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in collaboration with J. R. Walsh, D. Pequignot, J. M. Vilchez,
(and A. Mesa-Delgado, C. Esteban, W. J. Henney et al.

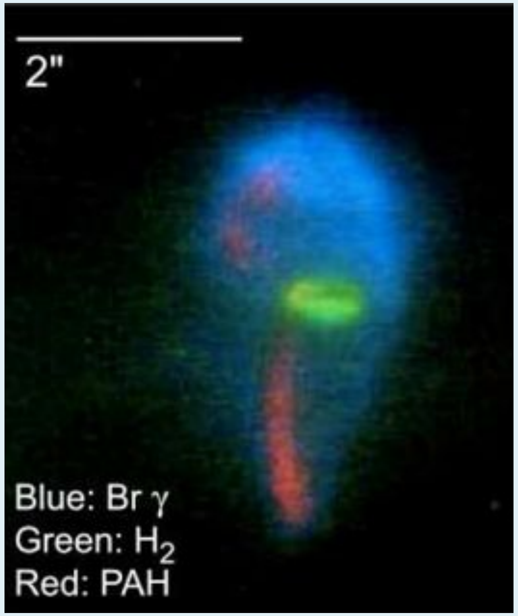
The Oxygen abundance of proplyds* in HII regions

*protoplanetary disks

Why study proplyds?

- They perhaps contain *planetary systems* in the making.
- Composition of proplyds relates to both stellar and stellar+planet abundance scales

HST10 (Orion)

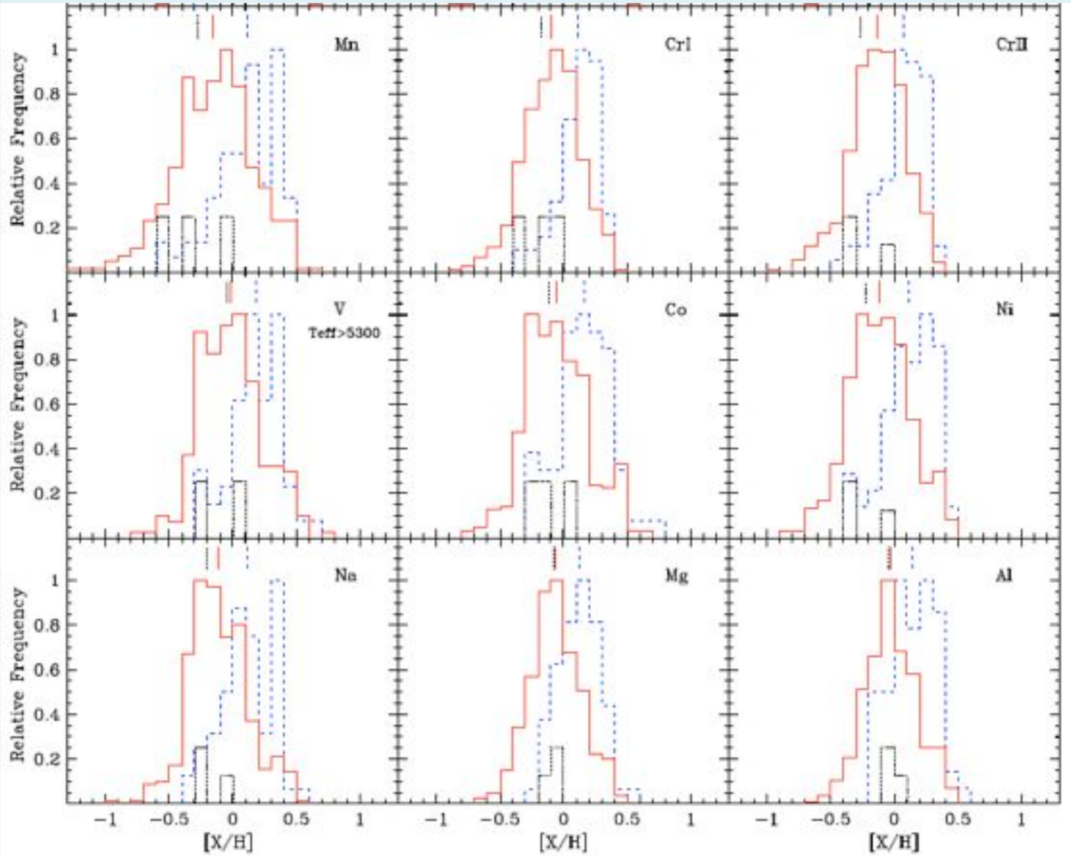


Keck AO: IR
Ionized/molecular H, dust
Kassis et al (2007)

HST: Halpha 656.3 nm
Ionized hydrogen
Bally et al (2000)

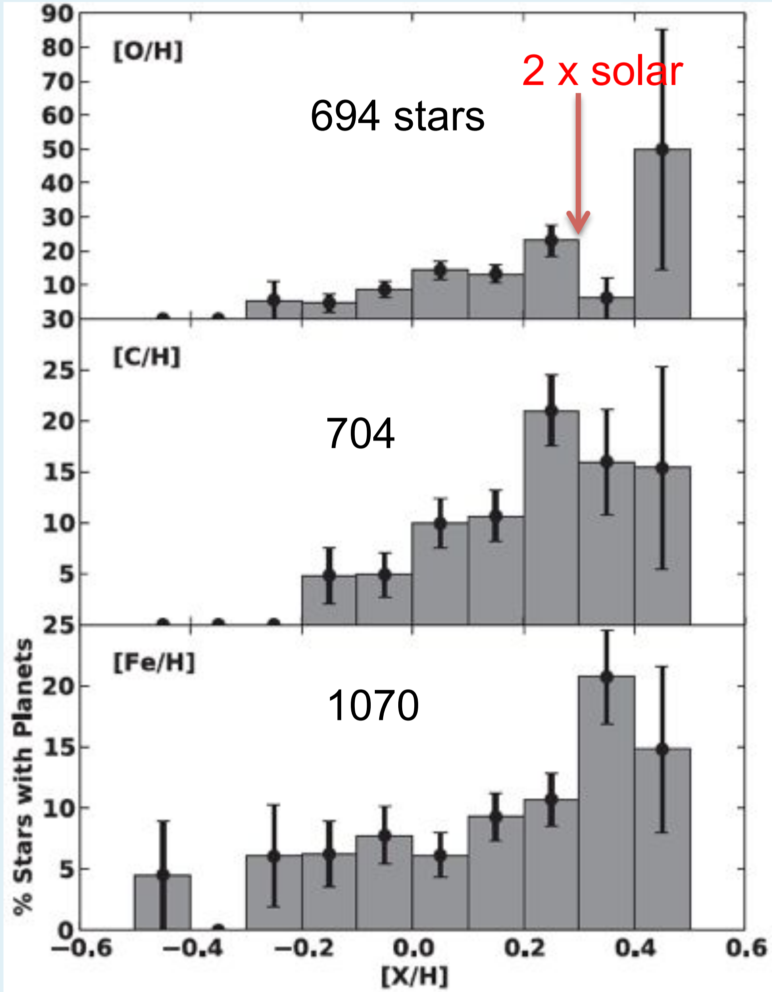
VLT: [O I] 630.0 nm
Atomic oxygen
Tsamis et al (in prep)

