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THE EVOLUTION OF DUST FORMATION IN SN 2005IP

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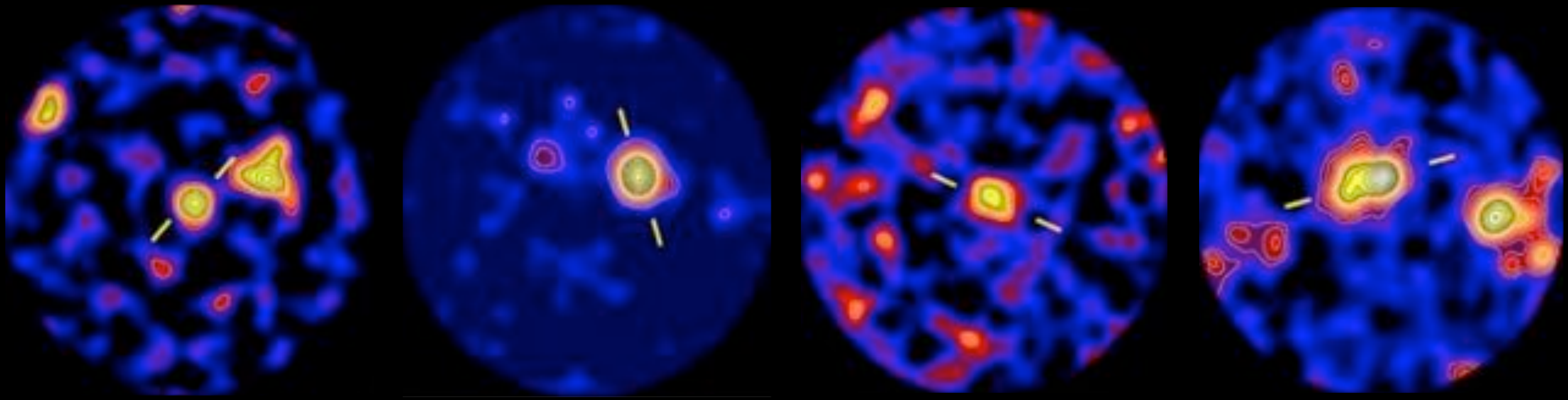
OVERVIEW

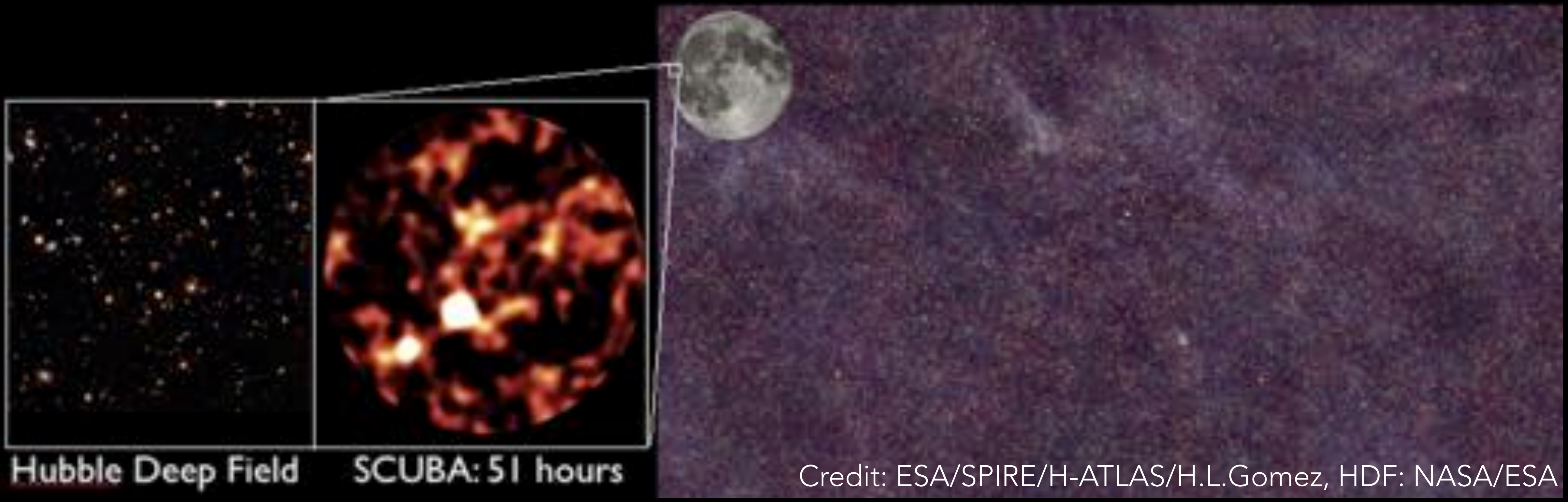
- DUST IN CCSNE
- MODELLING DUST-AFFECTED LINE PROFILES IN CCSNE
- DUST FORMATION IN SN 2005IP
- CONCLUSIONS AND FUTURE WORK

SCUBA: IR-emitting high redshift galaxies



LARGE MASSES OF DUST ARE SEEN IN THE EARLY UNIVERSE

Herschel - SPIRE (16hrs): high redshift dusty galaxies

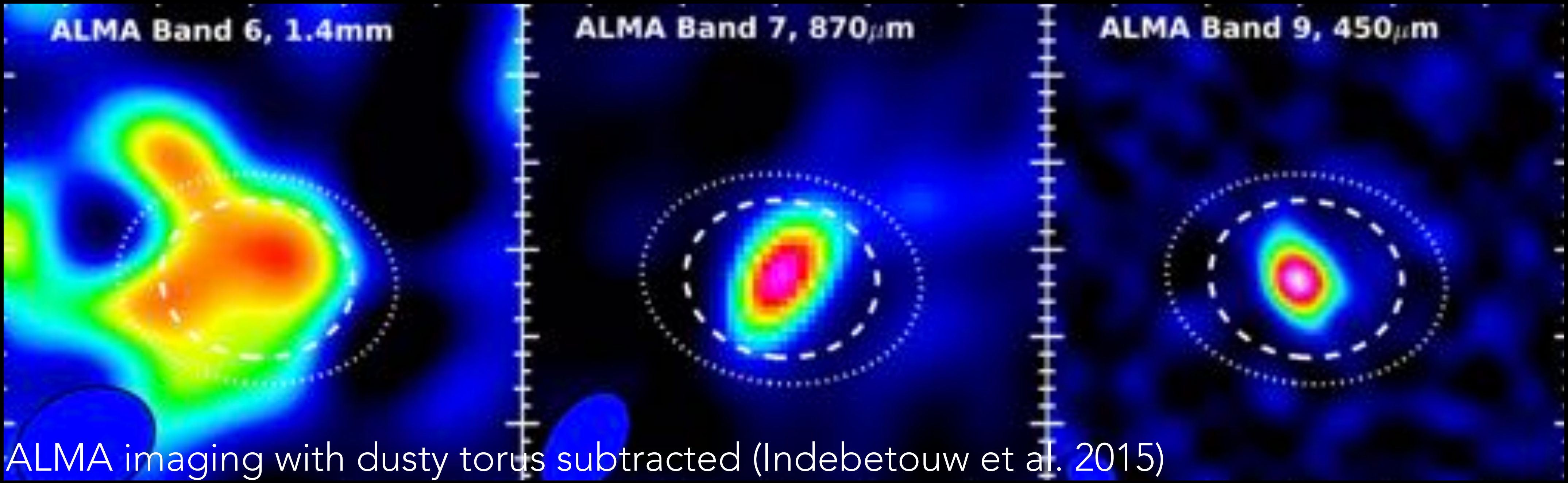


Credit: ESA/SPIRE/H-ATLAS/H.L.Gomez, HDF: NASA/ESA

SO WHERE DOES IT COME FROM?

CORE-COLLAPSE SUPERNOVAE?

LARGE MASSES OF COLD DUST (0.1 - 1.0 $M_\odot$) HAVE BEEN DETECTED IN THE FAR-IR IN A FEW CCSNE AND SNRs

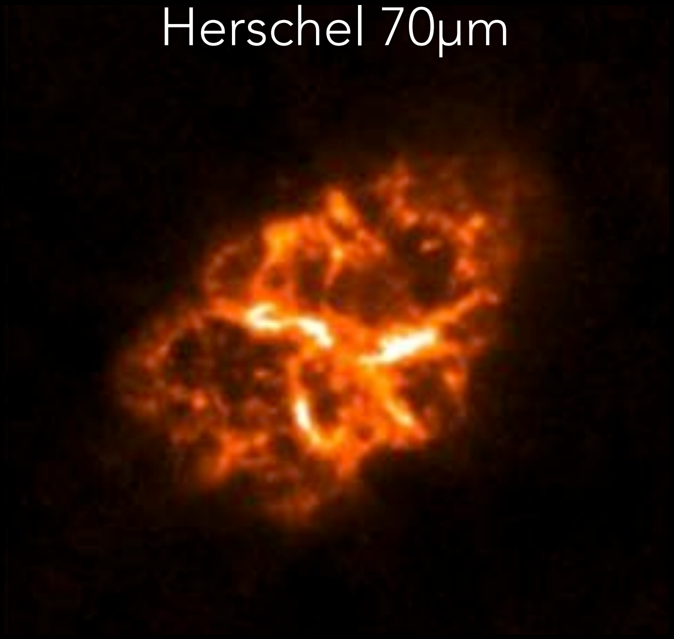


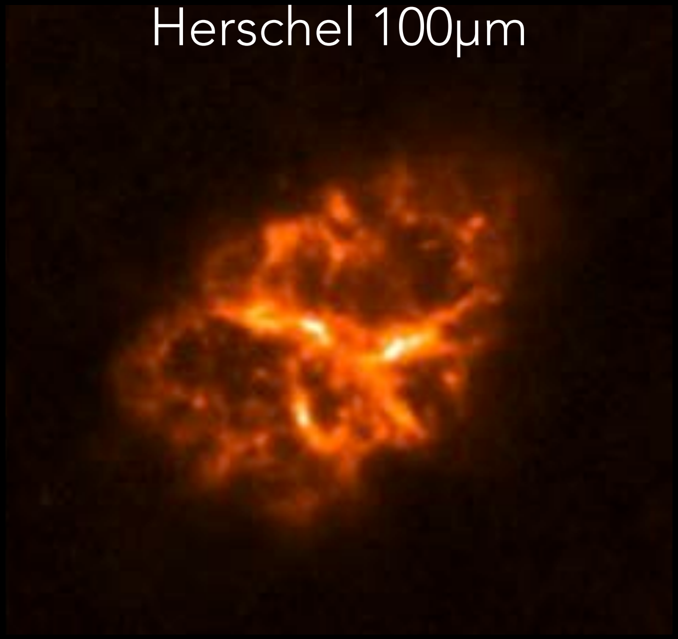
ALMA imaging with dusty torus subtracted (Indebetouw et al. 2015)

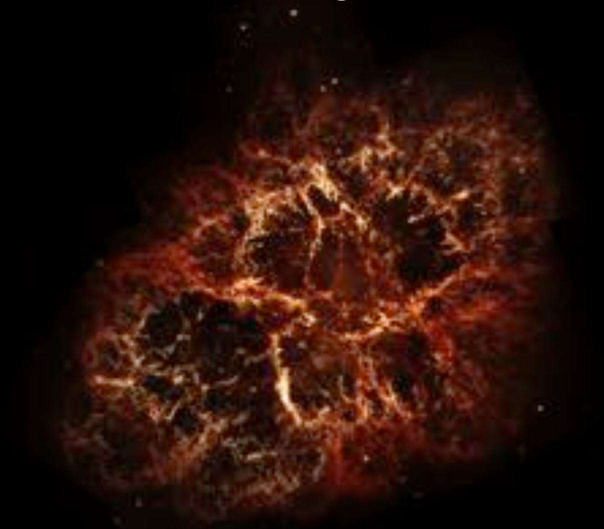
SN 1987A @ 30YR:
0.4 - 0.6 $M_\odot$ (MATSUURA ET AL. 2015)

CORE-COLLAPSE SUPERNOVAE?

LARGE MASSES OF COLD DUST (0.1 - 1.0 $M_\odot$) HAVE BEEN DETECTED IN THE FAR-IR IN A FEW CCSNE AND SNRs


Herschel 70µm


Herschel 100µm


HST

THE CRAB NEBULA @ 1000YR:
0.2 - 0.4 $M_\odot$ (OWEN & BARLOW 2015)
0.1 - 0.2 $M_\odot$ (GOMEZ ET AL. 2012B)

CORE-COLLAPSE SUPERNOVAE?

LARGE MASSES OF COLD DUST (0.1 - 1.0 $M_\odot$) HAVE BEEN DETECTED IN THE FAR-IR IN A FEW CCSNE AND SNRs

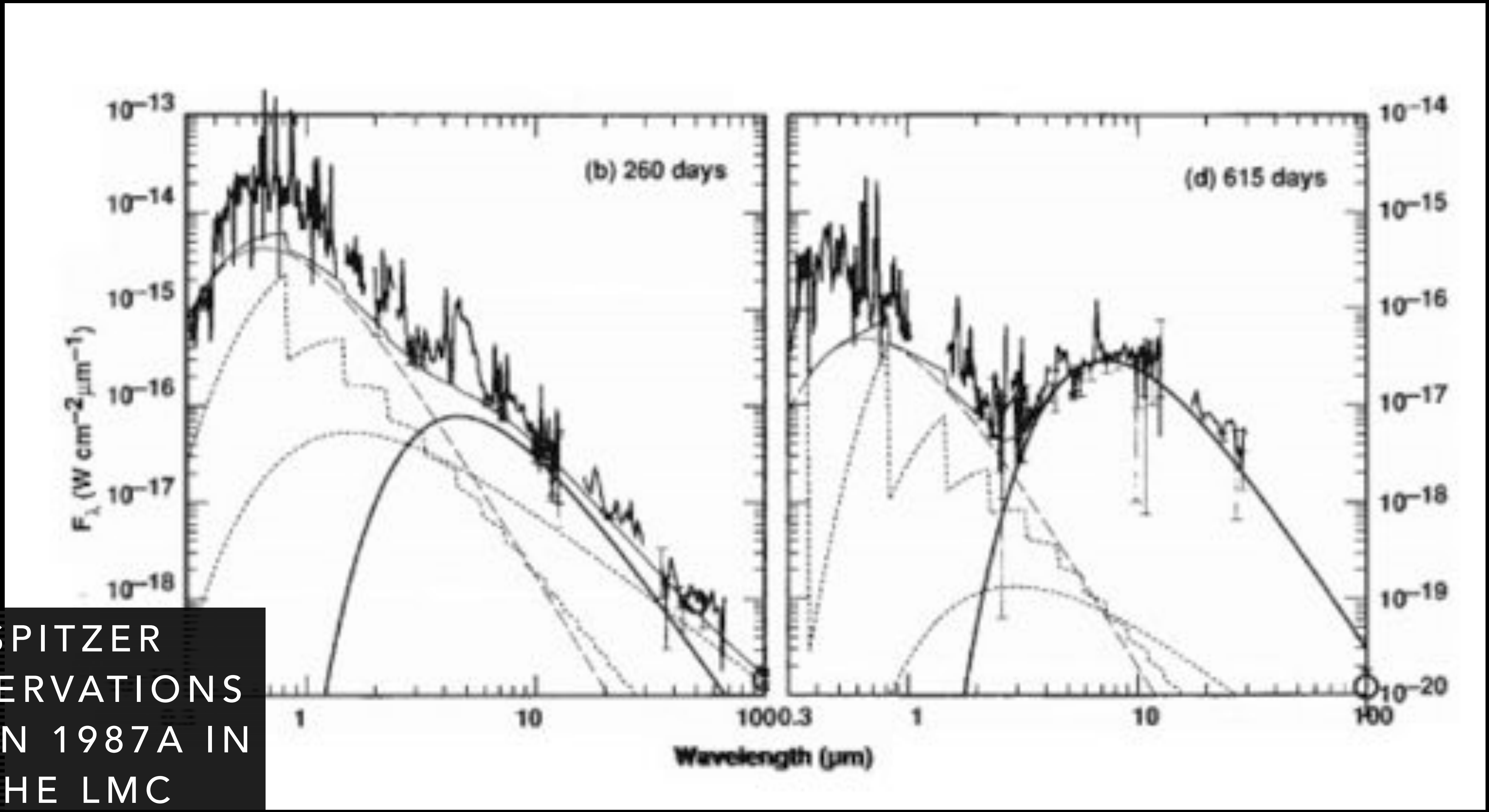
Herschel, Planck and Spitzer imaging

Careful modelling by De Looze et al 2016 distinguished cold ejecta dust (blue) from interstellar clouds (red)

CASSIOPEIA A @ 330YR:

0.3 - 0.5 $M_\odot$ (DE LOOZE ET AL. 2016)

