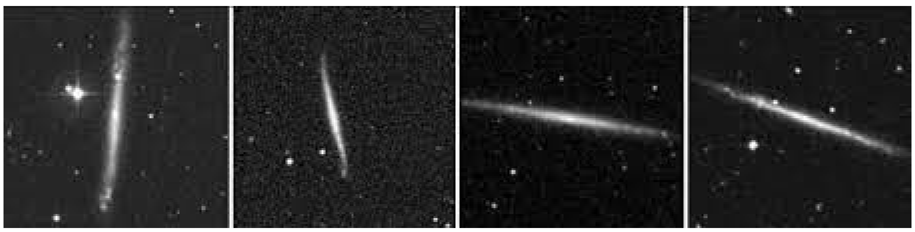
Research Highlights of Arunima Banerjee
(Work done @ IISER Tirupati)

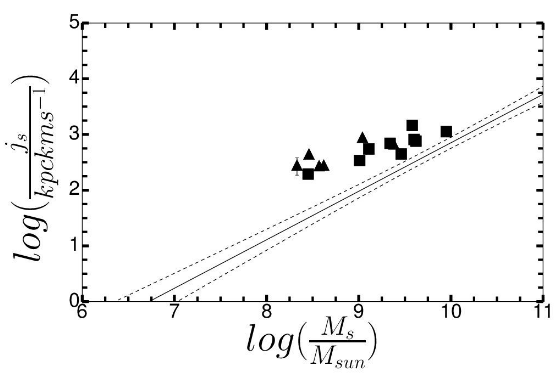
1. Why are some galaxies "superthin"?



Optical images as sharp as razor blades
(klima-luft.de/steinicke/Artikel/sg/sg_e.htm)

Superthin (or ultra-flat or ultra-thin) galaxies are a class of low surface brightness, bulgeless, disc galaxies, exhibiting sharp, needle-like images in the optical, implying strikingly high values of planar-to-vertical axes ratios of the stellar disc, which possibly indicates the presence of an ultra-cold stellar disc, the dynamical stability of which continues to be a mystery. Although superthin galaxies are ubiquitous, curiously, the number of superthin and extremely thin galaxies produced in the cosmological, hydrodynamical simulations is not significant.

- **Specific angular momenta of superthins: Cue to their origin?**

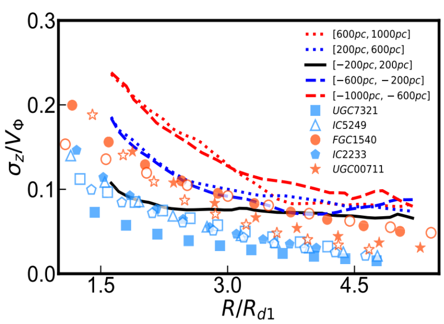


➢ **We find that for a given stellar mass, superthin galaxies have higher specific angular momentum than ordinary bulgeless disc galaxies**

We calculate the specific angular momenta of a sample of six superthins and nine other bulgeless LSBs using stellar photometry, atomic hydrogen (HI) surface density and high resolution HI rotation curves available in the literature. We find that the stellar specific angular mometum, and hence the stellar disc size given by the exponential stellar disc scale length of three superthins and seven LSBs lie above the 95.4 % confidence band of the stellar specific angular momentum-stellar mass regression line for ordinary bulgeless disc galaxies, thus implying that a higher value of the stellar specific angular momentum is possibly responsible for a superthin stellar disc.

Jadhav Y, V., and Banerjee, A. 2019, MNRAS, 488, 547
arXiv: 1906.10039

- **How “cold” are superthin galaxies?**



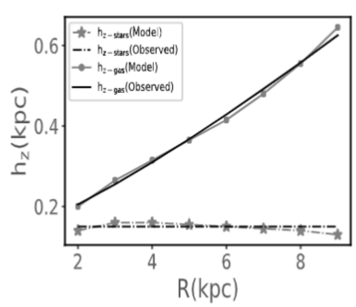
➢ **Vertical stellar dispersion of superthins normalized by their rotational velocity is comparable to that of the thin disc of the Milky Way. Hence we conclude that the stellar discs of superthins are ‘cold’.**

