A compendium of distances to molecular clouds in the Star Formation Handbook

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ABSTRACT

Accurate distances to local molecular clouds are critical for understanding the star and planet formation process, yet distance measurements are often obtained inhomogeneously on a cloud-by-cloud basis. We have recently developed a method that combines stellar photometric data with Gaia DR2 parallax measurements in a Bayesian framework to infer the distances of nearby dust clouds to a typical accuracy of \(\sim 5\%\). After refining the technique to target lower latitudes and incorporating deep optical data from DECam in the southern Galactic plane, we have derived a catalog of distances to molecular clouds in Reipurth (2008, Star Formation Handbook, Vols. I and II) which contains a large fraction of the molecular material in the solar neighborhood. Comparison with distances derived from maser parallax measurements towards the same clouds shows our method produces consistent distances with \(\lesssim 10\%\) scatter for clouds across our entire distance spectrum (150 pc \(\sim 2.5\) kpc). We hope this catalog of homogeneous distances will serve as a baseline for future work.

Key words. local interstellar matter – solar neighborhood – catalogs

1. Introduction

The Star Formation Handbook, divided into two volumes for the Northern (Reipurth 2008a) and Southern (Reipurth 2008b) sky, contains around sixty of the most important star forming regions within 2 kpc. Written by a team of 105 authors, the Handbook spans 1900 pages, and includes the most comprehensive discussion of individual low- and high-mass star forming regions published to date. Since the proximity of these clouds facilitates high-resolution observations across the electromagnetic spectrum, together these regions inform much of our knowledge of how molecular gas is transformed into stars.

Characterizing the specifics of this process relies on robust distance estimates to star-forming regions, and while many of the Handbook’s clouds are well studied, their distances are not well constrained. Several clouds in the Handbook have distance estimates in the literature that vary by at least a factor of two (e.g. Circinus Molecular Cloud, North America Nebula, Coal-sack Nebula, NGC 2362, IC 5146), while many others (e.g. Lagoon Nebula, Pipe Nebula, IC 2944, NGC 2264) may show better agreement, but with large distance uncertainties (\(\gtrsim 30\%\)).

In this work, we leverage the technique presented in Zucker et al. (2019) to produce a supplementary catalog of distances to molecular clouds in the Star Formation Handbook (Reipurth 2008a,b) with a typical distance uncertainty of \(\approx 5\%\). Our method relies on the colors of stars, taking advantage of the fact that stars behind a dust screen appear redder. An alternative method of determining the presence of dust is to track stellar magnitudes/parallaxes across the apparent magnitudes of stars. Wolf determined the distance to dark nebulae by characterizing the apparent magnitudes of stars (Wolf 1923). In what is now known as a “Wolf diagram”, Wolf plotted the number of stars per unit solid angle versus their apparent magnitudes in both extinguished and unextinguished regions towards the nebulae. Under the assumption that all stars have the same absolute magnitude, Wolf determined the distance to dark nebulae by characterizing the apparent magnitude at which one observes a drop in stellar density towards the obscured sightlines (see e.g. discussion in Chap. 6 of Shore 2002).

A more precise study of cloud distances based on stellar photometry requires modeling the colors of stars and their types, and in a more modern sense, our methodology is similar to that presented by Neckel & Klare (1980), which has a rich history in the literature (see e.g. Schlafly et al. 2014; Sale & Magorrian 2018; Lallement et al. 2019; Green et al. 2019; Marshall et al. 2006; Rezaei Kh. et al. 2018; Yan et al. 2019). By combining Gaia DR2 parallax measurements with stellar photometry, we...
infer the distance, extinction, type, and \( R_V \) of stellar sources in sightlines towards local molecular clouds. Unlike Wolf (1923), we require stars to be detected both in front of and behind the cloud, and we fit a simple line-of-sight dust model to the set of \textit{Gaia}\-constrained stellar distance and extinction estimates to infer the distance at which we observe a "break" in stellar reddening.

While Zucker et al. (2019) provided a uniform catalog of distances to over twenty-five named clouds, it did not incorporate deep optical data in the southern Galactic plane (e.g. towards the Southern Coalsack, Circinus, IC 2944), nor was the technique intended to target clouds near \( b = 0^\circ \), particularly towards the inner galaxy (e.g. M 16, M 17, M 20, NGC 6604). Here, we refine the technique to target approximately thirty additional named regions selected from the Star Formation Handbook. When combined with the results of Zucker et al. (2019), this includes distance estimates to almost every major cloud in Reipurth (2008a,b). In Sect. 2, we briefly summarize the methodology presented in Zucker et al. (2019) to infer distances to each cloud along with updates to data and methods implemented in this work. In Sect. 3, we present our new catalog of distances to clouds in the Star Formation Handbook, as well as an interactive 3D figure of the entire distance catalog. A machine readable version of the catalog is available on the Harvard Dataverse and will be made available via the CDS. In Sect. 4, we compare our dust-based distances from stars to gas-based distances from masers, finding good agreement between the two independent methods. Finally, we conclude in Sect. 5.

2. Data and methods

Our technique is identical to Zucker et al. (2019) save for three improvements summarized in Sect. 2.4. Here, we recapitulate the core data products and methodology we employ from Zucker et al. (2019) to infer the per-star distance extinction measurements and the line-of-sight dust distribution. For a detailed description of the data and methods, see Sects. 2 and 3 in Zucker et al. (2019).

In brief, we derive the distance, extinction, type, and \( R_V \) towards stars along sightlines through local molecular clouds using optical and near-infrared photometry. For sightlines above a declination \( \delta = -30^\circ \), we use optical point spread function (PSF) photometry from the PanSTARRS1 survey (Magnier et al. 2016; Chambers et al. 2016) and PSF near-infrared photometry from the 2MASS survey (Skrutskie et al. 2006). For stars below a \( \delta = -30^\circ \) and outside the southern Galactic plane (Galactic latitude \( |b| > 5^\circ \)), we use optical aperture photometry from the NOAO Source Catalog (NSC; Nidever et al. 2018) and near-infrared data from the 2MASS survey. Finally, for stars in the Southern galactic plane (\( \delta < -30^\circ \) and \( |b| < 5^\circ \)) we employ optical PSF photometry from the DECaPS Galactic Plane Survey (DECaPS; Schlafly et al. 2018) and near-infrared data from the 2MASS survey. When available, we cross-match sources with \textit{Gaia} (Gaia Collaboration 2018) to obtain parallax measurements for each star. A \textit{Gaia} parallax measurement is not required for inclusion, but is incorporated as an additional Gaussian likelihood term. The incorporation of \textit{Gaia} has the largest effect for stars with high signal-to-noise parallax measurements in the solar neighborhood, but is also able to resolve distance degeneracies for stars with low signal-to-noise parallax measurements beyond a few kiloparsecs (for more details, see Sect. 3.1 and interactive Fig. 1 of Zucker et al. 2019). Stars are selected in either 0.7° beams (for nearby clouds) or 0.2° beams (for more distant clouds) centered on sightlines of interest through each cloud, as discussed further in Sect. 2.3.

2.1. Per-star inference

We model the observed magnitudes \( \hat{m} \) of the stars\(^3\) (in the optical and near-infrared bands) as a function of distance, extinction, stellar type, and \( R_V \) using a technique similar to that outlined in Green et al. (2014, 2015, 2018):

\[
\hat{m} = m_{\text{inc}}(M_\ast, [\text{Fe/H}]) + A_V \times (R + R_V \times R') + \mu
\]

Here, \( m_{\text{inc}} \) is the set of intrinsic (un-reddened) magnitudes for the star as a function of stellar type, \( A_V \) is the extinction, \( R \) is the "differential extinction", and \( R' \) and \( R'' \) characterize the overall reddening as a function of magnitude, and \( \mu \) is the distance modulus. The intrinsic colors of stars are based on a set of empirical templates derived from fitting a stellar locus in a low reddening region of the sky; these templates parameterize the star’s colors as a function of its metallicity ([Fe/H]) and absolute magnitude in the PanSTARRS1 \( r \)-band (\( M_r \)). The baseline and differential reddening “vectors” \( R \) and \( R' \) are derived using the results from Schlafly et al. (2016) and are identical to those used in Zucker et al. (2019).

For northern clouds (\( \delta > 30^\circ \)), the stellar templates and reddening curve we use are identical to those employed in Green et al. (2019). For the southern clouds, we transform these templates into the DECaPS \( grizy \) bands using color transformations derived on low-reddening calibration fields. For the NSC data, we additionally apply zero-point corrections derived on similar calibration fields to bring their measurements in line with the AB photometric system. The reddening vectors are converted to the DECam system by integrating the interpolated curve from Schlafly et al. (2016) through the relevant DECam filter set. See Appendix A for more details.

