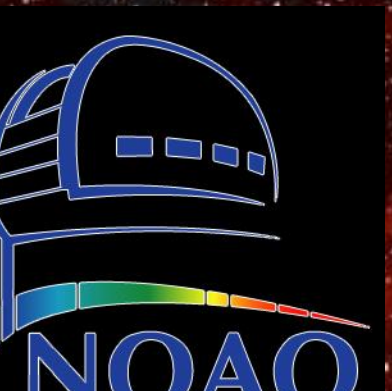
Echoes of Ancient Supernovae in the Large Magellanic Cloud

Tom Matheson Armin Rest
and the SuperMACHO Team



Why should you care about echoes?

- Light scattered by dust ("echoes") have been observed from a few recent supernovae: 1986G, 1987A, 1991T, …
- Probes the spatial 3-D structure of the dust
- SN light echoes should in principle be visible hundreds to thousands of years after explosion
- Light echoes from ancient supernovae could allow us to observe the same light seen by Tycho and Kepler
- By taking spectra of light echoes, we may type ancient supernovae directly
- Light echoes offer the only opportunity to study both the initial explosions and remnants in the *same* supernovae

The SuperMACHO project:
A next generation microlensing survey

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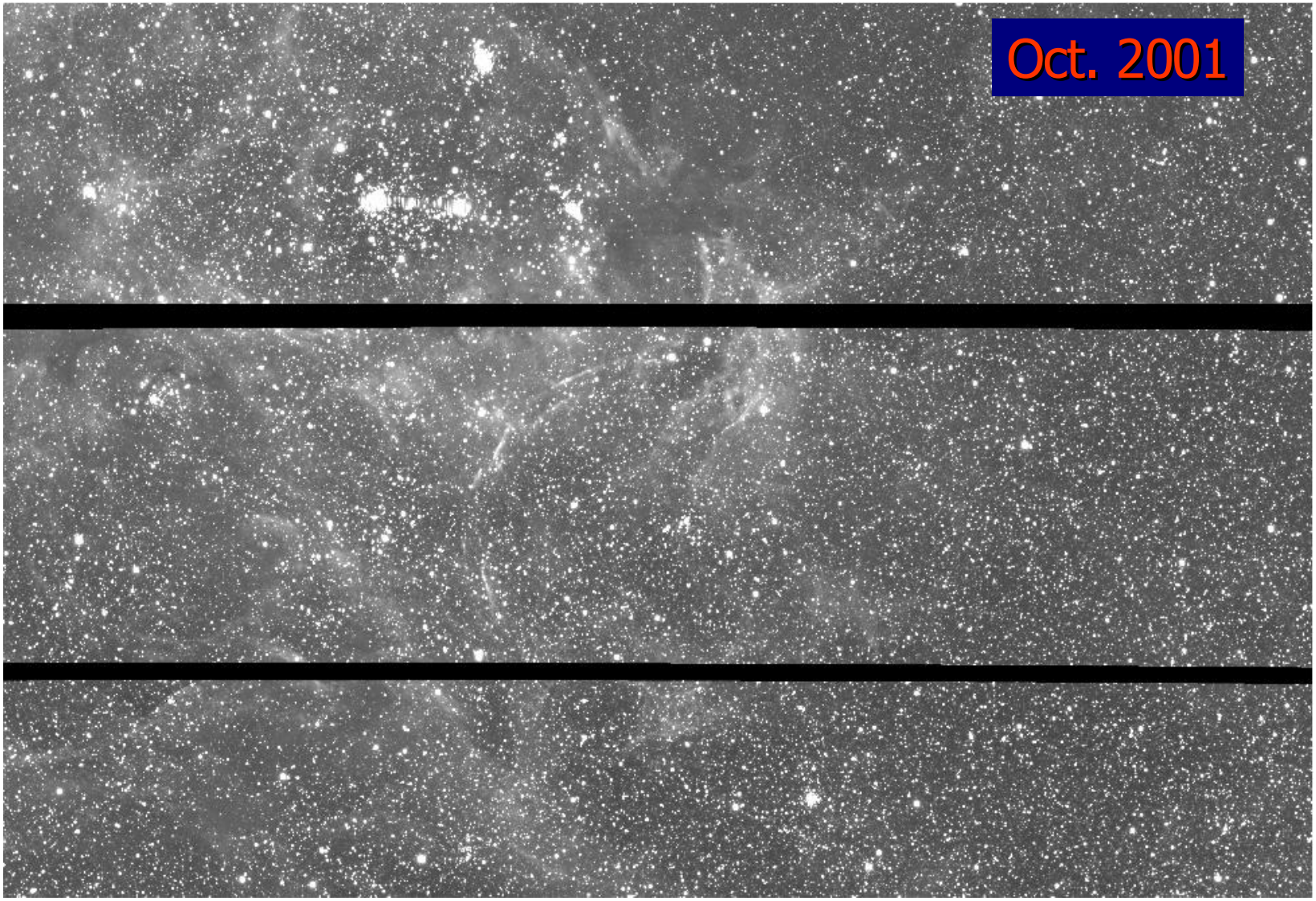
Primary science goal:
How much do "MACHOs" contribute to the Galactic dark matter halo?

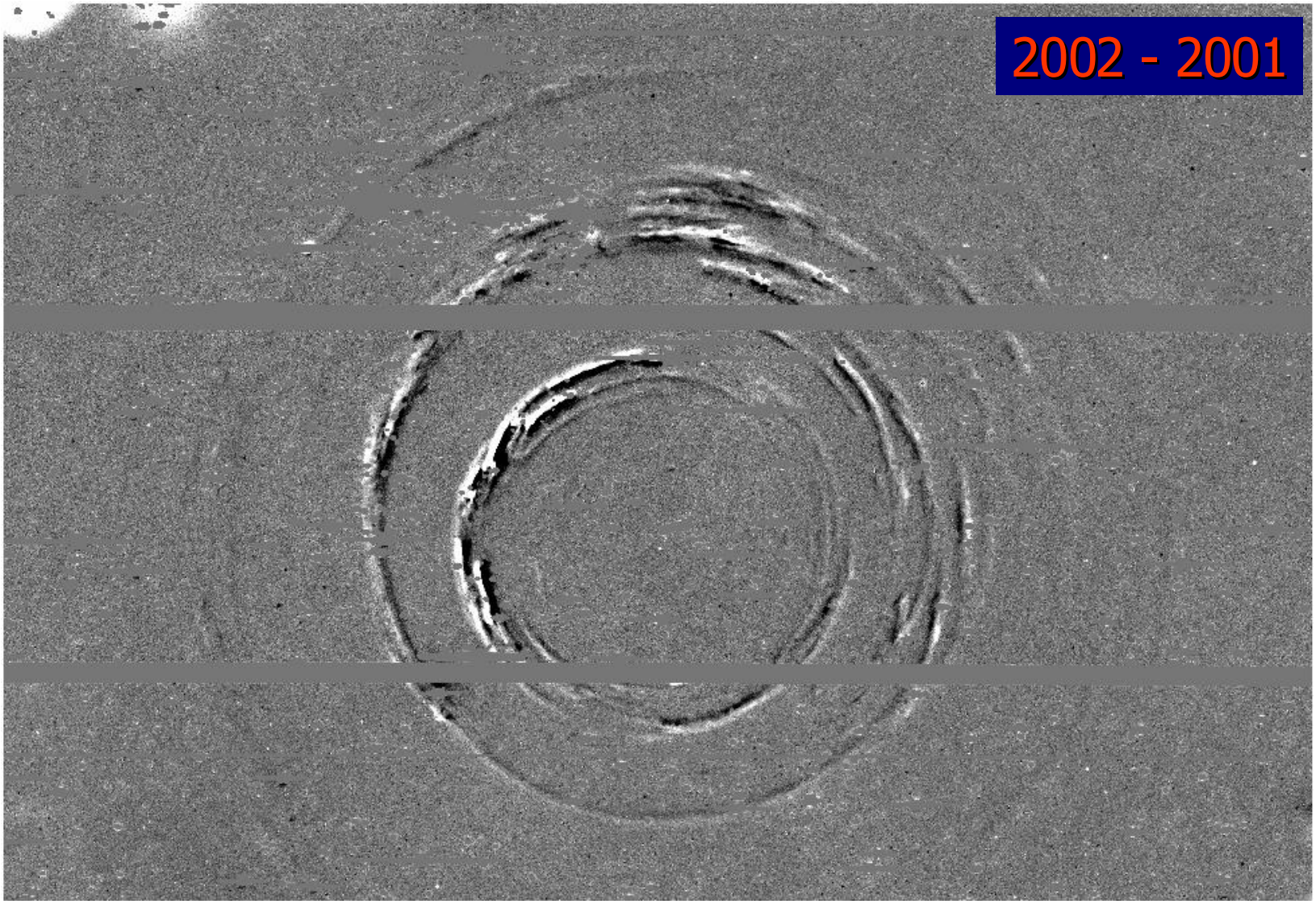
SuperMACHO Survey:
Microlensing Survey towards the LMC

