Accretion of Jupiter's Atmosphere from a Supernova-Contaminated Molecular Cloud

Henry Throop
Southwest Research Institute, Boulder, CO

John Bally
University of Colorado, Boulder, CO

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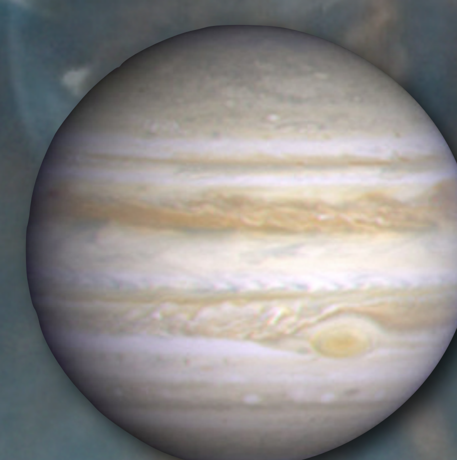
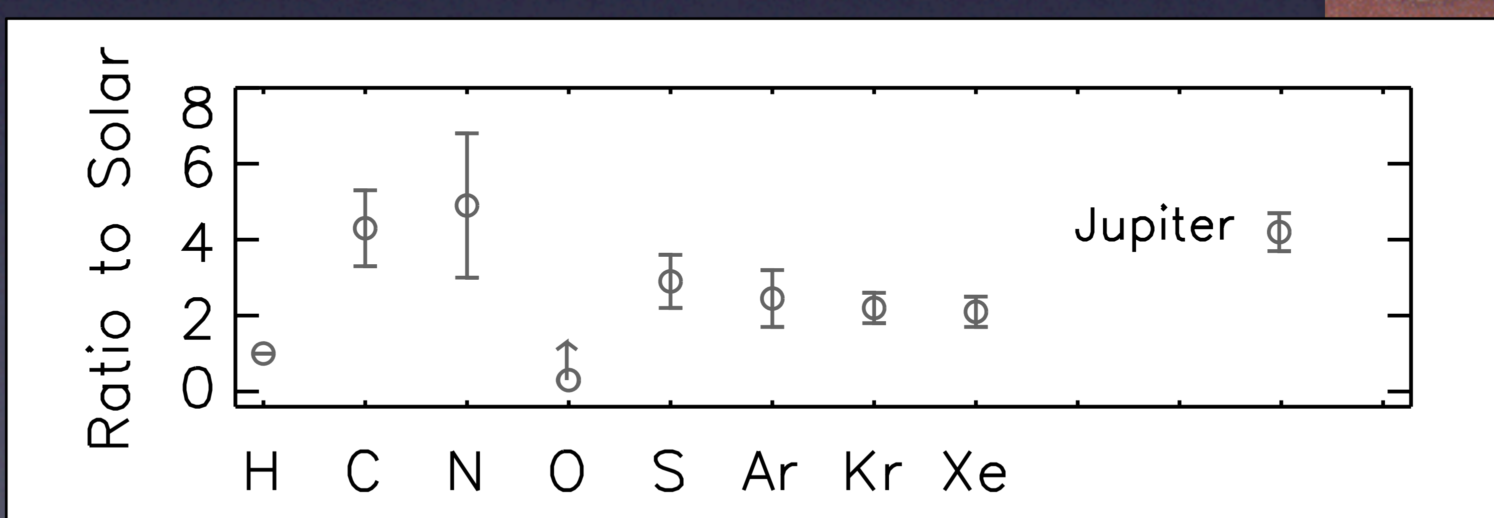
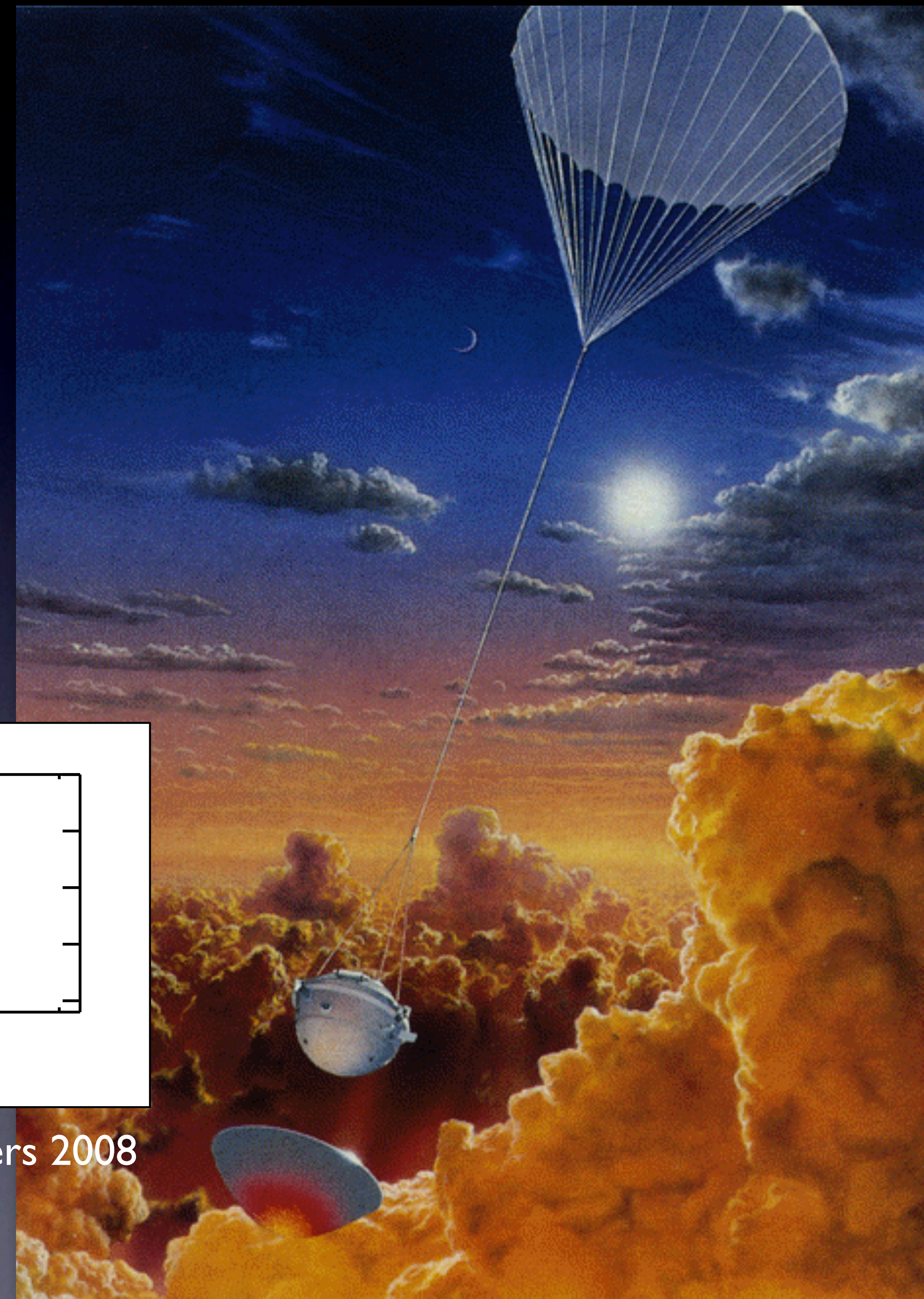


