
SN 1987A with HST
Robert Kirshner & the SAINTS

Observing Supernovae with HST

Supernova INtensive Study

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Panagia, Scuderi Garnavich
Fransson
Chevalier, Plait
Wheeler, Clocchiatti, Wang
Branch
Wagoner, Montes
Phillips, Suntzeff
Fillippenko

Observations of SN 1987A

+ A supernova to be named later

Cycle 1, 2, 3, 4 Early & late

Investigators:

	Investigator	Institution	Country
PI	Dr. Robert P. Kirshner	Harvard University	USA/MA
CoI	Dr. Patrice Bouchet	CEA/DSM/DAPNIA/Service d'Astrophysique	France
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CoI	Dr. John I. Danziger	INAF, Osservatorio Astronomico di Trieste	Italy
CoI	Dr. Eli Dwek	NASA Goddard Space Flight Center	USA/MD
CoI	Dr. Kevin France	University of Colorado at Boulder	USA/CO
CoI	Dr. Claes Fransson	Stockholm University	Sweden
CoI	Dr. Peter Garnavich	University of Notre Dame	USA/IN
CoI	Dr. Kevin Heng	ETH Zurich Institute for Astronomy	switzerland
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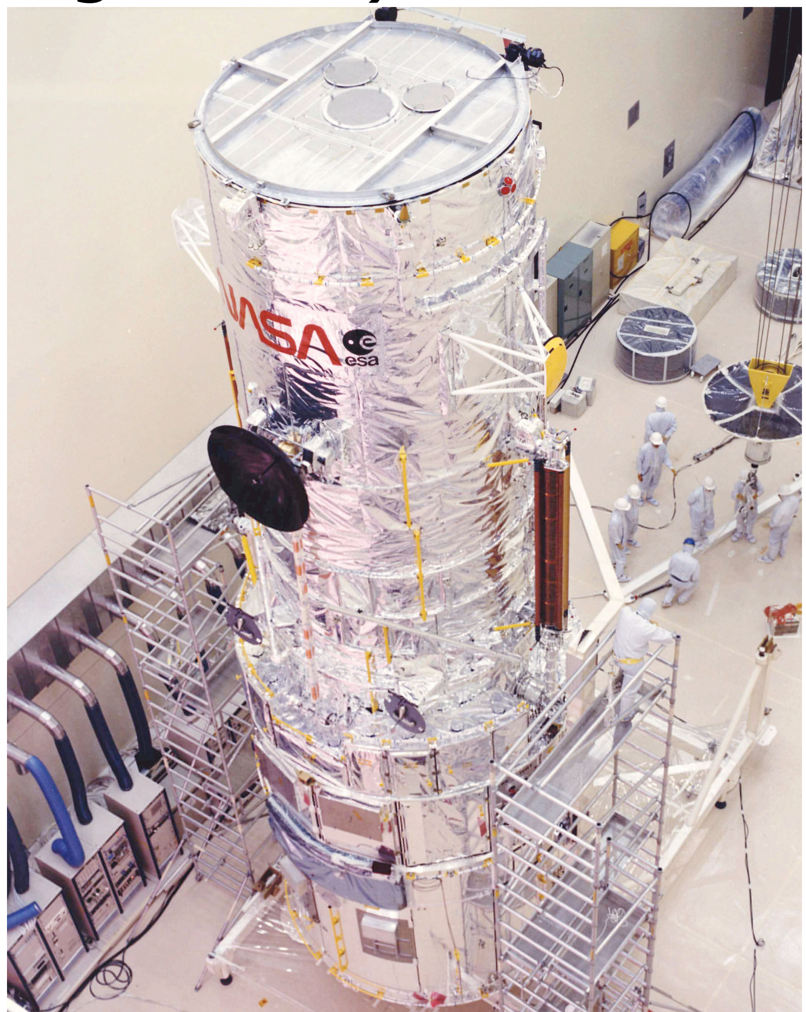
CoI	Prof. Nino Panagia	Space Telescope Science Institute	USA/MD
CoI	Dr. Jason Pun	University of Hong Kong	China
CoI	Dr. Nathan Smith	University of Arizona	USA/AZ
CoI	Dr. Jesper Sollerman	Stockholm University	Sweden
CoI	Dr. George Sonneborn	NASA Goddard Space Flight Center	USA/MD
CoI	Dr. Ben E. Sugerman	Goucher College	USA/MD
CoI	Dr. Nicholas B. Suntzeff	Texas A & M Research Foundation	USA/TX
CoI	Dr. Lifan Wang	Texas A & M Research Foundation	USA/TX
CoI	Dr. J. Craig Wheeler	University of Texas at Austin	USA/TX

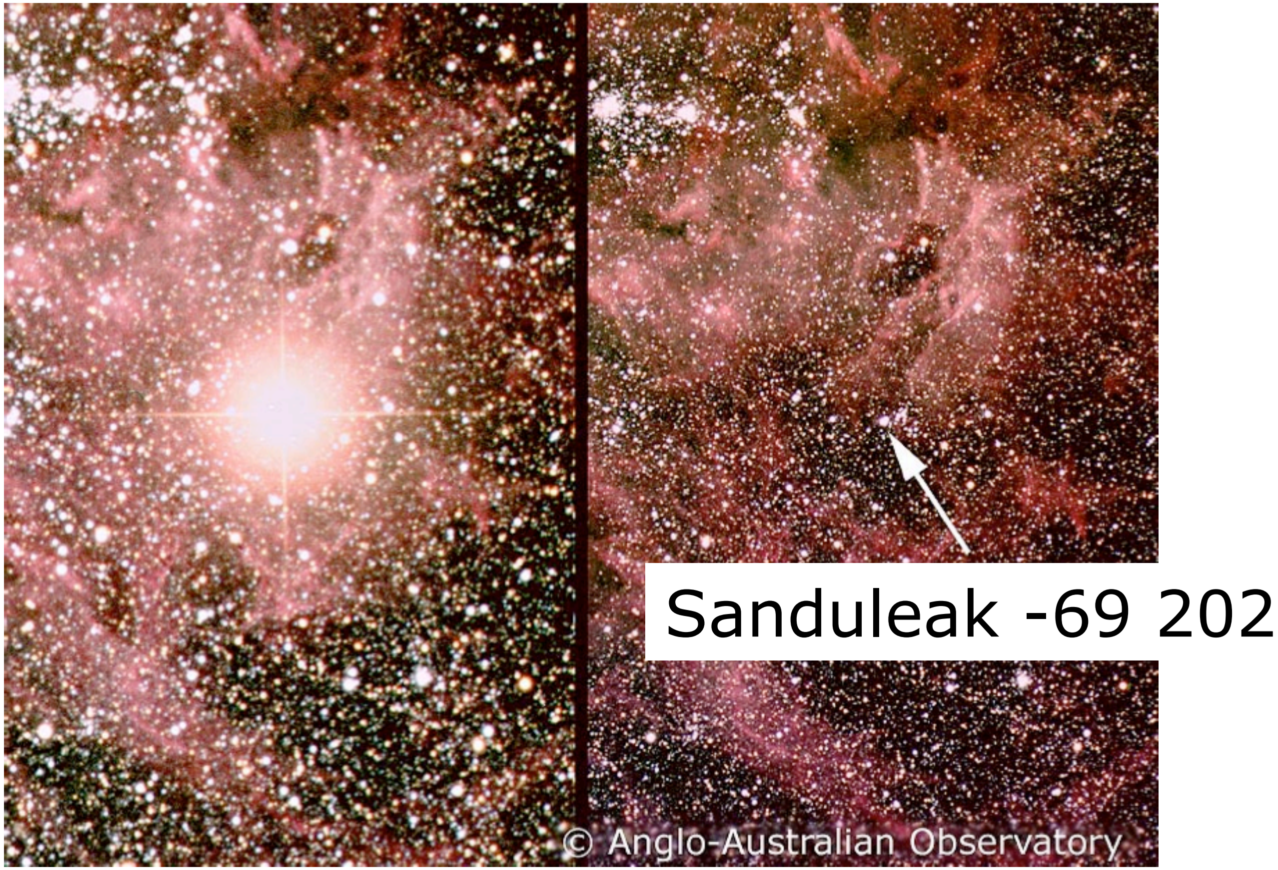
Number of investigators: 25

SN 1987A & HST

Discovered in February 1987 (while HST was on the ground!)



SN 1987A



A page from Nick Sanduleak's Catalog of bright stars in the LMC

TABLE III (cont.)

Star	Chart	R.A.	Minu: Dec.	Sp.	Mpg	Other designations
			-69° Zone (cont.)			
181	45b	$5^h32^m.5$	69°14'	OB	12.0	
182	45b,53	33.2	24	F2I	11.5	269735, FDD
183	53	33.3	31	WR:	14.1	
184	53	33.7	20	OB	13.0	
185	53	33.8	08	OB:	12.7	
186	53	33.9	28	OB	12.6	
187	53	34.1	33	OB	12.5	
188	53	34.3	00	AOI	11.4	269762, FDD
189	53	34.3	04	OB	12.3	FDD
190	53	34.5	02	A7I	12.5	
191	53	$5^h34^m.6$	69°46'	WR	13.4	37680, WS 35, L-286
192	53	34.7	11	OB	12.6	
193	53	34.8	48	OB	11.7	269769, -69°392, W 28-3
194	53	34.8	47	OB	12.2	W 28-10, L-289
195	53	35.1	15	OB	13.1	
196	53	35.1	39	OB	12.4	W 28-32
197	53	35.2	45	OB	12.2	269784, W 28-29
198	53	35.3	45	WR:	14.1	W 28-30
199	53	35.3	00	OB	12.8	
200	53	35.3	46	OB	11.3	269786, -69°399, W 28-34
201	53	$5^h35^m.5$	69°42'	OB(e)	1[illegible].9	37836, R 123, W 28-39, S 124, L-291
202	53	35.6	18	OB	1[illegible].2	
203	53	35.6	15	OB	1[illegible].5	
204	53	35.6	28	OB	11.6	
205	53	35.7	43	OB	[illegible]2.2	W 28-47, L-294?
206	53	35.8	08	OB	[illegible]3.3	
207	53	35.9	12	WR	14.3	269818, WS 36
208	53	35.9	30	OB	12.8	
209	53	36.1	32	OB	11.7	
*209a	53	36.1	13	WR+OB	10.9	269828, -69°409, WS 38
210	53	36.2	03	OB	13.1	W 27-27
211	53	$5^h36^m.3$	69°25'	OB	11.0	269832, -69°414, FDD
212	53	36.3	13	OB	12.0	
213	53	36.4	12	OB	12.5	
214	[illegible]	36.4	33	OB	12.3	
215	53	36.5	08	OB	11.7	269846, -69°417
216	53	36.7	24	Be	11.6	37974, R 126, S 127, AL-361, -60°4[illegible]2
216a	53	36.8	50	OB	13.1	
217	53	36.8	30	OB	12.1	
218	53	36.8	31	OB	12.0	
219	53	36.8	10	F2I:	12.0	269860, -69°422, FDD
220	53	36.9	31	Bep	11.4	269858, -69°427, R 127, S 128, AL-363, FDD
221	53	$5^h37^m.0$	69°31'	OB	10.1	269859, -69°428, R 128
222	53	37.1	27	WR	13.4	38030, WS 39
*223	53	37.1	13	WR	14.2	38029, WS 40
224	53	37.1	13	OB	11.8	
225	53	37.1	17	B8I	12.6	
226	53	37.2	31	OB	12.1	
227	53	37.3	39	OB	12.4	W 28-93
228	53	37.3	21	OB	12.1	
229	53	37.4	31	OB	12.5	
230	53	37.6	27	OB	12.6	
231	53	$5^h37^m.7$	69°22'	WR	13.7	WS 41
232	53	37.8	43	OB(e:)	12.8	
233	53	37.8	09	WR	14.1	269883, AL-369
234	53	37.9	15	WR	14.5	269888, WS 42
235	53	37.9	06	WR+OB	11.7	269891, -69°442, R 130, WS 43
236	53	38.0	25	OB	12.2	
237	53	38.2	23	CP	12.3	

Nothing special noted about -69 202

The events in the inside before collapse were not apparent on the outside of the star.

Supernova 1987A • December 6, 2006

Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, P. Challis, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics)

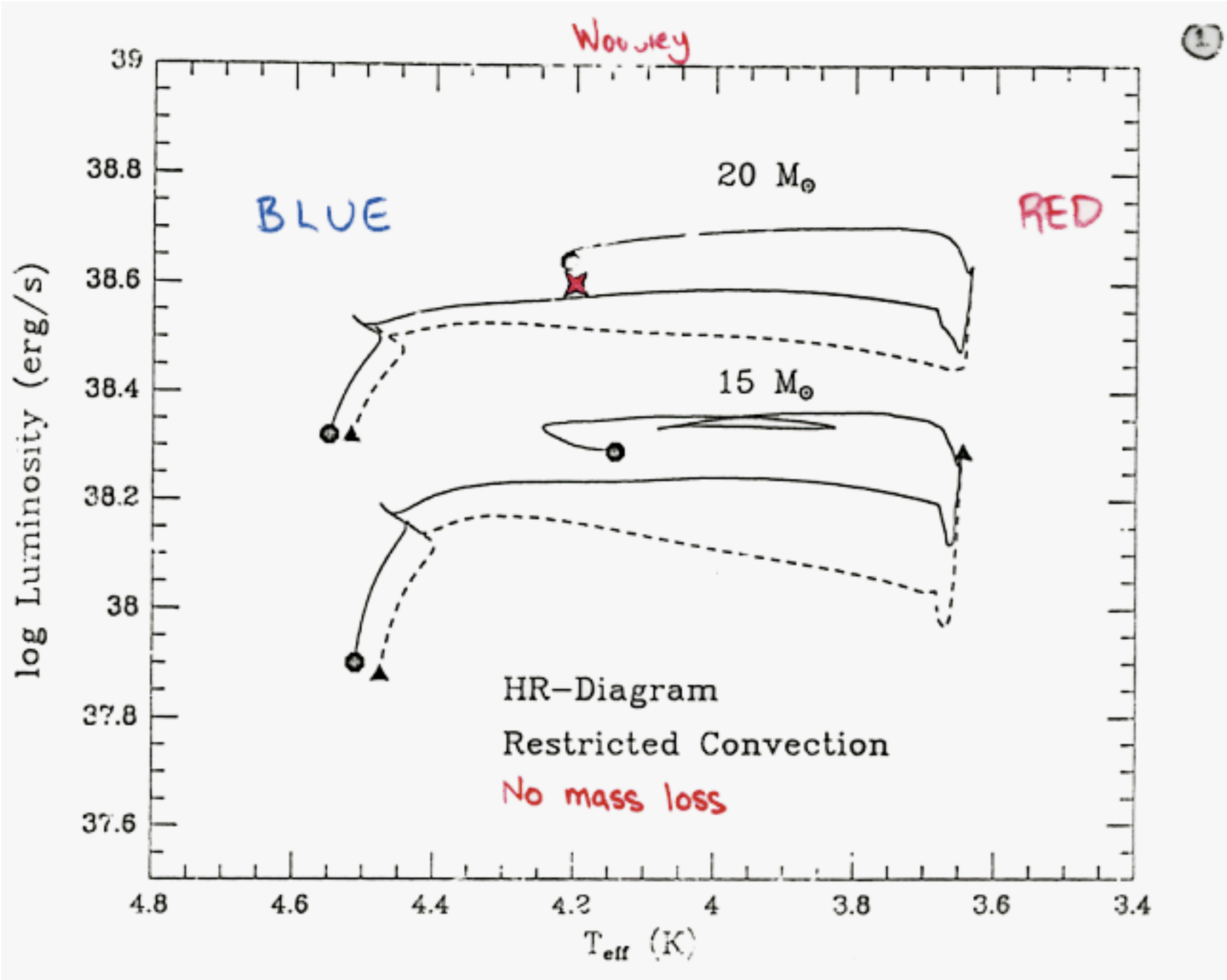
STScI-PRC07-10a

Coincidence is not enough!
You need to show that the progenitor has disappeared.