- More events
  - CTIO 4m
  - Mosaic Imager: big FOV
  - 150 half nights over 5 years
  - Blocks of 3 months per year
  - One Filter: “VR”
- **Spatial Coverage**
  - 68 fields, 23 deg^2
- **Difference Imaging**

“False” alerts



The Light Echoes of SN 1987A



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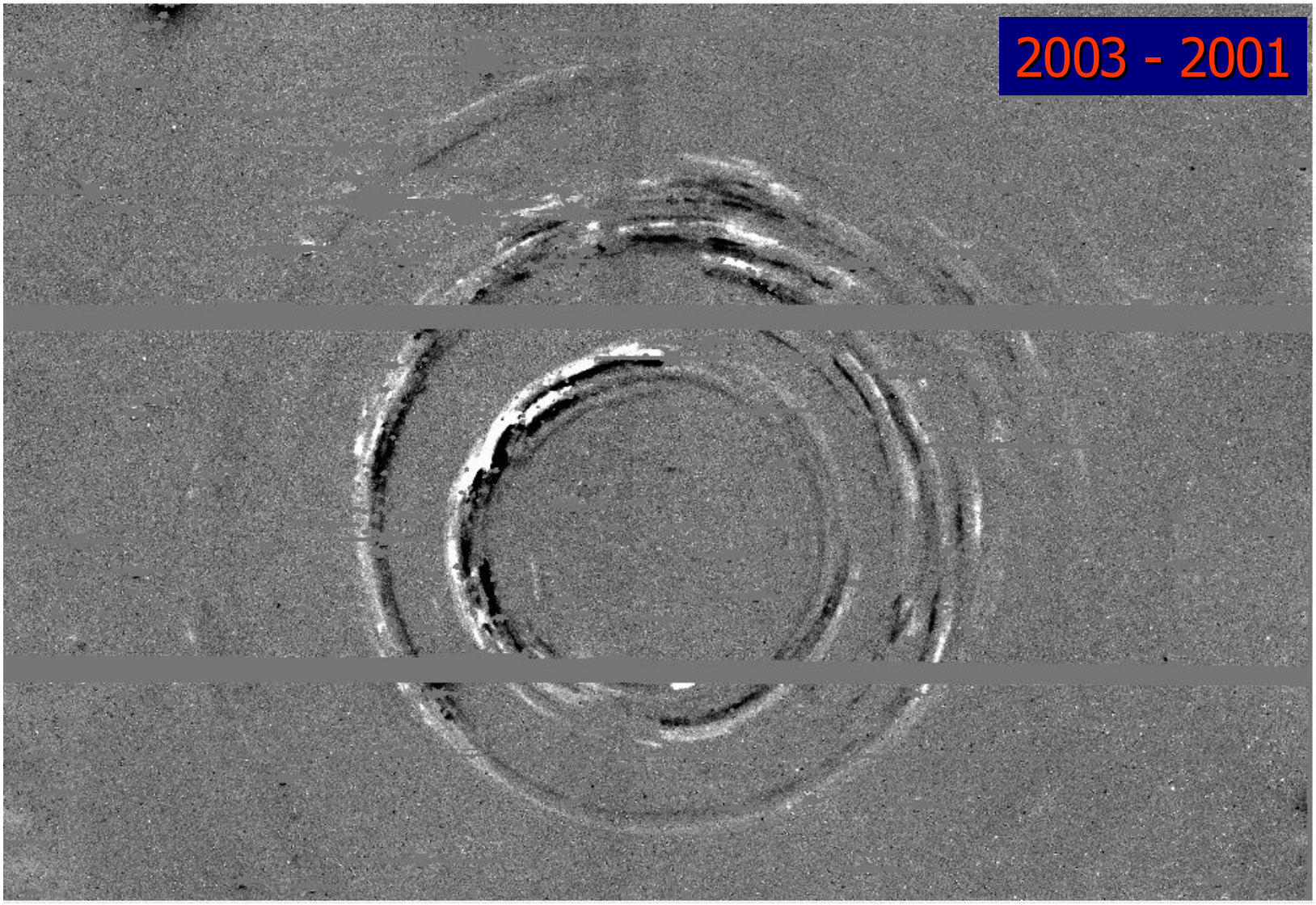

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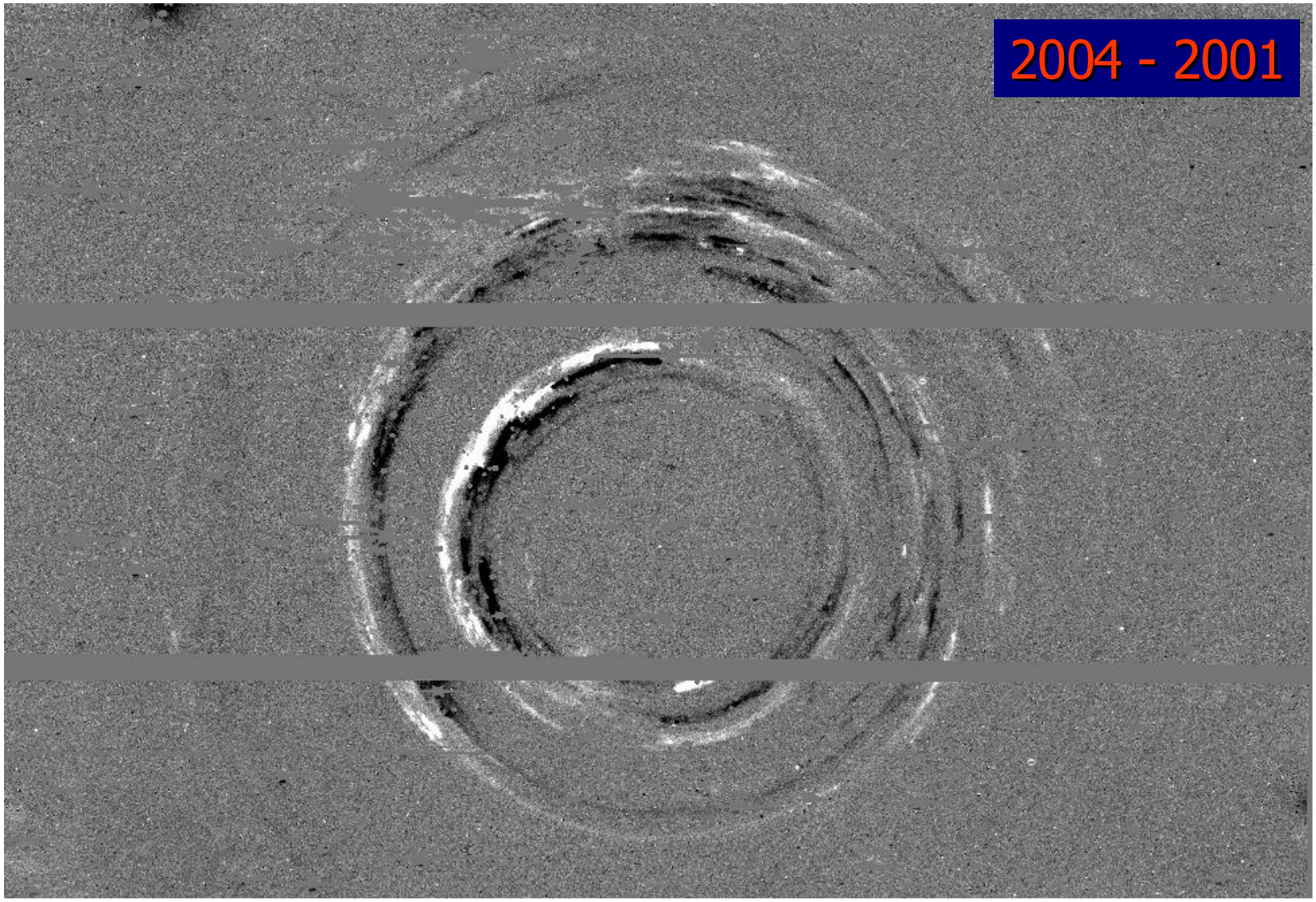
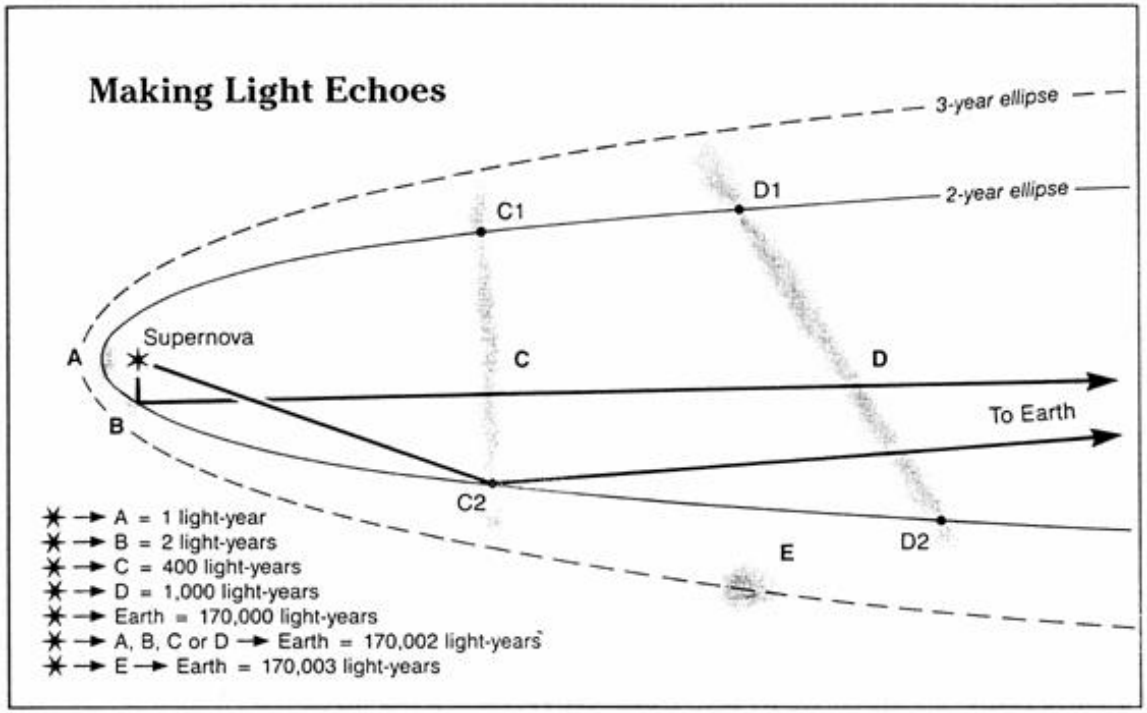