The posterior probability, \( P(\theta | \hat{m}, \hat{\sigma}) \), that our observed magnitudes \( \hat{m} \) are consistent with the predicted model magnitudes \( m(\theta) \equiv m(M_\ast, [\text{Fe/H}], A_V, R_V, \mu) \) and the measured \textit{Gaia} parallax measurement \( \hat{\sigma} \) is based on Bayes’ theorem:

\[
P(\theta | \hat{m}, \hat{\sigma}) \propto P(\hat{m} | \theta, \hat{\sigma}) P(\hat{\sigma} | \mu) P(\theta)
\]

The probability of observing our given magnitudes \( P(\hat{m} | \theta) \) and corresponding parallax \( P(\hat{\sigma} | \mu) \) is based on Gaussian measurement noise. The prior probability \( p(\theta) \) of our underlying parameters \( \theta \) incorporates previous work on the luminosity, number density, and metallicity of stars in the Galaxy (Bressan et al. 2012; Ivezić et al. 2008; Jurić et al. 2008) as well as the variation of the optical-extinction curve across the Milky Way disk (Schlafly et al. 2016).

Like Zucker et al. (2019), we fit for our model parameters \( (M_\ast, [\text{Fe/H}], A_V, R_V, \mu) \) using the public code \textsc{brutus}\(^2\) (Speagle et al., in prep.). We marginalize over stellar type \( (M_\ast, [\text{Fe/H}]) \) and \( R_V \) to obtain the 2D distance-extinction posterior \( P(\mu, A_V | \hat{m}, \hat{\sigma}) \) for each star, which is subsequently used in our line-of-sight fit.

\(^2\) The stellar templates we employ are derived using photometry in the native magnitude system of each survey. The PS1, DECaPS, and NSC surveys use AB magnitudes, while 2MASS uses Vega magnitudes. As a result, the magnitude system of the observed photometry \( \hat{m} \) depends on the available bands.

\(^3\) The brutus source code is available on GitHub as well as Zenodo: https://doi.org/10.5281/zenodo.3348370

https://doi.org/10.7910/DVN/07L7YZ
2.2. Line-of-sight inference

We fit a simple line-of-sight dust model to the set of stellar distance-extinction posterior distributions to determine the distance to each cloud. We model each cloud as a thin dust screen at a particular distance modulus \( \mu_{\text{C}} \). The total extinction through the screen towards each star \( f \) is based on two components. The first is the extinction due to the dust cloud parameterized by \( N \times C \), where \( C \) is the reddening towards the star at 353 GHz based on measurements from Planck (Planck Collaboration XI 2014) times the star’s typical \( R_\text{B} \) (see Sect. 2.1) and \( N \) is a normalization constant. The second is due to a small amount of foreground extinction \( f \) caused by nearby dust unassociated with the cloud. The line-of-sight extinction as a function of distance towards a star in each sightline of interest is then:

\[
A_v(\mu) = \begin{cases} 
  f, & \mu < \mu_{\text{C}} \\
  f + N \times C, & \mu \geq \mu_{\text{C}}.
\end{cases}
\]  

(3)

In addition to the simplistic model above, we also allow for additional scatter in the extinction from star to star in the foreground \( \sigma_{\text{foreground}} \) and background \( \sigma_{\text{background}} \) of each sightline. Finally, we reject outlying stars unassociated with the cloud based on an adaptive threshold \( (P_b) \) as part of a Gaussian mixture model.

The probability of our cloud having a particular set of parameters \( \sigma = \{ \mu_{\text{C}}, N, f, \sigma_{\text{foreground}}, \sigma_{\text{background}}, P_b \} \) is based on a prior \( P(\sigma) \) as well as the distance and extinction of each of the \( n \) stars in the cloud. To account for measurement uncertainties from each star, we marginalize over all possible distances and extinctions to get:

\[
P(\sigma|\{\hat{m}_i\}_{i=1}^n) \propto P(\sigma) \prod_{i=1}^n \int P(\mu_i, A_v^i|\sigma) P(\mu_i, A_v^i|\hat{m}_i) d\mu_i dA_v^i
\]

where \( P(\mu_i, A_v^i|\sigma) \) is the posterior for each star based on Sect. 2.1 and \( P(\mu_i, A_v^i|\sigma) \) is the probability of observing a given distance and extinction given our line-of-sight model. Our prior \( P(\sigma) \) follows the same functional forms as those used in Zucker et al. (2019) except for two small changes. First, we have increased our allowed range for the normalization factor \( N \) (relative to Planck) to be from 0.01 to 2.0 to better account for larger amounts of background dust. Second, we have increased the upper bound of \( f \) to be 50% of the mean stellar-based extinction to the cloud to account for greater amounts of foreground material. We find these two changes allow us to substantially better model behavior in the Galactic plane at \( b \approx 0^\circ \). We caution that for sightlines with low normalization factors, the spatial information from Planck is not providing any additional constraint on the distance. Planck clearly provides a poor description of the data in these cases, and a flat dust template would work equally well in these scenarios. Nevertheless, the jump in extinction is large enough that the templates have little effect on the distance determination, and are simply employed to remain consistent with other, less extinguished sightlines where the spatial information is expected to play a larger role.

We sample for our line-of-sight model parameters \( \sigma \) using the public nested sampling code dynesty (Speagle 2019) with the same setup as described in Zucker et al. (2019).\(^4\)

2.3. Sample selection

About 25 of the 60 clouds highlighted in the Star Formation Handbook are targeted in Zucker et al. (2019). This constitutes \( \approx 125 \) sightlines towards some of the most famous nearby clouds (e.g. Perseus, Taurus, Orion, CMA OB1, California, etc.). Here we target \( \approx 30 \) new clouds using 200 new sightlines. Following Zucker et al. (2019) and guided by discussion of each region in the Star Formation Handbook, we choose representative sightlines in and around the clouds of interest that are well suited to the technique described above. Our technique requires actually seeing stars both in front of and behind each cloud, so we consequently avoid targeting particularly dense regions (\( E(B-V) \gtrsim 5 \) mag) in favor of lower density envelopes (0.15 mag < \( E(B-V) < 5 \) mag). Consequently, while these sightlines are generally near the traditional star-forming cores and clumps associated with each star-forming region, they are not centered on them.

We apply three general cuts to improve the quality of our stellar sample. First, we restrict our sample to stars lying in pixels with \( E(B-V) > 0.15 \) mag (based on Planck estimates at 353 GHz). Second, we remove stars whose photometry is inconsistent with our stellar modeling at the 2–3\( \sigma \) level (equivalent to a \( p \)-value < 0.01). Finally, novel to this work, we apply a cut to remove stars whose inferred distance is inconsistent with its Gaia parallax measurement (when available) at the 2\( \sigma \) level. This occurs primarily when our modeling mis-identifies faraway giant stars towards the Galactic plane (which have measured parallaxes \( \ell \approx 0 \)) as nearby dwarfs.

As in Zucker et al. (2019), we adopt two different samples of stars to determine distances in different regimes. For faraway clouds \( (d \gtrsim 300 \text{pc}) \), we select all stars within a 0.2\( ^\circ \) beam. For nearby clouds \( (d \approx 100–300 \text{pc}) \), we instead select only M-dwarf stars using a set of color and magnitude cuts (the same employed in Zucker et al. 2019) within a larger 0.7\( ^\circ \) beam. For these very nearby clouds, this M-dwarf cut prevents the large number of background stars from overwhelming the sparse number of foreground stars\(^5\).

2.4. Summary of updates to Zucker et al. (2019)

To summarize, our methodology is largely similar to Zucker et al. (2019), save three improvements:

– We extend our technique to the southern Galactic Plane by incorporating deep optical data from the DECam Galactic Plane Survey (DECaPS; Schlafly et al. 2018). The first DECaPS data release targeted the sky at \( (b, l) \approx (22.8, 22.3, 21.9, 21.0) \) in the \( g, r, i, z, \) and \( Y \) bands, respectively, the survey obtained PSF photometry for around 2 billion stars, allowing us to expand our distance catalog to southern clouds including the Southern Coalsack, Carina, IC2944, Vela C, RCV38, Ara, Circinus, and Norma.

– We modify the prior on our line-of-sight fit to accommodate greater amounts of unassociated foreground dust and background dust along the line-of-sight to improve our modeling in the Galactic plane.

– We identify and remove giant stars misclassified as dwarfs by our stellar modeling using a parallax-based cut.

The full catalog of distances is presented in Sect. 3.

\(^4\) See their Appendix C.

