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New results on the giant dark silhouette disk 114-426 in the Orion Nebula

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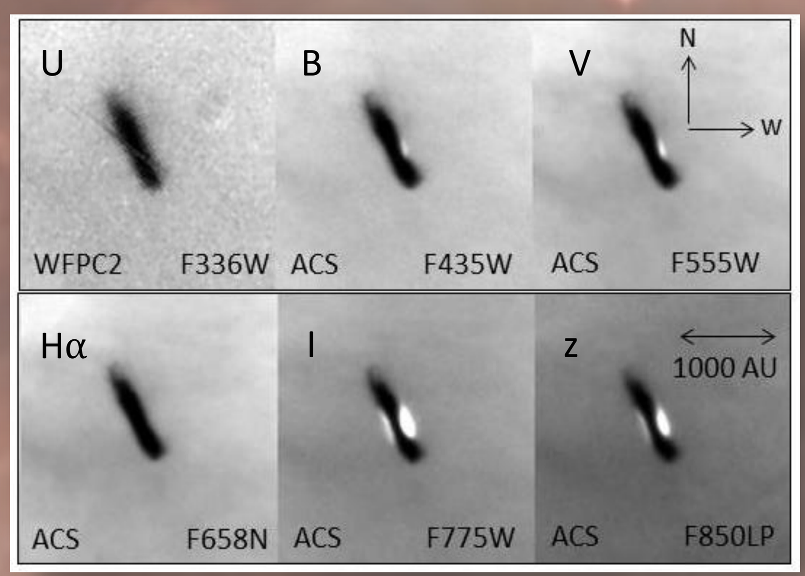
ABSTRACT

The HST Treasury Program on the Orion Nebula Cluster (Cycle 13, GO 10246, P.I. M. Robberto) has provided us with the most detailed images of 114-426, the largest (~1000AU diameter) protoplanetary disk seen in silhouette in the region. The new data allow us unveiling the complex geometry of the disk, which appears eccentric, warped and photoevaporated. Multicolor photometry allows reconstructing for the first time the spatial distribution of the dust grain size in the outer disk regions through the analysis of the extinction coefficient. Unlike all the other proplyds in the Trapezium cluster core, this disk appears photoevaporated by the diffuse non-ionizing FUV flux of the nebular environment. We estimate the mass-loss rate from the disk surface, and use the current constrains on the disk mass to derive its lifetime. Our analysis indicates that this unique system , previously considered in a quiescent state at the edges of the Orion Nebula, is approaching the final stages of its lifetime and its gasous content will be dissipated in a few 10^4 years.

Observations



HST high resolution images of 114-426 in six photometric filters equivalent to the standard *U, B, V, Hα, I* and *z* passbands.