Jupiter's Atmosphere

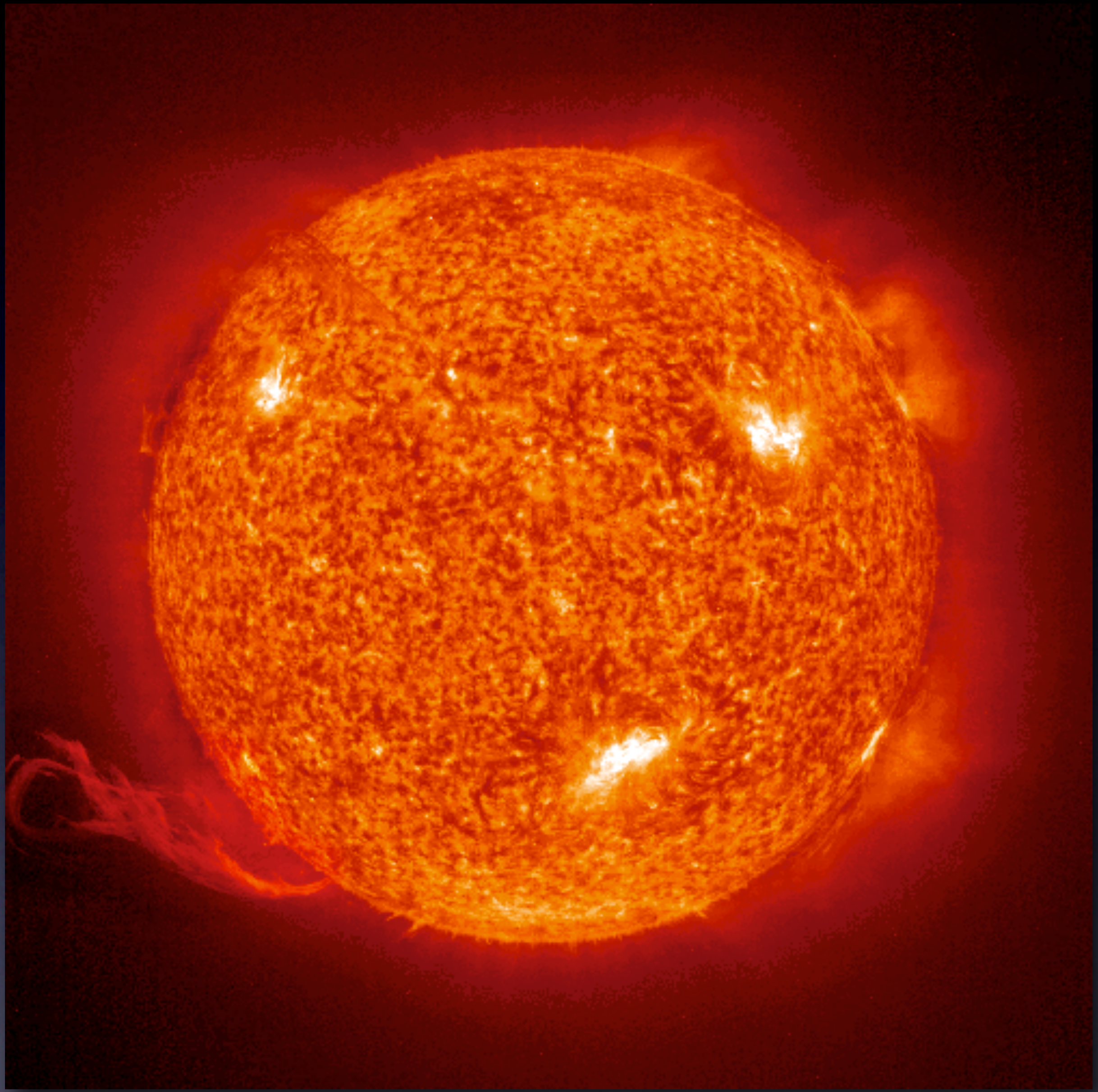
- Mass Spectrometer aboard Galileo Probe
- Measured atomic and molecular species to ~20 bars
- Found Jupiter atmosphere to be 2-6x higher in metals vs. Sun
  - C, S, Ar, Kr, Xe
  - All these are stable and long-lived: enrichment was a surprise.



