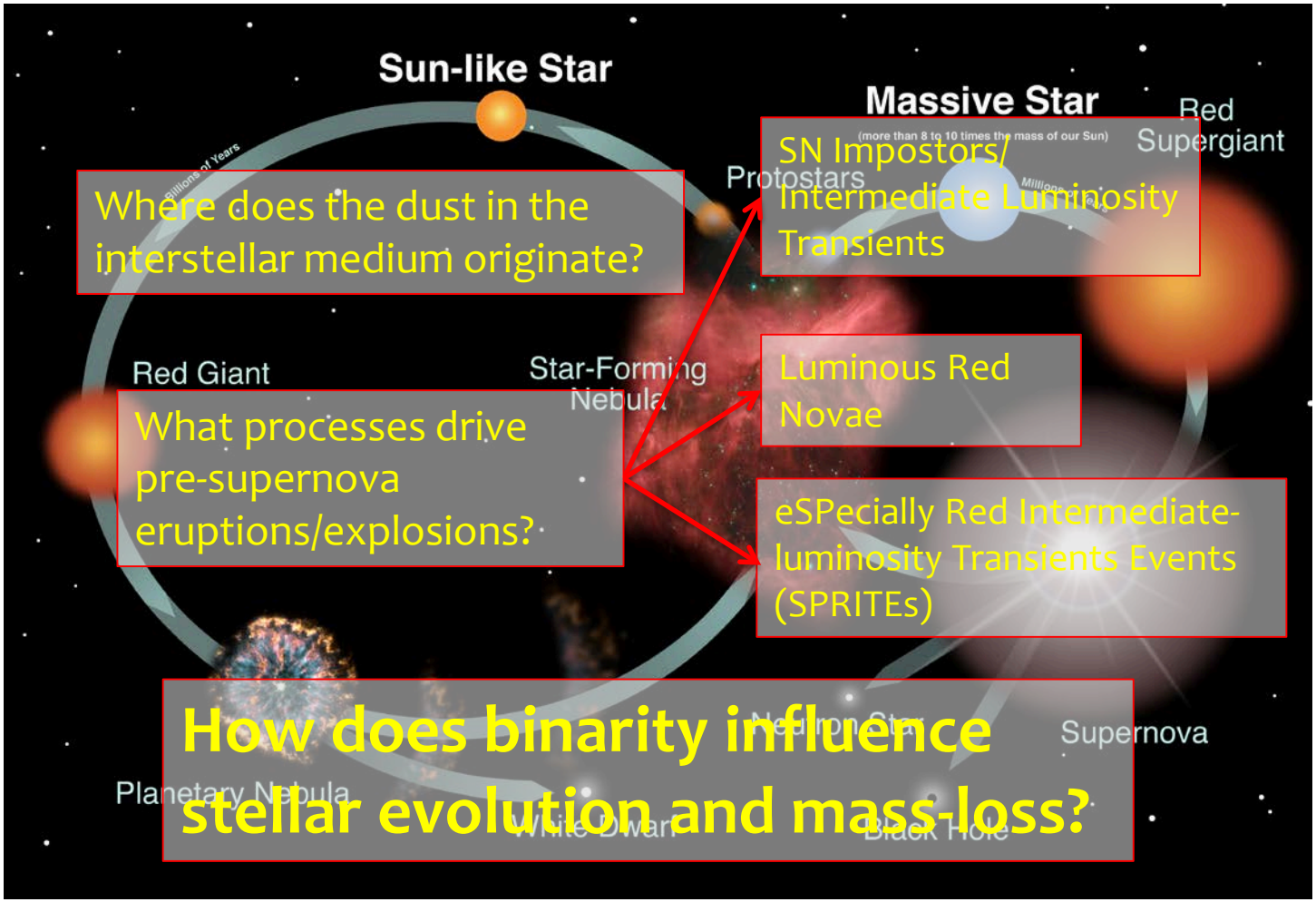
Where does the dust in the interstellar medium originate?

What processes drive pre-supernova eruptions/explosions?

Loose Threads and Plot Holes in the Story of Stars and Dust

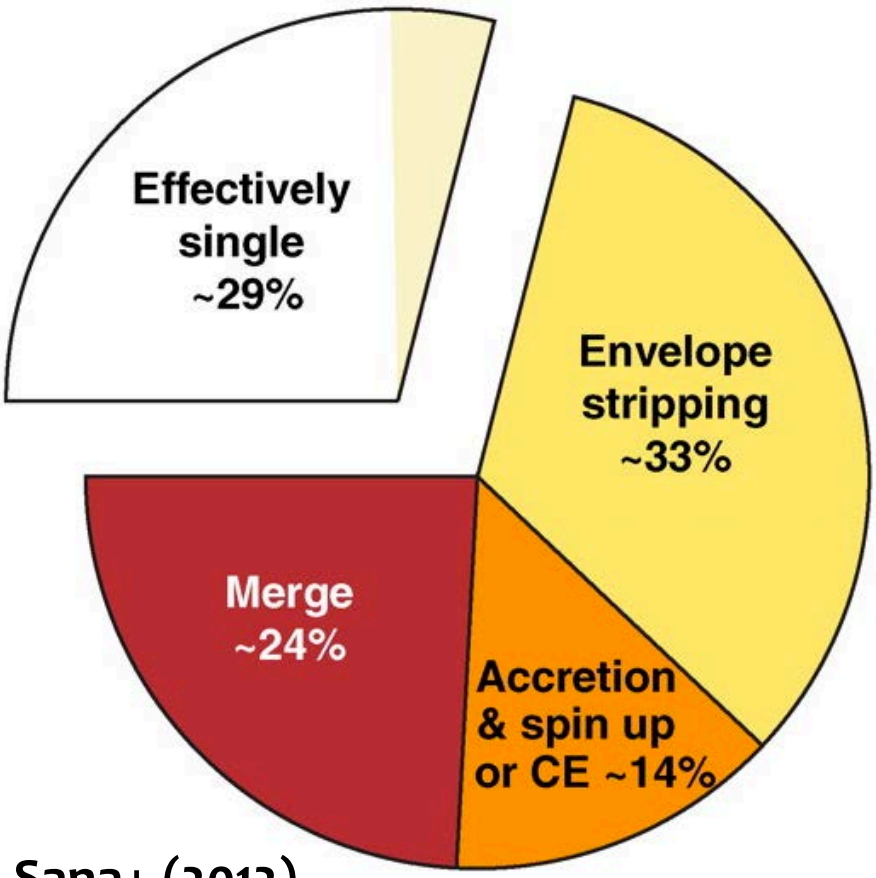


Loose Threads and Plot Holes in the Story of Stars and Dust



Stellar Binarity, a paradigm shift

Binary Interaction Pie Chart

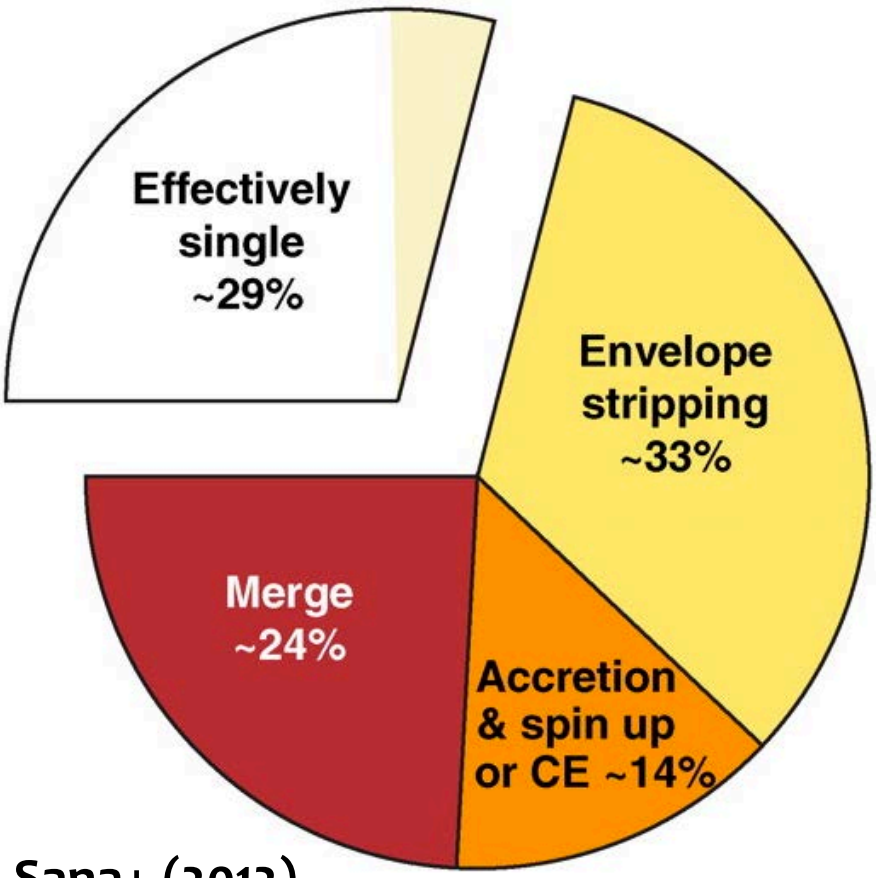


Sana+ (2012)