Geometry of Light Echoes

- Ellipsoids trace out surfaces of constant arrival time



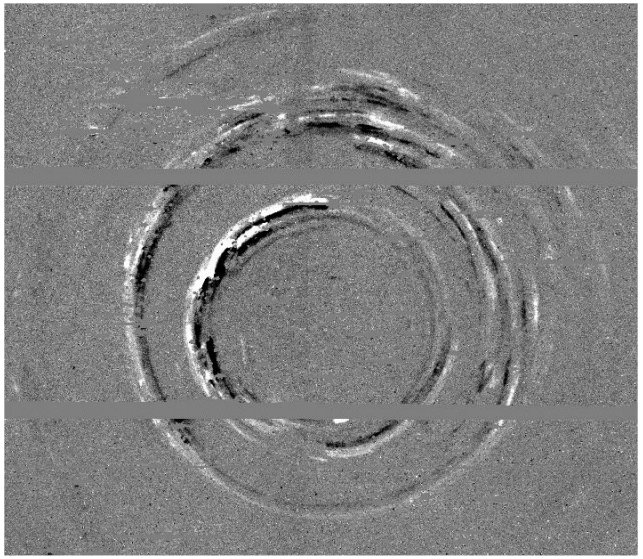
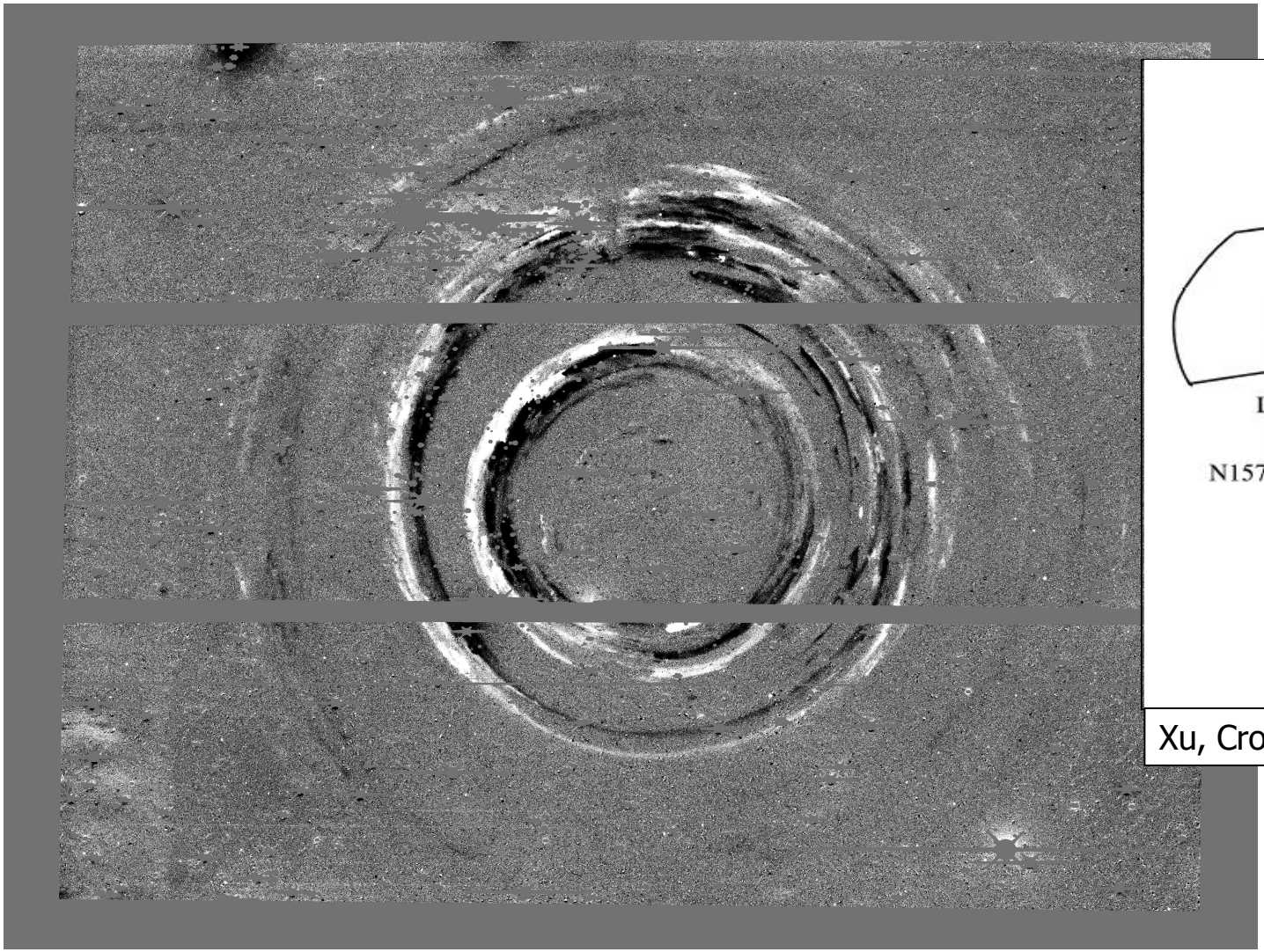
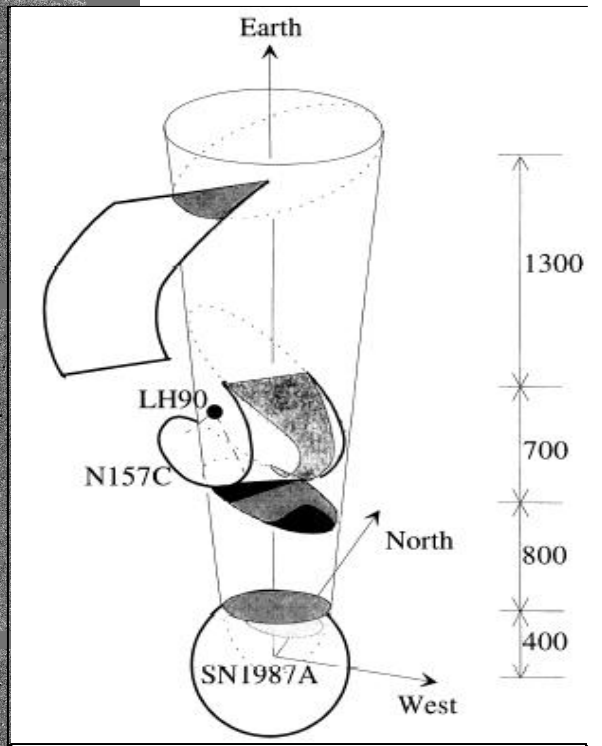


Illustration by David Malin, AAO
http://www.aao.gov.au/images/image/light_echo_3.gif