Wong et al 2008; Grevesse et al 2007; Lodders 2008



Jupiter vs. The Sun



If the Sun and Jupiter both formed from the same cloud, why are they made of such different stuff?

Jupiter's Enrichment: Enrichment by Condensation in a Cold Disk?

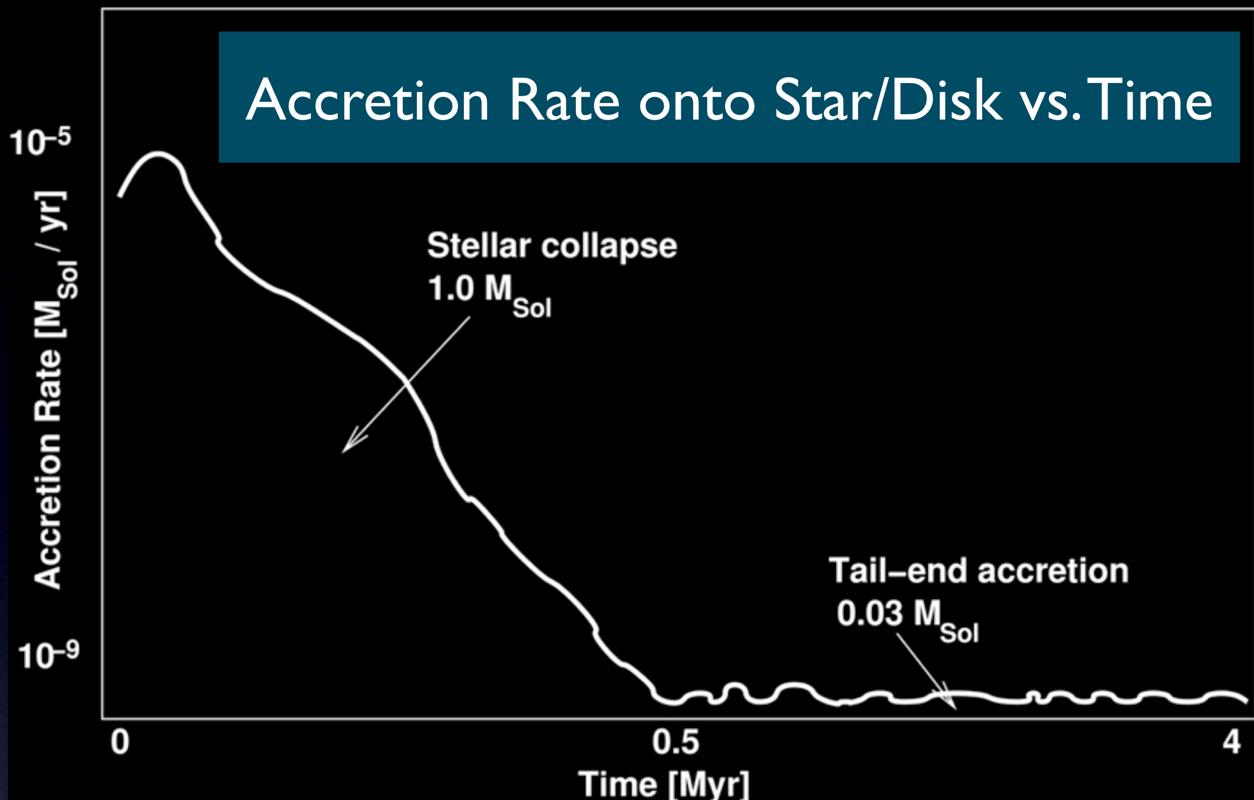
- Almost all existing models explain Jupiter's heavy element enrichment by condensation of volatiles (Kr, Xe, Ar, etc.) in cold disk.
- But this requires an extremely cold disk: Ar doesn't condense until ~ 22K.
- Disk temperatures are far too warm for condensation: even at 100 AU, typical temp is 30-50K, both observed and modeled.
- Molecular cloud temperature is 20K-30K: Disk cannot be any colder than this.
- Clathrate hydrates relax the condensation temperatures to ~35K for Ar, but this doesn't solve the problem, and makes Jupiter's core mass too heavy with ices.