>70% of all massive stars will exchange mass with companion

Stellar Binarity, a paradigm shift

Binary Interaction Pie Chart



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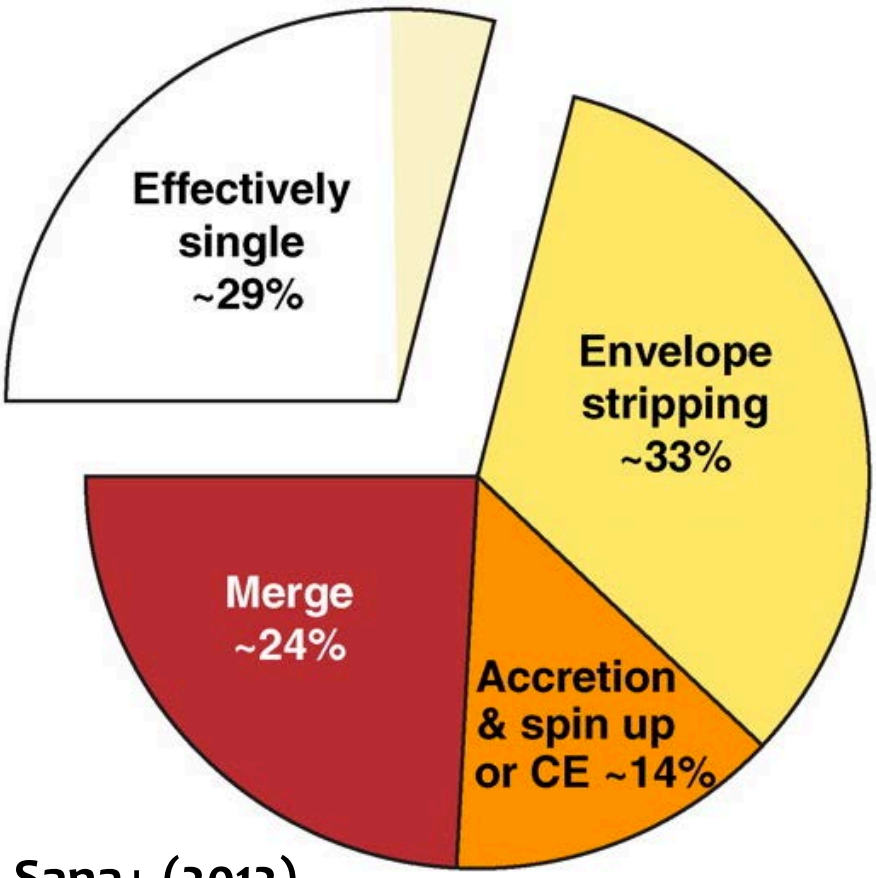
Mass exchange will effect stellar luminosity and mass-loss rates…

Stellar Binarity, a paradigm shift

Binary Interaction Pie Chart



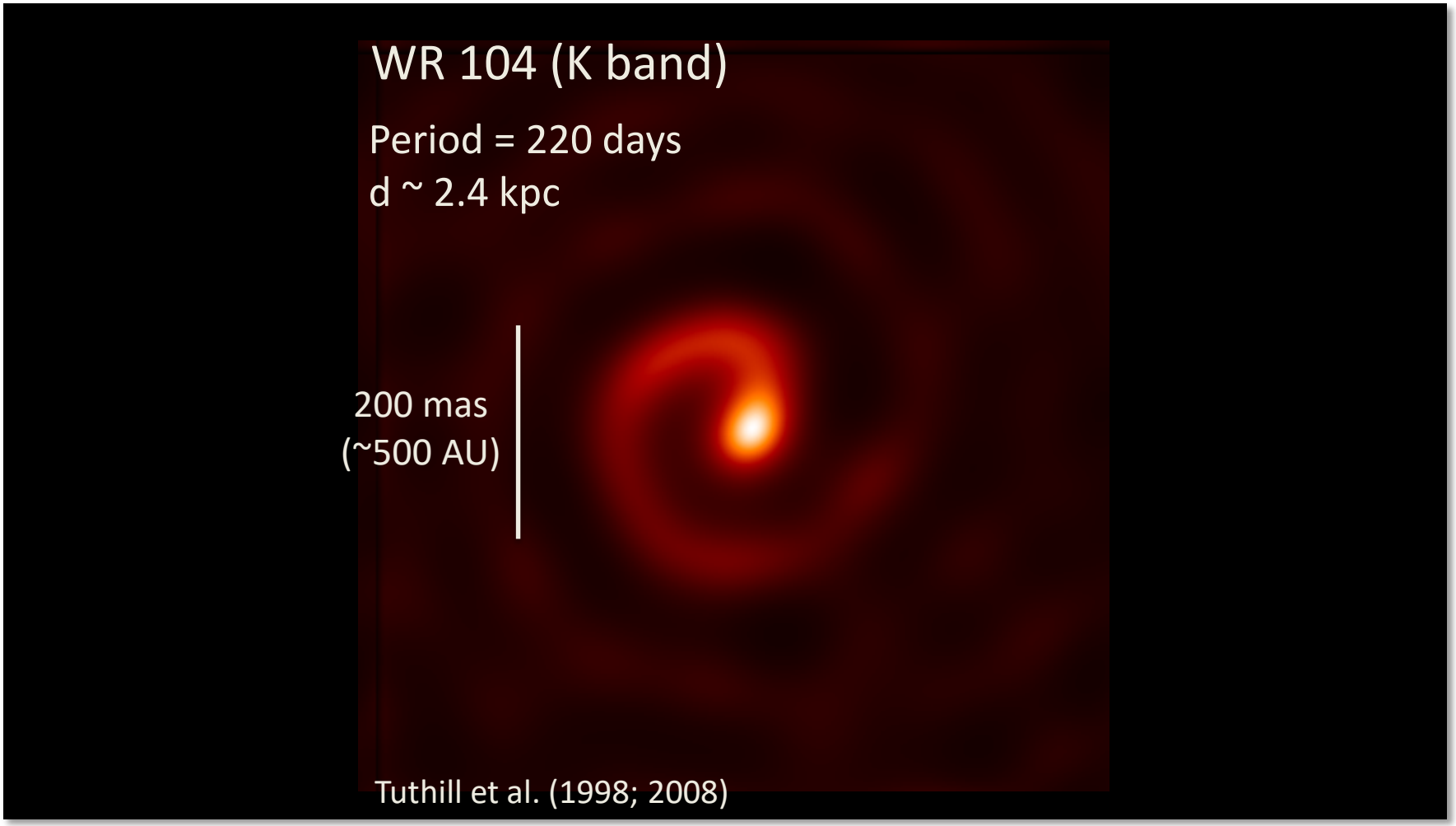
Sana+ (2012)

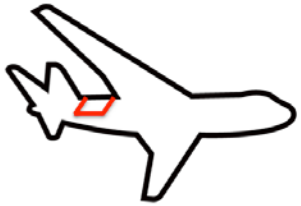
>70% of all massive stars will exchange mass with companion

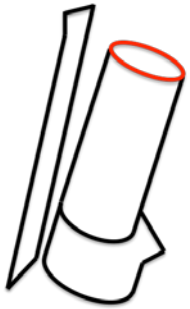
Mass exchange will effect stellar luminosity and mass-loss rates…

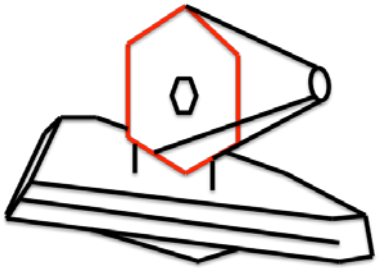
Binary interaction heavily influences massive star evolution

Dusty Wolf-Rayet "Pinwheels"