The Geometry of the SN 1987A Light Echoes





Xu, Crotts, & Kunkel (1995)

Light Echo Surface Brightness

Dust density

Scattering function

$$B_{SC}(\lambda, t, \phi) = F(\lambda) n_H(\boldsymbol{r}) \frac{c\Delta z}{4\pi r \rho \Delta\rho} S(\lambda, \mu)$$

Surface brightness

SN flux

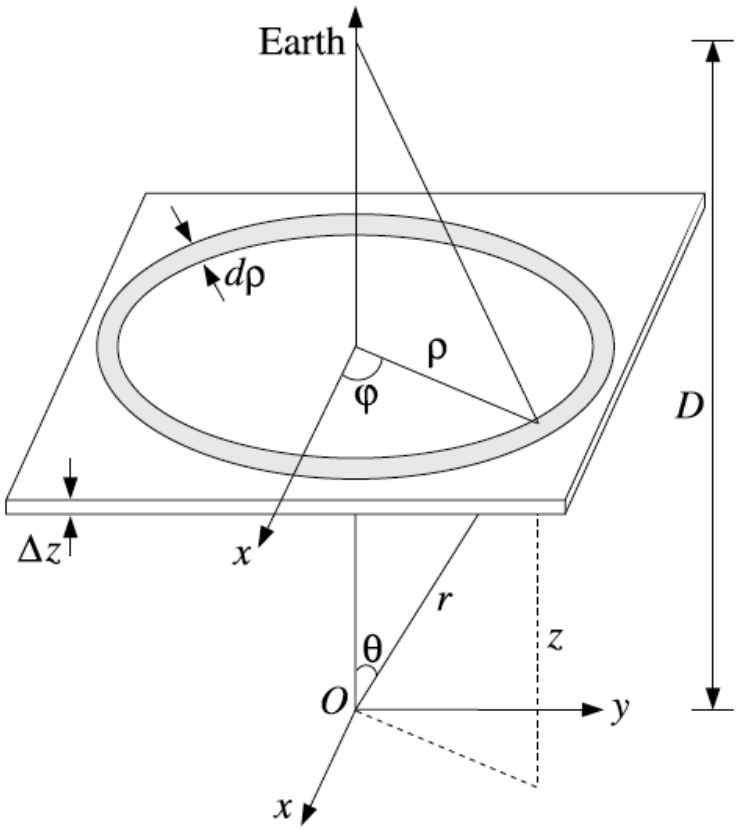
Geometric factor

Simpler parameterization, with assumptions:

$\Sigma_2 = \Sigma_1 + (V_{SN,2} - V_{SN,1})$

$-2.5\log_{10}[r_1 t_1/(r_2 t_2)]$

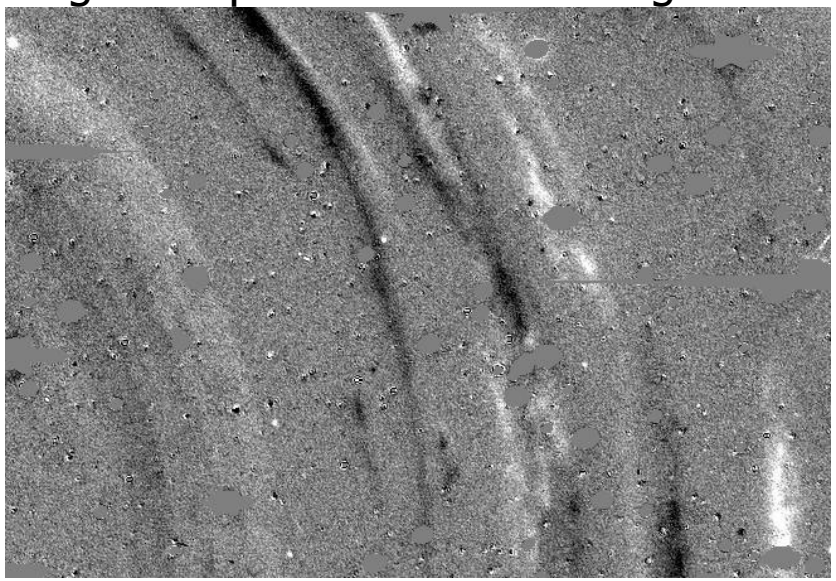
$-2.5\log_{10}(\Phi_2/\Phi_1)$



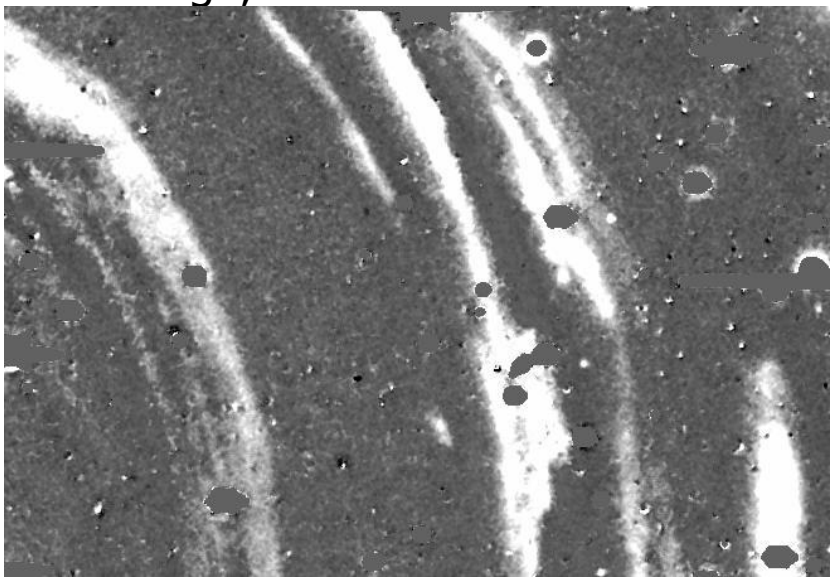
Sugerman (2003), Xu et al. (1994)

Extracting Light Echoes with NN2: Zero-flux correction (Newman & Rest, PASP, 2006)