Properties of Sk -69 202

- Luminosity ~ 10^5 L_{sun}
- Temperature ~ 15 000 K
- Radius ~ 40 R_{sun}
- About 6 M_{sun} in the core (He and beyond)
- Main sequence mass ~20 M_{sun}

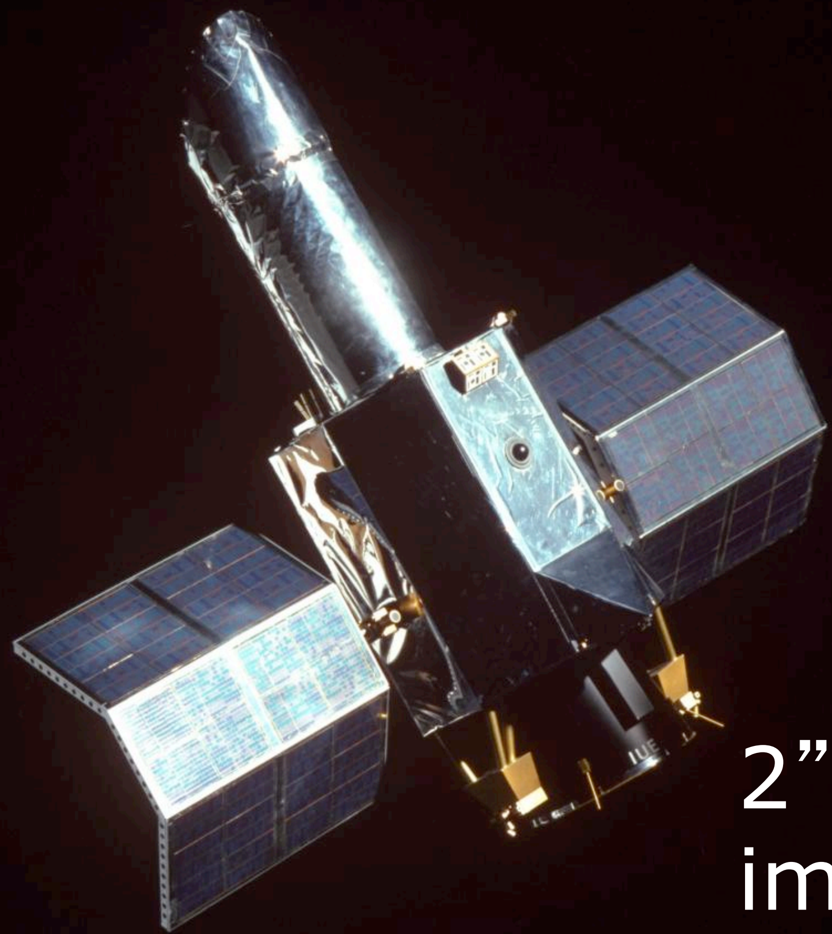
The Evolution of a Massive Star




World's Tallest Bear
Kodiak
Bear
2.86m
how do you compare to a bear?
1.5 metres

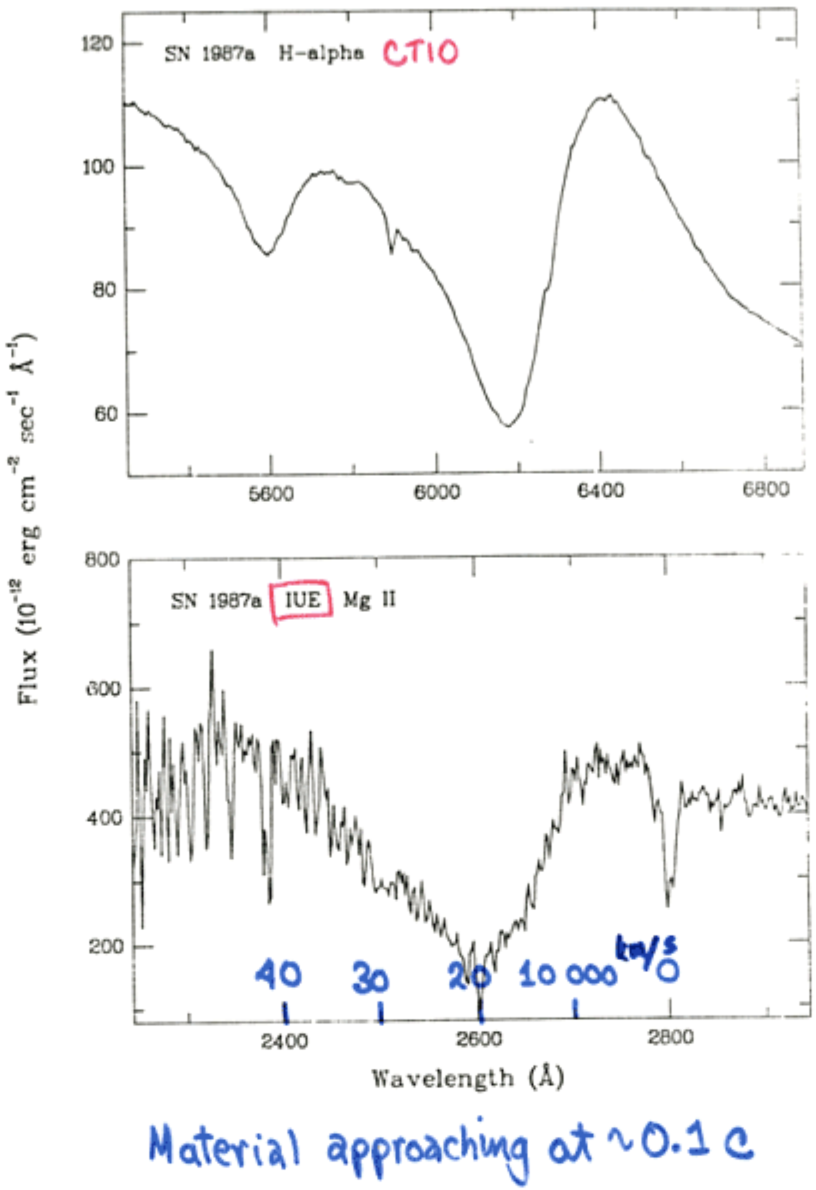
How big?

45 cm telescope!



2”
imaging

Expanding debris + external target



If distance to ring ~200 light days and

Velocity of the fastest debris ~ 1/10 c

Then we should expect some interaction in about 2000 days ~ 7 years ~1994

First evidence in 1995!

THE JOHNS HOPKINS UNIVERSITY
HOMEWOOD
TEMPORARY PARKING PERMIT

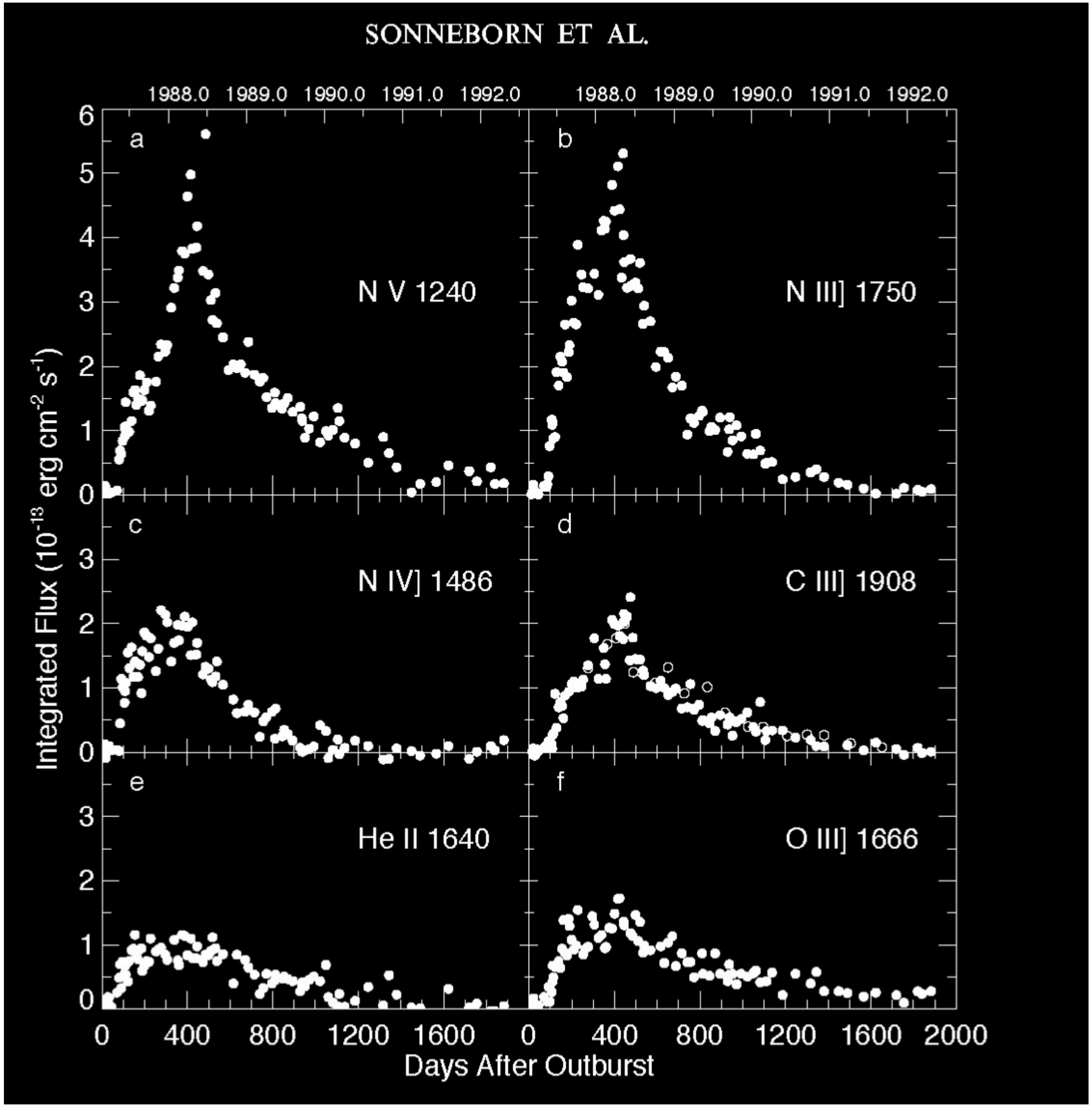
Area TYPE-II ONLY   Lic. No. GUEST

Dept. Meeting

Date Feb. 20-1986

Permit No. 319   Robert L. Larkin
AUTHORITY

PLACE THIS CARD IN FRONT WINDOW, DRIVERS SIDE



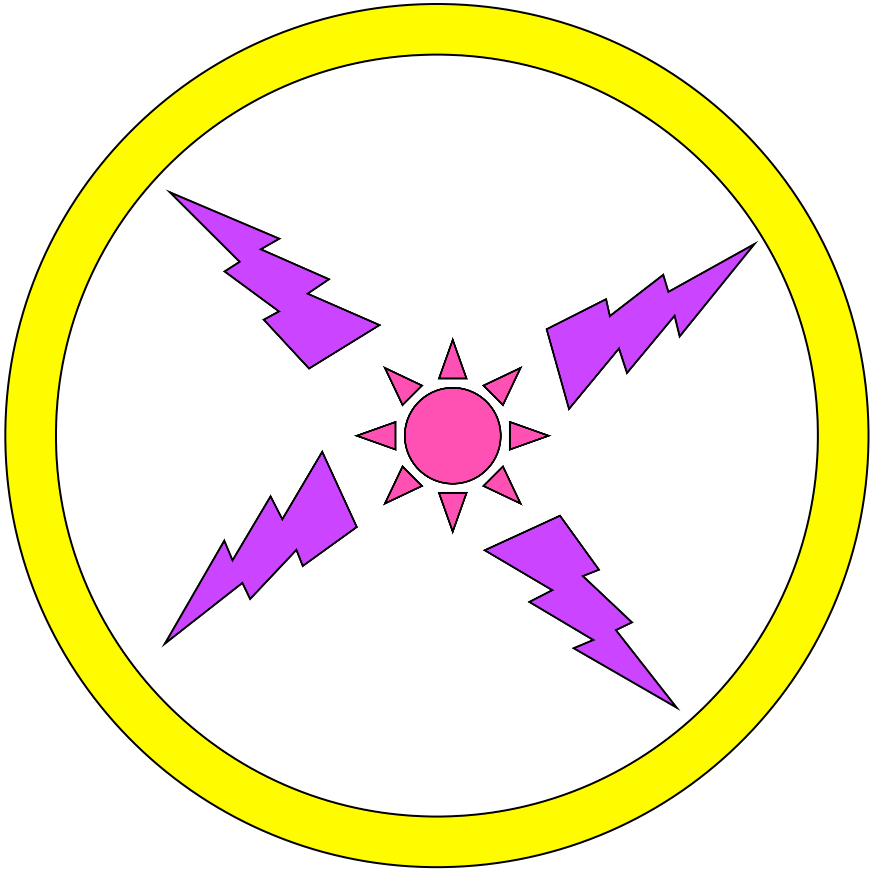
UV emission: delay, then peak after 400 days

Mental Image before HST

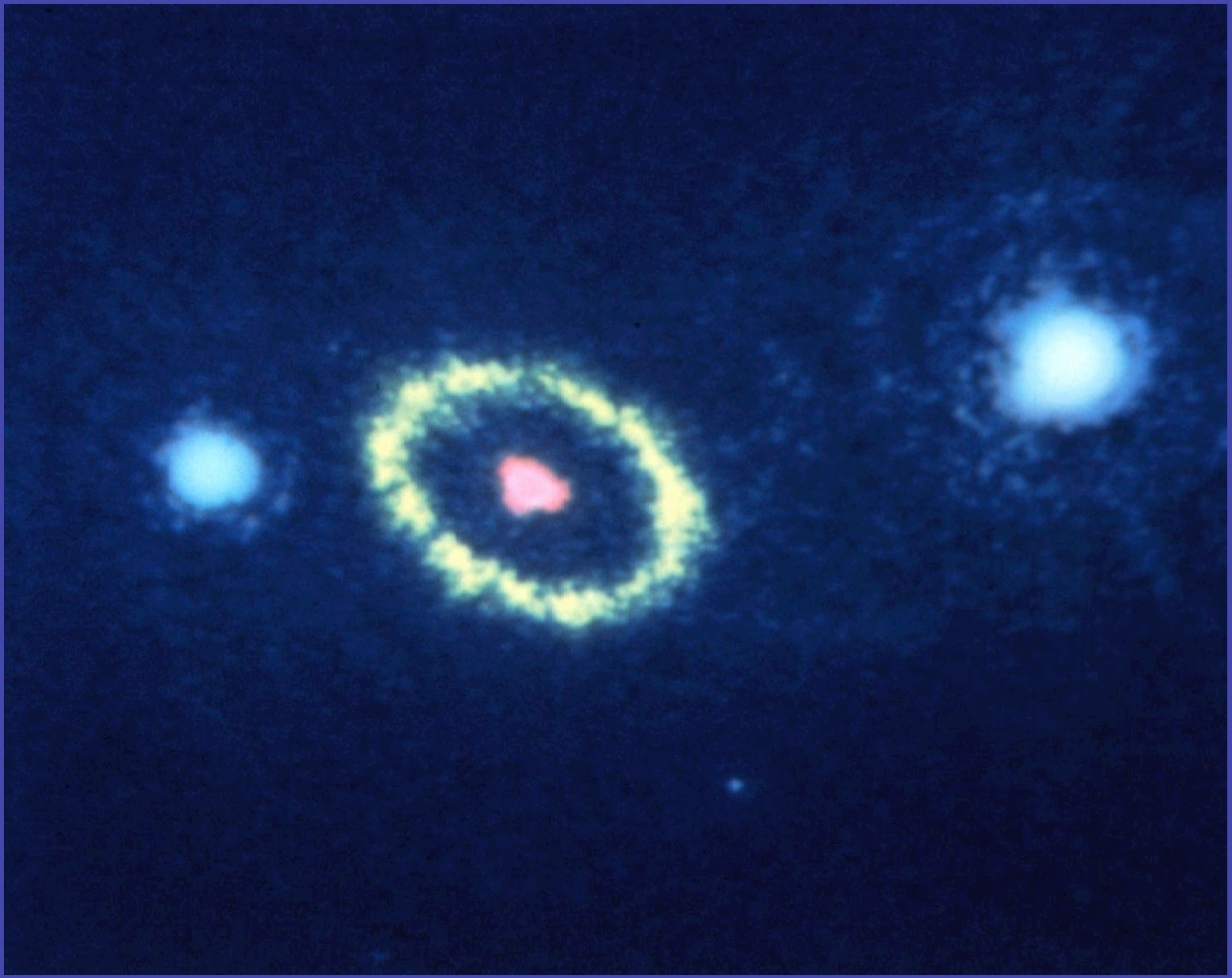
UV burst from SN exciting a shell of pre-existing gas from mass loss

t_{max}~400 days

R~ ct/2~200 light days



1990 Image from HST



Science

The Puzzling Pulsar That Wasn't There

A one-shot observation of supernova 1987A last year revealed a pulsar that seemed too bizarre to be real—and it wasn't

AFTER TANTALIZING THEORISTS and frustrating observers for more than a year, the mysterious pulsar signal from Supernova 1987A will trouble astronomers no more: the observers who saw it during its one and only appearance in January 1989 have now concluded that the signal was spurious, the result of interference between their detector and other electronics in the telescope.