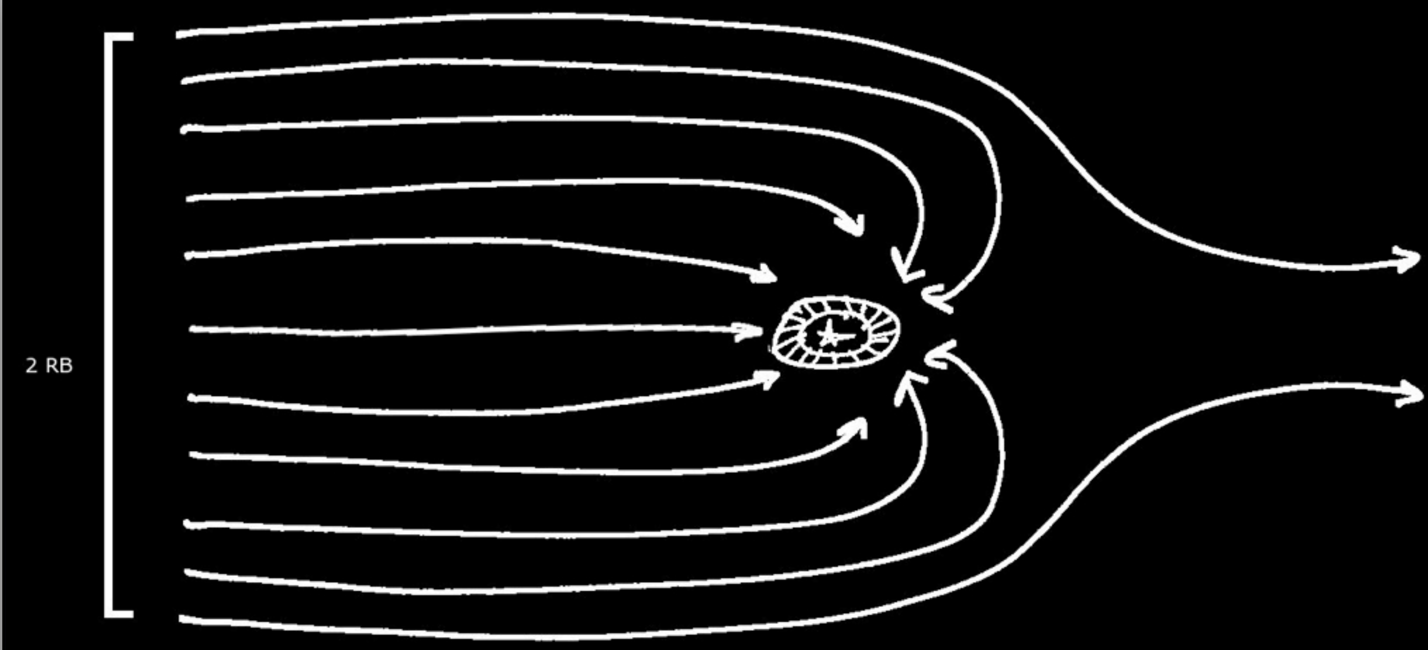
How do we solve this major problem?

Birth Environment of Solar System

- Near dense star cluster with high-mass stars
- Near supernovae
  - ^{60}Fe: Within few pc and few Myr of solar nebula condensation
- In heterogeneously mixed molecular cloud
  - Isotopic evidence from ^{54}Cr, ^{94}Mo, ^{135}Ba, etc.
  - Late injection of multiple heterogeneously mixed SN sources