DUST MASS ESTIMATES ARE GENERALLY INFERRED FROM FITTING THE IR SED…

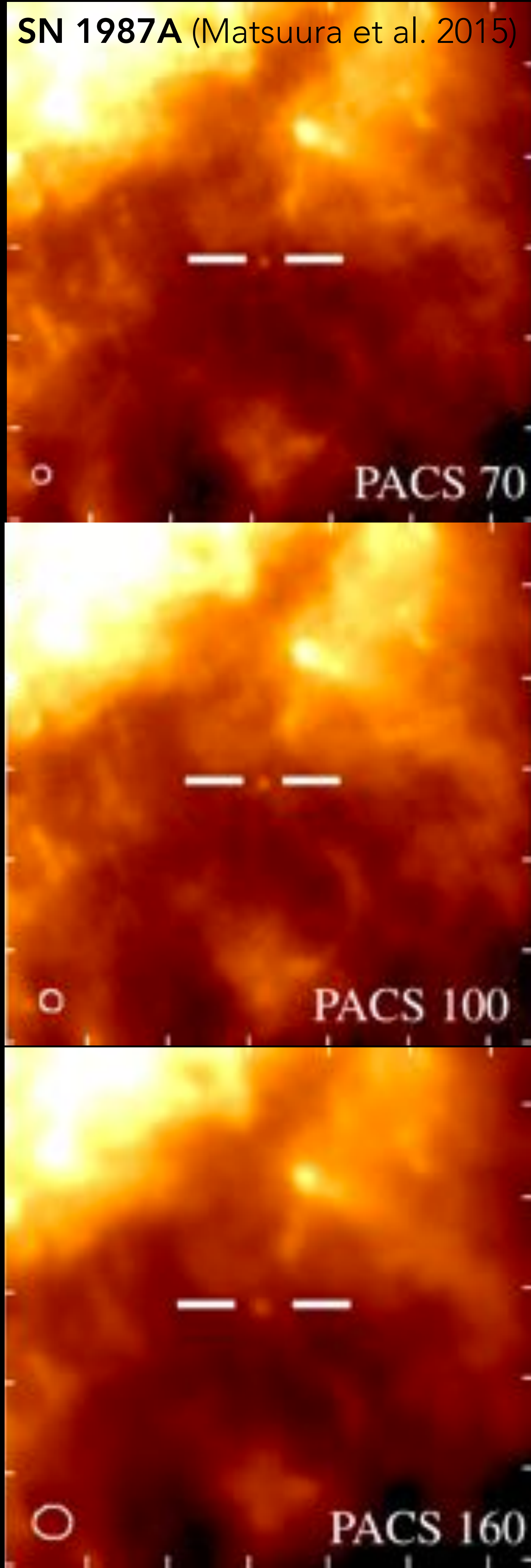


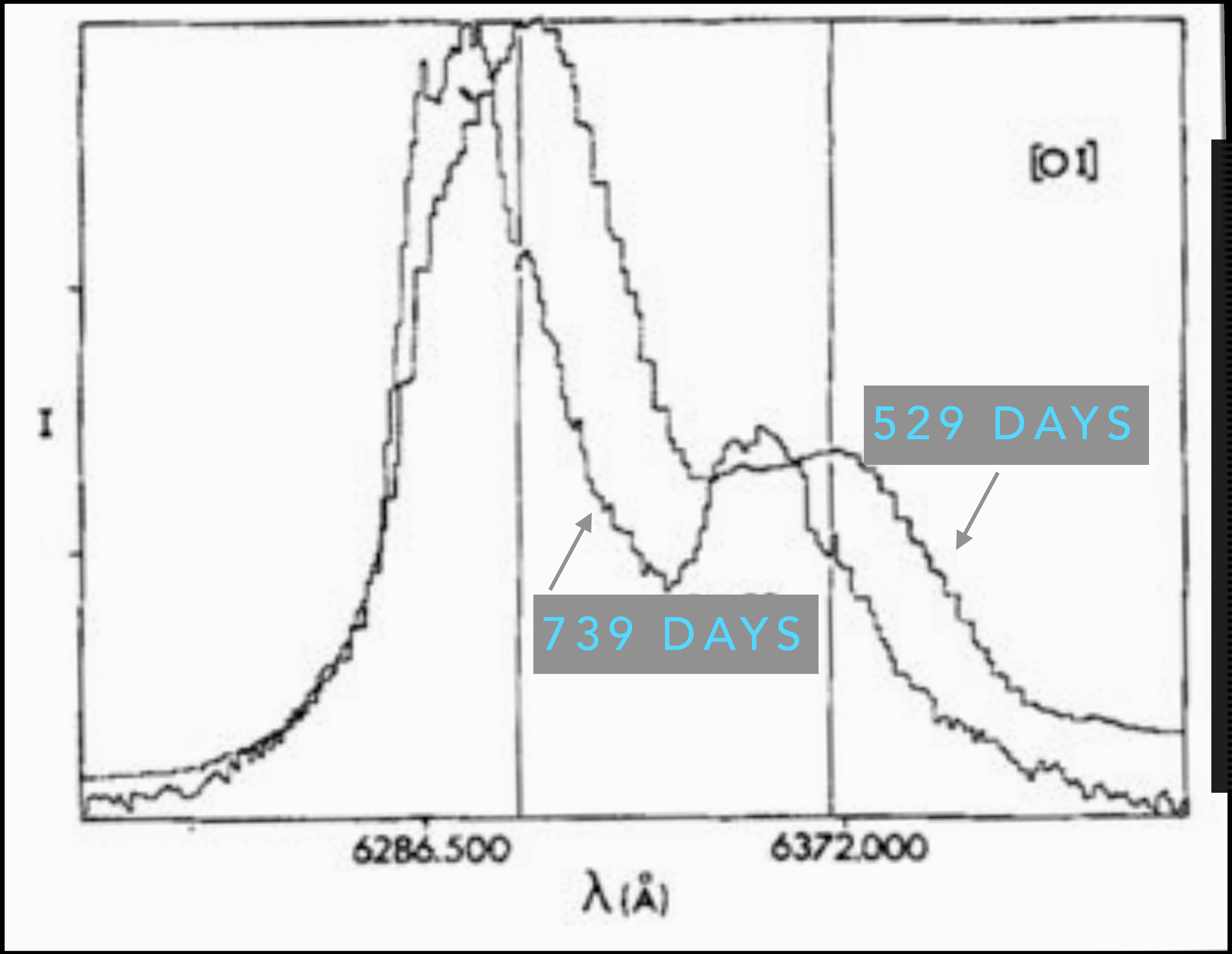
SPITZER OBSERVATIONS OF SN 1987A IN THE LMC SHOWING ONSET OF DUST FORMATION

…BUT THERE ARE DIFFICULTIES WITH THIS

- Far-IR observations are required to trace cold dust masses
- Difficult to distinguish between pre-existing dust and newly-formed dust
- Difficult to trace location of dust

SN 1987A (Matsuura et al. 2015)





SN 1987A [OI] DOUBLET AT 529D & 739D (LUCY ET AL. 1989)

THE LATTER PROFILE IS SUBSTANTIALLY BLUE-SHIFTED

AN ALTERNATIVE METHOD IS TO MODEL BLUE-SHIFTED LINE PROFILES IN OPTICAL/IR

Monte Carlo radiative transfer code

Dust absorption and scattering

Smooth or clumped dust distribution

Smooth or clumped emissivity distribution

DAMOCLES

Simple electron scattering

Any dust grain size distribution

Any combination of dust species

Velocity field at fixed time

WHY TYPE IIn?

- Visible years after outburst due to ongoing interaction
- Cool dense shell may provide ideal conditions for rapid dust formation **behind reverse shock**
- Can potentially gain insight into destructive effects of reverse shock on ejecta dust on short timescales
- Useful to distinguish newly-formed dust in ejecta/CDS from pre-existing circumstellar dust

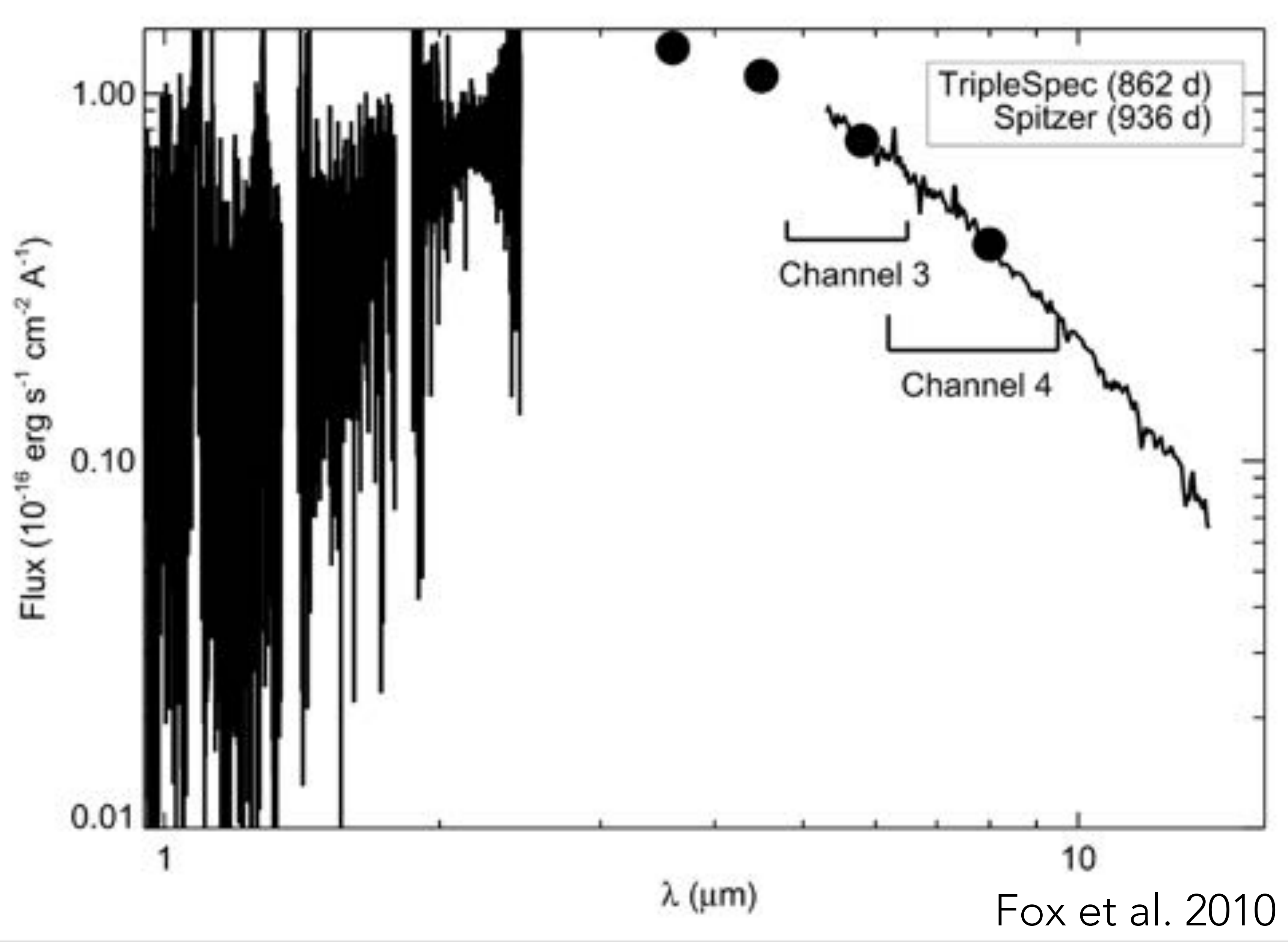
NGC 2906 - 30 MPC - TYPE IIN

SN 2005IP

BVI Image Credit: Sergio Castellon

DUST IN SN2005IP FROM SPITZER

- Dust predicted from IR data (Fox et al. 09, 10)
- ~0.05 M⊙ 'warm' dust attributed to pre-existing dust in CSM
- 5 x 10^{-4} M⊙ of 'hot' dust formed @ 936d in CDS or ejecta



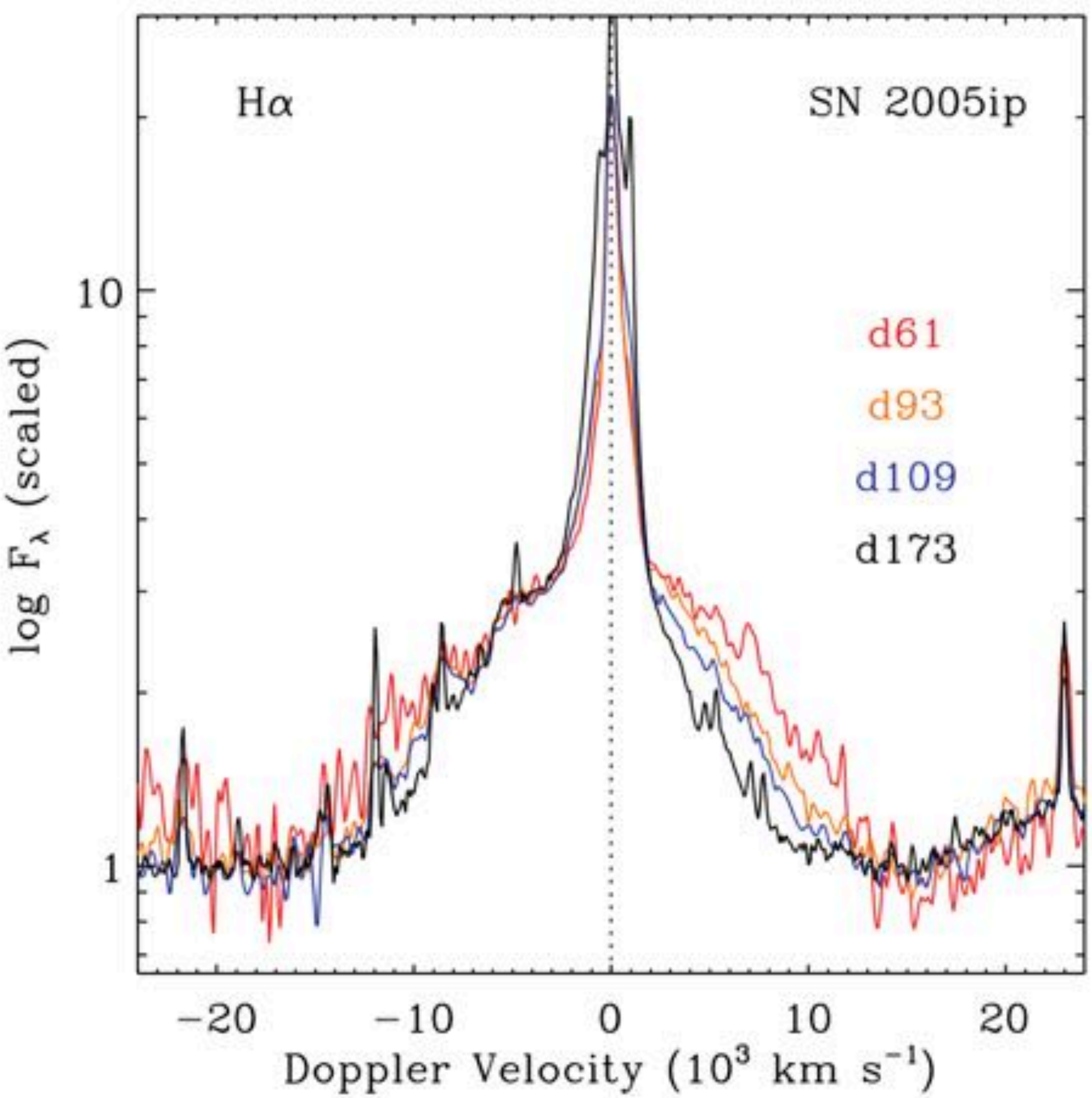
Fox et al. 2010

Optical spectra show increasing blueshifting in broad H**α** at early times (61d - 173d)

Attributed to dust formation in ejecta

(Smith et al. 09)