Planet-hosts (in blue) are on average more metal-rich than planet-less stars (red)



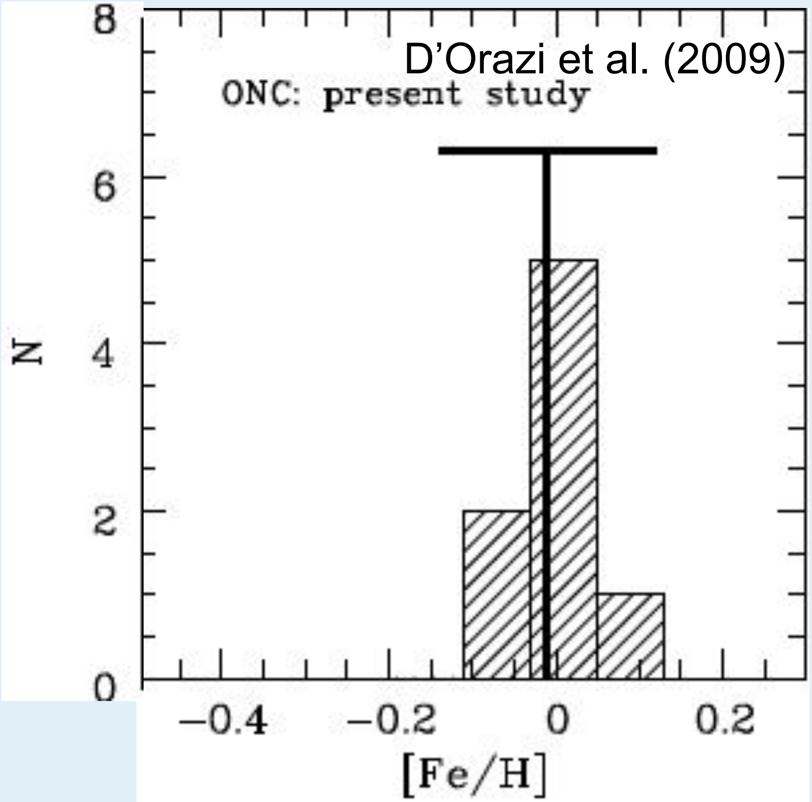
Neves et al. (2009)

O, C, Fe in planet hosting FGK-type stars

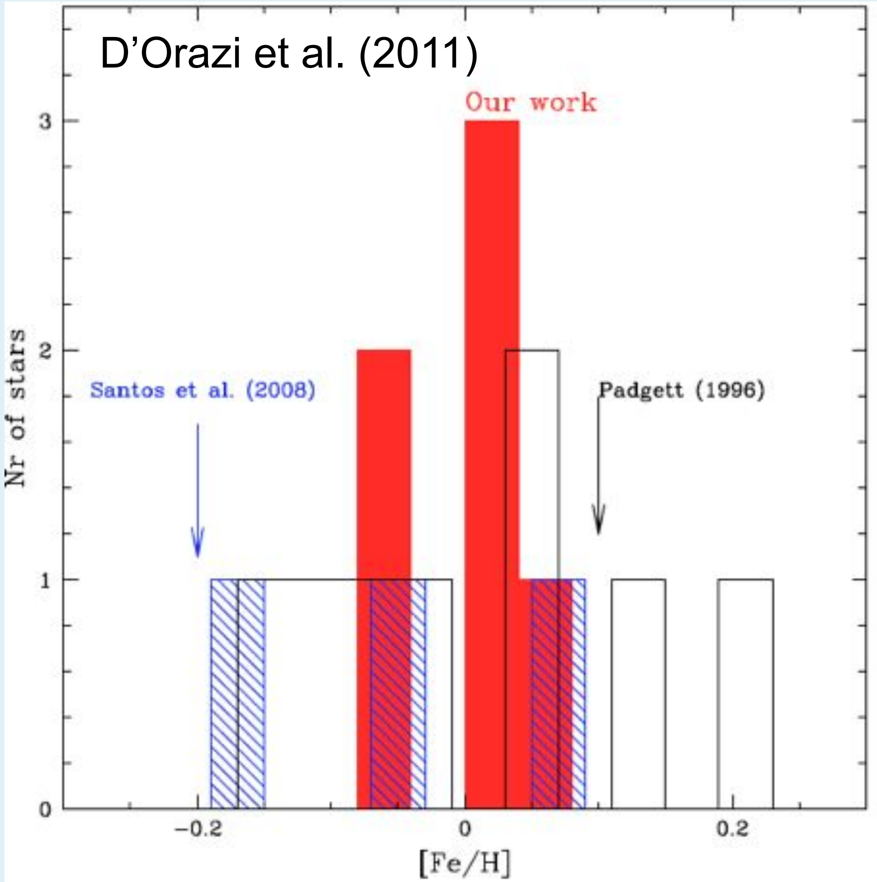


Petigura & Marcy (2011)