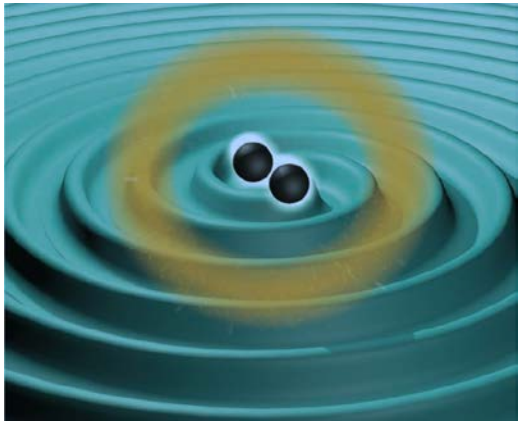




Resurgence of IR and Time-Domain Astronomy

Resurgence of IR and Time-Domain

- LIGO detection of gravitational waves from stellar mass black holes
  - The search is on for electromagnetic counterparts!
  - IR-signatures expected from dust in ejecta from neutron star mergers (e.g. Takami et al. 2014)



- Exploration and systematic study of transients with the LSST and WFIRST ranked top ground and space-based project in Astro2010

New Worlds, New Horizons in Astronomy and Astrophysics

LSST Large Synoptic Survey Telescope

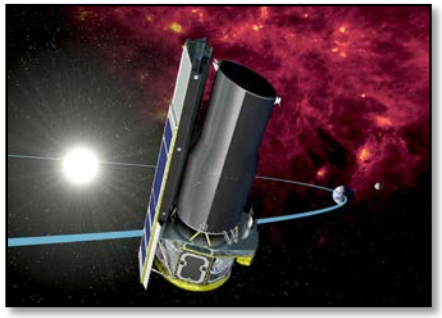
WFIRST Wide-Field Infrared Survey Telescope Astrophysics • Dark Energy • Exoplanets

Present and Near-Future IR Platforms

SOFIA
(2014 - ~2034)

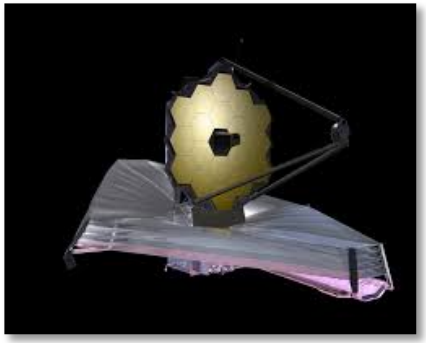
D_{Tel} : 2.5 meters
λ_{Sens}: 0.3 – 1600 μm
Mid-IR Sens*: ~10^5 μJy

Spitzer
(2003 - ~2019)



D_{Tel} : 0.85 meters
λ_{Sens}: 3.6 & 4.5 μm
Mid-IR Sens*: ~1 μJy

JWST
(2018 - ~2024+)



D_{Tel} : 6.0 meters
λ_{Sens}: 0.6 – 28 μm
Mid-IR Sens*:~ 0.01 - 10 μJy

*10-sigma in 10^4 sec

Present and Near-Future IR Platforms

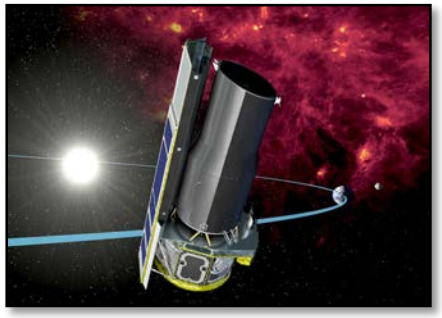
SOFIA
(2014 - ~2034)

D_{Tel} : 2.5 meters
λ_{Sens}: 0.3 – 1600 μm
Mid-IR Sens*: ~10^5 μJy

+ Wavelength coverage
+ Spatial resolution
+ Mobile!

- Not very sensitive
- A bit expensive

Spitzer
(2003 - ~2019)

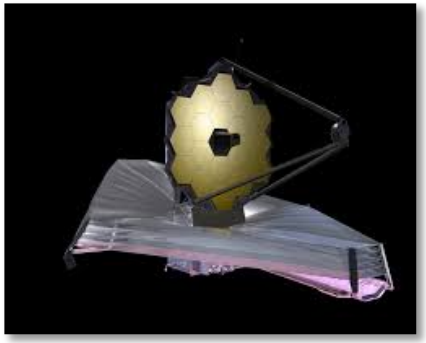


D_{Tel} : 0.85 meters
λ_{Sens}: 3.6 & 4.5 μm
Mid-IR Sens*: ~1 μJy

+ Sensitivity
+ Efficient and Nimble!

- Limited wavelength
- Low spatial resolution

JWST
(2018 - ~2024+)



D_{Tel} : 6.0 meters
λ_{Sens}: 0.6 – 28 μm
Mid-IR Sens*:~ 0.01 - 10 μJy

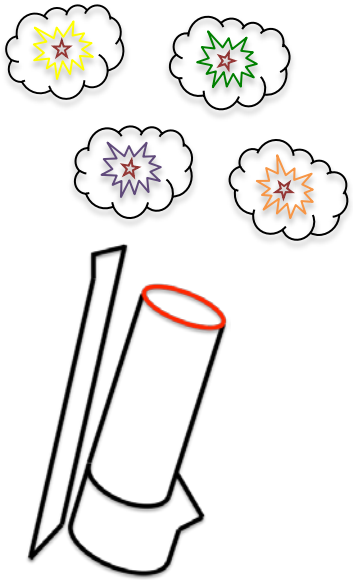
+ Sensitivity!!
+ High spatial resolution

- High overheads (e.g. 30 min slew tax per target)
- Quite expensive

Unique Roles and Synergies

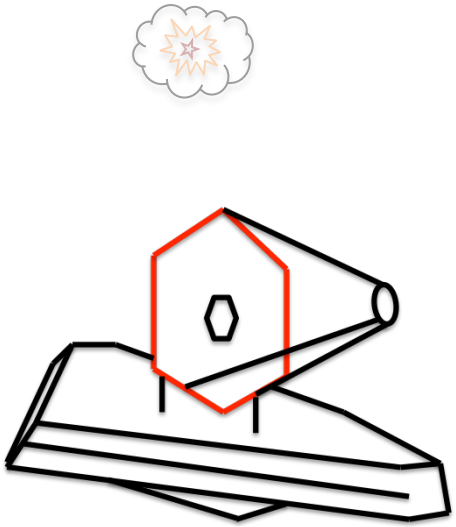
Targets: SNe, galactic IR transients/variables

Role: Characterize and establish templates of dusty eruptions/explosions within the Galaxy



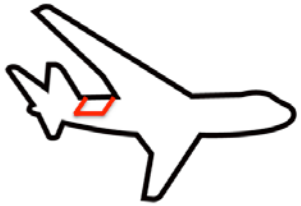
Targets: Extragalactic IR transients/variables

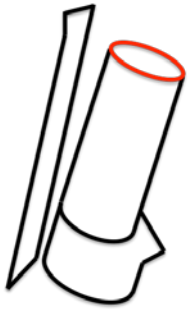
Role: Pioneer the search of IR transients and variables with extensive, systematic surveys of local group galaxies