Smith et al. 2009

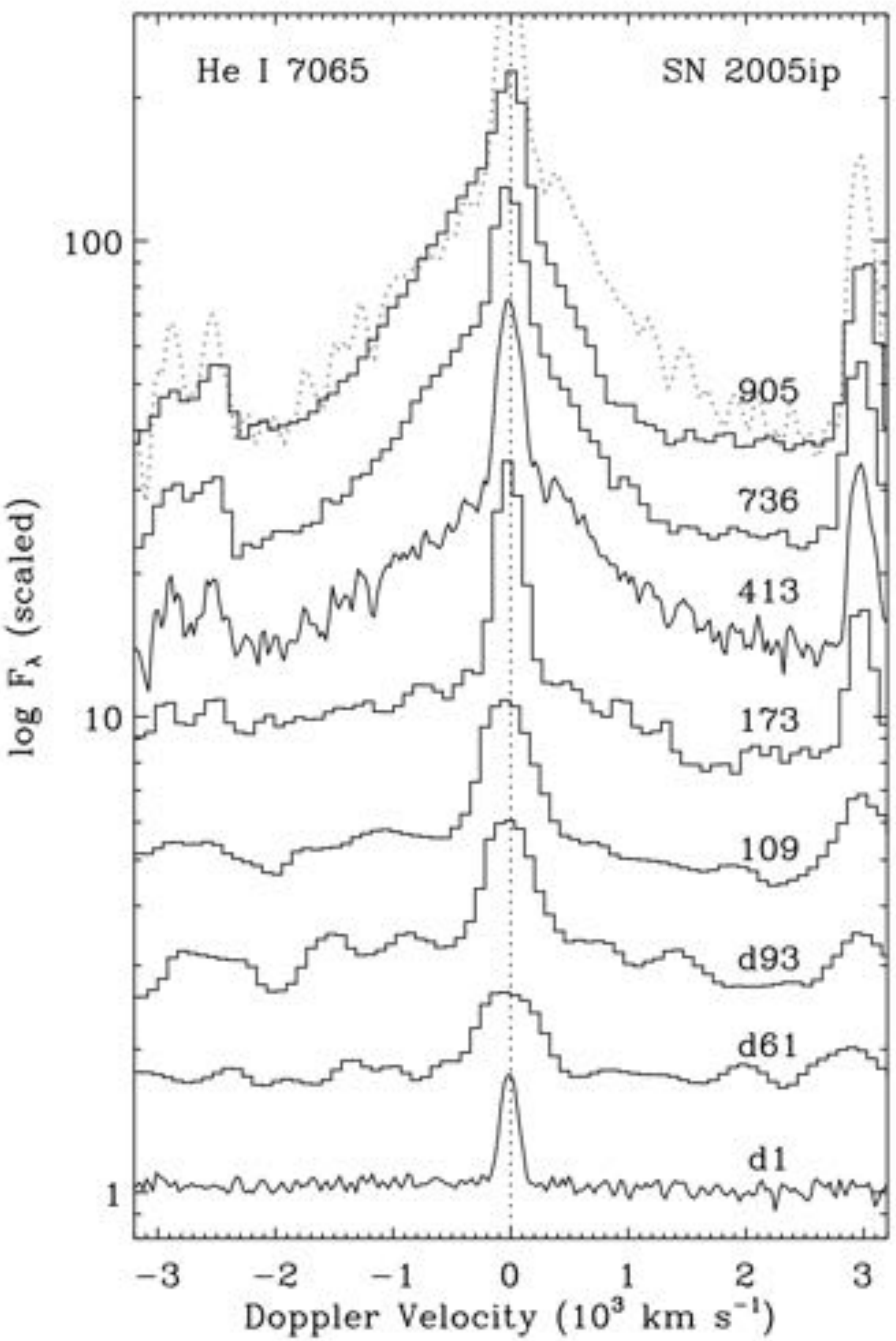


Optical spectra also show increasing blueshifting in post-shock HeI 7065 at later times (413d - 900d)

Attributed to dust formation in post-shock region

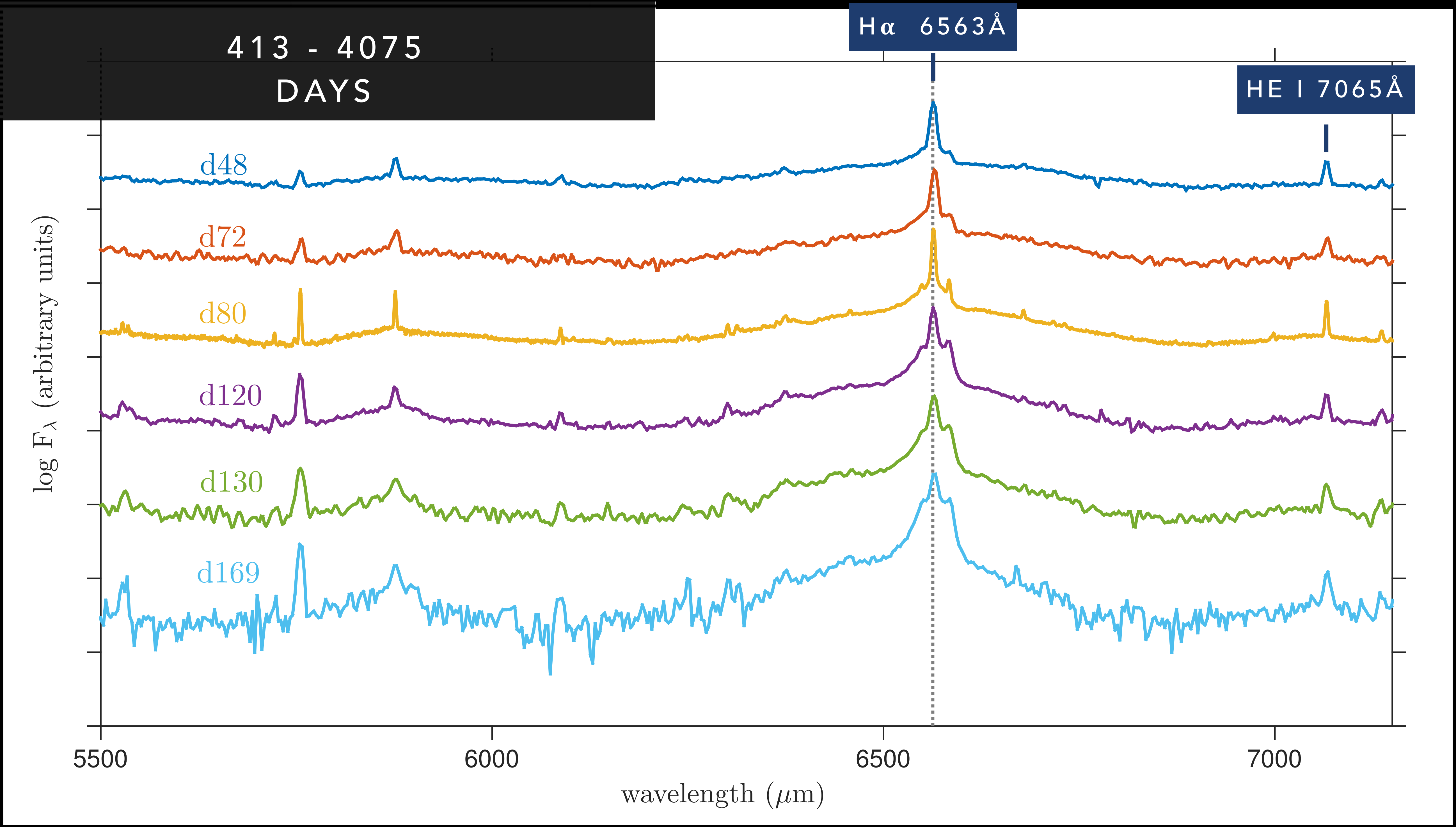
(Smith et al. 09)

Smith et al. 2009



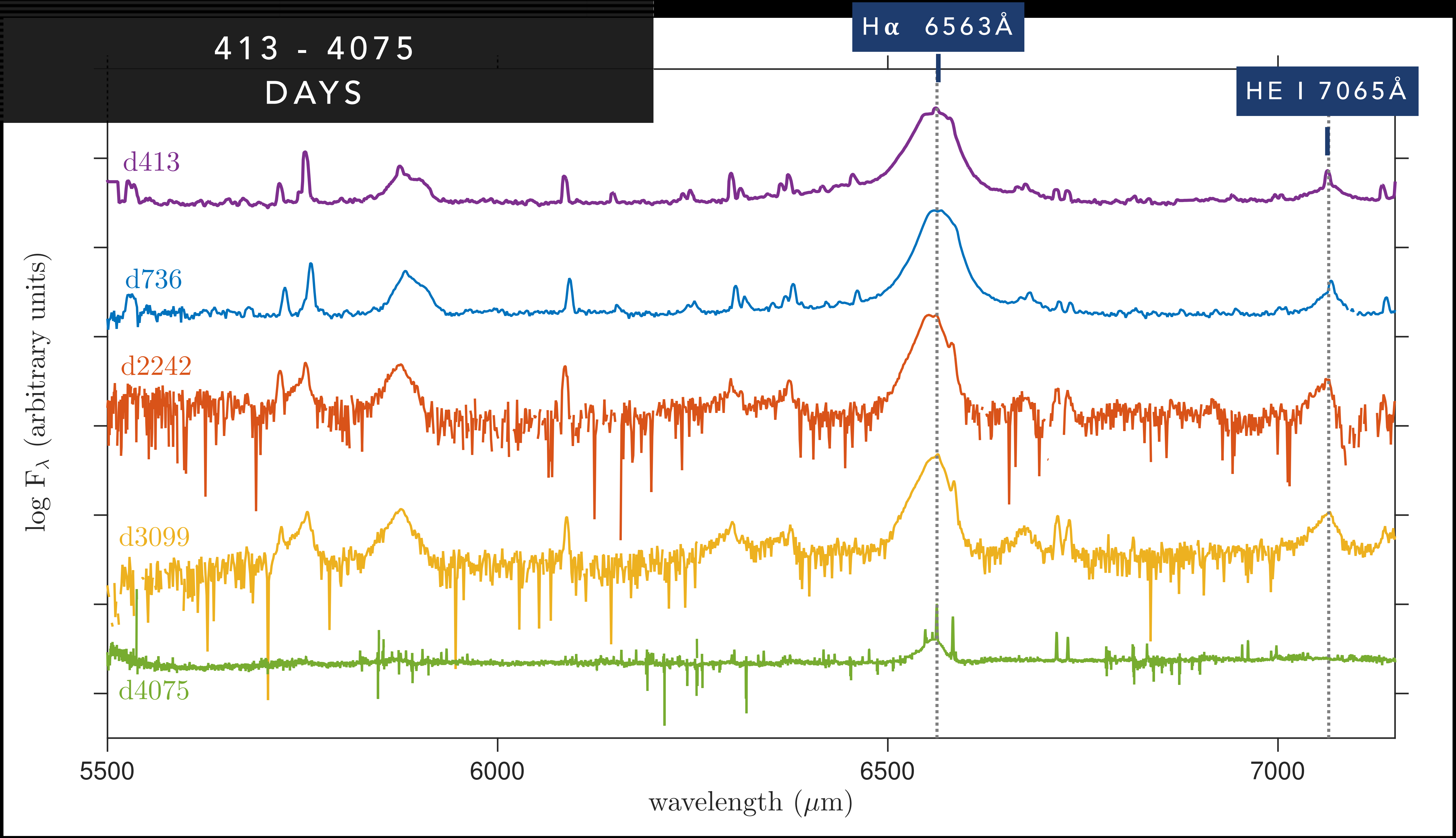
SN 2005IP SPECTRA FROM KECK ARCHIVE, WISEREP DATABASE AND RECENT VLT XSHOOTER DATA

413 - 4075 DAYS

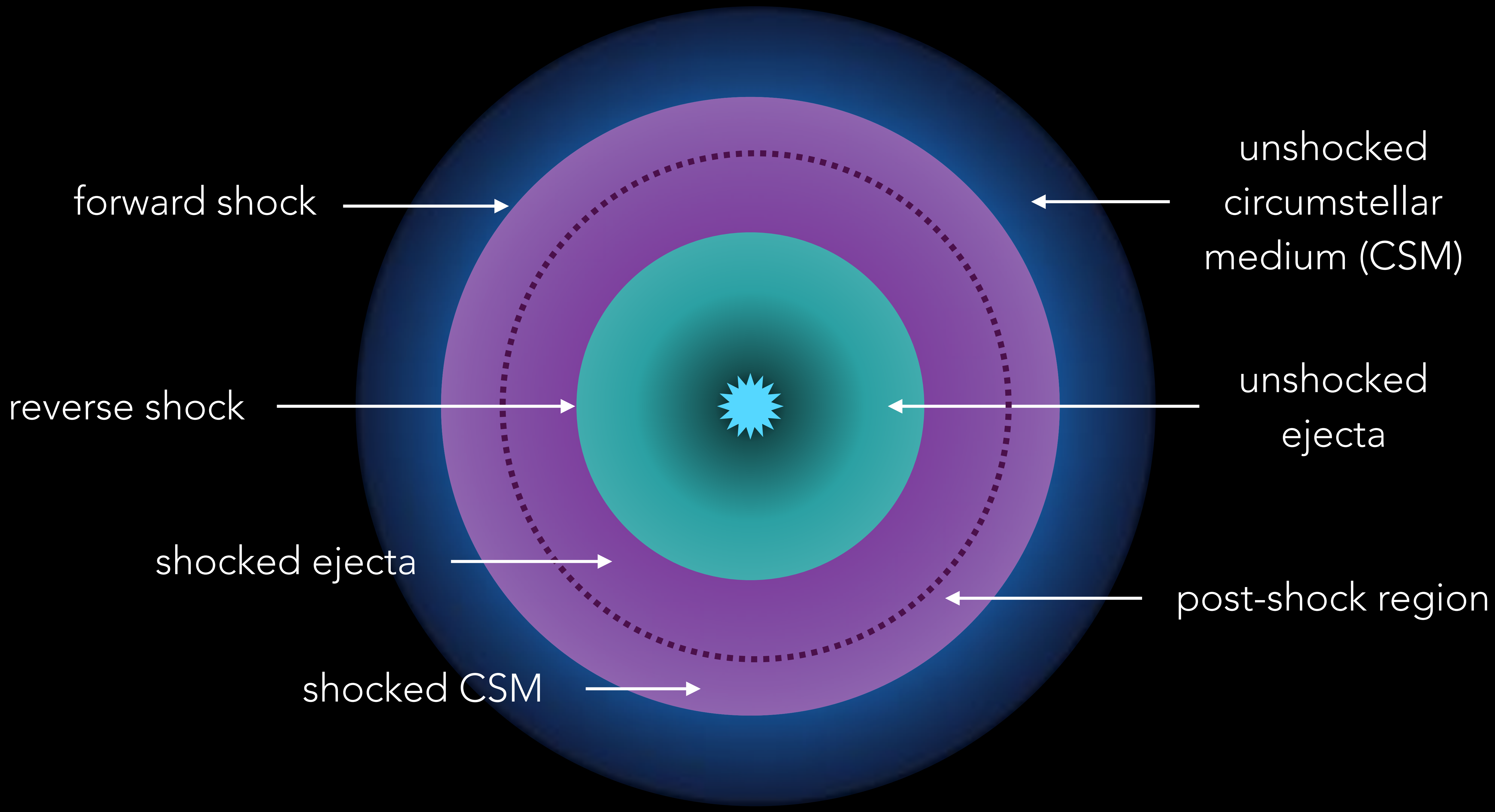


SN 2005IP SPECTRA FROM KECK ARCHIVE, WISEREP DATABASE AND RECENT VLT XSHOOTER DATA

413 - 4075
DAYS



SN 2005IP MODEL STRUCTURE



forward shock

reverse shock

shocked ejecta

shocked CSM

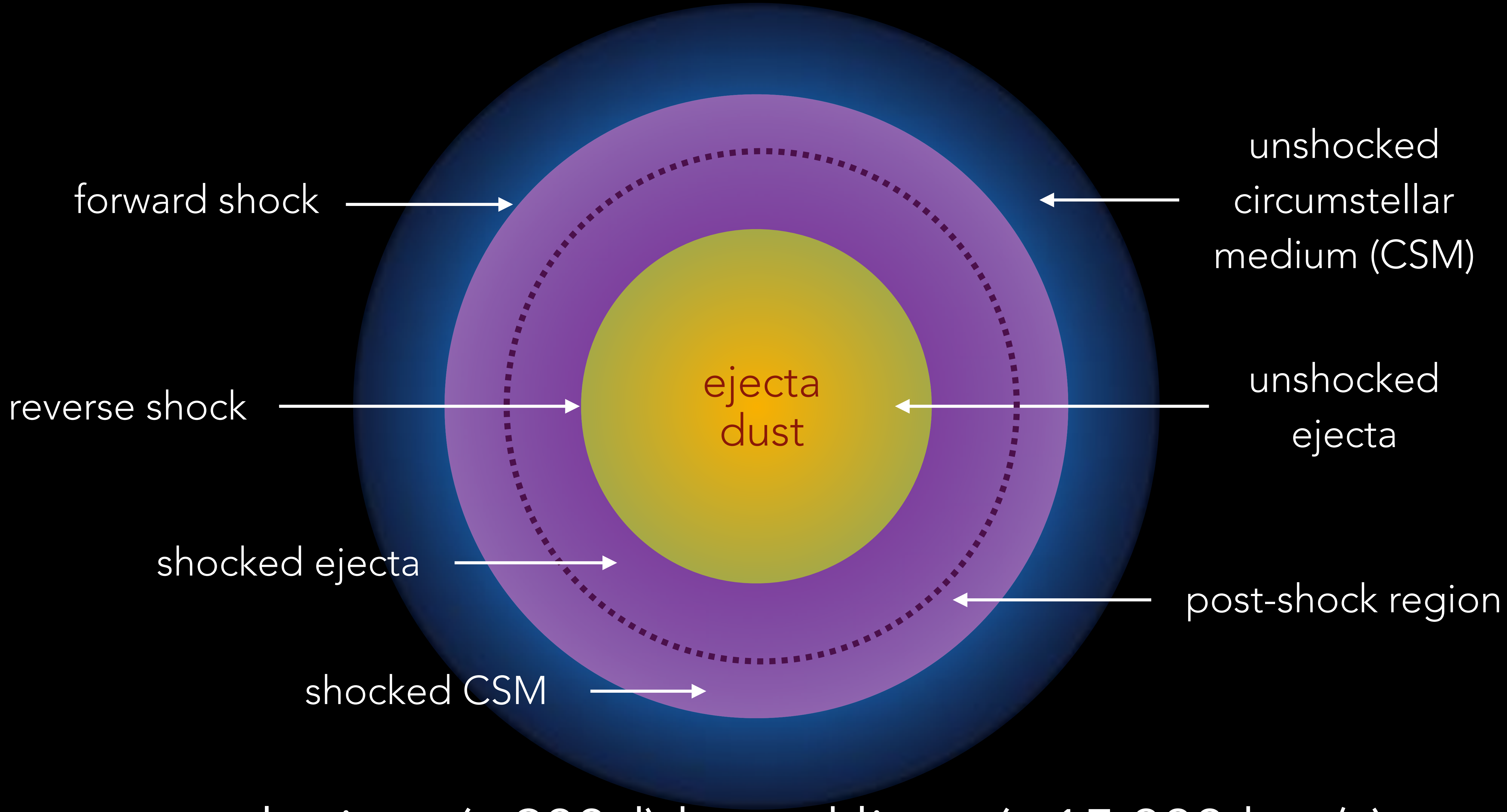
unshocked circumstellar medium (CSM)

