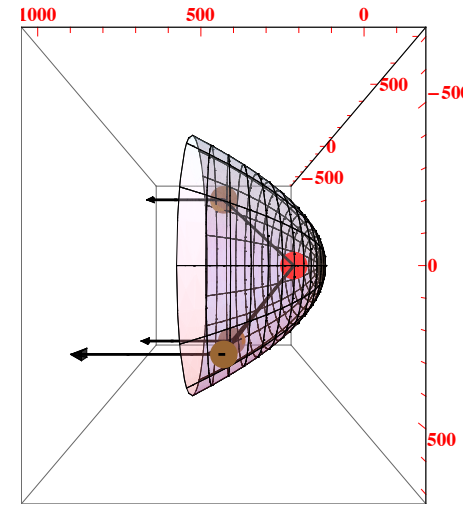
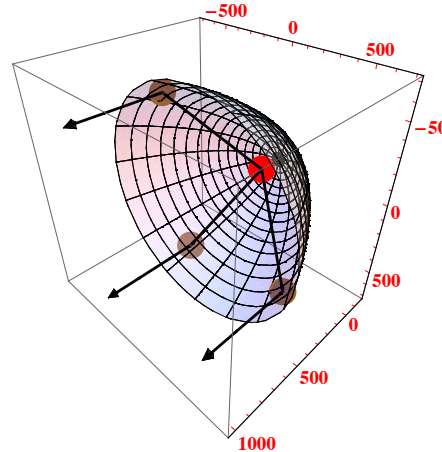
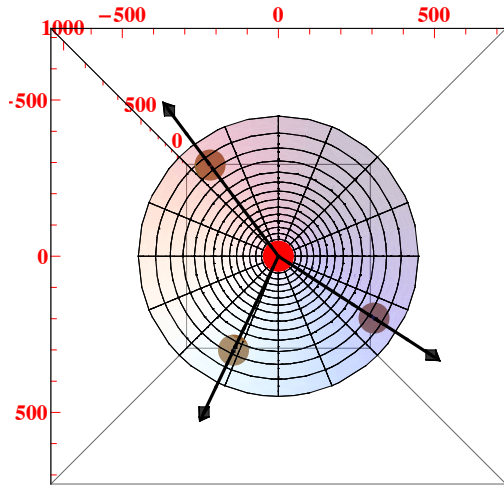


Light Echoes of an Unknown Supernova Remnant in 30 Doradus

Armin Rest (STScI)

Collaborators: Charlotte Woods, Elizabeth Johnson, Jennifer Mack, Elena Sabbi,
Xialong Li, Rodrigo Angulo, Jacob Jencson, Ryan Foley, Charlie Kilpatrick

Why Light Echoes?



Extragalactic SNe

- Many surveys
- 1000s of SNe per year!
- Populations, rates, properties
- Unresolved

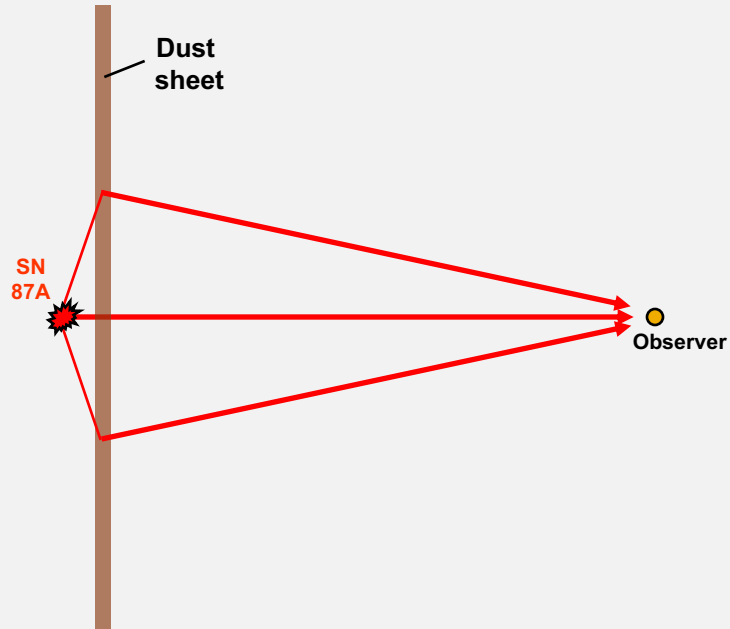
Light Echo Spectra

- Spectroscopic classification of historic events
- 3D view!
- ~10 MWG SNe in the last 1000 years

Milky Way Galaxy

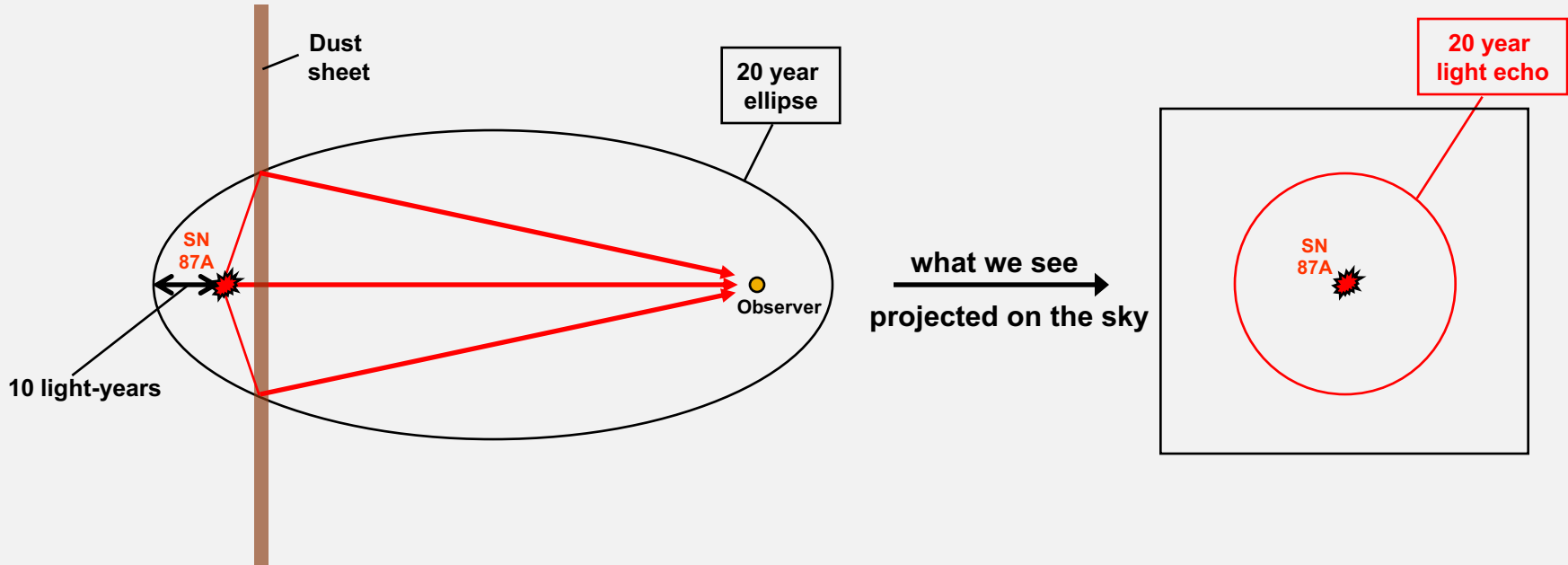
- 1 per 100 years
- Close!
- Environment
- Remnant
- Progenitor
- Composition
- No spectra!

Geometry of Light Echoes



Geometry of Light Echoes

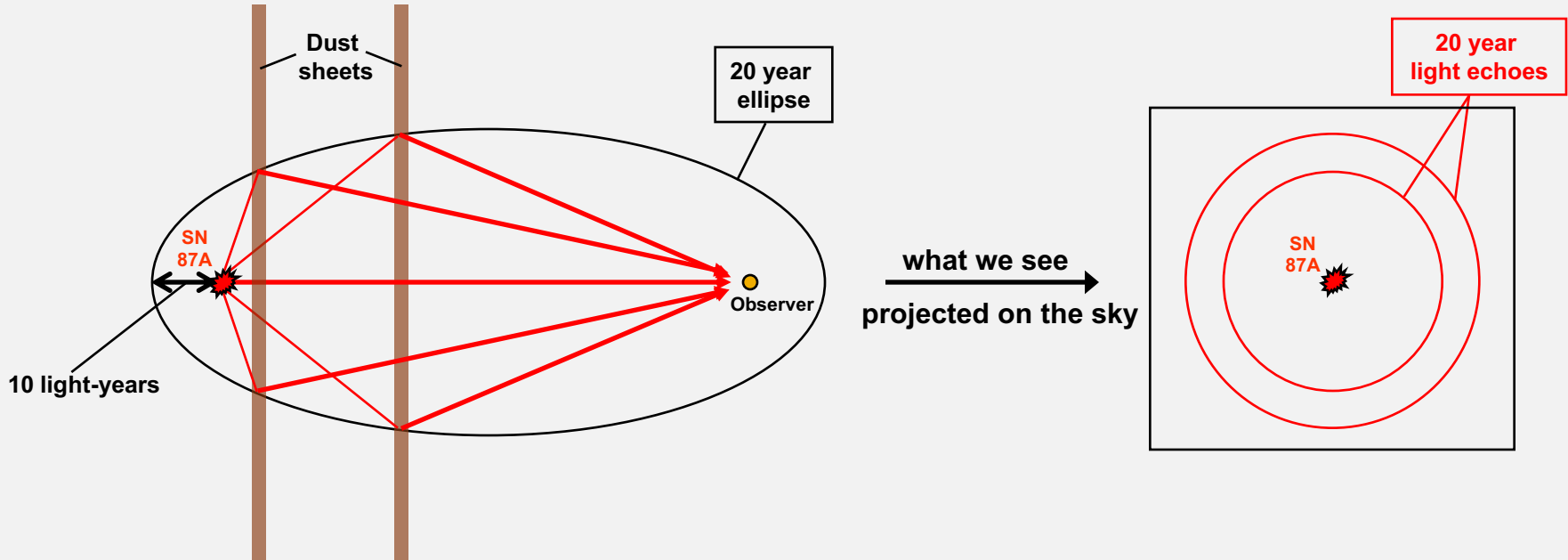
Ellipsoids trace out surfaces of constant arrival time