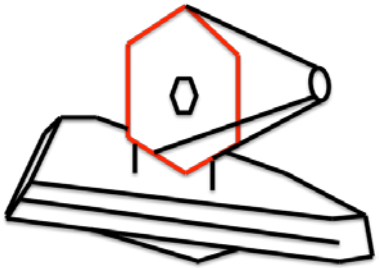


Targets: Targeted IR transients/variables

Role: Follow-up characterization of interesting IR transients/variables







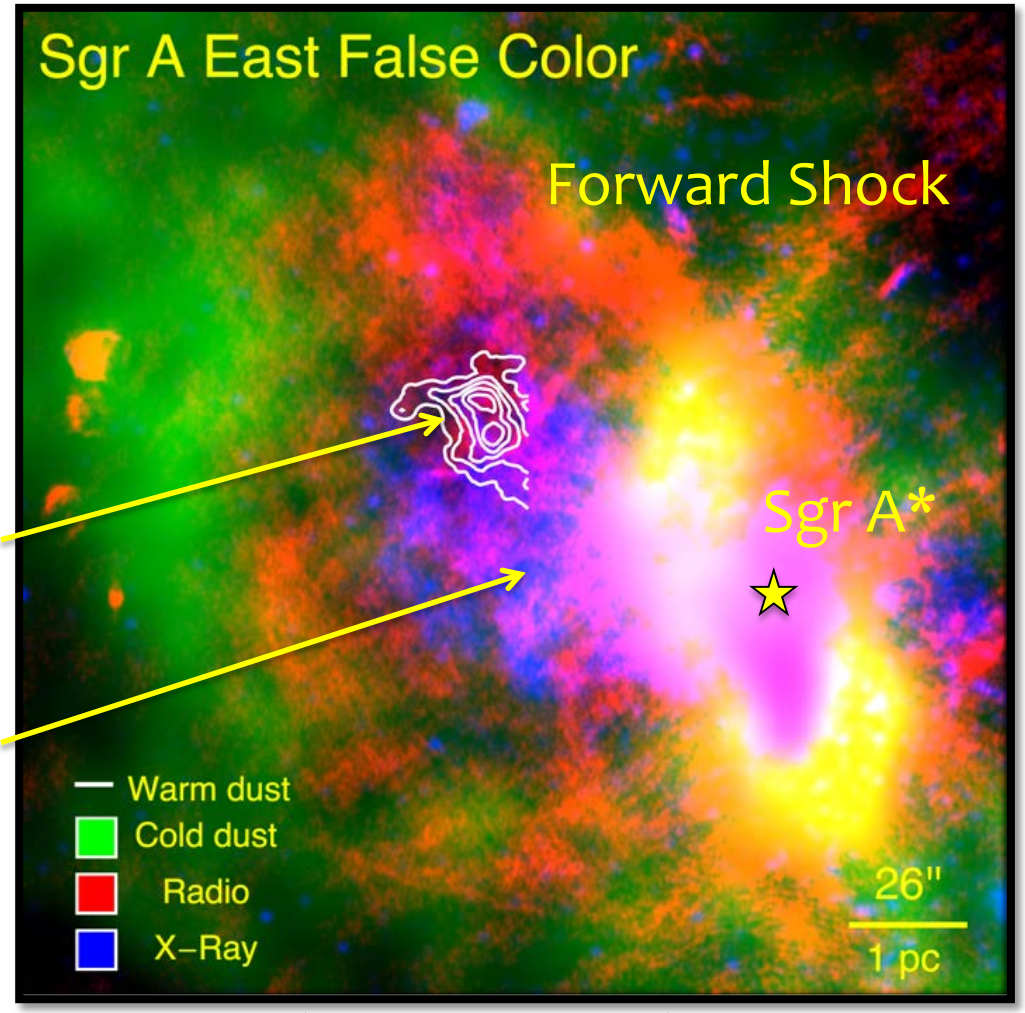
Accomplishments, Milestones, and Goals

An Answer for the Question of Dust Production and Survival in Supernovae…

Sgr A East, a 10,000 yr-old SNR located near the Galactic Center

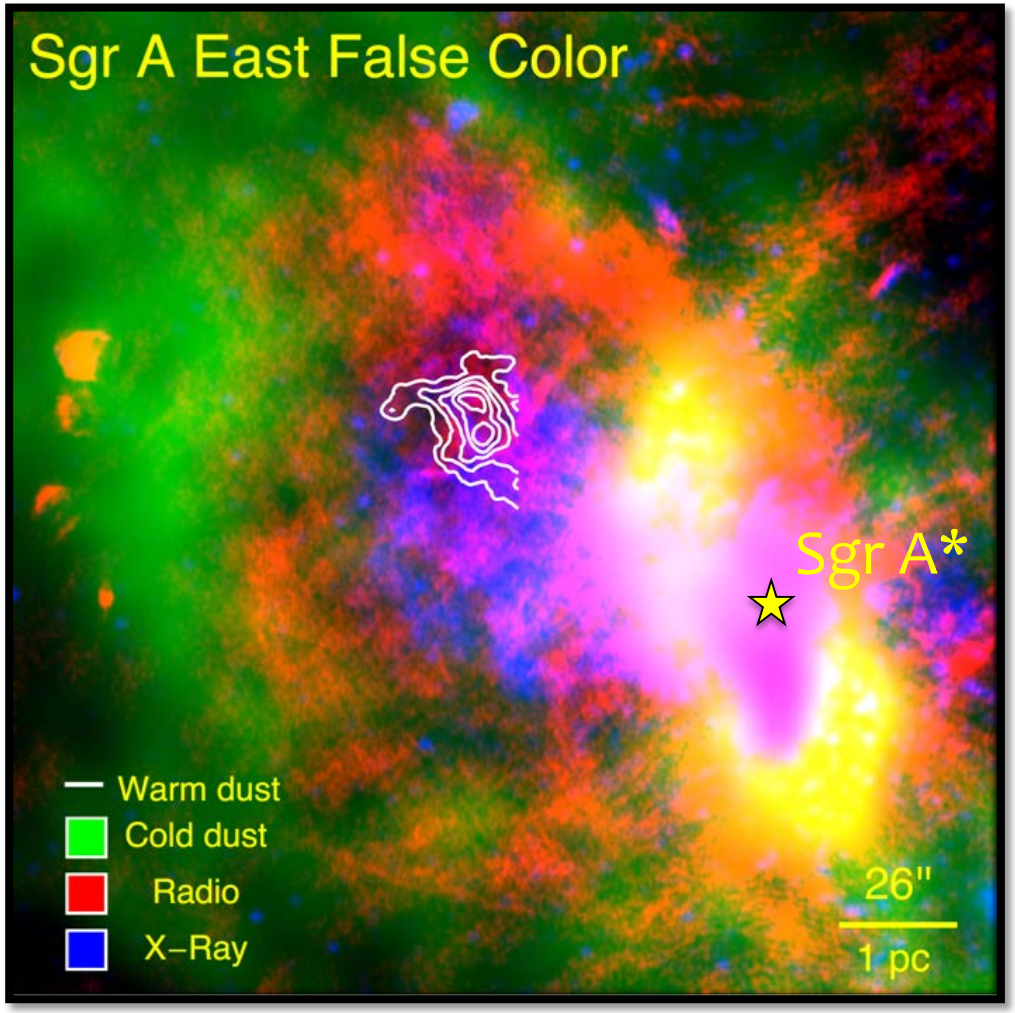
Ejecta Dust

Shocked SNR Ejecta



Lau et al. (2015, Science)

Sgr A East Dust Mass



Warm Dust

~0.02 M_{Sun}

>20 % of observed dust mass in most younger SNR

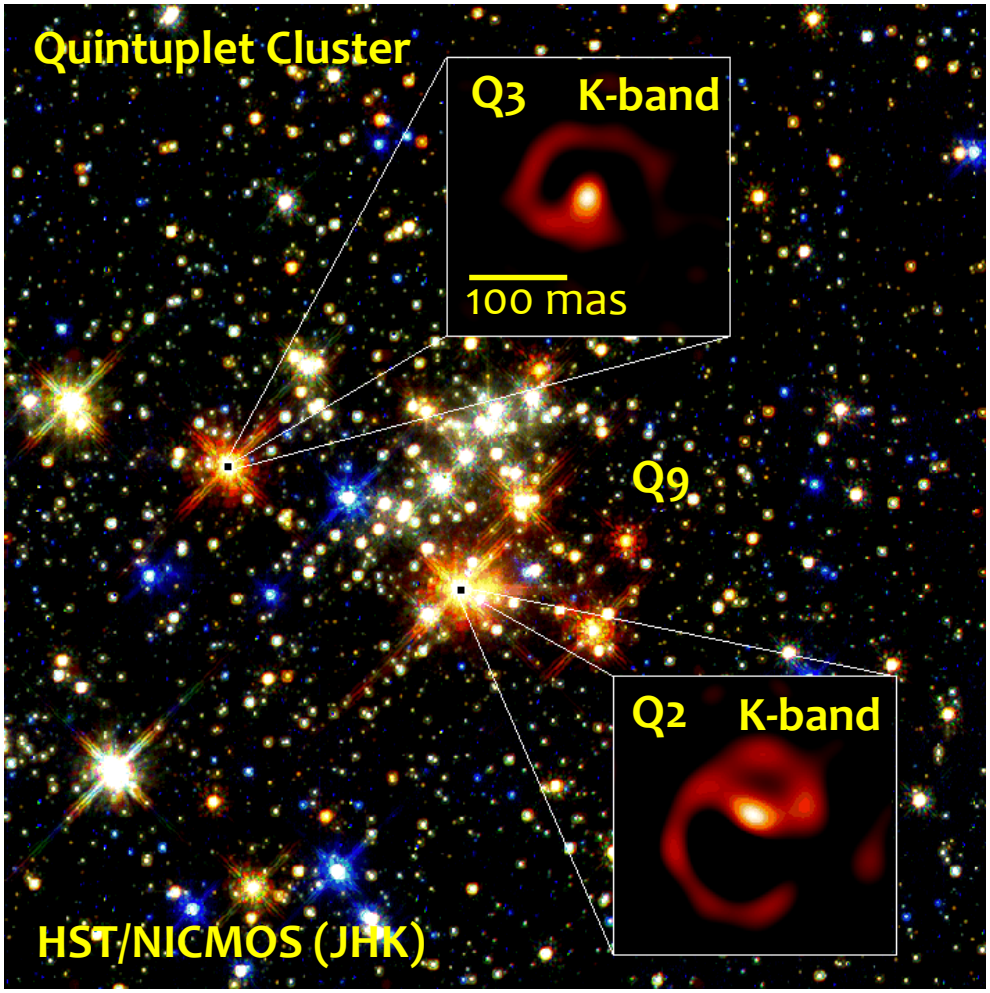
SN Dust Input in Early Universe Galaxies