unshocked ejecta

post-shock region

SN 2005IP MODEL STRUCTURE

EJECTA EMISSION + EJECTA DUST



forward shock

unshocked circumstellar medium (CSM)

reverse shock

unshocked ejecta

shocked ejecta

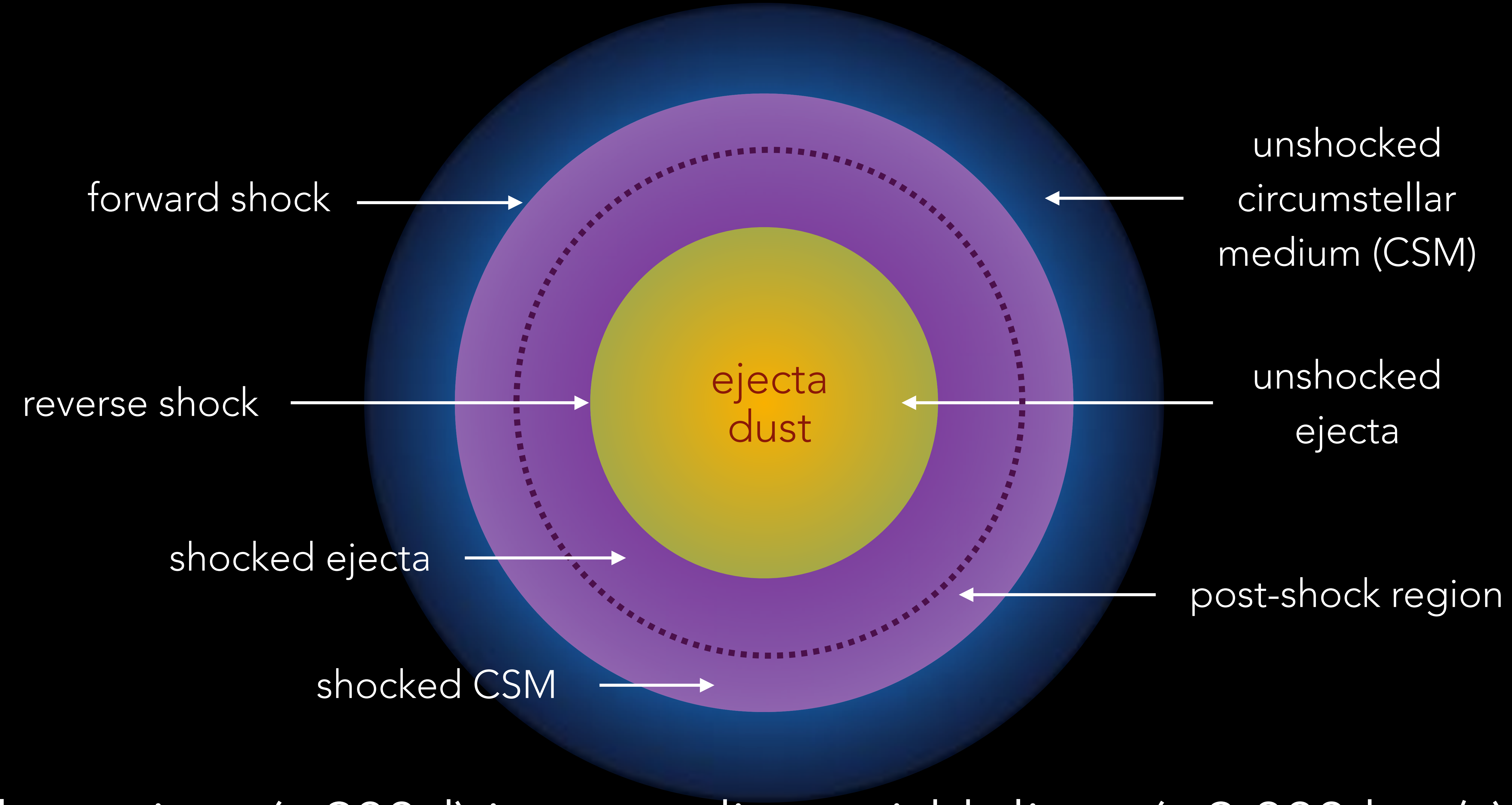
post-shock region

shocked CSM

early time (<200d) broad lines (~15,000 km/s)

SN 2005IP MODEL STRUCTURE

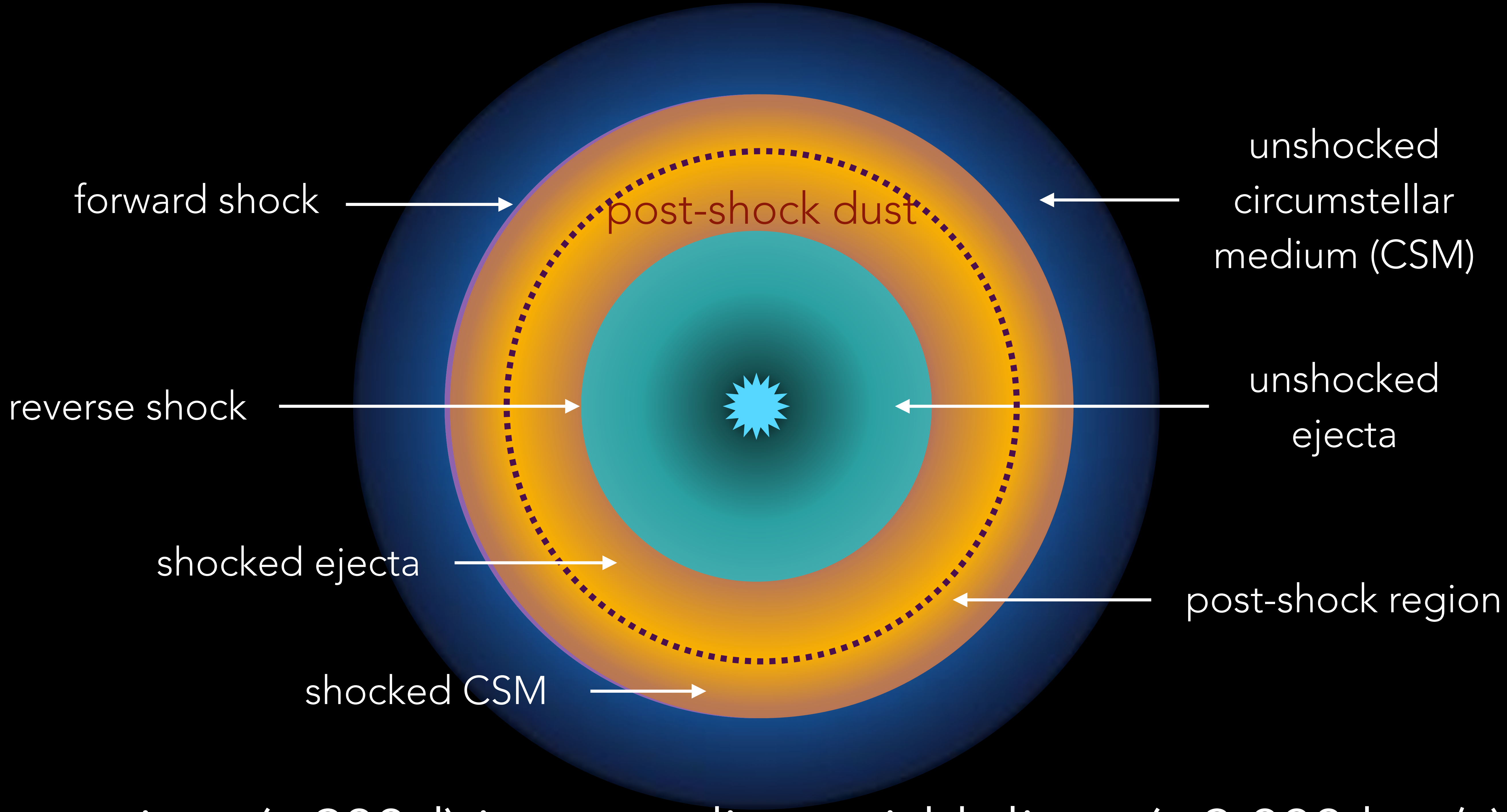
POST-SHOCK EMISSION + EJECTA DUST



later time (>200d) intermediate width lines (~3,000 km/s)