"I'm a little bit let down and a little bit disgusted," says astronomer John Middleditch of Los Alamos National Laboratory, one of the principals in the discovery group* and until now one of the most articulate defenders of the data. "We regret this. But what can I say?"

Not much, except perhaps to express relief that he and his colleagues caught the error themselves—about a week before their review article on the pulsar signal was to go to press in *Science*.

In fairness, however, neither Middleditch nor his colleagues were alone in their enthusiasm. Not only did the observation seem to offer astronomers a once-in-a-lifetime chance to study a pulsar at virtually the moment of its creation, but *this* pulsar was so bizarre that it might have rewritten the physics texts. Says another leading supernova observer, Robert Kirshner of the Harvard-Smithsonian Center for Astrophysics, "It's too bad [it wasn't real]. It was such a weird pulsar."

There was nothing weird about finding a pulsar per se, of course. People had been watching for it practically from the first minute the supernova went off. The explosion itself had presumably been triggered as the ultradense core of a very massive star collapsed inward under its own weight; the formation of a pulsar—the remnant of the core once gravity had compressed it into a furiously rotating ball of solid neutrons—was therefore almost inevitable. All the astronomers had to do was wait until the supernova's expanding shell of debris had thinned out enough to let the pulsar shine through. And on the night of 18 January 1989, that moment seemed to have arrived.

Working at the Cerro Tololo observatory in Chile, Middleditch, and his colleagues detected a very faint, very rapid, but very definite flickering in the light from supernova 1987A. Extracting the signal required massive amounts of computer analysis. But when that was done, the signal was clearly present for the whole 7-hour period that the supernova had been under observation. Moreover, the signal disappeared just the way it should have when the astronomers turned their telescope away from the supernova and checked it against another source, a nearby globular cluster.

The discovery caused a sensation in the astronomical community. The pulsar seemed to be rotating so much faster than any other known pulsar—1968.629 times per second—that it should have been on the ragged edge of breaking apart. Could it be that the physicists' theories of pulsar structure were wrong, that nuclear matter is actually much tougher than it seemed? Theorists quickly rushed in with whole new sets of equations that said Yes, it was. Or could it be that the pulsar was not rotating at all, but vibrating like a bell that has somehow been given a sharp blow? Other theorists explained exactly how this would work.

And then there was the intriguing fact that the time between the pulsar's flickers varied over the 7-hour interval in a smooth sinusoid, just as if it were being tugged back and forth by an orbiting companion with roughly the mass of Jupiter. Could it be that the pulsar was rotating so fast that it *had* broken apart and sent a fragment into orbit?

"I'm a little bit let down and a little bit disgusted."

No one could say—which is why everyone waited eagerly for confirming observations. And yet those observations never came, despite the best efforts of observers all over the world. Middleditch and company checked and rechecked their equipment. They analyzed and reanalyzed the 18 January data for internal consistency. They took refuge in the hope that the expanding supernova shell was turbulent and patchy—that the pulsar had just happened to shine through a thin spot on 18 January and would one day shine again. Their one night of data looked unassailable. But the pulsar remained hidden.

The awful truth began to dawn only in January of this year, when the group was making yet another attempt to find the pulsar from the Las Campanas observatory in Chile. They saw a clear signal at 7874 cycles per second—far too fast for any conceivable pulsar, and worse, precisely four times the frequency they had seen a year earlier. The situation reeked of electrical interference. If that were the case, moreover, there was only one piece of electronics in the telescope that could be responsible: a television camera used to transmit an image of what the telescope was seeing to the observatory control room. And most disturbing of all, this camera was the same type as the one used at nearby Cerro Tololo, where the group had made their original observation.

The researchers' worst suspicions were confirmed after they went back to Cerro Tololo for further observations on the night of 5–6 February. When Middleditch completed the computer analysis on the evening of Sunday, 11 February, he knew: the data showed precisely the same kind of signal they had seen a year earlier, with precisely the same frequency and much the same kind of slow variation—except that this time, the telescope had been looking not at supernova 1987A, but at the well-known (and very different) pulsar in the Crab nebula.

So—what happened? Why didn't the camera's interference show up in any of the group's other observations during the past year, or in any of their many calibration tests? No one knows, says Middleditch. Perhaps the effect is temperature-related since January is a summer month in Chile.

But, he says, it's all too easy to see in retrospect why the signal went away on 18 January when the researchers moved the telescope from the supernova to the globular cluster. That observation was made as dawn was beginning to light the sky. And the cameras, which are extremely sensitive, were turned off to protect them from damage. "It was good observing practice," says Middleditch, "but bad scientific method."

Embarrassing? Of course. And yet Kirshner, for one, is not unsympathetic. "You don't want to be too hard on these guys," he says. "A lot of people are going to say 'Har, Har, I knew it all the time!' But I don't know—their data looked very nice." And it had a lot of astronomers convinced.

■ M. MITCHELL WALDROP

*J. Kristian, *et al.*, "Submillisecond pulsar in supernova 1987A," *Nature* 338, 234 (1989).

Pulsar reported, then retracted-- science is not a smooth path!

See *The Extravagant Universe* for more details

2005 Senior Thesis by Jenny Graves-- best limit on a neutron star or black hole at the center of SN 1987A

We have done ~ 3 x better as the debris has faded.

Is the ring around SN1987A excited by a central pulsar?

A.C. Fabian

Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK

Submitted to Nature, 1991 Jan 2

A bright ring of optical emission, with a maximum radius of about 1.2 arcsec, has been discovered[1–4] around SN1987A. A detailed image of it has been obtained with the Hubble Space Telescope[5]. Most of the emission appears to be line radiation, with the line of [OIII] particularly strong[4]. It is proposed here that the ring is excited by a pulsar in the centre of the remnant. The apparent thinness of the ring then reflects the narrowness of the pulsar beam, which does not intersect our line of sight but is inclined to it at about 50 deg. A comparison of the line luminosity of the ring with that of planetary nebulae in the Large Magellanic Clouds shows that the proposed pulsar has an ultraviolet luminosity of about $10^{38}\,\mathrm{erg\,s^{-1}}$.

SN 1987A with HST

Bright neighbors made ground-based work very difficult

Things got better after COSTAR

3-rings (complex mass loss ~10^4 years before the explosion)

FOUR YEARS OF SN 1987A!

"The best years of our lives" Arnett, Bahcall, Woosley
"I hope not" Kirshner

COME CELEBRATE, EXPAND, FLUORESCE, COLLAPSE, SHOCK, RADIATE, AND FORM DUST!

SATURDAY MARCH 2, 1991

$7^{\underline{30}}$ pm

Bring a friend

The Kirshners'
174 Walden St
Concord
(508) 371-2674
or
TICKETRON

finding chart on reverse

N

E

F501N

Robert Kirshner & Jayne Loader

present

SINS '97 – The Dinner, The Collison, The Glow

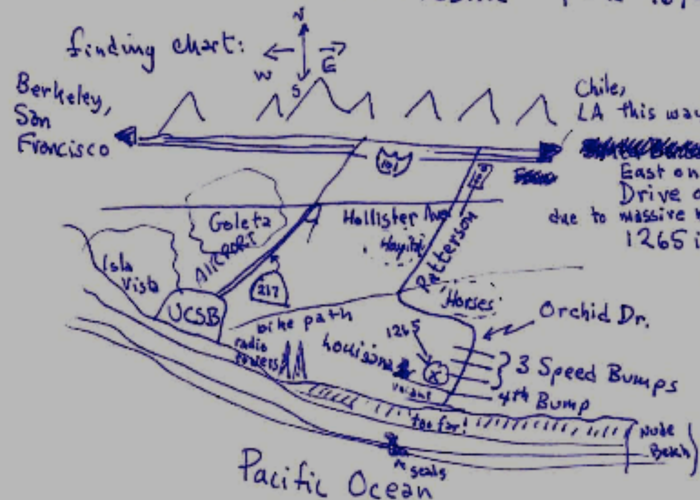
Who: The SINS Team and some who are without SINs.

What: Totally informal buffet and mental feast (bring your own brain)

When: Wednesday, August 6, 7 PM

Where: 1265 Orchid Drive : phone 967-6184

finding chart:



From UC vicinity —
East on Hollister to Patterson
Drive on Patterson toward the ocean —
due to massive neutrino, it becomes Orchid Dr. in ~1 mile
1265 is located at the
4th Speed Bump
on Orchid Dr — on your
right at the intersection
of Louisiana Place
Park near the vacant lot.

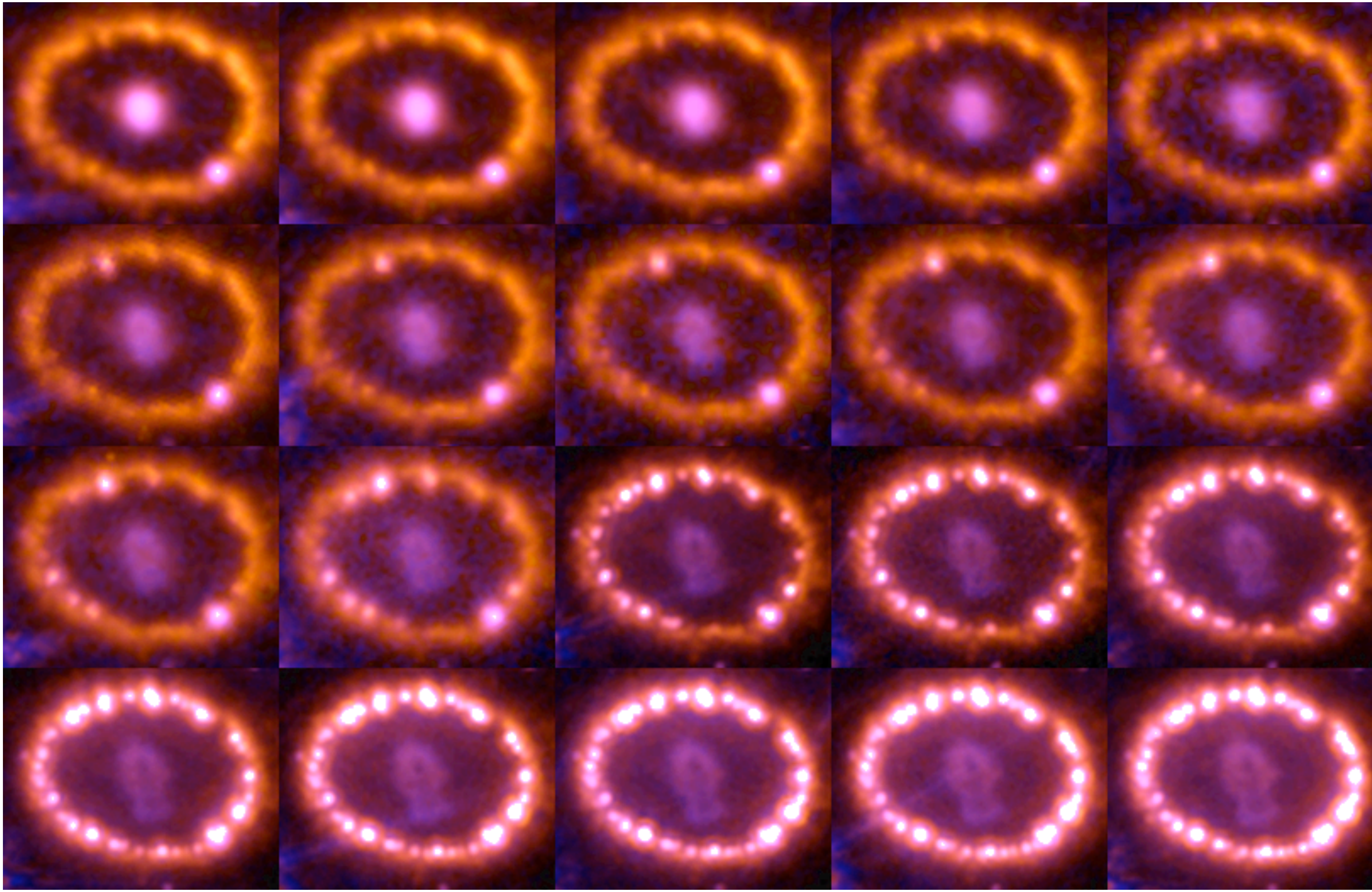
⇒ MORE SINS events —

Please contact RPK concerning your contribution title & schedule!

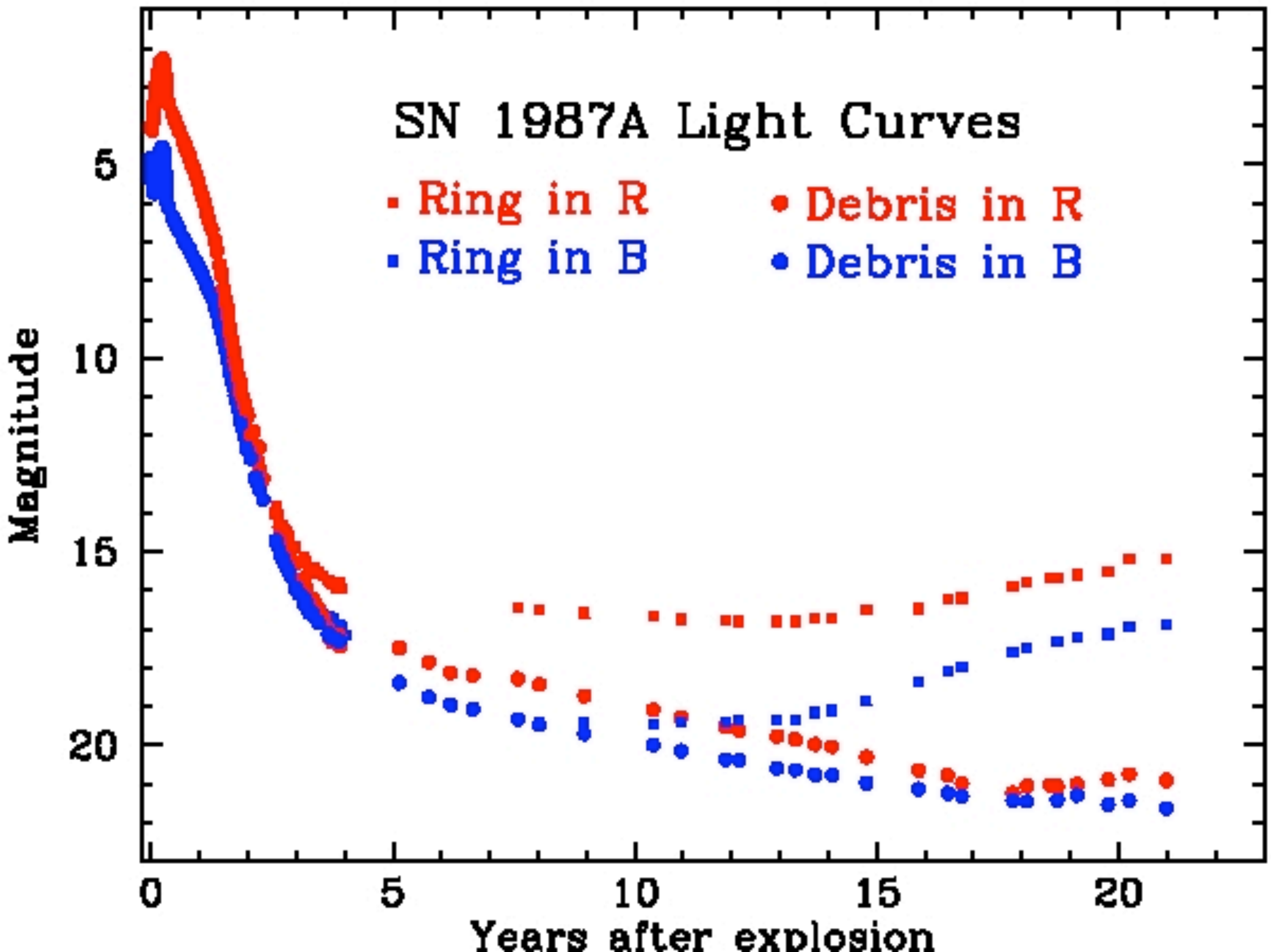
Sunday, 9 AM at the ITP — seminar room
⇒ review of SINS observations & interpretation {please contact RPK!}
4 PM — adjourn to Orchid Dr for beach & nourishment
bring your swim suit (or use the nude beach)

Monday 9AM — 12 noon +/-
⇒ plans for SINS Cycle 7^{+}, Cycle 8, ToO
⇒ 2-3 PM budget meeting for Co-I's only
3 PM - 5PM more discussion...