Detailed geometry

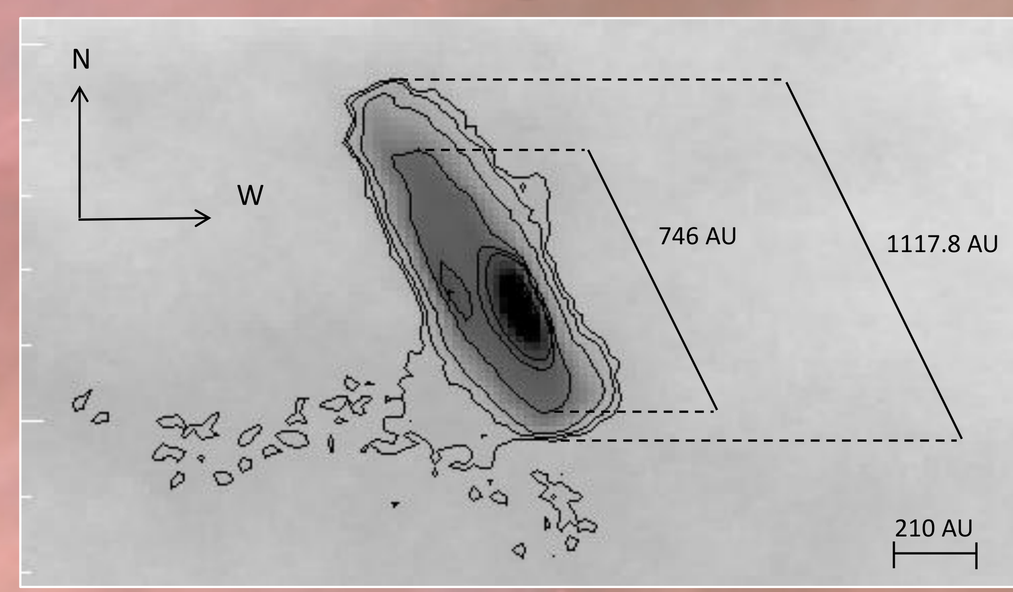