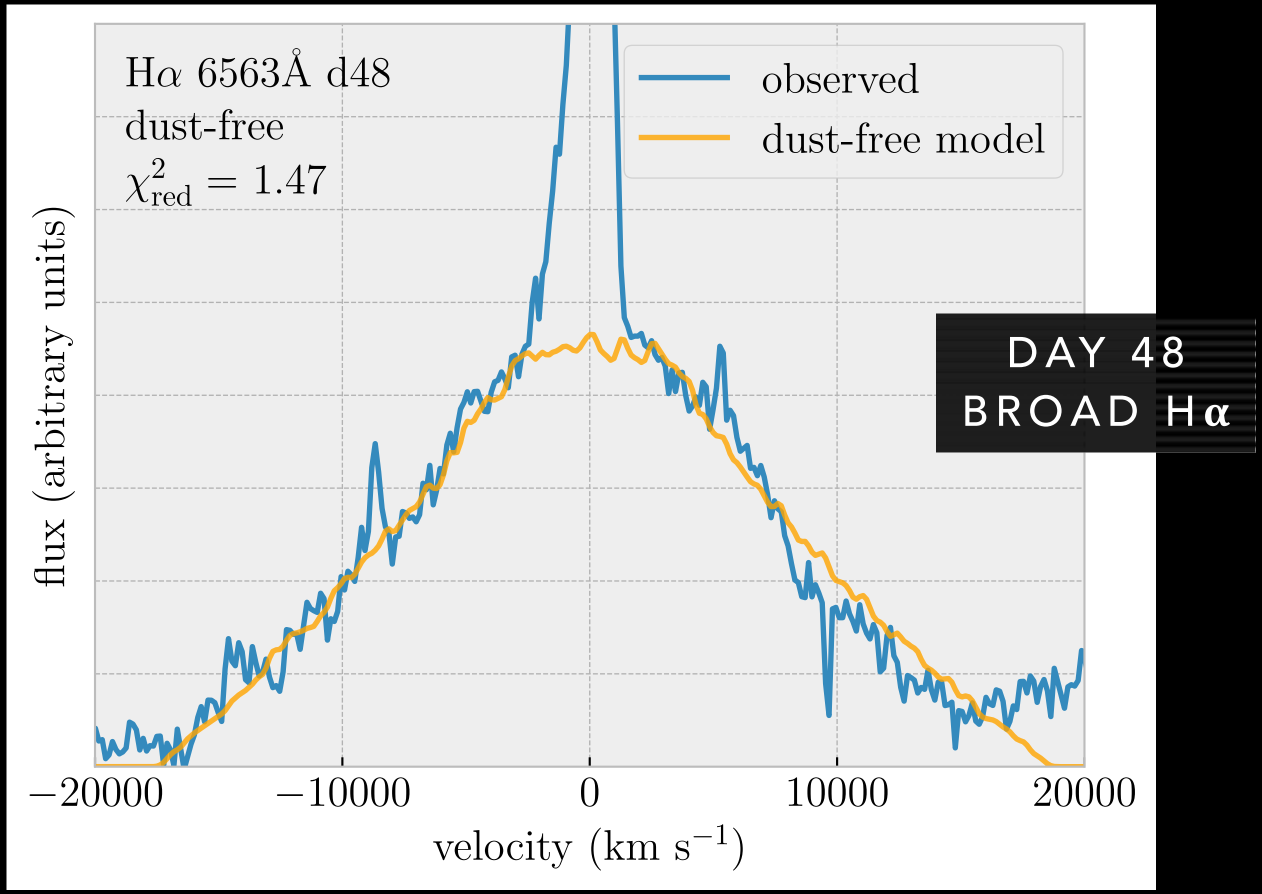
SN 2005IP MODEL STRUCTURE

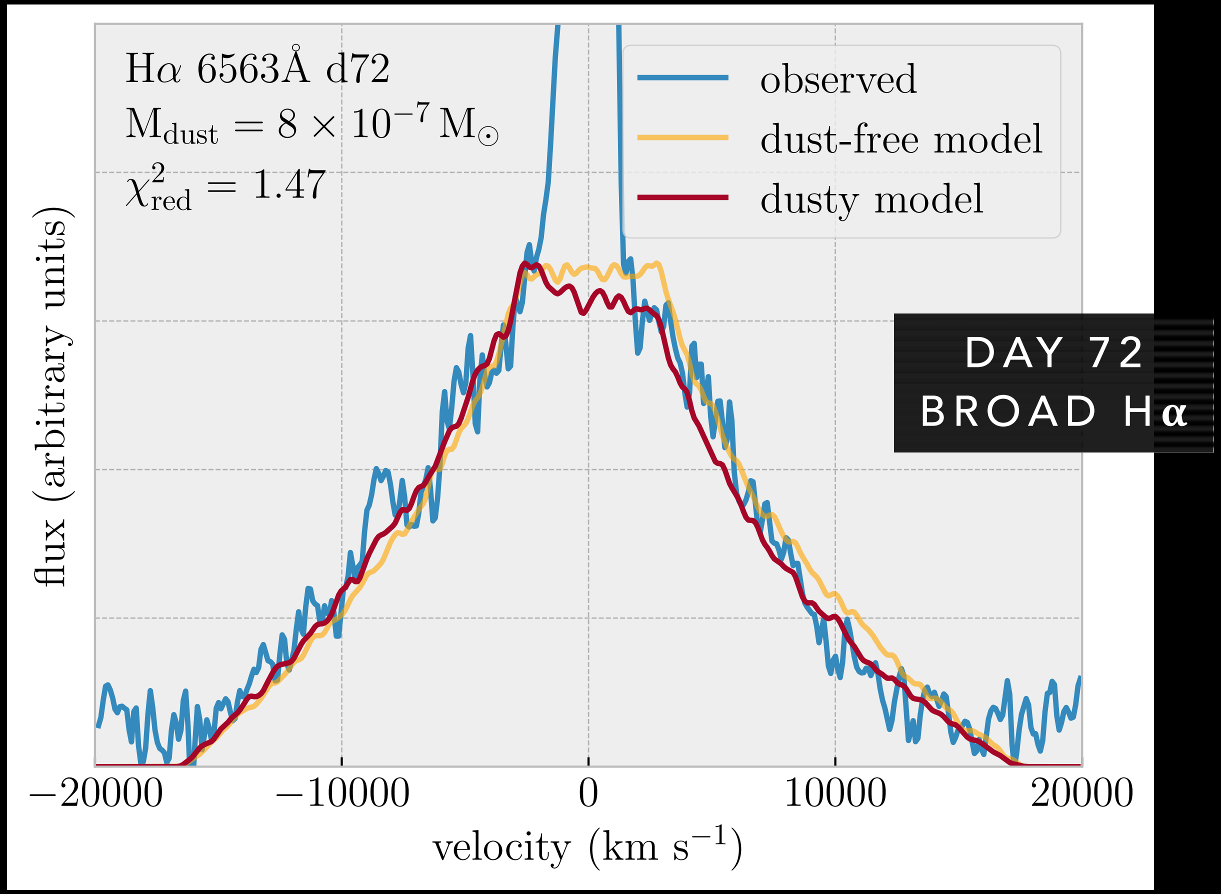
POST-SHOCK EMISSION + POST-SHOCK DUST

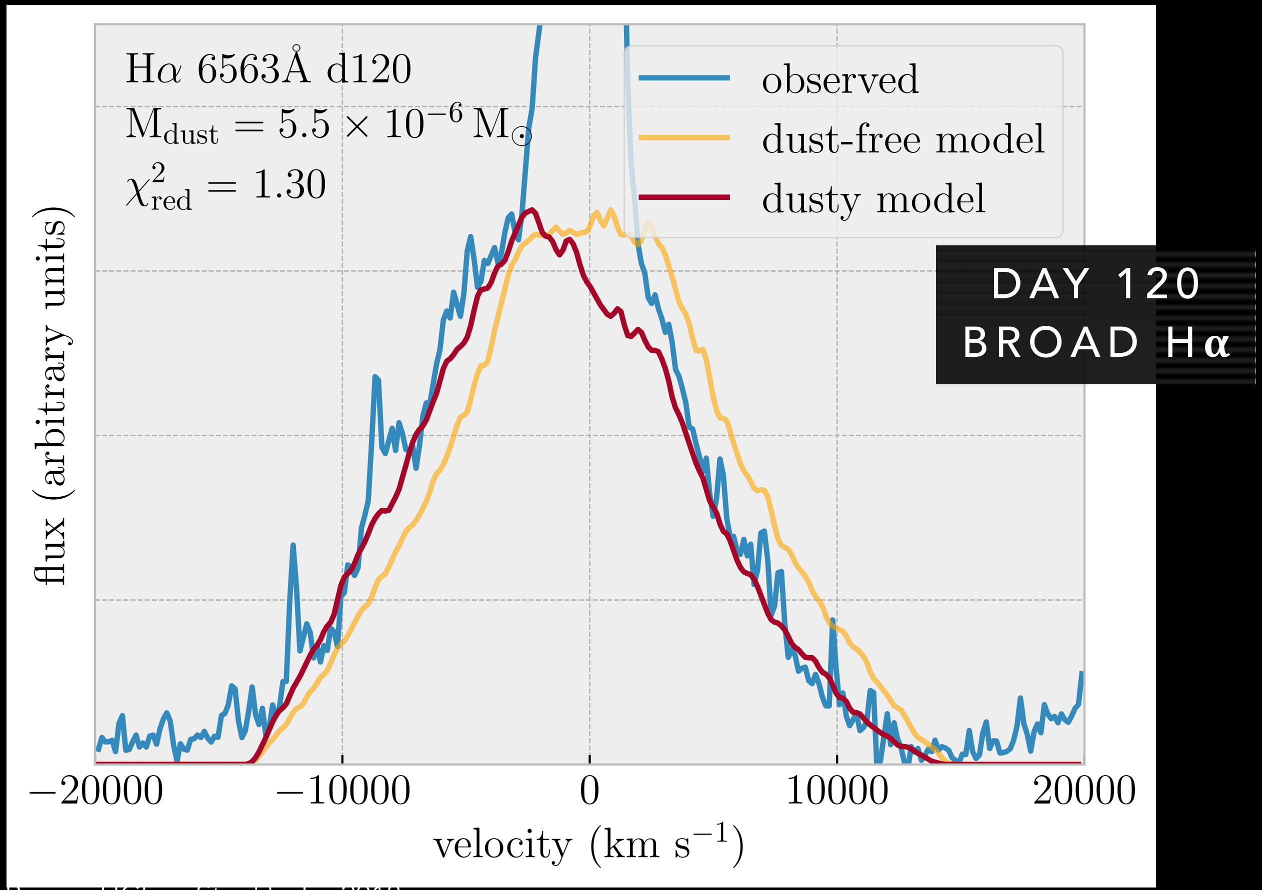


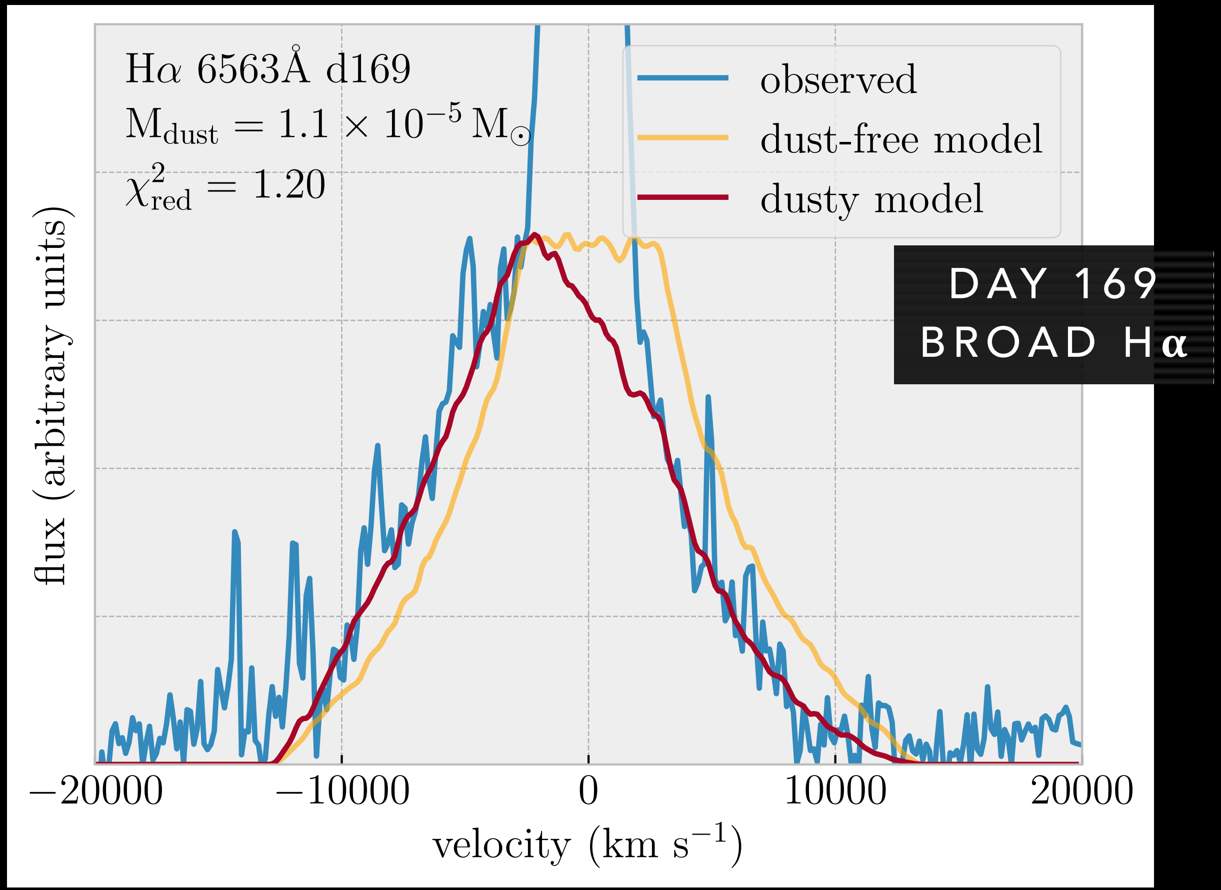
later time (>200d) intermediate width lines (~3,000 km/s)