\(^5\) The exceptions are the southern clouds Circinus and Norma, which lie at \( \approx 700 \text{pc} \); the “near” technique was used for these clouds because they lie in the Galactic plane, and the higher stellar density combined with the greater depth of the DECaPS survey meant the number of background stars quickly overwhelmed the number of foreground stars with the “faraway” technique, which led to an unreliable fit.
Our line-of-sight extinction model as a function of distance towards the Vela C cloud ($l, b = 264.7\degree, 1.4\degree$). The background grayscale shows the probabilistic distance and extinction estimates for all the stars used in the fit, with the most probable distance and extinction to every star marked via a red cross. The blue step function shows the typical extinction profile inferred for the sightline. The median foreground extinction prior to the cloud distance $D_c$ (at distance modulus $\mu$) is shown as a blue horizontal line. The range of estimated distances to the cloud is shown as an inverted blue histogram, with the median cloud distance and the corresponding 16th/84th percentiles marked with solid and dashed blue vertical lines, respectively. Beyond the cloud distance, the bottom and top blue lines show the 16th and 84th percentile of the Planck-based extinction towards the stars. The distance uncertainties do not include systematic uncertainties, which we estimate to be roughly 5%.

3. Catalog

In Table A.1, we summarize our distance results for the 326 sightlines targeted towards clouds in the Star Formation Handbook. We include the central coordinates of the sightline, the named region the sightline is associated with, and the volume (Northern or Southern) and page number for the Star Formation Handbook chapter in which it is discussed. A machine-readable version of this table is available for download on the Dataverse and at the CDS, and also includes values for the ancillary model parameters determined for each sightline. On the Dataverse, we also include a set of complementary figures for each sightline, including 1D and 2D marginalized posterior distributions of our model parameters and how the line-of-sight extinction varies as a function of distance towards each cloud. An example figure, showing how extinction varies as a function of distance for the Vela C cloud (towards $l, b = 264.7\degree, 1.4\degree$) is shown in Fig. 1.

The distances we report in Table A.1 represent the median cloud distance for each sightline determined using the set of distance samples returned by dynesty (Speagle 2019). The first set of error bars represent our 1σ statistical errors, computed using the 16th and 84th percentiles of our distance samples. The statistical uncertainties are usually low (on the order of 1–2%), with the exception of sightlines with very few foreground stars, where the fit is poorly constrained, resulting in higher statistical uncertainties. The second set of errorbars is our systematic uncertainty, estimated to be 5% in distance (see discussion in Zucker et al. 2019), though we caution here, as in Zucker et al. (2019), that this systematic uncertainty is likely higher for clouds at farther distances (beyond $\approx 1.5$ kpc) or with more complicated line-of-sight dust structures, due to the simplicity of our line-of-sight dust model. We also anticipate higher systematic uncertainties for clouds in the NSC footprint, as discussed in Appendix A. These systematic uncertainties are reflected in Table A.1. We recommend the statistical and systematic uncertainties be added in quadrature.

Our results cover most chapters in the Star Formation Handbook. The primary exceptions are open clusters or OB associations which are not associated with significant and extended dust emission, thereby rendering them unsuitable for this technique. These include:

- the young open clusters NGC 6383 (Southern Volume, p. 497), NGC 6231 (Southern Volume, p. 401), and ω-Orionis (Northern Volume, p. 732),
- the extended OB association Sco OB2 (Southern Volume, p. 235),
- the chapter on Young Nearby Loose Associations (Southern Volume, p. 757), and
- the chapter on Dispersed Young Population in Orion (Northern Volume, p. 838)

Certain clusters, like the LkHα 101 cluster (part of NGC 1579), are not specifically targeted, but are known from the literature to be associated with the larger California Molecular Cloud (Lada et al. 2009), to which we are able to obtain a reliable distance. We likewise exclude the chapter Star Formation in Bok Globules and Small Clouds (Southern Volume, p. 847) as the size of many globules is equivalent to the pixel scale of our dust templates from Planck; a tailored approach employing higher angular resolution templates (e.g. from Herschel) would be better suited for these objects, provided enough background stars could be seen through the globules. While we targeted NGC 6334 (Southern Volume, p. 456), RCW 120 (Southern Volume, p. 437), and GM 24 (Southern Volume, p. 449), these regions were simply too extinguished (near $b = 0\degree$) and too confused (towards the Galactic center and beyond 1 kpc) that we were unable to obtain a reliable distance to them.

Finally, we note that a few clouds in Table A.1 are not explicitly mentioned in the Handbook (e.g. Pegasus, Hercules, Aquila South, Spider, Draco, Maddalena). These were targeted in Zucker et al. (2019) and are included here for completeness.

4. Discussion

In Fig. 2 we show a bird’s-eye view of our distance catalog, overlaid on the 3D “Bayestar19” dust map from Green et al. (2019) integrated over $z = \pm 300$ pc from the plane. As expected, our dust distances are broadly consistent with the Green et al. (2019) 3D dust map, with any small discrepancies arising from the fact that our technique is optimized for molecular cloud distance determination, while the Green et al. (2019) technique characterizes all the dust along the line of sight. As is apparent in Fig. 2, our distance catalog includes a majority of the molecular emission (and associated dust) out to 2.5 kpc. Much of the catalog is not randomly distributed, but instead forms coherent quasi-linear complexes such as those seen in the nearby Sco-Cen clouds consisting of Serpens, Aquila, Lupus, Chamaeleon, and Corona Australis. However, we do see some evidence of the “fingers of God” effect, owing to our angular resolution being much finer in comparison to our distance resolution. This effect is clearly seen towards the W3, W4, and W5 star-forming regions, where we obtain similar average distances to recent results obtained using Gaia DR2 data for OB stars in the complex (Navarete et al. 2019) but with significantly more scatter along the line-of-sight.

6 https://doi.org/10.7910/DVN/87L7YZ
7 https://doi.org/10.7910/DVN/SBFENG7
In the caption of Fig. 2 we also link to an interactive 3D version of this figure, where users can pan, zoom, and hover over any sightline to view the name of the cloud.

To gauge the accuracy of our catalog, we compare our star- and dust-based distances with those obtained independently using trigonometric parallax observations of masers in low-mass and high-mass star-forming regions. Based on the BeSSel surveys (Reid et al. 2014, 2016; Brunthaler et al. 2011) and GOBELINS surveys (Loinard et al. 2013), we identify sightlines within a projected distance of 50 pc from VLBI source positions in the following regions:

- Taurus (Galli et al. 2018),
- Ophiuchus (Ortiz-León et al. 2017a),
- Perseus (Ortiz-León et al. 2018),
- Serpens/Aquila (Ortiz-León et al. 2017b),
- Gemini OB1 (“IRAS 06061”, “S252”; Reid et al. 2014),
- Monoceros R2 (“G213.70–12.6”; Reid et al. 2016),
- Sh2-232 (“G173.48+2.44”; Sakai et al. 2019),
- L379 (“G016.86–2.15”; Reid et al. 2016)$^9$,
- L977 and L988 (“G090.21+2.32”; Xu et al. 2013),
- NGC 2362 (“VYCMa”; Zhang et al. 2012),
- S106 (“G076.38–0.61”; Xu et al. 2013),
- Orion (Reid et al. 2014),
- Cepheus-Far (“IRAS 22198”, “G108.18+5.51”; Reid et al. 2014), and
- the W3 star-forming region (“W3OH”; Reid et al. 2014).

While we determine distances to the same regions, each approach targets different parts of the clouds using different observations: the maser distances are obtained using radio data towards the most extinguished sightlines while our star- and dust-based distances are obtained using optical to near-infrared data towards the lower density envelopes.

One small complication is that our method can often obtain multiple distance estimates across a single cloud, while maser parallax measurements are usually limited to one or two per star.

$^8$ Since maser emission is rare and highly variable in low-mass star forming regions, the GOBELINS survey is not preferentially targeting masers, and we include any published VLBI observation of radio emission from the GOBELINS survey associated with YSOs (e.g. Ortiz-León et al. 2018).

$^9$ This distance will appear in Rygl et al. (in prep.), and is publicly available on the BeSSel website as an accompanying data product from Reid et al. (2016), which forms the core of the maser catalog comparison. See http://bessel.vlbi-astrometry.org/bayesian
In the clouds themselves. or that the masers are not capturing cloud substructure that is 10%. While this is consistent with our estimated uncertainties distance compared to the respective maser distance is just under distances explored, the typical scatter between our average dust agreement between the two methods. Across the range of dis-
tances derived from each method. This lack of systematic dis-
tance offset is evident in Fig. 3, with the data providing a very good fit to the 1:1 line. The good agreement underlines the accu-
racies of both the statistical and systematic uncertainty, added in quadrature. The shaded region bounding the 1:1 indicates the typical combined uncertainty we estimate for our dust distances.

The relationship between our average dust distances and the maser distances is shown in Fig. 3. Overall, we find good agreement between the two methods. Across the range of dis-
tances explored, the typical scatter between our average dust distance compared to the respective maser distance is just under 10%. While this is consistent with our estimated uncertainties for faraway clouds, this is a few percent higher than our estimated uncertainties for nearby clouds. This could indicate that we slightly underestimate our uncertainties (by a few percent) or that the masers are not capturing cloud substructure that is present in our averaged dust distances, leading to discrepancies in the cloud distances caused by, for example, distance gradients in the clouds themselves.