ISM-Disk Accretion Within Molecular Clouds



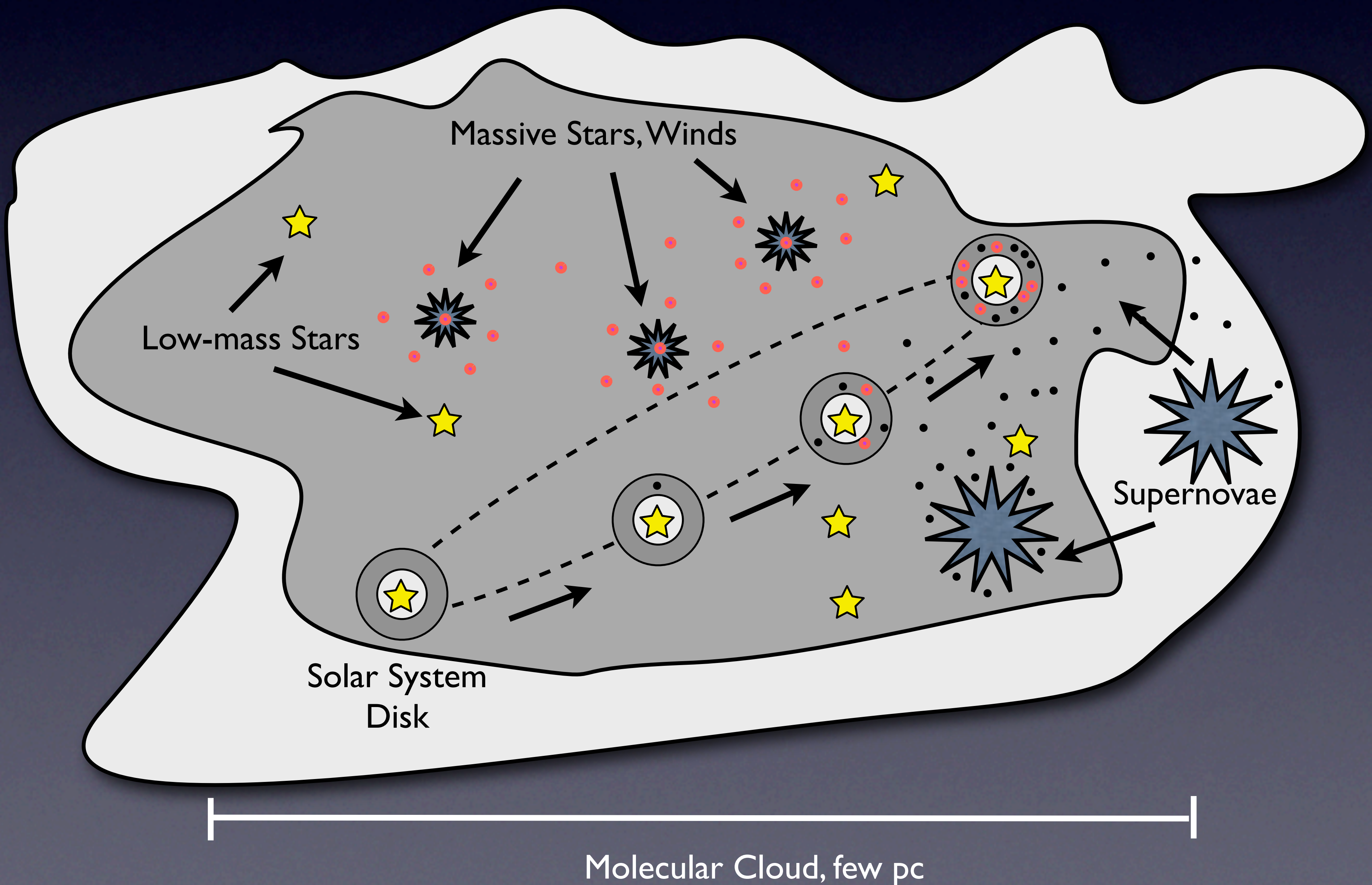


Bondi-Hoyle Accretion from ISM onto Disk

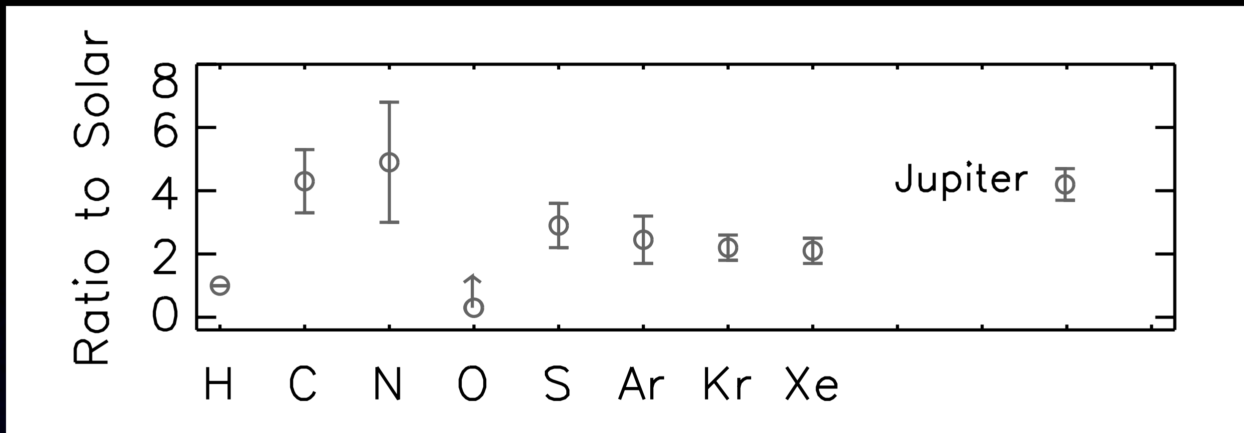
- Solar nebula disk forms in 10^5 years
- Disk and star spend 1-4 Myr orbiting through molecular cloud, before OB stars turn on and ionize gas.
- **Tail-end Bondi-Hoyle** accretion causes gravitational sweepup of 10^{-8} $M_\odot$/year = 1 MMSN per Myr (Throop & Bally 2008, *AJ* 135)
- This accretion is primarily onto disk, **not** star.
- Disk can be easily contaminated by accretion, but not star is not.
  - Disk has **lower mass and higher surface area** relative to star.