EARLY-TIME BROAD EJECTA EMISSION + EJECTA DUST

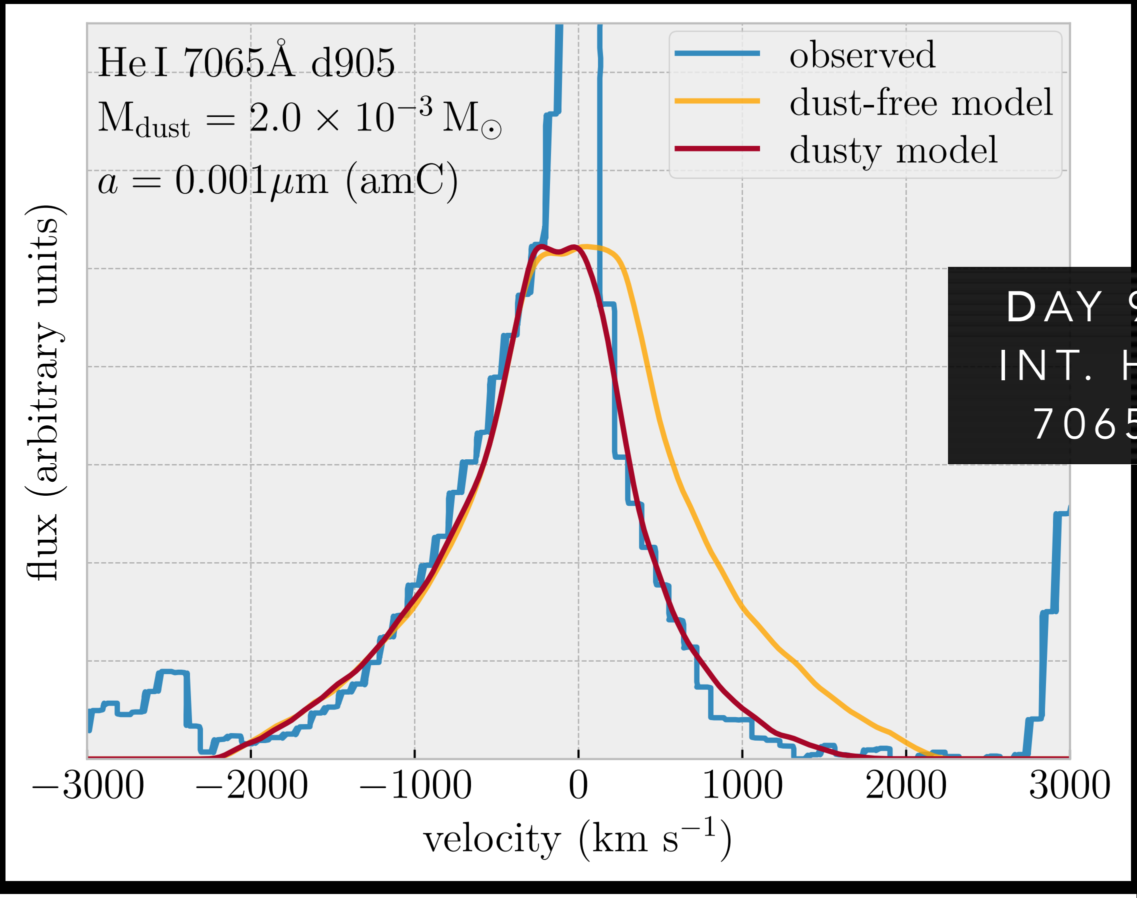

DAY 48
BROAD Hα


DAY 72
BROAD Hα

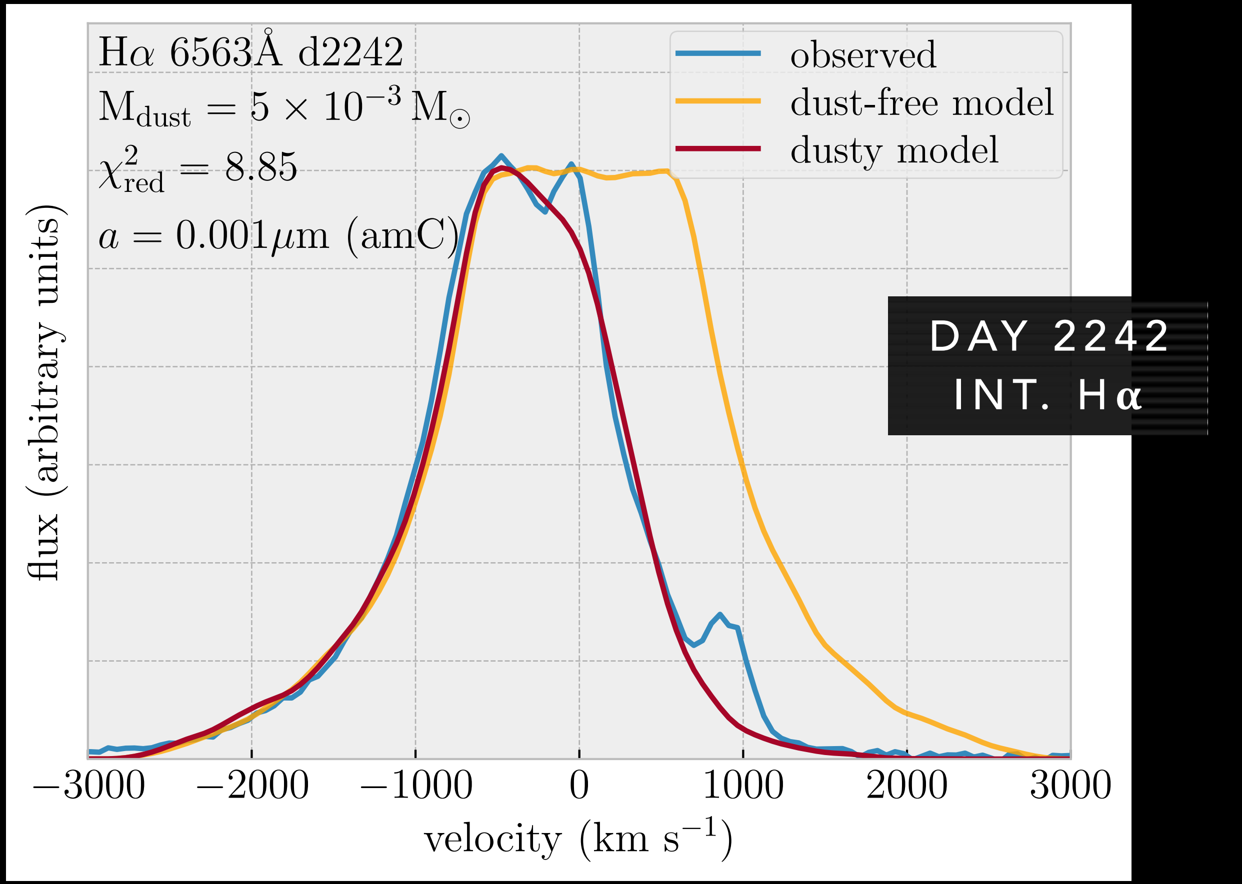

DAY 120
BROAD Hα


DAY 169
BROAD Hα

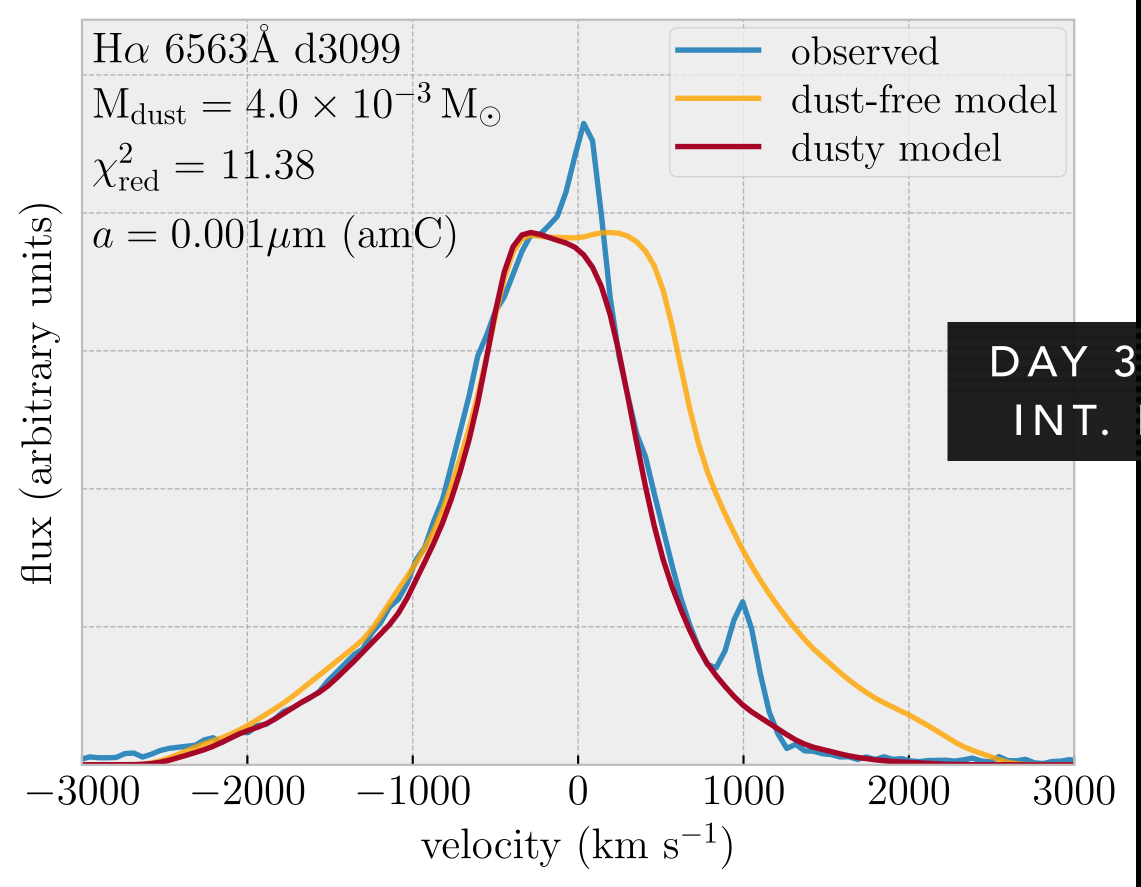
LATE-TIME POST-SHOCK EMISSION + EJECTA DUST



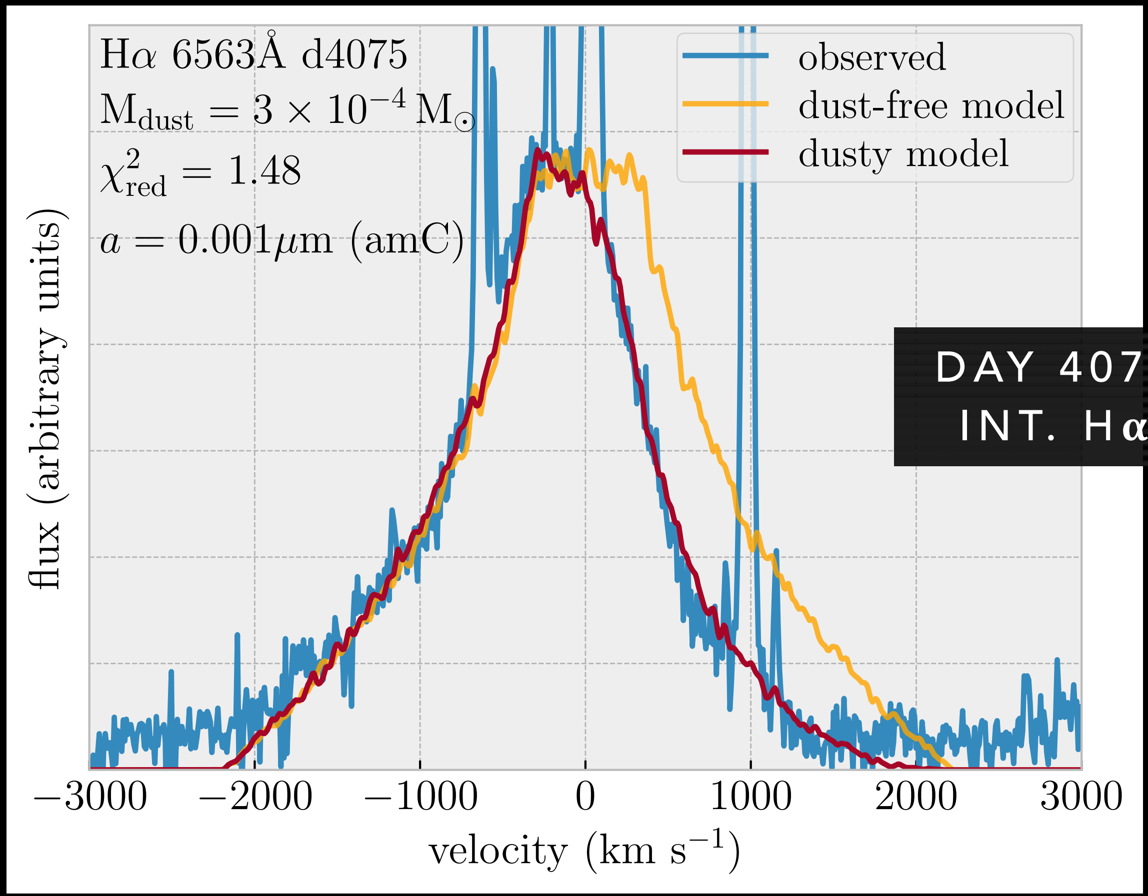
DAY 905
INT. HE I
7065Å



DAY 2242
INT. Hα

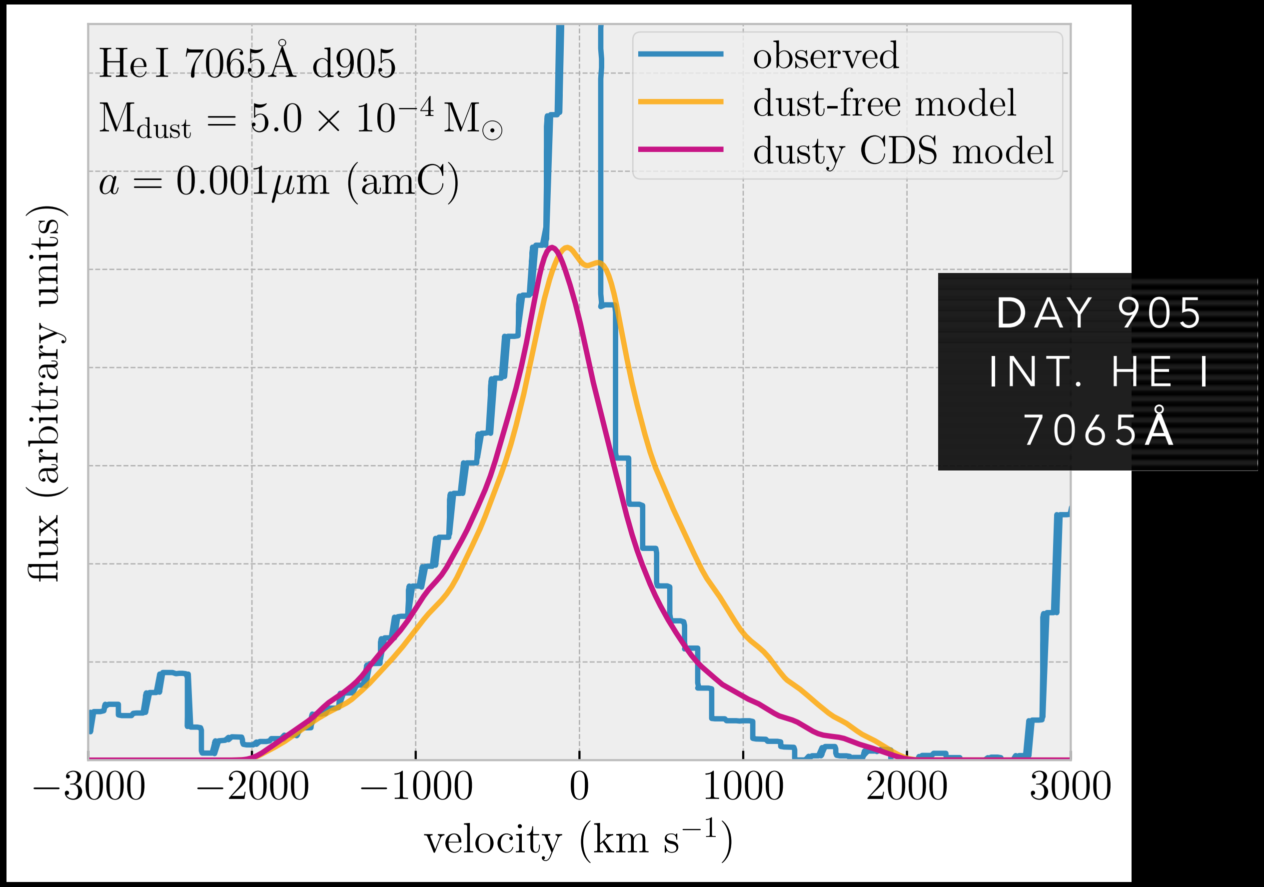


DAY 3099
INT. Hα

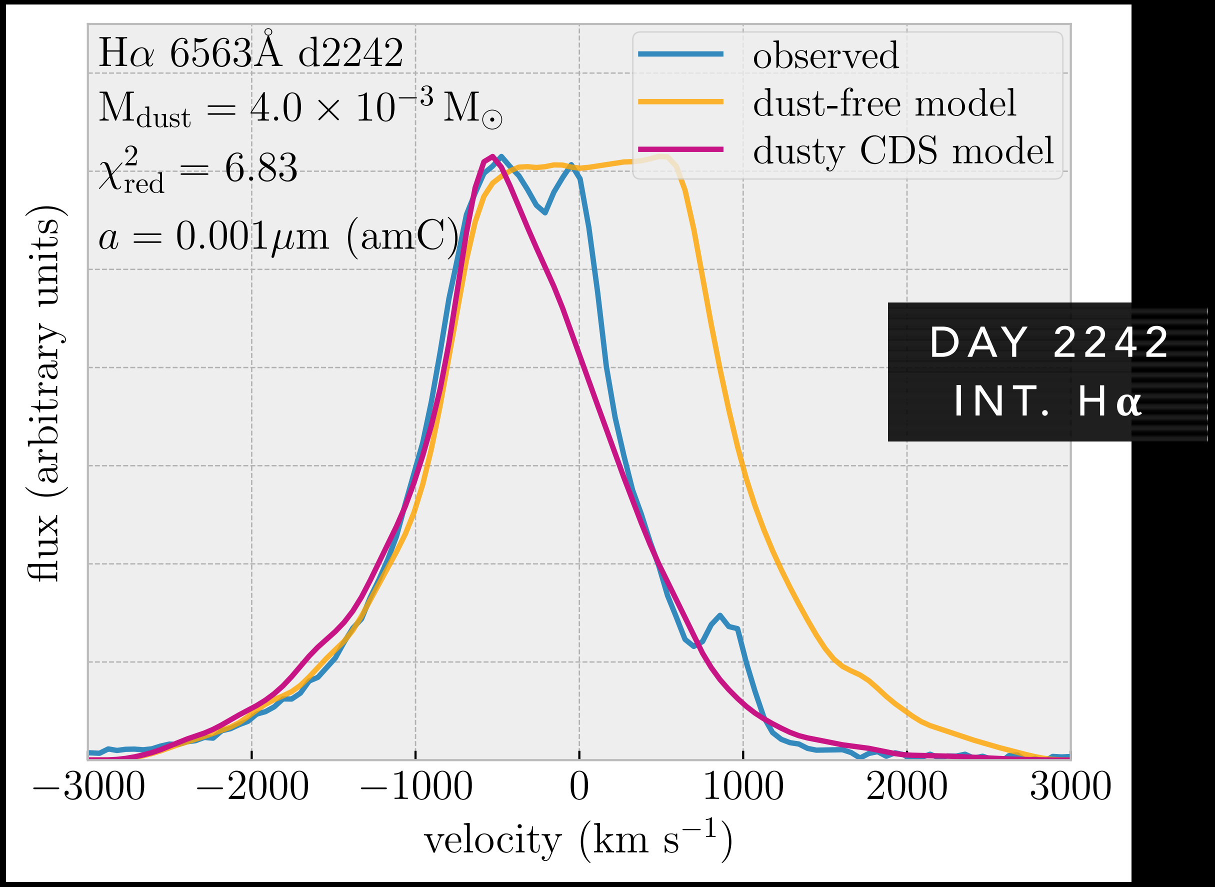


DAY 4075
INT. Hα

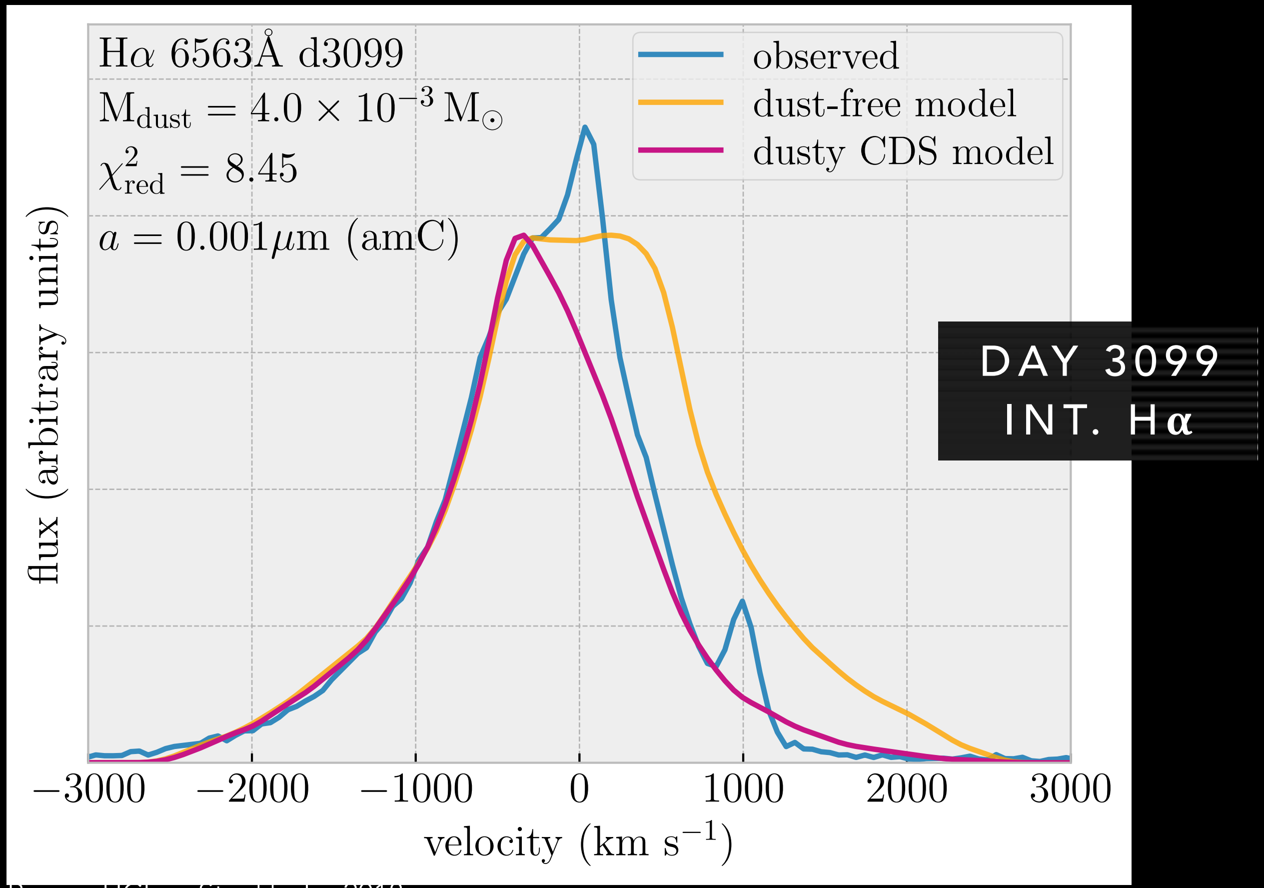