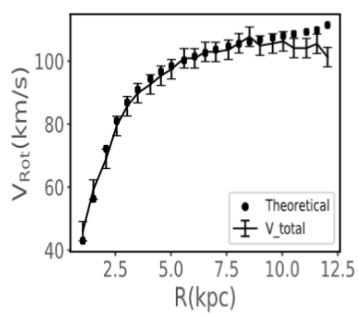
We construct dynamical models of a sample of superthin galaxies using stellar photometry and HI 21cm radio-synthesis observations as constraints and employing a Markov Chain Monte Carlo method, also checking the consistency of our model results using AGAMA i.e. Action-based Galaxy Modelling Architecture (Vasilev 2018). Finally, we compare our modelled kinematics of superthin stellar discs with the observed kinematics of the Galactic stellar disc as given in Gaia DR2 to assess how “cold” superthin galaxies really are. We found that the vertical stellar dispersion of superthins comparable to that of the thin disc of the Milky Way, and hence ‘Cold’.

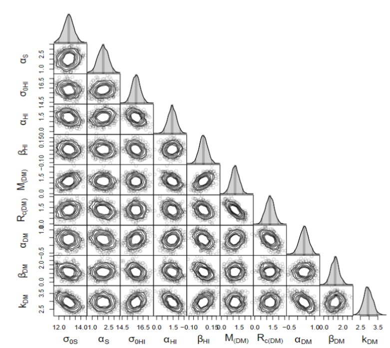
Aditya, K. and Banerjee, A. 2021,MNRAS, 502,5049, arXiv:2002.0919

- **Superthins in Alternative Theories of Gravity**

Model vs Observation







Scaleheights: Star + Gas **Rotation Curve** **MCMC: Correlation Plots**

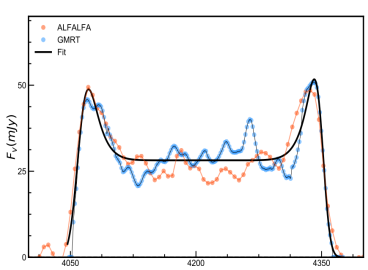
➢ **The best-fitting dynamical model of a superthin UGC7321 in a braneworld model, an alternative theory of gravity, as determined by a Markov Chain Monte Carlo method, complies with the observed vertical thickness of stars and gas as well over and above the rotation curve.**

Although the “dark matter” is generally thought to resolve a host of astrophysical and cosmological problems, the fundamental particles constituting the dark matter have evaded detection in dark matter search experiments. In this work, we consider a gravitational origin of dark matter in the brane world scenario, where the higher dimensional Weyl stress term projected onto the 3-brane acts as the source of dark matter. In the context of the braneworld model, this dark matter is referred to as the ‘dark mass’.This model has been successful in reproducing the rotation curves of several low surface brightness and high-surface-brightness galaxies. Therefore it is interesting to study the prospect of this model in explaining the vertical structure of galaxies which has not been explored in the literature so far. Using our 2-component model of gravitationally-coupled stars and gas in the external force field of this dark mass, we fit the observed scale heights of stellar and atomic hydrogen (HI) gas of superthin galaxy ‘UGC7321’ using the Markov Chain Monte Carlo approach. We find that the observed scaleheights of ‘UGC7321’ can be successfully modelled in the context of the braneworld scenario. In addition, the model predicted rotation curve also matches the observed one. The implications on the model parameters are discussed.

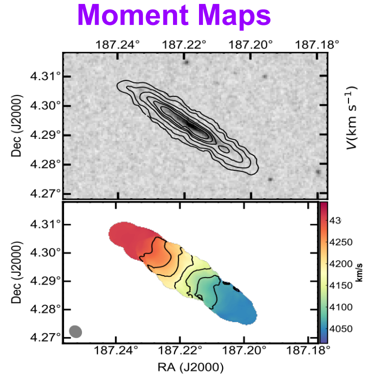
Komanduri, A., Banerjee, I., Banerjee, A. and Sengupta, S. 2020, MNRAS, 499, 5690, arXiv:2004.05627