Our Model

1. Sun and solar system disk form within a molecular cloud
2. Molecular cloud ISM is contaminated by nearby SN and massive stellar winds
3. Disk continues to orbit molecular cloud / cluster for several Myr
4. Accretion from ISM-to-disk continues for several Myr, enriching disk but not star.
5. Jupiter forms from disk, already enriched relative to Sun.



Three-Component Model for Jupiter’s Atmosphere



Jupiter Composition

Wong et al 2008

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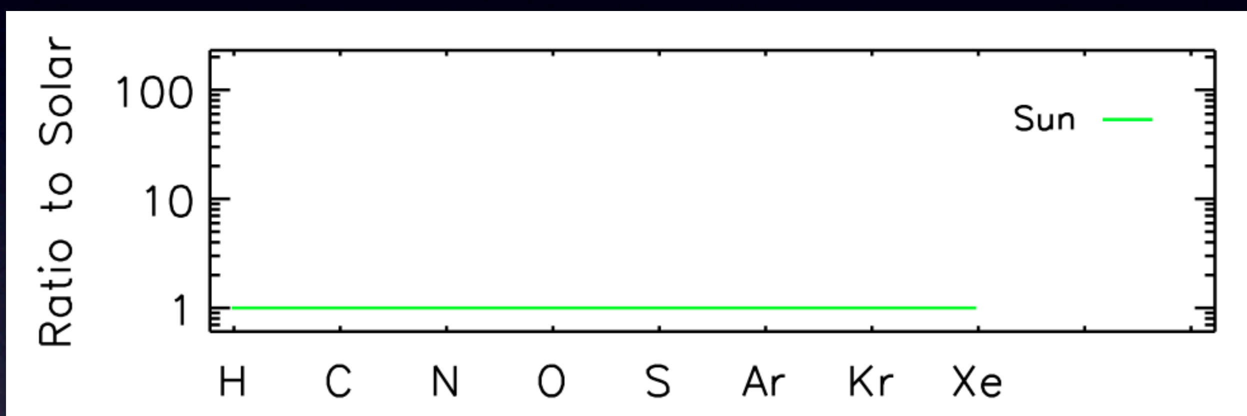

Solar Composition

Lodders 2008

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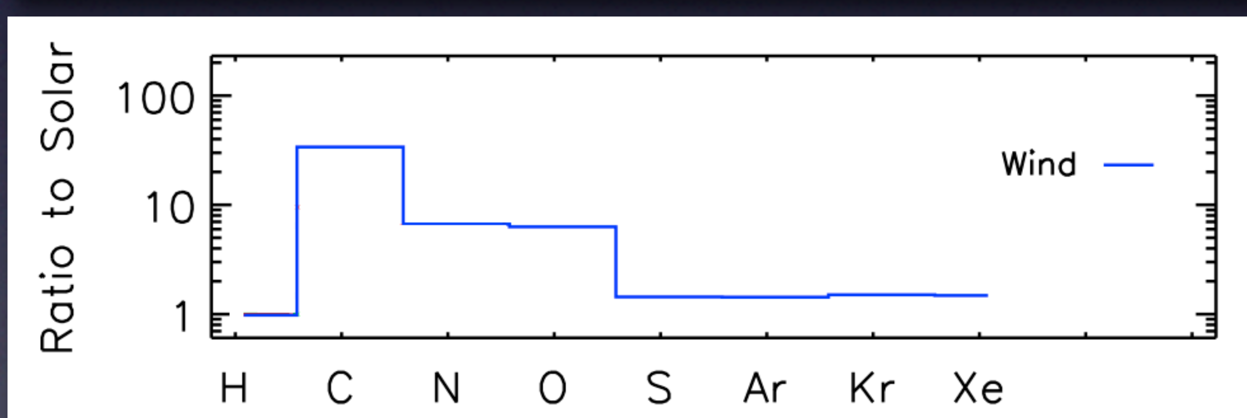