Extra path: 2×10 light years \rightarrow Light echo after 20 years

Geometry of Light Echoes

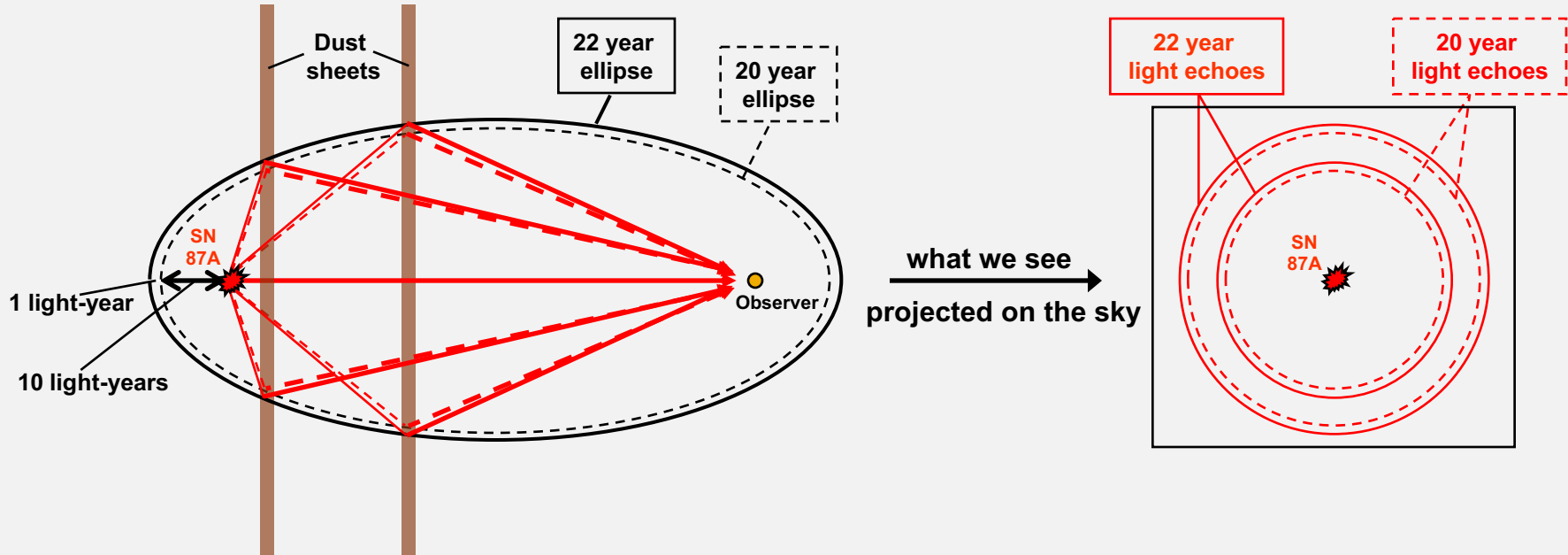
Ellipsoids trace out surfaces of constant arrival time



Extra path: 2×10 light years \rightarrow Light echo after 20 years

Geometry of Light Echoes

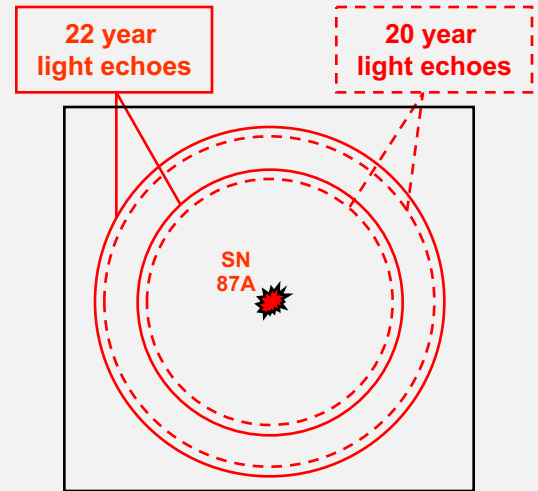
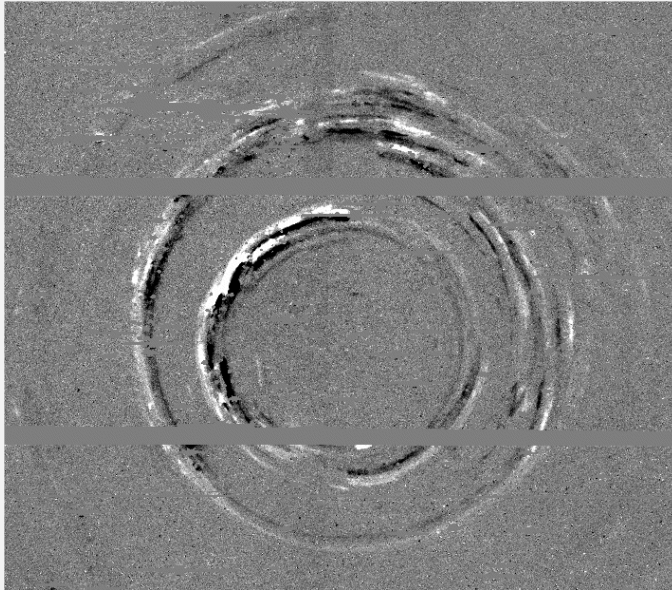
Ellipsoids trace out surfaces of constant arrival time



Extra path: 2×10 light years \rightarrow Light echo after 20 years
Extra path: 2×11 light years \rightarrow Light echo after 22 years

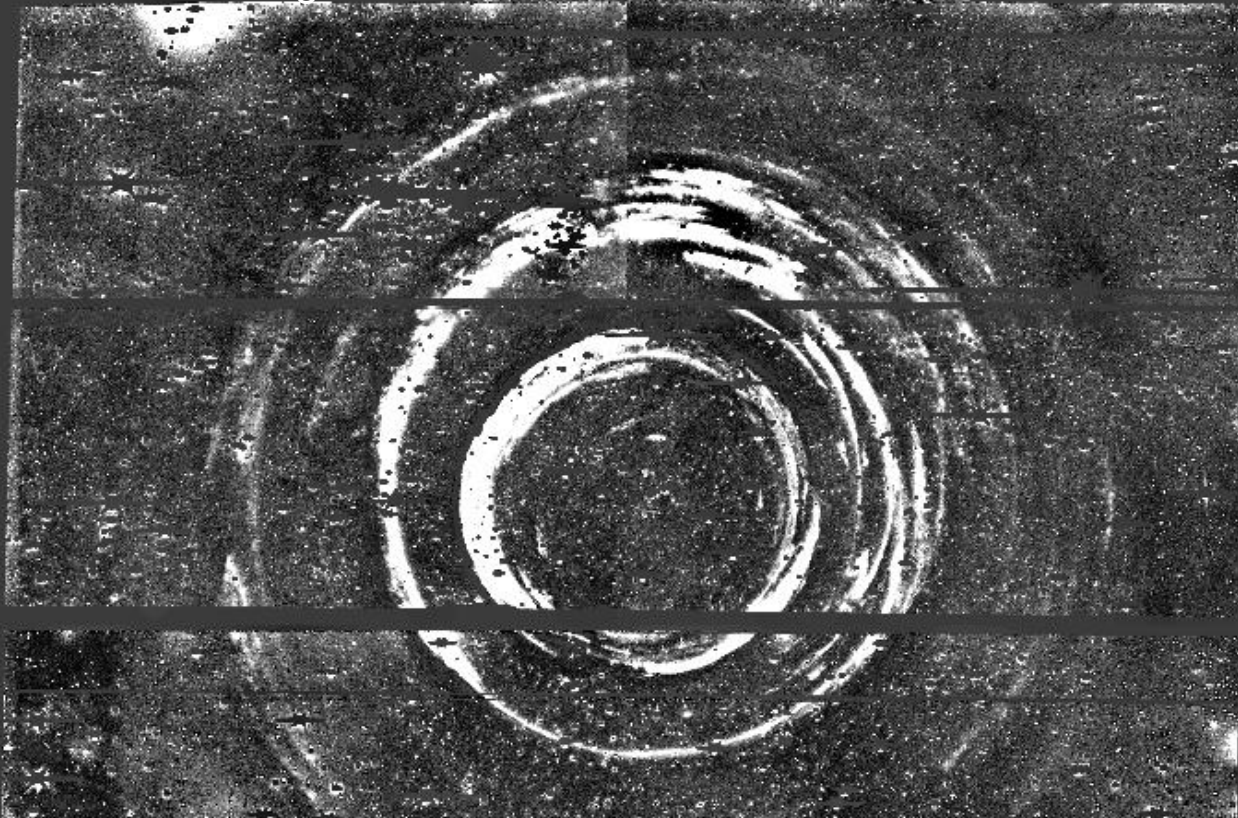
Geometry of Light Echoes

SN 87A difference image, 2003-2001



SN 87A Light Echoes

Difference images 2001-2005



You can find the source of light echoes by extrapolating backwards from the expanding circles or arclets!