- **Dynamics of the “thinnest” of the superthins: FGC1440 & FGC2366**

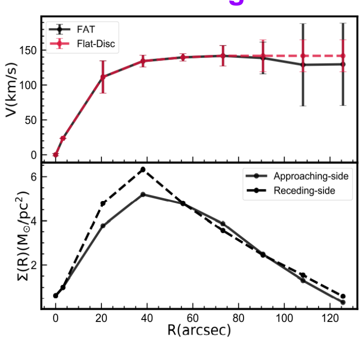
HI Line Profile



Moment Maps



3-D Tilted Ring Models



➢ **GMRT HI 21cm radio-synthesis observations of one of the thinnest galaxies: FGC1440**

Giant Meterwave Radio Telescope (GMRT), Narayanganj (near Pune)

[Allocated 16 hours of GMRT Time to observe 2 of the thinnest galaxies in cycle 36 (2019)]

We present observations and models of the kinematics and distribution of neutral hydrogen (H I) in the superthin galaxy FGC 1440 with an optical axial ratio a/b = 20.4. Using the Giant Meterwave Radio telescope (GMRT), we imaged the galaxy with a spectral resolution of 1.7 km s-1 and a spatial resolution of 15.9″× 13.5″. We find that FGC 1440 has an asymptotic rotational velocity of 141.8 km s-1. The structure of the H I disc in FGC 1440 is that of a typical thin disc warped along the line of sight, but we cannot rule out the presence of a central thick H I disc.

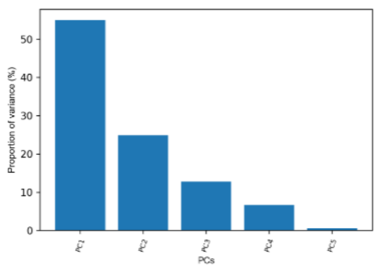
Aditya, K., Kamphuis, P., Banerjee, A. et al. 2022, MNRAS, 509, 4071, arXiv:2104.04216

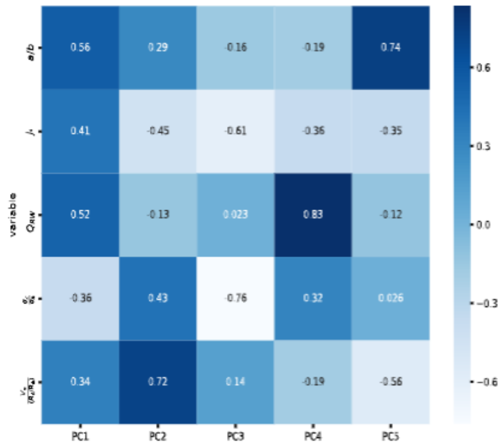
- **Which dynamical parameter primarily drives a superthin vertical structure?**

Principal Component Analysis of dynamical parameters of superthins

Dynamical Parameters:

- Specific Angular Momentum
- 2-component disc dynamical stability
- Ratio of the vertical-to-radial velocity dispersion
- Central mass concentration





Principal Components

Decomposition of Principal Components

- **The compactness of the mass distribution is fundamentally responsible for the existence of superthin stellar discs.**

To identify the key physical mechanisms responsible for the superthin vertical structure, we carry out a Principal Component Analysis of the data corresponding to all the relevant dynamical parameters and a/b for a sample of superthin and extremely thin galaxies studied so far. We note that the first two principal components explain 80% of the variation in the data, and the significant contribution is from the compactness of the mass distribution, which is fundamentally responsible for the existence of superthin stellar discs.

Aditya, K., Banerjee, A., Kamphuis, P., et al. 2023 (Under Review)