Wind from 20 M$_\odot$ star

Woosley & Heger 2007

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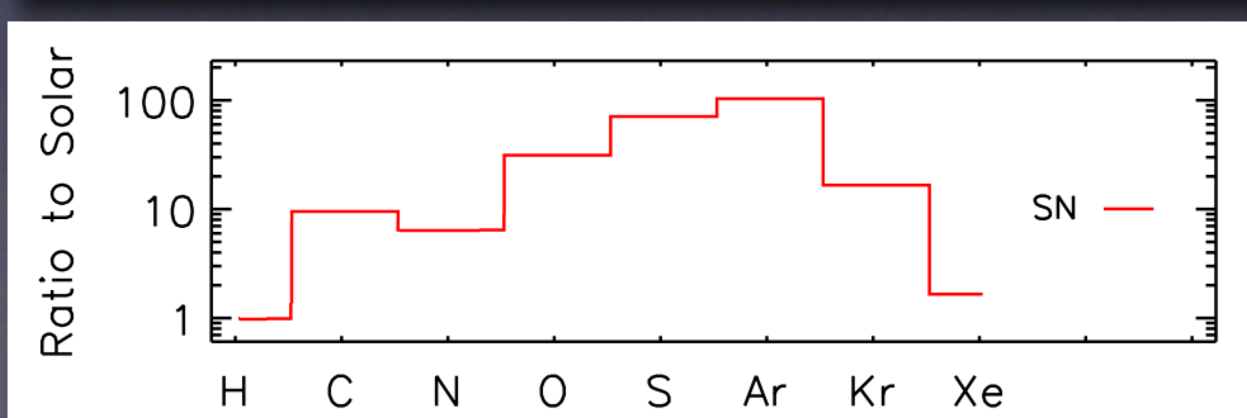
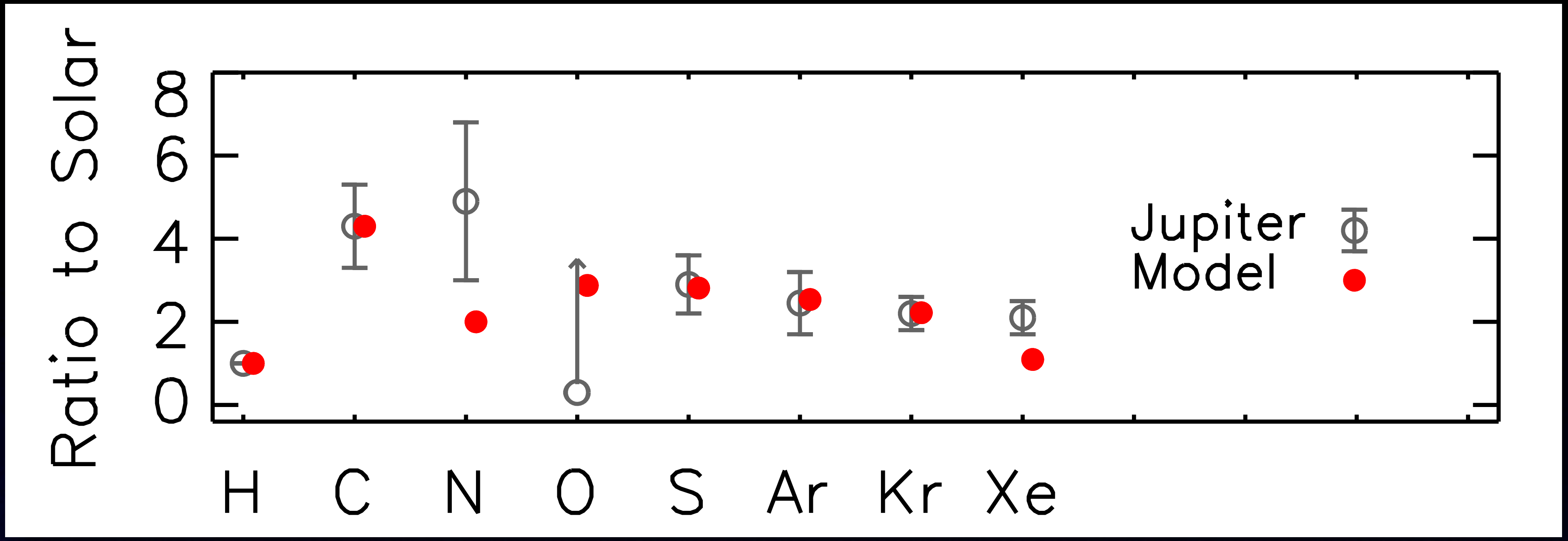


Ejecta from 25 M$_\odot$

Woosley & Heger 2007

Jupiter 'Polluted Accretion' model



- Jupiter's atmospheric composition can be matched using mixture of:
  - 87% Solar nebula material
  - 9% Stellar winds from 20 $M_\odot$ star (provides C, N)
  - 4% SN from 25 $M_\odot$ star (provides S, Ar, Kr, Xe)
- Requires total of ~0.13 M_J of accretion to explain Jupiter's current metallicity.
  - Bondi-Hoyle accretion supplies 10 M_J of accretion per Myr -- plenty of mass.
- Similar models account for differences in solar Ar (Lodders 2008 vs. Grevesse et al, etc.)