Light Echoes from Ancient Supernovae in the Large Magellanic Cloud

- Three distinct light echo groups
- Apparent proper motion: between $0.7c$ and $1.8c$
- R magnitudes between 22.5 and 24.0

Rest et. al., 2005, Nature, 438, 1132

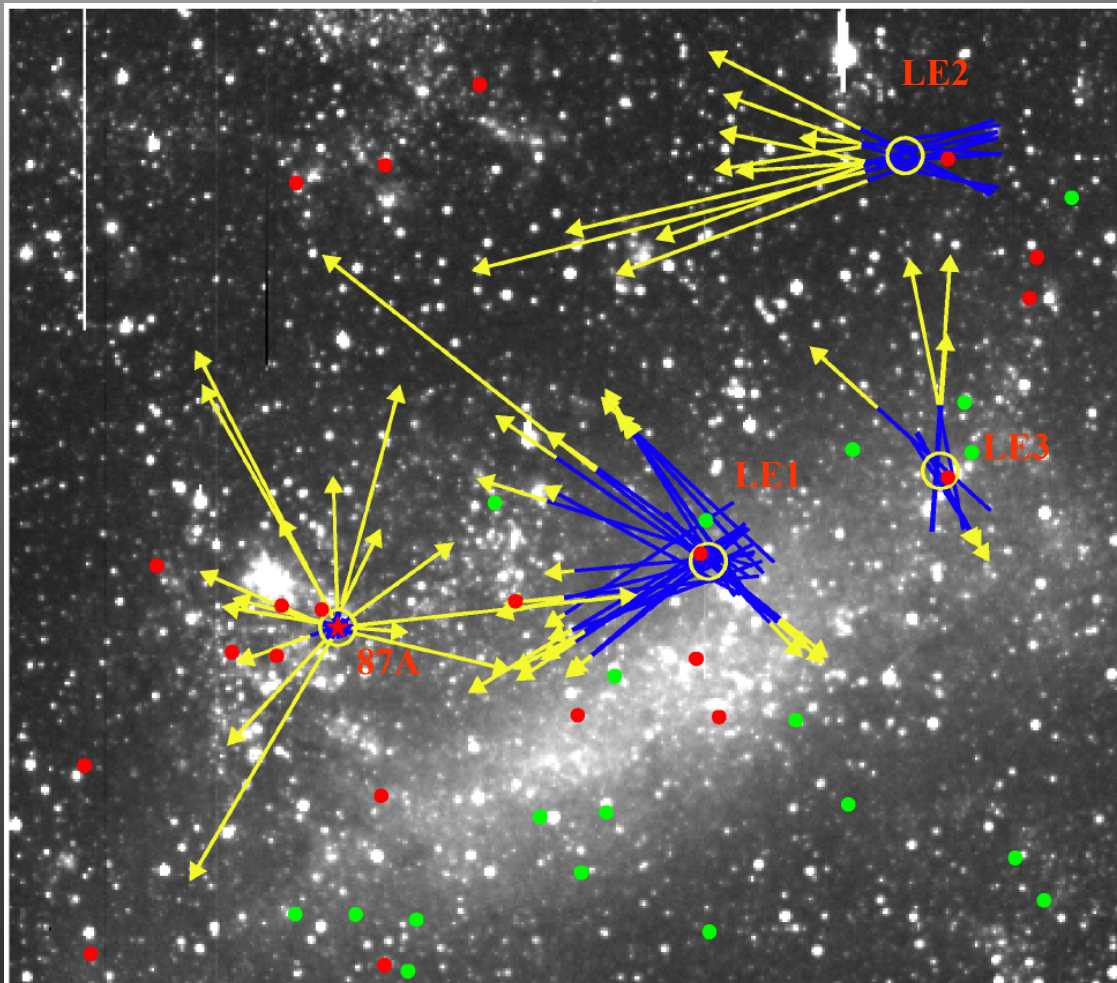


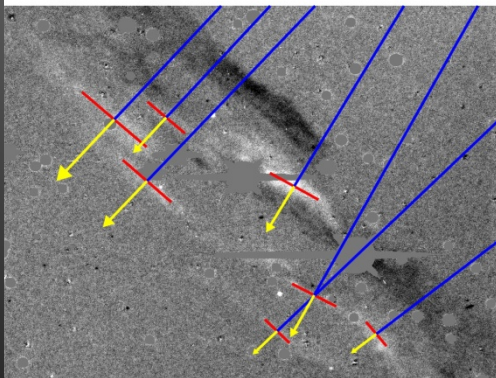
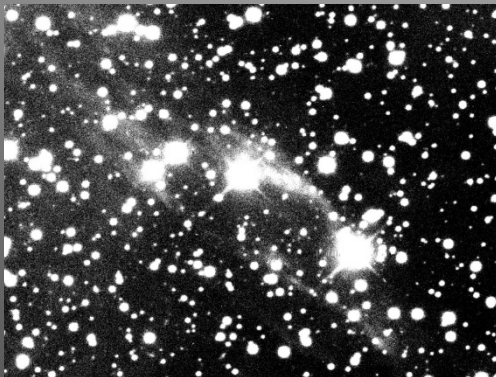
TABLE 1