Nevertheless, we find no systematic difference in the dis-
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5. Conclusion

Using the technique presented in Zucker et al. (2019), we obtain accurate distances to ≈60 star-forming regions within 2.5 kpc described in the Star Formation Handbook (Reipurth 2008a,b).

Averaged over a molecular cloud, we find that our dust dis-
tances agree with traditional maser-based distances to within ≈10% with no discernable systematic offsets. Our catalog con-
tains famous molecular cloud associations (e.g. the Sco-Cen clouds) as well as other possible structures that will be the study of future work. A machine-readable version of the full catalog is publicly available on the Dataverse and at the CDS\textsuperscript{10}. Upcoming data releases from Gaia, in combination with future all-sky deep optical surveys (e.g. LSST; Abell 2009), should present exciting new opportunities to further improve these distances, in pursuit of better 3D maps of molecular clouds in the solar neighborhood.

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Appendix A: Photometric Calibration and Stellar Modeling

To obtain stellar templates for the southern clouds ($\delta < -30^\circ$) for both the NSC (Nidever et al. 2018) and DECaPS (Schlafly et al. 2018) surveys, we start by selecting a low-reddening field (a beam of radius $5^\circ$ centered on $\alpha, \delta = 7^h, 0^\circ$) in the NSC footprint that also overlaps with the Pan-STARRS1 survey.

Using this field to link NSC to PS1, we derive a color transform to convert our model intrinsic PS1-2MASS colors and absolute PS1 $r$-band magnitudes from our northern stellar templates (from Green et al. 2019) to the DECam system. Specifically, we follow a similar procedure to that employed in Schlafly et al. (2018) (see their Sect. 6.2) and model the color transformations to expectations from the filter systems of DECam and PS1 following the same procedure as outlined in Sect. 5.2 of Schlafly et al. (2018). This procedure revealed that the NSC photometry was significantly offset from the PS1 AB system, requiring offsets of

\[ g_{\text{NSC}} - g_{\text{DECam}} = -0.006 \]
\[ r_{\text{NSC}} - r_{\text{DECam}} = 0.102 \]
\[ i_{\text{NSC}} - i_{\text{DECam}} = 0.088 \]
\[ z_{\text{NSC}} - z_{\text{DECam}} = 0.090 \]
\[ Y_{\text{NSC}} - Y_{\text{DECam}} = 0.047. \]

These were applied to the NSC magnitudes before performing the stellar inference. In addition to these overall zero-points, we also found strong evidence for a magnitude-dependent trend in these offsets, with shifts of $-0.03$ mag between 15 and 20th mag. We opt not to include an additional correction for this trend for simplicity.

As the DECaPS survey has already been calibrated to the PS1 system following the same procedure, no further photometric corrections were needed for clouds in the DECaPS footprint.

Although we have attempted to bring DECaPS and NSC onto the PS1 photometric system, there might still be systematics in the derived distance estimates between the different datasets. While there is overlap between DECaPS/NSC DECam observations and PS1 towards the Galactic center, it is difficult to compare results between the three surveys due to the extreme amount of reddening, cloud confusion, and other systematics present in those sightlines. Unfortunately, there is very limited overlap in molecular clouds in uncrowded regions where NSC aperture photometry performs well, so we are not able to confirm agreement between NSC and DECaPS in this regime.

Comparisons of DECaPS and NSC-derived distances over a low-reddening footprint give consistent distances at the 5% level. This is on par with the overall 5% systematic uncertainty of our technique and has been added in quadrature to the systematic distance uncertainties for the NSC-derived distances to Lupus, Corona Australis, and Chamaeleon in Table A.1.
Table A.1. Molecular cloud distances.

| Cloud       | l ° | b ° | Distance pc | Targeted in Zucker+2019? | Volume | Page |
|-------------|-----|-----|-------------|--------------------------|--------|------|
| Aquila Rift | 21.8| 9.2 | 278^{11}_{13} ± 13 | N                        | Northern | 18   |
| Aquila Rift | 16.7| 11.1| 208^{11}_{13} ± 10 | N                        | Northern | 18   |
| Aquila Rift | 18.3| 12.7| 254^{12}_{13} ± 12 | N                        | Northern | 18   |
| Aquila Rift | 21.5| 11.9| 280^{13}_{14} ± 14 | N                        | Northern | 18   |
| Aquila Rift | 16.0| 16.6| 163^{13}_{14} ± 8  | N                        | Northern | 18   |
| Aquila S    | 38.9| -19.1|123^{13}_{14} ± 6 | Y                        | –      | –    |
| Aquila S    | 39.3| -16.8|128^{13}_{14} ± 6 | Y                        | –      | –    |
| Aquila S    | 37.8| -17.5|135^{13}_{14} ± 6 | Y                        | –      | –    |
| Aquila S    | 36.8| -15.1|143^{13}_{14} ± 7  | Y                        | –      | –    |
| Ara         | 336.7| -2.0|1064^{12}_{15} ± 53| N                        | Southern | 388  |
| Ara         | 336.4| -1.7|1046^{15}_{14} ± 52| N                        | Southern | 388  |
| CB28        | 204.0| -25.3|398^{12}_{15} ± 19 | N                        | Northern | 801  |
| CB29        | 205.8| -21.6|374^{10}_{14} ± 18 | N                        | Northern | 801  |
| CB34        | 187.0| -3.9|1322^{13}_{14} ± 66| N                        | Northern | 869  |
| CMa OB1     | 225.4| 0.3|1268^{14}_{14} ± 63| Y                        | Southern | 1    |
| CMa OB1     | 225.0| -0.2|1266^{14}_{14} ± 63| Y                        | Southern | 1    |
| CMa OB1     | 222.9| -1.9|1169^{12}_{14} ± 58| Y                        | Southern | 1    |
| CMa OB1     | 224.5| -0.2|1262^{14}_{14} ± 63| Y                        | Southern | 1    |
| California  | 162.5| -9.5|436^{14}_{14} ± 21 | Y                        | Northern | 390  |
| California  | 161.2| -9.0|454^{14}_{14} ± 22 | Y                        | Northern | 390  |
| California  | 163.8| -7.9|466^{18}_{20} ± 23 | Y                        | Northern | 390  |
| Cam         | 148.8| 17.8|368^{10}_{14} ± 18 | Y                        | Northern | 294  |
| Cam         | 144.8| 17.8|220^{11}_{12} ± 11 | Y                        | Northern | 294  |
| Cam         | 146.1| 17.7|235^{11}_{12} ± 11 | Y                        | Northern | 294  |
| Cam         | 148.4| 17.7|365^{18}_{14} ± 18 | Y                        | Northern | 294  |
| Cam         | 146.6| 17.2|215^{14}_{14} ± 10 | Y                        | Northern | 294  |
| Carina      | 286.2| -0.2|2558^{25}_{22} ± 255| N                       | Southern | 138  |
| Carina      | 288.1| -1.1|2439^{32}_{34} ± 243| N                       | Southern | 138  |
| Carina      | 286.3| 0.2|2501^{50}_{40} ± 250| N                       | Southern | 138  |
| Carina      | 287.4| -0.6|2492^{48}_{40} ± 249| N                       | Southern | 138  |
| Cepheus     | 110.1| 17.4|337^{16}_{20} ± 16 | Y                        | Northern | 136  |
| Cepheus     | 104.0| 9.4|1045^{24}_{24} ± 52 | Y                        | Northern | 136  |
| Cepheus     | 111.5| 12.2|958^{13}_{14} ± 47 | Y                        | Northern | 136  |
| Cepheus     | 108.3| 17.6|346^{11}_{12} ± 17 | Y                        | Northern | 136  |
| Cepheus     | 107.0| 6.0 |901^{13}_{13} ± 45 | Y                        | Northern | 136  |
| Cepheus     | 103.7| 11.4|867^{12}_{13} ± 43 | Y                        | Northern | 136  |
| Cepheus     | 104.0| 14.5|341^{14}_{15} ± 17 | Y                        | Northern | 136  |
| Cepheus     | 107.7| 5.9 |850^{16}_{16} ± 42 | Y                        | Northern | 136  |
| Cepheus     | 111.5| 20.8|331^{11}_{12} ± 16 | Y                        | Northern | 136  |
| Cepheus     | 114.6| 16.5|346^{12}_{13} ± 17 | Y                        | Northern | 136  |