Orion Nebula Cluster
low-mass K-type stars

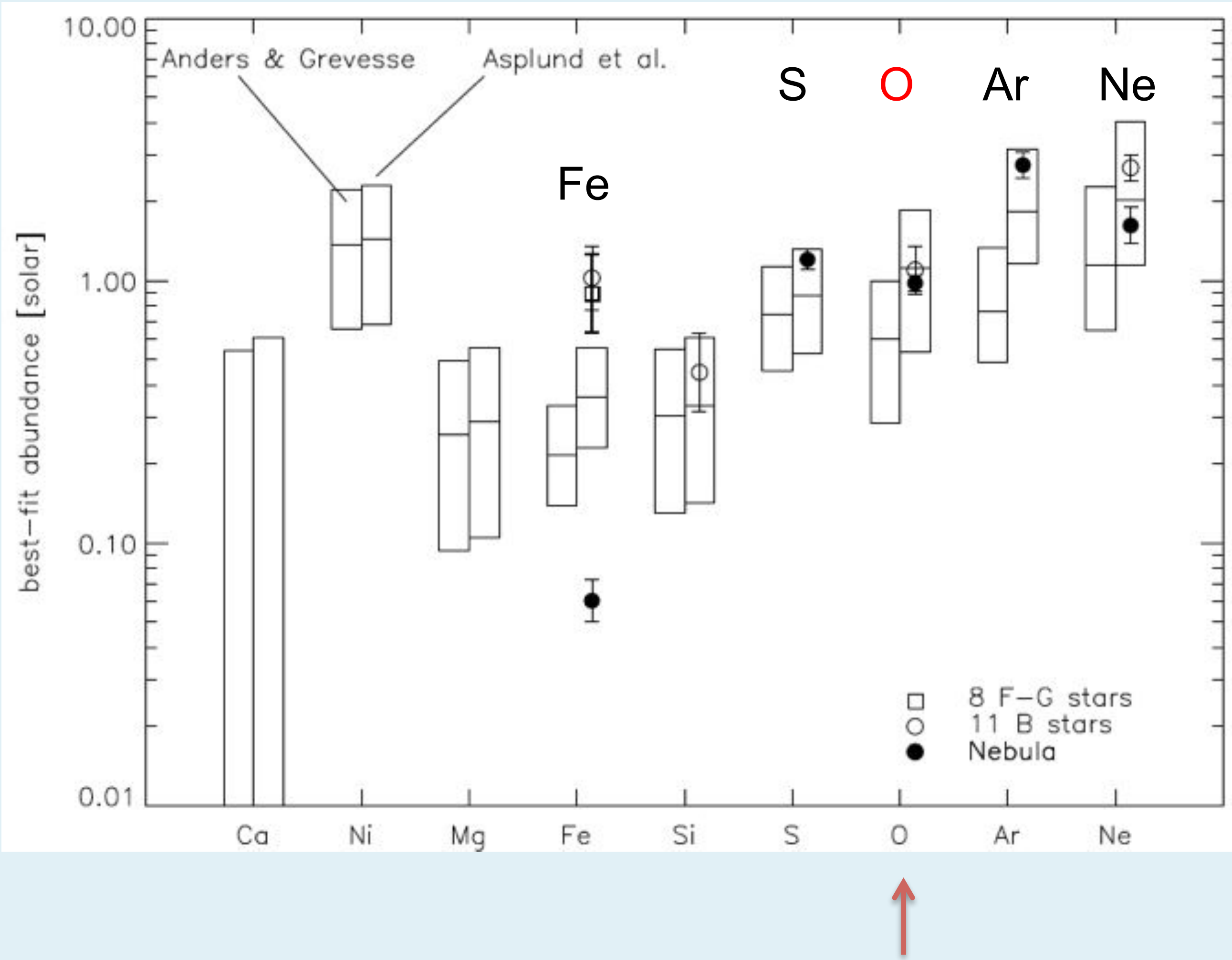


T-Tauri stars in Taurus



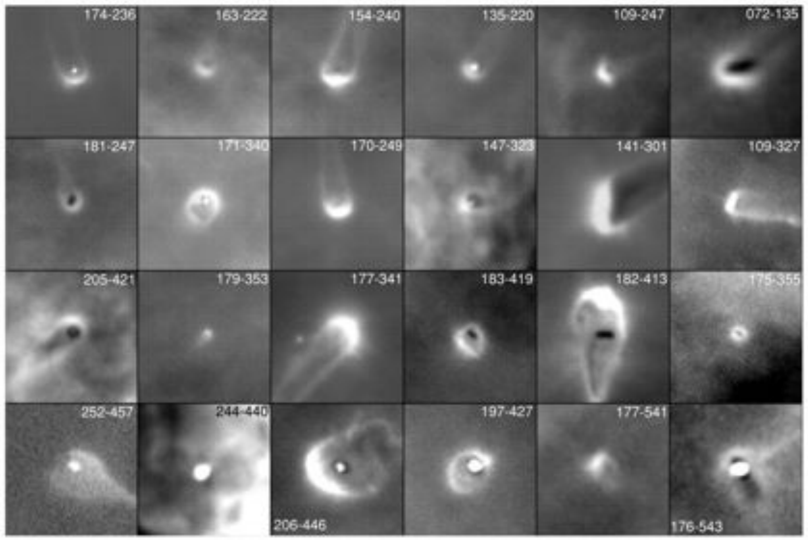
Solar Metallicity

Coronal abundances of X-ray emitting pre-main sequence Orion stars (Maggio et al. 2007)



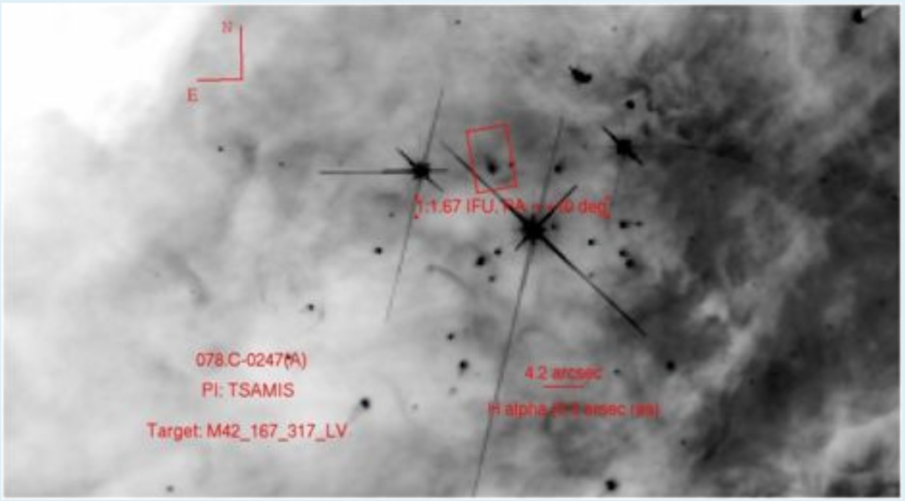
- S, O, Ar, Ne agree with B-stars and the HII region gas abundances
- Fe depleted compared to Solar and stellar values by up to ~3