Single-template difference image

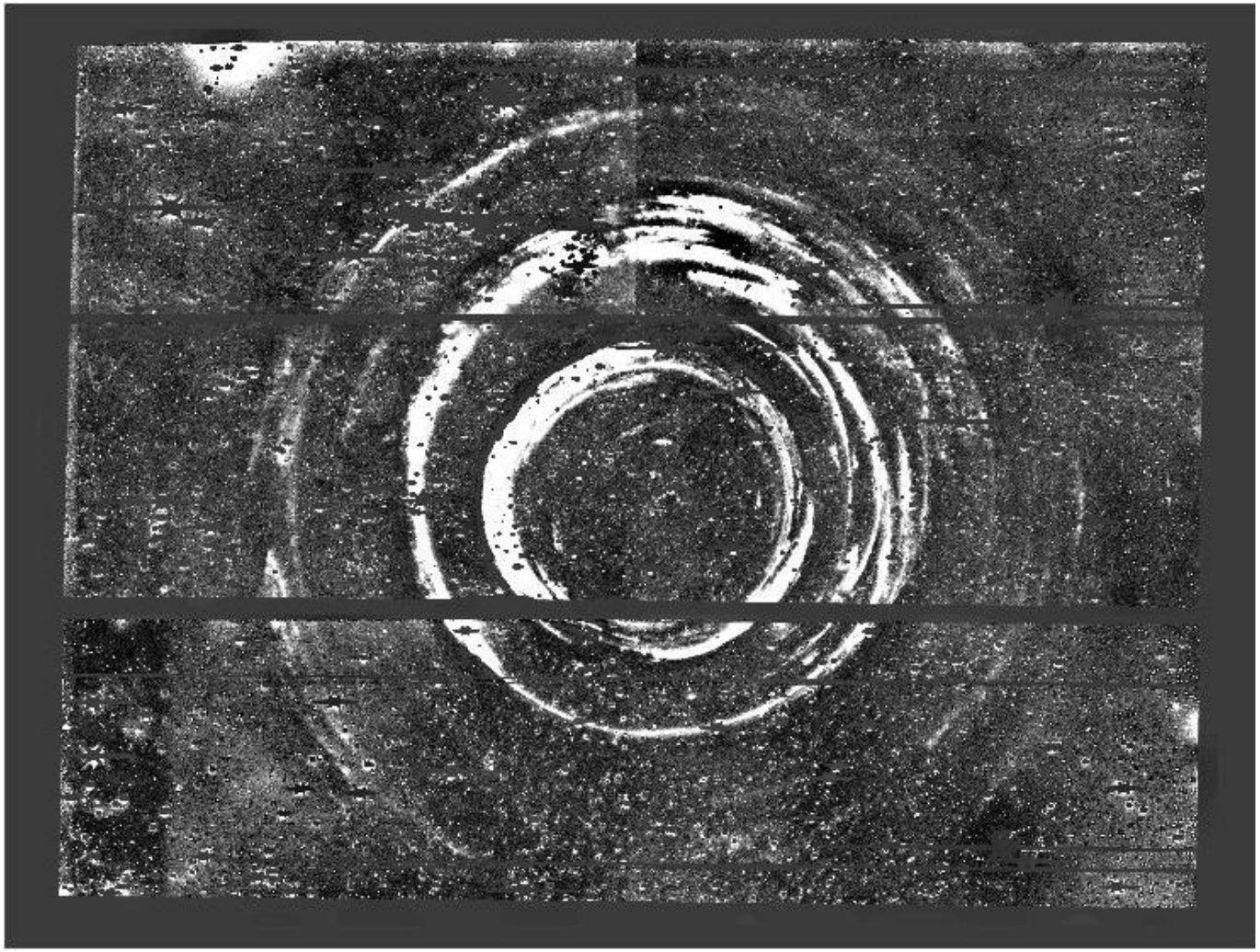


NN2 image, combined and smoothed



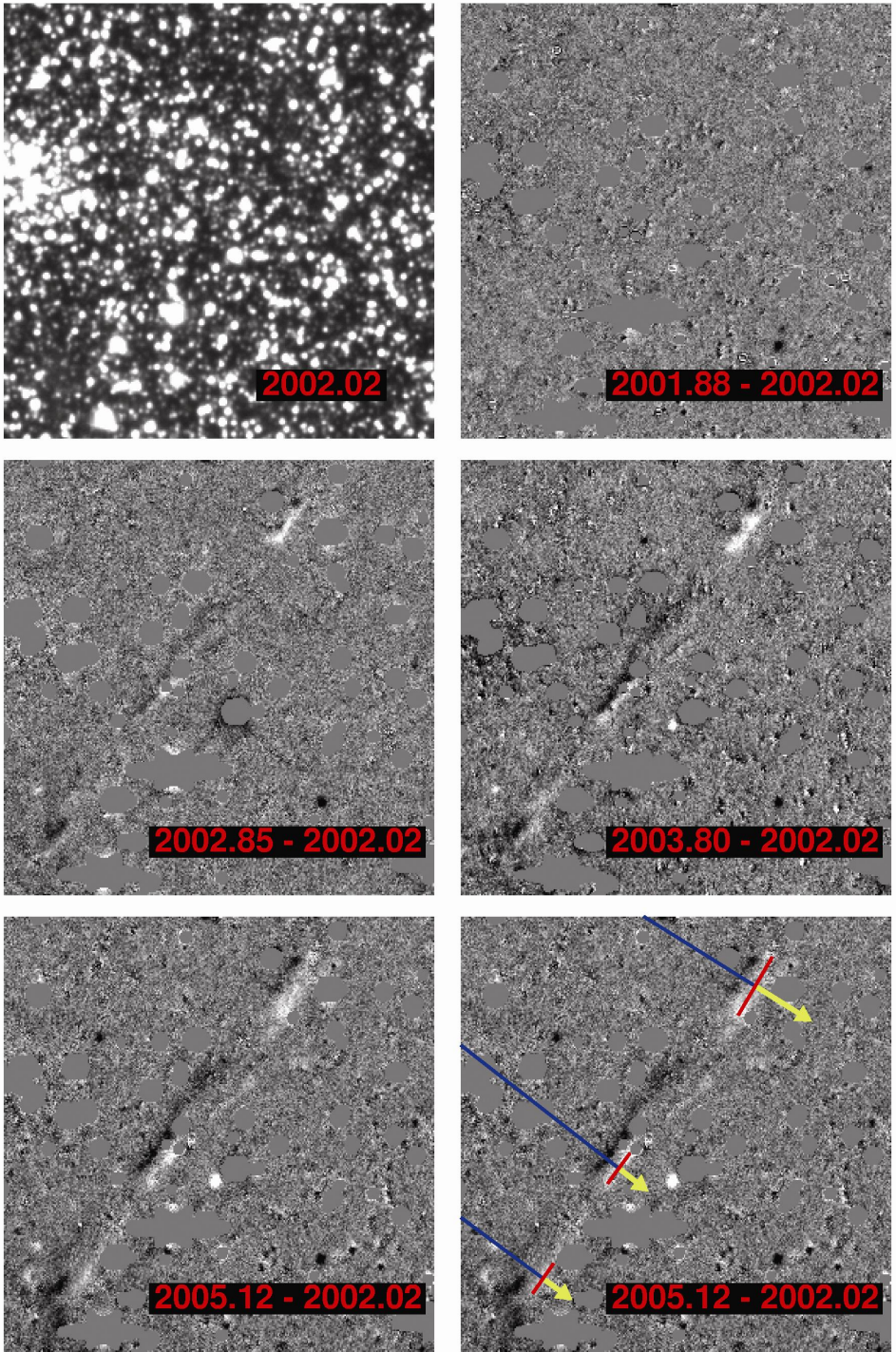
- Combine each year
- Smooth with 3x3 kernel
- http://www.ctio.noao.edu/~supermacho/lightechos/

SN 87A Light Echoes with NN2 Difference Imaging (each season combined and smoothed)



Newman & SuperMACHO collaboration, in preparation

Light Echoes from a source other than SN 1987A?



Light Echoes from Ancient Supernovae in the LMC

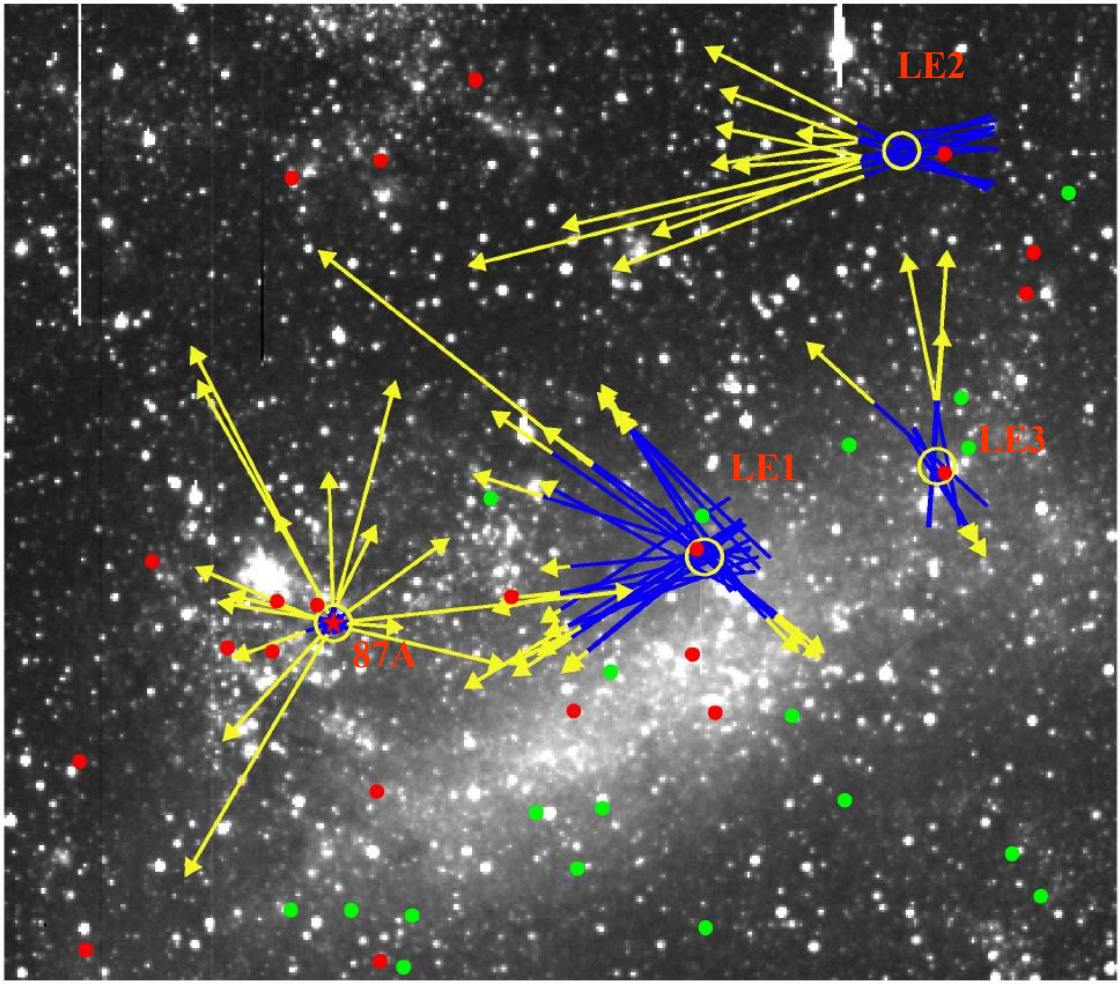
- Three distinct light echo groups
- Apparent proper motion: between 0.7***c*** and 1.8***c***
- R magnitudes between 22.5 and 24.0