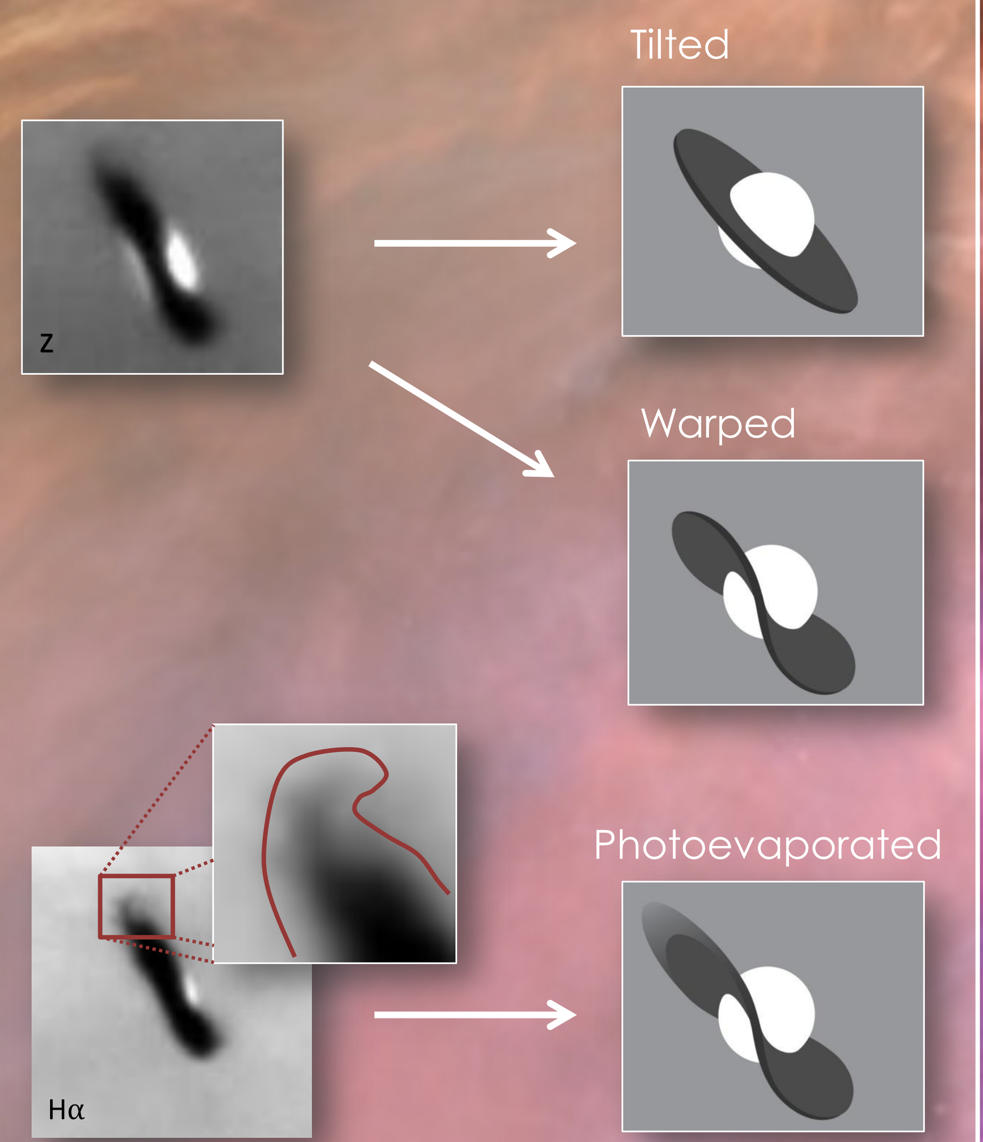
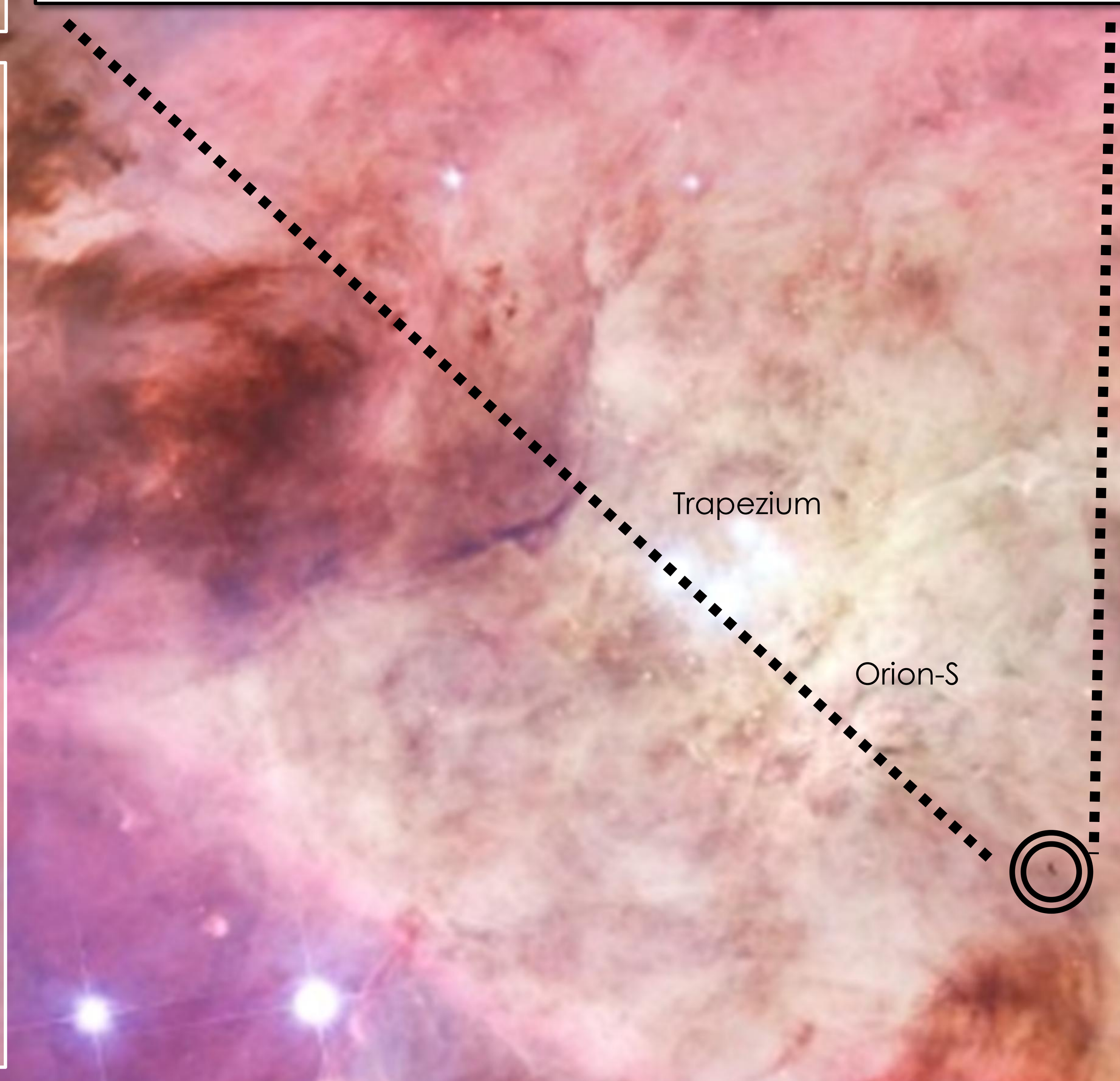