~0.15 $M_\odot$ of dust per SN required based on specific star formation history…

(Dwek & Cherchneff 2011)

… given a dust mass survival rate of ~20%, SNe like 1987A ($M_d \sim 0.5\ M_\odot$) can account for a significant fraction of the dust input

Unusually high dust production from a "Pinwheel" WR-binary

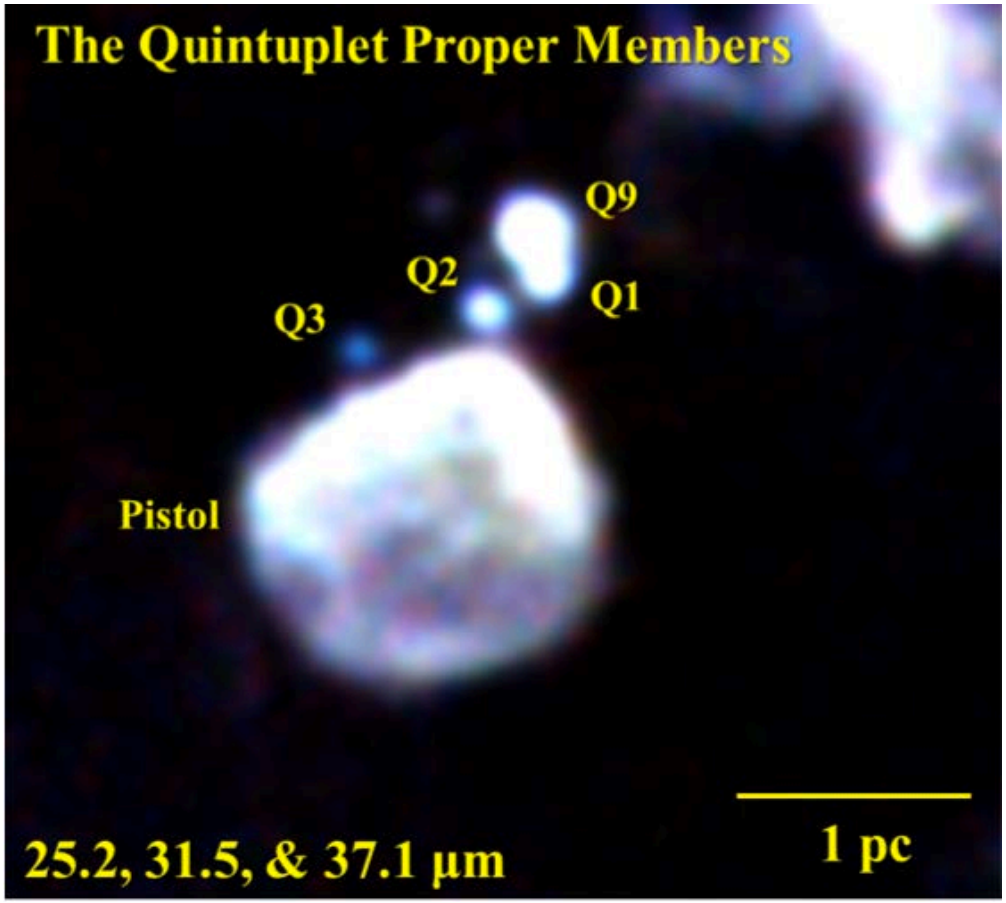


Tuthill et al. (2006)

Mysterious "Quintuplet Proper Members" are thought the be dusty "pinwheel" WR-binaries

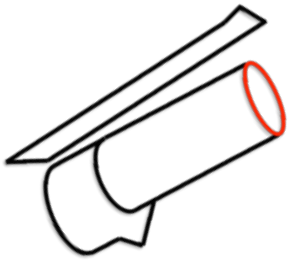
Unusually high dust production from a "Pinwheel" WR-binary

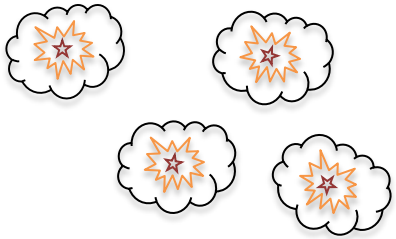
SOFIA/FORCAST



Hankins et al. (2016)

Q9 has a factor of ~10 more mass in dust than other dusty WR systems!





Exploring the Dynamic Infrared Sky With Spitzer

Exploring the Dynamic Infrared Sky With Spitzer

- **SPIRITS** - SPitzer InfraRed Intensive Transients Survey (P.I.: Mansi Kasliwal)
  - Cycle 10: 190 galaxies at 3 epochs in the mid-IR with Spitzer (338 hr)
  - Cycle 11 and 12: 190 galaxies at 7 epochs in the mid-IR with Spitzer (792 hr)

- Committed ground-based near-IR (JHK) spectroscopic/photometric follow-up is crucial
  - Facilities: Keck, IRTF, Palomar

Exploring the Dynamic Infrared Sky With Spitzer

- **SPIRITS** - SPitzer InfraRed Intensive Transients Survey (P.I.: Mansi Kasliwal)
  - Cycle 10: 190 galaxies at 3 epochs in the mid-IR with

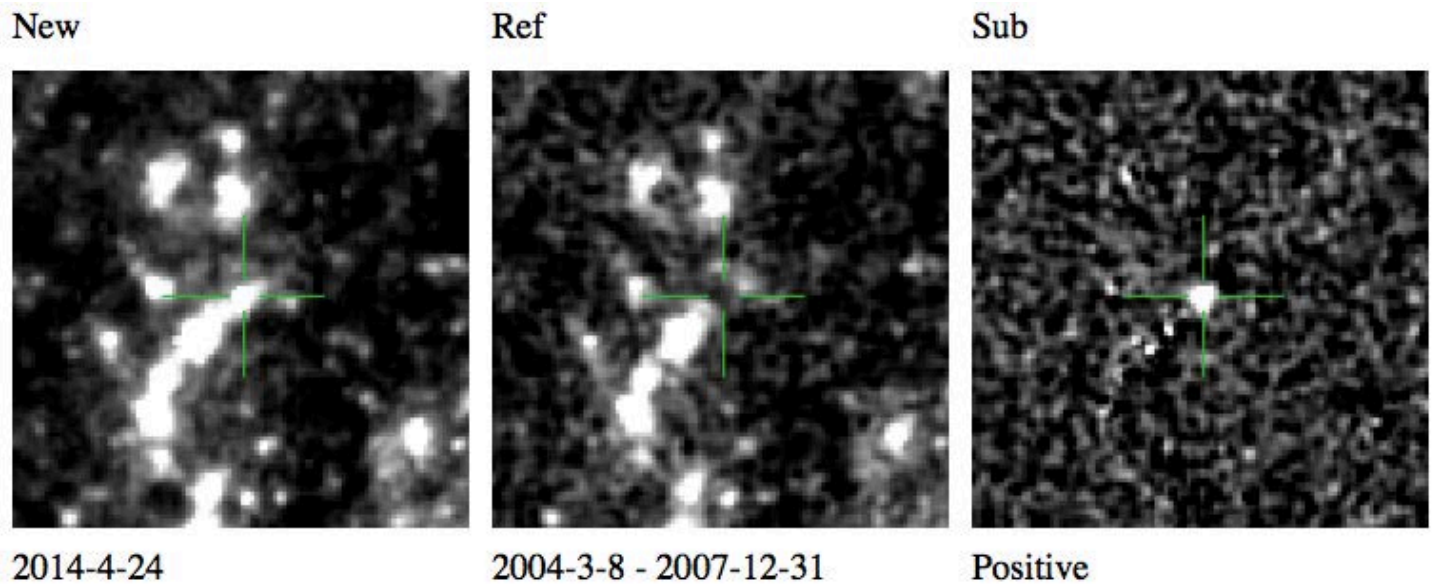
SPIRITS Cycle 13 Proposal Successful!
280 hr over 2 yr for more discoveries and preparation for JWST