Notes. (1)Name of the cloud associated with each sightline. We generally favor the lower density envelopes (where we can see more stars through the clouds) over the most extinguished regions. (2)Longitude of the sightline. (3)Latitude of the sightline. (4)Distance to the cloud. The first error term is the statistical uncertainty, while the second is the systematic uncertainty (estimated to be ≈5% in distance for nearby clouds, ≈10% in distance for faraway clouds ≳1.5 kpc, and ≈7% in distance for the NSC clouds Chamaeleon, Lupus, and Corona Australis; see Sect. 3.6 in Zucker et al. (2019) for more discussion on the systematic uncertainties). We recommend the uncertainties be added in quadrature. (5)Whether the sightline was taken from Zucker et al. (2019) (Y) or is novel to this work (N). (6)Whether the cloud appeared in the Northern or Southern volume of the Star Formation Handbook. (7)The page in the Northern or Southern volume of the Star Formation Handbook in which the cloud appeared.
Table A.1. continued.

| Cloud         | 1°  | b°  | Distance (pc) | Targeted in Zucker+2019? | Volume | Page |
|---------------|-----|-----|---------------|--------------------------|--------|------|
| Cepheus       | 109.6 | 16.9 | $344^{+8}_{-6} \pm 17$ | Y | Northern | 136 |
| Cepheus       | 113.5 | 15.9 | $336^{+3}_{-2} \pm 16$ | Y | Northern | 136 |
| Cepheus       | 108.2 | 5.5  | $891^{+4}_{-3} \pm 44$ | Y | Northern | 136 |
| Cepheus       | 107.7 | 12.4 | $961^{+1}_{-1} \pm 48$ | Y | Northern | 136 |
| Cepheus       | 115.3 | 17.6 | $358^{+6}_{-6} \pm 17$ | Y | Northern | 136 |
| Cepheus       | 112.8 | 20.8 | $375^{+1}_{-1} \pm 18$ | Y | Northern | 136 |
| Cepheus       | 111.8 | 20.3 | $364^{+6}_{-5} \pm 18$ | Y | Northern | 136 |
| Cepheus       | 106.4 | 17.7 | $377^{+3}_{-3} \pm 18$ | Y | Northern | 136 |
| Cepheus       | 109.0 | 7.7  | $816^{+2}_{-1} \pm 40$ | Y | Northern | 136 |
| Cepheus       | 112.8 | 16.5 | $344^{+2}_{-2} \pm 17$ | Y | Northern | 136 |
| Cepheus       | 103.5 | 13.5 | $359^{+2}_{-2} \pm 17$ | Y | Northern | 136 |
| Cepheus       | 107.0 | 9.4  | $986^{+2}_{-2} \pm 49$ | Y | Northern | 136 |
| Cepheus       | 110.7 | 12.6 | $989^{+2}_{-2} \pm 49$ | Y | Northern | 136 |
| Cepheus       | 108.4 | 18.6 | $332^{+1}_{-1} \pm 16$ | Y | Northern | 136 |
| Cepheus       | 109.6 | 6.8  | $881^{+1}_{-1} \pm 44$ | Y | Northern | 136 |
| Cepheus       | 108.3 | 12.4 | $915^{+1}_{-1} \pm 45$ | Y | Northern | 136 |
| Cepheus       | 105.9 | 13.8 | $951^{+1}_{-1} \pm 47$ | Y | Northern | 136 |
| Cepheus       | 116.1 | 20.2 | $349^{+1}_{-1} \pm 17$ | Y | Northern | 136 |
| Chamaeleon    | 303.3 | -14.2 | $190^{+8}_{-6} \pm 13$ | N | Southern | 169 |
| Chamaeleon    | 297.5 | -15.3 | $210^{+8}_{-7} \pm 14$ | N | Southern | 169 |
| Chamaeleon    | 303.0 | -16.7 | $161^{+2}_{-1} \pm 11$ | N | Southern | 169 |
| Circinus      | 318.4 | -3.2  | $683^{+1}_{-1} \pm 34$ | N | Southern | 285 |
| Circinus      | 316.9 | -3.9  | $675^{+1}_{-1} \pm 33$ | N | Southern | 285 |
| Coalsack      | 302.9 | -2.6  | $188^{+8}_{-6} \pm 9$ | N | Southern | 222 |
| Coalsack      | 301.4 | -2.6  | $182^{+8}_{-6} \pm 9$ | N | Southern | 222 |
| Coalsack      | 301.4 | 3.1   | $192^{+8}_{-6} \pm 9$ | N | Southern | 222 |
| Coalsack      | 302.8 | 1.8   | $187^{+8}_{-6} \pm 9$ | N | Southern | 222 |
| Coalsack      | 302.9 | 3.1   | $191^{+8}_{-6} \pm 9$ | N | Southern | 222 |
| Coalsack      | 300.0 | 3.1   | $193^{+8}_{-6} \pm 9$ | N | Southern | 222 |
| Corona Australis | 0.8 | -20.1 | $155^{+8}_{-6} \pm 10$ | N | Southern | 735 |
| Corona Australis | 359.5 | -17.8 | $147^{+8}_{-6} \pm 10$ | N | Southern | 735 |
| Corona Australis | 359.5 | -21.0 | $165^{+8}_{-6} \pm 11$ | N | Southern | 735 |
| CygnusX       | 82.9  | 0.7   | $1272^{+13}_{-12} \pm 63$ | N | Northern | 36 |
| CygnusX       | 76.8  | 2.2   | $1622^{+12}_{-12} \pm 162$ | N | Northern | 36 |
| CygnusX       | 77.2  | 2.1   | $1309^{+24}_{-12} \pm 65$ | N | Northern | 36 |
| CygnusX       | 80.3  | -2.4  | $1441^{+4}_{-4} \pm 72$ | N | Northern | 36 |
| CygnusX       | 80.5  | 1.1   | $1214^{+21}_{-9} \pm 60$ | N | Northern | 36 |
| CygnusX       | 79.0  | 3.7   | $1507^{+13}_{-12} \pm 150$ | N | Northern | 36 |
| CygnusX       | 77.7  | 1.3   | $898^{+6}_{-6} \pm 44$ | N | Northern | 36 |
| CygnusX       | 80.0  | -0.7  | $991^{+10}_{-10} \pm 49$ | N | Northern | 36 |
| CygnusX       | 79.1  | 3.0   | $1003^{+12}_{-12} \pm 50$ | N | Northern | 36 |
| CygnusX       | 80.3  | 2.9   | $973^{+11}_{-11} \pm 48$ | N | Northern | 36 |
| CygnusX       | 80.2  | 0.1   | $1226^{+20}_{-10} \pm 61$ | N | Northern | 36 |
| CygnusX       | 82.3  | 1.0   | $761^{+14}_{-14} \pm 38$ | N | Northern | 36 |
| CygnusX       | 78.7  | 0.6   | $919^{+14}_{-14} \pm 45$ | N | Northern | 36 |
Table A.1. continued.