THE SMALLEST SUPERNOVA REMNANTS
IN THE LARGE MAGELLANIC CLOUD

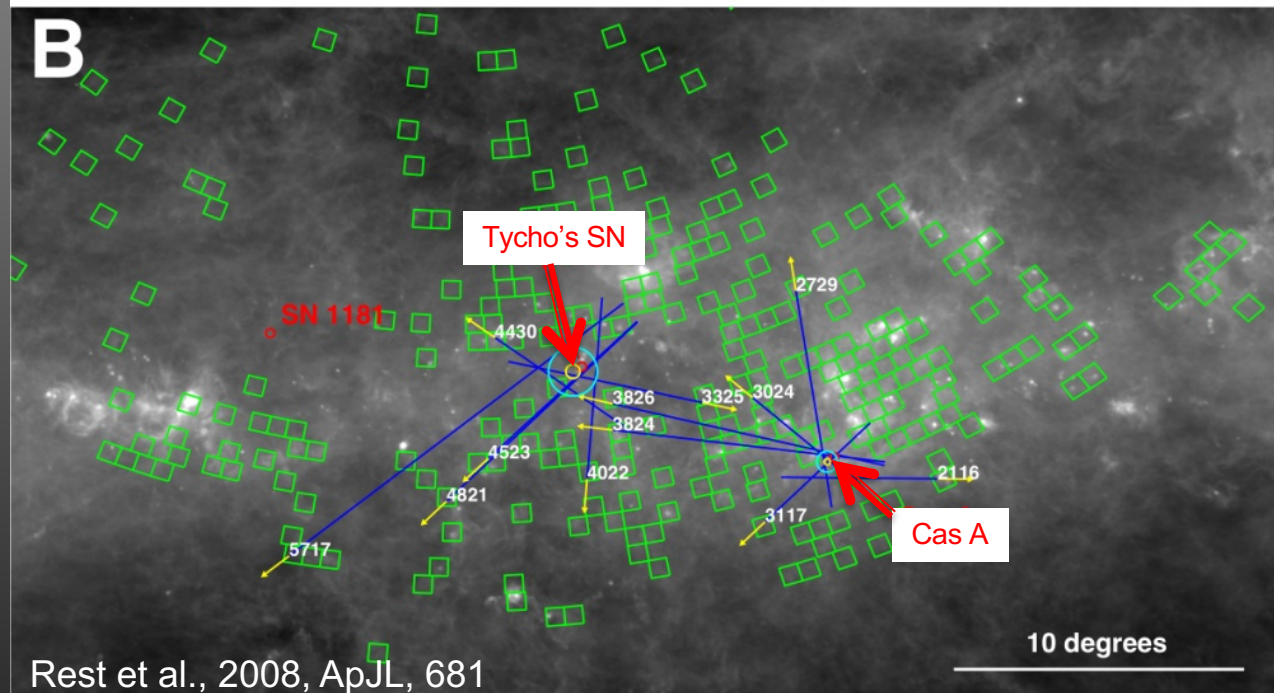
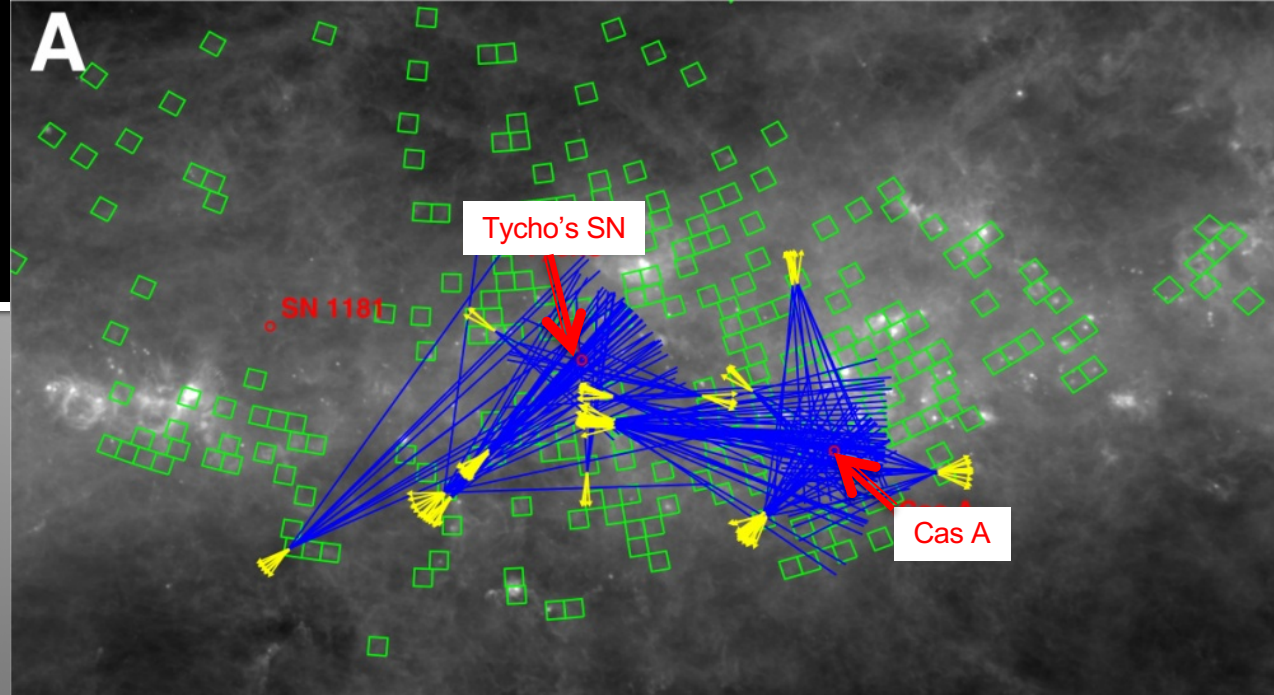
SNR Name	Age or Radius	SN Type	
SN 1987A	8 yr	II	
0540-69.3	1.5 pc	II	
N157B	1.8 pc	(II)?	
N103B	3.0 pc	Ia	LE3
0509-67.5	3.3 pc	Ia	LE2
0519-69.0	3.6 pc	Ia	LE1

Hughes et. al. (1995)

Tycho SN (1572) Cas A (1680)