LATE-TIME POST-SHOCK EMISSION + POST-SHOCK DUST



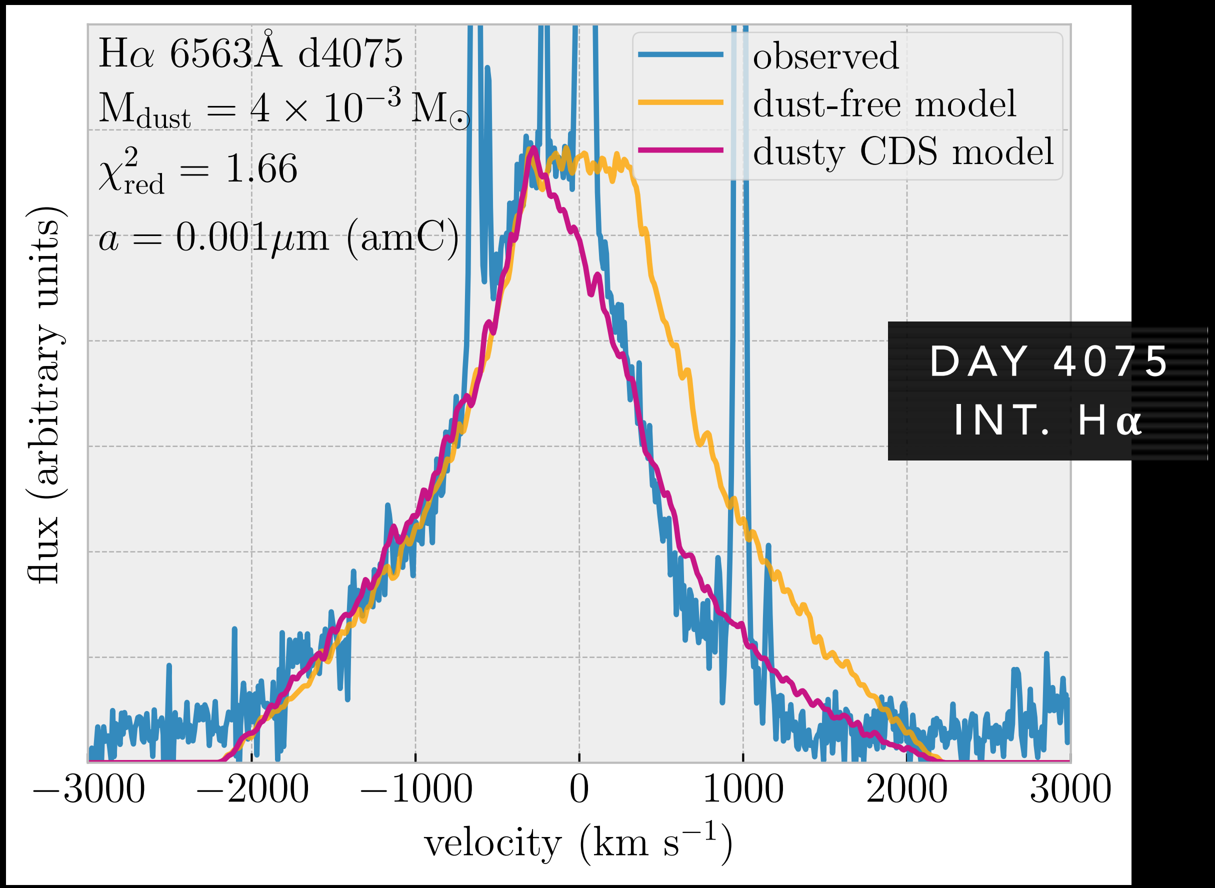
DAY 905
INT. HE I
7065Å



DAY 2242
INT. Hα

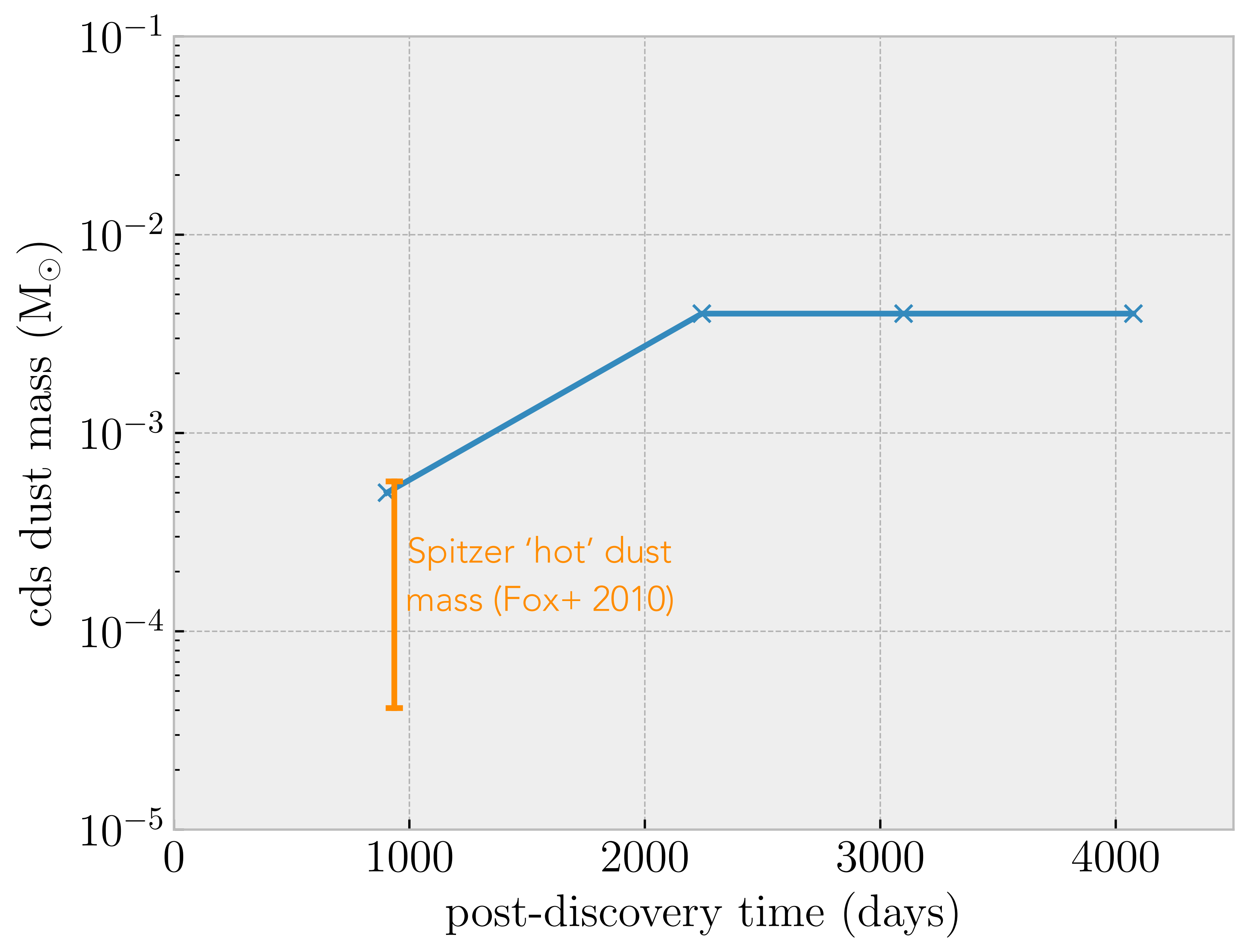


DAY 3099
INT. Hα



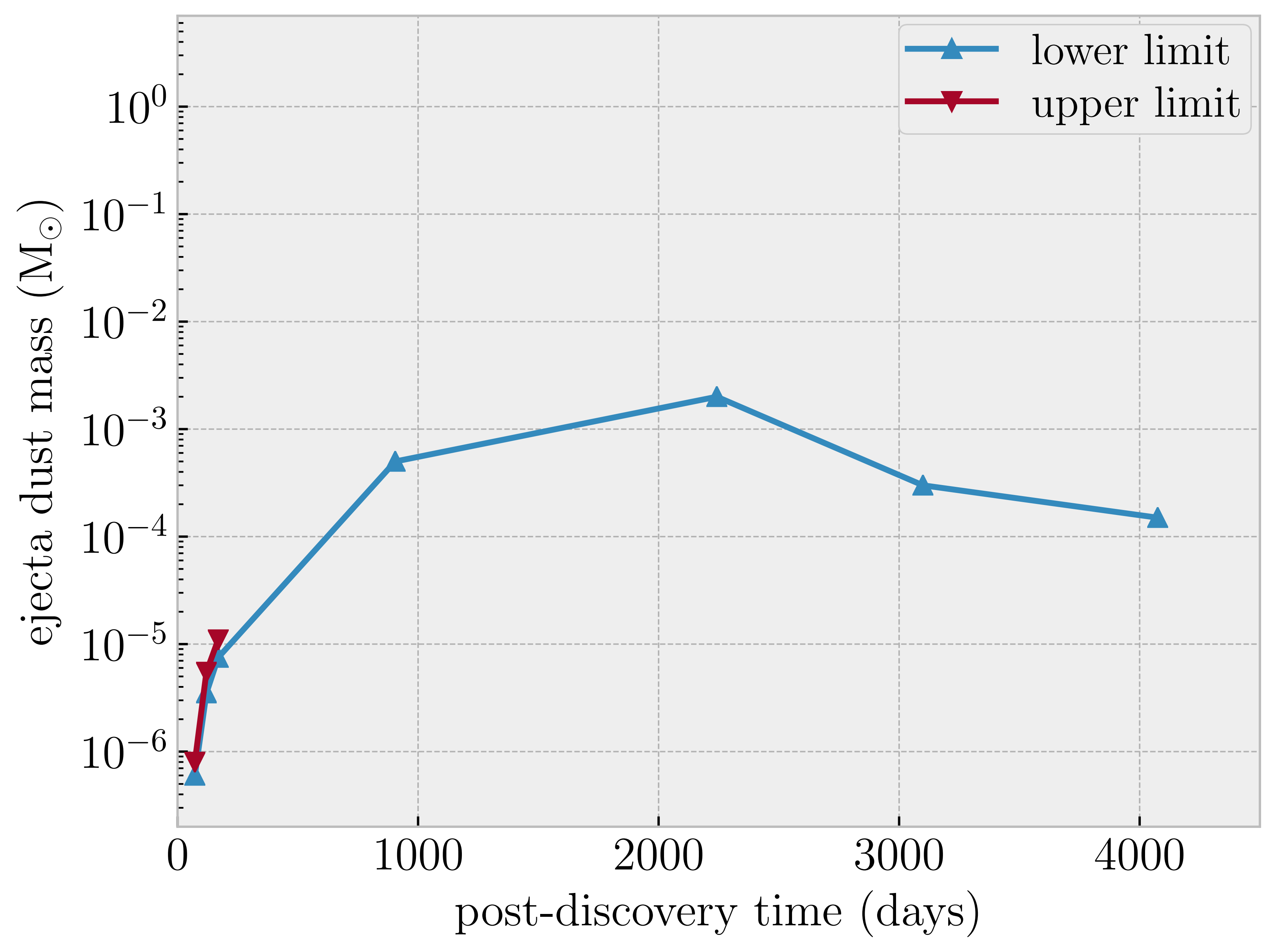
DAY 4075
INT. Hα

POST-SHOCK DUST FORMATION



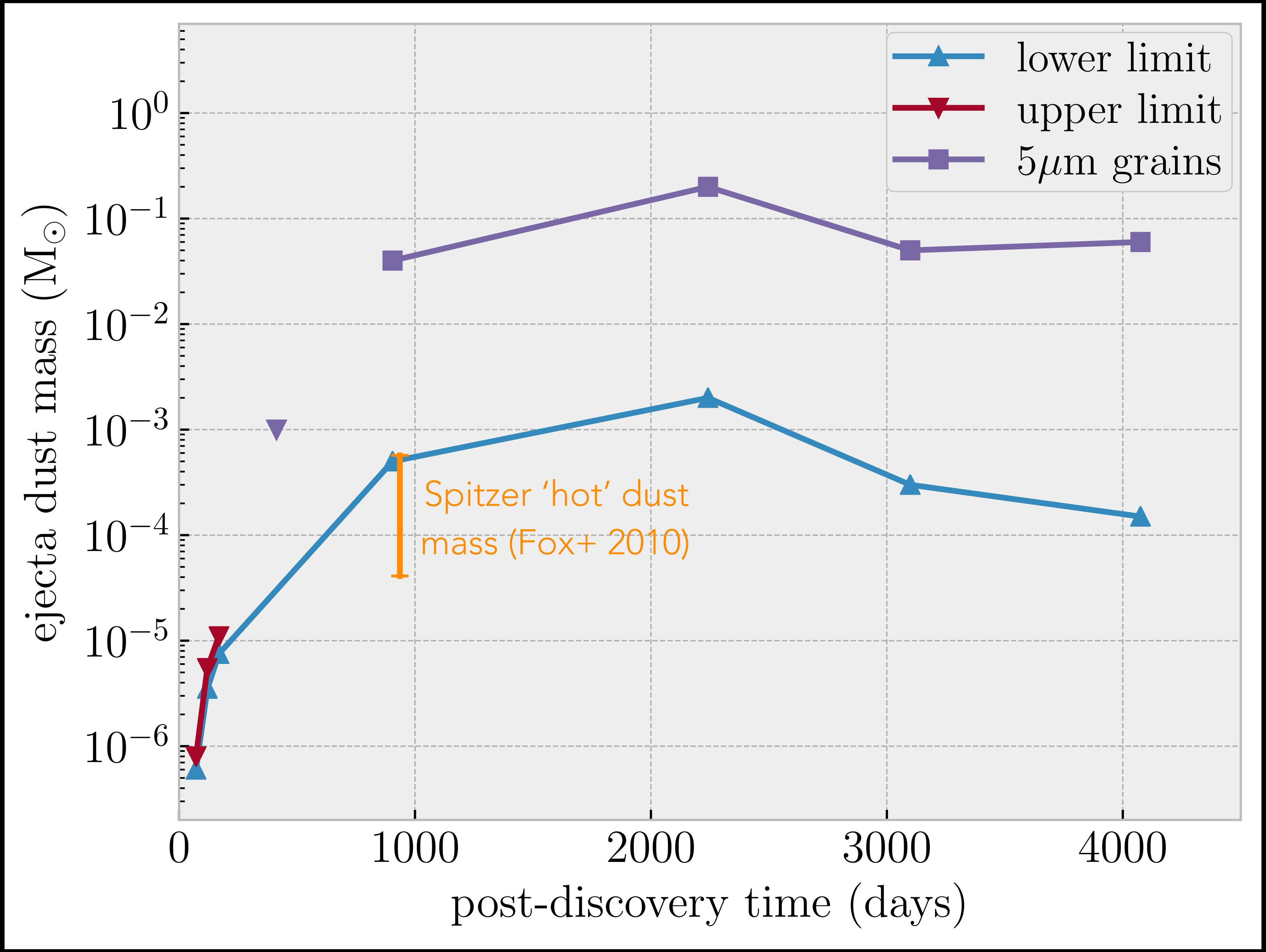
Dust formation in post-shock region leading to plateau in dust mass

EJECTA DUST



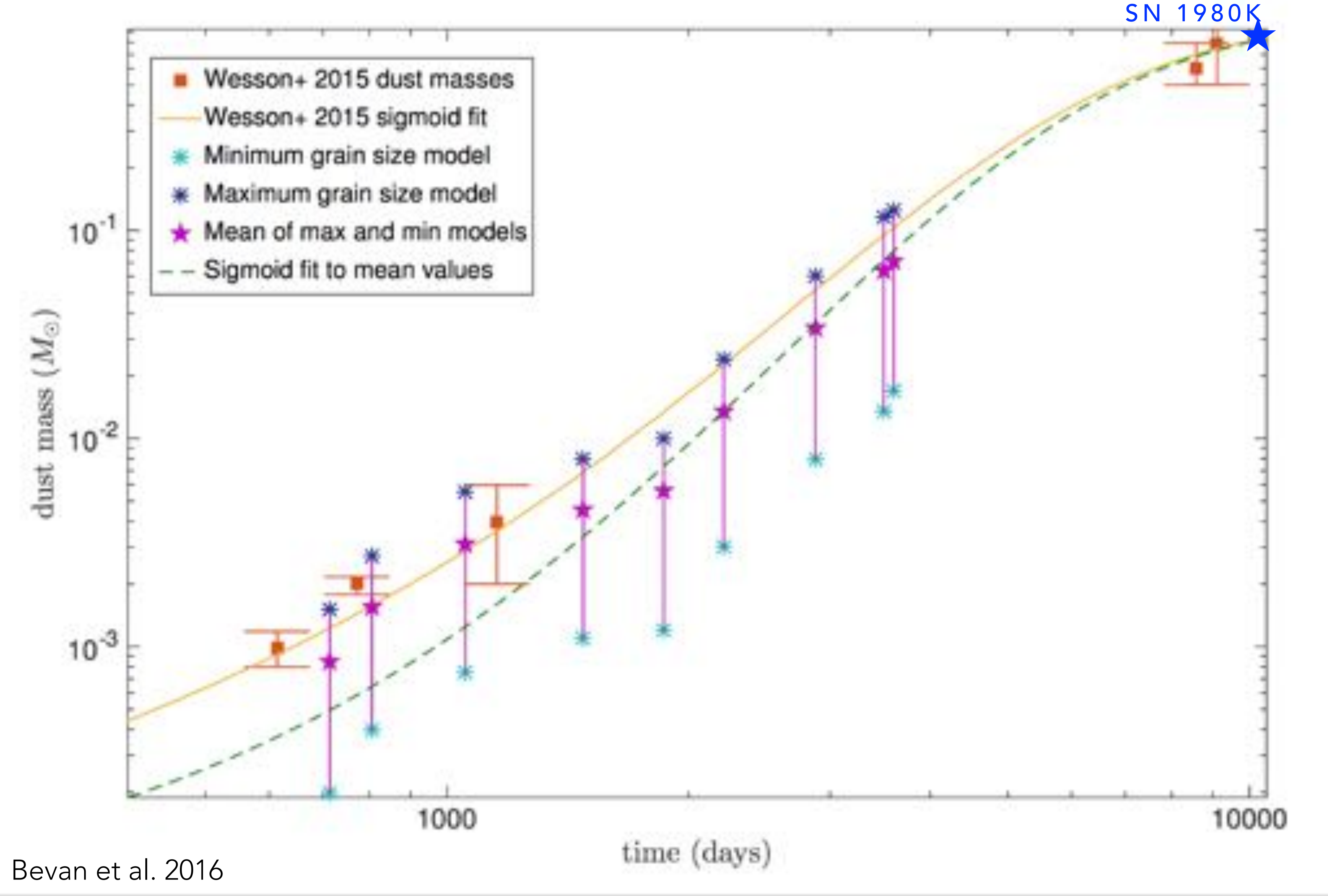
Optically thick dust at later epochs ➡ lower limit