For Type Ia SN, assuming dust sheet at z=150 pc, same dust density as sheets close to 87A

At 500 yr, Σ_V = 22.5 mag arcsec^{-2}, ρ = 0.29 deg (250 pc)

At 1000 yr, Σ_V = 24 mag arcsec^{-2}, ρ=0.5 deg (420 pc)

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



SNRs Associated with the Light Echoes: Ages

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

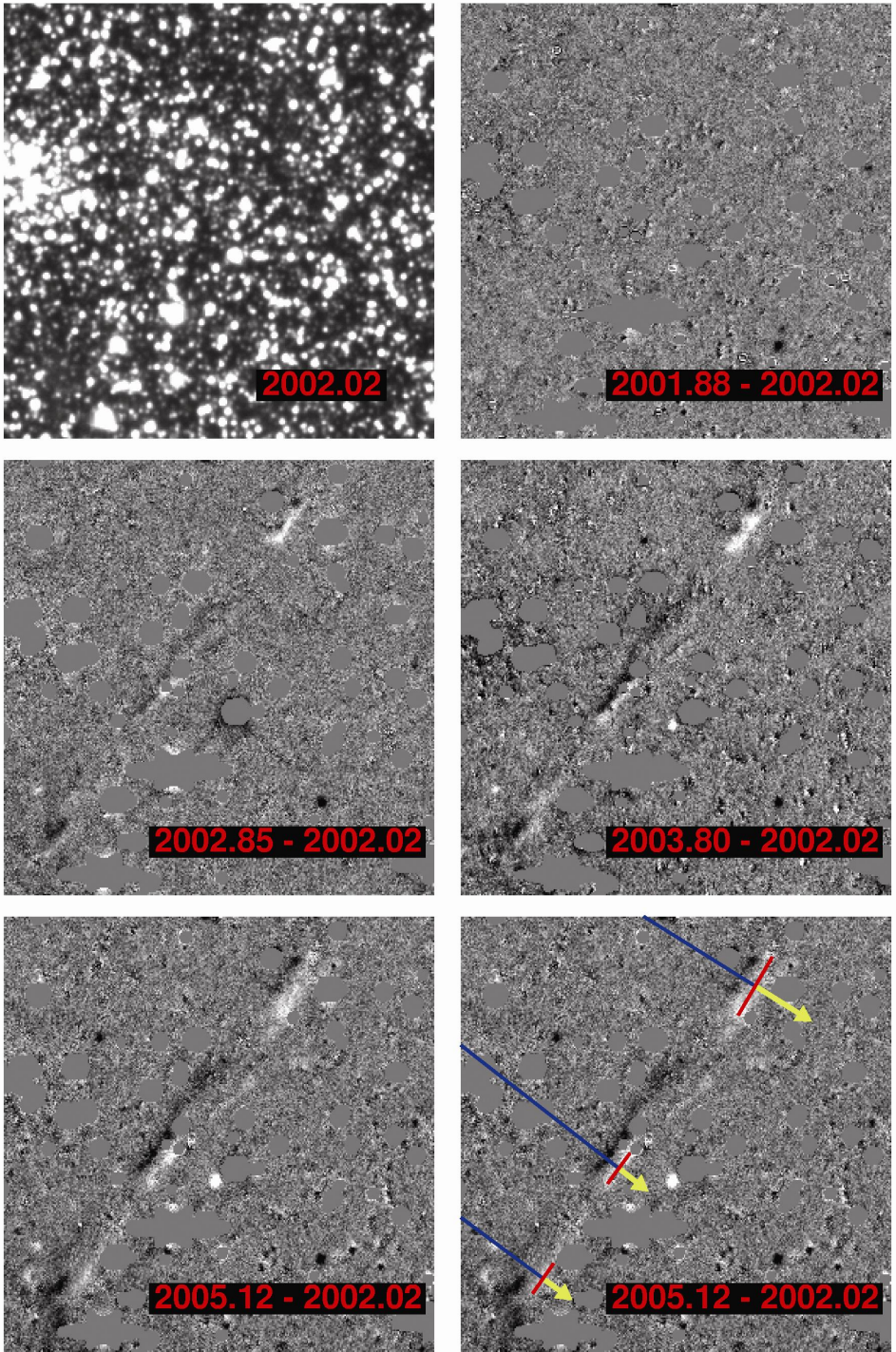
Hughes et. al. (1995)

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

Echo	SNR	Age(yrs)
SN 87A		15.9 ± 1.4
LE1	0519-690	600 ± 200
LE2	0509-675	400 ± 120
LE3	0509-687	(860)

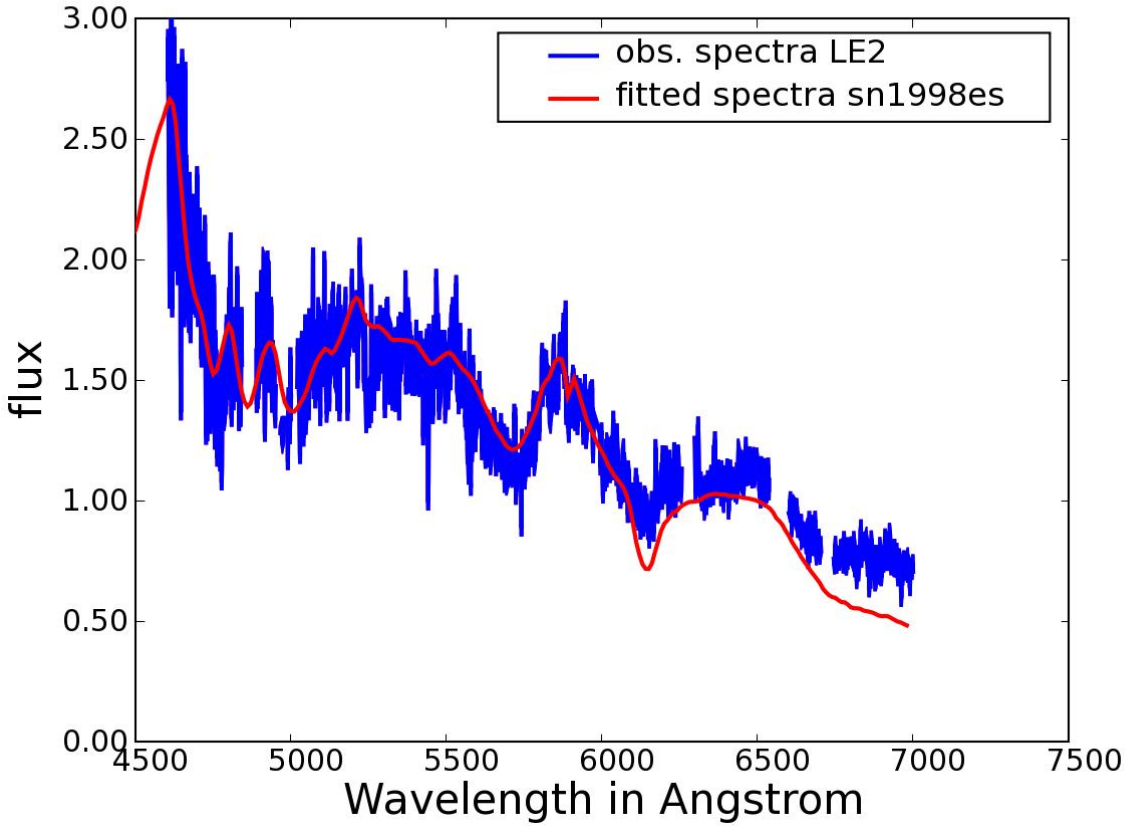
CAVEAT: Assumes perpendicular dust sheet

Light Echoes from a source other than SN 1987A?