| Cloud     | $l$  | $b$  | Distance pc | Targeted in Zucker+2019? | Volume | Page |
|-----------|------|------|-------------|-------------------------|--------|------|
| Draco     | 89.5 | 38.4 | $481^{+51}_{-45}$ $\pm$ 24 | Y                      | Southern | 813  |
| GGD4      | 184.3| −4.2 | $1349^{+121}_{-108}$ $\pm$ 67 | N                      | Northern | 869  |
| GGD4      | 185.1| −4.3 | $1396^{+22}_{-18}$ $\pm$ 69 | N                      | Northern | 869  |
| Gem OB1   | 189.9| −0.3 | $1815^{+11}_{-9}$ $\pm$ 181 | N                      | Northern | 869  |
| Gem OB1   | 189.5| 0.7  | $1864^{+12}_{-10}$ $\pm$ 186 | N                      | Northern | 869  |
| Gem OB1   | 190.9| 0.0  | $1865^{+12}_{-10}$ $\pm$ 186 | N                      | Northern | 869  |
| Gem OB1   | 188.7| 1.0  | $1971^{+12}_{-10}$ $\pm$ 197 | N                      | Northern | 869  |
| Gen OB1   | 193.0| 0.6  | $1726^{+51}_{-39}$ $\pm$ 172 | N                      | Northern | 869  |
| Hercules  | 45.1 | 8.9  | $223^{+1}_{-1}$ $\pm$ 11 | Y                      | –       | –    |
| Hercules  | 44.1 | 8.6  | $223^{+1}_{-1}$ $\pm$ 11 | Y                      | –       | –    |
| Hercules  | 42.8 | 7.9  | $230^{+1}_{-1}$ $\pm$ 11 | Y                      | –       | –    |
| IC1396    | 98.9 | 4.0  | $916^{+12}_{-10}$ $\pm$ 45 | N                      | Northern | 136  |
| IC1396    | 100.1| 4.2  | $905^{+21}_{-18}$ $\pm$ 45 | N                      | Northern | 136  |
| IC1396    | 100.4| 3.4  | $941^{+20}_{-18}$ $\pm$ 47 | N                      | Northern | 136  |
| IC1396    | 99.1 | 4.7  | $909^{+18}_{-16}$ $\pm$ 45 | N                      | Northern | 136  |
| IC2118    | 206.4| −26.0| $328^{+15}_{-13}$ $\pm$ 16 | N                      | Northern | 459  |
| IC2118    | 207.3| −27.2| $273^{+18}_{-16}$ $\pm$ 13 | N                      | Northern | 459  |
| IC2118    | 206.9| −26.6| $283^{+16}_{-14}$ $\pm$ 14 | N                      | Northern | 459  |
| IC2944    | 294.1| −1.6 | $2363^{+39}_{-35}$ $\pm$ 236 | N                      | Southern | 213  |
| IC2944    | 294.9| −1.5 | $2452^{+24}_{-21}$ $\pm$ 245 | N                      | Southern | 213  |
| IC2944    | 294.6| −2.0 | $2342^{+20}_{-18}$ $\pm$ 234 | N                      | Southern | 213  |
| IC443     | 189.2| 3.2  | $1629^{+26}_{-24}$ $\pm$ 162 | N                      | Northern | 869  |
| IC443     | 189.2| 4.7  | $1593^{+26}_{-24}$ $\pm$ 159 | N                      | Northern | 869  |
| IC443     | 189.6| 4.0  | $1558^{+56}_{-48}$ $\pm$ 155 | N                      | Northern | 869  |
| IC443     | 189.1| 4.1  | $1588^{+50}_{-48}$ $\pm$ 158 | N                      | Northern | 869  |
| IC5146    | 93.7 | −4.6 | $774^{+12}_{-10}$ $\pm$ 38 | N                      | Northern | 108  |
| IC5146    | 93.4 | −4.2 | $792^{+12}_{-10}$ $\pm$ 39 | N                      | Northern | 108  |
| IC5146    | 94.0 | −4.9 | $730^{+15}_{-13}$ $\pm$ 36 | N                      | Northern | 108  |
| IC5146    | 94.4 | −5.5 | $751^{+18}_{-16}$ $\pm$ 37 | N                      | Northern | 108  |
| L1228     | 111.8| 20.2 | $366^{+18}_{-16}$ $\pm$ 18 | N                      | Northern | 136  |
| L1228D    | 112.3| 13.8 | $491^{+20}_{-18}$ $\pm$ 24 | N                      | Northern | 136  |
| L1251     | 114.6| 14.5 | $351^{+10}_{-8}$ $\pm$ 17 | N                      | Northern | 136  |
| L1265     | 115.9| −2.0 | $344^{+34}_{-32}$ $\pm$ 17 | N                      | Northern | 240  |
| L1293     | 121.7| 0.1  | $1083^{+12}_{-10}$ $\pm$ 54 | N                      | Northern | 240  |
| L1302     | 122.0| −1.4 | $906^{+12}_{-10}$ $\pm$ 45 | N                      | Northern | 240  |
| L1306     | 125.6| −0.6 | $903^{+12}_{-10}$ $\pm$ 45 | N                      | Northern | 240  |
| L1306     | 126.8| −0.8 | $941^{+12}_{-10}$ $\pm$ 47 | N                      | Northern | 240  |
| L1307     | 124.3| 3.3  | $834^{+65}_{-58}$ $\pm$ 41 | N                      | Northern | 240  |
| L1307     | 124.6| 2.6  | $902^{+20}_{-18}$ $\pm$ 45 | N                      | Northern | 240  |
| L1333     | 128.9| 13.7 | $283^{+13}_{-11}$ $\pm$ 14 | N                      | Northern | 240  |
| L1335     | 128.9| 4.3  | $647^{+26}_{-24}$ $\pm$ 32 | N                      | Northern | 240  |
| L1340     | 130.0| 11.5 | $858^{+10}_{-8}$ $\pm$ 42 | N                      | Northern | 240  |
| L1355     | 132.8| 8.9  | $948^{+34}_{-30}$ $\pm$ 47 | N                      | Northern | 240  |
| L1355     | 133.6| 9.3  | $924^{+13}_{-11}$ $\pm$ 46 | N                      | Northern | 240  |
| L1616     | 203.5| −24.8| $392^{+8}_{-7}$ $\pm$ 19 | N                      | Northern | 801  |