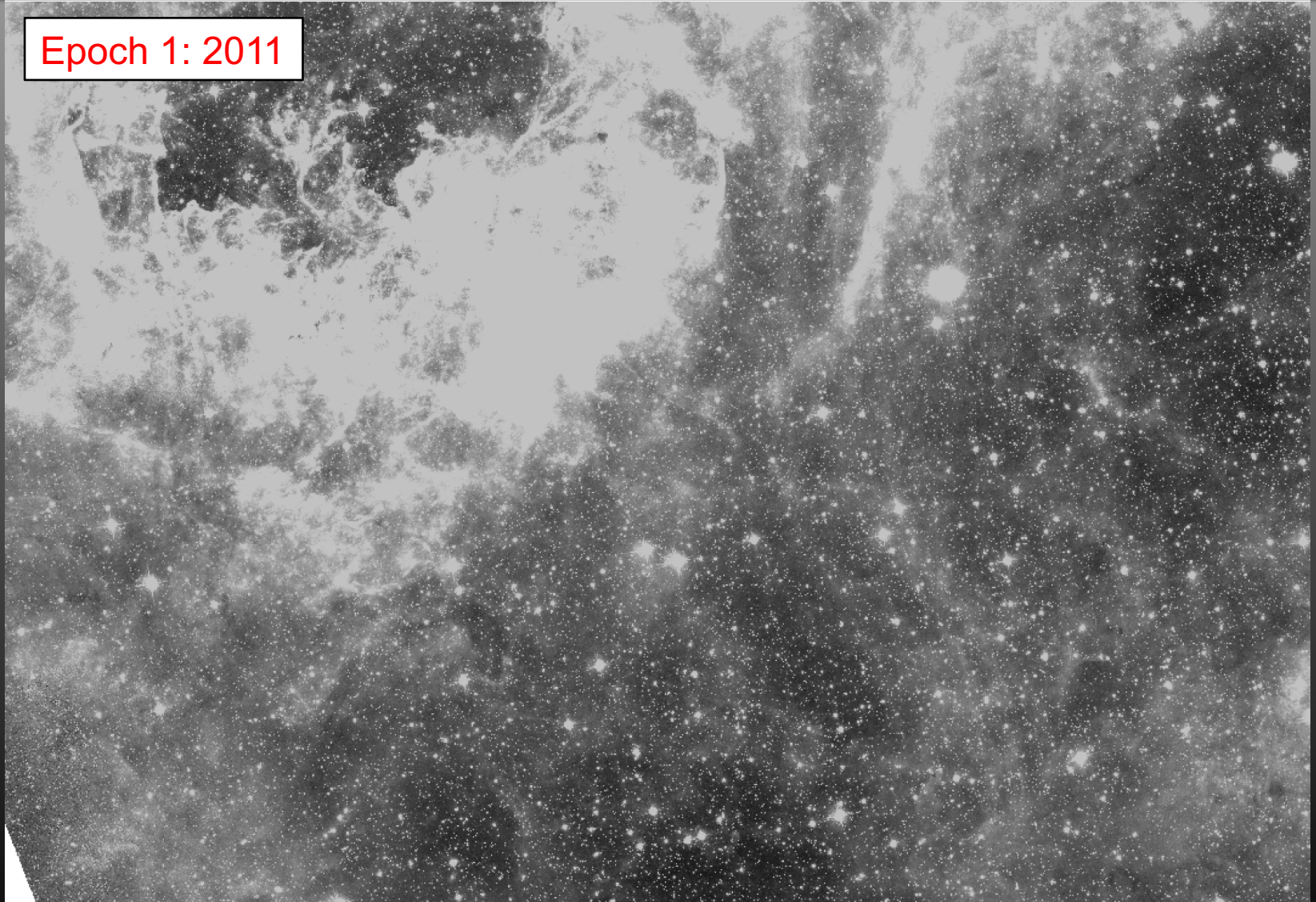
Rest et al., 2008, ApJL, 681



Rest et al., 2008, ApJL, 681

HST ACS/F775W observations of 30 Dor in LMC

Epoch 1: 2011



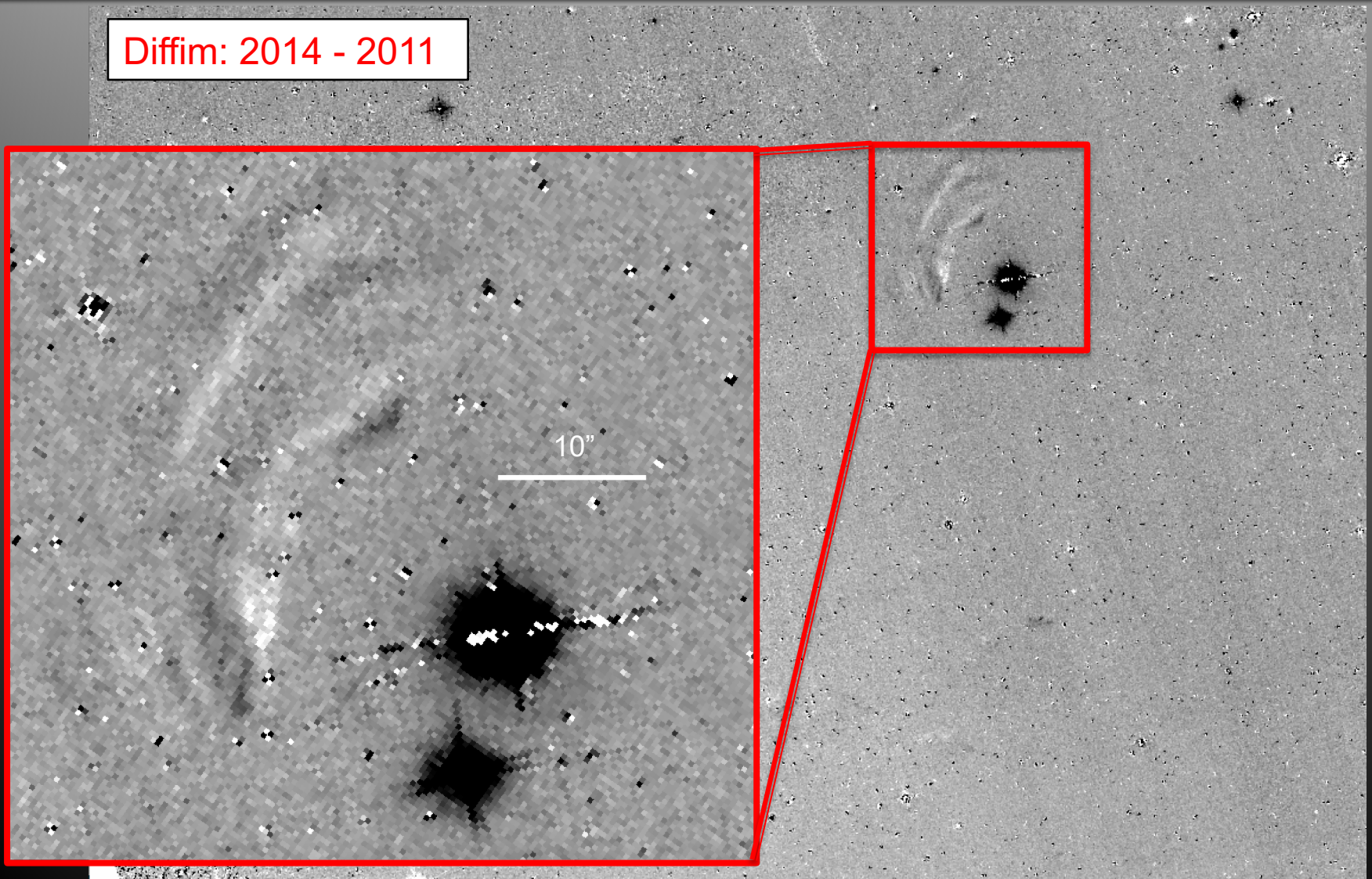
HST ACS/F775W observations of 30 Dor in LMC

Diffim: 2014 - 2011



HST ACS/F775W observations of 30 Dor in LMC

Diffim: 2014 - 2011

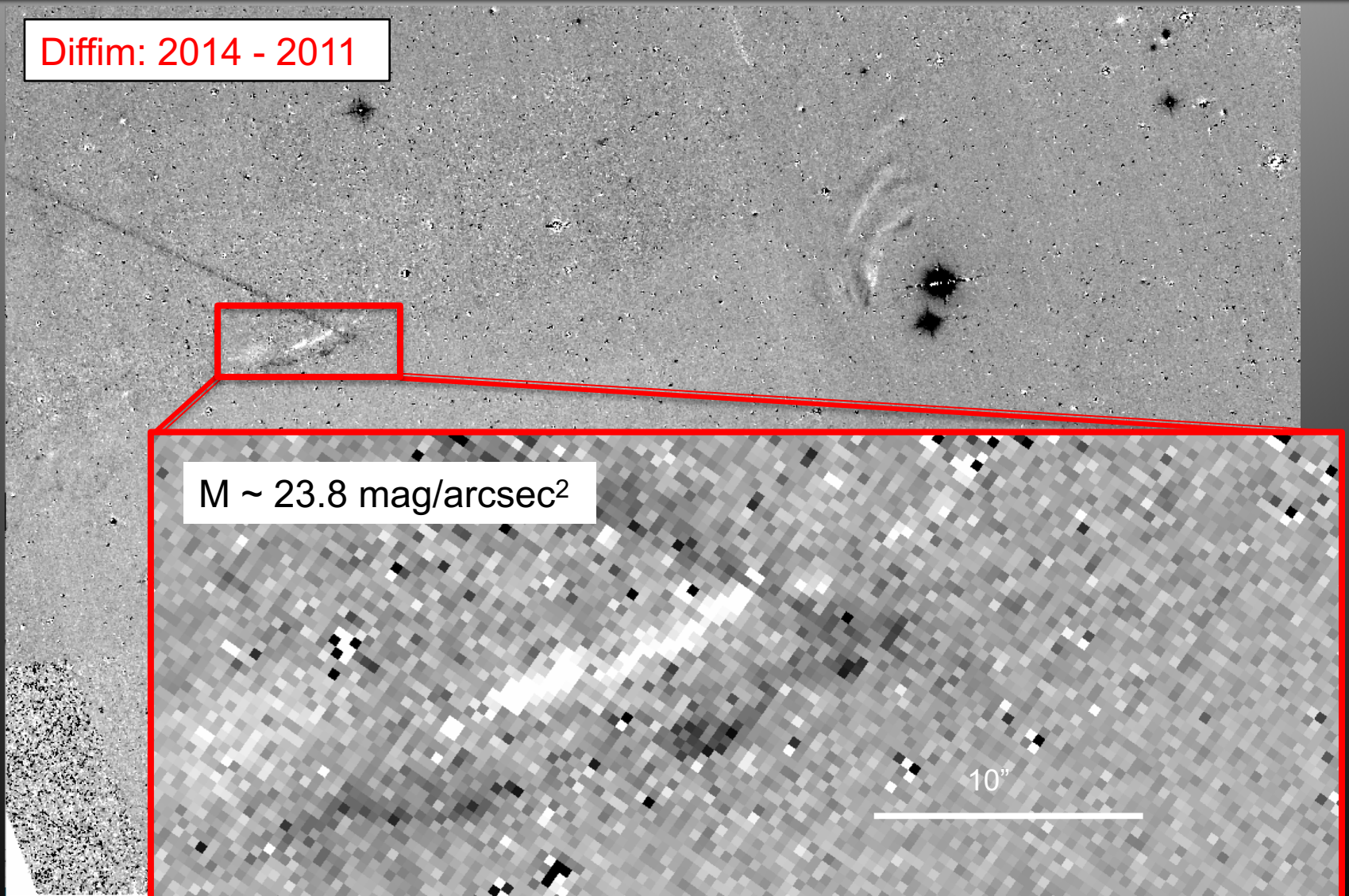


HST ACS/F775W observations of 30 Dor in LMC

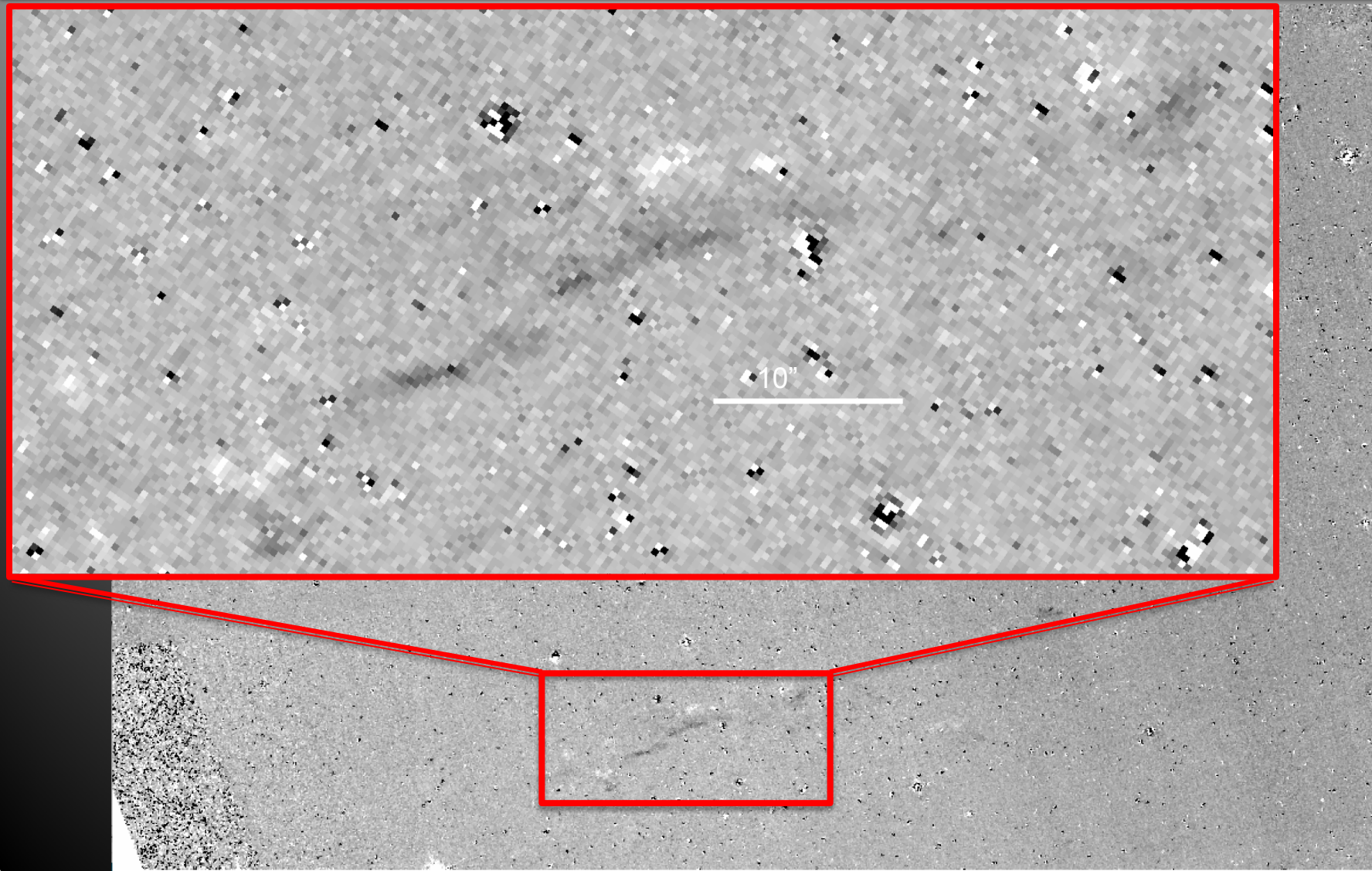
Diffim: 2014 - 2011

$M \sim 23.8 \text{ mag/arcsec}^2$

10"