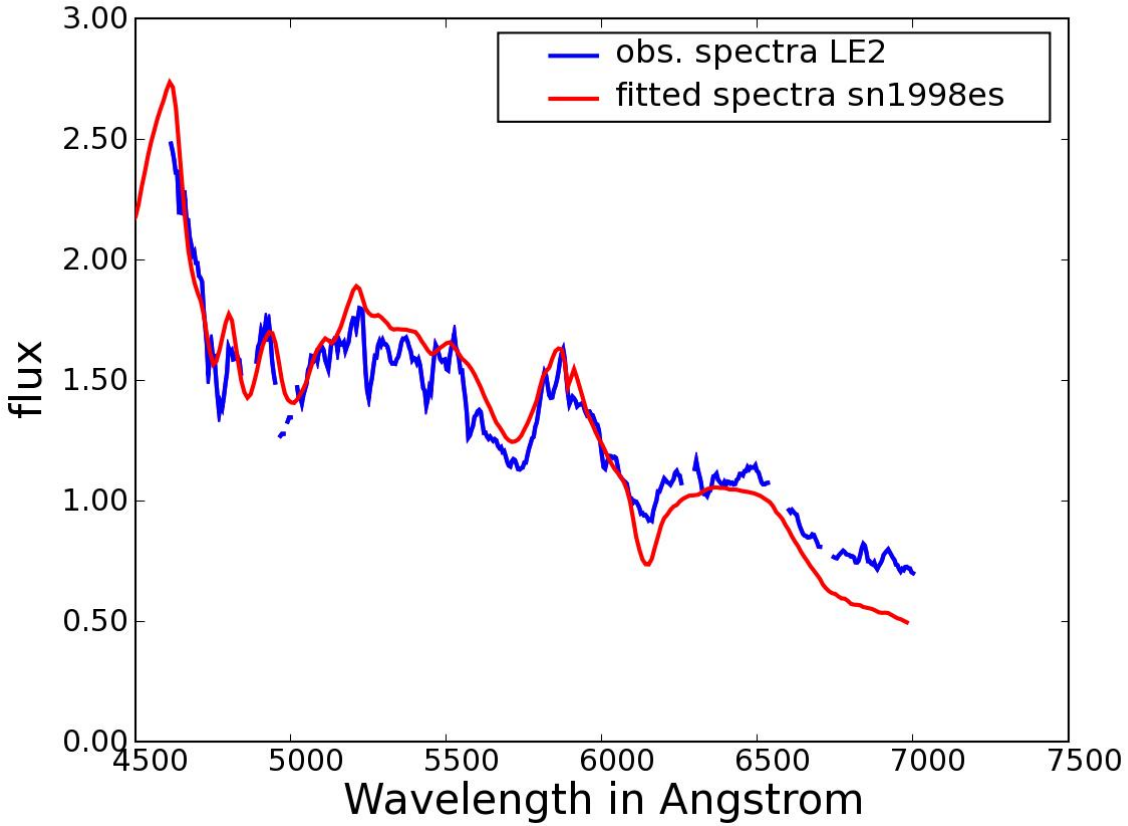
Light Echo Spectrum LE2

- Gemini-S GMOS
- Nod&Shuffle Mode
- Light Echo group LE2 (SNR 0509-67.5)
- SN 1998es (Ia) template fitted (integrated, scattered)



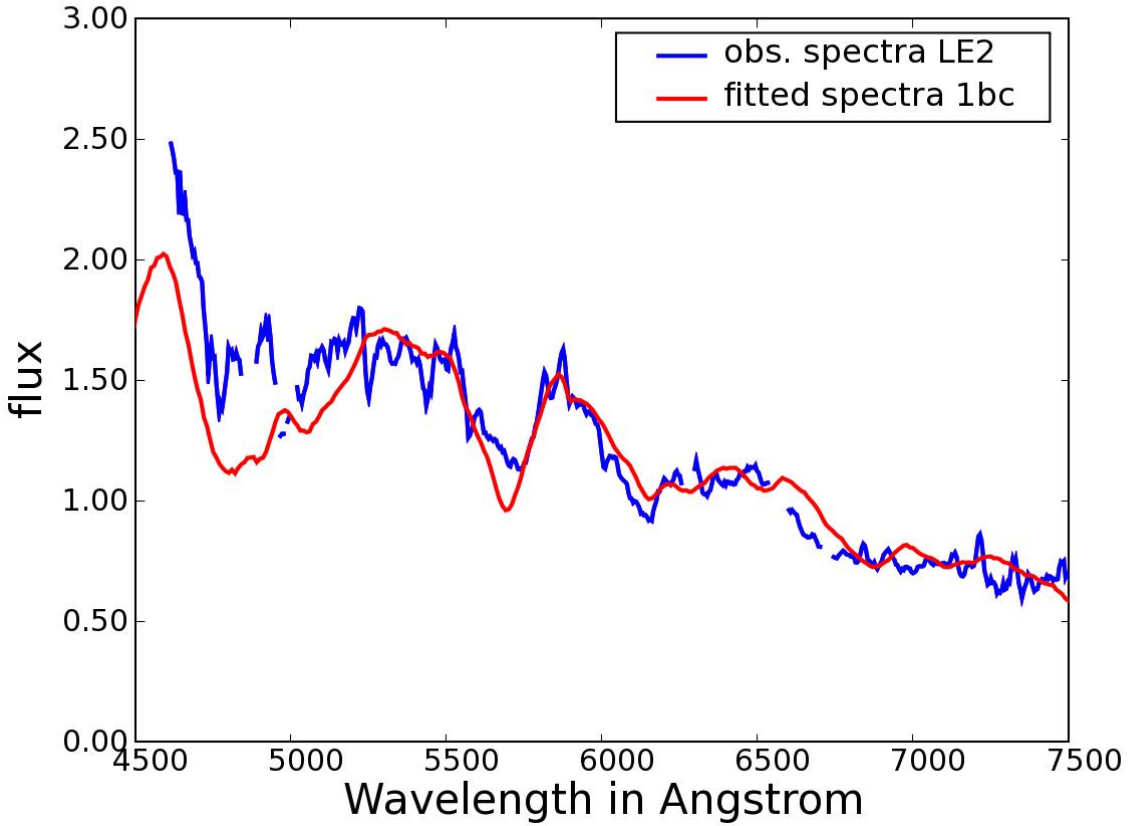
Light Echo Spectrum LE2

- Smoothed observed spectrum (blue)



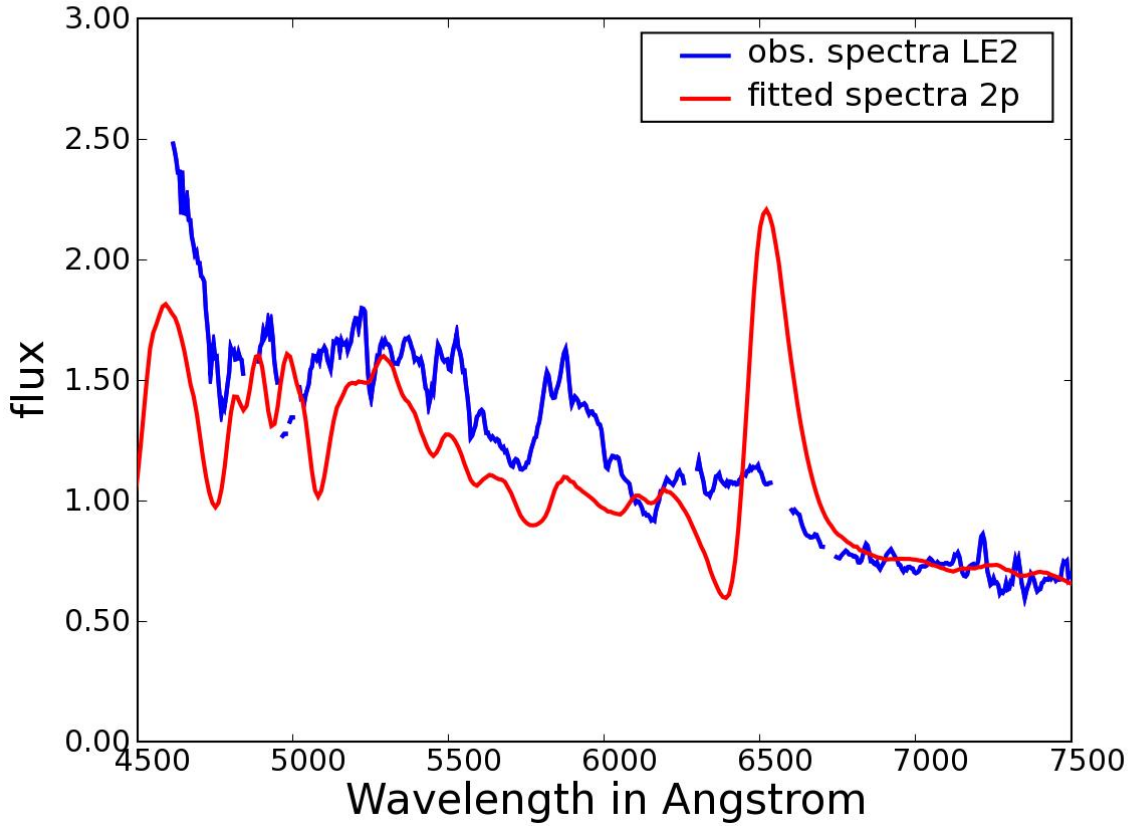
Light Echo Spectrum LE2

- Nugent Ibc template (red)