C. Zucker et al.: A compendium of distances to molecular clouds in the Star Formation Handbook
Table A.1. continued.

| Cloud          | l       | b       | Distance (pc) | Targeted in Zucker+2019 | Volume | Page |
|----------------|---------|---------|---------------|-------------------------|--------|------|
| L1617          | 203.5   | −12.0   | 414.9 ± 20    | N                       | Northern | 782  |
| L1622          | 204.7   | −11.8   | 418.1 ± 20    | N                       | Northern | 782  |
| L1634          | 207.6   | −23.2   | 389 ± 19      | N                       | Northern | 801  |
| L1634          | 207.6   | −22.8   | 364 ± 18      | N                       | Northern | 801  |
| L291           | 10.7    | −2.8    | 1439 ± 71     | N                       | Southern | 578  |
| L291           | 11.3    | −2.1    | 1336 ± 66     | N                       | Southern | 578  |
| L291           | 11.4    | −2.7    | 1348 ± 67     | N                       | Southern | 578  |
| L379           | 16.9    | −2.2    | 2406 ± 240    | N                       | −       | −    |
| L379           | 17.1    | −2.9    | 1890 ± 189    | N                       | −       | −    |
| L379           | 16.8    | −2.7    | 2061 ± 206    | N                       | −       | −    |
| L977           | 89.5    | 2.0     | 660 ± 33      | N                       | Northern | 36   |
| L977           | 89.8    | 2.2     | 642 ± 32      | N                       | Northern | 36   |
| L988           | 90.7    | 2.4     | 627 ± 31      | N                       | Northern | 36   |
| L988           | 90.2    | 2.3     | 612 ± 30      | N                       | Northern | 36   |
| LBN906         | 202.2   | −31.4   | 287 ± 14      | N                       | Northern | 801  |
| LBN917         | 203.7   | −30.3   | 232 ± 11      | N                       | Northern | 801  |
| LBN942         | 205.6   | −22.0   | 257 ± 12      | N                       | Northern | 801  |
| LBN968         | 208.4   | −28.4   | 319 ± 15      | N                       | Northern | 801  |
| LBN969         | 208.4   | −22.2   | 274 ± 13      | N                       | Northern | 801  |
| LBN991         | 213.6   | −28.9   | 408 ± 20      | N                       | Northern | 801  |
| Lacerta        | 96.1    | −10.2   | 504 ± 25      | Y                       | Northern | 124  |
| Lacerta        | 95.8    | −11.5   | 473 ± 23      | Y                       | Northern | 124  |
| Lagoon         | 6.9     | −2.2    | 1325 ± 66     | N                       | Southern | 533  |
| Lagoon         | 7.3     | −2.4    | 1220 ± 61     | N                       | Southern | 533  |
| Lupus          | 347.3   | 6.6     | 230 ± 16      | N                       | Southern | 295  |
| Lupus          | 338.7   | 17.4    | 160 ± 11      | N                       | Southern | 295  |
| Lupus          | 339.0   | 16.3    | 151 ± 10      | N                       | Southern | 295  |
| Lupus          | 341.1   | 9.8     | 197 ± 13      | N                       | Southern | 295  |
| Lupus          | 341.1   | 6.4     | 108 ± 7       | N                       | Southern | 295  |
| Lupus          | 339.0   | 14.9    | 156 ± 10      | N                       | Southern | 295  |
| M16            | 17.9    | 1.0     | 1640 ± 164    | N                       | Southern | 599  |
| M16            | 17.5    | 1.2     | 1739 ± 173    | N                       | Southern | 599  |
| M17            | 15.5    | −0.8    | 1488 ± 74     | N                       | Southern | 624  |
| M17            | 15.2    | −0.3    | 1509 ± 150    | N                       | Southern | 624  |
| M17            | 15.3    | −1.1    | 1574 ± 157    | N                       | Southern | 624  |
| M20            | 7.4     | −0.5    | 1253 ± 62     | N                       | Southern | 509  |
| M20            | 6.7     | −0.5    | 1234 ± 61     | N                       | Southern | 509  |
| M20            | 6.6     | −0.1    | 1184 ± 59     | N                       | Southern | 509  |
| M20            | 7.0     | 0.1     | 1186 ± 59     | N                       | Southern | 509  |
| Maddalena      | 216.5   | −2.5    | 2110 ± 211    | Y                       | −       | −    |
| Maddalena      | 217.1   | 0.4     | 1888 ± 188    | Y                       | −       | −    |
| Maddalena      | 216.4   | 0.1     | 2099 ± 209    | Y                       | −       | −    |
| Maddalena      | 216.8   | −2.2    | 2113 ± 211    | Y                       | −       | −    |
| Mon OB1 (NGC2264) | 202.1  | 2.7     | 771 ± 38      | N                       | Northern | 966  |
| Mon OB1 (NGC2264) | 202.8  | 2.3     | 759 ± 37      | N                       | Northern | 966  |
| Mon OB1 (NGC2264) | 203.1  | 1.8     | 780 ± 39      | N                       | Northern | 966  |
| Cloud                  | l      | b      | Distance | Targeted in Zucker+2019? | Volume | Page |
|-----------------------|--------|--------|----------|--------------------------|--------|------|
| Mon OB1 (NGC2264)     | 201.2  | 1.0    | 715 ± 35 | Y                        | Northern | 966  |
| Mon OB1 (NGC2264)     | 200.4  | 0.8    | 719 ± 35 | Y                        | Northern | 966  |
| Mon OB1 (NGC2264)     | 201.4  | 1.1    | 748 ± 37 | Y                        | Northern | 966  |
| Mon R2                | 213.0  | −12.5  | 799 ± 39 | N                        | Northern | 899  |
| Mon R2                | 219.3  | −9.5   | 923 ± 46 | Y                        | Northern | 899  |
| Mon R2                | 215.3  | −12.9  | 767 ± 38 | Y                        | Northern | 899  |
| Mon R2                | 219.2  | −7.7   | 943 ± 47 | Y                        | Northern | 899  |
| Mon R2                | 220.9  | −8.3   | 915 ± 45 | Y                        | Northern | 899  |
| Mon R2                | 213.9  | −11.9  | 788 ± 39 | Y                        | Northern | 899  |
| NGC 2362              | 239.5  | −4.9   | 1317 ± 65| N                        | Southern | 26   |
| NGC 2362              | 237.2  | −4.9   | 1173 ± 58| N                        | Southern | 26   |
| NGC 2362              | 238.7  | −4.2   | 1358 ± 67| N                        | Southern | 26   |
| NGC 6604              | 17.8   | 2.2    | 1352 ± 67| N                        | Southern | 590  |
| NGC 6604              | 18.1   | 1.9    | 1524 ± 152| N                       | Southern | 590  |
| NGC 6604              | 18.2   | 2.5    | 1334 ± 66| N                        | Southern | 590  |
| Norma                 | 338.8  | 1.8    | 721 ± 36 | N                        | Southern | 381  |
| North America         | 85.8   | −2.2   | 834 ± 41 | N                        | Northern | 36   |
| North America         | 84.8   | −1.2   | 878 ± 43 | N                        | Northern | 36   |
| North America         | 85.3   | −0.8   | 784 ± 39 | N                        | Northern | 36   |
| North America         | 86.6   | −2.1   | 731 ± 36 | N                        | Northern | 36   |
| North America         | 84.6   | 0.1    | 792 ± 39 | N                        | Northern | 36   |
| North America         | 82.8   | −2.1   | 809 ± 40 | N                        | Northern | 36   |
| North America         | 83.7   | −2.1   | 781 ± 39 | N                        | Northern | 36   |
| North America         | 81.7   | −1.7   | 852 ± 42 | N                        | Northern | 36   |
| North America         | 84.2   | −1.3   | 811 ± 40 | N                        | Northern | 36   |
| North America         | 84.8   | −1.7   | 821 ± 41 | N                        | Northern | 36   |
| Northern Coalsack     | 91.3   | 4.2    | 577 ± 28 | N                        | Northern | 36   |
| Northern Coalsack     | 92.6   | 3.5    | 561 ± 28 | N                        | Northern | 36   |
| Northern Coalsack     | 92.2   | 4.3    | 547 ± 27 | N                        | Northern | 36   |
| Ophiuchus              | 352.7  | 15.4   | 139 ± 6  | Y                        | Southern | 351  |
| Ophiuchus              | 355.2  | 16.0   | 128 ± 6  | Y                        | Southern | 351  |
| Ophiuchus              | 357.1  | 15.7   | 118 ± 5  | Y                        | Southern | 351  |
| Ophiuchus (Arc)        | 349.9  | 16.6   | 167 ± 8  | N                        | Southern | 351  |
| Ophiuchus (Arc)        | 349.3  | 14.9   | 155 ± 7  | N                        | Southern | 351  |
| Ophiuchus (Arc)        | 352.4  | 18.3   | 130 ± 6  | N                        | Southern | 351  |
| Ophiuchus (B44)        | 359.2  | 12.0   | 149 ± 7  | N                        | Southern | 351  |
| Ophiuchus (B44)        | 357.1  | 13.1   | 145 ± 7  | N                        | Southern | 351  |
| Ophiuchus (B44)        | 354.5  | 15.0   | 154 ± 7  | N                        | Southern | 351  |
| Ophiuchus (B45)        | 358.6  | 15.3   | 139 ± 6  | N                        | Southern | 351  |
| Ophiuchus (B45)        | 357.1  | 15.6   | 142 ± 7  | N                        | Southern | 351  |
| Ophiuchus (B45)        | 356.6  | 16.1   | 132 ± 6  | N                        | Southern | 351  |
| Ophiuchus (L1688)      | 353.2  | 16.6   | 139 ± 6  | N                        | Southern | 351  |
| Ophiuchus (North)      | 8.4    | 22.0   | 109 ± 5  | N                        | Southern | 351  |
| Ophiuchus (North)      | 4.2    | 18.2   | 151 ± 7  | N                        | Southern | 351  |
| Ophiuchus (North)      | 6.5    | 20.4   | 134 ± 6  | N                        | Southern | 351  |
Table A.1. continued.