R

- Committed ground-based near-IR (JHK) spectroscopic/photometric follow-up is crucial
  - Facilities: Keck, IRTF, Palomar

Exploring the Dynamic Infrared Sky With Spitzer

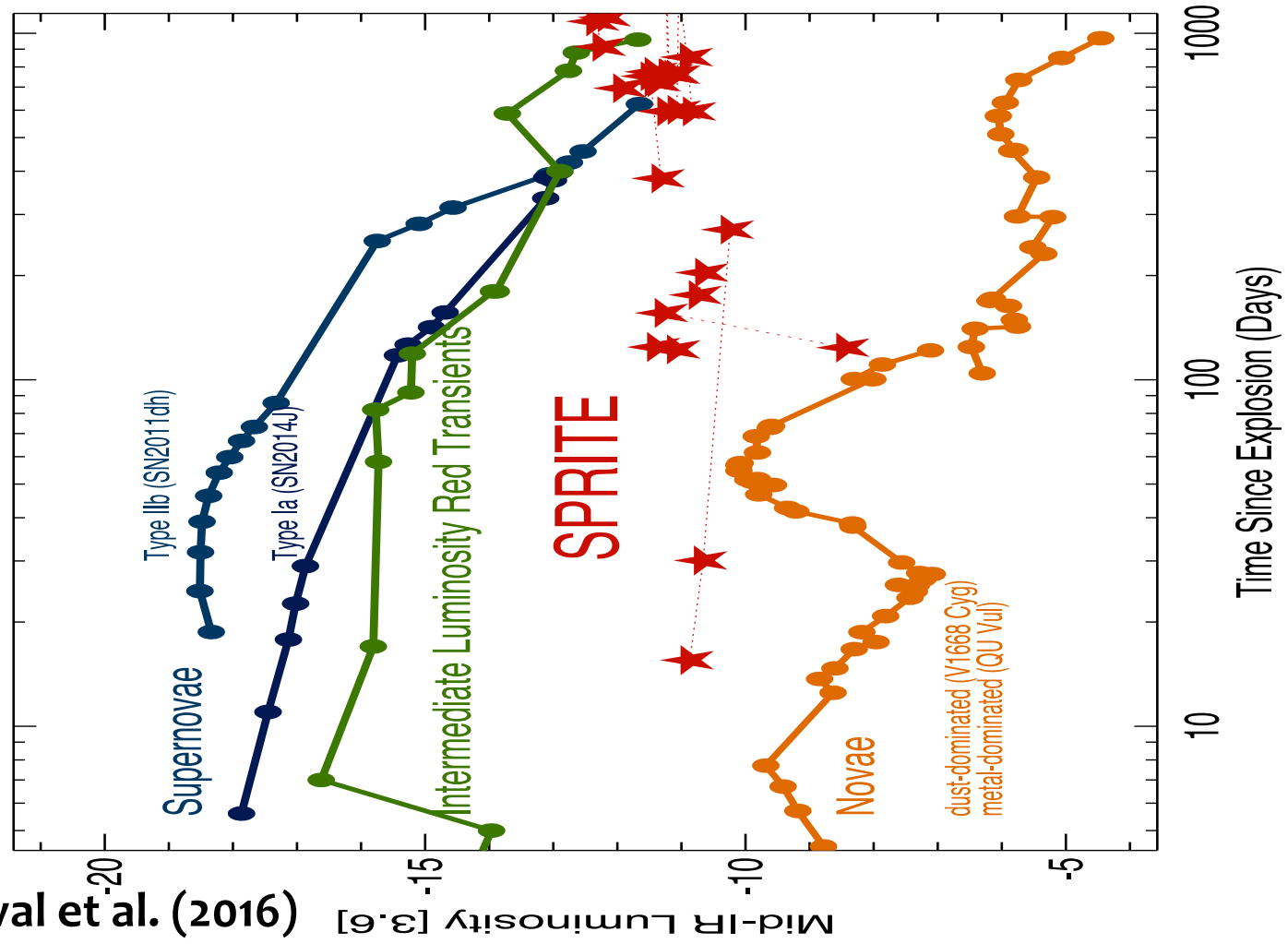
40+ IR transients and 1200+ variables revealed per year!



What are the IR Transients?

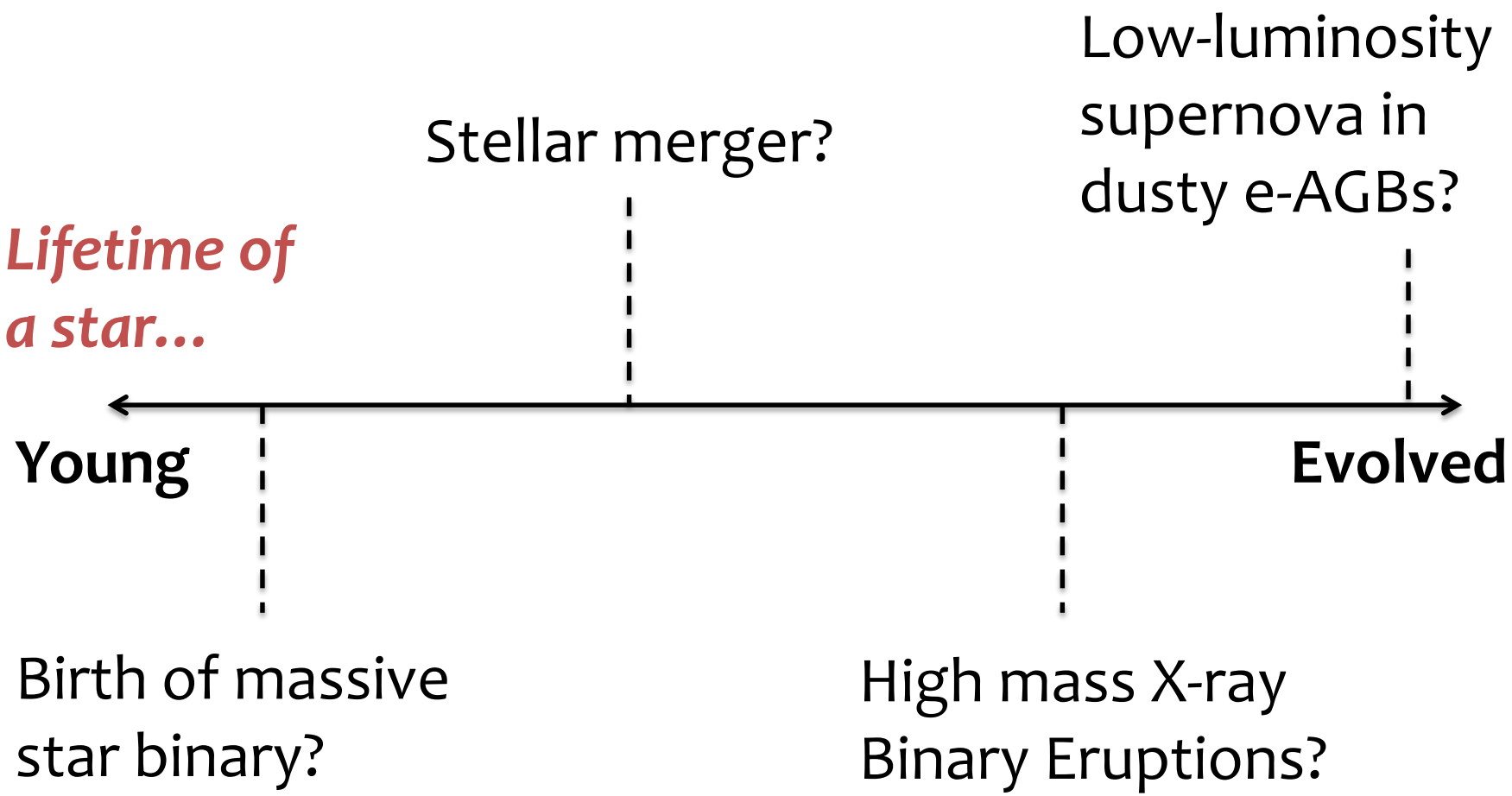
- 21 were known supernovae
- 4 were in the luminosity range of classical novae
- *15 were mysteries with no optical counterparts!*
  - *Exist in the luminosity gap between novae and supernovae*

eSPecially Red Intermediate-luminosity Transient Events (SPRITEs)