HST ACS/F775W observations of 30 Dor in LMC

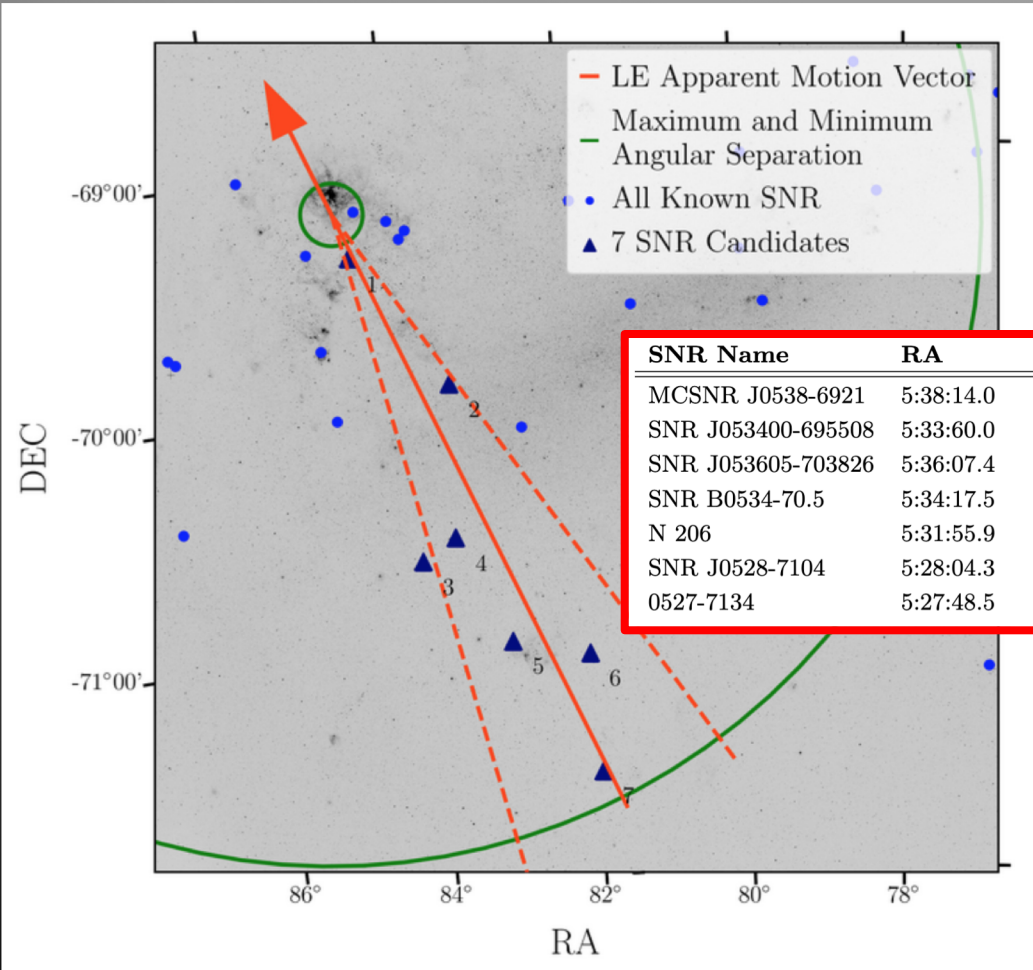


HST ACS/F775W observations of 30 Dor in LMC

Diffim: 2014 - 2011



Possible sources for the LEs?



SNR Name	RA	Dec	Published Age	Ang Sep (deg)	z (ly)	$\sim \rho$	$\sim \theta$
MCSNR J0538-6921	5:38:14.0	-69:21:37		0.19			
SNR J053400-695508	5:33:60.0	-69:54:58	10000	0.85	-4690	2330	150
SNR J053605-703826	5:36:07.4	-70:38:47	12500	1.49	-5530	4150	140
SNR B0534-70.5	5:34:17.5	-70:33:25	12500	1.43	-5580	3990	140
N 206	5:31:55.9	-71:00:14	25000	1.92	-11900	5370	160
SNR J0528-7104	5:28:04.3	-71:04:40	25000	1.18	-12200	3600	160
0527-7134	5:27:48.5	-71:34:06		2.56			

Are these SNR associated with these LEs?

Criteria 1: Surface Brightness

L: Intrinsic Luminosity

F_{SB} : Surface Brightness

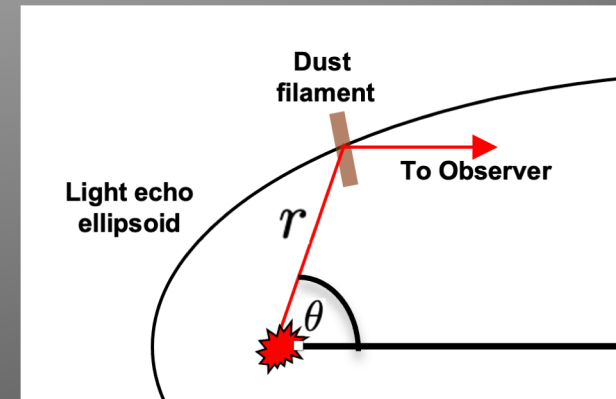
S: Scattering Efficiency

$$F_{\text{SB}} \propto L n_{\text{Dust}} \sigma_{\text{Dust}} \frac{S(\theta)}{r^2}$$

Dust Filament Properties

r: Distance Source to Dust

$$r \propto t$$



Idea: We take the brightest LMC light echo and assume it has the most favorable dust filament properties and similar luminosity

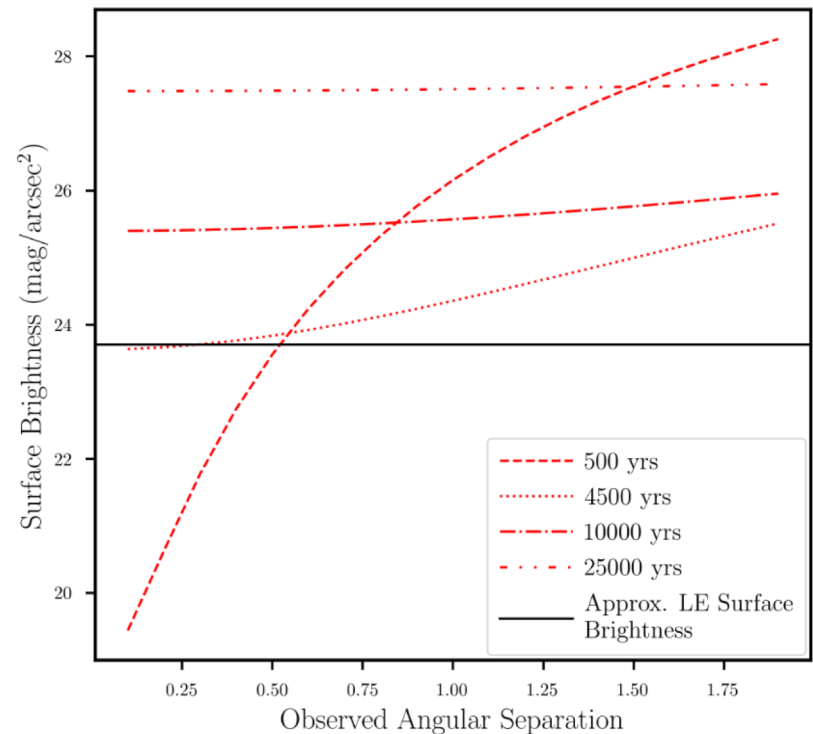
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$$F_{\text{SB}} \propto L n_{\text{Dust}} \sigma_{\text{Dust}} \frac{S(\theta)}{r^2}$$

- SNR older than 4500 years need either a brighter SN or an even more favorable scattering dust filament!