Image obtained using z and Hα filters.

Disk structure





114-426 in its environment

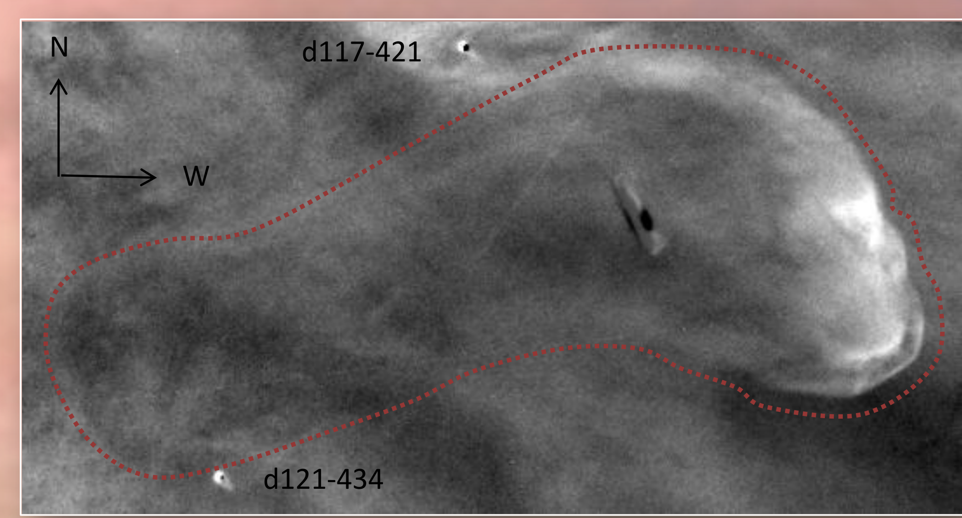


Image obtained using B, V and Hα filters.

In this figure we show 114-426 with its immediate surroundings. An extended filamentary shell emitting in Ha line encircles the western side of the disk. The shell radius has a projected distance of ~ 0.01 pc. The filament can be traced, with much lower brightness, to the eastern side of the disk, up to a projected distance of ~ 0.03 pc. The tenous bright rim delineates a characteristic "foot-like" structure which seems to represent a region of enhanced density, externally illuminated by the diffuse radiation field of the nebula.