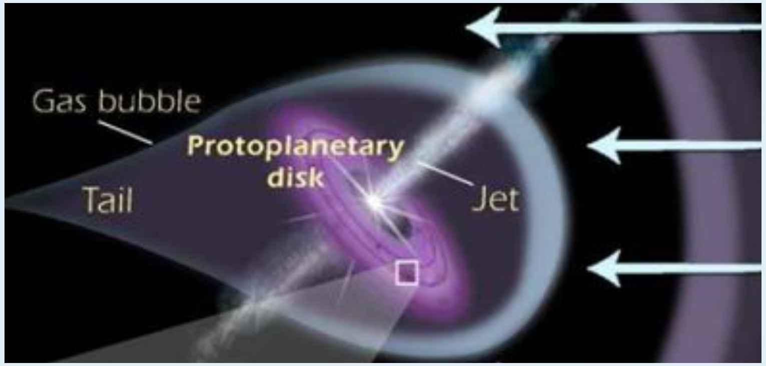
The Orion Nebula proplyds



HST Hα (Bally et al 2000)

- The Sun was born in an Orion type cluster (Adams 2010)
- Orion is distant (410 pc), but it contains massive hot stars capable of ionizing the proplyds.
- **Bright emission lines: abundance diagnostics.**

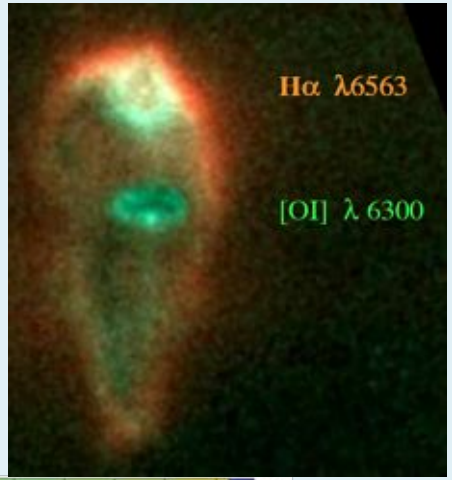


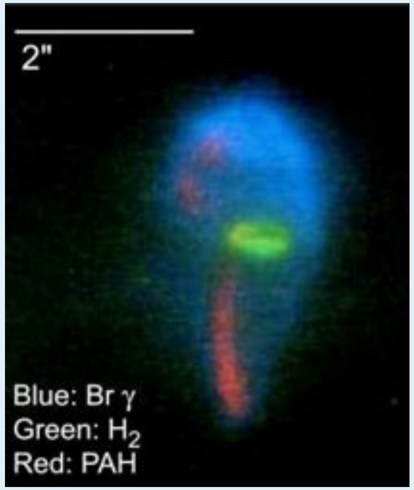


From grains to planets in Orion proplyds
(according to Throop & Bally 2005)

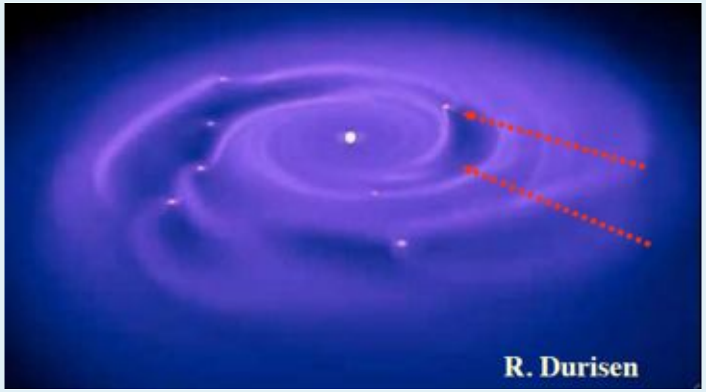
- Grain growth: Solids settle to mid-plane of disk
- External UV blows away dust-depleted gas
- Result: High density of solids in mid-plane

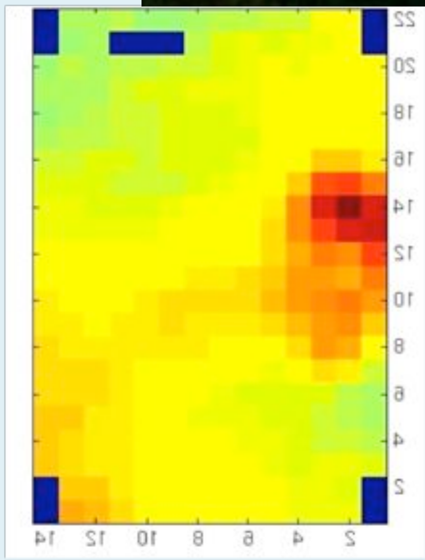
- Gravity ---> Instability
- Formation of 1-100 km planetesimals





Keck AO: IR
Ionized/molecular
H2, dust
Kassis et al (2007)