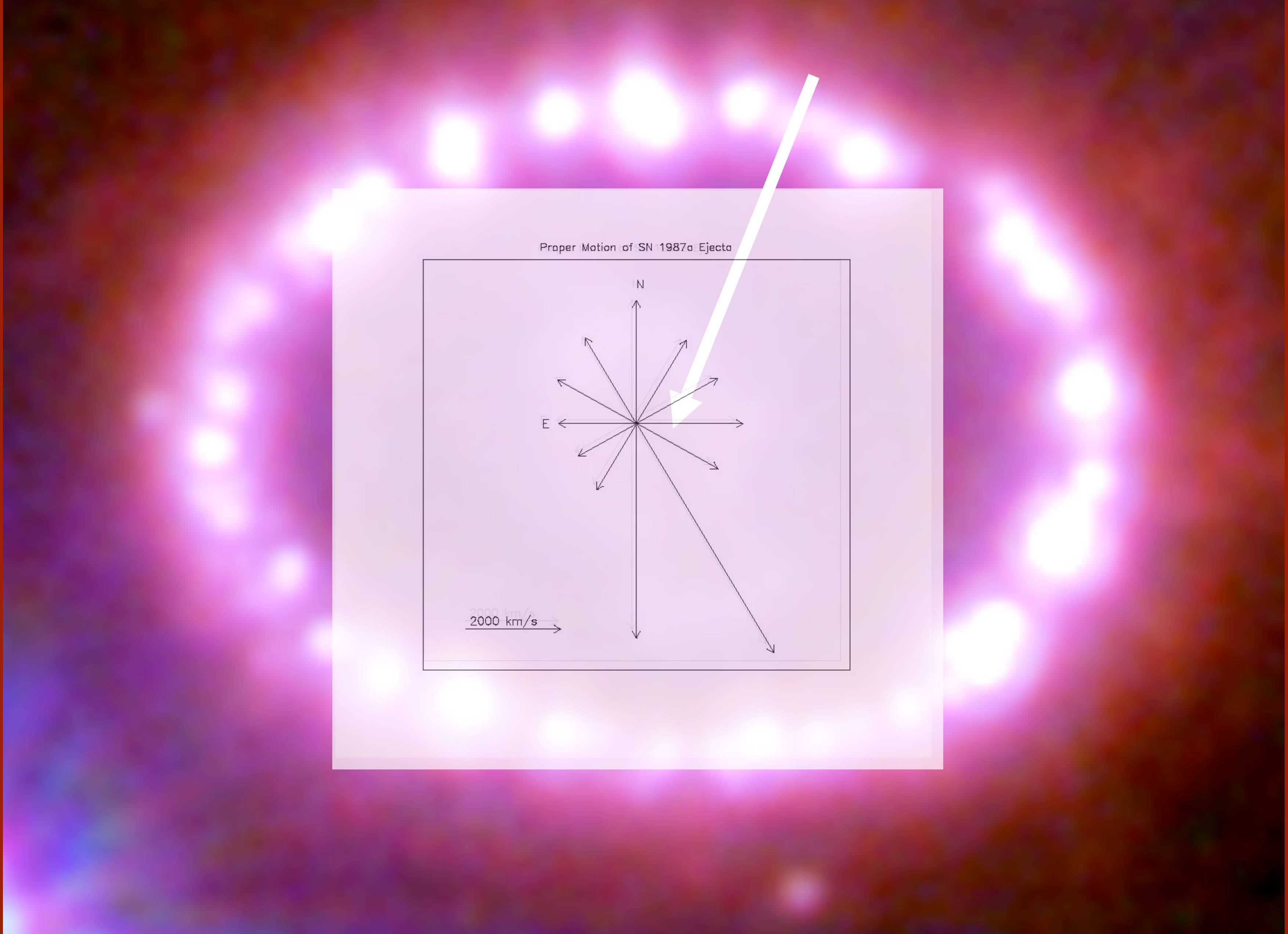
A series of images we took with the HST: exploded star (blob in the center) hits the circumstellar ring and lights it up.

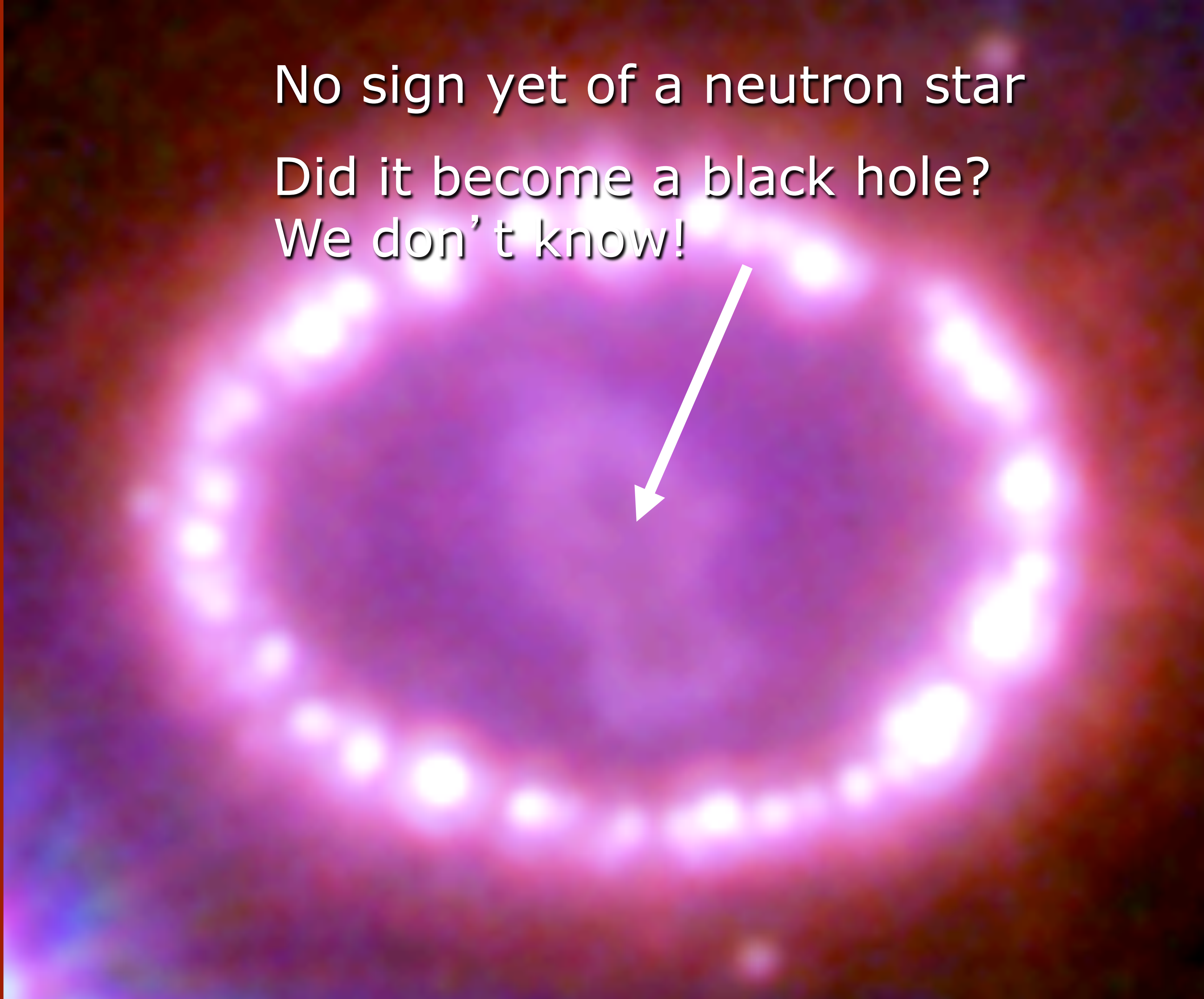


The supernova has been glowing for decades due to radioactive isotopes made in the explosion-- kinetic energy is going to be the future source! (upcoming talk by Josfin Larsson)



Expansion of the Debris (Ti^{44})




No sign yet of a neutron star
Did it become a black hole?
We don’t know!

Fiction Based on Fact

Astronomy & Astrophysics manuscript no. 14538
July 2, 2010

The 3-D Structure of SN 1987A's inner Ejecta★

Karina Kjær[1,2], Bruno Leibundgut[2,3], Claes Fransson[4,5], Anders Jerkstrand[4,5], and Jason Spyromilio[2]

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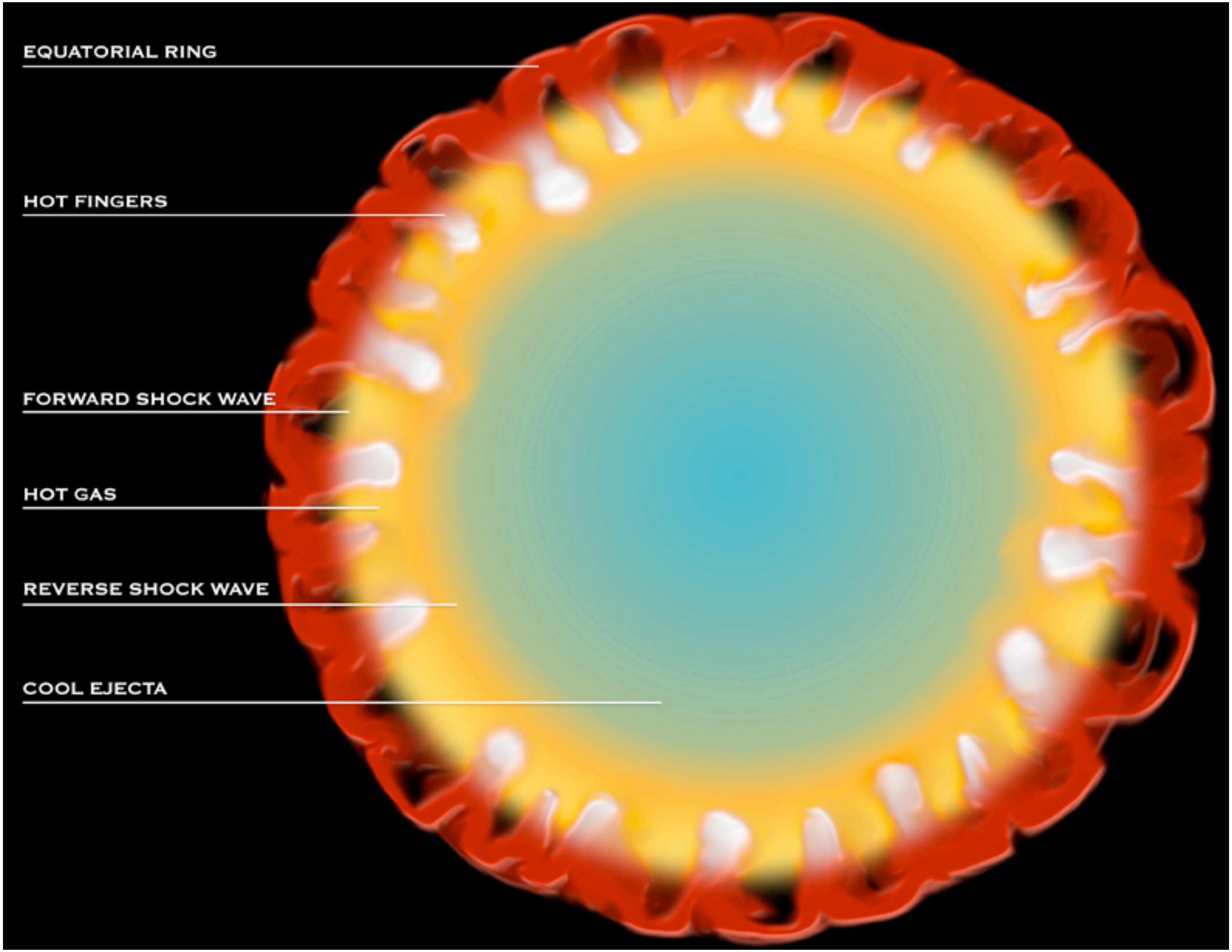
Received: / Accepted

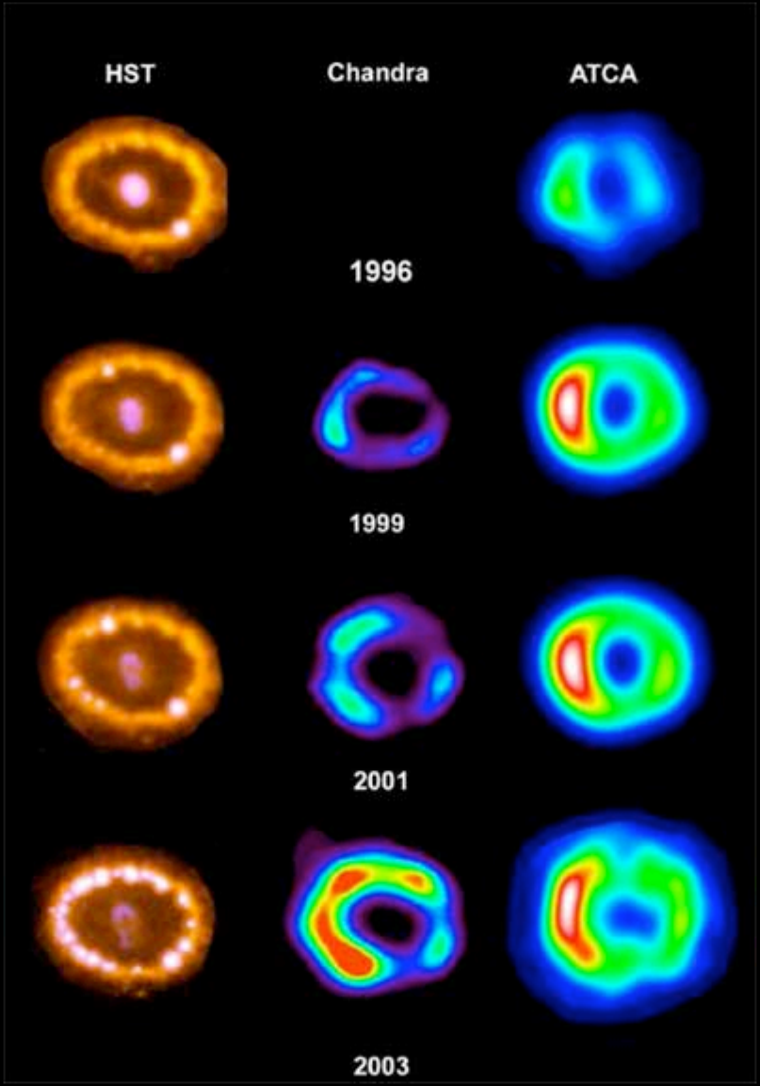
ABSTRACT

Context. Observing the inner ejecta of a supernova is possible only in a handful of nearby supernova remnants. The core-collapse explosion mechanism has been extensively explored in recent models and predict large asymmetries. SN 1987A is the first modern stellar explosion that has been continuously observed from its beginning to the supernova remnant phase. Twenty years after the explosion, we are now able to observe the three-dimensional spatially resolved inner ejecta of this supernova.
Aims. Detailed mapping of newly synthesised material and its radioactive decay daughter products sheds light on the explosion mechanism. This may reveal the geometry of the explosion and its connection to the equatorial ring and the outer rings around SN 1987A.
Methods. We have used integral field spectroscopy to image the supernova ejecta and the equatorial ring in the emission lines of [Si I] + [Fe II] (λ 1.64 μm) and He I (λ 2.058 μm). The spectral information can be mapped into a radial velocity image revealing the expansion of the ejecta both as projected onto the sky and perpendicular to the sky plane.
Results. The inner ejecta are spatially resolved in a North-South direction and are clearly asymmetric. Like the ring emission, the northern parts of the ejecta are blueshifted, while the material projected to the South of the supernova centre is moving away from us. We argue that the bulk of the ejecta is situated in the same plane as defined by the equatorial ring and does not form a bipolar structure as has been suggested. The exact shape of the ejecta is modelled and we find that an elongated triaxial ellipsoid fits the observations best. The velocity measured in the [Si I] + [Fe II] line corresponds to $\sim$ 3000 km s^{-1} and is the same as the width of the IR [Fe II] line profiles during the first years. From our spectral analyses of the ejecta spectrum we find that most of the He I, [Si I] and [Fe I-II] emission originates in the core material which has undergone explosive nucleosynthesis. The He I emission may be the result of α-rich freeze-out if the positron energy is deposited locally.
Conclusions. Our observations clearly indicate a non-symmetric explosion mechanism for SN 1987A. The elongation and velocity asymmetries point towards a large-scale spatial non-spherical distribution as predicted in recent explosion models. The orientation of the ejecta in the plane of the equatorial ring argues against a jet-induced explosion through the poles due to stellar rotation.