2. Dynamics of low surface brightness galaxies: Open problems

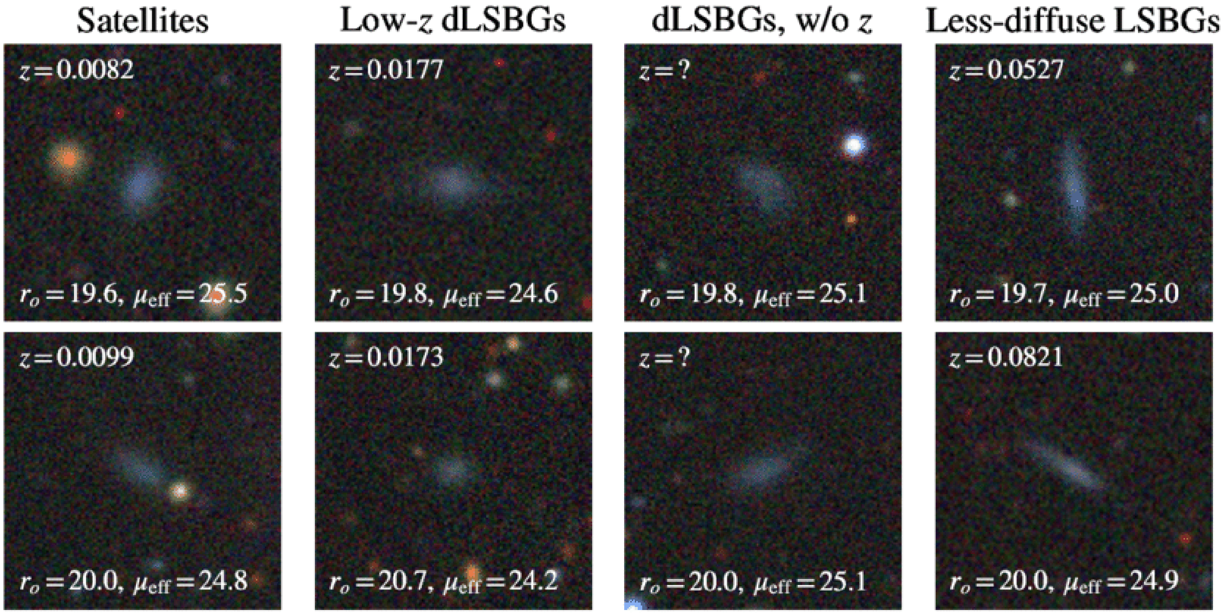
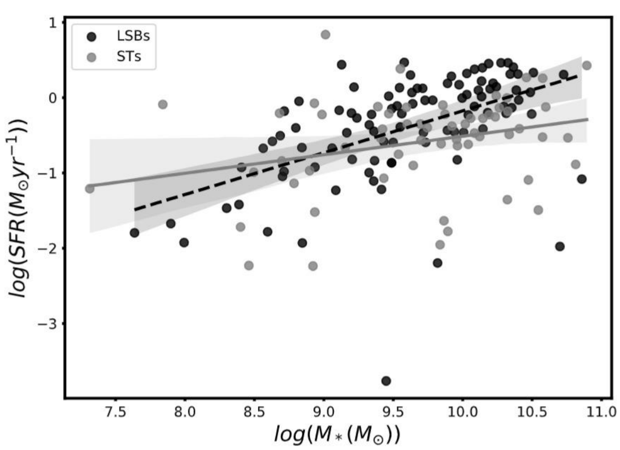


Image Courtesy: The SAGA Survey. II. Building a Statistical Sample of Satellite Systems around Milky Way-like Galaxies

- **Are superthin galaxies galaxies low surface brightness galaxies seen edge-on?**



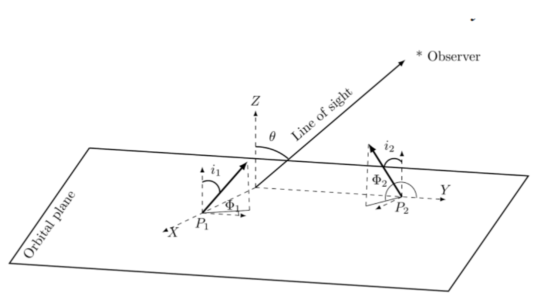
➢ **Comparison of the star formation histories of superthins and low surface brightness galaxies constructing Spectral Energy Density (SED) using optical, UV and NIR bands and fitting the same with stellar population synthesis models**

Superthin galaxies (STs) are edge-on disc galaxies with strikingly high planar-to-vertical axes ratios of $\sim 10 - 20$ with no bulge component, and central surface brightness in B-band $>$ 23 mag arcsec^{-2} comparable to low surface brightness galaxies (LSBs). Although STs and LSBs have similar dynamical, stellar and atomic hydrogen (HI) masses on an average, it is tricky to conclude if they constitute the same galaxy population, given the edge-on and face-on orientations of the STs and the LSBs respectively. We systematically study star formation rate (SFR) in a sample of STs and LSBs using SED fitting of photometric data in ten bands including GALEX: FUV, NUV, SDSS: u,g,r,i,z \& 2MASS: J, H, Ks using stellar population synthesis models employing the publicly-available software MAGPHYS (Multi-Wavelength Analysis of Galaxy Physical Properties). For a given stellar mass, a superthin has a lower star formation rate than a similar face-on low surface brightness galaxy. However, the difference can be attributed to the dust extinction effect due to the edge-on geometry of the former.