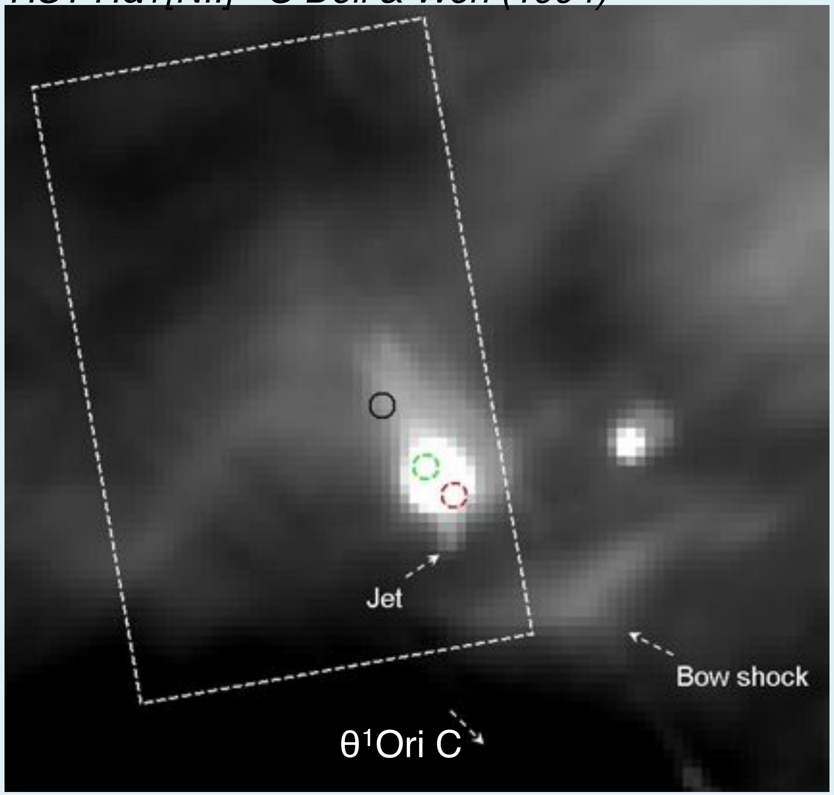




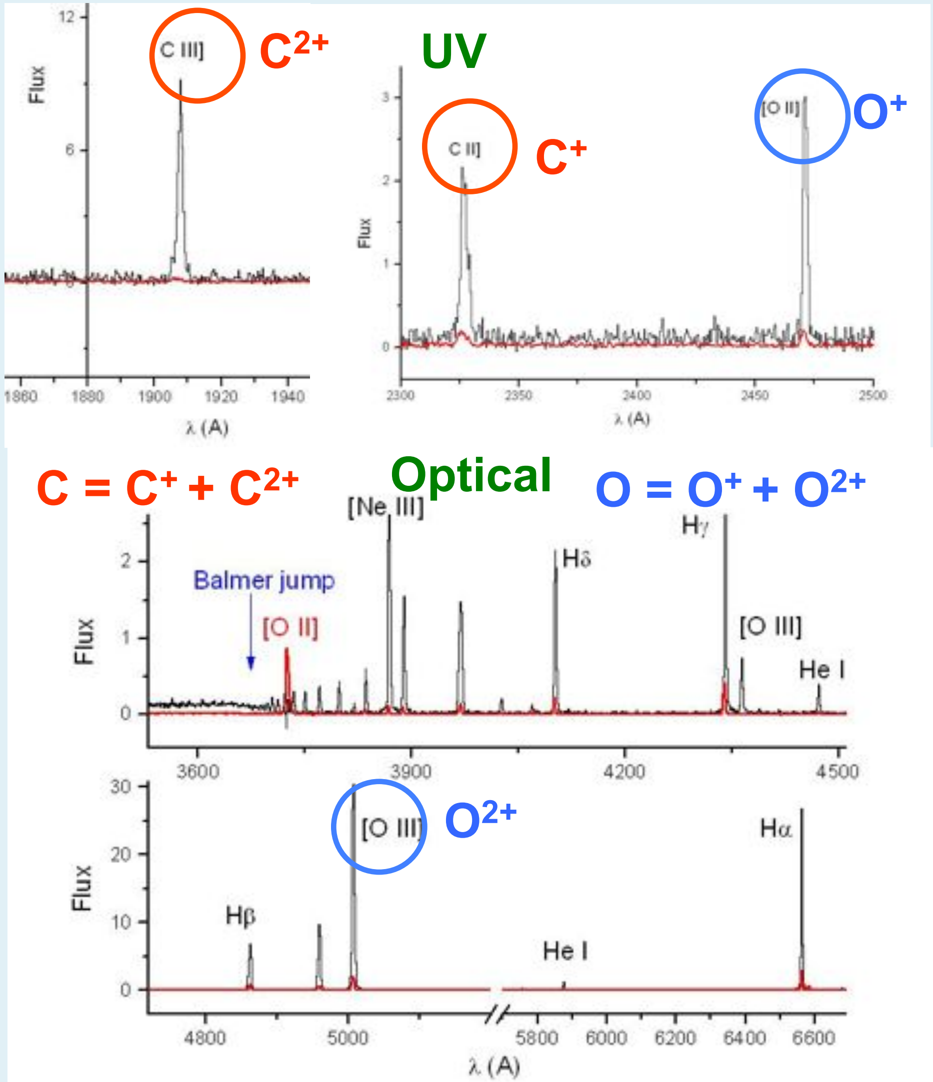
VLT IFU line maps in Hα
and [OI] 6300 A
Tsamis et al in prep

The LV2 proplyd - *HST* FOS single-aperture spectra
(Tsamis et al. 2011)

HST Hα+[NII] - O'Dell & Wen (1994)

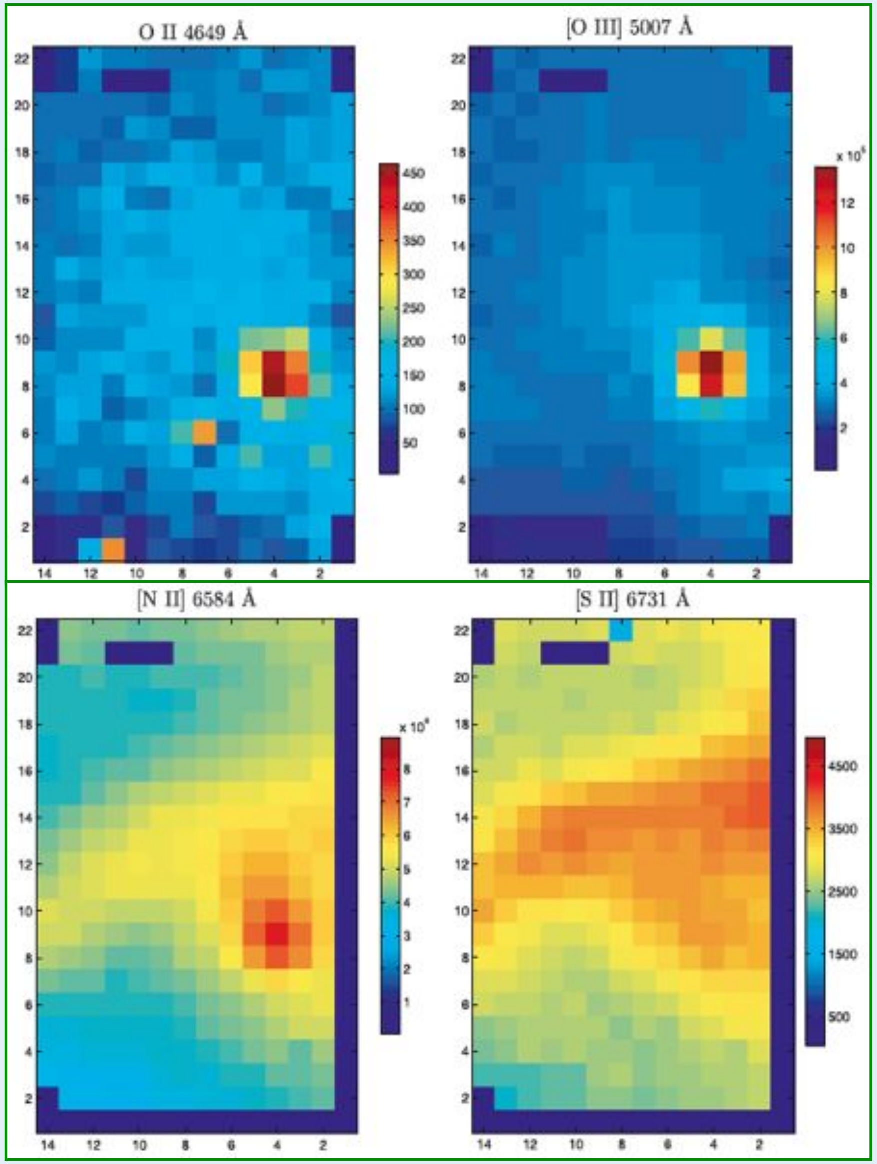


3 pencil beam HST Faint Object Spectrograph apertures (0.26”) within the 6.6”x4.2” VLT FLAMES IFU field (dashed box)