Conclusion

'Polluted Accretion' model for Jupiter:

- Avoids extremely cold temperature requirements of existing Jupiter formation models.
- Consistent with dense cluster birth hypothesis for Sun, and heterogeneous solar nebula.
- Timescales, chemistry, enrichments amounts all consistent with ISM physics.

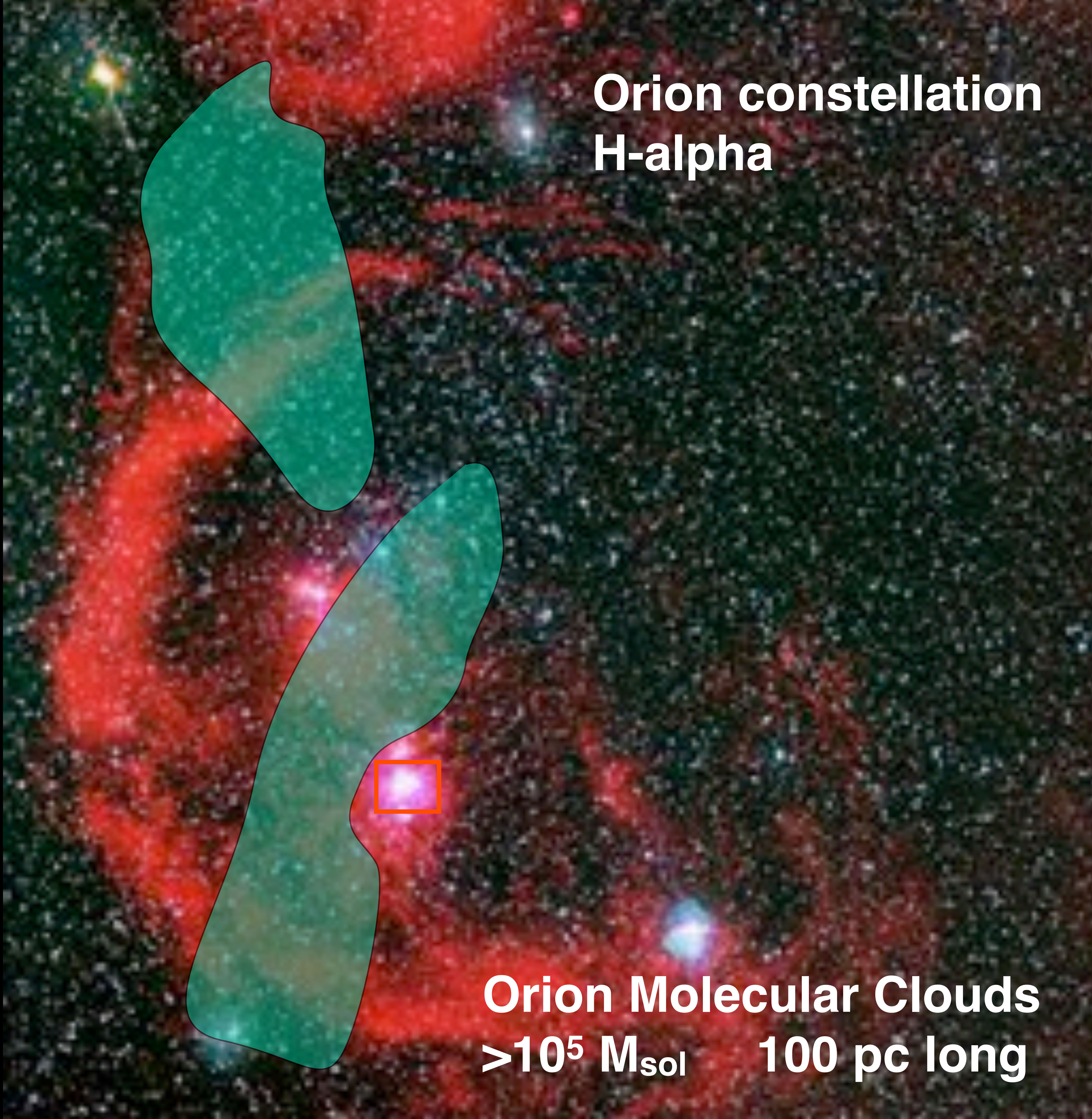
Throop & Bally, paper accepted by Icarus
Available at http://www.boulder.swri.edu/~throop/papers.html

Doesn't the SN Destroy the Molecular Cloud?

- Orion has had dozens of SN within last 10 Myr and is still actively forming stars several pc away from SN sites. Still has 10^5 $M_\odot$ in giant molecular clouds (GMC).

- Orion 1-S molecular cloud is 1 pc away from Trapezium cluster, but remains molecular. Stellar orbits take Orion nebula stars through 1-S molecular cloud.

- Additionally, SN 'droplet' model (Stasinska et al 2007) shows that the observed dense, cool, highly enriched AU-scale globules seen in Orion can be captured SN ejecta from many kpc away.


Orion constellation
H-alpha
Orion Molecular Clouds
$>10^5$ M_{sol} 100 pc long