Key words. supernovae: individual: SN 1987A - ejecta - explosions

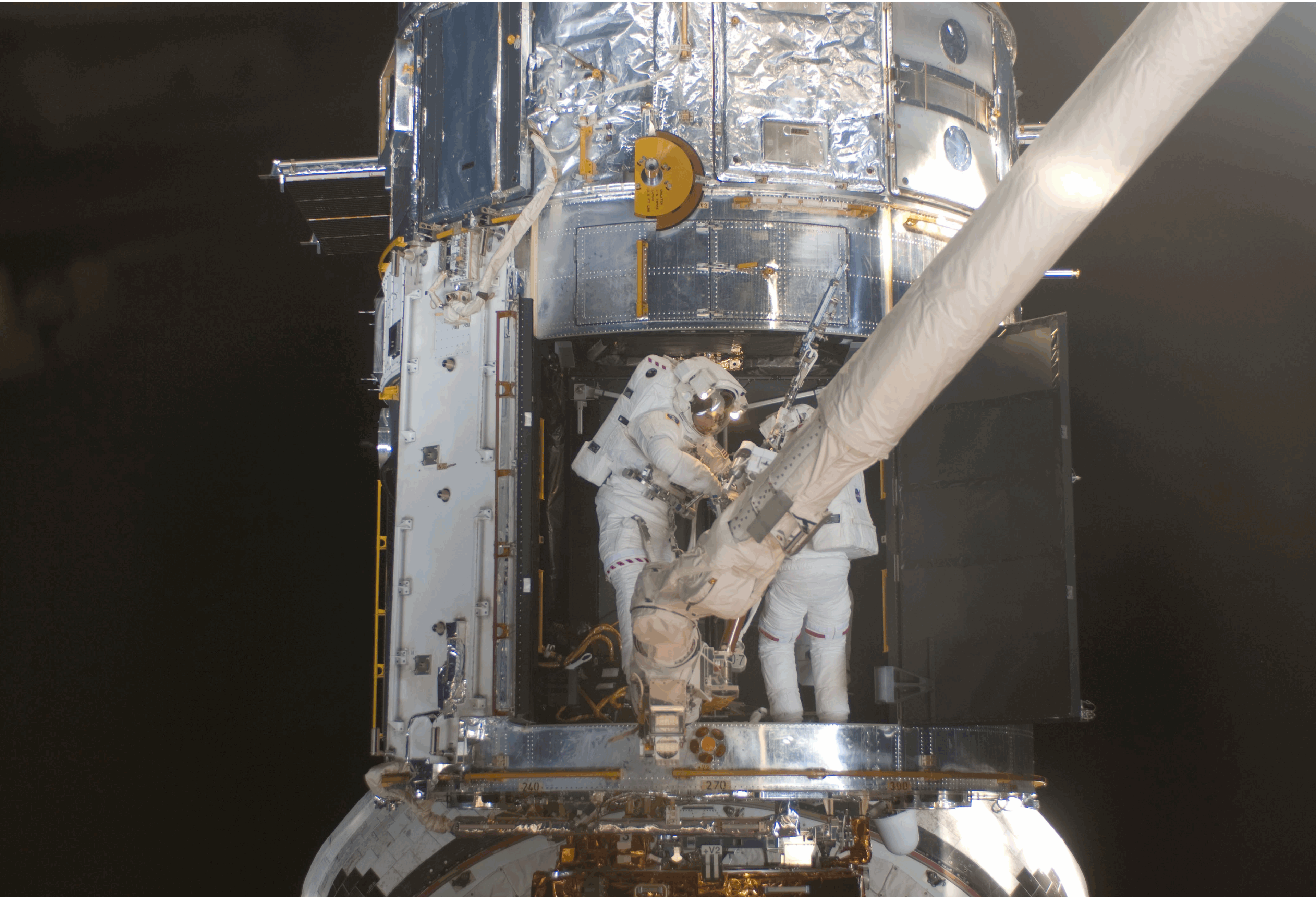

EQUATORIAL RING
HOT FINGERS
FORWARD SHOCK WAVE
HOT GAS
REVERSE SHOCK WAVE
COOL EJECTA

Interaction of the Outgoing Shock with the Circumstellar ring



Upcoming talks by Park and Ng.

Just 109 more!



Observing Supernova 1987A with the Refurbished Hubble Space Telescope

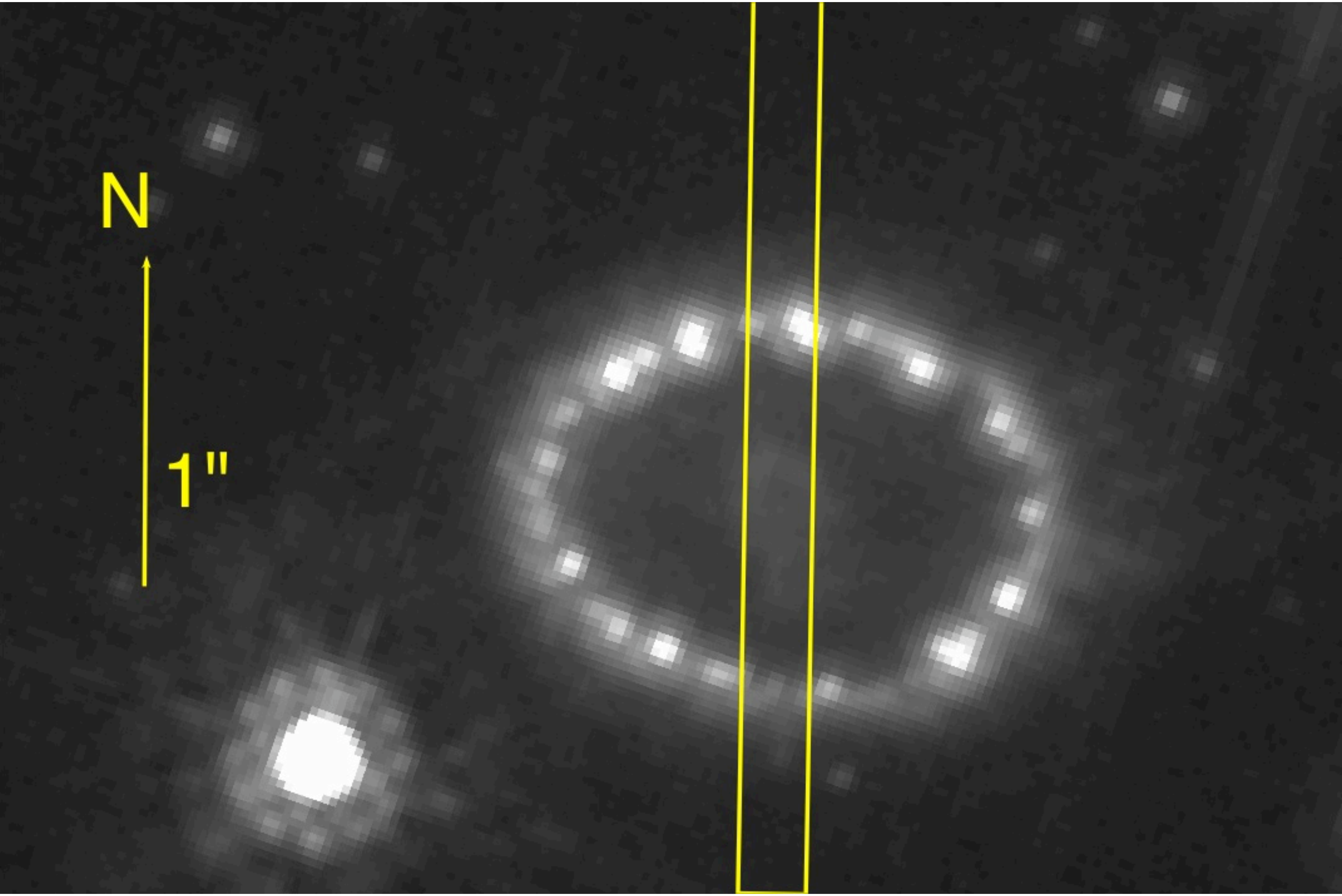
Kevin France,[1] Richard McCray,[2] Kevin Heng,[3,4*] Robert P. Kirshner,[5] Peter Challis,[5] Patrice Bouchet,[6] Arlin Crotts,[7] Eli Dwek,[8] Claes Fransson,[9] Peter M. Garnavich,[10] Josefin Larsson,[9] Stephen S. Lawrence,[11] Peter Lundqvist,[9] Nino Panagia,[12,13,14] Chun S. J. Pun,[15] Nathan Smith,[16] Jesper Sollerman,[9] George Sonneborn,[8] John T. Stocke,[1] Lifan Wang,[17] J. Craig Wheeler[18]

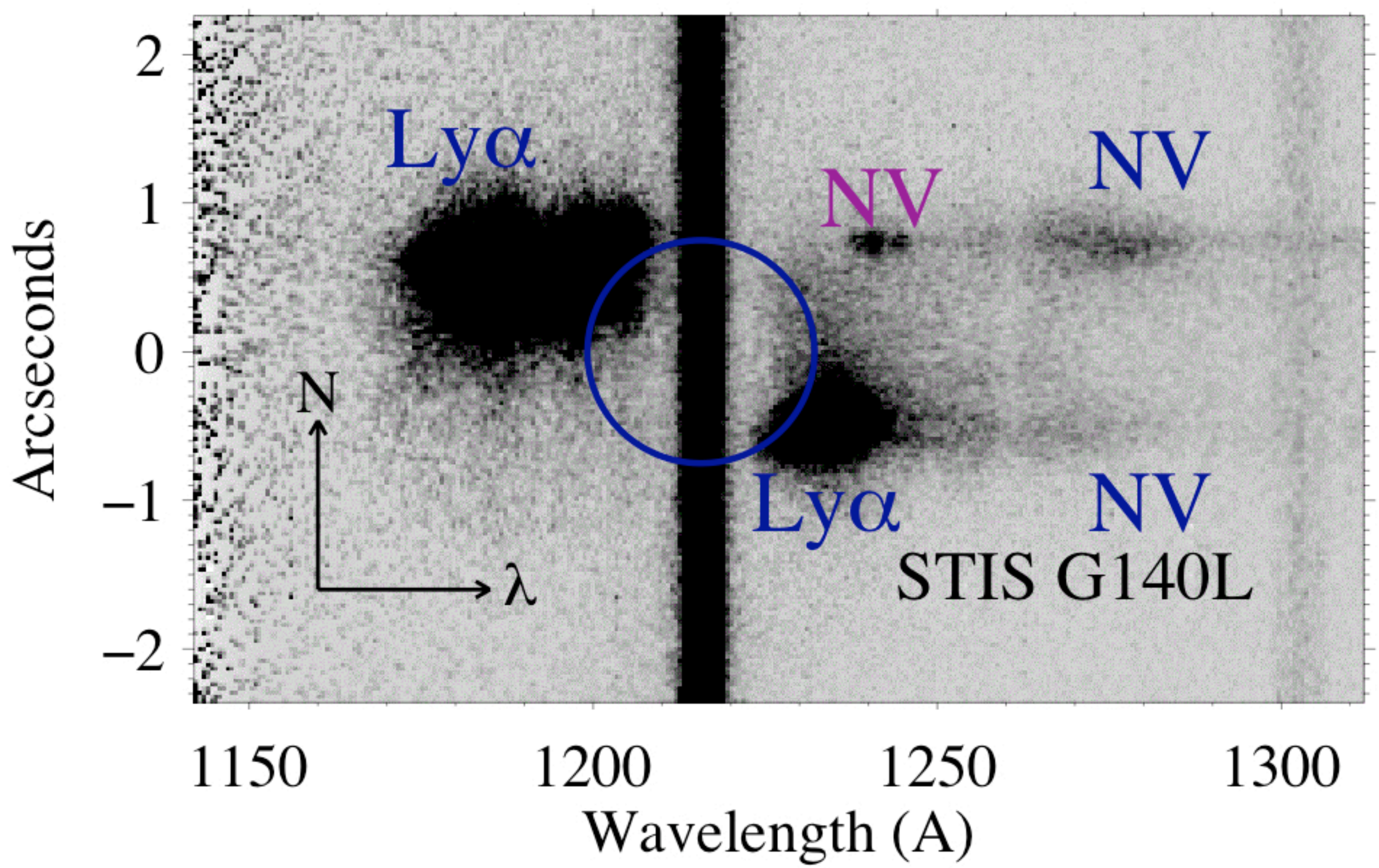
Observations with the Hubble Space Telescope (HST), conducted since 1990, now offer an unprecedented glimpse into fast astrophysical shocks in the young remnant of supernova 1987A. Comparing observations taken in 2010 with the use of the refurbished instruments on HST with data taken in 2004, just before the Space Telescope Imaging Spectrograph failed, we find that the Lyα and Hα lines from shock emission continue to brighten, whereas their maximum velocities continue to decrease. We observe broad, blueshifted Lyα, which we attribute to resonant scattering of photons emitted from hot spots on the equatorial ring. We also detect N V $\lambda\lambda$1239, 1243 angstrom line emission, but only to the red of Lyα. The profiles of the N V lines differ markedly from that of Hα, suggesting that the N^{4+} ions are scattered and accelerated by turbulent electromagnetic fields that isotropize the ions in the collisionless shock.

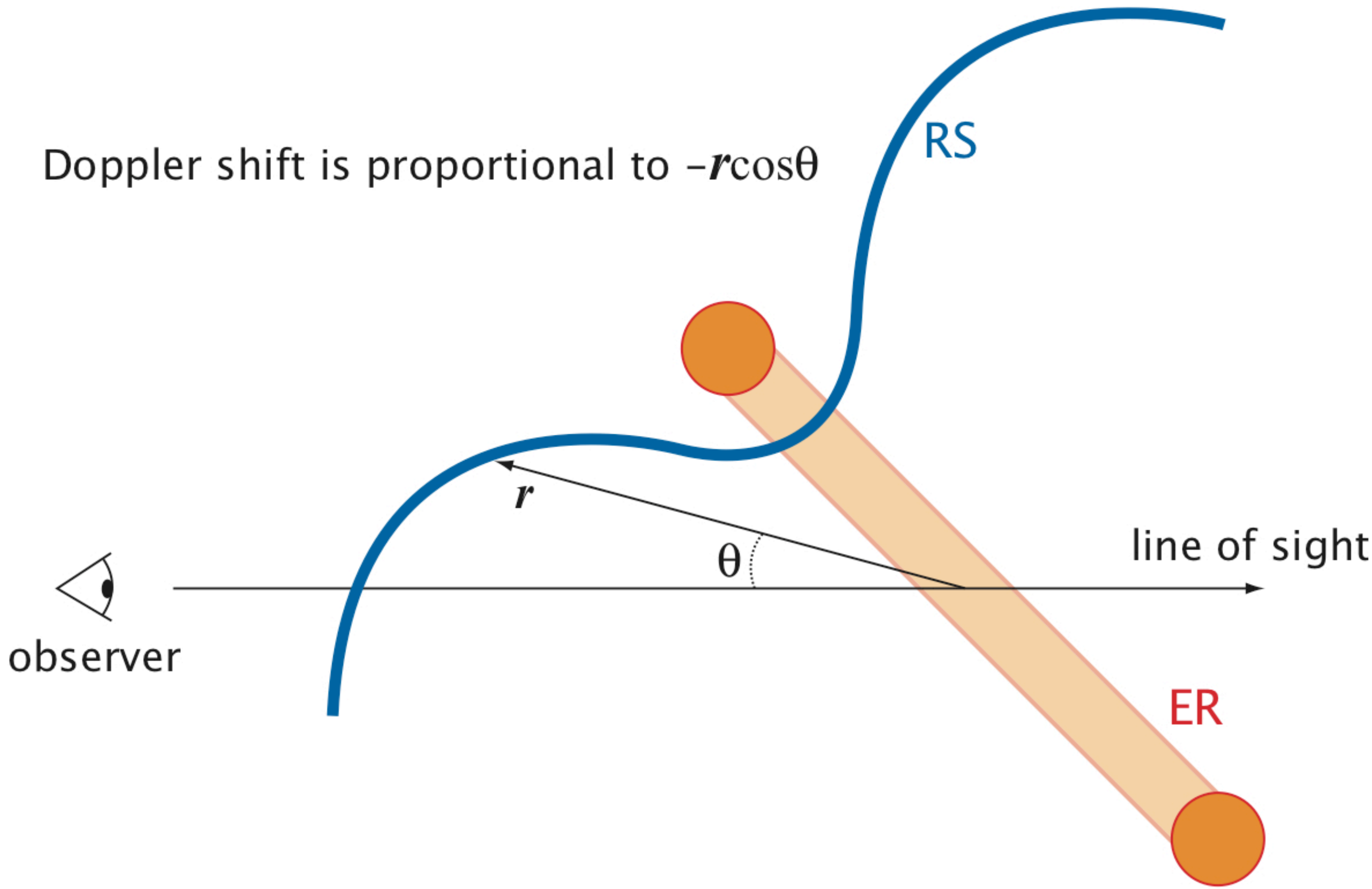
The death of a massive star produces a violent explosion known as a supernova (SN), which expels matter at hypersonic velocities. Supernovae deposit large amounts of mechanical energy and nucleosynthesized elements into the surrounding interstellar medium, driving the physical and chemical evolution of galaxies. The shock impact of the SN debris with ambient matter creates a radiating system known as a supernova remnant. SN 1987A (first observed on 23 February 1987), the brightest such event observed since Kepler's supernova (SN 1604) (*1*), provides a unique opportunity to witness the development of a supernova remnant (*2*, *3*). Because SN 1987A is only 50 kpc away in the Large Magellanic Cloud, the Hubble Space Telescope's (HST's) superb angular resolution is sufficient to re-