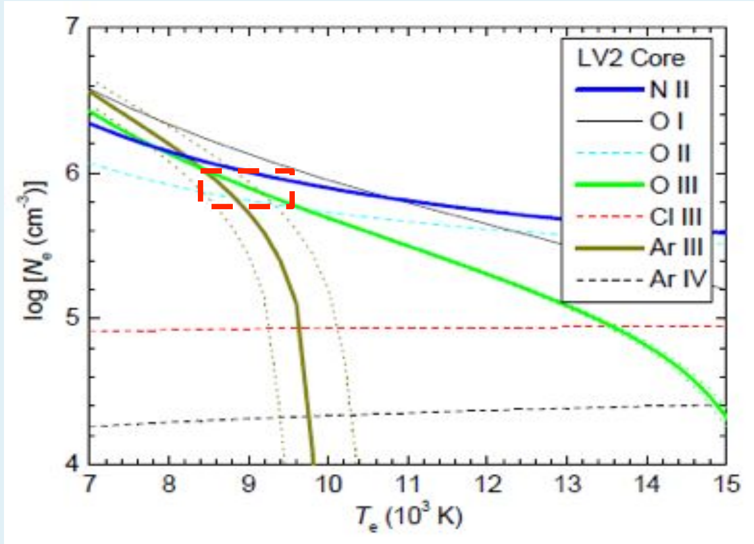


Tsamis et al. (2011), MNRAS, 412, 1367

Integral field spectroscopy of LV2 with VLT FLAMES IFU



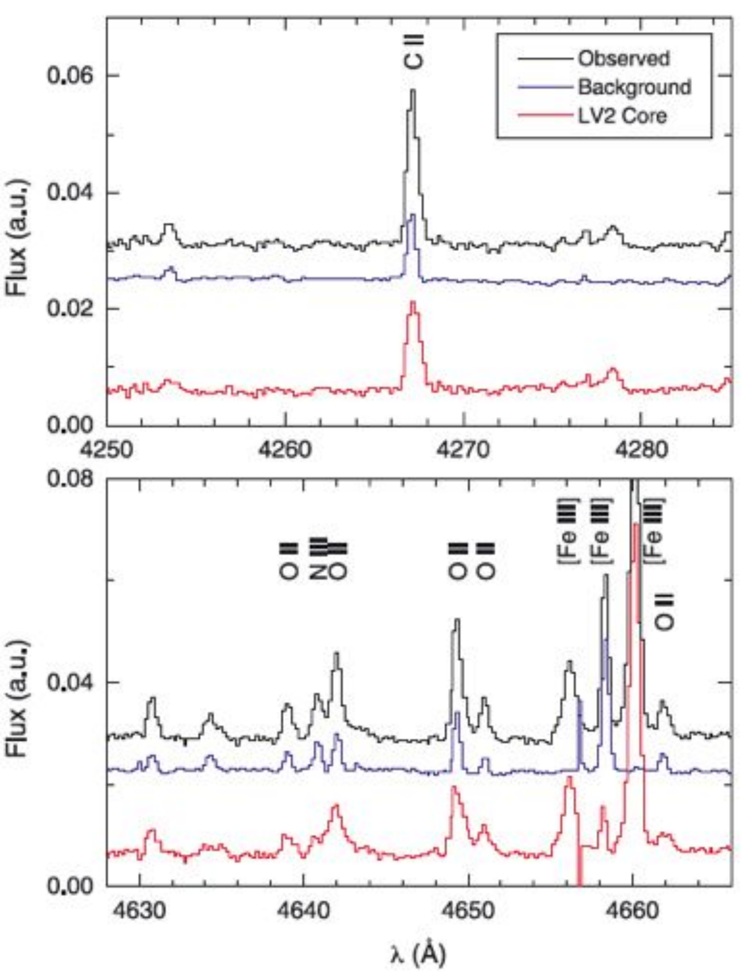
Tsamis et al. (2011)



From ratios of temperature and density-sensitive collisionally excited lines and comparing with theoretical emissivities:

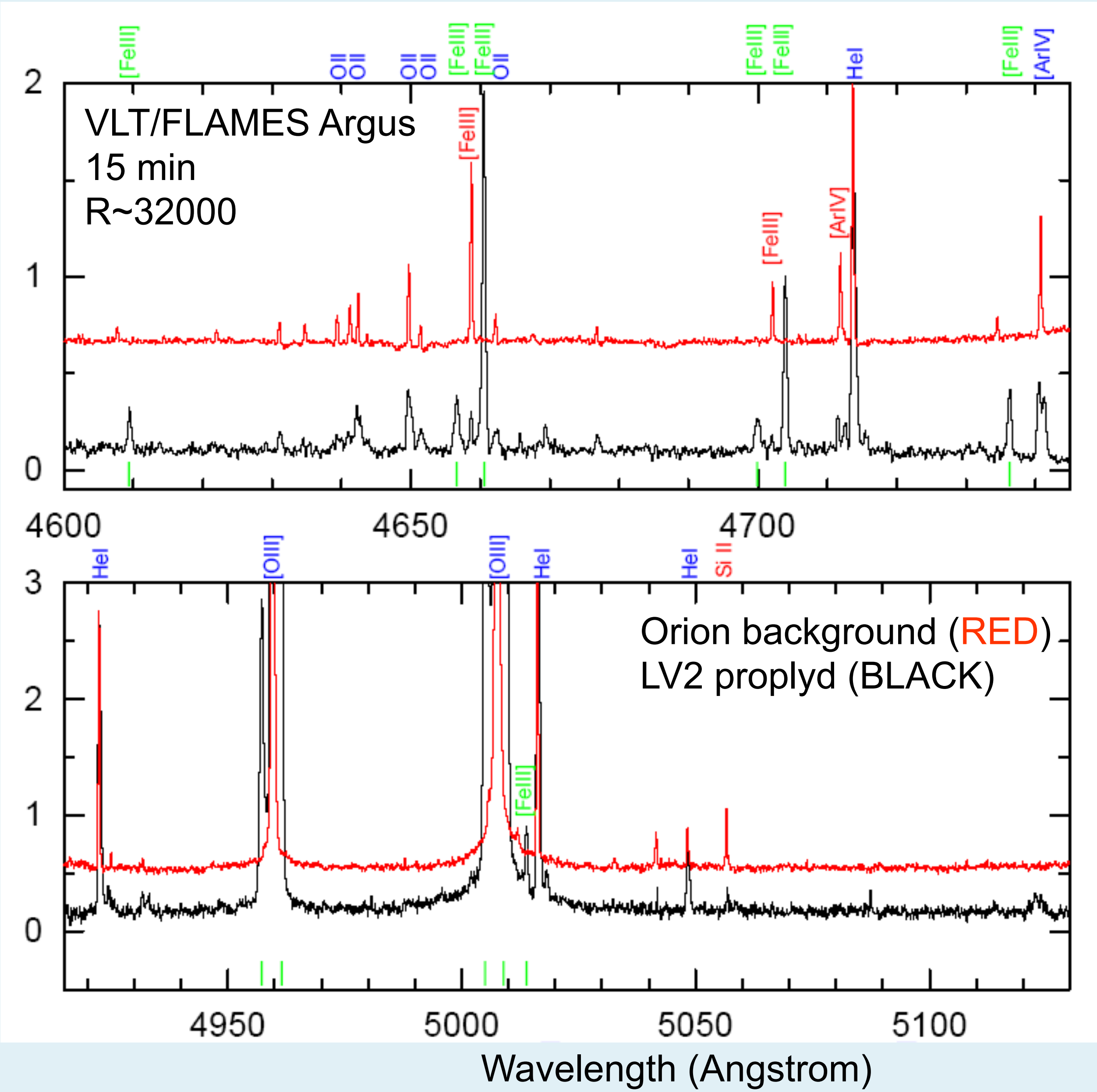
Electron Temp = 9000 – 10000 K,
Electron Density ~ 10^6 cm^{-3}

CII and OII recombination lines (RLs) in protoplanetary disks: novel metallicity diagnostics

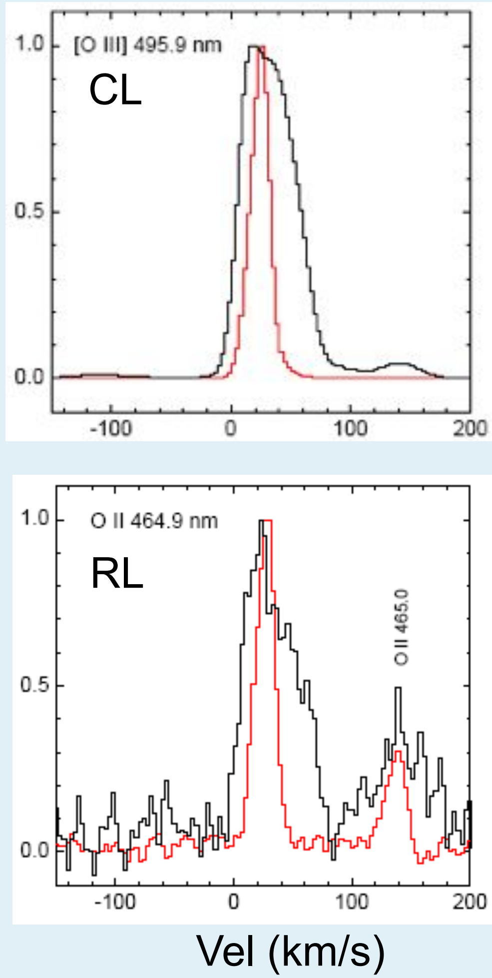


VLT/FLAMES IFU (R~12000)

- Thus far these lines had not been detected from proplyds: prominent in planetary nebulae and HII region spectra (e.g. Liu et al. 1995, 2000; Tsamis et al. 2003ab, 2004, 2008; Esteban et al. 2004, 2005).
- They are weak (<1% of Hbeta) but can be accurately measured in deep spectra.
- Atomic data for their analysis exists since the 1990s (Pequignot et al. 1991; Storey et al. 1994; Liu et al 1995; Davey et al. 2000; Storey in prep.)
- Abundances relative to H are a very weak function of temperature and density, hence, in principle, “bias-free”?



Tsamis & Walsh (2011)



Abundances in LV2 vs. Orion HIIR vs. Sun

Element	Proplyd LV 2 Core [1]	Orion HIIR LV 2 Background [1]	Sun (photosphere) Sun [3]
He	10.973	11.033	10.93±0.01
He	11.017	11.179	–
C	8.98±0.15	(8.40±0.13)	8.43±0.05
C (RL)	8.66±0.10	8.55±0.08	–
N	7.86±0.17	7.46±0.15	7.83±0.05
O	9.03±0.13	8.51±0.05	8.69±0.05
O (RL)	8.96±0.10	8.65±0.05	–
Ne	8.28±0.06	7.86±0.07	7.93±0.10
S	6.83±0.25	7.04±0.13	7.12±0.03
Cl	5.36±0.15	5.25±0.04	5.50±0.30
Ar	6.59±0.05	6.43±0.05	6.40±0.13
Fe	4.96±0.20	6.03±0.05	7.50±0.04

Tsamis et al. (2011)

B-stars (Simon-Diaz'10)