Narayanan, G. and Banerjee, A. 2022, MNRS, 514, 5126, arXiv:2104.04216

3. Applications of machine learning in galaxy astrophysics

- **Identification of dynamical parameters of an interacting galaxy pair using convolutional neural network**



Two interacting galaxies:
NGC 5426 and NGC 5427 ((ESO's VLT)

➢ **We developed a CNN model to identify the angle of inclination and the position angle of an interacting pair of galaxies.**

Constructing dynamical models for interacting galaxies constrained by their observed structure and kinematics crucially depends on the correct choice of the values of their relative inclination (i) and viewing angle (θ) (the angle between the line of sight and the normal to the plane of their orbital motion). We construct Deep Convolutional Neural Network (DCNN) models to determine the i and θ of interacting galaxy pairs, using N-body + Smoothed Particle Hydrodynamics (SPH) simulation data from the GALMER database for training. GalMer simulates only a discrete set of i values (0°, 45°, 75° and 90°) and almost all possible values of θ values in the range, $[-90^\circ, 90^\circ]$. Therefore, we have used classification for i parameter and regression for θ. In order to classify galaxy pairs based on their i values only, we first construct DCNN models for (i) 2-class ($i = 0^\circ, 45^\circ$) (ii) 3-class ($i = 0^\circ, 45^\circ, 90^\circ$) classification, obtaining F1 scores of 99% and 98% respectively. Further, for a classification based on both i and θ values, we develop a DCNN model for a 9-class classification using different possible combinations of i and θ, and the F1 score was 97%. To estimate θ alone, we have used regression, and obtained a mean squared error value of 0.12. Finally, we also tested our DCNN model on real data from Sloan Digital Sky Survey. Our DCNN models could be extended to determine additional dynamical parameters, currently determined by trial and error method.

FEATURE MAPS

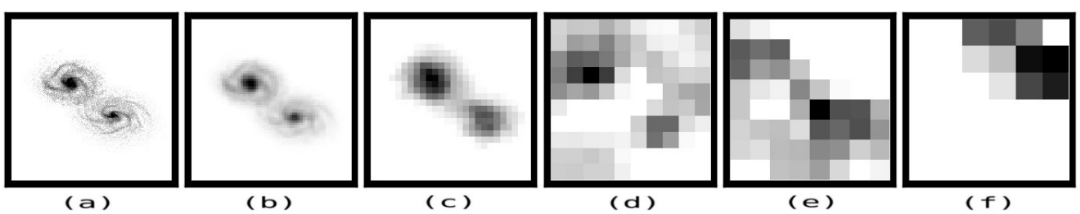


Figure 2. CNN automated feature extraction. (a) Input Image (b)-(f) Feature maps obtained for (a) using one kernel window from each of the five convolutional layers

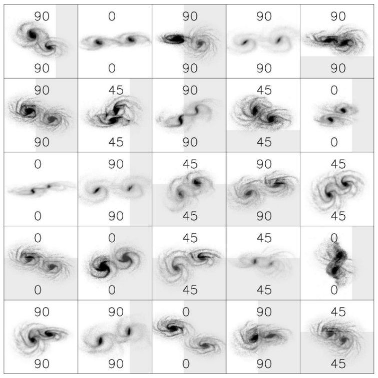
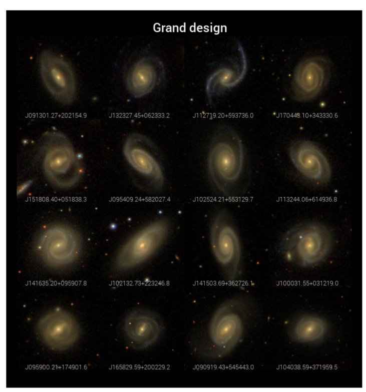