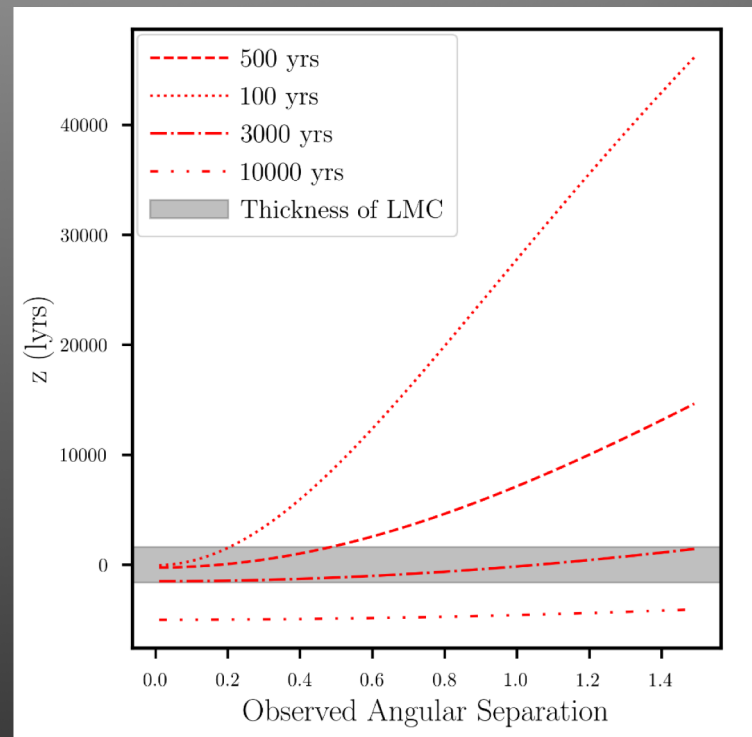


Are these SNR associated with these LEs?

Criteria 2: Relative position z

Idea: Both the SNR and the scattering dust are very likely to be within the LMC (disk)

- LMC scale height is < 1800 ly
- SNR older than 3000 years have $z < -1800$ ly

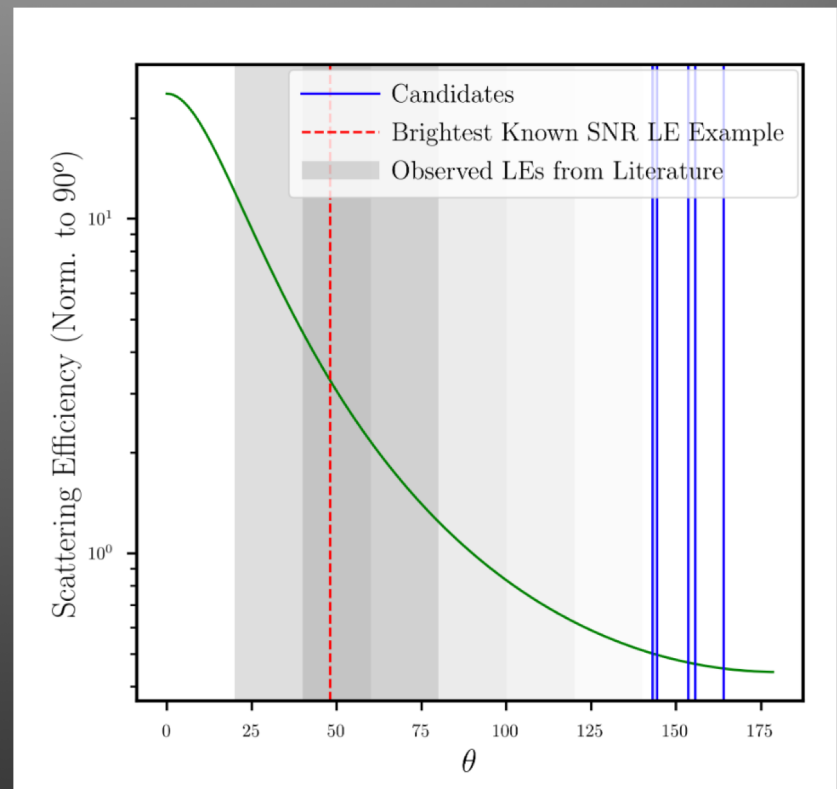


Are these SNR associated with these LEs?

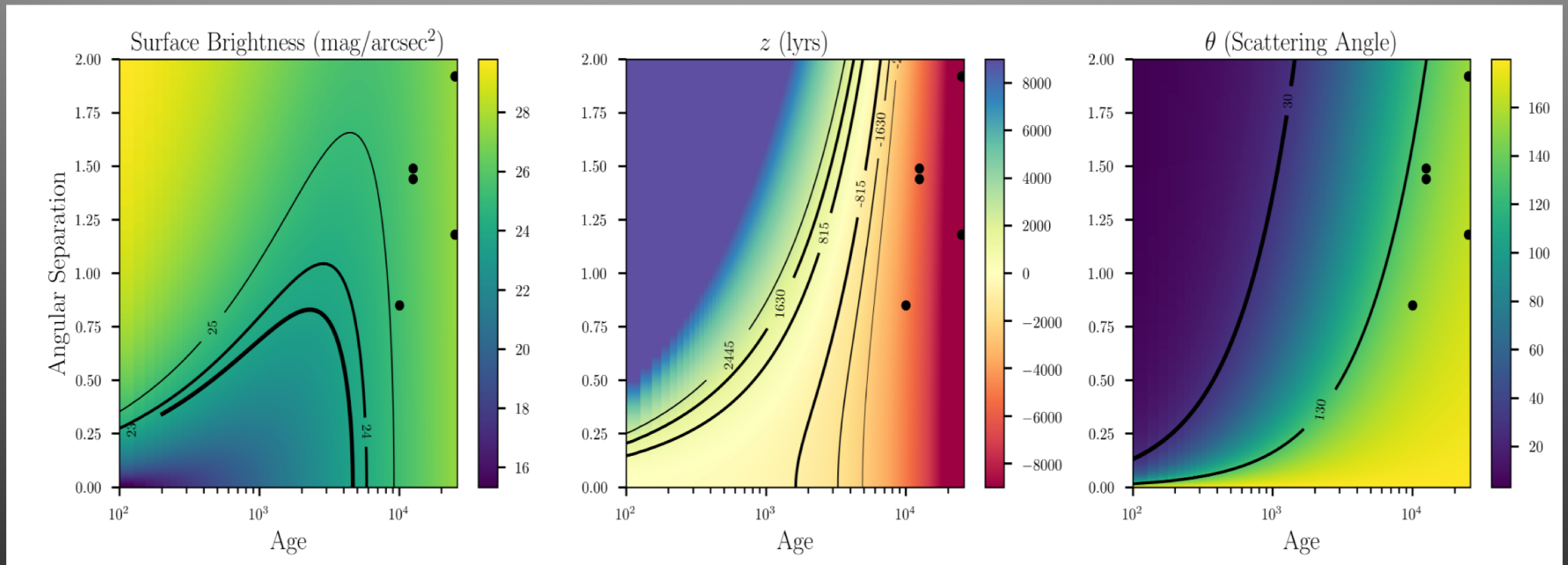
Criteria 3: Empirical Theta Distribution

Idea: What is the empirical distribution of theta values, and how does it compare to the thetas of the SNR candidates?

- No scattered light echoes have been found with $\theta > 125$
- There are many Cas A IR echoes with $\theta > 125$!
- Scattering efficiency drops significantly for large theta



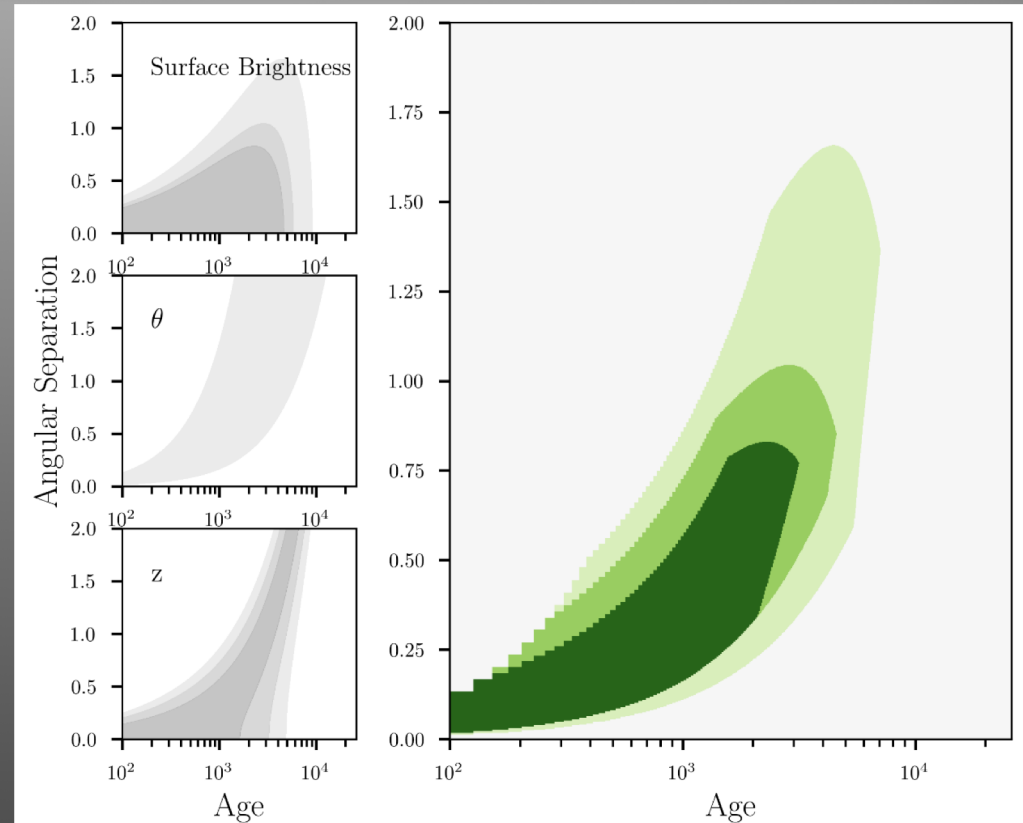
Combining the 3 criteria!