Kevin France

Kevin Heng

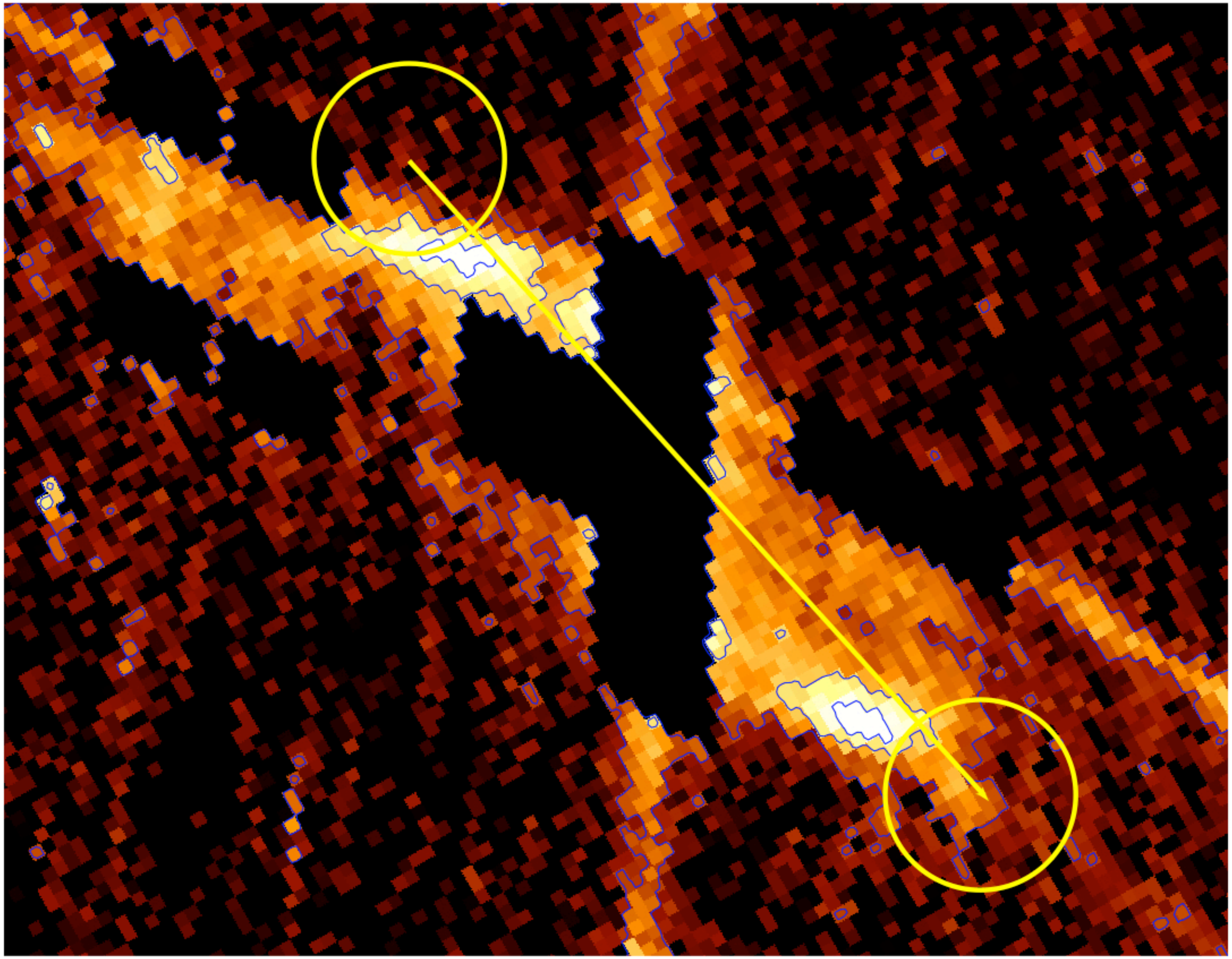

N
1"


Lyα
NV
NV
Lyα
NV
N
λ
STIS G140L
Arcseconds
2
1
0
−1
−2
1150
1200
1250
1300
Wavelength (A)



Doppler shift is proportional to $-\boldsymbol{r}\cos\theta$
RS
$\boldsymbol{r}$
θ
line of sight
observer
ER

The Reverse Shock: Emission concentrated just inside the ring



What about N V?

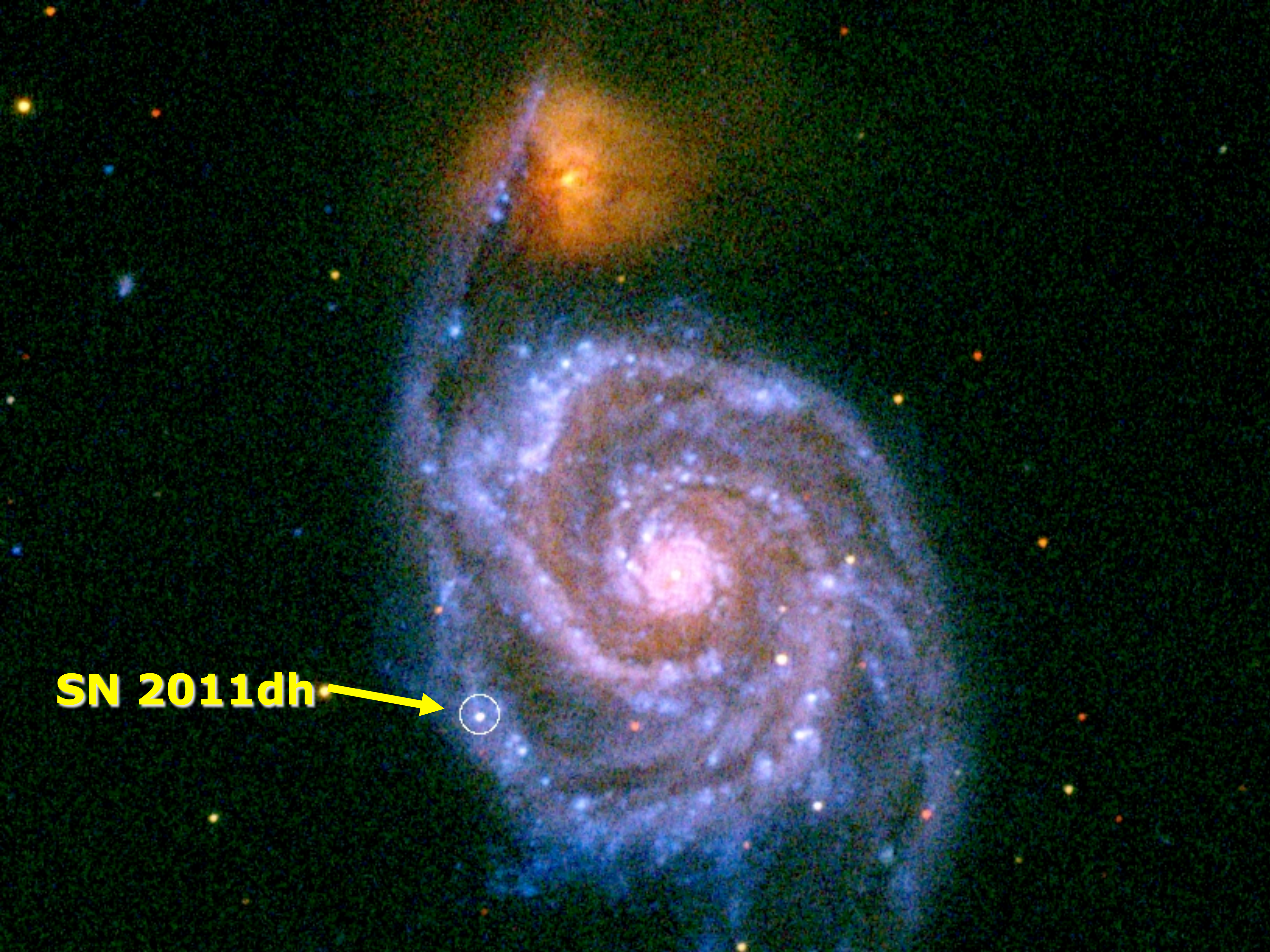
Expect many photons per ionization (~600)

This is seen redshifted by +12000 km/s

(Blueshifted emission buried under Ly α)

If this is right-- look for C IV 1548, 1550 with the same line profile.

Observations with COS coming up! (Upcoming talk by Kevin France)


SN 2011dh

Investigators:

	Investigator	Institution	Country
PI	Dr. Robert P. Kirshner	Harvard University	USA/MA
CoI	Dr. Stephane Blondin	Centre de Physique des Particules de Marseille	France
CoI	Mr. Peter Challis	Harvard University	USA/MA
CoI	Dr. Roger A. Chevalier	The University of Virginia	USA/VA
CoI	Dr. Bruno Leibundgut	European Southern Observatory - Germany	Germany
CoI	Dr. Claes Fransson	Stockholm University	Sweden
CoI	Dr. Alicia M. Soderberg	Smithsonian Institution Astrophysical Observatory	USA/MA
CoI	Dr. Jesper Sollerman	Stockholm University	Sweden
CoI	Dr. Nathan Smith	University of Arizona	USA/AZ
CoI	Dr. Ryan Chornock	Harvard University	USA/MA
CoI	Dr. Ryan Foley	Smithsonian Institution Astrophysical Observatory	USA/MA
CoI	Dr. Kevin France	University of Colorado at Boulder	USA/CO
CoI	Dr. G. H. Marion	Harvard University	USA/MA

Number of investigators: 13

Target Summary:

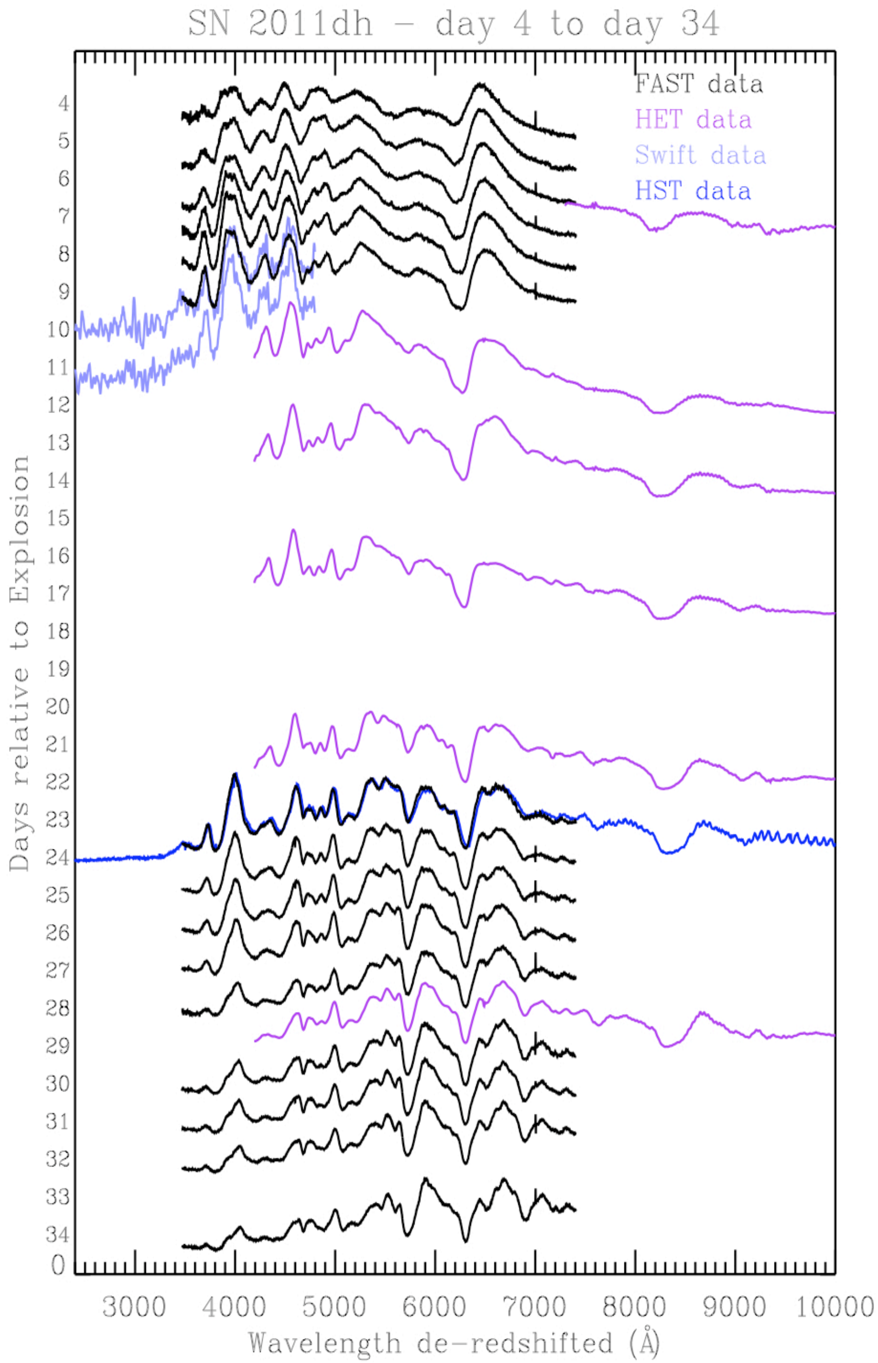
Target	RA	Dec	Magnitude
SN-2010JL	09 42 53.3300	+09 29 41.80	V = 16 +/- 1
CYCLE19-SUPERNOVA-TOO			

Observing Summary:

Target	Config Mode and Spectral Elements	Flags	Orbits
CYCLE19-SUPERNOVA-TOO	STIS/CCD Spectroscopic G230LB (2375)	TOO	6 (2x3)
	STIS/CCD Spectroscopic G430L (4300)		
CYCLE19-SUPERNOVA-TOO	COS/FUV Spectroscopic G130M (1300)	TOO	4 (2x2)
	COS/FUV Spectroscopic G160M (1600)		
SN-2010JL	COS/FUV Spectroscopic G130M (1300)		3
	COS/FUV Spectroscopic G160M (1600)		
SN-2010JL	STIS/CCD Spectroscopic G230LB (2375)		1