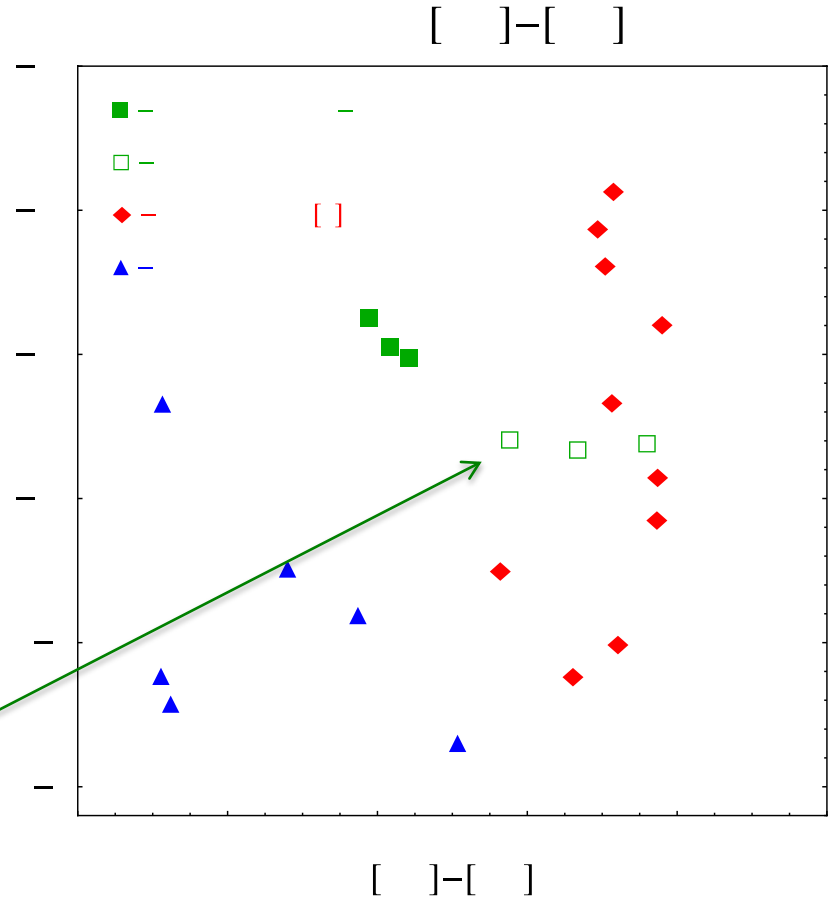


Kasliwal et al. (2016)

What are SPRITEs?



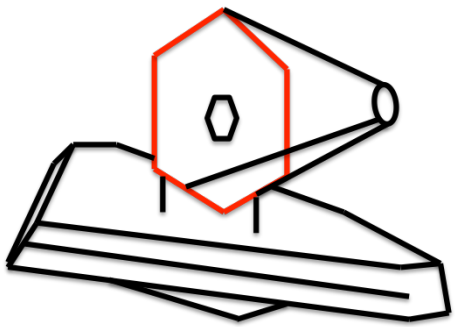
SN 2010 da/SPIRITS 14bme – A Supergiant B[e] High Mass X-Ray Binary!



Mid-IR outburst and re-brightening events coincident with X-ray and optical…

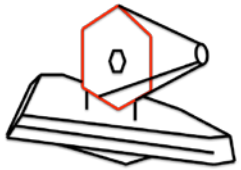
Luminosity, color, and dust mass consistent with a sgB[e] star

Lau et al. (Accepted to ApJ)
Bonanos et al. (2009)



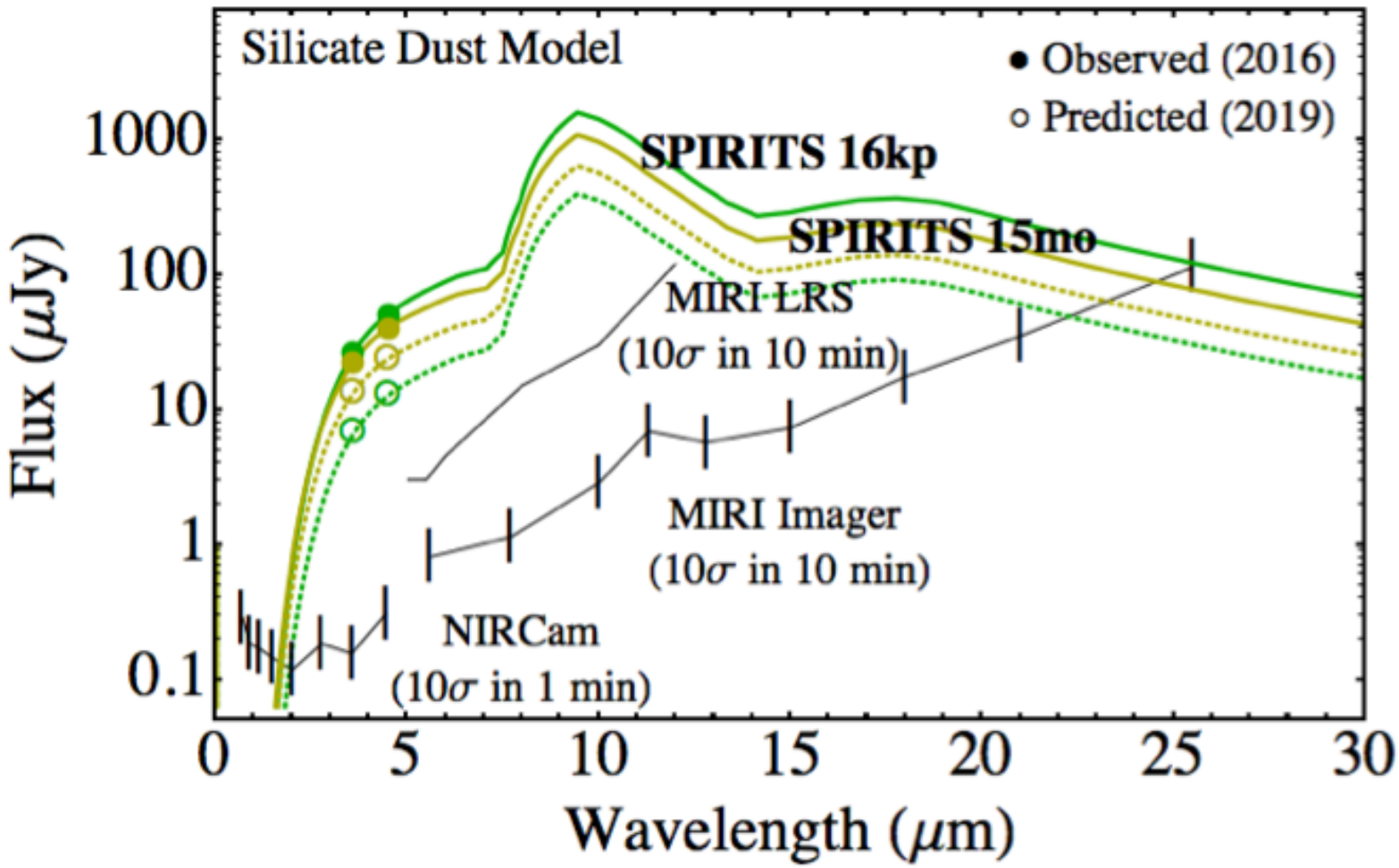
Follow-up Characterization with JWST

MIRI, the Mid-Infrared Instrument



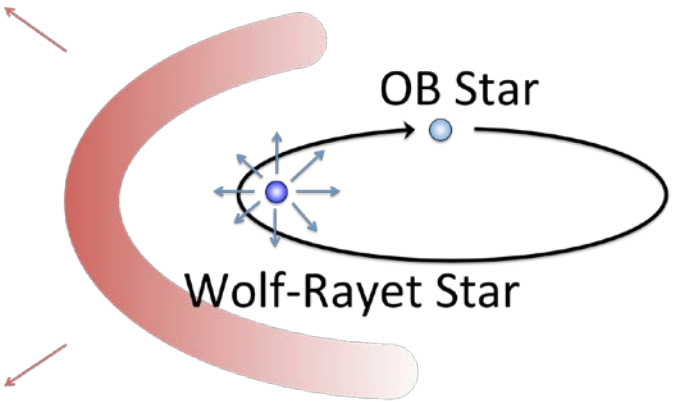
- **Imaging** from 5.6 to 25.5 μm
  - 9 filters, 1.9 x 1.4 arcmin field-of-view
- **Low res slit spectroscopy**, 5 - 12 μm, R ~ 100
- **Medium res IFU spectroscopy** with ~ 5" FOV, 5 - 28 μm, R ~ 3000
- **Coronagraphy** with suppressions ~ 500 – 1000