- Black circles are SNR candidates
- Black contours indicate preferred region

Combining the 3 criteria!

- Most likely SNR is <3000 years old and with an angular separation smaller than 0.75 degree
 - None of the 7 candidates fulfill both criteria
- At most, SNR could be 6000 years old, and at a distance of at most 1.5 deg from the Les
- **Unknown (young) SNR in low-density environment?**

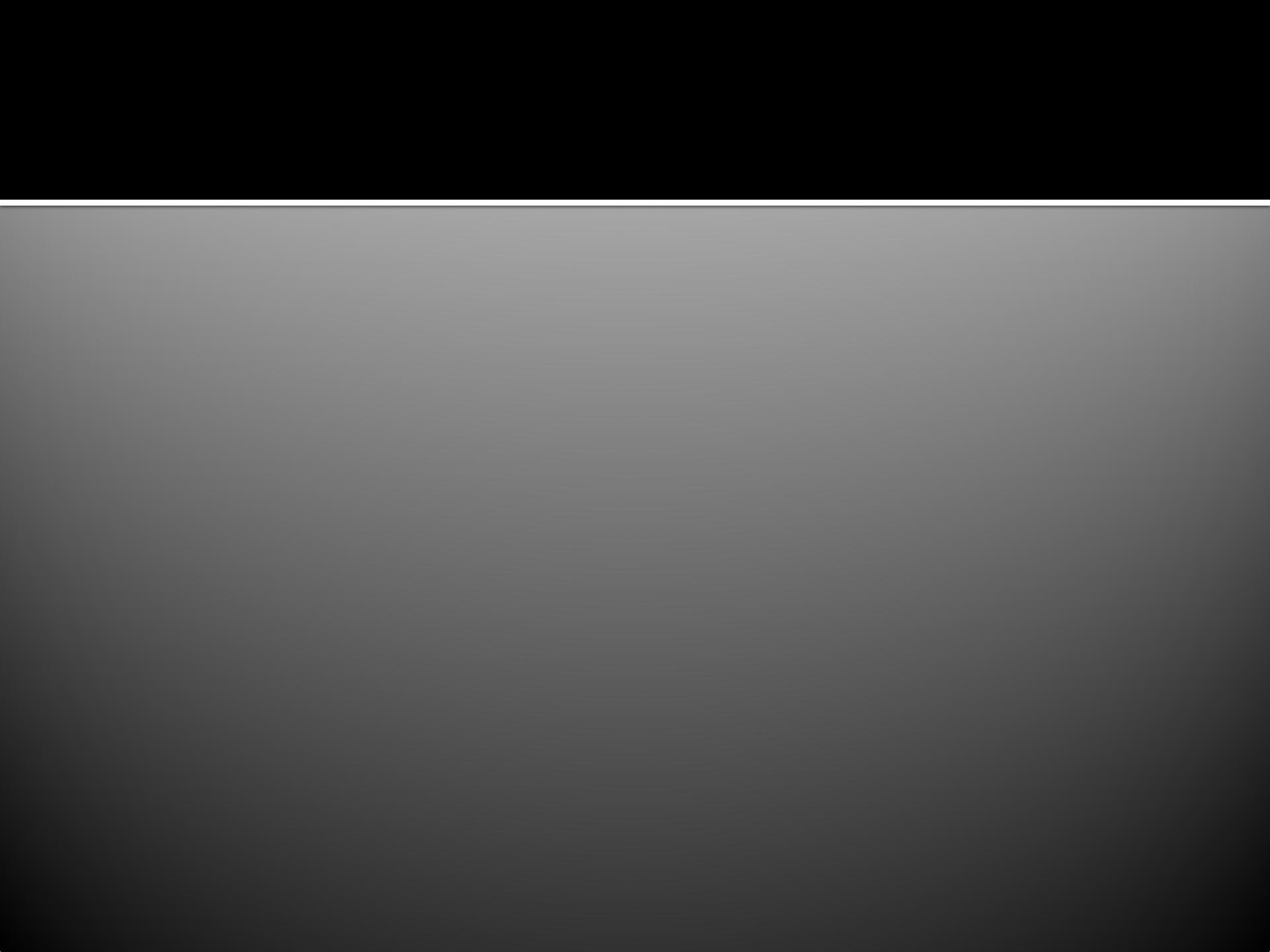


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Conclusions

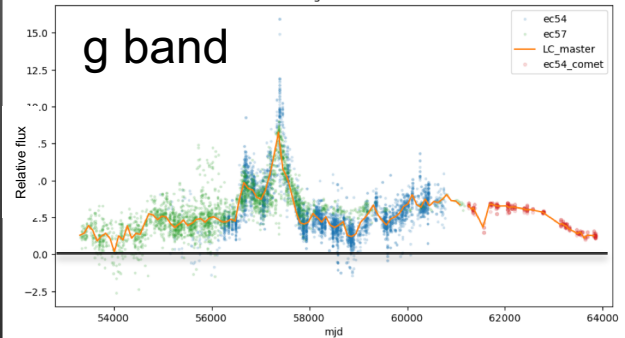
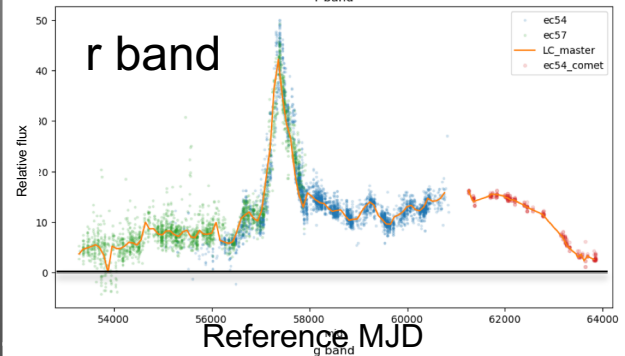
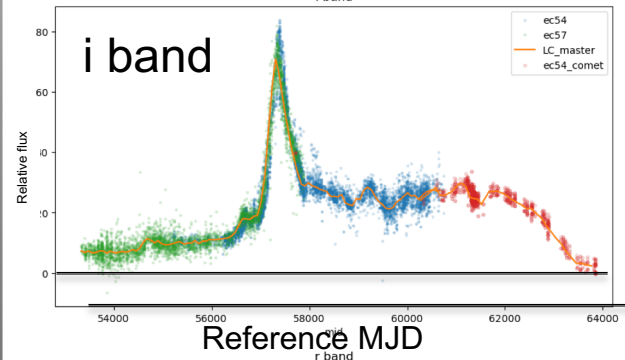
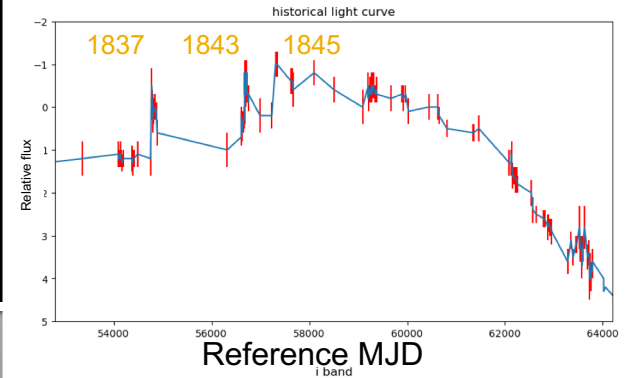
- We have found light echoes most likely from a SN
- There are 7 known SNR candidates as source of these light echoes
- We find that the SNR associated with the LEs should be less than 3000 years old and at most 0.75 deg from the LEs
 - None of the 7 candidate SNR candidates fulfill both criteria
- Unknown (young) SNR in low density environment?

*Ask me about the newest results about Eta Car's light echoes



Eta Car's GE light curve from light echoes

- 12 years of DECam imaging
- A given position gives 12 year light curve segment
- Stitch segments together
- 3 main segments
 - Still some issues to solve to stitch red segment to the rest.
- 3 peaks, line up timewise with historic LC
- 1845 peak extremely red!!



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