| Cloud     | 1°      | b°     | Distance (pc) | Targeted in Zucker+2019? | Volume | Page |
|-----------|---------|--------|---------------|--------------------------|--------|------|
| Orion     | 206.4   | −15.4  | 433$^{+27}_{-23}$ ± 21 | N                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 209.0   | −20.1  | 394$^{+10}_{-7}$ ± 19  | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 209.1   | −19.9  | 445$^{+25}_{-20}$ ± 22 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 212.2   | −18.6  | 473$^{+7}_{-6}$ ± 23   | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 202.0   | −13.3  | 481$^{+10}_{-14}$ ± 24 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 205.7   | −14.8  | 436$^{+23}_{-24}$ ± 21 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 212.4   | −19.9  | 415$^{+10}_{-16}$ ± 20 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 208.4   | −19.6  | 399$^{+14}_{-11}$ ± 19 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 207.9   | −16.8  | 411$^{+9}_{-14}$ ± 20  | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 214.7   | −19.0  | 416$^{+46}_{-46}$ ± 20 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 209.8   | −19.5  | 438$^{+27}_{-27}$ ± 21 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 202.0   | −14.0  | 399$^{+2}_{-2}$ ± 19   | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 204.7   | −19.2  | 418$^{+13}_{-18}$ ± 20 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 207.4   | −16.0  | 451$^{+8}_{-3}$ ± 22   | N                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 204.8   | −13.3  | 415$^{+4}_{-3}$ ± 20   | N                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 212.4   | −17.3  | 522$^{+20}_{-54}$ ± 26 | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion     | 201.3   | −13.8  | 420$^{+6}_{-10}$ ± 21  | Y                        | Northern | 459, 483, 544, 662, 693 |
| Orion Lam | 192.3   | −8.9   | 406$^{+15}_{-13}$ ± 20 | Y                        | Northern | 757          |
| Orion Lam | 196.7   | −16.1  | 426$^{+10}_{-9}$ ± 21  | Y                        | Northern | 757          |
| Orion Lam | 195.5   | −13.7  | 399$^{+14}_{-12}$ ± 19 | Y                        | Northern | 757          |
| Orion Lam | 199.6   | −11.9  | 393$^{+8}_{-4}$ ± 19   | Y                        | Northern | 757          |
| Orion Lam | 194.8   | −12.1  | 423$^{+12}_{-7}$ ± 21  | Y                        | Northern | 757          |
| Orion Lam | 194.7   | −10.1  | 425$^{+25}_{-5}$ ± 21  | Y                        | Northern | 757          |
| Orion Lam | 196.9   | −8.2   | 394$^{+13}_{-8}$ ± 19  | Y                        | Northern | 757          |
| Pegasus   | 104.2   | −31.7  | 292$^{+15}_{-18}$ ± 14 | Y                        | –       | –             |
| Pegasus   | 88.8    | −41.3  | 238$^{+9}_{-10}$ ± 11  | Y                        | –       | –             |
| Pegasus   | 92.2    | −34.7  | 258$^{+31}_{-99}$ ± 12 | Y                        | –       | –             |
| Pegasus   | 95.3    | −35.7  | 257$^{+19}_{-15}$ ± 12 | Y                        | –       | –             |
| Pegasus   | 105.6   | −30.6  | 256$^{+15}_{-15}$ ± 12 | Y                        | –       | –             |
| Perseus   | 159.9   | −18.1  | 305$^{+14}_{-20}$ ± 15 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 158.6   | −19.9  | 291$^{+15}_{-6}$ ± 14  | Y                        | Northern | 308, 346, 372 |
| Perseus   | 158.5   | −22.1  | 243$^{+12}_{-13}$ ± 12 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 159.3   | −20.6  | 276$^{+12}_{-8}$ ± 13  | Y                        | Northern | 308, 346, 372 |
| Perseus   | 159.7   | −19.7  | 347$^{+22}_{-25}$ ± 17 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 159.9   | −18.9  | 279$^{+13}_{-11}$ ± 13 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 159.4   | −21.3  | 234$^{+39}_{-70}$ ± 11 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 157.8   | −22.8  | 264$^{+11}_{-7}$ ± 13  | Y                        | Northern | 308, 346, 372 |
| Perseus   | 160.8   | −17.0  | 276$^{+7}_{-4}$ ± 13   | Y                        | Northern | 308, 346, 372 |
| Perseus   | 160.8   | −18.7  | 285$^{+18}_{-15}$ ± 14 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 159.1   | −21.1  | 291$^{+15}_{-14}$ ± 14 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 157.7   | −21.4  | 240$^{+11}_{-12}$ ± 12 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 158.2   | −20.9  | 287$^{+8}_{-4}$ ± 14   | Y                        | Northern | 308, 346, 372 |
| Perseus   | 157.5   | −17.9  | 287$^{+8}_{-4}$ ± 14   | Y                        | Northern | 308, 346, 372 |
| Perseus   | 160.4   | −17.2  | 284$^{+14}_{-16}$ ± 14 | Y                        | Northern | 308, 346, 372 |
| Perseus   | 160.0   | −17.6  | 331$^{+15}_{-10}$ ± 16 | Y                        | Northern | 308, 346, 372 |
| Cloud            | l°  | b°  | Distance pc | Targeted in Zucker+2019? | Volume | Page  |
|------------------|-----|-----|-------------|--------------------------|--------|-------|
| Perseus          | 160.4 | −16.7 | 256.21 ± 12 | Y                        | Northern | 308, 346, 372 |
| Perseus          | 160.7 | −16.3 | 296.30 ± 14 | Y                        | Northern | 308, 346, 372 |
| Pipe (B59)       | 356.9 | 7.3  | 180.57 ± 9  | N                        | Southern | 415   |
| Polaris          | 123.5 | 37.9 | 472.35 ± 23 | Y                        | Southern | 813   |
| Polaris          | 129.5 | 17.3 | 341.20 ± 17 | Y                        | Southern | 813   |
| Polaris          | 126.3 | 21.2 | 343.19 ± 17 | Y                        | Southern | 813   |
| RCW38            | 268.0 | −1.2 | 1595.15 ± 159 | N                        | Southern | 124  |
| RCW38            | 267.7 | −1.2 | 1650.37 ± 165 | N                        | Southern | 124  |
| Rosette          | 205.2 | −2.6 | 1413.16 ± 70 | Y                        | Northern | 928   |
| Rosette          | 206.8 | −1.2 | 1356.15 ± 67 | Y                        | Northern | 928   |
| Rosette          | 207.8 | −2.1 | 1261.20 ± 63 | Y                        | Northern | 928   |
| S106             | 76.0  | 9.7  |               | N                        | Northern | 90    |
| Serpens          | 29.6  | 3.9  | 501.11 ± 25  | N                        | Southern | 683,693 |
| Serpens (Low)    | 29.2  | 4.1  | 556.18 ± 27  | N                        | Southern | 683,693 |
| Serpens (Low)    | 28.5  | 3.0  | 489.19 ± 24  | N                        | Southern | 683,693 |
| Serpens (Low)    | 28.1  | 3.6  | 439.13 ± 21  | N                        | Southern | 683,693 |
| Serpens (Main)   | 31.8  | 2.6  | 494.17 ± 24  | N                        | Southern | 683,693 |
| Serpens (Main)   | 30.1  | 2.7  | 466.10 ± 23  | N                        | Southern | 683,693 |
| Serpens (Main)   | 31.9  | 3.0  | 487.18 ± 24  | N                        | Southern | 683,693 |
| Serpens (Main)   | 32.9  | 2.7  | 526.14 ± 26  | N                        | Southern | 683,693 |
| Serpens (Main)   | 30.3  | 5.2  | 490.14 ± 24  | N                        | Southern | 683,693 |
| Serpens (Main)   | 31.2  | 5.2  | 425.15 ± 21  | N                        | Southern | 683,693 |
| Serpens (W40)    | 28.8  | 3.5  | 487.27 ± 24  | N                        | Southern | 683,693 |
| Serpens OB2      | 18.8  | 1.2  | 1569.28 ± 156 | N                      | Southern | 590   |
| Serpens OB2      | 18.0  | 1.6  | 1577.21 ± 157 | N                      | Southern | 590   |
| Serpens OB2      | 18.4  | 1.3  | 1611.22 ± 161 | N                      | Southern | 590   |
| Sh2-231          | 173.0 | 2.4  | 1616.24 ± 161 | N                      | Northern | 869   |
| Sh2-232          | 173.5 | 2.9  | 1713.18 ± 171 | N                      | Northern | 869   |
| Spider           | 134.8 | 40.5 | 369.12 ± 18  | Y                        | –       | –     |
| Taurus           | 173.5 | −14.2 | 147.15 ± 7   | Y                        | Northern | 405   |
| Taurus           | 171.6 | −15.8 | 130.14 ± 6   | Y                        | Northern | 405   |
| Taurus           | 175.8 | −12.9 | 156.13 ± 7   | Y                        | Northern | 405   |
| Taurus           | 172.2 | −14.6 | 137.12 ± 6   | Y                        | Northern | 405   |
| Taurus           | 170.2 | −12.3 | 170.10 ± 8   | Y                        | Northern | 405   |
| Taurus           | 174.5 | −15.6 | 159.13 ± 7   | N                        | Northern | 405   |
| Taurus           | 171.7 | −17.2 | 149.14 ± 7   | N                        | Northern | 405   |
| Taurus           | 166.2 | −16.6 | 138.13 ± 6   | Y                        | Northern | 405   |
| Taurus           | 171.4 | −13.5 | 154.14 ± 7   | Y                        | Northern | 405   |
| Taurus           | 169.9 | −19.2 | 129.13 ± 6   | N                        | Northern | 405   |
| Ursa Major       | 158.5 | 35.2  | 352.11 ± 17  | Y                        | Southern | 813   |
| Ursa Major       | 143.4 | 38.5  | 408.15 ± 20  | Y                        | Southern | 813   |
| Ursa Major       | 146.9 | 40.7  | 330.16 ± 16  | Y                        | Southern | 813   |
| Ursa Major       | 153.5 | 36.7  | 352.19 ± 17  | Y                        | Southern | 813   |
| Vela C           | 266.1 | 1.4  | 866.11 ± 43  | N                        | Southern | 43    |
| Vela C           | 265.3 | 1.2  | 947.15 ± 47  | N                        | Southern | 43    |
Table A.1. continued.

| Cloud | l   | b   | Distance | Targeted in Zucker+2019? | Volume | Page |
|-------|-----|-----|----------|--------------------------|--------|------|
|       | °   | °   | pc       |                           |        |      |
| Vela C| 265.3 | 1.8 | 878$^{+6}_{-43}$ | N                         | Southern | 43   |
| Vela C| 264.7 | 1.4 | 931$^{+10}_{-6}$  | N                         | Southern | 43   |
| Vela C| 264.3 | 2.5 | 965$^{+15}_{-48}$ | N                         | Southern | 43   |
| W3    | 133.3 | 1.1 | 1873$^{+11}_{-29}$ | N                         | Northern | 264  |
| W3    | 133.7 | 1.3 | 2184$^{+19}_{-28}$ | N                         | Northern | 264  |
| W3    | 133.3 | 0.5 | 1659$^{+11}_{-16}$ | N                         | Northern | 264  |
| W4    | 135.6 | 1.3 | 1825$^{+31}_{-18}$ | N                         | Northern | 264  |
| W4    | 135.3 | 1.0 | 1647$^{+20}_{-164}$ | N                         | Northern | 264  |
| W4    | 135.6 | 0.2 | 1451$^{+13}_{-61}$ | N                         | Northern | 264  |
| W4    | 135.6 | 1.2 | 1755$^{+29}_{-27}$ | N                         | Northern | 264  |
| W5    | 136.5 | 1.2 | 2026$^{+14}_{-26}$ | N                         | Northern | 264  |
| W5    | 137.0 | 1.4 | 2077$^{+28}_{-18}$ | N                         | Northern | 264  |
| W5    | 137.8 | 1.5 | 1962$^{+13}_{-28}$ | N                         | Northern | 264  |
| W5    | 138.0 | 0.9 | 1739$^{+16}_{-18}$ | N                         | Northern | 264  |
| W5    | 136.9 | 1.0 | 2103$^{+13}_{-210}$ | N                         | Northern | 264  |