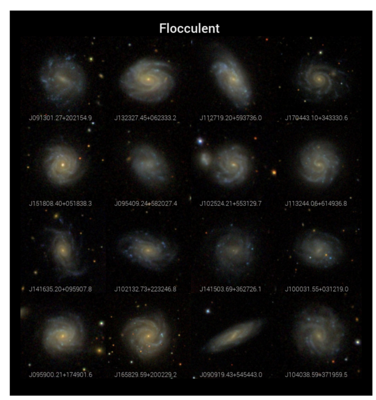
Figure A2. Montage of the training images for 3-class classification. Top and bottom values on each image represent the actual and the predicted class labels respectively.

Testing Accuracy of our CNN model: 98%

Prakash, P., Banerjee, A. and Perepu, P. K. 2020, MNRAS, 497, 3323
arXiv:2002.01238

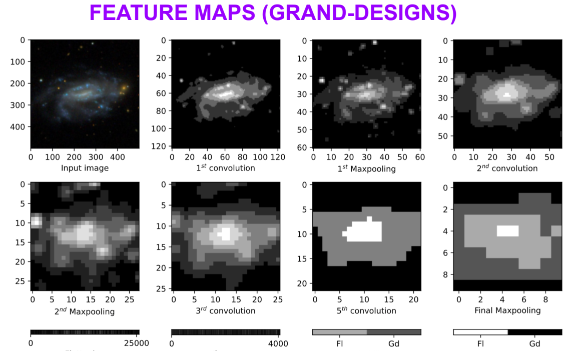
- **Identification of new Grand-designs and Flocculents from the SDSS using convolutional neural network**





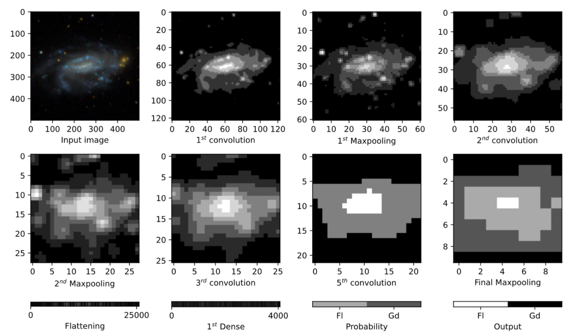
➢ **We identified 499 new grand-design and 721 flocculent spiral galaxies using our CNN model from SDSS DR17.**

FEATURE MAPS (GRAND-DESIGNS)



Testing Accuracy of our CNN model: 97.4%

FEATURE MAPS (FLOCCULENTS)



Spiral galaxies can be classified into the Grand-designs and Flocculents based on the nature of their spiral arms. The Grand-designs exhibit almost continuous and high contrast spiral arms and are believed to be driven by stationary density waves, while the Flocculents have patchy and low-contrast spiral features and are primarily stochastic in origin. We train a Deep Convolutional neural network (DCNN) model to classify spirals into Grand-designs and Flocculents, with a testing accuracy of 97.2%. We then use the above model for classifying 1,354 spirals from the SDSS. Out of these, 721 were identified as Flocculents, and the rest as Grand-designs. Interestingly, we find the mean asymptotic rotational velocities of our newly classified Grand-designs and Flocculents are 218 ± 86 Km s−1 and 146 ± 67 Km s−1 respectively, indicating that the Grand-designs are mostly the high-mass and the Flocculents the intermediate-mass spirals. This is further corroborated by the observation that the mean morphological indices of the Grand-designs and Flocculents are 2.6±1.8 and 4.7±1.9 respectively, implying that the Flocculents primarily consist of a late-type galaxy population in contrast to the Grand-designs. Finally, an almost equal fraction of bars ~ 0.3 in both the classes of spiral galaxies reveals that the presence of a bar component does not regulate the type of spiral arm hosted by a galaxy. Our results may have important implications for formation and evolution of spiral arms in galaxies.

Sarkar, S., Narayanan, G., Banerjee, A. and Prakash, P. 2023, MNRAS, 518, 1022, arXiv:2205.08733

last updated on 07.08.2023