De-Mystifying SPRITEs with JWST

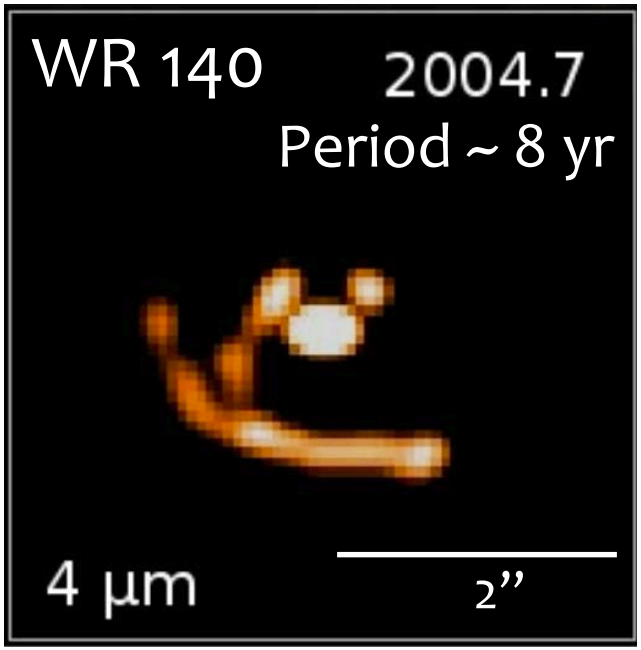


WR Systems and Dust Production

- *Revisiting an important question…* what is the WR Binary Contribution to Galactic Dust budgets?

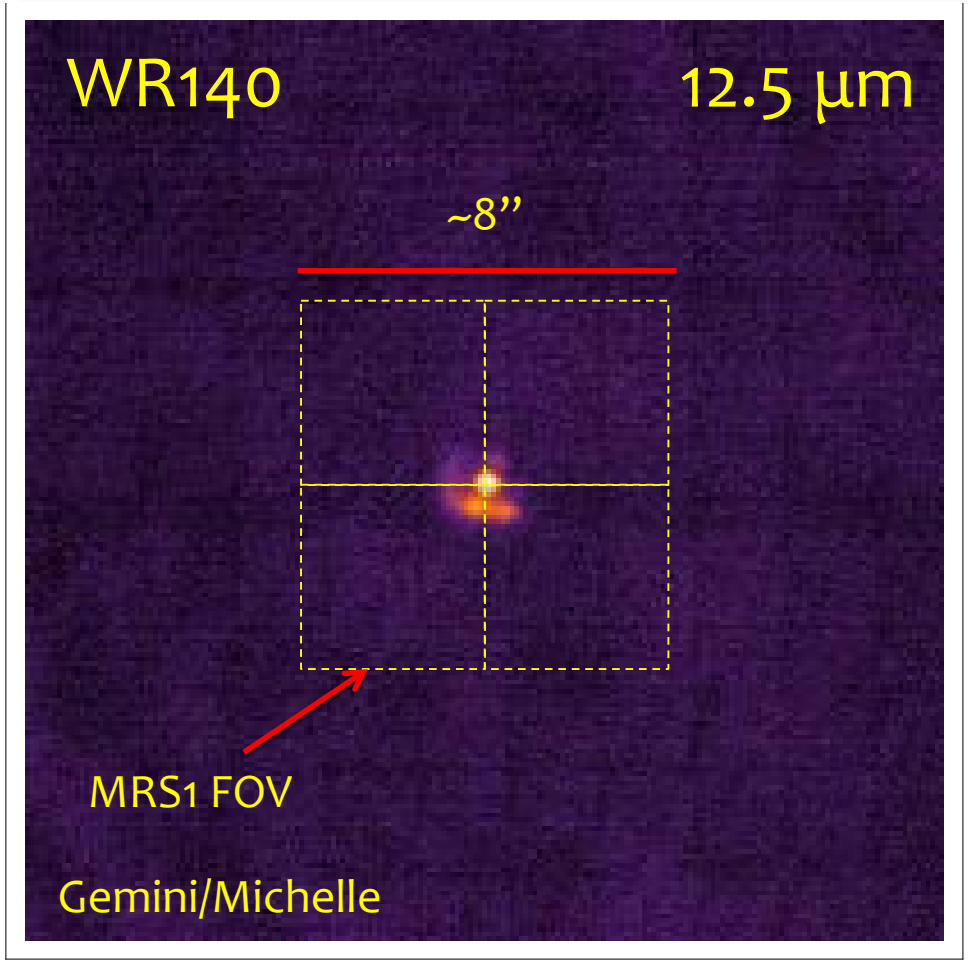


"Periodic" Dust Producer

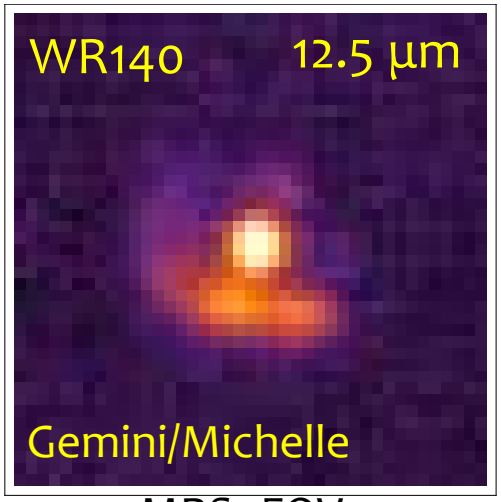


Williams+ (2009)

Mapping WR140 with the MIRI Spectrometer



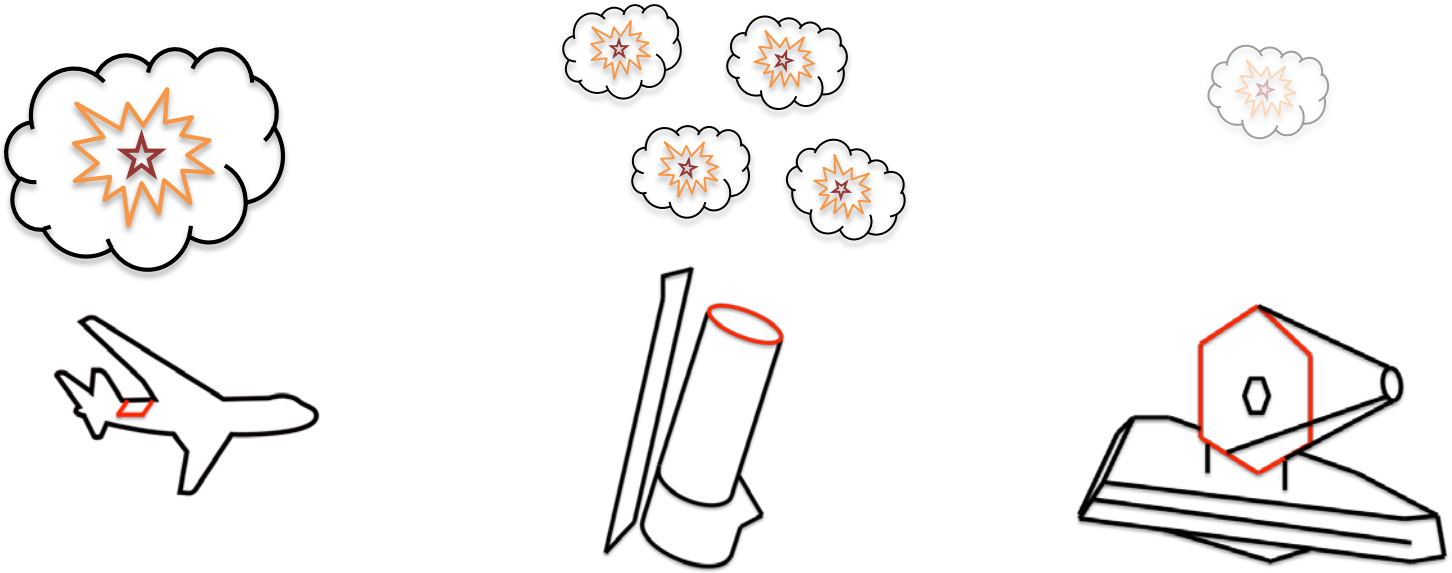
MIRI IFU Map will contain ~3 dust outbursts



MRS1 FOV

Mid-IR spectra (R ~ 3000) will reveal…

- Kinematics
- Dust mass and energetics
- Chemical evolution through previous dust outbursts



Thanks!