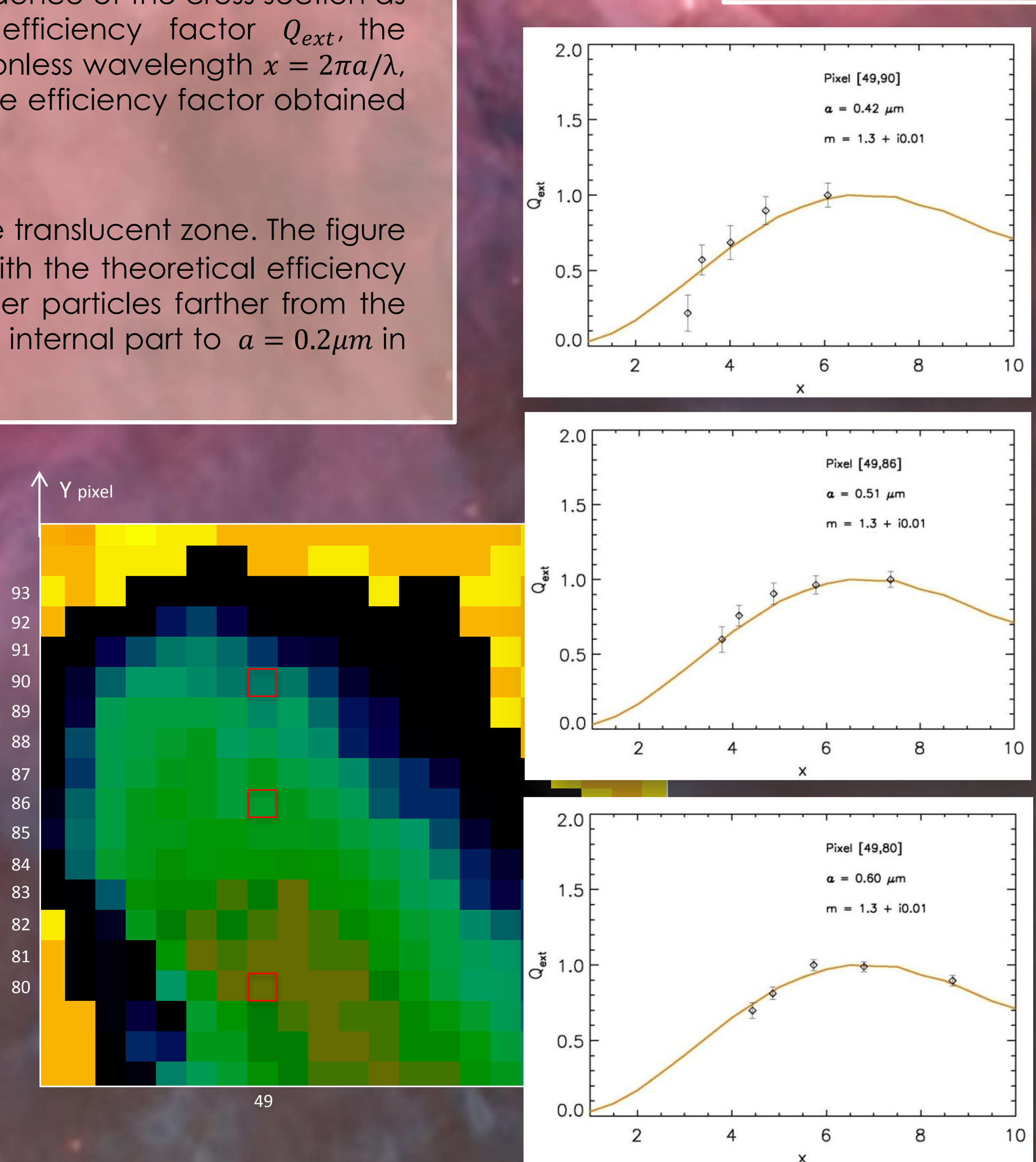
Remarkably, the two closest sources immediately to the east of 114-426, 117-421 and 121-434 (Ricci et al. 2008), are clearly resolved in our ACS images in two photo-ionized disks, pointing in the direction of θ^1Ori-C, lying about 100'' to the north-east (≃ 0.2 pc projected distance). The small size of the two disks , ~ 50 AU radius due to the presence of ionized cups, is in striking contrast with the huge dimensions of 114-426, about 20 times larger in size, without any sign of influence of θ^1Ori-C EUV flux. The disk surface appears shielded to the eastern part and only θ^1Ori-C FUV photons reach its surface. It is intriguing to notice that between the disk and the Trapezium lies, projected on the plane of the sky, the high density neutral region hosting Orion-S, a secondary center of star formation in the Orion Nebula. It represents a local hump, a dense ridge in foreground of the nebular cavity. In this scenario, while the Orion-S ridge prevents EUV photons from the Trapezium stars to reach 114-426, the two proplyds 124-434 and 117-421 are simply further away, far enough from the bottom of the cavity to see directly the Trapezium stars.

Particle sizing

As shown by Throop et al. (2001) and by Shuping et al. (2003), it is possible to investigate the properties of dust particles of 114-426 via the wavelength dependence of the attenuation of background light in partially-opaque areas of the disk. The method we have used to estimate the particles typical size is based on the well known Mie theory for the computation of radiation scattering from spherical particles, a case that allows an exact estimate of the series expansion of the field. The cross section of a sphere depends mainly on the radius a and also on the refractive index n of the particles, that can be determined with good accuracy from the knowledge of the typical dust grain composition (Ricci et al. 2010). This fundamental property allows to easily measure the size itself from the dependence of the cross section as a function of the wavelength. The parameter we consider here to be compared to the observation is the efficiency factor Q_{ext}, the extinction cross section divided by the geometrical cross section $G = \pi a^2$. Plotted against the reduced dimensionless wavelength $x = 2\pi a/\lambda$, this parameter exhibits an oscillating behavior for radii of the order of the wavelength or larger. The value of the efficiency factor obtained by the observations is given by:

$$Q_{ext} = (ln\frac{F_{\lambda,back}}{F_{\lambda,pix}})/\pi a^2 \qquad (1)$$

where $F_{\lambda,back}$ is the mean flux (counts/sec) of the nebular background and $F_{\lambda,pix}$ is the flux in a single pixel of the translucent zone. The figure to the right shows three plots, for pixels [49,80],[49,86] and [49,90], of Q_{ext} as a function of x and we fit them with the theoretical efficiency curves. We can identify different behaviors in different areas of the photoevaporated zone. We found smaller particles farther from the center of the disk; in particular we obtain typical values for the grain size that range from $a = 0.6\mu m$ in the more internal part to $a = 0.2\mu m$ in the outer parts.