C = 8.35

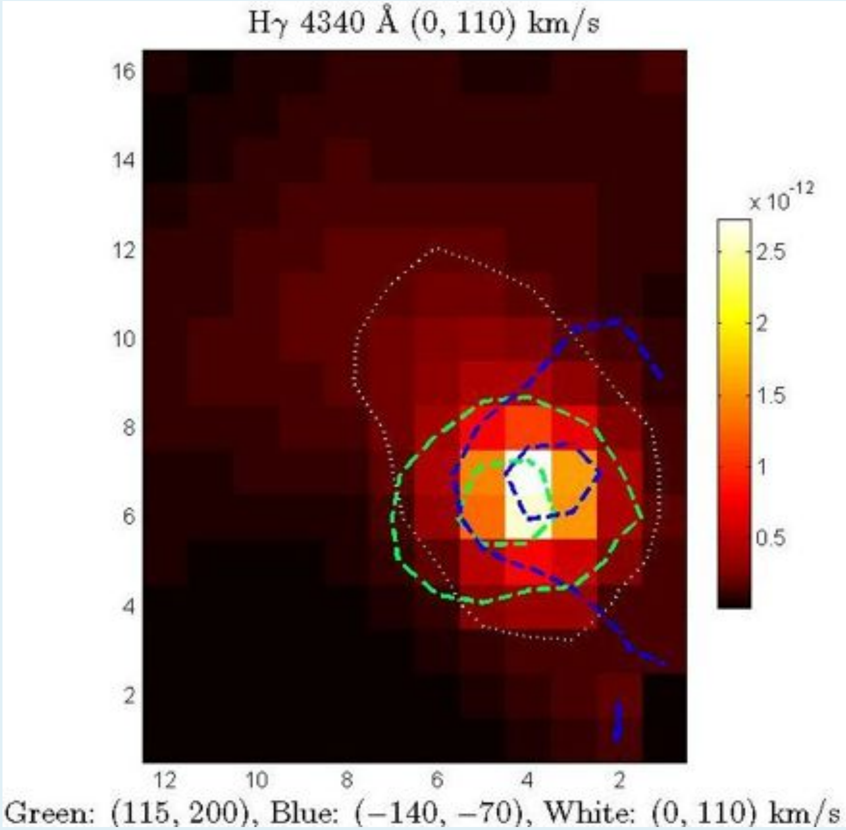
N = 7.82

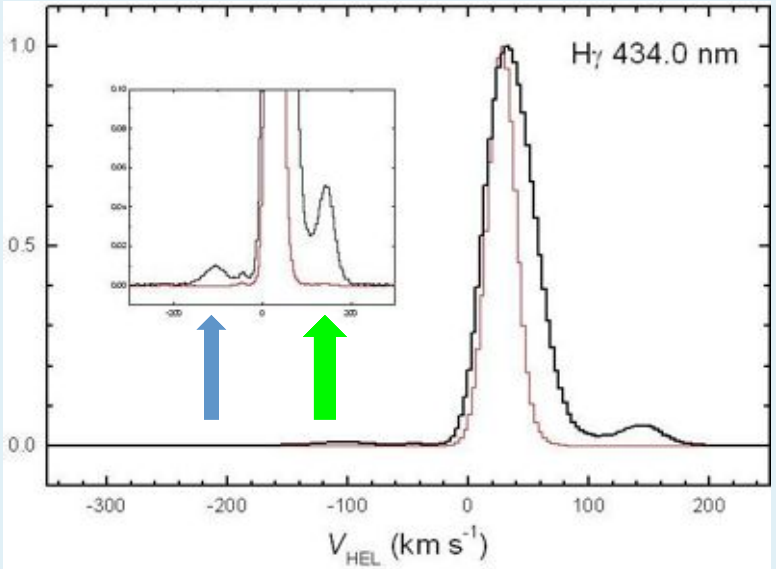
O = 8.74

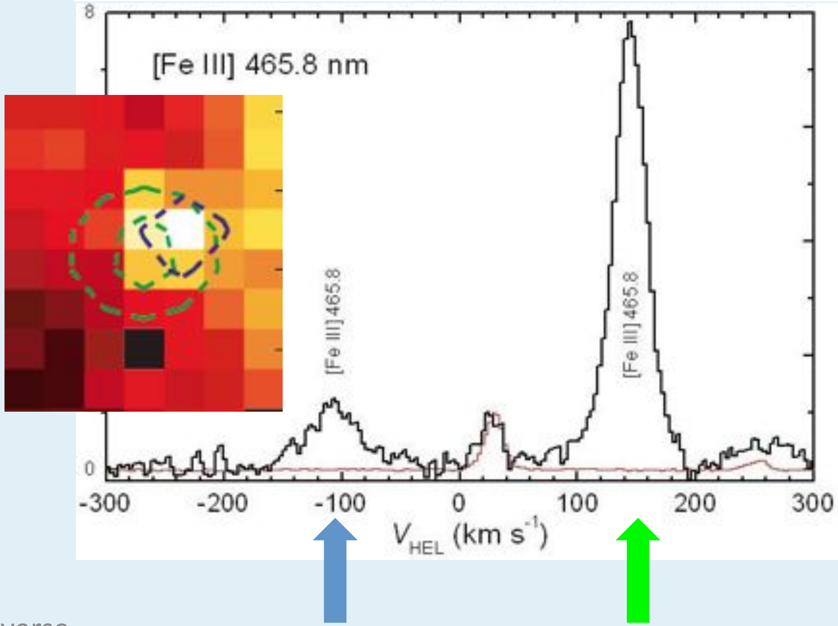
Ne = 8.09

- **Super-solar values by factors of:**
  C (1.7 – 3.5), O (1.9 – 2.2), Ne (2.2)
- The Ne/S ratio is > 2x Solar
- Iron is 0.3% Solar (-2.5 dex) and 9% of the Orion gas value. Dust depletion similar to that seen towards cold ISM sightlines.
  →Evidence for grain-growth

The jet of LV2 (VLT/FLAMES) (Tsamis & Walsh 2011b)





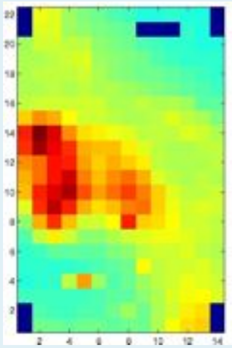


- Spatially and spectrally resolving LV2's bipolar jet (200 AU peak to peak)
- Fe/H (in jet lobe) ≥ 30-50% Solar
  Due to grain destruction, iron is ejected into the gas phase (Tsamis & Walsh 2011)

Summary/Outlook

- i) Enlarge VLT/FLAMES sample with proplyds farther away from the Trapezium, ii) publish VLT/Xshooter near-IR spectra; iii) use future VLT/MUSE array to do all proplyds together (1 sq. arcmin field)

- Preliminary results for HST10 proplyd (VLT/FLAMES data):



O = 8.77 +/- 0.10 , S = 6.90 +/- 0.04, Fe = 5.78

Orion proplyd
HST10 in [SII]

- See also Mesa-Delgado et al. (2012) Calar-Alto 3.5m PMAS IFU array results for 2 more proplyds