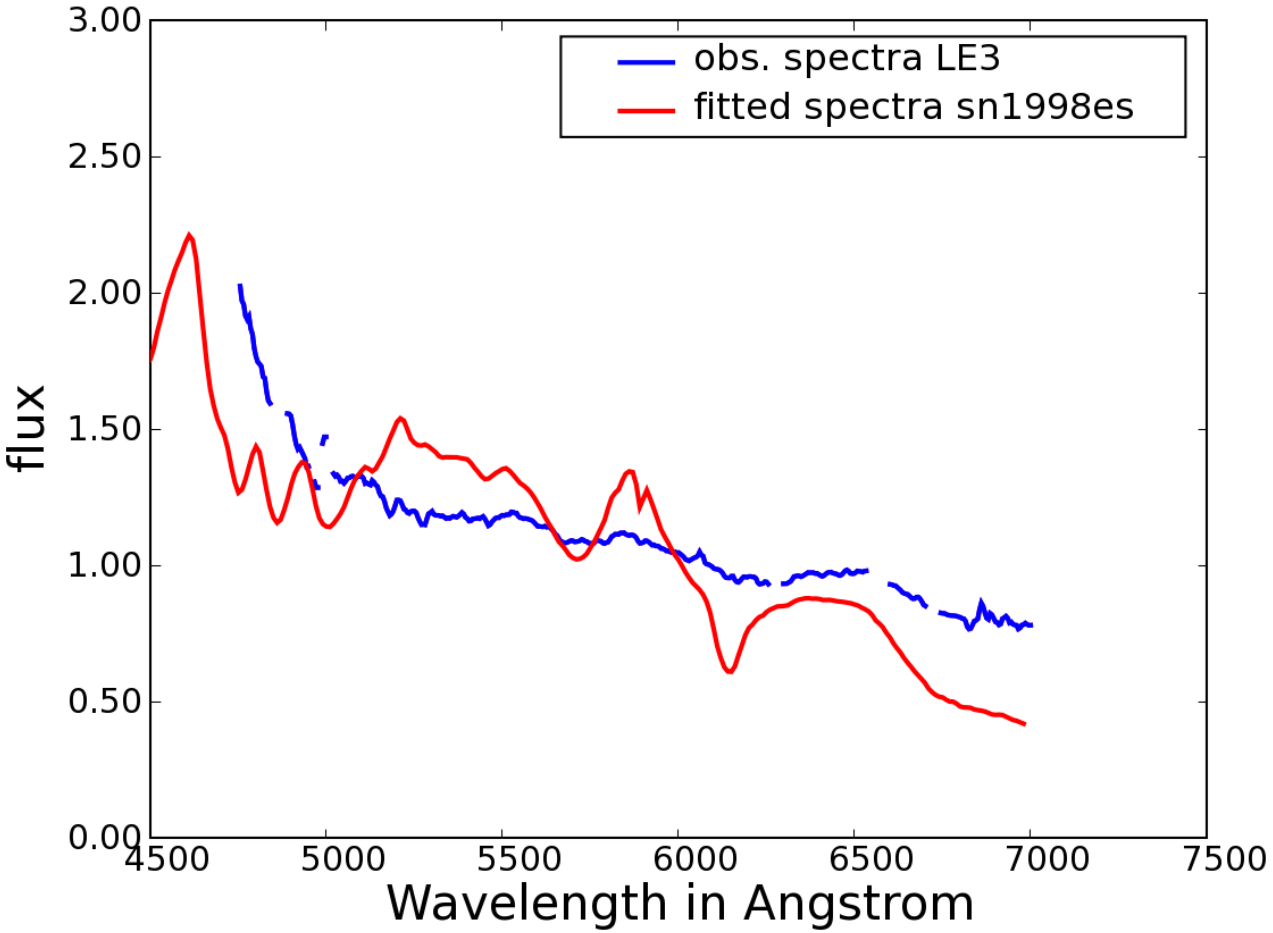


Light Echo Spectrum LE2

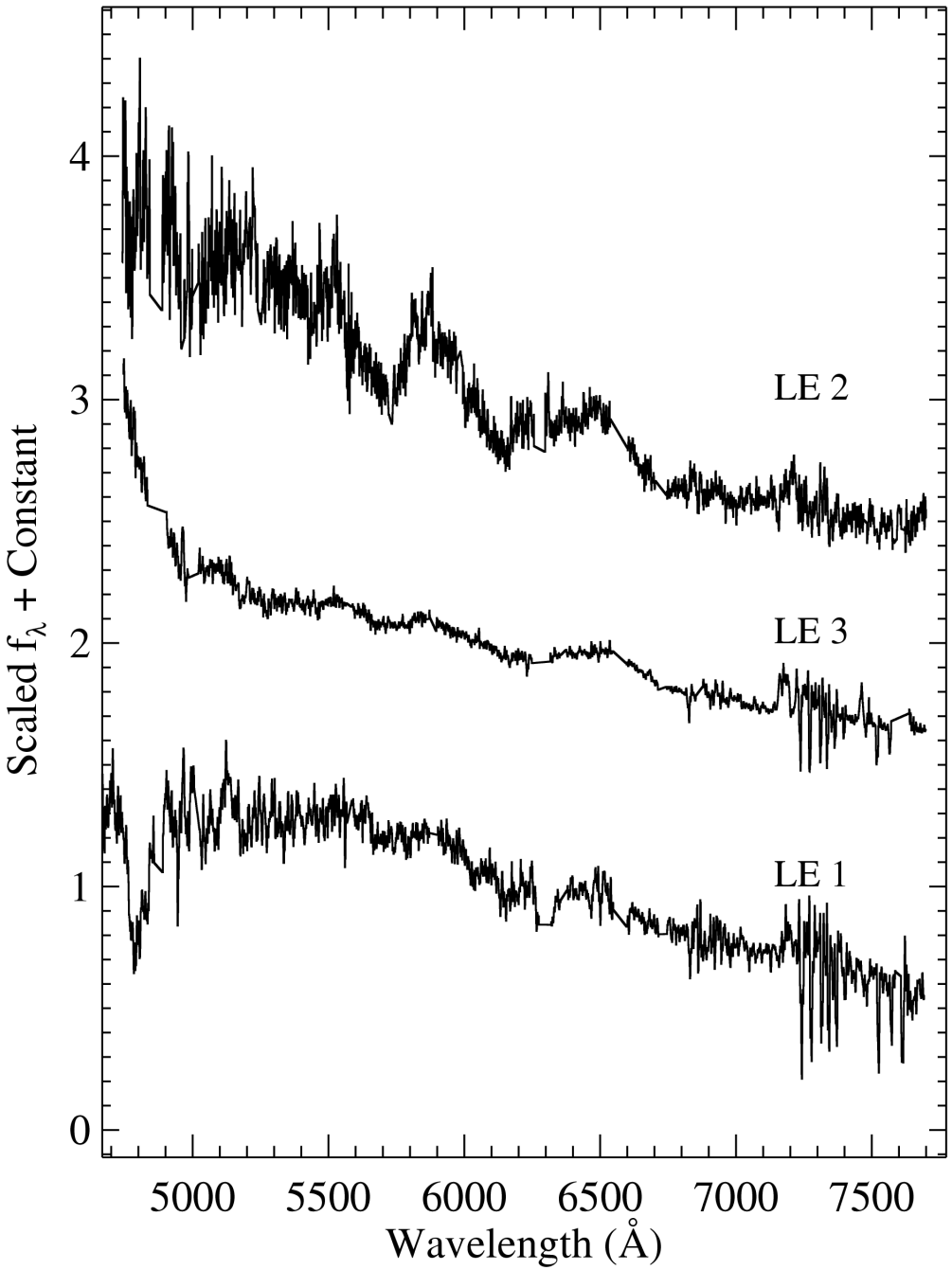
- Nugent IIp template (red)



Light Echo Spectrum LE3



Spectra of all three light echoes



Conclusions

- Light echoes from supernovae are visible hundreds of years after explosion
- Light echoes by themselves allow exploration of three-dimensional structure of dust in nearby galaxies
  - Light echoes of SN 87A in unprecedented detail and depth
  - Extended dust sheet 1 kpc in front of SN 87A
- With spectra of light echoes, we can establish Type Ia/Type II SN rates over baselines of hundreds of years in individual galaxies
- Light echoes offer the *only* opportunity to study both the initial explosion *and* its after-effects in the same objects

Future: Historic Galactic Supernovae

SN name	Explosion date	Type
Cas A	1680 AD?	SN Ib?
Kepler	1604 AD	SN Ia or Ib?
Tycho	1572 AD	SN Ia
SN 1181	1181 AD	?
SN 1006/Lupus	1006 AD	SN Ia
Crab Nebula	1054 AD	SN II
RCW 86	0185 AD	SN II?

Example Galactic SN: Tycho

- V_{max} = -6.5, distance 3100 pc
- Dust sheet 400 pc in front of Tycho:
  - Surface brightness about V=22.0
  - Arcs about 6.5 deg away from SNR
  - Apparent proper motion: 30”/yr
  - Light echo width 30”