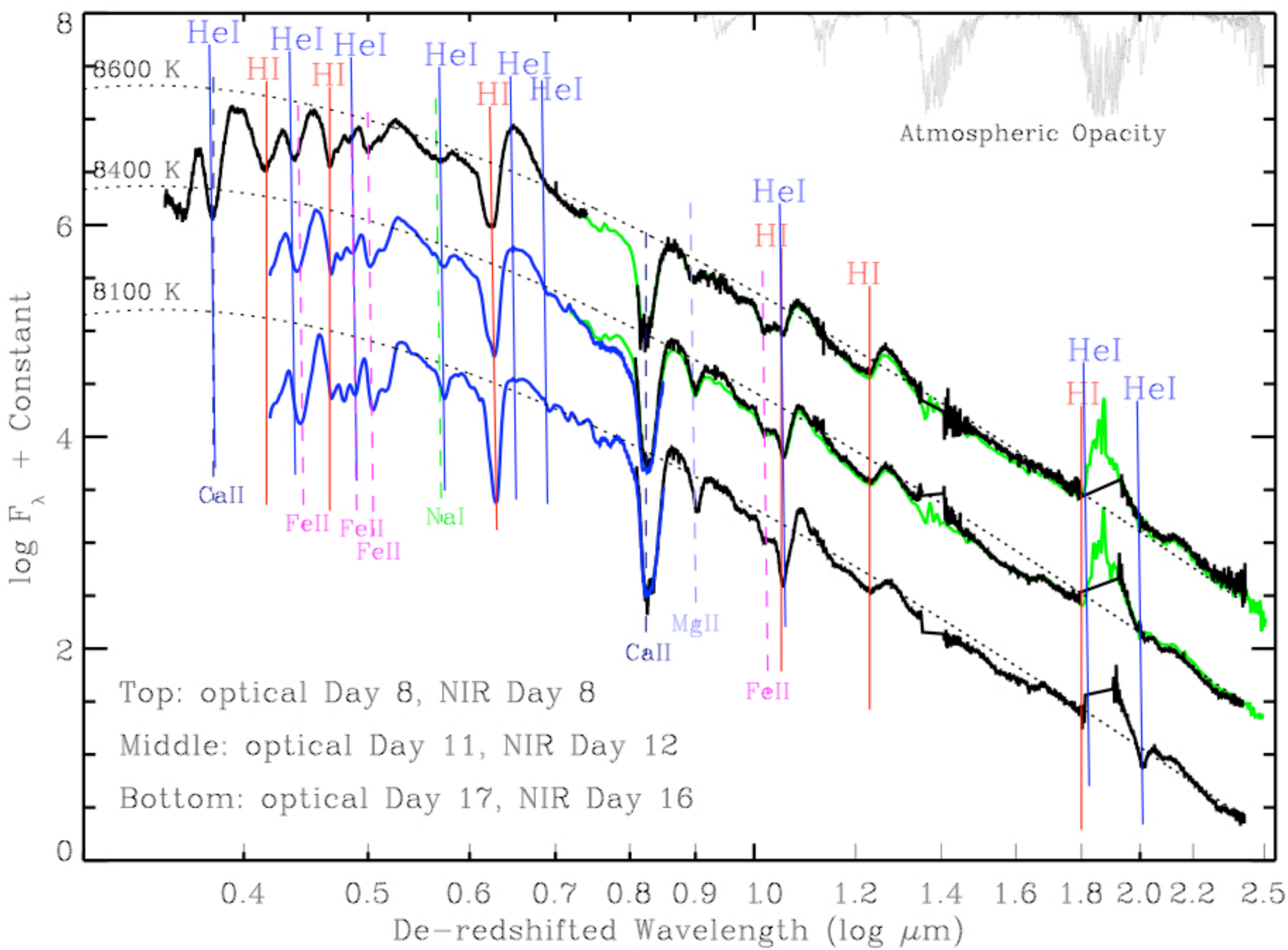
Total prime orbits: 14

Howie Marion



Early spectra make SN 2011dh a SN II

NIR Helium Lines make SN 2011dh a SN IIb



THE JOHNS HOPKINS UNIVERSITY
HOMEWOOD
TEMPORARY PARKING PERMIT

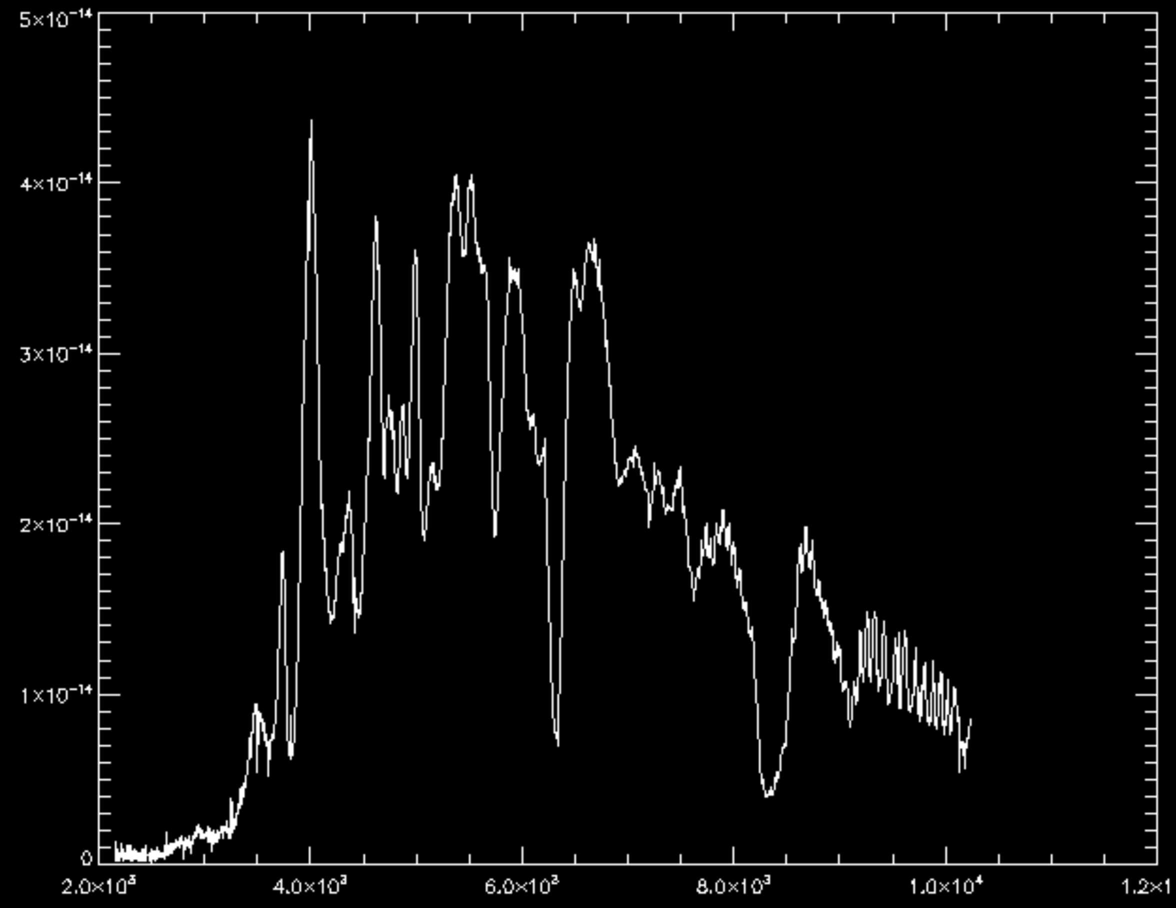
Area TYPE-IIB ONLY Lic. No. GUEST

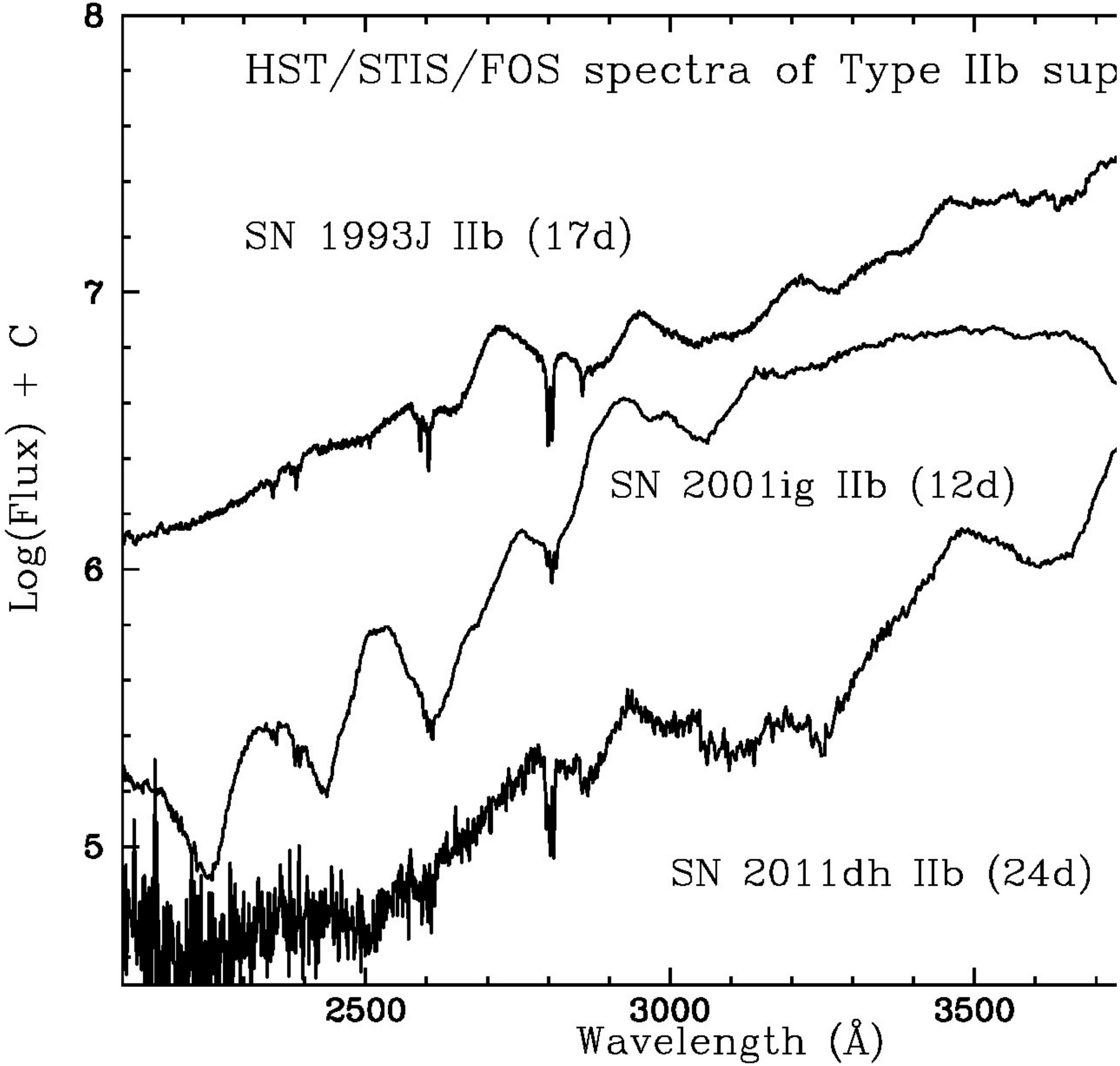
Date Feb. 20 - 1986 Dept. Meeting

Permit No. 319 Robert L. Larkin
AUTHORITY

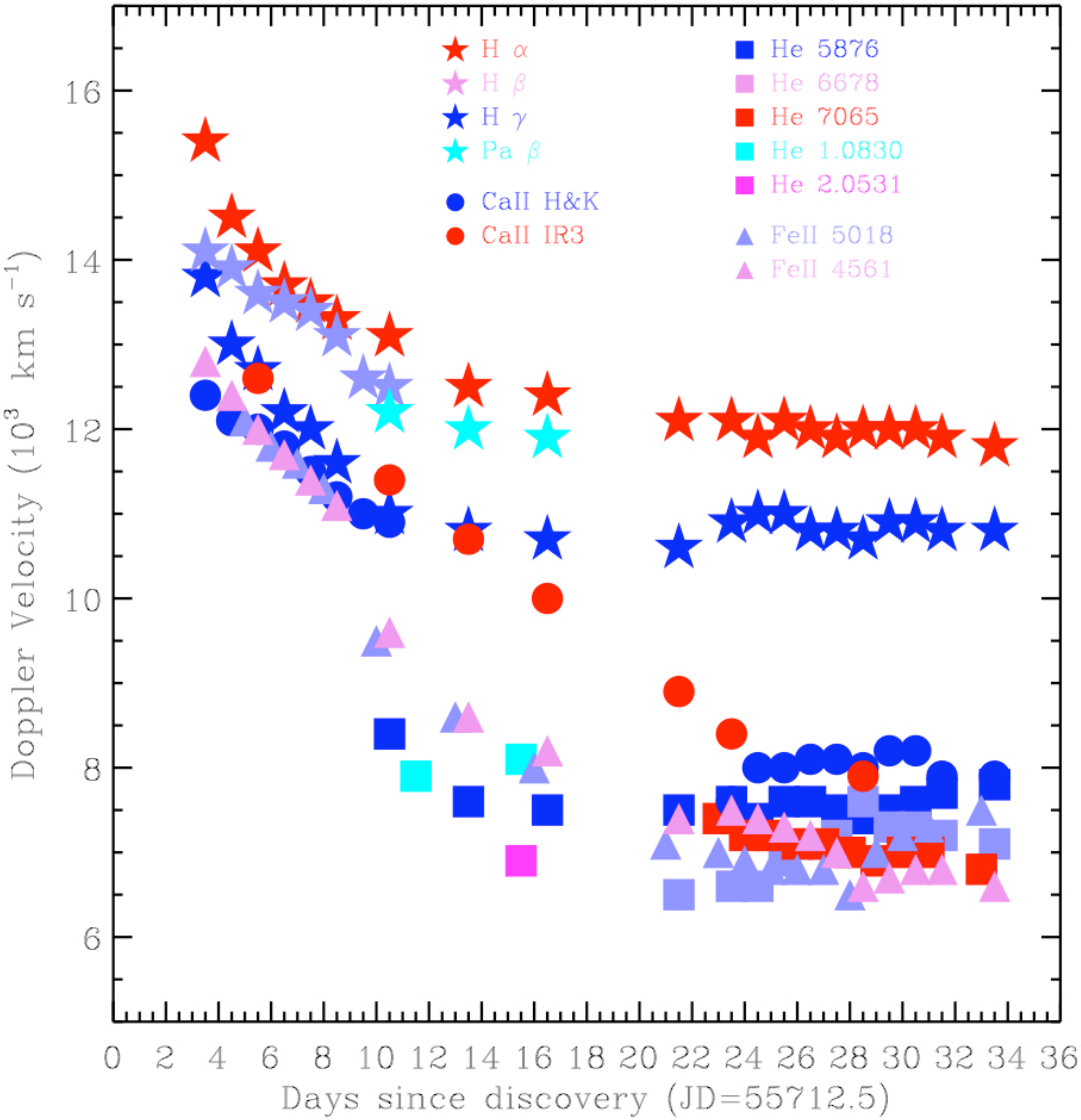
PLACE THIS CARD IN FRONT WINDOW, DRIVERS SIDE

SN 2011dh with HST





HST/STIS/FOS spectra of Type IIb sup
SN 1993J IIb (17d)
SN 2001ig IIb (12d)
SN 2011dh IIb (24d)
Log(Flux) + C
Wavelength (Å)
8
7
6
5
2500
3000
3500



Hydrogen velocity is distinct from all others:

Declines to 12 000 km/s @ day 12, then static

Ca II , Fe II switch from

12 000 down to

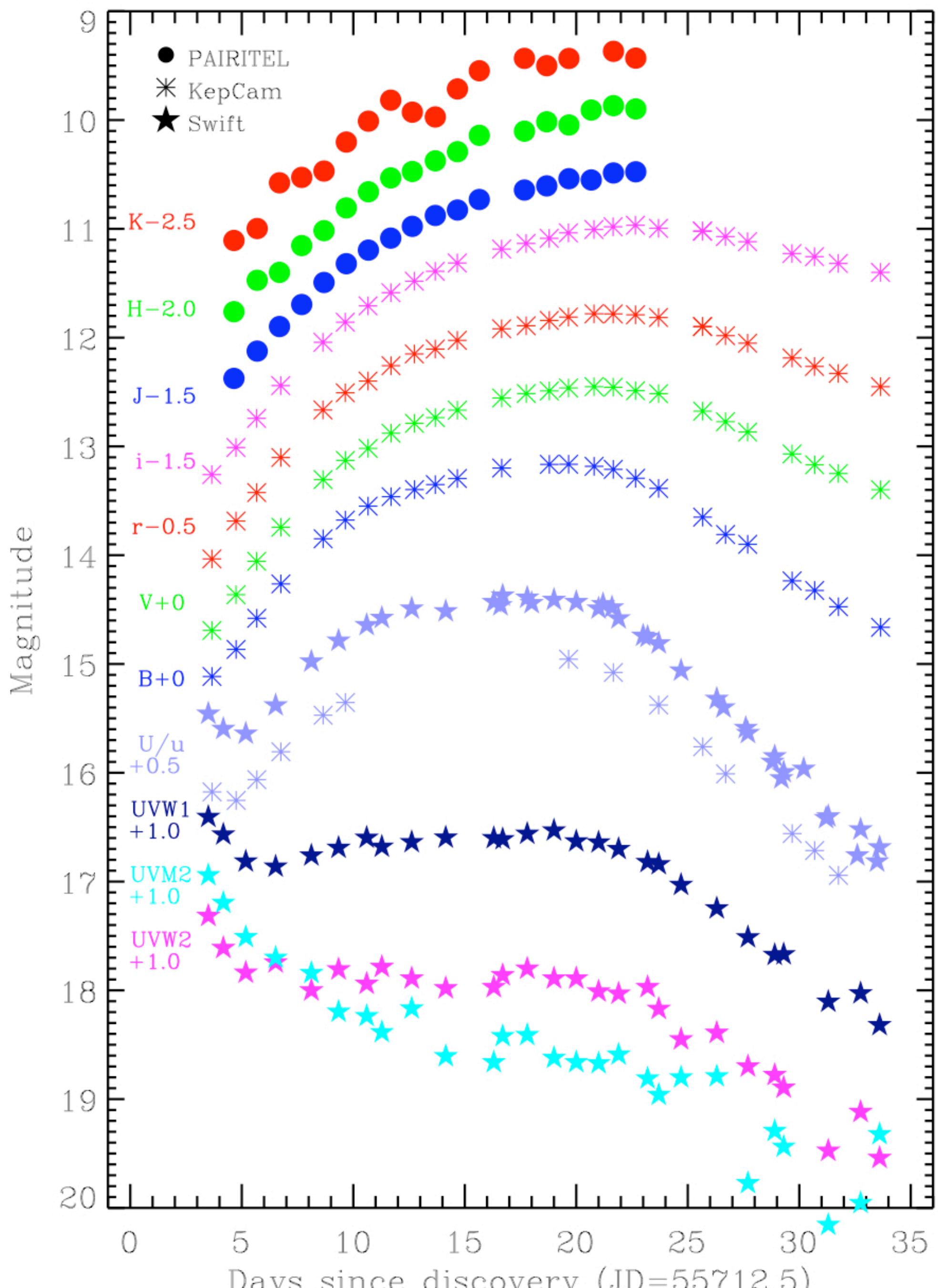
7 000 after day 12

He settles at 7000

H shell @ 12 000,

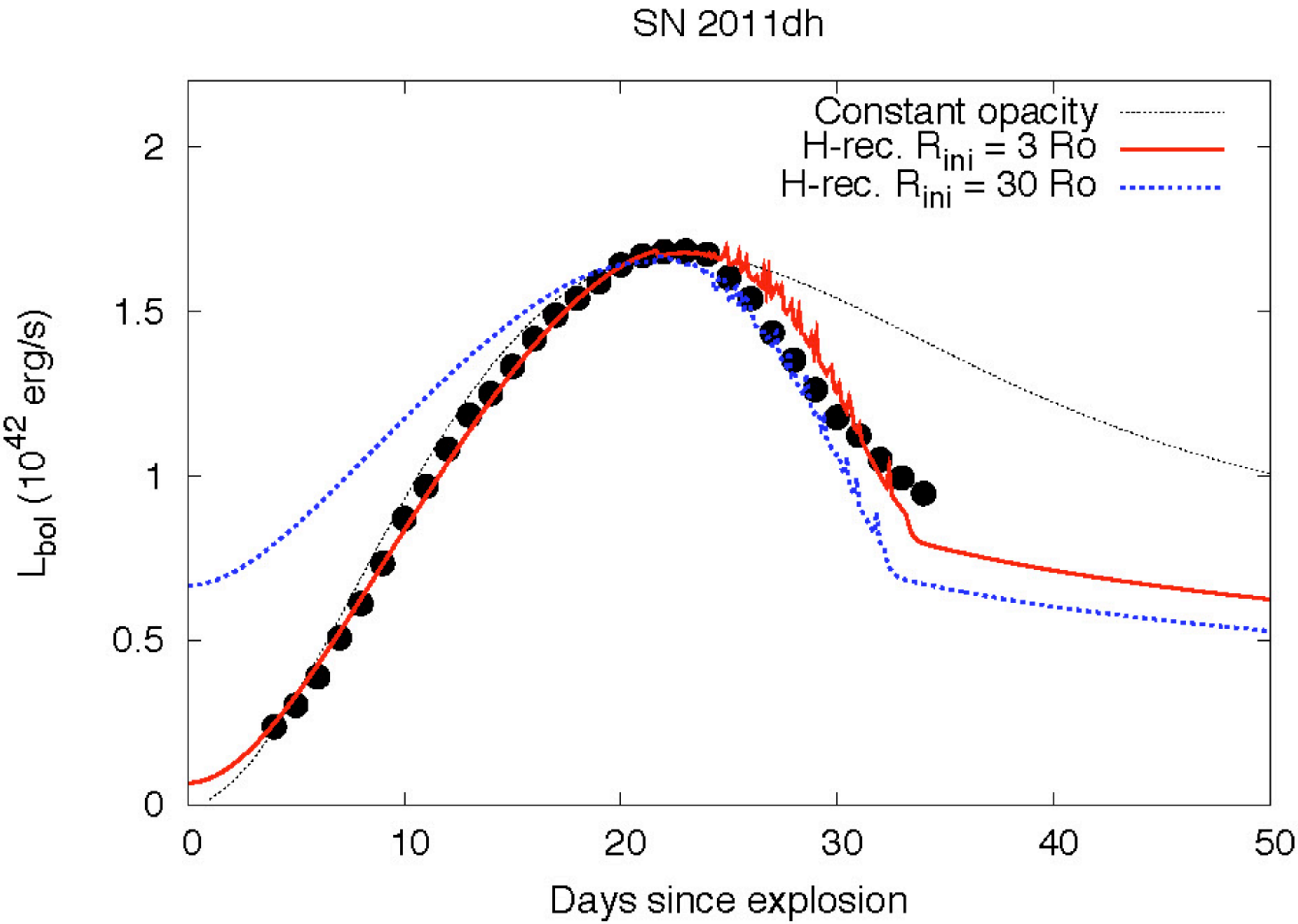
He photosphere

@7000

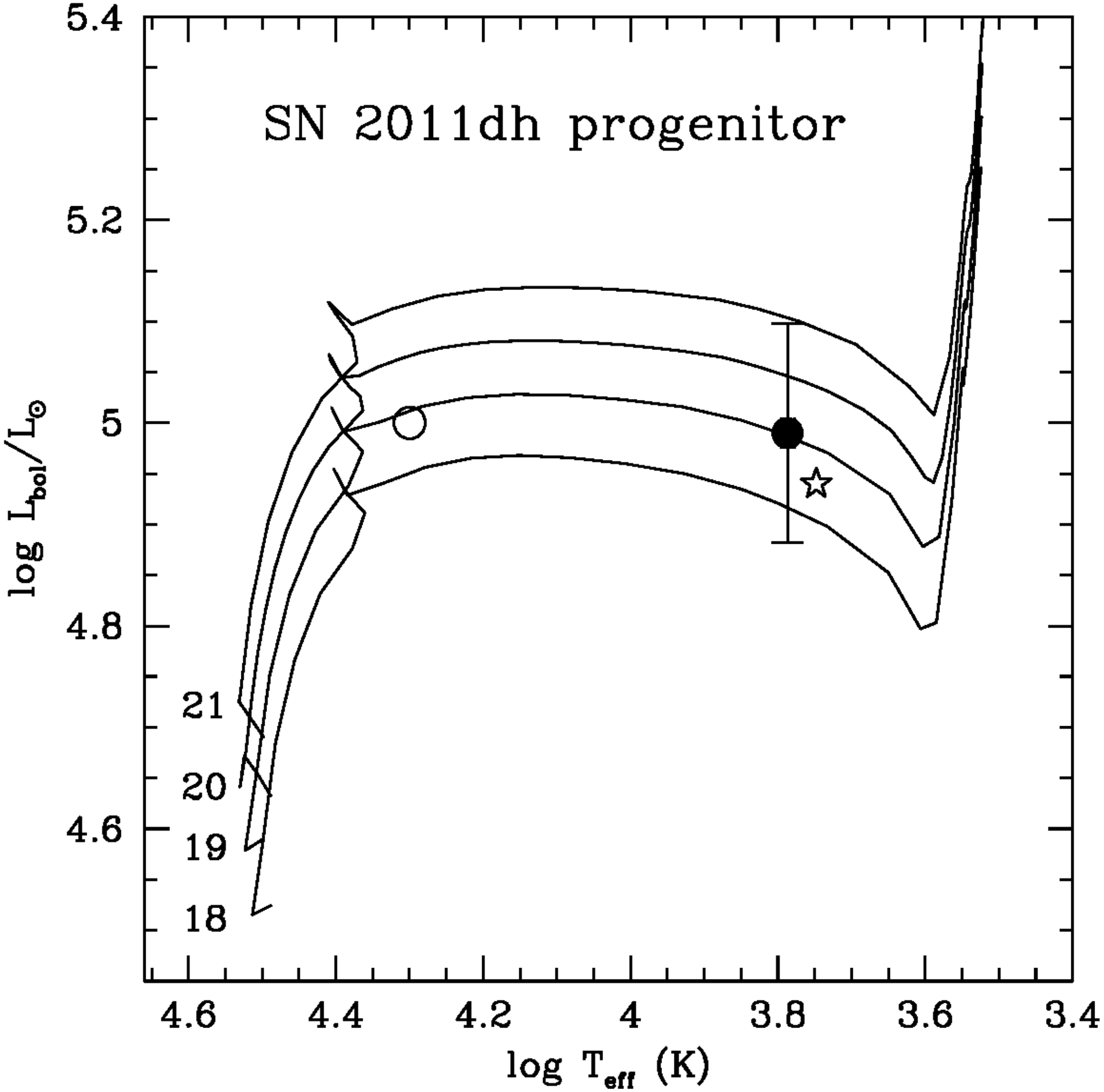


Maximum in blue bands first-- drift in color.

Slight change in slope at day 12-- when the helium appears in the spectrum



Small radius as also inferred by Soderberg et al. 2011



— Hertzsprung-Russell diagram showing the locus of the progenitor of SN 2011dh (*filled circle*). Also shown are STARS (Eg: dridge & Tout 2004) model stellar evolutionary tracks at solar metallicity for initial masses 18–21 $M_\odot$ (the numbers in the figu .ass in $M_\odot$). Furthermore, we show the locus of the SN 1993J companion (Maund et al. 2004, *open circle*), as well as the rem: *nted star*) when the light of a star similar to the SN 1993J companion is subtracted from the detected SN 2011dh progenito: object could be the primary in an interacting binary system, and the actual star that exploded.

10^5 L_{sun}

~100 R_{sun}

Yellow supergiant?

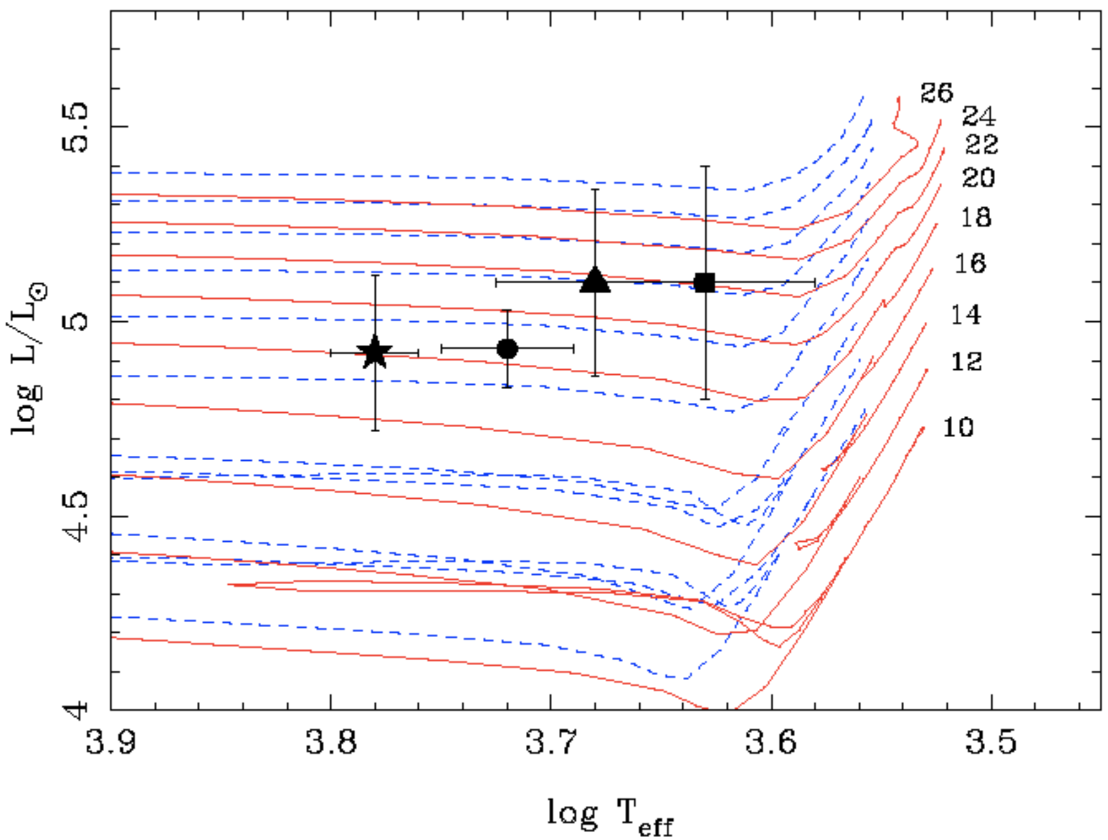
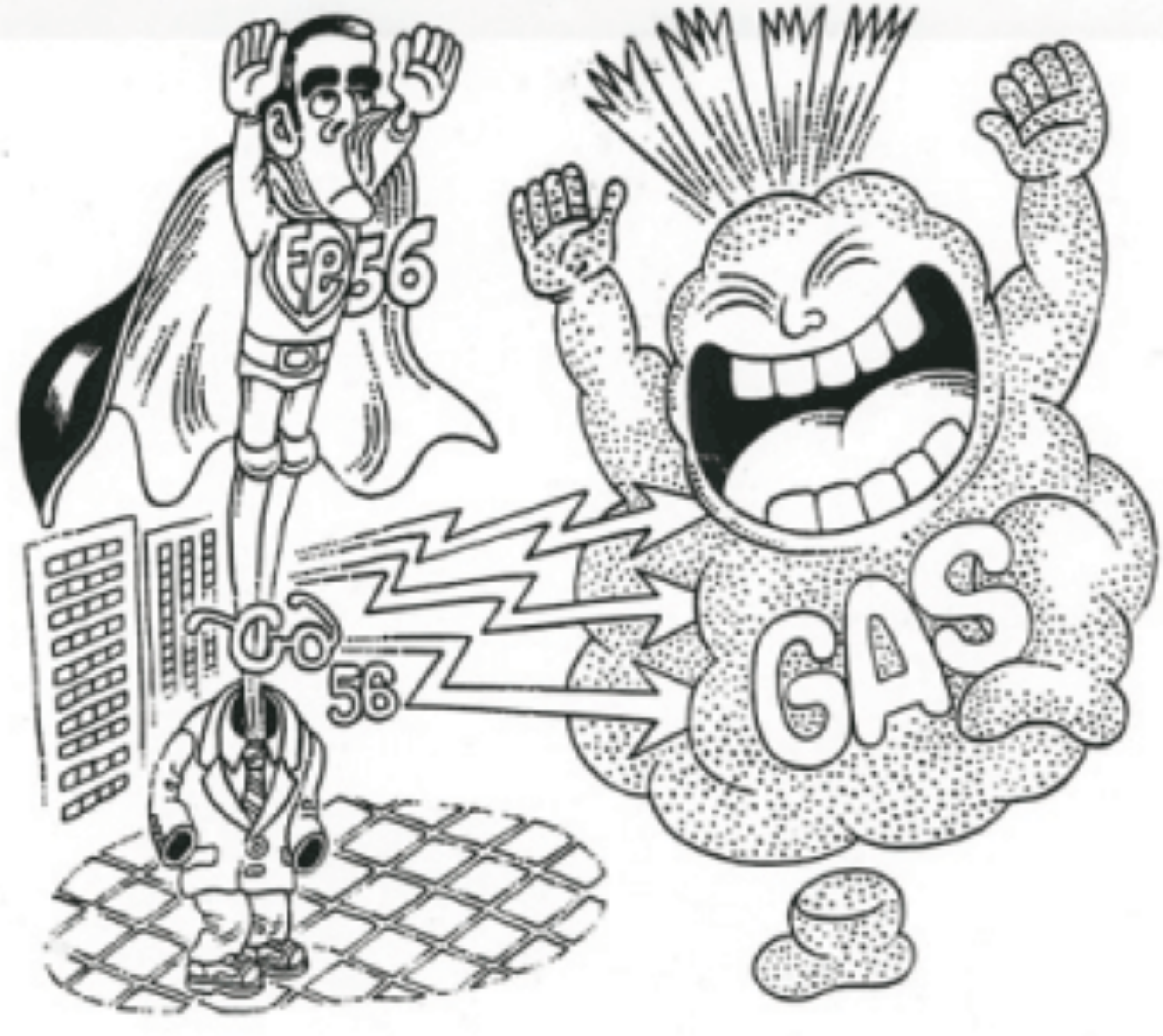


FIG. 4.— Hertzsprung-Russell diagram showing the luminosities and temperatures of the progenitors of SNe 2011dh (★), 1993J (■; Maund et al. 2004; Aldering et al. 1994), 2008cn (●; Elias-Rosa et al. 2009), and 2009kr (▲; Fraser et al. 2010b; Elias-Rosa et al. 2010). Overlaid are STARS stellar evolution tracks for solar (red solid) and LMC (blue dashed) metallicities. At the end of each track the corresponding initial mass is indicated.

Maund et al. 2011

Also $R \sim 100 R_{sun}$

Coincidence is not enough--let's see what's there when the SN fades!


Fe56
Co56
GAS