Lifetime and unicity

Using HST/NICMOS high resolution near-infrared images of 114-426 McCaughrean et al. (1998) deduce a minimum disk mass of 10 $M_\oplus$, and possibly $\geq 5 \times 10^{-4} M_\odot$. On the other hand d114-426 was not detected by the Submillimeter Array survey (Mann & Williams 2010). This non-detection places an upper mass limit of $1.2 \times 10^{-2} M_\odot$, confining the disk mass into a range of two orders of magnitude.

Assuming that the mass loss rate for 114-426 is essentially given by the photoevaporation in the FUV external field, the disk's **life time scale** ranges between 2.5×10^3 yr to 6×10^4yr. This is clearly a very short time scale, but it may be appropriate for a rather unique object like d114-426. At the current evaporation rate, d114-426 will be entirely dissipated in ~ 10^4 yr. It may well have formed 1 Myr ago (about the age of the ONC) with the typical disk mass of ~ $0.1 - 0.5\ M_\odot$ and be reduced to the current mass while maintaining a level of photoevaporation nearly constant at the measured level.

Overall the picture seems consistent with d114-426 being a relatively low mass disk inflated and photoevaporated by the diffuse field of FUV radiation within the nebula, seen in the very last phases of its evolution.

Mass-loss from 114-426

The mass-loss rate, $\dot{M}$, for large disks that evaporate in an external FUV field is given by (Adams et al. 2004):

$$\dot{M} = 4\pi f \langle\mu\rangle {\sigma_{FUV}}^{-1} a_s r_d \qquad (2)$$

We assume for the geometric factor f ~ 1 and using the dust grains size found with our previous analysis we derive ${\sigma_{FUV}}^{-1} \sim 8.8 \cdot 10^{19}\ cm^{-2}$, whereas for the outer radius we use $r_d \sim$ 370 AU. The sound speed a_s, controlled by the temperature at the disk surface, depends on the amount of FUV flux illuminating the disk which can be estimated as follows.

Both ionizing (EUV : $h\nu \geq$ 13.6 eV) and non-ionizing (FUV: 6 eV $\leq h\nu \leq$ 13.6 eV) fluxes emitted by the Trapezium stars are scattered within the HII region. The EUV radiation, carrying about 2/3 of the original ionizing energy, is scattered by recombination processes, whereas FUV radiation is scattered only by dust particles. Most of the scattering occurs at the edges of the HII region so that the diffuse field can be assumed to be constant within the cavity.

A shielded disk will only receive FUV radiation given by:

$$F_{diff} \sim \frac{1}{2} Q_{s\,ca} \cdot \frac{(1-\rho)Q}{4\pi {R_{HII}}^2}, \qquad (3)$$

assuming that ½ of the radiation is reflected back by the cavity walls, a scattering efficiency $Q_{sca} \sim$ 0.5, a fraction of Lyman continuum photons ρ = 0.4 emitted by the ionizing stars (mostly θ^1Ori-C), and a typical radius of the cavity R_{HII} =0.3 pc, the distance between θ^1Ori-C and the ionization front. If we assume that θ^1Ori-C has a Lyman continuum luminosity $Q \simeq 1.5 \times 10^{49}\ photons\ s^{-1}$, a shielded disk will receive a FUV flux of ~ $2 \cdot 10^3\ G_0$ (where $G_0 = 1.6 \times 10^{-3} erg \cdot cm^{-2} \cdot s^{-1}$ is the Habing Flux), assuming an effective wavelength of 1200Å . The disk surface will be heated to about 300 K, thus powering a PDR outflow at about $a_s \simeq 1\ km\ s^{-1}$ from the disk.

From equation (2) we derive for the **mass loss rate of 114-426**

$$\dot{M} \simeq 2 \cdot 10^{-7} \frac{M_\odot}{yr} \qquad (4)$$

a rather high value , considering that our estimate, roughly independent of location within the nebula, may be enhanced by the contribution from the diffuse EUV flux.

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