EJECTA DUST



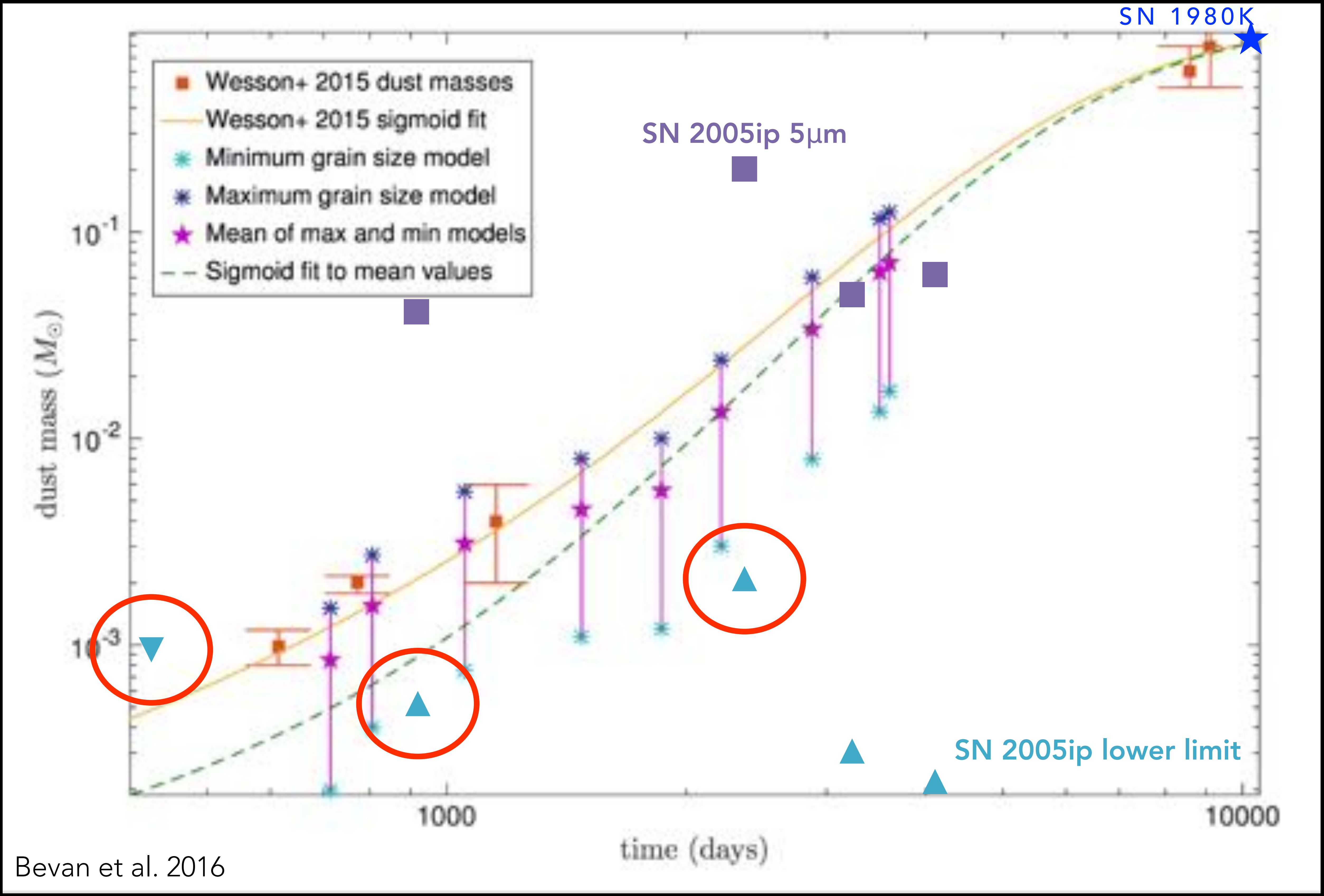
Grain size crucial for determining dust mass

SN 1987A DUST MASS EVOLUTION FROM SED AND LINE PROFILE FITTING



Bevan et al. 2016

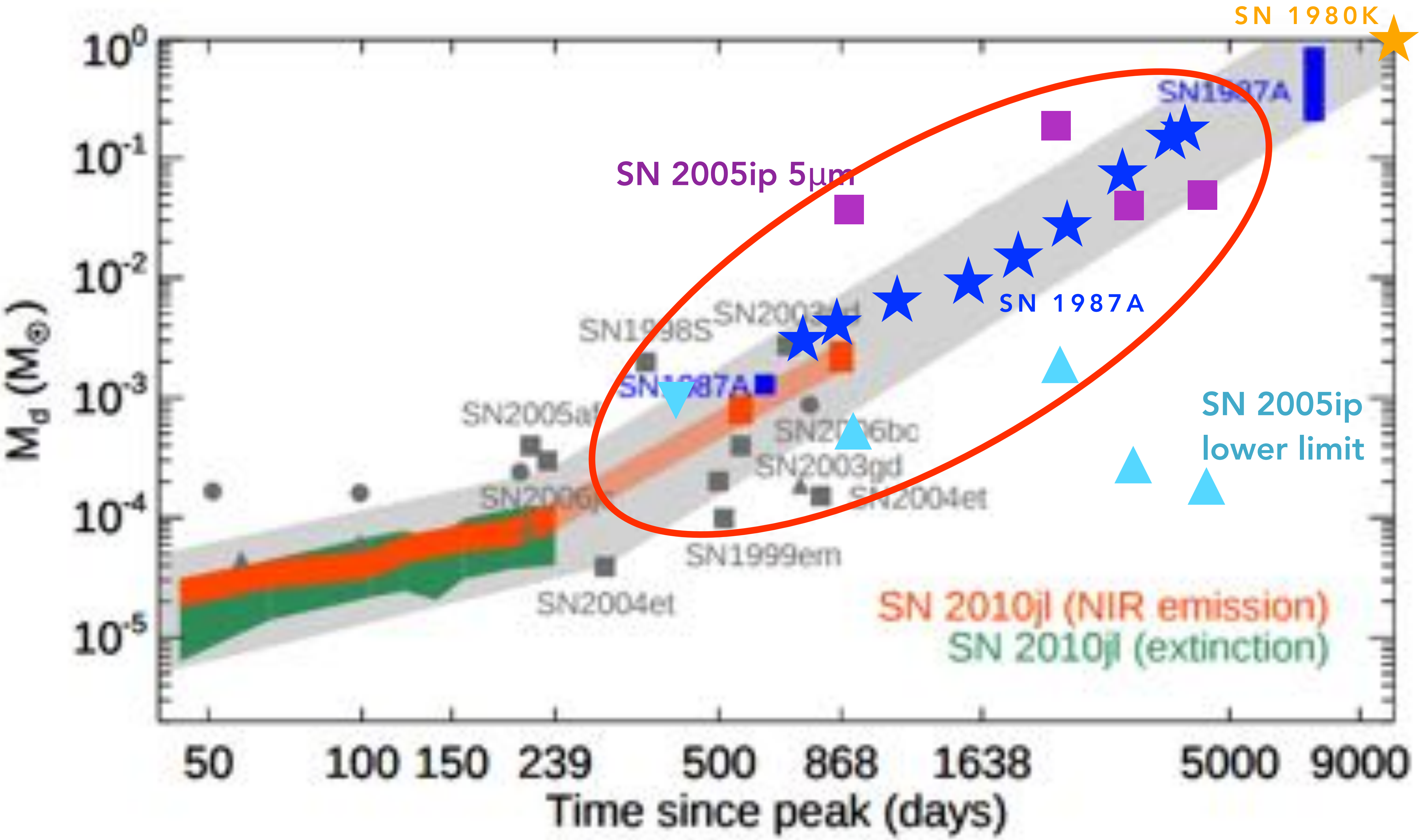
SN 2005IP VS SN 1987A



Bevan et al. 2016

SN 2005IP VS OTHER CCSNE

EJECTA DUST MASS SUMMARY FROM LINE PROFILE FITTING

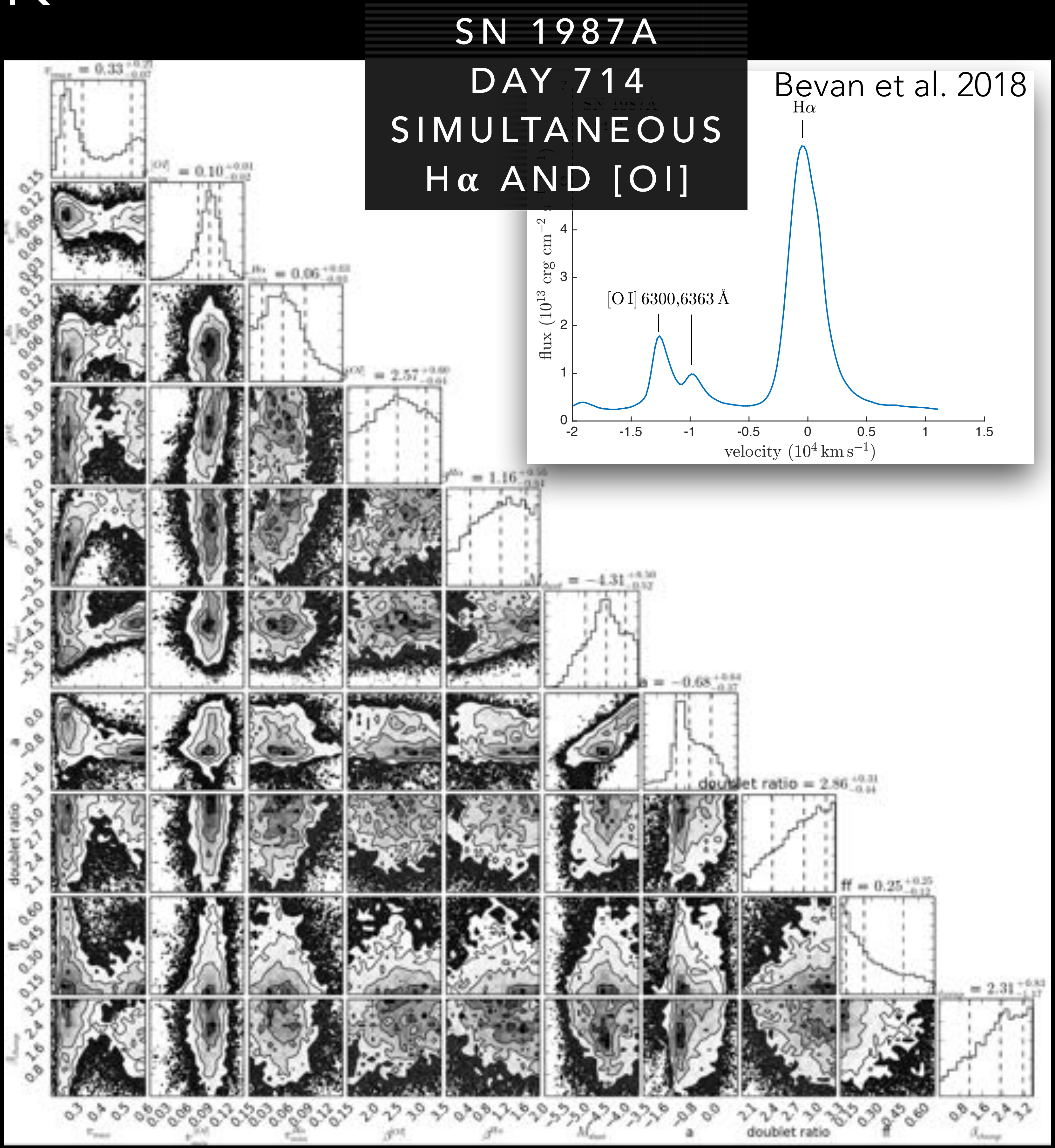


Altered from Gall et al. 2014

FUTURE WORK

BAYESIAN MODELLING

RIGOROUS PARAMETER SPACE INVESTIGATION USING AN MCMC ENSEMBLE SAMPLER



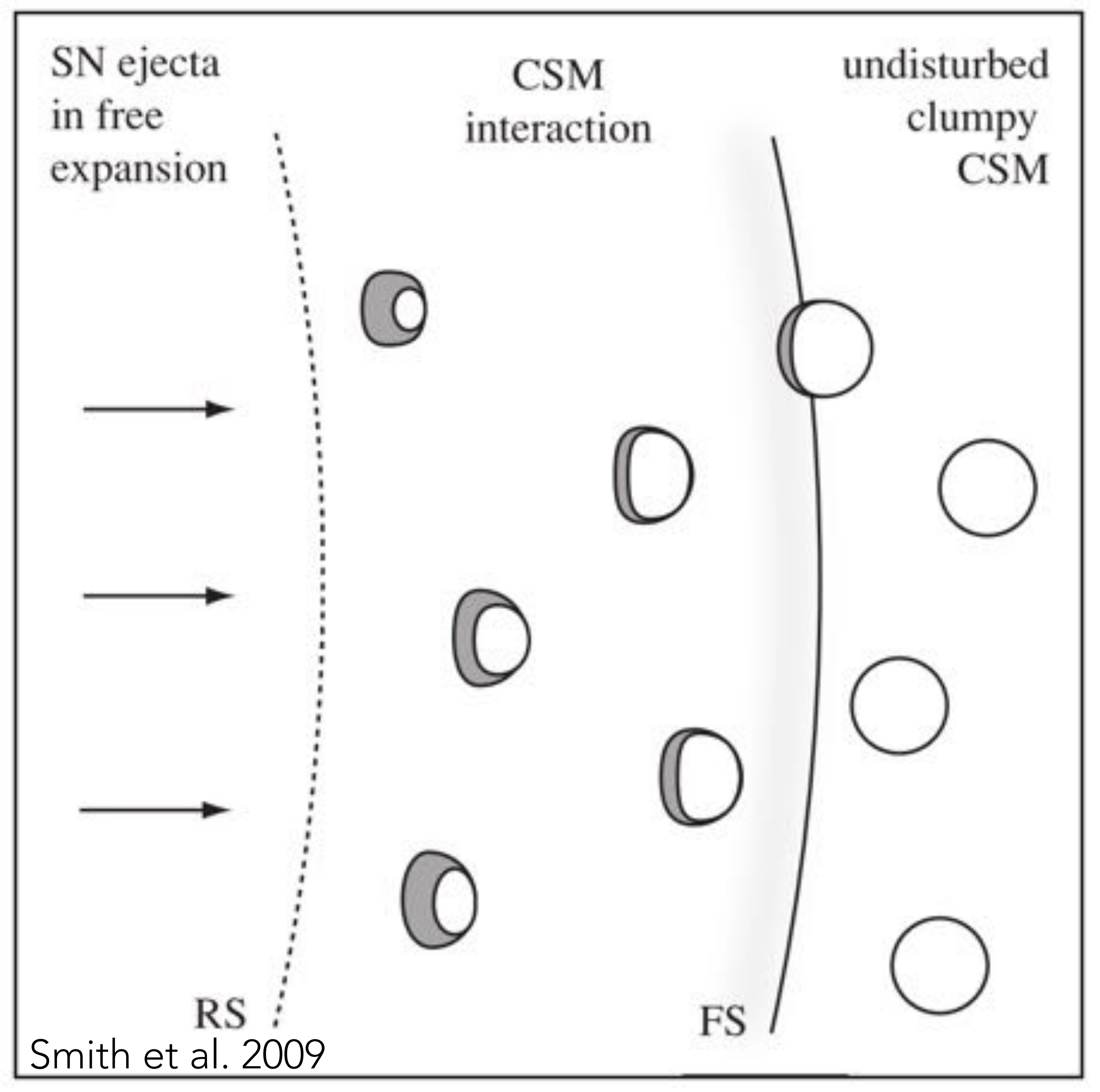
SN 1987A
DAY 714
SIMULTANEOUS
Hα AND [OI]

Bevan et al. 2018

FUTURE WORK

CLUMPS

PRELIMINARY RESULTS SUGGEST CLUMPING AFFECTS DUST MASSES BY A FACTOR OF A FEW



Smith et al. 2009

CONCLUSIONS

- Either dust in the ejecta or dust in the post-shock zone (or both) could account for observed asymmetries but ejecta dust gives better line profile fits
- Dust masses can be well-constrained given dust properties (in some cases even without)
- Initial ejecta dust formation rate is consistent with other CCSNe but possibly hints at dust destruction earlier than in non-interacting SNe